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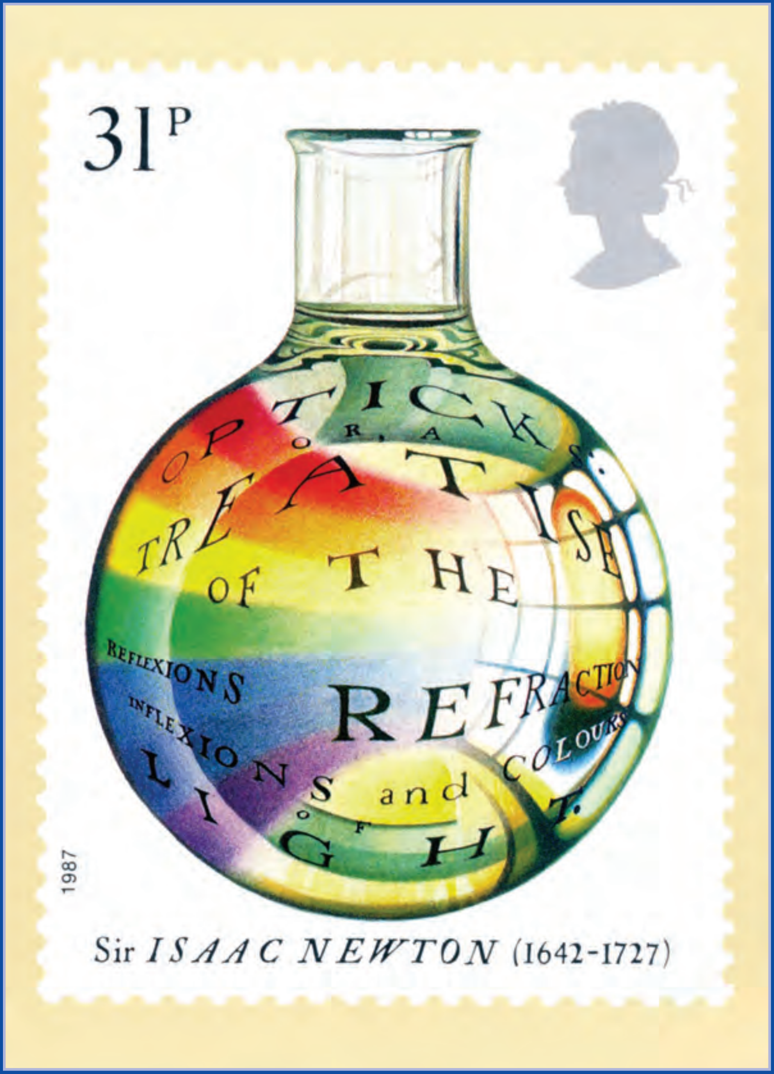

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INSIDE THIS ISSUE

Harmony of the Spheres, Part II · Unveiling Asteroids
Meteor Video Camera Networks · Canadian Thesis Abstracts

December / décembre 2003

Journal

Vol. 97, No. 6 Whole Number 703

contents
table des matières

FEATURE ARTICLES/ARTICLES DE FOND

259 Johannes Kepler's *Harmonices mundi:* A "Scientific" Version of the Harmony of the Spheres, Part II
by Bruno Gingras

283 Unveiling Asteroids: International Observing Project and Amateur-Professional Connection
by Mikko Kaasalainen

RESEARCH PAPERS/ARTICLES DE RECHERCHE

271 The January 26, 2001 Fireball and Implications for Meteor Video Camera Networks
by Martin Connors, Peter Brown, Douglas P. Hube, Brian Martin, Alister Ling, Donald Hladiuk, Mike Mazur, and Richard Spalding

277 Canadian Thesis Abstracts
by Melvin Blake

EDUCATION NOTES/RUBRIQUES PÉDAGOGIQUES

278 What is Sidereal Time and What Is It Good For?
by William Dodd

280 The Story of Skyways: The RASC's Astronomy Handbook for Teachers
by Mary Lou Whitehorne

COLUMNS/RUBRIQUES

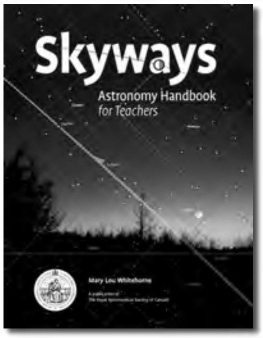
266 Reflections: Newtonian Opticks
by David M.F. Chapman

268 Second Light: Asteroid Spins are Solar Powered
by Leslie J. Sage

288 Orbital Oddities: Martian Motion IV: The Zeus Effect
by Bruce McCurdy

Harmonices mundi
p. 259

January 26 Fireball
p. 271



The Story of Skyways
p. 280

DEPARTMENTS/DÉPARTEMENTS

254 President's Corner
by Rajiv Gupta

256 Editorial
by Michael Attas

257 News Notes / En manchettes
Gemini Surprise At Epsilon Indi; SCUBA-2 A Go; GRB Induced Mass Extinction; Early Chinese Eclipse Records: A Second Look

257 Correspondence / Correspondance
Erratum

270 From the Past / Au fil des ans
Falling Stars

296 Reviews / Critiques
Solar Sytem Voyage, by Serge Brunier; The Bible and Astronomy: The Magi and the Star in the Gospel, by Gustav Teres, S.J.; Parallax: The Race to Measure the Cosmos, by Alan W. Hirshfeld; The Big Splat, or How the Moon Came to Be, by Dana McKenzie

301 Index to Volume 97, 2003

Book Reviews
p. 296

AstroCryptic
Answers
p. 293

B	A	A	D	E	■	T	R	A	N	S	I	T
E	■	L	■	L	■	H	■	N	■	C	■	H
S	A	G	I	T	T	A	■	I	C	H	O	R
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I	M	P	L	O	D	E	■	G	E	M	M	A
C	■	L	■	M	■	G	■	I	■	E	■	A
T	R	A	C	E	■	I	O	N	I	S	E	D
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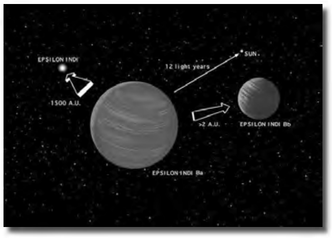

News Notes
p. 257

ACROSS THE RASC
DU NOUVEAU DANS LES CENTRES

281 Society News/Nouvelles de la société
by Kim Hay

282 International Astronomy Day 2004 is Saturday April 24
by Bruce McCurdy

291 Observation of the 1761 Transit of Venus from St. John's Newfoundland
by Frederick R. Smith

294 Edmonton's Amazing Marzathon 2003
by Sherrilyn Jahrig

Cover:
Newtonian Opticks
p. 266
Photo: Royal Mail

President's Corner

by Rajiv Gupta (rgupta@telus.net)

As many of you know, 2003 has been a special year for the Society, as it has marked the 100th anniversary of our Royal charter. The celebration of our Royal Centenary has been an ongoing source of pride for me for about a year now, ever since the celebration kicked off personally for me on October 7, 2003 when I represented the RASC at a function attended by Her Majesty Queen Elizabeth II. I celebrated during my extensive travels to the Centres in the fall of 2002 and winter/spring of 2003. And, the celebration continued well into the summer of 2003, when another regal woman, The Honourable Iona Campanoglo, Lieutenant Governor of British Columbia, graced us with her presence at the 2003 General Assembly in Vancouver.

But, I've been keeping some secret news within me for over three months that elevates our special year to yet another level of celebration. I learned this wonderful news on June 26, shortly before the commencement of the 2003 GA, in the form of a telephone call from Dr. Tom Brzustowski, president of NSERC, Canada's major scientific granting agency. He informed me that the RASC was one of 5 recipients of a 2003 Michael Smith Award for Science Promotion, out of approximately 25 nominations submitted to NSERC. While I shared the news with the RASC Executive and the three RASC members mostly responsible for the nomination, James Edgar, John Percy, and Roland Dechesne, I could not inform our members at large until the official ministerial announcement, which is scheduled for mid-November. I was *dying* to announce the award at the 2003 GA, and can finally inform all of you in this column, which will appear only after the official announcement by the Canadian government.

I'll travel to an awards ceremony in Ottawa on November 19 to receive the Society's medal and a framed citation, which will be proudly displayed at our Toronto office. The Society has already received a $10,000 prize cheque from NSERC, which is especially welcome in a year that could, as I've explained previously in an earlier column, be a difficult one financially for the Society because of the unfavourable US-dollar exchange rate.

But beyond the medal, certificate, and cheque, the receipt of a Michael Smith Award should remind us of something all of us already know: The RASC is a special, unique organization. We all know how special the RASC is, but isn't it nice to have our belief validated by the receipt of one of the premier science awards in Canada? We should all thank not only NSERC but also the three individuals mentioned above who put in a great

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.

Editor-in-Chief
Wayne A. Barkhouse
136 Dupont Street
Toronto ON M5R 1V2, Canada
Internet: editor@rasc.ca
Web site: www.rasc.ca
Telephone: (416) 924-7973
Fax: (416) 924-2911

Associate Editor, Research
Douglas Hube
Internet: dhube@phys.ualberta.ca

Associate Editor, General
Michael Attas
Internet: attasm@aecl.ca

Assistant Editors
Michael Allen
Martin Beech
Pierre Boulos
Ralph Chou
Patrick Kelly
Daniel Hudon

Editorial Assistant
Suzanne E. Moreau
Internet: semore@sympatico.ca

Production Manager
David Garner
Internet: jusloe@wightman.ca

Contributing Editors
Martin Beech (News Notes)
David Chapman
William Dodd (Education Notes)
Kim Hay (Society News)
Bruce McCurdy
Harry Pulley
Leslie Sage
Russell Sampson (News Notes)
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Proofreaders
James Edgar
Maureen Okun
Suzanne Moreau

Design/Production
Brian G. Segal, Redgull Incorporated

Advertising
Isaac McGillis
Telephone: (416) 924-7973

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deal of work to put forth the successful nomination.

Further details on the award will be given in a future issue of the *Journal*, but I'd like to say just a bit about the Michael Smith Awards here. According to NSERC's official literature, the award "honours individuals and groups who make an outstanding contribution to the promotion of science in Canada, through activities encouraging popular interest or developing science abilities." The award is named for Dr. Michael Smith, a 1993 Nobel laureate who performed revolutionary genetic research at the University of British Columbia. Equally remarkable as his research was his decision to donate the half-million-dollar Nobel prize to other underfunded researchers and to science outreach activities. Michael Smith, who passed away in 2000, was a singular scientist and person, and the Society is privileged to have won an award bearing his name. I am sure Dr. Smith would have been impressed with the diverse activities — ranging from publishing world-class astronomical resources to myriad outreach and public awareness programs carried on by 27 Centres — performed by the RASC in fulfillment of its mandate. I think Dr. Smith would have been especially pleased with the Society's recent decision to proceed with *Skyways*, a new publication aimed at teachers that makes it easier for them to deliver high-quality astronomy content to their students at various grade levels.

In this, my final column of 2003, I can't help but feel a tingle up and down my spine when I think about all the special things that have happened to the Society in the past year. If our Royal Centenary celebrations had been scripted by a Hollywood screenwriter, would they have beaten reality? Could we have asked our scripter for anything better than an inspirational visit by the Lieutenant Governor of British Columbia at our General Assembly and recognition by Canada's premier scientific granting agency in the form of the granting of a prestigious award named for one of Canada's most inspirational scientists? Yes, 2003 has been a very good year! Let's give each other heartfelt pats on the back, and continue all the good work into 2004 and beyond.

Editorial

by Michael Attas (attasm@aecl.ca)

Some evenings after sunset but before the stars come out, I look west and see a brilliant streak of light moving slowly through the sky. "It's just a jet trail," I tell myself. Since this phenomenon is not astronomical at all, in the past I never gave it a second thought. On one occasion, though, I recalled trying to spot Halley's Comet in 1986. After much searching I saw a faint smear, but it was much less impressive than this vapour trail. So why was I so much more excited about the comet?

Eventually I realized that the impact of what we see is very much influenced by its context; namely, what we think about it. This is not a new idea, of course, but it's very much at the heart of observational astronomy — okay, stargazing. Seeing the faint fuzziness of the Andromeda galaxy through binoculars for the first time can be disappointing, but only if you're expecting a photo-quality view. It can instead be quite thrilling if you're thinking about how far away the galaxy is, how long it took the light to arrive, how huge it is, how many stars you're seeing at once, how many of them have planets, how many planets might be inhabited, and so on. Our mind interprets what our eyes see and sets us up to respond, either emotionally or objectively or both.

A friend once asked me if a scientific understanding of astronomy diminished the wonder of the night sky. I said no, with some hesitation, because my sense of wonder was coming and going — certainly diminished during tedious searches for dim NGC objects during frosty nights! Sometimes these searches were hindered by auroral displays, which bathed the sky in washes of light, drowning out the faint fuzzies. I had to pull back from the eyepiece and readjust my priorities. After all, the aurora was a spectacular display in its own right, even though it wasn't a deep-space phenomenon. I know the shimmering gray-green light comes from molecules of oxygen and nitrogen in the upper atmosphere, excited by high-energy subatomic particles from the sun. Does that diminish my awe at seeing the whole sky dancing? Not a bit.

It turns out that knowing what's behind certain phenomena usually makes them more exciting to observe, rather than less exciting. You've probably seen bird watchers thrilled at hearing a particular call or seeing unusual markings. Archaeology buffs also get excited about things that look pretty mundane to the uninitiated. I've recently realized that geology can do the same to otherwise sane human beings, including myself.

Every fall I crack open the brand new *Observer's Handbook* and study the map of meteorite impact craters of North America, prepared by R.A.F. Grieve. Canada has such a broad expanse of old, hard rock that impact sites are more common than one might imagine. They can be tricky to identify, though, since the signs are often subtle. Deep, round lakes on the Canadian Shield are suspicious, especially if they are ring-shaped or have central islands. West Hawk Lake, around the corner from where I live, is the deepest lake in Manitoba and has been proven to be an old crater by researchers who drilled into its bottom. To my eyes it looks pretty normal, but I'm impressed nonetheless.

Last June I decided to visit another classic impact site, the Brent crater in Algonquin Park. The Ontario road map showed it to be a few kilometres down a dirt road off Highway 17, so after a business trip to Chalk River, I headed that way. It's well marked, and in fact there is an observation tower on the rim, a visitor's brochure, and a hiking trail to the bottom. Except for the hordes of mosquitoes and a few larger animals, I was alone on the trail. The silence on the cool floor of the crater heightened the eerie feeling in my bones while I pondered that half a billion years ago on this very spot a stupendous explosion had transformed the landscape in a millisecond. But if the spot had not had a road sign, I would have driven right by it. The traces of the impact are evident only to trained eyes (and minds). That's the point I'm trying to make: education doesn't diminish our sense of astronomical wonder; it enhances it. The more we know about what we are looking at, the better we can appreciate it. So next time you're showing someone the night sky through your telescope, take the time to explain the view. Knowledge — it's the natural experience enhancer.

Correspondence
Correspondance

Erratum:
In the August 2003 "Orbital Oddities" column (JRASC, August 2003), the author made reference to the irrational number "Φ" which was reproduced as "M" due to a typographical error. The second sentence in the middle column of page 182 should read:

"Indeed, last year at this time I was invoking the so-called 'most' irrational of all numbers (although certainly not the most illogical),Φ, as I examined a first-order pseudo-Fibonacci relationship between Earth and Mars."

In the News Notes item "The Universe is Just A 'Click' Away" (*JRASC*, August 2003) we forgot to mention that the Director of the project is Dr. John Percy of the University of Toronto.

News Notes
En Manchettes

GEMINI SURPRISE AT EPSILON INDI

While searching for planet-sized bodies that might accompany the nearby star system Epsilon Indi, astronomers using the Gemini South telescope in Chile made a related but unexpected detection. Epsilon Indi was known to host an orbiting companion, dubbed Epsilon Indi B, which was discovered last year and is the nearest known specimen of a brown dwarf. Brown dwarfs are small, low-temperature stars thirty to forty times more massive than Jupiter but of similar size. Even though the Epsilon Indi system has been intensively studied since its brown dwarf companion was discovered, it required the combination of Gemini's powerful infrared capabilities and the extremely sensitive spectrograph/imager called PHOENIX to reveal a third and unexpected companion body. "Epsilon Indi Ba is the closest confirmed brown dwarf to our solar system," says Dr. Gordon Walker (University of British Columbia), who led the Gemini research team. "With the detection of Epsilon Indi Bb," Walker continues, "we now know that Epsilon Indi Ba has a close companion that appears to be another, even cooler brown dwarf. One certainty is that the Epsilon Indi system is even more interesting than we previously thought."

"When the target was acquired and we saw that there were clearly two objects close together, we initially thought it must be the wrong object. Epsilon Indi Ba, formerly called Epsilon Indi B, had been observed before and in those observations, no one noticed the companion object. It was a tremendous surprise for us," says Dr. Kevin Volk (Gemini Observatory, La Serena, Chile) who was actually making the observation at the Gemini South telescope along with Dr. Robert Blum (CTIO, La Serena, Chile).

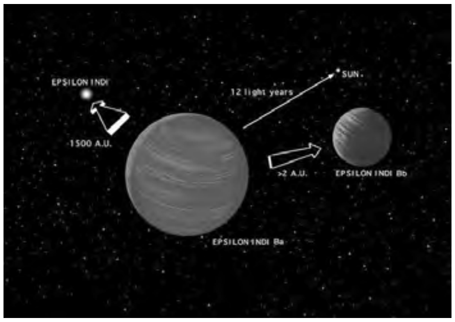

Figure 1. Artistic recreation of the Epsilon Indi system. The picture shows Epsilon Indi and its brown-dwarf binary companions. The relative sizes are not shown to scale in this illustration. Artwork by Jon Lomberg, supplied courtesy of Gemini Observatory Illustration.

The serendipitous nature of the detection took the science team — whose members are from Canada, the U.K., the U.S., and Chile — by surprise. Dr. Blum elaborates, "We then found that the companion, Epsilon Indi Bb, is invisible in the methane band where previous Gemini observations had been taken. The coolest brown dwarfs are very faint and hard to detect, but there may be vast numbers of them — which makes this detection important."

Epsilon Indi is the fifth brightest star in the southern constellation of Indus and is located about 11.8 light years away from our Solar System. The star is similar to but cooler than our Sun. The projected separation as seen on the sky between Epsilon Indi A and Indi Ba is approximately 1500 AU, and the distance between Epsilon Indi Ba and the newly discovered Epsilon Indi Bb is at least 2.2 AU.

The new Gemini observations show that Epsilon Indi Bb is cooler and less massive than Epsilon Indi Ba, a result that follows from its significantly lower brightness and deep methane absorption. Methane absorption is a key indicator for low-mass objects since gaseous methane can only exist in the lower temperature environments of the atmospheres of brown dwarfs and planets.

Epsilon Indi Ba and Bb are members of a recently discovered type of astronomical object: the so-called T class brown dwarfs. These T-dwarfs have diameters approximately equal to Jupiter but with more mass. Spectra of Epsilon Indi Ba, taken with PHOENIX by Dr. Verne Smith (University of Texas, El Paso) and collaborators, show that Epsilon Indi Ba has 32 times the mass of Jupiter and a 1500-degree surface temperature. It is spinning about three times faster than Jupiter. Epsilon Indi Bb has less mass, is cooler, but is still much more massive and hotter than Jupiter. Like Jupiter, the T-dwarfs do not have enough mass to make energy the way the Sun does from nuclear fusion. Epsilon Indi Ba and Bb are glowing from heat resulting from the mass pushing down on the interior.

PHOENIX, the instrument responsible for producing the new data, is a near-infrared, high-resolution spectrometer built by the National Optical Astronomy Observatory (NOAO) in Tucson, Arizona, and commissioned on Gemini South in 2001. Dr. Ken Hinkle (NOAO, Tucson, Arizona) comments, "PHOENIX was designed for exactly this type of research. It is the first high-resolution infrared spectrograph on a Gemini telescope, and the first high-resolution infrared spectrograph on any Southern Hemisphere telescope."

Further details and images of the Epsilon Indi system are on the Gemini telescope Web page at `www.gemini.edu`.

SCUBA-2 A GO

An international collaboration, which includes astronomer Dr. René Plume of the Department of Physics and Astronomy, University of Calgary, has recently announced it is moving ahead with the construction of a new generation of astronomical camera. The camera, thousands of times more powerful than its predecessor, is called the Submillimetre Common User Bolometer Array-2, or SCUBA-2 The project has received $12.3 million in funding from the Canada Foundation for Innovation (CFI). Once complete in 2006, SCUBA-2 will be installed on the James Clerk Maxwell Telescope (a radio telescope jointly operated by Canada, the UK, and the Netherlands) at the Mauna Kea Observatory in Hawaii. With its unprecedented sensitivity and field of view, SCUBA-2 will help researchers better understand how stars and galaxies are formed. The cutting-edge technology to be incorporated in SCUBA-2 is expected to provide much better images than those currently provided by SCUBA-1. In addition, with some 6400 detectors, SCUBA-2 will be able to observe much larger areas of the sky than SCUBA-1, which uses only 130 detectors.

"To understand how stars and galaxies are made, you need to first study the material that they are made from and how it is distributed throughout the universe," says Plume, and "in order to do this, we need to survey the sky at radio wavelengths. The new technology in SCUBA-2 will give us a more detailed picture of the sky and it will also allow researchers to complete in one night what would normally take three years with SCUBA-1."

The CFI funds for the SCUBA-2 project was awarded to a consortium of eight Canadian universities under its International Access Fund. Researchers at the University of Waterloo are leading the consortium.

GRB INDUCED MASS EXTINCTION

Gamma Ray Bursts (GRBs) rank among the most energetic of explosive events that occur within the Universe. Produced when massive stars undergo gravitational collapse, GRBs literally constitute an intense burst of lethal gamma rays that propagate through space. Any habitable planet caught in the near-by vicinity of a GRB-producing event would suffer devastating effects. Indeed, such a withering gamma-ray blast may have struck the Earth some 443 million years ago at the end of the Ordovician era according to a new research report published in the September 24 issue of the *New Scientist*.

Astrophysicist Dr. Adrian Melott (University of Kansas) and collaborators, including University of Calgary geologist Brian Chatterton, reached their conclusions after studying the trilobite extinction record at the time of the late Ordovician. The fossil data gathered by Chatterton from the Mackenzie Mountains of northwestern Canada, in particular, indicate that those trilobite species that lived in the plankton rich layer near the ocean surface were more adversely affected during the Ordovician extinction than those that dwelt in the deeper ocean. This pattern of ocean surface devastation is exactly what would be expected from a GRB interaction, Melott and co-workers argue.

The key gamma-ray induced extinction mechanisms that Melott and co-workers identify (for both ocean-surface-dwelling trilobites and land animals) are the destruction of the Earth's ozone layer and the production of deadly toxins. As the gamma rays interact with the Earth's atmosphere a veritable "witch's brew of nitrogen oxides" would be produced, Melott *et al.* argue. In particular, the new research report singles out nitrogen dioxide (NO_2) as being a particularly potent agent for blocking out substantial quantities of sunlight and for destroying ozone. The combined effects of prolonged darkness and UV radiation over-exposure are the agents that devastate life on and near the Earth's surface.

It has been estimated that a GRB capable of affecting life on Earth occurs once every five million years (or so).

EARLY CHINESE ECLIPSE RECORDS: A SECOND LOOK

The interpretation of ancient astronomical records is, even at the best of times, a difficult and demanding task. With this in mind, Dr. Ciyuan Liu (of the Chinese Academy of Sciences) and co-workers, including Xueshun Liu (Ph.D. candidate, School of Asian Studies, University of British Columbia), have re-evaluated a series of two-thousand-year-old astronomical records from the Xia, Shang, and Western Zhou Dynasties. Writing in the June issue of *The Journal of Astronomical History and Heritage*, Liu and co-workers discuss a series of supposed solar eclipse records found in *Spring and Autumn Annals* as well as on oracle bone inscriptions and in passages from the *Book of Songs*.

The researchers find that many of the eclipse records are, in fact, very vague and indeed, the conclusion drawn for most of them is genuine solar eclipses are probably not being referred to. What Liu *et al.* have deduced in a number of cases is that the records actually indicate is that a "test" was being made. That is, the accounts do not actually say that an eclipse took place, but rather they are divining the possible consequences should a solar eclipse be seen. As a result of this new and continuing study, Liu and co-workers call into question the method of dating ancient Chinese chronicles by solar eclipse observability matching.

Figure 2. – Fragment of a Shang dynasty oracle bone (circa 10 BC). The three characters in the upper portion of the bone fragment are *ri* (the sun) *you* (has) *shi* (eclipse). Liu and co-workers argue that rather than this being a record of an actual solar eclipse, it is a divination concerning what would happen **if** a solar eclipse were to be seen. Unlike the records relating to lunar eclipses, Liu and co-workers argue that no clear-cut solar eclipse accounts have been found in the ancient oracle bone inscriptions. Image courtesy of Xueshun Liu.

Johannes Kepler's *Harmonices mundi:* A "Scientific" Version of the Harmony of the Spheres, Part II[1]

by Bruno Gingras, McGill University (bginger@po-box.mcgill.ca)

Perhaps in order to show the seriousness of his procedure, and to show that harmonic ratios are not to be found in several relations in which they might have been expected to occur, Kepler gives a summary of his successive unsuccessful attempts. First, he shows that no harmonic proportions are to be found in the periodic times of the planets (that is, the time required for a planet to complete its revolution around the Sun). He then compares the ratios of the extreme distances of planets (distances from the Sun at aphelion and perihelion), with harmonic intervals. This comparison is done not only for an individual planet, but also for two adjacent planets, by comparing their divergent extreme distances (the aphelion of the planet farther from the Sun with the perihelion of the planet that is closer to the Sun) and their convergent extreme distances (the perihelion of the planet farther from the Sun with the aphelion of the planet that is closer to the Sun). These comparisons yield a few harmonic proportions, but do not give a satisfying result for every planet (Figure 1). For example, the convergent extreme distances of Mars and Earth yield a ratio of 27/20, which corresponds to an interval between a perfect fourth and a tritone. Furthermore, Kepler observes that harmonies are related to motion, therefore one should expect to find harmonic ratios in the motions of planets and not in their relative distances. Trying to explain how musical harmonies could be perceived through the motion of the planets, he argues "in fact, there are no real sounds in the heavens, and the motion is not so turbulent that a whistling is produced by friction with the heavenly air" (Kepler 1619). In one short sentence, nested in the middle of a lengthy paragraph, a tradition that stood for nearly two thousand years had been swiftly debased. The celestial harmonies must then be perceived by another sense, and Kepler tells us that they are brought to us through the light perceived by our eyes, which informs us of the motions of the planets.

Accordingly, he proceeds to look at the daily paths of the planets (that is, the actual distance traveled by a planet around its orbit in one day). Clearly, there are no harmonic relations to be found there (Figure 2). However, Kepler is not daunted by this apparent failure, remarking that the estimation of daily paths require complex calculations and thus could not be perceived by "natural instinct." Finally, Kepler examines the relations between the apparent daily planetary motions (the apparent daily arcs created by the motion of a planet, measured in degrees) as if they were seen from the Sun, the idea being that the harmonic relations that could be found in these motions would be conveyed in some way with the light from the Sun. Since the perception of apparent daily motions requires no calculations, harmonic relations could instinctively be felt by all living creatures. The results show that musical intervals (albeit not necessarily consonant intervals) are obtained for every planet, when comparing its apparent daily motion at aphelion and at perihelion. Moreover, when comparing the extreme convergent and divergent apparent daily motions of pairs of adjacent planets, consonant intervals are obtained in every case (Figure 3). The margin of error is very small in most cases, being generally less than a syntonic comma (81:80), and amounting to less than a diesis (25:24) in all cases except for the divergent motions of Jupiter and Mars.[2] There is, however, one glaring omission in this table: the perfect fourth, one of the primary consonances, is not to be found between the extreme motions of any individual planet, nor between the convergent or divergent motions of any pair of planets. Fortunately for Kepler's system, the relation between the extreme apparent daily motions of the Moon as seen from the Earth (that is, when comparing the motion of the Moon at apogee and its motion at perigee) gives a perfect fourth. Although the theoretical coherence of the system is jeopardized

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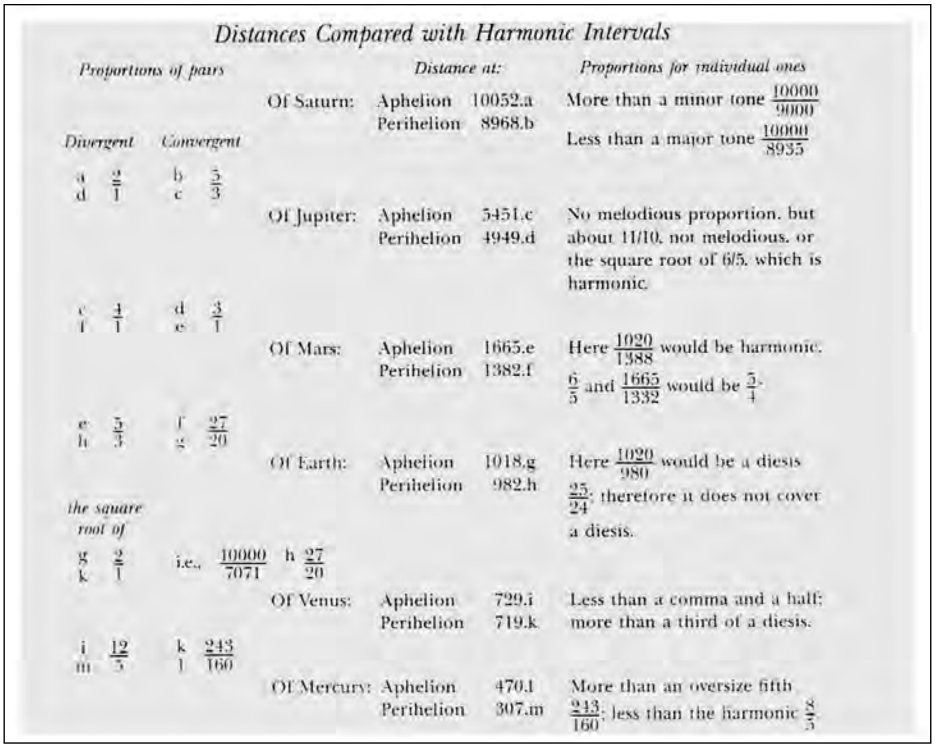
[1] The first installment of this article appeared in the October 2003 issue of the *Journal*.

[2] The syntonic comma (81:80) is the difference between a Pythagorean major third (81:64) and a just major third (5:4). The diesis (in just intonation) is the difference between a major third (5:4) and a minor third (6:5). Note that the diesis is smaller than the semitone (16:15), calculated as the difference between a perfect fourth (4:3) and a major third.



Distances Compared with Harmonic Intervals

Proportions of pairs					*Distance at:*		*Proportions for individual ones*
Divergent		*Convergent*					
				Of Saturn:	Aphelion Perihelion	10052.a 8968.b	More than a minor tone $\frac{10000}{9000}$ Less than a major tone $\frac{10000}{8935}$
a d	$\frac{2}{1}$	b c	$\frac{5}{3}$				
				Of Jupiter:	Aphelion Perihelion	5451.c 4949.d	No melodious proportion, but about 11/10, not melodious, or the square root of 6/5, which is harmonic.
c f	$\frac{4}{1}$	d e	$\frac{3}{1}$				
				Of Mars:	Aphelion Perihelion	1665.e 1382.f	Here $\frac{1020}{1388}$ would be harmonic. $\frac{6}{5}$ and $\frac{1665}{1332}$ would be $\frac{5}{4}$.
e h	$\frac{5}{3}$	f g	$\frac{27}{20}$				
				Of Earth:	Aphelion Perihelion	1018.g 982.h	Here $\frac{1020}{980}$ would be a diesis $\frac{25}{24}$; therefore it does not cover a diesis.
the square root of g k	$\frac{2}{1}$	i.e., $\frac{10000}{7071}$	h $\frac{27}{20}$				
				Of Venus:	Aphelion Perihelion	729.i 719.k	Less than a comma and a half; more than a third of a diesis.
i m	$\frac{12}{5}$	k l	$\frac{243}{160}$				
				Of Mercury:	Aphelion Perihelion	470.l 307.m	More than an oversize fifth $\frac{243}{160}$; less than the harmonic $\frac{8}{5}$.

Figure 1 – Relative distances of the planets compared with harmonic intervals (from Kepler, *Harmonices mundi* [English translation by Aiton, Duncan & Field]).

by the addition of the Moon (which is not, properly speaking, a planet), and the use of the Earth as a vantage point (all other daily planetary motions are perceived from the Sun in Kepler's system), one can almost hear a sigh of relief from Kepler upon discovering this relation, as the absence of a primary consonance such as the fourth would have been a serious problem for a system that is supposed to reflect the work of the Creator.

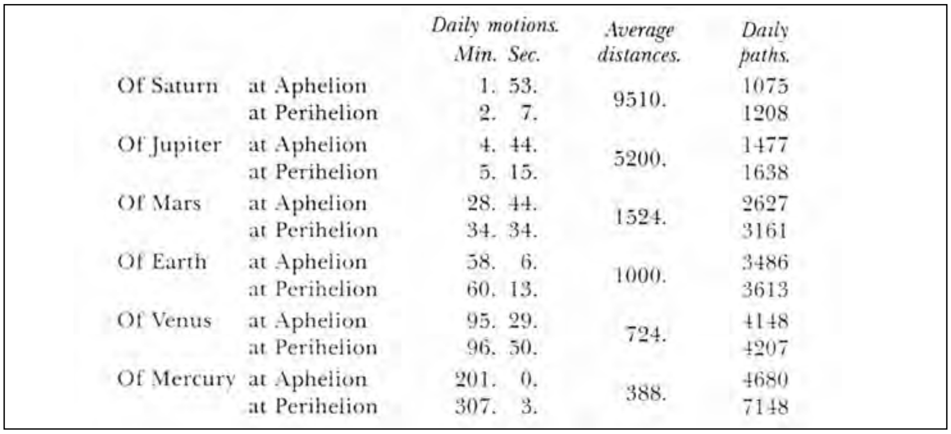
Proportions of pairs: ratios found when comparing the divergent or convergent extreme distances to the Sun of adjacent planets. The mean distance from the Earth to the Sun is arbitrarily set at 1000, and all other distances are evaluated in proportion. The letters (a, b, c, *etc*...) refer to the quantities found in the second column (distance at aphelion/perihelion).

Proportions for the individual ones: ratios obtained when comparing the extreme distances of a single planet.

Daily motions: apparent daily motions as seen from the Sun, measured in minutes and seconds. *Average distances*: average distance from the Sun (again the distance from the Earth to the Sun is arbitrarily set at 1000). *Daily paths:* average distance traveled by a planet in a single day in its orbit around the Sun (the arbitrary unit used here is the same as that used in the "average distances" column).

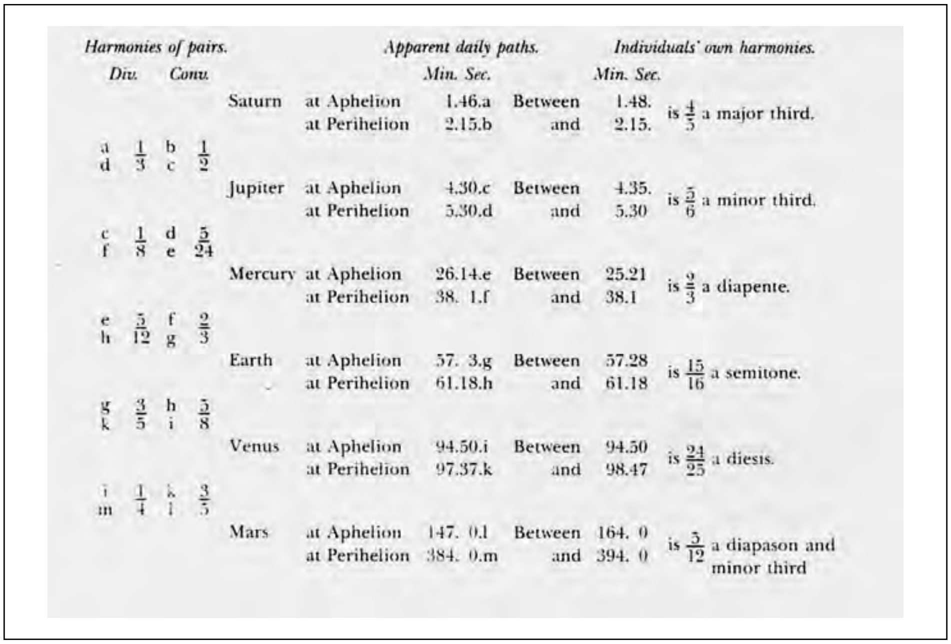
Harmonies of pairs: harmonic ratios found when comparing the extreme divergent (*div.*) or convergent (*conv.*) motions of adjacent planets. The letters (a, b, c, *etc.*) refer to the quantities found in the second column (apparent daily paths). *Apparent daily paths*: apparent daily motions of the planets as seen from the Sun, measured in minutes and seconds. *Individuals' own harmonies:* ratios obtained when comparing the extreme motions of a single planet. Note that there is a typographic error in the table (which was taken from the translation by Aiton, Duncan & Field): Mars and Mercury were inverted. The reader should therefore read "Mars" instead of "Mercury" and vice-versa. *Analysis of the harmonies of pairs:* a harmonic ratio of a twelfth (1:3) is observed between the extreme divergent motions of Saturn and Jupiter, and a ratio of an octave (1:2) is found between their convergent motions. A ratio of three octaves (1:8) is found between the divergent motions of Jupiter and Mars, while an interval of a double octave plus a minor third (5:24) is found between their convergent motions. A ratio of a minor tenth (5:12) is observed between the divergent motions of Mars and Earth, while a ratio of a perfect fifth (2:3) is found between their convergent motions. A ratio of a major sixth (3:5) is observed between the divergent motions of Earth and Venus, while a ratio of a minor sixth (5:8) is found between their convergent motions. Finally, a interval of a double octave (1:4) is observed between the divergent motions of Venus and Mercury, while a ratio of a major sixth (3:5) is found between their convergent motions.

Kepler remarks that an important distinction should be made between harmonies set out between the extreme motions of a single planet, and those that are found between combinations of planets, "because the same planet when it is situated at its aphelion cannot at the



		Daily motions. *Min.*	*Sec.*	*Average distances.*	*Daily paths.*
Of Saturn	at Aphelion	1.	53.	9510.	1075
	at Perihelion	2.	7.		1208
Of Jupiter	at Aphelion	4.	44.	5200.	1477
	at Perihelion	5.	15.		1638
Of Mars	at Aphelion	28.	44.	1524.	2627
	at Perihelion	34.	34.		3161
Of Earth	at Aphelion	58.	6.	1000.	3486
	at Perihelion	60.	13.		3613
Of Venus	at Aphelion	95.	29.	724.	4148
	at Perihelion	96.	50.		4207
Of Mercury	at Aphelion	201.	0.	388.	4680
	at Perihelion	307.	3.		7148

Figure 2 – Extreme daily motions of the planets (from Kepler, *Harmonices mundi* [English translation by Aiton, Duncan & Field]).



Harmonies of pairs.				*Apparent daily paths.*				*Individuals' own harmonies.*	
Div.		*Conv.*				*Min. Sec.*		*Min. Sec.*	
				Saturn	at Aphelion	1.46.a	Between	1.48.	is $\frac{4}{5}$ a major third.
					at Perihelion	2.15.b	and	2.15.	
a d	$\frac{1}{3}$	b c	$\frac{1}{2}$						
				Jupiter	at Aphelion	4.30.c	Between	4.35.	is $\frac{5}{6}$ a minor third.
					at Perihelion	5.30.d	and	5.30	
c f	$\frac{1}{8}$	d e	$\frac{5}{24}$						
				Mercury	at Aphelion	26.14.e	Between	25.21	is $\frac{2}{3}$ a diapente.
					at Perihelion	38. 1.f	and	38.1	
e h	$\frac{5}{12}$	f g	$\frac{2}{3}$						
				Earth	at Aphelion	57. 3.g	Between	57.28	is $\frac{15}{16}$ a semitone.
					at Perihelion	61.18.h	and	61.18	
g k	$\frac{3}{5}$	h i	$\frac{5}{8}$						
				Venus	at Aphelion	94.50.i	Between	94.50	is $\frac{24}{25}$ a diesis.
					at Perihelion	97.37.k	and	98.47	
i m	$\frac{1}{4}$	k l	$\frac{3}{5}$						
				Mars	at Aphelion	147. 0.l	Between	164. 0	is $\frac{5}{12}$ a diapason and minor third
					at Perihelion	384. 0.m	and	394. 0	

Figure 3 – Apparent daily motions of planets (from Kepler, *Harmonices mundi* [English translation by Aiton, Duncan & Field]).

same time also be at its perihelion, which is opposite, but of two planets one can be at its aphelion and the other at its perihelion at the same moment of time. Thus the proportion of simple melody or monody, which we call choral music and which was the only kind known to the ancients, to the melody of several voices, called figured and the invention of recent centuries,[3] is the same as the proportion of the harmonies which are indicated by individual planets to the harmonies which they indicate in combination" (Kepler 1619). In other words, not only does Kepler's theory of celestial harmony take into account the most recent developments in astronomy, such as the heliocentricity of the solar system and the eccentricity of the planetary orbits, but it also incorporates what he believed to be recent developments in music, such as polyphony and counterpoint.

In Chapter V Kepler proceeds to show how musical scales can be assembled out of the relations between the planetary motions that were presented. Assuming octave equivalence, he divides the apparent daily motions of the planets by two until all the motions can be comprised within an octave (or within a factor of two, to put it another way). The motion of Saturn at aphelion, which is the slowest apparent motion of all planets, is taken to be the lowest note of the system, which is G. A *durus* scale (which corresponds more or less to our major mode)[4] is then built by associating apparent motions of other planets to notes of the scale in such a way that the relation between the apparent motions corresponds to the musical interval between notes of the scale (Figure 4). All the notes of the *durus* scale beginning on G (within a single octave) are obtained except for A. Kepler justifies the fact that A is left out by pointing out that it was not represented either by the harmonic divisions that were carried out in Book III in order to build the *durus* scale. Undoubtedly, this correspondence between the musical theorems presented in Book III and the actual scale created by the apparent motions of the planets must have been seen by Kepler as an eloquent confirmation of his theory. Although the seventh degree of this scale is usually F natural, F# was frequently used, and this is mentioned by Kepler as a justification for including the motion of Mars at aphelion. C sharp, representing the motion of Mercury at aphelion, is also included, as Kepler indicates all apparent motions that fit notes within a comma, even if they are not part of the scale. All the extreme motions of the six known planets are thus represented, except for the perihelion motions of Earth and Venus.

Figure 4. Construction of the *durus* (top) and *mollis* (bottom) planetary scales (from Kepler, *Harmonices mundi* [English translation by Aiton, Duncan & Field]).

As for the *mollis* scale (Figure 4), corresponding to our minor mode, the perihelion motion of Saturn is taken as the lowest note this time. F is left out (again, Kepler justifies this by saying that it was not represented by the harmonic divisions used to construct the *mollis* scale in Book III). All planetary motions are represented except Saturn at aphelion, Mars at perihelion, and Venus at aphelion. For Kepler, the fact that the two main types of musical scales used by musicians of his time are found in the heaven indicates that musicians are merely "aping God the Creator, and as it were acting out a particular scenario for the ordering of

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[3] Kepler believed polyphony to be a recent invention.

[4] Walker (1978) notes that in Book III, Kepler "describes the two genera, *molle* and *durum*, in such a way that they seem to be the same as our minor and major modes." Although this seems to work with scales, it does not seem to be the case with chords (see footnote 6).

the heavenly motions" (Kepler 1619).

So far, only the extreme apparent daily motions of the planets have been considered. However, by including all the intermediary motions (that is, the apparent motions observed when a planet moves from its perihelion to its aphelion around the course of its orbit), one would obtain a particular range, or tessitura, for each planet.[5] This is shown by Kepler in Chapter VI, where he assigns a particular mode to each of the planets, remarking that, although his musical representations of these intermediary motions seem to indicate an discrete intervallic motion, the pitch would in fact be continually changing, in a way likened by Walker (1978) to the "wailing of a siren." The lowest note for each planet is taken from the *durus* scale previously constructed, except in the case of Jupiter and Mercury, for which the lowest note is that assigned in the *mollis* scale (Figure 5). Saturn, which covers a major third from G to B, is assigned the Mixolydian or Hypomixolydian mode, while Jupiter, going from G to B*b*, is associated with the Dorian or Hypodorian mode. Since the range of Mars covers a fifth, and given that the aphelial note of Mars is close to F in the *durus* scale (in fact, it is F#), it would indicate the Lydian or Hypolydian mode. The difference between the extreme motions of Earth is only a semitone, so Kepler assigns it to the Phrygian or Hypophrygian mode, which is the only mode beginning with a semitone. He remarks, in a marginal pun, that "the Earth sings '*mi-fa-mi*', so that even from the syllables you may guess that in this home of ours *mi*sery and *fa*mine hold sway" (Kepler 1619). Venus stays on a single note, but because this note is E in the *durus* scale, Kepler also associates Venus to the Phrygian-Hypophrygian modes. Finally, Mercury, covering a minor tenth, is suited to all the modes.

In Chapter VII Kepler, who clearly sees the development of polyphony and counterpoint as an impressive achievement of "modern" music, expresses the wish that a contemporary composer will attempt to write an "ingenious motet" that will reflect the harmonies of the planets. He proceeds to construct in a systematic fashion all the "universal harmonies" that could be created, by having the combination of the apparent motions of all six planets stand in harmonic relation at a given time. Because of the very slow motion of outer planets such as Saturn, which takes 30 years to complete its revolution around the Sun, and considering the limited "vocal range" of some planets, Kepler acknowledges that six-part celestial harmony will occur very infrequently. Indeed, he remarks that "harmonies of four planets begin to spread out over the centuries, and those of five planets over myriads of years," and actually doubts whether a six-part harmony among the planets could occur more than once over the course of history. He suspects that, if one could calculate a past moment of universal harmony, it would be the exact moment of Creation.

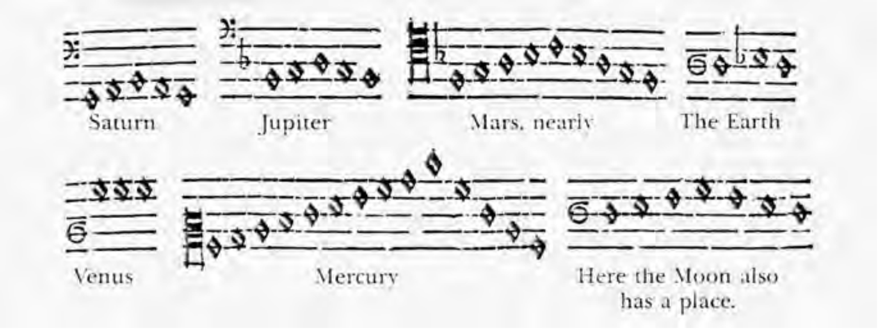

Figure 5 – The "vocal ranges" of the planets (from Kepler, *Harmonices mundi* [English translation by Aiton, Duncan & Field]).

Because of the limited tessitura of Venus and the Earth, these two planets cannot make more than two consonances between themselves: a major sixth (Earth at aphelion and Venus at perihelion), and a minor sixth (Venus at aphelion and Earth at perihelion). Two "hard" chords, in which there is a major sixth between the notes sung by the Earth and Venus, involving all six planets can be obtained: the first chord is an E minor chord in first inversion, and the second a C major chord in 6/4 position (Figure 6).[6] Two "soft" chords, in which one finds a minor sixth between the Earth's note and Venus' note, can be obtained, one being a E flat major 6/3 chord, and the other a C minor 6/4 chord (Figure 12).[7] Since Venus can only "sing" E (in the *durum* scale), or Eb (in the *mollis* scale) it is the most limiting planet, and Kepler therefore discusses possible five-note harmonies excluding Venus, and four-note chords, excluding

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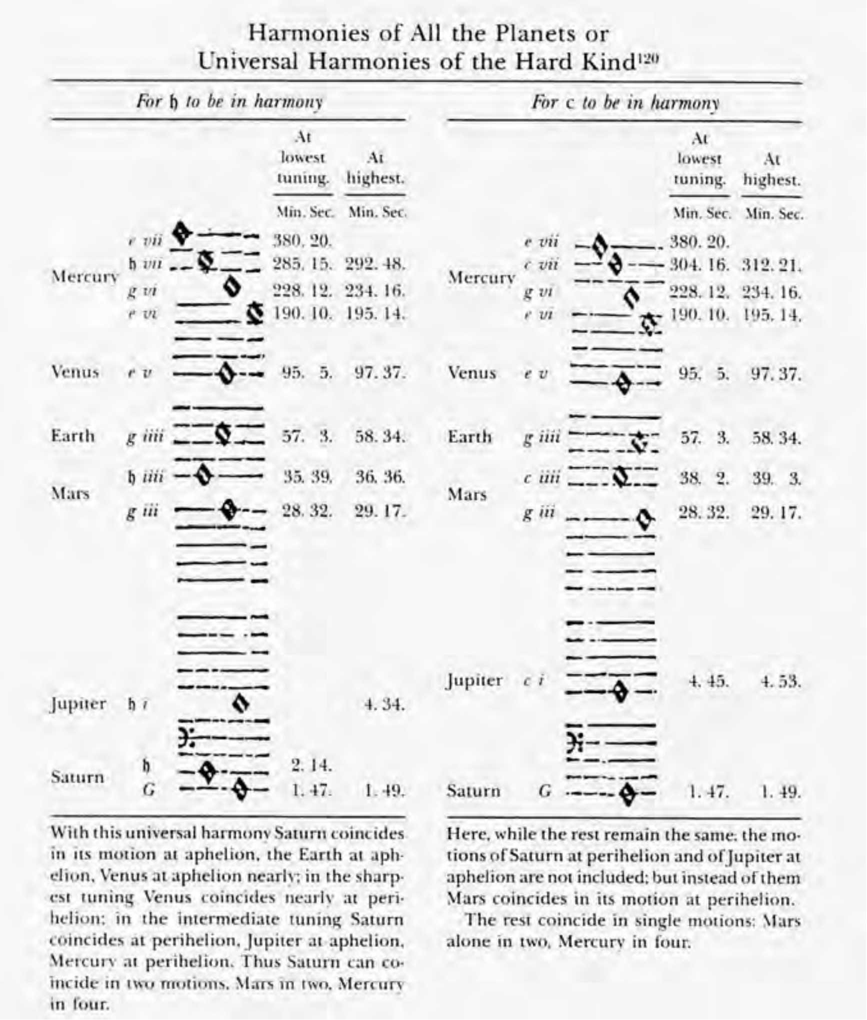
[5] Although Kepler does not explicitly say so, it should be understood that, the eccentricity for the orbit of each planet being different, the "musical range" of each planet would be different (for a planet whose orbit is very eccentric, such as Mercury, the difference between the apparent motions at aphelion and perihelion would be much greater than for a planet whose orbit is only slightly eccentric, such as the Earth or Venus).

[6] Here, "hard" or *durus* apparently refers to chords using B natural, while "soft" or *mollis* refers to chords using B flat. Hence, Kepler's classification of chords into "hard" and "soft" has nothing to do with their major or minor quality. To indicate the distinction between Kepler's use of the terms *durus* and *mollis* for scales and for chords, we chose to use the English equivalents "hard" and "soft" when discussing harmonies.

[7] According to Aiton, Duncan & Field, Kepler was aware that the 6/4 chord was treated as a dissonance by most composers, but accepted it on the grounds that the fourth had been geometrically demonstrated to be a consonance in Book III of *Harmonices mundi*.



Harmonies of All the Planets or
Universal Harmonies of the Hard Kind[120]

For ♮ *to be in harmony*

		At lowest tuning. Min. Sec.	At highest. Min. Sec.
Mercury	*e vii*	380. 20.	
	♮ *vii*	285. 15.	292. 48.
	g vi	228. 12.	234. 16.
	e vi	190. 10.	195. 14.
Venus	*e v*	95. 5.	97. 37.
Earth	*g iiii*	57. 3.	58. 34.
Mars	♮ *iiii*	35. 39.	36. 36.
	g iii	28. 32.	29. 17.
Jupiter	♮ *i*		4. 34.
Saturn	♮	2. 14.	
	G	1. 47.	1. 49.

With this universal harmony Saturn coincides in its motion at aphelion, the Earth at aphelion, Venus at aphelion nearly; in the sharpest tuning Venus coincides nearly at perihelion; in the intermediate tuning Saturn coincides at perihelion, Jupiter at aphelion, Mercury at perihelion. Thus Saturn can coincide in two motions, Mars in two, Mercury in four.

For c *to be in harmony*

		At lowest tuning. Min. Sec.	At highest. Min. Sec.
Mercury	*e vii*	380. 20.	
	c vii	304. 16.	312. 21.
	g vi	228. 12.	234. 16.
	e vi	190. 10.	195. 14.
Venus	*e v*	95. 5.	97. 37.
Earth	*g iiii*	57. 3.	58. 34.
Mars	*c iiii*	38. 2.	39. 3.
	g iii	28. 32.	29. 17.
Jupiter	*c i*	4. 45.	4. 53.
Saturn	*G*	1. 47.	1. 49.

Here, while the rest remain the same: the motions of Saturn at perihelion and of Jupiter at aphelion are not included; but instead of them Mars coincides in its motion at perihelion.

The rest coincide in single motions: Mars alone in two, Mercury in four.

Figure 6 – Universal harmonies of the "hard" kind (from Kepler, *Harmonices mundi* [English translation by Aiton, Duncan, & Field]).

Venus and the Earth (whose range, being only a semitone, is also a limiting factor).

Kepler uses an idiosyncratic notation in which the musical lines added above the bottom staff, although grouped by five, must still be read in the bass clef. Moreover, the octaves are indicated by using lowercase Roman numerals (i, ii, iii, *etc.*). Note that Kepler does not assume octave equivalence when building universal harmonies. Since the apparent daily motions of planets closer to the Sun are greater, these planets will "sing" in a higher register; hence, Mercury has the highest register, while Saturn has the lowest.

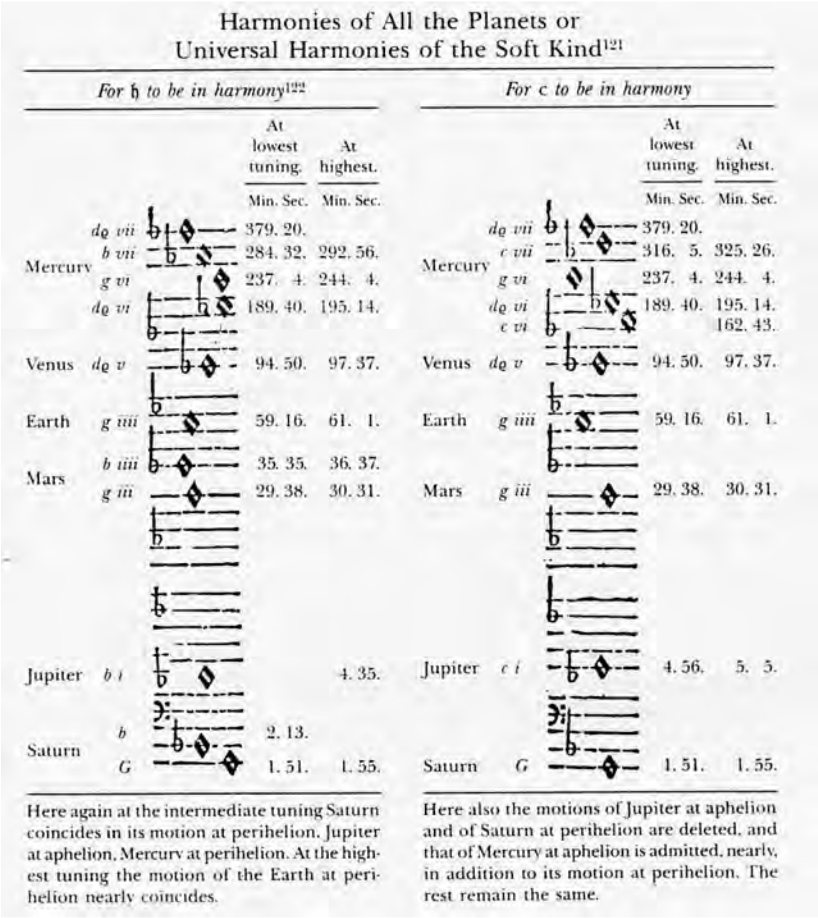
Since Kepler uses all the intermediary apparent motions of the planets to build these chords, certain planets, such as Mercury, can "sing" several notes that belong to the chord. Kepler also indicates the lowest and highest "tunings" possible for a given chord; these tunings indicate the range of apparent motions possible for a given planet within a single harmony.

The first chord is an E minor 6/3 chord, while the second chord is a C major 6/4 chord. In the first chord, Saturn and Mars can "sing" G (g in the case of Mars) or h, while Mercury can take G, h, or e at some point in its orbit. The remaining planets, Jupiter, Earth, and Venus, are much more restricted, and can take only one note (h for Jupiter, g for the Earth, and e for Venus). In the second chord, Saturn can take G, Jupiter c, Mars c and g, the Earth g, Venus e, and Mercury can take all three notes.

See Figure 6 for an explanation of the musical notation, the register of the planets, and the "tunings." The first chord is an E flat major 6/3 chord, while the second chord is a C major 6/4 chord. In the first chord, Saturn and Mars can "sing" G (g in the case of Mars) or b (b stands for B flat), while Mercury can take G, b, or d_e (d_e stands for E flat) at some point in its orbit. The remaining planets, Jupiter, Earth, and Venus can take only one note (b for Jupiter, g for the Earth, and d_e for Venus). In the second chord, Saturn can take G, Jupiter c, Mars g, the Earth g, Venus d_e, and Mercury can take all three notes (it actually can "sing" five different notes in this chord, given its wide tessitura).

Chapter VIII briefly describes the vocal attributes of each planet: although he reminds the reader that planetary motions are soundless, Kepler notices analogies between the roles of the planets and those of singers in a choir. Jupiter and Saturn cover harmonic intervals and have a distance between them varying from an octave to a twelfth, just as a bass part that makes harmonic leaps, Mars "is free, but proceeds modestly," in analogy to a tenor part, while the narrow range of Earth and Venus is, according to Kepler, typical of an alto part. Finally, Mercury, which is the planet that moves the fastest and has the largest range, is likened to a soprano.

In Kepler's view, every particularity of the solar system has to be explainable, since God would not have created the world using random or arbitrary proportions. Hence, the fact that the eccentricity of planetary orbits varies from planet to planet (an element that could not be explained by his planetary laws) is seen as necessary in order that harmonies of all kinds be established. Chapter IX constitutes an extremely sophisticated attempt to prove that, since the harmonies between the motions of the planets are perceived by comparing the extremes of their motions (apparent motions at perihelion and aphelion), God created the solar system so that the eccentricities of the orbits of each planet would be built according to those relations.



Harmonies of All the Planets or
Universal Harmonies of the Soft Kind[121]

For ♄ to be in harmony[122]

		At lowest tuning. Min. Sec.	At highest. Min. Sec.
Mercury	*dǫ vii*	379. 20.	
	b vii	284. 32.	292. 56.
	g vi	237. 4.	244. 4.
	dǫ vi	189. 40.	195. 14.
Venus	*dǫ v*	94. 50.	97. 37.
Earth	*g iiii*	59. 16.	61. 1.
Mars	*b iiii*	35. 35.	36. 37.
	g iii	29. 38.	30. 31.
Jupiter	*b i*		4. 35.
Saturn	*b*	2. 13.	
	G	1. 51.	1. 55.

Here again at the intermediate tuning Saturn coincides in its motion at perihelion, Jupiter at aphelion, Mercury at perihelion. At the highest tuning the motion of the Earth at perihelion nearly coincides.

For c to be in harmony

		At lowest tuning. Min. Sec.	At highest. Min. Sec.
Mercury	*dǫ vii*	379. 20.	
	c vii	316. 5.	325. 26.
	g vi	237. 4.	244. 4.
	dǫ vi	189. 40.	195. 14.
	c vi		162. 43.
Venus	*dǫ v*	94. 50.	97. 37.
Earth	*g iiii*	59. 16.	61. 1.
Mars	*g iii*	29. 38.	30. 31.
Jupiter	*c i*	4. 56.	5. 5.
Saturn	*G*	1. 51.	1. 55.

Here also the motions of Jupiter at aphelion and of Saturn at perihelion are deleted, and that of Mercury at aphelion is admitted, nearly, in addition to its motion at perihelion. The rest remain the same.

Figure 7 – Universal harmonies of the "soft" kind (from Kepler, *Harmonices mundi* [English translation by Aiton, Duncan & Field]).

A lengthy set of propositions, axioms, and theorems, which will not be discussed here on account of its complexity, is listed in order to justify this proposition.

Kepler concludes his book with a philosophical epilogue in which he entertains the possibility that the Sun, being the centre of the solar system, and the place from which the harmony of the world radiates, would in fact be the seat of the government of nature, populated with princes and chancellors, and perhaps even spiritual beings (although Kepler is careful about not stating anything that would be contrary to Catholic faith). He also presents his dreamy vision of other planets and their inhabitants, concluding with a prayer to God, who shall be praised by the heavenly bodies, by the celestial harmonies and all those who can perceive them, and finally by his own soul.

Although the *Mysterium cosmographicum* was warmly received in 1596 and even enjoyed a reprint in 1621, and in spite of the fact that Kepler was widely recognized as a brilliant astronomer and mathematician, the *Harmonices mundi* seems to have had little influence on his contemporaries. Besides the fact that it was understood by very few readers given its complex array of metaphysical speculation, its use of advanced mathematical and geometrical tools, and obviously its reliance on the latest developments in astronomy, the treatise was written at a time in which theoretical speculation was quickly being superseded by experimental science, championed by Kepler's occasional correspondent, Galileo. Moreover, although the belief in a God-created world was prevalent in the 17th century, an increasing number of scientists and philosophers doubted that the structure of the world should reflect archetypes, whether Pythagorean ratios, Platonic solids, or harmonic relations.

Among the few contemporaries who discussed Kepler's theory of celestial harmonies, the opinions are very diverse. The English astronomer Jeremiah Horrocks (1618–1641), an ardent proponent of Kepler's physical and harmonic theories, wrote an *Astronomia Kepleriana defensa & promota*, published posthumously in 1673 (Stephenson 1994). Horrocks, praising Kepler for his pioneering work in the field of celestial harmonies, remarked that his *Harmonices mundi* went well beyond the speculative writings of the *musica mundana* tradition. One can suppose that, had Horrocks not died at such a young age, he might very well have pursued Kepler's ideas further. The Jesuit Giovanni Riccioli (1598–1671), whose unfinished *Almagestum Novum* (an encyclopaedic anthology of astronomical theories) includes a summary of Kepler's *Harmonices mundi*, agreed that celestial harmonies should be sought in the motions of the planets and not in the relative distances, but questioned the very idea of *musica mundana*, wondering why harmonic proportions should be intrinsic to the heavens and remarking that this tradition should be understood as a poetical metaphor. Another Jesuit, Athanasius Kircher, criticized Kepler's margin of error in his *Musurgia universalis* (1650), arguing that Kepler was playing a game that he was bound to win. However, as Walker (1978) points out, one can suppose that Kepler was very critical about his own work, having tried various solutions for twenty years before he found one that satisfied him.

Meanwhile, other cosmogonies were developed by contemporary writers, such as the aforementioned Kircher and Robert Fludd (*Utriusque cosmi majoris scilicet et minoris metaphysica, physica atque technica historia*, published in 1617–1621). In contrast to Kepler, whose theories relied heavily on observation and physical laws, Kircher and Fludd emphasized occult doctrines such as the macrocosm-microcosm correspondence, and did not rely on empirical laws (Gouk 2002). However, although Kepler, who criticized Fludd's theories, clearly believed that his theory of celestial harmony was definitive (he hoped that if it was to be ignored by his contemporaries, it would certainly be appreciated by readers in a few centuries), he nevertheless attempted to explain the structure of the world in terms of concepts, such as universal harmonies and geometrical archetypes, that we would define today as "occult" or "metaphorical." A few decades later, Newton's astronomical theory was entirely based on mathematics and physics, while the growing science of acoustics had superseded the age-old tradition of the harmony of the spheres.

As for the physical significance of Kepler's celestial harmonies, although his observations are still considered valid and quite accurate by today's astronomers, the validity of his cosmological theory has been shattered by the discovery of Uranus in 1781, and later of Neptune and Pluto, since the relative distances to the Sun and the apparent motions of these planets cannot be accounted for by his theory. So far, modern science has not been able to provide an satisfying explanation for the harmonic ratios found between the six "ancient planets," and, in retrospect, one might be tempted to say that Kepler built a monumental theory to account for, and explain, what seems today to be merely an intriguing coincidence.

References

Chailley, J., & Viret, J. 1988, L'Harmonie des Sphères, in La Revue Musicale, 408, 75

Field, J.V. 1988, Kepler's Geometrical Cosmology (Athlone Press: London)

Godwin, J. 1987, Harmonies of Heaven and Earth (Inner Traditions International: Rochester)

Gouk, P. 2002, The Role of Harmonics in the Scientific Revolution, in The Cambridge History of Western Music Theory, ed. T. Christensen (Cambridge University Press: Cambridge), 223

Kepler, J. 1619, *Harmonices mundi* [The Harmony of the World], translated into English with an introduction and notes by Aiton, E.J., Duncan, A.M. & Field, J.V. 1997 (American Philosophical Society: Philadelphia)

Martens, R. 2000, Kepler's Philosophy and the New Astronomy (Princeton University Press: Princeton)

Murchie, G. 1961, The Music of the Spheres (Riverside Press: Cambridge, Massachusetts)

Stephenson, B. 1994, The Music of the Heavens (Princeton University Press: Princeton)

Walker, D.P. 1978, Studies in Musical Science in the Late Renaissance (Warburg Institute: London)

Bruno Gingras is a Ph.D. candidate in music theory at McGill University, Montreal. He is interested in counterpoint and music perception/cognition, and more generally in ways to combine his interest in music with his interest in science.

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Reflections

Newtonian Opticks

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

Figure 1 – A postcard depicting one of four stamps issued by the Royal Mail in 1987 to commemorate the 300th anniversary of the publication of Newton's *Principia.*

> "Nature, and Nature's Laws lay hid in Night:
> God said, *Let Newton be!* and All was *Light*."
>
> — Alexander Pope

The coming year marks the 300th anniversary of the publication of Isaac Newton's *Opticks,* subtitled *a treatise on the reflexions, refractions, inflexions, and colours of light*. This is one of two significant publications by Newton, the other being *Philosophiae naturalis principia mathematica* (often shortened to *Principia*), which laid out Newton's laws of motion and the theory of universal gravitation. Although Newton published the *Principia* in 1687 and *Opticks* in 1704, the concepts in these two major works originated in Newton's "miraculous year" in 1665-66, when he was only 22 years old, playing hooky from Trinity College, Cambridge, and avoiding the Great Plague.

I will not go into a detailed biography of Newton here (there is too much to tell!). Newton was born on Christmas Day, 1642, (Julian calendar) in Woolsthorpe Manor, Lincolnshire. His father had died only months before, and Isaac was raised by his grandmother after age 3, when his mother remarried and moved away. His great intellect lay dormant until his mid-teens. He entered Trinity College as an undergraduate in 1661 and remained there for 40 years, resigning in 1701 the professorship he had held for over 30 years. In the latter part of his life, he turned to politics, sitting as Member of Parliament for Cambridge University and accepting an appointment as Master of the Royal Mint. He was President of the Royal Society from 1703 until his death in 1727 at the age of 84. He was knighted in 1705, not for his scientific achievements but for his service to the Crown. He had good health all his life and never married. Isaac Newton is buried in Westminster Abbey, London.

The two books, *Principia* and *Opticks,* make an interesting comparison: *Principia* (1687) is the longer of the two, by far, and was written entirely in Latin, as was the custom for scientific works of the day. *Opticks* (1704) was written in English, as scientists had begun to write in their native languages by that time; however, it was translated into Latin for export! *Principia* was the culmination of all of Newton's ideas on dynamics and gravitation, and it would not have seen the light of day without the financial assistance and moral support of Edmond Halley (1656-1742), clerk and editor of the Royal Society. Newton, for his great intellect, was very sensitive to criticism, and several times in his career threatened to stop publishing his findings, in reaction to the harsh critiques of other scientists. *Principia* is a triumph of physical theory and mathematics, and turned the somewhat obscure Newton into a celebrity. After its publication, however, his interest in mathematics waned.

Opticks, on the other hand, has hardly a shred of mathematics in it (if you don't count geometry!). It is very much an account of Newton's own experiments with light, and all his conclusions are carefully established through direct observation. Newton's very first words in *Opticks* (after the Preface) are:

> "My design in this book is not to explain the properties of light by hypotheses, but to propose and prove them by reason and experiments."

His closing remarks in *Opticks* echo this theme, and suggest that he regards experiment to be superior to theory:

> "...the investigation of difficult things by the method of analysis ought ever to precede the method of composition. This analysis consists of making experiments and observations, and in drawing general conclusions from them by induction, and admitting no objections against the conclusions but such as are taken from experiments, or other certain truths."

These mildly defensive remarks stem from the reaction he received years earlier, in 1669-76, when he presented his initial findings on light and colour to the Royal Society. Because Newton "believed" in the corpuscular nature of light, he was ridiculed by Robert Hooke (1635-1703), curator of the Royal Society, and Dutch physicist Christiaan Huygens (1629-95), who both favoured a wave theory of light. He was astonished at their rejection of the evidence he had carefully assembled in support of his findings. There are several ironies in this story: although Newton believed that light had a particle nature, this belief did not play a large role in his deductions of the properties of light from experiment. On the other hand, his critics had developed only a primitive version of wave theory, and could explain very few phenomena. For instance, the connection between wavelength and colour was not known, and the superposition (*i.e.* interference) of waves was not understood. The world had to wait until the following century for an improved wave theory of light, developed by Thomas Young (1773-1829) and Augustin Fresnel (1788-1827), among others (but that is another story). In the meantime, Newton allowed for a certain "waviness" in his light rays, in his attempt to explain coloured interference fringes and what were evidently diffraction effects in his experiments. Newton had the last laugh, in a sense: in the early 20th century, Albert Einstein (1879-1955) was awarded the Nobel Prize in part for his work on the photoelectric effect in metals, in which he was compelled to conclude that light interacted with matter as a particle! In fact, the current model of light has a dual nature, neither exclusively a wave nor exclusively a particle (spanning the electromagnetic spectrum, one never hears scientists speak of "radio rays" or "gamma waves"). I like to think of light as travelling and diffracting as a wave but interacting and exchanging energy as a particle.

A large part of *Opticks* is devoted to an examination of the dispersion of light passing between two media of different refractive indices, or "refrangibility" as Newton would say. Working with prisms, lenses, and a ray of sunlight passing through a small hole in a window blind, Newton performed a series of experiments showing that blue light was "bent" more than yellow, yellow more than red, and so on. He also proved that white light was made up of all the colours. He convinced himself that refracting telescopes, with their dispersive objective lenses, were inherently faulty, and would always suffer from chromatic aberration, focussing light of different colours at different focal lengths, thus creating composite images with multi-hued coronas. Accordingly, Newton followed up on the suggestion by the Scottish mathematician James Gregory (1638-75) that a telescope with a curved objective mirror would direct all light to the same focus, irrespective of colour. Newton made several telescopes based on this principle, using metallic mirrors, and presented one to the Royal Society in 1671, after which he was elected a Fellow. His description of mirror-grinding may be of interest to modern telescope-makers! (I did not see any account of Newton using his telescope for astronomical purposes, but I did not look that hard.)

There is an epilogue to the chromatic aberration story: Newton was wrong! His friend David Gregory (1659-1708), professor of astronomy at Oxford and nephew to James Gregory, noticed that glass prisms of different composition refract the same colour of light to different degrees. He reasoned that a compound refracting objective made with lenses of two different types of glass could be made virtually free of chromatic aberration. Optician John Dolland (1706-61) constructed such a lens in 1758, and was widely recognized for the achievement (in 1729, the London barrister Chester Hall (1703-71) had devised a similar lens, but did not purse it commercially). Such achromatic lenses and their variants are used in all good quality modern refractors, but Newton's reflecting telescope (and its variants) remains king of the large-aperture telescopes.

Perhaps the crowning achievement of *Opticks* is Newton's explanation of the colours of the rainbow. The fundamental ray theory of the bow, explaining the geometry and angles, had been developed earlier by René Descartes (1596-1650) and others. Applying his new-found understanding of dispersion of light, Newton was able to explain how different pure colours of white light are dispersed and deviated into overlapping angular bands. In this way, he explained the order of the colours of the primary bow and the reverse order of the colours of the secondary bow. He also explained the under-appreciated fact that the colours of the rainbow are not pure (due to the overlapping bands) as are the colours derived from a prism. In other words, there is no unique mapping of wavelength to angle in the rainbow.

All in all, astronomers have a lot to thank Newton for. I find it astonishing that so much insight could emerge from a 22-year-old brain in such a short time, even if it did take nearly a lifetime to document. As a mark of respect for this great intellect, each one of us should find time to crack open a copy of *Opticks* in the coming year, its 300th anniversary. There is a Dover Books edition; Volume 34 of Encyclopedia Britannica's *Great Books of the Western World* contains it (and the *Principia*); and it is available online as a pdf file at `dibinst.mit.edu/BURNDY/Collections/Babson/OnlineNewton/Opticks.htm`.

> "The marble index of a mind forever
> Voyaging through the strong seas
> of thought, alone."
> — William Wordsworth,
> contemplating Newton's bust

David (Dave XVII) Chapman is a Life Member of the RASC and a past President of the Halifax Centre. This is his 40th article since he started writing Reflections *in 1997. By day, he is a Defence Scientist at Defence R&D Canada-Atlantic. Visit his astronomy page at* `www3.ns.sympatico.ca/dave.chapman/astronomy_page`.

Second Light

Asteroid Spins are Solar Powered

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

We all experience daily the effects of the second law of thermodynamics, which loosely stated declares that the amount of disorder in any system will increase over time (unless external work is done). This is particularly obvious in the bedrooms of our children, but the same principle applies throughout the Universe. Within our Solar System, asteroids bang into each other. Not frequently, but often enough that over time their spins should be pretty randomly distributed. About a year ago, however, Steve Slivan of the Massachusetts Institute of Technology reported that a family of asteroids — a group arising from the destruction of a larger body during a collision — had several clusters of spin orientations and speeds (see September 5, 2002 issue of *Nature*), rather than a random distribution. This was unexpected, though Richard Binzel (also of MIT and Slivan's Ph.D. advisor) had seen hints of it 15 years ago. Slivan had no explanation for his result. Now David Vokrouhlický of Charles University in the Czech Republic and his collaborators at the Southwest Research Institute in Boulder, Colorado have found that those peculiar asteroid spins result from the effects of sunlight (see September 11, 2003 issue of *Nature*).

The asteroids with the peculiar spins are in the Koronis family (in the main asteroid belt), which resulted from a catastrophic collision several billion years ago. The asteroid family members have orbits that are quite close to each other, and therefore they should have collided with each other and many more "background" asteroids since the family was formed. The asteroids with prograde spins (counterclockwise as seen from above the plane of the Solar System, and the direction of orbital motion of all the planets) have nearly identical "days," with spin periods of 7.5-9.5 hours. They also have similar obliquities (inclination of the spin plane with respect to the plane of the Solar System) of 42-50 degrees. The asteroids with retrograde spins all have obliquities between 154 and 169 degrees, and periods of either less than 5 hours or greater than 13 hours. This is a very non-random distribution and was about as expected as a bunch of marbles spontaneously rearranging themselves into a nice square over time.

David Vokrouhlický, along with his collaborators David Nesvorný and Bill Bottke, have now figured out why the asteroids have the spins they do. In addition to explaining this puzzling result, their work has wide-ranging implications for our understanding of all asteroids.

The explanation lies in the way sunlight is reflected from and re-emitted (in the infrared) by irregularly shaped asteroids. The sunlight acts like wind on a windmill, producing a torque. Part of it comes from the difference between morning and afternoon temperatures. We're all familiar with the fact that daytime temperatures on the Earth are not distributed symmetrically around local noon. Rather, it is hotter three hours after noon than it is three hours before noon. This means that the afternoon side of a planetary body emits more thermal (infrared) radiation than the morning side, and there will be a slight recoil because of this asymmetry. A Russian engineer named Yarkovsky wrote about the effect on planets in the early part of the 20th century, and the application to asteroids was first determined around the beginning of the 21st century. The "YORP" effect (for Yarkovsky-O'Keefe-Radzievskii-Paddick) includes the Yarkovsky effect, in addition to the direct effect of the sunlight hitting the asteroid.

A model applying the YORP effect, as well as solar gravitational torques and planetary gravitational perturbations, was constructed by Vokrouhlický *et al.*, who let the Koronis asteroid family evolve numerically for several billion years. What they found was that asteroids in the size range of 20-40 km that had prograde spins slowed down and their obliquities twisted until they were in a resonance with changes in Saturn's orbit. Vokrouhlicky has named these "Slivan states," after the discoverer. The obliquities and spin periods coming from the model matched what is seen in the real Koronis family. The retrograde-spinning asteroids aren't affected by planetary resonances, so the torque arising from the thermal effects first have their obliquities driven till they are almost "upside down," and then they are either spun up or spun down, as observed. The smaller the asteroid, the more quickly it is driven towards one of these spin states.

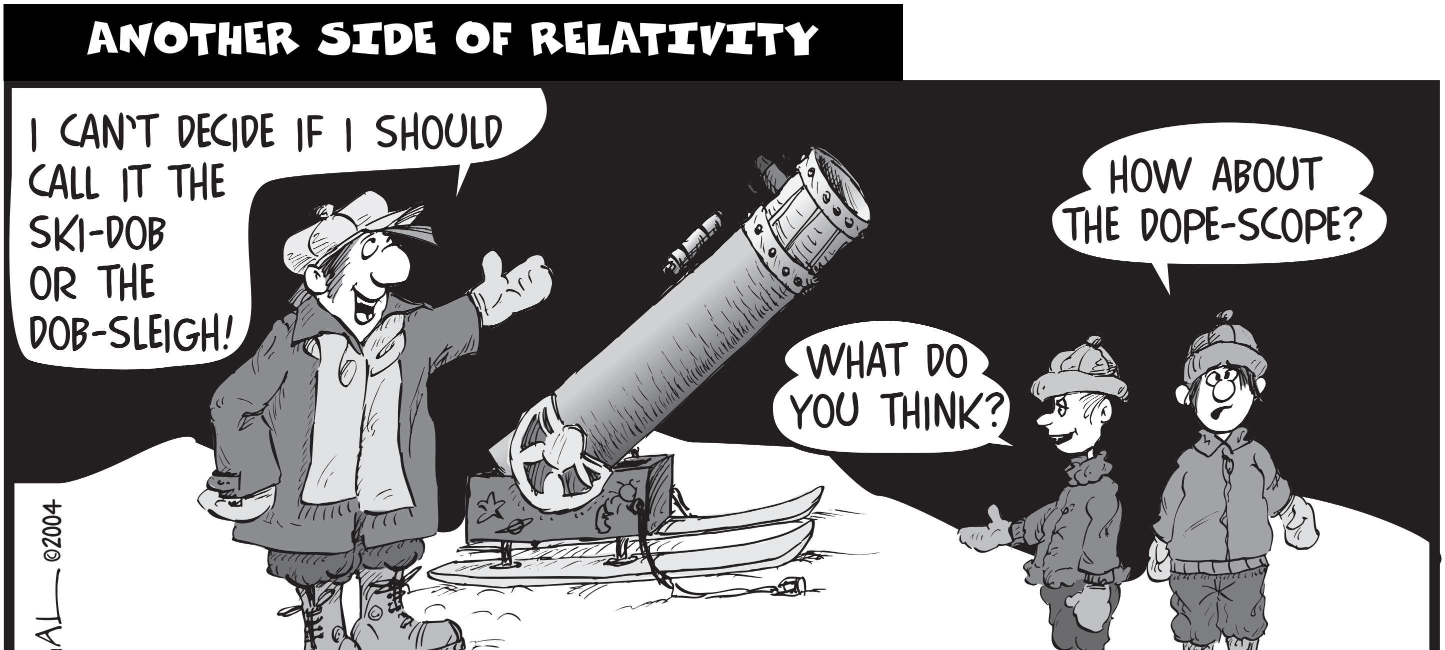
The model results are such a good match for the observational data that it is hard to imagine that this isn't the right explanation.

Beyond explaining Slivan's results, Bottke thinks that the YORP effect may well explain some other anomalous observations. There are many asteroids with diameters less than 40 km that have either very fast or very slow rotation rates, which may have been driven by sunlight. Some asteroids may have been spun up so much that they start ejecting mass, especially if they are "rubble piles" — asteroids that are loosely held together only by gravity, rather than being solid rock. Such shedding might even give rise to asteroidal moons, which appear to be more common than expected. In particular, Vokrouhlicky suggests that the satellite Dactyl of the asteroid 243 Ida may have arisen this way.

This is not to say that collisions between asteroids don't have any effect. But it may well be that collisions generally are an inefficient means of transferring angular momentum to the target asteroid. It looks like solar power isn't just for calculators anymore — now it moves around mountain-sized asteroids!

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

Amateur astronomers could fairly easily be involved in observations similar to those done by Slivan. He used a 61-cm telescope with a 384 × 576 pixel CCD and a *V*-band filter. The key is to take relatively short exposures (Slivan used 5-min unguided exposures, simply tracking at the sidereal rate), because you get the spin rates from periodic variations in the light curves of the asteroids. Differential photometry from stars in the same image gives you the relative brightness changes from exposure to exposure — this must be done very carefully in order to achieve the kinds of results necessary to be useful to professionals. You don't need particularly good seeing to do this, though of course everything is faster and easier with good seeing. But Slivan's data were taken in suburban Massachusetts, where he had to use a stellar "size" of about 12 arcseconds when reducing his data. For more information, see the Web site `www.koronisfamily.com`.



FALLING STARS

Bright falling stars I greet you with a smile,
For you beguile,
My loneliness, with pleasure pure and sweet
In moment's fleet.
In coloured beauty and in lustre dressed,
Never at rest,
You span the sky and gild the heav'nly way
With sparkling ray.
I only know the moments of your birth,
Above the earth;
As she performs her yearly round in space
You run your race
And pierce the blue just as a flashing blade
To quickly fade.
Along your flight the burning embers sow
An after-glow,
To mark your path amid the stars of night,
With guiding light.
I never know the instant when you will
Disturb the still
Of Heaven's stars and speed athwart the sky
All silently.
Nor can I tell in Nature's open book,
Just where to look,
To watch your coruscations wax and fade
Amid night's shade.
Adown the east or west your fiery ball
May headlong fall,
Or, slowly, stream along the starry height
In graceful flight.
Whene'er you come you bring a joyous thrill
My soul to fill.
Oh messsengers from distant worlds! I yearn
Your tale to learn,
And I await, amid earth's frosted dews,
Celestial news.

by W.F. Denning,
from *Journal*, Vol. 9, p. 60, February, 1915.

THE JANUARY 26, 2001 FIREBALL AND IMPLICATIONS FOR METEOR VIDEO CAMERA NETWORKS

BY Martin Connors

Athabasca University
Electronic Mail: martinc@athabascau.ca

Peter Brown

University of Western Ontario
Electronic Mail: pbrown@uwo.ca

Douglas P. Hube

University of Alberta
Electronic Mail: dhube@Phys.UAlberta.CA

Brian Martin

The King's University College
Electronic Mail: brian.martin@kingsu.ca

Alister Ling

Edmonton Centre

Donald Hladiuk

Calgary Centre
Electronic Mail: Don_Hladiuk@hotmail.com

Mike Mazur

University of Calgary

and Richard Spalding

Sandia Laboratories
Electronic Mail: respald@sandia.gov

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Abstract. A bright fireball was observed from central and southern Alberta in the early evening of January 25, 2001 (January 26 UT). The event was recorded with three all-sky video cameras in and near Edmonton, on one video camera located in Calgary, and by many visual observers. Visual and taped observations indicate an agreement of a duration of 2 to 4 1/2 seconds. There were several reports of sonic booms. The peak brightness was comparable to the Full Moon. Analysis of all available data indicates that a meteorite fell near Big Valley, Alberta, although several field searches failed to recover any fragments. Improvements to equipment and methods of analysis will improve the chance of recovering meteorites in future using all-sky cameras and refined astrometric measurement techniques.

Résumé. Un bolide brilliant a été observé le soir du 25 janvier 2001 (26 janvier, temps universel) du centre et du sud de l'Alberta. L'événement a été enregistré par trois appareils vidéo captant tout le ciel visible des environs d'Edmonton, par un appareil à Calgary, ainsi que par maints observateurs visuels. Ces observations ont indiqué que l'événement a duré de 2 à 4,5 secondes. Des éclats soniques ont été entendu et l'intensité lumineuse se rapprochait de celle de la pleine lune. Une analyse de toutes les données recueuillies indique qu'un météorite est tombé près de Big Valley, Alberta, quoique des recherches dans les champs environnants n'ont réussi à récupérer aucun fragment. Des améliorations de l'équipement et des méthodes d'analyse devront à l'avenir améliorer la probabilité de récupérer des météorites, en se servant de caméras 'tout ciel' et de techniques de mesure de données astrométriques.

1. Introduction

The value of meteorites as sources of information about the formation and early evolution of the Solar System is well recognized (Wasson 1985). The value of a meteorite is greatly enhanced if its solar orbit is known and, hence, if its original dynamical relationship with other Solar System objects can be established.

Several meteor camera networks have been operated in Canada, Europe, and the United States (Halliday *et al.* 1978). Observation of a meteor event from two or more sites, along with angular velocity information, permits determination of a fall zone for any surviving fragments. This information also allows determination of the trajectory in space prior to entering Earth's atmosphere, and with appropriate corrections, the original orbit. In addition, it has been possible to estimate the initial mass and derive limited information about the physical and mineralogical characteristics of some meteoroids from camera records using either the integrated brightness of the event or the observed deceleration (Halliday *et al.* 1989).

The Canadian Meteorite Observation and Recovery Project (MORP) was in operation in the Prairie provinces from 1971 until 1982. The Innisfree (Alberta) meteorite was recovered as a direct result of MORP observations (Halliday *et al.* 1978). The MORP cameras were optically very sophisticated, used film to record observations, and were expensive to build and to operate. One of the authors (RS) has developed an all-sky camera using inexpensive, off-the-shelf components. One such camera is illustrated in Figure 1. Arrays of four (usually) such cameras have been installed at several locations in North America. The Northern Alberta array in early 2001 consisted of a camera mounted on the roof of the Physics Building on the campus of the University of Alberta (hereafter UA); a camera at King's College Observatory, 18 km east of Edmonton (hereafter BM); another located at Alister Ling's home in southwestern Edmonton (hereafter AL); and a fourth camera on the campus of Athabasca University, approximately 130 km north of Edmonton (hereafter AU). The geographic coordinates of the four cameras are listed in Table 1.

Table 1.
Northern Alberta All-Sky Camera Array

Camera 1-UA	University of Alberta (113° 30.4′ W 53° 31.5′ N)
Camera 2-BM	King's Observatory (113° 10.1′ W 53° 30.8′ N)
Camera 3-AL	Ling Home (113° 34′ W 53° 28.5′ N)
Camera 4-AU	Athabasca University (113° 18.4′ W 54° 42.9′ N)

Each camera consists of a Chungai Camera Model FC-08B, supported on a tetrapod approximately one metre above a 46-cm diameter convex mirror of the type commonly mounted in the ceiling above intersecting corridors in hospitals. The signal is sent to an array of three VHS video recorders, each of which operates for 8 hours in sequence, to provide 24-hour coverage of the entire sky. A simple heating cable mounted inside the hemispherical mirror prevents condensation and a build-up of snow except under very extreme conditions. The cameras have operated through three winters, and have proven to be very robust; some minor problems have arisen due to low temperatures, extremes of humidity, and tape and video recorder wear.

Figure 1. – Sandia meteor camera on the roof of Athabasca University. A video camera is housed in the vertical white tube and aimed downward at the convex mirror. Power and video cables run to recorders inside the building.

The monochrome cameras used have a nominal minimum illumination of 0.08 lux at f/1.2 and a 1/3 inch CCD with 771 by 492 approximately 7 micron pixels. A Computar TG0812FCS-3 lens, with 8mm focal length and auto-iris control from f/1.2 to f/360, is pointed down at the dome mirror, which is effectively hemispherical with radius 23 cm. This combination results in a limiting apparent stellar magnitude of about −2 from a dark, rural site, and of approximately −3 from within Edmonton city limits. As a result, stars are not detected on individual frames. The two brightest planets, Venus and Jupiter, have been recorded routinely. The stated magnitude limit easily recorded the fireball events of interest, since those that drop meteorites are usually brighter than −10 magnitude. There is, however, a limitation in calibrating the images, that is, in converting a pixel coordinate on an image to a position (azimuth and altitude, or Right Ascension and Declination) on the sky. It is possible to detect stars by stacking successive frames from the videotapes and this provides known points for direction calibration. For this we have also used the Iridium satellite system. The Iridium satellites produce "flares" when, for brief intervals, they are so positioned relative to Sun and a ground-based observer that a reflection of sunlight is directed toward the observer. Iridium flares are predictable: we have used data provided at `www.heavens-above.com`. Even with allowance for events lost due to inclement weather, there had been sufficient numbers of Iridium flares well distributed over the sky to permit calibration of the system and determination of the location of events in the sky to an accuracy of 0.5 to 1 degree. Despite our calibration prior to the event using these methods, we recalibrated, for this event, using stacked sky images that showed bright winter stars near the path of the fireball. This would not have been possible had the fireball been seen in a different direction.

During approximately 12 months of operation preceding the January 25 fireball, the Edmonton array recorded several bright meteors. Numerous fireballs were subsequently recorded during the November 2001 Leonid meteor storm. The January 25 fireball was the only one recorded until the end of 2001 with characteristics of surviving meteoritic material that might easily be found on the ground.

2. Observational Data

On the night of Thursday, January 25, 2001, at 19:21 MST (02:21, January 26, UT), several undergraduate student volunteers at the

Figure 2. – Stacked image of fireball as seen from the University of Alberta. This composite of about 120 frames shows the fireball trajectory much as it would have been perceived by the eye. In contrast, each frame shows the fireball "frozen" at each point along the path. The apparent width of the fireball trail is due primarily to blooming in the camera. The lack of sky objects to use for calibration is apparent: only Venus (near bottom) and Jupiter (left of fireball) are apparent in this image despite stacking. East is at the top and south is at the right.

Campus Observatory of the University of Alberta in Edmonton visually observed a fireball falling toward the southern horizon with a duration of a few seconds. Figure 2 gives an idea of the visual appearance of the fireball and some idea of the appearance of the taped output from one of the all-sky video cameras. A check of the all-sky camera tapes at the nearby UA camera confirmed the event. Shortly thereafter, members of the public began to phone the universities and science centres in Calgary and in Edmonton. Over the following month or so, we sent requests to radio stations and to newspapers requesting additional reports. Good sky conditions and a suitable time of day resulted in a large number of people over a wide geographic area seeing the event.

The event was recorded with the two all-sky cameras within Edmonton (UA and AL) and with the one a short distance east of Edmonton (BM). The AU camera experienced a tape failure several minutes before the event. Several months earlier, one of us (Hladiuk) had begun to monitor a small portion of the sky with an ordinary video camera pointed through a window of his home located in Calgary. Fortunately, the camera was pointed toward the north and this event was recorded. All visual observers in the Edmonton area agreed in placing the event low toward the south and moving right-to-left (*i.e.* west to east), while all observers in the vicinity of Calgary placed it low in their northern sky moving left-to-right (*i.e.* again, west to east). Observers in central Alberta (*e.g.* Red Deer, Ponoka) observed it high in the sky, in some instances close to the zenith, and moving toward the southeast.

Many observers reported a terminal burst, and this was also apparent in all the video records. Only a few individuals, located near Stettler, claimed to have heard a "sonic boom" (Hildebrand 2001). Most observers reported a visible duration of 2 to 4 seconds, which was confirmed on the videotapes. At its peak, the fireball was said by eyewitnesses to have been as bright as the Full Moon.

From the initial analysis of the observations it appeared that the fireball had traveled from NW to SE, passed close to the zenith near Red Deer (113° 48′ W, 52° 16′ N), had a terminal burst SE of Red Deer, and a projected fall zone north, or northeast, of the town of Big Valley (112° 46′ W, 52° 2′ N). Several individuals reported fragments continuing very briefly after the terminal burst. A subsequent frame-by-frame analysis of the tapes confirmed the survival of material after the principal burst.

The duration as determined from the tape records was 3.83 s (UA), 4.27 s (AL), 2.27 s (BM) and 3.13 s (DH). The BM record was shorter than the others due to frost on the mirror.

3. Camera Calibration

Iridium satellite "flares" and stars on co-added (stacked) frames provide the principal means for calibrating positions. At times, stellar objects as dim as apparent magnitude +2 are detectable through image stacking, which builds up brightness where they are located while averaging out noise. The apparent motion of the stars due to rotation of the Earth limits how much stacking can be done. Once a star's "motion" shows up on the image, all advantage of stacking is lost. Since the stars in the southern sky were needed for the Edmonton area calibrations, in practice about 1000 images could be stacked and only the brightest winter stars emerged in the images. For a particular event, the limitations to accuracy in determining the trajectory of the fireball are the lack of reference objects near the path and strong field curvature, especially close to the horizon. Luckily, this fireball passed near the bright southern winter stars, minimizing the first problem. To counteract the second problem, a quadratic relation between radial location of pixels and altitude above the horizon was used.

To further increase accuracy, for calibrating azimuths from the three cameras in or near Edmonton, we used artificial lights near the horizon. Their azimuths were determined via GPS relative measurements, aerial photo measurements, and surveyed measurements from the camera sites.

To calibrate DH's video camera in Calgary, a 35-mm camera was used to take calibration photographs from the same location. The 35-mm camera frames were digitally overlaid on video frames, with reference to ground-horizon features and to measuring staffs, to extract the required astrometric information.

4. Trajectory Solution

To solve for the atmospheric path of the fireball the technique of Borovicka (1994) was employed. This algorithm uses an initial "best-guess" atmospheric path as a starting point for a least-squares solution to sightlines from all stations. The program iterates the path until a minimum is reached in the deviations of the sightlines summed over all stations. Calibrated frames spaced approximately evenly across each of the video records from stations AL, DH, BM, and UA had fireball positional measurements made and employed for a first solution. Due to frosting of the mirror, the absolute BM astrometry was noticeably poorer than at other stations; its positional information was dropped from the final solution. We do not expect this to significantly affect the final results, as the positional information from AL, BM, and UA are very similar, due to the closeness of these stations. Thus our solution uses AL, DH, and UA results to define the atmospheric path. The program was executed for slight variations of input parameters and found to give a stable solution. Table 2 summarizes the result. The earliest point is defined by the start at AL as near as 90 km, somewhat above typical start heights for fireballs in this size range, but not unrealistic (Ceplecha & McCrosky 1976). The burst and endpoint both occurred at very typical altitudes for such a modest fireball. We expect, that had photographic methods been used with greater sensitivity than our video equipment, the end height might have been determined as several kilometres lower than what we determined.

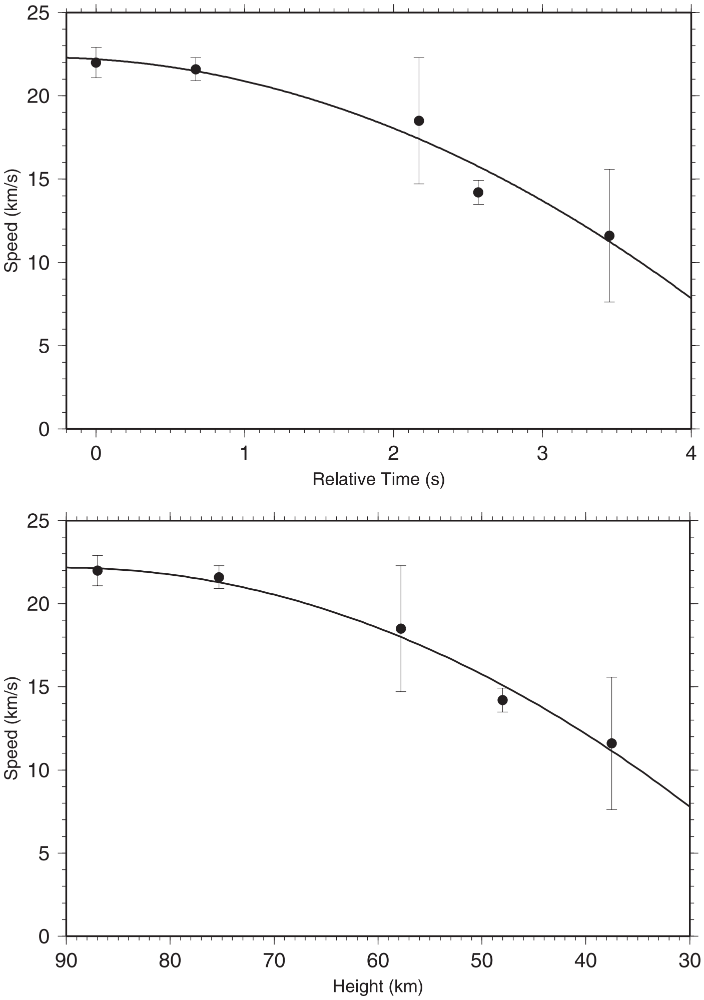


Figure 3. – Velocity as a function of time (top) and of height (bottom) for the January 26, 2001 fireball. Error bars reflect the uncertainty in measured positions as defined by the deviations of the sight lines (in km) from the best-fit trajectory.

Table 2.
Computed Fireball Trajectory

	Altitude	Longitude (W)	Latitude (N)
Begin Point	87.0 ± 0.7 km	113.392 ± 0.007°	52.730 ± 0.009°
Burst Point	37.8 ± 1.5 km	112.870 ± 0.12°	52.407 ± 0.060°
End Point	35.8 ± 0.6 km	112.747 ± 0.005°	52.400 ± 0.007°
Radiant altitude	39.2 ± 1.1°	Radiant azimuth	135.1 ± 1.2°

5. Detailed Velocity Analysis

The camera in Calgary (DH) achieved the best spatial resolution, since it was recording directly through its lens and not having its scale reduced by use of a convex mirror. With a preliminary determination of the trajectory obtained by combining all reliable camera and visual observations, an approximate entry velocity of ~22 km s^{-1} was found from a frame-by-frame analysis of the DH tape. Repeating the analysis with the AL tape also resulted in an entry velocity of ~22 km s^{-1}. However, the precise velocity profile is relatively poorly determined due to the low astrometric accuracies of individually measured images relative to the high temporal resolution (30 frames per second). As a result, the best velocity profile was found by using only those sets of points from AL and DH that had the smallest line-of-sight deviations from the fireball path. The fits shown are quadratic and for velocity vs. time the curve has the form:

$$v = \left(22.2 \pm 1\right) - \left(0.563 \pm 1\right)t - \left(0.720 \pm 0.4\right)t^2 .$$

For unknown reasons, the velocities obtained from the UA tape show a large scatter, especially in the early sections of the trajectory. The varying error bars reflect in part distances from the cameras and in part uncertainties in measuring the true position due to blooming, and we consider the velocity profiles to be fairly crude. Nevertheless, some quantitative information about the fireball can be obtained from them.

Our formal analytic fit suggests a velocity of 22.2 ± 1 km s^{-1} at 90 km altitude. We expect some additional deceleration before this point, but cannot quantify the magnitude without knowledge of the mass of the body. However, as estimated below, with a mass between a few tens to (more likely) hundreds of kg, the correction to V_∞ amounts to <0.1 km s^{-1}, which is much smaller than our formal error margin (Spurny 1997). An estimate of the mass for the fireball can be made either by integrating the total light produced from the fireball (photometric mass) or by examining the deceleration of the fireball with some precision (Halliday *et al.* 1978). As we do not have an absolute photometric calibration, application of the first method is not possible. Our velocity errors are such that only near the end of the fireball path does the value of the deceleration become large compared to its error. From this measured deceleration, we may estimate the dynamic mass (m_d) as:

$$m_d = \frac{\Gamma A \delta \rho v^2}{\left(dv/dt\right)^2}$$

where Γ is the drag coefficient (~0.9), *A* is the shape factor (which for a sphere has a value near 1.2), δ is the meteoroid bulk density, and ρ is the atmospheric density (Ceplecha *et al.* 1998). In practice, this is the mass of the largest fragment surviving at the end of the path (terminal mass). Applying this to the deceleration at the endpoint we get a terminal dynamic mass near 1.4 ± 0.5 kg, suggesting that some material should have reached the ground.

6. Orbit

Computation of the meteoroid's nominal orbit is from the estimated initial velocity and our trajectory solution. The orbital results are shown in Table 3. This is a relatively typical Apollo-type orbit, though with a larger than average aphelion distance and a slightly large inclination. However, the associated errors are quite large, so the

Table 3.
Orbit of the January 26, 2001 Meteoroid

V_∞ (km s−1)	22.2 ± 1.1
V_h (km s−1)	39.5 ± 0.9
α_R (J2000.0)	313.0 ± 1.9
δ_R(J2000.0)	56.8 ± 1.4
α_G (J2000.0)	307.9 ± 1.9
δ_G (J2000.0)	53.5 ± 1.5
a (Semi-Major axis; AU)	3.69 ± 1.14
e (eccentricity)	0.74 ± 0.08
q (perihelion distance; AU)	0.957 ± 0.005
i (inclination; degrees)	27.3 ± 1.7
ω (argument of perihelion; degrees)	159.1 ± 1.9
Ω (Longitude of Ascending node; J2000)	306.188 ± 0.001
Q (Aphelion distance; AU)	6.4 ± 2.2
θ (True anomaly; degrees)	20.9 ± 1.9
Time since perihelion (days)	15 ± 2

aphelion may well be inside Jupiter's orbit, as is the case for most meteorite-producing fireballs (Wetherill & Revelle 1981). Comparison of this orbit with known orbits of near-earth asteroids, comets, and meteoroids reveals no close associations despite there being several thousand meteoroid orbits resulting largely from MORP. Comparisons were done using the D criterion (Ceplecha *et al.* 1998) where a value over 0.1 would have indicated a significant similarity to a given orbit.

7. Field Searches

The brightness, terminal burst, and phenomena reported by witnesses suggested early on that meteoritic material had fallen (the orbit and mass, determined later, support this). The predicted fall zone was near the village of Big Valley, approximately 75 km east-southeast of the city of Red Deer. Three field searches were conducted in April 2001, after the winter's accumulation of snow had melted, and before significant new vegetative growth. The area is typical of western prairie agricultural lands consisting largely of open and hilly fields used for grazing cattle and for the growing of crops. Stubble from the previous year's crops plus a scattering of small stones covers the open ground. A significant fraction of the stones are smooth, dark clay stones of the type commonly misidentified by the public as being meteorites. There are scattered small swamps, small stands of trees, and a few oil wells and associated hardware.

A total area of approximately two km^2 was searched by systematic sweeps, but no meteoritic material was found. Local residents, many of whom had observed the fireball, were alerted to the possibility of meteorites being found, but no finds were reported during, or following, our search.

8. Lessons Learned and Developments for the Future

One should not underestimate the time required to assemble and calibrate equipment, and the difficulty in identifying suitable locations and local operators. We knew in advance that the spacing of the Edmonton-area cameras was not good. For the purpose of determining a reliable trajectory and fall zone, the cameras should be spaced 50 to 100 km apart. In 2001, the three Edmonton-area cameras lay along a roughly east-west line of length 20 km, or so. The Athabasca University camera is well separated (north-south) from the others, but was not fully operational on the night of interest and would, for this event, have served only to confirm the azimuth obtained from the others.

The positions of cameras in their present form necessitate on-site management (*e.g.* for the purpose of changing video tapes daily). Automatic, non-mechanical operation is preferred. To that end, others and we are developing software for event detection through flash monitoring. That is, successive images are automatically compared and changes above a certain threshold from one to the next trigger the storage of a sequence of images for later analysis. With digitization directly from video, storage on a hard drive, and linking of local computers to a central site, one person could operate an array of cameras. Local events such as airplane flyovers could be distinguished from fireballs through inter-comparisons of records from two or more suitably sited cameras.

Substantial effort was put into calibrating the images, but a more refined calibration is desirable. Much of the work to calibrate the cameras took place after the event. It is important to mount the camera rigidly in what will be its permanent location, and to calibrate frequently using planets, stars, and Iridium flares widely distributed over the sky. Calibration of altitude close to the horizon is particularly difficult, but very important since most fireball events are likely to be distant from the camera and, hence, close to the horizon. Even with good calibration, the angular resolution of the cameras will not be better than 0.5 to 1 degree. Any lower resolution would preclude determination of reliable velocities.

As noted previously, the original video cameras are too insensitive to record any but the brightest planets, and the brightest stars can only be seen by stacking images. Newer, often less-costly low-light video cameras are becoming available, as are low-cost wide-angle lenses suited to meteor detection (Horne 2003). Cameras should be replaced as newer, technically superior devices become available.

Eyewitness reports are open to interpretation when they refer to local everyday events such as road accidents, but even more so when they refer to a sudden once-in-a-lifetime event such as a brilliant fireball. Eyewitness accounts have greatest value when obtained under the track or near the endpoint. The details presented by eyewitnesses can change with time, so the earlier one collects such reports the more accurate they will likely be. Objective instrumental records are much preferred, and should, in general, carry the greatest weight.

9. Conclusions

The mass of the meteoroid at atmospheric entry is estimated to have been tens to hundreds of kilograms. There would have likely been around a kilogram of surviving meteorites, but none were found in field searches in the likeliest location.

The orbital determination places the meteoroid in a typical Apollo orbit with, however, a higher-than-normal inclination.

With improved calibrations, better camera mounts, a wider distribution of the cameras in north-central Alberta, and the installation of a camera network in southern Alberta, we anticipate greater success in analyzing future fireball events, and improved prospects for the recovery of meteorites. We are waiting patiently for Nature to produce that next event.

Acknowledgements

This research was supported in part by operating grants from the Natural Sciences and Engineering Research Council of Canada to Brown, Hube, and Connors. Fieldwork was conducted in cooperation with Alan Hildebrand of the University of Calgary and partly funded by the Meteorites and Impacts Advisory Committee of the Canadian Space Agency. We thank J. Borovicka for providing the program used in determining the fireball trajectory, and Z. Ceplecha for providing the software used in determining the orbit.

References

Borovicka, J. 1990, Bull. Astron. Inst. of Czech., 41, 391

Ceplecha, Z., & McCrosky, R.E. 1976, J. Geophys. Res., 81, 6257

Ceplecha, Z., Borovica, J., Elford, W.G., ReVelle, D.O., Hawkes, R.L., Porubcan, V., & Simek, M. 1998, Sp. Sci. Rev., 84, 327

Hildebrand, A. 2001, personal communication

Halliday, I., Blackwell, A.T., & Griffin, A.A. 1978, JRASC, 72, 15

Halliday, I., Blackwell, A.T., & Griffin, A.A. 1989, JRASC, 83, 49

Horne, J. 2003, Sky & Telescope, 105, Number 2, 57 (February, 2003)

Spurny, P. 1997, Pl. Space Sci., 45, 541

Wasson, J.T. 1985, Meteorites: Their Record of Early Solar-System History (W.H. Freeman: New York)

Wetherill, G.W., & Revelle, D.O. 1981, Icarus, 48, 308

Martin Connors
Centre for Science, Athabasca University
1 University Drive
Athabasca AB T9S 3A3

Martin Connors is an Associate Professor at Athabasca University, recently named as Canada Research Chair in Space Science, Instrumentation, and Networking. His main interests are in planetary astronomy and space physics.

Peter Brown is an Assistant Professor and holds the Canada Research Chair in Meteor Science at the University of Western Ontario. He has recently started the NEAPS (Near-Earth Asteroid Physical Studies) program using the UWO Elginfield 1.22-m telescope.

Douglas P. Hube is now Professor Emeritus in Physics at the University of Alberta. His studies focus on binary stars. The U of A Devon Observatory now hosts an automated meteor camera.

Brian Martin is a Professor at The King's University College in Edmonton. His main astronomical interest is precision photometry of cataclysmic variable stars. The King's College Observatory now hosts an online automated meteor camera.

Alister Ling is an active amateur astronomer in the Edmonton Centre and a regular contributor to astronomical publications. Due to his full-time job at Environment Canada he is much sought after for detailed weather predictions for observing.

Donald Hladiuk, an active amateur astronomer in the Calgary Centre, runs his own video monitoring system that contributed to this article. His employment as a geologist at Conoco Canada has an astronomical connection through the Steen River impact structure, a trap for oil and gas.

Mike Mazur is a graduate student in Geology and Geophysics at the University of Calgary. He has been involved with meteoritic events including the Tagish Lake fall and the finds of the Prairie Meteorite Search.

Richard Spalding, a senior engineer at Sandia National Laboratories, specializes in satellite sensor research, developed the all sky cameras used for this article, and has provided these cameras to several groups in North America. His own network operates under the clear skies of New Mexico.

CANADIAN THESIS ABSTRACTS

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

A Wide-Field Imaging Survey of Low-Redshift Galaxy Clusters By Wayne A. Barkhouse (wbark@head-cfa.harvard.edu), University of Toronto, Ph.D.

This thesis presents the results from a comprehensive study of 26 low-redshift galaxy clusters in order to study the radial dependence of various cluster properties. The observations were acquired using the 8k mosaic camera on the 0.9-m KPNO telescope. This dataset was supplemented by 43 clusters from the survey of López-Cruz (1997), and an additional 2 clusters from Brown (1997). Thus, a total sample of 71 clusters covering a redshift range from ~0.01 to 0.20 was available for analysis. The dynamical radius of each cluster (r_{200}) was estimated from the photometric measurement of cluster richness (B_{gc}). The cluster galaxy colour-magnitude relation (CMR) was used as a tool to minimize the inclusion of contaminating background galaxies by selecting galaxies relative to this relation. The luminosity function (LF) of individual and composite galaxy samples were constructed via the statistical subtraction of background galaxies. A robust method of comparing LFs for a variety of galaxy samples over a range of cluster-centric radius was presented. The general shape of the LFs were found to correlate with radius in the sense that the faint-end slope was generally steeper in the cluster outskirts. Colour selection of galaxies into a red sequence and blue population indicates that the blue galaxies become fainter toward the cluster central region. This result supports the scenario that infalling field galaxies have their star formation truncated by some dynamical process. The construction of a non-parametric dwarf-to-giant ratio (DGR) and the blue-to-red galaxy ratio (BRR), allowed the investigation into the change in these parameters with various cluster properties. The radial dependence of the DGR and BRR suggests that blue dwarf galaxies are tidally disrupted in the inner cluster environment or fade and turn red. The red, mainly nucleated, dwarf galaxies remain relatively unchanged with respect to cluster-centric radius, while giant blue galaxies have transformed into their red galaxy counterparts. These results provide support for the model proposed by López-Cruz *et al.* (1997) to explain the formation of cD and Brightest Cluster Galaxy halos in which dwarf galaxies get tidally disrupted in the inner cluster region.

Wayne Barkhouse, Editor-in-Chief of the Journal, *is currently a post-doctoral researcher at the Harvard/Smithsonian Center for Astrophysics.*

W4 Revisited: A Chimney Candidate in the Milky Way Galaxy Explored Using Radio Continuum and Polarization Observations By Jennifer Lorraine West (westjl@cc.Umanitoba.CA), University of Manitoba, MSc.

Compelling evidence for the existence of a fragmented superbubble above W4 that may be in the process of evolving into a chimney has been found. High latitude extension fields above the W3/W4/W5 star forming region have been processed at both 1420 and 408 MHz (21 and 74 cm) Stokes I total power as well as Stokes Q and U polarization. These observations reveal an egg-shaped structure with morphological correlations between our data and the Hα data of Dennison, Topasna & Simonetti (1997, ApJ 474 L31), as well as evidence of breaks in the continuous structure. Assuming an estimated distance of 2.3 kpc, the egg structure measures ~165 pc wide and extends ~240 pc above the mid-plane of the Galaxy. In addition the polarized intensity images show depolarization extending from W4 up the walls of the superbubble providing strong evidence that the observed continuum and Hα emissions are at the same distance as the W4 region.

A temperature-spectral-index map indicates that there are no high-energy losses in the region via synchrotron emission. This implies that energetic cosmic rays retain sufficient energy to escape into the Galactic halo. In addition the rotation measure in the region has been calculated allowing an estimate of the line of sight magnetic field ($B_{//}$) in the region to be determined. We find $B_{//} = 9 \pm 8\ \mu G$ assuming a wall thickness of 20 pc or $B_{//} = 13 \pm 11\ \mu G$ assuming a wall thickness of 10 pc and directed *towards* the observer.

In addition, some interesting features appearing in the polarization and 408 MHz datasets are examined. These features are not likely related to the W4 superbubble.

Jennifer West is currently a Ph.D. candidate at the University of Manitoba.

Education Notes
Rubriques pédagogiques

WHAT IS SIDEREAL TIME AND WHAT IS IT GOOD FOR?

by William Dodd, Toronto Centre (wwdodd@sympatico.ca)

Introduction

Each day, as viewed from the surface of the Earth, the Sun, and the stars rise in the east and set in the west, however, the stars appear to move across the sky a little faster than the Sun, and each day the constellations advance towards the west another 1° ahead of the Sun. After a whole year the constellations return to their starting positions. The different motions of the Sun and stars give rise to two different systems of time. The daily rotation of the Earth relative to the position of the Sun is used to define solar, or civil time. The daily rotation of the Earth relative to the stars is used to define sidereal time.

Sidereal Time

As viewed from far above the North Pole, a *sidereal day* begins when the vernal equinox crosses an observer's upper meridian and ends when the vernal equinox next crosses that meridian. During a sidereal day the Earth rotates 360° around its polar axis.

From the same viewpoint, a *civil day* begins when the Sun crosses an observer's lower meridian and ends when the Sun next crosses that meridian (*i.e.*, a civil day begins at midnight). During a civil day the Earth rotates just under 361° around its polar axis and *also revolves just under 1° in its orbit around the Sun*. The extra time required for that degree of revolution makes the civil day about 4 minutes longer than a sidereal day. Over a complete year that time difference accumulates to one complete rotation of the Earth. During a civil year the Sun passes overhead 365 times while the vernal equinox passes overhead 366 times.

Since the sidereal day is the interval of time between two successive passes of the vernal equinox across any observer's meridian, *the sidereal time at any location is equivalent to the hour angle of the vernal equinox*. This is the essential property of sidereal time that is useful to astronomers.

Sidereal time and civil time at Greenwich, England (Universal Time or UT) match up with each other about September 21. After that date, sidereal time edges ahead an extra 3^m56^s each day. At the spring equinox, sidereal time is 12^h ahead of UT. By the next autumnal equinox the times match up again.

Equatorial Coordinates

The equatorial system of Right Ascension (RA) and Declination (Dec) is analogous to terrestrial longitude and latitude and offers at least three distinct advantages to astronomers.

1. The RA and Dec of a celestial object are unique and relatively constant over decades. Most star charts and catalogues give stellar coordinates in RA and Dec.
2. As Earth's rotation carries a star across the sky, its Dec coordinate remains constant.
3. If a telescope has an equatorial mount and is correctly oriented, then its RA axis is parallel to the Earth's axis of rotation. Once a celestial object has been located with such a telescope, the object can be kept in view by a simple westward rotation about the RA axis that counteracts the Earth's rotation.

Uses of Sidereal Time

Sidereal time and RA are both defined relative to the vernal equinox. These definitions lead to an important result:

Your Local Sidereal Time (LST) is the same as the RA of any object on your meridian.

Once you have located Polaris and the celestial equator, you can use LST to quickly construct a mental grid of RA and Dec for the sky. Suppose at a particular moment your LST is $12^h 00^m$. Then you automatically know that all objects along your meridian have an RA of $12^h 00^m$. You also know that all the objects one hour, or 15°, towards the east have an RA of $13^h 00^m$. And all the objects one hour towards the west have an RA of $11^h 00^m$. Dec can be estimated relative to the celestial equator.

The RA of an unknown object can be determined by recording the time of its transit across your meridian. The sidereal time of that moment equals the RA of the object. The RA of an object can also be estimated by measuring its hour angle (HA): RA = LST + HA.

Knowing that the RA of a transiting celestial object is the same as your LST, you can make better use of star charts and catalogues. Once you know your LST, you can go directly to the star chart that shows the sky above your head at that moment. Astronomical catalogues usually list objects by increasing RA. Once you know your LST, you can immediately locate the objects in a catalogue that are potentially observable at your location at that moment.

Using the equation HA = RA − LST, you can calculate the HA of any object once you know its RA and your LST. With the ability to predict the hour angle of a celestial object at any given time, you can plan an observing session to proceed from object to object as they move into convenient positions for viewing. With this approach you can minimize the time spent searching for objects and adjusting equipment for different viewing angles, and maximize the time spent on target.

To locate a celestial object with an aligned equatorial telescope, all you have to do is set the object's HA and Dec, and the object should automatically be in your finder scope.

How Can You Determine the Sidereal Time?

There are a variety of methods for determining sidereal time. In all cases, you need the date, the longitude of your location, and the standard time in your time zone. A particular method may refer to Local Sidereal Time (LST), Local Mean Sidereal Time (LMST), or Local Apparent Sidereal Time (LAST). In this section, no distinction is made among these terms. For precision applications of sidereal time, readers should refer to texts, or Internet searches on *astrometry*.

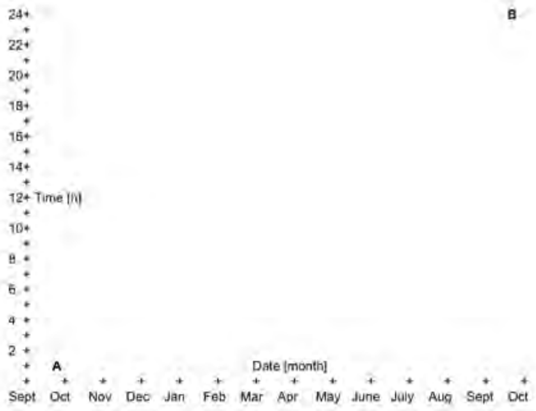
1. You can calculate Local Mean Sidereal Time (LMST) using the formulas provided on page 41 of the *Observers Handbook 2003* (RASC). A programmable calculator can be set up to perform these calculations without too much difficulty. Finding LMST depends on Greenwich Mean Sidereal Time (GMST). Instead of calculating GMST, you can read the precise GMST from an on-screen digital clock at `home.att.net/~srschmitt/clock.html`.

2. The U.S. Naval Observatory at `tycho.usno.navy.mil/what.html` provides a menu item "Compute Local Apparent Sidereal Time" that calculates LAST for the moment when the "Submit" button is pushed. To take advantage of the accuracy available, you need to know your own longitude precisely.

3. You can harness your own computer's calculating power to generate a sidereal clock. Three of the many astronomical sites that provide free sidereal clock software are listed here:
   - `astronomy.physics.tamu.edu` The Learning Observatory at Texas A&M University. Look under "downloads/astronomy clock."
   - `asds.stsci.edu` Astronomical Software & Documentation Service (funded by NASA)
   - `www.radiosky.com` The Radio Sky site also provide lots of other information for radio astronomers.

4. You can use a planetarium program, such as *Starry Night*, to determine the RA of the meridian for any given moment at any location. That RA is also the LST for that moment at that location.

5. You can purchase a sidereal clock. Search on the Internet under the topics "sidereal clocks horology." One site with sidereal clocks for sale is `www.bmumford.com/clocks/sidereal`. Once a sidereal clock is correctly set and hanging on your wall, you have sidereal time available at a glance.



A Graph to Estimate Greenwich LST at Midnight

6. You can estimate LST by constructing a simple graph. As shown in the figure, mark the months on the horizontal axis and the hours from 0 to 24 on the vertical axis. Then estimate the locations of the points **A** (Sept 21, 0^h) and **B** (Sept 21, 24^h). The line **AB** describes Greenwich LST (GLST) at midnight for any day of the year. To find your LST, first use the graph to estimate the GLST for a particular date. Then express your longitude (L) as a time in hours. The quantity GLST – L will provide an estimate of your LST at the civil time corresponding to 12 – L. You can add or subtract civil hours to estimate LST for any other time during that day.

7. For a simple, but temporary, sidereal clock simply set any digital clock to the 24-hour mode and then enter the sidereal time using one of the methods listed above. Your standard clock will only lose 1 minute of sidereal time for every 6 hours of observing.

Summary

Sidereal time depends on the position of the vernal equinox, the date, the time, and your longitude. LST can be found in a variety of ways. Once you have determined your LST, that time provides the RA of all celestial objects on your meridian. That knowledge can assist you in making full use of your astronomical resources and equipment.

Notes

Duncan Steel is an Australian astronomer and has recently written a book, *Marking Time: The Epic Quest to Invent the Perfect Calendar* (Wiley, 2000). It is recommended if you are interested in reading more about the history and definitions of time.

Your comments on this article are welcome. If you have comments on any of the items that have appeared in recent *Education Notes,* send an e-mail message. If there is a topic that you would like to see discussed in this column, let us know.

William Dodd is a member of the Toronto Centre. He is a retired mathematics teacher with particular interests in the educational and historical aspects of astronomy.

THE STORY OF SKYWAYS: THE RASC'S ASTRONOMY HANDBOOK FOR TEACHERS

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

"You, my dear," she declared, "should write a book!" I stared back at her, sure that she was speaking to someone else, but Margaret Myles was addressing me. There were only the two of us in the room. It was the end of the day and all the other teachers who had spent the day in the Starlab had already left. She continued, "Nobody has ever explained astronomy to me before so that I could understand it. You made it so easy and so much fun. You have a real gift. You should use it."

I thanked her for the compliment and together we packed up the Starlab, left the school, and went our separate ways. It had been a good workshop. Although I dismissed her words at the time, they kept coming back to haunt me. They came from other teachers at other workshops. Those words haunt me still, for they were the genesis of *Skyways*.

Myles is one of many remarkable teachers with whom I have had the pleasure of working over the past 14 years. Full of life, energy, humour, and fun, I can only imagine what a vibrant place her classroom must be. As I worked hard to make *Skyways* into something that teachers would find helpful, I thought of the many "Margarets" in Canada's classrooms and I wrote for them. The formula seems to have worked reasonably well, since the teacher feedback from last year's draft version of *Skyways* was very positive. Teacher comments and suggestions guided all of the changes and additions, and reshaped the book into its present form.

Skyways is an astronomy handbook for teachers. It is quite different from anything that the RASC has ever done before. The Society is used to producing publications for its own members and for amateur astronomers and astronomy enthusiasts. We know that audience and its needs quite well. The *Skyways* project is taking the Society into territory that is not quite so familiar.

The RASC has long worked with schools, teachers, science centres, planetaria, museums, and youth groups to promote and enhance astronomy education. For many educators, the RASC is an important resource. We have been very successful in these informal efforts and have established a solid reputation as a credible and effective educational resource. *Skyways* aims to build on our existing, firm educational foundation by taking our expertise into the more formal environment of the curriculum-driven classroom.

Skyways is national in scope. There is a new science curriculum in Canada called the *Common Framework of Science Learning Outcomes,* published by the Council of Ministers of Education, Canada.[1] The document is sometimes called the "pan-Canadian Curriculum," and is the parent document from which most provinces and territories have drawn their own curricula. These new curricula have been introduced across the country and teachers are now teaching more astronomy than before. It is showing up at more grade levels, and in more depth and detail.

My own experience, and the experience of many RASC 's members, is that there are plenty of teachers who are looking for help with the new curriculum. There are very few Canadian resources to help them. *Skyways* is the RASC response to that need. *Skyways* is unique in that it uses the pan-Canadian Curriculum to govern its content. *Skyways* addresses each of the specific, astronomy requirements of the new Canadian science curriculum.

Skyways aims squarely at the needs of Canadian teachers, and is organized with them in mind. The first section of the book deals with the required curriculum objectives and includes some pedagogy to improve the teacher's comfort level. *Skyways* is one-stop-shopping for Canadian teachers looking for resources to help them with their astronomy units.

The book is organized by topic and grade-level grouping. There is a handy one-page chart that lists activities according to topic and grade-level-appropriateness. There is a section on common misconceptions and how to dispel them and replace them with correct ideas.

The second and third sections of the book are devoted to elementary/middle-school grades, and high-school grades, respectively. These sections contain background information, classroom and observing activities, and student worksheets. Each topic and activity refers the teacher to additional online resources, if the teacher wants to explore further. The fourth section of the book is a resource section with FAQs, a book list, Web resources, Canadian observatories and planetaria, and Canadian contributions to astronomy.

The layout and illustrations for *Skyways* are professionally done. The book is very attractive inside and outside. Its look speaks clearly for the quality that can be found between the covers. The illustrations, tables, and graphs make the material clear, and the overall design allows text to flow smoothly for fast, easy reading. The page design, typeface, and graphics have excellent eye-appeal. The 8.5 × 11-inch format with spiral binding makes it easy for teachers to photocopy student worksheets and other pertinent pages, as they choose. The tone is friendly and down-to-earth. Everything about the book is governed by the desire to meet the needs of teachers, and to make astronomy fun and accessible at the same time.

There are almost 300,000 teachers in Canada.[2] We have all heard them ask for help. We continue to answer with classroom visits, observing sessions, and other activities. Now, with *Skyways,* we can strengthen our educational partnerships. The RASC is now set to have a tangible, targeted, educational presence in Canadian classrooms.

Yes, Margaret, I was paying attention. We should never underestimate a teacher's influence. *Skyways* is proof positive of what happens when someone takes a teacher's words to heart.

Skyways is available for $19.95 Cdn + GST, including shipping (RASC members $16.95 Cdn + GST), and can be ordered through the RASC by either:

Phone:	(888) 924-RASC
Fax:	(416) 924-2911
E-Mail:	`orders@rasc.ca`
Web:	`www.store.rasc.ca`
Mail:	RASC Orders, 136 Dupont Street, Toronto ON M5R 1V2 Canada

Mary Lou Whitehorne has over 14 years of astronomy education experience working with teachers and students of all grade levels in classrooms, workshops, planetaria, conferences, and summer institutes. She is the author of Skyways.

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[1] Common Framework of Science Learning Outcomes, Council of Ministers of Education, Canada, 1997, `www.cmec.ca.`

[2] Statistics Canada, Full-time Teachers, `www.statcan.ca/english/Pgdb/educ22a.htm.`

Society News/Nouvelles de la société

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

National Council Meetings

At the time of the writing of this note, there will be a National Council meeting on October 25, 2003 (NC035). Details of that meeting will be in the next *Society News*. A change of venue for that meeting will bring us to the Ontario Science Centre. This year, once again, the Toronto Centre is extending an invitation to the Council to observe at the Carr Observatory, Beaver Valley (near Collingwood, Ontario).

October also marked the launch of the new RASC publication *Skyways*. This has been a project for the Education Committee and author Mary Lou Whitehorne for a few years now, and copies are available online at the RASC eStore at `www.store.rasc.ca`.

A note from the **Membership & Promotion Committee:**

As you may already know the Vancouver Centre created a wonderful keepsake of the Royal Centenary year as part of this year's GA celebrations. The Royal Centenary Coffee Mug is an excellent-quality drinking vessel with the Commemorative logo emblazoned in full colour.

In 2003 the RASC celebrated its 100th anniversary as a Royal Society. A limited quantity of commemorative mugs is available with a special design celebrating the Centenary. These dishwasher-safe ceramic mugs have the Royal Centenary logo on both sides (front and back). Perfect for home, office, or observatory.

The cup is 9.5 cm high (3.75-inch) and holds 300 ml (10 fl. oz). The price is $10.00 Cdn. (price includes postage and handling within Canada. GST/HST will be added as appropriate).

Upcoming Events

This is a reminder to all Centres and individuals for any of the RASC awards listed in the table below that nominations should be sent to the National Office by December 31, 2003. For an expanded description of the awards, visit `www.rasc.ca/award/`.

C.A. Chant Medal
for significant astronomical work

Ken Chilton Prize
recognition of significant astronomical work carried out during the year

Simon Newcomb Award
for literary achievement

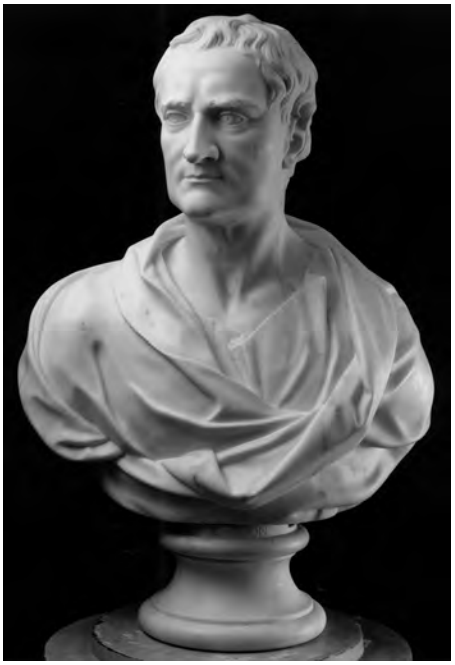
The Service Award
for contributions to the RASC over a minimum 10 year span

On a further note, a notice was sent to National Office on September 19 from the Chelminski Gallery in Chelsea, London, in regards to their bust of Sir Isaac Newton.

> Dear Sirs/Mesdames,
>
> Please find attached a photo & description of the fine white marble 18th Century bust of Sir Isaac Newton which has recently arrived at the Gallery here, and which I thought you would be interested to see.
>
> This is after the original by Roubiliac for the Royal Society, repeated at Trinity College, and may also have a connection with Sir William Herschel having been acquired from Datchet House, close to where he lived, and home of the Needham Family - Earls of Kilmorey & Barons of Armagh.
>
> If you would like any further information, please do not hesitate to contact me.
>
> Yours truly,
> Hilary Chelminski
>
> Chelminski Gallery Antique Sculpture
> & Garden Ornament
> 616 King's Road, Chelsea, London
> SW6 2DU. U.K.
> Tel: 020 7384 2227
> Fax: 020 7384 2229
> `www.chelminski.com`
> Email: `hilary@chelminski.com`

No: 292
Height: 28 inch (71 cm)
A WHITE MARBLE BUST OF SIR ISAAC NEWTON (1642-1727) AFTER LOUIS FRANCOIS ROUBILIAC (1695-1762)

English – Late 18th Century
Inscribed: NEWTON
Provenance: Datchet House, Nr. Windsor.



"A white marble bust of Sir Isaac Newton, mounted on a circular socle base, after the original made for the Royal Society in 1738 by Louis Francois Roubiliac. Another version, signed and dated 1751, is in the Wren Library, Trinity College, Cambridge.

"Louis-Francois Roubiliac, the French-born sculptor, settled in London in the 1730s, and made his reputation with a full-length seated statue of the composer Handel (now in the Victoria & Albert Museum), remarkable for its lively informality, and quickly became recognised as the most brilliant portrait sculptor of the day. He is generally regarded as one of the greatest sculptors ever to work in England, certainly the greatest of his period, having both a vivid imagination and being a superb craftsman.

"The original Bust was made without a base — a square socle being supplied separately at the request of the Royal Society. Roubiliac's terracotta model is at the Royal Greenwich Observatory. Another marble version with a round socle is at the Royal Astronomical Society, Burlington House, and a marble version by Edward Hodges Baily, dated 1828 (1751), is in the National Portrait Gallery.

"There are indications that the Sculptor of this present Bust may have had an association with Joseph Nollekens (1737-1823). It is also possible that this Bust may have a connection with Sir William Herschel (1738-1822), the Royal Astronomer and discoverer of Uranus whose name is often linked with Newton's. He lived in Datchet in the 1780s before later moving to Old Windsor. Datchet House was home to the Needham Family, Earls of Kilmorey, and Barons of Armagh. Herschel was also involved with the establishment of the Armagh Observatory, in 1790."

Since this year is coming to a close, and another soon to start, I would like to wish everyone in the RASC a warm, clear, and Happy Holiday Season.

Clear Skies

International Astronomy Day 2004 is Saturday April 24

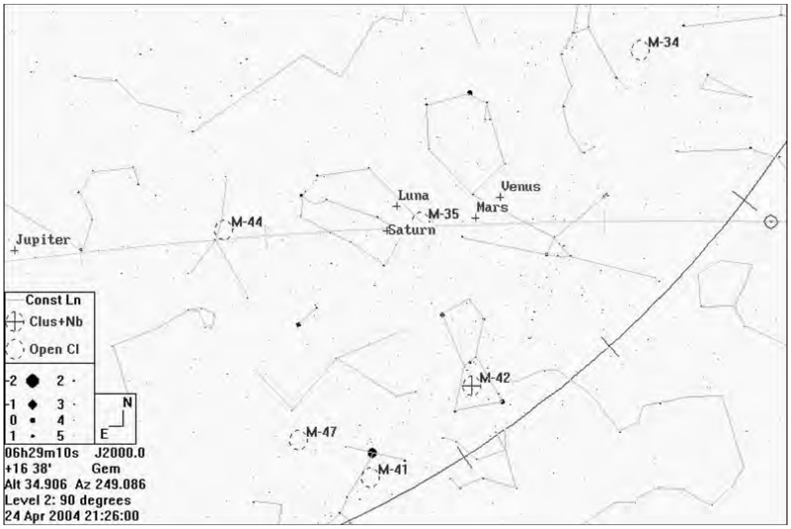
by Bruce McCurdy, National Astronomy Day Coordinator (bmccurdy@teusplanet.net)

On that day, professional and amateur astronomers all over the world bring the Universe to the public, through observing sessions, displays, and information booths in malls, science centres, and planetaria. The RASC joins groups from nearly 30 countries in celebrating International Astronomy Day.

The 2004 spring sky will offer a cornucopia of delights for a public-observing session. The pictured chart shows the panorama visible from Edmonton, Alberta 30 minutes after sunset on April 24, at which time the Moon and four naked-eye planets will all be between 30° and 45° altitude. The western horizon is depicted by the curve at lower right. Particulars for other locations across the country will be very similar.

Centres wishing to plan additional or alternative observing sessions may also want to consider Saturday, March 27. On that date Mercury will also be readily visible in its best evening apparition of the year, while the outer planets will be bigger, brighter, and further from the Sun. Venus and Mars will straddle the Pleiades. Also, Standard Time will still be in effect, with sunset occurring almost two hours earlier than during Daylight Saving Time.

Centres planning their local A-Day may wish to consider the Transit of Venus as an appropriate theme for 2004. Much more information is available on the RASC Web site, at `www.rasc.ca/activity/astroday/`. Please contact the writer to advise of your Centre's plans and to request further ideas and assistance.



Unveiling Asteroids:
International Observing Project and Amateur–Professional Connection

by Mikko Kaasalainen, Rolf Nevanlinna Institute, University of Helsinki (mjk@rni.helsinki.fi)

Abstract

I review methods (other than spacecraft flybys) of obtaining detailed information on the shapes, spin states, and other characteristics of minor planets. Non-directly resolvable asteroids can actually be imaged with these methods by making use of various data sources and modern mathematical techniques. Especially photometric observations play a key role in the construction of a large sample group of models representing the asteroid population. Amateur observers, in their turn, have an important and necessary role in providing such observations.

1. Introduction

Asteroids and comets form the largest and, perhaps paradoxically, the least well-known population of celestial bodies in our solar system. The shortage of detailed information is mainly due to the fact that, because of the large interplanetary distances, disk-resolved images can be obtained only of a limited number of these targets. Nevertheless, our view of this population has started to change dramatically over the past few years. Spacecraft images and detailed radar observations, though very limited in their ability to cover the asteroid population, have already revealed to us that asteroids come in just about all possible shapes (from spheroids to "dogbones"), configurations (from single bodies to contact or separate binaries or satellite systems), and structures (rubble piles, solid or fractured rocks, smooth or bombarded surfaces). The need for detailed information on a large sample of asteroids is thus now pressing, and fortunately, it turns out that there are rich data sources readily available. I will discuss below how the present golden age of asteroid research applies also to amateurs, who now have, thanks to modern equipment and CCD cameras, a remarkable opportunity to participate in important scientific research.

In addition to their importance in completing the big picture of our solar system today, asteroids also carry important information from the past. They are, in a way, dinosaurs of the solar system. Unlike planets that are thoroughly moulded by various physical and geological processes, asteroids still contain material from the primordial stages. By studying their composition, structure, shapes, rotational states, and orbits, we can reconstruct much of the history of our system.

2. Asteroid models from remote sensing

Disk-resolvable direct images of asteroids are available only from flybys (*e.g.* Thomas *et al.* 1994, 1996; Zuber *et al.* 2000); there are some very crude low-resolution snapshots of the largest few asteroids taken with the Hubble Space Telescope, but we cannot expect much better resolution because of physical limitations. Other methods of obtaining information (including radar) are indirect, so they constitute inverse problems. We never properly see the target, so we have to find a way of making a full model of it that explains the observations. In fact this is precisely what our brains do every day with the data from our senses, including images, so in that sense we all solve inverse problems all the time — we are just accustomed to doing it with instinct and experience, not mathematics. When we have to invoke mathematics, the first step is to solve the direct problem, that is, to give detailed mathematical and physical rules accurately describing how the observed quantities are determined by the parameters describing the target and the observational circumstances. In our case, we are primarily interested in the rotational state, shape, and surface characteristics of the target. The second step is to check whether we can trace this originally one-way path back to the starting point. Usually it turns out that this cannot be done without some constraints and/or additional information, so the second step is considerably harder than the first. This is why inverse problems are a very active field of study in applied mathematics. The third step is to make the actual backward trip for each target, starting with the real instrument readings and ending up with model figures and images on the computer display.

2.1 Photometric data

A previously much unused but major and easily available source of information on small solar system bodies consists of their photometric light curves, that is, measurements of their total brightnesses that vary as the viewing/illumination geometry changes. We can now well say that the resolving capacity of light curve inversion lies, roughly speaking, between space telescope and radar, and its range extends from near-Earth to Jupiter Trojan asteroids (Kaasalainen *et al.* 2002c).

Let us first write the mathematical model describing an asteroid's brightness (Kaasalainen & Torppa 2001). This is done by integrating over all visible and illuminated surface patches of infinitesimal area ds. In a coordinate frame fixed to the asteroid, the contribution dL to the total brightness $L = \int dL$ is, at some point r on the surface (ignoring the trivial distance-squared factors)

$$dL = S\Big[\mu(\mathbf{r}),\mu_0(\mathbf{r})\Big]\mathbf{v}(\mathbf{r})ds, \qquad (1)$$

where ϖ and S are the albedo and the so-called light-scattering model of the surface; $\mu = \mathbf{E} \cdot \mathbf{n}(\mathbf{r})$ and $\mu_0 = \mathbf{E}_0 \cdot \mathbf{n}(\mathbf{r})$, where $\mathbf{E}$ and $\mathbf{E}_0$ are, respectively, unit vectors towards the observer (Earth) and the Sun at the moment of observation, and $\mathbf{n}(\mathbf{r})$ is the surface unit normal. Lambert's law, for example, is $S_L = \mu\mu_0$, while the Lommel-Seeliger law is $S_{LS} = S_L/(\mu + \mu_0)$. Note that L is given in intensity units rather than magnitudes. In practice, brightness changes are ascribed almost completely to shape; potential albedo variegation over the surface can be separated from shape to some extent, but from physical considerations and spacecraft images we can expect such effects to be quite small. The integral is in practice computed by tessellating the surface into small planar facets and replacing the integral by a sum. In the inverse problem we solve for the parameters defining such a surface (*i.e.* **r**) by minimizing with suitable optimization procedures the chi-square residual

$$\chi^2 = \sum_{i=1}^{N}(L_i^{obs} - L_i)^2, \qquad (2)$$

where L_i^{obs} and L_{i} are, respectively, the observed and modelled brightnesses at the N observation epochs.

Rotation parameters are easily introduced through rotation matrices transforming coordinates between the asteroid frame and a global frame such as the ecliptic or equatorial one (Kaasalainen *et al.* 2002c; also cf. Fairbairn 2003). For most asteroids these parameters are the direction of the spin axis and the sidereal rotation period. Some asteroids are precessing, that is, their rotational states have not yet relaxed to the so-called principal-axis rotation due to energy dissipation in the tumbling asteroid material. Such precession can also be described mathematically and the corresponding parameters can be included in the coordinate transform (Kaasalainen 2001). Light curve observations can also reveal binary asteroids revolving around each other (Pravec *et al.* 1998, Mottola & Lahulla 2000).

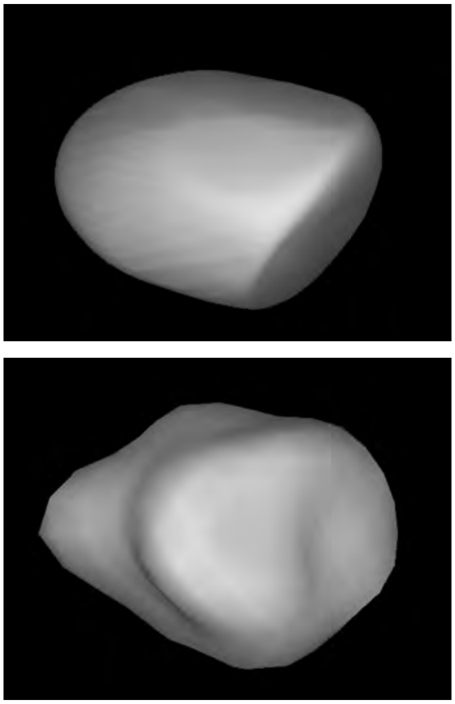


Figure 1. – Equatorial views of the light curve-based models of asteroids 1580 Betulia (top) and 3908 Nyx bottom).

The direct problem is thus quite straightforward via (1). The inverse problem, however, is notoriously difficult, and has often been thought unsolvable. Indeed, it was something of a surprise to find out that, when merely natural and simple constraints are applied, the problem has a well-defined solution. The path to this solution is rather a winding one and involves a number of mathematical and physical considerations I will not discuss here (Kaasalainen & Torppa 2001; Kaasalainen *et al.* 2002c). The main results are that the rotation parameters can be deduced very accurately, and the *global* shape can be well inferred. This shape can be thought of as the convex shape best mimicking the silhouette of the body in all viewing directions. Detailed topographic/nonconvex features can seldom be confirmed using disk-integrated photometric data alone (Ďurech & Kaasalainen 2003). This is typical of any inverse problem: some information is often inevitably lost on the way, in this case due to the smoothing effect of integration over the disk. Our job is to make sure we gather everything that the information source has to offer. The important thing here is to have data from various observing geometries, and above all when the solar phase angle $\alpha = \arccos(\mathbf{E} \cdot \mathbf{E}_0)$ is not low, that is, the shadowing effects revealing the shape are prominent. We show examples of the models and light curves of two near-Earth asteroids (NEAs) 1580 Betulia and 3908 Nyx in Figures 1–3.

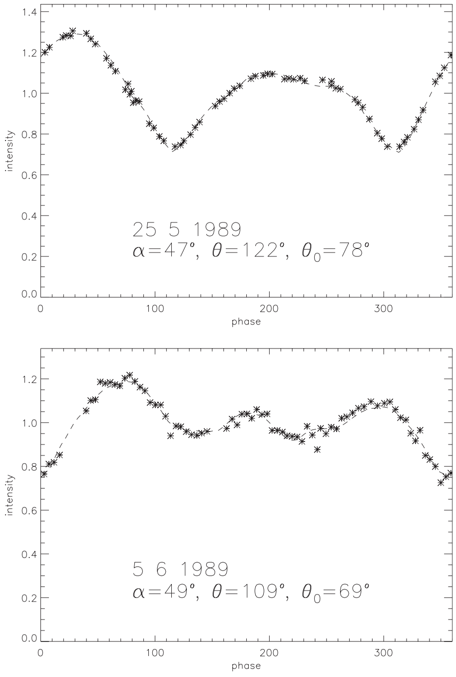


Figure 2. – Two light curves of 1580 Betulia. Asterisks are the observed intensity points (in relative units), and the dashed line is the model fit, plotted against the rotational phase (in degrees). The polar angles of the Earth and the Sun, as seen from the asteroid, are θ and θ_0, respectively. The solar phase angle is given by α. Note the very rapid change of the light curve shape as the observing geometry changes, caused by the irregular shape and the high solar phase angle.

There are some 10,000 recorded light curves of several hundreds of objects (Lagerkvist *et al.* 2001), and the numbers are growing. We have so far built models of over eighty objects (*e.g.* Kaasalainen

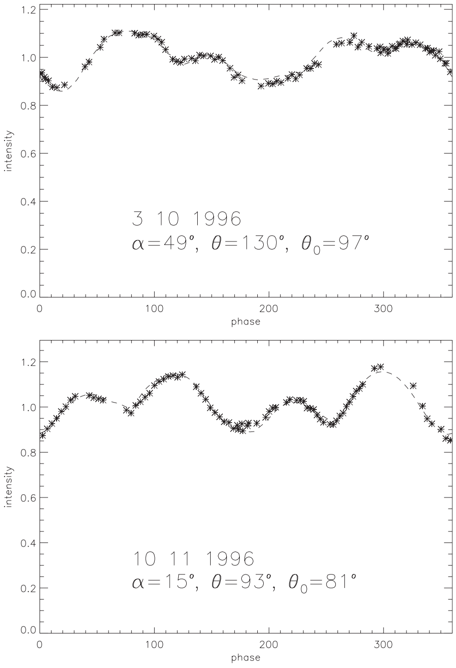


Figure 3. – Two light curves of 3908 Nyx, together with the model fits.

et al. 2002a,b, 2003; Slivan *et al.* 2003; Torppa *et al.* 2003), and at least as many can be analyzed in the near future with the aid of well-planned observations. NEAs are especially rewarding targets. Due to the quickly changing observing geometries, a comprehensive model of a NEA can often be constructed after an observation span of only a few months. In addition to NEAs, there are numerous main-belt asteroids (MBAs) for which only one or two more observation campaigns are needed to compile a good data set.

2.2 Complementary data: radar, interferometry, occultations

There are other sources of information that are perhaps not as robust and easily available as photometry, but have a complementary character. Combining even a limited number of such data with photometry can result in a more detailed solution. We have recently started doing this with radar and interferometric observations and occultation timings. In the following I briefly list the basic models for these sources to show that the mathematical relationship between the model parameters and the observables is always quite straightforward. It is the backtracking that is the hard part.

Radar is a powerful tool for asteroid observations (Ostro *et al.* 2002). A delay-Doppler experiment not only measures the intensity of the reflected radar signal as a function of the Doppler frequency (different surface points have different radial velocities due to asteroid's rotation); it also measures the intensity as a function of (very accurately determined) time. This gives the radar depth coverage as parts of the body further away from the radar reflect the same signal back later. Now the observable "coordinates" (d, D) (d for depth and D for apparent Doppler velocity in the radial direction away from the observer) and the surface point $\mathbf{r} = (x, y, z)$ in the asteroid's own coordinate system are related by

$$\begin{aligned} d &= -(x\cos\phi + y\sin\phi)\cos\delta - z\sin\delta, \\ D &= \omega\cos\delta(y\cos\phi - x\sin\phi), \end{aligned} \tag{3}$$

where ω is the angular speed of the asteroid's rotation about its axis, δ is the sub-radar latitude, that is, the latitude of the radar as seen from the asteroid, and φ is the sub-radar longitude. The often-shown radar "image" of an experiment is a plot of the combined observed intensities of all visible surface patches in the (d, D)-plane, so it should never be mistaken for a snapshot of the target. For one such plot, there are still several surface patches that correspond to the same (d, D)-pixel. The "brightness" of one pixel is the integrated radar cross section (echo strength) of these patches, computed just as in (1) (now $\mu = \mu_0$ and $S \sim \mu^n$).

If there are delay-Doppler experiments for several epochs, and the latitude δ is different from zero, the many-to-one pixel mapping is different for different images, and one can use this to create a model of the target (Ostro *et al.* 2002). In practice, this results in standard least-squares optimization. For asteroids not close to the Earth, however, the echo power is usually not sufficient for depth resolution, so we get a Doppler-only signal (also known as CW, continuous wave). Now the echo power for one frequency is given by integrating over surface patches corresponding to one D-bin. These data are usually not sufficient for reliable object modelling by themselves. Since their information is "orthogonal" to photometry, they can be employed to give additional accuracy to models based on light curve inversion. An example of this is shown in Figure 4. A contact-binary type asteroid shows the waist between its two main parts in a Doppler profile, but lightcurves seldom carry information on such indentations unless they are very large and are observed at very high solar phase angles (Ďurech & Kaasalainen 2003).

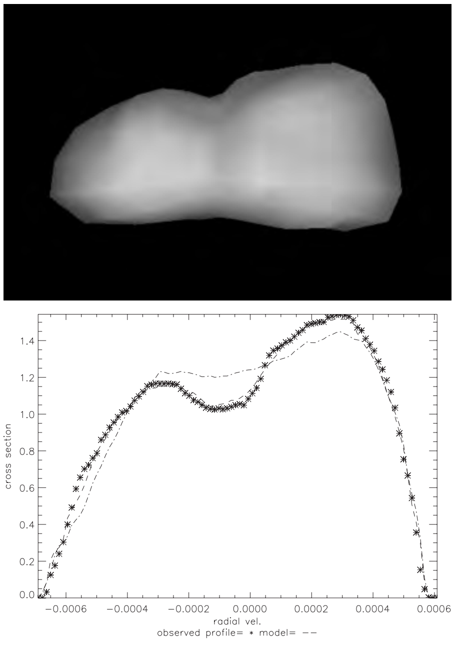


Figure 4. – A test shape and its Doppler radar profile (asterisks), together with the fits from a light curve+radar-based model (dashed line) and light curves-only model (dot-dash).

Interferometry is another major remote sensing technique. It is based on the fact that even though the target cannot be resolved, its nonvanishing angular size inevitably disturbs the optical standard interference pattern that would be obtained from a pointlike source. The disturbances have a much larger angular width than the source. The disturbed pattern is a convolution of the undisturbed one with the plane-of-sky image of the target. Denoting the plane-of-sky distance along the scanning direction by x we have

$$P(x) = \frac{1}{L}\iint I(u,v)T(x - u\cos\gamma + v\sin\gamma)\,du\,dv, \tag{4}$$

where we integrate over the plane-of-sky image intensity $I(u, v)$ of the target (u, v are the chosen plane-of-sky coordinates), $T(x)$ is the standard interference pattern strength, and γ is the plane-of-sky tilt angle between x- and u-directions. The final pattern P is normalized with the target's total disk-integrated brightness $L=\iint I(u,v)\,du\,dv$. The model image distribution $I(u,v)$ is directly given by the plane-of-sky projections of the surface facets and their brightnesses dL from (1), so the interferometric case is simply an extension of the photometric one, and the inverse problem can be handled accordingly. One cannot reconstruct an image from one scanning session, but we can use all available data from several dates and geometries to make a full model.

We use, for example, the Fine Guidance Sensor interferometry from the Hubble Space Telescope with two orthogonal scanning directions (Hestroffer *et al.* 2002; Tanga *et al.* 2003). Interferometric data are, of course, obtained much less often than photometric data, so again they alone are not sufficient for modelling in practice, but they are a valuable addition to photometric information.

Timings of stellar occultations by asteroids are gathered almost exclusively by amateur astronomers. These are rather fragile and fortuitous events, but in principle contain snapshot profiles of the target if well observed. Here the direct problem is again easily expressed. For a given occultation timing Δt from some epoch, the proper observed quantities (coordinates of a "profile point") can be written as

$$(\xi,\eta)=\left[\hat{\mathbf{s}}_{\xi}\cdot(\mathbf{x}+\Delta\mathbf{v}\Delta t),\ \hat{\mathbf{s}}_{\eta}\cdot(\mathbf{x}+\Delta\mathbf{v}\Delta t)\right] \quad (5)$$

where $\boldsymbol{x}$ is the observer's position on the Earth in the sidereal equatorial frame, given by $\boldsymbol{x} = (R\cos\beta\cos\theta\,, R\cos\beta\sin\theta\,, R\sin\beta)$ (with R the local Earth radius, β the latitude, and θ the local sidereal time), $\Delta\mathbf{v}$ denotes the differential space velocity $\mathbf{v}_{\text{Earth}} - \mathbf{v}_{\text{asteroid}}$, and the silhouette plane projection unit vectors can be chosen to be

$$\begin{aligned}\hat{\boldsymbol{s}}_{\xi} &= (-\sin\delta\cos\alpha, -\sin\delta\sin\alpha, \cos\delta),\\ \hat{\boldsymbol{s}}_{\eta} &= (\sin\alpha, -\cos\alpha, 0),\end{aligned} \quad (6)$$

where α and δ are the right ascension and declination of the occulting star. The corresponding projection point of a surface point $\mathbf{r}$ of an asteroid model is simply

$$(\xi_{\text{mod}},\eta_{\text{mod}})=(\hat{\boldsymbol{s}}_{\xi}\cdot\boldsymbol{r}_{eq},\ \hat{\boldsymbol{s}}_{\eta}\cdot\boldsymbol{r}_{eq})+(\xi_0,\eta_0), \quad (7)$$

where $\mathbf{r}_{\text{eq}}$ is $\mathbf{r}$ transformed to the equatorial coordinate system by the rotation parameters, and (ξ_0, η_0) is some offset. The inverse problem consists of adjusting the model $\mathbf{r}$ and rotation parameters such that the theoretical profile line coincides with the observed profile points as well as possible. Now even some large concave formations are resolvable in principle, and we also get the size scale of the target directly as with radar and interferometry.

There are some other remote sensing sources as well, most notably thermal infrared observations and polarimetry. The former is, again, closely related to ordinary photometry, but in this case we also have to invoke a thermal model to explain the transfer of heat in the surface material, which brings us to slightly less well-known practical physics. The same applies even more to polarimetry: models of the polarization states caused by the surface material are as yet virtually nonexistent.

3. Amateur observations are important

A revolutionarily efficient practice in photometry is the extensive (and intensive) use of small telescopes. Accurate CCD photometry of targets brighter than about magnitude 15 is quite feasible with relatively inexpensive telescopes less than 40-cm in aperture. Even high-quality telescopes of only 20-cm or somewhat smaller are still useful. This means that there are at least hundreds of instruments in the world equipped for the asteroid modelling project. Most remarkably, many of these are operated by dedicated and skilful amateur astronomers. Best amateurs can routinely make observations on a par with small professional observatories at an automated level (or actually surpass them — so far, only amateurs have been able to deliver a desired light curve overnight with complete instrumental reductions!). Amateur observations are thus just as important as professional ones — occultation timings or light curve data from a 20-cm telescope are analyzed simultaneously with those from the large Arecibo radio telescope or the Hubble Space Telescope! It is also important to note that getting good photometric coverage for hundreds of asteroids takes thousands of hours of telescope time. This makes amateur observers indispensable: it would be physically impossible to get enough observing time from professional telescopes for this project. What is more, this observing mode is extremely flexible and nonbureaucratic. Amateurs can also perform intensive observing campaigns on a specific target — this is often useful during one apparition of a NEA (see, *e.g.* Koff *et al.* 2002). Two examples of very good amateur observations of relatively bright MBAs are shown in Figure 5. The data are consistent and have very little noise even though they were obtained with a small telescope.

A natural form of organization for asteroid light curve observers is a flexible network mainly communicating over the Internet. I list here a few hubs of this network; links and people cited on these sites form a natural guide for those interested in the subject. An introduction to the project, an alert list of good asteroid targets, some publications, and other material are presented on the Web pages of our project on inverse problems in astronomy (`www.astro.helsinki.fi/~kaselain`). Once the equipment is there, making actual scientific observations of an asteroid is quite straightforward after some practice. An excellent link containing plenty of advice and other links is Brian Warner's CALL (Collaborative Asteroid Lightcurve Link) site `www.MinorPlanetObserver.com/astlc/default.htm`. Another informative link is Richard Kowalski's ALPO (Association of Lunar and Planetary Observers) asteroid observing program site `www.bitnik.com/mp/alpo/`. Information on occultation timings is given on the IOTA (International Occultation Timing Association) pages `www.lunaroccultations.com/iota/asteroids/astrndx.htm`.

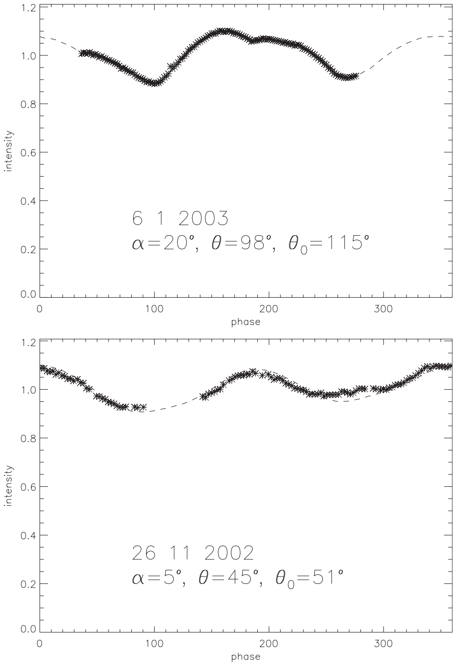


Figure 5. – Two light curves of 37 Fides and 129 Antigone by R. Kowalski, obtained with an 18-cm Maksutov telescope and an SBIG ST-7E CCD camera.

The first stage of photometric asteroid observations is to get the first few light curves of a target, enabling one to get the first estimate of its rotation period and perhaps some hints of its shape character. Rotation periods are already known for hundreds of asteroids, and it is possible to draw important statistical inferences from such a set (Pravec *et al.* 2002).

The second stage is to get more light curves at new apparitions, thus providing information at new viewing/illumination geometries. An efficient way of getting the most of one asteroid apparition is to obtain two light curves at the largest useful solar phase angles (to get a meaningful part of the period covered; more than one night is good for this), and one at a smaller phase just to get as long a stretch as possible. The high phase angles are important for reaching maximal shadowing effects (and light-scattering behaviour different from the simple near-geometric mode near opposition). A dense light curve sequence contains a wealth of information and helps to rule out errors. Several tens of points per rotation period are the optimum, so an automatic observation mode is necessary. A good practice is to eliminate potential systematical errors by observing on two adjacent or at least nearby nights, particularly if the rotation period is not short enough for overlapping rotational phases during one night. In this way one can be sure that possible features in the light curve are really repeated and not artificial.

Finally, sending the observations to be analyzed is very easy. The data can be sent by email (in a flexible format) to me or to Brian Warner (or to anyone else who is gathering and forwarding observations to us for analysis); we are also in the process of building an automated Internet service for this purpose. The observer always gets author credit in the paper where the data are published.

4. Conclusions and encouragement

Solar system bodies are fascinating already from the point of view of data acquisition as few astrophysical targets offer such a wide repertoire of data sources. We live in the golden era of planetary research, and particularly for small solar system bodies this era has just begun. Amateur observers have now a great chance to participate in solar system exploration and help to make the asteroid population as well known as the larger planets.

While “what do they look like?” is the natural prime incentive for acquiring photometric data, the follow-up question “why do they look like that?” is just as important. When we have a large number of asteroid shape and spin models at our disposal, we can draw important statistical inferences on the origins and evolution of this population. To mention just one example, Slivan *et al.* (2003) used these methods to investigate the curious clustering of the spin states of small (20–40 km) members in the Koronis asteroid family. Recent results (Vokrouhlicky *et al.* 2003) suggest that such clustering could generally take place in this size region in the outer asteroid main belt at low inclinations. If evidence for this is found in the overall asteroid population, we will have important new clues to dynamical evolution particularly due to the so-called YORP (Yarkovsky-O’Keefe-Radzievskii-Paddack) thermal radiation pressure effect.

References

Ďurech, J., & Kaasalainen, M. 2003, A&A, 404, 709

Fairbairn, M. 2003, JRASC, 97, 92

Hestroffer, D., Tanga, P., Cellino, A., Guglielmetti, F., Lattanzi, M., Di Martino, M., Zappalà, V., & Berthier, J. 2002, A&A, 391, 1123

Kaasalainen, M. 2001, A&A, 376, 302

Kaasalainen, M., & Torppa, J. 2001, Icarus, 153, 24

Kaasalainen, M., Torppa, J., & Piironen, J. 2002a, A&A, 383, L19

Kaasalainen, M., Torppa, J., & Piironen, J. 2002b, Icarus 159, 369

Kaasalainen, M., Mottola, S., & Fulchignoni, M. 2002c, in Asteroids III, eds. W. Bottke, R. Binzel, P. Paolicchi, & A. Cellino (University of Arizona Press: Tucson), 139

Kaasalainen, M., & 16 colleagues 2003, A&A, 405, L29

Koff, R.A., Pravec, P., Šarounová, L., Kusnirak, P., Brincat, S., Goretti, V., Sposetti, S., Stephens, R., & Warner, B. 2002, Minor Planet Bulletin, 29, 51

Lagerkvist, C.-I., Piironen, J. & Erikson, A. 2001, Asteroid Photometric Catalogue, Fifth update (Uppsala University Press: Uppsala)

Mottola, S., & Lahulla, F. 2000, Icarus 146, 556

Ostro, S., Hudson, S., Benner, L., Giorgini, J., Magri, C., Margot, J.-L., & Nolan, M. 2002, in Asteroids III, eds. W. Bottke, R. Binzel, P. Paolicchi, & A. Cellino (University of Arizona Press: Tucson), 151

Pravec, P., Wolf, M., & Sarounova, L. 1998, Icarus 133, 79

Pravec, P., Harris, A.W., & Michalowski, T. 2002, in Asteroids III, eds. W. Bottke, R. Binzel, P. Paolicchi, & A. Cellino (University of Arizona Press: Tucson), 113

Slivan, S., Binzel, R., Crespo da Silva, L., Kaasalainen, M., Lyndaker, M., & Krco, M. 2003, Icarus, 162, 285

Tanga, P., Hestroffer, D., Cellino, A., Lattanzi, M., Di Martino, M., & Zappalà, V. 2003, A&A, 401, 733
Thomas, P.C., Veverka, J., Simonelli, D., Helfenstein, P., Carcich, B., Belton, M.J.S., Davies, M.E., & Chapman, C. 1994, Icarus, 107
Thomas, P.C., Belton, M.J.S., Carcich, B., Chapman, C., Davies, M.E., Sullivan, R., & Veverka J. 1996, Icarus 120, 20
Torppa, J., Kaasalainen, M., Michalowski, T., Kwiatkowski, T., Kryszczynska, A., Denchev, P. & Kowalski, R. 2003, Icarus, 164, 346
Vokrouhlicky, D., Nesvorny, D., & Bottke, W. 2003, Nature, 425, 147
Zuber, M.T. et al. 2000, Science, 289, 2097

Mikko Kaasalainen earned a D.Phil. in theoretical physics at Oxford University. After a grand tour of European institutes as a postdoc, he returned to Helsinki University, got married, built a house, and is now a senior researcher at the Rolf Nevanlinna Institute for mathematics. He still hopes to actually look at something through a telescope one of these days.

Orbital Oddities

Martian Motion IV: The Zeus Effect

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

When the moon is in the seventh house
and Jupiter aligns with Mars
Then peace will guide the planets
and love will steer the stars
This is the dawning of the Age of Aquarius
— James Rado and Gerome Ragni,
"Aquarius"
(from the Broadway musical Hair)

"What!? *Another* sequel?" the imaginary reader may be saying upon seeing that title. "Isn't this Mars thing getting kind of old?"

Welcome back to *Orbital Oddities,* imaginary readers, where the old, the new, the past, present, and future all get balled up to the extent that I frequently am confused as to which tense I'm in. If in the process, I forget how tense I *am,* it will have been worth the diversion.

Over the summer as Mars approached, I fell into an e-conversation with the man I consider the Orbital Oracle, Jean Meeus. The Belgian Calculator had a 27-year head start on me, and at 75 this amazing man continues to widen the gap with his prodigious mathematical skills. But I wrongly assumed that he knew something about all things orbital, and was surprised when he admitted to me, "I have not studied the effect of Jupiter in the perihelion distances of Mars." (Meeus 2003a) This proves if nothing else that the number of problems is truly infinite.

While a very good first-order approximation of a planet's orbit can be made considering only the Sun, the planets do influence each other to a tiny degree. Nowhere near as much as the astrologers would have you believe, but a measurable amount. Collectively these are rather mysteriously referred to as secular variations. I figure I'm a secular kind of guy, why not have a go?

In Parts I and III of the Martian Motion series, I concluded, without quantitative analysis, that the position of Jupiter influences Earth-Mars distances. By evaluating its influence on Mars' perihelion, I am now closer to quantifying "The Jupiter Effect" (to invoke the title of a rather unfortunate book that spectacularly failed to bridge the ever-widening gulf between astronomy and astrology). Let's call it the "Zeus Effect" instead.

According to Meeus (1983-95), Mars reaches perihelion every 687 days at slightly different distances from the Sun. In the 61 years (1960-2020) listed in the table, these range from 1.38115 to 1.38156 AU, a seemingly tiny difference of ~0.0004 AU that nonetheless amounts to some 60,000 km. I note perihelia of < 1.38130 AU occur (only) in the following years: 1967, 1979-81, 1992, 2003, and 2014-16. Surely this ~12-year periodicity suggests a commensurate relationship with Jupiter and its 11.86-year orbit. A good way to test this is to lay out the data in a Meeus-style panorama, shown as Table 1.

There seems to be sufficient evidence to claim a periodicity with a primary minimum (extreme close perihelion) of ~1.3812 AU at 12-year intervals clustered roughly under column 1967, and a secondary minimum of ~1.38135 under column 1962. In the first instance, as seen from Mars, Jupiter is in conjunction with the Sun around the time of perihelion, in the second near opposition. Distant perihelia ~1.3815 occur when the two are near quadrature. Figures along each diagonal show a consistent rise and fall as they slice through the implied peaks and valleys. Last-digit "noise" in the data can be attributed to the influences of other planets, primarily Earth.

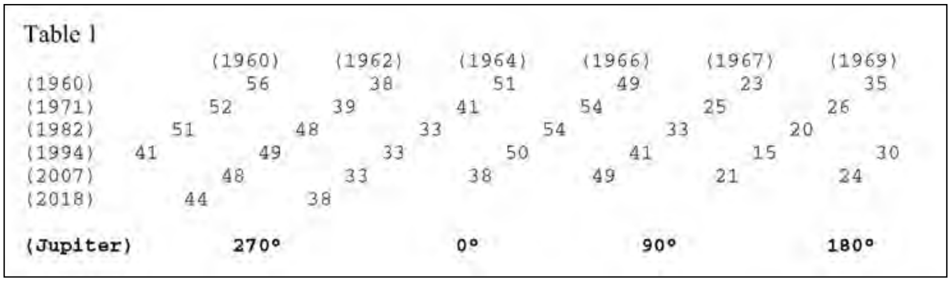


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Table 1
                (1960)      (1962)     (1964)     (1966)      (1967)     (1969)
(1960)              56         38         51          49         23         35
(1971)          52          39         41         54         25          26
(1982)       51         48          33         54         33         20
(1994)    41         49         33          50         41         15         30
(2007)            48         33         38         49          21         24
(2018)        44         38

(Jupiter)          270°                0°               90°              180°
```

Table 1. – There are roughly 6.3 revolutions of Mars for every one of Jupiter. The Red Planet reaches perihelion around 336° heliocentric longitude at each of the data points shown, which occur from left to right at intervals of 1.88 years. The date of the first event of each "column" is shown at top; of each row, at left. The perihelion distances, showing just the last two digits (1.381xx AU; e.g. 1967 = 1.381**23** AU), are laid out as a panorama on this scale of 6.3:1. Implied vertical columns occur at roughly 12-year intervals and correspond to Jupiter at a particular heliocentric longitude (shown at bottom). The table indicates that the closest perihelia are clustered when Jupiter is near celestial longitude 156°, with a secondary minimum around 336°.

This seems analogous to the Moon's perigee cycle, which is essentially a tidal relationship. The closest perigees occur when the Moon is at syzygy, either new or full, but the *most* extreme perigees *all* occur at Full Moon. The geometry of Earth and Sun on the same side is for some reason, slightly better than at 180 degrees in pulling the Moon particularly close. In the case of Mars, close perihelia occur with Jupiter in opposition, closer ones when it's in conjunction, poor ones when Jupiter and the Sun are working at cross-purposes. (Call them "spring" and "neap" perihelia!) It was high tide with a vengeance on August 30, 2003, when the Sun, Jupiter, Earth, and even Venus were all in near alignment to one side of Mars. (See Figure 1).

A similar panorama of Mars' aphelia (Table 2) reveals a more subtle pattern. In this case there *appears* to be only one minimum under column 1963, and one maximum, centred roughly under column 1968. I suspect in the latter case, that there are actually two maxima balanced on the shoulders of a very shallow secondary minimum, in a manner roughly analogous to Algol's light curve; there are insufficient data to fully reveal this. The diagonals aren't quite so pleasingly consistent, but the pattern strongly suggests a periodicity of about twelve years. As is the case with the Moon, the range of aphelion values is significantly lower than that for perihelion.

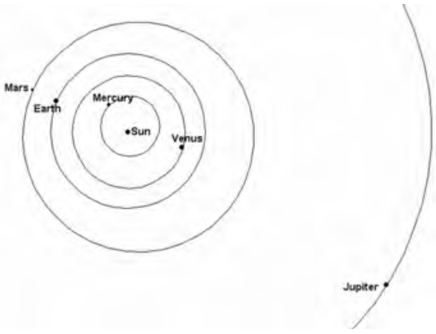

Figure 1. – An overview of the solar system as Mars reached perihelion on August 30, 2003 shows the favourable alignment of three other planets with the Sun.

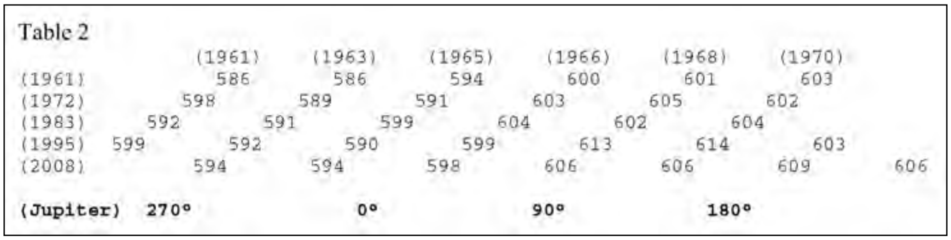

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Table 2
                (1961)     (1963)    (1965)     (1966)     (1968)    (1970)
(1961)            586       586        594        600       601        603
(1972)         598       589        591        603       605        602
(1983)      592       591        599        604       602        604
(1995)  599        592        590       599        613        614       603
(2008)          594        594       598        606        606       609        606

(Jupiter)   270°               0°              90°             180°
```

Table 2. – Mars' aphelion distances from 1961-2019, showing the last three digits (1.66xxx AU). The Red Planet is near longitude 156° at each data point. The shallowest aphelia are clustered when Jupiter is around 336°, once again indicating that Jupiter in conjunction with the Sun has the effect of bringing Mars slightly closer. Exactly half of the 32 aphelia on this period have values of 1.66600 or higher, and all 16 are located on the right half of the panorama; the 16 events of 1.66599 or below are all on the left. A comparison of the top and bottom rows (1961 and 2008) reveals that all values have increased by 0.00004-0.00008 AU, due to Mars' increasing eccentricity. Note that the two deepest aphelia of the entire period occur consecutively in 2002 and 2004, indicating that the current "wobble" of Mars, evolving orbit is particularly eccentric, achieving modern records for distance from the Sun at both extremes of the orbit.

I noted in Martian Motion I (McCurdy 2003), the unusual slope and asymmetric flattish peak of the current 79-year series of close approaches of Mars to Earth. Let's look at it again in the context of Jupiter's position in Table 3.

The 1766 figure of 1.38148 AU was, in the context of its times, an extremely close perihelion, as was that of 2003, which was almost certainly the closest since many millennia. The orbital circumstances of Earth-Mars were not quite as favourable as 1924, *except* Mars was particularly close to the Sun, and therefore to Earth in inferior conjunction, largely due to the influence of Jupiter in superior conjunction. In essence Jupiter was pushing the Sun away from the barycentre of the solar system in the direction of Mars, with slightly more influence than it was pushing Mars itself. To paraphrase Meeus (2003b), the gravitational effect of Jupiter on Mars is of the "second order": what counts is not the direct attraction of Jupiter on Mars, but the *difference* between the attractions Jupiter-Sun and Jupiter-Mars.

Of course, these gravitational relationships don't happen in a vacuum (so to speak). A related question is how much Earth's orbit is itself deformed closer to the Sun for the same reasons. This is more difficult to determine: ephemerides are for Earth itself, which wobbles ± 0.00003 AU to either side of the Earth-Moon barycentre. The variations introduced by lunar phases can advance or delay the *date* of perihelion by up to two days, nearly overwhelming the subtle residuals of the secular variations (Meeus 1997). That said, surely it's no coincidence that Earth's closest perihelia in the 41-year period 1980-2020 (the only three < 0.983250 AU) occur in early January of 1985, 1996, and 2020; and the two shallowest aphelia (<

Table 3

Year	Mars-Earth (AU)	Mars- Sun Perihelion	Jupiter's Longitude	"Adjusted" Perihelion	"Adjusted" Mars-Earth
1766	0.37326	1.38148	152° (+176°)	1.38178	0.37356
1845	0.37302	1.38167	29° (+53°)	1.38167	0.37302
1924	0.37285	1.38159	261° (-75°)	1.38159	0.37285
2003	0.37272	1.38115	150° (+174°)	1.38145	0.37302
2082	0.37356	1.38131	25° (+49°)	1.38131	0.37356

Table 3. – The current 79-year series of close Mars-Earth approaches, with perihelion calculations graciously provided by Jean Meeus. Earth is in virtually the same location in all five cases, eliminating the primary source of "noise" in the data and further isolating the "Zeus Effect." Bracketed figures after Jupiter's longitude show its relationship to Mars: In the two cases where Jupiter is in conjunction nearly 180°, Mars is unusually close to Earth, presumably because it is having unusually close perihelia. Applying our previous findings that Mars is ~0.0003 AU closer to the Sun under these circumstances, we can "correct" for this variable by adding in this amount to the perihelia of 1766 and 2003. This yields the near-regular slope of ~0.00015 AU/Cy in the "adjusted perihelion" column, which can be attributed to Mars' increasing eccentricity. A similar adjustment for the Mars-Earth distance shows a very regular curve in the series, supporting the author's original supposition that this series "should" have peaked in 1924, and that only the position of Jupiter led to its record-setting status in 2003.

1.016660 AU) occur in July 1990 and 2001. As we found with Mars, without exception each of these five "extreme" events occurs within a couple of weeks of a conjunction of Jupiter with the Sun.

Even with the influence of the Moon, the range of variation of Earth's perihelion distance is just 0.00012 AU, only some 30% that of Mars. One can conclude the difference between the attractions of Jupiter-Earth and Jupiter-Mars when the King of Planets is ~ 180° from both, would have the net effect of drawing Mars slightly closer to Earth as well as to the Sun, as we have witnessed in 2003.

We know that the Earth-Mars closest approach record will be broken in 2287, however, the Martian perihelion record will surely fall much sooner than that. Mars achieves perihelion on each revolution of the Sun, not just once every 79 years or whatever, and the gradual increase in its eccentricity makes the near continual approach of perihelion inevitable. What is moderating this, in that a new record is not set *each orbit,* is tiny differences in the "waves" due (primarily) to Jupiter's changing aspect at each instance.

I checked out future Mars perihelia beyond 2020 on *Guide 7.0,* which I first determined to be extremely accurate to Meeus' table. Considering the factors in this order of importance: 1) ongoing increase in Mars' eccentricity; 2) position of Jupiter; 3) position of Earth, and noting the 47:25:4 near resonance among the three, I figured 2050 as a likely date for a new record.

Aug. 30, 2003	1.38115	(Jupiter 150°, Earth 337°)
Dec. 12, 2014	1.38121	(Jupiter 133°, Earth 81°)
Oct. 29, 2016	1.38124	(Jupiter 186°, Earth 36°)
Feb. 11, 2028	1.38116	(Jupiter 170°, Earth 142°)
May 26, 2039	1.38111	(Jupiter 154°, Earth 246°)
Sept. 7, 2050	1.38111	(Jupiter 138°, Earth 345°)

It turns out that Jupiter is particularly well aligned in 2039 some 182° from Mars' perihelion, so the 2003 perihelion record will be broken then. The new mark will be equaled, or very nearly so, in 2050 when Jupiter's position is somewhat less favourable but Earth's much more so.

In the course of our correspondence, Meeus (2003c) stated: "It was amusing to read what your wife said about my Tables ("how can you read that? Nothing than numbers!"). Actually, there is much poetry in those tables, if you can look at them carefully. Certainly astronomical tables are on a higher level than such things as telephone books...!"

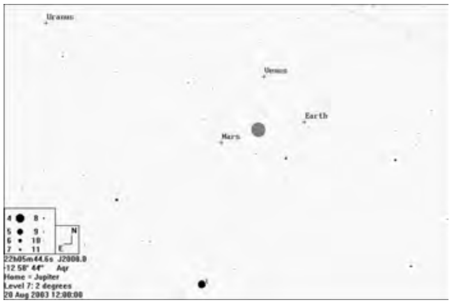

Figure 2. "The Age of Aquarius" as seen from Jupiter. On August 20, 2003 (shown), Venus, Earth, and Mars all clustered within 20 arcminutes of the Sun, against the backdrop of the constellation of Aquarius. Uranus can be seen only 1.5° away. While only 3.7° distant and also in Aquarius, Mercury was near maximum western elongation, and Saturn too was well out of alignment.

If you'll forgive a philosophical moment, the anarchy of true randomness (numbers in the phone book) is as uninteresting as the fascism of absolute certainty (*e.g.* 1.0000000...). The real Universe is a delicate, indeed poetic, balance between order and chaos, the interface of which can be best appreciated from the water's edge. The waves breaking on the shore are superficially the same but when examined closely each is unique. Is there a pattern? I try to pick out those little ripples at the extreme edges of the tables and see if I can discern the logic behind them. And the little moments of "discovery," even as they inevitably prove to not be truly original, are nonetheless profound.

Segue to the trivial: in 2003 Jupiter *did* align with Mars, with the latter appearing in Aquarius. Just because I'm a curious kind of guy, I looked up the astrological position of the Moon on the date of Mars' closest approach to Earth and Sun, and found it to be - to the best of my limited understanding and interest - in the sixth and seventh houses, respectively.

But I'm still waiting for that peace and love thing to kick in. Until it does, consider my belief in astrological prophecies to be on indefinite hold.

Acknowledgement

The writer gratefully acknowledges the assistance of Jean Meeus (RASC Honorary Member), to whom this article is dedicated.

References

McCurdy, B. 2003, JRASC, 97, 98

Meeus, J. 1983-95, Astronomical Tables of the Sun, Moon and Planets (2ed: Willmann-Bell Inc.: Richmond), 30

Meeus, J. 1997, Mathematical Astronomy Morsels, (Willmann-Bell Inc.: Richmond), 169

Meeus, J. 2003a, 2003b, 2003c, private communications

Bruce McCurdy is active in astronomy education with RASC Edmonton Centre, Odyssium, and Sky Scan Science Awareness Project. He currently serves National Council as Astronomy Day Coordinator. He is perversely delighted that his only child was born under the "sign" of Ophiuchus.

Observation of the 1761 Transit of Venus from St. John's, Newfoundland

by Frederick R. Smith, St. John's Centre (frsmith@morgan.ucs.mun.ca)

On May 9, 1761 the province–sloop *Massachusetts* left Boston and in 13 days arrived in St. John's, Newfoundland. The passengers were John Winthrop, Hollisian Professor of Mathematics and Philosophy, and two of his students from Harvard College. They were headed to St. John's to observe the transit of Venus on what appears to have been the first American scientific expedition. This was one of a number of world-wide expeditions attempting to use Edmond Halley's method to measure the solar parallax and thereby determine the length of the astronomical unit.

While institutions throughout Europe had a long history of scientific research, few people in North America had very much training in astronomy and mathematics. However there was one outstanding scientist at Harvard College, John Winthrop. Winthrop had published on comets, sunspots, and other astronomical phenomena and had been well aware of the up-coming transit of Venus and also that St. John's, Newfoundland would be the most convenient place in North America where the transit could be observed; the coast of Labrador was considered out of the question. Unfortunately, less than an hour of the transit could be observed from St. John's since the transit started well before sunrise in Newfoundland (the 2004 transit will present a similar situation).

Winthrop's colleagues conveyed a letter to Francis Bernard, Governor of the Province of Massachusetts, requesting that the legislature fund a trip to St. John's, Newfoundland to observe and measure the transit. The governor supported the expedition and had little trouble in convincing the legislature of the importance of the event. The legislature assigned the province-sloop *Massachusetts,* under Captain Thomas Saunders, to take Winthrop and his students to St. John's.

The administrators of Harvard College also wanted to contribute to the expedition and gave Winthrop permission to take any of the college instruments, as long as they were insured against loss or damage.

To quote Winthrop:

> "The Reverend the Preſident and Fellows of Harvard College, in order to promote ſo laudable an undertaking, granted their Apparatus of aſtronomical inſtruments, to be imploy'd in this affair. Accordingly, I carried an excellent Pendulum clock; one of Hadley's Octants with Nonius diviſions, and fitted in a new manner to obſerve on ſhore as well at ſea; a refracting telescope with croſs wires at half right angles for taking differences of Right Aſcenſion and Declination; and a curious reflecting teleſcope, adjuſted with ſpirit-levels at right angles to each other, and having horizontal and vertical wires for taking correſpondent altitudes; or differences of altitudes and azimuths."

The sloop took 13 days to travel from Boston to St. John's. and upon arrival Winthrop and his two students were given a good reception.

> "The town of St. John's being bounded with high mountains towards the Sun-riſing, ſo that no houſe in it would anſwer our need, we were obliged to ſeek further; and, after a fatiguing and fruitleſs attempt or two, fix'd on an eminence at ſome diſtance."

It took several days to get all of their equipment to the observing site where they then had to set up several tents and drive posts securely into the ground for the pendulum clock and other equipment. Before the transit they had lots of time to check out the equipment and adjust the clock and be assaulted by

> "ſwarms of inſects, that were in poſseſsion of the hill..."

On the morning of June 6, 1761 it was "ſerene and calm." The sun rose behind a cloud but soon became visible, and the transit was observed and measured.

Where did Winthrop make his observations of the transit of Venus?

The local gentlemen who turned out to watch the transit named the place "Venus Hill" in honor of the occasion, but that name has never turned up in any official documents or maps.

When Simon Newcomb was documenting the sites of transit observations, he wrote the St. John's Harbour Master and was told Winthrop must have observed from the Fort Townshend area (Newcomb 1891). The fort was actually built a couple of years after Winthrop's visit.

In his journal Winthrop gives the coordinates of his place of observation. He and his assistants had measured the latitude many times and the value 47° 32′ recorded in his journal is probably fairly accurate. It is interesting to note that in the *Philosophical Transactions* the latitude is given as 47° 31′. Longitude determination is another matter. This period was before the development of reliable chronometers, and there were no solar or lunar eclipses while he was in St. John's, and because of the weather he was not able to observe either of the two eclipses of Jupiter's moons that occurred during his visit. Having no way to measure longitude, he quoted the value listed in the literature, a point out in the Atlantic Ocean and of no use in locating his observation site.

What do we look for in trying to locate Winthrop's observing site?

1. I used his latitude line as quoted in his journal and explored an area one nautical mile north and south of this line.

2. On June 6, 1761 the azimuth of sunrise from St. John's was approximately 54 degrees true. One obviously must be able to look in that direction and have a clear view of the horizon.

3. The ground must be suitable for driving heavy posts securely in place.

4. The high point must be such that it would take several days to get all the equipment to the site but be within walking distance (there were horses in St. John's in those days).

5. It must be an area where one would expect biting flies in large numbers.

Observations

I walked and drove over all of St. John's and surroundings with compass, map, and GPS in hand and noted on the map any area where the horizon could have been seen at an azimuth of 54 degrees true.

The easiest site to deal with was Fort Townshend. Newcomb would have been able to eliminate it immediately if adequate topographic maps had been available. Even a quick drive by will show that, at the azimuth of the 1761 sunrise, the horizon is blocked from view by the White Hills and Signal Hill. However there is a beautiful view of the horizon through St. John's narrows, and the harbour master must have taken for granted that the Sun would have been visible in that direction.

Anyone with even a casual knowledge of St. John's would assume that the obvious place to view any sunrise would be Signal Hill. However Signal Hill was well known and named, and this would have been known by the local residents in 1761. It is also well north of Winthrop's latitude line.

The next most obvious candidate for an observing site would be the South Side Hills, also known as the South Hills during this period. The areas on the hill tops suitable for observing sunrise are too far north, and once again the locals would have known the name.

When plotted on a modern day topographic map, Winthrop's quoted latitude line runs straight through the highest point of Kenmount Hill, an "eminence at some distance" from the centre of the 1761 town and on the south-west periphery of the present day city.

Support for Kenmount Hill

All parts of St. John's are near the Atlantic Ocean, but it is surprising that there are so few areas where it is possible to get a clear view of the horizon and even fewer in a particular azimuth.

Kenmount Hill is one of the highest hills in the area, giving excellent visibility of the ocean horizon in the azimuth of sunrise in June 1761. The ground is suitable for driving in poles for the clocks and telescopes, and there are "lots" of biting flies there during June.

In the 21st century Kenmount Hill is known by St. John's residents as a hill covered by a coniferous forest and communications towers. However as Head (1976) and others have pointed out, the early residents needed wood for fuel, house building, ship repair, and structures for drying fish (fish flakes), and by the 17th century the land was cleared of trees for miles around the town. In addition roads extended in all directions from St. John's (Mannion 2002), including over and around Kenmount Hill. Even photographs taken of the St. John's area in the late 19th and early 20th centuries show few trees, and most of the spruce and fir on the hill are growth from the last quarter of the 20th century.

St. John's has a history of being invaded by land forces, and in fact the town was captured by the French the year after Winthrop's visit and recaptured by the English in the last battle of the Seven Years War (the Battle of Signal Hill). So there would naturally have been some military interest in Kenmount Hill, and this is supported by the remains of a trail known, in old deeds, as Soldier's Path, and near which a former resident of the area (Sandland) had recovered 18th century coinage.

Therefore, in the mid-18th century it would have been fairly easy for Winthrop and his assistants to walk along the relatively low sloping hills, known in those days as "the Barrens," on a route from the centre of the town to Kenmount Hill, perhaps using horses to carry the equipment. It would also have been easy for the residents to reach the hill to watch the astronomer at work.

Conclusion

Based on the evidence given above, I conclude that John Winthrop and his students observed the 1761 Transit of Venus from Kenmount Hill, St. John's.

References

Head, C.G. 1976, Eighteenth Century Newfoundland: A Geographer's Perspective, (Carleton University Press: Ottawa)

Hindle, B. 1956, The Pursuit of Science in Revolutionary America 1735–1786, (University of North Carolina Press: Chapel Hill)

Mannion, J.J. 2002, Department of Geography, Memorial University of Newfoundland, private communication

Mannion, J.J., ed. 1977, The Peopling of Newfoundland, Essays in Historical Geography, (University of Toronto Press: Toronto)

Newcomb, S. 1891, Discussion of Observations of the Transits of Venus in 1761 and 1769, Astronomical Papers prepared for the American Ephemeris and Nautical Almanac, Vol. 2, No. 5

Prowse, D.W. 1895, A History of Newfoundland from the English, Colonial and Foreign Records

Sandland, T., private communication

Winthrop, J. 1761, Relation of a Voyage from Boston to Newfoundland for the Observation of the Transit of Venus June 6, 1761, Boston N.E.

Winthrop, J. 1769, Royal Society of London, Philosophical Transactions (12) 1763–1769

Acknowledgement

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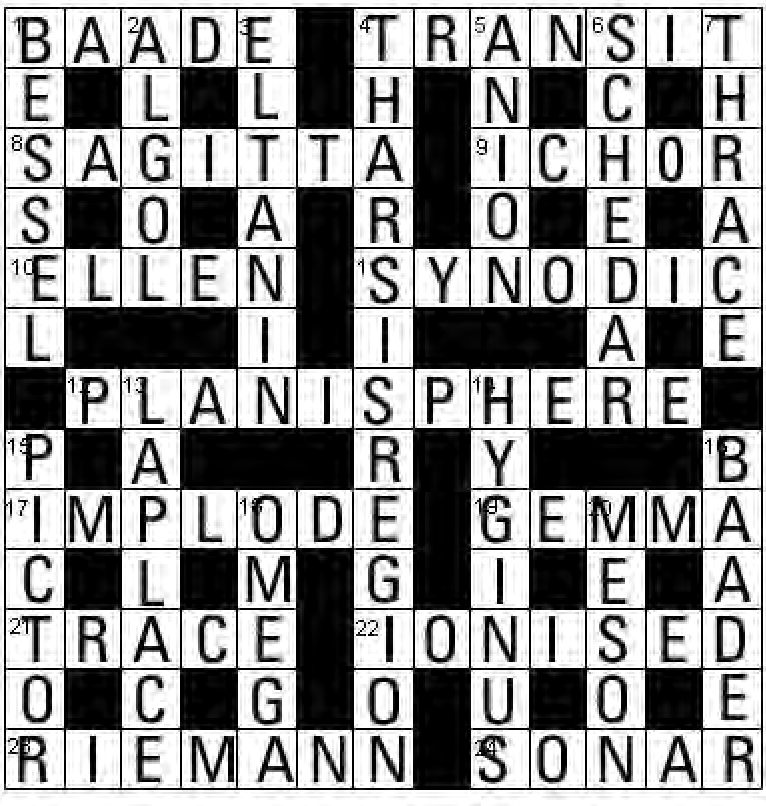
Frederick R. Smith is a member of the RASC St. John's Centre. He teaches introductory astronomy and astrophysics at Memorial University of Newfoundland in St. John's.

Astrocryptic

by Curt Nason, Moncton Centre

Here are the answers to last issue's puzzle



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S	■	O	■	A	■	R	■	O	■	E	■	A
10 E	L	L	E	N	■	11 S	Y	N	O	D	I	C
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15 P	■	A	■	■	■	R	■	Y	■	■	■	16 B
17 I	M	P	L	18 O	D	E	■	19 G	E	20 M	M	A
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21 T	R	A	C	E	■	22 I	O	N	I	S	E	D
O	■	C	■	G	■	O	■	U	■	O	■	E
23 R	I	E	M	A	N	N	■	24 S	O	N	A	R

Edmonton's Amazing Marzathon 2003

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

Edmonton Centre's Mars-watch began by mid-August when Observatory assistants began staying late to watch Mars rise over the Coronation Park tree line. The smoke haze from the many fires ravaging the western provinces still permitted the South Polar Cap to inspire exclamations from the guests. The first ripples of excitement and intimations of big crowds for the event were evident as the phone on deck began ringing constantly with questions about the "big orange light in the south that moves around" or "how do I tell the difference between Mars and the Moon?" The newspaper and screen-sized images were going to be hard to beat with the "skin-of-your-eye" telescopic view. Many people came out mid-afternoon demanding to see Mars and had to be content with an eyeful of daytime stars.

The Observatory and RASC members' telescopes set up in the field gave a full spectrum of Mars views, interpreted as a "little white dot" or a "Big Red Ball," depending on your inner imaging system! One interpretation of the amazing and mostly accurate Edmonton media coverage was that our telescopes were going to give whoppingly huge views of Mars that were bigger than your face. The real treats came in assorted sizes, from the donation of mini-*Mars Bars®* to the big dome of clear sky that accompanied most of our twelve official viewing nights. After a year of clouded-out events, it was a relief to say to the crowd, "You came on an excellent viewing night!" Features such as the S.P. Cap, Syrtis Major, Solis Lacus, Hellas Basin, and even Phobos were visible. The computer on deck was a great aid. With *Mars Previewer* set up and coupled with *Starry Night Pro*, we could show things to the bottleneck crowd at the door. Features of Mars and some short clips with Carl Sagan and even *War of the Worlds* were popular. The new RASC display board had a "Hiker's Guide to Mars" map and some prime *Global Surveyor* shots. These were the nights when we were at our best: busy, taking pride in our equipment and knowledge, running not only on our own enthusiasm but that of new observers. Overall, the crowds were very appreciative, and many returned for another sampling of sky through the month of September.

And what crowds...! On Friday, August 29, we hit the peak with several thousand people in a serpentine line from the telescopes, through the parking lot, right out to 142nd St. The following night, Brian from the Odyssium came up with a more efficient crowd design that used the looping sidewalks to more advantage. This enabled some of our impromptu Sky Walk presenters to reach more people with their informative talks and the aid of the great green laser pointer. Inside the Odyssium, Frank Florian gave extra "Sky at Night" live shows, up to three consecutive presentations, highlighting Mars. Sometimes it was very difficult to persuade the public that some of the telescopes in the field gave equal views and had shorter line-ups. Those who chose to believe had a variety of experienced sky-guides and good equipment to choose from. On some nights these field lines were so magnetic that they were half an hour long, still better than the three- to four-hour Observatory line-up. At our peak on Friday night we wrapped things up with a nice image of Saturn in the east...at 4:30 a.m.

Several Odyssium staff donated their time as did the dedicated RASC volunteers. Each night there was anywhere from a handful to over twenty volunteers. One night Ardith Edwards, the Odyssium Volunteer Coordinator, handled the coffee and hot chocolate sales with Chris, the receptionist. Chris' daughter Stacey took her glowing angel wand and handed out planet cards and chocolate to the kids in line. Whenever possible, after midnight we would find families with small children and the elderly or handicapped guests to bring past the line-up and in the back of the Observatory. I have to admit that some nights we were overwhelmed by the crowd/volunteer ratio, couldn't quite live up to our best-laid plans and had to go with Plan B. To quote Patti Jeske, who must be personally responsible for recruiting hundreds of new Observatory fans, "We'll stay open until the last visitor has seen Mars, or until the Sun rises, whichever comes first." The greatest heroes were those who topped off "giving their best" with keeping their humour intact. Mars tips its S.P. Cap to you!

One of my favourite nights was the close approach on Tuesday, August 26-27. We had some cloud cover but still had a line-up of a few hundred. An artillery of telescopes all centred to snipe Mars stood at attention along with a deck of expectant people. When it finally blazed through in all its horizon-distorted glory, the crowd went "OOOooooooooo...!!!" and then a long "Awwwwwwww..." as it ducked immediately into the cloud bank again. This repeated many times and the crowd began to exaggerate the Oos and Aws. Later we joked among ourselves about the best public view of Mars. Putting the planet out of focus (never deliberately of course...) brought some satisfying comments: "Wow, it looks like bacteria, there is life on Mars; It's huge and I think it's on fire; I can see yellow and blue stuff in the atmosphere..." Kevin Jeske and Bruce McCurdy stayed until the wee hours to glimpse the actual closest approach and were blessed by a poignant cloud break. The following night it actually rained. I shut myself in the Observatory and answered chain-ringing phone-calls about Mars, shouting answers above the din of downpour on the metal roof. Larry Wood helped me with a roof leak, and as we walked through the rain to the parking lot, a teenage girl, one of the many soaked visitors that night, ran from her car asking if she could still view Mars.

Early in the Mars-watch I realized we needed a little entertainment near the line-weary entrance wall to the Observatory. Past-president Richard Vanderberg with his patient, informed explanations and on-going humour was a big help. I also placed a big whiteboard near the door with a red lamp and some coloured markers. Each night the board was filled with a multitude of new Martians. Artists of all ages tried their hand at conjuring other life in the universe. No creation was as strange and wonderful as the people, tigers, dolphins, and toucans that already populate our Earth. One night we even had a theatrical troupe of "green-light dancers" on the little green hill north of the deck; I had coincidentally met them as I went into my "day-job" at the Observatory that afternoon.

During the last few nights with our humour wearing a little thinner, I found myself pointing out the Martian feature *Beer Crater* on the computer, or at least the *Near Beer Crater,* as you really had to zoom-in to find it. No liquid there. Maybe some atmospheric ice? There was not much of this type of indulgence during our Mars-watch...after all, what was open and respectable in the pre-dawn hours? We took turns running the rails behind the Observatory with hot-chocolate and TiM57s (donuts). On our more desperate nights a person could feel like her feet were duct-taped to the concrete for many hours. Every morning in kitchens across Edmonton, Marzathoners did the Marswalk, a very slow gliding motion with bent knee, with care taken not to shatter calluses. When the long nights were done, we all felt we had truly donated our soles to science.

So it's over, but it was everything we had been rehearsing for: a historical event, great weather, no major dust storm on Mars, excellent media coverage, dedicated and energetic RASC and Odyssium volunteers/staff, and chocolate. Now, whenever I turn my house-key in the front door lock I have to sneak a peek at Mars over my shoulder. Still there. Doesn't really feel like an alien planet anymore. More like a fellow conspirator, bringing all those workaday people out at odd hours to look into space and wonder.

As I complete this article, the North Saskatchewan River valley is alive with colour and a fiery promise for the renewal of our earthly greens and blues. Mars lingers as a dusky terracotta disc, maybe not as mysterious now that we know so much more about it, but I find the facts even more fascinating. After the 2003 opposition Mars is a closer companion in the mind of the public. Ideas like terraforming and the current missions were hot topics during the event. As we gain more knowledge about the diversity of space and persistence of life's struggle, science has more opportunity to affect the course of human history in the universe. This is reliant on public awareness and interest. Will we be part of an uncommon future with our close companion? This Mars event may have played a small part in enabling future exploration of our solar system.

We'll be waiting for the next close encounter. Come "by" us another round, Mars...

Sherrilyn Jahrig is Edmonton Centre's Public Education Director and works summers as an Odyssium Observatory operator. Although cosmology and deep-sky objects are her preferred focus, the Solar System seems to rule her daily life.

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Reviews of Publications
Critiques d'ouvrages

Solar System Voyage, by Serge Brunier, pages 248 + 0, 25.5 cm × 36 cm. Cambridge University Press, 2003. Price $40 US hardcover (ISBN 0-521-80724-7).

It is always interesting to review coffee-table books, as they are usually chock full of interesting photographs. *Solar System Voyage* is no exception, but in a way most of the book was anticlimactic for me. One of the first photographs, of a distant astronaut in a Manned Maneuvering Unit, set against a black sky and hovering over the Earth, was awfully hard to top! Some images were enlarged too much and appear quite grainy, but most of the images are extremely sharp. That may originate in part from thick paper stock, so thick that it took a while before I stopped trying to separate two pages that I thought were stuck together!

The book is divided into chapters like those you would find in an introductory astronomy text, starting with the Sun and working outwards to Pluto. There are a few exceptions, such as separate chapters for Phobos and Deimos, Gaspra, Comet Shoemaker-Levy 9, and Triton. Comet Halley gets its own chapter, situated between those of Uranus and Neptune. Titan also gets its own chapter despite the fact that its few images all look like an orange tennis ball! The rest of Saturn's moons are forced to share a chapter. The Jupiter system suffers a similar oddity; Io gets its own chapter, while the other three Galilean satellites are put together into one.

Most chapters begin with a double-page photograph of the chapter's topic. The text begins with a description of what it would be like to be on the surface of the object about to be discussed. You can imagine that you are standing there, surveying the terrain while your spacesuit struggles to maintain livable conditions against a hostile world. The romantic prose then turns into a fairly detailed scientific examination of the body, something I was not expecting. Sometimes the text discusses a fact from a point of view not normally seen, and makes one pause to reflect. A discussion of the Apollo missions states that "these footprints will remain in the lunar soil for millions of years, perhaps long after the species that left them has disappeared."

While many of the images that grace the pages of *Solar System Voyage* are familiar to most amateur astronomers, there are bound to be some that the reader will not have seen before. That is especially true of the chapter on Earth, where images of mountains in Nepal and of the Grand Canyon, even with no objects in the picture to give a sense of measure, show the beauty of the Earth on the grandest of scales. The chapter on Mars sports a wonderful image of the Red Planet from the *Viking 2* orbiter with a black blob on one side of the image: Phobos seen in silhouette. Another amazing image is that of M101, with its spiral arms and most of the star field embedded in the blue tail of Comet Hyakutake.

Given that so many of the images have had their colours enhanced by computer processing, I was disappointed to find no "disclaimer" warning readers that the colours in many of the images are not what one would see if they were actually there looking at the objects. The pictures of Mercury, for example, are all black-and-white images sent back by *Mariner 10*, yet they are tinted orange-red. While it does give a much better impression of the planet as being parched and baked, at first glance it would be easy to mistake them for pictures of Mars. Io's colouring is even more extreme; in some images it look like a mouldy orange. Strangely, the caption for an image of Uranus does mention that the brightness of the rings and moons had been increased to make them visible.

The book concludes with an appendix that contains a wide variety of information, covering topics such as planetary cartography, telescopes, how best to observe the planet, and eclipses. There are also tables of data about the planets and moons, major planetary space missions, and upcoming eclipses. The eclipse tables show the book's European origins, having a special column for "Visibility in Europe."

There are some errors that detract from the book, but many would go unnoticed by a non-astronomer. Page 18 states that since the Big Bang the Universe has undergone "constant expansion"; "continual" might be a better adjective. As the book was originally written in French, that slip may have been one of translation. Others cannot be explained so easily. A list of stars, all supposedly 100,000 times more luminous than the Sun, includes stars ranging from Bellatrix ($M_V = -2.8$) to Deneb ($M_V = -7.5$), a brightness ratio of almost 100. A statement that the Sun's energy output has been constant over the last four billion years appears on page 29. Mars suffers two slips: page 86 claims that the stars visible from the surface of Mars "do not... form the familiar animals and mythical beasts," and later in the chapter it is stated that "the wind doesn't affect anything," in contradiction to earlier statements about the wind being the cause of dust storms. Particularly annoying is a serious production error in the chapter on Europa, Ganymede, and Callisto. While the page numbers are in the correct order, the contents of the pages were accidentally transposed so that the order in which they have to be read to make sense is 144, 145, 149, 147, 146, 148, and 150.

Despite the errors, the book does a wonderful job of charting our solar system, and I would not hesitate to give it to a passing alien as a photographic souvenir of its visit to our little corner of the Milky Way.

Patrick Kelly

Patrick Kelly is currently the first vice-president of the Halifax Centre and an assistant editor of the Journal.

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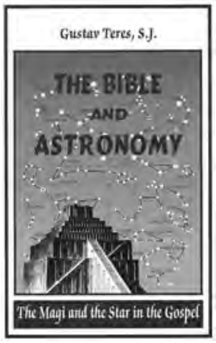

The Bible and Astronomy: The Magi and the Star in the Gospel, by Gustav Teres, S.J., pages 340 + xvi; 14 cm × 22 cm, Solum Forlag A.S., Oslo, 2002. Price $39.00 US softcover (ISBN 82-560-1341-9).

The mystery surrounding the Star of Bethlehem and whether or not there was an actual celestial signal at the time of the birth of Jesus has been the subject of countless books and articles. Gustav Teres has added one more text to the long list of discourses on the subject, but one that, unlike many of its predecessors, is well grounded in both astronomy and biblical science. In the process the author presents a very solid case for his own favourite interpretation of the Christmas Star, one that has been advocated by many astronomers for several years now — the triple conjunction of Jupiter and Saturn in Pisces of 7 BC. Along the way he also discusses a variety of other astronomical mysteries raised in the scriptures, resolving each in a manner befitting someone who is a scientist and active in the church ministry. On the whole, *The Bible and Astronomy* is a very interesting and educational book that tackles many of the obvious questions that come to mind when one reads biblical passages in the light of current knowledge about science and astronomy. I give it a thumbs-up overall, but with several reservations.

There is great deal that is of interest to Christmas Star specialists in *The Bible and Astronomy*. For example, Teres refers to triple conjunctions of Jupiter and Saturn by the less frequently used term "great conjunctions." The rationale for that becomes clear in the text. The great conjunction of 7 BC must have been important for Babylonian astronomers because three separate copies of the planetary tablet for that year have been found. Yet the actual dates for the three conjunctions of Jupiter and Saturn that year are not recorded on the tablets; only the reversal points of the planets (where they switch from prograde to retrograde motion, and vice-versa) are noted. Our present fascination with the actual dates of the three conjunctions therefore misinterprets what the star watchers of that era considered important.

One of the lesser-known proposals put forward regarding the Star of Bethlehem is that of Ferrari d'Occhieppo, who many years ago noted the interesting alignment of the zodiacal light with the planets Jupiter and Saturn on the evening of November 12, 7 BC, when the planets stood together above the southern horizon at the top of the zodiacal light cone in evening twilight, as viewed from Jerusalem. The configuration is viewed as significant with regard to matching the description of the Star presented by Matthew, but is little mentioned in most studies of the Star, possibly because the original work was published in German. Teres deserves a lot of credit for reviving the alignment in *The Bible and Astronomy* as his preferred candidate for the Star. It must have been a spectacular sight in the skies of Palestine. As he also notes, it matches exactly the astronomical description of the Star recorded in *Matthew*, once one translates the original biblical text into the language of star watchers.

Inevitably any argument regarding a good candidate for the Star of Bethlehem must answer the fundamental question of why the event in question was able to prompt the visit by the magi. What possible reason is there for a group of magi from Mesopotamia to journey to Judaea in search of a newborn Messiah? The matter is discussed at length by Teres, who concludes that they must have been savants living in Babylon, rather than simple astrologers. Among other details, for example, he notes that the magi brought gifts for the newborn child but did *not* cast a birth horoscope. As concluded by many others previously, Teres also suggests that the details of the birth story must originate from Mary.

Here are a few more details that only a knowledgeable astronomer would note. In 7 BC both Jupiter and Saturn were near perihelion, therefore closer to Earth than normal when in opposition, and Saturn's rings were also close to being face-on rather than edge-on. Both planets were therefore near maximum brightness in our sky that year, so would have been more prominent objects than otherwise. All of the greatest Jewish feasts other than Passover and Pentecost also occur in the fall, when Pisces is highest in the sky. These are just a few of the reasons why Teres prefers a birth date in November of 7 BC.

Teres does discuss previous great conjunctions of Jupiter and Saturn and why they are important (although some of the cited dates seem to vary from one sentence to the next). There was a triple conjunction in Pisces in 861 BC, for example, in an era close to the birth of the prophet Elijah. There was a simple conjunction of Jupiter and Saturn in Sagittarius in 134 AD, during a revolt by the Jewish rebel Bar Kochba. Jupiter and Saturn were also briefly in conjunction in Leo in 34 AD, although that seems a bit late relative to when Jesus confronted the Jewish scribes, as argued by Teres. More importantly, the 30-year orbital period of Saturn can be related to the "age of maturity" for Jewish teachers or priests. In another section there is a discussion of six-pointed stars. In short, nothing is considered too trivial to be included in *The Bible and Astronomy.*

Many of the discussions in *The Bible and Astronomy* involve numbers, although not always in coherent fashion. I have previously noted in these pages (*JRASC*, 92, 278-279, 1998) some reasons why the perfect number six (6) permeates astronomically-based number systems: the 24-hour day, astronomical co-ordinates, divisions of a circle. Teres opened my eyes to a reason why 60 is also an important number: it is divisible by ten different numbers (2, 3, 4, 5, 6, 10, 12, 15, 20, 30) without a remainder.

What *The Bible and Astronomy* does lack is an enlightened discussion of the history of that era. Although historical questions may not be necessary for discussions related to Teres's preferred candidate for the Star, concerns about some of the more controversial dates in the reign of Herod the Great are essential for countering other candidates for the Star that have been presented. Teres appears to cite conventional historical dates as given, despite a variety of current arguments for revisions to some of them. A lot of very exciting and innovative discussions have recently been published concerning biblical dates, but none of that pervades *The Bible and Astronomy*. Also missing are detailed remarks about the origin of the relevant books of the *New Testament* and the many discrepancies between their accounts.

Teres writes in the *Preface to the Third Edition of The Bible and Astronomy* that readers have commented to him that the text "contains some difficult chapters." I found myself in full agreement with such sentiments. The text is *very* difficult to read, for several reasons. There are many awkward sentences and paragraphs, perhaps resulting from translation problems, and the text does not always flow logically from one sentence to the next, which makes it difficult to follow the train of thought. There are several typographical errors that permeate the book, from frequently generated spelling errors related to the English homonyms "led" and "lead," and "past" and "passed," to punctuation marks that omit the mandatory following space. Such typos create frequent distractions from the storyline. Teres also writes in a very voluminous style that attempts to include all pieces of information, however extraneous. The text therefore reads much like a church sermon in places and becomes very pedantic for the reader. Much of what is written could be made considerably more concise without detracting from the excellent arguments presented. It should not be necessary to read and reread sections of the text in order to establish what is being said. In other places the reader is advised to skim lightly over the written text since the main point has already been made several times earlier.

A good example of a lack of continuity in the text is provided by the following passage from *Dates in the Vision of Daniel:*

> *"To understand these revelations, we must refer to the history of numbers. The ancient Hebrews and Greeks used their alphabet numerically, having no independent numeral system. All numbers were denoted by letters, and each word had its own particular number. The Hebrew alphabet consists of twenty-two consonants: Alef = 1 and the last one, Tau = 400. The Greek alphabet consists of twenty-four letters: Alpha = 1, and the last one, Omega = 800."*

It took me a bit of head scratching and a visit to the Internet to discover that the counting system being referred to for the Hebrew alphabet goes by ones from 1 to 10, then by tens from 10 to 100, and thereafter by hundreds from 100 to 400, or that the Greek number system being referred to is similar but contains three extra symbols, one following omega, that count as the numbers 6, 90, and 900. There is no explanation for the statements given in *The Bible and Astronomy*.

Christmas Star specialists will likely be most interested in the first half of *The Bible and Astronomy,* which is devoted to a discussion of the Star of Bethlehem. There is one later section on *Precession of the Earth's Axis and World Eras* that also pertains directly to the Star and that raises a very important subject in my view, but most other sections in the last half of the book tend to be extraneous. Teres does discuss a variety of other Bible mysteries, not always successfully. The section on *Joshua's Long Day: The Halting of the Sun* presents a generally convincing resolution to a rather absurd and often-misinterpreted statement in the *Old Testament*, although the supplementary map is not particularly useful. The section on the *Cosmic Vision of Ezekiel* is more of a diatribe, however, and begs the obvious solution, presented by others, of the simple but rare sighting of a complex pattern of solar parhelia. Many following sections seem to be little more than articles of faith reiterated for the reader.

The last few chapters of *The Bible and Astronomy,* on the Galileo Affair and how faith and science are essentially the same, could be omitted entirely. Perhaps they make comforting reading for Church elders, but the reality is that the Catholic Church is founded on some rather tenuous principles, one being the literal truth behind statements made in the Bible. That principle was adopted by early popes but is difficult to reconcile with what we know about the origin of the various texts of the Bible. Most of the controversies in the Galileo Affair and in present-day conflicts between educators and fundamentalists regarding the teaching of evolution in the schools relate to specific statements made in books of the *Old Testament*. It is difficult to argue that they are "inspired texts" when they provide incomplete records of events that transpired several centuries prior to the ages when they were written, according to biblical scholars. Why Teres spends several chapters discussing such matters is beyond my comprehension. Perhaps he feels some duty to the Church to espouse principles that help to foster the belief that science and religion are fundamentally the same. But the text here is not nearly as convincing as in earlier chapters.

Many of my complaints about *The Bible and Astronomy* could easily be rectified by running the text through spelling and grammar check in Microsoft Word, and although that would not address the problem of lack of conciseness, it would be a good first step. On the basis of its detailed assessment of the many factors surrounding the question of the Star of Bethlehem, I am still inclined to recommend the book to others. Be prepared for a long, tedious read, however, and try to avoid reading the last few sections entirely.

David Turner

David Turner is the Review Editor for the JRASC *and a member of the Department of Astronomy and Physics at Saint Mary's University. He has reviewed several books on the Christmas Star for the* Journal, *far too many for his own sanity, having spent six years as a planetarium director/script writer earlier in his career.*

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Parallax: The Race to Measure the Cosmos, by Alan W. Hirshfeld, pages 314 + xiii; 15 cm × 24 cm. W.H. Freeman and Co., 2001. Price $23.95 US hardcover (ISBN 0-7167-3711-6).

The publication of Copernicus's *De Revolutionibus* in 1543 is often considered to be the fulcrum on which the teeter-totter of astronomical history rests. Prior to the "revolution," opinion solidly favoured an Earth-centred Universe, but the weight of evidence accumulated until the balance tipped in favour of a heliocentric system. As Hirshfeld explains, measurable stellar parallax was originally pursued as an incontestable demonstration that the Earth really did orbit the Sun. But even before astronomers actually detected the telltale annual wobble in star positions, the motivation for their quest had shifted to the much broader task of finding how far away the stars are. Since stellar distances are the basis for all of astrophysics, a single pivotal point in the history of astronomy might better be the first definitive determination of stellar parallax by Bessel in 1838.

Most of *Parallax* is devoted to the development of astrometry, or the measurement of star positions, in the three centuries between the two significant dates 1543 and 1838. So the subtitle is a bit misleading. The "cosmos" does not refer to more distant stars and galaxies, and events spread out over centuries are only a "race" for an astronomer! Within such a framework, Hirshfeld weaves a wonderful tapestry of tales. At first, many of them appear to have little to do with the main narrative, but before long we see that the threads really do form a broad and elegant picture. How our eyes work, and the problems in fabricating glass, lenses, and precision telescopes add important elements to our appreciation of the struggles involved, while issues like education, patronage, and politics remind us how formidable such forces can be in achieving the ultimate goal.

Hirshfeld clearly intends his book to be a popular account. He begins many chapters with cute little stories about his father's influence, his first telescope, his first view of a comet, his experiences at college, and so on. For some readers, such anecdotes may make the book more friendly, but I found them mildly intrusive. The author does provide references for all his quotes and an extensive bibliography; they add greatly to the book's value without taking away from its appealing and relaxed style. (Appropriately, among the citations is J.D. Fernie's "The Historical Search for Stellar Parallax," which appeared in three parts in 1975 in the *JRASC*.) Nonetheless, there are many undocumented details in Hirshfeld's text, making it clear that it is not intended to be a truly scholarly treatise. Some examples of unsupported statements include Ibn as-Shatir's proposal, two centuries before Copernicus, that each planet circles at constant speed in a small epicycle whose centre moves uniformly around the Sun; James Gregory's idea, put forward in 1663, that the parallax of Mercury might be measured when it transited the Sun; various biographical details in the lives of many of the characters; the original proponents of the words "satellite" and "telescope"; the alleged role of Gamma Draconis in the alignment of Egyptian pyramids; the designer of the London monument. I cite these examples as much to illustrate the wide-ranging territory that Hirshfeld covers as to illustrate limitations in the references.

Like most popular books, *Parallax* contains almost no math, so readers are left with no real understanding of why the Astronomical Unit can be determined by finding the parallax of any one body in the solar system. They will also be confused by the discussion in Chapter 9 of how apparent brightness depends on distance — a discussion that completely ignores the logarithmic response of the eye and erroneously asserts that if a light bulb appears 1/5th as bright as an identical but nearby bulb, it is situated 25 times farther away.

Nonetheless, I would highly recommend *Parallax: The Race to Measure the Cosmos* to anyone from high school student to professional astronomer. Those with no previous interest in the history of science would enjoy the development of the plot, the controversies, and the interplay of the characters, while at the same time learning a great deal about the scientific process, its frustrations, and its often-unforeseen rewards. For those who may think they have heard it all before, there are plenty of new twists to the familiar tales to keep even a specialist eagerly turning to each new chapter. Hirshfeld, himself a professional astronomer, says in the preface that as he researched and wrote the book, he came to know a set of extraordinary astronomers in a way he never had in his formal studies. Fortunately for us, he has shared his findings with eloquence and style.

Peter Broughton

Peter Broughton is a former President of the RASC and an aficionado of the history of astronomy.

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The Big Splat, or How the Moon Came to Be, by Dana McKenzie, 221 pages + xi, 23.5 cm × 16.5 cm, John Wiley & Sons, Inc., 2003, Price $38.95 Cdn clothbound (ISBN 0-471-15057-6).

Reading astronomy books is one of the principle preoccupations of the armchair astronomer. If one lives in Canada's light-pollution capital, it is often the only way to truly enjoy our hobby when the combined forces of clouds, cold, chiggers, and children keep one away from one's instruments. One of the problems with reading too many astronomy books is the difficulty in finding something truly exciting and interesting that has not been published before.

Dana McKenzie's new book is one of those excellent finds. A mathematician who has turned his attention to science journalism, McKenzie, in his book *The Big Splat*, presents a focused volume that tells the story of how we have developed the modern theory of the origin of the Moon (also known as the "Big Whack" hypothesis or more prosaically as the "giant impact hypothesis"). The story as laid out by McKenzie shows how both Victorian and modern scientific processes work as he explores the three classical theories (fission, capture, and co-accretion) of lunar origins and contrasts them with the development of the modern giant impact theory. The "Big Whack" hypothesis emerged in the mid-1980s at a conference in Kona, Hawaii, where lunar scientists were asked to focus on the question of lunar origins. Rather than inspiring a fierce debate, the conference attendees found themselves to be in almost unanimous agreement that the "Big Whack" hypothesis was the only theory that fit the information brought back from the Apollo missions and other lunar probes in the 1960s and '70s. The "Kona Consensus," as it became known, marked the official debut of the giant impact hypothesis as the leading theory of selenogony (lunar origin) after several false starts.

One of the subtexts that runs through the book is how lunar science was fairly neglected throughout much of the 20th century. The renaissance in thinking that came about as a result of the Apollo program provided huge advances in understanding for both the Moon researchers and by extension for planetary science in general. The "science payoff" from the Apollo program is only now being well reported in the popular press.

McKenzie does an excellent job of producing a well-researched, readable, and exciting account of the development of selenogony, and introduces us to a number of interesting characters along the way. In particular, people like George Darwin (father of the fission hypothesis) and Thomas J.J. See (capture hypothesis proponent) make for interesting reading. Both would be better known today had their hunches turned out to be more correct.

My one disappointment with the book is the relative lack of illustration. The mind-boggling violence and explosive energy released in the impact between Earth and "Theia" (a name for the impactor proposed by Alex Halliday – Theia is the mother of Selene the Greek goddess of the Moon) is communicated with a few small black and white diagrams showing computer models and a few artists' conceptions. Given that Bill Hartmann, the noted space artist, was one of the original proponents of the impact theory in the 1970s, that is a shame.

The impact theory continues to gain momentum as various issues and concerns with the proposal are eliminated by further research. Advanced computer modeling can now generate the Moon with a wide variety of Theias, Earths, impact velocities, and impact angles. Theoretical research on the origin of the solar system provides a number of mechanisms in which migrating planets could set in motion the chain of events necessary for an impact. The make-up of both the lunar surface and the Earth's mantle appears to be increasingly consistent with a major collision early in Earth's history, and of course the role and frequency of giant impacts of all types is much better accepted now.

All in all, McKenzie has done an excellent job of telling an as yet untold story. The tale of the Moon's origin weaves through the tapestry of astronomy from the time of Kepler up to 2001, by which time computer models of the impact were being further refined. The book is an excellent read both for the scientific detective work as well as for the well-told introduction to planetary science as it exists at the beginning of a new century. It is highly recommended.

Denis Grey

Denis Grey is a RASC Life Member attached to the Toronto Centre. He is working on the RASC's new I. K. Williamson lunar observing certificate, in part because the Moon is one of the few things that are easy to see from downtown Toronto.

INDEX TO VOLUME 97, 2003

TITLES

Abstracts of Papers Presented at the 2003 CASCA Annual Meeting Held at The University of Waterloo in Waterloo, Ontario, June 1-3, 2003, Oct., 207
A Leonid Meteor, *Roy Bishop,* Jun., 128
Canadian Thesis Abstracts, *Melvin Blake,* Feb., 32, Jun., 132, Dec., 277
Fifty Years of Canadian Ph.D.s in Astronomy, *Peter Broughton,* Feb., 21
Heliocentric Conjunctions of Jupiter, Saturn, Uranus, and Neptune, *Jim Decandole*, Aug., 173
January 26, 2001 Fireball and Implications for Meteor Video Camera Networks, The, *Martin Connors, Peter Brown, Douglas P. Hube, Brian Martin, Alister Ling, Donald Hladiuk, Mike Mazur, and Richard Spalding*, Dec., 271
Millman Fireball Archive, The, *Martin Beech*, Apr., 71
Recollections of a Canadian Astronomer, *Donald C. Morton,* Feb., 24
Variations in 11612-MHz OH Line Emission from IRAS 19566+3423, *John Galt*, Feb., 15
Wideband Photometry of Saturn: 1995-2002, *Richard W. Schmude,* Jr., Apr., 78

AUTHORS

Adrian, Terry, Photos Through the Eyepiece, Apr., 107
Attas, Michael, Editorial, Dec., 256
Attwood, Randy, MOST: Canada's First Space Telescope Part 2, Feb., 7
Auclair, Raymond, La trigonométrie sphérique en astronomie, Aug., 163
Auclair, Raymond, Les mesures du temps, Apr., 54
Barkhouse, Wayne, Editorial, Feb., 4, Jun., 116, Oct., 192
Beech, Martin, Millman Fireball Archive, The, Apr., 71
Bishop, Roy, A Leonid Meteor, Jun., 128
Blake, R. Melvin, Canadian Thesis Abstracts, Feb., 32, Jun., 132, Dec., 277
Bratton, Mark, Scenic Vistas: Cyg-nice!, Jun., 141
  Scenic Vistas: The Beta/Zeta Arc, Aug., 184
  Scenic Vistas: The Deeper Sky of Corona Borealis, Apr., 101
Broughton, Peter, Fifty Years of Canadian Ph.D.s in Astronomy, Feb., 21
Broughton, Peter, What's in a Name?, Oct., 199
Campagnolo, The Hon. Iona, PC, CM, OBC, Lieutenant Governor of British Columbia, Remarks to the 2003 General Assembly Delegates, Oct., 196
Chapman, David M.F., Reflections: J. W. Christy and the Discovery of Charon, Pluto's Satellite, Jun., 126
  Reflections: Maarten Schmidt and the Discovery of Quasar Redshifts, Feb., 13
  Reflections: Martian Discoveries, Aug., 169
  Reflections: Meteor Showers and Comets, Oct., 204
  Reflections: Newtonian Opticks, Dec., 266
  Reflections: The Astronomer's Spouse: The Ultimate Accessory, Apr., 66
Connors, Martin, Kevin A. Douglas, and David A Lyder, A Decade's Progress in Distance Education Astronomy, Oct., 218
Connors, Martin, Peter Brown, Douglas P. Hube, Brian Martin, Alister Ling, Donald Hladiuk, Mike Mazur, and Richard Spalding, The January 26, 2001 Fireball and Implications for Meteor Video Camera Networks, Dec., 271
Decandole, Jim, Heliocentric Conjunctions of Jupiter, Saturn, Uranus, and Neptune, Aug., 173
Dodd, William, Web Site Reviews, Apr., 87, Jun., 145
Dodd, William, What is Sidereal Time and What Is It Good For?, Dec., 278
Edgar, James, An Evening with Rajiv Gupta, Aug., 177
Enright, Leo, A Tribute to David Levy, Oct., 224
Fairbairn, Maxwell B., Computation of Model Asteroid Lightcurves: Practice vs. Theory, Oct., 232
Fairbairn, Maxwell B., Photometry of Rotating Planetary Triaxial Ellipsoids, Apr., 92
Galt, John, Variations in 1612-MHz OH Line Emission from IRAS 19566+3423, Feb., 15
Gingras, Bruno, Johannes Kepler's Harmonices mundi: A "Scientific" version of the Harmony of the Spheres, Oct., 228
Gingras, Bruno, Johannes Kepler's Harmonices mundi: A "Scientific" version of the Harmony of the Spheres, Part II, Dec., 259
Gupta, Rajiv, President's Corner, Feb., 2, Apr., 46, Jun., 114, Aug., 150, Oct., 190, Dec., 254
Hay, Kim, Society News/Nouvelles de la société, Feb., 40, Apr., 89, Jun., 136, Oct., 223, Dec., 281
Hudon, Daniel, Editorial, Apr., 48
Jahrig, Sherrilyn, Edmonton's Amazing Marzathon 2003, Dec., 294
Jahrig, Sherrilyn, STS-107, Apr., 108
Kaasalainen, Miko, Unveiling Asteroids: International Observing Project and Amateur-Professional Connection, Dec., 283
Mackie, Guy, Draconian Discoveries, Disparities and Doppelgängers, Oct., 225
Mackie, Guy, Okanagan Centre Astronomy Contest, Aug., 179
McCurdy, Bruce, International Astronomy Day 2004 is Saturday April 24, Dec., 282
McCurdy, Bruce, Orbital Oddities: Eclipse Flips, Oct., 234
  Orbital Oddities: Martian Motion I: Zoom In, Apr., 98

  Orbital Oddities: Martian Motion II: Zig Zag, Jun., 137
  Orbital Oddities: Martian Motion III: Zoom Out., Aug., 180
  Orbital Oddities: Martian Motion IV: The Zeus Effect, Dec., 288
Moreau, Suzanne E., Editorial, Aug., 152
Morton, Donald C., Recollections of a Canadian Astronomer, Feb., 24
Mozel, Philip, Nocturnal Musings Concerning a Winged Horse, Apr., 61
Mozel, Philip, The Sky Disk of Nebra, Oct., 245
Orenstein, David, Mars in Motion: Keplerian Earth Centred Orbits?, Jun., 13
  Mars in Motion: Using Vectors to Investigate the Retrograde Loop, Apr., 82
Orenstein, David, Measuring Mars, Feb., 33
Percy, John R., Two Good Things About Light Pollution, Feb., 24
Pfannenschmidt, Ernest, Boosting Performance by Apodization, Apr., 103
Sage, Leslie J., Second Light: Asteroid Spins are Solar Powered, Dec., 268
  Second Light: Magnetically Powered Gamma-ray Bursts, Jun., 124
  Second Light: Measuring the Properties of the Universe, Feb., 11
  Second Light: Pluto's Expanding Atmosphere, Aug., 171
  Second Light: Probing the Atmospheres of Extra-Solar Planets, Apr., 68
  Second Light: Starburst in a Distant Quasar, Oct., 203
Sampson, Russell D., The Visibility of Jupiter During the Day, Jun., 144
Schmude, Richard W., Jr., Wideband Photometry of Saturn: 1995-2002, Apr., 78
Smith, Frederick R., Awards for Excellence in Astronomy at the 2003 Canada Wide Science Fair, Oct., 239
Smith, Frederick R., Observation of the 1761 Transit of Venus from St. John's Newfoundland, Dec., 291
Waldron, Ron, Astronomy - A Personal Journey, Aug., 186
Whitehorne, Mary Lou, Altitude and Limiting Visual Magnitude, Feb., 35
Whitehorne, Mary Lou, The Story of Skyways: The RASC's Astronomy Handbook for Teachers, Dec., 280
Young, Scott, The 40th Anniversary of Alouette I - Canada Celebrates Four Decades in Space, Apr., 90
Zimmerman, Brett, Nineteenth-Century American Astronomy and the Sublime, Jun., 120
Zimmerman, Brett, The Plurality of Worlds: Nineteenth-Century Theories of Extraterrestrials, Aug., 158

DEPARTMENTS

Across The RASC

40th Anniversary of *Alouette I* - Canada Celebrates Four Decades in Space, The, Apr., 90
An Evening with Rajiv Gupta, Aug., 177
AstroCryptic, Feb., 44, Apr., 112, Jun., 148, Aug., 185, Oct., 238, Dec., 293
Astronomy - A Personal Journey, Aug., 186
A Tribute to David Levy, Oct., 224
Awards for Excellence in Astronomy at the 2003 Canada Wide Science Fair, Oct., 239
Boosting Performance by Apodization, Apr., 103
Draconian Discoveries, Disparities, and Doppelgängers, Oct., 225
Edmonton's Amazing Marzathon 2003, Dec., 294
International Astronomy Day 2004 is Saturday April 24, Dec., 282
Okanagan Centre Astronomy Contest, Aug., 179
Photos Through the Eyepiece, Apr., 107
Sky Disk of Nebra, The, Oct., 245
Society News/Nouvelles de la société, Feb., 40, Apr., 89, Jun., 136, Oct., 223, Dec., 281
STS-107, Apr., 108
Visibility of Jupiter During the Day, The, Jun., 144

Columns

Orbital Oddities: Eclipse Flips, Oct., 234
Orbital Oddities: Martian Motion I: Zoom In, Apr., 98
Orbital Oddities: Martian Motion II: Zig Zag, Jun., 137
Orbital Oddities: Martian Motion III: Zoom Out., Aug., 180
Orbital Oddities: Martian Motion IV: The Zeus Effect, Dec., 288
Reflections: J.W. Christy and the Discovery of Charon, Pluto's Satellite, Jun., 126
Reflections: Maarten Schmidt and the Discovery of Quasar Redshifts, Feb., 13
Reflections: Martian Discoveries, Aug., 169
Reflections: Meteor Showers and Comets, Oct., 204
Reflections: Newtonian Opticks, Dec., 266
Reflections: The Astronomer's Spouse: The Ultimate Accessory, Apr., 66
Scenic Vistas: Cyg-nice!, Jun., 141
Scenic Vistas: The Beta/Zeta Arc, Aug., 184
Scenic Vistas: The Deeper Sky of Corona Borealis, Apr., 101
Second Light: Asteroid Spins are Solar Powered, Dec., 268
Second Light: Magnetically Powered Gamma-ray Bursts, Jun., 124
Second Light: Measuring the Properties of the Universe, Feb., 11
Second Light: Pluto's Expanding Atmosphere, Aug., 171
Second Light: Probing the Atmospheres of Extra-Solar Planets, Apr., 68
Second Light: Starburst in a Distant Quasar, Oct., 203

Correspondence:

Apr., 50, Jun., 117, Aug., 154, Dec., 256

Education Notes

A Decade's Progress in Distance Education Astronomy, Oct., 216
Mars in Motion: Keplerian Earth Centred Orbits?, Jun., 133
Mars in Motion: Using Vectors to Investigate the Retrograde Loop, Apr., 82
Measuring Mars, Feb, 33,
Story of Skyways: the RASC's Astronomy Handbook for Teachers, The, Dec., 280
Web Site Reviews, Apr., 87, Jun., 145
What is Sidereal Time and What Is it Good For?, Dec., 278

Editorial

Feb., 4, Apr., 48, Jun., 116, Aug., 152, Oct., 192, Dec., 256

Feature Articles

Altitude and Limiting Visual Magnitude, Feb., 35
Computation of Model Asteroid Lightcurves: Practice vs Theory, Oct., 232
Johannes Kepler's *Harmonices mundi*: A "Scientific" Version of the Harmony of the Spheres, Oct., 228
Johannes Kepler's *Harmonices mundi:* A "Scientific" Version of the Harmony of the Spheres, Part II, Dec., 259
La trigonométrie sphérique en astronomie, Aug., 163
Les mesures du temps, Apr., 54
MOST: Canada's First Space Telescope Part 2, Feb., 7
Nineteenth-Century American Astronomy and the Sublime, Jun., 120
Nocturnal Musings Concerning a Winged Horse, Apr., 61
Photometry of Rotating Planetary Triaxial Ellipsoids, Apr., 92
Plurality of Worlds: Nineteenth-Century Theories of Extraterrestrials, The, Aug., 158
Remarks to 2003 General Assembly Delegates, Oct., 196
Unveiling Asteroids: International Observing Project and Amateur-Professional Connection, Dec., 283
What's in a Name?, Oct., 199

From the Past
Feb., 31, Apr., 70, Jun., 127, Aug., 172, Oct., 206, Dec., 270

News Notes

Feb., 5, Apr., 51, Jun., 118, Aug., 155, Oct., 193, Dec., 257

Obituaries

Robert Hanbury Brown (1916-2002), Feb., 42, Hugh Noel Alexander Maclean (1915-2003), Oct., 246, Anne Barbara Underhill (1920-2003), Oct., 247

President's Corner

Feb., 2, Apr., 46, Jun., 114, Aug., 150, Oct., 190, Dec., 254

Research Papers (see **TITLES**)

Review of Publications

Bible and Astronomy: The Magi and the Star in the Gospel, The, by *Gustav Teres, S.J.,* Dec., 297
Big Splat, or How the Moon Came to Be, The, by *Dana McKenzie,* Dec., 299
Celestial Harvest, by *James Mullaney,* Oct., 249
How the Universe Got its Spots: Diary of a Finite Time in a Finite Space, by *Janna Levin,* Apr., 110
Mars Observer's Guide, by *Neil Bone,* Oct., 250
Misfortunes as Blessings in Disguise: The Story of My Life, by *Dorrit Hoffleit,* Jun., 146
Parallax: The Race to Measure the Cosmos, by *Alan W. Hirshfeld,* Dec., 299
Solar System Voyages, by *Serge Brunier,* Dec., 296
Star-Crossed Orbits: Inside the U.S.-Russian Space Alliance, by *James Oberg,* Apr., 111
Star Testing Astronomical Telescopes: A Manuel for Optical Evaluation and Adjustment, by *Harold Richard Suiter,* Jun., 147
Walter Baade: A Life in Astrophysics, by *Donald E. Osterbrock,* Apr., 109
What Your Astronomy Textbook Won't Tell You: Clear, Savvy Insights for Mastery, by *Normand Sperling,* Oct., 249

Auroral Fire and Ice
Here is a study in contrasts that join the Sun's energy to Earth's soil and air. Dark foreground trees point to high thin clouds, which glow like ice backlit by an aurora's red flames. As the recent solar maximum subsides, these displays will become rarer in the next few years. From the January page of the *Observer's Calendar 2004*

– Photo by Rod Innes

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Observer's Calendar — 2004

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

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

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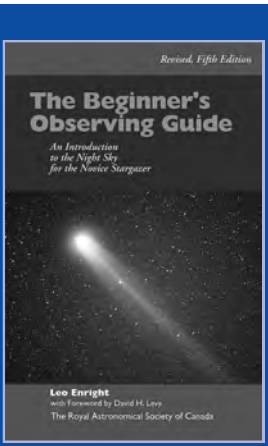

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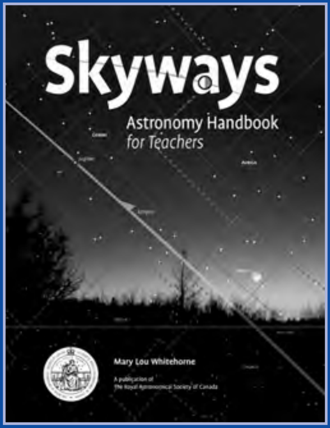

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