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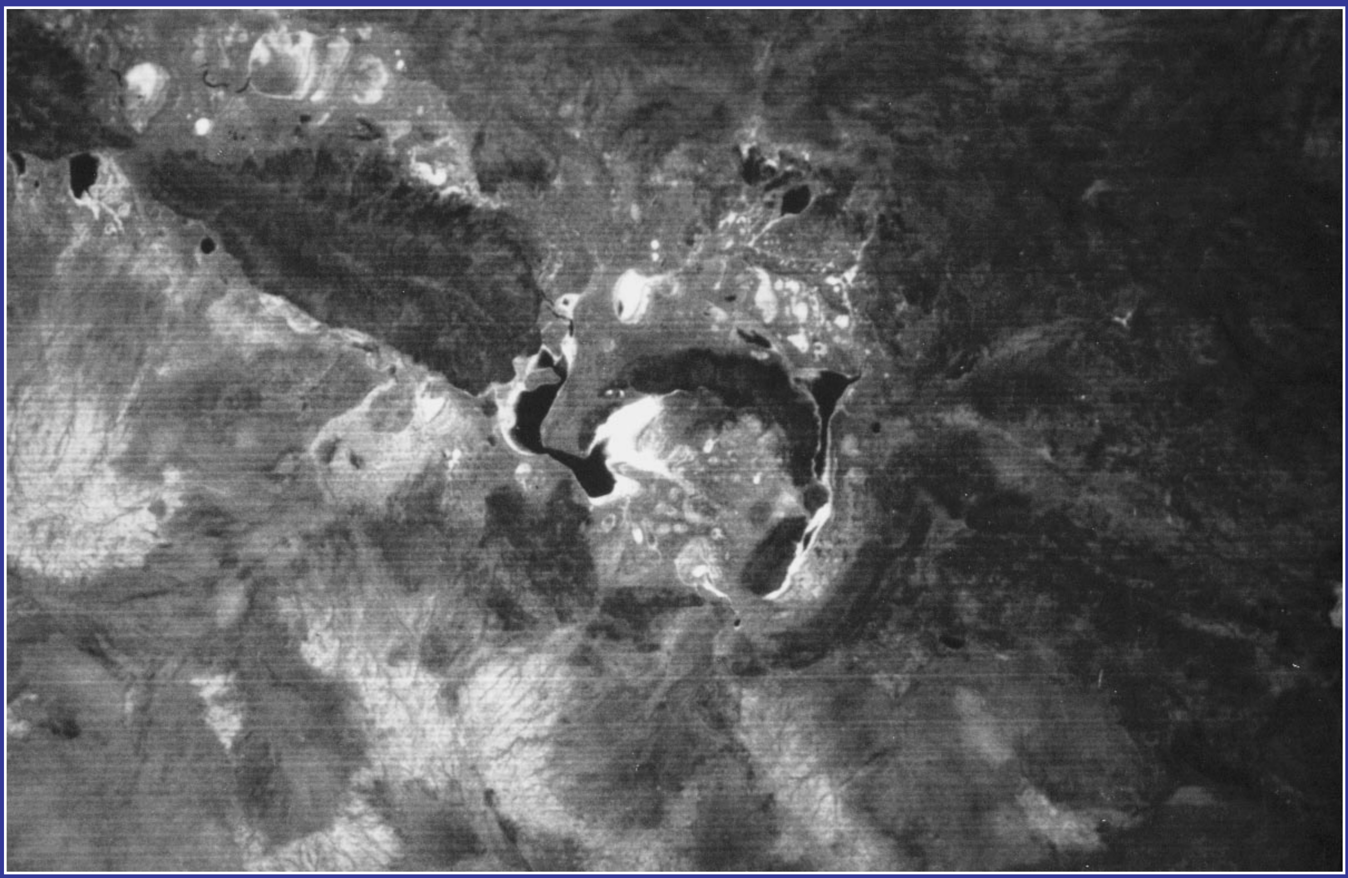

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December/décembre 1998

Journal

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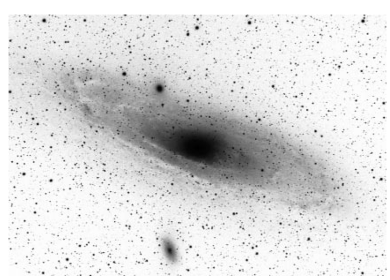

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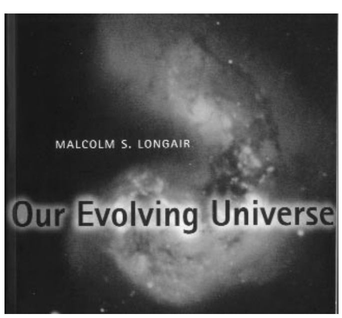

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ACROSS THE RASC
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Landsat image of the Shoemaker Impact structure.

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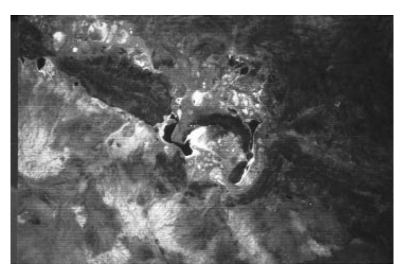

From the Editor

by David Turner

Numbers. They pervade our daily lives in so many ways that we are often unaware of them. From the current value of the Canadian dollar and the prices of common stock shares to the equity in our principal residence or the baud rate of our Internet connections, there is a certain fascination with numbers that is timeless. A similar appeal for numbers was also common in ancient times, with many interesting consequences. One particular number game related to the factors of various integers, in other words those numbers — including unity but not including the number itself — that can be divided evenly into an integer. The number 20, for example, has factors 1, 2, 4, 5, and 10. The number 22 has factors 1, 2, and 11. In the case of the number 20, its factors sum to 22, while the factors of 22 sum to 14. Because the factors of 20 form a sum that is greater than the number itself, 20 is considered to be an "abundant" number, while 22 is considered to be "deficient" since its factors form a sum that is less than the number.

A select group of numbers has factors whose sum is identical to the number itself. They are referred to as "perfect" numbers. Two such "perfect" numbers are 6 — with its factors 1, 2, and 3 — and 28 — with its factors 1, 2, 4, 7, and 14. They are not that common. The first five are 6, 28, 496, 8128, and 33,550,336, and there are something like twenty or so known, the largest containing thousands of digits. It is interesting that the first two perfect numbers are related to two familiar calendar time scales — the week and the month. Specifically, it takes about six days for the Moon to pass from "New Moon" phase as a thin crescent visible in the western sky just after sunset to First Quarter phase, and about twenty-eight days to pass from the same "New Moon" phase until its disappearance in the glow of the Sun following waning crescent. A period of twenty-eight days also corresponds exactly to four weeks, and we recognize the week to be a calendar device that honours the seven bright planets of the ancients (including the Sun and the Moon) visible to the unaided eye. Such coincidences seem to imply a divine importance to perfect numbers.

It is from such thoughts that one can catch a glimmer of understanding about the origins of two other numbers. The division of a complete circle into 360 equal segments, called degrees, would seem to relate to the fact that the number 360 $= 6 \times 6 \times 10$, in other words it is the product of the number 10, which is the basis for our decimal system, with two perfect number 6s. The fact that the number 360 is also close to the number of days in the year is also relevant.

The same perfect number 6 would also seem to tie directly into our timekeeping system. For example, one can easily imagine ancient peoples dividing the Sun's daily path in the sky into roughly equal segments: six marking its passage from the eastern horizon to the meridian, and another six marking its passage from the meridian to its setting point. Add another

Journal

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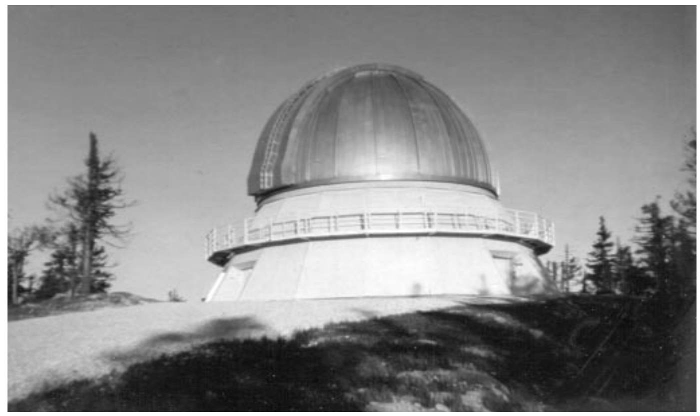
twelve divisions to account for the Sun's unseen motion while below the horizon, and you have fully explained the origin of a 24-hour day. The reason for choosing six equal portions rather than, say, five or ten likely relates to the fact that six is a perfect number. In other words, we have a 24-hour day because six is a perfect number.

Time zones and Daylight Saving Time are more recent additions to our method of keeping time, and they in turn produce some rather curious results. The interesting effect produced on the observed times for sunrise throughout the year as a result of the switch from Daylight Saving Time to Standard Time in late October is addressed in this issue by David Chapman. The even more remarkable local variations in daylight saving time arrangements, or non-arrangements, that exist across Canada are described by H. David Matthews and Mary Vincent in their GeoMap article "It's about time" appearing in the September/October 1998 issue of *Canadian Geographic*. The article makes a fascinating read for those interested in knowing the exact details of how watch time is regulated in different parts of Canada.

News Notes
En Manchettes

MONT MÉGANTIC HAPPENINGS

The Mont Mégantic Observatory, shared by l'Université Laval in Quebec City and l'Université de Montréal, celebrated its twentieth anniversary in an asteroidal manner. A mid-sized main-belt asteroid discovered February 20, 1990, by the Belgian astronomer Henri Debehogne has been named in its honour (see JRASC, 92, 227, 1998, October). Situated in the Eastern Townships of southern Quebec, the observatory has been a focal point for astronomical activity and popularization, and recently the research facility has been joined by the new "Observatoire Populaire du Mont Mégantic," which has educational facilities including telescopes available for public viewing.



The Mont Mégantic Observatory celebrated the 15th Festival d'Astronomie Populaire du Mont-Mégantic July 10–12, 1998

LEONID METEORS

By the time this note is published the 1998 Leonid meteor shower may have turned out to be a meteor storm reminiscent of that of 1966, although it was not expected to reach the levels of up to 150,000 meteors per hour reported that year from western North America. Although the forecast storm levels were only one-tenth of that peak rate, the present recurrence is significant in that there is now far more space hardware susceptible to damage by the micron-sized meteoroids. Such a potential for damage, as well as scientific interest in the event, led to international expeditions being mounted, including a paired expedition to Mongolia and Australia conducted by the Toronto-based Centre for Research in Earth and Space Technology (CRESTech), with participation by Canadian universities, the United States Air Force, the Canadian Space Agency, the Canadian Department of National Defence, the Hughes Space Corporation, and the European Space Agency. With the aid of electro-optical camera systems and radar, those participating in the expedition hoped to obtain real-time data about the hazard levels from meteoroids during the storm period.

The Leonid meteoroids have high space velocity, of order 70 km s^{-1}, and upon impact with a spacecraft vapourize into small plasma clouds capable of causing short circuits in sensitive electronic components. There has been increasing awareness of the hazards of the near-Earth environment resulting from solar and magnetospheric activity, but the meteoroid hazard has not been seriously evaluated despite the loss of a spacecraft during high Perseid activity several years ago. The storm period for 1998 is brief, only about one hour long, thus necessitating travel to a favourable longitude for proper observation. Generally a 33-year recurrence period is associated with the Leonids, with enhanced levels for one to three years. Thus it is quite likely that the Leonids will be strong again in 1999. Unfortunately for Canadian ground-based observers, the present prediction is for prime viewing in Eastern Europe in 1999. More information on the Leonids can be found at the web site www.imo.net/news/leohints.html.

KITCHENER METEORITE

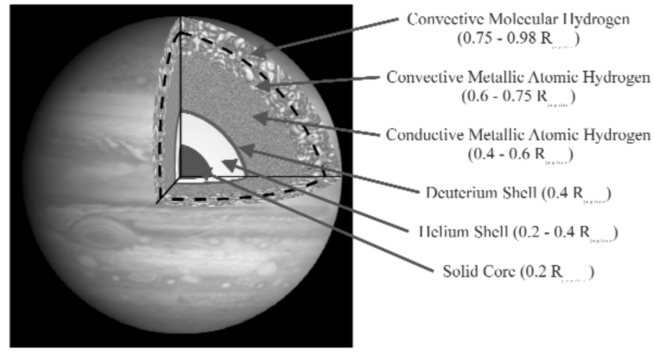
According to a newspaper story in the *Kitchener-Waterloo Record*, golfing may be more hazardous than previously thought. Golfer Orville Delong had a meteorite pass close to his head while he was golfing at the Doon Valley Golf Club on the morning of Sunday, July 12. The golf course is located just northwest of Highway 401 and somewhat east and south of Kitchener near the village of Doon. Mr. Delong subsequently retrieved the fist-sized piece of space debris and had it confirmed as a stony meteorite — complete with fusion crust — by scientists from the University of Toronto. The meteorite, now known as the Kitchener Meteorite, presently resides with curator Richard Herd of the National Collection. While meteorite finds are common (although not as common as finds of misidentified "meteor-wrongs"), falls occur much less frequently. If enough observations are gathered, a fall may be used to identify the likely origin of a meteorite based upon its orbit. Only four meteorites have ever had reliable enough sighting data for their precise pre-collision orbits to be established with certainty, and it is unlikely that this daylight event will be analyzed in such fashion. The prompt recovery of the specimen permitted study of the short-lived radioactive isotopes that are present in small amounts in freshly fallen meteorites. Meanwhile, one wonders who is responsible for yelling "fore" when a meteorite is seen flying over a golf course.

A SUPERLATIVE CANADIAN SATELLITE

The Microvariability and Oscillations of STars project (see JRASC, 92, 223, 1998, October), or *MOST*, will place a small telescope in Earth orbit to study stellar structure and evolution. Under Principal Investigator Jaymie Matthews of the Department of Physics and Astronomy of the University of British Columbia, a team of Canadian and U.S. researchers and designers will develop an instrument capable of doing extremely accurate stellar photometry over extended periods of time. Working above the atmosphere, an instrument of a size familiar to most amateurs, with a novel stabilization and pointing system, will be able to record extremely small variations in stellar light. Much like seismic waves have certain favoured frequencies tied to the structure of the Earth, it is expected (and known already to be so in the case of the Sun) that stars will show preference for oscillations at certain frequencies depending upon their structures. As a result, the expected changes in the structure and dimension of stars as they mature should affect their modes of oscillation in such a manner that a knowledge of them can be used to determine their ages. *MOST* is part of the Canadian Space Agency's (CSA) Small Payloads Program, and CSA will contribute $4 million to its cost.

IS JUPITER A NOT-SO-FAILED STAR?

For decades astronomers have been perplexed by the excess amount of heat coming from the planet Jupiter; the planet actually emits slightly more energy than it receives from the Sun. Now a group of Canadian astronomers, led by Rachid Ouyed of Saint Mary's University in Halifax, may have a solution that could radically change the way we think about our largest planet (July 1 issue of the *Astrophysical Journal*).



A new interior model of Jupiter proposed by Ouyed *et al.*

Previously the accepted explanation for the extra heat was through the slow release of gravitational potential energy associated with the planet's formation and contraction. According to such a model, heat from the interior of the planet is transported to the surface through convection. The model does have problems, however, since it has difficulty accounting for Jupiter's powerful magnetic field and also results in an estimated age for the planet that is perhaps 500 million years older than the accepted value of 4.5 to 4.6 billion years.

Ouyed, with his collaborators Wojciech Fundamenski of the University of Toronto and Gregory Cripps and Peter Sutherland of McMaster University, have put together an alternative and potentially revolutionary explanation for the excess heat. They propose that it may be produced by nuclear fusion, the same basic engine that powers the Sun and stars. In the core of the Sun, 15 million-degree temperatures and 250,000 Mbar pressures (approximately 250 billion sea level atmospheres) are sufficient to fuse hydrogen nuclei into helium, releasing huge amounts of energy. Jupiter, on the other hand, has a core temperature of only about 20,000 K and central pressures of 40 Mbar. According to Ouyed's team, such conditions are still sufficient for deuterium – deuterium fusion to produce the isotope ^{3}He (helium-3). Deuterium is an isotope of hydrogen that has a nucleus composed of a neutron and proton instead of the single proton found in the nucleus of the hydrogen atom. The Ouyed *et al*. model requires that 5% to 15% of Jupiter's deuterium must have been deposited relatively quickly into the core of the planet during its formation in order to account for present observations of the planet's heat and interior sound velocities. The exact mechanism capable of transporting that amount of deuterium has not yet been thoroughly established. Ouyed and his collaborators argue, however, that deuterium sedimentation could be possible if Jupiter was formed from the collision and coalescence of planetesimals rather than forming directly from a primordial gas cloud.

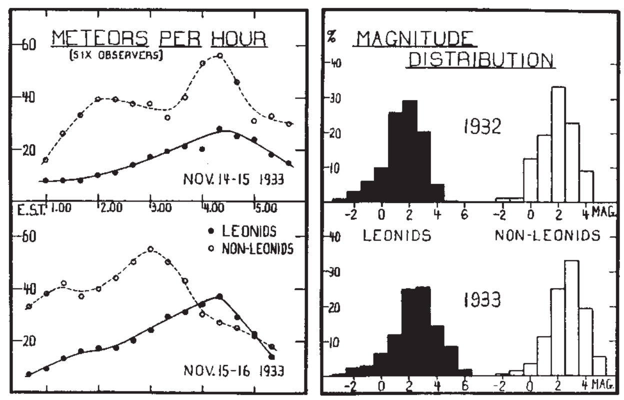
The total energy output is estimated to be less than a billionth the amount from the Sun. However, according to the calculations presented by Ouyed *et al*., Jupiter would be able to sustain such a tiny nuclear power plant for 100 billion years, outlasting our Sun ten times over. Ouyed has also extended the concept to the other gaseous planets. The team concluded that if they formed under similar conditions, then deuterium fusion might also be taking place deep in the cores of Saturn, Uranus and Neptune.

For many years Jupiter has been called a "failed star" owing to its Sun-like composition and apparent absence of a nuclear furnace. That way of thinking may have to change.

FROM THE PAST | AU FIL DES ANS

OBSERVATIONS OF THE 1933 LEONIDS — PART I

A program of photographic and visual observations of the Leonid meteors was carried out at a number of stations in and near Toronto on the nights of Nov. 14-15, 15-16, and 16-17, 1933. It is proposed this month to discuss those observations made at the David Dunlap Observatory and next month to report on the others.



The visual observations were organized on the same general plan as those of 1932 at the Harvard Observatory. Groups were made up of one recorder together with three to six observers. All meteors seen were plotted and recorded to the nearest second. Each group worked independently, covering a certain portion of the sky. Later, the records of the various groups were compared, all duplicate meteors picked out, and thus the total count for the whole party determined. Mr. K. O. Wright, of the Department of Astronomy at Toronto, took complete charge of the organization and the carrying out of the observations at the David Dunlap Observatory, the writer being located at the Harvard Observatory during the Leonid period. Mr. Wright also performed the above reduction, the chief difficulty encountered being uncertainties in timing owing to the fact that some of the timepieces did not function properly in the below-zero weather which greeted the observers. Observations were also made with a reticle similar to that described in Popular Astronomy, 41, 283, 1933.

* * * * *

The nights of Nov. 14-15 and 15-16 were clear and cold. Nov. 16-17 started to cloud in shortly after midnight and after alternate clearing and clouding till 3 a.m. the sky clouded up for the rest of the night. For that reason no estimate of the total number of meteors appearing on Nov. 16-17 can be obtained from the Toronto observations. The total number of meteors observed by the whole party is given in Table I. These numbers contain no duplicate meteors.

Of these meteors 630 were plotted on the maps. Since the number of observers varied throughout the night it was thought best to reduce the above counts to a standard of six observers and this was done by multiplying the actual count for each twenty-minute interval by the factors in Table II. These factors depend on the number of observers and were formed from an average of tables given by Denning, (Obs., 80, 373, 1897), and Kleiber, (A.N., 110, 69, 1884). Denning concluded that six observers will see half the meteors visible.

The reduced rates for the first two nights are shown in the diagram, each plot being for the thirty minutes preceding and following. The steady increase of the Leonid rate to a maximum is very noticeable on both nights. This maximum rate occurred about 4.25 a.m. on Nov. 15 and at 4.15 a.m. on Nov. 16. In the 1932 observations at Harvard the maximum rate on Nov. 16 was at 3.55 a.m. The corresponding local mean times are 4.08, 3.58, and 4.09 respectively, showing very good agreement. The Non-Leonids were surprisingly numerous in 1933, many seeming to come from radiants to the west of the Leonid radiant. Their varying hourly rate throughout the night is in marked contrast to the behaviour of the Leonids. The six brightest meteors on the morning of Nov. 17 were all Non-Leonids with an average magnitude brighter than –1. Two daylight meteors were observed on Nov. 15, shortly before sunrise, as the party was leaving the observatory. These meteors appeared within thirty seconds of each other and were apparently Leonids, leaving trains that remained visible for several seconds.

* * * * *

by Peter. M. Millman,
from *Journal,* Vol. 28, pp. 137–142, March, 1934.

Questions and Answers
Questions et réponses

Predicting Sky Transparency and Seeing Conditions

Is there any relationship between weather patterns and good observing conditions?

Here are a few general rules for picking a promising observing night:

The best transparency (clean, unpolluted air) normally occurs when the sky first clears behind a strong cold front. That is because the source region of the air mass behind the cold front is normally an area of higher latitude to the northwest (which is essentially an uninhabited area in most parts of Canada). Such a night, however, is apt to be restricted to low-power viewing because, while the transparency is excellent, the seeing (image steadiness) is poor as a result of all of the turbulence aloft caused by the strong winds and wind shear associated with active weather systems.

If a *large* high-pressure area builds in behind the cold front, the seeing will probably improve night after night, as the winds become lighter both at the surface and aloft. The downside of that, of course, is that as the seeing improves the transparency will probably deteriorate as your local pollution sources cause increasing concentrations of pollutants in the now stagnant air.

I find that the best overall observing conditions are frequently the second night after the cold front passes through. The air is still clean enough to offer transparency that ranges from very good to excellent, and the seeing may, by then, have improved as the wind shear aloft decreases.

The very best seeing occurs just as the *upper ridgeline* passes overhead. For a few hours the winds may be light all the way from the surface to the stratosphere and your telescope's resolution may indeed be "diffraction-limited" for once! That is the rare night on which you can use high power to split very close double stars and see incredible planetary detail, things like details in Jupiter's Great Red Spot; not only Cassini's Division in Saturn's rings but perhaps even Encke's Division.

As an upper ridge passed on October 12th, 1983, I saw Sirius's white dwarf companion through my Meade 20-cm Newtonian at 34× using a polarizing filter in bright morning twilight. (They were 9″ apart in 1983, but are separated by only 3″.5 now.) Another upper ridge allowed me to split Gamma Andromedae BC at 0″.43 using 522× and a polarizing filter utilizing my Meade 40-cm Newtonian on October 29th, 1995. [The well-known components of Gamma Andromedae are golden (A) and blue (B), but I am talking about splitting B into its two components, B and C.]

If you have had a long, hot, dry spell and the forecast is for a change beginning tomorrow (either increasing high cloudiness or a forecast cold frontal passage), *observe tonight* because the upper ridge line is forecast to pass through shortly and image steadiness (seeing) could be the stuff of legends. (I use the term "could be" because in meteorology there are always qualifiers that cannot be discussed without going into a textbook-length reply!)

As soon as the upper ridge passes, you will probably get thin, high cirrus or cirrostratus cloud pushing in and your seeing quality will plummet. Even if the winds aloft remain relatively light for a day or two, the ice crystals in cirrus and cirrostratus clouds destroy image quality. Conversely, you can view planets or the Moon quite happily through clouds formed of water droplets, like thin altocumulus clouds, thin stratocumulus clouds, or fog, if the winds aloft are light. These thin water-droplet clouds just act as a neutral density filter.

Other things being equal, the best seeing in a high-pressure area usually occurs towards dawn. That is because: (a) the radiational cooling of the ground has largely ceased so you are not dealing with rising warm air as you were in the evening, and (b) the lower layers of the atmosphere become stratified as an inversion forms and the winds frequently are nearly calm for several thousand feet above the surface. (If, however, a morning low-level jet forms just above the inversion, your hoped-for fine seeing will not then materialize — there are no sure things, but there are very promising patterns that repeat over and over again.)

Your immediate observing environment also improves towards dawn for two reasons: (a) your telescope should be in thermal equilibrium with its surroundings after an all-nighter, and (b) most of your heat-producing fellow observers have gone home to bed! The Prince George Observatory's 0.6-m Cassegrain is in a dome with a classical slit. The heat from all the bodies in the dome rises through the same slit through which you are trying to view. I have never had a high-resolution view when more than one other observer was in the dome at the same time. Worse yet, every time that someone enters the dome from the warm room, the surge of warm air through the open door instantaneously destroys the seeing until the door is closed and the warm air exits the dome.

While I am at it, let me mention one of my pet peeves. The word "seeing" is misused by far too many amateur astronomers, including experienced ones who should know better. Seeing refers *only* to image steadiness and the potential for achieving high resolution. Seeing has nothing to do with sky clarity and cleanliness — that is *transparency*. The transparency will likely be poor after the air in a high pressure area has stagnated over you for a few days, but the *seeing* should improve night after night, with the best seeing as the upper ridge passes, even though your limiting magnitude may be down to a murky magnitude four by then.

Alan Whitman (retired weatherman)
Okanagan Centre

How To Stay Warm at a Cold Eyepiece

by Tony Wallace, Hamilton Amateur Astronomers
(bravhart@interlynx.net)

Winter is one of my favourite seasons. No, I am not deranged, but I have learned to harmonize rather than fight with the weather it brings. I have spent many a weekend winter camping and enjoyed it thoroughly, day and night, even in temperatures of −35° C.

That learning came at the cost of numbness, shivers, and generally living through my mistakes in the early boldness of such ventures. Last winter I was able to confirm that the same techniques that warmed me on the trail and in camp would keep me cozy at the eyepiece of my telescope. Here, then, is some of what I now know about dressing for comfort as applied to winter observing.

> **"In order to be comfortable we need to dress for a temperature about 10 degrees lower than the air temperature"**

How warmly should I dress?

Observing consists mostly of sitting or standing around as opposed to walking, chopping wood, *etc*. Add to that the effects of radiating our heat into the inky night sky and you have a recipe for disappointment. The cure is simple. We need only to dress somewhat warmer than if we were outside doing some physical activity. In order to be comfortable we need to dress for a temperature about 10 degrees lower than the air temperature. That, by the way, is good advice for observing at any time of the year, but particularly so in winter.

Know thine enemy!

Rather than provide you with a list of solutions, I would like to explain some of the processes at work that counteract efforts to keep warm and the basic remedies for them. Once you understand what is happening, you become able to recognize symptoms and devise your own solutions to problems that may arise while you are outside on a winter's night.

The major culprit in making us feel cold is our perspiration. We are all familiar with the perspiration of summer, but what about at other times? It may surprise you to know that we perspire continually, all year round, all day long. It seems our skin is very partial to life in a tropical rain forest and tries to create the same humid conditions wherever it may be. In fact our comfort demands such conditions. Skin loves moist air and sets about making the same environment by perspiring into the adjacent atmosphere. The perspiration emerges from our pores as water vapour. We are generally unaware of the process and only feel a change when it forms on the skin as a film of water and then evaporates directly from the skin's surface. In that case, the perspiration is being used for cooling rather than just avoiding dryness.

The process of evaporation, you may recall from high school physics, requires an additional amount of heat (latent heat of vaporization is the technical term) to bring a liquid to its gaseous state at the same temperature. It gets that heat from the skin's surface, thus cooling us in the bargain. The problem is that we do not want to lose heat on cold winter nights, so we put some clothing next to our skin to feel warmer. Well, perhaps…

It depends on what that undergarment is made of. The most popular fabric for underclothes is cotton. We like its soft feel, and it is both inexpensive and durable. The difficulty is that it is just about the worst thing one can wear next to the skin on a cold night. You see, cotton likes water. That is, cotton absorbs and retains water, which is why we use it in the best towels. One reason it feels so nice is that it is much easier to have a rain forest next to your skin when what you are wearing is sopping wet. So, getting back to our skin, cotton soaks up the water and holds it like a jug. Then, in order to stay warm we not only have to keep ourselves warm, but that wet garment must be kept warm, too. What we need is a fabric that abhors water and would rather dump it out than retain it. Polypropylene is the best known of such hydrophobic fabrics. It is a bit more expensive than cotton and you have to be careful to wash it in cold water and hang it to dry (otherwise you will be lucky if it will fit the cat after a good hot wash and dry). We refer to such fabric as having the ability to wick the water away — and that is just what happens. The perspiration is conducted away from the skin, often before it can even condense. Condensation, if it occurs at all, takes place on the outside surface of the garment undetected by our lily whites and we feel warm.

The Layered Look

We have seen how important it is to choose the right kind of undergarment fabric for staying warm in winter. The undergarment (winter lingerie, if you will) is part of a system of layers designed to maximize our heat retention and to stay cozy while at the eyepiece or some other activity. The garment ought to fit snugly. We will refer to it as Layer 1.

Next comes Layer 2, the insulation layer (or the fluffies). Its purpose, as the name states, is to insulate us from the cold of night. Garments are better if they fit loosely, not tightly. Appropriate fabrics are characteristically bulky, lightweight, and able to trap still air in their tangled fibres or tiny air pockets — air movement being a no-no for heat retention. Roughly speaking, they can be divided into two types, natural and synthetic. Each of them has pros and cons.

"Wool has the wonderful quality of retaining much of its insulation value even when it is wet."

The most popular natural fabrics are down and wool. Down is "nature's own snuggly blanket" and the most efficient insulator for our purposes. High-grade goose down is able to provide more insulation value per unit weight and per unit volume than any other material for such an application. It has, however, one serious drawback. If it ever gets damp, or, God forbid, wet, you have big trouble! It takes days to dry out and its insulating value plummets to the point of making it useless in that state. Down is definitely not hydrophobic. Remember the perspiration that passes through Layer 1? If it collects in Layer 2 (and it will) you are in for discomfort. Down is beautiful stuff and a great temptation, but I have come to avoid it in clothing for that very reason. Well, that, and the fact it is so expensive that they want my firstborn for it.

Wool, on the other hand, is relatively affordable and, while not having as high an insulation value as down, does a pretty good job in clothing. One can always make up for its lower insulation value by putting on two sweaters, right? I will say more about that later.

What about dampness? Wool has the wonderful quality of retaining much of its insulation value even when it is wet. It is much more forgiving than down. Think of it as having built-in insurance. I like it. My skin does not. Many people, like myself, have skin that rebels against dressing up like sheep. We either put up with the itching, tickling, and general torture, or find something else.

Enter the synthetics. There are now on the market several great synthetic fabrics with excellent insulation qualities. Names like Hollofil, Quallofil, and Thinsulate come to mind. They are all hydrophobic and a good choice for Layer 2. My favourite, though, is Polartec by Malden Mills. The stuff is very lightweight, has a luxurious fluffy feel to it, does not pill (the technical term for forming little balls of fabric on the surface after repeated use, a.k.a. nubblies), and comes in an endless array of colours and patterns. It is so hydrophobic that, if you get it completely soaked, just squeeze out the water and it will hang dry in twenty minutes. It will even dry while you are wearing it. I had the privilege of confirming that empirically on a fall canoe trip once, but that is another story.

Okay, there you have it. Some Layer 2 facts and personal biases. The last thing to remember about Layer 2 is that it is far better to wear multiple thin layers than a single thick one. The wisdom in that is as follows: if you are warm to the point that you are feeling perspiration, then you can (must) peel off a layer or two until your brain turns off the water tap. If not, you continue to push moisture through Layer 2 at a high rate. Even the best will have trouble keeping up with such a process, and that will leave you with a jacket full of water to keep warm. So, Layer 2 is simply as many thin layers of insulation as you will need for the coldest temperature of the night in question.

Layer 3 (the wrapper) is an outer shell with two important functions. It must be able to keep the wind and rain from getting to you, and, it must allow the moisture that has been travelling out through Layers 1 and 2 to escape from your skin. We do not do much observing in the rain, so that is not a concern here, but keep it in mind for other outings when buying.

Wind? If it is clear but windy, astronomers stay inside, not! Even the slightest of breezes will meander through Layers 1 and 2 and kiss you with frozen lips. We need to keep that air movement, however small, outside Layer 3. At the same time, Layer 3 must allow our inner moisture free access to the universe. Those two requirements may seem to be mutually exclusive in a single garment. They used to be, but not any more.

There are now a number of high-tech synthetic fabrics that can do just that. The best known of them is undoubtedly Gore-Tex. Gore-Tex is as waterproof as a rubber glove, yet will allow water vapour or air to pass through the micropores in its waterproof barrier. If absolute waterproofing is not a big concern for you, then consider a fabric known as Super Microft. It is what the manufacturer calls "water repellent." My experience with it has been that it will keep you dry long enough to get to shelter, if you run! I like it because it is an excellent wind barrier, lightweight, soft and comfortable, and, above all, is a good breather that will vent my own moisture to the world outside. Get clothes a size larger than you normally would, and they will be perfect at the eyepiece or any other cold outing. Such specialty fabrics, and consequently the garments, are a bit pricey, but consider the following.

I have two shells: one is Gore-Tex, the other is Super Microft. My last Gore-Tex jacket is ten years old and still going strong. (Actually, I grew out of it.) I do not own or need a raincoat, overcoat, leather coat, parka, snowmobile suit, fall or spring jacket, K-way shell, or umbrella; I have avoided a lot of purchases over the years. The two jackets mentioned above are functionally superior and look good as well, at least to those who know the magic they hold!

Extremities in Extreme Weather

So far we have discussed materials for covering our torso, arms, and legs, but what about our head, hands, and feet? They are generally subject to the same three-layer concept, but require some special attention. The hands and feet, and to a lesser extent the head, are indicators that warn us that we need to adjust our clothing. They are the first discomfort we feel when we are not quite dressed for the part.

Head

There is a lot of truth in the old adage: if your feet are cold, put your hat on. I have read and heard various reports that the amount of heat lost from an uncovered head lies between 25% and 40%. Even conservative estimates indicate that is in the "Wow, that's a lot!" category. It may seem at first that it is a detriment. To the contrary, it gives us a range of control over our body heat just through changing headgear. So, get out your earmuffs, headbands, balaklavas, berets, babushkas, turbans, hoods, and what-have-you. They constitute your arsenal of fine-tuning weapons with which you can maintain a balance of warmth and ventilation for the rest of your body (including those cold feet).

We must not forget about ventilation of the ever-present perspiration making its journey from skin to the outside air. Be aware that bundling up your head may impede the process and result in condensation in Layer 2 of your headgear. I find it useful to think of the head and its garments as a sort of chimney conducting heat and moisture in an upward direction. My various combinations of headgear then become a damper that regulates the chimney action. Too little, and you lose a lot of heat; too much and you retain heat but your head ends up wet (like when the fireplace damper is closed too far and smoke fills the room).

I tend to dispense with Layer 3 on headgear when observing since it allows better moisture flow and winds will be low or absent at such times. Layer 2 is supplied by all manner of non-cotton headgear. I must admit to a personal neglect of Layer 1 in cold weather observing because I do not like snug-fitting headwear. Nevertheless, I do own a polypropylene balaklava which gets use in very cold and windy conditions. The key to headgear is to have a number of options available and to vary them to suit conditions at the eyepiece.

Hands

Your hands, and in particular your fingers, will be required, at a minimum, to change eyepieces and make fine adjustments to your telescope throughout the observing session. At the other extreme, you may be continually thumbing through charts and sketching the objects that you find. As a result, they are quite vulnerable to the icy wiles of Old Man Winter.

The range of available handwear includes three- and five-fingered gloves, slit-fingered gloves, fingerless gloves (a.k.a. urchin gloves, like the ones that Bob Cratchit wore in Charles Dickens' *A Christmas Carol*), mitts, combination glove-mitts, and the ever-useless and hard-to-find muff. They are available in a mind-boggling array of materials from polypropylene to neoprene; Polartec to what-the-heck. The easy way out of the maze is to apply our three-layer principle to handwear. The basic warmth requirements are met with a polypropylene inner glove, a Layer 2-type overglove that insulates, and an outer mitt of Gore-Tex or some other breathable material. The last layer is a mitt since mitts are always warmer than gloves.

There is, however, another important criterion affecting our choice, and that is the need to be able to make fine mechanical adjustments. That can be as frustrating as picking fly droppings out of pepper while wearing boxing gloves unless we make allowances. That is where the particular style of hand-wear comes in. Fingerless gloves are a boon in such situations. They actually have only the finger tips missing and so allow good tactile sensation as well as keeping most of your hand warm at the same time. They are excellent choices for Layer 2 and should be worn over a full-fingered Layer 1. Layer 3 can be quite a nuisance because it has to come off each time you have to fiddle with things. A good candidate for such an outer layer is a Gore-Tex mitt with a Velcro closure applied to a slit across the palm. They are made for the express purpose of freeing your fingertips for work without having to remove the mitt.

My own experiences at the eyepiece have resulted in my choices as follows. I wear full-fingered polypropylene inner gloves. Over them I wear a pair of wool urchin gloves. The combo has me comfortable in most cases, however, I occasionally resort to my "cold killer combo." I replace the inner gloves with a pair of fisherman's neoprene slit-fingered gloves. Neoprene is the type of closed-cell foam rubber used in wet suits. The fingertips (and thumb) are slit on the palm side at the first joint, allowing me to peel them back and expose my fingertips for fiddling about with filters and such. Bits of Velcro keeps the "flaps" out of my way until I am ready to cover up again. That provides me with the ultimate in warm hand-wear and dexterity. "But it is not breathable!" you say. You are right, but read on a bit further.

Feet

Feet are unforgiving! Let us face it, the threat of cold feet is responsible for many of us refusing to even go outside in winter. Feet are the first to complain when they get cold — and they do it so-o-o-o well, don't they? Well, we can look at it positively too. The same attribute makes them the early warning sensor in detecting heat loss and signaling the need to adjust our garb. Do we need to put on our hat?

The above assumes we are properly attired in the foot department. Starting with Layer 1, we would wear a pair of polypropylene, or other wicking, socks, and, over them, one or more insulating Layer 2 types of socks. Our winter boots would suffice for the windproof Layer 3, except that they are often not breathable at all, or are grossly inadequate for the task. That fact alone is the cause of nearly all cold feet at the winter observing site. Extreme countermeasures may be called for.

Recall the neoprene gloves? They are as impenetrable as rubber gloves, because, well, that is what they are. What they do is prevent any moisture from leaving the surface of my skin. The skin on my hands perspires enough to create its beloved "rain forest," and then stops, as long as I am not too active. The insulating Layer 2 has absolutely no way of getting damp from the inside, and we are not about to observe in the rain. The layer is known as a vapour barrier when used next to the skin. It is a technique used by avid campers in extremely cold conditions. They (I) go so far as to spend the night using a vapour barrier sleeping bag liner to eke out a ten to fifteen degree advantage over life without one. The vapour barrier is a type of Layer 0. It can be used to advantage when you are not physically very active. Get too active and you will drown in your own perspiration!

Getting back to our feet, it is the same secret weapon we will deploy to guarantee that the familiar cozy feeling prevails. All we need is to don a couple of plastic bags as the first layer and cover them with Layer 2 socks. Do not laugh, but I find bread wrappers are great for this, the kind without holes in the bottom. The extra length makes all the difference. I first discovered it while on a fall camping trip with the local motorcycle club. It was a cold and rainy return from wherever we had been and I was intrigued to see the more experienced among us snap up all of the bread wrappers left over from our food supplies and wear them inside their socks. One has to be a quick study in a bike club. I found it made a big difference on the ride home. Are you too shy to try it? Nobody is going to see anyway.

I have not yet needed to resort to that level of footwear while observing, but some people are different in their, let us say, cold tolerance limits. My wife, for example, would pack snowmobile boots for a trip to hell and would still complain of cold feet. I suppose that is exactly what she will give me for writing that — hell and cold feet!

My personal solution to cold feet is a bit more conventional.

"Let us face it, the threat of cold feet is responsible for many of us refusing to even go outside in winter."

I start with polypropylene socks, then a layer of wool or synthetic socks. I will include a second layer of them if I am to wear my size twelve hunting boots. I take a size ten shoe, but the size twelve boot keeps the Layer 2 socks thick and fluffy! My preference, though, is to wear a pair of moon boots over the polypros and a single pair of wool socks. Moon boots are a wonderful invention fashioned directly after Inuit mukluks. They are available at many specialty outdoors stores. They consist of a mid-calf length upper of ripstop nylon that has been stuffed with Hollofil or some other synthetic insulation. That is attached to a thick sole of Evazote (the yellow spongy closed-cell foam that some sleeping pads are made of) that has been finished by covering with heavy Cordura material for durability. The ripstop nylon seems to form enough of a wind barrier and still allows moisture to escape freely. They are the best when the snow has no chance of melting.

Fuel for Extra Heat

Now that we have learned how to dress ourselves, there is one more area to cover. While we are observing we need to consume copious amounts of hot drinks. They go a long way to make a cold night a pleasure for all but the most obstinate curmudgeons.

A word about alcohol — don't use it. There is nothing wrong with a glass of wine or a "wee dram" of the aqua vitae. I would not refuse one. There is, however, a danger in downing a few of them. The ability to sense subtle changes in temperature is easily impaired without one even noticing. By the time you become aware of the cold, the best thing to do is pack up and go home because, in reality, you are probably well down the road to hypothermia, from which some never return. Enough said.

The usual hot chocolate, Ovaltine, and herbal teas are fine companions. Be aware that strong tea and coffee result in a net loss in the body's water reserves. Take water along to drink as well. Hot Dr. Pepper is great, as is hot fresh cider, mulled if you like (skip the rum). Here is one of my favorite cold night recipes. I usually make two litres.

Pour 1 package raspberry Jello into a bowl.
Add 1 litre hot water.
Stir until dissolved.
Add fruit punch drink crystals to taste.
When it is okay to the taste, add some more.
Stir and pour the lot into a thermos.
Go to the observing site.
Pour the lot into you and your friends.

Do not let it go cold in your mug lest it become sloppy jello! Oh yes — be careful around the scopes. I just hate those sticky Naglers.

Parting thoughts

There you have it! Remember the three-layer formula and a few tricks with the extremities and you will be a winter observer in comfort. Exercise an extra bit of common sense before deciding to venture out. That is, do not expect great results in −40˚ temperatures. Your scope will likely tell you when it has had enough of that nonsense by creaking loudly or just refusing to move. If you should get cold and are not sure what to do about it, just go for a walk. It is surprising how little you will have to do to become warm. I would bet it takes less than a hundred metres to restore your comfort.

Now then, no more excuses. I expect all of you to be ogling the skies at observing sessions from December right through March.

Tony Wallace's interest in astronomy has recently come to include telescope making. He can often be found suffering the rigours of the "Parabolic Willies" during yet another attempt to inflict his will upon some obstinate piece of Pyrex.

The Wilkinson Memorial Observatory

by R. A. Clark, Windsor Centre (rclark@wincom.net)

The town of Eastend is in southwestern Saskatchewan, near the borders of Alberta and Montana. The population numbers seven hundred and fifty-two. It nestles in a wide coulee that was carved by an ancestor of the Frenchman River. The stream winds peacefully southward through the prairie wheat lands. To the west, the Cypress Hills shelter the town from the infamous prairie winds. These picturesque hills were once home to the mighty Tyrannosaurus Rex dinosaur, but are now a place where gentle white-faced cattle, mule deer, and antelope graze.

The Wilkinson Memorial Observatory at Eastend, Saskatchewan.

Eastenders live in unique but quiet isolation. The nearest large community is Swift Current, almost one hundred kilometres to the north. They are a community-minded people. They have created resources that are unsurpassed by many larger towns. There are five churches, a high school, an arena, a curling rink, a nine-hole golf course, a 14-bed hospital, and a café where most of the community's business deals are consummated. They have plans for a million dollar museum to display the complete skeleton of a Tyrannosaurus Rex that was recently discovered in a nearby canyon wall — and on a hill, just south of town, they have an astronomical observatory that would be the envy of most educational institutions having an astronomy program. It is called the Wilkinson Memorial Observatory.

In 1927 when a young blacksmith named Wilkinson immigrated to Canada, Eastend was already a bustling cow town. The ranchers and the wheat farmers needed someone who was good with a forge and who could repair their specialized equipment. Jack Wilkinson's smithy business boomed and soon he had expanded into a machine shop, using his own handcrafted tools. Jack had a lively curiosity about almost everything. His need to know and to discover extended to the stars that shone so brightly from the clear skies of Saskatchewan. Mostly from mail-order sources, he began to assemble information about astronomy and optics.

His first telescope was an ambitious 10-cm refractor, made from scrap tubing and welded in his own shop. Lenses were ground and polished with his own hands. Eyepieces were constructed as needed, from brass cylinders turned on his shop lathe. Next came a 15-cm reflector. The grinding of the mirror took the Wilkinson family one whole winter. A testing jig was designed and built to test the parabolic accuracy of the mirror. The town's pharmacist supplied the coating for the mirror, and the jeweler assisted with the application.

In order to provide a rigid mounting for the telescope, the Wilkinson machine shop truly came into its own. Many of the components came from a World War II Anson training aircraft that had crashed nearby. To track the stars according to the Earth's rotation, an equatorial mount was designed and constructed by the community blacksmith.

A 20-cm telescope was next with a mount so heavy that it sat at the back of the shop. When the stargazers of Eastend wanted a viewing session, they had to have enough strong men to roll the telescope onto the sidewalk with steel rollers. From there they gathered to observe the craters of the Moon, the rings of Saturn, star clusters, and nebulae. A whole new dimension had been opened for the citizens of this small agricultural town.

A new and permanent site was needed. As with his previous efforts, Jack Wilkinson designed a circular building with a rotating dome. By trial and error and with the help of many friends, the observatory was built on the roof of the high school.

Jack Wilkinson died in 1953, but the interest that he had awakened in the town lived on. A club was formed, with membership shares that would pay for the care and the improvement of the observatory. The structure was moved to a hill, on land donated by a local rancher. A Celestron C11 was purchased, and the little town could boast that they had an observatory with one of the largest telescopes in western Canada. They called their observatory the Wilkinson Memorial Observatory.

Times have changed for small prairie towns. Many young people have moved away and others have found new interests. The Wilkinson Observatory now sits alone, awaiting an eager face to press against the eyepiece. Occasionally classroom tours arrive during daylight hours. The students are able to look for sunspots or to try reading the signs on the Shaunovon grain elevators, 30 kilometres away. Wade Selvig of Shaunovon and Richard Drockner of Maple Creek make the long drive as frequently as possible. Jim Young of the Saskatoon Centre visits to help with the maintenance and to give advice.

My sister Beryl resides at Eastend, and so on a visit during the past summer I inquired at the town hall about a tour of the observatory. In true western hospitality the reply came, "Yes, you may. We'll send the key over and you may use it as long as you wish."

It was Kendal McCuaig, the local Plumbing and Heating contractor, who brought the key. Generously he offered to drive to the observatory to ensure that all was in good working order. The road took us along the "Red Coat Trail," the original route of the Northwest Mounted Police when they were establishing forts for the protection of Canada's southern border. It was on the same trail that Commissioner Walsh rode out to meet Chief Sitting Bull. The Chief and his Sioux army had retreated into Canada after the battle of the Little Big Horn. Walsh and a few of his officers intended to remind the Chief that he was now in Canada and must respect Canadian laws. The Chief agreed and he kept his word.

Kendal and I entered the observatory, and I was amazed by the spacious installation. A well-maintained C11, resting on its steel mount, was anchored in concrete. Its electronic drive is powered by solar panels. There is a fine assortment of eyepieces and filters, a solar filter, and a modest but adequate library of star charts and astronomy books. The dome moved easily with a generous opening slide. Under the sparkling skies of southern Saskatchewan and with no Moon, that night was going to be a wonderful experience for me.

My sister, her family, and some neighbours all expressed interest in joining me for a star party. Alas, as evening came, clouds rolled in and the rain began to fall. It rained all that night, the next day, and the next night. The following day I had to make a run for Regina to catch my flight home.

The happy part of this story is that the area had been suffering from a drought. The farmers and the ranchers were beginning to have concern for their crops and their cattle. There was great rejoicing in Eastend as the life-giving rain fell on my star party. As for me, I can only hope that the Wilkinson Observatory will be found by more of the curious with the same hunger for knowledge as that of the young blacksmith. His spirit lives in Eastend and on that lonely spot in the Cypress Hills.

Rod Clark has been a member of the Windsor Centre for ten years. He became acquainted with the stars and constellations through lessons in astral navigation taught by the Royal Canadian Air Force during World War II. He retired in 1989 from a career in radio broadcasting, mostly with the CBC in technical operations, but with writing opportunities. His interest in astronomy was rekindled by the return of Halley's Comet. (His father was fond of relating how he had being awakened during the night by his grandfather to watch the 1910 apparition of Halley's Comet, but unfortunately did not live to see it during its 1986 apparition.) Following retirement Roy purchased a Celestron C8 and joined the RASC. He has been writing a monthly column on astronomy for the Tecumseh Tribune *for the past seven years.*

Starfest for the First Time

by Phil McCausland, London Centre (pjam@julian.uwo.ca)

When I moved to Ontario last winter, one of my first thoughts was that it would now be possible for me to go to Starfest, as I had wanted to do for several years. I hoped I would not be scheduled for geological fieldwork at the same time. As it happened, I returned from Manitoba the week just before Starfest, so was able to attend after all. With me were my girlfriend Rachel Jones and her parents Peter and Helen, who had made a timely visit from Nova Scotia. We arrived at dusk on Thursday evening, after driving from London through brooding skies and occasional sprinkles. We were anxious to set up the tent, and Rachel's parents were anxious to check into the B&B just outside the campground before their room was given away. Fortunately, it did not rain, and our tent went up quickly.

I knew very little about Starfest except for the fact that it was an annual gathering of astronomy enthusiasts. Two years ago St. John's Centre member Garry Dymond came back from his first Starfest raving about the 'scopes, the people, and the atmosphere totally devoted to astronomy that pervaded the event. He was right. I was immediately impressed, even on that first cloudy night, by the friendly communal atmosphere at Starfest. You could talk to anyone present, all of whom were there for a similar reason — to enjoy astronomy and the company of their colleagues. The most obvious indicator of the amiable atmosphere was the widespread red lighting. While red lighting was in evidence almost as if it was required by law, it turned out to be a community response rather than the result of an onerous decree. Streetlights were not in evidence (hooray!) and the permanent camp facilities were operating in all-red mode. Normally a building such as the two-storey Recreation Centre illuminated internally by red lights would look eerie and blood chilling, much like Hallowe'en, but in the context of Starfest it was downright cozy, an inviting centrepiece to the community.

The campground as viewed from a distance, with some of the vendors' tents in the foreground.

The "Red Light Cafe" as seen in the blazing Saturday afternoon sunlight. Nearly everyone present is in the shade. It was about then that Peter Ceravolo flew overhead.

Having a Red Light Café is a great idea. I think cafés are great anyway, but this one was a lot of fun and was located in just the right place. It was also open until 2 a.m. How did they know my normal waking hours so well? Rachel and I enjoyed discovering it and other parts of the campground, wandering about under the clouds until well after midnight.

Friday morning arrived partly sunny and hot. During the day all four of us attended the beginner-level talks. Steve Dodson's "Getting Started in Astronomy" was fairly comprehensive, and it was good to have the opportunity to try out assembled versions of his build-it-and-the-stars-will-come Dobsonian kits. Glenn LeDrew endured the heat of the upper level meeting room in the Recreation Hall to present "Getting Started in Astrophotography." It was already warm in the room when he described some of the basic terms of astrophotography, and then it was necessary for him (reluctantly) to shut all of the blackened sliding doors and to turn on the projector to illustrate his talk. It became seriously hot in that room! Rachel and I ducked out for a few minutes to appreciate the deliciously cooler outdoor comfort of the 28° sunny afternoon. We returned again to the hot and humid interior of the room in time to catch the rest of Glenn's talk, as well as many good questions. I am just developing an interest in astrophotography (no pun intended!), and truly appreciated the opportunity to pick up so much basic information at one time. For instance, I never knew that there were three colour layers in standard colour film, each with differing rates of diminishing sensitivity (which is why Fuji slide film turns out dominantly green in astronomical exposures). Something I regret not attending was the Barn Door Tracker building bee, which followed shortly after Glenn's talk in the much cooler outdoors Swap Table tent. Perhaps next year…

Towards the end of the afternoon on Friday it began to cloud over, with a major thunderstorm cell visible to the north. Luckily that never hit us, but the clouds did, so the evening observing session was a patchwork affair at best. At times there were many "sucker holes" to choose from. With 11 × 80 mounted binoculars I was able to take advantage of the fleeting opportunities to spot Jupiter, M13 in Hercules, and the Andromeda Galaxy, and to sample parts of the prominent Milky Way drifting enticingly overhead in the Summer Triangle and running down through Sagittarius. Upon closer inspection, most of the clear patches proved to host a milky haze of Earthly cloud that robbed our dark skies of contrast. When viewed through binoculars, Jupiter was accompanied by three of its four bright moons—two trailing and one preceding (Callisto, Ganymede and Io) — and an additional one (Europa) was visible telescopically just emerging from crossing in front of the gas giant. About fifty people came out for the Sky Tour, led enthusiastically by Tony Ward. His 20-inch Dobsonian 'scope gave appealing views of M13 and the Jovian system, much to my babbling amazement (he said I was "saying all the right things" before I realized that I was saying anything at all).

A view of the main tent with much of the campground lying beyond it. The grassy area in the foreground is the general gathering-place where the Sky Tour took place in the evening.

It was as this session broke up under increasing cloud that we were introduced to another feature of Starfest: Lightwars! Illegal white flashlights and strobes aimed into telescope focusing assemblies proved to be a handy tool for lighting up the cloud bottom — and each other. I felt inspired to poke my red pocket light beam into one of the 11×80 oculars, and was rewarded with an ~80 mm red spot on the side of the Red Light Cafe, some 120 feet away! Marvellous! Even more gratifying was the discovery that I could monitor the progress of my red beam more closely by looking through the other ocular… Hey, at least I was legal!

Saturday morning brought more sunshine (it had cleared off at 3:30 in the morning) and a cooler day. We were up just in time for the solar eclipse. The solar eclipse wrap-up talk, that is, presented by five folks who took in last February's Caribbean wonder from various locations: Terry Dickinson, Bob Sandness, Rob Dick, Randy Attwood, and Dave Petherick. Not only were there photos of the eclipse itself, but each speaker also presented his personal eclipse experience. The panel later fielded several questions from the eclipse-eager. A camcorder video of the end of totality (Rob Dick) was my favourite; the sudden (so fast!) appearance of the diamond ring drew a deserved gasp from the audience. Book my flight to Europe!

Prospects are not great for a shot at a 1998 Leonid meteor storm in North America, as we learned from Wayne Hally in the next talk. However, if you can find the cash for a trip to East Asia (especially Manchuria or Mongolia) on November 17, you may catch the estimated peak of the shower with its radiant high overhead. In the meantime, those of us remaining on this continent will likely get two nights (the 16th and 17th) of elevated, but off-peak rates (I guess our counts can add definition to the sides of the meteor rate curve).

It is fun to ramble around outside the tents at Starfest. We visited vendors' tents to check out their astronomical wares. I got copies of *Sky & Telescope* and *Astronomy* at special Starfest rates, and enjoyed the rare luxury of browsing through astronomy books in the warm sunshine. Between us Rachel and I picked up four copies of the "Whizwheel," a nifty planisphere-like nomographic device designed by Glenn LeDrew for easy dial-up estimation of the photographic exposure times required for various astronomical objects, given the f-stop and ISO film speed. Further afield there were purpose-built observatory tents, and many, many varieties of telescopes to investigate. An amazingly portable custom-made wooden 6-inch binocular telescope was an excellent find (would that I had the money to buy one!). The Swap Table tent was open and busy during lunchtime. There were the usual assortment of observing and astrophotography accessories (binoculars, eyepieces, cameras), and also more organized items like "How to Build Your Own Observatory," a guidebook complete with building plans. I was casually looking for a camera, but instead managed to buy a nifty slide carousel from Dave McCarter for 25 cents (gee, I hope it was his…).

A series of maps mounted to accept pushpins was set up on tables outside the main tent. Upon closer inspection, this odd attraction turned out to be a great idea: "Make Starfest last all year," a sign called to passers-by, "Share your knowledge of dark sky sites with others!" Numbered blank index cards, pins, and cut ribbons were provided to pass on such useful information to anyone who cared to browse the maps of Ontario, the eastern U.S., and Atlantic Canada for the numbered dark sky sites. I filled out index cards for four locations in Newfoundland, and took down information for sites in Ontario, New England, and even one in the Florida Keys! As I did this, a high-wing aircraft buzzed and circled the River Place campground. It was the newly licensed Peter Ceravolo trying out his wings and getting a few aerial snapshots of the Starfest gathering.

Rachel, along with her parents and I, attended one more talk in the afternoon, that by Ivan Semeniuk. He enthusiastically launched into the early history of asteroid discovery, highlighting the discovery of Ceres nearly 200 years ago, coming full circle to our own opportunity to personally discover Ceres in the fall as it passes through opposition in the Hyades — very close to its original discovery position. Emerging from the main tent, we were dismayed to find the western sky scudded with herringbone clouds in front of a higher icy whitewash. It was not a good sign for the evening observing session or for good weather the next day. Sure enough, over suppertime the Sun disappeared prematurely, taking with it the last clear skies of Starfest '98. Final score: Clouds 2.5 nights, Stargazers 0.5 nights (not counting the two clear nights enjoyed by those who came in the days before Starfest).

After supper Lief Robinson of *Sky & Telescope* gave a wide-ranging talk on the opening horizons for amateur collaboration with professional astronomers. He echoed the feeling I have (and I am sure the feelings of many in the hall) that we are in the "golden age of amateur astronomy." With widely available quality equipment, personal computing power, and Internet communications, it is now more possible for the amateur to engage in useful, serious research. A particular strength for amateurs is their ability to dedicate extended observing time to projects, unlike professional astronomers who are sorely squeezed for observing time. Leif showed many examples of useful, exciting amateur astronomy, including sensitized camcorder videos of Perseid meteor fireballs (voices on tape in excited Japanese), and the 4-second asteroidal occultation of a 2nd magnitude star. I found the last video even more breathtaking than the solar eclipse video offered earlier in the day, probably because I have tried (and failed) many times to see and time an asteroid occultation. I felt (and feel) duly inspired!

By then it was time for a reluctant last look around. Rachel and I settled into the Red Light Café for an extended cozy stay. What better pastime is there for clouded out astronomers than coffee, games and conversational company… and even the occasional song?

The view of the grassy area on Friday instead of Saturday. Joe O'Neil (in white shirt at left) is standing by his table of goodies, while fellow London Centre member Marc St. Clair (pony tail) is demonstrating his freshly-built, Dobsonian, binocular 20-cm telescope.

As you might guess, my first Starfest was a lot of fun, even though we woke up to thundershowers and drizzly rain on the Sunday getaway day. The hot breakfast available from the Red Light Café was especially welcome that morning! My thanks are extended to the folks at the River Place campground for providing excellent facilities, and to the North York Astronomical Association for organizing and running a wonderful gathering. Next year's Starfest runs from July 15–19; I am hoping even now that I will not be doing field work then…

Phil McCausland is a planet-watcher and avid stargazer presently attached to the London Centre of the RASC, who also has close ties to the Windsor and St. John's Centres. In his alter-life he is working on a Ph.D. in geophysics at the University of Western Ontario. He hopes that his interests in geophysics and astronomy will soon dovetail together nicely.

Reflections

Dark Mornings

by David M. F. Chapman (dave.chapman@ns.sympatico.ca)

By the time you receive this issue of the *Journal,* the days will have become very short and the Sun, being low in the sky, will cast only feeble rays upon the ground (assuming you are reading in Canada, not lounging in a wicker chair at some sunny southern resort). For those who rise early to go to work or school, the mornings can be gloomy, even dark. But reflect on this question: when is the darkest morning of 1999? To make it easier to answer, I'll make it a multiple-choice question:

1. December 22.
2. January 2.
3. October 30.
4. None of the above.

The most correct answer is number 2, and the subject of this month's column is why I used the adjective "most."

The cycle of Earthly seasons owes its existence to the 23°.4 tilt of the Earth's equator relative to the Earth's orbital plane. That is common knowledge, although many otherwise well-educated people remain confused about the origin of the seasons. The seasonal cycle is driven by the annual variation in solar heat delivered to the Earth's surface at temperate latitudes. In northern-hemisphere summer, when the Earth's North Pole tilts towards the Sun, the days are long and the rays from the high-altitude Sun are tightly concentrated at the Earth's surface. In winter, the North Pole tilts away from the Sun, the days are short, and the rays from the low-altitude Sun are spread over a wider area. For anyone (like me) who habitually rises at the same early time each morning for work (6:30 a.m.), the cycle of seasons is portrayed by the brightness of the sky: winter mornings are dark, summer mornings are bright, and equinoctial mornings are twilit.

Imagine how dull life would be if the Earth's axis were not tilted! The Sun would rise exactly east at the same time every day, arc through the sky, and set exactly west twelve hours later. That would be true whatever the latitude, the only variance being the elevation of the Sun at noon. As one day would be like another, there would be no seasons. The Polar Regions would be permanently frozen, the equatorial zone would be insufferably hot (as now?), and one would have to search out a habitable intermediate latitude where the temperature would be "just right." (This is beginning to sound like Goldilocks and the Three Bears!) Following the same train of thought further, consider how the polar tilt — through its influence on the weather — has shaped the history and culture of human life on our planet, and how things might have turned out differently if there were no tilt.

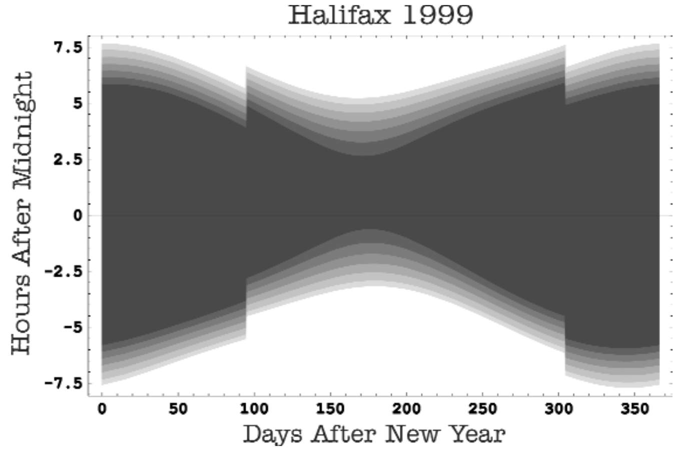
But I digress: this column is about light and dark, not hot and cold, although the two are clearly intertwined. In the celestial sphere, the ecliptic is a great circle inclined at an angle of 23°.4 to the celestial equator. As the Sun moves along the ecliptic through the year, its declination (angular distance north or south of the equator) cycles between +23°.4 and −23°.4. By manipulating the angular relations found on page 24 of the *Observer's Handbook 1999*, anyone who is trigonometrically adept can work out how the length of the day varies with the day of the year, and how the observer's latitude influences the result. (Alternatively, simply peruse the "Times of Sunrise and Sunset" section of the *Handbook*, beginning on page 84.) In the equatorial zone, the latitude is low, and there is only a small variation in day length throughout the year. In temperate zones at higher latitudes, there is significant annual variation in the length of the day. At the high latitudes beyond the Arctic and Antarctic Circles, the length-of-day calculation can become singular, indicating that the Sun may never rise or never set on certain days.

Based on what has been presented so far, it seems obvious that the latest sunrise (and hence the darkest morning) of any year would be the day of the winter solstice, which is December 22 in 1999. (After all, it is the day of the year with the fewest daylight hours.) Not so! The calculation of sunrise and sunset times is actually a bit more complicated than working out the day length from the angular relations and dividing it into two equal parts before and after noon. A correction known as the "Equation of Time" must be applied to the nominal sunrise and sunset times symmetrically spaced about noon. The correction is made up of two components. The largest component results from the Earth's tilt and accounts for the fact that the Sun moves steadily along the ecliptic, not the celestial equator; the correction amounts to as much as plus or minus 10 minutes and cycles back and forth twice during the year. The second component of the correction results from the eccentricity of Earth's orbit, and accounts for the fact that the Sun appears to move faster along the ecliptic when the Earth-Sun distance is smaller (Kepler's Second Law); the correction has an annual cycle of up to plus or minus 7.5 minutes. The two corrections considered together form a fairly complicated correction formula by which the Sun can lead the clock by as much as 16 minutes and lag behind the clock by as much as 14 minutes. Evidence for that is found in the Ephemeris for the Sun in the *Handbook* (page 76). The time of the Sun's transit of the meridian (*i.e.* when it is highest in the sky) is not 12 noon sharp, but varies throughout the year.

By some quirk of fate, around the time of the winter solstice, the equation of time is changing rapidly from "lead" to "lag." For that reason the dates of earliest sunset, shortest day, and latest sunrise, are not all the same. The precise dates are somewhat latitude-dependent, but in mid-northern latitudes, the earliest sunset occurs in mid-December, about a week "early." In many European countries, the day is traditionally celebrated on December 13, St. Lucy's Day (Lucy = lux = light, get it?). On the other hand, the latest sunrise occurs around New Year's day, about a week "late." So the correct answer to the pop quiz, must be number 2, January 2… but not always!

I must confess that the exception involves a bit of a trick, as one needs to invoke Daylight Saving Time. Between the first Sunday in April and the last Sunday in October, all Canadian provinces except Saskatchewan advance the clock by one hour to brighten the evenings, which in turn darkens the mornings. As a result, it is possible that sunrise on the Saturday before the last Sunday in October can be later than sunrise on the mornings of early January! Whether or not that is precisely true, it can be about as dark on late-October mornings as on mornings in the depths of winter. The amount of daylight is rapidly shrinking in October, so the morning darkness invades quickly, then vanishes as the clock is put back in its rightful place on the last Sunday of the month. For about a week, I can go out for my morning paper and see the constellation Orion, already past the meridian and sinking in the southwest. For some, the appearance of Orion in the morning just before sunrise is a herald of approaching winter.

I have attempted to capture the effect in the accompanying figure, which represents the darkness of the nighttime sky between sunset and sunrise at a latitude of 45˚ N throughout 1999, including the sudden steps at the beginning and end dates of Daylight Saving Time. The chart is calculated for an observer's *standard* meridian (exact multiples of 15 degrees east or west of Greenwich), but is easily corrected for longitude within a time zone according to the instructions on page 84 of the *Handbook*. The lightest part of the figure represents full daylight, before sunset and after sunrise. The darkest part of the figure denotes complete darkness, *i.e.* the time between the end of astronomical twilight in the evening and the start of astronomical twilight in the morning. The various shades of gray in between denote different degrees of twilight in evening and in the morning. The pinched effect in midsummer is very latitude-dependent, the length of night becoming shorter as one moves north. As Roy Bishop points out in the *Handbook* article "Midnight Twilight & Midnight Sun" (new to the 1999 edition), astronomically speaking there is no "night" in midsummer north of the 49th parallel, and much of Canada becomes the "Land of the Midnight Twilight," along with all of the British Isles, Scandinavia, and most of Russia.



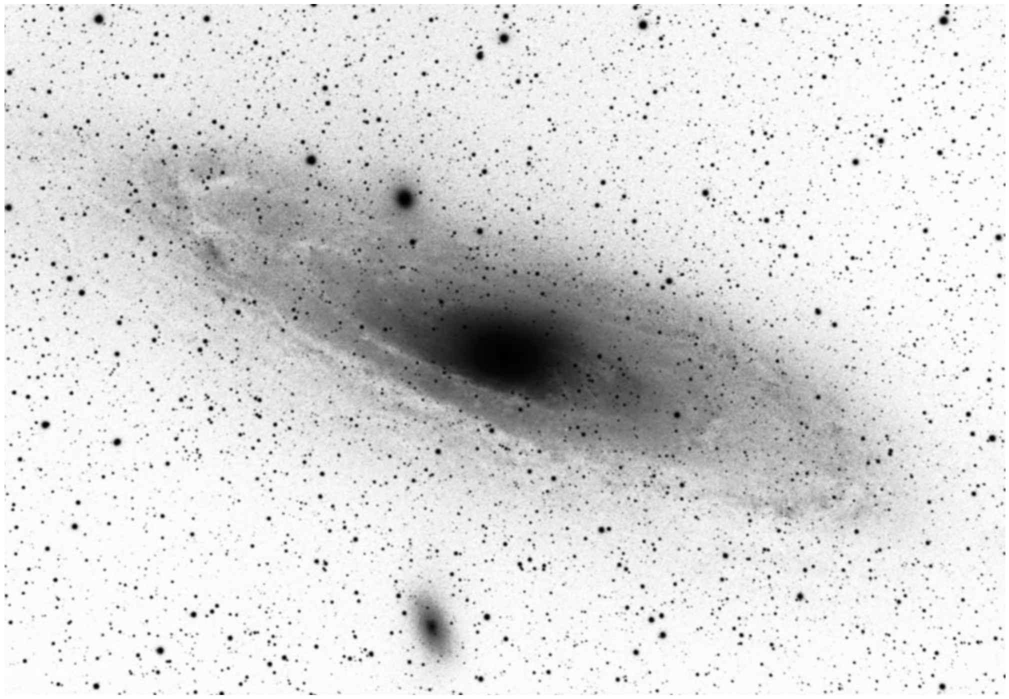
Times of daytime, twilight, and nighttime throughout 1999 for an observer at latitude 45˚ N on a standard meridian of longitude.

The figure clearly shows that the date of earliest sunset precedes the date of latest sunrise. To see the variation in morning darkness throughout the year, lay a ruler across the diagram at the appropriate time of day and read the gray level. In the upper right hand corner of the figure, one can see that the mornings at the end of October are about as dark as those near the end of the year, at the latitude 45° N. At lower latitudes (Florida, say), the annual variation in day length is reduced; however, the switch to Daylight Saving Time actually makes the mornings of early Autumn darker than winter mornings!

David Chapman is a Life Member of the RASC and a past President of the Halifax Centre. In addition to writing "Reflections" for the last ten issues, he has written for SkyNews *and the U.S. National Public Radio program* StarDate, *mostly on historical and calendrical aspects of astronomy. In his other life, he is Head of the Naval Sonar Section of the Defence Research Establishment Atlantic.*

Counting Molecules in Galaxies

by Leslie J. Sage (l.sage@naturedc.com)



The Andromeda Galaxy, M31 (Image by Peter Ceravolo).

Political pollsters and astronomers have a similar problem: both groups often have to make interpretations based on sparsely sampled data. To illustrate why this matters, say you ask a hundred people selected at random whether they support fiscally conservative government policies. You will get a completely different result if you conduct your poll at the intersection of King and Bay in Toronto or in an unemployment office in a small town. When one observes molecular gas in another galaxy, the mass one infers from the data could be in error by a factor of ten or more because of biases in the way the gas is polled. The result is that, despite thousands of papers on the topic, just how much molecular gas there is in a normal galaxy remains quite uncertain.

Spiral galaxies generally contain lots of gas; up to 10% of their mass could be in the form of gas, which is generally a mixture of atomic and molecular hydrogen (H I and H_2, respectively), though the phases themselves are usually not well mixed. In most respects molecular gas is much more important because it is the "active" gas that makes new stars. The evolution of galaxies depends on the formation and evolution of stars, which are born exclusively (as far as we can determine) in clouds of molecular hydrogen.

Atomic hydrogen is quite easy to "see" — the atoms radiate photons at radio wavelengths, particularly in the famous 21-cm line. With an instrument like the Very Large Array or the Arecibo telescope, it is easy to count the 21-cm photons and therefore calculate how many hydrogen atoms there are in a galaxy, with only a few assumptions. In essence one is counting the whole population of atoms, rather than conducting a poll.

Molecular hydrogen, however, is a lot more difficult to study because it can only be polled. By the laws of quantum mechanics, hydrogen molecules can emit photons only under rather special conditions, which are not at all representative of the bulk of the gas. Molecular hydrogen is therefore studied by observing trace molecules, such as carbon monoxide (CO). Within our Galaxy, CO is thought to constitute about 1 part in 10,000 relative to molecular hydrogen, which is not very much. (It is still enough, though, that CO is generally considered to be the second-most abundant molecule in the universe after H_2.) Even within the Milky Way, however, there has been a lot of argument about whether CO is 1 part in 5,000 or 1 part in 20,000, and whether that factor varies according to the conditions in the gas. Conditions in the gas in other galaxies are even more uncertain. Despite that, many of the participants in the debate hold their positions with an almost religious fervour.

The dispute surrounding how accurately CO traces molecular gas is now closer to being resolved, according to Michel Guélin and collaborators (see the 29 October issue of *Nature*). They find that CO is a very accurate tracer of the total amount of molecular gas. Guélin and company have obtained detailed maps of CO emission in the nearby Andromeda galaxy (M31), which they compare to optical images that show the absorption of starlight. Within our Galaxy it is well known that the ratio of gas to dust is quite constant — if you have more gas, then you get more dust. The dust is responsible for the dark nebulae, such as the Horsehead Nebula in Orion — the dust associated with a dense molecular cloud absorbs the light of the stars on the other side. When the gas is less dense, the light is reddened and dimmed, just like sunlight at sunset. Yet much of it still passes through. One can therefore use the amount of obscuration of starlight to trace the density of gas, under the assumption of a common gas-to-dust ratio.

M31 is a particularly important test case because it is sufficiently nearby that it is possible to examine the correspondence in great detail. In more distant galaxies one is reduced to saying that there is a general consistency between the CO and the dust, but that is insufficient to settle the debate. Guélin *et al.* find an amazing degree of correlation between CO emission and dust obscuration, which shows that CO can be used as a tracer of H_2. Such a result also serves to settle a separate debate about M31, and by implication other galaxies. Another group has claimed evidence for a huge reservoir of very cold molecular gas, which is not traced by CO emission. The idea is that the gas is so cold that the CO does not emit much radiation, just as cold objects emit less radiation than a warm stove, so there could be a lot of gas that we simply cannot see directly. Guélin *et al.* see such a close correlation between CO emission and dust obscuration that there is no method for hiding the amounts of gas proposed, unless one declares that such a pool of gas, unlike any other observed, has almost no dust associated with it. That seems rather unphysical, and therefore unlikely.

Will this finding really settle the debate about CO and its relationship to H_2? It does demonstrate that in another spiral galaxy there is a linear correlation between the amount of molecular gas traced by CO and the amount of dust, although there is still leeway to debate whether the absolute ratio is the same as in the Milky Way. Since the fraction of "heavy" elements (anything heavier than helium to an astronomer) is roughly the same across a broad range of spiral galaxies, and varies over the inner regions of spiral galaxies by only a small factor, the relative abundance of both carbon and oxygen with respect to hydrogen ought to be comparatively stable. It does provide some confidence that the end of the debate is in sight. Instead of arguing over a small technical point, we can use the CO data collected to derive new insights into the nature and evolution of galaxies.

Dr. Leslie J. Sage is Assistant Editor, Physical Sciences, for Nature *Magazine and a Research Associate in the Astronomy Department at the University of Maryland. He grew up in Burlington, Ontario, where even the bright lights of Toronto did not dim his enthusiasm for astronomy. Currently he studies molecular gas and star formation in galaxies, particularly interacting ones.*

IMPACT CRATERING THROUGH GEOLOGIC TIME[1]

by Eugene M. Shoemaker
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(Received July 20, 1998)

Abstract. New data on lunar craters and recent discoveries about craters on Earth permit a reassessment of the bombardment history of Earth over the last 3.2 billion years. The combined lunar and terrestrial crater records suggest that the long-term average rate of production of craters larger than 20 km in diameter has increased, perhaps by as much as 60%, in the last 100 to 200 million years. Production of craters larger than 70 km in diameter may have increased, in the same time interval, by a factor of five or more over the average for the preceding three billion years. A large increase in the flux of long-period comets appears to be the most likely explanation for such a long-term increase in the cratering rate. Two large craters, in particular, appear to be associated with a comet shower that occurred about 35.5 million years ago. The infall of cosmic dust, as traced by ^{3}He in deep sea sediments, and the ages of large craters, impact glass horizons, and other stratigraphic markers of large impacts seem to be approximately correlated with the estimated times of passage of the Sun through the galactic plane, at least for the last 65 million years. Those are predicted times for an increased near-Earth flux of comets from the Oort Cloud induced by the combined effects of galactic tidal perturbations and encounters of the Sun with passing stars. Long-term changes in the average comet flux may be related to changes in the amplitude of the *z*-motion of the Sun perpendicular to the galactic plane or to stripping of the outer Oort cloud by encounters with large passing stars, followed by restoration from the inner Oort cloud reservoir.

Résumé. De nouvelles données sur les cratères lunaires, ainsi que de récentes découvertes au sujet des cratères sur la Terre, ont permis une réévaluation de l'historique du bombardement de la Terre durant les dernières quelques 3,2 milliards d'années. L'ensemble des rapports sur les cratères lunaires et terrestres indique que la moyenne à long terme de la production de cratères dépassant les 20 kms en diamètre a augmentée, peut-être près de 60%, durant les dernières 100 à 200 millions d'années. Il paraît aussi que la production de cratères dépassant les 70 kms en diamètre aurait augmentée durant la même période, et selon un facteur de 5 fois au-delâ de la moyenne des 3 milliards d'années précédentes. Une grande augmentation du flux de comètes à longue période semble être l'explication la plus raisonnable pour une telle augmentation à long terme du taux de bombardement. En particulier, deux cratères paraissent être associées à une pluie de comètes qui aurait eu lieu il y a environ 35,5 millions d'années. La tombée de la poussière cosmique, tel que l'indiquent les traces de ^{3}He dans les sédiments océaniques profonds, l'âge des grandes cratères, les couches de globules de verre résultant des impacts et d'autres jalons stratigraphiques des grands impacts semblent indiquer une correlation avec les périodes de passage du Soleil à travers le plan galactique, au moins durant les dernières 65 millions d'années. Ces périodes prévoient une augmentation du flux de comètes s'approchant de la Terre à partir de l'amas d'Oort, le résultat des effets combinés des perturbations de la marée galactique et des rencontres avec d'autres étoiles qui croisent le Soleil. Les changements à long terme dans la moyenne du flux des comètes pourraient être liés aux changements dans l'amplitude de la motion *z* du Soleil perpendiculaire au plan galactique ou au dépouillement de l'extérieur de l'amas d'Oort par de grandes étoiles qui croisent le Soleil, suivi d'une restauration depuis le réservoir intérieur de l'amas.

SEM

1. Introduction

Presented here are some ideas about the Earth's history, or more specifically the impact history of the Earth, as thought to be known at the present time. It is recognized that there was an early period in the history of the inner solar system of at least one episode, and perhaps several episodes, of heavy bombardment that produced most of the craters on the Moon. The episode of bombardment, or at least one part of it, may have peaked about 3.85 or 3.9 billion years ago, before decaying away. From about 3.2 billion years ago to the present the bombardment has been at a very much lower rate. The lunar highlands are densely covered with craters, essentially as many craters as there can be, and they are considered to be very old. For any such surface new impacts will obliterate craters left by older ones, so it is said to represent an equilibrium population. Younger surfaces on the Moon are represented by the maria, not all of the same age, two of the younger ones being Oceanis Procelarium and Mare Imbrium. Some of the lava plains are very well dated from the return samples of the *Apollo* program, the youngest maria being about 3.2 billion years old. The present discussion is restricted to the 3.2 billion-year period following the period of the last heavy bombardment.

A point was reached recently in planetary research, perhaps ten years ago, when the average rate of bombardment over the past 3.2 billion years was known to within a factor of two. It is possible to compare what happened on Earth with what happened on the Moon over that period of time, and one obtains essentially congruent answers to within a factor of two. It is also possible to estimate the population of near-Earth objects, and that yields a similar number

[1]The 1997 Ruth J. Northcott Lecture, delivered at Queen's University, Kingston, Ontario, June 30, 1997, during the RASC General Assembly.

for what the bombardment rate should be at present.

In this discussion I examine the problem via a less established approach by addressing the variations that have probably occurred in the rate of bombardment. The usual assumption has been that the rate has remained reasonably constant for the last 3.2 billion years; basically that is an assumption made in ignorance. A point has now been reached, however, where we have enough information to begin looking at possible variations over geologic time. Since such an approach deals with numerical estimates that are not always well established, the presentation attempts to indicate what the uncertainties are at each step. They will become evident for those steps where the statistical base of the results is rather small.

2. Lunar Cratering

One of the advances that has been made on the problem has come from a small spacecraft, a "faster, better, cheaper" spacecraft, called *Clementine*, sent to the Moon in early 1994. The mission was deliberately planned — literally on the back of an envelope during an airplane flight — to image the Moon at high Sun angle, as high as possible for the low-lying regions, over the course of two months. Reflected lunar light was observed through a selection of narrow band filters centred on wavelengths covering spectral regions in the visible and near infrared, from which it was possible to identify the major rock types on the lunar surface, *i.e.* the mineralogy of the lunar surface. There was no intent to study the morphology of the lunar surface, although that was done at the poles. A byproduct of the endeavour was an excellent map from which one could obtain the albedo of the Moon, essentially very close to full face. That enabled us to examine the far side of the Moon systematically for the first time.

A mosaic of the far side of the Moon was produced by computer from several thousand individual images obtained by *Clementine*. It was found that there is a pattern to the rayed craters there. Large ones are readily identified from the background elements; actually, rayed craters as small as 10 km in diameter can be identified confidently from the images. McEwen *et al.* (1997) subsequently revisited the problem of the spatial density of rayed craters on the Moon. The study was restricted to an examination of the very uniform rock type covered by the lunar highlands on the far side, and resulted in the re-calibration of the crater density for rayed craters.

A stratigraphic classification for craters on the Moon was proposed about 35 years ago (Shoemaker & Hackman 1962). In that scheme the younger systems of craters are divided broadly into two groups: the oldest craters, designated Eratosthenian, date back 3.2 billion years and forward to the boundary of the Copernican era; the younger Copernican system extends from that boundary to the present time. Determining the age of the boundary has been one of the problems. There are some indicative samples, particularly from the *Apollo 12* mission that landed on a ray of Copernicus, which, as best can be determined, is the lowest-lying stratigraphically. Copernicus is the oldest rayed crater on the basis of rays superposed on the highlands. However, there are other rayed craters that can be sampled directly to determine their ages, and sometimes one finds rays that stretch out across the dark maria surfaces from much older craters. To explain the discrepancy, it was proposed that rays on bright surfaces, like the highland surfaces, fade at a standard rate and disappear into the background at a given point in time. That point is what we define as the boundary of the Copernican system.

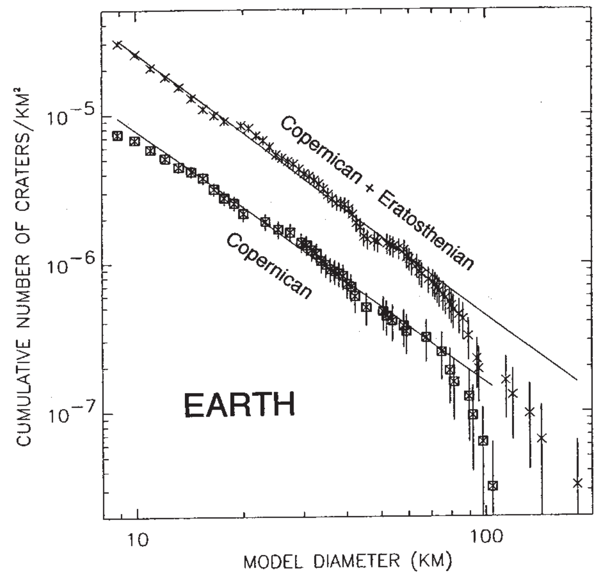

Fig. 1 — Lunar cratering rates scaled to model terrestrial distributions (McEwen *et al.* 1997).

McEwen *et al.* (1997) used the *Clementine* observations to count the rayed craters on both the near side and the far side of the Moon, in the process re-examining all of the large rayed craters. The study provided a firm estimate for the density of such craters on the lunar surface, in addition to knowledge about the density of the remaining post-maria craters (post 3.2 billion year old craters), which are of Eratosthenian age. Figure 1 depicts the calculated density of combined Copernican and Eratosthenian era craters (top slope), as well as the density of Copernican era craters alone (bottom slope) extrapolated to Earth, *i.e.* with the crater sizes scaled to sizes that would be expected for impacts on the Earth rather than on the Moon. What is shown is the cumulative number of craters, starting with the largest, which is a little over a 100 km in diameter. The values are plotted on a logarithmic scale where the values refer to the cumulative number of craters per square kilometre. (If the values are multiplied by a million, one obtains the number of craters per million square kilometres.) By the time one considers 10-km diameter craters on the Copernican-era surface, the number density has increased by a factor of about three hundred.

In figure 1 the upper curve indicates what one obtains for the combined Copernican and Eratosthenian era crater density, as extrapolated to Earth. By subtracting the density of Copernican era craters, one can examine the density of Eratosthenian era craters alone, in which case one obtains an average cratering rate both for the Eratosthenian era and the Copernican era. It is apparent from the data that the distribution falls off steeply — on both faces of the Moon — as one considers larger and larger craters, in particular those 70 km or 80 km in diameter and up to something approaching 100 km in diameter. That is true whether one considers all craters younger than 3.2 billion years in age or just the youngest, the Copernican era craters.

The largest crater formed on the Moon in the last 3.2 billion years is only slightly larger than the giant Chicxulub crater at the northern tip of the Yucatan peninsula, which has a diameter of 170

Table I
Estimated Crater Production Rates for Earth[1]

Data Set	Time Period	Production of Craters With D ≥ 20 km (10^{-15} km^{-2} yr^{-1})
Eratosthenian Craters	0.8–3.2 Ga	3.7 ±0.4 (asteroidal velocities) 3.0 ±0.3 (50:50 asteroids:comets)
Copernican and Eratosthenian Craters	≤ 3.2 Ga	4.1 ±0.2 (asteroidal velocities) 3.3 ±0.1 (50:50 asteroids:comets)
Proterozoic Impact Structures in Australia	0.54 – 2.6 Ga	3.8 ±1.9
Far Side Rayed Craters (this study)	≤ 0.8 ±0.2 Ga	5.3 ±1.8 (asteroidal velocities) 4.3 ±1.4 (50:50 asteroids:comets)
U.S. Mississippi Lowland	≤ 0.5 Ga	6.3 ±3.2
Young Craters on North American & European Cratons	≤ 0.12 Ga	5.6 ±2.8
Astronomical Surveys	Present	5.9 ±3.5

[1] From McEwen *et al.* (1997). Rates are given accompanied by an uncertainty corresponding to one standard deviation.

km according to Hildebrand *et al.* (1991). The area of the Earth is a little over thirteen times the surface area of the Moon. Since almost nothing is known about craters on the ocean floor, one is left to examine craters on the land surface, which is slightly more than four times the area of the Moon. On the basis of the lunar impact crater density studied by McEwen *et al.* (1997), the Chicxulub crater is the largest crater produced in the past 3.2 billion years, which means that, within the uncertainties of small number statistics, one crater with the dimensions of Chicxulub is produced on a time scale of slightly less a billion years on average. The Chicxulub crater is only 65 million years old, however, which is a difference that is very meaningful. When the statistics are examined in detail in order to obtain the average rate for forming 170-km diameter craters on Earth, it turns out that there is about an 11% chance that a crater the size of Chicxulub would have formed in the last 65 million years. That is significant, but it is not the only statistic.

Table I presents estimates of crater production rates on Earth for various samples of craters. The statistics for crater densities and mean cratering rates are credible at least for craters down to 20 km in diameter. For Eratosthenian-era craters created from about 3.2 billion years ago to eight hundred million years ago — our best estimate for the boundary between the Eratosthenian and Copernican eras — the predicted cratering rate on Earth is $(3.7 \pm 0.4) \times 10^{-15}$ km^{-2} yr^{-1} for craters larger than 20 km in diameter. The units may seem a bit bizarre, but represent simply the number of craters of that diameter created on a surface area of a million square kilometres every billion years. With the combined results for Eratosthenian-era and Copernican-era craters, the predicted cratering rate on Earth is slightly higher, $(4.1 \pm 0.2) \times 10^{-15}$ km^{-2} yr^{-1}. Based on lunar far side rayed craters or Copernican-era craters alone, the predicted cratering rate increases to $(5.3 \pm 1.8) \times 10^{-15}$ km^{-2} yr^{-1}, with a much larger uncertainty. There is a suggestion of a difference in the two cratering rates since 5.3 is larger than 3.7, but, since the difference of 1.6 falls just within the cited uncertainties, it may be merely a counting error. Yet there is still a hint that the cratering rate may have changed.

In order to convert cratering rates obtained for the Moon to equivalent ones for the Earth, it is necessary to factor in the velocities of the impacting objects. The top set of numbers in Table I were calculated under the assumption that the impacting objects strike at the typical asteroidal velocities observed for Earth-crossing asteroids. If the mix contains equal numbers of asteroids and comets, the cratering rates — indicated on the second line — are slightly smaller, but in either case the predicted rates increase when one examines the far side rayed craters (McEwen *et al.* 1997). That is the situation inferred from lunar craters.

3. The Australian Cratering Record

Let us now consider the Earth itself by examining the cratering rate in Australia. The importance of Australia lies in the fact that it is one of the most stable pieces of continental crust on Earth; it has a record of impact that goes back into Precambrian time, more than 540 million years ago. In 1995 there were exactly six recognized impact craters in Australia of which we were certain: Teague Ring, Spider, Strangways, Kelly West, Lawn Hill, and Acraman. They are all craters that I studied with my wife Carolyn, except for Acraman, which has been studied by George Williams. Carolyn and I have also examined that crater a number of times, however.

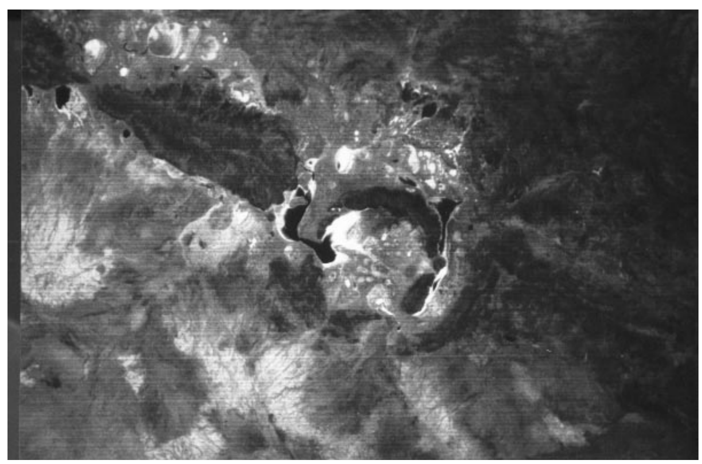

Fig. 2 — Landsat image of the Shoemaker Impact structure (Shoemaker & Shoemaker 1996).

Figure 2 is an image of the Teague Ring structure[2] taken from the *Landsat* satellite. The Archaean terrain, which is older than 2.5 billion years, consists mostly of granites. The dark ridge is called the Frere Range; it appears dark because of the iron formation in the sequence of beds that make lots of black rocks on its surface. The beds dip off or flank off to the northeast into the edge of the Nabberu

[2] The Teague Ring structure was renamed by the Geological Survey of Western Australia in 1998 to honour the author of this paper. It is now formally called "The Shoemaker Impact Structure."

Basin, and are tilted about 10° or so to the northeast. The whole sequence is interrupted by a structure that can easily be seen from space. It is 30 km in diameter and the rocks are dropped down in part of a ray-shaped depression; because they are buried under still higher strata, they do not appear dark in the illustration. The whole sequence is then turned on end in an inner collar of the structure which surrounds an uplift of Archaean rocks. The structure that we see is therefore a ringed structural depression with a central uplift. That is the typical structural signature of a deeply eroded complex crater; the crater itself has long since disappeared. The feature is about 1.6 billion years old, whereas the whole region was tilted and flanked off perhaps 1.2 billion years ago. The structure has been at or near the surface of the crust in Australia since then. It is the oldest impact feature yet recognized in Australia. The very complicated structure of the feature must be deciphered by finding the outcrops

Fig.3 — Oblique aerial view of the low-impact Spider structure showing beds near the centre skidded successively and stacked in ridges along thrust faults (Shoemaker & Shoemaker 1996).

of older rocks. They are turned up more or less on end and are covered with folds, much like the folds created when one pulls a napkin through a napkin ring. They are also bifurcated by many faults. All of these are diagnostic structural features.

Figure 3 illustrates another kind of structure that Carolyn and I mapped in detail — the Spider structure in the Kimberley district of Western Australia. In the centre there are ridges of quartzite rocks, three units of which have been duplicated along faults and across the centre. Visible in the image is the central uplift, and it is also possible to see why it is called Spider since it looks much like a twenty-legged spider. On a geological map of the whole structure the spider is in the middle and is surrounded by a complex structural depression. It appears in this case that there was a weak impact from the north, so that the beds near the centre were skidded successively and stacked up as plates as they repeated along a whole series of thrust faults. The central uplift punched up through those plates. This was a low-impact structure.

Shatter cones can be detected in the field for each of the structures shown here. Shatter cones are beautiful structures visible only in impacted rock. Figure 4 illustrates one found on the Spider structure, where they are located on the central uplift. Shatter cones have conical surfaces, or portions of conical surfaces, that are decorated with fantail or horsetail kinds of striations formed by shock. They can be created by shock on a small scale in laboratory experiments; they

Fig. 4 — Large shatter cones on the central uplift of the Spider structure are conical features with horsetail striations formed in nature only as a result of the shock pressures generated by extraterrestial impact (Shoemaker & Shoemaker 1996).

can also be found in craters formed by explosives, so we have a good idea of the range of shock pressures needed to form them. Shatter cones are diagnostic features that, when found in the field, provide direct evidence that the rock has been shocked. They are abundant in the central 2 km of the Spider structure, which measures about 11 km × 13 km across.

Another crater that Carolyn and I have studied is the Lawn Hill structure in northwestern Queensland. It has a central uplift surrounded by a structural moat that is concealed by limestone breccias. It was a target that was already structurally complex and folded with middle Proterozoic rocks when the crater was formed, after which material eroded away. The structure was next covered by seawater for some time, during which limestone rocks were laid down. The limestones are Cambrian rocks about 500 million years in age; even today Lawn Hill is recognized as a crater-formed feature. There is a central depressed region with ranges surrounding it. At present, Lawn Hill is basically an exhumed crater about 20 km across.

One of the larger structures in Australia is Lake Acraman — a salina. It is located on the Eyre Peninsula in South Australia. George Williams, who discovered it (Williams 1994a,b), has described it as a very large crater; he believes that the outlying ring structures found there might define the original crater. The beds in the surrounding ranges are basically flat lying and undeformed, with no shatter cones;

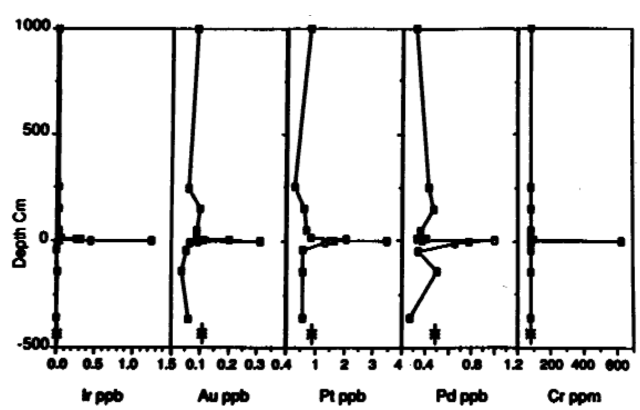

Fig. 5 — Density of noble metals (iridium, gold, platinum, palladium) and chromium, another iron-loving metal, reveal elevated abundances in the Lake Acraman fallout layer (Wallace *et al.*1990).

they appear to be fairly normal-looking rocks that have not been subject to shock. The actual crater is a topographic basin about 40 km in diameter. The reason why the lake is present is that the rocks in the centre, which were crushed and broken by shock, eroded to form the low spot presently visible in the topography. The age of the crater is estimated quite accurately on the basis of stratigraphy. Victor Gostin of the University of Adelaide discovered a fallout deposit from the crater in the steeply inclined rock beds in the Flinders Range about 250 km from Acraman. Within the Range there is a bed of material a couple of centimetres thick that was ejected from the Acraman crater. It is part of a 10-km-thick sequence of late Proterozoic sediments, a very specific tracer in that huge stack of sedimentary deposits. The rock is of Precambrian age, about six hundred million years old; it is the first distant fallout deposit discovered from a relatively large crater.

Close examination of a fallout deposit reveals shocked rocks that have small shatter cones within them. Also detected are features containing tiny spherules of material that was once molten, quartz grains that have structural features formed by shock, and contaminating fragments of the impacting body. The abundance of the so-called noble metals — iridium, gold, platinum, and palladium — and other iron-loving elements like chromium is about ten thousand times higher in the average meteorite than in the average rock in the Earth's crust. Elevated abundances of such elements are therefore a nice tracer of the impacting body. Samples obtained for the beds in the Acraman structure, for example, provide evidence for the presence of a distinct fallout layer (figure 5), where there is an increase in the abundance of iridium to a peak of close to one and a half parts per billion. That is a lot of iridium, given that the average amount found in sediments in crustal rocks is about ten parts per trillion. The gold abundance is also anomalous, as is platinum, which is about two to

Table II
Sizes and Ages of Australian Proterozoic Impact Structures

Crater	Diameter	Probable Age	Method
Acraman	~35 km	600 Ma	Stratigraphic
Lawn Hill	20 km	500–1000 Ma	Stratigraphic
Strangways	~40 km	~1000 Ma (?)	$^{39}Ar/^{40}Ar$ Dating
Kelly West	~8 km	500–1600 Ma	Stratigraphic
Spider	12 km	700–1600 Ma	Stratigraphic
Teague Ring	30 km	~1600 Ma	Rb/Sr Dating
Liverpool	1.7 km	< 1500 Ma	Stratigraphic
Glikson	~18 km	< 1000 Ma (?)	Stratigraphic

three times as abundant as iridium in impacting objects. In fact, platinum is the most abundant of the elements brought to Earth through impacts.

Table II lists all Australian structures of Precambrian or Proterozoic age, where the Proterozoic represents the last part of the Precambrian era. One of the structures may belong to the Cambrian era, and there are a couple of newly studied structures that are probably in the same time range, although their ages are not known accurately and they are smaller than the others. Small structures are lost by erosion and are therefore more difficult to find, so their numbers are usually unrepresentative of the entire sample. There are four structures that are 20 km or larger in diameter: Acraman, Lawn Hill, Strangways, and Teague Ring. In a cumulative frequency distribution they produce the results presented in figure 6, which plots the logarithm of the cumulative number as a function of the logarithm of the diameters. Remember that the grand statistic for craters greater than or equal to 20 km in diameter is just four structures in Australia. The best fit for the lunar data is given by the dotted line. The diameters of the four features are reasonably well established, but of course the uncertainties in the cumulative number densities are very large for such a small sample. The cratering rate for Australia is established from an area of a little over a million square kilometres covered by the gently deformed Proterozoic rocks, where one can actually search for craters on an exposed surface, and from an exposure age equivalent to the duration of the Proterozoic era — slightly less than a billion years. The combination implies an average cratering rate for Australia of $(3.8 \pm 1.9) \times 10^{-15}$ km^{-2} yr^{-1}, as given in Table I, compared with an estimated cratering rate for lunar craters of $(3.7 \pm 0.4) \times 10^{-15}$ km^{-2} yr^{-1} for the Eratosthenian era. Normally one would not expect to obtain such good agreement to within the statistical uncertainties, but the result is nevertheless intriguing.

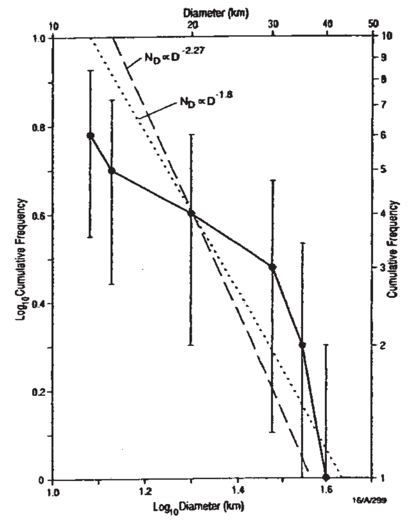

Fig. 6 — Cumulative size-frequency distribution of Proterozoic impact structures in Australia (Shoemaker & Shoemaker 1996).

4. Young Craters

Let us now examine young craters on the Earth. Australia is the only place where one can examine the cratering rate for early Earth history, but one can also examine a larger area of the Earth by considering the global distribution of craters. Figure 7 is a map from Grieve & Shoemaker (1994) that is revised annually as more craters are discovered. Figure 7 represents the status, as of 1994, of craters that Grieve is willing to consider as true impact structures. There are several interesting features of the distribution. There are no craters in the ocean, of course, and for the continents the distribution is very non-uniform. There is also a large cluster of craters in North America, another one in Europe, and a fairly large one in Australia. Why is that? Since impacting objects strike the Earth fairly randomly, the history of such impacts should be recorded as a relatively uniform distribution of craters. However, three factors contribute to the observed non-uniformity: one is geological and two are sociological.

The geological factor concerns portions of the continents, called cratons, which are relatively stable against the forces of erosion. For example, the Canadian Shield is a portion of a larger stable region called the North American craton, parts of which are very thinly

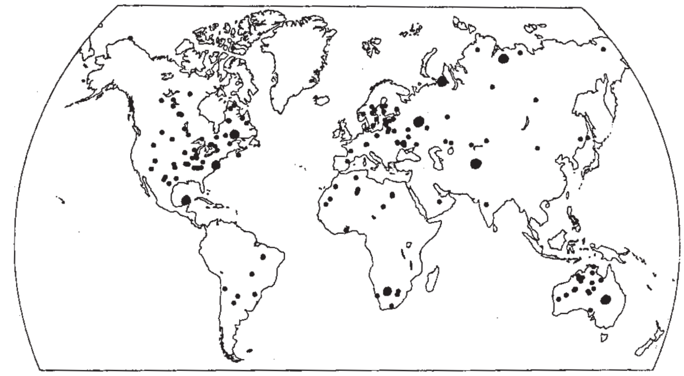

Fig. 7 — Location of currently known terrestrial impact craters (Grieve & Shoemaker 1994).

veneered with younger sedimentary rocks and Phanerozoic rocks. Another recognized craton is the European, sometimes called the Eoeuropean, craton. Australia is also a very stable region of the Earth. Because of their stability, cratons represent regions of continents where one can expect the cratering record to be preserved.

There are also sociological reasons contributing to the non-uniformity of our knowledge of impact craters on Earth. Parts of the Earth, for example, are better mapped geologically than other regions, owing to the presence of a large population of active geologists. That is the case for North America, Europe, and Australia, although even here North America and Europe are better mapped than Australia. A second sociological reason relates to the fact that Australia in recent years has been the target of a particular husband and wife team that has been interested in examining terrestrial craters. The mapping of impact structures in Australia is therefore reasonably well established owing to the activities of a few individuals. In such fashion were discovered exposed craters larger than 20 km in diameter and which are very ancient — the Proterozoic craters of Australia.

One can do the same type of analysis for young craters in North America and Europe, where the statistics are much better. Figure 8 illustrates the cumulative number distribution for craters that are fairly accurately dated, all of which are 20 km in diameter or larger and located on the North American and European cratons. It is a

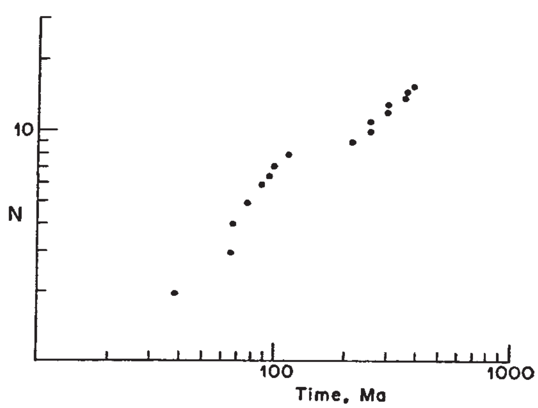

Fig. 8 — Cumulative number of craters of $D > 20$ km for North American and European cratons. The two apparent distributions of younger and older craters suggest a record of erosion for craters older than 120 Ma (Grieve & Shoemaker 1994).

standard logarithmic plot from which one gets the impression that the logarithmic cratering rate increases fairly linearly with age up to about 120 million years ago, and then something happened that caused the rate to change. Or it may be that craters are starting to disappear as we go farther back in time. The opinion of Grieve, with which I concur, is that we have an incomplete sample of craters at least over part of the period, so the record is incomplete. The sample is probably complete for the last 120 million years.

On that basis let us examine the cratering rate over the last 120 million years. According to Table I, the cratering rate for young craters is $(5.6 \pm 2.8) \times 10^{-15}$ km^{-2} yr^{-1}, with a rather large uncertainty. The number is based upon eight craters, so the uncertainty probably represents one sigma scatter or smaller, but Grieve is always conservative in his estimates. Although the rate is larger than that for Proterozoic impact structures, it is very close to the rate of $(5.3 \pm 1.8) \times 10^{-15}$ km^{-2} yr^{-1} derived for lunar far side rayed craters. It is encouraging that both numbers are so similar despite their large uncertainties. An independent estimate can also be obtained for just those craters in the Mississippi Valley lowlands of North America, a part of the North American craton where one can sample 10 km diameter craters reliably (Shoemaker 1977). The equivalent cratering rate for 20 km diameter craters, with our standard slope, is given in Table I as $(6.3 \pm 3.2) \times 10^{-15}$ km^{-2} yr^{-1}. The Mississippi Valley craters constitute a completely different set from the previous sets we have discussed, although again with a large uncertainty. The statistics for the Mississippi Lowlands and for young North American and European craters are rather interesting, however, and both, as well as the cratering rate for lunar far side rayed craters, are larger than the results for either Eratosthenian-era craters or the combined Copernican-era and Eratosthenian-era craters.

Any one estimate considered by itself would not be convincing, but combined they suggest that the cratering rate for 20 km diameter craters has actually increased. But what is the situation for very large craters? That is where the account becomes interesting. All craters larger than 50 km in diameter, at least ones that I have determined are larger than 50 km in diameter, are plotted in figure 7 by large symbols. Let me enumerate them. First there is Chicxulub. Then there is one that was not even on the map three years ago, the Chesapeake Bay Crater. One can argue about the true size of that crater, but I will demonstrate later why I believe it should be there. Both craters just mentioned are subsurface craters. Next is Manicouagan, which is a large crater in Québec. In Asia there are four, entirely covered by younger beds, which lie in the former Soviet Union. The largest is Popigai, which is a 100 km-diameter crater. Then there is Kara, which is a 65–70 km-diameter crater, and then Puchezh-Katunki, a buried crater. Finally there is the Kara-Kul crater in Tajikistan, which may be very young. Next in rank is a buried crater in Australia, the Tookoonooka crater, and finally there is a crater that has just recently been reported (Corner *et al.* 1997), the Morokweng crater in South Africa.

Table III summarizes what we know about the sizes and ages of the structures just identified. The age for Chicxulub, 170 km in diameter, is known very accurately to be 65 million years. The next largest craters are Popigai and Manicouagan. Popigai is only about 35½ million years old, while Manicouagan is nominally 214 million years in age. Another crater very close in age to Popigai according to Poag (1997) is Chesapeake Bay, 85 km in diameter. The crater Morokweng is so eroded that it is difficult to determine its size exactly.

Table III

The Largest Impact Craters on Earth with Ages ≤ 220 Ma

Crater	Diameter	Age
Chicxulub, Mexico	170 km	64.98 ±0.05 Ma
Popigai, Russia	100 km	35.7 ±0.8 Ma
Manicouagan, Canada	100 km	214 ±1 Ma
Chesapeake Bay, U.S.A.	85 km	35.5 ±0.5 Ma
Puchezh-Katunki, Russia	80 km	220 ±10 Ma
Morokweng, South Africa	>70 km	146.2 ±1.5
Kara, Russia	65 km	73 ±3 Ma
Tookoonooka, Australia	55 km	128 ±5 Ma
Kara-Kul, Tajikistan	52 km	<25 Ma

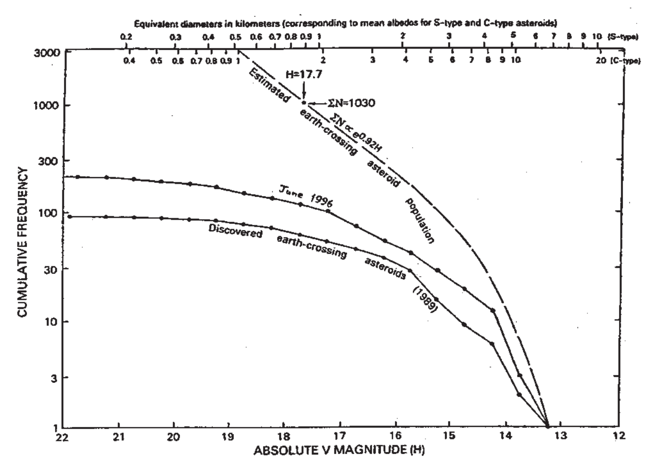

Fig. 10 — Cumulative frequency and absolute magnitude of Earth-crossing asteroids (Shoemaker *et al.* 1990), updated to June 1996.

It is probably at least 70 km in diameter, and some of those working on it believe it may once have been as large as 300 km or 340 km in diameter, which would put it at the top of the list. Although I am very skeptical about that, it may well be larger than 70 km in diameter. The indicated age may also not be accurate. It is interesting that the age for the Chicxulub crater places it at the boundary between the Cretaceous and Tertiary periods, while the age for the Morokweng crater, as near as can be determined, places it near the boundary between the Jurassic and the Cretaceous periods. The Manicouagan and Puchezh-Katunki craters could very well coincide with the boundary between the Triassic and the Jurassic periods, although the ages of those periods are not known very well.

5. Cratering Rates

It was noted previously that there is roughly an 11% probability of forming a crater the size of Chicxulub within the last 65 million years. There is roughly a 25% probability of forming a crater as large as Popigai within the last 35½ million years. One could continue down the list individually, but what is important is what is observed in the overall distribution.

One way of considering the distribution relates to what objects in space can collide with the Earth and the Moon. Two years ago, Carolyn described the observing program for asteroids and comets undertaken with the 18-inch Schmidt telescope at Palomar (Shoemaker 1996). The main purpose of the program was to calculate the population of Earth-crossing asteroids, from which one could calculate the terrestrial cratering rate once orbital information was obtained. A knowledge of the physical properties of such asteroids is the long-term goal.

Fig. 9 — Orbits of Earth-crossing asteroids, 1990 (Binzel 1992). Orbits for the terrestrial planets are indicated by dashed lines.

Figure 9 represents the situation for large Earth-crossing asteroids, as of 1990 (Binzel 1992). At present there are over 250 known Earth-crossers, and they would make the diagram even more cluttered than it is. The purpose of the diagram is simply to illustrate how such objects are distributed in space. In order from the Sun are Mercury, Venus, Earth, and Mars. Only Earth-crossing asteroids are plotted here, which is why the diagram appears relatively empty past the orbit of Mars. Of course it is not empty but rather gets more and more crowded, but the point should be evident — the Earth is revolving in a storm of Earth-crossing asteroids. Our aim is to estimate the numbers of such objects and from there to calculate cratering rates. Figure 10 represents the count as of June 1997.

When the equivalent of figure 10 was first published in 1990, it represented the situation known at the time. The plot represents the cumulative frequency of objects of different size, so a little fewer than 100 had been discovered at that time, as opposed to 250 in 1997. Although the parameter plotted on the abscissa is magnitude, the numbers can be converted to a frequency distribution in size by making some assumptions about the albedo of typical objects, or one can tackle the problem statistically.

First of all, the largest of the Earth-crossers is well established — asteroid (1620) Ivar. It has been found repeatedly, and no larger objects await discovery. At magnitude 17 or 18, however, the known sample is relatively incomplete. In order to determine the true number of such objects, it is necessary to factor in some assumptions about asteroid albedos, from which we estimate that magnitude 17 or 18 objects are about 1–2 km in diameter. Our best estimate in 1990 was that there are about a thousand such objects to asteroid magnitude 17.7. The number has not changed; it is based on the detection of about 100 objects from our Palomar survey. More Earth-crossers are known now, but that is because of new detections.

Once orbits are established, one can calculate collision probabilities, as in figure 11. The plot represents the sample from 1990, which has not changed except for the recognized bias against the discovery of very small asteroids and the fact that the collision probability is low. The frequencies are in units of 10^{-9} yr^{-1}, so the numbers plotted correspond to the probable number of impacts per billion years, if that is easier to consider. Of course, none of the asteroids will be around in a billion years, according to the current probabilities. What is needed is the arithmetic mean, which is very close to 4×10^{-9} yr^{-1}.

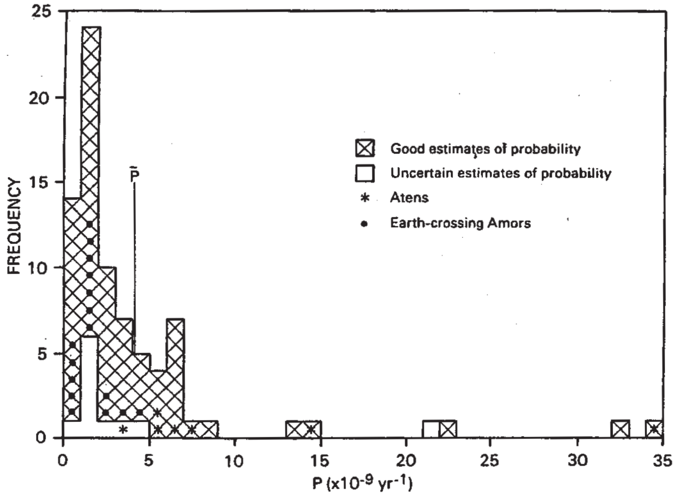

Fig. 11 — Probability of collision for Earth-crossing asteroids (Shoemaker *et al.* 1990).

According to our best estimates of the distribution of such objects, the number of about a thousand objects brighter than 17.7 corresponds to roughly 1500 objects larger than a kilometre in diameter. With the factor of 4×10^{-9} yr^{-1} included, it means that we should expect approximately six such objects to hit Earth every million years. That is a significant geological figure.

From that number one can derive the mean cratering rate as a function of crater diameter, a step that involves knowledge of typical asteroid densities, for which there is considerable evidence. Figure 12 illustrates the results; it is a plot of the currently best-calculated cratering curve for asteroids, and corresponds to the curve shown in figure 1. Recall that for craters on the Moon there was a steep, very steep, decline in number densities for the largest craters, and that applies also to the cratering rates for large impactors. Plotted separately is the estimate given by Grieve (1984) for the production rate of 20-km-diameter or larger craters in the last 120 million years, and a previous estimate (Shoemaker 1977) for the production rate of 10-km-diameter or larger craters. Within the large uncertainties of both points, the line between the two points is not very different from the crater production relation expected from collisions with asteroids. But now when one considers very large craters like Chicxulub (figure 12, a plot for continental craters), the existence of such a large crater on Earth cannot be reconciled with the relationship describing the asteroidal crater production rate. Although it is a statistic based upon only one crater, it is nevertheless interesting. In fact, the crater count reproduced here is based upon only craters that are recognized on the continents, and one must convert those numbers to ones applying to the entire Earth. It seems certain that the distribution tails off for large crater diameters, although it is certainly incomplete. Actually, the Morokweng crater is not included here, because its diameter is uncertain. If it is included, the points describing the observed cratering frequencies on Earth will all be larger. It is therefore at the large crater diameter end of the distribution that we can be truly confident that the flux of impacting objects is high. It also remains higher than expected even when one considers craters that are an order of magnitude smaller than Chicxulub, but then becomes progressively smaller.

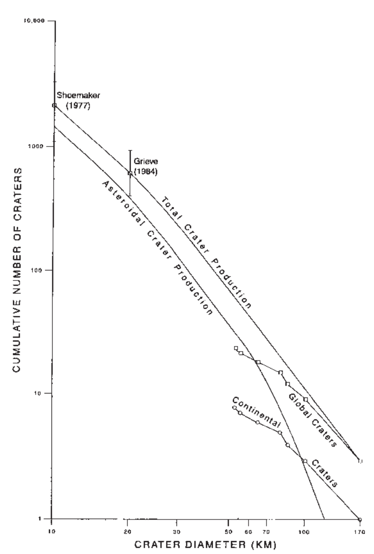

Fig. 12 — Crater production on Earth during the last 220 Ma, based only on craters recognized on the continents and converted to apply to the entire Earth.

6. The Role of Comets

What is it that causes the difference for the largest craters? Comets provide one straightforward answer. A well-known periodic comet is Comet Halley; it has a geometric mean diameter of 9 km, not quite large enough to create a crater like Chicxulub, but close. Another comet that is almost exactly the same size as Comet Halley was discovered by *IRAS*, the infrared astronomical satellite, as it passed by in 1983. It was also discovered from the ground by Araki in Japan and by George Alcock in Britain, who found it by using binoculars looking out his front window. The comet missed the Earth by a little over 4½ million kilometres. How often do comets come that close to Earth? Occasionally they appear to come that close, but actually do not, such as Comet Lexell in 1770. Two hundred years before that it made another somewhat closer pass. The orbital characteristics of early comets are somewhat uncertain, but it also appears that about two hundred years before that there was another close pass of a comet to Earth. Comet Halley itself came almost as close a little over a thousand years ago. For two of the comets we know their dimensions reasonably well, but for others such as Comet Lexell we can only make rough guesses. The accumulated evidence suggests that something about the size of Comet IRAS-Araki-Alcock passes within 4½ million kilometres of Earth at least once every two hundred years. That is probably a lower bound; the true flux of comets may be higher. Indeed, we know there are larger comets, while the largest Earth-crossing asteroid, Ivar, is only 9 km across. Yet there are multiple comets that are in the same size range, almost certainly. The most recent example is Comet Hale-Bopp, which is an exceptionally large comet about 40 km in diameter and which is also Earth-crossing.

It only takes a little mental calculation from such small statistics to consider how often objects of this type will hit the Earth. Imagine that the Earth is the bull's eye on a target 4½ million kilometres across struck once every two hundred years. The probability that an object of cometary size will hit the bull's eye amounts to about one strike every 100 million years. That is a lower bound, but it is much higher than the impact rate for asteroids. I therefore suggest that comets are primarily responsible for the high rate of crater production.

If true, then there is something else that can be examined. We must ask if it is reasonable that comets formed the large craters. It is difficult to prove, but the abundance of the siderophile elements platinum, iridium, and gold is suggestive, particularly in the case of platinum. The abundance of such elements is known for the most primitive meteorites, which can be used for comparison, or one can make a comparison with other, differentiated, more evolved meteorites. In each case where there is information, as for example with the Chicxulub crater, the pattern of the siderophile elements in the fallout was examined. There was probably a certain amount of shifting around of the elements once they were deposited, but the abundance pattern is clearly primitive. That is at least what one should find for a comet impact, but it does not prove that was the case. For the Chicxulub crater the best one can say is that there is a 90% probability that the impactor was a comet.

In similar fashion, a primitive abundance pattern is found for the siderophile elements examined in rocks at the Popigai crater. That is to say, the abundance pattern matches the standard ratio of two platinum atoms to one iridium atom found in the most primitive meteorites, and the results for other element ratios are similar. There is an 80% probability that the Popigai crater was created by a comet impact.

In the case of the Manicouagan and Chesapeake Bay craters there are very weak siderophile signatures, which may also be a signature of comets; at least the results in both cases are consistent with a comet impact. In fact, the fallout deposit of the Chesapeake Bay crater, which is found in the ocean along with a striking impact spherule horizon, does not exhibit the presence of any siderophile elements. There is an 80% probability that the Manicouagan crater was formed by comet impact, while for the Chesapeake Bay crater the probability is 70%. Very little can be said about the Puchezh-Katunki crater — there is just not much there — but the probability of comet impact is 65%. Those are the five largest impact sites, and they show consistency.

7. Galactic Tidal Forces and Passing Stars

One further test can be made. An interesting feature of the long-period comets, those coming from the Oort cloud, is that their delivery to Earth is influenced by two factors: galactic tidal forces and encounters with other massive objects, namely stars in the solar neighborhood that comets pass on their way to Earth. The motion of the Sun in the Galaxy, though not known perfectly, has been the subject of some study. Figure 13 illustrates a solution for the solar motion perpendicular to the galactic plane as obtained by Matese *et al.* (1995). Over the past hundred million years the Sun's orbit in the Galaxy has carried it first towards and then away from the galactic centre; in other words,

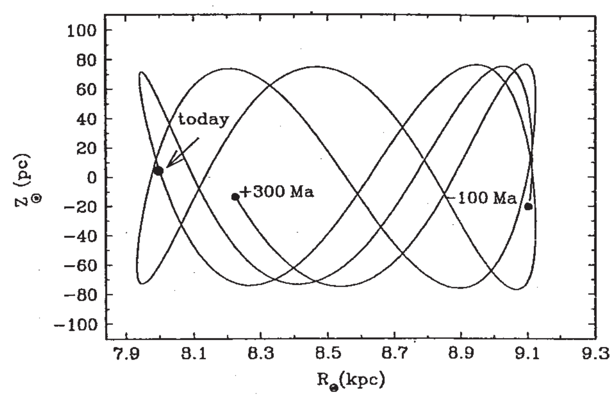

Fig. 13 — The motion of the Sun perpendicular to the galactic plane according to Matese *et al.* (1995). Illustrated here without encounters, the Sun exhibits a smooth orbital path above and below the galactic plane with a motion periodicity of about 30–35 million years.

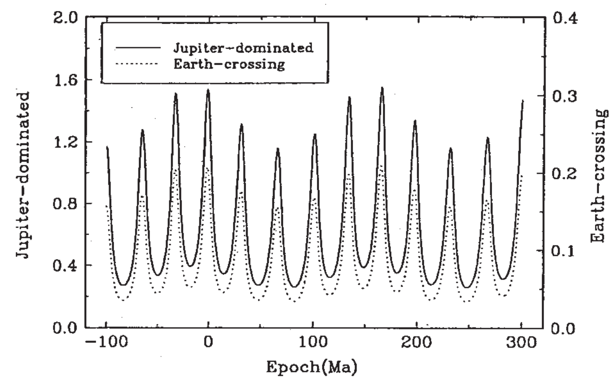

Fig. 14 — Predicted comet flux from the Oort cloud according to Matese *et al.* (1995), as affected by galactic tidal variations and the random passage of stars.

its orbit is not perfectly circular. The graph illustrates a smooth orbital path, that is, one without any encounters, although the Sun does encounter other objects about once every quarter million years as it goes around the Galaxy. The Sun's motion also carries it above and below the galactic plane, which is an important point. The actual distance it moves away from the plane is not well determined; its velocity is known, but its motion perpendicular to the plane depends upon the mass and density of stars near the galactic plane. The Sun appears to be close to the galactic plane now and moving above it, in other words, toward galactic north, but we do not know for certain how far above the plane it will go. The best estimates suggest that its excursions may be about ±75 pc away from the plane, and the best estimate for the periodicity of such motion is about 30 to 35 million years. Matese *et al.* (1995) addressed the question of how that affects the delivery of comets into the inner part of the solar system, and figure 14 illustrates their results. It depicts their best estimate for the density, for which one gets somewhat different models. It shows that the flux of objects passing Jupiter, namely comets delivered directly out of the Oort cloud, varies temporally by about a factor of four. Those that become Earth-crossers are depicted by the dotted line. Their calculations indicate that the perihelia of such comets, the very long-period comets, are becoming smaller as a result of galactic tidal variations.

Another important factor was considered by Matese *et al.* (1995), namely that, as the perihelia of comets become smaller, passing stars become more effective at delivering comets into the inner solar system. The effect can be pictured as a synergistic interplay between galactic tidal variations and the more or less random passage of stars. Because the perihelia have become smaller for some of the comets, it means that it is easier to deliver still more comets by an impulse from a passing star. As a result, the true delivery rate of comets will probably appear similar to that depicted in figure 14, except that it will not be nearly as uniform. The relation will probably appear much spikier and at a different angle.

The important point is that the mean period between major comet perturbations into the inner solar system is on the order of 30 to 35 million years. That is what one expects if the conjectures are correct. The significant point is that the Sun is very close to a plane crossing now. Some 30 to 35 million years in the future it should be near a plane crossing again, some 35 million years in the past it should have been near a plane crossing, and so on. Is there any observable evidence for that? I suggest there is.

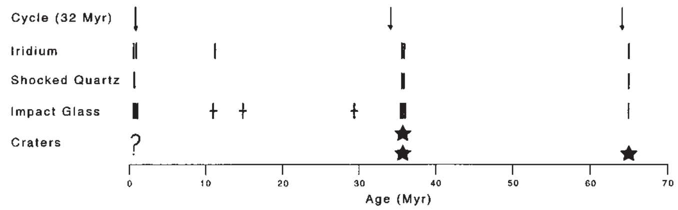

Fig. 15 — Impact indicators from 70 Ma to the present (iridium, shocked quartz, impact glass, craters) imply that the ages of very large craters may be periodic.

If one examines the ages of very large craters, it is my guess that they should be periodic. Figure 15 depicts the distribution of iridium in a stratigraphic section. There are two event horizons at or near the present time, a couple of event horizons 35 million years ago (Ma), and of course there is a well-known one at 65 Ma. The presence of shocked quartz in the section is found near the present time, there are a couple of event horizons at 35 Ma, and there is also the well-known one at 65 Ma. For impact glass spherules there are actually three known event horizons near the present time, a couple in between — our impact glass is not entirely spherules — and three quite well spaced event horizons at about 35 Ma, 35.5 Ma, and 65 Ma. For large craters, there is Chicxulub at 65 Ma, and Popigai and Chesapeake Bay at 35 Ma. I will argue later that there is one that we have not found yet, namely an unrecognized large crater. It must have an age close to the present, at the left of the chart. The periodicity is about what one would expect at roughly 30 to 35 million years.

One other feature worthy of examination is the nature of the craters themselves. Figure 16 is a map of the geology of the Chesapeake Bay crater, the source of the glassy spherules — tektites — associated with the North American strewnfield. It has now been very thoroughly explored by seismic lines. In particular, there are lots of drill holes, which are depicted by little circles on the map. One can actually detect the ejecta surrounding the crater; in some cases there are tidal deposits as well. There is an inner crater and a very curious disturbed bench on the outside, 85 km in diameter.

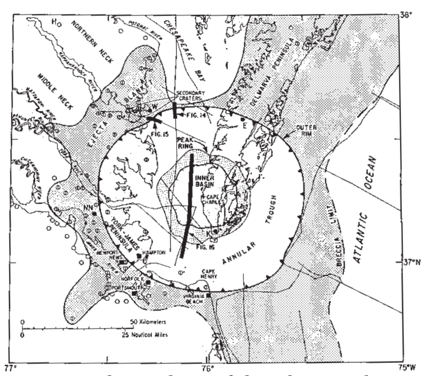

Fig. 16 — The geology of the Chesapeake Bay crater (Poag 1997), source of the North American strewnfield of tektites.

In lieu of a map for the Popigai crater, figure 17 presents a cross-sectional view as published by Masaitis (1994). The crater is filled with impact melts, sheet impact melts. The heavy black rings represent some solid melts, in contrast to the breccias marking the rubbish heap of melted material and non-melted material that we call suevite (numbered 2 on the chart). There is also a zone of breccia or broken rock (numbered 4 on the chart) on both flanks of the crater, separated by a distance of 100 km. For the impact craters formed 35 Ma ago we have examined both the usual impact indicators and the craters themselves. We also have the same type of evidence at 65 Ma for the Chicxulub crater.

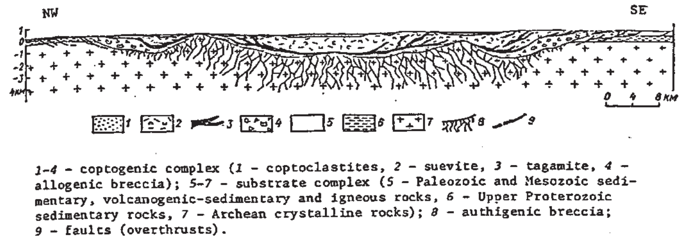

Fig. 17 — A cross-sectional view of the Popigai crater (Masaitis 1994) reveals the nature of the crater with impact melts and breccia.

8. Infall of ^{3}He

One other line of evidence that can be examined relates to a very exciting result published by Farley (1995), who is an isotope geochemist at the California Institute of Technology. He approached the problem in a very interesting way when it was suggested by Don Anderson that the ^{3}He emitted by the Earth from volcanoes in minute trace amounts was actually interplanetary ^{3}He brought to the Earth by interplanetary dust particles which were cycled into the Earth by convection. Farley and other geochemists believed that they could demonstrate that this was incorrect. After considering where he could get a sample of deep-sea sediments to measure the content of ^{3}He, he decided that the easiest place to get it was from a giant piston core taken from the north side of the Pacific Ocean. It has been examined fairly carefully, and covers 70 million years in 20 m of core at a very slow sedimentation rate. Farley took just one specimen from the core sample and placed a 2-g sample into a mass spectrometer. He expected to find very little ^{3}He, but more ^{3}He was detected by the mass spectrometer than had ever been seen in a core before.

Farley next went back and obtained from Frank Kyte at UCLA all of the samples from the core, and measured the content of ^{3}He. An important feature about ^{3}He in ocean sediments is that normally there is only one significant source. The background level on Earth is minimal, essentially zero. The primary source is cosmic dust particles in the size range of a few microns up to tens of microns. At sizes below a few microns the dust is blown out of the solar system by radiation pressure from the Sun. Very large dust particles, on the

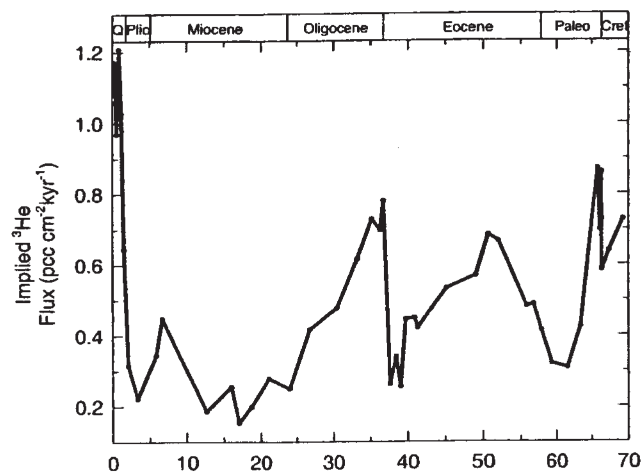

Fig. 18 — Implied ^{3}He flux from 70 Ma to the present (Farley 1997). The large peak at the left represents present time and the other peak is at 35 Ma. Dust particles with solar wind-implanted ^{3}He provide a tracer of the infall of cosmic dust onto the Earth.

other hand, get too hot when they come into the Earth's atmosphere. Only for a narrow size range can particles pass through the atmosphere without becoming too hot. Such particles bring in solar wind-implanted ^{3}He. It is a marvelous tracer of the infall of cosmic dust onto the Earth, totally independent of anything else mentioned previously.

Figure 18 depicts Farley's results for the implied flux of ^{3}He (Farley 1997). The spike at the left edge covers the last 2 million years — about a million years for the very high points — and then falls off by a factor of six. There is another spike 35 million years ago, before the rate declines again. There is an interesting peak around 50 million years ago and it looks like there is another peak at the Cretaceous-Tertiary boundary, but to calculate the flux requires knowledge of the sedimentation rate. There could be artifacts in the peaks after 35 Ma, but the peak at 35 Ma is unquestionably real.

When Carolyn and I returned from Australia in 1995, I promptly contacted Farley. We talked about his results and entered into a joint effort. The problem is that the results were based upon just one sample. It was argued by Karl Turekian, Farley's old professor at Yale, that the peaks in figure 18 simply reflected some strange pattern of ocean currents affecting the rate of sedimentation, and that they may not represent the true flux of ^{3}He.

Two features of figure 18 stand out distinctly: the large peak at the left that represents the present time and the other large peak at 35 Ma. We examined the stratotype section for that time period (the late Eocene into the Oligocene ages). It is located in a small quarry, the Massignano Quarry, by a little village in the Apennine Mountains near Ancona, Italy. Figure 19 depicts the results for metre levels 4–8, which cover that time period. They are limestone beds interspersed with marley beds, some of which have more clay in between them. Figure 19 also reproduces the results of a previous study of the iridium content, which exhibits a peak between metres 5 and 6 (= 35 Ma). The abundance is not large, but the background level is about fifty parts per trillion whereas the peak corresponds to parts per billion. There is also shocked quartz present at the same level, as well as an obvious peak in the variation in skeletal spinel crystals, which we are quite sure relates to the influx of large objects into the atmosphere. The peak between 5 and 6 metres is an impact horizon.

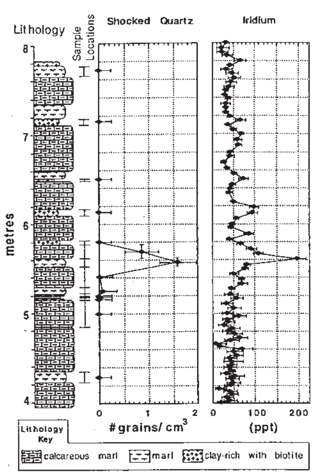

Fig. 19 — A simplified stratigraphic column from the Massignano Quarry section (Clymer *et al.* 1996).

In the summer of 1996 Carolyn and I decided to sample the section, for which Farley ran the ^{3}He test. Figure 20 presents the results. For standardization we normally start below the iridium peak. We therefore covered about 13 metres of the section, equivalent to a little bit more than 2 million years. The time period covered is known very accurately on the basis of microfossils in the rock, measurements of magnetic reversals, argon-argon age dating results, and biotite crystals for chronostratigraphy. We began at the lowest exposed section (between 0 and 1 metres), and then went up 13 metres. The lowest exposed section has background levels of ^{3}He as expected, but there is a substantial increase at metres 4 and higher. There is a lot of scatter in the results. Statistically we know that ^{3}He is carried in few enough grains that one may be sampling just the large grains. That will produce scatter, not analytical scatter but true scatter.

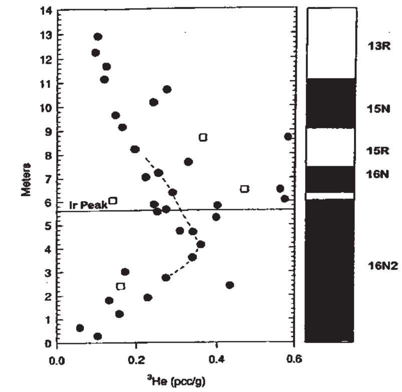

Fig. 20 — The concentration of ^{3}He during the late Eocene era from the Massignano Quarry section represents a comet shower.

The theoretical expectations for the distribution of ^{3}He corresponding to a comet shower are plotted in figure 20 with a dotted line. The distribution of ^{3}He does appear to match predictions reasonably well. It does not mean that the grains responsible for depositing ^{3}He on Earth are from comets, however. The grains may well have originated in a shower, but at the velocity of icy cometary particles, it is possible to grind a lot of particles off asteroids that are then delivered to Earth. Such particles must impact Earth at low enough speed that the ^{3}He is retained. In fact, a peak appears exactly where it was expected, and the time interval is specified exactly by means of stratigraphy. It is not a one-time effect arising from currents in the Pacific Ocean, since the rock section is in the Mediterranean.

I maintain that the peak represents a comet shower. With reference to figure 18, consider for a moment the other peak corresponding to the present. There is a true peak at 35 Ma that coincides with two large craters and all sorts of impact signatures. What about the peak almost 1 million years ago, the largest one? I have some concerns about it because it may be that some of the ^{3}He leaks out. We are not certain. We know that the implied ^{3}He flux indicated at time zero is the present flux; that is well established in many other studies. Yet it could be that the flux decreases further in the past because of the loss of ^{3}He. I prefer to believe otherwise, that what is seen in figure 18 is actually a peak. It means that we are in a

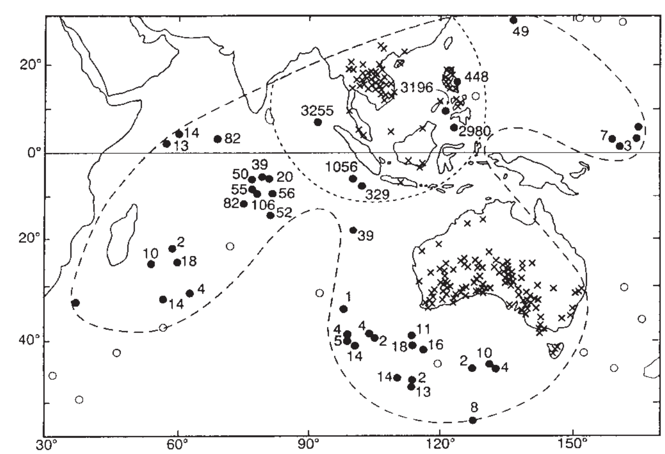

Fig. 21 — The Australasian strewnfield shown by the dashed line (Glass & Pizzuto 1994) is the youngest recognized impact glass strewnfield and may have originated from an impact perhaps 770,000 years ago in Indochina.

peak now. We are presently in a comet shower. We should therefore be able to recognize some large craters here on Earth that were produced by the shower.

Figure 21 depicts the region of Southeast Asia and Australia and plots the distribution of the youngest recognized strewnfield of impact glass, known as the Australasian strewnfield. The places where impact glass has been found are indicated: *X*s for those on land and black dots for those on the sea floor. In the region marked by short dashes one begins to find very young glass, and occasionally one finds other shocked material as well. Particularly in Indochina there are huge chunks of glass. Therefore, it is believed that the source is the enormous region (marked by the long dashes) running from the extreme western edge of the Indian Ocean well out into the western Pacific, from southern China to well south of Tasmania into the southern ocean. The strewnfield, as best can be determined, is intermediate in size between the strewnfield of impact glass associated with the Chesapeake Bay crater and what is believed to be the strewnfield originating from the Popigai crater, which occurs in deep sea cores usually about 30 cm below the Chesapeake Bay glass.

I believe that the impact horizon detected in the Massignano sections is actually associated with the Popigai crater. Thus, if one considers the Popigai and Chesapeake Bay craters as upper and lower limits in size for the crater associated with the Australasian strewnfield, we should be searching for a fairly large crater. It should be on land, or at worst in very shallow water in or near Indochina. So far no one has recognized it. It is also very young, probably 770,000 years old, and we ought to be able to detect it. Given enough time to search, we should find it. But it shows just how incomplete our knowledge of the impact record is. I believe that we have probably already had a large crater formed within less than a million years ago.

9. Conclusion

How is it that the cratering rate could have increased in late geologic time? I suggest that if you examine the actual distribution of ages for craters larger than 20 km in diameter on the Moon and on the Earth, there appears to be a substantial increase in the cratering rate roughly 200–300 million years ago. It might even represent an increase of a factor of two in the cratering rate for 20 km diameter craters. For the largest craters the rate is clearly an order of magnitude higher.

What could cause the average cratering rate to increase if it is due to comets? Two things could happen. One possibility is that a massive star or a molecular cloud stripped the outer part of the Oort comet cloud. Such a circumstance could have happened in the Proterozoic era. It would have taken a long time after that for the outer part of the Oort cloud to be replenished from the inner cloud. There is also something very interesting about the motion of the Sun perpendicular to the galactic plane, its z-motion. For other stars in the solar neighborhood of spectral type G, stars more or less like the Sun and about the same age, their oscillation perpendicular to the galactic plane is not 75 pc. It is typically more like 300 pc, in which case the Sun's orbit is rather atypical. Could it be that something happened to the Sun? It may have been an event, perhaps the event, which stripped the outer part of the Oort cloud, following which the Sun's oscillation about the galactic plane was reduced. Perhaps a succession of such encounters decreased the extent of the Sun's z-motion relative to the galactic plane. Since its galactic orbit has it spending much of its time in region of higher star density where tidal perturbations on the Oort cloud are stronger, the delivery of comets to the Earth would be increased. The average long-term flux could increase at least by a factor of two, and perhaps by an order of magnitude. There is much yet to be worked out, but I will leave you with the following consideration. The study of the impact history of Earth is in reality a way to study the history of the motion of the Earth in the Galaxy.

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References

Binzel, R. P. 1992, in The Spaceguard Survey, Report of the NASA International Near-Earth-Object Detection Workshop, chair D. Morrison

Corner, B., Reimold, W. U., Brandt, D. & Koeberl, C. 1997, Earth and Planetary Research Letters, 146, 351-364

Clymer, A. K., Bice, D. M. and Montanari, A. 1996, Geology, 24, p. 484

Farley, K A. 1995, Nature, 376, 153-156

Farley, K A. 1997, personal communication

Glass, B. P. & Pizzuto, J. E. 1994 J. Geophysical Research, 99, 19077

Grieve, R. A. F. & Shoemaker, E. M. 1995, in Hazards Due to Comets and Asteroids, ed. T. Gehrels (University of Arizona Press: Tucson), pp. 417-462

Hildebrand, A. R., Penfield, G. T., Kring D. A., Pilkington, M., Camargo, A. Z., Jacobsen, S. B., and Boynton, W. V. 1991 Geology 19: 867-871

Masaitis, V. L. 1994, in Large Meteorite Impacts and Planetary Evolution, ed. B. O. Dressler, R. A. F. Grieve & V. L. Sharpton, Geological Society of America Special Paper No. 293, 153-162

Matese, J. J., Whitman, P. G., Innanen, K. A. & Valtonen, M. J. 1995, Icarus 116, 255-268

McEwen, A. S., Moore, J. M. & Shoemaker, E. M. 1997, J. Geophysical Research, 102, 9231-9242

Poag, C. W. 1997, Sedimentary Geology, 108, 48

Shoemaker, C. S. 1996, JRASC, 90, 18-41

Shoemaker, E. M. 1977, in Impact and Explosion Cratering, ed. D. J. Roddy, R. O. Pepin & R. B. Merrill (Pergamon Press: New York), pp. 617-628

Shoemaker, E. M. & Hackman, R. J. 1962, in The Moon, ed. Z. Kopal et al. (Academic Press: San Diego), pp. 289-300

Shoemaker, E. M. & Shoemaker, C. S. 1996, AGSO J. Australian Geology & Geophysics, 16, 379-398

Shoemaker, E. M., Wolfe, R. F. & Shoemaker, C. S. 1990, in Global Catastrophes in Earth History: An Interdisciplinary Conference on Impacts, Volcanism, and Mass Mortality, ed. V. L. Sharpton & P. D. Ward, Geological Society of America Special Paper No. 247, 155-170

Wallace, M. W., Gostin, V. A. & Keays, R. R. 1990, Geology, 18, 132-135

Williams, G. E. 1994a, In Large Meteorite Impacts and Planetary Evolution, ed. B. O. Dressler, R. A. G. Grieve & V .I. Sharpton, Geological Society of America Special Paper No. 293, 209\226224

Williams, G. E. 1994b, In Proceedings of the Royal Society of Victoria, 106, 105\226127

EUGENE M. SHOEMAKER (1928-1997) was a native of Los Angeles, California, and a graduate of the California Institute of Technology and Princeton University. First and foremost a geologist, Gene took part in regional investigations of the geochemistry, volcanology, and structure of the Colorado Plateau and wrote his signature work on Meteor Crater, Arizona. He followed that with an investigation of the structure and history of the Moon, and an ongoing investigation of the impact history of the Earth, impact processes in the solar system, and the effects of large body impacts on the evolution of life. He was involved with the Ranger, Surveyor, *and* Apollo *missions to the Moon and an investigator on the* Voyager *and* Clementine *Missions. From 1984 until his untimely death in July 1997, Gene took part in a dual investigation with his wife Carolyn searching for comets and asteroids and studying Australian impact structures. A member of the National Academy of Sciences and a fellow of the American Academy of Arts and Sciences, he received many awards, including the National Medal of Science.*

ABSTRACTS OF PAPERS PRESENTED AT THE 1998 CASCA ANNUAL MEETING HELD IN QUÉBEC, MAY 19–22, 1998

Carlyle S. Beals Award Lecture/Conférence du prix Carlyle S. Beals

Challenges for the New Millennium: Some Persistent Astronomical Mysteries, Gordon Walker, University of British Columbia.

Carl Beals identified the strongest of the diffuse interstellar features sixty years ago and remained fascinated by them all his life. Their origin and significance still remain largely a mystery, but satellites such as the *Far Ultraviolet Spectroscopic Explorer* (FUSE) may provide crucial clues through better understanding of interstellar chemistry. Acquiring direct images and spectra of extra-solar planets has emerged as one of the greatest challenges for the new space and 8-m ground telescopes. Here I discuss some of the efforts made together with my Montreal colleagues to meet the special problems of observing through the Earth's atmosphere and to speculate on our chance of success.

J. S. Plaskett Medal Lecture/Conférence de la médaille J. S. Plaskett

Star Formation in Molecular Clouds and Globular Clusters, Dean E. McLaughlin, University of California at Berkeley.

The process of star formation is investigated in two complementary ways. First, a new model is developed for the internal structure of the dense cores of gas inside giant molecular clouds (GMCs), which are the main sites of star formation in the Galaxy today. This model, which posits that the total gas pressure in these cores varies logarithmically with density, allows for an explicit description of the significant non-thermal motions that support them, for a time, against their self-gravity. It is in good agreement with a range of observational data. This "logotropic" equation of state is used to explore the implications of turbulent initial conditions for the gravitational collapse of GMC cores. Second, the collective properties of globular cluster systems (GCSs) in galaxy halos are used to gain some insight into the important phenomenon of clustered star formation. In particular, a theory is constructed for the globular cluster luminosity function (GCLF). The GCLF is considered as having been built up by collisions between gaseous protocluster "cores" within much larger (but subgalactic) "supergiant molecular clouds" in the halos of protogalaxies. Observations of the GCLFs in the Milky Way, M31, and M87 are used to constrain basic ingredients of the model, and the implications for present-day cluster formation are discussed.

CITA Lecture/Conférence CITA

Migrating Planets, N. Murray and B. Hansen, Canadian Institute for Theoretical Astrophysics, M. Holman, CITA/Harvard Center for Astrophysics, and S. Tremaine, CITA/Princeton University.

A planet orbiting in a disk of planetesimals can experience an instability in which it migrates to much smaller orbital radii. Resonant gravitational interactions between the planet and planetesimals remove angular momentum from the planetesimals, thereby increasing their eccentricities. Subsequently, the planetesimals either collide with the planet or are ejected by close encounters with it; ejecting a planetesimal reduces the semi-major axis of the planet. If the surface density of planetesimals exceeds a critical value, corresponding to ~0.03 solar masses of gas inside the orbit of Jupiter, the planet will migrate inward a large distance. Such an instability may explain the presence of Jupiter-mass objects in small orbits around nearby solar-type stars.

Keynote Address/Conférence principal

Observations of Extrasolar Planets, Geoff Marcy, San Francisco State University.

Eight candidate extrasolar planets have been identified by Keplerian Doppler shifts in their host stars. The masses ($m \sin i$) lie between 0.5 and 7 Jupiter masses and the semi-major axes are less than 2.1 A.U. For three of the companions (47 UMa, ρ CrB, and 55 Cnc), their circular orbits must be primordial rather than tidally induced, indicative of formation in a disk. Eccentric orbits may be explained by gravitational perturbations, either by companion stars, other planets, or disk resonances. The detections imply that 5% of solar-type stars have giant planets within 2 A.U. Orbital migration during the T Tauri disk phase provides a likely mechanism to explain the small orbits. New planet searches of 400 stars are underway at Keck and elsewhere, with the latest findings reported here.

Contributed Papers/Présentations orales

Observations Fabry-Perot de spirales tardives, Sébastien Blais-Ouellette and Claude Carignan, Université de Montréal.

Les galaxies spirales tardives semblent se situer à une transition quant à la relation entre les paramètres de la matière sombre et le type morphologique. Dans ces galaxies, les contributions lumineuses et sombres sont d'importance comparable bien avant le diamètre optique R_{H0}. Pour déterminer cette relation comme pour bien contraindre les paramètres de la distribution de masse, nous ajoutons à la grande sensibilité des données H I existantes, la haute résolution spatiale et spectrale de données Fabry-Perot pour un échantillon de galaxies spirales tardives.

Isotopic Anomalies of Platinum in the HgMn Star HR 7775, David Bohlender, Herzberg Institute of Astrophysics, and Michael Dworetsky and Chris Jomaron, University College London.

High resolution, high signal-to-noise ratio, Canada-France-Hawaii Telescope Gecko spectra have been obtained for the regions of the five strongest optical lines of Pt II in the spectrum of the cool HgMn star HR 7775. Model line profiles have been constructed based on isotopic and hyperfine structure laboratory analyses, and abundances for the individual isotopes have been determined from spectrum synthesis. The total abundance of platinum is 4.46 dex greater than the adopted solar abundance. The isotopic composition is clearly non-terrestrial, with a pronounced relative enhancement of the heaviest isotope, ^{198}Pt, and deficiencies of the isotopes lighter than ^{196}Pt. The pattern of isotopic composition does not follow the widely assumed fractionation formalism; the lighter isotopes are far more deficient than a single-parameter fractionation pattern would predict.

The Mystery of Wolf-Rayet Emission-Line Variability: A Shocking Behaviour from a Clumpy Wind[1], Sébastien Lépine and Anthony F. J. Moffat, Université de Montréal.

We present the results of a study of line-profile variability (lpv) in emission-lines of Wolf-Rayet stars. High-resolution spectroscopic observations from the Canada-France-Hawaii Telescope shed new light on the behaviour of such stochastic lpv. We show that the lpv is broadly consistent with line emission from a clumpy wind. However, strange behaviour from the clumps suggests that the wind inhomogeneity arises in dramatic hydrodynamical events that may be related to radiative instabilities generated by the intense radiation field from the underlying star.

HST Studies of Second-Parameter Globular Clusters in the Outer Galactic Halo, P. B. Stetson, J. E. Hesser, and S. van den Bergh, Herzberg Institute of Astrophysics/NRC, M. Bolte and J. A. Johnson, University of California Observatories/Lick Observatory, W. E. Harris, McMaster University, D. A. VandenBerg, University of Victoria, R. A. Bell, University of Maryland, H. E. Bond and L. Fullton, Space Telescope Science Institute, G. G. Fahlman and H. B. Richer, University of British Columbia.

We have observed the globular clusters Palomar 3, Palomar 4 and Eridanus with the Wide Field Planetary Camera 2 on the *Hubble Space Telescope*. These three are classic examples of the "second parameter" anomaly because of their red horizontal-branch morphologies in combination with their low-to-intermediate metallicities. Our (V, I) colour-magnitude diagrams (CMDs) reach V (limit) ~ 27.8 and clearly delineate the subgiant and turnoff regions and about three magnitudes of the unevolved main sequence. The slopes and dereddened colours of the giant branches are consistent with published [Fe/H] estimates that rank the clusters (Pal 3, Eri, Pal 4) in order of increasing metallicity, with all three falling near or between the abundance values of the classic nearby halo clusters M3 and M5. From differential fits of their CMDs, we find that the three outer-halo clusters differ from those of the nearby ones in a way that is consistent with the distant objects being younger by ~1.5–2 Gyr. Such an inferred age difference could be smaller (< 1 Gyr) if either [Fe/H] or [α/Fe] for the outer-halo clusters is significantly lower than we have assumed. Possible age spreads of order 1 Gyr among both the nearby and outer-halo clusters may also be present.

Liquid Mirror Telescopes: A Progress Report, Ermanno F. Borra, Université Laval.

I briefly review the status of the Liquid Mirror Telescope (LMT) project. In a nutshell, liquid mirrors do work. Optical shop tests show that the optical qualities are very high (diffraction limit). The largest LM built so far (in the Laval lab — see paper by Tremblay) has a diameter of 3.7-m. Several liquid mirror telescopes have been built and operated for several years. The largest working LMT (operated by NASA) has a diameter of 3.0 metres and has yielded so far over 100 nights of deep sky images. Several articles dealing with astronomical results are currently being written (see paper by Cabanac). A 6-m LMT is presently being built at UBC. The future of the technology looks bright, promising very large diameters and greater versatility. A novel corrector design indicates that fields of regard as large as 20 degrees (with 20 arcminute corrected patches) should be feasible. In the laboratory, efforts to develop novel reflecting liquids are also very encouraging. Heeding the calls by the national granting agencies, we are also successfully exploring industrial applications that exploit the unique qualities of LMs (*e.g.* large diameters at low cost). A three-dimensional scanner using a LM as its main optical element has been demonstrated.

Cosmic Parameters from the Cosmic Microwave Background, J. Richard Bond, Canadian Institute for Theoretical Astrophysics.

A long-standing goal of theorists has been to constrain cosmological parameters that define the structure formation theory from cosmic microwave background (CMB) anisotropy experiments and large-scale structure (LSS) observations. The status of the enterprise is described using full Bayesian analysis for high weight CMB experiments, such as those provided by the *Cosmic Background Explorer* (COBE) satellite's Differential Microwave Radiometer (DMR) and Saskatoon 1995, approximate band-power techniques from cluster abundances, and shape constraints from observations of galaxy clustering. The initial fluctuation spectrum is not far off the scale invariant form (slope near unity) that inflation models prefer — *e.g.* for tilted Λ cold dark matter (ΛCDM) sequences of fixed 13 Gyr age, $n_s = 1.01 \pm 0.05$ for CMB experiments alone, as well as when LSS constraints are included. Open models are slightly preferred over Λ models by the CMB data, but are much less likely than Λ models when LSS information is included. The Λ values found are the same as those obtained using high redshift Type I supernovae.

Innovations in Altair, the Gemini Adaptive Optics System, Glen Herriot and Simon Morris, Herzberg Institute of Astrophysics/NRC.

Altair includes some interesting new design ideas, because of the infrastructure provided by the Gemini Observatory and because of the decision to put Altair's deformable mirror at an image of the plane 6.5 kilometres in front of the telescope.

Hélioséismologie de la tachocline solaire, Paul Charbonneau, High Altitude Observatory, National Center for Atmospheric Research.

[1]Selected as the best student oral paper at the 1998 meeting.

La tachocline est une région de forte rotation différentielle située directement sous la zone convective du soleil. Je décrirai quelques inversions hélioséismiques récentes visant à determiner la structure de la tachocline, et discuterai brièvement des conséquences de ces résultats pour les modèles de la dynamo solaire.

Coherent Emission Mechanisms in Radio Pulsars, Maxim Lyutikov, Canadian Institute for Theoretical Astrophysics.

A theory of pulsar radio emission generation, in which the observed waves are produced directly by maser-type plasma instabilities on the anomalous cyclotron-Cherenkov resonance $\omega - k_{\|}v_{\|} + \omega_B/\gamma_{\rm res} = 0$ and the Cherenkov-drift resonance $\omega - k_{\|}v_{\|} - k_{\perp}u_{\rm d} = 0$, is capable of explaining the main observational characteristics of pulsar radio emission. The instabilities result from the interaction of the fast particles of the primary beam and from the tail of the distribution with the normal modes of a strongly magnetized one-dimensional electron-positron plasma. The waves emitted at such resonances are vacuum-like electromagnetic waves that may leave the magnetosphere directly. The cyclotron-Cherenkov instability is responsible for the core emission pattern, and the Cherenkov-drift instability produces conal emission. The conditions for the development of the cyclotron-Cherenkov instability are satisfied for both typical and millisecond pulsars provided that the streaming energy of the bulk plasma is not very high, $\gamma_p = 5 \div 10$. In a typical pulsar the cyclotron-Cherenkov and Cherenkov-drift resonances occur in the outer parts of the magnetosphere at $r_{\rm res} \approx 10^9$ cm. The theory can account for various aspects of pulsar phenomenology including the morphology of the pulses, their polarization properties, and spectral behaviour.

The Discovery of an Open Cluster Associated with Two Wolf-Rayet Stars, Steve Shorlin, University of Western Ontario, and David G. Turner, Saint Mary's University.

CCD photometry reveals a very young open cluster, at a distance of 12.6 kpc, associated with two Wolf-Rayet stars: WR 38 and WR 38a. WR 38 is the first Wolf-Rayet star of spectral subtype WC4 to be found in a galactic open cluster; its estimated absolute magnitude is far brighter than has become accepted for WC4 stars in our Galaxy. The absolute magnitude estimated for WR 38a confirms what is known about other stars of spectral subtype WN6.

Searching the Galaxy for Wolf-Rayet Stars, A. F. J. Moffat, Université de Montréal, M. M. Shara, Space Telescope Science Institute, L. F. Smith, University of Sydney, V. S. Niemela, La Plata, M. Potter, Space Telescope Science Institute, and R. Lamontagne, Université de Montréal.

We have just completed an optical Schmidt plate survey and spectroscopic confirmation of the Southern Milky Way for new Wolf-Rayet (WR) stars as faint as 19$^{\rm th}$ magnitude. The 31 newly detected WR stars are amongst the reddest and/or most distant known in the Galaxy. They clearly demonstrate an increasing number ratio of WN to WC subtypes with increasing galactocentric distance. The total number of known galactic WR stars now stands at over 200. We use a simple galactic model to predict the total number of galactic WR stars that should be discovered in future infrared surveys in the whole Galaxy.

Modeling the Diversity of Outer Planetary Systems, Martin James Duncan, Queen's University.

It has been made clear in the last few years that the dynamical structure of extra-solar planetary systems can vary significantly from system to system. In order to understand the range of possible systems better, we present the results of a set of bottom-up numerical simulations designed to generate plausible giant planet systems from a large number of planetary embryos. Our simulations produced systems stable for at least a billion years with a wide range of characteristics, including some reminiscent of our own planetary system. The number of planets ranged from one to seven. Many systems contained only Uranus-mass objects. We constructed systems that were more compact than our own and systems that were much less compact with planets on very eccentric orbits. Perhaps most surprisingly, we constructed systems that were stable for at least a billion years despite undergoing macroscopic orbital changes on much shorter time scales.

Anchor's Away, Jayanne English, Queen's University, A. Russell Taylor, University of Calgary, and Judith A. Irwin, Queen's University.

We present preliminary results of a study of an anchor-shaped atomic hydrogen structure whose base occurs south of the Milky Way's mid-plane and which extends to more negative latitudes ending in a "cap." The data were acquired as part of the Canadian Galactic Plane Survey project using the Dominion Radio Astrophysical Observatory's (DRAO) Synthesis Telescope (ST). After the incorporation of data from the 26-m DRAO single-dish telescope, the mosaic data cube has full information on all spatial scales down to the resolution limit of 1 arcminute. The velocity resolution is 0.82 km s^{-1}. Although the projected extent of the "anchor" is only a few hundred parsecs, it may be fountain-like or may represent the initial stages of a kiloparsec-scale blowout structure. In either case it could illuminate the processes by which gas in the Galaxy's halo is replenished and how the halo's energy input is maintained.

Helical Fields and Filamentary Molecular Clouds, Ralph Pudritz and Jason Fiege, McMaster University.

Molecular clouds are observed to be filamentary structures that are supported by magnetic fields and non-thermal (magneto-hydrodynamic) turbulence of some sort. Most theoretical models for self-gravitating filaments have featured magnetic fields that are aligned with the long axis of the filaments. However, observations suggest that some of these clouds could be wrapped by helical magnetic fields (Heiles 1987). We present a new and more general model for filamentary molecular clouds that incorporates the important possible role of helical fields.

High Spatial Density of the Disk Population Contact Binaries, Slavek Rucinski, Canada-France-Hawaii Telescope Corporation.

Analysis of the OGLE micro-lensing survey data in terms of the presence of contact binaries of the W UMa-type has permitted derivation of the luminosity function for these objects from a volume-limited (3 kpc) sample to absolute magnitude $M_V = 5.5$. With (large) sampling-volume corrections, the function can be estimated approximately to fainter levels, down to the short-period end of the contact binary sequence at $M_V = 7.5$. Comparison of the luminosity function with that for main sequence stars gives a high apparent frequency of occurrence of the W UMa-type binaries of one such a system for about 100–120 main sequence stars. This frequency is the apparent one and does not take into account missed systems with low orbital inclinations; the correction for those would increase the frequency by 1.5–2 times. When compared with the frequency of binary stars in the galactic field, derived by Duquennoy & Mayor (1991) and extrapolated to the shortest orbital periods, the contact binary stars show a large excess in the period range of 0.25–0.6 day, which suggests that many (or all) originated from close binary systems with somewhat longer periods that lost large amounts of their angular momenta.

A roAp Star Survey in the Northern Hemisphere, François Chagnon and Jaymie Matthews, University of British Columbia, and Philippe Eenens, Universidad de Guanajato.

The rapidly oscillating Ap stars represent powerful objects to test asteroseismology owing to their high-overtone *p*-mode pulsations. As only three of the stars are known in the northern hemisphere, where we can use very good spectroscopic sites, it is of vital importance to find more roAp stars in order to apply the techniques of asteroseismology. We conducted a photometric search for such roAp stars in the northern hemisphere at the Observatório Astronómico Nacional, México. The results of the search are presented, along with some new photometric data for a recently discovered roAp.

Polarimetric Variability of Binary Young Stars, Nadine Manset and Pierre Bastien, Université de Montréal.

Young stars are surrounded by accretion disks in which dust grains scatter and polarize stellar light. In binary systems, models predict such polarization will show phase-locked variations with a double sine behaviour. About fifteen binary young stars have been observed at the Observatoire du Mont Mégantic to seek such polarimetric variations. Preliminary results show that a majority of binary young stars are polarimetric variables, and some show phase-locked variations. If the existing models can be successfully applied to such young stars, observations can be used to find their orbital inclinations. Since the systems are also spectroscopic binaries, the known inclinations will then specify the masses of the young stars, a very important parameter for testing evolutionary models.

Events in the Star Forming Region Cepheus A, Victor A. Hughes, Queen's University.

A monitoring of the star forming region Cepheus A, over a period of 13 years, using the Very Large Array has revealed a number of events that are associated with the early stages of star formation. The events are unique in that no other region has been monitored for such a long period, whether it is a star forming region or not. The events include the demonstration of a jet exhibiting both the Mach and jet shocks, a source that shows two diverging radio sources, two sources that can appear and disappear in periods of 100 days and that have brightness temperatures of 10^6 to 10^9 K, and an object that contains three individual components which appear to be in orbit. An attempt is made to put these observations into perspective with regard to protostar formation.

Origin and Observables of the Cosmic Web, D. Pogosyan and J. R. Bond, Canadian Institute for Theoretical Astrophysics, and L. Kofman, University of Hawaii.

Observations indicate galaxies are distributed in a filament-dominated web-like structure. Numerical experiments at high and low redshift of viable structure formation theories also show filament-dominance. We have shown that the final state web is actually present in embryonic form in the overdensity pattern of the initial fluctuations, and is largely defined by the position and primordial tidal fields of rare events in the medium, with the strongest filaments between nearby peaks (clusters at low redshift, galaxies at high redshift) whose tidal tensors are nearly aligned. Here the web theory is used to craft *N*-body and hydrodynamical simulations that confront observations probing low redshift cluster-cluster bridges by weak gravitational lensing, X-rays, and the Sunyaev-Zel'dovich (SZ) effect. Our results indicate that lensing at moderate redshift can probe the filaments best among the three observational strategies, but also that the SZ effect will be useful for probing the outskirts of clusters.

Variabilité cyclique d'étoiles Wolf-Rayet apparemment isolées, Thierry Morel and Nicole St-Louis, Université de Montréal.

Nous discutons de récentes observations photométriques et spectroscopiques illustrant le caractère strictement périodique — bien que fortement dépendant de l'époque d'observation — des variations dans les étoiles Wolf-Rayet apparemment isolées WR 6 (3.77 jours) et WR 134 (2.3 jours). Nous présentons des arguments contre l'éventuelle association de ces deux étoiles avec un compagnon dégénéré (*i.e.* "invisible") et proposons que, à l'instar de certaines étoiles OB, la périodicité observée serait plutôt induite par la modulation par rotation d'un vent largement anisotropique. Les mécanismes susceptibles d'engendrer une telle situation seront également discutés.

Dust Formation Episode in the Long-Period Binary WR137: Direct Imaging with HST/NICMOS 2, Sergey Marchenko, A. F. J. Moffat and Y. Grosdidier, Université de Montréal.

We report preliminary results of medium-band (H' and K') direct imaging of the dust-forming binary WR 137 with the NICMOS-2 camera of *Hubble Space Telescope*. The images were obtained during periastron passage in this long-period (~13 yr) binary. We have resolved, for the first time, infrared-emitting dust in the close environment of HD 192641. The dust emission occurs in a few strong clumps within about 0″.5 of the star and likely arises in the shock-cone zone where the winds collide. We estimate the mass of the resolved dust features to be $5^{+7}_{-3} \times 10^{-8}\,\mathcal{M}_{\odot}$.

Star Formation in Bar Environments, Pierre Martin, Télescope Canada-France-Hawaii, and Daniel Friedli, Université Laval.

Galactic bars are the sites of highly diversified star formation activities. Along certain bars no star formation is present, while in others numerous giant H II regions are seen. To better understand how massive star formation is triggered or quenched in bar environments, we describe a general study of the morphological and physical properties (*i.e.* density, excitation, abundances) of H II regions found along the bars of eleven spirals. The results were then used to investigate the star formation process along bars by means of numerical simulations. In a wider context, the implications of star forming activity along bars for the fueling of active galactic nuclei and the evolution of barred spiral galaxies in general are briefly discussed.

H I in Dwarf Spheroidal Galaxies, Claude Carignan, Université de Montréal.

H I has now been detected in the field of three Local Group dwarf spheroidal galaxies: Tucana, Sculptor and Phoenix. While, as will be described, the H I in the field of Tucana is probably not associated with the galaxy but is more likely a component of the Magellanic Stream, the spatial and velocity coincidences of the gas mapped in the field of Sculptor suggest that it is most likely associated with the dwarf galaxy. As for Phoenix, it is difficult to draw any conclusions about the origin of the gas since no optical velocity is yet available for the galaxy.

Wide Field Imaging of Low Redshift Galaxy Clusters, W. A. Barkhouse and H. K. C. Yee, University of Toronto, and O. López-Cruz, Instituto Nacional de Astrofísica Optica y Eléctronica.

The advent of large format mosaic CCD cameras has given us the unprecedented ability to sample efficiently the galaxy population in low redshift galaxy clusters. We are presently conducting a photometric study of galaxy clusters in the redshift range of 0.02-0.04 with the 8k CCD mosaic camera on the KPNO 0.9-m telescope. This telescope/detector combination, with a pixel scale of 0″.42 pixel^{-1}, provides a one-square-degree field of view, giving an areal coverage of 1–2 h^{-1} Mpc^2. The observations will allow us to determine the projected spatial distribution and luminosity function (LF) of cluster galaxies. With such data we will test the cD formation scenario based upon the disruption of dwarf galaxies (López-Cruz *et al.* 1996, ApJ, 475, L97) by: a) measuring LFs as a function of cluster-centric radius; b) determining the spatial distribution of dwarf galaxies; and c) measuring the colour gradients for dwarf galaxies as well as the halos of cD and brightest cluster galaxies (BCGs). We report here on the current progress of the project.

The Far Ultraviolet Spectroscopic Explorer Mission, Alex Fullerton, University of Victoria/The Johns Hopkins University.

The *Far Ultraviolet Spectroscopic Explorer* (FUSE) is a free-flying satellite that has been developed for NASA by a consortium of institutions under the leadership of the Johns Hopkins University. It is scheduled to be launched into low-Earth orbit in late 1998 or early 1999. Over its lifetime of at least 3 years, it will obtain high-resolution (R ~ 30,000) spectra of many astronomical sources between 905 and 1195 Angstroms. Although this spectral region is extraordinarily rich in atomic and molecular resonance lines, it has not been routinely accessible for nearly 20 years. Thus, results from FUSE are expected to have a significant impact on many current problems in interstellar, stellar, and extragalactic astrophysics. The present paper provides an brief overview of the FUSE mission, including instrumentation, operations, Science Team projects, and the Guest Investigator Program. As part of the co-operative agreement between NASA and the Canadian Space Agency (who provided the fine error sensors for FUSE), Canadian investigators have access to at least 5% of the total observing time. Consequently, FUSE represents a particularly valuable resource for the Canadian astronomical community.

MOST: Probing Stellar Interiors with Canada's First Space Telescope, Jaymie Matthews, University of British Columbia.

The MOST (Microvariability & Oscillations of STars) mission will be a microsatellite carrying a 15-cm optical telescope in a polar low-Earth orbit. MOST is designed to detect rapid oscillations at the level of a few micromagnitudes in bright solar-type stars, as well as microvariability in a variety of stellar targets including Wolf-Rayet stars. One of the mission goals is to estimate the ages and global properties of some of the oldest metal-poor stars in the solar neighbourhood, setting independent lower limits on the age of the universe.

Astronomy Education/Pédagogie d'astronomie

La Trousse d'exploration du système solaire: un outil pédagogique pour les écoles, Pierre Chastenay, Planétarium de Montréal.

La Trousse d'exploration du système solaire est une valise pédagogique autonome destinée aux élèves du niveau préscolaire et des premier et deuxième cycles du primaire. Elle se compose de trois unités indépendantes qui abordent chacune un thème précis. Le "Loto des planètes" est un jeu de mémoire qui permet aux participants d'apprendre à reconnaître et à nommer les principaux objets qui composent le système solaire: le Soleil, les planètes et leurs principaux satellites, les astéroïdes et les comètes. L'activité "Le système solaire à l'échelle" permet aux enfants de construire un modèle à l'échelle du diamètre du Soleil et des planètes, puis un modèle des distances qui les séparent dans l'espace. Enfin, l'activité "Le cadran solaire" permet aux élèves de construire un cadran solaire simple et d'apprendre à lire l'heure à l'aide du Soleil. La Trousse d'exploration du système solaire circule dans les écoles de la région de Montréal depuis janvier 1998 et devrait être disponible dans toutes les régions du Québec dès septembre 1998.

Poster Papers/Présentations "Posters"

Classification of LMC, SMC and Milky Way Carbon Stars Between 7700 Å and 8800 Å, Loïc Albert and Serge Demers, Université de Montréal, and Willam E. Kunkel, Carnegie Institution of Washington.

We present a spectral classification of carbon (C) stars based on the red part of the continuum. It is inspired by Richer's classification (1971, ApJ, 167, 521) of photographic spectra. Our effort is based on 100 Milky Way C stars observed at the Observatoire du mont Mégantic and 70 Magellanic Cloud C stars observed at Las Campanas. Most of the stars selected were classified by Richer and, in the blue domain, by Barnbaum *et al.* (1996, ApJS, 105, 419). At 1 Å resolution we could identify two criteria to classify spectra of these AGB stars, namely the strength of the CN molecular bands between 7800 Å and 8200 Å, and the strength of the Ca II triplet at 8498 Å, 8543 Å and 8662 Å. No atomic line was identified except the Ca II triplet. Its strength is found to correlate with $T_{\rm eff}$ determined from *JHK* photometry and weakly with luminosity as determined from the LMC C stars. The goal of our project was to seek spectral criteria to differentiate SMC from LMC C stars. No obvious differences are seen in the spectra of the LMC, SMC and Milky Way families of C stars. Higher than a certain Ca II strength threshold, however, all Milky Way C stars pertain to the hotter C-R, C-H families, which originate from carbon-rich mass transfers in a binary system (McClure, 1997, PASP, 109, 256). We conclude that the 7700 Å – 8800 Å spectral range is not ideal for spectral classification.

Structural and Evolutionary Models of Helium Core White Dwarfs, Josep M. Aparicio and Gilles Fontaine, Université de Montréal.

We present the calculation of a series of evolutionary tracks of helium core white dwarfs, from the loss of the hydrogen-rich envelope onwards.

NGC 7129: SVS 13 and Other Stars, Pierre Bastien, Roger Hajjar[1] and Daniel Nadeau, Université de Montréal. [1]also Notre Dame University, Lebanon.

Polarimetric observations carried out at the Mont Mégantic Observatory have revealed SVS 13 to have the highest linear polarization in NGC 7129. On polarization maps it also exhibits the largest disk, as determined by the angular distance between the two null points at the edges of the parallel vector pattern. At the distance of NGC 7129, 1.25 kpc, the disk has a size of approximately 5600 A.U. in the *I* band. The *J* band polarimetric map (from the Canada-France-Hawaii Telescope) also exhibits a large disk. The measured emissivity index of $\beta = 0.22$, deduced from millimetre and sub-millimetre continuum photometric measurements at the James Clerk Maxwell Telescope, is compatible with what is found for young stellar objects. We have found four new infrared sources around SVS 13, and a large number of infrared sources are also present around LkHα 234. They fall on or around a V-shaped ridge of enhanced emission in the infrared, also visible in H_2, which provides insight into their star formation history. Based on such information, we confirm this scenario: the formation of BD+65° 1638 triggered the formation of the other stars through shocked molecular gas by the stellar wind. It is an ongoing process where presently SVS 13 and LkHα 234 are triggering star formation. (This paper is part of the Ph.D. thesis of Roger Hajjar.)

Observations of p*-mode Pulsations in Hot B Subdwarfs*, M. Billères, G. Fontaine, P. Brassard, and S. Charpinet, Université de Montréal, J. Liebert, University of Arizona, R. A. Saffer, Villanova University, and G. Vauclair, Observatoire Midi-Pyrénées.

We present some results of our ongoing search for pulsating stars of a new type in the field of asteroseismology — the EC14026 variables or pulsating sdB stars, whose existence was predicted theoretically. Seven such objects are now known. All are multiperiodic pulsators showing excited *p*-modes. We discuss some of our observations of the objects and also compare the class properties with further theoretical predictions described in a related paper.

A New Generation of White Dwarf Evolutionary Models, P. Brassard and G. Fontaine, Université de Montréal.

We present a new generation of white dwarf models that incorporate the latest developments in the constituent physics. They are evolutionary models especially designed for studying the cooling, spectral evolution, and seismology of white dwarfs.

A Search for Peculiar Objects with the NASA Orbital Debris Observatory 3-m Liquid Mirror Telescope, Rémi Cabanac and Ermanno Borra, Université Laval, and Mario Beauchemin, Centre canadien de télédétection.

The NASA Orbital Debris Observatory (NODO) survey uses a transit 3-m liquid mirror telescope to observe a strip of sky in twenty narrow band filters. Here we analyze a subset of data from the 1996 season. The catalogue consists of 18,000 objects with *V* between 10 and 19 in ten narrow-band filters from 500 nm to 950 nm. We first demonstrate the reliability of the data by fitting a Bahcall-Soneira model of the Galaxy to the NODO star counts. We then perform a hierarchical clustering analysis in order to extract objects exhibiting peculiar energy distributions. The present study marks the first instance in optical astronomy of astronomical research completed with a new type of optics.

Theory of Pulsating Subdwarf B Stars: A Set of Testable Predictions, S. Charpinet, G. Fontaine, and P. Brassard, Université de Montréal, P. Chayer, University of California, Berkeley, F. J. Rogers and C. A. Iglesias, Lawrence Livermore National Laboratory, and B. Dorman, Goddard Space Flight Center, NASA.

Pulsating subdwarf B (sdB) stars, now called EC14026 stars after the class prototype (Kilkenny *et al.* 1997, MNRAS 285, 640), were first predicted theoretically from stellar pulsation theory (Charpinet *et al.* 1996, ApJ, 471, L103). The identified mechanism that destabilizes such stars, a k-mechanism associated with local accumulations of iron resulting from heavy metal diffusion processes (Charpinet *et al.* 1997, ApJ, 484, L123), also reveals several characteristics of excited acoustic modes that can be tested. In this paper we summarize our theoretical predictions to allow comparison with observed pulsators.

The Mode Switch of the RR Lyrae Star V79 in M3, Christine M. Clement, University of Toronto.

A recent investigation of variable stars in the globular cluster M3 by Clement, Hilditch, Kaluzny & Rucinski (1997, ApJ, 489, L55) revealed that the RR Lyrae variable V79 had switched modes. Their observations, obtained in 1996, showed that V79 was a double-mode (RRd) variable with the first overtone mode dominating, but all previously published data (1962 and earlier) had indicated that the star was a fundamental mode (RRab) pulsator with an irregular light curve. They considered the mode switch to be observational evidence for blueward evolution of horizontal branch stars in the Oosterhoff type I cluster M3. Subsequently, Corwin, Carney & Allen (1998, IBVS, No. 4548) confirmed that V79 was an RRd star with the first overtone dominating, based on observations that they made in 1992 and 1993. Meanwhile, in a study of V79 on M3 photographs in the Sternberg Observatory plate collection, Goranskij (1980, Astronomical Circular, 1111, 6) showed that the pulsation period of V79 decreased substantially and its B amplitude varied between 1956 and 1976, although he was unable to detect any oscillations in the first overtone mode. An analysis of approximately 1000 observations of V79 made in the Soviet Union between 1950 and 1991 is presented here. It appears that the mode switch took place in late 1991 or early 1992. Prior to the switch, however, the star exhibited chaotic behaviour.

Near-Infrared Observations of the Metal-Poor Inner Spheroid Globular Cluster NGC 6287, Tim Davidge, Canadian Gemini Project Office/HIA/UBC.

Deep *JHK* images are used to probe the stellar content of the metal-poor ([Fe/H] ~ −2) globular cluster NGC 6287, which van den Bergh (1993, ApJ, 411, 173) suggests may be one of the oldest objects in the Galaxy. The data, which extend to the main sequence turn-off, are used to investigate the metallicity, distance, reddening, and age of the cluster.

The Youngest Stars of the Sculptor Dwarf Spheroidal Galaxy, Serge Demers, Université de Montréal, and Paolo Battinelli, Osservatorio Astronomico di Roma.

The discovery of neutral hydrogen in the periphery of Sculptor by Carignan *et al.* (1998) has inspired us to look for young stars associated with the region of largest H I velocity dispersion. This small area, located 15 arcminutes from the centre of Sculptor, was imaged in December 1997 with the Tek 2K CCD attached to the CTIO 1.5-m telescope. The colour-magnitude diagram contains nearly 200 blue stars brighter than the populous turnoff seen at $V = 23$. Isochrone fittings imply that the stars, if they are not blue stragglers, are 1 Gyr and older. Such blue stars are distributed, in the field observed, like the bulk of the stars and do not appear to be associated with the gas.

KIR: First Light, R. Doyon and N. St-Louis, Université de Montréal, C. Robert, D. Devost, J.-R. Roy, and L. Drissen, Université Laval.

KIR is the 1024 × 1024 (K) high-resolution near-infrared (IR) camera used with the adaptive optics bonnette on the Canada-France-Hawaii Telescope. First light on KIR was obtained on December 8, 1997, for a program devoted to starburst galaxies. The seeing conditions were excellent (0″.6 to 0″.7) with typical spatial resolution of 0″.2 to 0″.3. A preliminary analysis of the observations is presented.

The Canadian Astronomical Data Centre Services/Les Services du Centre Canadien des Données Astronomiques, Daniel Durand, Institut Herzberg d'Astrophysique, David Bohlender and David Shade, Herzberg Institute of Astrophysics.

After many years of existence, the Canadian Astronomical Data Centre (CADC) is now an important international service for astronomers. This paper presents an overview of the different services offered by the CADC as well as a presentation of future services.

A Study of the Gas and Dust Content of NGC 7129, Andreea Font and George F. Mitchell, Saint Mary's University, and Henry Matthews, Joint Astronomy Center.

NGC 7129 is a molecular cloud containing photon heated gas (a photo-dissociation region, PDR) and gas shocked by an outflow. Using the Sub-millimetre Common User Bolometer Array (SCUBA) on the James Clerk Maxwell Telescope, we have obtained 850 μm and 450 μm continuum maps of the two overlapping fields. In order to compare gas and grain properties, we obtained $C^{18}O$ $J = 3–2$ spectra at nine positions in the same region. The line ratio $^{13}CO/C^{18}O$ has been used to find the optical depth, excitation temperature column densities, and the mass of the clumps at each position. We found excitation temperatures in the range of 20–40 K along the ridge and much lower, ~12 K, in the outflow. The masses of the clumps are of the order of few solar masses. The frequency dependence of the dust extinction ($\tau \sim \nu^{\beta}$) is a clue to the dust properties. We investigated the spectral variation in the dust properties by calculating β from the 850 μm /450 μm flux ratio. The values differed at each position, lying in the range of 1.50–2.75. In the assumption that the gas and the dust are tightly coupled ($T_{gas} = T_{dust}$), we calculated the dust masses at both wavelengths and compared them with the mass of the gas.

Cosmological Hydrodynamic Simulations with Molecular Hydrogen Chemistry, Todd Fuller and Hugh Couchman, University of Western Ontario.

The first objects in cold dark matter (CDM)-like cosmologies form at a redshift of $z \sim 10 – 30$, have a baryonic mass of $\sim 3 \times 10^4 \mathcal{M}_{\odot}$, and have virial temperatures of several hundred degrees. At such a low temperature fragmentation and cooling is possible only through molecular hydrogen cooling. Numerical simulations of first object formation must therefore model H_2 chemistry. We have included the chemical reactions involving H, H^+, H^-, H_2, H_2^+ and e^- in our *N*-body gravitational + gas dynamic code. To test the code, we simulate a top-hat collapse and compare the results with an analytic model. We report some preliminary results and discuss the effects H_2 cooling has on object formation.

H I Self-Absorption in the Canadian Galactic Plane Survey: First Results, Steven J. Gibson and A. R. Taylor, University of Calgary, and P. E. Dewdney, Herzberg Institute of Astrophysics.

Neutral hydrogen 21-cm line emission is widely used to chart the warm and cool diffuse components of the interstellar medium. Less studied is the colder constituent revealed by H I self-absorption against background H I emission, though, where detected, it has often shown a significant correlation with dense clouds of molecular gas and dust. While there is some evidence that H I self-absorption may be a more sensitive tracer of cold gas than CO emission, detailed examination of the exact relationships between them and other constituents of the interstellar medium (ISM) requires both high angular resolution and an unbiased sample. The ongoing Canadian Galactic Plane Survey (CGPS) meets such criteria to an unprecedented degree, permitting the comparison of H I, CO and dust features at arcminute scales over hundreds of square degrees of the Milky Way. We present the first results of an investigation of neutral hydrogen self-absorption features in the CGPS data set.

WFPC2/Hα Imagery of the Nebula M1–67: A Clumpy Wolf-Rayet Wind Imprinting Itself on the Nebular Structure?, Yves Grosdidier and A. F. J. Moffat, Université de Montréal, G. Joncas, Université Laval, and A. Acker, Observatoire de Strasbourg.

With the Wide Field Planetary Camera 2 on the *Hubble Space Telescope*, we have obtained a deep, net *Hα* image of the relatively young ejection-type nebula M1–67 around the runaway population I Wolf-Rayet (WR) star WR124 (spectral type WN8). Our image shows a wealth of complex details, some of which have never been seen before in such a nebula. In particular, besides large arcs of nebulosity extending chaotically in many directions yet with no overall global shell structure to the nebula, we note the presence of numerous, bright, resolved knots of emission, often surrounded by what appear to be their own local "wind" bubbles. Is this the first direct evidence of spatially resolved clumps being ejected from the wind of a hot central star?

IDEFIX, un imageur polarimétrique pour l'Observatoire du Mont Mégantic, Olivier Hernandez, Université de Montréal.

L'Observatoire du Mont Mégantic se dote d'un imageur polarimétrique. Idefix est un instrument qui permettra d'obtenir deux images de polarisation perpendiculaire de façon simultanée sur le CCD Loral. Le champ de chaque image sera de plus de deux minutes d'arc et cela permettra l'étude d'étoiles très jeunes. Grâce à un choix de quatre filtres *BVRI*, une étude en longueur d'onde pourra être effectuée. Enfin, autant les polarisations linéaire et circulaire pourront être étudiées grâce aux lames demi-ondes ou quart d'onde placée à l'entrée d'Idefix. Les premières lumières sont prévues pour le mois de juin 1998.

Resolution of QSOs with the Adaptive Optics Bonnette on the Canada-France-Hawaii Telescope, John Hutching, David Crampton and Simon Morris, Herzberg Institute of Astrophysics/NRC.

We have used the Adaptive Optics Bonnette to obtain high-resolution images of QSOs at redshift ~1 and higher. While signal levels are low with small pixels, we have resolved at least half the host galaxies in early processing, and in many we detect faint tails or arms that imply tidal interactions. In the higher redshift QSOs, the host galaxies have compact or faint old stellar populations, and appear to be dominated by young stellar populations.

Orbital Motion in the Symbiotic Nova HM Sge, H. T. Kenny, Royal Military College, and A. R. Taylor, University of Calgary.

HM Sge is a D-type symbiotic star system that exhibited a symbiotic nova eruption beginning in 1975. Very Large Array images at 5 and 22.5 GHz are presented along with data extending from 1982 to 1998. The morphology and evolution of the radio emission is analyzed in terms of a model that considers the effects of both colliding winds (Kwok, Purton & Fitzgerald 1978; Girard & Willson 1987; Kenny 1995), and differential ionization (STB model: Seaquist, Taylor & Button 1984; Taylor & Seaquist 1984). The outer shell, of radius ~ 2″, is characterized by a ratio of mass loss rate to velocity of $\dot{\mathcal{M}}_c/v_c = 5.1 \pm 0.3 \times 10^{-8}\ D_{\rm kpc}^{3/2} [\dot{\mathcal{M}}_\odot\ {\rm yr}^{-1}][{\rm km\ s}^{-1}]^{-1}$. The inner shell, of radius ~ 0″.3, is characterized by a value that is ~4 times larger, *i.e.* $\dot{\mathcal{M}}_c/v_c = 1.9 \pm 0.9 \times 10^{-7}\ D_{\rm kpc}^{3/2}\ [\dot{\mathcal{M}}_\odot\ {\rm yr}^{-1}][{\rm km\ s}^{-1}]^{-1}$. At 22.5 GHz the radio morphology includes two features that evolve in separation and position angle. They are analyzed in terms of a model of orbital colliding winds. The derived orbital elements imply a highly inclined orbit ($i = 78^\circ \pm 4^\circ$) with a period of 80^{+60}_{-20} years and a binary separation of 24^{+10}_{-5} A.U. for a total system mass of $2\ \mathcal{M}_\odot$. Spectral analysis (the STB model) suggests an angular binary separation of ~ 0″.1, and yields a distance of 300^{+130}_{-65} pc. A distance as great as 750 pc is permitted if the present mass loss characteristics of the cool component have returned to their pre-outburst values, as represented in the outer shell.

The Dominion Radio Astrophysical Observatory, Tom L. Landecker, Herzberg Institute of Astrophysics/NRC.

The Dominion Radio Astrophysical Observatory (DRAO) is part of the Herzberg Institute of Astrophysics, within the National Research Council. The principal fields of astronomical research at the DRAO are interstellar medium studies, all aspects of research with space very-long-baseline interferometry, and solar radio astronomy. The themes of DRAO engineering and technical expertise are: (a) the design and operation of aperture synthesis telescopes; (b) antennas; (c) digital signal processing systems, especially correlator systems; and (d) image processing. The major facilities at the DRAO are the Synthesis Telescope, the 26-m Telescope, and the telescopes of the Solar Radio Flux Monitoring Program. DRAO supports six major projects: (a) the Canadian Galactic Plane Survey; (b) the operation of the Canadian correlator for the Very Long Baseline Interferometry Space Orbital Project (VSOP); (c) the Solar Flux Monitoring program; (d) ACSIS, the development of a correlator for the focal plane arrays on the James Clerk Maxwell Telescope; (e) the program to define the future of Canadian Radio Astronomy; and (f) work to protect the radio astronomy spectrum allocations.

Mise en évidence des régions de formation d'étoiles à la périphérie de la galaxie spirale NGC 628[2], Mario Lelièvre, Université Laval.

Discussion des résultats obtenus suite à la détection et à l'analyse des régions H II au-delà de R25 pour la galaxie spirale tardive NGC 628. Le but est d'étudier les processus de formation d'étoiles massives dans les régions du disque non affectées par l'onde de densité spirale. Au terme de cette étude, nous mettrons à l'épreuve certaines théories discutant de conditions particulières en densité de gaz nécessaire à la formation d'étoiles massives.

Évolution des abondances chimiques dans les atmosphères d'étoiles naines blanches froides, Alain Malo and F. Wesemael, Université de Montréal, and P. Bergeron, Lockheed Martin Canada.

Les étoiles naines blanches montrent des changements dramatiques dans la composition chimique de leur enveloppe au cours de leur refroidissement, en particulier à $T_{\mathrm{eff}} \sim 6000$ K où on observe que les naines blanches de type non-DA se transforment en naines blanches de type DA. A ces températures, la majorité des étoiles froides peuvent être modélisées à l'aide d'atmosphères composées soit d'hydrogène soit d'hélium. Cependant, une demi-douzaine d'objets semblent caractérisés par des distributions d'énergie typiques d'atmosphères riches en hydrogène, alors que leurs spectres ne montrent pas la raie d'absorption $H\alpha$. Nous passons en revue les mécanismes proposés dans le but d'expliquer les propriétés de ces objets, et démontrons qu'aucun de ceux-ci n'arrive à reproduire adéquatement les observations.

Aberrations du miroir primaire du mont Mégantic: Avons-nous un bon télescope?, Christian Marois and René Racine, Université de Montréal.

Dans le processus d'implantation d'un système d'optique adaptative, il est essentiel de connaître les limites intrinsèques du télescope. Les aberrations ainsi détectées permettent de fixer les performances futures du système et d'envisager des mesures de correction si cela s'avère nécessaire. Nous présentons donc les résultats de nos recherches portant sur le miroir primaire du mont Mégantic.

The Distribution of Mass in the Core of Virgo and Dynamics of the Globular Cluster System around M87, Dean E. McLaughlin, University of California at Berkeley.

Radial velocities for a sample of 205 globular clusters around M87, recently obtained by Cohen & Ryzhov (1997), are used to investigate the dynamics of the globular cluster system (GCS) of this cD galaxy. Previous analyses of similar (but sparser) data have made *a priori* assumptions on some property of the GCS (*e.g.* isotropic orbits) in order to use the cluster velocities to constrain the dark matter density profile in the core of Virgo. Here, we instead refer to the distribution of stars and gas in M87 to construct a mass model for the Virgo cluster independently of any data on the GCS. This is then used, along with the observed GCS density profile, to solve the Jeans equation for the GCS velocity dispersion as a function of radius in M87. The orbital anisotropy of the cluster system is a free parameter in such an approach, and is constrained by comparing model line-of-sight velocity dispersions with the data of Cohen & Ryzhov.

Spectrophotométrie de la Croix d'Einstein dans le proche infrarouge, D. Nadeau, R. Racine, and R. Doyon, Université de Montréal.

Nous présentons des images spectrophotométriques ($\lambda/\Delta\lambda = 60$) du quadruple mirage par lentille gravitationnelle Q2237+0305 obtenues avec MONICA au Télescope Canada-France-Hawaii en 1992, 1993 et 1994 dans le domaine spectral 1.700 μm < λ < 2.40 μm. Ces données sont utilisées pour séparer l'emission continue de l'emission par la raie $H\alpha$, décalée à une longeur d'onde de 1.77 μm, et étudier les différences de microamplification reliées aux différentes dimensions de la source d'émission continue et de la source d'émission $H\alpha$. Ces données permettent aussi de détecter la cinquième image du quasar, quasi-coïncidente avec le noyau de la galaxie.

A Thermal Mass-Transfer Model for Supersoft X-Ray Sources, Lorne A. Nelson and M.-P. Portelance, Bishop's University.

We analyze a binary model for the recently identified class of objects known as Supersoft X-ray Sources. According to the model, a subgiant companion fills its Roche lobe and loses matter onto a C-O white dwarf accretor. We show that the donor loses mass on its Kelvin timescale and that this rate of accretion onto the degenerate dwarf is sufficiently high to ensure that stable nuclear burning occurs on its surface (*i.e.* the mass of the degenerate companion can increase). Using population synthesis techniques, we compare the theoretically expected number of supersoft sources with that which is actually observed and investigate the possibility that these sources are the progenitors of Type Ia supernovae.

Calculating Re-Ionization: The Effect of Diffuse Population III Stars, Alexei Razoumov, University of British Columbia.

Recombination of the universe at $z \sim 1000$ gave rise to the cosmic dark age which lasted until "moderate" redshifts. However, the observable universe is almost entirely ionized and transparent to radiation. The details of re-ionization are closely related to the growth of structure between redshifts 30 and 10, with light coming from the first generation of stars and quasars. A numerical scheme for three-dimensional time-dependent radiative transfer, to be merged with an existing cosmological hydrodynamical code, is being developed. Prior work in the field usually focused either on one-dimensional problems, or on using some local approximation (self-shielding, local optical depth). We present here a method to solve the moment equations of the radiation field, allowing for a complex geometry of ray propagation. Hopefully, the technique will allow us to compute the growth of ionized bubbles from collapsed objects into a clumpy medium.

[2] Selected as the best student poster paper at the 1998 meeting

SCUBA Observations of the Light Curves of Ceres, Vesta and Pallas, Russell O. Redman, Henry E. Matthews, and Paul Feldman, Herzberg Institute of Astrophysics/NRC.

Ceres and Vesta were observed on the night of 1997 October 14, and Pallas on the night of 1998 April 25, using the Sub-millimetre Common User Bolometer Array (SCUBA) on the James Clerk Maxwell Telescope. Vesta exhibited single-peaked light curves at 450 and 2000 microns, with the same shape at both wavelengths. The data for Ceres suggest a double-peaked light curve at both wavelengths, with much larger amplitude than is observed at visible wavelengths. Both results are completely unexpected and cannot be tied simply to the optically determined triaxial shapes of the asteroids. Pallas was too faint to exhibit light variations at 2000 microns.

Atomic Hydrogen Near the Cygnus Loop, Robert S. Roger, Herzberg Institute of Astrophysics/NRC, and Denis A. Leahy, University of Calgary.

H I 21-cm line observations of the Cygnus Loop have been made with the Dominion Radio Astrophysical Observatory's Synthesis Telescope and 26-m Telescope. Spectral line maps for 128 channels with 1.65 km s^{-1} velocity separation were constructed for a 6 degree square field encompassing the supernova remnant (SNR). A number of features are detected in and around the Cygnus Loop, but no features are clearly identified with the interior of the remnant. However, several features have interior edges closely matching the outer boundary of the SNR. They provide evidence for the wall of the cavity into which the Cygnus Loop is hypothesized to be expanding.

The Orbits of Two Giant Binary Stars, C. D. Scarfe, University of Victoria.

HD 90512 and HD 121212 are both single-spectrum binary stars, whose primaries are giants. Their orbital elements have been determined from radial velocities obtained with the Dominion Astrophysical Observatory 1.2-m telescope and coudé radial velocity spectrometer. Their periods are near 100 days and their orbital eccentricities are low. Thus they provide two new points near the boundary between circular and eccentric orbits in the period-eccentricity diagram for binaries containing giants.

H I in the Field of the Dwarf Spheroidal Galaxy Phoenix, Julie St-Germain and Claude Carignan, Université de Montréal.

We present new results based on a mosaic of the H I emission in the field of the dwarf spheroidal galaxy Phoenix done with the Australia Telescope Compact Array. H I emission is seen in four different velocity components (−23, 0, 56, and 140 km s^{-1}). While the component at 0 km s^{-1} is of galactic origin and the one at 140 km s^{-1} is probably related to the Magellanic Stream, one of the two other components could be associated with Phoenix. However, optical velocities are needed to verify whether that is the case.

Vents en collision dans γ Velorum/Colliding Winds in γ Velorum, Nicole St-Louis, Université de Montréal.

La preuve de l'existence de vents stellaires en collision dans le système binaire WR+O γ Velorum a été obtenue par l'entremise d'une importante série de spectres optiques. Les caractéristiques du choc déduites de l'analyse de ces spectres sont présentées. Evidence for the presence of colliding winds in the WR+O binary system γ Velorum has been obtained through an extensive series of optical spectra. The characteristics of the shock region deduced from the spectra are presented.

The Sun's Energy Output and the 10.7-cm Flux, Kenneth Frank Tapping, Herzberg Institute of Astrophysics/NRC.

The Sun's energy output has been measured over more than a solar activity cycle by orbiting radiometers. The National Research Council of Canada has made accurate measurements of the 10.7-cm solar flux over the same period. The 10.7-cm flux is an effective measure of the total magnetic flux in the lower solar atmosphere. In addition, there are connections between the Sun's total energy output and magnetic activity: sunspots cause dips and faculae enhancements. In a comparison between measurements of the energy output and the 10.7-cm flux, each averaged over solar rotations, we find a strong, positive correlation. The processes modulating the Sun's energy output over time scales up to a solar cycle also modulate the density and magnetic field strength in the lower corona, where the 10.7-cm emissions originate. There are signs of hysteresis between the energy output and the 10.7-cm flux between the rising and falling parts of the cycle. However, there are insufficient data to determine whether this is a systematic phenomenon.

The Canadian Galactic Plane Survey, A. R. Taylor, S. Gibson, D. Leahy, M. Peracaula, and S. Dougherty, University of Calgary, C. Carignan and N. St-Louis, Université de Montréal, M. Fich, University of Waterloo, N. Ghazzali, G. Joncas, S. Pineault, and S. Mashchenko, Université Laval, J. Irwin and J. English, Queen's University, C. Heiles and M. Normandeau, University of California, P. Martin, D. Johnstone, and S. Basu, Canadian Insititute for Theoretical Astrophysics, W. McCutcheon, University of British Columbia, D. Routledge and F. Vaneldik, University of Alberta, P. Dewdney, J. Galt, A. Gray, L. Higgs, L. Knee, T. Landecker, C. Purton, R. S. Roger, K. Tapping, B. Wallace, and T. Willis, Herzberg Institute of Astrophysics, C. Beichman, California Institute of Technology, N. Duric, University of New Mexico, D. Green, Cambridge University, M. Heyer, University of Massachusetts, H. Wendker, Hamburger Sternwarte, and Z. Xi-Zhen, Beijing Astronomical Observatory.

In April 1995 the Dominion Radio Astrophysical Observatory (DRAO), in collaboration with a consortium of university astronomers, began a project to image the atomic hydrogen and radio continuum emission from the interstellar medium of the Milky Way galaxy. By constructing a mosaic of almost 200 synthesis fields, the survey will cover the region $75° < l < 145°$ and $-3 < b < +5°$, with angular resolution of 1 arcminute. The atomic hydrogen cube will yield three-dimensional images with spatial resolution of order 1 parsec over regions several kiloparsecs in extent. In the continuum, full Stokes *I, Q, U* and *V* images are produced at 1420 MHz and a Stokes *I* image at 408 MHz. Approximately 50% of the DRAO observations have now been completed, and the first complete mosaic images were created in December 1997. Here we present a description of the survey project and highlights of the discoveries and results from the initial data products.

A Spectroscopic Study of Binary B-Type Subdwarf (sdB) Stars, Pascal Thériault, Robert Lamontagne, and F. Wesemael, Université de Montréal.

The sdB stars are extended horizontal-branch members, having suffered important mass loss sometime on their evolutionary paths. It is worth asking what role binarity might have in this scenario. Earlier photometric studies estimated that about 60% of the B-type subdwarfs are in binary systems, where the spectral type of the secondary, which resides either on the main sequence or on the subgiant branch, ranges from late-G to early-M. Here we present optical spectra of several suspected binary sdB stars that permit a deconvolution of the components of the system. Values for the parameters of each component are presented.

A 3.7-m Liquid Mirror, Grégoire Tremblay and Ermanno Borra, Université Laval.

We have constructed a 3.7-m liquid mirror in our laboratory and are currently testing it using a variety of optical shop tests. Presented here are some of the results we have obtained so far.

Monitoring Cepheid Period Changes from Saint Mary's University, David G. Turner, Andrew J. Horsford and Joseph D. MacMillan, Saint Mary's University.

The 0.4-m telescope of the Burke-Gaffney Observatory at Saint Mary's was used with a CCD camera during the summers of 1996 and 1997 to image a selection of Cepheid variables in blue light. Seasonal light curves for each program star were constructed using the calculated magnitude differences of the Cepheids relative to reference stars in the same fields of view, and the data were then matched to existing light curve templates for each variable in order to establish O–C corrections to existing ephemerides. Examples of the results obtained for individual program stars are presented here. The long temporal baselines of O–C data that now exist for the observational histories of northern hemisphere Cepheids provide excellent material for studying their period changes. Such changes in turn are related directly to the rate at which the stars are evolving through the instability strip in the H-R diagram. From the results of our photometric monitoring it is possible to identify the probable crossing modes of our program objects with a fair degree of confidence. Extensive studies of a larger sample of Cepheids provide rather interesting revelations about the instability strip crossing modes of various objects. Some of the more controversial findings are described here.

Magnetism in Molecular Clouds: Monstrous Mayhem and Mild Madness, J. P. Vallée, Herzberg Institute of Astrophysics/NRC, and P. Bastien, Université de Montréal.

In young clouds the magnetic field is expected to be simple or at most to show mild madness (because of clump collisions, Alfven waves, etc.). In old clouds the magnetic field is expected to be complex and to show monstrous mayhem (attributable to star-forming regions, bending magnetic lanes, etc). We present new linear polarization observations at a wavelength of 800 microns of nearby dusty molecular clouds made with the James Clerk Maxwell Telescope (JCMT) in Hawaii. The JCMT observations show that the magnetic field is often observed to be perpendicular to a cloud's elongation, constraining the possible geometries and time evolution. For extended clouds the length scale of the magnetic field is of the order of the cloud itself or larger. We assume that the polarization comes from emission by nonspherical grains aligned by a magnetic field, and that the direction of the tangential component of the magnetic field is given by perpendiculars to the observed position angles of the linear polarization.

A Detailed Investigation of the Environment of Active Galaxies, Marcel Vandalfsen, McMaster University, and M. M. De Robertis, York University.

An analysis of some of the properties and environmental parameters of a sample of CfA Seyfert galaxies and a control sample of non-active galaxies is presented. To reduce selection effects, the two samples are well matched in redshift, luminosity and overall morphology. In particular, the distribution of host galaxy properties, including disk and bulge scale radii and surface brightnesses, are shown to be similar. The distribution of properties of the host galaxy "companions" — galaxies in the field of a Seyfert or control galaxy out to a common projected distance — are also illustrated. The distributions of relative companion frequency, projected separation (from the host), angular distribution, apparent magnitude difference relative to the host, and maximal tidal influence are found to be similar between both samples. Moreover, the frequency of "morphological disturbances" (bars, rings and distortions) between the Seyfert and control galaxies is found to be very similar. Though there is room for a more thorough investigation, nuclear activity does not appear to correlate with host-galaxy properties or the properties of the local environment.

Radiative Transfer and SPH Simulation, Serge Viau and Pierre Bastien, Université de Montréal.

We study in three dimensions the hydrodynamical collapse of interstellar clouds to form stars with a Smooth Particle Hydrodynamics (SPH) code. In the SPH simulation of a collapsing cloud, the main advantage is that the code does not require a grid to compute spatial derivatives. Instead, we use point particles. Each particle possesses its own properties (mass, density, temperature), and those properties are smoothed out over an extended region by a given function called the kernel. The object of the research here is to add radiative transfer to the energy conservation equation. The new version of the SPH code will be very helpful in studying the behaviour of a molecular cloud during its collapse once we include radiative transfer. For example, we are particularly interested in the accretion disk. We should be able to measure the distribution of the temperature along the disk.

Analysis of Two-Colour Data for Seyfert and Normal Galaxies, S. Virani and M. De Robertis, York University.

A non-linear least-squares fitting algorithm was developed to determine the surface brightness structural parameters from a data set consisting of 22 *B* and *R* images of Seyfert galaxies and 59 *R* images of non-active galaxies matched in redshift, luminosity and overall morphology. Rather than adopt a de Vaucouleurs law, a more general relationship was used. In particular, the exponent for the bulge component was not adopted *a priori*. Recent studies have shown that assuming an $r^{(1/n)}$ "law," where n does not equal 4, may provide better fits than the standard $r^{(1/4)}$ law. We present results obtained from fitting a general Sersic form to our data set. The best-fitting value for n is found to vary between 2 and 4. Comparisons of the *B* and *R* data for the Seyferts, as well as the *R* data for the Seyferts and non-active sample, are provided.

The Missing Interstellar Medium of NGC 147 and M32, G. Welch, Saint Mary's University, and L. J. Sage, Univ. of Maryland.

We present the results of a search for CO (J = 1–0) emission from NGC 147 and M32, two of the four dwarf elliptical companions of M31. Return of gas from evolved stars to the interstellar medium of these galaxies should have resulted in detections, but we find instead upper limits of 5500 and 6700 solar masses for NGC 147 and M32, respectively. Including an earlier H I limit, we find that the gaseous interstellar medium of NGC 147 comprises less than 2% of what is expected. The large published H I mass limit for M32 prevents us from reaching a similarly extreme conclusion for it. Our results stand in stark contrast to what is seen in NGC 185 and NGC 205, where the observed gas is approximately what is expected from stellar mass loss, though some of the gas in NGC 205 must have had an external origin. There are no obvious differences in masses or luminosities that would explain the results. The proposal that differences may be related to the recent interaction histories of the galaxies with M31 does not seem to be viable. The results may point to a fundamental gap in our understanding of galaxy evolution.

Les naines blanches variables de type V777 Her, F. Wesemael, Université de Montréal, A. Beauchamp, CAE Électronique Ltée, P. Bergeron, Lockheed Martin Canada, and G. Fontaine, Université de Montréal.

Les naines blanches de type V777 Her forment un groupe homogène d'étoiles variables à atmosphères composées d'hélium (types DB et DBA). Ces objets, en pulsation non radiale, sont tous caractérisés par des températures effectives de l'ordre de 20,000 K. Nous présentons une analyse spectroscopique détaillée des huit étoiles V777 Her connues, ainsi que d'un échantillon de 21 autres étoiles de même type spectral, toutes plus chaudes que 17,500 K. Les températures effectives déterminées permettent d'identifier les bornes de la bande d'instabilité des étoiles V777 Her, ainsi que de contraindre les analyses séismologiques de ces objets.

Large-Scale Structure of Molecular Gas in M17, C. D. Wilson, McMaster University, J. E. Howe, University of Massachusetts, and M. L. Balogh, University of Victoria.

Large-area CO maps of the molecular cloud M17 obtained at the James Clerk Maxwell Telescope have been used to study the CO line ratios and physical conditions in the cloud. The CO emission lines up to the J = 3 level do not appear to be sensitive to small amounts of very hot gas. The ^{12}CO/^{13}CO line ratios correlate with the ^{13}CO intensity, primarily because of variations in the column density from one position to another. Physical conditions (density, temperature) derived from globally averaged line ratios agree well with results obtained along individual lines-of-sight, which suggests that typical physical conditions can be measured successfully using global CO line ratios. The ^{12}CO/^{13}CO J = 2–1 and J = 3–2 line ratios indicate a systematic increase in these line ratios as we move to larger physical scales. These results suggest that emission from low column density "diffuse" molecular gas makes an important contribution to the CO emission in galactic disks.

Education Notes
Rubriques Pédagogiques

VARIABLE STARS IN YOUR CLASSROOM

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Abstract. The observation and analysis of variable stars can develop and integrate a wide range of science, mathematics, and computing skills, from junior high school to university level. The American Association of Variable Star Observers (AAVSO) has recently completed a major project *Hands-On Astrophysics* to use variable stars to enhance science and mathematics education. We describe the project and other variable star activities for your classroom.

Résumé. L'observation d'étoiles variables et l'analyse des données qui en découlent encouragent le développement et l'intégration de connaissances de la science, des mathématiques et des ordinateurs, spécialement chez les étudiants, allant des débutants au secondaire jusqu'à ceux au niveau universitaire. L'Association américaine des observateurs d'étoiles variables (AAVSO) a récemment complété un programme important intitulé *Hands-On Astrophysics* dont le but est d'utiliser l'étude d'étoiles variables pour améliorer l'instruction en sciences et en mathématiques. Nous décrivons le projet et d'autres activités concernant les étoiles variables qui conviennent à vos élèves
SEM

1. Introduction

For many years one of us (JRP) made visits each year to small colleges as part of the American Astronomical Society's Harlow Shapley Visiting Lecturer Program. He would often find astronomy instructors who were looking for sky activities that involved real science and that could be done successfully with little or no equipment — even in climatically-underprivileged locations. He realized that his own favourite research objects — variable stars — could be used for that purpose. Variable stars are stars that change in brightness; they provide astronomers with important information about stellar properties and evolution. In some cases the variability can be measured with the unaided eye. Each student could make a few measurements over the course of a month or two. Such measurements could be pooled with those of other students for analysis and interpretation in a daytime lab. Through variable stars, students could be given "eyes-on" exposure to both the process and the excitement of science.

For equally many years the other of us (JAM), as Director of the American Association of Variable Star Observers (AAVSO), had been answering requests from teachers for lab activities, and from students for science fair projects. As a scientist and former teacher, she recognized that variable star observing is simple but challenging, and therefore suitable for school settings. She also recognized that variable star observers can make a significant contribution to scientific research, and that such a prospect could provide motivation and excitement for students.

The AAVSO is the largest organization of variable star observers in the world, with members and observers in 46 countries. About 575 observers submit over 300,000 measurements of thousands of stars to the AAVSO each year. The AAVSO data base now contains over 8½ million measurements, and is a unique and precious resource for science and education. The educational opportunities for the AAVSO and its data base were opened up by a small but influential meeting on "An Education Initiative in Astronomy" (Brown 1990), and by the availability of National Science Foundation funding for science education projects.

Together, we harnessed our long-standing interests in variable stars and in education, and developed a proposal for *Hands-On Astrophysics (HOA)* — a project that would use variable star observation and analysis to develop and integrate a wide range of skills in science, mathematics, and computing. The project was generously funded by the National Science Foundation, and, five years later, the project is complete and available for your school or university classroom.

As we developed ideas for simple activities and projects, we included them in our annual "Variable Star of the Year" column in the Royal Astronomical Society of Canada's *Observer's Handbook*, because we recognized that they would be of interest to both new and experienced amateur astronomers as well as to teachers and students (MacRobert 1996). We described the observation of δ Cephei — a "core" activity in HOA — in the 1994 *Handbook*, Algol (β Persei) in 1995, photographing variable stars in 1997, the bright red giant variable α Herculis in 1998, and another bright red giant variable W Cygni in 1999. See Levy (1989) for an introduction to variable star observing.

2. Variable Star Activities in the Classroom

Variable star astronomy is well suited for student activities and projects. It is simple in process, but sophisticated and powerful in its applications to science and mathematics education. The 550-page *HOA* teachers' and students' manual, written primarily by curriculum specialist Donna Young, links the activities to current science and mathematics education standards, as well as providing a wealth of information on the science, mathematics, history, and people of variable star astronomy. Astronomy is poised to play an enhanced role in science education in Canada (Percy 1998). Variable star activities connect naturally to many of the topics proposed for the grade 9 and 11/12 levels, and beyond.

Ideally, students can identify and measure variable stars in the real sky. Even in the most light-polluted environment, students can measure the brightness of the red supergiant variable star Betelgeuse, as it sets in the west, relative to Aldebaran (V = +0.85) on the right, and Procyon (V = +0.38) on the left. The data can then be used in the classroom to discuss measurement, measurement uncertainties, mean, and standard deviation. Betelgeuse, because of its enormous size, its potential to explode as a supernova, and its sometimes-corrupted pronunciation, is always of special interest to students.

Many other variable stars are 3rd magnitude or brighter, and can be seen and measured in most urban, suburban, and rural locations. There are bright eclipsing variables such as β Lyrae and β Persei (Algol). There are Cepheid variables such as δ Cephei, ζ Geminorum, and η Aquilae, conveniently spread around the sky. Each student in the class can measure δ Cephei, for instance, a few times over the course of a month or two. The class data set can then be used for analysis and interpretation in the classroom or lab to illustrate many more concepts and skills — variability, periodicity, and graphical analysis (Carlson 1989; Percy 1993). *HOA* includes 45 charts for 15 variable stars in five constellations, along with their comparison star sequences.

During the development of *HOA*, we held two workshops for expert teachers who could advise and assist us. For several weeks before the autumn 1994 workshop, 14 teachers, from many parts of the U.S., measured δ Cephei whenever they could, and submitted their measurements to AAVSO Headquarters. At the workshop, the teachers were able to work with the combined data set of 202 measurements, including their own. For them it was the highlight of the workshop — doing real science with real measurements. They could compare the observed time of maximum brightness with the predicted time, and even detect the effect of the star's evolution. They could see how their own measurements compared with others, and how the efforts of many people could be combined, for the benefit of all.

What about the problem that "the stars come out at night, but the students don't?" One solution is to use photographs. *HOA* includes a set of 31 slides, and 14 prints, that students can use in the classroom or lab to learn the process of variable star measurement. Some teachers or students may wish to make their own set of slides, as Toronto high school student Laura Syczak did. She succeeded in photographing the variable star RT Aur (period 3.7 days) on eight consecutive nights, as described in our article in the 1997 *Observer's Handbook* and in Percy *et al.* (1997). One of us (JRP) has used the images in variable star observing workshops on several occasions.

Students — especially those with a special interest in mathematics and computer science — can also enjoy variable star analysis indoors, on the computer. *HOA* includes three PC software programs: a computer-based tutorial *HOAFUN*, a data entry program *HOAENTER*, and a powerful data analysis program *VSTAR*. It also includes a data base of over 600,000 measurements of 50 variable stars from the AAVSO International Database. Students can analyze "their own" star and report on their results. *VSTAR* gives students a hands-on introduction to *time series analysis* — a technique that is now used in almost every branch of science, engineering, and commerce.

Or students may just want to watch videos! *HOA* includes a video cassette with three separate videos on *Backyard Astronomy*, *Variable Stars*, and *How to Observe Variable Stars*. The first is inspirational, the second is informational, and the third is instructional. They were produced in co-operation with Sheridan College, Oakville, Ontario.

HOA can be ordered from: AAVSO, 25 Birch Street, Cambridge MA 02138-1205, U.S.A.; Electronic-mail: aavso@aavso.org; WWW: www.aavso.org. The cost is US$200 (US$150 for AAVSO members). The software and the videos are available separately, for US$62 and US$23, respectively; (US$52 and US$18 for AAVSO members). The AAVSO web site includes a wealth of information about variable stars and variable star observing, as well as web pages that specifically support *HOA*.

3. Extensions

Once students have mastered the techniques of variable star observation and analysis, the sky's the limit! They can become regular variable star observers and contribute to astronomical research. The best way to do that is to become an AAVSO member and observer. Contact the AAVSO at the addresses given above for more information.

Students with an interest in the life sciences may want to find out more about the physiology of visual measurement of variable stars. How does the eye make such measurements? What are the sources of error? How do the brightness and colour of the star affect measurements? Are there systematic differences between measurements from different observers?

Variable stars make excellent science fair projects. One active variable star observer — 16-year-old Mary Dombrowski of Glastonbury CT — was the 1998 winner of the National Young Astronomer Award. For such projects students can analyze their own data, or data from *HOA*, or from the AAVSO web site, or even from the European Space Agency's *Hipparcos* satellite. This satellite made photometric observations of 120,000 stars for over three years and the observations are now publicly available on the *Hipparcos* web site: either the research tools page (astro.estec.esa.nl/Hipparcos/research.html) or the animations page (astro.estec.esa.nl/Hipparcos/animations.html), or via either link from the education page (astro.estec.esa.nl/Hipparcos/education.html), which we recommend highly. The *HOA* software package *VSTAR* can be used on any variable star data, including *Hipparcos* data. There are still many new results and discoveries waiting to be made in this gold mine of data, and such potential discoveries make wonderful incentives for science and mathemetics students from the senior high school to the senior university level.

For many years one of us (Percy 1990) has used variable star projects for students in the University of Toronto Mentorship Program, which enables outstanding senior high school students to work on research and education projects at the university. These students have already published a dozen research and education papers based on their work. The program has been a "win-win" proposition — for the university, for the high schools, and for faculty and students in many academic disciplines from anthropology to zoology.

4. Epilogue

One of our goals is to encourage more young people in North America and beyond to take up amateur astronomy — both for their own benefit and for the benefit of science and education. Amateur astronomy is hands-on science — observing, recording, analyzing, interpreting, understanding, and appreciating. Astronomy is one of the few areas of science that can become a lifelong hobby. We hope that other branches of amateur astronomy — the Sun, the Moon and planets, comets and asteroids, occultations, double stars, and deep-sky astronomy — can be linked to science education, bringing real science to students and bringing young people to amateur astronomy. In the words of the song (and the title of an eloquent book by variable star astronomer Helen Sawyer Hogg), "The Stars Belong to Everyone." So do the Sun, Moon, and planets. They can bring the excitement of science into classrooms and into the lives of millions of people of all ages.

Acknowledgements. *Hands-On Astrophysics* was partially funded by NSF grant ESI-9154091. We are deeply grateful to NSF and to Program Director Dr. Gerhard Salinger for encouragement and support. We thank the dozens of astronomers (both amateur and professional) and educators who have contributed to *HOA*, either directly or through the AAVSO, for their advice and assistance.

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References

Brown, R. A. 1990, An Education Initiative in Astronomy, NASA
Carlson, G. A. 1989, Scientific American, November, p. 128
Levy, D. H. 1989, Observing Variable Stars: A Guide for the Beginner (Cambridge University Press: Cambridge)
MacRobert, A. M. 1996, Sky & Telescope, 91, No. 3, March, p. 48
Percy, J. R. 1990, JRASC, 84, 49
Percy, J. R. 1993, The Physics Teacher, 31, 541
Percy, J. R. 1998, JRASC, 92, 38
Percy, J. R., Syczak, L. & Mattei, J. A. 1997, The Physics Teacher, 35, 349

JOHN PERCY is a Professor of Astronomy at Erindale Campus, University of Toronto. He is President of the Astronomical Society of the Pacific and Past President of the IAU's Commission on Teaching of Astronomy. For more than thirty-five years he has worked to bring more and better astronomy to Canadian schools, as indicated by his previous Education Note on the Pan-Canadian Science Project published in the February issue.

JANET MATTEI is the Director of the American Association of Variable Star Observers.

Society News /Nouvelles de la société

THE NEWLY-MODIFIED SIMON NEWCOMB AWARD

At the request of National Council, the Awards Committee and the Halifax Centre have completely revised the rules for the Simon Newcomb Award, the RASC's national award for exemplary writing on the topic of astronomy. It was felt by many that the old rules were overly restrictive, contributing to a low number of eligible submissions. With the new rules in place, the RASC will have a better opportunity to recognize good writing by Society members, so members of the Awards Committee hope to see an increase in nominations for the award.

The new rules — printed below and soon to be updated in the RASC Manual — are self-explanatory, but please note a number of important changes in some of the key elements: the new Simon Newcomb Award will be open to *all* RASC members, whether amateur or professional; proposed recipients must be nominated by another member (or members); and the written work must already be published in some form, either in a Society publication or elsewhere. The last is the most significant change.

In view of the announcement of the changes so late in the calendar year, the deadline for 1998 year is being extended to March 31, 1999 (instead of December 31, 1998).

Web-surfers may be interested in visiting the Simon Newcomb sites at:

gsb-www.uchicago.edu/fac/owen.lamont/research/newcomb.html
www-groups.dcs.st and.ac.uk/~history/Mathematicians/Newcomb.html

The revised rules are given below. They were passed at the June meeting of National Council held in Victoria.

The Simon Newcomb Award

The Simon Newcomb Award is intended to encourage members of the Royal Astronomical Society of Canada to write on the topic of astronomy for the Society or the general public, and to recognize the best published works through an annual award.

Background

The award is named in honour of the astronomer Simon Newcomb (1835–1909), who was born in Nova Scotia and later served for twenty years as Superintendent of the American Ephemeris and Nautical Almanac Office at the United States Naval Observatory in Washington. The award was created in 1978 by the National Council of the RASC on the initiative of the RASC Halifax Centre.

Who is Eligible?

Any member of the Society is eligible for the award. Nominations may be submitted by another member, a group of members, or an RASC centre.

What Writing is Eligible?

An eligible entry should be a recently published piece of writing with an astronomical theme. This could be one of: a book or a portion of a book; an article in the *Journal* of the RASC, a centre newsletter, or another RASC publication; an article in a commercially published magazine; and so on. A series of articles or a history of exemplary writing would also be considered eligible.

Judging

The Awards Committee will judge nominations according to several criteria, including: originality, literary merit, scientific accuracy, educational value, and promotion of the Society's objectives. The Committee is not bound to make an award in a given year if the nominated works do not meet a suitable combination of these criteria.

Submission of Nominations

Send nominations to the Awards Committee (c/o RASC National Office, 136 Dupont Street, Toronto, Ontario, M5R 1V2). To be considered for an award in a given year, nominations must arrive by December 31st. Letters of nomination must include: (a) the name and address of the nominator; (b) the name, address, and RASC centre affiliation of the nominee (if attached to a centre); (c) the title(s) of the author's work(s) to be considered for distinction; (d) full publication details; and (e) a statement establishing the suitability of the author's writing.

For an article in a magazine or journal, the publication details should include the journal or magazine name, the volume and issue numbers, the page range, and the date of publication. For a book, the publication details should include the publisher's name, the place of publication, and the year of publication.

The nominator may be requested to supply a good copy of the nominated work if it is not known to the members of the Awards Committee or not readily available.

Presentation

The award is a trophy which will be presented at the General Assembly and remains in the hands of the recipient until the following April. A cash prize of $250 will be awarded to the recipient by the RASC.

Promotion of the Award

The Awards Committee will regularly promote the Simon Newcomb Award in the Society's *Journal* along with the other distinctions of the Society, and will take further action to encourage nominations as necessary.

STARFEST "BRING HOME THE BACON" AWARD

At Starfest '98 on August 22, during the evening program, the North York Astronomical Association announced the Starfest "Bring Home The Bacon" Award. The award was inspired by a comment made by Brian Marsden several years ago at a joint meeting of the Royal Canadian Institute and the Royal Astronomical Society of Canada, Toronto Centre. At that meeting, Brian indicated that Canadian Amateurs were not keeping pace with other amateurs around the world in the discovery of asteroids and other things that go bump in the night. The intent of the new award is therefore to stimulate observational activity among Canadian amateur astronomers by providing a cash prize for the next person who makes an astronomical discovery.

The Starfest "Bring Home the Bacon" Award will be awarded to the next Canadian amateur astronomer or group of Canadian amateur astronomers to make an astronomical discovery, such as of a near-Earth asteroid, comet, nova, or supernova. The discovery must be announced and authenticated by a recognized authority such as the International Astronomical Union.

In keeping with the spirit of Starfest, the award will consist of:

500 Loonies
a pound of back bacon
a toque

If you require further information about the award, please contact Andreas Gada at NYAA@interlog.com or write to Andreas Gada, 26 Chryessa Ave., Toronto, Ontario, M6N 4T5.

HELP IMPROVE YOUR SOCIETY

The RASC Membership and Promotion (MAP) Committee is looking for input from all members of the Society regarding the following topics:

- What can be done to improve the services supplied to members at the national level?
- New ideas for advertisements in *SkyNews* to better promote the RASC,
- The desirability of creating new membership categories (*e.g.* Family, Educator, Associate, etc.),
- Ways to attract and retain more Youth members,
- Any new RASC promotional items that would be of interest,
- Other issues of concern.

Now is the time for members to think about the above items to help determine if there is a desire to initiate major changes to the Society. Discuss the topics at Centre council meetings and with other members, since membership input is crucial to the process. Please share your thoughts and concerns with us before January 31, 1999.

If you have ideas on how the RASC can become a better Society, send them to one of the MAP Committee members listed below:

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RR #2
Perth Rd Village, Ontario
K0K 2L0
Email: Kimhay@adan.kingston.net

Don Hladiuk (chairman)
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Email: Keser@duke.usask.ca

CONGRATULATIONS TO…

David Levy, who won an Emmy in the award category of "Individual Achievement in a Craft in News & Documentary Programming — Writers." David shared the award with co-writers Martyn Ives, David Taylor, and Benjamin Wooley for the Discovery Channel show "Three Minutes to Impact."

Rajiv Gupta, whose *RASC Observer's Calendar 1998* was the "Best Calendar" winner for 1998 in the Ontario Printing and Imaging Association's annual competition.

An Evaluation of Canon Image Stabilized Binoculars

by Chris Baldock (cbaldoc@ibm.net)

A Very Brief Background

One of the local camera stores here in London recently loaned me a pair of the new Canon 10 × 30 Image Stabilization binoculars and I thought that an independent critique might be of some value. Please note that the evaluation is based strictly on my personal opinion and limited experience. I would be interested in hearing from others, especially regarding additional tests that might be of interest.

On my last two vacations I toted along a pair of Fujinon 7×50 FMTR-SX binoculars. The binoculars were spectacular for astronomy (or general viewing) when mounted on a tripod, but they were heavy and cumbersome while hiking. Tired arms and shaky images quickly relegated them to the bottom of the knapsack. I vowed that before I went on my next vacation I would buy a small, lightweight, high-quality pair of binoculars intended strictly for daytime viewing of wildlife and scenery.

Lunchtime trips to a few of the dealers in town provided a good overview of the selection and prices of binoculars that would suite my purposes. It came down to a handful of Nikon, Fujinon, Canon, and Swift models in the 7–10 power, 25–40-mm, $200–$400 range. A few final comparisons of each of the models while standing outside the front of the store and it would be a done deal, right? Wrong! It was a tough decision. Each was of comparable optical quality (based upon cursory tests), size, weight and (within reason) price. Back inside the store an off-hand comment about Canon Image Stabilization (IS) binoculars quickly produced a pair of 10×30s from behind the counter. My first reaction was that they were way beyond my price range, but it would be fun to give them a try. After one look through them, all of the other binoculars screamed in unison, "No contest!" The overwhelming abundance of additional detail that could be seen in a stabilized image made it impossible for the others to compete, regardless of the quality of their optics.

It should be said that with the image stabilization feature turned off, the Canon optics were comparable to those of other binoculars. Alternatively, they would provide similar images with the IS turned on if the other binoculars were mounted on a tripod. Keep in mind the use for which I intended them. Quick views of scenery, furry critters scampering through the underbrush, or birds soaring overhead while hiking do not easily lend themselves to use of a tripod. Since it was a bright, sunny day with good prospects for a clear evening, I asked the proprietor if I could borrow them to run a few tests. Without any hesitation he said, "Yes!"

Image Stabilization

Dennis di Cicco does a good job of describing image stabilization in the article titled "Revolutionary New Binoculars" that appeared in the February 1998 issue of *Sky & Telescope*. I will add a couple of my own comments.

Image stabilization effectively removes the small, rapid vibrations introduced by the hands and arms. Vibrations of lower frequency and larger amplitude are still present, but dampened to the point where they become non-intrusive in the six-degree field of view. The damping effect introduces a slight delay, or "hesitation" when sweeping, as di Cicco put it. When you first use the binoculars, the feature imparts a visual oddity that the brain cannot quite "put a finger on," but once you realize what it is you get used to it.

After using the binoculars for a while, you become accustomed to the steady image and begin to notice slow back-and-forth movements imparted by your body that the image stabilization does not correct. That might lead you to question if the IS system is functioning. Simply take your finger off the button and your question will be answered quickly. Instantly the world returns to its former "California quake" appearance.

There is one aspect of IS that I would like to clear up. Dennis di Cicco stated, "It takes a fraction of a second for the stabilization to kick in." That is essentially correct, but I noticed that it might take up to two seconds. I tested it with a second pair in order to be sure that it was not a defect. It is important to establish such expectations beforehand for a couple of reasons. First, my heart rate jumped the first time the system engaged, since I feared that I had broken the binoculars, but a brief pause solidified the image stability completely. Second, when a friend took a casual glance through the binoculars he said, "So, what am I looking for?" He had not given the system enough time to stabilize the image.

Daytime Tests

The first set of tests was done during daytime. Pointing the binoculars at distant, impossible-to-read signs and license plates proved the true power of stabilization. Text that was once a blur became legible. Next, they were tested on scenery and wildlife. The views were nothing less than spectacular. I will not ramble on about everything I looked at and all of the detail IS brings out. I will ask you this: have you ever seen the reflection in a dove's eye?

One of the most irritating things I find about using unmounted binoculars is trying to achieve an accurate focus while the image is jumping around. With the IS system, focusing becomes a snap. Focus once as you normally would, then turn on IS and do the fine focusing.

Even while fiddling with the dioptric adjustment ring for the left eye or the centre focus ring, the image is steady. That facilitates quick, precise focusing beyond what can normally be achieved with regular hand-held binoculars. The value of that becomes even more apparent when the binoculars are used for astronomy. That last little bit of perfection allows you to see stars that you would typically think were beyond the grasp of a pair of binoculars of the same aperture. Speaking of which...

Nighttime Tests

A number of tests were done at night from my backyard in the moderately light-polluted skies of London. The limiting visual magnitude of stars at the zenith was about four to five. There was a crescent Moon low in the southwest. A pair of Fujinon 7×50 FMTR-SX's was used for comparison. Admittedly, it was not an accurate or fair comparison for a number of reasons. First, the larger aperture of the Fuji gathered two-and-a-half times more light. Not only were the Fuji images brighter, but in the low light levels of dusk the Fuji binoculars blew away the Canons. Second, the higher magnification of the Canons made it easier to resolve things such as close binary stars. It also darkened the sky's background. I have no doubt that the Fuji would blow away the Canon if mounted on a tripod, but the comparison did have some merit as discussed below.

The intent of the first star test was to determine the faintest stars that could be seen. Two areas near the zenith were used as targets — one near Alpha Cygnii (Deneb) and the other between Gamma and Beta Lyrae. With IS turned on there was no problem seeing all of the stars in the *Uranometria 2000.0* down to ninth magnitude. While the Fuji presented a much brighter image, no additional stars could be seen with the larger aperture. There is one last comment about the stars — they were sharp right to the edge of the field. The Canon IS binoculars use a doublet field flattener to reduce field curvature and distortion. It works. (Recall that the ones that I was using were 10×30s… can you imagine what the Canon 15×45 IS must be like?)

The Canon binoculars clearly outperformed the Fuji binoculars in a couple of respects. Close stars that were blurred together by vibrations in the Fuji were easily split in the Canon. Albireo was a prime example (and a pretty sight, I might add). Faint, extended objects, such as M57 (the Ring Nebula), were also visible through the Canon binoculars but not through the Fuji binoculars. Obviously the Canon's views of faint objects could not compete with a telescope, but it was fun doing a quick jaunt around the sky for some of the brighter Messier objects — M11 (the Wild Duck Cluster), M31 (the Andromeda Galaxy), M13 (the great globular cluster in Hercules), M8 (the Lagoon Nebula), M27 (the Dumbbell Nebula) — and being able to hold them steady in one's gaze.

Next, both pairs of binoculars were turned on Jupiter, which was rising in the southeast. The Fujinon image was bright and crisp. Three of the moons stood out like jewels to the planet's west. The Canon IS images were steadier, although somewhat subdued. It was much easier to hold one's gaze on the moons, but… what is that? There was a fourth moon just off the planet's western limb. Further attempts with the Fuji still did not reveal the fourth moon. Chalk another one up for steady images and higher magnification!

Now it was time to go on to the Moon. What can I say? It was the first time I have had a steady, clear view of mountain peaks greeting the lunar sunrise in a pair of hand-held binoculars. The uncountable craters and deep shadows cast across the plains were as pretty a sight as I have ever seen of the Moon through binoculars.

One favorite pastime is looking at satellites through binoculars as they drift through the star-splashed blackness of space. It is wonderful way to discover the night sky serendipitously. The only problem is that most of the stars bob and weave zigzags across the field of view. With the Canon IS binoculars the stars "float" through the field of view, giving you the feeling that you are drifting through space with the satellites. It is an experience that you must see to believe!

A Few Caveats

There are a number of things that should be noted about such binoculars:

1. There is an LED light on top of the binoculars that turns on whenever the IS system is activated. Dennis di Cicco mentions in his article that the light is red and only goes on for a couple of seconds. On the 10×30s the light is green and stays on for as long as you have your finger on the button. (That may be a difference between the three models.) It is important to note that the light is bright enough to compromise one's night vision should one inadvertently look at it.

2. The manufacturer warns that air bubbles "may" form in the vari-angle prism if the binoculars are taken to high altitudes, such as may be experienced when flying in a plane. They state that they usually disappear after a week. Take note of that point should you be taking a pair of them to far-off lands to observe an eclipse.

3. There is no tripod thread on the binoculars, although mounting them on a tripod does seem a little redundant.

Conclusion

Would I recommend such binoculars for astronomy? No... or should I say, not strictly for astronomical purposes. Their aperture is too small to satisfy the average experienced amateur astronomer, but they are fun for casual glances at the night sky if they are all that you have at your disposal. On the other hand, if the performance of the small 10×30s is any indication of what the 15×45s can do, I know what will be on my Christmas wish list this year.

Chris Baldock fell in love with astronomy twenty-nine years ago when he spied the rings of Saturn through his brother's brand-new Tasco refractor on a crisp, clear winter evening. Since then humans have walked on the Moon, interplanetary probes have visited all of the major bodies in the solar system, and most of the celestial mysteries of childhood have been explained with the aid of quantum leaps in technology. He cannot wait to see what marvels the next Saturnian year will bring.

Choosing an Eyepiece

by Gary Angers, Montreal Centre, reprinted from Skyward

At this time of year it seems quite appropriate to write about eyepiece selection, since it is getting too cold for frequent and extended observing sessions and it just so happens that Christmas is around the comer or has just passed. For some that may mean acquiring an additional eyepiece, while others may be faced with the decision of which eyepiece(s) to purchase for a brand new telescope. Selecting an eyepiece is easy, right? Nothing could be further from the truth.

Although most good quality commercially made instruments are supplied with one or two eyepieces, they are usually general-purpose eyepieces that perform well in the medium–low to medium–high range of magnification. To make better use of your instrument the range must be extended to include low and high powers — especially if your interest lies in viewing rich star fields, splitting double stars, or doing planetary work.

Table 1, although far from exhaustive, lists the data for several widely used telescopes available on the market today. It is intended as a guide for eyepiece selection and, as such, does not rule out other combinations. The abbreviations refer to D = diameter of objective lens (or mirror), FL = distance from objective lens to prime focus, and FR *(focal ratio)*= FL/D. Magnification values are based on $0.2 \times D$ and $2 \times D$ for low and high powers, respectively (for D in inches use $5 \times D$ and $50 \times D$); the term Eyepiece = the theoretical value required for an eyepiece to achieve the associated magnification values; D_p = the size (in mm) of the image of the objective lens formed at the eyepiece.

You may have noticed that the values of D_p are constant throughout. The reason for that is that the average pupil dilates to 5 mm or 6 mm and contracts to 0.5 mm. A value of D_p larger than a fully dilated pupil results in light being wasted, but also makes it easier to line up the eye at the eyepiece. At the other extreme, a value of D_p smaller than 0.5 mm will seldom improve the image under less than exceptional skies.

Choosing an eyepiece is more a function of the telescope's focal ratio than of its aperture or focal length. While it is true that an eyepiece will magnify differently on instruments of different apertures with similar focal ratios, it is equally true that the eyepiece will project the exact same value of D_p with these instruments. In a comparison of a 125-mm $f/10$ and a 200-mm $f/10$ telescope, the table shows that, in order to achieve an appropriate value of D_p, both must use a 50-mm eyepiece for low magnifications and a 5-mm eyepiece for high-power views. The 200-mm telescope will yield higher magnifications simply because of its longer focal length. In short, it is the focal ratio of the instrument that will help determine the focal length of the eyepiece(s).

Table 2 proposes a selection of eyepieces based essentially on focal ratios. It is important to point out that only small focal ratios, or fast instruments, can truly benefit from extremely short focal length eyepieces. One of the common problems with department store telescopes is that they usually have f-ratios between $f/12$ and $f/16$ and are supplied with a 3-mm or 4-mm eyepiece for maximum magnification. With such a setup it becomes impossible to see anything useful.

A quick example should suffice. Imagine using a 50-mm (2.1-inch) refractor with a 3-mm eyepiece. It is an $f/15$, which means that the focal length is (15×50 mm) = 750 mm. The magnifying power is ($750 \div 3$) = 250×. The size of the exit pupil will then be ($50 \div 250$) = 0.2 mm — far too small for even the best of eyes. With that type of instrument one would be well advised to consider acquiring no less than an 8-mm eyepiece. The magnification would be reduced to about 90×, but at least the telescope would become usable.

After selecting the appropriate eyepiece, one more decision must be made — what type? There are a multitude of standard eyepiece types available and an even greater number of variations on them. For the time being, I will briefly focus on four types: Kellners, Orthoscopics, Plössls, and Erfles.

Kellners are, in some circles, referred to as being the budget-minded choice. They are inexpensive and work well, especially with longer focal length telescopes. These eyepieces consist of three optical elements, and their apparent field of view can reach 40°–45°. They are frequently fuzzy around the edge of the field and suffer from some chromatic aberration.

Orthoscopics are a step up from Kellners in both price and quality. Their four elements correct for chromatic aberration and can yield a 45°–50° field but with sharper definition around the edges. Orthoscopics are a good choice for high power viewing on a budget.

Plössls are increasingly popular with amateurs since they offer views that are quite precise at all levels of magnification. Their four-element design typically provides a field of view of about 50°. Plössls are definitely worth considering.

Erfles are excellent, especially for precise low-power observing. They consist of five optical elements and boast an apparent field of about 65°, resulting in breathtaking low-power views. If that is any indication, Erfles would appear to be the choice eyepiece for rich field observing.

Gary Angers' interest in astronomy dates from his childhood when he used to sneak out of bed to join his father, who loved observing lunar eclipses. He has been an active member of the Montreal Centre for nine years, holding the positions of Librarian, Vice-President, and President — but not simultaneously! He is currently responsible for maintaining the Centre's web site. His favourite astronomical book is Starlight Nights *by Leslie Peltier.*

Table 1

Aperture (D)	Focal Ratio (FR)	Focal Length (FL in mm)	Magnification Min/Max	Eyepiece (mm)	Exit Pupil D_p
80-mm (3.1-inch)	*f*/11	910	16/160	56/6	5/0.5
125-mm (5-inch)	*f*/10	1250	25/250	50/5	5/0.5
150-mm (6-inch)	*f*/7	1050	30/300	35/3.5	5/0.5
150-mm (6-inch)	*f*/8	1200	30/300	40/4	5/0.5
200-mm (8-inch)	*f*/10	2000	40/400	50/5	5/0.5
200-mm (8-inch)	*f*/6	1200	40/400	30/3	5/0.5
250-mm (10-inch)	*f*/6	1500	50/500	30/3	5/0.5

Table 2

Focal Ratio	Ultra Low	Low	Medium	High
f/6	36-mm	18-mm	9-mm	3-mm
f/7	42-mm	20–24-mm	10-mm	4-mm
f/8	50-mm	24–26-mm	12-mm	5-mm
f/10	56-mm	30-mm	15-mm	6-mm
f/11	56-mm	32-mm	16–18-mm	6-mm

At the Eyepiece

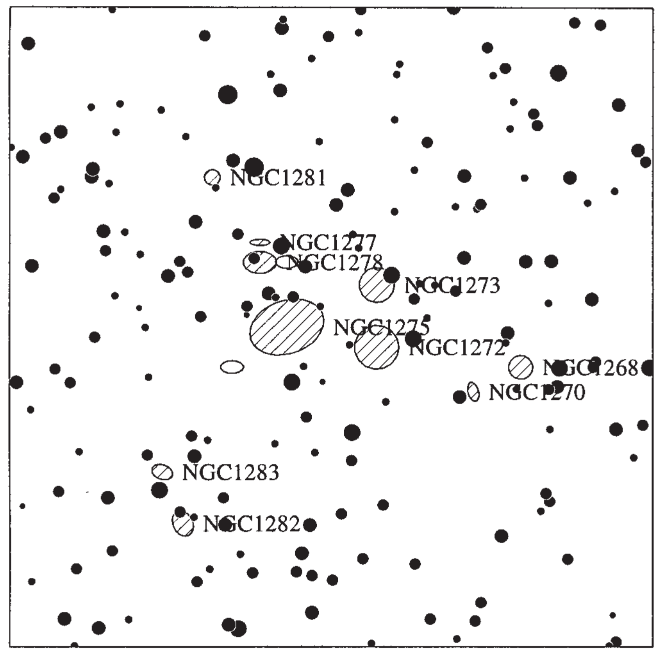
Navigating the Perseus Archipelago

by Lucian J. Kemble[1], *OFM (luckem@sk.sympatico.ca)*

One often hears of the "Perseus Cluster" and most often the term refers to the famous Perseus Double Cluster — two lovely open clusters visible to the unaided eye halfway between δ Cas and γ Per. There is another wonderful Perseus Cluster, however, Abell 426, a cluster of galaxies centred on its brightest member NGC 1275. Since Edwin Hubble's work in the 1920s and the realization that the so-called "spiral nebulae" are in reality other galaxies — "island universes" — outside our own system, there has been an explosion of information about (including spectacular detailed images of) the countless external galaxies that fill our universe. They may often appear as single, isolated worlds, yet most often they are grouped into small-to-larger clusters, super clusters, etc.

One such galaxy cluster, appearing like a celestial archipelago, is Abell 426, which lies about 12^{m} in right ascension (~2° 15´) east of Algol, β Per. The brightest member of this tight cluster, about 350 million light years distant, is NGC 1275 located at 3^{h} $19^{m}.8$ and +41° 31´. The Webb Society's *Deep-Sky Observer's Handbook*, pp. 123–132, contains a very thorough explanation of the cluster with accompanying charts and data. (It must be noted, though, that the table of some of the cluster galaxies listed on p. 127 wrongly lists their right ascension as 1^{h} instead 3^{h}.) *Burnham's Celestial Handbook*, vol. III, pp. 1448–1451, is also an excellent source of information. Keep in mind that both publications are for the epoch 1950.0. One of the finest photos I have ever seen of the cluster is to be found in Timothy Ferris's *Galaxies*, p. 150. It shows very well the condensed, inner portion and the long extension to the west, like some celestial chain of Aleutian Islands.

From such sources, and from many more that have appeared since the books were printed, it becomes clear that NGC 1275 and its companions are indeed a most unusual collection of galaxies. NGC 1275 is at once a strong radio source as well as a powerful X-ray source. Images in red light show a rich system of filaments extending away from it on all sides, and the galaxy, also known as the radio source Perseus A, may actually be an example of a collision of two galaxies. Some studies indicate that the whole inner portion of the Perseus cluster is a general source of diffuse radio emission. NGC 1275 itself is often described in the literature as being a most unusual "irregular" type of galaxy. It was that feature and its accessible magnitude of 11.6, within range of my C11, that led me to observe the galaxy and, in subsequent observing sessions, many of its companions, as



The brighter members of galaxy cluster Abell 426 are shown in this 0.5 degree field which shows stars to about 15th magnitude (ECU Chart prepared by Dave Lane).

part of an island-hopping journey. In all, I have made drawings and notes for about 22 individual members of the cluster, many of which are actually Herschel objects. Depending on which chart(s), catalogue, or atlas one uses, there is richness enough for any size aperture above 8 inches.

My notes for the first observation, made with my C11 at Cochrane, Alberta, on March 11, 1983, read as follows: "Looking specifically for NGC 1275 and noting many galaxies listed in the *NGC 2000.0 Catalogue*, I was surprised to find seven galaxies in the same low power eyepiece field; I had accidentally stumbled on part of the Perseus Cluster without realizing it. One of my greatest observing thrills. As is occasionally the case, windy conditions actually helped by slight jiggling of the scope. Identification of other galaxies in the field was made with the Webb Society's *Deep-Sky Observer's Handbook*, volume 5."

In the table (see next page), are the data for the cluster galaxies including 22 out of a total of 27 that I have observed since that memorable night in 1983. Data are taken from the *NGC 2000.0 Catalogue* and *MegaStar*. Only the NGC and IC Catalogues were used — there are far more, and fainter, galaxies

[1]Father Lucian Kemble's article is a replacement for Alan Whitman's column this issue.

listed in other catalogues, *e.g.* MGC, UGC, CGCG, etc.

As can be noted, all members of Abell 426 listed here are within the range of observation — *i.e.* ~11.5 to 15.5 magnitude — of moderate aperture telescopes. I have located them quite easily with my C11, most of them appearing as rather featureless, faint, small, diffuse blobs.

An interesting feature of this area of sky, crossing the border of Perseus and Andromeda, is that the Perseus cluster diminishes into a long, thinning streak, followed by a few stragglers, then passes Algol. Before reaching the Andromeda border, one passes the rich open cluster M34, then moves into another wonderful archipelago of clustered islands — those around the beautiful, edge-on, giant galaxy NGC 891. I have traveled the latter chains of island universes, but that is another story. One night soon I shall resume my island voyage and pick up the ones I have missed in the Perseus Archipelago.

Meantime, I encourage you to sail among these enchanted isles and to go exploring. Good luck.

Like as the waves make towards the pebbled shore,
So do our minutes hasten to their end;
Each changing place with that which goes before,
In sequent toil all forwards do contend.
– William Shakespeare, Sonnet LX

Father Lucian was born in 1922 on a small farm in southern Alberta. After spending four years during World War II as a radio operator, he entered the Order of Friars Minor — the Franciscans — in 1946. Ordained in 1953 after seven years' study in philosophy and theology, he has spent almost all of his priestly life in teaching and preaching. A longtime member of the RASC, he works with a C11 on a Byers Mount in a shelter at St. Michael's Retreat, Lumsden, Saskatchewan. His main interest in astronomy is searching out deep-sky objects, of which he has well over five thousand observed, drawn and noted on file.

Galaxy	RA (1950)	Dec (1950)	Mag.	Size	Comments
NGC 1250	3:15.4	+41:21	14p	2´.7	
NGC 1257	3:16.4	+41:32	14.6p	1´.6	
IC 310	3:16.7	+41:20	12.7p	1´.4	
NGC 1259	3:17.0	+41:21	15.7p	0´.7	(not observed)
NGC 1260	3:17.5	+41:24	14.3p	1´.1	
NGC 1264	3:17.9	+41:31	15.4p	0´.8	
IC 312	3:18.1	+41:45	14.4p	1´.4	(not observed)
NGC 1265	3:18.3	+41:52	12.1p	1´.7	
NGC 1267	3:18.7	+41:28	14.1p	0´.8	
NGC 1268	3:18.8	+41:29	14.2p	1´.0	
NGC 1270	3:19.0	+41:28	13.1p	1´.0	
NGC 1272	3:19.3	+41:29	11.7p	1´.8	
NGC 1273	3:19.4	+41:33	13.2p	1´.8	
IC 1907	3:19.6	+41:35	14.2p	0´.9	
NGC 1274	3:19.7	+41:33	14.0p	0´.8	
NGC 1275	3:19.8	+41:31	11.6p	2´.2	
NGC 1276	3:19.9	+41:33	—	0´.5	(not observed)
NGC 1277	3:19.9	+41:34	13.4p	0´.8	
NGC 1278	3:19.9	+41:34	12.4p	1´.4	
NGC 1281	3:20.1	+41:38	13.3p	0´.9	
NGC 1282	3:20.2	+41:22	13.9p	1´.2	
NGC 1283	3:20.3	+41:24	13.5p	0´.9	
IC 313	3:21.0	+41:53	15.1p	0´.8	(not observed)
IC 316	3:21.3	+41:56	14.9p	1´.2	
NGC 1293	3:21.6	+41:24	14.5p	0´.8	
NGC 1294	3:21.7	+41:22	14.3p	1´.0	
IC 319	3:23.4	+41:24	—	0´.5	(not observed)

The Light Side of Research

Home Research

by Orla Aaquist, Keyano College, Fort McMurray (Orla.Aaquist@keyanoc.ab.ca)

My VLA observing run last March was a success, and now I am going to reduce the data at home. We have home care, home making, home schooling, home business, and now we have home research. I retrieved my data via FTP the week following my March observing run and stored it safely away on a hard drive at the Space Astronomy Laboratory at the University of Calgary. Eight hours of data awaited my analysis, which I planned to tackle during my summer vacation. Summer, however, never lasts as long as I anticipate. In fact, as I write this, summer is over and data reduction has yet to occur. Another project distracted me.

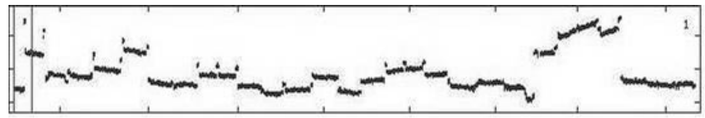
The *other* project began from an innocent remark made by Dr. Sun Kwok while I was preparing my observing run. He mentioned that someone had managed to install AIPS on a PC. AIPS is the Astronomical Image Processing System, the software generally used to process VLA data. Sun thought I might wish to install it on my home computer. After I purchased a new computer in May, the seed took root and I discovered Linux (Unix for PCs). After installing Linux seven times, installing AIPS just as many, replacing my video card, reading a very thick book on Linux, and reading the latest AIPS Cookbook, I was finally ready to start my data reduction… and the fall term.

Now, every other weekend I boot up my Linux partition, start AIPS, sift through my data, examine my old images, and think strange thoughts. Then, suddenly I realize, "God! I haven't prepared any lessons for Monday morning!" Weekends are just not long enough to start my research motor.

Before I became too imbedded in the term, I did manage to scan the data for major problems. They looked good, so I was inspired to plunge in and edit out data that were obviously bad. My plan was to do a trial run through the data and hope that the unused knowledge and techniques would re-emerge from the recesses of my brain. After all, it had been ten years since I last used the software.

Reading through the Cookbook, I read the warning, "Often when switching source position, the initial scans have slightly high or low flux levels and should be edited out." While imaging my fields, I noticed many narrow high and low peaks just before and after each source observation. So, of course, I began to edit out the offending peaks. After two days of clipping, I discovered a program that would do it automatically. "I'll use it next time," I thought calmly.

Then began the calibration process. That involved checking the phases and amplitudes of the so-called "phase calibrators." The phase calibrators are point sources near the target object, and their purpose is to make sure that you know what a point source looks like through the instrument. Because of atmospheric turbulence, sources become distorted; but if you know what a point source looks like, you can correct for the distortion. Neat, eh? The strange thing was, though, I could not find any of my phase calibrators. Do you know how it feels when you suddenly remember that you were supposed to be at an important meeting two days ago? There is no recovery. You cannot get there from your current space-time co-ordinates. The event lies outside your light cone. You quickly look around for a rotating wormhole, but find none.



Often when switching source position, the initial scans have slightly high or low flux levels and should be edited out.

A sinking feeling washed over me. Had I forgotten to observe the phase calibrators? The feeling of pure desperation lasted for almost five seconds before I realized that I had just spent the last two days painstakingly flagging the calibrators as bad data. As quickly as it arrived, the feeling of desperation was replaced by a wave of pure relief. I unflagged the calibrators and went to bed. My sleep was surprisingly sound that night.

It does not bother me to start over. As a graduate student I must have started my thesis at least ten times. Now, as a teacher, I start over every year. Why do I tinker with research when I have a full-time job that I love and that does not require me to do research? Some people spend their entire life doing it. I do it in my basement office late at night with a cat on my lap. I find it exhilarating and satisfying and I do not care what the neighbours think. My friends think it strange that I would consider it a vacation to work on data reduction. They could be right.

Orla Aaquist is the physics instructor at Keyano College in Fort McMurray. His rather varied career has included periods as an undergraduate at the University of Alberta (B.Sc.) and Queen's University (B.Ed.), a graduate student at the University of Calgary (M.Sc., Ph.D.), a high school teacher of physics and mathematics in Toronto, and "telescope instructor" at the Calgary Centennial Planetarium.

Scenic Vistas: Anchor Star

by Mark Bratton, Montreal Centre (mbratton@generation.net)

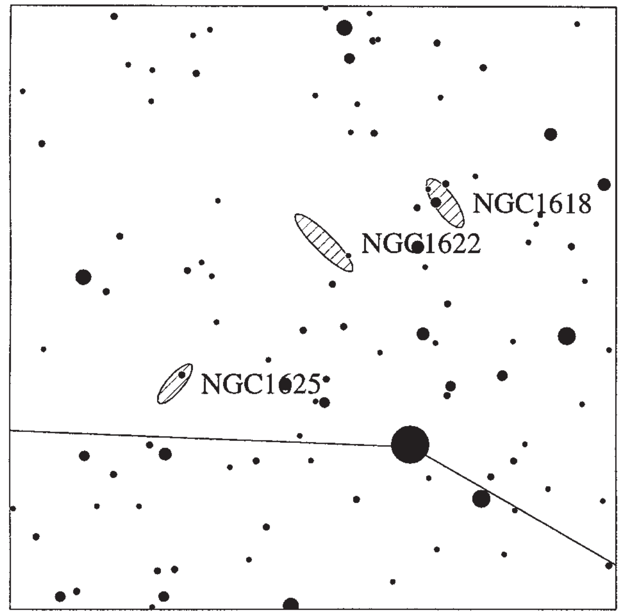
As I am an observer, one of my greatest aids has always been the anchor star. Such a star is a moderately bright, naked eye object that acts as a guidepost to regions of the sky of particular interest. As an example, each of the "corner" stars of the constellation Pegasus are excellent anchor stars. The skies around the stars are rich in deep-sky objects that are faint and not-so-faint. It is easy to sight on one of the stars and then push off into the depths in search of hidden treasure. With an anchor star handy, one can sit down and take a few moments to do a detailed job on one's notes, make a sketch, or even have a cup of coffee and consult one's charts. If the target drifts out of the field of view, it is easy to go back to the anchor star to quickly retrace the star hop that led you to the object of interest.

The early winter sky has a fine "anchor star" located just west of Rigel in Orion. The star is fourth magnitude Nu Eridani (ν Eri), and pointing your telescope at the star leads you into a field populated by almost fifty NGC galaxies, many of which are visible in telescopes with apertures less than 25-cm. The payoff begins immediately, for in a low power field one will see three galaxies immediately north and east of the bright field star. The galaxies, NGC 1618, 1622 and 1625, are remarkably similar in size and brightness and they all huddle around magnitude 12.5. NGC 1618 is marginally fainter than the other two, but visually quite similar to the galaxy that follows it, NGC 1622, in that both display bright cores and are extended in almost identical position angles. NGC 1625 appeared cigar-shaped in my 38-cm reflector with a magnitude 14 star visible at its northwest tip.

Sweeping 1°.75 southwest from Nu brings us to a tight, though difficult, group of four galaxies. NGC 1600 should be easy with a small telescope as it shines at magnitude 10.9. In my reflector it was a round, patchy glow, growing gradually brighter to the centre with an irregular, mottled disk. Two other galaxies, both magnitude 13.8, were visible in the field as small round objects. NGC 1601 was immediately north of NGC 1600, and NGC 1603 was visible to the east-southeast. A fourth galaxy at magnitude 15.1, NGC 1606, was invisible.

Returning to Nu and now moving east-northeast about 1°.5 will bring you to NGC 1637, one of the largest, brightest galaxies visible in the region. The galaxy appeared as a fat oval of light with extremities fading gradually into the sky background. The central region appeared bright and oriented NNE-SSW. High magnification revealed a mottled core and two separate condensations near the centre. One degree immediately north is NGC 1638, a fairly bright, small and condensed galaxy with a bright core. The galaxy is gradually elongated east-west.

A little over a degree to the northeast the observer will come to NGC 1653. At magnitude 12 the galaxy should be visible



The three galaxies, NGC 1618, 1622 and 1625 are just north of the "anchor star" Nu Eridani in this 0.5 degree field (ECU Chart prepared by Dave Lane).

in a 20-cm reflector. Visually it is quite similar in appearance to NGC 1638, though the outer regions appear slightly more diffuse. Sweeping 2°.5 SSE will bring you to magnitude 12.5 NGC 1659, an oval, well-defined patch of light oriented ENE-WSW with a bright, elongated core.

Less than one degree to the southeast is the fainter NGC 1665, an oval patch of light oriented SW-NE and just a little brighter to the middle. About 2°.5 to the northeast is a loose grouping of a half dozen galaxies, four of which I viewed with my reflector. NGC 1670 is a small galaxy with diffuse extremities and a well-condensed, small and bright core. NGC 1678, which follows it, is preceded by a magnitude 10 field star. It is brighter and more conspicuous than NGC 1670. Although it is oriented ENE-WSW in photographs, the extremities are rather faint and all that I saw was the bright core that appeared quite round.

NGC 1682 and 1684 appear together in a high power field. Although they are nominally the same brightness, NGC 1684 is by far the more conspicuous of the two. It is very gradually extended east-west, and both galaxies have moderately condensed cores. NGC 1682 appears stellar at low magnifications. NGC 1700 is a bright galaxy, so bright in fact that I was able to pick it up with my old 20-cm SCT from my light-polluted back yard location many years ago. In my telescope the galaxy appeared as a subtle object, though well seen with direct vision. At the centre was a sharp, stellar nucleus surrounded by a very smooth, well-defined outer envelope. The galaxy appeared very slightly oval in shape and gradually extended east-west. NGC 1729 lies just west of a magnitude 10 field star and immediately south of one of magnitude 12. It is a diffuse, uncertain patch of light, poorly defined and a little brighter to the middle. It appears to be very slightly extended almost due north-south.

These are but a small sample of the galaxies visible in the fields that surround Nu Eridani. They can be returned to again and again by the patient amateur willing to hitch his telescope to a star

Mark Bratton has had a life-long interest in astronomy and first became acquainted with the RASC in November 1966 at the age of eleven. He did not become a member until twenty-five years later. He is currently the editor of the Montreal Centre's newsletter Skyward *and entering his second term as president of the Centre. He is the single parent of a twelve year old boy, Kristopher, and his greatest joy, besides his son of course, is slowly exploring the skies with a 375-mm reflector from the deck of his small country cottage near Sutton, Québec.*

Reviews of Publications
Critiques d'ouvrages

After the First Three Minutes: The Story of Our Universe, by T. Padmanabhan, pages xiv + 215, 19 cm × 25 cm, Cambridge University Press, 1998. Price US$19.95 soft cover. (ISBN 0-521-62972-1)

"And now we come to the end of the first three minutes, and nothing else of interest will happen in the history of the universe."

So, reportedly, said physicist and Nobel laureate Steven Weinberg while wrapping up a Harvard lecture on the origins of matter in the Big Bang. The lecture later formed the basis of Weinberg's 1977 best-selling account of modern cosmology, and his droll remark inspired the book's catchy title: *The First Three Minutes*.

Two decades later *The First Three Minutes* remains a classic of popular science literature. Few authors have since matched Weinberg's success at elucidating the connection between the macro-world of astronomy and the micro-world of particle physics, and their convergence at the beginning of time. So ubiquitous was the book that in 1980 Alan Guth, then a young physicist at Stanford, recalls cramming from it before a debut of his own inflationary universe theory, for fear "that I would reveal my status as a greenhorn cosmologist." The episode is recounted in Guth's 1997 book *The Inflationary Universe*.

Yet, as acclaimed as *The First Three Minutes* is by scientists and non-scientists alike, at its core lies a conceit that should be treated with caution, namely that the entire history of the universe is little more than an afterthought in the wake of the primordial inferno. While the laws of nature were certainly laid down in the initial moments following the Big Bang — if not sooner — the ways in which those laws have played out over the last 13 billion years are far from obvious. As the *Hubble Space Telescope* and other great observatories are currently showing us, the universe is a dizzyingly rich and complicated place. Its history also contains a troublesome gap, revealed as a wall of darkness by telescopes that look ever farther away into space in order to see farther back in time. This so-called "dark age" is what separates the smooth, hot plasma universe of the distant past from the slightly more recent, and definitely more lumpy, universe of the earliest stars and galaxies. How the former universe came to be the latter remains one of cosmology's outstanding mysteries.

In *After the First Three Minutes*, cosmologist T. Padmanabhan attempts to illuminate the universe's shadowy depths with a non-mathematical treatment of recent developments in the field. The book follows a "just the facts" format, in stark contrast to the storytelling style favoured by most writers in this arena. "Ideas and discoveries are more important than people," Padmanabhan writes in the preface, explaining the book's dearth of anecdotes and photos. "I hope the clarity of the content compensates for the lack of colour."

Regrettably for the reader, it does not. Padmanabhan's content is, at times, far from clear, and the arrangement of material in the book is perplexing. After a brief reconnoitering of the universe as we now find it, the book launches into a review of subatomic physics that seems unnecessarily dense. The third chapter is a rather detailed history of astronomical observation across various wavelengths which, although scattered with interesting details, brings the reader no nearer to the book's purported subject matter. Indeed, in the absence of a more logical structure, the background knowledge required by the reader to follow the first half of the book is essentially what the text itself is trying to provide.

In a fourth chapter on stellar astrophysics, Padmanabhan makes at least two factual errors. He lists Polaris as an example of a main sequence star, which it is not. And — far more worrisome — he several times incorrectly defines the Chandrasekhar mass of 1.4 solar masses as the limit beyond which a neutron star will collapse into a black hole. In fact, it is the upper mass limit for white dwarf stars. Such a fundamental error would be unforgivable in a first-year course on astronomy, and it is equally intolerable here.

For those who persist, the payoff in *After the First Three Minutes* comes in the second half of the book, particularly in the lengthy sixth chapter on the formation of structure in the early universe, clearly the author's forte. Here the progression of ideas becomes intelligible and the writing lucid. Padmanabhan does a good job of explaining the role of hot and cold dark matter in the formation of "density fluctuations," the cosmic watering holes around which ordinary matter gathered in the early universe. Neither forms of dark matter adequately satisfy the observed distribution of galaxies in space, and Padmanabhan demonstrates why. He then offers a timely discussion on the potential of a "cosmological constant," Einstein's infamous fudge factor, as a way out of the dilemma.

Although the book improves dramatically when the author is in familiar territory, it nowhere approaches the best writing on cosmology available to a general audience. Perhaps it is unfair to hold *After the First Three Minutes* up to the standard of Weinberg's popular classic, but the comparison is invited by the book's title and more explicitly in Padmanabhan's suggestions for further reading. There, at the very top of his list, is none other than Weinberg's *The First Three Minutes*, which Padmanabhan considers "a model for popular science writing."

In cosmology a good model is everything. In science writing it apparently is not enough.

Ivan Semeniuk

Ivan Semeniuk is the book review editor of the Journal.

Our Evolving Universe, by Malcolm S. Longair, pages xii + 185, 23.5cm×27cm, Cambridge University Press, 1996. Price US$34.95 hard cover (ISBN 0-521-55091-2), US$19.95 soft cover (ISBN 0-521-62975-6).

It has been more than twenty years since I attended a class in introductory astronomy as a first year education student at the University of Windsor. My professor at the time was charged with the rather daunting task of making exciting and understandable the mysteries of the universe to a lecture hall largely filled with non-physics majors. Since I was a keen amateur astronomer at the time, it was not hard to hold my attention. My professor likewise had a personal interest in astronomy and it helped make the course much more engaging than it might otherwise have been. The book used for the course was a thick paperback called *Dynamic Astronomy*, by Robert T. Dixon. It was a sweeping survey of astronomy as it stood in the 1970s, and it served to round out and strengthen my basic astronomical knowledge.

In the intervening years I have read many astronomy books, but most of them have leaned in their content towards the more practical aspects of backyard observation and telescope making. So it was a definite change of pace to sit down with a thoroughly modern treatment like *Our Evolving Universe*. Reading Malcolm Longair's work has left me with the feeling that I now have a well-rounded appreciation of the major issues confronting modern astronomy and cosmology.

With five chapters totaling 159 pages (not including the glossary, index and picture acknowledgments at the end of the book), *Our Evolving Universe* is not a particularly lengthy work. But it is information-dense, and deals crisply with a succession of topics that summarize the state of astronomy and cosmology at the end of our century.

In Chapter One, "The grand design," Longair delivers a brief summary of some of the major historical events that made modern astronomy possible. The key nineteenth century discoveries of spectroscopy and astronomical photography, for instance, enabled the eventual rise of astrophysics as a scientific discipline. Longair stresses how our present understanding of the universe is possible only though an examination of what is revealed across the entire electromagnetic spectrum. He also uses a type of comparative method to portray the size of the universe in this chapter, which avoids the need for exceedingly large numbers. That is a nice change of pace. However, Longair's repeated referral to M31 as the "Andromeda Nebula," seems quaint and out-of-place.

In Chapter Two, "The birth of the stars and the great cosmic cycle," Longair deals with the nature of stars and how they shine. Spectroscopy, combined with the relatively new science of helioseismology as well as the issue of neutrinos and the "solar neutrino problem" are discussed in terms of their contributions to our understanding of stars like the Sun. The Hertzsprung-Russell (H-R) diagram is introduced, and a fairly extensive treatment of the Orion Complex, including M42 — the Great Nebula in Orion — is given in order to illustrate questions related to star formation. His use of the expression "great cosmic cycle" to describe the life of a star from birth to death seems a bit overblown, especially when considering what issues are to come as the book progresses.

In "The origin of quasars" the discussion turns to radio galaxies and the discovery of quasi-stellar radio sources, pulsars, and neutron stars. Einstein's Special and General Theories of Relativity are introduced, which lead to an extensive discussion of black holes and the very probable existence of supermassive black holes within active galactic nuclei.

The mystery of dark matter rears its head in the fourth chapter, "The origin of galaxies". With no more than ten per cent of the universe accounted for as matter visible to us, possible theories as to the nature of dark matter and its relationship to "ordinary" matter, are explored.

In Chapter Five Longair grapples with the truly big question — the origin of the universe. Here he summarizes nine cosmologically important facts about the universe, the "four great problems" of current Big Bang cosmology, and the need for a quantum theory of gravity if we are to have any hope of advancing our knowledge of the very early universe.

Longair ends his final chapter by providing cautious commentary on such questions as multiple universes and the ultimate fate of the universe. He approaches the issues strictly as a scientist, and is careful not to cross boundaries into issues more appropriately addressed, he insists, by philosophers and theologians.

One is reminded while reading *Our Evolving Universe* of how rapidly advancing technology during this century has allowed the development of the tools necessary for astronomers to make such significant strides in our knowledge of the universe. The increasingly sophisticated instrumentation and techniques being used in ground-based research, combined with the indispensable capabilities of Earth-orbiting astronomical satellites, have helped to define the scope of current astronomy. Moreover, the challenges facing astronomers today will influence the design of the next generation of astronomical tools.

To which audience is *Our Evolving Universe* aimed? Bookstore browsers will perhaps be influenced by the advertising hype on the back cover that proclaims the work as a non-technical treatment for the general reader, student, or professional wanting to understand the key questions of modern astronomy and cosmology. But is it realistic to expect that such a wide-ranging audience could be satisfied by just this one source?

In his book *A Brief History of Time*, Stephen Hawking remarked that someone told him that for each equation he introduced, sales would be cut by one half. He therefore chose not to have any, other than Albert Einstein's famous equation $E = mc^2$. *A Brief History of Time* became a runaway best seller, and is currently enjoying a tenth anniversary printing. From a purely marketing standpoint, it would seem that Hawking's decision was astute.

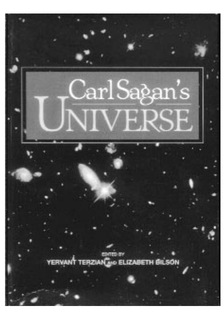
Had he intended *Our Evolving Universe* to reach a truly general audience, Longair would not have introduced so many technical charts, diagrams, and equations that appear throughout the book in quite generous supply. Even so, there is nothing in that regard that should discourage any astronomy enthusiast with a good grounding in at least high school-level physics or mathematics. Undergraduate physics students will be right at home within its pages. But, for all the so-called "naturalists of the night" in search of a good introductory astronomy book, it is probably safe to say that most will look elsewhere for their reading.

The book itself is gorgeously produced and is otherwise profusely illustrated with beautiful photos and artwork, most of which are in colour. Typos are few and far between, and minor in nature. Combined with Longair's obvious passion for his subject as revealed in a very enthusiastic style of writing, *Our Evolving Universe* is all the while written with a discipline and brevity that keeps the reader moving. It is definitely worth a look.

Randy Groundwater

Randy Groundwater has been an active amateur astronomer for thirty years, and has been a member of the RASC's Windsor Centre since 1977. He may be reached by Email at ragroun@ibm.net.

Carl Sagan's Universe, edited by Yervant Terzian and Elizabeth Bilson, pages xiii + 282, 17.7 cm×25.3 cm, Cambridge University Press, 1997. Price US$59.95 hard cover (ISBN 0-521-57286 X), US$22.95 soft cover (0-521-57603-2).



Nowhere on the cover of *Carl Sagan's Universe* does it mention that it is a collection of speeches taken from a symposium in October 1994. It would have been fair warning.

The symposium was organized by Cornell University to celebrate Carl Sagan's sixtieth birthday. Of the twenty-five speakers, twenty-two have been included in the book. It is rounded out with a lecture delivered by Sagan himself at the symposium, and an address given by Frank Rhodes, the president emeritus of Cornell, at a banquet afterwards.

The speeches have all been lightly edited. Sometimes it seems the only changes made were to replace "next slide" with "Figure 9-3." The light editing allows the colours of the original talks to shine though. The enthusiasm and knowledge of the better speakers come out clearly; those who were stiff or confusing on the stage remain so on paper. Luckily, the former far outnumber the latter.

The book, like the symposium, is divided into four sections: Planetary Exploration; Life in the Cosmos; Science Education; and Science, Environment, and Public Policy. Planetary Exploration comes off as the most dated, because of the spectacular progress in the planetary sciences that the last four years have brought. But that is not entirely a bad thing. The reader is left with a snapshot of scientific thinking at the time and a strong urge to find out what happened next. There is a strange impetus to knowing that you can immediately discover just how the hopes so vividly described by the speakers turned out. The speakers of the Life in the Cosmos section take a more historical approach, and the debates of the other two sections remain evergreen so they suffer less from the four-year lag.

The individual chapters in each section range over the breadth of Sagan's interests. Rather than simply lauding Sagan, for which he probably would not have sat still, they each discuss a field he affected during his life. Unless the reader is as great a polymath as Sagan, there will be many chapters revealing interesting new topics and new points of view.

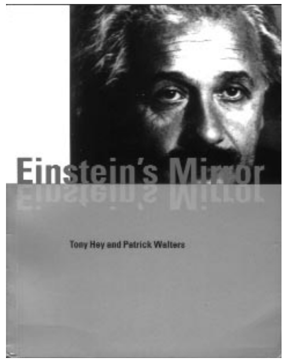
While the level of quality in the book is generally high, several outstanding chapters deserve mention. Bruce Murray gives a clear and well-illustrated talk on the search for life on Mars. Paul Horowitz takes us inside SETI for a fun and enthusiastic look at its history. Kip Thorne discusses the possibilities and impossibilities of using wormholes for time travel. Jon Lomberg lavishly illustrates the past and future of science art. Georgi Arbatov's engaging chapter on nuclear proliferation and disarmament is given new resonance by the recent demonstrations in India and Pakistan. Joan Campbell gives us the view from the other side of the divide between science and religion. Finally, Sagan's own chapter is a vivid illustration of just why he deserves a two-day symposium in his honour.

While the chapters comprising *Carl Sagan's Universe* stand on their own strengths, together they are synergistic. Although Sagan appears rarely as a main character in the talks, his influence is always felt. As a whole, the book presents a portrait of one of the last of the great generalists, a man who cared about people as much as he did about ideas. It serves as a call to try one's best to live up to Sagan's standard: to learn more about a field outside one's own, to speak out when one's knowledge may be of help, to build bridges between cultures and disciplines, or to simply bring more heart to one's research, teaching and service.

William Jacobs

William Jacobs is a science journalist and graduate student at Boston University.

Einstein's Mirror, by Tony Hey and Patrick Walters, pages xii + 291, 19 cm×24.6 cm, Cambridge University Press, 1997. Price US$69.95 hard cover (ISBN 0-521-43504-8), US$27.95 soft cover (ISBN 0-521-43532-3).



My first thoughts when I first sat down to read *Einstein's Mirror* were something like, "Okay, another popularization of relativity that is bound to leave the reader disappointed in the end." I thought that because it is pretty much impossible, in my opinion, to understand relativity without doing some math.

I was wrong. Hey and Walters's book did not disappoint me because they include a bit of math in the Appendix and their physical explanations of the principles of relativity, especially special relativity, are very well done. I was particularly impressed by their explanation that $E = mc^2$ arises from a consideration of conservation of momentum. The explanation was much clearer than some that I have seen in college texts.

Hey and Walters use stories about the starship *Enterprise* of *Star Trek* fame to illustrate many of the principles of special relativity as they might appear in the day-to-day life of starship people. In chapter one there is a story about trying to outrun photon torpedoes (which happen to travel at the speed of light) to illustrate the relativistic velocity addition formula. However, when it comes time to work out the details (the math!) in chapter four, the authors resort to more traditional stories about trains in a world where the speed of light is very slow. A train is also employed in chapter five to explain relativistic mass increase. But the explanation of $E = mc^2$ that I like so much is done completely on the *Enterprise*. As is to be expected, the *Enterprise* is also used in the famous story about the astronaut and her twin sister who stays behind on Earth. They explain that the traveling twin feels forces when she turns around so that she is not physically equivalent to her sister back on Earth. In other words, although Hey and Walters do not introduce the concept of inertial frames, the Earthbound sister is confined to an inertial frame while the traveling sister is not.

The explanation of the ideas behind general relativity is done well also, in chapter nine. I am especially impressed with the inclusion of Einstein's field equations for general relativity, in a box on page 189. Novices, beware of the terminology here. The field equations are written as $E_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$, which looks like a single equation but is a shorthand for sixteen equations, ten of them independent, that are obtained by substituting the numbers 0, 1, 2, and 3 into the double subscripts μ and ν. Of course, you cannot understand general relativity just by looking at the field equations. You have to know that $E_{\mu\nu}$ is a function of the metric tensor $g_{\mu\nu}$ via combinations of contractions of the Riemann-Christoffel curvature tensor, *etc.*, *etc*. Hey and Walters discuss the "metric" of space time and say that it is related to $E_{\mu\nu}$, but that is as far as they go. It is better than most popularizations of relativity, but does not go as far as one of my favourite childhood books called *The Nature of the Universe* by Clive Kilmister, published by Thames and Hudson, London, 1971. However, Kilmister writes in a harsher style than do Hey and Walters, and I must admit that I did not fully understand everything in Kilmister's book when I was 12.

The authors claim that their book is aimed at final-year students at high school, general readers with an interest in science, and undergraduates in science subjects. I think that younger people would also find the book accessible, especially those comfortable with their algebra. In other words, the book should be accessible to a large number of RASC members.

Hey and Walters present their ideas in an historical narrative that is liberally spiced with small facts about the personal lives of the scientists involved. For example, we learn that George Fitzgerald flew experimental gliders while wearing his top hat and that Hermann Minkowski died of appendicitis. The historical narrative covers a lot of ground, including the history of electricity, thermodynamics, and, extensively, atomic physics. As with most historical accounts of science, this one might be subtitled "A brief look at the lives of some geniuses in physics." There is even a famous person index on pages 288 and 289. The biographies of the people listed are very interesting, and I must say that I am in awe of the likes of Richard Feynman, who at the age of 22 was a group leader for the Manhattan Project. Historical accounts that focus on big names in science are pretty standard, and, given a short amount of space, are perhaps the best way of presenting the history. Of course, true life history happens through contributions from everyone, not just the most famous.

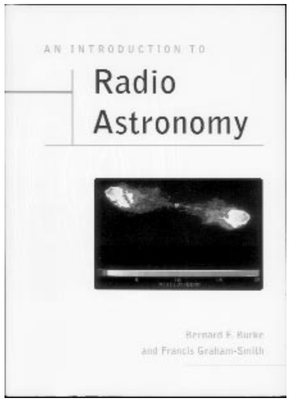
The historical narrative in *Einstein's Mirror* takes a fairly substantial sidetrack first in chapter six, with an account of the history of atomic physics, and then in chapter seven, which recounts the development of the atomic bomb. Chapter seven is actually a substantial sidetrack because, while $E = mc^2$ explains where atomic energy ultimately comes from, the discovery of atomic energy was made in the laboratory and is not the result of a theoretical prediction of relativity. Nevertheless, theory-and-experiment are always a chicken-and-egg proposition, and I enjoyed reading the story.

In the end, that is what Hey and Walters have — a story. A story about what relativity is and how it is relevant to our lives. They have told a story about how a modern theory of space and time has been added to the foundation of science. It is a story worth reading, especially if you want a not-so-dry introduction to the ideas of relativity theory that borrows from history and science fiction to explain ideas in science.

Gordon E. Sarty

Gordon E. Sarty is a medical imaging researcher in Saskatoon. He would like everyone to remember that straight lines in space-time diagrams represent inertial frames and that straight lines cannot be changed into crooked ones.

An Introduction to Radio Astronomy, by Bernard F. Burke and Francis Graham-Smith, pages ix + 294; 17.5cm×25cm, Cambridge University Press, Cambridge, 1997. Price US$32.95 soft cover. (ISBN 0-521-55604-X)



The authors of *An Introduction to Radio Astronomy* state their intention clearly. "The plan of the book is twofold," they write. "We hope that the scope and impact of radio astronomy observations will be shown in the astrophysical discussion, and at the same time we intend to give a brief but comprehensive treatment of the elegant methods that have developed." Their double-barreled objective is an ambitious one, and hard to accomplish in 294 pages.

Where this book succeeds best is in its wide coverage of radio astronomical observational phenomena. It introduces and explains in some detail a broad range of radio-observable phenomena, including: the galactic synchrotron and thermal radiation, supernova remnants, the Galaxy's spiral structure, interstellar and circumstellar masers, radio stars, pulsars, radio galaxies and quasars, jets, superluminal motion, gravitational lensing, and the cosmic microwave background. The book also introduces and explains many technical aspects of radio astronomy, such as the principles of aperture synthesis and digital autocorrelation spectrometers, but because of the brevity of the treatment it is somewhat less successful in these areas.

Five of the sixteen chapters deal with the techniques of radio astronomy, from the principles of radiometry and interferometry (including Very Long Baseline Interferometry, or VLBI) to aperture synthesis and image improvement using self-calibration, CLEAN, and the Maximum Entropy Method. It is this reviewer's opinion that those chapters do not communicate to the non-radio-astronomer as well as, for example, *Radio Astronomy* by Kraus, or *Interferometry and Synthesis in Radio Astronomy* by Thompson, Moran, and Swenson.

The book is explicitly intended for advanced readers. According to the authors, "In addition to the astronomy graduate student and those professionally committed to radio astronomy, there is a wider audience for whom this book is intended: the interested astronomers from outside the field who want to be informed of the principle ideas current in radio astronomy, and may even be thinking of carrying out radio observations that would complement other work in progress."

In keeping with the stated objectives, some "practical" concerns of radio observers are highlighted. One example is a discussion on the choice of calibration sources for phase, flux, and polarization in the section entitled "Calibration of interferometer data." A very practical concern is the fact that aperture synthesis telescopes, which are widely used for high resolution imaging, are generally blind to much of the structure of extended objects. Thus, it becomes important for the observer to augment aperture synthesis telescope data with data from a large single-dish telescope before analyzing his or her images. The coarser Fourier structural components of the object are not obtained from the interferometers comprising synthesis telescopes, and must be obtained elsewhere. In fact, the image of the supernova remnant IC 443 shown as figure 9.11 is an unintentional example, since the large-scale structure of IC 443 is mostly absent in the image. The authors mention the problem in a single sentence in chapter ten, but they do not give such a practical concern any emphasis.

There are few production errors in the book. A minor flaw is that Appendices 1, 2, and 3 are referred to throughout the text as Appendices A, B, and C. Most illustrations are excellent, but there are exceptions. Figure 15.4 is referred to frequently in the algebra-heavy section on gravitational lensing, yet none of the quantities used in the equations are indicated in the diagram. Figure 9.8 is too small to be legible, and two diagrams, figure 10.10(c) and a 5 GHz map of the jet in 3C 390.3, are missing.

The authors are both highly respected radio astronomers of great experience. For example, it was Graham-Smith's measurement of the position of Cygnus A in 1951 by radio interferometry that permitted its optical identification. His later work on pulsars, including two books, is highly regarded. Similarly, Burke was co-discoverer in 1955 of the decametric radio bursts emanating from Jupiter, and has contributed many years' work in VLBI, including VLBI from space.

The authors raise an interesting point in the preface, connected with the steady advance of radio astronomy toward higher frequencies, when they write: "...it is no longer clear where radio astronomy stops and infrared astronomy begins." They propose the definition that "radio astronomy is the study of the universe by observing electromagnetic radiation after it has been coherently amplified" and suggest that preservation of the phase information is the mark of radio astronomy. Interestingly, true separated-element aperture synthesis at the 830 nm wavelength has now been achieved by the radio astronomy group at Cambridge University (J. E. Baldwin *et al.*, Astron. Astrophys., 306, L13, 1996). The spectroscopic binary Capella was imaged with 0.02 arcsecond resolution, clearly showing the binary components and their orbital motion. Aperture synthesis was achieved without coherent amplification, but the phase information was preserved by phase-closure techniques developed for synthesis radio telescopes. Radio astronomy techniques are indeed being employed at the edge of the visual band.

For both astrophysical and technical topics, the book gives excellent bibliographical references. The authors have tried to provide "recent, comprehensive references to the extent that they are available." In that they have succeeded very well. In summary, the book is a valuable addition to the literature, and it is definitely a bargain at the price.

David Routledge

David Routledge is a professor of electrical engineering at the University of Alberta. He is an avid user of the synthesis radio telescope at the Dominion Radio Astrophysical Observatory, and his graduate students have contributed to its technical enhancement for several years.

Astrocryptic

by Curt Nason, Halifax Centre

HERE ARE THE ANSWERS TO LAST ISSUE'S ASTROCRYPTIC PUZZLE

1 M	E	2 S	S	3 I	E	4 R	■	5 D	I	6 R	A	7 C
I	■	O	■	R	■	O	■	I	■	A	■	A
8 N	I	M	B	I	■	9 B	R	A	N	D	O	N
U	■	M	■	D	■	E	■	L	■	I	■	C
10 T	H	E	M	I	C	R	O	S	C	O	P	E
E	■	■	■	U	■	T	■	■	■	■	■	R
■	11 G	A	M	M	A	B	U	12 R	S	T	S	■
13 P	■	■	■	■	■	U	■	I	■	■	■	14 A
15 L	I	16 M	B	17 D	A	R	K	E	N	18 I	N	G
O	■	A	■	R	■	N	■	M	■	S	■	O
19 S	K	Y	H	I	G	H	■	20 A	T	A	U	R
S	■	O	■	V	■	A	■	N	■	A	■	A
21 L	Y	R	A	E	■	22 M	O	N	O	C	L	E

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