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Journal

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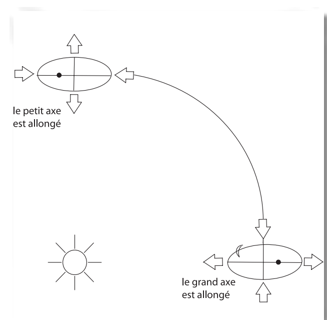

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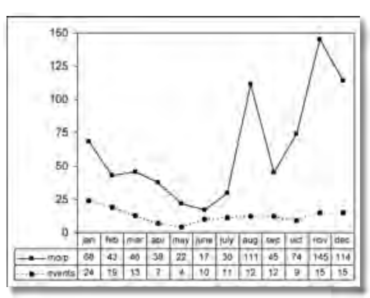

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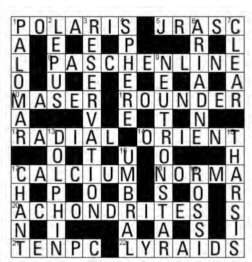

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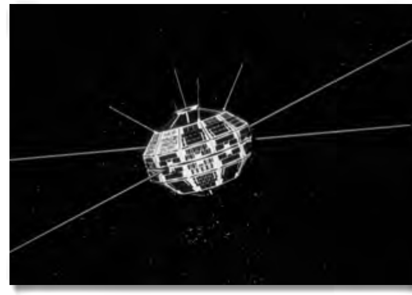

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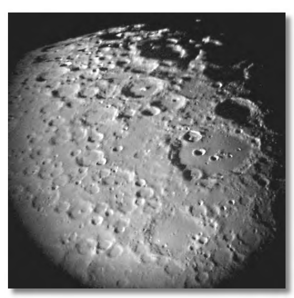

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President's Corner

by Rajiv Gupta (gupta@interchange.ubc.ca)

Every one of the close to 5000 members of the RASC has a unique story of involvement in astronomy and the Society. Over the course of my travels to Centres, one of my duties as President, I've heard many such stories and been impressed with their breadth. In this month's column, I'd like to share with you a little bit more of my own story, and give you a sense of how important the Society has been to my pursuit of astronomy as a hobby.

My story starts in December, 1985, when I received a small telescope as a gift from my parents. While I had taken physics and astrophysics courses in university, I had never actually looked through a telescope or really *learned* the sky. I knew all about the orbit of the Moon about Earth, but was nevertheless surprised to discover when I started observing the Moon that it rose later on successive nights. Owning a telescope transformed my relationship with the sky from a passive one based on Kepler's laws into an active one based on *observation*. I loved it!

A few months later, I had upgraded my optics from a 60-mm Tasco to a 130-mm Astro-Physics refractor. At the same time, I learned about the Vancouver Centre of the RASC and started attended meetings. The meetings always featured a fascinating speaker, and I learned a lot of astronomy. More importantly though, I found dedicated observers with whom I could share a night under the stars. On one of my first visits to the Centre's observing site, I arrived around midnight on a cold January night, when most of the observers were getting ready to leave after several hours of stargazing. One veteran observer though stayed to keep me company. I learned about that other, older star cluster in the vicinity of M35 and compared views through my refractor and my selfless and shivering companion's larger reflector.

As my interest moved from visual observing to astrophotography, my fellow RASC stargazers continued to play an important role. One member who had considerable experience with darkroom work taught me how to develop film, a member who had a metalwork shop at home spent a weekend building a tank for me so that I could hypersensitize my own film, another member built a custom camera for me; and occasionally in the observing field in the middle of a long exposure while I was glued to my guiding eyepiece, someone would drop by just to keep me company or to politely inform me that I had left the lens cap on my telescope.

My passion for astrophotography is what led me to become involved in the RASC at the national level. At the urging of the

Journal

The *Journal* is a bi-monthly publication of the Royal Astronomical Society of Canada and is devoted to the advancement of astronomy and allied sciences. It contains articles on Canadian astronomers and current activities of the RASC and its Centres, research and review papers by professional and amateur astronomers, and articles of a historical, biographical, or educational nature of general interest to the astronomical community. All contributions are welcome, but the editors reserve the right to edit material prior to publication. Research papers are reviewed prior to publication, and professional astronomers with institutional affiliations are asked to pay publication charges of $100 per page. Such charges are waived for RASC members who do not have access to professional funds as well as for solicited articles. Manuscripts and other submitted material may be in English or French, and should be sent to the Editor-in-Chief.

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then-President of the Vancouver Centre, I compiled several of my black-and-white images together into a local astronomical calendar for the year 1992. The following year, National Council gave approval to a 1993 national edition. Since then, I've edited and produced the *Observer's Calendar*, and have come to know many members across the Society through this project. It has also profoundly influenced by my own development as an astrophotographer, since many of the composite imaging techniques I've developed over the years arose at calendar production time, when I was pressed to produce the best images I could for the next edition.

I also became the Vancouver Centre representative to National Council in 1993. Surprisingly, I found myself becoming very interested in the business that was discussed at National Council meetings, and in particular in the finances of the Society. I served as the Society's treasurer from 1994 to 1998, and ultimately that led to my current position as well as an invitation to become the editor of the *Observer's Handbook*.

I often am asked why I spend so much of my time on Society business. In addition to being President, I still edit and produce the *Observer's Calendar* and *Observer's Handbook*, and these two activities consume most of my summer. I have no simple answer to this question. Perhaps my deep involvement in the Society is a way of giving something back to all those members who helped and encouraged me when I was a novice, or perhaps it's because of the intense sense of accomplishment that results from my various RASC activities. Or, maybe it's because of an inspiring talk by David Levy I attended at my first RASC General Assembly in 1994. I knew after that talk, with utter certainty, that of all the hobbies I might have become immersed in, I had chosen the one that was absolutely *the* most rewarding one in existence. Members across the Society who share this conviction, and each with their own story, are the reason the Society, as it celebrates its Royal Centenary, is such a strong organization with a key presence in the Canadian and worldwide astronomical community.

Editorial

by Daniel Hudon (dhudon@wwonline.com)

I've long had a soft spot for the space shuttle. From its spectacular Phoenix-like launches to its awesome images of the blue Earth and live-action shots of astronauts with weightless hairdos to the occasional tantalizing space walk, the shuttle never fails to fire the imagination.

Like so many others, I was shocked to see the endless film loop on television of the disintegration of the shuttle Columbia on the morning of Saturday, February 1. After a successful science mission, Columbia was re-entering Earth's atmosphere, zooming in at Mach 18, and was only 16 minutes from landing when it began to break apart. The crew of seven astronauts — space enthusiasts — died.

Two days later, during my Monday night "Introduction to Astronomy" class at Ryerson University, still thinking about the accident, I couldn't bear to wrap up my discussion of Newtonian gravity in my usual way: showing how the space shuttle's orbit is a modern example of Newton's Universal Law of Gravitation. Instead, I used Newton's own example of firing a cannonball around the Earth.

With his cannonball, Newton showed that a projectile behaved just like a satellite, and it's there in the pages of *Principia*, almost three centuries before the launch of Sputnik, that the space age had its beginnings. However, the elegance and simplicity of Newton's laws fail to indicate the hazards of space flight. Due to the tremendous speeds, re-entry is the most difficult part of the mission.

In 113 flights so far, I've only seen the shuttle once. In December 1985, I was sitting in an astronomy class at the University of Calgary when the instructor stopped the lecture and said, "The shuttle's supposed to fly overhead at 5:17, let's go see if we can see it." I don't know why I remember the time, but I do. A half dozen of us put on our coats and went outside. We had barely zipped up our coats when, right on schedule, the space shuttle Atlantis sailed overhead. In the early winter dark, it was like a low-flying, silent aircraft — a satellite, brighter than Venus. Someone said it was flying upside down. And, in a moment, it was gone. It happened so quickly that I half anticipated another to follow behind. For a long time, I marveled at the punctuality of the "Calgary fly by." I had no idea orbits could be known so precisely.

Until then, aside from the fiery launches, I hadn't been that impressed with the shuttle program. I thought it was just a high-flying jet and didn't appreciate the complexities of sending a vehicle into low-Earth orbit and returning it safely to Earth. Similarly, though wowed by the power of Newton's laws as an undergraduate, I didn't truly appreciate their versatility until I began to teach them years later.

In its capacity as a delivery vehicle, the shuttle was responsible for deploying — and repairing — the Hubble Space Telescope (HST) into a 90-minute orbit. Subsequent shuttle service missions to the HST have kept the telescope in top working condition. Thanks to the shuttle, jaw-dropping HST images continue to pop up on the Internet.

The shuttle also deployed the Chandra X-Ray Observatory, the Gamma Ray Observatory, as well as the planetary probes Magellan and Galileo, among others, opening up other realms of the electromagnetic spectrum and the nearby Universe.

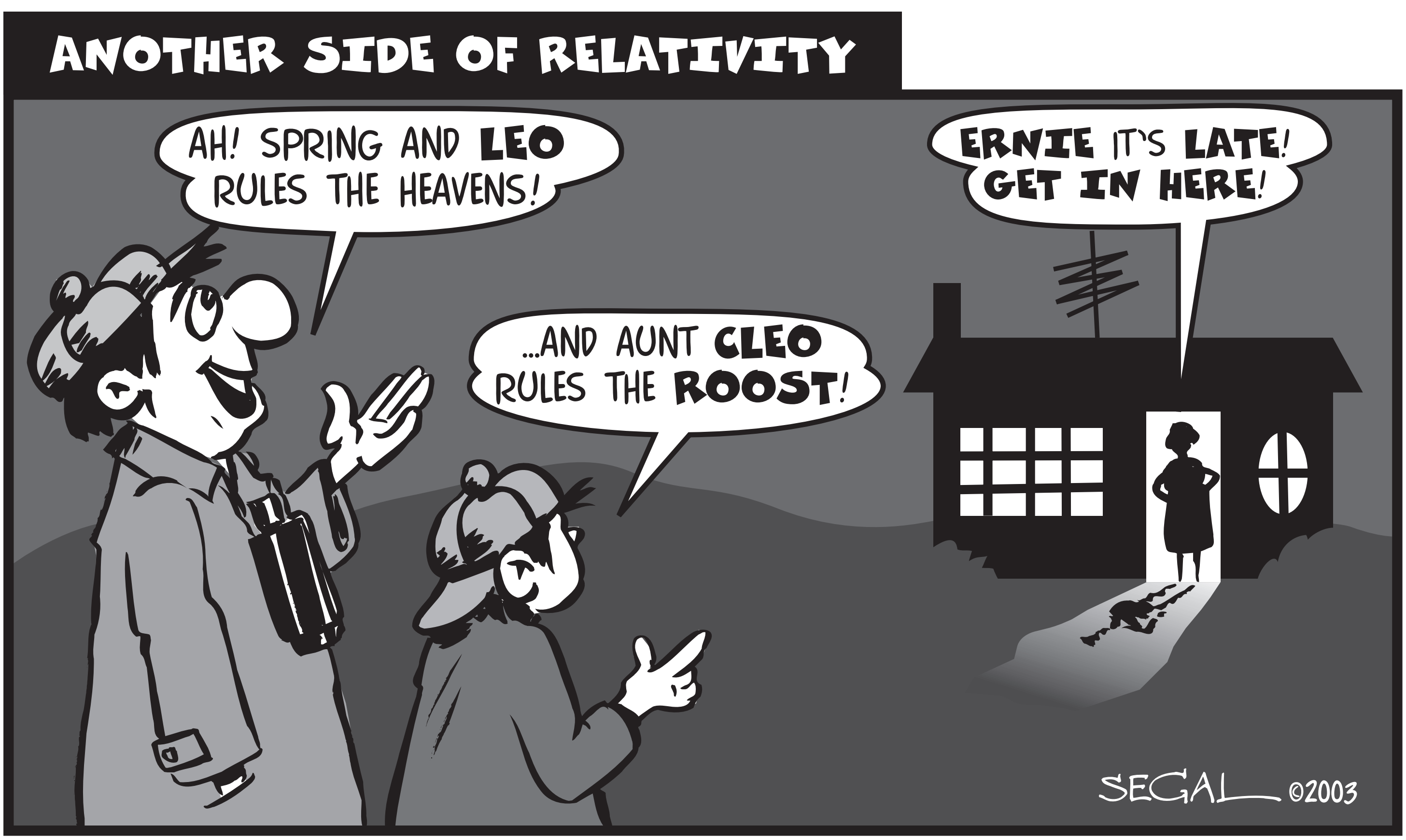
Recent shuttle missions have focussed on ferrying goods for the International Space Station. However, for this mission, Columbia became an orbiting science laboratory, carrying more than 80 physics, biology, and space habitat experiments. One of the more bizarre experiments studied flame balls — Ping-Pong ball sized flames suspended in a gaseous chamber. While flames on Earth have a teardrop shape due to air rising in a gravitational field, in a microgravity environment such as the shuttle, flames break apart into tiny spheres a few millimetres in diameter. Apart from their quirky organism-like behaviour as they search for more fuel, understanding the mystery of flame balls may help in the design of more efficient combustion engines.

As the experiment proceeded, the astronauts began naming the flame balls. A pair that flew around in a DNA-like spiral pattern were dubbed “Crick and Watson.” A large one was named “Zeldovich,” after the Russian physicist who predicted flame balls in 1944. Others were given more common names like “Howard” or “Kelly.” Evidently, with this experiment (and others), the astronauts were having fun. “Kelly” became the longest lasting flame ball ever recorded, thriving for 81 minutes — almost completing an orbit around the Earth. Though some of the data (from this and other experiments) was downloaded to the ground, much was lost during the spacecraft’s disintegration.

For most of us, our enthusiasms for the Universe don’t lead us into peril. We go to our backyard telescopes, drive to dark sites in the country, stay up late to finish analyzing some data or writing a research paper, or pore over some new astronomy book aware that our greatest dangers are bleary eyes and a lack of sleep. Our orbits are safely on the ground.

News of the accident was shocking because I realized that, after more than 100 flights, things can still go wrong. Space flight is not routine: accidents can still happen. Knowledge is hard won. Newton, famously quoted as “standing on the shoulders of giants,” summarized more than 150 years of baby steps and leaps by his predecessors with his publication of *Principia*. His laws of dynamics are the Law of Universal Gravitation now taught in schools and universities around the world.

But the pursuits of knowledge and wonder at the highest level still come with considerable risks and their tragic consequences. The Columbia accident and the legacy of the astronauts who died are reminders that we are a young civilization still taking baby steps into the cosmos.



Correspondence
Correspondance

RASC
General Assembly 2003 — Vancouver Thursday 26 June to Tuesday 1 July 2003

History of the Royal Astronomical Society of Canada

The Vancouver Centre of the RASC was selected by the National Council of the Society to host the General Assembly 2003. The Society's history dates back to its founding in 1868, but it was not until 1903 when the then-monarch of England, King Edward VII, granted the Society its Royal Charter. At present, the Society has nearly 4700 members in 26 Centres across Canada. It was considered appropriate that GA 2003 be an occasion for celebration.

The Occasion

General Assembly 2003 of the Royal Astronomical Society of Canada to coincide with the 100th Anniversary of the granting of the Royal Charter to the Society. The Assembly will be formally opened by *Her Excellency the Right Honourable Adrienne Clarkson, Governor General, representing the Queen.

The Speakers and Workshop Leaders

Speakers and workshop leaders will include well-known astronomical personalities including David Levy, Jack Newton, Alan Dyer, Peter Broughton, David Dodge, Pal Virag, *Jaymie Matthews, John Nemy, Carole Legate, Peter Ceravolo, and Gordon Walker. Their talks will be geared to the general public and amateur astronomers of all levels.

The Venue

The Assembly will take place on the beautiful campus of the University of British Columbia, Vancouver. The city and its surroundings are well known world wide for their quality of life and scenic beauty, especially in the late spring and early summer.

The Events

In addition to the business meetings of the GA and the submission of astronomy-related papers, talks, workshops, exhibits, etc., there will be spousal/companion/family tours, door prizes, a ribbon dance, a tour of the TRIUMF research facility, a wine and cheese party, a Murphy Night and song contest, a dinner cruise, a salmon BBQ at the Museum of Anthropology, a tour of the RASC Vancouver Centre's supernova search observatory, a tour of UBC's Liquid Mirror Observatory, and a Planetarium show at the McMillan Space Centre.

The Costs

Registration fees: RASC members: $110.00 Cdn, late RASC registrants (after 31 May 2003): $125.00 Cdn. RASC spouses/companions $55.00 Cdn, non-RASC members $125.00 Cdn. Accommodation (at Gage Residence, UBC): $35 Cdn/night to $129 Cdn/night for suites. Meals and costs of special events are additional.

Non-members Welcome

All the activities of the GA, except for the business meetings of the Society, are open to the public.

Additional Information

For detailed information, including schedules, speakers' resumes, their topics, and subjects of their workshops, visit our Web site `www.rasc.ca`

* Subject to confirmation

Errata:

Dr. Ed Cloutis is at the University of Winnipeg (*JRASC*, 96, 182).

The URL for the NASA Astrophysics Data System is:
`adsabs.harvard.edu/article_server.html`
(*JRASC*, 96, 141).

News Notes
En Manchettes

Allie Vibert-Douglas honoured

Allie Vibert-Douglas (1894–1988). Images and biographical details are available at: `library.usask.ca/herstory/douglа.html`.

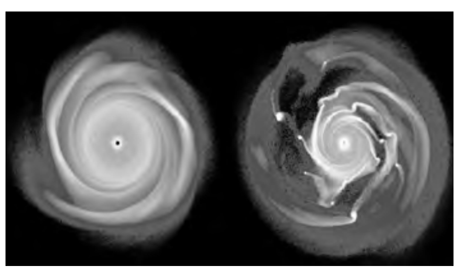
The International Astronomical Union has recently decided to name a crater on the surface of Venus in honour of Canadian astronomer Allie Vibert-Douglas.

Born in Montreal in 1894, Vibert-Douglas began her studies in mathematics and physics at McGill University. During the years of World War I, however, she interrupted her studies to work at the London War Office as a statistician. And, in 1918, at the age of 23, she was awarded the Order of the British Empire in recognition of her work. After her return in Montreal, she earned a Bachelor degree in 1920 and a Master's degree in 1921. She studied at Cambridge University in England under the direction of Arthur Eddington. In 1925, she was awarded a doctorate in astrophysics at McGill. An asteroid was named after Vibert-Douglas following her death in 1988.

The new crater naming and honour follows from the efforts of Yvan Dutil, an astrophysicist working for ABB (Analytical and Advanced Solutions) in Quebec City. Dutil approached the International Astronomical Working Group on Planetary System Nomenclature and suggested Vibert-Douglas as a candidate for a venusian feature.

For Venus the adopted procedure is that large craters are named after famous women, while smaller craters (less then 20 km in diameter) are given feminine names; all other features are named after mythological characters. Since no large crater was "available," the name of Vibert-Douglas has been given to a Patera, a term used to describe irregular, or complex, craters with scalloped edges. The Vibert-Douglas Patera is located at 11.6° south latitude, 194.3° east longitude.

It's a runaway — by Jupiter!



Face-on view of a protoplanetary disk generating Jupiter-mass planets through gravitational collapse on a time scale of about 500 years. Image courtesy: Thomas Quinn

Putting a Jupiter-mass planet together might take less time that was previously thought. So write Lucio Mayer and Thomas Quinn (of University of Washington), James Wadsley (of McMaster University), and Joachim Stadel (of the University of Victoria) in the November 29, 2002 issue of *Science* magazine. Reporting on a new computer analysis of gravitational instabilities in protoplanetary gaseous disks, they find that Jupiter-mass planets might form within just a few thousand years. Canonical wisdom has previously argued that to form gas-giant planets like Jupiter, 10-20 Earth-mass cores must first be formed. The cores then accumulate massive gas envelopes from the protoplanetary disk. The new study provides an alternative to the slow accretion scenario by allowing for the possibility of Jupter-mass planets forming directly via gravitational collapse. In the new computer study, fluctuations in the protoplanetary disk's density were followed with the self-gravity of the collapsing gas being implicitly included in the calculations.

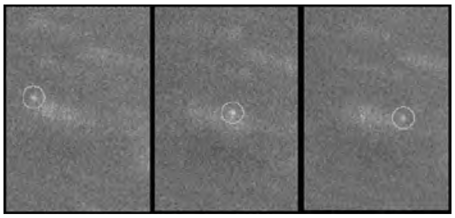
The simulations studied by Mayer and co-workers find that gravitational instabilities in a protoplanetary disk can form self-gravitating protoplanets that are long-lived, and have masses and orbits similar to those observed for Jupiter and Saturn in our solar system and extrasolar planetary systems in general. The authors suggest that icy giant planets (such as Uranus and Neptune in our Solar System) might also be formed via self-gravitating collapse.

Tagish Lake: a meteorite ripe for development

The Tagish Lake carbonaceous chondrite meteorite that fell on January 18, 2000 has recently added yet another "first" to its list of "firsts." The new results relate to the discovery of micron-sized hollow hydrocarbon bubbles. Commenting upon the new find in the December 17 issue of *New Scientist* Magazine, Michael Zolensky

(NASA Johnson Space Center), and Iain Gilmour (Open University, UK) note that such structures might afford "shelter" for the early development of primitive organisms. In essence, the hydrocarbon bubbles act as a protective framework within which cell development can take place. (For further details on the Tagish Lake fall, see: `phobos.astro.uwo.ca/~pbrown/Tagish/`).

New Moons for Neptune



The new moons of Neptune. To locate the new Neptunian moons, Holman and Kavelaars employed an innovative observing technique. Using the 4.0-metre Blanco telescope at the Cerro Tololo Inter-American Observatory, Chile, and the 3.6-metre Canada-France-Hawaii Telescope, Hawaii, they took multiple exposures of the sky surrounding the planet Neptune. After digitally tracking the motion of the planet as it moved across the sky, they then added many frames together to boost the signal of any faint objects. Since they tracked the planet's motion, stars showed up in the final combined image as streaks of light, while the moons accompanying the planet appeared as points of light. Image courtesy: NRC.

A team of astronomers led by J.J. Kavelaars of the National Research Council of Canada (NRC) and Matthew Holman of the Harvard-Smithsonian Center for Astrophysics has recently discovered three new moons in orbit around Neptune. The new finds boost the number of known satellites of Neptune to eleven. The new moons are the first to be discovered orbiting Neptune since the Voyager II flyby in 1989, and are the first to be discovered with a ground-based telescope since 1949.

It now appears that Neptune's irregular satellite population is the result of an ancient collision between a former moon and a passing comet or asteroid. "These collisions result in the ejection of parts of the original parent moon and the production of families of satellites," said Dr. Kavelaars. The new satellites were a challenge to detect since they are only about 30-40 kilometres in size. Their small size and distance from the Sun prevent the satellites from shining any brighter than 25th magnitude, about 100-million times fainter than can be seen with the unaided eye.

The team that discovered these new satellites of Neptune includes Holman and Kavelaars, graduate student Tommy Grav of the University of Oslo & Harvard Smithsonian Center for Astrophysics, and undergraduate students Wesley Fraser and Dan Milisavljevic of McMaster University, Hamilton, Ontario, Canada.

Visualizing the Shape of the Universe

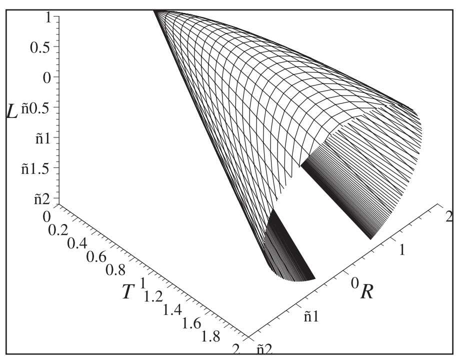


Figure 1.

Our view of the universe is becoming increasingly complex. Dark matter, dark energy, inflation, and possible hidden extra dimensions have made it harder and harder to imagine what our universe really *looks* like. Even though much of our understanding of the cosmos is based on solid mathematical models, it is often helpful to use graphic tools in our attempts to fathom the seemingly unfathomable. With this in mind, a group led by Paul Wesson of the University of Waterloo has devised a graphical technique to illustrate the shape of the universe (*Astronomy and Geophysics*, December 2002 and *Ap. J. Letters*, September 10, 2001).

Known as the 5-D Space-Time-Matter Consortium, the team has been exploring the possibility of a five dimensional version of Einstein's general theory of relativity. The more familiar 4-D version uses three spatial dimensions and one temporal dimension. The added fifth dimension is used to explain the very existence and behavior of matter itself.

Other higher-dimensional theories, such as superstrings, have "compacted" ten or eleven extra dimensions into unimaginably small volumes — smaller than the nucleus of an atom. This essentially hides their weird geometry from our view. Wesson's group has sought to embed the fifth dimension into the realm of our everyday life — essentially forming the very matter and energy we can touch and measure. According to Wesson this extra part of our reality is "not apparent to the eye but controls the interactions of particles and therefore ultimately the matter of everyday existence."

To help the Consortium progress and maybe to help the rest of us understand such bizarre concepts, Wesson, along with Andrew Billyard and Sanjeev Seahra, has developed a way of graphing the evolution of a 5-D universe. Since our universe, on the grandest of scales, appears to be uniform in every direction, Wesson ignores two of the three spatial dimensions. Their graphical interpretation of a 5-D universe uses only time T, radius R, and the added spatial dimension L. The corresponding dimensions in such a stripped down 4-D Universe would be only t and r. The functions describing T, R, and L are so complex that computers

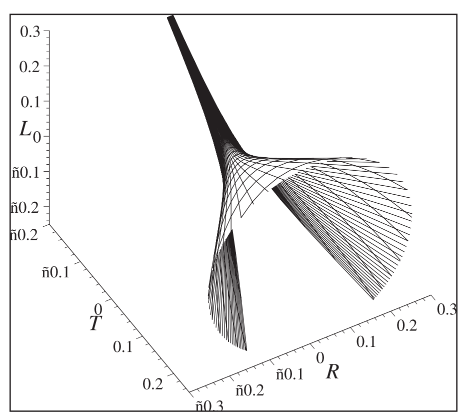


Figure 2.

were needed to plot the results.

In the graphs accompanying this news note (see Figure 1), the cone shaped structure represents our 4-D universe with the Big Bang at the apex. As time progresses along the T axis, the universe expands, carrying the galaxies upon the "surface" of the cone. The trumpet shaped graph (Figure 2) is the very early universe, a tiny fraction of a second after the Big Bang. The sudden flaring of the structure signifies the onset of the "inflationary era," when the universe may have briefly expanded at an unbelievably high rate. The whole premise of a large-scale fifth dimension is still unproven. Yet, if cosmologists hope to validate or refute such notions, they may need to go outside the box of observation or mathematics and seek the assistance of these more picturesque tools.

Les mesures du temps

par Raymond Auclair, membre indépendant et à vie, SRAC (auclair@cyberus.ca)

À chaque année, lorsqu'on reçoit son *Observer's Handbook*, on s'amuse à le feuilleter. On s'attarde sur certaines pages pour voir s'il y a eu changement au cours de la dernière année (par exemple, les satellites de Saturne) ou encore s'il se passera quelque chose d'astronomique le jour de son anniversaire de naissance.

Il est rare qu'un habitué s'arrête aux pages qui contiennent les définitions et les unités de base car, après tout, celles-ci demeurent fixes et, pense-t-on, bien connues.

Mais, le sont-elles vraiment? Voici une visite des unités de temps qui sont offertes en page 29 du *Observer's Handbook 2003*.

Les unités les plus utiles

La journée

L'intervalle de temps le plus utile à l'humain est la journée. Plusieurs ouvrages utilisent le mot jour dans le sens où l'on utilise ici le mot journée. Cette utilisation est très acceptable, surtout lorsque le contexte évite toute confusion. Puisqu'on a besoin des deux sens, on utilise ici deux mots: journée (période de 24 heures) et jour (opposé à nuit).

Très vite, la vie sur Terre s'est réglée sur le cycle du jour et de la nuit. Dès qu'il a été possible de mesurer le temps (même de façon grossière), on a séparé le jour en douze heures. Avant les calculatrices et les ordinateurs, les bases étaient choisies pour la facilité avec laquelle on pouvait les diviser. Douze se divise par 2, 3, 4, et 6. Au début, ces heures étaient flexibles. Quelle que soit la saison, le jour comptait toujours 12 heures. Dès 1500 av. J.-C., les Égyptiens dotaient leurs cadrans solaires de gnomons pour corriger l'équation du temps. Un siècle plus tard, ils avaient des clepsydres (horloges à eau) assez précises pour fixer la durée d'une heure.

La nuit étant moins utile aux humains, on attendra un millénaire avant de la diviser elle aussi. Chez nos aïeux culturels, ce sont les Romains qui divisent la nuit pour déterminer les quarts de veille des troupes.

Il y a donc, depuis au moins 2000 ans, deux fois 12 heures dans une journée.

Les 24 heures de la journée sont divisées en minutes de temps qui, à leur tour, sont divisées en secondes. Les mots viennent d'expressions latines: *pars minuta prima* (première petite partie) et *pars minuta secunda* (deuxième petite partie). Les divisions angulaires du degré se nomment aussi minutes et secondes. Lorsqu'il y a risque de confusion, on utilise minute d'arc (pour l'angle) et minute de temps.

La journée compte 24 heures; chaque heure a 60 minutes ; chaque minute compte 60 secondes. Au total : 86 400 secondes dans une journée.

La seconde se fixe

Jusqu'en 1960, la seconde est définie en fonction de la journée solaire moyenne. Mais les horloges de plus en plus précises montrent que la rotation de la Terre est irrégulière. On tente de redéfinir la seconde en fonction d'une moyenne entre différentes horloges, mais la technologie évolue si vite qu'il faut souvent modifier les détails de la définition.

En 1967, on s'entend que la 86 400^{e} partie de la journée solaire moyenne équivaut à 9 192 631 770 périodes de radiation de la transition entre deux niveaux hyperfins d'énergie de l'état fondamental de l'atome de Césium 133. La seconde est redéfinie.

L'horloge atomique

Un électron en orbite autour d'un noyau atomique a un niveau très précis d'énergie. Pour chaque atome et chaque électron, il existe un niveau d'énergie minimal en deçà de laquelle l'orbite de l'électron ne peut aller. Lorsque l'électron a un surplus d'énergie (l'atome est excité), il se retrouve sur une orbite à un niveau d'énergie plus élevé. Au moment où il revient à son niveau minimal d'énergie, l'électron émet un photon d'une fréquence très précise qui dépend directement de la différence d'énergie entre les deux orbites. Dans le cas de l'atome et des niveaux orbitaux choisis, cette fréquence est exactement 9 192 631 770 Hz (cycles par seconde).

Dans l'horloge, une source d'énergie maintient le niveau choisi d'excitation des atomes, puis l'horloge calcule le nombre de périodes en observant les photons émis par les électrons qui reviennent à leur orbite de base. La précision de telles horloges est de l'ordre d'une seconde par million d'années.

La journée et la journée solaire moyenne

À long terme, la rotation de la Terre ralentit constamment. Ce ralentissement est infime mais inexorable. Il est dû à la friction engendrée par les effets de marée (causés surtout par la Lune) et est connu depuis environ deux siècles. Il est si lent que son effet sur la journée n'était pas mesurable à court terme.

À court terme, on note des changements plus brusques dans la vitesse de rotation de la Terre. Ceux-ci sont dus à des phénomènes astronomiques (influences gravitationnelles de la Lune, du Soleil et des autres planètes) et géologiques (glissements de la croûte et du manteau terrestres sur le noyau). D'une année à l'autre, ces effets peuvent dominer le ralentissement dû à la marée; certains des effets peuvent même sembler aléatoires.

Dans *l'Observer's Handbook 1982*, on notait l'existence d'une différence entre les deux journées (la vraie et la solaire moyenne), mais on nommait *mean solar* day celle qui mesure exactement 86 400 secondes. Ce n'est qu'en 1984 que *l'Observer's Handbook* fait la distinction que l'on connaît maintenant et on note alors une différence de 0,003 seconde. La rotation de la Terre a accéléré au cours des deux dernières décennies (à cause d'effets à court terme), de sorte que l'écart n'est maintenant que d'un millième de seconde.

Ainsi, l'unité de base qu'on appelle la journée mesure exactement 86 400 secondes mesurées par les horloges atomiques au Césium. Comme symbole, *l'Observer's Handbook* utilise la lettre **d** (de l'anglais *day*) pour la journée. On utilisera ici la majuscule **J** mise en exposant (par exemple, juin dure 30^{J}).

Les années

Armé d'une unité précise, on peut apprivoiser les autres mesures du temps. On imagine un univers peuplé d'étoiles éloignées les unes des autres. Près d'une étoile moyenne, localement isolée des autres, il y a une planète. Pour faire plus vrai, on imagine que l'étoile a la masse de notre Soleil et la planète celle de notre Terre (et utilisons ces noms). La masse du Soleil est presque 333 000 fois celle de la Terre.

On imagine aussi que les autres étoiles sont trop loin pour avoir une influence gravitationnelle ou autre. Elles forment une toile de fond qui permet de prendre des mesures.

Les deux masses sont en orbite autour de leur centre commun situé très près du centre du Soleil qui comprend presque toute la masse du système. Sans nuire aux raisonnements, on peut imaginer que le Soleil est immobile et que seule la Terre est en mouvement.

L'année sidérale

Si l'orbite est parfaitement circulaire, alors il est difficile de distinguer un point sur l'orbite d'un autre point sur l'orbite. Identifions l'écliptique: la ligne que semble suivre le Soleil sur la toile de fond des étoiles; c'est aussi la projection de l'orbite de la Terre, si elle était vue du centre du Soleil.

Trouvons, sur l'écliptique, une étoile qui se distingue des autres (par son éclat ou sa couleur, par exemple) et imaginons une droite qui relie le Soleil à cette étoile.

Au moment où la Terre traverse le prolongement de cette ligne (l'étoile est alors en conjonction avec le Soleil), on commence la mesure du temps, qu'on arrête dès que la Terre croise à nouveau cette ligne (un an plus tard). Les Égyptiens utilisaient le lever héliaque de Sirius: le premier matin où on voyait Sirius se lever, juste après sa conjonction avec le Soleil.

L'année ainsi mesurée, en rapport avec les étoiles, est l'année sidérale (du latin *sidus* = astre). Pour la Terre, cette année mesure $365{,}256\,363^{J}$ (journées de 86 400 secondes).

L'orbite est une ellipse

Une ellipse est comme un cercle un peu écrasé. Plus précisément, une ellipse est une courbe fermée, partout concave, qui possède deux points focaux (A et B). Pour tout point C sur la courbe, la somme des distances (AC + BC) est toujours la même. Le cercle est un cas spécial de l'ellipse: celui où les deux points (A et B) sont exactement au même endroit.

Kepler, Newton, et d'autres ont démontré qu'une orbite planétaire peut être représentée par une ellipse où le Soleil occupe un des points focaux (disons A).

On trace une droite à travers les points focaux. Cette droite traverse l'ellipse à deux points. Un des points sera le point de l'ellipse le plus près de A, donc le point le plus près du Soleil. C'est le périhélie (du grec *péri* = autour et *hélios* = Soleil).

Dans l'autre direction, la droite traverse l'ellipse au point le plus près de B et le plus éloigné de A, donc le plus éloigné du Soleil, l'aphélie (en grec, *apo* = loin).

La longueur du segment de la droite, entre le périhélie et l'aphélie mesure le grand axe (ou l'axe majeur) de l'ellipse. La perpendiculaire élevée au centre du grand axe forme le petit axe (ou axe mineur).

Le grand axe et le petit axe se coupent au centre de l'ellipse, mais le Soleil n'est PAS au centre (sauf si l'ellipse est un cercle).

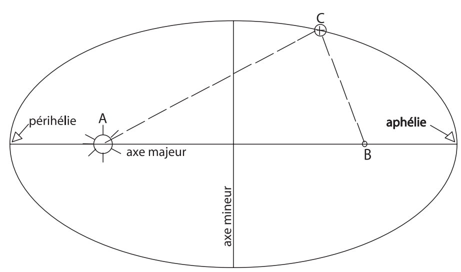


Figure 1 — L'orbite est une ellipse

L'année anomalistique

Pour mesurer une position sur une orbite circulaire, on mesure l'angle au centre entre le rayon original (par exemple, la ligne joignant le Soleil à l'étoile repère) et le rayon entre le Soleil et la Terre.

Sur une ellipse, on peut faire quelque chose de similaire mais pas identique (puisque le soleil et le centre ne coïncident pas). L'angle (ou la différence entre les angles) s'appelle *anomalie*. Si on mesure l'année en mesurant l'intervalle entre deux passages au périhélie, alors on a une année *anomalistique*.

Dans l'univers imaginaire où les deux seules masses, localement, sont le Soleil et la Terre, les deux années devraient être de même durée. Si jamais on observait une différence, ce pourrait être parce que l'étoile choisie n'est pas immobile et que son mouvement propre cause une erreur dans le calcul de l'année sidérale.

Dans l'univers réel, le système solaire compte d'autres planètes, des masses qui perturbent l'orbite de la Terre. Si une masse extérieure était fixe alors elle accélérerait la Terre pour une moitié de son orbite puis la ralentirait pour l'autre moitié. Mais les masses (par exemple, Jupiter) sont elles aussi en orbite, par conséquent l'effet n'est pas exactement symétrique.

Bien que Jupiter soit la planète qui a le plus d'influence dans ce domaine, elle n'est pas la seule, ce qui complique le calcul.

Un des effets de perturbation est que le grand axe de l'orbite de la Terre pivote autour d'un point très près du centre du Soleil, à un rythme de 11,6 secondes d'arc par année, dans le même sens que la Terre sur son orbite.

Donc, une année sidérale après un passage au périhélie, on penserait être revenu au même point, mais il faut ajouter environ 4,7 minutes de temps pour rattraper le périhélie qui avance. L'année anomalistique de la Terre est de 365,259 635[J].

La Terre est un gyroscope

L'attraction du Soleil agit également sur tous les points de la Terre et, pour la plupart des calculs, on peut faire semblant que toute la masse est concentrée au centre.

Jusqu'à présent, on a considéré la Terre comme une masse sans forme. Mais la Terre a une forme et cette forme peut accentuer un effet gravitationnel du Soleil.

La Terre n'est pas une sphère parfaite. Elle est plutôt de forme ellipsoïde (si on prend une tranche en coupant du nord au sud, la coupe formerait — presque — une ellipse). C'est un peu comme si la Terre était un peu écrasée aux pôles et renflée à l'équateur. La Terre a un bourrelet équatorial.

La Terre tourne sur elle-même (rotation) autour de l'axe qui relie les pôles. La masse de la Terre est très grande, et la rotation, même si elle paraît lente (un tour en 24 heures), suffit pour que l'inertie de rotation soit immense.

L'axe de rotation de la Terre est incliné par rapport au plan de l'orbite terrestre, ce qui fait que la ligne qui relie le centre de la Terre au Soleil ne passe pas toujours à l'équateur.

Au solstice d'été (en juin), l'inclinaison de l'axe fait en sorte que le pôle nord est penché vers le Soleil. Le bourrelet du côté qui fait face au Soleil est en dessous de la ligne qui joint le centre du Soleil et le centre de la Terre. La gravitation, lorsqu'on considère le bourrelet, a une composante qui tend à ramener le bourrelet vers cette ligne. C'est la même chose pour la partie du bourrelet qui est de l'autre côté (au-dessus du prolongement de la ligne joignant les centres).

Au solstice d'hiver, c'est le pôle sud qui est tourné vers le Soleil, le bourrelet du côté du Soleil est au-dessus de la ligne. Puisque la Terre, en décembre, est à l'opposé de sa position orbitale de juin (par rapport au soleil), la poussée virtuelle sur son axe est dans la même direction dans les deux cas.

L'effet équivaut à pousser l'axe de rotation vers le pôle de l'écliptique. Mais, à cause de sa rotation sur elle-même, la Terre fera comme tout gyroscope: quand on pousse l'axe dans une direction, il chasse exactement à 90 degrés de cette direction. Donc, l'inclinaison de l'axe reste toujours la même, mais l'orientation change.

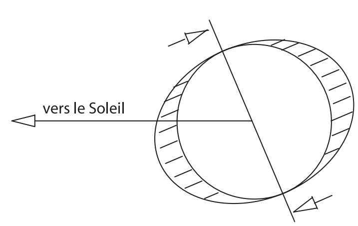


Figure 2 — L'attraction du Soleil sur le bourrelet tente de redresser l'axe

La précession des équinoxes

L'axe de rotation de la Terre est incliné. L'inclinaison est de 23,4393 degrés. L'écliptique qui est la projection du plan de l'orbite de la Terre, ne coïncide pas avec la projection de l'équateur dans le ciel. Les deux cercles se croisent à deux endroits (séparés de 180 degrés).

Cette inclinaison est nettement suffisante pour que les terriens s'en aperçoivent. Pour plusieurs, les jours s'allongent durant une partie de l'année, puis raccourcissent durant une autre partie; le climat est saisonnier. Le cycle des saisons semble coïncider avec l'année. On identifie un point précis par exemple, le moment où le Soleil semble passer au point où l'équateur et l'écliptique se croisent, et que la déclinaison du Soleil passe de Sud à Nord. Ce point se nomme point d'Aries, du nom latin du Bélier (constellation où se trouvait le point lorsqu'il a été nommé).

À ce moment précis, la durée théorique de la journée égale celle de la nuit et ce moment se nomme équinoxe. Dans l'hémisphère nord, les journées continuent à allonger et la température devient clémente. C'est l'équinoxe du printemps.

Si on mesure l'année selon l'intervalle entre deux équinoxes du printemps, on note une petite différence entre cette année tropique (du grec *tropikos* = qui tourne) et l'année sidérale ou l'année anomalistique. C'est parce que la direction dans laquelle pointe l'axe de rotation de la Terre change. Il dessine un cône autour d'une droite qui pointe vers la constellation du Dragon. On peut voir la Terre comme une toupie dont l'axe de rotation vacille.

Pour l'instant (en 2003), l'axe de rotation de la Terre pointe vers l'étoile au bout de la queue de la constellation de la Petite Ourse, mais en 2900 av J.-C., l'axe pointait vers l'étoile la plus brillante du Dragon (Thuban); dans un avenir assez lointain, ce sera Aldéramine qui servira d'étoile polaire, puis Véga.

L'axe de rotation de la Terre trace, autour d'un point dans la constellation du Dragon (le pôle de l'écliptique), un cercle qui a un rayon de 23,439 3 degrés. L'axe met environ 25 800 ans à compléter ce cercle. Si la projection du pôle se déplace sur la sphère céleste, alors la projection de l'équateur bouge aussi, ce qui entraîne un déplacement, le long de l'écliptique, des points où l'équateur et l'écliptique se croisent. Le point d'Aries, qui sert à déterminer l'équinoxe du printemps, recule de 50,29 secondes d'arc par année.

La vraie année, l'année tropique

L'année tropique est plus courte que l'année sidérale (d'environ 20 minutes) et vaut 365,242 190^{J}. Lorsque *l'Observer's Handbook* mesure en années (symbole **a**), c'est de l'année tropique qu'il s'agit. C'est la plus utile car elle est synchronisée au rythme des saisons qui doivent leur existence à l'inclinaison de l'axe de rotation de la Terre. On l'appelle aussi année solaire, année des saisons et souvent, simplement année.

Les années de calendrier

Il serait compliqué d'avoir un calendrier dont l'année mesure exactement 365,242190^{J}. Par exemple, si on fête le Nouvel An à minuit, l'année suivante il faudra fêter à $5^{h}48^{m}45{,}2^{s}$ du matin.

La solution la plus simple est d'adopter des années avec des nombres entiers de journées et où le nombre de journées est choisi de façon à ce que la durée moyenne soit le plus proche possible de 365,242 190^{J}.

Le calendrier julien

Le calendrier julien nous a été légué par Jules César, empereur romain, qui l'a lui-même emprunté aux Égyptiens. Il a été réformé par Auguste, petit-neveu de Jules, qui a précisé le cycle de 4 ans des années bissextiles et pour qui on a nommé le mois d'août (pour lequel on a volé une journée à février alors dernier mois de l'année). Chaque année compte 365 journées sauf si l'année est divisible par 4 auquel cas l'année en compte 366. Ce rythme donne une moyenne de 365,25^{J}.

Le calendrier grégorien

La différence entre le calendrier julien et l'année tropique est de 0,007 81 journée par année, donc de huit journées par millénaire. Vers le 4^{e} siècle, un pape avait déclaré que le printemps devait débuter le 21 mars. Au 16^{e} siècle, la différence est de 10 jours (le printemps commence le 11 mars) et le pape Grégoire XIII émet un édit qui fait disparaître dix journées du calendrier de l'an 1582. Cela n'a pas été facile à faire avaler par tous et certains pays n'ont changé qu'au 20^{e} siècle. Même aujourd'hui, certains calendriers fêtent Noël alors que nous sommes le 7 janvier.

Le calendrier grégorien a des années de 365 journées, plus une année bissextile (de 366^{J}) si l'année est divisible par 4 sauf si l'année est divisible par 100 mais pas par 400. En résumé, 97 années bissextiles par 400 ans, pour une moyenne de 365,242 5^{J}.

La Lune et les mois

Jusqu'à maintenant, notre univers imaginaire n'avait que des masses qui tournent autour du Soleil. Une de ces masses (la Terre) a la forme presque sphérique d'un ellipsoïde aplati aux pôles.

On ajoute une masse (la Lune) qui est en orbite autour de la Terre et on regarde ce qui arrive. Juste pour compliquer un peu plus les choses, l'orbite de la Lune n'est pas au dessus de l'équateur de la Terre, mais plus près de l'écliptique. C'est comme si la paire (Terre et Lune) formait une double planète. Le plan de l'orbite lunaire fait un angle d'environ 5 degrés avec l'écliptique.

Le mois synodique

Les terriens remarquent que la Lune présente des aspects différents (des phases) selon un cycle d'environ 29 jours. Ce cycle prend le nom de mois. Il existe, quelque part dans les langues proto-indo-européennes, un lien direct entre le mot Lune et le mot Mois. Ce lien demeure apparent dans certaines langues (comme en anglais : *Moon* et *Month*).

On prend la moyenne de la durée entre les retours successifs d'une phase: c'est le mois synodique. Plusieurs peuples ont suivi et certains suivent toujours un calendrier lunaire où le premier jour du mois est annoncé par des prêtres selon un rite officiel (déterminé par un *synode*). Dans plusieurs cas, le mois commence avec l'apparition du premier croissant de Lune. La durée du mois synodique est en moyenne de 29,530 589^{J}.

Le mois sidéral

Il est facile de déterminer la période de rotation de la Lune selon sa position relative aux étoiles fixes. Il suffit de compter le temps entre deux passages successifs de la lune devant (ou en ligne avec) une étoile donnée. Le mois sidéral ainsi déterminé mesure en moyenne 27,321 662^{J}.

La différence semble grande. C'est qu'en un mois sidéral, la Terre a parcouru presque un douzième de son orbite autour du Soleil. Par conséquent, au moment où la Lune revient vis-à-vis la même étoile, le Soleil s'est apparemment déplacé d'un douzième d'orbite (et un douzième de 27^{J} vaut environ 2,2^{J}).

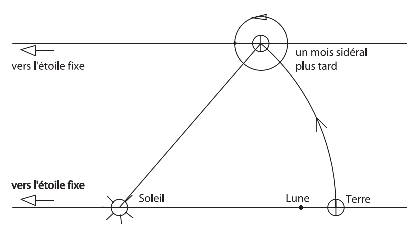


Figure 3 — Après un mois sidéral, la Lune n'a pas complété son mois synodique.

Le mois anomalistique

L'orbite de la Lune est aussi une ellipse. Il y a donc un point de l'orbite qui est le plus près de la Terre (périgée, de *Gaia* ou *Gê*, divinité de la Terre chez les Grecs), et un point de l'orbite au plus loin (apogée). La ligne qui relie ces deux points en passant par les points focaux est le grand axe de l'orbite lunaire.

Puisque la Lune et la Terre ne sont pas les deux seules masses de l'univers, l'ellipse est perturbée. Le grand axe de l'orbite lunaire tourne sur lui-même une fois en 8,776 ans (dans le même sens que la Lune tourne sur son orbite). Si la mesure d'un mois commence au passage de la Lune au périgée, alors un mois sidéral plus tard, il reste encore 1/117 de mois sidéral pour rattraper le périgée.

Le mois anomalistique dure, en moyenne 27,554 550^{J}.

L'ellipse et ses anomalies

À cause de la proximité de la Lune, les effets de l'anomalie (due à l'ellipse) sont très visibles. C'est pourquoi il nous faut préciser, en parlant de nos mesures, que ce sont des durées moyennes. Il est très rare qu'un vrai mois (par exemple, de Nouvelle Lune à Nouvelle Lune) dure exactement 29,530 589^{J}, la durée moyenne du mois synodique.

Par exemple, *l'Observer's Handbook 2003* (pages 83 et 85) nous apprend que la Nouvelle Lune d'avril a lieu le premier avril à 19h19 (TU) alors que la suivante, en mai, a lieu le premier mai à 12h15 (TU). La durée du mois synodique d'avril est 29^{J} 16^{h} 56^{m} (29,71^{J}). *L'Observer's Handbook* donne l'heure en Temps Universel (TU), dont l'ancêtre est l'heure moyenne de Greenwich. On en reparle plus loin (dans les suggestions d'exercices).

Le mois synodique suivant se termine le 31 mai à 4h20 (TU) et dure 29^{J} 16^{h} 5^{m} (29,67^{J}).

Des anomalies aux anomalies?

Le mois anomalistique est sujet à des écarts de même ordre. En plus, à cause de la complexité des perturbations, la forme même de l'ellipse est affectée. Si on regarde la distance du centre de la Terre au centre de la Lune lors du périgée, celle-ci ne changerait pas si la Terre et la Lune étaient les deux seules masses de l'univers et si leurs formes étaient très régulières. En réalité, la distance change à chaque passage au périgée: 357 157 km le 17 avril vers 5h (TU); 357 449 km le 15 mai vers 16h (TU).

La forme même de l'orbite lunaire se comporte comme un objet soumis à un effet de marée solaire. Lorsque le grand axe de l'orbite lunaire est pointé vers le Soleil, la différence entre le périgée et l'apogée est à son maximum. Lorsque l'axe est pointé à 90 degrés du soleil, la différence est à son minimum. C'est comme si l'orbite elle-même était un objet soumis à l'effet de marée du Soleil. On en reparle à la fin de l'article.

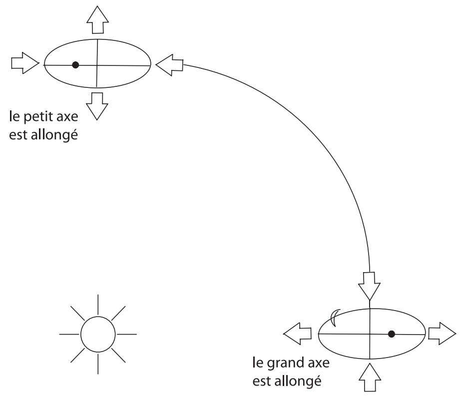


Figure 4 — L'effet de marée du Soleil sur l'orbite lunaire

Puisque l'orbite de la Terre autour du Soleil est aussi une ellipse, perturbée par les autres corps du système solaire, elle subit des anomalies de même nature. En plus, lorsqu'on détermine la distance entre la Terre et le Soleil au périhélie, il faut tenir compte de la position de la Lune, car c'est le centre de gravité du système Terre-Lune qui suit l'orbite elliptique autour du Soleil. Par exemple, si le périhélie survient à la Nouvelle Lune, alors la Terre sera un peu plus loin du Soleil. Si c'est à la pleine Lune, alors la Terre sera un peu plus près du Soleil.

Le mois tropique

Le point d'Aries qui détermine l'année tropique (de la Terre) recule de 50,29 secondes d'arc par année le long de l'écliptique. Donc, en un mois, il recule d'environ 4 secondes d'arc. La position relative des astres est donnée selon des coordonnées (ascension droite et déclinaison) mesurées à partir de ce point.

L'idée d'un mois tropique était peu utile lorsqu'on utilisait des cartes célestes dont les coordonnées étaient fixées à une époque précise. Mais, grâce aux ordinateurs, il est maintenant possible d'utiliser des coordonnées célestes constamment révisées pour tenir compte de la précession du point d'Aries.

Si on mesure la durée de passages successifs de la Lune devant le point d'Aries, le mois tropique dure en moyenne 27,321 582^{J}, une différence de sept secondes (de temps) avec le mois sidéral.

Le mois draconique

L'orbite de la Lune ne coïncide pas parfaitement avec l'écliptique. Donc, le cercle qui définit l'orbite lunaire sur la sphère céleste coupe l'écliptique en deux endroits. Ces points se nomment nœuds. Il y a un nœud ascendant (où la Lune traverse de sud à nord) et un nœud descendant.

L'orbite lunaire peut être vu comme un objet doué d'une très forte inertie de rotation. La masse de la Lune est moindre que celle de la Terre mais le rayon autour duquel elle tourne est immense. Nous pouvons considérer la Lune sur son orbite (ou l'orbite lui-même) comme un gyroscope.

Puisque l'orbite de la Lune ne coïncide pas avec l'écliptique, alors la gravité du Soleil va essayer de redresser l'orbite, mais l'effet gyroscopique fera vaciller l'orbite sans en changer l'inclinaison. Par conséquent, les nœuds vont reculer autour de l'écliptique et feront un tour complet en environ 18,69 ans.

Puisque les noeuds reculent, la Lune les rattrape plus vite; le mois draconique est donc plus court que le mois sidéral. Le mois draconique moyen dure 27,212 221^{J}.

La position des nœuds est importante pour la prédiction des éclipses. En effet, puisque l'orbite lunaire et l'écliptique ne coïncident pas, nous n'avons pas d'éclipse solaire à chaque Nouvelle Lune. Pour qu'il y ait éclipse solaire, il faut que la Nouvelle Lune survienne très près d'un nœud.

L'année solaire et l'année lunaire

L'année la plus utile aux habitants de la Terre est celle qui correspond au cycle des saisons. C'est pourquoi la vraie année est l'année tropique (l'année solaire, l'année des saisons) de 365,242 19^{J}. Le calendrier grégorien (97 années bissextiles par 400 ans) vaut 365,242 5^{J}, ce qui est mieux que l'ancien calendrier julien de 365,25^{j}.

Le mois le plus utile est celui qui correspond aux phases lunaires. C'est le mois synodique de 29,530 589^{j}. Certains peuples utilisent un calendrier lunaire synodique. Les musulmans utilisent un calendrier où l'année dure 12 mois lunaires; donc leur année ne dure que 354,367^{j}. On peut observer le retour plus rapide des années de ce calendrier en notant que le Ramadan (9^{e} mois) revient un peu plus tôt par rapport au calendrier grégorien.

D'autres peuples utilisent un calendrier lunaire où certaines années ont douze mois alors que d'autres en ont treize, selon un cycle visant à garder le calendrier lunaire assez près du calendrier des saisons.

Les journées

La journée

La journée la plus utile pour le terrien moyen est celle qui marque le cycle des levers et couchers de soleil. Si on prend l'intervalle moyen entre les passages successifs du Soleil au méridien, on obtient la durée de base, celle qui a été divisée en 24 heures de 60 minutes, chacune de 60 secondes.

Lors de la redéfinition de la seconde en 1967, on a voulu que la " vraie " journée dure exactement 86 400 secondes. Dans *l'Observer's Handbook 2003*, on note une différence de 0,001 s entre la journée officielle et **la** journée solaire moyenne.

La journée sidérale et la rotation de la Terre

Jusqu'ici, le mot sidéral indiquait une période basée sur les étoiles dites fixes, alors que le mot tropique basait une période sur le point d'Aries.

Depuis 1971 (et peut-être avant), *l'Observer's Handbook* définit la journée sidérale comme l'intervalle moyen entre deux passages au méridien du point d'Aries. Depuis l'édition de 1982, on donne une valeur pour une journée sidérale (86 164,092^{s}) et une valeur pour la durée de la rotation terrestre (86 164,1^{s}) en relation avec les étoiles fixes.

On remarque que la différence est infime (huit millièmes de seconde par journée). En fait, il faudra 25 800 années (la période de précession des équinoxes) pour que la différence accumulée donne une journée complète.

Pour faire certains calculs avec un excès de précision (par exemple, pour calculer la vitesse d'un observateur entraîné par la rotation terrestre), il faut utiliser la rotation dont la journée mesure 86 164,1 secondes.

La rotation *versus* La journée

Si la rotation est la vraie période de la Terre, pourquoi est-elle différente de **la** journée? On suppose qu'une étoile et le Soleil passent simultanément au méridien. On part le chrono. Après 86 164 secondes, l'étoile revient au méridien. Où est le Soleil? En une journée, son mouvement apparent, le long de l'écliptique, est de 1/365 de cercle (presque un degré) et il faudra dont 1/365 de journée (environ 236 secondes) pour qu'il passe à son tour au méridien. C'est de là que vient la différence.

Suggestions d'exercices

Pour mieux visualiser ces phénomènes orbitaux, on peut mesurer des intervalles entre le retour de certains phénomènes. C'est ainsi que s'est développée l'astronomie. Le mieux serait de faire ses propres observations et de noter soigneusement ses résultats.

Par exemple, on peut mesurer des mois sidéraux en observant le temps que prend la lune pour revenir en ligne avec une même étoile. En prenant un grand nombre d'étoiles réparties autour de l'écliptique, on peut augmenter le nombre de valeurs afin de calculer une moyenne plus précise.

Pour pratiquer, on peut mesurer les intervalles indiqués dans *l'Observer's Handbook*. On note d'abord que *l'Observer's Handbook* donne l'heure en Temps Universel (TU), dont l'ancêtre est l'heure moyenne de Greenwich. Pour le fuseau horaire de l'est (le Québec et presque tout l'Ontario), il faut soustraire 5 heures au TU pour trouver l'heure normale de l'est. En été, là où on observe l'heure avancée, il faudra alors soustraire 4 heures au TU pour trouver l'heure avancée de l'est. Ne pas oublier d'ajuster la date.

Par exemple, à la page 87, on lit que Mercure sera très près de Vénus à 2h (TU) le samedi 21 juin 2003. Si on soustrait quatre heures, on se retrouve le vendredi 20 juin à 22h (heure avancée de l'est). Pour les observateurs en Colombie Britannique, il faudra soustraire 7 heures au TU: la conjonction a lieu le 20 juin à 19h, heure avancée du Pacifique.

En avril (page 83), on note que la Pleine Lune et le périgée coïncident (presque). Au moment de la Pleine Lune, la droite qui passe par la Terre et la Lune passe aussi par le Soleil. Au moment du périgée, la Lune est directement sur le grand axe de l'ellipse de son orbite. Donc, en avril 2003, le grand axe de l'orbite lunaire est pointé vers le Soleil. Puisque l'effet du soleil est d'allonger l'orbite dans le sens qui est orienté vers le Soleil (voir figure 4), alors on devrait observer que la longueur du grand axe (distance du périgée PLUS distance de l'apogée) est à son maximum relatif.

En août (page 91), c'est le dernier quartier et l'apogée qui coïncident presque. Le grand axe pointe à 90 degrés du soleil et sa longueur devrait être à son minimum relatif. On peut ainsi mesurer l'effet de marée du Soleil sur l'orbite lunaire.

On peut comparer la durée moyenne des mois synodiques, obtenue en mesurant l'intervalle entre deux nouvelles lunes avec celle obtenue entre deux pleines lunes. On peut faire de même avec les mois anomalistiques.

C'est en feuilletant *l'Observer's Handbook* qu'on y découvre les trésors. Au cours des mois à venir, d'autres articles permettront de se familiariser avec les données qu'il contient et de les utiliser dans un cadre astronomique élargi.

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Summary

The *Observer's Handbook* of the RASC is a very useful tool for any amateur astronomer. However, it can appear daunting for non-English speakers. Sometimes, subtle differences between qualifiers can change the meaning of otherwise simple words.

We instinctively know what are days, months, and years. Until one talks of tropical, anomalistic, draconic, sidereal... What mechanisms are behind these words? Much of the information in this article is found, in essence, throughout the *Observer's Handbook*, although not in the same format (e.g. in 2003, pp. 29, 35-39, 42).

Exercises encourage the use of the *Observer's Handbook* to bring life to the definitions. For example, one can measure time intervals between New Moons throughout the year to see how far the real synodic month varies from its mean value of 29.530 589 d.

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Nocturnal Musings Concerning a Winged Horse

by Philip Mozel, Toronto Centre (phil.n.mozel@attcanada.net)

Introduction

Pegasus: the very name conjures up visions of a magnificent winged beast soaring effortlessly through the sky. Yet, when we look at the corresponding constellation, we see an upside-down horse chopped in half. Why should this configuration be so?

Explanations for the existence of half a horse are easy enough to come by and can be sought in the name Pegasus itself. According to some sources, Pegasus may trace its lineage back to Phoenician times. The name may then be derived from the Phoenician *pag* and *sus*, the "bridled horse" used for a ship's figurehead. In this case the constellation is to be seen in a nautical context and only half a horse is required (Olcott 1911).

Other meanings for the name have been suggested, however, and include "springs" or "waters," from the Greek *pegai*. In this case, we are to picture the forepart of the horse as the animal is born from the sea. Euripides suggested Pegasus was Hippe, daughter of the centaur Chiron. Artemis turned her into a horse and hid her hindquarters so that her father would not discover her pregnancy. Alternately, perhaps we are simply to imagine Pegasus emerging from a cloud (Allen 1963; Bernal 1991; Condos 1997; Liddell & Scott 1940; Ridpath 1988; West 1988; Yalouris 1977).

In many of these associations the horse is linked with water. Its location in the sky is therefore appropriate since it resides near such "watery" constellations as Pisces, Cetus, Aquarius, and Delphinus. The ancients called this part of the sky "the sea" since it was here that the Sun resided during the rainy season in the Middle East (Lovi 1979; Lum 1948; Olcott 1911).

Yet the larger mystery is Pegasus' strange posture. Perhaps the inverted position fits the available stars better, but this explanation seems unlikely. After all, few, if any, of the constellations actually resemble what their names imply. Indeed, the suggestion has even been made that Pegasus *was* erect in the distant past but an error by an anonymous ancient astronomer resulted in its inversion (Hartner 1969; Plunkett 1903).

Precession might be the culprit, and for this explanation there is precedent. Hercules is currently standing on his head but in the past was upright. The wobble of the Earth's axis is responsible for shifting the heavens sufficiently to turn this constellation over. However, Pegasus' more southerly position means that at no time during the 26,000 year precessional cycle does the constellation appear erect for mid-northern viewers. There are other possibilities, though, and these may be investigated by exploring the labyrinth of ancient myth, religion, and astronomy.

The Pegasus Myth

No other creature of Greek myth was ever accorded such divine origins as the horse. The winged horse is perhaps the greatest and most noble of all ancient mythical creations.

As generally related, Pegasus' fabled birth occurred when the hero Perseus lopped off the head of the gorgon Medusa, whose face was so repulsive onlookers were turned to stone. From Medusa's body immediately sprang the warrior Chrysaor armed with a golden sword, and Pegasus. Both were conceived from an earlier union between Medusa and Poseidon, god of the sea and of horses. Perseus and Pegasus quickly went their separate ways, but before long the winged steed became associated with another Greek champion: Bellerophon.

Bellerophon, being a son of Poseidon from another relationship, was also half-brother to Pegasus. Together they battled the fire-breathing chimaera, a patchwork monster part lion, goat, and snake. The goddess Athena, who equipped Bellerophon with the first bridle with which to tame the wild Pegasus, provided essential help in this struggle.

After other great deeds, Bellerophon became so arrogant that he attempted to ride Pegasus to Olympus, the realm of the gods. Outraged at this insolence, Zeus sent a fly to sting the horse's belly, causing it to buck and throw Bellerophon back to Earth. Pegasus continued to the heavens alone and became the bearer of thunder and lightning for Zeus (West 1988; Graves 1960; Gregory 1958; Proctor 1972).

This myth, like others, is open to several interpretations. For example, Medusa's demise may depict a raging storm with the gorgon as cloud, Chrysaor as lightning, and Pegasus' hoofbeats as thunder. The powerful symbolism of the winged horse has also come to epitomize speed and wisdom, the gods' wrath, soaring inspiration, water, fertility, and the leaping, white-maned waves lashed to a fury as they draw Poseidon through the sea. Bridling the horse represents nature's subjugation by humanity.

Figure 1 – Bellerophon astride a winged horse. The halo around his head links Bellerophon to Helios, the Sun god. Drawing by Bill Ireland after a south Italian wine-mixing vessel, ca 420 BCE.

Perseus and Bellerophon have also been interpreted as solar heroes (Figure 1). Perhaps they stand for the Sun in its daily or annual journey (Olcott 1914; Cox 1883) with the birth of Pegasus representing sunrise and the fall of Bellerophon representing sunset. The slaying of a monstrous being then represents the victory of light and warmth over darkness and winter or perhaps the starry night that is doomed to perish with the dawn (Cirlot 1988; Roscher 1965; Yalouris 1977). This solar theme will be explored later.

While Greek myth provides us with our most familiar picture of Pegasus, the idea of a winged horse was already old by Greek times. Art from more ancient lands to the east commonly depicted a number of animals bearing wings, the horse among them (Figure 2). Greece readily accepted this motif as evidenced in works from early times (Figure 3) and throughout its history (Figures 4 and 5; Malten 1925; Roscher 1965; Yalouris 1977).

Figure 2 – Winged horse. Drawing by Bill Ireland after a Hittite seal, ca. 13th to 8th century BCE. On the reverse are the signs for *Sun god* and the name *Pikku*.

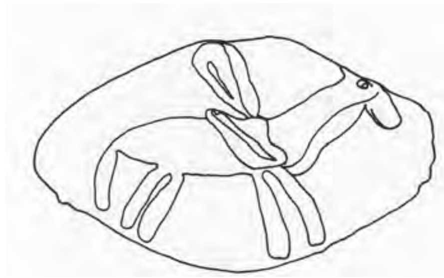

Figure 3 – Winged horse. Drawing by Bill Ireland after a seal from the sanctuary of Hera Limenia near Corinth. Mycenaean period. This may be the earliest known depiction of the winged horse on Greek territory.

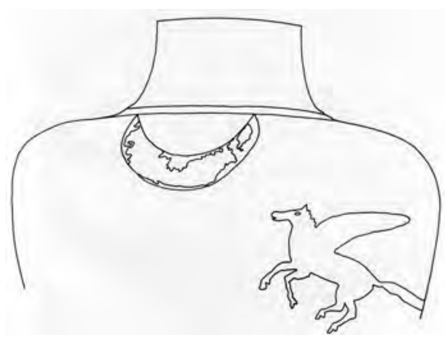

Figure 4 – Pegasus flying to a crescent Moon. Drawing by Bill Ireland after a Greek water jar, ca 425 BCE.

The first specific reference to *Pegasus* in Greek literature is found in the eighth- or seventh-century BCE book of myths *Theogeny*, by Hesiod. (Curiously, at about this same time, Homer, while relating the myth of Bellerophon in the *Iliad*, makes no mention of a flying horse (Lattimore 1951)). By the time Greek civilization reached its zenith, the myth of Pegasus was well known and had been incorporated into poetry, prose, and theatrical productions, where it was often used as a vehicle for social commentary.

Nowhere in Greece, however, was Pegasus more popular than in Corinth.

Figure 5 – Pegasus. Drawing by Bill Ireland after an oil flask found at Athens. This may represent the constellation or simply Pegasus emerging from the sea. Last quarter of the 5th century BCE.

This city-state laid claim to Bellerophon as a local hero and, from the earliest days of coinage, depicted the winged horse and its rider on local currency (Figure 6). Due to its role as an international trading port, Corinth also acted as a conduit through which the concept of the winged horse passed from the east to the west (Yalouris 1977).

Figures 6a & 6b – Silver stater of Corinth. A complete Pegasus is depicted on the obverse but a demi-horse is depicted with Athena on the reverse. 4th century BCE. Courtesy of the Royal Ontario Museum.

The Horse in the Sky

Long before any Greek references to a horse in the sky, older civilizations were using some of the same stars to form other images. In ancient Sumeria, for example, sometime before 1000 BCE, the Pegasus square seems to have been known as *Iku*, the standard measure of a field (Gleadow 1968; Hartner 1969; Santillana and von Dechend 1969; van der Waerden). Incised squares on Babylonian seals have sometimes been seen to represent this ancient constellation. Intriguingly, some of these seals also bear the likeness of an inverted animal (horse?) on what may be an altar (Figure 7).

Figure 7 – Mesopotamian seal depicting an animal (a horse?) on an altar with what some interpret as the Great Square of Pegasus above (Amiet 1961).

Many of the Babylonian constellations can be shown to have been incorporated into the later Greek sky, but Iku seems, at first glance, not to have been one of them. Yet sometime between 1000 BCE and classical Greek times the celestial horse was brought into being, perhaps because of a simple failure of communication. It has been suggested that Iku may be a mistranslation into the similar sounding, indogermanic *ekuos* and thence into Greek as *ikkos* and *hippos*. All three terms mean *horse* (Hartner 1969). A Persian pot of the first millennium BCE has been interpreted by some as actually representing this transition. Allegedly, both the Pegasus square (*i.e.*, iku) and a putative horse are shown together (Figure 8).

The earliest known Greek reference to the *constellation* comes from the third century BCE poem *Phenomena* by Aratus (this work was based on the previous

Figure 8. – Persian spouted pot with checkerboard and quadruped. Some see this as a representation of the transition of the Pegasus square (*i.e.* Iku) from a field to a horse (despite the apparent horns). 800-100 BCE. Courtesy of the Nelson-Atkins Museum of Art.

century's prose work of the same name by Eudoxus, which no longer exists). The poem describes each of the then-recognized constellations and, while mentioning certain elements of what was to become the Pegasus myth, refers to the constellation itself only as *Ippos*, The Horse (Mair 1921; Olcott 1911).

In the *Catasterisms* (Condos 1997; Robert 1963), sometimes ascribed to Aratus's younger contemporary Eratosthenes, we find for the first time a catalogue of constellations specifically containing the name Pegasus. This designation did not immediately achieve wide popularity, however, and for several centuries to come the horse in the sky remained essentially nameless.

This situation changed by the very early years of the first century CE when a Roman nobleman, Germanicus, wrote a Latin version of Aratus' work. One significant alteration was his use of our currently accepted name for the constellation (Gain 1976; Roscher 1965). Only from this time, then, did the celestial horse become widely known as Pegasus.

We see now that a marriage has taken place. An existing star pattern was wedded to a widely known myth, and the great winged horse we know today was born.

The Horse in Religion

Early fascination with the horse extended beyond the constellation. The animal became a highly prized possession, a status symbol, and eventually a manifestation of the gods on Earth (Nichols). As depicted in everything from stone-age cave paintings to classical art, the horse has figured prominently in religion. Specifically, many cultures perceived the horse as providing the motive power for the Sun's daily journey across the sky (Figure 9). The Greeks, for example, often depicted Helios and Apollo this way (Frazer 1966; Howey 1923; Olcott 1914; Yalouris 1977).

Figure 9. – The Trundholm Sun Chariot. A wheeled horse draws a gold-plated bronze disk: the Sun. Danish ca. 13th century BCE. Courtesy of the Danish National Museum.

It became clear from even the earliest times that the Sun's motion also included an annual component: its noontime elevation varied from a summer high, when the horses were fresh, to a winter low, when they grew weary. To prevent the Sun disappearing entirely, horses were often sacrificed, thereby releasing their spirit to rejuvenate the Sun's failing steed. Horse offerings were in fact made by many cultures around the world (Howey 1923). For example, the *Rigveda* (an ancient Hindu book of hymns) contains references to rites in which the horse is not considered to be killed but merely "conveyed" to the gods. The victim was also regarded as the symbol of the heavens, the counterpart of Pegasus (Griffith 1963; Olcott 1911).

In Greece, Spartans annually sacrificed horses on the peak of Mount Taygeta, behind which they saw the Sun set; the people of Rhodes hurled a chariot and four horses into Poseidon's realm, the sea (Burkert 1979; Frazer 1966; Levi 1971; MacCulloch 1964). The latter act was certainly intended to placate the god, creator of the horse. But perhaps the fact that Poseidon's watery domain daily accepted the setting Sun, and provided the avenue for its return to the east, figured in as well; in some mythological traditions, the setting Sun is returned to its starting point via an underground sea on a horse-powered ship (in which case Pegasus would be upright). Horse and ship are therefore linked in the daily solar cycle (Gelling and Davidson 1969; Hawkes 1962; Olcott 1914).

This widespread association of horse and Sun leads us to conjecture whether the constellation itself ever bore a special relationship with the Sun in the distant past.

Pegasus and the Sun

Through the ages the Sun has been known to occupy specific constellations each season. Due to precession, however, these positions have slowly changed with the millennia. One effect of this motion is that, over the centuries, different star patterns were to be seen low in the east just before dawn or low in the west just after sunset. For example, someone watching an early winter dawn around 4000 BCE would see Pegasus suspended above the brightening eastern horizon (Hartner 1965, 1969; Santillana and von Dechend 1969). Is it conceivable that the constellation, seen in such close proximity to the blazing Sun, was perceived as a fiery, celestial sacrifice (Reiche 1991)? Unfortunately, horses were not then known in those near-Mediterranean civilizations likely to have originated, or transmitted knowledge of, our constellations (Bernall 1991). Donkeys *were* available, but the idea that Pegasus began as one of these, while possible, is not very alluring!

A more likely period is the late third and early second millennium BCE. By this time precession had twisted the sky so that Pegasus was seen hanging above the *setting* point of the winter solstice Sun suggesting again, perhaps, a sacrifice. What better way to refresh the Sun's fatigued horses than by sacrificing a terrestrial counterpart (as possibly represented in the Babylonian seals)? Did seeing the stars of Pegasus above the altar of the setting Sun prompt early observers to conceive of the constellation as an inverted, sacrificial horse? Did the twilight glow of those long-vanished evenings correspond to flames consuming a holy offering? We may never know, but it is interesting to note that many writers place the establishment of our currently accepted "Greek" constellations at this time (Brown 1899; Ovenden 1966; Roy 1984). Pegasus may have been among them. Coincidentally, this very period saw the first widespread use, in Greece, of the animal admired above all others for its speed, grace, and strength: the horse (Campbell 1964).

Finally, there is a character in the Pegasus story that has received scant attention: the stinging fly responsible for Bellerophon's fall. Perhaps it is in the sky still, buzzing about, just a blur beside the winged horse's belly. Today, however, it is given another name: the Andromeda Galaxy. Known long before the introduction of the telescope, perhaps ancient naked eye observations of this deep-sky object were interpreted in terms of legend. Conceivably, such speculation may have begun the process that culminated in the creation of some of our early star patterns and associated myths. And perhaps it was simply this "insect," by causing Pegasus to rear over backward and throw Bellerophon, which was the ultimate cause of today's upside-down horse.

We will probably never know. This article has certainly only scratched the surface. But it is fun to speculate about those mysterious fossil patterns called constellations. And whatever Pegasus may have represented to ancient observers, it has at least one lesson to teach today: looking at connect-the-dot constellations is to observe the sky superficially. *Truly* seeing a star picture means looking into the minds of those early skywatchers who painted the heavens with their imaginations.

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The Astronomer's Spouse: *The Ultimate Accessory*

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This issue, we suspend the familiar light-hearted tone of *Reflections* to address a topic of deep import: the specification and acquisition of the astronomer's spouse (AS). Although an AS is a critical accessory for the amateur astronomer, it is surprising how little forethought goes into choosing one, in most cases. Astronomers who are particularly careful in all other aspects of their hobby can be surprisingly casual when it comes to this item. In fact, we often see astronomers acquiring an AS too soon, even *before* choosing their telescope or settling on an observing program. It is no use telling these misguided souls that they are flouting the principles of capability-based planning; it is simply too late for them. For those already in partnerships, this article is not for you. You may as well stop reading now. Lord help you. I believe there are various resources and self-help groups available for this condition. (You might be interested in the Web site `www.cloudynights.com/commentary.htm`, which has a section devoted to this.)

Already, I can hear objections: "Hold on! I am happily married already, and my spouse shares (or puts up with) my love of astronomy and the joy it has brought to our lives." To those fortunate couples, I say: You are truly blessed with a marriage made in heaven. Go forth and multiply.

The Benefits of Capability-Based Planning

My recent experience with planning and managing science in the Public Service (thankfully over) has exposed me to many project management tools and techniques. The Canadian Forces have adopted capability-based planning as their credo. Without much editing, it is possible to re-write their definition in astronomical terms:

> "To have a capability means to have the ability to act in a specific way in a specific situation. Capability-based planning is the process to determine the right blend of plans, people, equipment, and activity to optimize the capacity of the astronomer to fulfill his/her goals."

By planning ahead, you can avoid the following typical complaints:

- "Cheryl says I can't buy another eyepiece until we get winter boots for the kids." [What's wrong with lining their old boots with newspaper?]
- "My brother-in-law is getting married, but I don't want to miss the occultation of SAO 98128 by asteroid 74 Galatea." [Absolutely: a once-in-a-lifetime experience]
- "Jim can't understand why I would rather be out late in the dark with my nerdy astro buddies than at home watching the hockey game on TV." [Have you heard the one about the dog that howls every time the Leafs lose?]

With this introduction, I think the best approach is simply to lay out the specifications of the astronomer's spouse, with substantiation to follow...

Specifications for the Astronomer's Spouse

- No interest in astronomy herself (or himself)
- A homebody
- Has a well-paying job
- No shift work or travel
- Tolerant of late-night rambling
- Trusting
- Undemanding
- (For RASC members) willing to schedule summer vacation around the time of the RASC General Assembly, and in the location of the host city

Discussion

Let's examine these one at a time...

No interest in astronomy:

You have two choices here, between someone who shares your passion, and someone who could not care less. After careful reflection, weighing the pros and cons, I recommend the latter. This may seem surprising, but consider the following: if your spouse shares your interest in astronomy, things will get expensive. It is unlikely that you will follow the same observing program; hence, you will need different telescopes, eyepieces, accessories, *etc*. You will need a larger vehicle, or a larger (or multiple) observatory. Otherwise, there will be difficult compromises: Who stays at home with the children? Should we even have children? Can we pay the rent/mortgage/credit card this month? And so on.

Choosing the uninterested spouse offers so many more possibilities. Firstly, amateur astronomers are not all that numerous in society, so the pool of potential (uninterested) spouses is much larger. The uninterested spouse will be only too happy to stay in while you are observing. (Just to be sure, you may as well specify that the spouse be a *homebody*.) He/she is unlikely to have a hobby that empties the bank account as quickly as you do, which may not be a problem if he/she has…

A well-paying job:

Unless you are independently wealthy, you cannot feed the amateur astronomer's addiction on a single income and live comfortably at the same time. Even if the primary income covers the essentials (telescopes, solar eclipse trips, *Sky & Telescope* subscription), one needs the second income for the things that make life tolerable (a roof over the head, groceries, clothes, beer). Therefore, the astronomer's spouse needs a good job with a steady, generous income; however, there should be no *shiftwork* or *travel* involved, for obvious reasons. An indeterminate 9–5 job with the Government of Canada would be ideal.

Tolerant of late-night rambling:

It is imperative that the AS be capable of accepting the following statement and its variants without flinching: "Goodnight, dear! I am going out now, don't wait up…not sure when I'll be back." I can think of several activities that this statement could precede. One of them is amateur astronomy. Say no more.

Trusting:

For a start, see *Tolerant of late night rambling*, above. A trusting spouse is essential if the finances are jointly managed.

Undemanding:

The benefit of a well-off, tolerant, and trusting spouse who is uninterested in astronomy and loves to stay home is totally wasted if he/she drains the family coffers to a similar extent or places equal demands on family time and scheduling. This simply will not do. You are looking for the spouse who (for example) at Christmas and birthdays says, "You don't need to get me anything," and *actually means it*. Other promising utterances are "Go ahead, you can have the car tonight," or " The lawn can wait," or "We don't need to paint this year." You get the picture.

Vacation planning:

See *Undemanding*, above. Be patriotic: visit Canada first, by visiting the GA cities in succession.

Conclusion

With appropriate planning, the choice of AS should not be too great a challenge. Even though the specifications seem restrictive, there is a wide latitude in choice, depending on how you weigh and balance the components to suit your individual requirements. For example, the spouse need not make a huge salary if he/she is particularly undemanding and willing to compensate by shouldering a reasonable burden of the domestic chores. The variations are endless. You sometimes even see tender moments between an astronomers and his/her AS: one fellow I know built his observatory just behind his house on the master bedroom side, so his wife could open the window and gently remind him to go to bed. (I didn't have the heart to tell him that he did not need a wife to do this; an alarm wrist watch would do.)

Whenever I have discussed this topic in the company of astronomers, I always find there is keen attention and lively discussion. These specifications are a living document: improvements are constantly being made. Let me know of your own experiences…I would love to hear from you.

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Probing the Atmospheres of Extra-solar Planets

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

The study of extra-solar planets has exploded since the planet orbiting 51 Peg was found in 1995 (see November 23, 1995 issue of *Nature*); over one hundred planets are now known, and astronomers are beginning to study their properties. Alfred Vidal-Madjar of the Institut d'Astrophysique de Paris and his collaborators have just found the extended upper atmosphere of the planet HD209458b (**see editor's note: Date to be added issue of** *Nature*), which appears to be a lot more extended than most astronomers had believed possible. The signature of the planetary atmosphere is imprinted in the star's spectrum during a transit of the planet across its parent star's disk. In a related discovery, Maciej Konacki of Caltech and his colleagues at Harvard have determined that another planet transits the face of its star (see January 30 issue of *Nature*).

A "transit" is the motion of a planet across the disk of its parent star; the last transit of Venus occurred on December 6, 1882 and the next will be on June 8, 2004. During the transit, Venus appears as a dark spot against the bright background of the Sun. Because it blocks some of the Sun's light, the Sun's apparent brightness decreases. Not very much, but a bit. Even before the first extra-solar planets were discovered, astronomers realized that there was a chance that we would be able to see the effect of a transit in another solar system. Although the stellar disk appears as only a point of light, the dimming due to a planet passing in front of the star will be measurable. In principle, this provides an alternative way to find new planets.

The "traditional" way extra-solar planets have been discovered is by measuring regular variations in the radial velocities of the parent stars. The star and its planet orbit their common centre of mass with the same period, so if you find a regular sinusoidal variation in the velocity, you have most probably found the signature of a planet. In the transit method, astronomers look for regular small dips in the apparent brightness of a star. But interpreting the results is trickier than with the radial velocity method. On the other hand, we could begin to study the planet's atmosphere.

As every amateur astronomer knows, many stars are variable. A lot of these vary in quite regular cycles, so it isn't enough to see a regular pattern of dimming to determine if there's a planet orbiting the star. The first transiting extra-solar planet — HD209458b — was confirmed to be doing just that only because the dimming was precisely coordinated with the phase of the orbit as determined by the radial velocity measurements. In other words, the light from the star dimmed only when the planet was due to be passing directly in front the star, according to the orbit from the radial velocity measurements. Also, we would expect only a small fraction of extra-solar planets to have their orbits so precisely aligned to our line of sight that the planet would transit. Even Venus does not transit very often! These problems meant that demonstrating that the transit technique could find planets is quite important.

It is now relatively easy to monitor the brightnesses of many stars all at once — several projects have been doing so for over ten years, to search for "gravitational lensing" from MACHOs (MAssive Compact Halo Objects). The first MACHOs were found in 1993 (see the October 14, 1993 issue of *Nature*).

One of these projects — the Optical Gravitational Lensing Experiment (or OGLE) — has recently spent part of its time looking for the signatures of planetary transits, and the group reported 59 candidates. (An additional 62 candidates have just been reported in a paper posted to the preprint server "astro-ph".) Konacki obtained radial velocity data for most of the 59 and found that for one of the stars — OGLE-TR-56 — the systematic dimming is coordinated with the phase of the orbit as determined by the radial velocities. OGLE-TR-56b is therefore the first planet discovered by the transit method, though of course it had to be confirmed by radial velocity measurements. It is now the second known transiting extra-solar planet.

Getting back to HD209458b, David Charbonneau of Caltech and his collaborators found the first signature of its atmosphere: absorption lines in the star's spectrum that were due to atomic sodium, and that appeared and disappeared in phase with its orbit. Solar-type stars have many absorption lines in their spectra, but these sodium lines were the only ones to come and go (see the *Astrophysical Journal*, volume 568, p 377; 2002). The spectral line was faint, and had to come from fairly deep in the planet's atmosphere (just to get enough sodium along the line of sight to produce a measurable line). Vidal-Madjar looked for absorption due to atomic hydrogen — probably the most abundant component of the planet's upper atmosphere. The line (Lyman alpha) is in the ultraviolet region of the spectrum, and therefore could only be detected using the Hubble Space Telescope. The line seems to come from hydrogen that appears to be escaping from the planet. Vidal-Madjar speculates that the planet could evolve faster than the star, ultimately coming to look more like Uranus or Neptune than its present Jupiter-like state.

This part of their result seems quite controversial, because most models of extra-solar planets have shown them to be remarkably stable — even when they are very close to their parent stars. The most straightforward way to explain the data would be to infer an atmosphere that is much more extended than was previously believed to be true. In fact, it is so extended that a portion of the atmosphere would lie beyond the Roche limit (the point where the star's gravity is stronger than the planet's), and would therefore be escaping from the planet.

It is possible that the current thinking is wrong, and the atmospheres of these close-in planets will be quite different than current thinking holds. Some work by Coustenis (reported in a conference proceeding) and Moutou (in *Astronomy & Astrophysics*, vol. 371, p 260; 2001) that is not well known had predicted Vidal-Madjar's result. It is clear that we have a lot more to learn about the atmospheres of planets that lie very close to their parent stars.

In just over seven years, we have gone from finding the first planets to probing their atmospheres. What a great time to be an astronomer!

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THE BRUDERHEIM METEORITE

Following the publication of a catalogue of Canadian meteorites in Meteor News some years ago (*Journal*, vol. 47, pp. 29, 92, 162; 1953) several additional objects found in Canada have been under investigation as suspected meteorites, but final conclusions concerning their nature have not yet been reached.

However, at 1:06 a.m. M.S.T. early Friday morning, March 4, 1960, a very brilliant fireball passed over southern Alberta, and this resulted in a shower of stony meteorites which were scattered over an area several miles across just north of Bruderheim, Alta. The centre of the area from which meteorites were collected is at latitude 53° 54´ N, longitude 112° 53´ W. The distribution of the stones was reminiscent of previous meteorite showers, such as the Homestead, Iowa, of 1875 or the Holbrook, Arizona, of 1912. The largest stones were all found at the eastern side of the fall area, indicating a general direction of fall from the west.

The Edmonton Centre of the Society, headed by Earl Milton of the meteor observation group, was active in the early stages of organizing the collection activity for this fall. Later, Professor R. E. Folinsbee, Head of the Department of Geology of the University of Alberta, Edmonton, took charge. The University has collected as many as possible of the Bruderheim stones, including most of the large members of this fall, and has made records of other specimens found, in an attempt to provide as complete a tally as possible of all the stones recovered. At last report somewhat over 500 lb. weight of stone meteorites had been weighted in. These ranged all the way from the 5 largest members, between 50 and 70 lb. each, down to small but completely encrusted fragments less than a fifth of an inch in diameter.

On a recent visit to Edmonton I was enabled to examine the Bruderheim stones, through the courtesy of the Department of Geology of the University of Alberta. I was impressed with the complete and well preserved character of the black fusion crust that covered the great majority of the specimens.

Professor Folinsbee and his staff are planning a detailed study of the circumstances of this meteorite fall, the largest of all Canadian meteorites whether find or fall. We will look forward with interest to hearing more about the Bruderheim in the future. It is fortunate that it occurred close to a centre population so that the recovery of the meteorites and the scientific study of the phenomenon are assumed.

by Peter M. Millman,
from *Journal*, Vol. 54, pp. 247-248, October, 1960.

THE MILLMAN FIREBALL ARCHIVE

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Abstract. The Millman Fireball Archive is a collection of 3876 report cards relating to 2129 visually-observed fireball meteors, seen from across Canada in the time interval 1962 to 1989. We provide an overview of the origin of the archive and present tables describing the monthly and yearly fireball numbers. We also present a selection of statistical results relating to fireball sounds (both sonic and simultaneous), finding that approximately one in fifteen of the observed fireball events was identified as producing some distinctive sound phenomenon. It is found that if sonic booms are associated with a given fireball event then some 12.8 ± 9.0 percent of the reports note the occurrence; if simultaneous sounds are associated with a fireball then 5.7 ± 1.8 percent of the reports acknowledge its detection. In addition, a comparison between the visually observed fireballs and the MORP camera survey results reveals that on average the visual observers recorded about one in five of the photographed fireball events. Finally, we find that a remarkably good, linear relationship exists between the average number of fireball events recorded per year and population density.

As oft along the still and pure serene,
At nightfall glides a sudden trail of fire,
Attracting with involuntary heed,
The eye to follow it, ere while it rest,
And seems some star that shifted place in heaven

Dante Alighieri,
The Divine Comedy, Il Paradiso, Canto XV

Résumé. L'archive Millman des bolides comprend une collection de 3876 rapports au sujet de 2129 bolides météoriques observés visuellement à travers le Canada durant une période allant de 1962 à 1989. Nous fournissons un aperçu de l'origine de l'archive et des tableaux auxquels sont décrits les nombres mensuels et annuels de ces bolides. Nous présentons aussi une sélection des résultats statistiques concernant les grondements (soniques et simultanés) de ces bolides, où nous trouvons qu'environ un sur quinze des cas des globes de feu sont accompagnés d'un son distinct. Nous constatons que si des bangs supersoniques sont associés à certains bolides, quelques 12,8 ± 9,0 pour cent des rapports notent le fait; si des grondements simultanés sont associés à des bolides, 5,7 ± 1,8 pour cent des rapports indiquent une détection de sons. De plus, une comparaison entre les bolides observés visuellement et les résultats de l'enquête de la caméra MORP révèle qu'en moyenne les observateurs visuels notent environ un sur cinq des bolides photographiés. Enfin, nous trouvons qu'une correlation linéaire remarquable existe entre le nombre moyen de bolides notés par année et la densité de la population.

Comme dans les cieux tranquilles et purs
glisse de temps à autres un feu soudain,
faisant mouvoir les yeux qui étaient immobiles,
et semble une étoile changeant de lieu,

Dante Alighieri
La Divine Comédie, Il Paradiso, Chant XV

1. Introduction

It is the unexpected brightness and rapid, transitory nature of fireballs that attracts eyewitness attention and makes them newsworthy events. Not only are the media interested in receiving accounts of fireball events, but so too is the astronomical community since a fireball possibly heralds the arrival of a new meteorite on Earth. Indeed, it is through this latter context that the compilation of fireball reports is of great scientific importance since it brings together multiple eyewitness accounts of a large meteoroid's passage through the Earth's atmosphere, and it potentially aids in the ground recovery of new meteorite samples. In Canada the Meteorites and Impacts Advisory Committee (MIAC) maintains a fireball reporting page at its internet Web site (`miac.uqac.ca/MIAC/fireball.htm`), and typically several reports are received per month from the public concerning bright meteors. Before the present MIAC fireball reporting Web page came into existence, however, the National Research Council (NRC), from the beginning of 1962 to the end of 1989, maintained an extensive and systematically collated catalogue of fireball report cards gathered from across the nation. The card set that constitutes the NRC fireball record, hereafter called the Millman Fireball Archive (MFA) in honour of Dr. Peter Millman[1], who oversaw its initiation, has recently been housed in Campion College at the University of Regina, and this article is a review and analysis of its contents.

2. Origins

The forerunner of the present day MIAC, the Associate Committee on Meteorites (ACOM), was formed as a direct result of the fall of the Bruderheim meteorite in Alberta on March 4, 1960 (Millman 1960; Millman 1962; Halliday *et al.* 1978). During the first ACOM meeting, Chaired by Dr. S.C. Robinson (of the then Dept. of Mines and Technical Surveys) on October 24, 1960, Millman outlined the essential purpose and duties of the committee[2]. The first two duties are described as follows:

(a) To arrange the establishment of a Canadian Centre to which all fireball and meteorite data would be reported;

(b) To prepare and circulate the necessary forms and instructions for the uniform recording of observational data on fireball and allied phenomena.

These two "principal" duties were, in fact, soon discharged by the committee, and the Meteor Centre at the NRC became the national fireball reporting centre[3], and designs for fireball report cards were being discussed and distributed at ACOM's second meeting[4] on May 5, 1961.

The minutes to the May 5, 1961 meeting of ACOM indicate that some considerable discussion had taken place as to how the committee might establish mechanisms for the enhanced gathering-in of fireball reports, and especially fireball reports from rural communities. In this respect it was soon realized that amateur astronomers, such as those attached to regional RASC Centres, could play a pivotal role in the acquisition of fireball data. Help was also sought from professional workers whose jobs required them to be outdoors at nighttime. Indeed, during the inaugural ACOM meeting in 1960 it was reported that formal discussions with the Royal Canadian Air Force had been initiated with respect to the forwarding of fireball sightings. Protocols for the reporting of fireball sightings were later established with the Royal Canadian Mounted Police and the Department of Transport[5].

The minutes to the April 27, 1962 ACOM meeting record that "30 fireball reports had come in to the Meteor Centre in the period October 1961 to April 26 [1962]. This was compared with a rate of 4 or 5 [fireball reports] per year before the establishment of the committee's reporting system." The minutes go on to further note that "the reports are being filed systematically for future study or reference." Clearly, the initial ACOM efforts were beginning to pay off, and by the April 19, 1963 meeting of the committee, Millman reported, "the Meteor Centre now had on file 287 reports on 119 fireballs."

Millman continued to present annual fireball reports to ACOM until 1987, at which time Ian Halliday (Herzberg Institute of Astrophysics, NRC) assumed charge of the reporting systems subcommittee. It seems generally clear from a "between the lines" reading of the ACOM minutes[2] that the NRC was beginning to struggle with the upkeep of the fireball reporting system from about the mid-1970s onward[6], its staff either being assigned to other duties or lacking in fireball investigation experience. Further, by the time of the October 26, 1990 ACOM meeting, Halliday observed that because of recent retirements, the entire Planetary Sciences Section at the NRC had "disappeared," and as such, he suggested that it was time to disband the reporting systems subcommittee. Indeed, the final card entry in the MFA is dated as being received on October 12, 1989.

Following its October 1991 meeting ACOM took on new terms of reference and became a subcommittee to the Canadian Space Agency (CSA). The new alignment of ACOM with the CSA resulted in the formation of MIAC. At the first MIAC meeting held on October 23, 1992, it was agreed that, while a fireball reporting subcommittee would no longer exist, a central fireball data bank would be maintained by Robert Hawkes (Mount Allison University). Regional MIAC and RASC representatives were then asked to forward fireball information to the central data bank (Hawkes & Lemay 1993).

3. General Overview

As indicated above, the MFA constitutes a series of fireball report cards systematically gathered from across Canada in the time interval January 1962 to October 1989. Reports were also received from observers in the United States during the same time interval, and several "historical" reports were received with respect to fireballs witnessed as far back as 1927. Prior to 1962 only a very few reports were catalogued. Two "historical" fireball reports are listed for 1950, five reports were catalogued during the years 1958 and 1959, two fireball reports were received in 1960, and nine were recorded in 1961. We note that over 275,000 visual meteor observations were collated and analyzed by the NRC meteor group between 1957 and 1986 as a result of studies begun during the International Geophysical Year (Millman 1956; 1986), but the data on those meteors are not contained in the MFA.

In our analysis we shall distinguish between reports and events. An "event" constitutes the observation of a particular fireball; the "reports" relate to the total number of cards received at the NRC concerning a particular event. During the 28 years over which records were kept, a total of 2129 fireball events constituting 3876 report cards were collated at the NRC Meteor Centre from observers located within Canada. Table 1 shows a breakdown of from where the various fireball reports were gathered. In the same 28-year interval, 410 reports on 351 events were received from U.S. observers. Three fireball report cards were received from Iceland, with single report cards being received from observers in Norway, Puerto Rico, and the Bahamas.

Table 1 indicates that the greatest number of fireball reports was received from observers in Ontario, with Quebec and British Columbia being the second and third most "active" regions. Saskatchewan observers produced the greatest average number of reports per event, with an average of 2.5 reports per event, while observers in British Columbia and Ontario were the next most "active" reporters with averages of 2.0 and 1.9 reports generated per event respectively. We find that the number of events reported by each of the Provinces and Territories correlates in a linear fashion with the population density (see column 4 of Table 1). Indeed, as one might well expect, it appears that the more people there are per square kilometre, the greater

Table 1.

Province / Territory	Events	Reports	Pop./km²
Yukon	37	54	0.04
British Columbia	248	501	2.76
Alberta	202	381	2.88
Saskatchewan	113	285	1.62
Manitoba	121	164	1.86
Ontario	623	1200	9.01
Quebec	299	517	4.59
Atlantic	268	382	4.36
North West Territories	78	93	0.01

Table 1 – MFA events and reports according to the geographical location of observers. The appellation "Atlantic" has been used in column one for the combined Atlantic Provinces of Newfoundland, Prince Edward Island, Nova Scotia and New Brunswick. The fourth column gives the population density in people per square kilometre as recorded in the 1976 national census. The 'Atlantic' population density is calculated according to the total population and total area of the Provinces included in its definition.

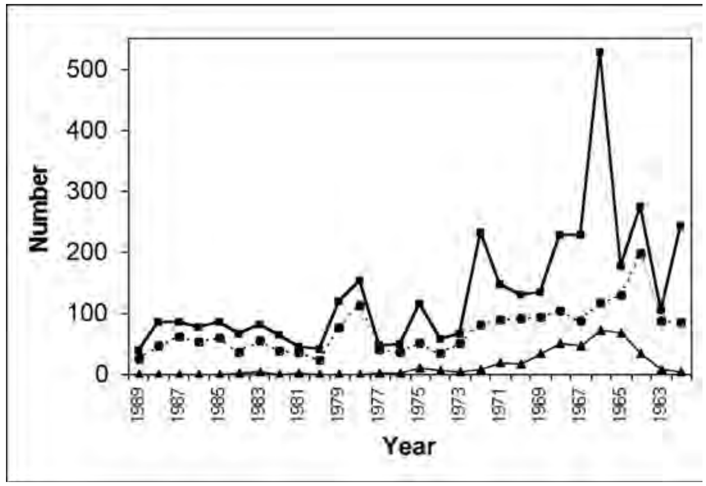

Figure 1 – Yearly variation in the number of fireball events witnessed by Canadian observers (dashed line with circles) and the number of reports received for those events (heavy solid line and squares). Also shown is the yearly number of reports received from U.S. observers (light solid line and triangles).

the number of fireball events observed and reported. A linear, least-squares fit between the average number of fireball events observed per year, E, and the population density (the number of people per square kilometre), P, yields the relationship $E = 2.46 \times P$, with a goodness of fit coefficient $r^2 = 0.974$. The population density data used in the derivation of the least squares fit to E were taken from 1976 Canadian census (Leacy 1983) — that year being about the midway point of the collecting time interval of the MFA. The good correlation found between the population density and the average number of fireballs reported is rather surprising and is interestingly much stronger than the correlations found to exist between the number of fireballs reported per year and the Provincial/Territorial populations and areas considered separately. Clearly, however, the relationship between population density and the number of fireballs reported must become non-linear at some stage and level off, there being a finite number of "actual" fireballs occurring in any given year. This turnover limit appears to have not been reached, however, at a population density of nine people per square kilometre.

The yearly variation in the total number of fireball events and reports observed in Canada is shown in Figure 1. There are several interesting trends discernible in Figure 1. We note, for example, that the average number of fireball events recorded per year in the first decade of the program (1962 to 1972) is 111.7 ± 32.0 events per year, while that in the last decade of the program (1979 to 1989) is 48.3 ± 12.6 events per year. The reasons for the decline in what might be called "reporting efficiency" in the last decade are no doubt complex but are possibly linked to diminishing NRC resources combined with a lower priority (*i.e.*, conflicts with other duties) for reporting events by the RCMP, the armed forces and Transport Canada[6]. The average number of reports per year was 74.2 ± 19.0 during that last decade of the program, compared to 224 ± 116.0 during the first decade of the program. This variation in the reports received suggests some additional reasons for the dramatic change in the "reporting efficiency", and these are outlined in Table 2. In "broad brush form," it would appear that the time period from 1962 to 1972 was "rich" in well-publicized meteorite falls and numerous, well-observed, very bright fireball events. And general experience indicates that the publicity surrounding a particularly noteworthy fireball will often spur eyewitnesses into submitting reports on previously seen but unrelated events – a process that feeds back into elevation of the historical number of reports. The last decade of the program, however, saw no meteorite falls and recorded only a few fireball events that produced more than 20 reports. Even the spectacular Grande Prairie fireball (Halliday 1985) of February 23, 1984 (UT) produced only 22 reports in the MFA. The reports

Table 2.

Year	Day	Province	Object	Comments
1962	May 29	BC	Fireball	142 reports, sonic booms heard
1963	Mar. 31	AB	Meteorite	Fall at Peace River
1965	Mar. 31	BC	Meteorite	Fall at Revelstoke
1966	Apr. 26	ON+QC	Fireball	246 reports, sonic booms heard
1966	Sept. 18	ON+QC	Fireball	127 reports, sonic booms heard
1967	Feb. 5	AB	Meteorite	Fall at Vilna
1967	Feb. 6	AB	Fireball	26 reports
1967	Apr. 6	ON	Fireball	24 reports; also bright fireballs on June 15 and Sept. 11 seen in ON for a further 17 and 15 reports respectively
1967	Dec. 15	SK	Fireball	30 reports
1972	Aug. 10	AB	Fireball	56 reports, sonic booms heard
1975	Feb. 16/17	SK	Fireballs	Two very bright fireballs seen on successive nights for a total of 41 reports
1977	Feb. 5	AB	Meteorite	Fall at Innisfree, MORP recovery

Table 2 – Meteorite falls and years in which the total number of fireball reports was greater than twice the total number of fireball events. Typically the high report count years are those years in which just one or a few well-observed fireballs were seen. Most fireball events in the catalogue have just a single report card.

received "peak" in 1975 is due to two very bright fireballs, seen on consecutive nights, in Saskatchewan and the "peak" circa 1978 is perhaps an enthusiasm "ripple-on effect" resulting from the fall and recovery of the Innisfree meteorite in February of 1977. We also note a clear distinction in the number of reports received from U.S. observers in the first and last decades of the program. The number of U.S. reports received at the NRC peaked in 1966 and declined steadily thereafter with just the occasional few reports being received from 1975 onwards. A study of the U.S. report cards reveals that they were received from just a few observers, and the decline in reporting presumably reflects their individual circumstances. In addition, the Smithsonian Astrophysical Observatory started its own fireball reporting system in the mid-1960s, as a consequence of the establishment of the Prairie Network of fireball cameras (Norton 2002), and presumably, this move "diverted" some of the U.S. fireball reports away from the NRC Meteor Centre.

The monthly distribution of fireball events is shown in Table 3. The greater number of recorded fireball events per year in the first decade of the program is clearly seen in the table (last column). It is also evident from Table 3 that the number of fireball events reported through the year generally decreases from January to June, but rises again from July through to December. The month in which the least number of fireball events was reported is June; the month in which the greatest number of fireball events was reported is August. The same variation in monthly activity as seen in the MFA data is also evident in the sporadic background of the fainter visually observed meteors (Murakami 1955). Interestingly, however, the June minimum is not evident in the fireball data gathered by satellite-borne optical sensors (Tagliaferri *et al.* 1994), nor is it present in the monthly distribution of meteorite falls (Hughes 1981). These latter observations suggest that the June minimum in the MFA data is a selection effect related to the reduced number of nighttime hours at that time of year.

4. MFA and Sounds

The fireball report card developed and distributed by ACOM had "sounds" as one of its entry headings. The reason for including such a heading is the fact that sonic booms are often generated during the descent of a meteoroid through the Earth's lower atmosphere (ReVelle 1975, 1997). The presence, therefore, of reported "sounds," typically described as 'loud bangs' or 'thunder-like rumblings,' is an extra indicator of a meteorite-dropping event having possibly occurred. In addition to sonic booms, bright fireballs may also be accompanied, on occasion, by simultaneous sounds. Since sonic booms propagate through the Earth's atmosphere at the speed of sound they are often heard several minutes after the optical fireball has passed. Simultaneous sounds, on the other hand, are heard at the same time as the fireball is seen. Keay (1980) has explained the origin of simultaneous sounds in terms of an interaction between the ionized fireball trail and the Earth's magnetic field. In this manner, simultaneous (or as they are often called, electrophonic) sounds are produced by the transduction of long wavelength (λ ~ tens of kilometres) electromagnetic radiation into audible sounds by objects in the locality of the observer.

Table 3.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Σ
1989	6	6	1	4	3	4	3	1	3	0	0	0	31
1988	8	3	6	7	0	0	2	3	2	5	7	7	50
1987	6	6	4	9	4	1	6	9	3	7	2	14	68
1986	10	7	5	1	4	2	1	3	5	8	5	10	61
1985	8	2	4	2	1	1	3	4	7	14	13	4	63
1984	3	7	3	2	1	0	2	3	2	5	4	11	43
1983	14	9	1	6	0	1	2	3	8	6	6	7	63
1982	2	4	1	2	4	6	1	5	5	5	6	4	45
1981	2	2	2	1	2	0	8	3	3	4	11	2	40
1980	6	2	2	5	2	0	4	0	3	1	2	0	27
1979	11	6	5	6	1	4	7	10	6	5	4	15	80
1978	18	7	16	6	12	3	4	12	8	10	17	8	121
1977	2	4	5	5	6	1	2	10	2	2	6	3	48
1976	1	4	2	8	0	2	6	7	0	6	2	2	40
1975	3	5	4	6	1	2	3	8	4	5	4	7	52
1974	2	4	4	2	5	5	2	4	2	4	4	1	39
1973	8	5	5	5	6	1	5	6	2	2	7	5	57
1972	7	4	8	6	7	4	10	9	11	4	8	6	84
1971	11	4	4	5	3	3	7	8	9	19	10	9	92
1970	11	8	8	2	4	12	6	11	3	11	7	13	96
1969	5	6	10	8	9	6	7	17	7	11	10	1	97
1968	4	9	12	9	4	3	13	16	11	11	7	7	106
1967	7	7	4	5	5	9	8	12	11	4	12	16	100
1966	10	6	7	12	4	8	14	19	20	6	10	3	119
1965	11	10	13	10	11	4	12	18	13	9	18	8	137
1964	9	5	10	3	8	16	27	41	14	28	23	13	197
1963	14	5	12	2	0	8	6	15	5	8	8	4	87
1962	3	3	5	14	6	2	1	25	9	7	6	5	86
Σ	202	150	163	153	113	108	172	282	178	207	219	185	

Table 3 – Monthly fireball event counts. The last column is the annual sum of fireball events, the variation of which is shown in Figure 1 (dashed line with circles). The last row is the sum of monthly fireball events.

Within the MFA there are a total of 268 reports, from 141 events, that mention distinctive sounds being heard. The breakdown of reports is such that 155 (58% of reports) relate sonic booms, with 95 (35% of reports) being simultaneous. Six of the report cards mention that sounds were heard, but the sounds were not described, and twelve of the reports mention that seismic effects occurred (*e.g.* windows rattling). We also note that a number of the report cards mention that both sonic booms and simultaneous sounds were heard, while others mention that both sonic booms and seismic effects occurred. Figure 2 shows the yearly variation of the percentage of fireball reports and events for which "sounds" were noted. On average, in the time interval from January 1962 to September 1989, it appears that one fireball event in fourteen produced some distinct sound, and one report card in fifteen contained mention of an audible occurrence. A summary of those fireball events that produced more than ten eyewitness reports and for which sound phenomena were noted is given in Table 4. We have distinguished between "sonic booms" and "simultaneous" sounds according to the descriptions given in the reports. Comments such as "booms," "rumbling like thunder," "roaring like a jet aircraft," "explosions," and "bangs" are taken to be sonic booms, and especially so if there is a delay in hearing such retorts. Whereas, when comments like "crackling," "popping noise," "hissing," "screeching," "like a sky rocket," and "air-rushing noise" are used we count the description as being simultaneous (Keay 1994; Kaznev, 1994), and especially so when the sound is stated as being heard concurrently with the passage of a fireball.

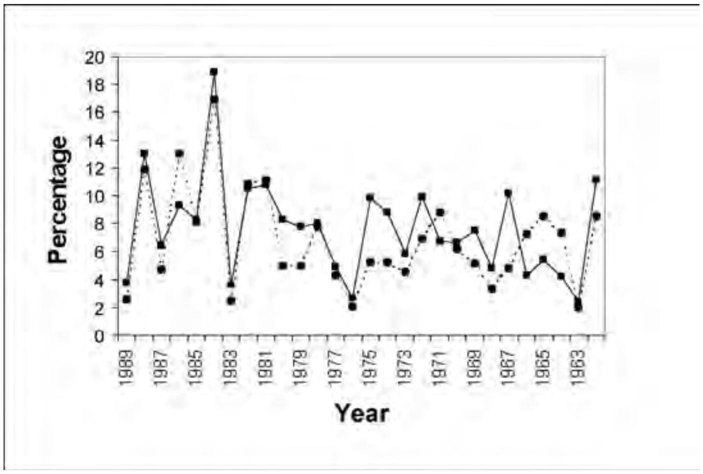

FIGURE 2 – Yearly variation in the percentage of fireball events (dashed line and circles) and reports (solid line and squares) where observers specifically noted sonic and/or simultaneous sounds.

On average it appears that if sonic booms do accompany a fireball event then 12.8 ± 9.0 percent of the observers actually "hear" the "booms" at a sufficiently distinctive level to comment upon them. Likewise, if simultaneous sounds are reported to accompany a fireball event then 5.7 ± 1.8 percent of the observers actually "hear" them in a distinctive fashion.

5. MFA and MORP

With Peter Millman in the Vice President's chair the members of Commission 22 at the 1961 IAU gathering in Berkeley, California passed a resolution calling for the introduction of "systematic programmes of fireball photography with all-sky cameras … in order to determine orbits and to recover newly fallen meteorites" (Sadler 1962). Shortly after this resolution was passed, and taking its directive to heart, the initial planning of the Meteorite Observation and Recovery Program (MORP) began in Canada at the Dominion Observatory (Halliday *et al.* 1978). Site research and construction took place during the mid-1960s and the first cameras became operational in 1968. The full twelve-station network of cameras, housed at observatories situated in Manitoba, Saskatchewan, and Alberta, started routine operations in 1971 and continued to gather data through to early 1985. The MORP produced an immense wealth of fireball data, enabling numerous detailed studies of both meteoroid structure and meteoroid orbital dynamics to be made (see *e.g.* Halliday *et al.* 1996), and the program fully vindicated its conceptual origins with the recovery of the Innisfree meteorite on February 5, 1977.

Although not strictly an integrated part of MORP, the fireball reporting network did, on occasion, provided useful information additional to the photographic record. Information on fireball colouration and sounds, for example, were not recorded by the MORP equipment, but were potentially available from eyewitness accounts. While we have discussed meteor sounds above, the one direct comparison we can make between the MFA reports and the MORP results is that of the observational acuity, OA, here defined as the MORP fireball count divided by the eye-witness fireball event count recorded in the same time interval. An OA of unity would indicate that all of the photographed fireballs had eyewitness counterparts, but the greater the OA, the greater the number of photographed fireballs without eyewitness counterparts. Table 1 of Halliday *et al.*

TABLE 4.

Event Time (UT)	Location	Total Reports	Sonic (%)	Simultaneous (%)
Apr. 18, 1988	NB, NS	17	2 (11.8)	1 (5.9)
Oct. 24, 1985	ON	9	3 (15.8)	0 (0.0)
Feb. 23, 1984	AB	22	3 (13.6)	2 (9.1)
Jun. 02, 1982	AB	13	3 (23.1)	1 (7.7)
Sep. 23, 1978	SK	24	4 (16.7)	1 (4.2)
Aug. 10, 1972	AB, BC	56	6 (10.7)	4 (7.1)
Oct. 28, 1971	ON	31	7 (22.5)	1 (3.2)
Sep. 20, 1968	NS	33	1 (3.0)	2 (6.1)
Dec. 26, 1967	SK	25	1 (4.0)	1 (4.0)
Apr. 06, 1967	ON	24	1 (4.2)	0 (0.0)
Feb. 06, 1967	AB	26	0 (0.0)	2 (3.8)
Sept. 18, 1966	ON, QC	127	12 (9.4)	9 (7.1)
Apr. 26, 1966	ON, QC	246	8 (3.3)	7 (2.8)
Jul 02, 1965	MB	13	1 (7.7)	1 (7.7)
Apr. 01, 1965	AB, BC	18	6 (33.3)	1 (5.6)
Jul 20, 1964	BC	33	8 (24.2)	2 (6.1)
May 29, 1962	BC	142	1 (0.7)	8 (5.6)

TABLE 4 – Summary of those events for which ten or more reports were received at the NRC and in which "sounds" were noted. The first three columns correspond to the time of the event, the Province over which the event occurred, and the total number of reports received. The last two columns indicate the number of reports mentioning sonic booms and/or simultaneous sounds. The numbers in brackets give the percentages of reports mentioning sonic and/or simultaneous sounds. We note that the percentages given are probably lower bounds since in many cases the reports were received from observers in moving cars and from aircraft in flight — locations that will typically mitigate against hearing external sounds. We also note that some report cards were summaries of observations gathered by multiple observers.

(1996) provides the monthly totals of MORP recorded fireballs, from April 1974 to March 1985, and Figure 3 here shows a comparison of the number of fireballs photographed by MORP and the number of eyewitness reported fireballs. The reported events correspond to just those fireballs observed in Alberta, Saskatchewan, and Manitoba (*i.e.*, the provinces containing the MORP cameras) during the interval of the survey[7].

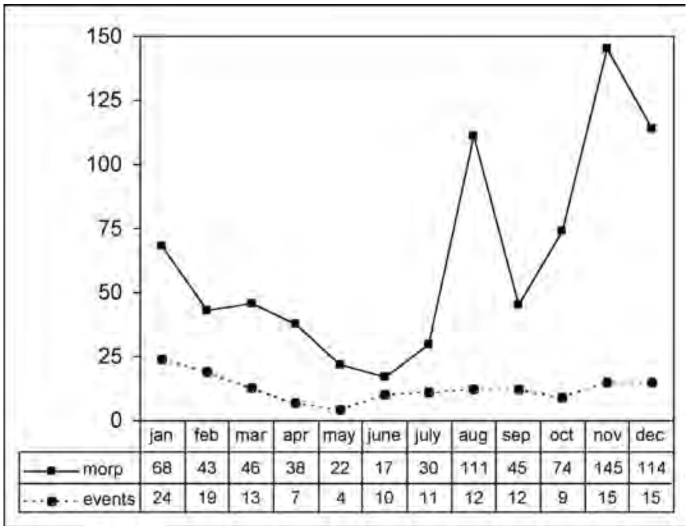

Figure 3 – Monthly totals of MORP detected (solid line and squares) and eyewitness recorded fireballs (dashed line and circles) in the time interval between April 1974 and March 1985. The eyewitness data are for the provinces of Alberta, Saskatchewan, and Manitoba only.

Figure 3 shows a number of interesting trends. The MORP data clearly indicate that more fireballs are recorded in the later part of the year, with especially high counts occurring in August, November, and December. The high fireball counts in these three months is probably a reflection of the occurrence of the Perseid, Southern and Northern Taurid, Leonid, and Geminid meteor — all of which showers are known for their fireball producing capabilities. A minimum in the fireball count occurs between May (visual accounts) and June (MORP observations), and this is possibly a reflection of the fewer nighttime hours available for observations near to the time of the summer solstice, and in the MORP case to scheduled instrument servicing. Interestingly, the fireball events recorded in the MFA do not show the same enhanced count in the latter half of the year. Between January and July, the average OA is 3.4 ± 1.4, which indicates that the visual observers witnessed and reported about two out of every seven fireball events. From August through December the number of reported events is remarkably constant at 12.6 ± 2.2 fireballs per month, but the average OA is 7.7 ± 2.1, indicating that only about one in eight of the actual fireballs recorded by the MORP cameras were eyewitness events. It is not clear to the author why the OA should double during the latter half of the year; however, it might be simply a result of low number statistics.

6. Discussion and Future Studies

The MFA is quite literally a national treasure, and it affords a great wealth of data on visual fireball observations gathered from across Canada during the time interval 1962 to 1989. We have presented in this article an overview of some of the more general statistics that have been gained by an initial study of the archive. Since the "gathering efficiency" of the fireball data varied considerably over the time that the archive was actively maintained we do not feel that a detailed statistical analysis of monthly and annual fireball fluxes is possible. We are confident, however, that general trends may be safely extracted from the data. The mid-summer minimum and latter half of the year enhancement in fireball rates, for example, have been noticed before (Halliday *et al.* 1996) and our analysis simply re-affirms their presence. The enhanced visual fireball counts in the latter half of the year can be contrasted against the minimum in meteorite falls over the same time interval (Hughes 1981). This observation and comparison suggests that we are "seeing" a richer selection of cometary-derived fireballs between June and December at the present epoch.

The sound generating capabilities of fireball meteors is deserving of much greater study, and we plan to expand upon the analysis presented above. In particular the distribution of observers reporting sounds relative to the fireball ground track can be extracted for a number of the events contained in the MFA, and these data can be compared against the classification schemes proposed by, for example, Annett (1980) and Kaznev (1994). The percentage of observers reporting sonic booms and/or simultaneous sounds that we derive from the MFA (6.9 % of all reports) is consistent with the four to eight percent of reports quoted by Norton (2002).

We have found a tantalizing linear correlation between the average number of fireball events per year and the population density. The correlation indicates that the more people there are per square kilometre the greater the fireball "detection" and reporting rate. There must be, however, a limit to such a correlation. As found by Beech (2002), with respect to meteorite fall recovery, it does not necessarily follow that the greater the number of potential observers, the greater the number of observations (or meteorite falls) reported. The population density for PEI, for example, is given as 54.51 people per square kilometre in the 1975 Canada census, and yet very few fireball reports were received from that location[8]. The reason why the observers in some Provinces are more "efficient" than others at reporting fireballs is not just a consequence of the population density; additional, complex social factors must also, at some level, play a role in dictating what is actually reported. In future studies we hope to address in detail the issue of fireball detection "efficiency" as a function of population density and location.

Acknowledgments

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Notes:

(1) The development of meteor astronomy in post second World War Canada, and an indication of Millman's pivotal role in those developments, can be found in Jarrell (1988), but see also Millman & McKinley (1967). Halliday (1991) provides a more personal

account of Millman's life and career.

(2) The entire set of ACOM and MIAC minutes from 1960 through to 2000 has been gathered together by Damien Lemay, and while presently only available in CD format, it is planned that access to the minutes will eventually be made public through the MIAC Web page.

(3) The NRC Headquarters in Ottawa was, in fact, well-positioned to take on the role of a national fireball reporting centre since it had previously established a network of workers to analyze the hundreds of thousands of visual meteor observations gathered during the International Geophysical Year (IGY) held between 1957–58. In addition, Millman, who was affiliated to the NRC, was a prominent member of the International Astronomical Union's (IAU) Commission 22 (then *commission des meteores et des meteorites*) and would have been well aware of the great international interest in the relationship between fireballs and meteorites (see *e.g.* Beech 2002). Indeed, a call to improve upon the speed of reporting fireball events had been made by Charles P. Olivier during the 1958 IAU Commission 22 meeting in Moscow (Sadler 1960). This call was further re-iterated by Zedenic Ceplecha at the 1961 IAU meeting of Commission 22 (Sadler 1962).

(4) The report card design is described in Appendix I of the minutes to the May 5, 1961 meeting of ACOM. Although it did undergo some re-design, the "mass production" of the report cards proceeded before the November 6, 1961, committee meeting. The ACOM members came back to discuss the design of the report cards repeatedly, some members feeling that the cards were too complex in their layout for the "typical" untrained observer to use.

(5) The protocol for fireball reporting established with the Department of Transport is outlined in Appendix 2 of the April 20, 1964 minutes. The actual memorandum was published in D.O.T. Air Services Circular Letter, no. 2-H95-64. The fact that training sessions on fireball reporting to new RCMP officers had taken place is also mentioned in the minutes to the April 20, 1964 meeting.

(6) During the November 24, 1972 ACOM meeting Millman is recorded as noting "staffing problems exist in the Meteor Centre, NRC, and that there are no experienced personnel actually on strength." Also, and with respect to the declining number of fireball reports being received at the NRC, it was suggested during the October 11, 1974 ACOM meeting that the drop-off might be due to a decrease in the "awareness [of] meteoritic phenomena among the services and police force."

(7) Halliday (1985) comments, "the camera network ... normally records one or two fireballs per week during those 30 per cent of night hours that are essentially clear." Nighttime weather statistics have been kept at Campion College for each night since April 19, 2000 as part of the Southern Saskatchewan Fireball Array (a network of three all-sky video camera systems) data analysis program (see *e.g.* Beech & Illingworth 2001). We find that 30.1 per cent of nights are cloud free at Regina, Saskatchewan, 26.6 per cent of the nights are partially clear, and 43.3 per cent of the nights are completely cloudy.

(8) To the authour's knowledge PEI has never had an ACOM or MIAC representative. In this respect the low number of fireballs reported from that Province may be due simply to a lack of public unawareness of "what to do with" any observations gathered. Indeed, one of the key preoccupations of present day MIAC members is the "development" of public awareness concerning the scientific importance of fireball observations, and the collection of new meteorites.

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WIDEBAND PHOTOMETRY OF SATURN: 1995-2002

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Abstract. Photoelectric magnitude measurements were made of Saturn in late 2001 and early 2002. The selected normalized magnitudes of Saturn are: −8.64 ± 0.01, −9.71 ± 0.01, −10.36 ± 0.01, and −10.62 ± 0.01 for the *B, V, R,* and *I* filters respectively. Data collected between 1995 and 2000 were combined with the 2001-2002 data in computing new equations relating the normalized magnitudes and colour of Saturn at different ring tilt angles. It is also concluded that Saturn had opposition surges of between 0.08 and 0.15 magnitudes in late 2001, which is consistent with there being lots of large particles in the rings. The north side of the rings and planet appear to reflect a bit less light than the south side of the rings and planet.

Résumé. Des mesures photoélectriques de la magnitude de Saturne ont été prises à la fin de 2001 et au début de 2002. Les magnitudes normalisées sélectionnées de Saturne sont: −8,64 ± 0,01, −9,71 ± 0,01, −10,36 ± 0,01, et −10,62 ± 0,01 respectivement, pour les filtres *B, V, R*, et *I*. Des données acquises entre 1995 et 2000 ont été combinées avec celles de 2001-2002 pour le calcul de nouvelles équations décrivant les magnitudes normalisées et la couleur de Saturne à différents angles d'inclination de ses anneaux. Nous pouvons aussi conclure que Saturne a enregistré une augmentation subite de 0,08 et de 0,15 magnitudes en opposition durant la fin de 2001, ce qui est compatible avec un grand nombre de grosses particules dans les anneaux. Le côté nord des anneaux et de la planète semble refléter un peu moins de lumière que le côté sud des anneaux et de la planète.

1. Introduction

In recent years, a great deal of progress has been made in the understanding of Saturn's rings. Nicholson and co-workers (2000) and French & Nicholson (2000) have combined Earth-based optical depth measurements of Saturn's ring system with *Voyager* data. These two groups conclude that there are few micron-sized particles in Saturn's ring system and that the ring structure at a scale of 18 km was stable between 1980 and 1989. Estrada & Cuzzi (1996) report that the rings are reddish in colour and that they are not pure water ice. The reddish colour of the rings is also supported by several Earth-based studies (Franklin & Cook 1965; Lebofsky *et al*. 1970; Irvine & Lane 1971, 1973; Clark 1980). More recently, Estrada & Cuzzi (1996) analyzed *Voyager* data and report colour differences within the rings and that the rings are relatively red as a whole.

In spite of these studies, we still have little knowledge of whether the north and south sides of the rings have the same albedo; furthermore, the magnitude of the solar phase angle coefficient and the normalized magnitude of Saturn as a function of the ring tilt angle (**B**) are not well understood. This paper will attempt to answer these uncertainties. Data collected between 1995 and 2000 will be reviewed in this report; furthermore, new photoelectric magnitude measurements made in 2001-2002 will be presented.

Throughout this paper, photometric constants of Saturn are given for the planet and rings combined.

2. Photoelectric Photometry

An SSP-3 solid-state photometer with filters transformed to the Johnson *B, V, R*, and *I* system were used along with a 0.09-metre f/5.5 Maksutov telescope in measuring the brightness, colour, and photometric constants of Saturn in 2001-2002. The photometer and filters are described in more detail elsewhere (Schmude 1992; Optec 1997). The comparison star for all measurements was Epsilon-Tauri; the respective *B, V, R*, and *I* magnitudes used for this star were 4.55, 3.54, 2.81, and 2.31. This star was selected to be the comparison star for three reasons: it was usually within 5° of Saturn, its colour is close to that of Saturn, and it is a standard *UBVRI* star (Astronomical Almanac 2000).

Photoelectric magnitude measurements were made in the same way as for Mars (Schmude 2002). All measurements were corrected for both atmospheric extinction and transformation. Transformation coefficients were measured using the two-star method (Hall & Genet 1988).

All photoelectric magnitude measurements are summarized in Table 1. Normalized magnitudes for **B** = 26°, $X(1,\alpha)$, were computed from:

$$X(1,\alpha) = X_{mag} - 5\,\log[r \times d] + 2.5\log[k] + 2.60\,\mathrm{Sin}[\mathbf{B}] - 1.25\,\mathrm{Sin}^2[\mathbf{B}] - 0.900, \quad (1)$$

where X_{mag} is the measured magnitude for filter X, r is the Saturn-Earth distance in AU, d is the Saturn-Sun distance in AU, k is the fraction of the disc and rings that are illuminated by the Sun and **B** is the angle between the ring plane and the line defined by the observer and the centre of Saturn. The value of k is computed from:

$$k = [\mathrm{Cos}(\alpha) + 1]/2. \quad (2)$$

The 0.900 term at the end of equation 1 is Δm for **B** = 26° where Δm = 2.60 Sin [**B**] − 1.25 Sin^2 [**B**] and it is the magnitude increase caused by the rings being open at a 26° angle (Harris 1961). Figures 1 and 2 are plots of the normalized magnitude versus the solar phase angle. The solar phase angle (α) is the angle between the Earth and Sun measured from Saturn. The normalized magnitudes for $\alpha > 1.5°$ were fit to a linear equation of the form $X(1,\alpha) = c_x\alpha + X(1,0)$ where c_x is the solar phase coefficient and $X(1,0)$ is the normalized magnitude. The normalized magnitude is the magnitude that Saturn would have if it were 1.0 astronomical unit from both the Earth and the Sun, and at a solar phase angle of zero degrees. The solar phase angle coefficients describe how quickly regions near the terminator dim. A large value

Table 1.

Photoelectric magnitude measurements of Saturn made during late 2001 and early 2002. All measurements were made near Barnesville, Georgia, which is at 33.1° N and 84.1° W. Both **B** and α are in degrees.

Date-UT	Filter	**B**	α	Magnitude Measured	Magnitude Normalized
(2001)					
Aug. 23.388	*V*	26.2	6.2	0.08	−9.54
Sep. 14.398	*R*	26.2	6.3	−0.68	−10.22
Sep. 14.409	*I*	26.2	6.3	−0.91	−10.45
Sep. 14.420	*V*	26.2	6.3	0.01	−9.52
Sep. 14.430	*B*	26.2	6.3	1.06	−8.47
Sep. 26.333	*I*	26.2	6	−0.96	−10.45
Sep. 26.345	*R*	26.2	6	−0.74	−10.23
Sep. 26.356	*V*	26.2	6	−0.05	−9.53
Sep. 26.370	*B*	26.2	6	1.02	−8.47
Oct. 8.405	*B*	26.1	5.5	0.92	−8.52
Oct. 8.417	*V*	26.1	5.5	−0.10	−9.54
Oct. 8.427	*R*	26.1	5.5	−0.78	−10.22
Oct. 8.438	*I*	26.1	5.5	−1.02	−10.46
Oct. 21.277	*I*	26.1	4.6	−1.08	−10.48
Oct. 21.289	*R*	26.1	4.6	−0.86	−10.25
Oct. 21.296	*B*	26.1	4.6	0.88	−8.52
Oct. 21.306	*V*	26.1	4.6	−0.17	−9.56
Nov. 7.238	*R*	26	3	−0.93	−10.29
Nov. 7.250	*I*	26	3	−1.18	−10.54
Nov. 7.263	*V*	26	3	−0.27	−9.63
Nov. 7.274	*B*	26	3	0.8	−8.55
Nov. 16.258	*B*	26	2	0.73	−8.60
Nov. 16.271	*V*	26	2	−0.31	−9.65
Nov. 16.287	*R*	26	2	−0.97	−10.31
Nov. 16.298	*I*	26	2	−1.23	−10.57
Nov. 28.237	*I*	25.9	0.7	−1.32	−10.65
Nov. 28.248	*R*	25.9	0.7	−1.08	−10.41
Nov. 25.289	*V*	25.9	1	−0.37	−9.70
Nov. 25.303	*B*	25.9	1	0.66	−8.67
Dec. 3.206	*B*	25.9	0.1	0.54	−8.79
Dec. 3.217	*V*	25.9	0.1	−0.45	−9.78
Dec. 3.228	*R*	25.9	0.1	−1.14	−10.47
Dec. 3.238	*I*	25.9	0.1	−1.40	−10.72
Dec. 15.121	*R*	25.9	1.4	−1.03	−10.36
Dec. 15.134	*I*	25.9	1.4	−1.26	−10.59
Dec. 15.161	*V*	25.9	1.4	−0.37	−9.69
Dec. 15.2	*B*	25.9	1.4	0.66	−8.67
(2002)					
Jan. 10.071	*B*	25.8	4.1	0.87	−8.52
Jan. 10.082	*V*	25.8	4.1	−0.19	−9.58
Mar. 7.135	*V*	26	6.2	0.09	−9.50

Table 2.

Normalized magnitudes, opposition surges and solar phase angle coefficients for (Saturn + rings) during the 2001 apparition. The opposition surge is at a solar phase angle of 0.1°. The ring tilt angle was 26°.

Filter	Effective Wavelength (nanometers)	Normalized Magnitude	Solar Phase angle Coefficient (magnitude/degree)	Opposition Surge (magnitudes)
B	420	−8.64 ± 0.01	0.027 ± 0.006	0.15
V	540	−9.71 ± 0.01	0.030 ± 0.004	0.08
R	700	−10.35 ± 0.01	0.022 ± 0.002	0.12
I	860	−10.62 ± 0.01	0.029 ± 0.002	0.11

of the solar phase angle coefficient means that there is a large amount of dimming near the terminator. Most of the dimming for Saturn occurs in the rings. The resulting $X(1,0)$ and c_X values are listed in Table 2.

The 2001-2002 c_B and c_V values are similar to the 1959 (Franklin & Cook 1965) and 1963 values (Irvine & Lane 1971). The c_V value for 2001-2002, however, is lower than 0.044 magnitude/degree, which is the value suggested by Harris (1961).

For asteroids, the opposition surge is the difference between the measured $V(1,0)$ value at $\alpha = 0°$ and the extrapolated $V(1,0)$ value based on magnitudes measured for different values of α exceeding ~ 7°. In the case of Saturn, α never exceeds 7° and so the opposition surge is the difference between the measured $V(1,0)$ value and the extrapolated $V(1,0)$ value based on measurements made between $\alpha = 2°$ and 7°. Figures 1 and 2 show the opposition surges for Saturn and its rings for **B** = 26°, and Table 2 lists the opposition surges along with the peak wavelengths for the *B, V, R*, and *I* filters. The opposition surge is higher for the *B* and *R* filters than for the *V* filter. Irvine & Lane (1971, 1973) measured a similar trend. Franklin & Cook (1965) report graphs of $X(1,\alpha)$ versus α for Saturn + rings in the *B* and *V* filters. Approximate opposition surges of 0.18 (*B* filter) and 0.16 magnitudes (*V* filter) are computed from Figures 2 and 3 in Franklin

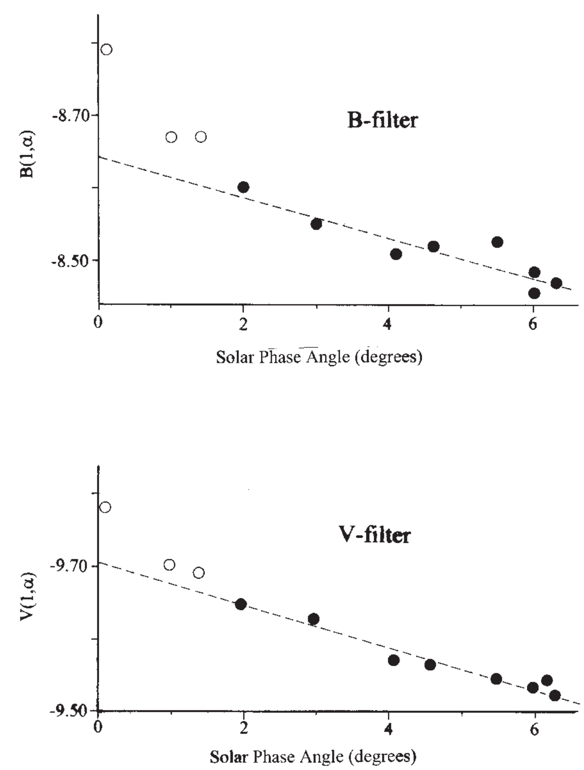

Figure 1 – Graphs of the normalized magnitudes (**B** = 26°) at a solar phase angle of α plotted against the solar phase angle. The top graph is the *B* filter and the bottom one is the *V* filter. The dashed line is the best straight line through all points for $\alpha > 1.5°$.

& Cook (1965). The opposition surge of Saturn is most likely due to the rings and not the atmosphere because Jupiter, a planet very similar to Saturn except for the rings, does not have much of an opposition surge. The large particles (diameters exceeding 0.1 mm) are believed to be responsible for Saturn's opposition surge; large particles backscatter light well (Fix 2001). Poulet *et al.* (2002) also conclude that backscattering is the main cause of Saturn's opposition surge.

3. Saturn Brightness and Colour Trends: 1995-2002

The author carried out an intensive magnitude study of Saturn between 1995 and 2000 and the results are presented elsewhere (Schmude 1997, 1998, 1999a,b, 2001; Schmude & Hallsworth 2000); the rings were tilted at angles of between 0° and 24°. The author did not take into account the opposition surge in the 1996-2000 studies and as a result revised normalized magnitudes and solar phase-angle coefficients are listed in Table 3. A few of the values in Table 3 are based on just three or four measurements and may thus be uncertain. The albedos of Saturn in 1995 were 0.295 ± 0.012, 0.443 ± 0.018, 0.528 ± 0.018, and 0.397 ± 0.017 for the *B, V, R*, and *I* filters respectively. These albedos are based on the solar magnitudes and formula described by Harris (1961). The *B* and *V* filter albedos are close to the values reported by Irvine & Lane (1971).

The normalized *V*-filter magnitudes of Saturn $V(1,0)$ extrapolated to $\alpha = 0°$ are plotted in Figure 3 as a function of the ring tilt angle (**B**). The data were fit to a quadratic equation of the form $y = a + bx + cx^2$ where $x = \text{Sin}\,[\mathbf{B}]$ and *a, b*, and *c* are coefficients to be computed. The resulting best fits for the *B, V, R*, and *I* filters are:

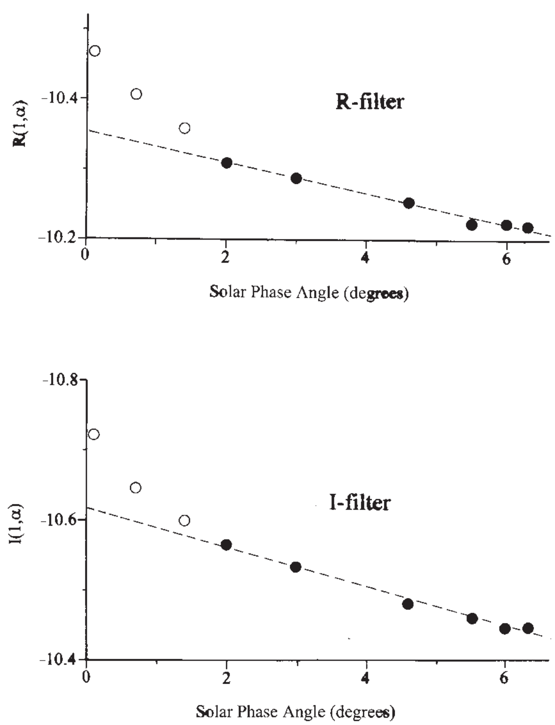

Figure 2 – Graphs of the normalized magnitudes (**B** = 26°) at a solar phase angle of α plotted against the solar phase angle. The top graph is the *R* filter and the bottom one is the *I* filter. The dashed line is the best straight line through all points for $\alpha > 1.5°$.

$$B(1,0) = -7.79 - 2.60\ \text{Sin}\,[\mathbf{B}] + 1.85\ \text{Sin}^2\,[\mathbf{B}] \quad (3)$$

$$V(1,0) = -8.86 - 2.49\ \text{Sin}\,[\mathbf{B}] + 1.33\ \text{Sin}^2\,[\mathbf{B}] \quad (4)$$

$$R(1,0) = -9.50 - 2.53\ \text{Sin}\,[\mathbf{B}] + 1.29\ \text{Sin}^2\,[\mathbf{B}] \quad (5)$$

$$I(1,0) = -9.52 - 3.40\ \text{Sin}\,[\mathbf{B}] + 2.26\ \text{Sin}^2\,[\mathbf{B}]. \quad (6)$$

These equations describe how the colour of Saturn changes with the changing ring tilt angle.

4. Relative Albedo of the Two Sides of Saturn's Rings

The *V*-filter magnitudes of Saturn when the north and south sides of the rings faced the Earth at the same values of α and **B**, are compared in Table 4. During 1959, 1963-1965, and 1991-1994 apparitions, the north side of the rings and globe faced the Earth and the normalized magnitudes for these years were compared to magnitudes predicted by equation (4); these comparisons are listed in the north-south magnitude column. Equation (4) is based on measurements made when the south side of the rings faced Earth. Magnitude measurements were taken from (Franklin & Cook 1965; Irvine *et al.* 1968a,b; Schmude 1995; Schmude & Bruton 1995). The average weighted difference is 0.05 magnitudes, which is consistent with the northern side of the planet and rings reflecting a bit less light than the corresponding southern sides.

5. Conclusions

In summary, three conclusions are reached: 1) Saturn had a significant opposition surge in 2001, 2) the normalized magnitude of Saturn + rings extrapolated to 0° obeys the relation $V(1,0) = -8.86 - 2.49\ \text{Sin}\,[\mathbf{B}] + 1.33\ \text{Sin}^2\,[\mathbf{B}]$, and 3) the north side of Saturn and its rings reflects

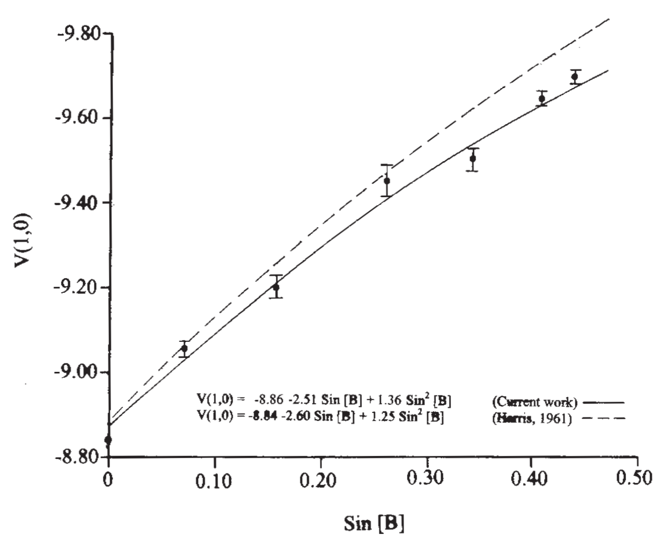

Figure 3 – A graph of the extrapolated normalized magnitude for the *V* filter as a function of the ring tilt angle. The data cover the years 1995 to 2001 when the ring tilt angle ranged from 0° up to 26°.

Table 3.
Re-computed normalized magnitudes and solar phase angle coefficients from data collected between 1995 and 2000.

	1995	1996	1997	1998	1999	2000
$B(1,0)$	−7.77 ± 0.04	−8.01 ± 0.03	−8.14 ± 0.02	−8.35 ± 0.01	−8.48 ± 0.01	−8.47±0.02
$V(1,0)$	−8.84 ± 0.04	−9.05 ± 0.02	−9.20 ± 0.02	−9.44 ± 0.01	−9.51 ± 0.02	−9.65±0.01
$R(1,0)$	−9.48 ± 0.03	−9.70 ± 0.02	−9.89 ± 0.02	−10.02 ± 0.01	−10.22 ± 0.01	−10.34±0.01
$I(1,0)$	−9.46 ± 0.04	−9.85 ± 0.02	———————	−10.23 ± 0.02	−10.38 ± 0.03	−10.52±0.02
c_B	———————	0.025 ± 0.013	0.028 ± 0.006	0.028 ± 0.009	0.023 ± 0.007	0.009±0.016
c_V	———————	0.015 ± 0.008	0.025 ± 0.004	0.034 ± 0.006	0.023 ± 0.009	0.026±0.003
c_R	———————	0.022 ± 0.012	0.021 ± 0.003	0.020 ± 0.009	0.031 ± 0.007	0.033±0.004
c_I	———————	0.034 ± 0.011	———————	0.010 ± 0.010	0.017 ± 0.014	0.020±0.011
$B–V$	1.07 ± 0.06	1.04 ± 0.04	1.06 ± 0.03	1.09 ± 0.02	1.03 ± 0.02	1.18 ± 0.02
$V–R$	0.64 ± 0.05	0.65 ± 0.03	0.69 ± 0.03	0.58 ± 0.02	0.71 ± 0.02	0.69 ± 0.02
$R–I$	−0.02 ± 0.05	0.15 ± 0.03	———————	0.21 ± 0.02	0.16 ± 0.03	0.18 ± 0.02

Table 4.
A comparison of Saturn *V*-filter magnitudes when the north and south sides of the globe and rings face the Earth. In the second column, Saturn's magnitude when the southern side is facing us is subtracted from that planet's magnitude when the northern side is facing us. Weights are assigned based on the number of data and the fact that in 1964, 1965, and 1994 the rings had a low tilt and thus the Sun altitude undoubtedly played a significant role in the brightness, resulting in a lower weight.

Opposition	North – South Magnitude difference	**B** – Ring Tilt (degrees)	Weight
1959	−0.05	26.1	6
1963	+0.10	14	10
1964	+0.05	8	6
1965	+0.08	4	2
1991	+0.05	20	2
1992	+0.10	17	1
1993	−0.02	13	1
1994	+0.02	8	1
Average difference	+0.05		

a bit less light than the south side of Saturn and its rings. It is hoped that the *Cassini* probe will last beyond 2009 so that the reflectivity and colour of the north and south sides of Saturn's rings can be compared.

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Education Notes
Rubriques pédagogiques

Mars in Motion: Using Vectors to Investigate the Retrograde Loop[1]

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This year's August opposition of Mars is its closest approach to Earth for the past 3000 years and until 2287 (Sheehan & O'Meara 2001). So, it is a fitting occasion to investigate the mathematical implications of the motion of Mars as indicated by the *Observer's Handbook* (OH).

In this article we'll look at a portion of the geocentric path, that is Mars' movement with respect to the Earth, which is itself moving around the Sun. Johannes Kepler was frustrated for years in his efforts to explain the strange movements of Mars. The geocentric coordinates can be used to see if they obey his famous laws of planetary motion. In a subsequent article, we'll also look at Mars' heliocentric orbit, that is, around the Sun.

Martian motion is also an excellent context for introducing or reviewing vectors. In high school math, students first make the intellectual breakout from mere arithmetic of numbers to a basic algebra where variables themselves have their own rules of operation. In the middle high-school years, functions themselves have their arithmetic. In senior mathematics and physics, vectors are presented as a way to describe changes across space.

This paper is limited to three-dimensional rectilinear vectors, just one of many types of vectors. Such a vector $\mathbf{v} = (v_x, v_y, v_z)$ where x, y, and z are distances in three different mutually perpendicular directions from a set starting point of origin.

We start with the position vector of Mars, $\mathbf{v} = \mathbf{r} = (r_x, r_y, r_z)$. To determine **r** from the OH, we turn to "The Sky Month by Month." There the distance (r), the right ascension (α) and the declination (δ) are listed for the 1^{st}, 11^{th}, and 21^{st} of each month. We'll be using the OH 2001 (Gupta 2001) for the last opposition, leaving a similar approach to 2003 as an exercise for your classes.

The derivation of the components of the position vector, **r**, is exactly the same as previously used for Saturn and Jupiter (Orenstein 2001) or the bright stars of Leo (Orenstein 2000):

$$r_x = r \cos \delta \cos \alpha$$

$$r_y = r \cos \delta \sin \alpha$$

$$r_z = r \sin \delta.$$

In this article I'll show you how to calculate the displacement, velocity, and acceleration of Mars near opposition in 2001. The units will stay in AU and days even though, for example, the velocity of Mars would usually be given in km s^{-1}.

The 2001 opposition was on June 19. The closest listed date is June 21, when

$$\begin{aligned}\mathbf{r} &= (r, \alpha, \delta)\\ &= (0.45\text{ AU}, 17^h\,17^m, -26°\,43')\\ &= (0.45\text{ AU}, 259.250°, -26.717°).\end{aligned}$$

So, on June 21, 2001

$$\begin{aligned}r_x &= 0.45\text{ AU} \cos(-26.717°) \cos(259.250°)\\ &= 0.45\text{ AU}\,(0.89324)\,(-0.18652)\\ &= -0.07498\text{ AU}\end{aligned}$$

$$\begin{aligned}r_y &= 0.45\text{ AU} \cos(-26.717°) \sin(259.250°)\\ &= -0.39490\text{ AU}\end{aligned}$$

$$\begin{aligned}r_z &= 0.45\text{ AU} \sin(-26.717°)\\ &= -0.20231\text{ AU.}\end{aligned}$$

Checking, $r = (rx_2 + ry_2 + rz_2)^{1/2}$ (vector length)

LS = 0.45 AU

$$\text{RS} = [(-0.07498)^2 + (-0.39490)^2 + (-0.20231)2]^{1/2}\ \text{AU} = [0.202496596]^{1/2}\ \text{AU}$$
$$= 0.45000\text{ AU to five significant figures.}$$

Remember we really only have two significant figures for r, our least precise original component.

Thus, **r** (t) = **r** (June 21) = (−0.07498, −0.39490, −0.20231) AU.

The nearest other dates tabulated are June 11 and July 1, 2001. After similar calculations you get:

r (June 11) = (−0.05021,−0.40896,−0.20453) AU

r (June 21) = (−0.07498,−0.39490,−0.20231) AU

r (July 1) = (−0.09927,−0.39822,−0.20776) AU.

[1] Illustrated by Ian Orenstein.

With just these three vectors, there are many investigations we can start. For example, how far did Mars travel between June 11 and 21? Just as you would subtract the successive positions along a path to find the distance travelled, you subtract the position vectors to get the displacement vector, $\Delta\mathbf{r}$.

$$\begin{aligned}\Delta\mathbf{r} &= \mathbf{r}(21) - \mathbf{r}(11) = (x_{21}, y_{21}, z_{21}) - (x_{11}, y_{11}, z_{11}) \\ &= (x_{21} - x_{11}, y_{21} - y_{11}, z_{21} - z_{11}) \\ &= (\Delta x, \Delta y, \Delta z) \\ &= [(-0.07498-(-0.05021), -0.39490-(-0.40496), \\ &\quad -0.20231-(-0.20453)]\text{ AU} \\ &= [-0.02477, 0.01406, 0.00222]\text{ AU}\end{aligned}$$

The distance travelled is the length of the displacement vector, $\Delta\mathbf{r} = |\Delta\mathbf{r}|$, in this case between June 11 and 21 Mars travelled

$$\begin{aligned}\Delta\mathbf{r} &= [(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2]^{1/2} \\ &= [0.02477^2 + 0.01406^2 + 0.00222^2]^{1/2}\text{ AU} \\ &= [(613.65 + 196.683 + 4.928) \times 10^{-6}]^{1/2}\text{ AU} \\ &= [816.263 \times 10^{-6}]\text{ AU} \\ &= 0.028570\text{ AU} \\ &= 0.028570\text{ AU} \cdot 1.495979 \times 10^8\text{ km/AU} \\ &= 4{,}274{,}100\text{ km} \\ &= 4{,}274{,}100\text{ km / (6794 km/Martian diameter)} \\ &= 629.10\text{ Martian diameters.}\end{aligned}$$

Its now easy to calculate a speed for Mars

$$\begin{aligned}v &= d / t \\ &= \Delta r / \Delta t \\ &= 0.028570\text{ AU / 10 days} \\ &= 0.0028570\text{ AU / d} \\ &= 427{,}410\text{ km / d} \\ &= 62.910\text{ Martian diameters / d.}\end{aligned}$$

This, of course, is an average speed, at a rough estimate most accurately representing the instantaneous speed of Mars halfway between the start and end times. In this case, halfway between June 11 and June 21 = (11+21) / 2 = 32/2 = 16 or June 16.

Similarly, we can find a linear estimate for the position vector of Mars on June 16:

$$\begin{aligned}\mathbf{r}(16) &= (1/2)[\,\mathbf{r}(11) + \mathbf{r}(21)\,] \\ &= (1/2)[(-0.05021, -0.40896, -0.20453) + (-0.07498, \\ &\quad -0.39490, -0.20231)\,]\text{ AU} \\ &= (1/2)[-0.12519, -0.8.386, -0.40684]\text{ AU} \\ &= [-0.06260, -0.40193, -0.20342]\text{ AU.}\end{aligned}$$

As with the displacement vector we can find its length:

$$\mathbf{r}(16) = |\mathbf{r}(16)| = 0.45480\text{ AU.}$$

Similarly,

$$\begin{aligned}\mathbf{r}(26) &= (1/2)[\mathbf{r}(21) + \mathbf{r}(31)] \\ &= [-0.08713, -0.39656, -0.20504]\text{ AU.}\end{aligned}$$

Note that because July 1 is 10 days after June 21

$\mathbf{r}$ (July 1) = $\mathbf{r}$ (June 31) = $\mathbf{r}$ (31).

Also the displacement from $\mathbf{r}$ (21) to $\mathbf{r}$ (31)

$$\Delta\mathbf{r} = \mathbf{r}(31) - \mathbf{r}(21) = [-0.02429, -0.03332, -0.005345\,]\text{ AU}$$

$$\Delta r = |\Delta\mathbf{r}| = 0.025114\text{ AU.}$$

The velocity and speed are very easy to find. The average velocity over our ten-day intervals is

$$\mathbf{v} = (1/\Delta t)\,\Delta\mathbf{r} = (1/10)\,\Delta\mathbf{r}.$$

In fact, we can approximate that the instantaneous velocity of the midpoint of the time interval as equal to the average velocity.

$$\begin{aligned}\mathbf{v}(16) &= (1/10\text{d})\,(-0.02477, 0.01406, 0.00222)\text{ AU} \\ &= (-0.002477, 0.001406, 0.000222)\text{ AU/d} \\ &= (-2.477, 1.406, 0.222) \times 10^{-3}\text{ AU/d}\end{aligned}$$

Similarly,

$$\mathbf{v}(26) = (-2.449, -0.332, 0.545) \times 10^{-3}\text{ AU/d.}$$

The average acceleration would also be based on the velocity change over the time interval and can be considered to occur instantaneously at the midpoint of the time interval.

$$\begin{aligned}\mathbf{a}(21) &= 1/(\Delta t)\,\Delta\mathbf{v} \\ &= (1/10\text{d})\,[\mathbf{v}(26) - \mathbf{v}(16)] \\ &= (0.1\text{d})\,[(-2.477, 1.406, 0.222) - (-2.499, -0.332, \\ &\quad 0.545)] \times 10^{-3}\text{ AU/d} \\ &= [0.028, 1.738, 0.767] \times 10^{-4}\text{ AU/d}^2\end{aligned}$$

Using the method for finding the length of a vector we can find the magnitude of this acceleration:

$$a = 1.8999 \times 10^{-4}\text{ AU/d}^2.$$

If Mars is being primarily attracted by the Earth, then

$$\mathbf{a}_{21} = -\mathbf{r}_{21}.$$

Here $\mathbf{a}_{21}$ and $\mathbf{r}_{21}$ are the vectors of length one in the acceleration and position directions respectively.

$$\begin{aligned}\text{LS} &= a_{21} = (1/a)\,\mathbf{a} \\ &= 1/(1.8999 \times 10^{-4}\text{ AU/d}) \cdot (0.028, 1.738, 0.767) \times 10^{-4}\text{ AU/d} \\ &= (0.01474, 0.91477, 0.40370)\end{aligned}$$

$$\begin{aligned}\text{RS} &= -r_{21} \\ &= -(-0.16662, -0.87756, -0.44958)\text{ similarly} \\ &= (0.16662, 0.87756, 0.44958)\end{aligned}$$

The left and right sides don't quite match. Both vectors are pointing to the same octant of rectilinear space since all the components are positive.

In fact we can calculate the angle θ between the two vectors using the dot product. The definition can be reworked to give

$$\begin{aligned}\cos\theta &= [(a_{21})(-r_{21})] / [|a_{21}| \cdot |-r_{21}|] \\ &= [0.00246 + 0.80276 + 0.18150] / [(1)(1)] \\ &= 0.987671 \\ \theta &= \arccos(0.98671) \\ &= 9.3°.\end{aligned}$$

Acceleration and negative position are close, but they don't align even for our relative low-precision data.

With your students you should use a longer sequence then the three dates from one month. The OH 2001 lists 36 positions for Mars, an adequate total for everyone in the class. If your class uses all 36 dates, they can find 36 position, 35 velocity, and 34 acceleration vectors.

In the next article, we'll examine activities using a complete compilation of these vectors for 2002 to encourage you to try this with 2003.

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Ian Orenstein is a Toronto based graphic artist with a special passion for cartooning. He publishes graphic chapbooks under the imprint ROSA COMICS.

Vector Operations:

With vectors;

$\mathbf{r} = (r_x, r_y, r_z) = (1, -2, 3)$
$\mathbf{s} = (s_x, s_y, s_z) = (3, 0, -3)$

and scalars k = 2.

1. Length or Magnitude of **r**, |**r**|

$$\begin{aligned}|\mathbf{r}| = r &= |(1, -2, 3)| \\ &= [r_x^{\,2} + r_y^{\,2} + r_z^{\,2}]^{1/2} = [1^2 + (-2)^2 + 3^2]^{1/2} = 14^{1/2}\end{aligned}$$

2. Scalar Multiplication, k · **r**

$$\begin{aligned}k \cdot \mathbf{r} &= k \cdot (r_x, r_y, r_z) = 2 \cdot (1, -2, 3) \\ &= (k \cdot r_x, k \cdot r_y, k \cdot r_z) = (2 \cdot 1, 2 \cdot (-2), 2 \cdot 3) \\ &= (2, -4, 3)\end{aligned}$$

3. Negative of **r**, −**r**

$$\begin{aligned}-\mathbf{r} &= -(r_x, r_y, r_z) = -(1, -2, 3) \\ &= (-r_x, -r_y, -r_z) = (-1, 2, -3)\end{aligned}$$

4. Unit Vector in Direction of **r**, r

$$\begin{aligned}&\hat{r} \\ &= (1/r) \cdot \mathbf{r} = 1/(14^{1/2}) \cdot (1, -2, 3) \\ &= (r_x/r, r_y/r, r_z/r) = (1/(14^{1/2}), -2/(14^{1/2}), 3/(14^{1/2}))\end{aligned}$$

5. Vector Addition, **r** + **s**

$$\begin{aligned}\mathbf{r} + \mathbf{s} &= (r_x, r_y, r_z) + (s_x, s_y, s_z) = (1, -2, 3) + (3, 0, -3) \\ &= (r_x + s_x, r_y + s_y, r_z + s_z) = (1 + 3, -2 + 0, 3 + (-3)) \\ &= (4, -2, 0)\end{aligned}$$

6. Vector Subtraction, **r − s**

$$\begin{aligned}\mathbf{r} - \mathbf{s} &= (r_x, r_y, r_z) - (s_x, s_y, s_z) = (1, -2, 3) - (3, 0, -3) \\ &= (r_x - s_x, r_y - s_y, r_z - s_z) = (1-3, -2-0, 3-(-3)) \\ &= (-2, -2, 6)\end{aligned}$$

7. Vector Dot Product

$$\begin{aligned}\mathbf{r} \cdot \mathbf{s} &= (r_x, r_y, r_z) \cdot (s_x, s_y, s_z) = (1, -2, 3) \cdot (3, 0, -3) \\ &= (r_x)(s_x) + (r_y)(s_y) + (r_z)(s_z) = (1)(3) + (-2)(0) + (3)(-3) \\ &= (r)(s)\cos\theta = 3 + 0 + (-9) = -6\end{aligned}$$

Fig. 1 Martian Position and Displacement Vectors

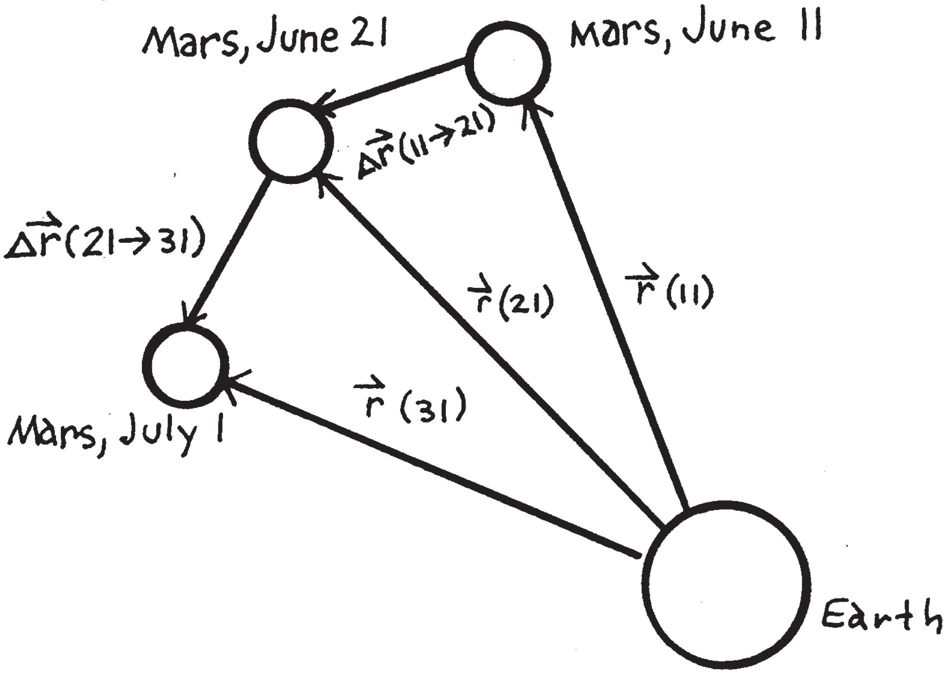
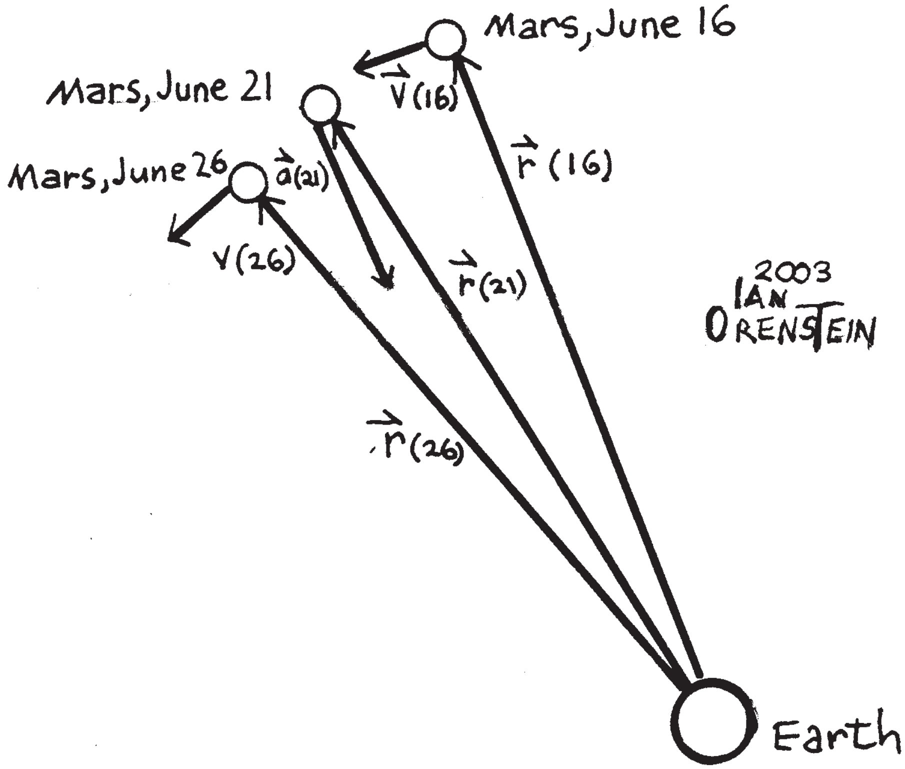
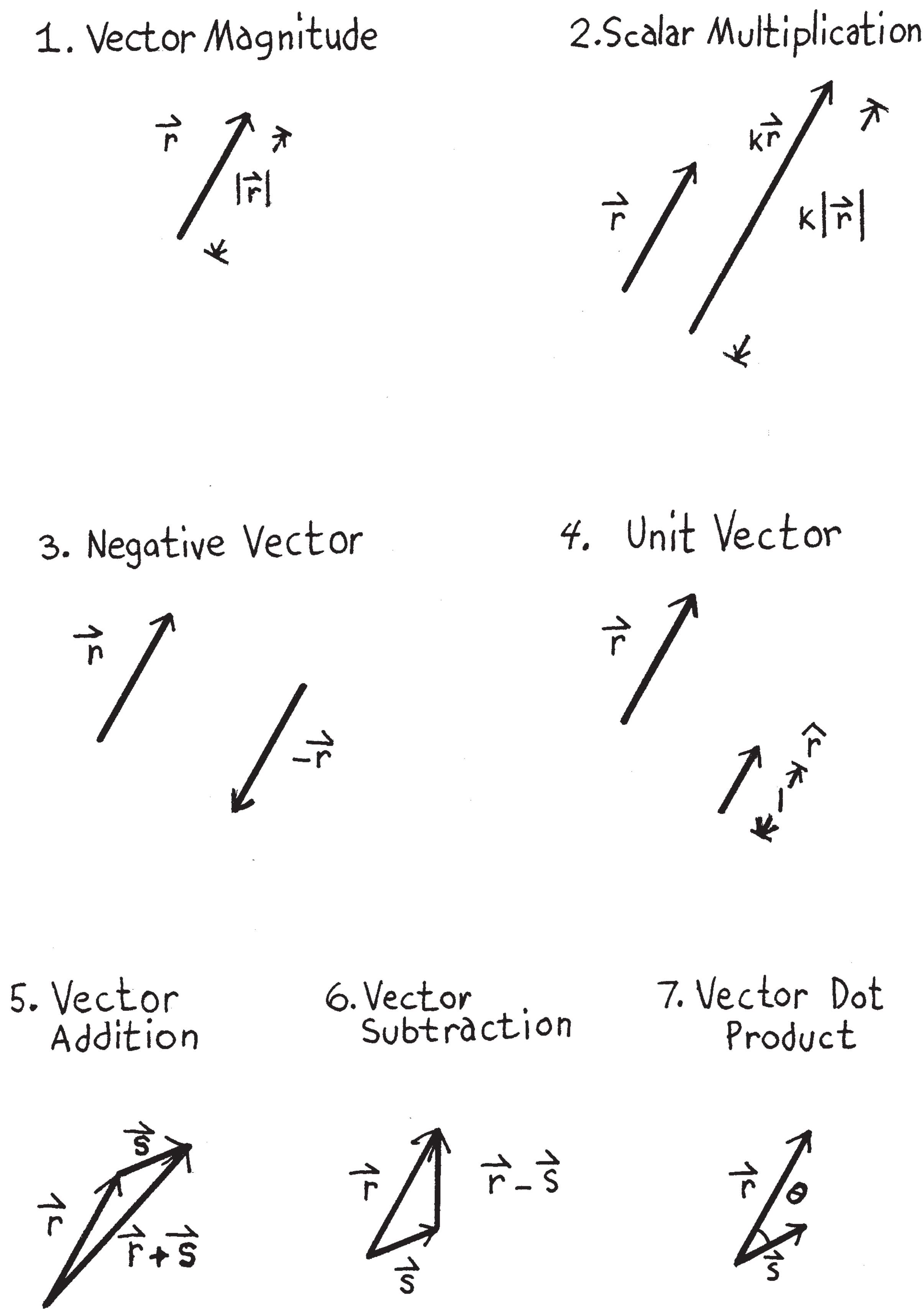


Fig. 2 Martian Velocity and Acceleration Vectors



VECTOR OPERATIONS



Web Site Reviews[1]

by William Dodd, Toronto Centre (wwdodd@sympatico.ca)

Name	**Web Address**
Canadian Space Agency	www.space.gc.ca
Category	**Rating**[2]
Canadian space program & education	☆☆☆☆☆

Overview

This Web site has been designed to increase public awareness of the Canadian Space Agency (CSA) and to provide a range of space-related resources that can be used in the classroom by teachers and students. This site is a great source of information, images, lesson plans at elementary and secondary level, student level projects, experiments, and links to many other educational and space-related Web sites.

Content

The CSA site contains hundreds of pages of information, activities, photo images, and links. The home page has nine sub-pages: (i) *About the CSA,* (ii) *CSA Sectors and Activities,* (iii) *Space Qualifications and Services*, (iv) *Business and Industry,* (v) *Science and Research*, (vi) *KidSpace*, (vii) *What's New*, (viii) *Space Resources and Events,* and (ix) *Image Gallery*. Each of these sub-pages contains many more topics and sub-topics. There is simply too much material to describe it all in suitable detail, but the *Educator Resources* topic, within (vi) *KidSpace,* provides an excellent example of the depth and breadth of what is available.

Educator Resources has five sections. The first section, *Mission Web sites*, provides information on four specific Canadian space projects. The *Canadarm2 — The Star Builder Project* provides all kinds of information about the Canadarm and a simulation game that lets you manipulate a Canadarm to build parts of the space station. The second section, *Learning Resources and Activities,* contains specific lesson plans and activities on 13 different space-related topics. For example, the astronomy topic contains five lessons, categorized by grade and curricular objective, in PDF and/or HTML format, with text materials and student activities. The third section, *Webcasts,* provides current, and archival, webcasts by Canadian astronauts on a variety of CSA projects. The fourth section, *Books and Videos,* explains how educators can borrow CSA books and videos through interlibrary loans. The fifth section, *Image Gallery,* provides access to 864 CSA images in either high or low resolution.

Aesthetics

Great care has been expended in creating an attractive Web site with a good mix of text, graphic images, and photographs. Colour has been used effectively to direct and help maintain a viewer's interest. There are no pages of simply text. The *KidSpace* pages may be a bit hokey with the use of large shaped balloons as menu buttons, but these can be avoided by accessing *KidSpace* through the site map rather than the main menu.

Organization

The Canadian Space Agency Web site is well organized with lots of reference points and opportunities to return to the top of the of page, home, or another item in the main menu. There are also many specialized buttons included on various pages. As examples: there is an index button on the main page that allows you to go directly to any topic within the site, and anywhere within *KidSpace* there is a button with a photograph of the Earth from space that returns you to the *KidSpace* home page.

Links

There are two types of links within the Web site. The first type takes you seamlessly from one page of information to related materials located at other sites. For example, several of the lesson plans in *KidSpace* are from the YES I CAN site at York University, and transferring back and forth is seamless. The second type of link is a reference to additional material that might be of interest. There is a wide range of "space and education" available in (viii) *Space Resources and Events*.

Final Comments / Recommendations

This site is highly recommended for all members of the Canadian public who want to know more about the activities and accomplishments of the CSA. In particular, this site is recommended for the teachers and students of elementary and secondary science. The five-star rating is well deserved.

Name	**Web Address**
American Association of Variable Star Observers (AAVSO)	www.aavso.org
Category	**Rating**
Variable Stars, Observing Programs, Contributing Data, Analyzing Data	☆☆☆☆☆

Overview

The AAVSO site is packed with historical and current information about pulsating stars, eclipsing binaries, novae, and supernovae. You can find everything you need to start an observing program and make real contributions to the knowledge of variable stars. The main menu

[1] Starting with this issue, the *JRASC* will occasionally publish reviews of educational Web sites. We encourage the reader to submit educational Web site reviews.
[2] Maximum five stars.

systematically leads to many related sub-pages. From the home page you can also access the "Latest News" and "Recent Publications" of the AAVSO. For those who are interested you can order an array of materials, or join the AAVSO, online.

Content

The AAVSO celebrates its 92nd anniversary in 2003, so this is not just a Web site. It is the research centre, the archives, the database, and the online educational resource, of a venerable astronomical organization. The following examples illustrate a few of the hundreds of items that you can explore at the site. Under the main menu item, *About the AAVSO,* you can work though the *Variable Star Telescope Simulator* and in about 15 minutes learn the basics of estimating the magnitude of variable stars. The *Variable Stars* section provides a thorough introduction to the whole field of variable stars. Under *Star Charts* you can learn how to access and use variable star finder-charts with labelled comparison stars, then you can download and print any of the thousands of specially prepared charts. Under *Publications* you can access a list of on-line publications, including a *Manual for Visual Observing of Variable Stars* and the *Journal of the AAVSO*. You also have the option of ordering hardcopies of any of the AAVSO publications. Under *Contributing Data* you can download a variety of software packages to assist you in collecting and entering observational data, analyzing data, making solar observations, and predicting the characteristics of eclipsing binaries. Under *Accessing Data* you can plot the light curves from the archives for any of thousands of variable stars. If you have been contributing data for a particular star, you can even highlight your own contributions to see how they compare with the data from other observers. The *Hands on Astrophysics (HOA)* section describes an extensive educational program developed by the AAVSO with funding from the National Science Foundation. A teacher can purchase one kit, including a 560-page manual, software, and a video for $200 US and then has permission to reproduce materials for classroom use.

Aesthetics

The AAVSO site has a simple, crisp design. The value of the site is in the content: the publications, the learning.

Organization

The site is well organized and has a consistent structure. To facilitate navigation, the main menu items are repeated on the left side of most sub-topic pages and the bottom line of most pages contains buttons that will take you to *Sitemap, Search, Contact Us, Links*, or *Privacy Policy*. Your own Web browser's *Back/Forward* buttons can also be used to retrace your path through the site.

You may encounter one minor navigation problem. *The Hands on Astrophysics (HOA)* is designed as a sub-page, and its *Home* button takes you back to *HOA* rather than *AAVSO*.

Links

The AAVSO material contains many embedded links that are directly related to the topic being displayed. In addition, there are excellent links to other astronomy sites accessible through the *Link* button at the bottom of most pages. These links are grouped by topic and accompanied by a brief commentary. It is worth visiting the AAVSO site just to review these links.

Final Comments / Recommendations

This is the premier site for all those who wish to learn about the nature and characteristics of variable stars, and/or those who want to participate in collecting and analyzing data related to variable stars. You can read the AAVSO manuals, newsletters, and publications. You can learn how to collect and contribute variable star observations. You can work through the sample *Hands on Astrophysics (HOA)* materials to develop your basic understanding of astronomy. Taking the time to explore the details of the site is an investment that can provide many astronomical dividends.

Editor's Note: John Percy is one of the co-directors of the *Hands on Astrophysics* project. Dr. Percy is a professor of Astronomy at the University of Toronto, is a former president of the RASC.

William Dodd is the Education Notes contributing editor for the Journal *and a member of the RASC Toronto Centre. A retired math teacher, he is now a keen student of history as well as astronomy.*

Society News/Nouvelles de la société

by Kim Hay, National Secretary (kimhay@kingston.net)

NATIONAL COUNCIL MEETINGS

At the time of press, the February 22, 2003 National Council meeting (NC031) had not yet happened, however, there will be more news in our next issue of the *Journal* to let you know about events at the meeting. Reports are available on our Web site at www.rasc.ca/members/ (members-only section). If you have any questions please feel free to contact your local Centre National Council representative or myself at kimhay@kingston.net.

UPCOMING EVENTS

The 2003 General Assembly will be held in Vancouver, B.C. from June 26-29, 2003. There will be more information presented at the February National Council meeting. In the meantime, please visit the RASC Web site at www.rasc.ca/ga2003.html for updated information.

The Niagara Centre's 2003 banquet is on April 12, 2003 at the Delphi Hall in Niagara Falls. Guest speaker is Ivan Semeniuk. Ivan has been the astronomy reporter for The Discovery Channel's science-news program, Daily Planet. Tickets are $45.00 per person, and you can contact the Niagara Centre at www.vaxxine.com/rascniag/banq2003.htm. If you wish to attend, please send a cheque payable to: Niagara Centre RASC, PO Box 4040, St.Catherines ON L2R 7S3.

The Hamilton Centre will be holding their banquet on May 10, 2003 at the Holiday Inn Select, Oakville, Ontario. Guest speaker will be Alan Dyer, speaking on "The Amazing Sky." Cost is $45.00 per person. Contact Grant Mcguire at (905) 815-0600 ext. 244, or go to the Hamilton Centre Web site, homepages.interscape.net/homeroom/rascsite/rascfiles/orbit.htm and download the February issue of their monthly newsletter, *Orbit*.

Below is an updated listing of 2003 star parties (there may be more, but at the time of the press run, details were unavailable).

All information was collected from the RASC Observer's Calendar 2003 and the star party Web sites.

OTHER NEWS

An article about the RASC, our goals and objectives, is in the *Canadian*

2003 STAR PARTIES

	EVENT	PLACE	CONTACT INFO
Apr 27–May 4 May23–25	Texas Star Party Riverside Telescope Makers Conference	Fort Davis, TX Big Bear, CA	www.metronet.com/~tsp www.rtmc-inc.org
June 25–29	Laurel Highland Star Cruise	Hazelton, West Virginia	www.lhstarcruise.org
July 26–Aug 3 Aug 1–3	Mt.Kobau Star Party Nova East 2002	Osoyoos, B.C. Smiley's Provincal Park, Nova Scotia	www.mksp.ca halifax.rasc.ca/ne
Aug 21–24	Starfest	Mt. Forest, Ontario	www.nyaa-starfest.com
Aug 22–24	Saskatchewan Summer Star Party	Cypress Hills , Interprovincial Park Saskatchewan	prana.usak.ca/~rasc
Aug 27–31	6th Annual Great Manitou Star Party	Gordon's Park & Carter Bay Resort	www.manitoulin-link.com/starparty Manitoulin Island, Ontario Contact Mark Oldfield at: greatmanitou@hotmail.com

Undergraduate Physics Journal, Vol.1, issue 2, January 2003 edition. It also includes a picture of our executive and centre representatives from the October 26, 2002 National Council meeting.

CONGRATULATIONS

Congratulations to Debra Tigner of the Ottawa Centre for the discovery of an apparent supernova, as follows:

SUPERNOVA IN UGC 2984

T. Puckett, Mountain Town, Georgia, and D. Tigner, Kanata, Ontario, report the discovery of an apparent supernova (mag 15.9) on an unfiltered CCD frame (limiting mag 18.8) taken with the Puckett Observatory 0.35-m automated supernova patrol telescope on Dec. 23.27 UT. The candidate is located at RA = $4^h13^m12^s.52$, Dec = +13°25′07″.3 (equinox 2000.0), which is 1″.9 west and 4″.2 south of the centre of UGC 2984. The new object was confirmed on unfiltered CCD frames taken by A. Sehgal, Woodinville, Washington, on Dec. 24.27. The candidate does not appear on unfiltered images taken by Puckett on 2001 Feb. 26, Sept. 22, and Dec. 5 (limiting mag about 19.5), or on Palomar Sky Survey images taken on 1990 Jan. 24, 1989 Nov. 5 (limiting mag about 21.0) and 1953 Oct. 10 (limiting mag about 20.0).

PASSING FRIENDS

Over the past several months, we have lost amateur astronomers, friends, and family. Let's take a moment to remember them:

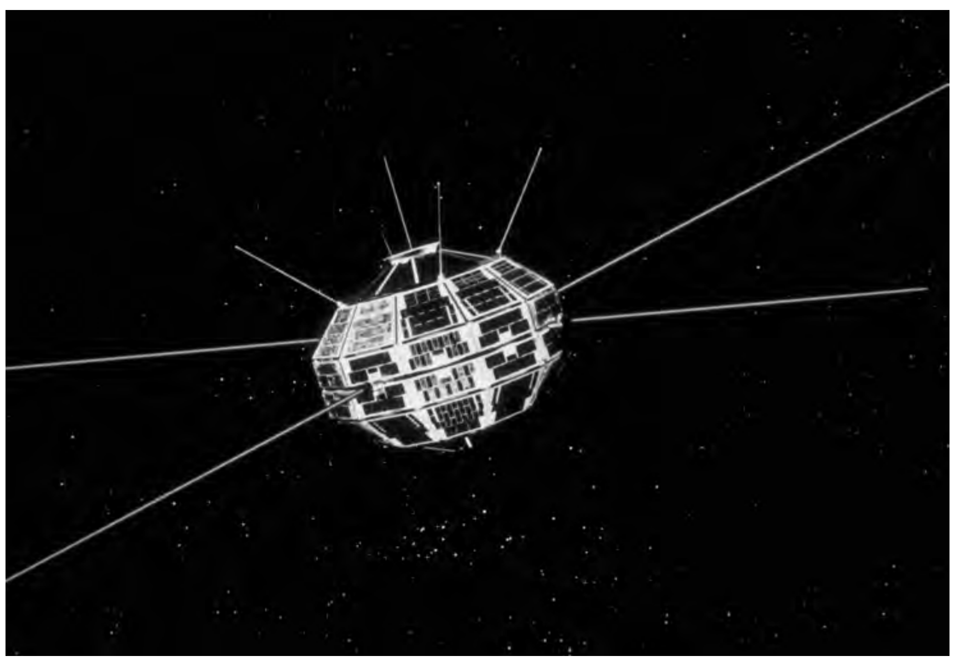
Edris Attwood (mother of Past President Randy Attwood), Grote Reber (Pioneer Amateur Radio Astronomer — Honorary Member of the RASC), Mark St. George (London Centre), and John Howell (Life Member of the Victoria Centre). Our prayers and sympathies go out to all family members and friends.

The 40th Anniversary of *Alouette I* — Canada Celebrates Four Decades in Space

by Scott Young (scyoung@manitobamuseum.ca)

This past fall, a significant anniversary passed largely unnoticed by the Canadian public. On a September evening 40 years ago, Canada took bold steps as a nation, completing a daunting technical challenge that firmly established a fledgling industry and opened up the farthest reaches of our country. On September 29, 1962, Canada became the third nation in space with the launch of the satellite *Alouette I*.

Canada had experimented with rocketry since the late 1950s, with the Black Brant sounding rockets built by Bristol Aerospace of Winnipeg and launched from the rocket range at Fort Churchill, Manitoba (Canada's only spaceport), but these rockets could spend only a few minutes studying the upper atmosphere or the northern lights before falling back to Earth; they were not powerful enough to get into orbit, where they could stay in space indefinitely and study the Earth over the long term.



Allouette I

Alouette was born out of a cooperative program with the United States in the early days of the "space race." On October 4, 1957, the Soviet Union orbited their first satellite, *Sputnik*. Within hours of its launch, the new satellite's radio "beep" was recorded by a young scientist by the name of John H. Chapman at the Defence Research Telecommunications

John Chapman

Establishment (DRTE). Chapman would become the driving force behind Canada's first satellite and play a key role in developing this country's aerospace industry.

The United States followed *Sputnik* with *Explorer 1* on January 31, 1958. The Americans also issued an invitation to their allies to design and build satellites for launch on future U.S. rockets. That opened the door to space for Canada, and Chapman jumped at the chance.

Canadian engineers and scientists worked to design a satellite that could measure the ionosphere, the region of the atmosphere from 80 km to 1000 km altitude, which was very important to long-range radio reception. In the days before satellite communications, long-range radio signals were bounced off the ionosphere to distant corners of the globe. For a country like Canada, with its population spread across a huge area, long-range communications were vital, and understanding the ionosphere was the key to worldwide communications. *Alouette I* would measure the ionosphere from above, over a wide range of radio frequencies.

Alouette I was an ambitious project for a country new to the space race, and the project pushed the limits of early 1960s technology. The Canadian engineers had to build a satellite that could withstand the rigors of a rocket launch, that could carry 40-metre long antennae yet fit inside the rocket's 1.5-metre diameter nosecone, and that could measure a wide range of radio channels at once. Constructing a satellite that advanced was something that had never been done by anyone, let alone a country new to space. In fact, American officials were certain that the satellite was too complicated and delicate to survive the stresses of launch. NASA experts privately estimated that the satellite would last perhaps a couple of hours before failing.

On September 29, 1962, *Alouette I* climbed into the evening sky atop an American Thor-Agena rocket launched from Vandenberg Air Force Base in northern California. The satellite deployed successfully and began transmitting its high-quality measurements of the ionosphere to ground stations across the globe. Canada had become the third nation to have its own satellite in orbit, and the seeds of the future Canadian space program had been sown.

Alouette I outlasted NASA's estimated two-hour lifetime by a huge margin: Canadian engineers on the ground turned the satellite off, or retired it, ten years after it was launched. It was joined by its sister, *Alouette II,* in 1965, and follow-ons *ISIS I* in 1969 and *ISIS II* in 1971. *Alouette I* is still in orbit today at an altitude of nearly 1000 km, where it will remain for thousands of years as a monument to Canadian ingenuity and accomplishment.

The legacy of *Alouette I* has had a direct and lasting impact on the nation of its birth. Today, Canada is a world leader in space systems, building scientific and remote sensing satellites such as *Radarsat* and communications satellites such as *Anik*. Canadian scientists have pioneered direct-to-home satellite television, geosynchronous communications satellites, and Earth observation from space. Canadian astronauts have flown aboard space shuttles, walked in space, and lived on the Russian space station *Mir* and the *International Space Station*. Canadian technology powers the shuttles' Canadarms and the space station's Canadarm2.

The *MOST* satellite, to be launched in 2003, will be Canada's first space telescope. Canadian science instruments are on the way to Mars aboard the Japanese *Nozomi* space probe and will ride the European rover *Beagle II* across the Martian plains. Canadian aerospace industry has become world-renowned, building instruments and satellite components for other countries around the world. All of these programs can trace their roots back over 40 years to John Chapman's dream: *Alouette I,* Canada's first satellite.

- For a complete listing of Canadian achievements in space, go to `www.space.gc.ca/about/canspamil/complete.asp`.
- Images of *Alouette I,* John Chapman, and other Canadian space achievements are available through the Canadian Space Agency's Web site at `www.space.gc.ca`.

Images of *Alouette I* and John Chapman courtesy of Canadian Space Agency/Agence spatiale canadienne.

Scott Young is Planetarium Managing Producer at The Manitoba Museum in Winnipeg, as well as National 2nd Vice-President of the RASC and a past-President of the Winnipeg Centre.

Photometry of Rotating Planetary Triaxial Ellipsoids

by Maxwell B. Fairbairn (mbfairbairn@hotmail.com)

Interest in the asteroids has soared in recent years, especially in those that may closely approach Earth and possibly collide with it. The theory of planetary photometry may be simplified considerably by assuming that the planets may be well approximated as spheres. This assumption is certainly not valid for the minor planets, since their *light curves* reveal that they are generally irregularly shaped, a property verified by images returned from fly-past missions and Earthbound radar scans. Although lack of sufficient observational data relegates most asteroids to the status of "equivalent spheres," the idea that a typical asteroid is shaped more like a potato than a sphere has led to the modelling of asteroids as rotating triaxial ellipsoids. The theory of the photometry of such objects is a straightforward extension of the photometry of spheres, although the resulting equations turn out to be quite cumbersome and consequently less amenable to analytical solutions.

Here the theory is presented up to the point where, and in such a manner that, interested readers with a knowledge of a procedural programming language may be able to generate for themselves the light curves of such objects on a computer. Some examples of the results of such computations are also presented.

Basic Principles. Unfortunately, there is a lot of inconsistency in the names and symbols used for photometric quantities in the literature. In the following, we adhere to the symbols, units, and nomenclature on the theory of planetary photometry as given by Lester, McCall & Tatum (1979), hereafter referred to as LMT, as summarised in the following table.

Quantity	Synonyms	Symbol	SI Units
Radiant Flux Density		F	$W{\cdot}m^{-2}$
Irradiance		E	$W{\cdot}m^{-2}$
Radiance	Surface Brightness Specific Intensity	L	$W{\cdot}m^{-2}sr^{-1}$
Intensity	Integrated Brightness	I	$W{\cdot}sr^{-1}$
Bidirectional Reflectance Distribution Function		f_r	sr^{-1}

Consider an object of any continuous and differentiable shape, "centred" in an OXYZ coordinate system *fixed in space,* and irradiated from the X direction with *radiant flux density F* , and a distant observer at phase angle α in the XY plane *(i.e.* α is the angle Sun-Asteroid-Earth, the *solar phase angle*).

The equation of the surface of this object (Figure 1) is given by $f(x,y,z) = C$, where C is a constant, and we have for the vector of the radiant flux density $\mathbf{F} = -F\mathbf{i}$ and its angle of incidence θ is the angle between the unit vector $\mathbf{i}$ and an (outward) surface normal vector given by $\mathbf{N} = \mathbf{grad}\, f = \nabla f$, so that $\cos\theta_i = \frac{\mathbf{N}\cdot\mathbf{i}}{N}$. The direction towards the observer is given by the unit vector $\mathbf{u} = \cos\alpha\ \mathbf{i} + \sin\alpha\ \mathbf{j}$ so that the angle of reflection θ is given by $\cos\theta_r = \frac{\mathbf{u}\cdot\mathbf{N}}{N}$.

In differential terms, we have

$$N = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2 + \left(\frac{\partial f}{\partial z}\right)^2} \qquad (1)$$

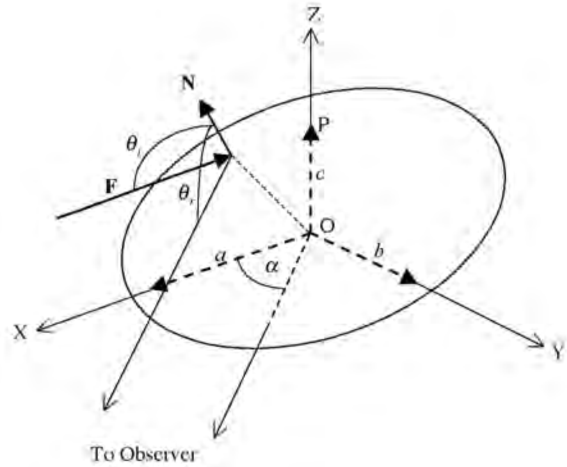


Figure 1

$$\cos\Theta_i = \frac{1}{N}\frac{\partial f}{\partial x} \tag{2}$$

$$\cos\Theta_r = \frac{1}{N}\left(\frac{\partial f}{\partial x}\cos\alpha + \frac{\partial f}{\partial y}\sin\alpha\right). \tag{3}$$

Element of Area. Eventually we will need to perform (numerical) integrations over the surface of an object. In spherical coordinates, the element of surface area for a sphere is $\delta A = r^2 \sin\Theta\delta\Theta\delta\Phi$ whereas for any surface the general expression is $\delta S = \delta A / \cos\psi$, where $\cos\psi$ is the angle between a surface normal **N** and the position vector **r** such that $\cos\psi = \frac{\mathbf{N}\cdot\mathbf{r}}{Nr} = \frac{\nabla f\cdot\mathbf{r}}{Nr}$. Thus

$$\cos\psi = \frac{1}{N}\left(\sin\Theta\cos\Phi\frac{\partial f}{\partial x} + \sin\Theta\cos\Phi\frac{\partial f}{\partial y} + \cos\Theta\frac{\partial f}{\partial z}\right). \tag{4}$$

Triaxial Ellipsoid. Consider such an object with semi-axes $a > b > c$ aligned such that, as shown in Figure 1, the equation of its surface is $f = \frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1$, so that initially the coordinates of its "north" pole P are (0, 0, c) in Cartesian coordinates and (c, 0, 0) in spherical coordinates.

Now let us align the object so that its north pole points in *any* direction determined by two angles, which I shall call *tilt* θ and *twist* ϕ, so that the spherical coordinates of the pole become (c, θ, 0).

First we twist the object by a rotation about the c-axis, so that the *twist matrix* is

$$\left[Twist\right] = \begin{pmatrix} \cos\phi & -\sin\phi & 0 \\ \sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

and then we tilt about the b-axis so that the *tilt matrix* is

$$\left[Tilt\right] = \begin{pmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{pmatrix}$$

and we then start our clocks and let the object rotate with angular velocity $\omega = 2\pi / P_{sid}$ about the c-axis, *i.e.* the axis about which it has the greatest moment of inertia, so that its *rotational phase angle* is ωt, and its *spin matrix* is

$$\left[Spin\right]=\begin{pmatrix}\cos\omega t & -\sin\omega t & 0\\ \sin\omega t & \cos\omega t & 0\\ 0 & 0 & 1\end{pmatrix}$$

At this point, the reader should appreciate that matrix multiplication is not commutative, and it is essential that the transformations be done in the correct order to obtain the desired result. The complete transformation is thus

$$\begin{pmatrix}\cos\omega t\cos\theta\cos\phi-\sin\omega t\sin\phi & -\cos\omega t\cos\theta\sin\phi-\sin\omega t\cos\phi & \cos\omega t\sin\theta\\ \sin\omega t\cos\theta\cos\phi+\cos\omega t\sin\phi & -\sin\omega t\cos\theta\sin\phi+\cos\omega t\cos\phi & \sin\omega t\sin\theta\\ -\sin\theta\cos\phi & \sin\theta\sin\phi & \cos\theta\end{pmatrix}$$

which we can represent much more concisely as

$$\begin{pmatrix}t_{11} & t_{12} & t_{13}\\ t_{21} & t_{22} & t_{23}\\ t_{31} & t_{32} & t_{23}\end{pmatrix}$$

so that the equation of the surface of the ellipsoid is

$$\frac{(t_{11}x+t_{12}y+t_{13}z)^2}{a^2}+\frac{(t_{21}x+t_{22}y+t_{23}z)^2}{b^2}+\frac{(t_{31}x+t_{32}y+t_{33}z)^2}{c^2}=1 \qquad (5)$$

and if we let $(x_1, x_2, x_3) = (x, y, z)$ and with $k = 1, 2, 3$ we may express the partial derivatives, in spherical coordinates, as

$$\frac{\partial f}{\partial x_k}=2r\left[\frac{t_{1k}(t_{11}\sin\Theta\cos\Phi+t_{12}\sin\Theta\sin\Phi+t_{13}\cos\Theta)}{a^2}+\frac{t_{2k}(t_{21}\sin\Theta\cos\Phi+t_{22}\sin\Theta\sin\Phi+t_{23}\cos\Theta)}{b^2}+\frac{t_{3k}(t_{31}\sin\Theta\cos\Phi+t_{32}\sin\Theta\sin\Phi+t_{33}\cos\Theta)}{c^2}\right] \qquad (6)$$

Radiances and Intensity. We are now in a position to calculate the radiances L of points on the surface of the ellipsoid. From LMT equation (2) we see that the radiance is the product of the *bidirectional reflectance distribution function*, abbreviated f and the *irradiance* E so that $L = f_r E$ and the irradiance is $E = F\cos\theta_i$.

In order to generate light curves, we need to determine the object's intensity I as a function of time. To do that we integrate the radiances over the *projected visible surface* S_p of the object.

$$I=\int_{S_p} L\,dS_p$$

Let δS be an element of surface area, *i.e.* the one defining surface normal vector, so that $\delta S_p = \delta S\cos\theta_r$ and it follows that the intensity is

$$I=F\int_0^{2\pi}\int_0^{\pi} f_r\frac{\cos\theta_i\cos\theta_r}{\cos\psi}r^2\sin\Theta\, d\Theta\, d\Phi \qquad (7)$$

so that the integration is performed over the entire surface, in which case at each step of the integration we must check the Boolean expression

$$\cos\theta_i > 0 \;\&\; \cos\theta_r > 0 \qquad (8)$$

(in which the ampersand symbolizes logical And), which must evaluate True for each element of area to be both irradiated and not obscured from the observer.

To proceed further we need a reflectance rule, and the Lommel-Seeliger law is often used in cases of *light curve inversion* (*e.g.*

Kwaitowski 1995). From table II of LMT, the bidirectional reflectance distribution function is $f_r = \frac{\gamma}{\cos\theta_i + \cos\theta_r}$, in which γ is a constant so that the intensity is

$$I(\alpha) = \gamma F \int\int \frac{\cos\theta_i \cos\theta_r}{\cos\psi(\cos\theta_i + \cos\theta_r)} r^2 \sin\Theta d\Theta d\Phi = \gamma F \Gamma(\alpha) \tag{9}$$

in which case we have denoted the integral factor as $\Gamma(\alpha)$. The dependence on α has been emphasized since, for a given real light curve, its value at the time of observation would be a known quantity, the other parameters being unknowns.

Magnitude. For our purposes a light curve is defined as a plot of magnitude versus time or, alternatively, *rotational phase*, over at least one cycle at constant phase. These are subject to five parameters θ, ϕ, α, a/b and b/c (the three axial parameters can be reduced to two by working in terms of the *axial ratios a/b* and *b/c*), since we are concerned with the proportions of the object rather than its actual physical size.

The apparent magnitude of an object seen from Earth may be written as

$$m = m_0 - 2.5 \log F_E \tag{10}$$

where F_E is the radiant flux density arriving at Earth and m_0 is a constant. Let I_s be the intensity of the Sun, so that $F = \frac{I_s}{r^2}$ where r is the heliocentric distance (not to be confused with the spherical coordinate in the previous section) to the asteroid. The intensity of the asteroid is thus $I(\alpha) = \frac{\gamma I_s}{r^2}\Gamma(\alpha)$ and the radiant flux density at Earth is $F_E = \frac{I(\alpha)}{\Delta^2}$ where Δ is the geocentric distance. Substituting into equation (10) and discarding any constant terms, we obtain the expression

$$5 \log r\Delta - 2.5 \log \Gamma(\alpha)$$

in which, in practice, r and Δ would be in astronomical units. Here we see that the first term is a correction for variations in heliocentric and geocentric distances and it is the second term that will provide the variations in magnitude that constitute the light curve profile. Hence I will define a term *relative magnitude* μ, so that

$$\mu = -2.5 \log \Gamma(\alpha) \tag{11}$$

and our light curves will consist of tables and plots of μ vs rotational phase $\omega t/2\pi$.

Some Example Light curves. Here we shall consider a hypothetical asteroid, Sebago[1], which has the same proportions as those deduced by light curve inversion of asteroid 1620 Geographos (Michalowski *et al.* 1994). Its axial ratios are $a/b = 2.6$ and $b/c = 1.1$; light curves extant of Geographos show (peak-to-peak) amplitudes in excess of 1 magnitude.

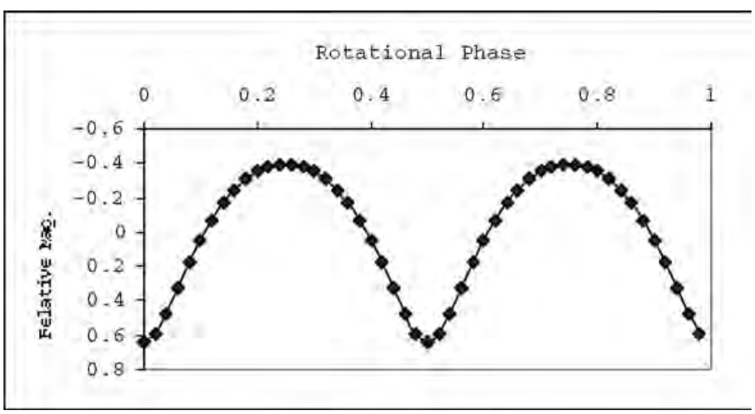


FIGURE 2 – $\theta = 0$, $\phi = 0$, $\alpha = 0$

In Figure 2 we see an equatorial view of Sebago at full phase. The amplitude is in excess of 1 magnitude and the curve shows characteristic broad maxima and deep narrow minima. As one would expect from symmetry considerations, the period of the

[1] Sebago is a variety of potato, *Solanum tuberosum*, typified by a smooth and elongated shape.

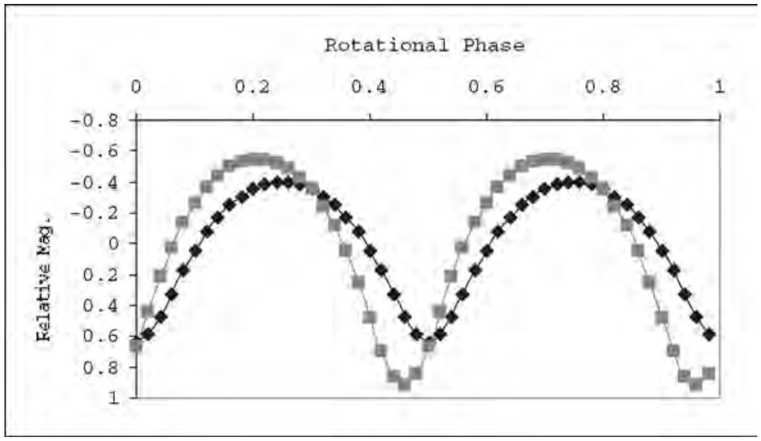


FIGURE 3 – $\theta = 0$, $\phi = 0$, $\alpha=0$

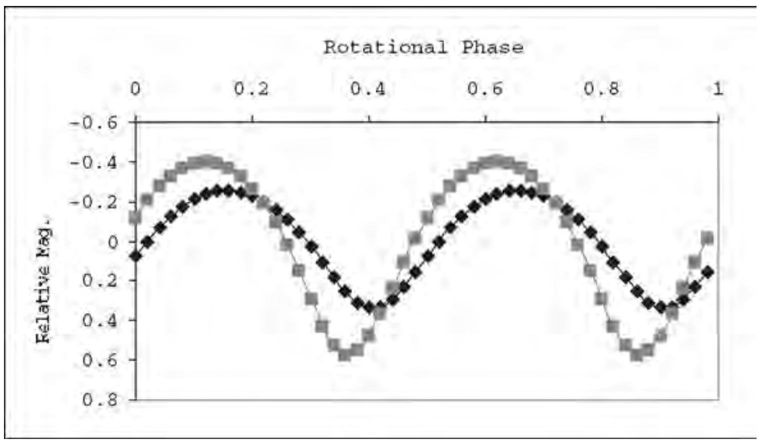


FIGURE 4 – $\theta = \pi/6$, $\phi = \pi/6$, $\alpha = 0, \pi/6$

light curve is exactly half that of the rotational period of the asteroid it is modelling. In Figure 3 we see the full phase equatorial view together with a view at phase 30 degrees. In Figure 4 we see an oblique view at a phases of zero and 30 degrees. In each case the magnitudes have been adjusted to a mean of zero, and we see that the effect of increased phase angle in both cases is to increase the light curve amplitude.

Conclusion

As can be seen from the few examples presented here, we have barely scratched the surface of the photometric properties of these objects, e.g. just what is the nature of the amplitude-phase relationship? The curves shown make interesting comparisons to the real light curves of Geographos, which are readily available electronically. Another asteroid that has been intensively studied is 6489 Golevka, for which quite a few light curves are available (Mottola *et al.* 1997). Both Geographos (Ostro *et al.* 1996) and Golevka (Hudson *et al.* 2000) have been subject to Earthbound radar scans revealing that the former is indeed shaped very much like a triaxial ellipsoid (albeit a bit bent and roughened) with similar proportions to Sebago, whereas Golevka proves to have a highly irregular shape. Some light curves of Golevka are suggestive of a triaxial ellipsoid, whereas others, such as those in which one of the two maxima disappears entirely, are not. A very interesting set of light curves for several asteroids at near zero phase angle may be found in Piironen *et al.* (1994). Readers could well peruse these light curves and decide for themselves which of these asteroids would be suitable candidates to be modelled as triaxial ellipsoids.

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All the above references, except those to Icarus (`icarus.cornell.edu`), are available through the NASA Astrophysics Data System (`adswww.harvard.edu`).

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Epilogue

Astrometric Considerations. Although it has been convenient to do theoretical photometry in the frame of reference centred on the asteroid, observational astronomers must work from an Earthbound frame, which in practice would be referred to the plane of the ecliptic rather than the equatorial plane.

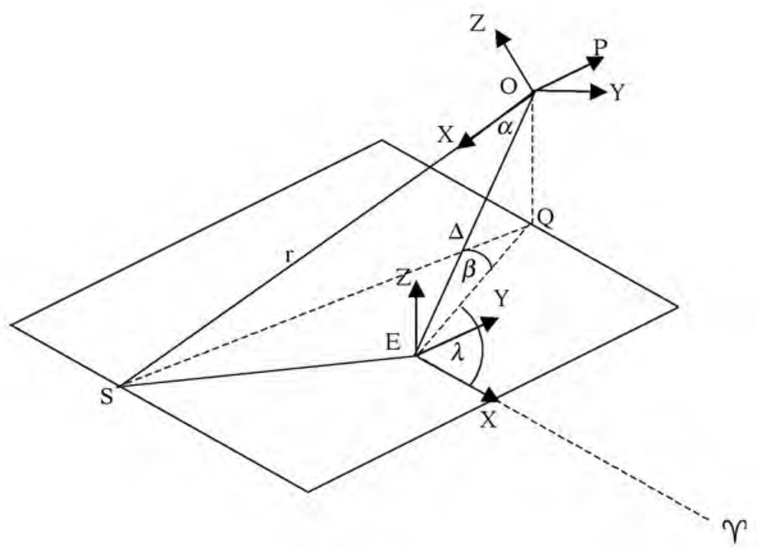

Figure 5

The situation is shown in Figure 5, where the (projected) rectangle represents the plane of the ecliptic and the asteroid at O has geocentric ecliptical coordinates $(\lambda,\beta) = (\angle ♈EQ, \angle QEO)$. S and E are of course the Sun and Earth, respectively. In the asteroid-centric frame of reference OXYZ, the X-axis points towards the Sun and the triangle SOE lies in the OXY plane and triangle SQE lies in the plane of the ecliptic.

Consider the geocentric frame of reference EXYZ, in which the X-axis aligns with the first point of Aries and the EXY-plane is the plane of the ecliptic. The direction of the spin axis OP of the asteroid may be specified by ecliptical coordinates (λ_p, β_p), which in the EXYZ frame will have directional spherical coordinates $(\pi/2 - \beta_p, \lambda_p)$ so that the unit vector in the direction of spin is $(\cos\beta_p\cos\lambda_p, \cos\beta_p\sin\lambda_p, \sin\beta_p)$ in Cartesian coordinates. I leave the following question to interested readers: What then, in terms of the ecliptical coordinates, (θ,ϕ) are the directional coordinates of the spin vector in the OXYZ frame, the frame we have used for our theoretical photometry?

Martian Motion I: *Zoom In*

by Bruce McCurdy, Edmonton Centre (bmccurdy@telusplanet.net)

…One way or another we're all in the dark

Fireflies, sparks, lightning, stars
Campfires, the moon, headlights on cars
The Northern Lights and the Milky Way
You can't see that stuff in the day

When the Earth turns its back on the Sun
The stars come out and the planets
Start to run around
They call that day is done
But really it is just getting started
Some folks take comfort in that

— Guy Clark, "The Dark"

No planet runs around more brazenly than Mars, and in the thousands of years in which the Red Planet has captured humankind's attention with its bizarre behaviour, it has never run quite as close to Earth as it will this upcoming August 27.

Some years ago, for reasons unknown, I undertook a detailed perusal of the table "Oppositions of Mars, 0-3000" in Jean Meeus' indispensable *Astronomical Tables of the Sun, Moon and Planets*. ("How can you *read* that?!" my long-suffering Astronomer's Spouse Anna inquired. "It's nothing but *numbers!!*")

Among other things, I noted the fact that in the summer of 2003 Mars would make its closest approach to Earth (0.37272 AU) at anytime since the beginning of the table. As my eyes swept from past to future, I was surprised to see that that "record" would be surpassed eight times in the current millennium. This suggested some sort of shifting conditions favouring a slow advance of Mars when under ideal circumstances, but I was utterly in the dark as to the root causes. I resolved to check this out further at some point, and now that 2003 has arrived, it seems to be a logical time to follow through (Meeus 1983-95).

As is invariably the case, to the trained eye there are interesting patterns embedded within the 1406 oppositions listed on the table. In previous columns I have discussed the increasing degree of repetition in perehelic oppositions of Mars at intervals of 15, 32, 47, 79, and 284 years, and these periodicities and combinations thereof hold the key to recognizing what is happening in the still longer term.

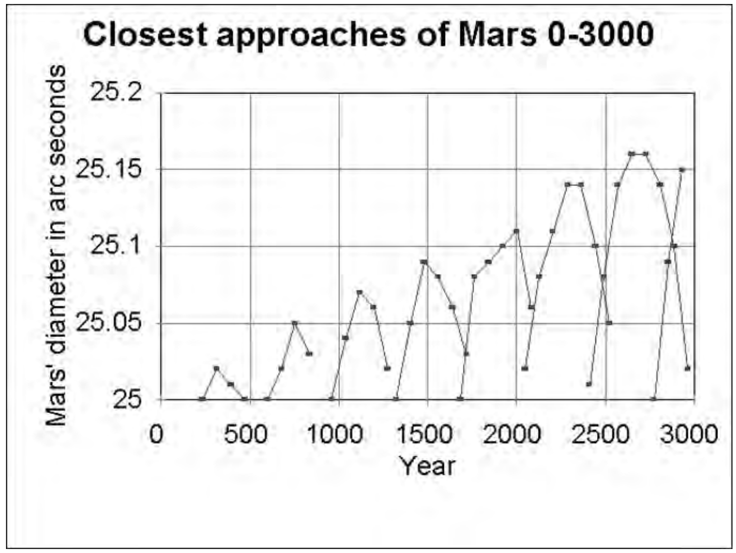

Figure 1 – Connecting the dots at 79-year intervals reveals an advancing series of wedges, which is reminiscent of the sight of Saturn's rings incrementally drifting into the field of view of my Dobsonian. While the shape of each wedge is unique due to the non-periodic influence of Jupiter, the overall slope of Mars' gradual approach is obvious. The incomplete eighth wedge can be predicted to hit new heights in 3013 and/or 3092, which indeed it does at 25.18″ in both instances.

While the Red Planet's approach appears inexorable, the above is merely a tiny portion of a much greater curve that oscillates with a period of millions of years.

This figure was developed independently, yet bears a remarkable mirror image similarity to the one appearing on P. 217 of *More Mathematical Astronomy Morsels* by Jean Meeus, acquired by the writer shortly before this column went to press. Meeus used a different trigger, specifically Mars < 0.37500 AU, which is equivalent to 24.97″. This slightly lower threshold yielded 5 additional events to the 43 shown here over 3000 years.

I use what I call a stroboscopic technique, identifying all events exceeding a certain threshold close to the extreme, in this case an apparent diameter of 25 arcseconds, which occurs only during exceptional oppositions. In the period 0-3000 C.E., Mars will achieve an apparent diameter of at least 25.00″ on 43 occasions, distributed as follows:

0-1000	9 occasions
1001-2000	14 occasions
2001-3000	20 occasions

In addition to the gradual approach

of the best apparitions, the increasing numbers of events exceeding the threshold level is another important clue that the orbit of Mars is inching closer to that of Earth.

The method will typically reveal groups of similar, or homologue, events at extremely regular intervals. In the current case the base periodicity of 79-year intervals is immediately apparent, as shown in both the table and in Figure 1. Indeed, this year's approach will break the previous "all-time record" of 25.10″ set in 1924, which itself broke the mark of 25.09″ set in 1845.

The base period is never perfect: each homologue series recedes from its maximum as it shifts out of phase with optimum conditions, and its successor follows in a sequence that is offset to its predecessor's pattern by a minor period, in this case by 32 years. (In algebraic terms, the relationship between any two dates a and b in consecutive series A and B is invariably ($b - a = 79x - 32$), solving for integer x.) Each series has a higher maximum and (typically) a greater number of threshold events than its predecessor. As series become longer in the current millennium they start to overlap, as can be seen in the irregular chronology towards the bottom of the table, in which case x can be zero or a negative integer.

Another fact of interest is the date of the first "event" of each series: 235, 598, 961, 1324, 1687, 2050, 2413, 2776, is in every instance separated from adjacent series by an interval of 363 years. That is a combination of the two best fits of established Martian cycles, 79 and 284 years. I was somewhat suspicious as to the meaningfulness of this super-period; as the groups grow larger, the first event of a series shifts gradually further away from the peak that defines that series. The peaks, shown in bold on the table, are therefore separated by various intervals, sometimes 363 years ($x = 5$), sometimes 442 ($x = 6$). In one exceptional instance (1482-2003), the interval is 521 years ($x = 7$), in another (2003-2287) only 284 ($x = 4$).

These last two intervals, which are consecutive, suggest the current maximum of 2003 is "late." While the overall pattern of incremental approach is plain enough, on closer examination the shape of each wedge in Figure 1 displays some asymmetry. In the current series, Mars grows progressively closer by 0.01″ from 1766 to 1845 to 1924 to 2003 before falling off by 0.05″ in 2082. A truly symmetrical series would not hit its peak at the fifth of six events. What is happening in 2003 to pull Mars just that little bit closer?

I attribute it to secular perturbations caused by the position of Jupiter. In *Astronomical Tables,* Meeus lists all perihelia of Mars from 1960-2020; of the 33 events listed, the closest, by a not-insignificant margin, occurs on August 30, 2003 when Mars will be 1.38115 AU from the Sun (or technically, from the barycentre of the solar system). It is to be expected that the proximity of Earth will draw the Red Planet a little bit closer; that would be a constant when considering any perihelic opposition. In 2003, Jupiter will be in conjunction with the Sun on August 22, pretty much maximizing the gravitational pull on Mars in the direction of the Sun, and by extension, towards Earth. In 1924, when the current series "should" have peaked, Jupiter's conjunction occurred in December, four months after perihelion. On that occasion, therefore, Jupiter would have had a mildly moderating effect on Mars' position.

More evidence exists for a 363-year periodicity. Mars' closest approach of the current millennium (0.37200 AU) occurs in 2729, which is 2 × 363 years from 2003. In the fourth millennium, Mars will come still closer on 13 occasions, with new records being set in 3013, 3092*, 3455*, 3534, and 3818* (0.37061 AU). The dates marked with an asterisk occur at 363-year intervals after 2729, with the two exceptions offset by 79 years and both occurring relatively close to a conjunction of Jupiter with the Sun.

These periodicities are the best "fit" for both Earth and Mars to return to the same spots in their respective orbits, but the slope implicit in the figure tells us the orbits themselves are clearly evolving. What might be the root cause?

Let's start in the confessional: this is an extremely complex problem that is a couple of orders of magnitude more difficult than the relatively simple matters normally considered by your humble and under-educated correspondent. Nonetheless, an examination of first principles should shed some light.

My first thought was that since the semi-major axes (the lines of apsides) of the two planets are gradually advancing but at different rates, they are effectively rotating relative to each other. As their orientation approaches 180°, Mars' perihelion will occur ever closer to Earth's aphelion, minimizing the distance between the two orbits. A little research quickly shot holes in that idea: Mars' longitude of perihelion (~336°) is currently 127° behind that of Earth (~103°). Both perihelion points are advancing, that of Mars a little more quickly (1560″/Century v. 1198″/Cy, or roughly a full rotation in 80,000 v. 110,000 years). Their relative orientation is therefore *receding* from 180°, and the net effect, taken in isolation, should be a gradual increase of the closest distance between the two orbits. Right idea, wrong epoch (`ssd.jpl.nasa.gov/elem_planets.html#elems`).

A second consideration is Mars' position relative to the ecliptic. It stands to reason that Earth's distance from Mars is minimized when the Blue Planet is on or near the Sun-Mars plane. At present that is far from the case. Mars currently has an inclination of 1.85°, which is most apparent 90° from the nodes of its orbit. The perihelion point is currently fairly close to that extreme, with a so-called argument of perihelion of 286°, meaning Mars at perihelion is about 74° behind its ascending node. Much as I like a good argument, this is one we northerners can't win, as it pushes Mars not only further away, but further south. This is exacerbated considerably by foreshortening; from Earth's perspective Mars will be some 6° south of an already unfavourable late-summer ecliptic. Over the longer term the Earth-Mars distance will be reduced when either of two conditions are met: a decrease of Mars' inclination, or, since we are really interested in only one point (perihelion) on its orbit, the approach of that point to one of the nodes. Both of these factors are currently tending in that direction, particularly the latter; like the Moon, the nodes are regressing and perihelion advancing with the net effect that the two points are rotating towards each other at a combined rate of 2580″/Cy.

Even with the presently unfavourable argument of perihelion, the situation could be a lot worse, as Mars' inclination is subject to fluctuations over a 1.4-million year super-period that can take it above 7°. At higher inclinations close approaches would only be possible when the perihelion point is passing through a node.

A third very significant effect is the changing eccentricity of Mars' orbit. Mars is noted for its highly eccentric orbit ($e = 0.0934$), which after all is reason for the different distances from one opposition to the next. What is not so well known is that that eccentricity undergoes a slow, dare I say eccentric, oscillation over a period of 96,000 years superposed on a super-period of some 2,200,000 years, which can be envisioned as a saw tooth curve. Currently that eccentricity is increasing, and will achieve its next maximum of 0.1051 around 25,000 C.E. According to Meeus (2002), at that time Mars will achieve its closest approach to Earth in the entire super-period starting in One Million Years B.C.E. (when Raquel Welch ruled the Earth). Meeus places perihelic oppositions at this maximum at 0.3613 AU, which works out to an apparent diameter of ~25.90″, only marginally closer than this summer's extravaganza (Simon *et al*. 1994).

The current close perigee is another incremental advance towards that extreme, a data point on the biggest tooth of the saw. It is just below the maximum of the penultimate tooth, so it's not quite the closest approach in millions of years, but not far from it. Meeus figures it to be the closest approach in some 73,000 years, a useful piece of information for those who will be sharing views of the Red Planet with the public this summer.

In theory, the minimum possible distance would be achieved when all of the factors cited above peaked together, Earth's own more moderate eccentricity also maxed out at 180° orientation, and Earth and Mars (and Jupiter) occupied the appropriate positions within their orbits simultaneously. When will the saw teeth of the various periods and super-periods all mesh in the closest fit to these idealized conditions? That is far beyond the capabilities of the writer, and may well be outside of the best current orbital theories.

Is any of this important? Certainly. Changing eccentricity and advance of the perihelion combine with other factors such as precession and obliquity of the ecliptic to cause long-term changes in a planet's climate. Collectively, these are known as Milankovitch cycles. A related effect, which would also play a crucial role in the evolution of a planet, is polar wandering (Ward 1992; Sheehan 1996; `aa.usno.navy.mil/faq/docs/seasons_orbit.html`).

The current situation, with quite high eccentricity, relatively low inclination, and moderately favourable orientation of the orbital ellipses of Earth and Mars, is much closer to feast than famine (especially for those planning a southern vacation). A million years ago, and again a million years from now, even an optimum perihelic opposition of Mars could be as distant as 0.48 AU, during which the Red Planet would never appear to be even 20″ in diameter, a much fainter spark in the dark. I guess I'll be needing a bigger telescope. Right, dear?

Year	Diameter
235	25.00
314	**25.02**
393	25.01
472	25.00
598	25.00
677	25.02
756	**25.05**
835	25.03
961	25.00
1040	25.04
1119	**25.07**
1198	25.06
1277	25.02
1324	25.00
1403	25.05
1482	**25.09**
1561	25.08
1640	25.06
1719	25.03
1687	25.00
1766	25.08
1845	25.09
1924	25.10
2003	**25.11**
2082	25.06
2050	25.02
2129	25.08
2208	25.11
2287	**25.14**
2366	25.14
2445	25.10
2524	25.05
2413	25.01
2492	25.08
2571	25.14
2650	25.16
2729	**25.16**
2808	25.14
2887	25.10
2966	25.02
2776	25.00
2855	25.09
2934	25.15

Acknowledgements:

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Scenic Vistas

The Deeper Sky of Corona Borealis

by Mark Bratton (mbratton@generation.net)

On late spring evenings, the little constellation of Corona Borealis tends to be overlooked by deep-sky observers who are drawn to richer fields in Ursa Major, Virgo, or Coma Berenices. A glance at a star atlas such as *SkyAtlas 2000.0* reveals the fact that not one deep-sky object is plotted within the borders of the constellation. On the surface, at least, the typical observer's lack of familiarity with this patch of sky would seem to be justified.

On the other hand, a more detailed atlas such as *Uranometria 2000.0* reveals a different picture. Thirty-eight individual galaxies are plotted on the charts, many of them in the northeastern corner of the constellation, hard by the border with Hercules. Consultation of *The Deep Sky Field Guide to Uranometria* indicates that, almost without exception, these galaxies are small and rather faint, typically fainter than magnitude +13 and smaller than one arcminute in both major and minor axis. When observing in that region of the sky, we are observing far beyond the confines of our local supercluster.

How far is a matter of conjecture. Astronomers are still not 100% certain of the distances of even nearby galaxies and the primary yardstick used for distant galaxies, measurement of a galaxy's radial velocity by means of its redshift, may not be entirely reliable. Nevertheless, if the core of the Virgo cluster (mean radial velocity around 1000 km s^{-1}, distance about 50-60 million light years) can be used as a rough gauge, the estimated distance to the clutch of galaxies located in Corona Borealis is interesting indeed. The sampler of galaxies discussed below all have radial velocities ranging from 8400 km s^{-1} to 10,200 km s^{-1}, or about eight to ten times the mean measured for the Virgo Cluster. It seems likely, then, that the galaxies located in this portion of the sky are about 400 to 600 million light-years from our home galaxy.

Even with a moderate aperture telescope (12- to 18-inch mirror), the following galaxies are faint and show little or no detail, even under high magnification. Sometimes it is difficult even to surmise whether these objects are round or oval in shape, or the orientation of their major axis. Often, success is measured in just being able to see the galaxy at all. The fun and challenge of this kind of observing comes from keeping a record of the observation, with a written description and a sketch with field stars plotted as accurately as possible. Later, accessing a photographic database on the Internet, like the Digitized Sky Survey, allows the observer to call up photographs of the fields observed to compare with his/her records. It's interesting to see how accurate the observation was, whether threshold objects suspected at the eyepiece actually exist and whether anything might have been missed.

The following observations were all made on the evening of July 5/6, 1997 with my 15-inch Dobsonian from my old cottage located outside Sutton, Québec. Transparency was excellent with sixth-magnitude stars visible with direct vision and seeing conditions varying between 3 and 6 (on a scale of 10) during the course of the evening.

NGC 6089

Situated about one degree southwest of Sigma Coronae Borealis, NGC 6089 is a small galaxy that glows faintly at magnitude +14. In my notes, I described it as very faint with a faint stellar core occasionally visible at a magnification of 272×. I also described it as oval in form and slightly elongated south-southwest/north-northeast. Later examination of a Palomar Sky Survey image revealed two galaxies seemingly in contact, with the smaller galaxy, evidently a spiral, located to the northeast.

One degree to the southeast of NGC 6089 is an isolated galaxy, NGC 6103. I described this galaxy as a little fainter than NGC 6089 (it is actually slightly brighter, at magnitude +13.8) and broadly concentrated to the middle. It appeared round with better-defined edges than NGC 6089. The Palomar Sky Survey image revealed what appears to be a spiral slightly elongated in an east/west direction with a slightly brighter core.

NGC 6103

Brighter than the preceding, NGC 6104 is at magnitude +13.2. My notes mentioned that it was pretty much brighter to the middle, though no stellar core was noted. The galaxy appeared very slightly elongated west-southwest/east-northeast. I also noted a possible anonymous galaxy or faint field star to the east-southeast. The Palomar Sky Survey image of this region was very interesting indeed. It revealed a galaxy with what appeared to be a double nucleus enclosed by a ring structure. In form, the galaxy reminded me of images of the Cartwheel galaxy

NGC 6104

taken by the Hubble Space Telescope. The second nucleus may be a satellite elliptical galaxy seen in front of the galaxy or perhaps the core of a spiral, which is interacting with the larger galaxy. The Palomar image also revealed an elliptical galaxy where I had suspected a galaxy or star to be located. This galaxy was later identified as MCG +6-36-12, magnitude +14.4.

Both NGC 6129 and NGC 6137 can be observed together in a medium magnification field. NGC 6129 is small and very faint, a round spot showing little concentration to the centre though its edges were well defined. Later examination of the Palomar Sky Survey image showed that NGC 6129 is an elliptical galaxy, the middle galaxy in an east/west chain of five faint galaxies.

NGC 6129

NGC 6137 was the brightest galaxy observed on the evening (magnitude +12.4), extending in a north/south direction with a faint star-like core visible using averted vision. A faint stellar spot was occasionally seen to the north. In the Palomar Sky Survey, NGC 6137 is an elongated elliptical galaxy with a companion galaxy (NGC 6137B) situated to the north-northeast.

NGC 6137

The final Corona Borealis galaxy observed on that summer evening six years ago was NGC 6142, a magnitude +13.8 spiral that I found faint and rather diffuse, more readily visible at 146× rather than 272×. A little brighter to the middle, this galaxy was much elongated in a north/south direction. A faint, round galaxy visible in the Palomar Sky Survey image was not even suspected.

NGC 6142

This kind of observing might not be everyone's cup of tea; it is a chore and a challenge to navigate through star-poor fields seeking faint patches of light barely brighter than the sky background. But there is a quiet sense of satisfaction exploring the night sky's back roads, seeking out galaxies seldom seen. Observers familiar with this kind of observing know that faint objects far outnumber bright objects in the deep-sky.

The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope. The plates were processed into the present compressed digital form with the permission of these institutions.

RASC member Mark Bratton, who is also a member of the Webb Society, has never met a deep-sky object he did not like. He is one of the authors of Night Sky: An Explore Your World Handbook.

Boosting Performance by Apodization

by Ernest Pfannenschmidt (angieandal@shaw.ca)

In moments of good seeing the telescopic image of a star will resemble the classic Fraunhofer diffraction pattern of a circular aperture, displaying an Airy disc surrounded by concentric rings of diminishing brightness. At best about 84 percent of the incident light is contained in the disc, the remainder being dispersed into the ring structure; hence contrast in an image is always less than the inherent contrast of the object being viewed.

Apertures other than circular, or those with obstructions in them, degrade contrast further by altering both the geometry and the energy distribution within the diffraction image. A central obstruction of 30 to 40 percent of the aperture's diameter — quite common in Schmidt-Cassegrain telescopes — is harmful to planetary detail, even when the optics are perfect. Obstructions of this size reduce the disc brightness by 24 percent and smear out the pattern so that while a planet's bright edge remains sharp against the dark sky background, low contrast features on its disc are noticeably softened.

Figure 1 – The author's 5-inch f/15 folded refractor with apodizing screen.

Contrast performance can be improved by apodization, which is used in microscopy, spectroscopy, and surveillance. The term derives from the Greek alpha or "α," to take away, and podoz, meaning foot. It refers to the process of suppressing the secondary maxima (or foot) of a diffraction pattern whose prominence can in some cases diminish the performance of an instrument to a point where some type of manipulation is called for, as when observing low contrast features or viewing close-binary stars where the difference in brightness between the components is extreme. In the latter case the image of a faint companion star is often completely obscured by the rings in the diffraction pattern of the bright star; Sirius being a good example. A two dimensional image, such as a planet, may be envisaged as composed of innumerable tiny object points, each emitting a light wave that is diffracted into an Airy pattern by the aperture. These patterns intermingle and overlap and so create a blurring matrix that reduces contrast.

The simplest way to modify the diffraction image in an advantageous way is to alter the transmission characteristics of the aperture. This can be accomplished by placing a graded glass apodizing plate or a wire mesh anti-diffraction mask at the upper end of the telescope tube. Such masks were first suggested by J.F. Herschel and used by William Dawes. Later on, W. Pickering and other renowned visual observers used them in their planetary and stellar work.

Only a clear and evenly illuminated aperture produces the classic diffraction image. If the illumination within the aperture is altered by a device that becomes increasingly more opaque as it spreads radially out from the centre towards the edges, then the transmitted energy will correspondingly decrease until it becomes negligible at the periphery of the entrance pupil. If this opacity increase fits a Gaussian or bell-shaped distribution curve, then the ring system will be attenuated or suppressed without noticeably broadening the Airy disc, which heightens contrast performance.

In the 1950s, the Edmund Scientific Company sold an apodizing screen devised by Hal Metzger. Arthur Leonard championed such screens during the '60s and the one I use and describe here is based on these models. One version is for use with refractors or off-axis reflectors, the other for scopes with central obstructions. The particulars are not written in stone, experimentation is encouraged for those using compound telescopes with large secondary mirrors.

An Apo-Mask consists of three wire screens sandwiched between two plywood rings that slip snugly over the telescope tube end. Use wire screen-door mesh purchased from any hardware outlet. To assemble a mask simply cut out three rings of mesh as per the enclosed table.

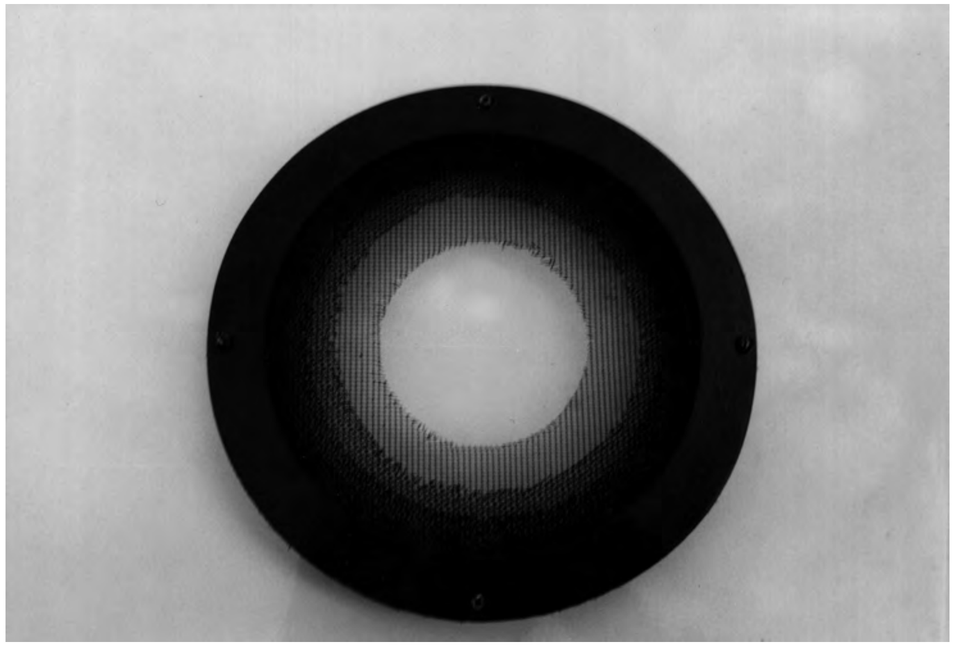


Figure 2 – Home made apodizing screen.

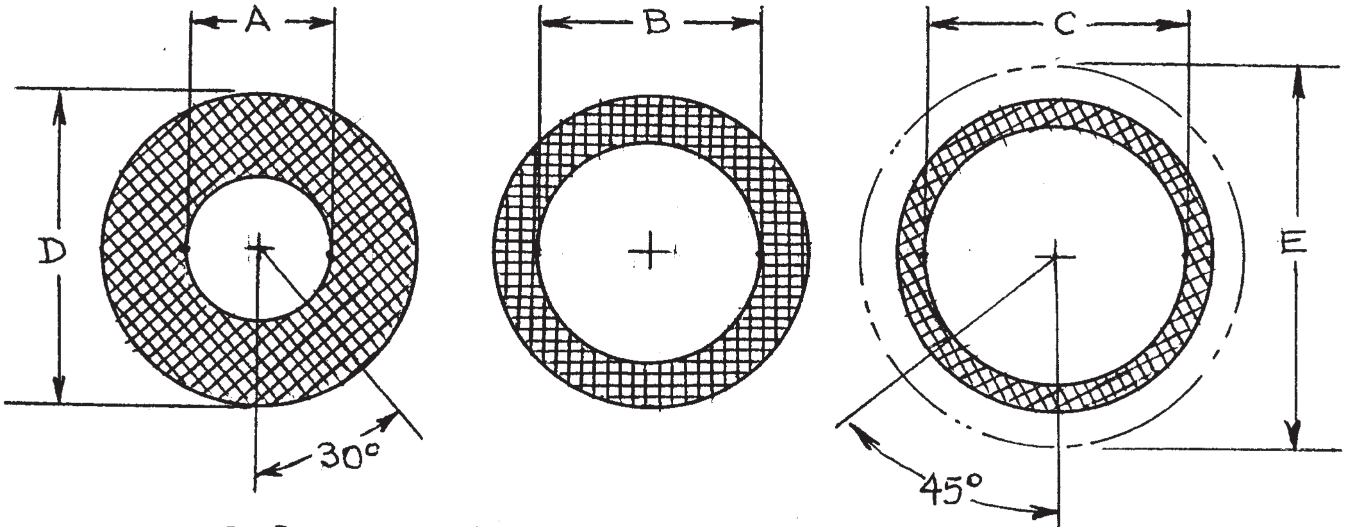
Fasten the screen with the smallest central hole to one plywood mounting ring (1/2 or 5/8-inch thick) using double-sided masking tape. Next, tape the second screen to the first one but with its mesh pattern rotated 30-degrees to the right. The last screen is then taped on to the others with its mesh rotated 45-degrees to the left. Position and screw on the outer plywood ring to hold things together and the job is done.

Use a jigsaw or a scrollsaw to cut out the rings, then use one of these as a template for cutting out the circular screens. It helps to tape the screen material to a cutting board, lay the plywood ring over it and with a hobby knife cut out the wire disc. Tape this disc to the board so it will lay flat and retain its shape. I use another suitably sized circular template cut from stiff poster board to cut out the central hole. When finished I spray-paint the mask and the mesh with two coats of flat black rust paint.

The mask works best on clear-aperture telescopes but improves images in reflectors as well. Subjectively speaking the mask enhances planetary detail by factors of 1.5 to over 2.0. These wire masks produce small diffraction spectra spaced radially outward and around the object, which one soon learns to ignore. The object is seen in its natural colours with practically the full effective resolution, though not with the full light grasp of the aperture (about 3/4 of a visual magnitude is lost). Apodization is a form of spatial filtering and observers soon find that the mask helps during poor seeing conditions and when objects are seen low in the sky. With the cost of materials and labor so low, it's puzzling that so few observers bother to give this rewarding telescope accessory a try.

Ernie Pfannenschmidt is a retired engineer in his eighth decade. He served with the National Research Council of Canada, Herzberg Institute of Astrophysics for 20 years as an observational astronomer and opto-mechanical instrument designer. He has conducted six years of site testing in Canada and Saudi Arabia.

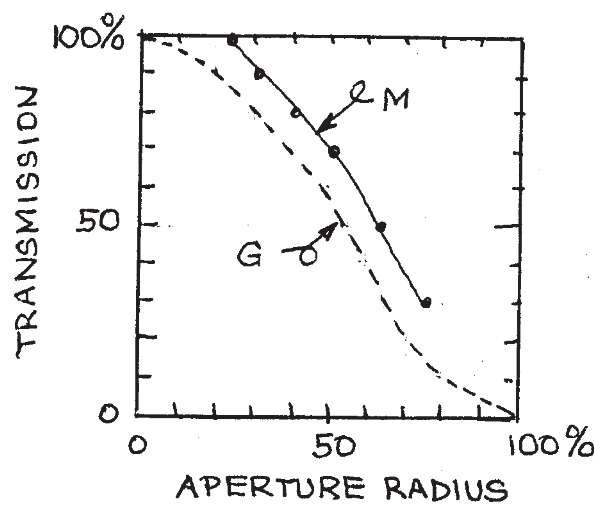
FLY-SCREEN APODIZING MASK GEOMETRY



HOLE DIAMETERS IN SCREEN MESH AS PERCENTAGE OF LENS OR MIRROR APERTURE:

OPTICS	A	B	C	OPTIONAL	
REFRACTORS	52%	76%	88%	94%	30°L
OBSTRUCTED APERTURES	55%	78%	90%	96%	30°L

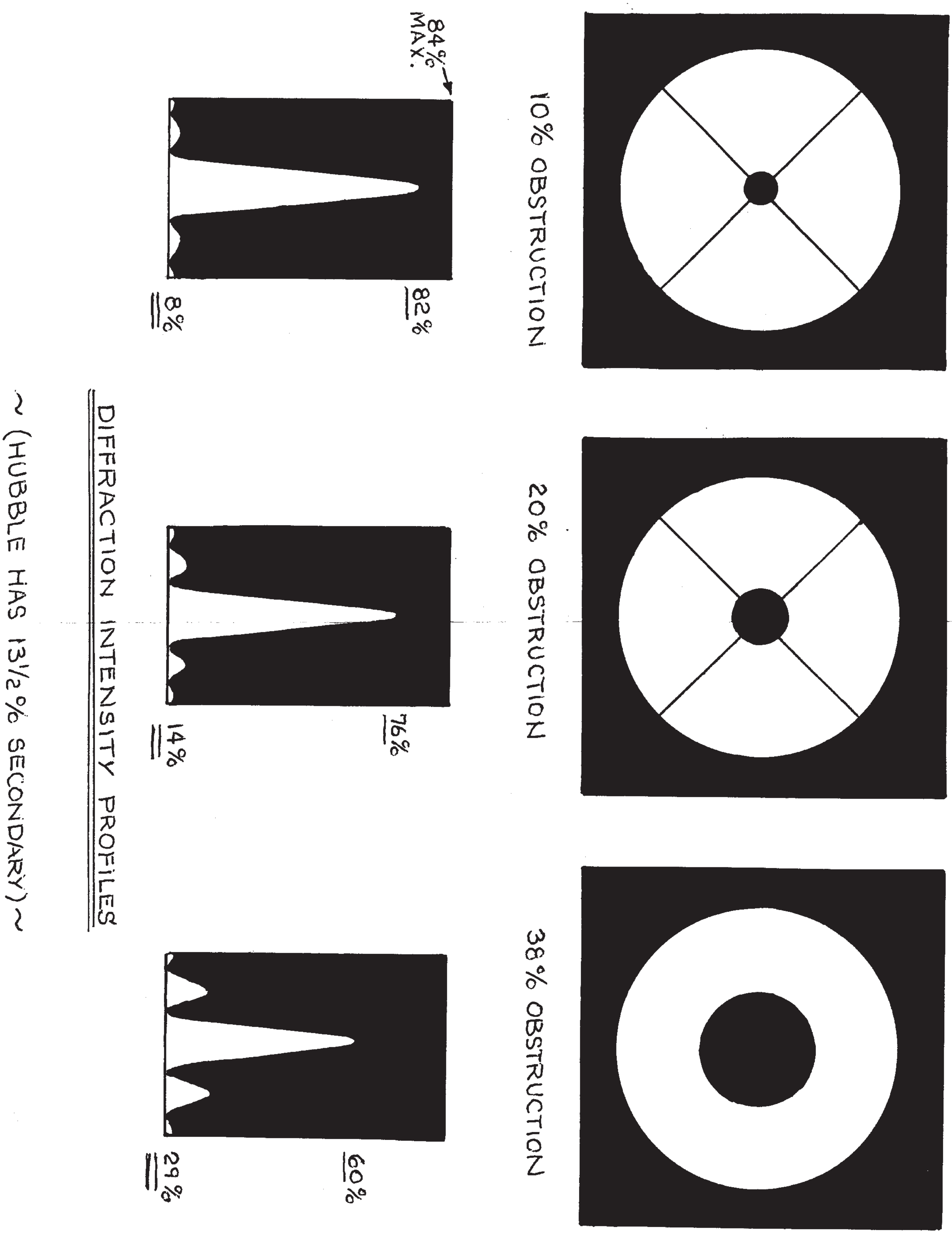
D = CLEAR APERTURE OF OBJECTIVE OR MIRROR.
E = OUTSIDE DIAMETER OF MOUNTING RINGS AND FLYSCREEN DISKS.



TRANSMISSION PLOT OF SCREEN MASK

G = GAUSSIAN IDEAL

M = MEAN OF DAYLIGHT & INCANDESCENT LIGHT AS MEASURED.


10% OBSTRUCTION
20% OBSTRUCTION
38% OBSTRUCTION
84% MAX.
82%
8%
76%
14%
60%
29%
DIFFRACTION INTENSITY PROFILES
~ (HUBBLE HAS 13½% SECONDARY) ~

Photos Through The Eyepiece

by Terry Adrian, Okanagan Centre (terryadrian@shaw.ca)

Not having any photographic experience, and being new to astronomy, I was initially overwhelmed by the complexity of setting up and taking astrophotos. Once I got over the shock that what is seen through the telescope looks nothing like the marvelous photos in most astronomy magazines, I set out in an attempt to capture my own images.

Having just joined the RASC Okanagan Centre, I started asking questions only to find out that very few amateur astronomers are interested in astrophotography. With a large family and having gone back to university I found myself unable to acquire the necessary equipment, and at best the cost of film processing would have meant many rolls of film just sitting in a drawer waiting for developing.

A friend had just acquired a digital camera and suggested that I try it. I was very reluctant and stuck on the fallacy that film is and has to be the only way to go, but after some persuasion I took the camera. Knowing that deep space targets would be out of my reach, I focused on the Moon; after all what better way to study the Moon? One night with a first-quarter Moon, I pointed my 8-inch Dobsonian at my target, held the digital camera to the eyepiece, and using the viewing screen on the back of the camera, I started taking shots. I was to find out later that this type of imaging is called prime focus photography. The camera was set on 800 × 600, which meant I was able to take 48 photos. After about an hour I had filled up the camera's storage cartridge, but I was not very excited about what I was sure were poor photos and I put the camera away.

The next day just as I was about to delete the memory cartridge (after all how good can a point and click astrophoto be anyway?), my wife convinced me to download them to the computer. After doing so, we started going through them one by one. What we saw astounded both of us. Flipping from one image to the next we found that not all but most of the images I took actually turned out. Not only that, they actually looked very good.

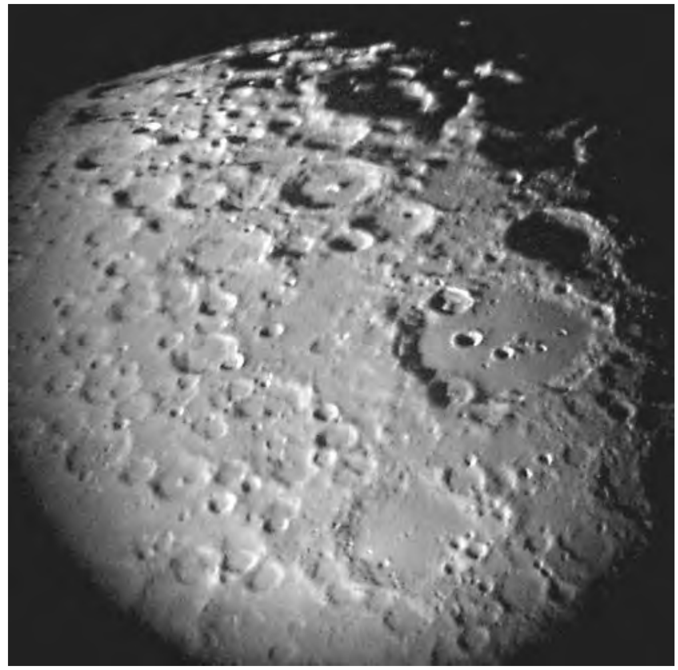


Figure 1. Lunar shot of the Moonscape around the crater Clavius, taken with an Epson Digital PC Camera. Telescope used was an 8-inch Skywatcher Dobsonion.

Having repeated this process many more times since, I find that 6 out of 10 are good enough to keep. I started examining my photos and trying to identify the lunar features. Thanks to my friend and the use of his digital camera, astrophotography was within my reach. I strongly recommend to anyone who has access to a digital camera, go out on a Moon-lit night and give it a try. The results just may surprise you.

Terry Adrian is the current editor of the Okanagan Centre newsletter the FOCUS. An avid astronomer for two years, Terry finds astronomy through the lens of a digital camera to be a truly rewarding experience (`www.members.shaw.ca/astronomy/`).

STS-107

by Sherrilyn Jahrig (sj_starskip@hotmail.com)

For the beauty of your death I write this poem
even as your limbs still slip through shocked fingers
even while Fate's refrain pulls the petals one by one

loves us
loves us not

questions spin
stillness answers

we have felt the thrill of meteors, fireballs
misnaming them Falling Stars, now we are too wise
knowing their particulars.

For the beauty of the earth you rode to space
searching for better questions
scouting our future through velvet vacuum of nothing

your fate sealed from launch
your planet sealed from you

friendly fire
thin air

particles . . . we really thought them pretty
burning plasma in upper atmosphere
pebble-sized, sand-grains, rocks in our heads to send

real hearts to flesh out truth.

* * *

We are learning things slowly now
even though there is a lot of noise

how a rat adapts to micro-gravity
see her floating like a drunk
careening toward the camera

how moss, unexpectedly
chooses spiral growth in space

how humans also lean toward the light
struggle free from gravity

how a tarnishing treasure of planet
looks to us from far away

how to prolong a human life
from a short breath to a long sigh.

* * *

I hold my fingers across the sky
measure degrees of sacrament

we cannot begin to countdown the loss
we know it was more than a sum of parts

to calculate a dream's mass
to determine velocity of hope

the sun rises, stars do fall
and science never promised magic.

I put my hands in pockets
kick a rock homeward
walk the walk of gravity
through this continuing
land of no return.

Sherrilyn Jahrig is currently Public Education Director at the Edmonton Centre, RASC. She has taught an astronomy and creative writing course, "If Stars Could Speak," to grade4-6 writing camps and has published many astronomical poems.

Reviews of Publications
Critiques d'ouvrages

Walter Baade: A Life in Astrophysics, by Donald E. Osterbrock, pages xii + 270, 16 cm × 24 cm. Princeton University Press, 2001. Price $29.95 US hardcover (ISBN 0-691-04935-X).

Donald Osterbrock refers to astronomer Walter Baade as little known, but that is certainly not the case among those who have studied galactic astronomy in the last 50 or 60 years. It is a well-known story among galactic astronomers how Baade, as a German resident alien, was left to work virtually alone at the 100-inch reflector of the Mt. Wilson Observatory from 1942 to 1945, most scientific and technical staff having been drafted for the war effort. That gave him a unique opportunity to use the world's largest telescope in the blacked-out skies of southern California. During that period he carried out observations of stars in open and globular clusters as well as of stars in the Milky Way Galaxy and nearby members of the Local Group (M31, M32, and the small, loosely-bound Sculptor and Fornax galaxies). It was on the basis of such observations that he was able to formulate and then substantiate the concept of two distinct types or populations of stars, which is a cornerstone of galactic structure and stellar evolutionary studies.

Walter Baade is a compilation of four papers, including revisions and augmented text, that the author published in the *Journal for the History of Astronomy* between 1995 and 1998. Osterbrock has drawn upon many sources for the information used in his biography, including numerous personal encounters with Baade, archival records from the United States (for example, the Mt. Wilson papers are in the Huntington Library, while others are preserved in the archival collections of the American Institute of Physics) and Germany (at the Hamburg Observatory), as well as papers and images from Leiden University. Osterbrock also consulted many of Baade's contemporaries for information about the man, and the book contains information supplied by virtually a who's-who of mid-20th century astronomers, including Celia Payne-Gaposchkin and Baade's Ph.D. students, Alan Sandage and Halton Arp, to name just a few. There is some repetition and in the early pages the language is a bit forced. At times Baade is deified a bit excessively. But the writing soon settles down, especially when the science is described.

Osterbrock's book also presents mini biographies for a few people with whom Baade closely worked, such as Rudolph Minkoswki and Jan Oort. Additional commentaries are given for all of the top astronomers of the 1920s to 1950s who were influential in Baade's professional advancement and the development of his stellar population theories, namely Shapley, Hubble, Mayall, Hoyle, Zwicky, *etc. Walter Baade* also renders an informal history of the Mt. Wilson Observatory, as well as glimpses of life, politics, and scientific work at Baade's first institution, the Hamburg Observatory, and the other institutions with which he was associated: the MacDonald Observatory, and the planning, building, and early years of the Mt. Palomar Observatory, all from the perspective of a working astronomer. Not overlooked by Osterbrock are insights into the situation of German scientists in Germany after the Nazis came to power, an example being Rudolph Minkowski, and how scientific institutions were made to deal with the political demands of the new regime in hiring staff or planning new facilities. The manner in which Osterbrock follows Baade's travels between work at various institutions and work with his contemporaries is also interesting and useful for the historical record.

From the perspective of the history of science, Osterbrock has done an excellent job of tracing the science of stellar populations, a thread that only a working astronomer would be equipped to present with such clarity. The story begins with Baade's fascination with globular clusters and the variables found within them, and proceeds to the novae and supernovae he and Fritz Zwicky were able to find and to show were distinct from novae with regard to maximum absolute magnitudes attained. The story then continues with Baade's developing interest in dwarf galaxies, and with the nearby spiral galaxy M31 and its close companions.

His use of the 100-inch telescope with improved red-sensitive photographic plates, along with his meticulous and careful work, gave Baade a distinct advantage over many of his contemporaries. Baade studied the Crab nebula in detail, from which he developed a picture of its expanding shells, even suspecting, although not in print, that not all of the pre-supernova mass was accounted for. Recall that such speculation was prior to the discovery of pulsars and the discovery of the Crab Nebula pulsar in particular. Osterbrock's documentation of Baade's lines of investigation and speculation leading to the identification of two populations of stars — older, metal-rich stars and younger, metal-poor stars found in distinct regions of galaxies — is the most important contribution in the book. He has completed that task masterfully.

Population studies were not the end of Baade's career. He and Minkowski went on to make the important link in 1951 between recently discovered radio sources (Cas A and Cyg A) and their optical counterparts. Baade's studies, of course, were also significant in attempts to determine distances and the scale of the Universe.

As I read the book, I repeatedly asked myself, "To whom is the book directed?" Baade certainly deserves to be the source of a biography, but I am not convinced that the current approach required an entire book. The four JHA papers would probably have been sufficient. The problem with Osterbrock's approach is that it requires a fairly good understanding of the methods used in mid-20th century astronomy or the reader will soon be overwhelmed by the astrophysical details. I found it peculiar, for example, that Osterbrock inserts a footnote on redshifts, a concept with which anyone even vaguely interested in astronomy is aware, yet also assumes that readers possess an understanding of other concepts far less familiar to casual or even enthusiastic amateurs. The book would be useful for astronomy students at the third-year level or beyond, since it shows how a number of important astrophysical concepts were developed in the 1920s and 1950s. It also demonstrates how instrumental limitations and the improvements that Baade conceived had an impact on developing and verifying his ideas, and how they influenced his career path. *Walter Baade* would also be a useful read for astronomy graduate students in order to provide an example of how to get ahead in the professional field by making and developing the right types of contacts. Well-read amateurs will have a tougher, but rewarding, read if they have had some exposure to the subjects of stellar populations and stellar-evolution theory.

Walter Baade is illustrated with 28 halftones, has an extensive and useful 10-page index (thanks to Irene Osterbrock, the author's wife), a bibliography, and 25 pages of endnotes. The copyediting is fairly tight, although the odd error has crept in. The copy editors have also chosen not to modify Osterbrock's style of written English, which is, at times, unusual.

Randall Brooks

Dr. Randall Brooks is a curator at the Canada Science and Technology Museum and is a specialist in the history of astronomical instrumentation.

How the Universe Got its Spots: Diary of a Finite Time in a Finite Space, by Janna Levin, pages ix + 208; 16 cm × 21cm, Princeton University Press, 2002. Price $22.95 US hardback (ISBN 0-691-09657-0).

A review of the current state of cosmology, which forms the introduction to this book, touches on a wide variety of subjects. At first sight one might find it a bit superficial, but the scope of the book does not call for much more. The author does not provide detailed descriptions of astrophysical ideas. The book is more like a walk through a garden, looking at the plants and the flowers without picking them and ripping them apart or putting them under a microscope. Yet it is still possible to get a good feeling for the plants and the flowers, and it is a very pleasant walk.

How the Universe Got its Spots is a book about geometry. If you enjoy geometry, this is a book for you. I do enjoy geometry, and much like the author Levin I can relate to Einstein who is reputed to have said that anyone who is not interested in geometry should be concerned about it. As noted by Levin, geometry is an essential concept of our knowledge of the cosmos as expressed in physics. Geometry is the heart of mathematics, and apart from that, geometry is beautiful. The author is clearly of the same opinion since geometry is the leading spirit throughout the book.

Readers already familiar with most of the subject matter of *How the Universe Got its Spots* will still find it a pleasant read. As Fermi once noted, one should not underestimate the pleasure of listening to a well-known subject well explained, once again. For readers not familiar with the material, *How the Universe Got its Spots* provides a good introduction. The book avoids the mistake of trying to explain complex mathematical and physics subjects with even more complex analogies. Such analogies are generally not very useful for the uninformed reader; they may actually make ideas more obscure because of the added confusion of analogy. Comparing energy values as they exist in quantum mechanics with prices on the stock exchange has never impressed me as a useful way of explaining what physics is all about. I concur with Levin that it is better simply to provide an approximate description of the object, put it in its context, and move on.

There is a deep personal engagement in this book, part of which originates in its format. It is written as a series of letters from the author to her mother. We assume that the mother does not understand more about the cosmos than the general public, but the daughter likes to keep her informed as to what she is thinking about, what is important in her life at the time, and what she is studying. A boyfriend appears on the scene and other personal adventures are part of the story. The first time I read something of this genre was Alan Guth's book on *Inflation*. In the middle of his explanation for the expansion of the Universe, he starts worrying about his career in physics or about moving from one part of the country to another. Such diversions are part of Levin's book as well, which I think suits it. It conveys the deep personal influence of thinking about the cosmos into the author's life. I would not like to see it becoming a general trend, to listen to an author's personal problems on moving from Cambridge to Brighton or to describe rain in foggy London in the middle of an exposé on the latest developments of topological theories of the cosmos. But it does bestow a particular character to the book. What would my own mother have thought if I had written such letters?

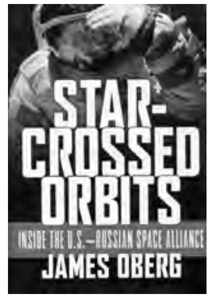
Such diversions overlook the main question raised by the author in her book: Is the Universe finite? If the Universe is flat, as some recent evidence seems to suggest, can it be finite? We always think of Eucledian geometry as the geometry of infinite space. I was intrigued by the arguments put forward to combine flatness with compactness and finite spaces. I am not fully convinced that you can turn a flat space into a finite space in such fashion. But the arguments are worth reading. Levin does not force her conclusions on readers; she just presents them for their consideration. There are interesting and fascinating questions asked and answers proposed. I certainly do not always agree with them, but I admit to a preference for a finite Universe (so did Einstein). It somehow feels better. I also admit to a bit of a problem with the gymnastics in topology that the book brings forward. If you identify one side of a geometric object with one of its other sides, does that really lead to a physical space or is it just a mathematical trick?

There is a bit of delightful fantasy in the book once in a while, and also some remarkable comments. Janna Levin says on p. 157 that it might be possible to determine the size of the Universe by studying the ages of the oldest stars. A recent examination of that type was done by Harvey Richer of the University of British Columbia and his team in a study of the white dwarfs in the globular cluster M4, but that appeared after publication of *How the Universe Got its Spots*. There are also occasional errors in the text, although none that cause major problems (e.g. Niels Bohr is given credit for Planck's distribution law on p. 163).

Reading *How the Universe Got its Spots* is like listening to a long intelligent conversation. Some of the ideas are unusual, and perhaps controversial, but the author gives a good reason for expressing such ideas: it is a defense against doctrine and fanaticism. I certainly liked to read about them.

Marc Verschueren

Marc Verschueren obtained his degree of Doctor in Science at the University of Leuven, Belgium. He spent part of his career as a Certified Management Accountant, only to return to observing the Universe with the RASC in Vancouver, where he is the Centre treasurer.



Star-Crossed Orbits: Inside the U.S.-Russian Space Alliance, by James Oberg, pages 352 + iii, 16 cm × 23.5 cm, McGraw Hill, 2001. Price $27.95 US hardcover, $9.95 US paperback (ISBN 0-07-137425-6).

The launch of *Sputnik* by the Soviet Union in 1957 sparked the space race between the world's two superpowers, the United States and Russia. After more than thirty-six years of rivalry and with great fanfare, the prevailing spirit of competitiveness was expected to turn into an alliance, a sort of "marriage of the heavens," between old cold war rivals. On the contrary, from *Apollo-Soyuz* to the *Mir Space Station* and ultimately to the *International Space Station* (ISS), both Americans and Russians have been involved in a never-ending series of misunderstandings, suspicions, and outright politically generated deceit.

In *Star-Crossed Orbits,* author James Oberg, a world authority on the Russian space program, provides an inside portrait of the U.S./Russian spaceflight co-operation, with all of its strengths and weaknesses exposed. Through hard-hitting investigative journalism, the author unveils the true costs and benefits of the shaky relationship. It is a riveting narrative that reflects an all-too-familiar human theme: how do you survive a forced relationship when two partners have such vast political and ideological differences?

After more than 22 years as a space engineer for NASA mission control, James Oberg is a leading expert on the history of the old Soviet Union space program and its Russian descendent. Oberg has written ten books and over a thousand articles on the business of space flight and its international political game. Corporate and government clients depend on Oberg's expert assessment of Russian space industry and technology. On several occasions he has testified before Congress regarding the Russian space program, and has been a space consultant for major television networks.

Oberg, page after page, openly criticizes but carefully documents America's reluctance to learn from old Soviet mistakes for which they had paid the price in space exploration. Oberg praises, however, the people in the background who built the ISS from the ground up. More worrisome today is that this flagship program appears bankrupt and in serious diplomatic and managerial crisis even though the technical experts, as usual, have performed miracles.

Through Oberg's detailed revelations, we learn that when it came time to put Americans on *Mir,* Russians seriously downplayed the dangers and provided NASA with "inaccurate" documents. Surprisingly, no probing questions were asked regarding the actual safety issues because high-level politicians ordered the west to blindly trust the Russians. *Star-Crossed Orbits* goes on to uncover that the Russians were keeping many space disasters and near-disasters under wraps. In fact, they had fires in space long before the Mir fiasco in 1997, which almost killed a U.S. astronaut.

Walking through a political minefield, space-sleuth Oberg has managed to keep a balanced approach in telling the intriguing untold story of the rocky space alliance, thanks to his unparalleled access to official documents and intimate knowledge of the space programs. Issues poorly understood by the public are revealed for the first time, with disclosures ranging from weak meteorite shielding and harmful high noise levels to guns in space. For those wanting to understand the background culture and political environment of human spaceflight in today's post-cold war conditions, this account is a must read as it documents the trials and tribulations that have plagued the space alliance. As well as revealing some of the most closely guarded secrets, *Star-Crossed Orbits* captures all of the public-relations spinning, duplicity, and political haggling that have absorbed countless dollars, potentially endangered lives, and continue to delay humanity's first permanent outpost in space.

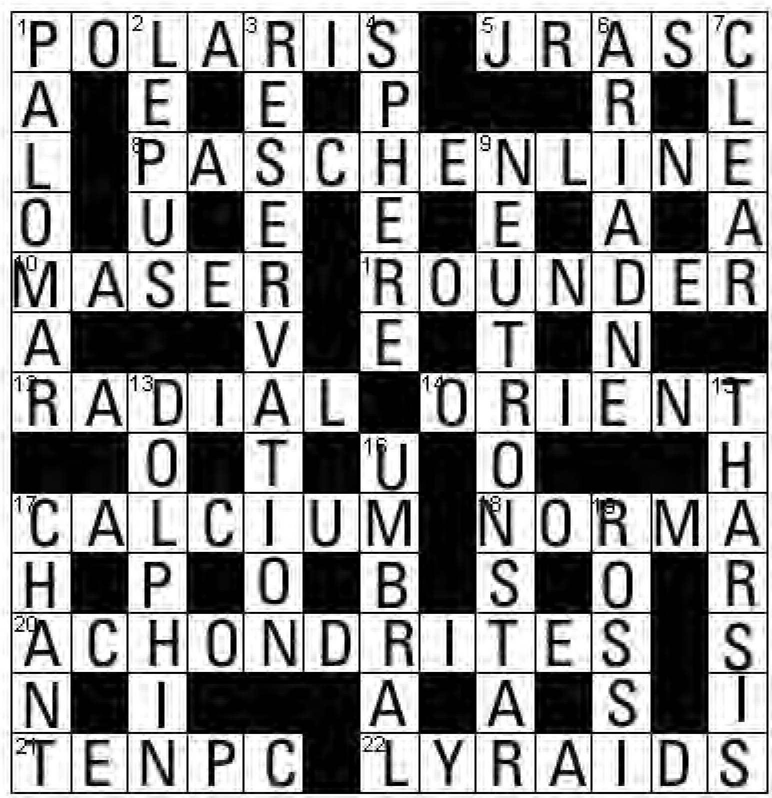
Andrew S. Fazekas

Andrew S. Fazekas is a freelance science communicator and astronomy columnist at the Montreal Gazette.

Astrocryptic

by Curt Nason, Moncton Centre

We present the answers to last issue's puzzle



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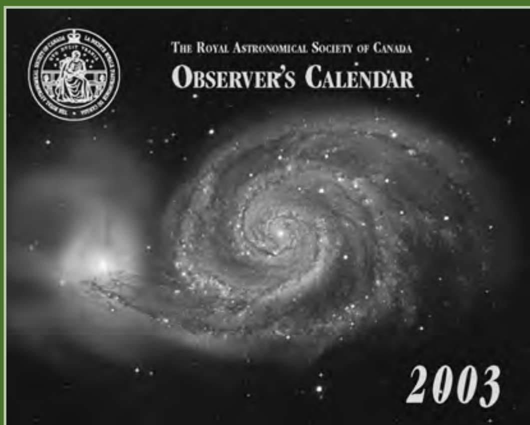

Observer's Calendar — 2003

This calendar was created by members of the RASC. All photographs were taken by amateur astronomers using ordinary camera lenses and small telescopes and represent a wide spectrum of objects. An informative caption accompanies every photograph.

It is designed with the observer in mind and contains comprehensive astronomical data such as daily Moon rise and set times, significant lunar and planetary conjunctions, eclipses, and meteor showers. The 1998, 1999, and 2000 editions each won the Best Calendar Award from the Ontario Printing and Imaging Association (designed and produced by Rajiv Gupta).

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Published to commemorate the 125th anniversary of the first meeting of the Toronto Astronomical Club, "Looking Up — A History of the RASC" is an excellent overall history of Canada's national astronomy organization. The book was written by R. Peter Broughton, a Past President and expert on the history of astronomy in Canada. Histories on each of the centres across the country are included as well as dozens of biographical sketches of the many people who have volunteered their time and skills to the Society (hard cover with cloth binding, 300 pages with 150 b&w illustrations).

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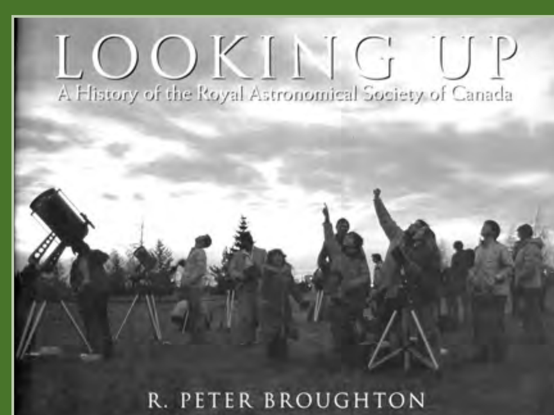

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