April / avril 2005 Volume/volume 99 Number/numéro 2 [711]

Journal

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INSIDE THIS ISSUE

Determining the Range of an Artificial Satellite

A Precise Measurement of a Leonid Meteor • A Young Astronomer

Astronomy of Ancient Egypt

April / avril 2005

Journal

Vol. 99, No. 2 Whole Number 711

contents

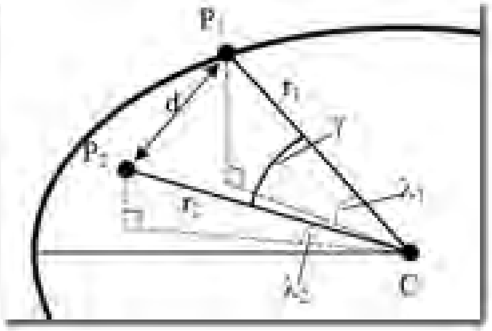
table des matières

FEATURE ARTICLES/ARTICLES DE FOND

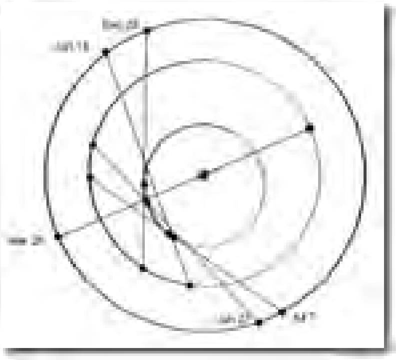
RESEARCH PAPERS/ARTICLES DE RECHERCHE

EDUCATION NOTES

COLUMNS/RUBRIQUES



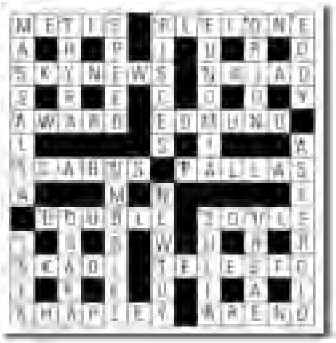
A Precise Measurement of a Leonid Meteor
p. 61



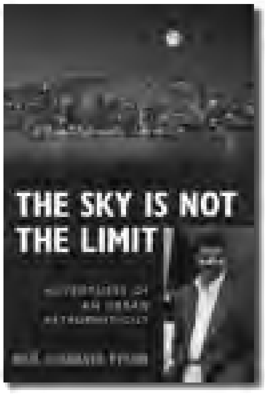
Orbital Oddities
p. 72

A Moment With…
Dr. Doug Welch
p. 75

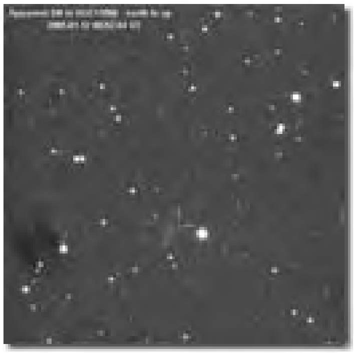
DEPARTMENTS/DÉPARTEMENTS



Astrocryptic Answers
p. 80



Book Reviews
p. 78



News Notes
p. 48

ACROSS THE RASC
DU NOUVEAU DANS LES CENTRES

Cover:
Reflections of a Young Astronomer
p. 57

Editorial

by Peter Jedicke, RASC President (Pjedicke@fanshawec.ca)

You would think these should be the best of times for our Society. There is tremendous excitement in every branch of astronomical research, amateurs have access to incredible technology that was unimagined a generation ago, and heightened public awareness is demonstrated by the popularity of television features, magazines, and even star nights. The number of members in the Society rose from 4,887 at the end of 2003 to a record 5,185 in late summer of 2004.

Yet the Society faces some difficult challenges in the coming months and years. After the largest increase in membership fees ever was approved at the Annual Meeting in St. John's during the General Assembly, the number of members slipped back under 5,000 to 4,655 on the last day of 2004. So while we gained at least 300 new members, at least 500 other members did not renew their association to the Society. The Membership & Promotion Committee has responded quickly and is conducting a survey of some of these recently-lapsed members. We hope this will give us a better understanding of the situation.

Meanwhile, first vice-president Scott Young and the Publications Committee he chairs have an unprecedented selection of products to manage. Sales of our highly-respected *Observer's Handbook* to non-members have declined somewhat of late. Are we finally seeing the influence of planetarium software and Internet resources on our venerable flagship publication? The successful *Observer's Calendar,* which has won awards for its quality, seeks a new editor to take over when Rajiv Gupta gives up that part of his portfolio. Meanwhile, on-time delivery of the *Journal* and *SkyNews* has been compromised by a variety of problems, some of them beyond our control. Regarding the *Journal,* I have heard it suggested that the time has come to consider further changes in the spirit of the revitalization that took place ten years ago.

The jump in our fees in 2004 was an early response to what many would argue is our most serious problem: financial deficit. After many years of healthy surpluses, the Society faced deficits of over $20,000 in 2003 and again in 2004. Treasurer Dave Clark, who has worked harder than anyone since taking office less than a year ago, projects that the deficit may be twice as bad in 2005. This is despite the fact that income has continued to rise and publication costs — which were often a concern in the past — have actually come down a bit. It's the other categories in our financial statements that have increased rather dramatically, such as membership services, office expenses, financial services, and insurance. If the accountant hiding inside you wants to gnash over the details, you will find them in the forthcoming *Annual Report*.

Maintaining our Society's considerable computer needs is the job of second vice-president Dave Lane and the Information

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 (Reflections)
William Dodd (Education Notes)
Kim Hay (Society News)
Bruce McCurdy (Orbital Oddities)
Philip Mozel (A Moment With…)
Leslie Sage (Second Light)
Russell Sampson (News Notes)
David Turner (Reviews)

Proofreaders
James Edgar
Maureen Okun
Suzanne Moreau

Design/Production
Brian G. Segal, Redgull Incorporated

Advertising
Isaac McGillis
Telephone: (416) 924-7973

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

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Technology Committee. Our two employees in the national office have a custom Membership & Publications Administration system among the tools they use to serve all of you. With email and a toll-free telephone line, they can respond to members' questions and needs without the long delays that characterized the relationship between headquarters and members for the first nine decades of our existence. This relationship has evolved rapidly in recent years, but many of the functions of national office are nominally the responsibility of the National Secretary. This year, Kim Hay will complete her second three-year term in that volunteer position. Whoever replaces Kim would have a lot to learn even in quiet times.

There is no shortage of enthusiasm and talent among our ranks, and across the country hundreds of members like you contribute incredible effort to the Society and to astronomy. The level of activity among the various national committees and Council members is amazing. I hear a lot of ideas and suggestions for "obvious" solutions to the problems we face. Things seem simple, don't they? But there is always another side to every simple suggestion, and that's what makes real solutions so difficult. Consider just one example: travel expenses, which have gobbled up about $30,000 of our budget annually for the last while. Could we reduce these? Well, no — because the reason we spend so much on travel is that we live in a big country and only by subsidizing travel can we hope to have meetings where a reasonable representation of the country participates. And that is just one of the complications.

Please stick with us. Astronomy is a wondrous hobby and sharing it is so worth the challenges. ◉

Correspondence
Correspondance

Hall of Fame

Dear Editor,

As a lifetime member of the Royal Astronomical Society of Canada (although I am not a Canadian), I was delighted to read in the RASC Journal of the induction of my great-great-grandfather Sir J.W. Dawson into the Canadian Science and Engineering Hall of Fame. Although not an astronomer himself, he did give a small telescope to his son George Mercer Dawson to take with him on his travels with the Geological Survey. In his diaries GMD mentions using this instrument to observe the heavens. I still have (and use) this telescope.

Best regards and thank you,
This means a great deal to our family.

Matt Dawson
Roeser Observatory, Luxembourg ◉

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Join the RASC's email Discussion List

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

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

WEB ACCESS TO JUNE 2005 ISSUE

The June 2005 issue of the *Journal* can be accessed from the RASC Web site at `www.rasc.ca/currentjrasc` .
This issue will be posted immediately after the final production version is complete (approximately June 7, 2005) and removed from the Web once the issue begins arriving by mail.

News Notes
En Manchettes

NEW SUPERNOVA!

Paul Gray and Dave Lane have recently recorded their second supernova success with the discovery of a supernova in UGC11066 (a magnitude 15.2 galaxy in Draco). Confirmation of the new supernova, which "weighs-in" at magnitude 17.5, was given in IAU Circular 8462 (see extract below). This new discovery is part of an organized search program at the Abbey Ridge Observatory (located at Stillwater Lake, Nova Scotia) that monitors some 2500 galaxies.

The new supernova (designated 2005B) was detected late in the evening of January 11, 2005 by Paul Gray while he was analyzing images taken earlier that evening from the semi-automated camera system at the Abbey Ridge Observatory. The supernova was confirmed by amateur astronomer Ramon Naves in Spain.

The actual discovery image was taken on December 17, but at that time it was thought to be "noise" on the image, and consequently it was not reported. Tom Boles, a well-known supernova searcher, reported an independent discovery of the supernova on an image taken early Friday morning and he is being credited as a co-discoverer. The supernova appears to be a type II, which results from the catastrophic collapse of a single massive star.

This is the second discovery by Gray and Lane — first discovery of supernova SN1995F being made in February 1995. These two supernovae are the only such objects to be discovered by Canadians actually observing from Canada.

Extract from IAU Circular # 8462:

Central Bureau for Astronomical Telegrams

Figure 1. Image of supernova 2005B taken on January 12, 00:02:14 U.T. Image courtesy of Dave Lane and Paul Gray.

INTERNATIONAL ASTRONOMICAL UNION SUPERNOVA 2005B IN UGC 11066

"D. Lane, Saint Mary's University, reports that he and P. Gray have discovered an apparent supernova (mag about 18.0) on unfiltered CCD images taken on Jan. 12.002-12.18 UT with a 0.28-m reflector at Stillwater Lake, NS; earlier images from 2004 Dec. 17.02 also show the object near limiting mag about 18.5. SN 2005B is located at R.A. = $17^h 54^m 48^s.8$, Decl. = +71° 32′ 35″ (equinox 2000.0), which is approximately 18″ west and 10″ north of the centre of UGC 11066. Nothing was visible at this location on earlier images taken on 2004 Aug. 23 and Sept. 15 (limiting mag 19.0). An independent discovery of SN 2005B (at mag 17.5) has been reported by T. Boles (*cf.* IAUC 8446) on an unfiltered CCD image taken on Jan. 13.227. Boles provides position end figures $48^s.72$, 34″.5, adding that nothing is visible at this position on his images from 2004 Oct. 2 and Sept. 4 (limiting mag 19.5), and it is not present on Digitized Sky Survey plates from 1993 (limiting red mag 21.0) and 1989 (limiting blue mag 20.5)."

This news note is based upon information provided on the Web site: `www.davelane.ca/aro/sn/`.

MEASURING SEEING USING THE MOON

The site of new cutting-edge observatories depends greatly on the quality of the sky. Not only must it be dark but more importantly the site must have the best possible "seeing." The poorer the seeing the more the stars "twinkle" and the blurrier highly magnified images become. The better the seeing the closer the telescope can come to achieving its theoretical resolving limit. Seeing depends on the turbulence of the atmosphere. As air of different temperatures mixes it produces bubbles of slightly different air temperature. These bubbles act as fleeting lenses that distort the images of celestial objects — the less turbulent the atmosphere, the better the seeing.

To find the best sites engineers and astronomers are seeking evermore-sophisticated means to measure the turbulence of the atmosphere and the resulting seeing (also called scintillation). Paul Hickson of the University of British Columbia and Kenneth Lanzetta of the State University of New York in Stony Brook have devised a novel method to measure this crucial parameter (*Publications of the Astronomical Society of the Pacific,* December 2004).

Employing an array of photodetectors, Hickson and Lanzetta used the light of the near-full Moon to measure the turbulence of the atmosphere. The sensors detected the scintillation of the lunar disk and a computer routine converted these fluctuations into measurements of the turbulence of the atmosphere. Stars and the Sun have traditionally been the chosen celestial sources for such measurements. Using the Moon provides increased flexibility in this method.

Telescope designers need to know the amount of turbulence and its vertical distribution — a turbulence profile. Hickson and Lanzetta found that the height of their measured turbulence profile depended on the separation of their detectors — the further apart the detectors the higher the profile. With the sensors mounted separately and spaced at a maximum distance of about 150 metres, the team measured turbulence to an altitude of about 10 kilometres. However, this configuration of the sensors proved cumbersome. Mounted on a single beam and with a separation of only 2.672 metres the team successfully measured the turbulence profile to a height of about 300 metres.

As expected the greatest turbulence was measured in the lowest one kilometre of the atmosphere. From the Sunspot, NM site — home of the National Solar Observatory (NSO) — the team found that the maximum contribution to the seeing came from the air between 8 and 50 metres above the sensors. At the Cloudcroft, NM site — home of the NASA Orbital Debris Observatory (NODO) — they found that the seeing came mostly from a layer of air between 25 and 130 metres above the sensors. The difference between the two sites appears to be caused by their topography. The NSO site is on the top of a steep ridge acting like a tall tower reaching into the higher and less turbulent part of the atmosphere. The NODO, on the other hand, is on a broad flat hilltop.

The computer program used to analyze the sensor data could only work when the Moon was very close to full phase. Further testing of their original system was cut short by the theft of their equipment. The team is currently testing a new 12-sensor system that can be effectively used a week on either side of full Moon.

Determining the Range of an Artificial Satellite Using its Observed Trigonometric Parallax

by Michael A. Earl, Ottawa Centre (earlm@sympatico.ca)

Observing artificial satellites is a relatively new and unique branch of astronomy that is very interesting and dynamic. One specific aspect of observing these objects is that although they appear within the celestial background, as deep-sky objects do, their apparent locations against this background depend on where you are standing on Earth at a given time. This effect is known as parallax.

When a satellite is observed at a specific time from a specific location, the satellite's equatorial (also known as celestial) coordinates can be determined using astrometric means. Its range (distance) from the observer, however, is still unknown unless the observer knows the satellite's precise orbit elements or has easy access to a radar station. However, when two or more observers, separated by a known distance, observe the same satellite at the same time, their observations can be used to determine the range of the satellite using the satellite's observed trigonometric parallax.

The Parallax Experiment – Theory

Most artificial satellites orbit the Earth at altitudes of 300 to 40,000 kilometres. Because artificial satellites are so much closer to us than most of the objects we observe in the night sky, the satellites will be seen at different positions against the stellar background from different locations on the Earth. In other words, when a specific satellite at a specific time is seen at specific equatorial coordinates (RA = α and Dec = δ) by one observer, another observer at another location will see it at different coordinates at that same time. The difference between the observed coordinates will depend on the distance between the observers and the range (distance) of the satellite from the observers. This parallax effect can even be seen using two telescopes located as close together as the opposite sides of a city.

Imagine two observers at points P_1 and P_2 who are separated a known distance d from each other as illustrated in Figure 1. These two observers are simultaneously observing a satellite located at point S at ranges R_1 and R_2 from P_1 and P_2 respectively. A simple triangle drawn using these three points forms the basis of the range determination.

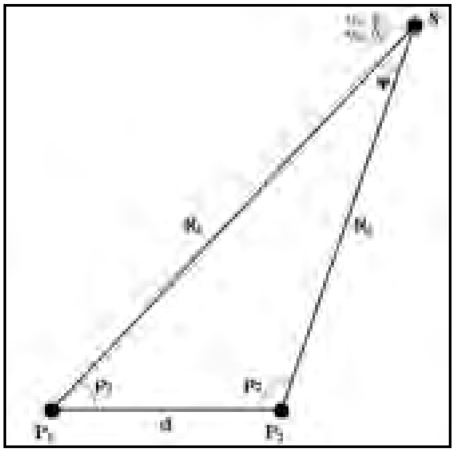

Figure 1 – An illustration of the parallax angle (ψ) that is observed for a satellite at point S at ranges R_1 and R_2 from observers P_1 and P_2, respectively, on the surface of the Earth a distance d apart.

Now imagine that both observers record the satellite's position at exactly the same time. Observer P_1 will see satellite S at equatorial coordinates α_1, δ_1, while observer P_2 will see the same satellite at coordinates α_2, δ_2. The parallax angle ψ is determined by using the observed coordinates as shown in Equation 1:

$$\cos\psi = \sin\delta_1 \sin\delta_2 + \cos\delta_1 \cos\delta_2 \cos(\alpha_1 - \alpha_2). \quad (1)$$

The ranges of the satellite from the two observers are determined by using Equation 2, which simply states the well-known sine law for the triangle shown in Figure 1:

$$R_1 / \sin\rho_2 = R_2 / \sin\rho_1 = d / \sin\psi. \quad (2)$$

In order to determine the ranges R_1 and R_2, all three angles within the triangle illustrated in Figure 1 (ρ_1, ρ_2, ψ), and the distance d between the observers, need to be known. Since the parallax angle (ψ) has already been determined, and the sum of all three angles in a triangle is 180°, only one angle, ρ_1 or ρ_2, needs to be determined in order to know all three of these angles.

To find angle ρ_1, it will be necessary to determine the equatorial coordinates of observer P_2 as seen by observer P_1. The assumption here is that the observers cannot see each other. How then can observer P_1 know where observer P_2 is with respect to his or her equatorial reference frame?

Fortunately, many observatories, professional and private, have an accurate knowledge of where their observatories are on the Earth's surface in the form of their latitude, longitude, and sometimes altitude above sea level. This information can be used to determine the values still required.

Geodetic Coordinates

The Earth is not a perfect sphere. Since it spins about an axis of rotation, it is slightly flattened at its poles. Its equatorial radius is 6378.14 km and its polar radius is 6356.75 km. Because of this slight difference, your local horizon will not be exactly perpendicular to a line drawn from the Earth's physical centre to the your location. Instead, your local horizon will be perpendicular to the line drawn from a geodetic centre to your location. Figure 2 illustrates the Earth spheroid and its geometry.

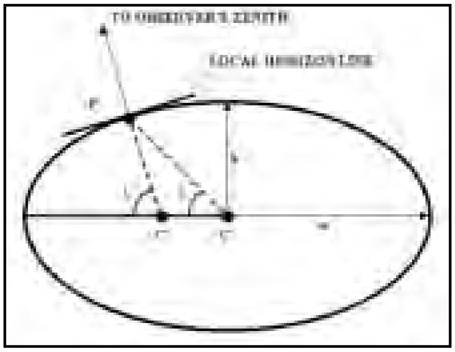

Figure 2 – The spheroid Earth, as illustrated by a simple ellipse. Point *C* depicts the geocentric centre of the Earth, while point *C′* depicts the geodetic centre as seen by the observer *P*. The eccentricity of the spheroid Earth has been exaggerated here to better accentuate the difference between the geodetic and geocentric latitude.

The coordinates of a location on Earth given by a survey map or a GPS receiver are generally given in geodetic coordinates. The simple difference between the geodetic latitude and geocentric latitude, assuming the spheroid Earth illustrated in Figure 2, is shown in Equation 3:

$$\tan \lambda = (b^2/a^2) \tan \lambda', \qquad (3)$$

where λ is the geocentric latitude of the location *P*, *a* is the semi-major axis of the spheroid Earth, *b* is the semi-minor axis of the spheroid Earth, and λ' is the geodetic latitude of the location *P*.

In order to find the distance between the two observing locations, the geocentric angle γ between them and the distances to the two sites (r_1 and r_2) from the geocentric centre of the Earth need to be determined, as illustrated in Figure 3. Equation 4, the simple cosine law for triangles, shows how to determine the distance *d* using these values:

$$d^2 = r_1^2 + r_2^2 - 2r_1 r_2 \cos \gamma. \qquad (4)$$

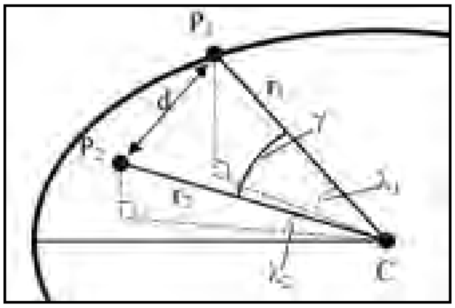

Figure 3 – Determination of the distance *d* between two locations on Earth using geocentric coordinates.

The values of r_1, r_2, and γ now need to be determined. The angle γ can be determined by using Equation 5, which requires the known geocentric longitude θ and latitude λ of each of the observing sites:

$$\cos\gamma = \sin\lambda_1 \sin\lambda_2 + \cos\lambda_1 \cos\lambda_2 \cos(\theta_1 - \theta_2). \qquad (5)$$

Both r_1 and r_2 can be found by using the fundamental equation for ellipses in polar coordinate form. Equation 6 shows the formula for r_1. The formula for r_2 is similar, but depends on λ_2:

$$r_i^2 = [\cos^2\lambda_i / a^2 + \sin^2 \lambda_i / b^2]^{-1}. \qquad (6)$$

Determining the angle ρ_1 is more difficult mainly because it requires a coordinate translation from the centre of the Earth to the observing site P_1.

Coordinate Translation

Many astronomers use the equatorial coordinate system to locate objects in the night sky. The equatorial coordinate system was originally defined with its centre at the geocentric centre of the Earth. Most of the objects observed are so far away that the location on Earth is not a consideration when observing them. However, when the object is not far away (such as an artificial satellite), changing your observing location on Earth will cause the object to appear to shift its position against the stellar background, thus changing its apparent equatorial coordinates. In other words, in most cases, the parallax is negligible for planets and deep-sky objects, but is significant for artificial satellites that reside much closer to the Earth.

Trying to locate an artificial satellite using its geocentric Right Ascension (RA) and Declination (Dec) coordinates will not work, since the parallax error would be too large. It becomes necessary to relocate the centre of the equatorial reference frame to the observer's location itself. That way, the equatorial coordinates of the satellite will be with respect to the observer's reference frame and not one that is about 6365 km away at the centre of the Earth. In other words, the centre of the equatorial reference frame must be translated to the observer's location. Figure 4 illustrates a coordinate translation from the geocentric centre of the Earth (point *C*) to observer P_1 in order to determine observer P_2's apparent equatorial coordinates with respect to observer P_1.

Looking at Figure 4, the coordinate translation involves the apparent Cartesian coordinates (x, y, z) of observer P_2. Cartesian coordinates are required because point *C* and point P_1 are related by the distance r_1, which is also the distance that separates the origins of their two reference frames.

The Cartesian coordinate system can be related to the equatorial system in the following way. The *x*-axis is directed toward the First Point of Aries, for which the RA coordinate is 0 hours. The *y*-axis

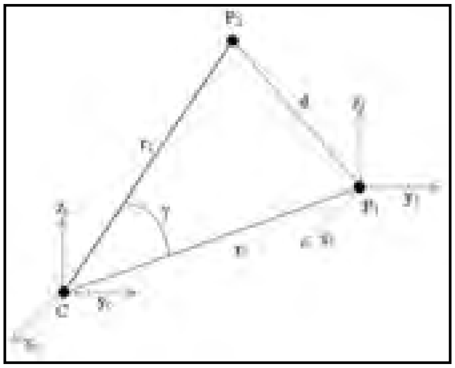

Figure 4 – The coordinate translation of the apparent equatorial coordinates of observer P_2 from the geocentric reference frame at point C to the topocentric reference frame of observer P_1.

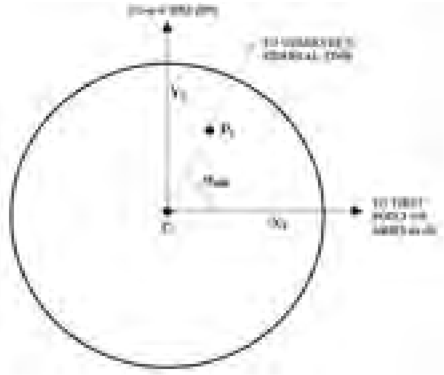

Figure 5 – The geocentric RA coordinate of a location on Earth is that location's local sidereal time. This illustration depicts the Earth as seen from above its northern pole.

is directed toward the RA coordinate of 6 hours (or +90 degrees). Finally, the z-axis is directed toward the North Celestial Pole, where the Dec equals +90 degrees. This way, the Cartesian x- and y-axes lie within a plane on, or parallel to, the equatorial plane of the Earth, and the z-axis coincides with, or is parallel to, the rotation axis of the Earth.

As Figure 4 indicates, the corresponding x-, y-, and z-axes of the Cartesian reference frames of points C and P_1 are parallel to each other. As a result, their axes are aimed at the same reference points, located at an infinite distance from Earth.

To determine the Cartesian equatorial coordinates required to perform the coordinate translation, the equatorial coordinates (RA and Dec) of both observers P_1 and P_2 with respect to the geocentric reference frame at point C need to be determined. The locations of P_1 and P_2 are already expressed as geocentric latitude and longitude. A coordinate transformation between geocentric longitude/latitude to geocentric equatorial coordinates could be done by using the angle difference between the Prime Meridian of the Earth and the First Point of Aries, but there is an easier method. Looking at Figure 5, it is evident that a line drawn from the centre of the Earth through the observer's location points approximately to the observer's zenith, but exactly along the observer's meridian. The convenient fact about the meridian is that at any time of day it corresponds exactly to the observer's sidereal time. In other words, the sidereal time is simply that RA that lies on the observer's meridian at a specific time. So, to make a long story short, the RA of a location on the surface of the Earth as seen from the centre of the Earth is precisely the surface location's sidereal time.

The Dec of an observer on the surface of the Earth with respect to the geocentric centre of the Earth is exactly the observer's geocentric latitude.

Now that observers P_1 and P_2 have their positions expressed as geocentric equatorial coordinates, they can be expressed in Cartesian equatorial coordinates using Equations 7 through 12. The negative signs in Equations 7 to 9 are required because the Cartesian equatorial coordinates of the centre of the Earth as seen by observer P_1 are simply the negative of the Cartesian equatorial coordinates of observer P_1 as seen from the centre of the Earth:

$$x_{1C} = -r_1 \cos \lambda_1 \cos \alpha_{side1}, \qquad (7)$$
$$y_{1C} = -r_1 \cos \lambda_1 \sin \alpha_{side1}, \qquad (8)$$
$$z_{1C} = -r_1 \sin \lambda_1, \qquad (9)$$

$$x_{C2} = r_2 \cos \lambda_2 \cos \alpha_{side2}, \qquad (10)$$
$$y_{C2} = r_2 \cos \lambda_2 \sin \alpha_{side2}, \qquad (11)$$
$$z_{C2} = r_2 \sin \lambda_2, \qquad (12)$$

where x_{1C} is the x coordinate of point C from point P_1 (and similarly for the y and z coordinates), x_{C2} is the x coordinate of point P_2 from point C (and similarly for the y and z coordinates), α_{Side1} is the sidereal time of observer P_1, and α_{Side2} is the sidereal time of observer P_2.

The coordinate translation can now be performed using Equations 13 to 15:

$$x_{12} = x_{C2} + x_{1C}, \qquad (13)$$
$$y_{12} = y_{C2} + y_{1C}, \qquad (14)$$
$$z_{12} = z_{C2} + z_{1C}, \qquad (15)$$

where x_{12} is the x coordinate of point P_2 from point P_1 (and similarly for the y and z coordinates).

The equatorial coordinates of observer P_2 with respect to observer P_1 can now be determined using Equations 16 and 17. Note that Equation 16 has special conditions that are required to determine the correct RA quadrant. In this case, the signs of the x and y coordinate of observer P_2 from observer P_1 are required to be correct:

$$\alpha_{12} = \tan^{-1} (y_{12} / x_{12}), \qquad (16)$$

where α_{12} is the RA of P_2 as seen by P_1.

Conditions for Equation 16:

If $x_{12} > 0$ and $y_{12} > 0$ then leave α_{12} as-is.
If $x_{12} > 0$ and $y_{12} < 0$ then add 360° to α_{12}.
If $x_{12} < 0$ then subtract α_{12} from 180°.

$$\delta_{12} = \sin^{-1} [z_{12} / d], \qquad (17)$$

where δ_{12} is the Dec of P_2 as seen by P_1.

The angle ρ_1 can now be determined using observer P_1's observed equatorial coordinates of both the satellite and the other observer P_2 as shown in Figure 1 and Equation 18. The angle ρ_2 can be found by using the angles ρ_1 and ψ (which was already determined with Equation 1) by using the simple triangle angle relation shown in Equation 19:

$$\cos \rho_1 = \sin \delta_1 \sin \delta_{12} + \cos \delta_1 \cos \delta_{12} \cos (\alpha_1 - \alpha_{12}), \qquad (18)$$
$$\rho_2 = 180° - \psi - \rho_1. \qquad (19)$$

Now that all three angles and the distance between the observers have been determined, the ranges of the satellite from both observers can finally be determined using Equation 2.

The Parallax Experiment — Practice

Of course, theory is fine, but to know the truth about the accuracies and best conditions in which to use this method, an actual satellite needs to be observed by two actual observing sites. The following two sites were chosen because telescopes located there could both be controlled remotely via the Internet.

CASTOR II

The Canadian Automated Small Telescope for Orbital Research II (CASTOR II) facility is being designed to study the orbits and characteristics of Earth-orbiting artificial satellites and to assist with the search for missing satellites. It consists of an 11-inch *Celestron* NexStar 11 GPS telescope, and an *SBIG* ST-9XE CCD camera. CASTOR II is located in Orleans at Ottawa's east end.

SMARTSCOPE

The SMARTScope facility is currently being developed by the RASC Ottawa Centre as a tool for public outreach and the advancement of astronomy awareness. It currently consists of a 16-inch *Meade* LX-200 telescope, a *Paramount* GT-1100ME robotic mount, an *Apogee* AP7p CCD camera, and a *HomeDome* observatory dome. At present, the facility is undergoing thorough tests as a fully remotely controlled observatory for use by the public. SMARTScope is located on the grounds of the Communications Research Centre (CRC) in Shirley's Bay at Ottawa's west-end.

Although SMARTScope was not specifically designed for observing artificial satellites, the satellite parallax experiment was conducted with the help of this facility as one way to test its remote control reliability and capabilities.

How The Experiment Was Conducted

Several criteria influenced the choice of the test satellite. The satellite should not be positioned near the horizon of either observation site, as a high atmospheric refraction would certainly taint the results. Since the observing sites chosen are mostly east-west in separation, the best satellite would be located near the northern or southern meridian in order to maximize the observed parallax angle. In order to minimize the timing errors, the satellite would need to be far enough away to make its apparent angular velocity small. In order to verify that the timing was as close to simultaneous as possible, the satellite had to be a quick tumbler, therefore inactive, and to exhibit bright enough reflections that the tumble rate could be easily measured.

The satellite chosen was the inactive Russian communications satellite *Molniya* 3-39 (#20813 in the NASA catalogue of satellites). Previous observations by the author have determined that its tumble period of 3.45 seconds per revolution has not changed appreciably in several years. This satellite also has a very variable range from the observing location due to its high eccentricity of orbit. Having an orbital inclination of about 63.5 degrees, it can easily appear in the northern or southern sky, which can satisfy the "near the meridian" criteria stated earlier.

The CASTOR II facility was operated locally from its location in Orleans. The SMARTScope facility was operated remotely from CASTOR II's location using the Virtual Network Computing (VNC) software. Each facility was controlled by its own computer. It was hoped that the cameras could be instructed to open at nearly the same time so that both images would be taken nearly simultaneously. Since the satellite would be quickly tumbling during the exposure, the simultaneity of the two exposures could be checked using the "flashes" observed within the satellite streaks obtained.

From previous experience, it was known that the shutters of both cameras opened approximately 0.5 seconds after the command to open them had been sent. Therefore an additional 0.5 seconds had to be added to each of the time tags indicated on the resultant Flexible Image Transport System (FITS) images.

The Images

The two images of the artificial satellite *Molniya* 3-39 are shown in Figure 6 (for CASTOR II) and Figure 7 (for SMARTScope). A combined image is shown in Figure 8. Within Figures 6 and 7, the satellite streak is within the black box, and black circles highlight three reference stars. In each image, the exposure time was 10 seconds. The quick tumbling of the satellite in space created the dotted pattern in the streak. The apparent travel of the satellite was right to left, therefore increasing in RA. The negative image was used to better highlight the satellite streaks and stars.

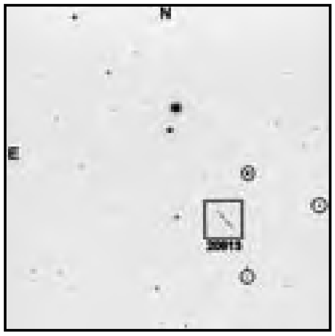

Figure 6 – Artificial satellite *Molniya 3-39* (#20813) as seen by the CASTOR II facility at 05:10:35.5 UTC on December 8, 2003. The field of view is 13.25 by 13.25 arcminutes.

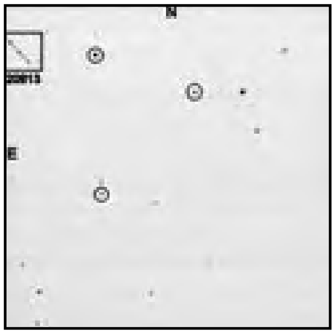

Figure 7 – Artificial satellite *Molniya 3-39* (#20813) as seen by the SMARTScope facility at 05:10:35.5 UTC on December 8, 2003. The field of view is 10.0 by 10.0 arcminutes. The streak looks slightly longer in this image compared to CASTOR II's image, despite the identical exposure times, because of the smaller field of view of the SMARTScope detector.

Looking at Figure 8, the highlighted endpoints of the CASTOR II and SMARTScope streaks seem to indicate that the satellite was exhibiting a flash (bright reflection) at the time both CCD shutters had opened. The CASTOR II image indicates that the flash was near its end when CASTOR II's CCD shutter opened, while the SMARTScope image indicates that the flash had nearly begun when SMARTScope's CCD shutter opened. Looking at the general satellite streak itself, the duration of the flashes was very small compared to the overall exposure time of 10 seconds, so the difference in time between the CASTOR II and SMARTScope images was certainly small enough to render this portion of the timing error negligible. The possibility that both images depict adjacent flashes (3.45 seconds apart) is not possible, since the GPS time tags of both images indicated that the "shutter open" commands were received nearly simultaneously.

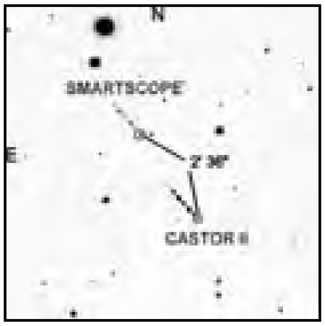

Figure 8 – The apparent positions of the *Molniya 3-39* satellite as seen by both the CASTOR II and SMARTScope facilities. The SMARTScope image of the satellite was grafted onto the cropped CASTOR II image and adjusted to the CASTOR II image scale. The measured parallax angle of the satellite is indicated.

The Results

The data from the CASTOR II and SMARTScope images shown were analyzed using the equations presented above. Several other images were taken that yielded similar results to those shown below. Some numbers seem to have more significant figures than they deserve. The large number of decimal places was preserved until the end of the calculations to avoid accumulating rounding errors.

OBSERVER 1 (P_1) = CASTOR II
OBSERVER 2 (P_2) = SMARTSCOPE

TEST SATELLITE = *MOLNIYA 3-39* (#20813)

OBSERVATION TIME = 05:10:35.5 UTC
OBSERVATION DATE = DECEMBER 8, 2003

The geodetic coordinates of both sites were obtained using a GPS receiver. A right-hand-rule convention was used for the longitudes to match that of the equatorial coordinate system.

$\Theta_1 = -75^\circ\,32'\,11'' = -75^\circ.536389$
$\lambda'_1 = +45^\circ\,28'\,27'' = +45^\circ.474167$
$\theta_2 = -75^\circ\,53'\,25'' = -75^\circ.890278$
$\lambda'_2 = +45^\circ\,21'\,14'' = +45^\circ.353889$

Using Equation 3, the geocentric latitudes of both sites were determined.

$\lambda'_1 = +45^\circ\,16'\,54'' = +45^\circ.281711$
$\lambda'_2 = +45^\circ\,09'\,41'' = +45^\circ.161425$

Using Equation 5, the geocentric angle subtended by both facilities was determined.

$\gamma = 0^\circ.276772 = 16'\,36''.38$

Astrometric analysis was performed on both the CASTOR II and SMARTScope images to determine the coordinates of the first endpoint for each case. For the best astrometric accuracy, the star catalogue used was the *United States Naval Observatory A 2.0* (USNO A2.0). To obtain the angular equivalent of the RAs, the original coordinate format (h-m-s) was multiplied by 15 degrees per RA hour.

α_1 (J2000.0) = $02^h\,59^m\,46^s.59 = 44^\circ.944125$
δ_1 (J2000.0) = $+55^\circ\,06'\,27''.94 = +55^\circ.107761$
α_2 (J2000.0) = $02^h\,59^m\,57^s.32 = 44^\circ.988833$
δ_2 (J2000.0) = $+55^\circ\,08'\,34''.45 = +55^\circ.142903$

The parallax angle between the two observed equatorial coordinates of the streak endpoints was determined using Equation 1.

$\psi = 0^\circ.043456 = 2'\,36''.44$

The geocentric distances of the two facilities were then determined using Equation 6.

$r_1 = 6367.312889$ km
$r_2 = 6367.357792$ km

The distance between the two facilities was determined using Equation 4.

$d = 30.757932$ km.

The apparent sidereal times for both facilities were determined using the observers' longitudes and the observation time entered into the United States Naval Observatory Multiyear Interactive Computer Almanac available on the Internet (see References section for the URL).

$\alpha_{side1} = 05^h\,14^m\,39^s.2892 = 78^\circ.663708$
$\alpha_{side2} = 05^h\,13^m\,14^s.3559 = 78^\circ.309833$

The Cartesian equatorial coordinates of the SMARTScope facility as seen by the CASTOR II facility was determined using Equations 7 to 15.

$x_{1C} = -880.656317$ km
$y_{1C} = 4392.771856$ km
$z_{1C} = -4524.452818$ km

$x_{C2} = 909.699373$ km
$y_{C2} = -4396.571864$ km
$z_{C2} = 4515.069008$ km

$x_{12} = 29.043056$ km
$y_{12} = -3.800000$ km
$z_{12} = -9.383810$ km.

The equatorial coordinates of the SMARTScope facility as seen by the CASTOR II facility were determined using Equations 16 and 17.

$\alpha_{12} = 352^\circ.545752 = 23^h\,30^m\,10^s.98$
$\delta_{12} = -17^\circ.763329$

In order to verify that the above equatorial coordinates were the true ones, a coordinate transformation from equatorial to Alt-Az coordinates was performed using the handy equations on page 31 of the 2005 *Observer's Handbook*. The Alt-Az coordinates of SMARTScope as seen by CASTOR II will not change with time as its RA will, and so they can be used as reference coordinates for any future experiments using both facilities.

AZ_{12} = 254°.701508 = 254° 42´ 05˝.43
ALT_{12} = –9°.921248 = –9° 55´ 16˝.49

The SMARTScope facility's geodetic coordinates are mainly west, but a little south of CASTOR II. Therefore, the SMARTScope facility should not be located exactly due west (270°) in azimuth, but slightly south as well. The Alt-Az coordinates are reasonable, so the recently determined equatorial coordinates can be used.

The angles ρ_1 and ρ_2 in Figure 1 were then determined using Equations 18 and 19.

ρ_1 = 85°.287476
ρ_2 = 94°.669068

Finally, the range of the *Molniya 3-39* satellite from both the CASTOR II and SMARTScope facilities at the time specified were determined using Equation 2 and the values of the angles ψ, ρ_1, and ρ_2 determined in this section.

R_1 = 40,419 km
R_2 = 40,417 km

The "true" ranges from both facilities were determined by propagating the most up-to-date Keplerian orbit elements of the satellite provided at the time. This was the best method to confirm the ranges calculated from the images.

R_1 (true) = 39,023 km
R_2 (true) = 39,018 km

Sources of Error

There are two significant sources of error that can certainly be minimized in the future. The first is the low apparent velocity of the test satellite. It is true that a satellite will appear to travel more slowly in the observer's sky the further away the satellite is, and therefore be less affected by timing errors. However, the further the satellite is from the observer, the smaller the parallax angle, and the more significant the error becomes for a specific baseline distance. The test satellite chosen was about 40,000 km from both observing locations, while the baseline between the sites was a mere 31 km. This combination of a large satellite range and a small baseline increased the error sensitivity because of the small parallax angle observed. The results of this experiment showed just how sensitive this error could be.

The second significant source of error is certainly the measurement of the streak endpoint. When determining where the endpoint of a satellite streak is most likely located, factors such as the resolution of the detector, the brightness of the endpoint compared to the image background, and the brightness variability of the satellite as it travels through space will introduce errors that can be large enough to be noticeable if the overall parallax angle is small enough. CASTOR II's resolution is currently 1.56 arcseconds per pixel, while SMARTScope's resolution is currently 1.15 arcseconds per pixel. It is likely that CASTOR II's lower resolution did introduce some error in the determined parallax angle. However, CASTOR II's resolution as a satellite tracking facility was chosen for two reasons. One was endpoint determination accuracy, and the other was sensitivity. If the resolution of CASTOR II is too high (pixels are too small), it may not be able to see the fainter satellites because the exposure time per pixel as the satellite image travels across the CCD detector would be too short. The trade-offs resulted in the necessity to sacrifice some accuracy for sensitivity, and vice-versa. Unfortunately, this sacrifice most likely resulted in the range error in this experiment. This is not to say that SMARTScope resolution did not cause any errors, but since its resolution is better, its endpoint detection errors were probably smaller.

The largest error in satellite tracking is indeed the endpoint detection error. Determining the apparent location of the satellite, corresponding to the times the shutter opened and closed, can be a very difficult process. This is especially true of tumbling satellites. A tumbling satellite can appear invisible at periodic times due to its brightness being too low to overcome the sky background, interfering background stars, or even the satellite's own brightness flare-ups. If this occurs at the time the shutter is opened or closed, the endpoint will not be seen and another part of the streak could be mistaken for the true endpoint location. It is also possible that SMARTScope's higher resolution made for a dimmer streak, thereby increasing the probability that an endpoint was tagged incorrectly. The endpoint of SMARTScope's streak indicated in Figure 8 might actually have been located several arcseconds away due to the brightness of the flash covering up the real (dim) endpoint. Since CASTOR II's streak endpoint coincided with the ending of a bright flare-up, it is less likely that CASTOR II's endpoint is inaccurate because of inaccurate endpoint detection.

To minimize these errors, it will be necessary to keep the test satellite range high, but increase the baseline distance between the two observing sites in order to increase the observed parallax angle. Increasing the detector's resolution may help, but if the test satellite is tumbling, or is difficult to detect in the first place, the increased resolution may ultimately increase the endpoint detection errors, and thus may defeat the intended purpose of improving ranging accuracy. This also presents a trade-off situation that could take much work to resolve. Increasing the timing accuracy by further investigating the timing offsets of the CCD shutter will reduce the need for a larger *a-priori* satellite range.

Ultimately, the sources of the errors experienced in this experiment are the same as those for any satellite tracking facility, and could be better explained quantitatively in a follow-up article to this one. This experiment, however, may be used to fine-tune the tracking data accuracies of all the tracking facilities involved, since the parallax angle is so sensitive to tracking data errors, especially for smaller distance baselines.

Conclusions

I did not expect to get results that were so accurate as to rival those of radar-ranging facilities. This was an initial investigation into how the accuracy of this method is affected by loose constraints. The CASTOR II and SMARTScope facilities were certainly not optimal for work such as this, especially given the small baseline distance. This experiment verified that indeed the resolution of both systems was too low to compensate for the small observing baseline distance used. Better results will be experienced if the baseline is increased. If a large satellite range is maintained, both observing sites have a better chance of viewing the same satellite at the same time, given a larger baseline distance. Overall, a very fun experiment to do!

Acknowledgements

Special thanks go to: SMARTScope Manager, Chris Teron, and the SMARTScope team for allowing me to use the SMARTScope facility for this experiment; Lt. Col. (retd.) Phillip W. Somers, who introduced me to the subject of satellite tracking and taught me most of what I know about it.

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United States Naval Observatory Multiyear Interactive Computer Almanac `aa.usno.navy.mil/data/docs/WebMICA_2.html`

Michael A. Earl was the Senior Technician of the Space Surveillance, Research, and Analysis Laboratory (SSRAL) at the Royal Military College (RMC) of Canada in Kingston, Ontario from 1997 to 2001. During that time, he designed, constructed, tested, and operated the Canadian Automated Small Telescope for Orbital Research (CASTOR) satellite tracking facility. He is currently a lead engineer at the Mechanical and Aerospace Engineering Department at Carleton University in Ottawa. He is designing his own satellite tracking facility (CASTOR II) to continue research in the subject of optical satellite tracking. He is currently serving as the Vice President of the Ottawa chapter of the RASC and is a proud member of the SMARTScope team.

ANOTHER SIDE OF RELATIVITY

Reflections

A Young Astronomer

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

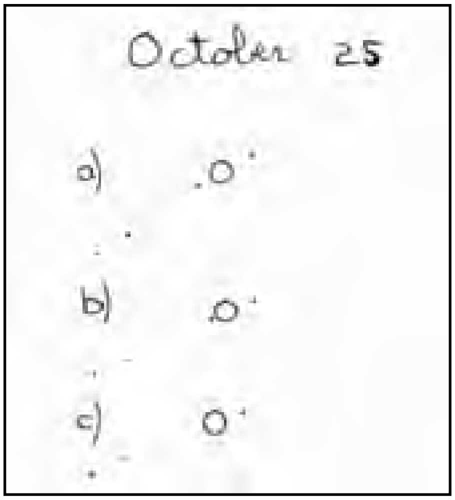

Figure 1 – One of the first entries in my observing log: an occultation of Io (October 25, 1963).

My first astronomical memory is at the age of eight years, in Winnipeg. My father took me outside in winter to show me the Big Dipper, Orion, and the "W" of Cassiopia. I am not certain from where he acquired his knowledge of the sky, but his trade was electronics, and he had been a radio operator in the Royal Air Force in the '30s and '40s. It is possible he learned a bit of celestial navigation along the way. Following that, I remember borrowing every book on astronomy in the children's section of the public library. My mother tells me that she had to come with me to the library one day to get special permission for me to borrow books from the adult section, as I had exhausted the children's section.

By age 10, we were living in Transcona, just outside of Winnipeg. One of the teachers at the elementary school subscribed to *Sky & Telescope*, and each one she lent me I devoured from cover to cover. I especially admired the telescope ads. For my birthday, I received a 60-mm *Tasco* refractor and a copy of Patrick Moore's *The Amateur Astronomer*. The book I still own. I had no one to teach me about the telescope, so I figured it out by myself. It had a kind of built-in *Barlow* lens, so you could slide between 15× and 60× with a couple of stops along the way. My first view of a bright star (Arcturus) yielded a big grey disk, until I discovered the focus knob. I still have my notebooks from back then, and my first observations and sketches were the Moon, Saturn, Jupiter with moons, and the Orion Nebula.

Figure 2 – My first decent sketch of the Moon (July 22, 1964). The dark-floored crater is Grimaldi, *A* is Riccoli, and *B* is Hevel.

It was not until later that I heard people bad-mouthing *Tasco* optics. Without a doubt, that telescope was critical in expanding my interest and participation in astronomy. Perhaps it was not the greatest, but could it have been that bad? Is it possible the optics were acceptable in the 1960s and have declined since? I still have a pair of 10 × 50 *Tasco* binos from that era, and I think they are pretty good still.

The Moon was a spectacular sight, and I still find it striking, as do most first-time viewers. With the emphasis these days on deep-sky observing, I feel sad about the "bad rap" the Moon gets. There is plenty to see in the sky when conditions are not optimal for "faint fuzzies." I made a lot of drawings of the Moon in those early days, and this must have honed my observing skills. (Recently, at Nova East 2004, I was observing the first-quarter Moon along with the others, and I noticed a curious X-shaped feature along the terminator. This was reported in the October 2004 *SkyNews* along with a chance photo by Tony Jones.)

One Saturday I took the bus all the way to the university bookstore to buy a copy of the *Observer's Handbook*, only to find the store closed. The trip from Transcona took a good part of the day, there and back. My father bailed me out by taking my one dollar (that's what it cost back then) and giving it to a colleague at work whose son was a student at the university. I eventually got the *Handbook!*

With the *Handbook,* I was able to anticipate events worth watching, such as eclipses of the Moon and occultations of Jupiter's moons. My first total lunar eclipse took place in the dead of winter, and I was in and out of the frigid night many times, much to the consternation of my family. Although my Dad supported my hobby, he did not share my enthusiasm for observing!

We moved from Transcona to Red Lake, Ontario, and then Kenora, Ontario. During these days I did little astronomy, and I cannot recall why. It is possible that our house was not in a good location for observing (tall trees!) and I did not have the means to travel to a better site. Anyway, this was a brief interlude, as we then moved to Ottawa, where the astronomy climate improved.

I met John Conville in Grade 8, and he was even more of an astronomy nut than I was. These were the exact conditions of our meeting: I wandered into the science room, where I found John suspending a scale model of the Solar System across the ceiling. His telescope, a 3-inch *Tasco* reflector, was bigger than mine, so he was naturally the top dog in our partnership, which we (inexplicably) called the Chapman-Conville Astro-Physical Observatory (CCAPO). It could be that I was the one who typed our reports, so I got to choose the name.

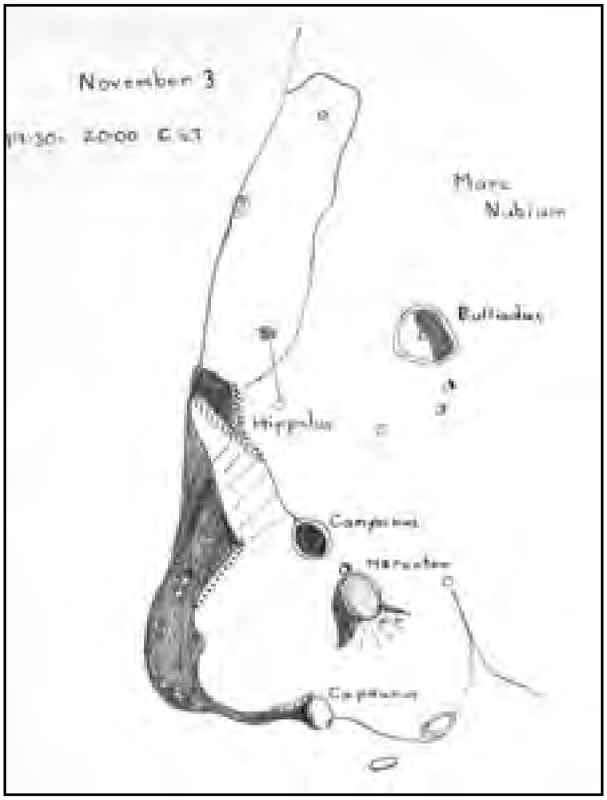

Figure 4 – Perhaps my most artistic sketch of the Moon (November 3, 1965).

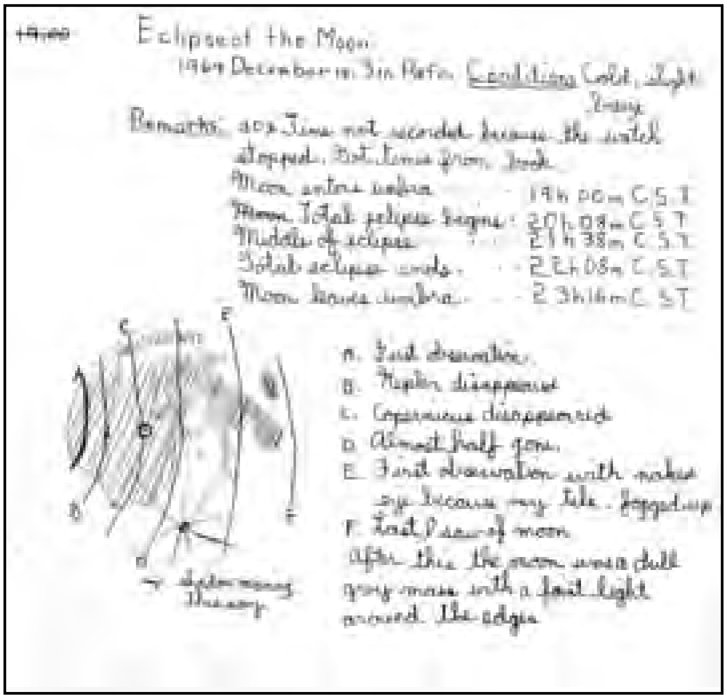

Figure 3 – My first total lunar eclipse, from Winnipeg (December 18, 1964). Brrr!

In high school, the two of us joined the Ottawa Centre of the RASC as student members, and we went to all of the Observers' Group meetings and most of the regular meetings (a total of two per month). By luck, we fell in with an enthusiastic group of young observers led by a lanky, long-haired, energetic Ken Hewitt-White. During those years, we became involved in all sorts of observing activities, such as meteor counts (summer AND winter), the Messier Hunt (not a Marathon back then), variable stars, novae, comets, and minor planets. During that time, which was the late '60s, I wrote my very first astronomy article for the Ottawa Centre newsletter, *Astro Notes*. I believe it was on observing the motion of the minor planet Pallas. I would be grateful if someone could find it and send me a copy.

When I left high school for university, I entered a physics program, but my astronomical activities declined. I have no explanation for this, but I think it is natural and common. I missed a lot of significant events, but I did make an effort to travel to New Brunswick to see my first total solar eclipse in 1972. In grad school at UBC, I stumbled across Ken Hewitt-White again, running planetarium programs at the MacMillan Planetarium in Vancouver. My interlude away from astronomy lasted longer this time, over ten years. When I moved to Halifax, my interest was re-kindled by Dale Ellis, a colleague at work. For over twenty years, I have been active in the Halifax Centre and nationally, through this column and other activities.

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

The Biggest Stars

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

Surprisingly, astronomers really do not know how massive stars can be. Observational studies over the past ten years have relentlessly found that what were once thought to be huge stars — over 200 times the mass of the Sun — really are compact groups of smaller stars. Part of the trouble is that the theory limiting their size is both incomplete and somewhat contradictory. Don Figer of the Space Telescope Science Institute in Baltimore now demonstrates that there is a hard upper limit of about 150 solar masses — stars more massive than that simply do not exist, at least not in our Galaxy (see March 10, 2005 issue of *Nature*).

The "stellar mass function" — a fancy name for the number of stars in each mass range — decreases quite strongly with increasing mass. This means that there are many more low-mass stars than massive ones. Amateur astronomers generally are well aware of this — there are lots more faint stars than bright ones in the night sky. While the relative numbers of faint and bright ones in the sky are a rather poor tracer of their actual abundance (there are distance effects, intervening dust that blocks some of the light, *etc.*), they do serve to highlight the issue.

I will use mass and luminosity somewhat interchangeably because that is the way astronomers tend to think. For high-mass stars, the luminosity is essentially directly proportional to the mass, so using luminosity is basically equivalent. (That is not true for stars like the Sun — a star just 20 percent more massive is more than twice as luminous.) Astronomers have therefore historically targeted the most luminous stars and estimated their mass using that linear relationship. The problem — as I mentioned above — is that, as the resolution of telescopes increased dramatically with the fixing of the *Hubble Space Telescope* and the installation of adaptive optics on ground-based ones, we have found that what once appeared to be single very luminous stars actually turned out to be groups of much less massive ones (though still quite massive stars).

Figer had to devise a strategy that would lead to a definitive result. There are multiple important and inter-related problems. First, the most massive stars are extremely rare — we could expect only a few in the portion of the Milky Way Galaxy that we can easily see. They also burn themselves out very quickly — in just a few million years — so Figer had to look in regions with very young stars. But the regions with the youngest stars tend to have the most gas and dust around — because those are the materials from which the stars are born — so some stars will be hidden or at least partially hidden behind the dust, making it difficult to determine their true luminosity (and therefore mass).

Figer selected the Arches cluster of stars, near the centre of the Galaxy. Its distance is well known, because it is associated with other structures near the centre. The total mass of the cluster is sufficiently big that a standard mass function predicts that there should be 18 stars with masses greater than 130 solar masses in the cluster. The cluster is between 2 and 2.5 million years old, and given its location near the galactic centre the cloud out of which it was born has already been torn apart by tidal forces. On the minus side, there is a lot of gas and dust between the galactic centre and us. To get around the problem of extinction by the dust, he observed the cluster at near-infrared wavelengths (where the extinction is much less) using the *HST*. He found no stars with masses greater than 130 solar masses, though there are some around the 120 solar-mass point.

There are several uncertainties associated with determining the masses of the stars — their luminosities depend somewhat on their ages, and on the abundance of "metals" (elements heavier than helium) in their atmospheres. But Figer estimates that the statistical chance of finding no stars where 18 are predicted, even given these uncertainties, is about 1 in 100 million. He therefore concludes that there is a hard upper limit of 150 solar masses to the most massive stars. A similar result for a cluster in the Large Magellanic Cloud, though with much lower significance, was recently reported by Pavel Kroupa and his collaborator (Kroupa *et al.* 2003, *MNRAS,* 348, 187).

Formally, this limit is lower than the estimated initial masses of several stars in the Milky Way. What gives? Figer points out that by applying new models of stellar atmospheres, as well as taking into account the uncertainties in the distances to these stars, their masses (or at least the allowed ranges of masses) come down to well below his limit. The remaining ones probably are tight multiples that have simply not been resolved as yet, or they might have formed through mergers of lower-mass stars after the initial star formation episode.

The mass of the most massive stars in the early Universe remains a topic of hot debate in astronomy. The conditions under which they formed are very different from those in which stars form today in our Galaxy — the very first ones, which seeded the Universe with heavy elements, might well have been more massive than 150 solar masses, but that will probably remain uncertain for quite some time, though we may be able to determine their masses using the *James Webb Space Telescope,* which is the *Hubble's* planned replacement.

The *JWST* currently is "scheduled" for launch in 2011, with science operations beginning in 2012. It will be optimized for operation in the infrared (the *HST* was optimized for optical and ultraviolet observations) and will have a diameter of 6.5 metres. It will therefore have greater resolution (at the same wavelength) and about seven times the light-collecting area of the *HST*. I was encouraged to see pictures of the fabrication facilities presented at the recent meeting of the American Astronomical Society, but I expect that the schedule will slip, because that is normal for a project of this scope. Given the current budget situation for the U.S. government, it is not at all clear which projects will survive and which (like the old Superconducting Super Collider) will not. Let's hope that the *JWST* survives. ◆

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.*

FROM THE PAST — AU FIL DES ANS

ARTIFICIAL SATELLITES

The launching of man-made satellites is one of the most spectacular projects being planned for the International Geophysical Year, July 1957 – December 1958. The satellites, some 20 to 30 inches in diameter and weighing approximately 20 pounds, will be filled with delicate instruments which will give us information which will be valuable in such fields as geodesy, atmospheric physics, ionospheric physics, auroral physics and solar radiation. During the eighteen months about a dozen satellites may be launched. Each satellite may stay in flight anywhere from a few days to a few months.

The orbit of a satellite will be an ellipse, which is expected to bring the satellite to within about 200 miles of the earth's surface at the closest point and possibly as far as 1,000 or 1,500 miles at the farthest point. The plane of the orbit will be inclined about 40 degrees to the equator. The motion of the satellite will be affected by both the gravitational pull of the earth and the density of the upper atmosphere. The slow changes in the orbit will provide accurate information concerning the density of the air and, from the precession of the orbit, the amount of flattening of the earth. Even the distribution of the mass inside the earth and the unevenness of the mass of the earth's crust can be deduced from observations of changes in the orbit of the satellite. By observing the satellite from a number of stations on the earth, the positions of locations on different continents can be determined with an accuracy much higher than that of present measures.

by R.J. Northcott
from *Journal,* Vol. 51, p. 173, April 1957.

A PRECISE MEASUREMENT OF A LEONID METEOR

BY JEREMY B. TATUM

Victoria, British Columbia
Electronic Mail: universe@uvvm.uvic.ca

AND ROY BISHOP

Avonport, Nova Scotia
Electronic Mail: rg@ns.sympatico.ca

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Abstract. A measuring engine and a detailed analysis have been applied to the photographs of the Leonid meteor reported by Bishop (2003). The radiant of the meteor has been determined, along with more precise values for the heights and geographic coordinates of the beginning and end points. The green-red-white colour sequence of bright Leonid meteors displayed on photographs is discussed.

Résumé. Un instrument de mesure ainsi qu'une analyse détaillée ont été utilisés pour les photographies du météore Léonide décrites par Bishop (2003). Le radiant du météore a été déterminé ainsi que les valeurs plus précises des hauteurs et des coordonnées géographiques des extrémités du trajet. Nous discutons de la séquence des couleurs vert-rouge-blanc des météores Léonides brillants apparaissant sur ces photographies.

> *A good photograph of a meteor is worth, at the very least, several hundred visual plots.*
>
> — Peter M. Millman (1934)

1. INTRODUCTION

In the cold dawn twilight of November 19, 2002, two members of the Halifax Centre of the Royal Astronomical Society of Canada, Barry Burgess and Michael Boschat, photographed a Leonid meteor from separate sites in Nova Scotia. The circumstances of the event together with a preliminary analysis of the trajectory have been described by Bishop (2003). On reading that paper, JBT, who has access to a precision measuring engine at the University of Victoria, realized that the photographs were ideally suited to measurement with this machine.

In the preliminary analysis described in the above paper, RB was able to identify a common point (the lowest edge of the terminal burst) in the two photographs, and by triangulation to determine the distance and height of the terminal burst. The upper part of the meteor trail was not sufficiently well defined to identify a common point for a parallax determination, but, by building a scale model based on the azimuth and altitude of the Leonid radiant, he determined the height at which the meteor first appeared and the length of the trail visible on the photographs.

2. MEASUREMENTS

The positions of the beginning and end points of the meteor trail on the original photographic films together with the positions of comparison stars situated around the meteor trail were measured with the two-coordinate measuring engine of the Climenhaga Observatory, University of Victoria, using the procedures that had been in use at the Observatory for 25 years for routine astrometric measurement of asteroid positions. Nine comparison stars were used with the Burgess photograph, and four with the Boschat photograph; in each case the stars were chosen as well as possible to surround the meteor image symmetrically. Each star was measured at least three times in each coordinate, and the film was reversed and the measurements repeated, giving a minimum of twelve micrometer settings for each star, to give a statistical error of 3 μm. The scale of the films was too small for stellar proper motion corrections to be significant, but differential atmospheric refraction was significant and corrected for in the determination of the zenith distances of the stars. Several points along the meteor trail on each photograph were measured and a least squares linear regression (with equal errors in x and y) was fitted to each. The statistical error of 3 μm corresponds to a mean internal error of measurement of about ± $0'.2$. The uncertainty of ± 30 seconds in the time of the event, however, introduces a possible systematic uncertainty of about ± 7′ resulting from the possible range in the altitudes and azimuths of the comparison stars.

Reduction of the measurements to the determination of the altitudes and azimuths of the beginning and end of the meteor trail was by the plate constants method identical with that used for the asteroid astrometry program mentioned above. For details, we refer the reader to Tatum (1982).

3. THE INTERSECTING PLANES METHOD

In the analysis of the high-precision measurements made possible by the availability of a suitable instrument, the "Intersecting Planes" method was used. One observer and the meteor trail define a plane. The second observer and the meteor trail define a second plane. The intersection of the planes is a straight line, a part of which is the visible path of the meteor. The method does not require the identification of a common point on the two photographs, and the radiant can be determined.

The intersecting planes method is described mathematically and with a numerical example by Tatum (1998) with reference to the analysis of eyewitness reports of fireballs. That paper included some approximations that are appropriate for crude eyewitness reports. Among these approximations was the assumption that the Earth is flat. (While current astronomical opinion is that the Universe is flat, this is no longer believed to be true of Earth.) The analysis of the photographic observations of the Burgess-Boschat Leonid required a less cavalier approach to the trigonometry, and, although the basic method of intersecting planes was used, account was taken, for example, of the spheroidal shape of Earth, of the heights of the observers above sea-level, and (as mentioned above) of the effects of atmospheric refraction on the altitudes of the stars.

4. RESULTS

The geographical coordinates of the two observers were as follows:

	North Latitude	West Longitude	Height (m) Above Sea Level
Boschat	44° 38′ 15″	63° 35′ 36″	65
Burgess	44° 56′ 53″	64° 02′ 27″	65

The altitudes and azimuths of the beginning and end points of the meteor trail on the Boschat and Burgess photographs were as follows:

	Beginning Point		End Point	
	Altitude	Azimuth	Altitude	Azimuth
Boschat	22°.8650	237°.5488	17°.8124	240°.1504
Burgess	24°.3143	225°.2689	18°.2293	228°.4216

In this table, "altitude" refers to the angle above each observer's horizon, and "azimuth" is the angle measured eastward around the horizon from each observer's north point of the horizon. Note that, because of the geographical separation of the observers on the surface of the spheroidal Earth, the coordinate systems centred on the two observers are inclined to each other, and, to bring them to a common coordinate system, one has to be rotated through the appropriate Euler angles by means of the direction cosine rotation matrix. For a comment on the meaning of "beginning point" and "end point," see below.

With a rectangular coordinate system, origin at Boschat's site, *xy*-plane tangent to Earth, *x*-axis to east, *y*-axis to north, *z*-axis to zenith, the plane containing the meteor's trajectory and the Boschat site was determined to be

$$x - 2.524311y - 1.210935z = 0, \qquad (1)$$

and the plane containing the meteor's trajectory and the Burgess site was determined to be

$$x - 1.522994y - 0.787062z + 87.839424 = 0, \qquad (2)$$

the unit of length in the latter case being the kilometre.

While it is a simple matter now to determine the height of the trajectory above the *xy* tangent plane, determination of the height above sea level requires some further plane and spherical trigonometry. We spare the reader the additional details of the analysis, though they could be made available on request from JBT.

The results are as follows. Where two uncertainties are given, the first is the mean error due to random errors of measurement, and the second is the possible systematic uncertainty due to the uncertainty in the time of the event.

Date and time of the event: November $19^{d}\ 10^{h}\ 09^{m}$ UT ± 30^{s}, 2002.

When meteor first detected:

Height above sea level = 112.16 km ± 0.02 km ± 0.7 km.
Geographical coordinates of the sub-meteor point:

Latitude	43° 31′.9 N ± 0′.6 ± 20′,
Longitude	66° 06′ W ± 1′.2 ± 40′.

When meteor last detected:

Height above sea level = 80.77 km ± 0.02 km ± 0.7 km.
Geographical coordinates of the sub-meteor point:

Latitude	43° 38′.5 N ± 0′.6 ± 20′,
Longitude	66° 11′ W ± 1′.2 ± 40′.

(About 22 km S of Yarmouth, Nova Scotia, over the Gulf of Maine)

Radiant (J2000.0):		
	RA	$10^{h}\ 18^{m}.9 \pm 0^{m}.4 \pm 13^{m}$,
	Dec	+21° 30′ ± 5′ ± 3°.

In the above figures, the expressions "beginning point" or "first detected" and "end point" or "last detected" refer to points where the meteor was first and last easily discernible on the original colour negatives through the microscope of the measuring engine. However, when RB displayed the digitized and enlarged colour positive images on a computer screen, the glow of the meteor was first detected rather earlier, at a height of 123 km. This does not, however, affect the calculated direction of travel of the meteor through the atmosphere (*i.e.* the radiant), nor its distance, and, within the errors of measurement, the preliminary (Bishop 2003) and definitive (this work) trajectories are in good agreement.

The investigation showed, however, that, although the height of a particular identifiable point on the meteor trail can be determined fairly well, the position of the radiant determined from two nearly parallel intersecting planes is quite sensitive to small errors in measurement. Thus the possible systematic error due to the uncertainty on the time results in a rather large uncertainty in the deduced radiant. Trigo-Rodríguez *et al.* (2002) state that the convergence angle between the two planes should be greater than 20° to yield an accurate radiant. Although the angle for the Burgess-Boschat planes was only 11°, the position of the radiant found in the investigation falls well within the range found by Trigo-Rodríguez *et al.* (2002) for 18 Leonids recorded photographically in November 1999, and agrees well with the Leonid radiant position cited by Campbell-Brown and Brown (2004), confirming RB's identification of this meteor as a Leonid.

5. COLOUR SEQUENCE OF A BRIGHT LEONID METEOR

A feature of this Leonid fireball noticeable in both photographs is the distinct green-red-white colour sequence of the trails. There are many factors that could conceivably affect the perceived colour of a meteor trail, and these include phenomena not connected to the nature of the meteor itself, such as atmospheric absorption, whether the meteor is sufficiently bright to excite cone vision, the vagaries of the photographic emulsion and the photographic process, the colour calibration of the computer monitor used to view the image, and differences in the colour vision of different observers. However, we have little doubt that the green-red-white colour sequence is real ("real" in the sense that the radiation from the green and red portions of the trail is dominated by wavelengths in these regions of the spectrum), since this colour sequence appears on several photographs of Leonid meteors obtained by different observers using a variety of cameras and emulsions. In addition to the two photographs investigated in this paper, the effect is shown distinctly on a photograph (also by Burgess) of a 2001 Leonid on the front cover of the *Observer's Handbook 2003* of The Royal Astronomical Society of Canada (Gupta 2002), and on photographs of a 2002 and several 2001 Leonids obtained by Martin Mobberley & Hazel McGee reproduced on the front cover of the *Journal of the British Astronomical Association* (McGee 2002) and in a paper by Evans (2003).

In the absence of a spectrum, it may not be possible to identify with certainty the precise origin of the colours shown by a meteor — a point that was also made by Tatum & Stumpf (2000) in a brief discussion of the possible causes of the green colour often reported for bright fireballs. There are some possible indicators, however.

Green: Although the green lines of magnesium and to a lesser extent nickel are common features of the light of bright meteors, these are by no means the only or even the strongest lines present in a typical meteor spectrum (Millman & McKinley 1967; Borovička *et al.* 1999). The dominant spectral line in the upper portion (heights ~ 100 km to 115 km) of the trail of fast (> 50 km s^{-1}) meteors is that of the forbidden (electric quadrupole) green line of neutral atomic oxygen [O I] ${}^1D_2 - {}^1S_0$ at a wavelength of 557.7 nm (Halliday 1958; Millman 1960; Gault 1970; Millman 1971; Millman *et al.* 1971; Evans 2003). This line is also responsible for much of the green colour observed in the aurora. The transition involves only excited levels of the oxygen atom, and is most apt to be excited by the fastest meteors, namely the Leonids, which have the highest speed of all meteor showers: 71 km s^{-1}, near the theoretical maximum for a head-on collision with Earth of bodies bound to the Sun at 1 AU.

In the Burgess photograph (which, because of the darker sky, best shows the colours), the green colour is strongest at a height of about 108 km. This agrees well with the 106 km cited by Millman (1971) for the mean height of the maximum intensity of the oxygen green line obtained from the spectra of more than 30 fast meteors. Also, the 557.7 nm light of oxygen in auroral emissions occurs at about 110 km (Tapping 2004a). Gault (1970) notes that the atomic oxygen green line height range generally agrees well with that of the neutral atomic oxygen layer in the atmosphere.

Although the green colour of the meteor appears to be due to the 557.7 nm oxygen line, it is interesting to note that, if the green colour of the meteor originated primarily from permitted (and short-lived) lines of Mg or Ni, and if the meteor were photographed with a rotating shutter in front of the camera, the trail would be broken into short dashes. If, on the other hand, the colour were primarily due to the forbidden oxygen line, which has a lifetime that is longer than the typical interval between rotating shutter slots, the trail would not be broken. Thus these two possibilities might be distinguished without the necessity of a spectrum!

Red: The red colour of an aurora is due largely to forbidden magnetic dipole transitions of neutral atomic oxygen at 630 nm and 636 nm, but they generally occur higher in the atmosphere than the green auroral line (Tapping 2004a), and are therefore unlikely to be the cause of the red colour in the meteor trail, which appears lower than the green colour, being brightest near 99 km. A series of auroral spectral bands between 650 nm and 680 nm attributable to oxygen and molecular nitrogen occur at heights near 90 km (Tapping 2004b), so these could be the source of the red colour. Evans (2003) attributes the red colour of the middle portion of fast meteor trails to atmospheric molecular nitrogen emissions between 620 and 670 nm. Millman (1971) also lists nitrogen as the main source in the red portion of the spectrum at heights near 90 km, although Millman & McKinley (1967) state that a pair of lines from ionized silicon is the strongest feature in the red portion of the spectrum of fast meteors. However, Ceplecha *et al.* (1998) list a number of other possibilities in the red, and a spectrum of a bright Leonid obtained by Carbary *et al.* (2003) did not show these molecular nitrogen emissions at all.

White: The bright blue-white of the lower portion of the meteor trail is brightest near 86 km, and is probably due to a combination of thermal radiation from the ablating meteor material, emissions from many metallic lines including Na, Mg, Ca, and Fe, and over-exposure of the photographic film.

In summary, here are the heights of various features:

	Height (km)
Beginning point[1]	123, 112
Green brightest	108
Red brightest	99
White brightest	86
End point[1]	83, 81

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[1] The first number is the height at which the meteor trail was detectable on enlarged colour positive images. The second number is based on where the beginning and end points were easily discernible on the original colour negative as viewed through the microscope of the measuring engine.

6. THE BURGESS-BOSCHAT PHOTOGRAPHS

In the past 70 years thousands of individual meteors have been photographically recorded from two or more sites (Millman 1933; Burland & Thomson 1937; Halliday 1957; Halliday, Blackwell, & Griffin 1989; Trigo-Rodríguez *et al.* 2002). However, to our knowledge, the Burgess-Boschat photographs are the best pair of photographs of a single meteor made in Canada by non-professionals. Although these two individuals were unaware that they had photographed the same meteor until it was brought to their attention, Barry Burgess and Michael Boschat provided the essential initiative, persistence, knowledge of the sky and technical skill that made this analysis possible. Nature favours the prepared observer.

7. A PLEA TO METEOR PHOTOGRAPHERS

An aspect of meteor photography highlighted by this investigation is the importance of recording accurate times (ideally to 1 second) for the appearance of the meteor (this will be a technical challenge) and for the beginnings and ends of the photographic exposures. The clock used must be compared with a UTC time signal both before and after the observing session (see the Time Signals section in the RASC *Observer's Handbook*). Accurate values for the geographic latitude, longitude, and height above sea level of the camera are also required, although these can be determined at leisure using a topographic map or GPS receiver.

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Jeremy B. Tatum
205-1680 Poplar Ave
Victoria BC V8P 4K7

Roy Bishop
465 Bluff Rd
Avonport NS B0P 1B0

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Jeremy Tatum was formerly a professor of physics and astronomy at the University of Victoria. He has served as Treasurer of the Canadian Astronomical Society, as Editor of the Journal *of the RASC, and on the Meteorites and Impacts Advisory Committee to the Canadian Space Agency. Asteroid (3748) is named Tatum.*

Roy Bishop was formerly a professor of physics at Acadia University. He has served on the former Associate Committee on Meteorites of the National Research Council of Canada, as Editor of the RASC Observer's Handbook, *as President of the RASC, and is currently Honorary President of both the national Society and the Halifax Centre. He is a recipient of the Service Medal and the Chant Medal. Asteroid (6901) is named Roybishop.*

Education Notes
Rubriques pédagogiques

EXPLORING THE ASTRONOMY OF ANCIENT EGYPT WITH SIMULATIONS II: SIRIUS AND THE DECANS

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

The first paper of this series, hereinafter Paper I, included simulations to investigate Egyptian observations of the myth of *Nut* and the rebirth of *Ra,* winter solstices, the beginning of a lunar month, and the 25-year lunar cycle. Paper II includes simulations to investigate characteristics of the heliacal rise of Sirius, and the use of stars called the "decans," to mark the hours of the night.

The Heliacal Rise of Sirius

With a visual magnitude of –1.44[1] , Sirius is the brightest object in the sky after the Sun, the Moon, and the planets. The ancient Egyptians associated Sirius with the goddess Sopdet, or Sothis. The heliacal rise of Sirius in July marked the beginning of the season of flooding of the Nile River. The time between successive heliacal risings of Sirius is known as the Sothic year. Of course, observing the heliacal rise of Sirius did not mean that the Egyptians expected the Nile to start to rise the next day, anymore than the arrival of the winter solstice in Canada leads Canadians to expect a blizzard the next day. Still, there was an aura of mystery surrounding the rise of the Nile. The rains that caused the Nile to flood occurred thousands of miles to the south in the heart of Africa and were never seen in Egypt.

The heliacal rise of Sirius is easily predicted. Only a week or two of critical observations are required after the constellation of Orion is clearly visible in the early morning sky, in late June. The actual observational task would have been as simple as looking towards the east, roughly along an azimuth of 115°, just before dawn. If you *did not* see Sirius before sunrise then you would put another pebble-in-a-jar for the old Sothic year[2] . If you *did* see Sirius before sunrise you would announce that fact, and put a pebble-in-a-jar for the new Sothic year. As a refinement, you could also note the azimuth of Sirius as accurately as possible.

If counts of the number of days between heliacal risings of Sirius were kept over many years, then the Egyptians could have taken an average and obtained an accurate estimate for the length of the Sothic year. The Greek philosopher and astronomer, Hipparchus of Nicaea (*ca.* 150 BC), purportedly made use of Egyptian data on the azimuth of the heliacal rise of Sirius to aid in his estimate of the precession of the equinoxes.

A simple observational standard is needed to identify the date for a simulated heliacal rise of Sirius. Schaefer (2000) considered all the factors that might influence the observation of a real heliacal rise. He determined that for the heliacal rise of Sirius to be observed in Egypt, the difference in altitude between the Sun and Sirius would have to be about 11°. Table 1 provides the dates that Schaefer calculated for the heliacal rise of Sirius, and the corresponding dates obtained with simulations using *Starry Night*. Schaefer's dates include fractions of days and indicate the moment when the altitude difference reached 11°. The simulation dates correspond to the first morning when the altitude of Sirius was at least 11° greater than that of the Sun. Thus, the dates for the simulations tend to be one or two days later than Schaefer's. The correlation between these sets of results tends to confirm the efficacy of the simulation technique.

The date for the heliacal rise of Sirius also depends on the latitude of the observer. Schaefer found the date for the heliacal rise of Sirius to be about one day later for a one-degree increase in latitude. Changing the latitude of the observer in this simulation produces similar results. Egyptians at Aswan would have observed the heliacal rise of Sirius about 7 days before it could be observed in the Nile delta.

Simulation V: The Heliacal Rise of Sirius

On a given day, if the difference in altitude between the Sun and Sirius is less than 11°, then Sirius is judged to be too close to the Sun to been seen and the heliacal rise has not yet occurred. The first day on which the difference in altitudes is more than 11° is taken to be the date of the heliacal rising of Sirius. In 3000 BC at Luxor, latitude 26° N, Sirius would have advanced ahead of the Sun about 0.8° a day, so the date for the heliacal rise of Sirius can be readily obtained. An ambiguity of one day can occur when the difference in altitudes is very close to 11°.

Refer to the setup for Simulation V in the appendix. Step [forward] or [backward] in time until the Sun is just more than 6° below the horizon. In the simulation, at 6:20 a.m. on July 13, 3000 BC, the Sun is 6.0° below the horizon and at the same time Sirius is just 4.9° above the horizon. Since the Sun and Sirius were not separated by at least 11° in altitude, the heliacal rise of Sirius did not occur on this day. However, on the next day the Sun was 6.1° below the horizon while Sirius was 5.7° above the horizon. Thus, according to the simulation criteria, the heliacal rise of Sirius in 3000 BC occurred on July 14th.

In the simulation one has to be wary of subtracting the calendar dates and taking averages, because for every four years a leap day is automatically added. The Julian Date provides a simple count of days

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[1] *Observer's Handbook* 2004, p242

[2] The pebble-in-a-jar method was introduced in Paper I as a simple technique that could have been used by the Egyptians to count the number of days between repetitive celestial events.

and is ideal for estimating the length of the Sothic year. The decimal part of the Julian Date can be disregarded for this estimate. The mathematics is particularly simple for time intervals of 100 years. For example, the heliacal rise of Sirius at 26° N in 3000 BC occurred on JD 625867, and in 2900 BC on JD 662392. Subtracting the Julian Dates, one finds that 100 Sothic years correspond to 36,525 days, or an average of 365.25 days per year. Note that when the length of the Sothic year is estimated by averaging the number of days between successive heliacal risings, any observational errors tend to cancel.

To estimate the length of the Sothic year, the Egyptians would have had to observe the heliacal rise of Sirius and count pebbles every year, for several years. They would not have recorded fractions of days. If their method of observation was consistent and systematic, on average they would have recorded 3 years of 365 days followed by one year of 366 days. Table 2 provides a summary of data from simulations of the heliacal rise of Sirius over several centuries.

The Civil Calendar in Ancient Egypt

"Early in the third millennium, probably for administrative and fiscal purposes, a new calendar was invented" (Parker 1974). The "civil calendar," as it became known, was based on a year of precisely 365 days. It consisted of 12 months of 30 days plus 5 supplementary, or epagomenal days. Each month consisted of three 10-day "weeks" or decades. The civil calendar was the official calendar of the Egyptian government, was used to name months and number the days, and was used to set the dates of most festivals. The dates of new Moons, the winter solstice, and the heliacal rising of Sirius were still celebrated on the days that they actually occurred.

The civil calendar seems to have an obvious flaw. It slid ahead of the Sothic year by one day, every four years. In 40 years the difference would have been 10 days. In 400 years the difference would have been 100 days, and the seasons would have been totally out of step with the calendar. Once initiated, the civil calendar would not have matched the seasons and the Sothic year again, for another 1461 years[3]. Yet the Egyptians persisted in using the civil calendar for thousands of years. There is even a Greek reference by Aratus (*ca.* 240 BC) to an oath in the ceremony for "crowning" a new pharaoh that included the obligation to: "neither introduce a month nor even a day nor ever alter the date of a feast day, but would continue to measure the 365 days as decreed by the Ancients" (von Bomhard 1999). Apparently a new pharaoh had to swear not to "correct" the civil calendar.

Why did the Egyptians adopt such a calendar and refuse to correct an obvious weakness? The simple step of inserting an extra day every four years would have kept the civil calendar aligned with the seasons. The concept of inserting extra time units to keep a calendar synchronized with the seasons was a standard practice with lunar calendars. There are at least two important factors to consider.

First, the Egyptians seem to have regarded a calendar not as a means for measuring a continuous flow of time and marking the dates of historic events, but as a means for following the cycles of the gods. The 365-day cycle was an integral part of the 25-year lunar cycle, as explored in Paper I. The Egyptians were aware that year-by-year the heliacal rising of Sirius moved systematically through the days of the 365-day year. They recognized a Great Year of 1460 Sothic years. There is historical evidence that Great Years began in the years AD 139, 1321 BC, and possibly 2781 BC (O'Neil 1975). Thus, the 365-day civil year meshed with a 25-year lunar cycle, and a 1460-year Sothic cycle. Their calendar paid homage to the cycles of the immortals in the heavens. The very cyclic nature of their calendar also paid homage to the concept of an eternal Egyptian civilization.

Second, the Egyptians sought symbols to help consolidate the union of Upper and Lower Egypt. For example, one of the standard images of a pharaoh shows him wearing the "double crown," a combination of the tall "white crown" of Upper Egypt and the shorter "red crown" of Lower Egypt. The civil calendar may have served as an administrative and religious tool to advance the unification process. Before unification, Upper Egypt seems to have followed a lunar calendar in which the heliacal rising of Sirius marked the beginning of a new year. At the same time, Lower Egypt also seems to have followed a lunar calendar, but used the winter solstice to mark the beginning of a new year. The "new" civil calendar of 365 days (*ca.* 2800 BC) may have been designed to supplant these lunar calendars while still including a strong lunar component (the 25-year lunar cycle) and a strong Sothic component (the 1460-year Sothic cycle).

The great disadvantage of Egypt's civil calendar was that it was disconnected from the seasons. It would not be surprising if ancient Egyptians also made use of an unofficial calendar, somewhat analogous to a farmer's almanac, to keep track of seasonal events in a given year.

Simulations II to V demonstrate aspects of Egyptian calendars describing cycles-within-cycles. This cycles-within-cycles concept for Egyptian calendars is a simplified version of a model proposed by von Bomhard (1999). The brief summary of Egyptian calendars presented here does not do full justice to the work of Egyptian scholars who have spent the last century interpreting fragmentary archeological material. Many issues are still unresolved. For example, Leo Depuydt (1997) begins his academic treatise on the civil and lunar calendars in Egypt with a chapter entitled, "How many calendars were there in ancient Egypt?" indicating that even such a basic question is still worthy of serious discussion.

The Decans and the Hours of the Night

To measure the flow of time at night, you could select a circumpolar group of stars, such as the "Big Dipper" ("Leg of an Ox" to the Egyptians) and monitor its change of orientation during the course of a night. Or you could select a single star near the eastern horizon, just after sundown, and monitor its progress across the vault of the sky to measure the flow of time. The Egyptians selected a set of stars, now known as the "decans,"[4] and measured time as, one after another, these decans moved past a fixed reference point.

Before discussing any details, an initial question is often overlooked. Our sense of time and the practice of doling out hours, minutes, and seconds are relatively modern phenomena. Why would the ancient Egyptians have wanted to measure the hours of the night? A basic Egyptian myth involved the nightly journey of *Ra* and the spirit of a deceased pharaoh through 12 regions of the underworld, or Duat. Access to each region was controlled by a gate and guarded by a powerful demon. In order to gain passage through a particular gate, a spirit had to first recite the proper incantation. The incantations were complex and there was always the danger that a vital phrase might be forgotten. To assist the memory of a pharaoh's spirit, a scroll

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[3] Note that 365 × 1461 civil years = 533,265 days, and that 365.25 × 1460 Sothic years = 533,265 days.

[4] The term "decan" is used because these stars are used to mark the hours of the night for 10-day periods, or decades.

with all the instructions for this nightly journey was often placed in his coffin. Such scrolls became known as the "Book of the Dead"[5] and versions were often included in the coffins of anyone with hopes of joining the immortals after death. To further assist the spirit of a deceased pharaoh through the Duat, groups of priests chanted the appropriate incantation as the spirit was assumed to be approaching each gate. The desire to space these chants at regular intervals to match this nightly journey may have been the Egyptians' inspiration for developing the system of decans.[6]

The basic Egyptian system of decans used 36 brighter stars, or star groups, which were spread around the ecliptic. During any given 10-day week in the Egyptian calendar, a set of 12 decans was used to mark the hours of darkness. At the beginning of the next decade, to correct for the accumulated sidereal motion of the stars towards the west, the westernmost star was dropped from the set and a new one in the east was added. The progression of the sets of decans for a whole year was summarized in a "Decan Chart" with 12 rows (one row for each of the 12 stars to be used in a particular decade) and 37 columns (one column for each of the decades in the year, plus one column for the epagomenal days)[7] .

It is thought that the sequence of decans began with Sirius and ended with the Orion group, but the identity of most of the decans is unknown. The Egyptians may have used different techniques, in different eras, to observe the decans. Choosing stars that were evenly spaced may have been more important than choosing the brightest stars.

Method I: The simplest technique is to monitor the setting of stars at the western horizon. The western horizon might have been preferred so that a setting star could carry the priests' message directly into the Duat. An early surveying instrument, called a *bay,* might have been used in such horizon observations. A *bay* is a short, notched staff used for sighting objects near the horizon.

Method II: According to Parker (1974), by the Twelfth Dynasty (*ca.* 1900 BC) decan observations were made on the meridian:

> "...two men sit facing one another on a north-south line. The northernmost would hold a sighting instrument like plumb bob...before him and would call out the hour when a [particular] star reached the meridian... as sighted against the target figure [of the second person]."

The frame for such a plumb bob was called a *merkhet*. The Egyptian Museum in Berlin has an example of a *bay* and a *merkhet* that once belonged to a priest named *Hor,* who was the Overseer of the Hour during the Twenty-sixth Dynasty (Wells 1999). A *bay* was probably held at arm's length (about 60 cm) while resting on a support. A line-of-sight would have been established through the *bay* towards an object of interest.

Simulation VI: Observing the Decans and the Hours of the Night

Imagine an Egyptian priest viewing the night sky and wondering how to space the incantations that would assist *Ra* and the spirit of the pharaoh through the 12 gates in the Duat. The stars could be seen to move uniformly across the sky. Why not select 12 evenly spaced stars, across the east-west vault of the sky, to use as time markers? As each of these stars set in the west, it would be time for the next incantation! Based on this scenario, the simplest approach is to simulate decan observations near the western horizon.

For Egyptian priests, the time of darkness extended from the end of twilight in the west (corresponding to the passage of *Ra* through the first gate of the Duat) to the beginning of morning twilight in the east (corresponding to the emergence of *Ra* from the twelfth region of the Duat). At Luxor, latitude 26° N, this time of darkness varies from about 12 hours and 40 minutes at the winter solstice, to 9 hours and 20 minutes at the summer solstice[8] . The corresponding average spacing for the decans varies with the seasons as shown in Table 3.

To become familiar with the decan concept, follow the setup for Simulation VI as described in the appendix, run time [forward], and watch the progression of bright stars over the western horizon as a few days and nights flow by. [Stop] the action with a bright star about 30° above the western horizon. Set the "Time Flow Rate" to 1 day, and [step forward] one day at a time. Note the day-by-day, sidereal progress of the star towards the western horizon.

To select potential-decans, reset the "Time and Date" to 7:20 p.m., April 15, 3000 BC. If DST is turned off, this time corresponds to the end of twilight. Then set the "Time Flow Rate" to 55 minutes, which is approximately one twelfth of the time of darkness at this time of year. The task is to locate 12 potential-decans that could have been used to divide the night of April 15/16, 3000 BC into 12 approximately equal segments. Search the region about 20° above the horizon, and within 40° of due west, for the brightest star that could have served as the first decan[9]. A bright star within an identifiable group would probably be preferable to an isolated star. Place the cursor over a selected star and push [control] to determine its name, altitude and magnitude. Record this information along with the time. Then [step forward] 55 minutes, and repeat the procedure. Continue until you reach morning twilight. Table 4 was produced using this procedure.

The starting point of April 15, 3000 BC at 7:20 p.m. at an altitude of 20° was somewhat arbitrary; however, 12 potential-decans were easily found. These potential-decans all had magnitudes brighter than 3.6, with 55-minute spacing, and all had altitudes within a few degrees of 20°. If this procedure were to be repeated again at both solstices, and the fall equinox, with appropriate changes in the "Time Flow Rate" as given in Table 3, then four lists would be produced with a total of 48 potential-decans. If all these stars were combined in a sequential list, and duplicates were eliminated, a list of potential-decans would be created that would be similar to the set of decans used by the ancient Egyptians. This list of stars could also be organized into a "Potential-Decan Table" with a structure corresponding to the structure of a "Decan Table" from ancient Egypt.

Observing the Decans: Practical Problems and Speculative Solutions

1. A decan system with 36 stars is conceptually neat and logical for a year consisting of thirty-six decades (10-day weeks). The five or six epagomenal days at the end of the Sothic cycle require

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[5] The papyrus of Ani, as presented in *The Egyptian Book of the Dead,* ed. von Dassaw (Chronicle Books, 1994) is one of the most complete and artistic examples.

[6] For example, Parker (1974) assumed that the Egyptians first identified the decans to divide the time of darkness into 12 portions, and only then divided the journey through the underworld into 12 sections. This assumption implies that the Egyptians were astronomers before they were religious practitioners. It may be more reasonable to assume that the mythical trip through the 12 divisions of the Duat is more ancient than the list of decans. The number "12" has a number of ancient mystic associations and may ultimately be related to the number of whole lunar months in a solar year.

[7] Photographic images of Decan Tables can be found at www.thebanmappingproject.com/sites. This site provides virtual tours of tombs in the Valley of the Kings along with hundreds of photographs. The tomb of Sety I (KV17) includes some of the best images of a Decan Chart (images #14, 22, 24, & 45).

[8] These times can be estimated by referring to "Twilight" (*Observer's Handbook 2004,* p 113) or by following the simulated Sun in 3000 BC from 6° below the western horizon, to 6° below the eastern horizon.

[9] According to Schaefer (2000), to be visible near the horizon an object should have an altitude of at least 5°. Since the stars advance about 1° per day and westernmost decan was observed for 10 days in a row, its initial altitude must have been at least 15°.

a 37th column in the Decan Chart. This column probably contained a selection of decans from the 1st and 36th columns.

2. Decans, when separated from each other by an average of 14°, or 55 minutes, create two basic concerns: i) only 26 stars are required to span the sky, and ii) during each 10-day period the stars advance about 10° towards the west, while the next column in the Decan Chart is based on advance of 14°. Thus the jumps from one column to the next in the Decan Chart are 4° too big. Unchecked, such an error would accumulate to 144° during a year. However, if every two or three decades, a column of the Decan Chart was simply a duplicate of the previous column, then the advance of the chart would be slowed to match the advance of the stars. A total of ten duplicate-columns per year would have kept the Decan Chart synchronized with the heavens[10]. If, in addition a duplicated column was marked by replacing one star with a new decan star, then a total of 36 decan stars would be required to complete the Decan Chart.
3. Based on Simulation VI, the spacing of the decans may have varied within a 5° range. Thus, the length of hours based on simple decan observations may have varied by up to 20 minutes. At some point the Egyptians seemed to have dealt with this problem by creating a supplemental chart to accompany the Decan Chart. Such a chart, and the figure of a kneeling man, is included in the inscriptions on the walls of the tomb of Ramses VII (*ca.* 1150 BC)[11]. The chart lists the decans with notations such as "opposite the heart," "on the right eye," "on the left ear," and "on the right shoulder." These instructions may have been used to refine the observations of decans by indicating how to adjust the line of sight by a few degrees. While Parker (1974) associates this chart only with meridian observations, similar charts may have also been used to correct horizon observations of unevenly spaced decans.
4. A clock based on the stars gradually shifts due to sidereal motion. A star passes a fixed sightline about four minutes earlier each day. Over the duration of a "decade" the sidereal shift would have amounted to about 40 minutes and the timing of incantations would have been disrupted. The Egyptians could have managed this difficulty simply by using a reference sightline based on the position of first (westernmost) decan each night, rather than the horizon or the meridian. This could have been accomplished in the following manner:
    - A short pillar was topped by a support for a *bay,* and the support was designed so that its height could be varied by several centimetres[12]. When held at a distance of 60 cm, raising or lowering a *bay* by 1 cm raises or lowers the line-of-sight by about 1°.
    - Each day, at sunset, the level of the support was set so that an observer's line-of-sight through a *bay,* was towards with the first decan.
    - The *bay,* at that platform height, was then used to observe the passage of the other eleven decans during the night.

The timing of the first incantation would have been determined by the onset of darkness, while the corresponding altitude of the first decan would have been used to establish the height of the *bay*. This technique would have the effect of resetting the decan clock to zero at the beginning of each night's observations and would automatically compensate for any sidereal shift.

Summary

Simulations have proved to be a useful tool for investigating the astronomical techniques and observations in ancient Egypt.

Working through a variety of simulations, relatively simple procedures have been designed that the Egyptians might have used to obtain the astronomical results that have been found in the archeological record.

It was demonstrated that observations of the heliacal rise of Sirius could be made to determine the beginning of any particular Sothic year, with an accuracy of one day. Averaged over a period of many years, at any time during the third millennium, the average length of a Sothic year was found to be 365.25 days.

The use of decans to divide the time of darkness into 12 equal parts may have been the most sophisticated Egyptian astronomical technique. To be effective over weeks and months, the technique required the construction of a Decan Chart with celestial spacing between the decans that depended on the season. An observational technique that depended on the position of the westernmost at sunset may have been used to "reset" the star clock each night. This resetting of the star clock would have avoided a number of systematic errors that would have occurred if observations had been based on the horizon, or the meridian.

I hope the six simulations presented in this two-part series have provided a useful hands-on introduction to the astronomy of ancient Egypt. For those who want to learn more about this topic, there is much more to be gleaned from the academic literature on the technology of ancient Egypt, and undoubtedly there will be more insights gained from future archeological discoveries.

Appendix

The following procedures have been designed to facilitate investigations of the astronomy of ancient Egypt using the computer program Starry Night (`www.starrynight.com`). "TOP TOOLS" refers to the horizontal tool bar across the top of the standard screen. "SIDE TOOLS" refers to the vertical tool bar at the side of the standard screen. Square brackets are used to indicate control buttons within the TIME window.

General Settings for Simulations in Ancient Egypt

The directions for creating the file called ANCIENT EGYPT can be found in the appendix to Paper I in this series.

Simulation V: The Heliacal Rise of Sirius

Open the file for ANCIENT EGYPT.
In the *Time Bar:*

- Set the date to July 13, 3000 BC. This date corresponds approximately

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[10] With 14° spacing and the duplication of ten columns, the 36 columns of the Decan Chart would have corresponded to a total advance of 26 × 14° = 364° per year.

[11] KV 1, image #15 at `www.thebanmappingproject.com/sites`.

[12] A support with a variable height could have been formed by carving a series of small steps in the edge of the support. Or, two wedges could have been stacked so their horizontal surfaces were parallel. Then the height of the top surface could then be changed, by sliding the top wedge horizontally. More simply, a series of flat boards could have been placed under the *bay.*

to the heliacal rise of Sirius.

- Set the time to 6:00 a.m. local (or 3:00 UT). At this time the Sun is about 6° below the horizon and Sirius has an altitude of about 5°.
- Recall the "Set Julian Day" option. Using this menu item you can obtain the current Julian Day value, and/or change it to another value.

From *Side Pane* use "Find" to locate and label Sirius, then select East again from the *Button Bar.* Use the "Hand" cursor to raise the horizon one third of the way up the screen.

Simulation VI: The Decans and the Hours of the Night

Open the file for ANCIENT EGYPT.
From the *Button Bar* select: West direction.
From the *Tool Bar* select Options > Stars > Star Options: Set the number of stars to fewer so only the brighter stars are shown.
In the *Time Bar* set:

- The "Time and Date" to 6:55 p.m. (Sun on the horizon) and April 15, 3000 BC (day of the vernal equinox).
- The "Time Flow Rate" to 5 minutes.

Use the "Hand" cursor to move the horizon to the bottom of the screen. The first gridline above the horizon marks +10° in altitude; the next gridline marks +30°. The intersection of green celestial equator with the red horizon marks the direction of west. The vertical gridlines mark 30° intervals in azimuth.

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TABLES

Table 1. The heliacal rise of Sirius at 30° N. A comparison of the Julian calendar dates calculated by Schaefer and those obtained with simulations using *Starry Night.*

Year	Schaefer (2000)	Simulations
3500 BC	July 16.4	July 19
3000 BC	July 16.9	July 19
2500 BC	July 16.6	July 19
2000 BC	July 17.3	July 19
1500 BC	July 17.8	July 19
1000 BC	July 17.2	July 19
500 BC	July 18.2	July 19
AD 1	July 18.3	July 20
AD 500	July 20.3	July 21

Table 2. Data from simulations of the heliacal rise of Sirius at 26°N.

Year (BC)	Day (Julian Calendar)	Julian Date	No. of Days in 100 Sothic years
3000	July 14	625867	N/A
2900	July 14	662392	36525
2800	July 14	698917	36525
2700	July 14	735442	36525
2600	July 14	771967	36525
2500	July 14	808492	36525
2400	July 14	845017	36525
2300	July 14	881542	36525
2200	July 14	918067	36525
2100	July 14	954592	36525
2000	July 14	991117	36525

Table 3. The time of darkness and average decan spacing at 26° N, in 3000 BC.

Time of Year	Hours of Darkness	Average Spacing for 12 Decans
Winter Solstice	12h 40m	63 min
Vernal Equinox	11h 5m	55 min
Summer Solstice	9h 20m	47 min
Fall Equinox	11h 5m	55 min

Table 4. Potential-decans for the Evening of April 15/16, 3000 BC.

Local Time	Star	Altitude	Magnitude
7:20 p.m.	Sirius	21.1	−1.47
8:15 p.m.	Castor	22.8	1.56
9:10 p.m.	Altarf	22.5	3.50
10:05 p.m.	Zeta Hydrae	20.0	3.09
11:00 p.m.	Omicron Leonis	18.8	3.50
11:55 p.m.	Nu Hydrae	22.7	3.09
12:50 a.m.	Gamma Centauri	22.6	2.81
1:45 a.m.	Kraz	20.8	2.62
2:40 a.m.	Menkent	22.7	2.03
3:35 a.m.	Gamma Lupi	20.9	2.96
4:30 a.m.	Sargus	21.8	1.84
5:25 a.m.	Arkab	21.5	3.09
6:20 a.m.	Morning twilight	—	—

William Dodd has a M.Sc. in astronomy and a D.Ed. in computer applications. He is a retired mathematics teacher with a particular interest in the fundamental and historical aspects of astronomy.

Society News/Nouvelles de la société

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

National Council Meetings & RASC Happenings

Since our last *Journal*, on the business side of things, we have had a National Council meeting on February 26, 2005 held in Toronto. Your National Council Representative should have come back to your Centre and let you know about the many issues that the National body has to deal with. If not, or you wish to read up on the reports yourself, please visit the `www.rasc.ca` Web site, in the Private members only section (put in the username "member" and password "chant99") and look for the National Council Meeting Saturday 2005-02-26(NC051) and read the reports of the various committees. If you have any questions, please do not hesitate to contact your National Council Representative or the National Office (`nationaloffice@rasc.ca`). Some of these items may be coming up at the Annual Meeting at the General Assembly and will need your input.

Spring is right around the corner, and March 22, the official day on the calendar, can't come soon enough for some of us. We have not had the greatest weather for observing this past winter, and for those who managed to observe, good for you; now pass the clear skies to the rest of us, and let's hope that the spring weather is better for observing our favorite Messiers and we can go for the Messier Marathon.

Well, if the weather does not clear up, we always have summer star parties to look forward to (visit `www.telusplanet.net/public/fenertyb/sp_list.htm`) and of course the General Assembly that will be held from May 20 to 23, 2005, hosted by the Okanagan Centre. For more information on the events and speakers, please go to `www.rasc.ca/ga` and click on the running GA banner. So don't wait — book your holidays now and enjoy the company of other RASCals.

All members will also receive information about the Annual Meeting (held at the General Assembly) in the April mail. Please read all the information, and if you wish to vote on any of the items, fill out your proxy form as per the instructions. This is your Society, so let your thoughts be known on the subjects at hand.

Canada-Wide Science Fair 2004

Since 2000, the RASC has been involved with the Canada-Wide Science Fair. In 2004 the CWSF was held in St. John's, Newfoundland. Engaging in a small project on behalf of the Education Committee, I took it upon myself to contact all the final winners to see if they would like to have their work showcased on the RASC Web site and in the *Journal*. To date we have received permission to publish the project of Brian Le, who received his award on his topic "Astrophysics for All."

Astrophysics For All

An in-depth investigation on how advanced theories on gravitational behaviour can be taught in the grade school classroom.

The purpose of this project is to show how astronomy and astrophysics can be integrated into the grade school curriculum through the development of easy-to-understand and fun experiments that are appealing to grade school students.

Due to the extraordinary breadth of the subjects of astronomy and astrophysics, I have decided to focus my investigation on one particular topic: gravity. I have developed the following problem to answer in my investigation:

Figure 1 – Mr. Brian Le, Junior Winner of the 2004 Canada-Wide Science Fair for his project "Astrophysics for All." Picture taken in the Legislature Building, St. John's, Newfoundland May 2004 by Dominic P. Tremblay.

What are the theories of gravity, their applications to the universe that we live in, and how can we integrate these theories into the grade school curriculum?

Addressing from this problem, I first did my preliminary research using a variety of resources including scientific periodicals, astronomy and physics textbooks, library books, and interviews with university students. From this research, I developed a comprehensive understanding of the following topics and equations that have been summarized below:

- Newton's Gravity Equations
    - $F_g = mg, F_g = G(m_1 m_2 / r^2)$
    - Describes the force that gravity applies on objects

- $a = 2\Delta d / (\Delta t)^2$
    - Describes the acceleration of freefalling objects
- Einstein's General Theory of Relativity
    - Describes how gravity affects the curvature of space
- Black Holes
    - $R_{sch} = 2Gm / c^2$
    - Incredibly dense masses where gravity is extraordinarily strong

From this newly acquired knowledge, I developed the following easy-to-understand and fun experiments for grade school students:

- Water Balloon Experiment
    - Students would take turns dropping water balloons out of a window to measure how gravity accelerates the balloons towards the ground
- Table Cloth Experiment
    - Students would hold a table cloth above the ground and use it to simulate how space curves around objects by placing objects onto the cloth and seeing how the curvatures of the cloth changes.
- Black Hole Experiment
    - Students would use the Schwarzchild formula to discover how massive black holes would be at different radii and would compare them to the density of everyday household objects.

I have found that teaching advanced astronomical concepts can be made very simple with creativity. With these experiments, I hope to take the first step in exposing students to the exciting world of astronomy and astrophysics so that they too may begin enjoying these subjects.

Brian Le received the Junior award, which included a $200 cash award, and a membership with the RASC. If you have any questions about his project or the Science Fair, contact Brian at `Brian_Le25@yahoo.com` or go to `www.rasc.ca/education` to read the expanded version of Brian's project.

The 2005 Canada-Wide Science Fair will be held in Vancouver, B.C. from May 15 to 22. For more information on the CWSF, please visit `www.cwsf.info`. Good luck to all, and we hope to see your project in the *Journal* next year!

Until next time, clear skies, and keep looking up.

British Columbia's scenic Okanagan Valley is the setting for this year's RASC General Assembly. Join your friends at the Okanagan Centre on the Victoria Day long weekend for a four-day conference that includes an exceptional slate of talks, fine dining, winery tours, and a visit to Canada's major Radio Astronomy observatory. Web site: `www.rasc.ca/8080/rasc`. Email: `ga2005@rasc.ca`. Telephone inquiries can be made toll-free to the National Office: 1-888-924-RASC (7272).

Orbital Oddities

Quirky Quints

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

> *... and on a very distant star*
> *slimy creatures scan the skies*
> *they've got plates for hands*
> *and telescopes for eyes*
> *and they say: Look! down there!*
> *a haunted planet spinning 'round*
> *watch it move! watch it shake!*
> *watch it turn! and shake!*
>
> *and we say: watch us move!*
> *watch us shake! we're so pretty...*
>
> — Laurie Anderson,
> *Kokoku*

Poet, philosopher, performance artist, Anderson demonstrated this outside insight into the bigger picture two decades before becoming NASA's first-ever artist in residence. By happy coincidence, her words worked their decidedly non-linear way into my head that mind-expanding summer of 1984.

The Edmonton Space Sciences Centre had just opened its spiral ramps to the public, and I took the opportunity to scratch an itch that had persisted ever since the *Apollo* Moon program captivated me in grade school. The dark space galleries, the planetarium show, especially the bookstore, rather increased the urge to scratch, a most pleasurable activity in which I have been engaging ever since.

One giant leap in my own perception of the cosmos came with the fundamental realization that what many perceive as two solitudes — the heavens and Earth — in fact share a single, almost limitless realm. Earth is a moving, turning, shaking participant in the process. What fellow RASCal Curt Nason of Moncton Centre so nicely called the "orrery in my head" began whirling of its own accord, starting with the motion of our frame of reference — Observing Station Earth.

It's perhaps an obvious point that dynamic events we see as conjunctions, appulses, occultations, transits, and eclipses are not so much the alignment of two bodies as of three, with Earth at one end of the line. When considering the frequency of such events, one needs to consider all three bodies. And if I have learned one thing from astrophysics, it is that a three-body problem is infinitely more complex than a two-!

One three-body alignment that always features Earth at one end, never the middle of the line, involves our two inner neighbours, Mercury and Venus. Due to the rapid motion of the three, conjunctions occur fairly frequently but can be difficult to observe in the glare of the Sun. It's best when Mercury is near maximum elongation. Even then, such events are often best seen telescopically in broad daylight when the planets are high in the sky.

A superb opportunity to do just that is upcoming on Monday, June 27, when the two planets will meet some 23° east of the Sun (and just 2° ENE of Saturn). Mercury and Venus will close to within 4 arcminutes of each other around 16h UT, and still be within 5´ when they achieve conjunction in right ascension at 20h UT. As this period brackets mid-day across North America, the two will be well-placed near the meridian about 22° north of the celestial equator. Mercury will be 61% illuminated and at magnitude –0.1 should be easy to spot sliding just south of 91% gibbous Venus.

With their relatively large inclinations and variable distances from Earth, our inner neighbours can be widely separated even at conjunction, by as much as 11° declination. This time they will be uncommonly close. Other than an unobservable appulse near the Sun in 1990, this pair hasn't had a closer approach since July 1965, when they were only 2´ apart under similarly favourable circumstances. Nor will they again be so tight until 2070. I plan to be dead by then, so this is an opportunity not to be missed.

Planetary observers should be familiar with the superb diagram *Right Ascensions of the Sun and Planets in 2005,* which appears on page 79 of the *Observer's Handbook 2005* (Gupta 2004). I noticed with considerable interest the following remarks in the caption: "The Mercury and Venus curves intersect four times: Jan. 14, Mar. 28, Jun. 27, and Jul. 7. These four events complete a rare *quintuple*-conjunction sequence that began on 2004 Dec. 29."

Ever heard of a quintuple conjunction? I hadn't, so away went the mental orrery on a new problem. Quintuple conjunctions (QCs) are possible only between speedy Mercury and a second planet that appears from Earth's perspective to move slowly behind the Sun: either Venus or Mars. We'll focus here only on those involving the innermost planets. All are geometrically similar: the 2004-5 QC is diagrammed in Figure 1.

But it was that lovely word "rare" that grabbed my attention, immediately prompting the question "*how* rare?" It has always been interesting to put current

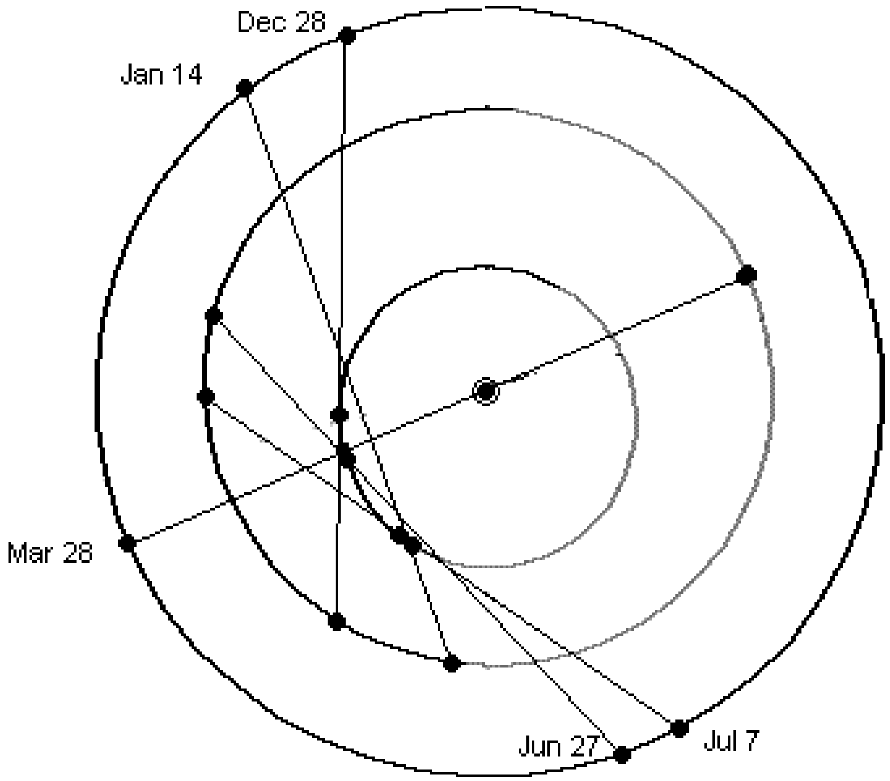

Figure 1 — The circumstances of the current quintuple conjunction. In 190 days Earth completes just over half of one (counter-clockwise) revolution, Venus about 85% of one, and Mercury a little over two full 88-day revolutions. Note that all five conjunctions occur with Mercury in the same quadrant of its orbit, near its aphelion from the Sun. Even so, the limiting events of December 28 and July 7 are virtually tangential to Mercury's orbit. All QCs follow the same approximate sequence: double conjunction at morning elongation ... [~88 days] ... conjunction of Venus, Mercury, and the Sun ... [~88 more days] ... double conjunction at evening elongation. (Diagram courtesy Alister Ling and the author.)

events and observing opportunities into their historical perspective. I started with my desktop bible, *Astronomical Tables of the Sun, Moon and Planets* by Jean Meeus (1983, 1995), which showed no previous QCs between Mercury and Venus since 1976, but a second one coming up rather quickly in 2008. While this initial evidence hardly suggested any sort of pattern for QCs, the rhythm of conjunctions caught my eye; however a mere 45 years of data were nowhere near enough. I initiated email correspondence with Dr. Meeus (2004, 2005), an honorary member of RASC and the author of the outstanding *Mathematical Astronomy Morsels* series. Once again Jean proved most accommodating to my inquiries, providing several batches of computer-generated tables that eventually covered all conjunctions of Mercury and Venus in both celestial longitude and right ascension for the period 0-4000!

This generated a 200-page printout with 9,620 conjunctions in RA on one side of the page, 9,764 in longitude on the other. I then applied a proven search mechanism: my eyeballs. Not that I'm a *total* technoflub (more like a deep partial), but a visual search is like star-hopping; one can learn lots along the way, seeing patterns develop even if they don't manifest in actual "events." The pattern-finding method is proven when it leads to successful prediction of future events. It's not as daunting as it sounds: a review of just the 20th Century yielded QCs in 1925, 1928, 1965, 1968, now 2005 and 2008, revealing the key periods of 40 and 3 years.

Armed with my highest-tech weapon, a highlighting pen, I succeeded in identifying 125 QCs in longitude and 84 in RA over four millennia, exactly matching totals subsequently derived by Dr. Meeus using a computer search. It turned out that QCs conform to a complex structure of seasons and hibernations that I consider a thing of beauty (see Table 1).

Every QC occurs near Venus superior conjunction, as our closest neighbour slowly dips behind the Sun. Each lasts just over six months, beginning with a double conjunction as faster Mercury loops around and outside plodding Venus near the former's western (morning) elongation. About three months later there is a central conjunction where both are near the Sun. (In 2005, this occurred on March 28; Mercury reached inferior conjunction on March 29, Venus superior conjunction on March 31.) Three months later is a second double conjunction near Mercury's eastern elongation. Mercury is therefore favourably placed for four of the five conjunctions, a significant observing window.

Of course, not all elongations of Mercury are created equal. The innermost planet has a highly eccentric orbit ($e = 0.206$) and its elongation can range from only 18° from the Sun at perihelion to 28° at aphelion. QCs occur if Venus passes within the limits of Mercury near an aphelic elongation. Over the subsequent six months Mercury completes two complete revolutions of the Sun while Earth does half of one revolution and therefore views another aphelic elongation *from the opposite direction*. (Watch us move!) In the same amount of time Venus advances about 50° with respect to the Sun, just barely less than the full range of Mercury's apparent motion. For this reason, QCs can only happen during certain times of year (optimally, late winter through late summer) and, like aphelic elongations generally, are almost invariably best seen from the southern hemisphere.

The QC of 2004-5 has been about as favourable as possible for northern hemisphere observers; it is in fact a limiting case, the end of a series. The two planets had a long dalliance in the morning sky around New Years, staying within a degree or so for three full weeks. I got a great view the morning of the first conjunction in longitude, December 28, when the pair was a comfortable 22° from the Sun and joined in the dawn sky by Mars, Jupiter, Saturn, and the Moon. Six months later, almost to the day, comes the spectacularly close afternoon appulse. As the old saying goes, "See you on the other side!"

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Bruce McCurdy has been a proud RASC member for 20 years.

IIa	IIb	IIc	IIIa	IIIb	IIIc	IVa	IVb	IVc
705			*1645*			**2625**		
745			**1685**			**2665**		
785			**1725**			**2705**		
825			**1765**			**2745**		
865	*868*		**1805**	*1808*		**2785**	**2788**	
905	**908**		**1845**	**1848**		**2825**	**2828**	
945	**948**		**1885**	**1888**		**2865**	**2868**	
984-5	**988**		**1925**	**1928**		**2905**	**2908**	
1024-5	**1028**		**1965**	**1968**		**2945**	**2948**	
1064-5	**1068**		**2004-5**	**2008**		*2985*	**2988**	*2991*
	1108	*1111*		**2048**	*2051*		**3028**	*3031*
	1148	*1151*		**2088**	*2091*		**3068**	*3071*
	1188	*1191*		**2128**	*2131*		**3108**	*3111*
	1228	*1231*		**2168**	*2171*		*3148*	*3151*
	1268	*1271*		*2208*	*2211*			*3191*
		1311			*2251*			*3231*
		1351			*2291*			*3271*
		1391			*2331*			*3311*

TABLE 1 – Quintuple conjunctions of Mercury-Venus, 500-3500, occur in long seasons separated by hibernations of 250+ years. The three full seasons in the data set are remarkably consistent; each contains exactly 29 QCs in longitude in three series over a period of 686 years! For geometric reasons QCs in RA are more rare, 18 to 19 per season. Events shown in **boldface** occur in both longitude and RA; those in *italics,* including all members of every series c, only in longitude. There is an approximate commensurability among the three planets' orbital periods of 166:65:40; various mutual phenomena display roughly a 40-41 year periodicity (Meeus 2004). The rows are actually 40 years less about 9 days, and gradually slip out of phase to be replaced by another series 3.2 years (two synodic periods of Venus and ten of Mercury) later. In mid-season, QCs usually occur in pairs just three years apart, reminiscent of paired transits of Venus. Comparison of analogous events across the seasons (including partial seasons I and V, not shown) indicates a super-period of 940 (+40) years. Note that the QC of 2004-5 is the only one after the Gregorian calendar change that encompasses two calendar years; it is a limiting event at the end of a series. An optimum QC, such as that of 2008, begins in February-March and ends in September. As with most observations involving Mercury, this favours observers in the southern hemisphere.

Dr. Doug Welch

by Philip Mozel, Toronto Centre (philip.mozel@osc.on.ca)

It wouldn't be inappropriate to call Dr. Doug Welch a macho man…or at least a MACHO man, for his research has led him to explore some rather large cosmic mysteries.

For example, observations of stars in galaxies indicate that they are moving in ways that cannot be accounted for by the gravitational influence of visible matter. There seems to be something else out there. This unseen matter could conceivably take the form of planets, brown dwarfs, and the like. These objects have been dubbed MAssive Compact Halo Objects (MACHOs). To see the unseen requires specialized equipment, great computing power, and not a little patience! Astronomers have always had the latter, but computing suitable to the task has only become available relatively recently. Thus the MACHO project was born.

Dr. Welch's assignment with MACHO involved looking at millions of stars for a period of years. If an unseen object of sufficient mass passes right between the observer and a star, the gravity of the object bends the starlight in such a way that the star appears to temporarily brighten. This is gravitational microlensing. Less than one in a million stars will be affected in such a way (hence the patience!). Observing dense star fields increases the odds of detecting an event, so the MACHO project turned its telescopes toward the Large Magellanic Cloud and the core of the Milky Way.

During Dr. Welch's involvement with the project, about a dozen events were bagged while looking at the LMC and more while observing our own galaxy. Analysis of the data suggests that the dark objects are not brown dwarfs. But what are they? Some theories argue that they are white dwarfs. Pinning down the identities, and locations, of these objects will be the job of astronomers doing spectroscopy in the "Next Generation Microlensing Survey," *i.e.*, SuperMACHO. Since "Spectroscopy really, really excites" Dr. Welch, his current involvement in such a program is much to his liking.

Dr. Doug Welch

A serendipitous offshoot of this work has been the discovery and study of variable stars, particularly Cepheids — variable stars that pulsate with periods from one to seventy days. The MACHO project has found Cepheids that pulsate with two separate, simultaneous periods. This behaviour seems to be dependent on the abundance of heavy elements within the star and will be investigated further. Until MACHO, only one Cepheid of this type was known.

Dr. Welch is a keen observer, which has afforded him the opportunity to use telescopes all over the world. He has been to, among other places, Hawaii, Kitt Peak in Arizona, Mount Palomar in California, and, his favorite because of the great altitude, the Chilean Andes. Using instruments in such places, he has worked on not only dark matter and pulsating stars but also the extragalactic distance scale and Type II supernovae. He is specifically interested in the amount of dust Type II outbursts blast into space, which, in turn, has a bearing on the kind of raw material available for the next generation of stars.

The Gemini Observatory consists of two 8-metre telescopes that work in the optical and infrared parts of the spectrum. One is located in Hawaii and the other in Chile. Dr. Welch is currently one of two Canadians on the Gemini board and became chairman in 2005. He is also on the Gemini committee with oversight for the telescopes' instruments.

Staying close to his amateur roots, he has been involved with four RASC centres on different occasions and maintains his involvement to the present day. Dr. Welch has even arranged observing time for amateurs on both the Canada-France-Hawaii Telescope and Gemini.

"I still go out whenever I get the chance to look at the night sky." — something Dr. Welch has been doing from a young age. His father gave him his first telescopic view of the heavens at age eight. The Moon was the first target followed by Saturn, shining nearby. By the time he was eleven, his father had died. One night, he went outside with the telescope to revisit those sights. The Moon was first and, being under the impression that Saturn was always near it, as on that first night, Dr. Welch turned the scope to such a bright point of light. It *was* Saturn. He has never looked back.

Joining the Ottawa Centre, he established himself as an observer of note. While many of us may have hunted down a few of the brighter asteroids, Dr. Welch located about a hundred *and* measured their positions accurately enough that corrections could be made to their calculated orbits. Globular star clusters came under his scrutiny as well, but not just those around the Milky Way: he located several huddled around the Andromeda Galaxy!

Dr. Welch claims to be in the business of changing specialties, always looking for new and different things to do. "I enjoy pushing the envelope," he says, even if, as in the case of MACHOs, that envelope cannot actually be seen by human eyes. ◆

Philip Mozel is a past National Librarian of the Society and was the Producer/Educator at the McLaughlin Planetarium. He is currently an Educator at the Ontario Science Centre.

The Skies Over Canada

Observing Committee News

by Christopher Fleming (observing@rasc.ca)

I watched CNN with keen interest in mid-January as the first images of Titan began coming in, and I was amazed at the detail that the *Huygens* probe was obtaining from that very remote cloud-enshrouded moon. Since the first telescopic observations, by Galileo Galilei in 1610, humankind has been endeavoring to see finer and finer details on the planets and moons of our solar system. Spacecraft missions to far-off places are remote observing at its best, and we, as Earth-bound observers, should feel a special bond with the people and technology that have made this possible. Whether we see an image of a distant object through the eyepiece of a telescope or through the lens of a camera, it is still observing, and that is what astronomy is all about.

The various planetary space missions over the years have been an inspiration to many people, and I am sure they have played a significant role in the growth of our hobby. During the sixties, the Moon program was very prominent at NASA, and coincidentally telescopic observing of the Moon was also extremely popular at that time. Other notable epochs occurred over the last few hundred years when serious amateurs were obtaining observations that mirrored what the major observatories were doing. Perhaps that explains why deep-sky observing is so popular today, since it is also very prominent at the major observatories.

From the early 1600s through the early 1900s observing interests among enthusiasts ranged from lunar and planetary to comets, asteroids, deep-sky, double stars, and variable stars. At certain epochs each one of those categories would have had its time in the spotlight and no doubt the equipment available during those centuries would have had an influence on what observers could do. For instance, in the early 1900s, many hobbyists studied double stars because the telescopes available at that time were not large enough to resolve faint deep-sky objects.

Today, with the wide range of equipment available, there is really no limitation to what type of observing one could do. For that reason, it will likely become more difficult to define a "most popular category," since observers now have the option of choosing whatever type they are keenly interested in. Another advantage brought forth by the equipment revolution is the option to get involved in more than one observing category. That, I think, is a very good approach since observing conditions at a particular time may be poor for one observing project but very suitable for another. A good example is to conduct lunar and planetary observing when the Moon is up, and then switch to deep-sky observing around new moon. Variable stars, double stars, and bright asteroids are also good targets when the Moon is shining brightly.

The Explore the Universe program was designed to give new observers a well-rounded introduction to astronomy, by including a variety of observing objectives and optional activities. This includes the most prominent constellations and bright stars that are visible from suburban areas in Canada. Anyone who has learned the constellations from a suburban area knows that it is an excellent place to do so because the multitudes of fainter stars, visible at a dark site, are washed out, making it easier to see the star patterns. Those folks will also be aware that the Zodiac constellations are not necessarily the brightest ones and that a couple of them are extremely difficult to identify from suburban areas. To avoid this problem we decided, reluctantly, to leave out the two faintest, namely Cancer and Pisces, neither of which have any significantly bright stars. Although they have been left out of the official list, we will be glad to accept observations of them from those observers who would like to seek out darker skies to identify them.

We are happy to report that one Explore the Universe Certificate was awarded during January, our coldest month, and that person is listed in Table 1.

There have been five Messier Certificates awarded since our last report, and we are delighted to welcome one from Wilmette, Illinois USA. They are listed in Table 2.

There has been one Finest NGC Certificate awarded since our last report, and that skilled observer is listed in Table 3.

Congratulations to all!

The Asteroids Section features charts containing the orbital positions of several bright asteroids that will be visible in 2005, and during May and June you will be able to print charts for the asteroids (1) Ceres, (2) Pallas, (7) Iris, (14) Irene, (15) Eunomia, (18) Melpomene, (32) Isis, and (129) Antigone. Those asteroids will all be brighter than tenth magnitude at that time, and the charts will display nearby stars to tenth magnitude on a five-degree or greater vertical field layout. Dates for the position of each asteroid will be listed at three-day (or longer) intervals, and nearby bright “finder stars” will be highlighted. In many cases the finder stars are bright enough to be seen visually, and therefore a *Telrad* or similar pointing device can be used to target the field printed on the charts. Otherwise a typical finder-scope or binoculars will be sufficient to find the brightest star in the field.

The Variable Stars Section features direct links to genuine American Association of Variable Star Observers (AAVSO) magnitude estimate charts for Mira-type Long-Period Variables that will reach maxima in 2005, and that will be brighter than magnitude 8.0. For May and June 2005, you will be able to print charts for Omicron Ceti (Mira), T Camelopardalis, R Lyncis, S Canis Minoris, R Leonis, U Herculis, R Cygni, RT Cygni, V Cassiopeiae, and R Cassiopeiae. We also have direct links to charts for several other variable-star types, and you will find them on the Sample Charts 2 page. Many of the most interesting variable stars in the night sky are listed there as well as the positions of possible nova outbursts.

The new Comets Section has provided accurate finder charts for several comets since being launched last autumn, most notably for C/2001 Q4 (NEAT), C/2004 Q2 (Machholz), and C/2003 K4 (LINEAR). We will continue to post charts for currently visible comets, some to as faint as fifteenth magnitude, that will challenge even the most demanding observers with large telescopes. The Special Projects section, as of this writing, is being upgraded with new content, and the results should be visible by the time this article reaches you. We are also planning a new Lunar and a new Planets section in the not-too-distant future.

The awesome beauty of the night sky, as seen visually or through the impressive array of telescopes that are available today, is something so fundamental to our human experience that, no matter how far technology takes us, humankind will always want to observe the stars and planets in real time. It is like so many other basic things in life that transcend technology, for example, nature walks, baseball, hockey, golfing, etc. As guardians of the night sky we should promote astronomy at all levels, and especially by continuing to appreciate its most primordial aspects.

Clear Skies.

Christopher Fleming is Chair of the RASC Observing Committee and Observers Chair in the London Centre. He enjoys all types of observing especially Deep-Sky, Lunar, Double Stars, and Variable Stars. Chris is also a musician and Webmaster of the London Jazz Society’s Web site.

Table 1 – Explore the Universe Certificate Recipient

Name	**Centre**	**Date Awarded**
Terry Leeder	Toronto, Ont.	Jan. 2005

Table 2 – Messier Certificate Recipients

Name	**Centre**	**Date Awarded**
Ray Drouillard	Windsor, Ont.	Sept 2004
Tim Bihuniak	Edmonton, Alta.	Dec 2004
Edward Hitchcock	Toronto, Ont.	Jan 2005
Paul R. Sheppard	Ottawa, Ont.	Jan 2005
Steven Swiryn	Illinois, USA	Jan 2005

Table 3 – Finest NGC Certificate Recipient

Name	**Centre**	**Date Awarded**
Brian White	Hamilton, Ont.	Jan 2005

Reviews of Publications
Critiques d'ouvrages

Concise Catalog of Deep-Sky Objects: Astrophysical Information for 500 Galaxies, Clusters and Nebulae, by W.H. Finlay, pages 248 + vii, 15.5 cm × 23.5 cm. Springer, 2003. Price $39.95 US softcover (ISBN 1-85233-691-9).

It is W.H. Finlay's fault this review is so late. When I first received the review copy, it did not look terribly interesting, and I put it aside. Then I took a closer look, and I was hooked. It immediately became a central part of my deep-sky observing tool kit, and, as such, I was using it too much to take the time to sit down and write a review of it. It is snowing outside right now and I cannot be out observing, so I thought I would settle down by the fire and finally write the review.

I did not quite know what to make of the book at first. It is not your typical star-hopper's guide to faint fuzzies. Instead it is a concise summary of the astrophysical information currently available for the deep-sky observer's favourite objects. The content is governed by the trinity of deep-sky observers' catalogs: Charles Messier's classic catalog of 110 objects; our own Alan Dyer's list of 110 Finest NGC objects, which appears each year in the *Observer's Handbook;* and the Astronomical League's *Herschel 400* list, created in part by the late Father Lucian Kemble. Because of overlap among the three lists, there are 520 objects in all, encompassing every deep-sky observer's best-loved objects. For each, Finlay has compiled the following data items in tabular form: constellation, object type, right ascension, declination, approximate transit date at local midnight, distance, age, apparent size, magnitude, and associated chart numbers for *Sky Atlas 2000.0* and the *Herald-Bobroff Atlas.* That information is followed by a brief note on the object, ranging from a single line to about half a page. In a few instances an image is included, only 15 in total. The main section of the book is organized by NGC number, placing the entries in order of right ascension. The Messier objects are repeated in their numeric order for convenience, and there is a third tiny section for the two IC objects that have made it onto the lists. Sounds pretty dull? That is what I thought, too, at first.

Then I got hooked! Once you have all of the data in organized form, apparently compiled with accuracy from the most recent information, they become absolutely essential and rather addictive. In seconds you can have all of the basic things you want to know about your favourites, right at your fingertips. Comparisons of different objects become easy.

It says in the fine print of my book reviewer's license that I am obligated to include a list of errata in every review. With a book as fact-intensive as this one, that should be easy, but I must confess that no obvious errors leaped out at me. I am sure that, with so many facts, there must be errors in the text, but it would take someone with a lot more astrophysical knowledge than I have to spot them. As a simple observer, I am just delighted to have all the information so readily available and so clearly and consistently presented. The only thing I truly miss is the surface brightness of each object. I also wish the page numbers were not printed in black ink on dark green circles, so that they would be legible. What is the good of an index if you cannot read the page numbers?

So I now find myself unable to function without Finlay's book at my side. I accidentally left it at the farm last week, and was forced to prepare my monthly talk on current astronomical events for the Toronto Centre without it. I nearly went crazy in the process. As I said at the outset, it is all W.H. Finlay's fault. And darned if I am not going to recommend that you go out and buy a copy of this book yourself!

GEOFF GAHERTY

Geoff Gaherty has been a member of the RASC, off and on, since 1957. He first observed the whole Messier catalog as a member of the Montreal Centre's Messier Club in the late 1950s and completed the RASC Finest NGC Certificate in 2001. He is currently two-thirds of the way through the Herschel 400.

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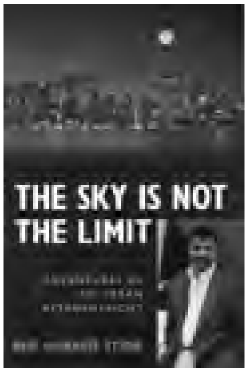
The Sky Is Not the Limit: Adventures of an Urban Astrophysicist, by Neil deGrasse Tyson, pages 203 + 0; 15 cm × 23 cm, Prometheus Books, 2004. Price $18 US softcover (ISBN 1-59102-188-X).



One of the nicer perks associated with being review editor of the *Journal* is that you get to suggest potential reviewers for books received at Head Office. In the case of *The Sky Is Not the Limit,* the decision was simple. I wanted to read the book myself, so I grabbed it on a recent visit to Toronto, and finished reading it prior to arriving back in Halifax. It is a book that I heartily recommend to others, not simply for the excellent writing style of the author, Neil Tyson, but for the insights it gives on the challenges facing traditional minorities in North America. The genuine warmth of Tyson's descriptive style of writing comes across marvelously in this short semi-autobiography, and permeates a nicely assembled synopsis of Tyson's adventures in astronomy, from early childhood to present day.

The book relates the progress of the author on the road to becoming an astrophysicist, from his first childhood visit to the Hayden Planetarium, which left an indelible impression on him, to his more recent television interviews talking about current discoveries. The story is told partly as an autobiography and partly in the form of short essays on astronomy that were modified for inclusion here. There is some unevenness in the text resulting from the juxtaposition, but the book is otherwise immensely readable.

As the incidents related in *The Sky Is Not the Limit* show, Tyson encountered more than the usual amount of prejudice along the road to becoming an astrophysicist. Most of us who have gone stargazing in populated areas have had our share of late-night encounters with the law, but for a black youngster growing up in the Bronx it appears to have been a regular experience, particularly when the observing site happens to be the roof of your apartment building! The experiences described by Tyson remind me of those described to me by a university colleague who, being both short *and* black, is regularly stopped by police when visiting his office during the evening.

Tyson appears to have survived a mediocre academic experience as a youth primarily through his interests in astronomy, which inspired him to complete several of the instructional programs developed at the Hayden Planetarium, and by an early fondness for mathematical puzzles shared with a childhood friend. Very early in his youth he decided to follow a path that would take him to his chosen career as an astrophysicist and was extremely fortunate to be assisted along the way by programs that enhanced his educational experience, from the Hayden courses and a summer astronomy camp to an eclipse cruise sponsored by the Explorer's Club in New York. All of this is described in the early chapters of the book. Tyson presently holds the position of Frederick P. Rose Director of the Hayden Planetarium, a fitting appointment for someone who was so strongly influenced by his childhood experiences there.

Later chapters follow Tyson's subsequent university experiences as well as his developing career in astrophysics and explore a variety of specific topics that sometimes bear no relationship to one another. Where else could you find the personal experiences of someone who survived the events of 9/11 from a vantage point only four blocks from ground zero published in tandem with first-hand experiences of racial prejudice in America? Or short essays about cosmology, theology, and electromagnetic theory combined with tales of service on Presidential advisory committees? Somehow it all works and makes for a story that is at times difficult to put down while reading.

There are a few minor errors in the text — missing words, transpositions, dangling participles — but they are infrequent and do not detract one whit from the easy-to-follow text. Tyson is an excellent writer, and it seems clear why he has been a popular choice for media interviews. He appears to have a fondness for relating unusual facts, from mathematical trivia to scientific oddities. He has also taken the trouble to include a physics joke for the use of non-scientists wishing to relate to their scientific colleagues at parties. What do you get when you cross a rabbit with an elephant? (Answer: Rabbit elephant sine theta.) But I was occasionally disappointed by his choice of astronomical oddities. His remarks about the ultimate collision of the Andromeda Galaxy with Earth, for example, promulgate a common misconception about the orbital speed of the Earth about the Galactic centre.

In whole, however, I was greatly impressed with *The Sky Is Not the Limit*. It is a short popular book that describes how one well-known astrophysicist overcame the inevitable obstacles that all budding scientists encounter on the road to their chosen career. I consider it a must-read for every youngster who wishes to become a professional astronomer. But it also makes delightful reading for just about everyone with astronomical interests. Be careful about taking it along with you on observing sessions for reading when you get clouded out, however. You just might get so engrossed that you forget to check the sky for a break in the clouds!

David Turner

David Turner is Review Editor for the Journal *and identifies with the author of this book in having been a planetarium director in a former life. He is presently on the academic staff of Saint Mary's University.*

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The Clementine Atlas of the Moon, by Ben Bussey and Paul D. Spudis, pages 376 + 0; 28 × 24 cm, Cambridge University Press, 2004. Price $80 US hardcover. (ISBN: 0-521-81528-2).

The Moon was the focus of global attention in the 1960s when two great space powers raced to place people on its surface. For years before that, and to some extent afterwards as well, it was perhaps more commonly observed by amateur astronomers. But now it seems to be re-emerging as a target for robotic and human exploration. The United States, the European Space Agency, Japan, India, and China are all conducting or actively planning robotic missions to the Moon, and in 2004 President Bush directed NASA to return astronauts to its surface within twelve to fifteen years. So now may be a good time for a new lunar atlas, and here we have an excellent candidate.

The authors are space scientists with impeccable credentials. Spudis in particular has a long history of involvement in lunar exploration and research. He was the deputy leader of the science team for the *Clementine* mission to the Moon, which provided the images used in the atlas. Bussey is also a planetary scientist, and both men now work in the Applied Physics Laboratory at Johns Hopkins University, actively planning for new spacecraft missions to the Moon.

The *Clementine Atlas* is not just a minor update of previous work. It is a record of a specific lunar exploration mission and a fresh new look at our neighbour world. *Clementine* photographed the entire lunar surface with a set of digital cameras. That had never been done before.

The only previous global photographic coverage was from NASA's *Lunar Orbiters* in the mid-60s, and those images — archived on film — are more difficult to obtain in our increasingly digital world. There have also been substantial additions to the set of place names on the Moon since the Apollo days, and they are incorporated here. In the atlas the lunar surface is divided into 144 regions, each of which is represented twice on facing pages. One is a mosaic of *Clementine* images with a latitude/longitude grid. The other is a shaded relief drawing made by the U.S. Geological Survey, with grid and place names.

The 144 areas cover the entire surface of the Moon at uniform scale, something that no other lunar atlas has done before. Offsetting that considerable strength is a weakness that some users may find troubling, but which stems from the nature of the *Clementine* mission itself. It was designed to reveal surface composition information by taking images through different colour filters, including the infrared. That works best if the sun is high, minimizing shadows in the images. Near the equator it produces images that are a confusing mass of light and dark spots. Only the steepest slopes, usually in recently formed craters, show up clearly. Sometimes it is hard to relate the relief drawing to the photograph opposite it, though that becomes easier with experience. Nearer the poles in each hemisphere the sun is closer to the horizon, and shadows clearly delineate topography.

The book also includes an excellent summary of the current state of knowledge about the Moon, including results from *Lunar Prospector,* the spacecraft that followed *Clementine.* Rounding it off is a detailed gazetteer listing all of the place names found in the *Atlas*. It is the only up-to-date published gazetteer of the Moon in existence.

The book has much to recommend it, as outlined above. It has only one obvious flaw, a smattering of errors in the place names. See, for instance, the crater Zucchius, spelled correctly on map 124 but incorrectly on map 125. Luckily, the flaws have been collected on a useful Web site, which is easy to find by searching the Web for "clementine atlas corrections" (I say this to avoid the problem of changing URLs).

Is it a book that may be recommended to RASC members? That will depend on a member's area of interest. One point must be emphasized: the book is not designed for amateur astronomers who want to see what their telescopes will show. Each separate region is depicted as if seen from overhead, which does not match the distant view of one hemisphere we see from Earth. Active lunar observers are better served by Antonín Rükl's atlas of lunar drawings or similar works. But for people interested in lunar science and the past and forthcoming periods of exploration, it is an excellent choice.

Philip J. Stooke

Philip Stooke, an Associate Professor in the Department of Geography at the University of Western Ontario, is a planetary cartographer with interests in planetary geology and the history of space exploration. He is currently compiling an International Atlas of Lunar Exploration, *also for Cambridge.*

Astrocryptic

by Curt Nason, Moncton Centre

The solution to last issue's puzzle

1 M	E	2 T	I	3 S	■	4 P	L	5 E	I	6 O	N	7 E
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8 S	K	Y	N	E	W	S	■	9 N	A	I	A	D
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10 A	W	A	R	D	■	11 E	D	M	U	N	D	■
L	■	■	■	■	■	S	■	I	■	■	■	12 A
13 I	C	A	R	14 U	S	■	15 P	A	L	L	A	S
A	■	■	■	M	■	16 N	■	■	■	■	■	T
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21 I	■	S	■	R	■	W	■	U	■	R	■	R
22 S	K	A	D	I	■	23 T	E	L	E	S	T	O
I	■	K	■	E	■	O	■	I	■	A	■	I
24 S	H	A	P	L	E	Y	■	25 A	R	E	N	D

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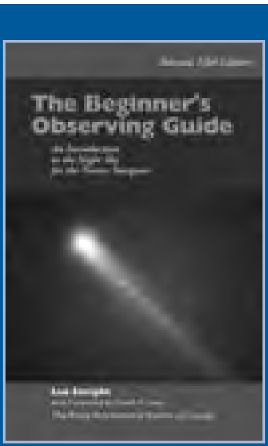

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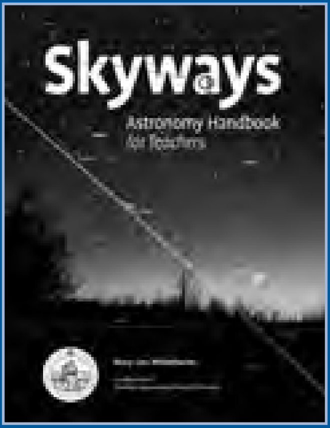

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