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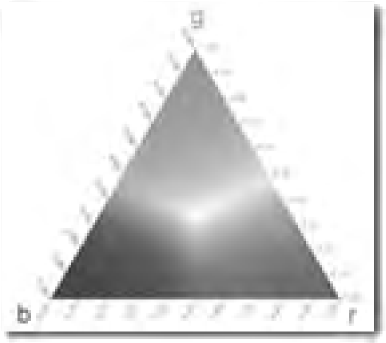

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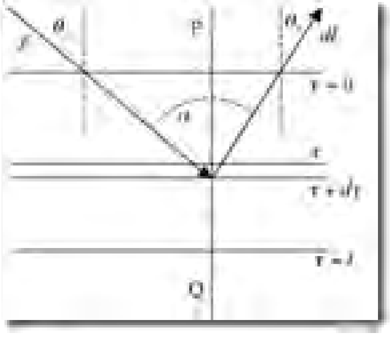

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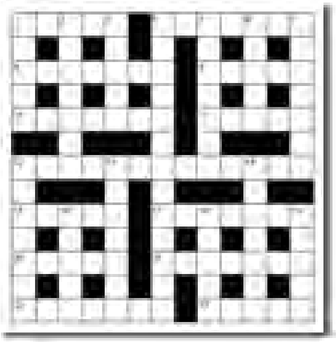

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Editorial

by Wayne A. Barkhouse (wbark@head-cfa.harvard.edu)

This issue of the *Journal* represents a personal milestone for me as it marks five years since I took over the position of Editor from David Turner (Halifax Centre). The first action undertaken as the new "Editor-in-Chief" was to revamp the production team in order to draw upon the skill and energy of several individuals instead of relying on the heroic strength of a single person to get the *Journal* to the production stage. I am forever grateful for those who have (and continue to) volunteer their precious time and energy in making sure that the *Journal* continues (please see the masthead for a list of those directly involved).

After five years as Editor-in-Chief, I have decided to step down and pass the reins on to someone else. I always felt that it is not a good idea to have one person occupy this position for "life." A fresh injection of new ideas and enthusiasm is key to maintaining a healthy production. I thank all of you who were responsible for allowing me to take on this position while I was a graduate student in the Department of Astronomy and Astrophysics at the University of Toronto. I am also grateful to those who have worked hard with me during the last five years to insure a high-quality product and something of which we can be proud!

In the last year, it has become clear that the financial state of our Society needs to be strengthened. One of the biggest investments is the production of this publication. As such, it has come under a lot of scrutiny (as it should) in an effort to minimize the cost of production. A healthy debate on the status and details of producing the *Journal* is a good thing and may lead to some obvious changes in the near future.

In less than two years, this publication will celebrate its centennial. I hope that the Journal and the Society will still be around to mark its 200th birthday. In closing, I leave you with a quote by our "founding father," that is even more relevant today than it was nearly one hundred years ago.

"There are few technical articles on astronomy, which, if clearly written, have not a real value to the amateur, while the work of the latter is always of interest to his professional brother. There will be room for both in the pages of the *Journal*. If all unite, the result will be highly creditable to Canadian science."[1]

---

[1] C.A. Chant, *Journal*, Vol. 1, p.1, January-February 1907.

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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Early Discovery of Sunspots

Galileo is known to have discovered sunspots and to separate successfully their regular rotation with the Sun itself from their proper movement relative to the Sun's disk, however, the existence of sunspots was noticed a few centuries earlier. The great traveller Marco Polo (*ca.* 1254–1324) described his conversation with the astronomer Jamal-ud-Din, a Persian, and his team of Chinese astronomers. They discovered the sunspots (and apparently observed them repeatedly) when "the desert dust veiled the Sun."

Marco Polo's narrative appeared in 1319. Its best-known English rendition supplemented by vast commentaries is Yule (1975), but the authors omitted this episode. I found it in Jennings (1985, p. 648). Polo's conversation with the astronomers took place in the last quarter of the 13th century somewhere near the present-day city of Tianjin in China.

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The Moons of Jupiter

Alan Whitman's article "Greybeard Nostalgia: That Sagging-scope Feeling" (*JRASC,* 99, 31) prompted me to consult observing notes from 1961 to 1969 that I still possess, not being one to discard anything unless forced to. In the early '60s I too owned a 60-mm department store refractor whose make I have long since forgotten but whose quality I now realize must have been exceptional. I can corroborate Mr. Whitman's observations of shadow transits of Jupiter's moons from detailed notes taken in that exceptional opposition year of 1963 and even further back, in 1961 and 1962.

On July 30, 1961 I made a drawing showing a transit of both Callisto and its shadow, just north of the NEB. There are two more observations of transits from that year: of Europa on August 15 and of Ganymede on August 29. The drawing for the latter date shows both the shadow and the disk of the satellite, with the note that the shadow was larger and dimmer than the satellite itself. On July 28, 1962 at 3:45 EDT, a drawing shows the shadow of Io transiting near the south edge of the NEB, as does a sketch done on August 21, at 10:30 p.m. EDT. September 13 of that year was a particularly interesting night: my drawing shows Ganymede and its shadow transiting at 8:30 p.m. EDT, with the notes that the shadow was "very dark and could easily be seen in the lowest power" (35×) and that "later I saw III emerge on the west side of Jupiter and also saw satellite I passing over Jupiter's surface." I also noted seeing the Great Red Spot and that at one point the shadow of Ganymede covered part of it.

On October 5, 1963, the date Mr. Whitman reports seeing Ganymede's shadow in transit, my notes read as follows: "I noticed first its shadow making a notch in the limb ... at 9:02; it seemed completely on the disk about 9:06. Since Jupiter was only 3 days before opposition, the shadow was only slightly w. of the satellite. The satellite itself began to enter the disk at 9:11 and did not come to second contact until 9:27, but it entered at quite a high latitude and therefore at an oblique angle. The satellite itself only remained visible (and only once in a while) for a short time after ingress, apparently because ... the limb of Jupiter is darker than the rest." The month before, on September 25, I noted a shadow transit of Io under "the best seeing I have ever experienced." Again on November 3, a drawing shows a shadow transit of Io at 8 p.m. EST under "very clear and steady" skies. My notes do not give details of the magnification used, but I had three eyepieces (35×, 78×, and 140×) and probably used the 78× most of the time.

Of later observations, I will quote only one, from September 5, 1964, as it gives more details regarding the visibility of such events: "I was watching the double transits of satellites I and II and their shadows. The shadow of I but not of II was clearly seen. This could well be explained if II's shadow were projected on the darker equatorial band. Satellite I itself was seen entering the disk, but not after. Satellite II was also seen as it entered but not after." I now realize these observations seem to stretch the limits of what is possible with a 60-mm scope, but at the time I was unaware that I was not supposed to be able to see such phenomena, so I did.

The trusty 60-mm was eventually sold as university studies took up more of my time, but I should note that it also provided fascinating views of the edge-on presentation of Saturn's rings in late 1966. As I recall, I used it almost exclusively for planetary and lunar viewing, given the limitations of aperture and the even then-light-polluted skies from which I was observing in a New Jersey suburb of New York City.

Frank Bayerl
Ottawa Centre, RASC

News Notes
En Manchettes

PROBING OLD OPEN CLUSTERS

Sometimes the most critical test of a model is how it stacks up against the most extreme cases that nature can throw at it. Take M67 and NGC 188 — familiar objects to deep-sky observers and considered to be two of the oldest open clusters known. Open clusters are often used to test stellar evolutionary models since all the stars were born at about the same time and from interstellar gas of about the same composition. The stars are also at nearly the same distance, making it much easier to estimate their absolute magnitude.

Once placed on a colour-magnitude diagram (a form of the famous Hertzsprung-Russell diagram) the age of the cluster can be deduced from the location in which the main-sequence stars turn off towards the red-giant and supergiant region. The exact location of this point is called the main-sequence turnoff. The more massive a star, the higher it appears along the main sequence, the sooner it runs out of available hydrogen fuel, and the quicker it turns off towards the red-giant region. The older the cluster the further down the main sequence this turn-off appears as less and less massive stars end their lives. Computer models can predict the shape and location of the main-sequence turnoff depending on the choice of model input such as the ratio of hydrogen to helium and the amount of elements heavier than helium (its metallicity). The closer the computer model comes to reproducing the observed turn-off the more confident astrophysicists are that their model is a true representation of how a star works.

Don VandenBerg of the University of Victoria and Peter Stetson of the Herzberg Institute of Astrophysics (National Research Council of Canada) have tested our understanding of an important stellar parameter against these two celestial senior citizens (*Publications of the Astronomical Society of the Pacific,* November 2004). Their work primarily looked at an effect called convective-core overshooting.

Stars have basically two kinds of core — radiative or convective. A radiative core primarily transports energy from the core through radiation like gamma rays. Convective cores on the other hand accomplish this by hot buoyant cells of gas rising from the core. The kind of core a star has depends essentially on its mass. Our sun has a radiative core, but stars just 10% to 15% more massive have convective cores.

Convective-core overshooting is a process where rising cells of hot gas shoot past their expected height. As the cell cools and falls back towards the centre of the star it drags hydrogen gas down from higher levels thus providing an extra source of thermonuclear fuel for the core. As a result, the overshooting core can extend the life of the star and change the expected time and appearance of the main sequence turn-off.

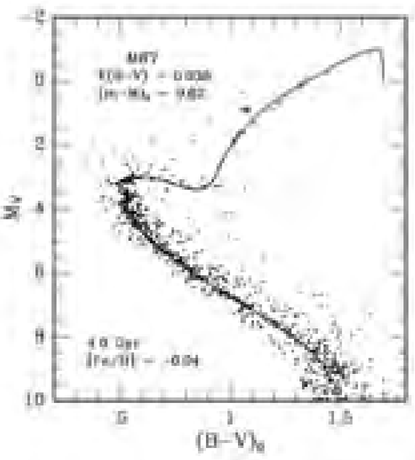

Figure 1 – Colour-magnitude diagram for the old open cluster M67 showing the best-fit stellar model isochrone.

VandenBerg and Stetson found that the best fit between their stellar model and the colour-magnitude diagram of M67 implied that the extent of convective-core overshooting was relatively small in the stars that remained on the main sequence. The same analysis applied to NGC 188 suggested that the cluster is too old for overshooting to play a role since the remaining stars along the main sequence appear to be too small to have convective cores. From their stellar models the two astronomers also found that the estimated age of the two clusters was 4.0 billion years for M67 and 6.8 billion years for NGC 188. This is consistent with other estimates and makes these objects the oldest known open clusters.

COLD-WAR-ERA TELESCOPE RE-ENLISTED

Canada has rejoined the international effort to map near-Earth space with the commissioning of a powerful wide-field search telescope at the University of Calgary's Rothney Astrophysical Observatory. A main purpose of the telescope will be to search for potentially threatening asteroids and comets, a research effort known as the Near-Earth Space Surveillance — Terrestrial (NESS-T) Project.

The initiative was made possible by the transfer of a decommissioned Baker-Nunn telescope (or patrol camera) to the University of Calgary by the Canadian Air Force. The Baker-Nunn telescope was originally built at the dawn of the Space Age in the 1950s to track satellites during the Cold War. Today, the Baker-Nunn telescope has been transformed into a state-of-the-art research tool thanks to a $500,000 retrofit project.

The retrofit project was funded by the Canada Foundation for Innovation (CFI); the Government of Alberta, through the Alberta Science and Research Investments Program; and the University of Calgary, via research grants earned by Dr. Alan Hildebrand, Department of Geology and Geophysics; Dr. Eugene Milone, Department of Physics and Astronomy; and Dr. Peter Brown, of The University of Western Ontario's Department of Physics and Astronomy. Drs. Hildebrand and Brown both hold Canada Research Chairs. The new project "represents an important boost for the University of Calgary to further their research in the field of astronomy," says Dr. Elliot Phillipson, President and CEO of the Canada Foundation for Innovation. "The investment we are celebrating today will strengthen Canada's capacity to effectively compete locally, nationally, and internationally in this important area of research."

"It's important that we continue to invest in world-class research equipment in Alberta and support initiatives like this one as we advance the province's innovation agenda," says Victor Doerksen, Minister of Innovation and Science. "I'm pleased that we were able to work with our partners and contribute to a state-of-the-art project that will play a key role for the international research community."

The Baker-Nunn telescope is based at the Rothney Astrophysical Observatory (RAO), located a short drive southwest of Calgary near Priddis, Alta. The NESS-T project will complement current international asteroid search efforts by patrolling the northern portion of the sky.

The refurbished and re-instrumented Baker-Nunn telescope incorporates a prime focus CCD camera to discover objects in two-minute exposures that would have required one-hour exposures using film-based methods. The retrofitted telescope also boasts the widest field of view of any professional asteroid search telescope. "Compared to an average telescope (with a field of view more than 200 times smaller), the Baker-Nunn can, in one exposure, image an area that would take an entire night with other telescopes. In the asteroid search business, the ability to detect faint objects within large search fields is golden," says Michael Mazur, a former U of C graduate student who conducted the retrofit project.

U of C researcher Robert Cardinal developed software to locate faint asteroids from the thousands of stars recorded in every image. "New approaches have been required to make a computer program capable of quickly finding the asteroids with available computing power. We will be modifying our processing routines further, but it has been most gratifying to begin reporting asteroid positions."

The retrofitted telescope will allow Canada to make important contributions to the world while exploring near-Earth space. "We want to assess the impact hazard that our civilization faces by discovering all the sizable objects in Earth-crossing orbits," says Dr. Hildebrand. "The individual asteroids that have the greatest impact risk are objects with the most Earth-like orbits. These are also the asteroids that are easiest for us to reach with exploration spacecraft for scientific purposes, and to exploit as future resources. We are particularly excited by the possibility of finding asteroids that will be used in construction of giant satellites to supply energy to the Earth from space."

Figure 2 – University of Calgary researchers Rob Cardinal, Mike Mazur, and Alan Hildebrand, with the newly refurbished Baker-Nunn telescope in the background. Photograph by Ken Bendiktson.

Images from the Baker-Nunn telescope will also contribute a vast amount of scientific data that will lead

WEB ACCESS TO AUGUST 2005 ISSUE

The August 2005 issue of the *Journal* can be accessed from the RASC Web site at `www.rasc.ca/currentjrasc` This issue will be posted immediately after the final production version is complete (approximately August 10, 2005) and removed from the Web once the issue begins arriving by mail.

to other astronomical discoveries. For example, Dr. Milone will use the images in a project to search for variable stars. "The wide field of view will permit a search across much of the northern sky for new variables, including supernovae in distant galaxies," he says. As well, U of C graduate students in the Faculty of Science will use the telescope for various research projects.

The above article is reproduced courtesy of the University of Calgary and is taken from an "In the News" article published February 16, 2005.

CITA DIRECTOR HONOURED

Professor Richard Bond, Director of the Canadian Institute for Theoretical Astrophysics (CITA) has recently been named a member of the Order of Canada. The Order of Canada was established in 1967 to recognize outstanding achievement and service in various fields of human endeavour, and it is Canada's highest honour for lifetime achievement. The citation for Professor Bond reads: "One of our pre-eminent theoretical astrophysicists and cosmologists, Richard Bond has been instrumental in establishing Canada as a major world centre for research in cosmology. As Director of the Cosmology and Gravity Program of the Canadian Institute for Advanced Research, he has helped to build an outstanding network of scientists from around the globe. A founding member and Director of the Canadian Institute for Theoretical Astrophysics at the University of Toronto, where he is also a Professor, he has enhanced the Institute's mandate and international reputation. An inspirational leader and mentor, he continues his pioneering work on the structure formation and evolution of the Universe."

MAKING THE *MOST* OF IT

Data gathered with the *Microvariability and Oscillations of STars (MOST)* satellite is now being archived to the public domain since it has passed the one-year proprietary period. In particular, the ultraprecise photometry data for the star Procyon, along with links to published data, has recently added to the archive. The data (in FITS format) can be accessed via `www.astro.ubc.ca/MOST/data/data.html`.

The commissioning data on the star kappa 1 Ceti is currently being converted into the public FITS format and these data will be linked to the ***MOST*** Public Data Archive soon. The *MOST* archive is funded and supported by the Canadian Space Agency and the Canadian Astronomy Data Centre.

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The Star on Roman Coins

by Robert S. McIvor (rsmcivor@aol.com)

Introduction

Few records of astronomical observations have survived from the distant past and this is especially true of Western sources. The best prospect for ancient sources was the library at Alexandria in Egypt founded in the third century BC. At its height the library housed about 500,000 rolls, "the equivalent, perhaps, of 100,000 modern books" (Hornblower & Spawforth 1996). Its archives may well have included astronomical observations because Eratosthenes, the famous astronomer and geographer, had once been chief librarian there. Its books might have documented a continuous catalogue of historical observations from 300 BC onwards, including, perhaps, the original eyewitness accounts. But all the books of this library were deliberately destroyed in 641 during the Islamic conquest. The tragic result is that only a few comet appearances have been preserved in Greek and Roman historians and they are "quite incidental, mentioned only as a portent of some great historical event" (Barrett 1978).

A more complete catalogue of observations has survived in China where emperors hired professional observers to keep constant watch of the heavens for unusual phenomena and to file written reports with a government ministry. But, even here, only summaries have been preserved in the dynastic histories, not the detailed original eyewitness reports. The summaries often consist of a short sentence and they frequently lack detail.

In addition to written records of the event, the most famous comet of long ago was commemorated on a Roman coin. The comet appeared shortly after Julius Caesar was murdered in March of 44 BC. Some twenty years after the event, around 24 BC, Augustus struck a coin to commemorate the comet and inscribed on it are the Latin words DIVVS IVLIVS, "divine Julius" (Coin 1). The comet is shown with a prominent tail. This was an authentic comet appearance because it was observed independently in the Far East.

In the same year, 44 BC, observers in China and Korea recorded a *hui-hsing* or tailed comet and described its reddish-yellow colour and the changing length of its tail. It was visible for "a few days" in the "fourth month" of the Chinese calendar, equivalent to May 18 through June 16. It appeared near the Chinese asterism called the Shen (21st lunar mansion) which Ho (1962) identifies as the triangular area of sky bounded by Betelgeuse, Alnitak, and Saiph, in Orion (Figure 1).

Figure 1 – The comet of 44 BC was observed near *The Shen* (21st lunar mansion), the triangular area of sky bounded by Betelgeuse, Alnitak, and Saiph in Orion.

This comet was not the only celestial event celebrated on Roman coins.

The Star on Roman Coins

Augustus died in AD 14, and his successor, Tiberius, struck a coin at the imperial mint in AD 15 or 16 that displays a six-pointed star above the portrait of Augustus with the Latin inscription, DIVVS AVGVSTVS, "divine Augustus" (Coin 2). Similar coins with a six-pointed star above the head of Augustus were produced at provincial mints in Spain, Gaul, Sicily, the Balkans, and Cyprus between AD 16 and 37 (Coin 3). The star is always shown with rays of light spread evenly in all directions. There is no comet tail.

Numismatists have been unable to explain why a star was added to the portrait of Augustus on these coins. "The significance of the star in front of the imperial bust is not clear," admits Burnett, Amandry, & Ripolles (1992). It is surprising that no astronomer seems to have researched the star on these coins. Surprising, because the existence of the comet coin is known everywhere, while these star coins seem to have been overlooked.

Some of these coins add the title PATER or the full title PATER PATRIAE ("Father of the Country") to the name of Augustus. Augustus listed this title among his greatest accomplishments. His words have been preserved in both Latin and Greek in an ancient inscription on the walls of the Temple of Rome and Augustus in Ancyra (Ankara in modern Turkey) called the *Monumentum Ancyranum*. "In my 13th consulship, the senate, the equestrian order and the whole people of Rome gave me the title PATER PATRIAE" (Brunt & Moore 1967). He was consul for the 13th time in 2 BC. The senate conferred the title of PATER on him in 2 BC. Several of these coins therefore have two features, namely, a star and a dating formula equivalent to 2 BC.

Tiberius issued another coin in AD 15 or 16 that adds a significant detail about the star and it is this detail coupled with the dating formula that helps explain why a star was added to the portrait of Augustus on all these coins. On the obverse, the coin shows the star above Augustus and is inscribed to DIVVS AVGVSTVS PATER, "divine Augustus, Father of the Country," but it is the distinctive eagle pattern on the reverse that cries out for explanation (Coin 4). Numismatists describe it as an eagle standing on the globe of the Earth but no one has explained what the eagle symbolizes.

It is certainly no ordinary bird of prey for it is larger than the Earth and holds the Earth in its talons. In view of the modest size of the Earth, the eagle must represent something on a huge scale. It appears to represent the constellation of Aquila the Eagle. Claudius Ptolemy, the famous astronomer of second century Alexandria, published the first star catalogue in history and he described this constellation as an eagle whose outline was configured by nine stars (Figure 2). The Romans distinguished constellation figures by adding the Earth for perspective and the obvious example is the constellation figure of Capricornus shown as a sea-goat holding the Earth between its forelegs or the Earth beneath it (Coin 5). The star-and-eagle coin therefore has three features: a star, a dating formula equivalent to 2 BC, and the constellation of Aquila, or simply, Star, 2 BC, Aquila. This particular coin, first produced under Tiberius in AD 15 or 16, was re-issued by emperor Domitian (81-96) in the final decade of the first century, around AD 95. This means that this star in Aquila was celebrated on Roman coins for nine decades.

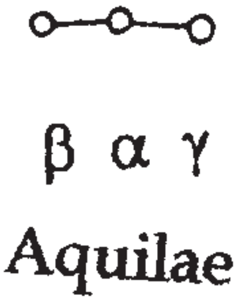

Figure 2 – The constellation of Aquila was figured or configured by nine stars. The three brightest stars, αβγ Aquilae, are circled.

This coin associates the star with the constellation of Aquila and with Augustus and the year 2 BC and this specific information on sky location and chronology raises the possibility that this had been an unusual star appearance in that constellation at that time. Since the comet coin inscribed to the "divine Julius" was prompted by an authentic comet appearance, it seems likely that these star coins inscribed to the "divine Augustus" were also inspired by an authentic celestial event.

The Sparkling Star in Aquila in 4 BC

A nova or comet was recorded in China in 4 BC. "In the reign of emperor Ai-ti, in the third year of the Chien-p'ing period, third month, day chi-yu, there was a *hsing-po* at Hoku" (Han Shu, *The History of the Former Han Dynasty*). The date is equivalent to April 24, 4 BC. This identifies the date when the object was first observed in China.

It was also recorded in Korea. "In the fifty-fourth year of Hyokkose Wang, in the spring, second month, day chi-yu, a *po-hsing* appeared at Hoku" (Samguk Sagi, The Historical Record of the Three Kingdoms). The Korean text is partially corrupt because Ho (1962) points out that "the *chi-yu* day did not fall in the second month that year but on the first (February 23) and on the third (April 24)." The original must have read "day chi-yu, first month" (February 23) or "day chi-yu, third month" (April 24). The latter would coincide with the date in the Chinese records although professor Ho suggests the date was "probably February 23, 4 BC."

The usual Chinese term for a tailed comet, *hui-hsing* (literally, broom-star), was not used to describe the observation of 4 BC and this indicates that the object was either a nova or a tail-less comet. Needham (1970) reminds us that "the dynastic histories do not always make a clear distinction between novae and comets." Hasegawa (1980) cautions that "it is rather difficult, when detailed descriptions are absent, to distinguish between a star (nova) and a comet."

Ho (1962) explains the word *po* as "light shooting in all directions" and he translates *po-hsing* as "a sparkling star" and indicates it was used of a comet that "sends out its rays evenly in all directions." He concedes that "a few of the *po* were probably novae." Stephenson (1976) describes a *po-hsing* sometimes as "a rayed star" and sometimes as "a tail-less comet" and he also concedes that "some of these stars were novae rather than comets." Xi & Bo (1966) translate *po-hsing* as "a sparkling star" and consider the object of 4 BC to have been a nova. Kukarin *et al.* (1971) calls it "a scintillating star" and lists the object of 4 BC as a nova. Pskovskii (1972) prefers "sparkling star" and considers the 4 BC phenomenon a nova.

The object appeared near *Hoku*, a Chinese star-group equated with αβγ Aquilae by Williams (1877) and Xi & Bo (1966). Loewe (1979) says this asterism was depicted on "at least one Han stone relief" and he reproduces the illustration as three circles or dots in a straight line (Figure 3). There is no indication how close the object appeared to αβγ Aquilae. The summaries are obviously incomplete for they do not state how bright the object was nor how long it remained visible.

The Coins Celebrate the Star in Aquila

The star on the Roman coins looks the same as the star in the Far Eastern records.

Figure 3 – The rayed star of 4 BC was observed near *Hoku,* αβγ Aquilae, depicted as three circles in a straight line on a stone relief of the Han period.

Its rayed appearance on the coins matches the description of "a sparkling star" emitting "its rays evenly in all directions," and the sky location in Aquila is the same in both sources. The star in 2 BC in Aquila on the coins is remarkably close to the star in 4 BC in Aquila in the Chinese and Korean records.

Evidently the star was added to the portrait of Augustus on the coins because it appeared in Aquila during his reign and was taken as a sign of the emperor's importance. The star was visible in 2 BC when the Romans expressed their approval of Augustus by conferring the title PATER PATRIAE on him and this unusual star was interpreted as heaven's simultaneous approval of the emperor. This is Roman propaganda.

The star was celebrated on imperial coins for nine decades and on provincial coins for four. This star is unique in numismatic history for no other star or comet has attracted this kind of numismatic attention. It was commemorated at mints all across Europe from Spain to Cyprus long after its appearance. Even decades after it had faded from view, it still had not faded from memory. It must have been a star of startling brilliance. And the re-issuance of the Aquila coin by Domitian as late as AD 95 means that this imperial coin celebrating the star was in circulation well into the second century in every country where Rome ruled, including all the countries encircling the Mediterranean.

The Far Eastern summaries do not state how long the star of 4 BC remained visible. The PATER title on the Roman coins is an unambiguous reference to 2 BC. Unless there had been two novae in the same constellation just two years apart, it seems likely that the star remained visible from 4 BC until 2 BC. A period of visibility of about two years would be similar to the spectacular nova of 1054 in Taurus, which has since been confirmed as a supernova that formed the Crab nebula and pulsar.

Roman Propaganda and Numismatic Artwork

The Romans exploited celestial events to enhance the status of their leaders. Augustus produced the comet coin about twenty years after the comet appearance and inscribed it to his predecessor, the divine Julius. Tiberius produced the star coins almost twenty years after the nova appearance and inscribed them to his predecessor, the divine Augustus. Roman coins were instruments of imperial propaganda.

However, the fact this was propaganda must not obscure the other fact that the coins commemorated real events in the heavens that were independently observed and recorded in the Far East. Propaganda often contains, and effective propaganda always contains a kernel of truth and these coins involve authentic astronomical events. The comet associated with Caesar and the star associated with Augustus were not fictitious.

Astronomy can explain the numismatic artwork of the eagle standing on the globe of the Earth as the constellation-figure of Aquila. The identification of the eagle as the Eagle constellation is critical in this investigation. It is also an attractive interpretation because it recognizes both the star and the eagle on opposite sides of the coin as astronomical symbols. The coin displays STAR, PATER, EAGLE, which can be interpreted as STAR, 2 BC, AQUILA. The star on the Roman coins is not just any star for it is defined by a date and a constellation on the coins as a star in 2 BC in Aquila.

All coins, ancient and modern, are miniature works of art. These Roman coins preserve evidence for a brilliant nova in Aquila near the beginning of the present era that was celebrated across Europe for many decades.

COIN 1. Imperial coin struck by Augustus *ca.* 24 BC to commemorate the comet in 44 BC is inscribed to the "divine Julius."

Mint: Rome, Italy
Obverse: Head of Augustus, CAESAR AVGVSTVS
Reverse: Tailed comet, DIVVS IVLIVS
Reference: RIC 271 (RIC = "Roman Imperial Coins" in bibliography)

COIN 2. Imperial coin struck by Tiberius in AD 15 or 16 shows a star above the head of Augustus and is inscribed to the "divine Augustus."

Mint: Rome, Italy
Obverse: 6-pointed star above Augustus, DIVVS AVGVSTVS
Reverse: Livia seated (Livia was the wife of Augustus)
Reference: RIC (Divus Augustus) 2

COIN 3. Provincial coins produced between AD 16 and 37 at mints in Spain, Sicily, Cyprus, Gaul, and the Balkans display a star above the head of Augustus.

Mint: Emerita, Spain (Colonia Augusta Emerita)
Obverse: 6-pointed star above Augustus, DIVVS AVGVSTVS PATER
Reverse: City gate, AVGVSTA EMERITA
Reference: RPC 21 (RPC = "Roman Provincial Coins" in bibliography)

Mint: Romula, modern Seville, Spain (Colonia Romula)
Obverse: 6-pointed star above Augustus, PERM. DIVI. AVG. COL. ROM.
Reverse: Crescent, Livia's head upon globe, IVLIA AVGVSTA GENETRIX ORBIS
Reference: RPC 73

Mint: Panormus, Sicily
Obverse: 6-pointed star above Augustus, PANORMITANORVM
Reverse: Capricorn, CN DO PROC A LAETO IIVIR
(Procul and A. Laetor were magistrates in Panormus)
Reference: RPC 644

Mint: Paphos, Cyprus
Obverse: Head of Tiberius, TI. CAESAR AVGVSTVS
Reverse: 6-pointed star above Augustus, DIVOS AVGVSTVS PATER PATR
Reference: RPC 3917

COIN 4. Imperial coin struck by Tiberius in AD 15 or 16 shows a star above Augustus and is inscribed to the "divine Augustus, Father of the Country." The reverse displays an eagle with spread wings standing on the globe of the Earth. This coin was reissued by Domitian *ca.* 95.

Mint: Rome, Italy (Produced in AD 15 or 16)
Obverse: Head of Augustus, DIVVS AVGVSTVS PATER
Reverse: Eagle standing on globe
Reference: RIC (Divus Augustus) 3

Mint: Rome, Italy (Produced in or about AD 95)
Obverse: Star above head of Augustus, DIVVS AVGVSTVS PATER
Reverse: Eagle standing on globe, IMP. D. CAES. AVG. RESTITVIT
Reference: RIC (Domitian) 456

COIN 5. The constellation of Capricornus is represented on Roman coins as a sea-goat with the globe of the Earth between its forelegs or underneath.

Mint: Lugdunum (Lyons, France)
Obverse: Head of Titus
Reverse: Capricorn

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Robert S. McIvor is interested in the history of astronomy, numismatics, and chronology. In 2000, the Journal *published a previous article of his on the Aztec Calendar Stone.*

Planetary Photometry: The Lommel-Seeliger Law

by Maxwell B. Fairbairn

Introduction

The use of the Lommel-Seeliger law is an enduring aspect of planetary photometry. It has the advantage of analytical simplicity as well as, in many cases, being an excellent first approximation to diffuse reflection and in spite of its shortcomings — in particular its inability to display an opposition effect — is still very much in use today in applications as diverse as lightcurve inversion (the determination of asteroid poles and shapes from their lightcurves; Kaasalainen 2003), and the prediction of photometric signatures of unresolved ringed extrasolar planets (Arnold & Schneider 2004). Indeed, it is the topic of exoplanets that has recently generated an interest in planetary photometry by astronomers who would otherwise not be concerned with the subject.

Here we present the Lommel-Seeliger law in some detail and as a result point out the existence and consequences of an insidious error that has percolated down through the literature.

Description

The Lommel-Seeliger law is based on a simple physical model of diffuse reflection. As such it is a *single scattering* model in which the scattering is *isotropic*.

The model assumes that light penetrates the surface, being attenuated exponentially as it does so. Here *attenuation* refers to any process that reduces the brightness of a beam of light, and thus includes scattering and absorption. Each element of volume encountered by the attenuated beam scatters part of it isotropically, *i.e.* equally in all directions into the 4π steradians (the imaginary sphere, if you like) surrounding it. Thus, of this diffuse scattered radiation, only *half* is directed back towards the surface, and this fraction will be further attenuated before emerging as diffuse reflected radiation.

Derivation

The following derivation is intended to be more illustrative than entirely rigorous and contains a few shortcuts. It is nonetheless correct; for a more robust and general proof see *e.g.* Hapke (1981).

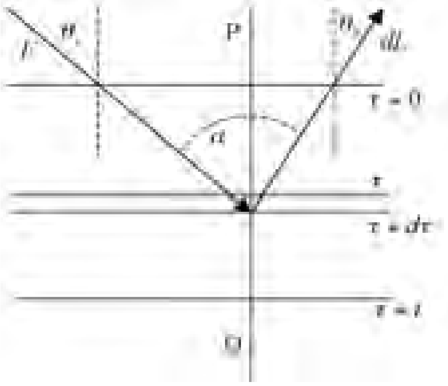

Figure 1 – In this diagram, the incident beam, the line *PQ,* and the reflected beam need not be in the same plane; imagine one half rotated about *PQ* with respect to the other half. The angle between the incident and reflected beams is the (solar) phase angle, α. The value of α is relevant only for anisotropic scattering.

Consider, as shown in Figure 1, a diffuse reflecting (and transmitting) layer of *normal optical thickness t,* in which the optical thickness includes attenuation by both scattering and absorption. In problems of this nature, it is more convenient to work in terms of optical thickness than actual physical thickness. Light traversing a path of optical thickness τ is attenuated by a factor $e^{-\tau}$.

The surface ($\tau = 0$) is irradiated by a plane parallel beam of radiant flux density F at an angle of incidence θ_i, so that the irradiance is $E = F \cos \theta_i$. We are concerned with the resulting radiance in the direction of an angle of reflection $\theta_r < 90°$. Now let $\mu_0 = \cos \theta_i$ and $\mu = \cos \theta_\gamma$ and consider the layer between τ and $\tau + d\tau$. The incident flux density that has penetrated to this level is $Fe^{-\tau/\mu_0}$. The contribution to the diffuse radiance in the direction μ by isotropic scattering is

thus $\dfrac{\varpi_0}{4\pi} Fe^{-\tau/\mu_0} \dfrac{d\tau}{\mu}$, where ϖ_0 is the single

scattering albedo. This radiation will be further attenuated by the factor $e^{-\tau/\mu}$ before emerging from the surface, so that the contribution to the radiance in the direction μ is:

$$dL = \frac{\varpi_0}{4\pi} Fe^{-\tau/\mu_0} \frac{d\tau}{\mu} e^{-\tau/}\mu. \qquad (1)$$

Note that dL is the contribution to the total radiance from the layer resulting from *single scattering*. The Lommel-Seeliger model considers only the scattering of the collimated incident light. It does not take into account scattering of diffuse light that has made its way indirectly to the same position by being scattered one or more times; *i.e.,* it does not consider *multiple scattering*.

For a planetary surface, the layer is "semi-infinite" ($t = \infty$) and the total radiance in the direction μ is:

$$L = \frac{\varpi_0 F}{4\pi\mu} \int_0^\infty \exp[-\tau(\frac{1}{\mu_0} + \frac{1}{\mu})] d\tau, \qquad (2)$$

resulting in:

$$L = \frac{\varpi_0 F}{4\pi\mu}\frac{\mu_0\mu}{\mu+\mu_0}, \qquad (3)$$

and since the irradiance is $E = F\mu_0$ and $L = f_\gamma E$ it follows that the bidirectional reflectance distribution function (BRDF) that defines the Lommel-Seeliger reflectance rule is:

$$f_r = \frac{\varpi_0}{4\pi}\frac{1}{\mu+\mu_0}. \qquad (4)$$

The use of the Lommel-Seeliger model is not restricted to planetary surfaces. For a layer of finite optical thickness *t*, *e.g.* an (exo)planetary ring, the reflected radiance is:

$$L_R = \frac{\varpi_0 F}{4\pi\mu}\int_0^t \exp[-\tau(\frac{1}{\mu_0}+\frac{1}{\mu})]d\tau \qquad (5)$$

resulting in

$$L_R = \frac{\varpi_0}{4\pi}\frac{1}{\mu+\mu_0}[1-\exp\{-t(\frac{1}{\mu_0}+\frac{1}{\mu})\}]\mu_0 F, \qquad (6)$$

and by similar reasoning the radiance L_T transmitted through the layer may be determined (Arnold & Schneider 2004).

Errors in the Literature

The oldest error that the author has been able to detect dates back to 1916 in a paper on planetary albedos by (no less than) Henry Norris Russell (Russell 1916). In that paper the BRDF is implicitly expressed as:

$$f_r = \frac{\gamma}{\mu_0+\mu}, \qquad (7)$$

in which γ is a constant. From this Russell derives the directional hemispherical reflectance (hemispherical albedo):

$$\rho(\mu_0) = 2\pi\gamma[1-\mu_0 \mathrm{1n}(1+1/\mu_0)], \qquad (8)$$

where it may be seen that the expression in brackets varies monotonically from 0.308 ($\mu_0 = 1$) to unity ($\mu_0 = 0$), and he then argues "Since (ρ) can never exceed unity it follows that $\pi\gamma$ cannot be greater than 0.5 nor (the Bond albedo) A than 0.409. Hence a planet for which (the geometrical albedo) ρ exceeds 0.25 cannot reflect light in strict accordance with the Lommel-Seeliger law."

Although this argument sounds entirely plausible, it is wrong. While it is true that ρ, like any albedo, cannot exceed unity, in the case of the Lommel-Seeliger law it cannot exceed 0.5, and therefore the maximum value of γ is (1/4π) not (1/2π); the value of γ is $\frac{\varpi_0}{4\pi}$. Such an error can affect albedo calculations by a factor of two. Unfortunately, this error has filtered down into subsequent publications (*e.g.* Lester, McCall, & Tatum 1979; Fairbairn 2002, 2004). The correct properties of the Lommel-Seeliger law are summarized in Table 1.

Properties of the Lommel-Seeliger Reflectance Law			
Surfaces		Spheres	
f_r	$\frac{\varpi_0}{4\pi}\frac{1}{\mu_0+\mu}$	q	$\frac{16}{3}(1-\mathrm{1n}\,2)$
ρ (0.5)	$\frac{\varpi_0}{2}[1-\mu_0 \mathrm{1n}(1+1/\mu_0)]$	ρ (0.125)	$\frac{\varpi_0}{8}$
ρ_n (0.125)	$\frac{\varpi_0}{8}$	A (0.2046)	$\frac{2}{3}\varpi_0(1-\mathrm{1n}2)$

Table 1 – Properties of the Lommel-Seeliger law for surfaces and spheres. Maximum possible values are shown in parentheses. p_n is the normal albedo and q the phase integral.

For some applications, the error of a factor of two is of no consequence. In cases where only relative magnitudes matter, so that the offset is arbitrary, the factor disappears into the offset. Asteroid lightcurve profiles are such examples.

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Max Fairbairn, of Sydney, Australia, obtained an M.Sc. in Astronomy from the University of Victoria in 1972. He taught Physics, Mathematics, and Computing Science at the New South Wales College of Technical and Further Education. He maintained an interest in astronomy as well as in the restoration and running of old engines of many types (steam, Stirling, and internal combustion engines among many others). Max died on January 5, 2005 at the age of 58.

The Perils of Amateur Astronomy, Part 1

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

At first thought, one would not include amateur astronomy in a list of life-threatening pastimes such as skydiving, white-water canoeing, or Russian roulette. The popular image of the astronomer is a meek, quiet, myopic chap who spends most of his evening hours peering harmlessly through the eyepiece of his telescope at some distant object of view — too distant to have any bearing on his physical well-being. Nevertheless, in my forty-odd years of astronomical observing, I have had a few hair-raising experiences: I have been attacked by a ferocious guard dog, forced to lie in a coffin, interrogated by the RCMP, challenged by a rifle-toting night watchman, nearly trampled by a herd of wild ponies, and subjected to a penetrating search by a customs official — not all at once, mind you! It is nothing short of a disgrace that the neophyte astronomer is not forewarned of such hazards in the many "How To" books, articles, and Web pages on the pleasures of amateur astronomy that entice one to take up the hobby. On second thought, what can one expect from a pastime that requires the enthusiast to get up to some (by normal standards) pretty strange antics that are conducted in the dead of night?

It was my father who lured me into amateur astronomy. When I was a lad in Winnipeg, he would take me outdoors at night and show me the principal star formations: the Big and Little Dippers, Orion (The Hunter), The Northern Cross, and so on. He probably learned these basics while training to be an R.A.F. radio operator. My interest expanded with my reading ability: books and libraries form a large part of my childhood memories and I was (as I am now) a voracious reader. For me, astronomy was dangerous even then, as I fell into the hazardous and silly practice of walking and reading at the same time, resulting in a spate of collisions with lamp posts, pedestrians, and door jambs. Not having learned the lesson, I graduated to reading while riding my bicycle, a habit that was thankfully nipped in the bud by an early collision with a parked car that bent my front forks so badly that I could ride only in circles thereafter. (The public will be relieved to know, now that I am grown, I do *not* drive my car and read at the same time — apart from the occasional map.) Despite these forebodings, as a young boy of eight years of age I knew I wanted to be a scientist of some kind — perhaps even an astronomer. I never became a professional astronomer, but I did follow a scientific career, maintaining a strong amateur interest in astronomy.

From the fifth grade, I have three indelible memories: an assassinated U.S. president, a chipped tooth, and a kind teacher who lent me a pile of old *Sky & Telescope* magazines. The President's name I remember; the teacher's, I do not. I would read the magazine articles, which were quite advanced for me at the time, and dream about owning one of the several impressive telescopes advertised on the back cover. Eventually, on my tenth birthday, my parents presented me with a modest department store telescope, the kind so often denigrated today. Either telescopes were better made in those days, or my boyish enthusiasm in some way compensated for sub-standard optics. In any case, my first telescope of 60-mm aperture and maximum magnification of 60 power was my passport to the Universe. In the eyepiece, objects that had previously been invisible or indistinct blobs of light started to resemble the drawings and photographs in my books: the craters and mountains of the Moon, the moons of Jupiter, the rings of Saturn, star clusters, gaseous nebulae, galaxies, and so on. My first view of the bright star Arcturus was a large, badly out-of-focus blob that I mistook for the star's disk; I learned at an early age the value of double checking my facts before announcing my "discoveries" to the world!

This first involvement with observational astronomy was relatively peril-free, being conducted entirely within the confines of our yard in Transcona (a suburb of Winnipeg). The most significant hazard I encountered was the bitterly cold Manitoba winter's night during which I observed my first eclipse of the Moon. My family was quite supportive of this project; I can still remember their cheerful, encouraging cries of "shut the @#$% door!" every time I came indoors to thaw out, which was about every five minutes. I also discovered an unintended feature of the dewcap provided to shield the telescope's principal lens from condensation: today — wherever it is — the telescope's dewcap bears the dents and scratches received while absorbing the frequent shocks received while striking the ground after being upset by a clumsy ten-year-old.

Along with my telescope, on my birthday I received a copy of Patrick Moore's *The Amateur Astronomer,* which still graces my bookshelf despite its dilapidated condition — actually, I recently had it re-bound, for sentimental reasons. Most of the astronomical ephemera in the appendices — eclipses, planetary positions, *etc.* — are long out of date, but

I still savour the words and pictures that I used to pore over. (I also savour the price: $3 for a new hardcover book with photographs!) There cannot be an astronomer, amateur or professional, who has not read one of Patrick Moore's books.

One Saturday morning, I set out on the bus from Transcona with a dollar bill in my pocket, bound for the University of Manitoba bookstore to buy a copy of the 1963 *Observer's Handbook,* an annual calendar of astronomical events and an indispensable reference book. The trip required a change of buses in Winnipeg and took about one and a half hours. (My parents trained their children to be self-reliant; it would not have occurred to me to ask my father for a ride in the car.) When I finally arrived, the bookstore was closed. During the trip home, I analyzed my dilemma: the bookstore was open on weekdays, when I was at school; when I was able to go on weekends, it was closed. My father stepped in and helped me out of the jam: he took my dollar to a colleague at work, who gave it to his son, a student at the university; he purchased the book, and passed it back along the chain.

My early astronomical adventures were solitary. Later, when our family moved to Ottawa, I found a kindred spirit in a fellow student at my new elementary school. I walked into the science room and met a fellow putting together a display of the solar system, complete with all the planets scaled according to size. His name was John Conville and he also owned a telescope: a 3-inch reflector. We instantly became fast friends and started observing together. With adolescent delusions, we formed the CCAPO — the Chapman-Conville Astrophysical Observatory — and started a newsletter to report our observations. Later, when in high school, we became student members of the Ottawa Centre of the Royal Astronomical Society of Canada.

The Ottawa Centre of the RASC held their monthly meetings in the Dominion Observatory. We teenagers found the lectures a little dry and technical, but there was also an Observers' Group composed of younger members who were keen observers; they also met monthly on a different day. We soon fell in with this group and were recruited into a corps of active observers who — among other things — camped out for several weeks every July and August to observe and record the annual Perseid meteor shower.

The procedure for the serious observation of meteors required eight of us to lie in a circle with our heads together at the centre, our bodies radiating outwards like the spokes of a wheel. In this way, each of us was responsible for monitoring a sector of the sky, with some overlap. All the while, a tape recorder would record the CHU radio time signal from the Dominion Observatory and the frequent shouts of "Time!", which was the observers' means of indicating the appearance of a meteor. These tapes were transcribed later onto meteor report forms. In addition, we had to learn the art of estimating the apparent brightness of the meteors. Particularly bright meteors, also called fireballs, would attract everyone's attention, eliciting a chorus of "Time! Time! Time!" from the entire group. On one occasion, a fireball appeared directly behind me, but it was so bright I thought it was someone playing with his flashlight, trying to mess me up. I turned to protest at the intrusion just in time to see the last remnants of the fireball fade away. I have no idea what we did with the observations, but I didn't mind too much, as we had fun recording them.

We did not lie directly on the ground. To keep out the wind and the cold (essential during the Geminid meteor shower in December), we had specially constructed wooden boxes to lie in. These were closed on all sides with an opening for the observer's head and shoulders. Appropriately, we called these meteor observing boxes "coffins."

When described to others, organized meteor observing always seems much stranger than it really is. My mother never fully approved of all this nocturnal activity, but she gradually became accustomed to it, eventually finding solace in the thought that her youngest son managed to survive his teenage years staying out all night without getting into trouble with the police.

More about my astronomical encounters with the police in the next installment…

A story about this article: in 1991, I submitted the article for consideration for the Simon Newcomb Award (under the old rules) but at the time it was found not to be serious enough. After licking my wounds, I submitted the same article as an entry in the Personal Essay category of the 15th Annual Writing Competition sponsored by the Writers' Federation of Nova Scotia. To my surprise, it won first prize in its category. It is on my Web page, but I have prepared this updated version (in two parts) for archival purposes.

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

Second Light

Infrared Light from an Extrasolar Planet

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

The world has recently been treated to yet another claim of the detection of light from an extrasolar planet — is this one different from the others? It seems so, because there already is an independent confirmation. Drake Deming of NASA's Goddard Space Flight Center and his colleagues have found the infrared signature of the planet orbiting HD 209458 (see the April 7, 2005 issue of *Nature*), while David Charbonneau of Harvard and his colleagues found a similar signature for the planet orbiting the star TrES-1 (see the June 20, 2005 issue of the *Astrophysical Journal*).

Past claims to have seen directly the light from an extrasolar planet have a rather dismal history, in essence echoing the false claims of the first extrasolar planets themselves that arose in the early 1990s. Andrew Collier Cameron and his colleagues claimed (see the Dec 16, 1999 issue of *Nature*) to have seen the planet orbiting τ Bootis, but that was subsequently shown to be wrong (though those authors never formally withdrew their claim). Most recently, Glenn Schneider of the University of Arizona recently claimed to have seen a possible planet orbiting the brown dwarf known as 2MASSWJ 1207334-393254 (the long number simply identifies the location of the object as mapped by the 2MASS project). The announcement was made at the January meeting of the American Astronomical Society, but does not seem to have attracted much attention so far.

Directly detecting planets around other stars is a very difficult problem — so difficult that NASA has yet to decide on what technology offers the best chance of success. To give a sense of the problem, imagine looking at a dim candle a few centimetres away from a bright car headlight, at a distance of hundreds of metres. You'd never see the candle — it would be swallowed by the light from the car. The star-planet problem is even harder. At visible wavelengths, a solar-type star is a billion times brighter than a companion Jupiter-like planet. You can try to beat the odds by going to the infrared, where the ratio drops to something like a million, but then the achievable resolution of the telescope has dropped by a factor of three or so, which means that the planet has to be further away from the star to be seen, or the telescope (or interferometer) has to be three times bigger.

Deming and Charbonneau haven't beaten the odds in quite this way, but by using a very clever technique involving planets whose orbital planes lie along the line of sight to the star, so the star eclipses the planet when the planet passes behind it. There are only a few known eclipsing planets because the geometrical requirements for the orientation (and size) of the planetary orbit relative to the line of sight are so stringent. (We can see that this must be so even in our own Solar System, or we would have lunar and solar eclipses every month, which we certainly do not.)

The planets are so close to their parent stars that they are significantly heated and therefore will emit infrared light. Deming and Charbonneau observed their stars in the mid-infrared, and looked for the dip in the light from the system as the planets pass behind the stars — in both cases, they found the dip to be exactly in phase with the orbital cycle determined from measurements of the radial velocity. That means that the signal outside of the eclipse is made up of light from the planet and the star combined. It might not be as satisfying to the public as directly imaging the planet (which is the aim of several proposed NASA satellites), but to astronomers it is just as interesting and important. Using the observed dip in the light curve, Deming and Charbonneau could estimate the "brightness" temperature in the mid-infrared, and they confirmed that the planets are strongly heated by the parent stars.

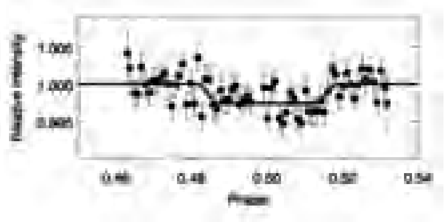

Figure 1 – Binned data from Deming *et al*. (2005; *Nature,* 434, 740). The dark black line shows the best-fit secondary eclipse light curve.

These results should hold up with time, marking the first glimpse of light from other planets. Seeing Earth-like planets around other stars remains, however, a hope for the future.

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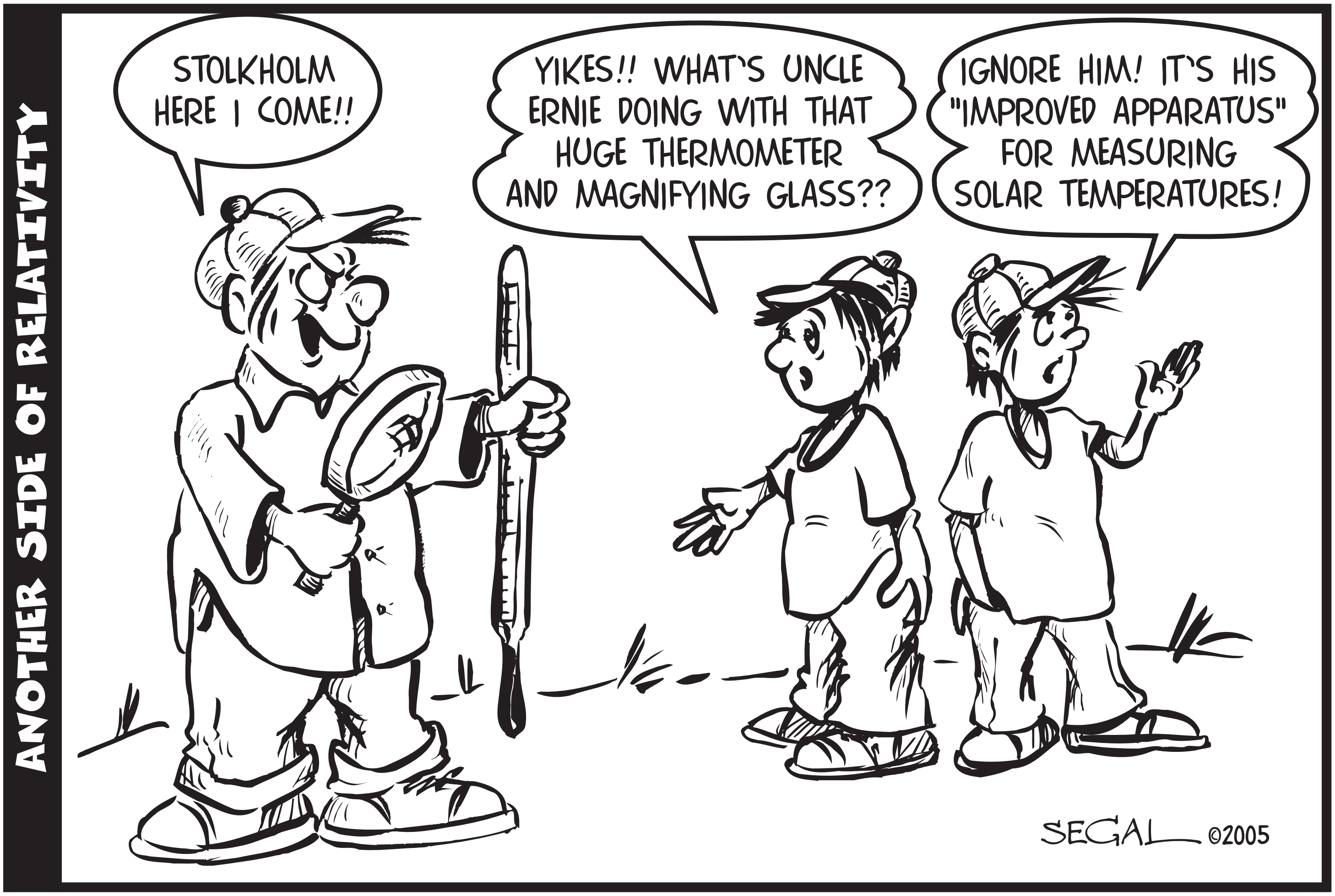
Progress in Astronomy and Astrophysics in 1906

The temperature of the Sun is another physical quantity of great interest, and a new approximate value has recently been found by M. Henri Moissan, who is noted for his work with the electric furnace. The metal titanium is plentiful in the Sun, and Moissan, having succeeded in volatilising it in his furnace at a temperature of about 3500° C., concluded that the temperature of the Sun where this substance is volatilised must be about the same as this. He concludes that the solar temperature is somewhere between Wilson's estimate of 6590° C. and that of Violle, of 2000 to 3000° C., the probability being that the latter is nearer the truth. (4000° C. = 7212° Fahr.)

by C.A. Chant
from *Journal,* Vol. 1, p. 6, January-February 1907.



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VISUAL STAR COLOURS FROM INSTRUMENTAL PHOTOMETRY

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Abstract. In order to display graphically the visual colours of stars and other astronomical objects, photometric broadband R, V, B colours are used to proxy for the r, g, b colours of the three visual sensors of the eye.

From photometric Johnson $B–V$ and $V–R$ colour indices, R, V, and B magnitudes ($V = 0$) are calculated, and from these the respective brightnesses (r, $v = 1 = g$, and b) are calculated. After suitable normalization these are then placed in a ternary diagram having r, g, and b as the vertices.

All $B–V$ and $V–R$ are adjusted so that the Sun falls in the same place as a blackbody at 5800 K. The resulting ternary plot shows all of its objects (stars, planets) in their visual colours at their relative positions in the ternary diagram.

The star colours displayed on a computer monitor screen or as a print with a colour printer are more vivid than the usual visual impressions of isolated stars, undoubtedly because of properties of the dark-adapted eye, but double-star pairs with contrasting colours correspond nicely to telescopic visual impressions.

Résumé. Pour démontrer sur graphique les couleurs visuelles des étoiles et d'autres objets astronomiques, les couleurs photométriques à bande large R, V, B, ont servi de substitut pour les couleurs r, g, b des trois détecteurs visuels de l'oeil.

Selon les indices de couleurs photométriques Johnson B-V et V-R, les magnitudes (V=0) R, V et B ont été calculées, et sur la base de celle-ci leurs intensités respectives (r, $v = 1 = g$, et b) ont été calculées. Après avoir été normalisées, elles ont été portées sur un diagramme ternaire ayant comme sommets r, g, et b.

Toutes valeurs B-V et V-R ont été ajustées afin que le Soleil agisse comme corps noir à 5800 K. Le tracé point par point qui en résulte montre tous les objets (étoiles, planètes) dans leurs couleurs visuelles par rapport à leurs positions sur le diagramme ternaire.

Les couleurs d'étoiles apparraissant sur un écran d'ordinateur ou sur papier imprimé sur imprimante couleur sont plus intenses que l'impression visuelle habituelle d'étoiles isolées, sans doute à cause des propriétés de l'oeil adapté à la noirceur. Toutefois, des paires d'étoiles doubles à couleurs divergeantes correspondent bien à l'impression visuelle téléscopique.

1. INTRODUCTION

Apparent visual colours of luminous objects are quite subjective and depend on the individual viewer's colour sensitivity. They are strongly influenced by the colour environment, also by the sizes of the objects, and possibly by their brightness. This is exemplified by the well-known enhancements of the apparent colours of double stars. The components of a binary pair may be perceived as brilliantly coloured, whereas stars of similar spectral types when seen alone are regarded as having relatively pale colours. It would be useful to have a way of expressing the colour of an object independently of its environment, size, brightness, and viewers' colour sensitivities.

2. VISUAL *r, g, b* COLOURS AND COLOUR FIELD

The colour of an object is given by the spectral distribution of its light through the range to which the human eye is sensitive. The human eye has three types of colour receptors, having maximum sensitivity for red, green, and blue light. The perceived colour of an object is determined by the relative stimulation of the three receptors, designated as r, g, and b, respectively. For each, the stimulation is the integral of the sensitivity at each wavelength times the intensity of the spectrum of the incident light at that wavelength:

$$J_r = \text{stimulation of red sensor} = \int S_r(\lambda)\, I(\lambda)\, d\lambda = \int S_r(\nu)\, I(\nu)\, d\nu$$
$$J_g = \text{stimulation of green sensor} = \int S_g(\lambda)\, I(\lambda)\, d\lambda = \int S_g(\nu)\, I(\nu)\, d\nu$$
$$J_b = \text{stimulation of blue sensor} = \int S_b(\lambda)\, I(\lambda)\, d\lambda = \int S_b(\nu)\, I(\nu)\, d\nu$$

The relative sensitivity functions of the three sensors, $S_r(\lambda)$, $S_g(\lambda)$, and $S_b(\lambda)$, according to Wald (1964), are shown in Figure 1 as the curves labeled r, g, and b, respectively. The maximum sensitivities occur at 582, 548, and 438 nm, respectively.

The peaks of the r and g curves are remarkably close. However, because of the overlap of these two curves, the region from the g peak through the r peak produces yellows and oranges. The sodium D line (589 nm), which is slightly on the long-wavelength side of the r peak (582 nm), appears to normal individuals as yellow. This can be explained if the absolute sensitivity of the g receptor is considerably greater than

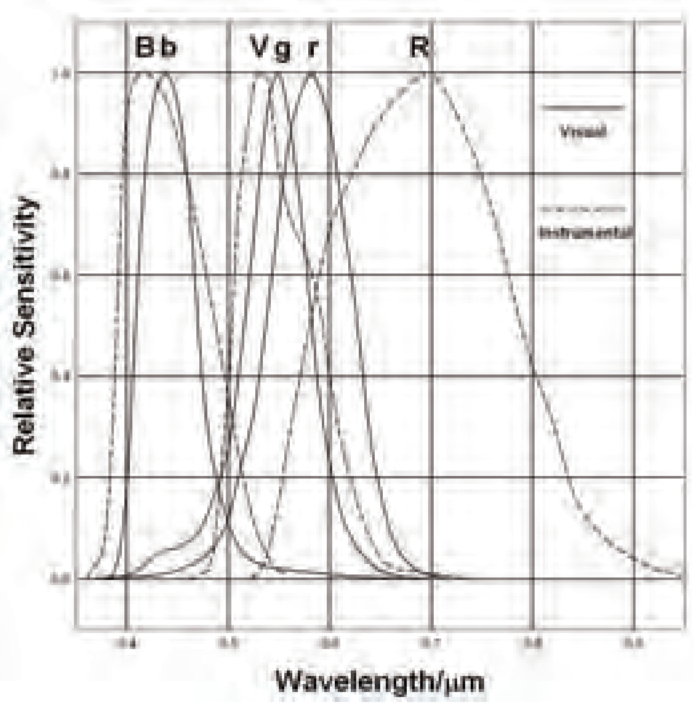

FIGURE 1 – Relative sensitivity functions of visual sensors *r* (red), *g* (green), and *b* (blue) of the human eye (averages of two subjects; Wald 1964), and of photometric detectors in the Johnson system *B* (blue), *V* ("visual" or green), and *R* (red) (Johnson 1965).

that of the *r* receptor. True red appears well to the long-wavelength side of the *r* peak, as exemplified by the hydrogen Balmer α line (656 nm).

A representation of the relative responses of the three sensors can be made by a ternary diagram in which the corners correspond to the red, green, and blue responses when the other two are zero. Points on the edges are saturated colours. Points in the interior are unsaturated colours, being mixtures of saturated colours and white, the point in the centre. Figure 2 shows the full range of colours possible in such a display. Here, the display is by 24-bit representation, 8 bits, or 256 shades of each basic colour.

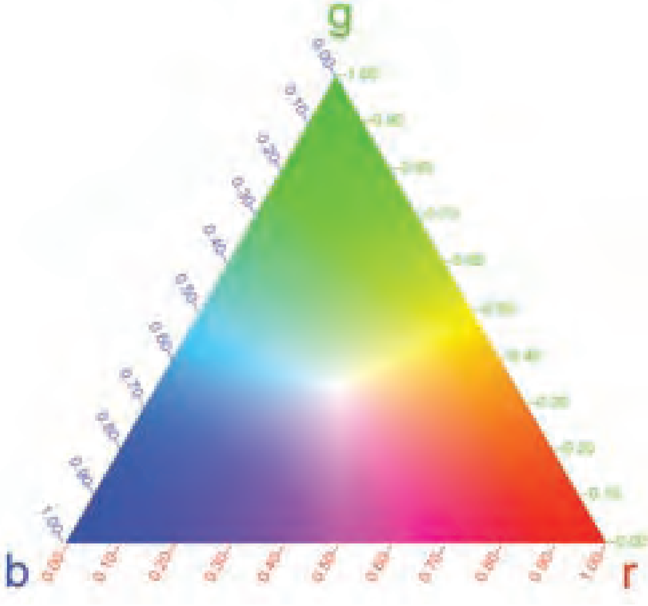

FIGURE 2 – Ternary diagram showing full range of colours in the *r, g, b* system. The entire colour field here consists of miniature triangles spaced at 0.01 on each of the three axes.

A particular point has coordinates normalized so that $r + g + b = 1$. Its colour is computed by multiplying each coordinate by 255 to generate an 8-bit colour (0–255) and combining to generate the 24-bit colour. The colours are further normalized so that the largest is 255, thus insuring that the central pixel is white (*r, g, b* = 255, 255, 255) instead of dark gray (255/3 = 85, 85, 85).

3. BLACKBODY RADIATION

Figure 3 displays the colour of blackbody radiation at various temperatures. Relative intensities at 582 nm (*r*), 548 nm (*g*), and 438 nm (*b*) were calculated by the Planck formula. These were normalized so that $r + g + b = 1$ and plotted on the ternary diagram. The colours were calculated as described above.

The point at 3200 K is the colour of light from an incandescent tungsten-filament light at that temperature, commonly used in photography. The point at 5800 K is the colour of the Sun.

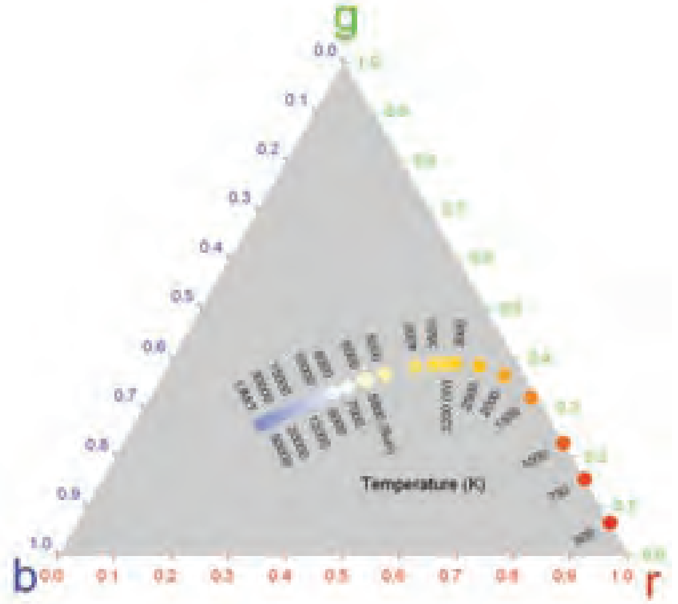

FIGURE 3 – Colour of blackbody radiation at various temperatures.

4. ASTRONOMICAL *B, V, R* PHOTOMETRY

Much astronomical photometry is broadband, using specified combinations of photoelectric detectors and filters, each to isolate a range of wavelengths covering a limited part of the spectrum. Commonly used is the Johnson system (*e.g.*, Johnson & Morgan 1953), initially consisting of magnitudes *U* (ultraviolet), *B* (blue), *V* ("visual" or green), *R* (red), and *I* (infrared), and extended into the infrared as *J, K, L*,.... The *B, V*, and *R* pass-bands cover the visual part of the spectrum, and their relative response functions are shown in Figure 1 as the curves labeled *B, V*, and *R* respectively.

The maximum sensitivities occur at 420, 530, and 700 nm, respectively (Johnson 1965). There are now several other photometric systems, some based on modern detectors, especially CCDs. The

Johnson system is used here because of the availability of *B, V, R* data for bright stars (Iriarty *et al.* 1965).

From inspection of Figure 1 it is apparent that the instrumental *R, V, B* system is a fair approximation of the visual *r, g, b* system. *B* is quite close to *b,* and *V* is quite close to *g*. *R* is not as close to *r* but overlaps it and extends into the near infrared. The similarities are such that *R, V,* and *B* can be used as proxies for *r, g,* and *b,* with adjustments to account for the deviation from exact matching.

Astronomical colour determinations are usually reported as differences such as *B–V* and *V–R* (the shorter-wavelength magnitude first). In general, these indices are small (even negative) for hot stars and large for cool stars.

5. STARS

Table 1 is a list of stars, selected so as to cover nearly the entire range of spectral types and to include many familiar bright stars, with their spectral types and *B–V* and *V–R* colour indices. In Figure 4 *V–R* is plotted versus *B–V* for these stars, with colours computed as explained above. For the main-sequence stars (spectral class V), there is a rather close correlation between these two indices (dashed line), but for red stars there is considerable scatter because of large and variable absorption by molecular bands.

Malin & Murdin (1984) have shown that colour impressions of stars by visual observers of the nineteenth century (F.G.W. Struve and W.H. Smyth) and mid-twentieth century (M. Minnaert) correlate fairly well with spectral types and *B–V* colour indices, though with considerable scatter. The close correlation of *V–R* with *B–V* for many stars led Malin and Murdin (1984) and also Steffey (1992) to claim that *B–V* alone can be used as an indicator of star colour. However, by itself the *B–V* index does not directly indicate colour *(r, g, b)*. Moreover, there are deviations from the *V–R* vs. *B–V* relationship, especially for red stars. Obviously, *R* must be included to quantitatively indicate the colour of an object.

It is proposed to use the instrumental *R, V, B* measurements to

TABLE 1. SELECTED STARS.

No.	Name	Spectrum	B–V	V–R	Source	r, g, b Colour
1	ζ Pup	O5 Iaf	–0.29	–0.06	a	82, 136, 255
2	Spica	B1 V	–0.25	–0.09	a	82, 141, 255
3	β Lib	B8 V	–0.11	–0.04	a	99, 161, 255
4	Regulus	B7 V	–0.12	0.00	a	102, 159, 255
5	Vega	A0 V	0.00	–0.04	a	109, 178, 255
6	Castor	A1 V	0.03	0.07	a	124, 183, 255
7	Deneb	A2 Ia	0.09	0.12	a	138, 193, 255
8	α^2 Lib	A3 IV	0.15	0.17	a	152, 204, 255
9	Altair	A7 IV+V	0.23	0.14	a	159, 220, 255
10	β Cas	F2 IV	0.34	0.31	a	206, 244, 255
11	Procyon	F5 IV-V	0.43	0.41	a	237, 255, 248
12	Sun	G2 V	0.65	0.52	b	255, 248, 195
13	Capella	G5 IIIe + G0 III	0.81	0.61	a	255, 228, 155
14	61 Vir	G6 V	0.71	0.58	a	255, 235, 175
15	Pollux	K0 III	1.00	0.75	a	255, 201, 114
16	o^2 Eri	K1 V	0.82	0.68	a	255, 214, 144
17	Arcturus	K2 IIIp	1.24	0.98	a	255, 162, 74
18	BS753 Cet	K3 V	0.97	0.85	a	255, 183, 107
19	61 Cyg	K5 V	1.17	1.02	a	255, 157, 76
20	Aldebaran	K5 III	1.55	1.22	a	255, 130, 45
21	61 Cyg B	K7 V	1.36	1.19	a	255, 134, 55
22	Antares	M2 I	1.83	1.56	a	255, 95, 25
23	Betelguese	M2 Iab	1.86	1.60	a	255, 92, 24
24	µ Cep	M2 Ia	2.26	2.10	a	255, 58, 10
25	Rasalgethi	M5 Ib-II	1.45	2.11	a	255, 57, 21
26	Barnard's	M5 V	1.74	1.83	a	255, 74, 21
27+	Mira-max	M4.5	1.42	2.01	c	255, 63, 24
27–	Mira-min	M7	1.60	4.49	c	255, 6, 2
28+	R Lep-max	N6 (=C)	4.20	1.95	d	255, 66, 2
28–	R Lep-min		4.77	2.74	d	255, 32, 1

a Iriarte *et al.* (1965)
b Allen (1973)
c Johnson *et al.* (1966)
d Eggen (1972)

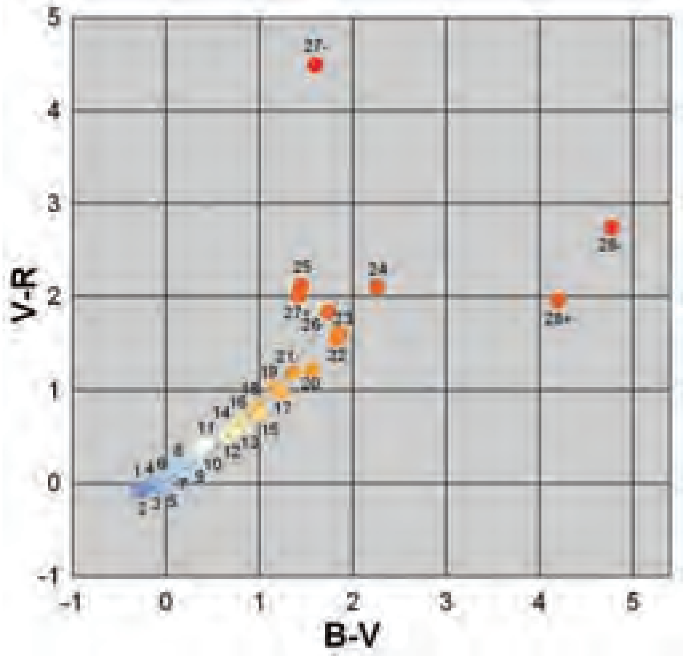

FIGURE 4 – $V–R$ versus $B–V$ for stars in Table 1. The dashed line is a least-squares fit to the main-sequence stars: $(V–R) = 0.026 + 0.564(B–V) + 0.259(B–V)^2$.

proxy for the visual *r, g, b* system. Figure 5 is a ternary plot of these stars, in which the $B–V$ and $V–R$ indices are used to directly calculate relative *B, V,* and *R* magnitudes (with $V = 0$), and from these logarithmic quantities the respective relative brightness (with $v = 1$). Using these brightnesses as *b, g,* and *r,* the positions and colours of the stars were calculated as described above.

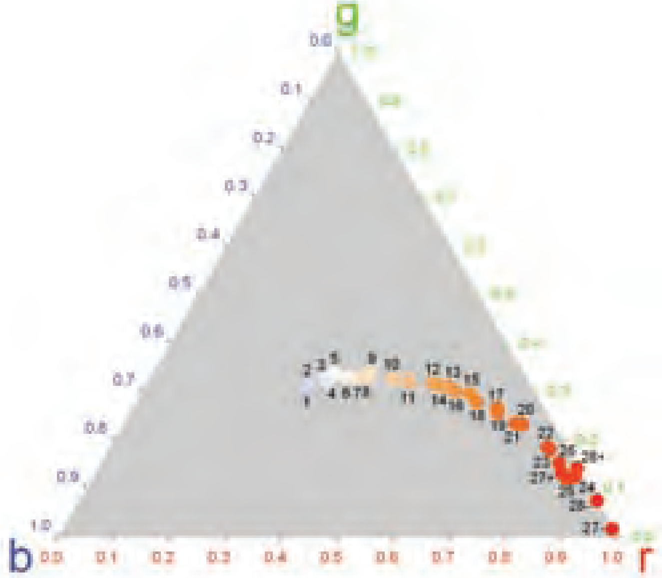

FIGURE 5 – Ternary plot of stars of Table 1, showing *r, g, b* colours calculated from $B–V$ and $V–R$ colour indices without adjustment.

The colours calculated in this manner are too red. For example, the Sun (#12) is much more orange than a 5800 K blackbody. This is due to a variety of reasons, especially the discrepancy between the *R* and *r* response functions. *R* contains a considerable contribution from the infrared. To reduce this, arbitrarily one-half of *r* is replaced by one-half of *r* times $r / (r + i)$. Here, *r* and *i* are the relative brightnesses calculated from *R* and *I,* respectively. For this, *I* is calculated from $(R–I) – (V–R) = –0.20$, a good average for all classes of stars (Cox 2000). An adjustment is then made by assuming that the Sun ($B–V = 0.65$, $V–R = 0.52$; Allen 1973) has the same colour as a 5800 K blackbody, for which the Planck formula yields $B–V = 0.26$ and $V–R = 0.03$. Thus $0.26 – 0.65 = –0.39$ should be added to all $B–V$. The correction to $V–R$ is not so straightforward; instead it is found empirically that –0.15 should be added to all $V–R$ so that the Sun has the same colour as a 5800 K blackbody (255, 248, 195). Adjusting the logarithmic quantities $B–V$ and $V–R$ is equivalent to linear adjustments of the relative *R, V,* and *B* detector sensitivities.

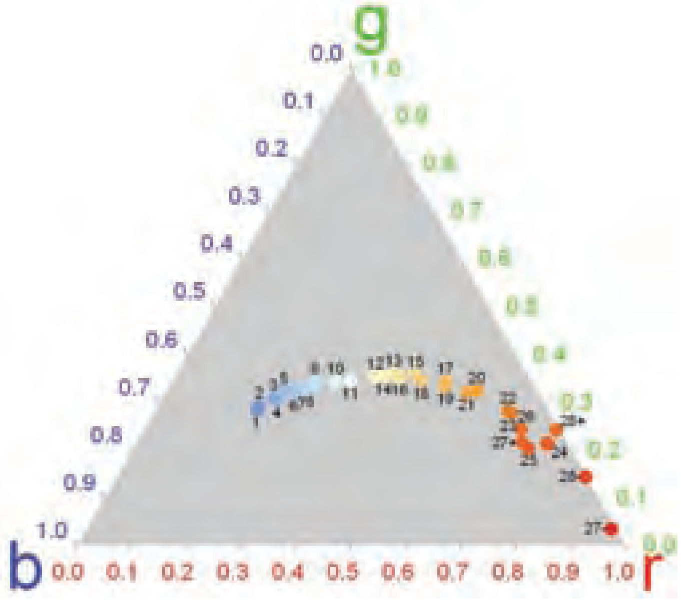

FIGURE 6 – Ternary plot of stars of Table 1, showing *r, g, b* colours calculated from 5800 K/Sun-adjusted $B–V$ and $V–R$ colour indices.

Figure 6 is a ternary plot using 5800 K/Sun-adjusted *R, V, B* as proxies for *r, g,* and *b*. The last column of Table 1 lists the computed *r, g, b* colours of these stars. An Algorithm for calculating *r, g,* and *b* from $B–V$ and $V–R$ is given in the Appendix.

It is seen that star colours run from red through orange, yellow, and white to blue. There are no green, violet, or purple stars. β Librae (#3) has been included because it has been claimed to be green (Burnham 1978), but it can be seen that it has a normal bluish colour. Possible explanations are given below (see section 8).

From the Earth's surface celestial objects are seen through the atmosphere. Photometric quantities, such as $B–V$ and $V–R$, are corrected for atmospheric extinction, so that they are as would be measured outside the atmosphere. Since the extinction is greater for the shorter wavelength light ($B > V > R$), passage through the air causes a "reddening." The effect is greater the lower the object's altitude. See section 6 as an example for a particular star.

Stars generally seem to have pale colours, whereas the computed colours as displayed on a computer monitor or as printed here are quite vivid. Since out-of-focus photographic images on colour film show the same vivid colours (Malin 1986, 1993), Figure 7, the discrepancy is due to properties of the eye. Steffey (1992) has provided an explanation. Colours are perceived with the retinal cones. In the dark-adapted eye the rods become much more sensitive than the cones, and to these

FIGURE 7 – Variable-focus photograph of stars in Orion (Malin 1986; by permission, David Malin, Anglo-European Observatory, and *Sky & Telescope*). With a stationary camera the focus was stepwise increased, so that the image became progressively fainter. At the optimum exposures, depending on star brightness, the vivid colours contrast with the pale colours perceived by the eye.

all colours appear white. Thus to the dark-adapted eye star colours appear as a mixture of the actual colour and white; in terms of colour theory, the colours are less saturated.

6. THE RISING AND SETTING SUN

In order to compute the Sun's colour at various altitudes, air masses were taken from Allen (1973). The exponential absorption coefficients for a clear atmosphere were interpolated from the table of Allen (1973):

Red	$\lambda = 582$ nm	$k_r = 0.18$ magnitude air mass^{-1}
Green	$\lambda = 548$ nm	$k_g = 0.195$ magnitude air mass^{-1}
Blue	$\lambda = 438$ nm	$k_b = 0.34$ magnitude air mass^{-1}

Figure 8 shows the apparent colour of the Sun at various altitudes at sea level in a clear atmosphere, and at low altitudes in heavy haze, represented by multiplying the air mass by 5. Since the atmospheric transparency varies from time to time even on clear days and nights, these are only typical colours.

7. PLANETS

Table 2 lists the available data on the planets, the first four asteroids, and the Moon, with the Sun for reference. *B–V* is available for all, but *V–R* is available only for some. Figure 9 is a plot of *V–R* versus *B–V* for these objects. Where *V–R* is not known a vertical line at *B–V* is drawn. Where this line passes through the points an estimated value of *V–R* was selected and entered in the table.

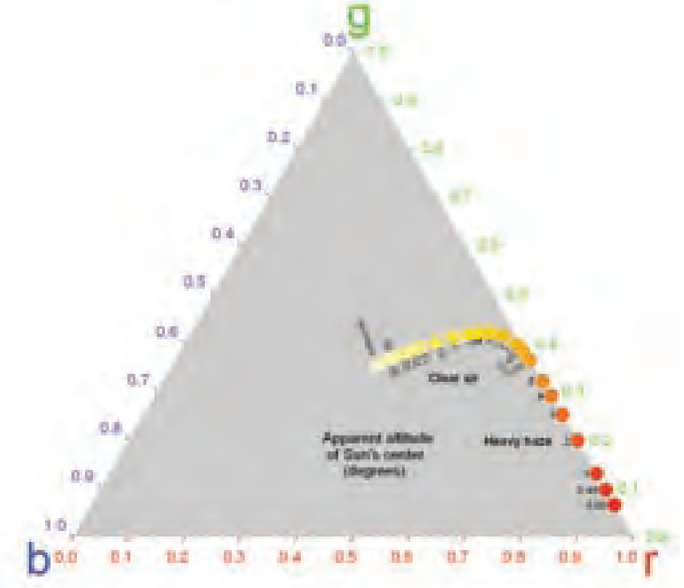

FIGURE 8 – Apparent colour of the Sun at various altitudes seen at sea level through clear air and heavy haze. When the apparent altitude of the Sun's centre is 0.49°, its true altitude is 0° (on the horizon); when its apparent altitude is 0° (on the horizon), its true altitude is –0.58°.

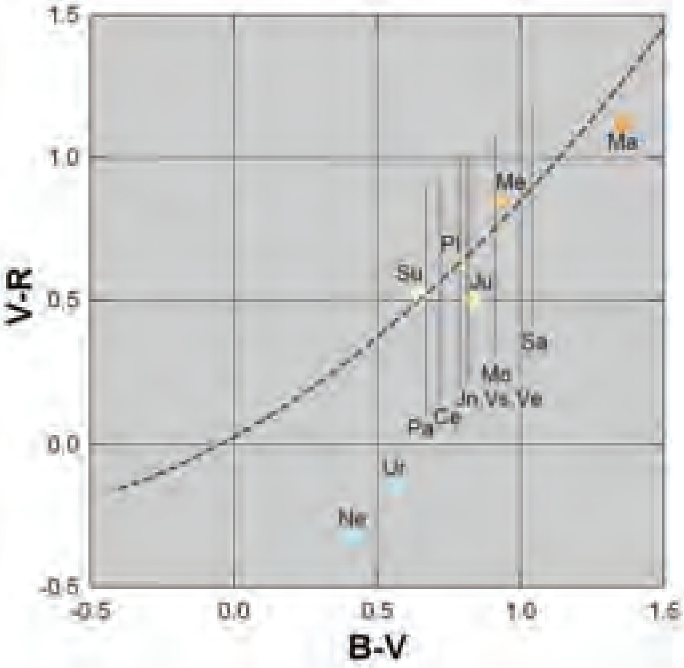

FIGURE 9 – *V–R* versus *B–V* for the planets, the first four asteroids, and the Moon, with the Sun for reference. Where *V–R* is not known a vertical line at *B–V* is drawn, enabling *V–R* to be estimated.

Figure 10 is a ternary plot of the colours of these objects. Most of them are somewhat reddened relative to the Sun, indicating that they reflect reddish light better than bluish. Mars is strongly reddish because of oxidized iron in its regolith. Uranus and Neptune are

Table 2. Planets.

Sym.	Name	*B–V*	*V–R*	Source	*r, g, b* Colour
Su	Sun	0.65	0.52	a	255, 248, 195
Me	Mercury	0.93	0.85	b	255, 183, 111
Ve	Venus#	0.82	(0.55)	b	255, 241, 162
Ma	Mars	1.36	1.12	b	255, 142, 58
Ju	Jupiter	0.83	0.50	b	255, 253, 168
Sa	Saturn#	1.04	(0.64)	b	255, 222, 122
Ur	Uranus	0.56	–0.15	b	141, 255, 218
Ne	Neptune	0.41	–0.33	b	119, 255, 250
Pl	Pluto+Charon	0.80	0.63	b	255, 224, 154
Ce	Ceres#	0.72	(0.57)	c	255, 237, 175
Pa	Pallas#	0.67	(0.48)	c	253, 255, 197
Jn	Juno#	0.79	(0.68)	c	255, 214, 148
Vs	Vesta#	0.81	(0.59)	c	255, 233, 158
Mo	Moon#	0.91	(0.76)	d	255, 199, 123

Where instrumental *V–R* is not available, a value has been estimated from Figure 9 and is enclosed in parentheses.

a	Allen (1973)
b	Harris (1961)
c	Cox (2000)
d	Allen (1973)

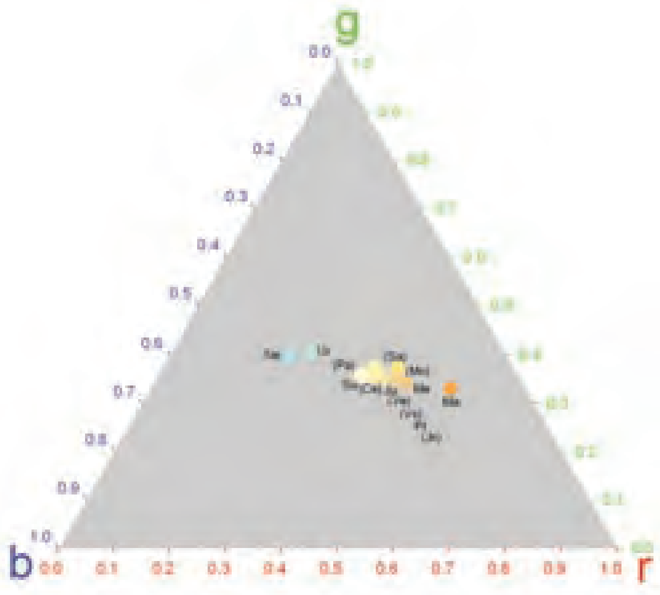

Figure 10 – Ternary plot of the colours of the planets, the first four asteroids, and the Moon, with the Sun for reference. Symbols in parentheses, like (Sa), are of objects for which *V–R* is estimated, not measured.

strongly blue-green because of the high concentration of methane, which absorbs in the red, in their atmospheres.

The Moon is also somewhat "redder" (actually more yellow) than the Sun. That it appears pale or colourless when high in the sky is probably due to the lack of a contrast. That it is generally regarded as yellow is undoubtedly because it is often seen at a low altitude (see Figure 8).

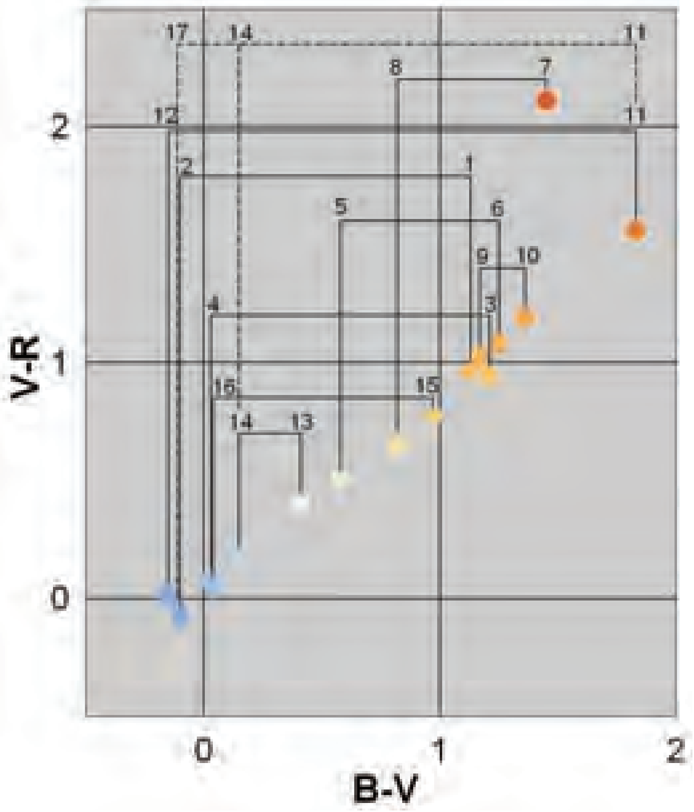

Figure 11 – *V–R* versus *B–V* plot of the components of a number of double stars, with colours determined as for a ternary plot. Paired components are joined by tie-lines. The special case of β Librae (#17, dashed tie-lines) is discussed in the text.

Table 3. Double Stars.

No.	Name	Spectrum	*V*	*B–V*	*V–R*	Separation
1	β^1 Cyg AB	K3 II [+B0.5 V]	3.08	1.13	(0.96)	
2	β^2 Cyg	B8 Ve	5.11	−0.10	(−0.08)	35″
3	γ^1 And	K3 IIb	2.26	1.37	(0.96)	
4	γ^2 And	B8 V + A0V	4.84	0.03	(0.08)	9.6″
5	η Cas A	G0 V	3.45	0.58	0.50	
6	η Cas B	K4 Ve	7.51	(1.25)	(1.08)	12.0″
7	α Her A	M5 Ib-II	3.48	1.45	2.11	
8	α Her B	G5 III + F2 V	5.39	(0.82)	(0.66)	4.9″
9	61 Cyg A	K5 V	5.21	1.17	1.02	
10	61 Cyg B	K7 V	6.03	1.36	1.19	29″
11	α Sco A	M1 Ib	0.96v	1.56		
12	α Sco B	B2.5 V	5.5	(−0.15)	(0.02)	2.9″
13	α^1 Lib (B)	F4 IV	5.15	0.41	(0.40)	
14	α^2 Lib (A)	A3 IV	2.75	0.15	0.17	3.8″
15	ε Boo A	K0 II-III	2.70	0.97	0.77	
16	ε Boo B	A2 V	5.12	(0.04)	(0.04)	2.8″
17	β Lib	B8 V	2.61	−0.11	−0.04	(single)

Colour indices in parentheses are estimated from spectra.

8. DOUBLE STARS

Figure 11 is a *V–R* versus *B–V* plot of the components of a number of double stars, with colours determined as for a ternary plot. Photometry is difficult for close binaries, so some colour indices have been estimated from spectra.

The stars plotted are listed in Table 3. Included are some doubles whose contrasting colours have been noted as remarkable. In the figure tie lines connect component stars of pairs. This allows one to see and compare the actual colours. In general, the colours shown confirm the claims of visual observers. The contrasts accentuate the colours.

Included is β Librae (#17), for which it has been claimed that the colour is green (see section 5). It is possible that this impression results from contrast with its neighbor α^2 Librae (#14, the brighter of the α pair), although it is more likely that contrast with Antares (#11, α Scorpii A), which can often be seen at the same time, is responsible (note the dashed tie lines).

9. CONCLUSIONS

It is hoped that this presentation will clear up some mysteries and misunderstandings about star colours. Readers are encouraged to compare their observations with the colours displayed herein. Note that the colours of stars may be enhanced by defocusing telescopic images.

ACKNOWLEDGEMENTS

I thank David Malin for a constructive criticism that led to the adjustment for the *I* sensitivity of the *R* detector in the procedure for computing star colours.

All figures were prepared with *SigmaPlot*.

APPENDIX

Algorithm for computing visual *r, g, b* from instrumental *B, V, R*.

Symbols:

BmV = B–V
VmR = V–R
VmI = V–I
delBV = adjustment to B–V for 5800 K/Sun
delVR = adjustment to V–R for 5800 K/Sun
delVRI = (R–I) – (V–R)
B = relative 5800 K/Sun-adjusted B
V = relative 5800 K/Sun-adjusted V
R = relative 5800 K/Sun-adjusted R
I = relative 5800 K/Sun-adjuisted I
r1 = relative red brightness
g1 = relative green brightness
b1 = relative blue brightness
i1 = relative infrared brightness
r1c = relative red brightness corrected for I
sum = sum of r1c, g1, and b1
r2 = red coordinate in ternary diagram
g2 = green coordinate in ternary diagram
b2 = blue coordinate in ternary diagram
largest = largest of r2, g2, and b2
r = red r,g,b value
g = green r,g,b value
b = blue r,g,b value

Algorithm

```
BmV = [enter]
VmR = [enter]
delBV = −0.39
```

```
delVR = −0.15
delVRI = -0.20
VmI = 2*(VmR + delVR) + delVRI
B = BmV + delBV
V = 0
R = –VmR – delVR
I = –VmI
r1 = 10^(–0.4*R)
g1= 1
b1 = 10^(–0.4*B)
i1 = 10^(–0.4*I)
r1c = r1/2*(1+r1/(r1+i1))
sum = r1c + g1 + b1
r2 = r1c/sum
g2 = g1/sum
b2 = b1/sum
largest = max(r2,g2,b2)
r = nint(255*r2/largest)
g = nint(255*g2/largest)
b = nint(255*b2/largest)
```

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Society News/Nouvelles de la société

by Kim Hay, Secretary (kimhay@kingston.ca)

Six years have come and gone. It's been a wonderful time to work with many great people across Canada and the U.S., some I have met in person, others only by email, but I consider them all friends. I have enjoyed my time.

This is my last writing as Secretary, as I step aside, and let our new Secretary come in and keep you all up to date on the RASC happenings and news.

By the time you read this we will have held our General Assembly in Kelowna, British Columbia over the Victoria Day weekend (May 20-23, 2005). I hope to read lots of interesting articles from members who had attended, and lots of great pictures, either here or on our Web site (`www.rasc.ca`).

Now that summer has arrived, and we are thinking and planning our vacations around Star parties, have a safe and happy observing season. Bag those Messier's in Sagittarius that you may have had to wait for from last year. Take a look through someone else's telescope and enjoy the view. It's a great Universe out there.

Me, well I have lots of observing to catch up on, a library that needs tending and reading, and I am sure there are a few other projects I can come up with.

Until later on an email list somewhere.Clear Skies and Wonderful Observing

---

The Skies Over Canada
Observing Committee News

by Christopher Fleming (observing@rasc.ca)

The evolution of telescope designs, from the time of Galileo through to the present day, is quite a fascinating story that could easily fill a book. It all started with small refractors and soon after reflectors came along. Since then many designs have been tried, some good and some bad, and some just for specialized uses. A notable epoch in the development of refractors came in 1820 when Wilhelm Struve went to visit Joseph Fraunhofer, a renowned German optician and maker of quality refractors. Wilhelm was an avid double-star observer and he wanted Fraunhofer to build him the largest refractor possible at that time. Fraunhofer proceeded to figure a 244-mm (9.6-inch) f/18 lens that became the largest refractor in the world in 1824.

That telescope is not only famous for its great optics but also for the "state of the art" equatorial mount on which it was placed. With its superior design and accurate driving clock, that telescope and mount combination was by far the most sophisticated up to that time, and has been referred to as the first professional observatory installation. It had a sturdy wooden pier and a fir-wood telescope tube, covered with veneer, which gave the appearance of polished copper. The accurately divided declination circles were made of shining silver and the instrument was shipped with quality micrometers and oculars. It must have been quite a site to view once it was all set up and I am sure Struve was anxious to try it out. Even today such an instrument would stir the soul of most astronomers and I think we can all relate to the excitement of bringing home a new telescope.

The "Giant Refractor," as it was described, performed flawlessly and Struve wasted no time in putting it to good use measuring double stars, a project he had started in 1819. The legendary astronomer William Herschel, who came before Struve, measured a great many double stars and Struve wanted to continue that work. After many discoveries it was clear that double stars were far more numerous than previously thought and he published several catalogues, the last appearing in 1852. His observations and measurements were of such quality that they are still in use today and many of his discoveries can be seen on the most popular double-star lists currently available.

The Struve family produced four generations of astronomers, several of whom measured double stars. The most notable among them were Wilhelm, and his son and grandson, who both were named Otto. Double-star measurement is a fascinating area of study but unfortunately there are not that many astronomers doing this important work these days. It is conceivable that amateurs could successfully measure double and multiple stars but it would require a serious commitment and a well-stocked observatory containing instruments such as a filar micrometer. Another issue is the availability of those instruments and for Canadians it may be difficult to find an observing location with good enough seeing for fine double-star measurement. Regardless of that I encourage anyone thinking of measuring double stars to give it a try.

The Explore the Universe Certificate program objectives are listed in a chronological order that we think a typical observer would normally follow as they are learning the night sky. It begins with the most prominent constellations and bright stars, which seems quite logical since astronomy is usually associated with the mythical constellation patterns and star names. These constellation objectives require that the observer not only find the major star patterns of a given constellation but also to clearly identify, by name, the brightest one or two stars within it. It has been shown that observers are more likely to remember a celestial object by a name rather than by a designation, such as a number or letter.

With that in mind, all objectives in the program that have a proper or common name associated with them are clearly identified as such. In my own experience I have found that remembering deep-sky objects by a descriptive name is much easier than trying to recall a random mix of NGC numbers. Remarkably though, I have known and heard of a few rare individuals who can recall NGC numbers like a machine, and that certainly is an admirable quality to have. Following the constellations and bright stars list, the Explore the Universe program continues with observations of the Moon that includes identifying lunar phases, lunar basins, and major craters. I will cover the Moon objectives next time, and in future articles the remaining categories will be featured including the solar system, deep-sky objects, double stars, and variable stars.

We are glad to report that one Explore the Universe Certificate was awarded since our last report, and that fine observer is listed in Table 1.

There has also been one Messier Certificate awarded since our last report and that talented observer is listed in Table 2.

In addition there have been two Finest NGC Certificates awarded since our last report and those skilled observers are listed in Table 3.

Congratulations to all!

The Asteroids Section features charts containing the orbital position of several bright asteroids that will be visible in 2005, and during July and August you will be able to print charts for the asteroids (1) Ceres, (2) Pallas, (7) Iris, (18) Melpomene, (20) Massalia, (39) Laetitia, and (32) Isis. Those asteroids will all be brighter than tenth magnitude at that time, and the charts will display nearby stars to tenth magnitude on a five-degree or greater vertical field layout. Dates for the position of each asteroid will be listed at three-day or longer intervals, and nearby bright "finder stars" will be highlighted. In many cases the finder stars are bright enough to be seen visually and therefore a telerad or similar pointing device can be used to target the field printed on the charts. Otherwise a typical finder-scope or binoculars with be sufficient to find the brightest star in the field.

The Variable Stars Section features direct links to genuine American Association of Variable Stars Observers' (AAVSO) magnitude-estimate charts for Mira-type Long-Period Variables that will reach maxima in 2005, and that will be brighter than magnitude 8.0. For July and August 2005, you will be able to print charts for S Hydrae, R Sagittarii, Chi Cygni, W Lyrae, T Ursae Majoris, V Cancri, R Corvi, SS Virginis, S Pegasi, R Aurigae, and W Ceti. We also have direct links to charts for several other variable-star types and you will find them on the Sample Charts 2 page (see: `www.rasc.ca/observing/variablestars/index.html`). Many of the most interesting variable stars in the night sky are listed there as well as the positions of possible nova outbursts. We sincerely congratulate David Lane and Paul Gray for their recent discovery of the ultimate variable star — a Supernova!

The new Comets Section has provided

Table 1. Explore the Universe Certificate Recipient.

Name	**Centre**	**Date Awarded**
Jnani Cevvel	Edmonton, Alta.	March 2005

Table 2. Messier Certificate Recipients.

Name	**Centre**	**Date Awarded**
Derek J. Lapointe	Moncton, N.B.	March 2005

Table 3. Finest NGC Certificate Recipients.

Name	**Centre**	**Date Awarded**
Ted Dunphy	Moncton, N.B.	February 2005
Norman Leier	Regina, Sask.	March 2005

accurate finder charts for several comets since being launched last autumn, most notably for C/2001 Q4 (NEAT), C/2004 Q2 (Machholz), and C/2003 K4 (LINEAR). We will continue to post charts for currently visible comets, some to as faint as fifteenth magnitude, that will challenge even the most demanding observers with large telescopes.

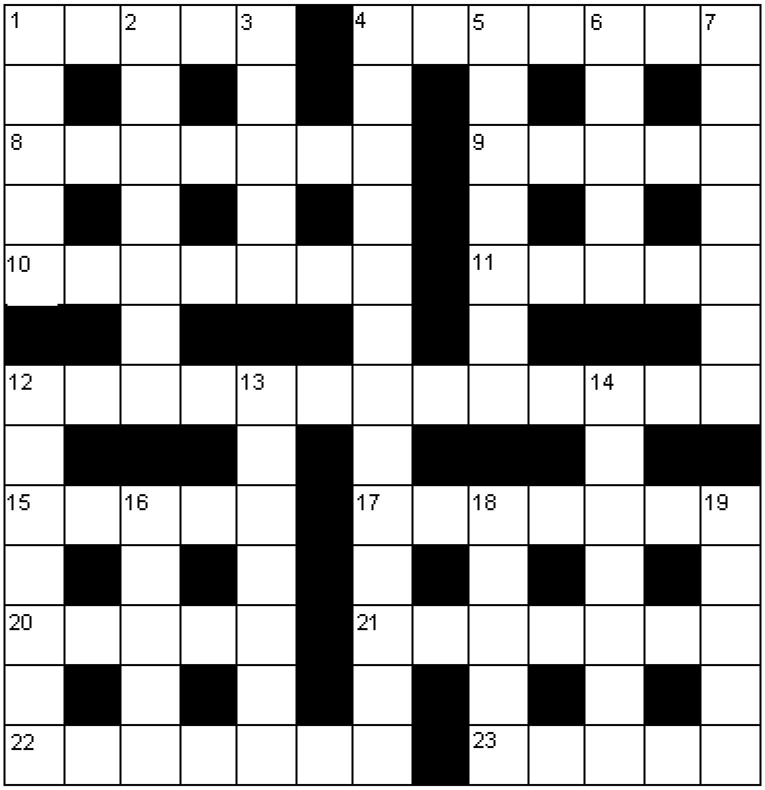
The Special Projects Section has been updated quite significantly and now features resources from across the RASC. The purpose of this upgrade is to provide a wider range of content than was possible by committee members alone. By tapping into key Web pages from Centres and individuals across Canada, visitors to the national Web site will be more likely to find the information they are looking for. This should increase internet traffic to and from the local Centres and that will be mutually beneficial. We invite you to have a look at `www.rasc.ca/observing/projects` and if you have a Web page that you would like us to post there, please let us know.

Clear Skies,

Christopher Fleming is Chair of the RASC Observing Committee and Observers' Chair in the London Centre. He enjoys all types of observing, especially deep-sky, lunar, double stars, and variable stars. Chris is also a musician and Webmaster of the London Jazz Society's Web site.

Astrocryptic

by Curt Nason, Moncton Centre



ACROSS

1. They colour Alan and his family (5)
4. He very quietly, while moving around, described comets (7)
8. Dark nebulae catalogue gives nuclear cross-section to a red dwarf (7)
9. A big dog star can hide at the University of Denver (5)
10. Genius endlessly rotates in each little asteroid (7)
11. Veg out at the eyepiece, thanks to putting beer back in the prescription (5)
12. See other worms turn out for these downpours (6,7)
15. Machholz lately seen in bed with me (5)
17. A light year around Capella leads one from the Pleiades (7)
20. Old name of a Leonis from before giant stage (5)
21. Spring holds your Dob when one isn't turned (7)
22. Say why you see a shade of brown at the famous crater site (7)
23. Sun is reflected off the lunar basin (5)

DOWN

1. The name he gave to the pointer sounds funny (5)
2. From east, Regulus first in the night to be seen in his observing guide (7)
3. Pisces origin with supernova around the foot of Leo (5)
4. Twin man stated odd figures in meteorites (13)
5. Dante wrote about non-fire, perhaps on Venus (7)
6. Keep a stiff upper lip around the emergency room when in danger (5)
7. Old astronomy writer is due back to hug and kiss us (7)
12. Following odd orbits, journalist has Miss Muffet's fast food at the gym (7)
13. Observing marathoner will do this to others to be this (7)
14. Dust mote turns to a charged particle with feeling (7)
16. First magnitude comet head appears from nowhere like this (5)
18. Bayer at the Moon by Orion (5)
19 Aquila's kin spotted in another nest (5)

A Moment With…

Dr. Peter Taylor

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

"Today from the Red Planet Weather Network: Clear skies with temperatures soaring to a balmy zero degrees Celsius. Dust devils likely but chances of a full-blown dust storm are low. Tonight, temperatures will drop to a brisk minus one-hundred twenty degrees…."

This type of sketchy prognostication of Martian weather should soon improve due to the *Phoenix* mission scheduled to arrive in the north polar regions of Mars in May 2008. On board will be a Canadian designed and built meteorology package (MET) to study Martian atmospheric temperature and pressure. Also included in MET will be a lidar (light detection and ranging) system whose laser will allow the levels of dust, fog, and ice clouds in the lower atmosphere to be measured. Information acquired by MET will be analyzed using computer models developed at Toronto's York University. One of the lead scientists for MET is York's Dr. Peter Taylor.

Dr. Taylor is Program Director in Earth & Space Science at York. His particular interest is the boundary layer, that region of the atmosphere that (on Earth) extends from the ground to about one-hundred metres altitude (during the night) and up to one or two kilometres during the day. Heated by the ground, this air is less stable than that found at greater altitudes. On Mars, the boundary layer is theorized to extend upward as high as five to ten kilometres, although no one knows for sure. Our current thinking in this area has been derived from information provided by past robotic missions to Mars and by extending what we know about Earth. Using the lidar and other sensors of MET, scientists such as Dr. Taylor hope to shed some light on this region which spawns, for example, the dust devils observed by previous spacecraft. Knowing as much as possible about these mini-tornadoes, and other aspects of Martian meteorology, will be important for the safety of future missions involving humans. Boundary-layer dynamics have a bearing on cloud formation and the Martian water cycle as well.


Dr. Peter Taylor

Dr. Taylor also has an interest in the work of *Phoenix's* robot arm which is designed to excavate sub-surface ice. He points out that retrieving and analyzing ice is not as simple as it sounds. The original plan called for the arm to grab the ice and then deliver it to the analytical equipment over a period of several days. This long period is necessitated by power constraints on the lander. Seems simple enough. But what about sublimation? How long will ice, no longer protected by Martian soil, persist before turning gaseous? Again, no one knows. But, using special chambers where the pressure and temperature can be dropped to Martian levels, Dr. Taylor has provided as good an answer as we currently have: as little as a few hours.

This rapid sublimation rate is not great news for mission designers, who had only partly taken it into account: First, the spacecraft will land with the robot arm facing north, away from the Sun (which will never set at the 70° north latitude of the landing site during the mission). This means no more random bouncing on bulging air bags during touchdown. Rather, the spacecraft will use a combination of parachute, retro-rockets, and precise steering to land and orient itself properly.

Secondly, due to Dr. Taylor's research, the sampling protocol will be modified: attempts will be made to use compact pieces of ice (rather than fragments that will sublimate more quickly) and to shelter them from the environment (insofar as that is possible). The robot arm will also be operated with all possible alacrity.

Dust blown about by the descent engine, or by the Martian wind, is also a concern as it will likely coat the lander's solar panels. The behaviour of moving Martian dust is a bit of a mystery but also comes under the purview of Dr. Taylor since he has studied the characteristics of windblown snow, which behaves in similar ways. He can speak from experience having spent six weeks in the Canadian arctic!

When asked if he considers himself a Martian meteorologist, Dr. Taylor declines the label. His interests are somewhat more wide ranging. As a youth, he became interested in aircraft, particularly in the way air flowed over the wings. It was, in fact, fluid dynamics that he eventually went on to investigate. He studied mathematics at the University of Bristol, eventually earning a Ph.D. He studied and taught oceanography (in particular, the interaction of wind and waves), investigated air pollution, and worked for a number of years for the meteorological service in Canada. Eventually coming to York, he acted as an advisor on a number of space missions bound for Mars before, most recently, finding himself working on *Phoenix*.

Martian meteorologist? Perhaps not. But when our descendants on the red planet want to know what it's like outside, their weather forecast will have its basis in the work of scientists like Peter Taylor.

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

Venusrise

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

Misty spring dawn.
Skywatchers gather on Wood Bison Lookout
anticipation rising with the light
a day not quite
like any other.

Sun pierces horizon
brilliant bronze flash
wearing crown of jade
day's first light a routine spectacular
magnitude minus twenty-seven.

Sol has not yet revealed his secret.
Knowing watchers await
the rarest of moments
now goddess of love is revealed
in transit within sun's glowing embrace.

Last seen in veils of white
and comely come-hither crescent
Venus now displays full round figure
her night side misshapen silhouette
heat of passion yielding to solar fire.

Conjoined pair undulates above horizon
exchanging compliments
in complementary colours
blood-red blob dissipates
a watercolour into thirsty stellar canvas.

In the valley below
bison ruminate
not easily impressed
by yin and yang
of light and absence.

On the lookout point
astronomers cheer
embrace warmly
as sated goddess disengages.
Dreams under cover of daylight.

Figure 1 – Edmonton Centre RASCals view the last minutes of the Transit of Venus at sunrise from Wood Bison Lookout near Fort McMurray, Alta. In the foreground, Sherry Campbell observes a projected image in her husband Paul's "Sunderbluss" telescope, a 60mm refractor salvaged and refurbished as a useful solar telescope.

Because Edmonton was on the extreme edge of the transit visibility zone, an expedition was organized to this site about 500 km northeast of Alberta's capital city. The last half-hour of the transit was successfully observed under undulating atmospheric conditions that rendered scientific measurement meaningless but provided a richly colourful observing experience. (Photo courtesy of the author.)

Bruce McCurdy is an experienced astronomy writer and fledgling poet. A Contributing Editor of JRASC, *he usually contributes theory-by-number in his* Orbital Oddities *column. Bruce recognizes that actual observations can be as much or more impressionistic as scientific, and that the best fully engage both hemispheres of the brain. One year later, the above is his only formal observing log of the Transit of Venus.*

Great Images*

A Comet's View of the Andromeda Galaxy
In early April 2002, Comet Ikeya-Zhang passed within two degrees of M31 and its satellite galaxies, M32 on its left and M110 on its lower right. The comet's great gas (blue) and dust (white) tails overflow the field of this picture, which is at least five degrees across, and dwarf M31, one of the largest of all deep-sky objects.

Photo by Gerald Rhemann from *Observer's Calendar, April, 2003.*

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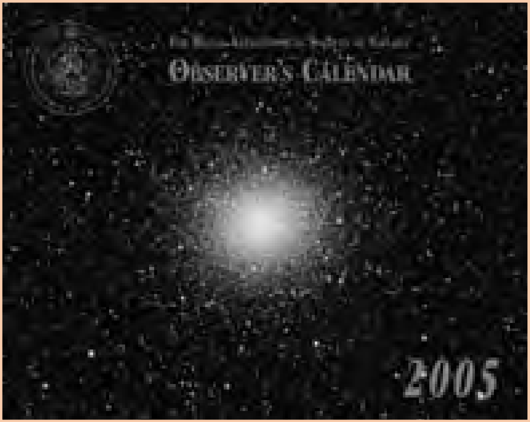

Observer's Calendar — 2005

The award-winning RASC Observer's Calendar is your annual guide

Created by the Royal Astronomical Society of Canada and richly illustrated by photographs from leading amateur astronomers, the calendar pages are packed with detailed information including major lunar and planetary conjunctions, meteor showers, eclipses, lunar phases, and daily Moonrise and Moonset times. Canadian and US holidays are highlighted. Perfect for home, office, or observatory.

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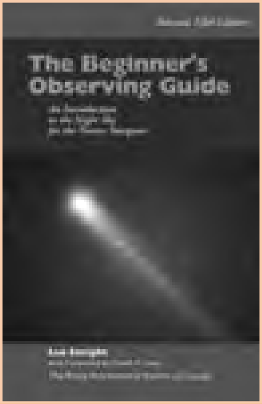

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Extensively revised and now in its fifth edition, The Beginner's Observing Guide is for a variety of observers, from the beginner with no experience to the intermediate who would appreciate the clear, helpful guidance here available on an expanded variety of topics: constellations, bright stars, the motions of the heavens, lunar features, the aurora, and the zodiacal light. New sections include: lunar and planetary data through 2010, variable-star observing, telescope information, beginning astrophotography, a non-technical glossary of astronomical terms, and directions for building a properly scaled model of the solar system.

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Price: $16.95 Cdn (members); $19.95 Cdn (non-members)
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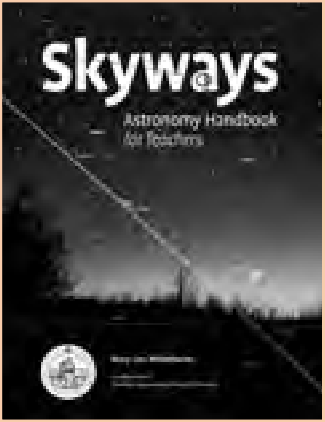

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