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Journal

The Journal of the Royal Astronomical Society of Canada Le Journal de la Société royale d'astronomie du Canada

INSIDE VOLUME #100!

The Mars Exploration Rover • Measuring the Heavens

Pumpkin Creek Observatory • The 14th Annual MIAC Meeting

The Lunar Volcanic Region in the South of Petavius

February / février 2006

Journal

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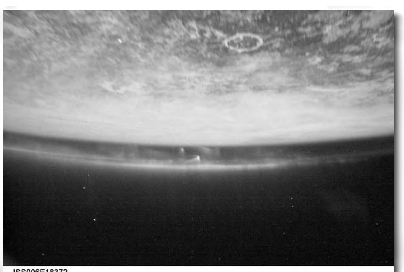

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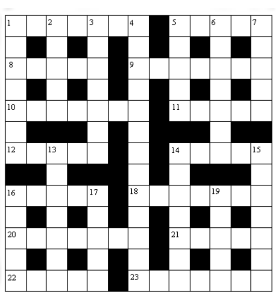

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ACROSS THE RASC
DU NOUVEAU DANS LES CENTRES

Cover Photo:
The Pelican Nebula in H-alpha photographed by Serge Théberge using a 8″ f/4.6 Vixen R200SS with a Paracorr corrector and a 6-nm H-alpha filter. This image is composed of nine 10-minute exposures using a SBIG ST-10XME camera. Photographed on July 9, 2005 from Collingwood ON. For more details see Serge Théberge's web page at `www.astrofoto.ca/serge`

Editorial

by Jay Anderson (jander@cc.umanitoba.ca)

In this volume, number 100 in the history of the *Journal of the Royal Astronomical Society of Canada,* you will find my first efforts at a re-shaping of its contents. It is apparent from discussions on the RASC list that there is a plethora of ideas about how to make the *JRASC* more popular. The suggestions rambled across the landscape: add this, delete that, enhance so-and-so, but there little is in the way of consensus. So I have tried to be inclusive, a good feminine trait, and put something in for all of us while at the same time preserving the format of the old.

You will find no less than seven new columns in this issue — a powerful indication of the depth of knowledge and experience within our Society. "Gizmos," written by Don Van Akker of the Victoria Centre, will focus on the design and construction of handy tools that make observational astronomy a little easier. Saskatoon's Rick Huziak, coerced by fellow RASCals to contribute a column on his favourite subject, has chosen the title "Ramblings of a Variable-Star Addict." Paul Langan ("Net Astronomy") will tempt us each issue with a description of Web pages that intrigue, teach, or boast of things astronomical. Warren Finlay and Doug Hube have joined to produce a column that extends visual and photographic astronomy more deeply into the science in "Deep-Sky Contemplations." Geoff Gaherty brings us a strictly visual perspective in a column entitled "Through My Eyepiece." For the astrophotographers, Albert Saikaley ("Film and Pixel") has recruited a few of his friends – Rolf Mier, Serge Théberge, and John Mirtle in this issue – to tempt us with examples of the best that amateur photographers can accomplish.

The newcomers join an established crew whose contributions you have been reading all along: Leslie Sage, Martin Beech, Bruce McCurdy, Phil Mozel, Stan Runge, Bill Dodd, David Turner, and Christopher Fleming. And, of course, the irregular contributors - in this issue, Gil Raineault, Robert Egler and Don Hladiuk.

This 100th volume also features a major paper on the crater Petavius by a group of Italian amateur astronomers. While the article is a tough slog if you want to follow the math, there is a wealth of information about the lunar surface that will be revealed by even a light reading of the article. Give it a try, and then go out and have a look for yourself.

If you have a contribution for the *Journal,* we are willing to put you into print (and into a little bit of history). You may submit articles, photos, drawings direct to the Editor. There is a *JRASC* style guide on the RASC's home page to help you out and an editorial staff to fix your journalistic shortcomings. The Journal is the "house salad" of the RASC but it is a potluck salad and you have to bring something to the table to help the feast.

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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Correspondence
Correspondance

Dear Editor:

In this her centennial year, I have been researching the life of Helen Sawyer Hogg (1905-1993). In addition to exploring the archival record (there are over 16 running metres of files in the University of Toronto Archives where she was on staff in the Astronomy Department from 1935 onward), I am also trying to compile an oral history.

RASC members who have any personal reminiscences about Dr. Hogg that they would like to share are invited to contact me with those memories.

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Yours celestially,

David Orenstein

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The RASCals list is a forum for discussion among members of the RASC. The forum encourages communication among members across the country and beyond. It began in November 1995 and currently has about 300 members.

To join the list, send an email to `listserv@ap.stmarys.ca` with the words "subscribe rascals Your Name (Your Centre)" as the first line of the message. For further information see: `www.rasc.ca/computer/rasclist.htm`

INTERNATIONAL ASTRONAUTICS LAURELS FOR NRC SCIENTISTS

The 2005 "Laurels for Team Achievement Award" of the International Academy of Astronautics (IAA) has been given to a team of fifteen scientists from Canada, Japan, the USA, Europe, and Australia. Dr. Peter Dewdney of the National Research Council of Canada (NRC) is the team's Principal Canadian Investigator; other Canadian members include Dr. Russ Taylor of the University of Calgary and Dr. Wayne Cannon of York University.

This year's award recognizes the exceptional astrophysics and engineering work of the Very Long Baseline Interferometry (VLBI) Space Observatory Program (VSOP) team. Together they have created a virtual radio-telescope dish with a diameter nearly four times the radius of the Earth. Canada provided the VSOP with one of its three radio-wavelength correlators. These instruments collect data from several Earth-bound radio telescopes and from ground stations that are tracking the Japanese HALCA radio-telescope satellite. In sum, the correlators process the gathered data and produce detailed radio images of stars and galaxies. This technique, known as very long baseline interferometry, was pioneered by NRC scientists in the late 1960s.

"One of NRC's strengths is its international collaborations with the best scientists in the world," said Dr. Pierre Coulombe, NRC President. "We are very pleased to have contributed to this boundary-breaking project and congratulate the team for their internationally acclaimed astrophysics and engineering work." The Canadian VSOP team was funded to the tune of $3.2 million by the Canadian Space Agency (CSA).

"VSOP marked the Canadian Space Agency's first space astronomy mission and successfully demonstrated our close collaboration with the National Research Council of Canada. The CSA-funded instrument, built and operated by the Canadian team, provided spectacular high-resolution radio images that help explain the nature of quasars and active nuclei of galaxies harboring massive black holes," said Marc Garneau, President of the Canadian Space Agency.

Past recipients of the prestigious award include the *Hubble Space Telescope* team, the US *Shuttle* team and the Russian *MIR Space Station* team. The award coincides with the 56th annual congress of the International Academy of Astronautics, held in Fukuoka, Japan

MOST EYES WR123

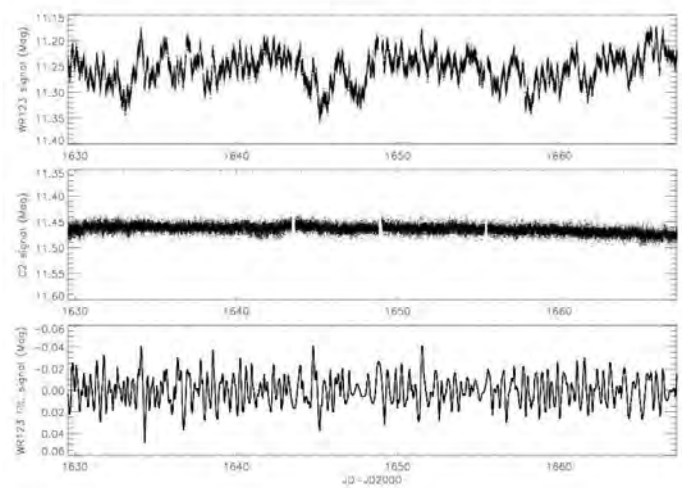


Figure 1 – This figure shows the full oscillation of WR123 over the whole 38-day interval observed non-stop by *MOST*. The upper panel shows the original data as it was extracted. The middle panel shows the signal extracted from a comparison star on the same scale. The lower panel shows the data for WR123 where all variability with time scales longer than about one day have been filtered out. The *MOST* mission is financed by the Canadian Space Agency and supported by the Natural Sciences and Engineering Research Council of Canada.

The *MOST* space telescope has given astronomers new clues about an exotic star, at least ten times more massive than our Sun, spewing gas into space at a rate of more than 100 trillion tonnes per second. And, according to a research paper (to appear in the Astrophysical Journal) the star – with the misleadingly bland name of WR123 – is even weirder than astronomers ever suspected.

The new findings, by Laure Lefevre and Anthony Moffat (Université de Montréal), Sergey Marchenko (Western Kentucky University), and the international *MOST* science team, are based on over five weeks of non-stop monitoring of the light variations of WR123. WR123 is a member of the relatively rare class of Wolf-Rayet stars (named after two French astronomers who discovered telltale strong plasma winds using a simple spectroscope in the Paris suburbs in 1867).

Wolf-Rayet stars like WR123 have long been known to exhibit complex-seemingly chaotic-brightness variations associated with the turbulent high-speed winds they eject into space. But the nearly continuous coverage possible with the *MOST* (Microvariability & Oscillations of STars) satellite has revealed a clock in the chaos - a stable variation repeating every 10 hours (see figure 1).

"Finding a clock in a star like WR123 is like finding the Rosetta stone for astronomers studying massive stars," explained Ms. Lefevre, a Ph.D. student at the Université de Montréal. "However, although WR123 may vary like clockwork, it must be a very strange mechanism indeed."

The only theories to explain the 10-

hour clock in WR123 would be: (1) the rotation of the star itself, (2) the orbit of another small star around WR123, or (3) vibrations in the structure of WR123 that are transmitted to its dense enveloping wind. All of these ideas are equally strange. If WR123 is spinning at that rate, the surface would be moving so fast (about 2000 kilometres per second) that the star should throw itself apart, unless that is the actual source of the wind! If the star is in a close binary system, it is so tight that its companion would be orbiting "inside" the star itself. If pulsations are the right answer, theoreticians will have to revise completely their current understanding of this class of massive stars.

One hundred times fainter than what the unaided eye can see, WR123 is located about 19,000 light-years from Earth, in the direction of the constellation Aquila (The Eagle). WR123 and other similar Wolf-Rayets (see, for example, the *Hubble Space Telescope* image of WR124 - figure 2) are believed to have had violent births: ejected by a supernova explosion in a binary system, or by a gravitational slingshot from a dense star cluster. "Either way, WR123 was probably kicked out from the nest rather abruptly," jokes Dr. Moffat, who helped develop these formation theories in the late 1970s.

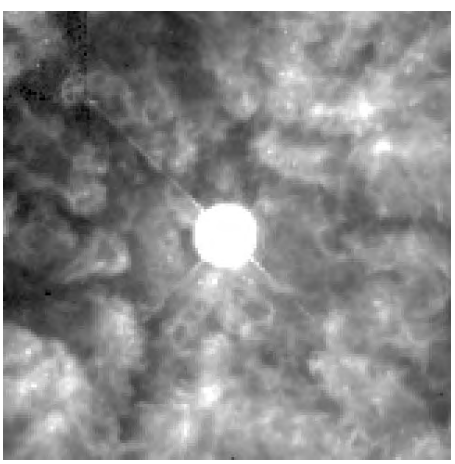


Figure 2 – Detail of the Wolf-Rayet star WR124 and its surrounding nebula M1-67. WR124 is a close cousin of WR123 recently studied by MOST. The "clumps" in the nebula probably result from instabilities in the mass outflow from WR124. (Image courtesy of STScI / NASA).

Stars that start off their lives with ten or more times the Sun's mass are capable of "burning" hydrogen into helium, helium into carbon, and so on up to the final nuclear ash, iron, before the iron-rich core collapses on itself in less than a second and produces the greatest of all stellar explosions, a supernova. Since H-burning lasts by far the longest, some 90% of stars that shine are actually consuming hydrogen in their cores at a prodigious rate. Given this result then about 10% of stars are in the He-burning stage, while an even smaller fraction are in the subsequent, ever-faster evolving stages. WR123 represents the fleeting final stages of helium-burning, before the rapid "death-spiral" to becoming a supernova.

The gases ejected from stars like WR123 will enrich the interstellar medium, and contribute to future generations of stars. Understanding such stars is vital if we are to properly understand the evolution of the Milky Way and other galaxies. "We may be seeing an example of one of the key stages in the stellar lifecycle that led to the Sun, Earth, and us, being here," noted Ms. Lefevre.

THE THINGS YOU SEE IN SPACE

International Space Station (ISS) Science Officer Don Pettit captured the dazzling aurora display shown in figure 3. From orbit Pettit reported that aurorae appeared to crawl around like giant green amoebae. Over 300 kilometres below, the vast circular lake associated with the Manicouagan Impact Crater (Quebec) can be seen. (**Credit:** Don Pettit, ISS Expedition 6, NASA. Further details are available at `antwrp.gsfc.nasa.gov/apod`)

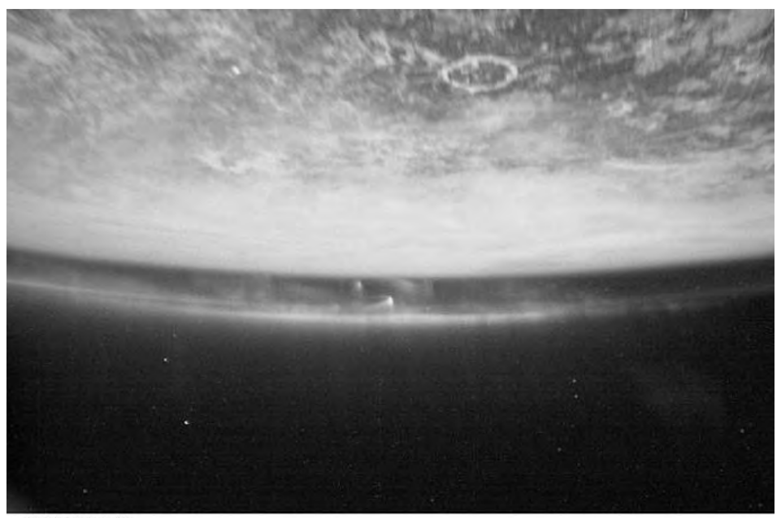


Figure 3 – Aurora and the Manicouagan Crater. (Image courtesy of NASA).

An Interview with Dr. Steven Squyres, Mars Exploration Rover Principal Investigator

by Don Hladiuk (Don.Hladiuk@conocophillips.com) & Steve Donaldson (sdonalds@telusplanet.net), Calgary Centre

Introduction

The annual convention of the American Association of Petroleum Geologists' (AAPG) was held in Calgary, Alberta from June 19-22, 2005. Included among the many excellent scientific presentations was a thematic session on "Sedimentation on Mars," featuring a talk by Dr. Stephen Squyres, the Mars Exploration Rover (MER) Principal Investigator. Calgary Centre RASC member and geologist Don Hladiuk recognized an opportunity for a unique interview and made arrangements to speak with Dr. Squyres immediately after his presentation. The article that follows is a transcript of that interview, which took place on June 20, 2005. Minor editorial changes have been made for clarity and a short addendum has been added to update the rovers' progress since the interview was conducted. An earlier version of this article appeared in the September 2005 issue of the *StarSeeker*, the monthly newsletter of the Calgary Centre.

Dr. Steven Squyres (MER Principal Investigator) being interviewed by Calgary Centre member Don Hladiuk (on the left) in June 2005 at the AAPG Conference. Photo Credit: Steve Donaldson

DH - Briefly describe what the rovers are up to today.

SS - Today Opportunity is moving very carefully back towards a dune that we got stuck in. We were barreling along at a high speed and we dug ourselves right into a sand dune, up over the hubcaps (all six wheels), a couple of months ago and got ourselves well and truly stuck. And it took many weeks to get unstuck. We are out of it now, we're safe, but we want to better understand the dune that got us. So we are going back very carefully (pause), very carefully, to try and figure out what was different about this one, because we have driven over many very similar looking forms before with no problems.

Spirit is mountaineering. Spirit has spent the last several months doing a very detailed in-depth geologic investigation at a place called Cumberland Ridge. But we have finished that and we are now ascending toward the summit of a large hill (about 120 m tall) called Husband Hill, sort of doing the first ever mountaineering on Mars, with the hope of getting over the top and starting to work our way down the other side.

DH - If both rovers continue operating for another 6 to 12 months where do you hope they will be?

SS - I learned a long time ago not to try and predict what's going to happen too far into the future. Many of our most important discoveries on this mission have been serendipitous ones and regions that we thought would have only limited interest have occupied our attention for months at a time. And other places that we thought might be very interesting

This artist's rendering shows a view of NASA's Mars Exploration Rover (MER) as it sets off to roam the surface of the red planet. Photo Credit: NASA/JPL

turned out to be a big nothing and we moved on right away. So all I can say is that I hope they are still alive six to twelve months from now and doing good science.

DH - For Spirit, do you want to go over the ridge and see what's on the other side?

SS - For Spirit the intention is to work our way southward either around or over the summit of Husband Hill and get to the south side of the hill where we think there might be some rather new and different geology from what we have seen previously exposed. So yeah, the idea is to head south.

DH - Is the goal for Opportunity to get to Victoria crater?

SS - Victoria Crater is awfully far away and there is an awful lot of very strange looking terrain between us and there. I have no idea whether or not the terrain between us and Victoria is remotely traversable. It's something totally new and different. Certainly we have had our problems traversing through the dune material that we have been in recently, so we will see what we see. I mean it's Mars, you just can't tell.

DH - What has been your biggest surprise so far from the MER program and why?

SS - Well, I think I would have to tell you my biggest surprise is that it's still going. You know we advertised this as a 90-day mission. If you would have sat me down and given me truth serum before we landed and said "Okay Squyres, how long do you think they will really last?" I would have said 120 to 150 (days), and if everything broke our way maybe 180 days. But today is day 520, and we are still going strong, climbing mountains, going down into impact craters. I never ever anticipated it was going to last this long. So that, to me, really is the biggest surprise of all.

DH - What in your opinion has been the most important discovery made by the two rovers?

SS - I think I would have to say the most important discovery was the realization that at the Opportunity landing site there was once liquid water, not just beneath the ground, but water that came to the surface. Water that you could wade in, or swim in, or something. It was an environment that at some level would have been suitable for some kinds of life. That's probably our most significant finding.

DH - Describe to us your favourite image returned to us by one of the two rovers.

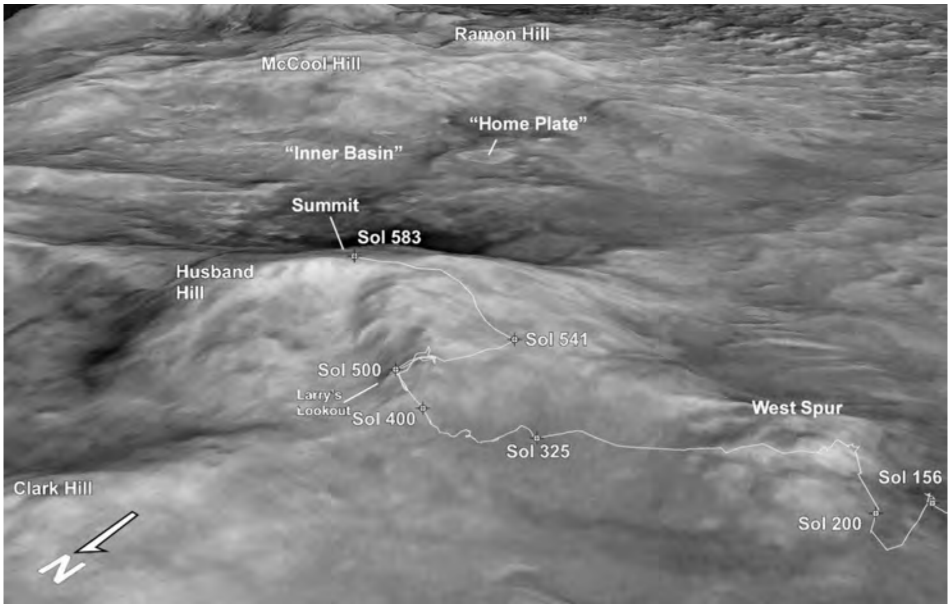
SS - Wow, great question. (Pause) I gotta tell you I think my favourite image of all was one we took with Spirit. The first picture that came down (on Sol 25) after we nearly lost the vehicle. On Sol 18 (the 18th day of our mission) we really almost lost Spirit. We had a software anomaly that was causing the rover to stay up all night and was burning down the battery. If it would have gone on a few more days we would have lost the mission for that vehicle. Some very smart engineers at the Jet Propulsion Laboratory figured it out. Saved the mission and I gotta say that if I could only put one picture up on my wall it would probably be the first picture we got from Spirit after she came back to life and letting us know things were still okay.

DH - And what was that picture?

SS - It was just a picture from the front. We call them Hazcams (Hazard Avoidance Cameras) showing the arm still kinda frozen against a rock. Just the pose she had been in when she almost died, but it just showed the vehicle had come back to life and we were still going to have a mission.

DH - Are the rovers showing any sign of wear after a combined 1000 sols working on Mars?

SS - Not as much as the team is, but yes, there are a few things. I guess the most significant problem has been on Opportunity, the right front steering actuator (the thing that swivels the wheel left or right for steering) has failed and



Spirit's "Road to the Top"
This perspective view of a three-dimensional model shows the route NASA's Spirit rover took to the top of "Husband Hill," and the shape of the surrounding terrain. Spirit reached the summit (~120-m elevation) on Martian day, or sol, 581 (Aug. 21, 2005). The solar-powered rover traversed the north slopes of the hills to maximize Sun exposure during the winter months. Spirit is currently heading towards "Home Plate." Image credit: NASA/JPL/USGS/MSSS

has locked up. Fortunately it locked up almost pointing straight forward. It's not a big deal. We can't steer quite as accurately as we used to, but we can still steer pretty well.

Few other odds and ends – we had a wheel on Spirit that was acting up for a while, but it sort of seems to have healed itself. So mechanically they are holding together remarkably well.

DH - What about the mini-TES [Thermal Emission Spectrometer] on Opportunity?

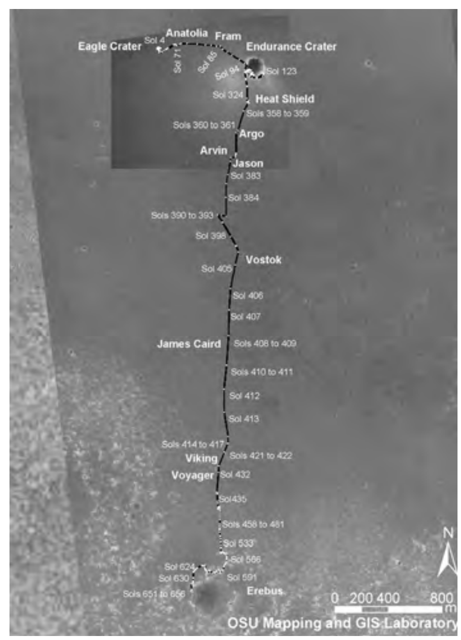
SS - That's right, good reminder. The mini TES infrared instrument on Opportunity is having intermittent failures. We voided the warranty on the Opportunity mini-TES in a serious way quite a while ago. We have a problem on Opportunity. Opportunity has a heater; it's a simple electrical heating element on the shoulder of its arm that ever since we landed has been stuck on. The switch is just stuck in the 'on' position. And if you let it run all night, it will suck up a huge amount of electrical power accomplishing absolutely nothing and we just can't afford to waste that much power. So the way we avoid doing that is by doing something we call 'deep sleep' where we essentially disconnect the batteries. We take the batteries offline overnight and reconnect them in the morning. And with the battery disconnected of course no electricity goes to that heater and we save lots of power. The problem is there is a survival heater (as it's called) on mini-TES that is explicitly there to keep mini-TES warm overnight and when you take the battery offline, all the heaters go off, including the mini-TES survival heater. So every time we deep sleep we take mini-TES to about 10 or 12 degrees colder than it was ever designed to go. We have done this hundreds of times and so we have apparently broken the instrument by doing this. It survived hundreds of days of this and now it's intermittent, it's flaky, it works some of the time and [does] not work other times. And so we use it a lot and we get some good data out of it.

DH - What is the latest prediction on how long the rovers will last?

SS - My wife keeps asking me the same question. We are beyond the ability to predict. We are doing what engineers would call lifetime testing on the surface of Mars now. We have exceeded all of our tests. We have absolutely no data on which to base any predictions. Every day is a gift at this point. They could die tomorrow. They could last for another year. I simply don't know. And it makes it very difficult to plan, as you might imagine, because if you don't know if the thing is going to last a day or year, it's hard to figure out how best to use the vehicle in the time you have left because you don't know how much time there is. What we try to do is plan for the long term, but each individual day use the vehicle as if there is literally no tomorrow. Try to squeeze the most science out of it that we can every day because there may be no tomorrow.

DH - What is the biggest threat to their survival?

SS - Several things. Potentially, dust build-up on the solar arrays. That we have been



Opportunity's Path, Landing to sol 656. This image shows the route that NASA's Mars Exploration Rover Opportunity has taken from its landing site inside "Eagle Crater" to its position on its 656th Martian day, or sol, (Nov. 27, 2005) at the edge of "Erebus Crater." The scale bar at lower right is 800 metres (one-half mile). As of sol 656, Opportunity had driven a total of 6502 metres. Image credit: NASA/JPL/USGS/MSSS lucky with, [in] that we have had several nicely timed gusts of wind that have cleaned off the arrays on several occasions.

A serious dust storm, a really bad global dust storm, could be very bad for the vehicles. We are in dust storm season right now. This is the storm season on Mars. So far we are surviving.

Mechanical parts could wear out. Now that's kind of a graceful degradation in a sense because you could have one or two motors go out here and there and there are still some ways you could work around that.

The other thing that could happen is [to] have some electrical part fail. There are a lot of single string electronics. There are electrical components with no redundancy inside these vehicles. And if one of those happens to go, then bang. You're done and you'll never see it coming. Just one morning it does not wake up. That could happen tomorrow and there is no way of telling.

DH - How will you feel?

SS - I don't know. I have thought about it a lot. I mean it will certainly be a sad day in some respects. I mean you use the word like love advisedly when you are talking about a hunk of metal. But we have grown very attached to these vehicles. They have personalities. They are something that we've poured our hearts and souls into for a very long period of time. It will be a hard day. But when they do die because they have lasted so long, I mean they have exceeded our expectations by so much. They will be honourable deaths. They have done everything we could have hoped for and more.

And we'll get our lives back. Our team has been doing daily tactical drive operations almost every day for the last 520 days and we are very tired. So there will be very mixed feelings I think, but overall it will be a hard day.

DH - Explain to the average person why is it important to explore Mars?

SS - The reason that we have chosen Mars as the target of our exploration is that alone among the planets it's the one place that you can imagine life as we understand it potentially having taken hold. Now if you don't believe that understanding how life comes to be or finding out how common life is through the Universe is an important question to answer not just from a scientific but from a fundamental human basis, then we can stop the conversation because that's what its about. There are no spin-offs, no Tang, no Teflon that's going to come out of this.

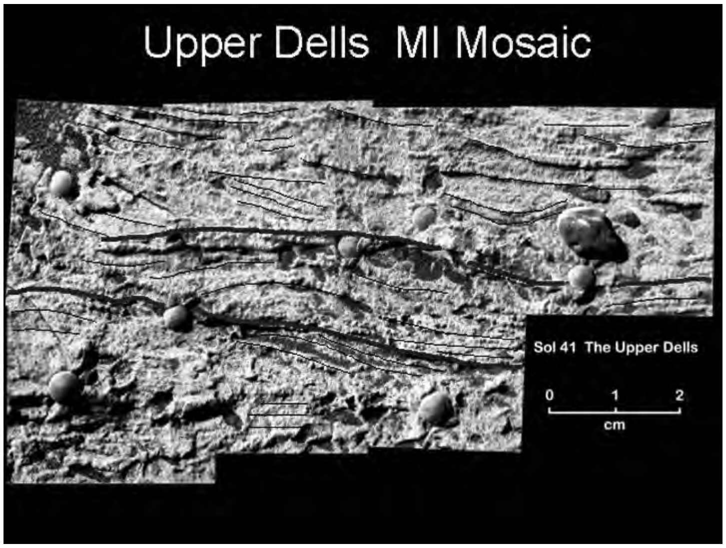
This is for pure human knowledge, but if you acknowledge [that] "where did we come from?" or "are we alone?" are things that people care about then that's what our program of Mars exploration is about. Right now we have one example of life, us. Here we are. We don't know how we came to be and we don't know if anybody else is out there. Mars is the place to go to try and address these questions. Mars was warmer and wetter at the same time in solar system history when life was coming into being in warm, wet environments here on Earth. If we can show that life independently arose on two different worlds just in one solar system, when you consider the multitude of solar systems that are out there, it takes no great leap of imagination or faith or anything else to believe that life could be a common phenomenon throughout the Universe.

Looking Back at "Purgatory Dune"
The wheels of NASA's Mars Exploration Rover Opportunity dug more than 10 centimetres deep into the soft, sandy material of a wind-shaped ripple in Mars' Meridiani Planum region during the rover's 446th Martian day, or sol (April 26, 2005). Getting the rover out of the ripple, dubbed "Purgatory Dune," required more than five weeks of planning, testing, and carefully monitored driving. Opportunity used its navigation camera to capture this look back at the ripple during sol 491 (June 11, 2005), a week after the rover drove safely onto firmer ground. The ripple that became a sand trap is about one-third metre (one foot) tall and 2.5 metres wide. Photo Credit: NASA/JPL

The other thing that I would love to know is how life first comes to be. And yet on this planet, the record of that event is gone. The Earth has been geologically active, very active for all of its history. You can't find rocks on Earth that are 4.2, 4.3 billion years old; they have simply been wiped out by the planet's geologic activity. The surface of half of Mars is covered with rocks that old and so if life arose on Mars, a big if, but if it did, the record of that event and how it took place could actually still be preserved in Martian rocks. It might be the place that we could go to see how life originates. So it makes it to me a very interesting place.

DH - Who or what event inspired you to pursue a career in planetary geology?

SS - I remember this very well. I was a geology major as an undergraduate. I



"Upper Dells" Clues to Watery History.
This magnified view from NASA's Mars Exploration Rover Opportunity of a portion of a Martian outcrop called "Upper Dells" shows fine layers (laminae) that are truncated, discordant, and at angles to each other. Interpretive black lines trace cross-lamination that indicates the sediments that formed the rock were laid down in flowing water.

This rock, like another called "Last Chance," preserves evidence for trough cross-lamination, likely produced when flowing water shaped sinuous ripples in underwater sediment and pushed the ripples to migrate in one direction. The direction of the ancient flow would have been toward or away from the viewer. The interpretive blue lines point to boundaries between possible sets of cross-laminae. Eight spherules can be seen embedded in the rock, and one larger pebble sits on the present-day surface of the rock. Image credit: NASA/JPL/Cornell/USGS

went to Cornell University where I teach now. I went into geology because I like doing science and I like climbing mountains and it seemed like a way to combine the two. But after several years of studying geology I came to realize that the geologists who have been studying this planet for the last couple of hundred years have actually done [a] really good job at figuring it out. And I was interested in finding more of a blank canvas to work on. A place where there just wasn't much known. My junior year at Cornell I signed up for a course on the Viking Mission to Mars. This was the late seventies and the professor (Dr. Joseph Veverka) was a member of the Viking science team. I was the only undergraduate in the course, everybody else was graduate students, and I remember going in there and because it was a graduate level course we were expected to write up some kind of original research as a term paper. So it's a few weeks into the semester and I'm thinking I had better start thinking about my term paper. So I got a key to the place they called the Mars Room, which was the place where they were keeping all the images that were coming down from the Viking spacecraft. Now this is before the Internet and CD ROMs. These are literally pieces of photographic paper. And I remember going in that room thinking, all right, I'll sit down and flip through pictures for 15 or 20 minutes and I'll see if I can come up with a topic for my term paper. I was in that room for four hours and I walked out of there knowing exactly what I wanted to do for the rest of my life. That was it.

(Post interview addition: Dr. Squyres's paper examined features in some of the images that resembled rock glaciers, which was a topic that he had worked on a few years before in British Columbia. The term paper became his first published scientific paper, in *Icarus* in 1978.)

DH - If a manned mission to Mars were to be possible in the next 5 to 10 years would you go?

SS - In a heart beat. Sure.

DH - Can you provide any advice for high-school or college students who might be interested in pursuing a career in the planetary sciences?

SS - First and foremost, there is no substitute for persistence. Studying space and exploring space is a very difficult thing. And you have to be very stubborn. You've got to decide what you want to do and really have to pursue it aggressively; it's not just going to happen to you. Nobody is going to walk up to you and say how would you like to work on a mission to Mars. Or how would you like to go to Mars. And the thing to realize [is that] the first people to walk on Mars are not astronauts today. They are high school or even elementary students [today]; they're the ones that are going to walk on Mars. But nobody is going to go to them and say "Hey, would you like to go to Mars?" They've got to make a conscious decision that that's the kind of career path they want to follow. Then to follow the career path requires real dedication to mathematics and the sciences. And you have to simply commit yourself with a passion to what you are doing. And if you do, it can pay off in a big way in the end.

DH - What's next for you after MER?

SS - A long rest. And I mean that very seriously. We have been doing this for 520 days and [before] then there were 16 years of work just to get the things to the launch pad. So we are very tired and I would enjoy just puttering around the house for about six months after this is over. Once I'm done puttering, then you look downstream and there is a steady stream of Mars missions going every 26 months to Mars. In 2005 we have the Mars Reconnaissance Orbiter in August, the Phoenix mission in 2007 and the Mars Science Laboratory, a big rover mission, probably launching in 2009. I'm involved in a couple of those but at a much lower level. Not in charge of anything. But [I] will be able to participate in those to the extent that I can have a lot of fun, but with less responsibility. And I'm really looking forward to it.

DH - How do you personally feel, now that Spirit has been actively exploring Mars for over one Martian year and Opportunity is close behind in achieving the same milestone?

SS - It feels really good. Of all our various milestones, this is the one that feels most significant to me. The others (90 sols, one Earth year, *etc.*) are all artificial in a sense, since they have little to do with the planet that Spirit and Opportunity actually reside on. But by exploring Mars for a full Martian year, we have now had a chance - at these two landing sites - to experience the planet in all of its seasons and moods. In a very real sense I think I'm starting to know what Mars really is like now, but that's something that can come about only if you've been there for a full year.

DH - Has the excitement waned a bit since the first days after the highly successful landings on the surface of Mars?

SS - Nope. The anxiety is definitely lower, and there are fewer distractions, but for me the excitement is just the same. We're making fewer dramatic new discoveries these days, of course, but I find that that's offset by the fact that we've gotten so much more sophisticated and aggressive about how we operate the vehicles. We're doing things with them now that we never would have dreamed of at the start of the mission, and that's very exciting and rewarding.

DH - Finally Dr. Squyres, MER has been a very successful mission, can you tell us why it was so successful?

SS - The worst thing you can take away from this mission is the idea that we've got Mars figured out now or somehow it's easy or we have cracked the problem and we know how to do missions to Mars now. There is no magic formula. The reason we succeeded was that we had some good fortune, some things could have gone against us, but it didn't happen. But primarily we had an extraordinary group of people, enough money to do the job right, and we built good stuff and tested and tested and tested and tested. In the end it comes down to the fundamentals, blocking and tackling, you've got to test. You've just got to test the living daylights out of your hardware. We tested very carefully, built good hardware and it worked. It's as simple as that.

DH - Thank you very much.

SS - You bet.

Addendum

As of late November (as Mars shines brightly in our evening sky), the Mars Exploration Rovers Spirit and Opportunity are respectively in their 673rd and 653rd day of operations, and continuing to function on the surface of Mars. Spirit celebrated its one Martian year anniversary on November 20 and Opportunity on December 12, 2005. Spirit has returned a magnificent panorama of the surrounding landscape within Gusev Crater from the top of Husband Hill and is descending down the south side heading for "Home Plate,"while Opportunity continues southward through the etched terrain at Terra Meridiani to explore Erebus and Victoria craters. One rover scientist (Dr. John Grotzinger) stated that there is a 50/50 chance that one rover will still be working on Mars six years after the landing.

Dr. Steven W. Squyres is Goldwin Smith Professor of Astronomy at Cornell University, and is the Principal Investigator for the science payload on the Mars Exploration Rover Project. He received his Ph.D. from Cornell in 1981 and spent five years as a postdoctoral associate and research scientist at NASA's Ames Research Center before returning to Cornell as a faculty member. His main areas of scientific interest have been Mars and the moons of the outer planets. Research for which he is best known includes study of the history and distribution of water on Mars and of the possible existence and habitability of a liquid water ocean on Europa.

Dr. Squyres has participated in many of NASA's planetary exploration missions, including the Voyager *mission to Jupiter and Saturn, the* Magellan *mission to Venus, and the* Near Earth Asteroid Rendezvous *mission. Along with his current work on* MER, *he is also a co-investigator on the* 2003 Mars Express, 2005 Mars Reconnaissance Orbiter, *and* 2009 Mars Surface Laboratory *missions, a member of the Gamma-Ray Spectrometer Flight Investigation Team for the* Mars Odyssey *mission, and a member of the imaging team for the* Cassini *mission to Saturn. Dr. Squyres has served as Chair of the NASA Space Science Advisory Committee and as a member of the NASA Advisory Council. His awards include the American Astronomical Society's Harold C. Urey Prize, the Space Science Award of the American Institute of Aeronautics and Astronautics, and the American Astronautical Society's Carl Sagan Award. He was recently elected to membership in the American Academy of Arts and Sciences.*

For more information about the *MER* mission on Mars, go to: `http://marsrovers.jpl.nasa.gov/home/index.html`

Deep-Sky Contemplations

by Warren Finlay (warren.finlay@interbaun.com) and Doug Hube (jdhube@telus.net)

This is the first in what we hope will be an ongoing feature focusing on the deep sky from a combined amateur observing and astrophysical point-of-view. Pondering the astrophysics of objects while at the eyepiece has always been a passionate pleasure for us, and we hope the present series can bring some of this enjoyment to fellow deep sky enthusiasts. The concept for this column arose from the mind of Jay Anderson, *JRASC* editor, and we were crazy enough to take Jay up on his idea. So, without further ado, let us turn to the late winter/early spring deep sky, the season when galaxies reign supreme in the eyepiece.

For those finished their Messier lists, an excellent spiral galaxy to view at this time of year is NGC 2841 at RA 9h 22.0m (2000) and DEC

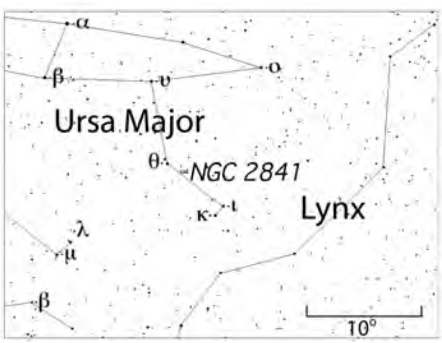


Figure 1 – Position of NGC 2841 in Ursa Major.

+50° 59´ (2000); see Figures 1-4. At a distance of about 50 million light years, it is bright enough (magnitude ~9.2) to easily see that its disk is inclined to our line of sight by approximately 68°, resulting in an oval shape. The NE side of this oval is the near side of this galaxy. Those with large telescopes might want to see if they can observe this galaxy's giant reflection nebula 0.5´ away from the galaxy centre on the minor axis in the NE direction and appearing as a 14˝ long bright strip in professional telescopes (Figure 4). Light from the galaxy's central bulge scatters off material in this nebula. The nebula is a whopping 4×7 *thousand* light years across. Compare this to M 42, which is a comparatively puny few *tens* of light years in diameter. As nebulae go, this is also a dense one: light is dimmed by 13 magnitudes for every parsec (3.26 light years) of transit through

Figure 2 – Finder chart shown with 0.5° and 2° Telrad circles (and part of 4° circle).

it, much more than the average 2 magnitudes of dimming per parsec in the central plane of our Galaxy. NGC2841 might reward regular monitoring: it is one of fewer than 10 known galaxies within which 4 or more supernovae have been detected.

Looking 23´ SE from the centre of NGC 2841 in the same field of view is what appears to be just another unremarkable double star in the foreground. Looks can be deceiving: the western star in this binary system parents a planet that is on a crazily eccentric orbit that takes it within 0.034AU of the star and then out to 0.905 AU every 112 days. For comparison, Mercury orbits at an average distance of 0.39 AU from the Sun. At its closest approach, this exoplanet flirts to within seven star-radii of its parent star. In the eyepiece, such daredevil antics of course

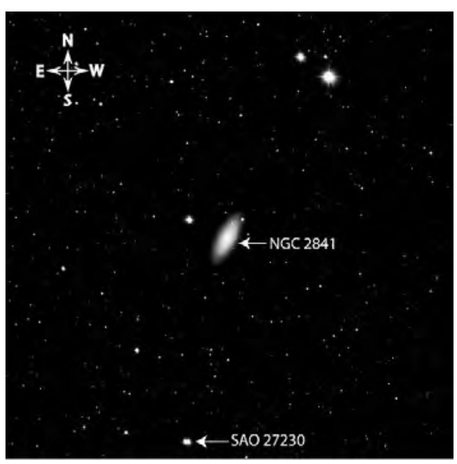


Figure 3 – 50´x 50´ POSS image of the field, that includes NGC 2841 and SAO 27230 [from "realskycd," AURA and ASP (1996)]

go unnoticed by the casual observer. All we see is an evenly matched pair of mag. 9.1 stars (see Figures 2 and 3) with a separation of 21˝ aligned east-west at the location labeled SAO 27230 on charts (or HD 80606, or any of about a dozen other labels - see e.g. SIMAB at `simbad.u-strasbg.fr/sim-fid.pl` to find this star's label in your favorite star catalogue). The two stars orbit each other with a separation of about two thousand astronomical units at their distance of a few hundred light years from us. The minimum mass of the exoplanet is 3.9 Jupiter masses. Its extraordinary orbit may be the result of the eastern star gravitationally perturbing an orbit that started out nearly perpendicular to the orbital plane of the two stars, yielding its present star-grazing orbit.

Meridian transit of NGC 2841 at local midnight occurs in mid-February. The next time you're observing, be sure to put NGC 2841 in the eyepiece and let your mind contemplate the wonders going on before your eyes in this little patch of sky.

Figure 4 – Image of NGC 2841 by Jyri Näränen with the 2.6-m Nordic Optical Telescope. A giant reflection nebula can be seen as a bright, thin strip above and to the left (NE) of the galaxy's centre.

Warren Finlay is the author of "Concise Catalog of Deep-sky Objects: Astrophysical Information for 500 Galaxies, Clusters and Nebulae" (Springer, 2003) and has been enamoured with the deep sky for over 30 years. Doug Hube is a professional astronomer retired from the University of Alberta.

The *Huygens* probe lands on Titan

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

The multi-billion dollar *Cassini* mission to Saturn included a landing probe – called *Huygens* – that landed on Titan's surface on January 14, 2005. The first results were published in the December 8, 2005 issue of *Nature*, coming from teams of scientists in Europe and the US, led by Jean-Pierre Lebreton of the European Space Agency.

Cassini entered orbit around Saturn in July 2004 after a seven-year trip from Earth, and released the *Huygens Probe* on its trajectory towards Titan on December 25. The probe entered Titan's atmosphere, deployed its parachutes and drifted down, landing after a descent of 2 hr 28 min. The probe continued to work on the surface of Titan for over an hour. The only real glitch in the mission was one discovered while *Cassini* was traveling to Saturn, when it was found that on the original mission profile the probe would be going too fast relative to *Cassini*, and the radio communications link would be Doppler shifted out of the range over which the *Huygens* receivers on *Cassini* worked. The modified path from *Cassini* to Titan ensured that all vital data were recovered.

Titan has long fascinated planetary scientists and astronomers because of its size (bigger than Mercury) and its thick atmosphere – the surface atmospheric pressure is even higher than Earth's. Astronomers have known for a while from the *Voyager* mission and later ground-based measurements that the atmosphere is mostly nitrogen, with methane being the next most abundant component, but a thick haze has prevented anyone previously seeing its surface. The presence of methane posed something of a problem, because the molecules should be broken apart by ultraviolet light from the Sun on a timescale of about ten million years (remember, the Solar System is about 4.6 billion years old, so ten million years is just the blink of an eyelash in comparison). Before *Cassini* arrived at Titan the most straightforward explanation for its presence was that the atmosphere was in "equilibrium" with a surface ocean of methane (the temperature and pressure permit that), but *Cassini* saw no evidence of oceans. The origin of the atmospheric methane is unresolved, but will most likely involve a layer of methane under the surface.

As the probe floated down to the surface, instruments sampled the atmosphere and the aerosols in the atmosphere, confirming that nitrogen and methane are the most abundant molecules, with noble gases other than primordial argon not detected. Noble gases are important indicators of the history of outgassing, as they do not get bound up in complex molecules. The relative abundances of isotopes of argon, combined with the measurements of nitrogen isotopic abundances, suggest that much of the atmosphere arrived on Titan in the form of ammonia and similar compounds, just as appears to have happened on Earth.

Aerosol particles can act as sites for the formation of clouds, and they "rain out" onto the surface, producing a layer that might be up to a kilometre thick. *Huygens* found that Titan's aerosols have solid organic cores, containing carbon and nitrogen. Winds blow on Titan, mostly in the same direction as it rotates, and there might be lightning.

The highlights of the mission, though, were the images sent back, and the measurements from the surface. *Huygens* passed over a landscape that, in some important ways, looks surprisingly Earthlike. It found bright highlands that drain in a river-like way to flat, dark lowlands, based upon pictures of channels cut into the underlying layers. From the surface, the probe appears to have landed in something like a dry river bed. The surface is relatively smooth, but not completely flat, and appears to be like wet sand. The wetness probably comes from liquid methane mixed in with frozen materials.

This is just the beginning of an analysis of the data that will last for years to come. Next time you look at Saturn in your telescope or binoculars, try to spot Titan (visual magnitude 8.4 according to the *Observer's Handbook*) and imagine the *Cassini* spacecraft on its looping orbits, taking in turns looks at the various moons. But most of all, imagine that we have landed a probe on Titan.

The surface of Titan as seen from the Huygens Descent Imager/Spectral radiometer instrument. Photo courtesy of the European Space Agency.

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

A COMBINED MORPHOMETRIC AND SPECTROPHOTOMETRIC STUDY OF THE COMPLEX LUNAR VOLCANIC REGION IN THE SOUTH OF PETAVIUS

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Abstract. In this study we examine a complex lunar volcanic region, composed of an extended smooth low-albedo unit associated with a domical structure and a vent, situated in the south of Petavius crater at selenographic coordinates 61.9° E and 26.9° S. We perform a spectrophotometric study of the volcanic region based on *Clementine* UVVIS data. Relying on ground-based high-resolution CCD imagery acquired under a variety of illumination conditions, we examine the morphometric characteristics of the domical structure situated on the edge of the low-albedo unit. For this purpose we make use of multi-image photoclinometry and shape from shading techniques especially suitable for surfaces displaying a strongly non-uniform albedo. We provide a geologic interpretation of the spectrophotometric and morphometric results we obtained for this volcanic region, arriving at the conclusion that the low-albedo unit represents a pyroclastic deposit and is accompanied by a vent and an effusive lunar dome, which is situated adjacent to a hummocky deposit. Possibly this region has undergone an effusive and a subsequent eruptive phase of volcanism. We thus demonstrate the analysis of a complex lunar volcanic region based on the combined interpretation of photogeologic and spectrophotometric spacecraft data and morphometric measurements derived from ground-based CCD images.

Résumé. Dans cette étude nous avons examiné une région volcanique complexe de la Lune, comprenant une zone lisse étendue à bas albédo associée à une structure en forme de dôme et une cheminée, qui est située dans le sud de la cratère Petavius, aux coordonnées sélénographiques 61.9° E et 26.9° S. Basé sur les données UVVIS de *Clementine,* nous avons entrepris une analyse spectrophotométrique de la région volcanique. En utilisant des images haute-résolutions d'origine terrestre prises sous conditions d'éclairage varié et disponibles sur CCD, nous avons examiné les caractéristiques morphométriques de la structure du dôme situé au bord de la zone à bas albédo. Dans ce but nous avons utilisé la photoclinométrie multi-images et la forme résultant de techniques d'analyse d'ombrage surtout appropriées pour l'examen de surfaces démontrant un albédo clairement non-uniforme. Nous avons fourni une interprètation géologique des résultats spectrophotométriques et morphométriques obtenus pour cette région volcanique. Nous avons conclu que la zone à bas albédo représente un dépôt pyroclastique et elle est accompagnée d'une cheminée et d'un dôme lunaire expansif situés près d'un dépôt accidenté. Il est possible que cette région a subie une phase expansive de volcanisme, suivi d'une phase éruptive. Nous avons donc démontré l'évaluation d'une région volcanique lunaire complexe en utilisant l'interprètation de données photogéologiques et spectrophotométriques provenant de sondes spaciales et de mesures morphométriques dérivées d'images d'origine terrestre sur CCD.

1. INTRODUCTION

The form and distribution of lunar volcanic domes and lunar pyroclastic deposits (LPDs) provide insight into the source regions and conditions of ancient volcanic eruptions on the Moon. More than 110 LPDs have been characterized across the Moon (Gaddis *et al.* 2003), using the *Clementine* UVVIS multispectral imagery. LPDs are low-albedo units observed as dark smooth areas in the highlands, on the floors of craters and near mare deposits, and they are often associated with fractures, irregular depressions, and other likely volcanic vents. These pyroclastic deposits often appear to drape over or mantle the underlying surface, which may be mare, smooth plains, or hummocky highland deposits (Gaddis *et al.* 2003). Fire fountaining occurs when rising magma begins the process of degassing (Head & Wilson 1992). Here gasses dissolved in the magma when it is under great pressure begin to come out of the solution (a process called exsolution). This happened as the magma approached the lunar surface, and as the gasses came out of solution they may have explosively erupted, fragmented the surrounding magma, and thrown small magma droplets high above the lunar surface (Head & Wilson 1979).

Lunar domes are formed either by outpouring of magma from a central vent or by a subsurface accumulation of magma that causes an up-doming of the bedrock layers, creating a smooth, gently sloping positive relief. Domes representing volcanic sources are smooth-surfaced and usually have a summit crater pit. Most vents related to domes appear to be associated with surrounding lava plains of known volcanic origin or in association with pyroclastic deposits (Head & Gifford 1980). The extrusive origin of lunar domes and their similarity to terrestrial features like small shield volcanoes have been described in the literature (*cf. e.g.* Head & Gifford 1980), and the presence of a summit crater pit argues against an intrusive or laccolithic origin for the majority of these features. Mare domes bear resemblance in scale and morphology to smaller terrestrial shield volcanoes of the Icelandic and Scutulum Types (Whitford-Stark 1975). In contrast, objects like the Valentine dome and the dome to its north, situated in western Mare Serenitatis, are probably formed by subsurface intrusions, similar to laccoliths on Earth, where magma has flowed under a surface of solidified lava and lifted it up (Douglass 2004; Pau & Lena 2004). The issue of intrusive lunar domes and how they are possibly related to equivalent terrestrial features is not yet well understood, since fundamental differences between terrestrial and lunar structures make the comparison uncertain without additional studies about the mechanisms of intrusions under lunar conditions.

In this study we will regard a complex volcanic region inside the lunar crater Petavius. Petavius is a large, Imbrian-age crater located at 60.0° E and 25.3° S on the southern edge of Mare Fecunditatis. It is a floor-fractured crater that has undergone uplift and fracturing due to magmas pushing up from below (Wilhelms 1987). The hilly areas located to the east and to the north of the central peaks contain several rilles, some straight and others sinuous. Much of the floor is rough, but there are smoother areas in the very north and south.

Two dark areas are localized in the northernmost and southernmost portion of the crater, as seen in Figures 1, 5, and 6a. Both the northern and southern deposit are included in Plate 4 of the USGS lunar geologic maps (Wilhelms 1987 and references therein). The large pyroclastic deposit in the northern part of the floor of Petavius (with an area of 1645 km^2 located at 61.0° E and 23.5° S) was characterized using *Clementine* UVVIS multispectral imagery by Gaddis *et al.* (2003). In

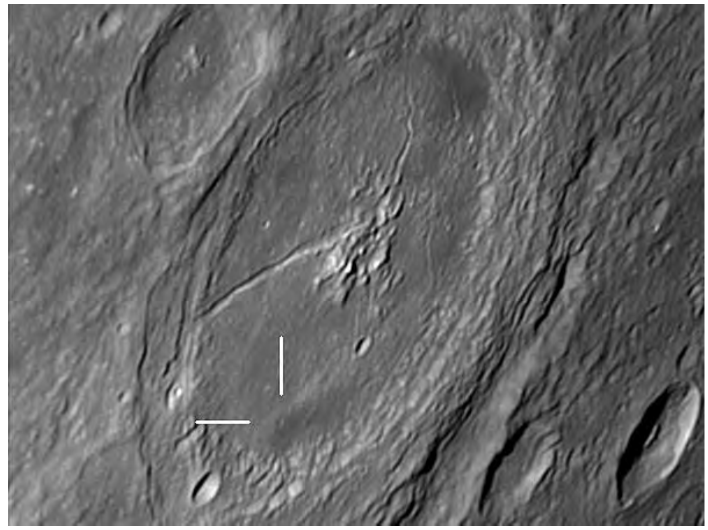

FIGURE 1 – Image by P. Lazzarotti, acquired on November 27, 2004, 23:35 UT. Solar altitude is 17.23°. White lines mark the domical structure.

this study we report *Clementine* UVVIS data and include new ground-based CCD images to investigate the low-albedo unit situated in the southern part of Petavius, centred at 61.9° E and 26.9° S, which likely represents another LPD according to an earlier spectrophotometric analysis by Gaddis *et al.* (2000). Moreover, we perform a detailed examination of the previously reported domical structure in the southern part of the crater floor at 60.7° E and 26.9° S (Wood 2004; Lena *et al.* 2004) and its relation to the nearby possible LPD. This feature distinctly appears in *Lunar Orbiter* image IV-053-H1 on the edge of the smooth low-albedo unit rather than at its centre. Relying on ground-based high-resolution CCD imagery acquired under a variety of illumination conditions, we examine its morphometric characteristics by making use of multi-image photoclinometry and shape from shading techniques. We provide a geologic interpretation of the spectrophotometric and morphometric results we obtain for this exceptionally complex volcanic region. We thus demonstrate the analysis of a complex lunar volcanic region based on the combined interpretation of photogeologic and spectrophotometric spacecraft data and morphometric analyses relying on ground-based high-resolution CCD imagery, obtained by means of sophisticated multi-image 3-D reconstruction techniques.

2. OBSERVATIONS, MORPHOLOGICAL CONSIDERATIONS

2.1 GROUND-BASED CCD IMAGERY

The images shown in Figures 1 to 5 are oriented with north at the top and west on the left. For each of the observations, the local solar altitude *H* and the solar selenographic colongitude *C* were calculated using the *Lunar Observer's Toolkit* (Jamieson 1992). Two images (Figure 1 and 3) were used to derive a digital elevation map (DEM) of the region localized at 60.7° E and 26.9° S (*cf.* section 3). The CCD images were taken with a Lumenera CCD camera (Figure 1), a Philips Vesta Pro Webcam (Figures 2 to 4), and a Philips ToUCam Pro Webcam (Figure 5). The Lumenera camera is a CCD camera for industrial purposes. Its image size amounts to 640 × 480 pixels, the size of the quadratic pixels to 7.4 μm. The Philips Vesta Pro and ToUCam Pro Webcams have the same image size of 640 × 480 pixels and a pixel size of 5.6 μm. We generated each image by stacking several hundreds

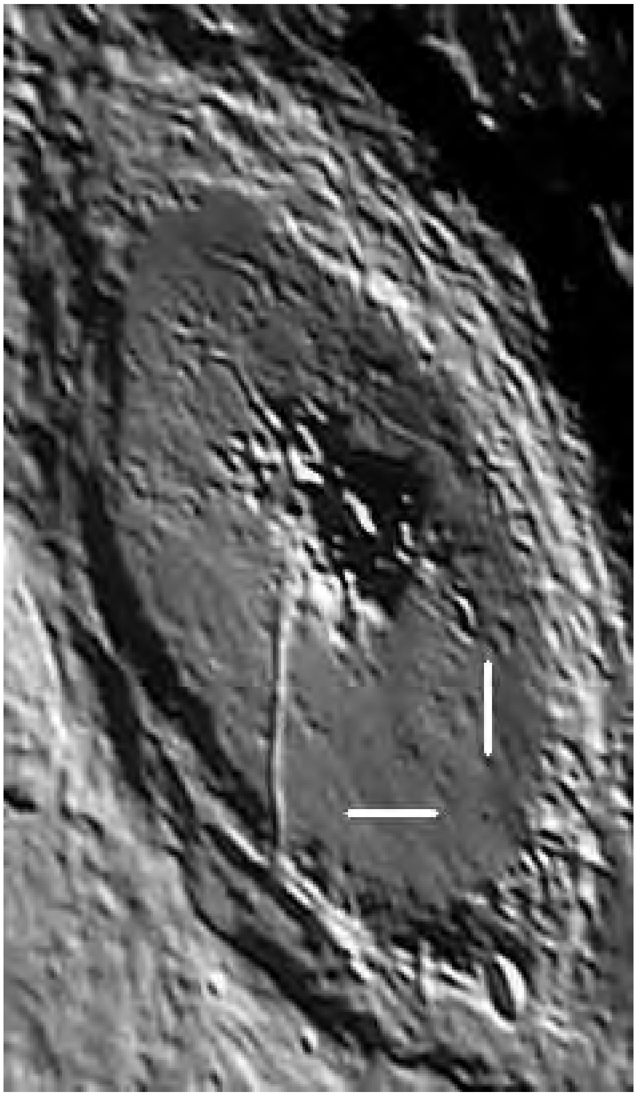

Figure 2 – Image by C. Zannelli, acquired on September 30, 2004, at 21:49 UT. Solar altitude is 5.27°. White lines mark the domical structure.

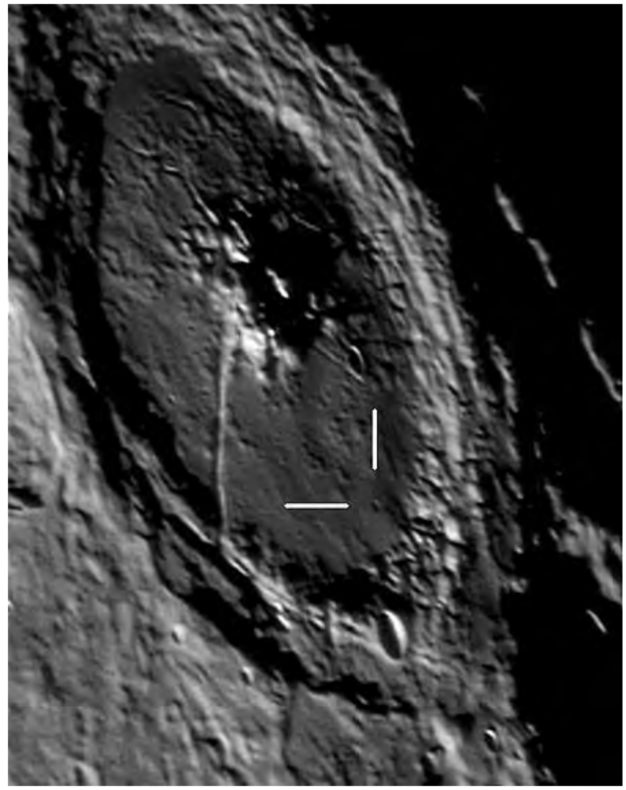

Figure 3 – Image by A. Bianconi, acquired on October 01, 2004, 00:10 UT. Solar altitude is 4.25°. White lines mark the domical structure.

of video frames. For this purpose we made use of the *Registax* and *Giotto* software packages, employing a cross-correlation technique similar to the one described by Baumgardner *et al.* (2000). In that work, however, digitized analog video tapes were processed, while we directly acquired digital video frames. The images are slightly oversampled with respect to the Nyquist limit imposed by the optical system, respectively (however, by no more than 30 percent). The scale of the images shown in Figure 1 and 3 used for 3-D reconstruction amounts to 300 m per pixel on the lunar surface. Due to atmospheric seeing, however, the effective resolution approximately corresponds to 1 km on the lunar surface. We did not utilize super-resolution techniques, but for better visibility of small detail at the resolution limit in the printed figures we applied slight unsharp masking to generate the images shown in Figures 1 to 5. For 3-D reconstruction, however, the effective point-spread function of the image was estimated by the procedure outlined in section 3.3 and then taken into account in equation 8.

Image-based 3-D reconstruction methods like those described in section 3 assume that the greyvalue I of a pixel is proportional to the incident flux F. Especially for Webcams this is not necessarily the case because it is often possible to adjust the gamma value γ manually from within the camera-control software, causing the greyvalue I to be proportional to F^γ. For the Philips Webcams used for Figures 2 to 5, we thus performed a calibration of the gamma scale in the camera-control software by evaluating flatfield frames of varying intensities acquired through different neutral-density filters with known transmission coefficients, then fitting a characteristic curve of the form $I=aF^\gamma$ to the measured flatfield intensities. From this calibration procedure we obtained $\gamma = 0.70$ for Figures 2 and 3, $\gamma = 0.80$ for Figure 4, and $\gamma = 0.94$ for Figure 5. The Lumenera CCD camera used for Figure 1 has a linear ($\gamma = 1.0$) characteristic curve.

Lunar Orbiter images are not suitable for 3-D reconstruction of lunar surface parts based on photometric methods since the relation between incident flux and pixel greyvalue is nonlinear and unknown. The reason is that the images were acquired on a photographic film scanned on board the spacecraft. The same problem arises for the high-resolution orbital images taken with hand-held and aerial cameras from the *Apollo* command modules. What is more, in most existing orbital lunar image data the illumination is not sufficiently oblique to derive 3-D information for shallow features like lunar domes with photoclinometric or shape from shading techniques. For example, solar altitudes are between about 20° and 30° for *Lunar Orbiter* images, and nearly all *Clementine* images were acquired at local lunar noon, corresponding to steep illumination angles in the equatorial regions. Finally, pairs of orbital images of the same region of the lunar surface acquired under different illumination conditions are not available for most surface parts, but our albedo-independent approach requires such image pairs. As a consequence, we have to rely on high-resolution telescopic CCD images acquired at oblique illumination for the purpose of 3-D surface reconstruction.

The image shown in Figure 1 was made by P. Lazzarotti on

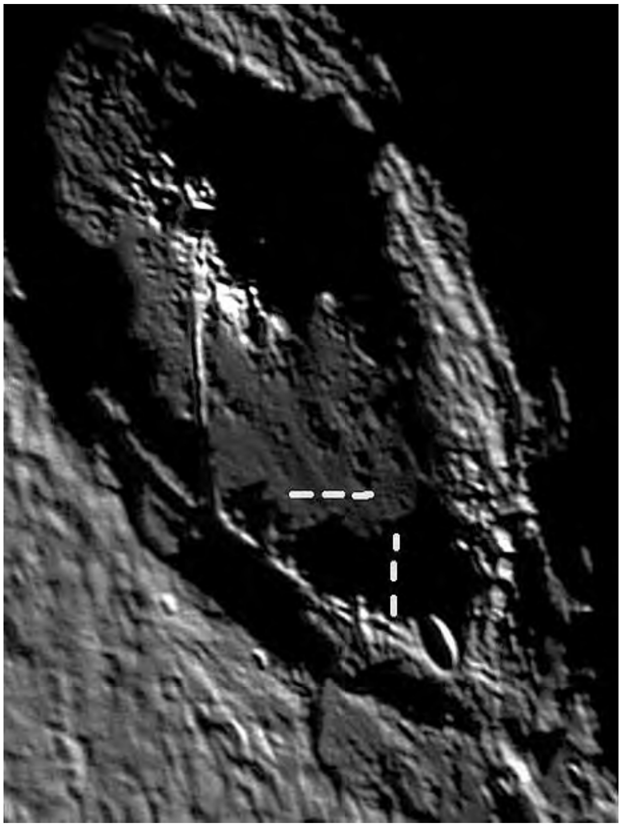

FIGURE 4 – Image by C. Fattinnanzi, acquired on December 29, 2004, at 00:42 UT. Solar altitude is 1.95°. White dashes mark the domical structure.

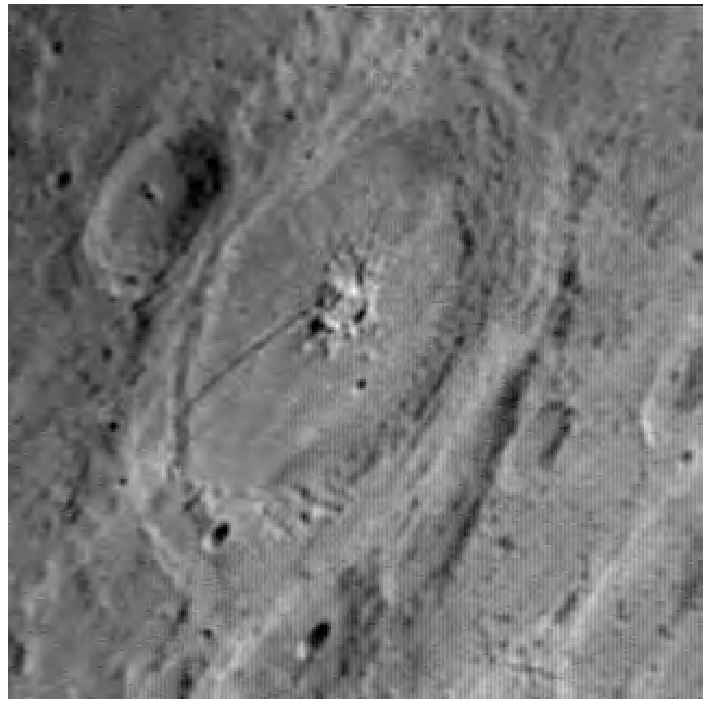

FIGURE 5 – Johnson *I*-band image by C. Wöhler, acquired on January 15, 2005, at 17:14 UT. Solar altitude is 36.60°.

November 27, 2004, at 23:35 UT (H = 17.27°, C = 100.66°, seeing II Antoniadi scale) with a 252-mm Newtonian telescope. In the southern part of Petavius a region is visible, which is smooth and of low albedo, as it is typical of pyroclastic deposits. Figure 2 displays an image taken by C. Zannelli on September 30, 2004, at 21:49 UT (H = 5.27°, C = 113.36°, seeing II) with a 180-mm Maksutov-Newtonian. The image shown in Figure 3 was taken by A. Bianconi using a Schmidt-Cassegrain 300-mm f/10 on October 1, 2004, at 00:10 UT (H = 4.12°, C = 114.51°, seeing II). The image shown in Figure 4 was taken by C. Fattinnanzi on December 29, 2004, at 00:42 UT (H = 1.95°, C = 118.15°, seeing II) with a 250-mm Newtonian telescope. Due to the very low solar altitude, the main rim of Petavius casts a shadow on the western flank of the domical structure, and the south-eastern flank of the domical structure itself casts a shadow on the surrounding surface. Figures 1 to 4 were acquired in integral visible light. The image shown in Figure 5 was taken by C. Wöhler on January 15, 2005, at 17:14 UT (H = 36.60°, C = 333.41°, seeing III) with a 200-mm Newtonian in the Johnson *I*-band, a bandpass filter transmitting near-infrared wavelengths between 700 and 1100 nm. This image distinctly reveals both the well-studied LPD in the northern part of Petavius (Gaddis *et al.* 2003) and the similar low-albedo unit in its southern part (Gaddis *et al.* 2000).

2.2 MORPHOLOGY OF THE DOMICAL STRUCTURE AND THE VENT

The domical structure situated on the edge of the low-albedo unit localized in the southernmost part of the crater Petavius appears to be smooth, with a shallow, rimless crater pit as a vent. It is marked by white lines in Figures 1 to 4. In Figure 1, 2, and 4, its diameter amounts to (10 ± 2) pixels, corrected for foreshortening, corresponding to (3.0 ± 0.6) km. Its depth was estimated by measuring the length l of the shadow cast by its rim in Figure 4, corrected for foreshortening. We obtained a shadow length of (7 ± 1) pixels, corresponding to (2.1 ± 0.3) km. The depth d_{cr} of the vent can then be calculated according to the relation

$$d_{cr} = l \tan H, \qquad (1)$$

which yields d_{cr} = (70 ± 10) m. The depth derived from the shadow length measurement must be considered as a lower limit because the shadow is not cast right into the middle of the vent but slightly off-centre on its inner wall. Nevertheless, this result is in good accordance with the depth of (80 ± 10) m derived by 3-D reconstruction in section 3.

The *Lunar Orbiter* high-resolution image LO IV-053-H1, here shown in Figure 6a (image scale is 300 m per pixel and solar altitude H = 23.0°), was used in order to further investigate the domical structure visible in Figures 1 to 4. Figure 6b shows a four-times enlarged section of this *Lunar Orbiter* image, displaying the vent. The diameter of the vent amounts to 3.0 km, consistent with the value derived from Figures 1, 2, and 4. Its rim does not cast a black shadow. Figure 6c is a four-times enlarged section of the same *Lunar Orbiter* frame showing a nearby fresh impact crater. Small lunar impact craters of this kind have a depth-to-diameter ratio of 1/5 (Pike 1974; Wood & Andersson 1978), corresponding to an average slope of the rim of 22°. Under the given solar altitude of 23°, approximately half of the crater is therefore filled by the shadow cast by the rim. The two impact craters in this image, which are of approximately the same size as the vent, are thus significantly deeper than the vent. Additional high-resolution orbital data of this region from *Lunar Orbiter V* (frame 033) are shown in Figure 6d. In this frame, captured at a much higher resolution than the *Lunar Orbiter IV* image in Figure 6a, the vent appears rimless and without a sharp outline, which supports our interpretation that it is of volcanic origin.

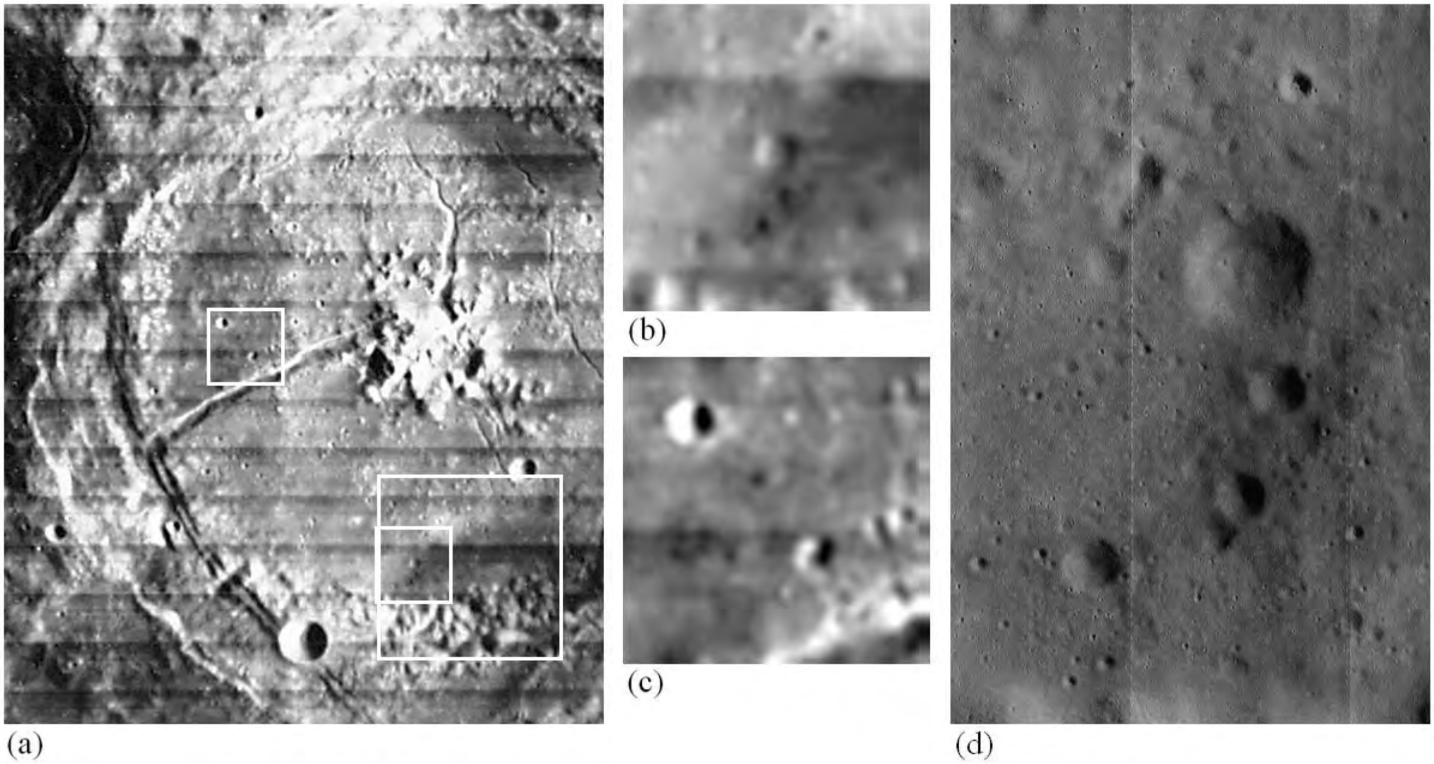

Figure 6 – *Lunar Orbiter* high-resolution image LO IV-053-H1. Image scale is 300 m per pixel, solar altitude is 23.0°. The two small sections showing the vent (b) and a nearby fresh impact crater of similar size (c) as well as the area covered by the *Clementine* 750-nm image in Figure 7a are indicated by white frames, respectively. (d) Part of *Lunar Orbiter V* high-resolution image 033, showing the vent in more detail. For further explanations see section 2.2.

Figure 4 proves the presence of a domical rise. There is a curved edge with the shadow bending around it, showing that the centre of the structure is higher than the edges. The domical structure around the vent has a diameter in east-west direction of (19.8 ± 0.6) km.

Head & Gifford (1980) present a least-squares fit to a set of domes of classes 1, 2, and 3 with summit craters, indicating that the crater pit diameter W_{cr} is related to the dome base diameter W_{do} such that

$$W_{cr} = 0.16W_{do} + 0.52, \qquad (2)$$

with a correlation coefficient of 0.83, where W_{do} and W_{cr} are given in kilometres. With our value of W_{do} = (19.8 ± 0.6) km, the expected value of the vent diameter therefore corresponds to 3.69 km, which is in reasonable agreement with the value of W_{cr} = (3.0 ± 0.6) km we determined from *Lunar Orbiter* frame IV-053-H1 and Figures 1, 3, and 4.

2.3 DETERMINATION OF RELATIVE ALBEDO

Most LPDs are recognized on the basis of their low albedo, mantling appearance, and association with a volcanic vent. The albedo of the dark region localized in the southernmost portion of the crater Petavius was evaluated using the images in Figures 1 and 3 as a byproduct of the multi-image 3-D reconstruction technique described in section 3. We found that the albedo of the eastern flank of the domical structure, situated inside the low-albedo unit, corresponds to (79 ± 2) percent of the albedo of the western flank, representative of the surrounding undisturbed surface.

Using Figure 5 acquired in the Johnson *I*-band, the albedo was determined to (82 ± 2) percent of the albedo of the surrounding undisturbed surface. In contrast to the images shown in Figures 1 to 4, the influence of topographic relief on pixel intensity is negligible due to the higher solar altitude, such that this second estimate of relative albedo was obtained by directly measuring pixel intensities.

Using the same pixel-based approach, the albedo of the eastern flank of the domical structure was determined to (83 ± 1) percent of the albedo of the undisturbed surface (western flank) in the *Clementine* 750-nm image. This value is in good correspondence with the results derived from the ground-based CCD images shown in Figures 1, 3, and 5, also demonstrating that the accuracy of gamma calibration (*cf.* section 2.1) is satisfactory. The results are summarized in Table 1.

Table 1

Albedo of the eastern flank of the domical structure relative to the albedo of the western flank (circles and up-triangles in Figures 7 and 8).

Figure	Solar Altitude *H*	Relative Albedo
1, 3 (*cf.* section 3)	17.27°, 4.12°	0.79 ± 0.02
5 (Johnson I-band)	36.60°	0.82 ± 0.02
7a (*Clementine* 750 nm)	≈ 63°	0.83 ± 0.01

2.4 CLEMENTINE UVVIS IMAGERY

The dark region corresponding to the southern LPD is well apparent in the *Clementine* 750-nm image shown in Figure 7a. We examined the *Clementine* five-band UVVIS multispectral data (415, 750, 900, 950, 1000 nm) in terms of 750-nm reflectance ("albedo") and the

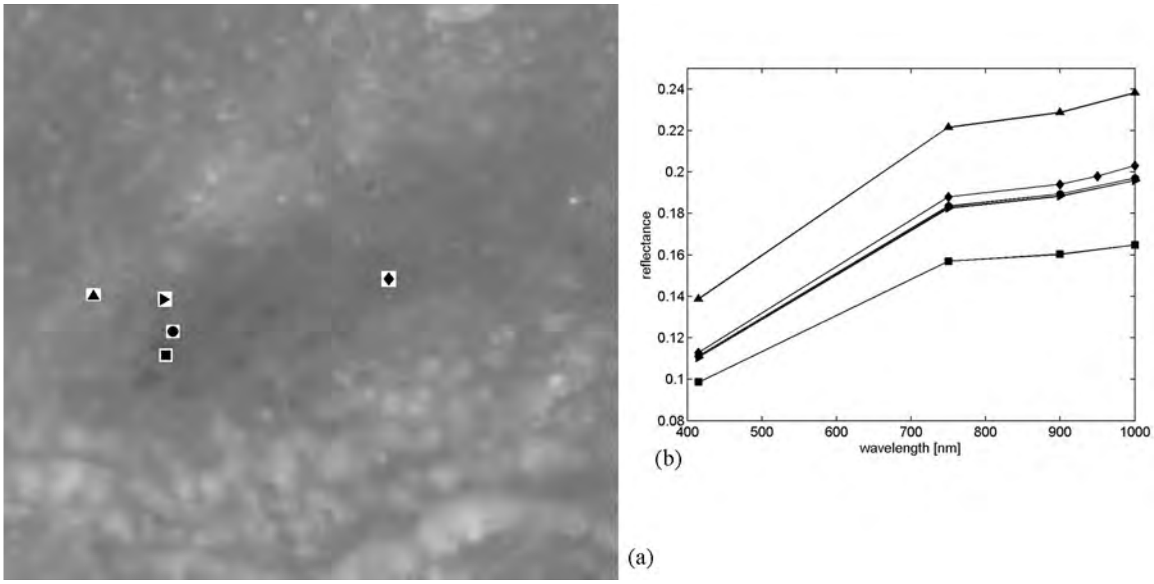

Figure 7 – (a) *Clementine* 750-nm image of the volcanic region. The dark area corresponding to the likely LPD is well apparent. (b) *Clementine* reflectance spectra of five representative locations in the volcanic region. The symbols denote the locations marked in the 750-nm image and correspond to the eastern part of the LPD (diamonds), the dark spot south of the vent (squares), the vent itself (right-triangles), the eastern (circles) and the western (up-triangles) flank of the domical structure (*cf.* also Table 2 and Figure 8).

415/750 and 950/750 colour ratios (Gaddis *et al.* 2000; Gaddis et al. 2003), making use of the calibrated and normalized *Clementine* UVVIS reflectance data as provided by Eliason *et al.* (1999). Albedo at 750 nm is an indicator of variations in soil composition, maturity, particle size, and viewing geometry. The 415/750 colour ratio essentially is a measure for the TiO_2 content of mature basaltic soils, where high 415/750 ratios correspond to high TiO_2 content and vice versa (Charette *et al.* 1974). The 950/750 colour ratio is related to the strength of the mafic absorption band, representing a measure for the FeO content of the soil, and is also sensitive to the optical maturity of mare and highland materials (Lucey *et al*. 1998).

Clementine UVVIS data have been used to characterize lunar pyroclastic deposits and their composition. The spectral properties likely represent a complex combination of the degree of crystallinity (*i.e.* ilmenite content) and of the FeO and TiO_2 content of LPDs. The Taurus-Littrow, Sinus Aestuum, Vaporum, and Rima Bode LPDs are all spectrally very blue (high 415/750 ratios) and are known or inferred to have a significant component of high-TiO_2 materials, in the form of ilmenite-rich black beads. A second class, exemplified by Sulpicius Gallus, is similar to *Apollo 17* deposits in overall composition and is likely to be rich in TiO_2, but may consist of a mixture of Fe^{2+} bearing orange glasses and black beads with a higher glass-to-bead ratio than that of the Taurus-Littrow LPD. The Aristarchus and Harbinger LPDs have low 415/750 values (Gaddis *et al.* 2003). Both orange and black beads were recognized as pyroclastic, with variations in cooling time in a fire fountain probably resulting in quenched, crystallized, and/or composite droplets (Weitz & Head 1999). According to Gaddis *et al.* (2003), black beads and orange glasses are compositionally equivalent although the spectral behaviours of these two components are different. Orange glasses have low 415/750 ratios because the TiO_2 generates an absorption feature extending from the near UV into the visible and the FeO causes absorption bands near 1000 and 2000 nm. In contrast, the higher crystallinity of the black beads implies a reduced spectral contrast and thus a weaker mafic absorption band, which in combination with the ilmenite absorption band at 600 nm results in a high 415/750 ratio. This difference occurs although the TiO_2 content of the black beads is comparable to that of the orange glasses. As a consequence the *Clementine* spectral ratios can be used for comparisons of LPDs enriched in orange glasses or black beads to other LPDs but not as strict indicators of their FeO and TiO_2 content. The orange glasses and black beads deposits, however, are not representative of the majority of LPDs.

Table 2

Clementine UVVIS reflectance values (see also Figure 7).

Location	Longitude	Latitude	415 nm	750 nm	900 nm	950 nm	1000 nm
Eastern part of low-albedo unit	61.26° E	26.84° S	0.113	0.188	0.194	0.198	0.203
Dark spot south of the vent	60.69° E	27.03° S	0.099	0.157	0.160	—	0.165
Vent	60.68° E	26.92° S	0.111	0.183	0.188	—	0.196
Eastern flank of domical structure	60.72° E	26.99° S	0.111	0.184	0.189	—	0.197
Western flank of domical structure	60.52° E	26.89° S	0.139	0.222	0.229	—	0.238

The *Clementine* five-band reflectance values inferred for the volcanic region in the south of Petavius are reported in Table 2 and Figure 7b; the sample area used to obtain the spectra amounts to 700 × 700 m^2. The area of the LPD amounts to roughly 530 km^2, which makes it belong to the class of "large" LPDs defined by Gaddis *et al.* (2003). Figure 8 displays albedos and colour ratios of the representative locations in the volcanic region. The grey background shapes are the ranges for typical mature mare and highland materials. They are

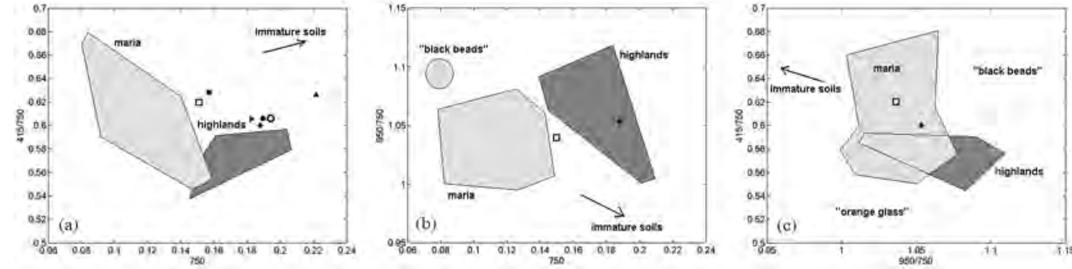

Figure 8 – Spectrophotometric analysis of five representative locations in the volcanic region (closed symbols, *cf.* Figure 7, diagrams after Gaddis *et al.* 2003). Several data points are missing in the 750 vs. 950/750 diagram (b) and the 950/750 vs. 415/750 diagram (c) since there are no *Clementine* 950-nm data available for the corresponding locations. For comparison, open symbols represent data for LPDs Petavius N (squares) and S (circles) reported by Gaddis *et al.* (2000).

shown for comparison in order to provide a context for the spectral properties of the examined LPDs according to Gaddis *et al.* (2003). The 750 vs. 950/750 diagram and the 950/750 vs. 415/750 diagram only display the eastern part of the LPD since there are no *Clementine* 950-nm data available for the region around the vent. Data for the LPDs Petavius N and S reported by Gaddis *et al.* (2000) are indicated in Figure 8 for comparison. According to Gaddis *et al.* (2003), LPDs were observed to display a wider range of albedos and spectral properties than previously known. While most large and very large LPDs appear to contain significant components of mare material, several LPDs of all sizes, including the LPD examined in this study, display substantially higher albedos, indicating contamination by highlands material (*cf.* section 4).

3. DIGITAL ELEVATION MAP OF THE DOMICAL STRUCTURE

Generating a DEM of a part of the lunar surface requires its three-dimensional reconstruction. The *Clementine* spacecraft entirely mapped the lunar surface in 3-D at a resolution on the ground of 0.25 degrees in longitude and latitude, *i.e.* better than 7.5 km, by means of laser altimetry. Although the obtained profiles nicely show large-scale features such as the huge South Pole Aitken Basin on the lunar far side, they do not reveal the 3-D structure of the lunar surface on small, *e.g.* kilometre, scales (Bussey & Spudis 2004). Parts of the lunar surface have been mapped in 3-D based on a stereoscopic analysis of image pairs acquired by the *Clementine* spacecraft and from the *Apollo* command modules orbiting the Moon (Cook *et al.* 1999). The resolution of the obtained surface profiles is 1 km on the ground, while the accuracy of the derived elevation values is not better than 100 m, which is not sufficient for measuring the height of shallow lunar volcanic features.

We therefore generated a DEM of the observed domical structure based on our telescopic CCD images. Well-known image-based methods for 3-D surface reconstruction are *photoclinometry* and *shape from shading* (SFS). They make use of the fact that surface parts inclined towards the light source appear brighter than surface parts inclined away from it. Both methods aim at deriving the orientation of the surface at each image location by using a model of the reflectance properties of the surface and knowledge about the illumination conditions. The photoclinometric approach performs a 3-D reconstruction of the surface along one-dimensional profiles (McEwen 1985), while the SFS technique yields an elevation value for each image pixel (Horn 1989). Wöhler & Hafezi (2005) introduce an extended framework based on combined SFS and shadow analysis and its application to the 3-D reconstruction of regions of the lunar surface.

In this section we present a multi-image 3-D reconstruction technique that relies on a combination of photoclinometry and shape from shading. In contrast to most state-of-the-art approaches, our method is also applicable in the case of non-uniform surface albedo, such as for 3-D reconstruction of lunar volcanic regions dominated by pyroclastic deposits.

3.1 SURFACE REFLECTANCE MODEL

Photoclinometric and SFS techniques take into account the geometric configuration of camera, light source, and the object itself. For parallel incident light and an infinite distance between camera and object, the intensity $I(u,v)$ of image pixel (u,v) amounts to

$$I(u,v) = \kappa I_i \, \Phi(\vec{n}(x,y,z), \vec{s}, \vec{v} \tag{3}$$

Here, κ is a camera-specific constant, $\vec{n}$ the surface normal, $\vec{v}$ the direction to the camera, I_i the intensity and $\vec{s}$ the direction of incident light, and Φ the *reflectance function*. A well-known example is the Lambertian reflectance function $\Phi(\vec{n},\vec{s}) = \chi \cos\theta_i$, where θ_i denotes the *incidence angle* between $\vec{n}$ and $\vec{s}$ with $\cos\theta_i = \vec{n} \cdot \vec{s} / (|\vec{n}| \, |\vec{s}|)$, and χ a surface-specific constant. The product $\kappa I_i \chi = \rho(u,v)$ is called *surface albedo*. In the following, the surface normal $\vec{n}$ will be represented in gradient space by the directional derivatives $p = \partial z/\partial x$ and $q = \partial z/\partial y$ of the surface function $z(x,y)$ with $\vec{n} = (-p,-q,1)$. Equation 3 can then be rewritten as

$$I(u,v) = R(p(u,v),\, q(u,v)). \tag{4}$$

The function $R(p,q)$ is called reflectance map. Analogous to $\vec{n}$, we define $\vec{s} = (-p_s,-q_s,1)$ and $\vec{v} = (-p_v,-q_v,1)$.

The Lambert model does not correspond very well to the true reflectance behaviour of the lunar surface. A much more appropriate relation is the physically motivated photometric model by Hapke (1993), which is based on the theory of radiative transfer. It allows conclusions about certain surface properties such as the average particle size, the particle density, the albedo of the surface material, and the macroscopic surface roughness. Sets of Hapke parameters valid for the lunar regolith are given *e.g.* by Warell (2004). It is not straightforward, however, to directly employ the Hapke model for 3-D reconstruction purposes. Therefore, in many astrogeological applications the comparably simple, empirical *Lunar-Lambert* law

$$R_{LL}(\rho,\theta_i,\theta_e,\alpha) = \rho\left[2L(\alpha)\frac{\cos\theta_i}{\cos\theta_i + \cos\theta_e} + (1 - L(\alpha))\cos\theta_i\right] \tag{5}$$

is used (McEwen 1991). In equation 5, θ_e denotes the *emission angle* between the surface normal $\vec{n}$ and the viewing direction $\vec{v}$ with $\cos\theta_e = \vec{n}\cdot\vec{s}/(|\vec{n}||\vec{s}|)$. The Lunar-Lambert parameter $L(\alpha)$ is an empirical value depending on the phase angle α between $\vec{s}$ and $\vec{v}$. The Lunar-Lambert model is a weighted sum of the *Lommel-Seeliger* law and the Lambert law. Given a suitable choice of $L(\alpha)$, it fits the true reflectance behaviour of many planetary surfaces equally well as the Hapke model. For oblique illumination and perpendicular view we have $\cos\theta_i << \cos\theta_e \approx 1$, such that the behaviour of the Lunar-Lambert law (equation 5) is essentially Lambertian. The domical structure regarded in this paper, however, is situated far off the centre of the Moon's apparent disk ($\theta_e \approx 60°$), where the Lunar-Lambert law displays distinct deviations from the Lambert model.

Values for $L(\alpha)$ have been tabulated by McEwen (1991) for planetary surfaces with a wide range of regolith properties. McEwen (1991) demonstrates that for low-albedo surfaces like that of the Moon, $L(\alpha)$ is mainly governed by Hapke's macroscopic surface-roughness parameter $\bar{\theta}$ (Hapke 1993). According to recent work on lunar photometric modelling by Warell (2004), we assume $\bar{\theta}$ =11°. The ground-based CCD images used for 3-D reconstruction have been acquired under phase angles of 13.2° (Figure 1) and 29.6° (Figure 3). In this range, a largely constant value of $L(\alpha) = 0.95 \pm 0.15$ is obtained from McEwen (1991) for a surface with the Hapke parameters of the lunar regolith (McEwen 1991, Figures 16 and 17 therein). The error interval for $L(\alpha)$ covers values of $\bar{\theta}$ between 10° and 20°, thus also covering somewhat larger values for $\bar{\theta}$ obtained in earlier work on lunar photometric modelling (Warell 2004).

3.2 INITIALIZATION BY QUOTIENT-BASED TWO-IMAGE PHOTOCLINOMETRY

According to equation 4 we attempt to determine three variables $\rho(u,v)$, $p(u,v)$, and $q(u,v)$ for each pixel from one single measurement, the pixel intensity $I(u,v)$, *i.e.* we are trying to solve an *ill-posed problem*. In a first step we therefore follow a photoclinometric approach, which consists of computing height profiles along image rows. In our example, the terrain is gently sloping ($|p|,|q| << 1$), and the scene is illuminated nearly exactly from the west ($q_s = 0$) and viewed approximately from the west ($|q_v| << |p_v|$). The Lunar-Lambert reflectance (equation 5) thus depends much stronger on p than on q, such that we may set $q = 0$. Note that this approximation is exact for cross-sections in east-west direction through the summit of a feature, while it is otherwise a reasonable approximation.

Even in the recent photogrammetric literature dealing with 3-D reconstruction of lunar surface regions (Lohse & Heipke 2002) it is usually assumed that the albedo $\rho(u,v)$ is constant over the surface. This assumption is clearly invalid for the domical structure regarded here, which is situated on the edge of a low-albedo unit. We therefore utilize the two images of the domical structure shown in Figures 1 and 3, acquired at different illumination conditions, to separate intensity variations due to topographic relief from those due to albedo variations. The images have to be pixel-synchronous, *i.e.* identical pixel positions on the images must correspond to the same physical point on the surface, which is achieved by an *image registration* step (*cf.* Gottesfeld Brown (1992) for a survey). The result is shown in Figure 9a. The images are then transformed to cylindrical projection as shown in Figure 9b, such that image columns and rows are parallel to the longitude and latitude grid, respectively. We assume that we have a reflectance map of the form $R(\rho,p,q) = \rho\tilde{R}(p,q)$. We can then perform photoclinometry along image rows by extending equation 4 as described by McEwen (1985) and determine $p(u,v)$ such that

$$\frac{I_1(u,v)}{I_2(u,v)} = \frac{\tilde{R}_1(p(u,v),0)}{\tilde{R}_2(p(u,v),0)}. \tag{6}$$

The surface gradient $q(u,v)$ is still kept zero, and the albedo ρ cancels out. With the reflectance function corresponding to the Lunar-Lambert law (equation 5), Equation 6 cannot be solved analytically, such that the Newton method is used. As the images are not absolutely radiometrically calibrated, their average pixel intensities have to be adjusted according to the different solar altitudes, relying on the assumption that on the average the surface is flat. As long as $\tilde{R}(p,q)$ is not strongly nonlinear in p and q it is sufficient to normalize image 1 by multiplying its pixel intensities with the factor

$$\frac{\tilde{R}_1(0,0)\left\langle I_2(u,v)\right\rangle_{u,v}}{\tilde{R}_2(0,0)\left\langle I_1(u,v)\right\rangle_{u,v}}.$$

The non-uniform surface albedo $\rho(u,v)$ is then recovered by

$$\rho(u,v) = \frac{1}{L}\sum_{l=1}^{L}\frac{I_l(u,v)}{\tilde{R}_l\ (u.v)}, \tag{7}$$

where we have $L = 2$ images in our example. A cross-section in east-west direction through the vent, obtained by integration of $p(u,v)$ along the corresponding image row, is shown in Figure 9c. The albedo map of the domical structure is shown in Figure 9d.

3.3 REFINEMENT BY A VARIATIONAL SHAPE FROM SHADING APPROACH

The result of photoclinometry is refined in a second step by means of a more sophisticated, variational approach described in detail by Horn (1989). It primarily consists of minimizing the sum of squared differences between the observed pixel intensities $I(u,v)$ and the modelled reflectances $R(\rho(u,v),p(u,v),q(u,v))$.

Our ground-based images are affected by a slight blur due to atmospheric seeing. Hence, the observed image $I(u,v)$ is assumed to be a convolution $G * I_0(u,v)$ of the true image $I_0(u,v)$ with a Gaussian point-spread function (PSF) G. The half width σ of the Gaussian PSF G is determined from the intensity profile of shadows cast by steep mountains, *e.g.* crater rims, where an abrupt transition from illuminated surface to darkness is expected. Convolving a synthetically generated abrupt change in intensity with a Gaussian PSF and comparing the result with the intensity profile observed in the image allows for an estimation of the PSF half width σ. A similar method is used by Baumgardner *et al.* (2000) to estimate the PSF for ground-based Mercury images, using the limb of the planetary disk as a reference. The intensity error term is then given by

$$e_i = \sum_{u,v}[I(u,v) - G * R(\rho(u,v), p(u,v), q(u,v))]^2 \tag{8}$$

(Joshi & Chaudhuri 2004). The non-uniform surface albedo $\rho(u,v)$ and approximate values for the surface gradients $p(u,v)$ in east-west

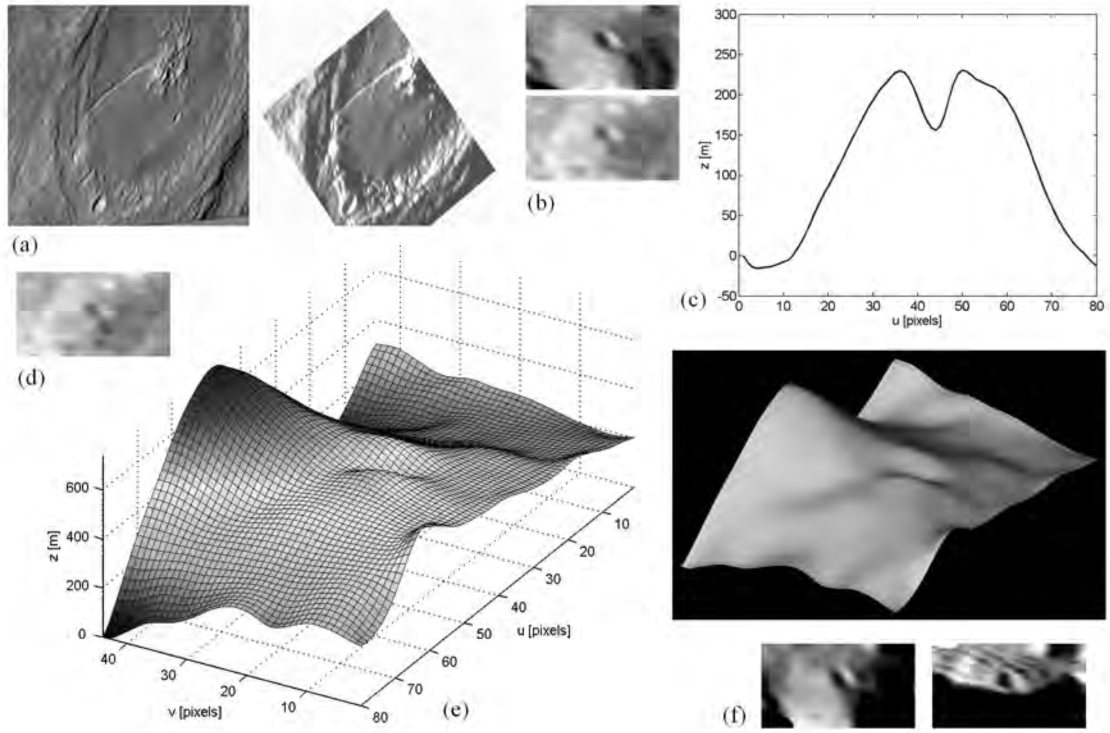

Figure 9 – DEM of the domical structure around the vent (*cf.* section 3). (a) Result of image registration of Figures 1 and 3; (b) Reconstructed surface section according to Figures 1 and 3, respectively, rectified to cylindrical projection; (c) Cross-section in east-west direction through the vent and (d) albedo map, derived by two-image photoclinometry; (e) DEM, viewed from the north-east, along with a rendered view of the scene (The vertical scale is 10-times exaggerated); (f) Synthesized view of the region around the vent under a solar altitude of 1.95° (left) along with the corresponding rectified section of Figure 4 (right). The western flank in the synthesized image cannot display a shadow because this shadow is cast from the outside by the main rim of Petavius, but the shape of the shadow on the eastern flank, which is cast by the domical structure itself, is in reasonable agreement with its real counterpart.

direction are known from section 3.2, obtained there under the assumption of zero values of the surface gradients *q(u,v)* in north-south direction. Horn (1989) emphasizes that *p(u,v)* and *q(u,v)* are not independent of each other but represent directional derivatives of the same surface *z(u,v)*. In other words, they have to be an *integrable vector field*. As a consequence, *z(u,v)* has to be chosen such that the *departure from integrability* error term

$$e_s = \sum_{u,v}\left[\left(\frac{\partial z}{\partial x} - p\right)^2 + \left(\frac{\partial z}{\partial y} - q\right)^2\right] \qquad (9)$$

is minimized. We therefore have to minimize the overall error term $e = e_i + \mu e_s$, where the Lagrange parameter μ denotes the relative weight of the error terms. For this purpose we utilize the iterative scheme by Horn (1989), which simultaneously adjusts *p(u,v), q(u,v)*, and *z(u,v)*. The iteration is initialized with the *p(u,v)* values obtained in section 3.2 and with *q(u,v)* = 0. In the course of the iteration process, *p(u,v)* hardly changes, and *q(u,v)* obtains values consistent with the integrability error term (equation 9). For this evaluation we utilized the image shown in Figure 3 because it most distinctly displays the topographic relief.

The DEM of the domical structure obtained with this method is shown in Figure 9e. It reveals that the vent is elevated by 240 m above the surrounding surface. To the south of the vent, the terrain rises further up to a height of 530 m. Figure 9f is a synthesized view of the domical structure derived by means of the DEM, illustrating how the region should look when illuminated at a solar altitude of 1.95°, as it is the case for Figure 4. The western flank does not display a shadow, because in Figure 4 this shadow is cast from the outside by the main rim of Petavius, but the shape of the shadow on the eastern flank, which is cast by the structure itself, is in reasonable agreement with its real counterpart observed in Figure 4. This kind of comparison is suggested by Horn (1989) as an independent test of the reconstruction result when no ground truth is available.

3.4 ESTIMATION OF ERROR BOUNDS

In the context of image-based 3-D reconstruction of the domical structure, three main sources of error can be found. The parameter $L(\alpha)$ of the reflectance function is not exactly known and may show variations over the surface for different terrain types. According to McEwen (1991), however, its dependence on the physical parameters of the surface (the Hapke parameters) is strongest for phase angles around 90° but not very pronounced at low phase angles. In our example we assume $L(\alpha) = 0.95 \pm 0.15$ (*cf.* section 3.1).

The half width of the Gaussian PSF for the image in Figure 3, which is used for the refined 3-D reconstruction of the domical structure described in section 3.3, was estimated to $\sigma = (1.5 \pm 0.5)$ pixels.

The uncertainties in $L(\alpha)$ and σ affect the measured height values even at the summit of the domical structure by no more than a few metres and can therefore be regarded as irrelevant. We expect the influence of the PSF to become more important for strongly wrinkled surfaces.

An important issue, however, is the nonlinearity of the CCD sensor, which is compensated by the gamma calibration procedure described in section 2.1. The uncertainty of the determined gamma values approximately amounts to ± 0.05 for the Webcams used to acquire Figures 2 to 5. The Lumenera CCD camera used for Figure 1 has a linear ($\gamma = 1.0$) characteristic curve. The resulting error interval of the height amounts to ± 20 m at the vent and ± 30 m at the summit.

4. RESULTS AND DISCUSSION

Petavius is a large, Imbrian-age crater. Much of the floor is rough, but there are smoother areas in the very north and south (Figures 1 to 3). Views under higher solar altitudes (Figures 1, 5, 6, and 7) show that these two regions have a lower albedo than the surrounding surface. A large pyroclastic deposit with an area of 1645 km^2 is located in the northern part of the floor of Petavius, at 23.5° S and 61° E. A further LPD, measuring roughly 530 km^2, is situated in the southernmost region of Petavius. The southern LPD has been included in Plate 4 of the USGS lunar geology maps (Wilhelms 1987 and references therein). Moreover, Gaddis *et al.* (2000) characterize two LPDs in Petavius, both without specific data and location, but described in general terms as Petavius N and S.

A domical structure associated with a shallow, rimless vent of (3.0 ± 0.6) km diameter is found on the edge of the southern LPD, centred at 60.7° E and 26.9° S. According to the DEM shown in Figure 9e, the vent has a depth of (80 ± 10) m. As a note of interest, the depth value is significantly different from the $D/5$ ratio, which is typical for small fresh impact craters of similar diameter (Pike 1974; Wood & Andersson 1978). For such an impact crater, the expected depth is roughly 600 m. Furthermore, the location of the vent on a typical dome relief (*cf.* Figures 1 to 4) and its association with the LPD is suggestive of a volcanic origin. The domical structure has a diameter of (19.8 ± 0.6) km and an effective height of (240 ± 20) m, resulting in a slope of (1.4 ± 0.2)°. The most elevated part of the surface section covered by the DEM has a height of (530 ± 30) m, resulting in an average slope of (3.1 ± 0.3)°. Some parts of the eastern flank, however, are steeper than 4.25° as they cast shadows in the image shown in Figure 3. The morphometric data are summarized in Table 3.

Table 3
Morphometric properties of the domical structure, the vent, and the hummocky deposit.

	Diameter (km)	Height or depth (m)	Slope (°)
Domical structure	19.8 ± 0.6	240 ± 20	1.4 ± 0.2
Vent	3.0 ± 0.6	80 ± 10	3.1 ± 1.0
Hummocky deposit	19.8 ± 0.6	530 ± 30	3.1 ± 0.3

The relation between dome diameter and vent diameter is consistent with the statistical data by Head & Gifford (1980) for lunar domes of classes 1, 2, and 3. According to their diameter-height considerations, the domical structure appears to be similar to the class 1 (shield volcano) type. The more elevated summit south of the vent, however, is too high and too steep to be of volcanic origin. Hence, our interpretation is that the dome is placed adjacent to a hummocky deposit, which is supported by the close proximity of this region to the rugged inner crater rim of Petavius.

The *Clementine* UVVIS data we report for the eastern part of the deposit and the vent (Table 2, Figures 7 and 8) are close to the Petavius S data of Gaddis *et al.* (2000), such that the LPD examined here presumably corresponds to that object. Unfortunately, no 950-nm data are available for the region around the vent, such that the data points denoting locations near the vent do not appear in Figures 8b and 8c. In the 750 vs. 415/750 diagram, the eastern part of the pyroclastic deposit (diamonds in Figure 8) appears to fall within the highlands material type, mainly due to its high 750-nm albedo of 0.19; this remains true when regarding its moderate mafic absorption in the 750 vs. 950/750 diagram. The observed reflectances are considerably higher than those of the Taurus-Littrow and Aristarchus LPDs (Gaddis *et al.* 2003). Such properties are found for many small but also for several large LPDs. A hummocky, high-albedo surface appears to be covered by a relatively thin layer of pyroclastic material containing highlands substrate. The most plausible explanation is that highlands wallrock was entrained into the deposit during eruption, or contamination was incorporated by lateral transport or vertical mixing. In the 950/750 vs. 415/750 diagram, the eastern part of the LPD falls within the mare type but close to the highlands type; both soil types strongly overlap in this diagram.

While the eastern part of the LPD, the vent, and the eastern flank of the domical structure (diamonds, right-triangles, and circles in Figure 8a) are of similarly high 750-nm albedo (around 0.19), the dark spot south of the vent (solid square in Figure 8a) has a considerably lower 750-nm albedo of about 0.16, indicating that it is dominated to a larger extent by pyroclastic material. In the 750 vs. 415/750 diagram, its signature is very similar to the LPD in the northern region of the floor of Petavius at 23.5° S and 61.0° E, characterized by Gaddis *et al.* (2003). If we were to assume a 950/750 ratio of the dark spot of around 1.05, similar to the value observed for the eastern part of the LPD, its position in the 950/750 vs. 415/750 diagram (Figure 8c) would imply a composition more mare-like than that of the other locations regarded, due to its higher 415/750 ratio. Possibly, the dark spot represents a small patch covered by a thicker layer of pyroclastic material. Further similar patches are apparent in the *Clementine* 750-nm image of Figure 7a to the south and south-east of the vent.

Interestingly, the domical structure shows on its eastern flank a spectral signature similar to that of the vent. This material likely consists of pyroclasts deposited by explosive activity from the vent. This assumption is also supported by the fact that the hummocky structure just south of the vent, rising up to a level several hundreds of metres higher than the vent itself (*cf.* Figure 9e), is covered by dark material presumably transported there by eruptions. Hence, this region might have undergone two subsequent volcanic phases: a phase of effusive volcanism building up the domical structure at the northern flank of the hummocky deposit, and a phase of eruptive volcanism generating the LPD, thus covering the southern and eastern part of the hummocky deposit with dark pyroclastic material.

5. SUMMARY AND CONCLUSION

In this study we have examined a complex lunar volcanic region, composed of an extended smooth low-albedo unit associated with a domical structure and a vent, situated in the south of Petavius crater at selenographic coordinates 61.9° E and 26.9° S. We have performed a spectrophotometric study of representative locations in the volcanic region based on *Clementine* UVVIS data. Relying on ground-based high-resolution CCD imagery acquired under a variety of illumination conditions, we have examined the morphometric characteristics of the domical structure situated on the edge of the low-albedo unit. To cope with the strongly non-uniform surface albedo of that region, we utilized sophisticated multi-image photoclinometry and shape from shading techniques. Our geologic interpretation of the spectrophotometric and morphometric results we obtained for this complex volcanic region arrives at the conclusion that the low-albedo unit represents a pyroclastic deposit and is accompanied by a vent and an effusive lunar dome situated adjacent to a hummocky deposit. Possibly this region has undergone an effusive and a subsequent eruptive phase of volcanism. We have thus demonstrated the analysis of a complex lunar volcanic region based on the combined interpretation of photogeologic and spectrophotometric spacecraft data and morphometric data derived from ground-based CCD images. We expect our approach to be suitable for the general scenario of detection and geologic interpretation of complex lunar volcanic regions.

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FROM ANTARCTICA TO MANITOBA – THE 14TH ANNUAL MIAC MEETING

The Meteorites and Impacts Advisory Committee (MIAC) to the Canadian Space Agency (CSA) held its annual business and research meeting this past October at Lakehead University, in Thunder Bay, Ontario. A rich diversity of talks on fireballs, meteorites, and terrestrial impact structures were presented during the research sub-committee meeting and the abstracts for these talks are presented over the following pages.

One of MIAC's official mandates is to provide the CSA with advice on matters relating to Canadian research on small-bodies within the Solar System, including asteroids, comets, fireballs, meteorites, meteor showers, and terrestrial impact craters. MIAC also has a public education mandate, and indeed, the recent meeting was opened by a set of well-attended public lectures. MIAC member Dr. Graham Wilson (Turnstone Geological Services) started the lecture session with an illustrated talk on meteorites and their origins. Dr. Bill Addison (Lakehead University) described the recent discovery and identification of the ejecta blanket associated with the Sudbury impact crater.

The origins of MIAC stretch back to the fall of the Bruderheim, AB meteorite on March 4, 1960. In response to this event, the Associate Committee on Meteorites (ACOM) was established to enable the coordinated investigation of meteorite falls within Canada. ACOM initially operated under the auspices of the National Research Council, and the committee held meetings each year through to 1991. During the 1991 to 1992 interval, however, the committee took on new terms of reference and the CSA became the parent funding body. The name change to MIAC also occurred at this time. All the above being said, one of the great pleasures for me during the recent gathering was to present the host of the meeting, Dr. Stephen Kissin (figure 1) with an appreciation plaque commemorating 25 years of contributions and membership to both ACOM and MIAC.

Martin Beech (MIAC chair),
Campion College, University of Regina.

Figure 1 – Host of the 14th MIAC meeting at Lakehead University, Dr. Stephen Kissin (to the left), being presented with an appreciation plaque for 25 years of ACOM and MIAC membership. The plaque displays a slice of the Toluca iron meteorite. (Photograph courtesy of G. Dymond).

Abstracts of talks presented

Towards an atlas of chondrule textures, R.K. Herd (Geological Survey of Canada), O.R. Norton (23028 Chisholm Trail, Bend, OR 97702), P.A. Hunt (Geological Survey of Canada), L.A. Chitwood (61644 Daly Estates Drive, Bend, OR 97702), and K.E. Venance (Geological Survey of Canada).

Introduction: Chondrites of all kinds are a major class of meteorites whose detailed provenance is poorly understood and complex. They are classified and named based in part upon their structure, mineralogy, and texture, and in part upon their bulk chemistry and mineral chemistry. Understanding their origin is critically dependent on understanding the origin of their chondrules and other constituents, how these have become associated, and what processes are documented by their lithology and petrology. Few studies examine the internal textures of chondrules with a view to interpreting their origin and that of the chondrites that contain them, or to compare chondrules from different groups and petrologic grades. The textures of Earth rocks and minerals, along with their chemistry, are studied to determine their origins; meteorite studies favour chemistry almost exclusively to derive the origins and classification of extraterrestrial rocks.

Current Situation: Recent books (Norton, 2002; Hutchinson, 2004; Sears, 2004) and articles (Grossman and Brearley, 2005; Norton, 2005) have published photomicrographs or back-scattered electron (BSE) images of chondrules, or of thin sections of chondrites (Lauretta and Kilgore, 2005). In research papers (*cf.* Grossman and Brearley, 2005) the illustrations support detailed mineral or isotope chemistry, and conclusions from those analyses, even though variations in chondrule texture along with chemistry are observable. Elsewhere the images support conclusions about classification without definitive textural details being compiled. Others are detailed pictures with no accompanying interpretation.

Data Needed: Textural interpretation down to the scale of the mineral and chondrule matrix analyses (a few microns), or comparative textural documentation of different chondrules from the same meteorite, is usually missing. Chemical and isotopic data need to be interpreted in the context of the textural and mineralogical characteristics of the analyzed objects within the meteorites, not independent of those characteristics. This requires a more rigorous textural documentation and classification of chondrites and chondrules than is currently common practice. In particular, it requires imaging and interpretation of chondrite structures and chondrule textures at all appropriate scales where information about their origin may be gleaned, and it requires reference materials. An atlas of chondrule textures is required.

Advances: The proposal to focus a community effort among researchers interested in systematic textural studies of chondrules and chondrites, through a dedicated web site and list, is moving towards implementation later this year. A host for the web site and other resources has been obtained. We have many of our own images and interpretations to start the compilation. Potential contributors and collaborators are invited to contact us.

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Preliminary Examination of the Pinawa Iron Meteorite, Stephen A. Kissin (Lakehead University).

An iron meteorite was found in 1998 or 1999 near Pinawa, Manitoba, by Derek Esterelle (Figure 2), who previously discovered the Bernic Lake iron meteorite 40 kilometres to the east. The new meteorite is provisionally named "Pinawa" after the town near its discovery locality. The 2.5-kg meteorite is extremely rusty on its ragged exterior, and its appearance resembles that of the Bernic Lake iron.

Examination of polished surfaces of slices of the meteorite reveal that although it has been subjected to severe mechanical deformation that has distorted the Widmanstaetten pattern, as in Bernic Lake, there are distinct differences. Notably, preliminary measurements indicate that the kamacite bandwidth is approximately half that of Bernic Lake at ca. 2mm. As well, there is an absence of Neumann lines, which require a shock pressure of 10-kbars for their formation. Thus, the mechanical deformation is more likely due to terrestrial impact than cosmic disruption of a parent body. "Pinawa" also contains abundant small troilite inclusions, which are much less abundant in Bernic Lake.

Although more details on structure and information on composition, which will enable definitive typing of the meteorite as to its chemical group, are needed, it is clear that "Pinawa" is a new Canadian meteorite. The proximity to the location of the Bernic Lake meteorite, together with the weathered state of both, suggests that they may have been transported and subsequently deposited at a glacial margin in the Pleistocene.

Figure 2 – Derek Erstelle holding one of the Bernic Lake meteorites. The Pinawa find makes Mr. Erstelle the first person in Canada to have found meteorites from two distinct falls. Additional images and information can be found at `www.geo.ucalgary.ca/PMSearch/`.

Non-destructive physical characterization of meteorites, D. L. Smith, C. Samson (Carleton University), R.E. Ernst, R. Herd (Carleton University, and Geological Survey of Canada), I. Christie, J-E Sink, and A. DesLauriers (Neptec Design Group).

Meteorites are an essential scientific resource that provides invaluable information about the evolution of the solar system. The characterization of meteoritic material is therefore of fundamental importance to our understanding of these processes of formation. Many meteorites are small and unique and thus their preservation is a priority. The current and most widely used classification techniques are time consuming and/or require the destruction of the meteorite. With the increasing backlog of meteorites worldwide, there is a need for a new non-destructive method of rapid and accurate classification.

We evaluate four parameters that show promise as classification tools: bulk magnetic susceptibility (MS) and its frequency dependence (825 and 19,000 Hz), and the degree and shape of the anisotropy of magnetic susceptibility (AMS). In addition, a new method of non-destructive density determination using a 3-D laser-camera imaging system has been evaluated.

Magnetic susceptibility measurements were performed on 361 meteorite specimens. 145 of these 361 specimens, covering 14 classes of chondrites, primitive achondrites and achondrites, have been measured for AMS at a frequency of 19000-Hz. In addition, the densities of eleven chondrites and achondrites of various shapes and sizes derived using the LCS are presented.

A clear trend can be seen in the chondrites as susceptibility increases from LL, L, H to E chondrites reflecting increasing Fe-Ni metal content. Achondrites display more variability in susceptibility values, reflecting their more complex petrogenesis. Frequency dependence is observed, with variations in strength among meteorite classes and individual specimens ranging from 1 to 34%. Degrees of anisotropy range from 1% to 53% with both oblate and prolate ellipsoids present along with variation among meteorite classes. The aubrite class is the most distinct and is marked by high degrees of anisotropy, low bulk magnetic susceptibility, and prolate fabric. The eucrite 'Camel Donga' is set apart from other eucrites, marked by higher magnetic susceptibility and degree of anisotropy and differing magnitude of oblate fabric. The Martian (SNC) meteorites show subclass distinction using frequency dependence and Chassigny is set apart with a relatively strong oblate fabric. In addition, the ureilites appear closer in origin to primitive achondrites than to achondrites, and the brachinite appears closer in origin to achondrites than to primitive achondrites using MS and AMS. The presence of both strong oblate and prolate fabrics among and within meteorite classes of chondritic and achondritic material points to a complex multiphase scenario for anisotropy formation, more so than previously thought.

Densities are determined by the LCS, mounted on a tripod. Raster scans capture the surface features of the meteorite as it is rotated in front of the camera by means of a turntable. Offline software is used to assemble the images into a 3-D closed model from which a density is then computed. LCS densities compare very well with published data (Brit and Consolmagno, 2003). Dataset differences range from 1.3% to 5.2%. Over the span of approximately 1.5 hours, the density of a meteorite or any other solid object can be determined with minimal interaction of the sample. In the context of a space mission, applications of this technique could readily be extended to any rock sample identified by the LCS mounted on a roving robot while it is exploring its geological environment.

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Martian meteorite characteristics: porosity measurements,
Martin Beech, Wenshuang Nie (Campion College, University of Regina), and Ian M. Coulson (University of Regina)

Much attention is presently being directed towards the study of planet Mars: numerous robotic and in-orbit reconnaissance missions are currently being planned and/or executed and future missions call for the extraction and return to Earth of Martian surface materials. Martian meteorites, however, already provide us with a first view of Martian crustal lithologies - and these samples are available for study in Earth laboratories at the present time. Indeed, Martian meteorites provide us with a history of distinct ancient impacts upon the surface of Mars; they also supply physical samples of basaltic and ultramafic rock from different regions of the planet's surface (Head, Melosh, and Ivanov, 2002).

While the chemical make-up and petrology of the 37 currently known Martian meteorites have been studied extensively, by many research groups, relatively little data exists on their basic structural characteristics, such as porosity. Porosity is of fundamental importance since it is a measure of the volume of empty space within a meteorite (Consolmagno, Britt, and Stoll, 1998). Indeed, to interpret fully the nature, origin, shock modification, and cosmic-ray exposure history of these (or any other) meteorites, some measure of its porosity must be known. A recent survey revealed that only eight fragments, from four distinct Martian meteorites, have measured (or modeled) porosity values that have been published (Britt and Consolmagno, 2003). Here we report on the initial results of a program recently begun at the University of Regina, to measure the porosity of Martian meteorites via scanning electron microscope (SEM) analysis of thin-section samples.

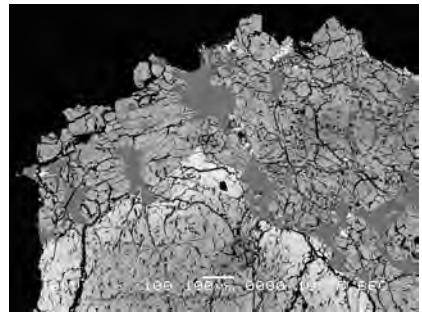

Figure 3 – SEM image of Martian meteorite EETA79001; lithology a (basaltic Shergottite). The micro-crack structures (void space) can be seen as the trelliswork of veins crossing the image.

Figure 3 shows a typical image obtained with the SEM at 100× magnification. The porosity is determined as the percentage ratio of the summed void area divided by the total area of the image. A summary of our porosity measurements appears in Table 1.

In common with the ordinary chondrite meteorite data, recently reviewed by Consolmagno, Britt, and Stoll (1998), the Martian meteorites display a wide range of porosity values - although the variation is much less than that determined for the chondrite meteorites, which vary from $0 < P(\%) < 30$. The variation in Martian meteorite porosity could be expected, however, given the greatly differing lithologies, crystallization ages, impact and weathering histories experienced (both on Mars and the Earth) by the various samples studied. For example, an important observation is that all Martian meteorites are moderately to strongly shock metamorphosed (e.g. Nyquist *et al.* 2001). This metamorphism has resulted in the injection of feldspathic glass along grain boundaries. Clearly, this will have had a significant impact on any primary porosity present within the meteorite. Hence, future work will attempt to "tie" the measured porosity to other physical properties of the meteorite, such as petrological type, density, shock alteration, and weathering history.

We have additional thin-section slides of ALH 84001, Zagami, and Nakhla for analysis, and the measured porosity values for these samples will be published at a later date. It is also our intention to begin collecting data measurements on the porosities and other

Table 1

Summary of Martian meteorite porosity data. Column 3 indicates the number of SEM frames used in the determination of the porosity (column four). **Key:** ANSMET indicates a loan from the Antarctic Search for Meteorites; CHUA corresponds to a loan from Dr. C. Herd, University of Alberta; NHML indicates a loan from Dr. C. Smith, Natural History Museum, London. The * indicates a refined error assessment of the data described in Beech and Coulson (2005).

Name	Type	# images	P(%)	Comments / notes
DaG 489	Shergottite	53	2.3 ± 1.8	Beech and Coulson, 2005
		53	2.1 ±(0.25	100 × magnification *
		339	3.1 ± 0.4	300 × magnification
EETA 79001 (a)	Shergottite	82	11.1 ± 0.6	ANSMET
ALH 84001	Orthopyroxenite	59	3.7 ± 0.1	ANSMET
NWA 3171	Shergottite	378	6.9 ± 0.8	CHUA
Chassigny	Chassignite	40	4.5 ± 0.1	NHML

fundamental characteristics of macroscopic samples of Martian meteorites in the near future.

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LIDAR, Satellite and Acoustic Measurements of a multi-kiloton Asteroidal Airburst over Antarctica on September 4, 2004, Andrew R. Klekociuk (Space and Atmospheric Sciences, Australian Antarctic Division), Peter G. Brown (University of Western Ontario), Dee W. Pack (Aerospace Corporation), Douglas O. ReVelle (Los Alamos National Laboratory), W.N. Edwards (University of Western Ontario), Richard E. Spalding (Sandia National Laboratory), Edward Tagliaferri, Bernard B. Yoo (Aerospace Corporation), and Joseph Zagari (Space and Atmospheric Sciences, Australian Antarctic Division).

Large meteoroids, able to penetrate through Earth's atmosphere to stratospheric heights, produce spectacular optical fireballs, and acoustic waves that propagate to the Earth's surface. The parent bodies of these bolide events often fragment in one or more explosive detonations during their atmospheric passage and deposit substantial dust in the atmosphere. Bolides provide important data for constraining theories for meteoroid ablation and disintegration. However, direct recovery of ponderable meteorites from large events is rare and the mass distribution of dust in fireball trails is currently unmeasured. As a result, relatively little direct information is available on the partitioning of material in the disintegration process. Here we show the first lidar measurements of a vapour trail that is unambiguously the result of a bolide event. This fireball was detected by space-based sensors operated by the US Departments of Energy and Defence at 12:07 UT, Sept 03, 2004 over the Antarctic sea-ice zone approximately 2400 km west of Australia's Davis Antarctic research station (68.6°S, 78.0°E) - see Figure 4. This is one of the most energetic fireballs detected impacting the Earth during the past decade and is among the most massive objects recorded reliably with multiple sensor systems since the Tunguska explosion of 1908. The pre-atmospheric orbit of this object is highly evolved, being an Aten-type orbit. Acoustic-

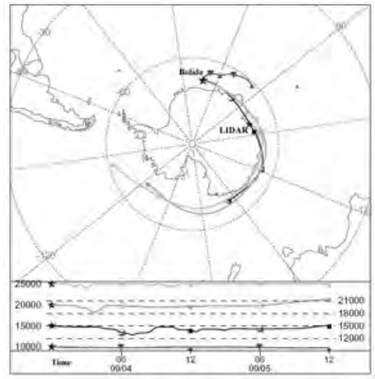

Figure 4 – Location of the September 3, 2004 bolide event off the coast of Antarctica. The curved lines indicate dust trajectories calculated according to deposition height and zonal wind speed.

gravity wave measurements of the detonation were made up to 14,000 km from the source and based on these data the bolide energy and its standard error is estimated to be 28 ± 6 kTon-TNT. The satellite optical yield estimates are roughly $^1/_2$ this value. The range of meteoroid initial mass is estimated to be (6-14) $\times 10^5$ kilograms, corresponding to a body of chondritic density 7 to 10 m in diameter.

The Millman Fireball Archive: identification of possible meteorite streams, Martin Beech. (Campion College, University of Regina).

The "time of appearance" data on 2373 fireball events documented within the Millman Fireball Archive (MFA - Beech, 2003) has been studied. The fireballs were observed from across Canada, during the time interval from early 1962 to late 1989.

By sorting the fireball appearance times according to solar longitude, distinct enhancements in fireball activity are found at the times of the α-Capricornid ($\lambda_\odot$ = 127°), Perseid ($\lambda_\odot$ = 141°), Taurid ($\lambda_\odot$ = 220 to 235°), Leonid ($\lambda_\odot$ = 235°), χ-Orionid ($\lambda_\odot$ = 250°), and Geminid ($\lambda_\odot$ = 262°) meteor showers. The cumulative number of fireballs, summed over one-degree intervals of solar longitude, is shown in Figure 5. The Geminids provide the most distinct peak of the annual meteor showers. Surprisingly the annual Perseid meteor shower is not particularly prominent within the data displayed. The Taurid meteor shower, consisting of both the northern and southern components, is likewise not particularly prominent in Figure 5, but its variable outburst activity is discernable within the data restricted

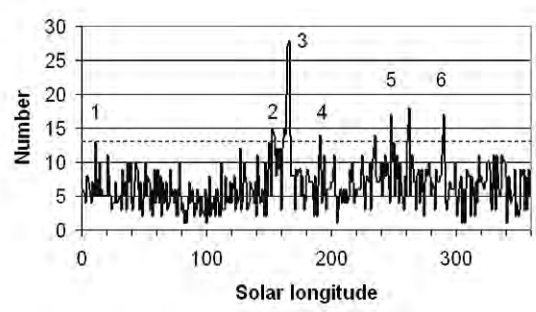

Figure 5 – The number of fireballs recorded in the Millman Fireball Archive arranged according to one-degree intervals of solar longitude. Labeled peaks correspond to Table 2 entries. The dashed horizontal line indicates the 'two sigma' level above the mean.

Table 2

Prominent peaks identified in Figure 5. Column 2 indicates possible stream and/or shower associations for each of the peaks. Columns 3, 4, and 5 provide the solar longitude of the peak, its full width half-maximum, and the number of fireballs recorded at the peak solar longitude.

Label in Figure 5	Possible associations	$\lambda_\odot$ (deg.) of maximum	FWHM (deg.)	Number
1	Peace River / Revelstoke	11.0	± 0.5	13
2	λ-Aqualid stream	154.0	± 3.0	15
3	Group 3 meteorite shower	165.0	± 4.0	28
4	HC34 meteorite stream	191.0	± 2.0	14
5	Group 4 meteorite shower	248.0	± 3.0	17
6	Group 4 meteorite shower (extreme)	290.0	± 2.0	17

to just the months of October and November in each year (Beech, Hargrove, and Brown, 2004). All of the annual meteor showers identified in Figure 5 are known for their ability to deliver bright fireballs, and consequently their appearance indicates that the data set is sufficiently robust to allow periodic or outburst fireball showers to be identified.

In addition to the identification of six annual meteor showers, a further six distinct peaks are also discernable in Figure 5. The times and characteristics of these "other" peaks are summarized in Table 2.

The most distinct peak listed in the Table 2 and indeed the strongest peak in the entire activity profile falls at $\lambda_\odot$= 165° (September 7) and we suggest that it may be related to the "Group 3" meteorite stream identified by Halliday *et al.* (1990). Likewise, the peak at $\lambda_\odot$ = 248° (November 30) is further identified as possible belonging to the "Group 4" meteorite stream of Halliday *et al.* In addition we also tentatively associate the peak at $\lambda_\odot$ = 191° (October 4th) with the HC34, H-chondrite meteorite stream identified by Wolf *et al.* (1995; 1997). It has been suggested that the Peekskill meteorite (which fell on October 9, 1992) is a member of this group.

The peak at $\lambda_\odot$= 11.0 (March 30) accommodates the approximate fall times of the Peace River and Revelstoke meteorites. These two meteorites are clearly not related, however, since the Peace River meteorite is an L6 olivine Hypersthene ordinary chondrite, while Revelstoke is a CI carbonaceous chondrite. This being said, the peak at $\lambda_\odot$ = 11.0 is reasonably distinct and may indicate that an intermittent fireball / meteorite-producing shower is active on, or near to, March 31.

The prominent peak at $\lambda_\odot$ = 290 (January 10) is also weakly evident in the study by Ahn (2003) who analyzed a set of historical Korean fireball records collected during the Koryo dynasty (AD 918 to 1392). The peak also falls within the possible time window allocated to the Group 4 meteorite stream of Halliday *et al.* 1990.

The peak at $\lambda_\odot$ = 154 (August 26) may correspond to the λ-Aqualid fireball stream, which according to Gavajdova (1995) is active from August 14 to 31. This peak also falls, however, between the activity windows allowed for the Group 2 and Group 3 streams of Halliday *et al.* (1990). Hasegawa (1993) finds within the historical record that a shower is intermittently active in the solar longitude interval from 150 to 153 degrees. This particular stream (Hasegawa's stream number 8) is identified according to a series of seven meteor-shower outbursts recorded over the time interval from AD 464 to 1888. If the $\lambda_\odot$ = 154.0 peak in Figure 1 and Hasegawa's stream number 8 are related, then a truly ancient heritage is implied with activity, at various levels of intensity, being in evidence for perhaps the past 1500 years. This time is short, however, compared to the expected decoherence time (about 104 years) for a meteorite producing stream (Gladman and Pauls, 2004).

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Estimates of Meteoroid Kinetic Energies from Observations of Infrasonic Airwaves, Wayne N. Edwards, Peter G. Brown (University of Western Ontario), Douglas O. ReVelle (Los Alamos National Laboratory).

Figure 6 – A deployed infrasound detector system showing noise-reduction hoses. Additional information and images can be found at aquarid.physics.uwo.ca/~pbrown/ infrasound.htm.

Signal properties from infrasonic observations of a series of meteoroids impacting the Earth's atmosphere in the approximate size range of 0.1 to 10-m diameter have been analyzed with the aim of deriving an empirical relation between the far-field acoustic amplitude of the bolide shocks and meteor source energies. Fireball infrasonic observations are becoming more common due to the increasing number of infrasound arrays operating worldwide as part of the international monitoring system of the Comprehensive Test Ban Treaty (CTBT). Such data, coupled with detection of bolides by Earth-observing satellites, permits a statistical examination of bolide airwave properties to be compared against range and satellite energy estimates. Adopting a similar approach as has previously been employed for man-made explosives, signal properties such as acoustic amplitude, signal energy/power, and signal-to-noise ratio, are shown, after high-altitude wind corrections, to be useful tools in estimating the kinetic energy of a bolide. Comparison of bolide infrasound data to ground-based explosive tests show that the acoustic amplitudes from airwaves generated by small bolide events (<7 kt TNT equivalent) attenuate more rapidly than nuclear or chemical explosions. As well, acoustic amplitude values for bolides are systematically lower than acoustic amplitudes measured for equivalent ground-based explosions. This is interpreted to be largely due to bolide acoustic sources being at high altitudes, which after correction is found to be typically located between 20 and 30 km altitude. Larger events (>7 kt) mimic man-made explosions in terms of range dependence, but offset in amplitude equivalent to ~20-km source altitudes. This is consistent with instrumental observations of fireballs and the expectation that larger meteoroids, greater than a few metres in diameter, should penetrate deeper into the atmosphere on average. Applying these new relationships to the 1908 Tunguska event, a source energy of 26.8 ± 10.7 Mt is found using European infrasonic observations and 10.9 ± 7.5 Mt using Soviet barometric measurements, in good agreement with previous seismic source energy estimates.

Through My Eyepiece

Geoff Gaherty, Toronto Centre, (geoff@gaherty.ca)

I was born in 1941 and first joined the RASC in 1957, and have been a member off and on ever since. October 4, 1957 was an important day: the USSR launched Sputnik, and Avro rolled out the Arrow. The next day was even more important for me personally. It was the first night I climbed the wooden stairs behind Molson Stadium in Montreal to attend my first meeting in what is now the Isabel Williamson Observatory.

Back in April I'd read newspaper articles about a bright comet, Arend-Roland, visible in the evening sky. On the evening of May 1, I went out on my back porch to look for it, never having spent any time under the stars. I never did find the comet, but with the help of the *New Handbook of the Heavens,* I identified my first constellations, Boötes, Leo, and Virgo, and in the latter a bright interloper. At first I thought that might be Arend-Roland, but some calculations convinced me that I had in fact "discovered" Jupiter. More importantly, I was as totally hooked on astronomy as only a geeky 16-year-old could be.

My first evening at the Observatory was unusual in that some of the major players were absent at an AAVSO meeting in Massachusetts. But I did come home armed with a copy of *Skyward* and a mimeographed sheet describing the Montreal Centre's observing programs. I was like a kid in a candy store! The Montreal Centre held two meetings a week at that time, and I attended every one, and soon came to know the wonderful people who would be my mentors for the next seven years. For the first time in my life, I was treated as an adult by my fellow adults, and this was perhaps the greatest gift they gave to me.

Tool of the month

Those of you who know me will know that I'm a telescope junkie. Over the years, I have owned nearly two-dozen telescopes of all kinds, plus countless eyepieces and other astronomical toys.

I'd like to tell you about my main working telescope, the one I haul out most often on clear nights. It is a 28-cm (11-inch) Starmaster reflector. Carl Zambuto, probably the finest mirror maker today, made its f/4.3 mirror. Mounted as a truss tube Dobsonian, it resides permanently on an Osypowski equatorial platform, giving me the best of two worlds: the ease of motion of a premium Dobsonian, with the bonus that as soon as I let go, the scope tracks perfectly.

There is an old adage that the best telescope is the one you use the most, and so my Starmaster qualifies as my best telescope. At home, I keep it assembled in a small shed. To observe, all I have to do is slide the tongue of my two-wheel handcart under it, snap on a bungee cord, and wheel it to my observing pad. Despite its size, it takes me less time to set up than any of my smaller scopes. If I need to transport it, it disassembles in a few minutes and fits into the cargo area of my station wagon with plenty of room to spare. Its short focal ratio means that I can observe anywhere in the sky while seated in a comfortable chair. The downside of the short focal ratio is that I must always have a Tele Vue Paracorr installed to eliminate coma. Starmaster scopes come balanced with the Paracorr taken into account.

The only aspect of my Starmaster with which I was less than happy was the Rigel QuikFinder that came as standard equipment. While the QuikFinder works well under dark skies, it was next to useless when I was living in the city, so I replaced it with an Antares 8 × 50 finder. This requires the addition of a small weight on the back of the mirror box to restore balance.

Thanks to Carl Zambuto's optical wizardry, the scope delivers exquisite lunar and planetary images despite its short focal ratio. On deep sky-objects, the high contrast produced by its smooth mirror surface delivers the performance of a somewhat larger scope.

I have used this scope just about every clear night for more than three years, and it continues to wow me every night. It is an amazing combination of fine optics, fine mechanics, and a "just right" size for me.

The Magic of Jupiter

Although I love the tools of astronomy, I love even more the things that I can see with them. I started an observing log that first night in 1957, and now treasure those early entries, as they remind me of the joys and frustrations I experienced as a beginning amateur astronomer. My log-keeping was erratic over the early years, but there was so much good stuff there, that when I got back into astronomy in 1997, I resolved to keep a more detailed log, and have done so ever since. I have dabbled in all sorts of astronomical observations over the years, but the object I've lavished the most time with by far is the planet Jupiter.

Jupiter is probably the most satisfying object in the sky for the amateur astronomer. It is second to Saturn for sheer beauty, but makes up for it by offering an incredible level of activity that is accessible to small telescopes. The smallest of scopes will reveal the dance of its four bright moons and at least a couple of dark bands in its atmosphere. As the telescope size and skill of the observer increases, Jupiter reveals more and more complex detail in its upper atmosphere. I am a sucker for *activity* in my astronomical subjects, so Jupiter's dynamic atmosphere makes it a winner for me.

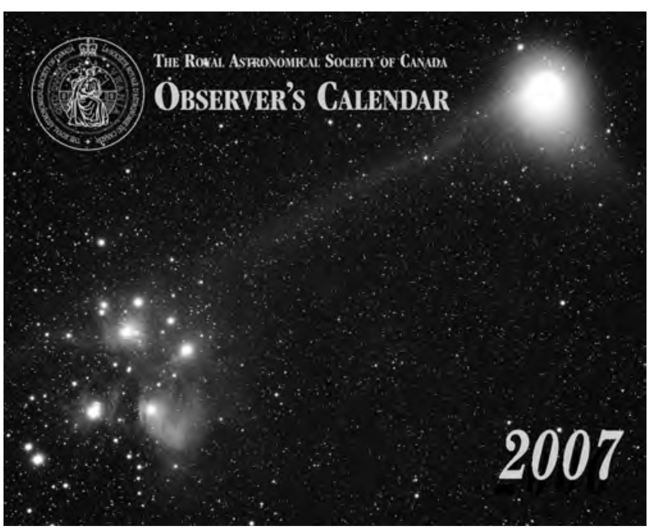
The first thing to notice when you spend a bit of time with Jupiter in a good telescope is that it is a planet in motion. First, there are the four bright moons discovered by Galileo in 1610. These are in constant motion back and forth in front of and behind the planet. They can be observed going into and out of eclipse, and both their shadows and the moons themselves can be observed as they cross the planet's face. Our *Observer's Handbook* gives you all the information you need to identify and follow these objects.

If your telescope is good enough to reveal detail within Jupiter's cloud belts, you will soon notice that this detail is moving across the disk as the planet rotates. The most famous piece of detail is the Great Red Spot, located just south of the first dark belt south of the equator, known as the South Equatorial Belt. Unfortunately, the Great Red Spot has lost much of its colour in recent years, and is often hard to distinguish from its background. Another area to watch for detail is in the first belt north of the equator, the North Equatorial Belt. There are often looping festoons along its southern edge, and dark reddish brown spots embedded in its northern half, known as "barges."

Because of the obvious movement of detail within Jupiter's belts, it is possible to time these features as they cross the planet's *central meridian,* the line joining the planet's two poles at right angles to its belts. While individual timings are usually only accurate to within a minute or two, Jupiter's rapid rotation, roughly once every ten hours, allows rotation periods of individual spots and the wind currents that carry them to be calculated to accuracies of a fraction of a second. You can read more about central meridian transits in an article I wrote for the *JRASC* in April 1962, pages 79 to 80. These timings of central-meridian transits are one of the areas where amateur astronomers can make a real contribution to astronomy. They also give you a wonderful excuse to spend hours gazing on the face of Jupiter!

Call for Photos — 2007 RASC Observer's Calendar

All members of the RASC are encouraged to submit astronomical photos for consideration for publication in the 2007 RASC Observer's Calendar.



Images can be of any type - deep-sky, solar system, or astronomically-themed landscape; prime focus, piggy-back, or fixed tripod; film or digital-based.

Electronic images under 5 MB in size may be sent by email to dave@davelane.ca.

CDs, DVDs, prints, negatives, or slides should be mailed to:

Dave Lane
PO Box 31013
Halifax, NS B3K 5T9

The submission deadline is April 15, 2006.

For further information about submissions, please contact me by email at the above address.

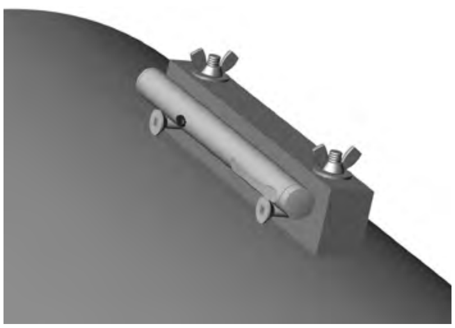
Dave Lane
Editor, RASC Observer's Calendar

A Finger for Your Dob

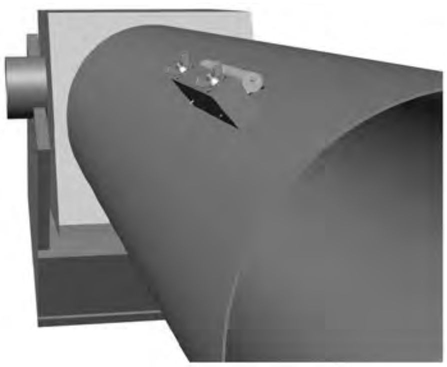
by Don Van Akker, Victoria Centre, (don@knappett.com)

I like to observe with an SCT that has all the bells and whistles. I like the technology and I like gadgets. My wife however has the heart of an explorer. She spends hours searching with binoculars and skycharts and bringing up what she finds in her 10″ Dob. You can tell she's been observing by the crick in her neck from pressing her cheek against the tube so she can line up that little red dot with her object.

Technology and gadgets to the rescue!



A green laser makes pointing the Dob a breeze. Mounted on the barrel, it gives you a finger that touches the sky. You pull it over to your object and there



it is, in your eyepiece. But how to mount it? Commercial mounts involve three alignment screws front and back and when you finish tinkering with those you can't use the laser for anything else.

This little mount gets around that problem. It is much easier to align than the commercial product and can be made with hand tools by anyone.

Use a 6″ piece of 1 × 2 and two #12 × 1¼″ flat-head screws. Predrill with a 3/16″ drill bit. The dimensions aren't fussy – just get it to look like the picture. Mount the laser with an elastic band and now, when you turn in the rear screw, the laser rides up on the head of it and the front points down. Ditto for the front screw. Mount it to your Dob with a #10 × 2″ round-head bolt at the back, align it to your scope with a low-power eyepiece and then drill for a bolt at the front. If you drill the holes a little oversize you can do a fine adjust by backing off the wing nuts slightly and tapping left or right. Always keep the pocket clip of the laser turned against the screw because the beam is not likely to be parallel to the laser tube and rotating it changes your alignment. Use the entire unit as a handle to swing your scope, the button switch will end up just under your thumb.

Sand it, paint it, use it, but don't take off your present finder. The green laser is wonderful in your back yard but might not be too welcome at star parties.

Don Van Akker makes his living by digging holes and putting buildings in them. He observes from the rain coast with his wife Elizabeth so he has many free evenings to work on these ideas.

THE SKIES OVER CANADA

Observing Committee News

by Christopher Fleming, London Centre (chrisfleming2@hotmail.com)

Since we live in an ocean of air that surrounds the Earth, the location of astronomical objects in the night sky greatly affects the quality of an observation, or image, especially for detailed high-magnification studies such as lunar and planetary or double-star observing. An observer seeking the most subtle features within the objects currently visible in the sky would be wise to focus his or her attention on, or near, the meridian and preferably high in the sky. The meridian is an imaginary line extending from north to south, directly overhead, that divides the sky into two equal parts. The area close to the meridian, high in the sky, is the least affected by what astronomers call the "seeing and transparency" and the reason for this is related to the thickness of the air as seen in various directions from a given location. The distance from ground level to the top of the atmosphere is thinnest directly overhead at the zenith, and as you move away from that point the thickness of the air you have to look through increases significantly.

There can be a noticeable decrease in the quality of the "seeing and transparency" at 45 degrees below the zenith, and you will likely notice a dramatic difference at 70 degrees or more. This is easy to understand when you realize that you are looking through tens of kilometres, or more, of atmosphere when viewing objects far from the zenith. If you have a choice of various objects to observe or image, always pursue the targets located higher in the sky. Double stars are particularly susceptible to less-than-great seeing, and if you are having difficultly splitting the closer ones, try choosing doubles located highest in the sky for your location. Of course, some nights are better than others for various weather-related reasons, but on average you will get better results when viewing higher in the sky.

For lunar and planetary observing or imaging, the best seeing usually occurs when the objects are located high along the ecliptic in the constellations normally associated with the winter season. Although it can be very cold in Canada at that time of year, it is definitely worth the effort to get out and enjoy the excellent lunar and planetary observing that is possible at that time. My best ever views of Saturn, Jupiter, and the Moon have occurred during the winter season and they were impressive sights indeed. It is quite amazing to scan the lunar surface, or the rings of Saturn, with virtually no shimmering of the image at high power. We are currently just past the best years for Saturn and Jupiter, although Saturn is still well placed high along the ecliptic. The Moon is always great to observe during the winter months, so if you can learn how to keep warm on those frosty nights, have a look at our nearest celestial neighbour and you will not be disappointed.

The Explore the Universe Certificate Program (available as a PDF in the Observing Certificates area of the RASC Web site at `www.rasc.ca/observing`) provides new observers with a complete introduction to the night sky, including Constellations and Bright Stars, the Moon, the Solar System, Deep-Sky Objects, Double Stars, and an optional Variable-Star List. The Double-Star portion requires that the observer identify and record observations of ten of the twenty options listed. The list includes many of the best and brightest double or multiple stars in the night sky. These objects were carefully chosen to be suitable for new or casual observers who may be using binoculars as their primary instrument. They are also relatively easy-to-find targets and most of them are visible during the warmer months from late spring to early autumn.

In addition, there are a few excellent telescopic double or multiple stars listed there including the famous double-double Epsilon Lyrae, which is both a binocular double and a telescopic double. Other great picks include Nu Draconis, 16 Cygni, Delta Cephei, Beta Lyrae (Albereo), the triple Omicron Cygni, Mu Bootis, Zeta Lyrae, Nu Coronae Borealis, and, of course, Zeta Ursae Majoris (Mizar and Alcor). Some observers have commented that the double-star list is one of the highlights of the Explore the Universe Program!

There have been two Explore the Universe Certificates awarded since our last report and those talented observers

Table 1: Explore the Universe Certificate

Name	Centre	Date Awarded
David Roeder	Kingston, Ontario	November 2005
Carl Roussell	Hamilton, Ontario	November 2005

Table 2: Messier Certificate Recipients

Name	Centre	Date Awarded
Jack Milliken	Calgary, Alberta	November 2005
Dean Huxley	Calgary, Alberta	November 2005

Table 3: Isabel Williamson Certificate Recipient

Name	Centre	Date Awarded
Christopher Fleming	London, Ontario	November 2005

can be found in Table 1.

There have also been two Messier Certificates awarded since our last report and those skilled observers are listed in Table 2.

Congratulations to all!

Although there are no Finest NGC Certificate recipients to report this month, there were a total of ten awarded in 2005 (as of the end of November), which ties the record number awarded in 1999. It is great to see such active participation in our Observing Certificate programs and we congratulate all those observers who have successfully completed one or more of them over the years.

The Isabel Williamson Lunar Certificate Program was launched in May 2005, and as we reported in the last issue, Bruce McCurdy of the Edmonton Centre was our first recipient. Bruce not only qualified for the certificate but also for the 100-or-more challenge features letter of recognition and the 1000-named-features letter of recognition, the highest honour. To qualify for these esteemed letters a lunar observer has to record observations of 100 or more of the challenge features listed in the Isabel Williamson Program or record 1000 named features. Each named feature has to have an official name recognized by the International Astronomical Union. This does not include lettered secondary craters associated with major impact structures, although a secondary crater with an official name, other than that of the parent crater, does qualify as a named feature and can be added toward the 1000 total.

Since I played a major role in developing the Isabel Williamson Program, and tested it thoroughly before it was released, I have decided to proclaim my qualifications for the certificate. You will find my name listed in Table 3 as the second recipient. I have been observing the Moon for many years and have enjoyed it immensely. I have also observed more than 100 of the nearly 200 challenge observations listed in the program, which entitles me to the 100 challenge observations letter of recognition. As far as the 1000-named-features goal is concerned I have a little way to go for that. I currently have almost 900 recorded and am looking forward to the challenge of finding another 100 or so to match the amazing accomplishments of Bruce McCurdy. Bruce actually reached that goal several years ago so it is fitting that he was the first to receive recognition for his lunar-observing expertise.

We encourage other experienced lunar observers, who have recorded the required number of observations over the years, to apply for the certificate. More details and an application form are available at the RASC Web site on the Isabel Williamson Program page at `www.rasc.ca/observing/moon.html`. You will also find a link there to deluxe observing forms that were custom made for the new lunar program. They feature individual fields for each objective that includes a generous area for observing notes and a circle for drawing lunar features.

The Observing Committee continues to update the observing sections that have been posted on the Web site over the last few years. There you will find information about asteroids, comets, variable stars, and special projects. Finder charts are posted for asteroids that are currently brighter than magnitude 10, and for comets visible from Canada. The Variable-Stars section has listings of the maxima date for long-period variables that reach magnitude 8 or brighter, and we have corresponding links to genuine American Association of Variable Star Observers (AAVSO) magnitude-estimate charts. The Special Projects section has links to many interesting RASC member Web sites.

Clear Skies

Christopher Fleming is Chair of the RASC Observing Committee and Observer's Chair in the London Centre. He enjoys all types of observing, especially Deep-sky, Lunar, Double Stars, and Variable Stars. Chris is also a musician and Webmaster of the London Jazz Society's Web site.

WEB ACCESS TO APRIL 2006 ISSUE

The April 2006 issue of the *Journal* can be accessed from the RASC Web site at `www.rasc.ca/currentjrasc` This issue will be posted immediately after the final production version is complete (approximately April 10, 2006) and removed from the Web once the issue begins arriving by mail.

Measuring the Heavens:
Astronomical Instruments before the Telescope

by Robert A. Egler (robert_egler@ncsu.edu)

Astronomy today is closely associated with telescopes. Tell someone that you are an astronomer, and often the first question you will get is "What kind of telescope do you have?" (Or else "Can you cast my horoscope?" but that is a different issue.) However, there were great astronomers before Galileo first turned his telescope toward the heavens in 1609, and these astronomers did not simply look up at the heavens with bare eyes - they had a number of different instruments at their disposal. Aristotle, Claudius Ptolemy, and Nicolaus Copernicus all lacked telescopes to aid their inquiries.[1] Even Galileo's most famous contemporaries, Tycho Brahe and Johannes Kepler, made their observations without a telescope. Clearly then, significant advances in astronomy took place before the invention of the telescope.

But what *did* they use?

Astronomical tools in use prior to telescopes were the astrolabe, the nocturnal, the armillary sphere, the cross staff, the quadrant, and the dioptra.[2] While each of these instruments is different from the others, they all share a common property, a property that tells us a good deal about the difference between ancient and modern astronomy.

The Astrolabe (pronounced: as' tro lāb)

Astrolabes come in two main types: mariner's astrolabes - basically a circular protractor with a sighting rod, used to measure the altitude of the Sun or stars for navigation; and planispheric astrolabes - instruments of a more complex nature that serve as a kind of analogue computer intended for use by astronomers.

The planispheric astrolabe is perhaps one of the most beautiful astronomical instruments ever made. Although hundreds of examples survive from the Middle Ages, the principles of the astrolabe were known at least as far back as Hipparchus in the 2nd century BC[3], and production of astrolabes in Arabic lands continued into the late 1800s.[4]

Different astrolabes were made with different features, depending on the needs of the user. Typically astrolabes were made to give the astronomer quick, approximate answers to common astronomical problems. If a more accurate answer was needed, the astronomer always had recourse to mathematics, but it was (and still is) the case that an approximate answer was often good enough. In those pre-calculator, pre-slide-rule days, the astrolabe saved astronomers the tedium of slogging through the calculations.

Some of the problems solved with astrolabes were:

1. finding the position of the Sun on the ecliptic on a given date
2. finding the azimuth of the Sun at sunrise on a given date
3. finding the time of sunrise and sunset on a given date
4. finding the Sun's altitude at transit on a given date
5. finding the length of daylight on a given date
6. finding the rising azimuth of a star
7. finding the altitude of a star at transit
8. finding the length of time a star would be above the horizon on a given date.

In addition to the predictions above, the astronomer could use the astrolabe to measure the altitude of the Sun, Moon, or stars. Not a bad set of abilities for an instrument that does not use electricity or have even one computer chip!

An astrolabe consists of six basic parts. All parts are usable at almost any place on Earth except the latitude plate, which must be made for a specific latitude. The parts are: a *rete* (rhymes with "sweetie"), which is a moveable ring showing major stars (of the maker's choosing) and the zodiac; a *mater,* which is the body of the astrolabe; a *latitude plate,* interchangeable with plates for other latitudes; two rules, one on the front and one on the back; and a small bolt for holding it all together (sometimes called the "horse").

A basic astrolabe is shown in Figure 1. The outer ring of the mater is divided into 360 degrees. The inner ring is divided into two sets of 12 hours each, starting with 12 at 0°, and marking an hour line every 15° around the circle, numbered

[1] Aristotle 384-322 BC, Claudius Ptolemy *ca.* AD 115-150, Nicolaus Copernicus 1473-1543.

[2] Examples of astrolabes, nocturnals, armillary spheres, a cross staff, and quadrants, are at the Museum of the History of Science, Oxford, and can be seen online at `www.mhs.ox.ac.uk/images/index.htm.`

[3] Evans, James, 1998, The History and Practice of Ancient Astronomy (Oxford University Press) 155.

[4] Astrolabe History (astrolabes.org/history).

Figure 1 – The Astrolabe

clockwise with 12 at the top and 12 at the bottom.

Making an astrolabe is an interesting project for amateur astronomers, and costs little money.[5] The latitude plate requires the most work. It is a stereographic projection of the sky from a particular latitude, and requires either a knowledge of spherical geometry and projections, or a set of clear instructions on how to make one.

Most antique astrolabes in collections today are brass; however. there are other materials that can work quite well. I chose to make an astrolabe from parchment paper and furniture-quality plywood, which is both easier and cheaper than brass, and not without historical precedent.[6]

A good place to begin for anyone interested in making a personal astrolabe would be a version modified for local use based on the excellent templates (and instructions) in *The History and Practice of Ancient Astronomy*.[7]

The Nocturnal

The nocturnal is a much simpler instrument. An example of my own construction is shown in Figure 2. Basically, it is the nighttime equivalent of a sundial, and is used to tell time after sundown. It consists of a back date plate marked with months and days of the year, a smaller central time disk inscribed with time (usually in the dual 12-hour format), a tab for Ursa Major (sometimes also for Ursa Minor, as in Figure 2), and a long arm that extends past the outer edge of the back plate.

Essentially the nocturnal is based on the principle that there is a relationship between solar and sidereal time. The sidereal time advances approximately 3m 56s a day in relation to solar time. The nocturnal simply makes this calculation for you when you set the date.

Figure 2 – The Nocturnal

Suspended from a ring, the central time disk is rotated so that either the tab for Ursa Major or Ursa Minor (depending on which one the user chooses) is aligned with the current month and date. Then either the bright star at the bottom of the Little Dipper's bowl (Kochab, β *Ursa Minoris*), or the star at the end of the Big Dipper's bowl (Dubhe, α *Ursa Majoris*) is sighted, and the long arm is adjusted to be parallel to the line between Polaris and the star. The local time is read from where the arm crosses the time on the inner time disk.

Other measurements and scales can be added to the nocturnal as well. Examples would be local sidereal time, and the altitude corrections for Polaris when used in celestial navigation, both of which are easily added to the outer disk to be read by aligning the arm between Dubhe and Polaris. Since neither of these requires the date to be known, just the position of Ursa Major relative to the celestial pole, the inner time disk is not used in these measurements.

I should mention that the nocturnal, like a sundial, does not display Civil Time (as does your watch), but rather local apparent solar time, so the time displayed on the nocturnal will not usually match that displayed on your watch.[8]

The Armillary Sphere

The armillary sphere is a three-dimensional model of the Universe, centered on the Earth. Ranging in size from desktop models of less than a foot in diameter, to

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[5] Depending on the materials chosen for construction, the cost could range from three dollars to a couple of hundred dollars. My wood and paper astrolabe cost under $10.

[6] Paper astrolabes, and wood and paper astrolabes, were not unknown in the Middle Ages. See, for example, Museum of the History of Science, Oxford, Item 91897 (a paper and cardboard astrolabe, dated 1492), and Items 49296 and 34268 (wood and paper astrolabes, dated 1542 and 1584 respectively). The preponderance of brass astrolabes in current collections may have more to do with the greater survivability of brass than the actual percentage of original astrolabes made from brass.

[7] Evans, James, *Op. Cit.* instructions p 141 -152, templates p 445 - 448.

large fixed models of five-foot diameter or larger[9], it consists of a small central sphere indicating the Earth, surrounded by a number of rings (*armillae* in Latin) representing the celestial sphere. The origins of the armillary sphere are not entirely clear, however the inventor may have been Hipparchus (190-120 BC). Armillary spheres also appeared in China sometime between 200 BC and AD 220.[10]

Armillary spheres usually have rings representing the ecliptic and the zodiac, the celestial equator, the meridian of the vernal equinox, and whichever other great circles the maker of that particular instrument choses to include.

They were used either as demonstration aids in teaching astronomy, or as observational instruments. Once aligned correctly in relation to north and the local horizon, the armillary sphere could be used to measure either the ecliptic coordinates of a celestial object, or its coordinates in respect to the celestial equator[11] (right ascension and declination) by noting the object's position in the heavens and finding the equivalent position on the calibrated armillary sphere.

The Cross Staff

The Cross Staff is a simple instrument that can be used to measure the angular separation between two objects. Mariners used a version of the cross staff to measure the altitude of the pole star, or of the Sun at noon, for navigational purposes. Astronomers used the cross staff to measure the angular separation of two stars, or of a star and a planet, and thus to accurately determine the position of the object under study.[12]

As the name suggests, a cross staff consisted of a single long rod with a moveable crosspiece. The long rod was held up to the eye, and the position of the crosspiece adjusted. The long rod was marked to read the angle of separation between two objects when the crosspiece was adjusted so that it exactly spanned the angle between those two objects. It is essentially a more accurate version of the common practice of using your hand or fingers to measure approximate angular distances between two objects.[13] Cross staffs were usually made with a number of interchangeable crosspieces to give a larger range of measurable angles.

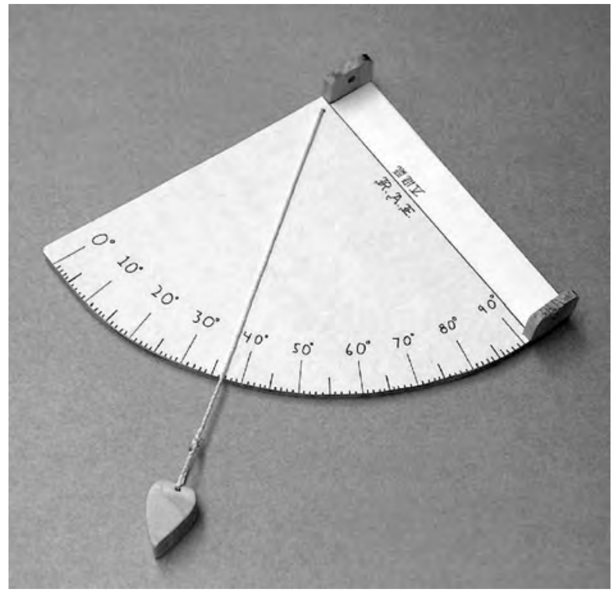


Figure 3 – The Quadrant

The Quadrant

A quadrant is a device made from one quarter of a circle, hence the name. The principle use of the quadrant, like that of its descendant, the sextant, is to measure the altitude of celestial bodies. Quadrants range from small handheld instruments to very large, permanently mounted devices, such as the several six-foot instruments Tycho Brahe used in his observatory. Typical small handheld quadrants had a precision of half a degree or so, while Tycho claimed that his large quadrants had a precision of about 10 arc seconds, a claim that may be a bit exaggerated.[14]

In its simple form as shown in Figure 3, a quadrant is essentially a protractor with a string and weight attached to the center of the flat side. The quadrant is raised until the object of interest is sighted through peepholes on one edge of the instrument. The string will hang vertically, and the arc is graduated in degrees, so the altitude

8 Civil time is the time used in our everyday lives, and includes the ideas of mean solar time, daylight saving time, and time zones, along with equal hours. Local apparent solar time is based on the actual movement of the Sun as seen from any specific location and has hours that vary in length throughout the year. For more information, see Observer's Handbook, (RASC, 2005), Rajiv Gupta (ed), pp 34 - 43.

9 See for example the giant armillary sphere at the ancient Beijing observatory, and an instrument constructed circa 1588 - 1593 by Antonio Santucci, now at the *Istituto e Museo di Storia della Scienza,* Florence, which can been seen at: www.mhs.ox.ac.uk/epact/picturem.asp?record=7.

10 About Inventors- Armillary Sphere. (inventors.about.com/library/inventors).

11 van Gent, Robert, Armillary Sphere, Epact: Scientific Instruments of Medieval and Renaissance Europe (www.mhs.ox.ac.uk/epact).

12 An example of a navigational cross staff can be seen at The Mariner's Museum in Newport News, Virginia, and online at www.mariner.org/exhibitions/highlights/scientific_crossstaff.php.

13 At arm's length, an index finger is about 2 degrees, a closed fist is about 10 degrees, and the angle between an extended little finger and thumb is about 20 degrees.

14 Unfortunately, none of Tycho's instruments survives. It is widely believed that they were destroyed during the riots in Prague in 1619.

of the object can be read by noting where the string crosses the arc.

The Dioptra

Several mediaeval illustrations can be found showing an astronomer looking through what appears to be a small telescope.[15] This may not strike a modern viewer as odd, until it is remembered that the telescope had not yet been invented. The instrument illustrated is not, in fact, a telescope, but rather a dioptra - essentially a hollow sighting tube.

The origins of the dioptra are ancient, and Euclid describes using a dioptra in *Phenomena,* dating to the 4th century BC.[16] The instrument continued in use even after the invention of the telescope, well into the Renaissance.

There are actually two slightly different instruments, both called a dioptra. The first is a simple hollow tube. While it offers no greater light grasp or magnification than the naked eye, there are two somewhat related advantages in using a dioptra.

The chief advantage is that when looking through the tube, extraneous light is blocked.

A secondary advantage is one of focused attention, and is more a psychological issue than an optical issue. By narrowing the field of view, you concentrate more fully on the small region you can see, and hence you actually have a slightly better view and see more detail than when using your naked eye alone.[17]

The second instrument called a dioptra is the same tube, but fitted with a small variable slit inside. It is used to measure the apparent diameter of objects by adjusting the slit size to fit the object as seen through the instrument.

Conclusion

All these instruments share a common use, subtly different from the use of most modern instruments. In modern astronomy, it is astrophysics that dominates, with its emphasis on analyzing celestial objects for what they are, how they work, what they are made of, and how they evolve.

The pre-telescope instruments were all designed to find the position of celestial objects in relation to the great celestial sphere and each other, and to determine their motions. In short, these instruments are not for analyzing the heavens, but rather for measuring the heavens.

I think that this difference in instruments reflects the often overlooked but quite important difference between astronomy before and after the invention of the telescope. The telescope not only gave us a better look at celestial objects, but also fundamentally changed the very nature of astronomy. We have largely ceased to investigate *where* things are, and are now more interested in *what* things are. That makes a very big difference in how we view our place in the Universe.

Robert Egler is Senior Lecturer in Astronomy, and Assistant Head of the Department of Physics, at North Carolina State University. He has a longtime interest in the history of astronomy.

[15] See, for example, an illustration *ca* 1120 by Matthew Paris showing Euclid using a dioptra in *Liber Experimentarius* by Bernardus Silvestris (Bodleian Library, Oxford).

[16] Evans, James, *Op. Cit.* p 34.

[17] I have often used a paper-towel tube in much the same manner when looking for some small object I know I have left around the house, but cannot find in a regular search. It often works, and I find the missing keys or such in an area I would have said was thoroughly searched just a few minutes ago.

Ottawa GA2006
Invitation to all RASC Members

The Ottawa Centre of the RASC is preparing to host you!

RASC members from across Canada are invited to join us in Ottawa next May for the 2006 General Assembly and to celebrate the Ottawa Centre's 100th Anniversary. Yes, Ottawa became the first Centre of the RASC in the year 1906! This special GA, on the Victoria Day long weekend, May 18 to 22, has an extraordinary agenda to offer. The four-day event, held at picturesque Carleton University, includes daily tours for spouses and companions, an impressive speaker schedule that includes a must-attend discussion forum on the future of astronomy, and plenty of great food and great friendship.

The Ottawa GA's roster of guest speakers has no less than 18 confirmed presenters. The speakers' presentations will focus on the two themes of GA2006: Canadian Space Astronomy, and The Changing Nature of Professional and Amateur Astronomy.

Friday will be devoted to "Astronomy Tools Presentations" that will feature talks by amateurs who do professional-level astronomy using highly advanced and sophisticated tools. The speakers include:

Tom Kaye: radial-velocity detection of extra-solar planets by non-professionals.

David Levy: comet hunting then and now.

Tim Puckett: running an amateur international automated supernova search program.

Paul Boltwood: developing a highly refined observatory for working with the pros.

Paul Mortfield: automating remote imaging and data acquisition for photometry.

Doug George: building an automated observatory with off-the-shelf components.

Friday afternoon has two tours planned for those wishing a different kind of fun. Staff at the David Florida Laboratory (DFL) satellite-assembly facility will give a guided tour to a maximum of only 60 people. At the DFL, you can see Canada's next space project, the nearly finished *RadarSat 2* satellite, in its glory. Register early or you will miss a space on this tour! For those who miss out, we have a tour of the Ottawa Centre's SMARTscope, a remote observatory on the same grounds as the DFL. If a broader tour of one of Ottawa's finest attractions whets your appetite, you can choose to join a guided visit to the Canada Science and Technology Museum, where, among many other things, you can view the 15-inch refractor used by Ottawa RASC members 100 years ago.

Friday evening promises to be a fun and entertaining time with a barbeque, cash bar, casual talks, and a chance to catch up with friends.

Saturday is jam-packed with the "Discussion Forum" kicking off the day.

This event promises to generate lots of interaction with the audience as it will centre on the effects that massive digital-sky surveys may have on the future of advanced amateur astronomy. The panelists are:

Dr. Rick Fienberg, Editor-in-Chief, Sky & Telescope magazine, and Chair of the Pro-Am Committee of the American Astronomical Society

Dr. Robert Jedicke, University of Hawaii, and Pan-STARRS

Dr. Douglas Welch, McMaster University, and Gemini Telescope Board of Directors

Tim Puckett, leader of an international group of amateur supernova hunters

David Levy, author, popular public speaker, and long-time comet hunter

Douglas George, creator of MaximDL, astronomy imaging software

Peter Ceravolo, as moderator, will be sure to keep things hopping. Audience participation will be encouraged.

Saturday afternoon will feature talks relating to "Canadian Space Astronomy." The speakers are:

Dr. Alan Hildebrand, University of Calgary: Hunting for Killer Asteroids from Earth and Space

Dr. Neil Rowlands, Com Dev: James Webb Space Telescope

Dr. Anthony Moffat, Université de Montréal: Nano-satellites for astronomy

Randy Attwood: An Historical Overview of Canada's Space Program

Dr. Jaymie Matthews of the University of British Columbia will chair this event.

The planned day tour in the afternoon will be to the National Gallery of Canada in downtown Ottawa.

The Helen Sawyer Hogg Public lecture on Saturday evening will feature a senior representative from the Canadian Space Agency speaking on Canada's continuing involvement in space astronomy and related science missions. Dr. Jaymie Matthews will speak on the MOST (*My Own Space Telescope*) observing-proposal contest and our CSA guest will present the MOST observing-time award.

Following the lecture, we will all enjoy a wine-and-cheese reception with live classical entertainment.

Don't miss the Annual General Meeting on Sunday morning and we'll have a surprise for everyone who attends.

To conclude the exciting menu of talks, the speakers on Sunday afternoon are:

Rick Fienberg: 2009 World Year of Astronomy.

David Clark: ClearSky, a 3-D astronomical program demonstration.

Terence Dickinson: Digital SLRs and the democratization of personal astrophotography.

Rolf Meier: Planetary imaging with Web cams.

For those wishing to see our beautiful city with the famous Tulip Festival in full swing, there will be a double-decker bus to provide a relaxing tour around the Nation's Capital on Sunday afternoon.

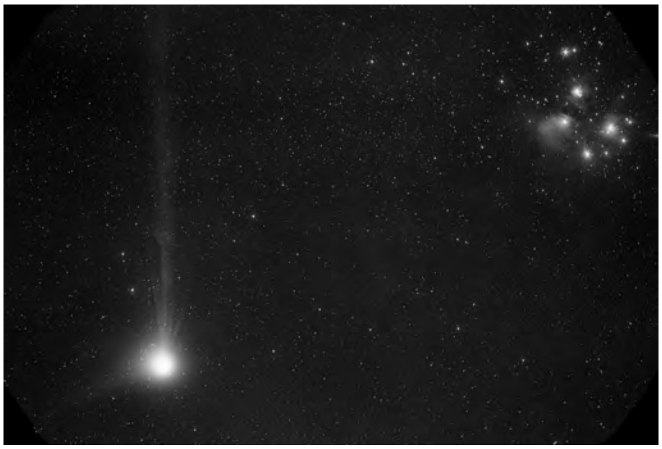
To wrap up GA2006, we will enjoy the Centennial Banquet with guest speaker Dr. Douglas Welch of McMaster University, and the Gemini Telescope Board of Directors with his talk "Coming Down from the Mountain: The Changing Nature of Professional Astronomy."

And for those that are still with us on Monday, Victoria Day, we have organized a boxed lunch at the Canadian Museum of Civilization with a private viewing of the IMAX film, "Magnificent Desolation-Walking on the Moon," and a guided tour of this wonderful museum.

The GA Committee expects that we have the makings of an outstanding and most enjoyable national convention. For additional information, check out the RASC National News Web page for updates in the schedule at `www.rasc.ca/rascnews/2006GA.shtml` or visit the GA's Web site: `www.rasc.ca/ga2006`.

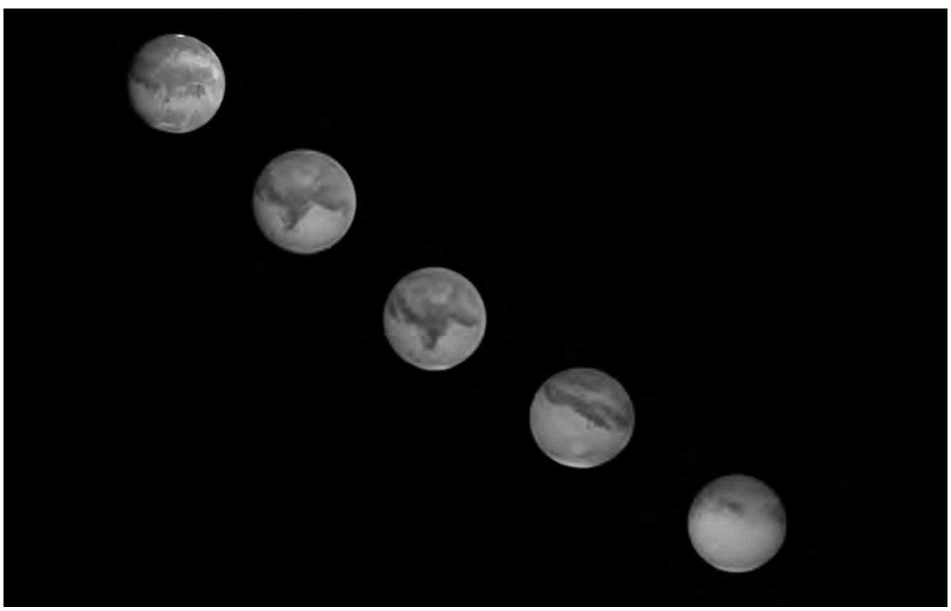
Register early and get ready for an exciting time in Ottawa. We'll be waiting for you!

We Present a Selection of Contributed Astrophotographic Images



Comet Machholz

C/2004 Q2 meets the Pleiades. This composite was originally a digital stack of three images - two colour and one black and white (unfortunately displayed only as a grayscale image in these pages). The black and white image was used for the detail and contrast. Photos were taken by John Mirtle using a Celestron 8" f/1.5 Schmidt Camera. Exposure was 3 minutes for each of the images.Unfiltered. Kodak Tech Pan was used for the black and white image and Kodak LE400 print film for the colour images. Taken near Bragg Creek, AB on January 5, 2005. For more details and the original colour image see John Mirtle's Web page at `members.shaw.ca/jmirtle/home.htm.`



Mars, Mars, Mars

This sequence of Mars images was acquired and assembled by Rolf Meier of the Ottawa Centre during the close opposition of Mars this past fall. Visible in these magnificent images is the changeable and complex meteorology of the planet.

top left:
October 22, 2005 06:17 UT
A major duststorm is underway, covering a wide area from Solis Lacus to Noachis Terra, having moved southward from Lunae Planum a few days earlier. The large canyon Valles Marineris, normally not visible from Earth as an albedo feature, is seen as a light streak with newly-deposited dust on the canyon floor. The North Polar Hood is partially transparent, showing a dark streak that is Acidalia Planitia below. The fine dark lines in Mare Erythraeum are actually areas lacking the lighter airborne dust. A bright streak of dust runs from Nioachis Terra to Sinus Meridiani.

second left:
October 29, 2005 04:47 UTC The South Polar Cap is almost hidden by mists. A morning mist runs all along the limb.

middle:
October 2, 2005 07:24 UTC
Bright clouds are visible on the morning terminator, covering the Hellas region.

second right:
November 9, 2005 05:27 UTC
Compare this image to the one from October 2 above.
The South Polar Cap is now much smaller. Morning mists are seen just over Syrtis Major on the terminator. The North Polar Hood is much more brilliant in this view. On October 2, Elysium Mons was a small dark feature, but on this date, it shows up as a bright cloud.

lower right:
November 12, 2005 03:31 UTC
A large cloud over Olympus Mons makes it appear brighter than normal.
The South Polar Cap has shrunk considerably.

Just the Bare Basics

by Richard Huziak, Saskatoon Centre (huziak@SEDSystems.ca)

The new editor has asked me to do a bi-monthly column on variable stars, and I figured, "Sure - got nothin' else on my plate!" In each issue of the *Journal,* I will endeavour to entice you to add variable stars to your observing program just for fun, or for even more fun – to add a scientific aspect to your nightly observations by recording the result of what you see. Either way, if you take my advice and observe the exotic undulations of a variable star, I will have accomplished my calling. "Pretty low expectations for my life," you may say, but I can get lower if I have to! From time to time, I will also try to feature the writings and anecdotes of other variable-star observers who will inspire you with their unending wisdom. I figure that others who know what they are talking about can share my editorial role.

I would be remiss if I assumed that everyone knows what a variable star is and why it is important in astronomy. For example, at a star party many years ago, an experienced but puzzled observer came up to me with a star atlas and stated, "I've been looking for this star marked 'R Herculis' for a while, and no matter how many times I've star-hopped to the field, it just doesn't seem to be there!" I smiled and explained that, "Well, it's a 'variable' star, and so it's, well…variable. In this case, it is so variable that it has become fainter than you can see in your telescope at this time, despite being plotted in the atlas." Variable stars can do that.

An honest mistake when you really haven't considered observing variable stars at all. We all make mistakes like this and have our own strengths and weaknesses. For example, I don't know my Adhafera from my Zubenelgenubi, although I'm sure someone else does. It is nothing to be ashamed of (unlike looking for the North Galactic Pole!) So from time to time, I will get back to the basics. It points out an opportunity for me to expand your horizons. Yep - expanding your horizons can be done even if you come from the 180-degree wide flatlands of the Prairies. What I really would like to do each month is to introduce a new variable to you that will demonstrate all the different types of variable stars you can observe. However, this month I will immediately break my plan, and just ramble on for a while on some stuff you really need to know before you pick up the scope tonight.

Variable-Star FAQs

So - what are variable stars? Variable stars are stars whose light varies from a fixed magnitude or brightness, sometimes a little and sometimes a lot. There are many reasons for this variation, but you can break down all variables into two basic types: intrinsic and extrinsic. Detailed descriptions of variable types and subtypes will make up the topic of my future articles.

Intrinsic variables go though physical changes and can pulsate, erupt, rotate, or have cataclysmic episodes. Stars can pulsate in periods of an hour and up to years for a single cycle, and anything inbetween. Pulsations are caused by physical shock waves in the stars that rarefy and compress their atmospheres. Eruptors can have flares or quick fades. Rotators may be sun-spotted stars. Cataclysmics just go "boom" - these are the dwarf novae, novae, and supernovae.

Extrinsic variables are (mostly) stable stars that change their light due to the geometry of the system such as eclipsing stars that block the light of their companions during their orbital revolutions. Recently, a new form of extrinsic variables – transiting planetary systems – has joined the celestial zoo of variable types. To add to the complications, many systems are both intrinsic and extrinsic.

Given enough time, all stars are variable, and becoming variable is a natural part of the evolution of a star. In a few billion years, the Sun itself, in its death throes, will swell to the red-giant stage and will begin to pulsate as it eats the last baked remnants of the Earth and humanity. Alien variable-star observers elsewhere in the Universe will measure the solar Mira-type variable's magnitude range and cycle of about one year, and will wonder if anyone ever lived there.

How do I identify a variable star on my atlas? Variable- stars usually have capital letter designations and are shown as open circles or bulls' eyes on charts. In the 1800s, astronomer Friedrich Argelander began a standard system of variable star nomenclature. For various reasons, Argelander began naming variables with the capital letter R, and then incremented the letter as each new variable star was discovered. This system begins anew with each constellation, so the first variable star discovered in Cassiopeia is called R Cas, then S Cas, then T Cas, and so on. New variables were discovered rapidly and Z was soon reached. To continue the sequence, the letters were doubled up as RR, RS, RT and eventually to ZZ. To Argelander's chagrin, someone had the gall to discover yet another variable, and so after ZZ, he began once again with AA, AB and so on until he reached QZ. (Just for good measure and for no good reason, the letter J is never used!). Someone then decided they should discover yet another variable star, and instead of going to RRR, he simply tired of the system and gave the newest stars the creative names V334, V335, and so on. Some constellations have many more variables. The name V5114 Sgr was given to a nova that occurred in Sagittarius in 2004! The brightest naked-eye variables stars are rarely renamed with these letter codes, so stars such as Polaris, Algol, delta Cephei, omicron Ceti (Mira), and others retain their common names. Check out your atlas. These stars will be shown with bull's eye symbols. In fact, the title of this *Journal* itself contains in its letter "o" the bull's eye symbol referring to Polaris, a variable star. (The line though the "o" means that Polaris is also a double star). I will explain the origin of this symbol in a future article. Some of you might also wonder why the Pleiades looks like only six sisters in recent years. Well, the seventh sister is the variable star BU Tau that at times fades to almost the limit of naked-eye observing.

Why bother looking at variable stars? The study of variable stars is one of the foundations on which our basic knowledge of the Universe is formed. Our knowledge of the distance to anything out there began with the study of variables known as Cepheids. At the turn of the last century, Henrietta Leavitt, working at the Harvard College Observatory, noticed that the Cepheids' periods were proportional to their luminosity. A method was devised such that distance could be found to the Cepheids using that relationship. One of the Hubble Space Telescope's program goals was to find Cepheid variables in more distant galaxies and thus refine distances to them with Leavitt's method. Although your observations will not redefine the distance scale of the universe, you can study both short- and long-term physical changes to the stars themselves. Amateur observers routinely see matter being exchanged between close binary stars, reflected in easily-measured changes in the system's orbital period after timing a few eclipse cycles. Because amateur astronomers can contribute valuable and meaningful variable star observations, researchers and educators eagerly seek them out. Groups such as the American Association of Variable Star Observers (AAVSO) and a dozen similar organizations around the world coordinate cooperative programs between professional and amateur astronomers. Besides, you get a really twingy feeling when an observation you did under the streetlight in the backyard sends the Hubble Space Telescope into action!

Beyond the science aspect, it is just a lot of fun to look at a star tonight and then realise that it has faded a magnitude or two since a week before. Variables are stars that change their appearance within minutes or days - unlike Messiers, galaxies and constellation patterns that have their own static beauty. Some, like the dwarf nova IP Pegasi, brighten and fade so rapidly that you can actually see the change as your stare amazed into the eyepiece!

The moon is up! Guess I had better watch TV since I can't see any Messiers! Won't I ever get dark skies again? Moon, schmoon! This also goes for not being able to get out of the city, or not having enough hours to get in a good observing session. Excuses, excuses! Variable stars, like sunspots, planets, and the moon itself, can be viewed under a wide variety of conditions that do not require the darkest skies. So you can't see a faint fuzzy galaxy! Who cares? Expand your horizons and get the scope out into the backyard. There is always a variable star that needs observing, and with a brighter sky, you just pick a brighter variable to look at! Even if TV does win at my house, I often estimate the changing magnitude of the eclipsing star RZ Cassiopeiae (Figure 1) during commercial breaks, since it only needs an observation every 10 minutes to generate a nice light curve! There are over 50,000 known variables catalogued, so there is no shortage of observing targets when yet another season of Survivor somehow begins to bore you to tears.

You don't understand magnitudes, so how will you ever be able to figure out the brightness of a variable star? That's easy. Take on a few variable star observations in your nightly program and you soon will know how magnitudes work.

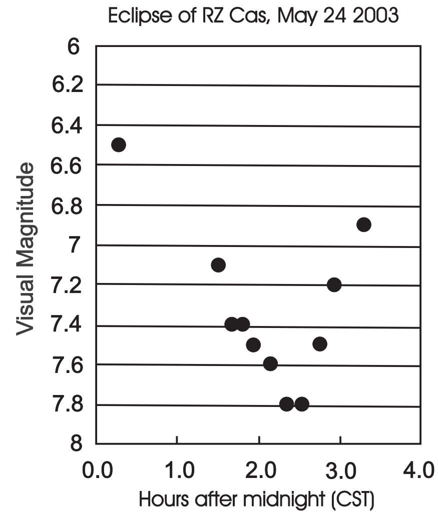


Figure 1 – The light curve of RZ Cassiopeiae constructed by the author based on observations conducted in May 2003. RZ Cas is an eclipsing variable with a rapid fading and recovery in primary eclipse. The period of variability takes just under 1.2 days, of which four hours is shown in this graph.

In the many clinics I've given at the SSSP and elsewhere, I have never found an observer who could not estimate magnitudes after a few minutes of practice. Variable stars are observed with reference charts in hand, on which magnitudes are assigned to standard stars that don't vary. Using the simple method of interpolating the brightness of the variable star to a standard star that is dimmer and one that is brighter becomes an amazingly simple, yet very rewarding, task. Increased knowledge of magnitudes from variable star practice can be extended to stars all over the sky and even for estimating the magnitudes of falling meteors (another science project). Practice makes perfect. In reality, estimating a variable star's magnitude is easy and can quickly become addictive once you have experienced the thrill of seeing a star change its brightness.

With this much knowledge already in hand, I will begin to woo you with a real and interesting variable star in my column next issue. Inspiration can be found from the philosophical words of the immortal earliest American variable star observers who witnessed the supernova explosion in the year 1054 that eventually created the Crab Nebula: "Geez! That was a mighty freakin' blast, eh?"

Really Cool Variable Star Websites

The American Association of Variable Star Observers (www.aavso.org) was formed in 1911 to promote the observation of variable stars by amateur astronomers. Currently the AAVSO's database contains more than 12 million observations and one million new ones are added every year. It is the largest variable star database in the world. From this site, you can download over 3700 variable star comparison charts or the light curve of any variable star in which you are interested. You do not have to be a member to use the site or to submit you observations.

The *General Catalogue of Variable Stars* - the authoritative listing of most variables stars excluding the newest stars found in massive surveys- can be found at www.sai.msu.su/ groups/cluster/gcvs/cgi-bin/search.htm. If you need to know the position, type and brightness of a variable star - go here!

The Astronomical Society of South Australia site www.assa.org.au/sig/variables/classifications.asp gives an excellent summary of how to distinguish all of the variable types and subtypes.

An excellent site out of the Krakow Pedagogical University (www.as.ap.krakow.pl/ephem) predicts local eclipse times for virtually all eclipsing variable stars in the sky.

The *Manual for Visual Observing of Variable Stars* from the AAVSO can be found at www.aavso.org/publications/manual. This manual will guide you through all the learning stages of getting into variables.

Really Cool Books on Variable Stars - Buy these new or find them in used bookstores!

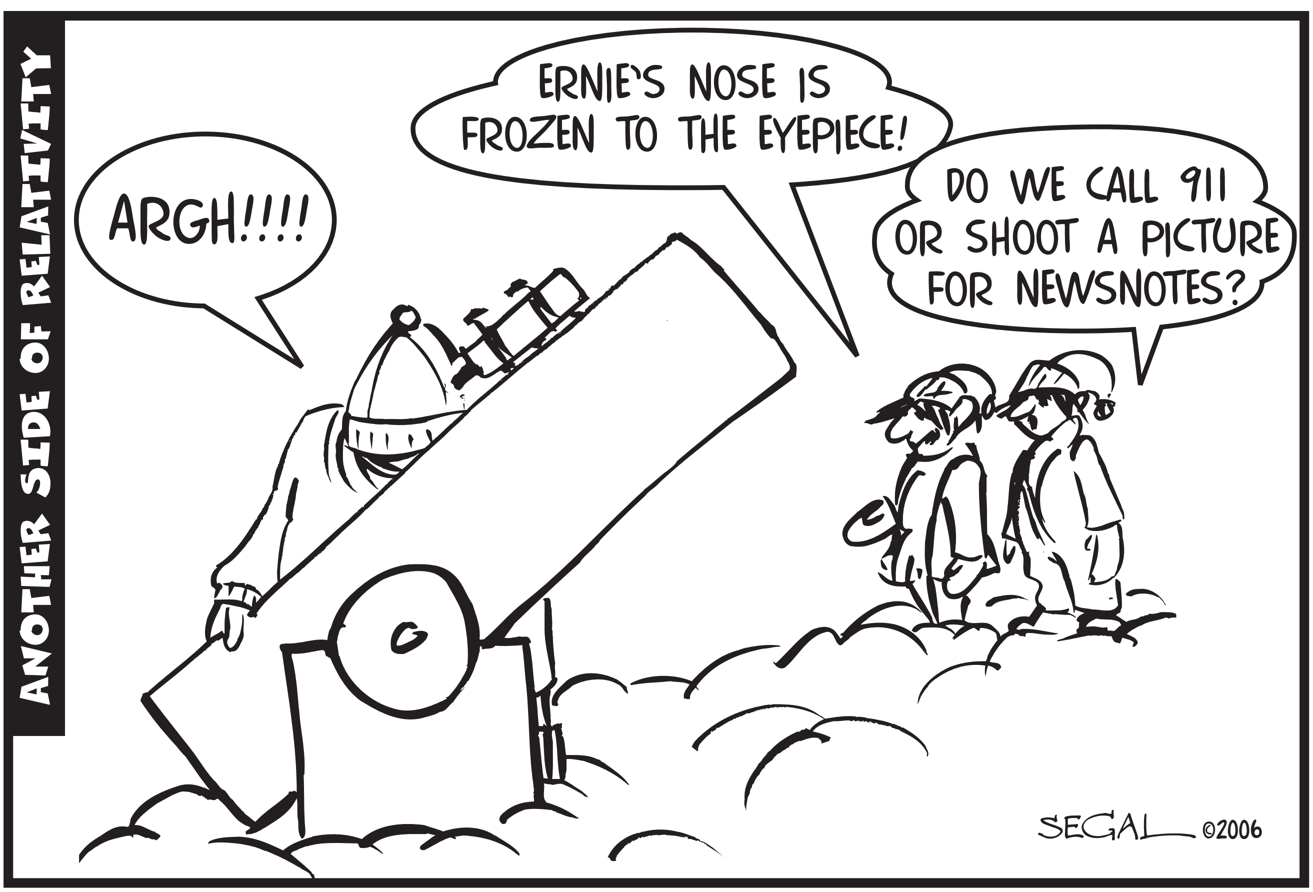
Observing Variable Stars - David Levy - An excellent handbook that takes you through all aspects of learning to observe variable stars.

Burnham's Celestial Handbook - R. Burnham, Jr. In addition to his wonderful writings on deep sky objects, Burnham describes a tonne of variable stars and provides charts for dozens. It was Burnham's enthusiastic writing that first got me interested in variable star observing in 1976.

RASC Observer's Handbook - Check out the variable star section at the back of the *Handbook* for a few charts and the most popular variable stars to start with.

Sky & Telescope magazine - The centre of this magazine has a monthly contribution by the AAVSO and a list of variable stars that will reach maximum light during the month.

The Manual for Visual Observing of Variable Stars - You can download this excellent and practical handbook from the AAVSO site, or if you prefer, purchase a printed copy from them.



Pumpkin Creek Observatory

by Gil Raineault, Winnipeg Centre (raineaul@mts.net)

Two years ago, my wife Marion and I opted for a major change in lifestyle when we traded urban life for country living in rural Manitoba. We sold our Winnipeg home of 31 years and built a small, energy-efficient bungalow on acreage up on the Manitoba Escarpment. Our parcel of land is located on PTH 245, some 30 km West of Carman. We own just over 25 acres, half of which are wooded, and the rest are crop land which we rent to a local farmer. The south end of our field drops almost 225 feet to the valley floor, where Roseisle Creek meanders on its way to Stephenfield Lake, located in a provincial park some 10 km away. To local residents, the stream is known as Pumpkin Creek, hence the name of the observatory.

Pumpkin Creek Observatory – outside view

Shortly after moving into our new home, I began finalizing plans for the construction of a roll-off roof observatory. I had spent a fair bit of time beforehand reading back issues of astronomy magazines, searching for articles about observatories that incorporated this design. I had also done a comprehensive search for similar articles on the Web. During this search, I had briefly entertained the idea of including a warm room in my plans, but finally decided to build a simple observatory that could be automated later, so that I could run the observatory equipment from the comfort of my basement office.

I came across the `www.backyardobservatories.com` site while searching for a design that met my needs. Its owner, Scott Horstman, is a contractor who sells observatory plans and equipment, and markets observatory kits. He will even deliver and assemble an observatory for customers. I wrote him a note inquiring about specific details of the Model CJE1 Observatory, a structure with an 11´6˝ × 11´6˝¸ footprint 6´ high walls, and a 2´ fold-down panel on the south wall. He replied promptly, answering all my questions. After a few more email exchanges, in February 2004 I ordered a set of plans, along with a set of six heavy-duty v-groove rollers. The plans arrived within ten days of my placing the order, and the rollers arrived a short time later. I was motivated to start construction as soon as possible, but a more realistic appraisal of my work slate made me realize that a construction start in the spring of 2005 was more feasible. There were simply too many tasks to complete before we were able to settle into our new home.

A large unfinished house had occupied the exact spot where we eventually built our home. Paul Cenerini, a long-time friend who happens to live some 15 km from us, offered to help me take down the structure. From this demolition we were able to salvage a large supply of dimensional lumber, up to and including a set of sixteen 2˝ × 12˝ fir planks over 20 feet in length. We also reclaimed over 2,000 sq. ft. of steel roofing. I set aside the best pieces of lumber and enough steel roofing for building the observatory and a garden shed. I gave Paul half of the steel roofing, as he was converting some old granaries into storage sheds. The remaining building material sold quickly.

I started preparing for the construction in the fall of 2004, pre-cutting all the lumber required for the project, and applying one coat of primer and two coats of porch enamel to each board. The lumber had badly stained over time, as the old building had never been properly sealed. The combination of water, dirt, and pigeons had discolored the wood,

Pumpkin Creek Observatory –inside view

which was otherwise in very good condition. I ordered a pre-hung steel slab door from the local Co-op. It had to be cut down to fit a 5´9˝ rough opening called for in the plans. I carefully disassembled the wood frame, cut the door, and reassembled the unit in reverse order. I had to move the upper hinge downward on the door frame, as I cut off the top edge of the door. This task requires careful planning, a degree of patience, and at least a full day's work. It is best to follow the advice of measuring twice and cutting once, as a mistake here is costly. Ordering a cut-to-measure door was not an option for me as quoted prices ranged between $450 and $700.

Spring was late in coming, as much of Manitoba was beset by cold and wet conditions for days on end. The startup was postponed until mid-May, when the ground had thawed. In the interim, I went about getting a steel pier ready for the observatory. I obtained a length of 6˝ diameter pipe with a thickness of 0.25˝ at no cost from an acquaintance. I then took it to a local machinist to have both ends trued. He spent 20 minutes on the lathe, machining both ends of the pipe. He refused any payment, saying that he had never done anything for me before. The same thing occurred when Paul brought the 0.375˝ base plate to another machinist to be cut into a 12˝ diameter disk with a laser torch. We went to a local steel supplier to have the base plate welded to the pipe; the owner refused payment when we told him that the pier would be used in an observatory. Currently the finished pier sits somewhere in a large rural manufacturing plant that fabricates hog sorting equipment. It waits for sanding and a powder coat. The cost for this - no charge.

Construction began on the first dry day in mid-May. Paul showed up with his tractor, which he equipped with a 12˝ diameter auger bit and enough extension pipe to drill a holes to a depth of 13 feet, a depth that was overkill for our needs. We carefully marked the exact location where each hole was to be dug, all the while assuring that the axis of the future building would be in exact north-south alignment. Drilling the holes went smoothly, because of a deep sandy soil. We then slipped a length of Sonotube in the hole designated for the pier mount. Instead of using standard anchor bolts to join the concrete pier to the steel mount, Paul had previously welded together a 30˝ long cage made of four 0.625˝ diameter threaded rods. We bolted the cage to the unfinished steel pier. The task of preparing the concrete was simplified by using Paul's electric mixer. When the Sonotube was filled with concrete, we sank the cage into it and set the tube plumb. We used bracing to prevent it from moving as the concrete hardened, then let it set.

Three days later, we cut the 4˝ × 6˝ treated posts to length and set them in the holes, leaving one end of each post sticking out of the ground a full two feet. We then temporarily nailed the end joists and rim boards to the posts, and then permanently fastened them in place with two 4" lag bolts at each point of connection. The joists and bracing were then nailed in place. A quick check revealed that deck frame was slightly less than 1/4˝ out of square. We employed a heavy chain and a ratchet to correct this error. The tongue and groove plywood flooring was then screwed to the deck frame. Finally, we backfilled the holes and then released the chain. A further check showed that the deck was now level and square.

Paul and I had spent some time studying the plans, trying to decide how to best complete each step. We quickly realized that some of the steps required more manpower than the two of us could provide. I decided to hire a carpenter and crew for one day to complete the walls, the track system assembly, and the roof. Roland Grenier, a local contractor, who has a reputation for doing quality work at reasonable rates, agreed to give us a hand. Rolly and his crew of two were somewhat surprised when they arrived to find all the pre-cut, pre-painted building material neatly stacked in separate piles, ready for each step in the construction. Work proceeded quickly, and the observatory was up by day's end. Rolly let out a shout when he rolled off the roof for the first time, and it performed flawlessly.

I later rented a Ditch Witch machine to cut a trench for the power cable. We tried many times to start it, to no avail. The machine went back and I dug the trench using a spade. We ran the underground cable from the house to the observatory and Paul completed the wiring with my assistance. I boxed in the joists on each side of the concrete pier so that Paul could run the cable under the floorboards, rather than stringing it between the wall studs around the building. The plywood decking over the joists can be easily removed to provide access to the cable. The electrical service includes three duplex receptacles, with one duplex box installed next to the concrete base, a red light with dimmer switch, and a compact fluorescent bulb.

The vinyl siding went up quickly. Using material left over from the construction, I built a bookstand, a table, some shelving, and a stool to furnish the interior. By the end of August, work was essentially complete, and Pumpkin Creek Observatory was ready for first light. John, my son-in-law, thought the building needed a sign, so he had one made by one of his friends. It is a beautiful oval plaque that bears the name of the observatory. I mounted it on the door, which was appropriately painted Pumpkin Orange using two cans of Krylon spray paint.

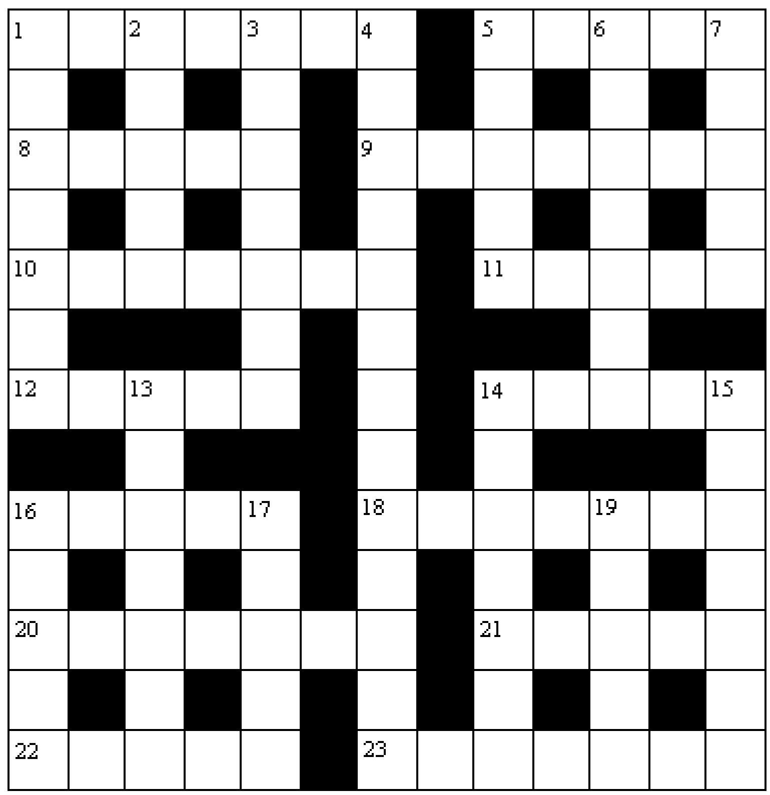
The observatory presently houses a 10″ F/6 Newtonian telescope on an alt-az mount. Next spring the steel pier will be installed, along with a Ceravolo HD145 Maksutov-Newtonian on a Losmandy GM8 mount.

Since completing the observatory, I have spent much more time observing as I make the best of each clear, moonless night. Travel time is nil, and the equipment is permanently set up. Access to the observatory is a pleasant 30-second stroll under dark skies. I only have to unlock the door, roll back the roof, put on some jazz or classical music, and begin observing. The walls offer protection from the wind, and from unwanted encounters with wildlife that is plentiful in the area. Easy access to the observatory has transformed my level of participation and involvement in the hobby. To those readers who are thinking of building an observatory, I can only say that my one regret is not having built it sooner.

Gil Raineault is a long-time member of the Winnipeg Centre who now owns an observatory and a dark-sky location that is the envy of the club.

Astrocryptic

by Curt Nason, Moncton Centre



ACROSS

1. One hundred shine from a bunch of stars (7)
5. A thousand pour out of another bunch of stars (5)
8. A radioastronomer looks the same from either direction (5)
9. This equilibrium is reached in another malfunctioning pyrometer (7)
10. Early 20th century computer dropped an echo in a Leave it to Beaver episode (7)
11. Homes for Cygnus and Tucana set oddly between north and south (5)
12. Meteor remnant in art array (5)
14. Elnath, Zeta Tauri and a trumpet (5)
16. Western telescope focused on Cetus (5)
18. Shakespeare's slave can bail out around Uranus (7)
20. Set ring around Shaula's location (7)
21. Company supporter has snaky head on the Moon (5)
22. Bethe revolved close to Jupiter (5)
23. Planetary orbit will spill back between extreme ends (7)

DOWN

1. Piscium asterism comes round to the border of Taurus (7)
2. Rumba dancing in the shadow of the Moon (5)
3. Twisting force makes Orion follow Taurus around the beginning of summer (7)
4. Surprisingly, turn cat over 10 times to chart a star's orbital speed variations (8,5)
5. Endless energy explodes in a rare flash (5)
6. Hydroxl, as seen in French sea, emitted from a stellar envelope (2,5)
7. Paul's disoriented in the lunar swamp (5)
13. A cab parks beside tellurium-nickel meteorite (7)
14. A focuser I can nearly finish in hell (7)
15. He worked on the Hubble Constant after the Stone Age crumbled (7)
16. Ottawa satellite firm holds a double in the twins (5)
17. Snoopy lost his head to Aquila (5)
19. Emulate comet hunter Thomas, losing his tail to jazz (5)

Shadow Shows

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

When the moon on a cloud-cast night
Hung above the tree tops' height
You sang me of some distant past
That made my heart beat strong and fast
Now I know I'm home at last

You offered me an eagle's wing
That to the sun I might soar and sing
And if I heard the owl's cry
Into the forest I would fly
And in its darkness find you by.

And so our love's not a simple thing
Nor our truths unwavering
Like the moon's pull on the tide
Our fingers touch, our hearts collide
I'll be a moonsbreath by your side

– Loreena McKennitt, *Samain Night*

I love eclipses. Unfortunately I am not wealthy enough to trot the globe in pursuit of totality, so with one glorious exception (Mazatlan, 1991) I have simply observed any eclipse visible from my home in Edmonton over the past two decades. Currently we are in a decade-long drought even between partial solar eclipses; however as if to compensate we have been favoured with a nice series of lunar eclipses of all types.

The most recent of these was the shallow (6%) partial lunar eclipse of October 17, 2005. With the event occurring very late on a cloud-cast night, it was not widely observed. I set my alarm for the wee hours of that Monday morning and was rewarded with a nice view of most of the event. The onset of the penumbral phase was heavily clouded, but by 5 a.m. it was obvious something was happening, and from then on the broken cloud actually added to the show, displaying frequent purplish-orange haloes near the Moon. By first umbral contact at 5:34 MST the Moon looked just a little out of round, as if the left edge had been sliced clean off. The clouds were scudding by from the northwest, so they crossed the Moon right to left. In binoculars the more opaque grey clouds seemed to hang on the Moon's left edge, when in fact that grey area was Earth's umbra near the south lunar pole, and it wasn't going anywhere in a hurry.

That they take their sweet time is one of the things I love about lunar eclipses; one really has time to ponder the cosmic clockwork being revealed. At least one does when they are shallow partial eclipses at six o'clock in the morning; no worries about thousands of visitors flocking to the Observatory for this one! Just me and my thoughts, adrift in a sea of serenity.

It was one of those mornings when I had awoken with my head full of music - not some silly Village People ditty, but real music in all its glory, the Allegretto (second) movement from Beethoven's *Seventh Symphony*: magnificent, majestic, magic, music *for* the spheres. As it glided inexorably through Earth's shadow to this stately if imaginary accompaniment, the Moon was joined in the southwest by brilliant Mars, the Pleiades and the Winter Hexagon. During the partial phase I serendipitously observed both a brilliant Iridium flare and a decent pre-dawn pass of the ISS, each in the southwest as well.

The lunar south pole was taking a cool bath in Earth's primary shadow, and much of the normally brilliant southern highlands was in the heavy shade of the deep penumbra. With the brightest portions of the Full Moon glare muted, the northern maria stood out in excellent contrast, and the area above the "rabbit's ears" (north of Mare Frigoris) was, for a rare change, the brightest spot on the Moon.

Figure 1 – The penumbral eclipse of April 24, 2005, as imaged by Tenho Tuomi (Saskatoon Centre). The Moon is shown sinking ever deeper into Earth's shadow. From upper right to lower left: 5:58 UT (24 degrees altitude), 8:52 (20 degrees), 9:52 (15 degrees) and 10:55 (7 degrees). According to Tenho, "the last picture besides being low had thin cloud over it."

As the slowly setting Moon hung above the tree tops' height, I realized that I'd completed a couple of personal firsts. This was the third consecutive lunar eclipse that I had observed, including the total eclipse of October 28, 2004 and the penumbral of April 24, 2005, so one of each major type at intervals of one Semester (six lunations).

More uncommonly, I was able to observe (successfully!) all four eclipses in a series at interval one lunar year. The first three of these occurred shortly after moonrise, this last a little before moonset, so for this particular series this would be possible only from a fairly narrow band of longitude, and the further north the better. Edmonton was just right.

The events in this "Samain series" all occurred in mid-autumn near the Moon's ascending node, with circumstances changing fairly significantly from one eclipse to the next.

Pooling my recollections from the four observations, it was easy to see how the Moon shifted through the centreline rapidly from one eclipse to the next. This

Date	Saros	Mid-Eclipse	Type	Gamma
2002 Nov 20	116	01:46 UT	Penumbral	-1.113
2003 Nov 09	126	01:18 UT	Total	-0.432
2004 Oct 28	136	03:04 UT	Total	+0.285
2005 Oct 17	146	12:03 UT	Partial	+0.980

is shown above in the gamma column, which is the least distance between the centres of the Moon and Earth's shadow, measured in Earth radii. The lunar year (12 lunations) is an imperfect fit for the eclipse year (11.74 lunations, defined by the movement of the nodes). So if the Moon crosses a node near Full phase one year resulting in a total lunar eclipse, it will cross that same node around first quarter the next year, and at New Moon the year following that causing a central solar eclipse and a grazing lunar one. For this reason central solar and lunar eclipses occur in anti-phase to each other. (See Table 1)

These four eclipses comprised all the members of a typical lunar-year series. By 2006 the nodes will have regressed still further, and no eclipse will occur in October. Instead, a new lunar-year series will start at the ascending node after eleven lunations, a grazing partial eclipse of the Moon's northern hemisphere on September 7, 2006, roughly the polar opposite of its predecessor. Unfortunately, that one will be invisible from North America.

A full rotation occurs roughly every 47 lunations (4 eclipse years * 11.74 lunations) or (4 lunar years minus a shift of one month). This is the eclipse period known as the Octon, so named because there are eight eclipse seasons in an Octon, four at each node. Thus there are commonly four members in series of the type I observed. What may be uncommon is having the good fortune (location *plus* weather) to see all four members of a single series and thus witness its evolution for myself.

In 2005 lunar eclipses were "late" and occurred a fortnight after solar eclipses; in 2006, there will be a shift and lunar eclipses will *precede* solar. The upcoming penumbral lunar eclipse of March 14, 2006 occurs only five lunations after the partial of October 17, 2005. This period, known as the Pentalunex, is symptomatic of such a shift of eclipse order.

Those of us in the west are destined to see only the subtle closing stages of this eclipse; however, those in the eastern part of the continent have an opportunity to see a rare subcategory known as a total penumbral eclipse (TPE). For one hour bracketing mid-eclipse at 23:48 UT, the entire Moon will fall within Earth's penumbral shadow. (Espenak, 2005; see Figure 2) This geometry is only possible near the apogee of the lunar orbit (which occurs on the 13th); nearer perigee the Moon itself has a larger angular diameter than the penumbral corona. According

Table 1.

Lunar	Solar	*Lunar*	Solar	*Lunar*	Solar	*Lunar*
					2000 Dec 25 P	***2001 Jan 09 T***
					2001 Dec 14 A	*2001 Dec 30 N*
				2002 Nov 20 N	**2002 Dec 04 T**	
				2003 Nov 09 T	**2003 Nov 23 T**	
			2004 Oct 14 P	***2004 Oct 28 T***		
			2005 Oct 03 A	*2005 Oct 17 P*		
		2006 Sep 07 P	**2006 Sep 22 A**			
		2007 Aug 28 T	2007 Sep 11 P			
	2008 Aug 01 T	*2008 Aug 16 P*				
2009 Jul 07 N	**2009 Jul 22 T**	*2009 Aug 06 N*				
2010 Jun 26 P	**2010 Jul 11 T**					

Table 1 – Panorama of solar and lunar eclipses at interval of one eclipse year, 2000-2010. Lunar eclipses (shown in *italics* for clarity) in this panorama all occur at the ascending node, solar at the descending. Eclipse types: T = Total; P = Partial; A = Annular (solar only); N = Penumbral (lunar only).

The columns are at interval one fortnight (half a lunation), the rows at interval one lunar year (12 lunations). The eclipse year of 11.74 years is an imperfect fit to this latter period, resulting in the gradual forward shift of the columns. Typically there are four members of either type of eclipse per lunar-year series; more uncommonly five with a very shallow event at either end of the series; very rarely three (such as the short solar eclipse series of July 22, 1990 - July 11, 1991 - June 30, 1992, which was the first three-member series in over 1,500 years).

During the current era most eclipse seasons include exactly two eclipses, one solar, one lunar; the only exception in the above list occurs in 2009 when there is a "duo" of penumbral lunar eclipses bracketing a deep central solar eclipse. Typically exactly one eclipse each season is central (T or A); again there is one exception on the above list when two marginal total eclipses occurred in 2003 November. Central eclipses of all types are shown in **boldface.**

A second, very similar panorama of the opposite eclipse season (lunar eclipses at the descending node, solar at the ascending), mostly occurring in the first half of the calendar years under study, is not shown.

to Meeus (1997), TPEs occur only five times this century, and not again until 2053. At that, we are currently near a *maximum* of this type of event that occurs in the familiar six-century cycle; there will be only one TPE in the 23rd Century, none at all in the 24th. TPEs occur in phase with the lunar tetrads (four consecutive lunar eclipses); both are dependent on grazing angles of terrestrial shadow against lunar limb. (McCurdy, 2003, 2004)

From an observational standpoint, it will be a subtle but nonetheless interesting event, well worth observing near mid-eclipse early on a Tuesday evening. As penumbral eclipses go, it is a very deep one, with Earth's shadow showing strongest on the Moon's southern limb and tapering off from there like a graduated neutral density filter, once again bringing the "rabbit's ears" of Mare Frigoris into unusual prominence. While an Earth-cast shadow will not aid in depth perception, it will result in improved contrast on the lunar surface, reduced glare, and a pleasing view to the aided or unaided eye. Don't pass up this opportunity to watch the inner workings of the cosmic clockwork.

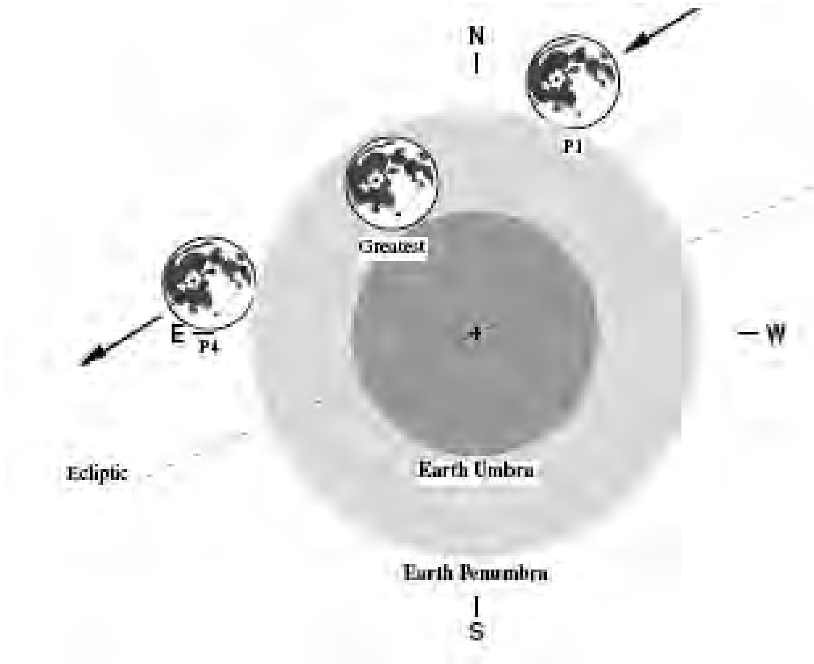


Figure 2. – The penumbral eclipse of March 14, 2006 will see the Moon pass entirely through Earth's penumbral shadow, as detailed in this extract from the relevant figure in Observer's Handbook 2006, courtesy Fred Espenak of NASA/GSFC.

References:

Espenak, F., 2005, Observer's Handbook 2006, ed. R.Gupta, (University of Toronto Press: Toronto) 110, 124

McCurdy, B., 2003 JRASC 97, 234

McCurdy, B., 2004 JRASC 98, 202

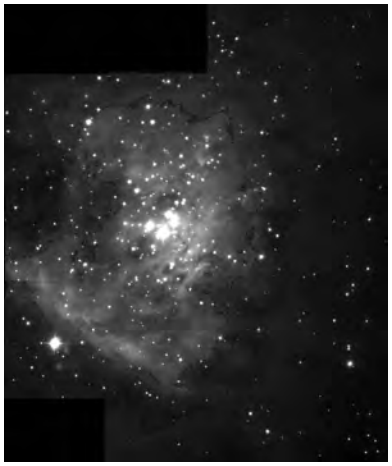
Meeus, J., 1997 Mathematical Astronomy Morsels, (Willmann-Bell Inc.: Richmond) 108

Bruce McCurdy marks Volume 100 of the Journal and welcomes incoming editor Jay Anderson with a minor milestone of his own. This is the 30th edition of Orbital Oddities, a product of Bruce's undying fascination with the dynamics of positional astronomy. Bruce dances to the music of the spheres.

Net Astronomy

by Paul J. Langan (Paul@langan.ca)

Intriguing Infrared



If the universe is a building, then infrared radiation is the blueprint - it pokes through the walls of dust and gas to show the internal layout of galaxies and nebulae. *CoolCosmos* is an educational site for all ages, jam-packed with images covering every aspect of infrared astronomy while remaining comprehensible and enjoyable. By combining breath-taking 2MASS simulations and Spitzer telescope animations, *CoolCosmos* displays the discoveries made by these projects and how they were obtained. Not content with just the infrared, *CoolCosmos* branches out into other frequencies as well, making it a must for a well-rounded understanding of multi-wavelength astronomy. Want to see M29 in x-rays, radio waves, and ultraviolet, or a lizard in infrared? *CoolCosmos* has them. While focussed on children and teachers, *CoolCosmos* is a well-formulated review of astronomy in all its colours and suitable for all ages!
`coolcosmos.ipac.caltech.edu`

Where Do I Begin!

After you discover the joy of astronomy though a public telescope, where can you go to find out how to do it for yourself? One answer is *AstronomyBoy* - a Web site useful for beginners and for those who want to try out a new endeavour such as astrophotography, deep-sky astronomy or even building and modifying a telescope and mount. The “Getting Started” section covers the essentials for a newcomer: buying a telescope, accessing useful books, or operating an equatorial mount. For those with a little experience and ambition, there are plans for a barn-door tracker or instructions on rebuilding a CG-5 mount to make it run a little smoother. A wonderful database of constellation images provides visual stimulation, and for those interested in going beyond Messier, there is a list of challenging objects for 10˝ to 12˝ telescopes compiled by active observers from *sci.astro.amateur.* Number one on the list? - NGC 253. This site clearly illustrates the adage that a book shouldn’t be judged by its cover. The opening page layout doesn’t have much pizzazz, but the site is crammed with helpful guidance.
`www.astronomyboy.com`

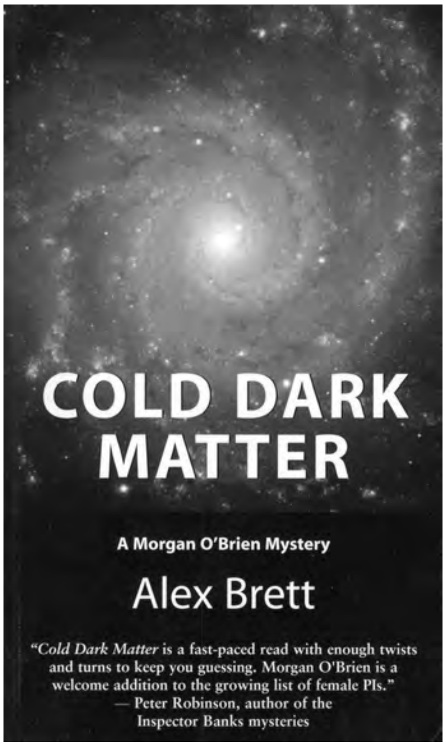
Latest Advances!

Astronomy moves forward at an unbelievable rate. Keeping up requires an encampment in a library or this nifty site. It’s not for the faint-of-heart, for this e-Print Archive, run by Cornell University, contains the latest papers in astronomy and other sciences. This service will not be new to active university researchers but probably has not received much attention in a popular magazine. I highly recommend it to members with a hearty science background and a strong interest in the most recent advances. The database has papers going back to 1992 and can be searched easily with the built-in search engine. A feature that I love and found most helpful when researching a new topic is the cross-referencing of authors. Papers are available for download in a number of formats. and the site works well in Linex and Windows.
`xxx.soton.ac.uk`

Paul Langan is President and CEO of a multi-national company and a Fellow of the Royal Commonwealth Society, but his heart is directed more toward the stars, judging by his degree in astrophysics, fellowship in the RAS, and membership in the RNZAS, the BAA, and the RASC. If you have suggestions for future sites please email him at Paul@langan.ca

Reviews of Publications
Critiques d'ouvrages

Cold Dark Matter, by Alex Brett, pages 348 + 0, 11 cm × 18 cm. A Castle Street Mystery, The Dundurn Group, Toronto, 2004. Price $11.99 paperback (ISBN 1-55002-494-9).



A package dropped in my mailbox last month, with an unknown return address in Saskatchewan. A letter bomb? Gingerly flexing it, I decided it was almost as dangerous: a paperback book. When I unwrapped it and saw the spiral galaxy on the cover, the penny dropped. It was a copy of *Cold Dark Matter*. My ex-government-scientist-friend in Ottawa had sent it to a colleague in Saskatoon, with instructions to forward it to me.

The danger was that I would start reading, and my life would be temporarily put on hold. That happened two weeks later, when I took the book on a business trip. Now, on the way back, circling over Toronto, I am taking a break from reading to write a review. I will not reveal the ending because I am not there yet. But this is what you need to know:

Cold Dark Matter is a murder mystery, and a good one. Alex Brett is a science writer, also good. The mystery is the apparent suicide of an astronomer, found hanging from the prime focus of the "FrancoCanadian Telescope" on the summit of Mauna Kea in Hawaii. The protagonist is a tough, determined investigator named Morgan O'Brien. She's a heroine much like Tempe Brennan, but her specialty is physical science, not forensic anthropology. The Hawaiian locations (Kona, the observatory offices in Waimea, the dormitory halfway up Mauna Kea, and the telescopes on the summit) seem authentic, as far as I can tell from my brief visit to the CFHT a few years ago. The characters are convincing - there is even one whose first name is Shelton. And the story is engrossing, with twists and turns in every chapter.

If you want to learn more, buy the book, or visit the CBC Quirks & Quarks website to hear Bob McDonald interviewing the author last spring. I am not going to tell you more right now. When I stopped reading to write this, Morgan had a gun pressed against her neck, and I need to find out what happens next.

Michael Attas

Michael Attas spends much time indoors reading and writing, as an Associate Editor of JRASC *and as an administrative chemist at Atomic Energy of Canada's Whiteshell Labs in Pinawa, Manitoba. But when Mars beckoned this fall, he answered the call.*

Janis Chodas

by Philip Mozel, Toronto Centre (phil.mozel@sympatico.ca)

"Teamwork!" This word came up several times during my conversation with Janis Chodas of the Jet Propulsion Laboratory (JPL). "Teamwork." It is not merely a word but an important precept and has helped her catapult spacecraft to the planets.

Growing up in Toronto, Janis Chodas obtained a Bachelor of Applied Science and Master of Applied Science in Aerospace Engineering at the University of Toronto. But what was the attraction of space when her engineering degree could be applied to so many other fields? The reasons are many. Space science certainly allowed her to apply the math she so much enjoyed, but her summer job at SPAR Aerospace (builder of the Canadarm) also fuelled her interest. The kind of work she sought would also be one-of-a-kind, work that no one had ever done before. There was also the basic attraction of exploring and, as with so many other space scientists, memories of watching the first steps on the moon proved impossible to resist. And, oh yes, a student, Paul Chodas, whom she met at university, helped fire her imagination. They eventually married and both found jobs at JPL (see *A Moment With...Dr. Paul Chodas* in last issue's column).

Dr. Janis Chodas

Shortly after leaving university she landed what must have seemed like a dream job – including working on the *Galileo* mission to Jupiter as a dynamics and control analyst for the attitude control system. Over ten years she assumed many roles including working on the scan platform control software, making preparations for in-flight operations of the spacecraft and, from the mid-1980s until launch, being technical manager with responsibility for hardware and software. Witnessing the "exhilarating" launch of Galileo on the Space Shuttle rewarded the hard work of her team.

Moving deeper into the solar system, from the autumn of 1990 through to its launch, Dr. Chodas co-managed the technical team that developed the attitude control system of *Cassini,* spending a total of eight years with the program.

She also applied her expertise for three years to the conceptual design of the computers, optics, sensors, actuators, structure, and software of SIM, the *Space Interferometry Mission.* This set of six 0.3-metre telescopes, to be placed in solar orbit, will use optical interferometry techniques to more accurately measure the positions and distances to stars than has ever been possible. A precision of one micro-arc second is the goal. The spacecraft will also be used to seek extra-solar planets while performing studies in stellar and galactic astrophysics as well as extragalactic astronomy.

Eyeing a planet a little closer to home, Dr. Chodas worked for two years on the development of the flight software for the *Mars Exploration Rovers*. She describes her role as project technical management, *i.e.,* working with the flight software architect to monitor the developers' progress, identify problems early and work out resolutions, and ensure that the flight software verification and validation is accomplished successfully. As with her other projects, "teamwork is critical!" As stated in a recent *Time* magazine article dealing with JPL, "When smart people ask questions of other smart people, often as not they get smart answers. That has saved more than one J.P.L. mission." Teamwork!

Traveling to the outer planets is a long-drawn-out affair consuming many years. During these relatively slow periods, technical people are generally "recycled" to other projects. The best part of the *Mars Rover* missions for Dr. Chodas was the short cruise phase that enabled her to stay longer with the project. In fact, she stayed three months past the landings and helped oversee the uploading of new software to the rovers. For example, the rovers have been programmed to avoid becoming stuck in the sand again.

Such uploading allows for greater flexibility of interplanetary missions since not everything required for the entire mission need be ready at launch time. Software can continue to be tinkered with and improved and sent when needed. In other words, the "body" can be sent now and the "brains" dispatched later.

Dr. Chodas explains that there was a time when spacecraft were hardware-dominated, but times are changing as our machines grow smarter. For example, while there has always been a certain level of on-board autonomy, the ability to take independent action is increasing. A case in point is fault protection software. Let's say a gyro fails; the software might turn it off, command the spacecraft to point at the Sun, and then use a sun tracker for subsequent orientation. To accomplish mission activities, we are now at the point where ground controllers don't have to issue a sequence of individual commands at all; they just send one and the spacecraft knows which sequence of steps to follow. "Goal-based planning" is currently in the works whereby the spacecraft itself figures out how to do a job both effectively and safely. Technology is currently being demonstrated that allows a spacecraft to watch for scientifically interesting events (dust devils on Mars, say, or volcanic eruptions on Earth), stop what it is doing and switch to observing the event. This mode of operation is what Dr. Chodas refers to as "science of the moment."

Working on projects as complex as those that send spacecraft hurtling into space, one is likely to experience "high highs" with each major accomplishment. There are also "low lows," but the end result can certainly make it all worthwhile. Looking up at night it's "unworldly to see Mars and imagine your stuff there!" (In fact, Dr. Chodas' favorite picture is the first one transmitted by the *Spirit* rover. That, she explains, was "unbelievably exhilarating!")

One of the "highs" certainly occurred in 1994 when Comet Shoemaker-Levy 9 collided with Jupiter. Because she had contributed to *Galileo*, there was definitely the feeling of "Gosh, there's a spacecraft up there I worked on!" but there's more. Her husband had been part of the group that determined when and where the spacecraft should point to witness the impacts. Each of the Chodases contributed to the success of a mission that observed something no one had ever seen before.

Now, that's teamwork!

Philip Mozel is a past National Librarian of the Society and was the Producer/Educator at the McLaughlin Planetarium. He is currently an Educator at the Ontario Science Centre.

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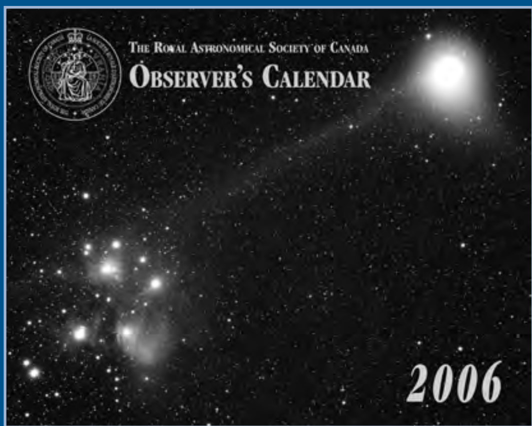

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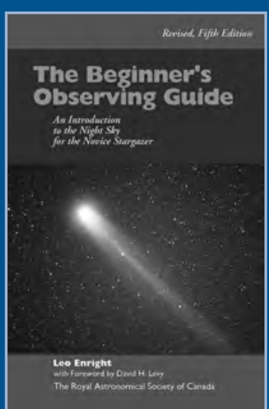

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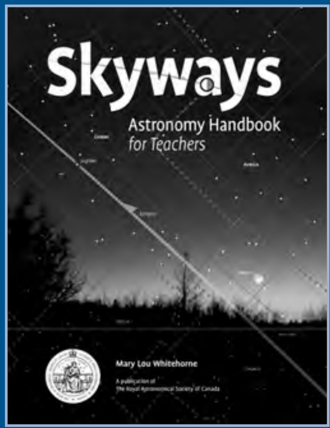

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