Share a Galileo Moment

February / février 2009 Volume/volume 103 Number/numéro 1 [734]

Journal

The Journal of the Royal Astronomical Society of Canada

Le Journal de la Société royale d'astronomie du Canada

INSIDE THIS ISSUE

Asteroid 298 Baptistina • Pulsating Red Supergiant Stars
Shakespeare and Elizabethan Telescopy • Calculating Meteoroid Orbits: Part II
Construction of a 16th-Century Telescope • RASC Member Larry Wood

Celebrating the International Year of Astronomy (IYA2009)

February / février 2009

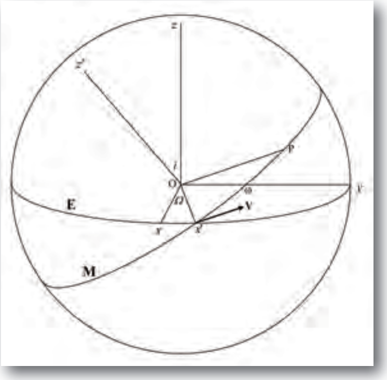
Journal

Vol. 103, No. 1 Whole Number 734

contents

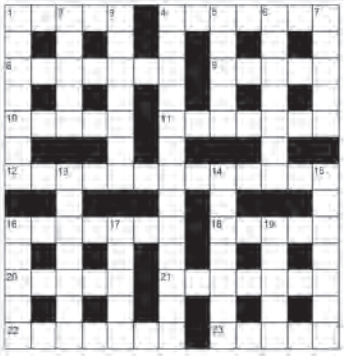
table des matières

FEATURE ARTICLES / ARTICLES DE FOND



Calculating Meteoroid Orbits: Part II
p. 25

Pen & Pixel
p. 22



Astrocryptic
p. 44

Royal Astronomical Society of Canada
Société Royale d'Astronomie du Canada

DEPARTMENTS

COLUMNS

On the Cover:
Where dreams are realized: Ph.D. candidate Ellen Milley of the University of Calgary gets a close-up view of one of the meteorites she discovered frozen into the ice of a pond near the Saskatchewan-Alberta border. Ms. Milley and her supervisor, noted meteorite researcher Dr. Alan Hildebrand, were the first to locate the fall zone, one week after a spectacular fireball was observed by thousands across the prairies. See p. 2

Editorial

by Bruce McCurdy, Edmonton Centre

Meteorites and Media Types

On 2008 November 20, a spectacular fireball blazed across the prairie sky, then erupted in a series of brilliant explosion points as it neared the horizon. For observers in Alberta, that was the eastern horizon; for viewers in Saskatchewan, the western.

And what a lot of observers there were! It was 5:26.43 p.m. MST on a weekday; for rush-hour commuters in Edmonton, an hour after sunset. From 911 to the Universities to the science centres, phone lines lit up. Radio and television stations had extensive local coverage, breaking into suppertime news hours again and again. Reports were featured on national and international news. The Meteorites & Impacts Advisory Committee (MIAC) received over 400 eyewitness reports on the first day, an unprecedented response.

The event made the front page of the Edmonton Journal no fewer than four times in the subsequent days. The headlines tell the tale:

"WATCHERS GAZE UP IN WONDER AS LIGHT FLASHES ACROSS SKY" (Nov 21)
"HUNT ON FOR SPACE ROCK" (Nov 22)
"RESEARCHER NARROWS SEARCH FOR METEORITE FRAGMENTS" (Nov 26)
"GRAD STUDENT WINS SPACE RACE" (Nov 29)

The researcher in question was MIAC meteorite expert Dr. Alan Hildebrand of the University of Calgary, and the grad student under his supervision was Ellen Milley (pictured on the front cover). After a busy week of field trips, interviews of eye witnesses, and triangulation calculations, Dr. Hildebrand narrowed the search to an area just inside the Saskatchewan border south of Lloydminster, near the rural community appropriately named Lone Rock. The duo conducted a visual search of the area and were rewarded late Thursday afternoon, November 27, when during a drive-by of a small pond, Ms. Milley's keen eyes spied a couple of suspicious black objects thrust from the ice. A closer examination revealed meteorites!

Media interest intensified. The next afternoon, a convoy of some 20 vehicles containing about 35 media personnel (including your roving *JRASC* reporter) met up in Lloydminster, and then joined a long cavalcade following a research team member some 35 km to the site. CHED radio even sent their traffic helicopter. Reporters scrummed around Ms. Milley as if she had just scored the Stanley Cup winning goal, which in a sense, she had. Studying fireballs for her Ph.D., Ellen had found the pot of gold at the end of the rainbow.

Journal

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

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

The Royal Astronomical Society of Canada
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Toronto ON M5R 1V2, Canada
Internet: nationaloffice@rasc.ca
Web site: www.rasc.ca
Telephone: (416) 924-7973
Fax: (416) 924-2911

Canadian Publications Mail Registration No. 09818
Canada Post: Send address changes to 136 Dupont St, Toronto ON M5R 1V2
Canada Post Publication Agreement No. 40069313

We acknowledge the financial support of the Government of Canada, through the Publications Assistance Program (PAP), toward our mailing costs.

Canada

U.S. POSTMASTER: Send address changes to IMS of NY, PO Box 1518, Champlain NY 12919. U.S. Periodicals Registration Number 010-751.
Periodicals postage paid at Champlain NY and additional mailing offices.
The *Journal* is printed on recycled stock.

Once the discovery zone was announced, a variety of amateur astronomers, geologists, and treasure hunters descended on the area. The local landowners, salt-of-the-earth types who had not asked for meteorites, media types, or meteoriticists to descend on their property, treated the whole situation with good humour, wisdom, and generosity. They allowed full access to the scientific research team while attempting to restrict the curious to the Crown Lands on the periphery of the fall zone.

The terrain in Buzzard Coulee on the north bank of the Battle River was varied, and difficult. The best opportunities were to search the icy surfaces of ponds and sloughs, where meteorites were most easily seen, and where time was of the essence. Landlocked meteorites might still be recoverable in the spring.

Reports began to filter in of specimens being recovered over a fall ellipse greater than 20 km^2. The largest fragment recovered in early days weighed in at over 13 kg and was turned over to the landowner. Meanwhile, a 7-kg specimen recovered just 2 metres off a public road was "finders keepers" for the lucky fellow who happened upon it.

Within a week, the snow flew, and the search became impossible until spring. The initial scientific haul of meteorite specimens underwent laboratory analysis, and began to yield a fresh perspective on the origin of the Solar System. This will be the most interesting story of all, but will have to be read in scientific journals, the mainstream media having already turned their attention back to more mundane matters like politics and the economy.

By then, however, the Lone Rock meteorite had made quite an impact on the public consciousness. What a grand preview to the International Year of Astronomy!

A Contributing Editor of JRASC *since 2000, Bruce McCurdy is an experienced meteor observer who experienced the double thrill of observing the fireball and later recovering a couple of meteorite fragments. A report of his personal experiences will appear in his column Orbital Oddities in April.*

Wanted:
Eager Beavers Who are Not Afraid to Get Creative

Your Society needs you, your energy, and your creative skills!

IYA2009 is here and there's lots to do. Apart from all the fun things that will happen during IYA, we still need quick-thinking astronomers to beaver away in the background, keeping the RASC lights on and the engines ticking over.

Would you like to hone your Web skills with us? Or maybe you would enjoy tackling marketing and promotions, or helping to coordinate a group of like-minded volunteers?

THE UNIVERSE YOURS TO DISCOVER
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Make your mark by contacting 2nd Vice-President Glenn Hawley [`glennhawley@shaw.ca`] or 1st Vice-President Mary Lou Whitehorne [`mlwhitehorne@hfx.eastlink.ca`].

News Notes/*En manchettes*

Compiled by Andrew I. Oakes, Unattached Member (copernicus1543@gmail.com)

Two Ancient Oceans on Mars

It looks like Mars may have harboured two ancient oceans on its surface, one of which could have covered about a third of the Red Planet. The larger extinct ocean is thought to be the oldest, and the smaller one (on the northern plains of Mars), younger.

Professor Emeritus William Mahaney, a retired York University professor who is part of an international group of scientists and sole Canadian contributor, helped to unearth this new evidence while participating in the analysis of data from the Gamma Ray Spectrometer (GRS) aboard NASA's Mars Odyssey orbiter. University of Arizona planetary geologist James M. Dohm led the international investigation.

The Odyssey's spectrometer detected areas of enriched potassium, thorium, and iron that scientists believe mark the shorelines of two ancient oceans. These oceans existed at different stages of the planet's evolution. Researchers estimate the larger, more ancient shoreline encompassed an ocean 20 times the size of the Mediterranean, while the younger shoreline is about 10 times the size of the Mediterranean, or about the size of North America, and existed a few billion years ago. The GRS can investigate the geology as much as a 1/3 metre, or 13 inches, below Mars' surface by the gamma rays the geological structures emit. That capability led to a previous dramatic discovery in 2002 of water ice near the surface throughout much of high-latitude Mars.

The findings appear in the article titled "GRS Evidence and the possibility of paleo-oceans on Mars," to be published in a special edition of *Planetary and Space Science,* an issue which stems from a June 2007 workshop on Mars and its Earth analogues held in Trento, Italy.

Recent NASA reports have also noted the discovery of glaciers below the planet's surface, while the Phoenix Lander found ice beneath Mars' surface exposed by the lander's robotic digging arm.

Still, the idea that oceans once covered portions of ancient Mars remains controversial, as detractors do not believe the resolution of imagery obtained by the GRS is conclusive. The actual debate on the existence of ancient Martian oceans dates back almost 20 years.

The Mars Odyssey spacecraft, launched on 2001 April 7, arrived at the Red Planet on October 24 that same year. It remains in Mars orbit.

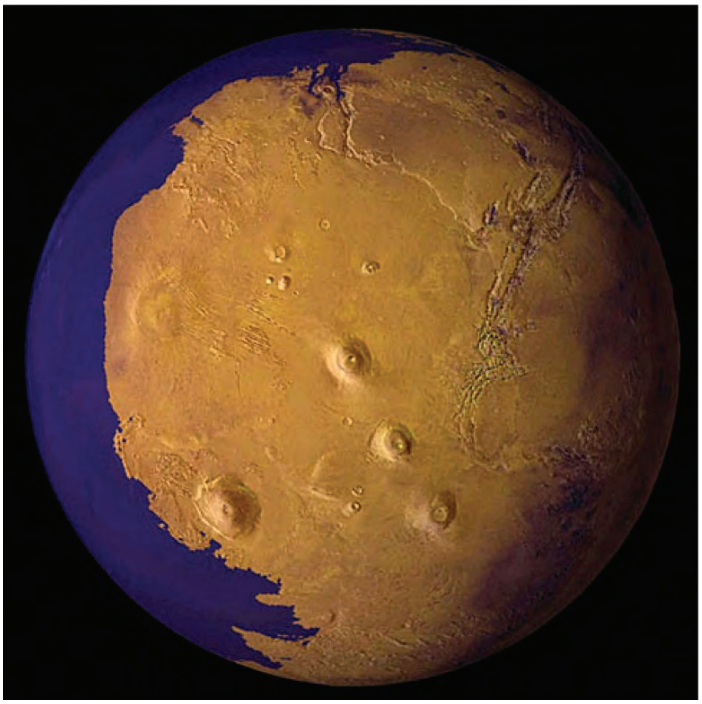

Figure 1 — Mars as it might have appeared more than 2 billion years ago, tipped 50 degrees from its orientation today and with an ocean filling the lowland basin that today occupies the north polar region. The largest feature on the planet, the Tharsis bulge, is at centre of the left image. Image: Taylor Perron/UC Berkeley

A Half Century of Extra-Terrestrial Science: Fifty years and still counting...

Over the last 50 years, the worldwide professional and amateur astronomy communities have benefitted significantly — both scientifically and observationally — thanks to the collaborative work of the National Aeronautics and Space Administration (NASA).

Canadian scientists have participated in various capacities in leading-edge research projects that continue to build knowledge about our Solar System, the neighbourhood beyond, and the deep Universe light-years away.

Meanwhile, the amateur astronomy community — some as armchair observers and others as dedicated nighttime field enthusiasts — has witnessed spectacular views of the planets, countless moons, asteroids, comets, and the broader cosmos as a result of the information sent back to planet Earth by robotic probes.

In the fall of 2008, NASA marked the 50th anniversary of its official start: 1958 October 1. Over the ensuing half-century, it has recorded a rich history of unique scientific and technological achievements in human space flight, aeronautics, space science, and space applications. For astronomy enthusiasts, NASA has an impressive string of accomplishments as a result of launching a number of significant scientific probes. These include, but are not restricted to, such robotic missions as:

* *Pioneers 10* and *11* (launched March 1972 and April 1973);
* *Voyagers 1* and *2* (launched on September 1977 and 1977 August 20);
* *Vikings 1* and *2* (launched August 1975 and September 1975);
* *Mars Pathfinder* (July 1997), which explored the surface of planet Mars with its miniature rover, *Sojourner;*
* The *Hubble Space Telescope,* a workhorse in astronomical image-gathering (launched in 1990);
* The *Spirit* and *Opportunity* Mars rovers (January 2004); and
* *Project Apollo,* which saw humans on the *Apollo 11* mission land for the first time on the lunar surface in 1969.

This collection of space programs has enabled scientists to gather new knowledge about our Solar System, information that would have awed Copernicus, Tycho Brahe, Galileo, Kepler, and Newton.

Figure 2 — Edwin E. "Buzz" Aldrin, Jr. descends from the *Apollo 11 Lunar Module.* He became the second human to walk on the Moon. Astronaut Neil A. Armstrong, commander of the mission and the first to walk on the lunar surface, took this historic photograph. Photo: NASA.

The next 50 years continue to hold much promise as new initiatives are in the pipeline for NASA. Announced in January 2004, NASA is focusing on a new Vision for Space Exploration — a vision that entails sending humans back to the Moon and on to Mars.

First Images of Another Planet and Planetary System

The world experienced two "Galileo Moments" in 2008, when two different groups of astronomers informed the world they had taken photographs of planets circling other stars.

The first moment occurred in September 2008 when University of Toronto astronomers David Lafrenière, Ray Jayawardhana, and Marten van Kerkwijk announced a planet eight times the size of Jupiter orbiting a young star named 1RSXJ160929.1-210524.

The star is about 500 light-years away. Their images were obtained with the Gemini Altair adaptive-optics system and the Near-Infrared Imager (NIRI) on the Gemini North telescope.

The second "Galileo Moment" followed two months later, when National Research Council astronomer Dr. Christian Marois (and an international team of researchers) announced the capture of images of three planets larger than Jupiter orbiting a star known as HR 8799, 130 light-years from Earth in the constellation Pegasus. Faintly visible to the naked eye,

Figure 3 — Gemini Observatory discovery image using the Altair adaptive optics system on the Gemini North telescope with the Near-Infrared Imager (NIRI). This image shows two of the three confirmed planets indicated as "b" and "c" on the image above: "b" is the ~7-Jupiter-mass planet orbiting at about 70 AU, "c" is the ~10-Jupiter-mass planet orbiting the star at about 40 AU. Image: Gemini Observatory.

HR 8799 is about 1.5-times the mass of the Sun, much brighter, and significantly younger. Astronomers estimate the star is about 60 million years old. The international team used the Gemini North and Keck telescopes on Mauna Kea to capture the images.

Like the September announcement, the one on 2008 November 13 in the journal *Science* also seized the public's imagination, as worldwide media disseminated the discovery photos, visually informing humanity again that such planets do exist.

In a manner similar to Galileo's visual discovery of the four moons of Jupiter, which he published in March 1610 in a short treatise entitled *Sidereus Nuncius (Starry Messenger),* the Gemini Observatory (September) and *Science* (November) announcements marked the first time that human beings on Earth were able to actually see planets orbiting around other stars. To date, some 329 exoplanets (planets beyond our Solar System) have been found, all through non-photographic means.

"We have known for a decade through indirect techniques that the Sun was not the only star to have planets in orbit around it," said Dr. Marois of the NRC Herzberg Institute of Astrophysics in Victoria, B.C. "We finally have an actual image of an entire solar system. This is a milestone in the search for planetary systems around stars." ◆

Andrew Oakes is a longtime Unattached Member of the RASC who lives in Courtice, Ontario.

Correction

In Peter Broughton's article on Daniel Winder in the December issue, the sentence

Janet Brodie, in her book *Contraception and Abortion in Nineteenth-Century America,* mentions a pamphlet by Daniel Winder entitled *A Rational or Private Marriage Chart: For the Use of All Who Wish to Prevent an Increase of Family* (1858) and the *History of Detroit and Michigan* (1884). She states that he was the author of "a work on the Aurora Borealis."

should have read:

Janet Brodie, in her book *Contraception and Abortion in Nineteenth-Century America,* mentions a pamphlet by Daniel Winder entitled *A Rational or Private Marriage Chart: For the Use of All Who Wish to Prevent an Increase of Family* (1858); the *History of Detroit and Michigan* (1884) states that he was the author of "a work on The Aurora Borealis."

Our apologies for this error.

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New Constraints on the Asteroid 298 Baptistina, the Alleged Family Member of the K/T Impactor

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Abstract

Bottke *et al.* (2007) suggest that a member of the Baptistina asteroid family was the probable source of the K/T impactor that ended the reign of the dinosaurs 65 Ma ago. Knowledge of the physical and material properties pertaining to the Baptistina asteroid family are, however, not well constrained. In an effort to begin addressing the situation, data from a collaboration of international observatories were synthesized to determine the rotational period of the family's largest member, asteroid 298 Baptistina (P_R = 16.23 ± 0.02 hrs). Discussed here are aspects of the terrestrial impact delivery system, implications arising from the new constraints, and prospects for future work.

Dans leur rapport, Bottke *et al.* (2007) suggèrent qu'un astéroïde de la famille des Baptistinas est tout probablement la source de l'impact du K/T qui a mis fin au règne des dinosaures environ 65 millions d'années passées. Les connaissances des propriétés physiques et matérielles de la famille des astéroïdes Baptistinas sont plutôt limitées. Afin de pouvoir aborder cette situation, les données provenant de la collaboration d'observatoires internationaux ont été synthétisées pour déterminer la période de rotation du plus grand membre de la famille, l'astéroïde 298 Baptistina (P_R = 16.23 ± 0.02 hs). Ce rapport examine les éléments du système de livraison de l'impact terrestriel, les conséquences de ces nouvelles contraintes et les perspectives de recherches à l'avenir.

Introduction

In this study, we begin by reviewing a scenario by which asteroids can escape otherwise benign orbits in the Main Belt and potentially strike Earth, we then revisit several lines of evidence put forth by Bottke *et al.* (2007), linking the asteroid 298 Baptistina to the terrestrial impactor that ended the reign of the Dinosaurs 65 Ma ago, and lastly, we provide observations that place new constraints on 298 Baptistina's rotational period and geometric morphology.

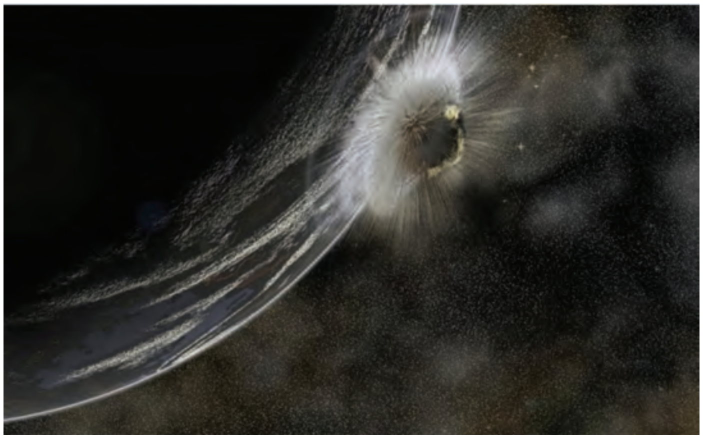

Figure 1 — A cataclysmic encounter between Earth and a large asteroid as envisioned by artist / astronomer Inga Nielsen.

Terrestrial impactors (asteroids and comets) have been suggested to play a major role in modulating the existence of life on Earth, as the dating of craters linked to kilometre-sized impactors at Popigai and Chesapeake Bay, Chicxulub (Hildebrand 1993), and Morokweng and Mjølnir strongly correlate in age with three of the last major global extinctions (late-Eocene, Cretaceous-Tertiary, and Jurassic-Cretaceous respectively). Indeed, readers can view images of the corresponding impact craters at the *Earth Impact Database* (`www.unb.ca/passc/ImpactDatabase`), which is maintained by the Planetary and Space Science Centre at the University of New Brunswick.

One of the challenges, undoubtedly, is to explain how such impactors transition from otherwise benign orbits in the Solar System to become near-Earth objects (NEOs). Historically, it has been suggested that the cause of such extinctions may be linked to an influx of comets by means of a perturbation of the Oort Cloud, a spherical zone of loosely bound comets thought to encompass the periphery of the Solar System. A litany of possible causes have been put forth as catalysts for such a perturbation, most notably density gradients (stars and the interstellar medium) encountered as the Sun travels throughout the plane of the Milky Way during its revolution about the Galaxy, or interactions with a suspected substellar companion to the Sun (Nemesis). Certain ideas are advocated because they inherently assume a periodicity to mass-extinction events, although unproven, rather than stochastic punctuations. A different impact delivery system, revisited below, is based primarily on orbital resonances, and favours a reservoir of projectiles from the asteroid belt located between Mars and Jupiter, in addition to comets from the Kuiper Belt and Oort Cloud, the former extending beyond Neptune from 35 AU to 50+ AU.

Resonances

Large bodies can be delivered from both belts into Earth-crossing orbits by means of resonances (secular and mean motion). Formally, a resonance occurs when the orbital periods of two bodies are commensurate (ratios of integers). For example, an asteroid that is near a 2:1 resonance with Jupiter will orbit the Sun twice for each orbit that Jupiter completes. Most importantly, asteroids near resonances may experience periodic perturbations from a planet that could lead to an increasing eccentricity and a subsequent close encounter, resulting in the asteroid being gravitationally scattered. Observations confirm that areas in the Main Belt associated with strong resonances with the orbit of Jupiter (or Mars) are indeed devoid of asteroids (Kirkwood Gaps, Figure 2), securing the resonance phenomenon as a feasible mechanism for transporting objects from the belt. Inevitably, a fraction of the asteroids depleted by orbital resonances become near earth objects (NEOs)

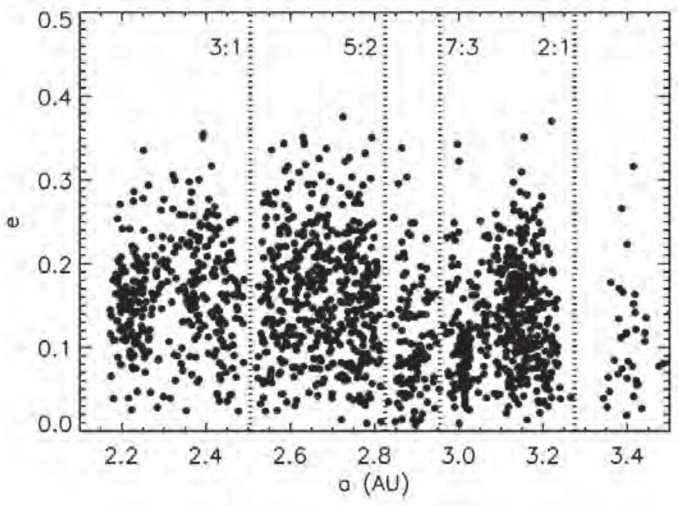

Figure 2 — The distribution of main-belt asteroids in semi-major axis (a) and eccentricity (e) space. Zones devoid of asteroids correlate with strong resonances.

A distribution analogous to the Kirkwood Gaps is also noted in computational models of the Kuiper Belt (Majaess 2004), where Neptune plays a major role in scattering comets. Moreover, simulations confirm that comets from the region could then enter other planet-crossing orbits, although the relevant impact probabilities are difficult to constrain because firm statistics on the Kuiper Belt's comet population lie beyond present limits of solid observational data. *The James Webb Space Telescope (JWST),* scheduled for launch in 2014, and the ongoing Canada-France Ecliptic Plane Survey (CFEPS) should place firmer constraints on the Kuiper Belt demographic. Indeed, many Canadian astronomers and institutions are active partners in *JWST* (*i.e.* John Hutchings, NRC-HIA & René Doyon, Université de Montréal) and CFEPS (*i.e.* J.J. Kavelaars and Lynne Jones, NRC-HIA & Brett Gladman, UBC).

The Yarkovsky Effect

The Yarkovsky Effect (YE) is another component of the delivery system that can work to enhance the transport of asteroids (or comets) into resonances, essentially increasing the possibility that bodies not near resonances may eventually arrive at such locations. In its simplest form, the canonical YE arises from a temperature differential between the sunlit and dark sides of a rotating object exposed to the Sun. Thermal energy from the object is reradiated asymmetrically, causing the body to experience a thrust that may result in an outwards or inwards orbital migration, depending upon its sense of rotation and the direction of the resulting rocket force (see Rubincam (1998) for details).

The YE also allows constraints to be placed on the ages of asteroid families (Vokrouhlický *et al.* 2006) — which is used below to connect the Baptistina asteroid family to the K/T impactor — although such a framework is still in its scientific infancy. The force causes smaller asteroids to undergo a greater orbital migration in comparison with larger bodies, producing a characteristic distribution in semi-major axis space (see Figure 1, Bottke *et al.* 2007). Computer simulations can then determine at what time after the fragmentation of a parent body is the present day distribution of an asteroid family reproduced satisfactorily. Such analyses depend on knowledge of several different parameters, which in the case of the Baptistina asteroid family (BAF) are not well established, as discussed below. Lastly, it is noted that the YE has been invoked to describe the motion of asteroid 6489 Golevka (Chesley *et al.* 2003), and additional efforts to assess and confirm the effect are forthcoming.

Summary

In sum, a three-component terrestrial impact delivery system could begin in the Belt, near a resonance, with the fragmentation of a parent body (*e.g.* by means of a collision) that spawns hundreds of smaller asteroids, thereby augmenting the statistical probability and likelihood of a terrestrial impactor. After fragmentation, a particular asteroid could then enter a nearby resonance, or drift there by means of the YE, where it may be scattered by a planet into an Earth-crossing orbit.

The Alleged Baptistina/KT Impactor Connection

In harmony with the delivery model revisited above, Bottke *et al.* (2007) postulate that the Baptistina asteroid family formed from the catastrophic breakup of its progenitor approximately 160 Ma ago, following which some debris entered a nearby resonance, leading eventually to the ejection of what would inevitably become the K/T impactor. Their proposal is argued, based in part (the reader is also referred to the comprehensive supplemental texts that accompany the Bottke *et al.* (2007) paper), on the following lines of evidence: (i) the asteroid family is located near a resonance capable of delivering passing asteroids into planet-crossing orbits. (ii) The purported destruction of the parent body 160 Ma ago, an age inferred from sorting the asteroids into orbital parameter space according to the YE, created a prodigious supply of BAF members that inevitably populated the NEO demographic, consistent with an alleged increase in the terrestrial impact rate during the same era. It should be noted, however, that the terrestrial record of impacts suffers from poor statistics owing to the subsequent erosion of craters with time, complicating any statistical interpretation. (iii) The K/T impactor and BAF share a similar composition (C-type). Yet the results of Reddy *et al.* (2008) appear to imply otherwise (at least *vis à vis* the family's largest member, 298 Baptistina), and moreover, the suggested C-type composition of BAF members would not be unique; such asteroids are found throughout the belt.

The final conclusions are based on statistical grounds, namely what is the probability that the impactor was a fragment from the creation of the BAF rather than a random C-type asteroid (or background population)? Bottke *et al.* (2007) suggest that there is a 90 percent chance that the K/T impactor was a BAF member, and that one or more BAF members of size d ≥10 km impacted Earth in the past 160 Ma. Readers should be aware that contributions from the background population are difficult to assess. In addition, accurate modeling of the YE requires knowledge of both physical and material properties that are conducive to BAF members, sensitive parameters that are poorly constrained and require further research by the community at large. Indeed, the rotational period derived here for BAF member 298 Baptistina (P_R = 16.23 ± 0.02 hrs, see below) is a factor of three greater than the value used in the simulations, although Bottke *et al.* (2007) adopted a value that may be consistent with smaller-sized BAF members ($P_R \cong 6 \pm 2$ hours, Pravec & Harris (2000), Pravec *et al.* (2002)). The difference in rotational periods noted above is sufficient to warrant additional investigations to confirm the mean rotational period and material properties conducive to kilometre-sized BAF members. Such work needs to be pursued in conjunction with increasing the number of known family members and reaffirming the family's taxonomy. Efforts to secure such parameters will invariably lead to stronger constraints on the properties of family members and might permit a more confident evaluation of whether the source of the K/T impactor was indeed a ~10-km sized BAF member. Lastly, and *most importantly*, irrespective of the conclusion regarding the putative source of the K/T impactor, the approach outlined by Bottke *et al.* (2007) provides the quantitative framework and a pertinent example needed to effectively characterize the terrestrial impact delivery system.

Observations

Asteroid 298 Baptistina was discovered over a century ago, in September 1890, by the French astronomer Auguste Charlois. The origin of the asteroid's designation (Baptistina) is unknown, an uncertainty that is also representative of the asteroid's rotational period, morphology, size, *etc.* A need to establish such parameters inspired the present study, especially in light of the asteroid's reputed status. Asteroid 298 Baptistina was therefore observed throughout March and April 2008 from the Abbey Ridge Observatory (ARO, Halifax, Canada), the Hunter Hill Observatory (HHO, Canberra, Australia), and the Calvin-Rehoboth Observatory (CRO, New Mexico, USA). Details regarding the observatories can be found elsewhere in Lane (2007) and Majaess *et al.* (2008) (ARO), Higgins *et al.* (2006) (HHO), and Molnar & Haegert (2007) (CRO). Image pre-processing and differential photometry were performed using *MPO Canopus (*Warner 2006) and *MaximDL* (George 2007).

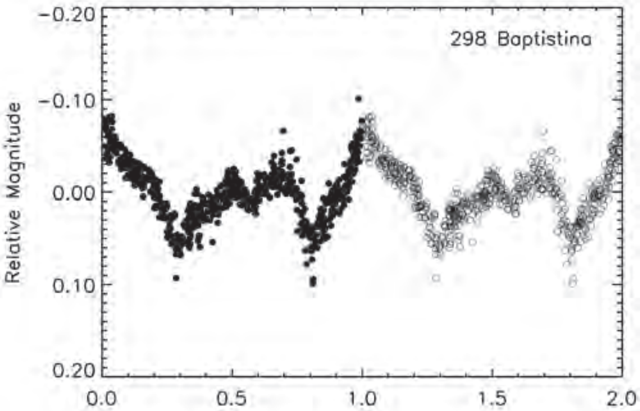

Figure 3 — The light curve for 298 Baptistina phased with a period of P_R = 16.23 ± 0.02 hours.

The asteroid's large proper motion required the selection of different reference stars on each night (Warner 2006, Henden & Kaitchuck 1998), consequently the FALC algorithm was employed to search both magnitude and temporal space for a period solution (Harris *et al.* 1989). The period analysis was carried out in the *MPO Canopus* (Warner 2006) and *Peranso* (Vanmunster 2007) software environments.

A rotational period of P_R = 16.23 ± 0.02 hours was determined for 298 Baptistina from the analysis, and the resulting phased light curve is presented in Figure 3.

The light curve exhibits a peak-to-peak amplitude of ~0.15 magnitude and displays complex characteristics that are likely indicative of irregular surface features. Continued photometric observations are envisioned to refine the rotational period, and in conjunction with archival observations by Wisniewski *et al.* (1997) and Ditteon & Hawkins (2007), to model the asteroid's shape and spin axis by light-curve inversion (Molnar & Haegert 2008, Kaasalainen & Torppa 2001). The data will also permit a detailed study of the asteroid's absolute magnitude and oppositional surge, fundamental for any subsequent research. Thermal imaging and spectroscopic follow-up would also be of value, permitting a precise determination of the asteroid's diameter and confirmation of its taxonomical class (*e.g.* Reddy *et al.* 2008). This paper's referee has estimated that 298 Baptistina may be *approximately* 20 km in size, which follows from the standard formula utilizing albedo (Reddy *et al.* 2008) and the H-magnitude.

Lastly, the present study appears to reaffirm the importance of small telescopes in conducting pertinent scientific research (Percy 1980, Turner *et al.* 2005). Indeed, modest telescopes can even be mobilized to help address questions surrounding the extinction of the dinosaurs.

Acknowledgements

We are indebted to Petr Pravec, Alan Harris, and Brian Warner for their help in mobilizing the collaboration. DJM also extends his gratitude to the Halifax RASC, Daniel U. Thibault, Dr. Aaron Gillich, Joris Van Bever, Arne Henden and the staff at the AAVSO, and Robin Humble and Chris Loken for facilitating simulations of the Kuiper Belt on the McKenzie computer cluster, which is part of the Canadian Institute for Theoretical Astrophysics (CITA) at the University of Toronto. Lastly, we also thank the referee for their comments.

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Long Secondary Periods in Pulsating Red Supergiant Stars

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Abstract: About one-third of pulsating red-giant stars shows long secondary periods, an order of magnitude longer than their primary radial pulsation period. The cause of these long secondary periods is not known. Kiss *et al.* (2006) have recently used Fourier analysis to study the variability of 48 pulsating red supergiant stars, using several decades of visual measurements collected by the American Association of Variable Star Observers (AAVSO). They found long secondary periods in several stars. (We use the term "period" with some caution because, in many cases, the datasets are not sufficiently long to show whether there are true periods present, or just "characteristic time scales" of variability.) In this paper, we use self-correlation analysis to study the variability of the same stars. For other types of variable stars, we have found this method to be a useful adjunct to Fourier analysis, especially if the variability is only semi-regular. We find that about one-third of pulsating red supergiants show long secondary periods that are coherent over a few cycles or more. Although the cause of the long secondary periods is not definitely known, they may be linked to rotation of large, long-lived convection cells across the disc of the star.

Resumé: Environ un tier des étoiles géantes rouges à pulsations présente des longues périodes secondaires, à un niveau de magnitude plus grande que celle de leur période de pulsation radiale primaire. La cause de ces longues périodes secondaires est inconnue. Kiss *et al.* (2006) ont récemment utilisé une analyse Fourier pour examiner la variabilité de 48 étoiles supergéantes rouges à pulsations, en se servant de mesures visuelles accumulées durant plusieurs décénies par l'Association américane d'observateurs d'étoiles variable (AAVSO). Ils ont découvert de longues périodes secondaires dans plusieurs étoiles. [Nous employons le terme "période" avec prudence car dans plusieurs cas l'accumulation des données n'est pas suffisamment longue pour s'assurer qu'en effect il y a de vraies périodes, et non seulement une "variabilité caractéristique de la période échantillonnée."] Dans ce rapport, nous utilisons une analyse d'autocorrélation pour examiner la variabilité de ces mêmes étoiles. Pour d'autres types d'étoiles variables, nous avons trouvé cette méthode un ajout utile à l'analyse Fourier, particulièrement si la variabilité est semi-régulière. Nous trouvons qu'un tier des étoiles supergéantes à pulsations montre de longues périodes secondaires qui sont cohérentes durant quelques cycles ou plus. Quoique la cause des longues périodes secondaires n'est pas définitivement connue, elle pourrait être liée à la rotation des grandes cellules de convection de longue durée à travers le disque de l'étoile.

Introduction

This paper presents an example of the important contributions that amateur astronomers — in this case, those who measure the changing brightness of variable stars for the American Association of Variable Star Observers (AAVSO) — can make to astronomical research.

Red supergiants are the coolest, largest, most luminous stars, up to a thousand times larger in radius than the Sun. They are massive young stars in the final rapid stages of thermonuclear evolution. They undergo a complex variety of physical processes, including convection, pulsation, and extensive mass loss, which causes most of them to be shrouded in gas and dust.

They are also all variable, though not strictly periodic, being classified as SRc if they are semi-regular, or Lc if they are irregular. They vary typically on time scales of hundreds to thousands of days, and amplitudes up to a few magnitudes. Some bright examples are α Ori (Betelgeuse), α Sco (Antares), and μ Cep ("The Garnet Star"). These three stars have relatively low-amplitude variability. VX Sgr shows the most spectacular SRc variability; its amplitude is several magnitudes.

The terms "semi-regular" and "irregular" are rather vague. "Semi-regular" means that the variability is not strictly periodic. This could arise because of short- or long-term variability in the amplitude, period, phase, or shape of the light curve, or because of the presence of another form of variability, such as an additional period, or because the cause of the variability is intrinsically non-periodic. "Irregular" means that there is no evidence of any periodic behaviour in the star. In reality, there is a continuous spectrum of behaviour in red giants and supergiants, ranging from relatively periodic, like VX Sgr and S Per, to irregular.

David G. Turner (Saint Mary's University, Halifax) and his colleagues have been especially active in studying these stars in the last few years, both in terms of their fundamental properties (Turner 2006) and the long-term behaviour of a specific star, BC Cyg (Turner *et al.* 2006).

Kiss *et al.* (2006) studied 48 SRc and Lc stars using visual observations from the American Association of Variable Star Observers (AAVSO) International Database. That paper is a good source of information about SRc stars and shows long-term light curves for many of them. The mean time span of the data was 61 years. Most of the stars showed a period of several hundred days that could be ascribed to radial (in-and-out) pulsation. This is the most basic and common kind of pulsation; it's the kind that is observed in Cepheids, Mira stars, *etc.* Two or more periods were found in 18 stars. In some cases, the second period could be an additional radial mode. In other cases, the second period was an order of magnitude longer than the radial period, and could be classified as a long secondary period, similar to those that have been found in about a third of pulsating red giants, *e.g.* by Percy *et al.* (2001), and whose cause is unknown (Wood *et al.* 2004).

Wood and his colleagues considered (and rejected) a wide range of possible mechanisms for the long secondary periods in red giants; this same list might apply to red supergiants. The most promising mechanism is rotational variability. Rotational velocities of red supergiants are not well known, but their rotational periods would not be inconsistent with the long secondary periods; the equatorial rotational velocities are a few km/s and the radii are a few hundred solar radii, so the rotational periods would be a few thousand days. And red supergiants have giant bright convective cells that could provide a basis for rotational variability, though the characteristic lifetimes of giant convective cells may be shorter than the long secondary periods (Gray 2008). Incidentally, this remarkable study of the long-term spectroscopic variability of Betelgeuse, by David F. Gray (University of Western Ontario, London) was possible only because of the fine instrumentation that he has developed for a 1.2-m telescope, his regular access to this facility, his patience in accumulating data over many years, and his long experience in interpreting the spectra of cool stars.

The primary purpose of this paper was to study the long secondary periods independently, using the same datasets as Kiss *et al.* (2006), but using self-correlation analysis. This method has proven, for other types of stars, to be a useful adjunct to Fourier analysis, especially for stars that are not strictly periodic. This has been demonstrated through its use in many refereed papers, such as Percy *et al.* (2001: red giants), Percy *et al.* (2003: RV Tauri stars), Percy *et al.* (2004: Be stars), and Percy *et al.* (2006: T Tauri stars).

Data

Visual measurements of the brightness of 48 stars came from the AAVSO International Database, spanning up to a century, but averaging 61 years (Kiss *et al.* (2006)). The accuracy of the measurements is typically 0.15 to 0.3 magnitude. The intercept of the self-correlation diagram on the vertical axis is a measure of the mean error of observation (see below), and is consistent with this estimate of the accuracy.

Determination of Periods by Self-Correlation

Visual inspection of light curves and Fourier analysis (power spectrum analysis) is commonly used for period analysis of variable-star data. Self-correlation analysis — a form of variogram analysis (Eyer & Genton 1999) — has proven to be useful, in conjunction with the other two techniques, for some kinds of stars, especially if the stars are somewhat irregular, and if there are "aliases" in the power spectra due to regular gaps (*e.g.* seasonal gaps) in the data. It can detect characteristic time scales — here denoted τ — in the data. It determines the cycle-to-cycle behaviour of the star, averaged over all the data. The measurements do not have to be equally spaced.

The algorithm works as follows (Percy *et al.* 1993): for every pair of measurements, the absolute value of the difference in magnitude (Δmag) and the difference in time (Δt) is calculated. Then Δmag is plotted against Δt, from zero up to some appropriate upper limit Δt(max) which, if possible, should be a few times greater than the expected time scales, but a few times less than the total time span of the data. If the maximum Δt is as large as the total time span of the data, there will be few if any instances of Δt with this value.

The Δmag data are binned in Δt so that, if possible, there are at least a few points in each bin; the Δmag values in each bin are then averaged. The choice of the number of bins will depend on how many measurements are available. Increasing the number of bins increases the time resolution of the method, but it decreases the number of points in each bin, which decreases the accuracy of the average Δmag. In this study, we typically used 50 to 100 bins for each star. Figure 1 is a self-correlation diagram, a plot of average Δmag versus average Δt in each bin; the accuracy of the points can be judged from the point-to-point scatter. The method is so simple that there is no equation involved — just the procedure described above!

If the variability is regular, with a period or characteristic time scale τ, then the average Δmag will be a minimum at multiples of τ. If several minima are present, we can conclude that the variability is reasonably regular. Each minimum can be used to estimate τ. The Δt of the Nth minimum, divided by N, gives a measure of τ, so the values derived from the several minima can be averaged to give a better estimate of the time scale. The scatter in these individually determined values gives an estimate of the error in the average value of τ.

If the variability were strictly periodic and the magnitudes had no error, then the minima should fall to zero, because measurements that are an integral number of cycles apart would always be exactly the same. In reality, the measurements have observational error. The value of Δmag for very small values of

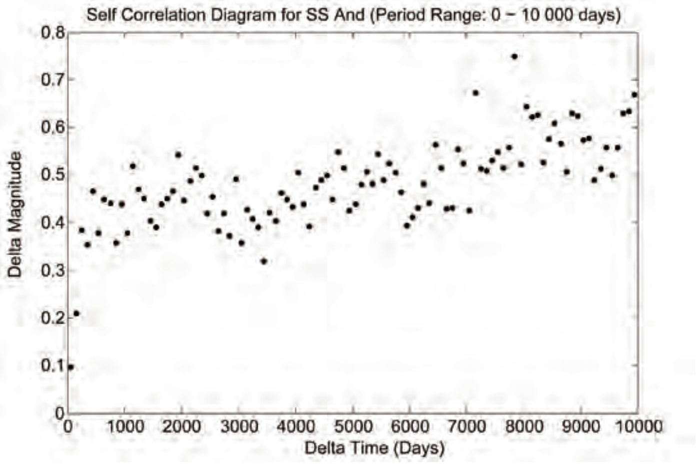

Figure 1 — An example of a self-correlation diagram — that of SS And. There are shallow minima at multiples of 3100 days, and maxima in between, indicating that there are variations on this timescale. This is an example in which the long secondary period self-correlation signal is weak. No long secondary period was reported by Kiss *et al.* (2006). The short period is 159±17 days (Kiss *et al.* (2006)). The intercept on the vertical axis is a measure of the average observational error. The depth of the minima is a measure of the amplitude of the variability.

Δt, *i.e.* the intercept on the vertical axis of the self-correlation diagram, will reflect observational error only, assuming that there is no variability on very rapid time scales. The height of the other minima above the zero line is also determined by the average error of the magnitudes, but also by the degree of irregularity, if any.

Measurements that are a half-integral number of cycles apart may have a Δmag ranging from zero to the full amplitude of the variations. As long as there is a sufficient number of Δmag values in each bin, the height of the maxima averages out to about half the peak-to-peak range of the light curve. The difference between the maxima and the minima is therefore a measure of the average amplitude of the variability. Specifically, it is about 0.45 times the average peak-to-peak range of the light curve (Percy *et al.* 2003).

The persistence of the minima to large Δt values is also determined by the degree of irregularity. The behaviour of the self-correlation diagram at a particular Δt depends on whether periodicity persists for that interval of time. For instance, if the periodicity remains coherent for only a few cycles, the minima will gradually disappear as Δt increases. Even if the self-correlation diagram does not show minima, it still provides a "profile" of the variability; the typical change in magnitude Δmag in a time of Δt.

Figure 1 shows the self-correlation diagram for SS And. In this case, the signal is weak, but there are minima of Δt at 3100, 6200, and 9300 days, and maxima half-way in between, suggesting a period of about 3100 days. The intercept on the vertical axis is about 0.1 magnitude; this is the expected observational error. The levels of minima 1, 2, and 3 are much higher than this: 0.4 to 0.5 magnitude. This result is an indication of the irregularity of the star. The difference between the maxima and minima is about 0.1 magnitude, so the corresponding full range of the light curve would be 0.1/0.45 or about 0.2 magnitude. The minima persist for at least three cycles; this is a measure of the coherence of the 3100-day time scale.

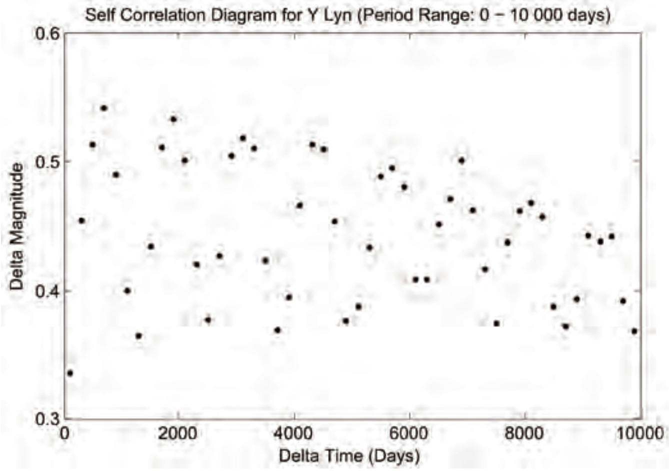

Figure 2 — The self-correlation diagram of Y Lyn. Here, the signal is very strong. The diagram is dominated by the 1240-day long secondary period. This is the same long secondary period reported by Kiss *et al.* (2006). The short period is 133±3 days, according to Kiss *et al.* (2006), Percy *et al.* (2001), and others.

Figure 2 shows the self-correlation diagram for Y Lyn. In this case, the minima are very well-defined, and persist for at least eight cycles. The observational error, as measured by the intercept on the vertical axis, appears to be about 0.3 magnitude. The levels of the minima are not much higher than this error, so the contribution of the irregularity must be considerably less.

Note that the self-correlation diagram is constructed from measurements that are no more than Δt(max) apart, and is not the same as a light curve. Nor is it like a phase curve, which combines all measurements into a single cycle.

For reasons already mentioned, our method requires of the order of ten or more Δmag values in each bin, simply to produce a meaningful average Δmag. Although our method is not subject to "alias" periods due to the periodicity of the seasonal gaps in the data, there may be gaps in the self-correlation diagram if there are no pairs of measurements with certain values of Δt — due to long seasonal gaps in the data, for instance.

For a more detailed discussion of self-correlation, its nature, strengths, and weaknesses, see Percy & Mohammed (2004) and references therein; this reference is freely available on-line. One weakness of self-correlation analysis is that it is not very effective if the star has multiple periods with comparable periods and amplitudes. Our self-correlation software is publicly available at:

`www.astro.utoronto.ca/percy/index.html`

and a manual for its use is available at

`www.astro.utoronto.ca/percy/manual.pdf`

Unfortunately, the statistical properties of self-correlation are not known, especially since it is usually applied to stars that are intrinsically non-periodic. Our interpretation of diagrams such as Figures 1 and 2 is based on our 15 years of experience with the method, including comparison with results from Fourier analysis.

Results

The results are listed in Table 1. This table includes only stars that have or may have a long secondary period *i.e.* a "short" (radial) period has been identified, and there is an additional period that is significantly longer. In the table, the short period is taken from Kiss *et al.* (2006), who give values both from their own work, and from the literature. In a few cases, we have determined it from our self-correlation diagrams (recall, though, that the primary purpose of our project was to study the long secondary periods). The long periods in the last column are those determined by Kiss *et al.* (2006). Sample self-correlation diagrams are shown and described in the two figures. One figure shows a star in which the long secondary period is weak (SS And); the other shows a star in which it is strong (Y Lyn). A colon indicates that the value is uncertain.

Kiss *et al.* (2006) did not find periods in AO Cru, BI Cyg, IS Gem, KK Per, or PR Per. They found BO Car to be not variable.

Several stars have basic (short?) periods that are 1000 days or more, *i.e.* no shorter period has been reported; but one may still exist. They include: VY CMa (1450 days), TZ Cas (1400 days), BU Gem (2400 days), RS Per (4400 days), KK Per (2500 days), and PR Per (2600 days).

The following stars do not appear to have detectable long secondary periods, or have long secondary periods greater than 10,000 days, which is the upper limit of our calculations: NO Aur, UZ CMa, VY CMa, RT Car, CK Car, PZ Cas, W Cep, T Cet, WY Gem, RV Hya, W Ind, XY Lyr, S Per, T Per, XX Per, AD Per, BU Per, FZ Per, PP Per, VX Sgr, AH Sco, α Sco, W Tri.

Discussion and Conclusions

Of the 48 stars, 19 show long secondary periods, 23 do not, and the other 6 are marginal. The incidence of long secondary periods is thus about the same as in pulsating red giants.

In 14 stars, our long secondary periods agree, to within the uncertainties of each method, with those determined by Kiss *et al.* (2006) (though, in two stars, Kiss *et al.* (2006)'s error bars were especially large). In 11 stars, we found long secondary periods that were not reported by Kiss *et al.* (2006).

The long secondary periods are typically 5-10 times the short period *i.e.* the two are correlated, but there is considerable scatter in the relation between the two. The fact that there is a correlation, however, suggests that the long secondary periods are such that they are related to the size of the stars, because the short (radial) period is determined primarily by the size of the star.

The amplitudes range from 0.02 to 0.3 magnitude, for the confirmed long secondary periods. Only four stars have long secondary period amplitudes greater than 0.1 magnitude, so the long secondary periods could be produced by a relatively subtle process.

There is no obvious correlation between amplitude of the long secondary period and the spectral type, or the short (radial) period *i.e.* the largest amplitudes are not necessarily found in the coolest or largest stars.

The coherence of the long secondary periods is determined by noting the number of minima in the self-correlation diagram. It ranges from very low (a cycle or two) to very high (ten cycles or more). Those that are notably coherent are: EV Car, μ Cep, and Y Lyn. There are also stars with long periods, but without obvious short periods, that are coherent: VY CMa, PZ Cas, and BU Gem, but it is not clear whether these periods are true long secondary periods.

Once again, self-correlation has proven to be a useful adjunct to Fourier analysis, which was used by Kiss *et al.* (2006) in their study of these stars. In a few cases, we have been able to detect long secondary periods that were not reported by Kiss *et al.* (2006). This may be because Fourier analysis assumes the variability to be periodic, whereas self-correlation analysis can detect characteristic time scales that are less coherent. In other cases, we have been able to determine the long secondary period somewhat more precisely than Kiss *et al.* (2006), using several individual minima in the self-correlation diagram. Again, the differences may occur because the two methods make different assumptions, and the behaviour of some of the stars may vary from decade to decade. So, we do not claim that self-correlation analysis is a better tool, just an additional tool.

Both Kiss *et al.* (2006), on the basis of the structure of photometric power spectra, and Gray (2008), on the basis of long-term spectroscopic observations of Betelgeuse, propose that the short period is a radial pulsation period, driven stochastically (randomly) by convective motions whose time scale is similar to that of the pulsation period. The lifetimes of these modes are several periods. Neither Kiss *et al.* (2006) nor Gray (2008) comments specifically on the nature and origin of the long secondary periods. If there are giant bright convective cells present and their lifetimes are long, then the long secondary periods could be rotational; however, some of the long secondary periods in Table 1 are very long lasting, which would require that the lifetimes of the convective cells were much longer than the rotation periods.

It is also possible that rotational variability could be caused by some other temporary bright or dark features, but large convection cells are expected to be present in red supergiants, and are expected to be temporary.

Finally, it should be obvious that the study of stellar variability on time scales of decades is challenging. Fortunately, organizations such as the AAVSO have been facilitating systematic, long-term visual measurements of such stars for a century or more. May their work continue for another century!

Acknowledgements: We thank the Natural Sciences and Engineering Research Council of Canada, and the Ontario Work-Study Program for research support; and the AAVSO observers and headquarters staff, without whose efforts this project would not be possible. We also thank the referees for their many helpful comments. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

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Table 1 — Long Secondary Period Determinations from Self-Correlation Analysis

Star	LSP (d)	Δm	Short Period (d)	Long Period (d)
SS And	3100	0.10	159±7	—
BO Car	2900	0.10	not variable	not variable
CL Car	3000:	0.10:	229±14, 490±100	—
EV Car	1150	0.15	276±26	820±230
IX Car	4500	0.30	408±50	4400±2000
TZ Cas	3500	0.10	—	3100
ST Cep	3200	0.05	—	3300±1000
μ Cep	4100	0.04	860±50	4400±1060
AO Cru	4000:	0.30	—	—
RW Cyg	3200	0.08	580±80	—
AZ Cyg	2000:	≤0.1	495±40	3350±1100
BC Cyg	3000:	0.05	720±40	—
BI Cyg	3000	0.10	—	—
TV Gem	2600	0.08	426±45	2550±680
BU Gem	2400	0.05	—	2450±750
IS Gem	5500:	0.01	—	—
αHer	1400	0.02	124±5	500±50, 480±200
Y Lyn	1300	0.20	133±3	1240±50
αOri	2100	0.02	388±30	2050±460
W Per	3000:	0.03	500±40	2900±300
RS Per	4400	0.06	—	4200±1500
SU Per	3500	0.03	430±70	3050±1200
KK Per	2500:	0.02	—	—
PR Per	2600	0.02	—	—
CE Tau	3600	0.03	140-165	1300±100

Shakespeare and Elizabethan Telescopy

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I essentially am not in madness,
But mad in craft.

— Prince Hamlet

In 1543, Nicholas Copernicus broke from the traditional view that had held sway for nearly 2000 years, that the Earth lay immobile at the centre of creation. Copernicus placed the Sun there instead and relegated the Earth to the rank of a planet circling the Sun. This demotion removed humans from the centre of the Universe, indirectly influencing branches of learning in which they were the primary focus of attention.

When William Shakespeare's writing career began in about 1589-93, the Copernican theory had existed in its fully developed form for well-nigh half a century. The Bard was well versed in many areas of learning and his knowledge was invariably ahead of that of his contemporaries, yet his canon appears to lack a coherent account of contemporary cosmological thinking. It is simply not credible that a poet of his stature could remain ignorant of the cultural impact that the so-called New Astronomy was having in his lifetime; or, if he recognized changing perceptions in worldview, that with all the literary devices at his command, he would refrain from addressing them.

The earliest model is the bounded Earth-centred or geocentric cosmic model, which comprised a rotating sphere of stars enclosing all of physical space and centred on a stationary Earth. Seven so-called Ancient Planets revolve about the Earth in the same sense but at different rates depending on their supposed distances from Earth. In the 2nd century AD, the Greco-Roman astronomer Claudius Ptolemy refined this model but did not alter its basic assumptions, relying instead on a plethora of geometric constructions in order to account for observed phenomena. Consequently, the model retained the limitations imposed by its flawed premises.

For example, Mars, Jupiter, and Saturn can lie at any angle away from the direction of the Sun, but the standard model needed contrived mechanisms to account for the fact that Mercury and Venus lie always within about 22° and 45° degrees of the Sun. Further contrivances simulated the anomalous behaviour of retrograde motion, which occurs when the apparent paths of planets in the sky reverse direction for intervals lasting weeks or months, before resuming their apparent eastward motion relative to the distant stars. Nor could the standard model explain why Mars, Jupiter, and Saturn appear brightest at opposition, *i.e.* when opposite the direction of the Sun, and when, coincidentally, these planets are in the throes of retrograde motion. In the 16th century, the Ptolemaic algorithm was arguably the standard against which to compare three other major contenders.

In the first half of the 16th century, the Polish mathematician Nicholas Copernicus grasped the difficulties of the standard model and developed an alternative Sun-centred or heliocentric model. He demoted the Earth from its place at the centre of creation and let it orbit the Sun, so that the order of the modern planets from the Sun outward became Mercury, Venus, Earth, Mars, Jupiter, and Saturn. Only the Moon retained its geocentric rank. In one fell swoop, this simple transformation of centre overcame many of the problems that beset the standard model.

Copernicus published his revolutionary new theory in *De Revolutionibus Orbium Coelestium* (On the Revolutions of the Celestial Orbs), which appeared in 1543, the year of his death. Eight years later in Wittenberg, Germany, Erasmus Reinhold calculated ephemerides based on the new theory. In 1556, John Field adapted these tables for use in England, and in the same year, Robert Recorde published *The Castle of Knowledge* in which he hinted at the superiority of the new model.

Copernicus had retained the ancient concept of a bounding sphere that held the stars, but in 1576, Thomas Digges published an essay, *A Perfit Description of the Caelestiall Orbes according to the most aunciente doctrine of the Pythagoreans, latelye reuiued by Copernicus...* in which he proposed that the Solar System lay in infinite space filled with stars. This is the first account of the so-called New Astronomy, which comprises both heliocentricism and a physically unbounded Universe.

At about the same time, the Danish astronomer Tycho Brahe proposed a hybrid geocentric model in which an immobile Earth remained the centre of the orbits of the Moon and Sun as well as of a bounding shell of stars, but in which the Sun became the centre of motion of the five remaining modern planets. The Tychonic model has therefore two centres of interest.

Pythagorean cosmology of the 6th to 4th centuries BC has many features in common with the New Astronomy, and by advocating a return to it, Thomas Digges became something of a revolutionary in his own right. He was aware of the peril in shattering the interface between physical and theological space, so he camouflaged his new view of the Cosmos by publishing it in an almanac, which learned schoolmen and theologians might not take too seriously. Correspondingly, we would expect

Shakespeare to disguise the cosmological advances of the 16th century.

In January 1997, at a meeting of the American Astronomical Society in Toronto, I suggested that Shakespeare's *Hamlet* is a cosmic allegory that describes the competition between the four chief cosmic models that vied for acceptance at the turn of the 17th century. Subsequent journal articles and published abstracts have further developed the theory (Usher 2006).

In the play, Claudius kills the king of Denmark, Hamlet's father, and usurps the throne, whereupon the ghost of Old Hamlet appears and orders his son to avenge his murder. Claudius personifies the bounded geocentric model perfected by his namesake, Claudius Ptolemy, and the twin sycophants Rosencrantz and Guildenstern represent Tycho Brahe's double-centred geo-heliocentric model. Prince Hamlet champions the new model of Thomas Digges. To cut a long story short, Hamlet disposes of the two courtiers before killing the false king, thereby knocking from contention the two false models of the Universe. By the end of 1601, about the time that Shakespeare completed writing *Hamlet,* both Thomas Digges and Tycho Brahe were deceased, and the Bard could write in an historical vein of their contributions to natural philosophy.

A few examples will illustrate the extent of the cosmological sub-text. Shakespeare goes to some lengths to establish that Hamlet is thirty years old when the prince exacts his revenge. As noted, Hamlet personifies the model of Thomas Digges, who was also about thirty when, in 1576, he published *A Perfit Description.* Heliocentricism had at least a modicum of support at the University of Wittenberg in Germany, and in opposing Hamlet's wish to resume his studies there, the geocentricist Claudius says that Hamlet's intent is retrograde to the desire of the royal couple. As mentioned, the Copernican thesis that had made its way into the curriculum at Wittenberg University readily explains retrograde motion, which occurs around the time of Opposition, to which Claudius refers when he characterizes attempts to overthrow geocentricism as "peevish opposition."

Shakespeare refers to the Diggesian model directly when he has Hamlet say, "O God, I could be bounded in a nutshell and count myself a king of infinite space." Here, Shakespeare contrasts the idea of infinite space with the three bounded models. The conceit is particularly apt in the case of Tycho Brahe's model since Tycho intended his design to be as compact as possible in order to conform to the pedantic dictum to minimize empty space. In this sense, the Tychonic model resembles a nut, which symbolizes something of trifling value and has a shell resembling the bounding sphere of stars.

Another instance in which Shakespeare divulges information with great economy of words occurs when a gravedigger unearths a skull and Hamlet comments, "Here's fine revolution, an we had the trick to see't." The "revolution" exists in the present tense, whereas the "trick to see't" exists in the past. If "revolution" refers to Copernicus' *De Revolutionibus* and if "trick" has the 16th-century meaning of a "contrivance or invention," then this seemingly idle and misplaced comment means that a certain "trick" enabled two or more persons ("we") to "see" the "revolution" in worldview wrought by the New Astronomy.

Before Hamlet dies, Fortinbras arrives on the scene fresh from a foray into Poland. By saluting the English ambassadors, Fortinbras unifies the English model of an infinite stellar distribution with the theory of heliocentricism that originated in Poland. Hamlet foresees that the election of the next head of state will light on Fortinbras, under whose aegis natural philosophy will prosper. In this sense, *Hamlet* is not a tragedy but a triumph.

The king's chamberlain Polonius tries to label Hamlet as "mad" (as in "mad scientist"), because Hamlet is a practitioner of the new organon of evidence-based theory. In *A Perfit Description,* Thomas Digges described the essentials of what we term today the "scientific" method, and as the alter ego of Thomas Digges, Hamlet employs "scientific" reasoning in his manipulation of the play staged by the touring thespians. To Hamlet, the play's the thing wherein he'll catch the conscience of the King. Later, in the 17th century, Francis Bacon and Galileo Galilei were to advocate the scientific (or hypothetico-deductive) method as an alternative to the syllogistic methodology of schoolmen.

In *Hamlet,* the Bard describes with comparative clarity the phases of Venus, craters on the Moon, sunspots, the stellar makeup of the Milky Way, the number of naked-eye stars, and the existence of stars lying beyond the pale of human vision. These data could only derive from telescopic observations. According to Thomas Digges in *Pantometria* of 1571, his father Leonard followed up on the work of Roger Bacon in the 13th century and developed a so-called perspective glass by which to magnify the images of distant objects. Independent evidence indicates that the Bard knew Thomas Digges, which suggests that Thomas Digges' essay of 1576 and Shakespeare's *Hamlet* of about 1601 both depended on Leonard Digges' novel two-element optical magnifier.

The difficulty is that no one has discovered direct physical evidence of a Diggesian telescope or any associated records, and consequently the existence of an Elizabethan telescope remains mired in uncertainty (Turner 1993, Ronan 1991, van Helden 1997). However, pursuant to an empirical approach to the history of astronomy that he espoused in 1981, Michael Gainer has opened up a new avenue of research into 16th-century telescopy by demonstrating that a functioning two-element telescope described by Thomas Digges was well within the capabilities of the Digges father and son (Gainer 1981, Gainer 2008).

As evident from their published works, the Diggeses were superb mathematicians and practical men of science who were sufficiently well-to-do that they could pursue their scientific and military studies privately. Their self-sufficiency suggests that they were skilled in designing and implementing their own experiments. They were adept at optics as evidenced by their ability to detonate distant ordinance with the help of parabolic mirrors and sunlight. However, at the same time, religious belief was intolerant of the "natural magic" of optical imagery, and in addition, England was menaced by hostile armies on the Continent and by the threats of the Spanish Inquisition and Armada. It is reasonable to suppose that Thomas Digges would have considered it prudent to disguise celestial discoveries, while in *Hamlet* it appears that Shakespeare pictured these advances in words and buried them in an allegorical sub-text.

It seems likely that Thomas Digges was an accomplished craftsman who continued to work after the death of his father in 1572 and up to the time of his own death in 1595, six years before the nominal time of writing of *Hamlet*. This, I suggest, is why Shakespeare characterizes Thomas Digges' dramatic counterpart, Prince Hamlet, as "mad in craft."

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Construction of a 16th-Century Telescope: An Experiment in the History of Astronomy

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I determined to accept nothing on faith, but to see with my own eyes what others had seen before me.

— William Herschel, 1783

The history of telescopic astronomy throughout the 17th century is well established. Reconstructions of telescopes from that period, for the purpose of evaluating their observations, have been documented (Gainer 1981). The history of observational astronomy in the 16th century however, apart from the monumental work of Tycho Brahe, is vague and unresolved. The possibility of pre-Galilean telescope observations has only recently been opened to conjecture through the study of the works of Leonard Digges and his son, Thomas. My interest here is to examine what kind of observations might have been available to 16th-century astronomers and how they might have influenced the acceptance of the Copernican worldview.

Evidence that Leonard Digges had invented some type of reflecting telescope comes from the following passage in his book *Pantometria,* which was published by Thomas posthumously:

> *By Concave and convex mirrors of spherical and parabolic forms, or by paires of them placed at due angles, and using the aid of transparent glasses which may break, or unite, the images produced by the reflection of the mirrors, there may be represented a whole region; also any part of it may be augmented so that a small object may be discerned as plainly as if it were close to the observer, though it may be as far distant as the eye can descrie.*

Another description of a Digges telescope appears in a treatise by a contemporary, William Bourne:

> *I am assured that glass is ground being of very clear stuff and of good largeness, and placed so, that the beam doth come through, and so received into a very large concave looking glass, that it will show the thing of marvelous largeness in a manner incredible to be believed by common people.*

These descriptions suggest that Leonard Digges may have experimented with a variety of telescope designs using reflective and refractive optics. William Bourne describes an instrument in which light passes through a large-diameter plano-convex lens and is reflected by a concave mirror, which serves as an eyepiece. A replica of the Bourne version has been constructed by Ronan (1991) and others. It uses a back-surface mirror and a plano-convex objective.

Contained within the Thomas Digges account is the possibility that his father had also experimented with an early version of what is now called the Herschelian telescope. In this design, the observer looks directly down to a tilted concave objective mirror. A plano-convex lens eyepiece is placed in such a way that it is aligned with the mirror axis and inclined by the same amount. William Herschel used this system for his larger instruments to avoid light loss by reflection from the secondary mirror in Newtonian telescopes. It is my contention that this was the original reflecting telescope design and that Thomas Digges used it for astronomical observation, through

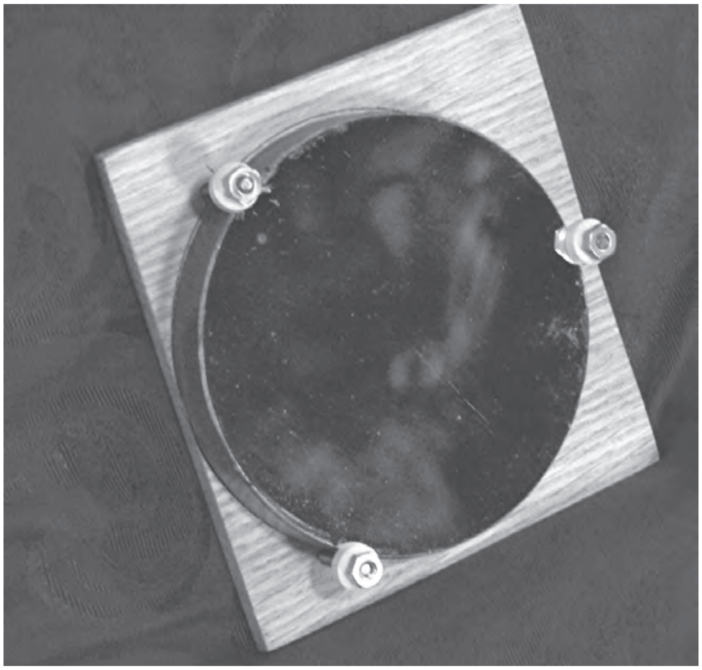

Figure 1 — The f/8, 114-mm diameter, front-surface plate-glass spherical mirror used in the experiments.

which he affirmed his advocacy of the Copernican system and the indefinite depth and distribution of stars.

Critics have suggested that small telescopes of this type were impractical because of the difficulty of preventing interference from the observer's head and because of extensive off-axis aberrations. A number of "modern Herschelians" have been built in which light from the primary is directed toward a diagonal mirror located on the side of the tube and then across the tube to the eyepiece. However, I was interested in determining the limits of feasibility of a small telescope in its most fundamental form.

My approach was to place myself in the mind of Leonard Digges. Through his experiments with mirrors and lenses, he would have discovered some interesting possibilities. How would he proceed to realize their potential?

The optical components, materials, and methods of construction I used are the same as those available in the mid-16th century. One component that may be questionable is the nature and quality of the mirror. Thomas Digges probably used an amalgam-coated front-surface mirror or one of polished bronze, tin, or steel. It should be remembered that Digges and other experimentalists of his day were alchemists and metallurgists who experimented with various alloys, so that metals with highly reflecting surfaces were familiar to them. If Digges himself did not have the proper material, he certainly would have been in touch with someone who could provide him with it. The methods for figuring and polishing spherical surfaces were well known at that time. A long-focal-length spherical mirror has the most forgiving of aberrations and is the easiest to produce.

In my construction, I used an f/8, 114-mm diameter, front-surface plate-glass mirror with a spherical figure whose surface had been subjected to several years of use, abuse, heavy dew, and storage, because I thought that it might be more representative of the best that Thomas Digges had available. The light grey areas in Figure 1 are not reflections but deteriorations in the coating. Nonetheless, it yielded good images when used in a Newtonian configuration. Its reflectivity is, at best, 60%. For eyepieces, I used plano-convex and double-convex lenses, each with a focal length of 25 mm, and a double-convex lens with a 50-mm focal length. These yielded magnifications of 36× and 18× respectively. The original form of the telescope was essentially an optical bench that could be attached to an equatorial mount for testing. The eyepiece holder was made so that the eyepiece could slide toward or away from the mirror for focusing and horizontally for alignment with its axis. The inclination of the mirror and eyepiece holder to incident light was 7 degrees.

After initial tests, I constructed a light shield around the mirror and added a smoothly sliding tube to the eyepiece holder to facilitate fine focusing (Figure 2). None of these improvements go beyond what might have occurred to 16th-century experimenters or would be beyond their capabilities.

I observed with this instrument from late March through early June of 2008, with the following results and conclusions. With the 50-mm eyepiece on a moonless night, stars fainter than 8th magnitude were clearly visible as well-defined points of light near M42 in Orion. The nebula was faintly seen. If the Digges mirror had lower reflectivity, he would have been able to see stars to between 7th and 8th magnitude, but could not have seen the nebula well enough to identify it.

I observed Saturn on a number of nights during this period with the 36× simple lens eyepiece. As I gained experience with the instrument's problems, I was able to correct them and eventually obtain well-resolved images. Focusing turned out to be a two-step procedure. The horizontal adjustment that I had provided for the eyepiece holder proved to be an important element. After preliminary focusing, I found it necessary to move the eyepiece horizontally to obtain precise alignment with the mirror axis for the sharpest image. Once I did this, Saturn appeared as a well-defined sphere with space between the planet and the edges of the ring at 36× — an appearance similar to Galileo's description. The double-convex lens gave a wider field and slightly sharper images than the plano-convex eyepiece. Early in the morning of May 28, in very stable air, Jupiter was high and well placed for observation. Its two major cloud belts were clearly defined at 36× with the plano-convex eyepiece; its four moons were easily visible points of light.

I took the photographs of the Moon on June 9th using the afocal method at 36× with a five-megapixel camera at 1/45 second and ISO 100. For one, I used a modern 25-mm Plössl eyepiece for the purpose of evaluating a photo against one with the plano-convex lens. The image with the modern eyepiece is

Figure 2 — The telescope, constructed in a fashion that mimics the capabilities of 16th-century craftsmanship.

slightly sharper and has better edge definition. The simple lens, however, yielded a surprisingly good image (Figure 3) and it is difficult to tell the two apart.

Sufficient inclination and displacement of the eyepiece kept my head from interfering with the optical path during observation. During the early cold March evenings, I did experience some interference from body heat — a problem I have also with modern Newtonians of the same size. With the tube mostly open, I did not have problems with tube currents.

I took the better part of four months of spare time (as a retiree, I have a lot of that) to construct, identify, and find solutions to problems presented by this type of telescope. Would Leonard and Thomas Digges have done the same? I would like to think they might, as it seems a common nature of those who persistently pursue their curiosity about natural phenomena.

This form of telescope was later constructed by Nicola Zucchi, possibly as early as 1608 (Gillispie 1980, Bangert 1972). His first experiences were disappointing. The difficulty was probably due to the use of short focal lengths that produced excessive spherical aberration. He apparently continued to experiment with longer focal lengths until he obtained satisfactory images, evidenced by his reported observations of the two major cloud belts on Jupiter. He is also reported to have presented one of his reflecting telescopes to Kepler.

As I have demonstrated, good images can be obtained with the Digges-Herschel reflecting telescope with spherical mirrors having focal ratios as low as f/8. A longer focal length would possibly have yielded better results. The telescope that Thomas Digges may have used was undoubtedly inferior in reflectivity and possibly resolution. It would, however, have easily shown him fainter stars, craters and mountains on the Moon, and the phases of Venus. He would have seen Mars, Jupiter with its moons, and Saturn as extended spheres rather than points of light.

This type of reflecting telescope was short-lived until its adaptation by William Herschel for his larger instruments. Difficult to use, even for an experienced observer, it is extremely sensitive to optical alignment and focusing. On cold nights, image deterioration due to the passage of the observer's body heat into the light path is a factor. Higher magnification can only be obtained with longer focal length mirrors that require the observer to stand on a ladder to look down at the mirror. Although the early refractors were also very long in order to minimize lens aberrations, the observer could sit or stand on firm ground in a much less precarious position.

Newton's improvement was to shorten the telescope by using a parabolic mirror and to view the image on axis. The observer could stand in a comfortable position at the side of the telescope where the effect of body heat was minimized. Even so, the refractor was favoured throughout the 18th and 19th centuries because of the loss of light by reflection from speculum metal mirrors.

If Thomas Digges had access to a telescope, did he use it for astronomical observations? If so, why didn't he write about them? Perhaps he did, but not overtly or specifically. He published, as an addendum to a 2nd edition of another of his father's books, *Prognostication Everlasting*, an interpretation of the Copernican system as being situated in space among stars that were indefinite in number and spatial distribution (Bangert 1972). This publication included a Copernican diagram with the stars distributed throughout space, rather than being fixed to a sphere. In 1579, in a list of "books began by the author, hereafter to be published," he lists "*Commentaries upon the Revolutions of Copernicus by Evident Demonstrations Grounded upon Late Observations...*" (Hogg 1952). Both his concept of stellar distributions and his reference to observations supporting the Copernican theory would seem to indicate that he had been influenced by telescopic observations.

At that point in history, advocating the Copernican philosophy and the infinite distribution of stars could have been risky business. These were among the ideas for which Giordano Bruno was tortured and burned in 1600. Galileo naively underestimated the opposition he would face to the publication of his discoveries. Had he not recanted, he probably would have been treated much more severely. Advocacy of radical views

Figure 3 — A photograph of the Moon taken afocally with a modern digital camera through the telescope in Figure 2.

of the structure and organization of the Universe was barely tolerated. To purport to give empirical evidence to support them challenged the very foundation of philosophical and theological reasoning and threatened ecclesiastical authority.

Many scholars of the time kept their ideas to themselves and discussed them only within a circle of close friends whom they could trust to be discreet. Among those who could have been privy to such discussions was William Shakespeare, as Usher (2006) has proposed in his book *Hamlet's Universe*. Usher maintains that the Hamlet plot is an allegorical comparison of the Digges-Copernican view of the world to those espoused by Ptolemy and Tycho Brahe. Throughout the play, there are comments and references that indicate Shakespeare had knowledge of astronomical phenomena such as the phases of Venus, lunar topography, and the distribution of stars in space. This information most likely came from the discoveries of Thomas Digges. According to Usher, Shakespeare used Hamlet to demonstrate the struggle between the rejection of the old philosophy and the acceptance of a new worldview.

The practice of telescopic astronomy did not begin at a point certain in time. It evolved as investigators, curious about light and optics, began to examine the potential of combining different optical elements, with varying degrees of success. Some made notes of their progress. Others did not. However, gradually a body of knowledge accumulated that permitted the beginnings of practical instruments. Ultimately, one person had the knowledge, audacity, courage, and naivety to announce his discoveries to the world in a loud voice. This was Galileo in *Sidereus Nuncius*.

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Great Images

"The stitched images were taken on 2009 January 03 from my back porch using my handheld Canon 50D, an image-stabilized 18-200-mm lens at 18mm, ISO 800, f/5.6, at 1/8000 second exposure, and combined with Canon PhotoStitch software. Roy Bishop tells me this is a Parhelic Circle, with the leftmost sundog 22 degrees from the Sun, and the rightmost 120 degrees away, separated by 98 degrees. The apparition was present in the east and somewhat in the north, but quite dim." (Photo by James Edgar)

Pen & Pixel

Figure 1 — This image, courtesy of Ron Brecher, KWRASC, is made up of 51 x 90-s unguided exposures using a modified Canon Digital Rebel XT, 105-mm f/6 refractor, and Hutech LPS filter. Acquired and processed with *Images Plus*. See page 24 for additional details.

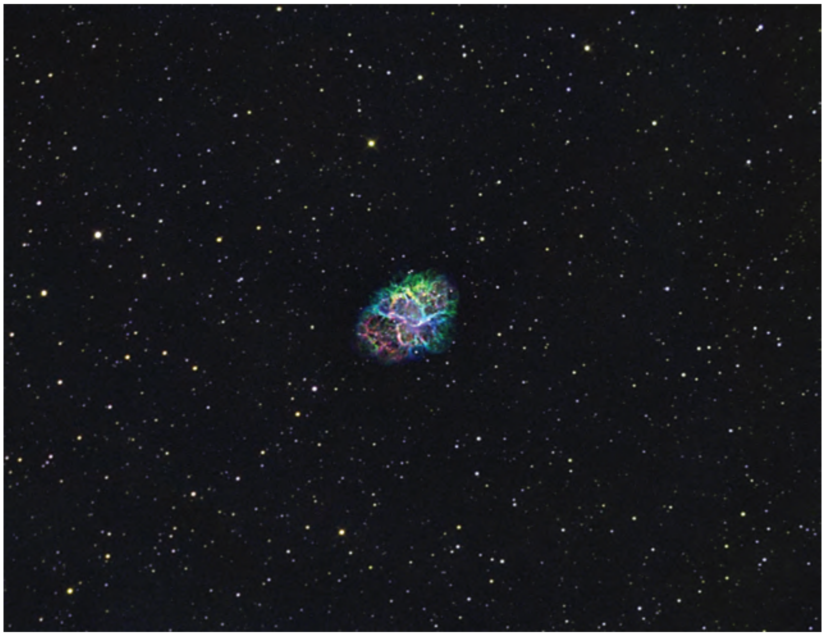

Figure 2 — The Crab in a different light: this colourful image of the Crab Nebula was acquired by Pierre Tremblay on 2008 September 18 using a Takahashi CN-212 with an ASA corrector/reducer. Pierre used a Starlight Express SXV-H9 camera to collect light in three wavebands: OIII, SII, and Hα. In the image, Hα is green, SII is red, and OIII is shown in blue. Total exposure for this three-colour composite was 190 minutes.

Figure 3 — Rémi Lacasse trapped the Bubble Nebula (NGC 7635) in Cassiopeia, also using OIII, SII, and Hα filters. The bubble is being inflated by the intense stellar wind of a massive central star. Opposing the expansion is the nebula in which the star is immersed. The fierce UV radiation from the central star heats up the surrounding nebula, causing the whole thing to glow in the many wavelengths of the composite gases. Rémi used a 12.5″ RCOS Ritchey-Chrétien telescope and an ST-10XME camera from SBIG. Total exposure time was 15 hours — 5 in each filter. In this representation, SII is used for red, Hα for green, and OIII for blue.

Figure 4 — A February *Journal* needs a Valentine, and Stuart Heggie has provided this one for the lovers in the RASC. The Valentine Nebula (IC 1805 or occasionally, the Heart Nebula) is a mixture of glowing hydrogen gas and dark clouds situated at a distance of 7500 light-years. Stuart took this image using an SBIG STL-11000 camera on a Takahashi FSQ telescope. Total exposure is 330 minutes, 300 of it through a 6-nm Hα filter. Happy Valentine's Day!

On Another Wavelength

The Rosette Nebula

By David Garner, Kitchener-Waterloo Centre (jusloe1@wightman.ca)

The Rosette Nebula (Figure 1, p 22) contains, among other things, an HII (ionized) region often favoured by astrophotographers at this time of year. It is a beautiful emission nebula, somewhat round in shape, hollowed out in the centre, and located in the constellation Monoceros, just 13 degrees to the east of Orion. Although it has low surface brightness, with an apparent magnitude of 9.0, it is still visible with smaller telescopes. It helps to have a wide field of view, as the Rosette is 1.3° across. A narrow-band nebula filter or OIII filter can also be beneficial on this object, particularly in less-than-ideal skies. The Rosette Nebula can be found 5200 ly away at RA: 06h 33m 45s and Dec: +04° 59′ 54″.

The catalogue designation of the Rosette (NGC 2237) may be confusing since it was previously thought to be four nebulae surrounding a central core. NGC 2237 was originally assigned to the patchy area just west of the central core, whereas the designation NGC 2246 was given to the nebula on the eastern side. Just beside NGC 2237, a third nebula was labeled NGC 2238. The fourth nebula, NGC 2239 (discovered by John Herschel in 1784), is attached to the southeastern edge of the core. All four were discovered and named long before astronomers realized that they are all part of one large nebula.

The heart of the Rosette Nebula, first noticed by Flamsteed around 1690, is occupied by an open cluster (NGC 2244) of hot O and B stars that emits copious amounts of ultraviolet light. The UV radiation from these hot stars ionizes the hydrogen atoms in the surrounding gas clouds. When an electron subsequently recombines with the ionized hydrogen atom and cascades down to a lower energy level, it emits the distinctive red (Hα) glow characteristic of most galactic emission nebulae.

The stellar winds from these hot O and B stars have also created an expanding shock wave, travelling at 4 km per second, that has cleared a hole in the centre of the nebula (giving it a wreath-like appearance) and is now slamming into cooler surrounding gas, raising temperatures there to 6 million K. This shock-induced thermal energy is subsequently radiated as X-rays, and along with the shock wave itself, is believed to have triggered the formation of many new stars.

If you look closely at some of the outlying nebulous areas in Figure 1, you will notice dark dust lanes and small dark clouds. The smaller dark clouds, known as Bok globules, are dense concentrations of gas and dust that are condensing to form new T Tauri stars — pre-main-sequence stars in the process of gravitational contraction. Bok globules are often found within glowing H II regions. The small, dark filaments of dust extending towards the centre of the Rosette are often referred to as "elephant's trunk" nebulae because of their visual appearance. At higher resolution, they are characterized by bright edges of strong emission, a sign of the high-energy processes occurring on their perimeter.

Dave Garner teaches astronomy at Conestoga College in Kitchener, Ontario, and is a Past President of the K-W Centre of the RASC. He enjoys observing both deep-sky and Solar System objects and especially trying to understand their inner workings.

Calculating Meteoroid Orbits

Part II: Three Dimensions

by Jeremy Tatum, Victoria, British Columbia

In Part I of this two-part article (Tatum 2008), we showed how to calculate the orbital elements of a meteoroid orbit in two dimensions. In a two-dimensional world, an orbit is described by four orbital elements, namely the semi-major axis *a,* the eccentricity *e,* the argument of perihelion ω, and the time of perihelion passage *T*. It was presumed in Part I that we knew, relative to a heliocentric coordinate system, the position vector of Earth and meteoroid at the time of encounter, and the velocity vector of the meteoroid. Each of these vectors has two components, and, from these four data, we were able to calculate the four orbital elements.

In three dimensions, we need two additional orbital elements to define the orbit, and we also need to define the element ω a bit more carefully. The position and velocity vectors each have three components (presumed known), and we shall see in this article how to calculate the six orbital elements from these six data.

The positions and velocities of Earth and meteoroid are referred to a heliocentric ecliptic coordinate system O*xyz,* in which the *xy*-plane is the plane of the ecliptic and is identical with the two-dimensional axes that we used in Part I.

In Figure 1, I have drawn a Sun-centred sphere of arbitrary radius, with the Sun at O, and a set of orthogonal axes, O*xyz,* with the *x*-axis directed towards the First Point of Aries, as described in Part I, and the *z*-axis directed towards the pole of the ecliptic. Figure 1 shows a plane **E,** which is the plane of Earth's orbit (*i.e.* the ecliptic) and a plane **M,** which is the plane of the meteoroid's orbit. Both bodies are assumed, in Figure 1, to be moving counterclockwise. Also indicated in Figure 1 is a second set of axes, O*x'y'z'*. The *x'*-axis is directed towards the ascending node of the meteoroid's orbit, and the *z'*-axis is directed towards the pole of the plane **M.** The *y'*-axis, which is in the plane **M,** is not drawn in the figure. Encounter of the meteoroid with Earth necessarily takes place at a node of the meteoroid's orbit. We suppose that the heliocentric velocity of the meteoroid (see Part I of this paper for a discussion of the pertinent velocity) is **V,** and that its components *u, v, w* relative to the O*xyz* axes are known. The vector **V** is, of course, in the plane **M.** If *w* is positive, the encounter is at the ascending node of the meteoroid's orbit, and Figure 1 has been drawn as though this were so. If *w* is negative, encounter is at the descending node. The line OP is the direction to the perihelion of the meteoroid's orbit. The additional orbital elements that we need in three dimensions (in addition to the *a, e,* ω, and *T* that we needed in two dimensions) are the angles *i* and Ω, which describe the orientation of the orbit in space. These angles are called, respectively, the *inclination* of the orbit and the *longitude of the ascending node*. The *argument of perihelion,* ω, which we have met before, is measured from the ascending node in the direction of the motion of the meteoroid in the range 0° - 360°. The angle Ω is measured eastward from the *x*-axis and is in the range 0° - 360°. The inclination is in the range 0° - 180°, inclinations greater than 90° corresponding to retrograde motion.

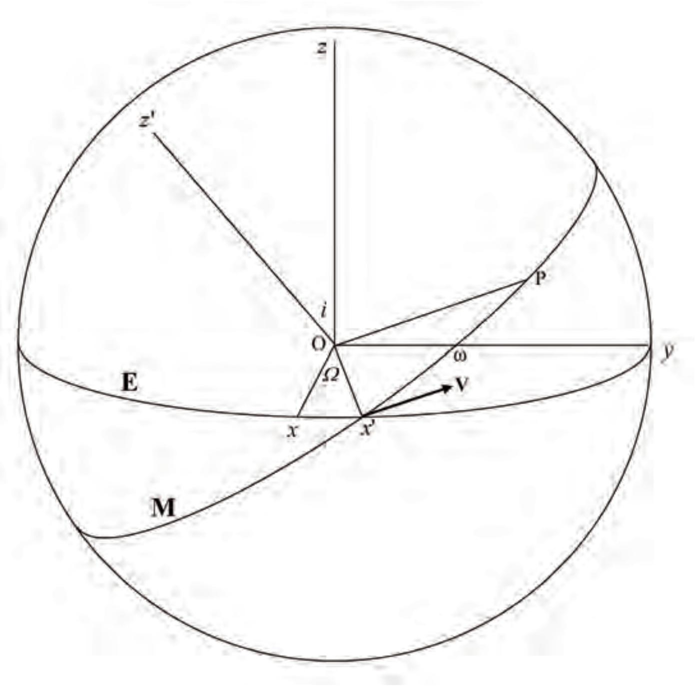

Figure 1 — Illustrating the geometry of an orbit in three dimensions.

The components of **V** referred to the system O*xyx* are, as we have said, *u, v,* and *w,* and are assumed known. Referred to the system O*x'y'z'*, the components of ***V*** are *u'*, *v'*, 0, and we need to be able to express the one set of components in terms of the other. Note that $V^2 = u^2 + v^2 + w^2 = u'^2 + v'^2$. This transformation is obtained by two rotations, first about Oz through Ω, followed by a rotation about Ox' in a way that will be familiar to some. Whether familiar or not, the result is

$$u' = u\cos\Omega + v\sin\Omega, \tag{1}$$

$$v' = (-u\sin\Omega + v\cos\Omega)\cos i + w\sin \tag{2}$$

$$0 = (u\sin\Omega - v\cos\Omega)\sin i + w\cos i. \tag{3}$$

The first of the six elements to be obtained is the semi major axis *a,* which, as in Part I of this paper, is found immediately from

$$a = \frac{1}{2 - V^2}. \tag{4}$$

The inclination *i* lies between 0° and 180°, and so it can be found immediately without quadrant ambiguity direct from equation (3), thus:

$$\tan i = \frac{w}{v\cos\Omega - u\sin\Omega}. \tag{5}$$

The velocity components u' and v' are found from equations (1) and (2). Since these are the components in the plane of the orbit, the remaining four elements can be found precisely as in the two-dimensional case covered in Part I — indeed rather more simply, since the argument of perihelion is to be measured from the ascending node.

Example:

Suppose that the ecliptic coordinates of Earth at the time of the encounter are $(x,y) = (0.965926\,, 0.258819)$. We immediately know that $\Omega = 15°$ or 195°, depending on whether the encounter is at the ascending or descending nodes of the meteoroid's orbit. Suppose that the ecliptic velocity components, in units of 29.78469 km s^{-1} (see Part I), are $(u,v,w) = (0.3, 0.9, 0.7)$, so that $V = 1.17898$. Since w is positive, the encounter must be at the ascending node, and hence $\Omega = 15°$. Further, from equation (4), we have $a = 1.639$ A.U. The inclination is given from equation (5), and is found to be $i = 41° \; 29'$, so we already have three of the elements.

Equations (1) and (2) give us $u' = 0.5227$ and $v' = 1.0568$. As a check for mistakes, note that $u^2 + v^2 + w^2 = u'^2 + v'^2$. Since encounter is at the ascending node, $\theta = 0°$ and therefore $\alpha = \psi = \tan^{-1}(v'/u') = 63° \; 41'$. (See Part I for definitions of these angles.) From equation (5) of Part I, we obtain $e = 0.5646$. Equation (6) of Part I, with, $\theta = 0°$ gives us $\cos\omega = 0.2068$ and hence $\omega = 78° \; 04'$ or $281° \; 56'$ As in Part I, we can determine which is the correct ellipse by drawing the two possible ellipses and comparing them with the direction of the vector **V,** and it is found that, with u' and v' both positive, the correct solution is $\omega = 281° \; 56'$. Using the methods described in Part I, we rapidly obtain

$E = 46° \; 12'$, $M = 22° \; 15'$, $T = t - 0.1315$

sidereal years, and the calculation is complete. ◆

Reference

Tatum, J.B. 2008, JRASC 102, 234

Society News

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

As I write this, we are in the process of selling the venerable old building at 136 Dupont Street in Toronto. While it has served our needs well for the past three decades (purchased in 1985), National Council has approved the motion at the last meeting to dispose of the property. There are several good reasons why we reached this decision, not least of which is that we, the RASC, are very poor landlords — none of the Executive have the time or the inclination to deal with the niceties of a landlord/tenant relationship, nor do we want to start. Our very recent travails with the former upstairs tenant has forcefully brought home to us that we can no longer afford to be complacent that all will be well "up there" with little or no attention.

In addition, we have to change with the times. We no longer have a vibrant lending library — it stagnates in cardboard boxes in the musty, leak-prone basement of the old National Office. Fortunately, steps have also been taken to find a new home for many of the important books there. The Canada Science and Technology Museum in Ottawa has graciously agreed to transport and house a good portion of the books, keeping them as a legacy library collection of the RASC. Which means that we no longer require quite the same square footage as in the past. In fact, Jo Taylor, Executive Secretary, has found a mailing fulfillment centre that stores and mails our Calendars and Handbooks, further reducing our storage needs.

Where do we go from here? Onwards and upwards! We have an active Property Committee, whose members are seeking new premises to lease or rent in Toronto (that last requirement is a must, unless 2/3

...Continued on page 43

An Interview with Longtime RASC Member Larry Wood

by Warren Finlay, (warren.finlay@interbahn.com), Edmonton Centre

Astronomers are a diverse bunch. Some like observing Solar System objects, others like variable stars, while others like the deep sky. In every club, there are usually a few die-hard deep-sky enthusiasts who spend hours trying to find some dim fuzzy object at the limit of visibility. If you ask to look through their scope, chances are that half the time you will see no sign of the object they are waxing on about. In the Edmonton RASC, there are several such observers, but probably the most currently active such member, whose vision has been dubbed "Larryvision" due its keenness, is Larry Wood. In an effort to understand the legend that is Larry, the following are his answers to a few questions I posed:

What got you into astronomy?

Comet Halley. I saw a chart in the newspaper and tried to find it in binoculars. I believe I saw it, but can't swear to it as I didn't know very much about astronomy then, as I had never looked through a telescope. The next summer I bought a 4.5″ scope, learned a bit of the sky, and observed the Moon, the planets, and some stars, then joined the RASC Edmonton Centre the following year.

Which is your favorite Messier object?

M77, the face-on spiral in Cetus. When using my 12.5″ scope, I have only seen the outer spiral structure of the galaxy a couple of times when conditions were very favourable. On most other occasions, all that is seen is the central core.

What is the most difficult object you have ever observed?

Probably the globular cluster Palomar 3, although NGC 2242 is a tough planetary nebula in Auriga. Maffei 1 is pretty tough, mostly because I first found it by star hopping from the Double Cluster, through the Milky Way star field, which made for a very difficult star hop. It probably took me three or four hours to find it that first time.

What is the deep-sky object you most frequently observe?

I would say the Ring Nebula (M 57), as it can easily be observed from the city using an OIII filter, although Nova Cassiopeia 1993 must rate a close second, as I tracked its slow decline in brightness over about 10 years.

Larry Wood

What advice would you give to someone just beginning deep-sky astronomy?

Keep track of your observations with drawings or notes, because I believe recording your observations will improve your observing abilities. Also, it is interesting and informative to look back, after a period of years, at your previous observations.

What advice would you give to someone who has a few years of deep-sky observing under their belt?

Learn to use averted vision; believe in your ability to see faint detail, and learn to trust what you are seeing. If you are not using a GOTO scope, I would suggest that you choose a recognized astronomical atlas and learn to use it well. Using a fixed set of charts with the same scale allows you to get a better feel for distances on the charts and makes finding objects much easier than using charts whose scale is often different (*e.g.* as occurs on a computer).

What advice would you give to an experienced deep-sky observer?

Keep observing! Use a good, well-collimated scope.

What motivates you to get out observing under dark skies so often?

I love to get out of the city, under a dark sky, where it is usually peaceful and quiet. It's also very satisfying to find difficult objects that I haven't seen before. As the years go by, I get out less than I used to. It is also more difficult to plan my observing sessions, as I have already observed the brighter and more northerly favourite objects, so those left are getting scarce or are located in less accessible skies. Oh no — I'll have to hunt for faint fuzzies (galaxies)!

Do you wish you had a bigger scope?

No. It's nice to occasionally look through a bigger scope to confirm an observation that I have made in my present scope. Maybe if I was younger, I would go after really faint stuff with a bigger scope, but I'm pretty happy with my 12.5".

What is your favorite eyepiece?

Without a doubt, my 7.5-mm Antares Plössl, which has a 55° field of view and gives me 250× magnification and 12' FOV. I use a 2× Barlow with 7.5-, 10.5-, and 13-mm oculars to attain higher magnifications. I also love my 20-mm Nagler as a finder eyepiece and when looking at large or diffuse objects, such as Stephan's Quintet.

What is your favorite telescope design?

A well-collimated Newtonian reflector is tough to beat. Refractors are nice, but more aperture is more useful for deep-sky observing.

What type of deep-sky object do you most like?

Planetary nebulae. I have observed over 300 of them. The fainter objects require using an OIII filter, but I get the most out of the observation without using any filter. I have a spectroscope that I use to help find the really small, dim ones since they can be nearly impossible to differentiate when seen in a crowded star field.

Who is your favourite professional astronomer of all time?

I would have to say Tycho Brahe. He didn't have many shoulders to stand on. Maybe William Herschel too, although not earning a living from astronomy rates right up there as well.

If you could take your telescope to observe anywhere on Earth, where would you go?

Do I have to stay on Earth? How about above the atmosphere? I suppose if I have to stay Earthbound, then it would be the high mountain deserts in Chile.

Warren Finlay is a Professor of Mechanical Engineering at the University of Alberta, a keen explorer of the night sky, and the award-winning author of Concise Catalog of Deep-Sky Objects.

Astronomical Art & Artifact

A Tale of Two Globes

R.A.Rosenfeld, RASC Archivist (randall.rosenfeld@utoronto.ca)

Concrete representations of astronomical theories, mock-ups of scientific instruments, and "scale" models of celestial phenomena have an allure that easily transcends their timebound usefulness. Orreries and simpler geared planetaria, astrolabes and equinoctial sundials, engineers' models of the last century's big telescopes, and celestial globes redolent of past astronomies seem not so much lifeless as merely in repose, as if we could animate them through our desire to know what they are, what they did, and who used them. Familiar in some aspects, in others they appear utterly unfamiliar, connecting us to a longer history of instruments, learned societies, collections, theories, applications, and symbols. A consideration of the Society's two remaining antique celestial globes can take us to unfamiliar places indeed.

The first of the globes is almost monumental, with a diameter of 18" (45.72 cm) and a combined height of 49" (124.46 cm) for globe and stand together (Figure 1).[1] Its sphere appears to be of plaster, with each hemisphere covered by 12 half-gores

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[1] Monumentality in globes, as in all else, is a relative thing. Fr. Vincenzo Coronelli's (1650-1718) twin 13'-diameter (4-m) globes (1683) for Louis XIV are of a whole different order of magnitude from the RASC globes (Nicolini De Marzio 2005; Hélène 2006; `http://expositions.bnf.fr/globes/index.htm`).

Figure 1

Figure 2

printed with white stars, gold constellation figures, black labels, and ecliptic and equator lines on a greyish-blue background.[2] The globe's surface is varnished, a treatment commonly used on 19th- and 20th-century globes to preserve their printed surfaces (the varnish has suffered some degradation, possibly due to exposure to sunlight). Its stand is made of copper-alloy, German silver (an alloy of nickel, zinc, and copper), japanned cast iron with gold and red polychrome highlights and decorative motifs, and carved and stained wood. It is equipped with a simple but effective lock-knob near the bottom of the polar axis. It seems likely, from the empty space between the globe's north pole and the bottom of the top finial, that some decorative or functional element of the polar axis is missing. Under the figure of the constellation *Hydra* is a cartouche with the inscription "18 INCH CELESTIAL GLOBE./W.&A.K. JOHNSTON/EDINBURGH & LONDON," and to the right of *Monoceros'* back legs is a legend indicating stellar magnitudes from 1 to 6, the white stellar symbols being differentiated by size and form (Figure 2). The globe is fairly well preserved, although there are several local dents in its fabric. The only noticeable design fault is in the wooden base of the stand, which is rather unstable due to the combination of the globe's high centre of gravity and the narrow spread of the stand's feet; it is quite susceptible to inadvertent toppling (doubtless the cause of its dents). There is no sign that the legs have been cut down, or that the stand has been altered from its original state. The stand, stylistically, decoratively, and technologically of the same vintage as the globe, is an elaborate and somewhat unusual support.[3] I do not at present know of a comparable W. & A.K. Johnston globe similarly mounted, but that firm may have undertaken it as a special order, or the stand may have been custom work by a specialist after the globe was manufactured by Johnston; it could conceivably have been crafted in Toronto, or elsewhere in Canada. The globe is to be dated between *ca.* 1875-1910.

The firm of W. & A.K. Johnston was founded in Edinburgh *ca.* 1830 and lasted there with permutations until 1953. They established a London (U.K.) branch *ca.* 1869, which folded around 1901. They did a brisk trade in maps, atlases, and globes, and during the second half of Queen Victoria's reign, rose to the top ranks in their field. The largest globe the firm produced had a diameter of 30", and was displayed at the Great Exhibition of 1851 in London (Dekker 1999, 55, 372).

I have been unsuccessful thus far in tracing the full provenance of the RASC's W. & A.K. Johnston globe. It is probably the globe given to the Society by Lady Wilson in 1892 upon Sir Adam Wilson's death (1814-1891; Parker 2000). It would not have been a trivial purchase, either new or "pre-owned." Some idea of its uncommon value in late-Victorian Toronto can be gathered from the earliest Society references to it: "It will afford me much pleasure," writes Lady Wilson, "if you (the Astronomical and Physical Society of Toronto) will accept the telescope and celestial globe of the late Sir Adam Wilson, as it was his express wish that they should be offered to the Astronomical Society, in which he took so much interest" (TA&P 1892, 35-36).[4] The Society, in gratitude, elected Lady Wilson a life member, and voted "that the telescope and celestial globe be known and inscribed as the SIR ADAM WILSON

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[2] A gore is a section of a sphere or hemisphere that takes the form of a lune or a spherical triangle respectively. After gores are printed they are cut to their borders and glued to the plaster or wooden sphere or hemisphere of the globe.

[3] I can find nothing like it in the globe catalogue of the Stewart Museum in Montreal, one of Canada's finest collections of such apparatus (Dahl and Gauvin *et al.* 2000).

[4] The whereabouts of Sir Adam's telescope, in common with much of the Society's historical apparatus, is presently unknown. Presumably, it miraculously developed legs and eloped with an ardent admirer in decades past.

MEMORIAL" (TA&P 1892, 36). In a meeting of 1893 October 17, it was reported that: "The Ladies' Committee, appointed for the purpose, having completed their labours, presented to the Society a very handsome cover, ornamented with astronomical designs skilfully worked in silk, to be used for protecting the Sir Adam Wilson Celestial Globe and other apparatus" (TA&P 1893, 97).[5]

That Sir Adam's globe was more than an impressive piece of moveable property in the Society's hands can be gathered from a report of a meeting of 1893 September 5: "Mr. Mungo Turnbull gave some practical illustrations of the method of using the celestial globe recently constructed and patented by him, using for the purpose the globe presented to the Society by Lady Wilson, in accordance with the wish of the late Hon. Sir Adam Wilson, Q.C." (TA&P 1893, 84).[6] The firm of W. & A.K. Johnston issued a manual for the use of celestial globes with features a little beyond Sir Adam's, presenting astronomical exercises requiring more than a passing familiarity with the basics of spherical trigonometry, rather along the lines of introductory university courses of the time (Johnston 1912). Some of these exercises could have been solved using Sir Adam's globe. Clearly his and Lady Wilson's gift to the Society was capable of rising beyond the status of a rich man's toy.

The second antique globe belonging to the Society, "The Husun Star Globe" (Figure 3), is a contrast in every way with the W. & A.K. Johnston globe, for although it is by no means tawdry, its 7" (17.78 cm) diameter attests to its relative compactness, its epochal 1920 date declares its more recent vintage, and its box, fittings, and accessories render it more specialized. It is one of a class of celestial globes called a "Star Finder" by its inventor, Lieutenant English of Her Britannic Majesty's Navy (Dekker *et al.* 1999, 301). Star Finders are well represented in major collections of scientific instruments around the world, with at least seven by four different makers at the National Maritime Museum, Greenwich (Dekker 1999, 300-303, 354, 366-368, 379-381), and one at the Naval Academy in Copenhagen (Andersen 1995, 42). Each of these collections has a Husun Star Globe identical to the RASC artifact. There are minor variations between the Star Finders by the competing firms, but the instruments are largely interchangeable (the most noticeable difference lies in the globe diameters, and in the proprietary retail labels!). This design, apart from periodic updates of the star positions, was virtually unchanged in production from approximately the late 1890s to the mid 1970s. A testament to the success of Lieutenant English's globe was the production of knock-offs by the Soviets during the Cold War. The Soviet star finders were made of cheaper materials and displayed rougher workmanship than their English exemplars, but they were still serviceable.

Figure 3

The sphere of the Husun Star Globe appears to be of plaster, and the printing is on twelve whole gores with polar *calottes* at both poles, and spherical zones marking the transitions between the *calottes* and the gores.[7] The background colour is ivory, with the stars, labels, equator, ecliptic, and declination scales, cartouche, and magnitude legend all in black. Constellation figures and boundaries are omitted, and only the most prominent of the stars are shown. The paper surfaces are all varnished, the Husun globe being much more heavily and evenly so treated than the W. & A.K. Johnston globe. The contrast between the printing and the background on the Husun Star Globe is much greater than on the W. & A.K. Johnston globe, although some of the present inadequate contrast on the latter may be due to the effects of decades-long exposure to sunlight already mentioned. The Star Finder was not subject to the same deterioration thanks to its being kept in its fitted mahogany box. The cartouche reads: "THE HUSUN STAR GLOBE/H.HUGHES & SON, LTD/LONDON/1920," and the legend indicates the symbols for stellar magnitudes, from 1 to 4.

The fitted case is of mahogany, with instructions pasted to the inside of the lid. The horizon and meridian rings are of copper-alloy, as is the detachable skeletal hemisphere, and the set of moveable index pointers. The rings are carefully divided (doubtless by an engine), and the incise marks are filled with black. The serial number (3439) is engraved on the inner horizon circle. The box has provision for the storage of two wax pencils, red and blue, which are missing (the present archivist

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[5] This artifact, like Sir Adam's telescope, can no longer be traced. I have not yet had any luck finding a photograph of the needlework.

[6] It is remotely possible that this statement is to be construed as meaning either that Sir Adam's globe was of Turnbull's design, or that Sir Adam's globe is not the W. & A.K. Johnston globe currently in the Society's possession. Turnbull was an early member of the Society, and the author of several works such as Turnbull 1892.

[7] A *calotte* is a spherical cap, and is named after the skull cap traditionally worn by clerics and scholars such as astronomers in the 19th century and earlier, *e.g.* the portraits of Pierre Gassendi (1592-1655) by Claude Mellan (1598-1688) or Ismael Boulliau (1605-1694) by Pieter van Schuppen (1627-1702). After *calotte* and spherical zones are printed, they are cut to their borders and glued to the plaster or wooden sphere or hemisphere much like gores.

has provided facsimile replacements).

The manufacturer, Henry Hughes & Son, was operational from *ca*. 1840 up to the period of the Second World War, at which time they joined with another manufacturer of scientific instruments, becoming Kelvin & Hughes Ltd. at War's end. The pre-amalgamation firm enjoyed a solid reputation for mathematical and nautical instruments (Dekker 1999, 366).

This globe was willed to the RASC by Ruth Northcott (1913-1969), a former professor of Astronomy at the University of Toronto, a protégé of C.A. Chant's, and a former editor of the *Observer's Handbook* (Broughton 1994, 79; Bishop 2008). For a while, this globe functioned as an unofficial symbol of office for the editors of the *Observer's Handbook* from 1958 to 2000 (Bishop 2000), ineluctably recalling the renaissance woodcuts, where one can spot the astronomer simply by locating the figure holding the armillary sphere.

The prime purpose of Lieutenant English's Star Finder was a nautical one, namely to enable the navigator during brilliant twilight to securely identify the single bright star that alone might be visible, and whose position he had just measured. The accurate plotting of the stars on the Star Finder, and its ample provisioning with a useful variety of divided great circles and moveable copper-alloy index pointers meant that it was a perfect apparatus for solving many if not all of the problems in spherical trigonometry requiring a globe in undergraduate astronomy courses. The fact that it could be written on with erasable wax pencils was a further advantage. Many of the scientists who taught the astronomy faculty who are retiring now would have cut their teeth on devices very similar to the Husun Star Globe. Still perfectly serviceable, it is unlikely these devices have seen didactic use for decades. Computer planetaria sounded their death knell. If any reader of this article should be fortunate enough to come across one of these Star Finders, he or she could not lose by working through the exercises in a book such as Wilson's *Laboratory Astronomy*.

It can come as somewhat of a shock for an avocational astronomer to suddenly realize that these post-Copernican celestial globes he or she admires in the local museum, planetarium, or observatory lobby are decidedly *not* post-Copernican at all; they embody a geocentric universe! What of the same astronomer's new prized Ritchey-Chrétien astrograph on a harmonic drive mount; the right ascension and declination coordinates it uses also presuppose a working geocentric system! Is this advanced and terminal recidivism out-of-the-box? How can this be, on the verge of IYA 2009, with so many technical advances since the publication of *Siderius Nuncius?* The worried hobby astronomer should relax, enjoy the wonder of a tried-and-true positional convenience that still works to her or his observational advantage after the passage of so many centuries, savour the connection it provides with earlier astronomers on whose shoulders we all stand, and take the time to ponder how old theoretical concepts and venerable practical techniques are recycled in a healthy scientific discipline. It is one of the glories of modern astronomy, and the sign of a mature field, that it can wear its heterogeneous history on its sleeve, and not be embarrassed by what it may find there. Who said a satisfying "Galileo Moment" can't be complex?

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A Blast From the Past

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

Supernovae seem to come in two broad categories: the sudden collapse of a massive star as its core turns to iron (generally known as type II), and the collapse of a white dwarf that has been accreting gas from a nearby companion. The latter is known as type Ia, and it is those supernovae that have been used to determine that the expansion of the Universe is accelerating. But we haven't had many nearby examples to study. Now Oliver Krause of the Max Planck Institute for Astronomy in Heidelberg, Germany, and his collaborators have been able to determine that Tycho's supernova of 1572 was a typical type Ia (see the 2008 December 4 issue of *Nature*), allowing it to be used for further investigations of type Ia supernovae.

The story starts back in the mid 1960s when, independently of each other, Igor Shklovski and Canada's own Sydney van den Bergh (now at the Herzberg Institute of Astrophysics in Victoria) suggested that it would be possible to determine the type and get the spectrum of an old supernova using "light echoes." The idea of looking for reflected light from supernovae in our Galaxy was first mentioned in passing in 1940 by Fritz Zwicky, who attributed it to Jan Oort. Photons from Tycho's supernova spread out through space in a constantly expanding sphere. Some photons (the direct ones) went past Earth in 1572. Others hit a cloud of dust and gas off to the side (in the sky) of the supernova, from which some were reflected towards Earth, to arrive years later. Think of dropping a rock into a still pond — the waves go outwards uniformly until they hit (say) a pier; new waves are generated, which also travel outwards. An observer on the far shore of the pond would first see the direct waves from the rock, and some time later the much weaker reflected waves from the pier. Previous observations of light echoes (some by Krause, and some by Armin Rest of Cerro Tololo Inter-American Observatory) had revealed the type of Cassiopeia A (a boring type II), and a type Ia in the Large Magellanic Cloud, respectively.

Krause and his colleagues have now obtained a spectrum of light emitted near maximum brightness of Tycho's supernova, 436 years after it happened. The spectrum reveals it to be a relatively standard type Ia supernova, though with a hint that the explosion was asymmetrical. In 2004, Pilar Ruiz-Lapuente of the University of Barcelona, in Spain, reported the discovery of the possible companion to the white dwarf that exploded in Tycho's Supernova — a star similar to the Sun — moving at a speed three times the average for stars in that region. This may connect with Krause's hint of an asymmetric explosion, because asymmetries are believed to be the explanation for the anomalous speeds of some pulsars (neutron stars remaining after the explosion of a massive star).

Astronomers care about type Ia supernovae because they are so useful for cosmology. The collapse of a white dwarf always happens at a critical mass, which is about 1.4 times the mass of the Sun, because of a quantum-mechanical effect. It is this constancy and our good understanding of the basic physics that gives astronomers the confidence to calibrate the "light curves" of type Ia supernovae sufficiently well to use them as cosmological probes. Theoretically, this all hangs together, but in fact there's been precious little observational evidence to support the theory, because nearby supernovae are rare, and in galaxies like the Milky Way, type Ia ones are less frequent than the explosions of massive stars.

There were previous indications that Tycho's Supernova was a type Ia, so this work will not lead to any great immediate revision in our understanding, but it certainly points the way for future study. In particular, Krause raises the possibility of reconstructing a three-dimensional view of the supernova explosion, using light echoes from different directions. If the polarization of the light can be measured, there's a chance of determining a geometric distance to the supernova, because polarization is a maximum for a scattering angle of 90 degrees — the supernova would then be at a distance of ct, where c is the speed of light, and t is the time since the explosion (assuming that the supernova-cloud distance is very small compared to the supernova-Earth distance).

The reason it has taken so long to realize the idea put forward by Shklovski and van den Bergh is that not much light is reflected from the clouds. The measurements are quite difficult (Krause used the 8.2-m Subaru telescope on Mauna Kea), and you have to be lucky enough to have the right cloud at the right distance from the supernova!

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

Through My Eyepiece

Stargazing

by Geoff Gaherty, Toronto Centre (geoff@foxmead.ca)

Frequently I see questions from beginners similar to this: "I'm interested in astronomy and would like to buy a telescope to look at stars."

Many beginners have the impression that the main things amateur astronomers look at through their telescopes are stars. Yet, when did you last look at a star through your telescope? Not a cluster of stars, not a galaxy of stars, but just a star. About the only time I ever look at a plain old star through my telescope is when I'm star-testing a telescope. So, the idea that astronomers look at stars is a major misconception among beginners and the public.

This leads me to the opposite question: What do amateur astronomers actually look at through their telescopes? There are two main areas: Solar System objects and deep-sky objects.

Solar System objects observed by a large number of amateurs include the Sun, the Moon, and the planets. They also include the smaller and more exotic members of the Solar System, such as comets, asteroids, and meteors. Aurorae are Solar System objects, though they've been rather scarce around solar minimum. Solar System observers are going to be deprived of two of their favourite targets for the next few years. Saturn's rings are about to turn edge on to us, and Saturn will turn into a plain ordinary gas giant for the next two years, a bit larger than Uranus or Neptune, but without the exciting meteorology of Jupiter. Mars is now on the far side of the Sun, but when it returns next it will be the first of several perihelic oppositions, with a disk not much larger than that of Mercury (14 arc-seconds vs. 12 arc-seconds for Mercury at its largest).

Deep-sky objects are the other main love of amateur astronomers. First come the Messiers, then the Finest NGCs. Other lists follow, including the RASC's deep-sky challenges and dark nebulae, and David Levy's new list. However, I must confess that, after struggling through the Herschel 400 list, I realized I would be quite happy if I never saw another nondescript faint galaxy!

So why don't we look at stars? Amateur astronomers a century ago used to spend a lot of time looking at stars, often with refractors so small that we wouldn't even think of using them as finders on our giant Dobs of today. When I first got involved in astronomy 50 years ago, there still were observers who specialized in double stars, but they were a dying breed. Until very recently, double star observers were pretty much extinct, but a few people like Sue French have been successfully rekindling an interest in doubles and multiples. It almost feels as if we've been forced to shift our attention to brighter objects as light pollution makes hunting faint fuzzies an increasing challenge. The availability of high-quality refractors at reasonable prices has also contributed to the return to doubles and multiples. There really is nothing quite so pretty as a multicoloured double star viewed through a high-quality refractor.

I've saved the best for last: variable stars! I find variables a constant source of excitement because I never know what they're going to do next. Every night at the eyepiece is filled with adventure as I seek out my favourite stars to see how they have changed since my last visit. Many of the variables I study are red giants — some of the most deeply coloured stars in the sky, such as U Cygni, one of my all-time favourites.

As soon as I start talking about variables, I start saying "my favourite this" and "my favourite that," much as my son David did when he was four years old: "my favourite one!" And that's what keeps me hooked on astronomy: having so many favourites keeps my interest stoked and my enthusiasm high. It doesn't matter what your favourites are: Solar System, deep-sky, doubles, or variables. There's just so much up there in the skies to be enthusiastic about! ◆

Geoff Gaherty is the recipient of the Society's Chant Medal for 2008. Despite cold in the winter and mosquitoes in the summer, he still manages to pursue a variety of observations, particularly of Jupiter and variable stars. Though technically retired as a computer consultant, he is now getting paid to do astronomy, providing content and technical support for Starry Night software.

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A Mockultation and a Miss

by Guy Nason, Toronto Centre (asteroids@toronto.rasc.ca)

The Mockultation

Tourist to New Yorker: Pardon me, sir, can you tell me how to get to Carnegie Hall?
New Yorker: Practice, practice, practice.
— [very] Old joke

As with most other things in life, occultation-timing skills are improved with practice. With that in mind, the RASC Toronto Centre recently held a mock occultation, or "mockultation," at a conservation area northeast of Toronto. We invited both old hands and newcomers to participate in this practice and demonstration session as part of our usual monthly observing program. Participants, in no particular order, were: Mark Steele and his "assistant," Teresa Smegal, Blake Nancarrow, David Zackon, Eric Briggs, Matti Anja, and me. Long-time occultationist Frank Dempsey joined us in an advisory role.

(An occultation occurs when one celestial object passes in front of another one, from the perspective of an observer on the ground. Lunar occultations happen all the time as the Moon sweeps up stars along its orbital path. Asteroids do this too, but much less frequently, because of their small size and more distant orbits. But when they happen, they can be spectacular, causing the star to wink out (or appear to dim a few magnitudes if the asteroid itself is visible), then return to its rightful place in the Universe a few seconds later.)

The participants were encouraged read the article "How It's Done" on the Toronto Centre Web site (`http://toronto.rasc.ca/content/HowItsDone.shtml`) and to bring along voice recorders, short-wave radios, stopwatches, or whatever devices were appropriate to their choice of method. Unfortunately, the stars and asteroids did not cooperate to produce a real occultation on the night in question, so we faked it. I pre-selected a ninth-magnitude star near Algenib (Gamma Pegasi) and distributed finder charts to our potential occultationists. They were advised that the mockultation was predicted to occur on the first clear night of the week of October 27 at 21:21 EDT as part of our regularly scheduled Dark-Sky Observing Session. (Oh! How I wish all occultations could be arranged to happen only on clear nights!) The first clear night turned out to Thursday, October 30. Sometime within several seconds of the predicted time, I would sound my car horn to signify the disappearance of the star. The reappearance would be marked by a second horn beep. Just as with a real occultation, there would be no delays or adjustments for people who weren't ready.

That's why I asked everyone to arrive by 19:30, so we would have plenty of time to set up our telescopes, track down the target star, and test our systems. Murphy and his Law just love occultations, especially in cold weather, so we built in extra time to deal with things that could go wrong. And go wrong they did, as we'll soon see.

Blake was the first to call me over to verify that he was "on" the right star. It took me a few minutes to reorient myself to his mirror-reversed view (SCT) since, being a Newtonian guy, I was unused to that orientation. With Blake's help and by turning the chart over and shining my red flashlight through it from behind, I soon got the knack and confirmed that he had indeed centred the target star in his eyepiece. Soon everyone was dialled in — except me, the old pro.

(A bit of a background: Some time ago the hand controller for my EQ-6 mount died. I ordered a replacement, but it took several weeks to arrive. In the meantime, I borrowed an old one from my friend Dietmar Kupke (Toronto Centre), who had replaced his with a new and improved model. It worked fine. My new one eventually arrived, so I returned the loaner, with my thanks.)

Back to the mockultation: As usual, I went through the three-star alignment procedure. I selected Vega as star #1 and off went the telescope to find it. It stopped with the star dead centre in the Telrad, but slightly off-centre in the telescope. I pushed a direction key to centre it in the view. As expected, Vega moved smartly toward the centre — but kept on going after I released the button! Oh no! Stop! Stop!! I tried the opposite button, but it had no effect. Quickly, I turned off the power switch on the mount before it could damage itself or my tube assembly. I tried again. Same thing. Murphy Lives!! Obviously, any hope I had of using a tracking mount was gone. So I unplugged the battery and reverted to manual mode. Without mechanical slow-motion controls, this was a tricky, jerky business. However, I did manage to find and confirm the target star and, with much trial-and-error, even got the star centred in the very tight field of view of my video camera. Keeping it there was not easy because the narrow field of view meant that it drifted across the frame in less than a minute. Constant attention was required.

But I was the facilitator here and had other duties. These included verifying that everyone was on-target, reviewing the procedures appropriate to each timing method, answering questions about occultations in general, and even enjoying views of a few deep-sky objects through others' telescopes and binoculars while we waited. This was a scheduled observing session after all, and there were a few non-mockultationists among us.

All was in readiness with several minutes to go. Blake and David, who opted for the radio/recorder method, had tested their gear and found the best relative positions for their radios, recorders, and themselves at the eyepiece. Mark, who opted for the stopwatch method, had reviewed and practiced pushing the right buttons at the right times. Eric was set with his video system. Matti was content to observe the observers.

I honked the horn 15 seconds earlier than the predicted time, simulating a not-uncommon real-life situation, and was amused to hear different voices yelling "Out" or "Gone" spread over a second or more. Ten seconds later, the star "reappeared" with the second beep. This time the "In" and "Back" calls were more or less simultaneous.

Afterwards we talked about reducing the data. The radio people would play back their recordings and compare the radio time signal with the sound of the voice calls, then apply their "personal equation" (reaction times) by measuring the time lapse between the horn and their voices. Mark listened to one of the others S/W radios and stopped his watch exactly at a known time. For him it was a matter of subtracting his elapsed and lap times to find the D and R (disappearance and reappearance times). Eric would simply play back his video recording, frame by frame, to find the exact D and R. Over the next several days, the participants reported their results. Here's what we learned.

Results

Mark Steele successfully used his stopwatch to time the event, but misplaced the paper on which he wrote his D and R times. However, he remembered that the difference, *i.e.* the duration of the mockultation, was 9.27 seconds. Bearing in mind that 0.01-second accuracy is impossible using human eyes and fingers, we rounded his duration time to 9.3 seconds.

David Zackon (radio and recorder) made his "Out" and "In" calls appropriately and his recording of those calls and the radio time signal was good. I reduced his data for him by measuring the time of the beeps and the times of his calls, and concluded that, for him, D = 01h 21m 05.2s (all times are UTC) and R = 01h 21m 14.5s so Duration = 9.3 seconds.

Blake Nancarrow got caught off guard and was away from his eyepiece for the disappearance. This is exactly why I chose to sound the horn several seconds early, to surprise people. Had this been a real event, Blake would have had only his R time, 01h 21m 14.5s, to report, which, reassuringly, was in exact agreement with David's R-time.

Eric Briggs, using video, found the times as follows: D = 01h 21m 06.07s. R = 01h 21m 15.00s. Dur = 8.93 seconds. Lacking a GPS-sourced on-screen-display device, he wired his S/W radio directly into the "audio in" port of his camcorder. This meant that he had no microphone with which to pick up the horn beeps or his voice. So he marked the D by placing his hat in front of his corrector plate when he heard the first beep and removing it when he heard the second one.

We see that there were small variations in the reported times. This is why the International Occultation Timing Association (IOTA) asks for an estimate of accuracy as part of the reporting process. With an accuracy adjustment of ± 0.2 seconds and allowing for some fuzziness in the estimated personal equations, the results are in reasonable agreement with each other.

All in all, we had a great evening learning about occultation timing. I thank everyone who participated. I highly recommend that other experienced occultationists conduct similar mockultations for their Centre members.

The Miss

Looking for Lova in all the wrong places
— Tom Luton, with apologies to Waylon Jennings *et al.*

Several occultations were predicted in southern Ontario in the weeks following the mockultation, but they were either clouded out or not feasible for other reasons. The first real opportunity to put our new skills to work came early on the morning of 2008 November 19, when the asteroid (868) Lova would occult an 11th-magnitude star in Taurus. However, none of the mockultationists was available at 02:30 on that Wednesday, so it fell to Tom Luton and me, plus others in Kingston and Minnesota, to try it. The occultation path was predicted to cross Ontario from Kingston to Kincardine. I made plans to observe from Fenelon Falls, 7 km north of the predicted centreline. Tom Luton (Toronto Centre) would watch from his parent's backyard in Cobourg, 46 km south of centre. The Kingstonians and Minnesotans were clouded out or "hazed out" (haze plus full Moon plus faint star equals zero). That left it to Tom and me.

First the good news. Between the mockultation and the Lova event, I again replaced my EQ-6 hand controller. I am pleased to report that the replacement of the replacement worked perfectly. A few days beforehand, I had entered into the controller the coordinates of the target star. On site, after conducting a careful three-star alignment, I called up the "user-defined object" and the mount went directly to it, putting the target well inside the one-degree field of view.

Now the bad news. I observed a miss. The star continued to glow merrily and steadily for the full five minutes that I recorded it, centred on the predicted time. Tom had the same experience. As he wrote to the IOTA Yahoo! Group, we were "looking for Lova in all the wrong places." Well, two of them, anyway. Since no one else observed the occultation, we can conclude nothing except that the path moved from its predicted line. Whether it went north or south is anybody's guess. We are left with nothing to report.

Guy Nason currrently lives in Toronto. He joined The Royal Astronomical Society of Canada in 1985 and has served on Toronto Centre Council continuously since 1986 (currently Coordinator of Observational Activities). He joined the International Occultation Timing Association (IOTA) in 1990, and successfully observed several lunar grazing occultations, total lunar occultations, and — so far — ten asteroidal occultations. He owns and operates Gneiss Hill Observatory at his cottage, 80 km northwest of Kingston, Ontario.

A Moment With…

Dr. Chris Jillings

by Phil Mozel, Toronto and Mississauga Centres (phil.mozel@sympatico.com)

Most of the interviews for these columns are conducted over the telephone, as, indeed, this one eventually was. However, the initial conversation was carried out at the "office" of its subject, Dr. Chris Jillings, two kilometres below the surface of the Earth. He was there to study things so elusive that they are referred to as "ghosts."

That Dr. Jillings finds himself deep underground today is perhaps not surprising. As a kid, he liked to dismantle things; he just needed to know how they worked at a fundamental level. He was inspired by a respected high school teacher to take up physics, which he eventually did as an undergraduate at McGill University. After earning a Ph.D. at Queen's University, he was then equipped to investigate the functioning of the cosmos. While astronomers look at the big picture and ask how the Universe works, scientists such as Dr. Jillings try to provide the basic underpinnings by researching what he calls "particle astrophysics."

To do this, he has travelled the world, both above and below its surface, to conduct his investigations. At the Pierre Auger Observatory, he studied cosmic rays using detectors spread across the pampas of Argentina. There, one type of detector looks for interactions of cosmic rays within large tanks of water, while another seeks ultraviolet photons emitted by cosmic rays colliding with molecules in the Earth's atmosphere.

At the California Institute of Technology, he conducted research on neutrinos using nearby nuclear reactors as sources of these elusive "ghost particles." Neutrinos' insubstantial nature stems from the fact that they react with ordinary matter hardly at all. Billions of them have just passed through your body. To catch some for study is a bit of a problem! Fortunately, it can be done using oversize detectors. Taking a break while at Caltech, Dr. Jillings travelled to Japan to work at KamLAND (Kamioka Liquid Scintillator Anti-Neutrino Detector), a subterranean instrument that used 1000 tons of a liquid scintillator to detect the occasional passing neutrino. Such detectors must be buried deep underground to shield against such things as the very cosmic rays that Dr. Jillings studied in Argentina. Dr. Jillings also spent time working in China at the Daya Bay Neutrino Experiment where reactor-born anti-neutrinos were used in the conduct of experiments.

Dr. Chris Jillings

In 1998, a magnificent new facility was completed in Canada: the Sudbury Neutrino Observatory (SNO). It too was buried deep, two kilometres underground in the Vale Inco Ltd. Creighton Mine near Sudbury, Ontario, and was constructed to address such issues as the so-called "solar neutrino problem." SNO's neutrino "trap" at the time consisted of a twelve-metre-wide acrylic sphere filled with heavy water. It was here that, as a grad student, Dr. Jillings first became "deeply" involved with neutrinos, gaining the experience he would apply elsewhere in the world before returning home to his current position as staff scientist at the Observatory.

Scientists had calculated that fusion reactions in the Sun's core should produce copious numbers of neutrinos, a few of which they planned to capture. However, early detectors came up short. Either something was wrong with our understanding of neutrinos or of how the Sun worked. The consensus was that we had a good grip on solar physics, so something must be amiss with neutrinos. Perhaps they changed their character on the trip from Sun to Earth? SNO provided clear evidence that this is indeed the case. The SNO has also been involved in determining that neutrinos have (a very small) mass, according to their type.

Dr. Jillings seeks answers to such questions as "What is the Universe made of?" Finding the answer, in the past, seemed simple: add up all the matter (stars, planets, etc.) you can see. Unfortunately, most of the mass of the Universe, the so-called dark matter, cannot be seen. Once again, the hunt is on for "ghosts," in this case WIMPs or Weakly Interacting Massive Particles.

During my visit to the observatory, Dr. Jillings pointed out DEAP-1 (Dark-matter Experiment with Argon and Pulse-shape discrimination). DEAP-1 is a proof-of-concept experiment using a seven-kilogram liquid-argon detector that was deployed underground in the autumn of 2007. The full-scale version, DEAP/CLEAN (Cryogenic Low-Energy Astrophysics with Nobles) will use 3600 kilograms of argon deployed in a newly blasted out cavern. No one knows how frequent the interactions in the detector will be, since this depends on how common WIMPs are and how they interact with ordinary matter. Theoretical models predict one WIMP interaction per 1000 tonnes of detector per year. Hardly a deluge! In fact, at the level of sensitivity required, neutrinos themselves become unwanted background that must be accounted for. However, chasing neutrinos has provided good training for WIMP detection as far as cleanliness, construction techniques, logistics, supply, *etc*. are concerned. Dr. Jillings feels that he and his team have a good chance of being the first to unmask WIMPs, although the task may require ten years or more. Patience is definitely a virtue!

Dr. Jillings spends about half of his working time underground and admits that the commute does take a big bite out of one's day. The commuter must first get kitted out in overalls, boots, web belt, hardhat, miner's lamp, and battery pack. He or she then waits for the scheduled departure of the cage (*i.e.* elevator) for the high-speed descent to the chosen level. Upon arrival, the kilometre-long trek to the lab commences. Here, all clothing and equipment is removed, a shower taken, and a whole new (clean) set of clothes donned. Following an air shower, admittance to the lab itself is finally permitted. It is important to make sure that you have everything you need for the day before setting out, because it's a long way to the surface and the cage does not come at just anyone's whim.

While Dr. Jillings has worked in a number of countries, every project has been international in scope with many collaborators. Though each nation tends to have its own way of doing things, Dr. Jillings' experience has been that cultural differences are subsumed as everyone focuses on the problem at hand (an excellent model for international relations in general!). Differences even exist between Canada and the US. For example, in the US, he has encountered the assumption that you will do great things but in Canada, you have to prove it. At Caltech, people thought going to SNO was cool, while many Canadians wondered why he would leave the US. The high calibre of the SNO facility is simply not well recognized in this country.

Dr. Jillings is not only a research scientist but, as became evident on my tour, an enthusiastic guide through the labyrinthine world of physics. Asked if he enjoys public outreach he replies, "Absolutely!" His obvious enthusiasm for teaching dates back at least as far as his post-doctoral days, when he taught astronomy and physics at Los Angeles City College. He currently manages the outreach programs for the subterranean lab despite his busy schedule of research and commuting. Even at parties, he is "on," as people are always interested to hear about what he does. He finds that astronomy is a good way to get people interested in science, because they are not afraid of it; then he can launch into a discussion about his physics.

The early 20th century saw a golden age of physics, as the nature of matter began to be revealed. It was at this time, for example, that Wolfgang Pauli predicted the existence of the neutrino. Dr. Jillings suggests that we have entered a second golden age of physics that began with the data collected by the *Cosmic Background Explorer (COBE)* satellite, an age that continues with the recent commissioning of the Large Hadron Collider and the work being carried out deep underground in places like Sudbury. What was once speculation has now become precise measurement, allowing constraints to be placed on hypotheses. The neutrino is a case in point.

While there are clear advantages for astronomers to perch atop mountains, such as a better view (and a less pressing need for showering!), obviously, good reasons exist for going in the opposite direction. It is ironic that keys to our understanding of the Universe may be found so far beneath our feet. ◆

Phil Mozel is a past librarian of the Society and was the Producer/Educator at the former McLaughlin Planetarium. He is currently an educator at the Ontario Science Centre.

Gizmos: Mystery and Magnificence

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

I think almost anyone with a camera and an interest in the stars has thought of putting the two together, and, although relatively few people have the skills or the equipment to make the APOD (although at least one APOD shot was done with a cell-phone camera), beautiful pictures can be had with almost any camera capable of manual exposure control. The best, of course, is a DSLR. These are capable of some pretty serious imaging when mounted on a telescope, but can make spectacular photos even through the lens with which they were supplied. You'll need a tripod, (the beefier the better, but almost any tripod will do for a start), and you'll need a clear night. Point your camera at the Milky Way, set the focus at infinity, aperture at full open, exposure for about 30 seconds, and shoot. Your first astro image!

A warning here — this is habit-forming, and if you are not prepared for the consequences, erase your image immediately, and go back to trying to understand cosmology.

If you're still with me, you've started on a great endeavour, to pluck mystery and magnificence from the sky and record it in an image — but probably not in the image you just took. You will need to work at this a bit. Play with the focus as infinity isn't quite where it says it is on most lenses. Use the playback feature, and zoom as close as you can. Adjust and shoot until the stars are sharp and distinct. You will also need to play with the exposure time. Too short, and you won't get much. Too long, and you will start to get elongated stars, and sensor noise will degrade your image.

Finally you will need to aim your camera, which is where this idea, from Chris Coppin of Powell River, will be very useful.

Chris became tired of twisting his head to look up through the viewfinder while the camera was on a tripod, so he built this very simple green-laser bracket. It's made of pipe strap and can be mounted to the flash shoe on the camera with the mounting bracket shown (available at camera stores), or even simpler, the strap alone can be secured between the camera and the tripod head. Chris lines up the laser's button with one of the holes in the strap and switches it on or off just by turning it. The laser is aimed by doing a bit of careful bending and twisting until the beam is more or less centred in the viewfinder.

Chris uses this together with binoculars to aim his camera. He's getting images that he's pleased with. Maybe this is the year you try it.

Thanks to Chris Coppin for sending this in. If you have ideas that should be presented in this space forward them to don@knappett.com.

Don and Elizabeth van Akker aim their cameras from their observatory on Salt Spring Island. They are members of the Victoria Centre.

The Star of the Magi: The Mystery that Heralded the Coming of Christ, by Courtney Roberts, pages 223; 15 cm × 23 cm, New Page Books, a division of The Career Press, Inc. 2007. Price $14.99 US paperback (ISBN 1-56414-962-5).

The Star of the Magi is yet another interesting addition to the constantly growing literature on the Star of Bethlehem, one that came to my attention too late to be reviewed for the Christmas shopping period. The book appears to be aimed primarily at refuting the claims presented in Michael Molnar's 1999 book *The Star of Bethlehem: The Legacy of the Magi,* which was also reviewed here (*JRASC,* 95, 234-236, 2001). In particular, Courtney Roberts argues that it is incorrect to use western astrology with its Greek roots to identify the Star of Bethlehem; it must be done using eastern astrology with its Persian roots. And, since western astrology is linked to the fortunes of individuals, whereas eastern astrology affects entire nations, the link to the birth date of a messiah is more involved in nature.

But I am oversimplifying the contents considerably. The main thread that permeates *Star of the Magi* is to explain why the book of Matthew contains the story of a star in the first place. Since the introduction of such a story ties directly to astrological predictions, for which the indicated audience of Matthew's narrative, the Jews of Palestine, are perceived to have no interest, several sections of the book are spent explaining the cultural links between the Jews and the Persians, and hence an ongoing interest in astrology on the Jews' part. That nominally dates to 583 BC, when the Persian emperor Cyrus II (the Great) freed the Jews from their Babylonian captivity, encouraged them to resettle Judaea, and provided funds for their resettlement and the rebuilding of Jerusalem, including restoration of the temple. According to Roberts, there are other links in terms of basic similarities in the religions of the two nations, but in that, she seems to be unfamiliar with the writings of David Rohl, such as *From Eden to Exile,* where she might find even stronger and more direct links to a common cultural and religious ancestry.

Star of the Magi is not the first book to discuss at length the possible link of Persian, or Zoroastrian, magi to the story of the Star. That was done in perhaps more convincing fashion by Gustav Teres, S.J., in his 2002 book *The Bible and Astronomy: The Magi and the Star in the Gospel,* which was also reviewed here (*JRASC,* 97, 297-299, 2003). The Teres book additionally contains many of the astronomical details that are missing from the Roberts treatise. In fact, the omission of astronomical basics and direct astronomical observations in preference for astrological details is the primary weakness of the book. Such omissions are unusual, given that the book otherwise contains a rich bibliography.

It seems clear that Courtney Roberts is familiar with much of the extensive literature on the Star of Bethlehem, so much so that the contents of *Star of the Magi* often present discussions and arguments as if the reader is, or should be, as familiar with the literature on the subject as she is. The result is an occasional unevenness in the text, particularly those sections where novices to the field are not presented with complete information about the arguments of others published previously. That unevenness is also evident in arguments that appear to present astrological points without regard to the fact that they conflict directly with astronomical facts. For example, why should astrological millennia (not millenniums) of 1000 years be of importance to someone with a solid astronomical background, as suggested here? The zodiacal eras are typically of 2000 years duration or more, with those that are tied directly to the location of the vernal equinox in a particular zodiacal constellation being of irregular length, depending upon the size of the constellation. Interested readers are encouraged to read Alex Gurshtein's delightful article *On the Origin of the Zodiacal Constellations* (*Vistas in Astronomy,* 36, 171-190, 1993) to find sound arguments, based upon constellation size, for when the zodiacal constellations were first identified. Roberts might benefit from the article as well, given that explanations are provided there for the importance of twins in ancient religions, as well as an answer to her question about why Masha'allah fixes the beginning of the conjunction cycle for Jupiter and Saturn in Taurus.

The contents of *Star of the Magi* are arranged to introduce the story of the Star as told in the book of Matthew, to discuss the likely origins of that book (done quite well), to link the Matthew story to its likely Persian roots, and then to relate the magi and their origins to the history of ancient Persia and Chaldea. From there the story diverts to possible astrological roots, brings in a bit of astronomy in terms of precession of the equinoxes, although with an unfortunate digression to the misguided concept of trepidation, and then proposes how Jupiter-Saturn conjunctions are of seeming importance in dating important historical dates. The implied link between the simple conjunction of Jupiter and Saturn in Scorpio in AD 571 and the birth of Islam is less convincing, given that Mohammed's birth is usually dated to AD 570. The difference between ordinary conjunctions of Jupiter and Saturn and great conjunctions (triple conjunctions) is also left unstated, nor is it pointed out that the triple conjunction of Jupiter and Saturn in Pisces in 7 BC was the first and only triple conjunction of those two planets in Pisces during the entire Piscean age, which is still with us, at least astronomically rather than astrologically, for another millennium (see Gurshtein's article for an explanation of why that is the case). All of that is on my own Web site in a story written for my university's alumni magazine, for those who are interested.

Overall, Star of the Magi is a useful addition to the extensive literature on the Star of Bethlehem mystery, but it is not without oversights and errors, and is far from a definitive document. Certainly, it is readable by a general audience, given that it is written in a colloquial, rather than academic, style. Much-needed copyediting is essentially non-existent, which unfortunately may leave some academic readers with a less-than-favourable impression. The review copy comes complete with extensive promotional material that, as usual, presents a glowing picture of its contents not borne out by careful perusal. I could repeat many of the same comments that I made of Michael Molnar's book, but there is no need to be repetitive. It can only be said that your own favourite candidate for the Star of Bethlehem is in no danger of being refuted here, depending upon how much credence you are inclined to give the story in Matthew. For that matter, none of the various candidates are discussed in *Star of the Magi.* Its purpose is mainly to show how the story in Matthew is a logical development of the times in which the author of Matthew lived. In that it succeeds quite well.

Perhaps my view of new explanations for the Star of Bethlehem has been jaded over the years by the dubious candidates promoted by new authors to the field in books that inevitably appear just in time for the Christmas buying spree? *Star of the Magi* otherwise has much to recommend it, if only for its clarifications of what was actually said in the Greek versions of Matthew, and for its detailed discussion of Persian history and the long-standing importance of Zoroastrianism to the peoples of Persia and the Middle East. The lack of basic astronomy in the text is a weakness, and is evident throughout. The triple conjunction of Jupiter and Saturn in Pisces in 7 BC, for example, is discussed in terms of astrological charts rather than as an observable event in the sky. Yet, there is evidence indicating that the ancient Chaldean astronomers observed it and recorded the details on clay tablets. In the fashion of the writing style contained in *Star of the Magi,* why is that overlooked?

In paperback format, *Star of the Magi* is a relatively inexpensive book for those wishing to learn more about why the book of Matthew contains a story of the Star. It should make a pleasant read for interested readers, although I would suggest one or more of the other books on the subject as companions. Mark Kidger's *The Star of Bethlehem: An Astronomer's View,* reviewed here previously (*JRASC,* 96, 79-81, 2002), is another good source, in addition to the books mentioned above. My own thoughts on the matter are presented on my Web site.

David Turner

David Turner is a professor of astronomy and physics at Saint Mary's University in Halifax and a former planetarium director/script writer who developed mixed-media presentations on the Star of Bethlehem in a previous life at Laurentian University (1976-78, 1980-84). His own thoughts on the Star can be found at apwww.smu.ca/~turner/xmas.html.

Stephen Hawking: A Biography, by Kristine Larsen, pages 215; 15 cm × 23 cm, Prometheus Books, 2007. Price $18.95 softcover (ISBN 978-1-59102-574-0).

Stephen Hawking (b. 1942) is the most famous physicist since Einstein, not only for applying general relativity and quantum mechanics to cosmology and "the theory of everything" in revolutionary ways, but also by having done so while under the debilitating effects of ALS (Lou Gehrig's Disease). He also managed to be a husband and a father throughout, has a wicked sense of humour (including placing bets on outcomes of research), is a champion of the rights of the disabled, and has become a *bona fide* television and film celebrity. This biography by Kristine Larsen (a professor of physics and astronomy) presents a balanced portrait of this remarkable man.

The softcover version of the 2005 hardcover original has a new afterword that updates Hawking's life to 2007. Presumably there will be other biographies to follow; this is the latest installment. The book is organized as follows:

Introduction
Timeline 1942-2007
Chapter 1. Destiny's Child: An Auspicious Birth and Eclectic Upbringing
Chapter 2. Scientist in Training: The Oxford Years
Chapter 3. Tragedy and Triumph: Deadly Disease and Dissertation
Chapter 4. Children and Calculations: Family Man and Theoretician
Chapter 5. "Stephen's Changed Everything": Black Holes Aren't Black
Chapter 6. Caltech and Cambridge: Exploring New Horizons
Chapter 7: Physics and Metaphysics?: The "No-Boundary" Proposal
Chapter 8. Challenges and Controversy: An Unexpected Silence and Time's Arrows
Chapter 9. The Best Selling Book That "No One Read": A Brief

History of Time
Chapter 10. To Boldly Go: Time Travel and Television
Chapter 11. Plays, M-branes, and Polls: Private Lives and Public Pronouncements
Chapter 12. Books and Bets: The Universe in a Nutshell and the End of a Paradox
Epilogue: Stephen Hawking: Man Vs. Myth
Afterword
Appendix A: General Relativity and Cosmology
Appendix B: The Laws of Thermodynamics and Black Holes
Appendix C: Inflationary Cosmology
Appendix D: The Anti de Sitter / Conformal Field Theory Correspondence
Glossary / Select Bibliography / Index / About the Author

There you have it: Stephen Hawking in a nutshell!

The chapters are subdivided into sections with relevant titles and there are copious notes at the end of each, including research articles, popular articles, books, and Web sites. In that way, the book is a like a wormhole to the vast universe of literature of contemporary gravitation and cosmology and Hawking trivia. (I found that several of the original research papers are freely available online.) There are also references to other biographies, notably that by his first wife. Mini-essays on specific cosmological topics are thankfully relegated to appendices, so the narrative flow is unimpeded. All of it makes for easy reading and the book can be finished enjoyably over a span of several days of casual reading. The author has done a very good job balancing the physics and the personal, leading the reader through Hawking's life and work as they unfold. The author is a physics and astronomy professor at Central Connecticut State University with an accomplished career in physics outreach and communication. During her graduate student days, she attended several conferences at which Hawking spoke, and consequently had the pleasure of meeting him. That having been said, she is neither a sycophant nor a muckraker. Her Web site `www.physics.ccsu.edu/LarsenHome.htm` is well worth a visit.

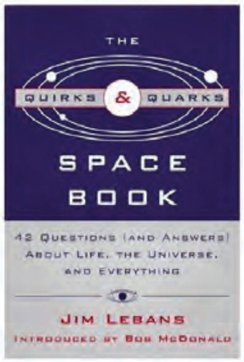
I have had a few close encounters with Hawking's work. The first was when I was a physics graduate student at UBC in the mid-1970s, learning about general relativity, field theory, and quantum mechanics. At that time, Hawking was not well known outside of physics circles, but his revolutionary ideas on combining gravitation and quantum mechanics to account for black hole radiation were fairly new and they excited us. Later, we learned about black-hole thermodynamics and cosmological inflation. My second Hawking encounter was when I was living in England 1986-88 and witnessed the amazing phenomenon of a book on cosmology by an active researcher dominating the best-seller lists for months, on both sides of the Atlantic Ocean. I recall from that time Hawking's pronouncement, "To ask what happened in the universe before t=0 is like asking what is north of the North Pole." That was the essence of his "no boundary" boundary condition on his solution to the cosmological field equations. *A Brief History of Time* was the most popular book that no one understood! It was the birth of Stephen Hawking, pop icon. Since then he has "popped up" on TV shows, in movies, cartoons — everywhere. Has he ceased to astonish us? Do such remarkable thinkers truly retire? (He is 68 now.)

The few illustrations in the book are adequate. (Why is it so hard to create good graphics in the present day and age?) There are fewer photographs than I would like to see in a biography, and none from the "early" years. I have one minor quibble with the author referring to the Cosmological Constant as a "fudge factor," but I already wrote a concise rant on that in a previous book review in *JRASC,* 100, 99-100, available online at `www.rasc.ca/journal/backissues.shtml.`

In writing such reviews, I like to think of myself as playing the part of a *JRASC* reader standing in a bookstore, flipping through a book, and deciding whether or not to buy it. There may be books that better explain Hawking's physics, but this is the book to read if you would like to learn more about the man, who is first and foremost a physicist who has changed how we look at the Universe. It is fascinating to read how science actually progresses as a human endeavour with all of the triumphs, foibles, and failings that entails. Highly recommended.

David M. F. Chapman

David M. F. Chapman is a Life Member of RASC, an Assistant Editor of JRASC, and a past-President of the Halifax Centre. He is a recently retired Defence Scientist actively promoting the International Year of Astronomy 2009 in Nova Scotia.



The Quirks & Quarks Space Book, by Jim Lebans, pages 240 + xv; 14 cm × 21 cm, McClelland & Stewart, 2008. Price $22.99, $18.95 US softcover (ISBN 978-0-7710-5003-9).

Radio in a book? Well, yes, in a way. CBC Radio One's weekly science show *Quirks & Quarks* is famous for making science understandable and entertaining to non-scientists. *The Quirks & Quarks Space Book* does the same thing, in print form. Written by space enthusiast and CBC producer Jim Lebans, this small volume addresses some of the most often-asked questions about a popular topic in 42 short and snappy chapters.

The introduction is written by one of Canada's best-known science journalists, Bob MacDonald, the host of *Quirks & Quarks.* He describes the purpose of the book in two sentences: "This is a book for anyone who is fascinated by the world around and above them. And as we say on *Quirks &*

Quarks, you don't need a Ph.D. to understand or enjoy it." He is correct.

The choice of 42 questions (and 42 chapters), of course, pays homage to Douglas Adams popular sci-fi story, *The Hitchhiker's Guide to the Galaxy*. Each chapter discusses one question, leading smoothly from one question (and chapter) to the next, in logical sequence. Chapters are written to stand alone, giving the reader the choice of reading the entire book from front to back, or picking chapters at random to enjoy individually. That structure means there is some repetition, but it is kept to a minimum.

As in many astronomy books, the first chapters deal with matters close to home. Subsequent chapters move the reader to ever-more-distant and exotic locales. Chapter One asks "Where does space begin?" and the final chapter asks "How will the Universe end?" The forty intervening chapters discuss everything else, including the challenges of space travel, the evolution of life, the structure of the Solar System, and the makeup of the Universe. There are no illustrations, other than those painted in the reader's mind by the descriptive text.

The subject matter is presented in everyday language that avoids opaque, specialist jargon. The author appears to have had fun employing light humour and word play to bring lofty topics down to Earth for his audience. The result is a work that is friendly and easily accessible to anyone from high-school students and on. For example, Chapter 16 is titled, "How do you loosen the asteroid belt?" The lead paragraph goes on to say, "Don't look now, but we're missing a planet. All we've got left is the pieces, and we're losing those." The reader is drawn into the narrative to find out why the Solar System is losing pieces of itself.

Do you want to know how fast we are moving through space? Or why some stars are blue? Or what happens when galaxies collide? Maybe you want a non-technical description of what it might be like to fall into a black hole. Why does Saturn have those spectacular rings, and how did Earth get such a big Moon? How empty is space and what are the chances of a planet-destroying impact event? *The Quirks & Quarks Space Book* has answers that will inform, intrigue, and delight.

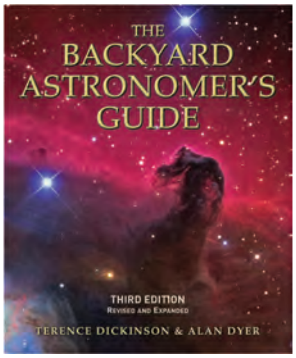
Like the radio program, the book aims to engage the interest of ordinary citizens whose lives do not revolve around science, but whose lives are affected by the knowledge that comes from scientific pursuits. Having engaged the reader's interest, the author informs and educates in a pleasant, conversational style. There is a very clear sub-text that runs through the entire book: science is enjoyable, accessible, and beneficial to society. Reading the book is a lot like sitting down for a relaxed weekend visit with your neighbour, who just happens to be an expert in science communications.

It is a small book with a worthy objective: improving the scientific literacy of the Canadian population. We live in an increasingly complicated world. Science plays an increasingly important role in our lives today and into the future. It is crucial to our survival as a species that we are comfortable with, and have an understanding of, what science is and how it works, as well as what it can and cannot do. *Quirks & Quarks* has been successfully working on that agenda since 1975. Thirty-three years later, they are still going strong. Here is yet another valuable contribution.

Mary Lou Whitehorne

Mary Lou Whitehorne is 1st Vice-President of the RASC, and enjoys the privilege of a seat in Halifax Centre's famed Heckler's Row. She is the author of Skyways, *and Asteroid 144907 Whitehorne was named in recognition of her 20-plus years of effort to improve scientific literacy among Canada's youth.*

The Backyard Astronomer's Guide, by Terence Dickinson and Alan Dyer, 3rd Edition, pages 368 + 0; 23 cm × 28 cm, Firefly Books Ltd., 2008. Price $49.95 hardcover (ISBN 1-55407-344-8).



If you are either an advanced beginner astronomer or an intermediate astronomer who is looking for a practical guide to amateur astronomy, *The Backyard Astronomer's Guide* is for you. As the authors point out, *The Backyard Astronomer's Guide* is not meant as a first book in astronomy (they suggest Dickinson's *Nightwatch* for that purpose). Neither is it for advanced astronomers, who will already know much of what is covered. Instead, while novice or advanced astronomers will find parts of the book interesting and useful, its target is actually the middling astronomer. The ideal fit for *The Backyard Astronomer's Guide* would be an individual who has spent time learning some of the night sky with the unaided eye, binoculars, or perhaps an entry-level telescope, and would now like to move to more serious telescopic observing or astrophotography.

The first edition of *The Backyard Astronomer's Guide* appeared in 1991. Since I have not read either of the first two editions, I cannot comment on how the 3rd edition compares with previous versions. There have been significant recent changes in amateur astronomy equipment, however, so that the present revision is warranted.

The Backyard Astronomer's Guide is an attractive book. The number and quality of photos, mostly taken by the authors, is impressive. Almost every page has multiple colour photos or graphics of excellent quality that add nicely to the text. The authors take a refreshingly candid stand on several topics, recommending specific telescope and camera brands, cautioning against overly complicated approaches to astrophotography and observing, pointing out overrated gadgets, and even warning the reader about immaturity that can occur in astronomy email groups.

Much of the material in *The Backyard Astronomer's Guide* is excellent, for example, how to assemble popular telescope models, an explanation of daytime and twilight phenomena, tips on lunar and solar observing, a summary of past comets in living memory, advice for making an observing trip to Australia, and how to get started in astrophotography. The book is not perfect, however. For example, while the chapter on choosing a telescope is very good, the number of possible choices is overwhelming, since there are so many telescopes on the market. That is not the fault of the authors. However, that section would truly benefit by the inclusion of a decision matrix or other complex-decision-making aid, such as are commonly used in engineering and other areas where many different options must be identified to yield an optimum choice.

I was also uncertain of the utility of the 20-page atlas of the Milky Way region of the sky that is included in the book, and the illustrations used to explain how the sky works are somewhat confusing. I would also quibble with the authors' favourable opinion of the use of binoviewers for deep-sky objects; I find only the very brightest benefit from their use, and would instead stick with raving about binoviewers for the Moon and planets. The book has a few minor editorial issues, such as mentioning terms before they are explained (*e.g.* "altazimuth-mounted") or not explaining terms (*e.g.* geometric dichotomy, Eastern and Western quadrature, light-year). They are all minor flaws though.

Given that it is a 3rd edition, the book would be expected to be nearly free of typos, and indeed, I found only two. Technical errors are also far and few between; I found only a few, mostly confined to minor astrophysical errors, such as where aurorae are explained as being the result of "electron beams," which ignores the major presence of protons in the solar wind, and E0/E1 galaxies are said to be circular when in fact they are spherical. Speaking of astrophysics, the book is not intended for someone whose interest in astronomy tends to the astrophysical side, since the flavour is very much that of hands-on amateur astronomy and astroimaging.

Despite a few minor flaws like those mentioned above, *The Backyard Astronomer's Guide* is an excellent guide to practical amateur astronomy. Any aspiring astronomer would benefit strongly by reading this beautiful book. The authors have laid out technical details and tips that will save a neophyte telescope user many hours of frustration, and allow said user more quickly to begin enjoying use of their equipment to view or image the night sky. In short, I highly recommend this thoughtful and thorough exposition of the practical aspects of our hobby.

WARREN FINLAY

Warren Finlay enjoys visual observing of the night sky from the darkest skies under which he can manage to find himself. He is author of the award-winning Concise Catalog of Deep-Sky Objects: Astrophysical Information for 500 Galaxies, Clusters and Nebulae *(Springer 2003). By day, he is a professor of engineering at the University of Alberta.*

Society News...continued from page 26

of Society members agree to a By-Law change). Preliminary queries show that it's a "renter's market" and we are well placed to find a suitable location that will fill our needs for some time.

Finally, we are already a month or so into the International Year of Astronomy, get out there and celebrate. Encourage someone to have a Galileo Moment!

LATE-BREAKING NEWS!

Dateline 2008 December 24....

National office has been sold. Here is a quote from President Dave Lane to National Council:

"The Executive and Property Committees hereby announce that our building in Toronto has been sold. The last condition of an accepted offer dated December 12 was met yesterday. These conditions included the buyer being able to arrange suitable financing, an inspection of the building being satisfactory to the buyer, and the buyer satisfying themselves that they can use the property after the sale for their intended usage."

The details are as follows:

- Selling price: $499,000 (same as listing price)
- A deposit of $30,000 has been received
- The property is sold "as is" (in its present condition without any repairs to the apartment, etc.)
- The closing date is 2009-March-20

Front entrance to 136 Dupont Street, soon to be vacated by the RASC. Photo: Denis Grey

We expect to realize just north of $470,000 from the sale after the 5% realtor commission and legal fees.

New Banners for Winnipeg Centre

by Jennifer West, Winnipeg Centre (jennifer_west@umanitoba.ca)

At the 2007 General Assembly in Calgary, Winnipeg Centre received a Centre Project Fund grant of just over $1000 to print two high-quality, full-colour roller-retractable-type banner displays for use at public events. In spring of 2008, the banners were completed, in time to be used at the Winnipeg Centre's Astronomy Day activities. This year, the International Year of Astronomy, we anticipate that they will be used frequently at many public events.

Other centres are welcome to use the design for their own banners or displays. The original files can be made available on request. Please contact Jennifer West (jennifer_west@umanitoba.ca) directly for more information.

Astrocryptic

ACROSS

1. Company supporter gets ahead on the Moon (5)
4. Familiar girl I met with garland, had a famously unused last name (7)
8. Another girl, almost like model Elle, discovered Triton (7)
9. Crater's identification with an offspring of Venus (5)
10. Machine loses direction reaching the speed of sound (4,1)
11. T Tauri types shortened for catalogue of argon spectra (2.,5)
12. No oar? A mystery unfolds for 2009 internationally (9,4)
16. Cousteau sailed it around Saturn (7)
18. We are hunters and gatherers of this (5)
20. Was Eridinus in Benford's great sky? (5)
21. Charged particle from an asteroid destroying the terrain (7)
22. Iron or tin moon craft in poetic evening before twilight ends (7)
23. Scads of GoTo searches (5)

DOWN

1. Mostly cold, a bum somehow dove in the sky (7)
2. One degree above half the Sickle, in easy programming language (5)
3. I care about meeting Diddley in the radio observatory (7)
4. Fellow hugs the greatest lion and mother of an IYA project (7,6)
5. Claus broken up when his sleigh crashed in a lunar lake (5)
6. His work in celestial mechanics explains Capella explosion (7)
7. Industrial test deleted from constellation (5)
13. A good eyepiece to measure shortened height above sea level in Tuesday class (7)
14. Ages of colourful Sun-like stars (7)
15. Stare in disarray with these (7)
16. Her radioactivity research gave a hint about infrared reflection (5)
17. ATMer Russell lost his tail in a French door (5)
19. Lead one to a tracking star (5)

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20					■	21						
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22							■	23				

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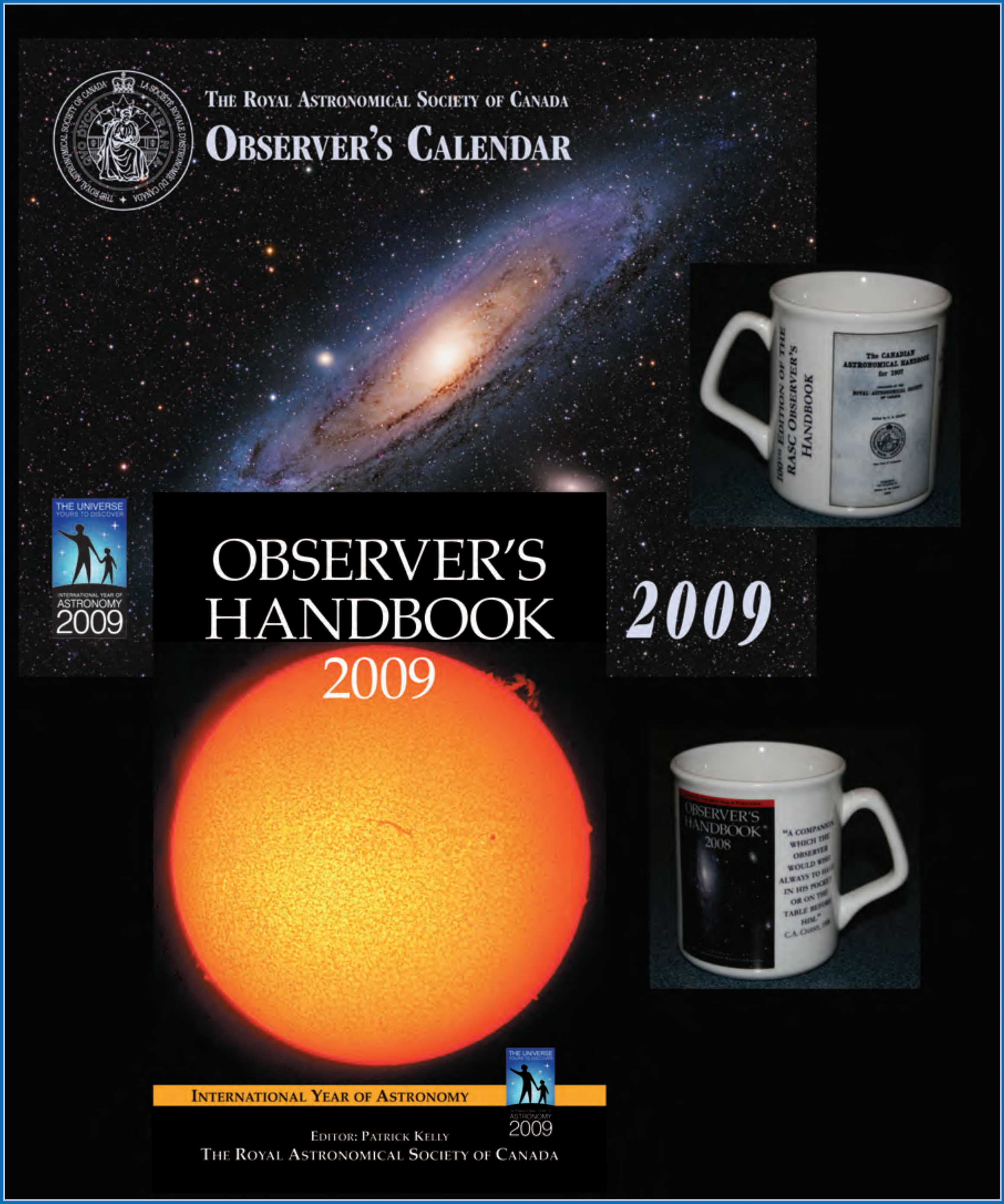
Gear up for the New Year with these great products from the Royal Astronomical Society of Canada!



Observer's Calendar Special!

Buy the 2009 Observer's Calendar and the Observer's Handbook Centenary Mug for only $29.95* (includes shipping and handling) and save $11.00 over the regular price.

The Observer's Handbook celebrated its 100th Edition in 2008. This 10-oz ceramic mug features the covers of the 1st and 100th editions in full colour - a special keepsake for a special anniversary.

To order yours, go to the RASC eStore or call 888-724-RASC.

* Residents of Canada please add $1.50 for GST.