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Journal

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INSIDE THIS ISSUE

The Saskatchewan "Webscope" · Mars Photometry · Gamma Ray Bursts
Astronomy in the K-12 Cirriculum · Lunar and Solar Calendars

June/Juin 2002

Journal

Vol. 96, No. 3 Whole Number 694

contents

table des matières

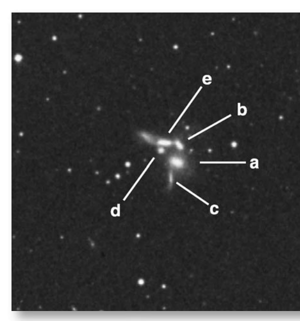
FEATURE ARTICLES/ARTICLES DE FOND

RESEARCH PAPERS/ARTICLES DE RECHERCHE

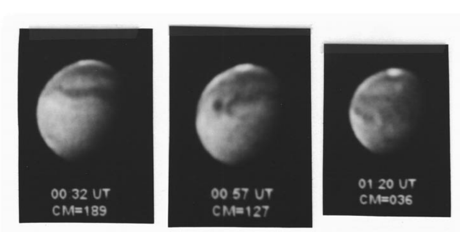
EDUCATION NOTES/RUBRIQUES PÉDAGOGIQUES

COLUMNS/RUBRIQUES

Reflections
p. 100

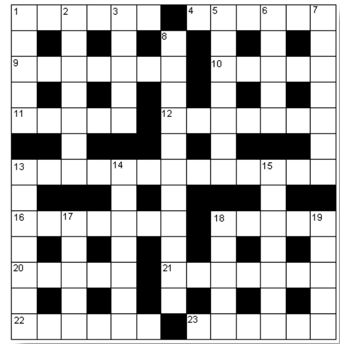


Scenic Vistas
p. 128



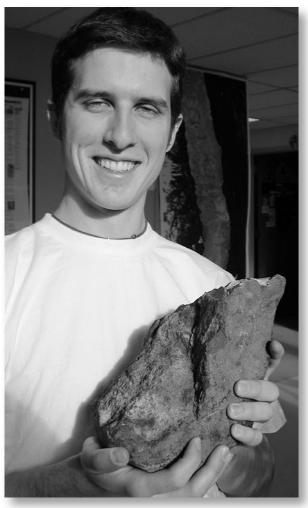
Photometric and Polarimetric Observations of Mars in 2000-2002
p. 105

DEPARTMENTS/DÉPARTEMENTS



AstroCryptic p.136

ACROSS THE RASC
DU NOUVEAU DANS LES CENTRES



News Notes p. 89

Cover:
Composite image of the Leonids in Orion and Taurus. Two 10 minute exposures using a 28-mm lens at f/2.8 on Kodak Ektachrome P1600 slide film at ISO 400. Photos by Karen Edmonds and image processing by Glenn Ledrew. p. 96

George Moores' Astronomy Workshop p. 130

President's Corner

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

By the time this *Journal* issue reaches you, I will have visited at least 23 of the 26 Centres spread over this magnificent country. (That number includes counting the upcoming GA as a visit to Montreal!) Giving lectures, meeting members, seeing facilities, and discussing problems with members in a great variety of situations has given me a unique perspective, which is well worth sharing. I wish it were possible to convey to the membership at large what a grand and wonderful society we have. Helen Sawyer Hogg, former President of the RASC, gave a fitting title to her book, "The Stars are for Everyone." The mandate of the RASC is to play out that idea with the public. The members are carrying out that mission admirably, and having lots of fun doing it. I am amazed that we are able to accomplish so much as volunteers: "amateuring for the love of it."

Prince George is our newest member Centre, but they joined after my whirlwind tour of British Columbia last year, so it is one of the few Centres that I missed. I hope that our next President, Rajiv Gupta from Vancouver, will be able to make an early visit to Prince George and welcome them to the family.

Visiting all the Centres during a two-year term may be an impractical goal for any President, especially one who is still employed. As a recent retiree, I had the freedom from classes and committees to be able to schedule regional tours, but it is not reasonable to expect others to have that flexibility. On the other hand, it is good for the National President to be in touch with the members, and not only through their representatives on National Council. Perhaps a four-year cycle of visits, covering the terms of two Presidents, is worth considering.

With increasing membership and more new Centres, we will have to give some consideration to ways of keeping in touch. The *JRASC*, the RASCals list, the National Council meetings, and the General Assembly are excellent ways to communicate with each other and to gain a large part of the perspective that I have found so valuable. When we know each other and the problems we are all facing, it is easier to trust, and trust is, in my opinion, a key element in any community, large or small. Without it, community breaks down. With trust, community thrives, so as a volunteer community, we need to build as much trust as possible. It would be nice if East/West, French/English, large/small, and other differences would disappear. We may not be able to achieve perfection, but that doesn't mean we shouldn't try; some trust is better than none.

Interdependence is another useful aspect of community. It is quite different from dependence or independence. One of the reasons for the success of the RASC is that we have joined together to produce some great products, like the *Observer's Handbook* and the *Journal*, which no one group could do so

Journal

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

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well. There are many other examples, but those two fine publications justify, in my mind, our choice to leave independence in favour of interdependence.

We have some really good news. The RASC is being nominated for an award! Professor John Percy, a former RASC president, has applied on our behalf for NSERC's prestigious Michael Smith award for the promotion of science. I suppose that, like the Oscars, even if we don't win the award, the nomination itself is prestigious. Promoting the science of astronomy enthusiastically is an activity that is at the heart of the RASC mandate and is one at which the Society excels.

I'm very much looking forward to this year's General Assembly which is being held in Montreal during the May long weekend (celebrating Queen Victoria's Birthday). My youngest son has an economics degree from McGill University, so I used that in the late 1990s as an excuse to visit Montreal frequently. I know the McGill area quite well. With Mark Bratton and his Local Organizing Committee arranging everything for us, I am sure that it will be a memorable GA.

This is my last President's Corner column. During these past two years, the emphasis has been on consolidation — getting the maximum productivity out of the new computer tools and new structure at National Office. The membership count is up; the *Journal* has a new look and is produced on time (though occasionally held up by *SkyNews* or by the lowest priority with Canada Post); the eStore is working well; two much-needed fee increases have eased budget pressures; and major problems with the By-laws are being seriously considered. With very few exceptions, things are running smoothly.

It is most fitting to end my last column with a tribute to Bonnie Bird, who has managed the operation of the Society's National Office during the past five years and without whom the RASC would not be in such good condition. Her computer skills have been essential in coping with all the problems in getting the new membership-tracking system up and running. Fielding astronomy questions from the public by telephone and e-mail, as well as knowing when to redirect them, saves the rest of us lots of problems. In addition to such valuable skills, her dedication, loyalty, and friendly warmth make visits to the office a pleasure. As we move in the direction of conference calls, it would be good to keep in mind that a good welcoming hug is difficult to transmit over thousands of kilometres!

Editorial

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

Despite being arguably the oldest science, astronomy has experienced several revolutions in modern times. The development of photography, computing machines, and CCD detectors has contributed to the tremendous increase in our knowledge of the universe around us. Today, we find ourselves in a new technological revolution brought on by the invention of the Internet. Like the previous developments, amateur astronomers are greatly affected as well.

For many years the Internet had been used by professional scientists for communication via email. The invention of the World Wide Web (No, not by Al Gore!) began an explosion in information availability. Today, amateur astronomers have access to inexpensive but powerful computers, as well as high-speed Internet connections in most areas. Despite cries from certain parts of society about the "evils" of the Internet, this same Internet has been a great windfall for astronomy. Amateur astronomers can communicate with each other around the world via email, chat rooms, and Web pages. Instant notification of supernovae, variable star outbursts, comet discoveries, and even the presence of the Aurora Borealis, has become commonplace. The Internet has also allowed astronomers to conduct observations using robotic telescopes (see the Saskatchewan Millennium Telescope article in this issue). Students can plan and conduct observations without even leaving their classrooms.

One of the greatest advantages of the Internet has been the easy access to archival data. This will be of increasing value in the near future as plans are implemented for huge databases of astronomical observations collected from ground- and space-based instruments. Astronomers already have the means to retrieve data from the AAVSO, HST, Chandra, Palomar Sky Survey, 2MASS, and SDSS, to name a few. Each of these archives has untold numbers of discoveries waiting to be made.

Recognizing the importance of maintaining archival data, the United States is working towards constructing the National Virtual Observatory, which will be a large repository of archival data from many different sources. This will make it more convenient for astronomers to conduct research, since data will be available at a single location rather than spread out over several Web sites.

Besides availability, another concern is the sheer volume of data that needs to be archived. For example, CFHT's newest instrument, MegaCam (which should begin operation later this year) will image one square degree of the sky at a time using 40 CCDs. This camera will produce single exposures of approximately 770 Megabytes in size! In order to deal with this amount of data, a dedicated data centre (Terapix) is being set up to handle the processing of MegaCam data.

In the future, astronomers (both amateur and professional) will have at their fingertips access to multi-wavelength data for any region in the sky, producing unforeseen discoveries in the years ahead. All of this is made possible with the invention of the Internet.

This issue will mark the end of Dave Lane's reign as Production Manager for the *JRASC*. After many years of dedicated work, he has decided to enjoy life a bit more. I am sure all of you share in my expression of thanks to Dave for a job well done!

I also pass on my congratulations to David Garner who will be taking over as Production Manager. I look forward to working with him to ensure that the *JRASC* contains interesting items and is produced in a timely fashion.

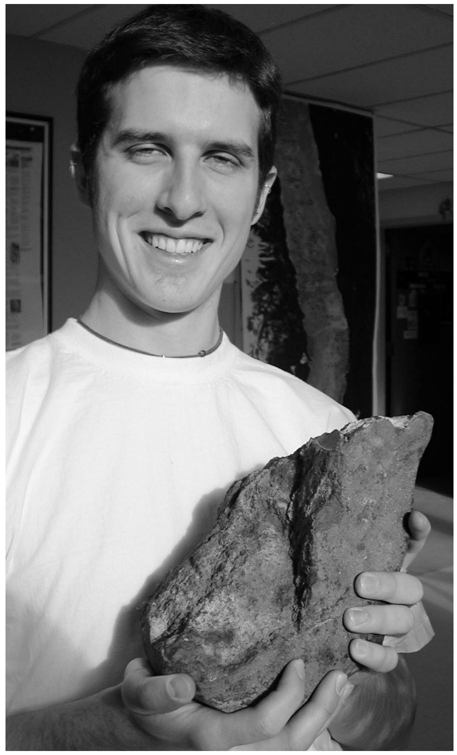
METEORITE FROM ELM CREEK

A large rock that Manitoba resident Tom Wood found while grading a road has been identified as Canada's newest meteorite by the Prairie Meteorite Search, a national project led by the Universities of Calgary, Regina (Campion College), and Western Ontario.

The Elm Creek meteorite, weighing 8.2 kilograms, is the second-largest stony meteorite 'find' ever recovered in Canada and is Manitoba's fifth and largest meteorite. The meteorite was found while Mr. Wood was grading a dirt road to the southeast of Elm Creek, Manitoba during late August 1997. "It seemed to be too heavy to be a normal stone," Wood recalls. "I thought then that it might be a meteorite, but I was half kidding when I told my wife so later that day." The recovered stone is a broken piece with scrape marks on it, presumably from road grading. The other half of the meteorite, estimated to weigh about five kilograms, is thought to be still embedded in the dirt road. Mr. Wood is not sure exactly where he recovered the first piece, so the recovery of the remainder is in doubt.

Dan Lockwood, a U of C student, was the Prairie Meteorite Searcher for the summer of 2001. The Elm Creek meteorite was his second discovery among about 600 samples of possible meteorites that he looked at. He was holding a rock identification clinic in the Co-op store in Carman, Manitoba, when Mr. Wood brought the rock in. "The rock was covered in dirt, but its density made it deserving of a wash and a closer look." The meteorite was eventually confirmed when Lockwood returned to the University of Calgary at the end of his field season. The Elm Creek meteorite has been well-weathered and probably fell to Earth thousands of years ago. Most of its fusion crust is weathered off revealing an interior that shows cracks from the shattering of its parent asteroid.

Additional information on the Prairie Meteorite Search can be found at `www.geo.ucalgary.ca/PMSearch/`



Prairie Meteorite Searcher Dan Lockwood with the Elm Creek Meteorite.

THE 2002 C. S. BEALS AWARD

Professor John D. Landstreet is the recipient of the Carlyle S. Beals Award for 2002. Established by the Canadian Astronomical Society (CASCA) in 1981, the Beals award is presented in recognition of the groundbreaking research of the late C. S. Beals.

Born in Philadelphia, John Darlington Landstreet obtained a B.A. in physics from Reed College in 1962. He then moved to Columbia University where he completed a doctoral thesis under the supervision of Prof. L. Woltjer in 1966. His thesis work was concerned with theoretical neutrino astrophysics. He became interested in stellar magnetism as a postdoctoral fellow at Columbia, and, with the help of his collaborator Roger Angel, he built the first astronomical photoelectric polarimeter, which led, among others, to the discovery of the first magnetic white dwarf. In 1970, he joined the faculty of the Astronomy Department of the University of Western Ontario.

The name of John Landstreet is closely associated on the international astronomical scene with stellar magnetism. Indeed, he pioneered the modern observational techniques (optical continuum and line polarimetry) that are used today all over the world to study the fascinating phenomenon of magnetism in stars. Exceptionally gifted, he designed and built top-of-the-line optical instruments, carried out observations at all the major astronomical observatories, and developed also a unique expertise in the modelization of magnetic stars. In particular, along with his students, he created the major theoretical tools needed to understand the observations of peculiar stars whose atmospheres are threaded by large-scale magnetic fields. His mastery of both the observational and theoretical aspects of our science made him one of the best all-around astronomer-astrophysicists in Canada.

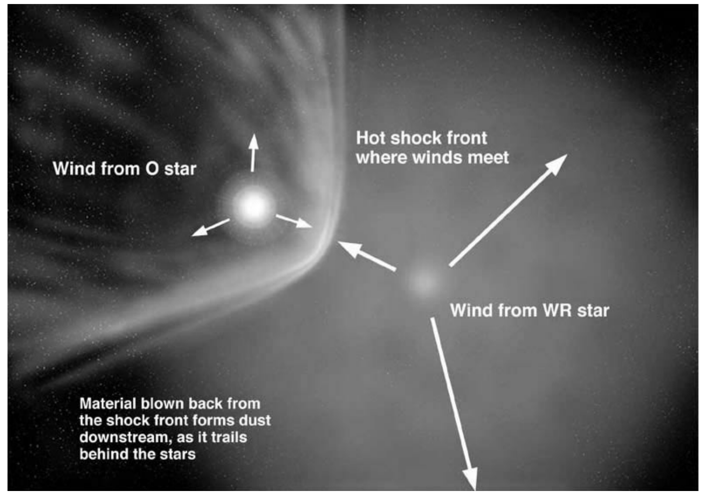
GEMINI FINDS A DUSTY SHOCK

A Canadian-led research team using the Gemini Observatory has released tantalizing evidence that tiny dust particles ejected by hot, massive stars may survive long enough to reach the interstellar medium. This kind of process might have provided some of the materials necessary for the early formation of planetary systems in the young Universe.

The research team, lead by Dr. Sergey Marchenko, formerly of the Université de Montréal (now at Western Kentucky University), used the advanced mid-infrared imaging capabilities of the Gemini North Telescope to study the dynamic interaction between a massive-binary star pair engaged in a dusty-orbital tango. The star system, named “WR 112”, pits stellar winds from one star against the other to produce a bow shock where the stronger wind pushes back the weaker. The extreme compression at the bow shock forms dust that subsequently flows out from the system, tracing a giant spiral that hints at the star-pair’s ongoing-orbital dance. WR112 is thought to lie at about 14,000 light-years away and consists of one fairly-massive Wolf-Rayet (WR) star that is gravitationally bound to another massive “O” type star. The two stars orbit each other once every 25 years.

“Looking at this system with Gemini we have revealed that the carbon dust particles, while tiny, are about 100 times larger than state-of-the-art theory predicts. In addition, a significant portion of the dust appears to be escaping into interstellar space before it can be destroyed by the lethal radiation field emanating from the hot, massive stars of the binary system,” says Marchenko.

Theory predicts that very early in the history of the Universe, the majority of stars may have been very massive, like those that become WR stars. Because of their high mass, these stars burn rapidly and intensely, living lives about 1000 times shorter than stars like our Sun. It is therefore likely that this process could have injected a large amount of heavy-element (mainly carbon from the nuclear fusion of helium) dust into the interstellar medium while the Universe was still relatively young. “As a result, we might need to consider a relatively early epoch in the history of the Universe when the necessary ingredients first became available in the interstellar medium to seed and form planetary systems,” said Marchenko.



This artistic impression shows a close-up view of what is believed to be happening in the WR112 system. The stellar wind from the WR star collides with the weaker stellar wind from the less-evolved O-type star. The shock-zone is where the larger carbon based dust particles are being produced. Artwork by Jon Lomberg and courtesy of the “Gemini Observatory.”

One mystery that remains is how the amorphous carbon dust particles form and survive in the harsh environment surrounding these stars. It is also unknown what processes lead to the formation of dust grains that are almost two orders of magnitude larger than theory predicts. Even at this size, each dust particle is still only about the size of cigarette-smoke particles, or about 1 micron across.

What is understood is that the stellar wind from the carbon-rich Wolf-Rayet star in the WR112 pair is much stronger than that of the companion. As the wind from the WR star encounters the weaker wind from its companion, a “shock-zone” is formed that bends back around the companion. The increased pressure in the shock-zone is believed to spark the formation of these larger grains of amorphous carbon dust. The dust then is obliged by the stronger WR stellar wind to flow away from and out of the system in the distinctive spiral pattern that was revealed by the Gemini mid-infrared images.

The results of the study by Marchenko and co-workers were published in the January 20, 2002 *Astrophysical Journal Letters*. Images of the WR112 system and further details on the Gemini Observatory can be found at `www.gemini.edu/media/MSImages.html`

CALL FOR NOTES

If you have any *News Note* items that you would like to bring to our attention please forward the information via email to `martin.beech@uregina.ca`.

RASC INTERNET RESOURCES

Visit the RASC Web site
`www.rasc.ca`

Renew your Membership
`www.store.rasc.ca`

Contact the National Office
`rasc@rasc.ca`

Join the RASC’s E-mail Discussion List

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

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

Feature Articles
Articles de Fond

The Saskatchewan Millennium Telescope

by James Edgar, Regina Centre (jamesedgar@sasktel.net)

People who manage large-scale, long-term projects sometimes find themselves "locked in" to original plans and subsequently have difficulty adjusting to changes. Just when they think they have it right, something new comes along that throws a wrinkle at them. Such was not the case with the Saskatchewan Millennium Telescope (SMT) project.

The RASC Regina Centre members (mostly through luck) weren't faced with the "locked-in" problem. Interestingly, they hadn't made a decision about any particular software or technology until recently — plans developed as needs arose. Only in February this year was a firm decision made to purchase a central-controlling program and telescope-aiming software. As a result, the software installed today is cutting-edge and capable of continued use for many years to come.

The project originated four years ago, after the Regina Centre members were approached by the Saskatchewan Science Centre in the fall of 1998 to find out what would be needed to make the old observatory operational. The telescope and dome suffered from lack of attention and old age more than anything. The balky dome didn't always turn as desired, the telescope was on an ancient mount, the dome doors wouldn't open (or close!) easily, and the telescope drive was broken. Faced with all these problems, the RASC Centre members decided that, rather than fix the old 15-cm refractor, it would be better to install a new telescope in the dome atop the Saskatchewan Science Centre.

As an aside, the dome is an historically significant part of the Regina landscape. It was built by the Regina Centre in 1952 and stood for many years on a corner site at Broad Street and College Avenue, near the city centre. At the invitation of the Saskatchewan Science Centre and in co-operation with an initiative in 1989 by Kalium Potash Mine to develop a public observatory, the Centre members donated their dome to house a refractor donated by the University of Regina. The dome is officially known as the Kalium Observatory.

The observatory on top of the science centre.

The original driving force behind the SMT project was a nucleus of Regina Centre members —Darcy Kozoriz, Steve Szuta, Andrew Kostiuk, Ron Haughey, and Kai Gauer. Andrew Kostiuk had the original idea in April 1999 for the robotic, Web-based telescope. By May, the Centre had formalized plans to install and manage a remotely controlled, Internet-accessible telescope and CCD-camera.

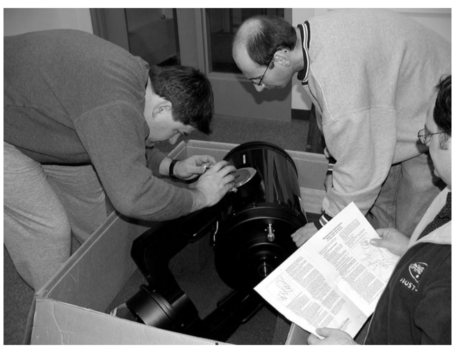
Before any work was done, co-operative support for the project was sought from several organizations that will benefit from the SMT: the Saskatchewan Science Centre itself; the University of Regina (U of R) Engineering Faculty; Department of Astronomy, Campion College, U of R; Ark Communications; Saskatchewan Institute of Applied Science and Technology (SIAST); and Science and Technology Unit, Saskatchewan Education.

After the members completed that step and realized they would need a lot more money than was available through the RASC Centre, the next part of the project was to distribute a formal "Request for Funding" to Saskatchewan businesses. The planners were not disappointed. SaskTel, the provincially owned Telecommunications Corporation, enthusiastically adopted and funded the major portion of the project. Smaller contributions of $800 came from Xerox Canada and $3500 from the Regina Centre coffers. As of January this year, SaskTel has contributed $32,700.

It was realized very early on in the project that the Regina Centre lacked sufficient expertise in technical engineering and computer software, so students from the U of R Engineering Faculty and SIAST were invited to the project. The association has proved very fruitful, both for the students and the Centre. The SMT project benefits from expert engineering and custom-designed computer code and the students get hands-on, practical experience toward their respective degrees.

The first major purchase, of course, was the all-important optics — the plans called for a 12-inch Meade LX200 telescope fitted with a SBIG ST-7E CCD digital camera. The telescope was ordered from EfstonScience in Toronto during May 2000.

Up to this point, things were going along in a relatively easy way, but then the action heated up and things began to happen at a more frenetic pace. With the telescope ordered, construction had to begin on a new pier. Designs, blueprints, and permits were required. Approvals were needed. Also, by then, it wasn't just that first handful of members involved; the entire Centre (with few exceptions) was in on the action. A bit of breathing room, but added frustration, came about when the telescope arrived in August 2000. During a trial run at the Centre's Davin Dark-Sky Site, east of Regina, the telescope worked okay a couple of times and then quit. There were many long faces around that day!



The telescope arrives!

In September, two computers were purchased to house and handle the Web software, and Meade sent out replacement parts for the telescope. Regular meetings of the SMT Committee had begun, sometimes with as many as 20 people attending, including U of R and SIAST students. The old telescope was removed, and the Science Centre graciously donated it to the RASC Regina Centre.

Grinding the frame.

Building the deck.

By October, work had begun on the new concrete pier, with a base welded right to the steel beams of the Science Centre roof. An elevated observation deck inside the dome was completed in November; the deck is isolated from the pier and has a metal safety railing, ensuring a practical and safe viewing area.

January 2001 saw work proceeding apace. This extraction from the January time-line gives a flavour for what was happening, namely lots of activity and not much rest:

- Engineering students fixed the roller mechanisms for rotating the dome
- A custom aluminium pier was built and received
- Engineering students made a working model of the dome
- The deck was sanded and puttied; however, it got wet and had to be removed
- SIAST students built the SMT Web site based on `mysask.com`
- A & C Blacksmith Shop completed the following work:
  - Constructed the stair hand rail
  - Cut the beam by the stairs and reinforced it
  - Built fence poles
  - Welded the pier to the building frame
- Replacement telescope parts came but did not work
- Members shipped the telescope back to Meade to be fixed

Pouring the concrete pier.

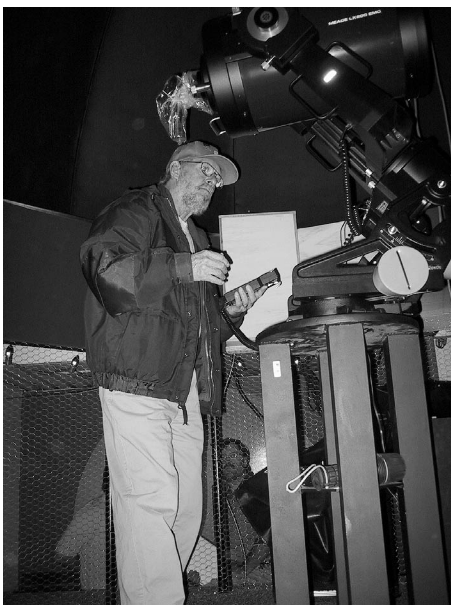
The metal pier atop the concrete.

The safety fence and railing.

By the end of the summer, enough had been done that the proverbial "light-at-the-end-of-the-tunnel" was in view. The telescope had arrived back from Meade in March, and it was working properly. (Even though it has been reported in other publications and is well known throughout astronomy circles, it is worthwhile mentioning here that the level of support and assistance from Meade left much to be desired. The frustration-tolerance threshold was at an all-time low when the hefty repair bill arrived from Meade!)

The opening in October 2001.

The SMT was announced to the astronomical world at the Saskatchewan Summer Star Party (SSSP) at Cypress Hills Interprovincial Park (yes, that was the same Star Party where Vance Petriew discovered his very own comet!) in August 2001.



John Mulvenna – October 2001.

An October visit by Dr. Robert Garrison, RASC President, gave the Centre an opportunity to create an official opening ceremony attended by this VIP from the National Office. Centre members were out in full force to meet Dr. Garrison and participate in the ribbon cutting.

Sadness gripped the Regina Centre in November when one of their number, John Mulvenna, was killed in a motor-vehicle accident. John was a steady force, both in the Centre and on the SMT project itself. He worked diligently at making the telescope operate as designed. Being a

During Astronomy Day 2002.

Meade owner, he was quite familiar with the new telescope's operating capabilities. John is missed by all those who knew him.

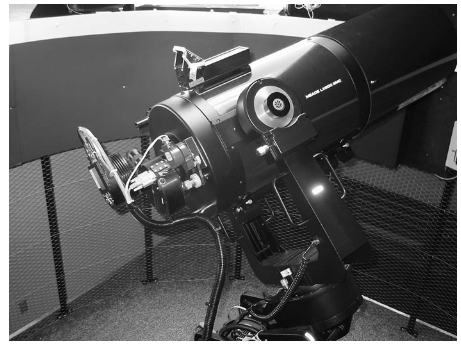
The project gathered impetus and moved on. By January 2002, a date was chosen to announce the telescope to the world. On Astronomy Day, 2002 April 20, the Regina Centre will have opened and readied the Saskatchewan Millennium Telescope for official public use. (For Web access, go to `www.telescope.mysask.com`) The telescope will be the first of its kind operated by an astronomy club in Canada.

From the SMT Web site comes this short description: "With the dawn of a new millennium there has been a renewed interest in science and technology, and wondering what the future will bring. One of the areas that have always fascinated people is astronomy. With the introduction of almost routine space-shuttle missions, the construction of an international space station and amazing images from the Hubble Space Telescope, more of the mysteries of the universe are being solved yet even more mysteries are being uncovered.

"The Regina Astronomical Society created the Saskatchewan Millennium Telescope project to encourage and promote interest in astronomy and the mysteries of the universe. The telescope is installed at the Saskatchewan Science Centre and is accessible...by amateur astronomers, students and teachers in Saskatchewan and world-wide."

There are other robotic telescopes in Canada and, indeed, around the world, but the SMT is the first one (of nearly 80 Canadian astronomy clubs) intended for public use with access through the Internet. Some other robotic and/or Web-based observatories soon to be unveiled are being made available by the following organizations:

- RASC - Ottawa Centre
- Big Sky Astronomical Society (AB)
- North York Astronomical Society (ON)



The Saskatchewan Millennium Telescope.

Two other Web-enabled telescopes exist in Canada, but they are not freely available to the public. One is owned by a private company in Ontario called Robosky Inc. (`www.robosky.com`) where time or images can be obtained for a price. The second, owned by the Royal Military College of Canada (`www.rmc.ca/academic/physics/castor/`), is used for tracking orbital satellites and is not available to the public.

The SMT Directors have established a "pecking order" of users, to ensure that Saskatchewan school students and RASC members get first use. Other requests for use would follow in a descending order, so that Saskatchewan residents get the nod ahead of out-of-province users, Canadians ahead of other countries, and so on. (Although how to do this remains an unknown at this stage.)

For the inquisitive reader, here are the specifications of the optical instruments and peripherals, along with brief explanatory write-ups:

The Telescope

- A Meade 12-inch LX-200, fully robotic telescope with GOTO features (65,000+ Object Database) (`www.meade.com`)

The Meade LX-Series catadioptric telescope was chosen for its robotic capabilities and its wide-spread acceptance within the astronomy community. The LX-200 series, with their telescope interfaces, make excellent instruments for connecting to the Internet.

Because these robotic telescopes are popular among amateurs, there is likely a high probability that common software exists to connect the telescope to the Internet.

The CCD Camera

- Santa Barbara Instruments Group (SBIG) Model ST-7e with 736 × 510 pixel resolution, colour capable with Red, Green, Blue, IR Blocking, and Neutral Density filters (`www.sbig.com`)
  The Model ST-7E is a self-guided imaging camera and contains two CCD detectors, one for guiding and the other for collecting the image. They are mounted in close proximity, both focused at the same plane, allowing the imaging CCD to integrate while the PC uses the guiding CCD to correct the telescope. Using a separate CCD for guiding allows 100% of the primary CCD to be used to collect the image. The imaging CCD on the ST-7E is the New Enhanced CCD from Kodak with antiblooming protection (ABG) and a Full Frame Resolution of 765 × 510.
  Carefully guided exposures of up to one hour are possible, although the light pollution from Regina will likely limit exposures to 10 minutes or less. Communication to the PC is through the parallel port.

Computer Software

- MaxIm DL/CCD by Diffraction Limited (`www.cyanogen.com`)
  MaxIm DL/CCD is a Canadian software package designed specifically for astronomical CCD imaging. This software provides instant access to all camera, autoguider, telescope, and focuser controls through one interface.
  Version 3 provides extra features, such as auto-focusing, that will simplify the connection of the telescope to the Internet. Because Diffraction Limited has partnered with DC-3 Dreams, this feature-rich package is even more attractive for Internet observatories.

- Astronomer's Control Program Version 2.1 (ACP2) by DC-3 Dreams (`acp2.dc3.com`)
  This program is designed specifically for robotic observatory control, automation, and remote access. It supports a growing number of motorized telescope mounts via the ASCOM (Astronomy Common Object Model) Telescope standard. ACP2 also supports the emerging Remote Telescope Markup Language (RTML) Version 2.1 as well as export lists from *StarryNight* and *TheSky*, and lists of 1-line orbital elements from the Minor Planet Center.
  ACP2's optional built-in Web and FTP servers make it possible…to provide hands-on automated use of [a] robotic observatory to anyone, anywhere on the Internet via a Web browser. A continuous connection is not required. A Web user can upload a plan in the formats listed above, start the run, and log off. The run is performed automatically by ACP at the observatory. Everything is journalled into a log file, and images are saved in Web-visible directories for later downloading via either the Web pages or the built-in FTP server. This was the type of software that the Regina Centre needed to control the observatory.

- PinPoint 3.0 by DC-3 Dreams (`acp2.dc3.com`)
  [This is] an ASCOM engine that provides sensitive, robust, high-speed research-grade astrometric image processing for FITS files from any camera. Fast mass plate solving and survey-level asteroid and supernova hunting are included in this software package. The Regina Centre purchased this product primarily for its digital finderscope capabilities. It will provide arcminute accuracy to find where the telescope is pointing and where it needs to go to find an object. The pointing accuracy of the LX-200 is not sufficient to centre an object in the small CCD Camera field of view every time.

- Proprietary Dome and Door software by RASC - Regina Centre
  The observatory dome and shutters were automated by engineering students from the University of Regina. The dome uses an array of 64 Hall-effect sensors to determine which direction the dome opening is facing. Dome rotation functionality is provided by an HC11 microcontroller. A second HC11 circuit was built to control opening and closing the observatory doors. Included in this design are door position sensors and a motion sensor. All of these components are controllable through a Web interface.

Peripherals

- ROBO-FOCUS by Home Dome Inc. (`www.homedome.com`)
  ROBO-FOCUS is a remote focus driver that attaches onto the existing telescope focus mechanism. It provides digital control and feedback of the focus position using a stepping motor controlled by a microprocessor. ROBO-FOCUS can be controlled remotely through a Web interface thanks to the ASCOM-compliant focuser driver. This robotic focuser has the ability to compensate for Schmidt-Cassegrain focuser backlash and to adjust focus based on changes in the telescope temperature. These features were all deemed necessary to remotely control a telescope from the Internet.

- CustomWheel Motorized Filter Wheel by True Technology Inc. (`www.users.dircon.co.uk`)
  The True Technology CustomWheel

represents a unique approach to filter wheels. It offers a flexible approach to users, by incorporating a diagonal mirror in place of one of the filter positions. This is a key feature for the SMT since changing between visual and CCD camera can be done without having to disturb either the telescope or CCD camera in any way. This helps preserve focus position and camera orientation since no components need to be swapped between the two modes.

- Future enhancement - Vantage Pro Weather Station by Davis Instruments (`www.davisnet.com`)
  Vantage Pro weather stations offer forecasting, on-screen graphing, and much more. This weather station has an optional Web interface to allow integration into the Web interfaces of all the other observatory components. Having a weather station right at the observing location will allow for up-to-the-minute weather information to determine observatory availability.

At the time of this writing, work continues on software to control the dome and the door-opening mechanism. A top priority is ensuring the observatory doors will only open when the weather is "good," to guarantee the instruments and electrical components are protected from a pouring rainstorm, for example. Such a guarantee requires a reliable weather sensing system and software control.

What does the future hold for the SMT? Will it do all and be all that is expected of it? Can young children use the telescope effectively? How can teachers best use it; how will both groups benefit? Will the public be able to find time in all this to use the SMT, too? These are some questions that remain for time to give us the answers.

In the meantime, the Regina Centre members remain confident their project will capture the attention of educators and their students who will discover ways to use the instrument(s) to their best advantage, possibly in ways never envisioned by the Centre members.

These tasks they know are achievable: to enable students to fulfill school science curricula; to learn about modern astronomy; to participate in interactive astronomy projects; and to interact with other amateur astronomers.

For the astronomical community, the SMT has these potentials for serious research: asteroid and comet discoveries using a blink comparator; image processing and analysis; supernova searching; astrometric data gathering; and photometric observations of variable stars.

The Centre members, of course, are quite excited by the prospects of having this high-tech instrument at their disposal, too. It has the capability to be used for visual observing, even with the CCD camera attached, so it will be no surprise to find the telescope in constant demand by numerous and varied groups. And that is exactly what was intended when the project was first envisioned — to develop a quality, Web-based telescope, open to the public.

For their inspiration, assistance, guidance, and support during the writing of this article, I thank Lee Beck, Al Andrews, and Vance Petriew of the Regina Centre.

James Edgar is a RASC Life Member, attached to the Regina Centre. His serious love affair with astronomy began in Vancouver, B.C. in the early 1970s when he volunteered as a docent at the MacMillan Planetarium. He enjoys many dark sky nights from his home in Melville, Saskatchewan.

Shooting *Shooting Stars*

by Doug Luoma, Ottawa Centre (dluoma@magma.ca)

I have been trying for 10 years, with little luck, to take a nice meteor photograph. With the high rates expected for the November 2001 Leonid meteor shower I figured I would finally get my chance. In the past, it seemed that bright meteors never appeared in the direction my cameras were pointing. To solve this problem, I decided to use a camera I had just built that would take a picture of the whole sky at once. This "all-sky" camera comprises a second-hand Sigma 16-mm f/2.8 fisheye lens for 35-mm cameras, the body from an old Zeiss Ikon folding medium-format (6×6) camera, and a large shutter from an oscilloscope camera. A shutter is not required for night exposures, but I also planned to photograph daytime solar halos.

Figure 1 — Composite image of the Leonids in Orion and Taurus. Two 10-minute exposures using a 28-mm lens at f/2.8 on Kodak Ektachrome P1600 slide film at ISO 400. Photos by Karen Edmonds and image processing by Glenn Ledrew.

Few modifications were necessary when making the camera. I cut off the lens-shade extensions on the 16-mm lens and removed the bellows and lens assembly from the Zeiss camera. The three parts were then stacked together and attached using PC-7 epoxy putty. The image circle produced by this camera is approximately 40 mm in diameter and encompasses almost 180 degrees. When the camera is pointing straight up it can take a photo of the entire sky with the horizon around the edge, similar to the all-sky star maps found in astronomical magazines. I tested the camera on my apartment balcony using distant streetlights as my test "stars." With the aperture set at f/2.8, the lens produced only marginally-acceptable images. Lights near the edge of the field were bloated arrows instead of pinpoint dots. The lens performed much better when stopped down to f/4, but was best at f/5.6 or slower. F/5.6 is pretty slow for meteor photography, so I compensated by using a high-speed emulsion (Ilford Delta ISO 3200 black-and-white film). In addition to the all-sky camera, I would also be bringing two 35-mm cameras fitted with 17-mm wide-angle lenses. I wanted to keep these lenses wide open at f/3.5, and wished to use Kodak P1600 slide film. Therefore, in order to have the same exposure duration for all three cameras (for convenience), the film would have to be processed at ISO 800.

My wife, Karen Edmonds, was also looking forward to photographing some Leonids. Her two Olympus OM-1 cameras had 28-mm and 50-mm lenses set at f/2.8. She selected P1600 and Kodak E200 slide films, but would develop both at ISO 800. Karen's cameras would be attached to her Super Polaris telescope mount, and I'd be putting mine on a sturdy "barn door" star tracker. Both of our mounts are equipped with electric-motor drives.

On Saturday, November 17, we kept checking the weather forecast. Clouds were expected to move in over Ottawa later in the evening and we were uncertain if they would clear out in time for the estimated peak meteor activity (just before dawn the next morning). Karen and I were prepared to travel as far as necessary to find clear skies, but it was difficult trying to predict where to go, even after checking some weather sites on the Internet. At about 5 p.m. I phoned my friend, Glenn LeDrew, who has more experience interpreting satellite imagery and weather maps. Glenn said that a few people would be watching the meteor show at Rob Dick's observatory (near Rideau Ferry, Ont.) and suggested we join them. We agreed only after he promised that the skies would clear up shortly after midnight.

Upon our arrival, everyone was eating supper in Rob's nearby cottage. The meteor activity wouldn't commence until at least

Figure 2 — All-sky camera.

11 p.m., when the radiant (the point in the constellation Leo from which the meteors seem to originate) rose above the horizon, so we spent the time chatting and kept checking the sky conditions as clouds drifted intermittently overhead.

At approximately 12:45 a.m., under mainly clear skies, everybody strolled over to the observatory. While the others were getting comfortable in their chairs or on the grass, Karen and I began to leisurely set up our equipment, starting first with Karen's mount. We quickly switched into high gear as bright meteors kept appearing and soon had her cameras up and running. Karen started her 10-minute exposures and I began to tackle my own gear. A few minutes later, a bright Leonid meteor streaked across the sky between the constellation Orion and the Hyades cluster in Taurus, right in the middle of the field of Karen's 28-mm lens. It was approximately magnitude −3 (brighter than Jupiter) and traversed almost 20 degrees. I was very happy for her, but I have to admit I was also a bit envious. This shot would be much better than any of my previous photos, taken over many years, and it was her first attempt at meteor photography. Karen kept her exposure going for the rest of the allotted time, which goes against a popular astrophotography "rule" advocating stopping exposures as soon as one meteor is imaged. If we had done that during this shower we would have quickly run out of film. (I found out later that at least two Ottawa Centre members followed that rule and, to their dismay, had no film left when the meteor rates were at their highest.)

I had trouble attaching the all-sky camera to my mount (the camera's mounting socket was loose), and while I was jury-rigging a solution, an even brighter Leonid slashed right through the Hyades cluster. Karen was now ahead of me, 2 to zip. Then another meteor, dimmer than the last ones, appeared lower down in the sky. If it was also bright enough to register on film, she'd have two meteors on the same slide. All of the observers were shouting, "Time!" whenever they saw a meteor, even though no one was actually recording exact counts. The volume and duration of the shouts tended to vary with the brightness and length of the meteor trails. Even if I was not seeing many meteors because of my equipment problems, I would hear a loud "*TIIIIIIIIME!!!*", and realise another good one had got away. My cameras were finally ready to go around 2 a.m. and I started my first 15-minute exposure. Now it was time to sit back and enjoy the sky show.

Everything seemed fine until the end of my second exposure. I gaped at my mount's motor. It wasn't moving! Had I forgotten to turn it on? I flicked the switch back and forth, but nothing happened. I checked the wires running to my 12-volt battery and the motor's 12-volt to AC power converter, but all was OK. The only thing that made sense was that my battery was dead. This theory was confirmed by touching the lens' dew-heaters, which were hooked up directly to the battery. They were cold. I couldn't believe it. I was sure I had checked the voltage a few days earlier. Just as I resigned myself to taking only star-trail meteor photos, a super-long extension cord plugged into the observatory saved the day (night). I sighed with relief as I heard the soft purring of the motor. The dew-heaters couldn't be used, but luckily the air was very dry, with no dew or frost. I recommenced shooting, and the rest of the night went by without major glitches.

The meteor rates gradually increased, and by 4:00 a.m., I figured that I had seen more than 30 meteors. That number would

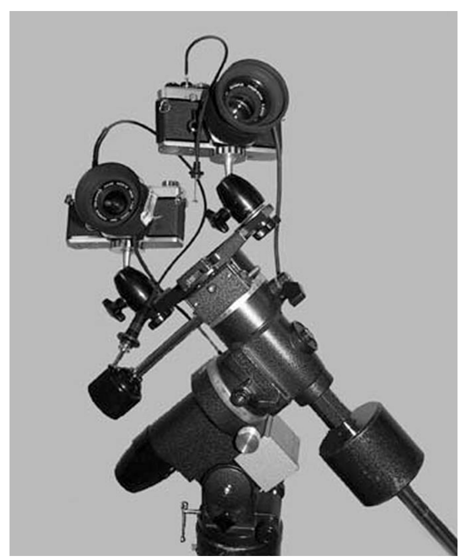


Figure 3 — My wife Karen's camera on her Super Polaris mount.

have been much greater had I not been working on my equipment for so long, but I didn't mind. This was already the best meteor shower I had ever witnessed and the greatest activity was yet to come. A few of the brighter meteors produced glowing trains (ionised gas trails), some of which lasted 15 or 20 minutes before high-altitude winds dissipated them completely. Looking through our binoculars, we could see intricate structure in the trains, and I wished we had brought along a wide-field telescope for even more-detailed views.

Shortly before 5:00 a.m., I finished the roll of film in my all-sky camera. I decided to switch to slower speed E200 film because the sky would soon be brightening during morning twilight. We were now seeing several meteors per minute, but no really long meteor trails. Earlier in the night, when the radiant was lower in the sky, the meteors took longer to burn up because they entered the atmosphere at a shallower angle. Now that the radiant had risen higher, the meteors were coming in more vertically and vaporising more quickly, resulting in shorter streaks.

The rates kept climbing. Many of the meteors appeared to come in groups. A couple would whiz by, then hardly any for a bit, then a bunch more. Occasionally, two or three meteors would appear simultaneously. Some ended with a terminal burst (explosion). The effect was similar to a camera flash going off, illuminating the surroundings for an instant. I lay down on the ground and stared straight overhead in order to see as much sky as possible. Very little horizon was visible, giving me the sensation of floating in space as the meteors flashed across the sky. It was utterly thrilling! I began to resent the chiming of my timer alarm, which forced me to take my eyes away from the spectacle and get up to start a new exposure.

From approximately 5:15 until 5:45 a.m., even though fainter meteors were getting lost as the sky got brighter, we were seeing 20 to 30 Leonids per minute. It is an experience I will never forget. I can hardly imagine how incredibly awesome it must have been for observers of the 1966 Leonid storm when the highest rates were over 50 meteors per *second*.

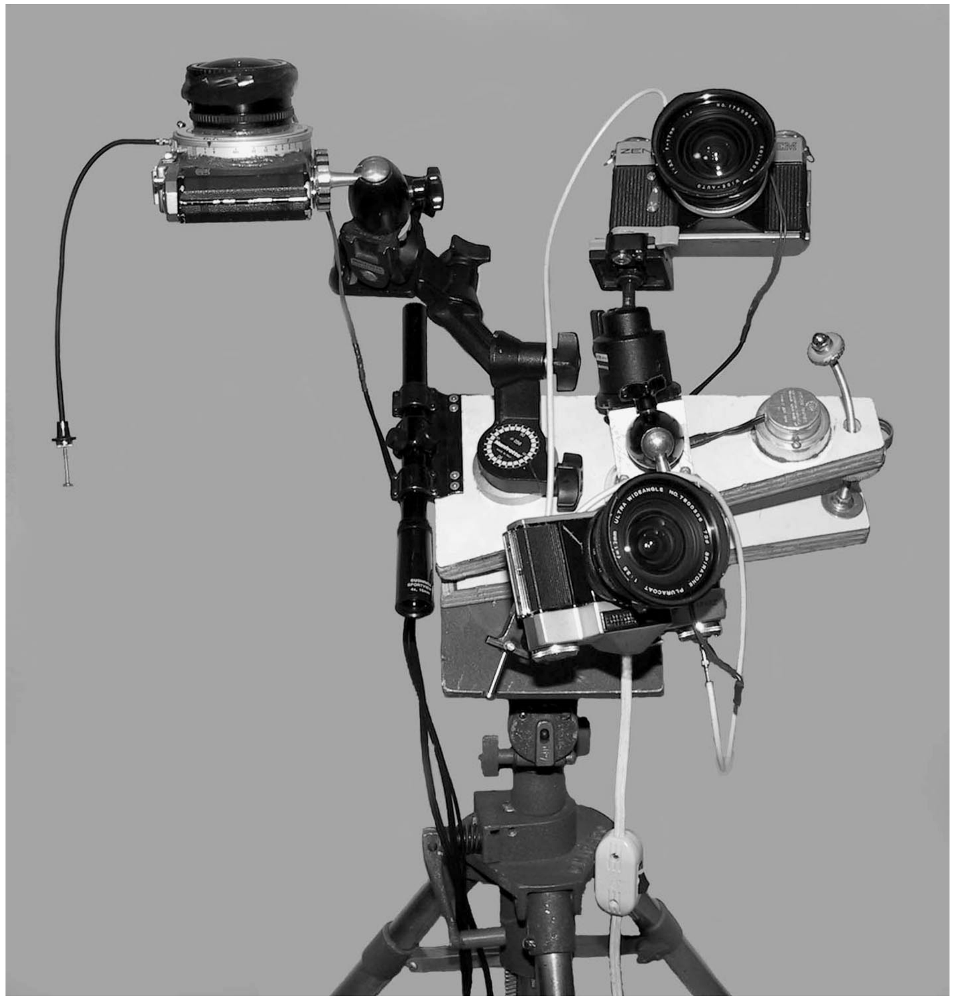


Figure 4 — Cameras mounted on "barn-door" mount.

The sky kept brightening and the number of visible meteors gradually decreased. By 6:30 a.m., only the odd flash was still noticeable, so Karen and I began packing up. It had been a perfect night. The sky had remained clear, the air hadn't been very cold or damp, we'd been bombarded by meteors, and I was certain that some of them had been captured on film. Shortly after sunrise we loaded up the car and headed back to Ottawa.

Just in case we had misjudged our exposure times, we initially developed only a couple of rolls of film. My all-sky images turned out fine, but the 35-mm slide films were somewhat overexposed. Therefore, all of our remaining rolls were processed at ISO 400 instead of 800. We were very satisfied with the results of the night's shooting. All meteors brighter than about zero magnitude could be seen in my ISO 3200 black-and-white negatives, but the slower E200 film, used when the meteor rates were higher, picked up just a few extremely bright ones. My other cameras also recorded some meteors, but I liked the all-sky images much better.

Karen's photographs showed lots of Leonids, but we noticed a problem with the ones taken with the 50-mm lens. When viewed through a high-magnification loupe, the stars were short, squiggly lines. When helping Karen hastily set up her mount, I (this is really embarrassing) must have aligned the polar sighting scope not on Polaris, but on some other nearby star, perhaps Kochab. Oops! Thankfully, her 28-mm photos were unaffected by the mount's misalignment because the lower magnification of the lens allowed for a greater margin of error. Karen's nicest images were the two shots taken early in the night of the long, bright meteor trails in Orion and Taurus.

In my opinion, a 28-mm lens is ideal for general-meteor photography with a 35-mm camera. It is a good compromise between sky coverage and image magnification. If one is on a limited budget, used 28-mm lenses are widely available and fairly inexpensive. With most f/2 or f/2.8 wide-angle lenses, I recommend stopping down the lens to f/4 for best results (less vignetting and off-axis aberrations), but some of the cheaper, older-style f/3.5 lenses produce fine images even when the lens is used wide open.

Karen and I decided to produce some composite images from our favourite photographs. This was something new for both of us. We had the slides and negatives scanned at high resolution, and Glenn Ledrew handled the image processing using *RegiStar* and *Adobe Photoshop* computer software. *RegiStar* recognises star patterns in multiple photographs and precisely merges the photos into one image. *Photoshop* and other similar programs let you tweak the image's brightness, contrast, and colour balance. The end result was everything we hoped for. Instead of nine 15-minute all-sky shots with a few streaks in each, I now have a 2 1/4 hour exposure with over 30 meteors visible, and Karen has a picture of Orion and Taurus with three meteor trails.

The Leonid meteor shower/storm last November was truly amazing. Who knows if I will ever see anything like it again? Motivating myself to go out and photograph future showers may prove to be difficult. However, I still do not have a photo of a really bright fireball, and maybe a 135-mm or 200-mm lens would be good for capturing detail in meteor trains. Hmmm, when is the next meteor shower?

Doug Luoma grew up in Northern Ontario, and works as a fitness trainer in Ottawa. He has been a member of the Ottawa Centre since 1991, and this is where he met his wife, Karen. They divide their spare time equally between observing the sky and bird watching. Doug has been taking astrophotos for more than ten years and is currently the Ottawa Centre's astrophotography coordinator.

The Astronomical Basis of Our Calendar, Part 2:
Lunar, Solar, and Lunar-Solar Calendars

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

Last issue, I introduced the basic astronomy necessary to understand the evolution of our calendar, covering the origins of the day, the week, the month, the seasons, and the year. This 3-part *Reflections* is a précis of a talk I presented in January 2002 to the RASC Halifax Centre entitled "A Date with the Stars: The Astronomical Basis of Our Calendar." This talk was developed from the knowledge and insight I have gleaned over the years from reading and thinking about the topic. Since then, I have presented the same talk to a small but enthusiastic crowd who gathered for the March 2002 meeting of the new RASC Moncton Centre, many braving the freezing-rain conditions to drive in from Saint John. In this second part, I will present the evolution of our calendar through successive approximations to the tropical year that governs the cycle of the seasons.

Lunar Calendars

Because the synodic month (T_M = 29.530589 d) and the tropical year (T_Y = 365.242190 d) are incommensurate, one cannot fit an even number of lunar months into the year, and strictly lunar calendars must ignore the cycle of the Sun and the seasons. The earliest calendars must have been lunar, closely aligned to the nocturnal activities of the hunt and the tidal rhythms of the sea. None of these remain, and the only extant example of a lunar calendar is the Islamic calendar. (The Islamic calendar is relatively modern, dating from 622 C.E.) Alternating months of 29 and 30 days provide an approximate month length of 29.5 days, but a strict alternation cannot be maintained without getting ahead of the Moon itself. In fact, the Islamic calendar is continually calibrated by linking the declaration of the new month to the actual observation of the young crescent. Twelve lunar months form a short "year": T_{Lunar} = 354 days, ending about 11 days before a tropical year. This lunar year leads the Sun, and major holidays tied to dates in the lunar calendar drift backward through the seasons from one instance to the next. Consider, for example, Ramadan (an important Islamic month, a fasting month). In 2001, Ramadan began on November 17; in 2002, it is *expected* to begin on November 6.

Figure 1 — Julius Caesar, calendar reformer.

Lunar-Solar Calendars

An intermediate stage of calendar evolution between the strictly lunar calendar and the strictly solar calendar is the lunar-solar calendar, exemplified by the Hebrew and Chinese calendars. It is necessary to understand the basis of such calendars to understand why some current religious festivals, Easter for one, do not have fixed dates in our modern, civil calendar. The cycle of the Sun became increasingly important as humankind became more agricultural and less nomadic. The growing season is driven by the seasons and hence by the Sun. Yet old habits died hard, and the phases of the Moon governed the months. The trick of the lunar-solar calendars was to add the occasional thirteenth month to the 354-day lunar year, creating a 384-day year, longer than the tropical year, but necessary to allow the Sun to catch up to the Moon. In this way, holidays fixed in the lunar calendar stay *approximately* in the same place in relation to the seasons, but jump around a bit. For example, the essentially springtime Hebrew festival of Passover always takes place just after the Vernal Equinox, at the first Full Moon.

To say that the lunar and solar cycles are incommensurate is overstating the case a little: there is a 19-year periodicity to the lunar-solar motions, known as the Metonic cycle. (The cycle, noticed by the Greek astronomer Meton of Athens, born in 440 B.C.E., was probably known to the Babylonians and others before that.) It turns out that 19 tropical years are the same as 235 synodic months, about 6939.6 days, plus or minus *one hour.* This means that phases of the Moon repeat on the same day of the year every 19 years. Incorporating this cycle, it is possible to create a lunar-solar calendar on a repeating pattern, with the 7 intercalary months inserted in years 3, 6, 8, 11, 14, 17, and 19 of the 19-year cycle. The existence of the Metonic cycle is not necessary to construct a lunar-solar calendar, but it does make the calendar a little more predictable! This cycle is still of importance today, as it forms the basis for determining the date of Easter. (More about Passover and Easter next time.)

The Egyptian Calendar

Eventually, in some cultures, the complications of the lunar-solar calendar gave way to the purely solar calendar, and the lunar months were abandoned. The principal instigators of this shift were the Egyptians, who had a compelling reason to respect the Sun. Ancient Egypt is known as "The Gift of the Nile," owing to the annual floods that brought water and nutrient-rich sediments to the land on either side of the river. Without this, there would have been no Egyptian agriculture and no Egyptian civilization. The source of the Nile's steady flow was the White Nile, emanating from Central Africa. Each July and August, this flow was joined by the flood from the Blue Nile, emanating from the highlands of Ethiopia, the catch basin for the annual monsoons locked into the cycle of the Sun. The Egyptians noticed that the annual flood was heralded by the heliacal rising of Sirius, the Dog Star. There would be a day when Sirius would rise, be fleetingly observed in the morning twilight, and then vanish into the Sun's glow. Before that day, Sirius would not be seen at all. This would take place just before the flood, so the heliacal rising of Sirius became the calibration point of the Egyptian calendar. The Egyptians discarded the lunar month and created 12 months of 30 days, followed by 5 days at the end of the year that did not belong to any month. However, this year is nearly 6 hours short of the tropical year and leads the Sun by a day every 4 years.

The Julian Calendar

In Rome, the calendar was a political instrument of the priests and was not laid down according to any understandable formula. One of the reforms of Julius Caesar was to introduce the Egyptian solar calendar, with an improvement suggested by Sosigenes of Alexandria. The Julian calendar, as we call it today, had a 365-day year with an extra day added every four years. Accordingly, the precise length of the Julian year is $T_{Julian} = 365 + 1/4 = 365.25$ d, to be compared with the Tropical year length $T_Y = 365.242190$ d. The Julian year is just over 11 minutes too long, and the Julian calendar consequently lags the Sun by 1 day every 128 years.

Julius Caesar also had to re-initialize the Roman calendar, to restore the Solstices and Equinoxes to their proper position. To do this, he added 80 days to the year 46 B.C.E. (also known as the "Year of Confusion"). The additional months Undecembris and Duodecembris were added to that year, having 40 days each.

Figure 2 — Pope Gregory XIII, calendar reformer.

The Gregorian Calendar

I am departing from the exact chronology of our calendar, as there were some important innovations introduced by Emperor Flavius Constantine, the first Christian ruler of Rome; however, these have to do with the determination of specific Christian holidays, such as Easter and Christmas, which I will defer to the next and final part of this series. From the point of view of creating a calendar that accurately represents the length of the tropical year, the next (and most recent) correction was introduced by Pope Gregory XIII.

By the middle of the second millennium, even the Julian calendar needed correction, losing 1 day every 128 years relative to the Sun and seasons. In 1582 C.E., the astronomical Vernal Equinox took place on March 10, eleven days too soon; the other Equinox and the Solstices were also early by the same amount. The religious feast of Easter was moving away from spring and headed for summer, which the Church did not like. With the advice of astronomer Christopher Clavius, Pope Gregory XIII once more reformed the calendar (just as Julius Caesar had reformed the calendar with the advice of Sosigenes). The correction amounted to cancelling the leap day in century years, unless those years were multiples of 400. In other words, the average length of the Gregorian year is $T_{Gregorian} = 365 + 1/4 - 1/100 + 1/400 = 365.2425$ d. Comparing this with the Tropical year length of $T_Y = 365.242190$ d, it is easy to work out that the Gregorian year is a remarkably small 27 *seconds* too long, and the Gregorian calendar lags the Sun by one day only every 3225 years.

In addition to making this length correction, the date in the year had to be adjusted (like Caesar's "Year of Confusion"). The month of October 1582 had 10 days removed, so that Thursday, October 4 was immediately followed by Friday, October 15. There was widespread dissent over this, as you can imagine: it would suddenly matter very much if wages were paid by the day or by the month; about one in 36 people would have missed their birthdays that year; and so on! This was the last reform to the calendar we use today, except for the fact that many nations (particularly Protestant ones) did not accept this reform until much later. Great Britain and colonies, for example, waited until September 1752 to effect the change, which by then had grown to 11 days difference. Even today, many Eastern churches maintain the Julian (or Old Style) calendar for the purpose of determining Christmas and Easter, while their host countries use the Gregorian (or New Style) calendar for civil purposes.

Conclusion to Part 2

I have briefly shown how various types of calendars were generated from the cycles of the Moon and the Sun, and how successive refinements have created a calendar year that very closely approximates the length of the Tropical year. The motivation for these refinements was to maintain the position of important holidays with respect to the seasons. Next installment, we will turn back the clock and look at the determination of special holidays and traditions such as Christmas, Easter, Hallowe'en, Groundhog Day, Chinese New Year, and Jewish New Year. I will show that these days have special connections with the Sun and the Moon, and that our "modern" calendar has embedded remnants of ancient beliefs and customs.

I would like to repeat the information of two books I have found useful in my research: Isaac Asimov's *The Clock We Live On* (Collier, New York, 1963) and Jacqueline de Bourgoing's *The Calendar: History, Lore, and Legend* (Harry N. Abrams Inc., New York, 2001). The first book is out of print, but may be found in used-bookstores; the second is current (the ISBN number is 0-8109-2981-3). The author is a French academic who has produced a television series on the calendar for French television. She published the book in 2000, and this is a translated version. Highly recommended!

Table: The Lengths of the Tropical Year and Several Calendrical Approximations

Year Type	Length (days)	Expanded Fraction	Error	Years to Gain or Lose 1 Day
Egyptian	365	= 365	$-5^h 49^m$	4
Julian	365.25	= 365 + 1/4	$+11^m 15^s$	128
Gregorian	365.2425	= 365 + 1/4 −1/100 + 1/400	$+27^s$	3225
Tropical	365.24219			

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

Second Light

A Stellar Double Bang

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

> **"The fact that we could see *Gamma Ray Bursts* at such immense distances implied they involved huge energies — by some estimates, up to 10 times the total energy from a standard supernova."**

Gamma-ray bursts — known colloquially to astronomers as GRBs — are fascinating objects. They were discovered during the height of the Cold War by satellites designed to look for nuclear explosions, and for 35 years had no known counterparts at any other wavelengths. A breakthrough took place in early 1997, when the Italian-Dutch *BeppoSAX* X-ray satellite pinpointed the position of a GRB through its X-ray afterglow sufficiently accurately that an optical telescope could find the dying light (see April 17, 1997 issue of *Nature*). Within a few months it was shown that at least several GRBs lay at cosmological distances, as had been suspected since the first results started coming out of the Burst And Transient Source Experiment (BATSE) on the *Compton Gamma-ray Observatory* in 1992.

The fact that we could see GRBs at such immense distances implied they involved huge energies — by some estimates, up to 10 times the total energy from a standard supernova. There are not that many conceivable options to release so much energy in so short a time — the bursts can last less than a second. The two leading contenders right now are 1) the merger of two neutron stars that are orbiting each other, and 2) a particularly energetic supernova oriented such that we are looking toward one of the poles. One way to distinguish between these options is to find clear traces of ejecta, because the composition of the material thrown out by the explosion could reveal what the progenitor was.

There have been several previous reports by Luigi Piro (of the Instituto Astrofisica Spaziale and Fisica Cosmica of CNR in Italy) and his colleagues of the detection of iron lines in the X-ray spectra of GRBs (see November 3, 2000 issue of *Science*, and references therein), with a surprisingly large amount of iron inferred from the data. Piro suggests a lower limit of 0.01 solar masses of iron, with the additional constraint that the iron must have been ejected in an event (such as supernova) that preceded the actual GRB by (less than) a few months. Piro concluded from his data that GRBs did not arise from the mergers of compact objects like neutron stars, but rather from the explosion of a massive star.

Piro's data were the source of a lively discussion at a meeting in Hawaii during November 2000. He had one line with a statistical significance of 4.7σ and another at 3σ, which he attributed to highly ionized iron, and another possible feature of marginal significance, which might be from highly-ionized sulfur. Four other bursts show weak evidence of iron features; Piro argues that, taken all together, the evidence is quite compelling. In the four cases with an independent optical measurement of the redshift, the line energies are consistent with those of iron. The problem with line identification is about the same anywhere in the electromagnetic spectrum — the more lines you have, the better you can constrain what elements give rise to them. Things are quite complicated in GRBs, though, because not only do you have the redshift of the burst (which might not be known) to contend with, but you also have an undetermined blueshift arising from the motion of the ejecta towards us.

James Reeves of the University of Leicester in Britain and his collaborators now have more lines, which he believes come from magnesium, silicon, sulfur, argon, and calcium (see April 4, 2002 issue of *Nature*). His best fit for the velocity of the material is about a tenth of the speed of the light — reassuringly close to Piro's — but he does not see any evidence for iron emission, contrary to Piro. Instead, Reeves sees a marginal nickel line. The isotope of nickel with atomic mass 56 decays to iron through two reactions; the first has a half-life of about six days, while the second's half-life is about 78 days. If the material truly is ejecta from an exploding massive star, then it would be about three months before significant amounts of iron should be seen. Piro's iron lines were seen within hours of the burst, and this gave rise to the suggestion that there were two explosions which were separated by several months, because it takes about three months for the nickel to decay to iron, meaning that a supernova

> **" The problem with the suggestion of a second explosion is trying to imagine what could be left after a supernova that would provide as much energy again as the original supernova."**

giving rise to the iron went off several months before the GRB. Reeves suggests that Piro's lines actually arose from nickel, which produces lines at energies near to those of iron.

The picture physically consistent with the data, and the interpretation Reeves adopts, is that of a massive star exploding some time (hours to days) before the GRB. Qualitatively, this is the same as Piro's interpretation, but the time delay and the composition of the ejecta seem more physically plausible. The supernova ejects at about a tenth of the speed of light a lot of material enriched in the heavy elements that form inside massive stars, then a short time later a "miracle happens" in the form of a second explosion and the burst of gamma-rays comes out along fairly narrow jets from (probably) the poles of the source. Because most of the surrounding stellar material has already been blown out, the gas from the second explosion does not get slowed down, and therefore the jets give rise to a pulse of gamma rays, which illuminate and heat the supernova ejecta as they catch up to it. This heated ejecta give us the X-ray afterglow and presumably the optical and radio emission also seen with some GRBs.

The problem with the suggestion of a second explosion is trying to imagine what could be left after a supernova that would provide as much energy again as the original supernova. One possibility is that the supernova left behind a neutron star on the verge of collapse to a black hole. Perhaps as some of the gas left after the supernova falls back (because of gravity), it puts the neutron star "over the edge," and it collapses catastrophically into a black hole. I suppose that imaginative theorists will rapidly concoct a scheme in which the acceleration of a small amount of gas to ultra-relativistic speeds is possible during such a collapse. Such a scheme might allow for varying compositions in the X-ray spectra because the collapse of the neutron star need not occur at the same time in all events. Perhaps this is the origin of the difference between Reeves' and Piro's results.

Curiously, though, not all GRBs have detectable afterglows, and sometimes an afterglow is seen at one wavelength but not another. And it is certainly true that not all supernovae are associated with GRBs, though a one-to-one correspondence isn't expected because we won't always be looking down the jet. Reeves' data certainly support Piro's suggestion of an association between a burst and supernova, while providing what may be a more physically plausible delay between them. What we really need, though, are lots of simultaneous observations of X-ray and optical emission within minutes of the burst to help us sort out the range of properties and to restrict what physically could give rise to those properties. There is hope that NASA's Swift mission (scheduled for launch in September 2003) will provide the data we need.

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PHOTOMETRIC AND POLARIMETRIC OBSERVATIONS OF MARS IN 2000-2002

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Abstract. A total of 326 photoelectric magnitude measurements and 58 photoelectric polarimetric measurements of Mars were made between November 11, 2000 and March 5, 2002. The normalized magnitudes of Mars for early 2001 are: −0.11, −1.45, −2.47, and −2.87 for the *B, V, R,* and *I* filters respectively; the respective solar-phase angle coefficients are: 0.0134, 0.0114, 0.0056, and 0.0024. Both visual observations and polarimetric measurements indicate that the great dust storm of 2001 was more opaque than the dust storms of 1971 and 1973. Mars was 0.25 magnitudes brighter in the V filter than normal during July and August as a result of the dust storm; however, light curve data indicate that the dust was not uniform at all longitudes. The effects of the 2001 dust storm lasted for 175 ± 10 days.

Résume. Un total de 326 mésures de la magnitude photoélectrique et de 58 mesures photoélectriques polarimétriques de Mars ont été obtenues entre le 11 novembre 2000 et le 5 mars 2002. Les magnitudes normalisées de Mars pour le début de 2001 sont respectivement : −0.11, −1.45, −2.47 et −2.87 prises avec les filtres *B, V, R*, et *I* ; les coefficients de l'angle de la phase solaire sont respectivement : 0.0134, 0.0114, 0.0056 et 0.0024. Les observations visuelles et les mesures polarimétriques indiquent que la grande tempête de poussière de 2001 était plus opaque que celles de 1971 et 1973. Durant les mois de juillet et août, Mars paraîssait 0.25 magnitude plus brillante que la normale sous le filtre V, suite à la tempête de poussière. Toutefois, les données de la courbe de lumière indiquent que la poussière n'était pas uniformément distribuée à travers toutes les longitudes. Les effets de la tempète de poussière ont durés 175 ± 10 jours. SEM

1. Introduction

Mars reached opposition on June 13, 2001, and on that date, it was 68.2 million km from Earth and it subtended an angular diameter of almost 21 arcseconds. The sub-Earth latitude was 3° N, and it was late winter in the southern hemisphere of Mars on opposition day. Four major developments occurred during 2001, which were: 1) the continued monitoring of Mars by the Mars Global Surveyor, 2) the insertion of the Mars Odyssey probe (Janke 2002), 3) the discovery of flashes within Edom Promontorium (Sheehan 2001), and 4) the development of an encircling dust storm in mid-2001.

A few recent and significant Mars discoveries/measurements made by professional astronomers include: 1) the existence of crystalline hematite, which indicates that liquid water was stable near the Martian surface for a long period of time in the past (Christensen *et al.* 2001), 2) dust storms having areas of at least 1000 square kilometres occurring 2-3 times a day on average across Mars (Cantor *et al.* 2001), 3) the existence of molecular hydrogen in the Martian atmosphere (Krasnopolsky & Feldman 2001), 4) photographic evidence of recent liquid-water activity near the Martian surface (Malin & Edgett 2000), and 5) the mapping of dust, temperature, and water-vapour abundance across Mars over a complete Martian year (Smith *et al.* 2001b). The 2001 opposition was well observed by amateur astronomers, and their observations are summarized elsewhere (McKim 2001; Minami 2000).

This paper summarizes whole-disk photometry and polarimetry of Mars made from November 11, 2000 to March 5, 2002. One reason why I carried out this study was to continue my multi-year photoelectric magnitude study of Mars. The second reason for carrying out this study was to monitor the great dust storm of 2001.

2. Method

An SSP-3 solid-state photometer with filters transformed to the Johnson *B, V, R*, and *I* system was used along with a 0.09-metre f/5.5 telescope in measuring the brightness and colour of Mars. The photometer and filters are described elsewhere (Schmude 1992; Optec 1997). The field of view was around 10 arcminutes and, as a result, it took Mars about 50 seconds to drift through the field of view; this was enough time to take three ten-second measurements of that planet. Likewise, the comparison star was also measured as it drifted across the large field of view. A measurement consisted of the sequence *SMSMSMS* where *S* was the difference between the average of three ten-second sky readings and three ten-second sky-plus-star readings. Each *M* value was computed in the same way as *S*, except that Mars was substituted for the comparison star.

The comparison stars used in the 2001 opposition are listed in Table 1. All observations made between December 22, 2000 and June 23, 2001, and July 17 to November 21, 2001 are based on beta-Oph

Table 1
Comparison stars used in the photoelectric magnitude study of Mars during the 2001 apparition. All right ascensions are from Hirshfeld *et al.* (1991).

Star	Right Ascensions	Declination	Magnitude B	V	R	I
HD 5848 [a]	$1^h 09^m$	86° 15^m	5.46	4.25	---	---
Nu-Psc [b]	$1^h 41^m$	5° 29^m	5.80	4.44	---	---
Alpha-CMa [b]	$6^h 45^m$	−16° 43^m	−1.46	−1.45	---	---
Beta-Vir [b]	$11^h 51^m$	1° 46^m	4.15	3.59	3.13	2.85
Alpha-Boo [b]	$14^h 16^m$	19° 11^m	1.18	−0.06	−1.04	−1.70
Tau-Sco [b]	$16^h 36^m$	−28° 13^m	2.57	2.82	2.93	3.18
Beta-Oph [a]	$17^h 44^m$	4° 34^m	3.94	2.77	1.95	1.38
Gamma-Cap [b]	$21^h 40^m$	−16° 40^m	3.99	3.67	---	---
Phi-Aqr [b]	$23^h 14^m$	−6° 03^m	4.23	5.78	---	---

[a] Magnitudes are from the Astronomical Almanac for the year 2002.
[b] Magnitudes are from Iriarte *et al.* 1965.

as the comparison star. The stars beta-Vir, and alpha-Boo were comparison stars during the periods November 11-15, 2000 and November 30-December 18, 2000, respectively. During the time intervals: (July 2-11, 2001), (November 27-December 8, 2001), (December 24-28, 2001), (December 31-January 21, 2002), (January 29, 2002), (February 3 – February 19, February 28 and March 5.050, 2002), and (February 24 and March 5.022, 2002), the respective comparison stars were tau-Sco, gamma-Cap, HD 5848, phi-Aqr, alpha-CMa, nu-Psc, and epsilon-Tau.

All photometric measurements were corrected for both atmospheric extinction and transformation in the same way as is described in Hall & Genet (1988). Transformation coefficients were measured using the two-star method. The two stars used in measuring the transformation coefficients are beta-Oph and gamma-Oph; these stars were selected because of their large colour difference and the fact that they are listed as standard stars in the *Astronomical Almanac* (2000b). The transformation coefficients were measured for the *B*, *V*, *R*, and *I* filters to be: 0.092, −0.051, −0.021, and −0.095.

Whole-disk polarimetric measurements of Mars were carried out with a 0.03-metre f/4 lens that was attached to the photometer. A polarizing filter was attached to the front of the lens. The plane of the polarizer was marked. Each polarization measurement consisted of the sequence *PRPRPRPRP*. The *P* value consisted of three ten-second sky readings, six ten-second Mars + sky readings followed by three more sky readings. The value of *P* was the difference between the sky readings and the Mars-plus-sky readings. The polarizer was then rotated 90°, and the sky, Mars-plus-sky, and sky readings were recorded and the *R* value was determined. This experiment was repeated until a total of five *P* values and four *R* values were measured. The polarization was computed in the same way as is outlined in Dollfus (1961), and Steigmann (1988), which is:

$$P \text{ (in polarization units)} = [(R - P)/(R + P)] \times 1000 \quad (1)$$

All measurements in Figure 5 were made with a filter and detector having a maximum light sensitivity of 540 nm. The same lens, polarizer,

Table 2
Photoelectric magnitude measurements of Mars made from November, 2000 up to June 18, 2001. All measurements were made under a nearly dust-free Martian environment.

Date (UT)	Central Meridian (°)	Solar Phase Angle (°)	Magnitude B	V	R	I
2000						
Nov. 11.443	200	24.8	3.19	1.73	---	---
Nov. 15.448	163	25.5	---	---	0.38	−0.12
Nov. 30.423	8	28.2	--	1.70	---	---
Nov. 30.449	17	28.0	3.05	---	---	---
Dec. 1.422	354	28.2	---	---	0.45	−0.01
Dec. 4.443	336	28.7	3.06	1.68	0.43	−0.09
Dec. 4.466	344	28.7	3.03	----	---	---
Dec. 18.408	187	31.0	2.95	1.46	0.18	---
Dec. 18.455	204	31.0	---	---	0.22	−0.28
Dec. 22.432	155	31.6	2.85	1.45	0.12	−0.42
Dec. 29.430	88	32.5	2.85	1.39	0.14	−0.44
Dec. 29.505	115	32.5	---	1.35	0.01	−0.50
Dec. 30.503	104	32.7	2.77	---	---	---
2001						
Jan. 3.418	36	33.2	---	1.28	0.15	−0.31
Jan. 3.466	53	33.2	2.71	1.28	0.08	−0.39
Feb. 20.404	290	37.9	2.13	0.78	−0.46	−1.00
Mar. 8.446	151	38.2	1.84	0.36	−0.94	---
Mar. 10.339	95	38.1	1.66	0.25	−0.99	−1.52
Mar. 10.400	116	38.1	1.68	0.23	−1.03	−1.56
Mar. 10.445	132	38.1	---	---	---	−1.54
Mar. 17.355	34	37.9	---	---	−0.87	−1.41
Mar. 17.401	50	37.9	1.48	0.14	−0.97	−1.52
Mar. 24.419	331	37.3	1.42	0.03	−1.19	−1.66
Apr. 1.408	271	36.6	1.22	−0.13	−1.28	−1.83
Apr. 2.325	232	36.5	1.21	−0.18	−1.31	−1.81
May 14.285	189	22.9	−0.24	−1.56	−2.70	−3.17
May 14.341	208	22.8	−0.21	−1.53	−2.65	−3.14
May 14.390	225	22.8	−0.23	−1.49	−2.64	−3.09
May 16.254	159	21.7	−0.19	−1.58	−2.78	−3.21
May 19.242	128	19.9	−0.23	−1.59	−2.88	−3.32
May 19.293	146	19.9	−0.33	−1.69	−2.89	−3.32
May 19.358	169	19.9	−0.33	−1.66	−2.85	−3.27
May 23.331	123	17.3	−0.44	−1.88	−2.97	−3.43
May 23.239	91	17.3	−0.39	−1.80	−2.96	−3.42
May 24.202	69	16.6	−0.46	−1.82	−2.93	−3.31
May 30.185	9	12.3	−0.57	−1.87	−2.95	−3.36
May 30.227	24	12.3	−0.60	−1.95	−2.97	−3.45
May 30.298	49	12.2	−0.64	−1.95	−2.97	−3.44
June 3.201	339	9.1	−0.69	−2.04	−3.12	−3.55
June 13.171	240	2.8	−0.99	−2.38	−3.38	−3.83
June 13.246	266	2.8	−0.98	−2.34	−3.35	−3.76
June 13.308	288	2.8	−0.90	−2.34	−3.31	−3.73
June 15.209	236	3.0	−1.03	−2.34	−3.41	−3.79
June 17.286	245	4.1	−0.98	−2.29	−3.28	−3.71
June 18.146	187	4.7	−0.95	−2.38	−3.49	−3.94
June 18.217	212	4.8	−0.97	−2.36	−3.40	−3.82

Table 3
Photoelectric magnitude measurements made between
June 18 and October 29, 2001.

Date (UT)	Central Meridian (°)	Solar Phase Angle (°)	Magnitude B	V	R	I
June 20.150	171	6.2	---	---	−3.51	−3.96
June 21.218	186	7.1	−1.08	−2.39	---	---
June 23.115	132	8.7	−1.06	−2.40	−3.54	−3.98
July 2.138	60	16.2	---	−2.12	−3.20	−3.73
July 2.200	82	16.3	---	−2.14	---	---
July 2.271	107	16.3	---	---	−3.25	−3.75
July 10.110	339	21.5	---	−2.17	−3.32	−3.82
July 10.150	353	21.5	---	−2.19	---	---
July 11.169	351	22.9	---	−2.22	−3.35	−3.89
July 17.109	275	26.9	−0.58	−2.12	−3.22	−3.65
July 17.182	301	27.0	−0.65	−2.11	−3.33	−3.69
July 18.205	300	27.6	−0.59	−2.13	---	---
July 19.134	265	28.2	−0.57	−2.05	−3.25	−3.68
July 22.113	231	29.9	−0.39	−1.97	−3.18	−3.60
July 22.156	246	29.9	---	---	−3.13	−3.56
July 23.099	217	30.4	−0.35	−1.97	---	---
July 23.138	230	30.4	−0.32	−1.98	---	---
Aug. 1.136	147	34.9	−0.14	−1.76	−2.95	−3.45
Aug. 2.113	130	35.3	−0.28	−1.78	−2.93	−3.39
Aug. 2.168	149	35.3	−0.10	−1.64	−2.87	−3.33
Aug. 5.215	138	36.5	−0.14	−1.61	−2.91	−3.30
Aug. 13.097	21	39.3	0.06	−1.47	---	---
Aug. 16.118	1	40.2	0.26	−1.44	−2.60	−3.04
Aug. 23.121	296	41.9	0.34	−1.35	−2.48	−2.91
Aug. 24.095	277	42.1	0.37	−1.33	---	---
Sep. 7.097	145	44.6	0.65	−0.90	−2.19	−2.67
Sep. 10.092	114	44.9	0.65	−0.91	−2.07	---
Sep. 17.085	45	45.6	0.86	−0.80	−1.94	−2.44
Sep. 18.076	32	45.7	0.83	−0.80	−1.94	−2.38
Sep. 23.092	349	46.0	0.86	−0.73	---	---
Sep. 28.072	294	46.1	0.99	−0.63	−1.77	−2.24
Oct. 1.088	271	46.2	1.10	−0.62	−1.79	−2.25
Oct. 3.068	244	46.2	1.13	−0.54	−1.74	−2.22
Oct. 8.072	197	46.3	1.24	−0.51	−1.70	−2.18
Oct. 9.067	186	46.3	1.27	−0.47	−1.69	−2.16
Oct. 16.078	122	46.1	1.39	−0.30	−1.50	−2.03
Oct. 16.124	138	46.1	1.46	−0.27	−1.50	−2.07
Oct. 18.042	90	46.1	1.31	−0.27	−1.40	−1.87
Oct. 21.053	64	46.0	1.31	−0.23	−1.34	−1.80
Oct. 27.037	358	45.7	1.45	−0.14	−1.28	−1.76
Oct. 27.070	12	45.7	1.45	−0.15	−1.28	−1.76
Oct. 29.024	336	45.6	1.51	−0.12	−1.26	−1.74

and photometer were used for all 2001-2002 measurements. A few measurements were also made in the *B, R,* and *I* filters. More details on the *B, V, R,* and *I* filters can be found in Schmude (2000), while the lens is described in Schmude (2001).

3. Results Before the Great 2001 Dust Storm

The measured magnitudes made between November 11, 2000 and June 18, 2001 are listed in Table 2, while measurements made between June 19 and October 29, 2001 are listed in Table 3, and measurements made after November 11, 2001 are listed in Table 4. The author wanted to monitor the long-term progress of the encircling dust storm of 2001, and this is why measurements were taken over such a long period of time.

All measurements summarized in Table 2 were placed into one of 12 longitude groups as was done in previous oppositions (Schmude & Bruton 1994; Schmude 1996, 1998, 2000). The normalized *B, V, R,* and *I* magnitudes at a solar-phase angle α were computed in the same way as is described in Schmude (2000). (The solar-phase angle is the angle between the Earth and the Sun measured from the centre of Mars.) Graphs of normalized magnitude versus the solar-phase angle for each of the filters in all 12 longitude regions were computed in the same way as in Figure 1 of Schmude (2000) and the resulting

Table 4
Magnitude measurements of Mars made between
November 12, 2001 and March 5, 2002.

Date (UT)	Filter	Magnitude	Date (UT)	Filter	Magnitude
2001			2002		
Nov. 12.006	V	0.16	Jan. 21.005	V	0.98
Nov. 18.001	V	0.20	Jan. 21.044	V	0.97
Nov. 21.001	V	0.20	Jan. 29.060	V	0.97
Nov. 27.009	V	0.28	Feb. 3.027	V	1.06
Dec. 1.983	V	0.39	Feb. 3.069	B	2.56
Dec. 3.014	V	0.35	Feb. 3.080	V	1.05
Dec. 7.028	V	0.44	Feb. 9.024	V	1.11
Dec. 8.013	V	0.40	Feb. 9.060	V	1.12
Dec. 24.046	V	0.68	Feb. 15.052	V	1.17
Dec. 24.062	B	2.19	Feb. 15.062	V	1.16
Dec. 28.016	V	0.76	Feb. 19.047	V	1.19
Dec. 31.004	V	0.76	Feb. 24.069	V	1.23
2002			Feb. 28.045	V	1.25
Jan. 4.026	V	0.82	Feb. 28.095	V	1.27
Jan. 10.051	V	0.86	Mar. 5.022	V	1.22
Jan. 13.034	V	0.90	Mar. 5.050	V	1.29
Jan. 16.008	V	0.92			
Jan. 19.010	V	1.00			

Table 5
Selected normalized magnitudes and solar-phase angle coefficients for
Mars in early 2001 based on data collected between
November 11, 2000 and June 18, 2001.

Filter	Normalized Magnitude	Solar Phase Angle Coefficient (mag./°)	Mean Apparition Magnitude[a]
B	−0.11	0.0134 ± 0.0007	−0.60
V	−1.45	0.0114 ± 0.0007	−1.94
R	−2.47	0.0056 ± 0.0008	−2.96
I	−2.87	0.0024 ± 0.0009	−3.36

[a] This is the magnitude that Mars would have if it were 1.524 astronomical units from the Sun and 0.524 astronomical units from the Earth extrapolated to a solar-phase angle of 0°.

normalized magnitude at α = 0° (y intercept) and solar-phase angle coefficient (slope) were computed. Average values for each filter were computed and the results are listed in Table 5. The solar-phase angle coefficients were lower than in previous years and the normalized magnitudes at α = 0° were fainter than in previous years. These differences are probably due to the decrease in cloud activity on Mars in late northern summer (Beish & Parker 1988).

4. Results During and After the Encircling Dust Storm of 2001

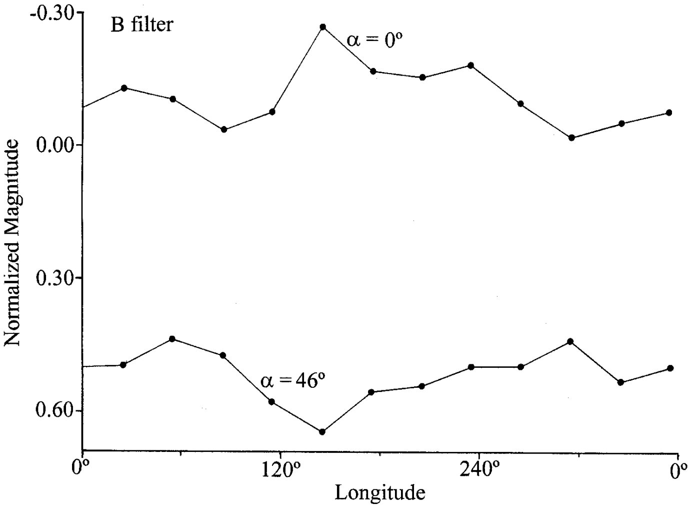

Figure 1

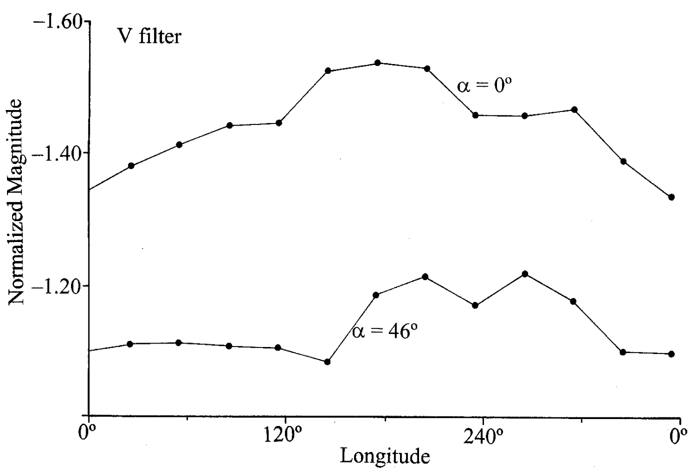

Figure 2

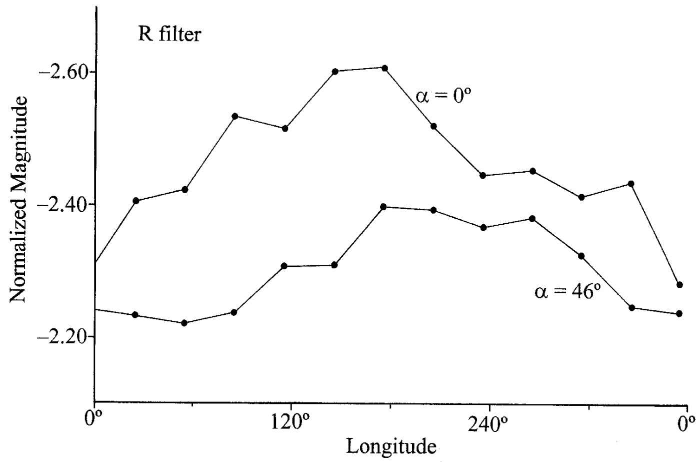

Figure 3

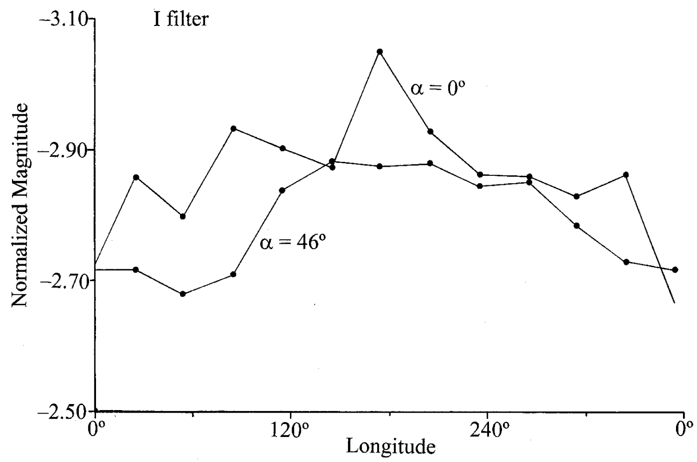

Figure 4

Figs. 1–4 — Light curves of Mars at solar-phase angles (α) of 0 and 46 degrees in the *B, V, R,* and *I* filters. The curve at 0 degrees is based on data collected when the Martian atmosphere was clear, whereas the 46 degree curve is based on data collected when the Martian atmosphere had lots of dust.

Figures 1–4 are plots of the normalized magnitude versus the longitude of the central meridian for α = 0° and α = 46°. The α = 0° data are based on data collected between November 11, 2000 and June 18, 2001, under a nearly dust-free Martian atmosphere, whereas the α = 46° data are based on measurements made between September 23 and October 29 when there was still a large dust influence. The α = 0° and 46° curves for the *I* filter are very similar with a brightness maximum at 175° W and a minimum at 0° W. This result is consistent with the dust having a minimal effect in the infrared brightness. The trend for the *B* filter, however, is opposite to that for the infrared. Before the dust storm, Mars was brightest at a longitude of 145° W and dimmest at 85° W and 295° W; however, during October, Mars was brightest at 55° W and 295° W and dimmest at 145° W. Therefore, there is almost a total anti-correlation for the *B* filter between the dusty and dust-free situations. Uncertainties in Figures 1–4 are around 0.025 magnitudes, whereas the uncertainties of the individual measurements in Table 2 are around 0.04 magnitudes.

Figure 5 shows the whole-disk polarization measurements made of Mars between August 16, 2001 and February 9, 2002 through the *V* filter. The solid line is the average of the 1922, 1924, and 1926 polarization measurements made by Lyot (de Vaucouleurs 1954). The dashed line represents Dollfus' 1969 measurements made at a wavelength of 550 nm (Ebisawa & Dollfus 1993). Figure 6 shows selected CCD images of Mars made by Don Parker. The uncertainty for each of the polarization measurements in Figure 5 is approximately 3 polarization units.

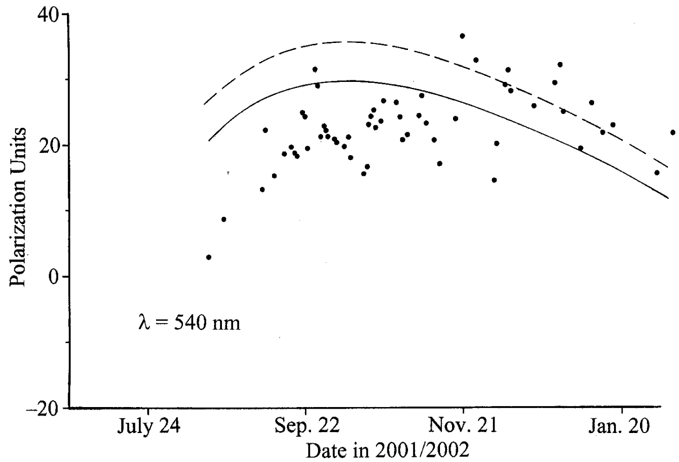

Fig. 5 — Whole-disk photoelectric polarimetric data collected between August 16, 2001 and February 9, 2002 (shown as individual points). The dashed curve represents polarimetric measurements made by Dollfus made in 1969 with a peak wavelength of 550 nm (Ebisawa & Dollfus 1993) and the solid curve is the average of the 1922, 1924, and 1926 opposition polarimetric measurements made by Lyot (de Vaucouleurs 1954).

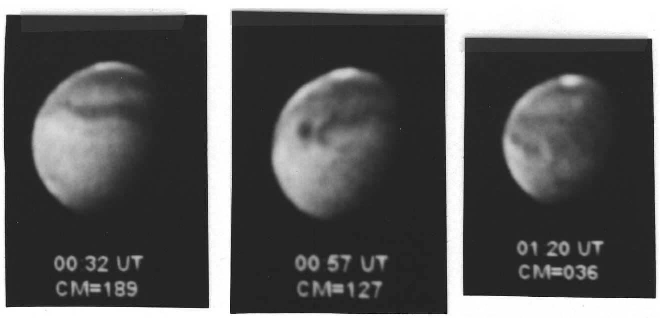

Fig. 6 — Red light CCD images of Mars made by Don Parker during the waning phases of the 2001 dust storm. The images from left to right were made on October 7, 2001 at 0:32 UT (central meridian = 189° W), October 14, 2001 at 0:57 UT (central meridian = 127° W), and October 24, 2001 at 1:20 UT (central meridian = 36° W).

5. Discussion

One explanation for the trends in Figures 1–4 is that unequal amounts of atmospheric dust were present across Mars. The greatest dust concentration was at a longitude of 300° W, and the lowest concentration was at 150° W. Furthermore, the atmospheric dust may have acted as condensation nuclei for water vapour; this has probably occurred in the northern hemisphere (Cantor *et al.* 2001; James & Cantor, 2001). Smith *et al.* (2001b) have also shown that significant amounts of water vapour are present near the equator at L_s = 200–240°, and some of this vapour may have condensed onto the dust. The area with the largest amount of dust would cause the *B* magnitude to rise dramatically, whereas areas with a lower dust concentration would have a more moderate effect on the *B* magnitude since there would be fewer suspended, icy-dust particles.

The dust storm caused the *V* filter brightness of Mars to increase by up to 0.3 magnitudes at some longitudes. Table 6 shows a comparison between the measured *V* filter magnitude (averaged over all longitudes) and the predicted magnitude (*Astronomical Almanac* 1999, 2000a, b). There is excellent agreement between the measured and predicted magnitudes before the dust storm. During the peak of the dust storm (July and August), Mars was 0.25 magnitudes brighter than what was predicted. This discrepancy continued into September through November. By January 2002, the Mars magnitude was back to what it was predicted to be.

Table 6

Summary of average *V*-filter magnitude discrepancies for different time periods. In all cases, the predicted magnitudes were taken from the Astronomical Almanac for the years 2000, 2001, and 2002.

Time Period	Mean L_s	Observed – Predicted Magnitude
Nov. 30, 2000 – Jan. 3, 2001	90°	+0.01 ± 0.02
Feb. 20 – Apr. 2, 2001	130°	−0.02 ± 0.03
May 14 – June 3, 2001	166°	+0.01 ± 0.02
July 10 – Aug. 13, 2001	203°	−0.25 ± 0.02
Aug. 16 – Sep. 18, 2001	225°	−0.25 ± 0.02
Sep. 23 – Oct. 29, 2001	250°	−0.18 ± 0.02
Nov. 12 – Dec. 24, 2001	283°	−0.07 ± 0.01
Dec. 28, 2001 – Jan. 29, 2002	308°	+0.02 ± 0.01
Feb. 3 – March 5, 2002	329°	−0.02 ± 0.01

The dust activity suppressed the amount of polarized light reflected by Mars in a similar way as the 1924-1925 dust storm (de Vaucouleurs 1954). In fact, very few surface features were seen at around December 10, 1924 (McKim 1999), which suggests that the 1924-1925 storm was very opaque like the 2001 storm.

If Dollfus' & Lyot's measurements are considered to represent a dust-free Mars, then the polarization measurements indicate that the effects of the dust storm disappeared in mid-December. The results in Table 6 are also consistent with the dust effects vanishing in mid-December. Based on the photometric and polarization measurements, it is concluded that the influence of the 2001 encircling dust storm lasted from June 24 to December 15, 2001 or 175 ± 10 days. It must be emphasized that this is the duration of the effects of the dust storm and not necessarily the lifetime of the dust storm.

Based on both polarization and photometric measurements, along with the definitions given by McKim (1999), the author concludes that by mid-July the 2001 dust storm became planet encircling. All longitudes of Mars were brightened by at least 0.15 magnitudes during late July and August. Furthermore, polarization measurements at all longitudes in August and September fell well below the 1969 curve of Dollfus and the 1922-1926 curves of Lyot. Although the opacity of this storm was great, the author was able to see faint dark areas within the range 50° S to 10° N on July 15, 16, 17, 19, 22, 23, 31; August 2, 3, 4, 7, 9, 13, 17, 23, and 24 with a 10-cm refractor.

There were several reports that the 2001 dust storm was more opaque than the planet-encircling events of 1956, 1971, and 1973 (McKim 2001; Minami 2001). The polarization data in both Figure 5 and in Ebisawa & Dollfus (1993) support this claim. During the 1971 and 1973 dust storms, the amount of polarized light reflected by Mars was about 10-15 units below a dust free Mars at α = 35° and 40°, whereas the results in mid-August show a drop of 20-25 polarization units at similar solar-phase angles. The drop in polarization may have even been greater on August 1, 2001, which was the peak of the dust storm (Smith *et al.* 2001a).

The altitude of the opaque dust layer near Olympus Mons is estimated to have been 9 km or less in late August and early September. The first piece of evidence for this low altitude is that Olympus Mons had a similar appearance in late August 2001 (Minami 2001) to what it had in the relatively dust free year of 1988 (McKim 1991). Essentially, Olympus Mons was reported to be more distinct when it was east of the terminator than when it was either on or west of the terminator during 1988 and in late August 2001. A second piece of evidence suggesting a low altitude for the dust is the size of the dark Olympus Mons spot in early September. Essentially, the author measured a diameter of 400 km for the Olympus Mons dark spot from Don Parker's red-light CCD images on September 6, 2001. This diameter was compared to a topographic map of Olympus Mons (Beatty & Chaikin 1990), and it was found that the 9-km altitude line along Olympus Mons made a circle having a diameter of 400 km. An analysis of CCD images made by Maurizio Di Sciullo, Ed Grafton, and Don Parker reveals that the mean diameter of the dark Olympus Mons spot on July 14 and 30-31 was 470 and 450 km respectively; these diameters are consistent with elevations of no more than 5 and 7 km for the opaque dust layers. The bright ring around Olympus Mons, imaged by the Hubble Space Telescope under clear Martian skies, shows up in Don Parker's July 30 CCD images; this suggests that the dust near Olympus Mons was relatively thin.

6. Conclusion

The normalized magnitudes were a bit fainter in 2001 than in previous years, and the solar-phase angle coefficients were somewhat lower in early 2001. Both of these trends may be due to the changing number of white clouds on Mars. The amplitudes of the Martian light curves in the *B, V, R*, and *I* filters for $\alpha = 0°$ were similar to those in previous oppositions.

A dust storm broke out in late June, and by mid-July it had become planet encircling (McKim 2001), but it never became a truly global storm. This dust storm affected both the amount of light reflected by Mars and the amount of polarized light reflected by that planet for 175 ± 10 days. Mars became up to 0.3 magnitudes brighter as a result of the storm, and both visual and polarization measurements indicated that the 2001 storm had a higher opacity than the planet-encircling storms of 1971 and 1973. The opacity of the 2001 dust storm, however, was not uniform at all longitudes; the storm was probably less opaque at around 145° W than at 295° W. Near Olympus Mons, the opaque dust layer had an altitude of 9 km or less on July 14, 30-31 and September 6.

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References

Astronomical Almanac for the Year 2000, 1999, (U.S. Government Printing Office: Washington D.C.)
Astronomical Almanac for the Year 2001, 2000a, (U.S. Government Printing Office: Washington D.C.)
Astronomical Almanac for the Year 2002, 2000b, (U.S. Government Printing Office: Washington D.C.)
Beatty, J.K., & Chaikin, A. ed, 1990, The New Solar System, (3d ed.; Cambridge University Press: Cambridge)
Beish, J.D., & Parker, D.C. 1988, Sky & Telescope, 75, No. 4, 370
Cantor, B.A., James, P.B., Caplinger, M., & Wolff, M.J. 2001, J. Geophys. Res. 106, 23,653
Christensen, P.R. et al. 2001, J. Geophys. Res., 106, 23,823
De Vaucouleurs, G. 1954, Physics of the Planet Mars, (Faber and Faber Ltd.: London)
Dollfus, A. 1961, Polarization Studies of Planets in Planets and Satellites, ed. G.P. Kuiper & B.M. Middlehurst (University of Chicago Press: Chicago), 343
Ebisawa, S., & Dollfus, A. 1993, A&A, 272, 671
Hall, D.S., & Genet, R.M. 1988, Photoelectric Photometry of Variable Stars, (2d ed.; Willmann-Bell: Richmond)
Hirshfeld, A., Sinnott, R.W., & Ochsenbein, F. 1991, Sky Catalog 2000.0, Vol. 1, (2d ed.; Sky Publishing: Cambridge, MA)
Iriarte, B., Johnson, H.L., Mitchell, R.I., & Wisniewski, W.K. 1965, Sky & Telescope, 30, No. 1, 21
James, P.B., & Cantor, B.A. 2001, Icarus, 154, 131
Janke, E. 2002, Astronomy, 30, 26
Krasnopolsky, V.A., & Feldman, P.D. 2001, BAAS, 33, 1122
Malin, M.C., & Edgett, K.S. 2000, Science, 288, 2330
McKim, R. 1991, J. Brit. Astron. Soc., 101, 264
McKim, R. 1999, Memoirs of the Brit. Astron. Assoc., 44, 1
McKim, R. 2001, BAA Mars Section Circular 2001, December
Minami, M., Murakami, M., Nakajima, T., & Nishita, A. ed. 2000, Communications in Mars Observations (Oriental Astronomy Society), No. 237-256
Optec Inc. 1997, Model SSP-3 Solid-State Stellar Photometer Technical Manual for Theory of Operation and Operating Procedures (Optec Inc.: Lowell, MI)
Schmude, R.W. Jr. 1992, J. Assoc. Lunar & Planet. Obs., 36, 20
Schmude, R.W. Jr. & Bruton, D. 1994, JRASC, 88, 69
Schmude, R.W. Jr. 1996, JRASC, 90, 193
Schmude, R.W. Jr. 1998, JRASC, 92, 190
Schmude, R.W. Jr. 2000, JRASC, 94, 241
Schmude, R.W. Jr. 2001, JRASC, 95, 17
Sheehan, W. 2001, Mercury, 30, No. 5, 14
Smith, M.D., Conrath, B.J., Pearl, J.C., & Christensen, P.R. 2001a, BAAS, 33, 1097
Smith, M.D., Pearl, J.C., Conrath, B.J., & Christensen, P.R. 2001b, Geophys. Res. Lett., 28, 4263
Steigmann, G.A. 1988, J. Brit. Astron. Assoc. 98, 106

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PROGRESS IN ASTRONOMY AND ASTROPHYSICS DURING 1907
THE PLANETS

During the year much interesting work has been done on the planets. During the summer there was an opposition of Mars very favorable for observation, and exceptional interest was shown both by astronomers and the general public. In the discussions the central figure is Percival Lowell, director of the Lowell Observatory, Flagstaff, Arizona, who has carried on his observations with enthusiasm, patience and skill, and has stated his views in an interesting and able manner. There are two problems, (1) To determine the facts, especially to secure accurate delineations of markings, (2) To interpret the observed phenomena. As is well known drawings of the planet's disc, made by Lowell and some others, show an abundance of fine markings, while other astronomers, equally accustomed to close observation, are quite unable to see these lines. During the summer Professor Newcomb endeavored to show, from considerations of aberration and diffraction in the telescope, that it is simply impossible to see such fine lines as appear on many drawings; but this view has been vigorously combated by Lowell, both from the theoretical and the practical side. "Who shall decide when doctors disagree?"

Great interest was aroused in the announcement that Lowell's very capable assistants, Messrs. Lampland, and Slipher, had actually photographed the so-called canals. Extremely creditable photographs were taken in 1905, and again last year, and an expedition in charge of Professor Todd was sent to South America, at the expense of Professor Lowell, to secure observations and photographs at a more suitable station. Reproductions of a number of these have appeared in some of the magazines, and recently some of the original negatives, with transparencies from them were exhibited in Boston. Professor Bailey, of the Harvard Observatory, reports that while they show nearly as much as is seen by conservative observers of Mars, he was unable to see any of the long, straight, sharply defined canals shown on many drawings, and no sign of doubling.

Two French observers, Messrs. Jarry-Desloges and G. Fournier, observing from the summit of the Revard, at an elevation of 1550 metres, reported seeing the doubling of the Solis Lacus. They also saw a number of canals, the Ganges appearing double. The Abbé Th. Moreux agrees with Lowell as to the bolder features, but doubts the objective reality of the fine rectilinear canals of which Lowell has enumerated 420. The Abbé has never seen any of the alleged oases, which are said to mark the intersection of the canals. From his series of observations during 1905 he concludes that the transparency of the Martin atmosphere has been overrated in the past. On several occasions cloud formations obscured detail on the planet's surface. M. Sola, of the Fabra Observatory (Barcelona), also detected atmospheric changes on the planet. He saw a "lac" at the intersection of the canals Phison and Orontes, and the Euphrates, though perfectly visible, was always diffuse.

Calculations of the temperature of Mars, deduced from the relative distances of Mars and the Earth from the Sun give –33° F. as the mean temperature of the planet. Lowell, however, from consideration of the albedos of the planets, the screening effect of clouds, the blanketing effect of the atmosphere, etc., deduces the value 72° F., if the heat were retained there as well as it is here. As the retention is greater in the case of the Earth, this value is considerably reduced, a mean temperature of about 47° F. being obtained. This result is important in considering the question of life upon Mars.

It is this latter aspect of the problem which appeals so strongly to the popular imagination, and the evidence for or against life on the planet comes from our interpretation of the observed markings. Professor Lowell does not hesitate to attribute an artificial origin to the canals and argues indeed that life on Mars must be strenuous and highly developed. As a rule, however, I believe astronomers are rather inclined to the opposite view, and will remain sceptical until further evidence is forthcoming.

by C. A. Chant,
from *Journal*, Vol. 2, pp. 5-7, January-February, 1908.

CANADIAN THESIS ABSTRACTS

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

The Formation and Survival of Disk Galaxies

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The dynamical evolution of substructure within dark matter halos is of central importance in determining many aspects of galaxy formation and galaxy evolution in cold dark-matter cosmologies. The overall sequence in which the different stellar components of galaxies are assembled, the survival of galactic disks, the number of dwarf satellites orbiting giant galaxies, and the nature of stellar material in galactic halos all depend on the dynamics of halo substructure. In this thesis, I develop an analytic description of the evolution of substructure within a dark-matter halo and use it to construct a semi-analytic model of the formation and evolution of disk galaxies.

Substructure within an individual halo is modelled as a set of distinct subhalos, orbiting in a smooth background. These subhalos evolve through three main processes: dynamical friction, tidal mass loss, and tidal heating. By including analytic descriptions of these three processes explicitly in a simple, orbital-integration scheme, it is possible to reproduce the results of high-resolution numerical simulations at a fraction of the computational expense. The properties of a subhalo can be estimated with an accuracy of 20%, until it has lost most of its mass or been disrupted.

Using this description of satellite dynamics, I construct a semi-analytic model for the evolution of a galaxy or cluster halo. I show that this model reproduces the basic features of numerical simulations, and use it to investigate two major problems in current galaxy formation scenarios: the prediction of excessive substructure in galaxy halos, and the survival of galactic disks in halos filled with substructure.

I show that the small number of dwarf galaxies observed in the Local Group can be explained by considering the effects of reionization on star formation in small halos. The stellar luminosities predicted in this case match the observed luminosities of local satellites. The predicted spatial distribution, sizes, and characteristic velocities of dwarf galaxies are also consistent with those observed locally.

Many of these satellite galaxies are disrupted by tidal stripping or encounters. I investigate the properties of their debris and show that its total mass and spatial distribution are similar to those of the stellar halo of the Milky Way. Furthermore, the stars in this debris are mainly old, satisfying another observational constraint on models of galaxy formation. Some satellites have been disrupted fairly recently, however, suggesting that coherent tidal streams may still be visible at the present day.

Finally, I investigate the effects of encounters on the central disk within the main halo. I find that the rate of disruptive encounters drops off sharply after the galaxy is assembled, such that the typical disk has remained undisturbed for the past 8–10 billion years. Less disruptive encounters are more common, and disks are often heated as they re-form after their last disruption, producing components like the thick disk of the Milky Way. These results may resolve the long-standing uncertainty about disk ages in hierarchical, cold dark-matter cosmologies. It is less clear whether the bulge-to-disk mass ratios predicted by the model, for the currently favoured LCDM cosmology, are consistent with observations. The relative mass of the bulge in typical disk galaxies may place an upper limit on the age of their stellar contents.

The Environmental Impact of the Virgo Cluster on the Evolution of Dwarf Irregular Galaxies

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Dwarf galaxies are the greatest contributor to the total number of galaxies and most are believed to be systems consisting of matter in a near-primordial state. Containing H I gas and H II regions, dwarf irregular galaxies (dIs) can be used as test bodies to evaluate the impact of the environment on their evolution. Oxygen abundances relative to hydrogen within H II regions are a measure of how far the conversion of gas in the interstellar medium into stars has proceeded as a whole, as abundances do not vary significantly with galactocentric radii in dIs. Measurements of the [O III]λ4363 emission line from H II region spectroscopy provide accurate probes of the electron temperature from which oxygen abundances are directly computed.

The impact of the Virgo Cluster environment is investigated by comparing the properties of a set of Virgo dIs with those of a set of dIs in the field. In particular, two diagrams are used as diagnostics of evolution. The relationship between metallicity (as represented by the oxygen abundance) and galaxy luminosity is roughly indicative of the link between metallicity and mass. The relationship between oxygen abundance and the fraction of baryons in the form of gas can be used to evaluate the significance of gas flows during evolution.

To ensure accurate measures of luminosity and abundance, dIs in the field are chosen to have distance determinations from well-calibrated techniques and oxygen abundances derived from [O III]λ4363 measurements. Spectroscopic data are obtained for H II regions in 11 dIs distributed in the central and outer regions of the Virgo Cluster. To ensure that oxygen abundances are derived in a homogeneous manner, oxygen abundances for field and Virgo dIs are computed using an indirect bright-line method and compared with abundances directly obtained from [O III]λ4363, where available. They are found to agree to within about 0.2 dex with no systematic offset.

There is no systematic difference in oxygen abundance between field dIs and Virgo dIs at a given luminosity, showing that there is no detectable difference in their stellar populations. Because there has been no significant fading or brightening of Virgo dIs with respect to field dwarfs and the metallicity–luminosity relation does not allow for any effects on the gas to be shown, this diagram is by itself insufficient to determine whether the environment has affected the evolution of dIs.

Oxygen abundances for field dIs are well correlated with the gas fraction in a way that shows definitively that evolution has been isolated, *i.e.*, consistent with the "closed-box" model of chemical evolution. Four of the eleven Virgo dIs exhibit much lower gas fractions than field dIs at comparable oxygen abundances. Using field dIs as a reference, a gas–deficiency index, GDI, for dIs can be constructed,

making it possible quantitatively to identify which objects have lost gas. There is no systematic difference in luminosity between gas-poor and gas-normal dIs at a given abundance.

For the gas-poor dI UGC 7636 (VCC 1249), the oxygen abundance of a newly discovered intergalactic H II region is combined with the optical luminosity of the dI and the gas mass of the adjacent HI cloud (STE1) to show that STE1 must have once been the interstellar medium of the dI. Tidal interactions of the dI with the elliptical NGC 4472, combined with ram-pressure stripping by the intracluster medium (ICM), best explain the observed properties of the detached cloud and the dI. That STE1 has remained intact and that there is no H I trail between the cloud and UGC 7636 suggest that the duration of the stripping event was short compared to the crossing timescale in the cluster.

A "staged" model is described to examine the chemical evolution of a gas-poor dI in the Virgo Cluster. Motivated by the observations, the model is characterized by three phases: isolated evolution, then sudden stripping that removes most of the gas, followed by a second stage of isolated evolution for the residual gas. The time since a typical stripping event is found to be approximately 1 Gyr or less. The GDIs for Virgo dIs correlate roughly with values of the projected X-ray surface brightness of the intracluster gas at the positions of the dIs. Thus, ram-pressure stripping best explains the observed gas-poor dIs in the Virgo sample. Together with the lack of significant fading, these observations suggest that dIs have recently encountered the ICM for the first time. A faded remnant of a gas-poor dI in Virgo will resemble a bright dE/dSph-like object like those presently seen in the cluster core.

ASTRONOMY IN THE CANADIAN CURRICULUM (K-12)

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1. Introduction

Most members of the RASC probably agree with Simon Lilly, past Director General of the Herzberg Institute of Astrophysics, who is quoted in the January/February 2002 issue of *SkyNews* as saying, "I've always seen...[astronomy]...as something fundamental to human existence and consciousness. Certainly, my own research has been motivated by this desire to understand why things in the universe are as they are. And, of course, our own existence in the universe is a key part of that." Astronomy is not only a fascinating subject, it also provides a perspective and a logical framework for all other studies.

In the past, the study of astronomy was largely ignored in the elementary and secondary schools of Canada. However, in the past few years the science curricula across Canada have been revised, from Kindergarten to Grade 12 (K-12), and one aspect of these revisions has been a substantial increase in the number of topics devoted to astronomy.

This article is designed to provide general information about the development of new science curricula in Canada and to provide specific information regarding the astronomy topics in the new curricula. This information may be of general interest. In addition, RASC members could utilize this information when making astronomy presentations in schools or when preparing educational materials. RASC members could also refer to this information if they decided to become involved in the review and development of the next generation of science curricula.

In theory, the study of astronomy includes the cosmos and everything within it. The whole school curriculum could be considered as astronomy, or as a derivative of it. Shakespeare was a self-organized collection of primordial hydrogen and supernovae debris that produced unique symbol combinations in the biosphere of the planet Earth. For practical purposes, "astronomy" in this article will be limited to properties of the Earth as a planet, the Solar System, celestial phenomena beyond the Solar System, and some topics in space science. Space science involves materials technology, rocketry, engineering, astronautics, and satellites of all types. The design and operation of space telescopes is an important new topic in astronomy. The following topics will not be included: weather (other than simple cyclical changes), biology, chemistry, and most physics topics. In high-school programs, topics such as electromagnetic waves, optics, nuclear forces, and the force of gravity are usually regarded as physics topics, with possible astronomical applications.

A cursory survey of the Web sites of the departments of education in the provinces and territories makes one aware of a wide array of educational issues. See `www.cmec.ca/educmin.stm` for convenient links to all Canadian departments of education. These departments are concerned with more than curriculum development and delivery. Perhaps the dominant issue is the financing of education. The provision of educational services in English, French, and First Nations languages is another major challenge, especially in regions where the students are geographically dispersed and few in numbers, such as in the territories. Departments of education must deal with equity issues involving gender, culture, religion, and provision of suitable learning opportunities for all students. Each province and territory is also striving to take advantage of computers and the Internet to enhance the education of students. The everyday issues of drugs, violence, and changing family structures also regularly percolate into the classrooms of the nation.

In any given class of students there tends to be a wide range of intellectual abilities, a wide range of socio-economic backgrounds, a wide range of health and social concerns, and a wide range of academic ambitions. Often many students in a classroom do not speak English, French, or a First Nations language as their mother tongue.

Elementary teachers are teachers of all subjects, including science, and have the challenges and rewards of working with energetic youngsters. For the elementary science program to be successful, teachers need clear, well-designed curriculum materials.

Secondary teachers tend to focus on one or two curriculum areas and have the challenges and rewards of working with adolescents. One or two high-school science courses are compulsory for all students, and a variety of more-advanced science courses are optional. Many high school students are interested in careers in medical science and tend to focus on biology and chemistry rather than physics and astronomy.

Despite these concerns and limitations, in the past five years there has been a significant increase in the quantity and quality of astronomical items in the science curriculum of Canadian schools.

2. Developments in Curriculum Development

Deciding what is taught to the next generation is an important power in any society. The Canadian constitution assigns exclusive control over education to the provinces. In the provinces, publicly controlled schools are run by local school boards that operate under provincial statutes. Education in the Northwest Territories, Yukon Territory, and Nunavut is funded by the federal government but is governed by ordinances of the assemblies of those regions.

Historically, the provinces developed distinct educational systems to serve their own populations. There is a recent trend towards more collaboration and sharing. In 1967, the Council of Ministers of Education, Canada (CMEC) was established. The CMEC has promoted a number of co-operative initiatives, including a set of national achievement tests designed to assess how well students are learning across the country. Partly in response to these test results and partly in response to other social and financial concerns, all the ten provinces and three territories have conducted major reviews of their educational systems within the past decade. In February 1995, the CMEC adopted the Pan-Canadian Protocol for Collaboration in School Curriculum. The goal of this protocol was the improvement of the quality of education in the provinces and territories through inter-jurisdictional cooperation. They recognized that shared resources, both human and financial, could increase the quality and efficiency of the process for developing educational activities and materials. The creation of new educational resources requires that relatively large groups of students follow similar curricula. For example, a publisher has to sell approximately 10,000 copies of a new high school textbook before development costs are recovered.

Provincial, national, and international testing of student skills, such as the School Achievement Indicators Program (SAIP, `www.cmec.ca/saip`), the Third International Study of Mathematics and Science Study (TIMSS, `nces.ed.gov/timss`), and the Programme for International Student Assessment (PISA, `www.pisa.gc.ca`) has led to a greater emphasis in Canada on systematic generation of curricula, setting of standards, and systematic student evaluations.

In December 1993, the ministers responsible for education in Manitoba, Saskatchewan, Alberta, British Columbia, Yukon Territory, and Northwest Territories signed the Western Canadian Protocol (WCP) for Collaboration in Basic Education, Kindergarten to Grade 12. Nunavut joined this organization in 2000. Several cooperative projects have been initiated, including the development of common curriculum frameworks for mathematics, language arts, and international languages.

In September 1995, the Atlantic Provinces Education Foundation (APEF) was formed by agreement of the Ministers of Education of New Brunswick, Newfoundland and Labrador, Nova Scotia, and Prince Edward Island. This foundation was designed to provide the framework for joint undertakings of the four departments in the area of K-12 education, in both official languages. The current focus is on common curriculum and outcomes, indicators, and assessment.

Educational jurisdictions in Canada have been reviewing, revising, and rewriting the curriculum in all subjects. In particular, the science curriculum in Canadian schools has been undergoing many changes in content and in methodologies. In the past five years, there has been a concerted effort by the Council of Education Ministers of Canada to align the science curriculum across all provinces and territories. As a result of this process, most new science programs now include a number of units involving astronomy and space science.

The new curricula contain more than lists of ordered topics. They are designed around general and specific outcomes and expectations or indicators. These are detailed statements that describe the new skills and behaviours that students are expected to demonstrate upon the successful conclusion of each unit. Outcomes include actions such as performing and recording, analyzing and interpreting, initiating and planning, exploring social and environmental contexts, communicating, and collaborating in teamwork. There simply is too much material and not enough time for students to learn only content. Students have to learn-to-learn, to plan and carry out investigations, and to communicate their findings to others.

The creation of new curriculum materials is not a simple process. Resources are devoted to curriculum development as a result of needs perceived by educators, parents, business interests, politicians, and the community at large. Guidelines are created, reviewed, and approved. Oversight committees are established. A small team of writers is organized. The task is divided, and work begins. The new materials are edited and revised several times. Then the materials are sent to third parties for review and comment. More editing and revisions occur. Finally, the new materials are approved, produced, packaged, and distributed. This whole process can take two years or more. Actual implementation of a new curriculum across twelve grades of study can take over a decade.

There is a potential for RASC members to contribute astronomical expertise at any of these stages in any future science-curriculum projects.

3. The Pan-Canadian Science Project (PCSP)

The Pan-Canadian Science Project (PCSP) was the first joint development project of the CMEC. The objective of the PCSP was to produce a framework of science learning outcomes from Kindergarten through to Grade 12. The PCSP materials are now available for provinces and territories to incorporate into their designs for new science curricula.

A project team, lead by Manitoba and British Columbia, created a framework of science outcomes. Research articles and international science-education documents were consulted. There was an extensive review process involving consultations with elementary and secondary school teachers and administrators, postsecondary institutions, business and labour organizations, parent groups, professional science organizations, science-interest groups, and representatives from other ministries during 1996 and 1997. The final version of the PCSP framework was released in October 1997. The process and the results are described in detail at `www.cmec.ca`

The general and specific outcomes of the PCSP curriculum were based on four foundation statements:

(1) Students will develop an understanding of the nature of science and technology, of the relationships between science and technology, and of the social and environmental contexts of science and technology.

(2) Students will develop the skills required for scientific and technological inquiry, for solving problems, for communicating scientific ideas and results, for working collaboratively, and for making informed decisions.

(3) Students will construct knowledge and understandings of concepts in life science, physical science, and Earth and space science, and apply these understandings to interpret, integrate, and extend their knowledge.

(4) Students will be encouraged to develop attitudes that support the responsible acquisition and application of scientific and technological knowledge to the mutual benefit of self, society, and the environment.

Each specific outcome is numbered for reference purposes. Outcomes with numbers in the 100s are related to science, technology, society, and the environment (Foundation 1). Outcomes with numbers in the 200s are related to the skills for scientific and technological inquiry (Foundation 2). Outcomes with numbers in the 300s are related to student knowledge (Foundation 3). And outcomes with numbers in the 400s are related to developing positive student attitudes towards science and technology (Foundation 4). Clarifying examples are given in Italics. The attitude indicators are not intended to be used for formal evaluation.

The PCSP includes resource materials for teachers as well as a framework of performance indicators. In Phase I, the Simcoe County District School Board, in Ontario, was contracted to design and develop a database of curriculum resources for K-12 science teachers. In Phase II the project was relocated to York University's Faculty of Pure and Applied Science and renamed YES I CAN! (York Educational Science Project, `yesican.yorku.ca`). The goal of YES I CAN! is to provide strong scientific resources with "easy-to use," "easy-to-understand" demonstrations and explanations. Contributions from educators across Canada continue to be added to this resource database. YES I CAN! is available to every teacher in Canada, free of charge.

4. Astronomy Content in the PCSP

Earth and Space Science is one of the main knowledge strands in the third foundation statement of the PCSP. The major topics for each grade within this strand are listed below.

Grade	Earth and Space Science Topic
1	Daily and seasonal changes
2	Air and water in the environment
3	Exploring soils
4	Rocks, minerals, and erosion
5	Weather
6	Space
7	Earth's crust
8	Water systems on Earth
9	Space exploration
10	Weather dynamics
11 - 12	Earth systems
	Earth resources
	Earth processes
	Historical geology
	Astronomy

The topics with astronomical implications are: Grade 1 – Daily and seasonal changes, Grade 6 – Space, Grade 9 – Space exploration, and Grades 11-12 – Astronomy. Within these topics, more detailed outcomes describe astronomical knowledge and skills that students are expected to master. These specific astronomical outcomes are given in detail below.

4.1 Grade 1 – Daily and Seasonal Changes

- 100.14 describe changes in heat and light from the Sun (*e.g., measure and compare temperatures and other weather conditions on cloudy and sunny days; measure and describe outdoor temperature changes at different times of the day; observe and describe how the position of the Sun influences the length and position of shadows*)

- 101.06 describe ways of measuring and recording environmental changes that occur in daily and seasonal cycles (*e.g., investigate and describe ways of measuring daily and seasonal changes in light and temperature; observe and describe changes that occur in a cyclic pattern, and relate these changes to the passage of time*)

- 102.03 observe and describe changes in sunlight and describe how these changes affect living things (*e.g., observe and describe the location of the Sun in the sky at different times of the day; describe changes from day to night and how these changes affect living things*)

- 202.02 place materials and objects in a sequence or in groups according to one or more attributes (*e.g., group pictures by season*)

These astronomy outcomes encourage young students to examine their environment systematically and measure daily and seasonal changes in the heat and light provided by the Sun. In Grade 1, the 100 and 300 level outcomes have been combined. Four of the 62 outcomes in Grade 1 science are related to astronomy. If 50 hours are devoted to science in Grade 1 and if all the outcomes are treated equally, then about 3.25 hours of classroom instruction should be devoted to the topic of daily and seasonal changes.

4.2 Grade 6 – Space

- 104.03 demonstrate and explain the importance of selecting appropriate processes for investigating scientific questions and solving technological problems *(e.g., explain why astrology is not a part of science*)

- 104.08 demonstrate the importance of using the languages of science and technology to compare and communicate ideas, processes, and results (*e.g., use appropriate terminology such as "constellations," "planets," "moons," "comets," "asteroids," and "meteors" to describe objects in space*)

- 105.06 describe how evidence must be continually questioned in order to validate scientific knowledge (*e.g., provide examples of ideas, such as the flat Earth, the Earth as the centre of the Solar System, and life on Mars, which were or are being challenged to develop new understandings of the natural world*)

- 106.03 describe examples of improvements to the tools and techniques of scientific investigation that have led to new discoveries (*e.g., describe innovations, such as the lunar buggy, the Canadarm, the Hubble telescope, and space probes, which have extended scientific knowledge*)

- 106.04 describe instances where scientific ideas and discoveries have led to new inventions and applications (*e.g., describe how a better understanding of tides has led to their harnessing for producing electrical energy*)

- 107.03 compare tools, techniques, and scientific ideas used by different people around the world to interpret natural phenomena and meet their needs (*e.g., compare how different cultures over time, such as the Celts, the Aztecs, and the Egyptians, have traced the positions of stars to determine the appropriate time to plant and harvest crops*)

- 107.12 provide examples of Canadians who have contributed to science and technology (*e.g., highlight Canadian astronauts such as Steve McLean, Marc Garneau, Roberta Bondar, and Chris Hadfield*)

- 107.15 describe scientific and technological achievements that are the result of contributions by people from around the world (*e.g., describe international contributors related to the construction of the space station*)

- investigations (*e.g., predict what variables might affect the size of craters on the Moon, using a flour and marble simulation*)

- 204.06 identify various methods for finding answers to given questions and solutions to given problems, and select one that is appropriate (*e.g., use local papers or science periodicals for listings of planets that are visible at a particular time*)

- 204.07 plan a set of steps to solve a practical problem and to carry out a fair test of a science-related idea (*e.g., plan a procedure to test a hypothesis in a simulated Moon crater activity*)

- 205.02 select and use tools in manipulating materials and in building models (*e.g., select appropriate materials to build model constellations*)

- 205.07 record observations using a single word, notes in point form, sentences, and simple diagrams and charts (*e.g., use a data table to record night sky observations*)

- 205.08 identify and use a variety of sources and technologies to gather pertinent information (*e.g., use electronic and print resources or visit a planetarium to gather information on the visual characteristics of planets*)

- 206.02 compile and display data, by hand or by computer, in a variety of formats including frequency tallies, tables, and bar graphs (*e.g., prepare a diagram showing the orbits of the planets*)

- 206.04 evaluate the usefulness of different information sources in answering a given question (*e.g., compare information received from science fiction stories about space with that from scientific sources*)

- 206.05 draw a conclusion, based on evidence gathered through research and observation, that answers an initial question (*e.g., conclude that simulated flour craters are deeper and wider when the marble is heavier or is dropped from greater heights*)

- 207.02 communicate procedures and results, using lists, notes in point form, sentences, charts, graphs, drawings, and oral language (*e.g., write a postcard describing your holiday on a planet other than Earth and include in the description the key characteristics of that planet*)

- 300.23 describe the physical characteristics of components of the Solar System; specifically, the Sun, planets, moons, comets, asteroids, and meteoroids

- 301.19 demonstrate how Earth's rotation causes the day and night cycle and how Earth's revolution causes the yearly cycle of seasons

- 301.20 observe and explain how the relative positions of Earth, the Moon, and the Sun are responsible for Moon phases, eclipses, and tides

- 301.21 describe how astronauts are able to meet their basic needs in space

- 302.13 identify constellations in the night sky

Twenty-three of the ninety-nine science outcomes in Grade 6 are related to space science and astronomy. Only four outcomes, in the 300 level, deal directly with astronomical content. The content of most of the other "space" outcomes provides a medium for developing skills in scientific inquiry and communication. If 100 hours are devoted to science in Grade 6 and if all the outcomes are treated equally, then about four hours of classroom instruction should be devoted to the Earth and the Solar System. Rather than teaching astronomy as a compact unit, over a week or two, it would be advisable to distribute these astronomy topics over several months so students can chart the positions of the Sun, Moon, and constellations during a significant fraction of the year.

4.3 Grade 9 – Space Exploration

- 109.03 describe and explain the role of experimentation, collecting evidence, finding relationships, proposing explanations, and imagination in the development of scientific knowledge (*e.g., explain how data provided by astronomy, radio astronomy, satellite-based astronomy, and satellite exploration of the Sun, planets, moons, and asteroids contribute to our knowledge of the Solar System*)

- 109.11 relate personal activities and various scientific and technological endeavours to specific science disciplines and interdisciplinary study areas (*e.g., relate analysis of meteorites or lunar materials to chemistry and geology*)

- 110.06 explain the need for new evidence in order to test existing theories continually (*e.g., explain the need for new evidence obtained from space-based telescopes and close- up observations by satellites, which can reinforce, adjust, or reject existing inferences based on observations from Earth*)

- 111.05 describe the science underlying particular technologies designed to explore natural phenomena, extend human capabilities, or solve practical problems (*e.g., describe how optical principles are demonstrated in a telescope and aerodynamic principles are applied in rocket and spacecraft engineering*)

- 112.06 provide examples of how Canadian research projects in science and technology are supported (*e.g., discuss government involvement in the development and use of communication satellites, and the private- and public-sponsored research experiments carried out as part of space shuttle missions*)

- 112.11 describe examples of science- and technology-based careers in Canada, and relate these careers to their studies in science (*e.g., discuss the careers of astronauts, astrophysicists, materials technologists, pilots, and computer programmers*)

- 113.03 describe possible positive and negative effects of a particular scientific or technological development, and explain why a practical solution requires a compromise between competing priorities (*e.g., describe effects such as the spinoffs from space technologies to everyday usage and the potential military use of space exploration, and recognize the need to evaluate these objectives*)

- 208.04 propose alternative solutions to a given practical problem, select one, and develop a plan (*e.g., design and describe a model space station*)

- 208.05 state a prediction and a hypothesis based on background information or an observed pattern of events (*e.g., predict the next visit of a comet based on past observations*)

- 209.04 organize data using a format that is appropriate to the task or experiment (*e.g., maintain a log of observations of changes in the night sky; prepare a comparative data table on various stars*)

- 210.03 identify strengths and weaknesses of different methods of collecting and displaying data (*e.g., compare Earth-based observations to those made from spacecraft; explain why the precise observation of stars is limited by their distance*)

- 210.09 calculate theoretical values of a variable (*e.g., calculate the travel time to a distant star at a given speed*)

- 210.16 identify new questions and problems that arise from what was learned (*e.g., identify questions such as the following: "What are the limits of space travel?" "How old is the Universe?" "Is Earth the only suitable home for humans?"*)

- 211.01 receive, understand, and act on the ideas of others (*e.g., take into account advice provided by other students or individuals in designing a space suit*)

- 211.03 work cooperatively with team members to develop and carry out a plan, and troubleshoot problems as they arise (*e.g., write and act out a group skit demonstrating tasks and interactions among astronauts during a mission*)

- 211.05 defend a given position on an issue or problem, based on student findings (*e.g., conduct appropriate research to justify a position on the economic costs or benefits of space exploration*)

- 312.01 describe theories on the formation of the Solar System

- 312.02 describe and classify the major components of the Universe

- 312.03 describe theories on the origin and evolution of the Universe

- 312.04 describe and explain the apparent motion of celestial bodies

- 312.05 describe the composition and characteristics of the components of the Solar System

- 312.06 describe the effects of solar phenomena on Earth

There are 22 out of 85 outcomes that are related to space exploration in the Grade-9 science program. Six of these outcomes, at the 300 level, deal directly with astronomy. If 100 hours are devoted to science in Grade 9 and, if all the outcomes are treated equally, then about seven hours of classroom instruction should be devoted to these astronomical topics.

As demonstrated in the examples at the 100 and 200 level, space-science and astronomy topics again provide a medium for developing scientific inquiry and communication skills.

These astronomy outcomes are really just short introductions to complete branches of astronomy. Many astronomers have spent their entire careers refining theories on the formation of the Solar System, determining the major components of the universe, developing theories on the evolution of the universe, or exploring the effects of solar phenomena on the atmosphere of Earth.

4.4 Grade 11 or 12 – Astronomy

- 114.02 explain the roles of evidence, theories, and paradigms in the development of scientific knowledge (*e.g., describe the historical development of theories to explain the origin of the universe*)

- 115.03 explain how a major scientific milestone revolutionized thinking in the scientific communities (*e.g., explain how the discovery of the redshift in the spectra of stars contributed to our understanding of the nature of the universe*)

- 115.05 analyze why and how a particular technology was developed and improved over time (*e.g., conclude that the evolution of telescopes from the optical to radio to the Hubble was in response to humankind's search for knowledge about the universe, or that the use of constellations in navigation was in response to the need to extend the ability to travel over long distances on Earth*)

- 116.06 describe and evaluate the design of technological solutions and the way they function, using scientific principles (*e.g., describe the way a telescope functions using appropriate principles of optics*)

- 117.06 analyze why scientific and technological activities take place in a variety of individual and group settings (*e.g., analyze* *the individual and group activities required to study various components of the universe*)

- 117.11 distinguish between questions that can be answered by science and those that cannot, and between problems that can be solved by technology and those that cannot (*e.g., distinguish between questions such as "What information has science provided about the universe?" and "How well does science provide explanations for the origin and composition of the universe?"*)

- 212.06 design an experiment and identify specific variables (*e.g., propose and test the variables that will change the eccentricity of an ellipse, using the string-and-pin method of drawing ellipses*)

- 212.07 formulate operational definitions of major variables (*e.g., given data such as diameter and density, describe the properties that divide the planets and moons into three groups: Jovian planets, telluric objects, and Ganymedian objects*)

- 212.08 evaluate and select appropriate instruments for collecting evidence and appropriate processes for problem solving, inquiring, and decision making (*e.g., evaluate remote sensing methods such as parallax, stellar magnitudes, and telescopes for determining different characteristics of components in the universe*)

- 213.03 use instruments effectively and accurately for collecting data *(e.g., observe and record the movements of celestial objects, using a telescope*)

- 213.04 estimate quantities (*e.g., use appropriate astronomical measurement units*)

- 213.06 use library and electronic research tools to collect information on a given topic (*e.g., use specialized journals to gather information on current research in astronomy*)

- 214.01 describe and apply classification systems and nomenclature used in the sciences (*e.g., classify stars according to temperature, luminosity, or mass*)

- 214.06 apply and assess alternative theoretical models for interpreting knowledge in a given field (*e.g., discuss different cultural interpretations of the constellations*)

- 215.03 synthesize information from multiple sources or from complex and lengthy texts and make inferences based on this information (*e.g., determine characteristics of different galaxies from information gathered from various multimedia resources*)

- 333.01 compare and contrast a variety of theories for the origin of the Universe emphasizing modern observational evidence

- 333.02 describe tools and methods used to observe and measure the Universe

- 333.03 identify and compare various components of the Universe

- 333.04 compare characteristics of various galaxies

- 333.05 describe the life cycle of stars

- 333.06 compare the composition of stars at different stages of their life cycles

The PCSP does not provide frameworks for complete senior science courses. Instead, it provides a total of 523 outcomes grouped into 22 subject areas. Courses can be created to meet local needs by combining any four or five subject areas. The scope and depth of the PCSP outcomes are sufficient to construct two biology courses, two chemistry courses, two physics courses, and one course in Earth and/or space science. Astronomy is one of the 22 topics and consists of the 20 outcomes listed above.

Senior-science courses are optional for students, and a course emphasizing astronomy would probably be regarded as an extra science course to be considered only after biology, chemistry, and/or physics. Most high schools do not have the personnel or the resources or sufficient numbers of interested students to be able to offer a senior science course in astronomy. Perhaps an on-line, distance-education course in astronomy could be developed from the PCSP framework. Such a course could deliver astronomy content and techniques to the far corners of Canada and serve as a model for any high school wishing to implement their own astronomy course.

There are also opportunities for RASC members to contribute their knowledge and expertise to enrich the astronomy experience of Grade 6 and Grade 9 students. Teachers would probably appreciate presentations of facts and demonstrations, as well as one or two follow up activities that could be assigned to students, along with a standard for evaluating student efforts.

5. Summary

Curriculum development has become a coordinated effort involving many jurisdictions. The CEMC has produced a new science curriculum framework, called the Pan-Canadian Science Project that is being refined and implemented in most provinces and territories. This new science curriculum contains a significant number of astronomical topics. There are opportunities for RASC members to contribute their astronomical knowledge and expertise to enhance the classroom learning experience of students, to contribute materials to the YES I CAN! data base, to participate in committees that will be refining science curricula in the future, and perhaps to participate in the development of an on-line course in astronomy for senior high-school students.

A final note of caution: While every effort has been made to ensure that the material in this article is accurate and up to date, anyone wishing to become actively involved in any aspect of a provincial or territorial educational system should first contact local authorities to verify that their efforts will be welcomed and then to verify that their understanding of the curriculum content is correct.

References

Council of Education Ministers of Canada (`www.cmec.ca`)
Atlantic Provinces Education Foundation (`apef-fepa.org`)
Western Canadian Protocol (`www.wcp.ca`)
YESICAN, York University (`yesican.yorku.ca`)

The Canadian Encyclopedia, McClelland and Stewart, *Educational Organization*, p737-739, Toronto, 2000

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Appendix

Some Comments on Astronomy in the Curricula of the Provinces and Territories

Although links to all the provincial and territorial departments of education can be found at `www.cmec.ca/educmin.stm`, it is not always a simple matter to find specific curriculum documents within a department's Web site. The complete Web address leading to curriculum documents, in English, is provided below for several of the provinces and territories. The same information can also be obtained in French. At many sites, the only way to view astronomy items in the curriculum is to download a pdf file for one or more complete courses and then search through that file page by page.

The Maritimes

In 1998, the Atlantic Provinces Education Foundation produced a *Foundation for the Atlantic Canada Science Curriculum*. Although this material is patterned closely after the PCSP, individual provinces in this consortium have utilized local expertise to produce their own science curricula with variations in emphasis and content.

Newfoundland & Labrador (`www.gov.nf.ca/edu/k12/k12.htm`**)**

In Newfoundland and Labrador the outcomes on "Daily and Seasonal Changes" have been moved to Grade 2 and expressed in more detail.

Grade 2: The Earth and Its Place in the Universe
- Identify the Earth, Moon, and Sun as part of a larger Solar System
- Depict the location of the Moon, Sun, and stars in relation to the placement of the Earth in the Solar System
- Collect and record information to compare the Moon, Sun, stars and Earth
- Explain that the Sun is the source of energy (heat and light) for the Earth
- Demonstrate how surface temperature decreases with distance from a heat source
- Record the (outside) temperature several times during a day. Discuss the results and their relationship with the position of the Sun
- Demonstrate the causes of night and day using a model

In Grades 4, 5, and 6, the "Space" topic has been elaborated on and divided into "The Solar System," "Space Exploration," "Relative Position and Motion of the Earth, Moon, and the Sun," and "Stars and Constellations." Reference numbers to outcomes in the PCSP have been retained.

Grades 4 – 6: The Solar System
- Describe how people's conceptions of Earth and its position in the Solar System have been continually questioned over time and have resulted in changes in conceptions from that of a flat Earth, to an Earth-centered system, to a Sun-centered system (105-6)
- Describe the physical characteristics of components of the Solar System – specifically, the Sun, planets, moons, comets, asteroids, and meteoroids (104-8, 300-23)
- Describe the Sun as the centre of the Solar System and the main source of energy for everything in the Solar System
- Describe planets as bodies that move around the Sun and do not give off their own radiation
- Describe moons as bodies that move around the planets and do not give off their own radiation
- Describe the general composition, relative size, appearance, and paths of asteroids, comets, and meteors.
- Select and use tools in building models of the Solar System that show approximate relative size of the planets and Sun, and the approximate relative orbits of the planets around the Sun (205-2)
- Identify and use a variety of sources and technologies to gather pertinent information about a planet, moon, asteroid, or comet, and display findings using diagrams, pictures and/or descriptions from recent explorations (105-1, 205-8, 207-2)
- Evaluate the usefulness of different information sources, such as science fiction books and TV programs, Internet sites, scientific books and magazines, when getting information about the components of the Solar System (206-4)

Grades 4 – 6: Space Exploration
- Describe how astronauts are able to meet their basic needs in space (301-21)
- Provide examples of Canadians, such as astronauts Marc Garneau, Roberta Bondar and Chris Hadfield, and the team that build the Canadarm, who have contributed to the science and technology of space exploration (107-12)
- Describe examples of improvements to the tools and techniques of scientific investigation of the Solar System, such as the development of the lunar buggy, the Candarm, the Hubble telescope, and space probes, that have led to new discoveries and scientific information about space (106-3)
- Describe scientific and technological achievements in space science, such as the construction of the space station and investigations on space-shuttle missions, that are the result of contributions by people from around the world (107-15)
- Identify and describe recent or current events in space and space exploration, for example, visibility of comets in the night sky, space-exploration missions (10-5-1)

Grades 4 – 6: Relative Position and Motion of the Earth, Moon and the Sun
- Demonstrate how Earth's rotation causes the day and night cycle and how Earth's revolution causes the yearly cycle of seasons (301-19)
- State a prediction and a hypothesis relating the angle of the Sun's rays to the temperature of a material like soil or water, and plan a set of steps to test this relationship (204-3, 204-7)
- Carry out the planned procedures to investigate the relationship

between the angle of the light and the temperature of a material like soil or water, making sure that variables are identified and controlled, compile and display the data collected, draw conclusions based on the data (205-1, 206-2, 206-5)
- Observe and explain how the relative positions of Earth, the Moon, and the Sun are responsible for the Moon phases, eclipses, and tides (301-21)

Grades 4 – 6: Stars and Constellations
- Record observations of the night sky using simple diagrams (205-7)
- Identify constellations in the night sky (302-13)
- Use electronic, print resources and/or visit a planetarium to gather information on the visual characteristics and mythology of constellations (205-8)
- Compare how different cultures over time, such as the Celts, the Aztecs, and the Egyptians, have used the positions of the stars to determine the appropriate time to plant and harvest crops, navigate the oceans, or foretell significant events (107-3)
- Explain the difference between astrology and astronomy, and explain that astrology is not part of a science (104-3)

Prince Edward Island, New Brunswick, and Nova Scotia

These provinces are in the process of implementing the Atlantic Canada Science Curriculum. Also of note: Prince Edward Island has created the Web site, "Links for Educators and Students to Educational Resources" (LESTER), as a Web-based resource for teachers and students in all subject areas; and Nova Scotia has provided on-line facilities to order hard copies or to download pdf files of all AEPF curriculum documents.

Quebec

In Quebec, elementary education is divided into cycles rather than grades. See `www.meq.gouv.qc.ca/GR-PUB/menu-curricu-a.htm` for pdf files of curriculum documents. There is a unit entitled "Earth and Space" in the Science and Technology curriculum for cycles 2/3 (roughly Grades 3 to 6). This unit contains the following topics:

Energy
- Solar energy
- Transmission of energy (*e.g.*, radiation)

Forces and motion
- Rotation of the Earth (*e.g.*, day and night, visible motion of the Sun and the stars)
- The tides

Systems and interaction
- System involving the Sun, the Earth, and the Moon
- Solar System
- The seasons
- The stars and [visual groups of stars] (e.g., constellations)
- Technologies related to the Earth, the atmosphere, and outer space (*e.g.*, seismograph, weather forecasting, satellites, space station)

Techniques and instrumentation
- Use of simple observational instruments (*e.g.*, binoculars, telescope)
- Design and manufacture of measuring instruments and prototypes

Appropriate language
- Terminology related to an understanding of the Earth and the Universe
- Conventions and types of representations (*e.g.*, globe, constellations)

Ontario

Ontario has made extensive use of the PCSP framework in designing its new science curriculum. Ontario emphasizes the term "expectations" rather than "outcomes" and has added specific details. The astronomical expectations for Grades 1, 6, 9, and 12 are listed below. Complete course descriptions are available at `www.edu.gov.on.ca/eng/general/elemsec/elemsec.html`

Grade 1: Daily and Seasonal Changes
- Identify the Sun as a source of heat and light
- Compare the different characteristics of the four seasons (*e.g., length of day, type of precipitation*)
- Use units of time related to the Earth's cycles (*e.g., days, months, seasons*)
- Communicate the procedures and results of explorations and investigations for specific purposes, using demonstrations, drawings, and oral and written descriptions *(e.g., write and illustrate a booklet about observations of seasonal changes; keep a journal recording and describing the weather for a given period of time*)

Grade 6: Earth and Space Systems
- Describe the physical characteristics of components of the Solar System — the Sun, planets, natural satellites, comets, asteroids, and meteoroids (*e.g., relative size, surface temperature*)
- Identify the bodies in space that emit light (stars) and those that reflect light (*e.g., moons, planets*)
- Describe, using models or simulations, the features of the Moon's surface (*e.g., craters, maria, rills*)
- Identify cycles in nature (*e.g., cycle of day and night, cycle of seasons)* and describe the changes within the cycles *(e.g., observe the phases of the Moon over several months to determine the pattern of change, and record these observations*)
- Describe, using models or simulations, how the Earth's rotation causes the cycle of day and night, and how the Earth's revolution causes the cycle of the seasons
- Recognize major constellations visible at night, and describe the origins of their names (*e.g., Orion, Leo*)
- Describe, using models or simulations, the effects of the relative motion and positions of the Earth, Moon, and Sun (*e.g., solar and lunar eclipses, tides, phases of the Moon*)
- Follow safety procedures when observing the Sun (*e.g., never look at the Sun directly or through a lens or coloured glass; look only at a projection of the Sun's image; do not use a lens or magnifier to focus the Sun's rays to a small area; exercise caution when using mirrors so that they do not reflect the Sun's image directly into someone's eyes*)

Grade 9

In order to graduate, high school students in Ontario are required to complete at least two science courses. These are normally taken in Grades 9 and 10, and courses are offered at two levels: academic and applied. Both the academic and the applied Grade 9 science courses contain an Earth and Space Science strand. In the academic course the specific topic is entitled "The Study of the Universe" and in the applied course the topic is entitled "Space Exploration." There are no specific references to astronomical topics in Grade 10.

Earth and Space Science: The Study of the Universe (Grade 9 Academic)

- Describe and compare the major components of the Universe, using appropriate scientific terminology and units (*e.g., record the location and movement of planets and satellites, and of stars, galaxies, and clusters of galaxies, using Astronomical Units and light years*)
- Describe the generally accepted theory of the origin and evolution of the Universe (*i.e., the "big bang" theory*) and the observational evidence that supports it
- Describe and compare the general properties and motions of the components of the Solar System (*e.g., the composition and the physical properties – such as size and state, rotation, size, and period of orbit – of the Sun, planets, moons, asteroids, comets*)
- Describe and explain the effects of the space environment on organisms and materials (*e.g., the effects of microgravity on organisms in a spacecraft*)
- Outline the generally accepted theory of the formation of the Solar System (*i.e., that it was formed from a contracting, spinning disk of dust and gas*)
- Describe the Sun and its effects on the Earth and its atmosphere (*e.g., explain the importance of the Sun as an energy source and the types of radiation emitted; describe the aurora borealis*)
- Outline models and theories for describing the nature of the Sun and stars and their origin, evolution, and fate
- Investigate the ways in which Canada participates in space research and international space programs (*e.g., the International Space Station, telecommunications, satellite technology*)
- Describe and explain how data provided by ground-based astronomy, satellite-based astronomy, and satellite exploration of the Sun, planets, moons, and other solar-system objects contribute to our knowledge of the Solar System
- Explore science and technology careers that are related to the exploration of space, and identify their educational requirements

Earth and Space Science: Space Exploration (Grade 9 Applied)

- Recognize and describe the major components of the Universe using appropriate scientific terminology and units *(e.g., record the location and movement of planets and satellites, stars, galaxies, and clusters of galaxies using Astronomical Units and light years*)
- Describe the generally accepted theory of the origin and evolution of the universe *(i.e., the "big bang" theory*) and the observational evidence that supports it
- Describe, compare, and contrast the general properties and motions of the components of the Solar System (*e.g., the composition and physical properties – such as size and state, rotation, size and period of orbit – of the Sun, planets, moons, asteroids, comets*)
- Describe the Sun and its effects on the Earth and its atmosphere (*e.g., the Sun as an energy source, solar activity, aurora borealis*)
- Describe and explain the effects of the space environment on organisms and materials (*e.g., the effects of microgravity and temperature on organisms during space exploration*)
- Conduct investigations on the motion of visible celestial objects, using instruments, tools, and apparatus safely, accurately, and effectively (*e.g., graph sunrise and sunset data and relate them to the motions of the Earth*)
- Gather, organize, and record data through regular observations of the night sky and/or use of appropriate software programs, and use these data to identify and study the motion of visible celestial objects (*e.g., track the position of the Moon and planets over time*)
- Relate the beliefs of various cultures concerning celestial objects to aspects of their civilization (*e.g., aboriginal beliefs, Greek mythology, Mayan civilization*)

The Ontario Ministry of Education has produced course materials to support the new Grade 9 science curriculum. In particular, there are 25 pages of notes in the Grade 9 academic course profile detailing "Unit 5: Study of the Universe." Included are descriptions and planning notes for six student activities:

1. Exploring the Universe
2. Observing the Night Sky
3. The Solar System
4. Formation and Fate of the Universe
5. Space Science
6. Culminating Task

By September 2002, Ontario students in Grades 11 and 12 may select a course in Earth and Space Science (if it is offered at their school). This course contains a strand that focuses on the Earth as a planet.

Grade 12: The Earth As a Planet

- Visualize and describe the size, shape, and motions of the Solar System, and the place of the Earth within it
- Describe the origin and evolution of the Earth and other objects in the Solar System, and identify the fundamental forces and processes involved
- Compare the Earth with other objects in the Solar System with respect to such properties as mass, size, composition, rotation, and magnetic field
- Describe and explain the following external processes and phenomena that affect the Earth: radiation and particles from the "quiet" and "active" Sun; gravity and tides of the Sun and Moon; and the impacts of asteroidal and cometary material
- Describe the properties of the near-Earth space environment
- Formulate scientific questions about the nature, origin, and evolution of the Earth and other objects in the Solar System
- Visualize and describe the size, shape, and motions of the Solar System, and compare the Earth with other planets and objects within it, on the basis of information gathered through research
- Formulate scientific questions, gather information, and assess these critically in order to identify the fundamental forces and processes that shape the interior, surface, and atmosphere of the Earth and other objects in the Solar System
- Identify surface features of the Earth and other objects in the Solar System (*e.g., craters, faults, volcanoes*), using light, infrared, and radio/radar images
- Investigate, either through laboratory activities or research, the

interaction of radiation and impacting particles with Earth materials such as air, water, and rock

- Assess the risks associated with solar ultraviolet radiation and with the collision of asteroidal and cometary material with the Earth
- Explain how the study of other planets and objects in the Solar System has led to a better understanding of the Earth (*e.g., explain how studying the greenhouse effect on Venus has increased understanding of the same effect on Earth*)
- Demonstrate an understanding of some of the historical, cultural, and aesthetic consequences of changes in the perception and understanding of the Earth's place in space (*e.g., evaluate the impact of images of the whole Earth taken from space*)
- Describe how observations and measurements of the Earth made from space are used to study and better understand natural physical elements of the Earth's environment (*e.g., its crust, water, air*) as well as human-made elements (*e.g., crops, cities, air and water pollution*)
- Describe the challenges of designing piloted and robotic spacecraft and of operating them in near-Earth space
- Investigate Canada's contributions to the study of our planet from near-Earth space (*e.g., Radarsat, International Space Station*), using information from various print and electronic sources; evaluate the negative effects of human activity on near-Earth space (*e.g., space debris, pollution of the electromagnetic spectrum*)

Western Canadian Protocol

There are no plans, at the moment, to develop a WCP common curriculum framework for science. The PCSP continues to provide the basis for science curricula in the WCP. There are still interesting variations in the detailed curricula of the WCP members.

Manitoba

The science curriculum in Manitoba is also based on the PCSP. Shown below are the general introductions to the astronomy-related topics in Grade 1 and Grade 6. The complete curriculum can be found at `www2.edu.gov.mb.ca/metks4/curricul/k-s4curr/science.`

Grade 1: Daily and Seasonal Changes
By observing their environment, students become aware of changes that can occur within it, such as changes in temperature, wind, and light, and in plant and animal life. Through observations and investigations, students learn that changes often occur in cycles, including the relatively short cycle of day and night and the longer cycle of the seasons. Recognizing these cyclical patterns prepares students to deal with daily and seasonal changes. Particular attention is given to studying ways in which humans are able to live comfortably throughout the seasons.

Grade 6: The Solar System
Students develop an understanding of the Earth in space, the Solar System, and the role of space research programs in increasing scientific knowledge. Positive and negative impacts arising from space-research programs are addressed, and the contributions of Canadians to these programs are highlighted. Students develop an appreciation for the nature of science by examining the changing conceptions of the Earth's position in space and by differentiating between astronomy and astrology. Students investigate the causes of phenomena such as the cycle of day and night, the yearly cycle of the seasons, Moon phases, eclipses, and the reasons why the apparent movements of celestial bodies in the night sky are regular and predictable. An important distinction is made between weight and mass.

Saskatchewan

In Saskatchewan, most of the astronomy in the elementary grades has been placed in Grade 3. The Grade 6 course focuses primarily on the space program and related technology. The complete curriculum is available at `www.sasked.gov.sk.ca/docs/science.html.`

Grade 3: The Solar System

- Describe and demonstrate the motions of the Earth and the Moon
  1. Define the terms revolution and rotation, with respect to the Earth and the Moon
  2. Describe how the rotation of the Earth produces day and night
  3. Recognize that the revolution of the Earth around the Sun produces the seasons
  4. Investigate why the full Moon and new Moon occur, using models
  5. Observe the full Moon and near the new Moon in the sky
  6. Show how the eclipses of the Sun and the Moon occur
- Describe the Solar System
  1. Compare the sizes of the Sun, the Moon, and the Earth
  2. Name the planets
  3. Describe some characteristics of each planet
  4. Locate the planets Venus, Mars, and Jupiter in the sky or on sky charts

Alberta

The curriculum documents available at `www.learning.gov.ab.ca/k12/curriculum/bySubject` are brief and to the point.

Grade 1 Topic B: Seasonal Changes

- Describe the regular and predictable cycle of seasonal changes:
  1. Changes in sunlight
  2. Changes in weather
- Record observable seasonal changes over a period of time

Grade 6 Topic C: Sky Science

- Recognize that the Sun and stars emit the light by which they are seen and that most other bodies in space, including Earth's Moon, planets and their moons, comets, and asteroids are seen by reflected light
- Describe the location and movement of individual stars and groups of stars (constellations) as they move through the night sky
- Recognize that the apparent movement of objects in the night sky is regular and predictable, and explain how this apparent movement is related to Earth's rotation
- Understand that the Sun should never be viewed directly nor by use of simple telescopes or filters, and that safe viewing requires appropriate methods and safety precautions
- Construct and use a device for plotting the apparent movement of the Sun over the course of a day; *e.g.*, construct and use a sundial or shadow stick
- Describe seasonal changes in the length of the day and night and

in the angle of the Sun above the horizon [at the same time each day]
- Recognize that the Moon's phases are regular and predictable, and describe the cycle of its phases
- Illustrate the phases of the Moon in drawings and by using improvised models. An improvised model might involve such things as a table lamp and a sponge ball
- Recognize that the other eight known planets which revolve around the Sun have characteristics and surface conditions that are different from Earth, and identify examples of similarities and differences in the characteristics of those planets
- Recognize that not only Earth but other planets have moons; and identify examples of similarities and differences in the characteristics of those moons
- Identify technologies and procedures by which knowledge, about planets and other objects in the night sky, has been gathered
- Understand that the Earth, the Sun, and the Moon are part of a Solar System that occupies only a tiny part of the known universe

British Columbia

British Columbia has one of the most comprehensive astronomical strands folded into its science curriculum. See `www.bced.gov.bc.ca/irp/curric` for more details.

Grades 2 – 3: Earth and Space Science (Sky above Us)
- Identify the Earth as part of a system of planets
- Describe the unique properties of the Earth that sustain life
- Demonstrate how the movements of the Earth cause day, night, and the seasons
- Distinguish between the features of the day and night skies

Grade 6: Earth and Space Science (Solar System)
- Describe the primary features of our Solar System
- Compare and contrast the conditions that support life on Earth with those on other planets and our Moon
- Relate the movement of the Sun, Moon, and Earth to seasons, tides, eclipses, and the phases of the Moon

Grade 7: Earth and Space Science (Astronomy)
- Identify characteristics of known objects outside the Solar System
- Outline the changes in human understanding of the universe from early times to the present
- Illustrate the seasonal position of various constellations

Grade 9: Earth and Space Science (The Solar System and the Universe)
- Describe the organization of the Solar System
- Describe a variety of remote-sensing techniques for assessing conditions beyond Earth
- Compare distances of objects in space
- Describe the characteristics by which stars are classified
- Compare the life cycles of stars of different sizes
- Explain, with examples, the relationship between astronomical discoveries and current understanding of the universe

British Columbia offers a complete course on astronomy as an option in Grade 11.

Grade 11: Astronomical Science Observing the Universe
- Compare the different kinds of tools and instruments used in astronomy to gather information
- Demonstrate a variety of methods for estimating the distance to stellar objects
- Distinguish between an astronomical unit and a light-year
- Compare the apparent magnitude, absolute magnitude, and luminosity of a star
- Demonstrate how spectra are used to determine the temperature, composition, and motion of a star
- Describe the Doppler effect and how it can be used to determine the speed and velocity of stellar bodies

Stars and Galaxies
- Classify stars using a Hertzsprung-Russell diagram
- Describe the life cycles of stars
- Describe the historical role of constellations in mythology and navigation
- Describe the characteristics of components of the universe, including galaxies and quasars
- Choose and critique a theory that explains the origin of the universe

The Sun and the Solar System
- Determine the diameter of the Sun
- Describe major characteristics of the Sun
- Predict the motion of orbiting bodies using Kepler's laws
- Outline the general features of each of the following components of the Solar System: inner planets, outer planets, comets, meteoroids, asteroids, planetary satellites (moons)
- Relate features of the Solar System to the protoplanet hypothesis for the origin of the Solar System and planet types, and their distribution

The Earth and Moon
- Demonstrate ways to determine the volume, density, shape, and circumference of the Earth
- Describe and explain the variation in day length over a year for several widely separated positions on the globe
- Describe evidence that shows the Earth rotates about its axis and revolves around the Sun
- Describe the motion of stars and planets caused by rotation and revolution of the Earth
- Use models to explain phases of the Moon
- Relate the motions of the Moon to low and high tides

In Grade 12, a course on geology contains a unit on comparative planetology.

Grade 12: Geology Comparative Planetology
- Propose and defend criteria that help divide the planets into two groups: the inner planets (Mercury, Venus, Earth, Mars) and the outer planets
- Relate the densities, compositions, and spacing of the planets to their formation, according to the nebular model for the origin of the Solar System
- Compare and contrast the following characteristics of Earth with the other inner planets and Earth's Moon: atmosphere, surface features, internal structures, magnetism, and cratering

- Determine the geologic history of a planet or Earth's Moon, using relative age-dating techniques

The Territories

Each of the territories belongs to the WCP and has curriculum-sharing arrangements with specific provinces or territories. Distance education is an important factor in delivering senior-science courses in the territories.

Nunavut

Nunavut is a new jurisdiction and is in the process of developing new curricula in all subjects. Nunavut currently uses the science curricula of the Northwest Territories from K to 9 and curricula from both Alberta and the Northwest Territories for Grades 10 – 12. According to Susan Ball, curriculum coordinator, the new science curriculum will be referenced to the Pan Canadian Protocol but will be built upon a foundation of knowledge and values provided by Inuit Elders. In particular, the plan for the new Grade 12 science course is to concentrate on the environment, weather, and space (including astronomy).

Northwest Territories

The Northwest Territories are in the process of implementing the Pan-Canadian Science Protocol as the basis of their new science curriculum.

Yukon Territory

The Yukon Territory makes extensive use of curriculum materials from British Columbia, including that for science courses.

Society News/Nouvelles de la société

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

National Events

On January 26, 2002, a National Council meeting was held in Toronto from 10:00 a.m. till 5:00 p.m. There were a total of 17 centres represented out of 26. We met in one of the boardrooms of the West Commercial Building, Gowlings Building — many thanks to Michael Watson for arranging the new meeting place.

Many topics were discussed at the meeting, with the largest portion of the time devoted to by-law amendments and the decoupling of fees. Each member by now should have some awareness of this topic, as there was a note included in the Annual Meeting package.

At the National Council meeting, Stewart Hill (Okanogan Centre) and Vic Smida (Kingston Centre) received their Messier Certificates, while David Crabtree (Unattached) and Brian Cheaney (Toronto Centre) received their Finest NGC Certificates. Congratulations to everyone from the RASC and its members.

The Nominations Committee proposed that the RASC Council appoint two new Honorary Members, Dr. J. P. Peebles and Dr. Carolyn Shoemaker. They were accepted and letters of congratulations were sent to both on behalf of the RASC.

At the Montreal General Assembly, two members of the RASC received awards. Dr. Roy Bishop received the Chant Medal. The Chant Medal is awarded to an amateur astronomer who is a resident in Canada on the basis of the value of original investigation in astronomy and closely allied fields. Vance Petriew of the Regina Centre was awarded the Ken Chilton Prize for his comet discovery (Comet C/2001 Q2), made on August 18, 2001 at the Saskatchewan Summer Star Party. Congratulations to both of these fine men on their achievements.

Upcoming Events

Now that summer is here, so are the summer star parties. On the next page is an updated list of Star Parties for the summer of 2002.

Canadian News

There were four new asteroids with Canadian connections announced in the Minor Planet Circular of January 28, 2002. Thanks to Peter Jedicke, 2nd Vice President, who always has an eye out for Canadian achievements in space.

(12014) Bobhawkes = 1996 VX1. *Discovered 1996 Nov. 5 by Spacewatch at Kitt Peak.*

Robert Lewis Hawkes (b. 1951) became head of the physics department at Mount Allison University in Sackville, New Brunswick, in 2000. His graduate work at the University of Western Ontario in 1979 was on the dustball theory of meteoroids.

(12343) Martinbeech = 1993 DT1. *Discovered 1993 Feb. 26 by Spacewatch at Kitt Peak.*

Martin Beech (b. 1959) is an assistant professor of astronomy at the University of Regina, Saskatchewan. He does research on meteor light curves, the dynamics of meteoroid streams, cometary aging and meteoroid-stream formation.

(12382) Niagara Falls = 1994 SO5. *Discovered 1994 Sept. 28 by Spacewatch at Kitt Peak.*

Niagara Falls is the thundering cataract on the Niagara River between Lake Erie and Lake Ontario and is famous as a honeymoon destination. Hydroelectric power has been generated there since 1916. P. Jedicke has corrected the date of power generation, as follows: "BTW, somebody typed something wrong, because power generation started in Niffles in 1906, not 1916."

(12397) Peterbrown = 1995 FV14. *Discovered 1995 Mar. 27 by Spacewatch at Kitt Peak.*

Peter Gordon Brown (b. 1970) studied at the University of Alberta and the University of Western Ontario and was appointed to the faculty of the latter. His specialties are meteoroid streams, meteor analysis and meteorite recovery.

Congratulations

Many of you know that Dave Lane has been looking for a replacement for his position as *Journal* Production Manager. Dave has done this job for many years and deserves a rest. Well, earlier this year, he told many of his friends of some "Supernova" news — that he and Michelle Gallant of Halifax would be getting married sometime in the warmer summer months. As some of Dave's friends have reiterated, "The terrible deletion of Dave Lane and another one bites the dust." Rest assured, Dave, we all know it's a good thing.

Congratulations from all of us, and we wish you both the best...now how many people will the reception hall hold, over 4500?

UPCOMING STAR PARTIES — SUMMER 2002

DATE	EVENT	PLACE	CONTACT INFO
July 12-14	North Bay Astronomy Club	Powassan, Ontario	Contact Merlin at 1-705-472-1182 Tom Ouellette at 1-705-474-7666 Galaxy@efni.com
Aug 3-11	Mt. Kobau Star Party	Kelowna, BC	www.mksp.ca
Aug 9-11	Saskatoon Summer Star Party	Saskatoon, Saskatchewan	Contact Steve Szuta at Sszuta@sk.sympatico.ca or visit prana.usask.ca/~rasc/
Aug 8-10	Astro Atlantik 2001	Armstrong Brook Campground, Mount Carleton Provincial Park, New Brunswick	www.osco.nb.ca/nbanb
Aug 8-11	Starfest	Mt. Forest, Ontario	www.nyaa-starfest.com
Aug 9-10	Stellafane Star Party	Springfield, Vermont	www.stellafane.com
Aug 9-11	Nova East 2002	Smiley's Provincal Park, Nova Scotia	halifax.rasc.ca/ne/
Aug 12-18	Great Manitou Star Party	Gordon's Park & Carter Bay Resort, Manitoulin Island, Ontario	www.manitoulin-link.com/starparty

If you know of an event that is not on the list, please send me a note at kimhay@kingston.net, so it can be included in the next issue of Upcoming Events, and on next year's list.

The Galaxies of Serpens Caput

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

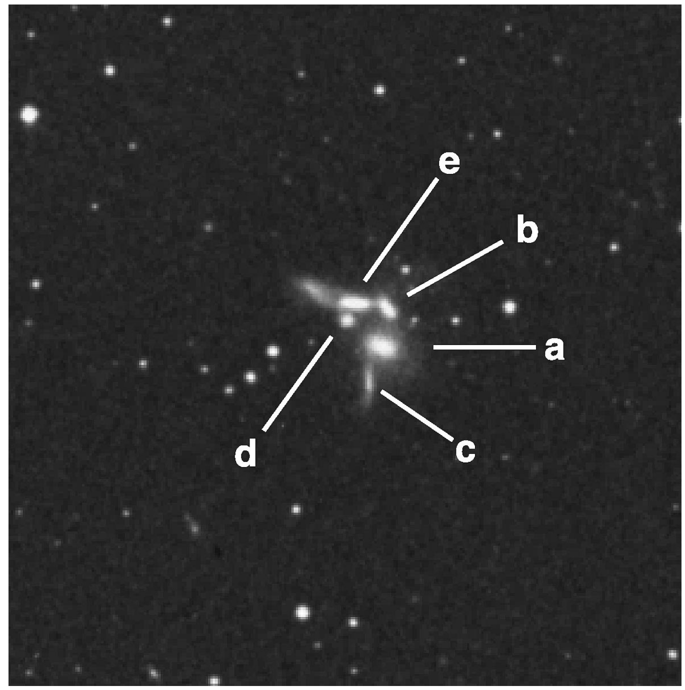
Except for the relative minority of amateur astronomers who conduct systematic scientific research with their telescopes, most of us are very much tourists in our approach to the universe. We set up our instruments when our busy schedules permit and are very much at the mercies of the fickle nature of the weather in these parts. Our time at the telescope is precious and we try not to waste too much of it in fruitless pursuit of unattainable objects. So we often stick to the tried and true, best exemplified by the entries on the Messier list.

One of the reasons why I started writing this column seven years ago was my intention was to draw attention to interesting sights in the universe that would otherwise not be well-known. In travel guides for tourists here on Earth, breathtaking scenery is often referred to as a scenic vista, hence the name of this series of articles.

I especially like to feature constellations that are sometimes overlooked as well. One of them is the subject of this month's column, Serpens Caput.

This moderately bright zigzag of stars, wedged between Virgo in the west and Ophiuchus to the east, is the home of the brilliant globular cluster M5; there are a number of rather bright galaxies in the vicinity as well. Unfortunately, after a spring spent viewing the galaxies of Leo, Virgo, and Ursa Major, some amateurs have had their fill of this class of object, which may explain why this region is sometimes neglected.

Located on a line joining beta and delta Serpentis, NGC 5970 is one of the brightest galaxies this region has to offer. Located about eight arcminutes southwest of a magnitude +8 field star, this spiral galaxy is oriented due east/west and features a very bright and small core embedded in a bright bar oriented along the major axis. In my 15-inch reflector, this bar appears quite mottled, and one's attention is drawn to a brighter condensation immediately east of the core. The outer envelope appears poorly defined, evidence of the outer spiral structure of the galaxy.



An ~8-arcminute Digitized Sky Survey[1] field of Seyfert's Sextet, a faint group of galaxies in Serpens Caput.

At magnitude +12.5, NGC 5984 is one full magnitude fainter than the preceding galaxy. An edge-on system oriented southeast/northwest, the galaxy is moderately well defined and very slightly brighter to the middle, though no bright core is visible.

Three degrees north-northeast of the brilliant globular M5, the observer comes to NGC 5921. Deceptively listed at magnitude +11.4, this delicate barred-spiral galaxy is a tough catch in a small telescope; only the round brilliant core will be easily visible in a field of faint stars. My 15-inch telescope brings out the faint, oval outer envelope oriented north/south.

Located just south of a line connecting an optical triple in the west and a bright, equal pair of stars in the east, NGC 5936 is a bright, well-defined circular glow with a thin, fainter outer envelope. Although no core is visible, the central region of this galaxy is quite granular in texture.

Easily visible even at 48×, NGC 5962 is a bright galaxy, elongated west-northwest/east-southeast. The outer edges of this broadly-concentrated galaxy fade slowly into the sky background and the central region is bright and fairly well-

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

defined, brightening quickly to the core.

The preceding five galaxies are plotted on the first edition of *SkyAtlas 2000.0*, but you will need the brand-new edition of this great atlas to locate the sixth galaxy in this article.

Located immediately southwest from kappa Serpentis, NGC 5996 is about magnitude +12.8 and may pose a challenge for 8-inch and smaller telescopes. In my 15-inch reflector, this was a round, moderately-bright galaxy, gradually brighter to the middle. No core was visible and the edges were diffuse. Unfortunately, none of the delicate structure evidenced in photos or CCD images is visible at the eyepiece, though if you have access to a telescope larger than 15 inches, you might want to see if you can make out some of this intriguing little galaxy's barred-spiral structure.

Because of the large number of bright stars in the region, star hopping to any of these galaxies is a relatively straightforward affair and a pleasant way to seek out interesting fare on warm June evenings.

A few of the fainter galaxies are not necessarily out of reach of 8-inch class telescopes and can be hunted down often with success. I urge everyone to at least attempt to track down Seyfert's Sextet, an odd specimen in the extragalactic zoo.

The brightest of the fainter galaxies in Serpens Caput is NGC 6012, a prominent, though ill-defined galaxy oriented north-northwest/south-southeast. Oval in shape, the edges fade uncertainly into the sky background. The central region is only a little brighter to the middle and slightly elongated along the galaxy's major axis. There is a nice image of this galaxy in the *Deep Space CCD Atlas: North*, which shows the galaxy as a classic "theta-shaped" barred spiral with a faint outer ring. Also of note is a bright, unequal pair of stars just beyond the outer envelope of the galaxy, located just slightly north of east.

A little fainter is NGC 6004, though 8-inch apertures should show it easily. It is quite round in appearance and brighter to the middle with surprisingly well-defined extremities.

At magnitude 13.0, NGC 6008 is a somewhat more difficult object to track down. Even in my 15-inch reflector I found it rather faint and diffuse, best seen at a magnification of 146×. The core appeared quite condensed, but only a little brighter than the extremities and only the central region of this barred spiral galaxy was visible.

A faint pair, likely beyond the grasp of telescopes smaller than about 12-inch aperture, is NGC 6018 and NGC 6021. They can both be seen in a high-power field of my 15-inch reflector, oriented along a north/south line. NGC 6021 is the brighter of the two and appears a little more concentrated to the center. The galaxies are superimposed over the field of the much fainter galaxy cluster Abell 2147.

The last group of objects under consideration this month is by far the most exotic. Seyfert's Sextet is that class of object known as a compact galaxy group, and like many of the objects of its class, there is some question about whether all members are related. The photo on the previous page shows five distinct objects (labeled *a* through *e*) and a sixth fainter plume of material seemingly connected to galaxy *e*. Deep photographs show luminous material connecting the individual galaxies, and indeed five of the six objects have similar redshifts, in the range of 4000 to 4500 km s^{-1} in recession. The sixth object, labeled *d* in the photo, has a redshift in excess of 19,000 km s^{-1}. A chance alignment, or perhaps a galaxy that is being ejected from the group as a whole? More study will be needed to ascertain the nature of this group.

On a typical night at Sutton, Quebec, my 15-inch reflector was easily able to find a blur of light indicating the group's location at 146×. Higher magnification made the blur a little fainter but aided resolution. The galaxy labeled *e* was easiest to see, visible as a brighter bar of light that may have also included the galaxy labeled *b*. I was also able to pick up the galaxy labeled *a* as a very faint patch of light intermittently visible southwest from the bar. The other members of the group, including the high-redshift galaxy, were beyond the grasp of my reflector on this occasion.

It is always interesting to go off the beaten track from time to time when out observing. On nights when you are alone and can concentrate on the task at hand, a relatively unknown constellation like Serpens Caput is a fascinating region to explore.

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

George Moores' Astronomy Workshop 2002 St. John's School of Alberta[1]

by Sherrilyn Jahrig, Edmonton Centre (sj_starskip@hotmail.com)

The weekend of April 5–7, 2002 dawned with a wintry-white sky and an Edmonton forecast unfriendly to astronomers — cloud. Despite the weather news, I still felt a thrill of anticipation, as I had attended the October 1998 workshop at the same location in the North Saskatchewan River valley and had a fabulous time. The feature presentations, round-robin workshops, round-the-clock food, and the prospect of being surrounded by like-minded people gave me a sunny outlook. The registration fee for this all-inclusive holiday was so low that it would have cost our family more to stay home.

The two featured speakers were Discovery Channel's "star of the stars" Ivan Semeniuk; and comet discovery man Vance Petriew.

"Worlds of Wonder — What Scientists Wish They Knew About The Planets" was Ivan's keynote presentation. About one hundred of us sat in the warm main hall after a crack in the overcast allowed a little solar observing early Saturday afternoon. "Worlds of Wonder" took us from one energy-extreme to another, from the cold, utter darkness of space, to the hot, inner brilliance of stars and left us tucked into the tenuous horizon of our own planet. Ivan planet-hopped through his discussion, keeping our minds alive with questions — what does the other half of Mercury look like; what forces produced such dissimilar results on our sister planet Venus; Mars — is there water, chlorophyll; what is the current thought on Jupiter's early formation; can we use Saturn and its rings for a miniature model for Solar System formation? These were all accessible queries, ending with a clear conclusion that Earth is the oddball planet. This led into the contemplation of life and physical characteristics within other star systems. A very cool 3-D motion simulation of the Orion Nebula, left us floating between protoplanetary disks and zooming in and out of the Trapezium — something none of us seem to accomplish in our regular observing sessions!

Figure 1. Ivan Semeniuk sends Scott Henderson into rotation.

"The Hula-Hoop Heavens", which I at first imagined would be about a Hawaiian Sun-god (I had just returned from visiting my sister on the island of Kauai), turned out to be a clear demonstration of the "unplugged" way to visualize the orbital paths of the planets. The most difficult one to "fit in" for me has always been the Earth itself, standing on this "flat" piece of stage trying to twist my brain around in space-time. While programs such as *Starry Night Pro* can do this with panache, I have often found myself at the observatory holding an imaginary cube of space and drawing ellipses in the air, talking my victim senseless. Ivan's use of a cardinally marked hula-hoop as the earthly observer's field of view, and his passage through time using "live" Sun, Venus, and Mars role-players, would require a little practice for most teachers, but would result in excellent mind's-eye comprehension of conjunctions, oppositions, risings, and settings. I'm sure the many public school teachers in attendance will try this later in their classrooms.

On a roll with his hoops, Ivan decided to give an encore. This was his ten-minute clip; a spontaneously and skillfully created rebuttal to Fox TV's program "Conspiracy Theory: Did We Land on the Moon?" Ivan's pointed argument is nominated for an award at the Worldfest Film Festival (Houston). This is a surprise to him as it was produced in a miraculously short timeframe. I was personally relieved to hear him refute the "evidence." I had recently been caught off-guard at a dinner party when challenged with this topic and was somewhat alarmed by the large shadows of doubt cast in the minds of intelligent guests.

Curiosity ignited, people attending the round-robin workshops were able to examine meteorites (with Murray Paulson), analyze sounds of the night (Warren Finley), de-mystify telescopes (the legendary Larry Wood), learn about radio astronomy (Dave Cleary), variable stars and solar observation (Pat Abbott), and teaching

[1] The George Moores' Astronomy Workshop is held every 12-18 months at a dark-sky location close to Edmonton. An ongoing special invitation is extended to schoolteachers and observers from any province. Updated information is made available on our Web site: `www.edmontonrasc.com`. Contact us if you would like to attend.

Figure 2. Ivan Semeniuk poses with Workshop organizers: (left to right) Rob Hughes, Ivan Semeniuk, Harris Christian, Donna-Lee May, Stephanie May, Paul Campbell, Sherry MacLeod, and Amy Huziak.

astronomy with innovative demonstrations (Orla Aaquist), while beginners had a "Getting Started in Astronomy" workshop with Arnold Rivera. Arnold also had his son's award-winning 8-inch Newtonian on display, along with the RASC's completed 6-inch Kidscope. This was one of five made for public education by member Dave Robinson and his crew. Edmonton Centre is always proud to have a broad base of talent and skill to draw on from their large membership. Many non-presenting members such as 14-year old Stephanie May, who set up and decorated, and Graham Christenson, who brought his meteorite collection, enhanced the busy event. Stand-by weather sensitive presentations — a binocular walk and a Southern Sky presentation — kept Bruce McCurdy and Dave Robinson waiting in the wings. The round-robin format worked very well because of the number of presenters and varied interests of attendees. My one complaint, however, was that I didn't see one real robin around the whole weekend.

After another round of all-you-can-eat-without-others-noticing, people settled in for another great experience, the story of Comet P/2001 Q2 (Petriew). Vance Petriew unpeeled his baby daughter Emily from his arm for just long enough to do his presentation, then throw up his hands and shrug, "...no one else had discovered the comet," to which Paul Campbell quipped, "...that's because we all found M1!" This produced a lot of good-natured laughter. Many of the people in the audience, besides Rick Huziak of Saskatoon Centre and Paul Campbell of Edmonton Centre (the main men confirming the discovery), had felt that the comet had just eluded their own signature. My husband, Bob Jahrig, and I had the club 18-inch scope at Cypress Hills for two clear nights before Vance's great discovery and we unfortunately failed to make our usual Crab Nebula star-hopping errors. Vance's "mis-hop" may have been lucky, but he followed his curiosity with chart checking, confirmation, and collaboration with experienced members. This reminds all levels of astronomers to keep references and reporting source information at hand, wherever you are observing.

Saturday night there was little difference between the snowy fields underfoot and the snowed-in star-fields overhead. We chatted and listened until very wee hours to starry songs by songwriters Orla Aaquist and Bob Jahrig, backed up by Rob Hughes on percussion.

On Sunday night, after a cruelly-clear afternoon, I returned to my regular observatory shift at the Edmonton Centre. I noticed the circles in my sky seemed attached by a more secure fabric, and the worlds of wonder were...well, more wonderful! I thought of the numerous parallels we observe between the details of our own birth, lives, and death; and those we try to observe in the stars, at such great distances. The apparent smallness of the stars against the unknown reaches, feels similar at times to our small daily roles. I felt truly fortunate to have spent this time within the orbits of other curious individuals, people who like to observe and define life with more clarity.

The George Moores' Astronomy Workshop was named for a respected former President of the Edmonton Centre. George Moores and Russ Sampson formed the idea to hold an annual astronomy workshop, launching the first in 1989, one of several to take place at the Maskepatoon Scout Camp. In fact the kitchen crew, which was comprised of children with assorted talents, was affectionately referred to by George as "The Chocolate Bunnies From Hell." During his presidency, George underwent a heart transplant. As an active RASC volunteer, he earned a fond and lasting admiration from the membership, both for his workshop cooking skills, (especially his chocolate chip cookies) and contributions to public education.

Sherrilyn Jahrig is Public Education Director for the Edmonton Centre and enjoys tying knots between music, poetry, food...and astronomy. She has found that almost anything ties in with astronomy. Her new telescope, built in Langley, B.C. by her father Richard Alcock, has a spring-form cake-pan cover and kitchen-knife spider-vanes.

Orbital Oddities

Lost in Transit

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

Are you out there?
Can you hear me?
Can you see me in the dark?

I don't believe it's all for nothing
It's not just written in the sand
Sometimes I thought you felt too much
And you crossed into the shadowland

Fallen Angel
Casts a shadow up against the sun
If my eyes could see
The spirit of the chosen one
— Robbie Robertson (*Fallen Angel*)

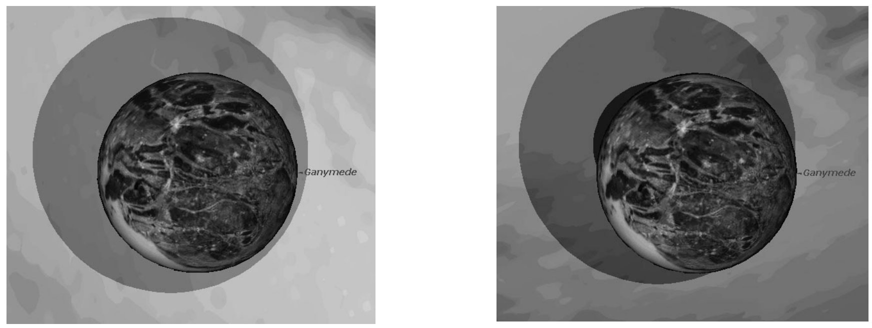


Figure 1 — These simulations depict the view of Ganymede as seen from Earth at the beginning and end of the transit. In the first figure, there is no umbral shadow whatsoever; in the second, a sliver of it is theoretically visible. In the eyepiece the penumbra does not appear as regular or well defined as shown here. (All graphics courtesy of Roger Fell, using *Starry Night Pro*.)

I will never forget my first observing session of the third millennium. It was January 7, 2001 and I had finally convinced my good friend Darcy to join me for my Sunday shift at the observatory. We'd been firm friends for 20 years, our interests not so much overlapping as interlacing. Darcy was instrumental in my astronomical awakening in the mid-1980s, but while he always enjoyed my anecdotes about observing, he was much more interested in the theoretical side. We shared many a late-night conversation about astronomy, physics, cosmology, mathematics, and across the gray divide from hard science to philosophy, art, music, and speculative fiction. If nothing else, our occasional two-person brainstorms were absolutely breathtaking in their scope.

What I managed to accomplish all too rarely was to get Darcy to look in *my* scope. Exceptional events like the three great comets of the '90s (Shoemaker-Levy, Hyakutake, and Hale-Bopp) managed to draw him to the eyepiece; otherwise, Darcy satisfied himself with being a keen naked-eye observer. But recently we had had a long chat about my fascination with mutual events on Jupiter, particularly with shadow transits in which visual proof of the shadow's intangible existence can be provided only by the canvas of Jupiter itself in a chiaroscuro of figure and ground. My enthusiasm won the day, and Darcy had agreed to come see a superb double-shadow transit of Io and Ganymede.

Except Darcy wasn't there.

The day before, I got the terrible news that Darcy had died, suddenly and tragically, at the age of 47. After a sleepless night, the Sunday was the worst day of all. In the afternoon I took on one of the year's most cheerless tasks, undecorating the Christmas tree. The last time I had seen Darcy was at our annual tree-trimming party a couple of weeks earlier, and here I was removing ornaments that I remembered seeing him put on those same branches. As I undertook the final act of dragging the forlornly naked tree out of the house and tossing it over the back fence for delivery to the city composter, I was overwhelmed by the symbolism embedded within this thankless chore which scraped like dead pine needles across every exposed nerve ending.

That same night I headed off to the observatory, alone. My co-workers Sherrilyn Jahrig and Terry Samuel soon joined me, and we settled into our usual routine. The conditions were perfect for a spectacular view of the double-shadow transit. The first act started right on schedule five minutes after we opened, with Ganymede's shadow reaching the Jovian disc, already high in the southeast. A half-hour later, Io's joined it, and for a time the two shadows co-existed on the canvas of Jupiter like a pair of comfortable old friends.

Despite the two moons' differences in size, the umbral shadows of Io and

Ganymede are not dissimilar, although Ganymede's is perhaps a little fuzzier due to its much larger penumbra. Io's shadow is much the faster, a direct reflection of the higher orbital velocity of Io itself (17.3 km s^{-1} vs. 10.9 km s^{-1} for Ganymede). However, try as it might, on this occasion Io's shadow couldn't catch up to its companion, which was situated at a higher latitude and therefore had a shorter chord of the Jovian disc to inscribe. All too soon, Ganymede's shadow was departing the screen of Jupiter and inexorably merging with the darkness of space. From figure and ground, to ground and ground; ashes to ashes, dust to dust. For the second time in a few hours, I was overwhelmed by profound symbolism, this time embedded within a routinely-exquisite astronomical event.

At that point I became acutely aware of the dwindling life expectancy of the lone remaining shadow in transit, not to mention my own mortality whose departure point cannot be predicted with such certainty. But unlike the unhappy Christmas tree episode, this experience was cathartic, even empowering. I found myself at my finest form, explaining the event to the visiting public in very clear terms. The comments and questions I got as feedback convinced me they were interested, engaged, getting it. I always *try* to be like that, you understand, but some nights it works and some nights it doesn't. This one was magic; I felt revitalized. The reassurance of the Universe unfolding as it must struck a chord of a different type, one that continues to resonate over a year later as I finally touch fingers to keyboard in an attempt to describe it.

Fast forward, if not fast enough, through the painful year that was 2001. My first observing session of the new year, 2002, was also unforgettable, featuring many of the same cast of characters. A shadow transit of Ganymede took place in the wee hours of New Year's morning.

Except this time, the shadow itself wasn't there.

The New Year is a time of revelry for some, reflection for others. Fortunately I have an 8-inch f/8 Newtonian to assist me with the latter. So when we returned from a New Year's party at three in the morning, the sensible ones in my family went to bed while I put the scope out on the deck and put on the layers. The obligatory glass of midnight champagne was all that dulled my senses, more than offset by an invigorating temperature of −22° C with a "freshening" breeze. For the next three hours, with frequent visits to the warm-up shack, I made a most remarkable observation: a sufficiently perfect line-up of four bodies that simultaneous transits could be observed in both directions!

As I had explained to Darcy, there are four types of mutual phenomena of the Galilean satellites: transits, shadow transits, occultations, and eclipses. These can be divided into two types. Once per orbit, a satellite takes a cold bath in Jupiter's shadow in an eclipse, then half an orbit later casts its own small shadow onto the tapestry of Jupiter in a shadow transit. These shadow effects are real and can be seen from anywhere in the solar system on the sunward side of Jupiter. As Earth oscillates in its own orbit, they can be seen from a variety of viewing angles, shadow preceding satellite prior to opposition, trailing thereafter. Occultations and transits, on the other hand, are line-of-sight effects that are dependent on the position of Earth. They are notoriously difficult to see against the limb of Jupiter, so I prefer the shadow events by far.

When Jupiter is at opposition, the angles involved are coincident, with some interesting consequences. After several previous failed attempts, I had observed the transit of Io about 10 hours after the opposition of November 28, 2000, when the small bright moon could be seen superposed on a sliver of its own shadow. Indeed, it was this observation that had triggered my conversation with Darcy.

In the early hours of the new year there was an even better opportunity to see the largest and most visible satellite in transit, within four hours of opposition. I took my bearings with Jupiter towering in the southwest, 40° directly above scintillating Sirius which itself reached culmination that very day. In my mind's eye I could picture Canopus a further 40° almost straight down, permanently trapped below my horizon. The Ganymede transit began at 3:16 MST, the shadow transit only one minute later. Tube currents spoiled my view of ingress, but soon enough I spotted Ganymede as an indistinct grey spot against the south temperate zone. I anticipated a sliver of umbral shadow accenting Ganymede itself, but could discern none whatever. Due to subtle lighting angles caused by Jupiter's wandering from the ecliptic, typically a shadow appears at a different apparent latitude on Jupiter than the moon itself, but Ganymede displayed no dark edge above or below. Why not?

I surveyed the big picture with the naked eye again. Situated near several well-known stars in southern Gemini, Jupiter was, I concluded, sitting directly *on* the ecliptic. Taking a warm-up break, I found my brand-new *Observer's Handbook 2002* had a convenient new column in "The Sky Month by Month" section, which showed the coordinates of the Sun for comparison purposes (Gupta 2001). On Jan 1.0, Jupiter and the Sun were 12 hours of right ascension removed at $6^h\ 46^m$ and $18^h\ 45^m$ respectively, exactly what one would expect at opposition. But the declination figures raised my eyebrows: −23° 02´ for the Sun, +23° 01´ for Jupiter. The planet was virtually on the anti-solar point!

Back at the eyepiece, in moments of perfect seeing I thought I could spot slightly more shading on the trailing edge of Ganymede, but as the big moon appeared gray and its penumbra gray, this asymmetry was extremely subtle to say the least. In my 8-inch, it was nowhere near as obvious as Figure 1 suggests. The leading edge of Ganymede was more distinct and round while the trailing edge was slightly blurry and ovallish. I saw nothing I would call black.

Flipping through my recently obsolete *Observer's Handbook 2001*, I found that Jupiter had passed the ascending node on December 30, a scant two days prior (Gupta 2000). That this would occur so close to opposition is a rare thing. Jupiter's orbit is tilted about 1.3° with respect to the ecliptic, which it crosses twice every 11.86-year orbit at well-determined points called nodes. As a general rule, Jupiter hangs a degree or so off the ecliptic and zooms across it relatively rapidly, the middle of the pendulum swing of a standard sine curve.

Completely independent of this is the relationship between Earth and Jupiter. The synodic period of any planet, which is the average period between oppositions, can be determined by the equation $p/(p{-}1)$, where p is its orbital period in years (ignore the minus sign for inferior planets). In Jupiter's case, that's 11.86/10.86 = 1.092 years = 399 days. Jupiter can therefore cross a node any time within ± 200 days of opposition; for it to do so within two days of opposition is to beat 100:1 odds. Such a perfect alignment should occur about twice per millennium.

It follows that a hypothetical observer on Jupiter could see Earth transit the Sun at such times. Indeed, the line-up doesn't have to be that perfect; Earth simply needs to be within a band about six arcminutes wide, the apparent diameter of the Sun as seen from Jupiter. According to Meeus (1989):

> The longitude of the ascending node of Jupiter on the ecliptic is 100°, that of the descending node is 280° (values for epoch 2000). The Earth reaches those heliocentric longitudes on January 1 and July 2, respectively. When an opposition of Jupiter with the Sun occurs near one of those dates, a transit of the Earth across the solar disk is seen from Jupiter.
>
> One sidereal period of Jupiter has a duration of 11.86 years, or approximately 12 years, and seven revolution periods of Jupiter are almost exactly equal to 83 years. As a consequence, the transits of the Earth generally repeat after 12 years (1972, 1984, 1996, 2008); after a time interval of 83 years the phenomena repeat under almost identical circumstances (1806, 1889, 1972...).

The table below indicates that transits of Earth can be seen from Jupiter up to at least 114 days from a nodal crossing.

There follows a 29-year gap until the next series at the descending node begins June 24, 2055, 83 years to the day after the beginning of the current series.

The table is designed to show the transits as two separate series, one at each node, and each at intervals of 12 years + ~5 days = 11 synodic years. The nodes are at opposite sides of Jupiter's orbit, and for transits to occur, Earth must be on the opposite side of its orbit as well. Thus one series occurs in December-January, the other in June-July. What appears at first glance to be a six-year periodicity between the two sets is actually 5.5, 6.5, 5.5... years, or 5, 6, 5... synodic cycles. They are therefore offset to one another slightly, as can be seen by the "missing" event in 2020. Meeus (*op. cit.*) states:

> "The 12-year series generally contain four transits. Exceptionally, the series of 1977-2026 contains five: that of 1977 December 23 was of short duration; that of 2002 January 1 will be almost exactly central, and that of 2026 January 10 will be a grazing one. The transit of 1977 was the first of a twelve-year series *and* the last of an 83-year series. On the other hand, the transit of 2026 will be the last one of a twelve-year series and the first of an 83-year series."

It follows that there are eight, or very exceptionally, nine transits of Earth per 83 years — let's say 10 a century.

How central was the 2002 transit? A computer simulation revealed that at the time of observation, the ecliptic was still within Jupiter's disc, dissecting the south equatorial zone only *one arcsecond* from Ganymede itself. So Ganymede's shadow was cast directly back in the vertical dimension. Our hypothetical freezing Ganymite would be experiencing

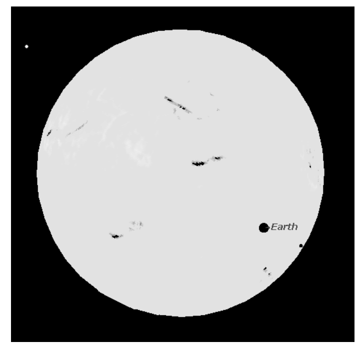


Figure 2 — The view of Earth as seen from Ganymede at the beginning of the satellite transit (10:16 UT — in the spirit of simultaneity, discrepancies in light time have been ignored). At this point the Earth transit is about four hours past the central point. The Moon is also visible as the smaller spot right on the solar limb.

The Big One, a nearly perfect central transit of Earth! (See Figure 2.)

The horizontal alignment was not quite so perfect. The Ganymede transit began about four hours after opposition, and ended three hours later. Since Ole Rømer first measured the speed of light, also using mutual phenomena on Jupiter,

Transit date	Descending node	Difference	Transit date	Ascending node	Difference
Jun 24, 1972	Sep 14, 1972	−82 days	Dec 23, 1977	Apr 10, 1978	−108 days
Jun 29, 1984	Jul 27, 1984	−28 days	Dec 27, 1989	Feb 19, 1990	−54 days
Jul 4, 1996	Jun 6, 1996	+28 days	Jan 1, 2002	Dec 30, 2001	+2 days
Jul 9, 2008	Apr 17, 2008	+83 days	Jan 5, 2014	Nov 9, 2013	+57 days
(Jul 14, 2020) (no transit)	Feb 26, 2020	+139 days	Jan 10, 2026	Sep 18, 2025	+114 days

astronomers have used time intervals to measure spatial relationships, and the same principle can be applied here. The shadow transit was predicted to begin one minute after the satellite transit, and end two minutes later. Using information readily available in the *Observer's Handbook*, and some very basic arithmetic, I made the following steps of logic:

- Ganymede is 1.7″ and its umbral shadow 1.1″ at mean opposition
- Therefore the umbra can only be ± 0.3″ from true centre
- Transit of January 1 lasted 182 minutes
- Jupiter's diameter at that latitude was ~ 40″
- Ganymede's apparent speed is therefore ~ 40/182 = 0.22″/min
- Shadow can only be ~ 0.3/0.22 = ~1.3 minutes before or after Ganymede for umbra to be fully hidden
- Near opposition, the time lag between Ganymede and its shadow changes by ~ 44 minutes per (172-hour) orbit, or roughly one minute of lag time per four hours real time
- The window of opportunity for a sufficiently direct line-up is therefore only around ((1.3 + 1.3) × 4 = ~10-11 hours)
- If you accept that the transit of Earth can begin or end *during* the transit of Ganymede, as indeed happened in this instance, that adds another 3 hours to either end of the event, giving a window of 16-17 hours, still only a 1-in-10 chance
- A 1-in-10 chance, 10 times a century, equates to a once-in-a-century occurrence
- The assumption that the observer is restricted to a specific location, as discussed in a previous column (McCurdy 2001), reduces the possibility of observing such an event by a further factor of 10 or so. I was exceptionally fortunate to view this rare alignment.

I further concluded that a central transit of Earth as seen from Ganymede would last 10-13 hours. What appears as a larger uncertainty is actually a range of durations, due to the orbital motion of the satellite itself. I'll spare you the details, but I calculated ± 8%, in this particular instance shorter to the max as Ganymede and Earth were moving in opposite directions relative to the Sun.

Only after completing these calculations did I find a reference that states a central transit of Earth as seen from Jupiter would last 11.5 hours. It's amazing what one can do with an *Observer's Handbook* and a pencil.

Of course, one could reasonably expect each of the moons to occasionally line up in such a manner, more frequently in the case of the inner satellites. I estimate simultaneous transits of Earth and Io ought to happen roughly three times a century, Europa twice, and Callisto once every several centuries. Fellow Edmonton Centre member Roger Fell conducted simulations for all inferior conjunctions of Earth as seen from Jupiter and found a total of five events in the 21st century. Besides "my" Ganymede event, a rare Callisto event will occur on January 10, 2026, and will be observable from North America. Two events involving Io and one with Europa will occur in the next series, late in this century. For more on these events, visit the following URL, courtesy of Roger: `www.telusplanet.net/public/rfell/bruce.htm`

As the Ganymede transit neared its conclusion at 6:20 a.m. New Year's morning, the satellite brightened, but unfortunately the trailing asymmetric shadow faded into the darkening limb behind it. I had no hope of seeing the hypothetical 0.1″ sliver of umbra that had emerged over the course of the transit (see Figure 1b). On this night of remembrance and regret, the shadow that I associated with my departed friend Darcy remained out of my sight.

But what *had* I seen? A rare fifth type of mutual event that I call a "shadow occultation," and indirect proof of the transit of Earth! Imagine the shadow cone of the umbra, defined by the limbs of the Sun and Ganymede; Earth would be situated inside the extended light cone. Ergo, no umbra visible to Earthlings, and from Ganymede, a small black spot "casts a shadow up against the Sun."

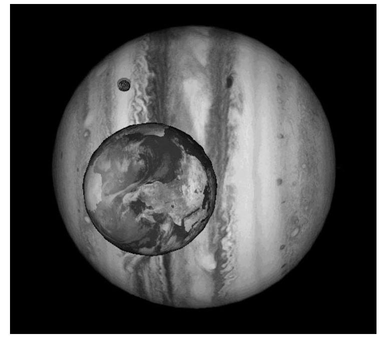


Figure 3 — The view from the Sun at 10:52 UT, the end of the Earth transit as seen from Ganymede. At only one-fifth the distance of Jupiter, Earth appears disproportionately large. Ganymede is the small spot visible above Earth, completing a very rare alignment of four bodies (including the Sun).

Dedication

This article is dedicated to the memory of Darcy Gillies, who always wanted to appear in a scientific journal.

Acknowledgement

The assistance of Roger Fell and Alan Schietzsch is gratefully acknowledged.

References

Fell, R., "Ganymede transit, Jan. 1, 2002, 3:16-6:20 am MST," www.telusplanet.net/public/rfell/bruce.htm

Gupta, R. ed. 2000, Observer's Handbook 2001, 81

Gupta, R. ed. 2001, Observer's Handbook 2002, 68, 186

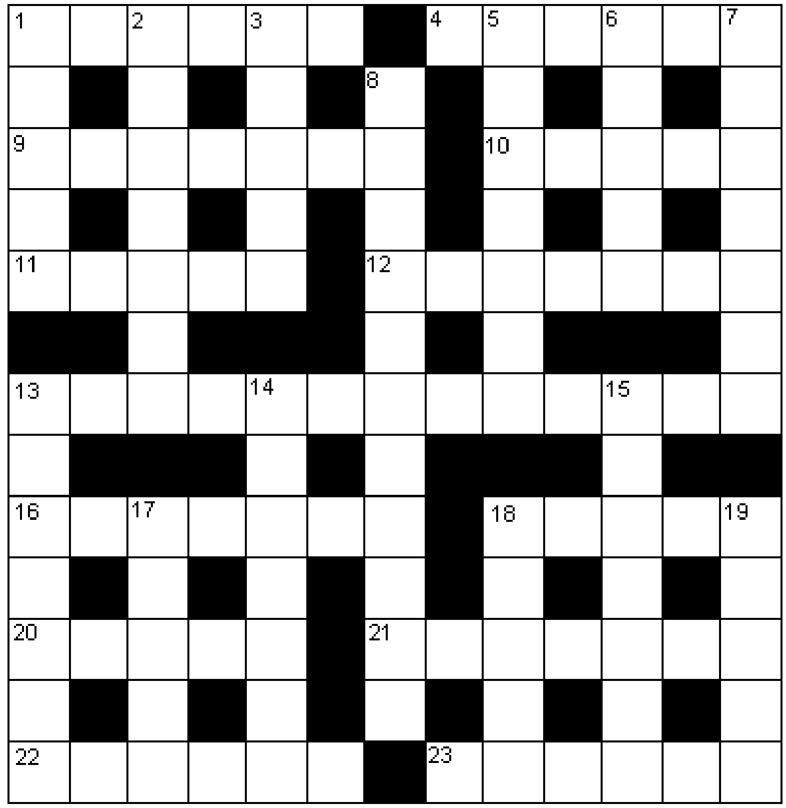
McCurdy, B. 2001, JRASC, 95, 280

Meeus, J. 1989, Transits, (Willmann-Bell, Inc.: Richmond), 34

Bruce McCurdy is an astronomy teacher, writer, and avid observer with an appreciation for unusual solar system dynamics. Recently appointed as the Education Development Coordinator of the SkyScan Awareness Project, a radio astronomy initiative for Alberta schools, Bruce currently represents the Edmonton Centre on the RASC National Council.

Astrocryptic

by Curt Nason, Moncton Centre



ACROSS

1. Maraca gets tossed in the River (6)
4. Variables have one of each ten days (6)
9. Just missed an occultation by an astrophysical heartbeat (7)
10. Around nine, Regulus starts to place the terrestrial planets (5)
11. Handy measurements of 25 degrees (5)
12. A constant factor in photon energy (7)
13. Medium starts a play before six with extremely tiny nuclear instability (13)
16. Precision focuser type puts it after gravity in the dial (7)
18. Add to the soundtrack a little helium pointer (5)
20. Geometric section fits in Draco nicely (5)
21. Our Muse singularly in her element (7)
22. Scutum is held in disarray (6)
23. Marble representation of a hydrogen spectral series (6)

DOWN

1. Belated credit for Neptune's discovery made him mad as could be (5)
2. Ralph goes nuts in Airy disc of Hydra's luminary (7)
3. Pleiades progenitor located back in Aquila's Altair (5)
5. Low point that is back around belongs to the sky river (7)
6. Charged ten nickels to start cosmology (5)
7. It's reserved for stargazers through an international organization (4,3)
8. IR pump cell I developed from an early telescope name (11)
13. Seducer somehow removes oxygen (7)
14. Turn Capitol dome to expose equipment for observing (7)
15. Basin nominally collects lunar rainwater (7)
17. Smart people get involved in Oxygen III filters (5)
18. An aid returns to possibly slay Orion (5)
19. Perkin's partner is a hole on the Moon (5)

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