October/octobre 1998 Volume/volume 92 Number/numero 5 [673]

Journal

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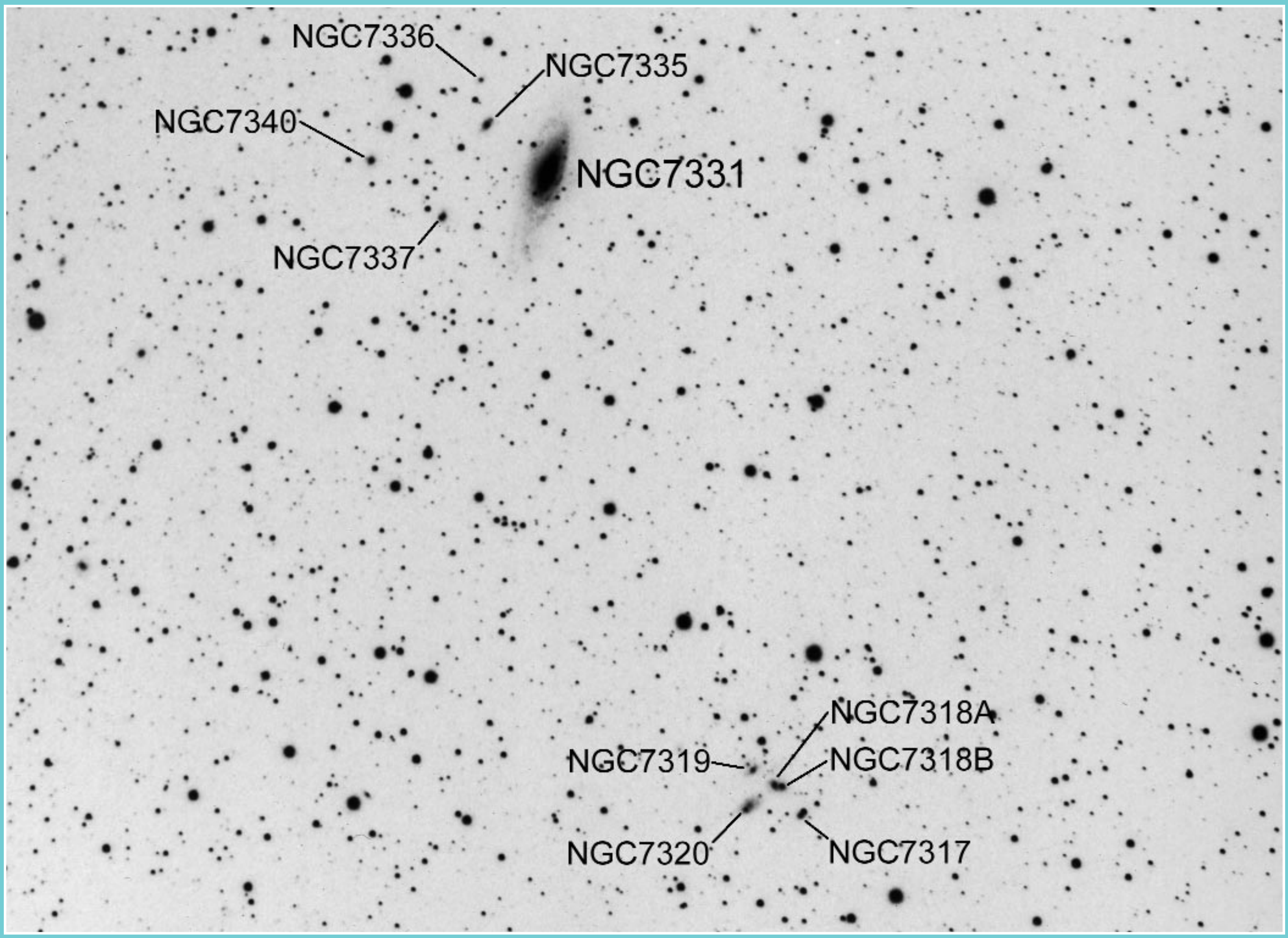

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Astronomy Day · Observing Galaxies

October/octobre 1998

Journal

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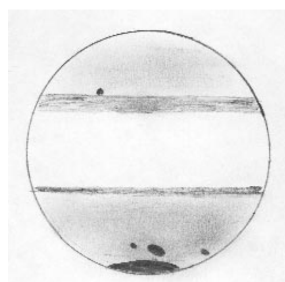

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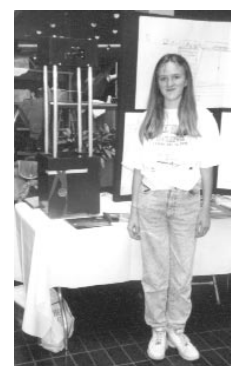

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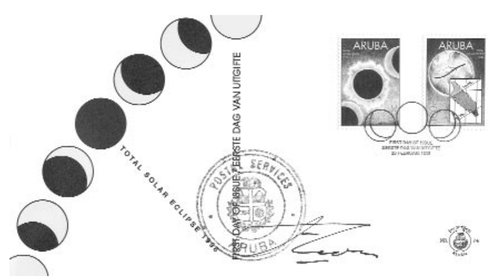

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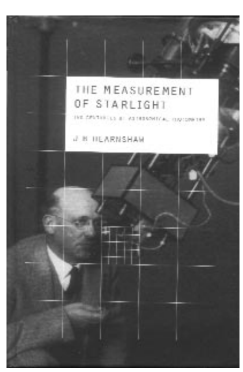

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Image of NGC7331 in the region known as Stephan's Quintet in Pegasus.

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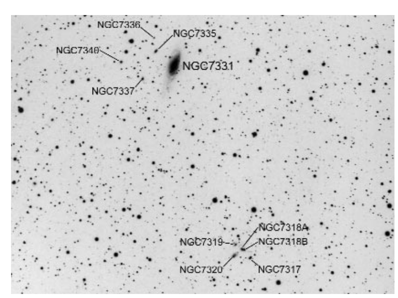
(Image by Rajiv Gupta)



From the Editor

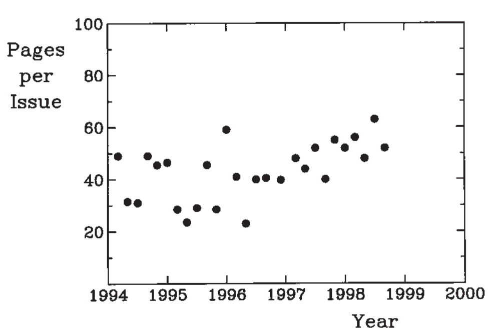
by David Turner

During the past two years, those of us who have been involved with the editing and production of the *Journal* have generally considered it to be a "work in progress." It should be evident from the chart below, however, that it is also a *growing* "work in progress." Plotted here is the number of equivalent standard-sized pages ($8\frac{1}{2} \times 11$ inch) published per single issue of the *Journal* (and *Bulletin*, prior to 1997) as a function of time for the period in which I have been editor. The point sitting well above the others at the end of 1995 corresponds to the publication of the trial issue of *Astronomy Canada*, for which the collection of material covered a longer-than-average time interval than is the case for standard issues. It is therefore a discrete anomaly.

A number of changes have taken place since the inception of the new *Journal* in 1997, and they are partly responsible for the growth in pages published. Noteworthy is the introduction of regular columns as well as a variety of new or modified features, but there has also been an accompanying growth in the diversity and amount of material submitted for publication. Current trends indicate a steady growth in publication during the past two years, although, given the genuine constraints on manpower and spare time that exist, it seems unlikely that the such a trend can continue indefinitely.

Coincident with the growth in the number of pages published in the *Journal* is a growth in the amount of volunteer effort required to produce it. The original plan for a paid production manager to do most of the editorial work has never been fully realized. While production is presently done by our publisher, Redgull Integrated Design, the bulk of the editorial functions continue to be done by unpaid volunteers in their spare time. If editorial correspondence is any indicator, this point is not well-known to *Journal* readers.

It is a pleasure to acknowledge the many persons who have stepped forward, or in some cases redoubled their efforts, to volunteer their time along with that of the editorial staff to work on the *Journal*. The production group currently comprises a number of sub-editors, proof-readers, columnists, and assistants, in addition to the three Halifax-based members of the editorial team. Without them the trend evident in the graph would have already taken a heavy toll on the latter in terms of mental and physical burnout.



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 one of the addresses given below.

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 1998, $36.00; life membership is $720. 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:

The Royal Astronomical Society of Canada
136 Dupont Street
Toronto, Ontario, M5R 1V2, Canada
Internet: rasc@rasc.ca
Website: www.rasc.ca
Telephone: (416) 924-7973
Fax: (416) 924-2911

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President's Corner

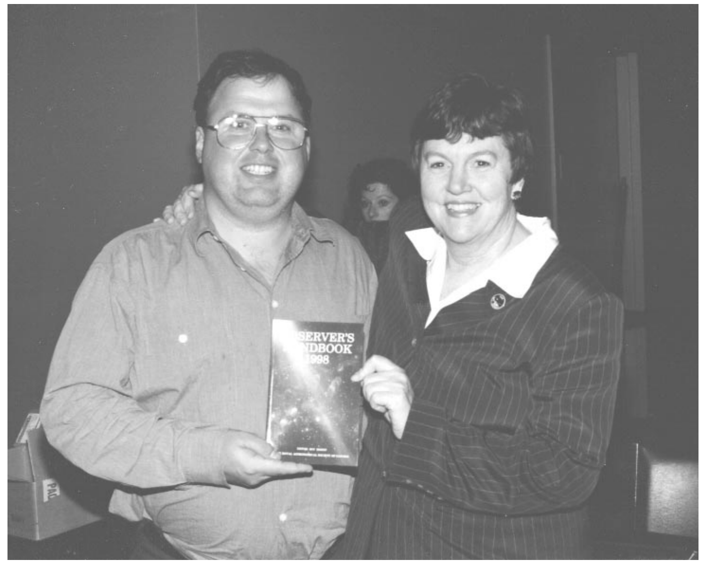
by Randy Attwood (attwood@istar.ca)

The cool, longer, and hopefully clear nights of autumn have arrived. With Jupiter and Saturn in position for early evening observing, it is a perfect opportunity to spend time in the backyard with telescopes and binoculars. Since the Sun is becoming more active, perhaps there will be some spectacular aurora displays as well.

I wish to pass on my thanks and appreciation to the organizers of the Victoria General Assembly that was held in June. Bill Almond and the Victoria Centre volunteers hosted an extremely enjoyable weekend filled with both observational and armchair astronomy.

The 1999 General Assembly will take place July 1–4, 1999, in Toronto as part of a seven-day (July 1–7) astronomy conference called Partners in Astronomy. Sponsored by the RASC, the Astronomical Society of the Pacific (ASP), and the American Association of Variable Star Observers (AAVSO), it will be one of the largest and most diverse astronomy conferences ever held in Canada. There will be scientific paper sessions sponsored by the RASC and ASP, a Teachers' Workshop, Universe '99 (a festival of presentations and exhibits for the general public), a series of presentations on the history of astronomy, and much, much more. The Partners in Astronomy sessions will examine the unique relationship that exists between professional and amateur astronomers. The science of astronomy benefits from the enormous contributions made by amateur astronomers. In fact, many amateur astronomers have access to equipment that produces results comparable to or exceeding that of professional institutions. The goal of the symposium is to encourage effective partnerships between amateur and professional astronomers. Look for more information on the 1999 General Assembly in future issues of the *Journal*.

I am pleased to report that a new project to put the first Canadian astronomical satellite into low-Earth orbit has been approved by the Canadian Space Agency. Scheduled for launch in 2001, the satellite is referred to as MOST, for Microvariability and Oscillations of STars. The mission objective is to do precision photometry from space involving the study of the luminosity variability of stars with time. The project should be a major improvement over stellar photometry that can be done from Earth because of the ability of a telescope in space to track target stars for weeks at a time without interruption. The RASC has been selected as a partner in this historic venture. Two years ago Project Manager Kieran Carroll of Dynacon approached me to express his interest in including the RASC as a partner in the project. It is intended that the RASC will contribute to the public outreach portion of the project, but at the moment our role is yet to be finalized. One option would be for us to organize and run a contest related to the satellite. In any event, RASC members will be able to follow the development, flight,



On to Mars! National President J. Randy Attwood presents a copy of the Observer's Handbook to Donna Shirley, Jet Propulsion Laboratory Mars Exploration Manager, in Toronto last July.

and results of the project in the pages of the *Journal*. I believe that the RASC is an excellent choice to be involved in Canada's first astronomical satellite, and I invite comments and suggestions from members as to how we can best participate.

For most members the coming of autumn means it is time to renew membership in the Society. If you have not renewed, please do so right away. The *1999 Observer's Handbook* should be mailed to all renewed members in late October. Also, if you have any problems with your membership, please contact the University of Toronto Press Journals Department. (The telephone number and E-mail address are printed on your renewal form.)

One of my projects over the next few months is to promote the *Observer's Handbook*. This indispensable guide, first published by the RASC in 1907, is a first-rate handbook, although many long-time members of the Society may take the *Observer's Handbook* for granted. Most members of the Society, unless they actually contribute to its production, have little idea how much work goes into producing the *Observer's Handbook* every year. The Editor, Dr. Roy Bishop, and the 35 contributors (see the inside front cover) are to be congratulated and thanked for volunteering their time and skills in the production of this excellent handbook.

The *Observer's Handbook* does very well in comparison with similar publications. According to the December 1997 issue of *Sky & Telescope* (page 74), such a comparison shows that in many areas, specifically in content and organization, the *Observer's Handbook* comes out on top. I hope to publicize the *Observer's Handbook* further and to tell the astronomical and space community more about it. I recently gave a copy of the *Observer's Handbook* to Donna Shirley of the Jet Propulsion Laboratory (JPL). She was the manager of NASA's Mars Exploration Program, and was the original leader of the team that built the successful Mars Rover *Pathfinder*. I hope that her copy of the *Handbook* finds its way onto the Mars Exploration bookshelf at JPL. Sales of the *Observer's Handbook* are very important for the financial health of the Society. According to the revenue sheet on page 7 of the 1997 Annual Report, it accounts for a large percentage of our annual income.

The next meeting of National Council is scheduled for November 7 and 8 in Montreal. National Council has been invited by the Montreal Centre to hold the meeting at the Montreal Planetarium. Council members will have an opportunity to attend a planetarium show and visit the Montreal Centre's Observatory. Canadian astronaut Bjarni Tryggvason has also been invited to attend and to present to the Society the RASC patch he took into space on the Space Shuttle *Discovery* last year.

Finally, I have a challenge for all members of the Society who have been unable to finish observations for the Messier Certificate. Like many of you, I fall into that category. My observing log indicates that the first "official" observation I made in pursuit of the Messier Certificate was in 1982. Since I live just a few kilometres from Toronto's Pearson Airport, the fainter Messier objects are not accessible from my backyard. My list is 60% complete — I was hoping to get most of it done over the summer, but the weather never co-operated when I was at a dark sky site. The challenge is to get out and complete the list within the next year. I hope that other members can join me in completing their Messier lists by December 31, 1999. I will keep you informed of my own progress.

Clear skies and good Messier Observing!

Correspondence
Correspondance

ARE THESE OPHIUCHIDS?

Dear Sir,

The accompanying fixed-tripod photo was taken about 300 metres from the brightly lit ferry dock at North Head on Grand Manan Island, New Brunswick, at approximately $04^h\ 15^m$, 29 June, 1998 UT. It was taken with a 50-mm lens at f/2 on Fujicolor exposed for 15 seconds at 2400 ISO. In this view towards the centre of the Galaxy, many ragged dark nebulae and at least five Messier objects are clearly seen. Two meteors appear to radiate from $\alpha = 17^h\ 02^m$, $\delta = -7°20'$ (J2000.0) and may be part of the Ophiuchid shower described in the British Astronomical Association Handbook as lasting from May 19 to July and showing weak activity from several radiants in this vicinity.

Peter Broughton (ac372@torfree.net)
Toronto Centre

1999 ECLIPSE VIEWING IN ROMANIA

Dear RASC Members,

I am a member of the RASC Toronto Centre, a permanent resident of Canada, and a former astronomer from Bucharest, Romania. In the last ten years I have collaborated with Romanian amateurs and professionals and helped to organize astronomy camps and public outreach programs. This message is to introduce you to "The Total Solar Eclipse on 11 August, 1999, in Romania," which is, as you probably know, the last total solar eclipse of the millennium and the most accessible over the next twenty years.

The Romanian Astronomical Society of Meteor Observers, the Bucharest Astroclub, the Astronomical Institute of the Romanian Academy, and "Amiral Vasile Urseanu" Astronomical Observatory are together organizing an international astro-tourist project to attend the eclipse from the best place to be seen: Romania. We would be pleased if (members of) your organization would be interested in participating in our project. More information can be obtained from the following web site: www.ipgnet.com/~ovidiu/eclipsa.htm.

Dr. Ovidiu Vaduvescu (ovidiu@ipgnet.com or vaduves@roastro.astro.ro)
Toronto Centre

News Notes
En Manchettes

THE NEXT GIANT RADIO TELESCOPE

In an attempt to see further and with ever increasing clarity, astronomers are preparing for the next huge leap in ground-based radio astronomy. The grand proposal is to build a radio telescope with a collecting area equivalent to no less than a full square kilometre. So far, institutions from Australia, Canada, China, India, the Netherlands, and the United States have signed an agreement to co-operate and at the same time compete for the final design of the telescope. The ideas range from a massive Arecibo-like single dish, proposed by the Chinese, to a Dutch design with thousands of stationary flat panels steered through phase array electronics.

Canada's entry into the competition is known as the Large Adaptive Reflector (LAR), the design of which is being directed through the Herzberg Institute of Astrophysics of Canada's National Research Council (NRC). The Canadian design envisions the construction of a long focal length parabolic reflector made of thousands of flat steerable 8-metre panels. The most unusual aspect of the design is the receiver. Since the reflector's focal length is between one and two kilometres, a solid structure is out of the question. Engineers and scientists at NRC have proposed using a triple-tethered aerostat (a helium-filled balloon tied down on three sides).

Between July 19 and 22, astronomers from ten countries met in the foothills of the Rocky Mountains near Calgary to discuss the scientific potential of such a gigantic antenna. Dr. Avery Meiskin of the Institute for Astronomy of the University of Edinburgh talked about one of the most important capabilities of the telescope. Meiskin said the huge collecting area would be able to probe the region of time before the formation of galaxies. Called the Dark Age, that epoch is before the era of galaxy formation seen by the Hubble Deep Field image and after the anisotropies in the cosmic background radiation observed by the *Cosmic Background Explorer* (COBE) satellite. According to Meiskin, observing the conditions inside the Dark Age is crucial to our understanding of how galaxies were born.

Jeremy Lim of the Academia Sinica Institute of Astronomy & Astrophysics in Nanking China proposed that the telescope would be ideally suited to examine the inner dynamics of quasars by observing the violent tidal disruptions of H I regions as they spiral towards the central engine. Lim also suggested that the telescope could be pointed at nearby red giant and supergiant stars. Its enormous aperture would be able to resolve coarse surface features on such stars as Betelgeuse.

Russell O. Redman of the Herzberg Institute of Astrophysics proposed that the instrument could be turned into a giant radar antenna in order to study the surface of asteroids and the orbits of small asteroid moonlets like Dactyl.

More in-depth information on the conference can be found at the Web sites www.ras.ucalgary.ca/SKA/meeting.html and www.drao.nrc.ca/web/ska/ska.html.

CANADIAN CITIES WERE TARGETS FOR CANCELLED ORBITING SOLAR REFLECTOR

On July 27 dark sky advocates around the world breathed a collective sigh of relief. The proposed test of the *Znamya-2.5* orbiting solar reflector and solar sail was cancelled as a result of a lack of funding.

Following construction by the Space Regatta Consortium (SRC) and led by Rocket Space Corporation Energia (RSC Energia), the idea was to place a 25-metre Kevlar fabric mirror into low Earth orbit to reflect solar light onto northern cities and towns during the dark winter nights. If successful, the fully operational stage of the project could have seen clusters of 200-metre reflectors illuminating the streets of northern towns with the combined brilliance of 10 to 100 lunettes (one lunette is equal to the light of the Full Moon). The motivation for the project appears to have been to provide cheaper alternatives to outdoor electric lighting.

If the *Znamya-2.5* test project got the go-ahead and deployment was successful, the Russians planned to light up the night sky over some of Canada's most populated centres. Vancouver, Calgary, Regina, Winnipeg, Quebec City and St. John's could have seen the satellite briefly light up with the intensity of 5 to 10 lunettes during the early morning hours of November 9, 1998.

More information on the project can be obtained from the Web site www.energialtd.com/znamya.htm.

CANADIAN ASTRONOMER VISITS INDIAN RADIO OBSERVATORY

Near the tiny village of Khodad some 150 km east of Mumbai (formerly Bombay), India's most ambitious astronomy project, the Giant Metre-Wave Radio Telescope (GMRT) is nearing completion. Queen's University radio astronomer Judith Irwin is attending its birth. From headquarters in the city of Pune (pronounced Poon-eh) 80 km to the south, it is a bumpy, 2-hour drive to the GMRT site. The landscape along the route has been transformed by the monsoon from barren yellow to lush green, reports Dr. Irwin. She also notes the contrast between ancient crowded villages with men wearing orange turbans and women in brightly coloured saris carrying heavy loads on their heads and the modern, 30-antenna array of the GMRT itself. Each parabolic antenna is 45-m in diameter, and fourteen are clustered in a central square near the control building, with the others stretched out over 25 km in a "Y" configuration. It is modeled after the Very Large Array (VLA) radio telescope in New Mexico, but the GMRT is designed to operate at relatively long radio wavelengths from 20 cm to 2 m (1500 MHz to 150 MHz). That has allowed each GMRT antenna to be built from open steel-mesh rather than requiring the careful machining of completely filled dishes needed for shorter wavelength work. With labour and other costs in India not expensive, the design has proved ideal for a developing country. India also has expertise in radio astronomy, having designed and operated a radio telescope at the Hill Station of Ooty in the southern state of Tamil Nadu since 1965.

While the GMRT is designed to address a variety of astronomical questions, there are some specific scientific objectives. The search for highly redshifted spectral lines from neutral hydrogen (H I) is one. Emission that is highly redshifted

must have been emitted at very early epochs when the universe was only a fraction of its current age. Since galaxies are believed to form out of H I clouds, detecting such emission could provide a new and unique probe for studying galaxy formation and conditions in the early universe. The study of general relativity through timing observations of pulsars, and even the search for extra-terrestrial intelligence are other scientific motivators for the project.

To date, only eight antennas have been linked, but already maps have been made of the Galactic Centre, nearby galaxies and quasars, and the first scientific paper based solely on GMRT results has been submitted. Dr. Irwin has been testing the newly installed 21 cm system by observing sources for which she has previous VLA data, for comparison. That will lead to more extensive GMRT observations of large scale radio halos and gas outflows from galaxies, which the GMRT is well-suited to detecting. On July 30, 1998, the final link in the system, the 30-station correlator, was shipped to the site to allow all 30 antennas to be connected and the full power of the telescope to be realized. Dr. Irwin hopes to work on high redshift H I observations later in her one-year stay in India, but meanwhile has been busy writing the GMRT User's Guide. Ultimately, she reports, with more than three times the collecting area of the VLA, the GMRT is poised to take the lead in low frequency radio astronomy observations well into the next century.

OUT-ICARUSING ICARUS?

While most asteroid searches concentrate on the region opposite the Sun in the sky, where asteroids are seen at full phase and thus are brightest, University of Hawaii astronomers recently pointed their telescopes in a more sunward direction and were amply rewarded. Observations made in late February by David Tholen and co-workers netted 1998 DK36, the only discovered object in the solar system with a mean distance from the Sun less than that of Earth (or in fact of Venus). The highly eccentric orbit takes the new asteroid from just outside the orbital distance of Mercury to just inside the Earth's orbit every 212 days. The inclination of the orbit is small, only about 2 degrees, which keeps it very near the ecliptic. Only a few consecutive nights of positions were obtained near the time of discovery, making the orbital information needed for attempts to re-observe the object somewhat uncertain. According to David Balam at the University of Victoria, there were no Canadian observations taken near the time of discovery, and in fact the only observations were from Hawaii. This particular object does not seem well-suited to observation from Canada, but there may exist other sunward asteroids of higher orbital inclination that might be. Only time will tell.

(4843) MÉGANTIC = 1990 DR4

Discovered 1990 February 28 by H. Debehogne at the European Southern Observatory.

Named for Mont Mégantic, the largest observatory in Québec. Founded in 1978, its mission is to promote research in astrophysics, to train students, and to promote astronomy in the local culture. The observatory is jointly operated by the Université de Montréal and the Université Laval. Name proposed by the discoverer, following a suggestion by P. Bastien and Y. Dutil.

ERRATUM AND ADDENDUM

In the *Research Paper* "A Search for the Parent Cluster of the Cepheid SU Cygni" by D. G. Turner, M. A. Ibrahimov, G. I. Mandushev, L. N. Berdnikov, and A. J. Horsford, published in the June 1998 issue (JRASC, 92, 145–152, 1998), the 1950.0 co-ordinates for the anonymous cluster studied in the paper were erroneously given as $19^h\ 40^m$, +29° 20´, when they are actually $19^h\ 41^m.6$, +29° 07´. It should also be noted that the field of study lies in the southern portion of Luminosity Function region 2 in Cygnus (LF 2), one of several Milky Way fields studied by McCuskey and co-workers in the early 1950s. Twelve of the stars in Table I and all of the stars in Table II therefore have objective-prism spectral classifications, many of which are classified two-dimensionally, that are included in a paper by McCuskey, S. W. & Seyfert, C. K. 1950, ApJ, 112, 90. The overlooked observational data supplement the available information for stars in the field, but do not affect the conclusions of the study. We are grateful to Brian Skiff for pointing out both of the above.

Eclipse Philately: Aruba 1998

by David K. Foot, Toronto Centre (david@footwork.com)

Philately is best described as collecting postage stamps and related material. The past two decades have witnessed a tremendous growth of interest in an area of philately now called "postal history." This field primarily involves the collection of intact envelopes, often called *covers,* with all stamps and postal markings attached. They may be studied to reveal the routes traversed from origin to destination and to confirm the amount of postage (or rates) required. They can also document other important information, including special events such as inaugurations, celebrations, centennials, victories, first flights, and even astronomical events.

Perhaps the most recognized of covers is the *first day cover* that records the first day of issue of a stamp or a set of stamps issued on the same day. Often there is an illustration, usually on the left side of the envelope, that draws attention to the event, and a postmark that records the important date. Any cover correctly postmarked on the first day of issue is strictly a first day cover. The illustration, or *cachet* as it is called in philately, is used to "advertise" the fact. Postmarks and cachets, however, may be used to draw attention to any special event (even one for which no special stamp was issued) and they are often referred to as commemorative or souvenir covers.

There are many events of interest to the astronomy enthusiast, such as the dates of birth and death of important astronomers, discoveries, expeditions, and relevant locations such as an observatory, but perhaps the most magical astronomical event is a total eclipse of the Sun. Occasionally a country will recognize such an event with a special stamp issue or a special postmark, or both. Even if that does not happen, it is possible to create a souvenir cover that records the event with an appropriate postmark, preferably from a location within the band of totality. Eclipse philately conveniently describes the esoteric overlap between the philatelist and the eclipse-chasing astronomer. This year was an eclipse philatelist's dream: a perfect total solar eclipse on a Caribbean island in the middle of the northern winter (February 26) on a weekday (Thursday) when post offices are open in a country that issues not one but two stamps to commemorate the event. The heavens opened up twice!

My trip to the 1998 eclipse was booked many, many months in advance. Not wishing to observe from a floating observing site, I decided to pass on the Galapagos and the cruise ship tours and to observe from one of the islands in the Caribbean, where a post office would likely be nearby. That ruled out Colombia, Panama and Venezuela, but left me with a choice of Aruba, Curaçao, Antigua, Montserrat or Guadaloupe, all of which lay in the path of totality, but not necessarily on the centre line. I made my decision — I chose Montserrat. Having visited Montserrat previously, I had found the residents to be most friendly. In addition, I knew of a perfect locally-owned hotel that would provide a wonderful viewing site with the added advantage of a volcano in the background for my wide angle photos.

How was I to know that the Soufriere volcano would erupt? When I heard that the airport was closed, I became concerned and called the hotel. They assured me that they were still open, but that they would be willing to return my deposit if I requested. A subsequent eruption that destroyed the capital, Plymouth, put an end to my eclipse plans on Montserrat. So I joined the "last minuters" in tracking down an appropriate tour that would meet my needs.

After quick consideration, I chose Aruba. While not on the centre line, the duration of totality would be over three minutes on most of the island, and weather prospects were outstanding. My friend (and weather expert) Jay Anderson would be nearby on a cruise ship between Aruba and Curaçao, and his *NASA Bulletin* co-author, Fred Espenak, was planning to leave his cruise ship in Aruba in order to do his eclipse observing. If it was good enough for the experts, it was good enough for me. My tour reservations were made.

I began to keep my eyes open for news of stamp issues related to the eclipse. I was not disappointed. In early February, U.S.-based *Linn's Stamp News* noted that "Aruba will salute a solar eclipse on two stamps to be issued February 26." I was thrilled. That called for an extra effort by the eclipse philatelist. Ordinary covers would no longer suffice. A phone call to Jay Anderson resulted in a lively conversation and a package by courier a few days later containing a number of specially-designed envelopes that had a colourful computer generated cachet on the left side showing a map of the path of totality and brief eclipse details (see figure 2). The format is typical of philatelists' first day and souvenir covers. Now it was up to me to get both a first day of issue and an eclipse souvenir cover in one.

Our group arrived on Aruba on Monday. The next day I was off to the main post office in the capital of Oranjestad to

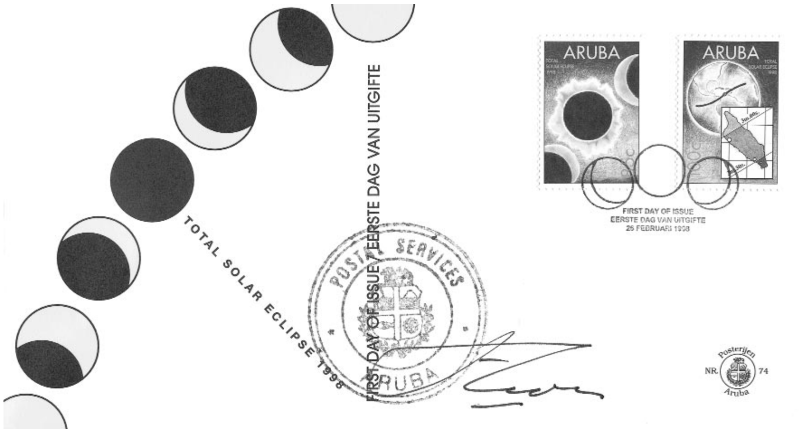


Figure 1

employees time to observe the celestial event. (The eclipse was to start at 12:38 p.m. local time with totality around 2:10 p.m.) That is crucial information for the eclipse philatelist. Never assume that the post office will be open for normal hours on eclipse day!

Eclipse day arrived. I caught the 7:00 a.m. local bus outside my hotel and arrived at the post office in Oranjestad just after opening time. There was already a line, so I had to be patient. What appeared to be a "local," who had pre-ordered like me, jumped the queue, which did not please me until I realized that it resulted in the appearance of the pre-order forms, including mine, which meant that my arrival at the counter went smoothly. Then it was off to a quiet place — an unused counter in the post office — to make up my covers. Sticking stamps neatly on envelopes can be a time consuming task especially when under pressure to get finished well before first contact.

confirm the stamp issue and to inquire about the postmarking of my covers. The philatelic counter, in a small separate room to the right just inside the entrance to the post office, had pictures of the two stamps on display. Denominations were 85 and 100 flg (Dutch florins, the local currency). My heart pounded. The stamps were colourful but not gaudy. The officer on duty offered me a pre-order form. I decided on one-and-a-half sheets or seventy-five stamps and twenty-five first day covers. (I have an increasing cadre of eclipse-chasing friends encouraging me in my offbeat hobby and who also like receiving a souvenir or first day cover.) To my surprise, all transactions on the island, even at a government department like the post office, could be settled in U.S. dollars at an exchange rate of 1.77 flg to the dollar.

Next, it is useful to determine postage costs to various destinations. The U.S. and Canada are obvious destinations for the North American-based eclipse philatelist, but I also would be mailing to Europe and Australia. Postcards to North America and to Australia — the furthest destination — were 60 and 140 flg, respectively, while regular letters were 75 and 175 flg, respectively. Since none of the rates matched the values on the eclipse stamps, I wondered how the denominations were determined, but there was no need to worry; one stamp on postcards and both on letters would overpay the required postage. While the "purist" philatelist would frown on such largesse, eclipse philatelists thrill at the opportunity to use eclipse stamps on their correspondence.

During my visit to the post office and subsequently, I did hear people, often from the cruise ships visiting for one day only, expressing their disappointment that they could not purchase eclipse stamps ahead of time to use on their correspondence. Certainly the issuance of stamps prior to the date of the eclipse would not only increase their use, but would enable the eclipse philatelist to prepare souvenir covers in advance without the anxiety of trying to do it all on eclipse day without missing any of the main event.

Before departing the post office, I "discovered" that it would not be open for normal hours (8:00 a.m. to 12:00 noon and 2:00 p.m. to 4:00 p.m.) on eclipse day, but instead would be open only from 7:30 a.m. until 11:00 a.m. to enable the

I also had postcards and letters to mail, including some official post office first day covers (see figure 1), and a couple of additional tasks to fulfil. First, how would I get my covers postmarked, preferably on a hand-back basis? (In such a process the stamped envelope is cancelled by a postal employee and handed back to the customer rather than being placed into the regular mail stream.) Previously I had been told that I could not use the official first day cancel. While the news was disappointing, it did not particularly surprise me since post offices throughout the world now appear to treat the official

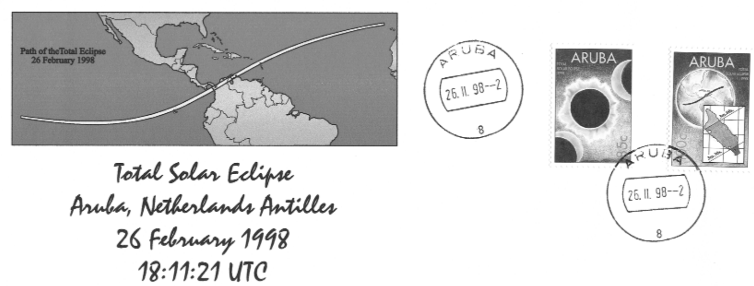


Figure 2

first day cancel as their own and not the public's property. Since resources are often strained on the first day of issue at any post office, I have learned that an offer to postmark your own covers is often accepted, since you are not making demands on overworked personnel. The release of a post office hand cancel to non-post office personnel, however, is often contrary to postal regulations, so it is very important that it be done under strict supervision. I am willing to be "locked up" if necessary, because if I can postmark (or cancel) my own covers, I am more likely to get clear cancellations that are placed on the envelopes where they will look nice. The post office personnel in Oranjestad were very co-operative in that regard, for which I am most grateful. I ended up with exactly what I wanted on my eclipse covers — regular postmarks clearly showing the 26 II 98 eclipse date, which was also an unofficial first day cover for the two eclipse stamps.

Second, could I get the postmaster to autograph a couple of covers for me? That task was not easy because a stamp issue day is often a very busy day, but my request was conveyed and suddenly he appeared and graciously agreed to my request. I have learned that such requests often come with an official stamp of one sort or another, and I was not disappointed in this case (see figure 1). Of course, I thanked him with a gift of one of my non-official first day covers, which, to my surprise, he then wanted me to autograph! I envision it as potential challenge to some future eclipse philatelist who comes across the cover and wonders which famous astronomer's autograph is on it.

Finally, if everything else has gone to plan and time still permits, I have a preference for a couple of registered covers. Registration not only elicits nice labels, but it usually means going to a different post office window, often with a different postmarking device. Unfortunately, registration rules are very strict, and post office employees are often nervous about handing back registered items. The idea of registering an envelope for immediate pickup by the same person is often beyond their comprehension and, therefore, suspect if not impossible. That was almost the case in Oranjestad, however, a sympathetic employee who had watched me carefully prepare my covers for over two hours and who had enjoyed pointing my activities out to other employees, went to bat for me. A heated discussion in papiamento (the local language) took place between her and two presumably and apparently equal senior officials (they each had three stars on their epaulets) — a male who opposed my request and a female who appeared to be arguing on my behalf. They disappeared and then reappeared, with the male appearing to wash his hands of the whole thing. The sympathetic employee then appeared with a registration book, filled out the details and got my signatures, and the covers — duly uprated with an additional stamp to pay the correct registration fee — were mine. I properly thanked the sympathetic employee with the gift of an appropriate pin.

Victory was achieved, but precious time had been lost, so I packed my precious covers in my waist pack, exited the post office quickly, took a photograph for posterity, and hurried back to the bus stop looking for a taxi *en route*. The main road was crowded with eclipse chasers heading to the southeastern end of the island, where totality was the greatest. My hotel was in the opposite direction, so once I got a taxi, it was a good 20-minute drive back to the hotel.

A group of about twenty amateur astronomers had set up their equipment on a quiet part of the sandy beach outside one wing of the hotel. Telescopes and cameras were trained on the Sun, which was in full view. On the other hand, the capital from whence I had come and the southeastern end of the island were covered in thick dark clouds — the eclipse chaser's nemesis. I decided to stay put at the hotel, trading about half a minute of totality for the prospect of clearer skies. It turned out to be the right decision for me. Our group had a perfect view of a wonderful eclipse from first to fourth contact. Other groups further southeast on the island went through many anxious times as clouds came and went. In the end, to everyone's happiness, it seems that all groups on Aruba at least witnessed totality in its entirely. There were many happy (and relieved) faces that evening throughout the island.

Then there was the anxious wait to see if all of my mailed covers arrived at their destinations. For the eclipse philatelist, happiness does not just end with the successful viewing of the total solar eclipse.

As for previous eclipses, my friends also returned the favour for the 1998 eclipse. I now have a few covers from the Galapagos and ship covers posted at Curaçao to add to my collection, together with a wonderful hologram miniature sheet issued by Curaçao, Aruba's sister island on the other side of the centre line for the eclipse. Another advantage of eclipse philately is that it does not have to be limited to the observing location of the eclipse chaser. The eclipse philatelist can enjoy the entire land-based path of totality if he or she has co-operative friends in the right places.

David K. Foot is a Professor of Economics at the University of Toronto, an avid eclipse chaser (ten so far), and a keen philatelist. This is his second article combining his avocations.

Our Changing Views of the Solar Neighbourhood

by Alan H. Batten, Dominion Astrophysical Observatory, Victoria, British Columbia

For most of recorded history human beings thought of the whole universe as the solar neighbourhood or, rather, as the terrestrial neighbourhood. Except for a few independent thinkers, like Aristarchos of Samos around 300 B.C., or Aryabhata in India, about eight centuries later, everyone, until the time of Copernicus and Galileo, accepted the common-sense notions that the Earth is the centre of the universe and that that universe is not inconceivably large. From Ptolemy until modern times, astronomers have thought they knew pretty accurately how large the universe is. Each of the planets — a term that in Ptolemaic times included the Sun and the Moon — moved within a spherical shell. On the assumption that the outer surface of one shell nestled closely inside the inner surface of the next, combined with the erroneous but widely accepted value for the solar parallax of three arcminutes, the distance to the outermost shell of all, the sphere of the fixed stars, could be calculated. Ptolemy estimated it at about 20,000 times the radius of the Earth, with the Sun at a distance of about 1,200 Earth radii. All later work, until that of Copernicus, was only a refinement of Ptolemy's original estimate.

It has been pointed out by Pedersen (1974) that, if we assume Ptolemy knew the correct value for the radius of the Earth — an uncertain assumption, because we do not know the modern equivalent of the *stadium*, the unit of length he used — then the distance to the fixed stars in his system was about 120 million kilometres, less than the modern value of the distance between the Earth and the Sun. In later, Christian, versions of this cosmology, beyond the fixed stars was the Empyrean — the abode of God. This comfortable cosmos could be traversed in reasonable time by human beings, at least with some supernatural aid. When Dante, early in the fourteenth century, wrote his great epic *The Divine Comedy*, which is, among many other things, an account of an imaginary journey through the entire known universe, he took just a week to go from the surface of the Earth, right through its centre out the other side, up a great mountain, and through all the spheres of the planets to the Empyrean — and he stopped to have a number of rather long conversations on the way! Of course we should not interpret Dante too literally; he was a poet and had both artistic and religious reasons for limiting his journey to a week. He knew the Ptolemaic cosmology of his day well, and he knew that his readers would know it also; he could take some artistic liberties but he could not condense his journey into a length of time that would seem too incredibly short to well-informed contemporaries.

Some 350 years later, the English poet John Milton writing *his* cosmic epic, *Paradise Lost*, had to be more careful. Milton, an older contemporary of Isaac Newton, had met Galileo. The first modern attempt to measure the distance of the Sun, which gave a result only about eight per cent too small, was made in the years 1671–3 by J.-D. Cassini, a few years after *Paradise Lost* appeared. Nevertheless, Milton probably knew that the leading astronomers of his day strongly suspected that the universe must be much larger than previously thought, and he wisely refrained from specifying how long Satan took to travel, in what we would call free fall, from Heaven to Hell, saying only that it took him

> *Nine times the space that measures day and night*
> *To mortal men*

to recover from the effects of the journey. Thus, as soon as modern scientific measurements of the universe began to be possible, ideas about the solar neighbourhood and its relation to the rest of the universe began to change, and that change was reflected in the literature of the day.

Early Modern Research

It is against the background of the ideas of Ptolemaic cosmology that we should judge the reluctance of the contemporaries of Copernicus, Kepler, and Galileo to accept the heliocentric theory of the solar system. They had been brought up to believe, with what they thought were good reasons, in a small universe in which the distance of the Sun from the Earth was an appreciable fraction of the distance to the fixed stars. If the Earth was really swinging round the Sun at such a distance, we could not fail to notice changes in the separations of stars, particularly those near the plane of the Earth's orbit, as the Earth first reached its minimum distance from them and then, six months later, receded to its maximum distance. All parties were agreed that the detection of such an effect would prove the heliocentric theory, and all parties, probably, overestimated what the size of that effect would be. It was much too small for Galileo's crude telescopes to measure. The Copernicans hit on the right answer: the stars are so immensely far away that the parallax could not be detected with the instruments of the day, but this was both a revolution in thought and a rather unconvincing *ad hoc* hypothesis. Had I been an early seventeenth-century astronomer, I am not at all sure that I would have been a Copernican.

Newton's *Principia*, published in 1687 several years after the death of Milton, of course largely overcame the resistance to heliocentricism; the dynamic arguments he provided made the empirical detection of what we now refer to as stellar parallax relatively unimportant. To be sure, the detection of parallax remained a great challenge to observers, and the only way to a proper understanding of the nature of the stars. We could not have had modern astrophysics or cosmology if nineteenth-century astronomers had not succeeded in measuring parallax, but, by the time they did, no working astronomer any longer needed to be convinced of the truth of the heliocentric theory.

For Ptolemy, the fixed stars were in a relatively thin spherical shell, all at much the same distance from the Earth. Copernicus himself did not change the concept, but Thomas Digges, writing in the late sixteenth century, saw that in the Copernican system stars could be spread throughout space and that the universe might even be infinite in extent. As astronomers came to accept that the stars might be at very different distances from us, so they came to see that the best way of measuring parallax would be to measure the apparent change of position of a nearby star as seen against the background of more distant ones. How do you select "nearby" and "more distant" stars before you know a single parallax? One way was to substitute for Ptolemy's idea that all stars are at much the same distance the assumption that all stars have much the same brightness. On that assumption, common in the eighteenth century, brighter stars are nearer ones. It was a reasonable guess, but it was wrong. It has a certain statistical validity: among the 20 or so stars regarded as of "first magnitude," four are within 17 light-years of the Sun (α Centauri, both components being counted as one, Sirius, Procyon and Altair — just), and others, such as Vega, are relatively nearby.

Another criterion, which could be used only after telescopic observation had shown that stars had proper motions across the sky, is the size of a star's proper motion. Just as objects near the roadside, when seen from a moving car, appear to whiz past while the more distant scenery appears to move in a stately fashion, so nearby stars appear to move past the Sun more quickly than do distant ones. It is also only a statistical criterion. Unlike most objects seen from a moving car, stars do have velocities of their own, and their apparent motions are not simply a reflection of the Sun's motion. Some stars move faster than others; nevertheless, proper motion is a more reliable criterion than apparent magnitude.

First Measurements of Stellar Parallax

Just about 160 years ago, three astronomers — F. W. Bessel, T. Henderson and F. G. W. Struve — succeeded almost simultaneously in measuring the distance to nearby stars, in a way that convinced their contemporary colleagues that their answers were correct. All of them found parallaxes of less than one arcsecond — less than the angle subtended by a penny viewed from a distance of about four kilometres. The result had been anticipated roughly a century earlier by the English astronomer, Rev. James Bradley, who tried and failed to detect a parallax, but believed that he could have detected it if it had been as large as two arcseconds. Bradley used a different definition of parallax from the modern one, and his two arcseconds would correspond to one, in modern terms.

Bessel was guided by the proper-motion criterion in choosing to measure the two relatively faint components of 61 Cygni. Henderson was lucky in having access to the southern sky, in which α Centauri is both bright and has a large proper motion. Struve placed most weight on apparent brightness and chose to measure the first-magnitude star Vega, mentioned above. That star *is* a relatively near neighbour of the Sun, but Struve had another reason for choosing it, besides its brightness. Vega has a faint optical companion that Struve correctly judged to be much more distant. He thought that the delicate measurements needed to detect parallax could best be made by measuring changes between the relative positions of the companion and Vega itself. Of the three, Henderson picked the closest star; except for its faint companion Proxima, α Centauri is still the closest known star to the Sun, at a distance of over four light-years from us, that is to say about 40 million million kilometres. How such a distance dwarfs the imaginings of Dante and Milton! Yet we are thinking only of the Sun's closest neighbour in space. Now we know that our own Galaxy is tens of thousands of times larger than that, and it is itself lost in the vast and silent immensity that so terrified Pascal in 1669.

The astronomers of 160 years ago were, however, greatly excited by the nearly simultaneous success of their three colleagues. Bessel was judged to have been the first to reach the goal and was duly awarded the Gold Medal of the Royal Astronomical Society, whose President then was Sir John Herschel. His address announcing the award of the Medal caught the mood of the time well (Herschel 1843):

> *I congratulate myself and you that we have lived to see the hitherto impassable barrier to our excursions into the sidereal universe: that barrier against which we have chafed so long and so vainly (aestuantes angusto limite mundi) almost simultaneously overleaped at three different points. It is the greatest and most glorious triumph which practical astronomy has ever witnessed. Perhaps I ought not to speak so strongly — perhaps I should hold some reserve in favour of the bare possibility that it may all be an illusion — and that further researches, as they have repeatedly before, so now may fail to substantiate this noble result. But I confess myself unequal to such prudence under such excitement. Let us rather accept the joyful omens of the time, and trust that, as the barrier has begun to yield, it will speedily be effectually prostrated. Such results are among the fairest flowers of civilization.*

Herschel's excitement was justified (his Latin phrase means "seething at the very edge of the world"), but the barrier was not so speedily prostrated as he had hoped. Measuring the parallax of stars was still difficult; many of those close to the Sun are intrinsically very faint objects, unlikely to have caught the attention of the early parallax hunters. Only when it became possible to apply photography to the problem, towards the end of the nineteenth century, did the number of measured parallaxes begin to grow. Only then could astronomers begin to distinguish the solar neighbourhood from the rest of what Herschel called "the sidereal universe." Early in the twentieth century it began to be useful to compile lists of nearby stars, and, as far as I can find out, the first astronomer to do so was Ejnar Hertzsprung (1907), in the second part of a two-part paper in which he laid the groundwork for what has since come to be known as the Hertzsprung-Russell diagram. His paper contained a list of all stars then known to have a parallax greater than 0″.1 — 95 in number. The table contains 33 stars with parallaxes greater than 0″.19, the limit adopted for many years in the table presented in the *Observer's Handbook* of the RASC. Hertzsprung knew, however, of a few more stars within that limit: he did not include the fainter components of known binaries unless he had a separate spectral type for them. Thus, at least three more stars, Sirius B, Procyon B, and 70 Ophiuchi B, should be added to the number of stars he knew of with parallaxes greater than 0″.19.

Hertzsprung's paper was probably one of the most important astronomical papers of the first decade of the twentieth century: reading it compels a great respect for the scientific insight of its author. It was the paper in which Hertzsprung pointed out that there are two kinds of red stars, one very much brighter (intrinsically) than the other. He did not use the terms giant and dwarf in his paper and he was not prepared, at that stage, to assert that stars in one group *were* larger than those in the other, but he did recognize a concept like our absolute magnitude — he adopted a standard distance of one parsec instead of ten — and saw that the majority of stars belong to what he called the "solar series" and we would call the "main sequence," and that the late-type "c-stars" classified by Antonia Maury (1897) must be, in some way, different from the other fainter late-type stars. That fact, he pointed out, could not be reconciled with the then-accepted theory of stellar evolution, according to which stars began as hot, bright blue stars and cooled and contracted to faint red ones. (Our very use of the terms "early-type" and "late-type" are the surviving relic of this theory.) Hertzsprung demonstrated the inability of that theory to account for all stars by a particularly insightful discussion of the (giant) components of Capella, which was the more remarkable in that the observational data available to him for the masses, and even the spectral types, were crude, or even wrong.

Hertzsprung made another important point in his paper: that any selection of stars down to a given magnitude limit is bound to exaggerate the proportion of very luminous stars, which can be seen from very great distances. The only way to study the relative proportions of different kinds of stars is to limit consideration to those stars within a definite volume of space — such as within five or ten parsecs of the Sun. He thus gave what is still the most important reason for studying the solar neighbourhood. He also found that four-fifths of the stars with parallaxes greater than 0″.1 and nine-tenths of those with parallaxes greater than 0″.2 are fainter than the Sun. He suggested that further research would increase the ratios. In fact, out of 74 stars now known to have parallaxes greater than 0".19, only four are brighter than the Sun. Finally, we should note that his paper contains a discussion of the possible effects of interstellar absorption on starlight — a possibility that most astronomers remained unwilling to admit for about another twenty years. Incidentally, on the matter of the terminology of giants and dwarfs, although Russell (1914) attributed it to Hertzsprung, Strand (1977) says that Hertzsprung neither used it nor approved of it!

For some reason Hertzsprung did not publish his paper in an astronomical journal, but in the *Zeitschrift für Wissenschaftliche Photographie, Photophysik und Photochemie*. One wonders what most of that journal's readers made of such a fairly specialized astronomical paper, of which astronomers, especially in North America, remained largely unaware until H. N. Russell (1914) independently discovered many of the results some years later. By coincidence, a table of nearby stars, presumably compiled by C. A. Chant, was published, also in 1907, in the first edition of the RASC *Observer's Handbook*. Both Chant and Hertzsprung must have compiled their lists some time in 1906. Chant's list is quite idiosyncratic. Although it includes two stars beyond Hertzsprung's limit of ten parsecs, it contains only eighteen stars. Either Chant had special reasons for selecting the stars he did, or he simply did not, at that time, have access to a full up-to-date astronomy library. I incline to the latter hypothesis, partly because the values given for the parallaxes of stars that are also in Hertzsprung's list usually differ from his values, often by more than can be accounted for by rounding-off. It suggests to me that Chant did not know the most modern determinations of parallax of that time. In a Canadian context, Chant's list is of interest in that it is the beginning of the tradition of including a table of nearest stars in the *Observer's Handbook*. Even in a wider context, it is of interest that others besides Hertzsprung himself were, at the same time, beginning to see the value of studying the nearest stars. Hertzsprung's list, however, is clearly part of a major astrophysical study, while Chant's remains a historical curiosity.

Hertzsprung (1922) once updated his list of nearby stars. His second list was limited only to stars with parallaxes greater than 0″.2 because, he said, the main feature of the list could be shown by such a smaller sample. More modern values of the parallaxes led him to reduce the number known within five parsecs to 29; he did, however, now include Sirius B and Procyon B, and pointed out the existence of the group of stars we now call "white dwarfs." He thought it improbable that we yet knew all stars within five, or even four parsecs, a statement whose validity was later to be demonstrated by Peter van de Kamp, who several times updated the list of stars within five parsecs of the Sun (van de Kamp 1930, 1940, 1945, 1953 and 1969). The growth in numbers is shown in Table I and figure 1.

Table I
Growth in the Number of Known Nearby Stars

Number	Source
36	Hertzsprung (1907)
29	Hertzsprung (1922)
36	van de Kamp (1930)
47	van de Kamp (1940)
51	van de Kamp (1945)
55	van de Kamp (1953)
59	van de Kamp (1969)
63	Batten (1976)
68	Batten (1979)
65	Batten (1985)
67	Batten (1994)
74	Batten (1999)

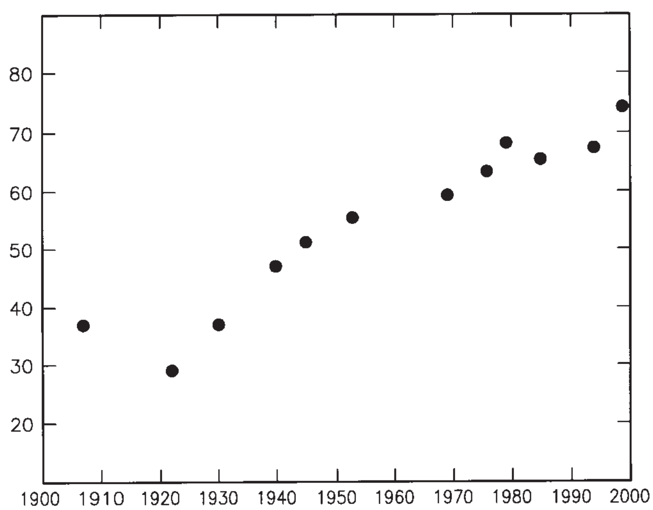


Figure 1: Numbers of stars known or believed to lie within approximately five parsecs of the Sun, plotted as a function of time.

During his lifetime, van de Kamp became one of the authorities on the nearest stars. I recall that on my only visit to Sproul Observatory, in 1972 for a celebration of Peter van de Kamp's seventieth birthday, there was a three-dimensional model of the solar neighbourhood on display, based on one of his compilations. Lists of nearby stars also continued to appear frequently, but not regularly, in the *Observer's Handbook*. Some were compiled anonymously (presumably by Chant), while in other years the table (but not the article) was credited to J. A. Pearce. The table became a regular feature in 1959, when R. M. Petrie and J. K. McDonald (now J. K. Petrie) wrote a short article and presented a table based on van de Kamp's 1953 version. Because light-years were preferred to parsecs in the *Observer's Handbook* and five parsecs is approximately 16.3 light-years, the tendency has been to round off our *Handbook* tables to 17 light-years — although I suspect the precise boundary, which has been variable, was determined by how many stars could be put on one printed page! In fact, neither van de Kamp nor the *Handbook* compilers have been completely rigorous about the lower limit of parallax set for inclusion — partly, I believe, because none of us could bear to exclude 70 Ophiuchi, which has a parallax of 0″.196!

When van de Kamp produced his own final revision in 1969, R. M. Petrie had died and J. K. Petrie was not free to revise the *Handbook* article to take into account the new data. The task fell to me, and I, too, depended very heavily on van de Kamp's list. At first, I had the help of Russell Redman, then a high-school student who was happy to do anything astronomical in the summer vacation, now a respected colleague at the Herzberg Institute of Astrophysics whose interests, however, are primarily concerned with more remote parts of the universe. Later I continued the compilation alone, making revisions as I became aware of new results. This article is stimulated by the coincidence that this year marks the thirtieth anniversary of my involvement, and a major revision has been required to take account of the results obtained by the European astrometric satellite *HIPPARCOS* (High-Precision Parallax Collecting Satellite).

Somewhat to my embarrassment, the *Observer's Handbook* article has come to be viewed as authoritative and I have more than once received requests for permission to reprint it, as if it were the result of my own research. In fact, apart from Sirius and Procyon, of which I have taken occasional spectrograms, the only stars in the list on which I have contributed original work are the components of 70 Ophiuchi (Batten & Fletcher 1991). In my early years of compiling the list, I enjoyed the friendship and advice of van de Kamp himself, and later of Wilhelm Gliese, the authority on stars within 25 parsecs of the Sun, whose catalogue has been supplemented (Gliese & Jahreiss 1979) and is still being kept up-to-date by Jahreiss. Later still, Robert Harrington and Charles Worley, both of the U.S. Naval Observatory and both of whom have died prematurely, would often help by pointing out additions and changes that should be made and errors that should be corrected. R. F. Wing once contributed a particularly useful set of homogeneously determined spectral types, of which I still make use. Without the generous help of such colleagues, the tables would have been much less useful. There is now an informal consortium of astronomers interested in the study of nearby stars, and if the *Handbook* table continues to be my responsibility, I shall no doubt become equally dependent on their results.

What of the Future?

Has the list of nearby stars reached its final form? That question is really two questions in one. First, do we know all the stars currently within five parsecs (or whatever) of the Sun; second, will the same stars always remain, unchanging, within that volume? The answer to the second question is certainly "no" and I strongly suspect that the answer to the first is also "no." Even while the *HIPPARCOS* results were still being reduced, a previously unrecognized system was found, from ground-based observations, to be within five parsecs of the Sun (Henry *et al.* 1997). Indeed, the purpose of *HIPPARCOS* was not to discover new nearby stars, but to measure more accurately the parallaxes and proper motions of a very large number of stars down to a visual apparent magnitude of approximately 12.5. In doing so, it changed our estimates of the distances of some stars, bringing some that we thought lay beyond the five-parsec limit within it and pushing others out; but it told us nothing about stars fainter than $12^{m}.5$. Many of the Sun's closer neighbours are much fainter than that limiting magnitude and the best source of information about them is still the *General Catalogue of Trigonometric Parallaxes* (van Altena *et al*. 1995).

The growth in the numbers of known solar neighbours, illustrated in Table I and figure 1, has up to now come about primarily from ground-based observations. In Table I are listed Hertzsprung's two tabulations, those of van de Kamp, and those years in which I made significant revisions to the list in the *Observer's Handbook*, together with the years in which each compilation was published. Figure 1 displays the same information graphically. There were two occasions when newer observations led us to reduce our estimate of the numbers of stars within five parsecs, namely between Hertzsprung's two tabulations and between my tabulations of 1979 and 1985. On each occasion, still newer observations either reinstated some of the rejected stars or brought new ones to our knowledge. The overall impression from both table and graph is of a steady increase in the number of the Sun's nearest known neighbours.

As we do approach a complete knowledge of the stellar content in this volume of space, we would expect the curve in figure 1 to tend asymptotically to the number of stars within the volume. Around 1970, it almost looked as if that was happening and the total number of nearby stars appeared to be close to 60. Since then, however, more effort has been put into the study of nearby stars and new detectors have made possible the measurement of fainter objects. The current number of known nearby stars is now 74. The curve is indeed beginning to level off, but looks likely to rise some more yet. I shall not be at all surprised if, within another decade or so, we recognize at least 80 stars within this volume of space and I would not rule out the possibility that there could be as many as 100. In fact, a seventy-fifth object, LP 944–20 with a parallax of just over $0''.2$ is already known (Tinney 1996); so far, most work on it has been in the infrared — it is among the least luminous objects known — and complete details about it are still not available. Here may be the best point at which to emphasize the great contribution to our knowledge of nearby stars made by W. J. Luyten. Many of the conventional designations for such objects contain the letter L, which always indicates one or another of the catalogues of stars with large proper motions that he compiled.

When we shall consider our list of nearby stars to be complete will depend upon how we define a star. For example, none of the known objects within five parsecs, probably not even L 944–20, is a brown dwarf — a body that can shine by its own gravitational energy but is not massive enough to be able to ignite thermonuclear reactions within its interior. Brown dwarfs radiate most of their energy in the infrared and are intrinsically very faint; even at a distance of one parsec they would be hard to detect. A nearby one with small proper motion might escape detection almost indefinitely. Only recently was one identified with any degree of certainty, Gliese 229B, which lies just beyond the five parsec or seventeen light-year limit (Nakajima *et al.* 1995).

Another source of new discoveries might be faint companions of known nearby stars, resembling some of the recently announced extra-solar planets (Mayor & Queloz 1995; Marcy & Butler 1996). Those objects were found from spectroscopic observations of stars that lie outside the volume of space we are considering. Van de Kamp was convinced that he and his associates had discovered similar bodies around several of the Sun's neighbours by astrometric observations. We used to list them in the *Observer's Handbook*, but many have been questioned, although some may withstand scrutiny. Gatewood (1996) discussed the evidence for planet-like bodies around Lalande 21185 (BD+36° 2147), which van de Kamp believed to have planets. While he is unable to support van de Kamp's interpretation in all details, the possibility of objects around the star cannot be ruled out.

Earlier, Gatewood (1995) also discussed in detail the evidence for planetary bodies around Barnard's Star, which was the star van de Kamp was most certain had planets somewhat larger than Jupiter. Again, Gatewood could not confirm van de Kamp's interpretation, although the residuals in the star's motion still present puzzling features. Recently evidence has been published for a planetary companion of Proxima Centauri (Schulz *et al*. 1998) in the form of a claimed image of the companion, which might have an orbital period of about a year. Probably we will never be able to say that we know all the objects within some given distance of the Sun — only that additions to the list will become very rare and correspondingly surprising.

Even if we do one day obtain complete knowledge of the objects within five parsecs of the Sun, our knowledge soon displays many gaps as we go to only slightly greater distances. According to the informal consortium working on the detection and study of nearby stars (Henry *et al.* 1997), even if our knowledge of stars within five parsecs were now complete, there still remain about 130 stellar systems to be detected in the region between five and ten parsecs from the Sun (the very region to which Hertzsprung's first survey extended).

Not only will our knowledge of the solar neighbourhood change, but the solar neighbourhood itself is also changing — if you look at it on a sufficiently large time-scale. Binary systems like Sirius, Procyon, and 70 Ophiuchi have orbital periods comparable with a human lifespan. Individuals can, therefore, follow the changes that the systems go through, one component being sometimes nearer to us and sometimes more distant from us than the other. Over time some stars will move out of the five-parsec sphere and others will move into it. The system of α Centauri A and B and Proxima — if it does indeed form a system with the other two — has not always been our closest neighbour. Approximately 32,000 years ago L726–8 was closer to us. In another 33,000 years Ross 248 will be (Matthews 1994). It has recently been calculated that Gliese 710, at present not even within the five-parsec sphere, will one day come close enough to the Sun (about 0.5pc) to perturb the Oort cloud of comets at the edge of the solar system (Weissman *et al*. 1997).

This stately dance of the stars will be matched by slow changes in the relative brightnesses of the stars. Sirius was not always and will not always be the apparently brightest star in the sky. As it is presently approaching us, however, it will continue to get brighter and in about 60,000 years will reach an apparent magnitude of −1.64 (Tomkin 1998). Imagine that one day in the distant future a B-type star should stray into this five-parsec sphere: it could easily outshine Venus at her brightest! According to Tomkin, some 90,000 years ago Canopus was the brightest star as seen from the Earth, while 210,000 years hence Vega will be. Calculations for Canopus are complicated by the fact that it is in a rapid stage of evolution, and therefore its absolute magnitude can change appreciably over the periods of time we are considering. Even the four stars within five parsecs (Sirius, Altair, Procyon and α Centauri A), that are brighter and more massive than the Sun, are going to take thousands of millions of years before evolution affects their luminosity very much, but over the longest conceivable periods of time all stars will change to some extent. The starry sky that looks so stable that the early Greek philosophers believed the heavens to be immutable is, in fact, changing all the time — but, most of the time too slowly for the changes to be noticed by this strangely limited species living on a small planet circling a rather typical star.

Despite our limitations, however, we have obtained some understanding of the vast scale of the universe in which we live, and that understanding has been dependent upon the study of the stars in the solar neighbourhood. We owe much to people like Ejnar Hertzsprung, who showed us nearly a century ago how the study of the nearest stars could help us to draw far-reaching astrophysical conclusions, but he would have been the first to point to the importance of the pioneering work of those who first measured stellar parallax, and even of those who tried but failed because of the inadequacy of their instruments. Since Hertzsprung's time it has been fashionable to push our researches as far away (literally!) from the Earth as we can. The universe beyond the solar neighbourhood is a wondrous place containing many strange objects that Hertzsprung could not have envisaged, even at the time of his death in 1967. His instinct that we could make progress by studying the more ordinary nearby objects was and is sound; we can use such stars to illustrate many of the results of modern astrophysics. Moreover, stars that can approach the Sun closely enough to perturb the Oort cloud may well have some influence on the ultimate fate of humanity. Our studies of the solar neigbourhood serve both as a foundation for study of the more distant universe and usefully bring us back to the Earth on which we live.

Acknowledgments

I am grateful to Dr. R. L. Bishop, current editor of the *Observer's Handbook*, for information on early tables of nearby stars in that publication. Access to the SIMBAD and *HIPPARCOS* catalogues was through the Canadian Astronomy Data Centre.

References

Batten, A. H. 1976, Observer's Handbook (ed. J. R. Percy) pp. 102-103

Batten, A. H. 1979, Observer's Handbook (ed. J. R. Percy) pp. 124-125

Batten, A. H. 1985, Observer's Handbook (ed. R. L. Bishop) pp. 150-151

Batten, A. H. 1994, Observer's Handbook (ed. R. L. Bishop) pp. 197-199

Batten, A. H. 1999, Observer's Handbook (ed. R. L. Bishop) in press

Batten, A. H. & Fletcher, J. M. 1991, Pub. Astron. Soc. Pacific, 103, 546-555

Gatewood, G. 1995, Astrophys. Space Sci., 223, 91-101

Gatewood, G. 1996, Bull. Amer. Astron. Soc., 28, 885

Gliese, W. & Jahreiss, H. 1979, Astron. Astrophys. Supp., 38, 423-488

Henry, T. J., Ianna, P. A., Kirkpatrick, J. D. & Jahreiss, H. 1997, Astron. J., 114, 388-395

Herschel, J. F. W. 1843, Mon. Not. Roy. Astron. Soc., 5, 89-98

Hertzsprung, E. 1907, Zeitschr. für Wissentsch. Photographie, Photophysik u. Photochemie, 5, 86-107

Hertzsprung, E. 1922, Bull. Astron. Inst. Netherl., 1, 21-22

Marcy, G. W. & Butler, R. P. 1996, Astrophys. J., 464, L147-151 & 153-156

Matthews, R. A. J. 1994, Quarterly J. Roy. Astron. Soc., 35, 1-9

Maury, A. C. 1897, Harvard Annals, 28, Part 1

Mayor, M. & Queloz, D. 1995, Nature, 378, 335-339

Nakajima, T., Oppenheimer, B. J., Kulkarni, S. J., Golimowski, D. A., Matthews, K. & Durrance, S. T. 1995, Nature 378, 463-465

Pedersen, O. 1974, A Survey of the Almagest, 454 pp., Odense Univ. Press, p. 395

Russell, H. N. 1914, Pop. Astron., 22, 275-294 & 331-351

Schulz, A. B., Hart, H. M., Hershey, J. L., Hamilton, F. C., Kochte, M., Bruhweiler, F.C., Benedict, G. F., Caldwell, J., Cunningham, C., Wu Nailong , Franz, O. G., Keyes, C. D. & Brandt, J. C. 1998, Astron. J., 115, 345-350

Strand, K. Aa., 1977, in In Memory of Henry Norris Russell, eds. A.

G. D. Philip and D. deVorkin, Dudley Obs. Report, No. 13, pp. 55-60
Tinney, G. 1996, Mon. Not. Roy. Astron. Soc., 281, 644-658
Tomkin, J. 1998, Sky and Telescope, 95, 59-63
van Altena, W. F., Lee, J. T.-L. & Hoffleit, E. D. 1995, General Catalogue of Trigonometric Stellar Parallaxes, 4th edn., Yale Univ. Obs.
van de Kamp, P. 1930, Pop. Astron., 38, 17-20
van de Kamp, P. 1940, Pop. Astron., 48, 297-302
van de Kamp, P. 1945, Pub. Astron. Soc. Pacific, 57, 34-41
van de Kamp, P. 1953, Pub. Astron. Soc. Pacific, 65, 73-7
van de Kamp, P. 1969, Pub. Astron. Soc. Pacific, 81, 5-10
Weissman, P. R., Garcia-Sanchez, J. Preston, R. A., Jones, D. L., Lestrade, J.-F. & Latham, D. W. 1997, Bull. Amer. Astron. Soc., 29, 1019

Alan Batten came to Canada in 1959, and has been associated with the Dominion Astrophysical Observatory ever since. Although formally retired, he continues to work at the observatory several days a week. He has held office as Editor of the Journal*, President, and Honorary President of the Society, and also as President of the Canadian Astronomical Society and Vice-President of the International Astronomical Union (IAU). He continues to work for the IAU in trying to help astronomers in developing countries.*

FROM THE PAST — AU FILS DES ANS

STELLAR DISTANCES — A CREDITABLE RECORD

Just a century has elapsed since the announcement of the first successful measurement of the distance of a fixed star. By 1910 the distances of approximately one hundred stars had been determined. In 1914 photographic work on the trigonometric measurement of stellar parallaxes was begun at the Leander McCormick Observatory of the University of Virginia. At a recent meeting of the National Academy of Sciences held at Chapel Hill, N.C., Dr. S. A. Mitchell, director of the above Observatory, and D. Renyl presented a paper in which it was stated that up to date 1,350 stellar parallaxes had been secured. These trigonometric parallaxes are in close agreement with the spectroscopic parallaxes determined elsewhere. The McCormick programme includes relatively faint stars of large proper motion, and also all the brightest stars accessible in its latitude. A report that the spectrum of the faint star Wolf 424 was our nearest neighbour has not been verified by the McCormick measures, according to which there are at least thirty nearer stars.

by C. A. Chant,
from *Journal,* Vol. 33, p. 30, January, 1939.

Sketches of Jupiter During its Collision with Comet Shoemaker-Levy 9

by Christopher J. Conselice, Department of Astronomy, University of Wisconsin-Madison (chris@astro.wisc.edu)

Comet Shoemaker-Levy 9 collided with the planet Jupiter in the summer of 1994. The event was unique in the history of astronomy in that nearly every active telescope was pointed toward Jupiter at the time, including the major observatories in space and on Earth. Many important results came from such observations. For most people, however, their personal experiences with the collision came from observations through a small telescope.

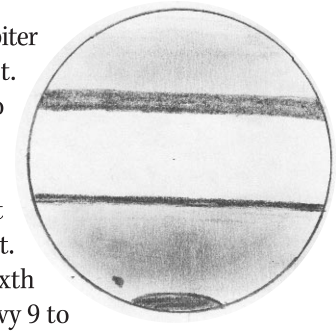
Before the collisions of the individual comet fragments with Jupiter, no one was quite certain if they could be detected visually through a telescope or if any changes to the planet's atmosphere would be seen afterwards. At the time I was an undergraduate at the University of Chicago, and for several weeks before the collisions I practised viewing and sketching Jupiter in preparation for recording what might be seen during and after the events. The instrument to which I had access was the old instructional telescope atop Ryerson Hall on the campus of the University of Chicago. The telescope is a 15-cm refractor that was figured by Octave Pedittier in 1911. Pedittier was a master optician who built the optics for the instrumentation used by Albert Michelson in his pioneering research on light.

I describe here what I observed using the Ryerson telescope between July 17, the first night following the first impact, to August 9, two weeks after the last piece of the comet struck Jupiter. In the descriptions and sketches I have made, no attempt is given to reproduce every detail on Jupiter. The sketches are meant to describe the colour, size and relative positions of the impact spots on Jupiter's surface. More generally, the series of observations is presented to allow comparison with the results of other observers who may have recorded the appearance of Jupiter on these dates.

My comments on the impact sites, as recorded in my observing log, are reproduced here in edited form in order to remove some of the ambiguities that arose in the excitement of the original sessions. They include estimates of when certain comet impacts occurred and the corresponding times at which they could be seen. Not all comet fragment impacts created changes to the atmosphere of Jupiter that I could observe. Also, the identifications presented here should be used only as a rough guide for comparison with more precise identifications.

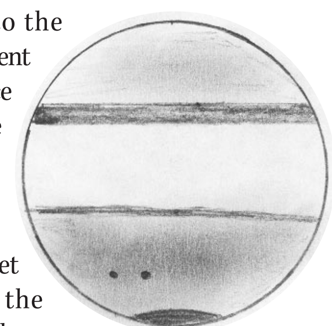
Night of July 17, 1994

I went to the observatory and looked first at the Moon. It was about 60% full. I viewed Venus and then Jupiter - I saw amazing things.



This is the appearance of Jupiter when I first began to observe it. An impact site, corresponding to the closely adjacent collisions with Jupiter of comet fragments E and F, can be seen as a dark spot on the eastern limb of the planet. It originated with the fifth and sixth pieces of Comet Shoemaker-Levy 9 to hit the planet. The two fragments struck the planet at nearly the same time, and the impact sites would have appeared as one through the telescope. The unresolved black spot reached transit position on Jupiter at about 22:50 CST (3:50 UT).

Following it, another marking, not as dark as the one before, came into view.



The lighter spot was grayish in colour and probably corresponded to the impact with Jupiter of comet fragment A or another that struck the surface at a similar time. I estimated the diameter of both impact sites to be no more than about two arcseconds.

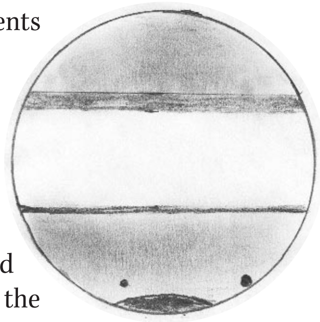
I attempted to view the planet again when it was just above the horizon, but could barely see the spot corresponding to impact site A, while impact site EF had rotated out of the field of view. The atmospheric seeing was very poor for this viewing. The actual size of the spots was about one half the size of the Earth. Five or six fragments had hit the planet at that point, with about 15 more to occur.

Day of July 18, 1994

I attempted to observe Jupiter during the day, but it was too cloudy to see the planet. After some investigation I was able to assign proper designations to the spots observed on the previous night. They are used in the edited version of my journal reported here.

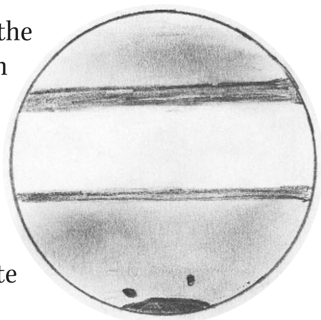
Night of July 19, 1994

The image of Jupiter was very nice tonight. At 22:30 CST I could see what I believed were sites associated with the impacts of comet fragments D/G (right) and H (left).



The spot associated with the impact of fragment H transited at about 22:45 CST (03:45 UT). The spot near the western limb (right), probably associated with the impacts of fragments D and G, was very large. It gave Jupiter the appearance of something having taken a bite out of its side. The impact scar for fragments D/G of SL-9 was estimated to be about six times larger than the Earth.

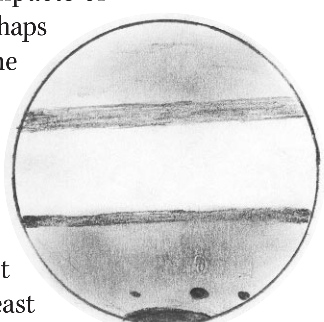
Day of July 21, 1994



Today I looked at Jupiter during the daytime. The best viewing was with a medium power eyepiece using a yellow polarizing filter. I could see a large dark spot (left) on the planet that was about an hour from transiting. The spot probably corresponded with the impact site for comet fragment K.

Night of July 21, 1994

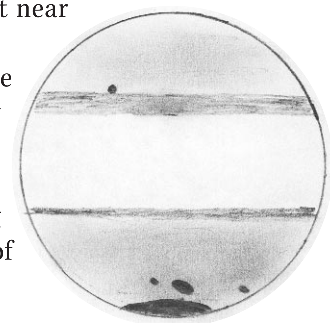
I observed Jupiter tonight only 10 degrees from the horizon. The seeing was very poor. I was able to see what were probably the sites associated with the impacts of comet fragments G and L, and perhaps another (Q?) just to the left of the meridian.



The site associated with the impact of fragment L was close to the limb of Jupiter (at far right) and was not very easy to detect. Neither was the "unknown" spot (from comet fragment Q?) to the east of the meridian. However, the site associated with the impact of fragment G (right of centre) was absolutely enormous. It was very plainly visible.

It clouded over tonight at 23:15 (4:15 UT) when fragment V hit the planet, and unfortunately I missed it. All of the fragments had now hit the planet and I was interested to see the consequences for Jupiter's appearance.

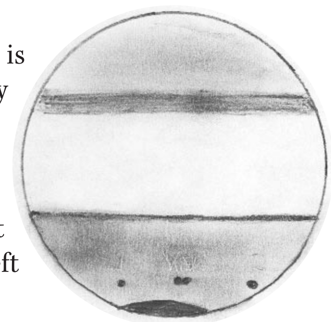
Night of July 22, 1994



I first observed Jupiter tonight near 22:30 CST (3:30 UT).

The large spot near the meridian of Jupiter is probably some combination of the sites associated with the impacts of fragments E and V. The marking to the right is probably the site of the impact of fragment H.

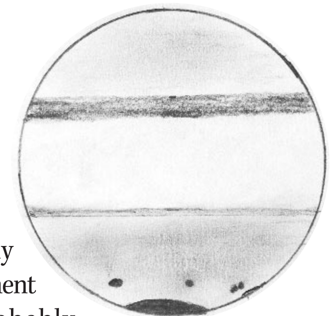
Night of July 23, 1994



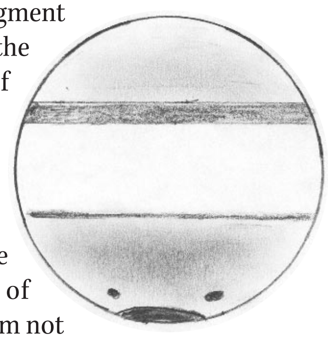
My first observation of Jupiter is shown below (spots probably associated with sites Q, D/G and L).

Later at 23:00 CST (4:00 UT) the site of the impact of fragment H came into view close to the left edge of the disk.

Night of July 24, 1994



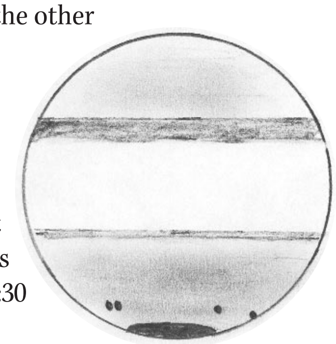
The "string" of spots is probably a combination of impact sites which include that associated with the impact of fragment D. The marking at far left is probably associated with the impact of fragment H, while the centre one is probably associated with the impact of fragment Q. At the right limb one can see the site associated with the impact of fragment L.



Later tonight, at 23:30 CST (4:30 UT), I looked at Jupiter again and had the following view.

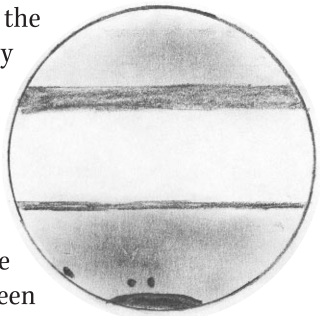
I think the large spot near the right is the site of the impact of fragment H (or possibly E/F). I am not certain of the identification of the other spot (A?).

Night of July 25, 1994



I observed Jupiter tonight, but had the impression that the spots were fading. Here is the view at 21:30 CST (2:30 UT).

The view here is similar to the one sketched on the night of July 23. The two spots near the left seem to be associated with the impact of fragment C, while the middle spot corresponds with the impact of fragment A. A moon of Jupiter was also in ingress at the time. Some white spots can be seen on the southern belt. I looked at Jupiter again at around 23:00 (4:00 UT) and had the following view.

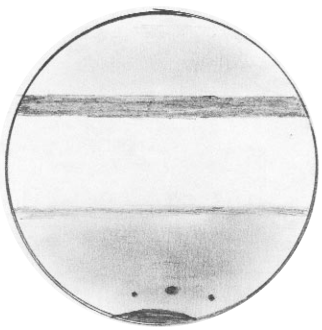


Jupiter appeared similar to its earlier appearance, but now the spot associated with the impact of fragment K was in view.

Night of July 27, 1994

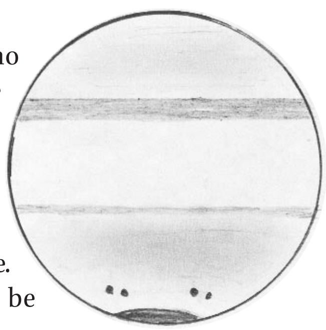
It was a bit cloudy tonight, but Jupiter was still easily visible.

I believe that the larger spot near the meridian of Jupiter was the site associated with the impacts of comet fragments E/F.



Night of July 28, 1994

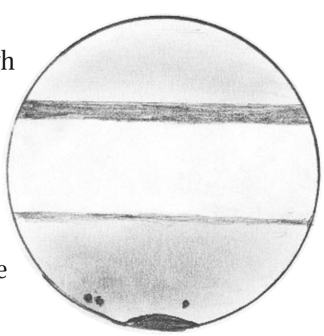
It was a very clear night with no clouds in the sky. However, the seeing was quite bad. Despite that I was able to view Jupiter successfully. I could observe four large spots. At 21:15 (2:15 UT) Jupiter had the following appearance.



The spots do not seem to be fading, despite my expectations.

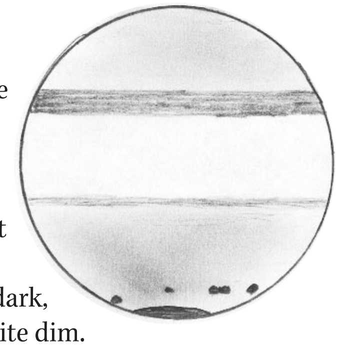
Night of july 30, 1994

It was very hazy tonight, although the seeing was good. I looked at Jupiter at 21:00 (2:00 UT) and could see what I thought were sites associated with the impacts of fragments K, W and C. Some white spots were also observable near the impact sites.



Night of July 31, 1994

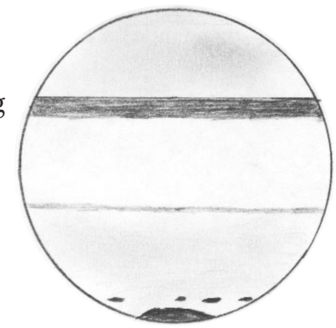
It was rather hazy tonight, but the seeing was very good. I could see about four spots. None of them seemed to be much dimmer than on previous nights. The view at 21:15 (3:15 UT) was as follows.



The double spot was very dark, while the one transiting was quite dim.

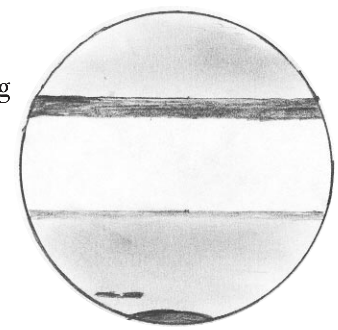
Night of August 2, 1994

The spots appear to be blending together and seem to be elongated along the direction of Jupiter's rotation.



Night of August 9, 1994

The spots appear to be blending more into each other, and I noticed that they were beginning to fade a bit.



Christopher J. Conselice is a graduate student in Astronomy at the University of Wisconsin-Madison, having graduated in 1996 with a degree in physics from the University of Chicago. He has been a member of the RASC since 1995, and has always had a fascination for the planet Jupiter. It was the first object he ever viewed through a telescope.

Reflections

Lazy Nature

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

September 28th marked the 300th anniversary of the birth of Pierre Louis Moreau de Maupertuis (1698–1759), a French mathematician born in St. Malo. Maupertuis is not a giant figure in the history of science, but his name deserves wider broadcast, as one of his ideas — the principle of least action — has turned out to be a fundamental concept in physics, common to the fields of mechanics, optics, relativity, and quantum field theory. But more of that later.

Isaac Asimov's *Biographical Encyclopedia of Science and Technology* (Doubleday: New York 1982) describes the young Pierre Maupertuis as "the spoiled child of well-to-do parents" who first became a musketeer in the army, but then left to become a mathematics instructor at the French Academy of Sciences. He must have been especially clever, as the Royal Society in London (a notoriously snooty gang) elected him a member during a 1728 visit. He was an ardent admirer of Isaac Newton and his theories, including Newton's hypothesis that the curvature of the Earth's surface was not constant, but bulged at the Equator as a result of its daily rotation.

In 1735 French surveys in Peru and in Lapland (in the north of Sweden) measured the Earth's curvature and validated Newton's claim; Maupertuis was the leader of the northern expedition, while Charles la Condamine led the southern team. (As an aside, the lack of internationally accepted standard units of measure made the surveys exceedingly difficult, and La Condamine afterward championed such a system, but did not live long enough to see the establishment of the metric system.)

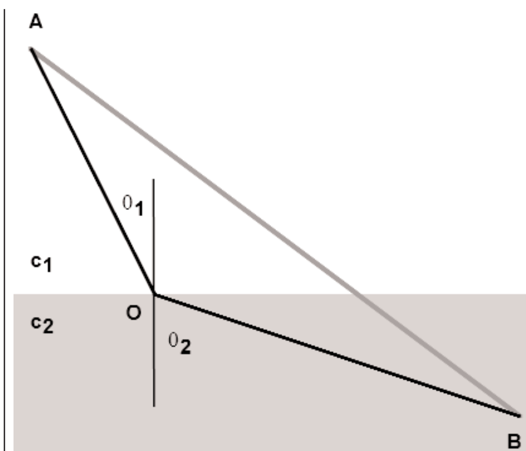
The French Academy elected Maupertuis for his accomplishments, but Frederick II of Prussia wooed him away to become head of the Berlin Academy of Sciences. That would be honour enough for most, but Maupertuis seemed intent on making a career out of conducting loud and vitriolic arguments with leading thinkers of the day. Always a Newton supporter, he quarreled over who deserved credit for the invention of calculus, not a popular view on the continent, where the German Leibniz was favoured. Maupertuis also picked a fight with French author Francois Voltaire, who is believed never to have lost an argument, owing to his sharp wit and expressive pen.

Voltaire was also a Newton promoter, having overseen the translation of Newton's *Principia Mathematica* into French. Maupertuis crossed Voltaire by espousing the "principle of least action," wherein Nature chooses the most economical paths of moving bodies, rays of light, and so on. (I admit that the idea sounds wacky, but when the principle is expressed in proper mathematical terms it leads to the same equations of motion prescribed by Newton's laws of motion.)

Pierre Louis Moreau de Maupertuis (1698–1759).

Such ideas were not exactly new in Maupertuis' day. The Greek philosopher Hero had noted that a reflected ray of light always travels by the shortest distance joining source, mirror, and eye. From this smallest-distance principle, one can derive the important optical rule that the angle of reflection equals the angle of incidence for a ray reflected by a plane surface. Much later, the French mathematician Fermat generalized the rule to apply to the passage of an optical ray through media having different indices of refraction (*i.e.* for which the speed of light differs from that in a vacuum). Fermat's principle states that, of all the possible paths joining source and eye, the actual ray path followed is that having the least travel time. (If the index of refraction is constant, then Fermat's principle reduces to Hero's case.)

With reference to the figure, consider the case of a ray travelling between two points *A* and *B* on either side of a plane boundary between two media having different indices of refraction.



Fermat's Principle states that light follows the path of shortest time (solid line *AOB*) rather than the path of shortest distance (dashed line *AB*).

The dashed straight-line path joining points *A* and *B* represents a longer travel time than the bent path *AOB*, which has a longer segment *OB* in the medium where the speed of light is higher and a shorter segment *AO* in the medium where the speed of light is lower. In fact, the path having the least travel time requires that *O* be that point which makes the geometry consistent with Snell's law of refraction: $\sin(\theta_1)/c_1 = \sin(\theta_2)/c_2$., where θ_1 and θ_2 are the angles of incidence and refraction, respectively, and c_1 and c_2 are the speeds of light in the two media. Fermat's Principle appears to be sound, but I personally find it a little odd that a photon, having spent thousands of years travelling from a distant star, would alter course through the optics of my telescope for the sake of shaving a minute fraction of a second off the journey!

In 1744 Maupertuis imagined that the mechanics of bodies could be explained by a similar principle of least "action," by which he meant the product of the mass of the object, the velocity, and the distance traveled. Although Maupertuis had a good intuitive grasp of the meaning of his principle, the mathematical expression of his ideas was somewhat crude. He was able to explain the inelastic collision of bodies, but his explanation of Snell's law turned out to be exactly backwards! What earned him the ire of Voltaire, however, was the claim that the least action principle was a manifestation of the wisdom of God, providing a metaphysical basis for Newtonian mechanics.

Like others before him, Maupertuis lost his argument with Voltaire; however, the principle of least action was eventually proved to have some validity by the Italian-French mathematician Joseph Louis Lagrange and the Irishman William Rowan Hamilton. Hamilton's formulation of the dynamics of rigid bodies forms the formal basis of the theory of classical mechanics. His concepts were also applied to continuous media and fields (such as the electromagnetic field). With some embellishments, Hamilton's ideas also provide the basis for the quantum theory of fields. Common to all these theories is the principle that the time evolution of a physical system minimizes the difference between the time average of the kinetic energy and the time average of the potential energy, which is one way of defining the "action" of a system. According to Einstein's General Theory of Relativity, the orbit of a planet around a star is a geodesic curve, which is the shortest "distance" in the peculiar geometry of curved space-time. Although such examples may seem abstract (and I have not done justice to them), I mention them only to show how long the thoughts of Maupertuis have endured, Voltaire notwithstanding.

While musing over the finishing touches to this piece, I mentioned to my wife over dinner how impressed I was that the fundamental laws of Nature could be expressed in terms of minimizing energy and energy differences, and how Nature's parsimonious tendencies have provided inspiration for my own work. Methinks I heard her mumble under her breath as she cleared away the dinner plates, "Might be the reason so little gets done around this place..."

David Chapman is a Life Member of the RASC and a past President of the Halifax Centre. His debut scientific paper analyzed the Lagrangian dynamics of a system of vortices in an ideal fluid, a piece of work that is notable for being completely useless. Currently he manages a project to develop new sonar for the Navy, and fills in his idle hours playing the acoustic guitar. He is exhausted after observing two great comets and a total eclipse of the Sun, all jammed into a two-year interval.

Second Light

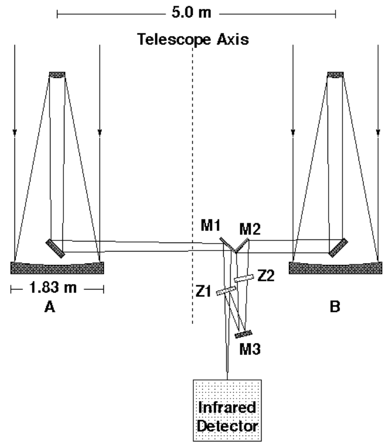
Searching for Other Planets

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

The National Aeronautics and Space Administration (NASA) in the U.S.A. has made seeing Earth-like planets around nearby stars a goal for the early part of the next century. The move has been triggered by the indirect detection of Jupiter-mass planets around other stars, but the hurdles to be overcome are enormous.

There are two main technical problems. The first is that the angular separation between a planet and a star will almost certainly be less than one arcsecond (that is one A.U. at a distance of one parsec, but the nearest star is more than one parsec from us). The second is the large difference in relative brightness of a planet relative to its parent star. The star will be at least a billion times brighter (in the optical part of the spectrum) than the planet; that is about the difference between the Sun and Venus at its brightest.

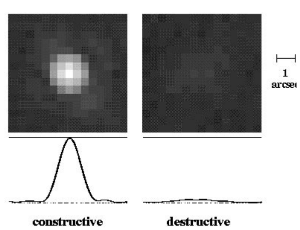
Roger Angel and a group at Steward Observatory in Arizona have just demonstrated that it is possible to overcome these barriers (see ** September 1998 issue of *Nature*), by showing that they can use an interferometer to cancel the light from a central star. The "nulling interferometer" was first proposed by Ronald Bracewell in 1978 as a way of getting around both technical problems simultaneously. In principle the idea is straightforward. Two mirrors, mounted on a rigid frame, reflect the light through an optical path that introduces a 180 degree phase difference. The beams are brought together, and the light from the central star is cancelled (just like the crest of a water wave will cancel the trough of another wave of the same amplitude). The difference in position between the star and the planets orbiting it means that the phases of light from the planets will add together, so the final image will show the planets but not the star.



A schematic diagram of the nulling interferometer at the Multiple Mirror Telescope on Mount Hopkins, Arizona. The six smaller mirrors have now been removed, in preparation for the upgrade to a single 6.5-m mirror.

If only it were that simple in practice. As is true in many other areas of astronomy, atmospheric effects interfere with these observations as well. In order to reduce the technical demands (and to be sensitive to the light from dust around other stars), Angel is conducting his experiments at mid-infrared wavelengths (10 microns). The difference in brightness between the star and the planet at such a wavelength is reduced to a factor of only about ten million, and the mechanical tolerances on the instrument do not need to be as stringent. But, atmospheric turbulence remains the limiting factor.

The intensity of the starlight in the image flickers as the light interference shifts randomly between being constructive and destructive, because atmospheric turbulence changes the optical path by about 5 microns (half a wavelength). Taking the brightest and faintest snapshots of the stars gives a difference of about a factor of 20 in intensity — the nulled image has only about five percent of the light of the un-nulled one. To demonstrate that light from outside a point-like stellar surface is not nulled, they observed Betelgeuse, which is known to be surrounded by an extended dusty nebula. The central star was nulled, leaving the surrounding nebula visible.



The left-hand panel shows an image made with constructive interference, and the right-hand panel demonstrates destructive interference.

Obviously, nulling by a factor of 20 will not make a planet visible. Angel is confident that with adaptive optics (which correct for the phase and wavefront variations resulting from atmospheric turbulence) installed on a suitable telescope, such as the Large Binocular Telescope now under construction on Mount Graham in Arizona, he will be able to image giant planets around stars as far away as 10 parsecs. The main challenge for now is to deal with the atmospheric turbulence. Much time, effort, and money has been put into adaptive optics, but there is not yet a system working at the level of precision required by Angel.

Detecting Earth-like planets is yet more difficult. They are smaller and therefore dimmer, so their signal may be lost in the background emission from dust in another solar system (like looking for a golf ball in the snow). We certainly have a significant amount of dust in our solar system, which gives rise to the "zodiacal light" — no one yet knows whether or how much similar dust circles other stars. The dust in our solar system is regenerated constantly by collisions between asteroids, so detecting zodiacal light around other stars will imply the presence of solid bodies like the asteroids, but not necessarily planets like the Earth. The dust will need to be carefully studied, using a ground-based nulling interferometer with adaptive optics, before the next step is taken.

NASA has bold plans to put a nulling interferometer in space. There has been talk of four 4-m to 6-m diameter mirrors, separated by about 100 m of rigid frame, and even some speculation about putting an interferometer with smaller mirrors somewhere around the orbit of Jupiter. Given the current lean budgets and the limited abilities of the shuttle, the latter is probably a pie-in-the-sky project right now. It seems that we are unlikely to know whether there are other Earth-like planets for another twenty years or so.

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

STAR QUOTE

"There is a story that once, not long after he came to Berlin, Planck forgot which room had been assigned to him for a lecture and stopped at the entrance office of the university to find out.

"Please tell me," he asked the elderly man in charge, "in which room does Professor Planck lecture today?" The old man patted him on the shoulder. "Don't go there, young fellow," he said. "You are much too young to understand the lectures of our learned Professor Planck."

Barbara Cline
American author (1965)

LOOKING DOWN AND LOOKING UP: COMMON VIEWPOINTS OF ARCHAEOLOGY AND ASTRONOMY[1]

by Michael Attas
Pinawa, Manitoba

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Abstract. The striking parallels between archaeology and astronomy are discussed. Several of the links between the two fields are fundamental, in particular their reliance on observation, the remoteness of the subject being investigated, and the critical importance of the time dimension. Exploring them helps to reveal general truths about how we conduct our search for knowledge. As well, a closer look indicates how approaches used in one discipline may be fruitful in the other.

Résumé. Nous discutons des parallels saillants entre l'archéologie et l'astronomie. Parmi les liens entres les deux disciplines sont leurs caractéristiques fondamentales, en particulier le besoin de se fier sur les observations, l'éloignement de la matière à l'étude, et l'importance essentielle de la dimension du temps. Leur examen aide à découvrir les faits généraux au sujet des méthodes selon lesquelles nous poursuivons notre recherche de connaissances. Aussi, un examen plus approfondi indique comment les méthodes utilisées dans une discipline peuvent servir avec succès dans l'autre. SEM

1. Introduction: Ways of Looking

Many people are fascinated by both archaeology and astronomy. Although some studies link the two by focusing on astronomy of ancient peoples (Aveni 1980; Brecher & Feirtag 1979; Hadingham 1985; Krupp 1983), they are most often thought of as quite distinct fields of study. In fact, there are striking parallels between the two disciplines. Some of the connections between the two fields are quite deep. In this paper the parallels are described and analyzed in the context of how we conduct our search for knowledge. General truths about mankind's insatiable curiosity are pointed out, and indications are given of how approaches used in one discipline may be fruitful in the other.

2. Observation and Experiment

One fundamental reason for the strong parallels between astronomy and archaeology is clear: both disciplines collect their primary data by a process of observation rather than experiment. That puts them in the same category as other natural sciences such as geology, and sets them apart from the laboratory sciences. Based on the primary data collected using observations, the theoretical principles of the fields are developed, as they are in other sciences. Of course, celestial phenomena must also obey the laws of nature; indeed, they have contributed to the discovery of such laws at least since the time of Newton. And though the subject of archaeology is mankind, we as creatures have always lived by Nature's laws as well.

A common aspect that distinguishes archaeology and astronomy from the other natural sciences is that the subject being investigated is inaccessible. An archaeologist can no more question a prehistoric person than can an astronomer scoop up a sample of galaxy for study in the lab. We are restricted to studying what comes our way, from afar and often in poor condition. So the primary data are collected by observation — sophisticated forms of observation, but observation none the less. In astronomy the observations may require powerful and expensive telescopes, orbiting observatories, and interplanetary probes. In archaeology the principal mode of observation is through excavation. It is difficult to conceive of other fields where the restriction of inaccessibility has so great an impact. Overcoming it has required extraordinary efforts and has led in some cases to extraordinary successes.

Experimentation plays a minor but important role in both fields. Laboratory experiments are performed to collect underlying data useful to the understanding of the astronomical and archaeological observations. For example, knowledge about the physics of light emission and absorption, the mechanical properties of flint, and the chemistry of metal corrosion is required to properly advance the study of starlight, stone tools, and ancient weapons, respectively. In the laboratory of mankind, ethnological studies of isolated, "primitive" tribes are the equivalent of physics experiments, though once again they are sets of relevant observations rather than experiments under

[1] Thanks to Peter Broughton for the inspiration for the title, from his excellent history of the RASC (Broughton 1994).

the researcher's control. There is also a sub-field called experimental archaeology that attempts to re-create artifacts and structures in their original form as well as in their present-day degraded form. But they are adjunct fields, providing supporting data.

As far as the main fields are concerned, we are restricted in our archaeological experimentation by the fact that humans evolved only once, and in the cosmological field by the fact that we know only one universe. There is really only one experiment to study in each case, namely the Big One, still in progress. The approaches to studying this big experiment are the same: collect data, then try to make sense of them; use the new knowledge to decide what new data to collect; repeat as necessary.

3. Living in the Field

Extracts from the Las Campanas journals published in the JRASC (Harris 1996; Madore *et al.* 1996; Matthews 1996) show a strong similarity to diaries from archaeological expeditions (Bacon 1976). The authors of the entries describe the isolation of research in the field, the frustrations of unco-operative equipment, staff, and weather, the often primitive living conditions, and the delights of an intense period of creativity in the company of like-minded souls.

Why are the trials and thrills of field stations so similar in archaeology and astronomy? In both cases the researcher is out collecting primary data. Going to where the data can best be collected is essential. And the highest-quality data are found where mankind's activities have corrupted the data the least. It is an issue of signal-to-noise ratio. The noise comes from light pollution, smog, vibration, and temperature instabilities in the case of stargazing, while in archaeology it is the result of construction, urbanization, paving, ploughing, flooding, and all of the other things we do to the Earth in the course of molding it to fit our needs. So astronomers go to remote mountaintops, and archaeologists to remote (but habitable, at least in the past) deserts and valleys.

"Remote" usually means primitive. Electricity, plumbing, heating, and entertainment are all rudimentary. To compensate for that, several of the richer countries (or patrons of research) have blessed their field researchers with living facilities offering at least some of the comforts of home. The American School of Classical Studies has a field house at Ancient Corinth that serves ouzo on the terrace at sunset, as well as containing an excellent library of archaeological reference works and pulp fiction. During the day it is home base for researchers doing a wide variety of innovative archaeological fieldwork in the region of Greece around Corinth. Observatory residences and dining halls have similar perks, such as the wonderful, sunny, wooden deck on the residence for Canada-France-Hawaii Telescope staff, perched on the southern slope of Mauna Kea. Such comforts make life in the wild just that much more bearable.

4. Show Me the Money

The existence of archaeological and astronomical facilities in the field highlights a related aspect of their similarity, namely funding shortages. Research in both fields is expensive, and costs continue to increase rapidly. Even for ground-based astronomy, the newest facilities fall into the category of "big science," requiring big budgets. The lack of so-called practical applications in both fields has meant that funding usually does not come from industry. Instead it is solicited from government granting agencies and private benevolent donors or foundations.

Both archaeology and astronomy have been particularly successful at attracting private funding. The Keck telescopes and the Sloan digital sky survey are only two examples of high-profile astronomy projects funded by interested private groups. The Smithsonian Institution and the Carnegie Institute fund research in both fields.

The two fields of study attract funding from potential benefactors partly because they can provide very positive publicity. They also have a high media profile. The public has a remarkable appetite for news of progress in astronomy and archaeology, and researchers are happy to oblige. Efforts at popularization have resulted in numerous books, exhibitions, and television programs highlighting the latest discoveries. The human angle is stressed by focusing as much on the astronomers and the archaeologists as on their findings (Bacon 1976; Goldsmith 1991). The popularity of the two fields also results in a steady stream of students to university programs in archaeology and astronomy. Those students are willing to risk limited career opportunities for the thrill, satisfaction, and lasting pleasure of the search for knowledge. It may seem paradoxical that such intense interest can be elicited yet funding continues to be a problem. But given the current emphasis by governments on funding "applied" or "practical" research to the detriment of "purer" fields of study, astronomy and archaeology researchers have been remarkably successful in finding money.

5. The Collectors and the Catalogues

From earliest times, ancient people have tried to make sense of their past. Information on where we came from can be found in texts that have survived to our day, such as the Old Testament, among others. Although they may include descriptions of man's origins, some would categorize them as received wisdom, myth, or metaphor rather than evidence based on observation.

Systematic investigations of the origins of civilization in the form of early material remains, *i.e.* artifacts, began much more recently. Sculptures and vases from the Greek and Roman world were studied during the Renaissance. Europeans learned of the civilizations of Egypt and the Etruscans soon after that. The basic division of prehistory into the Stone, Bronze, and Iron Ages by C. J. Thomsen of the Copenhagen Museum came in 1819 (Daniel 1975). The history of archaeological thought since that time has been studied in detail, most recently by Bruce Trigger (1990).

Ancient observers of the night sky were probably just as curious to understand it as to understand their own past. Groups of stars were organized to form constellations, and wandering stars distinguished from fixed ones. Star catalogues were produced by Hipparchus and others, giving names, positions, and magnitudes for hundreds of the brighter stars. Ptolemy's *Almagest* (Toomer 1984) is the only one to have survived from ancient times. The catalogues were key documents in the retention and transmission of knowledge over centuries. [The sub-field called archaeo-astronomy examines the astronomical knowledge of prehistoric mankind, most often by studying orientations of postulated ancient observatories such as Stonehenge (Hawkins 1973). Study of more recent astronomical instruments falls into the sub-field called history of astronomy.]

Astronomical catalogues gradually became much more comprehensive, detailed, and specialized, especially after the invention of the telescope. Charles Messier compiled one of the earliest, and certainly the most famous, of the catalogues of non-stellar objects. Since his time, catalogues have appeared for every imaginable category of space object, from minor planets to peculiar galaxies. There is even a catalogue of catalogues, namely the *NASA/IPAC Extragalactic Database* (NED), on the Internet of course (Madore 1997). On the archaeological side, collectors of art objects produced lists of their holdings, as did museums and galleries. Often the collections and the catalogues were organized in some logical fashion, such as by artist or period for sculptures and painted vases, or by style for jewelry and coins.

The ultimate archaeological catalogue is the monumental *Corpus Vasorum Antiquorum* (*e.g.* Beazley 1927). The product of an international collaboration, its lofty goal is to publish, with high-quality illustrations, every Classical (primarily Greek, Roman, and Etruscan) painted vase in museum collections around the world. Scores of volumes have appeared since early this century, and the project is far from complete. Nevertheless, it is an invaluable (and very expensive) reference for specialists in painted pottery from ancient times.

In both fields the catalogue was an end in itself and also a springboard to further analysis and discovery. The publication of a catalogue allowed scholars access to descriptions, drawings, and eventually photographs of the objects under study. In that way, dissemination of the information through the scholarly world brought many more analytical minds to help interpret the significance of the objects. The availability of a published corpus of all known objects of a given type greatly facilitated theoretical progress, most remarkably in enabling the decipherment of ancient scripts such as the Linear B tablets (Chadwick 1970). At the same time, it was recognized in both fields that direct study of objects provided information beyond what was included in the catalogue. That was a consequence of the limitations of publication, especially in early days, but also of the biases, implicit or explicit, of the cataloguer. Modern information technologies, such as digital imaging, CD-ROMs and the World Wide Web, allow for more detailed descriptions and better use of catalogued data, but the complementary need for direct observation remains.

The urge to observe and collect new data sometimes outpaces the ability of the researcher to publish the data. That is another problem common to both fields, and many others. The excitement of field sessions, be they at the observatory or in the excavation trenches, can lead to optimistic predictions of how much effort is required or available to properly study and publish the observations. Back in the office, financial and time pressures often result in delays of years, or even decades, before final reports are issued. It is much easier to persuade graduate students to participate in fieldwork that generates new data than to study previously collected data and write up results. In archaeology the problem is so widespread that grants exist specifically to fund study and publication of finds from old excavations.

6. Sampling the Population

Another result of modern information technology is the ability to examine large data sets such as catalogues more methodically. Statistical analysis, exploratory data analysis, graphical display, and development and testing of models all take place in both fields of research. The concept of probabilistic sampling was a radical change in archaeological thought. Instead of focusing on the treasures and unique finds, some archaeologists in the 1960s began to realize that to draw valid quantitative conclusions from their data required a robust sampling plan. For example, for true rigour it became important to subdivide excavation areas with the help of tables of random numbers, and to determine potsherd abundances on the basis of clearly defined collection procedures (Cherry *et al.* 1978). Researchers could then infer characteristics of the population (of artifacts, and ultimately of humans) as a whole. It led to a new type of research design, which in archaeology had its greatest impact in regional studies done by surface survey.

The technique of surface surveys as a means of discovering promising sites for excavation by examining remains lying on the ground has a long history (Trigger 1990). But in its modern conception, the goal was not so much to discover new sites as to examine the density and distributions of populations and how they changed with time. In such a framework, barren areas and periods were intrinsically just as interesting and informative as rich ones. Given the expense of complete coverage in regional surveys, statistical sampling proved remarkably cost-effective as well as providing some rigour and objectivity.

In astronomy the same issues of cost-effectiveness have been dealt with in the same way. Sky surveys have sampling plans that emphasize either deep or broad coverage, and intensive or extensive examination of selected areas, as appropriate. Many discoveries have arisen from new, computer-assisted ways of looking at vast quantities of data. Indeed, the largest known structure in the universe, the "Great Wall" of galaxies stretching across the remote sky, (Geller & Huchra 1989; Geller 1994) can be seen *only* with the help of a computer plot. In archaeology the tedium of plotting by hand the location of every find in an excavation has been relieved by the use of computers and geographic information systems (GIS). Isometric and perspective depictions of structures and of artifact distributions can be produced, rotated, and examined from fresh angles, providing additional insights into the relationships of the objects being plotted. The use of global positioning systems (GPS) to instantly document surface survey results and excavation findspots is another area where computers (and artificial satellites) have allowed researchers to record and visualize large data sets in productive ways.

7. Distance = Age

A central aspect common to archaeology and astronomy is the fundamental importance of the time dimension. Both fields examine messages reaching our time and space from the distant past. In astronomy almost all of the messages are forms of light organized in some way, while in archaeology they are materials altered by the activities of man. Teasing out the information contained in the messages takes patience and ingenuity.

The basic sciences of physics and chemistry play a crucial role in the interpretation of such messages from the past. Finding out how far in the past they originated is a fundamental prerequisite for more involved research. In astronomy a major breakthrough was

Edwin Hubble's discovery of the connection between redshift and distance, attributed to the expansion of the universe (Hubble 1929). That resulted in a time/distance scale, and it fixed objects onto their proper place in the space-time continuum. Not only are more distant objects receding more rapidly, but they are also being seen by us as they were longer ago, *i.e.* at an earlier stage of their evolution and the evolution of the universe as a whole.

The equivalent breakthrough in archaeology was the invention of radiocarbon dating (Libby 1955). The incorporation into living tissue of carbon-14, itself produced as the result of cosmic-ray bombardment of the upper atmosphere, allowed the time elapsed since the death of organisms to be calculated from a measurement of their residual radioactivity. Measurement of other naturally occurring unstable isotopes extended radiometric dating back millions of years. All such techniques gave archaeologists a powerful tool for determination of absolute age.

Of course, relative-dating methods had been established many decades previously. The study of strata, or layers, had been adapted from geology and extensively developed by 20th century archaeologists (Daniel 1975; Trigger 1990). That provided the relative ages of layers found in excavations, and therefore yielded information on the objects embedded in them. Reduced to its most basic form, the "fundamental law of stratigraphy" states that younger deposits overlie older ones. It is just the "distance = age" principle applied to looking down instead of looking up!

A unique application of stratigraphic analysis, not to archaeology but to astronomy, was the recent identification of the Chicxulub crater as the remains of the meteorite impact that caused the end of the Cretaceous period. In his masterful summary article, Hildebrand (1993) described his comparison of stratigraphic profiles from various places in North America, not only to establish the date of the event at the end of the Cretaceous (65 million years ago), but also to pinpoint its location to the Yucatan peninsula. It was possible to identify a signature layer marking the boundary between the Cretaceous and the Tertiary strata, the so-called K/T boundary. For each stratigraphic core, Hildebrand and other researchers found a strong correlation between proximity to the Gulf of Mexico and the thickness of the layer of debris at the K/T boundary. Geomagnetic and hydrogeological data confirmed the Yucatan as the site of a large, buried crater. By looking down, he and other researchers were able to solve a puzzle whose extraterrestrial cause has now been clearly established.

Somewhat similar, widespread, signature layers occasionally appear in archaeological strata as well, marking general, simultaneous destructions of many ancient settlements as a result of earthquakes or volcanic eruptions. They are sometimes termed "event horizons" — which means something quite different to an astronomer! — and serve to form valuable chronological links among sites across an entire region. There is often a temptation to ascribe synchronicity to destruction layers found at excavations of neighbouring sites, however, and that leads to the risk of circular argument, which can be avoided by using dating methods independent of stratigraphy. A similar situation, with the same need for independent dating methods, recently appeared in the astronomical literature as well, in connection with some craters on Earth that have similar ages and may form linear patterns if their positions are plotted on maps that take into account plate-tectonic motion of the continents (Spray *et al.* 1998).

8. Chronologomaniacs

The title of this section is a made-up word referring to scholars who devote their careers to refining the time-scale of past events. Such activity has become an obsession for many archaeologists as well as a few astronomers, and has led to bitter feuds lasting decades. In archaeology, controversy has surrounded dating of all major events, from Biblical ones (the Great Flood, the Exodus from Egypt) to the antiquity of Egyptian civilization, where the conflict between supporters of the so-called long and short chronologies, almost a thousand years apart, lasted for decades. It was resolved only with the eventual success of radiocarbon dating, particularly after its calibration using tree-ring dates (Clark & Renfrew 1973). The 19th century debate on the age of the Earth was relevant both to archaeology and to cosmology. Radioactive clocks helped there as well, initially based on the accumulation of helium in rock as a result of alpha decay, and more precisely once Rutherford and others had sorted out the complex decay sequence of uranium and its daughter elements (Rutherford 1905; Romer 1964).

The greatest cosmological debate of the 20th century concerned the age of the whole universe and the distance of its remotest parts. Edwin Hubble's first determination of the rate of expansion of the universe (Hubble 1929) has since been revised many times (Trimble 1996). For the past three decades another debate has raged, this time between proponents of a young and small universe and those arguing for an old, large one. Recent evidence suggests a compromise may be called for (van den Bergh 1995), but the absurd conclusion that certain globular clusters are older than the universe is a clear warning sign that more rearrangements are in order.

Although fascinating in their own right, arguments about chronology are sterile unless their implications are explored. Knowing dates alone does not help us learn about ancient people, nor does the age of galaxies give direct information on their structure. What the dates do is allow us to examine change, study evolution, and look for cause and effect. The chronologies provide a framework for study, but they do not provide answers to archaeological or astronomical problems in and of themselves. The archaeological pioneer Mortimer Wheeler (1954) expressed this frustration best when he said, "We have… been preparing time-tables; let us now have some trains."

9. Evolution and Seriation

Stars evolve; so do civilizations. They are born, develop, flourish, and ultimately die. From the ashes of one, another can be born. Looking up or looking down, we can see examples at all stages of evolution. A collection of stars, galaxies, stone tools, or hatpins can be put into relative sequence on the basis of rules of development, or even just intrinsic similarities. For stars, the H-R diagram was a major success, not just because of the relationship it demonstrated between their colours and luminosities, but because it inspired thinking about how the changing properties of stars over their lifetimes would change their location within the diagram as they evolved.

In archaeology the ordering of artifacts into a linear sequence on the basis of similarities is called seriation. In its purest form it is a mathematical exercise involving manipulation of matrices of numerical similarity coefficients until the artifacts they represent show the smoothest progression of characteristics such as shape, style, or decoration (Deetz 1967). The classic example is the sorting out of tombs in a graveyard from oldest to most recent on the basis of their style and their contents. When no other dating information is available, seriation can be a powerful tool for understanding relationships among objects. But it is most effective when used in conjunction with other ways of studying the material (*e.g.* stratigraphy) to obtain a more complete picture of the significance of a collection of artifacts.

10. Facts and Artifacts

The travel through time of the astronomical and archaeological messages from the past alters them from their original state. Although the scales are vastly different, both the light and the artifacts get quite a battering along the way. That makes sorting out the original state of the message a challenge. The process of message collection contributes further distortions resulting from the imperfections of the collection process or instrument. Similar effects occur in archaeology as well, as a result of the destructive nature of excavation or from inevitable, though subconscious, sampling biases.

Ironically, in astronomy such effects are known as artifacts, and are avoided wherever possible. The dual use of the word artifact is explained by its Latin etymology, as meaning something made by skill, *i.e.* man-made as opposed to natural in origin. Archaeologists search for evidence of man's activities, while astronomers study natural objects, devoting considerable effort to reducing man-made effects in the observations.

Along with distinguishing the alterations from the original, researchers seek to squeeze out all the information hidden in the message. Such techniques make the best use of the effort of collecting the data in the first place. For starlight collected on a photographic plate or a CCD, extensive numerical analysis in the form of digital image processing has the best chance of maximizing the information gained. For artifacts, traditional analysis of form, style, and decoration has been recently supplemented by scientific analysis of physical and chemical properties. This form of attack has revealed a wealth of new types of information, and has spawned a new field of specialization called archaeometry.

Archaeometric researchers work to "get the facts out of the artifacts." The field began in the late 1950s, and has grown to maturity since then. The use of chemical and radiometric analysis for dating artifacts, mentioned above, is a large sub-field. Other techniques are used to reveal the method of manufacture of artifacts, for example the kiln firing temperature and conditions for pottery. A particularly successful application of chemical analysis has been to determine the origin, or provenance, of manufactured articles by their trace-element content or particular isotope ratios. Distinctive patterns of trace-element concentrations in the raw materials are often preserved in the final article, especially if the manufacturing process involves little or no chemical change. Flint, chert, and especially obsidian tools are good examples of artifacts with the same chemical compositions as their raw materials. For pottery, the composition of the fired ceramic has a strong connection to that of the original clay bed, and transport of articles in ancient times, especially luxury goods, can be traced (Jones 1986), often over surprisingly long distances.

One of the most powerful techniques of trace element analysis, because of its sensitivity and multi-element capability, is neutron activation analysis, or NAA. It has been applied to almost all types of artifacts, including those of stone, bone, metal, glass, and pottery. The author has used the technique to study pottery trade in Early Bronze Age Greece (Attas *et al.* 1977, 1987), following work performed by one of the pioneers in the field, the chemist Frank Asaro (Perlman & Asaro 1969). More recently, Asaro gained fame in astronomical circles by his neutron activation analysis of the thin layer of rock separating Cretaceous from Tertiary sediments. The high iridium concentration of the layer relative to all others was the first clue that an extraterrestrial body had hit the Earth 65 million years ago (Alvarez *et al.* 1980), as described above.

In astronomy, physical and chemical analysis are also applied to the most substantial of the messages from beyond the Earth, namely meteorites. The most spectacular result of that effort came from study of the rock ALH84001, found in Antarctica in 1984. Determining that it originated on Mars was a first-class scientific achievement, based on its undisputed membership in a meteorite class for which other members had isotopic analyses of gas trapped in microscopic glassy inclusions compare very closely with the results of *Viking* lander measurements of the Martian atmosphere. Determining that it left Mars 15 million years ago and arrived on Earth 13,000 years ago took subtle reasoning and delicate radiometric measurements. Most recently, chemical, mineralogical, and structural (microscopic) analysis has indicated that it may have harboured a primitive form of life billions of years ago (McKay *et al.* 1996; Gibson *et al.* 1997). The unspectacular looking rock hides amazing secrets, revealed to precise and focused investigative attempts. So it is with archaeometric research as well. The results hardly ever make headlines, except perhaps when a museum piece — or the Shroud of Turin — is proven to be a fabrication. Of course, obtaining permission to sample a museum piece or meteorite for scientific analysis can be a taxing exercise, and methods that use only a tiny sample or which are non-destructive are more likely to be accepted by the keepers of the material.

11. Answering the Big Questions

What do we hope to learn by looking down and looking up? In some cases we want to gain a better understanding of our origins, our place on Earth and in the universe, perhaps our ultimate fate. Some researchers decide to specialize deeply in a restricted topic of study, so they become experts in Ap stars, or Cretan seal-stones, or solar seismology, or ancient fingerprints. There is nothing wrong with this! In all cases they are pushing back the frontiers of knowledge, increasing our understanding of this or that part of the world around us or of mankind's past. Based on the data such researchers generate, it is possible to formulate and test general laws of the formation, development, and extinction of various types of object, be they stars, galaxies, planets, cultures, economic exchange systems, or civilizations.

Other researchers focus instead on what could be called the Big Questions: Where did we come from? How will it all end? And biggest of all, Why? Tackling them takes a synthesis of the findings of many, and a talent for making sense of a wide variety of facts, observations, evidence, and theories. Philosophical tendencies and boldness of intellect are called for. The fact that such big questions can be asked in both archaeology and astronomy, indeed have been asked since the beginnings of human curiosity, is one of the deepest similarities between the two fields. Maurice Maeterlinck (1930) expressed the sentiment most eloquently by quoting the medieval alchemist Hermes Trismegistus. He wrote, "The absolute similarity in contrivance, in framework and structure, proves once again the truth of what Hermes Trismegistus said, in a phrase that sums up all prehistoric science: 'What is above is like what is below, what is below is like what is above'."

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Michael Attas
Box 744
Pinawa, Manitoba
R0E 1L0

References

Alvarez, L. W., Alvarez, W., Asaro, F. & Michel, H. V. 1980, Science, 208, 1095
Attas, M., Yaffe, L. & Fossey, J. M. 1977, Archaeometry, 19, 33
Attas, M., Fossey, J. M. & Yaffe, L. 1987, Journal of Field Archaeology, 14, 77
Aveni, A. F. 1980, Skywatchers of Ancient Mexico (University of Texas Press: Austin)
Bacon, E. (ed.) 1976, The Great Archaeologists (Bobbs-Merrill: Indianapolis/New York)
Beazley, J. D. 1927, Corpus Vasorum Antiquorum: Oxford: Ashmolean Museum (Clarendon Press: Oxford)
Brecher, K. & Feirtag, M. (eds.) 1979, Astronomy of the Ancients (MIT Press: Cambridge, Mass.)
Broughton, R. P. 1994, Looking Up, A History of the Royal Astronomical Society of Canada (RASC: Toronto)
Chadwick, J. 1970, The Decipherment of Linear B (Cambridge University Press: Cambridge)
Cherry, J. F., Gamble, C. & Shennan, S. 1978, Sampling in Contemporary British Archaeology, B.A.R. 50 (British Archaeological Reports: Oxford)
Clark, R. M. & Renfrew, C. 1973, Nature, 243, 266
Daniel, G. E. 1975, A Hundred and Fifty Years of Archaeology (Harvard University Press: Cambridge, Mass.)
Deetz, J. 1967, Invitation to Archaeology (Natural History Press: Garden City NY)
Geller, M. J. 1994, JRASC, 88, 283
Geller, M. J. & Huchra, J. P. 1989, Science, 246, 897
Gibson, E. K., Jr., McKay, D. S., Thomas-Keprta, K. & Romanek, C. S. 1997, Sci.Am., 276, December, p. 58
Goldsmith, D. 1991, The Astronomers (St. Martin's Press: New York)
Hadingham, E. 1985, Early Man and the Cosmos (University of Oklahoma Press: Norman)
Harris, W. E. 1996, JRASC, 90, 7
Hawkins, G. S. 1973, Beyond Stonehenge (Harper and Row: New York)
Hildebrand, A. R. 1993, JRASC, 87, 77
Hubble, E. P. 1929, Proc. Natl. Acad. Sci., 15, 168
Jones, R. E. 1986, Greek and Cypriot Pottery: A Review of Scientific Studies (British School at Athens: Athens)
Krupp, E. C. 1983, Echoes of the Ancient Skies: the Astronomy of Lost Civilizations (Harper & Row: New York)
Libby, W. F. 1955, Radiocarbon Dating (University of Chicago Press: Chicago)
Madore, B. F 1997, in Bishop, R. (ed.) Observer's Handbook 1998 (RASC: Toronto), p. 239
Madore, B. F., Jedsrejewski, R. & Matthews, J. M. 1996, JRASC, 90, 69
Maeterlinck, M. 1930, The Magic of the Stars, 60-61 (Allen & Unwin: London)
Matthews, J. M. 1996, JRASC, 90, 115
McKay, D. S., Gibson, E. K., Thomas-Keprta, K. L., Vali, H., Romanek, C. S., Clemett, S. J., Chillier, X. D. F., Maechling, C. R. & Zare, R. N. 1996, Science, 273, 924
Perlman, I. & Asaro, F. 1969, Archaeometry, 11, 21
Romer, A. 1964, The Discovery of Radioactivity and Transmutation (Dover: New York)
Rutherford, E. 1905, Phil. Trans. Roy. Soc. Lon. A, 204, 169, reprinted in Romer (1964)
Spray, J. G., Kelley, S. P. & Rowley, D. B. 1998, Nature, 392, 171
Toomer, G. J. 1984, Ptolemy's Almagest, translated and annotated by G. J. Toomer (Springer: London)
Trigger, B. G. 1990, A History of Archaeological Thought (Cambridge University Press: New York)
Trimble, V. 1996, PASP, 108, 1073
van den Bergh, S. 1995, JRASC, 89, 6
Wheeler, R. E. M. 1954, Archaeology from the Earth (Clarendon Press: Oxford)

MICHAEL ATTAS is a scientist with Atomic Energy of Canada Limited at AECL's Whiteshell Laboratories in Pinawa, Manitoba. During his archaeological and radiochemical studies at McGill University and Orsay in France, he participated in excavations at Senneville in Québec, Perakhóra in Greece, and Sallèles d'Aude in France. He is co-developer of the Cerenkov Viewing Device (CVD), an ultraviolet viewer used internationally to inspect used nuclear fuel, and has trained inspectors in its use in Austria, Sweden, Finland, Luxembourg and Spain. Despite embracing digital CCD technology at work, Mike claims there is no sensation to equal that produced by an extragalactic photon directly striking the retina of an observer's eye in his backyard in Pinawa. In his spare time, Mike also proofreads the Journal *and occasionally provides editorial advice.*

SUDBURY IMPACT STRUCTURE MODELING WITH HIGH RESOLUTION SEISMIC REFRACTION SURVEY RESULTS[1]

by W. M. Moon and L. X. Jiao

The University of Manitoba
Electronic Mail: wmoon@cc.umanitoba.ca, lingxiu@cc.umanitoba.ca

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Abstract. The Sudbury Structure is a widely known geological feature, but is still being investigated extensively because its origin and formation history have many unanswered questions. It is believed to be a meteorite impact structure and is composed of the Sudbury Igneous Complex (SIC) along the border, young sedimentary rocks in the Basin, and the Levack Gneiss Complex (LGC) outside along the north range of the Basin structure. The 1992 high-resolution refraction seismic survey, carried out as a part of the *Lithoprobe* Abitibi-Grenville Transect experiments, included two in-line profiles in cross pattern and two sets of fan-shot data perpendicular to the two in-line profiles. The scientific objectives of the project included two-dimensional and three-dimensional imaging of the crustal structures beneath the Sudbury Structure and the surrounding area. Results of forward and inverse modeling, tomographic inversion, and preliminary interpretation of the refraction seismic data indicate that there is a clearly defined high velocity layer with a lenticular shape below the Sudbury Basin structure at a depth range of approximately 4.5 to 9.0 km. Even after two billion years of deformation, including truncation by erosion and several stages of subsequent geological evolution, the upward concave shape of the velocity anomaly conforms with the proposed original meteorite impact model, and has a close correlation with it.

Résumé. La structure de Sudbury est un système complexe géologique bien connu, mais un qui néanmoins continue de faire l'objet de nombreaux à cause des questions sur son origine et sa formation que restent toujours sans réponses. On croit qu'elle est le résultat de l'impact d'un météorite et qu'elle se compose du complex igné de Sudbury le long des marges, de jeunes rochers sédimentaires dans le bassin, et du complex Levac Gneiss en dehors, le long de la frontière nord de la structure du bassin. L'enquête sismique réfraction à haute résolution, faisant partie des essaies lithosonde de la virée transversale Abitibi-Grenville, comprenaient deux profils en lignes en forme de croix et deux series de données en forme d'évantail perpendiculaire aux deux autres profils. L'objet scientifique du projet comprenait la présentation en images, en deux et trois dimensions, de la croûte des structures en dessous de la structure de Sudbury et des régions adjacentes. Les résultats des modèles inverses et avant, l'inversion tomographique, et les interpretations préliminaires des données sismiques réfraction indiquent qu'il y a une couche clairement définie provenant d'une grande vitesse, en forme de lentille sous le bassin de Sudbury, à environ 4,5 à 9 kms de profondeur. Même après deux milliards d'années de déformation, y compris de la troncature à la suite d'érosion et de plusieurs phases subséquentes d'evolution géologique, la forme concave vers la surface résultant de la vitesse se conforme au modèle original d'impact de météorites, et présente une correlation étroite avec les paramètres de ce modèle.

SEM

1. Introduction

The Sudbury Basin is a well-known geological structure that has been extensively mapped and studied. On the surface the Sudbury Basin and surrounding areas are composed of the Sudbury Igneous Complex (SIC) along the rim, younger sedimentary rocks in the Basin, and the Levack Gneiss Complex (LGC) outside along the north range. The Archean Superior Craton is the main feature northwest of the Basin (figure 1). The northeastern area outside the Basin towards Temagami is covered by Huronian supergroup rocks. Southeast of the Basin the Grenville Front Tectonic Zone (GFTZ), which is approximately 30 km wide, and the Britt Domain are representative features of the younger Grenville Province in the area of study. The GFTZ is characterized by a series of south-east dipping stacked ductile deformation crustal sheets (Epili & Mereu 1991; Miao 1995).

The detailed processes involved in the formation of the present day Sudbury Structure are not well understood. In order to probe the elliptical pattern marking the unusual deformation of the Sudbury Structure in a three-dimensional perspective, integrated geophysical surveys were planned and carried out as a part of the *Lithoprobe* Abitibi-Grenville Transect (AGT) experiments (Irving *et al.* 1993). Their purpose was to study and resolve some of the questions about the original meteorite impact hypothesis and the structure's subsequent deformation through geological times. The integrated geophysical experiments planned as a part of the *Lithoprobe* AGT included a large-scale high-resolution refraction seismic experiment across the provinces of Ontario and Quebec. Among the five profiles, lines *AB* and *XY* traversed the Sudbury Structure (figure 1) and imaged the structures of the crust and upper mantle beneath it (Lithoprobe Report #30, 1993).

The evolution of the Sudbury Structure has been a central issue of many geological studies for more than one hundred years (Boerner *et al.* 1994). Since Dietz (1964) first proposed three decades ago that the Sudbury Structure might have evolved from a meteorite impact during the Precambrian era (approximately 1.85 Ga ago), based on the discovery of shatter cones in the footwall rocks surrounding the SIC, whether the Sudbury Structure was formed by exogenic impact or by endogenic igneous activity has been a controversial question. During that time various pieces of evidence for shock metamorphic effects in the Sudbury area have been found that strongly support an impact origin for the Sudbury Structure. Some of them include planar deformation features in quartz, shatter cones, and the occurrence

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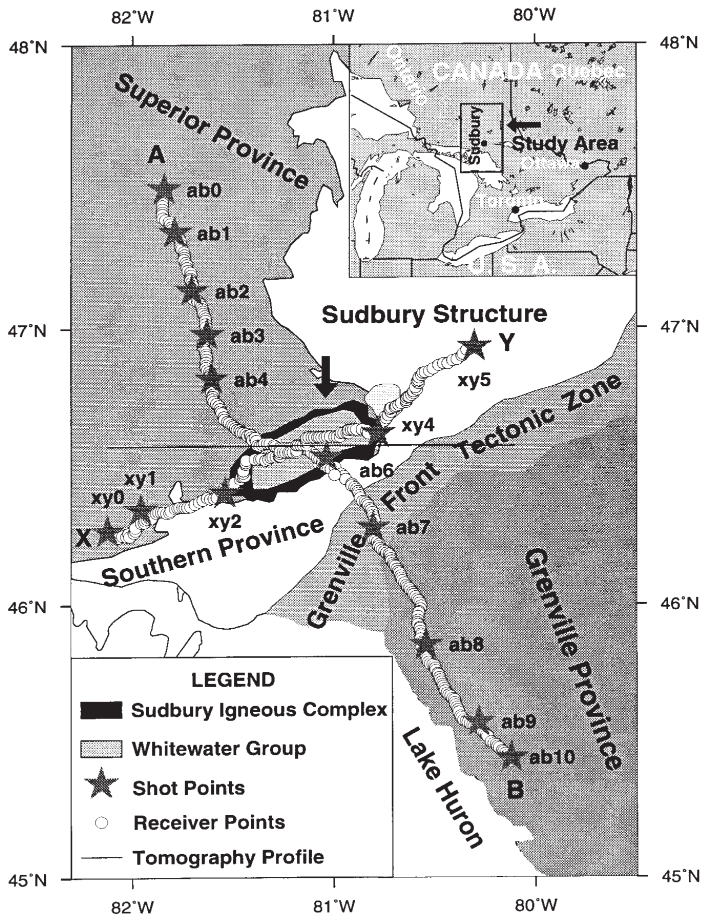


Fig. 1 — A schematic map showing the general geology of the Sudbury Basin region and the location of the 1992 *Lithoprobe* AGT Sudbury high-resolution seismic reflection and refraction survey. The alphanumeric numbering represents the shot points used in the *Lithoprobe* AGT experiment.

of pseudotachylyte (French 1967; Dressler 1984; Spray & Thompson 1995). The elliptical shape of the Sudbury basin was interpreted as the result of northwest thrusting deformation during the Penokean and Grenville orogenies, according to high resolution seismic reflection data (Milkereit *et al.* 1992; Wu *et al.* 1995). Nevertheless, the genesis of the SIC still remains to be explained through further field studies.

Recent results of the *Lithoprobe* AGT experiment's high-resolution seismic reflection survey show an asymmetric geometry for the Sudbury Basin at depth (Milkereit *et al.* 1992; Wu *et al.* 1995). The seismic reflection image reveals that the North Range units dip towards the south, while there are numerous south-dipping reflection events under the South Range that clearly reflect thrust faults (Milkerreit *et al.* 1992; Wu *et al.* 1995). Such thrust faults imply that the Sudbury Structure underwent a NW-SE shortening deformation (Milkereit *et al.* 1992; Milkereit *et al.* 1994; Wu *et al.* 1995), and they provide probable evidence for impact origin. The non-circular shape can be attributed to deformation during a period of tectonic activity in the surrounding region following the Sudbury impact event.

Interpretation of regional magnetic and gravity modeling based upon the high-resolution reflection seismic survey indicated that there was no need to model a large hidden ultra-mafic mass to explain the potential field data (Hearst *et al.* 1994; McGrath & Broome 1994). The results also implied that the SIC might represent an impact melt sheet (Grieve *et al.* 1991). Hence, Boerner *et al.* (1994) presented a summary of geophysical studies by stating that "no clear indication was obtained of a hidden layered intrusion of the type postulated in the previous studies, effectively reducing the scope of plausible endogenic interpretations."

Isotopic data for the elements Sr, Re-Os and Nd show that the components of the Sudbury Igneous Complex (SIC) are mostly derived from ancient crustal rocks (Faggart & Basu 1985; Walker *et al.* 1991; Grieve *et al.* 1991). Least squares mix models have also been carried out to explain successfully the correlation of the average components of the igneous complex and the mixing compositions of Archean granite-greenstone terrain with a small amount of Huronian cover rocks (Grieve *et al.* 1991). Rb-Sr dating of the Footwall breccia indicates that the formation of the Footwall breccia is related to the cooling of the hot SIC 1.825 ±0.021 Ga ago (Deutsch *et al.* 1989). Spray & Thompson (1995) described the radial distribution of the friction melt (pseudotachylyte) around the SIC. The friction melt observed at distances of 1 to 13 km, 25 to 35 km, 42 to 48 km and 78 to 80 km beyond the SIC forms ring-shaped spatial patterns. Spray & Thompson (1995) pointed out that the ratio of adjacent ring diameters is approximately in the ratio $\sqrt{2}$, which is what is found for the diameters of adjacent rings in lunar multi-ring impact basins (Melosh 1989; Spray & Thompson 1995). Hence, the Sudbury Structure might be the remnant of a large multi-ring impact basin.

2. High-Resolution Seismic Refraction Survey

One of the main objectives of the *Lithoprobe* seismic experiments was the probing of the Earth's crust and upper mantle. The high-resolution refraction seismic survey across the Sudbury Structure was carried out with an approximately 30 km shot spacing and 1 to 1.5 km receiver spacing (figure 1). All shot and receiver points were surveyed using *Trimble* Pathfinder Global Positioning Satellite (GPS) receivers with the base station at the *INCO* Copper Cliff Exploration office. Horizontal accuracy of the differential GPS positioning of the shot and received points was estimated to be approximately ±5 metres after routine corrections.

A total of fifteen shot holes were drilled with an average diameter of 20 cm and an average depth of 40 m. Dynamite charge sizes used in the experiments ranged from 200 kg to 1600 kg. Four different device types were deployed for recording the data, including the Geological Survey of Canada (GSC)'s PRS1 and PRS4 recorders and two different types of U.S. Geological Survey (USGS) recorders (Irving *et al.* 1993). Seismic data recorded using the USGS instruments were converted to the GSC data format following the experiment, and re-sampled.

Line *AB* traversed the Abitibi subprovince in Superior Province, the Sudbury Structure, the Huronian group in Southern Province, and the GFTZ and Britt Domain in Grenville Province. The total length of the profile was about 265 km in an approximately northwest to southeast direction (figure 1). Originally eleven shots were planned along line *AB*, but one of the shots was abandoned because of environmental concerns. Line *XY* was set at roughly a right angle to line *AB* in an approximately southwest to northeast direction. A total of five shots were successfully recorded along the line.

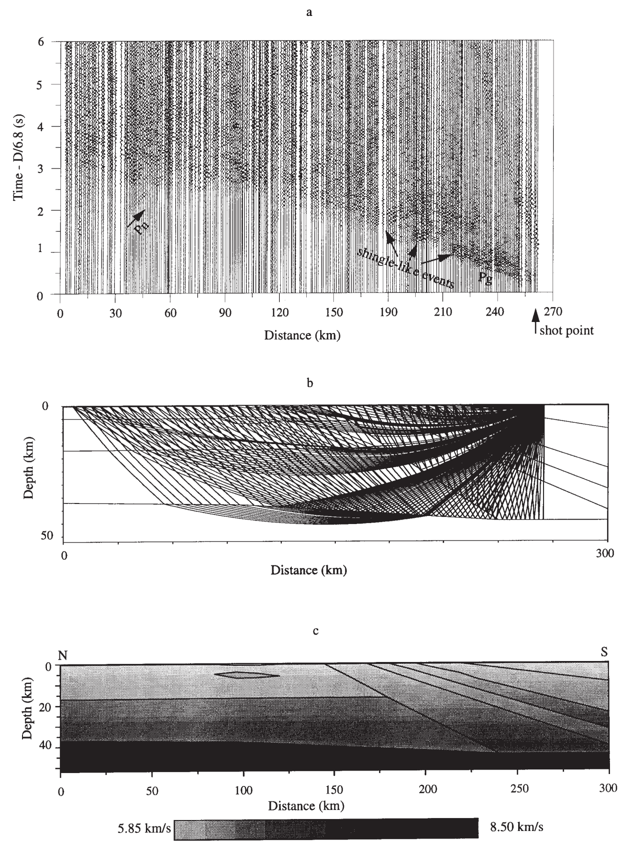


Fig. 2 —A seismic refraction section of in-line *ab10* (a), ray path diagram (b), and velocity model (c) obtained along profile *AB* (from top to bottom). The solid lines in (b) and (c) represent the seismic velocity structure boundaries. Shot point is marked on the seismic data figure with an arrow.

In addition to the above two in-line profiles, the receivers along line *AB* recorded the fan-shot data for each shot in line *XY*, while the receivers along line *XY* recorded the fan-shot data from the shots in line *AB*. Therefore, there were ten sets of fan-shot data from line *AB* recorded on the line *XY* receivers and five sets of fan-shot data from line *XY* recorded on the line *AB* receivers. As the offset distance increases the subsurface coverage decreases, but the surface extent of lines *AB* and *XY* were such that three-dimensional spatial coverage of the fan-shot data was more than adequate for studying the Sudbury Structure down to the Moho (Jiao *et al.* 1998).

3. Data Processing and Modeling

The original field data were already edited preliminarily in the field before they were archived for later distribution. Processing of the edited and archived field data included most basic steps, such as filtering, trace editing, event picking, such as the seismic *Pg*, *PcP**, *PmP*, and *Pn* phases for subsequent forward modeling, velocity inversion, and forward synthetic seismogram modeling. The *Pg* and *Pn* phases are the refracted seismic phases along the mid-crust seismic velocity discontinuity and the Moho seismic velocity discontinuity, respectively. Similarly, *PcP** and *PmP* are the seismic phases that are reflected off the same two crustal discontinuities. (In certain references, *PcP* represents the seismic reflection phase from the Earth's outer core and mantle boundary.)

For in-line data modeling, a RAYINVR ray tracing and inversion algorithm (Zelt & Smith 1992; Zelt & Forsyth 1994) and Cerveny's ray tracing algorithm were employed (Miao 1995). The RAYINVR algorithm inverted the crustal structure information directly under the survey lines, while Cerveny's ray tracing algorithm was used to model complicated crustal structure in each vertical profile cross-section. The velocity models along the *AB* and *XY* profiles are shown in figures 2 and 3, respectively.

For modeling the fan-shot data, a Fletcher Reeves forward numerical travel-time modeling algorithm was developed using the conjugate gradient method in multi-dimensional space (Press *et al.* 1989). A damped linear least-squares inversion technique was applied to form the Fletcher Reeves damped least-squares method (Aki & Richards 1980; Kanasewich & Chiu 1985; Lee 1990). Figure 4 illustrates the results of modeling one refraction section from the fan shot data. A three-dimensional seismic tomographic modeling was carried out,

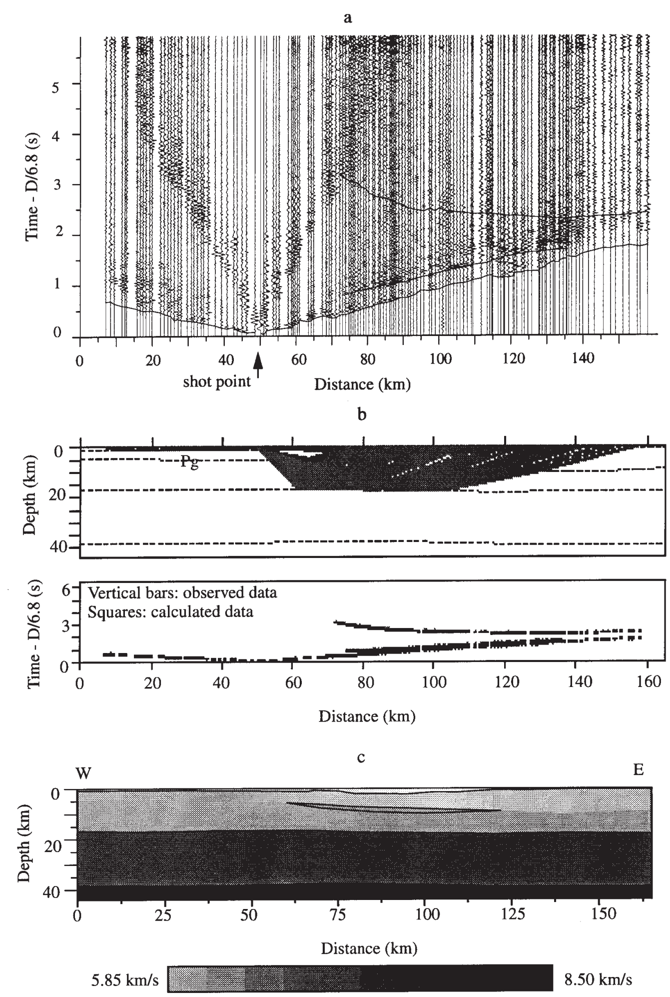


Fig. 3 —A reflection section of in-line *xy3* (a — line: picked seismic events), ray path map and travel time curves including observed and calculated data (b), and velocity model (c) along profile *XY* (from top to bottom). The solid line in (a) represents the picked travel times and the solid lines in (c) represent the seismic velocity structure boundaries.

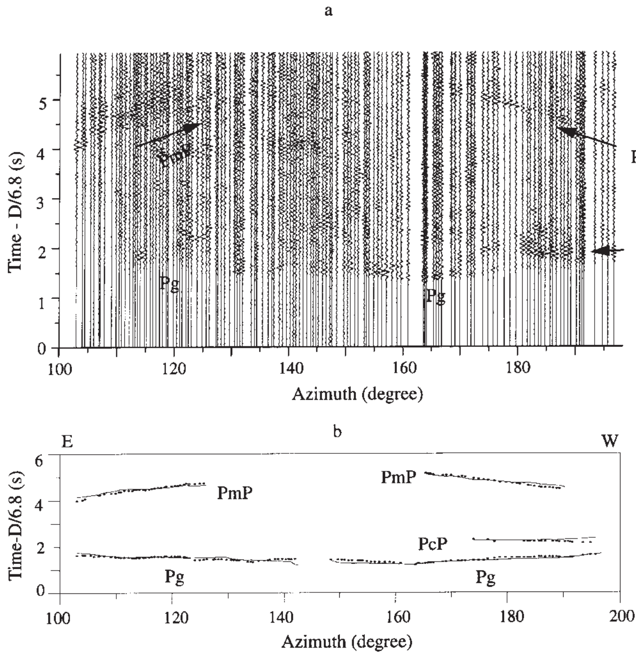


Fig. 4 —A seismic refraction section of fan shot *ab2* (a), travel time modeling for fan shot *ab2* (b). Dotted and solid lines represent the observed and calculated travel-times, respectively.

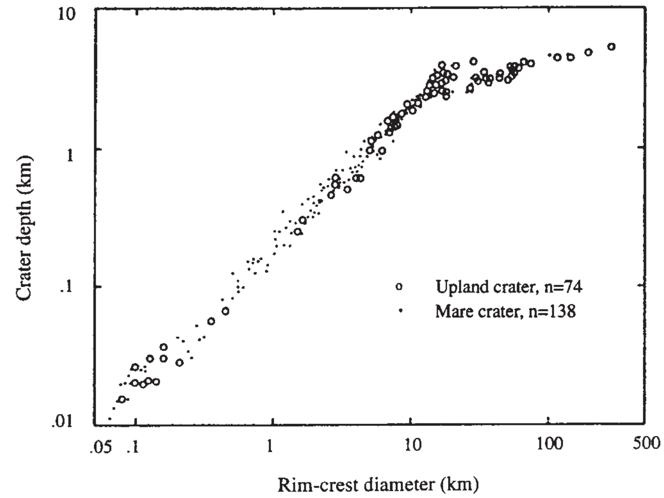


Fig. 5 — The relationship between the depth and diameter for fresh, unflooded, lunar craters (after Melosh 1989).

using the first arrival signals picked from fifteen shot recording sections, in order to investigate and to reconstruct the velocity information under the Sudbury Structure to better understand the deep structures. The weighted back-projection method (Hole 1992) was also applied in the tomographic models to produce a three-dimensional velocity structure. There are limits to the solution resolution in this type of seismic tomographic modeling, however, a consequence of insufficient coverage of ray paths away from the intersection of the fan-shot profiles.

4. Modeling of the Impact Structure

The original dimension of the Sudbury Structure has recently been discussed by Grieve *et al.* (1991) and Rondot (1994). An important parameter in estimating the dimension of an impact crater is the diameter of the transient crater that is formed at the end of the excavation phase (Melosh 1989) by displacement attributable to the flow field associated with the shock crater (Grieve *et al.* 1991). The transient crater is highly modified by further gravitational collapse during later stages of the impact process (Peredery & Morrison 1984). The original diameter of the transient cavity for the Sudbury Structure has been estimated to be about 100 km by Grieve *et al.* (1991) through analysis of observations of the outermost occurrence of shatter cones, the radial distribution of the shock-induced microscopic planar features in quartz, and the outlier of Huronian rocks. According to the scaling relationship between the final rim and the transient crater, the diameter of the final rim of the Sudbury Structure has therefore been estimated to lie between 150 km and 200 km (Grieve *et al.* 1991).

It is usually more difficult to determine the crater depth than the diameter because there is less information available for estimating the depth of a crater. Nevertheless, a depth of less than 20 km for the original crater of the Sudbury impact structure was inferred by Shanks & Schwerdtner (1991) on the basis of an estimation of the metamorphic grades.

Observed relationships between the depth and the diameter of fresh lunar craters, which are mainly deduced from the dimensions

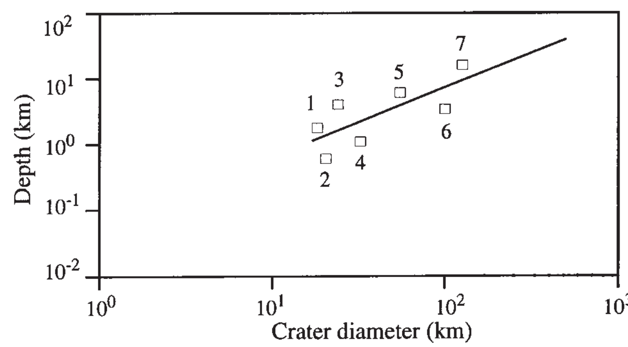


Fig. 6 — The relationship between the depth and diameter of large complex terrestrial craters: 1 = El'gygytgyn, Russia, 2 = Haughton, Canada, 3 = Ries, Germany, 4 = West Clearwater Lake, Canada, 5 = Siljian, Sweden, 6 = Manicouagan, Canada, and 7 = Vredefort, South Africa (based on Pilkington *et al.* 1992; Rondot 1994).

for 211 craters (Melosh 1989), show that the ratio of depth to diameter for large complex craters (≥ 15 km in diameter) is much smaller than that for smaller simple craters (< 15 km in diameter) (figure 5). Such a result might be explained by a reduced efficiency for the excavation energy at greater depth for impact processes producing large complex craters (Rondot 1994). Figure 5 shows that there is a good scaling relationship between the depth and diameter for large, fresh, unflooded, complex lunar craters. Such a scaling relationship between crater depth and diameter is exhibited not only for lunar craters, but also for terrestrial craters. The relationship between crater depth and diameter has also been discussed by Grieve *et al.* (1991) and Pilkington

& Grieve (1992). By analogy, therefore, a scaling relationship between the depth at the bottom of a crater's breccia lens and its diameter is estimated for large terrestrial craters on the basis of information for craters on Earth larger than 17 km in diameter (figure 6). With the exception of the Vredefort crater, the depths to the bottom of the breccia lens were obtained from gravity models (Pilkington & Grieve 1992). The depth for Vredefort was taken from Rondot (1994). Relative to such an empirical scaling relationship, the best estimate for the original depth of the SIC of the Sudbury impact crater falls in the range between 11.2 km and 15.2 km for the corresponding diameter range of 150 to 200 km.

5. Results of Modeling the Seismic Refraction Data

Preliminary results obtained from forward modeling using the current seismic refraction data show that the Moho depth increases from 37 km at the northern end of line *AB* for a velocity of 6.9 km s^{-1} to 44 km at the south end of line *AB* for a velocity of 7.1 km s^{-1}. The average depth to the upper layer crustal boundary is about 17 km along line *AB*, and is truncated by the dipping structure that inclines by about 25° towards the southeast under the GFTZ. The latter extends from the upper crust into the lower crust in figure 2a (Epili *et al.* 1991; Miao 1995).

Along line *XY* the Moho discontinuity and the mid-crustal discontinuity between the upper and lower crustal layers are approximately horizontal. The average depths of the Moho and to the top of the lower crustal layer are 38 km and 17 km, respectively. The Moho depth approximately 45 km north of the centre of the Sudbury Basin is on average 35.9 km, for an average velocity of 6.53 km s^{-1}. The values also include an interpretation of the fan shot data.

Interpretation of the data for shallow surface waves indicates that the depth of the shallow lower-velocity layer beneath the surface increases from 1.0 km to 2.2 km from the peripheral border of the Sudbury Basin structure to its centre, for an average velocity of approximately 5.9 km s^{-1}. Outside the Sudbury Basin structure the thickness of the layer ranges from about 1.0 km to 0.2 km along the profile.

One of the most interesting features of the new modeling is the existence of a high velocity zone, a lenticular-shaped layer, under the Sudbury Basin at depths of 4.5 km to 9.0 km (figures 2 and 3), with an average velocity from modeling with in-line refraction data of 6.4 km s^{-1}. The average velocities in the surrounding materials above and below the anomalous velocity zone are 6.1 km s^{-1} and 6.28 km s^{-1}, respectively. The high velocity zone starts approximately at 88 km from shot point *ab0* and ends at approximately 120 km from that point (figure 2c). In the east-west direction the anomalous high velocity layer starts approximately 60 km from shot point *xy0* and ends at approximately 120 km from that point (figure 3c). The average thickness of the zone is approximately 2.0 km, but it tapers out at the edges along the perimeter. Such a high velocity zone corresponds roughly to the hidden ultra-mafic body interpreted by Gupta *et al.* (1984). However, there is no evidence in our study for an igneous "feeding-root" source for the high velocity material below the lenticular high velocity zone. Results from both forward and inverse modeling of the data for lines *AB* and *XY* agree well, and results based on the fan-shot data also agree within the limits of the numerical errors.

The existence of a relatively high velocity zone of lenticular shape under the Sudbury basin is shown not only by modeling of the in-line data, but also by the west-east velocity structure profile modeled by the seismic tomography technique (dashed lines in figure 7). However, the top boundary of the high velocity zone in the tomographic model seems to be shallower than that in the in-line models. Such an anomalous high velocity zone may be related to the SIC as well as the Onaping formation. In figure 7 it appears that the seismic velocities tend towards relatively lower values directly below the Sudbury Basin in the lower upper crust, which might be related to the lower velocities found for the Footwall breccia and Sudbury breccia. There is a small high velocity block about 10 km deep under the western border of the basin structure along the profile, which probably corresponds to the high density body responsible for the high gravity anomaly belt in the south range of the SIC. As the distance and depth increase from the centre of the Sudbury basin, the interpretation of the velocity structure becomes less accurate owing to poor ray path coverage.

The high velocity anomalous zone beneath the Sudbury Structure may be related to the SIC gabbro-norite sublayer, which has the characteristics of strong reflectivity and high density. The location of the high velocity zone modeled from line *XY* indicates that the attitude of the sublayer dips slightly towards the east. The boundary for the anomalous high velocity zone is better constrained at the west end, where weak reflection events are observed, than at the east end, where there are strong reflection events. The slightly east-dipping structure is probably associated with the northwest trending deformation that occurred during the Penokean and Grenville orogenies. The seismic reflection image along the northwest-southeast direction clearly delineates a southeast dipping structure in the Sudbury Basin, which was strongly folded by the northwest thrusting deformation (Green *et al.* 1988; Milkereit *et al.* 1992; Wu *et al.* 1995).

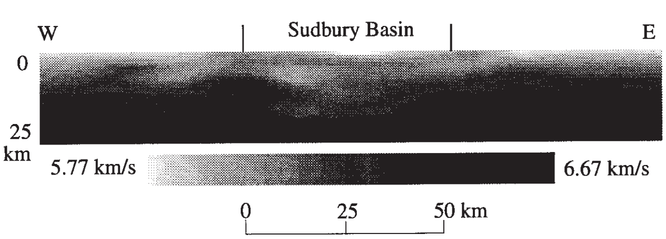


Fig. 7 — The west-east seismic velocity structure profile from the seismic tomography modeling.

6. Discussion and Conclusion

Results of forward and inverse modeling of the refraction seismic data, an interpretation of both in-line and fan shot data, and tomographic modeling have provided us with a three-dimensional velocity model for the material across and beneath the Sudbury Structure and the surrounding areas. Most of the results fit well with the currently known geology of the study area, and correlate well with the existing regional tectonic models. However, the high velocity layer beneath the Sudbury Structure requires further geological and detailed high-resolution seismic investigation for more accurate interpretation.

Modeling results for the high-resolution seismic refraction data

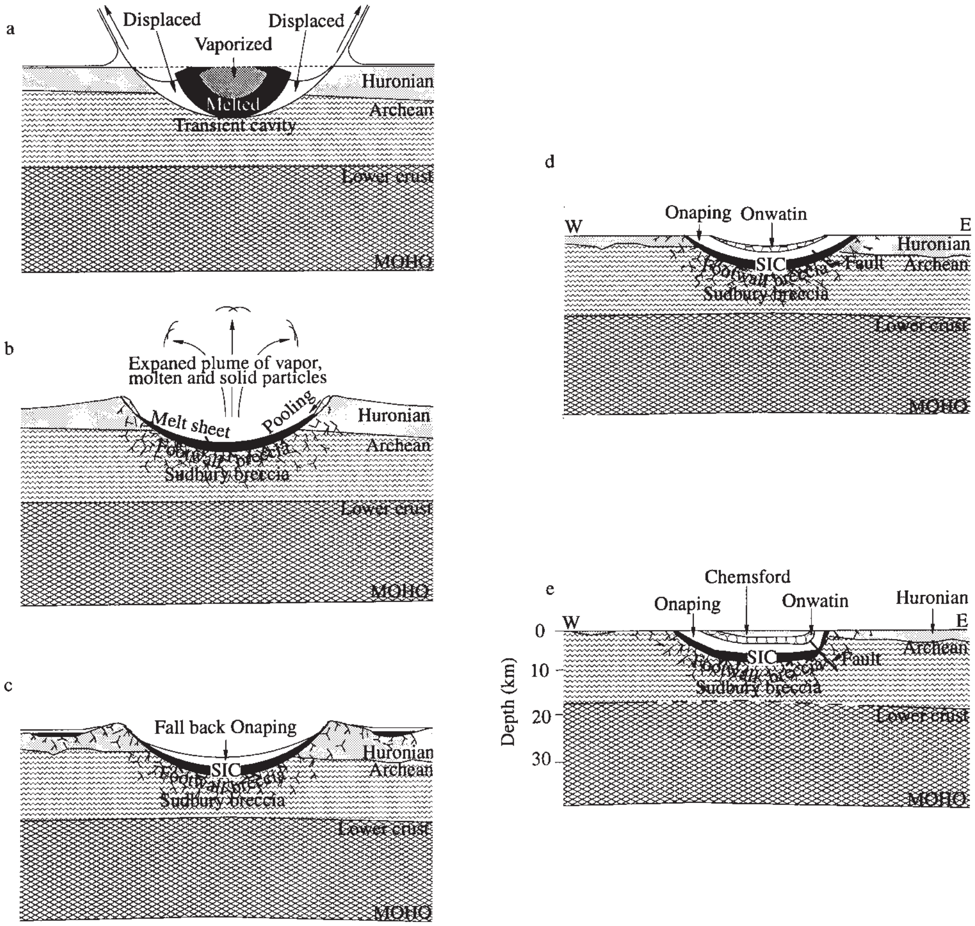


Fig. 8 — A schematic cartoon of the development sequences of the Sudbury impact structure: (a) impact cratering, vaporizing and melting (based on Grieve *et al.* 1991), (b) formation of melting sheet and the Sudbury and Footwall breccias (after Avermann *et al.* 1994; Miao *et al.* 1995), (c) final stage of the impact cratering and emplacement of the melting sheet, (d) formation of the sediments, thrusting and erosion, and (e) the present Sudbury structure after strong northwest-southeast compressive deformation and subsequent erosion during the Penokean and Grenville orogenies.

indicate that under the Sudbury basin there is no significant uplift in the Moho discontinuity and the mid-crustal interface. There is no high velocity and high-density mafic rock body modeled in the lower crust beneath the Sudbury Structure. Hence, there is no evidence from seismic refraction modeling for an endogenic igneous origin for the SIC and the Sudbury Structure. The lenticular high velocity zone under the Sudbury basin might therefore be the impact melt sheet. In addition, seismic refraction modeling also supports the idea that the Sudbury impact structure is a relic of a large terrestrial cratering process, but without a central-uplift, as proposed by Grieve *et al.* (1991). The thrusting environment created in the Sudbury area by the Penokean orogeny (1.83 to 1.89 Ga ago) and Grenville orogeny (1.0 to 1.3 Ga ago) can be considered as one interpretation for the lack of a local central uplift in the Sudbury impact structure.

The maximum depth of the high velocity zone is estimated to be approximately 9 km according to the current refraction seismic study. From the discussion above, the depth to the top of the SIC in the Sudbury impact crater is estimated to fall in the range from 11.2 km to 15.2 km. In that case, the region should have experienced erosion of approximately 2.2 km to 6.2 km throughout the period of geological evolution. This estimate is based on the scaling relationship between crater depth and diameter developed by Pilkington & Grieve (1992) with the aid of a gravity model. Since there are only a small number of large terrestrial craters available to provide accurate dimensions for such a relationship, such an interpretation is limited.

Figure 8 explains the speculated development stages of the Sudbury impact structure in the east-west direction. The evolution of the structure in the south-north direction has been discussed in great detail by Wu *et al.* (1995) and Miao (1995). The first stage was the impact cratering and the melting and vaporization of Huronian and Archean rocks (figure 8a,b). The Huronian sediment was thickened in the southeast over the extended crust during the development of a south-facing continental margin ~2.4–2.5 Ga ago. The Sudbury breccia, the Footwall breccia, and the impact melting sheet (SIC) were then formed, and the Onaping breccia was subsequently deposited over the impact crater (figure 8c). That was followed by a northwest-southeast compression during the early stage of the Penokean orogeny, which deformed the original Sudbury structure towards its present-day elongated form. The impact structure was less deformed in the east-west direction however. The Onwatin Formation was deposited during the northwest–southeast thrusting deformation (figure 8d). During the late Penokean orogeny, a northwest-southeast thrusting deformation was still active in the area, and the impact structure was slightly

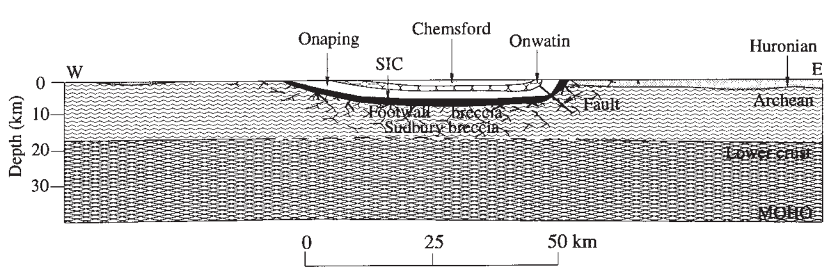


Fig. 9 — The enlarged present Sudbury structure after strong northwest-southeast deformation and erosion during the Penokean and Grenville orogenies. Because of uncertainties resulting from poor data resolution, the mid-crustal velocity boundary beneath the Sudbury structure is represnted by a dashed line.

deformed in the east. The Sudbury Basin was created (figure 8e) by the time that the Chelmsford Formation overlaid the top of the Onwatin Formation. During the evolution of the impact structure, the Moho discontinuity and the mid-crustal interface underwent a slight uplift, but not a strong uplift. It is believed that the Sudbury Structure deformed further and was then modified during the younger Grenville orogeny.

Preliminary interpretation of the AGT reflection seismic data and also the 1992 high-resolution refraction data provides us with a clear velocity structure for the Sudbury Structure and the surrounding areas. The results of in-line seismic refraction modeling and three-dimensional tomographic modeling using first arrival waves reveal a velocity structure that delineates a lenticular high velocity zone under the Sudbury basin. Even though the location of the high velocity zone corresponds to the hidden ultra-mafic body proposed by Gupta *et al.* (1984), the size and shape of their reported hidden ultra-mafic body is too vague. Further study will be necessary before any definite geological conclusions can be drawn. Interpretation of both in-line and fan shot data also indicates that there is no apparent uplift at the Moho discontinuity under the Sudbury Structure. The geometrical shape (figure 9) of the Sudbury Structure outlined by seismic high-resolution data (Milkereit *et al.* 1992; Wu *et al.* 1995), refraction data (this study), gravity data (McGrath *et al.* 1994), and magnetic data (Hearst *et al.* 1994) therefore agree in general with the least squares mix model of Grieve *et al.* (1991) for explaining the composition of the SIC. They also provide a strong argument for the meteorite impact origin of the Sudbury Structure. The seismic refraction model of the Sudbury Structure satisfies most geophysical and meteorite impact model constraints compiled here. However, a geological interpretation of the anomalous high seismic velocity zone under the Sudbury Structure would require further investigation.

This research was supported by an NSERC operating grant to W. M. Moon. The work was also supported partly by an NSERC *Lithoprobe* (AGT) grant. The authors thank Drs. Colin Zelt and John Hole for providing copies of the RAYINVR ray tracing/inversion algorithm and three-dimensional tomographic modeling source codes. Helpful comments by X. G. Miao, H. Wu, Y. X. Li, and F. L. Meng at various stages are gratefully acknowledged. Dr. Kris Vasudevan and staff members of the LSPF (*Lithoprobe* Seismic Processing Facility) provided us with timely help when needed.

W. M. Moon and L. X. Jiao
Geophysics
The University of Manitoba
Winnipeg, Canada
R3T 2N2

References

Aki, K. & Richards, P. 1980, Quantitative Seismology: Theory and Methods, Vol. II (W. H. Freeman and Co.: San Francisco and London)

Boerner, D. E., Milkereit, B. & Naldrette, A. J. 1994, Introduction to the Special Section on the Lithoprobe Sudbury Project, Geophysical Research Letters, 21, 919-922

Cowan, E. J. & Schwerdtner, W. M. 1994, Fold Origin of the Sudbury Basin, in the Proceedings of the Sudbury–Norilsk Symposium, Ontario Geological Survey, 45-55

Deutsch, A., Lakomy, R. & Buhl, D. 1989, Strontium and Neodymium Isotope Characteristics of a Heterolithic Breccia in the Basement of the Sudbury Impact Structure, Canada Earth Science Letters, 93, 359-37

Dietz, R. S. 1964, Sudbury Structure as an Astrobleme, J. Geology, 72, 412-434

Dressler, B. O. 1984, General Geology of the Sudbury Area, in The Geology and Ore Deposits of the Sudbury Structure, ed. E. G. Pye, A. J. Naldrett & P. E. Giblin (Ontario Ministry of Natural Resources: Toronto), pp. 57-82

Epili, D. & Mereu, R. F. 1991, The Grenville Front Tectonic Zone: Results from the 1986 Great Lakes Onshore Seismic Wide-angle Reflection and Refraction Experiment, J. Geophys. Res., 96, 16335-16348

Faggart, B. E. & Basu, A. R., Jr. 1985, Origin of the Sudbury Complex by Meteorite Impact: Neodymium Isotopic Evidence, Science, 230, 436-439

French, B. M. 1967, Sudbury Structure, Ontario: Some Petrographic Evidence for Origin by Meteorite Impact, Science, 156, 1094-1097

Green, A. G., Milkereit, B., Spencer, C., Hutchinson, D. R., Cannon, W. F., Lee, M. W., Agera, W. F., Behrendt, J. C. & Hinze, W. J. 1988, Central Structure of the Grenville Front and Adjacent Terranes, Geology, 16, 788-792

Gupta, V., Grant, F. S. & Card, K. D. 1984, Gravity and Magnetic Characteristics of the Sudbury Structure, in Sudbury Structure and Ore Deposits, ed. E. G. Pye, A. J. Naldrette & and P. E. Giblin, Ontario Geological Survey Special Publication No. 1, 381-410

Grieve, R. A. F., Stoffler, D. & Deutsch, A. 1991, The Sudbury Structure: Controversial or Misunderstood?, J. Geophys. Res., 96, 22753-22764

Hearst, R., Morris, W. & Thomas, M. 1994, Magnetic Interpretation Along the Sudbury Structure Lithopobe Transect, Geophys. Res. Letters, 21, 951-954

Hole, J. A. 1992, Nonlinear High Resolution Three Dimensional Seismic Travel Time Tomography, Journal of Geophysics Research, 97, 6553-6562

Irving, R., Asudeh, I., Forsyth, D., Mortimer, D., Argyle, M., Zelt, C., Mereu, R., Hamilton, D., Kohler, W., Carrol, P., Vasudevan, K., Barnes, A., Kellet, R., Moon, W. M., Seguin, M. & Jessop, J. 1993, 1992 Lithoprobe Abitibi-Grenville Seismic Refraction Survey: Acquisition and Processing Report, Lithoprobe Report No. 30

Jiao, L. X., Moon, W. M. & AGT Refraction Seismic Experiment Team 1998, Investigation of Sudbury Structure Processing from the Lithoprobe AGT Refraction Seismic Experiment, Jour. Geophysical Research, submitted

Kanasewich, E. R. & Chiu, S. K. L. 1985, Least Squares Inversion of Spatial Seismic Refraction Data, Bull. Seism. Soc. Am., 75, 865-880

Lee, M. W. 1990, Travel-time Inversion Using Transmitted Waves of Offset VSP Data, Geophysics, 55, 1089-1099

McGrath, P. H. & Broome, H. J. 1994, A Gravity Model for the Sudbury Structure Along the Lithoprobe Seismic Lines, Jour. Geophys. Res., 21, 955-958

Melosh, H. J. 1989, Impact Cratering: A Geologic Process (Oxford University Press: New York)

Miao, X. G. 1995, Integrated Seismic Study for the Sudbury Structure and Surrounding Area, Ph.D. Thesis, The University of Manitoba

Milkereit, B., Green, A. & Sudbury Working Group 1992, Deep Geometry of the Sudbury Structure from Seismic Reflection Profiling, Geology, 20, 807-811

Milkereit, B., Green, A., Wu, J., White, D. & Adam, E. 1994, Integrated Seismic and Borehole Geophysical Study of the Sudbury Igneous Complex, Geophys. Res. Letters, 21, 931-934

Peredry, W. M. & Morrison, G. G. 1984, Discussion of the Origin of the Sudbury Structure, in Sudbury and Ore Deposits, ed. E. G. Pye, A. J. Naldrette & P. E. Giblin, Ontario Geological Survey Special Publication No. 1, 491-511

Pilkington, M. & Grieve, R. A. F. 1992, The Geophysical Signature of Terrestrial Impact Craters, Reviews of Geophysics, 30, 2, 161-181

Press, W. H., Flannery, B. P., Teukolsky, S. A. & Vetterling, W. T. 1989, Numerical Recipes, (Cambridge University Press: Cambridge)

Rondot, J. 1994, Recognition of Eroded Astroblemes, Earth Science Reviews, 35, 311-365

Shanks, W. S. & Schwerdtner, W. M. 1991, Crude Quantitative Estimates of the Original Northwest-Southeast Dimension of the Sudbury Structure, South-Central Canadian Shield, Canadian Jour. of Earth Sci., 28, 1677-1686

Spray, J. G. & Thompson, L. M. 1995, Friction Melt Distribution in a Multi-Ring Impact Basin, Nature, 373, 130-132

Walker, R. J., Morgan, J. W., Naldrett, A. J., Li, C. & Fassett, J. D. 1991, Re-Os Isotope Systematics of Ni-Cu Sulfide Ores, Sudbury Igneous Complex, Ontario: Evidence for a Major Crustal Component, Earth and Planet. Sci. Letters, 105, 416-429

Wu, J., Milkereit, B. & Boerner, D. E. 1995, Seismic Imaging of the Enigmatic Sudbury Structure, Jour. Geophys. Res., 100, 4117-4130

Zelt, C. A. & Forsyth, D. A. 1994, Modeling Wide-angle Seismic Data for Crustal Structure: Southeastern Grenville Province, Jour. Geophys. Res., 99, 11687-11704

Zelt, C. A. & Smith, R. B. 1992, Seismic Travel-time Inversion for 2-D Crustal Velocity Structure, Geophys. Jour. Int., 108, 16-34

WOOIL M. MOON is a professor of geophysics at the University of Manitoba. He received his B.A.Sc., M.Sc., and Ph.D. degrees from the University of Toronto, Columbia (New York), and the University of British Columbia, respectively, and has participated in a number of major crustal seismic experiments such as Co-CRUST *and* Lithoprobe. *Wooil has also participated in a number of satellite science verification programs such as* SEASAT *(NASA),* ERS-1 *(ESA),* JERS-1 *(Japan), and* RADARSAT *(Canadian Space Agency). Wooil's research interests embrace the fields of theoretical geodynamics, including the rotation of the Earth and Earth's core dynamics, satellite altimetry, space-borne microwave remote sensing, and digital data fusion and imaging, in addition to seismology. He recently spent two weeks in the Bolivian-Chilean Andes ground truthing the* RADARSAT *data over high altitude evaporite lakes at 5,000 to 6,000 metres above sea level. Currently Wooil is also involved in projects investigating the Cambodian meteorite impact features and the space-borne SAR responses of several volcanoes, including Baktu-san and Halla-san in Asia and Cerro Caquaella in South America.*

JIAO LING-XIU is a Ph.D. candidate in seismology at the University of Manitoba. She earned a B.S. degree in applied geophysics in 1984 from Chuangchun University of Geophysics in China, and an M.S. degree in geophysics in 1990 from the Institute of Geophysics at the Chinese Academy of Sciences. From 1984 to 1994 she worked at the latter institute as a research assistant and later as a research associate, and from 1994 to 1995 she was employed as a visiting scholar in the Department of Geological Sciences at the University of Manitoba. Her interests include seismic imaging, data modeling, inversion, processing, signal analysis with fractal-based techniques, and geophysical data modeling and interpretation. She is a student member of the Society of Exploration Geophysicists, the Canadian Society of Exploration Geophysicists, and the Canadian Geophysical Union. Her hobby is listening to classical and light music.

ABSTRACTS OF PAPERS PRESENTED AT THE 1998 RASC GENERAL ASSEMBLY HELD AT PEARSON COLLEGE IN VICTORIA, JUNE 19–21, 1998

Does the Moon Influence Our Weather?, Raymond Auclair, Unattached Member.

Governments often throw money at a problem in the (vain) hope that it will go away. In this investigation the author throws numbers at a question in the (vain?) hope that an answer will pop out. The Moon does provide energy to Earth's weather engine. It reflects light from the Sun, it generates its own infrared photons, it pulls the oceans around in circumplanetary tidal bulges. We can estimate how much energy is involved, but do we know if it has an impact?

Comments on the Distance Scale in our Galaxy, David Turner, Halifax Centre.

The distances to objects in the Milky Way are established by a variety of methods; most depend upon the establishment of a reliable set of trigonometric parallaxes for nearby stars. A boon to studies of the distance scale occurred recently with the publication of new, high-precision, absolute parallaxes for stars included in the *HIPPARCOS* satellite's program of measurement. High precision parallaxes have associated uncertainties, and in a statistical sample there will be many stars for which the parallax measured by *HIPPARCOS* is in error by more than its stated uncertainty. Distant stars, for which the *HIPPARCOS* parallaxes are negative to within their stated uncertainties of measurement, provide excellent examples of the limitation. An interesting case is provided by the sample of Cepheid variables belonging to open clusters, since such stars also have distances established by cluster parallaxes derived from zero-age main sequence fitting for the associated clusters. It is shown that the measured parallaxes for cluster Cepheids do not always provide good measures of the distances to such stars. For only about two thirds of the stars is the *HIPPARCOS* parallax in agreement with the cluster parallax. While such a result is expected statistically, it means that one should not form conclusions about the distances of specific Cepheids on the sole basis of their *HIPPARCOS* parallaxes. The conflicting evidence for Polaris is discussed as a specific example.

The Vancouver Island Fireball of 1996 December 7, Laura Stumpf and Jeremy Tatum, Victoria Centre.

An exceptionally bright fireball was reported over Vancouver Island on the morning of 1996 December 17. As part of the work of the Meteorites and Impacts Advisory Committee (MIAC) to the Canadian Space Agency, we have computed the probable trajectory of the meteoroid in its passage through the atmosphere. It is not known if any meteorites landed. If they did so, the most likely strewnfield would be in an area of Vancouver Island, which is likely to be visited by some delegates who are combining this conference with a holiday. We seek your help.

Formation of the Earth-Moon System: Collision Then Capture?, Phil McCausland, St. John's Centre.

Where did the Moon come from? Is its formation related to that of the Earth? Among many theories of Earth-Moon formation, the one currently accepted is collisional-ejection, in which a Mars-sized planetesimal struck the proto-Earth an off-centre blow during accretion of the early solar system, directly producing the Moon and the distinct lunar and terrestrial compositions. However, numerical models that produce a lunar-mass body of correct composition in orbit about the Earth also produce ~4 times the present angular momentum of the Earth-Moon system. If the collisional-ejection theory (and modeling of it) is correct, how was the "excess" angular momentum from the collision lost? One possible mechanism is collision-capture, in which a lunar-mass body produced by collisional-ejection passes into solar, rather than terrestrial, orbit. The Moon is later (re)captured by the Earth, thus defining new starting conditions for the angular momentum of the Earth-Moon system while retaining distinct compositional features produced by the initial collision.

The St. John's Planetarium: The Best-Kept Secret, Garry Dymond, St. John's Centre.

Very few people know that the city of St. John's has had a permanent planetarium since the sixties. This paper discusses the history of the planetarium and the involvement of the St. John's Centre in its operation.

Revving Up the Saskatoon Centre for the Next Millennium, Erich Keser, Saskatoon Centre.

The Saskatoon Centre is developing plans to improve the services that can be offered to members and is also stepping up its public outreach programs. Described here are the projects that Centre members are addressing, with emphasis on: (a) searching for, acquiring, and moving to a new, very dark observing site, and what it has done for the Centre, (b) creating a star party at a place that Nature and the provincial park system designed for it, (c) turning kids on to astronomy via our junior and youth programs, (d) getting the membership involved, making meetings attractive, giving our centre a human face with social functions, and servicing distant members via newsletters and satellite events.

Magnetism in Astronomy: A Coloured Oral View, Jacques P. Vallée, Toronto Centre.

Magnetic fields in astronomy have strengths ranging from below 1 microGauss, such as is found in distant interplanetary space, to above 1 petaGauss, such as occurs on the surface of a magnetar. Astronomical magnetic fields also exhibit various organized shapes, notably dipolar, spiral, shell, cellular, etc.

The Solar System as a Vortex, John Howell, Victoria Centre.

The orbits of objects in the solar system are viewed as a mass of material consisting of a loose number of systems circling like a liquid continuum, or vortex, as seen in a basin that is draining through a hole. The axes of all planets are tilted chaotically, with the exception of the Earth, which has maintained its modest inclination under the influence of its large lunar satellite. That has been responsible for the climatic conditions that have existed since the Earth's formation 4.5 billion years ago, and has allowed the development of life as we know it. The *big* question is posed: if that makes the Earth/Moon vortex a very unique place, are we all alone in our galaxy and indeed the universe?

Our Changing Views of the Solar Neighbourhood, Alan H. Batten, Victoria Centre.

Only after the time of Copernicus did people begin to think of a universe centred upon the Sun and of the possibility that not all the stars were at the same distance from us. The determination of a distance to a nearby star (other than the Sun) still eluded astronomers until the middle of the nineteenth century, when Bessel, Struve and Henderson, all within a few years, succeeded in determining distances to nearby stars in a way that carried conviction to their contemporary colleagues. It was not until the beginning of this century that astronomers realized the importance of listing stars out to a given distance. The first to do so was Hertzsprung (of the Hertzsprung-Russell diagram), who pointed out that, if we listed stars down to a given apparent-magnitude limit, we inevitably produced a selection effect in favour of the most luminous stars. Since his time, van de Kamp, Gliese, and others have compiled lists of all the stars known out to a given distance. The results have, for many years, been incorporated in the tables of nearest stars in the *Observer's Handbook* of the RASC. This year, we revised the table to take account of the latest results obtained by the *HIPPARCOS* satellite, launched to provide us with high-precision determinations of stellar parallaxes. The study of nearby stars has implications for the study of astrophysics in general, and is not a matter of pure curiosity.

Ninety Editions of the Observer's Handbook, Roy Bishop, Halifax Centre.

With an annual circulation of 10,000 copies, the *Observer's Handbook* is the RASC's most widely known publication. Described here are some facets of the *Observer's Handbook* and its nine-decade history.

Astrophotography: The State of the Art, Jack B. Newton, Victoria Centre.

The presentation traces the author's astrophotography efforts spanning thirty years, and features work with film, a foray into cold camera use and film hypering, and culminates with state-of-the art CCD imaging. The presentation is embellished with over one hundred and fifty colour slides capturing the awesome beauty of deep space.

Society News /Nouvelles de la société

GENERAL ASSEMBLY REPORT: COMPANY HAS COME AND GONE

I helped myself to a bag of raisins from Hélène's kitchen, and contemplated the past few days while I munched and watched the sea-emerald water lapping beneath her sundeck. Hélène: "Mind if I join you? Quite the crowd, wasn't it?"

Thursday afternoon had been much like any other. School was out for the summer, the tall firs scented the warm, still sea air. I drowsed in the ditch by the parking lot. Suddenly voices raised the dust in the afternoon heat. Signs pointed the way, and strangers followed them to naps and dinner. The food was not bad, not bad at all! I hopped on the bus to visit Jack and Alice Newton. Twenty-six people, according to Alice, but I can't count. Lots of Marks and Spencer chocolate cookies to make it worth the trip. Oh yeah, Jack's observatory was pretty good too. Alice is cute and a great hostess. We were sleepy, but just had to observe. Pearson College has a fantastic observatory with Jack Newton's 25-inch scope and the Victoria Centre's 20-inch scope. Lots of local people brought their scopes up as well. The night rolled in on the back of the strait fog, and we stayed up to see the ashen dawn.

On Friday I went out on a boat to Race Rocks with Julie Payette, Jean Godin, and a couple of other people. We saw seals and seagulls, and wandered around the lighthouse. We walked all of the way to the top of the lighthouse, and then they took us on a bumpy ride back to the college. A glass wall with west-coast trees behind it was the backdrop for homemade telescopes and accessories, and displays. Sandy Clarke's art lit up the auditorium entrance walls with colour. I slept through the business meetings. Those who went on the tours to Fort Rodd Hill Park and lighthouse reported having a great time. Only two members were lost in action. Their registration fees come out of Chuck's paycheck.

There was great wine and a lot of cheese and goodies available on Friday night. It was a chance to mingle with fellow astronomers from all across the country, and fortification for the music we would have to face a little later that evening. According to Alice: "They didn't do the wave. I knew that they would be a tough audience, but I wasn't expecting so many squishy tomatoes. I poked fun at everyone I knew would be in the audience — and they just sat there! Except when I said that our telescope-making group was cerebral and hadn't made any telescopes. A nameless heckler said that the group wasn't cerebral at all — they hadn't made any scopes because they sat around and B.S.ed." Cerebral, indeed! The slides put everyone to sleep, and when the time came for the Song Contest, only two souls were awake and able to perform. Even though they could not remember the words to the songs they sang, they cleaned up… won every prize that evening. Gary and Peter went away with an armload of goodies. Julie Payette is one great astronaut! I am going to go up in space with her and take pictures of Canada. I did not know that the first feet to touch down on the Moon were Canadian. The lander had "Made-in-Canada" booties. I will bet the Moon astronauts did not have to assemble them. Then there was more observing. Peter set up his 20-inch Dobsonian, and Jean Godin gave out tips on how not to be hunted.

Saturday was talk, talk, talk. Jack Newton, Jeremy Tatum and David Crampton played to a packed house. Then we all got our picture taken. That is me in the shadow, just behind your imagination. A Victoria Centre member set up her 6-inch/8-inch scope for solar observing and we all got a look. She said that the most exciting part was that everyone knew where to look without being told. Bert Rhebergen even sketched the Sun using her scope. The salmon feast was superb… the west coast at its best! On Saturday night we got exciting, privileged news about some newly discovered planets. Geoff Marcy had a very appreciative audience. Later on another huge group set off for Alice and Jack's to devour cookies and to see how Jack makes those gorgeous images. That was followed by more observing. Lots of people enjoyed the Cygnus section of the Milky Way and sharing views through telescopes.

On Sunday I woke up in time for the tour to the Dominion Astrophysical Observatory, but slept right through breakfast, lunch, and a great talk by Dean McLaughlin. We wandered through the main observatory, the smaller one down the hill a bit, and saw displays set up in the office building. The best part was visiting the machine shops. I could do a lot with some of that equipment. Chuck did a wonderful job getting everybody up to the DAO. He even managed to get everyone back. We got back in time for the banquet and awards ceremony. We were introduced to the new National Council, and had a great party afterwards. The Meade ETX was raffled off and the money raised will go towards the purchase of a hydrogen-alpha filter for the College observatory. Jack must have bought half of the tickets they sold — he really needed a good telescope. Then followed another night of observing. I think I am star partied out. I will have to be frisky in the morning to see everyone off.

by Sandra Barta

SONG CONTEST WINNER

Provided here, courtesy of Phil McCausland, are the lyrics for the winning entry in this year's Song Contest held at the General Assembly.

Pulsars and Quasars: a Song of Humility and Wonder

(sung to the tune of "My Favorite Things" ©1997 Damien Spracklin)

Pulsars and quasars and nebulous gases
Things that can suck up the light as it passes
Gas giant planetoids with icy rings
These are a few of the Galaxy's things.

Star birth and sunspots and blobs of dark matter
Comets with tail streams and star nova splatter
Trails of hot plaa-sma stretched out like strings
These are a few of the Galaxy's things!

When the job's done, when the game's won
When you're feeling tall
You simply remember the Galaxy's things
And then you will feel… real small…

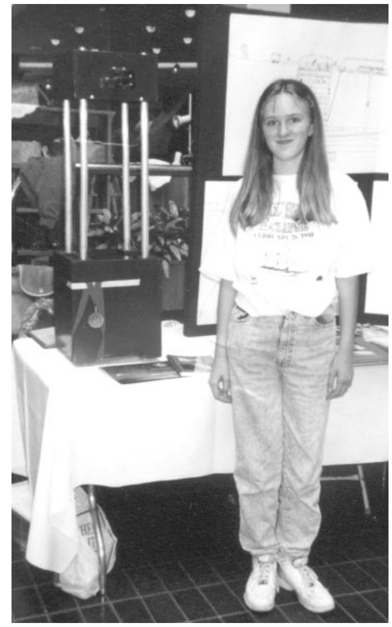
Black holes and 'bursters and binary systems
Things gone forever, too bad if you missed 'em
Planets in orbit in gravity slings
These are a few of the Galaxy's things.

Light years and light speeds and particle tailspin
Gamma and X-rays and light you can see in
Boulders and pebbles in asteroid rings
These are a few of the Galaxy's things!

When the job's done, when the game's won
When you're feeling tall
You simply remember the Galaxy's things
And then you will feel…
Real small…

GOLD MEDAL SCIENCE FAIR WINNER IN KINGSTON

The Kingston Centre is pleased to announce that one of its most active youth members, Kendra Angle, has recently won a gold medal for designing and constructing a telescope for the 1998 Frontenac, Lennox & Addington Science Fair.



Kendra Angle with the telescope that won her the gold medal. The medal can be seen hanging on the base of the scope. *(Photo by Cathy Hall.)*

In addition to the work on the telescope itself, Kendra prepared a display which documented the construction of the telescope and the grinding and testing of the mirror. She designed the mount herself, in order that she would be able to disassemble the telescope and transport it to the national competition. The top box nests into the bottom box for transport. It is very lightweight, being made of plywood and aluminum. The mirror is 18 cm in diameter and was ground by Kendra. She was awarded a gold medal for her project, and has since been helping the Kingston Centre's Telescope Makers' Group with the construction of a 20-cm telescope based on her design. What is even more impressive is that she is only twelve years old!

In Kendra's own words:

"My total grinding time was 31 hours 28 minutes. Here are my zonal measurements, the measurements done in the Foucault test.

Zone	1	2	3	4
Measurement 1	0.674	0.722	0.747	0.819
Measurement 2	0.650	0.716	0.740	0.825

"When I tested the performance of my mirror looking at a transformer and a bolt head 400 metres away, I found that the number on the transformer was clearer in my scope at 77× than a 10-cm Astrophysics lens at 88×. The head on a bolt was sharper in the 10-cm telescope than in my mirror. M97 looked like a grey fuzzy spot. I could split Mizar, but Castor I could not. I believe I was not able to split Castor because my scope was off collimation.

"My conclusions are: the mirror is accurate to $^1/_8$th wave with almost that much measurement error. I found that my telescope was better than my Dad's telescope for contrast and brightness, but not for resolution.

"I used the four-truss tube design because I did not think two tubes would be enough, but eight tubes were not necessary so I decided to use four tubes. The top box fits inside the bottom box for easy transportation. I found that an f/5.6 mirror is short enough to be able to look through standing up. I had wanted an f/7 mirror, but I ground too long. I did not get the focal length I had wanted. When taller people look through my telescope, they will have to crouch down more. An f/7 would have been longer, so it would not fit in vehicles as easily. I liked using an 18 cm blank because it was free and it is not heavy. I did not like the difficulty of designing and making the tube because I had to redesign parts of the tube as I was making it and I do not like using the table saw. I also did not like the difficulty of figuring my mirror, because I could only polish for five minutes then I had to let it cool for half an hour before testing. I also did not like the difficulties of collimation (aligning of optics) because the process is 'fiddley.' I liked building a reflector instead of a refractor because there was only one surface to grind."

Congratulations, Kendra, from the Kingston Centre! Those seeking more information about Kendra's scope and the Telescope Makers' Group of the Kingston Centre, can contact Kendra at: angle@istar.ca.

by Laura Gagné (rainbow@adan.kingston.net)

CONGRATULATIONS TO…

- J. Edward Kennedy, who was awarded a **Lifetime Service Award** by a special resolution of National Council at its June meeting.

- Carol Weis (Calgary Centre) and Alan Whitman (Okanagan Centre) on the recent awarding to them of a **Finest NGC Certificate** by National Council. Carol's award was accepted on her behalf by Glenn Hawley at the Victoria General Assembly (see JRASC, 92, 208, 1998).

- Raymond Auclair, Brian J. Clarke, Blair Colborne, Roland G. Dechesne, J. Cam Fahrner, Dennis Goodman, Ulrich Haasdyk, Don Hladiuk, Philip Johnson, Fr. Lucian J. Kemble, Robert F. Loblaw, John C. Mirtle, Kenneth Pawson, and Peter Sim, who were all awarded **Membership Certificates** by National Council at its June meeting.

Solar Eclipse 1999 in France

by Raymond Auclair, National Secretary

When I returned from the General Assembly of 1998 in Victoria, I received communications from Jean-Pierre Urbain, a member of the Royal Astronomical Society of Canada who lives near Montreal. Mr. Urbain had organized the astronomical visit to the Soviet Union in 1988. Some remember that, on that trip, I was afflicted by appendicitis that had to be treated in Kiev (Ukraine). This time, Jean-Pierre will keep me closer to western-style hospitals. He just finished making arrangements with the French Astronomical Society and here is the proposal for the August 1999 total solar eclipse.

"Le soleil a rendez-vous avec la lune..."

There is a famous French song that begins, "The Sun has a date with the Moon, but the Moon, as usual, stands him up" and, by the time she shows up, he has set for the evening.

Well, on August 11, 1999, the Moon will wait for the Sun and they will put on quite a show for those of us with front row seats. It will be the last total solar eclipse of the millennium — there will be no total solar eclipse in 2000, so the statement is true regardless of when you want the next millennium to begin.

Solar eclipses are rare enough and spectacular enough that they are worth the trouble of travel. A total solar eclipse can only be experienced by those located in the Moon's very narrow shadow cone. The cone crosses Earth from one horizon to the other (as seen from the Moon) from west to east — only once per eclipse! Its path can be drawn on a map as a corridor, and for the August 1999 eclipse the corridor will be 100 km wide in Europe. Much information can be found on pages 117, 120–122, in the *Observer's Handbook 1998*.

Canadian Astronomers to Chase the Eclipse

Mr. Jean-Pierre Urbain has contacted *Agence Voyages Loisirs* to arrange a group tour that will take us to a good location to view the eclipse and to provide an entire week of visits and travel in and around the Noyon and Paris regions of France. Using their services is convenient because they have many specialized groups on the road at any given time, and they offer good fares from various airports in Canada. Thus, there is no need for our group to fill or charter a plane or to worry about empty seats. There is no need to fill hotels either. The agency fills their planes by combining many tours.

Voyages Loisirs does not specialize in eclipse tours or in astronomical work. However, they do specialize in finding whatever is needed for specialized tours (and they are doing that for our group). *Voyages Loisirs* holds a Quebec Government Permit.

For this eclipse tour they propose using two-star hotels (budget conscious according to the New French Norms) and a professional bilingual escort (a guide but not an astronomer) who will stay with us throughout the tour. The eclipse-related activities will be in the hands of the Société astronomique de France (SAF), which plans to watch the eclipse from Noyon, 100 km north of Paris.

The trip will not be exclusively astronomical in nature; we will also take in some of those famous Parisian sites such as the Seine River, the Eiffel Tower, Notre Dame Cathedral, the Opera (of Phantom fame) and so on.

Noyon (49°.35 N, 3°.00 E)

Noyon is a lovely town, one of France's fifty-two Cities of Art and History. It dates back to Roman times, has an exquisite gothic cathedral, and is the site of John Calvin's birthplace, today a museum. Its architecture is rich and varied, including its 16th century town hall, and a beautiful assembly of church buildings. You will be as impressed looking around as looking up!

The chosen site is one that the SAF will use. Because many of them will set up the day before the eclipse, it will be a guarded site (*i.e.* with guards). According to plans (at least at this point), we should also arrive at the site the day before to stake our claims and, for the bold or heavily leaden, set up heavy equipment. The SAF and the town of Noyon will have reserved the appropriate space for us on the site.

Noyon is located right on the centre line. The totality will last approximately two minutes and 12 seconds, from $10^h 22^m 56^s$ to $10^h 25^m 08^s$ UT (France will be on double daylight saving time, so it is nearly half past noon local time). The Sun will be almost 52 degrees above the horizon.

If you look at the map on page 120 of the *Observer's Handbook* 1998, you will see that where the path of totality crosses France, the 50%-mean-August-cloud-cover line enters the corridor from the south, then skims the northern border of the path of totality, and finally turns south again. Statistically, it is better to be south of that line than north of it. The only place in western Europe where one can be in the path of totality and south of that 50% line is just north of Paris, and that is where we will be.

The Tour

The one-week tour should cost no more than CAN$2,000, based on a Montreal departure. Contact *Voyages Loisirs* directly for fares from other cities. Included in the price are air travel, hotels, breakfasts and suppers, bus transportation in modern, air conditioned, washroom-equipped coaches, the services of *Voyages Loisirs'* escort throughout the tour, as well as all visits and tours that are part of the tour. Not included are additional optional activities. You may extend your trip either before or after (or both) without affecting the cost of the week-long tour, but you will be responsible for any costs for additional services beyond the basic itinerary.

For further information contact:

Voyages Loisirs (éclipse 1999)
4545, avenue Pierre-De Coubertin
C.P. 1000, Succursale M
Montréal (Québec)
H1V 3R2

Téléphone: (514) 252-3129
Direct line: (800) 932-3735
Email: voyagesloisirs@loisirquebec.qc.ca

Résumé

Monsieur Jean-Pierre Urbain organise une visite en France pour l'éclipse totale du Soleil qui aura lieu le 11 août 1999. Le coût total du voyage d'une semaine sera d'au moins 2 000 $ CAN, par personne (pour ceux et celles qui partent de Montréal). Le coût comprend l'avion, les petits-déjeuners et les soupers, l'hôtel (deux étoiles selon les nouvelles normes françaises), l'autocar de luxe, un guide bilingue et certaines visites.

Pour ce qui est de l'éclipse et des activités qui l'entourent, nous serons pris en charge par la Société astronomique de France. Le site choisi est à Noyon, une ville qui vaut le déplacement, même sans l'éclipse. Noyon est en plein sur la ligne centrale de la totalité; le Soleil y sera à 52 degrés au dessus de l'horizon et la phase totale durera 2 min. et 12 sec. Selon l'*Observer's Handbook 1998*, Noyon se trouve là où, dans le corridor de la totalité, la probabilité de nuages est la plus basse en août pour l'Europe de l'ouest.

Il vous sera possible d'allonger votre voyage (à vos frais, bien sûr) mais le voyage de base pour l'éclipse commence le vendredi 6 août arrivée à Paris le matin du 7 août et se termine le samedi 14 août. L'éclipse a lieu le mercredi 11 août de 09^{h}06 à 11^{h}47 (T.U.). Contactez Voyages Loisirs pour plus de renseignements ou pour réserver votre place.

Raymond Auclair has been a member of the RASC for twenty-eight years. In his career he has been a ship's navigator, teacher, and a Dean of Nautical Science, and he now applies statistics to issues of public safety. Well-known as an unattached member of the Society, he is currently serving as National Secretary. He lives in Orleans, Ontario, just outside Ottawa.

SUMMARY OF TRAVEL SCHEDULE

Friday, August 6, 1999: Departure

Saturday, August 7: Arrival in Paris, guided sightseeing tour of the city, and hotel check-in. You will have lots of free time on Day One. Since many of us have visited Paris before, we will take you along on walks and unofficial visits (optional). Since nothing is planned for most of the evenings in Paris, many of us will want to take in shows at theatres, the Opéra, or elsewhere. Now, thanks to the Internet, such soirées are easy to plan. They are optional and thus are not included in the price of the trip.

Sunday, August 8: Visit to the Cité des Sciences La Villette, a science museum with a modern planetarium and an Omnimax movie theatre, and then an afternoon cruise on the Seine aboard a bateau-mouche, those boats which are so well-known and beloved the world over.

Monday, August 9: We will meet our friends from the Société astronomique de France (SAF), who will take charge of our group for the eclipse day. We will visit the Discovery Palace, one of the oldest planetariums in the world, and the Paris Observatory, whose first director was Cassini.

Tuesday, August 10: Travel to Noyon. Astronomical activities related to the eclipse are planned with local astronomical clubs as well as with the Association's national astronomy groups. We will stop at the site, doing whatever we can beforehand to be ready for the big event.

Wednesday, August 11: Plan for an early start in order to get set up at the site (or elsewhere if the site is clouded over). The eclipse begins at 09:06 a.m. UT and ends at 11:47 a.m. UT (nearly ten to two in the afternoon local time). Bring a baguette of bread, some pâté, and a bottle of wine for lunch.

Thursday, August 12: Activities and visits in Noyon organized by the Astronomical Association. In the afternoon it is back to Paris.

Friday, August 13: No events are scheduled, but we will have informal outings for sightseeing, walking, or shopping, which our escort will help us set up.

Saturday, August 14: Departure before noon, with late afternoon arrival in North American gateway cities.

How to Have Fun at Astronomy Day

by Cathy Hall, Kingston Centre

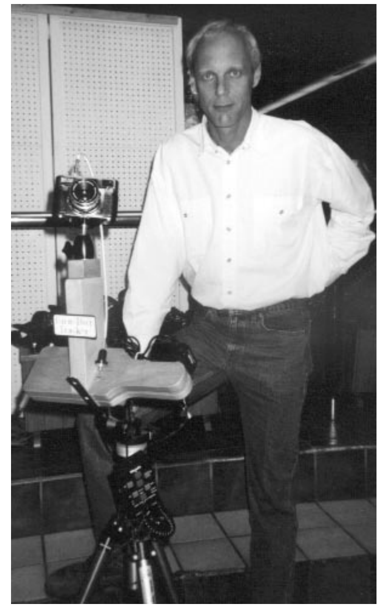
The Kingston Centre had a wonderful turnout this year for International Astronomy Day, celebrated locally on Saturday May 2nd at the Cataraqui Town Centre mall in Kingston, Ontario. We even had our newest Kingston member in attendance, the alien "CSAR," thanks to Hank Bartlett, our extra-terrestrial recruiter!

Peggy Hurley, Centre President, and her husband John Hurley, Centre Treasurer, manning one of the display tables. On the far right is Tom Dean who chairs the Observing Group and the Amateur Telescope Making Group *(all photos by Cathy Hall).*

This year we had a great deal of fun doing our planning and organizing, and our sense of humour was constantly tested. We booked early to assure ourselves of a choice location in Kingston's largest shopping complex, and were very amused to learn at the last minute that our mall contact had overbooked. I thought that only happened on airlines! We were kept in a "holding pattern" for a while, but everything finally worked out.

Leo Enright, the editor of the *Beginner's Observing Guide*, was always ready to answer questions from members of the public.

We contacted the mall by telephone several days before the event in order to guarantee that everything was in place for setting up our exhibits on Saturday morning. "Yes," the lady assured me, "everything is fine." I reminded her that we would be using all five tables again this year. "Oh, you're bringing tables with you?" was her reply. I reminded her (cheerfully) that the mall provided the tables. "Oh, you will be pleased to hear that we will have a notice about Astronomy Day on our outdoor billboard again this year," she told me. "Yes, it will read 'Astrological Displays here today!' ". Smiling through the phone, I politely corrected her, saying that would be a spelling mistake and could she please correct it. She said she would try to remember to tell the night staff.



Frank Hitchens with his barn-door tracker.

At that point I racked my brain for any other obvious points that might be open to misinterpretation. Our prime spot in the mall is a large, round, recessed area used as a sunken fountain, that is normally kept filled. I reminded her that she should speak to the night staff to remind them that our area should be drained on the Friday night. She replied, "Oh, yes! I must remind the night staff of that too!" I smiled through my teeth, thanked her profusely for all her help, and kept my fingers crossed for Saturday.

"CSAR," the Kingston Centre's newest member!

Being Kingston Centre members, of course, we are always

The Centre's National Rep, Susan Gagnon, adding a new dimension to astrophotography.

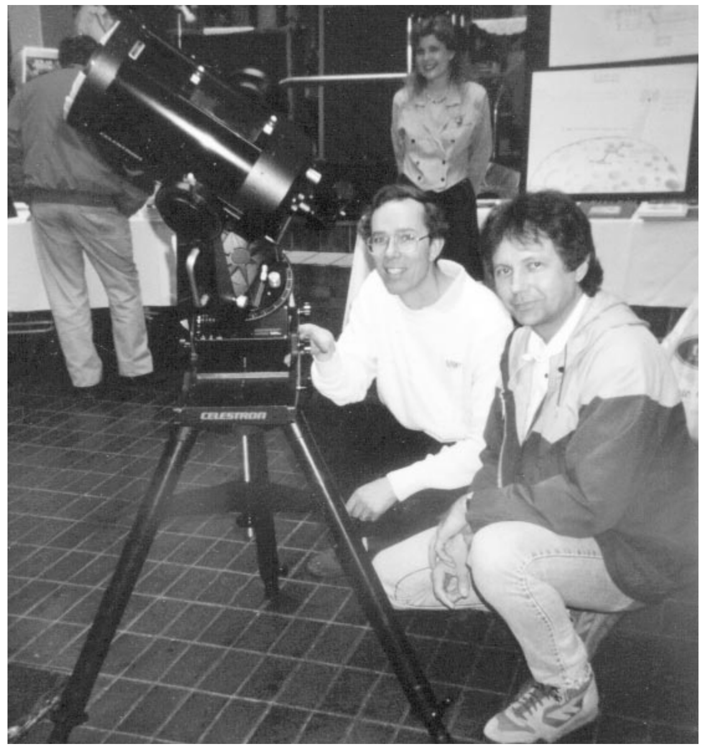
prepared for anything. Hank Bartlett volunteered to bring his rubber raft, just in case our area had not been drained. We decided we could put our new alien member in the raft, holding a pair of binoculars to demonstrate the Kingston Centre's method of teaching about deep sky objects. As it turned out, our area was high and dry for Astronomy Day.

Various members brought a large assortment of colourful astronomical display boards. I contributed a large inflatable sky globe containing all of the mythical sky creatures, and a colourful assortment of astronomical balloons, which we attached to all the displays.

Telescopes were varied and plenty. We had so many offers of telescopes that we had to turn some down! Those bringing telescopes were Joe Shields, Kendra Angle, Doug Angle, Leo Enright, Hank Bartlett, Brenda Shaw, Tom Dean, Norm Welbanks, Laura Gagné, Karel Chrastina, and others. We also had a barn-door mount, courtesy of Frank Hitchens, who demonstrated what can be done with an innovative camera setup. We had a display on mirror grinding, courtesy of Tom Dean, who also brought along several examples of the Centre's efforts.

There was also a special display by the Kingston Centre's Youth Group. It is a special group, with its own astronomical activities, for which the Centre applied and received a sizable government grant for 1998. Kendra Angle's award-winning telescope (see elsewhere in this issue for a separate report) was also on display.

Hank Bartlett, the Centre's extraterrestrial recruiter.



Doug Angle (left) and Vic Smida (right) with one of the many telescopes that were on display.

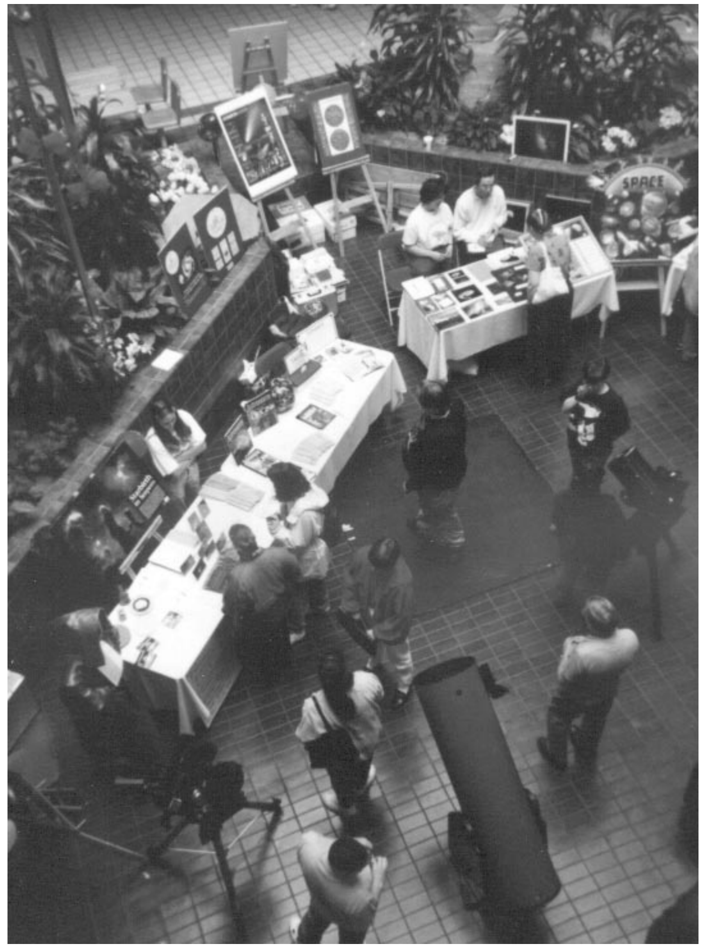
Available for the public were more handouts than we have ever had before. *Astronomy* magazine basically adopted us. They sent us display material, eight incredible astronomy books as door prizes, a gift of a year's subscription as an additional door prize, and literally hundreds of copies of various 1998 issues of *Astronomy* to hand to the public. We were absolutely overwhelmed! We sent them back a very special letter and several gifts from our Centre. We were also assisted by *Sky & Telescope* magazine, which sent us reams of material for beginners as well as catalogues. They were much appreciated.

We also had brochures on the RASC. Never before have we had available so many different pamphlets. We had three-fold brochures on the Kingston Centre, brochures on the Centre's Youth Group, and brochures on getting started in astronomy, all designed and produced by Kim Hay and Kevin Kell. We had brochures on the Belleville Astronomy Club, courtesy of Joe Shields, and we had brochures on how to get into meteor observing, produced by me on behalf of the North American Meteor Network. We had information sheets on choosing telescopes, and ones introducing astrophotography, written by Frank Hitchens. We also had many different handouts put together by Kevin Kell, on everything from times for Mir's overhead passes to complete kits of put-together cardboard spacecraft. Special handouts were full-colour astronomical postcards, courtesy of Dieter Bruekner. They were very popular. A special treat was Leo Enright's photographic table display, a highlight each year. He captivated many members of the public with his incredible photos.

There were many other Kingston members not already mentioned who helped with talking to the public or in other ways. Every year we have between twenty-five and thirty members who come out to help. Every year we seem to have inclement weather for our planned evening observing, yet every year Kathy Perrett of the Astronomy Group at Queen's University has been ready and willing to show the public through the observatory at Queen's. Thank you, everyone, so much for all your efforts.

All in all, Astronomy Day 1998 was a great success. In spite of a number of interesting episodes, we had a very large turnout, in terms of both our members who contributed in various ways to making it a very special day, and the public who stopped by to chat and find out information on astronomy.

Laura Gagné is the co-chair of the Centre's youth group. She is standing in front of Kendra Angle's telescope display.



A partial view of the exhibit area.

Cathy Hall has co-ordinated astronomy exhibits and activities for the Ottawa, Toronto, Hamilton and Kingston Centres over the past thirty years. She has also held a variety of positions at both Centre and national levels, including National Librarian, Ottawa Observering Group Chairman, Toronto Council Member, Hamilton Treasurer, and Kingston Astronomy Day Co-ordinator. Her main observing interests have always been meteors and comets, and she is an active member of both the North American Meteor Network and the International Meteor Organization.

Galaxies — A Matter of Subtle Contrast

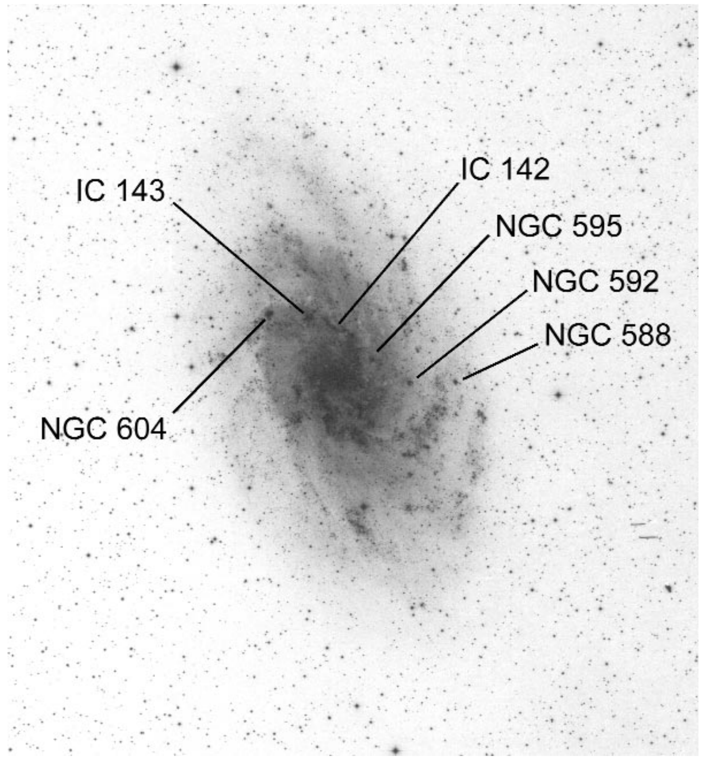
by Alan Whitman, Okanagan Centre (awhitman@vip.net)

The Pinwheel Galaxy, M33, is a magnitude 5.7 face-on Sc spiral a degree long. Since it more than fills the field of view of most telescopes, it can remain undetected in light-polluted skies. A typical lament was the following from southern Ontario on the RASC E-mail discussion list: "I have three Messier objects left. Two are fainter galaxies that will have to wait until I can get away from city lights, and then there is M33. It is the Triangulum Galaxy, and it has a magnitude that should allow me to see it unaided. Nevertheless, the object has proven to be the most frustrating on the list. *I cannot see it!* Has it recently disappeared? Shouldn't it be an easy target in binoculars if not by naked eye? Has anyone got any observing hints?"

Many observing hints were offered in reply, such as these from Sid Lee: "I hate to break it to you, but make that three that you are going to have to get away from city lights to view. …M33 is actually fairly tough to see, especially when you are not certain what you are looking for.

"Do not be fooled by its listed magnitude. Like all such extended objects, the listed magnitude is an 'integrated magnitude,' meaning that if you add up all the light from it and say 'if this much light were coming from a star it would have a magnitude of such and such.' In the case of M33 and many other extended objects, the light is spread over a fairly large area of the sky and, as such, the surface brightness is a lot lower than you would think looking solely at the magnitude figure. It is quite a large object, about one-degree across (two Full Moons), and fairly evenly illuminated. It is likely that you have looked directly at it several times while trying for it and not recognized it for what it was. Use a low power eyepiece and try again from a dark clear site."

Mark Kaye's story truly illustrates the case: "I spent three years looking for M33 from the Bloor and Spadina region [of Toronto]. I knew the foreground stars so well that I could find them in my sleep. I had found nearly all of the rest of the Messier catalogue from my light polluted skies, but M33… remained unspied! I also wondered about the catalogues — they made a mistake with M102, did they do it to M33 as well? I had one object left on my Messier list when we went on a canoe trip in Northern Ontario in September 1984. The first clear night after a storm during the trip cleared out the air and brought us beautiful skies. M31 rose off the horizon, and a little while later M33 was plainly visible to the naked eye — a spiral the size of the Moon! I was so amazed I awoke all of my canoeing friends

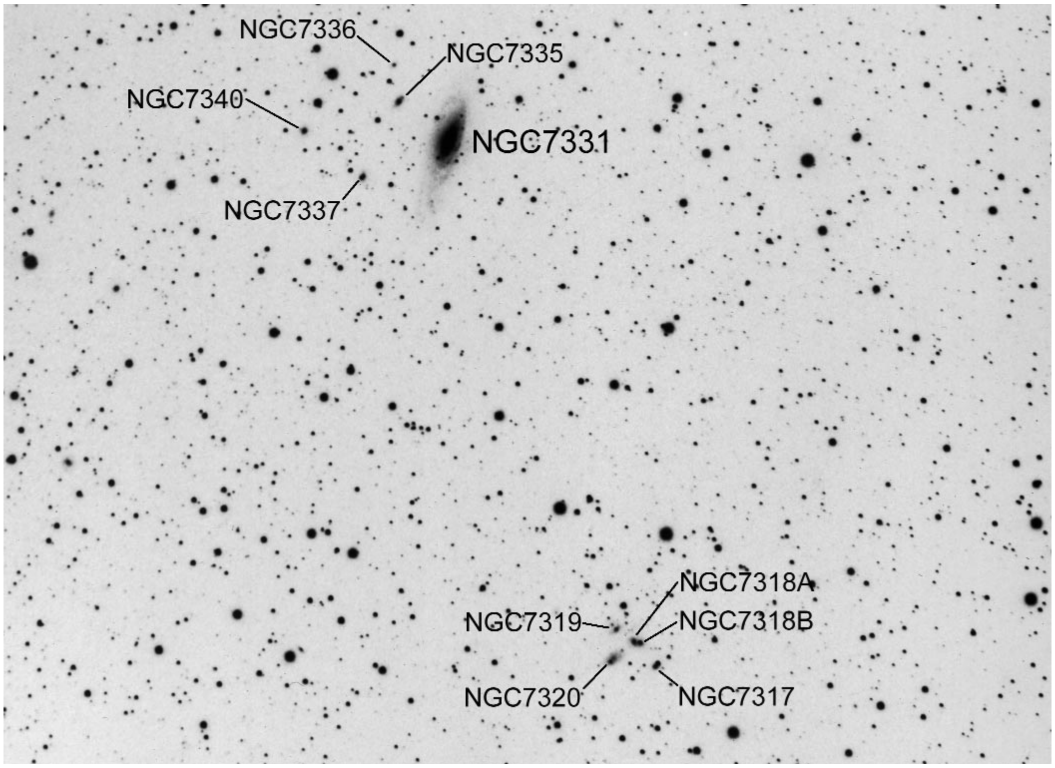


M33, in Triangulum, with its brighter H II regions marked (Palomar Observatory Sky Survey Image).

and they thanked me after a good long view. Those could well have been once in a lifetime stars, the skies were so incredibly clear."

My M33 story goes back to my youth in the Moncton suburbs. At that time an eye examination included drops that greatly enlarged the pupils. A late fall afternoon visit to the opthalmologist was fortuitously followed by the passage of a strong cold front that both cleared the skies and downed power lines, blacking out the normal light pollution. Early that evening for an hour my suburb enjoyed transparent black skies like Mark Kaye experienced on his wilderness trip. Because of the artificial enlargement of my pupils caused by the drops, I temporarily enjoyed "owl-eyes" and made my first and easiest naked-eye sighting of M33.

On nights when the sky is transparent enough to find this galaxy with the unaided eye, trained eyes can discern a great deal of subtle detail through telescopes. My 20-cm Newtonian reveals segments of the two main spiral arms at 61× . The southern arm has brighter condensations than the northern



The NGC 7331/Stephan's Quintet region of Pegasus (image by Rajiv Gupta ~60 min on hypered Tech Pan with 5″ f/6 refractor).

one. The huge emission nebula NGC 604 (more than a thousand times the size of M42) is obvious 10 arcminutes northeast of the nucleus. At 91× in my 41-cm reflector a line of six H II regions, appearing as slightly brighter condensations, stretches southwestwards across the northern and western sides of M33. Beginning with NGC 604, the others in order are IC 143, IC 142, NGC 595, NGC 592, and NGC 588. They constitute all of the emission nebulae that I have identified in careful searches with that telescope, although there are certainly other knots visible — they are probably stellar associations. The 0.6-metre Cassegrain in Prince George adds the two faint outer spiral arms for a total of four arms.

Here is Rick Wagner's evocative description of M33 as seen in Atilla Danko's 64-cm reflector at Starfest in 1997: "One of those remember-all-your-life sights. All the arms were there — not just visible but glaringly obvious — twirling outwards, splitting, scattering clumps of stars. About a dozen H II regions, some brighter than a very good Messier object appears in a 20-cm scope. Truly a spectacular view — that alone made the trip to Starfest worthwhile."

Slew over to Pegasus. NGC 7331 is a large (10.0′ by 2.4′) magnitude 9.5 galaxy found four degrees NNW of Eta Pegasi. While it is a rather standard Sb galaxy in my 20-cm equatorial (elongated with a very bright nucleus and a hint of another bright spot just north of the nucleus), it flowers in the 41-cm reflector. After an excellent night my logbook entry was: "174×: very elongated, bright middle with stellar nucleus, long faint spiral arms with a star barely following the south tip."

Stephan's Quintet (NGC 7317-20) is a popular challenge object 0.5 degrees SSW of NGC 7331. Daryl Dewolfe observed the tight group of small and faint galaxies (ranging from magnitude 12.7 to 13.6) with his fine 145-mm Ceravolo Maksutov-Newtonian at last year's Astro Atlantik Star Party in Fundy National Park. Here is his report: "The Sunday night was probably the best night for seeing of the year that I have experienced. I was able to see the [magnitude] 6.4 star near Polaris directly unaided. I was able to see Stephan's Quintet as four fuzzy blobs (one was a twin member) at 325× using a 7-mm Nagler and a 2.8× Klee Barlow lens."

There are different depths to observing. The first challenge is to find an object like M33 for the first time. But that is only the beginning. Any of the following may result in seeing fine details that you have never been able to discern before: steps to improve a telescope's contrast, giving in to aperture-fever, the training of an observer's eye to better see low contrast detail, or the occurrence of a night when both the transparency and seeing are superior.

Object	Right Ascension	Declination	Comments
M33	$01^h 33.9^m$	+30° 39′	Local Group G-Sc
NGC 604	$01^h 34.5^m$	+30° 48′	H II region in M33
IC 143	$01^h 34.1^m$	+30° 47′	H II region in M33
IC 142	$01^h 33.9^m$	+30° 45′	H II region in M33
NGC 595	$01^h 33.5^m$	+30° 42′	H II region in M33
NGC 592	$01^h 33.2^m$	+30° 39′	H II region in M33
NGC 588	$01^h 32.7^m$	+30° 40′	H II region in M33
NGC 7331	$22^h 37.1^m$	+34° 25′	G-Sb
NGC 7317-20	$22^h 36.1^m$	+33° 57′	Stephan's Quintet

Retired weatherman Alan Whitman's last three homes in rural British Columbia have been adjacent to wilderness, and so his backyard skies have occasionally yielded M33 to the unaided eye. He invites detailed observing reports from experienced amateurs, who have largely completed their Messier list, for use in this column.

Scenic Vistas: The Pisces Group

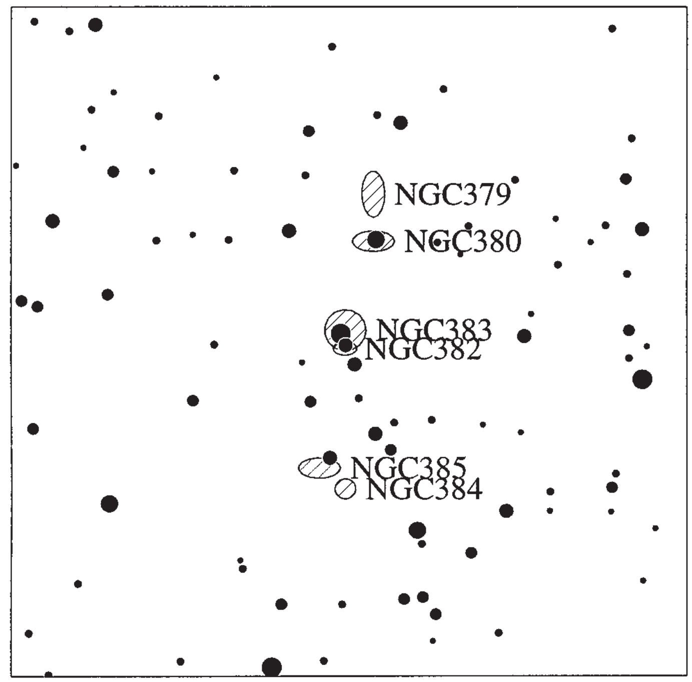
by Mark Bratton, Montreal Centre (mbratton@generation.net)

One of the unavoidable realities of observational astronomy for amateurs, particularly for deep sky observing, is the fact that there are relatively few "showpiece" objects in the night sky. The sight of the Pleiades, the Orion Nebula, or the Andromeda Galaxy has thrilled anyone who has attempted the Messier List, but few would claim to be awestruck at the sight of M89 or M91. There are a number of bright and interesting objects in the *New General Catalogue*, but the overwhelming majority consists of small, faint and nondescript objects. How, then, is one supposed to maintain one's sense of adventure and discovery when so much of the observable universe is so remote as to be, on initial examination, visually uninteresting?

The obvious answer would appear to be to get a larger telescope, but as anyone who has ever used a large telescope will tell you, a big mirror will give you more light but, for remote objects, not necessarily more detail. What is required is a change in attitude of the observer himself. As Robert Burnham, Jr., remarked in his *Celestial Handbook*, "As a Japanese sage has said, 'One must be open to the experience of the Ah! of things...' " As the constellations of summer give way to the dimmer ones of fall, we are once again presented with a clear view into the remotest corners of the universe. Unlike the spring sky, however, which is dominated by the Virgo Cluster and the many bright, nearby galaxies of Ursa Major, Leo and Canes Venatici, the galaxies of fall tend to be small, faint and at chillingly vast distances from our own Milky Way. Nevertheless, there is much of interest here for the patient, well-equipped observer, if he knows where to look.

In the fall of 1993 I had the opportunity to track down a small group of galaxies that I had heard about but never seen. That is the Pisces Group, a collection of six small, though moderately bright, galaxies arranged in an almost straight north-south line and observable together in the field of a medium to high power eyepiece. The galaxies are predominantly elliptical in nature and range in brightness from magnitude 12.4 to 13.2. To find the field I initially used a Meade 40-mm super-wide angle eyepiece that gave me a magnification of 48×, but even at such low power the view was enticing. In a field peppered with tiny foreground stars, an unresolved nebulous streak was visible. As I worked my way up to 313×, the streak of light revealed itself to be six individual galaxies that were best seen at 313×.

The brightest of the group was NGC 383, which occupied the central portion of the chain. The galaxy's envelope was fairly well defined and slightly elongated. A faint, nebulous glow appeared attached to the outer envelope to the southwest. That was NGC 382, the faintest galaxy visible. In fact, high magnification revealed that the other members of the group were paired off



A 0.5° square field of the Pisces Group. Stars to near magnitude 15 are shown *(Chart prepared by Dave Lane).*

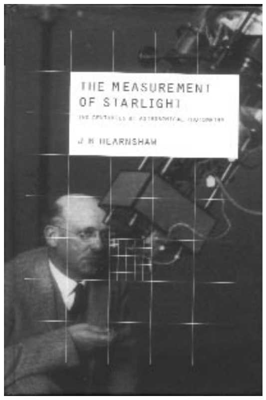
as well, with NGC 379 and 380 together in the north and NGC 384 and 385 together in the south. All the galaxies appeared well defined, and NGC 379 seemed quite noticeably elongated north-south.

The small group of galaxies is part of a much larger structure, one that was first noted by Clyde Tombaugh during his photographic survey for distant planets at Lowell Observatory. It is a vast, filamentary assembly of individual clusters of galaxies stretching from Perseus to Pegasus delineating one of the largest objects in our universe visible to astronomers. Most of them can be well-observed in 20-cm and larger telescopes and dominate the sky from now until the beginning of the New Year.

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

Reviews of Publications
Critiques d'ouvrages

The Measurement of Starlight: Two Centuries of Astronomical Photometry, by J.B. Hearnshaw, pages xiv + 511; 16cm × 23.5cm, Cambridge University Press, 1996. Price US $89.95 hardcover. (ISBN 0-521-40393-6)



In the words of the author, "This book tells the story of the historical development of stellar photometry, the science of the measurement of the magnitudes and the colours of the stars. [It] has been written for the practising astronomer…" Given that stellar photometry is critical to our understanding of the spatial scale of the universe and to an understanding of the structure and evolution of stars and galaxies, the book is really much more than is stated by the author. It is also an introduction to the development of many areas of modern astrophysics and to the people responsible for those developments.

The book is organized into ten chapters that address four technologically-defined areas: visual photometry, photographic photometry, photoelectric photometry, and electronic area detectors. The books ends with a brief — less than one page — reference to CCDs, a development so recent with a history so brief, that it can be traced in other current publications. As with any history, the book is intended to be read chronologically from beginning to end. Nevertheless, it is possible to open it at almost any page, read a short section about a particular person, observing program, or technology, and still see how it fits into the broader story.

The history of quantitative photometry is brief, but its antecedents go back more than two millennia. We are usually told that the concept of a stellar magnitude originated with Hipparchus in the third century B.C., but Hearnshaw gives most of the credit to Claudius Ptolemy. It is easy to forget that magnitude — the most basic of a star's measured properties — was not formally defined, and its scale not quantified (by Pogson), until the middle of the last century. Those important developments were not arrived at easily, were not without controversy, and did not end debate on these most fundamental features of photometry. Indeed, little more than a half century ago it was still being suggested that the inverted scale — numerically smaller magnitudes corresponding to higher luminosities — should be abandoned. Many of our students today would vote in favour of that!

The term "photometry" includes the measurement of colour. Systematic estimates of colour were begun early in the nineteenth century. Not previously known to me is the fact that Karl Schwarzschild — of black hole fame — created the earliest quantitative "colour index" and found a relationship with temperature. Photometry also includes the measurement of polarization — polarimetry — which was first accomplished approximately 60 years ago. Modern photoelectric systems, *e.g. UBV*, have been developed only within the past 50 years; and reliable photoelectric sequences of standards did not appear until the late sixties and early seventies.

Hearnshaw tells many interesting stories and dispenses with a few apocryphal tales. The story told me many years ago that Argelander made the observations for the *Bonner Durchmusterung* while his wife recorded data in response to his stomping on the floor and calling-out information as a star crossed the meridian may have to be abandoned. As described by Hearnshaw, the *BD* owes its existence largely to the work done by two assistants using more pedestrian procedures. Even today, a century-and-a-half after its publication, I have a copy of the *BD* charts close by. (You never know when the computer will crash, rendering all those star charts on CD-ROMs useless!) The research by Bailey, Leavitt, Hertzsprung and Shapley on the pulsating variables, which revealed the period-luminosity relation and led to the first determination of the structure of the Milky Way, is described in detail. In sharp contrast to those successes is the sad story of the *Carte du Ciel* and its companion *Astrographic Catalogue*, a project conceived in 1887 and completed — the *Catalogue* but not the *Carte* — in 1962! By then it had little, if any, value.

For amateurs who make visual estimates of magnitudes, the struggles of pre-photographic era observers may be humbling, while the discussions of the effects of colour (the Purkinge Effect, for example), of atmospheric extinction, and of the sensitivity of colour to mirror coatings will be useful guides in their own work. For those who are drawn to the people who made the history, the book identifies the individuals who deserve the credit for each technical development as well as those who receive credit undeservedly. Birth and death dates are usually included as well as an occasional anecdote that gives life to the person or to the era in which he or she worked. A nice feature of the book is that the author identifies the often-overlooked assistants who did so much of the tedious observing, recording, and calculating. Numerous quotations from the published literature and from personal correspondence go far to reveal, for example, the justifications for some observing projects, the particular difficulties which an individual had to overcome, and the scientific (and personality) conflicts that played roles in determining the directions in which science and technology developed.

The book is also very well-referenced. On average, 182 references accompany each of the ten chapters. At several places within the text, subsets of references that have a common theme are separately listed in chronological order, a bonus for anyone who wishes to read the original literature in proper sequence. The book has been written, edited, and assembled with great care — not until page 439 was I able to find a typographical error. The text is complemented with a generous number of photographs of people and instruments, and reproductions of drawings and graphs that have been reproduced to a very high standard. All of that comes at a price, of course, which means this book may find few buyers outside of the professional astronomical community. That would be unfortunate because the book is a useful and informative introduction to a vibrant area of astronomical research — one that can be enjoyed by historically and technically minded professionals and amateurs alike. The future always builds on the past, and Hearnshaw has described that past in painstaking but never boring detail.

Douglas P. Hube

Douglas P. Hube is a professor in the Department of Physics, University of Alberta. His professional interests are in the area of spectroscopic and photometric studies of binary and variable stars, and the optical detection of supernova remnants. He is also a former National President (1994–96) of the RASC.

Explorers of the Southern Sky: A History of Australian Astronomy, by Raymond Haynes, Roslynn Haynes, David Malin and Richard McGee, pages xiii + 527; 18 cm × 25 cm, Cambridge University Press, 1996. Price US$90.00, hardcover. (ISBN 0-521-36575-9)

Canadian astronomers were delighted to learn recently that Australia has been admitted to the *Gemini* Project, the international collaboration through which are being constructed two eight-metre telescopes, one in each of the northern and southern hemispheres. Like Canada, Australia has a proud history of excellence in astronomy, and will bring to the project a peculiarly Australian panache — a mix of imagination and practicality, with high scientific standards and a certain earthy frankness that is unhampered by stuffy academic pretension.

So, at least, was my experience of the Australian astronomical scene during four years spent working there in the early 1980s; and return visits have not dimmed that impression. A more energetic community, and more engaging and forthright characters, would be hard to find! It is a great pleasure, then, to read this comprehensive and beautifully-produced history, reliving recent events and recalling some of the principal players, but also learning much of interest about the astronomical contributions of prior generations of Australians.

Indeed, the history is as far-reaching as any on Earth. The story begins with an exposition of astronomical representations in aboriginal myth and art, and the book's dust cover is appropriately graced with a modern depiction in traditional style, by aboriginal artist Tim Tjapaltjarri, of the stars of the Pleiades. Other attractive illustrations, and the legends they represent, are described in a brief first chapter. This stage of the history, however, is necessarily incomplete, and the remainder of the book deals with developments since the voyages of Captain James Cook, just over two centuries ago.

As in many new nations contending with the privations of frontier surroundings, short supplies, and limited technical support, the pioneer astronomers of Australia had to be a particularly resilient and resourceful breed. Naturally enough, interactions between such strong-willed parties often led to real hostility, and it is sobering to read of the numerous astronomers who were opposed by their colleagues and occasionally deceived and disgraced by their superiors, usually government agencies. We learn of William Cooke, for example, appointed the Government Astronomer in Sydney but fated to disappointment in all he was promised: provided with no "fine modern observatory with modern instruments," later faced with abrupt closure of his observatory rather than relocation to a long-promised better site, and doomed to a pensionless old age eking out a living teaching bridge after his unjust dismissal.

Such pen portraits bring to life the characters of earlier centuries, fleshing out what seems an admirably complete and well-researched scientific history. Yet that represents only a part of the whole: well over half of the book deals with what would, by any reasonable definition, be described as "modern" astronomy. Many of the principals described, occasionally in surprisingly frank and colourful terms, are still with us, and the complex history surrounding, for example, the founding of the Anglo-Australian Telescope, is told without varnish.

At times the story becomes a little confusing thanks to the stylistic approach of dedicating a chapter each to various developments that ran simultaneously (astronomy in the University of Sydney; the emergence of radio astronomy; the development of the Mount Stromlo Observatory; etc.). Although I approve of that division — a strict chronological recounting would have been too intertwined for easy comprehension — it is sometimes difficult to keep track of the parallel progress along different fronts. It may be an inevitable failing, but in this volume it is a minor one. In general, the writing is not only engaging but also surprisingly seamless, given that no fewer than four authors participated.

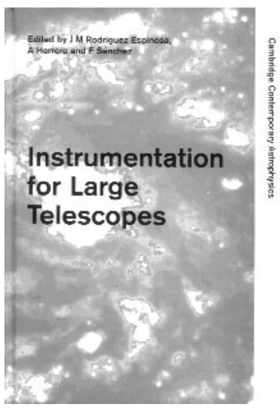
Early in this century astronomy grew to incorporate the science of astrophysics, and no modern history of astronomy can be complete without some explanation of the scientific motivation for the development of new instrumentation, the theoretical basis for astronomical prediction, and the excitement of confirmation and discovery. To its credit, this book makes every effort to provide that scientific perspective and merges it into the narrative in fine fashion. However, certain discussion may prove opaque to the lay reader, so the book may appeal more to professional astronomers.

Cambridge University Press is to be congratulated on a fine production, with generous numbers of well-presented illustrations, both old and new. The book concludes with some useful endnotes, a glossary of acronyms — the bane of modern astronomy — and abbreviations, a set of definitions of common astronomical terms, a rich bibliography, and both a name and a subject index. Such thoroughness is to be applauded.

We likewise applaud and welcome the Australian presence on *Gemini* — a development far too recent to feature in this very handsome book, but cause for true celebration. Read this volume to find out what a wealth of imagination and talent they will contribute!

David A. Hanes

David A. Hanes is a professor of astronomy at Queen's University, Kingston.



Instrumentation for Large Telescopes, edited by J. M. Rodriguez Espinosa, A. Herre, and F. Sanchez, pages xv + 329; 18 cm × 25 cm, Cambridge University Press, 1997. Price: US $69.95 hardcover (ISBN 0-521-58291-1)

Observational astronomy is one of the most exciting areas in the physical sciences, thanks in no small part to the ingenuity and dedication of the builders and designers of successive generations of superb telescopes and their auxiliary instruments. From the ground one can now realize sub-arcsecond resolution across the available visible and near-infrared spectrum. High transmission fibres offer a huge multi-object gain in spectroscopy. Solid-state detector arrays with millions of independent elements (pixels) are able to exploit this multiplex gain and detect almost 100 percent of the light falling on them with a system noise of only a few photons. Such capabilities, coupled to telescopes of increasing size — now up to ten metres — provide a view of the universe and quality of spectra of unprecedented sharpness and clarity. Nowhere is the gain more dramatic than in the near-infrared (1 to 5 microns).

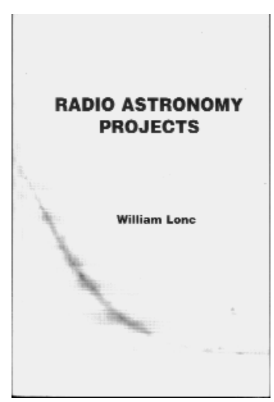
This book is a compendium of the lectures given at the 1995 VII Canary Islands Winter School of Astrophysics for advanced graduate students. It covers the range of current instrumental technology and analytical techniques, with particular emphasis on the many 8-m to 10-m class telescopes that will come on line by the end of the millennium. There are eight chapters by acknowledged experts in their fields: Jacques Beckers on high angular resolution and adaptive optics, Michael Irwin on detectors and image analysis, Richard Puetter on image reconstruction, spectroscopic techniques by Ken Taylor, high resolution spectroscopy by David Gray, Ian McLean on the infrared, Barbara Jones on the mid-infrared, and polarimetry by Sergo Alighieri. While the information in some rapidly changing areas such as detectors is no longer up to date, the basic concepts and the majority of the material are completely valid, providing excellent coverage.

Each chapter comes complete with useful references, and the treatment ranges from the astrophysical basis for the observations to the careful extraction of information, to the purely instrumental challenges. In each case the impact of fundamental limitations on experimental design and analysis are fully discussed — including topics such as photon shot noise, diffraction and optical transfer functions, and parasitic noise from sky and equipment. There is broad reference to existing instruments and supporting surveys both from space and from the ground.

In view of the many important topics covered, this book would have benefited greatly from a good index. It is difficult for the casual user to dip into it for reference. It would also have been improved further by a final editing pass from Cambridge University Press to correct rather obvious errors in usage and spelling. Such minor criticisms aside, I highly recommend the book to readers with some background in astronomy and physics and an interest in how modern observations are made. The book is particularly suitable as a text for a senior undergraduate or graduate course on astronomical instrumentation and techniques. For any graduate student who expects to contribute to frontier research with the new 8-m class telescopes, it should be required reading. Finally, it is an invaluable resource for engineers and other groups building instruments. Only with an awareness of the underlying science can the best instruments be built.

Gordon Walker

Astronomical instrumentation and techniques have always fascinated Gordon Walker, who recently retired as a Professor of Astronomy from the University of British Columbia. Among other things, he developed digital low-light-level detection systems based on TV cameras, diode arrays and CCDs. His book, Astronomical Observations, *was published by Cambridge University Press in 1986.*



Radio Astronomy Projects, by William P. Lonc, pages 217; 14.5 cm × 22 cm, Radio-Sky Publishing, 1996. Price US$20.00 soft cover. (ISBN 1-889076-00-7)

Building and operating a radio telescope has been compared in its level of difficulty to constructing a television set given only a block diagram. This book shows that it is possible to succeed with much less expertise by using mainly off-the-shelf and surplus equipment, primarily from TV satellite receiving systems. For example, in the section entitled "Beginner's Microwave Radio Telescope," Lonc says, "The essence of the proposed system for the *beginning* radio astronomer is that a domestic satellite TV system is already a radio telescope…". In the section entitled "4 GHz Interferometer: 4 m Baseline," he states "…the basic approach was to assemble something quickly with available off-the-shelf surplus components."

This little book contains descriptions of no fewer than twenty-one operating radio telescopes, all constructed on the roof of a building in Halifax on the campus of Saint Mary's University. Of the twenty-one telescopes, five are used for undergraduate student projects, *e.g.* to measure the brightness temperature of the Sun at 6 GHz or to measure its angular diameter at 4 GHz. The range of frequencies over which these individual telescopes operate is 0.14 GHz to 12 GHz.

All but one of the twenty-one radio telescopes described in the book are used to observe the Sun. Two are used to detect the Galactic Centre. Why are so few attempts made to "get down to the noise" and attempt to observe other strong sources such as radio galaxies Cygnus A and Hercules A, or supernova remnants Cassiopeia A and Taurus A? For example, why does Lonc not generally employ output low-pass filtering of the D.C. signal to the recording device? The answer must lie in the fact that all of his radio telescopes have to operate in the interference-cluttered environment of a city. To keep costs down and maintain simplicity, he does not use bandpass radio-frequency filters to suppress out-of-band interference. Observations of the Sun produce such good signal-to-noise ratio, even in an urban environment, that the observer can concentrate on simply making sure that there is enough output signal to drive the recording device.

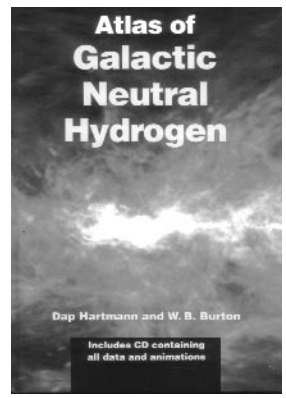
One is prompted to ask, however, why Lonc does not employ phase-switching in his interferometers, since he introduces the idea in the early section "Some General Concepts." Given that the technique is the best defence against receiver gain variations and local interference, it would seem natural to use it. (All professional radio interferometers and synthesis radio telescopes use it.) But phase-switching requires a bit more electronic expertise than the author may have been willing to demand of his students and his readers. One quibble: the lengths of interferometer baseline that will produce zero fringe visibility (*i.e.* zero output from the radio telescope) when observing a bright disk of specified angular size are given "to three significant figures," and the angular diameter of the Sun at 4 GHz is calculated from the fringe visibility measured with an east-west interferometer. However, the expression given for the fringe visibility (a sinc function) is that for a uniformly bright rectangle, not a disk. The correct expression (a jinc function) uses Bessel functions and gives results that are considerably different.

William Lonc holds doctorates in physics and philosophy, and taught mathematics and physics at Saint Mary's University from 1964 to 1995. He has been mentor to many young engineers and physicists, and is widely known for his ability to demonstrate physical principles with very low-cost equipment. He is now professor emeritus.

The book is based to a considerable extent on articles published by Lonc and his students over the years. That occasionally produces some repetition, but it is minor. The book succeeds very well in what the author intended: to show that amateur radio astronomy can be undertaken successfully anywhere, and by non-experts in electronics. It therefore fills a need, and joins the "how to build it" ranks of F. Roy and K. Tapping's detailed paper on a 238 MHz interferometer (JRASC, 84, No. 4, p. 260, 1990), K. Tapping's series in the RASC National Newsletter (February-August 1978) and G. W. Swenson's series in *Sky & Telescope* (May-November 1978, and April 1979).

David Routledge

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



Atlas of Galactic Neutral Hydrogen, by Dap Hartmann and W. B. Burton, pages x + 235; 21 cm × 30 cm, Cambridge University Press, 1997. Price US$150.00 hardcover. (ISBN 0-521-47111-7)

Hydrogen atoms are one of the most ubiquitous constituents in the universe, comprising about 90% of all atoms. Outside of the ionized nebulae surrounding hot young stars, the interstellar medium of our own Milky Way and other spiral galaxies is filled with hydrogen atoms in a neutral state. The possibility of detecting neutral atomic hydrogen by means of its 21-cm wavelength radio line was first suggested by H. C van de Hulst in 1945, and the race to observe the line culminated in 1951 when three groups in the Netherlands, United States, and Australia reported detections.

Over the subsequent decades, several efforts have been made to map the atomic hydrogen in our galaxy. The *Atlas of Galactic Neutral Hydrogen* presents images from the Leiden/Dwingeloo Survey, the latest and most comprehensive survey of galactic neutral atomic hydrogen. Taking advantage of modern radio receiver technology and digital electronics mounted on the 25-metre telescope at Dwingeloo, the authors have constructed high-fidelity images of the galactic atomic hydrogen gas north of declination −30 degrees.

Because of the rotation of our Galaxy, there is a general correlation between the Doppler shifted velocity of the 21-cm emission line and the distance of the emitting hydrogen gas. In the solar neighbourhood interstellar gas rotates with the local stars, and thus has nearly zero velocity shift with respect to the so-called local standard of rest. Further from the Sun, the magnitude of the velocity difference increases. The basic data of the Leiden/Dwingeloo survey is a three-dimensional data cube, with galactic latitude and longitude as the first two dimensions and Doppler shifted velocity along the third axis. The *Atlas* contains 182 pages of colour and gray scale images of hydrogen gas over a range of Doppler shifted velocities, showing how the hydrogen is distributed in the plane of the Galaxy as a function of distance from the Sun. The velocity depth of the survey is also sufficient to detect emission at anomalous velocities from high and intermediate velocity clouds associated with the Milky Way, and emission from nearby local group galaxies. The images of galactic hydrogen are visually stunning. No line of sight from the Earth is free from hydrogen emission. Nearby, the bright emission from the plane of the galaxy, combined with the emission from bright filaments of local gas at high galactic latitude, renders an overall effect suggestive of Dante's Inferno. At larger distances, large loops and supershells give evidence of the violent energization of the interstellar medium by supernovae.

The *Atlas* includes a CD-ROM, containing images in "gif" format that are easily viewed on a personal computer. The disk also contains animation files of the three-dimensional data cube that can be viewed with AutoDesk Animator. For the more serious browser, or those wishing to use the data for astrophysical purposes, the CD-ROM has a directory of FITS (Flexible Image Transport System) images containing the actual data. Browsing software is not included. To view and extract information from the FITS files you will need access to one of the major astronomical reduction software suites such as IRAF or AIPS, or a FITS file viewer. A simple viewer program, FITSVIEW, for PC Windows, Macintosh or Unix operating systems is available free from the National Radio Astronomy Observatory web site at www.cv.nrao.edu/~bcotton/fitsview.html.

The Leiden/Dwingeloo survey was Dap Hartman's Ph.D. research project, and the text accompanying the images in the *Atlas* is largely condensed from his Ph.D. thesis. It describes the observing and processing methods used, and, in good thesis manner, provides the analysis critical to understanding the reliability and photometric accuracy of the data. There is, unfortunately, little commentary on the images themselves. Those who enjoy the technical side of radio astronomy observations, however, will be gratified by the explanation of the observing strategy and the technique used to correct for stray radiation picked up by the antenna side-lobes. The text also contains a brief summary of the history of the prediction and detection of the atomic hydrogen line. A particular treat is the reproduction of the minutes of the 75th meeting of the Nederlandse Astronomen Club at which van der Hulst published his prediction that the 21-cm line would be detectable from interstellar space.

The *Atlas of Galactic Neutral Hydrogen* has an attractive cover, and the images within provide a dramatic view of the principle component of the interstellar medium of our Galaxy. It is a worthwhile addition to the bookshelves of serious students of the interstellar medium or those interested in a view of our Galaxy that is not generally available in popular astronomy publications.

Russ Taylor

Russ Taylor is a radio astronomer and professor of astronomy at the University of Calgary. He is the principal investigator on the Canadian Galactic Plane Survey, a project to image the interstellar medium of the Galaxy using the Synthesis Radio Telescope at the Dominion Radio Astrophysical Observatory in Penticton, B.C.

Astrocryptic

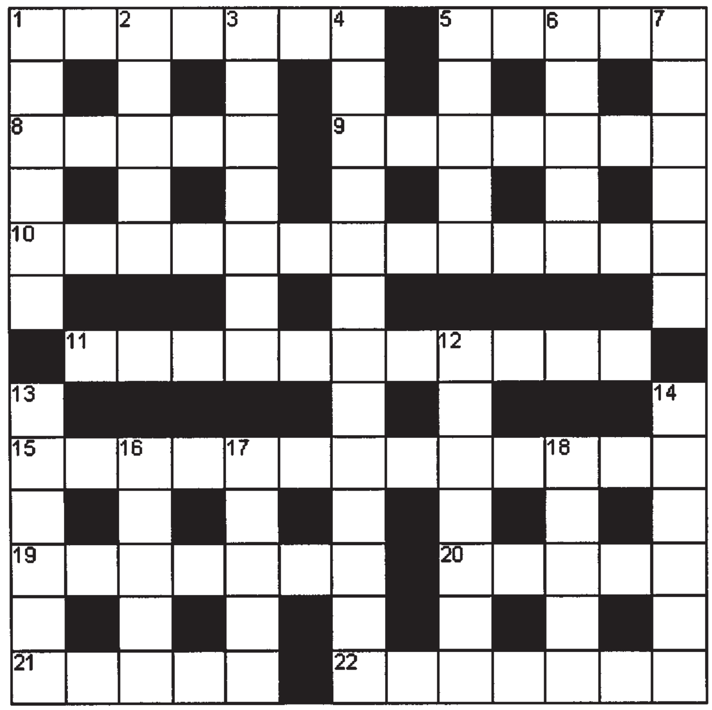
by Curt Nason, Halifax Centre

Across

1 Relatively untidy comet hunter (7)
5 Card flipped back around one positron predictor (5)
8 I'm in a mixed bin of clouds (5)
9 Cowmark on Questar's eyepiece (7)
10 Chip comet ores from the translated constellation (3,10)
11 Photon pops from distant neutronium collisions (5,6)
15 Solar phenomenon akin to trucker's tan? (4,9)
19 Apparent stellar distance is the benchmark for explosions (3,4)
20 The Bull variation in that Auriga region (5)
21 Associated with stars around Vega in early formation (5)
22 One eyes with it to see the Moon around as clearing begins (7)

Down

1 A bit of time to some degree (6)
2 The riviere runs in the Epsom meteor crater (5)
3 A flashy satellite at the K-T boundary (7)
4 Bar or burn them badly, unless written by either stellar author (6,7)
5 Instrument faces tell time after the sun (5)
6 A medium part of the spectrum (5)
7 Sickness is tropical in name only (6)
12 In re man around who can describe curvature of space (7)
13 An ocular to view sun-up in postscript before light begins (6)
14 Listener returns from the past, having visited Plato's markets (6)
16 Mr. Bishop rises with the morning to see the city official (5)
17 Doctor, I've used it to follow the stars (5)
18 Is a current name in the laws of motion and robotics (5)



Solution next issue.

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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. This year all of the photos are in full colour.

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. (designed and produced by Rajiv Gupta)

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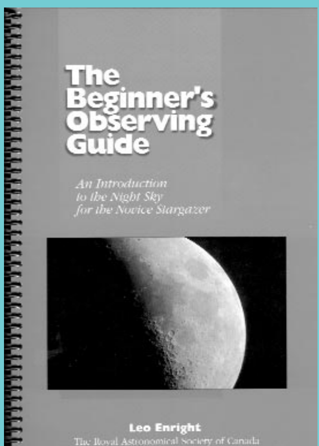

The Beginner's Observing Guide

This guide is for anyone with little or no experience in observing the night sky. Large, easy to read star maps are provided to acquaint the reader with the constellations and bright stars. Basic information on observing the moon, planets and eclipses through the year 2000 is provided. There is also a special section to help Scouts, Cubs, Guides and Brownies achieve their respective astronomy badges.

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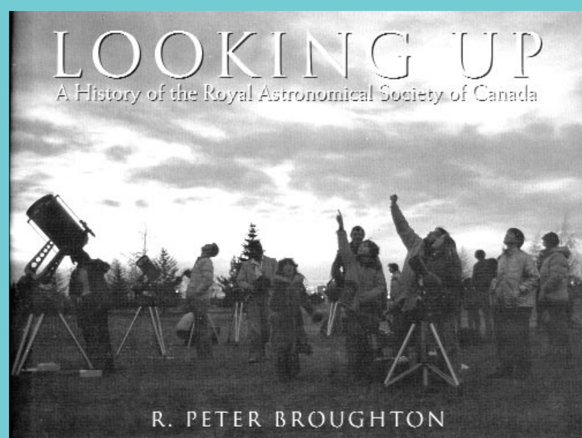

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