The Journal of The Royal Astronomical Society of Canada

Journal

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IN CANADA

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Société Royale d'Astronomie du Canada

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Front cover: *Astronomy doesn't always have to be dead serious. Jim Chung braved the -15 °C temperatures of downtown Toronto, and casual eclipse watchers, to put himself under the CN Tower to get this shot of the lunar eclipse on December 21 last year. He used an Olympus camera with a f/1.7 20-mm lens at ISO 200 to capture this 3-second image.*

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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Canada

President's Corner

Mary Lou Whitehorne
President, RASC

Summer in Canada has arrived, and with it the busy summer star-party season. Let's hope for better weather over the summer months than what most of Canada endured this spring. I am constantly amazed by the energy, enthusiasm, and dedication RASC members continue to pour into public education and outreach activities through the year, and especially during the summer months. The warmer and kinder weather brings the observers out in large numbers, even though the nights are short and the mosquitoes abound!

The legacy of IYA2009 lives on in the many expanded and enriched programs carried out by RASC members and Centres throughout Canada. It is impressive and rewarding to see the number of partnerships that have been built and that continue to thrive between the Society, our Centres, and non-RASC organizations. This is an astonishingly successful effort that provides relevant and enjoyable outreach opportunities for all Canadians.

The collaborative connections between the RASC, the Canadian Astronomical Society (CASCA) and the Fédération des Astronomes Amateurs de Québec (FAAQ) continue to strengthen, especially through the Beyond IYA (BIYA) national executive committee. The goal is to keep open lines of communication between the three groups, and to share best practices between organizations for the benefit of all three. One major project of the group was to create a joint national ducation and Public Outreach (EPO) award to be given annually to one member of each of the three organizations. Watch for this award to be announced later in 2011.

The second big project of BIYA is a new online astronomy training program, *Discover the Universe/ À la découverte de l'Univers*. This project is developed through a joint RASC/CASCA/FAAQ PromoScience grant and is intended to help outdoor interpreters (parks, camps, etc.) provide interesting and innovative astronomy programs to their public. The pilot project, in French only, ran in June, and the full bilingual program will be offered in the spring of 2012. For more information visit the Web site: www.decouvertedelunivers.ca

Our Society continues to move forward through the dedicated efforts of many volunteers and with the able talents of our National Office staff. Progress is being made on many fronts with the guidance of our new strategic plan and marketing communications plan. We are establishing new membership-retention and -growth programs and new publicationspromotion programs. We have made a good start on a member and volunteer support program. For more information about this, point your browser to www.rasc.ca/private/resources.shtml

The 2012 edition of the *Observer's Handbook* will include a special version of the Earth Centered Universe software. We have entered the world of social media with our new Twitter account. Facebook will soon follow if all goes according to plan. Thanks to a generous anonymous donor, we now have a large supply of excellent information brochures on the safe and responsible use of green-laser pointers (GLPs). I hope every RASC summer star party will distribute these to GLP users and other interested persons.

The first half of 2011 has clearly been a busy and productive time for the RASC. I expect the second half of the year to be more of the same. My thanks and appreciation go to everyone who has worked and contributed to the variety of projects undertaken this year. You know who you are, so please stand up and take a bow! ✶

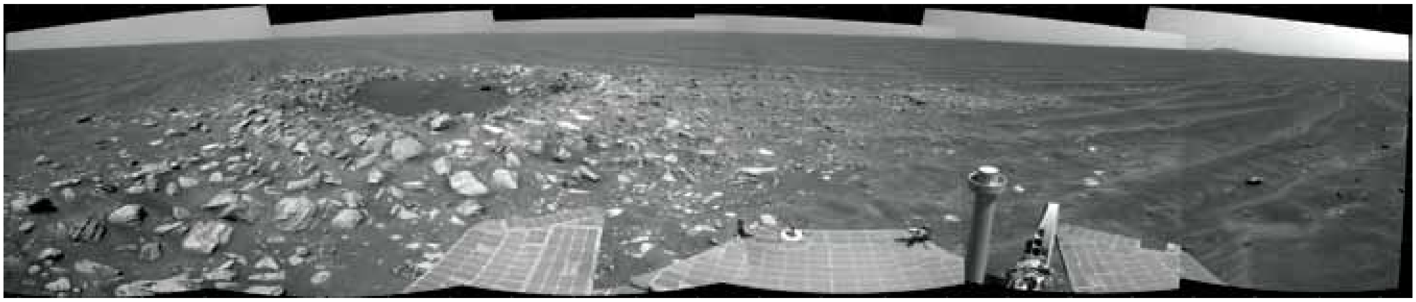

Figure 1 — The view out of the window of the Opportunity rover on Mars. The splash of rocks in the foreground is the ejecta from Skylab *crater in the beyond. Barely visible on the distant horizon are the peaks of the rim of Opportunity's next goal, the crater Endeavour.*

News Notes

by Jay Anderson

One Mars Rover Still Chugging Along

NASA's remaining operational Mars rover, *Opportunity*, has ambled past the 30-km mark in its seemingly unstoppable exploration of our outside neighbour. Originally scheduled for a 3-month vacation in the sands of Mars, the rover has now endured for 88 months, chugging along from crater to crater in an otherworld imitation of the Energizer Bunny. Opportunity's latest vacation stop – more of a passing wave, actually – was a 9-metre crater nicknamed "Skylab." In the latest imagery, "Skylab" appears as a shallow rocky splash in the endless sea of sand that characterizes the Meridiani Planum plains of Mars (Figure 1).

Skylab is a mere youngster by Martian standards, with an estimated age of 100,000 years, based on the appearance of the surrounding sand ripples on which the blocky boulders ejected by the impact are sitting. The interior of the crater is a darker colour than the surroundings, a testimonial to the fine-grained wind-blown sand that has accumulated there. In the distance, two peaks mark the crater walls of *Opportunity*'s destination, the 22-km-wide crater "Endeavour." The trek to Endeavour began in August of 2008; if the unstoppable rover is able to complete the remaining 3.5 kilometres, Endeavour will be the largest impact crater that it visits in its exploration of Mars. On a good day, the rover moves 100 to 150 metres.

Dead Galaxies Still Showing Signs of Life

Two astronomers at the University of Michigan have discovered that at least some elliptical galaxies are still producing new stars, although at a very low rate. Elliptical galaxies had been thought to have used up all of their star-forming reservoirs of

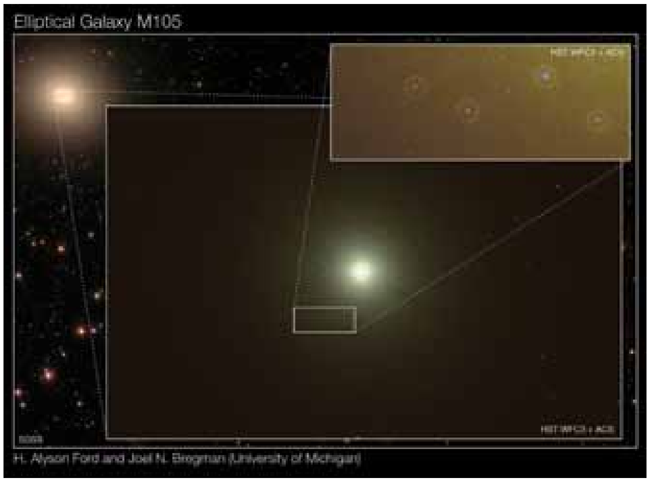

Figure 2 — Messier 105, seen in the top-left corner in an image from the Sloan Digital Sky Survey. The outlined region in the centre of M105 is expanded to reveal Hubble's unique view of the galaxy's inner region, which is further expanded to unveil several individual young stars and star clusters (denoted by dashed circles; top right). Image: H. Alyson Ford and Joel N. Bregman (University of Michigan).

dust and gas and so were incapable of making new stars. However astronomers Alyson Ford and Joel Bregman presented observations at the Canadian Astronomical Society meeting on May 31 that seem to revise that understanding.

Their breakthrough came when they used the superior resolution of the *Hubble Space Telescope* to examine individual stars and star clusters in four galaxies, all lying about 40 million light-years away. One of these was M105, an otherwise normal elliptical, in which they were able to spot a few bright very blue stars. Blue stars are massive stars that derive their colour from a rapid consumption of their hydrogen, and, as such, must be young objects, since the fuel is fairly soon consumed, after which the stars fade away to a redder old age. Ford and Bregman also spotted clusters of blue stars, a further sign of new-star formation that must be related to the presence of at least some gaseous nebulae. They estimate a creation rate of one star every 10,000 years, well below the typical spiral-galaxy rate of one star every year. "This is not just a burst of star formation but a continuous process," Ford said.

Now the question becomes "What is the source of the dust and gas that forms these new stars?"

"We're at the beginning of a new line of research, which is very exciting, but at times confusing," Bregman said. "We hope to follow up this discovery with new observations that will really give us insight into the process of star formation in these 'dead' galaxies."

Now That is a Telescope!

Astronomers in Hawaii have plucked unprecedented details from the life of an early galaxy using an unusually lucid gravitational lens and the observational capabilities of the 10-metre Keck II Telescope on Mauna Kea. Gravitational bending has been used for years to determine the characteristics of very distant galaxies, but in most cases, the magnified images from the Universe's distant past are of poor quality. The smeared and distorted images from a typical gravitational lens don't offer much in the way of direct information about what the earliest galaxies looked like.

That is not the case for an elegant little spiral galaxy called Sp1149, located 9.3 billion light-years away. The galaxy's image has come through a gravitational lens magnified 22 times and is fairly intact, as seen in a *Hubble Space Telescope* image. Sp1149 is lensed by a giant cluster of galaxies lying between it and the Earth, and the clarity of the magnified image is due to Sp1149's position nearly directly behind the cluster. The cluster appears beside Sp1149 in the *Hubble* image.

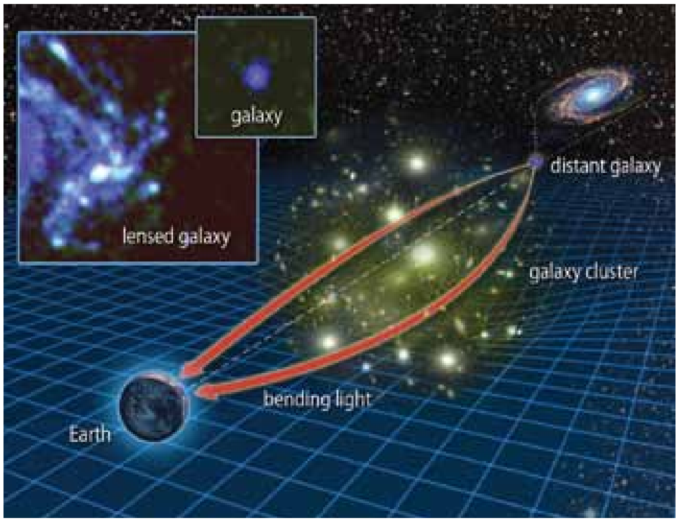

Figure 3 — In this artist's impression, the gravity of a gigantic cluster of galaxies has bent and magnified the light of the distant spiral galaxy Sp1149, making its spiral arms visible and available for study by astronomers. Normally, gravitational lensing distorts the structures of distant galaxies beyond recognition. The inset labelled "galaxy" shows how Sp1149 would look without lensing. Image: Karen Teramura, University of Hawaii Institute for Astronomy

After its initial capture by *Hubble*, the University of Hawaii's Tantian Yuan, Lisa Kewley, and colleagues turned the Keck II telescope onto Sp1149. Using the Laser Guide Star Adaptive Optics, which cancels out much of the distortion caused by the Earth's atmosphere, and the OSIRIS spectrograph, they were able to examine the distribution of elements, particularly oxygen, in the spiral arms of the lensed galaxy. "This is the first time anyone has done such a detailed and precise oxygen gradient that wasn't on a local galaxy," said Kewley.

Oxygen, which accumulates in regions of past star formation, was highly concentrated in the core of Sp1149. The resulting sharp oxygen gradient from core to outer disc suggests that stars in the cores of early galaxies form first and create the oldest stellar neighbourhood, followed later by the disc and arms. That supports what's called the inside-out model of galactic evolution. That model predicts that the inner galactic bulge undergoes a rapid collapse with vigorous star formation at its centre in the early stages of galaxy evolution, building a steep radial metallicity gradient from the core to the outer disc. Subsequent radial mixing and infall causes the gradient to flatten over the following billions of years, resulting in a weaker gradient on average in late-type galaxies today.

Messenger's Messages

NASA's *Messenger* spacecraft continues to send back new and detailed images of the surface of Mercury since its orbital insertion on March 17. The spacecraft isn't new on the scene – it has spent the past six years making a dozen passes around the inner Solar System, getting lined up for the eventual transition into a Mercurian (Mercurial?) moon. During its cruise phase, the spacecraft made one flypast of Earth, two of Venus, and three of Mercury.

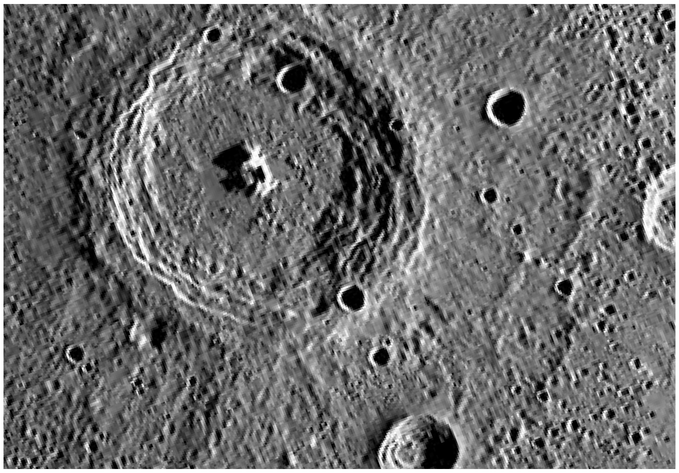

Figure 4 — Mercury's Brahms crater, named for the nineteenth century German composer and pianist Johannes Brahms. Date acquired: 2011 May 10

To most RASC observers, Mercury orbit is an anticlimactic event, with most of the photos that are returned looking like the Moon, redux. It's not all the same, however, as the dynamics of the Solar System's inner planet lead to subtle differences between Mercury's craters and those of the Moon. The major importance of Mercury is what it can teach us about the formation and evolution of the Sun's suite of planets, a topic even more pressing, now that hundreds of other unusual "big Jupiter" planetary systems have been found.

So, for the time being, we'll have to be content with the images, as the science side of *Messenger* has yet to report.

Older and Older (or is that Younger and Younger?)

Just a week apart, astronomers announced successive "most distant object in the Universe" titles for a pair of gamma-ray bursts (GRBs). The first pronouncement, on May 26, gave the honour to (GRB) 090423, a dim red object with a redshift of 8.2, equivalent to a distance of 13.035 billion light-years. The second, just a week later, introduced (GRB) 090429B, another gamma-ray burst, this time with a redshift of 9.4 and distance of 13.14 billion light-years. Both of the distance-record GRBs were initially detected by the *Swift* satellite; the subsequent afterglows were detected at infrared wavelengths by the Gemini North telescope and the UK Infrared Telescope (UKIRT). 090429B was a short-lived event, lasting less than 10 seconds, and automated *Swift* satellite observations showed it to have a relatively faint X-ray afterglow.

Gamma-ray bursts, the brightest explosions known, occur somewhere within the observable Universe at a rate of about two per day. They are explained as originating with the death of a massive, short-lived star, 30 or more times the mass of our Sun, when exhaustion of the nuclear fuel in its core regions causes the core to collapse into a black hole. As the newly formed black hole consumes gas from the star's outer layers, it emits two powerful jets that erupt from the star's surface, accelerate to speeds very near the speed of light, and power a beamed and highly luminous burst of high-energy emission – the gamma-ray burst.

Light from the original burst is redshifted as it travels toward the Earth, so that very distant objects can be seen only in longer wavelengths. While the bursts themselves last for minutes at most, their fading "afterglow" light remains observable by the largest astronomical facilities for days to weeks. Detailed studies of the afterglow allow astronomers to measure the distance to the burst as the GRBs become invisible at shorter wavelengths in proportion to their distance from the Earth.

Whether GRB 090429B is the most distant object in the Universe depends on several factors that are not precisely known. First, it must lie beyond the 13.07-billion-light-year distance to a galaxy reported in 2010 by a team of astronomers led by Matthew Lehnert at the Observatoire de Paris. It also has to lie beyond the distance of a galaxy reported in 2011 by a team of astronomers led by Rychard Bouwens of UC Santa Cruz. The Bouwens team estimates that there is a 20-percent chance that their galaxy is not a record breaker at all, but simply a faint galaxy at a relatively modest distance. If the Bouwens galaxy is a record-breaker, it is very distant indeed, from 13.11 to 13.28 billion light-years away, and there is only a 4.8-percent chance that GRB 090429B is more distant than that. Overall, and treating these uncertainties as perfectly understood, there is a 23-percent chance that GRB 090429B is now the most distant known object in the Universe.

Figure 5 — The two most distant objects in the Universe – this week.

Bad-Weather Months on Saturn

NASA's *Cassini* spacecraft and a European Southern Observatory ground-based telescope tracked the growth of a giant early spring storm in Saturn's northern hemisphere that is so powerful it stretches around the entire planet. Many RASC members have been observing and photographing the unusual storm, which is easily visible through a telescope. The rare storm has been wreaking havoc for months and shooting plumes of gas high into the planet's atmosphere. The dramatic effect of the deep plumes has disturbed Saturn's usually stable stratosphere, generating regions of warm gas that shine like bright "beacons" in the infrared.

"Nothing on Earth comes close to this powerful storm," says Leigh Fletcher, a *Cassini* team scientist at the University of Oxford in the United Kingdom. "A storm like this is rare. This is only the sixth one to be recorded since 1876, and the last was way back in 1990." The violence of the storm – the strongest disturbances ever detected in Saturn's stratosphere – took researchers by surprise. What started as an ordinary commotion deep in Saturn's atmosphere punched through the planet's serene cloud cover to roil the stratosphere.

Other indications of the storm's strength are the changes in the composition of the atmosphere brought on by the mixing of air from different layers. The Composite Infrared Spectrometer aboard *Cassini* found evidence of such changes by looking at the amounts of acetylene and phosphine, both considered to be tracers of atmospheric motion. Observations from the visual and infrared mapping spectrometer, also aboard *Cassini*, show clouds of large ammonia ice crystals dredged up from a depth of 50 km, confirming that the storm is especially violent. The head of the storm – presumably a monster thunderstorm – is particularly rich in large ammonia particles. ✶

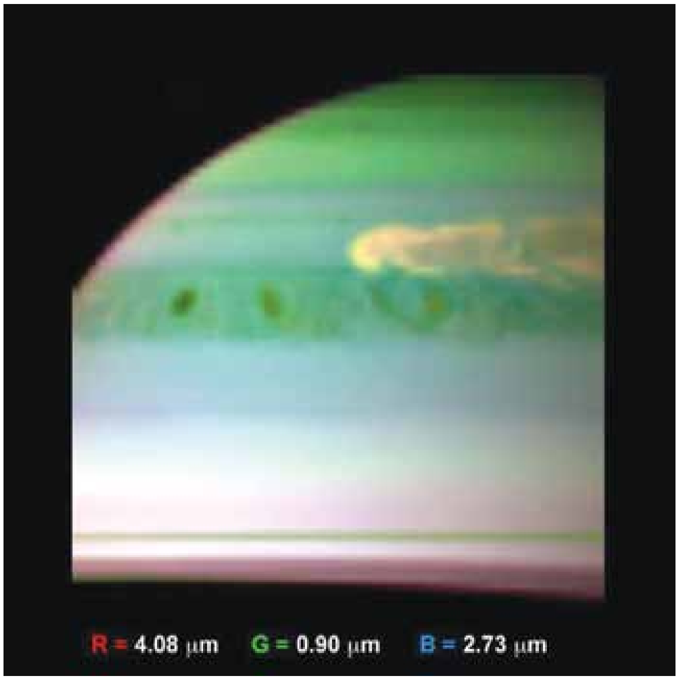

Figure 6 — A false-colour image from the Cassini *spacecraft showing the dramatic changes brought on by the storm on Saturn. Red represents large particles that reflect sunlight well; green shades represent high, cold clouds. The storm's colour, yellow, is a mixture of red and green, and indicates that clouds in the area are composed of large, high-altitude particles.*

The Royal Astronomical Society of Canada

Vision To inspire curiosity in all people about the Universe, to share scientific knowledge, and to foster collaboration in astronomical pursuits.

Mission The Royal Astronomical Society of Canada (RASC) encourages improved understanding of astronomy for all people, through education, outreach, research, publication, enjoyment, partnership, and community.

Values The RASC has a proud heritage of excellence and integrity in its programmes and partnerships. As a vital part of Canada's science community, we support discovery through the scientific method. We inspire and encourage people of all ages to learn about and enjoy astronomy.

Revealing the Innermost Regions of Active Galaxies

by Luigi C. Gallo, Saint Mary's University
(lgallo@ap.smu.ca)

Abstract

X-ray observations of active galactic nuclei (AGN) reveal the physics at work closest to the event horizon of supermassive black holes. I will discuss some recent X-ray observations of AGN and describe the processes responsible for the appearance of the spectra and the variability in the light curves. I will also discuss what this tells us about the black-hole environment and even about the black-hole itself.

Résumé

Des observations de rayons X provenant du noyau de galaxies actives (NGA) révèlent la physique en fonction le plus près de l'horizon des évènements des trous noirs supermassifs. Je discuterai de certaines de ces observations des NGAs et je décriverai le processus responsable pour l'aspect du spectre et la variabilité de la courbe lumineuse. Je discuterai aussi de ce que ceci révèle au sujet de l'environnement du trou noir, et ainsi que du trou noir lui-même

1. Introduction

Black holes that are millions to billions of times more massive than our Sun reside at the centres of most large galaxies, and are known as supermassive black holes (SMBHs). The most direct evidence of the existence of such objects is from the centre of our very own Milky Way, where the mass and density of the SMBH have been determined from the observed orbits of stars trapped in the black hole's gravitational field (Schödel *et al.* 2002; Ghez *et al.* 2003). However, in comparison to the host galaxy, the SMBH represents only about 0.3 percent the mass of the stellar component. Consequently, the black-hole "sphere of influence," within which it dominates the gravitation potential, is small and unresolved for all galaxies except our own. To gain understanding of black holes in nature requires indirect methods, such as the observation of relativistic effects that can only occur in the regions around black holes. This can be achieved by observing active galactic nuclei (AGN).

A small fraction of SMBHs are considered "active." These black holes interact strongly with their surrounding environments, and are distinct from inactive SMBHs at the centres of most normal galaxies like our Milky Way. A normal galaxy shines due to the collective brightness of all its stellar members. An active galaxy stands out in several ways. For example, the emission from the central active region can be so intense that it outshines the entire host galaxy of stars. An AGN can emit energy over the entire electromagnetic spectrum from radio waves to X-rays and gamma rays. In contrast, the spectrum of normal galaxies is due to the collective emission of all the stars and is blackbody in shape, typically peaking at optical and infrared wavelengths. Active galaxies are highly variable, changing in brightness by many orders of magnitude over all observable time scales. In some cases, huge jets propagate outward from the central engine, extending to scales larger than the host galaxy. An AGN will exhibit at least one – but more typically several – of these characteristics.

The mechanism responsible for driving AGN behaviour is the accretion of matter by the SMBH. As matter plunges into the black-hole sphere of influence, it carries some angular momentum. As material following different trajectories spirals in towards the black hole, it forms into an accretion disc. The revolution of the disc is governed by gravitational forces, with material closer to the black hole moving faster than matter farther out in the disc. The differential velocity in the disc generates viscosity (friction) between adjacent regions in the disc, transferring angular momentum outward, thereby allowing matter to flow further inward. The accretion process is very efficient at generating radiation (light), as high as 40 percent compared to the 0.7-percent efficiency of nuclear processes in the Sun. The average temperature reached in the disc depends on the black-hole mass, and the radiation spectrum typically peaks in the ultraviolet (UV) for SMBHs.

2. The X-ray-emitting region

AGN are often strong X-ray emitters, but this high-energy radiation is not normally attributed to the accretion disc, since the associated temperatures are simply too high to be generated in the disc. Variability studies provide some clues about the nature of the emission. From causality arguments, we know that an isotropic emitter cannot vary faster than the time it takes for light to travel across the region. X-ray emission in an AGN varies significantly on time scales as short as hours, implying that the X-rays are generated in a very compact region. For an SMBH that is 10^7 times more massive than the Sun, the X-ray-emitting region is about the size of the Solar System. Even for the nearest active galaxy, a region this size is completely unresolved. Our understanding of X-ray-emitting regions is based on detailed analysis of the spectral and timing properties of AGN.

In Figure 1 (top diagram), we depict the inner black-hole environment with a cartoon motivated by our understanding of the X-ray spectral components. In the bottom panel of Figure 1, we illustrate how each component contributes to the observed X-ray spectrum.

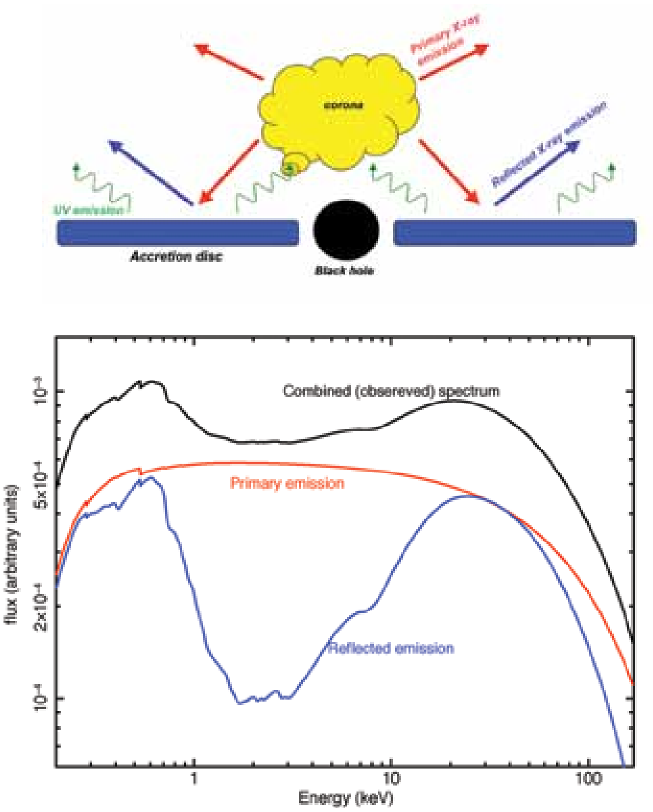

Figure 1 — Top diagram: A depiction of the central region of an AGN where the X-rays are generated. UV photons emitted from the accretion disc will traverse the corona of hot electrons, where they are up-scattered to X-ray energy via Comptonization. The corona emits the X-rays isotropically, so that some will be detected directly by the observer, while others will strike the accretion disc. Those striking the accretion disc will be backscattered, producing the reflection emission. Bottom diagram: The combined spectrum (black line) that is observed is a composition of the primary power-law emission from the corona (red line) and the reflected emission (blue line). The low-energy cut-off in the spectrum is due to absorption in our own galaxy.

2.1 The primary emitter

Surrounding the inner regions of the SMBH and accretion disc is a corona, an extended atmosphere of hot electrons. The electron gas has a temperature on the order of 10^7 K and the electrons are likely dredged up from the accretion disc, and deposited in the corona through reconnection of magnetic fields in a manner similar to the generation of solar flares (Galeev *et al.* 1979). UV photons emitted from the disc traverse the corona and collide with the hot particles. With each collision, the electrons transfer energy to the photons, and after multiple collisions, the photons emerge from the corona as X-rays with much higher energy. The process is called Comptonization, or inverse Compton scattering, and results in a power-law[1] spectrum with a high-energy cut-off in the X-ray spectral range (lower panel, Figure 1). The high-energy cut-off reveals the temperature of the corona. This is the origin of the high-energy X-rays, and as such, the corona is often referred to as the primary emitter.

Comptonization is a scattering process. With each collision between photon and particle, neither the original photon energy nor the direction is conserved. The new X-rays can be emitted in any direction, thus the corona radiates isotropically. Light from the corona that is emitted toward the observer will show the power-law spectrum mentioned above, but the primary emitter will also illuminate the inner accretion disc.

2.2 Reflection from the accretion disc

The material in the top layers of the accretion disc is bombarded by high-energy X-rays from the corona, and will become ionized as the atoms are stripped of their electrons. For the heavier atoms, the remaining bound electrons in higher-energy states will transit to lower-energy states, releasing photons in the process (*i.e.* fluorescence). This produces an emission-line spectrum that reveals the composition and ionization state of the inner accretion disc. This secondary component is seen by the observer, and is commonly referred to as the reflection spectrum[2] (Figures 1 and 2) (*e.g.* George & Fabian 1991; Ballantyne *et al.* 2001; Ross & Fabian 2005). At higher energies, where ionization is no longer an issue, this component peaks and then resembles the intrinsic power-law spectrum of the primary emitter.

The reflection spectrum reveals important information about the accretion disc (*i.e.* composition and ionization), but it also reveals information about the dynamics in the region. The reflection spectrum originates in an accretion disc that is revolving around a supermassive black hole. While the emission lines in the spectrum are intrinsically narrow, the dynamics in the environment are imprinted on the observed spectrum (see review by Miller 2007).

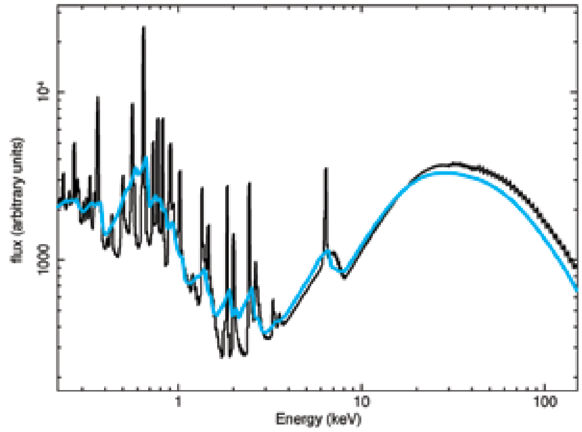

Figure 2 — The reflection spectrum that originates from illuminating a mildly ionized accretion disc with a power-law emitter is shown in black. Below 10 keV, emission lines from various metals that are generated via fluorescence dominate the spectrum. A strong feature is the Fe Kα emission line at about 6.4 keV. Above 10 keV, the reflection spectrum increases and peaks at about 20-30 keV. The blue line is the exact same reflection spectrum, but modified by the effects in the black-hole environment.

In Figure 3, we consider the effects of the black-hole environment on the appearance of the reflection spectrum by considering how an intrinsically narrow emission line is modified. For starters, the accretion disc is revolving in the plane of the galaxy with some parts of the disc moving toward the observer and some parts of it moving away. The radiation from those parts moving toward us appears bluer (*i.e.* blueshifted), and the radiation from those parts moving away from us appears redder (*i.e.* redshifted). This leaves a double-peaked profile in the observed emission line (green profile in Figure 3). The phenomenon is called the Doppler effect and is the same reason why an ambulance with its siren on will have a higher pitch as it moves toward us and a lower pitch as it moves away.

Closer to the black hole, material is moving at a significant fraction of the speed of light, and is subject to special relativistic effects. Light emitted from material that is moving toward us very quickly will appear brighter (*i.e.* beamed) whereas light moving away will be dimmed. This results in an asymmetric profile of the emission line (red profile in Figure 3). In addition, the profile as a whole will be shifted to lower energies (*i.e.* redshifted).

Very close to the black hole, the reflection spectrum is subject to general relativistic effects; the gravitational-potential well is deeper, and photons lose energy escaping from it. All photons that make up the emission line become redshifted. The closer the photon originates to the black hole, the more energy it loses, resulting in a line profile that is preferentially stretched to lower (redder) energies (blue profile in Figure 3).

The observed profile is thus the combination of all these effects and the superposition of emission from different distances from the black hole. The blurred reflection spectrum appears substantially different as a result of these manifestations (Figure 2, blue curve). Accurate modelling of this modified spectrum reveals the dynamics around the black hole.

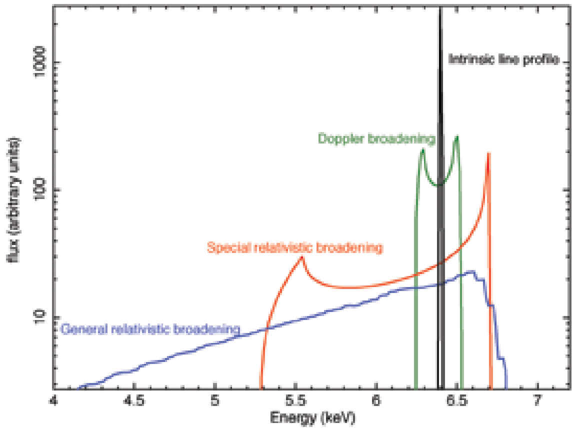

Figure 3 — The effects of the accretion disc and black-hole environment on the intrinsically narrow iron emission line (black profile) are depicted. Doppler effects from motion in the accretion disc give the line a double-peaked profile (green profile). Special relativistic effects closer to the black hole result in an asymmetric and broadened profile (red profile). Very close to the black hole, general relativistic effects become important, and the profile is significantly stretched to lower energies (blue profile).

The strongest feature in the reflection spectrum is the iron line at about 6.4 keV (Fe Kα). This line is commonly seen in AGN to various levels of significance (*e.g.* Nandra *et al.* 2007), but is typically much weaker than in the prototype MCG-6-30-15 (*e.g.* Tanaka *et al.* 1995; Miniutti *et al.* 2007). The Fe Kα feature stands out in the spectrum for a number of reasons; iron has a relatively high cosmic abundance; iron fluoresces well; and the Fe Kα line is a relatively isolated feature in the spectrum. Other expected features are less prominent, as the emission lines of most of the other metals occur at energies below about 2 keV. This spectral region is overcrowded with weak emission lines from numerous elements, and individual features are impossible to identify when blurred by relativistic effects (Figure 2). In addition, warm gas associated with the AGN or host galaxy can often leave its signature on this spectral region in the form of absorption lines and edges, thereby further weakening the appearance of reflection features. As a result, the discovery of relativistic features in the low-energy regime has been challenging.

A breakthrough was achieved in 2009 when the AGN 1H0707-495 was observed for 500 ks with *XMM-Newton*. Although a relativistic Fe Kα line had been recognized in earlier observations (Fabian *et al.* 2004), there did exist other interpretations (*e.g.* Gallo *et al.* 2004a). What sets 1H0707-495 apart from other AGN is the putative strength of the iron feature. In addition to light bending (see Section 3.1), the object must have a significant overabundance of iron to account for the strength of the emission line. The 2009 high signal-to-noise data revealed a second feature that was expected, but had never been observed previously: relativistic emission from Fe Lα at about 0.9 keV (Figure 4; Fabian *et al.* 2009). A feature predicted to accompany Fe Kα had finally been detected, giving credence to the reflection scenario described for the X-ray emission in AGN.

3. X-ray observations of SMBH

3.1 Light-bending

As discussed in Section 2.1, the primary X-ray emitter (the corona) is an isotropic emitter, and when some of the primary X-rays illuminate the disc, the reflection spectrum is formed. It would follow that in the most basic scenario, the power-law component produced by the primary emitter should dominate the X-ray spectrum (Figure 1), since that is what drives the formation of the reflection spectrum. However, in some cases (*e.g.* like in the case of 1H0707-495), the data indicate the reflection features actually dominate the spectrum (*e.g.* Figure 4). That is, the primary component (*i.e.* the power-law component) appears weaker than the supposed secondary component

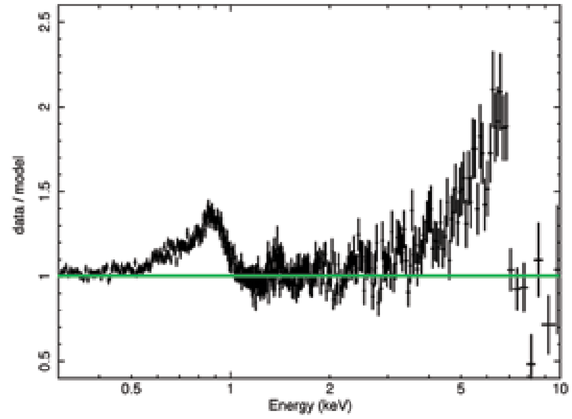

Figure 4 — Shown are the remaining residuals after removing the power-law component from one of the long XMM-Newton observations of the AGN 1H0707-495. The skewed peak at about 6 keV is attributed to the relativistic Fe Kα emission line. The second peak at about 0.9 keV is attributed to Fe Lα emission. Modelled separately, each profile reveals similar model parameters, indicating that both features are generated in the same environment (Fabian et al. *2009).*

(*i.e.* the reflection component). This seems counterintuitive, unless there is some way to diminish the primary emission, while not significantly dimming the secondary component, as seen by the observer.

Light-bending close to the black hole (*e.g.* Miniutti & Fabian 2004) can indeed produce this effect. Light bending is simple to comprehend if one keeps in mind that light travels the most direct path between two points. Typically, the most direct path between two points is a straight line. This is obviously true when the space between the points is flat; however, this is no longer the case when the space between the points is curved. When we consider long-distance travel on the surface of the Earth, for example, the curvature of the Earth is not negligible. This is evident when one considers international air travel. Airplanes do not fly along straight lines, but follow an arc of a great circle[3] connecting the points. For example, the most direct path between Frankfurt and Calgary does not go over Toronto as you might expect when looking at a map, but rather travels over the Arctic.

Light also travels the most direct path between two points, but over the fabric on which it moves, *i.e.* spacetime. This path is called a geodesic, and it is determined by the distribution of mass in space. A common analogy is to consider a small marble rolling across a drum skin. The marble will move from point A to point B in a straight line. Now suppose that we place a heavy mass on the drum skin such that the centre sinks. The trajectory followed by the small marble from A to B is no longer straight, but bends around the mass at the centre. Indeed, if the small marble does not have sufficient speed to complete its journey to point B, it will sink and spiral inward toward the mass at the centre. Such is the geometry around any massive object in space, including black holes.

Returning to the primary isotropic emitter, one can imagine a situation in which the primary emitter is sufficiently close to the black hole that most of the geodesics (light paths) of the photons emitted by the corona actually curve back toward the black hole and inner accretion disc (Figure 5, Top diagram). In this way, the direct power-law emission that reaches the observer is significantly diminished, even though the amount of radiation emitted by the corona is actually constant. At the same time, the level of the reflection component changes little or may even be enhanced, since more primary emission illuminates the inner disc. The reflection component may actually appear stronger than the primary component in the spectrum (Figure 5, Bottom diagram).

This is a rather straightforward explanation for some of the extreme X-ray variability we find in AGN. In some cases, we observe flux variations in the same object by about a factor of ten accompanied by significant spectral changes (Figure 6). Attributing these variations to intrinsic changes in the AGN (*e.g.* physical changes in the corona and disc) is complex, as

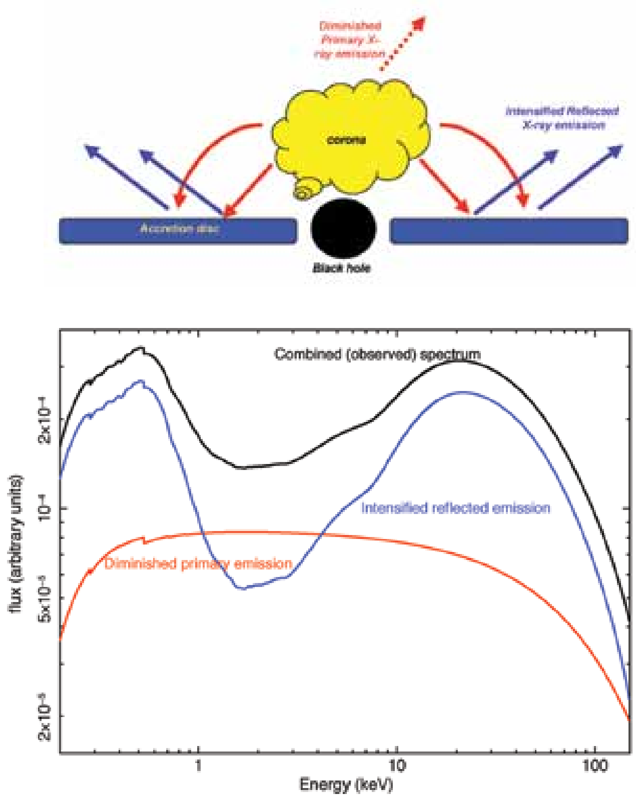

Figure 5 — Top diagram: Like Figure 1, a depiction of the central region of an AGN where the X-rays are generated, in this case for the light-bending scenario. The primary power-law emitter is located very close to the black hole, and most of the geodesics are curved inward toward the black hole and inner accretion disc. The primary emission that reaches the observer directly is significantly diminished. The reflected emission from the inner part of the accretion disc is actually enhanced in this scenario. Bottom diagram: The power-law component seen by the observer (red line) is diminished relative to the reflection component (blue line). The combined spectrum is shown in black.

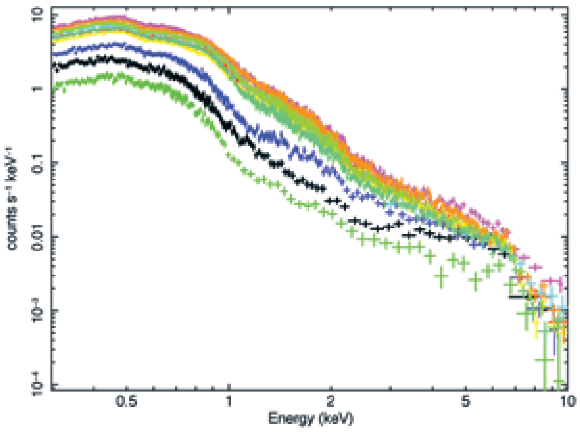

Figure 6 — The XMM-Newton spectrum of the AGN 1H0707-495 is shown at nine different epochs between 2000 and 2008. In the low-flux state, the spectra show much more curvature than in the high state, when they appear to be dominated by a power law.

inducing such significant changes over the entire X-ray-emitting region on such short timescales is problematic. The light-bending scenario is simpler, since the observed changes are attributed to geometric effects (*i.e.* in the source frame, the corona is still an isotropic emitter with relatively constant luminosity).

The light-bending scenario is successful at describing the variability in a number of sources (*e.g.* Fabian *et al.* 2004; Crummy *et al.* 2006; Gallo *et al.* 2007, 2011a, Grupe *et al.* 2008a, Ponti *et al.* 2010). In Figure 7, we illustrate the scenario for the AGN PG 0844+349 (Gallo *et al.* 2011b). The source was observed with *XMM-Newton* at three epochs: in 2000, 2001, and 2009. When the object is in a relatively bright state, the X-ray spectrum assumes a power-law form. However, in the low-flux state, the X-ray spectrum takes on a much more complex shape (Figure 7). It was realized that for PG 0844+349, the significant X-ray variability could be attributed mostly to the diminishing of the power-law component during the low-flux state (Figure 8).

Moreover, it is noteworthy that the UV emission is comparable in both the high- and low-flux states (Figure 9). The UV component, from the accretion disc, does not exhibit changes that could be responsible for the X-ray fluctuations. This behaviour was recognised by Gallo (2006) in a sample of objects, which strongly favours the light-bending and reflection scenarios for the general nature of X-ray spectra of AGN.

Light bending is applicable in many cases, but certainly not all. In some situations, it appears that there are intrinsic changes in the structure of the corona that lead to the variability (*e.g.* Miniutti *et al.* 2009; Grupe *et al.* 2008b).

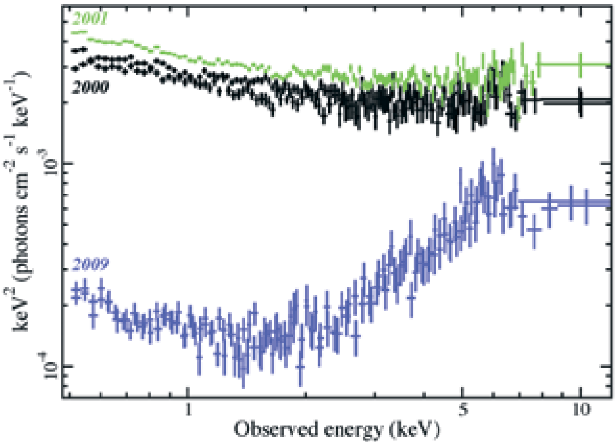

Figure 7 — XMM-Newton observations of the AGN PG 0844+349 in 2000 (black data), 2001 (green data), and 2009 (blue data), exemplify the significant spectral changes that occur in the low-flux state. In the brighter states (2000 and 2001) the AGN spectrum is flatter, whereas significant curvature is evident in the 2009 low-flux state. Adapted from Gallo et al. *(2011b).*

3.2 Reverberation in the inner region

The reflection component is driven by the primary spectrum, and, as Figure 1 demonstrates, the two X-ray-emitting regions are physically disjoint. As such, one would expect the reflector to respond to changes in the primary emission only after some delay due to light travel time across the region, *i.e.* reverberation lags.

Given the compactness of this region, such delays will be very small and only detected in the highest-quality and longest observations. To see this, we turn our attention once again to the long observation of 1H0707-495. The model that is used to describe the spectrum of 1H0707-495 is shown in Figure 10 (Zoghbi *et al.* 2010). The intermediate energy range 1–4 keV

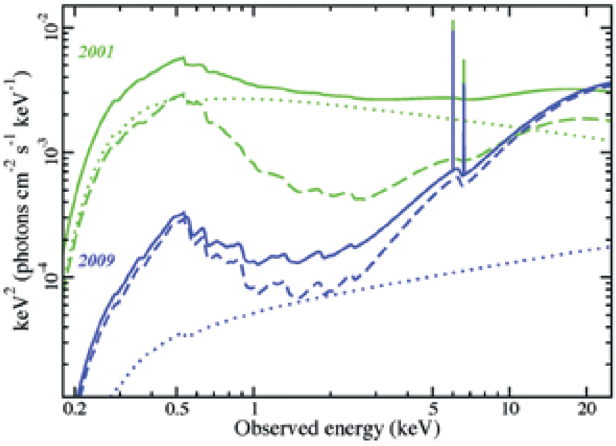

Figure 8 — Decomposition of the PG 0844+349 spectral model in the 2001 high-flux state (green) and the 2009 low-flux state (blue). The most obvious change between the two spectra is the diminishing of the power-law component (dotted curve) relative to the reflection component (dashed curve) during the low-flux state. In 2009 (solid blue curve), the spectrum was dominated by the reflection component, whereas in 2001 (green solid curve), the spectrum was power-law dominated. Adapted from Gallo et al. *(2011b).*

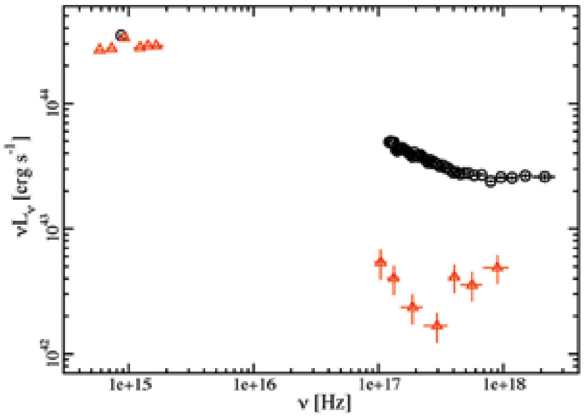

Figure 9 — The UV-to-X-ray spectral-energy distribution of PG0844+349 observed with XMM-Newton in 2000 during an X-ray high-flux state (black circles) and Swift in 2009 during an X-ray low-flux state (red triangles). At both epochs, the UV emission remains consistent. Adapted from Gallo et al. *(2011b).*

is dominated by the power-law component (*i.e.* the primary emitter). At higher and lower energies, the reflection component dominates the spectrum. The spectrum is described well with the light-bending scenario (Section 3.1). Considering Figure 5, one would expect that, if the primary X-ray source and the accretion disc were physically disjoint, one would see a delay in the spectral variation of the two. That is, the fluctuation seen in the power-law-dominated part of the spectrum (*i.e.* 1–4 keV band) should be echoed sometime later at other energies. As demonstrated with the delay analysis of Zoghbi *et al.* (2010; Figure 11), this is indeed the case.

Figure 11 describes the lag as a function of variability frequency. Negative lags indicate that the power-law component changes before the low-energy component. The positive lags on long time scales have been known for some time and arise due to the accretion mechanism. However, the rapid, negative lags are attributed to reverberation and arise due to the light travel time between the corona and the disc.

After this initial discovery, a number of similar sources have been re-analyzed and found to exhibit similar characteristics, but with a lower signal-to-noise ratio. The evidence was so favourable in one other object, IRAS 13224-3809 (Ponti *et al.* 2010; see also Gallo *et al.* 2004b for earlier suggestions of negative lags in this source), that the AGN is being observed with *XMM-Newton* for 500 ks this summer.

3.3 Measuring black-hole spin

The relativistically broadened emission lines described in Section 2.2, especially the Fe Kα line, contain a wealth of information. In addition to determining the ionization, composition, and kinematics, one can even estimate the black-hole spin directly from the line profile. The key factor is the extent of the red emission associated with the line.

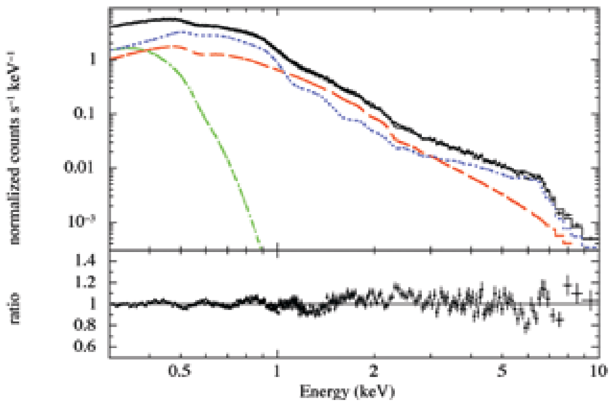

Figure 10 — Top diagram: The model used to fit the spectrum of 1H0707-495. The red dashed line represents the power-law component, which dominates the spectrum in the range 1–4 keV. The blue dotted line corresponds to the reflection component, which is the dominant component at higher and lower energies. The green curve is the tail of the UV disc emission that extends into the X-ray regime. Lower diagram: The residuals (data - model) that remain after the model is applied to the data. Adapted from Zoghbi et al. *(2010).*

Recall that intrinsically all the photons in the line are emitted at 6.4 keV. However, the closer the photons are to the black hole when they are emitted, the deeper is the gravitational potential well from which they emerge, and the larger the redshift the photons experience. This arises because a photon emitted from a deep gravitational potential well has to do more work to escape from it and hence loses more energy. Consequently, the closer material gets to the black hole, the more extended the red wing of the line profile becomes.

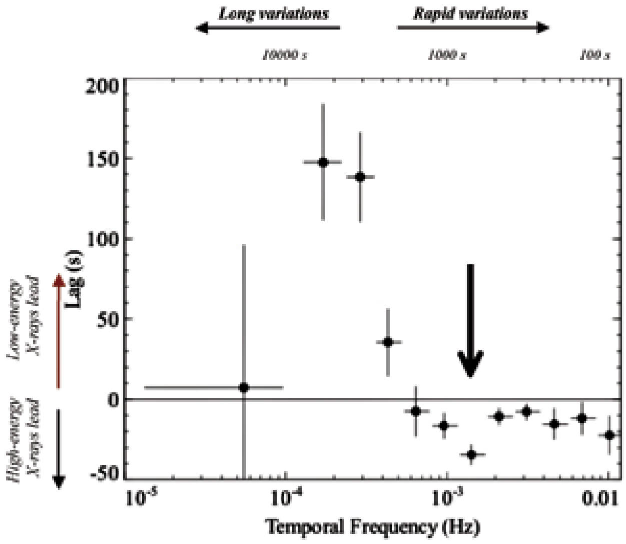

Figure 11 — The time lag as a function of Fourier frequency (time scale shown on the top axis) between the reflection-dominated band (0.3-1 keV) and the power-law-dominated band (1-4 keV) in 1H0707-495. A positive lag indicates that the high-energy variations lag the low-energy fluctuations (attributed to accretion processes). The black arrow points to the significant negative lag (~ 30 s) at short time scales, which is attributed to reverberation. Adapted from Zoghbi et al. *(2010) and modified.*

How close the material gets to the black hole is defined by the inner edge of the accretion disc, and this is driven, in part, by the spin of the black hole. The spin of the black hole is responsible for dragging space inward (*i.e.* frame dragging), thereby allowing the inner edge of the accretion disc to be closer to the event horizon. The innermost stable circular orbit[4] (ISCO) around a non-spinning black hole is about five times farther from the event horizon than the ISCO around a spinning black hole (Figures 12 and 13).

We are now obtaining sufficiently high-quality data that we can estimate the black-hole spins in stellar-mass black holes (*e.g.* Miller *et al.* 2009) and AGN (*e.g.* Brenneman & Reynolds 2006; Schmoll *et al.* 2009; Gallo *et al.* 2011a) via this line-profile-fitting technique. The spin of SMBHs has implications on the evolution of black holes over cosmic time. Whereas in a stellar-mass black hole the spin is defined at creation, in an SMBH, the spin is modified as the black hole grows. How the black hole grows, whether by accretion or merging events, can modify its spin. The spin has been measured for only a handful of AGN due to the high-quality data demanded. In general, moderate-to-high spin values are being measured, but there are still too few accurate measurements to speculate as to the implications of these results.

4. Future X-ray studies of SMBHs

We are living in a golden age for X-ray astronomy. At this time, three of the most sensitive X-ray observatories ever are currently in orbit (*XMM-Newton*, *Suzaku*, and *Chandra*). The instruments on these observatories have generated the high-quality data that is required to carry out the type of work described here. However, this is only the tip of the iceberg. Significant work will be achieved with future X-ray observatories.

Proposed future telescopes like *Athena*, *IXO*, and *Astro-H* are expected to make further breakthroughs in the field of AGN physics. Particularly close to home is the JAXA-led *Astro-H* mission in which Canada is an international partner. The observatory will include four focussing telescopes and a soft-gamma-ray detector, which in combination, will effectively and simultaneously observe the 0.3–500 keV range. The various instruments will allow scientists to observe different components of the AGN at the same time, thereby allowing more accurate modelling of AGN phenomena. *Astro-H* will be launched in 2014.

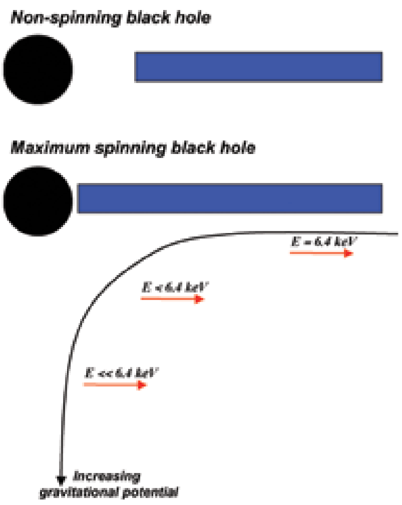

Figure 12 — The inner edge of the accretion disc extends closer to the black-hole event horizon as the black hole spins. Photons emitted closer to the black hole climb out of a deeper gravitational potential well and lose more energy in the process - they are gravitationally redshifted.

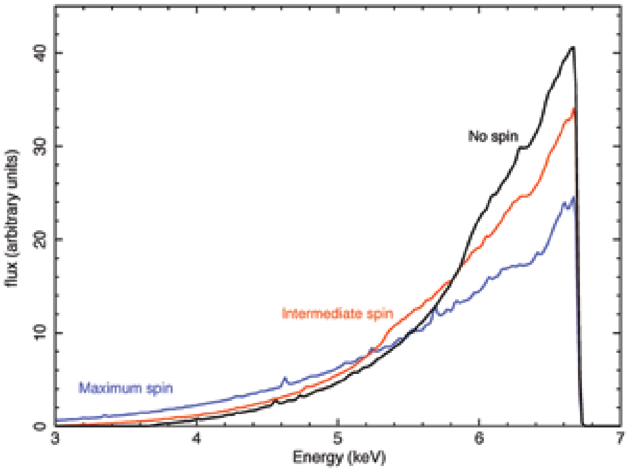

Figure 13 — The relativistically broadened Fe Kα line profile is plotted for three situations. The line profiles differ only in the spin parameter of the black hole. The profile of the emission line extends to lower energy as the spin of the black hole increases.

5. Conclusions

The first detection of non-solar X-rays was a diffuse background emanating from the entire sky (Giacconi *et al.* 1962). Since then, this diffuse background has been resolved into point sources and attributed to AGN. The ability of X-rays to penetrate through high levels of obscuration allows us to get a true understanding of how many AGN are actually present in the Universe and what role AGN play in the evolution of galaxies.

Deep X-ray studies of AGN, like those described here, are important in their own right. In particular, they allow us to probe the closest regions surrounding SMBHs. In this work, we have discussed how the X-ray studies of AGN provide a picture of how matter falls into a black hole. We are determining what this matter is made of. We are viewing the dynamics in the region and discerning the geometry of the region. We are even ascertaining the spin of black holes. These are achievements that at one time could only be considered thought experiments, but now are being examined with real data. ✶

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References

Ballantyne, D.R., Ross, R.R., & Fabian, A.C. (2001). X-ray reflection by photoionized accretion discs. *MNRAS, 327*, 10-22.

Brenneman, L.W. & Reynolds, C.S. (2006). Constraining Black Hole Spin via X-Ray Spectroscopy. *ApJ, 652*, 1028-1043.

Crummy, J., Fabian, A.C., Gallo, L., & Ross, R.R. (2006). An explanation for the soft X-ray excess in active galactic nuclei. *MNRAS, 365*, 1067-1081.

Fabian, A.C., Miniutti, G., Gallo, L., Boller, Th., Tanaka, Y., Vaughan, S., & Ross, R.R. (2004). X-ray reflection in the narrow-line Seyfert 1 galaxy 1H0707-495. *MNRAS, 353*, 1071-1077.

Fabian, A.C., Zoghbi, A., Ross, R.R., Uttley, P., Gallo, L.C., Brandt, W.N., Blustin, A.J., Boller, T., Caballero-Garcia, M.D., Larsson, J., Miller, J.M., Miniutti, G., Ponti, G., Reis, R.C., Reynolds, C.S., Tanaka, Y., & Young, A.J. (2009). Broad line emission from iron K- and L-shell transitions in the active galaxy 1H0707-495. *Nature, 459,* 540-542.

Galeev, A.A., Rosner, R., & Vaiana, G.S. (1979). Structured coronae of accretion discs. *ApJ, 229*, 318-326.

Gallo, L.C., Boller, Th., Tanaka, Y., Fabian, A.C., Brandt, W.N., Welsh, W.F., Anabuki, N., & Haba, Y. (2004b). The X-ray variability of the narrow-line type 1 Seyfert galaxy IRAS 13224-3809 from an XMM-Newton observation. *MNRAS, 347*, 269-276.

Gallo, L.C., Tanaka, Y., Boller, Th., Fabian, A.C., Vaughan, S., & Brandt, W.N. (2004a). Long-term spectral changes in the partial-covering candidate narrow-line Seyfert 1 galaxy 1H 0707-495. *MNRAS, 353*, 1064-1070.

Gallo, L.C. (2006). Investigating the nature of narrow-line Seyfert 1 galaxies with high-energy spectral complexity. *MNRAS, 368*, 479-486.

Gallo, L.C., Brandt, W.N., Costantini, E., Fabian, A.C., Iwasawa, K., & Papadakis, I.E. (2007). A longer XMM-Newton look at I Zwicky 1: variability of the X-ray continuum, absorption and iron Kα line. *MNRAS, 377*, 391-401.

Gallo, L.C., Grupe, D., Schartel, N., Komossa, S., Miniutti, G., Fabian, A.C., & Santos-Lleo, M. (2011b). The quasar PG 0844+349 in an X-ray weak state. *MNRAS, 412*, 161-170.

Gallo, L.C., Miniutti, G., Miller, J.M., Brenneman, L.W., Fabian, A.C., Guainazzi, M., & Reynolds, C.S. (2011a). Multi-epoch X-ray observations of the Seyfert 1.2 galaxy Mrk 79: bulk motion of the illuminating X-ray source. *MNRAS, 411*, 607-619.

George, I.M. & Fabian, A.C. (1991). X-ray reflection from cold matter in active galactic nuclei and X-ray binaries. *MNRAS, 249*, 352-367.

Ghez, A.M., Becklin, E., Duchjne, G., Hornstein, S., Morris, M., Salim, S., & Tanner, A. (2003). Full Three Dimensional Orbits For Multiple Stars on Close Approaches to the Central Supermassive Black Hole. *ANS, 324*, 527-533.

Giacconi, R., Gursky, H., Paolini, F.R., & Rossi, B.B. (1962). Evidence for X-rays from sources outside the Solar System. *PhRvL, 9*, 439-443.

Grupe, D., Komossa, S., Gallo, L.C., Fabian, A.C., Larsson, J., Pradhan, A.K., Xu, D., & Miniutti, G. (2008a). XMM-Newton Observations of the Narrow-Line Seyfert 1 Galaxy Mrk 335 in a Historical Low X-Ray Flux State. *ApJ, 681*, 982-997.

Grupe, D., Leighly, K.M., & Komossa, S. (2008b). First Detection of Hard X-Ray Photons in the Soft X-Ray Transient Narrow-Line Seyfert 1 Galaxy WPVS 007: The X-Ray Photon Distribution Observed by Swift. *ApJ, 136*, 2343-2349.

Miller, J.M. (2007). Relativistic X-Ray Lines from the Inner Accretion Discs Around Black Holes. *ARA&A, 45*, 441-479.

Miller, J.M., Reynolds, C.S., Fabian, A.C., Miniutti, G., & Gallo, L.C. (2009). Stellar-Mass Black Hole Spin Constraints from Disc Reflection and Continuum Modeling. *ApJ, 697*, 900-912.

Miniutti, G. & Fabian, A.C. (2004). A light bending model for the X-ray temporal and spectral properties of accreting black holes. *MNRAS, 349*, 1435-1448.

Miniutti, G., Fabian, A.C., Anabuki, N., Crummy, J., Fukazawa, Y., Gallo, L., Haba, Y., Hayashida, K., Holt, S., Kunieda, H., et. al. (2007). Suzaku Observations of the Hard X-Ray Variability of MCG -6-30-15: the Effects of Strong Gravity around a Kerr Black Hole. *PASJ, 59*, 315-325.

Miniutti, G., Fabian, A.C., Brandt, W.N., Gallo, L.C., & Boller, Th. (2009). PHL 1092 as a transient extreme X-ray weak quasar. *MNRAS, 396*, 85-89.

Nandra, K., O'Neill, P.M., George, I.M., & Reeves, J.N. (2007). An XMM-Newton survey of broad iron lines in Seyfert galaxies. *MNRAS, 382*, 194-228.

Ponti, G., Gallo, L.C., Fabian, A.C., Miniutti, G., Zoghbi, A., Uttley, P., Ross, R.R., Vasudevan, R.V., Tanaka, Y., & Brandt, W.N. (2010). Relativistic disc reflection in the extreme NLS1 IRAS13224-3809. *MNRAS, 406*, 2591-2604.

Ross, R.R. & Fabian, A.C. (2005). A comprehensive range of X-ray ionized-reflection models. *MNRAS, 358*, 211-216.

Schmoll, S., Miller, J. M., Volonteri, M., Cackett, E., Reynolds, C.S., Fabian, A.C., Brenneman, L.W., Miniutti, G., & Gallo, L.C. (2009). Constraining the Spin of the Black Hole in Fairall 9 with Suzaku. *ApJ, 203*, 2171-2176.

Schödel, R., Ott, T., Genzel, R., Hofmann, R., Lehnert, M., Eckart, A., Mouawad, N., Alexander, T., Reid, M.J., Lenzen, R., *et al.* (2002). A star in a 15.2-year orbit around the supermassive black hole at the centre of the Milky Way. *Nature, 419*, 694-696.

Tanaka, Y., Nandra, K., Fabian, A.C., Inoue, H., Otani, C., Dotani, T., Hayashida, K., Iwasawa, K., Kii, T., Kunieda, H., Makino, F., & Matsuoka, M. (1995). Gravitationally redshifted emission implying an accretion disc and massive black hole in the active galaxy MCG-6-30-15. *Nature, 375*, 659-661.

Zoghbi, A., Fabian, A.C., Uttley, P., Miniutti, G., Gallo, L.C., Reynolds, C.S., Miller, J.M., & Ponti, G. (2010). Broad iron L line and X-ray reverberation in 1H0707-495. *MNRAS, 401*, 2419-2432.

(Endnotes)

1 A power-law function y(x) takes the form $y = a xb$, where a and b are real constants, and assumes a linear relation $\log y = \log a + b \log x$ when displayed in log-log format, allowing the power b to be readily estimated.

2 The process is more correctly called backscattered emission, as it is not truly analogous to "reflection" like in a mirror.

3 A great circle is a circle on the surface of a sphere whose centre is also the centre of the sphere. The Equator is a great circle, as are the Lines of Longitude. The Tropics of Cancer and Capricorn are examples of small circles.

4 The ISCO is the nearest distance from a black hole that a circular orbit can be completed. Any nearer and the orbit is perturbed and not closed.

The Curious Case of Lemaître's Equation No. 24

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In August of 1961, Abbé Georges Lemaître told me (with a twinkle in his eyes) that, being a priest, he felt a slight bias in favour of the idea that the Universe had been created. It must therefore have been a particular pleasure for him (Lemaître 1927) to have been the first to find both observational and theoretical evidence for the expansion of the Universe. His observational discovery was based on the published distances and radial velocities of 42 galaxies. Lemaître's theoretical result was based on the finding that the Universe is unstable, so that perturbations tend to grow. These results, which were published in French and in a relatively obscure journal, anticipated the work of Edwin Hubble (1929) by two years. It might therefore have been appropriate to assign the credit for the discovery of the expansion of the Universe to Lemaître, rather than to Hubble (Peebles 1984). The early evolution of our understanding of the expansion (and the scale-size) of the Universe has recently been discussed in detail by Kragh & Smith (2003) and by Nussbaumer & Bieri (2009).

Because it had been published in such a low-impact place, an authorized translation of Lematre's discovery paper was reprinted in the widely read *Monthly Notices of the Royal Astronomical Society* (Lemaître 1931). It is this translation, rather than the French original, that formed the basis of most subsequent discussions of the discovery of the expansion of the Universe. A comparison between the original French text and its English translation shows a few, but very interesting, differences (*e.g.* Peebles 1984, Way & Nussbaumer 2011). It does not previously seem to have been noted that one of the 31 equations in Lemaître's paper is also different in the original and in its translation. [The unknown translator did his work well and corrected a typographical error in one of these equations in the French original version of the paper.] In the English translation the term

$$\frac{v}{rc} = \frac{625 \times 10^{5}}{10^{6} \times 3{,}08 \times 10^{18} \times 3 \times 10^{10}} ,$$

in which v is the radial velocity, r the distance, and c the velocity of light, is omitted. Of the three numbers given above, the speed of light in cm/s and the length of the parsec are well known. Only the cosmic expansion term 625 × [corresponding in modern parlance to a Hubble constant of 625 km/s] might possibly be considered to be controversial. The fact that dropping this term from Lemaître's Eqn. 24 was intentional is supported by the fact that a short paragraph in the paper, which deals with the determination of what we now call the Hubble parameter, was also omitted from the English translation of the text (the latter fact had already been noted previously by Peebles (1984) and by Way & Nussbaumer 2011)). That mention of the expansion of the Universe was omitted from the English version of both Eqn. 24 and from the English text suggests that this exclusion by the translator was deliberate rather than accidental. The Editor-in-Chief of the *Monthly Notices* has kindly informed me that his office no longer has any records of the events related to the translation of Lemaître's article in 1931. Another factor that may have influenced the lack of credit assigned to Lemaître for the discovery of the expansion of the Universe is that the English translation of the article did not include the footnotes to the original French version of the article. One of these footnotes explains in detail how using weighted and unweighted radial velocities for galaxies leads to slightly different values for the Hubble parameter. In summary it appears that the translator of Lemaître's 1927 article deliberately deleted those parts of the paper that dealt with the determination of what is presently referred to as the Hubble parameter. The reason for this remains a mystery.

Figure 1 — Abbé Georges Lemaître.

I am indebted to Bob Carswell for information on the files of the Monthly Notices and to Harry Nussbaumer for helpful exchanges on early work related to the expansion of the Universe. ✶

References

Hubble, E. (1929). A relation between distance and radial velocity among extra-galactic nebulae. *Proc. National Acad. Sci. 15, Issue 3*, 168.

Kragh, H., & Smith, R.W. (2003). Who discovered the expanding universe? *History of Sci. 41*, 141.

Lemaître, G. (1927). L'univers en expansion. *Ann. Soc. Sci. de Bruxelles, 47*, 49.

Lemaître, G. (1931), Expansion of the universe, A homogeneous universe of constant mass and increasing radius accounting for the radial velocity of extra-galactic nebulae. *MNRAS, 91*, 483.

Peebles, P.J.E. (1984). In A. Berger (Ed.), *The Big Bang and Georges Lemaître* (p. 23). Dordrecht: Reidel Publ. Co.

Nussbaumer, H. & Bieri, L. (2009). *Discovering the Expanding Universe*. Cambridge: Cambridge University Press.

Way, M. & Nussbaumer, H. (2011). The linear redshift-distance relationship: Lemaître beats Hubble by two years. *arXiv*:1104.3031

Figure 1 — Arne Danielsen found the weather and the lenticular clouds to his liking on June 1, when he travelled to the top of Fjellheisen (Fløya) in Tromsø, Norway, to view the partial solar eclipse. Arne used a Canon 5D at ISO 100 with a 70-200-mm lens set at 200mm and f/19. The image is a 12-image HDR composite, with exposures from 1/2000 to 1 sec.

Partial Solar Eclipse, 2011 June 1

Success in Yellowknife

by Stephen Bedingfield, RASC
(stephen@skyriver.ca)

On 2011 June 1, I successfully observed the partial solar eclipse from downtown Yellowknife, NWT. My location was N 62° 27′ 14.11″, W 114° 22′ 37.85″, elevation 183 m. Sky conditions were clear (clouds had moved off just 15 minutes before), transparency average, winds estimated south 20 km/h. I was using my 12.5-inch (317.5-mm) Portaball with a 13-mm Ethos eyepiece (~122×) with a Baader visual filter. The wind load caused the scope to vibrate on slight gusts. The calculated partial eclipse duration for Yellowknife was 12 minutes 29.1 seconds. I was able to observe the eclipse for approximately 12 minutes 2 seconds, having spotted the eclipse at ~21:46:20 UTC and last losing sight in the scope vibrations at 21:58:22 UTC. This was approximately 11 seconds prior to the calculated egress.

I was also able to easily observe the PSE using my Canon 12×36 IS binoculars during the central 8 minutes (according to my memory). This partial eclipse was also observed and confirmed by fellow observer Zhang Xian Yu on the same equipment.

My wife was returning to Yellowknife from Norman Wells aboard the RCMP Pilatus PC-12 at 27,000 ft. and observed the eclipse with no magnification, using only eclipse glasses. Her estimated location was (at one instance) N 65° 06′ 20″, W 126° 29′ 30″. She viewed the eclipse from approximately 21:16:00 through to 21:40:00 UT. Estimated obscuration was 0.80 percent. It was very cramped and awkward sitting on the floor between the seats and straining sunward, so she was not able to use the 10×50 binoculars in her possession. This was her first eclipse of any kind!

This certainly was the lowest magnitude solar eclipse I have observed. Magnitude at maximum in Yellowknife was calculated at 0.00308, with a 0.02-percent obscuration. Imagine watching that slight indentation covering just 1/5000th of the solar disc, and sporting my TSE 2009 Eclipse of the Century t-shirt – extreme observing for sure. My impression of this partial eclipse, with the Moon just grazing along the solar rim and the added disturbance of occasional wind vibration, was like that of an overturning wave slowly breaking the surface of a pitch-black sea. ✶

Stephen Bedingfield is an unattached life-member of the RASC living in Yellowknife, NWT. He is plagued by bright summer nights, cold winter observing conditions, and an interminable bug for astronomy and eclipse chasing.

The Bucket List for Backyard Stargazers

by Brian Ventrudo, Ottawa Centre
(bventrud@gmail.com)

> *"To die is nothing; but it is terrible not to live."*
> *-Victor Hugo*

Stroll through a bookstore and you see on the shelves thick books full of fascinating things to see and do before you die: places to go, or great music to listen to, or exotic foods to eat, or exhilarating activities to do. All are worthy, no doubt. But, you are a stargazer, so you must think bigger. What sights should be on your must-see list before your final sunset arrives?

Here are some ideas to get you thinking; a totally subjective list of ten celestial sights to see before you die, or "kick the bucket." Call it the "Bucket List for Backyard Stargazers."

Yes, there are many more than ten things to see in the night sky – millions, in fact. But let us go for quality over quantity. This list is targeted at the casual stargazer, with no special expertise or training or ambition other than to see some of the most beautiful, and in some cases, transient sights in nature. Yet even the most experienced amateur astronomer will need to make an effort and have a little luck to see all ten.

For some of these objects, you will need to use a pair of binoculars or a small telescope. Others require travel, good timing, and luck. For a few, you need simply to look up. None of these sights are hard to see, once you know how and when and where to look for them.

Once you see these ten sights, then whatever else happens in your life, you can be assured you have seen some truly remarkable sights that few people, even the most celebrated professional astronomers, ever get to see.

Sight #10 - The Omega Centauri Star Cluster

The list opens with the 800-pound gorilla of globular clusters, Omega Centauri. So breathtaking is this swirling mass of stars in a small telescope that astronomy writer Stephen James O'Meara says, "observing Omega Centauri is like peering into the working mind of the Creator."

Omega Centauri packs 5-10 million stars into a diameter of 150 light-years, a density some 10,000 times greater than we see in our own night sky. By some estimates, it is at least 5-10× more massive than any other globular cluster in the Milky Way. And, it is exceptional in another way: it seems to have formed more slowly than other globulars, with two episodes of star formation over two billion years. Some astronomers speculate that it may be the remains of a separate dwarf galaxy absorbed by the Milky Way billions of years ago.

Figure 1 — Omega Centauri, from Arizona

It is easy to see. Even in binoculars, the cluster is magnificent. Its misty glow spans a nearly a full degree of sky, twice the width of the full Moon. Turn a 3- or 4-inch telescope on this cluster and it becomes a shimmering ball of stars, glowing like a frosted light bulb against a rich background of closer-by stars. In a small scope, individual stars are visible around the edge; a slightly larger scope resolves 12-billion-year-old stars right to the core.

To see Omega Centauri at all, you need to be south of 43°N latitude, roughly. It is easy to see south of 30°N latitude. Ideally, you can venture south of the equator, where the cluster is high in the sky, and well placed for viewing from March to October. But, a diligent few have seen it from as far north as Point Pelee, the southernmost point in Canada. From there, the cluster can appear to skim the surface of Lake Erie for a few nights each spring.

Sight #9 - Sunrise on the Moon

Now to one of the most moving and dynamic scenes you will ever see in a small telescope: the Sun slowly rising over Copernicus, one of the Moon's most spectacular craters. A fairly young crater just 800 million years old, Copernicus spans some 100 km, just north of the lunar equator and south of Mare Imbrium. The crater has tall, terraced side walls, and a cluster of peaks near its centre. There are many hilly features that cast long shadows when the crater lies along the terminator.

Copernicus graces the terminator about nine days after new Moon each month and about five days before full Moon. At that time, it is well placed for viewing in the evening: you do not need to stay up late. At the critical moments, you can watch sunlight fan out over Copernicus during the course of an evening. It is a stirring sight to see the crater's walls and central peaks catch the Sun's first rays, followed by the low-lying crater floor.

While you can certainly see the crater in binoculars, a telescope gives you a much better view. Since the Moon is bright, you can use high magnification, if you have steady air. Try different eyepieces and magnifications to see what gives you the best view.

And the best part? You get to see the same show each month, as the Moon follows its trajectory around the Earth with clockwork-like regularity.

Sight #8 - Total Solar Eclipse

The classical Greek poet Archilochus wrote of a solar eclipse: "Zeus, the father of the Olympic Gods, turned mid-day into night, hiding the light of the dazzling Sun; and sore fear came upon men."

The sudden disappearance of the Sun is, understandably, an unsettling sight. But, Zeus has nothing to do with it. A solar eclipse results from the mechanics of the Solar System, as the Moon passes between the Earth and the Sun, and casts a shadow across a narrow band of the Earth's surface, the so-called "band of totality." By chance, our Moon, which has a diameter 400 times smaller than our Sun, lies almost exactly 400 times closer. This means the disc of the Sun and Moon sometimes overlap exactly, which yields an amazing view of the glowing outer reaches of the solar atmosphere: the chromosphere, and corona.

Though it lasts just a few minutes, a total eclipse presents one of the most impressive and shocking sights in nature. A few minutes before the peak of the eclipse, the sky and Earth darken, the temperature drops, and animals and insects are persuaded into their nighttime routine. In the final seconds before totality, bright beads of light appear along the limb of the merged disc, the so-called Baily's Beads, caused by the last remnants of the Sun shining through lunar valleys. The last drop of sunlight through a single valley, just before and after totality, brings the "diamond ring," a mainstay of eclipse chasers. Science writer Timothy Ferris, in his book *Seeing in the Dark*, describes his view of totality during the eclipse of 1970 March 2 in North Carolina:

Figure 2 — 2010 total eclipse, south of Tahiti

> *Suddenly the sky collapsed into darkness and a dozen bright stars appeared. In their midst hung an awful, black ball, rimmed in ruby red and surrounded by the doomsday glow of the grey corona. No photograph can do justice to this appalling sight: The dynamic range from bright to dark is too great, and the colors are literally unearthly.*

During the brief minutes of totality, you can look towards the Sun without eye protection. But, keep your wits about you. As the Sun emerges and the diamond ring appears, make sure you look away and watch the rest of the show through the proper solar filters.

Solar eclipses occur almost annually, but it may take centuries for an eclipse to grace any particular point on Earth. So, if you want to see one, you need to pack your bags and travel. It's worth the trip.

Sight #7 - The Green Flash

As night falls on Key West, Florida, a large crowd gathers in Mallory Square at the foot of Whitehead Street. Most simply browse the tourist shops and take in the buskers. But, some come to see the dramatic sunset over the Gulf of Mexico, and a few hope to glimpse an unusual and beautiful sight – the fleeting "green flash" of light that appears on the Sun's limb as it vanishes over the horizon.

The green flash is an effect of our atmosphere. When the Sun sinks low on the horizon, its light passes through a thick layer of atmosphere, which scatters blue and green light out of the line of sight, making the Sun appear red-orange. As the red-orange disc sinks out of sight, our atmosphere bends (or refracts) the Sun's light from below the horizon. So, when you see the Sun's disc just above the horizon at sunset, the Sun has already set. You are seeing an image of the Sun refracted from below the horizon. Since the different colours of light are all refracted by different amounts, the image that you see at the horizon is actually the superposition of many different-coloured images of the Sun. The separation is very small – about 20 arcseconds – so magnification is required to see the consequences. Most often, the about-to-set Sun is topped by a thin green arc.

As the refracted Sun continues to sink, a mirage may spread out the light of the last of the overlapping coloured solar discs, effectively separating the various colours in a kind of atmospheric magnification. The most refracted colours are the last to sink below the horizon; if the horizon is cloud free and the air sufficiently transparent, the last view will be an apple-green limb or blob that can last for as long as 15 seconds. If the air is particularly transparent and the mirage particularly well formed, the last view of the Sun may turn a distinct blue.

Figure 3 — Green flash, from Tahiti

You can only see the green flash if you have a cloud-free view toward the Sun over a great expanse of atmosphere. Sunset over an ocean is a good bet, and Key West is one of the most famous places to see the green flash. A flat prairie, or desert, or mountain range can work as just well, even a sunset seen from an airplane. Next time you have a clear view of the horizon, look for this sublime and fleeting sight. And, check one more off your celestial bucket list.

Sight #6 - The Transit of Venus

While not as striking as a solar eclipse, a transit of the planet Venus is far rarer, with just seven transits recorded since the invention of the telescope more than 400 years ago. The next transit, in June 2012, will be your last chance to see this remarkable event and cross it off your "bucket list." There won't be another transit as seen from Earth until December 2117.

As it turns out, the geometry of the orbits of Earth and Venus, and the period of the planets' orbits, cause Venus to pass in front of the Sun at well-defined intervals of 121.5 and 101.5 years, in either June or December. The transits occur in pairs separated by eight years. Right now, we are between transits. The last occurred on 2004 June 8. The next is on 2012 June 6. The previous transits came on December of 1874 and December 1882.

A transit of Venus was once a huge deal for astronomers. In the early 18th century, Edmond Halley determined a way to measure the distance from the Earth to the Sun by timing the transit of Venus from widely separated locations on Earth. If the distance to Venus could be measured, then the distances to other planets could be determined through Kepler's Laws. The transits were so important that most advanced nations sent astronomers around the world in 1761 and 1769 to measure the circumstances of Venus' passage.

The transit of Venus in 1761 yielded few conclusive results, despite hundreds of attempted measurements. So, the pressure was on for 1769. It all worked out – the transit of 1769 was measured precisely by, among others, the team led by one Lieutenant James Cook, RN, who witnessed the event from Tahiti before sailing on to claim Australia for England. Astronomers used Cook's measurements to calculate the Earth-Sun distance to be 150 million kilometres, close to the now-accepted value of 149,597,870.7 kilometres. It is the history and the rarity of the event that makes the transit of Venus such a compelling sight. It is a beautiful sight, too, even for the casual stargazer.

The 2012 transit begins at 22:09 UT (GMT) on June 5, and ends at 04:50 UT on June 6. The western Pacific, including most of Australia and New Zealand, can see the entire transit. Western Africa, Spain and Portugal, and eastern South America will not see the transit at all because it occurs when the Sun is set. And, the rest of the world, including much of Canada, can see some of the transit after the Sun rises or before it sets.

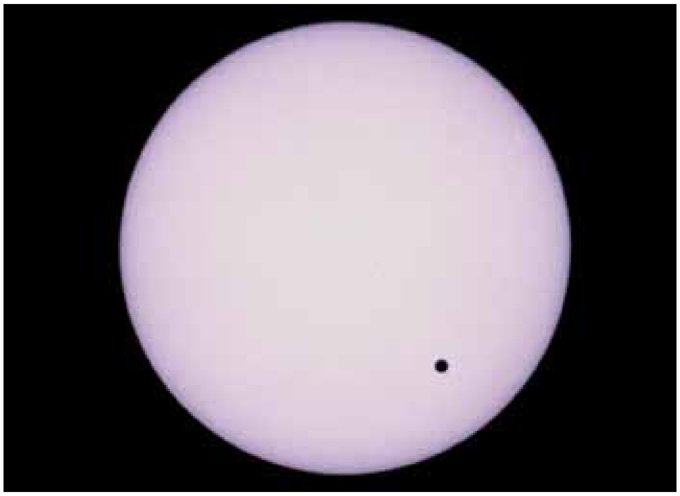

Figure 4 — Transit of Venus, from Crete

Sight #5 - A Meteor Storm

A meteor storm! The very term makes an honest stargazer's heart beat faster. While a good meteor shower, like the Perseids, may show 50-60 meteors every hour, a meteor storm sprays shooting stars at a rate of hundreds or thousands an hour. While magnificent, a meteor storm may be the most difficult to see because they are brief, rare, and largely unpredictable, though this is changing.

The Leonid meteor shower, which peaks on November 17, has offered stargazers the most reliable opportunity to see a meteor storm. The shower flares up reliably every 33 years, presenting a deluge of meteors for a few hours on the early morning on or around November 17.

There have been some remarkable Leonid storms in the past. The great Leonid meteor storm of 1833 was perhaps the most spectacular in recorded history. Visible from eastern North America on November 12, the storm produced meteors at the absurd rate of 200,000 per hour, startling 19th-century observers into a glazed stupor or near-catatonic terror. The storm lasted nearly four hours. According to astronomer Agnes Clerke, "the frequency of meteors was estimated to be about half that of flakes of snow in an average snowstorm."

Alas, the Leonids have been quiet of late. But, the Draconids in 2011 may be the next big storm. NASA is already preparing to deal with a possible outburst this year from this usually lacklustre shower. So, you may see a good show then, although the Moon phase is unfavourable. Since such events are hard to predict, there may be more opportunities in the coming years. One thing for sure, if you do see a meteor storm, you'll never forget it.

Sight #4 - The Southern Sky

The southern sky beckons to all stargazers who wish to glimpse, at least once, the parts of the Universe stubbornly hidden by the Earth under our feet. By chance, the south side of our planet gives a better view into the most star-rich portions of the next-nearest spiral arm in the direction of the galactic centre. As a result, there are more bright stars, star clusters, and nebulae along the band of southern constellations from Sagittarius through Crux and Carina than in any other part of the sky. The southern skies also hold many bright objects, including globular clusters and peculiar galaxies that lie outside the plane of the Milky Way.

Figure 5 — The southern Milky Way, from the Bolivian altiplano

Here's just a partial list of Southern Hemisphere celestial sights unmatched in northern skies…

- three of the four brightest stars in the night sky: Sirius, Canopus, and Rigil Kentaurus A (also known as Alpha Centauri, a part of the nearest star system to Earth),
- the Magellanic Clouds: two irregular dwarf galaxies gravitationally interacting with our own, and easily visible to the unaided eye,
- Omega Centauri and 47 Tucanae: the two brightest globular clusters in the sky,
- NGC 5128: a giant elliptical galaxy caught in the act of devouring an entire spiral
- The Coalsack: the largest and most conspicuous dark nebula in the sky, which stands out from the glittering star field in Crux, the Southern Cross
- The Eta Carinae Nebula: the largest and brightest emission nebula in the sky, even more spectacular than the Orion Nebula.

Perhaps the most magnificent sight from the Southern Hemisphere is the thick star clouds towards the centre of the Milky Way in the constellation Sagittarius. In the north, these star clouds are dimmed by the murky air near the horizon. Go far enough south, from June through August, and they are directly overhead. Lie back under the Milky Way south of the equator, in the deserts of Australia or northern Chile, and you'll easily grasp our true place at the edge of a vast disc of stars.

Sight #3 - A Bright Comet

While half a dozen comets come and go each year, most are too faint to see without optical aid. But, a bright comet, with a swollen head brighter than Venus and a tail streaking a third of the way across the sky, is a stunner, one that should make the Bucket List of even the most casual stargazer.

On average, a bright and truly spectacular comet comes about once a decade. The last was Comet McNaught in 2007, a dazzling sight for southern-hemisphere observers that (so far) is considered the "comet of the century." Before that, there were the back-to-back appearances of Comet Hale-Bopp and Comet Hyukutake in 1997 and 1996. Before that, Comet West put on a lovely show in the pre-dawn skies in 1976.

The last return of Comet Halley in 1986 came with an unfavourable planetary alignment, and turned into a media dud. The comet gave its dimmest performance in recorded history, though it's been reliably bright over the past millennia. This most famous of comets has a rich historical background that makes it rewarding to observe. It gave Edmund Halley a chance to test Newton's newly discovered laws of gravitation, showing that several historical comets were actually the same comet, returning every 76 years.

Most bright comets arrive sporadically from the distant Oort Cloud, so the chance to see a bright comet is hard to predict more than a few months ahead. They're often discovered accidentally by amateur and professional astronomers with large telescopes and complex imaging equipment. One such discovery, made last December, yielded what's now called Comet Elenin, which may put on a good show in August and September of 2011, though it is nearly impossible to predict accurately just how bright it will become. The brilliance of Comet McNaught caught astronomers by surprise in 2007, and so Comet Elenin may yet turn out to be spectacular, or at least respectably bright. Or, it could be another dud. We will know soon enough.

Sight #2 - The Great Orion Nebula

As beautiful an object as you will ever see in the night sky, the Orion Nebula is just a small part of the vast star-making machinery in our own Orion Arm of the Milky. The nebula is one of the grandest sights in our sky, giving birth to a cluster of bright new stars out of a dark cloud of interstellar gas and dust. Unlike other sights on this Bucket List, you can see the

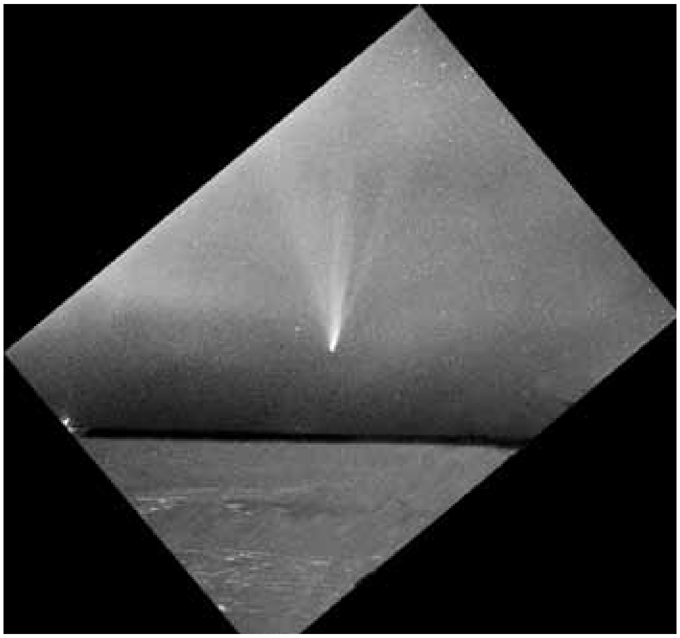

Figure 6 — Comet West, from east of Winnipeg

Orion Nebula year after year, on any clear night from late fall through early spring, in the "sword" of stars that appears to hang off Orion's Belt.

The nebula is visible with the unaided eye and offers a respectable view in binoculars. Turn a telescope toward the Orion Nebula and you will see a greyish bat-shaped mist, lighted by dozens of blue-white stars. Try a small magnification at the start, say at 40-50×, and work your way up. The nebulosity extends much farther than you might first think; use averted vision to glimpse its full expanse. At high magnification, you will lose the overall shape, but you can see the fine detail in the nebula's mottled structure and the beautiful diamond-like stars near the centre that sparkle like a jar full of fireflies.

The energy that lights up the gas and dust of the Orion nebula comes from dozens of hot new stars that have recently coalesced out of the nebula itself. At the heart of the nebula is the young multiple-star system Theta Orionis, also called the Trapezium, so-named because it looks like a tiny trapezoid. There are actually six stars here, though you need good seeing, a 4-inch or larger telescope, and magnification of 100× or more to resolve them all. The stars of the Trapezium, only 100,000 years old, have blown a bubble in the surrounding gas to give us a view of the nebula's inner core.

Astronomy writer Walter Scott Houston said of the Orion nebula, "No amount of intensive gazing ever encompasses all its vivid splendor." It's truly one of the most beautiful celestial things you will ever see.

Sight #1 - A Supernova

During an after-dinner stroll on a cool autumn evening in 1572, the great Danish astronomer Tycho Brahe was stopped in his tracks by the sight of a blazing new star in the constellation Cassiopeia. Since his youth, Tycho had known every star in the sky, so when he saw this new one, he was, as he later wrote, "so astonished at this sight that I was not ashamed to doubt the trustworthiness of my own eye." Tycho was amazed by what is now called a supernova, a massive exploding star, which for a few weeks can outshine an entire galaxy. It's a sight you should see for yourself, as luck allows, and it tops this celestial "Bucket List."

Today, we know Tycho's supernova was likely a white-dwarf stellar remnant that suddenly blew itself to bits in a planet-sized, fission-fueled explosion after taking on too much mass from a close companion. This is known as a Type Ia supernova.

There's another flavour to supernovae: the Type II supernovae. These are massive stars that run out of fuel and suddenly collapse upon themselves, crushing their innards into a dense, scorching brew of radiation and atomic particles before rebounding outwards to release light and radiation and millions of tons of heavy elements such as carbon, oxygen, iron, and gold. Both types of supernova create more energy in a few weeks than our Sun creates in its entire lifetime. A blast of visible light signals a supernova, along with neutrinos, atomic, and subatomic particles travelling at high speed. The X-rays and gamma rays from a supernova would destroy or degrade life (as we know it) on any planet within a 50 light-year radius.

Fortunately for life, supernovae are quite rare. There is one every 50-100 years in the Milky Way on average. Astronomers discover one or two each year in other galaxies, and that is your best bet to see one in the near future. Many of the bright stars in our skies will eventually detonate as Type II supernovae, and there is a short list of nearby stars that will lead the way: Betelguese, Eta Carinae, Rho Cassiopeiae, Spica, and Antares. Astronomers don't know when any of these stars will go supernova; it might be next week, it could be a million years. But, all will one day shine bright enough to see in our daytime skies and cast shadows by night for weeks before fading away. Luckily, none of these is close enough to be dangerous to us, though we will detect the gamma rays and neutrinos from these stellar explosions.

That's the "Bucket List for Backyard Stargazers." If you have not seen all ten yet, then start planning. Or, make your own list of 10, or 20, or a 100 grand celestial sights to check off your own list. ✶

This article was adapted from a longer series entitled "The Bucket List for Backyard Stargazer," which is available at the Web site One-Minute Astronomer (www.oneminuteastronomer.com/bucket-list)

Brian Ventrudo is an Ottawa-area stargazer, and the writer and publisher of the stargazing Web site One-Minute Astronomer.

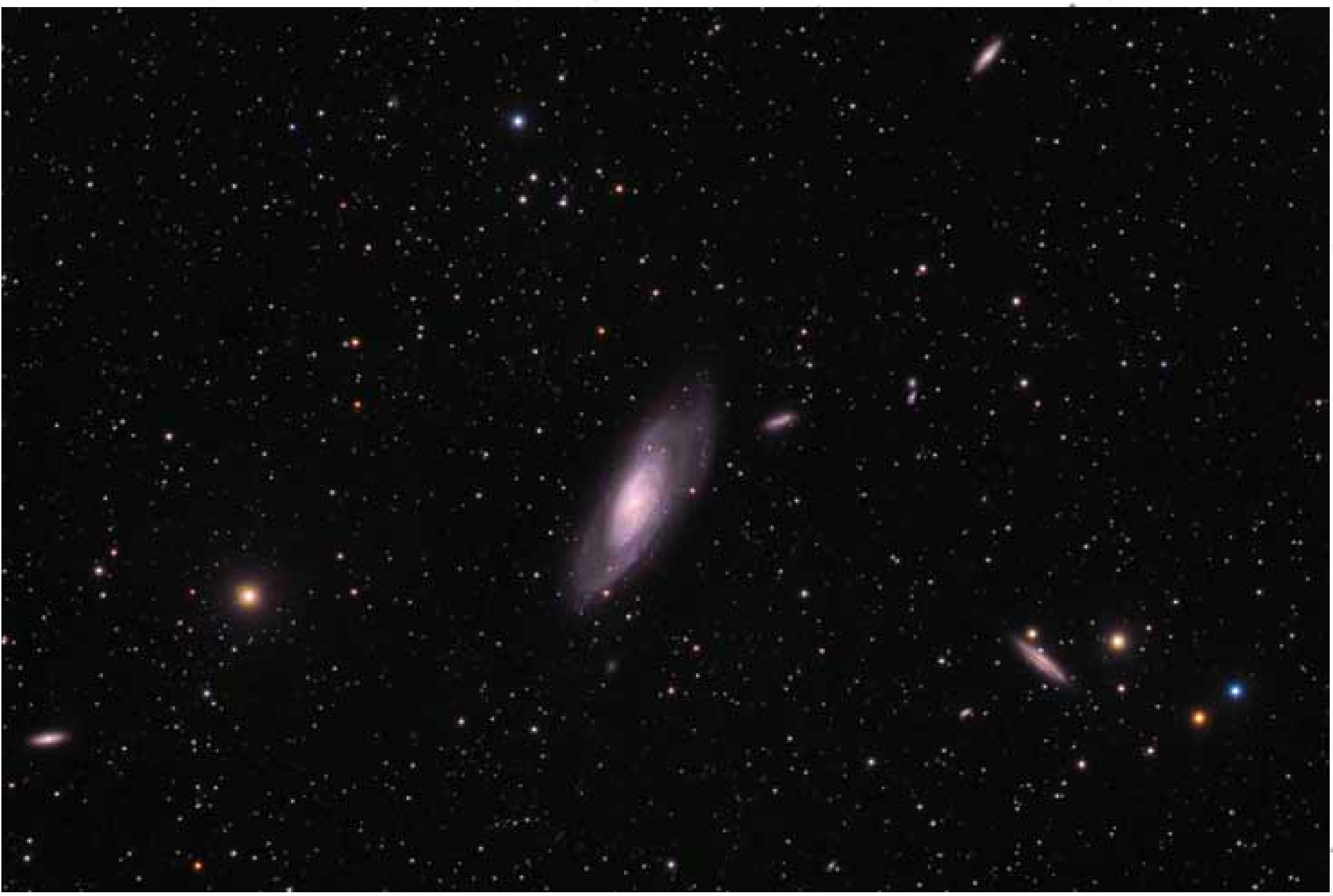

Figure 1 — Stuart Heggie collected 180 minutes of starlight (or galaxy light) from 25 million light-years away to construct this lovely image of M106 and its environs. Also visible in the photo are the galaxies NGC 4248, NGC 4232, NGC 4220, and NGC 4346. Stuart used an Apogee U16M camera aboard an AstroPhysics AP155 with a 4-inch field flattener. Exposure was 9×10 minutes in Luminance and 3×10 minutes per channel in RGB.

Figure 2 — Lynn Hilborn assembled this image of the Whirlpool Galaxy, Messier 51, from images acquired on March 24 and June 7. The June image contained a recently discovered supernova (SN2011dh), which is visible here above the pointer. Lynn used a TEC 140 refractor and an FLI ML 8300 camera.

Figure 3 — Les Marczi grabbed this shot of the Sun on May 31 using a Solar Scope 50-mm H-alpha filter on his Takahashi Sky90 telescope and a DMK-21AU04 camera. This image is composited from the best 1000 frames of a 2000-frame recording session.

Figure 4 — While the rest of us were huddled around winter fires, Serge Théberge braved February 2009 temperatures to collect 7.5 hours of H-alpha light to make this two-panel mosaic of the emission nebula SH2-261. Serge used a Takahashi FS-152 at f/8 and an SBIG ST-10XME camera. SH2-261 (Lower's Nebula) is a faint emission nebula in Orion located approximately 3,000 light-years away with an apparent size of 30 × 50 arc-minutes.

Science Fair Winner Puts the Spotlight on Light Pollution

by John Crossen, Kingston Centre
(johnstargazer@xplornet.com)

Francesca Elliott is a Grade 11 student at Kenner Collegiate. She is also an astronomy buff and a member of the Peterborough Astronomical Association. It's no small wonder then, that her project for the Peterborough Regional Science Fair involved the bane of city-bound star gazers: light pollution.

Her objective was to study the effect of light pollution on the number of stars visible from different locations within Peterborough, Ontario, and the neighbouring countryside. She began her study in the city's glowing pit – the No Frills at the corner of George and Sherbrooke Streets. Here the combination of unshielded street lamps and inefficiently lit businesses made it difficult to spot the North Star. But, find it, she did. Then, using a three-second exposure on her digital camera, she took a photograph of the star. The photograph showed Polaris and 64 surrounding stars.

Before jumping ahead, you should know that the human eye sends a fresh "photograph" to your brain every 1/25 of a second, so a three-second exposure is quite long by comparison: it allows many more photons of light to land on the camera's CCD chip than in your eye. As a result, you see more stars in the photograph than you can with your eyes.

As the study progressed, Francesca moved further away from the city core. Each step out, she took another shot of the North Star using the same settings on her camera. The only variable was the distance out from the city. Her best count came from a point that was 10 kilometres away from her starting point, where the number of photographed stars rose to 114.

While none of this is Earth-shattering news to those involved in astronomy, Francesca pointed out that there are other lessons to be learned – lessons that can save both non-renewable energy resources and, in the long run, big money for municipalities.

Figure 1 — Francesca Elliott (left) receives the Frank Hancock Award from Peterborough Astronomical Association member Trish McCloskey (right).

For starters, light pollution is the direct result of poorly designed, ineffective lighting. Most of the inefficient fixtures were designed at a time when energy was cheap. They shoot the light out in all directions, including sideways and up. Such lights create glare and illuminate the bottoms of clouds and bird bellies. North America wastes about $2 billion annually, thanks to these antiques.

Eliminate the up- and side-lighting, and all the light can be concentrated on the ground. With the light going where it's needed, we can use about half the wattage to achieve the same results, and pocket a substantial saving. Moreover, in addition to wasting money, light pollution has detrimental effects on foliage and wildlife, and creates health problems in humans.

Francesca Elliot saw the light and dedicated her project to making the public aware of light pollution. As a result, she took home the Peterborough Astronomical Association's Frank Hancock Award – a cheque for $100, which she plans to apply towards – what else – a new telescope. ✶

John Crossen runs Buckhorn Observatory (www.buckhornobservatory.com)

The Naming of Two Rocky Mountains after Canadian Astronomers

by Donald C. Morton
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Abstract

This is the account of how a team of astronomers, in 1967, made first ascents in the Rocky Mountains of British Columbia and named two peaks after past directors of the Dominion Astrophysical Observatory.

Figure 1 — Mt. Petrie (2900 m) and Dr Robert M. Petrie (1906-1966), Director Dominion Astrophysical Observatory 1951- 1966 (insert). Photos from the archives of the author and the National Research Council.

1. The Team

This story begins in the spring of 1967 when George Wallerstein of the University of Washington in Seattle noted some unclimbed peaks in the Canadian Rocky Mountains east of Prince George, B.C. He invited Bob O'Dell, and graduate student Tom Grenfell of the Yerkes Observatory, Lyman Spitzer, and me, of the Princeton University Observatory, to join him and his teacher wife Marcia for a two-week expedition. There is report of the expedition in the appropriate mountaineering journal (Morton 1968), but the astronomical connections deserve elaborating here. I was the only Canadian in the party, though Tom's grandfather, Dr. Wilfred Grenfell, had been the renowned medical missionary in Labrador.

2. The Climbs

We met in Prince George on 1967 July 24. In two trips by floatplane, we flew 150 km east to land on Dimsdale Lake in what is now Kakwa Provincial Park. There we set up our Base Camp at 1350 m on the west shore, sharing it with countless mosquitoes. Early the next morning, we set off to the west for an attractive unclimbed peak marked with alternate bands of rock and snow. The route was steep enough in places that we roped together and reached the 2900 m summit in 7 hours.

Late the next day, we set out from our base carrying climbing and camping gear and four day's food to explore southward. We hiked across Grey Pass, which divides the Arctic and Pacific watersheds, and camped where Barbara Creek begins its descent to the westward-flowing Jarvis Creek. However, we had underestimated the difficulties of travelling in British Columbia bush. The following day we fought our way through thick alder, prickly devil's club, and huge fallen trees. Sometimes the easiest route was a horizontal one, along these trees a metre or more above the ground. Exhausted, we eventually reached Jarvis Creek, but we had taken five hours to travel 4 km downhill. Worn out, we decided to limit our objectives to the unclimbed 2790-m Mt Walrus, rising 1830 m above the far side of the creek. In knee-deep water, we waded across the creek, and spent the next five days thrashing through more bush, eventually reaching the summit on July 29, following the rock of the south ridge. We returned to our base on Dimsdale Lake, rather hungry.

We rested a day and looked for a climb that avoided the bush. We found a snow gulley south of our first peak that led west up to a broad glacier with a view to interesting summits beyond. After we pitched our tents on the snow, we were surprised to see a herd of a dozen elk wander across the glacier. We spent one day exploring routes to the rock peaks on the west side of the glacier and another waiting for the weather to clear. Then, on August 5, we roped together, climbed a steep snow gulley, traversed the snow on the far side of one rocky peak, and reached the 2970-m summit of another unclimbed crest to the north by its west ridge. We had a rainy descent to our Base Camp the next day, but the evening was clear enough for our pilot to fly us out.

3. Proposed Names

We thought that the first and third peaks we had climbed were unnamed, so we considered honouring two prominent British Columbia astronomers. Consequently, I wrote to the Canadian Permanent Committee on Geographical Names proposing that our first peak be named after Robert M. Petrie, Director of the Dominion Astrophysical Observatory (DAO) near Victoria, B.C. from 1951 to 1966, and the third peak after Dr. John S. Plaskett, Founding Director from 1917 to 1935. The Committee accepted Mt. Petrie for the peak we climbed on July 25 (Figure 1), but noted that our peak of August 6 already had been named Mt. Ovington after Private Roy E. Ovington from Alenza Lake, B.C., who was killed in action on 1944 August 28. Instead, the Committee suggested Mt. Plaskett for the

2940-m peak (Figure 2) immediately south of Mt. Ovington, behind which we had traversed. We found this very acceptable, so now the topographical maps of the region (Figure 3) show a Mt. Petrie and a Mt. Plaskett.

4. Sequel

It is interesting to note the later developments in the careers of the astronomers who made the 1967 climbs. George Wallerstein continued as a Professor of Astronomy at the University of Washington and was a frequent guest observer on the 1.2-m telescope at the DAO. Tom Grenfell switched his studies to geophysics and became a Research Professor of Atmospheric Sciences at the University of Washington, specializing in polar ice. Bob O'Dell left his position of Director of the Yerkes Observatory to become the founding Project Scientist for the *Hubble Space Telescope* from 1971 to 1983, then Professor of Astronomy at Rice University, and later a Distinguished Research Professor at Vanderbilt University. Lyman Spitzer continued as Chairman of the Department of Astrophysical Sciences at Princeton University. After his death in 1997, the U.S. National Aeronautics and Space Administration recognized his scientific contributions by naming its 0.85-m infrared satellite telescope the *Spitzer Space Telescope*. The author of this article moved to Australia for ten years as Director of the Anglo-Australian Observatory, and then returned to Canada in 1986 to be Director General of the Herzberg Institute of Astrophysics, the parent organization of the Dominion Astrophysical Observatory, where Plaskett and Petrie had been so influential. ✶

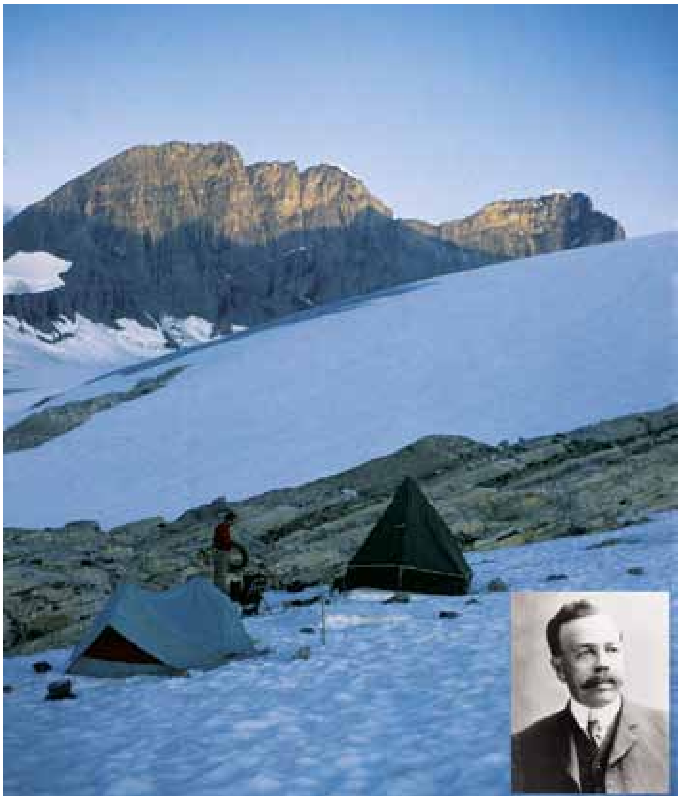

Figure 2 — Mt. Plaskett (2940 m) (left) and Mt. Ovington (2970 m) (right), and Dr. John S. Plaskett (1865-1935), Director Dominion Astrophysical Observatory 1917 - 1935 (insert). Photos from the archives of the author and the National Research Council.

Figure 3 — Parts of topographic maps 93-I/2 and 93-I/1, Natural Resources Canada, showing Mts. Plaskett, Ovington, and Petrie west of Dimsdale Lake.

Reference

Morton, D.C. (1968) *Can. Alpine J.*, *51*, 176

Cosmic Contemplations

Supersize your PST

by Jim Chung, Toronto Centre
(jim_chung@sunshine.net)

One of the overlooked consequences of global warming is the loss of fresh-water reservoirs held at the poles and on mountain-top glaciers. Although I do count my blessings daily, as an astroimager living in Toronto, I am frustrated by the impact that the Great Lakes has on my local climate. Seeing is often poor and nights are often cloudy. Given these conditions, it became natural to pursue solar imaging as a means of maximizing my opportunities to observe the cosmos. Even before I purchased my Coronado PST (Personal Solar Telescope), I was familiar with the modifications made on the instrument by an innovative group of UK amateurs to increase the effective aperture of the PST. Following their lead would allow me to do high-resolution and long-focal-length solar imaging at a price even my CFO could condone.

Even though the PST has a 40-mm aperture, its economical price was made possible by using a much smaller 20-mm air-spaced etalon. This is placed 200-mm ahead of the focal point of a 40-mm doublet f/10 refractor (the long gold anodized barrel). The rectangular metal housing contains a pentaprism and a 5-mm-diameter H-α blocking filter (BF5). The pentaprism travels up and down the focusing shaft and is subject to misalignment and image distortion. The BF5 is too small, causing image vignetting at higher focal lengths. In fact, the only piece of the PST to be used in this modification is the etalon itself.

The gold barrel and etalon (Figure 1) are heavily secured with thread adhesive and are best dismantled with a boa strap wrench (available from Canadian Tire). The etalon has a 50-mm-diameter 1-mm-pitch thread; a 2-inch (50.8-mm) barrel adaptor to fit this can be purchased from a telescope shop in Linz, Austria (www.teleskop-austria.com). Along with some plastic PVC plumbing pipe and a BF10 blocking filter, the critical 200-mm separation between etalon and focal point is preserved (Figure 2).

Figure 1 — The disassembled PST.

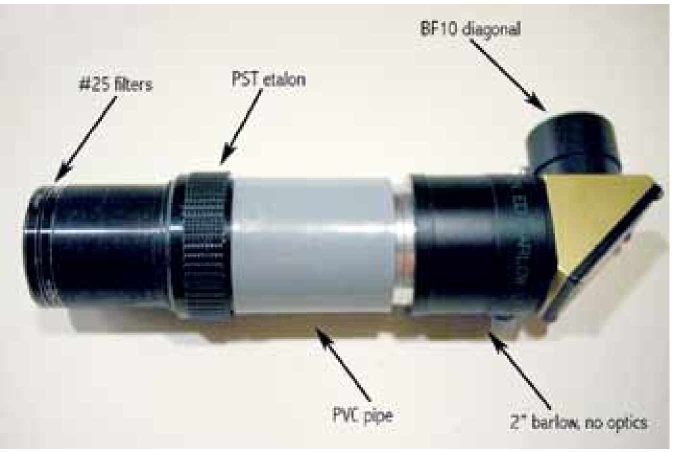

Figure 2 — The reassembled "PST," ready for the telescope.

Figure 3 — An early 80-mm PST attempt using a 2× Siebert telecentric Barlow, AP f/6 Traveler, and Daystar 80-mm ERF.

This PST module must be installed into the 2-inch (50.8-mm) focuser of an f/10 refractor. Alternatively, one of the many common short f/5 refractors could be used in conjunction with a telecentric Barlow such as a 2× Tele Vue Powermate or 2× Siebert (Figure 3). A regular Barlow will not work, because the etalon must be exposed to parallel light rays. I decided to go for broke and used a 6-inch (152.4-mm) Celestron achromat masked down to 5-inches (127-mm) to bring it from f/8 to f/10.

An energy-rejection filter is required at the very front of the optical train (the refractor objective) and is typically made of optically polished Wratten #25 red glass. This eliminates dangerous IR radiation and also reduces light intensity. Daystar makes these in a variety of sizes for their rear-mounted

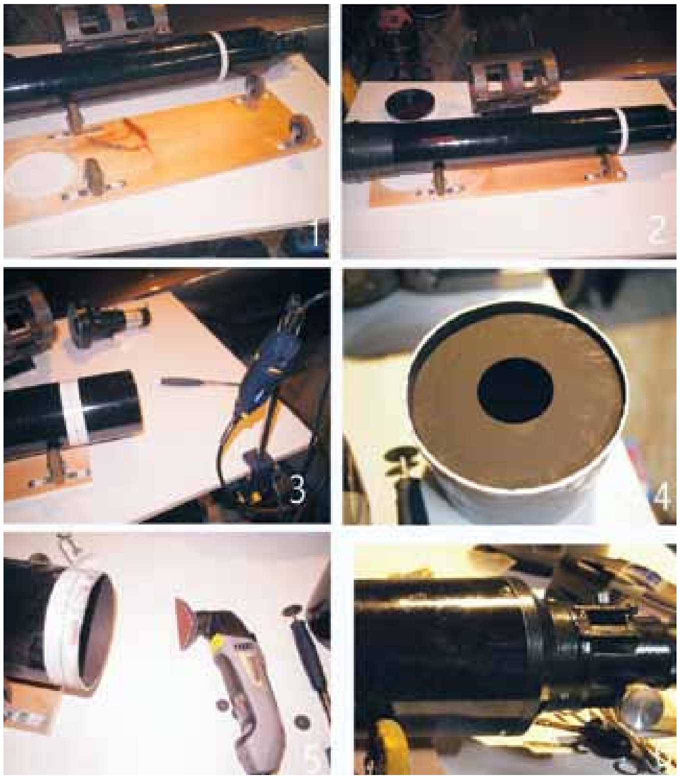

Figure 4 — Modifications to the Celestron telescope to ready it for the etalon.

solid-etalon systems. Baader also manufacturers the D-ERF, optical-quality glass polished to 1/10th wave peak-to-valley with dielectric coatings. Both these choices tend to get rather expensive in large-diameter sizes, and an affordable alternative is sold by Rosco International (www.rosco.com), a company that specializes in lighting equipment for theatrical, TV, and movie productions. They sell custom-sized UV/IR blocking glass designed to protect their coloured filters from the heat of stage lamps for unbelievably reasonable prices. I added a pair of #25 red camera filters to the PST etalon 2-inch (50.8-mm) adaptor nosepiece for additional safety and light attenuation.

To reach focus, the optical tube assembly was shortened on a custom rotating jig made from rollerblade wheels and a Dremel cutting tool (Figure 4, 1-6). The final assembly is shown in Figure 5.

Figure 5 — 5-inch (127-mm) monster PST with 6-inch (152.4-mm) Celestron achromat and Rosco UV/IR blocking filter in a masked-down lens cover.

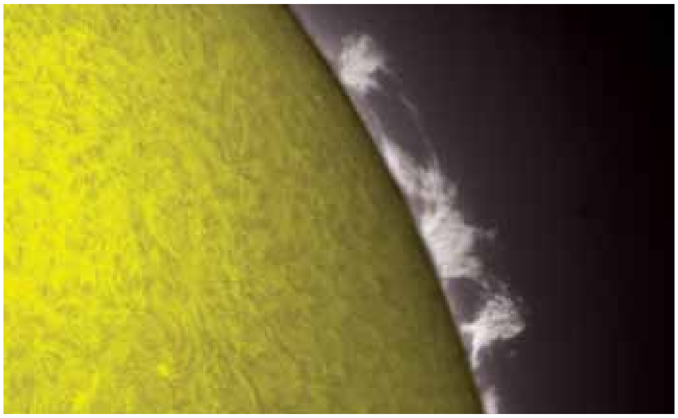

Figure 6 — It works! A solar image taken with the modified 6-inch (152.4-mm) Celestron.

The high-quality performance of my modification to the PST has resulted in images that show good surface granulation and filament detail consistent with the 7-nm resolution of the single-stack air-spaced etalon. Unlike planetary imaging, solar imaging does not require the combination of multiple images because the surface features fluctuate too quickly, and light intensity is so high that zero-gain noise levels are extremely low. On June 5, I was fortunate to experience good daytime seeing and an active high-summer Sun. The atmospheric stability allowed me to actually stack about 60 out of 300 frames that were shot at 30 fps with a Point Grey Research Flea2 CCD. Using *AstroIIDC for OSX*, I was able to improve registration accuracy by selecting 10-14 multiple-alignment points centred on distinctive surface features. I think the results (Figure 6) were most impressive!

In completely unrelated news, I would like to conclude with a tribute to Dr. Willard S. Boyle who died on Saturday, May 7. Dr. Boyle shared in the 2009 Nobel Prize for Physics for his invention of the charged coupled device (CCD). He was born in Nova Scotia, and when his physician father set up practice in a remote Northern Quebec logging town, he was home schooled by his mother until high school. He joined the Royal Canadian Navy during the war and flew carrier-based Spitfire fighters. After getting his doctorate from McGill, he worked at Bell Labs and rose steadily to executive positions. It was here in 1969, over a brainstorming coffee break, that he and Dr. George E. Smith devised the concept of the CCD. He retired in 1979 and returned to Nova Scotia to open an art gallery with his wife. He was 86. What an invention and what a life! ✶

Jim Chung has degrees in biochemistry and dentistry and has developed a particular interest for astroimaging over the past four years. He is also an avid rider and restorer of vintage motorcycles, which conveniently parlayed into ATM projects, such as giving his Sky-Watcher collapsible Dobsonian a full Meade Autostar GOTO capability. His dream is to spend a month imaging in New Mexico away from the demands of work and family.

On Another Wavelength

The Centre of Globular Cluster M15

by David Garner, Kitchener-Waterloo Centre
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We can learn a lot from globular clusters, a spherical collection of very old, red-giant stars bound by gravity. They are almost always found in the halo of a galaxy, orbiting the galactic core. They contain some of the first (and therefore oldest) stars to be produced in a galaxy. M15 (NGC 7078) is one of the oldest globular clusters orbiting the Milky Way core and is estimated to be 13.2 billion years old (Figure 1).

M15 was discovered by Jean-Dominique Maraldi in 1746, and later included in Charles Messier's catalogue in 1764. It is known to contain hundreds of thousands of stars within a sphere 80 light-years across. Among all of the red-giant stars in the cluster, M15 also contains well over 100 RR Lyrae variable stars. There is a very close relationship between the pulsation period and absolute magnitude of RR Lyrae stars. By observing the pulsation period, we can use them as standard candles for calculating the distance to objects, particularly within the Milky Way. From this period-luminosity relationship, we know that the distance to M15 is 33,600 light-years. By studying the position and distance of many globular clusters orbiting the Milky Way, we have been able to determine the shape and size of our galaxy.

Figure 1 — M15 - The Globular Cluster in Pegasus, courtesy of Ron Brecher, K-W Centre. Image acquired using QHY8 camera (Gain=0; Offset=125) with UV/IR filter and an 8-inch f/8 Ritchey-Chrétien telescope on an MI-250 mount. The mount was autoguided using PHD software and the QHY5 KwiqGuide system. The calibration was done in Images Plus 3.0. Photoshop CS4 was used for final processing. Shot from his SkyShed POD just north of Guelph, Ontario.

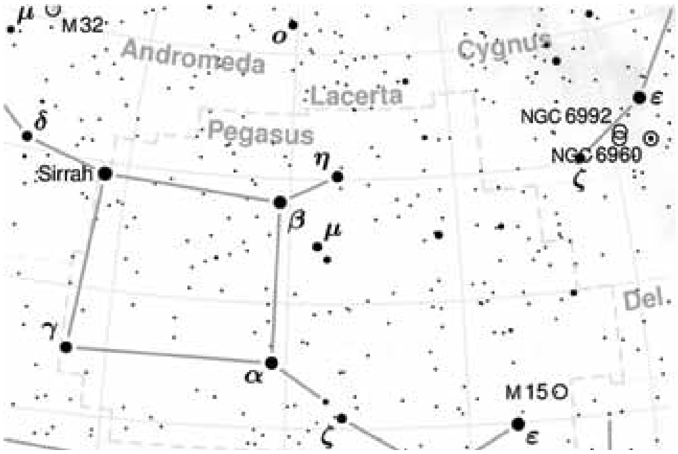

Figure 2 — A map of the constellation Pegasus.

Using globular clusters to learn about our galaxy is a good thing, but what about the cluster itself? M15 contains nine pulsars and a planetary nebula named Pease 1 (after Francis Pease's discovery in 1928), which was the first planetary nebula ever found in a globular cluster. Furthermore, M15 is probably the densest of all globular clusters in the Milky Way, and a significant percentage of the mass of this cluster is concentrated in the innermost sphere. Over billions of years, the extremely dense core of M15 has resulted in a process of gravitational contraction called core collapse.

An analysis of the distribution of the stars in this cluster has shown that, in the distant past, this process of core collapse created a central density cusp with an enormous number of stars surrounding a small core of very high mass. Trying to figure out what is happening at the centre of clusters like this has been the focus of many astronomers for several decades. It is unknown whether this extremely compact core in M15 consists of objects such as neutron stars or white dwarfs, or, as some astronomers suspect, contains a massive black hole at the centre.

So far, after many studies in radio, IR, UV, and X-ray, there has not been any conclusive proof of a black hole in any globular cluster, but M15, with its high-density core, could very well be the first. If it turns out that there is a black hole in M15, it should be easily observable compared to the black hole at our galactic centre, which is heavily obscured by interstellar matter.

If you want to have a look at M15, find Pegasus (Figure 2) and mentally draw a line from θ Pegasi (Baham) through ε Pegasi (Enif). Extend just beyond ε Pegasi, and you'll have found it. Alternatively, you can set your scope to RA $21^h\ 29^m\ 58^s$ and Dec. +12° 10′ 0.6″. With an apparent magnitude of +6.2, it can be observed with a small scope. ✶

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

Imager's Corner

Background Correction

by Blair MacDonald, Halifax Centre
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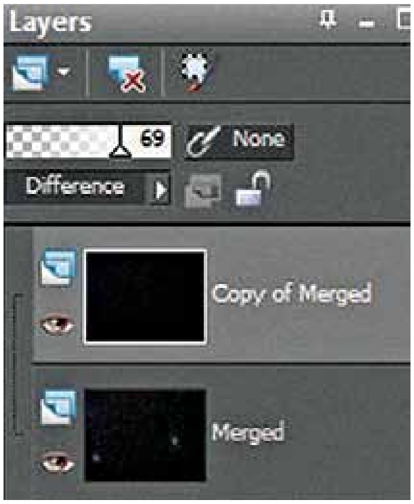
This edition continues a group of Imager's Corner articles that will focus on a few techniques that are useful in processing astrophotos. Over the next several editions of the *Journal*, I'll attempt to give a guide to image stretching, background correction, SIM processing, and any other technique that I happen to find useful. All the techniques discussed will be useable with nothing more than a standard image processor that supports layers and masks. No special astro-image processor is required.

This edition will deal with background correction using processing to get that smooth dark-sky look, even from the city. There are several common background problems that we can correct in processing; here we are correcting colour splotches and gradients.

Let's start with the M97 image below. There is a slight under-correction from the flat field, a darker strip along the bottom, and a purple blotch in the upper-right edge.

The first thing to do is to remove the gradient and colour blotches. Start by duplicating the layer and cloning out the galaxies and any bright stars. This will take a while, so have some patience: getting this step right has a big impact on the final result. Next use a median filter with a radius much larger than the remaining stars (10 to 30) to remove those stars from the image. If you don't get a smooth result, apply a Gaussian blur, but if you've done a good job cloning out the bright stars and DSOs, you should not have to use further blurring. This gives a layer that has no image detail, but contains the colour spots and gradient as shown in the next image (top of page).

Now set the combine mode of this layer to difference and adjust the opacity to get the result you want. If you leave the opacity at 100 percent, the background will be zero and you will clip some faint data. If you make the layer too transparent, then the resultant image will be under-corrected. The layer stack is shown below.

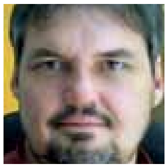


The resulting image when the layers are combined is free from the colour blobs and gradient as shown below.

Remember, this column will be based on your questions, so keep them coming. You can send them to the list at hfxrasc@lists.rasc.ca or you can send them directly to me at b.macdonald@ns.sympatico.ca. Please put "IC" as the first two letters in the topic so my email filters will sort the questions. ✶

Blair MacDonald is an electrical technologist running a research group at an Atlantic Canadian company specializing in digital signal processing and electrical design. He's been a RASC member for 20 years, and has been interested in astrophotography and image processing for about 15 years.

Gustav Hahn's Graphic Record of the Great Meteor Procession of 1913 February 9



by R.A. Rosenfeld[1]*, RASC Archivist (randall.rosenfeld@utoronto.ca) and Clark Muir*[2] *(cmuir10@rogers.com)*

ABSTRACT: The Great Meteor Procession (GMP) of 1913 February 9 (also the Cyrillid Shower, or the Great Fireball Procession, or Great Meteoric Stream, or the Canadian Fireball Procession of 1913 February 9) was one of the most remarkable astronomical incidents to be seen over southern Canadian skies. The professional artist Gustav Hahn was among numerous observers who reported the GMP to C.A. Chant. The professional astronomer clearly thought that the professional artist had deftly used his artistic skill in the service of scientific accuracy. This paper provides a summary of the meteoritic event, the first in-depth analysis of how Hahn created his lasting visual record of the GMP, and argues that Chant and the RASC took measures hitherto unprecedented by a Canadian astronomical periodical to reproduce and disseminate a vivid copy of a striking astronomical image of a remarkable event.

"I have been in the habit of watching the heavens since 1865 and have never noticed anything similar. There are meteors occasionally seen with multiple, crumbling heads and broad spark trains, but the wonderful stream of successive meteors seen on February 9 seems, like Saturn's rings, without a parallel" – Denning 1913, 404

"... the most important and interesting meteoric event of the past ninety years..." – Pickering 1922, 633

The records of some of the most impressive, astonishing, and intriguing astronomical events attest to the surprise experienced by those who happened to look up at the right place at the right time. Contemporary accounts of the great comet of 1744, the 1799 and 1833 Leonid showers, and SN 1987A have come down to us coloured by wonder, either open or veiled depending on the temperaments of the observers (Kronk 1999, 408-411; Brown 1999, 287-291; Littmann 1999; Madore *et al.* 1996). The role of chance in delivering unexpected marvels for visual observation might seem to have been greater in the past, before all-sky camera networks, digital sky surveys, patrols, and probes, computer-generated ephemera, and the theoretical constructs that assisted at their birth, presently feed on their data, and will in turn be transformed by their results. The factor of chance and our capacity for surprise are potent still in human experience of the phenomenal sky through the senses and the imagination. Nearly a century ago, the Great Meteor Procession (GMP) was spectacular enough to surprise, delight, and awe the most experienced of meteoriticists, not to mention the casual observer. The same event would doubtless have a comparable impact today.

What did witnesses experience on that memorable night, and how was the scientific record of the phenomenon established?

The GMP Witnessed

C.A. Chant's name is inextricably linked with the lasting scientific record of the GMP. It is a capital irony of the observational history of the event that he neither saw the meteors, nor heard their passage, nor felt their shock waves. Perhaps before the night itself was spent, Chant was informed of the GMP by witnesses among neighbours, friends, and members of the Society. He was interviewed by a reporter for *The Globe* – predecessor of the *Globe and Mail* – either then or early on the next morning (and one suspects he was similarly contacted by other news organs). The event was front-page news:

> **SCORES OF METEORS ILLUMINATE THE SKY**
>
> Hundreds of People Watched a Beautiful Spectacle Lasting Two or Three Minutes
>
> A meteoric performance of stupendous dimensions occurred in the heavens last night.... Scores of meteors shot through the skies...and so brilliant was the accompanying illumination that hundreds of people in various parts of the city witnessed it.... For an hour after the phenomenon The Globe was besieged with telephone calls from people either eager to give or obtain information about it. There were curious divergences in the stories told to The Globe by eye-witnesses of the falling meteors.... Prof. C.A. Chant of the University of Toronto told The Globe he had not seen the celestial show but judging from the description given to him he thought it must have been an ordinary meteoric performance. It was not scheduled, he said, but no extraordinary importance could be attached to it.
>
> *(Globe 1913 February 10, 1)*[3]

Newspapers up and down the observational path of the GMP likewise accorded front-page coverage to the event the next day (*e.g. Berlin Record* 1913 February 10, 1).

Figure 1 — Gustav Hahn, Great Meteor Procession 1913 February 9. Watercolour and guache on paper. UTARMS A2008-0023. Copyright Natalie McMinn. Reproduced with permission.

Chant evidently soon changed his mind about the ordinariness of the "meteoric performance." Several days later, *The Globe* and other Toronto dailies made good on their offer to Chant to publish *gratis* notices requesting eyewitness accounts, and the request was picked up by other papers along the observational path of the GMP (Chant 1913a, 145). *The Globe*'s ran as follows:

> **Asks Information About the Meteors** — *Prof. C.A. Chant of the University of Toronto is seeking information regarding the meteoric display of Sunday evening. Reports from those living some distance from Toronto would be especially valuable, particularly in regard to the position in the sky in which the meteors were seen – that is, whether apparently overhead or to the east, the west or any other direction; and if not overhead how high above the horizon they were. Prof. Chant wishes as definite information as possible regarding the following: Time of occurrence, position in the sky, direction of the motion, how many were seen in all, how many at once, how long [the] whole phenomenon lasted. if any sound was heard and what it was like; if the bodies remained intact or broke up, if bodies had tails and how long they were, [and] how long any one body was in sight." (Globe 1913 February 13, 8)*[4]

The public appeal provided Chant with abundant material for a substantial paper, including details of 143 reports of witnesses and eleven accounts of possibly related meteoric events (Chant 1913a).[5] Chant must have worked expeditiously to have his paper ready for the May 1913 issue of the *Journal*. It remains the largest published collection of eyewitness accounts, and with Chant's synthesis and analysis, the starting place for any discussion of the GMP. According to Jack Heard, "It was probably the first astronomical research paper of any account coming from this University [*i.e.* the University of Toronto]," and Lincoln LaPaz referred to it as "monumental" (Heard & Fernie 1979, 128; LaPaz 1956, 402). The details of the phenomenon that follow are derived from Chant 1913a and other scientific literature that appeared in its wake.

The sky over Toronto was clear when the lead meteor came into sight around 21:05 EST, and the whole procession continued for about 3.5 minutes, ending at approximately 21:08:30 EST (Chant 1913a, 146-149; Pickering 1923a, 98 argues for 5-6 minutes). The meteors seemed to arrive in groups, and as to be expected, observers differed as to the number of groups and the number of members within each group. Some witnesses were under the impression that the GMP consisted of more than 50 separate groups of meteors, others reported no more than three (*e.g.* Chant 1913a, 171). The number of individual meteors ranged just as widely, from 15 up to 1000s (Chant 1913a, 148-149). The general direction of the GMP as seen from Ontario was NW to SE (Chant 1913a, 146, 150) with corrected average heights estimated variously between *ca.* 40-80 km. According to Chant, the path over observers on the ground covered 10% of the Earth's circumference, which was later extended by reports published by Denning to over 25%, and even further by O'Keefe, from Didsbury, Alberta, to past Cabo de São Roque near the eastern tip of Brazil (Denning 1916, O'Keefe 1968; Pickering 1923b, 447 estimated the length of the GMP at 2414 km). The meteors were considered to be relatively slow moving, both by those who submitted eyewitness reports and those who reduced the data in the reports to model the orbit of the GMP. Estimates varied between *ca.* 4 km/s to 16 km/s (see Chant 1913a and the sources in note 5 below for the data in its rawest form, and Pickering 1923 a, 103-104 for a summation of the published reductions up to that time).

Estimates for the lengths of the tails of the individual members of the GMP or that of the groups comprising it varied from *ca.* 5 to 80 km (Pickering 1923a, 103). Some observers reported colours, such as white, blue, "fire red," and "golden yellow" (Chant 1913a, 174-178; 170; 147 respectively). One observer said the most luminous meteor was brighter than Venus (Chant 1913a, 173). A handful of observers remembered associated aural phenomena, such as the explosive fracturing of the bolides, a "thunder-like rumbling" in the wake of the procession, or a shaking of the ground or a building (Chant 1913a, 148, 159-161).

Eyewitnesses were struck by the aesthetic aspect of the phenomena that left them feeling "spellbound" and "privileged," inducing them to employ adjectives such as "finer," "beautiful," "wonderful," "amazing," "magnificent," "outstanding," "remarkable," "entrancing," "grandest," "splendid," and "awful [*i.e.* in the older sense of sublime]" (Chant 1913a, 185-186; 169, 176, 180, 182, 184, 192-193, 197, 202, 206, 212).

The GMP Theorized

Events out of the ordinary seem to draw extraordinary explanations, like sailors to grog, mosquitoes to spring stargazers, or "UFOs" to the mid-West. Some who sought to account for the GMP valiantly attempted to keep a firm grasp of Occam's razor while doing so. Others, however, were less concerned with commensurability or incommensurability with the laws of classical physics, conformity to established celestial mechanics, or the simple salvific virtues of well-tempered caution.

Chant's conclusion was that "It would seem that the bodies had been travelling through space, probably in an orbit around the Sun, and that on coming near the Earth they were promptly captured by it and caused to move about it as a satellite" (Chant 1913a, 151). It was, in other words, a meteor stream that entered into a temporary Earth orbit due to gravitational capture, according to his reading of the evidence regarding the path, direction, velocity, and height of the objects. Chant presented his analysis and conclusions rationally, with commendable restraint and due qualifications, and he was open to considering well-argued emendations to his interpretation (*e.g.* the Rev'd Davidson in Chant 1913b, 441-443).

Denning, in his earliest printed speculation, while he accepted Chant's view in its essentials, modified the latter's estimates for altitude, speed, and distance (he is apparently the first to coin the phrase "Chant trace"), and he proposed a single mass that broke up as the parent body for the meteors. He wrote of attempting to fix a radiant for the meteors (Denning & Chant 1913a). Monk threw mild doubt on Denning's theory of a breakup of a single mass, and wonders if origin of the GMP was not rather to be found in planetary volcanic ejecta (Monck 1914, 114-115).

Approximately a decade after the event, W.H. Pickering, in a succession of papers in *Popular Astronomy*, confirmed the main tenets of Chant's analysis, and like Denning before him, attempted to refine determinations of the path and origin of the meteors (Pickering 1922, 1923a-c). Pickering was at pains to point out contra Denning that "This remarkable phenomenon was in no sense a meteoric shower," but, in agreement with Chant and Denning, that the meteors were "prior to their final destruction a series of minute temporary terrestrial satellites" (Pickering 1922, 632). He speculated that the GMP was made up of both stony and iron meteorites (!), and that they were of unusual size (Pickering 1923a, 100-103; 1923b, 445). Fisher (1926), in the same journal, cast doubt on Chant's and Pickering's theories of meteors as temporary satellites, and Harvey Nininger (1934) raised the possibility that a much lesser display of 1934 February 12 could be related to the GMP, after detailing what he thought were relevant parallels.

Five years later, Wylie (1939) offered what he thought was a cogent argument denying the reality of the GMP, a view he aired in subsequent decades (1953a-b): "This sensational story is based on nothing more than a fine shower of shooting stars in the Toronto area, a very few fireballs or shooting stars observed in other places, and practically nothing from the United States" (1953b, 145). Wylie was not an eyewitness to the event in 1913.

Wylie's views were roundly rejected by LaPaz (1956), who was able to utilize previously unpublished eyewitness accounts from the United States (Mebane 1955; 1956). LaPaz endorsed the soundness of Chant's analysis as modified by Dennison, Pickering, and others. The distinguished NASA meteoriticist John A. O'Keefe, apparently unaware of LaPaz's treatment, through more rigorous analysis came to the same general conclusion, supporting the soundness of Chant's work over Wylie's (O'Keefe 1959).

It was O'Keefe who first proposed the name "Cyrillids" for the GMP, identifying it as a shower without a radiant or cometary connection, hence naming it after a saint's feast day occurring in some calendars on February 9 (1961, 562). O'Keefe, while confirming the reality of the Chant trace and the modified versions of Chant's satellite orbit, attempted to invoke the presumed orbital dynamics of the GMP as a mechanism for terrestrial delivery of "lunar" tektites, part of his lengthy campaign to prove that tektites were of lunar origin. As late as 1991, he repeated the hypothesis with the further modification that the Cyrillids, before they processed across the Chant trace, were part of a circumterrestrial ring of "lunar" tektites (O'Keefe 1991).

The GMP has even attracted attention outside the ranks of the astronomical community. The Canadian entomological taxonomist and outstanding ichthyologist Bill Ricker co-authored a study with the ichthyological mathematician Jon T. Schnute that attempted to extend the path of the Chant trace westward into pre-Christian times via First Nations' oral traditions (Ricker & Schnute 1999; Schnute 2006, 103-104).

It is as regrettable as it is predictable that interest in the GMP was evidenced by UFOlogists even prior to the coining of the term. (Mebane (1956, 407), not a believer in little green men, cites a believer from 1926). The GMP was mentioned often enough in pursuit of irrational causes that the reliably rigorous William K. Hartmann (1968, 961-962) had to dispose of the alien spacecraft interpretation in the Condon report! Hartmann's discussion should have been the end of it for all but the conspiratorially inclined. For some ailments, there is no cure.

D.A.J. Seargent, in his entertaining *Weird Astronomy* (2011, 257-267), groups the GMP with the now much better known Tunguska Event (1908 June 30). The connection is more analogical than taxonomic: a) both were out of the ordinary; b) neither has been explained to the entire satisfaction of the diverse interested scientific constituencies (less has been settled about Tunguska than the GMP); and c) both have been invoked by little-green-men conspiracy theorists (Rubtsov 2009, 291-310 for Tunguska).

It is also interesting to note the silences in the literature where one might reasonably expect to encounter the GMP. It tends to receive scant mention in the few books on the history of astronomy in Canada (the most extensive such treatment remains Millman & McKinley 1967, 279-280). Its absence from McKinley's famous monograph (1961) and even more so from Burke's standard history of meteoritics (1986) is surprising. Less unexpected is its lack of mention in Jenniskens' exhaustive work on *Meteor Showers and Their Parent Comets* (2006), given that no comet paternity has been seriously pursued for the GMP.

It is a testament to the quality of Chant's work of collecting, collating, and analysis that a modified version of his interpretation of the events on the night of 1913 February 9 still stands as both the best-supported account of the GMP and the authoritative anthology of observations. One account in particular was influential in forming Chant's conception of the GMP, and through him, that of all scientists who used his published anthology of observations. It was an eloquent account of few words, yet as the frontispiece to Chant's "monumental" paper, it literally came before all other eyewitness records. It was Gustav Hahn's painting of the GMP. It is arguably the most important extant hand-drawn meteoritical image by a Canadian.

The Artist

The artist, Gustav Hahn (1866-1962), belonged to a family of German origin that supplied Canada with several generations of trained and cultivated professionals in the graphic, plastic, and musical arts. As with many figures entwined in the formative fabric of Canada, the Hahn's still await their historian.[6] Gustav was born in the Swabian state of Baden-Württemberg, and received his training in Stuttgart at the Kunstgewebeschule and the Technische Hoschule. He became a Canadian vector for *Jugendstil* (German Art Nouveau) in Canada. He divided much of his career between teaching as a faculty member of the Central Ontario School of Art and Industrial Design/Ontario College of Art (now the Ontario College of Art & Design University), and his own flourishing and fashionable interior-design studio catering to the wealthy and influential of late-Victorian and Edwardian Toronto (Gibson 2006, 36 and fig. 2.20; Sauer 2009, 140-141). Few of his commissions survive *in situ*; a more lasting legacy might be sought in his place in the biographies of students, acquaintances, and friends now considered more prominent, such as Group of Seven members Franklin Carmichael and Franz Johnston, or the Arts & Crafts architect Eden Smith (Mason 1998, 18; Adams 1993). Conveniently, he was an amateur astronomer with connections to the Society through Chant.

Family example may have played a formative influence in nourishing Hahn's astronomical interests, for his father was Dr. Otto Hahn, a lawyer with a doctorate in geology, who made his mark with *Die Meteorite (Chondrite) und ihre Organismen* (1880; *Chondritic Meteorites and Their Life Forms*). It was not a fortunate way to make, or rather un-make a scientific reputation. While *Die Meteorite* was notable for the novelty of its photographs of thin sections (and the skill that went into making them), Hahn was roundly criticized for uncritically interpreting the visual features in his thin sections as fossils of once-living organisms, and therefore as "evidence" for the seeding of life throughout the Universe by the delivery mechanism of meteors, panspermia (Burke 1986, 171-172; Crowe 1986, 405-406). The reception of Hahn's book killed panspermia as a theory for at least eight decades. Otto's work did, however, mean that his son grew up with a research collection of meteorites in the house.

Prepared by the family interest in matters meteoritical and a thorough training and long experience in accurate draughtsmanship, Gustav Hahn was the right man at the right place at the right time when the GMP roared overhead. In Chant's words:

> *In obtaining my results I used only observations on which I thought I had especial reason to depend. Mr. Hahn, who supplied the drawing for the frontispiece, besides being an artist is an amateur astronomer. He is the son of the late Otto Hahn of Toronto, who possessed a large and valuable collection of meteorites" (Denning & Chant 1913, 412-413).*

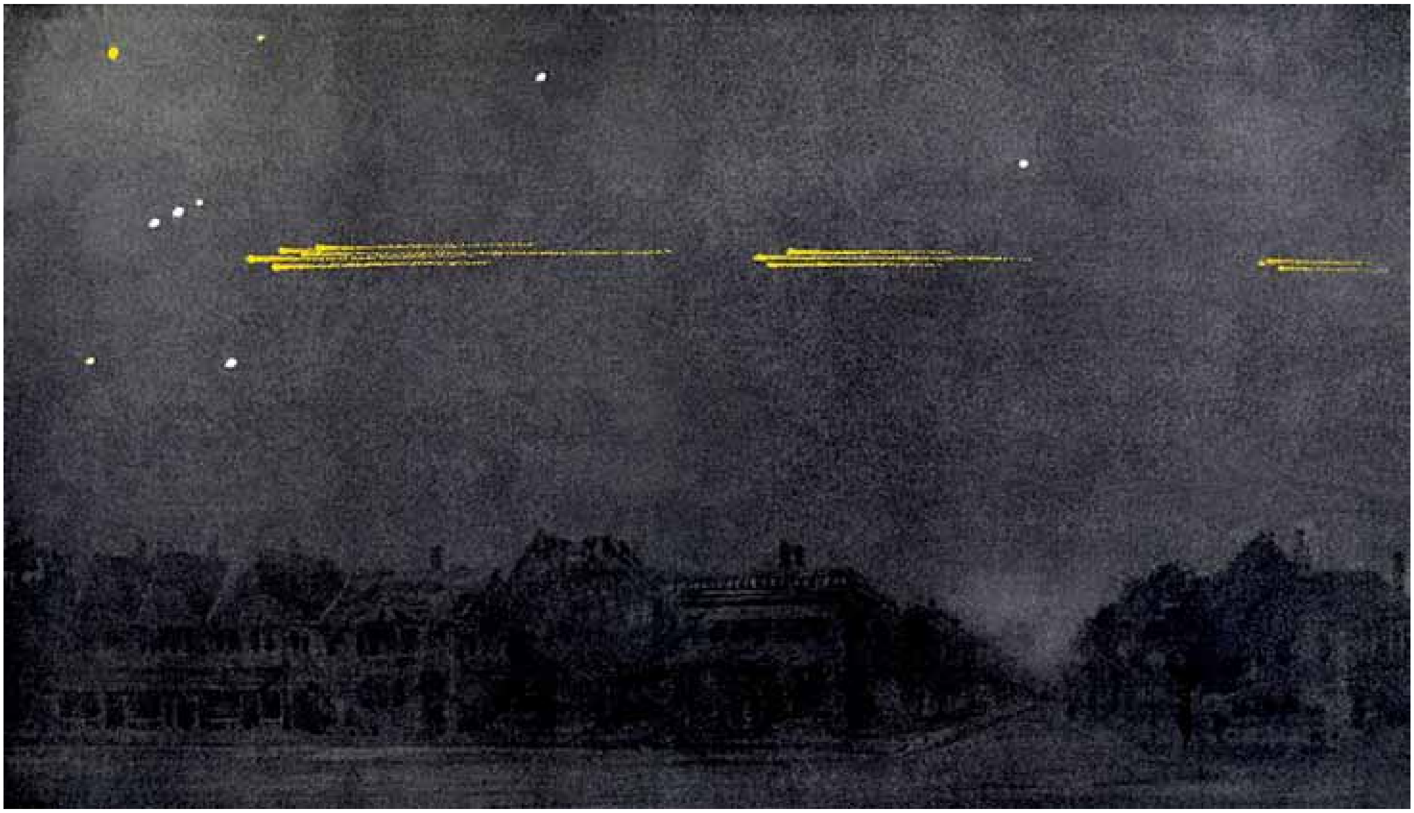


Figure 2 — Gustav Hahn, Great Meteor Procession 1913 February 9. Relief half-tone print with hand-painted details on tinted paper, from JRASC 7,3 *, pl. IX (frontispiece).*

The Scientific Image

The original of Hahn's scientific image of the GMP is now in the University of Toronto Archives and Record Management Services (UTARMS), accession number A2008-0023 (Figure 1). For decades it was on display in the administrative offices of the David Dunlap Observatory. The image has received some notice within the last year thanks to its casting in a minor supporting role in a *Sky & Telescope* piece by Olson and colleagues on Frederick Edwin Church's canvas "The Meteor of 1860" and Walt Whitman's poem "Year of Meteors (1859-1860)," and a follow-up story by Dan Falk in the *Toronto Star* concentrating directly on Hahn's painting (Olson *et al.* 2010; *Toronto Star*). The description below is the first full account of the image and aspects of its creation.

The painting measures 37×21.7 cm. The support is un-textured cream-coloured paper of medium thickness. It was not possible to directly check the paper's pH, but there are no immediately visible signs of deterioration due to elevated acid levels. No underdrawing is visible in white or ultraviolet wavelengths (375 nm and 405 nm) with either direct, oblique, or backlit illumination. With the exception of a tiny hole (only visible when backlit) at the very end of the street receding into the background, the painting is in a good state of conservation. Direct comparison with the colours in the published version of Hahn's image shows that little or no fading or alteration of colour values has occurred in the original. The back of the support is somewhat marked and scuffed.

The medium is watercolour, applied for the most part quite thinly. The streetscape (trees, buildings, sidewalks, roads) is in shades of off-white, grey, and black. Darker greys at times verging on black are used for windows, roofs, chimneys, porches, entryways, tree trunks, and parts of the canopy. Dirty ivory white is used for snow lumps in the street. After the streetscape was laid down, most of it was covered by a thin wash of a yellowish cast (horizontal brush strokes), to evoke the veiled nature of a night landscape (the wash was not applied to the top of the most prominent tree to the left of centre – from the viewer's perspective – and the tops of the canopy along the side street receding into the background).

A novel technical feature is Hahn's use of a sharp razor or a thin-profiled knife blade to incise the outlines of the top of the streetscape (roofs, chimneys, canopy). This feature is best seen under low-powered microscopic examination (6×+). His use of the knife shows great skill and delicacy, for while following the contours of the upper buildings and canopy closely, he did not once cut the paper fibres through to the back of the support. The artistic purpose of the technique appears to have been to create a subtle but definite demarcation between the streetscape and the celestial drama above, which it accomplishes quite successfully with a precise but very understated hint of a shadow.[7]

The background of the sky above the streetscape is gunmetal grey. The three meteor groups are in lemon yellow. The base of the heads along with the tails of each meteor appear to have been constructed with an economic use of a few continuously drawn horizontal strokes. The paint has been applied to allow the inkiness of the night sky to show through in many places. The meteor heads have each been overlaid with a sub-circular daub of gouache of the same colour to give them more substance, to indicate a concentration of luminous matter (the second thickest application of paint in the image). The visual effect recalls pastels, but examination under magnification reveals telltale cracks in the heads indicative of gouache. The stars were created using a similar technique. The stars of Orion are white, except for Betelgeuse, which is rendered yellow-white (this pigment is lighter in effect than that used for the meteors, perhaps achieved by a combination of white and yellow layers). To form each star, Hahn first painted an irregularly rayed shape in semi-transparent white, and then applied on top a daub of much thicker white gouache, yellow-white in the case of Betelgeuse (the thickest application of paint in the image).

The painting is not signed, either on the back or front. The frame does bear a printed label in lieu of a signature, which reads in black on a gold ground: "METEORIC DISPLAY of February 9, 1913, as seen near High Park[.] Drawn by Gustave [*sic*] Hahn." From the slight fading around the margins of the painting, this may very well be the original frame (dimensions 43.4×27.9 cm). The wood of the utterly plain mouldings is dark-stained oak (it would have been a very cheap frame in 1913). The label is mounted on cardboard in a central position on the lower moulding with copper-alloy coloured dome-headed brads.

Hahn may have done a quick sketch as soon as the GMP had passed his line of sight, or made textual notes of what he saw. If so, these materials do not survive or have not thus far been located. He had no need to make an immediate sketch, however, for according to information from his family (private communication 2010 January 15), his visual memory was acute, and like many professional artists of the time, he could work up a finished drawing from memory without the intervening stage of a sketch (this ability had been possessed by several earlier astronomical artists; Warner 1983, 5, 111).

It is difficult to say, none the less, whether the image evokes what Hahn saw exactly, or whether it is in some particulars generalized. Given that the caption to the published version states: "The spaces between succeeding clusters were actually somewhat greater than shown here" (Chant 1913a, frontispiece), we know that at least one feature is not exactly as it was seen. This may also be the case for the streetscape itself. Much of the High Park area of Toronto retains its domestic and small commercial structures from the pre-WWI era, but some areas have seen subsequent development that has radically altered their appearance. An exhaustive examination of the

area using Google Maps with Street View©, an examination of digitized period photographs from the City of Toronto Archives, combined with on-the-ground searches, have so far failed to locate an exact match for Hahn's streetscape, particularly the distinctive building with a flat roof at the junction of the two streets. Unless a likely match can be found, either with the present streetscape or in old photographs, it will be impossible to locate the exact spot from which the GMP was seen in Hahn's painting or even decide whether the streetscape is approximately or precisely rendered.

There is no record of Hahn's having been influenced by any prior meteoric image. The closest parallels are Thomas and Paul Sandby's images of the Great Meteor of 1783 August 18 (Olson & Pasachoff 1998, 69-74), and Matthew Cotes Wyatt's mezzotint of a bolide over London, seen 1850 February 11 (NMM Gabb Collection, PAJ3495) – but it is not known if he had ever set eyes on these, or similar images.

We do not know whether Hahn was so impressed by the GMP that he executed his painting for his own purposes, or whether Chant commissioned the painting upon learning that he was an eyewitness. We do know that he had such faith in both the evidential and evocative value of Hahn's image that he had it reproduced as the frontispiece to his major GMP article (Figure 2). He wanted this visual image to be transmitted as far as the *Journal* could travel in space and time. There are several remarkable aspects to this decision, and the production of Hahn's image.

For the first time in the *Journal*'s history, the RASC decided to reproduce an image in relief half-tone print on tinted paper, with details apparently applied by hand to get the colours as close as possible to the original. In 1913, relief half-tone was nothing out of the ordinary and not a particularly costly process, but the order was made memorable by the use of special stock, hand work, and the striking effect created. Unfortunately, the council minutes extant for the period mention little in regard to the manufacture of this number of the *Journal,* nor have we succeeded thus far in locating references in surviving correspondence, or extant bills or receipts (*RASC Minute Book* 1913 April 29; October 7).

Several of the colours Chant and his colleagues desired in the reproduction were not best reproduced mechanically through the photo-chemical half-tone process. It was decided to execute the stars in white, white and gold, and the meteors in gold individually by hand to every single copy of the *Journal* as the penultimate stage in production prior to tipping-in to the binding. A careful examination of different copies of the print shows that while the general placement of the meteors and stars is quite close, as are their shapes, they are far from identical from print to print. This seems an extravagant way to mass-produce an image now, but it must be remembered that features added by hand were part of the printing industry from the 15th to the early 20th century, chiefly in the matter of colour (*Grove Art*). The use of the technique for reproducing Hahn's GMP image occurred within the context of a venerable industrial practice.

There are clearly divergences between Hahn's original and its reproduction in the *Journal.* The two additional non-meteoritic bodies to the right of Orion are not in the original. For the date and time in question, the likeliest candidates are Aldebaran and Saturn, but their placement relative to Orion is wrong. Those features in the original done in lemon-yellow are rendered gold in the reproduction. The dull-yellow wash over the streetscape in the original is missing in the reproduction, as is the effect created by the skilful incision technique. The off-white snow lumps in the street of the original are omitted from the reproduction. It has to be admitted that the addition of other celestial bodies (Aldebaran and Saturn?) and their apparently inaccurate placement does not appear to add to the verisimilitude of the image as a precise record of the GMP. Replacing the original yellow of the meteors with gold in the reproduction, while it does agree with some of the original reports, is not the colour Hahn saw, to judge by his original rendering. It may have been chosen to make a more dramatic and spectacular image.

Gustav Hahn was 47 when he saw and painted the GMP, and he lived for nearly another half century. At Christmas of 1961, when he was 95, it was reported that he reminisced to the University of Toronto community about: "... the meteoric display of 1913 which he was able to paint. He was an amateur astronomer and a friend of the late Dr. Chant" (*The Monthly Letter*). He had witnessed the astronomical event of a lifetime, crafted its iconic image, and thereby fashioned the common visual memory of a spectacular meteoric phenomenon. The scientific record of this event was almost entirely a Canadian creation, and a chief engine of its propagation was the *Journal*.

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References

Manuscripts

Greenwich, National Maritime Collection, Gabb Collection, PAJ3495, M.C. Wyatt, *A Representation of the Meteor Seen at Paddington about 12 Minutes before 11 o'clock, on the Evening of the 11th of Feb. 1850*

Toronto, University of Toronto, UTARMS, A2008-0023, Gustav Hahn, *METEORIC DISPLAY of February 9, 1913, as seen near High Park*

Toronto, RASC Archives, *RASC Minute Book* 1913

Books and articles

Adams, A. (1993). Eden Smith and the Canadian Domestic Revival. *Urban History Review 21*, *2*, 104-115

The Monthly Letter [of the Arts & Letters Club of Toronto]: News and Views of Club Programmes and Activities 1961 January, 3.

Berlin News Record 1913 February 10, 1.

Brown. P. (1999). The Leonid Meteor Shower: Historical Visual Observations. *Icarus 138*, 287-308.

Burke, J.G. (1986). *Cosmic Debris: Meteorites in History*. Berkeley-Los Angeles-London: University of California Press.

Chant, C.A. (1913a). An Extraordinary Meteoric Display. *JRASC 7*, *3*, 145-215.

Chant, C.A. (1913b). Further Information Regarding the Meteoric Display of February 9, 1913. *JRASC 7*, *6*, 438-447.

Coffin, J.H. (1868). The Orbit and Phenomena of a Meteoric Fire-Ball Seen July 20, 1860. *Smithsonian Contributions to Knowledge 16, 6* (whole no. 221), 1-51 (Washington, DC: Smithsonian Institution).

Crowe, M.J. (1986). *The Extraterrestrial Life Debate 1750-1900: The Idea of a Plurality of Worlds from Kant to Lowell.* Cambridge: Cambridge University Press.

Denning, W.F. (1915). The Great Meteoric Stream of February 9, 1913. *JRASC 9*, *6*, 287-289.

Denning, W.F. (1916). Great Meteoric Stream of February 9th, 1913. *JRASC 10*, *6*, 294-296.

Denning, W.F. & Chant, C.A. (1913). Notes on the Great Meteoric Stream of 1913, February 9th Seen in Canada and the United States[, with] Remarks on Mr. Denning's Paper. *JRASC 7*, *6*, 404-413.

Fisher, W.J. (1926). Remarks on the Meteoric Procession of 1913 February 9. *Popular Astronomy 36*, *7*, 398-403.

Hahn, O. (1880). *Die Meteorite (Chondrite) und ihre Organismen.* Tübingen: Laupp'sche Verlagsbuchhandlung.

Hartmann, W.K. (1968). Processes of Perception, Conception, and Reporting. In E.U. Condon, *Scientific Study of Unidentified Flying Objects* (pp. 943-975). Boulder: University of Colorado.

Heard, J.F. & Fernie, J.D. (1979). People and Places: Collected Reminiscences of John Frederick Heard. *JRASC 73*, *3*, 109-132.

Kronk, G.W. (1999). *Cometography: a Catalog of Comets. Volume 1: Ancient–1799*. Cambridge: Cambridge University Press.

LaPaz, L. (1956). The Canadian Fireball of 1913 February 9. *Meteoritics 1*, *4*, 401-405

Littmann, M. (1999). *The Heavens on Fire: the Great Leonid Meteor Storms*. Cambridge: Cambridge University Press.

Madore, B.F., Jedzrejewski, R. & J.M. Matthews (1996). Extracts from the Diaries of the University of Toronto Southern Observatory. II. The Night of the Supernova. *JRASC 90*, *4*, 69-73.

Mason, R.B. (1998). *A Grand Eye for Glory: a Life of Franz Johnston*. Toronto-Oxford: Dundurn Press.

McKinley, D.W.R. (1961). *Meteor Science and Engineering*. New York-Toronto-London: McGraw-Hill.

Mebane, A.D. (1955). A Preliminary Report on U.S. Observations of the Great Fireball Processions of 1913 February 9. *Meteoritics 1*, *3*, 360-361.

Mebane, A.D. (1956). Observations of the Great Fireball Procession of 1913 February 9, Made in the United States. *Meteoritics 1*, *4*, 405-421.

Millman, P.M. & McKinley, D.W.R. (1967). Stars Fall Over Canada. In R.J. Northcott, *Astronomy in Canada: Yesterday, Today and Tomorrow* (pp. 277-294). Toronto: RASC.

Monck, W.H.S. (1914). The Great Meteor of 9th February, 1913. *JRASC 8*, *4*, 112-116.

Nininger, H.H. (1934). The Meteoric Display of February 12, 1934: A Preliminary Report. *Popular Astronomy 42*, *5*, 280-281.

O'Keefe, J.A. (1959). A probable Natural Satellite: The Meteor Procession of February 9, 1913. *JRASC 53*, *4*, 59-65.

O'Keefe, J.A. (1961). Tektites as Natural Earth Satellites. *Science 133*, *3452*, 562-566.

O'Keefe, J.A. (1968). New Data on Cyrillids. *JRASC 62*, *3*, 97-98.

O'Keefe, J.A. (1991). The Cyrillid Shower: Remnant of a Cirumterrestrial Ring? *Lunar and Planetary Science Conference 22*, 995-996.

Olson, D.W., & Olson, M.S. et al (2010). Walt Whitman's "Year of Meteors." *Sky & Telescope 120*, *1*, 28-33.

Olson, R.J.M., & Pasachoff, J.M. (1998). *Fire in the Sky: Comets and Meteors, the Decisive Centuries, in British Art and Science*. Cambridge: Cambridge University Press

Pickering, W.H. (1922). The Meteoric Procession of February 8, 1913, Part I. *Popular Astronomy 30*, *10*, 632-637.

Pickering, W.H. (1923a). The Meteoric Procession of February 8, 1913, Part II. *Popular Astronomy 31*, *6*, 96-104.

Pickering, W.H. (1923b). The Meteoric Procession of February 8, 1913, Part III. *Popular Astronomy 31*, *7*, 443-449.

Pickering, W.H. (1923c). The Meteoric Procession of February 8, 1913, Part IV. *Popular Astronomy 31*, *8*, 501-505.

Richer, W.E & Schnute, J.T. (1999). A Westward Trajectory Extension for the Earth-Grazing Fireballs Seen on 9 February 1913. *Canadian Field-Naturalist 113*, 693-697.

Rubtsov, V. (2009). E. Ashpole (trans.) *The Tunguska Mystery*. Berlin-Heidelberg-Dordrecht-New York: Springer.

Sauer, A.E. (2007). The Unbounded German Nation: Dr. Otto Hahn and German Emigration to Canada in the 1870s and 1880s. *Canadian Ethnic Studies 39*, *1-2*, 129-144.

Schnute, J.T. (2006). Curiosity, Recruitment, and Chaos: a Tribute to Bill Ricker's Inquiring Mind. *Environmental Biology of Fishes 75*, 95-110.

Seargent, D.A.J. (2011). *Weird Astronomy: Tales of Bizarre, and Other Hard to Explain Observations.* Berlin-Heidelberg-Dordrecht-New York: Springer.

Warner, B. (1983). *Charles Piazzi Smyth, Astronomer-Artist: His Cape Years*, 1835-1845. Cape Town: A.A. Balkema.

Wylie, C.C. (1939). The Radiant and Orbit of the Meteors of February 9, 1913. *Popular Astronomy 47*, *6*, 292-302.

Wylie, C.C. (1953a). Those Flying Saucers. *Science 118*, *3057*, 124-126.

Wylie, C.C. (1953b). Review of Menzel Flying Saucers. *Science 118*, *3057*, 145-146.

The Globe 1913 February 10, 1.

The Globe 1913 February 13, 8.

Toronto Star 2010 June 6, IN 2.

Web sites

City of Toronto Archives Photographs
www.toronto.ca/archives/description.htm#photographs *(accessed 2011 March 10)*

Google Maps with Street View
http://maps.google.com/maps?f=q&source=s_q&hl=en&q=high+park&aq=&sll=43.646293,-79.45128&sspn=0.014347,0.038581&ie=UTF8&rq=1&ev=p&split=1&radius=1.16&hq=high+park&hnear=&ll=43.64738,-79.460506&spn=0.057387,0.154324&z=13
(accessed 2011 May 2)

Grove Art Online-Oxford Art Online, E. Miller, Prints-colour
www.oxfordartonline.com.myaccess.library.utoronto.ca/subscriber/article/grove/art/T069624pg3
(accessed 2011 June 3) ✶

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[1] RASC Archivist, 203-4920 Dundas St. W, Toronto ON M9A 1B7

[2] Kitchener-Waterloo Centre RASC, 133 Weber Street N, Suite 127, Waterloo ON N2J 3G9

[3] Chant 1913a strongly implies that he immediately realized that the GMP was a "very exceptional occurrence" (145). The evidence of the newspapers indicates that the realization was far from immediate.

[4] It may strike a modern reader as curious that no contact information more precise than "the University of Toronto" is provided by which prospective informants might reach Chant. It is possible that the papers were to act as intermediaries, or witnesses were expected to contact the university for a more complete address, or perhaps "Prof. Chant, University of Toronto" was deemed sufficient.

[5] Further witness reports were published in Chant 1913b, Denning 1915, Denning 1916, Pickering 1923b, Mebane 1956, O'Keefe 1961 & 1968. According to Heard & Fernie (1979, 128) the original reports were kept on display at the David Dunlap Observatory. They do not at present appear in the University of Toronto Archives and Record Management Services catalogue (they may, however, have been added to the existing fonds A1974-0027). Literary features of Chant 1913a seem to be modelled on Coffin 1868.

[6] None of the Hahns has separate entries in the *Dictionary of Canadian Biography*, a very serious lacuna. Gustav's younger brothers Paul and Emmanuel merit entries in the *Encyclopedia of Music in Canada* and the *Canadian Encyclopedia* respectively. An interesting account of how the family became Canadian is Sauer 2007.

[7] One of us (RR) originally thought the incisions indicated that Hahn had salvaged the streetscape from an earlier attempt at depicting the GMP, and pasted it on to a new support before painting the celestial portion, but in such a case the streetscape would be raised slightly above the level of the celestial scene, magnification would reveal traces of glue at the join, and it is very likely that, after a century, there would be signs of delamination in the composite support. The absence of these features disallows this explanation.

Second Light

How Many Planets Are There?

by Leslie J. Sage
(l.sage@us.nature.com)

It seems like a simple question, but it is tricky to answer. I just checked the exoplanet app on my iPhone and, as of 10 a.m. on 2011 May 4, there are 547 confirmed planets. The *Kepler* mission has released so far 1235 planetary candidates that are awaiting confirmation. But, there are (at least) several hundred billion stars in the Milky Way – are there that many planets? A recent study of microlensing by Takahiro Sumi of Osaka University in Japan and a global team of collaborators, suggests that there are almost twice as many planets as stars (see the May 19 issue of *Nature*).

Up until the time of the *Kepler* mission, about three-quarters of the discovered planets were found using the radial-velocity technique, and about 20 percent through transitting. (The balance of the discovered planets have been directly imaged, found through microlensing, or through perturbations to the regularity of orbits of binary stars or pulsars.) Both the radial-velocity and transitting techniques are biased towards finding large planets close to their parent stars, simply because they are easier to see.

Gravitational microlensing depends upon a property of mass that arises from general relativity – a body will bend light. When the geometry is just right, a mass passing in front of a background star can magnify the light of the star, just like a magnifying glass. This causes the star to brighten for a time; the length of time is related to the mass of the lensing body – the lower the mass, the shorter the duration of the event – as well as transverse motion in the plane of the sky and its distance from us. The amount of brightening is related to how closely the lensing body passed the star in the sky.

Microlensing was initially conceived as a way to look for dark matter. It's been rather unsuccessful in that regard, but it was quickly realized that it would be a good way to look for planets orbiting stars, as the planet would produce an extra peak in the light curve. Unlike the radial-velocity and transit methods, microlensing works best for planets that are relatively distant from their parent stars. If the planet is too close to the star, the chances that it will be microlensed are very small.

The problem with microlensing is that the events are very rare. A Japanese-New Zealand team set up the Microlensing Observations in Astrophysics (MOA) collaboration to monitor the brightness of 50 million stars once an hour for two years, with some of those stars being monitored every ten minutes, so that they were able to detect very low-mass lenses. They later joined together with Optical Gravitational Lens Experiment (OGLE), based in Poland, whose independent data supported the MOA conclusions.

Out of the 474 microlensing events, 10 had durations shorter than two days. This is a lot more than expected from what we know about the population of stars and brown dwarfs in the galaxy. None of the 10 events showed the signature of lensing from a parent star, meaning that the planets were at least 10 AU from the star. There already are limits on the fraction of stars with planets in the range of 10-500 AU from their parent stars, based upon direct imaging, so Sumi and his collaborators conclude that less than a quarter of their 10 microlens observations are from planets bound to stars. In other words, there is a substantial population of free-floating planetary-mass bodies in the galaxy. Sumi estimates, based upon the number of events, that there are about 1½ free-floating planetary masses for each star in the Milky Way, if the typical mass is a Jupiter mass or more.

If these bodies are free-floating, Sumi argues that planetary dynamics likely freed them from their star. We already know that planets can migrate substantial distances from their birthplace in the system and interact with other planets.

Whether this happens often enough to provide such a substantial population of bodies seems to be an open question.

In a News & Views article to accompany Sumi's paper, Joachim Wambsganss of the University of Heidelberg raises the question of just what we should call these free-floating bodies. "Planet" pre-supposes that the body is orbiting a parent star. Amongst the numerous suggestions listed by Warmsganss, my favourites are "objects formerly called planets" and "rogue planets."

A related question is the abundance of planets bound to stars – does every star have at least one planet around it? We do not yet know, but the early evidence from both the microlensing project and the *Kepler* mission seems to suggest that the answer is "Yes." I am sure this will be the topic of a future column! ✶

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

Through My Eyepiece

Countries to Discover

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

But that the dread of something after death,
The undiscovered country, from whose bourn
No traveller returns, puzzles the will,
And makes us rather bear those ills we have
Than fly to others that we know not of?

– William Shakespeare: Hamlet

How do you keep your interest in astronomy alive?

Rather than dreading the undiscovered country ahead, I have always sought to discover new countries to explore, which makes my astronomy, and my life, forever new, fresh, and exciting.

Shortly after I got back into astronomy in 1997, I foresaw a dry patch coming. I was living in Toronto at the time and mainly interested in the planets, something I could observe under heavily light-polluted skies. However, early in 2000, I noticed that there weren't going to be any planets in the sky for many months. What to do?

I suddenly realized that, despite many years of observing, as far as I could remember, I had never, ever seen an asteroid. A quick look in the *Handbook* told me that there were several asteroids visible currently or over the next few months. So, the very next night, January 27/28, I went in search of 7 Iris with my 250-mm reflector and a chart from *Starry Night.* It was located in Cancer, just south of the open cluster Messier 67. Over the next four clear nights, I followed Iris as it crossed Cancer, just above the head of Hydra. It was really exciting to actually see something move in the sky, even if it was only 8th magnitude.

On February 7/8, I went after my second asteroid, 2 Pallas, way down in Puppis. This is a very rich area of the Milky Way, so I had plenty of stars to mark Pallas' progress. I noticed in *Starry Night* that it was heading almost directly towards the open cluster Messier 47. On the night of February 28/29, I watched it skim the west side of the cluster, and also observed NGC 2438, the planetary nebula right in front of Messier 46.

Over the next few months, I observed eight more asteroids: 1 Ceres, 15 Eunomia, 51 Nemausa, 44 Nysa, 20 Massalia,

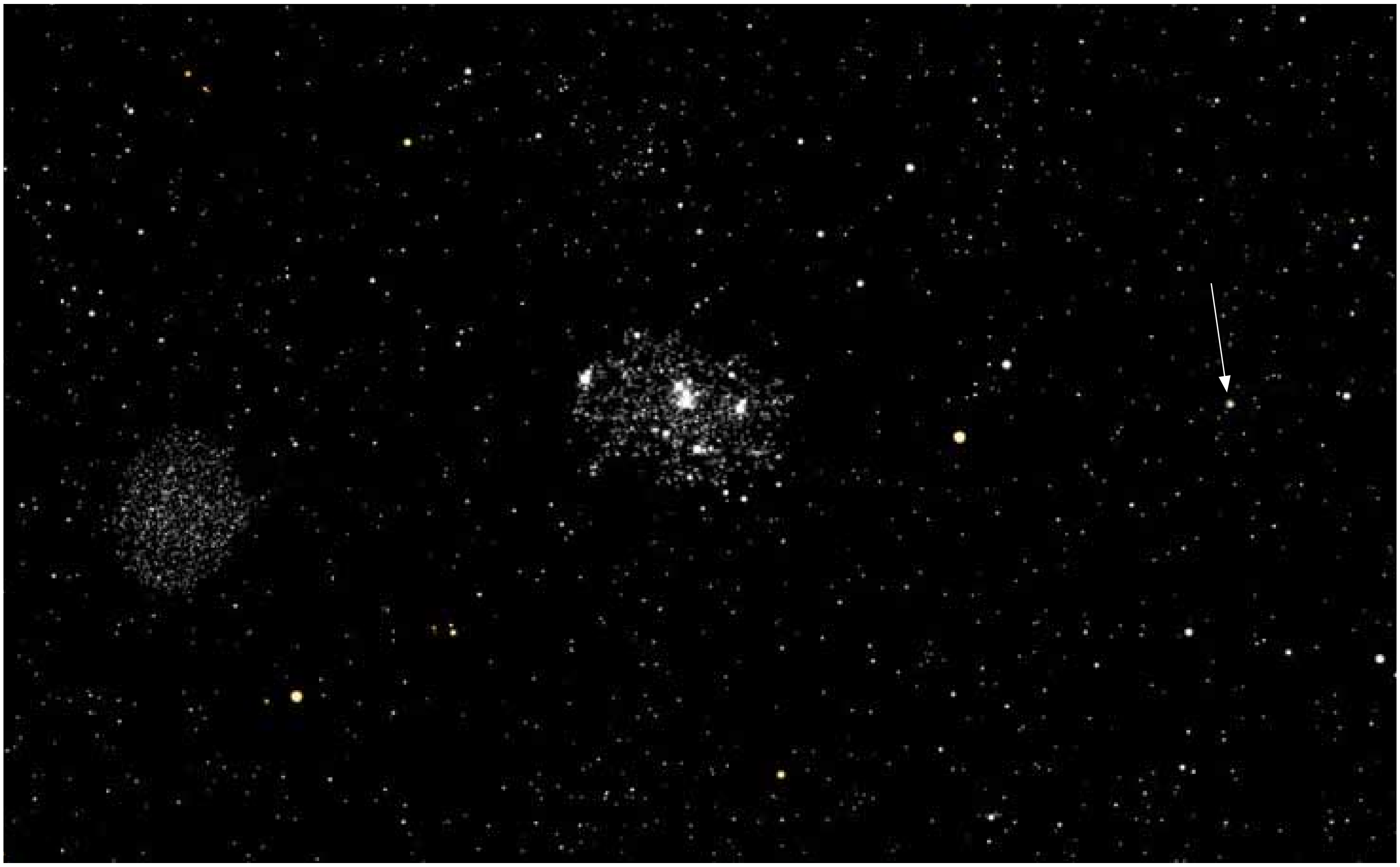


Figure 1 — Messier 46 (containing NGC 2438), Messier 47, and Pallas (arrow) as seen on 2000 February 28/29. Credit: Starry Night Software.

4 Vesta, 8 Flora, and 3 Juno. I was so intrigued by these observations that I gave a couple of talks about them at member's night at the Toronto Centre, the beginning of a long tradition there.

Fast forward to 2011. Feeling a bit bored with same old, same old, I've started looking around for a new country to discover. As many of you know, I've sworn up and down for years that I'm strictly a *visual* observer. But, a couple of years ago I bought a DSLR, a Canon Rebel XT. Slowly I've been accumulating a gadget here and a gadget there: a remote shutter release; an adapter to fit my lovely old Nikkor lenses to it; a T-ring adapter; and 2-inch tube; a piggyback bracket; and, most recently, a right-angle magnifying finder.

This spring, as I'm sure you've all experienced, has been one of the most dismal on record, weather-wise, all across Canada. I'm really keen to try playing with my new toys, but so far the weather has been against me.

I'm not interested in fancy-dancy deep-sky images like my many imaging friends pursue. I'd more like to have some sort of record of some of the things that I observe, mostly to paste into my observing log book. But, given past experience, I've no idea where this may lead. Stay tuned! ✶

Geoff Gaherty received the Toronto Centre's Ostrander-Ramsay Award for excellence in writing, specifically for his JRASC *column, "Through My Eyepiece." Despite cold in the winter and mosquitoes in the summer, he still manages to pursue a variety of observations, particularly of Jupiter and variable stars. Besides this column, he contributes regularly to the* Starry Night Times *and writes a weekly article on the Space.com Web site.*

The Royal Astronomical Society of Canada is dedicated to the advancement of astronomy and its related sciences; the Journal *espouses the scientific method, and supports dissemination of information, discoveries, and theories based on that well-tested method.*

Gizmos

Not Just For Styling Your Hair

by Don Van Akker, Victoria Centre
(dvanakker@gmail.com)

If you are into astronomy you are, by default, into batteries, because almost everything to do with astronomy is powered by batteries. Even if you are a purist and your gear consists of nothing but glass and a tube and something to swivel it around on, you still have lights or lasers or even socks that operate on batteries. They are great when they work.

Aside from the obvious, that they run down quickly and turn into toxic waste, batteries all share another problem, corrosion. This is what the problem is when you turn on a flashlight that you know has good batteries and nothing happens. Nothing happens a lot in the moist coastal climate we live in, but I expect it happens everywhere else, too. A microscopic layer of corrosion builds up on the terminals, and you are left in the dark.

When I was a teenager, my passion was not for stars but for cars. Since the kind of cars I drove usually had a few problems, I learned a bit about how to keep them running, and one of the first things I learned was that if you turned the key and nothing happened, you probably had dirty battery terminals. Then, you pop the hood, unbolt the clamps (of course, you had a wrench), scrape at them a bit with your knife, scrape the terminals, put the clamps back on, put the hood down, turn the key, and away – while the young lady beside you looks on in admiration and wonder.

Making your flashlight work won't get you the same reaction, but you do it much the same way. You take out the batteries and rub them on your pants, clean the terminals as best you can, put it back together and bingo!

"Can't you make it so it stops doing that?"

Well, as a matter of fact, you can, with the same unlikely sounding solution that we used in our cars.

Vaseline.

A liberal coating of Vaseline on the terminals and clamps of automobile batteries will protect them from corrosion and, surprisingly, will not interfere with the metal-to-metal contact required for a good connection. I tried it in a flashlight and a green laser. I used only a smidgen. Worked like a charm. Vaseline turns almost to a liquid when it gets warm. If you use more than a smidgen, you will get an awful mess.

There is actually a product intended specifically for this purpose, which Vaseline is not. It is called dielectric grease and costs twenty times as much as Vaseline, which makes it right at home in an astronomy setting. It comes in a small tube, and is recommended for all kinds of electrical contacts. It is available at any auto parts store and at Canadian Tire. ✶

Don Van Akker is old enough to remember putting grease in his hair. He observes with Elizabeth from their home on Salt Spring Island. His flashlight always works.

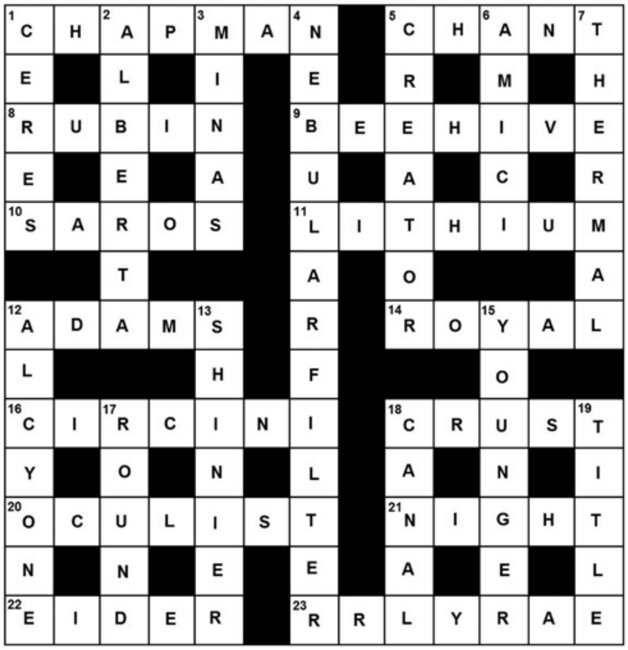
It's not all Sirius

by Ted Dunphy

I feel like my mirror's not big enough,
He's always thumbing through Sky News!

Astrocryptic Answers

by Curt Nason



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12 A	D	A	M	13 S	■	R	■	14 R	O	15 Y	A	L
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22 E	I	D	E	R	■	23 R	R	L	Y	R	A	E

Society News

by James Edgar
(jamesedgar@sasktel.net)

What have you done to carry forward the Beyond IYA concept? We are now two years past that momentous time, but there is still much to be done. Do you go out with your Centre when an event is planned? Do you set your telescope up on a sidewalk just for the fun of it? Do you visit your local schools; give talks; show kids the Sun or stars? This is what it's all about – Beyond the International Year of Astronomy!

The Society is you; our Centres are where the action is, and members make it happen.

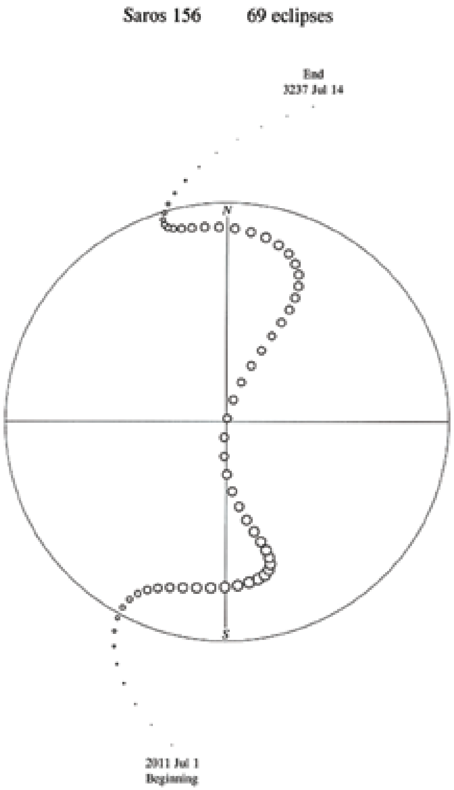
With the warmer weather upon us, get yourself some bug spray and get out there! **Do it!!**

Now that I've got that out of my system, have you seen the Twitter tweets coming out of National Office? Fiona Wilson frequently sends them, so if you're not a follower, get with it. There is a wealth of information out there – go on-line and take advantage of it.

The Public Speaker Programme is doing well. The Society has sponsored speakers in the Sunshine Coast, Calgary, and Regina Centres so far this year, and more are waiting in the wings. What better way to fulfill our mandate of education and outreach than to arrange a talk open to the public? Has your Centre considered this way of bringing a speaker to your location? Go here for more information www.rasc.ca/education/PSP_Procedure_2010.pdf. ✶

Errata

In the last issue Bruce McCurdy's article *Saros Start* (Orbital Oddities, page 120) contained a figure that was inadvertently cut off at the top and bottom. The complete diagram is included here. ✶



THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

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The most current contact information and Web site addresses for all Centres are available at the Society's Web site: www.rasc.ca

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Charlottetown Centre
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St. John's NL A1E 5H9

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Vancouver Centre
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Vancouver BC V6J 3J9

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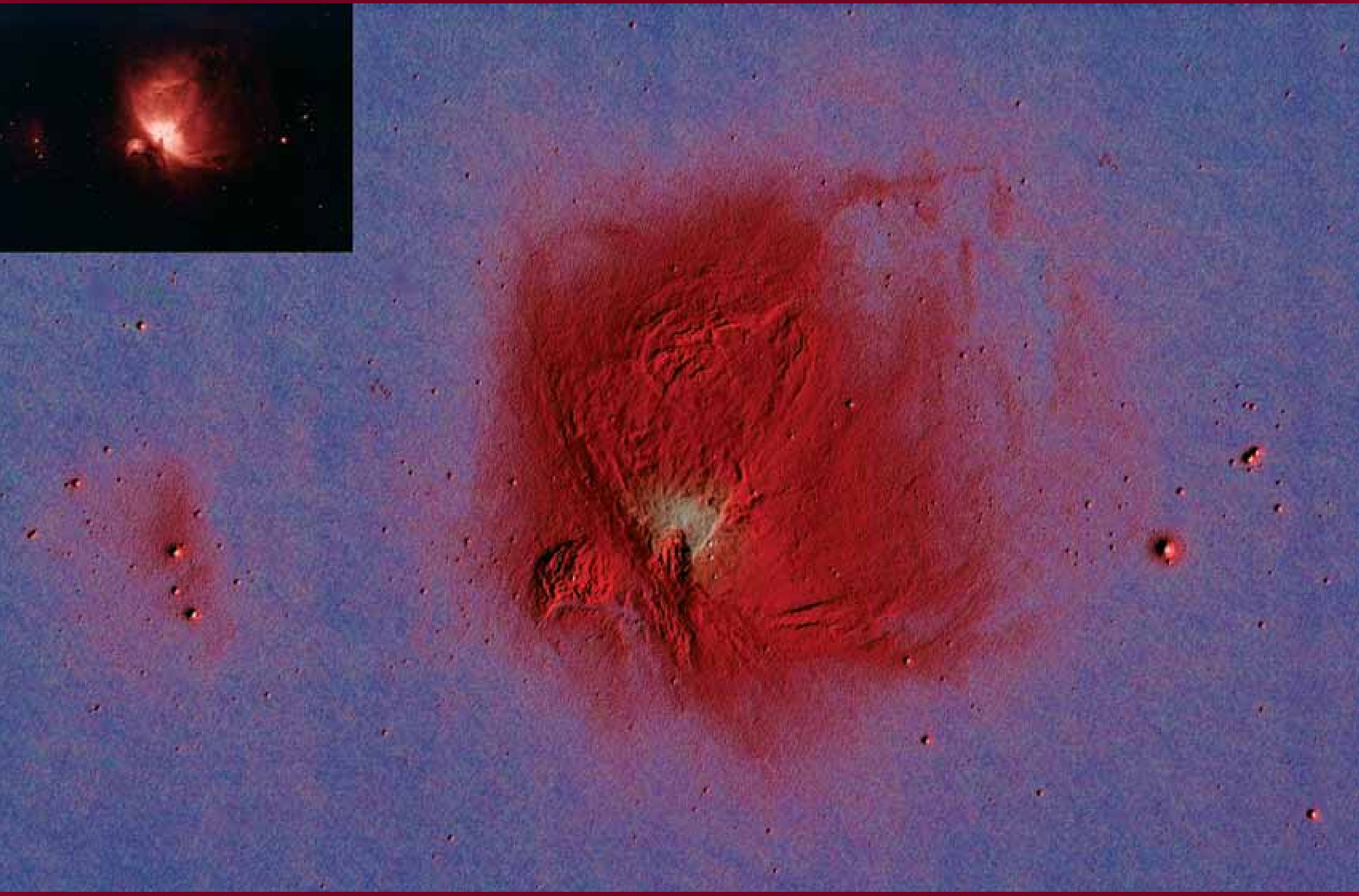
Victoria BC V8T 3Z8

Windsor Centre
c/o Greg Mockler
1508 Greenwood Rd
Kingsville ON N9V 2V7

Winnipeg Centre
PO Box 2694
Winnipeg MB R3C 4B3



Great Images

Victoria Centre's John McDonald captured the Orion Nebula in H-alpha light on January 2010 from Yellowpoint Lodge on Vancouver Island and then converted it to a topographic representation in AIP4win *software. The image was composited from 126 30-second frames, acquired using a 105-mm refractor and a modified Canon T1i camera. The inset shows the original image.*

Journal