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April/avril 2004

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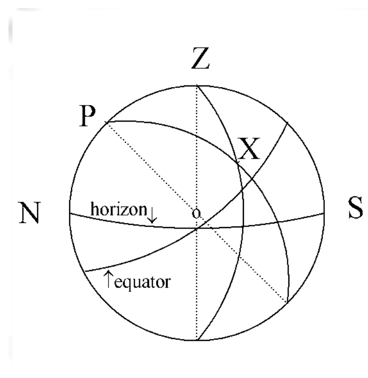

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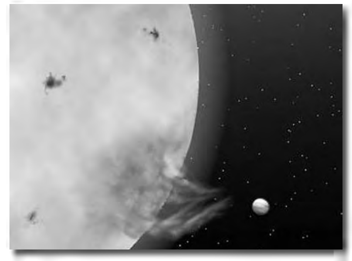

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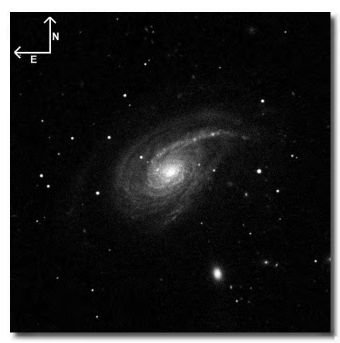

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President's Corner

by Rajiv Gupta (gupta@interchange.ubc.ca)

Budgets and finances are the last thing most RASC members want to think about. We participate, and enthusiastically so, in the Society and in our Centres because of the excellence of the night sky, not because we love to spend late nights poring over *Excel* spreadsheets. But in the coming weeks many members of the Society will be doing exactly the latter, as they prepare for the annual budget-setting meeting of National Council in early March (about a month after I write this column).

The setting of the Society's budget is the time when Council reviews the activities of the Society, predicting the financial impact of those that are ongoing and deciding which new ones to support. Council then attempts to predict what the numbers have in store for the Society over the coming year, with varying degrees of success. For example, in February of 2002 Council approved a budget for 2003 that forecast a net profit of a few thousand dollars, about 1% of the Society's annual income of a bit over $400,000. In fact, there was a large deficit in 2003; while the final figures are still being ironed out, it currently seems that the Society will report a deficit in 2003 of over $20,000, or about 5% of its annual income. This is in spite of the unexpected (and unbudgeted) $10,000 Michael Smith Award received by the Society in 2003.

The two main contributors to the unexpected deficit in 2003 were as follows:

As I mentioned in an earlier column, the drastic change in the US-dollar exchange rate resulted in approximately $25,000 less in publications revenue. Since publications revenue, most notably sales of the *Observer's Handbook*, accounts for about 60% of our total income, and most sales of the *Observer's Handbook* are in US-dollar prices to American customers, our current pricing structure means our publication-sales income is largely dependent upon the exchange rate, over which we have no control.

Our liability insurance cost increased by about $9000, quadrupling over its 2002 level. The Society purchases third-party liability insurance that allows Centres to hold public events. Often, cities and regional governments require proof of liability insurance before allowing a Centre to hold an event. The increased insurance premium was a lingering effect of 9/11, which in general turned the insurance business upside-down. Since public events are the lifeblood of many Centres, the Society had no choice but to pay the going insurance premium.

Without these two effects, the Society would have

Journal

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

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approximately broken even in 2003, even if it had not won the Michael Smith Award. In other words, we ran a deficit in 2003 because of bad luck. Increased airfare and postage costs also contributed to the size of the deficit.

So, when Council sets the budget for 2004 at its next meeting, it will be a sobering exercise. We are certainly not alone in dealing with the change in the US-dollar exchange rate; the entire export sector of the Canadian economy is feeling this effect, just as many organizations are experiencing increased insurance costs. And, like everybody else, we'll have to make some adjustments to compensate for these structural and likely lingering effects.

Just what these adjustments might be are pretty hazy in my crystal ball right now, but the haze should have at least partially lifted after the March Council meeting. It may very well be too late now to implement any adjustments in time to avoid another deficit in 2004, but something will have to be done to avoid three successive deficit years. One possible adjustment may be a membership fee increase; since publication-sales income subsidizes the costs the Society incurs to service its members, it is natural that if the subsidy decreases (because of effect 1 above) then the fees members pay for these services should increase. I hope that the level of service to our members, which I think most members are very happy with, will not have to be reduced.
Thus, financially challenging times are ahead for the Society. But many of us sturdily head out to our observing locations — most of which are located half way or more from the equator to the North Pole — in the middle of winter, so we're used to a few challenges. I'm sure we'll get ourselves out of our current financial straits, and be a stronger and healthier Society for the effort.

Editorial

by Douglas Hube (dhube@phys.ualberta.ca)

"They" say that you should not live in the past; however, astronomers are fortunate in being able to look *into* the past. That is something we do every time we put eye to eyepiece and observe a galaxy or other distant object. The finite speed of light is one of the keys to the Universe's past. (Imagine how dull the astronomer's life would be and how successfully Nature would hide many of her secrets if a photon traveled from point A to point B instantaneously!)

As astronomers there is yet another aspect of the past available to us. We can *relive* the past. Many of the most intriguing and spectacular astronomical events involve objects that move in periodic orbits. Certainly, that is the case for all objects, large and small, in the Solar System. The geometric characteristics of eclipses, close approaches, and other apparitions we have observed and that we will observe during our lifetimes are near-repeats of events that occurred during the lives of our ancestors. Successive eclipses within a Saros cycle and eclipses separated by the Metonic interval are examples of astronomical events that connect the past with the future. When our present has become our descendants' past, those same events at later points in the same cycles will allow our descendants to relive some of our astronomical experiences.

In the immediate future the recurrent astronomical events that will most dramatically connect the present with the past will be the transits of Venus on June 8, 2004 and June 5, 2012. The trials and tribulations of previous (by several *centuries*) generations of astronomers in their efforts to observe what were then scientifically important transits have been told dramatically and humorously by a former National President of this Society, Professor Donald Fernie, in his books *The Whisper and the Vision* and, more recently, *Setting Sail for the Universe*. While we would not wish to relive the physical discomforts that many of those astronomers and explorers experienced in reaching their assigned observing sites, we will all want to see with our own eyes what they saw and relive the emotional impact of the transits.

On June 8, 2004 many of us will have the good fortune to enjoy a replay of the transit of June 6, 1761. Fittingly, only a few weeks following this year's passage of our nearest planetary neighbour across the face of the Sun, members of the RASC will gather in St. John's, Newfoundland, for their annual General Assembly. GA delegates will find themselves just a short distance from the site chosen by Harvard College observers for their successful observations of the final stages of the 1761 event.

On June 5, 2012 we can relive the transit of Venus that was observed 243 years earlier by Capt. James Cook, the great naturalist Joseph Banks, and others. While we will be able to see most of the 2012 transit from all parts of Canada, an especially poignant connection with the past will be felt by those who are fortunate enough to observe from Cook's site at *Pointe Vénus* on Tahiti. Given the much better instruments available to amateur astronomers of our generation, we will be able to see for ourselves the infamous "black drop" effect that may have been recorded first by Cook and his companions.

The leisurely progress of a transit of Venus and the ease with which it can be observed with the simplest of optical devices, including the protected but unaided eye, provides members of the RASC with an invaluable opportunity to contribute to one of the Society's mandates, namely, public education. As is true of so many astronomical events, the transits will be experiences whose aesthetic value must be shared with others. Sharing the beauty of the astronomical universe with others is one of the things that members of the RASC do best. Vicariously take your family, your friends, and your neighbours back to 1882, 1874, 1769, and 1761.

As you observe the slow, elegant passage of Venus across the face of the Sun in June, give thought to how it connects you with our scientific and cultural past. Think, too, about how it is connecting you, and those with whom you share the experience, with future generations. Consider how fortunate you are to be able to observe a phenomenon denied those who were born and died during the 121½ years that followed the occurrence of the most recent transit. The scientific value in observing a transit may be negligible but the cultural and historical significance grows with the passage of time.

News Notes
En Manchettes

MAGNETIC ATTRACTION

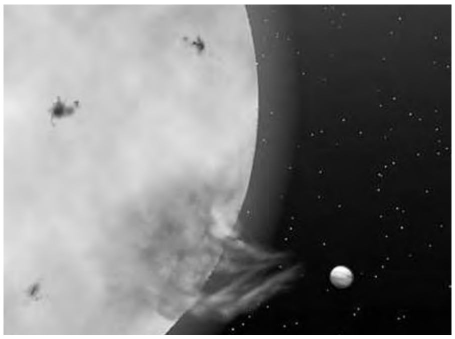

Figure 1 — Shane Erno's conception of a flare on HD179949. (Image courtesy University of British Columbia.)

The first evidence of a magnetic field on a planet outside of our Solar System has been discovered by a team of Canadian astronomers. Doctoral candidate Evgenya Shkolnik, along with Dr. Gordon Walker (University of British Columbia), and Dr. David Bohlender of the National Research Council of Canada, Herzberg Institute for Astrophysics in Victoria, reported their new findings at the meeting of the American Astronomical Society in Atlanta, Georgia this past January.

The trio of astronomers observed the sun-like star HD179949 with the 3.6-meter Canada-France-Hawaii Telescope situated atop Mauna Kea, Hawaii using its high-resolution spectrograph called Gecko. HD179949 is 90 light years away in the direction of the southern constellation of Sagittarius but it is too faint to be seen without a telescope. The planet is at least 270 times more massive than the Earth, being almost, therefore, as big as Jupiter, and orbits the star every 3.093 days at a speed of some 360,000 km h^{-1}. Such tightly orbiting "roasters" or "hot Jupiters" make up 20% of all known extrasolar planets.

The star's chromosphere (the thin, hot layer just above the visible photosphere) was observed in the ultraviolet light emitted by singly ionized Calcium atoms. Giant magnetic storms produce hot spots that are visible as bright patches in this light. Such a persistent hotspot is observed on HD 179949 keeping pace with the planet in its 3-day orbit for more than a year (or 100 orbits). The hotspot appears to be moving across the surface of the star slightly ahead of, but keeping pace with the planet.

The best explanation for the traveling hot spot is an interaction between the planet's magnetic field and the star's chromosphere, something predicted by Steve Saar of the Center for Astrophysics and Manfred Cuntz of the University of Texas at Arlington a number of years ago. If so, this is the first ever glimpse of a magnetic field on a planet outside of our Solar System, and may provide clues about the planet's structure and formation. "If we are indeed witnessing the entanglement of the magnetic field of a star with that of its planet, it gives us an entirely new insight into the nature of closely bound planets," commented Dr. Gordon Walker.

Further observations are required to determine if the magnetic interaction is a transient event or something that is longer lasting. To this end, observations with the 8-meter Gemini-South Telescope in Chile of this stellar system are underway in the infrared light emitted by Helium. These new observations will map hotspots at higher levels of the chromosphere.

YOUNG GALAXIES: OLD FOR THEIR AGE

A team of astronomers using the Frederick C. Gillett Gemini North Telescope has recently removed a critical blind spot in observational cosmology. The astronomers have been able to study the Universe at a look-back time corresponding to some 8 to 11 billion years ago, and they have found that many of the galaxies that they "see" are not behaving as expected.

The surprise is that the galaxies appear to be more fully formed and mature than expected at this early stage in the evolution of the Universe. "Theory tells us that this epoch should be dominated by little galaxies crashing together," said Dr. Roberto Abraham (University of Toronto), who is a Co-Principal Investigator in the team conducting the observations at Gemini. "We are seeing that a large fraction of the stars in the Universe are already in place when the Universe was quite young, which should not be the case. This glimpse back in time shows pretty clearly that we need to re-think what happened during this early epoch in galactic evolution. The theoreticians will definitely have something to gnaw on."

The new results were announced at the 203rd meeting of the American Astronomical Society in Atlanta, Georgia this past January. The observations are from a multinational investigation, called the Gemini Deep Deep Survey (GDDS), which used a special technique to capture the faintest galactic spectra ever detected. In all, spectra from over 300 galaxies were collected, most of which are within what is called the "Redshift Desert," corresponding to an era when the Universe was only 3 to 6 billion years old. Studying the faint galaxies at this epoch when the Universe was only 20-40% of its current age presents a daunting challenge to astronomers, even when using the light-gathering capacity of Gemini North with its 8-meter mirror. All previous galaxy surveys in this realm have focused on galaxies where intense star formation is occurring, which makes it easier to obtain

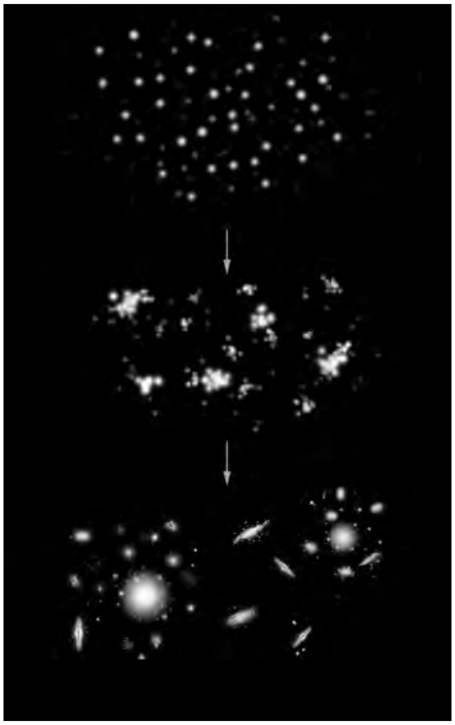

Figure 2 — The Hierarchical Model of Galaxy Formation: From top to bottom the image shows the build-up of galaxies through multiple "collisions" of small structures. The Gemini Deep Deep Survey brings into question a number of the key predictions of the Hierarchical Model. (Figure by Jon Lomberg, courtesy of Gemini Observatory Illustration). Additional images can be found at `www.gemini.edu/media/images_2004-1.html`.

spectra, but produces a biased sample. The GDDS was able to select a more representative sample of galaxies, including those galaxies that hold the most stars (normal, dimmer, and more massive galaxies) and those that demand special observing techniques to coax a spectrum from their dim light.

The survey astronomers are still trying to understand the implications of the new results. "It is unclear if we need to tweak the existing models or develop a new one in order to understand this finding," said Dr. Patrick McCarthy (Observatories of the Carnegie Institution). "It is quite obvious from the Gemini spectra that these are indeed very mature galaxies, and we are not seeing the effects of obscuring dust. Obviously there are some major aspects about the early lives of galaxies that we just don't understand. It is even possible that black holes might have been much more ubiquitous than we thought in the early Universe and played a larger role in seeding early galaxy formation."

What is arguably the dominant theory of galactic evolution suggests that the population of galaxies at this early stage should have been dominated by evolutionary building blocks. Aptly called the "Hierarchical Model" it predicts that normal to large galaxies, like those studied in the new survey, should not exist in the "Redshift Desert." Instead they should be forming from local "beehives" of collisional activity.

Trying to make observations in the "Redshift Desert" has frustrated modern astronomers for the last decade. While astronomers have known that plenty of galaxies must exist in the "Desert," it is only a "desert" because of the great difficulty in obtaining good spectra. The problem lies in the fact that the key spectroscopic features used to study these galaxies have been redshifted into a part of the optical spectrum corresponding to the faint, natural, obscuring glow of the Earth's nighttime atmosphere. To overcome this problem, a sophisticated technique called "Nod and Shuffle" was used on the Gemini telescope. "The Nod and Shuffle technique enables us to skim off the faint natural glow of the night sky to reveal the tenuous spectra of galaxies beneath it. These galaxies are over 300 times fainter than this sky glow," explains Dr. Kathy Roth, an astronomer at the Gemini observatory. "It has proven to be an extremely effective way to radically reduce the noise or contamination levels that are found in the signal from an electronic light detector."

Each observation lasted the equivalent of about 30 hours and produced nearly 100 spectra simultaneously. The entire project required over 120 hours of telescope time. "This is a lot of valuable time on the sky, but when you consider that it has allowed us to help fill in a crucial 20% gap in our understanding of the Universe, it was time well spent," adds Dr. Glazebrook who helped developed the use of "Nod and Shuffle" for faint galaxy observations while at the Anglo-Australian Observatory a few years ago. A more complete history and explanation of the technique, including its original development in the mid 1990s can be found on the Web page, `www.gemini.edu/project/announcements/press/2004-1-nod.html`.

The spectra obtained in the new survey were also used to determine the "pollution" of the interstellar gas by the heavy elements (or, so-called metals) produced by stars. This is a key indicator of the history of stellar evolution in galaxies. Sandra Savaglio (Johns Hopkins University), who studied this aspect of the research said, "Our interpretation of the Universe is strongly affected by the way we observe it. Because the GDDS observed very faint galaxies, we could detect the interstellar gas even if partly obscured by the presence of dust. Studying the chemical composition of the interstellar gas, we discovered that the galaxies in our survey are more metal-rich than expected."

NOT ENOUGH HOURS IN THE DAY?

The National Research Council of Canada's Herzberg Institute of Astrophysics has released a new sunrise/sunset calculator. The calculator is available at `www.hia-iha.nrc-cnrc.gc.ca/sunrise_adv_e.html`. Just type in your location data and the program will return information on twilight, and sunrise and sunset times.

MOST EYES PROCYON

MOST (Canada's Microvariablity and Oscillations of STars satellite) officially entered the science-operations phase of its mission this January, and started observations of its first Primary Science Target: the star Procyon (α Canis Minoris A). Procyon is the eighth brightest star in the night sky and is similar to the Sun, but is a little hotter, about twice its size, 1.5 times more massive, and some 7.5 times more luminous.

The MOST science team has assigned Procyon as one of its highest scientific priorities. Specifically the satellite will "search" for sun-like oscillations in Procyon's brightness, ultimately allowing for the unprecedented determination of its internal structure and age. Astronomers have, to date, struggled to identify oscillations in Procyon from observatories on the Earth, but theorists have built elaborate models of this star's internal structure — models that will shortly be tested against the new MOST data.

MOST is expected to observe Procyon until February 10, 2004. For the latest MOST news, see `www.astro.ubc.ca/MOST/`.

Astrocryptic

by Curt Nason, Moncton Centre

The solution to last issue's puzzle

RASC INTERNET RESOURCES

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Contact the National Office
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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`

Feature Articles
Articles de Fond

Spherical Trigonometry in Astronomy

by Raymond Auclair, unattached life member, RASC (auclair@cyberus.ca)

This article was published in French (Auclair 2003) in August 2003. The translation is by the author who has upgraded page references to the *Observer's Handbook* (now 2004) and uses Saskatoon as the setting of examples. Why Saskatoon? The idea for these articles came while spending a weekend in downtown Saskatoon, in January 2002, where it was cold enough to freeze the balls off a brass monkey.

What? A monkey? It was a triangular device affixed to the deck of ships, near the cannons. It held stacks of cannonballs arranged in a pyramid, normally 10, 6, 3, 1, with the bottom tier being a triangle of 4 cannonballs to a side (yes, that's 10). The size of the triangle was chosen to ensure a snug fit for the cannonballs so that there would be just enough room for the bottom tier, yet no slack (with a moving ship, we do not want the bottom tier to move around, as it holds the upper tiers). Permanent external fixtures on ships were often made of brass in order to deter corrosion. Expendable materials (*e.g.* cannonballs) were made of iron. Because expansion rates differ from one type of metal to another, when it got cold enough, the triangle was no longer a snug fit and some cannonballs fell off the brass monkey. Hence the nautical expression.

Back to our translation. This article is meant to invite readers to read the *Observer's Handbook* and make use of the data it contains. In order to get the most out of the article, we should look up the definition of basic words, preferably in an illustrated dictionary. Some of the basic words we need are altitude, azimuth, cosine, declination, ecliptic, latitude, longitude, pi, right ascension, sine, sphere, time zones, and zenith.

Angular Relations

On page 31 of the *Observer's Handbook 2004,* under *angular relations* we find a list of trigonometric relations that rarely catch the reader's eye.

2 π radians = 360°

In a circle, the length of an arc is often given as the value of the angle at the centre that subtends the arc. For example, the quarter circle is said to measure 90° because the angle at the centre, which subtends the quarter circle, measures 90°. A complete circumference is 360°.

The number π represents the ratio of the circumference to the diameter ($C = \pi \times D$). Because the circumference measure $2\pi R$ (R is the radius), then an arc with a length equal to the radius is subtended by an angle of $360°/2\pi$ = 57.29577951...° (57° 17′ 44.8″). This angle value is called a *radian*. Thus, 2π radians are 360°.

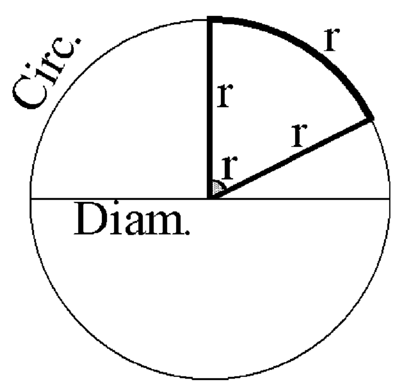

Figure 1 — Radian and radius. The angle at the centre (*r*) measures one radian and the arc it subtends also measures one radian (*r*) because its length, measured along the arc, is equal to the radius (*r*).

Astronomers often use degrees. In general, calculators take angles in degrees. However, some spreadsheets (*e.g.* Microsoft's Excel) work with radians. *Excel* uses the variable **PI()** — with an empty bracket — for the value π. Therefore, if x is the value of an angle in degrees and we need the cosine of x, we have to write **COS(x*PI()/180)**. Similarly, *Excel* gives results in radians; we will have to multiply the result (given in radians) by **180/PI()** in order to have the result in degrees.

For $360° = 24^h, 15° = 1^h, 15' = 1^m, 15'' = 1^s$

Astronomers also express some angles (and arcs) in "hours" instead of degrees or radians. The position of a body on the celestial sphere is given by the Right Ascension (symbol: RA or α) and the declination (δ). The declination — the angle between the body and the celestial equator — is normally given in degrees.

Because of Earth's rotation, the celestial sphere appears to rotate around the observer. One rotation takes approximately 24 hours. If we measure in relation to so-called "fixed" stars, a complete rotation takes $23^h\ 56^m\ 04.1^s$. Observatories are equipped with clocks that move at that rate. That is how *Sidereal Time* is defined.

Right Ascension, α, of stars is

measured along the celestial equator, from the Vernal Point where the ecliptic crosses the equator. This point, also called the First Point of Aries, is where we find the Sun at the moment of Spring Equinox[1]. The body's position is taken from the *hour circle* on which it sits. The body's hour circle passes through the body and both celestial poles. The body's Right Ascension is the angle between the hour circle that crosses the body and the one that crosses the Vernal Equinox.

Let us set the Sidereal clock to $0^h\ 00^m\ 00^s$ at the instant when the Vernal Point crosses our meridian. From then on, each hour circle passes overhead in accordance with the time shown on our Sidereal Clock (Dodd 2003). For example, our Sidereal Clock should show $6^h\ 45^m\ 18^s$ at the moment Sirius ($\alpha = 6^h\ 45.3^m$ from page 242 of the *Observer's Handbook 2004*) crosses our meridian.

We now see that there may be advantages in measuring some angles in hours rather than degrees. However, for spherical trigonometry, we need to convert hours to degrees. Because there are 24 hours in a circle (360°), each hour is worth 15°. Dividing both units by 60, we find that one minute of "time" is 15′ and one second is 15″ of arc.

The Sphere

A sphere is a surface where every single point is at an equal distance from a special point called the *centre*. The distance from the centre to the surface is the radius.

On the sphere, there are *great circles* whose centre coincides with the centre of the sphere. Perforce, a great circle has the same radius as the sphere.

On a great circle, distance (*i.e.* the length of an arc) is measured in units based on the angle, at the centre of the sphere, which subtends the arc.

Lengths on Earth's Great Circles

Mathematicians often use the length of the radius as their unit of length. Thus, they measure lengths in radians. We see in Figure 1 that the radian measures distances as well as angles. We can do the same with any other unit normally used to measure angles.

Navigators use degrees and minutes. There are 360° in a circle and each degree is further divided into 60 minutes of arc (1° = 60′). Distances on the Earth's surface can be measured in minutes of arc. An angle of 1′ at Earth's centre subtends a distance defined as one *nautical mile* on Earth's surface. Earth's circumference is 21,600 nautical miles (360 × 60).

When the metric system was designed, the circle was divided into 400 grades and each grade was further divided into 100 centigrades. An angle of one centigrade at Earth's centre subtends a distance defined as one *kilometre* on Earth's surface. Earth's circumference is 40,000 km (400 × 100).

Great Circles and Small Circles

All great circles share a common centre and have the same circumference as the sphere. Distances are measured with the same units along any great circle.

Any other circle (whose centre is not the same as the sphere) is called a small circle; they cannot be used directly in our spherical trigonometric calculations. We must restrict ourselves to great circles.

We know the Earth is not a perfect sphere. However, the accuracy we get by assuming the Earth to be spherical is sufficient for most nautical and astronomical applications.

On the spherical Earth, the equator and all longitude lines (meridians) are great circles. Circles of latitude (such as the line of 60° N on a globe) are small circles.

On the celestial sphere, the equator, the ecliptic, and the hour circles (also called meridians) are great circles. Circles of declination (other than 0°) are small circles.

The Spherical Triangle

On a sphere, let us trace three arbitrary great circles. In general, these three circles will form eight triangles on the sphere.

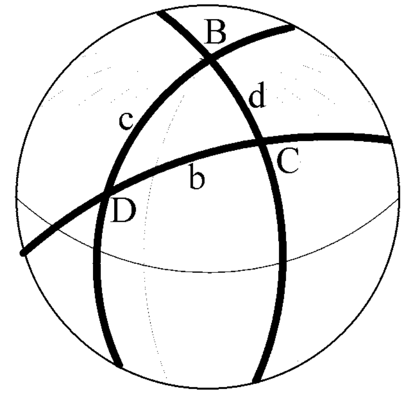

Figure 2 — The spherical triangle. Three great circles define a *BCD* triangle. The "length" of a side is measured in degrees; in this example, the length of *c* is 90° minus the latitude of the point *D*.

Often, only one of the triangles interests us. We then draw only the one triangle, without showing the others. Let us identify the angles with capital letters *B, C,* and *D*. The "sides" of the triangles are arcs and will be identified by lower case letters *b, c,* and *d* such that *b* faces *B*, *c* faces *C*, and *d* faces *D*.

Because the sides are measured in degrees, we can apply trigonometric functions to them. We will not prove the equations, simply use them.

First, let us see the *cosine formula,* the most useful one. We use it when we know the value of an angle and its two adjacent sides (in order to find the third side) or when we know all three sides and we need to find one or more angles. By permutation, we find three equivalent versions:

$$\cos b = \cos c \cos d + \sin c \sin d \cos B$$
$$\cos c = \cos d \cos b + \sin d \sin b \cos C$$
$$\cos d = \cos b \cos c + \sin b \sin c \cos D.$$

We omit the multiplication sign: cos *b* cos *c* means cos *b* multiplied by cos *c*.

Next, we look at the *sine formula,* a relationship between the length of a side and the value of the angle it faces:

$$\sin b/\sin B = \sin c/\sin C = \sin d/\sin D.$$

The sine formula does not allow us to

[1] The start of the Fall season for readers in the Southern Hemisphere.

distinguish between two possible answers when the values are close to 90° while the cosine formula has the same problem when the values are close to 0°. The second ambiguity is not as frequent in nautical astronomy.

Sine and cosine are cyclical and symmetrical functions:

$\sin x = \sin(180° - x)$ $\sin x = -\sin(-x)$
$\sin x = -\sin(360° - x)$
$\cos x = -\cos(180° - x)$ $\cos x = \cos(-x)$
$\cos x = \cos(360° - x)$
$\sin x = \cos(90° - x)$ $\cos x = \sin(90° - x)$.

The Position of the Observer

To make use of the equations, we must know our position in latitude measured from Earth's equator and in longitude measured from the First Meridian (of value 0°) at Greenwich, England.

There are many ways of finding our position: a GPS receiver, a map or a chart, a list (such as in *Norie's Tables*), or Web sites.

For our examples, we will pretend to be in Saskatoon (Saskatchewan), at position 52° 07.8´ N 106° 39.2´ W near the intersection of Spadina Crescent (also called Esplanade on some maps) and 24th Street East, just Southwest of University Bridge.

The Celestial Sphere

The celestial sphere is a sphere of indeterminate radius, centred on the observer's eye. Imagine a radius so large that Earth's radius, by comparison, is negligible. In this manner, we can claim that the centre of the celestial sphere coincides with the centre of the spherical Earth.

Next, imagine that the small sphere of Earth is oriented so that the observer appears vertical. From the same centre, draw a much larger celestial sphere. We will leave Earth immobile in relation to the observer; let the celestial sphere rotate around the observer.

On the celestial sphere, the most interesting triangle is the one that allows us to go from the equatorial system (Right Ascension and Declination) to the horizontal or *alt-azimuth* system (altitude and azimuth).

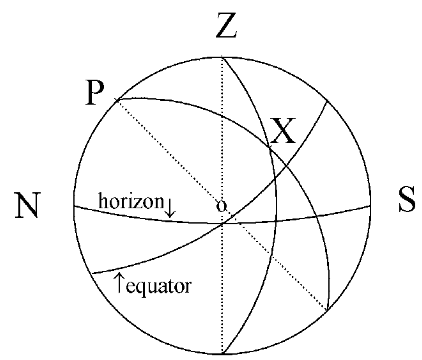

Figure 3 — The Celestial Sphere. Imagine the observer standing on the "*o*" which represents the Earth, at the centre. The length of the arc *NP* is equal to the observer's latitude.

From the equatorial system, we take the poles (where Earth's rotation axis is projected onto the celestial sphere). The elevated pole (for us, the North Pole) is identified by the letter *P*. For our now immobile observer, the celestial sphere appears to rotate around the celestial poles. At 90° from the poles, we place the *celestial equator,* sometimes identified by the letter *Q*.

When a problem implies a single body, its position is marked by *X*. Its declination δ is measured from the equator; in Figure 3, it is the distance between *X* and the equator. The complement of the declination $(90° - \delta)$ is called the *polar distance;* in Figure 3, it is the length of the arc *PX*.

The half great circles that go from pole to pole are hour circles and their value is measured from the Vernal Point. The hour circle that goes through *X* is the Right Ascension of *X*.

From the horizontal system, we take the *zenith,* located directly (and vertically) above the observer; we label it *Z*. By definition, the declination corresponding to the position of *Z* on the celestial sphere, is the (astronomical[2]) *latitude* of the observer. At 90° from the zenith we define a great circle called horizon. This would represent the horizon as seen by the observer if the Earth were perfectly spherical, if the observer's eye was exactly at the same level as the surface of the sphere, and if there were no atmospheric refraction.

Computing the Altitude

Altitude and Zenith Distance

The arc of a great circle through *Z* and perpendicular to the horizon is called a *vertical*. The great circle through *P* and *Z* forms the observer's *meridian*. The points where the meridian crosses the horizon define North and South as directions.

Verticals which, at *Z*, are perpendicular to the meridian, are called *prime verticals;* they define East and West.

On the vertical that passes through the body *X,* the portion of the arc from the horizon to *X* is the *altitude* (a). The complement of the altitude ($PX = 90° - a$) is the *zenith distance* of the body.

The PZX Triangle

Using the points *P* (pole) *Z* (zenith) and *X* (celestial body), we draw a spherical triangle on the celestial sphere.

Let us identify the values of angles and sides in the *PZX* triangle:

h is the *hour angle* (the polar angle, at *P*)
ϕ the observer's latitude ($PZ = 90° - \phi$)
A is the azimuth (the angle at *Z*)
a is the altitude ($ZX = 90° - a$)
X also represents the angle at *X* (rarely used)
δ is the declination of *X* ($PX = 90° - \delta$).

The Hour-Angle Equation: $h = t - \alpha$

The hour angle h (also called the polar angle) changes continuously. For calculations involving stars (or any object "fixed" in relation to the stars), it changes as the sidereal time *t*. If we have a Sidereal Clock, we know the value of the hour

[2] Normally unsaid, however, with increased use of GPS, there are now many flavours of latitude.

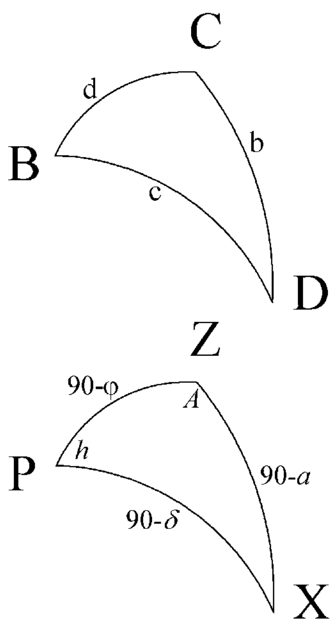

Figure 4 — The *PZX* Triangle. By linking elements from the *BCD* triangle to the *PZX* triangle, we can find the required trigonometric formulas.

circle at the meridian (*PZ*). The value of the hour circle passing through the star is the Right Ascension α of the star. Therefore, the hour angle is the difference between the two values: $h = t - \alpha$. If we get a negative value, we add 24^h. If we get more than 24^h, then we take away 24^h. We want h to be from 0^h to 24^h (corresponding to a range of 0° to 360°).

Right Ascension α for many bright stars is found on pages 240 to 248 of the *Observer's Handbook 2004*. RA for other objects can be found on pages 252 to 290. Right Ascension for the Sun is given in a table (four-day intervals) on page 103. Later in the article we will use shortcuts for calculations involving the Sun.

Computing the Sidereal Time *t*

To find sidereal time *t* without a sidereal clock, we can use the *MEAN SIDEREAL TIME 2004* table on page 42 of the *Observer's Handbook 2004*.

For example, let us find the sidereal time at our chosen position (52° 07.8′ N 106° 39.2′ W) on November 14, 2004, at $22^h\,24^m$ CST (Central Standard Time, 6 hours late on UT).

At $22^h\,24^m$ CST on November 14, 2004, Universal Time (UT) is $4^h\,24^m$ (4.40^h) on November 15. The longitude of Saskatoon (106° 39.2′ W = 106.6533° W) corresponds to an angle of $7^h\,06^m\,37^s$ (= 7.1102^h) in "time" units. We also note that the correction given for 0 Nov at 0^h UT is 2.6424^h.

Using the equations given under the table, we find:

GSMT = 2.6424 + 0.0657(15) + 1.002738(4.4)
GSMT = 2.6424 + 0.9855 + 4.4120 = 8.0399^h
GSMT = $8^h\,02^m\,24^s$
LSMT = $8.0399^h - 7.1102^h$ = 8h $02^m\,24^s$ $- 7^h\,06^m\,37^s$
LSMT = $0^h\,55^m\,47^s$ (= $0^h\,55.8^m$).

In order to apply our equations to the star Alpheratz, the brightest star in Andromeda, we find, on page 240 of the *Observer's Handbook 2004,* for the star α And:

RA = $0^h\,08.6^m$ (that is our value α for Right Ascension), and δ = +29° 07′ (meaning 29° 07′ N).

Therefore, at $22^h\,24^m$ CST on November 14, 2004, the hour angle of the star Alpheratz, seen from Saskatoon, is $h = t - \alpha = 0^h\,55.8^m - 0^h\,08.6^m = 0^h\,47.2^m \equiv 11° 48' = 11.8°$. The symbol ≡ is read as "equivalent to" as in 47.2 minutes in time units is equivalent to 11.8 degrees.

$$\sin \alpha = \sin \delta \sin \phi + \cos h \cos \delta \cos \phi$$

Going from the *BCD* triangle to the *PZX* triangle, and using the corresponding symbols, we find:

$\cos d = \cos b \cos c + \sin b \sin c \cos D$
$\cos (ZX) = \cos (PX) \cos (PZ) + \sin (PX) \sin (PZ) \cos P$
$\cos (90° - \alpha) = \cos (90° - \delta) \cos (90° - \phi) + \sin (90° - \delta) \sin (90° - \phi) \cos h$
$\sin \alpha = \sin \delta \sin \phi + \cos \delta \cos \phi \cos h.$

By reordering the factors in the second term (the product remains the same), we find the equation given in the *Observer's Handbook*.

Let us continue with our example, where we seek the altitude of Alpheratz (α And) at $22^h\,24^m$ CST on November 14, 2004, for an observer at our Saskatoon position.

$\sin \alpha$ = sin 29° 07′ sin 52° 07.8′ + cos 29° 07′ cos 52° 07.8′ cos 11° 48′
$\sin \alpha$ = 0.384116 + 0.524964 = 0.9090805
α = 65° 22.7′

We note that the angle 114° 37.3′ has the same sine value as the angle 65° 22.7′. We also note that if we turn our back to the star, then look up 90° to the zenith, then continue bending backwards a further 24° 37.3′, we should be looking at the same point *X* (albeit less comfortably). Therefore, both answers are correct; let us choose the more useful answer α = 65° 22.7′.

The Sun

In the case of the Sun, there are shortcuts. The Sun's hour angle h increases at an average rate of 15° per hour. The angle h is exactly 0° at the time of transit (upper meridian passage). If we know the exact time at which h = 0°, then it is easy to calculate h for any other time of the day.

Ephemeris for the Sun

On page 103 of the *Observer's Handbook 2004,* we find the Sun's ephemeris for the year. The column titled *Greenwich Transit*

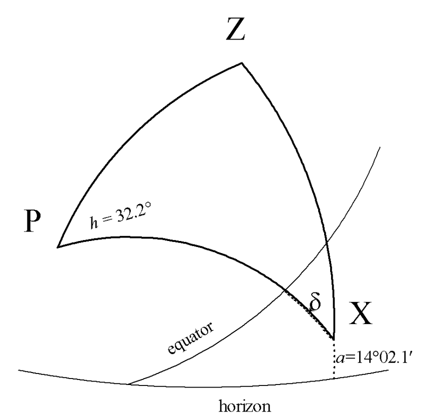

Figure 5 — The *PZX* Triangle for the Sun as seen from Saskatoon at 3 p.m. CST on November 14, 2004. δ being south (negative), $PX = 90° - \delta$ is greater than 90°.

gives the transit time (in UT) for longitude 0° at four-day intervals. We must interpolate.

For example, on November 12, 2004, Greenwich transit is to take place at 11:44:12 UT and on November 16, at 11:44:52. The rate of change is 10 seconds per day.

On November 14, 2004, Greenwich transit of the Sun occurs at 11:44:32 UT. The longitude for Saskatoon (106° 39.2′ W) corresponds to $7^h\,06^m\,37^s$ in "time" units. For calculations involving the Sun we can use this figure directly and conclude that the Sun crosses the meridian of our Saskatoon observer some $7^h\,06^m\,37^s$ after crossing the meridian at Greenwich: 11:44:32 UT + $7^h\,06^m\,37^s$ = 18:51:09 UT = 12:51:09 CST.

For extra accuracy, we note that $7^h\,06^m\,37^s$ is three tenths of a day. The rate of change of Greenwich transit is 10 seconds per day. Therefore, we add three more seconds.

Thus, near Ramon Hnatyshyn's statue in Saskatoon, h = 0° at 12:51:12 CST on November 14, 2004. We note that even though we are in November, Saskatoon is on the equivalent of daylight saving time for its longitude. That explains why the province of Saskatchewan does not add yet another hour during Summer; it stays on CST (Central Standard Time) ≡MDT (Mountain Daylight Saving Time) year round.

Photo: Statue of Ramon Hnatyshyn near the selected position; in the background, the Bessborough Hotel.

If we seek the Sun's altitude a at 3 p.m. (15:00:00 CST) on November 14, we calculate h directly as 15:00:00 – 12:51:12 = $2^h\,08^m\,48^s \equiv 32°\,12' = 32.2°$.

We have h, let us find δ then a

The table on page 103 (OH'04) gives δ for 0^h UT on November 12 (17° 44′ S) and on November 16 (18° 46′ S). The rate of change is 62′ in four days (or 15.5′ S per day). We need δ at 21^h UT on November 14 (2.875 days after 0^h UT on Nov. 12), therefore we find: δ = 17° 44′ S + (2.875 × 15.5′ S) = 18° 28.6′ S = –18.476°.

We can now find the altitude a of the Sun as seen from our Saskatoon position at 3 p.m. on November 14, 2004 (using the cosine formula from page 31 of the *Observer's Handbook 2004*).

$\sin a = \sin \delta \sin \phi + \cos h \cos \delta \cos \phi$
$\sin a = \sin(-18.476°) \sin(52.13°) + \cos(32.2°) \cos(-18.476°) \cos(52.13°)$
$\sin a = -0.250168 + 0.492679 = 0.242511$
$a = 14.0348° = 14°\,02.1'$

Computing the Azimuth

Definition(s)

The azimuth of a celestial body is the direction we face when looking directly at the body. Navigators measure the azimuth in degrees, starting from North and turning to the right. By convention, three digits are used. North is indicated by 000°, East is 090°, South is 180°, West is 270°, Northwest is 315°, and so on until we reach North again (360° ≡ 000°).

In the *PZX* triangle, the Azimuth is angle A at the point Z of our triangle (navigators use the letter Z for both the angle and the summit of the triangle). Angle A is the angle between the observer's meridian and the vertical going through the celestial body. It is possible to use the cosine formula (once we have the three sides of the triangle). However, we are curious about the sine formula. It may help us avoid ambiguities.

The sine formula:
$\cos \delta \sin h = -\cos a \sin A$

One way to avoid ambiguities is to use signs (+ and –). Because A is measured from North, latitude and declination will be considered positive when North, negative when South. As for the hour angle h, the *Observer's Handbook* uses the convention that h increases to the West: a value between 0 and 180° (or 12^h) indicates that the body is west of the observer's meridian.

However, the azimuth A increases to the East and a value of A between 0° and 180° indicates that the body is to the East of the observer's meridian. Thus the need for a negative sign (–) in the formula.

The sine formula comes from $\sin D / \sin d = \sin B / \sin b$.

In the *PZX* triangle, h is at the pole and faces the zenith distance (90° – a) while A is at the zenith and faces the polar distance (90° – δ). Therefore, we have the following relationship:

$\sin h / \sin(90° - a) = \sin A / \sin(90° - \delta)$.

Eliminate the fractions to get $\sin(90° - \delta) \sin h = \sin(90° - a) \sin A$.
Replace $\sin(90 - x)$ with $\cos x$ to get: $\cos \delta \sin h = \cos a \sin A$.
We are still left with the problem that A is measured to the left of North when h is positive. The negative sign takes care of the problem. Thus we have found the equation given in the *Observer's Handbook*:

$\cos \delta \sin h = -\cos a \sin A$.

To compute the azimuth, we isolate $\sin A$: $\sin A = \cos \delta \sin h / -\cos a$.

We apply the formula to the example for Alpheratz where we have:

$22^h\,24^m$ CST on November 14, 2004
$\delta = 29°\,27'$ N (North = positive)
$h = 11°\,48'$ (west of meridian)
$a = 65°\,22.7'$ (positive = above horizon)
$\sin A = \cos \delta \sin h / -\cos a$
$\sin A = \cos(29°\,07') \sin(11°\,48') / -\cos(65°\,22.7')$

$\sin A = -0.42881 \Rightarrow A = -25.4°$.

Because of the negative sign, we know that the azimuth will be measured towards the West. We do not know if it must be measured from the North (360° − 25.4° = 334.6°) or from the South (180° + 25.4° = 205.4°). We could simply check on a star-finder (as do navigators) however, we will allow our mathematical curiosity to take us further.

The cosine formula for A:
$$\mathbf{\sin \delta = \sin a \sin \phi + \cos a \cos A \cos \phi}$$

This is a permutation of the cosine formula we used to find the altitude a. It comes from one of the basic permutations in the *BCD* triangle:

$$\cos b = \cos c \cos d + \sin c \sin d \cos B$$
$$\cos (90° - \delta) = \cos (90° - \phi) \cos (90° - a) + \sin (90° - \phi) \sin (90° - a) \cos (A)$$
$$\sin \delta = \sin \phi \sin a + \cos \delta \cos a \cos A.$$

Rearranging the order of the factors does not change the value of the terms, so we can find the equation as given on page 31 of the *Observer's Handbook 2004:*

$$\sin \delta = \sin a \sin \phi + \cos a \cos A \cos \delta$$

Because we will apply the cosine formula from the North pole (by making North latitudes and declinations positive), we know the resulting angle will be measured from the North. However, the equation cannot distinguish East from West.

The Azimuth of Alpheratz

We seek A so let us isolate $\cos A$:
$\cos A = (\sin \delta - \sin a \sin \phi) / (\cos a \cos \phi)$,
where we have for Alpheratz:

$\delta = 29° 27'$ N (North ⇒ positive)
$\phi = 52° 07.8'$ (North ⇒ positive)
$a = 65° 22.7'$ (+ ⇒ above horizon)
$$\cos A = (\sin 29° 07' - \sin 65° 22.7' \sin 52° 07.8') / (\cos 65° 22.7' \cos 52° 07.8')$$
$\cos A = -0.903376 \Rightarrow A = 154.6°$.

Which could be 154.6° or 360° − 154.6° = 205.4°. Fortunately, we have two clues to help us pick the correct value of 205.4°:

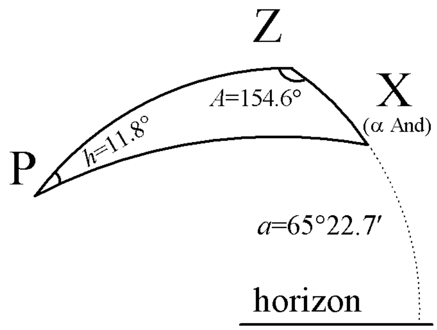

Figure 6 — The *PZX* triangle for Alpheratz as seen from Saskatoon at $22^h 24^m$ CST on November 14, 2004.

1. The hour angle h is between 0 and 180° (thus the star is West of the meridian); and
2. The sine formula, because of its use of the sign, places Alpheratz west of the meridian.

Note that if, as we did, one computes A using both formulae, then the correct answer is the value satisfying both. Therefore, we can conclude that the azimuth of Alpheratz is 205.4°.

Conclusion

The equations given in the middle of page 31 in the *Observer's Handbook 2004,* show the relationships between the angles and the sides of the *PZX* triangle. They allow us to move from the equatorial to the horizontal system and vice-versa.

Our examples show how to apply the equations in one direction. It is just as easy to go the other way. For a navigator, this feature is important. When using a sextant, the sky must still be bright enough for the navigator to see the horizon clearly. Thus, the sky is still bright, few stars are visible; patterns, such as constellations, are not apparent.

The navigator takes the altitude measured with the sextant and the azimuth measured with the compass, along with the approximate latitude of the ship, in order to determine an approximate Declination and Right Ascension (via the hour angle). In this way, the navigator identifies the star and can then use the exact RA and δ to determine a more precise value for the ship's position.

These calculations were arduous in the days before calculators and computers. Shortcuts were created and some are explained in Auclair (2004).

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www.mapquest.com/maps/latlong.adp (for approximate latitudes and longitudes of geographical positions)

The author has been a member of the RASC since 1969. After working as a marine navigation officer, he taught nautical astronomy (the use of astronomy in marine navigation) and was a dean of Nautical Science. In addition to his Coast Guard College degree in Nautical Science, he holds a B.A. (French Literature) and a B.A. with concentration (mathematics); he is completing a B.A. with Honours (mathematics). He received the RASC Service Award in 1989 and served as National Secretary of the RASC in the late nineties. He still works for Transport Canada (Transportation of Dangerous Goods) and claims to be preparing for retirement.

Christiaan Huygens

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

In the December issue, we highlighted Isaac Newton (1642-1727) and his optical work. In this issue we cross the English Channel to the Netherlands and celebrate the life and work of Dutch physicist and astronomer Christiaan Huygens (1629-95), whose 375th birthday takes place this year on April 14. Huygens made enormous contributions to mathematics, physics, and astronomy and should be regarded along with Newton as a giant of 17th century science.

Huygens was born into a wealthy and influential family in The Hague. His father was a diplomat and a poet, and personally knew the French mathematician René Descartes (1596-1650), who was a frequent houseguest. Christiaan received a good education, first studying law and then mathematics, and he wrote one of the first textbooks on probability theory.

In 1655, Christiaan and his brother developed an improved objective lens for long-focus telescopes, and constructed a telescope with which he made several important astronomical discoveries. The telescope was an "aerial" telescope: a drawing of the apparatus shows the objective mounted near the top of a fixed mast, on a swivelled contraption raised and lowered by a pulley. The observer stood on the ground seven metres away, holding a tube containing the eyepiece, connected to the objective by a long cord, whereby the objective was trained on an object and the eyepiece aligned to the optical axis. Using this telescope, Huygens discovered the Orion Nebula and the principal satellite of Saturn, Titan. He was the first person after Galileo (1564-1642) to discover a satellite of a planet.

With his improved telescope, he was able to resolve the curious appearance of Saturn as noticed by Galileo. In the previous century, Galileo had observed Saturn as three "blobs," the central one being larger, with two equally smaller blobs on either side. Huygens' telescope revealed that the blobs were actually a ring surrounding the planet. (The rings of Saturn never fail to disappoint casual observers today, so we can only imagine the thrill of their discovery three centuries ago!) The Italian-French astronomer Cassini (1625-1712) improved on Huygens, discovering four more satellites of Saturn and the division of the rings that we call the "Cassini Division." Those readers who keep back issues of *The Journal* may wish to review the *Reflections* column on Cassini from June 2000. (More on Cassini and Huygens later.)

Huygens contributed to the knowledge of mechanics and dynamics, correctly analyzing the collision of bodies. He proposed the principle of conservation of momentum, that is, the product of mass and velocity is a constant. His prime contribution in mechanics was on timekeeping: Galileo had noticed the constancy of the temporal period of the simple pendulum, but Huygens found the mathematical formula $T=2\pi\sqrt{l/g}$, in which T is the period, l is the length of the pendulum, and g is the acceleration due to gravity. He also noticed that this formula is only valid for small-amplitude oscillations, as the true period of a simple pendulum increases slightly with amplitude. (For physics students, this is because the restoring force for the oscillatory motion does not increase linearly with angle, but as the sine of the angle. At small angles, the linear approximation is close enough.) Huygens proposed a modification to the fulcrum of the simple pendulum that made the period truly independent of amplitude of motion, paving the way for the design of an accurate pendulum clock. He constructed the first such clock and presented it to the Dutch government. Pendulum clocks of the Huygens design introduced precision timekeeping into science, and two were installed at Greenwich Observatory in England, to establish a time reference in combination with the passage of the stars across the Prime Meridian.

Figure 1 — Christiaan Huygens (1629-1695), Dutch physicist and astronomer.

Huygens is perhaps best known for introducing the wave theory of light, although the full mathematical development of this theory was not worked out until the following century, by Young (1773-1829) and others. In analogy with sound waves, Huygens imagined light waves propagating by successive radiation: each wavefront acts as an extended source of secondary waves, which carry the wave forward, creating a new wavefront, and so on. Such a model correctly reproduces the laws of reflection and refraction at plane surfaces, and also explains the phenomenon of diffraction around edges, noticed by the Italian physicist Grimaldi (1618-1663). The bending of light at the boundary of two dissimilar optical media had been discovered by the Dutch physicist Willebrord Snell (1580-1626) and was known as the "law of sines" to Huygens, although we call it "Snell's law" these days. It is interesting that Huygens's wave theory was espoused as an alternative to Newton's "particle" model. In fact, Huygens's model was still mechanically based, depending on space being filled with microscopic particles of "aether" in close contact, with the wave motion transmitted by successive collisions between adjacent particles *. Science took several centuries to dispel the concept of the "aether" and to realize that light waves and other energetic fields could exist in a vacuum, with no material support. One significant attribute of the wave theory is the property of superposition, that is, two waves arriving from different directions can combine at a crossing point, but proceed unimpeded and unaffected by each other. In this way, as Huygens points out in his *Treatise on Light,* published in 1690, two observers can peer unhindered in different directions through a small hole in a screen, and people have no difficulty looking into each other's eyes.

Huygens's brilliance as a physicist was recognized internationally. He was elected as a charter member of the Royal Society in 1663 during a visit to England. He lived in France for fifteen years at the invitation of Louis XIV and helped found the French Academy of Sciences. It was during his stay in Paris that he wrote his *Treatise on Light*. In the Preface, he apologized for not translating it into Latin, the custom for important scientific works; however, by doing so he was helping to set a new trend, as Newton wrote *Opticks* in English at about the same time.

This year, in mid-April, the European Space Agency (ESA) is sponsoring a major conference "Titan, from Discovery to Encounter" to mark the anniversary of Huygens's birth and the Cassini-Huygens mission to Saturn. This summer, the NASA/ESA space probe Cassini-Huygens will arrive at Saturn for a four-year stay. The orbiter is Cassini, and the lander is Huygens, designed to enter Titan's atmosphere and descend to the ocean of the satellite by parachute. (More on these at `sci2.esa.int/huygens/conference/` and `sci.esa.int/`.)

Huygens's *Treatise on Light* is contained in Volume 34 of Encyclopedia Britannica's *Great Books of the Western World,* the same volume that contains Newton's *Principia* and *Opticks*.

As luck would have it, I will be travelling to The Netherlands to attend an acoustics conference at about the time Cassini-Huygens arrives at Saturn. I will not be far from The Hague, where Huygens died in 1695 at the age of 66. Perhaps I will be able to make a pilgrimage to the home of this productive and influential scientist.

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* Have you seen that desktop diversion that consists of a line of large ball bearings, independently suspended, but in contact? If you draw an end ball back and let go, it strikes the row, and the one at the other end shoots off, leaving the others apparently undisturbed.

A Crucial Rung on the Distance Ladder of the Universe

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

A fundamental question that any astronomer will ask about any object in the sky is "how far away is it?" The answer, combined with the brightness of the object, tells us a lot about it. The *Hipparcos* satellite was launched by the European Space Agency in the early 1990s with the express purpose of determining accurate distances to many thousands of stars in our Galaxy. But a problem arose — the distance determined by Hipparcos for the Pleiades, a nearby open cluster, was significantly less than the distance from the standard "main-sequence-fitting" technique. Shri Kulkarni of Caltech and his collaborators Xiaopei Pan and Michael Shao at the Jet Propulsion Laboratory recently used an optical interferometer to determine an independent geometrical distance to the Pleiades: they find that the old main-sequence method is right, and *Hipparcos* is wrong (see January 22, 2004 issue of *Nature*). This is not to say that the *Hipparcos* measurements are all wrong, but it does seem that their precision was not sufficient to get a good distance to the Pleiades.

Historically, a lot of effort has been devoted by astronomers to determining distances ever further out in the Universe to produce the "distance ladder." The idea behind the ladder is to use a series of techniques to measure ever further distances, with each "higher" rung being calibrated using the next lower rung, or a combination of techniques.

The best and most reliable distances have historically been determined by parallax — the orbital motion of the Earth around the Sun leads to an apparent periodic motion of nearby stars against the more distant background stars in the sky. A simple example of parallax is to hold up your index finger in front of your face, close one eye, and look at the position of your finger with respect to more distant objects. Then close that eye and open the other — your finger appears to move with respect to the background objects. That's parallax. In the sky, astronomers take pictures of star fields six months apart, to maximize the deflection as the Earth moves from one side of the Sun to the other. Unfortunately, the parallax distance method only works for measuring distances to the nearest stars — the advantage of *Hipparcos* was that because it was in space the positions of the stars were not smeared by atmospheric turbulence, so it could determine distances to stars that are farther away.

One of the next fundamental rungs on the ladder is the distances to open clusters, as that provides the calibration for Cepheids, which are essential for getting distances to nearby galaxies. Cluster distances are determined using "main-sequence fitting." The general idea is quite simple, and based on the fundamental physics of stellar evolution: the position of a star in a Hertzsprung-Russell diagram (a plot of colour vs. brightness) is uniquely determined by its mass, age, and composition (the abundance of elements heavier than helium). Most stars near the Sun have "metallicities" not too different from the Sun, so in practical terms composition has little effect. The colours and brightnesses of stars in the cluster are plotted on an H-R diagram, which typically shows a sharp up-turn. This is the point at which the stars evolve to leave the main sequence and start the giant phase of their lives. The position of the up-turn in the diagram determines the age of the cluster. A comparison of the H-R diagram of a cluster with an unknown distance with the H-R diagram of the Hyades cluster lets an astronomer determine the unknown, simply by comparing the observed

Table 1.
The "Historic" Distance Ladder

Object	Method
Nearest stars	trigonometric parallax
Hyades open cluster	moving cluster method
Open clusters	main-sequence fitting to Hyades
Classical Cepheids	period-luminosity relationship calibrated on open clusters
RR Lyrae stars	statistical methods to field RR Lyrae stars
Globular clusters	RR Lyrae stars
Type II Cepheids	P-L relation from Cepheids in globular clusters
Nearby galaxies	Cepheids, RR Lyrae stars, brightness of globular clusters
More distant galaxies	Fischer-Tully, type Ia supernovae, photometric redshift

brightness of the main-sequence stars, because the distance to the Hyades is known. It sounds a bit complicated when explained in words, but is really pretty straightforward.

The Hyades itself contains no Cepheids, which is why the younger clusters are important to calibrate the Cepheids. Once the distances to some Cepheids were known it was clear that there was a systematic relationship between the luminosity of the star and its variability — this is known as the period-luminosity law. It means that all you have to do is observe the period of a Cepheid's variability and you know immediately how luminous it is. A comparison with the observed brightness gives the distance. Within the past five years the use of type Ia supernovae has superseded almost all other techniques for galaxies other than the ones closest to us.

Stellar evolution theory has evolved to the point where the brightnesses and colours of stars can be specified very exactly, calibrating to the observations of the Hyades. Everything fit together very well until *Hipparcos* came along with a distance to the Pleiades of 10 percent less than the models of stellar evolution predicted. Did this mean that those models were really in error by so much? (It was generally believed at this time that the uncertainties in the models were at the level of a few percent — at most.) There also were differences between the *Hipparcos* and main-sequence-fitting distances of other clusters, but the Pleiades result was the distance that generated the most controversy. The distances agreed for the Hyades. Because the Hyades cluster is much closer than the Pleiades, the *Hipparcos* measurements were more accurate. In addition, the Hyades are spread over a larger part of the sky than the Pleiades, so averaging the results for all of the stars removed the kind of systematic errors that might have affected the Pleiades results.

If the *Hipparcos* result is right, then distances to globular clusters and nearby galaxies are wrong, and the ages of the clusters are wrong. Moreover, it means that something about the standard model of basic stellar physics is wrong. On the other hand, if the main-sequence distance to the Pleiades is right, then there must be some systematic error with the *Hipparcos* measurements, which were supposed to be very accurate. None of the previous attempts to resolve the controversy led to any agreement by both sides of the debate.

Pan, Shao, and Kulkarni have used a straightforward (but technically quite difficult) measurement to determine the distance. One of the brightest stars in the Pleiades — named Atlas — is a binary with a period of 290.7 days. Using an optical interferometer, Kepler's third law of orbital motion (which relates the physical semi-major axis of the orbit to the total mass of the two stars and the orbital period) and a bit of footwork with the mass-luminosity relationship between stars, Kulkarni gets a distance of ~136 parsecs (compared to the *Hipparcos* distance of 118 pc and a main-sequence distance of ~132 pc). He also gets a hard lower limit to the possible distance of 127 pc, which is more than 2σ above the *Hipparcos* distance.

What went wrong with *Hipparcos*? It experienced an engine failure during orbital insertion, which led to a highly elliptical orbit. Bohdan Paczynski of Princeton University speculates that the error is a result of this unplanned orbit (see January 22, 2004 issue of *Nature*). Will this settle the issue? I have to wonder. It is not often that the managers of spacecraft missions admit to a flaw — the out-of-focus images from the HST forced NASA to admit that something was wrong, but that's the exception. One weak point in Kulkarni's method is that it does depend on the present stellar models, although that dependence is itself weak.

The next step in confirming Kulkarni's distance will be the determination of radial velocity shifts in the spectra of the stars and/or observations of other binaries in the Pleiades. When combined with Kulkarni's original data the distance should be accurate to ±2 percent, independent of stellar models and very definitive. The debate should be completely resolved within the next year or two.

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VISUAL PERFORMANCE IN ASTRONOMY NEAR THE SCOTOPIC THRESHOLD PART 1: TEMPORAL INTEGRATION

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Abstract. The integration time of vision near the scotopic threshold was measured for four observers while viewing astronomical targets. This appears to be the first time such measurements have been made using natural targets in the night sky. The targets included: (1) a point source (a faint star), (2) an extended complex white-light source (a spiral galaxy), and (3) extended dark structure in a line-spectrum source (silhouetted dust in an emission nebula). Integration times were, respectively: (1) 0.92 ± 0.14 s, (2) 0.32 ± 0.14 s, and (3) 0.57 ± 0.19 s (averages with standard deviations).

Résumé. La période d'intégration de la vue au seuil scotopique de quatre observateurs a été mesurée durant l'observation d'objects astronomiques divers. Nous croyons que c'est la première fois que ces mesures ont été prises en observant des objets célestes durant la nuit. Les objets ont compris : (1) un point brillant (une étoile à peine visible) ; une source de lumière blanche complexe et étendue (une galaxie spirale) ; et une structure étendue de matière noire au sein d'une source spectrale rayée (de la poussière foncée en silhouette dans une nébuleuse d'émission). Les périodes d'intégration sont, respectivement : (1) 0.92 ± 0.14 s, (2) 0.32 ± 0.14 s, et (3) 0.57 ± 0.19 s (en moyenne, avec écarts types).

1. Introduction

Just as a photographic film or a charge coupled-device (CCD) requires an exposure time interval to register an image, so too does the retina. Within limits, all three devices sum or integrate light. The longer the exposure, the larger will be the signal-to-noise ratio. A CCD ceases to give an output proportional to the light received once its individual pixels are full. For long exposures photographic film has a non-linear response (reciprocity failure) and, like a CCD, fails completely once it is saturated. Provided luminances do not exceed about 10^5 cd/m^2 the retina does not saturate. However, vision evolved to provide an optimum compromise between time resolution and light sensitivity for an active primate (Rose 1973; Warrant 1999); as a consequence, the maximum integration time of vision is much shorter than that of a CCD or photographic film, and decreases as light levels increase.

Extra-retinal photoreceptors (for example, in the pineal gland of many vertebrates) that are not designed to detect transient changes in illumination can, like a CCD, have integration times that extend to hours (Lythgoe 1984). Thus it is the necessity of time resolution that determines visual integration times and not any fundamental limit on the ability of biological systems to integrate light.

Within the limit of its integration time the visual response is determined not by the intensity I of a light source, but by the total amount of luminous energy received. The eye sums luminous energy over time in a non-dissipative fashion (Schade 1956). This behavior is known as "Bloch's law" (Bloch 1885).

The maximum exposure time during which Bloch's law holds is called the "critical duration" t_c. For a constant response Bloch's law may be written:

$$\int I\,dt = k \quad (t \le t_c), \tag{1}$$

where k is a constant. Bloch's law is occasionally referred to as the Bunsen-Roscoe law; however, the Bunsen-Roscoe law concerns photochemical effects in general whereas Bloch's law concerns vision only (Ejima & Takahashi 1988).

If I is unchanging during the exposure, equation (1) becomes:

$$I = k / t \quad (t \le t_c), \tag{2}$$

and the value of I for a constant response is inversely proportional to the exposure time. For a light source that has an intensity I_o when viewed continuously, Bloch's law may be written:

$$I_A = I_o\, t / t_c \quad (t \le t_c), \tag{3}$$

where I_A is the apparent intensity of the source. For times less than t_c, I_A increases linearly with the exposure time t.

Like most empirical psychophysical laws, Bloch's law only approximates the complex behavior of vision (Donner 1992). For very short exposures (< 20 ms) Bloch's law is obeyed, but for longer times it begins to fail until for sufficiently long exposures $I_A = I_o$. That is, looking for an even longer time at a fixed source of light will not make it appear any brighter. Among the parameters influencing the intensity-time behavior are: the state of dark adaptation, the intensity of the source, the angular size of the source, the luminance of the background, retinal location of the image, the wavelength of the light in the case of foveal vision, and whether detection or resolution is involved (Sperling & Jolliffe 1965; Brown & Black 1976; Montellese, Sharpe & Brown 1979; Harwerth, Fredenburg & Smith 2003). Temporal integration is greatest (large t_c) for small dim stimuli, for low background luminances, and possibly for retinal regions about 5° or 10° from the fovea (Barlow 1958; Ronchi 1971).

For dark-adapted foveal (cone) vision, t_c is near 100 ms, and decreases with light adaptation to 20 to 60 ms. At scotopic levels (dark-adapted, peripheral rod vision), some reports place t_c in the range of 100 to 270 ms (Rose 1948; Long 1951; Baumgardt & Hillman 1961; Battersby & Schuckman 1970; Baron & Westheimer 1973; Montellese, Sharpe & Brown 1979; Gegenfurtner, Mayser & Sharpe 2000), whereas others report partial summation for durations up to 1 or 2 s in the case of small diameter stimuli (Barlow 1958; Sperling & Jolliffe 1965). Baumgardt (1959) says that partial summation can occur for up to 3 s, and Blackwell (1946) found that minimum thresholds are not reached until exposure times approach 15 s!

Pieron's law represents an attempt to describe the gradual transition from the complete summation of Bloch's law to no summation when $t >> t_c$ (Baumgardt 1959):

$$I = k / t^{1/2} \tag{4}$$

A single equation that attempts to model the overall constant-response intensity-time behavior of vision has been given by Blondel and Rey (Langmuir & Westendorp, 1931):

$$I = I_o\,(t + 0.21)/t \tag{5}$$

For large t, $I = I_o$, the intensity for a steady light (no integration). For small t equation (5) approaches equation (2) (complete integration) where $0.21\, I_o = k$. The constant time (0.21 s) marks the transition from integration to no integration except that the transition is abrupt in equation (2) and gradual in equation (5). Long (1951) reports that an abrupt transition occurs in the case of small targets.

Langmuir and Westendorp found that for very low background luminances (less than 0.1 that of the moonless night sky) the constant in equation (5) is 1.7 s, indicating that the eye integrates for a substantially longer time when light levels are very low. For background luminances equal to the moonless night sky and brighter, they used the constant 0.21.

We are not aware of any published measurements of t_c made under other than controlled laboratory conditions with artificial targets. Our investigation appears to be the first attempt to measure visual integration times using astronomical targets in the night sky.

2. Apparatus

Measurements were made during four moonless nights in April 2002 using the University of Hawaii 0.61-m telescope on the summit of Mauna Kea (altitude 4200 m, latitude 19° 50′ N, longitude 155° 28′ W), arguably the best observing site on Earth (Schaefer 1990) (see Figure 1). This site facilitated our multi-observer project by providing clear, transparent, steady skies on several successive nights, and a telescope large enough to accommodate our equipment.

Figure 1 — The summit of Mauna Kea looking northwestward. From the left: the J.C. Maxwell telescope, the California Institute of Technology telescope, the Subaru 8-m telescope, the twin Keck I and Keck II 10-m telescopes, the United Kingdom IR telescope, the NASA IR telescope, the U of Hawaii 2.2-m telescope, the Gemini North 8-m telescope, and the Canada-France-Hawaii 3.6-m telescope. The 0.61-m observatory is on the ridge in the centre, directly in front of Keck I. On the horizon 130 km distant is 3050-m Haleakala on the island of Maui. (Photo by Richard Wainscoat, & reproduced with his permission.)

All visual observations were made using a 35-mm Panoptic TeleVue™ eyepiece at the f/15.2 Cassegrain focus, yielding a magnification of 264×, a 2.3-mm diameter exit pupil, a 68° diameter apparent field, and a 15′ actual field. A 2.3-mm exit pupil is near the optimum for minimizing the combined influence of optical aberrations in the eyes of the observers and blurring due to diffraction (Campbell & Gubisch 1966; Vos, Walraven & vanMeeteren 1976; Lythgoe 1979; Liang, Williams & Miller 1997). Also, the relatively small exit pupil ensured that the scotopic Stiles-Crawford effect did not reduce the eye's response to the incoming light (Van Loo & Enoch 1975).

Obscuration by the secondary mirror of the telescope, light losses at three mirrors (one of which was in less than pristine condition), and light losses in the eyepiece were estimated to reduce the amount of light transmitted by the telescope by a factor of about 0.6. Assuming an average unaided eye entrance pupil diameter of 6 mm, the luminance of the background sky as viewed through the telescope was about $0.6\,(2.3/6)^2 = 0.09$ of the luminance of the moonless night sky on Mauna Kea as viewed by the unaided eye. The latter luminance is about 2×10^{-4} cd/m^2 (Schaefer 1990), so the telescopic background sky luminance was only about 2×10^{-5} cd/m^2. Nevertheless this was still above the scotopic threshold (~10^{-6} cd/m^2) and was visually obvious in comparison to the black border provided by the field stop of the eyepiece.

A large, solenoid-driven mechanical shutter was placed in the light path on the telescope side of the eyepiece. The circuit controlling the shutter used a single chip microcontroller from Microchip Inc., model PIC16F628 (see `www.microchip.com`). A 12.288 MHz quartz crystal provided the time base ensuring accurate timing over a wide temperature range. The "PIC" integrated circuit contains ROM and RAM memory, input/output ports, and an RS232 serial interface. A program was written in the Basic programming language and compiled for use with the "PIC" using *PicBasic Pro* (see `www.melabs.com` for details) to make the "PIC" perform as required. A 12-volt regulated power-supply was used to power the shutter and the timer circuit. A TIP110 Darlington NPN power transistor interfaced the high-current shutter with the low voltage and low current output from the "PIC."

Twenty-eight selectable time intervals were programmed, ranging from 43 ms to 5.2 s in a geometric sequence, each step being approximately 20% longer than the preceding one. This range was chosen to more than span anticipated integration times, and the 20% increment was chosen as a "small yet detectable" change. Because the shutter was a spring-loaded mechanical device and therefore did not respond instantly to electrical signals, each of the 28 shutter time intervals was calibrated using a photocell and a digital oscilloscope. For each shutter time, three measurements were made and the mean of these calculated. At longer shutter times the display on the oscilloscope was a sharply-defined square pulse making measurements easy. At shorter shutter times the mechanical response of the shutter caused the rise and fall edges of the pulse to appear rounded. In these cases the pulse widths were measured at the half-maximum values.

An observer could move up or down the sequence of interval times by pressing one of two large, well-spaced buttons. With each button press, an audible signal indicated that the interval had been altered and the frequency of the tone indicated whether the change was an increase or a decrease. This acoustic feature was necessary since the shutter was operated in the dark, and with gloves because of the freezing temperatures on Mauna Kea.

A third button reset the shutter timing to either the shortest or longest step. Pressing it twice in succession altered the setting from the longest to the shortest step or vice versa, and an audible tone indicated the result. A toggle switch allowed the timing circuit to be bypassed, leaving the shutter open (see Figure 2).

Figure 2 — A view of the lower end of the 0.61-m telescope. The shutter control circuit is in the rectangular box upon which are mounted the five switches that were used to adjust and activate the shutter. The 35-mm eyepiece is near the left side. (Photo by Roy Bishop)

To activate the shutter, the observer pressed a fourth button (having its own unique audible signal) and, after a 2-second delay to allow the observer to concentrate on the about-to-be-presented view, the shutter opened for the pre-determined time interval. The RS232 interface was connected to a laptop computer that indicated the buttons the observer was pressing and the un-calibrated shutter time intervals being selected.

3. Targets

Three types of targets near the threshold of scotopic vision were selected: (1) a point source (a faint star); (2) an extended complex white-light source (a spiral galaxy); and (3) an extended dark structure in a line-spectrum source (silhouetted dust in an emission nebula). These provided minimum coverage of the variety of faint objects encountered in astronomy: narrow-band and broad-band sources, point and extended sources. We were interested to see if temporal integration time showed any correlation with these parameters.

The faint star target was chosen from a calibrated visual magnitude sequence of stars within the open star cluster NGC 2682 (M67) (Schaefer 1989; Pitcairn 2003). A star of visual magnitude 16.31 was selected just prior to making the measurements. Although this star was not the faintest one detectable, it was near threshold, being visible to the observers about 50% of the time. A 50% criterion is the usual definition for an object at threshold (Barlow 1956). With a colour index (B–V) of 0.99 this star is similar to Pollux, which appears pale yellow. During the measurements the star was at altitudes in excess of 45° above the horizon.

NGC 5194/5 (M51), a double galaxy system with well-developed structure, was chosen as the extended white-light target. Although M51 is a relatively bright object (integrated visual magnitude 8.4), it contains much complex structure, only some of which is visually apparent. During the measurements M51 was at altitudes in excess of 59° above the horizon.

NGC 6611 (M16) was used as the third target. In its central region "elephant trunk" structures of opaque dust are silhouetted against a dim emission nebula (Currie *et al.* 1996). The fluorescing gas is visible primarily because of three emission lines at wavelengths 486 nm (Hβ), 496 and 501 nm (O^{++}). All three lines lie near the 507 nm peak response of scotopic vision (Bishop 2003). During the measurements M16 was at altitudes in excess of 38° above the horizon, for which atmospheric extinction is no more than 0.1 magnitude.

4. Measurements

"*Few astronomers, amateur or professional, have attempted to make serious visual observations at Mauna Kea's 14,000-foot (4200 m) altitude, where oxygen deprivation clouds the mind and reduces the eye's ability to perceive dim objects*." (Ferris 2002)

Despite this statement, determinations of naked-eye limiting visual magnitudes with and without supplementary oxygen at three different altitudes (2100 m, 2900 m, and 4200 m) indicated that for our group of acclimatized observers visual sensitivity was not affected by the low oxygen levels (60% of sea-level) at the summit (Whitehorne 2003). Prior to the measurements reported here, we acclimatized to the altitude by spending 54 hours at the Onizuka Center for International Astronomy at Hale Pohaku (altitude 2800 m) including 9 hours at the summit prior to commencing observations (see Figure 3), and did not return to sea level until a week later when the observations were complete.

Figure 3 — Greg Palman, Roy Bishop, and Bill Thurlow beside the 0.61-m observatory. (Photo by David Lane)

All observations were done under full dark adaptation, and the usual technique of "averted vision" was employed in order to place targets 5˚ to 15˚ from the fovea in the most sensitive portion of the retina (Wyszecki & Stiles 1982). Each observer viewed a target for several minutes in order to become familiar with it. In the case of the two extended targets, prior to measuring the integration time the observer made a sketch of the target to focus his attention on the structure visible in the target and to provide a permanent record for later comparison with CCD images of the target (see the following paper, Bishop & Lane 2004b). The thought that we were doing visual sketches next door to the Keck, Gemini, and Subaru telescopes crossed our minds.

After becoming familiar with the target, the observer activated the shutter and attempted to determine *the shortest shutter time interval that presented the target as well as it had been seen with the shutter open continuously*. In the case of the extended targets, this was the time needed to glimpse any particular faint detail in the target. To direct attention to the various parts of an extended target in order to assimilate the *entire* visible image an observer requires a considerably longer time. However, this is true whether viewing an extended target directly or viewing a photographic or CCD image of the target.

When the observer was satisfied with the shutter interval selected, another person recorded the result from the computer. Neither the sketches, the shutter interval times, nor comments concerning the visual impressions of the two extended targets were shared until all observations were complete.

Although it might seem a simple procedure to select the minimum shutter interval that provides a view equivalent to the uninterrupted view, in practice this determination required much effort on the part of the observer. This was, in part, due to the random occurrence of photon events in the retina (a Poisson distribution in time). A complicating factor was the decision criterion used by the observer, the balance chosen between sensitivity and reliability (Sakitt 1972; Donner 1992). The extent to which the transition from Bloch's law to no summation was abrupt or gradual was another variable. Yet another complication, particularly for monocular vision as used in this investigation, is the "blind spot" where the optic nerve exits the retina. Not only is the blind spot large (about 6˚ in diameter), but the brain fills in this space with a copy of the surrounding field making this blank region of the retina itself invisible (Ramachandran 1992; Murakami 1995; He & Davis 2001). In the case of the faint star target, a similar difficulty was that the vascular network of the retina lies in front of the peripheral photoreceptors. Whenever the optical image of a faint star happens to fall on a vein or artery it cannot be seen.

The faint star target required the most effort, especially since even when the shutter was open continuously the star was visible only about 50% of the time. In this instance the minimum shutter time interval selected was the one that revealed the star on about half of several trials using this interval. With shorter intervals the star was seldom if ever visible; with longer intervals the star was visible on more than half the trials. The presence of several brighter cluster stars in the telescopic field enabled the observer to direct attention to the location of the test star (without foveating it), thereby optimizing the chance of seeing it (Langmuir & Westendorp 1931; Bashinski & Bacharach 1980; Saarinen 1993; Nachmias 2002); however, the observer still had to search for the star over a small area, and as Blackwell (1946) noted in his comprehensive study of visual thresholds: "under these conditions, the motivation and fatigue of the observers became extremely important."

The ages of the observers were: 38, 53, 60, and 62. There are significant age-related declines in the scotopic sensitivity of the human visual system, attributable to both optical and neural factors (Devaney & Johnson 1980; Bowen 1991; Spear 1993; Schefrin *et al.* 1999; Jackson & Owsley 2000). In three instances (one described in the next paragraph and the other two in the following paper (Bishop & Lane 2004b), the observations indicated such a trend.

The table below gives the measured integration times in seconds. Observers are numbered in ascending order of age. Not included in the table is a fifth observer who was unable to see the target star, was not present during the galaxy measurements, and used supplementary oxygen during the nebula measurements. Observer 3 had difficulty with the nebula target and was unable to produce a sketch or determine an integration time; this difficulty may have been due to the altitude or possibly to the decline of scotopic vision with age.

Table 1.
Measured Integration Times (seconds)

Observer	Star	Galaxy	Nebula	$<t_c>_o$
1	1.03	0.23	0.73	0.66
2	0.73	0.20	0.36	0.43
3	0.87	0.36	—	0.62
4	1.03	0.50	0.61	0.71
$<t_c>$	0.92	0.32	0.57	
$\pm\sigma$	± 0.14	± 0.14	± 0.19	

The penultimate row gives the average integration time obtained for each target. The last row gives the associated standard deviation. The right-hand column gives the integration time for each observer averaged over all the targets.

5. Discussion

The only significant difference among the observers as far as integration times are concerned was that observer 2 had the shortest time for all three targets, but it was not apparent whether this was due to the sensitivity/reliability criterion used, to a physiological difference, or to some other factor. Also, aside from the difficulty observer 3 had with the nebula target (described above), there is no indication that integration time is age-dependent; however, only four observers participated in this investigation and their range of ages was somewhat limited (38 to 62).

Of the three targets, the galaxy was the brightest and the star the dimmest, thus it is not surprising that the integration times became longer in the same order. Also, the target with the smallest size had the longest integration time, consistent with Barlow's (1958) results for the retina 6.5° from the fovea. Other than these anticipated inverse correlations of integration time with brightness and size, no dependence upon source spectrum can be inferred from our limited data.

The individual integration times, from about 200 ms to 1.0 s, are within the range of values reported for scotopic vision under controlled laboratory conditions: 100 ms to about 2 s (see the introduction). Our results indicate that the most-often-cited integration time, 100 ms, appears to be too small, at least for observations near threshold.

Also, our results do not support visual integration times beyond about 1.0 s. There are at least three possible reasons why longer times are sometimes cited: (1) Momentary loss of the target signal due to the vascular network overlying the retina, to the blind spot associated with the optic nerve, or to the observer not consistently using averted vision; (2) Confusion between the time required to see a single detail in an extended image and the time required to assimilate the entire image; (3) Confusion between the integration process and statistical fluctuations in the signal from a target near the scotopic threshold. In the last case, a *very* faint star will be glimpsed sporadically, at intervals of possibly 5 seconds or longer, when random fluctuations in the rate of photons triggering rod photoreceptors occasionally cause the signal to exceed threshold (Pirenne 1967).

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*It is with deep regret that we record the unexpected death of Bill Thurlow on February 14, 2004

VISUAL PERFORMANCE IN ASTRONOMY NEAR THE SCOTOPIC THRESHOLD PART 2: VISION VERSUS CCD

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Abstract. Based on the integration times reported in Part 1 (see the preceding paper, Bishop & Lane 2004a), the performance of vision and of a CCD in registering images of a faint star, a spiral galaxy, and an emission nebula are compared. Also, the images of the galaxy are compared to a pre-photographic mid-19th-century sketch made using the largest telescope of that era. The results indicate that, contrary to common wisdom, within the limit of its integration time the performance of vision near the scotopic threshold exceeds that of a CCD. That the eye can perform so well despite its low quantum efficiency, warm operating temperature and limited spectral response is attributed to two properties of the scotopic visual system: (i) the displacement of the rod photoreceptor spectral response toward higher quantum energies; (ii) the binning of rod photoreceptors into a variety of parallel summation pools.

Résumé. Basées sur les périodes d'intégration présentées dans la Section 1 (voir l'article précédent, Bishop & Lane 2004a), les performances de la vue et d'une caméra CCD enregistrant des images d'une étoile à peine visible, d'une galaxie spirale et d'une nébuleuse d'émission sont comparées. Aussi, les images de la galaxie sont comparées à un croquis pré-photographique du milieux du 19ième siècle fait à l'aide du plus grand téléscope de cette ère. Les résultats indiquent que, contrairement aux notions communes, dans les limites de sa période d'intégration la performance de la vue près du seuil scotopique dépasse celle d'un CCD. Le fait que l'oeuil peut fonctionner si bien, en dépis de sa basse efficacité quantique, de la température assez élevée dans laquelle l'oeuil fonctionne et de sa sensibilité spectrale limitée peut être attribué à deux caractéristiques du système scotopique visuel : (i) le déplacement de la réponse spectrale des bâtonnets photorécepteurs vers les quantums d'énergies plus élevés ; (ii) le binning des bâtonnets photorécepteurs dans divers sommaires parallels.

1. Introduction

The history of astronomy spans more than two millennia, and for most of that time all observations were visual. The many discoveries of those centuries were enabled and constrained by the properties of human vision. With the introduction of photography into astronomy in the last half of the 19th century (Lankford 1984) visual astronomy gradually became the exclusive privilege of the amateur astronomer. The advent of radio telescopes in the mid-20th century and of charge-coupled devices (CCDs) later in that century reinforced this trend. "Thus, for the last century, modern astrophysics has passed by questions relating to visual observations of the sky" (Schaefer 1993). Yet despite the advance of technology, vision remains an essential link between the Universe and brain. Images from the Hubble Space Telescope and contour maps displaying radio telescope data remain unknown until viewed by the eye.

Along with advances in astronomy, much has been learned about vision during the last several centuries. Alhazen, Kepler, Descartes, Newton, Young, Maxwell, Helmholtz, Schultze, Hering, Hecht, Hartline, Wald, Rushton, and Hubel are among those who have made major contributions to visual science (Crone 1999). Yet some of the most fundamental insights and discoveries concerning vision are not yet common knowledge, even among scientists in other fields such as astronomy.

Our investigation appears to be the first attempt to compare vision with a CCD on an equal-time basis using astronomical targets in the night sky.

2. Apparatus

Observations were made using the University of Hawaii 0.61-m telescope on Mauna Kea (see the preceding paper, Part 1, Bishop & Lane 2004a). Visual impressions of the two extended targets of Part 1 were sketched using a soft (5B) pencil and artist-quality paper supported on a small, portable clipboard illuminated by a very dim, red-orange, shielded light attached to the clipboard.

Digital images were obtained using a Santa Barbara Instrument Group ST-8 CCD camera using a standard Kodak KAF 1600 CCD. The camera was mounted on the side of the housing holding the

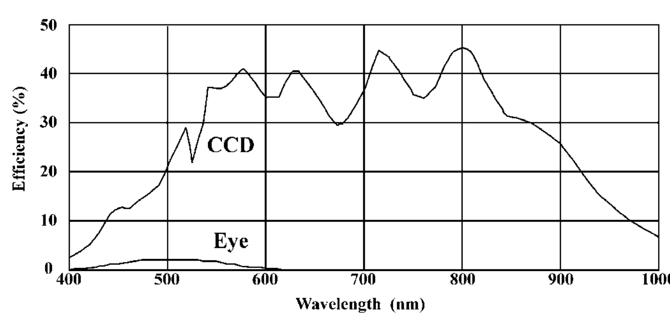

Figure 1. The quantum efficiencies of the CCD and of vision near the scotopic threshold are shown as a function of wavelength. The CCD curve is derived from a graph on the PixCellent Imaging Ltd. Web site: `www.pixcellent.com`. The "Eye" curve approximates the standard spectral luminous efficiency function for scotopic vision (Wyszecki & Stiles 1982) and is adjusted for a peak effective quantum efficiency of about 1% (see the Discussion section of this paper).

shutter and eyepiece described in Part 1. A flip-mirror diverted the light beam from the eyepiece to the camera. The CCD was binned 3×3 yielding a pixel size of 27×27 μm and a resolution of 512×341 pixels (overall dimensions: 13.8×9.2 mm). A tele-compressor reduced the focal ratio of the telescope to f/7.7 giving a binned pixel size of 1.19×1.19 arcseconds and a field of view of $10.1' \times 6.7'$ (the visual field diameter was 15´. The quantum efficiency of the CCD varies between 30% and 44% in the 530-nm to 860-nm wavelength band (see Figure 1). The CCD was operated at a temperature of –15˚C. The camera had its own integral shutter controlled by the software *MaxImDL/CCD* (see `www.cyanogen.com`) running on a laptop computer.

3. Targets

Three targets were selected (and are described in more detail in Part 1): (1) a point source (a faint star), (2) an extended complex white-light source (NGC 5194/5, M51, a double galaxy system), and (3) extended dark structure in a line-spectrum source (NGC 6611, M16, silhouetted dust in an emission nebula). The respective visual integration times reported in Part 1 are: (1) 0.92 ± 0.14 s, (2) 0.32 ± 0.14 s, and (3) 0.57 ± 0.19 s (averages with standard deviations).

Several possible extended targets had been pre-selected, but the two used (M51 and M16) were not chosen until observations were underway on Mauna Kea. This was dictated by the conditions encountered on Mauna Kea, including wind strength and direction, and time of night. This approach also avoided stimulating interest in any particular target during the weeks leading up to the observations and thereby possibly biasing the results.

The star of target 1, with its colour index of +0.99 corresponding to a temperature of about 4600 K (Allen 1973), emits the majority of its photons at wavelengths longer than 600 nm where scotopic vision is unresponsive. In contrast the CCD responds particularly strongly between 600 and 900 nm (see Figure 1). The spectral response advantage of the CCD is less pronounced for the other two targets. The spectrum of target 2 spans Figure 1. Most of the light of M51 is from spectral class O, B, and A stars, which are a better match to the spectral response of scotopic vision. As mentioned in Part 1, the visible light of target 3 consists primarily of three emission lines at wavelengths 486 nm (Hβ), 496 and 501 nm (O^{++}) that lie near the 507 nm peak response of scotopic vision. Although the quantum efficiency of the CCD is only about 20% in this region, M16's strong but invisible 656 nm (Hα) line lies near the peak of the CCD response (Allen 1973).

4. Images

All sketches and CCD images presented below are negatives. That is, bright areas are dark and vice-versa. Also, they are shown mirror-reversed since the telescope, with an odd number of reflections (3) in its optical train, presented the images in this fashion. Mirror-reversed views were advantageous in the case of M51 and M16 since any familiarity an observer had with published images of these objects was less apt to bias the visual observations. It is notable that observer 3, who was unable to produce a sketch or determine an integration time for M16 (see Part 1), produced a sketch of M51 in which the star patterns were mirror-reversed (as they appeared in the eyepiece) but the galaxy itself was mirror-correct, apparently from memory.

Figures 2a and 2b are CCD images of a small section of the M67 star field with exposure times of 0.40 s and 1.0 s, respectively. Target 1 is not detectable in Figure 2a, but when the exposure time is comparable to the visual integration time for this star, the star is apparent (the arrow in Figure 2b points at the target star). Intermediate exposures (0.60 and 0.80 s) show a hint of the star, but the 1.0 s exposure was needed to make this definite.

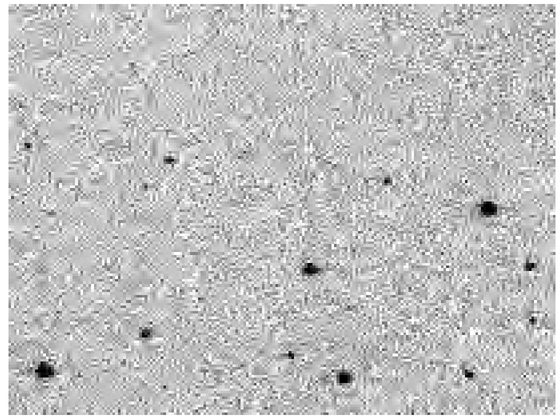

Figure 2a —This is a CCD image of a small section of the M67 star field (exposure time 0.40 s). The target star is not apparent.

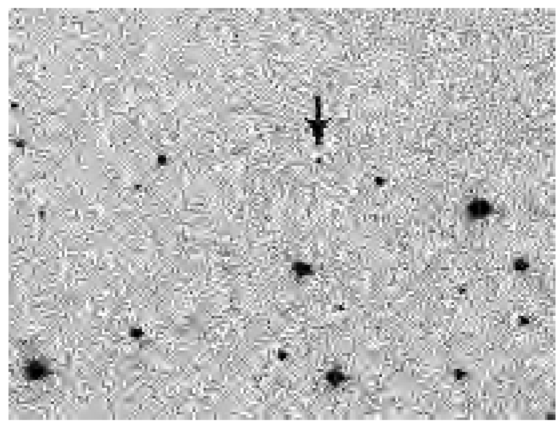

Figure 2b — This is similar to Figure 2a but with a 1.0 s exposure time. The arrow points at the target star.

In this instance the eye appears to perform about as well as the CCD; however, as mentioned, the star's spectrum favours the CCD. Had the CCD been restricted to the 400 – 600-nm range of the eye, it would probably have required an exposure of at least 3 seconds to have produced Figure 2b.

The sketches of M51 (Figures 3a and 3b) and M16 (Figures 6a and 6b) would not win any awards for artistic merit. This is not surprising considering that the targets were difficult to see, only a few minutes were spent on each sketch, the sketches were not intended to be anything but a rough record of the visual impressions, and the sketches were done on the summit of the highest mountain on Earth (as measured from its base on the floor of the Pacific), in very dim light, in the middle of the night, in freezing temperatures by individuals not noted for their artistic talent. The sketches are unaltered originals, just as they were drawn at the eyepiece on Mauna Kea.

Only two of the four sketches of M51 were usable: Figures 3a and 3b. The numbers designating the observers are in ascending order of age (see Part 1). In Figure 3a the observer initially drew the lowest spiral arm too close to the nucleus of the main galaxy, and instead of erasing it, inserted an arrow to show its proper location and drew it again. The small-scale scratchy detail in both sketches is not real; it is just a crude depiction of what, visually, were smooth, ghostly spiral arms. No attempt was made to smudge the pencil marks so that they more closely resembled the visual impression. Of the four sketches produced, Figure 3a is the most accurate rendering of M51, and it is notable that, of the four observers, observer 4 had the longest integration time (see Part 1).

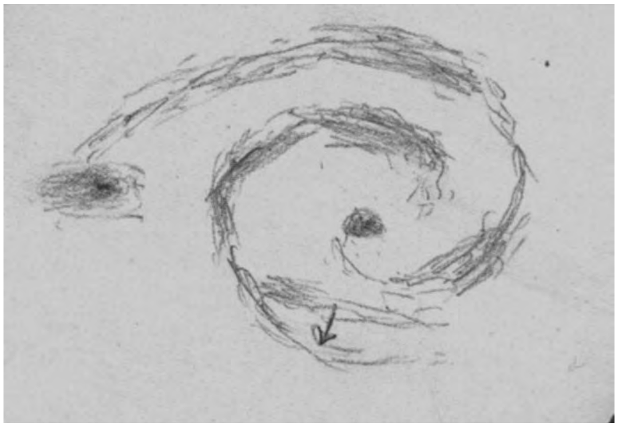

FIGURE 3A — This is a pencil sketch of M51 drawn by observer 4 while observing the two galaxies at the eyepiece of the 0.61-m telescope.

FIGURE 3B — This is similar to Figure 3a but was drawn by observer 2.

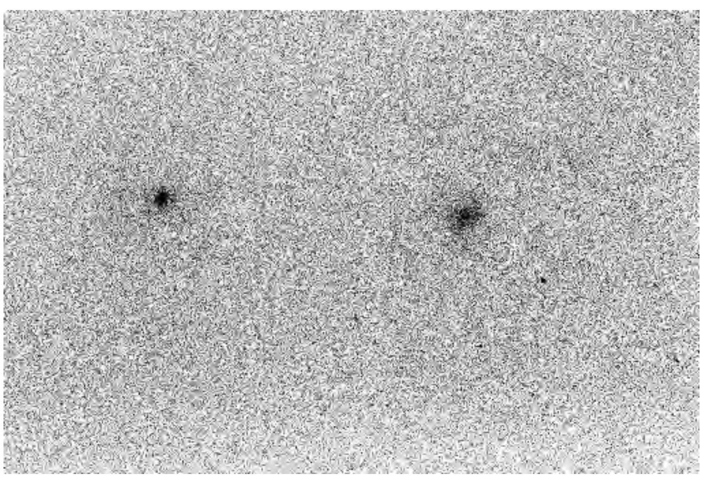

FIGURE 4A — CCD image of M51 (exposure time 0.40 s).

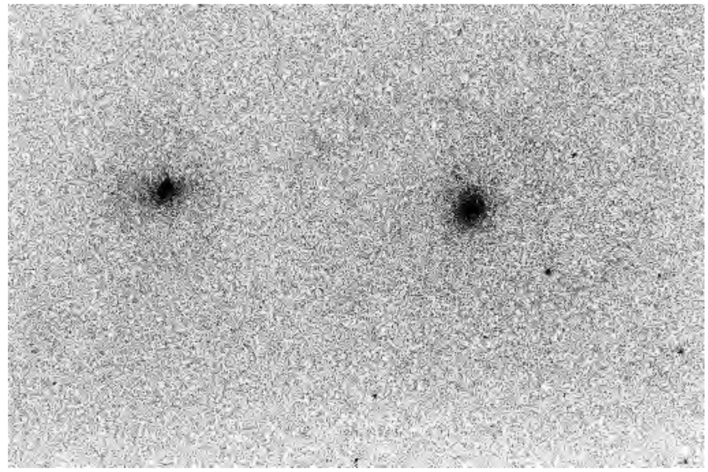

FIGURE 4B — CCD image of M51 (exposure time 1.0 s).

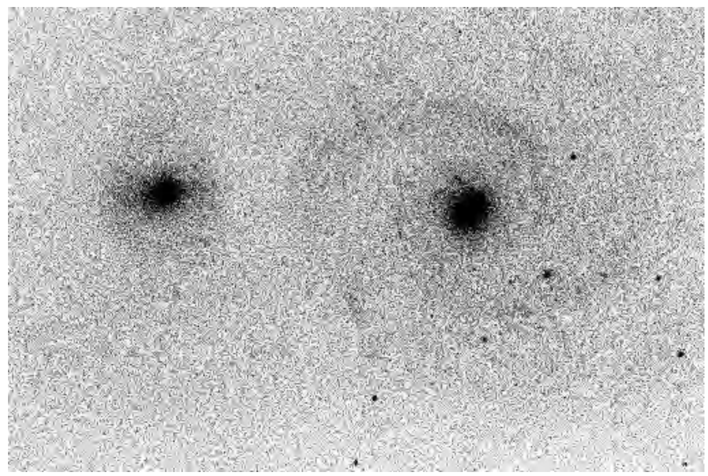

FIGURE 4C — CCD image of M51 (exposure time 2.0 s).

Figures 4a, 4b, 4c, 4d, and 4e are CCD images of M51, with exposure times of 0.40 s, 1.0 s, 2.0 s, 5.0 s, and 30 s, respectively. Note that the exposure time of Figure 4a is comparable to the visual integration times for M51. Comparison of Figures 3 with Figures 4 indicates that to reveal the detail seen by the eye, the CCD required an exposure of at least 2 s, four to ten times longer than the visual integration times. For equal integration times, even a state-of-the-art CCD with 80% quantum efficiency (about double that of the CCD used in this investigation) would not match vision.

Figure 5 is a famous sketch (shown here mirror-reversed) made in 1845 by William Parsons, the third Earl of Rosse, using the largest telescope of that century, his “6-foot” “Leviathan of Parsonstown” (King 1955; Hewitt-White 2003; Levy 2004). This sketch was made prior to the application of photography to astronomy, and was the first image to show the spiral structure of any galaxy (Abetti 1952). The scattered dark spots in Figure 5 are labels marking the positions of stars and certain bright regions of the galaxy. Although the Rosse telescope had nine times the aperture area of the 0.61-m telescope, the low reflectivity of its speculum-metal mirrors and light losses in its uncoated eyepiece lenses would cancel most if not all of its advantage in light grasp. As in Figures 3a and 3b, small-scale detail in Figure 5 is obviously an artifact of the drawing technique. Although Figure 5 is artistically more elegant than Figure 3a, in some respects

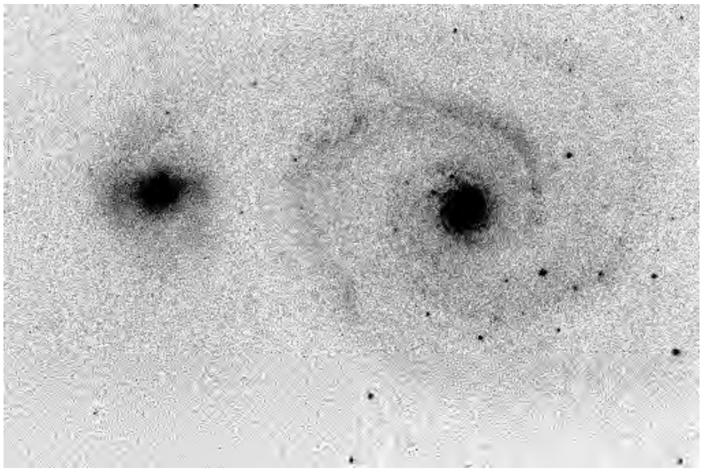

Figure 4d — CCD image of M51 (exposure time 5.0 s)

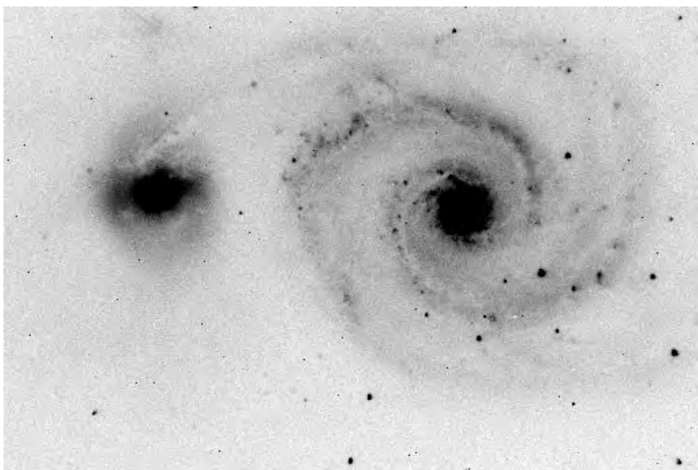

Figure 4e — CCD image of M51 (exposure time 30 s).

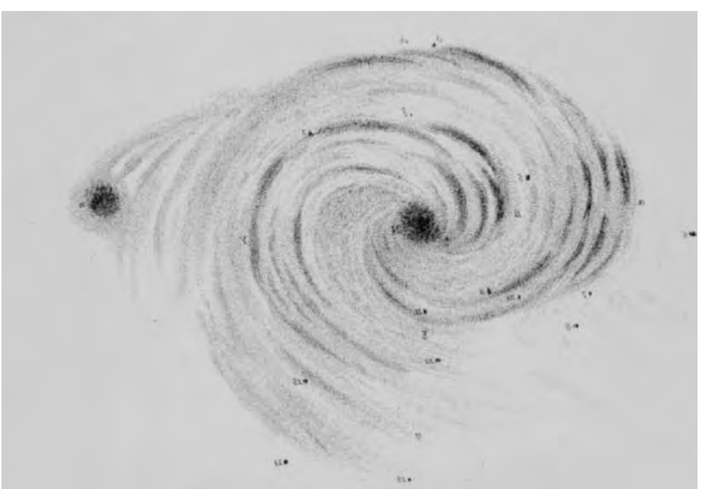

Figure 5 — This is a sketch of M51 (shown here mirror-reversed) drawn by William Parsons in 1845 using his 1.83-m (6-foot) telescope.

Figure 3a is a more accurate depiction of M51. For example, Figure 3a shows the kink in the spiral arm passing between the two galactic nuclei, and the asymmetric bar-like structure in the smaller galaxy.

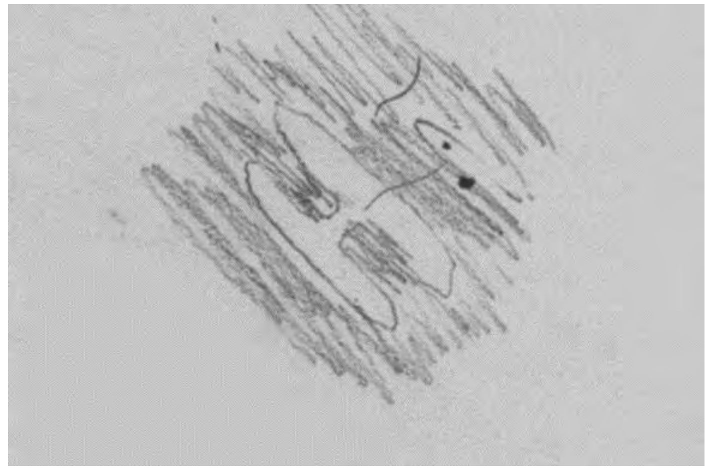

Figure 6a — This is a pencil sketch of the central dust clouds of M16 drawn by observer 1 while observing the nebula at the eyepiece of the 0.61-m telescope.

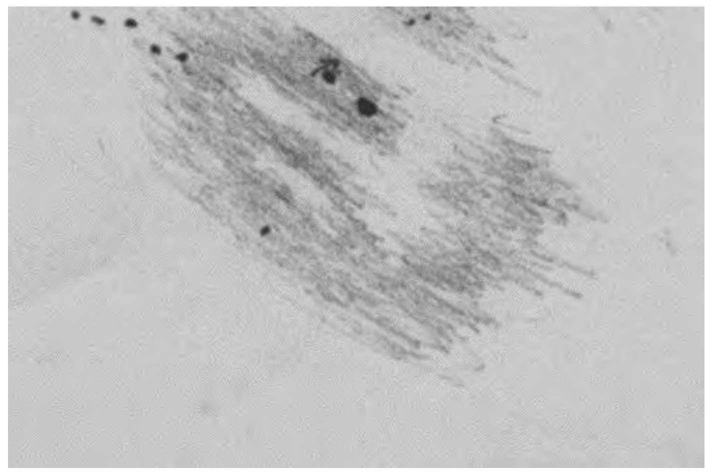

Figure 6b — This is similar to Figure 6a but was drawn by observer 4.

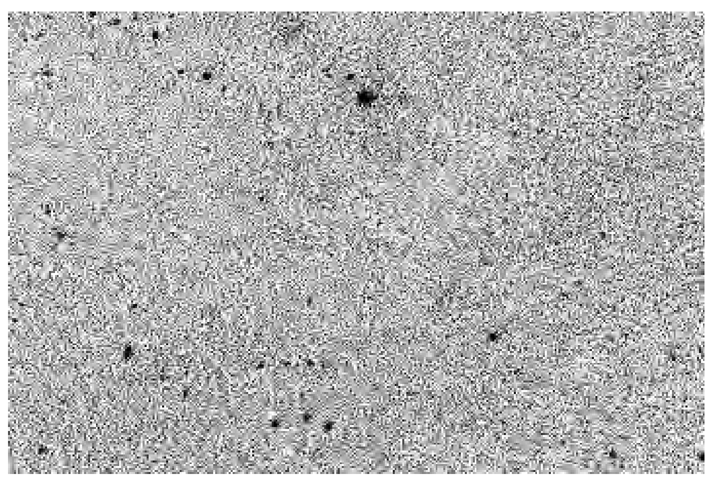

Figure 7a — CCD image of the central dust clouds of M16 (exposure time 0.60 s).

Two sketches of the central dust clouds in M16 are shown in Figures 6a and 6b. In Figure 6b the small arrow pointing to the upper right beside the dimmer of the two bright stars indicates that this star should have been drawn slightly further in that direction.

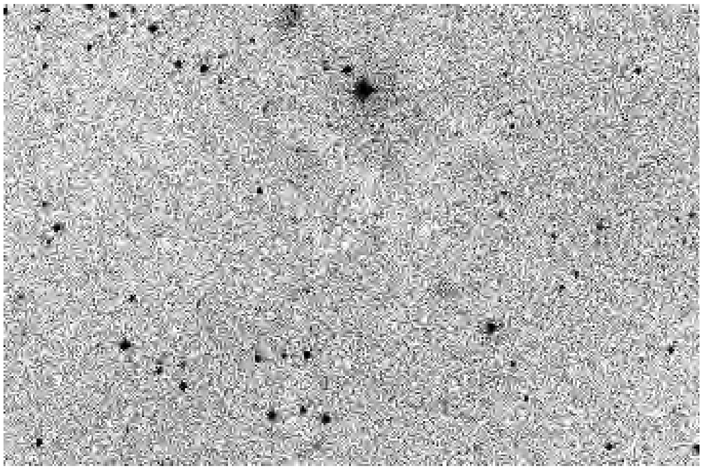

Figure 7b — CCD image of the central dust clouds of M16 (exposure time 1.0 s).

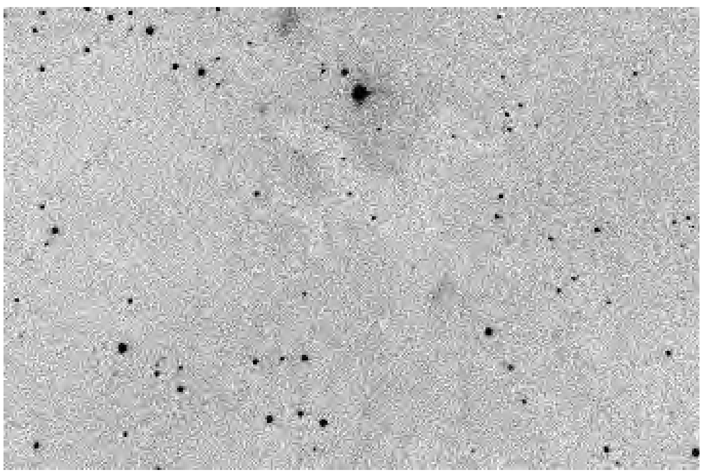

Figure 7c — CCD image of the central dust clouds of M16 (exposure time 2.0 s).

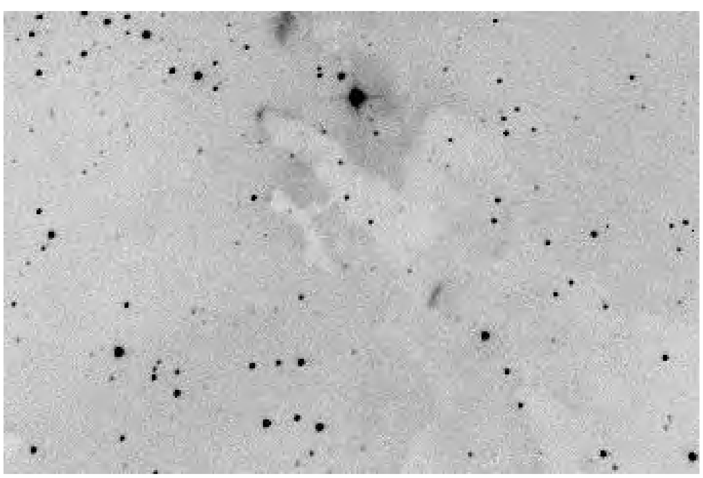

Figure 7d — CCD image of the central dust clouds of M16 (exposure time 10.0 s).

Figures 7a, 7b, 7c, and 7d are CCD images of the central dust clouds of M16, with exposure times of 0.60 s, 1.0 s, 2.0 s, and 10 s, respectively. The exposure time of Figure 7a is comparable to the visual integration times for M16. Comparison of Figures 7 with Figures 6 indicates that to reveal the detail seen by the eye, the CCD chip required an exposure of about 2 s, three times longer than the visual integration times.

Note that observer 1 saw the small bridge connecting the two dust pillars, a feature that is barely noticeable in Figure 7c. That only the youngest of the observers noticed this bridge is consistent with the decline in scotopic high spatial frequency cut-off with age (Schefrin *et al.* 1999).

5. Discussion

The retina of the eye is part of the brain. The retina contains about 120 million rod and about 6 million cone photoreceptors (about 80 times as many photoreceptors as in the *unbinned* ST-8 CCD used in this investigation), yet the optic nerve that carries visual signals to the rest of the brain has only about 1 million nerve fibers. As a consequence most of the retina's photoreceptors are combined in groups, and the pooled signals undergo considerable processing in the neural circuits of the retina before they begin their journey along the limited-capacity optic nerve to the visual cortex. Only the 25,000 or so cone photoreceptors in the central fovea (the region of high acuity) have direct-line connections into the optic nerve (Pirenne 1967). Thus it is not surprising that the decline of visual acuity with retinal eccentricity is determined by neural, not optical, limitations (Lennie & Fairchild 1994; Williams *et al.* 1996). Having high-acuity vision limited to a small fovea minimizes the neural complexity of the retina.

There are several sources of noise in the scotopic visual system: Poisson fluctuations in the photon rate comprising the original signal; sporadic thermal activation of the light-sensitive rhodopsin molecules in the rod cells (Baylor *et al.* 1984); spontaneous fluctuations in the various biochemical processes occurring in the rod cells; synaptic noise in the retina and cortex; and fluctuations in threshold criteria in the visual circuits. However, the second of these appears to dominate, implying that "evolution has successfully optimized the other retinal and cortical factors, but cannot further improve the thermal stability of rhodopsin" (Sharpe 1990). The fluctuating ghostly patterns seen in total darkness apparently arise from this source (Lamb 1990).

To reduce thermal noise the CCD was operated at a temperature of −15° C. In contrast, the retinas of the observers operated at 37° C. At −15° C thermal noise is much less of a problem for a CCD. For rod cells thermal noise decreases about 4-fold for every 10 C° temperature decrease. Animals with body temperatures 20 C° lower than that of humans (for example, toads) have visual thresholds unattainable by humans (Aho *et al.* 1988). Since noise is more of a problem in dim light (because of the small signal-to-noise ratio), relative to bright-light (cone) vision, dim-light (rod) vision evolved with its spectral response shifted toward shorter wavelengths where the energy barrier for excitation is higher (Barlow 1957). As a consequence, at scotopic luminances red objects appear black and blue objects appear relatively bright (the Purkinje shift), although colourless. A warm retina can compete with a cold CCD, in part, because its response is at the left side of Figure 1.

To distinguish photon signals from thermal noise the visual system generates sensations only when multiple photon hits occur within the integration time. One difference between the visual sketches and the CCD images of the extended targets is that the former do not show the granularity of the patter of photons displayed in the latter. The reason for the visually perceived uniformity of dim light despite the punctate arrival of photons is that it is only the larger units of the pooled rods in the mosaic structures of the peripheral retina that receive enough photons from extended areas in the target to achieve a sufficiently high signal-to-noise ratio to generate a visual sensation (Pirenne & Denton 1952; Snyder *et al.* 1977). That is, those channels in the retinal circuits that report a larger size are favoured. Thus, dim extended objects near threshold tend to be seen in their entirety, despite the scattered distribution of photon-induced photoreceptor events. If individual photons elicited a sensation, we would be unable to distinguish photon signals from signals produced by the numerous random thermal events in the warm visual system (Barlow 1988). The longer integration time at low light levels increases the signal-to-noise ratio, but it is the response of each coarse mosaic unit in the peripheral retina that, in the higher visual centers, generates the smooth blobs of perceived brightness that merge into a uniform glow. "If this were not so, surfaces would dissolve in the night into collections of scintillating spots, and the shower of photons from the dim night-sky would obscure the perception of the star formations." (Ross & Campbell 1978).

Vision cannot attempt to resolve fine structure in dim extended images because there are too few photon-induced signals occurring in smaller rod pools for these signals to emerge above the photon-mimicking thermal noise. Thus the visual images of the extended targets M51 and M16 contain only low spatial frequency (coarse) detail. This restriction of vision to low spatial frequencies in dim light is well documented (Van Nes & Bouman 1967; Daitch & Green 1969; van Meeteren & Vos 1972; van Meeteren 1990). Graphically expressed as modulation (or contrast) sensitivity versus spatial frequency, the data show that in dim light high spatial frequency detail cannot be seen, the high frequency cut-off lowers as luminance decreases, and under scotopic conditions the spatial frequencies most readily visible are the lowest: 0.5 periods per degree and less (that is, spatial periods of 2° and larger). The magnification used in this investigation (264×) gave the main structural features of the two extended targets spatial periods of approximately 7° (M51) and 3° (M16), in the range of optimum visibility.

The pooling of rods (spatial integration) is described by Ricco's law, which states that for target areas smaller than a certain critical angular size, for a constant response, there is a reciprocal relation between the area and its luminance. This is analogous to Bloch's law for temporal integration (see Part 1), and both forms of integration are used by vision to cope with dim light levels. The critical area increases as luminance decreases, and reaches about 1° near the scotopic threshold (Hallett 1963; Cohn & Lasley 1975; Donner 1992), consistent with 2°(+) spatial periods having optimum visibility.

Rod cells have about 100 times less thermal noise than cone cells because of the displacement of their response toward higher photon energies (Donner 1992). Thus, since noise varies as the square root of the average signal, mosaic units composed of upwards of 10,000 rods (corresponding to an area about 1° in diameter in the visual field, or a 2° spatial period) are possible before noise approaches cone-like levels. Hence the rod threshold for extended targets is nearly 10,000 times lower than the cone threshold (luminances of about 1 versus 5000 μcd/m^2, respectively), and angular resolution near the scotopic threshold is about $\sqrt{10{,}000}$ = 100 times worse than the acuity of photopic (cone) vision (about 2° versus 1′ or 2′, respectively, or in Snellen notation, 20/2000 versus 20/20).

In the case of the faint star (target 1), photon events were focused on a small region of the retina causing the smallest units of the pooled rods to achieve a threshold signal (Snyder *et al.* 1977). Thus, because of the nature of the optical image, those channels in the retinal circuits that report a small size were favored, and a corresponding point-like luminous sensation was experienced by the observer. Although the retina responds to individual photons (Barlow 1956), the neural circuits process these raw signals such that representations of faint stars but not of individual photons reach an observer's conscious level.

Since individual rods and cones are about equally efficient at capturing incoming photons (Weale 1958), and because comparable small numbers of cones (for foveal vision) or rods (for averted vision) are involved in seeing a star, the rod threshold for a star is only 2 or 3 magnitudes dimmer than the cone threshold, the higher thermal noise of cones resulting in rods having the lower threshold (Donner 1992). This approximately 10-fold advantage of the rods over the cones for individual stars is dramatically smaller than the nearly 10,000-fold rod advantage for extended targets made possible by pooling.

The ability of pooled rod photoreceptors to synthesize either extended or point-like luminous sensations from scattered, noisy signals is consistent with another property that only pooled receptors can accomplish: the regulation of visual sensitivity in dim light. Near the scotopic threshold the photon activation rate of individual rods is far too small (of the order of one isomerization per rod per 100 seconds) for the individual rods to form a rapid and accurate estimate of retinal illuminance. Adaptation to the light level is performed at a later neural site where signals from many rods are pooled (Rushton 1963; MacLeod e*t al.* 1989).

According to Sharpe (1990), when light of wavelength 507 nm (optimum for the scotopic response) enters the dark-adapted eye: about 1 in 3 photons is lost due to reflection, absorption, and scattering in the optical media of the eye; about 1 in 5 strikes the less-sensitive cone cells, or falls in spaces between the rod cells; and about 5 out of 8 photons that enter a rod cell fail to trigger the cell and are degraded into heat. Thus the fraction of photons entering the eye that trigger rod cells is $2/3 \times 4/5 \times 3/8 = 0.20$. Adopting generally more pessimistic losses, Savage & Banks (1992) give 0.066 for this fraction. Since a threshold signal corresponds to about 10 to 15 photons triggering rhodopsin molecules within the retina's integration time (Hecht, Shlaer, & Pirenne 1942; Hallett 1987; Lamb 1990), these numbers therefore correspond to about (10 to 15)/0.20 = 50 to 75, or (10 to 15)/0.066 = 150 to 230 photons entering the cornea. In view of the uncertainties in these numbers, about the best that can be said is that approximately 100 photons of wavelength 507 nm at the cornea correspond to a single threshold luminous sensation. That is, the peak effective quantum efficiency of scotopic vision is about 1% (Barlow 1956; van Meeteren 1990) (see Figure 1). Baum (1962) assumed an integration time of 0.1 s and cited an efficiency of 3%; however, using the minimum integration time found in this investigation (about 0.3 s for M51), Baum's figure would also be about 1%. With white light the number of photons required at the cornea for a single threshold luminous sensation is considerably larger, although the number of rods triggered and the photometric value of the light would be unchanged.

In contrast, astronomical-grade CCDs have average quantum efficiencies in the central portion of their spectral response curve of 40% to 80%. Also they are much less noisy because of their lower operating temperatures. And CCDs have an third advantage, already mentioned: a wider spectral sensitivity than scotopic vision, spanning wavelengths of approximately 400 to 1000 nm or greater compared to 400 to 600 nm for scotopic vision (see Figure 1). Nevertheless our results indicate that despite a low effective quantum efficiency, a warm operating temperature, and a limited spectral response, during its temporal integration time vision near the scotopic threshold exceeds the performance of a CCD. Only in the case of the cool target star, the majority of whose photons had too low an energy to excite rod cells, did the CCD used in this investigation manage to equal the eye on an equal time basis.

When a retinal mosaic unit consisting of hundreds or thousands of rod cells receives a threshold signal of 10 to 15 photon hits within its integration time from a dim extended target, the visual circuits generate the sensation of a barely-perceptible glow in that portion of the field. A CCD viewing the same part of the field for the same time interval records not a uniform glow but about 40 separate photon signal events (and possibly more depending upon its quantum efficiency, the width of its spectral sensitivity response, and the spectral characteristics of the light source). Although the target may have considerable structure within the portion of the field being sampled, the $2(40/\pi)^{1/2} = 7$-event-wide patch of speckles reported by the CCD is too sparse to convey more information about this part of the target than the visual system finds. The CCD expends its superior quantum efficiency "looking for" higher spatial frequency detail that, because of the quantum character of light, simply does not exist in short exposures of this dim region of the field. No detector can surpass the limit inherent in the Poisson statistics of the photon catch. By matching its receptor pools to the information available in the optical image, vision avoids looking for detail that isn't there.

In the case of a faint star viewed against background airglow a CCD displays the star image against a randomly distributed background of individual photon hits. The CCD expends its high quantum efficiency in making the star image sufficiently intense that it can be distinguished against this mottled background of star-like speckles. Vision avoids the problem by displaying the perceived star against a uniform background glow.

CCDs are binned (for example, 3×3 as in this investigation) to increase the signal-to-noise ratio in each pixel while matching the pixel size to the larger of the resolution limit imposed by the observing circumstances or the resolution desired in the image. The pixels of a CCD could be binned into very large groups in an attempt to mimic the dark-adapted eye; however, the CCD would not report any more photons than does the unbinned array. Also, such binning turns images of stars into ill-defined blobs and hides the higher spatial frequency detail available in the brighter extended areas of the target. Vision avoids these problems by having a variety of parallel summation pools to handle the various scales of available detail in the optical image.

Another mechanism that can help vision extract as much information as possible from the incoming light is *lateral inhibition* (Falk *et al.* 1986). This takes place in the retina. Light striking an annular region surrounding a spot on the retina decreases (inhibits) the response of the central spot. This serves to enhance contrast at borders, producing the phenomenon of Mach bands and making shapes and patterns easier to see. A well-known illusion that demonstrates lateral inhibition is the Hermann grid: a rectangular grid of white bars on a black background appears to display grey spots at the intersections of the bars. However, lateral inhibition does not occur in the dark-adapted retina (Barlow 1958; Dowling 1987), and thus, for the dim extended targets in this investigation, lateral inhibition did not affect the direct visual images (Figures 3a, 3b, 6a, and 6b). This is likely because there are too few photons during the brief integration time to sharply delineate the borders (as in Figures 4a and 7a), and this would prevent lateral inhibition from operating. An equivalent statement is that, near the scotopic threshold, the size of the spatial summation pools is greater than the size of the lateral inhibition units. Paradoxically, lateral inhibition *does* augment a long-exposure CCD image of a faint target. For example, when Figure 7d is viewed by the eye, lateral inhibition enhances the visibility of the borders of the silhouetted dust.

A CCD records the spatial distribution of photons in a two-dimensional optical image. Vision does much more. Beginning with photon-induced neural signals, the brain actively constructs the visual world we perceive (Zeki 1992). Like the dust-removal program of a slide scanner, one stage of processing removes the silhouette of the retina's overlying vascular system, fills in the blind spot occupied by the optic nerve head, and, in the case of scotopic vision, fills in the part of the visual field occupied by the effectively blind fovea. The optical image on the retina disappears with every blink, yet the brain fills in the missing information so that we are unaware that the light momentarily vanishes. Another stage of processing constructs a single, upright, three-dimensional perceived internal visual model of the external world from the two, dissimilar, inverted, two-dimensional optical images on the retinas. Like the image-stabilizing feature of some binoculars and video cameras, another processing stage compensates for shifts of the optical image on the retina caused by motions of the eye, giving us a stable perceived visual world. Provided signals are strong enough to activate photopic vision, yet another stage of processing interprets the relative responses of the three types of cones in terms of hue sensations with which it paints the internal model. The elaboration of neuron electrical pulses as hue, brightness, and depth sensations lies at the heart of the mystery of consciousness (Valberg 2001). Relevant to this investigation is another facet of the processing involved in vision (described above): the binning of rods into a variety of parallel summation pools to optimize sensitivity for the detail available at various spatial frequencies over a wide range of scotopic luminances. This capability, together with the shift of the rod spectral response to higher photon energies to minimize thermal noise, is apparently what enables vision near the scotopic threshold to out-perform a CCD on an equal-time basis.

For integration times significantly longer than that of vision, a CCD accumulates more information than can the eye. However, the ultimate recipient of the resulting image, the brain, now has a layer of technology insulating it from the target object. The direct image has been replaced by an intermediate simulated image on a phosphor- or LCD-based computer monitor, or by pigments on paper or plastic. The high quantum efficiency, wide spectral response, long integration time, linearity, and digital nature of a CCD are major advantages, yet the aesthetic impact of the direct visual image has been lost.

"*Given the biological constraints within which the living cell has to operate, it would seem that the photoreceptor performs exceedingly well. In many ways it appears that our visual system outperforms most electronic devices operating at low light levels and at the same temperature*" (Lamb 1990).

Our results show that Lamb's comment is valid for astronomical observations, even though vision is at an appreciable thermal disadvantage relative to a cooled CCD. It is this remarkable performance of vision that enabled astronomers to achieve so much prior to the introduction of photography and CCDs.

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A native of Nova Scotia, Roy Bishop was a professor of physics at Acadia University for many years. He has served the Royal Astronomical Society of Canada as Editor of the Observer's Handbook, *as President, and is currently Honorary President both of the National Society and of the Halifax Centre. He is a recipient of the Service Medal and the Chant Medal of the Society. He is a member of the Canadian Astronomical Society, the International Astronomical Union, the American Association of Physics Teachers, and a life member of the RASC. In 1997 the IAU named asteroid 6901 Roybishop.*

David Lane calls himself a Nova Scotian, although he arrived there at age 8. He is a Technician and Systems Administrator with the Department of Astronomy and Physics at Saint Mary's University. He is a life member of the Royal Astronomical Society of Canada and is a recipient of the Ken Chilton Prize, the Service Medal, and the Chant Medal of the Society. He has served the RASC as Production Manager of this Journal, as president of the Halifax Centre, and he is currently chair of the Information Technology Committee for the National Society. He is the author of the popular planetarium program Earth-Centred Universe.

*It is with deep regret that we record the unexpected death of Bill Thurlow on February 14, 2004

National Council Meetings and RASC Happenings

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

At the time of this writing, the March 6, 2004 National Council meeting has not yet occurred. The meeting will be held at the JPR Arbitration Centre, 390 Bay Street, 3rd Floor, Toronto, Ontario. More information on the meeting and its happenings will be submitted to the next *Journal* edition.

It is always an exciting meeting of the year as new council members arrive, some to their first ever National Council meeting. The Awards Committee announces any winners for the Society's Awards, which can be viewed at: www.rasc.ca/award.

Also coming up is the General Assembly and Annual Meeting, being hosted by the St. John's Centre. We are all waiting in anticipation to attend the 2004 GA. The dates this year are July 1 to July 4, 2004. Come and visit the East Coast of Canada. Visit the RASC Web site for updates and information for the GA at: www.rasc.ca/ga2004.

I hope that the cold weather, from all over Canada, has not deterred anyone from trying to observe on any clear evening. The planets in the sky are: Venus in the west, Mars, still a rusty colour but dim past zenith at dusk (EST), Saturn in the east, with Jupiter rising after 9:00 p.m. EST. At the time of International Astronomy Day, April 24, all four planets are in the sky for our springtime observing, plus a five-day-old waxing Moon. For more information on the RASC Astronomy Day and week festivities visit www.rasc.ca/activity/astroday/.

Clear Skies Everyone

Adventures in Proofreading[1]

by James Edgar (jamesedgar@sasktel.net)

Some time ago (April 2000), the Editor-in-Chief of the RASC *Journal* put out a request for assistance, to which I responded by email. After many weeks (approaching five months) a new Editor had taken over, and I sent another email to him enquiring about what had become of my offer. The response was, "Welcome aboard — we can always use help!"

That was on September 5, 2000. The very next day, I received my first assignment from Dave Lane, who was the Production Manager at the time. It was the "galley proofs" of the August/October 2000 issue. (Things were a bit behind by then, since August was well past!) "Galley proofs" refer to the document before it went to the printer — allowing one final look over before printing.

I quickly found that the system in use was a bit unwieldy because we proofreaders (six of us) would get an *Adobe Acrobat* "portable document format" (pdf) file to read. To tell the Editor which word or phrase needed correcting, we would have to write a direction such as "p. 150, col. 1, line 8 "Societies" should be "Society's"" or "Page 211, col. 1, para. 1, "...could conceivable be..." should read "...could conceivably be..."

It would have been far simpler (in my mind) to check each article as a document before it was put into *Acrobat* format. That way changes could be made right in the document and then sent back to the Editor. Eventually, after a few email discussions, that practice was adopted. The Editor sends each article to one of us proofreaders (there are only three now) for perusal. We check out the article for errors, make corrections, and send the article back. *Microsoft Word* has a handy feature called "Track Changes" that allows one to make a change in a different colour, making it stand out and easy to see.

Suzanne Moreau is the premiere French proofreader, living in Montreal; Maureen Okun lives in B.C. on one of the Gulf Islands; and I live in Melville, Saskatchewan. Dr. Wayne Barkhouse, our current Editor-In-Chief, was living in Toronto but is now at the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts.

Every now and then, Wayne Barkhouse asks if we will do a little editing as well as proofreading. This is always a challenge, since it involves rephrasing sentences, or sometimes substituting words, but at the same time keeping the original author's thoughts or writing style intact.

Some guides I use are such periodicals as *Canadian Geographic, Scientific American, Sky and Telescope, National Geographic,* and *SkyNews*. Even though you may find small variances, these publications are a good general guide for acceptable "English."

Our Canadian language is a curious mixture of British English, American English, and French English, and though many of our readers are American, we use mostly Canadian conventions in our RASC style. A *Journal* Style Guide is online at: `www.rasc.ca/journal/guide.html`.

These are some of the things we proofreaders look for (besides the obvious spelling errors):

- commas should follow each item in a list, for example, "Jupiter, Saturn, and Uranus";
- punctuation should be inside quotes — an example from June 2003: Webb's thesis is entitled "The Formation and Evolution of Galaxies: A Deep Submillimeter Survey" and should end like this "…Survey." (and it does!);
- the spelling of "Submillimeter" above should be "Submillimetre";
- there should be no spaces between initials of a person's name, as in "W.A. Barkhouse";
- "u" should be used in words like "humour," neighbour," and "rumour";
- "z" instead of "s" should be used in such words as "organize," "recognize," and "energize";
- addresses should follow the Canada Post Addressing Standards, found at this Web site: `www.canadapost.ca/tools/pg/standards/`;
- "Web site" is two words; "email" is one, without a hyphen;
- for prices, the currency symbol follows the dollar amount, as in "$40 Cdn";
- compound adjectives are usually hyphenated — "deep-sky object," or "24-mm eyepiece";
- dates are given as "November 11, 2003";
- "Universe" has a capital "U";
- punctuation following italics should also be emphasized, as in this example "*The Beginner's Observing Guide,* an RASC publication…";
- and finally, "which" should be used instead of "that" in certain clauses (typically a "Briticism" that has found its way into our spoken language, but really doesn't belong). The *Chicago Manual of Style* says "which" introduces a non-restrictive clause, while "that" introduces a restrictive one. Non-restrictive clauses are usually set off with commas. Commas don't show up very well in spoken language, so people often get away with the spoken use of "which" in a restrictive

[1] This article originally appeared in the Regina Centre newsletter, the Stargazer, in November 2003. It is slightly modified here to make it current.

clause, but it can lead to some ambiguity in the written form.

That's only part of the proofreader's challenge, though — it helps to have a smattering of astronomical knowledge in order to understand what is being written and to make sure it is correct.

When a new journal is starting up, the Editor may find himself with only one proofreader, as sometimes happens during summer vacations. Then things get really hot, as letters flow back and forth at a frantic pace. From August 16 to 20, 2003, Wayne Barkhouse and I exchanged 40 emails regarding the October 2003 *Journal*, encompassing 20 documents and totaling 97 pages of text.

Going back a couple of years to January 2001 (by then I was warming to the task of proofreading), I sent a letter to the Editor of the *Observer's Handbook*, Dr. Rajiv Gupta, pointing out some errors in the 2001 edition. He graciously thanked me for my observations. In March of that year, Dr. Gupta asked if I would be the official proofreader for the 2002 *OH*. I was thrilled, and of course answered enthusiastically in the affirmative!

At that point, I didn't realize what a challenge it was going to be. The email exchange for the *Journal* seems puny compared to that of the *Observer's Handbook* — we (Rajiv Gupta, Betty Robinson [the copy editor], and I) sent over 400 letters back and forth during the month and a half that we prepared that edition!! As Rajiv said in his Editor's Comments on page 7, "We had several lively discussions on many fine points of grammar and style, but each of us derived great satisfaction and pleasure from our extensive interaction."

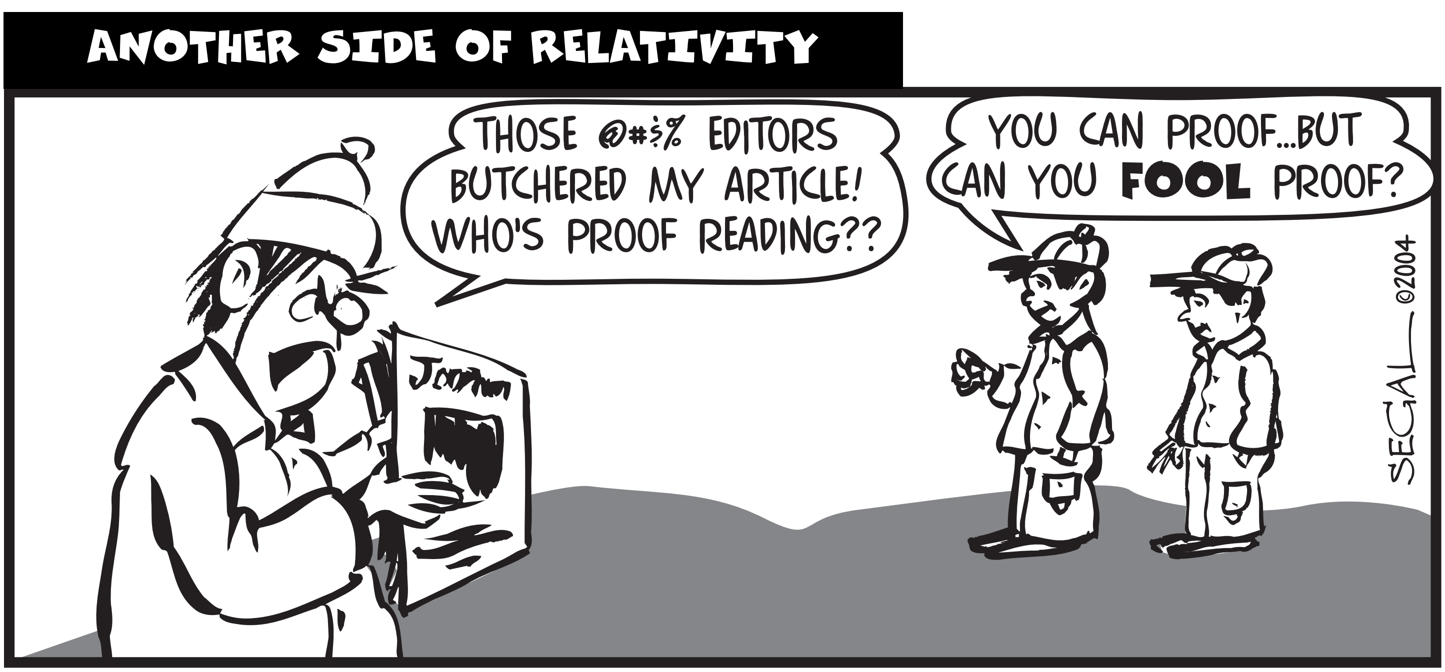
Not only do we get satisfaction and pleasure, the whole experience is one of learning — about astronomy as well as grammar and usage.

Word soon got around to our Executive Secretary, Bonnie Bird, because in February 2002 she asked my assistance in proofing the Society *Annual Report* for 2001. It worked out so well that she asked again for me to proofread the 2002 *Annual Report* in preparation for the 2003 General Assembly.

Not very long ago, I was asked to help Leo Enright with *The Beginner's Observing Guide*. Over the course of one week in September 2003, I proofed the entire 200 pages of this newly published 5th edition. It is much improved, with new pictures, graphics, and updated information.

This has been a great adventure, and one that promises to continue. As I look at my *Observer's Handbook 2004*, I must say the finished copy is a joy to behold!

James Edgar is an RASC Life Member, attached to the Regina Centre. His serious love affair with astronomy began in Vancouver, B.C. in the early 1970s. His home in Melville, Saskatchewan provides many dark-sky nights.



Salue Umbistineum Geminatum Martia Proles[1]

by Thomas Kovacs (hfo@sympatico.ca)

This past August it finally happened for me: On the night of the 26/27, I observed Phobos and Deimos, the two moons of Mars — and this view of Phobos was my first. Even better was that I was able to share the view with a true "Lucky 21" — 21 visitors to the observatory at Haliburton Forest. It is here that I have the pleasure of bringing the night sky to folks from all over, using our three 10- and 12-inch *LX200* telescopes.

The telescopes performed wonderfully that night, the long-awaited night of Martian opposition. Deimos first appeared in the 12-inch Schmidt Cassegrain Telescope (SCT) at 03:17 UT and remained plainly visible to the entire group. Ultimately, Deimos remained in view for an astonishing 165 minutes — and I would have been satisfied with the barest glimpse! (I had a small laugh as the night wound down — the group left long before Deimos did!)

Shortly after acquiring Deimos in the 12-inch, I moved to observe it in one of our 10-inch *LX200s* — the award was immediate. Deimos was a larger challenge in the 10-inch as it appeared much more washed-out in the glare of Mars. But thanks to the ease of observation in the 12-inch, everyone knew exactly where to look (and what to look for). All in all, there were no significant problems with individuals finding it.

Returning to the 12-inch at 03:50 UT, I rotated the eyepiece 180 degrees (I use a half-moon shaped occulting disk, described later in this article) and at 03:58 UT, Phobos popped into view. Again, *the entire group saw it,* although not quite with the same ease as with Deimos. The difficulty seemed similar to locating Venus or Jupiter in a bright, early evening sky — they are there, but you have to know exactly where to look. But in the end everyone saw it, resulting in a very successful night! These two tiny rocks, Jonathon Swift's "children" of piercing, *freakish* logic — and a comedy of errors — stood out for all to see. There they were! The event instantly became another one of those astronomical sights or events that never seem to leave my mind — you know the type because your mind has its own. Have a look at the photograph showing the relative sizes of Mars and Phobos — intimidating, huh? When I first saw it, I nearly, very nearly, gave up hope of ever seeing it! Happily, as things turned out, much of my joy is a *result* of that photo!

However, it gets better: I can see no reason why anybody now reading this cannot also view the moons. The logic is simple: if 21 people aged 16 to 60, most enjoying their first view through a telescope, were able to spot the moons, it makes sense that *anybody* can see them, right? Well, sure! And it is all just that simple, correct? Not a chance!

Now, I don't mean to try to scare you off, it's just that there may be steps you have to take for such observations to be successful. Aside from one or two of these steps, all are quite easily accomplished — in fact, it is likely that you are already aware of or even applied a few of the tasks, techniques, or tips at some point. (Although this article deals mainly with older *Meade* SCTs, the new line of *LX200s, Celestron* SCT, and even reflector/refractor owners may benefit from adopting of one or two of these points. Owners of top-shelf instruments likely do not have too much to be concerned about: certainly nothing I ever tried with my *Tele-Vue* NP101 has ever improved its performance.) In addition, many of us enjoy tinkering with our telescopes. Perhaps we perpetually clean them, collimate them, tinker with pointing precision, or even like to take them apart (I know I do — occasionally with rather alarming results). Knowing your habits and abilities will assist you in recognizing your limits; of the tasks I am about to list, you will know which you will be able to handle yourself, and which tasks would be best left to others. I will be talking about the removal of the corrector plate and primary mirror, for example — doing this should not be approached lightly! If you are unsure of how to do it, then do not attempt it! There always seems to be somebody around who knows what they are doing. Each RASC Centre always has knowledgeable folks around who are willing and able to help. I myself will always be happy to help tune up your telescope at my new machine shop in the town of Haliburton.

You will also see that I do not usually give any instructions on how to perform a given task. To do so would make this article far too lengthy, and different brands and sometimes different model years will require their own directions. However, to find this information is easy — many popular telescope brands and models have their own user discussion groups on the Internet, where loads of advice and information can be found.

But before I get started, there is one important thing we must get out of the way: Mars and its moons. Regardless of how much cleaning or monkey wrenching

[1] Hail, twin companionship children of Mars.

you do, the challenge of catching the moons in an eyepiece is only going to get progressively tougher, including the 2005 nearest–approach (on October 30, one week before opposition). My group departed at about 04:25 UT, which allowed me to concentrate on seeing how long I could watch Phobos track in towards Mars. Not very long, as it turned out. When Phobos closed to within 30″ of Mars, it was extremely difficult to detect. When 29″ from Mars — just barely 29″, I might add — very nearly 30″, Phobos let me have one more faint flicker of a glimpse — possibly. This was with almost perfect skies and me knowing precisely where to look. However, come the 2005 opposition, Phobos will be 3″ closer in still. Of course, Mars will be 0.6 magnitude fainter — but so will Phobos…

Each successive Martian opposition will find the planet 15,000,000 km (a *very* rough average, Mr. McCurdy!) further away each time Earth sweeps by, and this falling away will continue until 2012, when the closest Mars approach will be almost twice the 2003 distance. After 2012, the distance slowly cycles down again. In 2018, we will enjoy an opposition comparable to last August's, but 2,000,000 km more distant. (There is *some* good news: keep this article stuck to your refrigerator until the year 294,851 A.D. — you will not regret it! Mars will be over two million kilometres closer than it was in August!)

So those are the facts. Regardless of what you do or what I suggest, the two Martian moons might simply be out of reach for one and a half decades anyway. Put it this way: if the editor headlined this as a Phobos/Deimos article — be careful. He might be toying with you.

So why write the article? Well, firstly, while the 2005 offer will not be as rich as 2003's, the chance of seeing the moons will certainly be at least *somewhat* better than remote. But a larger reason is really there are thousands upon thousands of chances to "split" Mars and its moons — if, that is, you think of the Martian planetary system in terms of primary stars, secondary stars and so on. Yes, double star observing offer challenges almost identical to that of seeing Phobos and Deimos. Think of the two moons as dim stars up tight to a brighter primary. Have you ever seen the Pup — the companion to Sirius? If you tried with a brand new SCT straight out of the box, chances are you have not. At the very least you will probably have to give the optics a careful collimation, and done properly, this step alone will do wonders. Yet there is more you can do. Commercial SCTs definitely have all the right ingredients — but I have found that it is necessary at times to give the ingredients a bit more of a stir. Challenging observations require the right tools. Once you have your telescope performing close to its theoretical limit, you will no longer have to wonder what you are missing — and tight doubles are only a small part of the story. There are tiny festoons on Jupiter, magnificent dust lanes in spiral galaxies, layers upon layers of wispy clouds in the Orion Nebulae that are *easily* within the grasp of SCTs. Once a doubter, I have come to learn that SCTs *can* be the right tools — but all the ingredients might need an additional stir and a dash of out-of-the-box thinking to wring out their maximum potential.

Contrast, contrast, contrast

Know where to look

My first suggestion may be a bit obvious — know where to look! My observation of Phobos when only 29″ (the final *possible* sighting, as measured later with software) from the centre of Mars was possible only because I knew *exactly* where to look, having, after all, tracked it for the previous 40 or so minutes. If I stepped up to the scope at that late point, I would not have made any observation of Phobos at all. That I was looking in exactly — *exactly* — the right spot made it possible. The same goes for many other UFOs (Ultra Faint Objects). Casual sweeping of the field has netted few PGCs (Principal Galaxy Catalog)!

Cleaning

We have all heard that cleaning your telescope optics too often is a no-no, and I absolutely agree that this is true. The coatings — especially on the primary mirror — truly are delicate. It only makes sense that the more the mirror is cleaned, the greater the chances are of it being scratched and dulled. But I have also heard that the optics should *never* be cleaned, and this I am not at all sure of. Like every other SCT owner on the planet, I was horrified at what I saw upon shining a flashlight into the optical tube assembly (OTA)! But I felt assured all was well when in many different places I read that this was normal, that optics *will* look terrible when subjected to the "flashlight test" (in fact, it was these ubiquitous assurances that prompted me to shine a flashlight down the OTA in the first place. I doubt I would have thought of doing so otherwise!) However, from one year to the next I became convinced that the primary mirror in one of the Haliburton Forest Observatory (HFO) telescopes *seemed* to have become cloudier. As I was never truly happy with the optical performance of the telescope — of *any* of the HFO telescopes — I decided to break the telescope down and give all of the optical surfaces a careful, thorough cleaning. It was only then when I realized just how dirty the interior optical surfaces truly were. The water the primary mirror was soaking in turned *black* (this of course comes from the entire surface of the mirror — the reflective surface, as well as the sides and back, but enough of the dirt came from the front to be of concern). Ditto for the *Kim Wipes* as they came away from the interior corrector plate surface.

The amount of dirt was remarkable enough for me to place a call to *Meade*. It was thought, I was told, that there was a possibility that the black paint used in pre-1994 scopes was out-gassing, thus causing the cloudiness on the interior surfaces. I do not know how accurate that is, but I do know that the optics benefited vastly from the cleaning — enough that I also cleaned the other two HFO scopes (which were also pre-'94, and did give up a large amount of dirt). The pay-off came on the next clear night: the views were so greatly improved it was hard to believe I was looking through the same telescopes!

Of all the tricks I employed to improve the overall visual quality and efficiency of the telescopes, the most dramatic improvement came from the cleaning.

The following year — shortly before the Martian opposition — I was very surprised to see that a cleaning was again needed — at least for the challenging type of observations I had in mind. By this time I had also been into an additional three older *Meades* (two 8-inch and one 10-inch), of which two had similar problems with clouding optics. Why the one scope did not have this problem I do not know — the owner never cleaned it and he purchased it well before 1994.

From this experience, I would say that owners of older *Meades* might want to have a closer look at their optics — they might be very "dirty," and if they are, a dramatic improvement in visual quality is likely if they are cleaned. Just be very careful! Note that on average it took me about three hours just to clean each primary mirror — that does not include removal and re-installation of the mirror or corrector plate. I followed the usual instructions for cleaning the primary mirrors: distilled water at ambient temperature (and lots of it, for soaking must be followed by multiple rinses) a touch of dish soap, surgical quality cotton — one thing that may not be written down enough is *the weight of the cotton itself applies more than enough pressure on the mirror* when it comes down to the actual "scrubbing." Of six SCT mirrors I cleaned — three of them twice — absolutely no harm resulted, only greatly improved performance. To clean the corrector plates (but not the secondary mirrors or aluminized spots on Maks — adhere to the primary mirror procedure to clean these), I had great success using methyl hydrate. It was harmless to the coatings and, unlike industrial alcohol, leaves no streaks whatsoever. The method I used here was first to blow off dust with canned air, dust with a camel-hair brush, *gently* buff with Kim Wipes dampened with methyl hydrate, then gently buff where and if needed with a dry *Kim wipe*. As you dry-buff, always keep an eye out for new dust depositing on the plate — it can potentially turn your *Kim Wipe* into sandpaper!

The corrector plate

There are a few things you can check for concerning the corrector plate. The first is the orientation. Normally the corrector plate is supposed to be matched to the primary mirror, meaning if you should ever take the plate off, you must be very careful to replace it in the original position. However, at one time one of the HFO telescopes — the 12-inch — proved impossible to collimate properly. I seemed to be able to do so using the out-of-focus collimation method, yet when I *thought* I was done and returned to focus, stars would display a faint flare off to one side. No amount of collimation screw tweaking could chase this flare out — nor did reseating the secondary mirror or corrector plate — nothing helped! Finally, I tried completely removing and rotating the corrector plate — and after a few experimental positions noticed an improvement. With the plate kept in the same position, I was able to eliminate the flare completely by adjusting the spacers between the corrector plate and its mounting flange. Alerted to this odd behaviour I checked the other two scopes: a 10-inch also benefited from a corrector plate rotation. And later, one of the three loaner telescopes benefited as well!

I took the shimming of the corrector plates — "squaring" them up — a step or two further. I was working with a US outfit in designing a one-piece light-suppressive liner/dew shield. Mounting the corrector plate in this gadget proved to be difficult, of course. However, I came up with a ring-type mount to hold the plate; on one side the plate is held in place by a third, spring-loaded ring, while the other side is held and adjusted by cam-style lobes that do a great job of squaring the corrector plate. Ultimately, the original sleeve idea turned out to be rather useless, but the cam-adjustable ring mount is the final piece of a puzzle I need to build a truss assembly resulting in a highly transportable, large aperture SCT. I plan to resume work on this in two or three months and soon after hope to make a report on the completed project.

"Critical" collimation

I agree that an improperly collimated SCT is hardly a telescope at all. Even "close" to perfect collimation does not really cut it — there is a wealth of detail that will remain hidden until the owner finds the one little *tweak* that really opens the curtains — and that "little tweak" is *necessary* for edge-of-the-envelope observations.

Personally, I stay away from SCT laser collimators. I simply find I am consistently able to get better results by using the end product as a collimation tool — the stars. As wars have nearly started on this topic I say no more!

There is a collimation method I prefer that is either not written down or not written down enough. It is quite simple, although you do need a night of near-perfect seeing to be able to do it. The first step requires that you point the scope at a nominal observing altitude, say 60 degrees, and collimate from there. This will help minimize any possible mechanical flop (including the primary mirror shifting on you) after you have collimated. This really is not that horrible of a thing, but since the focus of this article is observations "on the cutting edge," let's stay sharp. For any truly tough targets you might be after, aim the scope at the altitude the target is expected to be at. For example, when I observed Phobos and Deimos I collimated (or at least checked the collimation of) the telescopes while pointing at an altitude of 30 degrees above the horizon — the altitude Mars was expected to be at an hour or two later. Some telescopes are less prone to mirror flop (I hope!) than others — certainly the scopes at HFO are particularly bad in this regard. You can almost hear the mirrors THUD as the scopes are raised or lowered through large slews in altitude!

The next step is of course the collimation itself. Rough collimate as you would normally, using an out-of-focus star, then refocus the telescope. On a night of very good seeing, when you look through the telescope at say a 3rd magnitude star, you will see the star's Airy disk and Fresnel (diffraction) rings. *Remaining in focus,* collimate using the pattern you see. The Airy disk — the star — should be surrounded by a relatively bright ring of light. Beyond that first ring, you should see successively fainter rings (you can pretty much ignore these outer rings — but take it as a nice sign that they are there!) Now simply collimate — if needed — using this pattern. Perfection will be had by making sure the Airy disk and first Fresnel ring appear concentric — the Airy disk in the dead centre of the ring, and the ring itself appearing smoothly illuminated all the way around, with no (or reduced) salients, flares, breaks, and so on. If there is a more accurate way to get a bang-on collimation, I do not know what it is. In fact, I believe (I am far from an optician!) that if you get this Airy pattern perfect, it is not possible to get a better collimation — the Airy pattern being the ultimate indicator. Beyond this your telescope's ability to resolve is then limited by the quality (and size, of course) of the optics.

Star diagonals

I have never come across a truly bad star diagonal, yet I have always considered them to be a potentially weak link in the optical train. This is not because I have ever really noticed any true image degradation, but more because it is simply another mirror in the system that is not always needed. Generally, when it is possible — such as when I am observing low altitudes in the sky — I simply remove them. However, this is not always convenient since when observing at high altitudes without a diagonal one would have to be a bit of a contortionist. More and more I have relaxed on this point and have been leaving it in at all times. When I observed the Martian moons, it was done with the diagonal in. I *would* have removed it in this case, but with an observing group present I deemed it necessary. (Some folks, especially older ones, have a very difficult time observing without it.)

I'd say a happy compromise would be simply to leave the diagonal in at all times — just buy a good diagonal. At $100.00 US, the *William Optics* diagonal, with a surface reflectivity of 97%, almost seems mandatory! You could double that price and buy the 99% dielectric model, but you have to decide if the 2% is worth the additional cost. I have closely compared a stock *Meade* diagonal (87%?) to a *Tele-Vue* dielectric model, and other than a slight increase in planetary contrast, I could not tell the difference in general use. It is just nice to know that there is a good diagonal between you and the sky!

One suggestion really does not have much to do with optical performance: if you do opt for an after-market diagonal, consider buying a refractor-type diagonal for your SCT (you will need an inexpensive adaptor). The refractor-type diagonals are a treat to use on SCTs — they are easy to remove when needed and it is easy to reposition the eyepiece to any viewing angle — invaluable when you have lots of kids looking through your scope.

Focusing

As far as I am concerned, it is mandatory to 1) fix the primary mirror at the "sweet spot" — the point of minimum spherical aberration, and 2) fine focus from there with an after-market focuser mounted on the visual back. (The more recent *LX200* line now comes with just such a focuser and the ability to lock the primary mirror down.) The coarse focusing on older *Meade* telescopes is very poor — at least it has been for every telescope I have ever used — they act as though the primary mirrors are mounted on a waterbed. Unfortunately, there is no simple way to lock the primary mirrors down on the older instruments — it can be done, but not very easily. (This spring I will be making this modification to the HFO scopes; I will report on the experience when completed.) As for 14-inch *Celestron* and 16-inch *Meade* SCTs, there is a commercial product available that allows you to lock the mirror. Although this product is relatively simple to install, they do require a hole to be cut into the OTA. Not pretty, but can be necessary in many cases.

Dampening stray light

This is another area where you can boost the performance of your SCT — big time. By reducing stray light, you are directly increasing contrast. Simply using a dew-shield can help here. Removing the corrector plate and going to work on the inside of the OTA is more involved, but it will be worth the effort. In general, the way I think about all this is that if I am willing to stand outside in temperatures as low as minus 20 for hours upon hours at a time, why *wouldn't* I want to ensure the scope was working at its best!

There are many things you can do to suppress stray light. I have applied several, but unfortunately, I have been unable (yet) to "prove" whether they *all* work. One example is when I had the primary mirror out of the OTA; before re-installing it I first painted the mirror's outside edge flat black, then (since I had some leftovers) I even flocked it. While it certainly cannot hurt, I cannot tell you if it was worth the effort. However, I would *definitely* say that it is not worth the effort to remove the primary mirror specifically to flock the mirror! In a few months when I bring the scopes home to enable locking the primary mirrors, I plan to put them through careful testing, to find whether flocking or painting flat black works or not. Overall, the flocking seemed worked. (As do all the other steps I have described — the proof is in the Phobos/Deimos pudding!)

Flock the OTA. I did it while the mirror was removed, which allowed me to easily extend the coverage all the way to the back of the OTA. While in there, any bright or shiny hardware or screws that are still exposed, if not possible to flock, should be painted flat black. (Flocking is much better at suppressing stray light than flat black paint.) Still on the inside, I fitted a ring of flocking material to the corrector plate flange. If the inside of the dew shield, is not already flocked — that is, if just painted black — flock it.

Having done this, when I look into

the completed OTA, it looks distinctly darker, very dark in fact, like a black hole! Going around to the back of the telescope, one thing I have tried was flocking the inside of the baffle tube. However, this has failed because the material keeps peeling off. (I managed to get the material in there by first spreading glue in the tube with a long brush, then loosely wrapping the flocking around a long balloon. Slide the whole shebang in the tube and inflate the balloon. Try locating flocking with a self-adhesive backing and save yourself the gluing step!)

Another light-suppressing move is to add an "aperture stop" just ahead of the diagonal mirror. The aperture stop can be made out of cardboard cut into a donut shape and covered in flocking material. The size of the "donut hole" will depend on the eyepiece you are using — the smaller the field lens is, the smaller the hole in the aperture stop can be. This then allows only the needed light rays through the diagonal and into the eyepiece, and absolutely stops any remaining stray light. Finding the size of the hole will depend on several things, such as whether or not you will be using a diagonal (which changes the focus, which in turn changes the size of the light cone reaching down the length of the baffle tube). Eyepieces with large field lenses will hardly benefit from this; I only use a stop with shorter focal-length eyepieces. Even then I only bother with it when I am trying to get every bit of contrast I possibly can. If the interior of your telescope is sufficiently dampened, this stop should have little benefit. However, if your telescope has no interior light damping, it would be worthwhile testing this gadget out.

Occultation bar

Now for removing Mars or any other bright primary light source from the picture. What you can do is make an *occulting* bar to physically block the contrast-destroying glare of Mars from entering your eye. Basically, a thin bar is inserted up into the bottom end of an eyepiece and pushed all the way up the chrome tube until it is very close to the first (bottom-most) lens (usually called the field lens), and that's all there is to it — very simple. The occulting bar is now close enough to the field lens that when looking through the eyepiece the bar will be seen in sharp relief against the planetary system or star field. The trick is to position the planet (or star, if you are trying to split a tough double like Sirius and the Pup) behind the bar — occulting it — to block its contrast-robbing light. The fainter companion is then revealed in the darker field of view. My preferred method of making an occulting bar for the really tough observations is to use semi-transparent blue plastic cut into the shape of a half-moon, covered on both sides with flocking material, and remove a tiny notch out of the flocking material only. This will give a tiny, dimmed window where you can keep an eye on the exact position of the bright primary (knowing the exact position of the primary will help you pinpoint the exact position of the companion). This is a finicky unit to make! Not necessary for "easier" doubles.

Summary

One of the things I *initially* disliked about SCTs was the aesthetics — the Airy disks always seemed "fattish" to me; sloppily re-assembled stars. Prior to using these SCTs I was accustomed to a decade of diamond-hard stars in *Tele-Vue* optics! But it is really more than just aesthetics. Much like a refractor bending different wavelengths and offering up nice, tight images in the eyepiece, an SCT also must re-assemble an image for the viewer's pleasure. And the tighter the final convergence, the more efficient the system will be. Add all of these stray-light-suppression techniques and you will bring out the full punch of the Schmidt-Cassegrain optical system. Admittedly, it would be better to take all the stray light and re-unite it with the re-assembled stars these rays came from in the first place, instead of turning the interior of your telescope into a light sponge. This of course can be accomplished only with high-calibre optics — with correspondingly high-calibre prices.

Ultimately, all this will allow for higher resolutions, better contrast — and a more aesthetically pleasing view. Of course, one can never hope to exceed the theoretical maximums for a given aperture, but by taking these steps I have learned I can at least hope to approach them.

Please write if you have any questions — and please, if you are unsure of how to take your telescope apart, do not do it! Remember that I will always be happy to help you with any problems it might be having, as would many other amateur astronomers around.

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Splendid Sight

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

Oh! then farewell, thou beauteous queen!
Thy sway may soften natures yet untamed
Whose breasts, bereft of native fury,
Then shall learn the milder virtues.
We, with anxious mind, follow thy latest footsteps here,
And far as thought can carry us;
My labours now bedeck the monument for future times
Which thou at parting left us. Thy return
Posterity shall witness; years must roll away,
But then at length the splendid sight
Again shall greet our distant children's eyes.

— Jeremiah Horrocks

As one of those distant children, my eyes eagerly await the splendid sight, for Horrocks' poem was about the rarest of astronomical spectacles: a transit of Venus. And Horrocks was uniquely qualified to speak on the subject, for he had predicted the transit himself, and then became the first person in history to actually observe one.

It is on the shoulders of such giants as Horrocks that we collectively stand. That he is not spoken of today in the same breath as his fellow Englishmen Halley and Herschel can be attributed to his sudden and tragic death at age 22. The loss to astronomy was incalculable.

Having lost an older brother at a similar age, I can relate to incalculable loss. I don't suppose he was a Horrocks, but to my eyes Dave was a genius. A musical mathematician — or is it vice versa? — Dave's influence on my life continues to be profound. For one thing, the last time we were together in our home town of St. John's, Dave took me to the darkest corner of Bowring Park and pointed out Comet Kohoutek; my first serious observing session. Still, he was only beginning to scratch the surface of his enormous potential when suddenly, he was gone.

This makes the accomplishments of young Mr. Horrocks all the more amazing in my eyes. As a teenager, Horrocks used Kepler's laws of planetary motion to prove that the Moon has an elliptical orbit (`www.transit-of-venus.org.uk/history.htm`). But his greater claim to fame is the transit of 1639.

The first man to predict such an event was the great Kepler himself, who in his Rudolphine Tables calculated transits of both inner planets, Mercury and Venus, a mere month apart in late 1631. Alas, Kepler died the year before these events occurred, and it was left to Pierre Gassendi to observe the transit of Mercury on November 7, 1631 (Gingerich 1992). The still rarer transit of Venus was visible only in the western hemisphere, and there are no records of anybody having observed it. A once-in-a-lifetime opportunity seemed lost; Kepler foresaw no future Venus events until 1761.

Enter Jeremiah Horrocks. The precocious Englishman inferred a second transit of Venus only eight years after the first. This was missed by Kepler because he did not know the distance from Earth to the Sun (but that's another transitory transit story), and applied incorrect topocentric corrections to his (accurate) geocentric calculations. Horrocks applied new corrections and realized that what Kepler had calculated as a near miss could actually be seen as a transit. Once again, science was advanced because a student refused to accept without question the word of the master.

Unfortunately, the appointed day, December 4 (November 24 Julian) was a Sunday, and young Jeremiah's first obligation was to conduct services at the local church in tiny Much Hoole, Lancashire, which he served as curate. By the time he returned to his telescope, it was 3:15 p.m., a bare half-hour before sunset. Using eyepiece projection, Horrocks immediately "beheld a most agreeable spectacle, the object of my sanguine wishes, a spot of unusual magnitude and of a perfectly circular shape, which had already fully entered upon the Sun's disc on the left, so that the limbs of the Sun and Venus precisely coincided." In other words, second contact. Horrocks therefore did not get a good timing, a missed opportunity that Simon Newcomb later called "a circumstance which science has mourned for a century passed, and will have reason to mourn for a century to come" (Maor 2000).

Horrocks' accomplishment was nonetheless exceptional. In the fleeting month between his calculations and the actual transit, he alerted a few acquaintances in the astronomical community; one of them, William Crabtree of Manchester, was able to catch a brief glimpse of the setting Sun through clouds and provide independent confirmation of the transit. Crabtree's more important role was to preserve the letters of Horrocks, who died before he could publish his observations.

The observation was impressive, the prediction sublime. Horrocks had discovered the unusual fact that transits of Venus occur in pairs. The question remains: why is this so?

Let's have a closer look. The distribution seems mysterious at first glance: 1631 and 1639 (both in December); 1761 and 1769 (both in June); 1874 and 1882 (December); 2004 and 2012 (June).

The eight-year interval is an important clue. In eight years Venus completes almost exactly 13 revolutions, and therefore laps Earth five times (synodic periods). In a given eight-year interval there are therefore five different apparitions of Venus as both morning and evening star, after which the pattern virtually duplicates itself. This repetition is apparent in the following table of inferior conjunctions of Venus, from 1994-2020. The second column λ represents the heliocentric longitude of Venus and Earth, as calculated from *Guide* 7.0; the third ± is Venus' distance from the ecliptic as seen from Earth (Meeus 1983-95).

Date	λ	±	
1994 Nov 2	40°	−5° 24´	
1996 Jun 10	**260°**	**−0° 30´**	
1998 Jan 16	116°	+5° 49´	
1999 Aug 20	327°	−8° 07´	
2001 Mar 30	190°	+8° 01´	
2002 Oct 31	38°	−5° 42´	
2004 Jun 8	**258°**	**−0° 11´**	**T**
2006 Jan 13	114°	+5° 31´	
2007 Aug 18	325°	−7° 59´	
2009 Mar 27	187°	+8° 10´	
2010 Oct 29	35°	−5° 59´	
2012 Jun 6	**256°**	**+0° 09´**	**T**
2014 Jan 11	111°	+5° 11´	
2015 Aug 15	323°	−7° 50´	
2017 Mar 25	185°	+8° 18´	
2018 Oct 26	33°	−6° 15´	
2020 Jun 3	**254°**	**+0° 29´**	

Note the similarity of all data between any two events separated by intervals of five synodic periods (eight years). Rather than sort the data into five separate columns I have merely highlighted, in **bold**, the sequence 1996-2004-2012-2020. In each case the next conjunction occurs two or three days earlier on the calendar, and therefore at a commensurate 2-3° less heliocentric longitude. The difference in Venus' separation from the Sun between any such pair of events is ≤20´.

What stands out in the highlighted sequence is the change in sign from minus to plus as the consecutive inferior conjunctions regress (upwards!) through the descending node of Venus. It seems obvious that this node is very close to 257° longitude, and a central transit would occur if Earth and Venus were in alignment on June 7. The current pair brackets that hypothetical central event. Because the Sun is a disc of some 32 arcminutes, a conjunction of Venus within 16´ of the ecliptic will result in a transit; therefore in the current instance we have a pair of transits, one in each hemisphere of the Sun.

This repetition is perhaps better explained graphically. I have borrowed a method introduced by Kepler (1606), as most recently reproduced by Etz (2000), where each connected the dots between the positions of consecutive Jupiter-Saturn conjunctions relative to the ecliptic circle. Applying the same principle to the Venus-Earth relationship, my mind's eye envisioned a nearly perfect pentagram over an eight-year period, very gradually precessing over the longer term. As I am wholly unskilled in the black art of computer programming, I turned to my unholy-skilled friend Alister Ling for help. Within hours, it seemed, Alister had come up with a program suited for the purpose. I input the data from the above table, and presto! My computer screen displayed exactly the pattern I had envisioned.

From black art springs black magic in the form of the pentagram. Long associated with the dark realms of magic and the occult, this geometric figure is more lustrously associated with the so-called "golden ratio" (Livio 2002), as is the well-known Fibonacci sequence, part of which (...5, 8, 13...) is manifest in the Earth-Venus resonance, as pointed out by the late Fr. Lucian Kemble (1985). Lamplighter Luc shared my fascination

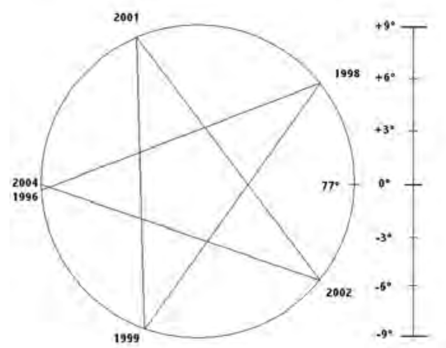


Figure 1. The position of Venus on the ecliptic at six consecutive inferior conjunctions inscribes a nearly perfect pentagram. This "overhead" view of the ecliptic circle is oriented so that the ascending node (77°) is at right. The descending node is very close to the position marked 2004 at left. Conjunctions occur when both Venus and Earth achieve the same heliocentric longitude; as seen *from* Earth, Venus would have values 180° removed from those shown.

This circular representation has a second, very nifty feature: a built-in sine curve. The vertical scale on the right can be used to estimate the distance of Venus from the ecliptic at each conjunction. With one of the points of the pentagram very near 0°, the remaining points are temporarily in almost symmetrical pairs: 1999 –8°, 2001 +8°; and 1998 +6°, 2002 –6°. Neither the vertical scale nor the symmetry is exact because neither planet has a truly circular orbit. The transits occur at the centre-line, the steepest portion of any sine wave, a contributing factor to the event's rarity.

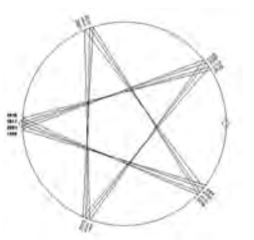
A similar pentagram would describe the positions of Venus at superior conjunction, except at six times greater distance the scale at right would extend only from minus to plus 1.5°.

with the many beautiful properties of the Fibonacci sequence and particularly its uncanny knack to cross from the realm of pure number theory into a surprising variety of natural phenomena.

In his Simon Newcomb Award-winning essay on the Venus-Earth orbital resonance, Chapman (1986) made note of Kemble's assertions, concluding, "I am not convinced that this has any physical basis, but the concept may deserve further exploration." I too am unwilling to ascribe any physical foundation to such a relationship, but will simply note without further comment that a low-order

Fibonacci relationship has been found with both Earth-Venus and Earth-Mars (McCurdy 2002).

As Jeremiah Horrocks' extraordinary observation proved, the eight-year cycle is exact enough that two (but no more) consecutive passes occur less than a Sun-diameter apart. One consequence is that the pentagram rotates at an extremely slow rate. It takes 240 years — thirty 8-year cycles at 2.4° per — to shift 72° (one-fifth of a rotation), after which the pentagram has resumed its original orientation. Of course, after thirty full cycles Venus is on the "wrong" point of the pentagram, and needs a further three years (two synodic periods) to return to almost precisely its original location. The 243-year periodicity of Venus is much more exact than even the 8-, and features series of more than 20 transits.



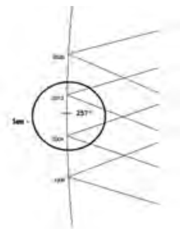


Figure 2 (left) — Over a longer period of time, the pentagram of Venus slowly rotates in a clockwise direction, some 2.4° every eight years. The small circles at left and right represent the Sun at the two nodes of Venus' orbit, which is of sufficient angular diameter for two consecutive conjunctions of the same series to result in transits.

The next transit pair will occur at the ascending node and come from the series at upper right: 1998, 2006, 2014, 2022…2046 (Jan 1), 2053 (Dec 30)…2109, **2117, 2125**…. At top left is the March series, which features extremely favourable "northern elongations" where Venus can be seen as both morning and evening star on the same day. Very well-placed as far back as 1977 (Chapman 1986; Kemble 2000), this series will remain above 8° throughout the current century as it makes a slow pass through the very top of the curve. It will likely peak at the conjunction of 2065 Mar 11, midway in the gap between transit pairs, when the pentagram will be upright.

Figure 3. (right) — A magnified view of the left side of Figure 2. The two transits straddle the descending node, shown as 257°.

Horrocks' dedication to both his clerical duties and his astronomical calling are appropriately encapsulated in one of the few lasting memorials to his work: a stunning stained-glass window in the local church in Hoole, depicting Horrocks gazing upon the projection of the Sun, a black spot fully entered on the left (Moore 1986).

Ironically, both Horrocks and Crabtree died within five years of the transit, and the world had to wait another 121.5 years for Kepler's predicted transit of 1761 before another living person could observe this rare spectacle. The upcoming transit of 2004 ends an identical gap, one 243-year cycle later. Today, more than three and a half centuries after Horrocks, just the third, and best-equipped, generation of "distant children" eagerly awaits another pair of opportunities.

DEDICATION

The foregoing article is dedicated in loving memory of David McCurdy, who introduced me to the music and the spheres, and in a very strange way, to the Fibonacci sequence.

ACKNOWLEDGEMENT

The assistance of Alister Ling (Edmonton Centre, and 2003 recipient of the Simon Newcomb Award) is gratefully acknowledged.

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Bruce McCurdy is active in astronomy education with the RASC Edmonton Centre, Odyssium, and Sky Scan Science Awareness Project. He currently serves National Council as Astronomy Day Coordinator. In this column, the 20th in this series, Bruce has returned to the subject of his very first column, thus proving he too is going nowhere, and not very fast at that.

Dr. Richard Crowe[1]

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

Dr. Richard Crowe can trace his interest in astronomy back to his grade five days in Edmonton. The completion of a project on the stars and constellations fired his imagination and he felt a growing affinity with the stars whenever he looked skyward. By the time he moved to Oakville, Ontario at age 12, he had already formed an astronomy club, demonstrating a desire to share his love of the sky with others that continues to this day.

By the time he had obtained a Master's degree from the University of Western Ontario, Dr. Crowe was ready to "take a break" from his studies: he became the Resident Observer at the University of Toronto Southern Observatory at Las Campanas, Chile. This afforded him the opportunity, from 1977 to 1979, not only to study skies not visible from the north but also to explore new regions of Earth.

Good use was made of time between the observing runs of visiting astronomers: spectra of Mira-type variables were taken and their emission lines studied to determine the processes involved in these stars' changes over a complete cycle of variation. From this came a catalogue of southern-hemisphere Mira variables detailing spectral types, emission-line ratios and absorption-line strengths, at a variety of phases over a cycle. A list was also made of radial velocities for many northern-hemisphere Miras at a variety of phases over one or two cycles. It was determined that "the irregular behaviour of absorption lines (veiling) can be explained by a second shock wave higher in the atmosphere than the one producing the hydrogen emission lines. Strong emission is associated with weak-line cycles (when the overlying absorption due to titanium oxide is weaker)." This work formed the basis of his Ph.D. thesis at the University of Toronto.

Moving to Hawaii, Dr. Crowe was for three years the Canadian Resident Astronomer for the Canada-France-Hawaii Telescope Corporation. He became Professor of Astronomy at the University of Hawaii at Hilo (UH Hilo) in 1987 and Chair of the Department of Physics and Astronomy from 1992 to 2002.

Working with JPL and Goddard Spaceflight Center scientists, Dr. Crowe has made observations of the naked-eye, small-amplitude variable Beta Cephei. His instrument, however, was nothing less than the Voyager II spacecraft, currently probing for the edge of the solar system. He found that "comparison of a large flux variation in the far-UV light curve (from the Voyager data) of the star with ground-based spectroscopic measurements taken simultaneously indicate that an atmospheric shock wave is responsible for this flux variation." The corresponding observations were made at the Dominion Astrophysical Observatory and on Mauna Kea.

Always the teacher, Dr. Crowe has taken numerous students under his wing in innovative ways. He is currently Principal Investigator of the UH Hilo New Opportunities Through Minority Initiatives in Space Science (NOMISS) program, which has seen internships for fourteen students funded by NASA during the last three years. Through this program, Dr. Crowe has been working closely with a core group of 24 local teachers at public, private, and charter schools. One of the program goals is to include more astronomy in K-12 curricula to stimulate careers in astronomy and in the science taking place on Mauna Kea. Dr. Crowe has also been a mentor for students supported by the NASA Space Grant College Fellowship Program and in this role has studied chaotic oscillator models for red

Dr. Richard Crowe

semiregular variable stars.

Under his tutelage students are literally getting "hands-on" astronomical experience. In 1991 Dr. Crowe supervised the renovation, by students, of the University of Hawaii at Hilo campus observatory. In 1997 he and Dr. William Heacox started the undergraduate astronomy program at UH Hilo which has seen enrollment rise to the sixth largest in the United States. Students are being trained using the 24-inch telescope of the University of Hawaii's Institute of Astronomy. That they are able to get up "on the mountain" at all is due to Dr. Crowe's successful acquisition of funds for a motor vehicle. Undergrads are also able to attend Dr. Crowe's new summer training course and even participate in true research: using CCD photometry, observations are made of the suspected Type I supernova progenitor KPD 1930+2752, a binary system containing a white dwarf. Student work has already been published in scientific journals.

The 24-inch is now showing its age

[1] This marks the inauguration of a new column that will highlight the careers of professional Canadian astronomers.

and is becoming difficult to use, although, as Dr. Crowe points out, unlike modern observatories, this one allows you to actually watch the stars through the slit in the dome. No warm observing room here! Nevertheless, in an effort to modernize, Dr. Crowe is working on another project on students' behalf: a telescope in the 32- to 36-inch range to replace the 24-inch.

Sounds like astronomy heaven: a large, student-accessible observatory at one of the best observing sites in the world. But Dr. Crowe suggests that seven layers of clothing would be a valuable observing aid!

Phil 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.

FROM THE PAST | AU FIL DES ANS

MARS: THE PLANET OF MYSTERY

There is perennial interest in the planet Mars. The mind of man has long speculated on the possibility of the existence, in the universe, of other worlds inhabited by intelligent beings; and with the development of astronomical knowledge, — especially since it has been shown that the Earth is but once of a series of planets revolving about the Sun, and further, that the numerous fixed stars are suns like our own, — our interest in other worlds has grown in intensity.

As we examine the different planets of our system, Mercury, Venus, Mars, Jupiter, Saturn, Uranus and Neptune, we soon conclude that the most likely places to look for evidence on the question are those planets nearest us, — Venus on one side and Mars on the other.

Now Venus is a very difficult body to study. It is almost a duplicate to the Earth as regards size and density, but as its position in the sky is never far from the Sun and as it is always enveloped in clouds, little or no detail can be detected on its surface. Close study has led to the belief that it always presents the same face to the Sun (just as the Moon presents the same face to the Earth), and thus one-half of the body is exposed to intense heat and the other to intense cold. If such is the case, Venus is not a suitable abode for intelligent beings in anywise like ourselves.

On the other hand much interesting information has been learned about Mars. Even a small telescope will show markings on the planet, while larger instruments, especially when mounted in a locality where the air is clear and steady, exhibit many striking details. Numerous and prolonged studies of Mars have given us a mass of interesting observations, the interpretation of which has led to many diverging views as to the condition of its surface.

by C.A. Chant,
from *Journal*, Vol. 5, p. 408-409, November-December, 1911.

Cruising the Southern Skies

by Tony Patrick, Ottawa Centre (m.t.patrick@sympatico.ca)

The following is my impression of watching the Southern skies from a cruise ship. The cruise was aboard the 45,000-ton ship Royal Princess, which departed from Valparaiso, Chile, rounded Cape Horn, went on to the Falkland Islands, and finally docked in Buenos Aires, with several stops along the way.

I came equipped with 7 × 50 binoculars and observed in January 2004 during the last and first quarters of the Moon. Observing from a moving ship, with all the vibrations and often-strong winds on the forward decks, is not ideal. Also, the weather conditions in Southern Patagonia, Tierra del Fuego, and the Falklands regions are usually overcast and this trip was no exception — only five of the fourteen nights were exceptionally clear. The clear nights happened around Valparaiso on the Pacific side and Northern Patagonia on the Atlantic side. However, this was more than adequate to see an amazing variety of objects. The best observing night was the last one, which was on the Rio de la Plata between Montevideo and Buenos Aires. Being in a river estuary, the winds were calm and the air was warm and pleasant, although the sky was not quite as dark as on the open sea.

My strongest impression was of the Southern Milky Way itself. Its brightness, especially in the Carina region, is truly breathtaking and awesome. For anyone interested in stargazing, seeing the Southern Milky Way from the Southern Hemisphere is an absolute must. There are so many bright stars in Carina that at first I was not sure just where the boundaries of the constellation were. The Eta Carina Nebula and the Southern Pleiades glowed with incredible clarity. The Orion Nebula was like I never saw it before, bright with an obvious blue hue to it. I was very impressed by the beauty of the blue star Canopus. The Tarantula Nebula in the Large Magellanic Cloud was amazingly bright for an object 170,000 light years away. Looking carefully with my binoculars, I could make out two dim nebulae in the Small Magellanic Cloud and just under it, the stunning globular cluster 47 Tucanae.

Other objects I observed were Alpha and Beta Centauri and the brightest globular cluster of them all, Omega Centauri, still low in the east. Right overhead, M41 in Canis Major was a delight to look at. Also observed were several open clusters I did not identify because there seemed to be so many of them. It was odd to see the constellations like Orion upside down and the Pleiades strangely isolated in the North. Finally, I saw the Southern Cross, near Centaurus, low in the east. This was the constellation every interested person on the ship wanted to see. I did not find it that impressive, but I easily detected the Jewel Box and the Coal Sack.

The cruise was extremely successful, and the Southern Sky has made a wonderful permanent impression on me. Next time I go to the Southern Hemisphere, I would like to do some land observing with a telescope.

Tony Patrick has been interested in astronomy for many years and originally joined the RASC Halifax Centre in the late 1970s. After a long hiatus, he joined the Ottawa Centre and has been a member for the last five years.

Coincidental Supernovae in Spiral Galaxy NGC 772

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

The Heavens always find interesting ways to surprise and amaze even the most seasoned observers. This event is certainly one of those ways.

On September 30, 2003 fellow member Roland Prevost noticed an extra object in his image of the spiral galaxy NGC 772 in Aries. He determined that this new object was the supernova SN2003HL, which had been detected by the Lick Observatory and Tenagra Observatory Supernova Searches (LOTOSS) on August 20. Roland's independent discovery of the supernova piqued my curiosity, since I had recently purchased a new SBIG ST-9XE CCD camera and was in the process of testing it. I did not expect to be looking at supernovae with it, but decided that it would not take much time to take a few images of this new supernova for the purpose of determining its light curve over time.

I took my first image of the supernova on the evening of October 2 and figured that its magnitude was nearly +16.5, which is quite bright, given that NGC 772 is at a distance of 105 million light years! If the same supernova had occurred 10 parsecs (32.6 light years) from Earth, we would have seen a brilliant new star with about twenty-five times the brightness of the full moon!

On October 10 I was analyzing images of SN2003HL taken on the evening of October 8, when I noticed a new object on the southern edge of the galaxy that looked out of place. Out of curiosity, I checked my previous images of the galaxy, and found that they did not contain any object in that same location. I looked at several more images of the galaxy taken on that day to make sure that the extra object was not a CCD camera artefact or a random cosmic ray hit. The object was indeed new to me, but it was uncertain at that time whether it had already been seen. At that moment I was thinking that it would have been too good to be true to have two supernovae flare up in the same galaxy a mere seven weeks apart. Besides, many short-period variable stars can seem to appear out of nowhere when reaching their maximum apparent brightness. So I checked my *USNO A2.0* star catalogue and my *RealSky* images to make sure that the new object was not simply a local variable star. It was not.

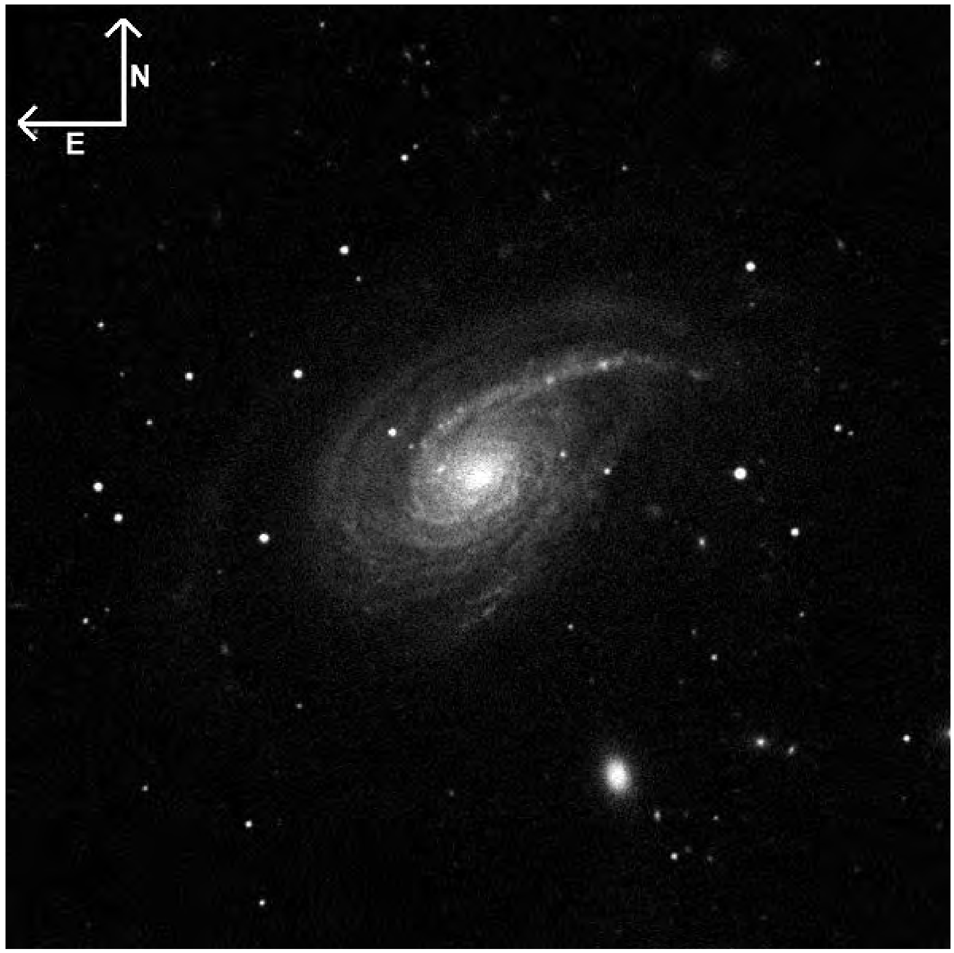

Figure 1 — Image of the Spiral Galaxy NGC 772 before the SN2003HL and SN2003IQ explosions were detected. This image was taken from the *Digitized Sky Survey* (DSS) that was created by scanning Palomar photographic plates originally obtained in 1953. The galaxy NGC 770, which is interacting with NGC 772, can be seen as a small hazy patch to the south-southwest. The compass directions were added to the original image using *Paint Shop Pro.*

After finally excluding all other possible reasons for the extra object, I checked an up-to-date supernova Web site and found that a new supernova had indeed been discovered at the same location in the galaxy about 48 hours before I noticed it. At least I found out that my

Figure 2 — Image of NGC 772 taken on September 30, 2003 by Roland Prevost indicating the supernova SN2003HL he had independently discovered. The light of the second supernova had not yet reached Earth when this image was taken, but unknown to anyone at the time, it was only nine days away. The compass directions were added to the original image using *Paint Shop Pro*.

new equipment had the capability of discovering new supernovae! I then determined that the new supernova had a preliminary brightness of about magnitude 17.

The amazing thing about this new supernova, designated SN2003IQ, was that it was located in the same galaxy as SN2003HL. The following night (October 11), I found that the newer supernova had brightened by nearly a full magnitude to 16, outshining SN2003HL by at least half a magnitude.

The supernovae were seen to appear about seven weeks apart as seen from our unique position in space. This does not mean that they actually exploded within that same time frame. Since the speed of light is finite (thank you, Einstein), there is a time variable involved here as well.

First, the galaxy's distance from us is estimated at 105 million light years. This means that the light of both supernovae needed 105 million years to reach human eyes. In other words, both supernovae actually exploded about 105 million years ago! Right now, both supernovae have long since extinguished, but their light is still travelling through space, and happened to finally reach us during our lifetimes. We're pretty lucky to see them if you think about it.

Second, the observed time between the detection of the supernovae changes when seen from different locations in space. If Earth were located at some other location

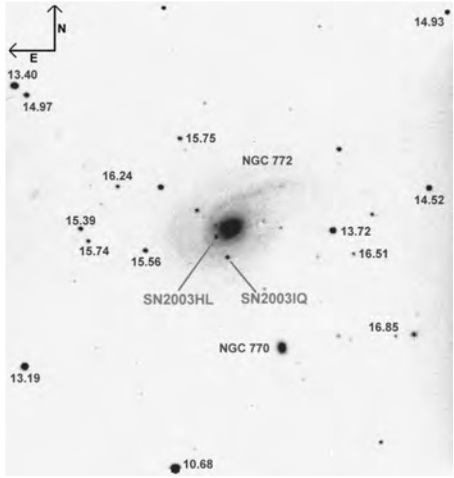

Figure 3 — Galaxy NGC 772 with supernovae SN2003HL and SN2003IQ. The numbers next to some of the stars are *USNO A2.0* star catalogue magnitude (brightness) values of the 14 calibration stars used to determine the brightness of both supernovae. The image was obtained by Mike Earl with a Celestron NexStar 11-inch GPS Schmidt-Cassegrain reflecting telescope and SBIG ST-9XE CCD camera in Orleans, Ontario at 02:46 UT October 14, 2003. The exposure time was 30 seconds. The limiting magnitude is about 19.0. This is a negative of the original image. All labels were added to the original image using *Paint Shop Pro*.

in space relative to NGC 772, the supernovae flare-ups could have been seen many generations apart! If we could see NGC 772 as a face-on galaxy, there would be a much better chance that the two supernovae had actually happened within the same time as seen to be from Earth. From Earth's location, however, NGC 772 is seen to be inclined 54 degrees from the face-on position and 7.2 arcminutes in diameter. This translates into an actual diameter of about 225,000 light years, more than twice the diameter of our own Milky Way galaxy. From our viewing location, the supernovae are seen to be located approximately 39 arcseconds apart. Using some basic trigonometry, and assuming that both supernovae were located within the galactic equatorial plane, the actual time between the explosions is more like 27,000 years. To sum it up, we are literally in the right place at the right time to see these two supernovae occur at nearly the same time!

Just imagine one star exploding violently some 105 million years ago. 27,000 years (or so) later, the light of this supernova just passes

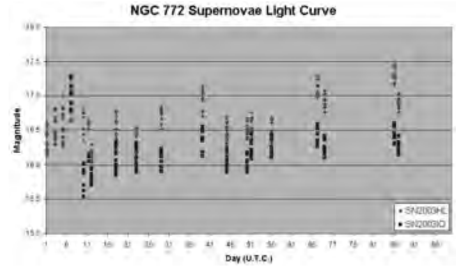

Figure 4 — Light curves of supernovae SN2003HL and SN2003IQ for 87 days. Day 1 corresponds to October 3, 2003 (UT). The many brightness values for each day correspond to the 14 stars used to determine the apparent brightness of the supernovae. It can be seen that the brightness of SN2003IQ increased significantly from Day 7 to Day 10 (October 9 to 12). For some days, not all of the 14 calibration stars could be used, especially when the full Moon interfered with the imaging on Day 11.

the position of another star when it also explodes, sending its brilliant light across the Universe and toward Earth just behind its predecessor by a mere seven weeks.

Also imagine if Roland and myself were

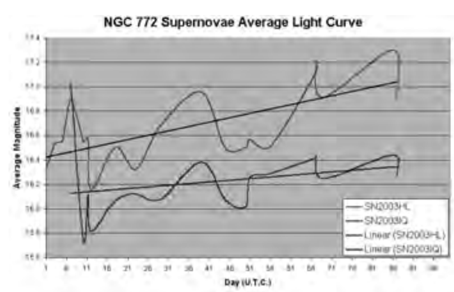

Figure 5 — Average light curves of supernovae SN2003HL and SN2003IQ for 87 days. Day 1 corresponds to October 3, 2003 (UT). The linear-trend line for each light curve has been plotted to indicate the dimming of each supernova over time.

the first humans to see SN2003HL and SN2003IQ respectively. It might have been the first time two members of the same chapter of the same club had discovered two supernovae in the same galaxy at nearly the same time! We were so close! Maybe next time!

Mike Earl has been an amateur astronomer for nearly 30 years. He is currently observing man-made satellites in orbit for the purpose of keeping track of interesting characteristics, such as their tumble periods.

Obituary
Necrologie

Henry Lee (1920–2004)

by Randy Groundwater, Past President of the Windsor Centre

On January 6, 2004, the Windsor Centre lost a long-time and faithful member and friend, when Henry Lee passed away peacefully. He was 83.

When Henry was a high-school student at Paterson Collegiate in Windsor, among his teachers was Mr. Cyril Hallam, who would become a founding member of the Windsor Centre in 1945. Henry had a keen interest in science and astronomy, and quickly became involved in the fledgling chapter's activities. He began serving on its council in about 1948, and held many positions over the decades, including Secretary, National Council representative, and President.

By profession, Henry was an electrical engineer and served with a number of large corporations throughout his life, including Green Giant Ltd. and the former Chrysler Canada. He was also a businessman and entrepreneur, administering a local family business known as the Oriental Centre in downtown Windsor, and also Dragon Brand Frozen Foods, the first of its kind in Canada.

Henry held long-standing memberships in The Industrial Mathematics Society, Sigma Pi Sigma (American Institute of Physics), the Torch Club of Detroit, and the Windsor Chinese Benevolent Association. He was also a volunteer member of the City of Windsor's Environmental Committee, and the Science and Technology Study Committee.

An avid collector, Henry surrounded himself with clocks, watches, geological samples, and tools of every kind; being the true professional he was, he knew their every use and application.

Through the years, hundreds benefitted from Henry's talent as a natural educator. During his life he was a Sunday School teacher and during the 1970s taught a course titled "Principles of Astronomy" for the local school board. During the 1980s and '90s he also became well known as an expert practitioner of the ancient martial art of T'ai Chi and taught its virtues extensively to night-school classes. He always encouraged the importance of "Clear minds, tranquil thoughts."

Henry was a mentor for generations of local stargazers and over the years, in his kind and gentlemanly way, provided guidance and inspiration to them through his own deep love of astronomy. One person at a time, through his lifetime love of the stars, his name became synonymous with astronomy to everyone who had the privilege of knowing him.

Henry served a term on National Council as Recorder (1989–1991) and was a recipient of the Society's Service Medal in 1984.

Figure 1 — Henry Lee at Willistead Manor addressing the RASC Windsor Centre as keynote speaker on the occasion of their 50th anniversary.

Just a few days before he died, on December 27, 2003, Windsor Centre members and guests gathered at Hallam Observatory to celebrate the dedication of the Henry Lee Telescope; a *Celestron 14* mounted on a *Software Bisque Paramount ME*. Although poor health prevented his attendance, Henry was well represented by his faithful wife of 45 years, Mamie, and his sister, Anna. It is fitting that this wonderful 21st-century instrument now bears the name of one of the 20th-century pillars of the Windsor Centre. We will miss you, Henry.

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Observer's Calendar — 2004

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

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

Individual Order Prices: $16.95 Cdn (members); $19.95 CDn (non-members)
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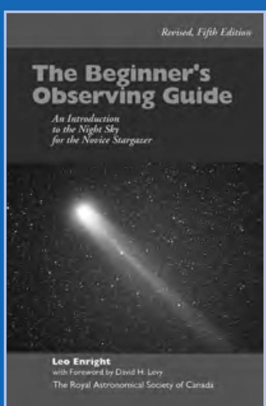

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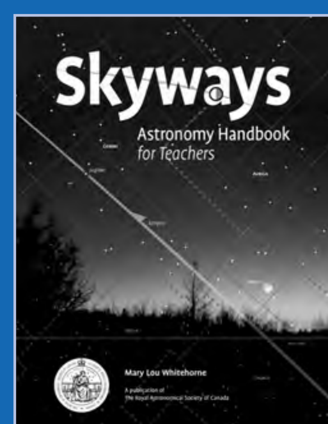
Skyways: Astronomy Handbook for Teachers



Teaching Astronomy? Skyways Makes it Easy!

Written by a Canadian for Canadian teachers and astronomy educators, Skyways is Canadian curriculum-specific; pre-tested by Canadian teachers; hands-on; interactive; geared for upper elementary, middle school, and junior-high grades; fun and easy to use; cost-effective.

Skyways is complete with conceptual background; teacher information; student worksheets; resource lists; Canadian contributions to astronomy section FAQ's, and more. Written by Canadian author and RASC member, Mary Lou Whitehorne.

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