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Journal

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December /décembre / 2000

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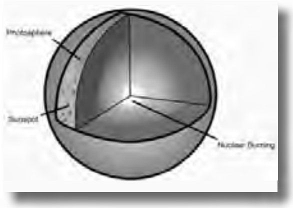

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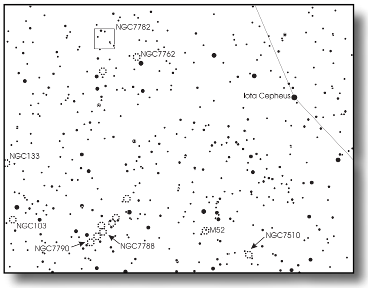

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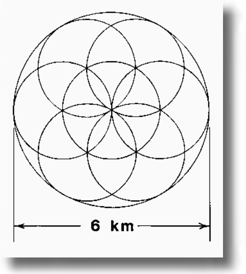

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Cover:
The largest pyramid, at the centre of the photograph, is the Great Pyramid of Giza, which was built as a tomb for the Egyptian King Khufu (also known as Cheops).

Photograph courtesy of Kate Spence

President's Corner

by Robert F. Garrison (garrison@astro.utoronto.ca)

After 13 years of searching, the pulsar powering Shelton's Supernova finally has been found (Middleditch *et al.* 2000, New Astronomy, 5, 243). The elusive pulsar remnant of Supernova Shelton 1987A is rotating with a period of 2.14 milliseconds, which is not the fastest known. Can you imagine a compact object so dense that only neutrons can exist in it? If you can imagine that, stretch your mind to picture an object more massive than the Sun squeezed into a sphere of diameter about 30 km (give or take a few), rotating almost 500 times every second. These are interesting times for being involved in astronomy.

Canadian Ian Shelton, the supernova's discoverer, was Resident Observer at the University of Toronto Southern Observatory (UTSO) on Cerro Las Campanas in the desert mountains of Chile. In the last semester of his four-year stint (1981-1983, 1985-1987), he spotted the supernova, which was the brightest since 1604, five years before the first use of a telescope. His claim to credit for the discovery is supported by photographic evidence: before and after plates of the Large Magellanic Cloud taken twenty-four hours apart. He used an ancient ten-inch, wide-angle telescope stopped down to five inches to improve the images for that first exciting night. The discovery images were followed by the first photoelectric photometry of the rapidly brightening supernova, using the UTSO 60-cm telescope. The next night, observers far enough south to see it at −69 degrees were looking at it and taking whatever data they could. Ian observed it every clear night from February 23 until July 1, sometimes changing instruments several times per night. A very large telescope would not have had the required observing time available, and instrument changes are often difficult and time consuming on the largest facilities.

At the UTSO, the late Jerry Kristian of the Carnegie Observatories installed a specially designed, high-speed photometer (referred to as The Black Box) for detecting the remnant, probably a pulsar, which was expected to have a period of order 1 millisecond (ms). Ian checked for it once every clear night for as long as the supernova was visible with the UTSO telescope, which turned out to be about a year and a half. After that The Black Box was transferred to the 4-meter telescope at the Cerro Tololo InterAmerican Observatory and used occasionally, but not every clear night. A 0.5-ms periodicity was later detected but discounted as an artifact of the equipment used.

My point here is to emphasize that not all discoveries are made with huge telescopes by professional astronomers. In 1987, Ian Shelton had only a B.Sc., though now he has a Ph.D. and is working at the giant 8.4-m Subaru Telescope. Also, it can be argued that many other important discoveries are made using telescopes within the range of amateur astronomers. For

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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The Royal Astronomical Society of Canada
136 Dupont Street
Toronto, Ontario, M5R 1V2, Canada
Internet: rasc@rasc.ca
Website: www.rasc.ca
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example, consider the large-scale structure of the universe which gave us the view of the "stick man" with bubbles (voids) and strings. Margaret Geller and John Huchra made that discovery during an extensive survey using a small (60-cm) telescope. As in the case of the supernova, the details have been filled in using larger telescopes.

Many large telescopes are being built today, and that is a good and wonderful thing. The problem is that, in Canada especially, most of the capital and operating funds come with a zero-sum condition, which means building the large telescopes takes away the support of small and moderate-sized telescopes, which are the foot soldiers of the observational army. We are in danger of producing only 5-star generals. I'm very much in favor of building the biggest and best instruments we can, but new money is needed. We can't build these instruments on the current budget, even after decimating the budgets of the supporting telescopes, which should not be sacrificed. The recent Long Range Planning Panel report, which requests new money, should be given the widest possible distribution. Talk to your Member of Parliament about it and stress the need for new investment. Canada needs a balance of telescope sizes and capabilities, for not all interesting objects are faint and not all faint objects are interesting.

GREAT ASTROPHOTOS WANTED

A new feature coming to the *Journal* is a regular gallery where we will feature members' astrophotographs. As well, we always have a use for photos that can be used to illustrate articles in the *Journal*.

For many of our members astrophotography is a passion. The search for the perfect shot of some faint fuzzy can consume countless frigid nights and buggy evenings — as long as the sky is clear and dark, some RASC member is out there shooting the stars and planets and other related phenomena such as aurorae and other atmospheric events.

We invite you to send us your best shots. We can handle prints, transparencies (from 35mm to 8×10 inches), and high resolution digital or scanned images in most popular formats. Your image will most likely be printed in black and white, but if you have a great colour shot, send it along as we try to print at least one colour section per year.

Contact the editors (addresses can be found on the masthead at the beginning of this magazine).

Editorial

by Wayne A. Barkhouse, Editor-in-Chief

Mathematically speaking, the end of the current millennium is upon us. This is a natural time to reflect upon the changes that have occurred in our society during the past one thousand years and to imagine what will happen in the future. Specifically, how has our knowledge of astronomy evolved since AD 1000? What have been the most significant astronomical discoveries during this period? What will the *Journal* editor write (or communicate by thought?) in December, AD 3000 about the past 1000 years? We are alive at a special time in human history to be able to witness the beginning of the new millennium.

Looking back, what was the extent of our knowledge of astronomy in AD 1000? Night-sky observations had been recorded for centuries and many cultures developed independent and sophisticated calendars. Greek science flourished for almost 1000 years from 600 BC and included quantitative measurements of the size of the Earth and relative distances of the Moon and Sun. Geocentric models were developed to calculate the positions of the planets. The model of Ptolemy was still in use by the Arabs in AD 1000.

The first significant breakthrough in human understanding of our place in the universe (since AD 1000) was the Copernican Revolution — the notion that the Earth is not the centre of the universe but instead orbits the Sun which is (near) the centre. Although one of the Greek philosophers, Aristarchus, had suggested this idea long before Copernicus, it was not until the late 16th century that it finally started to take root. The demotion of the Earth from the special place at the centre to being "just another planet" was one of the most important paradigm shifts to occur in the history of the human race and was truly "revolutionary."

The next major advance took place in the early 1600's with the Dutch invention of the telescope and its use by Galileo for astronomical study. His discovery of the phases of Venus, the moons of Jupiter, and the fact that the Milky Way could be resolved into thousands of stars showed how technology could be used to improve our understanding of nature. Also during this time, Kepler developed his three laws of planetary motion, laying important mathematical groundwork.

The Copernican Revolution culminated in 1687 with Newton's publication of the *Principia*, unifying the work of Galileo and Kepler in a set of dynamical laws that were applicable to objects on Earth or in the heavens. The motions of projectiles and planets could now be understood using a model that was physically and mathematically sound.

In the last one hundred years, the pace of acquiring knowledge has increased dramatically. Einstein's General Theory of Relativity initiated a major revolution in the way we view gravity and, along with his Special Theory of Relativity, superseded the work of Newton. This occurred at a time when technology was beginning to make possible the building of large telescopes, which would dramatically extend the observational frontiers. Hubble's extragalactic work demonstrated that the Milky Way was but one of many "star systems" spread throughout an expanding universe, and could be understood in large part by Einstein's equations of General Relativity.

In the 1930's Hans Bethe discovered that the source of power for the Sun, and therefore all stars, was nuclear fusion. With this theoretical foundation and the remarkable progress gained in understanding the spectroscopic observations, the field of stellar astronomy approached a level of maturity that was only dreamed of in the 19th century.

In the later half of the 20th century, the most profound achievements have been brought about by our relentless drive to understand the workings of our universe on the largest scales. The discovery in the 1960's of the birth pang of the Big Bang, the cosmic microwave background, put a nail in the coffin of the major rival theory at that time and placed cosmology on a strong scientific foundation.

Today we find ourselves in a very interesting period. Observations indicate that the majority of matter in the universe does not radiate like ordinary matter but is instead "dark." Also, recent high-redshift supernovae and, independently, measurements of the fluctuations in the cosmic microwave background, imply that approximately 70% of the mass-energy of our universe may be in some form of a "repulsive-force" that causes the rate of the expansion of the universe to increase with time.

What wondrous and profound discoveries will occur in astronomy and astrophysics in the next millennium? What will the editor of the *Journal* in December, AD 3000, write as our most significant accomplishment in the past 1000 years? Please send me your thoughts, and I will list some of the most interesting ones in a future issue.

Happy holidays and a very happy new millennium!

OMISSION

In the August/October issue we neglected to credit the GA group photo (printed on the cover and on page 161) to Murray Paulson, Edmonton Centre.

Correspondence
Correspondance

A LIFE OF VARIABLE STARS

Dear Sir,

My first contact with the Royal Astronomical Society of Canada was in 1952. It was fortunate that a five-month lecture tour of North America was to commence in Vancouver and then to continue to other Canadian astronomical centres. I knew that most of my audiences had forgotten more astronomy than I knew. Professional astronomers throughout Canada were all so helpful and encouraging that they gave me the confidence for the U.S. tour. Helen Hogg, Jack Heard, and many others freely gave helpful advice on the problems that concerned me. A very happy result was life-long friendships.

After service in the Royal New Zealand Navy, I settled on Rarotonga in the Cook Islands at the end of World War II. There I established my observatory to continue my observations of variable stars. I also dreamt of establishing a professional observatory and of having astronomy taught at a New Zealand University. I had no idea how I would bring this about, but Brad Wood of Pennsylvania had expressed interest and hence this first lecture tour.

I had established the Variable Star Section (V.S.S.) of the Astronomical Society of New Zealand many years before. This later became the R.A.S.N.Z. Directing its activities was a part time job until October 1969 when I retired as Astronomer-in-Charge of the Mt. John University Observatory, Lake Tekapo, New Zealand. I had, by then, seen my dreams come true after heading the Site Selection Survey of New Zealand. Along the way I led the multi-national Eclipse Expedition to the South Pacific in 1965; helped establish the National Committee for Astronomy in New Zealand, and being its Chairman for many years; got New Zealand to adhere to the IAU; and became New Zealand's first official delegate to the IAU.

Since I retired from Mt. John Observatory, my life has been devoted full time to directing the activities of the V.S.S., R.A.S.N.Z. We now have a database of around three million observations of southern variables and have taken part in just over 1,000 special programmes requested by professionals worldwide. The only paid staff we have is a part-time secretary. Our work is financed by subscriptions to our charts and other publications and by sales of *Paradise Beckons*. Grants have supplied our computers.

I have visited Canada on many occasions, especially when my elder daughter was alive. I have visited several Canadian observatories during these trips but have not been able to be in the country during the annual meetings of your society. My daughter was a medical missionary in Saskatoon working with Metis and Indian people. This has given me a great love for Canada and its people, especially as I have been privileged to experience many facets of life unknown even to many Canadians. Some of my grandchildren and great-grandchildren live in various parts of Canada, but my days of travel are over.

Frank M. Bateson
Tauranga, New Zealand

[*Editor's Note: Frank M. Bateson has been an honourary member of the RASC since March 1984.*]

MEDICINE WHEELS

Dear Sir:

I read with great interest David A. Rodger's letter in the April 2000 issue (*JRASC*, 94, 44, 2000) responding to my article on medicine wheels. The facts he puts forth do challenge the theory of medicine wheels being active observatories and I, for one, would like to have additional information. Progress is not made by agreement, but by disagreement.

Still, certain points should be made. Prehistoric peoples may not have needed such accuracy. If a hill stood in their way and the Sun rose 30 minutes later than our instruments tell us, it may not have mattered to them. What was important was that it rose in a certain spot.

There is the question of the sunburst stone patterns, such as the one found at the Minton Turtle Medicine Wheel, near what could be a sunrise alignment. Were these arrangements made for a set purpose?

There still remains the question of the shapes of these wheels. Were they accidental or not? The similarity between the medicine wheels and stone circles found in Britain, a point raised by Mr. Rodger, is most interesting. Another question concerns the relationship of the main axis of a Cree sundance lodge and possible sunrise alignments, as well as its similarity to the Roy Rivers medicine wheel.

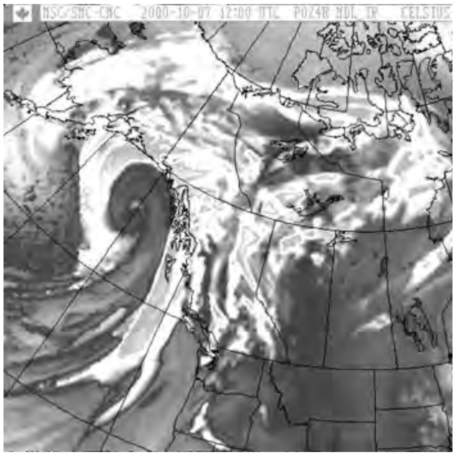
Questions and more questions, all serving to inspire the imagination and push others to seek the answers! These answers may never be found, but seeking them will help to push outward the boundaries of our knowledge concerning prehistoric societies. Mr. Rodger's theories may be correct. The medicine wheels may never have been used as observatories by the Plains Indians; however, until certain questions can be answered, they may have been.

In the meantime, I would be glad to hear from anyone who has information or theories on the subject. I will be writing more articles on prehistoric astronomy in the future and perhaps some of these questions will be answered. Perhaps more questions will be raised. Whatever happens, I am sure there will always be that which cannot be known and that which will always be questioned.

Barbara Silverman
St. Laurent, Québec

News Notes
En Manchettes

WEATHER FORECASTS FOR CANADIAN ASTRONOMERS



A sample cloud forecast image for western Canada from the CMC web site. The original image uses colours to represent the highest and lowest clouds so some information is lost when converted to black and white. Image courtesy of Allan Rahill and CMC.

During a night of deep sky observing or high precision photometry a thin veil of cirrus cloud can often spoil the sky and ruin a night's observing. Yet the weather forecast may have predicted clear skies for that night. For most people the sky would be clear enough, but for astronomers it is a disaster.

For years the public forecast may not have been specific enough to predict this kind of situation. Now, Allan Rahill of the Canadian Meteorological Centre (CMC) in Dorval, Quebec has developed a 48-hour web forecast specifically for astronomers (`www.cmc.ec.gc.ca/cmc/htmls/astro_e.html`). Rahill's product is based on work done by Arne Alfheim, also from CMC. Alfheim used the output from the Canadian regional meteorological forecasting model to produce a simulated satellite image of the cloud cover. The image is fashioned after the 10.70-micron channel from the Geostationary Operational Environmental Satellites (GOES-8 and GOES-10). In these simulated infrared images the higher, and thus colder clouds show up as brighter areas, while darker areas indicate lower and warmer clouds. An animation loop shows the motion of the forecasted cloud deck and helps reveal the movement of low cloud, which can easily be mistaken for terrain, especially in the colder months.

Rahill is not only a meteorologist but is also an avid amateur astronomer with a robotic 0.56 metre Newtonian and 30 years of observing experience, so he knows what astronomers want out of their weather forecasts. Eventually, he would like to include actual transparency and seeing values.

These cloud cover forecasts come with the same caveat as the regular forecasts. Since meteorologists can never obtain perfect knowledge of the current state of the atmosphere, the forecasts can never be 100-percent accurate. The further into the future the forecast looks, the less certain it becomes. Nonetheless, this new product should improve astronomers' chances of finding clear skies.

WHERE ARE EARTH'S TROJANS?

How do you look for asteroids in Trojan orbits with the Earth? Well, for one thing, don't look exactly in the place where you might expect them to be. So writes Dr. Paul Wiegert, of the Department of Physics and Astronomy at York University, and co-workers in a recent article published in the journal *Icarus*.

Trojan asteroids occupy special orbits. Their extraordinary nature stems from the fact that they orbit the Sun at the same distance as one of the planets, but they always remain either 60 degrees ahead of, or behind, a line drawn between the planet and the Sun. Joseph Louis Lagrange first demonstrated the existence of these special orbits, in which the asteroid remains stationary in the reference frame rotating with the planet, in 1772. Indeed, Lagrange was able to show that within the so-called three-body gravitational problem five stable points should exist in the reference frame rotating with the planet. The Trojan orbits correspond to asteroids orbiting the Sun at the Lagrange L4 and L5 points, and they fall at the apexes of two equilateral triangles drawn either side of the planet–Sun line.

The first Trojan object, asteroid 588 Achilles, was discovered in 1906, and it resides at the L4 point of the Jupiter–Sun system. At the latest count, Jupiter has some 466 Trojan companions, and the planet Mars has two. In principle the Earth may have an accompanying troop of Trojan objects, but to date none have been discovered. This may be, as Paul Weigert, Kimmo Innanen and Seppo Mikkola point out in their recent publication, because the best search strategy for finding Earth Trojans is not necessarily the one that simply monitors the region of the sky containing Earth's L4 and L5 points.

Weigert and co-workers highlight two important points in their study. Firstly, asteroids near the L4 and L5 points can, in fact, move on "tadpole-like" orbits, which enables them to temporarily move ahead of and behind the stable positions. This effect alone can widen the sky search area by several tens of degrees on either side of the Lagrange points. In addition, the brightness of an asteroid is not only related to its distance from Earth, but also to its phase angle (the angle subtended between the Earth, the asteroid, and the Sun). By modeling both the brightness effect, and including "tadpole" orbits, Weigert *et al.* find that the best place to look for, and detect, Earth Trojans are not at the L4 and L5 points, but in regions that are displaced some five degrees closer to the Sun.

After examining several hypothetical

populations of Earth Trojan asteroids, Weigert and co-workers conclude that within the limits set by previous surveys, there may well be a whole host of Earth accompanying Trojans, and that some of them could conceivably be as large as several hundred metres.

SOS (SAVING OSHAWA SKIES)

Light pollution has been a growing urban problem for many years. So the occasional victory for the astronomer is all the more sweet, and indeed as recently announced by Michael Cook, of the Toronto Centre, Oshawa City astronomers appear set for an improvement in their nighttime skies.

Acting upon the recommendations of a city review panel, Oshawa city councillors have recently agreed to adopt a new lighting policy. The new policy will specifically ensure that all new and replacement streetlights will be of a full cut-off (FCO) design. These lighting fixtures direct all their light downward with essentially no spillover to the sides and, more importantly for astronomers, above. The city has also agreed to negotiate with commercial and industrial developers to install FCO lighting as part of site plan control (prior to issuing new building permits).

Michael offers some sound advice for other astronomers who might want to approach their city councils about lighting policies. Firstly, he comments, focus on the energy waste and environment protection aspects. Secondly, get as many councillors as you can directly involved with the project, and take them on a tour of the city, demonstrating good and bad lighting. After these first two steps, stick with the process — you will have to contact city staff, write letters, and make phone calls. Finally, you will have to prepare a formal, but succinct, submission for municipal consideration. The municipal clerk will have to be consulted with respect to placing the item on the council agenda. At this stage it would be a good idea to prepare a five to ten minute presentation on the issue of light pollution (and the benefits of using FCO lighting) — you might also be called upon to support the submission when Council eventually hears it. The process takes time, but with a little planning and forethought, even city councils can be won over.

Further details on the light pollution problem can be found in David Crawford's article in *The Observer's Handbook*. The web site of the International Dark-Sky Association can also be consulted at `www.darksky.org`.

MORE TAGISH LAKE METEORITE SURPRISES

The Tagish Lake meteorite is one of a kind. Well, at the very least, it appears to be a new, intermediate type of carbonaceous chondrite. The strange composition of the Tagish Lake meteorite has been the focus of two recent studies, both of which concluded that the meteorite is a misfit with respect to the present classification scheme.

Following its fall on January 18th, fragments of the Tagish Lake meteorite were studied by Dr. Michael Lipschultz and his graduate student Jon Friedrich at Purdue University. Lipschultz and Friedrich performed a detailed study of the meteorite's chemical make-up using a plasma mass spectrometer, and they found that the meteorite was genuinely unique, differing in several important aspects from previously studied carbonaceous chondrites. Since the carbonaceous chondrite meteorites are believed to be among the oldest and least processed meteorites, the new findings indicate that the Tagish Lake meteorite contains material from a previously unsampled region of the solar nebula.

The recent announcements by Lipschultz and Friedrich complement an earlier electron microprobe study of the Tagish Lake meteorite samples by Dr. Michael Zolensky, of NASA Johnson Space Center, and co-workers. Presenting their results at the 63rd Annual Meteoritical Society Meeting at the Fields Museum of Natural History (held at the University of Chicago this past August) Zolensky and co-workers commented that the meteorite was clearly "something new." The Zolensky study specifically notes that while the Tagish Lake meteorite has characteristics similar to those of the two known carbonaceous chondrite classes, the so-called CM and CI classes, it also indicates signs of extensive aqueous alteration, sulfidation, and oxidation.

Further details and developments concerning the Tagish Lake meteorite may be found at a dedicated web page located at `phobos.astro.uwo.ca/~pbrown/tagish/`.

PRAIRIE METEORITE SEARCH – TWO UP!

Wilfred Kunz and son Wayne display the new Saskatchewan meteorite find. The 3-kg chondritic (stony) meteorite was found this past May at Delaine Lake, near Annaheim. It is quite likely that companion meteorites will reside in the surrounding area.

Saskatchewan and Alberta are now tied as Canada's leading provinces for meteorite finds. The discovery of the 14th Saskatchewan meteorite was recently announced by the project leaders of the Prairie Meteorite Search, making it the second Saskatchewan find of the summer and the 55th Canadian meteorite to be identified.

The new meteorite was actually collected this past May by Wilfred Kunz of Humbolt, Saskatchewan, while picking rocks on his son's farmstead. "I noticed when I picked it up that it was different — rusty and heavy with pockets on its surface — though I didn't think it was a meteorite at the time," commented Kunz. That the "odd rock" was, in fact, a meteorite became clear this August after Andrew Bird, a third-year geology student at the

University of Calgary, hosted a Prairie Meteorite Search "Show and Tell" session at Watson Museum. Kunz took his newly-found rock along to the Museum and showed it to Bird, who commented that he "immediately suspected that the rock was a meteorite." Dr. Alan Hildebrand, of the University of Calgary, further commented that the 'rock' had "the characteristic texture of a weathered meteorite," and that the meteorite probably fell several thousand years ago.

The new meteorite was found near Delaine Lake in Central Saskatchewan, not far, in fact, from the town of Annaheim, where an iron meteorite was found in 1914. That two totally different meteorite finds have been made at locations just 14.5 kilometres apart is a nice indicator of just how thickly these extraterrestrial rocks lie upon the prairies.

More details on the Prairie Meteorite Search can be found at its home page: `www.geo.ucalgary.ca/PMSearch/`.

The Space Surveillance Research and Analysis Laboratory

by Michael A. Earl (earl-m@rmc.ca)

INTRODUCTION

The Space Surveillance Research and Analysis Laboratory (SSRAL) at the Royal Military College (RMC) was founded in 1996 to establish an optical sensor to be used specifically for high altitude satellite tracking. The laboratory began its research into tracking Russian communications satellites in the summer of 1997 in order to study their unique orbits. This work spawned other research into the dynamics of satellites, such as determining satellite tumbling periods and predicting orbit decay.

The history of the SSRAL is a short but very interesting one. When the laboratory began, it had virtually no equipment with which to track satellites. As the laboratory grew, it acquired technologies that greatly increased its data output and data precision. Today, SSRAL has nearly completed the construction of its automatic satellite tracking facility, called The Canadian Automated Small Telescope for Orbital Research (CASTOR).

This is a brief description of the past, present, and future of the SSRAL as viewed through the eyes of its senior technician, who has worked at the lab from May 1997 to the present time.

HISTORY

When I began working for the SSRAL, I did not know anything about satellite tracking except that artificial satellites orbited the Earth and that I could see some of them crossing the sky at night. I was, however, a 20-year veteran, so to speak, of observational backyard astronomy. In May 1997, the SSRAL had not yet assembled its office furniture, which lay in boxes in one corner of the lab. It owned no telescopes with which to track satellites. The only thing it did have was four Sun workstations with satellite orbit analysis software. My job was to learn how to use this software to analyze data collected by the University of Victoria (UVic). The goal at that time was to determine the orbital characteristics of specific satellites.

A typical Molniya satellite consists of a cylinder of 1.6-metre diameter and 3.4 metre length surrounded by six 5-metre solar arrays. Its total mass is 1600 kg. There are currently 73 of these satellites in orbit. Fewer than 25 percent of the orbiting Molniya satellites are still operational.

Very little data were actually collected at UVic before the satellite-tracking project there ran out of funding and closed down. The SSRAL was then left in a quandary. The SSRAL still had no equipment to perform the data collection, but my own 8-inch reflecting telescope was available. I decided to attempt to see a Molniya satellite from the roof of the Sawyer building at RMC using my own equipment.

Molniya satellites are Russian communications satellites first launched by the Soviet Union in 1965 to provide television, telephone, and telegraph services for much of the Russian sub-continent. Molniya satellites' orbits are inclined at 63 degrees to the equatorial plane (the plane defined by the Earth's equator). Their orbits are also highly eccentric. As a result, the difference between the apogee (furthest distance from Earth) and perigee (closest distance to Earth) of the satellites is substantial. At apogee the satellites can reach an altitude (the height above the Earth's surface) of about 40,000 km while at perigee the altitude is a mere 400 km. The high eccentricity of the orbits ensures that the satellites are well placed over Russia for a large portion of their orbits. They generally stay over the Northern Hemisphere for about 10 hours of their 12-hour total orbital period. Since the Molniya satellites orbit twice every 24 hours, this means that at every second orbit each satellite is over North America and not Russia. For those readers who are wondering, some of the Molniya satellites were indeed used as spy satellites during the Cold War.

Molniya satellites have three distinct designations. The first series is named Molniya 1-1, 1-2, etc, in order of launch. The most recent of these has been Molniya

The orbit of a typical Molniya satellite. The high altitude at apogee ensures a long observing opportunity for satellite trackers in the Northern Hemisphere.

1-91 which was launched September 28, 1998. This series is primarily for government and military use.

The second series of Molniya satellites is named Molniya 2-1, 2-2, etc. This series was originally used for emergency communications between the U.S. and the Soviet Union (the Hotline if you will). The last of these satellites (Molniya 2-17) was launched in February 1977, and this series is no longer used. Only five of the original 17 launched (2-9, 2-10, 2-13, 2-14, and 2-17) are still orbiting Earth. The rest have since fallen back to Earth.

The third and final series is named Molniya 3-1, 3-2, *etc*. These satellites are used for private companies (mainly television and telephone). The most recent of these satellites (Molniya 3-50) was launched on July 8, 1999.

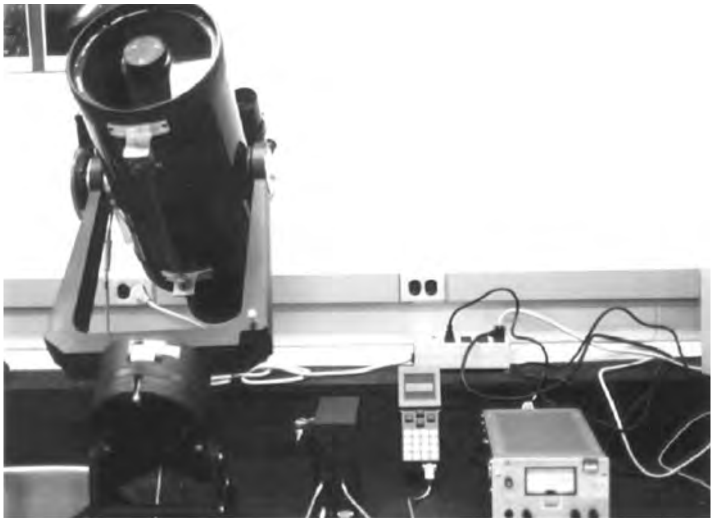
In order for me to predict where a specific Molniya satellite would be, it was necessary to use the satellite orbit analysis software that SSRAL had at the time. It could generate an ephemeris (a list of times and coordinates to find a specific object) for an observer's location, but it used only the alt-azimuth coordinate system (most common for Dobsonian telescopes). The 8-inch aperture telescope that I was using had a fork mount that used equatorial coordinates, that is Right Ascension (RA) and Declination (Dec). I wrote a program to do a coordinate conversion from alt-azimuth to equatorial coordinates, and made predictions for a few Molniya satellites. On June 15, 1997, I successfully detected the satellite Molniya 3-37 passing through my telescopic field of view. The satellite was about 17,000 km from RMC at the time. Its brightness was about 9th magnitude (about the brightness of the planet Neptune). I detected the satellite again five minutes later to make sure I had indeed seen the right object. The Molniya satellite cannot be confused with an airplane because Molniya satellites are so much further away, so they appear to move much slower across the sky. My most memorable sighting of a Molniya satellite was Molniya 1-75 on July 31, 1997. When I first glimpsed this object, it appeared to be flashing brightly once every minute. The satellite was actually tumbling, and the bright flashes resulted from the reflection of sunlight off its solar panels. The brightness of the flashes was estimated to be 6th magnitude (about the brightness of the planet Uranus). Because of the brightness, the color of the satellite could be seen as a brilliant yellow-gold. This satellite was about 40,000 km from RMC at the time and could be seen only when the flashes occurred. The light intensity when it was not flashing was fainter than 13th magnitude (about the brightness of the planet Pluto) since it disappeared from detection by eye in an 8-inch telescope. A peculiar aspect of the sighting of this object was that it had entered the field of view a full 1 ½ minutes before the predicted time. The next day SSRAL investigated this and discovered that the orbital elements for that particular satellite had not been updated since May 1997, a full two months earlier. (The orbital elements for a satellite are not constant, since forces such as the Moon's gravity, the solar wind, and atmospheric drag (friction) change these elements daily.) Normally the orbital elements are updated every day or two. In effect, the satellite had been lost for approximately two months. SSRAL immediately contacted the U.S. Space Command at Cheyenne Mountain, Colorado to report its sightings, and the orbital elements for Molniya 1-75 were updated the following day. The SSRAL had made a contribution by finding a lost satellite with borrowed equipment.

This is one of the first photographs of a Molniya satellite taken at the Royal Military College. Molniya 1-75 appeared to have a flash period of about one minute. The small streaks made by the satellite as it was orbiting the Earth are circled. This photo was taken at about 06:30 UT on August 6, 1997. The telescope used was a Criterion 8-inch Schmidt-Cassegrain reflecting telescope with a 35mm camera mounted at prime focus. The exposure time was 5 minutes with Fuji 1600 ISO film. The field of view is 38 by 57 arcminutes.

The next step was to obtain actual images of a Molniya satellite in orbit. I set up my 8-inch reflector and mounted my 35mm camera at the telescope's prime focus. My target was Molniya 1-75, the satellite that exhibited bright flashes. I had never taken an image of a satellite before, at least not intentionally, so I decided to use a fast (1600 ISO) film to improve my chance of capturing an image of the satellite. On August 6, 1997, SSRAL obtained its first film images of the Molniya 1-75 satellite. The flashing satellite was easily seen within the test image.

On August 19, 1997, Mr. Phil Somers (one of the founders of the SSRAL) and I set up two telescopes on the roof of the Sawyer building for an all-night visual satellite tracking session of the satellite Molniya 1-75. This satellite had been exhibiting 6th magnitude flashes since it was found by SSRAL. The aim was to gather accurate data on the satellite's position. Star maps of the predicted positions of the satellite at specific times were created. Whenever the satellite was observed to flash, its position was drawn on the appropriate star map, and the time was recorded. This was done every five minutes for the entire night. Nearly 100 observations of the satellite were made during this night.

While these observations were being carried out, the satellite's flashing became unusual. Instead of flashing brightly once every minute, every alternate flash was growing dimmer as the night progressed. At the end of the observing session only every alternate flash was visible. What this told us was that Molniya 1-75 had not been tumbling once every minute as we had believed, but every two minutes since we were seeing two different sides of the satellite.



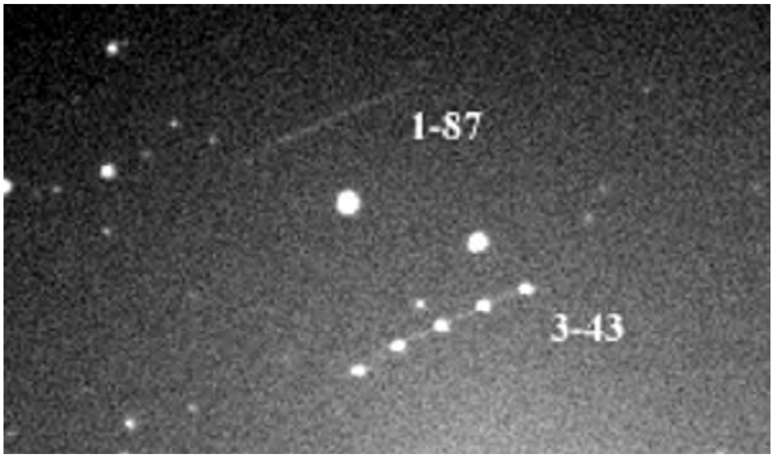
The Meade 10-inch Schmidt-Cassegrain reflecting telescope is seen with the equipment used to control it. This was the primary satellite tracking system used by SSRAL until its more advanced system went online on January 29, 2000.

The data were used to update the orbital elements of the satellite in order to find it again. On September 4, 1997, film images of Molniya 1-75 were collected. From 03:54 to 05:02 UT I obtained twelve photos of the satellite and analyzed these images using my own astrometry software. The data collected were used to update the orbital elements of the satellite.

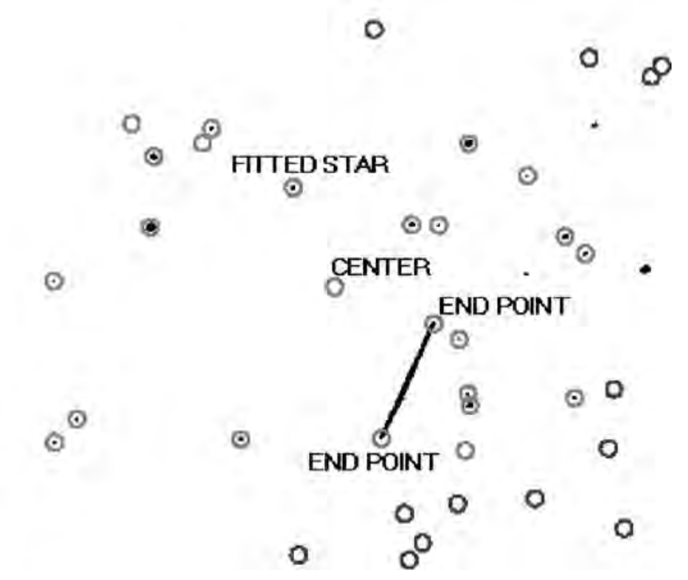
It was obvious to us that analyzing film images of the satellite streaks was an impractical exercise and that a more efficient means of imaging was needed. In January 1998, SSRAL had learned of a Meade 10-inch reflecting telescope and an SBIG ST-6 CCD (Charge Coupled Device) digital camera that were not being used. SSRAL decided to acquire this equipment from the Astronomy Lab at RMC to begin tracking Molniya satellites using CCD technology. Unlike my telescope, the Meade 10-inch was stepper-motor driven and could be controlled via a telescope controller assembly. The 10-inch Meade also had 1.6 times the light-gathering capability of my 8-inch telescope. This meant that dimmer objects (such as satellites with higher ranges) could be detected. There were many advantages to using a CCD camera instead of film. The major one was its superior sensitivity. Another advantage over film was that CCD images did not cost money to develop.

The first SSRAL satellite tracking apparatus that employed a CCD camera was used for the first time on February 6, 1998 to track the satellite Molniya 3-10. By coincidence, that satellite also exhibited bright flashes. More practical CCD images of another Molniya satellite (1-75) were taken three days later. A total of 24 images of the satellite were acquired for analysis. During that tracking run, the satellite's range had decreased from 38,000 km to 13,500 km as the satellite headed for its perigee. After the initial CCD success with Molniya 1-75, SSRAL began an analysis of how sensitive the CCD camera was by examining other Molniya satellites over many viewing conditions. During that analysis, SSRAL obtained many images of those Molniya satellites that exhibited flashes with periods much smaller than that of Molniya 1-75. SSRAL began doing a tumble analysis of every Molniya satellite it found that exhibited flashes. The most notable at that time was Molniya 3-43. This satellite had been accidentally imaged by SSRAL during routine tracking of the Molniya 1-87 satellite. On April 12, 1998 an all-night tracking session of the satellite was undertaken to provide the data for the most accurate tumble analysis of that satellite to date. A total of 159 images of the satellite were gathered during that night, yielding a total of 450 individual flashes. Using the data collected from the images, the tumble period for Molniya 3-43 was found to be about 4.5 seconds.

Tumbling satellites exhibit varied light curves since different sides of the satellite are being illuminated as it tumbles. This could confuse the observer into believing that the satellite is tumbling at a faster rate than it actually is. To date, fourteen other Molniya satellites have been found to flash and therefore could have their tumble periods determined.



Molniya 1-87 was being tracked on March 17, 1998 when another satellite appeared in the field of view. Later analysis confirmed this object as Molniya 3-43. It is extremely rare that two Molniya satellites are seen in the same 11 by 14 arcminute field of view. Molniya 3-43 is the most analyzed satellite as far as tumble period is concerned because of its easily seen flashes and small flash time. This was a 20-second exposure using the Meade 10-inch reflector and SBIG ST-6 CCD camera at prime focus.



Until January 2000 the Image Reduction and Analysis Facility (IRAF) was used by SSRAL to perform the necessary astrometry to determine the coordinates of the centre of the image and the satellite streak end-points. The accuracy of the determined coordinates was within 2 arcseconds.

The tumble periods range from as low as 3.5 seconds (for Molniya 3-39) to over 2 minutes (for Molniya 1-75).

When analyzing an image, the SSRAL took a specific approach. First, the image was examined to make sure there was a satellite streak to analyze. If the image contained a satellite streak, the image was then loaded into the software package Image Reduction and Analysis Facility (IRAF). IRAF determined the coordinates of each end-point of the streak (called astrometry). Any object that was not a satellite (such as a faint galaxy, asteroid, nebula, *etc.*) had astrometry performed on it as well. The Right Ascension and Declination coordinates of the centre of the image were also determined in order to construct an index of images taken of the sky. This index contains the coordinates of the center of the image, the year, month, date and time of the exposure, and the name of the satellite(s) within the image. The image itself is stored in the SSRAL image archive. This process generally took 3 minutes per image if only a satellite streak was being analyzed. The maximum time was about 10 minutes per image. The data extracted from the images were used to update the orbital elements of the satellite. Molniya satellites were tracked regularly throughout 1998. At the beginning of 1999, the SSRAL began to upgrade its facility with remote control and automation in mind.

The present: Canadian Automated Small Telescope for Orbital Research (CASTOR)

Before January 1999, the SSRAL had a skeleton satellite tracking facility in the sense that it had the means to track satellites, but it did so impractically. Steps were taken to upgrade the existing system during 1999. These steps included acquiring a more sensitive CCD camera, a larger aperture telescope, and astronomical software that allowed telescope automation.

SSRAL obtained new astronomical software called TheSky, manufactured by Software Bisque. This software provided a virtual display of the objects in the sky over RMC, including Molniya satellites. It could also be used to control the Meade 10-inch telescope. Instead of typing the equatorial coordinates of the object you wanted the telescope to slew to, all that was needed was a point and click onto the object and then another click onto the “slew” command.

The trick was getting the software to communicate with the telescope controller. After one week’s worth of work, I finally succeeded. An image of a satellite could be taken every two to three minutes, instead of every three to five minutes, which was previously required. The bulk of the time was the download time of the ST-6 CCD camera (1.5 minutes).

SSRAL received a new Celestron 14-inch Schmidt-Cassegrain optical tube assembly in December 1998 and the Apogee model AP-7 CCD camera in May 1999. The new CCD camera could be used right away since it could be attached to the Meade 10-inch telescope without difficulty. The new CCD camera had many advantages over the older ST-6. One advantage was that the Apogee CCD chip was larger (512 by 512 pixels). Another advantage was that the Apogee AP-7 camera had a maximum of 85% quantum efficiency over the wavelength region from 600 nm to 800 nm. A final advantage was that the download time was just 10 seconds which was $^1/_9$ the download time

The Celestron 14-inch Schmidt-Cassegrain reflecting telescope and the Software Bisque Paramount GT-1100 robotic mount are thoroughly tested in the SSRAL lab before being sent to the new observatory dome for preliminary night viewing trials. The Apogee AP-7 CCD camera is shown at the prime focus of the telescope.

for the SBIG ST-6 CCD.

The SBIG ST-6 CCD camera was officially retired on May 13, 1999 when the Apogee camera took its first images of the satellite Molniya 3-14. At that time this satellite was undergoing slow orbital decay. SSRAL did get an image of the satellite, but the satellite appeared in the field of view of the camera a full minute after the predicted time. This was expected since satellites that are decaying in their orbits have rapidly changing orbital elements. This is mainly due to the increased atmospheric drag as the satellite gets nearer the Earth. The period of the orbit decreases steadily as the decay progresses.

A new name was needed for the still unfinished satellite tracking facility. The name had to suggest a Canadian identity in the space surveillance realm. I had drawn up several acronyms, but CASTOR seemed to be the best overall. CASTOR made an excellent acronym (Canadian Automated Small Telescope for Orbital Research), and it is French for beaver, a Canadian symbol. Since the name is French, it also encompasses this bilingual nation. Castor is also a star in Gemini (Alpha Geminorum) and therefore suggests the astronomical nature of the facility.


The senior technician of the SSRAL looks out from the shutter of the CASTOR observatory. The telescopes encircling the dome are some of the many reflecting telescopes that RMC has in its possession for general purpose work such as open houses and undergraduate astronomy labs.

The summer and fall of 1999 was a busy time for the SSRAL and me especially because of the acquisition and testing of new equipment. The observatory dome that would eventually house the new CASTOR facility had to be assembled and tested. The GT-1100 robotic mount and the Apogee AP-7 CCD camera had to be tested in the lab before they could be used for serious satellite tracking.

The construction of the 10.5-foot diameter observatory dome to house the CASTOR components was planned thoroughly. Mr. Orest Koroluk and Mr. Steve Lockridge, both of RMC, planned and carried out the dome's construction. Thanks to their expertise the dome was built by October 1999. The telescope, robotic mount, and CCD camera were all brought up to the newly constructed dome in November 1999. Following preliminary alignments, such as proper balancing and polar alignment of the robotic mount, and power installation, on December 8, 1999 the CASTOR saw first light when Polaris was viewed through a 26mm focal length eyepiece. A preliminary polar alignment was performed using Polaris so that the telescope could be used on other objects. The satellite Molniya 1-32 was viewed through the eyepiece in order to test the tracking efficiency of the mount. The colour of the satellite was easily detected as a golden yellow, which is the colour of the solar panels. The computer link to the robotic mount was tested that night by writing a script to tell the robotic mount to follow the satellite. The Software Bisque scripting software called Orchestrate allows the user to automate many processes including the pointing of the scope itself. One night later, on December 9, 1999, images of Saturn were taken with a 35mm camera attached to the prime focus of the 14-inch telescope.

The first CASTOR image of a Molniya satellite (Molniya 1-75) was obtained at 04:00 UT on December 10, 1999. The CCD camera did not yet have a cable long enough to reach the lab from the observatory so the controlling computer had to be brought up to the dome in order to obtain CCD images. Today, the CASTOR facility can be totally controlled from within the lab itself. The facility will be automated as soon as automatic dome control hardware is installed near the end of 2000. Regular satellite tracking runs are made whenever clear skies present themselves. Even in its present state the CASTOR facility has already been used for graduate thesis projects and provides accurate satellite tracking data for data analysis in both Canada and the U.S. At present the timing accuracy of the CCD camera is 1 millisecond. Plans are being made to better this accuracy to 0.1 millisecond. The present accuracy of the astrometry performed on images is about 2 arcseconds.

Since there are many satellites to track in a given night, it is necessary to find some way of automating the scheduling process as well. Scheduling involves finding those satellites that are accessible to the facility at a specific time and creating a schedule to optimize tracking them. Obvious factors for a satellite schedule are the apparent angular velocity of the satellite, the brightness (phase) of the satellite, and the elevation of the satellite above the horizon at different times. I have developed satellite-scheduling software that reads the ephemeris files generated by our satellite orbit analysis software. The scheduler automatically chooses the exposure time for the satellite based on its range from the facility and its elevation above the horizon (for sight obliquity). This scheduler has been thoroughly tested, and it is now ready to be integrated into the CASTOR system for future automation.

The CASTOR project is currently in its research and development stage and the first CASTOR facility in Kingston (CASTOR K) should be automated by the summer of 2001.

The Future

The CASTOR K facility at RMC in Kingston will be the first of three CASTOR facilities located in Canada. The second CASTOR facility (CASTOR S) will be located at the Defense Research Establishment Suffield (DRES) in southern Alberta. The third CASTOR facility (CASTOR V) has been proposed for the Defense Research Establishment Valcartier (DREV) in southern Quebec. The purpose of having three facilities is twofold. First, the weather is a major concern for optical telescopes. The probability of overcast skies at all three facilities is smaller than that at one single facility. Second, satellite tracking data obtained from more than one facility is better than those obtained from a single one, because data from two or more facilities can be used for parallax determinations of the satellite's range. As a result, not only angle data are obtained from the facilities, but range data as well. This improves the orbital determination accuracy and therefore will provide a better ephemeris for finding the satellite at a later time.

These three facilities will be linked via a secure network to a single command centre located at the SSRAL. After this link is established, the three facilities will be used remotely from the command centre. Weather sensors at each site will provide a synopsis of the respective facility's sky conditions in real-time. ◉

Michael Earl is currently a senior technician at the Space Surveillance Research and Analysis Laboratory at the Royal Military College, Kingston, Ontario. For the past three years, he has been responsible for the design and testing of various satellite tracking facilities, including the Canadian Automated Small Telescope for Orbital Research.

Astronomy at RMC

The Royal Military College of Canada has in its possession many astronomical telescopes for general purpose uses such as open houses and undergraduate projects. The Department of Physics at RMC currently owns ten 5-inch reflecting telescopes, two 8-inch Celestron telescopes, and the 10-inch Meade Quartz telescope that was originally used by the SSRAL for tracking satellites.

Plans are being made for at least three open houses to be held every summer. These open houses are generally for the staff at RMC as well as RASC members. RMC also offers undergraduate and graduate degrees in Space Science. See the RMC web site for more details: `www.rmc.ca`.

RASC INTERNET RESOURCES

Visit the RASC Website
`www.rasc.ca`

Contact the National Office
`rasc@rasc.ca`

Join the RASC's E-mail Discussion List

The RASCals 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 265 members.

To join the list, send an e-mail 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`

Illustration by Brian G Segal

HOW THE SUN SHINES*

by John N. Bahcall

What makes the sun shine? How does the sun produce the vast amount of energy necessary to support life on earth? These questions challenged scientists for a hundred and fifty years, beginning in the middle of the nineteenth century. Theoretical physicists battled geologists and evolutionary biologists in a heated controversy over who had the correct answer.

Why was there so much fuss about this scientific puzzle? The nineteenth-century astronomer John Herschel described eloquently the fundamental role of sunshine in all of human life in his 1833 *Treatise on Astronomy*:

> The sun's rays are the ultimate source of almost every motion which takes place on the surface of the earth. By its heat are produced all winds, ... By their vivifying action vegetables are elaborated from inorganic matter, and become, in their turn, the support of animals and of man, and the sources of those great deposits of dynamical efficiency which are laid up for human use in our coal strata.

Sunshine makes life possible on earth.

In this essay, we shall review from an historical perspective the development of our understanding of how the sun (the nearest star) shines, beginning in the following section with the nineteenth-century controversy over the age of the sun. In later sections, we shall see how seemingly unrelated discoveries in fundamental physics led to a theory of nuclear energy generation in stars that resolved the controversy over the age of the sun and explained the origin of solar radiation. In the section just before the summary, we shall discuss how experiments that were designed to test the theory of nuclear energy generation in stars revealed a new mystery, the Mystery of the Missing Neutrinos.

I. The Age of the Sun

How old is the sun? How does the sun shine? These questions are two sides of the same coin, as we shall see.

The rate at which the sun is radiating energy is easily computed by using the measured rate at which energy reaches the earth's surface and the distance between the earth and the sun. The total energy that the sun has radiated away over its lifetime is approximately the product of the current rate at which energy is being emitted, which is called the solar luminosity, times the age of the sun.

The older the sun is, the greater the total amount of radiated solar energy. The greater the radiated energy, or the larger the age of the sun, the more difficult it is to find an explanation of the source of solar energy.

To better appreciate how difficult it is to find an explanation, let us consider a specific illustration of the enormous rate at which the sun radiates energy. Suppose we put a cubic centimeter of ice outside on a summer day in such a way that all of the sunshine is absorbed by the ice. Even at the great distance between the earth and the sun, sunshine will melt the ice cube in about 40 minutes. Since this would happen anywhere in space at the earth's distance from the sun, a huge spherical shell of ice centered on the sun and 300 million km (200 million miles)

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in diameter would be melted at the same time. Or, shrinking the same amount of ice down to the surface of the sun, we can calculate that an area ten thousand times the area of the earth's surface and about half a kilometer (0.3 mile) thick would also be melted in 40 minutes by the energy pouring out of the sun.

In this section, we shall discuss how nineteenth-century scientists tried to determine the source of solar energy, using the solar age as a clue.

A. Conflicting Estimates of the Solar Age

The energy source for solar radiation was believed by nineteenth-century physicists to be gravitation. In an influential lecture in 1854, Hermann von Helmholtz, a German professor of physiology who became a distinguished researcher and physics professor, proposed that the origin of the sun's enormous radiated energy is the gravitational contraction of a large mass. Somewhat earlier, in the 1840's, J. R. Mayer (another German physician) and J. J. Waterson had also suggested that the origin of solar radiation is the conversion of gravitational energy into heat.[1]

Biologists and geologists considered the effects of solar radiation, while physicists concentrated on the origin of the radiated energy. In 1859, Charles Darwin, in the first edition of *On The Origin of the Species by Means of Natural Selection*, made a crude calculation of the age of the earth by estimating how long it would take erosion occurring at the current observed rate to wash away the Weald, a great valley that stretches between the North and South Downs across the south of England. He obtained a number for the "denudation of the Weald" in the range of 300 million years, apparently long enough for natural selection to have produced the astounding range of species that exist on earth.

As Herschel stressed, the sun's heat is responsible for life and for most geological evolution on earth. Hence, Darwin's estimate of a minimum age for geological activity on the earth implied a minimum estimate for the amount of energy that the sun has radiated.

Firmly opposed to Darwinian natural selection, William Thompson, later Lord Kelvin, was a professor at the University of Glasgow and one of the great physicists of the nineteenth century. In addition to his many contributions to applied science and to engineering, Thompson formulated the second law of thermodynamics and set up the absolute temperature scale, which was subsequently named the Kelvin scale in his honour. The second law of thermodynamics states that heat naturally flows from a hotter to a colder body, not the opposite. Thompson therefore realized that the sun and the earth must get colder unless there is an external energy source and that eventually the earth will become too cold to support life.

Kelvin, like Helmholtz, was convinced that the sun's luminosity was produced by the conversion of gravitational energy into heat. In an early (1854) version of this idea, Kelvin suggested that the sun's heat might be produced continually by the impact of meteors falling onto its surface. Kelvin was forced by astronomical evidence to modify his hypothesis and he then argued that the primary source of the energy available to the sun was the gravitational energy of the primordial meteors from which it was formed.

Thus, with great authority and eloquence Lord Kelvin declared in 1862:

> That some form of the meteoric theory is certainly the true and complete explanation of solar heat can scarcely be doubted, when the following reasons are considered: (1) No other natural explanation, except by chemical action, can be conceived. (2) The chemical theory is quite insufficient, because the most energetic chemical action we know, taking place between substances amounting to the whole sun's mass, would only generate about 3,000 years' heat. (3) There is no difficulty in accounting for 20,000,000 years' heat by the meteoric theory.

Kelvin continued by attacking Darwin's estimate directly, asking rhetorically:

> What then are we to think of such geological estimates as [Darwin's] 300,000,000 years for the "denudation of the Weald"?

Believing Darwin was wrong in his estimate of the age of the earth, Kelvin also believed that Darwin was wrong about the time available for natural selection to operate.

Lord Kelvin estimated the lifetime of the sun, and by implication the earth, as follows. He calculated the gravitational energy of an object with a mass equal to the sun's mass and a radius equal to the sun's radius and divided the result by the rate at which the sun radiates away energy. This calculation yielded a lifetime of only 30 million years. The corresponding estimate for the lifetime sustainable by chemical energy was much smaller because chemical processes release very little energy.

B. Who was Right?

As we have just seen, in the nineteenth century you could get very different estimates for the age of the sun, depending upon whom you asked. Prominent theoretical physicists argued, based upon the sources of energy that were known at that time, that the sun was at most a few tens of millions years old. Many geologists and biologists concluded that

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[1] von Helmholtz and Mayer were two of the codiscoverers of the law of conservation of energy. This law states that energy can be transformed from one form to another but the total amount is always conserved. Conservation of energy is a basic principle of modern physics that is used in analyzing the very smallest (sub-atomic) domains and the largest known structure (the universe) and just about everything in between. We shall see later that Einstein's generalization of the law of conservation of energy was a key ingredient in understanding the origin of solar radiation. The application of conservation of energy to radioactivity revealed the existence of neutrinos.

the sun must have been shining for at least several hundreds of millions of years in order to account for geological changes and the evolution of living things, both of which depend critically upon energy from the sun. Thus the age of the sun, and the origin of solar energy, were important questions not only for physics and astronomy, but also for geology and biology.

Darwin was so shaken by the power of Kelvin's analysis and by the authority of his theoretical expertise that in the last editions of *On The Origin of Species* he eliminated all mention of specific time scales. He wrote in 1869 to Alfred Russel Wallace, the codiscoverer of natural selection, complaining about Lord Kelvin:

> Thompson's views on the recent age of the world have been for some time one of my sorest troubles.

Today we know that Lord Kelvin was wrong and the geologists and evolutionary biologists were right. Radioactive dating of meteorites shows that the sun is 4.6 billion years old.

What was wrong with Kelvin's analysis? An analogy may help. Suppose a friend observed you using your computer and tried to figure out how long the computer had been operating. A plausible estimate might be no more than a few hours, since that is the maximum length of time over which a battery could supply the required amount of power. The flaw in this analysis is the assumption that your computer is necessarily powered by a battery. The estimate of a few hours could be wrong if your computer were operated from an electrical power outlet in the wall. The assumption that a battery supplies the power for your computer is analogous to Lord Kelvin's assumption that gravitational energy powers the sun.

Since nineteenth century theoretical physicists did not know about the possibility of transforming nuclear mass into energy, they calculated a maximum age for the sun that was too short. Nevertheless, Kelvin and his colleagues made a lasting contribution to the sciences of astronomy, geology, and biology by insisting on the principle that valid inferences in all fields of research must be consistent with the fundamental laws of physics.

We will now discuss some of the landmark developments in the understanding of how nuclear mass is used as the fuel for stars.

II. A Glimpse of the Solution

The turning point in the battle between theoretical physicists and empirical geologists and biologists occurred in 1896. In the course of an experiment designed to study x-rays, discovered the previous year by Wilhelm Röntgen, Henri Becquerel stored some uranium-covered plates in a desk drawer next to photographic plates wrapped in dark paper. Because it was cloudy in Paris for a couple of days, Becquerel was not able to "energize" his photographic plates by exposing them to sunlight as he had intended. On developing the photographic plates, he found to his surprise strong images of his uranium crystals. He had discovered natural radioactivity, due to nuclear transformations of uranium.

The significance of Becquerel's discovery became apparent in 1903, when Pierre Curie and his young assistant, Albert Laborde, announced that radium salts constantly release heat. The most extraordinary aspect of this new discovery was that radium radiated heat without cooling down to the temperature of its surroundings. The radiation from radium revealed a previously unknown source of energy. William Wilson and George Darwin almost immediately proposed that radioactivity might be the source of the sun's radiated energy.

The young prince of experimental physics, Ernest Rutherford, then a professor of physics at McGill University in Montreal, discovered the enormous energy released by alpha particle radiation from radioactive substances. In 1904, he announced:

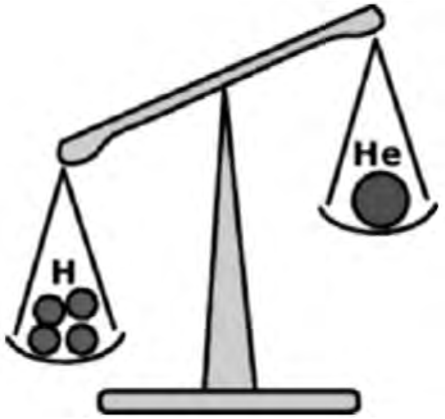
> The discovery of the radio-active elements, which in their disintegration liberate enormous amounts of energy, thus increases the possible limit of the duration of life on this planet, and allows the time claimed by the geologist and biologist for the process of evolution.

The discovery of radioactivity opened up the possibility that nuclear energy might be the origin of solar radiation. This development freed theorists from relying in their calculations on gravitational energy. However, subsequent astronomical observations showed that the sun does not contain a lot of radioactive materials, but instead is mostly hydrogen in gaseous form. Moreover, the rate at which radioactivity delivers energy does not depend on the stellar temperature, while observations of stars suggested that the amount of energy radiated by a star does depend sensitively upon the star's interior temperature. Something other than radioactivity is required to release nuclear energy within a star.

In the next sections, we shall trace the steps that led to what we now believe is the correct understanding of how stars shine.

III. The Direction Established

The next fundamental advance came once again from an unexpected direction. In 1905, Albert Einstein derived his famous



Aston showed in 1920 that four hydrogen nuclei are heavier than a helium nucleus.

relation between mass and energy, $E = mc^2$, as a consequence of the special theory of relativity. Einstein's equation showed that a tiny amount of mass could, in principle, be converted into a tremendous amount of energy. His relation generalized and extended the nineteenth century law of conservation of energy of von Helmholtz and Mayer to include the conversion of mass into energy.

What was the connection between Einstein's equation and the energy source of the sun? The answer was not obvious. Astronomers did their part by defining the constraints that observations of stars imposed on possible explanations of stellar energy generation. In 1919, Henry Norris Russell, the leading theoretical astronomer in the United States, summarized in a concise form the astronomical hints on the nature of the stellar energy source. Russell stressed that the most important clue was the high temperature in the interiors of stars.

F. W. Aston discovered in 1920 the key experimental element in the puzzle. He made precise measurements of the masses of many different atoms, among them hydrogen and helium. Aston found that four hydrogen nuclei were heavier than a helium nucleus. This was not the principal goal of the experiments he performed, which were motivated in large part by looking for isotopes of neon.

The importance of Aston's measurements was immediately recognized by Sir Arthur Eddington, the brilliant English astrophysicist. Eddington argued in his 1920 presidential address to the British Association for the Advancement of Science that Aston's measurement of the mass difference between hydrogen and helium meant that the sun could shine by converting hydrogen atoms to helium. This burning of hydrogen into helium would (according to Einstein's relation between mass and energy) release about 0.7% of the mass equivalent of the energy. In principle, this could allow the sun to shine for about a 100 billion years.

In a frighteningly prescient insight, Eddington went on to remark about the connection between stellar energy generation and the future of humanity:

> If, indeed, the sub-atomic energy in the stars is being freely used to maintain their great furnaces, it seems to bring a little nearer to fulfillment our dream of controlling this latent power for the well-being of the human race — or for its suicide.

IV. Understanding the Process

The next major step in understanding how stars produce energy from nuclear burning resulted from applying quantum mechanics to the explanation of nuclear radioactivity. This application was made without any reference to what happens in stars. According to classical physics, two particles with the same sign of electrical charge will repel each other, as if they were repulsed by a mutual recognition of "bad breath." Classically, the probability that two positively charged particles get very close together is zero. But some things that cannot happen in classical physics can occur in the real world which is described on a microscopic scale by quantum mechanics.

In 1928, George Gamow, the great Russian-American theoretical physicist, derived a quantum-mechanical formula that gave a non-zero probability of two charged particles overcoming their mutual electrostatic repulsion and coming very close together. This quantum mechanical probability is now universally known as the "Gamow factor." It is widely used to explain the measured rates of certain radioactive decays.

In the decade that followed Gamow's epochal work, Atkinson and Houtermans and later Gamow and Teller used the Gamow factor to derive the rate at which nuclear reactions would proceed at the high temperatures believed to exist in the interiors of stars. The Gamow factor was needed in order to estimate how often two nuclei with the same sign of electrical charge would get close enough together to fuse and thereby generate energy according to Einstein's relation between excess mass and energy release.

In 1938, C. F. von Weizsäcker came close to solving the problem of how some stars shine. He discovered a nuclear cycle, now known as the carbon-nitrogen-oxygen (CNO) cycle, in which hydrogen nuclei could be burned using carbon as a catalyst. However, von Weizsäcker did not investigate the rate at which energy would be produced in a star by the CNO cycle, nor did he study the crucial dependence upon stellar temperature.

By April 1938, it was almost as if the scientific stage had been intentionally set for the entry of Hans Bethe, the acknowledged master of nuclear physics. Professor Bethe had just completed a classic set of three papers in which he reviewed and analyzed all that was then known about nuclear physics. These works were known among his colleagues as "Bethe's bible." Gamow assembled a small conference of physicists and astrophysicists in Washington, D. C. to discuss the state of knowledge, and the unsolved problems, concerning the internal constitution of the stars.

In the course of the next six months or so, Bethe worked out the basic nuclear processes by which hydrogen is burned (fused) into helium in stellar interiors. Hydrogen is the most abundant constituent of the sun and similar stars, and indeed the most abundant element in the universe.

Bethe described the results of his calculations in a paper entitled "Energy Production in Stars," which is awesome to read. He authoritatively analyzed the different possibilities for reactions that burn nuclei and selected as most important the two processes that we now believe are responsible for sunshine. One process, the so-called $p - p$ chain, builds helium out of hydrogen and is the dominant energy source in stars like the sun and less massive stars.

The CNO cycle, the second process which was also considered by von Weizsäcker, is most important in stars that are more massive than the sun. Bethe used his results to estimate the central temperature of the sun and obtained a value that is within 20% of what we currently believe is the correct value (16 million degrees Kelvin)[2]. Moreover, he showed that his calculations led to a relation between stellar mass and stellar luminosity that was in satisfactory agreement with the available astronomical observations.

In the first two decades after the end of the second world war, many important details were added to Bethe's theory of nuclear burning in stars. Distinguished physicists and astrophysicists, especially A. G. W. Cameron, W. A. Fowler, F. Hoyle, E. E. Salpeter, M. Schwarzschild, and their experimental colleagues, returned eagerly to the question of how stars like the sun generate energy. From Bethe's work, the answer was known in principle: the sun produces the energy it radiates by burning hydrogen. According to this theory, the solar interior is a sort of controlled thermonuclear bomb on a giant scale[3]. The theory leads to the successful calculation of the observed luminosities of stars similar to the sun and provides the basis for our current understanding of how stars shine and evolve over time. The idea that nuclear fusion powers stars is one of the cornerstones of modern astronomy and is used routinely by scientists in interpreting observations of stars and galaxies.

W. A. Fowler, Willy as he was universally known, led a team of colleagues in his Caltech Kellogg Laboratory and inspired physicists throughout the world to measure or calculate the most important details of the $p-p$ chain and the CNO cycle. There was plenty of work to do, and the experiments and the calculations were difficult. But the work got done because understanding the specifics of solar energy generation was so interesting. Most of the efforts of Fowler and his colleagues M. Burbidge, G. R. Burbidge, F. Hoyle, and A. G. W. Cameron) soon shifted to the problem of how the heavy elements, which are necessary for life, are produced in stars.

V. TESTING THE HYPOTHESIS OF NUCLEAR BURNING

Science progresses as a result of the clash between theory and experiment, between speculation and measurement. Eddington, in the same lecture in which he first discussed the burning of hydrogen nuclei in stars, remarked:

> I suppose that the applied mathematician whose theory has just passed one still more stringent test by observation ought not to feel satisfaction, but rather disappointment—"Foiled again! This time I *had* hoped to find a discordance which would throw light on the points where my model could be improved."

Is there any way to test the theory that the sun shines because very deep in its interior hydrogen is burned into helium? At first thought, it would seem impossible to make a direct test of the nuclear burning hypothesis. Light takes about ten million years to leak out from the center of the sun to the surface and when it finally emerges in the outermost regions, light mainly tells us about the conditions in those outer regions. Nevertheless, there is a way of "seeing" into the solar interior with neutrinos, exotic particles discovered while trying to understand a different mystery[4].

A. DISCOVERY, CONFIRMATION, AND SURPRISE

A neutrino is a sub-atomic particle that interacts weakly with matter and travels at a speed that is essentially the speed of light. Neutrinos are produced in stars when hydrogen nuclei are burned to helium nuclei; neutrinos are also produced on earth in particle accelerators, in nuclear reactors, and in natural radioactivity. Based upon the work of Hans Bethe and his colleagues, we believe that the process by which stars like the sun generate energy can be symbolized by the relation,

$$4\,{}^1H \rightarrow {}^4He + 2e^+ + 2\nu_e + \text{energy} \qquad (1)$$

in which four hydrogen nuclei (${}^1H$, protons) are burned into a single helium nucleus (${}^4He$, α particle) plus two positive electrons (e^+) and two neutrinos (ν_e) plus energy. This process releases energy to the star since, as Aston showed, four hydrogen atoms are heavier than one helium atom. The same set of nuclear reactions that supply the energy of the sun's radiation also produce neutrinos that can be searched for in the laboratory.

Because of their weak interactions, neutrinos are difficult to detect. How difficult? A solar neutrino passing through the entire earth has less than one chance in a thousand billion of being stopped by terrestrial matter. According to standard theory, about a hundred billion solar neutrinos pass through your thumbnail every second and you don't notice them. Neutrinos can travel unaffected through iron as far as light can travel in a hundred years through empty space.

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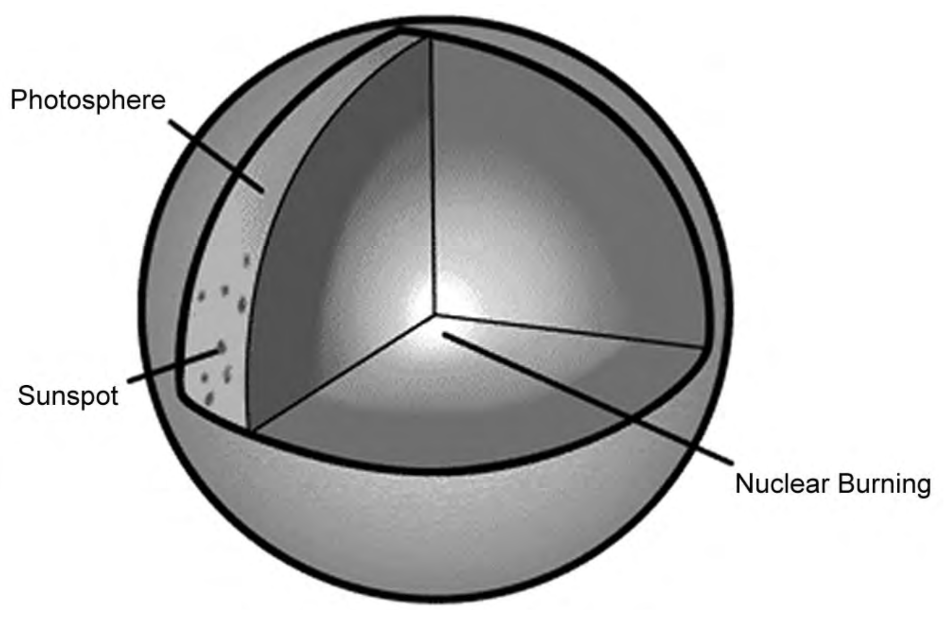
[2] According to the modern theory of stellar evolution, the sun is heated to the enormous temperatures at which nuclear fusion can occur by gravitational energy released as the solar mass contracts from an initially large gas cloud. Thus, Kelvin and other nineteenth-century physicists were partially right; the release of gravitational energy ignited nuclear energy generation in the sun.

[3] The sensitive dependence of the Gamow factor upon the relative energy of the two charged particles is, we now understand, what provides the temperature "thermostat" for stars.

[4] The existence of neutrinos was first proposed by Wolfgang Pauli in a 1930 letter to his physics colleagues as a "desperate way out" of the apparent non-conservation of energy in certain radioactive decays (called β-decays) in which electrons were emitted. According to Pauli's hypothesis, which he put forward very hesitantly, neutrinos are elusive particles which escape with the missing energy in β-decays. The mathematical theory of β-decay was formulated by Enrico Fermi in 1934 in a paper which was rejected by the journal *Nature* because "it contained speculations too remote from reality to be of interest to the reader." Neutrinos from a nuclear reactor were first detected by Clyde Cowan and Fred Reines in 1956.



This figure is a cross section of the sun. The features that are usually studied by astronomers with normal telescopes that detect light are labeled on the outside, *e. g.*, sunspot and prominences. Neutrinos enable us to look deep inside the sun, into the solar core where nuclear burning occurs.

In 1964, Raymond Davis Jr. and I proposed that an experiment with 100,000 gallons of cleaning fluid (perchloroethylene, which is mostly composed of chlorine) could provide a critical test of the idea that nuclear fusion reactions are the ultimate source of solar radiation. We argued that, if our understanding of nuclear processes in the interior of the sun was correct, then solar neutrinos would be captured at a rate Davis could measure with a large tank filled with cleaning fluid. When neutrinos interact with chlorine, they occasionally produce a radioactive isotope of argon. Davis had shown previously that he could extract tiny amounts of neutrino-produced argon from large quantities of perchloroethylene. To do the solar neutrino experiment, he had to be spectacularly clever since according to my calculations, only a few atoms would be produced per week in a huge Olympic-sized swimming pool of cleaning fluid.

Our sole motivation for urging this experiment was to use neutrinos to:

> enable us to see into the interior of a star and thus verify directly the hypothesis of nuclear energy generation in stars.

As we shall see, Davis and I did not anticipate some of the most interesting aspects of this proposal.

Davis performed the experiment, and in 1968 announced the first results. He measured fewer neutrinos than I predicted. As the experiment and the theory were refined, the disagreement appeared more robust. Scientists rejoiced that solar neutrinos were detected but worried why there were fewer neutrinos than predicted.

What was wrong? Was our understanding of how the sun shines incorrect? Had I made an error in calculating the rate at which solar neutrinos would be captured in Davis's tank? Was the experiment wrong? Or did something happen to the neutrinos after they were created in the sun?

Over the next twenty years, many different possibilities were examined by hundreds, and perhaps thousands, of physicists, chemists, and astronomers[5]. Both the experiment and the theoretical calculation appeared to be correct.

Once again experiment rescued pure thought. In 1986, Japanese physicists led by Masatoshi Koshiba and Yoji Totsuka, together with their American colleagues, Eugene Beier and Alfred Mann, reinstrumented a huge tank of water designed to measure the stability of matter. The experimentalists increased the sensitivity of their detector so that it could also serve as a large underground observatory of solar neutrinos. Their goal was to explore the reason for the quantitative disagreement between the predicted and the measured rates in the chlorine experiment.

The new experiment (called Kamiokande) in the Japanese Alps also detected solar neutrinos. Moreover, the Kamiokande experiment confirmed that the neutrino rate was less than predicted by standard physics and standard models of the sun and demonstrated that the detected neutrinos came from the sun. Subsequently, experiments in Russia (called SAGE, led by V. Gavrin), in Italy (GALLEX and later GNO led by T. Kirsten and E. Belotti, respectively), and again in Japan (Super-Kamiokande, led by Y. Totsuka and Y. Suzuki), each with different characteristics, all observed neutrinos from the solar interior. In each detector, the number of neutrinos observed was somewhat lower than standard theory predicted.

What do all of these experimental results mean?

Neutrinos produced in the center of the sun have been detected in five experiments. Their detection shows directly that the source of the energy that the sun radiates is the fusion of hydrogen nuclei in the solar interior. The nineteenth century debate between theoretical physicists, geologists, and biologists has been settled empirically.

From an astrophysical perspective, the agreement between neutrino observations and theory is good. The observed energies of the solar neutrinos match the values predicted by theory. The rates at which neutrinos are detected are less than predicted but not by a large

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[5] Perhaps the most imaginative proposal was made by Stephen Hawking, who suggested that the central region of the sun might contain a small black hole and that this could be the reason why the number of neutrinos observed is less than the predicted number.

factor. The predicted neutrino arrival rate at the earth depends approximately upon the 25th power of the central temperature of the sun, T × T ×...T (25 factors of the temperature T). The agreement that has been achieved (agreement within a factor of three) shows that we have empirically measured the central temperature of the sun to an accuracy of a few percent. Incidentally, if someone had told me in 1964 that the number of neutrinos observed from the sun would be within a factor of three of the predicted value, I would have been astonished and delighted.

In fact, the agreement between normal astronomical observations (using light rather than neutrinos) and theoretical calculations of solar characteristics is much more precise. Studies of the internal structure of the sun using the solar equivalent of terrestrial seismology (*i.e.*, observations of solar vibrations) show that the predictions of the standard solar model for the temperatures in the central regions of the sun are consistent with the observations to an accuracy of at least 0.1%. In this standard model, the current age of the sun is five billion years, which is consistent with the minimum estimate of the sun's age made by nineteenth-century geologists and biologists (a few hundred million years).

Given that the theoretical models of the sun describe astronomical observations accurately, what can explain the disagreement by a factor of two or three between the measured and the predicted solar neutrino rates?

B. New Physics

Physicists and astronomers were once again forced to reexamine their theories. This time, the discrepancy was not between different estimates of the sun's age, but rather between predictions based upon a widely accepted theory and direct measurements of particles produced by nuclear burning in the sun's interior. This situation was sometimes referred to as the Mystery of the Missing Neutrinos or, in language that sounded more scientific, the Solar Neutrino Problem.

As early as 1969, two scientists working in Russia, Bruno Pontecorvo and Vladimir Gribov, proposed that the discrepancy between standard theory and the first solar neutrino experiment could be due to an inadequacy in the textbook description of particle physics, rather than in the standard solar model. (Incidentally, Pontecorvo was the first person to propose using a chlorine detector to study neutrinos.) Gribov and Pontecorvo suggested that neutrinos suffer from a multiple personality disorder, that they oscillate back and forth between different states or types.

According to the suggestion of Gribov and Pontecorvo, neutrinos are produced in the sun in a mixture of individual states, a sort of split personality. The individual states have different small masses, rather than the zero masses attributed to them by standard particle theory. As they travel to the earth from the sun, neutrinos oscillate between the easier-to-detect neutrino state and the more difficult-to-detect neutrino state. The chlorine experiment only detects neutrinos in the easier-to-observe state. If many of the neutrinos arrive at earth in the state that is difficult to observe, then they are not counted. It is as if some or many of the neutrinos have vanished, which can explain the apparent mystery of the missing neutrinos.

Building upon this idea, Lincoln Wolfenstein in 1978 and Stanislav Mikheyev and Alexei Smirnov in 1985 showed that the effects of matter on neutrinos moving through the sun might increase the oscillation probability of the neutrinos if Nature has chosen to give them masses in a particular range.

Neutrinos are also produced by the collisions of cosmic ray particles with other particles in the earth's atmosphere. In 1998, the Super-Kamiokande team of experimentalists announced that they had observed oscillations among atmospheric neutrinos. This finding provided indirect support for the theoretical suggestion that solar neutrinos oscillate among different states. Many scientists working in the field of solar neutrinos believe that, in retrospect, we have had evidence for oscillations of solar neutrinos since 1968.

But we do not yet know what causes the multiple personality disorder of solar neutrinos. The answer to this question may provide a clue to physics beyond the current standard models of sub-atomic particles. Does the change of identity occur while the neutrinos are traveling to the earth from the sun, as originally proposed by Gribov and Pontecorvo? Or does matter cause solar neutrinos to "flip out"? Experiments are underway in Canada, Italy (three experiments), Japan (two experiments), Russia, and the United States that are attempting to determine the cause of the oscillations of solar neutrinos, by finding out how much they weigh and how they transform from one type to another. Non-zero neutrino masses may provide a clue to a still undiscovered realm of physical theory.

VI. Nature: A Wonderful Mystery

Nature has written a wonderful mystery. The plot continually changes, and the most important clues come from seemingly unrelated investigations. These sudden and drastic changes of scientific scene appear to be Nature's way of revealing the unity of all fundamental science.

The mystery began in the middle of the nineteenth century with the puzzle: How does the sun shine? Almost immediately, the plot switched to questions about how fast natural selection occurs and at what rate geological formations are created. The best theoretical physics of the nineteenth century gave the wrong answer to all these questions. The first hint of the correct answer came, at the very end of the nineteenth century, from the discovery of radioactivity with accidentally darkened photographic plates.

The right direction in which to search for the detailed solution was revealed by the 1905 discovery of the special theory of relativity, by the 1920 measurement of the nuclear masses of hydrogen and helium, and by the 1928 quantum mechanical explanation of how charged particles get close to each other. These crucial investigations were not directly related to the study of stars.

By the middle of the twentieth century, nuclear physicists and astrophysicists could calculate theoretically the rate of nuclear burning in the interiors of stars like the sun. But, just when we thought we had Nature figured out, experiments showed that fewer solar neutrinos were observed at earth than were predicted by the standard theory of how stars shine and how sub-atomic particles behave.

At the beginning of the twenty-first century, we have learned that solar neutrinos tell us not only about the interior of the sun, but also something about the nature of neutrinos. No one knows what surprises will be revealed by the new solar neutrino experiments that are currently underway or are planned. The richness and the humor with which Nature has written her mystery, in an international language that can be read by curious people of all nations, is beautiful, awesome, and humbling.

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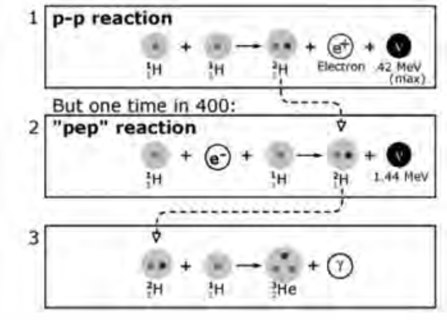
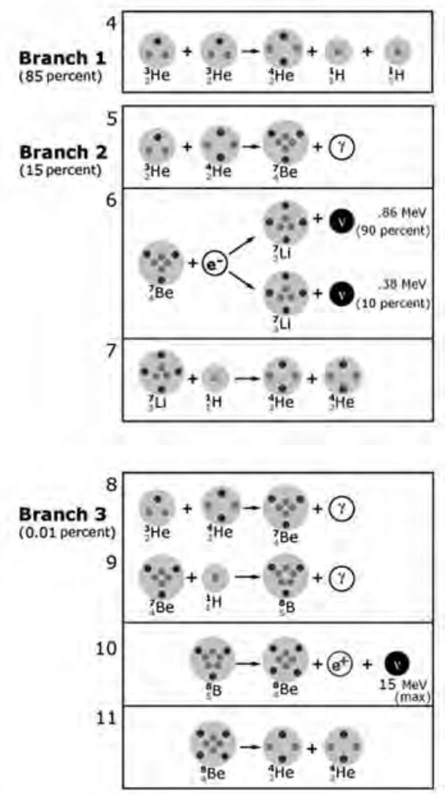
Appendix

The *p—p* chain reaction

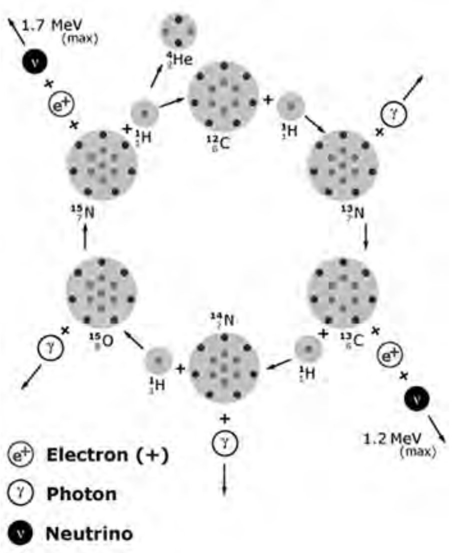




In theoretical models of the sun, the *p–p* chain of nuclear reactions illustrated here is the dominant source of energy production. Each reaction is labeled by a number in the upper left hand corner of the box in which it is contained. In reaction 1, two hydrogen nuclei (^1H, protons) are fused to produce a heavy hydrogen nucleus (^2H, a deuteron). This is the usual way nuclear burning gets started in the sun. On rare occasions, the process is started by reaction 2. Deuterons produced in reactions 1 and 2 fuse with protons to produce a light element of helium (^3He). At this point, the *p—p* chain breaks into three branches, whose relative frequencies are indicated in the figure. The net result of this chain is the fusion of four protons into a single ordinary helium nucleus (^4He) with energy being released to the star in accordance with Einstein's equation. Particles called 'neutrinos' (ν) are emitted in these fusion processes. Their energies are shown in the figure in units of millions of electron volts (MeV). Reactions 2 and 4 were not discussed by Hans Bethe.

The figure is adapted from J. N. Bahcall, *Neutrinos from the Sun*, Scientific American, Volume 221, Number 1, July 1969, pp. 28-37.

The CNO cycle



For stars heavier than the sun, theoretical models show that the CNO (carbon-nitrogen-oxygen) cycle of nuclear fusion is the dominant source of energy generation. The cycle results in the fusion of four hydrogen nuclei (^1H, protons) into a single helium nucleus (^4He, alpha particle), which supplies energy to the star in accordance with Einstein's equation. Ordinary carbon, ^{12}C, serves as a catalyst in this set of reactions and is regenerated. Only relatively low energy neutrinos (ν) are produced in this cycle.

The figure is adapted from J. N. Bahcall, *Neutrinos from the Sun*, Scientific American, Volume 221, Number 1, July 1969, pp. 28-37.

John Bahcall has been a Professor of Natural Sciences at the Institute for Advanced Study, Princeton, NJ since 1971. He is best known for his research work on solar neutrinos, quasars, stars in the Galaxy, and atomic processes. Bahcall is a former President of the American Astronomical Society and led the survey by US astronomers to set priorities for astronomical research in the 1990's.

Illustration by Brian G Segal

Transient Phenomena on the Moon

by Patrick Moore

"The Moon is a changeless world." This is certainly the general view, and in the main it is correct. Very little has happened there for a long time, and no craters have been formed apart, no doubt, from a few small impact structures. Yet the Moon is not totally inert.

Most long-term observers have seen traces of activity there, in the form of localized glows or obscurations. They are known as TLP or "Transient Lunar Phenomena" — a term for which I admit to being responsible (I introduced it around 1950). The reality of TLP has long been questioned, mainly because most of the reports — not all — have come from amateur observers, but the situation now is different. It is significant that a few professionals who paid close attention to the Moon in the pre-Apollo period also saw occasional TLP; among these observers were E.E. Barnard and W.H. Pickering. All these early reports are contained in the TLP catalogue published by NASA in 1968 (Middlehurst *et al.* 1968); a further list appeared in 1971 (Moore 1971), and another update is now in preparation.

There are various areas which are particularly event-prone, notably the brilliant crater Aristarchus. Moreover, most TLP are seen near the boundaries of the regular maria, and in regions rich in rills. They also seem to be commonest near perigee, when the lunar surface is under maximum strain.

TLP became widely discussed in 1959 following an observation of an event in the walled plain Alphonsus recorded by N.A. Kozyrev from the Crimean Astrophysical Observatory (Kozyrev 1959). In this episode I played a minor and totally undistinguished part (Moore 1977). In 1955 D. Alter, using the Mount Wilson 60-inch reflector, had taken photographs which indicated temporary obscurations in Alphonsus. In correspondence with Kozyrev, I suggested that the area would be worth watching, and on November 3rd, 1958 Kozyrev recorded a "reddish cloud" over the central peak; he obtained spectrographic confirmation. He believed that there had been a sharp rise in temperature. This I frankly doubt, but at least the observation appeared to be valid, and it is worth adding that as long ago as 1882 the German astronomer Klein had claimed that he had seen "volcanic phenomena" inside Alphonsus.

Had there been any permanent change in the area? During the following months several observers, including Brian Warner at the University of London Observatory, described a bright red patch. I was never able to see it, and it certainly seems to be absent now, but another spectrographic observation was made by Kozyrev on October 23rd, 1959; on that occasion nothing unusual was seen visually.

Another professional report came in 1963, when J. Greenacre and E. Barr, at the Lowell Observatory, recorded coloured events inside the crater Gassendi (Greenacre 1965). On April 30th, 1966, using my 15-inch reflector at Selsey in Sussex, I observed an orange streak inside Gassendi (Moore 1967), and this was independently confirmed by other observers at different sites. Over the following years many reports came in — one, of special interest, on 23 May 1985 from the Greek observer G. Kolovos and his colleagues, who photographed a brief TLP in the Palus Somnii (Kolovos 2000). It covered an area of 3 × 3.5 miles and was attributed to gases sent out from below the lunar crust. Attempts were made to explain away this event as reflected sunlight from an artificial satellite, which just happened to be in the line of sight, but the images indicated that the obscuration was linked with the topography of the area, so that the satellite theory is not at all convincing.

The reality of TLP has now been confirmed by an observation made from Meudon (Paris) by Audouin Dollfus, whose experience is second to none. Dollfus wrote (Dollfus 2000):

> "On 30 December 1992, glows have been recorded at the lunar surface, on the floor of the crater Langrenus. They were not present the day before. Their shape and brightness were considerably modified three days later. These glows appeared also in polarized light. They are apparently due to dust grain levitations above the lunar surface, under the effect of gas escaping from the soil. The Moon appears as a celestial body which is not totally dead."

Lunar activity is of course very mild, but it does occur, and further observations of TLP will be of great interest. However, the greatest care must be taken, as it is only too easy to be deceived by effects in

> **“ Most long-term observers have seen traces of activity [on the Moon], in the form of localized glows or obscurations. They are known as TLP or “Transient Lunar Phenomena — a term for which I admit to being responsible (I introduced it around 1950).”**

our atmosphere. For a purely visual observation, confirmation is needed from at least two observers at different sites, and I am sure that many reports in the original NASA catalogue are spurious. Above all, more spectra are needed, and it is hoped that the programme now organized by the Lunar Section of the British Astronomical Association will produce some results.

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Patrick Moore has been an honourary member of the RASC since July 1993. He is well known for his numerous books and articles which have served to popularize astronomy for generations.

A Lamplighter Moment:[1] Daytime Observations of Venus at Inferior Conjunction[2]

by Fr. Lucian J. Kemble, OFM (with comments by David M. F. Chapman)

Abstract. The inferior conjunction of Venus on April 3, 1985 exhibited one of the widest apparent separations of Venus above the Sun (over 8°). An explanation of the phenomenon and the distinction made between equatorial and ecliptic conjunctions is followed by descriptions of daytime observing techniques (and dangers!). Five observations obtained at about noon on the days immediately before and after conjunction are described. Atmospheric glow was noted around the whole disk of the planet. The author has previously made observations of a similar inferior conjunction of Venus on April 6, 1977 (almost exactly eight years earlier) when Venus and the Sun were even closer: 7°.13. A comparison is made of the two events and reference given to other near-Sun observations of Mercury, Mars, Jupiter, and Saturn.

In Quebec City one fine sunny day of 1948, when I was a young Franciscan student of philosophy, my confrères and I were playing volleyball. As I leaped up to return a shot, my eyes reached beyond the ball and chanced to focus on Venus — my first-ever daytime view of a heavenly body other than the Sun or Moon. [There was an inferior conjunction of Venus on June 14, 1948.] I missed the ball, lost the point and the game, and had my confrères searching for the object of my excited finger pointing. Thus was born a new and fascinating facet of a life-long interest in and passion for astronomy.[3]

In 1972, with my first pair of binoculars and a Celestron-5 telescope,

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[1] Dedicated to the memory of Father Lucian Kemble (1922–1999), *a.k.a.* “Lamplighter,” who touched the lives of countless members of the RASC through his love for all aspects of observing. A “Lamplighter moment” is simply an occasion where, through careful observation of the mundane, one unexpectedly discovers something profound, something achieved by Lucian Kemble fairly regularly during his lifetime. This section is a regular part of the *Journal* devoted to guest articles by authors describing their Lamplighter moments.

[2] Text of a paper presented at the General Assembly of the RASC, Edmonton, June 28 – July 1, 1985.

[3] Lucian Kemble, “Daytime and Twilight Observations,” RASC National Newsletter, October 1976.

> **"As I leaped up to return a shot [in volleyball], my eyes reached beyond the ball and chanced to focus on Venus — my first-ever daytime view of a heavenly body other than the Sun or Moon."**

I began a continuing series of exciting daytime observations. I shall never forget my first noontime view of a star in the telescope: Arcturus — a golden glitter of fire-ice in a sea of blue. My searches have reached to stars as faint as the fifth magnitude, such as the "double-double" in Lyra; to Mercury, Venus, Mars, Saturn, and Jupiter within 10° of the Sun; to Uranus and Neptune shortly after sunset; to the splitting of otherwise difficult doubles, *etc*.

Venus of course has retained its special appeal, and very early I began to wonder, when I realized that it could sometimes pass above or below the Sun at inferior conjunction, if it would be possible to observe it at such times. Wonder, coupled with much experience and perfecting of technique, led to research, calculating, and plotting. The first attempt, in April 1977, was successful and was followed by the more recent event in April 1985.

Before I describe those events, I would like to give a brief review of the orbital elements of Venus and Earth responsible for these opportunities.[4] The orbit of Venus, with a sidereal period of revolution of 224.7 days, is inclined to the ecliptic by 3°.39, with ascending node in December, maximum heliocentric latitude north in March, descending node in June, and maximum heliocentric latitude south in September. Venus returns to inferior conjunction, *i.e.* its synodic period, every 584 days, or roughly every 19.4 months. By a curious 8/5 resonance, that means that every eight Earth years Venus will have passed through inferior conjunction five times (almost exactly, with a difference of only 2.5 days). Series of similar inferior conjunctions occur in pairs of 8 years apart. Hence, when the conjunctions occur at the nodes, there are transits of Venus across the Sun's disk eight years apart and in pairs separated by 122 and 115 years. The last pair of transits was in December 1874 and 1882; the next in June 2004 and 2012. Springtime pairs, such as the two I have observed, occur near the time when Venus is at greatest heliocentric latitude north and nearest Earth. They are therefore most favorably placed for observation,[5] with Venus well above the Sun, on average 7°.75. The maximum separation, at 8°.3, is reached in March 2017.

It may come as a surprise that there are in reality two sorts of inferior conjunction, depending on whether one is speaking of equatorial or ecliptic coordinates, since the ecliptic is most often inclined with respect to celestial right ascension, most pronounced at the equinoxes. Thus on April 1, 1985 Venus had the same R.A. as the Sun at 12:50 MST, but it reached ecliptic inferior conjunction, with the same celestial longitude as the Sun and therefore at its closest to the Sun, on April 3 at 3:00 p.m. MST. The two types of inferior conjunction would coincide only at the time of summer or winter solstice, when a given planet would be north or south of the Sun in both R.A. and celestial longitude at the same time.

Daytime telescopic observation demands some rather refined but simple techniques and, when carried out near the Sun, considerable care and caution. An accurately aligned finder scope and a solid, clock-driven mount are essential, as are familiarity and practice with accurate polar alignment. The latter can be achieved using a permanent pier or by setting up the night previous and leaving one's tripod and mount outside, or at least by using markers to assure setting the tripod in the same position. With proper polar alignment assured, the main telescope is left covered and is pointed to the Sun until the Sun's projected disk shines directly centred through and on the shadow of the finder. With accurate solar co-ordinates for the specific time of observation previously calculated from an Ephemeris[6] or *The Observer's Handbook*, set the R.A. setting circle accordingly. If the Moon or Venus is in the sky, remove the telescope cover (duly pointed away from the Sun) and use the Moon or Venus to focus the telescope more accurately. Then, using co-ordinates, locate a bright star such as Capella, Arcturus, Vega, Betelgeuse, *etc*., more accurately reset the R.A. setting circle, and refine the focus. When a star is found, it may even be sighted in the finder. Observing a star, Mercury, or Venus near the Sun requires an added refinement, both to enhance observing and to reduce risk of eye damage. I use a long, tubular dew shield on the open end of the telescope tube and tape a piece of cardboard over half the front end of the shield, on the side nearest the Sun. This, of course, stops down the aperture, but it greatly cuts down on solar glare and increases contrast. Great care must be taken to not allow the telescope to drift freely, so that it does not point directly at the Sun.

Frequent successful use of the above procedure encouraged me to attempt observation before, during, and following

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[4] Data obtained from the highly recommended, useful, and comprehensive *Astronomical Tables of the Sun, Moon, and Planets* by Jean Meeus (Willmann-Bell, Inc. 1983).

[5] See *Sky & Telescope*, March 1985, p. 244, for the geometry involved.

[6] For example, the *Astronomical Almanac* published annually by the U.S. Government Printing Office, Washington, DC; obtainable from Willmann-Bell, Inc.

"Without being coached or told what to look for, she exclaimed, "I can see the whole round planet, with a soft glow all the way around." In all, a pleasant rebuttal to some of my friends who sometimes jokingly remark when I spot a faint object, "Lucian, you're seeing things!""

the inferior conjunction of Venus on April 6, 1977, when the planet was 7°.13 above the Sun. At the time I was using a pier-mounted Celestron-8 telescope. With Venus moving rapidly westward, I found it most rewarding to see the extremely thin, sunlit crescent of the planet's huge disk slide around from lower right of the Sun before conjunction, to directly under, then to lower left afterwards.

The similar event eight years later happens 2.5 days earlier each cycle, so in 1985 it occurred at 22 hours UT on April 3. Both events, in 1977 and 1985, fortunately happened on our daylit side of the globe. In preparation for the event, I calculated very exactly the co-ordinates for both the Sun and Venus for every day at 20:00 hours UT (1:00 p.m. MST) from March 27 to April 8 inclusive, using data in the *Astronomical Almanac*. Using the pier-mounted Celestron-11 telescope, I achieved successful observations on March 29, March 31, and April 1 with Venus exactly north of the Sun, and on April 5 and April 6, *i.e.*, three good observations before inferior conjunction and two following. The day of closest approach, unfortunately, was cloudy. On all occasions the 59 arcsecond-diameter disk of Venus was fully seen and best observed at 166× in an eyepiece with an orange filter. Extending from the elongated cusps of the very thin crescent, lit from behind and below, there was an atmospheric glow completely encircling the disk. The so-called ashen light was not observed. My best view was had at mid-morning, April 5, with Venus 8°.05 from the Sun. I noted a slight brightening of the atmospheric glow on the upper rim exactly opposite the centre of the sunlit crescent. A visitor at my site provided an interesting confirmation of the observation on that occasion. She had never looked through a telescope before and was greatly thrilled at seeing the gorgeous crescent. Without being coached or told what to look for, she exclaimed, "I can see the whole round planet, with a soft glow all the way around." In all, a pleasant rebuttal to some of my friends who sometimes jokingly remark when I spot a faint object, "Lucian, you're seeing things!" Wind and heat turbulence prevented any photographic record of the event.[7]

I have succeeded on other occasions in obtaining daytime photographs of Arcturus, Jupiter, and Venus in its crescent phases. And, of course, I have enjoyed many fine visual daytime observations besides those mentioned: Mercury as close as 10° to the Sun, Saturn 12° west of the Sun, Saturn at 2:00 p.m. on the day of the *Voyager 2* fly-by, the April 7, 1976 occultation of α Geminorum by Mars (mine was one of only three daytime observations reported to *Sky & Telescope*[8]), the seven brightest stars of the Pleiades, *etc*. An interesting note about Venus: since it is possible to view the planet close to the Sun and sometimes even through inferior conjunction, one can see Venus almost any day of the year, to within its greatest elongation of 47°. The only time it is hidden by solar glare is a week or so either side of superior conjunction.

I encourage other RASC members to try their hand at this aspect of their observing programmes, taking advantage of the long summer twilight hours in our northerly latitudes. Be prepared for some more forthcoming inferior conjunctions of Venus: August 22, 1991, 8°.23 south of the Sun; April 1, 1993, 7°.87 north of the Sun (*i.e.* the next eight-year cycle); and, of course, for those of us/you still around, the great pair of transits in June 2004 and 2012. Good Luck!

[The next inferior conjunction of Venus of the type described above takes place on March 30, 2001, continuing the eight-year cycle 1977, 1985, 1993… A few days earlier, on March 27 and 28, Venus is more than 5° above the horizon at both sunrise and sunset, providing an opportunity to view Venus as an evening star and a morning star on the same day.]

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[7] See *Sky & Telescope*, April 1985, p. 340, for a photograph of a similar event.

[8] *Sky & Telescope*, June 1976.

Reflections

New Year 's Day

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

Have you ever wondered why New Year's Day is January 1st? That may seem to be a silly question, but it has not always been so: historically speaking, New Year's Day has wandered around the calendar, and there always have been calendars that start on days other than January 1st. (I once asked a Chinese woman how to determine the date of Chinese New Year. Giving me a strange look, she replied "You look on the calendar!")

The calendar we use today, and which the world commonly uses for civil purposes, has its origins in the 365-day Egyptian solar calendar. The flooding of the Nile was a key date in Egyptian agriculture, a yearly event driven by the annual motion of the tilted Earth around the Sun. The peak of the flood happened to coincide with the heliacal rising* of Sirius, the Dog Star (Alpha Canis Majoris), and New Year's Day on the Egyptian calendar occurred during the "dog days" of what we now call August.

Another source of our modern calendar — at least for month names — is the Republican Roman calendar, which was a type of lunar-solar calendar. This calendar started when the Earth itself was observed to experience rebirth, on the first day of the month of Martius (March). Evidence of the March beginning can be found in today's month names. Following Martius, there were Aprilis, Maius, and Junius. The early Romans ran out of name ideas after 4 months, and they simply numbered the next months: Quintilis, Sextilis, September, October, November, December. Bringing up the rear were Januarius and Februarius, later additions. You can begin to understand why the leap days in calendars to come were inserted into the month of February: it used to be the last month of the year. The republican Roman calendar proved to be unsatisfactory, often being arbitrarily modified by minor officials whose quest for personal gain outweighed the public good.

In 46 BC Julius Caesar (with expert advice from the Alexandrian astronomer Sosigenes) reformed the Roman calendar after the Egyptian model. During the "Year of Confusion," he inserted 67 days to put it in step with the seasons, introduced the well-known 4-year cycle of leap years, and confirmed New Year's Day as January 1st, bringing it closer to the Winter Solstice. Following Caesar's assassination, the month Quintilis was renamed Julius, and eventually the month Sextilis was renamed Augustus after Julius' grand-nephew, who was the first Roman Emperor. Starting the year in January put the last four months of the year in numerical positions two beyond those suggested by their names. (I struggle with this constantly: *Sept*ember is 9, *Oct*ober is 10, *Nov*ember is 11, *Dec*ember is 12.) These month names and their order have persisted to this day, even during the ascent of the Church as a unifying political power.

Meanwhile, many pagan cultures simply divided the year into quarters, the *quarter days* being the Equinoxes and the Solstices. Traditionally, these were March 25th, June 24th, September 26th, and December 25th on the Julian calendar, but the true dates of the astronomical phenomena immediately began slipping earlier, due to a small imprecision in the length of the Julian year. Dividing further, the *cross-quarter days* were midway between the quarter days: occurring in early May, August, November, and February, these days are cluster points for traditional festivals which have survived to the present day. This is described well in Guy Ottewell's *Astronomical Companion*. The Celtic year began with the gloomy festival of Samhain, which survives today as Hallowe'en followed by All Saints Day. The Germanic tribes, and others, began their year with the Winter Solstice.

The Christians helped spread the use of the Julian calendar, but they were mostly interested in keeping the date of Easter near the Vernal Equinox, which had become the focus of the ecclesiastical year. Early Church leaders were wary of the pagan rituals that took place around the Winter Solstice and decided that March 25th (the traditional date of the Vernal Equinox) made a better New Year's Day. Better yet, in the Church calendar, March 25th is Annunciation Day, exactly 9 months before the December 25th, which had been chosen as Christmas Day, the celebration of the birth of Christ.** In many European countries, including England, March 25th was New Year's Day well into the Second Millennium.

In 1582 Pope Gregory XIII reformed the Julian calendar, correcting the backward slide of the Equinoxes and the Solstices. He also standardized New Year's Day as January 1, one week after the traditional date of Christmas. It took time for Protestant countries to toe the line; for example, England and its colonies did not make the calendar shift until 1752. The ghost of March 25th lingers on: when England made the change, March 25th Julian was the same as April 5th Gregorian,

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*The heliacal rising of a star is the first appearance in the morning sky of a star which was previously invisible owing to its conjunction with the Sun.

** There is little evidence that Jesus was born in December. A better case could be made for the spring, when shepherds would indeed "watch their flocks by night," as this is the lambing season.

and April 5th still marks the start of the UK Taxation Year.

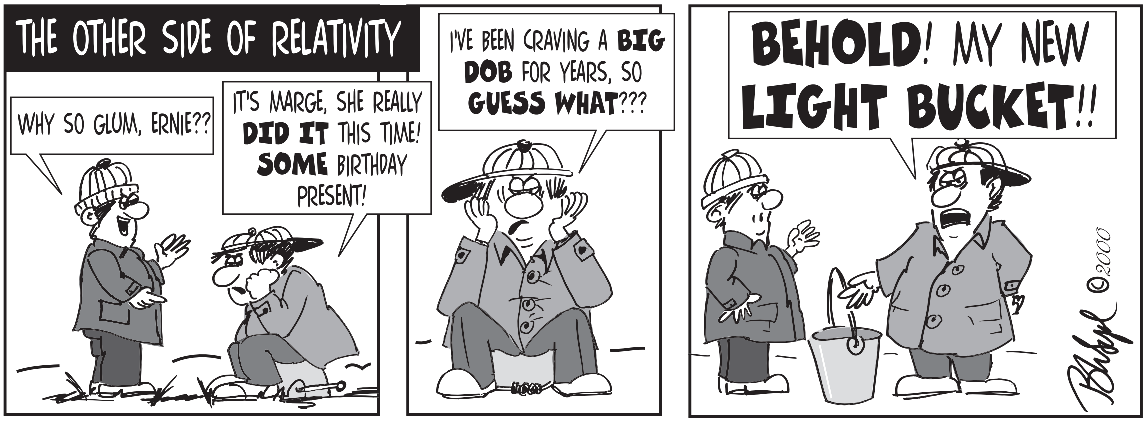
What I have just written is a much-simplified version of the story. A recent book that delves into minute detail on the history of our calendar is Duncan Steel's *Marking Time* (John Wiley & Sons, New York, 2000). A similar book (with a slightly pompous title) is David Duncan's *Calendar: Humanity's Epic Struggle to Determine a True and Accurate Year* (Avon Books, New York, 1998). A lighter read is Isaac Asimov's *The Clock We Live On* (Collier, New York, 1963), but this has become hard to find. (My copy is a battered paperback.)

* * *

Expect widespread confusion over dates in the coming year. Despite all the hoopla last year about Y2K and the demise of civilization, very little attention has been paid to the fact that the world has not settled on an unambiguous date standard for printed records and forms. Up until now we have suffered with DD/MM/YY and the U.S. variant MM/DD/YY. I have also seen YY/MM/DD. The year 2000 was a grace period, since "00" could only represent the year. Now we will be presented with dates like 03/02/01, and we will be left scratching our heads. In these pages two years ago, I made a plea to adopt the ISO date standard: YYYY-MM-DD. I will not repeat my argument; I think the standard speaks for itself. Since that time, several people have criticized the standard on the basis of its awkwardness in speech and writing: it is simply not the way we express ourselves colloquially. To this I would have to agree. ISO never meant to standardize speech and writing, only in the representation of dates used in electronic data processing and communication. By all means say "The second of January, 2001" or write "2001 January 1" if you want. My amended appeal is "please use the ISO standard in *cases where only numbers are used to represent the date*." Be careful out there.

David Chapman is a Life Member of the RASC and a past President of the Halifax Centre. Visit his astronomy page at `www3.ns.sympatico.ca/dave.chapman/astronomy_page`.

As they say…
be careful what
you wish for…!



FROM THE PAST AU FIL DES ANS

THE LENGTH OF THE YEAR

The following note arose from inquiries over the telephone which revealed that considerable confusion prevails in the use of the term *year*. Perhaps the writer may be pardoned for an attempt to elucidate the matter here.

The two chief units of time are the *day* and the *year*. The former is the rotation-period of the Earth on its axis; the latter, its revolution-period round the Sun.

At the instant when the centre of the Sun is on the meridian we say it is solar noon, and the interval between two successive such noons is a solar day. The lengths of such intervals are not all equal, and their average length is a *mean solar day.* This is the day in common use; it contains 86,400 seconds as ticked off by your watch.

How shall we determine the length of the year? While we are persuaded that the Earth revolves about the Sun, to us the Sun appears to move, in the course of the year, about the sky in a circle which we call the ecliptic, and which intersects the celestial equator in two points. When the Sun is at one of these points as it is moving from the south side to the north side of the celestial equator, it is the spring equinox (March 21); when at the other, it is the autumn equinox (September 23). The interval from one spring equinox to the next one is a *tropical year*, or a year of the seasons. By it our lives are governed. Such years vary in length considerably, and their average length is 365d. 5h. 48m. 46s. (approximately).

It may be interesting to give the actual length of some of these tropical years. In the *Observer's Handbook* is stated each year the date of the spring equinox, correct to one minute, and by writing down these dates for a series of years one can calculate the length of the tropical year elapsing from one equinox to the next. In this way the following table was prepared for years 1928-45.

Year	Equinox			Length of Year		
	d	h	m	d	h	m
1928	Mar. 20	15	45	…	.	..
1929	Mar. 20	21	35	365	5	50
1930	Mar. 21	03	30	365	5	55
1931	Mar. 21	09	07	365	5	41
1932	Mar. 20	14	54	365	5	47
1933	Mar. 20	20	43	365	5	49
1934	Mar. 21	02	28	365	5	45
1935	Mar. 21	08	18	365	5	50
1936	Mar. 20	13	58	365	5	40
1937	Mar. 20	19	45	365	5	47
1938	Mar. 21	01	43	365	5	58
1939	Mar. 21	07	29	365	5	46
1940	Mar. 20	13	24	365	5	55
1941	Mar. 20	19	21	365	5	57
1942	Mar. 21	01	11	365	5	50
1943	Mar. 21	07	03	365	5	52
1944	Mar. 20	12	49	365	5	46
1945	Mar. 20	18	38	365	5	49

It will be seen that the year 1931 was 17m. shorter than the year 1938.

The cause of this variation lies partly in the attraction of the other planets, particularly the massive Jupiter and Saturn, upon the earth, helping it forward at some parts of its orbit and holding it back at others.

The remainder of the variation is due to changes in the position of the equinoxes themselves; this is known as nutation, and is produced by varying lunar attractions.

by C. A. Chant,
from *Journal*, Vol. 39, pp. 30–31, January, 1945.

"Of Pale Kings and Pyramids"

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

When I was a child, I liked Egyptian mummies almost as much as I liked stars, and the Egyptian galleries at the Royal Ontario Museum were a favourite place. Thirty years later, it gives me great pleasure to write about stars and mummies. Although the subject of this column is somewhat different than usual, I hope that my readers will enjoy the topic as much as I do.

It is a commonly held, but erroneous, view that people living in ancient times were not as intellectually sophisticated as we are today. In fact, given the technological and engineering limitations of the times, they often came up with extremely elegant solutions to practical problems. Aficionados of astronomy know that the ancient Greeks proved that the Earth is a sphere orbited by the Moon, and that the Moon shines by reflected sunlight. Less well known is that some of the pyramids of ancient Egypt are aligned with rather uncanny precision to true north. Writing in the journal *Nature*, Egyptologist Kate Spence, of the University of Cambridge, has recently shown, however, just how simply this alignment was possibly achieved 4500 years ago, during the Old Kingdom.

The precision in the pyramid alignments is uncanny because at that time there was no north star to act as a heavenly marker. The nearest relatively bright star to the celestial pole around 2600 BC was about 2 degrees from true north, while the alignment of the Great Pyramid at Giza is only 3 arcminutes from north. Even today, using Polaris, pyramid builders would not be able to achieve the precise alignment realized around 2550 BC, because Polaris is almost a degree away from the north celestial pole.

> **"The precision in the pyramid alignments is uncanny because at that time there was no north star to act as a heavenly marker. The nearest relatively bright star to the celestial pole around 2600 BC was about 2 degrees from true north, while the alignment of the Great Pyramid at Giza is only 3 arcminutes from north."**

You might imagine that the Egyptians could have used the transit of the noon hour Sun, then turned to face the opposite direction, to find north. But the Sun is about half a degree across, and the source of considerable heat — which disturbs the seeing — so the errors in alignment would most probably be randomly scattered over at least a degree. Using the transit of the Moon or a single star might produce better results, although the size of the full Moon is also about half a degree on the sky.

But the curious thing about the alignments of the pyramids is that the precision does not vary randomly with a Gaussian (or bell curve) distribution, as one would expect if the measurements had been made using transits of the Moon or single stars. In fact, the alignments during the Old Kingdom start off relatively badly (about 20 arcminutes from north), get better over the space of about 50 years, then get worse again for another hundred years. You would think that if the Egyptians had worked out an absolute system of determining north, they could continue to apply it with equal precision over the space of several hundred years, given that their civilization lasted several thousand years.

Spence has found a technique with variable accuracy that fits very well with the observed precision of the alignments. She proposes that the Egyptians used the simultaneous transit of two relatively bright circumpolar stars to determine north; one star would be at its uppermost point, heading west, the other would be at its lowermost point, heading east. At the time of the transits, surveyors could drop a plumb line against the line connecting the two stars to lay out the western edge of the pyramid. This is intrinsically much more accurate than using the transit of a single circumpolar star. And, because of the precession of the Earth's orbit, the technique is variable in time.

By definition, if the transits are simultaneous, the line connecting the two stars in the sky passes through the north celestial pole. But that will be true only for a relatively brief period of time (a year or so, in fact). At other times, one star will transit slightly ahead of the other, and a vertical line connecting them —

The west side of the Great Pyramid of Giza was aligned to the north celestial pole 4500 years ago, with an astonishingly small error of about 3 arcminutes. Spence's recalibrated chronolgy of the Old Kingdom indicates that Khufu's reign began in 2480 +/– 5 BC, rather than the 2254 BC previously believed. *Photograph courtesy of Kate Spence.*

against which the surveyors dropped their plumb line — will not pass directly through north. As the Earth's orbit precesses, the difference in time between the upper and lower transits increases, and therefore the alignment error also increases.

In order to determine which pairs of stars were viable candidates, Spence used a standard precession program. Only two pairs of stars could have been used around that time: ζ Ursae Majoris — β Ursae Minoris, or ε Ursae Majoris — γ Ursae Minoris. The first pair had simultaneous transits around 2467 BC, while the second pair had them around 2443 BC. To gauge which pair of stars the Egyptians might have used, Spence plotted the errors in alignment that would result from each pair; the ζ Ursae Majoris — β Ursae Minoris combination had exactly the characteristics of the measured alignment errors. She shows that alignments of six out of eight pyramids built during that time fall right along a straight line of error versus time, if the surveying was done between the summer and autumnal months. The two anomalous points, though, are what really clinch the case. If the surveying for the other two pyramids was done sometime during the winter or spring months, the error in alignment would have the opposite sign, because circumpolar constellations have opposite positions in the sky, relative to the north celestial pole, when separated by six months in time. Simply reversing the sign of the error of those two anomalous pyramids brings them right into agreement with the others.

Leading up to the year or so when the stars transit simultaneously, the method will produce ever more accurate alignments, and afterward the technique becomes increasing less precise. At some point, the difference in transit times would have become so noticeable that the technique was abandoned, and for the next 500 years the errors in alignments seem to scatter randomly (though there are few data points in the latter time period).

The result of modeling the errors arising from the astronomical facts, and then fitting the observed errors in alignments of the pyramids, is that the surveying for the Great Pyramid seems to have been done about 2478 +/– 5 BC. This result provides a precise anchor point for Old Kingdom chronologies, because it is generally accepted that the surveying was done early in the king's reign.

The only problem is that this anchor point is about 74 years later than the commonly accepted chronology. Spence points out that it is not possible simply to slide the whole accepted chronology forward by 74 years because there are dates soon after 2000 BC that also have been fixed by astronomical observations. This means that the Old Kingdom chronology will need to be compressed, which will require a careful reassessment of the historical data. Spence is about to start surveying pyramids for which there are no accurate alignment data and hopes that with additional modeling she can produce for two kings accession dates that are accurate to plus or minus one or two years — quite an achievement, for events that happened so long ago. ◆

Dr. 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.*

SPACE MIRROR EXPERIMENTS: A POTENTIAL THREAT TO HUMAN EYES

by James G. Laframboise

Physics and Astronomy Department, York University, Toronto
Electronic Mail: laframboise@quasar.phys.yorku.ca

and B. Ralph Chou

School of Optometry, University of Waterloo
Electronic Mail: bchou@sciborg.uwaterloo.ca

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Abstract. We show that space-mirror experiments reflecting sunlight to Earth can produce resolved images having surface-brightness sufficient to damage human eyes looking through telescopes or binoculars.

Résumé. Nous démontrons que les essaies avec le mirroir spacial qui réflète les rayons du soleil sur la Terre peuvent, à l'aide de télescopes ou de jumelles, produire des images dont la face est suffisammant brillante pour endommager l'oeil humain. SEM

1. Introduction

Astronomers have expressed alarm over possible long-range implications of the Russian *Znamya* space-mirror experiment, which was attempted with partial success in 1993 (*Sky & Telescope* 1999) but unsuccessfully in 1999 (*Sky & Telescope* 1999; *Toronto Globe and Mail* 1999). This experiment may be attempted again. A more immediate concern with this experiment appears to have been overlooked, namely the possibility of eye damage to anyone on the ground who uses binoculars or a telescope to look at the spot of light in the sky. The danger would be similar to that involved in looking at the Sun just before or after a total eclipse. In both cases, the risk is that the eye is exposed to the Sun's full surface-brightness over a very small solid angle, too small to prevent the eye from being fully dark-adapted and therefore most sensitive to damage, but large enough that an image of some portion of the Sun's surface is fully resolved on the eye's retina. We present results of two separate calculations, both of which indicate that this danger is real.

In order to examine this issue, we have used information from news reports of the second attempt of the *Znamya* experiment (*Sky & Telescope* 1999; *Toronto Globe and Mail* 1999). According to this information, the illuminated region on the ground was to have a diameter of 6 to 8 km. The spacecraft's orbital altitude was 225 miles or about 360 km. Dividing 360 by 6 gives a beam-spread of 1/60 radian, or about one degree. Since the Sun itself subtends an angle of about half a degree, this rather small anticipated beam-spread implies that the mirror, which was made of aluminized flexible plastic sheeting, would have been nearly flat, with irregularities of about half a degree or less. Therefore, near the centre of the beam, an observer would have seen a surface-brightness close to that of the Sun.

2. Rudimentary Calculation

We consider first an amateur astronomer looking through an 8-inch (20 cm) telescope, which has an angular resolution of about one arc-second in the best atmospheric seeing conditions. At a distance of 360 km, the length which subtends this angle is: 360,000 m / 3,600 arc-seconds per degree × $\pi/180$ radians per degree = 1.75 metres.

Therefore, an object must be at least this large to be fully resolved at this distance. Since the *Znamya* mirror in the 1999 attempt was to have had a diameter of 25 m, it would have been fully resolved. Therefore, if an amateur astronomer happened to be observing with such a telescope at lowest power, so that the telescope's exit pupil and his/her eye's dark-adapted entrance pupil were well-matched at about 7 mm each, and *Znamya's* illumination came into view, a serious risk of eye damage would have existed.

If someone merely looked at *Znamya's* illumination through standard two-inch (7 × 50) binoculars, the minimum resolvable object size would then be four times larger, or about 7 m. Again, this is substantially less than the diameter of *Znamya's* mirror, so risk of eye damage would be implied in this case also.

Would the period of illumination have been too brief to cause eye damage? The spacecraft orbited at a speed of 8 km s^{-1}, so if the orientation of its mirror were unchanging, the illuminated spot would then take roughly one second to pass over an observer on the ground. This would not have been long enough to cause significant eye damage (Ham *et al.* 1980). However, the *Toronto Globe and Mail* 1999 also gives the locations of nine cities, at each of which the light was planned to shine for about three minutes, presumably as a result of deliberate aiming of the light-beam at those cities. There, the hazard would have been greater, and the likelihood of substantial numbers of people looking at the illuminated spot with binoculars would have been very great. However, the mirror failed to deploy during attempts on two successive days by the crew of the *Mir* space-station. The *Progress* supply-spacecraft on which the mirror was mounted was then separated from *Mir* and reentered the Earth's atmosphere.

What about the risk to a naked-eye observer? The angular resolution of the eye is usually between 45 and 60 arc-seconds, so the minimum resolvable object size would then be roughly 80 to 100 m. This is larger than *Znamya's* mirror, but only by a factor between roughly three and four. To protect itself during the daytime, the eye decreases its aperture by approximately a factor of two, but the low levels of total illumination from *Znamya* would be insufficient to cause such a decrease. Therefore, a naked-eye observer would be safe by only a narrow margin. Larger mirrors would pose a greater risk.

For an observer looking through an 8-inch telescope, "*Iridium* flashes" (Chien 1998) are safe by a similar margin. The *Iridium* satellites orbit at higher altitudes than *Znamya's*: a temporary orbit at 500 km while their performance is verified, followed by an operational orbit at 792 km (Chien 1998). Their "main mission antennas" are flat, highly reflective rectangles whose dimensions are 1.88 m × 0.86 m (Chien 1998). At 500 km, these antennas would subtend 0.78 arc-second × 0.36 arc-second = 0.28 square arc-second at normal incidence; at 796 km, the corresponding values are 0.49 arc-second × 0.22 arc-second = 0.11 square arc-second. These values are below the limit of resolution of an 8-inch telescope, but not by large factors.

In bright sunlight, the eye also protects itself by an aversion reflex which limits its exposure times to roughly one second. However, this reflex becomes inactive at the low levels of total illumination which occur in eclipse conditions or in the situation studied here.

3. Detailed Calculation

We make the following assumptions: mirror 25 m in diameter, aluminum-coated with reflectance 0.90, at a distance of 360 km above the Earth's surface; mirror segmented with 30% less reflecting area than that of a continuous mirror (*Sky & Telescope* 1999); diameter of illuminated area on surface of Earth = 6 km; uniform illumination across target area; air mass 1 with the mirror perpendicular to the line of sight (worst case); mirror viewed with 7 × 50 binoculars with 7 mm pupil in observer's eye (young adult).

We calculate ocular exposure as follows:

Solar irradiance at *Znamya* orbit = 1367 W m^{-2} with 49.6% reaching the ground (Pitts & Kleinstein 1993a);

Radiant flux collected by *Znamya* and reflected to Earth: $P_{vis} = 1367 \times 0.496 \times \pi \times 12.5^2 \times 0.70 \times 0.90 = 2.097 \times 10^5$ W;

Irradiance in the illuminated zone: $E_{vis} = 2.097 \times 10^5 / (\pi \times 3000^2) = 7.42 \times 10^{-3}$ W m^{-2};

Radiant flux collected by 50 mm objective: $P_{bin} = 7.42 \times 10^{-3} \times \pi \times 0.025^2 = 1.456 \times 10^{-5}$ W.

We allow for 98% transmittance through optics of binoculars and 72.5% transmittance through ocular media, and we assume an emmetropic (normal) eye with posterior focal length 22.22 mm and refractive index 1.333 (Pitts & Kleinstein 1993b).

We calculate retinal image size as follows:

Angle subtended by *Znamya* mirror = arctan (25/360000) = 0.004 degree;

Apparent size when viewed through binoculars: 0.028 degree = 100.8 arc-second;

Retinal image size = (22.22 tan 0.028)/1.333 = 0.00815 mm = 0.000815 cm.

Therefore the retinal irradiance is: $E_{ret} = 1.456 \times 10^{-5} \times 0.98 \times 0.725 / (\pi \times 0.000407^2) = 19.88$ W cm^{-2}.

We compare this with viewing the Sun with unaided eye with 3 mm pupil through air mass 1:

Retinal image size = (22.22 tan 0.5)/1.333 = 0.145 mm = 0.0145 cm.

The retinal irradiance now is: $E_{ret} = 1367 \times 0.496 \times 0.725 \times (0.0015/0.0073)^2 = 20.76$ W cm^{-2}.

4. Discussion

These calculations assume a geometry which permits the *Znamya* mirror to irradiate a circular spot on the surface of the Earth directly below it with uniform illumination at normal incidence. In reality, the departure of the beam from normal incidence at the Earth's surface may be significant, and an increased air mass must then be taken into account. In this sense, our detailed calculation represents a worst-case scenario. However, within the illuminated zone, the irradiance is not uniform from edge to edge, but is peaked towards the centre (Appendix). Our calculation is therefore conservative, because it may underestimate the actual ocular exposure for a ground-based observer viewing *Znamya* through 7 × 50 binoculars from a location near the centre of the illuminated zone.

The flatness of the *Znamya* mirror is a crucial issue in our calculations. As noted in Section 1, available data on the second *Znamya* attempt imply an intended flatness to within half a degree. In comparison with this, a photo of the deployed mirror in the first attempt (*Sky & Telescope* 1999) appears to show substantially more wrinkling. Even with this wrinkling, and "although much of the target area was blanketed by clouds, a few observers reported seeing a one-second flash nearly as bright as the full Moon" (*Sky & Telescope* 1999). In that experiment, the mirror's diameter was 20 m (*Sky & Telescope* 1999), so this brightness was concentrated within a subtended angle of about 11 arc-seconds, which is approximately 4 to 5 times smaller than the limit of resolution for a naked-eye observer. In this case, the relative brevity of the flash probably prevented the use of binoculars or telescopes. This factor may have fortuitously combined with the wrinkling and/or the limitation of the number of observers by cloudy conditions to prevent any cases of eye damage from having been reported.

Retinal photoreceptors at the centre of the fovea (cones on the visual axis of the eye) have centre-to-centre spacing of approximately 2 μm (Bennett & Rabbetts 1989). The retinal image of *Znamya*, when viewed through 7 × 50 binoculars, would therefore cover approximately 16 foveal cones. The computed retinal irradiance level is 96% of the level for daylight unaided exposure with the Sun at the zenith. Thus the threshold exposure duration for photochemical retinal damage for observing *Znamya* is only slightly longer than that required for threshold damage from unaided sungazing.

While the retinal image of *Znamya* is extremely small, it has a very high associated retinal irradiance. It could be a very serious retinal hazard when viewed through binoculars or telescopes.

On every clear day, near the beginning of sunrise and the end of sunset, most of the Sun's disk is obscured by the Earth's limb, and humans would therefore face an equivalent ocular hazard, except that the large intervening air mass which is present in such situations protects us. An astronaut on an airless moon or planet would face such a hazard at these times, or even if most of the Sun's disk were obscured by an opaque object such as a large rock, unless his spacesuit provided visual protection greater than that from air mass 1. Equivalently, if an astronaut were to travel substantially farther than 1 AU from the Sun, so that the resulting decrease in solar irradiance caused his eyes' entrance pupils to expand significantly, he would be subject to eye damage unless he were farther than roughly 40 AU from the Sun, so that it was no longer fully resolved on his retinas.

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James G. Laframboise
Physics and Astronomy Department
York University
4700 Keele Street
Toronto, Ontario, M3J 1P3

B. Ralph Chou
School of Optometry
University of Waterloo
Waterloo, Ontario, N2L 3G1

APPENDIX

VARIATION OF IRRADIANCE ACROSS THE ILLUMINATED SPOT

As noted in Section 1, the announced width of the spot of light on the ground was to have been 6 to 8 km in the second *Znamya* attempt. We again assume 6 km, because this gives us the "worst case." Also, 8 km may correspond to nonvertical incidence of the beam. Again, 6 km corresponds to an angular width of the spot on the ground of about one degree, as seen from the spacecraft. In comparison, the angle subtended by the Sun's disk, at the Earth, is about 1/2 degree, and therefore, a perfectly flat mirror would produce a spot of light about 3 km wide on the ground (1/2 degree × $\pi/180$ radians per degree × 360 km = 3.14 km). Also, tilting such a mirror by half a degree would displace such a spot about 3 km. Since 3 km + 3 km = 6 km = the assumed width of the spot on the ground, the *Znamya* mirror, as announced, can be considered as a mosaic of smaller flat mirrors whose maximum tilt relative to each other is 1/2 degree. We note that all 3 km disks inside a 6 km circle will overlap at its centre (Figure 1). Therefore, as viewed by an observer at the centre of the illuminated spot on the ground, every part of the mirror would be seen to be reflecting some portion of the Sun's surface: so for this observer, the mirror would be seen as *fully illuminated*.

For an observer located at a distance *r* from the centre of the illuminated spot, we calculate the fractional irradiance as follows. We note that the *centres* of the 3 km disks all lie within a radius of 1.5 km from the centre of the 6 km illuminated spot (Figure 2). We assume that within this 1.5 km radius, these centres are distributed randomly (uniformly), implying that the tilts of all the small mirrors in the

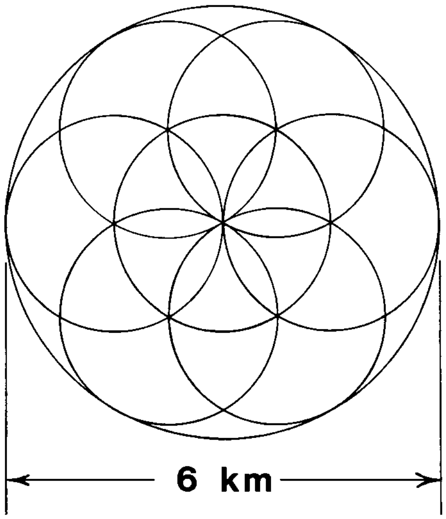

FIG.1 — All 3 km disks inside a 6 km circle will overlap at its centre.

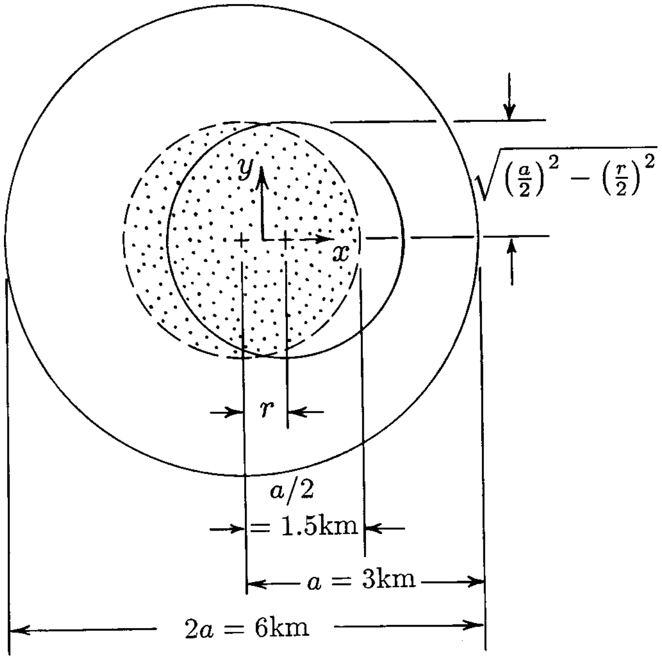

FIG. 2 — An observer at radius *r* sees an amount of illumination proportional to the area of overlap between the two 3 km disks shown. The disk whose boundary is shown as dashed contains the central points of all the overlapping illuminated spots. The other 3 km disk contains all such points located within 1.5 km of the observer.

assumed mosaic are distributed in the same way. Therefore, an observer at radius r from the centre of the 6 km spot will see illumination from all 3 km disks whose centres lie less than 1.5 km from his/her location, and this observer will then see an irradiance proportional to the area of overlap of the two 3 km (diameter) circles shown in Figure 2.

We calculate this area as follows. We choose a new origin halfway between the centres of the two 3 km circles in Figure 2. Then the undisplaced circle has the equation:

$$\left(x+\frac{r}{2}\right)^2+y^2=\left(\frac{a}{2}\right)^2 \Rightarrow x_\pm=-\frac{r}{2}\pm\sqrt{\left(\frac{a}{2}\right)^2-y^2}$$

For a separation distance r between these two centres, the overlap area $A(r)$ is now given by:

$$A=4\int_{y=0}^{y=\sqrt{\left(\frac{a}{2}\right)^2-\left(\frac{r}{2}\right)^2}} x_+\,dy=4\int_0^{\frac{1}{2}\sqrt{a^2-r^2}}\left[\sqrt{\frac{a^2}{4}-y^2}-\frac{r}{2}\right]dy$$

$$=\int_{\alpha=0}^{\alpha=\cos^{-1}(r/a)} a^2\cos^2\alpha\,d\alpha-2r\int_0^{\frac{1}{2}\sqrt{a^2-r^2}}dy=\frac{a^2}{2}\cos^{-1}\left(\frac{r}{a}\right)-\frac{r}{2}\sqrt{a^2-r^2}$$

As $r \longrightarrow 0$, $A \longrightarrow {}^1\!/_4\,\pi a^2$, as expected. As $r \longrightarrow a$, $A \longrightarrow 0$, also as expected. Therefore the normalized irradiance $I(r)/I(0)$ is equal to:

$$A(r)/A(0)=\left[\frac{a^2}{2}\cos^{-1}\left(\frac{r}{a}\right)-\frac{r}{2}\sqrt{a^2-r^2}\right]\Big/\left(\frac{\pi a^2}{4}\right)$$

$$=\frac{2}{\pi}\left[\cos^{-1}\left(\frac{r}{a}\right)-\frac{r}{a}\sqrt{1-\left(\frac{r}{a}\right)^2}\right]$$

This result is plotted in Figure 3. The sharpness of the peak in Figure 3 is a consequence of our fortuitous assumption that the angle subtended at the spacecraft by the illuminated spot is exactly twice that subtended by the Sun's disk. We have also ignored effects of solar limb-darkening on this result.

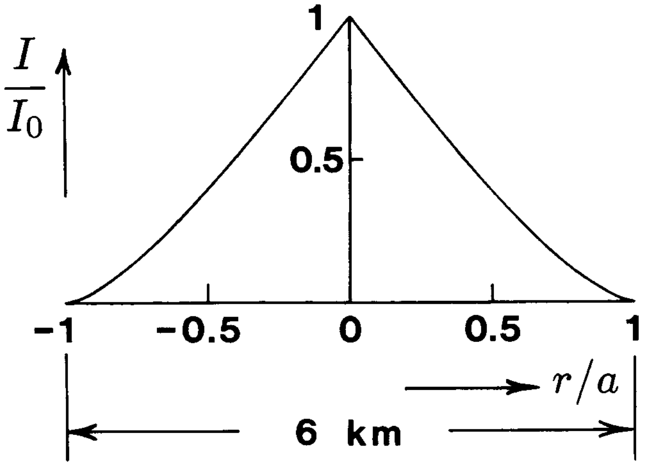

Fig. 3 — Variation of normalized irradiance (energy per unit area) with distance across the illuminated spot on the ground.

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JAMES G. LAFRAMBOISE is an amateur astronomer and a professional physicist. His professional interests involve analyzing the electrically disturbed regions which are created around spacecraft by their plasma environment. He has worked closely with spacecraft experimenters in studies of high-voltage antennas, instruments for electrical measurements, electrical discharge hazards, current-carrying tethers, and high-voltage electric power systems. As an amateur astronomer, he has benefited enormously from his association with the professional astronomers at the York University Astronomical Observatory. He especially enjoys Messier-hunting, star parties with astronomy students, and giving tours of the universe to young people of all ages. He is keenly interested in the battle against light-pollution.

B. RALPH CHOU is an Associate Professor of Optometry at the School of Optometry, University of Waterloo. His research is in environmental and industrial eye hazards, particularly ocular protection from optical radiation and impact hazards. He is Academic Editor of the Canadian Journal of Optometry *and Vice Chair of the Canadian Standards Association Technical Committee on Industrial Eye and Face Protection. A life member of the Toronto Centre, he has served as President, Secretary and Treasurer of that Centre, as well as National Newsletter Editor, National Treasurer and currently Assistant Editor with the* Journal. *An avid solar-eclipse chaser, he has observed 13 total and 2 annular eclipses, and is a contributor to the* NASA Eclipse Bulletins. *He received the* RASC *Service Award Medal in 1999 and will mark 30 years as a member of the Society this fall.*

PHOTOELECTRIC MAGNITUDE MEASUREMENTS OF MARS MADE DURING THE 1998–2000 APPARITION

by Richard W. Schmude, Jr.
Kingston Centre, RASC
Gordon College, Barnesville, GA
Electronic Mail: schmude@falcon.gdn.peachnet.edu

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Abstract. An intense photoelectric magnitude study of Mars was carried out between 1998 and 2000. The selected normalized magnitudes for Mars in 1999 are: B(1,0) = -0.30 ± 0.02, V(1,0) = −1.60 ± 0.02, R(1,0) = −2.68 ± 0.03 and I(1,0) = −3.17 ± 0.03. The selected solar phase angle coefficients for Mars are: c_B = 0.0185 ± 0.0010, c_V = 0.0152 ± 0.0010, c_R = 0.0110 ± 0.0010 and c_I = 0.0109 ± 0.0010. In late 1998 and early 1999, Mars was 0.04 magnitude brighter than was predicted in the Astronomical Almanac. The brightness and colour measurements of Mars are consistent with mid–summer being cloudier than mid–spring.

Résumé. Une étude de la magnitude photoélectrique intense de Mars a été effectuée entre 1998 et 2000. Les magnitudes normalisées de Mars sélectionnés en 1999 sont : B(1,0) = −0.30 ± 0.02, V(1,0) = −1.60 ± 0.02, R(1,0) = −2.68 ± 0.03 and I(1,0) = −3.17 ± 0.03. Les coefficients de l'angle de la phase solaire sélectionnés pour Mars sont : c_B = 0.0185 ± 0.0010, c_V = 0.0152 ± 0.0010, c_R = 0.0110 ± 0.0010 and c_I = 0.0109 ± 0.0010. Vers la fin de 1998 et au début de 1999, Mars présentait une magnitude de 0.04 plus brillante que prévue à l'Almanac astronomique. Ces mesures de la brillance et de la couleur de Mars se conforment à une mi–été plus nuageuse que la mi–printemps. SEM

1. Introduction

Mars reached opposition on April 24, 1999 and attained an angular size of 16 arc–seconds, which is the largest it has been since 1990. By opposition day, most of the north polar cap had dissipated; it was mid–summer (L_s = 129°) in Mars' northern hemisphere. In 1999, the *Mars Global Surveyor* probe reached its mapping orbit and sent back hundreds of high resolution images of that planet. This probe also measured the topography of Mars to an accuracy of 13 meters (*Sky & Telescope* 1999). Professional astronomers have found that water vapor was more abundant on Mars in 1999 than in previous years (McKim, 1999, BAA Circ. #5). Tom Clancy also reported that temperatures were 5–10 Kelvins higher on Mars in early 1999 compared to 1997 (McKim, 1999, BAA Circ. #5). Earth based observers noted two Martian dust storms in late February and late March of 1999, both occurring near Vallis Marineris. Observers also noticed the gradual brightening of Hellas, which peaked in February and March, and several equatorial cloud bands that were most frequent in February and March. Both the *Hubble Space Telescope* and Earth-based observers recorded a huge cyclone near 85°W, 65°N in late April; this storm had a diameter of 1500 km. These observations as well as others are explained further elsewhere (McKim 1998–1999; Minami, 1998–1999).

The author is planning to make photoelectric measurements of Mars for another three oppositions, and this will cover all seasons and latitudes for that planet. Brightness and color measurements will then be compared to cloud and polar cap behavior. Finally this complete set of photometric data will yield better values for the geometric and bond albedos for all orientations of Mars and may improve global climate calculations for Mars. In this report the author summarizes his photoelectric magnitude measurements of Mars, which were made between Nov., 1998 and March 2000.

2. Method

An SSP–3 solid–state photoelectric photometer with filters transformed to the Johnson BVRI system were used in all measurements; this instrument is described elsewhere (Optec 1997; Schmude 1992). The peak wavelengths and half–maximum bandwidths for the filter–detector systems are: B–(420 nm and 100 nm), V–(540 nm and 85 nm), R–(700 nm and 210 nm) and I–(860 nm and 220 nm). In all of the measurements through September 5, 1999, a 0.51-metre Newtonian telescope was used for the measurements. This instrument was stopped down to an aperture of 0.05 metres to prevent saturation of the detector.

Characteristics of the comparison and check stars used in the photoelectric measurements are summarized in Table I; α Boo was the comparison star for all measurements between November 29, 1998 and May 20, 1999. Although α Boo is listed as a standard star in The Astronomical Almanac (1998), it is listed as a questionable variable star in Hirshfeld *et al.* (1991) and as a variable star with an amplitude of less than 0.1 magnitude in Sinnott & Perryman (1997). Indeed, it appears that α Boo is a variable star; however, the change in magnitude is less than 0.02 magnitude (Belmonte *et al.* 1990; Hatzes & Cochran, 1994). In fact, this star is probably a member of a new type of low amplitude K–type variable star (Edmonds & Gilliland 1996). The small variation in brightness of α Boo is small and can be considered negligible. The average measured magnitude of the check star, ϵ Crv, are 4.33 ± 0.03, 2.98 ± 0.01, 2.02 ± 0.02 and 1.38 ± 0.03 for the B, V, R and I filters, respectively. These measurements are close to the literature values listed in Table I. The purpose of using a check star is to confirm the magnitude of the comparison star.

All photometric measurements were corrected for both atmospheric extinction and transformed in the same way as is described in Hall and Genet (1988). Transformation coefficients were measured using the two star method. The two stars used were χ Peg and γ Peg since these are listed as standard stars in The Astronomical Almanac (1998);

the resulting transformation coefficients are: 0.091, –0.019, –0.072 and –0.107 for the B, V, R and I filters, respectively. Each of these values has an estimated uncertainty of 0.01, and part of this uncertainty is due to the slight variability of χ Peg (Sinnott & Perryman 1997).

3. Results

Individual photoelectric magnitude measurements of Mars are listed in Table II. As in previous studies, Mars was broken up into 12 longitude ranges. Normalized magnitudes at a solar phase angle α, for each filter were calculated. The normalized magnitude of Mars for the V–filter was calculated from:

$$V(1,\alpha) = -5.000 \log [rd] + 2.5 \log [k], \qquad (1)$$

where V is the measured V–filter magnitude, r is the Mars–Earth distance, d is the Mars–Sun distance and k is the fraction of Mars' disc that is illuminated by the Sun as seen from the Earth; both r and d are in astronomical units. Normalized magnitudes for the B, R and I filters were calculated in a similar way. The normalized magnitude for each filter was then plotted against the solar phase angle (α) as in previous studies; there was a total of 48 graphs (four filters for 12 longitude ranges); a sample graph is shown in figure 1. The data for each graph were fitted to a least squares routine and both the slope and y–intercept were evaluated. The slope is the solar phase angle coefficient [c_B, c_V, c_R and c_I for the B, V, R and I filters] and the y–intercept is the normalized magnitude at a solar phase angle of 0°; the symbols for the normalized magnitude for $\alpha = 0°$ in the B, V, R and I filters are: B(1,0), V(1,0), R(1,0) and I(1,0). Average values of the solar phase angle coefficient and normalized magnitude for each filter were determined from an equally weighted average of the values of all 12 longitude ranges; the results are listed in Table III.

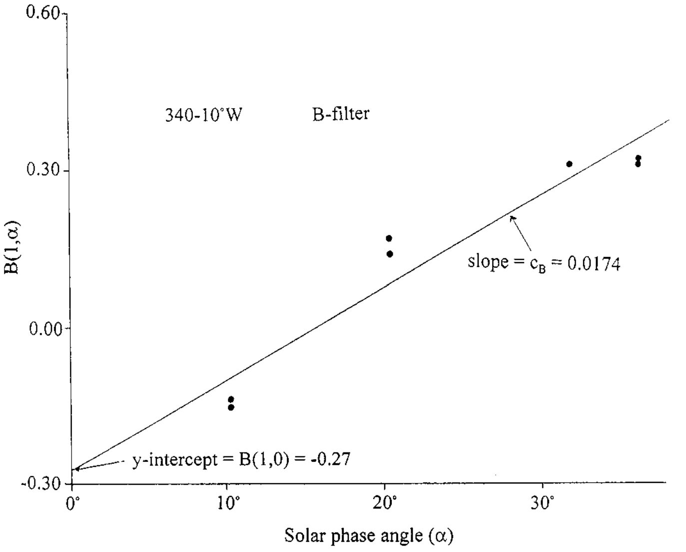

Fig. 1 — A plot of the normalized magnitude versus the solar phase angle.

4. Discussion

The normalized magnitudes at a solar phase angle of 0°for the last four Mars apparitions are summarized in Table IV along with the B–V, V–R, and B–R colour indices. One trend in the data is that Mars was redder in the 1995 and 1997 apparitions compared to the 1999 apparition. This colour change may be seasonal and due to the 1999 measurements being made during a cloudy season on Mars. Beish & Parker (1988) report that the frequency of discrete clouds reaches a peak in early northern summer (L_s = ~ 110°). Increased clouds will make Mars both brighter and less red. Based on the cloud trends summarized by Beish & Parker (1988) the author expects Mars to be redder and have a dimmer V(1,0) value in 2001, since the number of clouds are expected to be lower.

Photoelectric magnitude measurements were made on February 22, 1999 at central meridians of 67°, 80° and 96°W, which were near a dust storm (McKim, BAA Circ. #4). The B–R colour indices, when the solar phase angle is taken into account, are about 0.05 magnitude higher than expected, indicating that the dust made Mars a little redder.

Table V lists the difference between maximum and minimum brightness at α=0° for different filters during the last four apparitions. The major trend here is that the difference between the brightest and dimmest longitudes increases with increasing wavelength. This is consistent with the fact that blue light photographs show less contrast than red light photographs (Slipher 1962). Figure 2 is a plot of the 1999 B–R colour indices at α = 0°, 18° and 36° as a function of the longitude of the central meridian. The figure shows that Mars is reddest at longitudes from 100°–220°W; furthermore the B–R colour indices changed by up to 0.3 magnitude (or about 30%) for different longitudes. It is therefore concluded that Mars' colour changed by up to 30% as a function of longitude in 1999.

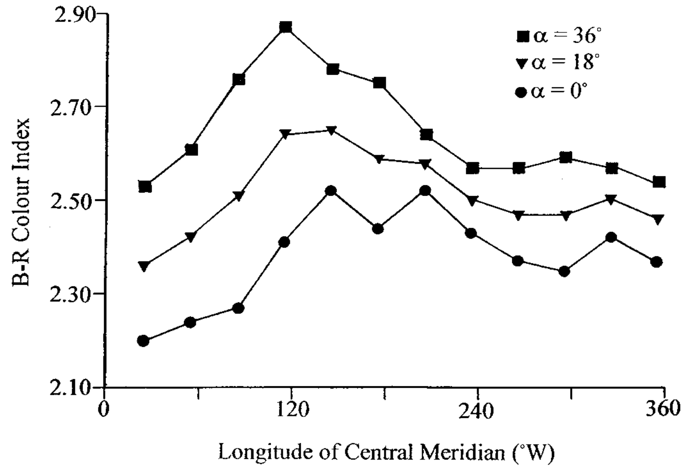

Fig. 2 — A plot of the measured B–R colour indices for solar phase angles of 0, 18 and 36 degrees as a function of longitude for 1999.

The V–filter magnitude between November 29, 1998 and May 20, 1999 are, on average, 0.04 magnitude brighter than the values listed in The Astronomical Almanac (1997, 1998). The discrepancy was even greater for the longitudes between 70° W and 220° W where differences of 0.06 to 0.11 magnitude were observed. These observations are consistent with the surface of Mars; essentially there are fewer dark areas in the northern hemisphere between 70° W and 220° W than at other longitudes, and so Mars should be brighter when the central meridian is between 70° W and 220° W longitude.

5. Summary

Besides the values in Table III, it is concluded that: 1) The normalized magnitude of Mars in the B, V, R and I filters became more negative between 1993 and 1999, 2) Mars became less red in 1999 probably because of more white Martian clouds as would be expected for the Martian season during which measurements were made, 3) The difference between the brightest and dimmest longitudes increased from 0.19 magnitude in the B–filter to 0.39 magnitude in the I–filter, for the 1993–99 oppositions, 4) the B–R colour index changed by 0.3 magnitude as Mars rotated in 1999, and 5) Mars was, on average, very close to predicted V–filter magnitude in the Astronomical Almanac. The author is planning to make photoelectric measurements of Mars for another three oppositions, and this will cover all seasons and latitudes for that planet. Brightness and colour measurements will then be compared to cloud and polar cap behavior. Finally this complete set of photometric data will yield better values for the geometric and bond albedos for all orientations of Mars and may improve global climate calculations for Mars.

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Richard W. Schmude, JR.
Gordon College
419 College Drive
Barnesville, Georgia, 30204

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Table I

Comparison and check stars used in the photoelectric magnitude study of Mars in 1999.
All right ascensions and declinations are from Hirshfeld *et al.* (1991) and
all magnitudes are from Iriarte *et al.* (1965)

Star	Right Ascension	Declination	Magnitude			
			B	V	R	I
α Boo	$14^h 16^m$	$19^\circ 11^m$	1.18	-0.06	−1.04	−1.70
ϵ Crv	$12^h 10^m$	$-22^\circ 37^m$	4.32	2.98	2.05	1.40
δ Sco*	$16^h 00^m$	$-22^\circ 37^m$	2.23	2.33	---	---
γ Cyg*	$20^h 22^m$	$40^\circ 15^m$	2.90	2.23	---	---
α And*	$00^h 08^m$	$29^\circ 05^m$	1.95	2.06	---	---

*These were the comparison stars for the September 5, 1999, January 16, 2000 and March 5, 2000 V–filter measurements and so R and I magnitudes were not used and are not listed. The B–filter magnitudes of these stars were used in the transformation corrections.

Table II

Photoelectric Magnitude Measurements of Mars made in 1998–2000

Date (U.T.)	Central	L_s	Solar Phase		Magnitude		
(°W)	Meridian (deg.)		Angle (deg.)	B	V	R	I
1998							
Nov. 29.385	198	63	32.7	2.80	1.39	0.15	−0.34
Nov. 29.421	211	63	32.7	2.81	1.41	0.18	−0.30
Nov. 29.447	220	63	32.7	2.81	1.42	0.19	−0.31
Nov. 29.475	229	63	32.7	2.81	1.43	0.21	−0.27
Nov. 29.496	237	63	32.7	2.78	1.43	0.21	−0.26
1999							
Jan. 11.335	126	82	36.2	2.47	0.91	−0.45	−0.99
Jan. 11.345	130	82	36.2	2.44	0.89	−0.42	−0.98
Jan. 11.379	142	82	36.2	2.36	0.87	−0.45	−0.99
Jan. 11.424	157	82	36.2	2.32	0.87	−0.43	−0.97
Jan. 11.459	170	82	36.2	2.33	0.88	−0.42	−0.95
Jan. 11.467	172	82	36.2	2.34	0.88	−0.41	−0.93
Jan. 25.340	354	88	36.2	2.00	0.63	−0.53	−1.01
Jan. 25.377	8	88	36.2	2.00	0.65	−0.51	−0.98
Jan. 25.428	26	88	36.2	1.98	0.65	−0.54	−1.02
Jan. 25.450	33	88	36.2	1.97	0.62	−0.57	−1.03
Jan. 25.479	43	88	36.2	1.95	0.60	−0.58	−1.05
Feb. 5.307	239	93	35.6	1.77	0.35	−0.78	−1.23
Feb. 5.347	253	93	35.6	1.79	0.41	−0.77	−1.23
Feb. 5.373	262	93	35.6	1.80	0.42	−0.77	−1.23
Feb. 5.422	279	93	35.6	1.79	0.40	−0.79	−1.25
Feb. 5.434	283	93	35.6	1.79	0.41	−0.79	−1.26
Feb. 5.458	291	93	35.6	1.79	0.41	−0.80	−1.26
Feb. 5.478	299	93	35.6	1.80	0.40	−0.80	−1.27
Feb. 22.268	67	101	33.3	1.36	0.01	−1.30	−1.80
Feb. 22.310	80	101	33.3	1.39	−0.03	−1.32	−1.83
Feb. 22.358	96	101	33.3	1.36	−0.05	−1.36	−1.89
March 4.258	329	105	31.9	1.20	−0.26	−1.36	−1.82
March 4.285	338	105	31.9	1.18	−0.24	−1.37	−1.85
March 4.324	352	105	31.9	1.19	−0.20	−1.36	−1.82
April 2.180	38	118	17.4	0.12	−1.15	−2.22	−2.75
April 2.202	45	118	17.4	0.13	−1.15	−2.24	−2.75
April 2.225	53	118	17.4	0.16	−1.14	−2.27	−2.76
April 2.269	69	118	17.3	0.17	−1.16	−2.34	−2.81
April 2.283	74	118	17.3	0.16	−1.18	−2.35	−2.80
April 12.160	302	123	10.4	−0.24	−1.50	−2.64	−3.08
April 12.258	336	123	10.3	−0.08	−1.43	−2.56	−3.00
April 12.293	349	123	10.3	−0.17	−1.46	−2.56	−3.02
April 12.302	352	123	10.3	−0.15	−1.45	−2.57	−3.03
April 18.224	271	126	5.5	−0.20	−1.58	−2.64	−3.13
April 18.246	279	126	5.5	−0.28	−1.60	−2.64	−3.12
April 18.272	288	126	5.5	−0.29	−1.62	−2.67	−3.15
April 18.327	308	126	5.4	−0.24	−1.55	−2.66	−3.15
April 18.360	319	126	5.4	−0.22	−1.57	−2.67	−3.16
April 18.396	332	126	5.4	−0.23	−1.63	−2.64	−3.18
April 19.123	227	126	4.8	−0.41	−1.73	−2.88	−3.39
April 19.145	235	126	4.8	−0.35	−1.66	−2.83	−3.29
April 19.179	247	126	4.8	−0.37	−1.67	−2.79	−3.28
May 1.290	181	132	5.7	−0.38	−1.62	−2.78	−3.32
May 2.104	108	133	6.4	−0.38	−1.75	−2.94	−3.46
May 2.129	116	133	6.4	−0.41	−1.74	−2.94	−3.42

May 2.147	122	133	6.4	−0.44	−1.76	−2.94	−3.46
May 2.201	142	133	6.5	−0.40	−1.76	−2.95	−3.46
May 2.220	148	133	6.5	−0.36	−1.76	−2.95	−3.45
May 2.252	159	133	6.5	−0.38	−1.77	−2.94	−3.42
May 2.271	166	133	6.5	−0.38	−1.76	−2.95	−3.42
May 2.317	183	133	6.6	−0.40	−1.76	−2.91	−3.43
May 2.344	191	133	6.6	−0.47	−1.80	−2.97	−3.49
May 2.361	197	133	6.6	−0.34	−1.77	−2.94	−3.46
May 9.082	38	136	12.2	−0.24	−1.49	−2.55	−3.01
May 9.103	45	136	12.2	−0.27	−1.51	−2.58	−3.03
May 9.229	88	136	12.3	−0.31	−1.62	−2.74	−3.25
May 9.265	102	136	12.3	−0.38	−1.69	−2.79	−3.34
May 20.082	300	141	20.5	0.05	−1.25	−2.42	−2.89
May 20.107	309	141	20.5	0.06	−1.24	−2.43	−2.91
May 20.141	321	141	20.5	0.11	−1.22	−2.43	−2.92
May 20.167	330	141	20.5	0.09	−1.23	−2.42	−2.90
May 20.201	342	142	20.5	0.06	−1.25	−2.42	−2.86
May 20.224	350	142	20.6	0.09	−1.25	−2.41	−2.88
Sep. 5.062[a]	353	200	44.0	---	0.59	---	---
2000							
Jan. 16.015[a]	111	283	29.2	---	0.99	---	---
March 5.043[a]	352	313	21.2	---	1.18	---	---

[a]The comparison star on the September 5 measurement was δ Sco; the comparison star for the January 16 measurement was γ Cyg while α And was the comparison star for the March 5 measurement. The September 5, January 16 and March 5 measurements were made when Mars was at low elevations and were not used in computing the values in Table 3.

TABLE III

Selected normalized magnitudes and solar phase angle coefficients for Mars in 1998-2000

Filter	Normalized Magnitude	Solar Phase Angle Coefficient (mag/deg)	Mean Apparition Magnitude
B	−0.30 ± 0.02	0.0185 ± 0.0010	−0.79 ± 0.02
V	−1.60 ± 0.02	0.0152 ± 0.0010	−2.09 ± 0.02
R	−2.68 ± 0.03	0.0110 ± 0.0010	−3.17 ± 0.03
I	−3.17 ± 0.03	0.0109 ± 0.0010	−3.66 ± 0.03

TABLE IV

Normalized magnitudes and colour indices for Mars during the 1993-99 apparitions. The solar phase angle of Mars equals zero degrees for all values; data are from Schmude & Bruton (1994) and Schmude (1996, 1998)

Apparition	B (1,0)	V (1,0)	R (1,0)	I (1,0)	B–V	V–R	B–R
1993	−0.23	−1.49	−2.60	−3.01	1.26	1.11	2.37
1995	−0.20	−1.54	−2.67	−3.14	1.34	1.13	2.47
1997	−0.26	−1.58	−2.72	−3.16	1.32	1.14	2.46
1999	−0.30	−1.60	−2.68	−3.17	1.30	1.08	2.38

TABLE V

Difference between maximum and minimum brightness of Mars as that planet rotates on its axis for different filters and in different years at $\alpha = 0°$

Apparition	B-filter	V-filter	R-filter	I-filter
1992–93	0.18	0.21	0.31	0.39
1994–95	0.21	0.19	0.23	0.42
1996–97	0.17	0.24	0.25	0.31
1998–99	0.20	0.24	0.40	0.44
Average	**0.19**	**0.22**	**0.30**	**0.39**

RICHARD W. SCHMUDE, Jr. grew up in Houston, Texas and graduated from Texas A&M University in 1994 with a Ph.D degree in Chemistry under the guidance of Dr. Karl Gingerich. Since 1994, Richard has taught Chemistry, Astronomy and Physical Science at Gordon College in Barnesville, GA. He has attended GA's in Windsor, Kingston, Toronto and Winnipeg, Canada. He has given over 150 professional and community talks about Astronomy and Chemistry. He is a member of the American Association of Variable Star Observers, The Association of Lunar and Planetary Observers, The Atlanta Astronomy Club, The Flint River Astronomy Club and the Kingston Centre of the Royal Astronomical Society of Canada.

ABSTRACTS OF PAPERS PRESENTED AT THE 2000 CASCA ANNUAL MEETING HELD IN VANCOUVER, MAY 25-28, 2000

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

3D Radiative Transfer to Compute the Inhomogeneous Reionization, Alexei Razoumov, University of California, San Diego

A numerical scheme for the solution of the three-dimensional, frequency and time dependent radiative transfer equation with variable optical depth is developed for modelling the reionization of the Universe. Until now, the main difficulty in simulating the inhomogeneous reionization has been the treatment of cosmological radiative transfer. The proposed approach is drastically different from previous studies, which either resorted to a very simplified, parametric treatment of radiative transfer or relied on one-dimensional models. The algorithm presented here is based on explicit multidimensional advection of wavefronts at the speed of light, combined with the implicit solution of the local chemical rate equations separately at each point. We have shown that this method is an attractive choice for simulation of astrophysical ionization fronts, particularly when one is interested in covering a wide range of optical depths within a 3D clumpy medium. This scheme is then applied to the calculation of time-dependent, multi-frequency radiative transfer during the epoch of first object formation in the Universe. In a series of models, the 2.5 Mpc (comoving) simulation volume is evolved between the redshifts of $z = 15$ and 10 for different scenarios of star formation and quasar activity. The current numerical resolution is 128^3 (spatial) $\times 10^2$ (angular) $\times$ 3 (frequency), and at each point in space we calculate various stages of hydrogen and helium ionization accounting for nine chemical species altogether. These models can be used to predict the observational signatures of the earliest astrophysical objects in the Universe. At present, the calculations are accurate enough to resolve primordial objects to the scale typical of globular clusters, 1×10^6 solar masses.

Contributed Papers/Présentations orales

Unveiling Dwarf Galaxies in Low Redshift Galaxy Clusters, W. A. Barkhouse and H. K. C. Yee, University of Toronto, and O. López-Cruz, Instituto Nacional de Astrofísica Óptica y Electrónica, Mexico

We have recently completed a comprehensive photometric survey of 27 Abell clusters ($0.02 < z < 0.04$) with the 8k mosaic camera on the KPNO 0.9-m telescope. The dwarf galaxy population has been characterized by constructing luminosity functions, measuring spatial variations, dwarf-to-giant galaxy ratios, and colour distributions. Preliminary results for several galaxy clusters will be presented.

The Magnetic Field Configuration in the Outer Region of the Galaxy, J.C. Brown and A.R. Taylor, University of Calgary

Several studies have demonstrated that the Galaxy has a magnetic field with an ordered large-scale structure. We do not, however, know how that field is generated, how it is evolving, or what its overall structure is. It is generally believed that the magnetic field follows the basic pattern of the spiral arms of the Galaxy, yet the field's strength and direction between and within the arms is unknown. Different theoretical models of the generation and evolution of the magnetic field predict different directions. Studying the magnetic field and looking for "reversals," where the field's direction changes by 180 degrees, will help identify which model is correct. The focus of our research is to use rotation measures from extragalactic point sources in the Canadian Galactic Plane Survey (CGPS), in conjunction with established data from pulsars to infer information about the Galaxy's magnetic field. In particular, we hope to resolve the debate over how many (if any) reversals are present in the outer region of the Galaxy. In our paper, we will discuss the status of our work to address this question and present a comparison between measured rotation measures and those calculated from different magnetic field models of the outer Galaxy.

H II Region NRAO 655 and its ISM Environment, T. Foster and D. Routledge, University of Alberta

New radio and optical observations of Galactic surroundings near (l, b) = (94°, 2°) are presented, revealing new information about the interstellar medium and objects in this locale. Of eleven Galactic objects in this neighbourhood, for example, only two have published distance estimates. In this paper, we present new CGPS radio continuum observations of the H II region NRAO 655 (G93.4 + 1.8) at 21 cm and 74 cm, and optical and radio emission line observations at 656 nm and 21 cm. The radio spectrum of this object confirms its emission as thermal in origin. From the CGPS H I data we find an atomic hydrogen cavity associated with this object at $\nu = -71.5$ km s^{-1}. This H I cavity corresponds in position and size to the brightest radio continuum emission from NRAO 655. The corresponding kinematic distance is 8.8 kpc, and NRAO 655's linear size is therefore 70 pc $\times$ 130 pc. To confirm the ($\lambda = 21$ cm) H I velocity we present the first recombination line detection of NRAO 655 H158 (α) line, $\nu = -72$ km s^{-1}, width 40 km s^{-1}, and the first observations of a molecular cloud interacting with NRAO 655 (at -72 km s^{-1}). The first detection of NRAO 655 in (Hα) emission line is also presented, and astrophysical properties are determined from the nebula's (Hα) emission line luminosity. We find good correlation between optical and radio morphology and between IRAS 60 μm infrared and radio morphology. We find anti-correlation between optical and infrared features, suggesting absorption of (Hα) light emitted from NRAO 655 by dust present in the nebula. A physical model for NRAO 655 and its environment is proposed.

Sub-millimetre Polarimetry of Star Forming Regions in Orion B, Gerald H. Moriarty-Schieven, National Research Council, Joint Astronomy Centre, Brenda Matthews, McMaster University, and Jason Fiege, Canadian Institute of Theoretical Astrophysics

Polarimetry of sub-millimetre dust emission allows one to trace the structure of magnetic fields perpendicular to the line-of-sight. We present polarimetric images, obtained with the SCUBA polarimeter at the James Clerk Maxwell Telescope, of three star forming regions within the Orion B molecular cloud. NGC 2024 contains a string of low- to intermediate-mass protostars embedded within a filamentary ridge, much like beads on a string. Percentage polarization is very small (< 2%) toward the ridge and increases away from the ridge to > 5%. The polarization is very ordered as well, with vectors along the ridge mostly parallel to the ridge, while vectors to the east and west of the ridge are oriented roughly +45° and –45° respectively with respect to the ridge. NGC 2071 IR contains a cluster of protostars dominated by a 15 solar mass YSO which drives a massive bipolar outflow. Toward the emission peak the polarization is very weak (< 1%), increasing away from the peak. The vector orientations are perpendicular to each other toward the north-east and south-west (*i.e.*, the orientation of the molecular outflow). The third region, LBS23 (HH 24-26) forms a chain of mostly isolated peaks. Here the polarization is very ordered, exhibiting a distinct change of direction in the south. These regions show polarization patterns which *cannot* be interpreted as due to uniform magnetic fields. One model which fits the data is that of a helical magnetic field inclined to the line-of-sight. This work is part of the Canadian Consortium for Star Formation Studies.

What MOST Can Tell Us about the Close-in Extrasolar Giant Planets, Sara Seager, Institute for Advanced Study, Princeton University

The discovery of 51 Peg b in 1995, only 0.05 AU from its parent star, heralded an unexpected, new class of planets. The recent transit detection of HD209458 b confirms that this class of extrasolar giant planets (CEGPs) — now with several members — are gas giants. Seven times closer to their parent stars than Mercury is to our Sun, the CEGPs are potentially bright in reflected light. With the ability to detect micromagnitude photometric variation, *MOST* will be able to observe the reflected light curves of the planet in the combined star + planet light. For a transiting planet, *MOST* may be able to detect moons and planetary rings (if they exist) as they occult the stellar disk. I will present results of theoretical computations, and discuss what can be inferred from *MOST* observations of a star with an orbiting CEGP.

The Chandra Observatory — Overview, Capabilities, Scientific Results, and Status, Martin Zombeck, Harvard-Smithsonian Center for Astrophysics

On July 23rd, 1999 the *Chandra X-ray Observatory* (CXO) was launched by NASA's Space Shuttle Columbia. The first celestial X-rays were observed on August 12th, 1999. Since then, after an initial on-orbit activation and calibration phase, the observing program was initiated. An overview of the *Chandra X-ray Observatory* will be presented along with its capabilities for high spatial resolution imaging and high resolution spectroscopy. Examples of a variety of initial and recent observations will be presented to highlight the observatory's capabilities and the level of science that can be done. The present status of the observatory and the observing program will be presented.

Poster Papers/Présentations "Posters"

FUSE Observations of the Subdwarf B Star PG 0749+658, P. Chayer, Johns Hopkins University/University of Victoria, R. G. Ohl and H. W. Moos, Johns Hopkins University

High-dispersion observations of the far-ultraviolet (FUV) spectrum of the subdwarf B star PG 0749+658 ($T_{\rm eff}$ = 24,600 K and log g = 5.5) reveal the presence of many photospheric and interstellar lines. The spectrum, obtained by the *Far Ultraviolet Spectroscopic Explorer* (FUSE), has a resolution of about R = 12000–15000 and covers a wavelength range of 905–1187 Å. We determine C, N, Si, P, S, Cr, Mn, Fe, and Ni abundances, and upper limits on the abundance of Cl and V, using a grid of synthetic spectra based on a LTE stellar atmosphere model. Abundance anomalies are observed in the atmosphere of this sdB star. He, C, N, Si, and Cl are depleted by a factor greater than 10 with respect to solar, while P, S, and Fe are diminished by less than a factor of 10. We measure a solar abundance of Cr and Mn, and a Ni enhancement of about 0.6 dex. We compute the predicted abundances within the framework of the equilibrium radiative levitation theory and compare them to the atmospheric observed abundances. The measured abundances are generally consistent with predictions based on the equilibrium radiative theory, except for He and Si. The under-abundances of He and Si are not explained by this theory alone.

A Side-band Separating Balanced Mixer for ALMA, Stephane Claude, Charles Cunningham, Jerry Sebesta, Luc Martin, and Lorne Avery, Herzberg Institute of Astrophysics, National Research Council

Current millimetre and sub-millimetre radio receivers generally rely on simple heterodyne mixers to down-convert the signal to the lower intermediate frequency. In this process the output of the mixer contains information received in both the upper and lower side-bands. This degrades the receiver performance as noise from the sky enters the unused side-band. Also, it can result in confusion as lines appearing in the spectra could have been received in either side-band. If offered, side-band separation is usually provided by a tuneable interferometer that terminates the unwanted side-band on a cold load. The Atacama Large Millimetre Array (ALMA) will have 64 antennas, each requiring receivers that cover 10 separate frequency bands. It is clear that for this project, interferometers cannot be used due to cost, size, and reliability considerations. In this paper we describe a mixer design that separates the side-bands internally and does so over a broad RF bandwidth. The mixer is physically very compact and has no moving parts. In addition, the mixer is balanced and as a result offers a very efficient mean of local oscillator injection. This is especially important for the ALMA project where local oscillator power is required over large bandwidths at high frequencies. The mixer is a split waveguide design. One in-phase power splitter divides the input signal and a 90 degree out of phase 3 dB hybrid coupler splits the local oscillator signal. After being combined using two 90 degree 3 dB hybrid couplers the signal and the local oscillator are injected into two balanced mixers. After down-conversion, the IF signal is separated into upper and lower side-bands using a micro-strip 90 degree 3 dB hybrid coupler.

Counting All the Stars, P. A. Delaney, York University, and R. M. Robb, University of Victoria

With the increasing availability of inexpensive CCD cameras and the improving situation with computer-IRAF resources, a new laboratory exercise has been developed that exposes students to a variety of interesting and useful astronomical concepts. Assuming a homogeneous distribution of stars and no interstellar extinction, a plot of the logarithm of the number of stars as a function of magnitude will have a slope of 0.6. The students use a SBIG ST-8 (or comparable) CCD camera with a 28-mm lens to obtain a wide field 10 second exposure of the night sky. After downloading this image into IRAF, DAOFIND is used to do the photometry to illustrate the relationship between the magnitude of the stars and the number of stars visible. When the students compare their results to the expected slope of 0.6, they find that it is significantly smaller. Discussion of this discrepancy illuminates the error in the assumptions. The same data can be used to crudely establish the central location of a cluster of stars. This exercise is useful at the first-or-second-year astronomy undergraduate level.

Diffuse Molecular Gas in the Milky Way, K. A. Douglas and A. R. Taylor, University of Calgary

Observations of the gas and dust content of high-latitude gas clouds have shown interesting relationships between the emission by the different constituents of these structures. Several studies comparing IRAS, H I and CO emission in these cirrus clouds have yielded evidence of a molecular component which is not traced by the emission of CO molecules (Reach *et al.* 1994, ApJ, 429, 672; Meyerdierks & Heithausen 1996, AA, 313, 929; Boulanger *et al.* 1998, AA, 332, 273). Infrared excess emission from IRAS data points to the possibility of a molecular gas component that is warmer and more diffuse than the component of molecular gas that is traceable by CO. In these studies, the "diffuse" component of molecular hydrogen is found to be comparable in mass to the H I content. This diffuse gas may be widely abundant in the plane of the Galaxy. If present, on the same scales as in these high latitude clouds, it has important implications for many areas of astrophysical interest. The Canadian Galactic Plane Survey (CGPS) offers an excellent opportunity to study the phenomenon of diffuse molecular gas in the plane of the Galaxy by combined analysis of pc-scale resolution images of CO, H i and dust emission over a large area of the Galactic disk.

A FUSE Survey of O vi in the Winds of LMC O Stars, A. W. Fullerton, University of Victoria/Johns Hopkins University, D. L. Massa, Raytheon ITSS, and J. B. Hutchings, DAO/HIA/NRC

High-resolution FUSE spectra of stellar wind profiles in the O VI resonance doublet are presented for a sample of O stars in the Large Magellanic Cloud. This transition is the best diagnostic of high-energy processes in the optical/UV range. It is present in the winds of all the stars in the sample, which cover spectral classes from O3 to B0.5 with emphasis on luminosity classes I–III. The strength and morphology of the P Cygni profiles change systematically along the temperature sequence: early types exhibit pronounced emission lobes, while later types show weaker emission but comparatively strong absorption at high velocity. This morphology suggests that the distribution of O *vi* ions is concentrated towards larger wind velocities, particularly for the later spectral types. Work is underway to quantify this distribution, in order to constrain the properties of the ensembles of embedded shocks that are the likely production mechanism for O *vi*.

Revisiting the Classics, R.F. Garrison, Christopher Capobianco and Cristina Fayet, David Dunlap Observatory, University of Toronto

The set of classical shell stars studied by Gulliver in the mid-1970s and by Merrill in the 1930s, 40s and 50s has been re-observed. The observations and reductions were carried out by two undergraduate students as part of a second-year, Research Opportunities Program at the University of Toronto. Shell stars have a wide variety of characteristics, which vary unpredictably, but with a characteristic timescale of the order of decades. A great deal can be learned by occasional monitoring of their spectra. This has not been done systematically since Gulliver's work. The 1.88-m telescope of the David Dunlap Observatory was used with the Cassegrain spectrograph and 1024 × 1024 CCD. The resulting two-pixel resolution is about one angstrom. Description of the current shell characteristics is given.

The Karma Astronomical Visualisation Software, R. Gooch, University of Calgary

Modern astronomical instruments are producing larger and larger quantities of data. New techniques are required to visualise and analyse these data. This poster discusses the Karma visualisation software (available for free down-load from `http://www.atnf.csiro.au/karma/`), which addresses these needs. The Karma visualisation software contains a set of programming libraries which provide a common infrastructure for a suite of visualisation tools. This design eases development of new visualisation tools and results in tools with a common user interface. A few features of this package are: support for a large variety of data formats, such as FITS, Miriad, GIPSY, DRAO, AIPS, AIPS++, Starlink and common image formats such as PPM, GIF, TIFF and so on, support for compressed data files and sub-sampling upon read support for astronomical co-ordinate systems (conventional FITS-style and DSS projections), including the ability to overlay images with different projections, pixel scales and rotations, linear, square-root and logarithmic intensity transformations, output PostScript and PPM for publication and output of FITS, Miriad and GIPSY for sub-sampled or computed datasets, axis labelling and user control of annotations, fully interactive zooming, panning and magnification, built-in analysis features (spectral, summed and radial profiles, Gaussian fitting, image statistics, moment maps, *etc.*) and much, much more. Karma comes with many specialised visualisation tools, some of which are displayed in this poster.

BD+61 2213: An Early-type Binary System in the Open Cluster NGC 7160, D. E. Holmgren, Brandon University, and A. E. Tarasov, Crimean Astrophysical Observatory

New spectral data and orbital parameters are presented for the short-period ($P = 1.2$ d) B3 binary system BD+61 2213. This star is a member of the open cluster NGC 7160. On the basis of a spectroscopic orbit and component line profiles (He I 6678 Å and Hα) recovered from a spectral disentangling solution, we find primary and secondary minimum masses of 4.3 and 3.2 solar masses respectively. As the system is known to be non-eclipsing, we find a maximum orbital inclination of 53 degrees, which implies that the masses must be at least 8.5 (primary) and 6.2 (secondary) solar masses. From measures of the equivalent width of the component He I 6678 Å profiles and comparisons of these data with non-LTE model atmosphere calculations, we conclude that both stars are slightly evolved.

The CFHT Open Star Cluster Survey: CCD Photometry of NGC 2099, Jasonjot Singh Kalirai, Harvey B. Richer, Patrick R. Durrell, and Gregory G. Fahlman, University of British Columbia, Gianni Marconi and Francesca D'Antona, Osservatorio Astronomico di Roma

We will present preliminary CCD photometric results for the open star cluster NGC 2099 (M37). NGC 2099 is the first of 19 carefully selected open clusters in a survey which was taken using the CFH12k CCD camera. This is the largest close-packed CCD currently being used for astronomical research. The goals of this survey are to identify a large collection of white dwarf stars (approximately 100) and to produce the first major observational tests for the theoretical models available for the white dwarf initial-final mass relationship. The colour-magnitude diagram of NGC 2099 shows that it contains a very rich stellar population and one of the longest (10 magnitudes) and most tightly constrained main sequences ever established for open star clusters. The CMD is also deep enough ($V = 24$) to reveal about a half dozen white dwarf candidates. Additionally, there is an excellent agreement between the theoretical isochrones and the data for the main sequence of the cluster. Consequently, our derivations of cluster parameters, such as age and distance, have refined previous values significantly.

The Canadian Galactic Plane Survey: Exploring the Interstellar Medium Using Radio Polarimetry, T. L. Landecker, P. E. Dewdney, A. D. Gray, and B. Uyanıker, National Research Council, Herzberg Institute of Astrophysics, Dominion Radio Astrophysical Observatory, J.C. Brown and A. R. Taylor, University of Calgary, and M. Peracaula, Universitat de Barcelona

The DRAO Synthesis Telescope is imaging a large part of the plane of the Milky Way as part of the Canadian Galactic Plane Survey, producing full polarization images of the continuum emission at 1420 MHz in addition to other data products. Widespread polarization structure is seen which has no corresponding variation in the total power of the emission. Because the effect is seen predominantly in polarization angle, it is interpreted as arising from irregular Faraday rotation in an intervening magneto-ionic medium (MIM), ionized gas threaded by magnetic fields. We refer to this as the Faraday screen. The state of the polarization when the signal arrives at the telescope tells more about the MIM through which the signal has passed than it tells about the source of the emission itself, the Galactic synchrotron emission, linearly polarized at the point of origin. Faraday rotation cannot destroy polarization, but rapidly varying Faraday rotation (for example in a dense, turbulent H II region) can reduce the apparent degree of polarization by vector averaging across the beam or the reception band of the telescope. Such effects are loosely referred to as "depolarization," and can be used to derive astrophysically useful information. Supernova remnants are polarized emitters, but at 1420 MHz their polarization does not stand out. Rather, the dominant feature in the images is the Faraday screen itself. This paper illustrates the use of polarimetry to explore physical conditions in the ISM.

On the Power-Law Relation between the Scalar Field and the Cosmic Expansion Factor in Brans-Dicke Theory, S. O. Mendes, M. N. Butler, and M. J. West, Saint Mary's University

We explore cosmological models in the context of Brans-Dicke theory. It is shown that a power-law relationship between the scale factor and the scalar field might be obtained in order to recover the Brans-Dicke expression for the effective gravitational constant. Furthermore, the exponent of such power-law relation is shown to constrain the coupling parameter Ω of the theory in a very specific way.

A Further Improved Light Curve Modeling Package: WD98, E.F. Milone, C. R. Stagg, and M.D. Williams, University of Calgary, J. Kallrath (BASF), Dirk Terrell (SwRI), and W. Van Hamme (FIU)

A guiding motivation for the development of efficient light curve modeling code is the opportunity to obtain fundamental stellar data from analyses of eclipsing binary light curves in the local field as well as in open and globular clusters. Previously we developed a self-iterating, damped least-squares light curve modeling program that was built around the Wilson-Devinney code of ~1993, but augmented by R. L. Kurucz's atmosphere models: WD95. (See Kallrath & Milone, Eclipsing Binary Stars: Modeling & Analysis, Springer, 1999, for a thorough discussion of the philosophy and practical considerations that led to this code). Meanwhile, R. E. Wilson further developed the basic code, replacing his least-squares engine, and expanding the treatment of reflection, limb-darkening, and adding treatment of local scattering effects. We have now applied all our previous improvements to this new WD version; we call the package WD98. In addition, this version can automatically generate a parameter grid with sequential variations of a certain parameter, *e.g.*, the mass ratio. This work has been supported by NSERC and the University of Calgary Research Grants Committee through grants to EFM.

IRMA: An Infrared Radiometer for the Correction of Phase Errors in Submillimetre Astronomical Interferometry, D. A. Naylor and G. J. Smith, University of Lethbridge, and P. A. Feldman, Herzberg Institute of Astrophysics

The performance of existing and planned millimetre and submillimetre astronomical arrays is limited by fluctuations in the amount of atmospheric water vapour along the antenna's line of sight. Correcting the resulting phase distortion of the received signals is seen as a significant technological challenge. Measurements of the variation in the line-of-sight water vapour abundance at the level of 1 micron precipitable water vapour on a time scale of 1 second and at arbitrary antenna positions are required. In this paper we will present the design of, and preliminary results obtained with, a water vapour monitor operating at infrared wavelengths which shows considerable promise for this application. Improvements in, and future plans for, the second generation water vapour monitor currently under development will be discussed.

VLBI Imaging of the Gravity Probe-B Guide Star HR 8703, R. R. Ransom, N. Bartel and M. F. Bietenholz, York University, D. E. Lebach, M. I. Ratner and I. I. Shapiro , CfA, and J.-F. Lestrade, Observatoire de Paris-Meudon

Multi-epoch VLBI observations at 3.6 cm have been made of the RS CVn binary star HR 8703 (IM Pegasi) in support of the NASA-Stanford relativity gyroscope experiment, Gravity Probe B (GP-B). We present phase-referenced maps of HR 8703 produced from thirteen sets of observations between January 1997 and December 1999. The maps reveal a variety of radio emission structures. Maps from temporal subsets of several observing sessions show both structural evolution in the stellar radio emission and sub-milliarcsecond motion of the radio brightness peak on hour time scales. We discuss what we have learned so far about the underlying processes responsible for the observed radio emission in HR 8703, and examine the implications of our astrometric results for the GP-B experiment.

Activity Related to Star Formation Associated with G79.3+0.3, R. O. Redman, NRC/HIA, D. D. Balam, University of Victoria, P. A. Feldman, NRC/HIA and S. J. Carey, Boston College

We have employed several telescopes in a multi-wavelength study of star forming activity in and around the nearby Infrared-Dark Cloud (IRDC) G79.3+0.3. The Midcourse Space Experiment (MSX) provided images of the region at 8 μm. The JCMT was employed with SCUBA to image the region at 850 and 450 μm, and with RxA3 to map the transitions of ^{13}CO (2-1) and C^{18}O (2-1). The NRC's 1.82-m Plaskett Telescope was used to image the region with various optical and IR filters, including the transitions of H α, [S ii] at 6716/6731Å, [Fe ii] at 1.64 μm, the S (1) line of H_2 (ν = 1-0) at 2.12 μm, and a narrow-band CO filter at 2.30 μm. The SCUBA images reveal a variety of objects in the early stages of star formation, including a Class-0 protostar and another protostar showing evidence of infalling gas. All of the bright, compact sources in the SCUBA images have line wings indicative of outflow. Magnetic fields inferred from the polarization images appear well-ordered and aligned with structures in the maps of dust and gas. The images made with the Plaskett Telescope have revealed the presence of one or two Herbig-Haro (HH) jets. The source of the strongest jet appears to be a T Tauri-like star embedded in an edge-on disk.

The Distribution of Calcium on the Surface of ϵ UMa: An Abundance Distribution Doppler Image, J. B. Rice and D. E. Holmgren, Brandon University

We present a surface abundance Doppler image of singly-ionized calcium for the Bp star ϵ UMa based on high signal-to-noise CCD spectra. This map shows striking similarities to that of neutral oxygen (Rice *et al.* 1997). The Ca ii 866.2 nm line has allowed us to obtain a detailed surface abundance map of calcium for ϵ UMa. The calcium abundance map has been used to locate the position of the positive magnetic pole on ϵ UMa at a longitude of 350.8 deg and a latitude of 25.8 deg. Calcium is distributed in a ring along the magnetic equator, along which the abundance is [Ca/H] = –5, close to a normal population I value. This represents an enhancement with respect to other regions by a factor of ~ 10^3. A secondary feature is present with [Ca/H]= –6.5. A chemically differentiated stellar wind is proposed as the main mechanism for generating the surface abundance distribution of calcium.

An Adaptive Optics Device for Teaching Astronomy, R. M. Robb and E. Steinbring, University of Victoria, and P. A. Delaney, York University

The excitement of high resolution imaging generated by the relatively expensive adaptive optics (AO) systems on large telescopes can be communicated to students. We purchased a tip-tilt AO system from the Santa Barbara Instruments Group for use with undergraduate labs at the University of Victoria. It has been mounted on a Celestron 8-inch located on the roof of our building. The ST-8 camera has an "imaging" CCD and mounted beside it is a small "guiding" CCD. The guiding CCD is read a few times per second and the position of the guide star is found. A calculation is made to find the correction displacement to tip or tilt the right-angle mirror enough to keep the guide star on the same pixels. The light going to the "imaging" CCD reflects from the same tip/tilt mirror so its image is also corrected. While the results are not as dramatic as one might hope, we do measure a small decrease in the FWHM of the images we have obtained. The students learn about feedback in electromechanical systems and the structure of images.

W UMa-type Binary Stars in Globular Clusters, Slavek M. Rucinski, David Dunlap Observatory, University of Toronto

A sample of 86 contact binary systems in 14 globular clusters with available colour index data in (*B-V*) or in (*V-I*) has been analyzed. A large fraction of all systems (at least one third) are numerous foreground Galactic Disk projections over long lines of sight to the clusters. Since the selection of the cluster members has been based on the MV (log P, colour) calibrations, the matter of a metallicity-correction required particular attention with the result that such a correction is apparently not needed at the present level of accuracy. Analysis of the colour-magnitude and period-colour relations shows that globular cluster members have different properties from the Galactic Disk contact systems. They are under-luminous mainly because of the smaller sizes and, consequently, have shorter orbital periods; the colour-index effect of the diminished blanketing is relatively less important, especially for (*V-I*). Because of the indications of a bias against discovery of small-amplitude systems below the Turn Off Point (TOP), efforts at determination of the frequency of occurrence of the contact systems below the TOP have been judged to be premature. However, the frequency among the Blue Straggler stars could be moderately well established at about 45 ± 10 BS stars per one contact BS binary; thus, contact binaries are about 3 times more common among the BS stars than among the Old Disk population dwarfs. Contact binary systems with periods longer than 0.6 days are absent in the sample, possibly because the more massive stars have left the contact binary domain.

Radial Velocities of IAU Standard Stars, Colin Scarfe, University of Victoria

As part of an ongoing international campaign, over 2000 radial-velocity observations of IAU standard stars have been obtained with the DAO radial-velocity scanner (RVS). In addition, over 100 new velocities from photographic plates have been added to those published ten years ago. The standard deviation of the RVS velocities is about three times larger than that of the photographic data. The RVS velocities were obtained with a variety of masks, but zero-point adjustments have been made empirically between them and between the RVS and the plates. An absolute zero-point has been provided by observations of bright asteroids. Comparison between the DAO data and large compilations published recently, by groups at the Center for Astrophysics and at the Geneva Observatory, reveals excellent agreement. In particular, a previously troublesome colour-dependent discrepancy between the Geneva observations and others has been eliminated, by adjustments made recently by the Geneva group, to an extent greater than even they had anticipated. The long task of revising the IAU standard system and providing a list of objects with radial velocities known absolutely to better than $100\ \mathrm{m\ s^{-1}}$, and constant at the same level, now seems to be nearly complete.

Interstellar Clumps: Physical Relations, Magnetism, and Energy, Jacques P. Vallée, National Research Council of Canada's Herzberg Institute of Astrophysics

Universal scaling relations exist in interstellar molecular clouds and clumps, governing the mean physical parameters such as the gas density n, diameter D, magnetic field B, and gas linewidth W (for recent reviews, see Vallée 1997, Fun. Cos. Phys., 19, 1; Vallée 1998, Fun. Cos. Phys., 19, 319). The relations follow the form: $<n> \sim D^c$, $<B> \sim <n>^k$, $<B> \sim <D>^p$, $<W> \sim <D>^q$. In molecular clouds, with $D > 1$ pc but < 100 pc, the exponents are: $c = -1.0$; $k = +0.5$; $p = -0.5$; and $q = +0.5$ (*e.g.*, Larson 1981, MNRAS, 194, 809). There is a natural separation between clouds and clumps, occurring near 0.5 pc. One does not expect the physical behaviours of clumps ($<$ 0.5 pc) to be the same as for clouds ($>$ 1 pc). In cold clumps, with $D > 0.01$ pc but < 0.50 pc, the gas density is higher than in clouds. Clumps are beginning to reveal their secrets, using observed findings at high angular resolution. Here I report on a statistical study of the exponent values c, k, p, q for clumps, and on the energy components for clumps. The exponent values for clumps are found to differ from those found by Larson (1981, MNRAS, 194, 809) for molecular clouds. The differences could be indicative of ongoing accretion processes in shocked media. The energy distribution in clumps reveals that the support against gravitational collapse in clumps with sizes $>$ 0.1 pc comes mainly from turbulent energy, while clumps with sizes $<$ 0.1 pc are supported by both magnetic and turbulent energies. The clump size of 0.1 pc is critical in many other aspects.

Pulsation of the δ Scuti star V369 Scuti, V. A. Volk, E. F. Milone, K. M. Volk and W. J. F. Wilson, University of Calgary

V369 Scuti is a low amplitude, short period δ Scuti star. These are known to pulsate in multi-frequency radial and non-radial modes. Photoelectric and CCD differential photometry in BVRI from the Rothney Astrophysical Observatory, University of Calgary, and radial velocity measurements from spectra taken at the Dominion Astrophysical Observatory, Victoria, were obtained over the summers of 1997 through 1999. Fourier analyses of the resulting magnitude, colour and velocity curves reveal periods consistent with the published principal period of 0.223 day and its frequency 1 cpd aliases. Multiple frequencies are clearly evident, some of which correspond to p-mode oscillations expected by stellar pulsation models. Using Baade-Wesselink precepts, attempts are being made to describe the change in shape and luminosity of the star.

Variable Analysis of Compact Sources in the Canadian Galactic Plane Survey, S. Wilder, and A. R. Taylor, University of Calgary, and L. A. Higgs, Herzberg Institute of Astrophysics

The 1420 MHz radio continuum images from Canadian Galactic Plane Survey contain tens of thousands of compact radio sources in the plane of the Galaxy down to a flux density limit of about 1 mJy. Some fraction of these sources will be exotic Galactic radio emitters such as energetic binary star systems, pulsars, and flare stars that can be identified by variable radio flux. We are carrying out a sensitive search for variable radio sources by combined analysis of the CGPS radio images and the Northern VLA Sky Survey, which has a similar radio continuum sensitivity and resolution to the CGPS. This variability search is an order of magnitude deeper than any previous survey for variable radio sources in the Galaxy. We present initial results of an analysis of about 5000 sources in an 80 square degree sub-region of the CGPS. The nature of the population of radio continuum sources is further investigated by measurement of spectral indices by comparison with the Westerbork Northern Sky Survey images at 327 MHz.

Simulations of Planetary Transits of Stars in the Globular Cluster 47 Tucanae, M.D. Williams, E.F. Milone, M. McClure, J. Kallrath and C. Stagg, University of Calgary

In an attempt to answer some of the questions about planets with short orbital periods, Gilliland *et al.* conducted an eight-day photometric search for planetary transits in the globular cluster 47 Tucanae. For the purposes of predicting lightcurves that may be observed, a database of lightcurves was constructed. The database spans systems with planetary radii from half a Jupiter radius up to those of brown dwarfs. Since the problem of modelling the lightcurves of planetary transits is similar to modelling the lightcurves of eclipsing binary stars, programs that were originally designed for binary stars were used to model the these systems. Two programs were used, the Wilson-Devinney (wd98k93) (Milone *et al.* 2000; Kallrath & Milone 1999) program and as an aid to constructing an archive, the visualization package Binary Maker 2 (Bradstreet 1993). In addition to predicting possible lightcurves, the database will also be used to speed up the modelling of observed systems by permitting the comparison of lightcurve properties such as the depth and the width of observed transits with those already modeled to estimate the system parameters. The parameters of the planetary system can then be refined using the Wilson-Devinney code and the method of differential corrections. The first observation of a planetary transit was made for the star HD209458. Photometric data from Charbonneau *et al.*, and Henry *et al.*, were used to determine the parameters, like planetary mass and radius, of the HD209458 system. This work was supported by grants to EFM from the U of C Research Grants Committee and NSERC.

Education Notes
Rubriques pédagogiques

IMPROVING THE TEACHING OF ASTRONOMY 101 THROUGH TUTORIALS

BY WAYNE A. BARKHOUSE
Halifax Centre, RASC
Electronic Mail: barkhous@astro.utoronto.ca

AND CHRIS R. BURNS
University of Toronto
Electronic Mail: burns@astro.utoronto.ca

ABSTRACT. While lectures are a vital component to teaching an undergraduate course in astronomy, there are certain topics which are more efficiently handled in a tutorial setting. In this paper, we discuss the role tutorials can play in helping students understand some of the basic concepts in astronomy by presenting specific examples from a first-year astronomy course offered at the University of Toronto. Five activities are described, two of which are excellent examples of the hands-on approach to teaching and learning, and are also suitable to the study of astronomy at the middle or senior high school level.

RÉSUMÉ. Bien que les cours sont d'une importance vitale dans l'enseignement de l'astronomie au niveau premier cycle universitaire, les classes dirigées sont plus pratiques pour permettre d'aborder des sujets particuliers. Dans ce rapport, nous discutons du rôle des classes dirigées pour aider les étudiants à comprendre certains principes de base en astronomie, en présentant des exemples particuliers puisés dans le cours de premier cycle offert à l'université de Toronto. Nous décrivons cinq activités, dont deux sont d'excellents exemples de la méthode 'sur le tas' d'enseigner et d'apprendre. Ces activités s'appliquent aussi à l'enseignement de l'astronomie au niveau secondaire.

SEM

1. INTRODUCTION

The traditional method of teaching first-year astronomy students has relied upon the use of the so-called "lecture" mode to convey information. Despite its convenient format for instructing large numbers of students, the "lecture" mode has several disadvantages, including the lack of direct interaction with each student and the inability to teach certain concepts which require different visualization techniques. These disadvantages can be addressed through the use of tutorials.

For the past several years, the Scarborough College at the University of Toronto has made extensive use of tutorials for teaching first-year astronomy students. The tutorials are conducted by graduate students and typically contain 15–30 students. The tutorials can provide a casual environment in which students feel comfortable contributing to the class.

In this article we present several examples of concepts which are more effectively taught in a tutorial-like atmosphere rather than the traditional lecture-style mode.

2. ACTIVITIES AND DEMONSTRATIONS

In this section, we present several examples of activities we have performed in tutorials at Scarborough College. We describe each activity, explain its motivation, and list its advantages and disadvantages.

2.1 The Seasons

A common problem with teaching astronomy is that students begin the course with preconceived notions about how the universe works. A good example is the reason why we have different seasons. In textbooks, students are introduced to the notion that the Earth revolves around the Sun in an ellipse. Unfortunately, most textbooks exaggerate the ellipticity, and the students can be left with the impression that the Earth is much closer to the Sun for part of the year. If students formerly thought that the Earth experiences seasons because of its changing distance to the sun, the ellipticity of the Earth's orbit will no doubt reinforce this notion.

In this activity we try to get the students to re-evaluate this concept individually through an active discussion, or debate. We begin by asking the students to propose any hypotheses to explain why there are seasons. Hopefully, the right answer will be suggested, but if not, the tutorial leader can propose it. The goal is not necessarily to get to the correct answer, but rather to show how one can falsify different hypotheses.

Once we have several suggestions, a vote is conducted on which one is the correct answer, eliminating all but the two (or more) most popular choices. We then split the students into teams and have them justify their choice. Finally, the tutorial leader initiates a discussion between the teams, where each team attempts to falsify the other's position.

Advantages:

- Students learn about how to apply deductive reasoning
- Students (hopefully) arrive at the correct conclusion on their own
- It is a good way to "break the ice"

Disadvantages:

- Can take a long time
- Can be frustrating to implement with unresponsive students

2.2 Constellations and the Zodiac

We have found that some students can examine a good diagram from a textbook and immediately understand what is being depicted. Other students have more trouble imagining what the two dimensional drawing is explaining about the three dimensional universe. In the following activity, we attempt to explain the Sun's apparent yearly motion through the constellations of the Zodiac by making the students a part of the demonstration.

We start by rearranging the classroom chairs to form a circle, with one chair placed at the centre where the tutorial leader sits. Pictures of the constellations are attached to the walls of the room, including the floor and ceiling, with the Zodiac constellations placed at eye-level.

The students are told that the tutorial leader is the Sun, while each person seated represents the Earth at some point in its orbit. To make the point even clearer, the tutorial leader can hold a large yellow ball, while the students pass around a smaller blue ball.

The tutorial leader then asks the students to pass the Earth around the circle and as each student gets the ball, they tell everyone which constellation the Sun appears to be in. If the constellations are in the correct order, then one can assign dates to each position along the Earth's orbit. By having the students turn around to face the wall (and hence away from the "Sun"), they can see which constellations are visible during the evening.

Advantages:

- Students get to think in three dimensions
- Students get to participate
- Students see the value of a model in understanding difficult concepts

Disadvantages:

- Difficult to do with large numbers of students (> 30)

2.3 Stellar Parallax

The setup is identical to the previous one except now a "foreground star" is placed between the circle of chairs and the wall of constellations (the "background stars"). The students should now be comfortable with the Earth going around the circle of chairs with the Sun in the middle. However, now their attention will be focussed on the star.

Each student in the circle tells the tutorial leader where the foreground star appears to be with respect to the background stars. The tutorial leader notes these positions and the students will be able to ascertain the periodic movement of the apparent position of the foreground star. The students can also attempt to measure the parallactic angle and use trigonometry to calculate the distance to the star.

The advantages and disadvantages are similar to that experienced for the "Constellations of the Zodiac" tutorial.

2.4 Sidereal vs. Solar Time

We have found that this concept is one of the most difficult ones to teach in astronomy. Even the best diagrams lack motion and therefore the notion of "time." Scarborough College is equipped with a small planetarium (which can fit about 15 people), which we find is an excellent resource for demonstrating difficult concepts, including sidereal time. We also use celestial spheres (clear plastic spheres on which the constellations are inscribed and which have the earth at the center of the sphere) to demonstrate the same things. In this way, the students can see what is happening from two different perspectives.

We begin with the usual introduction to the night sky, including the constellations of the Zodiac. We then define, and demonstrate, a solar day and a sidereal day. Our planetarium is equipped with a large "Sun" and a meridian, so it is very simple to demonstrate a solar day: the time between meridian crossings of the Sun. We then demonstrate the sidereal day as the time between meridian crossings of the stars. The students are then asked whether these times are the same. The students are quick to realize that during the time between successive meridian crossings, the sun has moved a little along the ecliptic, whereas the stars are still in the same location. The whole exercise is repeated using the celestial spheres (which also have a meridian and moveable Sun).

Advantages:

- Students see phenomena in "real time"
- Requires student participation to work well
- Good practice for the teaching assistant's "showmanship"

Disadvantages:

- For some students, seeing things from both perspectives can be more confusing than enlightening
- Requires technical expertise

2.5 Telescope Simulation

With class sizes of about 150, it is not practical to have students visit an observatory and actually use a telescope to collect data. Fortunately, with the advent of networked computers, a lot can be done in a computer lab to simulate how a real telescope works. Students can also acquire real data from the Internet, which they can use to do projects like main-sequence fitting of clusters. For many students, this type of activity gives them the feeling of doing "real" astronomy and an appreciation of the many uncertainties involved in acquiring data through instruments.

Until recently, we used the "TS24" telescope simulator to have students perform main sequence fitting of an open cluster. The simulator was very sophisticated, and one could easily incorporate real data into the program, including interstellar extinction and proper motion. The students were presented with different telescopes (finder, main mirror) and several instruments (eyepieces, photometers, CCD's). The objective was to find a cluster, centre the telescope, and take exposures with U, V, and B filters. The students then calculated the colour indices, classified the stars, plotted an HR diagram, and did the main-sequence fitting.

Unfortunately, TS24 is no longer maintained and does not work well with the Windows operating system. Therefore, we were forced to abandon it (the Scarborough computer centre only maintains Windows NT computers). However, other telescope simulator programs are available, one of which is "Project CLEA." This program is free and contains astronomy laboratories which are written for the Windows and Macintosh operating systems. We have not had a chance to use these in a tutorial setting, but one of their labs, entitled "Photoelectric Photometry of the Pleiades," will be implemented in the coming year.

Advantages:

- Incorporates many concepts into a single activity (experimental uncertainty, signal-to-noise ratio)
- The activity is very "hands-on," which many students prefer

Disadvantages:

- Requires substantial setup and testing of software

In order to gauge how successful tutorials are in helping to teach first-year astronomy students, it should be noted that for the past five years, students who regularly attend weekly tutorial sessions have, on average, a 20% higher grade compared to those students who do not attend tutorials. Students in general prefer the tutorial-style mode of teaching, and this preference is reflected in the higher grades achieved.

3. CONCLUSION

For the past several years, an extensive program of using tutorials to teach first-year astronomy students has been in place at Scarborough College, University of Toronto. These tutorials are implemented by graduate astronomy students who generally teach approximately 15 to 30 students per session. In each case, the tutorial activity offers the students a learning opportunity they may not get in a large classroom environment. In the case of the seasons debate, they see first-hand the thought processes involved in hypothesizing and verifying a theory. For the zodiacal constellations and parallax activities, they get to interact with the model instead of just looking at it. With the planetarium and celestial sphere exercises, they can "play with the knobs" and experiment with the night sky. Lastly, the virtual telescope lets them appreciate what goes into the scientific results we present most often as a *fait accompli*. We therefore believe that the most effective method for teaching these students is to use tutorials to complement the lecture-style mode of teaching.

Wayne A. Barkhouse
Department of Astronomy
University of Toronto
Toronto, Ontario, M5S 3H8
Canada

Chris R. Burns
Department of Astronomy
University of Toronto
Toronto, Ontario, M5S 3H8
Canada

WAYNE A. BARKHOUSE is a Ph.D student in the Department of Astronomy at the University of Toronto. He received his BSc. in Physics and MSc. in Astronomy at Saint Mary's University. He is an attached member of the Halifax Centre, RASC, and is the Editor-in-Chief of the Journal of the Royal Astronomical Society of Canada.

CHRIS R. BURNS received his BSc. in Physics from Bishop's University, then his MSc. in Physics from the University of Toronto. He is currently working on a Ph.D in Astronomy in the Department of Astronomy at the University of Toronto.

Society News/Nouvelles de la société

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

It's hard to believe that Christmas is just around the corner. I would like to wish all members of the Royal Astronomical Society of Canada a Very Merry Christmas and a Happy New Year (New Millennium or not… that is still the debated question). May all your Christmas wishes come true, and may you get that new Nagler eyepiece you have been dreaming of. Remember, there are great astronomical gifts available from the National Office, such as the *2001 Observer's Calendar, The Observer's Handbook*, *The Beginner's Observing Guide*, or perhaps a membership for a friend. Please visit the RASC website at `www.rasc.ca` and look under RASC Promotions.

On September 23rd, 2000, the Belleville Astronomy Club (`www.magma.ca/~glisk`) and the Kingston Centre, RASC (`www.rasc.ca/kingston`) had an astronomical get-together at Presqu'ile Provincial Park. Though the weather did not co-operate, it was an excellent first attempt at a local star party. There were 27 in attendance, with talks from both clubs at night. Topics of the talks included homemade tripods for binoculars and telescopes (Les Dempsey, `www.blvl.igs.net/~ldempsey`), youth group observing (Hank Bartlett – Kingston), amateur telescope making (Kendra Angle – Kingston, Dave Pianosi – Belleville/Kingston, Greg Lisk – Belleville), and a solar system made to scale out of wood for demonstration purposes from Joe Sheilds (Belleville).

Some members elected to stay up and wait out the clouds by watching movies, roasting marshmallows, or watching and chasing the racoons that tended to visit the campsite. Around 3:30 a.m., the clouds did part somewhat, with the appearance of Orion, Jupiter, Saturn, the Pleiades, and Taurus. This, however, was short-lived and the clouds rolled in again. By daybreak the clouds started to clear, with the sun shining in the early afternoon.

On his own accord, a local Kingston member has purchased a Star Lab Portable Planetarium to bring education and entertainment to the public. Theodore Micholias operates it, all for the love of astronomy, under the name of Gemini Space Exploration. So far, Theodore has shown his planetarium to two public schools and has set it up at the local Chapters bookstore. His program is made up of presentations on the Canadian Space Agency, Greek mythology, and the constellations. If you are interested in the Star Lab Portable Planetarium, please contact Theodore at `geminispace@home.com`.

This year's junior RASC award for excellence in astronomy was awarded to Jonathan Sick for his project *Predicting Solar Activity*.

RASC Award for Excellence in Astronomy

This year, the RASC award for excellence in astronomy was presented at the Canada-Wide Science Fair held in London, Ontario from May 14 to 20, 2000. The award is given to junior and intermediate/senior students who are judged to have an outstanding project related to astronomy in the area of observations, instrument construction, or other related areas. This year's junior prize winner is Jonathan Sick, Queen Elizabeth Jr. & Sr. High, Calgary, AB. Jonathan won a cash prize of $200 for his project entitled *Predicting Solar Activity*. The intermediate/senior award was presented to Heather Hughson from Waterloo Collegiate Institute, Waterloo, ON. Heather won a $300 prize for her project entitled *Vacuum Primordium*. Congratulations!

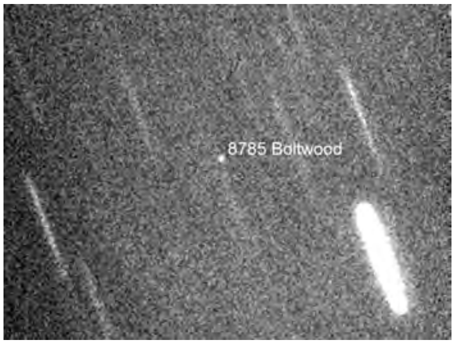
This year's senior RASC award for excellence in astronomy was awarded to Heather Hughson for her project *Vacuum Primordium*.

Congratulations to...

At the National Council meeting held in

Toronto on October 14th, 2000, several members of the RASC received their Messier & NGC Certificates. Recipients of the Messier Certificates were Arnold L. Rivera (Edmonton), Paul Ellard (Okanagan), Lawrence J. Burgess (Windsor), and David Marchand (Windsor). Recipients of the NGC Certificates were Arnold L. Rivera (Edmonton), Guy Mackie (Okanagan), and Ron Scherer (Okanagan). Congratulations to everyone on completing the requirements for the certificates, and may your next venture take you to the next level.

Paul Boltwood (Ottawa Centre), of Stittsville, Ontario has been honoured with an asteroid named after him. This is the citation, forwarded from Brian G. Marsden of the IAU Minor Planet Centre:



(8785) Boltwood — A series of stacked images taken on October 25th, 2000 with a total exposure of 76 minutes (image by Paul Boltwood with his 16-inch Newtonian telescope and homebuilt CCD camera).

From MPC 41384 on Oct. 13: (8785) *Boltwood* = 1978 RR1, *discovered 1978 Sept. 5 by N. S. Chernykh at the Crimean Astrophysical Observatory. Paul Boltwood (b. 1943) is a Canadian specialist in computer systems and outstanding amateur astronomer. He monitored the peculiar object OJ 287 for some two years. He also obtained deep-sky CCD images with limiting magnitude 24.5 using a home-built 0.4-m reflector. Congratulations, Paul, for a great personal accomplishment and for all of us in Astronomy.*

David Levy, at the fall meeting of the *American Association of Variable Star Observers* (AAVSO), was awarded the *William Tyler Olcott Award*. This new award of the AAVSO is intended to honour individuals who have had an impact in increasing the public awareness of astronomy and variable stars.

Astronomical Society of the Pacific Awards[1]

Two Canadian astronomers, one professional (Peter Stetson, Victoria Centre) and one amateur (Paul Boltwood, Ottawa Centre), receive awards from the Astronomical Society of the Pacific.

Maria and Eric Muhlmann Award

Peter B. Stetson of the Dominion Astrophysical Observatory is this year's recipient of the Maria and Eric Muhlmann Award, given annually for recent, significant observational results made possible by innovative advances in astronomical instrumentation, software, or observational infrastructure. He is the author of one of the most widely used (and praised) data-reduction packages in astronomy — his DAOPHOT was first described in the astronomical literature in 1987. The program, which can precisely determine the brightness of point sources imaged with area detectors, was specifically designed for measuring stars in very crowded globular cluster fields. DAOPHOT allows for the two-dimensional characterization of the brightness distribution of a point-source and then applies this "point-spread-function" to all objects in a CCD image. Overlapping stellar profiles can be accurately deconvolved by fitting the point-spread-function simultaneously to many objects in an image. The development of DAOPHOT was as significant to the advances in the study of globular clusters as was the availablity of CCDs. DAOPHOT has been steadily improved in the decade since its introduction with its latest incarnation named ALLFRAME. Stetson has put his code to good use and has been one of the leaders in the broad field of globular cluster studies. He has also played a major role in the steady refinement of our knowledge of the absolute age of the Galaxy and the distribution of ages in the halo of the Galaxy — this latter work is key to understanding the early epoch in the formation of the Galaxy.

Steven Vogt

Amateur Achievement Award

Paul Boltwood has been an amateur astronomer for forty years. He is this year's recipient of the Society's Amateur Achievement Award in recognition of his individual accomplishments in the development of hardware and software for precise deep-sky imaging, his research on brightness variations in active galactic nuclei, and his studies of near-nucleus activity in Comet Hyakutake. In May 1998 Boltwood obtained the deepest image ever obtained with amateur equipment — a V magnitude of 24.1 collected over a twenty-hour period. Prior to the invention of CCD imaging, even the 200-inch Palomar telescope could only achieve a limiting magnitude of 23. Boltwood, however, used a 40-cm, homebuilt telescope and CCD camera located in his backyard observatory in suburban Ottawa, Ontario, Canada. What is notable about his accomplishments is the care and attention to detail he applies to his research. He strives for the best possible standard of care and achieves professional-quality results. His nomination included letters of recommendation from astronomers at Yale University, the University of Colorado, the University of Toronto, and the Royal Astronomical Society of Canada. He has published numerous scientific papers and has collaborated with researchers at a number of institutions throughout the world. The award committee was particularly impressed with the breadth and sustained nature of Paul Boltwood's contribution to astronomy. He is a model of how amateurs can make unique and valuable contributions to science.

Wayne Rosing

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[1] Reprinted with permission from *Mercury* and the Astronomical Society of the Pacific.

A Candle in the Dark

by Bill Broderick, Kingston Centre (broderic@kos.net)

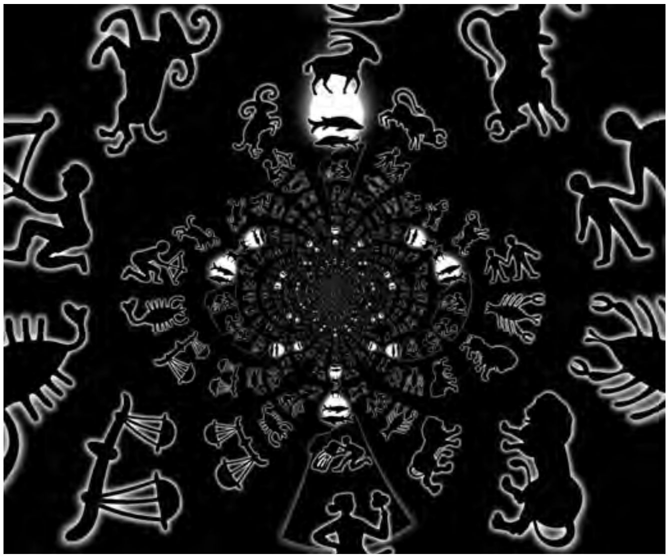


Illustration by Brian G Segal

My "Candle in the Dark" project began a few months ago when I conceived the idea of writing an astronomy column for an *astrology* publication. As it happens, I have a friend who publishes an astrology newsletter, and she is also interested, somewhat, in astronomy. She has actually taken a popular astronomy course and so knows more about astronomy than most astrologers I have met. She is particularly fascinated by eclipses (as they pertain to astrology) and has become something of an expert on them, particularly on the Saros cycle, the 18-year period after which solar and lunar eclipses tend to repeat themselves under nearly the same conditions.

She had already published several items I had written, so the idea of a regular column appealed to her. I dashed off three one-page essays for the upcoming fall months, and we were in business. Over the summer, with all kinds of other things going on, ideas still came fast and furious, and before the season was over I had enough essays to go for a couple of years (if it lasts that long).

Why an astronomy column in an astrology newsletter? Well, astrologers (at least the ones I have known) tend to be fairly smart people. They are not uneducated. Some of them even run reasonably successful businesses or follow professional careers in various fields. In other words, a lot of them are not dummies. (Considering the sheer amount of information and work that used to go into setting up a standard horoscope before the age of computers, astrologers had to be smart then, and I think most are still smart now.) They just happen to believe fervently in astrology. By extension, they have an interest in astronomy, although they usually do not know that much about it. Astrologers are your classic "seekers of truth." They believe they have found it in astrology.

What exactly do astrologers believe?

Tenets of Astrology

Carl Sagan, one of the most brilliant scientific popularizers of science and astronomy of our time, once made reference to the "tenets of astrology." I have never been able to find them anywhere, but I once studied astrology, so I wrote up my own. My astrology friend agrees with them, so here they are:

1. Life and events on Earth and in our lives are influenced by forces and events in the cosmos.
2. The Sun and planets, individually and in combination, are the major sources of cosmic influence.
3. The influence of each planet is different but is altered or coloured:
    - a) by its position on the zodiac (that is, the ecliptic, the apparent path of the Sun in the sky),
    - b) by its position in the houses (the 12 divisions of the sky which supposedly rule various aspects of our lives. These begin at the eastern horizon, continue around under our feet to the western horizon, and continue over our heads and back to the eastern horizon), and
    - c) by the angles (or aspects) it makes relative to other planets (trines, squares, sextiles, conjunctions, oppositions, *etc.*).
4. Certain points, such as the rising point and mid-heaven, lend particular strength or emphasis to a planet which happens to be situated there at the moment of birth.
5. The 12 signs, Aries, Taurus, Gemini, *etc.*, begin at the point of the vernal (spring) equinox, where the Sun (on the ecliptic) crosses the celestial equator on or about March 21 each year. Traditionally, this is the First Point of Aries.
6. The 12 houses begin at the point on the ecliptic that was on the eastern horizon at the moment of birth.
7. Signs are labeled "Air", "Earth", "Fire" and "Water", and are further labeled "Cardinal", "Fixed" and "Mutable." These terms are derived from supposed qualities of the signs, which modify or colour the influence of the planets.

"Very often we even resent the implication that it is a *belief*. We do not believe, we know. Certainly, astrologers are convinced that theirs is not just a belief but ancient knowledge. They also think that they have personally verified it and that, therefore, they *know*, they do not believe."

Beliefs are Fixed

One of the things I have learned over the years is that you cannot change the beliefs or opinions of people by arguing with them. Rightly or wrongly, an attack on one's belief or opinion is perceived as an attack on the person and is rebuffed. Whether it is religion, politics, natural healing, chiropractic, homeopathy, astrology, I Ching, or any other brand of belief, if we have made it our own, we resent any attempt on the part of someone else to make us change it.

Very often we even resent the implication that it is a *belief*. We do not believe, we *know*. Certainly, astrologers are convinced that theirs is not just a belief but ancient knowledge. They also think that they have personally verified it and that, therefore, they *know,* they do not believe. For that reason, I am very careful not to say anything critical about astrology. Even if my editor allowed me to do so, I would very quickly lose credibility with the readers.

My Focus

The focus of my articles, then, is simply to write about astronomy and things that relate to it, such as my own fascination with the subject. These include my first eclipse trip, what can be seen in the sky, how to find things in the sky, how to buy a telescope (buy binoculars first), how the planets move (in ellipses), current events (water on Mars, possible life on Mars), the nature of the "face" on Mars (it is a hill), the scientific method, some of the controversies that have arisen (expanding universe versus steady state), UFOs, extraterrestrial life, interstellar travel, *etc*. The idea is not to challenge the astrological world view but to awaken an interest or curiosity in astronomy and science.

I try to make my titles provocative. Here are a few examples:

- The Thief Who Stole the Night: an essay about urban light pollution and its solutions;
- A Pinch of Stardust: how heavy elements (everything heavier than hydrogen) were created in the stars and stellar explosions and how, therefore, we are all pinches of stardust;
- Air, Earth, Fire, Water: how these "traditional" elements have shaped our planet;
- Johannes Kepler and His Wonderful Ellipse: about planetary motions, of course;
- Ice and Snow in Space: comets and such; and
- Oh Be a Fine Girl, Kiss Me!: the classification of stars based on the Hertzsprung-Russell temperature-luminosity diagram. The title is a mnemonic used by astronomy students to remember the order of stellar classification beginning with the hottest: O, B, A, F, G, K, M.

Stars for Sale

An article published just before Christmas was "Stars for Sale." The essay concerned star-naming companies, such as the International Star Registry. For $35 or $50 or whatever, these companies will name a star after you, your loved one, your kid, maybe even your dog. You get a nice fancy certificate attesting that henceforth, star such-and-such will be known by the name you have requested. You also get a chart which is supposed to help you locate "your" star, but of course it is much too dim to be located with the naked eye. If you take your chart to an astronomer and ask to see it in a telescope, chances are you will be told that the chart is too imprecise to possibly be of any help, that if we do find the right field there will likely be several stars in it, and anyway, none of them is "your" star because only the International Astronomical Union (IAU), an organization of professional astronomers, has the authority to name stars. People are generally shocked to learn that their certificate has no official validity whatsoever, that it is only a novelty item not worth the paper it is printed on, that they have in fact fallen for a rather silly scam that happens to be, if not illegal, at least not very ethical. Maybe the article will help put a dent in the sales of star-naming companies. That would be nice.

Conclusion

We live in a pretty dark world, full of misconception, ignorance, false belief, fear, and superstition. The "forces of darkness" want it to remain that way, and they seem to get their way far too often. Belief in astrology, as the 1997 York University *Second Survey of the Attitudes of University Students to Astrology and Astronomy* by Michael De Robertis and Paul Delaney showed (see the June 2000 issue of the *Journal*), is widespread even among the fairly scientifically literate. Will a few essays about astronomy in an astrology publication make any difference? I do not know. I do know that in order to see, we must have light. In the modern world, science is the brightest light we have. Carl Sagan's book *The Demon-Haunted World: Science as a Candle in the Dark* reminds us that by letting this light shine wherever we can, we may help those who are having trouble seeing.

That is what my "Candle in the Dark" project is all about; shedding a little light, revealing a little truth, helping someone to see a few things more clearly. It is possible I will get a few readers seeing and thinking, and when you get people really thinking, as opposed to only thinking they are thinking, wonderful things can happen.

> **"That is what my 'Candle in the Dark' project is all about; shedding a little light, revealing a little truth, helping people to see a few things more clearly."**

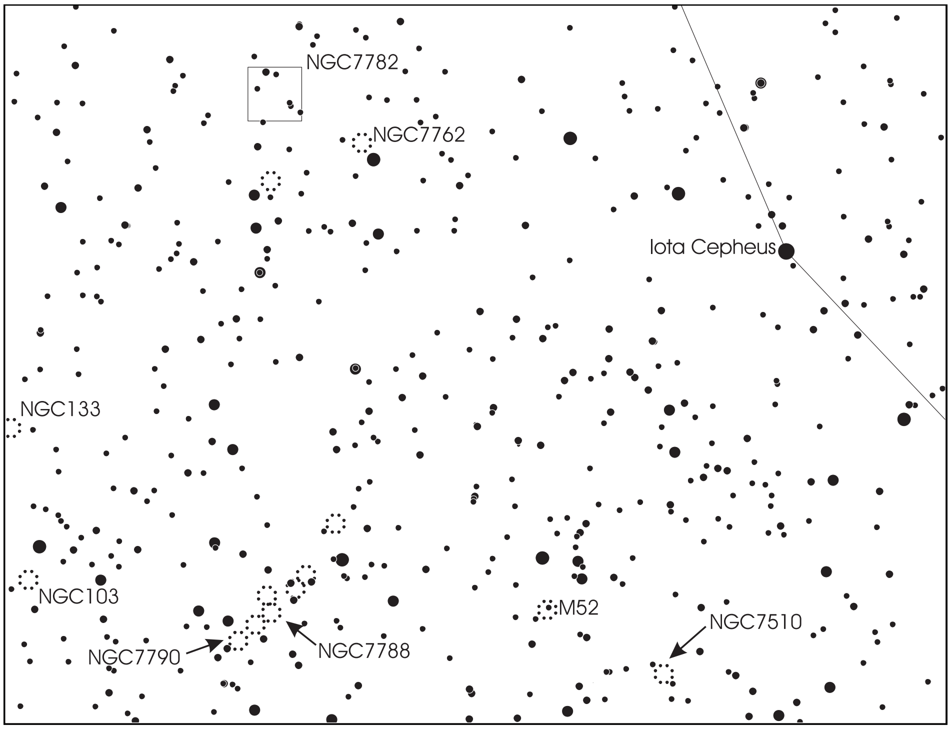
Bill Broderick is a member of the Kingston Centre and served as editor of the centre's newsletter Regulus *for several years. He chaired the National Light Pollution Abatement Committee from 1995 to 1998, and continues as a member of the committee. He is involved with various public issues, among them smoking and light pollution. A member of the Ontario Skeptics, he rides herd on astrology and other voodoo-sciences from his lair near Belleville, Ontario.*

At the Eyepiece

Royal Reflections

by Guy Mackie, Okanagan Centre (guy.m@home.com)

As patriarch of the northern skies, the constellation Cepheus wears its reflection nebulae with a subtlety reminiscent of the "Emperor Who Wore No Clothes." When I decided to observe all the diffuse nebulae in Cepheus that are listed in *Burnham's Celestial Handbook*, I was unaware of the ambitious nature of the observing challenge I had set for myself. Vast sweeps of faint cloud and small but bright nebulae with tantalizing hints of structure combined to make an excellent exercise for developing observing skills. Stellar ejection nebulae contain elements of both emitted and reflected light, and I was pleased to find (for the sake of this article's title) that all of the nebulae in Cepheus listed by *Burnham's* contained enough reflected light to be visible without using any light filters.



A 10-degree high finder chart for NGC 7782 showing stars to about 8.5 magnitude (ECU Chart by Dave Lane).

The first target for my 12.5-inch Dobsonian telescope is situated on the front step of the house-shaped Cepheus. Just a few steps southwest of the conspicuous yard-light "Garnet Star" Mu Cephei is a cluster and an extremely large diffuse nebula with the combined designation of IC 1396. Using a low power of 63×, the centre of the cluster is marked by the close triple system of Struve 2816, containing a bright yellow star with two dimmer white/blue companions. This distinctive triple sparkles, along with several dozen other members of the moderately rich cluster IC 1396, to nearly fill the entire low power field against a dark background encircled by a faint fringe of nebulosity. A slight nudge of the scope off of the cluster in any direction will reveal a faint murky cloud that, like the Rosette Nebula, is detected more by the reduced stellar population than by the presence of nebulosity. This very dim nebula requires a dark transparent sky and well-developed dark adaptation before the eye can be tuned to truly appreciate this elusive shade of pale. I found that a UHC filter did offer a slight enhancement; however, while exploring the full extent of this sprawling nebula, I came to prefer the unfiltered view as it allowed the full contrast with the rich star fields in this area, which brushes the nearby Milky Way.

On a night of excellent seeing, when sweeping the area southwest of Beta Cephei with medium/low power, I used averted vision to notice NGC 7023 as a small, moderately bright cloud surrounding a light, straw-coloured 7th magnitude star. It soon became apparent that the star and its associated cloud were themselves set within a large faint circular haze. Increasing the magnification to 158× reveals structure in the cloud similar to a very faint Orion nebula as the central star is muted by a glowing arc, extending in a north to south direction, with long tendrils sweeping off the ends. An extended observation period using averted vision enhances the bright region north of the central star and reveals dark lanes and bays. The entire 0.4-degree field is strongly affected by the dim haze of the encompassing nebula, which a move to the surrounding rich dark star field reveals to best advantage.

Using the 1/2 degree distance between M52 and NGC 7635 (the Bubble Nebula) as a guide, travel just less than 1 degree slightly north-of-west from NGC 7635, and the faint glow of NGC 7538 will enter the view. If you use a low power to yield 63×, NGC 7538 is a dull gray oval glow around two faint stars. At 88× magnification, the oval, extending from northwest to southeast, fans out and is slightly brighter at the northwest end. NGC 7538 "brightens" moderately with the use of a UHC filter, but even at higher power, none of the filamentary structure mentioned in *Burnham's* was revealed to me.

As a member of the Finest NGC list, NGC 7129 was a familiar visual object for me, and I was delighted that it was also included in a talk given by Dr. Chris Purton at a monthly centre meeting. In his studies of Dissociating Stars, Dr. Purton has thus far only found 3 such stars in our galaxy, and one of them makes its home in NGC 7129. Dissociating Stars are believed to be newly formed stars that can be identified by the presence of their surrounding atomic hydrogen nebulae, which can be detected in radio signals at a 21-cm wavelength. The 10th magnitude type B star (BD65+6138) is surrounded by an atomic nebula of over 3.5 light-years in extent, much larger than the visual size of NGC 7129. Dr. Purton estimates that this dissociating star is only 1000 to 1800 years old, a mere infant by cosmological standards! At my low power of 63×, NGC 7129 is seen as a moderate glow around a small triangle of stars. At 158× a bright knot of nebulosity appears star-like on the north edge of the triangle, to make a squashed diamond shape. It may be that the two easterly stars of the triangle are actually nebulosity, but they appear stellar in my scope. Amazingly there are four other reflection nebulae easily contained within this narrow (0.4°) field. I was able to pick out the faint combined glow of IC 5133 and IC 5132, appearing as a meager mist around an L-shaped asterism just north of NGC 7129. Using averted vision with some tube movement I was just able to detect the subtle glow of IC 5134 around a star near the edge of the field to the northeast.

It is little wonder, with this plethora of mirrored majesty, that confusion reigned in the royal house of reflections when I went in search of NGC 7133, the fourth companion to NGC 7129. Unlike the IC objects, the reclusive NGC 7133 is listed by *Burnham's*, but it is so much a part of NGC 7129 that I kept overlooking it. After failing to positively locate NGC 7133 a number of times, I examined a Digital Sky Survey image of the area, wherein the faint cloud of NGC 7133 is shown snuggled up to the south-east edge of NGC 7129. Using a 10-mm Radian eyepiece (158×) for a lengthy observation of over an hour I was able to detect NGC 7133 for just a few brief periods when the diffuse glow would burst into averted vision momentarily. I am not confident of this observation as it may well be that, like the Emperor, I was fueled by suggestion provided by the photograph and saw only what I hoped to see.

Presenting a real challenge to this observer, NGC 7822 well deserves its first place position on the *RASC Challenge Objects* list. Using open cluster NGC 7762 and its 5th magnitude companion star as a convenient pointer, I had to sweep 5 or 6 times to the northeast before the subtle glow of NGC 7822 registered on my consciousness. This near 2-degree gull-winged arc of faint nebulosity is best appreciated by drifting beyond the cloud to the bordering inky blackness. After growing familiar with the contours I could follow the northern edge with some ease. On a night of excellent seeing at the Mount Kobau Star Party I noticed dark lanes sweeping from west to east within this dusty denizen of the king's realm.

After completing the project with a 12.5-inch mirror I re-observed with my 8-inch Celestron Starhopper Dobsonian. Of the six reflection nebulae listed by *Burnham's* only NGC 7133 refused to yield to the 8-inch aperture. The guideposts of Struve 2816 and a subdued NGC 7762 remain relevant, and reacting very well to the use of averted vision, NGC 7023 showed its N-S extension. A first-time positive observation of NGC 7822 with an 8-inch mirror may have been more of a challenge than I could have met, but like shadow ripples on a pond, the subtle waves of reflection were there.

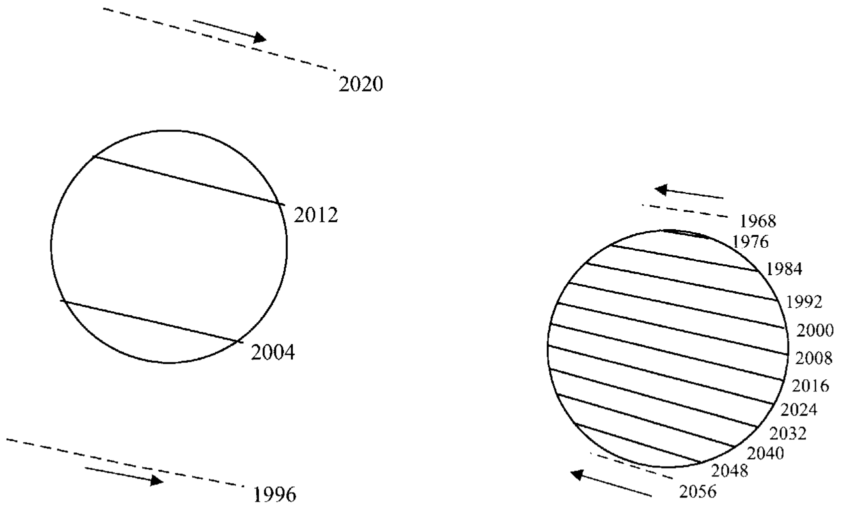
My experience exploring the reflective cloak of Cepheus has been an enjoyable challenge, and I encourage others to accept his royal patronage. ◆

Guy Mackie enjoys observing from the clear and dark hillsides near Kelowna, British Columbia. He recently completed the RASC *Messier list, and over half of the Finest NGC Objects with his 8-inch Dobsonian. He enjoys skiing, hiking, and camping with his family.*

Orbital Oddities

Conjunction Junction

by Bruce McCurdy (bmccurdy@freenet.edmonton.ab.ca)



The relationship between transits and occultations of Venus is depicted in this pair of diagrams. Whereas transits occur in pairs (as shown upcoming in 2004 and 2012) or even single events, occultation series last much longer due to perspective effects. In the first case Venus' heliocentric latitude (distance from the ecliptic) is greatly exaggerated by its close proximity to Earth; in the other it appears compressed due to the planet's position beyond the Sun at superior conjunction. The chords of the successive occultations are therefore roughly six times closer together than those of the transits. In the transits shown, Venus moves east to west (left to right) relative to the Sun near its descending node, and in the opposite direction near the ascending node during the occultations. Note that the chords are not precisely parallel due to the gradual eastward displacement of the node from one event to the next (diagrams courtesy of Russell D. Sampson and the author).

I have long been captivated by the music of the spheres. The interplay among the orbits of the planets, their satellites, and debris of the solar system, results in an enormous variety of harmonics, resonances, and variations on a theme. The cyclical interactions among a fascinating cast of characters can range from the subtle but steady rhythmic buildup of an occultation series to the cymbal crash of a total eclipse.

In this first article of what I hope becomes a series, let's look at interactions between Earth and Venus, which are largely played out in the "simple" time signature of 13:8.

I made my first acquaintance with the planets in the winter of 1985. A friend pointed out a fine conjunction between Mars and Venus, which I had never previously identified despite having achieved the ripe old age of twenty-something. I expected the more famous (at least in science fiction circles) Mars to be the more impressive object, but it was a relatively faint red dot about 1% as bright as its companion. It was Venus therefore that left the lasting impression of a neighbouring world; in fact, despite Mars' reputation, in many ways Venus is the more Earth-like planet in diameter and mass, not to mention its acid rain and greenhouse effect. Its large, steady, and brilliant spot of pure white is a sight that to this day has never failed to bring me pleasure.

As *Sky & Telescope's* E. C. Krupp once wrote in an attention-grabbing opening sentence, Venus was "named by the Romans for the voluptuous goddess of erotic love." To the telescopic observer, however, Venus is downright demure, never shedding her atmospheric veil for any man, no matter what size his instrument! Surface details which are brazenly strutted by the Moon and more grudgingly revealed by Mars are forever hidden on Venus by a bland yet crushingly dense, poisonous atmosphere. The earthbound observer must therefore be content watching dramatic changes in our sister planet's size and shape as her distance from us varies by a factor of six during each cycle.

This past June Venus reached the far side of its orbit as seen from Earth, its so-called superior conjunction. But this wasn't any old superior conjunction; in 2000 June Venus was in fact occulted by the Sun, an unobservable but not uninteresting event that occurs on average less than once per decade. This occultation approximates the reverse of a still-rarer phenomenon: a transit of Venus across the face of the Sun. One of the most eagerly anticipated events in astronomy will occur on 2004 June 8, namely the first transit of Venus since 1882. Think about that for a second: nobody alive today has observed a transit of Venus. What can we learn about transits from this year's happenings? "Superior" conjunctions of Venus are spectacularly misnamed. At its furthest possible distance from Earth, the tiny (10 arc second) full disc of the planet crawls ever so slowly nearer the Sun for several months and takes equally long to finally put enough apparent distance between itself and our brilliant star to make its next appearance in the evening sky. By contrast, at so-called "inferior" conjunction, Venus swoops between the Earth and Sun at breakneck speed, its huge (60+ arc second) but skinny crescent rapidly changing in appearance as it catapults from evening to morning sky virtually overnight.

The reason for all this is the relative distance of the two events. At 0.72 astronomical units from the Sun, Venus' distance from Earth varies from roughly 0.28 AU from Earth at inferior conjunction to 1.72 at superior. At superior conjunction it is therefore some six times the distance, and one-sixth the apparent size, as at closest approach. Its apparent speed is slower still, as it is now moving "with" the Sun, whereas at inferior conjunction it is going in the opposite direction.

But some conjunctions are more superior than others. While this June's occultation was unobservable in the conventional sense, in this day and age such events are easily available to the virtual observer. Idle thought experiments can actually be tested. Equipped with the software program Guide 6.0, I "observed" long series of Venus conjunctions to test and confirm some conclusions I had already reached. And, by golly, logic wins out yet again.

All Venus watchers become aware of the eight-year periodicity of its apparitions. As noted by the Mesopotamians, Mayans, and others, it takes almost exactly eight years (actually, eight years minus about 2.3 days) for Venus to orbit the Sun thirteen times. In that time, Venus "laps" Earth five times (synodic revolutions), after which the two planets return to a very similar alignment as their "starting point" eight years previous. There are therefore five morning and evening apparitions of Venus that repeat themselves to a high degree of similarity over the course of a human lifetime.

An even more exact periodicity of 152 synodic revolutions per 243 years comes into play when considering long-term cycles. Why 243? In that time there have been 30 eight-year cycles, meaning the deficit of 2.3 days from each will now have amounted to roughly 69 days. Two more 584-day synodic cycles of Venus amount to three years *plus* about 72 days, eliminating that deficit more efficiently than a modern government. The "interest" of three days is attributable to Earth's precession, which in 243 years would have completed about 1% of a cycle.

As an aside, my dear friend the late Father Lucian Kemble, a self-proclaimed "Fibonacci nut" who pondered the Fibonacci sequence in the relationship between 5 synodic cycles to 8 Earth years to 13 Venus orbits, would have been amused to note that the periods of 8 and 243 years can be represented in exponential notation as 2^3 and 3^5!

In a 243-year cycle there are, in the current era, two pairs of Venus transits, each at eight-year intervals and separated by more than a century. One pair will occur in June at the descending node, the other pair in December at the ascending. (Transits can also act alone, but there hasn't been a singleton since 1396, nor will there be another until 3089. Indeed, in the long term — the 9000 years from 2000 BCE to 7000 CE were reviewed — single transits are almost as common as pairs. The fascinating pattern of these events is best left for a future article.)

But shouldn't transits and occultations be inter-related? Given the 13:8 periodicity, after four Earth years Venus will have completed 6.5 orbits, or 2.5 synodic revolutions. As in the relationship between solar and lunar eclipses, Venus should be at one node of its orbit at the transits, and the opposite at the midway points. This explains why Venus was occulted in 2000, almost four years to the day before the transit.

As I pondered all this it occurred to me that from our perspective Venus should also stick about six times closer to the ecliptic when at superior conjunction. Accordingly, there should be about six times as many occultations of Venus by the Sun as there are transits. (The same thought occurred independently to Michael Watson, who posted his similar findings on the RASCals Discussion List in mid-June.) I examined every superior conjunction of Venus between 1960 and 2060 on Guide (using geocentric coordinates), and the pattern emerged as shown in the table.

Occultations of Venus:			Transits of Venus:		
Date	Midpoint	Duration	Date	Midpoint	Duration
1976 June 18	01:26 UT	8.3 hours			
1984 June 15	19:58	28.1			
1992 June 13	14:34	36.8			
2000 June 11	09:14	42.0	2004 June 8	8:21 UT	6.2 hours
2008 June 9	03:41	44.8	2012 June 6	1:31 UT	6.7
2016 June 6	21:52	45.7			
2024 June 4	16:17	44.6			
2032 June 2	10:32	41.4			
2040 May 31	04:30	35.7			
2048 May 28	22:06	25.5			

One can readily see the 8 year minus ~ 2.3 day periodicity. The first occultation occurs near the north limb of the Sun. The events grow in duration as they become progressively more central until the one in 2016, then recede as the southward progression continues. On 2056 May 26, Venus just grazes the south limb of the Sun without being occulted, thus ending the series. Indeed, the series resembles occultation patterns of the Moon against a given star, or for that matter the well-known Saros cycle of solar and lunar eclipses.

Significantly, the above occultations of Venus are the only ones that occur in the century under study. There are *no* random occultations, just this series of ten surrounding the two transits. Conjunction Junction is in eastern Taurus, where all twelve events occur, gradually regressing westward into the horns of the Bull. And whereas the two transits occur at the descending node, all of the occultations occur at the ascending.

I examined several further series with virtually identical results. The transit pair of 2117 December 11 and 2125 December 8 is surrounded by a series of nine occultations between 2081 December 19 and 2145 November 30. And the transit pair of 2247 June 11 and 2255 June 9 is surrounded by another series of ten occultations between 2219 June 21 and 2291 June 1. Note that each of these dates in the 23rd century occurs exactly 243 years (plus about three days) after its analogue in the current series.

Even though this year's occultation is over, visually you didn't miss a thing; it was unobservable. Moreover, thought experiments and computer observations simply aren't subject to real time and can be virtually recreated at the leisure of the user. Better yet, as with previous events in this series, an occultation is always followed by an inferior conjunction which is extremely favourable to northern observers. At the upcoming inferior conjunction of 2001 March 30, Venus will pass a full eight degrees north of the Sun, slightly better than the conjunctions of 1977, 1985, and 1993 described elsewhere in this issue of *JRASC* by Father Lucian Kemble. Now that will be something you can get out and see for yourself, in both morning and evening twilight, and, with proper care, all day long!

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The assistance of Dave Chapman, Russ Sampson, and Michael Watson is gratefully acknowledged.

Past President of the Edmonton Centre RASC, Bruce McCurdy is also the resident "semi-pro" astronomer at the Edmonton Space & Science Centre's Public Observatory, where he has provided volunteer service for the past 14 years and has enjoyed paid employment for the past five summers. He has an omnivorous appetite for all things astronomical, be they observational or theoretical in nature. His friends consider Bruce to be something of an oddity in his own right.

Scenic Vistas

Beyond the Orion Nebula

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

Showpiece deep-sky objects such as the Andromeda Galaxy, the Hercules Cluster, or the Orion Nebula dominate the constellations in which they appear, often to the exclusion of all else in their respective regions of the sky. The situation is understandable; after all, who can resist the allure of M13 or the brilliant, complex structure of M42?

But digging a little deeper into star charts and into the sky itself will often bring the observer face to face with marvels every bit as fascinating as these celestial wonders. The constellation of Orion is home to dozens of deep-sky challenges suitable for amateur-sized telescopes; two of these targets will be discussed in the present article.

One of the more fascinating aspects of "real-time" deep-sky astronomy is comparing the results of visual observation to those of imaging (whether by astrophotography or CCD). It has been my experience that neither technique is superior to the other; each reveals important information about the object under study. Observations of NGC 1999 and NGC 2194 are a case in point.

Located little more than one degree south-southeast from the Orion Nebula, NGC 1999 is surprisingly little known amongst amateur astronomers, but this complex object is fascinating to observe. Classified as an emission-reflection nebula, it features a prominent triangular absorption region, so the term "dark nebula" could also be added to its description. The T Tauri-type variable star V380 is presumed to be the exciting star of the nebula, but in the Palomar Sky Survey photograph at bottom right, the long exposure brings out the nebula at the expense of the star. My observation of this nebula (illustrated on the top left) occurred on October 7–8, 1994 and reveals the star as well as a bright, crescent-shaped nebulosity that surrounded the star on all sides except to the southwest. Here, my notes indicate that a dark zone was visible. This dark zone is shown clearly in the Palomar image at bottom left. While the drawing and the photo have some vague similarities, it is interesting to note what an astrophoto (albeit overexposed) reveals as compared to a visual observation.

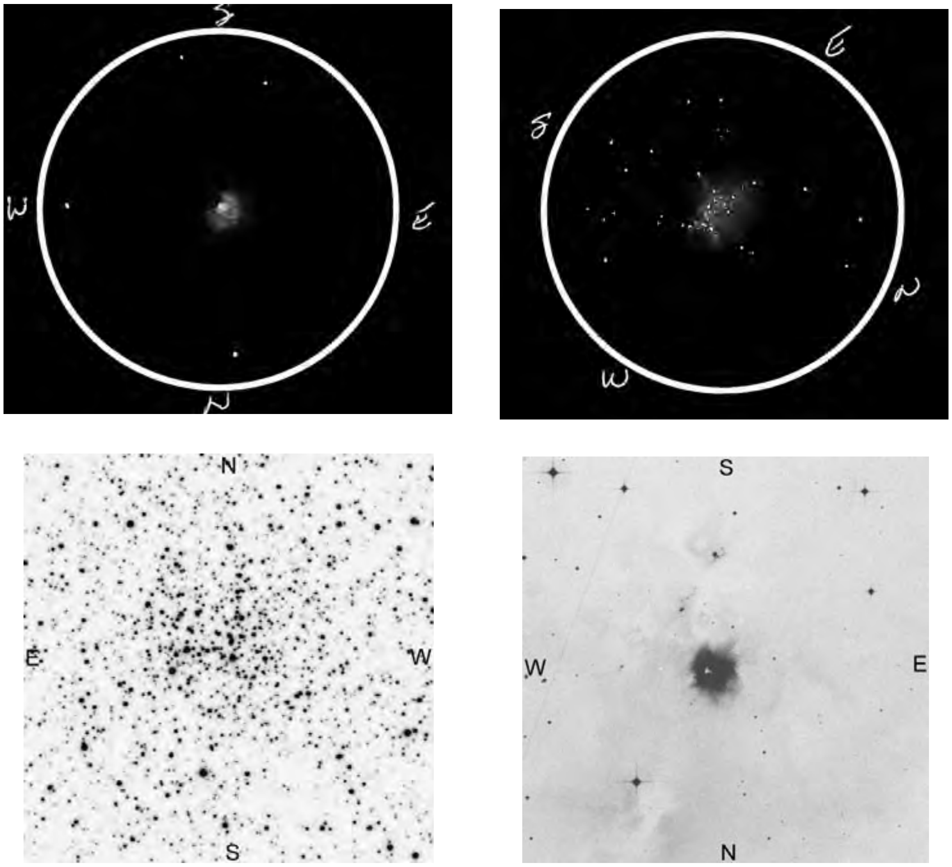
NGC 2194 is a small, rich open cluster located in the northeastern region of Orion. Its isolated location, far from any bright star, might make it difficult to locate, but under very dark skies the stars 73 and 74 Orionis may be faintly visible, leading observers to the open cluster.

The visual observation (top right) was made on the evening of February 25–26, 1995 from Sutton, Quebec on a night when stars to magnitude +5.5 were visible at the north celestial pole. My notes describe the cluster as small, though bright and fairly compressed and well isolated from surrounding field stars. Resolved stars were in the range of magnitude +12 to +14, and I counted about forty stars as being individually visible. My notes describe the cluster as "wasp-waisted," appearing concave towards the center. A soft glow of unresolved stars indicates the richness of the cluster.

When we study the Palomar Sky Survey image (bottom right), a chain of stars is clearly visible running due east-west: the "wasp-waist." In the photo, stars to about magnitude +18 are visible, but otherwise there is generally good agreement between the photo and the structure I sketched at the eyepiece.

With patience and a light touch, any observer can make an accurate sketch of the view through a telescope. And the fun part comes later when we compare what the eye sees to what the camera reveals.

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



Visual sketches (above) and Digitized Sky Survey images (below) of NGC 1999 (left) and NGC 2194 (right).

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Astrocryptic Answers

by Curt Nason, Moncton Centre

Answers to AstroCryptic #8

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Observer's Calendar — 2001

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

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

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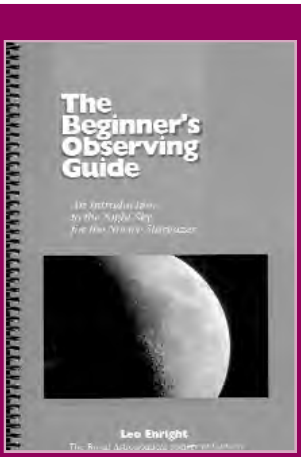

The Beginner's Observing Guide

This guide is for anyone with little or no experience in observing the night sky. Large, easy to read star maps are provided to acquaint the reader with the constellations and bright stars. Basic information on observing the moon, planets and eclipses through the year 2005 is provided. There is also a special section to help Scouts, Cubs, Guides and Brownies achieve their respective astronomy badges.

Written by Leo Enright (160 pages of information in a soft-cover book with otabinding which allows the book to lie flat).

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