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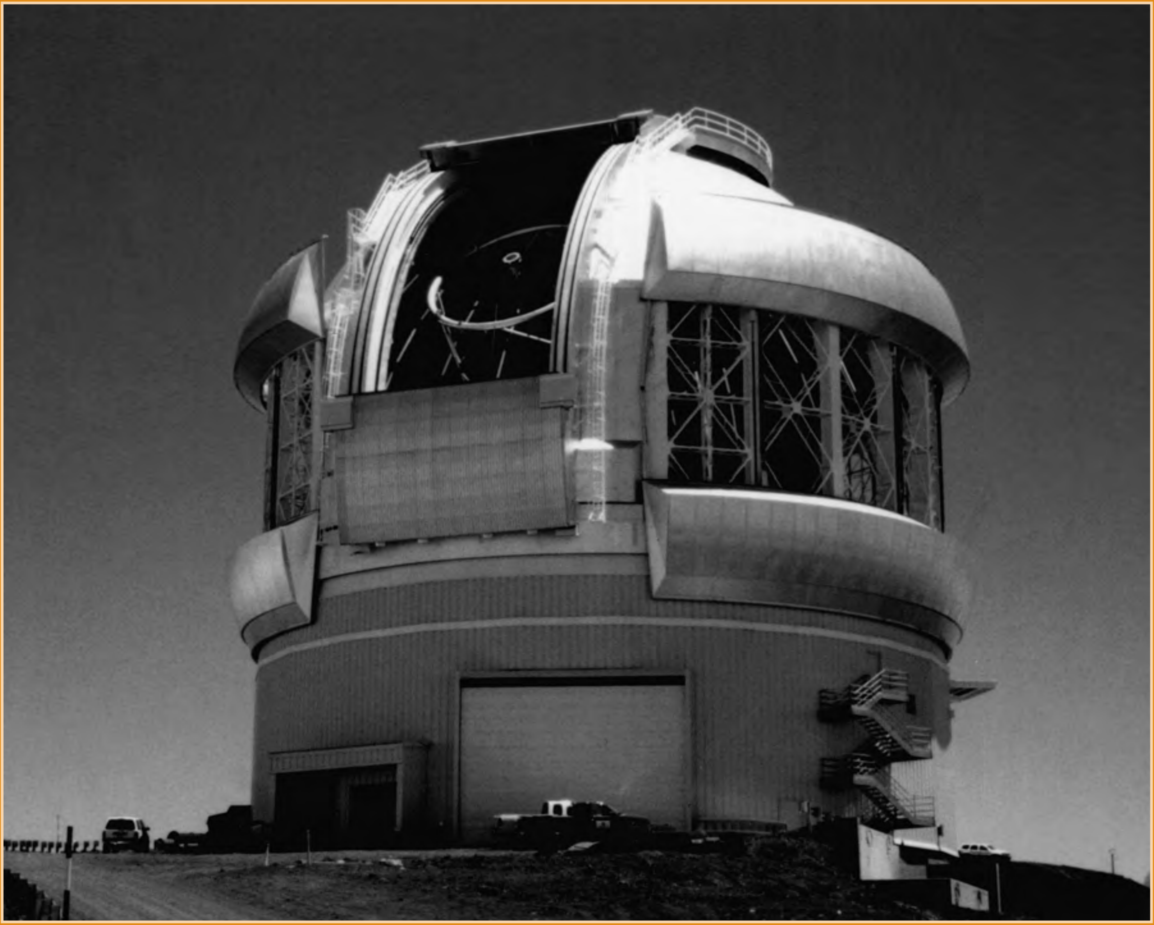

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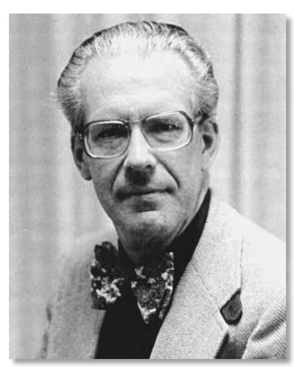

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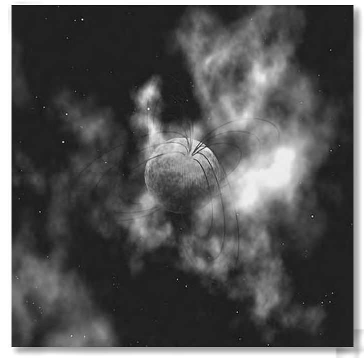

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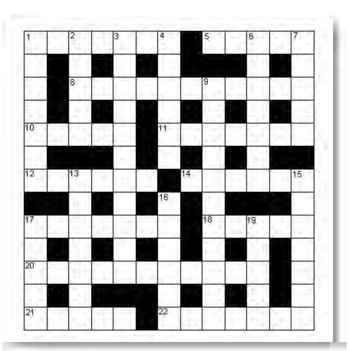

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President's Corner

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

The Council of the RASC holds four business meetings each year. Topics of discussion usually are administrative or financial: officers and editors deliver reports on their recent activities, Messier and Finest NGC certificates are approved, prices and marketing of publications are discussed, the budget is set, and bylaw amendments are debated. Only matters arising from the last item in this incomplete list require the involvement of the entire membership, as final approval of changes to the Society's bylaws comes from members at an Annual Meeting, not from Council. At its October 26, 2002 meeting, Council gave the necessary 2/3 approval to three bylaw amendments. I regard the approval of two of these amendments, the establishment of two new standing committees, which might at first glance seem to be purely administrative changes, as an exciting and significant event in the Society.

There are several committees of Council, which report on their activities and present relevant motions to Council at its meetings. The committees are of two types: standing and special. Standing committees are listed in the Society's bylaws, and their mandates are specified in the bylaws. Establishment of a new standing committee (or decommission of an existing standing committee) requires a bylaw change, and is therefore only possible with 2/3 approval of both Council and the entire membership. Special committees, on the other hand, are established solely by Council, without the need for any bylaw changes.

The two new standing committees approved by Council on October 26 are the Education Committee and the Observing Committee. Currently, there are two associated special committees, the Public Education Committee and the New Observing Certificates Committee. The scope of the proposed standing Education Committee will be similar to that of its precursor, and that of the Observing Committee will be broader.

If associated special committees already exist, why am I so excited at the prospect of the creation of these standing committees? For one thing, the change in status will give the committees some permanence and a presence in the structure (*i.e.* bylaws) of the Society. While it might be argued that the actual activities of the committees may not be much altered by the change, I think this enhanced presence is significant. Status as standing committees will, I believe, make these committees a more important part of the Society's operation.

In broad terms, I see the creation of these two new standing committees as an indication that the Society and its Council

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.

The *Journal of The Royal Astronomical Society of Canada* is published at an annual subscription rate of $80.00 by The Royal Astronomical Society of Canada. Membership, which includes the publications (for personal use), is open to anyone interested in astronomy. Annual fees for 2003, $44.00; life membership is $880. Applications for subscriptions to the *Journal* or membership in the RASC, and information on how to acquire back issues of the *Journal* can be obtained from:

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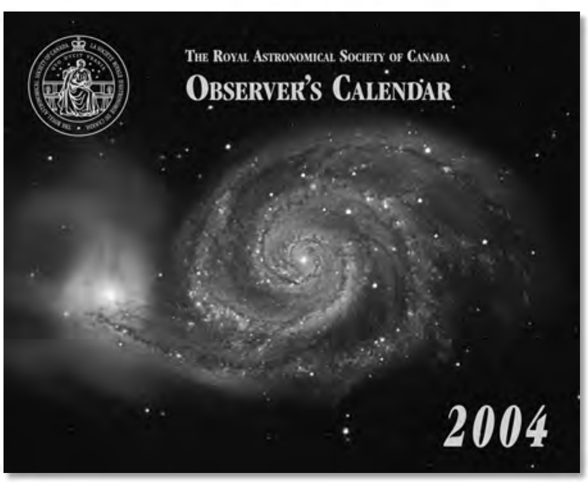
will place more resources into *astronomical activities* than it has in the past. Most of the current standing committees of Council serve administrative purposes (for example, the Constitution, Finance, and Nominating Committees); relatively few (for example the Publications Committee) actively fulfill the mandate of the Society, which is the promotion of astronomy and the allied sciences. The new proposed standing committees go to the heart of what the RASC is all about.

It is important to recognize, however, that most of the astronomical activities the Society engages in must primarily be carried out at the Centre level. (Publishing is a notable exception; only by pooling its collective resources can the Society produce world-class publications such as the *Observer's Handbook*.) Most Centres are already actively involved in educational and observing activities. The role for the Society here, as I see it, is as a facilitator and organizer. The new Observing Committee could, for example, promote and coordinate inter-Centre observing projects; the Education Committee could assist Centres in sharing with each other their various local educational programs and experiences. Both committees could maintain Web sites that would serve Centres and members, and that would also be a valuable resource to the astronomical community at large (just like the *Observer's Handbook*). Also, these committees could initiate educational and observing projects that are nationwide in scope. The exact nature of the activities of the committees (if they come into existence) remains to be seen, but an ongoing presence, in the form of these committees, by the Society in these core activities cannot help but foster the fulfillment of the Society's mandate.

Of course, any initiative taken on by the volunteer-based RASC is successful only if members put their energies into the initiative. Both prospective committees are blessed with strong leadership, but for the committees to be truly successful, involvement by members across the Society will be necessary. Since members love observing and sharing their passion for astronomy with others (especially school children), I expect that this involvement will indeed be present.

So, I encourage members to support the establishment of the proposed new standing Education and Observing Committees. You can express this support at the Vancouver General Assembly, where you may vote at the Annual Meeting (in person or by proxy) on the bylaw changes necessary for the creation of these committees. I personally expect these bylaw changes to be approved handily, and for the new committees to have a significant long-term impact within the Society.

CALL FOR PHOTOS — 2004 RASC OBSERVER'S CALENDAR



All members of the RASC are encouraged to submit astronomical photos for consideration for publication in the 2004 RASC Observer's Calendar. Images can be of any type — deep-sky or solar system; prime-focus, piggyback, or fixed-tripod; film- or CCD-based.

Electronic images under 2 megabytes in size may be sent by email to `gupta@interchange.ubc.ca`. For larger images, CDs may be mailed to the address below. Film-based images should be submitted, or be made available on request, as 8- by 10-inch prints or as original negatives or slides.

Prints, negatives or slides, and CDs should be mailed to:

Rajiv Gupta
2363 18th Ave W
Vancouver BC V6L 1A7

so as to arrive by **April 30, 2003**. Submissions that are accompanied by a return email address will be acknowledged, and original slides and negatives will be returned.

For further information about submissions, please contact me by email or by phone at 604-733-0682.

Rajiv Gupta
Editor, *RASC Observer's Calendar*

Editorial

by Wayne A. Barkhouse, Editor-in-chief (barkhous@astro.utoronto.ca)

In a recent issue of *Sky & Telescope* (December 2002), two articles discussed the impact of light pollution on astronomy and the methods that some people have undertaken to tackle this ever-growing problem. While reading these items, I was reminded of a conversation I had last year with a university student who was taking a first-year, non-science, astronomy course. This student approached me after one of my lectures and remarked that she had never seen the Milky Way before. Apparently, she had spent most of her life in Seoul, South Korea, where light pollution makes it impossible to see the Milky Way. My first reaction was to smile, but upon reflecting for an instant, I soon realized that it had been several months since I had seen the Milky Way. In fact, the last time at that point was when I had been on an observing run at Kitt Peak National Observatory in Arizona.

Growing up in rural Nova Scotia, one took for granted that the Milky Way was always there to see during any clear night. In fact, dark starry nights certainly contributed to the reason that I wanted to become an astronomer (either professional or amateur), another factor being the space program. I have often wondered what fraction of professional astronomers — who knew at an early age that they wanted to be astronomers — grew up in rural areas where light pollution was not a concern.

When I moved to Toronto to enter the Ph.D. program at U of T, I had expected that much of the sky would be awash in light (I wasn't disappointed!). On my first trip to the David Dunlap Observatory in Richmond Hill (about one hour north of my residence), I made a point of looking for the Milky Way. To my surprise, I soon discovered that the light pollution was too overwhelming to allow me the pleasure of becoming reacquainted with an old friend.

Having recently moved to the Boston area, I find myself once again living in a location where light pollution prevents me from seeing the Milky Way. It is not hard to imagine that a large number of children have never seen the beauty of the Milky Way stretching across the sky on a summer night.

What can we do to save the Milky Way for future generations? For several years a few organizations, like the International Dark-sky Association (IDA), have attempted to inform the public about the disadvantages of light pollution. One main avenue of attack has been trying to get bylaws passed that call for the installation of lights that are more efficient, produce less glare, and minimize the amount of light directed skywards. The implementation of this type of lighting would save the taxpayer money, and that should be motivation enough to undertake the necessary change.

In Canada, the Light Pollution Abatement Committee (LPAC) was established by the RASC in 1991 to help reduce light pollution by educating the public and providing advice to government organizations. Some benefits that have emerged from this initiative include the passing of a number of bylaws in provinces such as Alberta and British Columbia.

As always, time, effort, and money are needed to help curb the growth of light pollution around the world. I would encourage all of you to make an effort to inform the public about this problem by giving public talks on this subject, discussing the issue during public observing events, and even writing editorials for your local newspapers. Remember, the squeaky wheel gets the grease!

For further information, see `www.darksky.org` and `www.rasc.ca/light/home.html`.

News Notes
En Manchettes

SATELLITES SPY OUT BOLIDES

Objects carrying the same amount of energy as 5,000 tons of TNT strike the Earth's upper atmosphere at a rate of about one per year. So concludes a recent report by Dr. Peter Brown (Department of Physics and Astronomy, the University of Western Ontario) and co-workers on the flux of metre- to decametre-sized objects entering the Earth's upper atmosphere. The report also finds that objects with energy equivalents of about 300 tons of TNT strike the Earth's upper atmosphere each and every month.

The new study by Brown and co-workers uses data gathered by a fleet of United States Department of Defense and Department of Energy satellites in geostationary orbit, and was published in the November 21 issue of the journal *Nature*. The instruments carried onboard the satellites were designed primarily to detect the "tell-tale" signatures of nuclear explosions, but for the past eight years data from optical events recognized to be due to very bright meteors, or bolides, have been archived for study.

The new flux estimates are based upon the optical data pertaining to 300 satellite-recorded events. The instruments provide data on the energy radiated by the bolides into space at optical wavelengths and Brown and co-workers have used various calibration methods to estimate the so called luminous efficiency, which then allows them to determine the total energy involved in each event. It is found that somewhere between 6% to 15% of the total energy of the "impact" is radiated at optical wavelengths.

While the satellite-detected bolide events are certainly bright and energetic, the parent bodies (mostly asteroid fragments) are typically destroyed in the Earth's upper atmosphere. The larger the parent object, however, the more likely it is that some ground damage will be evident. In recent history, the most damaging impact event was the Tunguska "explosion" that occurred in Siberia in 1908 (for more details on the Tunguska impact, see the following Web link: `www-th.bo.infn.it/tunguska/`). Brown and co-workers find that the flux of Tunguska-class objects (having energies equivalent to 10 megatons of TNT) is something like 1 per 1000 years, which is a three to five times longer time interval than previously thought for such impacts.

NEW SMU ICA

The Department of Astronomy and Physics at Saint Mary's University (SMU) in Halifax, Nova Scotia has recently announced that it will be forming a new Institute for Computational Astrophysics (ICA). While formally founded by the University Senate in December, 2001, the Institute has now received a Canada Research Chair and starting in February, 2003 its new Director will be Dr. Robert Deupree. Deupree is known for his work on multi-dimensional stellar simulations and will be moving to Halifax from Los Alamos National Laboratory.

The ICA has been formed with three main objectives in mind. Firstly, the ICA will foster excellence in research in computational astrophysics. Secondly, it will serve as a focus for computational astrophysics both in Canada and internationally by providing opportunities for visiting faculty, post-doctoral fellows, and graduate students to work and interact in a stimulating and congenial environment. And thirdly, the ICA will provide the astrophysical community at large with a suite of computational tools (both in hardware and software) and the expertise to use them.

THIS STAR HAS A MAGNETIC PERSONALITY

Back in 1979, a huge energy outburst was observed in space — an outburst that marked the discovery of a new class of stars now known as Soft Gamma-ray Repeaters (SGR). Scientists theorized that these objects must be highly magnetic in order to produce the bursts observed, and subsequently coined the term "magnetars" for them. One such magnetar, the star SGR 1806-20 situated some 40,000 light-years from us, has been the object of a recent investigation by an international group of astronomers headed-up by Dr. Samar Safi-Harb of the University of Manitoba.

"Scientists have been puzzled for a decade about the nature of these mysterious stars," said Safi-Harb. "For many years, a great deal of evidence suggested that these stars were magnetars, but we didn't have a direct measurement of their magnetic fields." A new set of observations, however, has finally been able to study a magnetar directly, and characteristic features seen in the X-ray spectrum of SGR 1806-20 revealed the presence of a magnetic field a thousand trillion times greater than the Sun's magnetic field.

SGR 1806-20 is a neutron star, formed during the supernova disruption of a star once about ten times more massive than the Sun. Extreme in size, density, and temperature, "this neutron star could be as small as Winnipeg, but with a temperature several million times warmer," Safi-Harb commented. In addition, "if the Moon were this magnetic, it would rearrange the molecules in our body," noted Dr. Alaa Ibrahim (a doctoral candidate at George Washington University, and member of the research team). "Although one would not want to get close to such an object, we now have a method of probing them from afar to learn about the physics of matter under extreme gravitational and magnetic forces" Ibrahim continued.

Ibrahim made the discovery of the extreme nature of SGR 1806-20 while working with Safi-Harb on a project funded by the Natural Sciences and Engineering Research Council of Canada and a University of Manitoba Research Grant. The data was acquired using NASA's Rossi X-Ray Timing Explorer (RXTE) satellite.

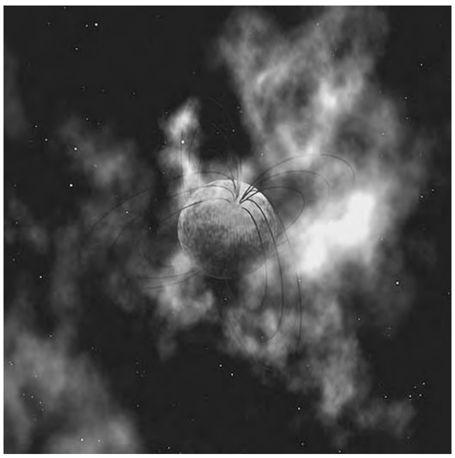


Figure 1 – Artist's impression of what a magnetar might look like. The lines emanating from the star's poles represent its powerful magnetic field (image by Robert Mallozzi, University of Alabama, Huntsville). In addition, an animation sequence showing the motion of particles inside a magnetar can be found at: nt.phys.gwu.edu/~kovac/magnetar/

DR. BRETT GLADMAN RECEIVES UREY PRIZE

The Harold C. Urey Prize for 2002 has been awarded to Canadian astronomer Dr. Brett Gladman (Department of Physics and Astronomy, University of British Columbia, Vancouver). The Urey Prize is awarded annually by the Division for Planetary Sciences (DPS), a branch of the American Astronomical Society, and is awarded in recognition of outstanding achievements in planetary science by a young scientist.

Gladman received his prize at a special ceremony on October 9, 2002 in the ballroom of the Birmingham Jefferson Convention Center in Birmingham, Alabama, the site of this year's DPS meeting. He then gave a lecture, entitled "Opening Pandora's Box: The Discovery of New Irregular Satellites of the Giant Planets," to the DPS membership.

Gladman is well known for his many studies on the dynamical structure of the solar system. In addition, his extensive simulations of the orbital evolution of meteorites from the Moon, Mars, and the main asteroid belt have fundamentally altered our understanding of how these meteorites are delivered to Earth. His observational work has concentrated on the study of outer-solar system objects, which has resulted in the discovery of eleven new moons of Saturn and five of Uranus, as well as several dozen small bodies beyond the orbit of Neptune.

2002 AA_{29} — IT'S A SHOE-IN FOR FURTHER STUDY

Newly discovered asteroid, designation 2002 AA_{29}, moves in an orbit almost identical to that of the Earth. This result, recently published in the October issue of the journal *Meteoritics and Space Science* by Dr. Martin Connors (Athabasca University, Alberta) and co-workers, makes 2002 AA_{29} unique among the known minor planets. The orbital characteristics of 2002 AA_{29} are such that when viewed in a reference frame that rotates with the Earth it follows a horseshoe-shaped curve, and, it turns out, transitions to a quasi-satellite status are also possible. The orbital semi-major axis of 2002 AA_{29} is determined to be 1.0006 AU while its eccentricity is 0.0120; which is an orbit comparable to that of the Earth's with semi-major axis of 1.000 AU and eccentricity 0.0167. The inclination of 2002 AA_{29}'s orbit, however, is some 10.565 degrees to the ecliptic. Further extensive discussion and animation sequences of 2002 AA_{29}'s orbit can be found at the following Web page by Dr. Paul Wiegert (Queen's University, Ontario): www.astro.queensu.ca/~wiegert/AA29/AA29.html.

The orbital evolution of 2002 AA_{29} has been investigated numerically by Connors and co-workers to reveal its quasi-satellite behaviour. Three time periods have been identified when 2002 AA_{29} was, or will be, a near-second Earth satellite. The last time was in 572 A.D., and the next two times will begin in 2575 and 3880 A.D. While not physically in orbit about the Earth at these times of quasi-satellite status, 2002 AA_{29} remains within about 0.2 AU (some 39 Moon orbit diameters) of the Earth for several decades on end. At such times, Connors and co-workers point out, 2002 AA_{29} would be a good target for space exploration.

At this stage, it is not believed that 2002 AA_{29} is actually unique, but that it is rather the first of a class of objects co-orbital to the Earth.

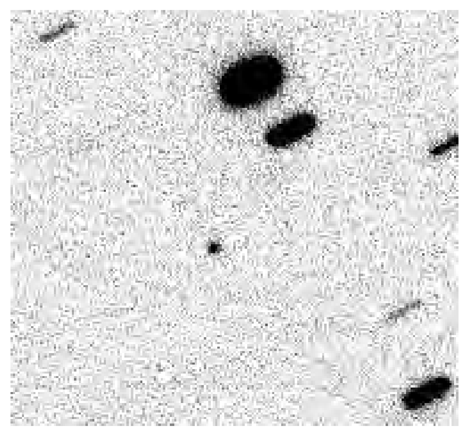


Figure 2 – Image of 2002 AA_{29} obtained with the Canada-France-Hawaii telescope. Optimized tracking has been used so that the asteroid appears as a point (centre of frame) while the stars are trailed. (Image courtesy: Martin Connors).

MOST: Canada's First Space Telescope Part 2

by Randy Attwood, Toronto Centre (randy.attwood@rogers.com)

In the first part of this article (*JRASC, December 2002*), I talked about the design of the MOST spacecraft, the history of the project, and the questions about the universe astronomers hope data from MOST will help answer. In this, the second and final part, I look at how MOST will take precise photometric readings of stars continuously for weeks at a time, as well as the trials and tribulations of finding a ride into Earth orbit.

The MOST satellite (Figure 1) will be Canada's first space telescope when it is launched into a 900-km-high Earth orbit in late June 2003. Its mission is to observe selected stars for extended periods of time, making precise measurements of the changing brightness of each star. MOST can detect changes in brightness of one part per million.

Figure 1 – Randy Attwood and MOST August 1, 2002, in the clean room at UTIAS/SFL (Photo: Dr. Kieran Carroll).

To be able to continuously observe an object, the satellite's orbit must follow Earth's terminator (the line separating day and night). From this vantage point, one area of the sky, away from the Sun, will always remain in view. This area — the continuous viewing zone (CVZ) — is 54 degrees in diameter (Figure 2). Stars can be observed in the CVZ without interruption for seven weeks. The side of the satellite with the telescope opening will always remain in shadow, while the opposite side of the spacecraft will always face the Sun. This latter side is covered with solar cells from which MOST will get its electrical power. To get the maximum solar power, MOST must remain in an attitude with this side perpendicular to the Sun's rays. The observation period is limited to seven weeks because, as the Earth moves in its orbit around the Sun, the star slowly moves out of this zone. To continue to point at a star, MOST would have to turn to an angle with respect to the Sun. This increased angle would result in less sunlight falling on the solar panels, which means less solar energy. It is only the fainter stars that require an extended observation period of up to seven weeks. Most of the stars on the observation list will require much less time, on the order of a few days to a few weeks.

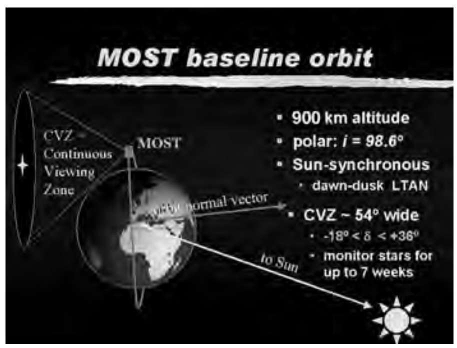


Figure 2 – MOST in its 900 km orbit as depicted by Dr. Jaylie Mathews.

MOST will not be in Sunlight all the time, as the principal investigator, Dr. Jaymie Mathews, explains:

> In order to stay in a Sun-synchronous orbit, the inclination cannot be exactly 90 degrees. It is offset from 90 so that the orbit precesses at the sidereal rate. But it is still close to a right angle to the Earth's equator, while the path of the Sun in the sky follows the ecliptic, tilted by 23.5 degrees to the equator. For our orbit, the Sun will dip beneath the horizon for a few minutes each orbit in the summer, from about June to August.

One challenge for the engineers has been controlling the temperature inside MOST. Since one side is constantly in sunlight and the other side is in shadow, there is a large difference in temperature. To combat the high temperatures, special reflective tape on the outside of the spacecraft reflects heat where needed. Another concern is that, at this high-altitude orbit, solar flares or radiation in the upper atmosphere of the Earth could damage the spacecraft's electronics. As a result, the systems have been treated to protect them from the radiation.

How does MOST point in a desired direction and then stay there? To maintain or change its position in space, a large satellite like the space shuttle uses small onboard rockets. The shuttle carries enough fuel and oxidizer onboard for these rockets to last the mission, a couple of weeks at most. Mixing a little fuel and oxidizer in the rocket creates a small explosion, and the gases are forced out of the rocket nozzle at a high velocity, pushing the shuttle in the opposite direction. For satellites like the Hubble Space Telescope (HST), which are intended to be in space for a long time, fuel cannot be used; it would run out. In addition, in the case of HST, the rocket exhaust would contaminate the optics. Instead, such satellites use large reaction wheels. These are heavy flywheels that spin at a high rotation rate in either direction. When the spacecraft's computer decides that it wants to turn one way, it sends a signal to increase the rotation of the desired reaction wheel the other way, applying Newton's third law. There are three reaction wheels, oriented at right angles to each other. This allows control in the three axes of pitch, roll, and yaw.

These reaction wheels, however, are too large for microsatellites, therefore, innovative new technology was needed. MOST has mini-reaction wheels, called microwheels, each the size of a small pop can. They can reach a speed of up to 10,000 rpm and provide very accurate pointing of the satellite.

Dr. Kieran Carroll at Dynacon Enterprises Ltd. in Mississauga, Ontario developed these microwheels (Figures 3 and 4). During my visit to Dynacon, Dr. Carroll showed me a personal computer sitting on a small computer cart. Cables from the PC led to a small cardboard box on a lower shelf. From inside the box, I could hear a whirring sound. Inside was a microwheel undergoing a lifetime test. The PC was running a program nonstop for months that slowed the microwheel down and sped it up. By launch time, it will have accumulated enough activity to simulate a five-year mission, MOST's anticipated lifetime.

Reaction wheels take care of the spacecraft's fine pointing. For the rough, or coarse, pointing, MOST will make use of the Earth's magnetic field.

Figure 3 – Dr. Kieran Carroll and a microwheel (Photo: Randy Attwood).

Figure 4 – A microwheel (Photo: Randy Attwood).

When MOST is deployed from the rocket shortly after launch, it will most likely tumble. The act of leaving the rocket stage will trip a switch and turn the spacecraft on. It will immediately run a computer program that will slow and ultimately stop the tumbling motion. MOST carries a set of magnetometers and electromagnets called magneto-torquers. As MOST moves in its orbit, the magnetometer will detect the changing magnetic field of the Earth, thus giving the computer an idea of how quickly the spacecraft is tumbling. The computer decides in which direction MOST must be pushed to stop this tumbling action. When a small electrical charge is passed through a magneto-torquer, it creates a magnet that wants to align itself with the magnetic field, thus creating a small force on the spacecraft. There are three magneto-torquers onboard, arranged at right angles to each other. A complex computer program will de-spin the spacecraft in a couple of hours. The computer decides which of the three magneto-torquers should receive an electrical charge and when, based on the existing magnetic field at the time, to give MOST the right "push."

Once the spacecraft is stable, the computer will switch to the coarse pointing mode. Using Sun sensors and magnetometer information, the magneto-torquers should get the spacecraft pointing to within a degree or two of the desired area of the sky. At this point, the telescope door opens and MOST photographs the star pattern to see if the target star is in the field of view.

The maximum a mini reaction wheel can spin in one direction is 10,000 rpm. The situation may arise in which the microwheel reaches the maximum spin rate, as a result of responding to a signal to move in a certain direction. The software will then automatically perform a de-saturation of the wheel: the magneto-torquers will cut in to provide a force to keep the satellite steady as the wheel spins down. Then the microwheel can continue its spin up to move the spacecraft in the desired direction.

During the several weeks of data taking, several forces will act on the spacecraft, trying to change its position. The changing magnetic field will always be tugging on the magnets on the spacecraft. There will be a small gravitational force; the force on the bottom of the spacecraft will be greater than that on the top. Plus there will be very small atmospheric and solar radiation forces. The reaction wheels will counteract all of these forces. Dr. Carroll says that during the mission, this tugging can be modeled and predicted; modified software can be sent up to predict what tugging the satellite will see, thus controlling the reaction wheels, resulting in a more stable platform for the telescope.

The telescope was designed by Spectral Applied Research of Mississauga, and the optics were ground by Peter

Ceravolo, known to many RASC members. It was a challenge for Spectral Applied Research to design the telescope as a lightweight structure able to withstand the launch and also maintain the focus over the expected operational temperature range of −40°C to +60°C. The camera mount is thermally isolated from the telescope structure and is cooled by a passive cryo-cooler, which radiates to dark space. The target temperature for the camera is −50°C.

Instead of placing one CCD at the focus of the telescope, two CCD detectors are placed in the camera at the focus, so each one sees just the part of the sky that the telescope sees. One of the CCDs will be used to make the prime observations, noting the changing brightness of a star for weeks at a time. The second CCD will act as a star tracker. A star tracker takes an image of a star and notes over time if the star has moved at all. Each CCD is split in two: one side is used for collecting data and is in the telescope's field of view. The other side acts as a buffer: instead of using a physical shutter, after the data is collected, it is quickly shifted into the adjoining CCD area from which it is read into the computer storage area for later transmission to Earth. This "virtual shutter" design allows MOST to take exposures electronically; a physical shutter, something that could fail, is not needed. While the data is being read, the data-collecting side can collect new data.

Once the astronomers have MOST pointing in the general area of the target star, MOST takes a picture using the star tracker CCD. This is sent to Earth, and the astronomers try to determine what they are looking at. They can then send commands to MOST to get the target star centred in the telescope.

Even though MOST will be kept fairly steady during the weeks of continuous observation, there will always be slight wobbles. If the starlight collected by the telescope was focused onto one pixel in the CCD, this image would wander across several pixels. Since each pixel has its own characteristic sensitivity, measuring the changes in the light source down to one part per million using a series of pixels would be impossible. To get around this, an array of 6 × 6 microlenses, each 100 microns across, has been placed in the light path (Figure 5). The focused starlight

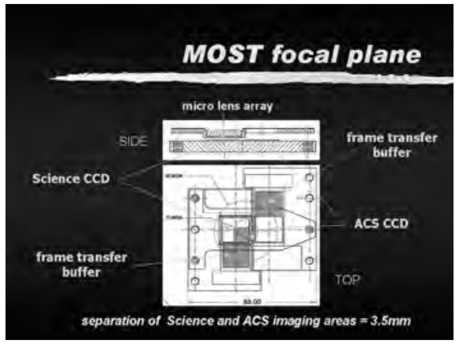


Figure 5 – CCD layout (Diagram: Dr. Jaymie Mathews).

will pass through one microlens, which will spread the starlight across 1000 pixels. The subtle wobbling of the satellite will not affect where the spread-out light hits the detector. The detector will essentially see an image of the exit pupil of the telescope.

Once the light from the target star strikes one of the microlenses, the entire spacecraft will be rotated so that the light from at least two stars of 8th magnitude or brighter near the target star falls on the star tracker CCD. Once that is done, the attitude control system will watch the guide stars and communicate with the three reaction wheels to ensure the satellite does not wander, keeping the target starlight on the science CCD detector. Over the period of data taking — from a few days to seven weeks — a measure of the brightness of the star will be taken every 10 to 15 seconds.

Data will be stored in the memory of the computer until the spacecraft passes over one of three ground stations. Receivers at the University of British Columbia, UTIAS/SFL in Toronto, and a backup in Vienna, Austria, will collect data for up to two hours a day. MOST will be smart enough to know when it is over a ground station, and the data transmission to the ground and reception at a ground station computer will all be automated.

Rocket Booster Blues

To get into space, MOST will have to piggyback on a launch of a larger satellite. Once the main payload is free of the booster, MOST will be tossed overboard. The orbit MOST requires to make its observations is unique, and not many satellites are sent into this kind of orbit. By coincidence, another Canadian satellite, RADARSAT 1, launched in 1995, is in the desired orbit. Its successor, RADARSAT 2, will share the same orbit so plans were made for MOST to hitch a ride with this other Canadian satellite, planned for 2001. Unfortunately, in 1999, the U.S. State Department raised concerns about the kind of sensitive data RADARSAT 2 would obtain. Also, there were concerns that the U.S. company that was to build RADARSAT 2 would be sharing high-resolution Earth photography technology with another country, so even in the days before 9/11, there were security issues that threatened to scuttle the whole project. RADARSAT 2 could not be allowed to ride into orbit on an American rocket nor could it be built of U.S. parts. RADARSAT 2 was delayed and MOST was left without a ride. There was concern that other astronomy space projects — specifically the COROT project in France and the MONS project in Denmark, which were designed to perform similar observations — could fly before MOST, possibly stealing its thunder. Time was of the essence.

A viable alternative came from an unlikely source. To satisfy agreements made with the United States, Russia was obligated to remove from its arsenal a certain number of ICBM boosters. These rockets, originally used to target nuclear warheads on the western hemisphere, would now serve as a relatively inexpensive booster for microsatellites instead of being destroyed. A German company, Eurockot Launch Services, which oversees the use of these rockets, announced in November 2001 that MOST and a Czech satellite called MIMOSA would be launched on an SS19 ROCKOT launch vehicle from the Plesetsk launch site, 800 km northeast of Moscow. (Roughly translated, ROCKOT means "rumble" or "roar"; See Figure 6.) Plesetsk has historically been the most active launch site of the world, responsible for over one-third of all launches. A third stage has been added to the ICBM, called Breeze, which is restartable in space to place the individual payloads into the desired orbit.

Figure 6 – The launch of a ROCKOT.

The outcome of all this is that MOST will fly in mid-2003, and RADARSAT2, with an Italian-built bus, will ride into orbit on an American rocket after all, in late 2003. As for the competition, COROT will not fly until 2005, and MONS may not fly at all because of budget problems.

As the launch date approaches, the MOST team is putting the spacecraft through a series of vibration and other tests to simulate what it will experience in the space environment. There have been some problems. Jaymie Mathews describes one very serious problem in early 2002. Two ceramic washers in the camera system were machined with an inner diameter 50 microns too large. During vibration testing to simulate what the instrument will experience on launch, these washers were partially pulverized, contaminating the instrument. Dr. Mathews says, "We disassembled the instrument and cleaned everything, including taking the CCDs by hand back to Marconi in England for refurbishing."

In December 2002, the satellite was at UTIAS/SFL in Toronto, after having successfully completed its vibration tests at the David Florida Lab (DFL) in Ottawa. The telescope/camera was undergoing tests at Spectral Applied Research and was scheduled to go to DFL for vibration tests in mid-December. The satellite will be delivered to the launch site at least a month before launch.

A successful mission for MOST will prove this new technology and will open the door for other missions. It will prove that sophisticated, small satellites can be flown at a reasonable cost. This means more organizations such as universities can afford to fly spacecraft. Off-the-shelf hardware can be used, making it even cheaper. A shorter turnaround between flights allows time to refine the data collectors and learn from previous flights.

Already another flight is in the planning stages using the MOST design. NESS (Near Earth Surveillance Satellite), with Dr. Alan Hildebrand as the principle investigator, will look for Aten-class asteroids, small asteroids inside Earth's orbit that could pose a hazard for the Earth. The satellite will use the same hardware as MOST, although the pointing accuracy will have to be improved because the CCD will be used to take photographs of these faint objects.

Like any space project, the MOST team has faced many hurdles. New technologies were developed, budget constraints forced innovations, and uncertain launch schedules meant delays. Although MOST will not transmit beautiful pictures, the results of its space investigation may prove that if a tool is designed to answer one very important question, its value can far exceed its cost. MOST's low cost may pave the way for future projects to look for answers to many other unanswered questions in the exploration of the universe.

For further information, visit these Web sites:

UBC MOST:
`www.astro.ubc.ca/MOST/2002/index.html`

Dynacon Enterprises:
`www.dynacon.ca`

Canadian Space Agency: `www.space.gc.ca/csa_sectors/space_science/space_astronomy/most/default.asp`

UTIAS/SFL: `www.utias-sfl.net/code/home.html`

Eurorockot Launch Services:
`www.eurockot.com`

Plesetsk launch site: `plesetsk.org`

Randy Attwood joined the Toronto Centre of the RASC in 1970 and is a Life member of the Society. He is a Past President (1998–2000) and is currently the Chairman of the Public Education Committee. He is the Society's unofficial representative for the MOST mission's public outreach program. Randy hopes to provide continuing coverage of the MOST mission in future issues of the Journal*, including plans for the RASC's participation in the MOST outreach project.*

Measuring the Properties of the Universe

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

A scientist servicing the Degree Angular Scale Interferometer (DASI) as the South Pole. Each of the small cylinders is a separate detector, and the entire structure is inside a ground shield to reduce scattered microwave "noise" from the surrounding snow. Photo: John Carlstrom

It is amazing to think that only thirty-eight years after the discovery of the cosmic microwave background (in 1965), and only ten years after the first detection of its fluctuations, we can now measure those variations well enough to determine some of the most fundamental properties of the Universe. John Carlstrom of the University of Chicago, and his collaborators there and at Berkeley, have made another leap in achievement, which may open a whole new way of doing cosmology (see December 19, 2002 issue of *Nature*).

The story started with the discovery by Arno Penzias and Robert Wilson of a uniform noise that they simply could not eliminate from their Bell Labs antenna, no matter where they pointed it in the sky. Very rapidly it was realized that this noise, with the characteristics of a "black body" at a temperature of just 3 degrees Kelvin (three centigrade degrees above absolute zero), was left over from the Big Bang that started the Universe. That in turn started the beginning of modern cosmology as we know it.

The last ten years or so have seen the evolution of what appears to be a self-consistent and fairly detailed picture of the basic properties of our Universe, though it is not universally accepted. We know that something happened to trigger the Big Bang, and rather early on (less than 10^{-30} seconds afterwards) the Universe underwent a period of extremely rapid "inflation," during which its size increased enormously. Tiny fluctuations arose in the dense "quark soup" of elementary particles and radiation forming the seeds of the groups and clusters of galaxies that we see today. Ordinary matter — the nuclei of hydrogen, helium, and a little bit of lithium — came out of the soup about one second after the Big Bang, but it was far too hot for atoms to exist. The charged nuclei, together with a cloud of electrons, created a thick haze that no light could penetrate. As the Universe expanded, it cooled.

About 400,000 years after the Big Bang, the gas had cooled sufficiently (to about 3000 K) that electrons could combine with the atomic nuclei (particularly hydrogen); this was like a sudden lifting of the fog, and the light could stream freely. This "decoupling" of matter and radiation provides a snapshot of what the Universe looked like at that time, and that snapshot is the cosmic microwave background.

Since then, the Universe has expanded in each spatial dimension by about a factor of 1000, so we see the 3000 K gas of that time as the 3 K background radiation of today. Increasingly accurate measurements during the twenty-five or so years after the discovery of the background radiation determined the temperature to be about 2.7 K.

The next breakthrough came in 1992 when the COBE satellite was able to measure fluctuations in the background radiation; these fluctuations are tiny differences in the temperature of the background across the sky. The physics of how the fluctuations reflect the fundamental properties of the Universe is very interesting. You can think of the early Universe (before decoupling) as a fluid with tiny concentrations of mass scattered through it. These concentrations come from the quantum fluctuations in the quark soup at the end of inflation; the areas with slight peaks in density grow in size because of gravity, while the slight holes lose matter to the surrounding peaks. This means there is always a net movement of matter towards the density peaks, but that movement is being opposed by radiation pressure — the peaks in matter also give rise to peaks in radiation.

The combination of these effects sets up waves, which you can think of as waves in the sea. It is possible to determine the "spectrum" of the waves (basically, the number of waves in a wavelength range), and to measure how these waves are correlated statistically with each other. The properties of the waves are of course related intimately to the material in which the waves exist. In the case of the Universe, that means dependence upon the total density of mass, the amount of normal baryonic matter (the elements we are familiar with on Earth), the "curvature" (whether the Universe is flat and light therefore travels in straight lines through empty space), and the value of the cosmological constant.

And that takes us to today. Carlstrom and his colleagues have measured the degree of polarization in the fluctuations in the microwave background, using an interferometric array of microwave detectors at the South Pole. Polarization is a measure of the relative amounts of light that oscillate perpendicular to each other. For example, polarized sunglasses cut glare because the light that is reflected off roads is preferentially made of waves that oscillate parallel to the surface of the road — like a snake slithering along the road. Regular sunlight straight from the Sun is unpolarized, so if we wear glasses that won't let through the light that is oscillating parallel to the road, we cut out the reflected glare without losing too much of the rest of the sunlight.

The degree of polarization of the cosmic microwave background is uniquely predicted by each set of cosmological parameters. That means that by measuring the polarization, you have uniquely determined the correct mix of parameters that describes the Universe. So, has Carlstrom given us the end of cosmology as we know it? Not really. These extremely difficult measurements produced a result that — within the observational uncertainties — is in agreement with the model of the Universe that has emerged over the last couple of years. Our Universe is made of about 5 percent baryons (only about a tenth of which is in the normal stars and gas we see shining at optical wavelengths), about 30 percent dark matter, whose nature is completely unknown at this time, and about 65 percent dark energy, which is even more mysterious than the dark matter. This dark energy is actually accelerating the expansion of the Universe at the present time.

Future and even more sensitive measurements of the polarization will certainly reveal surprises about the Universe. In another ten years or so the polarization data might be good enough to reveal the subtle effects of gravitational waves, which may help us to determine what went on at the time of the Big Bang and possibly even before it, if some extremely speculative ideas being considered by cosmologists today turn out to be closer to the truth than our present picture. In the meantime, cosmologists will be trying to figure out just what the dark matter and dark energy are.

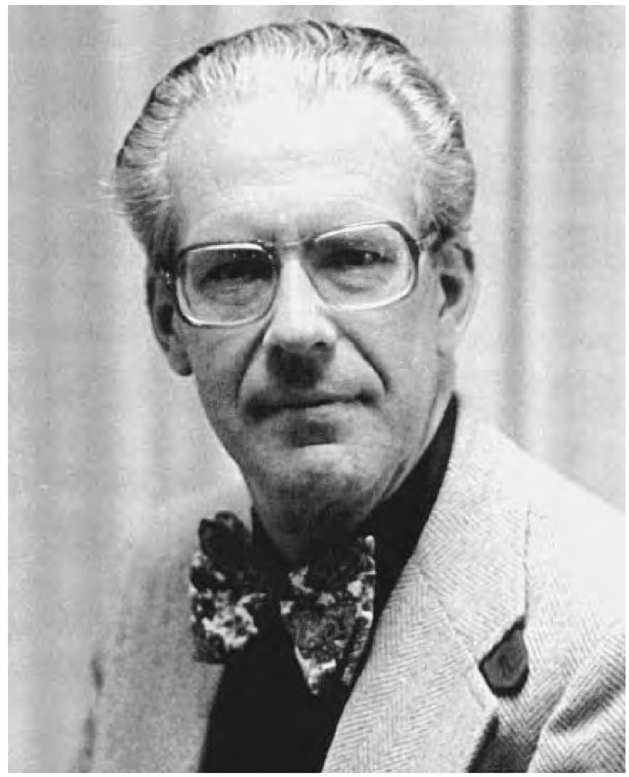
Dr. Leslie J. Sage is Senior Editor, Physical Sciences, for Nature Magazine *and a Research Associate in the Astronomy Department at the University of Maryland. He grew up in Burlington, Ontario, where even the bright lights of Toronto did not dim his enthusiasm for astronomy. Currently he studies molecular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

Maarten Schmidt and the Discovery of Quasar Redshifts

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

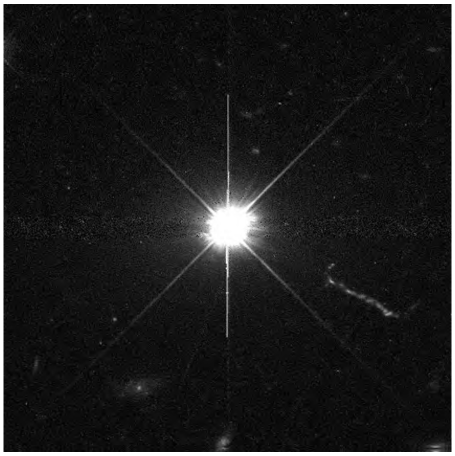
Maarten Schmidt, Emeritus Professor at the California Institute of Technology, turned 73 last December; however, this column actually marks the anniversary of his discovery of quasar redshifts 40 years ago on February 5, 1963. Schmidt was born in 1929 in Groningen, The Netherlands, and studied at Groningen University and the University of Leiden. In 1956 he received his Ph.D. under Jan Oort (1900–1992), another famous Dutch astronomer. (Oort is best known for detecting the rotation of the Galaxy and for proposing a theory for the origin of comets, that is, the "Oort Cloud.") In 1959 Schmidt emigrated to the U.S. and joined the staff of Caltech, where he studied the mass distribution and dynamics of galaxies. He became Director of the Hale Observatories (Mount Wilson and Mount Palomar) in 1978, a post he held until 1980.

Following the end of the Second World War, the physicists who had been involved in radar defence trained their equipment skyward to study the cosmos at radio wavelengths. Soon they were discovering powerful, compact emitters of radio wave energy. At Cambridge, Martin Ryle (1918–84) and F. Graham Smith (1923–) conducted three sky surveys. Several radio objects (with catalogue numbers starting with "3C") were investigated by optical astronomers, as radio telescopes were not able to determine distances. The very long wavelengths of radio waves, compared with those of light waves, provide very poor angular resolution. (The dominant radio wavelength of hydrogen is 21 centimetres, compared with 656 nanometers for the optical hydrogen alpha line, a ratio of 3 million!) The trick used to pinpoint the radio-wave emitters was to wait for the Moon to occult the source: knowledge of the Moon's motion through the sky, coupled with the precise instant of disappearance (and reappearance) of the radio source, provides information that allows the determination of the source coordinates to a higher degree of precision than the radio telescope alone can provide. In 1960, Allan Sandage (1926–) had identified the strong radio source 3C 48 as a faint stellar object with a highly unusual spectrum that defied explanation. Maarten Schmidt studied the spectrum of another object, 3C 273, which has turned out to be the strongest source of all, despite its dim visual magnitude of 13.0. He proposed the idea that the observed lines in the optical spectrum of the were in fact the Balmer lines in the ultraviolet part of the spectrum for atomic hydrogen, strongly redshifted into the visual band, implying a large recessional velocity of 16% of the velocity of light. The term "quasi-stellar object" or "quasar" was invoked to label these odd radio sources. (Ironically, the vast majority of quasars known today are "radio quiet," having little or no radio-wave emission.)



Prof. Maarten Schmidt (1929–)

Having established that quasars are receding at a significant fraction of the speed of light, the next step involves the cosmological theory of the expanding universe. If one looks at quasars in all directions, they appear to be receding from us at mind-boggling speeds. It is unlikely that we inhabit a preferred location in the universe, but there is an alternative explanation: the entire universe is expanding, just as the surface of a balloon expands as it is being inflated. There is no centre; every point in space recedes from every other point, with a recession speed proportional to distance. Edwin



Quasar 3C 273, showing a jet of ejected matter.

Hubble (1889–1953) had already established this fact in 1929 from optical observations of ordinary redshifted galaxies. Applying Hubble's law to quasar 3C 273, one gets an estimated distance of 2–3 billion light years. The most distant quasar known today is of the order 10 billion light years away!

With the quasars being so distant, their dim magnitude actually translates into a huge energy output, 10–100 times that of a normal galaxy. Today, quasars are thought to be the active centres of galaxies, and these centres are so concentrated that most astrophysicists cannot conceive of any energy source other than matter falling into a black hole. Investigating the enigma of the quasars was one of the compelling arguments in favour of the Hubble Space Telescope project. Looking at these energetic sources, truly we are looking at the birth of the known universe, so far away and so long ago! The secrets of the quasars are the key to the origin of everything we know.

For more about quasars, see `casswww.ucsd.edu/public/tutorial/Quasars.html`.

Today, Maarten Schmidt continues to perform research and publishes frequently in scientific journals. His personal Web page can be found at `www.astro.caltech.edu/people/bluebook/schmidt.html`. His description of his work reads as follows:

> "Maarten Schmidt's current interests are centered on the space distribution and luminosity function of quasars, at radio, optical, and x-rays. He is engaged in a long-term observational survey program for high-redshift quasars, aimed in particular to get information about the 'redshift cutoff.' Such data would provide direct constraints on the epoch of galaxy and quasar formation. This work involves transit observations (with the telescope tracking disabled) with CCD arrays, both in direct and slitless spectroscopic mode. Colors for hundreds of thousands of stars and galaxies, and very low-dispersion spectra for tens of thousands of objects are obtained in the course of this program. Besides the search for high redshift quasars, this material will be of interest for studies of different types of stars in our Galaxy and of galaxies and clusters of galaxies. Other active interests of Schmidt include counts of x-ray sources (clusters of galaxies, Seyfert galaxies, galaxies, BL Lacs and quasars) as well as the nature of the extragalactic x-ray background, statistics of gamma-ray bursts, and the luminosity function of stars (both disk and halo) in our Galaxy. His earlier interests included the statistics and evolution of radio galaxies, the distribution of mass in our Galaxy, and the chemical evolution and star formation history of our Galaxy."

Maarten Schmidt received the 1992 Bruce Medal from the Astronomical Society of the Pacific, plus a host of other distinctions from scientific societies in several countries. More of his accomplishments can be found at `phys-astro.sonoma.edu/BruceMedalists/Schmidt/index.html`.

Although we have alluded to the faint visual appearance of the quasar 3C 273, this object is still within the reach of amateur telescopes, and is a tantalizing object to search for, as its exceedingly great distance of 2–3 billion light years makes it the most distant object that can be seen in a small telescope. A finder chart for 3C 273 can be found on page 292 of the 2003 *Observer's Handbook*. It is located not far from the magnitude 3.9 star η Virginis.

David (Dave XVII) Chapman is a Life Member of the RASC and a past President of the Halifax Centre. By day, he is a Defence Scientist at Defence R&D Canada–Atlantic. Visit his astronomy page at `www3.ns.sympatico.ca/dave.chapman/astronomy_page.`

Variations in 1612-MHz OH Line Emission from IRAS 19566+3423

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Abstract. IRAS 19566+3423 has been observed 24 times over an interval of 5.2 years beginning in 1988 using a 25.6-m diameter paraboloid and two low-noise receivers. Its spectra undergo obvious changes in shape and polarization. Spectra have been subject to Gaussian analysis in an effort to show how the amplitudes and velocities of the individual components change with time. The flux of energy integrated over all 1612-MHz lines and both polarizations have increased by a factor of two during the survey. This result is in general agreement with the recent results of Lewis (2001b), who has observed a dramatic increase in both strength and width of the OH lines in this source.

Résumé. Durant un intervalle de 5.2 années à partir de 1988, IRAS 19566+3423 a été observée 24 fois à l'aide d'un parabolique de 25.6 metres et de deux recepteurs à faible bruit. Ses spectres subissent des changements évidents de forme et de polarisation. Ces spectres ont fait l'objet d'analyse de Gauss dans le but de montrer comment les amplitudes et les vitesses des composantes individuelles changent avec le temps. Le flux d'énergie intégré dans toutes les lignes 1612-MHz et les deux polarisations ont augmenté d'un facteur de deux durant l'enquête. Ce résultat s'accorde en grande mesure avec ceux de Lewis (2001b) qui a observé une croissance importante de la force et de l'ampleur des ligne OH provenant de cette source.

1. Background

Before 1983 a few astronomical objects were known that emitted both in the infrared and in the radio spectrum where lines from OH molecules can be detected. These objects were called "OH/IR stars." Such stars often show a characteristic double-peaked radio spectrum suggesting that the lines arise in an expanding shell with one half of the spectrum originating in approaching gas and the other half in receding gas. In 1983 the Infrared Astronomical Satellite (IRAS) surveyed most of the sky detecting some 250,000 point sources and measuring the infrared spectra of many of the brightest objects. Some of these new sources showed strong emission or absorption features at a wavelength of 9.7 µm and it was noted that this feature was often present in known OH/IR stars. It was realized that infrared spectra from the IRAS satellite could now be used to generate "finding lists" to search for new OH/IR sources in the radio spectrum. During one such search at Penticton the spectrum of IRAS 19566+3423 was found to consist of many lines rather than the usual two. Moreover, these lines showed changes in intensity and polarization over a few months. This source was therefore observed repeatedly for more than five years to try to elucidate the cause of its anomalous activity.

2. Introduction

Unusual behaviour of the 1612-MHz OH spectrum of IRAS 19566+3423 was noted during a survey of IRAS sources whose infrared spectra showed silicate features (Galt, Kwok & Frankow 1989). This high luminosity object has a blackbody temperature of 226 K, and a deep-silicate absorption at 9.7 µm. Lewis (2001c) gives the luminosity of this object as $\sim 1.8 \times 10^5$ $L_\odot$. Zuckerman & Lo (1987) detected H_2O (22 GHz) from this object and suggested that it is an oxygen-rich evolved post-main-sequence star located near the tip of the asymptotic giant branch. Lewis (1999) refers to it as "probably a hypergiant or supergiant star, which may well have lost its present circumstellar shell in a sudden mass ejection event." Likkel (1989) has observed both H_2O (22 GHz) and OH (1612 MHz) emission from the source. It has since been studied extensively at Arecibo by Lewis (1999, 2000, 2001a, 2002), who has observed a dramatic increase in the strength and width of all three OH spectra, particularly of the 1667-MHz line. At the same time he finds the water masers in the source to be weakening. Moreover, Lewis (2001a) has used recent data from the *Midcourse Space Experiment (MSX)* and the *Two Micron All Sky Survey (2MASS)* to establish more accurate positional coordinates.

The present paper describes observations of the source over a 5.2-year period beginning in 1988. A preliminary report on a portion of this work appeared in the proceedings of a conference on astrophysical masers (Galt 1993).

3. Observations

The Penticton 26-m telescope was used to observe this object with both circular polarizations simultaneously. The two receivers, each with cryogenically cooled preamplifiers, gave system noise temperatures of about 25 K (Walker *et al.* 1988). Most observations were made using a bandwidth of 0.5 MHz with frequency switching by 0.25 MHz. Final spectra therefore were 0.25 MHz or 46.5 km s^{-1} wide. A 3-level spectrometer produced spectra with a resolution of 1.2 km s^{-1}. Each spectrum required at least one day's observing (15.5 hours) but most spectra represent an average of several days. Observing efficiency was low because of interference from GLONASS satellites. Two methods were used to try to prevent spurious emission from these satellites appearing in the final spectra. While actually observing, data were averaged for 16 seconds and those spectra that showed sloping baselines were rejected automatically. Later, 11-minute averages of previously accepted spectra were examined visually and rejected or edited if suspicious. For each polarization, all spectra from one epoch (1 or 2 days) were averaged and plotted against channel number. The resulting spectra showed plus and minus deflections characteristic of frequency switching as well as a curved baseline that represented departures of the pass-band from ideal. The baseline was straightened by fitting a 4th-order polynomial to a spectrum from which the two obvious OH features had been removed. The final spectrum was obtained by "folding" so as to average the spectra obtained on each side of the frequency switch. Channel numbers were then converted to velocity with respect to the local standard of rest.

4. Results

Observations at 24 epochs over a 5.2-year period have been combined in Figure 1 to show the spectra as they were observed. Sums and differences of the two circular polarizations (Stokes parameters I and –V) are plotted in Figure 2.

A few spectra observed at two- and four-times higher resolution are shown in Figure 3. Due to spectrometer limitations, the highest resolution spectra show almost no baseline. Additional spectra obtained at 1665, 1667, and 1720 MHz are shown in Figure 4 together with the 1612-MHz spectra for JD 2448631. Only the 1665-MHz line shows emission at velocities near those observed at 1612 MHz. The 1667-MHz frequency was observed in 1988 and 1991 for a total of 41.6 hours but no line was found. The line was also reported as a nondetection by Likkel (1989) but it was later seen at Arecibo by Lewis (1999). It may be significant to note that the two lines detected arise from the same upper energy level.

5. Analysis

The first two figures appear to show that the line intensities rather than their velocities change with time. To test this idea, I have attempted to measure the velocities and intensities of these lines by fitting Gaussians to each spectrum. To begin the process, the spectra for JD 2447785 (which have high signal-to-noise ratio and lie near the middle of the observations) were analyzed by a program that fitted six Gaussians to each spectrum with no restrictions on initial parameters. The resulting velocities, amplitudes, and widths (listed in Table 1) were then used as initial parameters to analyze the spectra for other epochs. In a few instances it was necessary to fix the line-width of the weakest lines to obtain a reasonable fit. The resulting intensities are plotted in Figure 5, and the velocities in Figure 6. The error-bars

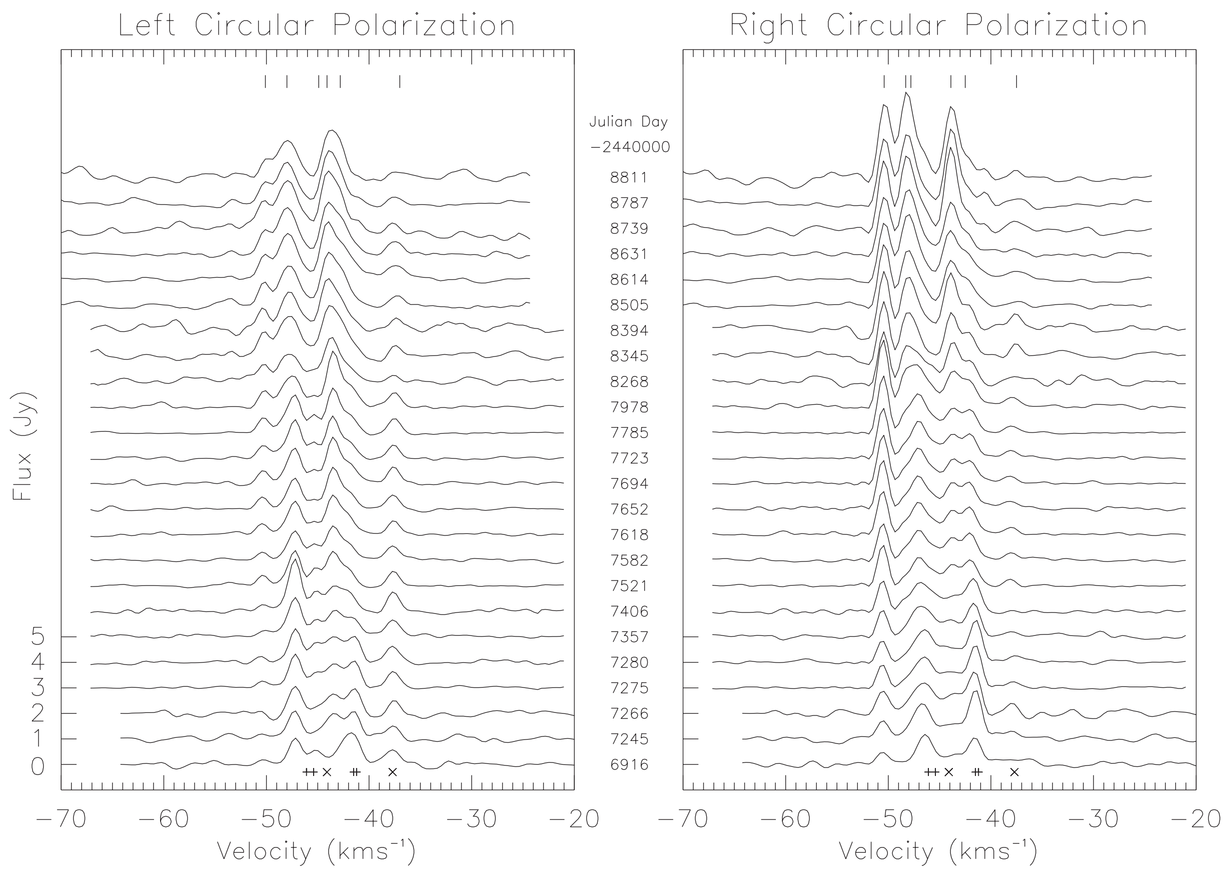

Figure 1 – Spectra of IRAS 19566+3423 as observed in both circular polarizations. The 1612-MHz OH velocities measured in 1986.8 by Likkel (1989) are indicated by + in the figure. Her H_2O velocities are indicated by ×. Short vertical lines above the spectra indicate the velocities of component lines determined by Gaussian fitting for JD 2447785 (See Table 1).

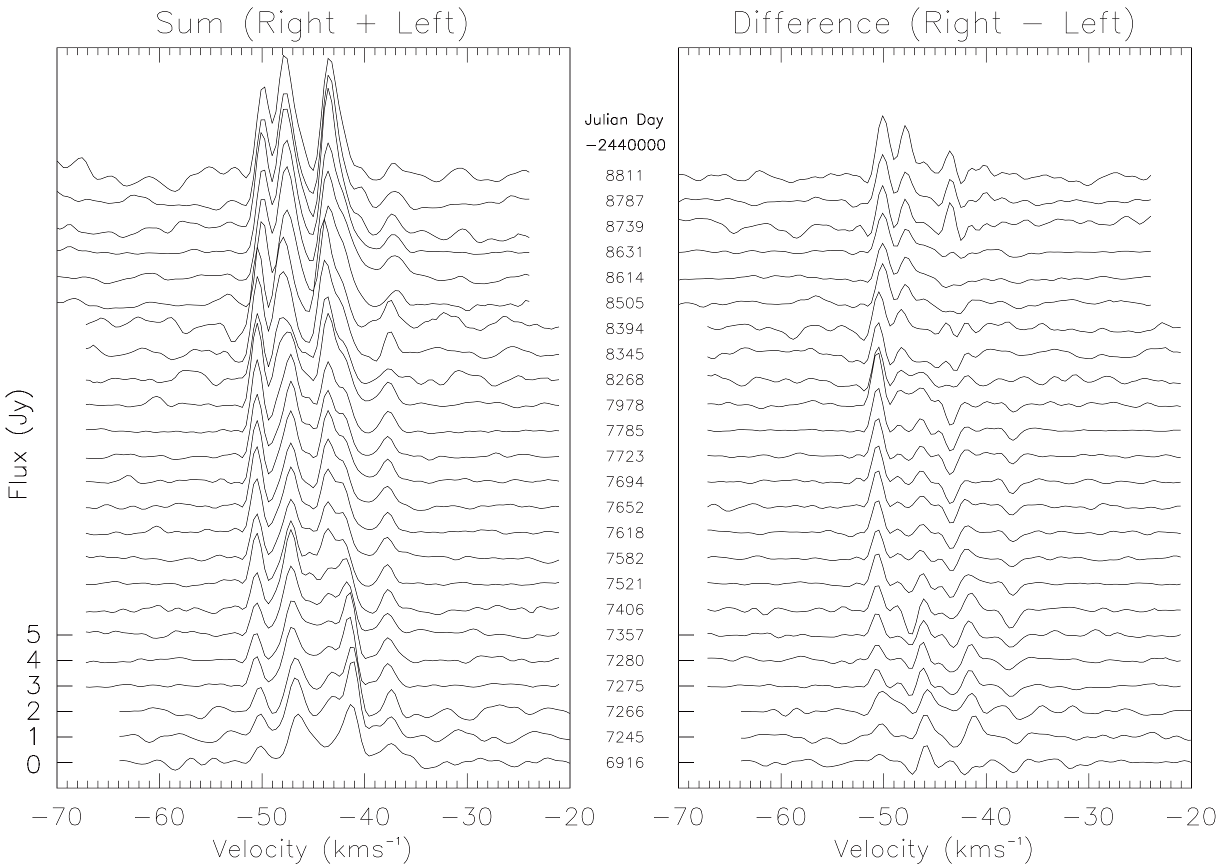

Figure 2 – Sum and difference of the two circular polarizations for IRAS 19566+3423.

were generated by the Gaussian-fitting program and represent ± 1σ for the quantity plotted. In general, the largest error-bars appear for the weakest lines. The plots show small gradual trends but no evidence of periodic behaviour. It would appear from these two figures that both the intensities and velocities of the lines vary with time. Mean velocities for the two polarizations differ by only 0.8 km s^{-1}.

The energy flux, integrated over all six lines and both polarizations, is plotted in Figure 7, which shows that the flux of energy has doubled over about five years.

Percentage polarization for the observations is shown in Figure 8. This diagram was generated from the spectra of Figure 1 using only those channels in which each spectrum is greater than 0.1 Jy. Channels

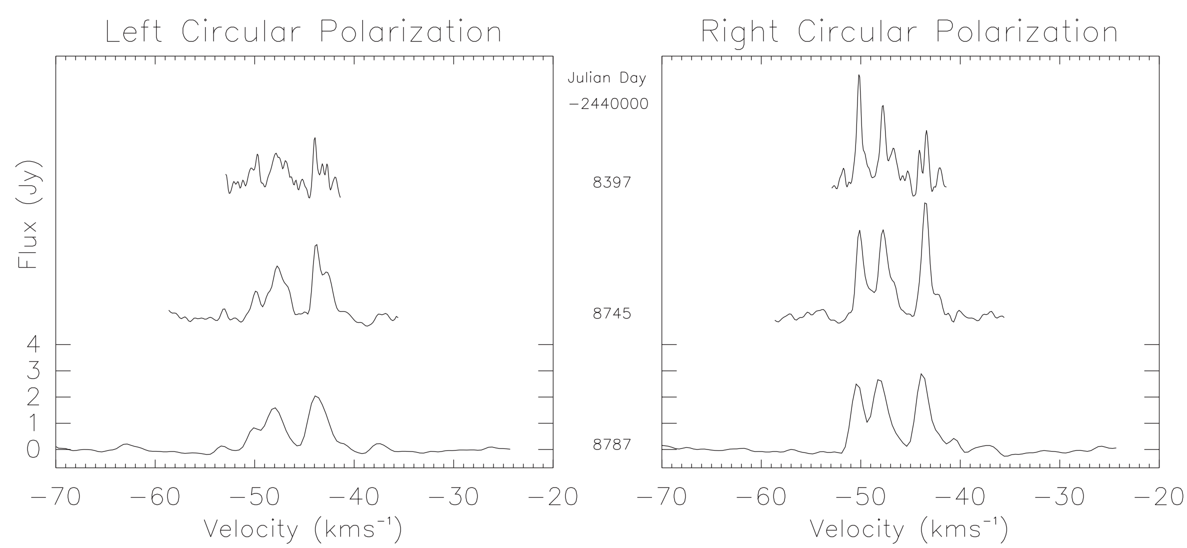

Figure 3 – Spectra of IRAS 19566+3423 as observed in both circular polarizations at three different resolutions: top 0.3 km s^{-1}, mid 0.6 km s^{-1}, bottom 1.2 km s^{-1}.

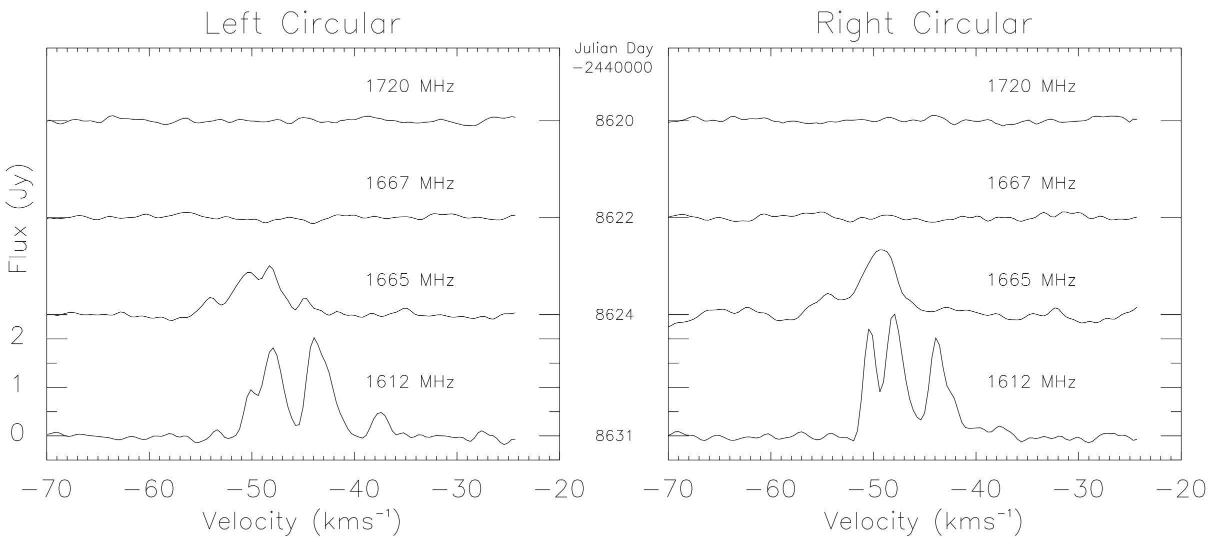

Figure 4 – Observations at all four OH lines for both circular polarizations.

where either spectrum is less than 0.1 Jy are indicated by a dot on the plot. Polarization is strongest at the edges of the spectra, probably because other lines are blended. It is tempting to look for Zeeman splitting even though the spectral resolution may be too low. The isolated spectral line at -37.8 km s^{-1} shows a distinct reversal in polarization across the line for about half of the spectra. The best example is for JD 2447785 which has the highest signal-to-noise ratio. If this polarization reversal is indeed a Zeeman effect it would correspond to a magnetic field of about 1 mG but, considering the low spectral resolution of the survey, it would be unwise to claim this as a definitive measurement. This conclusion is further justified by examining spectra taken at higher resolution (Figure 3), which indicate that most spectral features are unresolved at the resolution used for the bulk of this survey.

6. Discussion

The spectra suggest that the source may consist of several shells. In

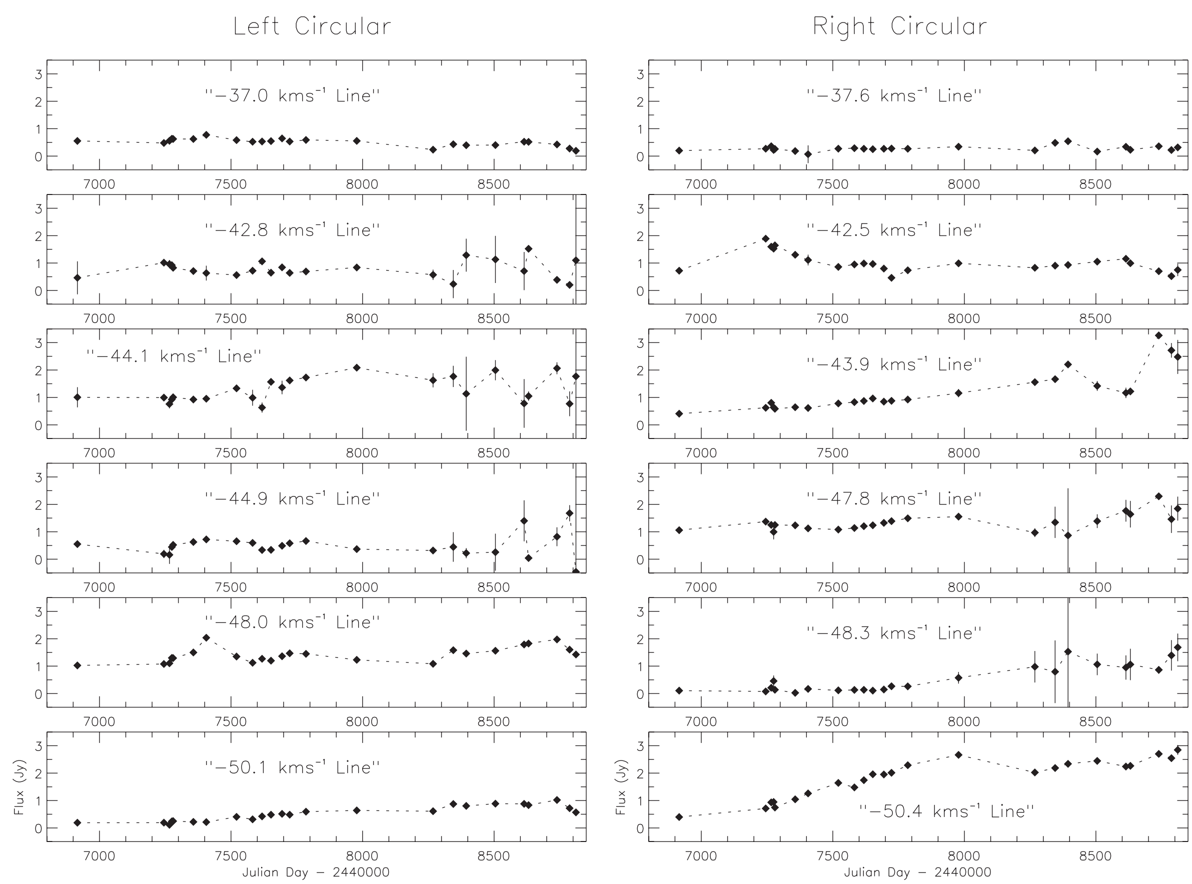

Figure 5 – Intensities of lines determined by Gaussian fitting plotted against time. Error bars for most points are smaller than the symbols.

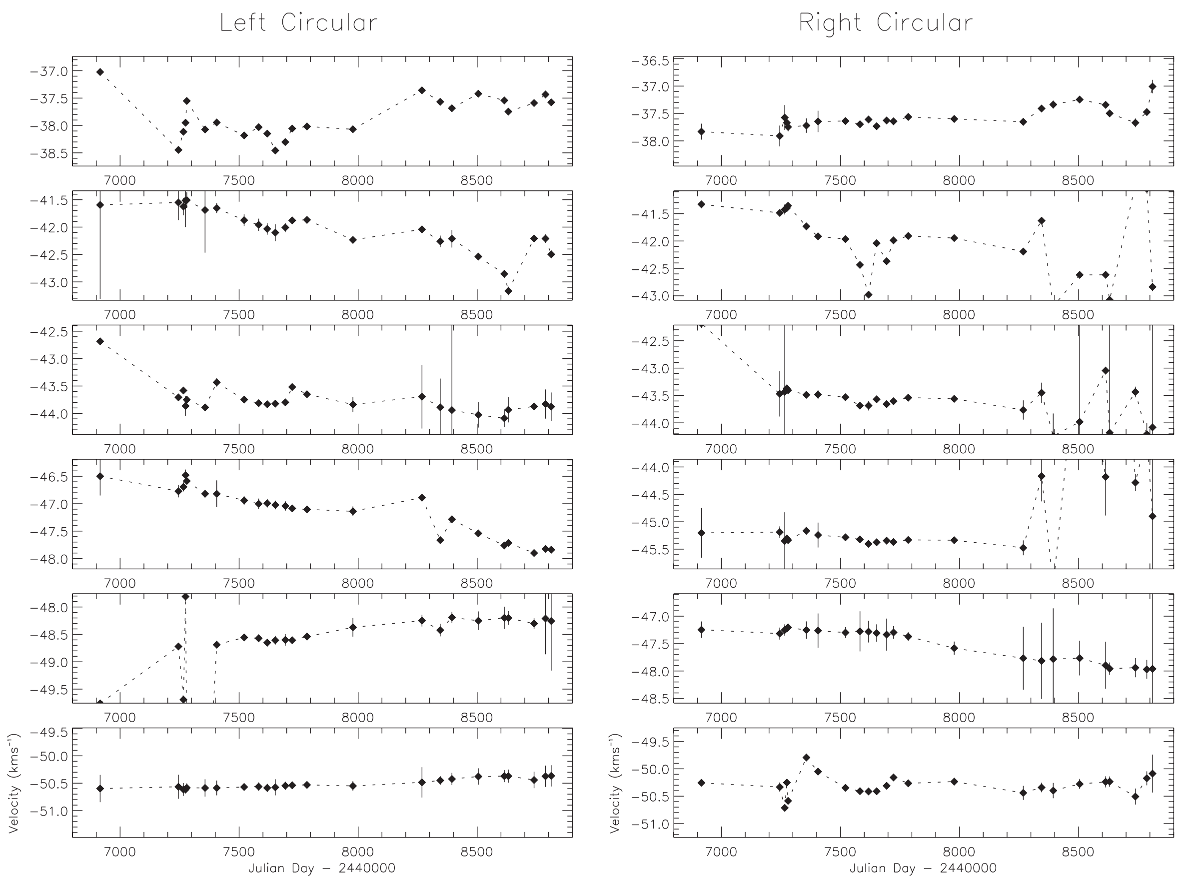

FIGURE 6 – Velocities of lines determined by Gaussian fitting plotted against time. Error bars for most points are smaller than the symbols.

a simplified model we might consider that the central star has blown off three shells, each of which has expanded at a high velocity and subsequently slowed down as they encounter interstellar dust. Thus the most recent shell would be represented by the peaks with the extreme velocities and the oldest shell by peaks closer to the mean velocity of the star. For this source such a simple model is probably not justified. Similar structures have been considered by Norris *et al.* (1984). In many OH/IR stars, maser intensity fluctuations result from changes in the flux of infrared radiation from the central star. A crucial confirmation of any such shell hypothesis would be the discovery of correlations (with appropriate time lags) between intensity fluctuations in the various lines. There is no obvious evidence for this effect in Figure 5 although observations were not made often enough to show fast fluctuations or for a long enough time to show slow periodic variations.

Acknowledgments

I have used the Canadian Astronomy Data Centre operated by the Herzberg Institute of Astrophysics, National Research Council of Canada.

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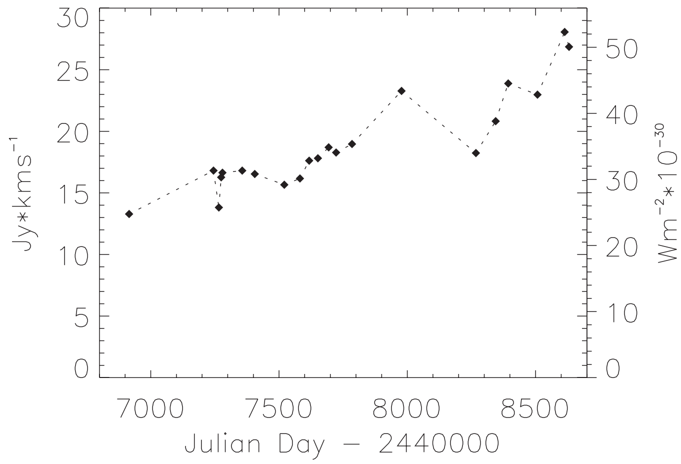

Figure 7 – Energy flux integrated over 250 kHz and both polarizations plotted against time.

Table 1.
Parameters for the "best-fit" of 6 Gaussians to spectra of JD 2447785.

Polarization Circular	Velocity (km s^{-1})	Height (Jy)	Width (km s^{-1})
Left	–50.3	0.59	1.41
Left	–47.4	1.45	1.89
Left	–45.3	0.66	0.95
Left	–43.5	1.73	1.48
Left	–41.9	0.69	1.55
Left	–37.6	0.59	1.30
Right	–50.5	2.29	1.15
Right	–48.5	0.26	0.66
Right	–47.1	1.49	2.37
Right	–43.7	0.92	2.17
Right	–41.9	0.74	1.36
Right	–38.0	0.27	1.55

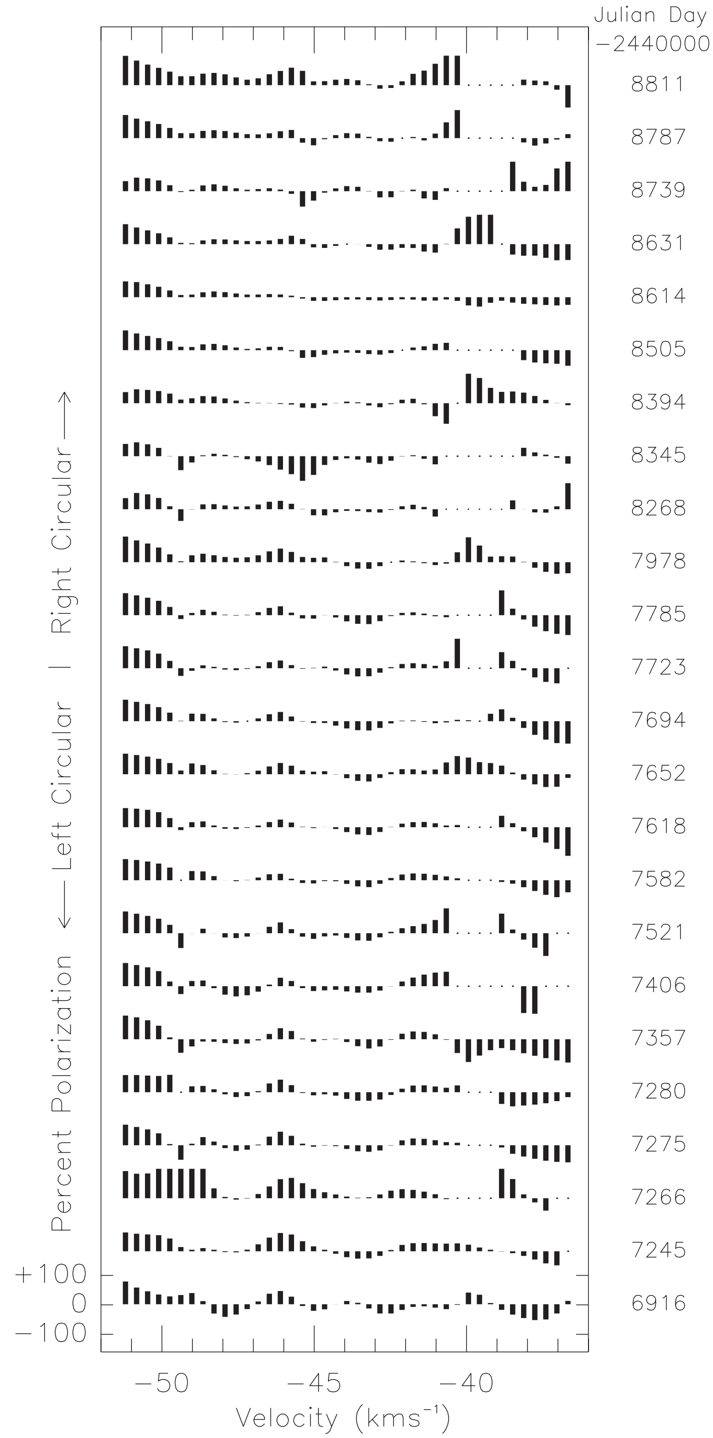

Figure 8 – Percentage polarization derived from the spectra of Figure 1.

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FIFTY YEARS OF CANADIAN Ph.D.s IN ASTRONOMY

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Abstract. Following a discussion of who earned the first Ph.D. in astronomy in Canada, statistics are presented showing the growth in numbers of doctoral degrees, where they were granted, and what became of a sample of the graduates whose undergraduate background is also known.

Résumé. Suivant une discussion au sujet d'à qui le premier doctorat en astronomie a été décerné au Canada, sont présentées des statistiques pour illustrer la croissance du nombre de diplômes de doctorat, où ils ont été décernés, et qu'est devenu d'un échantillon de ces diplômés dont les études de premier cycle sont connues.

1. A Golden Anniversary of Sorts

It is generally thought that this year, 2003, marks the fiftieth anniversary of the first Ph.D. in astronomy awarded by a Canadian university. The graduate was William R. Hossack and his thesis was entitled *On the application of oscilloscopic microphotometry to astronomical spectroscopy*.

His supervisor was Frank Hogg, head of the Department of Astronomy at the University of Toronto (UT) and Director of the David Dunlap Observatory. Hogg was a natural person to initiate doctoral study since he himself had been the first man to earn a Ph.D. in astronomy at Harvard University. Another Canadian, H. H. Plaskett, had in fact set up the Harvard doctoral program at the invitation of the Director of the Harvard College Observatory, Harlow Shapley. Unfortunately, Hogg did not live to see his first doctoral student complete his Ph.D. thesis in Toronto. In Hogg's obituary, his successor, J.F. Heard (1951) wrote:

> Many research programs came to completion under his active direction. Graduate students worked on such varied problems as spectrophotometry, binary stars, instrument design, and micrometeorites. The graduate work in astronomy was extended to include the Ph.D. degree; the first Ph.D. student is submitting a thesis this year on a problem completed under Dr. Hogg's direction.

As this quote implies, a Master's program had been operating for some time at Toronto. In fact, what may have been the first MA thesis on astronomy at UT was submitted in 1917, and there were sixteen more before 1953 including Hossack's in 1949, *White dwarfs and short period light variations*. The quote also suggests that Heard thought that Hossack would complete his Ph.D. in two years, rather than the four that were actually required. Plus ça change!

Sadly, it was just ten years after Hogg's death that Heard (1961) had to write another obituary, this time for Hossack, who was killed along with his wife in a car accident, leaving a five-year-old son. At the time of his death, Hossack had a promising career in operations research.

Ian Halliday earned the next astronomy Ph.D., also at Toronto in 1954, but then there was a dry spell until 1960 when a more-or-less steady flow began.

Although Hossack is considered the first Ph.D. student in astronomy, he was certainly not the first person in Canada to write a doctoral thesis on an astronomical topic. Even at UT there were two earlier theses written under the aegis of the Mathematics Department but with quite astronomical titles. One dated 1949 is listed under the heading "Astronomy" in a compilation by Mills and Dombra (1968). It was *Stellar exteriors - a study of radiation problems in mathematical astrophysics* by John A. Rottenberg who stated "I wish to thank Dr. C. S. Beals [Canada's Dominion Astronomer in Ottawa] and Prof. S. Chandrasekhar [University of Chicago] for their aid and encouragement of these studies." Two members of Rottenberg's examining committee were F. S. Hogg and R. E. Williamson of the UT Department of Astronomy. He published three papers on PCygni and Wolf-Rayet stars. (See Rottenberg 1948, 1952, Beals & Rottenberg 1952) and worked at the Dominion Observatory from 1949 to 1961 (American Men of Science 1961 and Burland 1962). He was an Ottawa Centre member of the RASC around 1958. Halliday remembers Rottenberg during his observatory days and believes he later taught at Macdonald College near Montreal. The other UT thesis was *A new approach to kinematic cosmology* by Alfred E. Schild in 1946. Schild worked under the renowned theoretical physicist, Leopold Infeld, and together they published a version of the thesis (Infeld & Schild 1945). As described online (see Oren), Schild had a distinguished career, mainly at the University of Texas where he cofounded the Texas Symposium of Relativistic Astrophysics in 1963 and many other centres of research.

The earliest Canadian doctoral thesis on astronomy seems to

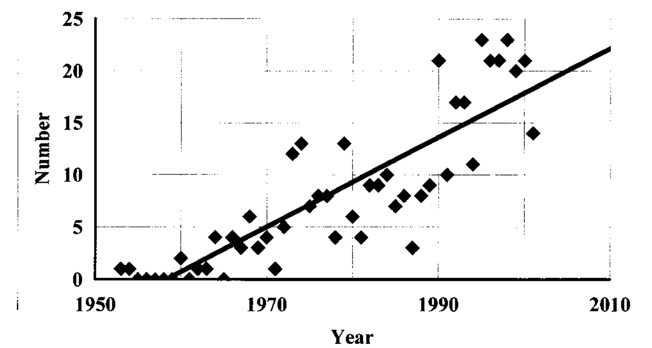

Figure 1 – The line of best fit shows the numbers growing at an annual rate of 0.43. The correlation coefficient, r, is 0.86. If an exponential relationship is assumed, and the zero values are omitted, the fit is less good with r = 0.74.

have been written by A. V. Douglas at McGill in 1926 and supervised by A. Gillson and R. Young of the Mathematics Department. It was entitled *Spectroscopic magnitudes and parallaxes of A-type stars*. Dr. Douglas became a noted educator, biographer of Eddington, the first woman RASC President (1943-44) and the founder of the Kingston Centre.

Even earlier Ph.D. theses written in Canada on topics relating to astronomy may exist but they will not likely be easy to find. The earliest published union catalogue of Canadian theses in science begins in 1947 (Thompson 1973), and in the UMI Proquest Digital Dissertations database, used extensively in the rest of this paper, the earliest Canadian doctoral theses in the related fields of mathematics and physics date from 1934, which is certainly not the case. However, until such time as someone can refute the claim, it appears that 1953 can stand as the first date for a Ph.D. thesis by an Astronomy student in Canada, and 1926 as the first date for a doctoral dissertation on an astronomical topic.

2. The UMI Database

Up to and including 1975, the UMI ProQuest Digital Dissertations database records astronomy and astrophysics as two separate disciplines, whereas they are combined into a single discipline after that date. These three categories, all lumped together as "astronomy" in this paper, were searched up to and including 2002, for Canadian universities. The growing numbers of doctoral degrees granted year-by-year is graphed in Figure 1. The cumulative total of Canadian astronomy Ph.D.s is 397. However, the database is evidently not complete for 2002, so the true fifty-year total is likely closer to 420. This database includes a few anomalies that likely do not belong in this study and there are probably some theses (Rottenberg's and Schild's for example) that should have been included but are not. However, the list has been accepted as is to avoid making subjective decisions about what really counts as astronomy or astrophysics. Another small technical detail is whether to use the year of graduation or the date on the thesis. The database appears to use the date of graduation.

A total of 41 graduates had names that were clearly female, but there could have been as many as 42 more whose names did not provide definite evidence. The proportion of women Ph.D. graduates has not changed significantly over the decades and is estimated to be about 12% (*i.e.* 4100/(397–42)).

The database was used to produce the chart shown in Table 1, which shows the proportions contributed by the various universities over the entire fifty years, and also over the last ten years alone. The University of Toronto continues to grant the greatest number of Ph.D.s in astronomy though its share is shrinking as more and more universities grant postgraduate degrees.

Comparisons suggest that Canada's production rate of astronomy Ph.D.s is not large. In other disciplines, for example mathematics, physics, and chemistry, the Canadian totals for the last fifty years are 2383, 4632, and 9117 respectively. And compared to the United States, two campuses of the University of California (Berkeley and Los Angeles) together generated 23 Ph.D.s. in astronomy in each of 1999 and 2000, exceeding the entire Canadian total for each of those years.

3. Is There a Brain Drain?

Apart from the information that can be gleaned from the UMI Dissertations database, an attempt has been made to find where the Ph.D. candidates came from and where they went after receiving their doctorates. The latter point may be of some interest because it is often alleged that Canada's brightest and best go elsewhere to work. But since it might be argued that some of the Ph.D. candidates originally came from elsewhere and are just returning home, the location of the undergraduate degree was also considered to be relevant. The place of birth could have been used, but it soon became clear that the vast majority of people in this study were not mobile until after their undergraduate education was complete. Information on birthplace and/or undergraduate degrees was found on personal Web sites or directories, such as *American Men and Women of Science* (AMWS) and, in the case of UT dissertations prior to 1991, in the theses themselves.

Since the postdoctoral period may not be a true indication of a permanent eventual career choice or location, those who received their doctorates in 1998 or later have been excluded from further study. This cut off date is arbitrary since some doctoral graduates find permanent careers before five years have elapsed while others do not. Even after five years, people may move. For the purpose of this study, the most recent known occupation and location (prior to retirement) was adopted.

To find out what happened to the graduates many strategies were used. The 2002 membership directory of the Canadian Astronomical Society (CASCA) was one good source of information. Among the 380 charter and ordinary members of CASCA there were 120 Canadian Ph.D.s. This statistic in itself is interesting, suggesting that the majority of CASCA members earned their doctorates outside Canada, though any conclusion must be tempered by an unknown number of members who have changed their names (through marriage), who do not hold Ph.D.s, or who have their degrees in other fields such as physics.

Other sources of career information included AMWS, Web sites of some astronomy departments, or of supervising professors, which include information on alumni. The astroplace Web site (`astroplace.com`) was also used and provided information on a few more people. As a further source of current information, publication databases such as ADS (`adswww.harvard.edu`) and Web of Science (`webofscience.com`) were examined to see if those who were not CASCA members had published and if they did what information these publications provided on institutional affiliation. Finally, personal Web sites and institutional Web sites were examined where available and up to date.

Of the total number of 316 Ph.D.s prior to 1998, the present whereabouts was found for 223 and of these there were 104 about whom information was found on their undergraduate education. Table 2 shows the percentages of these 104 who are pursuing careers in Canada, the United States, and elsewhere in the world. They are then divided into four approximately equal groups to show any trend that may have occurred. A few cases of astronomers located, for example, in Hawaii or Chile on Canadian contracts were considered to be pursuing careers in Canada.

The overall sample indicates that the brain drain has not been a huge problem affecting Canadian astronomy since only 15/71 or 21% of those who took both their undergraduate and doctoral degrees in Canada made careers outside the country. Ideally, of course, one would like to see even those Ph.D. students who grew up outside Canada staying here to pursue careers, but it is not surprising that most do not. In fact, if a tie to home is the dominant factor in immigrants deciding their future location, the same phenomenon appears to keep the great majority of those who grew up in Canada from emigrating. The table does suggest that the brain drain was worst in the period 1983–90, and shows a growing number of overseas students taking their Ph.D.s in Canada.

4. Other Studies

Another question that naturally arises concerns the proportion of astronomy Ph.D.s who go on to careers in astronomy. This has already been the subject of a study by Gibson *et al* (1999). They found that over the period 1975–1994, 55 to 75 % of astronomy Ph.D.s, regardless of where the degree was earned, remain active in the astronomical research community. Though no attempt was made here to substantiate this figure, it may be of some interest to note that people were found to have careers in imaging technology, information analysis, communications, remote sensing, geophysics, mathematics, teaching, writing, museums, and science centres. One can only imagine what other careers would be represented among those who could not be traced. Careers of astronomers worldwide have been studied extensively by Heck (2000).

5. Questions and Conclusions

The thesis topics of today could scarcely have been contemplated when the first Canadian Ph.D. was granted in astronomy. Radio astronomy was just getting started and the first satellite was still years in the future. Electronic computers were in their infancy and so model building to study dynamical systems or the evolution of stars was yet to be done. Will the next fifty years see such revolutionary change as the past fifty? Will the numbers of Canadian Ph.D.s continue to increase as they have in the past and will the majority of them continue to find suitable work in Canada?

Though these questions are impossible to answer, it is true that demographic studies show that developing countries have a much larger proportion of young people than we do in Canada. It therefore seems likely that the trend for students to come here for their doctoral degrees and then to return home will continue to grow.

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Table 1

The number of Ph.D.s granted in astronomy by Canadian universities in the last fifty years and also in the past ten years. The percentage share of each university and its rank is also given.

Universities granting Ph.D.s in Astronomy

Name	Overall	Percent	Rank	Since 1992	Percent	Rank
Toronto	133	34	1	38	20	1
BC	43	11	2	20	10	3
Montreal	34	9	3	23	12	2
Victoria	29	7	4	17	9	4
Western	26	7	5	9	5	10
Calgary	25	6	6	12	6	6
Queen's	24	6	7	14	7	5
York	15	4	8	5	3	12
Alberta	15	4	8	12	6	6
Waterloo	14	4	10	10	5	9
McMaster	13	3	11	11	6	8
Laval	9	2	12	8	4	11
McGill	5	1	13	4	2	13
Others	12	3		9	5	

Table 2

The percentage of those with Canadian Ph.D.s in astronomy for whom their place of undergraduate degrees and the location of their careers is known. The column headed "overall" refers to the full fifty year period; the other columns to various sub-periods.

Percentage of those with Canadian Ph.D.s in Astronomy

First Degree	Career	Overall	Up to 1972	1973–1982	1983–1990	1991–1997
	Canada	56	72	64	41	46
Canada	USA	14	12	7	26	12
	Elsewhere	1				4
	Canada	3	4	4	4	
USA	USA	10	8	21	4	4
	Elsewhere					
	Canada	5	4	4	4	8
Elsewhere	USA	4			7	8
	Elsewhere	8			15	17

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RECOLLECTIONS OF A CANADIAN ASTRONOMER

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Abstract. This memoir recounts my fifty years of adventure as an astronomer, from a summer student at the David Dunlap Observatory to the Director General of the Herzberg Institute of Astrophysics of the National Research Council.

Résumé. Ce mémoire raconte cinquante ans de l'aventure astronomique d'un étudiant d'été à l'observatoire David Dunlap et qui devint Directeur général de l'Institut Herzberg d'astrophysique du Conseil national de recherches Canada.

1. Introduction

Retirement has given me the opportunity to record some of my experiences during the past fifty years as an astronomer, initially in Canada, then for twenty years in the United States and ten in Australia. On returning to Canada I was responsible for the astronomy in the Federal Government from 1986 to 2000 and Canada's participation in three international telescopes.

2. David Dunlap Observatory

Both astronomy and engineering had interested me from a very early age, but I did not think that a career in astronomy would be feasible. Consequently, while I did join the Toronto Centre of the Royal Astronomical Society of Canada in early 1952, I enrolled in Engineering Physics at the University of Toronto in September of that year.

When I finished at Toronto's Northern Secondary School in June of that year, however, I inquired at the David Dunlap Observatory (DDO) to see whether a summer job might be available. Dr. John F. Heard, the director, was absent at the time, but when I did meet him a couple of days later, he thought that he might be able to use me. When I started soon after, the job turned out to surpass my wildest hopes. The senior technician, Jerry Longworth, immediately took me to the dome to show me how to use the 1.9-m telescope. After two half-nights of instruction by Dr. Heard, I was on my own, using the world's fourth-largest telescope at that time to collect photographic spectra of G and K stars for a radial-velocity program. My day job was measuring the plates visually with a microscope micrometer. The salary was $100 a month. At the DDO I found Ruth Northcott particularly helpful in introducing me to the practical details of being an astronomer.

Research funds were scarce in those days, so the observatory would order the cheaper, larger spectroscopic plates from Kodak and then cut them in half. During my first summer all the observatory staff participated in planting coniferous seedlings, which now form a fine protective forest around much of the dome. In late August each year, I joined other RASC members at the Canadian National Exhibition showing stars and planets to the public. We set up telescopes each evening near the Ontario Government Building.

Jack Heard convinced me that I could have a career in astronomy, so after six weeks as an engineering student I transferred to Mathematics and Physics in the Faculty of Arts. In my fourth year 1955–1956, I was the only student taking the astronomy option and consequently received the RASC Gold Medal without competition. I enjoyed my work at the observatory so much that I spent five summers and four Christmas vacations there. Winter observing had special challenges, including climbing alone to the top of the dome shutters without any safety harness to brush away accumulated snow.

When I started in 1952, Toronto had its first two astronomy Ph.D. students — Bill Hossack, who was later killed in an automobile accident, and Ian Halliday, who had a distinguished career studying meteors at the Dominion Observatory and the National Research Council. John Galt and Vic Gaizauskas were graduate students in physics, and Vic's future wife Barbara was the observatory's secretary. In 1954, Don MacRae joined the astronomy faculty and began a program in radio astronomy in collaboration with Allen Yen from electrical engineering. Helen Hogg photographed globular clusters during the summer dark time, for her studies of variable stars, and she showed me how to observe at the Newtonian focus of the telescope. Already in the 1950s she commented that the night sky to the south over the city was bright enough to read a newspaper by. As part of my radial-velocity measurements, I worked with Jack Heard on three spectroscopic binary systems, resulting in a joint publication of their orbits (Heard & Morton 1956, 1962).

3. Princeton University Graduate School

My choice of Princeton University for Ph.D. studies in 1956 was much influenced by Bev Oke, who had obtained his doctorate there and joined the Toronto faculty during my final year, and by Peter Wellman, who was visiting that year from the Hamburg Observatory. I spent a stimulating three years at Princeton under the guidance of Lyman Spitzer and Martin Schwarzschild. When I expressed my interest in binary stars from my Toronto days, Martin suggested for my thesis that I look for a theoretical explanation of Zdenek Kopal's observation that whenever a binary component fills its Roche lobe, it was the less massive star, though the more massive one was expected to evolve first. My model calculations (Morton 1960) demonstrated that an instability occurred when the more massive star evolved to fill its lobe, causing it to transfer so much mass that it became the less massive component.

4. U.S. Naval Research Laboratory

Although I much enjoyed the theoretical work, I was attracted to the new field of space astronomy, which was developing rapidly following the Soviet launch of *Sputnik* at the beginning of my second year as a

Figure 1– DDO staff viewing the aluminized 1.9-m mirror in the summer of 1954. Left to right are Don Morton*, Don MacRae, James Hogg*, Gerry Longworth, Jack Heard, Frank Hawker, unidentified man*, Gus Bakos, and John Martin*, with asterisks indicating the summer students. Gus was a Graduate student from Czechoslovkia, who later taught at the University of Waterloo. The photographer probably was either Helen Hogg or Ruth Northcott.

graduate student. In the informal way appointments were made in 1959, Spitzer telephoned his friend Herbert Friedman at the U.S. Naval Research Laboratory in Washington. I spent two years there, initially on a theoretical interpretation of recent observations of the solar Lyman-alpha emission line by Dewitt Purcell and Richard Tousey (Morton & Widing 1961) and then flying rocket-borne instruments to investigate the nighttime Lyman-alpha airglow (Morton & Purcell 1961; Morton 1962).

5. Princeton University

In October 1961 Spitzer invited me back to Princeton to lead a program of ultraviolet rocket spectroscopy as a precursor to the satellite mission he was planning. My first rocket instrument was a simple photographic Schmidt camera with a 5-cm aperture looking at an objective grating, adapted from a similar design that the Perkin Elmer Corp. had developed for Al Boggess of NASA. The correcting lens had to be made from calcium fluoride or lithium fluoride to transmit the far ultraviolet wavelengths. Gyroscopes controlling gas jets on the rocket would position the target stars within the 5-degree field of the camera, but to avoid smearing the expected spectral lines, additional stabilization was needed. Acting on a suggestion by Jim Kupperian, also from NASA, I used a heavy passive gyroscope following the same principle used to stabilize a ship at sea. With significant help from Spitzer in the perfection of the passive system, a rocket flight in 1965 obtained the first spectra of hot stars (δ and π Scorpii) with sufficient resolution to show the absorption lines (Morton & Spitzer 1965).

A second successful flight that year recorded the three luminous hot stars δ, ε, and ζ Orionis that form the belt of the constellation. To my surprise, these had emission lines of three-times ionized silicon and carbon as well as absorption on their short-wavelength edges. When I described these puzzling features to Jack Heard in Toronto, he suggested that I look at the classic paper by C.S. Beals (1951) on P-Cygni profiles in the *Publications of the Dominion Astrophysical Observatory*. Beals had interpreted similar emission-absorption profiles in the ground-based spectra of a few rather unusual stars as evidence for mass ejection. I had discovered that the phenomenon was much more common (Morton 1967a), occurring in ordinary supergiants and bright giants. My subsequent analysis (Morton 1967b) showed that the Orion stars were ejecting about 10^{-6} solar masses per year at velocities of 1400 km s^{-1}.

In 1966 I was fortunate to be able to add Edward Jenkins to the Princeton rocket program fresh from completing his Ph.D. at Cornell University. Some years later I learned that Ed's father had been a prominent spectroscopist at the University of California at Berkeley. Ed told me that his father had discouraged him from a career in physics and particularly the dying field of spectroscopy. Ed has continued at Princeton, however, achieving a well-deserved international reputation for his contributions to ultraviolet astronomical spectroscopy from space.

During my years at Princeton I was on two mountaineering expeditions that had astronomical connections. In July 1965 Lyman Spitzer and I joined an Alpine Club of Canada expedition to what later became Auyuittuq National Park on Baffin Island. Rain confined us to the base-camp tent during most of the first week, which provided an opportunity to write the first paper on the rocket spectra. Then as the weather began to clear, Lyman, who enjoyed mental calculations, suggested that if we were to climb a certain peak on a clear night we would be able to see the upper limb of the midnight sun. He had considered the location of the peak about 22 km north of the Arctic Circle, its altitude, the date (22 days past the solstice), and the half-degree refraction at the horizon. We set out midafternoon on July 13, but unfortunately, the rain returned before we could reach the summit. Our experimental check of the hypothesis failed, but my subsequent calculations confirmed that a sliver of the solar limb could have been visible from the summit depending on the details of the topography on the northern horizon. Now on the official map of this part of Baffin Island there is a Midnight Sun Peak. Later, in better weather, Lyman and I hiked down the Weasel Valley and made the first ascent of Mt. Thor, one of the many spectacular peaks in the region that rise 1500 m from the valley floor (Morton 1966).

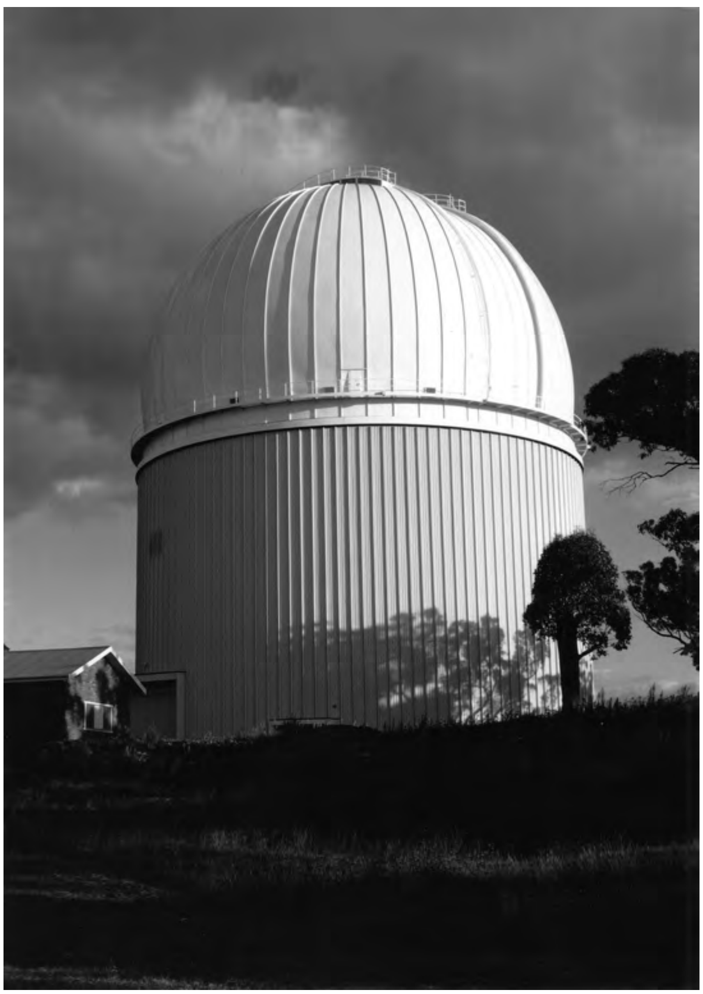

Figure 2 – Dome of the 3.9-m Anglo Australian Telescope near Coonabarabran N.S.W. The structure was designed to place the telescope high above thermal perturbations from the ground, but unfortunately with offices and laboratories and their heat sources in the intervening space. Peter Gillingham installed powerful fans to help equalize the outside air temperature with that around the telescope.

Two years later Lyman and I participated in an expedition organized by George Wallerstein to the Canadian Rockies directly east of Prince George. We made three first ascents, including two nameless peaks. For these I petitioned the Board of Geographical Names to honour two British Columbia astronomers, so that now the maps show a Mt. Plaskett and a Mt. Petrie (Morton 1968).

In 1970 I met and married my most helpful and understanding wife, Winifred. She was a chemist by training, but soon was applying her expertise to astronomy at Princeton.

At this time, Spitzer was developing a television detector, the SEC Vidicon, for future space missions. Unlike the image intensifiers common then, the SEC gave a direct electronic readout that was nearly linear with the incident intensity. Thanks to Bev Oke, then on the faculty of Cal Tech, I was able to test this system on the 5-m Hale Telescope. In a 5-hour exposure at the coudé focus we were able to obtain a spectrum of the 16th-magnitude quasar PHL 957 with unprecedented resolution and place a new limit on the sharpness of the absorption lines (Lowrance *et al.* 1972).

NASA launched the *Copernicus* satellite on August 21, 1972 carrying an 80-cm mirror and a spectrometer with a resolution of 15 km s^{-1} from 90 to 300 nm that was developed by Spitzer and his team at Princeton (Rogerson *et al.* 1973). The resulting high-resolution ultraviolet spectra provided many new insights into mass loss from hot stars (Snow & Morton 1976) and into the atoms and molecules between the stars (Morton 1975).

In June 1976, very early one morning, Lyman and I, along with graduate student Mike Shull, began another climbing expedition, this time on the Gothic tower of the Princeton Graduate College. Mike was an essential accomplice because, as a member of the College committee, he had access to the key that permitted me to reach the top by the internal stairs and lower a rope. Mike was the first to climb, but he untied half way up to rest on a sloping ledge hidden from my view. A lot of shouting followed when I discovered that the rope no longer had an attached student! Lyman tried next and almost reached the top when the university authorities arrived and demanded that we cease and desist, threatening to call the town police. Soon after, I departed for Australia, as described below, leaving Lyman, Chairman of the Department of Astrophysical Sciences, to deal with an admonishing letter from the Dean of the Faculty.

6. Anglo-Australian Observatory

My experience with ground-based observing using the SEC Vidicon certainly was helpful when I saw that the recently completed Anglo-Australian Observatory (AAO) was looking for a director. I successfully applied for the position. The Mortons, with a young son Keith, moved to Sydney in mid-1976 and spent a wonderful 10 years there as the observatory established itself on the world scene and fostered the development of optical astronomy in both Britain and Australia. Although the site of the 3.9-m telescope near Coonabarabran N.S.W. typically had only 65% clear nights, there was a dedicated team of astronomers, engineers, programmers, and technicians who more than compensated for the weather.

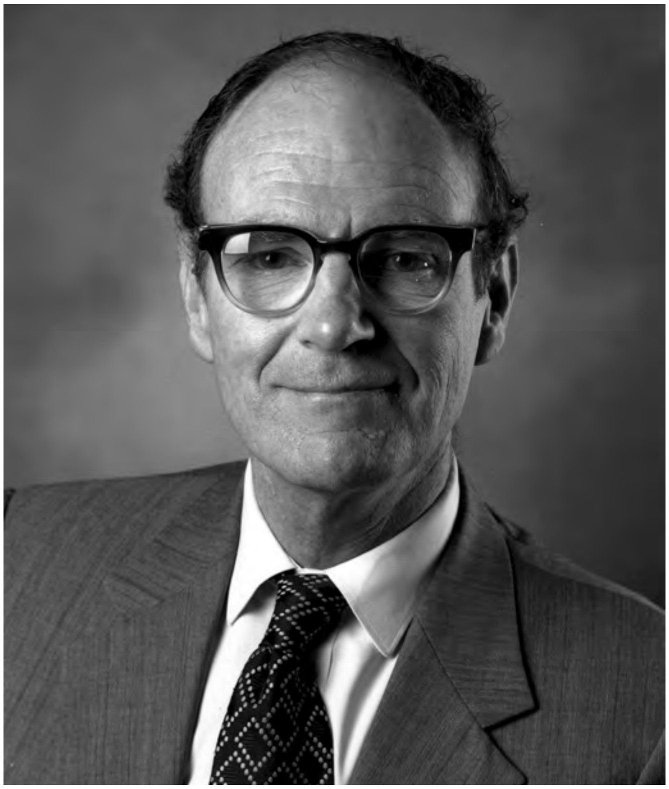

Figure 3 – Don Morton as Director General of the Herzberg Institute of Astrophysics of the National Research Council. Photo: NRC.

When I arrived at the AAO I found that Graham Bothwell already had given the telescope superior computer capability and John Straede and Pat Wallace had written control software that pointed the telescope much better than its predecessors did. John and Pat did so with only 64 kilobytes of computer memory and two disks of 2.5 megabytes each! It was a marvelous place for me to encourage further developments. Soon astronomer David Allen and electronics engineer John Barton were constructing a new infrared photometer that had exceptional sensitivity and our mechanical engineer Peter Gillingham and summer student Peter Gray were investigating how to minimize dome seeing. Later, Peter joined the staff and perfected optical fibres for multi-object spectroscopy. Meanwhile David Malin was filling textbooks with photographs from the telescope. My successors at the AAO, Russell Cannon and Brian Boyle, have continued the emphasis on instrument development, making it a major activity of the observatory as the United Kingdom reduces its share in the telescope.

7. National Research Council

After 30 years away from Canada, I was pleased when Sidney van den Bergh alerted me in mid-1985 that the National Research Council (NRC) had advertised for a successor to Jack Locke as the Director of the Herzberg Institute of Astrophysics (HIA). I was the successful candidate, so the Mortons, now with a son and a daughter Christine, made another move across the Pacific Ocean and settled in Ottawa in March 1986.

Astronomy in Canada had advanced wonderfully since my departure almost 30 years earlier. Some 15 universities, including two in French Canada, now had astronomy programmes, often as part of physics departments, and they were awarding Ph.D.s in astrophysics. In 1970 the Federal Government had consolidated all of its astronomy at NRC, which in turn created HIA in 1975 in honour of Gerhard Herzberg, Nobel Laureate in Chemistry for 1971. The 3.6-m Canada-France-Hawaii Telescope (CFHT) had begun operation in 1979 and was helping Canada to become a leading country in astrophysical research.

When I arrived the Institute had 207 staff and a wide diversity of sections, each operating essentially independently. These were

(a) the Dominion Astrophysical Observatory (DAO) in Victoria, B.C. with 1.8-m and 1.2-m telescopes representing optical astronomy,
(b) the Dominion Radio Astrophysical Observatory (DRAO) in Penticton, B.C. with a 26-m telescope and an interferometer using 9-m telescopes for decimetre astronomy,
(c) the Algonquin Radio Observatory in Ottawa, with a 46-m telescope for centimetre radiation in Ontario's Algonquin Park,
(d) Solar-Terrestrial Physics and Planetary Sciences in Ottawa, two sections investigating the magnetosphere, airglow, and meteors,
(e) Molecular Spectroscopy in Ottawa, which was the continuation of Herzberg's laboratory team. In early 1987 NRC transferred to HIA, High-Energy Physics in Ottawa, which specialized in instrumentation for international experiments.

NRC also was responsible for paying Canada's 42.5% share of the CFHT.

My management of the institute soon had further challenges as NRC, and consequently HIA, faced large budget cuts. Between 1986 and 1996 HIA had four major decreases in staff, leaving only half the complement that I started with. Some who lost their positions were relatively close to retirement, but others were scientists in the middle of productive careers.

The first reduction that I had to deal with came in September 1986 when NRC cancelled a project to resurface the Algonquin radio telescope for millimetre wavelengths and subsequently transferred the observatory to Ontario authorities. As an alternative I recommended joining the James Clerk Maxwell Telescope (JCMT), an initiative that I had planned to propose at my interview for the directorship, but the President of NRC, Larkin Kerwin, had just approved the Algonquin resurfacing. Following consultation with community representatives, Clive Willis, the NRC Vice-President responsible for HIA, was very helpful in diverting the $10 million capital for the resurfacing to purchase a quarter share in the JCMT. This 15-m telescope, just completed by the United Kingdom and the Netherlands, was designed for millimetre and submillimetre astronomy and located at the much-favoured site of Mauna Kea, Hawaii. Its 4000 m elevation places it above most of the water vapour that absorbs high-frequency radio waves. The collaboration in the JCMT moved Canada solidly into submillimetre astronomy and eventually made HIA a desirable partner for the Atacama Large Millimetre Array.

It was clear from the start of my appointment in Ottawa that I had to establish a unique role for astronomy in NRC, different from the teaching and research being done so well in Canadian universities. Their leaders were telling the government that curiosity-driven research was more appropriate for universities than NRC. HIA astronomers no longer could justify their NRC salaries simply by their personal research, no matter how good. Thus I identified the primary mission for HIA as providing facilities for university researchers, both as the Canadian sponsor for the CFHT, JCMT, and other telescopes, and as

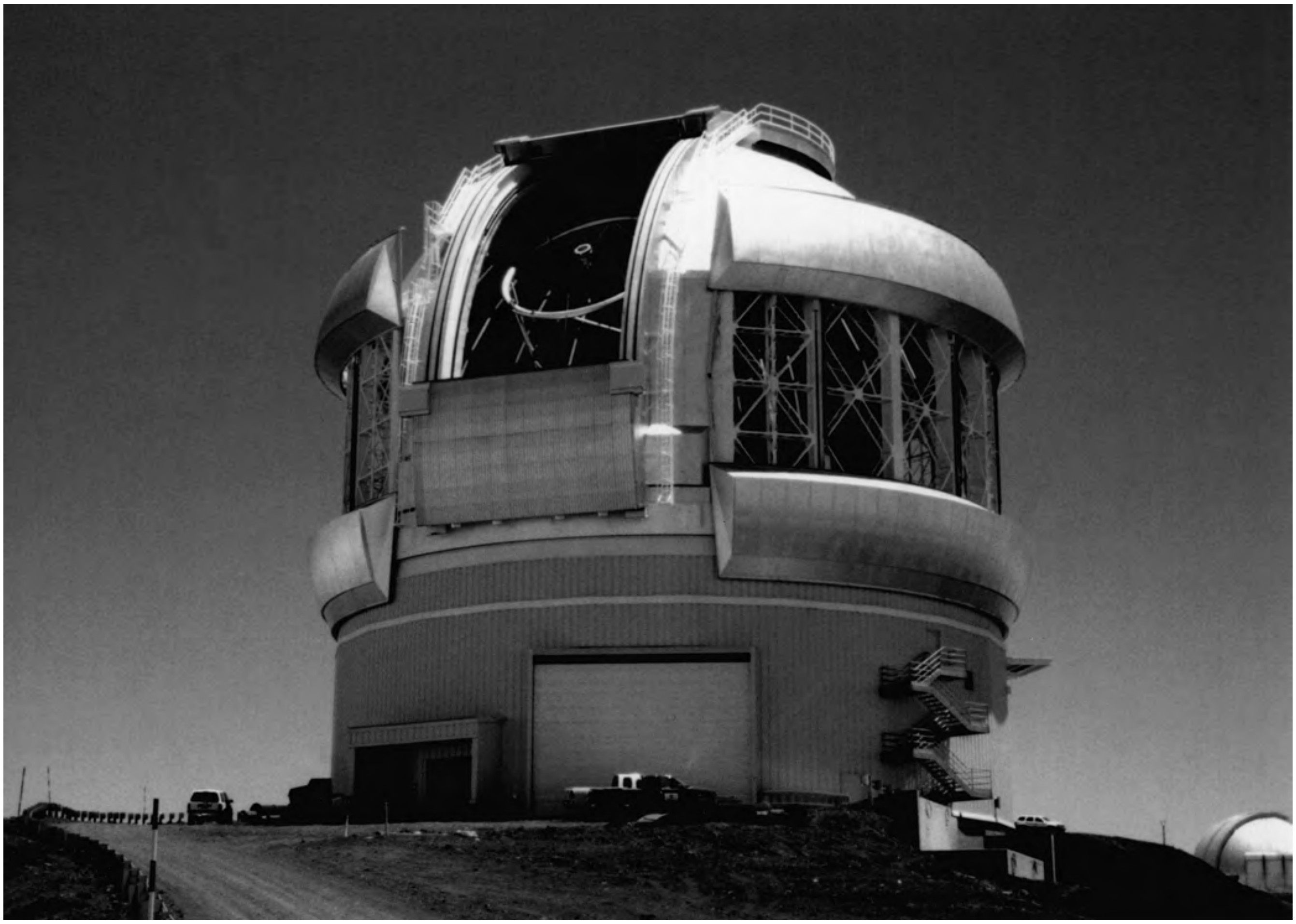

Figure 4 – The enclosure for the 8-m Gemini North Telescope showing the side panels open to enhance air circulation and hence minimize temperature gradients, which harm the seeing.

a developer of instruments and software for these telescopes. Of course, to be at the forefront of modern instrumentation HIA had to have a staff of leading researchers who wanted the best instruments possible. When I arrived at NRC, the DRAO leaders Lloyd Higgs, Tom Landecker, and Peter Dewdney had already seen the need for that approach. However, Sidney van den Bergh was unhappy with the change of emphasis and resigned as Director of DAO. Since then, Jim Hesser, as Director of Optical Astronomy for HIA, David Crampton, as head of the Optical Instrumentation Group, and Andy Woodsworth, as head of Data Archiving, made HIA an international leader in these specialties. One significant early accomplishment was the seeing compensator for the CFHT which enabled Pierce *et al.* (1994) to measure Cephied variables in a galaxy in the Virgo cluster for a reliable determination of the Hubble constant before the Hubble Space Telescope did so.

Pierre Perron became President of NRC in July 1989. He tightened many lax administrative practices that could have caused legal difficulties for the organization. He also gave all institute directors the title of Director General to match the practice of other government departments for managers of similar responsibility. In January 1990 he abruptly withdrew NRC from the field of high-energy physics. Fortunately, an arrangement with Carleton University negotiated by my deputy, Bryan Andrew, permitted the transfer of the staff. Later, in 1994, Perron decided to phase NRC out of solar-terrestrial physics and planetary sciences, resulting in another round of staff reductions. He moved the molecular spectroscopy group into the Steacie Institute of Molecular Science, keeping these excellent researchers within NRC. HIA's mission was now entirely in astrophysics. With only the JCMT group and HIA administration left in Ottawa, it was no longer cost effective to maintain a presence there. I moved about 20 staff and my office to the Dominion Astrophysical Observatory in Victoria beginning in the summer of 1994.

Arthur Carty, from the University of Waterloo, became President of NRC in July 1994. He gave the organization a vision of how it could lead in the development of innovation in Canada and contribute to local technology clusters. However, during his first year, he was hit by a major budget reduction as part of the government's Program Review. HIA was slated for a cut of $2 million in our operating budget, but thanks to the strong encouragement from David Routledge of the University of Alberta, many astronomers sent messages to Dr. Carty explaining the importance of HIA to their research. As a result, the Institute suffered only half the anticipated reduction.

8. Gemini TElescopes

When I moved back to Canada in 1986, astronomers in both the United States and Europe were thinking seriously about optical and infrared telescopes with apertures of 8 to 16 m. I made it my goal that Canada would become a partner in one of these projects so that our astronomers could continue to be competitive. Following initial discussions with potential partners and extensive consultation with university astronomers, the Canadian steering committee concluded that the best collaboration would be with the United States National Science Foundation (NSF) and what is now the United Kingdom Particle Physics and Astronomy Research Council (PPARC). We wanted to build identical 8-m telescopes in Hawaii and Chile to give us access to the skies of both hemispheres. The NSF would take a 50% share, while PPARC and NRC would each have 25%. With the experience of using the CFHT on Mauna Kea, Canadian astronomers wanted the new telescopes to be designed for the best possible images, including the use of adaptive optics to correct for atmospheric distortion, and I wanted HIA to build the instrument. Gordon Walker of UBC led in the preparation of a proposal titled "GEMINI — Twin 8-Metre Telescopes," which was released in April 1991. Unfortunately, in June of that year the Council of NRC rejected the plan because they believed that the operating costs for such a large share would eventually be an impossible burden for the Institute and NRC.

With the support of NRC management, I returned to the Council in November 1991 with a proposal for a 15% share in Gemini and strong representation from the university community — specifically Gretchen Harris of Waterloo, Jean-René Roy of Laval, Russ Taylor of Calgary, and UBC's Gordon Walker. Particularly helpful was the statement from Russ Taylor that Canada's radio astronomers agreed that this optical facility should be the next priority for Canadian astronomy. Now with Council support NRC made the necessary submission for Treasury Board approval. President Perron arranged for capital contributions of $10 million from the Natural Sciences and Engineering Research Council (NSERC) and $5.3 million from the WESTAR University Consortium, which had the proceeds from the sale of the mirror NRC had purchased for the Queen Elizabeth II Telescope on Mt. Kobau before its cancellation. NRC would provide the balance of $20.7 million for a total of $36 million to cover Canada's 15% share of the agreed cost of $176 million US. At that time, the Canadian dollar was worth about $0.88 US, but I took a pessimistic view that it might fall as low as $0.73 US! Fortunately, our early payments with a strong dollar balanced the final ones when our dollar dropped far below my estimated minimum. The operating funds were to come entirely from the existing NRC allocation to HIA. Later, when operations began, our weak currency added such an extra burden to the Institute that President Carty provided additional funds to cover the shortfall.

NRC and PPARC accepted the NSF proposal that the Association of Universities for Research in Astronomy, Inc. (AURA) manage Gemini because that contractor was already responsible for the U. S. National Optical Astronomy Observatory (NOAO) and Gemini South would be located on AURA property in Chile. We insisted, however, that the Gemini Board, rather than AURA, have scientific and technical control of Gemini. AURA recognized the need to separate its management of an international facility from its advocacy for ground-based optical astronomy in the United States through NOAO and the U.S. Gemini Office based in NOAO.

In late 1992, while NRC was waiting for all the approvals to join Gemini, the mirror controversy erupted. The U.S. Gemini team in Tucson, Arizona had scrupulously evaluated the bids for the first 8-m mirror blank and selected a meniscus of Ultra-Low-Expansion (ULE) fused quartz by Corning Glass, and AURA had signed a contract. The choice was very disappointing to the team at the University of Arizona, who had been developing, with NSF funds, an alternative lightweight mirror using borosilicate. This is the chemical name for Pyrex®, which Corning had used to cast the 5-m mirror in 1934 for the Palomar telescope. The Arizona team argued that their mirror would be less susceptible to wind gusts and proposed that Gemini cancel the Corning contract in favour of borosilicate, even though that technology had its own rigidity and thermal problems and the bid was more costly and had greater risks in meeting the delivery schedule.

As usual in such disputes, NSF appointed a committee, but unfortunately it was uncompromising in its recommendation that both Gemini mirrors must be borosilicate and ignored the consequences for the budget and schedule as well as the engineering uncertainties in the Arizona design. Both Canada and Britain, however, refused to accept any additional costs and Mike Pawlowski, the chief financial officer for NRC, stated clearly that Canada would not join Gemini if there was any chance of litigation from Corning. NSF could not bear the extra costs alone. The unofficial Gemini Board strongly supported the choice of the Corning ULE mirror by the fledgling project office and eventually NSF agreed. In December 1993 the preliminary design review for the primary mirror assembly concluded that the proposed mirror cell would provide the needed rigidity. Recent tests on Gemini South have verified the design performance and confirmed that the principal effects of wind gusts are the buffeting of the top end and vibrations of the enclosure that are transmitted to the telescope through the ground.

Canada became a financial partner in Gemini when President Perron of NRC signed the agreement in October 1993 along with corresponding officials in the United States and Britain. In October 1994 we added Chile (5%), Brazil (2.5%), and Argentina (2.5%) to make up the 10% Canada had to give up. We had invited Australia to take the 10% but internal debate there over astronomy priorities prevented a decision. In November 1995 the Gemini Board increased the construction budget to $184 million US, with Canada's $1.2 million US share coming from interest earned by WESTAR. Later, in May 1998, when it seemed that Chile would not complete its capital contribution, Australia did take a 5% share, though eventually Chile met its obligation, so that Gemini benefited from another capital increase of $9.2 million US. Then, in November 2002, Chile formally withdrew as a financial partner and the others redistributed their shares as 50.1% for the USA., 23.8% for the UK, 15.0% for Canada, 6.2% for Australia, 2.5% for Brazil, and 2.4% for Argentina. Since the University of Hawaii and Chilean astronomers automatically receive 10% of the observing time on the telescope each group hosts, Canada's share of Gemini nights is 13.5%.

Our participation in Gemini benefited much from having a university representative as Canadian project scientist — initially Gordon Walker from 1990 to 1997 and then Jean René Roy until October 2000 when he became Associate Director for Gemini North and was succeeded by Harvey Richer of UBC. Within HIA, Andy Woodsworth, as head of the Canadian Gemini office, brought effective organization and planning to our participation. In the International Gemini Office Matt Mountain, as Project Scientist, successfully championed the telescopes during the days of doubt within the United States community and later became the observatory's Director. At the agency level my counterparts Wayne Van Citters at NSF and Ian Corbett at PPARC were strong, dedicated supporters.

In Canada AMEC Dynamic Structures Ltd. built the two Gemini enclosures for a total of $26.6 million US, almost equaling the $27.6 million US Canada contributed to the capital cost of Gemini. In addition, HIA developed instruments and software, including multiobject optical spectrographs for both telescopes in collaboration with British laboratories, and ALTAIR, the adaptive optics module for Gemini North. ALTAIR uses the signal from a star in the field and a deformable mirror in the light path to correct atmospheric distortions in the wave front, thus taking the twinkle out of starlight.

9. The Long Range Plan for Canadian Astronomy

When NRC Vice President Jacques Lyrette assumed responsibility for HIA in April 1997 he began looking for ways to understand the community priorities and promote astronomy with the government in order to increase the available funds. In discussion with the HIA Advisory Board in March 1998 we decided on a national priority-setting exercise similar to the astronomy survey that reviews the entire discipline in the United States every 10 years. With advice from (NSERC) and the Canadian Astronomical Society, I appointed a small but effective panel consisting of Ralph Pudritz of McMaster University (Chair), Andrea Dupree of the Harvard-Smithsonian Center for Astrophysics, William Harris of McMaster University, Gilles Joncas of Université Laval, Simon Morris of the HIA, Ernie Seaquist of the University of Toronto, and Jack Welch of the University of California at Berkeley to prepare the Long Range Plan (LRP). Their well-written report of August 1999 on *The Origins of Structure in the Universe* described this unifying theme for research in the 21st century and recommended a combined new investment of $264 million over ten years by NRC ($147 million), NSERC ($17 million), and the Canadian Space Agency (CSA) ($100 million).

Both university and NRC astronomers received the LRP enthusiastically and made exceptional efforts to meet with members of Parliament, cabinet ministers, and Parliamentary committees to explain what is needed to keep Canada competitive in our field. The CSA has already recognized the primary recommendation for space astronomy and committed Canada to be a partner in the Next Generation Space Telescope, now renamed the James Webb Space Telescope. Pending an anticipated government commitment of new funds for ground-based astronomy, NRC has allocated initial funds to HIA to begin design work on some of the major projects recommended by the panel such as the Atacama Large Millimetre Array (ALMA), the Square Kilometre Array for longer radio waves, and the Very Large Optical Telescope.

10. Retirement

Simon Lilly from the University of Toronto succeeded me as Director General of HIA in October 2000. He worked diligently preparing funding scenarios and selling the LRP to government, in cooperation with Russ Taylor, who was the President of the Canadian Astronomical Society at the time. Lilly, however, left NRC after 16 months for an academic position in Switzerland. Jim Hesser has been Acting Director General of HIA since February 2002 and Greg Fahlman, presently Director of the CFHT, will take over in February 2003.

Since my retirement in January 2001, I have been climbing high-altitude mountains in South America and Asia and lower ones in North America. Scientifically, with an NRC appointment as Researcher Emeritus, I am continuing a hobby I started while analyzing *Copernicus* spectra at Princeton — the critical evaluation and compilation of atomic and molecular spectroscopic data (Dinerstein & Morton 1976; Morton 1991; Morton & Noreau 1994; Morton 2000).

The past fifty years have been an exciting time for astronomy, with discoveries of quasars, pulsars, gamma-ray bursters, and short-period extra-solar planets, to mention only a few of the strange objects we never expected. We also have seen remarkable advances in instrumentation, with lasers, solid-state detectors, and telescopes in space. It has been a wonderful time to be an astronomer learning about each new discovery and even contributing a little oneself. After taking on administrative responsibilities in Australia and then back in Canada, I have also had the immense pleasure of participating in the development of two leading research institutions and the careers of scientists and engineers committed to excellence in astronomy and instrumentation.

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Don Morton was born in Kapuskasing, Ontario in 1933, grew up in Toronto, and joined the RASC in 1952. As a professional astronomer he has worked in the United States, Australia, and Canada making observations from space and from the ground, developing instrumentation, and managing research organizations. Following his retirement in 2001 from Canada's National Research Council, he has continued with astronomical research as well as his longtime hobbies of mountaineering and model building with Meccano.

OFFICIAL OPENING OF THE DOMINION RADIO ASTROPHYSICAL OBSERVATORY, WHITE LAKE, PENTICTON, B.C., JUNE 20, 1960

On the afternoon of Monday, June 20th, in fine weather, but with a stiff breeze troubling the speakers a little, the Hon. Paul Comtois, Minister, Department of Mines and Technical Surveys, formally opened the Department's new Observatory, to be known as the Dominion Radio Astrophysical Observatory, before an audience of over 150 scientists and other guests from both Canada and abroad. The Minister emphasized the importance with which the Government regards fundamental scientific research and contrasted the unprejudiced and international manner of science with the unsatisfactory nature of mankind's achievements in the more general fields of international relations and mutual tolerance. The Dominion Astronomer, C. S. Beals, traced the history of astronomical research in Canada, and showed how the need for a large radio telescope developed from the general galactic researches already pursued and showed the continuity of this new effort with instrumental developments in the past. The President of the National Research Council, E. W. R. Steacie, speaking as a chemist, gently rebuked his astronomical colleagues for their ill-concealed pride in the very large and costly apparatus they require, with the advent of space explorations becoming costlier than ever, and in their ability to choose beautiful sites for their studies. He referred to the fact that science and politics are now inextricably connected, giving rise to many very difficult decisions but also leading to a great increase in governmental scientific effort. The officer-in-charge of the new Observatory, J. L. Locke, described the search for a suitable site and enlarged on the eminently satisfactory qualities of the valley in which we found ourselves, both aesthetically and for the purposes of radio astronomy. The problems of the structure and motion of gas-clouds in the galaxy, and the existence of large-scale magnetic fields would be vigorously pursued with the new telescope, one of the finest such instruments in operation, he stated.

Not to be forgotten was the comment of his Worship, Mayor Oliver of Penticton, "what a tourist attraction"!

by G. J. Odgers,
from *Journal*, Vol. 54, pp. 269, December, 1960.

CANADIAN THESIS ABSTRACTS

Compiled By Melvin Blake (blake@ddo.astro.utoronto.ca)

A Multi-Wavelength Study of Star Formation Around H II Regions
By Jennifer Karr (karr@ipac.caltech.edu), University of Toronto, Ph.D.

The environment of high-mass star formation is turbulent and complex. New stars are continually forming while the H II region, stellar winds, and supernovae of the current generation of massive stars destroy the parent molecular cloud. One of the more interesting premises connected with high-mass star formation is the possibility that one generation of massive stars and its associated H II region could trigger further star formation as the H II region expands into the surrounding interstellar medium.

This thesis uses the Canadian Galactic Plane Survey (a multi-wavelength survey of a portion of the outer Galactic plane) and other archived survey data to study star formation around H II regions, with a particular emphasis on the identification and analysis of evidence for triggered star formation. The use of multi-wavelength data is essential to investigate the ionized, neutral, and molecular components of the gas, the dust, and the population of young stellar objects (YSOs). The survey nature of the data is exploited to study multiple H II regions and star formation in different environments (from energetic to quiescent) in a uniform manner.

A variety of H II regions have been explored: W5 and W3/W4, large bright H II regions in the Perseus Arm; W1, a bright H II region in the local arm; LBN 140.77–1.42, LBN 139.57+2.70, and LBN 140.07+1.64, a series of faint H II regions in the Perseus Arm; Sh 2-183, Sh 2-170, Sh 2-173, smaller H II regions at distances of order 2.2 kpc; and Sh 2-185, a nearby H II region. Evidence for direct interactions between the YSOs and molecular gas and the H II region have been found on large and small scales. The interaction between components of the ISM and the distribution and luminosity of star formation has been analyzed. Time scales for star formation and triggering have been calculated where possible and the plausibility of triggering evaluated. The nature of star formation outside the neighbourhood of the H II region has been explored and compared with the more active regions.

Properties of star formation and molecular clumps in different regions over the sample have been studied, including the areal density of star formation, molecular clump parameters, and the size–linewidth relation.

On the Evolution of the Clustering of Galaxies By Charles William Shepherd (shepherd@astro.utoronto.ca), University of Toronto, Ph.D.

Explaining the origins and evolution of the structure seen in the local universe is one of the main challenges of modern astronomy. Observations of the evolution of galaxy clustering are a primary constraint on any model of structure formation. How this evolution depends on galaxy properties, however, has not yet been comprehensively investigated.

In this work, the dependence of galaxy clustering on spectral energy distribution (SED), evolution-compensated RC-band absolute magnitude M0RC, and redshift z is investigated within a sample of ~3000 galaxies from the CNOC2 redshift survey. Techniques for estimating the galaxy correlation function and its uncertainty from survey data spanning a wide range of redshifts are developed.

Galaxies with early-type SEDs, M0RC < –20, and $0.12 < z < 0.47$ are ~2.4 times more strongly clustered and have a steeper correlation function slope than late-type galaxies in the same magnitude and redshift range. The relative bias between the two samples is consistent with that observed for nearby galaxies.

The comoving correlation amplitude is moderately sensitive to galaxy luminosity, with brighter galaxies being more strongly clustered, independent of SED. The luminosity dependence of the correlation amplitude for galaxies with $0.12 < z < 0.40$ is similar to that seen in local surveys.

The correlation amplitude for galaxies of all SED types and M0RC < –20 is independent of redshift for $0.12 < z < 0.47$. This is consistent both with the predictions of the biased structure formation scenario and with earlier observations. These results would seem to indicate that the clustering of galaxies has changed little during the past 3 Gyr.

The correlation amplitudes of the early- and late-type samples evolve remarkably rapidly, however, with both samples becoming less clustered with time. Galaxy mergers, luminosity evolution, and SED evolution are considered as possible causes of the clustering evolution. While the apparent evolution of the clustering in the SED-selected samples is probably caused by evolution of the properties of individual galaxies, it is clear that the situation is somewhat more complex than is indicated by the results described above.

Education Notes
Rubriques pédagogiques

MEASURING MARS

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The year 2003 will feature an especially good opposition of Mars. To celebrate this fine celestial event, let's start looking at the mathematical possibilities inherent in the Martian data found in the *Observer's Handbook*. The mathematics in this article involves solving a simple formula using conversion factors and scientific notation. Conversion from degree to radian measure is introduced.

Mars was at opposition in 2001 on June 13. The closest approach of Mars to the Earth listed in the *Handbook's* "The Sky Month By Month" is actually June 21. Then Mars was at a distance (r) of 0.45 Astronomical Units (AU) from the Earth. Its angular diameter (θ) was 20.8 seconds of arc (″). From the "Basic Data" section we see that Mars has an equatorial diameter (d) of 6794 km.

We can approximate the diameter by a small arc of a circle (see Figure 1). The three Martian measurements can then be related by the simple formula:

$$d = r\,\theta$$

For the formula to work, θ must be a radian measure. Radian measure uses the well-known geometry formula for the circumference, C, of a circle in terms of its radius, r (*i.e.*, $C = 2\pi r$). Mathematically, the unit of radian is the dimensionless ratio of the distance traveled along the circumference and the radius (for a given angle). To convert to seconds of arc we need a conversion factor. This factor can easily be derived from two basic angle definitions:

360 degrees = $2\,\pi$ radians

1 degree = 3600″

3600″ = $(2\,\pi)/360$ radians = $\pi/180$ radians

1″ = $(\pi/180)/3600$ radians
= $\pi/648{,}000$ radians
= 4.8481×10^{-6} radians

With this conversion factor we can now calculate the diameter of Mars from the near Opposition data.

$d = r\,\theta$
= 0.45 AU × (20.8″ × 4.8481×10^{-6} radians/″)
= (4.53782×10^{-5} AU) × (1.49598×10^{8} km/AU)
= 6788.5 km (to one more significant figure than our expected result)

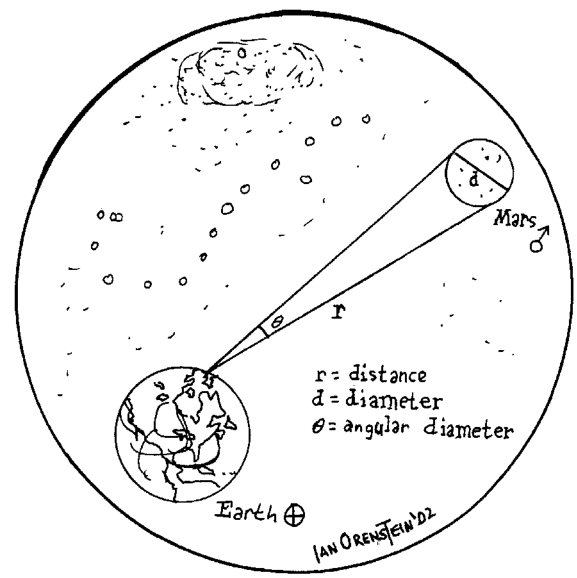

Figure 1

In the above calculation, we made use of the conversion factor from AU to kilometres. With our result, we can now calculate a percent error.

Percent Error = [(Observed – Expected)/Expected] × 100%
= [(6788.5 – 6794) km / 6794 km] × 100%
= [–5.5 km / 6794 km] × 100%
= $-8.1 \times 10^{-4} \times 100\%$
= –0.081 %

Wow! That's close. We can't expect any better when, of our two starting observations, we have one with three significant figures and the other with only two.

The same relationship can be reworked to calculate the distance, r, and the angular diameter, θ.

If $d = r\,\theta$

then $r = d / \theta$

and $\theta = d / r$.

The first stationary point of the retrograde loop occurred May 11, 2001, with $\theta = 15.9''$ and, of course, $d = 6794$ km. How far was Mars from the Earth?

$$
\begin{aligned}
r &= d / \theta \\
&= 6794 \text{ km} / 15.9'' \\
&= (6.794 \times 10^3 \text{ km}) / (15.9 \times 4.8481 \times 10^{-6} \text{ radians}) \\
&= (6.794 \times 10^3 \text{ km}) / (7.70848 \times 10^{-5} \text{ radians}) \\
&= (6.794 / 7.70848) \times 10^{3-(-5)} \text{ km} \\
&= 0.881367 \times 10^8 \text{ km} \\
&= (8.81367 \times 10^7 \text{ km}) / (1.49598 \times 10^8 \text{ km/AU}) \\
&= 0.58916 \text{ AU}
\end{aligned}
$$

Compared with the tabulated value of 0.59 AU, this result is an exact agreement to the two quoted significant figures.

Similarly, for the second stationary point, we can calculate the apparent angle Mars takes up at the given distance. This point occurred on July 19, with the nearest data listed for July 21, 2001, when $r = 0.51$ AU, keeping $d = 6794$ AU.

$$
\begin{aligned}
\theta &= d / r \\
&= (6.794 \times 10^3 \text{ km} / 1.49598 \times 10^8 \text{ km/AU}) / 0.51 \text{ AU} \\
&= (4.5415 \times 10^{-5} \text{ AU})/(5.1 \times 10^{-1} \text{ AU}) \\
&= 8.9050 \times 10^{-5} \text{ radians} \\
&= (8.9050 \times 10^{-5} \text{ radians}) /(4.8481 \times 10^{-6} \text{ radians}/'') \\
&= 18.368''
\end{aligned}
$$

The tabulated value is 18.5″. Using the same method as before, the percent error is only –0.714%. Again, this result is very accurate when considering that one of our inputs has only two significant figures.

Except for the introduction of the idea of radian measure, all the calculating techniques in this article are covered by the end of a typical Grade-9 math course. All the required data are found in the RASC's *Observer's Handbook*. Teachers should try this with their own classes for the current Opposition, using the 2003 edition of the *Handbook*.

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David Orenstein teaches mathematics at Danforth CTI and observes from Trinity-Bellwoods Park, both in downtown Toronto. Cloudy evenings are spent enjoying the local cultural riches, weekends and holidays of other Canadian cities. He is a member of the RASC's National Education Committee and the Toronto Centre.

Altitude and Limiting Visual Magnitude

by Mary Lou Whitehorne (mlwhitehorne@hfx.eastlink.ca)

The sky from the summit of Mauna Kea, Hawaii is like no sky I have ever seen; deep, clear blue during the day, vibrant with a full palette of colour at sunrise and sunset, and extraordinary beyond belief at night. So clear; so filled with stars that it didn't seem real. There was no need for a flashlight to navigate about the summit at night; the starlight was bright enough for casual strolls around the observatories there. The core of the Milky Way cast obvious shadows. In the west after darkness fell, we could see the Zodiacal Light as a triangular glow above the horizon. Above it and clearly visible was the Zodiacal Bridge that arched over the sky and vanished into the opposite horizon. The Gegenschein appeared as a pale glow at the anti-solar point along the Zodiacal Bridge. We could see the planes of both the Milky Way and the Solar System arcing across the sky and intersecting one another. After midnight on those early spring nights, the Milky Way settled into a tilted ring that circled the horizon. It seemed so obvious that we are indeed embedded within this huge disk of glittering stars.

I am one of a group of five amateur astronomers who traveled to the Big Island of Hawaii in April 2002. We planned to observe from the Visitors' Information Station at the Onizuka Centre for International Astronomy at the 9,300-foot level on Mauna Kea (see *Sky & Telescope*, June 2002, page 100), and from the summit at 13,800 feet.

We have heard that a person cannot see as many stars at the summit of Mauna Kea[1] (or any other similarly high elevation) because the low atmospheric pressure at this altitude makes less oxygen available in each lung-full of air. At the summit of Mauna Kea the pressure is only 60 per cent of that at sea level. The widely accepted wisdom states that more stars (a fainter minimum visual magnitude, or MVM) can be seen from lower altitudes where the atmosphere is denser and therefore contains more available oxygen.

Figure 1 – On the summit of Mauna Kea, in front of the University of Hawaii's 0.6m telescope dome. From left to right are Dave Lane, Mary Lou Whitehorne, Bill Thurlow, Greg Palman, and Roy Bishop.

We set out to investigate whether or not this is actually the case. We determined our five individual MVMs at three different altitudes, both with and without supplementary oxygen. We did the experiment after we were well acclimatized to the altitude of Mauna Kea; we had stayed continually at either the 9300-foot level or the summit for five days and nights. On the evening of our sixth night on Mauna Kea (April 12), we loaded oxygen tanks and a pulse oximeter (a medical device that measures pulse rate and blood oxygen level (SPO_2)) into our SUV and descended to the 6800 ft level (the intersection of the Saddle and Summit Roads) for our first MVM determination. Although we were nearly dark-adapted by this time, we waited an additional 15 minutes before beginning our observations.

We had MVM charts prepared for a section of the sky in Leo (see Table I and Figure 3) where we were unfamiliar with the magnitudes of the stars. The charts simply labeled the target stars as "A, B, C, D" and so on, so we had no idea what MVM we were actually observing. With each observation we recorded pulse rate and blood oxygen level for each observer. The first set of observations was without supplementary oxygen, the second set was with the extra oxygen. This procedure was repeated at 9400 ft. and again at the summit of Mauna Kea (13,800 ft.). The results are listed in Table II.

We noted no significant difference in MVM at the three altitudes regardless

[1] Ferris ,T. 2002, Seeing In The Dark (Simon & Schuster: New York), 47

Figure 2 – Mary Lou Whitehorne, in the dome of the 0.6m telescope, with an oxygen tank and pulse oximeter used in the experiment. Dave Lane, the incurable observatory technician, is seen in the background fiddling with the telescope.

of whether or not supplementary oxygen was used. This does not follow the commonly held belief! Why is this so? Where did the "accepted facts" come from? Were observers not allowing themselves to fully dark adapt at the summit? Were they not acclimated to the altitude? Is it a ploy on the part of the observatories to discourage itinerant amateur observers from coming to the summit? It is, after all, a dangerous place with many hazards to threaten the unwary and careless!

I had, on previous nights, found that my personal MVM on the summit was at least as good as, if not better than, that at lower altitudes. In fact, in seventeen years of observing from many different places, I have never seen a sky so splendidly filled with stars as that at the summit of Mauna Kea.

As an interesting diversion I checked the blood oxygen levels of all five observers at many different times on the mountain.

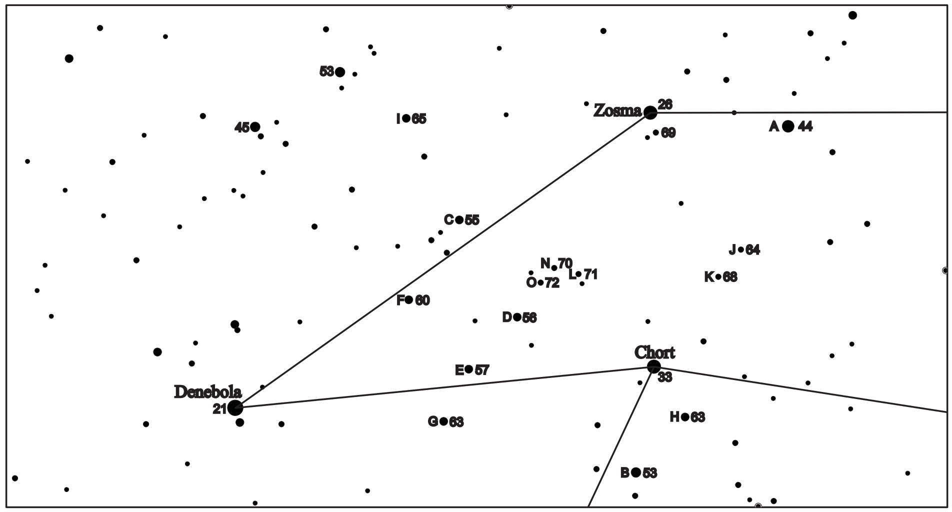


Figure 3 – Chart in eastern Leo showing visual magnitudes, to the nearest tenth of a magnitude, of the stars used in this study. ECU chart by David Lane.

We were able to easily maintain good levels because we had taken the time to acclimate to the altitude. The oxygen levels of some visitors at the summit who had not taken time to adapt to the altitude were, on the other hand, appallingly low; most were between 80 and 83 percent but a few were as low as 75 per cent. I was amazed at how trustingly these visitors would stick their fingers into the strange-looking pulse oximeter!

The physiology of the eye is extraordinary. The choroid, which supplies nourishment to the retina, has the highest blood perfusion rate per unit mass of all vascular beds within the human body. Also, the eye is capable of adapting to conditions by ensuring adequate blood flow to the retina in order to meet the demands being made by its user.[2] The eye can actually strip more oxygen out of the blood to meet its needs.[3]

Although the air is thin on the summit of Mauna Kea, our results indicate that, given sufficient time to acclimatize, the visual system compensates for the shortage of oxygen. Observers may still feel several minor symptoms arising from lack of oxygen at such altitudes, but if they take time to adapt to the altitude, a reduced MVM is apparently not one of them.

Caution: At high altitudes, such as that of the summit of Mauna Kea, some individuals can occasionally experience life-threatening symptoms, involving pulmonary and/or cerebral edema, either of which necessitates a quick return to

Table I

LEO MVM series

Star	Magnitude (V)[4]	B-V
A	4.42	0.053
B	5.31	1.189
C	5.54	1.056
D	5.58	0.390
E	5.74	1.371
F	5.95	-0.156
G	6.27	0.570
H	6.30	0.209
I	6.45	1.010
J	6.40	1.555
K	6.80	1.025
L	7.14	0.120
N	7.03	1.064
O	7.22	0.141

[2] Fuchsjäger-Mayrl, G., *et al.* 2001, Vision Research 41, 2919

[3] Sample, I. 2002, New Scientist, June 8, 18

[4] Data from the ESO Hipparcos Catalog (astro.estec.esa.nl/Hipparcos/HIPcatalogueSearch.html)

TABLE II

MVM vs. Altitude With and Without Supplementary Oxygen

April 12 - 13/02 6800 ft. 11:30 p.m.

	NO O2		SUPPLEMENTARY O2	
	SpO2	**MVM**	**SpO2**	**MVM**
Observer 1	96	6.27	99	6.27
Observer 2	97	6.45	99	6.45
Observer 3	94	7.14	98	7.14
Observer 4	95	5.95	100	7.14
Observer 5	97	6.27	99	6.30
Average	**96**	**6.43**	**99**	**6.66**

April 12 - 13/02 9400 ft. 12:30 a.m.

	NO O2		SUPPLEMENTARY O2	
	SpO2	**MVM**	**SpO2**	**MVM**
Observer 1	91	6.30	100	6.30
Observer 2	95	6.30	98	6.45
Observer 3	92	7.14	98	7.14
Observer 4	91	6.27	98	6.27
Observer 5	95	6.27	99	6.27
Average	**93**	**6.46**	**99**	**6.49**

April 12 - 13/02 13,800 ft. 1:30 a.m.

	NO O2		SUPPLEMENTARY O2	
	SpO2	**MVM**	**SpO2**	**MVM**
Observer 1	92	6.45	100	6.30
Observer 2	84	6.27	99	6.30
Observer 3	75	7.14	97	7.14
Observer 4	80	6.27	99	6.27
Observer 5	96	6.27	98	6.27
Average	**85**	**6.48**	**99**	**6.46**

lower altitudes. An ambulance is kept at the summit of Mauna Kea for such emergencies. Fortunately, no one in our group was so affected, and we doubt that such an experience would enhance MVM results.

Thanks to Roy Bishop, David Lane, Greg Palman, and Bill Thurlow for participating in these MVM measurements and for their company under the skies of Mauna Kea, and to Michael West for his help in making our visit to Mauna Kea possible.

Mary Lou Whitehorne is just finishing her third term as president of the Halifax Centre. She served on the Centre executive for 15 years and has been active in many aspects of amateur astronomy including visual observing, astrophotography, stellar spectroscopy, education, and observatory construction and maintenance. She is presently a full time student of public relations.

Global Star Cluster

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

Who on earth d'you think you are,
A super star,
Well, right you are.

Well we all shine on,
Like the moon and the stars and the sun,
Well we all shine on,
Ev'ryone come on.

— John Lennon, "Instant Karma"

At the Odyssium's Public Observatory, our mandate has always been to bring the stars to the people. In recent summers, I have turned the tables somewhat and let the people bring their stars to me.

I have been a weekend volunteer at the Observatory since 1987, and have also found seasonal employment in recent summers when the facility is opened on a daily basis between Canada Day and Labour Day, as it should be. I consider our Observatory the best exhibit in the entire Science Centre, predicated as it is on real photons rather than simulations, models, and artists' conceptions. (But I'm biased.)

While the long summer days here in the far north are not entirely conducive to stargazing, there is lots of astronomy that can be done in daylight, or at best twilight, especially with the battery of fine telescopes with which we are blessed. I like to tell folks my office isn't pretty, but it has the best view in the entire city. But the highlights of every summer for me are the people, relaxing on vacation from all over the world. In exchange for showing them the planets, I get to learn a lot about this one.

In mid-July, 2000, the crucial third stage of the International Space Station was launched, and so, indirectly, was my (first) summer project. The module was named ЗВЕЗДА (*Zvezda*), the Russian word for star. It occurred to me that after decades of watching both the stars and the Russians, I should have known this. In pondering this gap in my knowledge, an idea sparked like a star in the voids.

Figure 1 – The Odyssium Observatory blackboard on Labour Day, 2000. Starting at top right, the list of international "stars" filled nearly three columns in six weeks. At left are the results of an ongoing sunspot count during the year of solar maximum. (Image: Michael Hoskinson)

With the heavy tourist traffic at Odyssium (formerly Edmonton Space & Science Centre), we frequently entertain visitors whose native tongue is not English. I have often struggled to understand people with heavy accents, waited for them to translate for others in their party, or have seen them shrug vaguely at my attempts to communicate. All too often, they seemed on the defensive, apologizing for their poor English. As an Anglophone who struggles with rudimentary French, I've felt powerless to help. The language barrier loomed as an unscalable "tower of babble," as I usually didn't know even a single word of their language.

That summer, I resolved to change this by learning *exactly* one word in as many languages as walked through the door. The word I chose was "star."

Stars are universal (so to speak). Forever within our sight yet beyond our grasp, they belong to everybody, or nobody. People the world over lay claim to the stars in their legends and lore. This can be illustrated by their ubiquitous presence on national flags. In a recent non-scientific survey by the writer, fully 40% of the world's current flags (90 of 223) display some sort of astronomical symbol, with stars being by far the most popular choice. Multiple stars are not uncommon; indeed, one nation with a reputation for self-aggrandizement, relentlessly follows the theory that "more is more" in displaying no fewer than 50 stars on its flag!

The other advantage to this word was that at the Observatory there were always stars to be seen. On clear afternoons I always swept up Sirius or Arcturus (to the astonishment of most visitors); in the evenings Vega, Izar, Albireo, the Double Double, or myriad others. Stars were the only reliable target in the planet-free summer of 2000.

I started by writing the few "star names" I knew on the blackboard: English, French, German, and the newly-learned Russian.

Then I began to ask foreign visitors how to say "star" in their language, how to pronounce it, how to spell it, and I (or they) would add it to the ever-growing list on the board.

Suddenly language differences were no longer a barrier, but a bridge. Visitors who began by apologizing for their English felt empowered by my interest in their tongue, and were always eager to assist. As the summer wore on the project took on a life of its own, with visitors sometimes grabbing the chalk to add a new star without prompting, or unilingual Anglophones frequently stopping to admire the mounting list. Even when a newcomer spoke a language that was already recorded, I used my hard-won knowledge in a different way. To a Hungarian visitor, for example, I would point to the eyepiece and announce: "Come and see the *csillag*!" People recognizing a familiar word would invariably respond with a beam of delight, and the ice would be broken. It was a beautifully inclusive process.

By summer's end our blackboard sported no fewer than 46 words, and ten different character sets (see Figure 1). And somehow I felt more in touch with the world.

It's been said one can learn a lot about cats by closely studying one cat. Likewise, one can learn something about languages by studying one word. So what did I learn in the fledgling science of astro-linguistics? Firstly, that there are many connections between the various languages. One can start with the three Latin words for star, namely *astrum, stella,* and *sidus,* the root words for astronomy, stellar, and sidereal among many others. Heading west across Southern Europe, there is the Greek *asteré*, the Italian *stella*, French *étoile*, Spanish *estrella*, and Portuguese *estrela* (the latter two, although similar, are spelled and pronounced differently). To the northwest, the Romanian *stea* mutates into the German *stern*, Dutch *ster*, Danish and Norwegian *stjerne*, Swedish *stjärna*, and of course, the English *star*. An eastward journey yields the Farsi (Persian, spoken in Iran) *setareh*, Urdu (Pakistan) *sitara*, and Punjabi and Hindi *tara* (both pronounced the same, but spelled in completely different character sets). And to the northeast the Slavic languages clearly have a different root, but share a common trait: Croatian *zvijezda*, Czech *hvězda*, Polish *gwiazda*, Russian *zvezda*.

Figure 2 – By summer's end 2001, a similar project featuring the word "sun" filled the entire blackboard, rather ironically forcing the relocation of our more scientific solar observations. Our earliest "new" word (third from top right), the Malay *matahari,* drew considerable comment and some skepticism, however several Malaysian visitors later in the summer confirmed its correctness. Not shown — because it has no written form — is International Sign Language. Sun can be signed by cupping a hand in a C shape in front of one's eye. (Image: Michael Hoskinson)

Even the Tagalog (Phillippines) *bituin* and the Indonesian and Malay *bintang* may share a common background. Meanwhile, the African tongues appear distinctly unrelated: I find no commonality among the Swahili *mwangaza*, Zulu *inkanyezi*, Luganda *munyenye*, Sotho naledi, Kikuyu *njata*, or the most unpronounceable of the lot, the Igbo *kpakpando*. To one with no formal anthropological training, this suggests a series of distinct cultures with minimal trade or travel. Only the Afrikaans *ster* betrays its Dutch origins.

One roadblock I encountered was in adding native North American languages to the list. I concluded this was due to three reasons. Firstly, native people tend to speak perfect English, robbing me of my most direct line of inquiry. Second and most disturbingly, the ones I did ask often demurred with an apology for their lack of fluency in their own language, unwelcome evidence of rich cultures being assimilated; indeed, indigenous languages are endangered species the world over. Finally, while each star group or individual luminary has its own unique name and associated lore, many native languages apparently do not have a generic word for "star." This seems to be especially true with the northern peoples.

The whole project had been such a delightful success that we repeated it in 2001, learning how to speak "sun" in 63 tongues, from Sanskrit to Dene. (See Figure 2) That summer the World Athletics Championships delivered athletes, spectators, and press from all parts of the world. One gorgeous midsummer evening we simultaneously hosted visitors from five different continents; as they passed the chalk around, the starlit evening air was abuzz with voices carrying all manner of accents, but a common overtone of fellowship.

This past summer of 2002, we learned to say "moon" 51 ways, among them Egyptian (*selene*), Tamil (*mama*), Tartar (*ai*), Finnish (*kuu*), and Welsh (*lleuad*, but don't ask me to pronounce it). We encountered several new languages that raised our three year total to some 80 different tongues. This represents barely one percent of the world's estimated 7000 languages, dialects, pidgins, and creoles. But enough of the major tongues have been included that my combined lists almost certainly represent a majority of the global population. In a unique way, we have been united by the stars.

May we all shine on...

Bruce McCurdy is the Education Development Coordinator of the Sky Scan Science Awareness Project, an initiative of the Edmonton Area Radio Astronomy Group, which offers Grade-9 students a science curriculum-related project observing meteors using FM radios. Active in astronomy and its public education outreach since the mid 1980s, Bruce is a past president of the RASC Edmonton Centre and currently serves the National Council as Astronomy Day Coordinator. Bruce's interest in the planets has only served to sharpen his appreciation of this one, leading to the foregoing departure from the usual thrust of this column. By next issue Bruce's head presumably will have returned to its customary position in the vacuum of outer space.

Society News/Nouvelles de la société

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

NATIONAL HAPPENINGS

At the time of this writing, our Executive Secretary, Bonnie Bird, was off to Africa with the Solar Eclipse expedition organized by the RASC Calgary Centre. For more information on this eclipse trip, visit `www.syz.com/rasc/eclipses.htm`. Other RASCals were in Australia to view the same December 4, 2002 Solar Eclipse. *Clear skies to all*! The rest of us left behind are very jealous. Let's hope for some good pictures and wonderful stories from these far away places.

On October 26, 2002 the fall National Council meeting was held in Toronto. Since not all Centre Representatives attended this meeting, it was the first one to use teleconferencing. As usual, there was a great deal of discussion, decisions made, and motions carried. Please talk to your National Council representative to learn what went on at the meeting, and please review the minutes at `www.rasc.ca/` when they become available from the National Recorder. They are located in the "Members Only" section of the National Web site, to which a password is required for access. If you do not know the password, contact your local Centre executive, the National Office (`rasc@rasc.ca`), or the webmaster (`webmaster@rasc.ca`).

After the meeting, the Toronto Centre invited all of the National Council members to have dinner at a small Mexican restaurant. Some of the group departed on a car convoy after dinner to visit the Carr Astronomical Observatory. It is located at the top of the Blue Mountains overlooking Georgian Bay and the Beaver Valley near Collingwood, Ontario, about 2½ hours north-west of Toronto.

National Council meeting October 26, 2002
(Picture by: Patrice Scattolin)

The Carr Astronomical Observatory, near Collingwood, Ontario.
(Picture by: Patrice Scattolin)

We arrived at the observatory after 8:30 p.m., with sleeping bags, some astronomical equipment, and lots of warm clothes. We were hoping that the weather forecast would be wrong and that there would be some observing time.

While waiting for the clouds to part, we were treated to a slide presentation and a description of the observatory construction over the last 3 years. The first light was obtained and dedication ceremonies were held on July 21, 2001.

Now this facility is a dream come true. The Toronto Centre acquired land and a house back in 1998, and soon after started to plan the future site of the observatory building. The house contains sleeping rooms upstairs (named the Aquila and Cygnus rooms). The downstairs, which is still undergoing renovations, has a comfortable library with a wood stove to take the chill off those cold nights.

The amazing story of the observatory's steel-frame construction kept everyone mesmerized through the slide show. The roof is 16 by 28 feet and rides on 6 steel wheels along steel tracks 6 ft off the floor. The total headroom of the building is 8 feet 4 inches. Over three years, the walls, interior, and exterior were put in place, along with the electrically driven roll-off roof, electrical work, and lots of other additions. One impressive feature of the observatory is the 16-inch Meade LX200, something we can all dream about owning someday.

I could go on trying to explain the details of this wonderful facility, but instead please visit the Carr Astronomical Observatory page at the Toronto Centre Web site, `webhome.idirect.com/~allusion/rasctoronto/observing.html`.

We never did get a chance to observe under the dark skies, but we did get a chance to have walking tour of the CAO. There are many features that make this facility comfortable and very user-friendly. After talking to some of the Observatory Committee members, there is always something that they would have done differently, but this is truly an observatory dream come true, so enjoy your observatory, Toronto Centre members — we sure did. Thanks to all the Toronto Centre members who made our stay enjoyable and relaxing, and provided us with breakfast and morning conversations. This was a great way to start a Sunday morning!

Inside the CAO, roof open, still waiting for clear skies (Picture by: Patrice Scattolin)

UPCOMING EVENTS

Our next National Council Meeting will be held in Toronto on Saturday February 22, 2003, at 10:00 am. Contact your local Representative for information on the meeting. You can also visit the National Web site (`www.rasc.ca`) for updates.

CONGRATULATIONS TO....

At the National Council meeting on October 26, 2002, certificates were awarded to several members who achieved their goals of observing the Messier and NGC lists.

Messier Certificates: Martin Weatherston (Unattached), Michael Gatto (Halifax), Bill Weir (Victoria), Donna-Marie Bonnett (Toronto), Harold Healy (Toronto), Terry Millard (Unattached), Jim Fisher (Okanagan), Vance Petriew (Regina), Bill Gardner (London), Keith Lowe (Halifax), and Matthew Weeks (Ottawa).

Pomponia Martinez and Bob Parry, Vancouver Centre (Picture by Patrice Scattolin)

Finest NGC Objects Certificates: Richard Keppler (Calgary), Scott Wilson (Regina), and Vance Petriew (Regina).

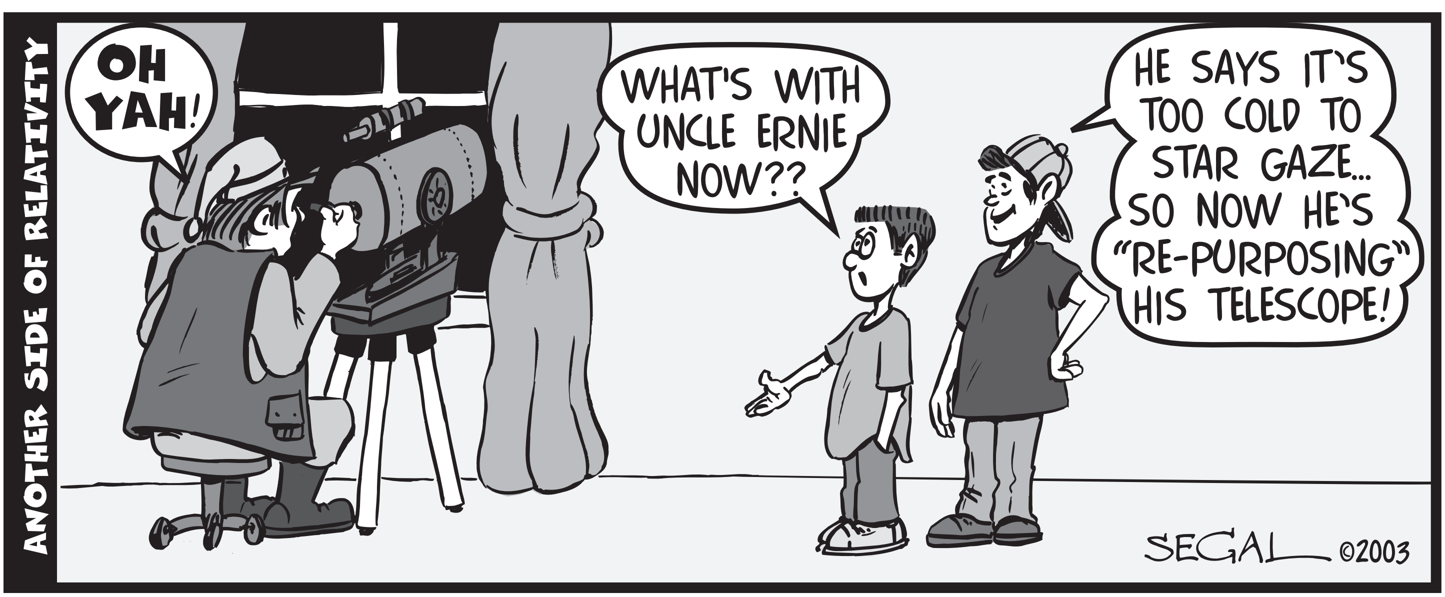
For details on these Certificate programs and our new Exploring the Universe Certificate program, visit `www.rasc.ca/observe.htm.`

On October 28, 2002, born to Jan & Mawgosa Wisniewskia, a baby girl, Magdeline, a sister to Kasia.

Also, in the 2002 summer season, Vancouver members Pomponia Martinez and Bob Parry were united in marriage. Congratulations to everyone!

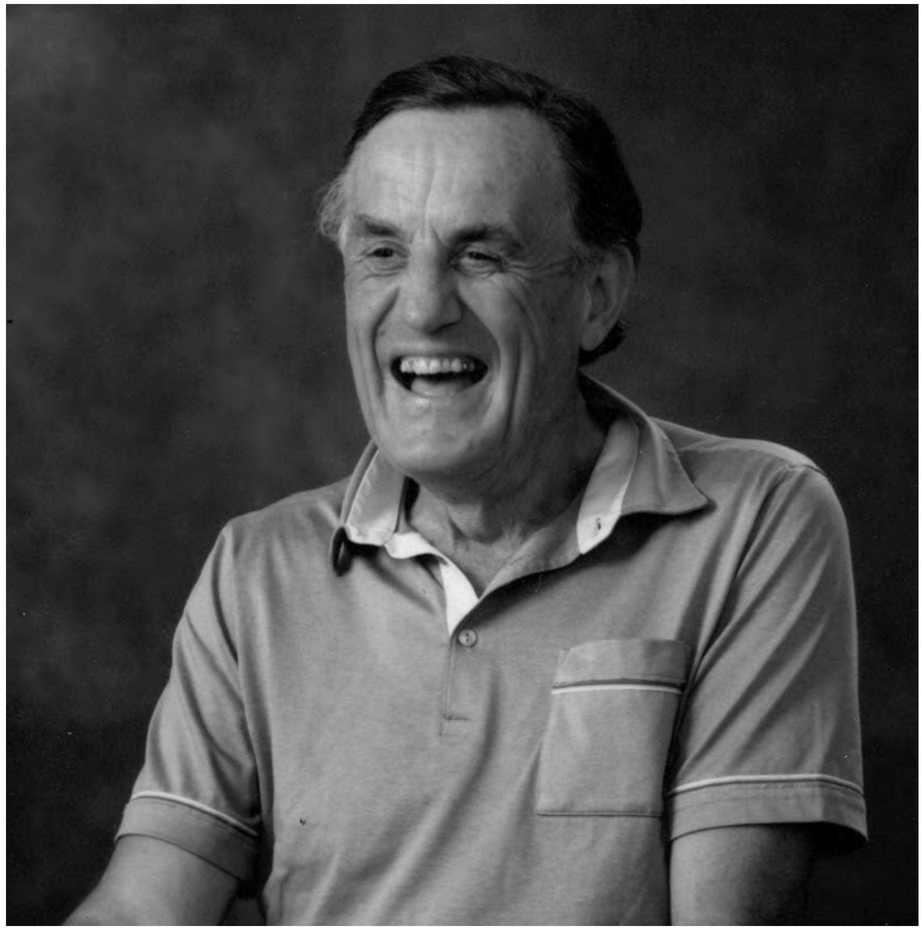
SAD NEWS

On November 29, 2002, Edris Abbie (Edie) Attwood, the mother of Past National President Randy Attwood, passed away after a short illness. Some people may not know that Mrs. Attwood used to do the Calligraphy work on the RASC service and membership certificates. We all feel your sorrow Randy, and our prayers and sympathies are with you and your family at this time.



Obituary
Nécrologie

Robert Hanbury Brown (1916–2002)



Robert Hanbury Brown (1916–2002)

Robert Hanbury Brown, elected an honorary member of our Society in 1987, died on January 16, 2002 in his 86th year. Born on August 31, 1916 in India, Hanbury was educated in England, studying electrical engineering at Brighton Technical College and then at the City and Guilds College (part of the Imperial College of Science and Technology in the University of London). There, in the years just before the Second World War, he was a keen member of the University of London Air Squadron. The combination of his knowledge of electronics and interest in flying attracted the attention of Sir Henry Tizard (then the Rector of Imperial College) and led to Hanbury being referred to the very secret group led by Robert Watson-Watt that was developing radar. Work on radar was to occupy him, in one way or another, throughout the war years; it was, of course, a major factor in the winning of the Battle of Britain and also important in the subsequent struggle against U-boats in the Atlantic Ocean and the North Sea. Hanbury's own unassuming, and amusing, account of these years can be found in his partial autobiography *Boffin*.

The word "boffin", or at least its precise significance, may be unfamiliar to many Canadian readers, although it passed into common currency in Britain in the early post-war years, as a term for scientists engaged in back-room research, primarily for the military. The word appears to have been coined by a senior RAF officer with whom Hanbury worked, while Watson-Watt considered Hanbury Brown himself to be the prototypical boffin.

After the end of the War, Hanbury was one of a small group who worked with Watson-Watt in a company of research consultants, but he left that company in 1949, when Watson-Watt decided to move to Canada, and went to the Jodrell Bank Experimental Station of the University of Manchester to work with Bernard Lovell in the newly emerging science of radio astronomy. At that time, radio astronomers were mostly concerned with studying radar echoes from meteors (they discovered many previously unknown daylight meteor showers) and optical astronomers were only slowly realizing the potential of this new method of observation. Hanbury, however, soon became interested in what were then known as "radio stars." At that time, only a few such radio sources had been detected and we now know, of course, that the overwhelming majority are not stars at all but extra-galactic objects. Also, radio astronomers did not have at their disposal anything like the resolving power that optical astronomers had, with the result that positions were not accurately known and we were completely ignorant of the angular diameters of these radio sources. Hanbury set himself the problem of measuring angular diameters and this necessarily involved using some form of interferometry.

If radio stars really were stars, their angular diameters would be so small that baselines of thousands of kilometres would be needed to measure them. Although interferometric measurements on such baselines are now routine (having been first successfully made in Canada in 1967), the problems of correlating phase or amplitude as observed from two such widely separated stations appeared insoluble in the 1940s and 1950s. Hanbury drew on his wartime experience with radar and suggested, instead, correlating measurements of the variations in intensity at the two different stations. He teamed up with Richard Twiss to work out the detailed mathematics and physics of the proposed intensity interferometer and his group at Jodrell Bank succeeded in 1952 in measuring the angular diameters of the radio sources Cassiopeia A and Cygnus A. As it turned out, these sources were both within our Galaxy and large enough for their diameters to be measured by conventional interferometry: similar results were obtained about the same time by Bernard Mills in Australia and Graham Smith in Cambridge.

The intensity interferometer was not sensitive enough to be used on many more of the then known radio sources, but Hanbury Brown and Twiss thought of applying the same technique in visible light, to measure the angular diameters of ordinary stars — something that had previously been done only by conventional interferometry, on the Mount Wilson 2.5-m telescope, for half a dozen supergiant stars. It may seem obvious that a technique that worked with radio waves should be applicable to light waves, but the proposal proved not only difficult to work out but also highly controversial amongst workers in physical optics, who had become used to thinking in terms of photons rather than waves. The intensity interferometer implied that there must be a correlation between the arrival of photons at two widely separated detectors, and this was something that workers in optics were very unwilling to accept.

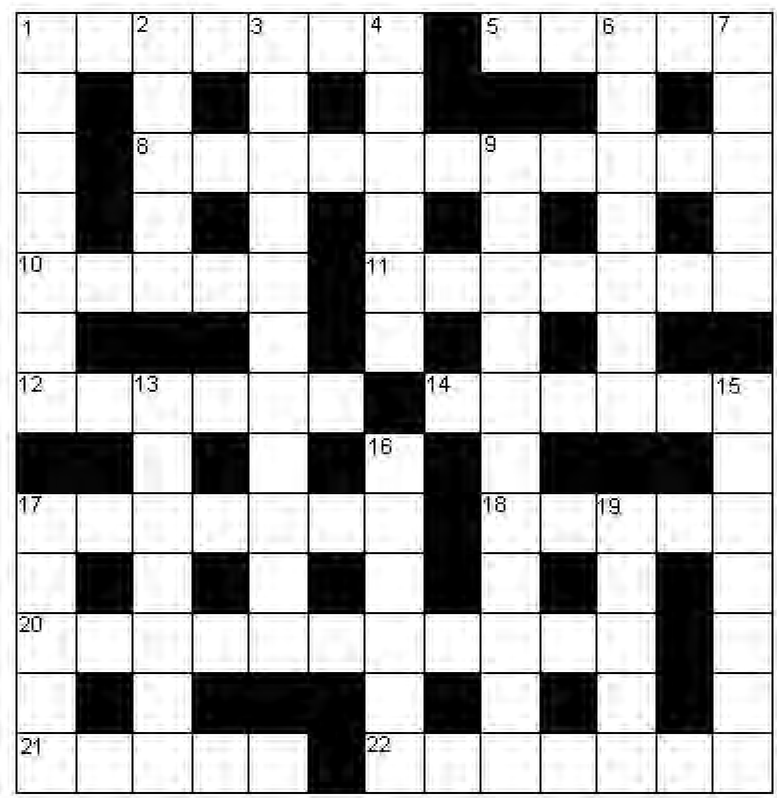
Hanbury Brown was working on this new concept when I went to Manchester as a graduate student in 1955. Our paths did not often cross then, although the few times we met were to prepare the ground for what later became one of my most significant friendships. As is now well-known, Hanbury Brown and Twiss succeeded, after many financial and practical difficulties, in building an intensity interferometer in Narrabri, Australia, and with it they measured the angular diameters of 32 stars. The results were submitted for publication in 1973 and appeared the following year. While the number of stars may seem small, it increased the number of known angular diameters by a factor of about six. The results included the first measurements of the angular diameters of main-sequence stars and made a major contribution to our knowledge of the stellar temperature scale. The spectroscopic binary Spica was also observed and the combination of the orbit thus obtained for it in the plane of the sky with the spectroscopic orbit enabled a very accurate value for the parallax of the system to be deduced. Almost incidentally, Hanbury Brown and Twiss had sparked completely new developments in quantum optics.

My wife and I often remember an evening spent with Hanbury Brown and Twiss, in 1970, in a small restaurant some distance outside Rome, which enjoyed (if that is the right word) the reputation of having been one of Mussolini's favourites. For my wife, as the only woman and the only non-astronomer in the group, the evening might well have been rather bleak, if Hanbury had not made it his business to keep her in the conversation. Our paths continued to cross from time to time at IAU meetings. In 1984, I organized an IAU symposium (again in Italy) on "Calibration of Fundamental Stellar Quantities." Hanbury, then President of the IAU, was an obvious choice for invited speaker. To my utter astonishment, during that symposium he invited me to become a Vice-President of the IAU; it is during those years while we were together on the Union Executive that I really got to know him and to enjoy his wonderful sense of humour — which, I am told, he did not lose even when he knew he was dying. By the mid-1980s he was retired and eventually returned from Australia to Britain. He began writing reflective books, of which *Boffin* was only one. Apart from the Presidency of the IAU, his honours included election to the Royal Society of London, appointment as a Companion of the Order of Australia, and an Honourary Fellowship of the Indian Academy of Science. He is survived by Heather, his wife of fifty years, their three children, and their grandchildren — for one of whom he completed his last book, shortly before his death.

A.H. Batten.

Astrocryptic

by Curt Nason, Moncton Centre



ACROSS

1. Halton Arp's oil mistaken for a beacon of the second magnitude (7)
5. Jupiter leads cars around the initial magazine on your lap top (5x1)
8. Chinese plan deviates in the near infrared H spectrum (7,4)
10. Microwave outburst detected in Gamma Serpentis region (5)
11. Our red motion around north is more circular (7)
12. Velocity measurement read from the right ascension dial (6)
14. The east meant nothing, nothing to Trudeau and to his head (6)
17. Calculus only half completed before I view Ursa Major's F-star component (7)
18. Southern constellation appearing in Canis Minor, maybe (5)
20. Broken china stored stony meteorites (11)
21. Computer follows the 'Net back a distance for absolute magnitude (3,2)
22. No May flowers from these, only Raid spray within (*var.*) (7)

DOWN

1. Father look to mother right by the telescope mountain (7)
2. Irregular pulse detected at Orion's feet (5)
3. Somehow, SETI overran its booked room (11)
4. Herpes gets around the globe (6)
6. Corona Borealis was at her head near 1 AD or so (7)
7. Race around London's capital in search of a sky clock (5)
9. Turn a stone around to the right to make extremely dense object (7,4)
13. Mammal leaping from Job's Coffin (7)
15. This surrounds a red spot initially on the volcanic ridge (7)
16. Twist lumbar hernia into an eclipse (6)
17. Gregorian's fame earned award for Bishop (5)
19. Meson pioneer also made drinks with Martini (5)

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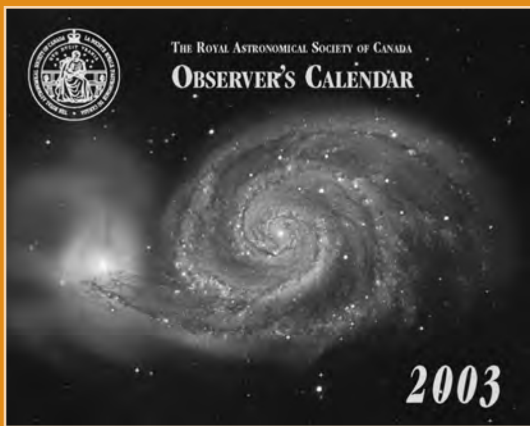
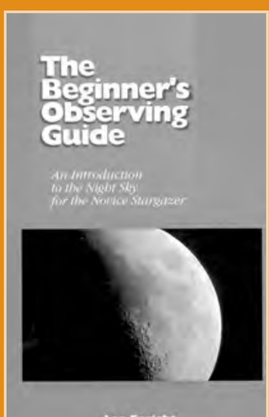


Observer's Calendar — 2003

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

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

Price: $15.95 (members); $17.95 (non-members)
(includes postage and handling; add GST for Canadian orders)



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.

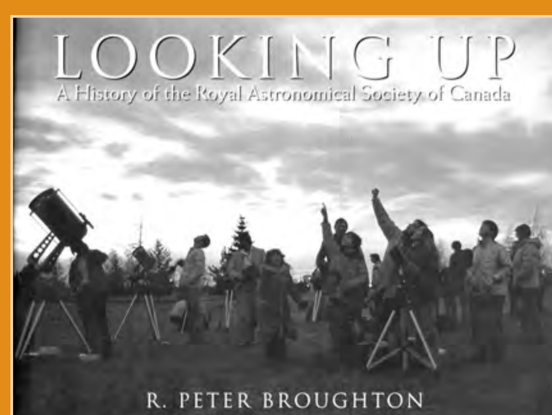
Written by Leo Enright (160 pages of information in a soft-cover book with otabinding that allows the book to lie flat).

Price: $15 (includes taxes, postage and handling)

Looking Up:
A History of the Royal Astronomical Society of Canada

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

Price: $43 (includes taxes, postage and handling)



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