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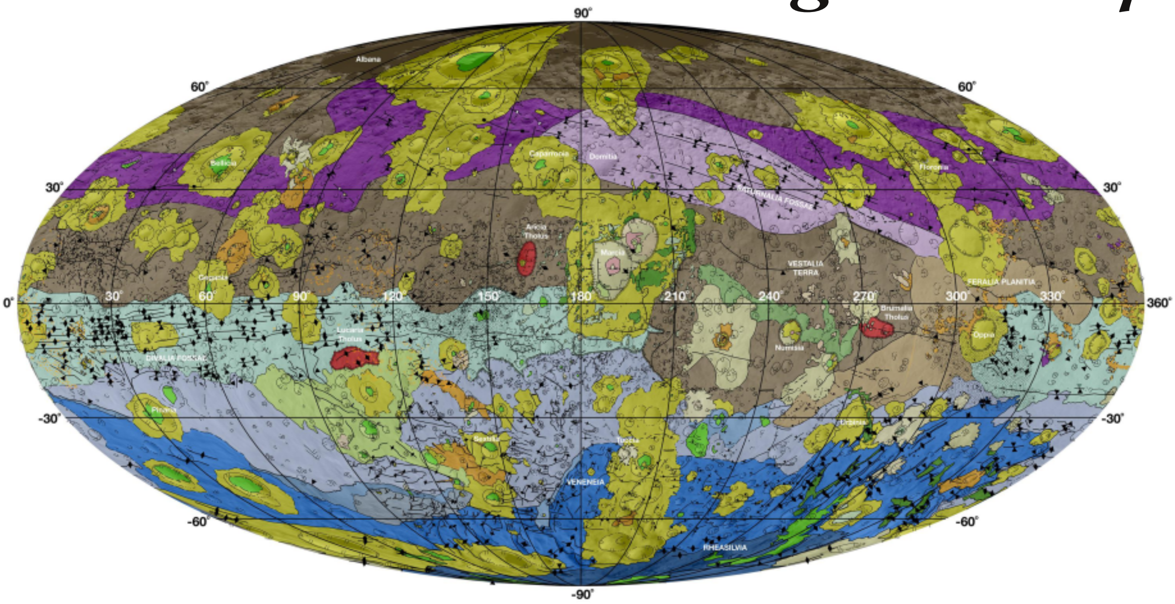
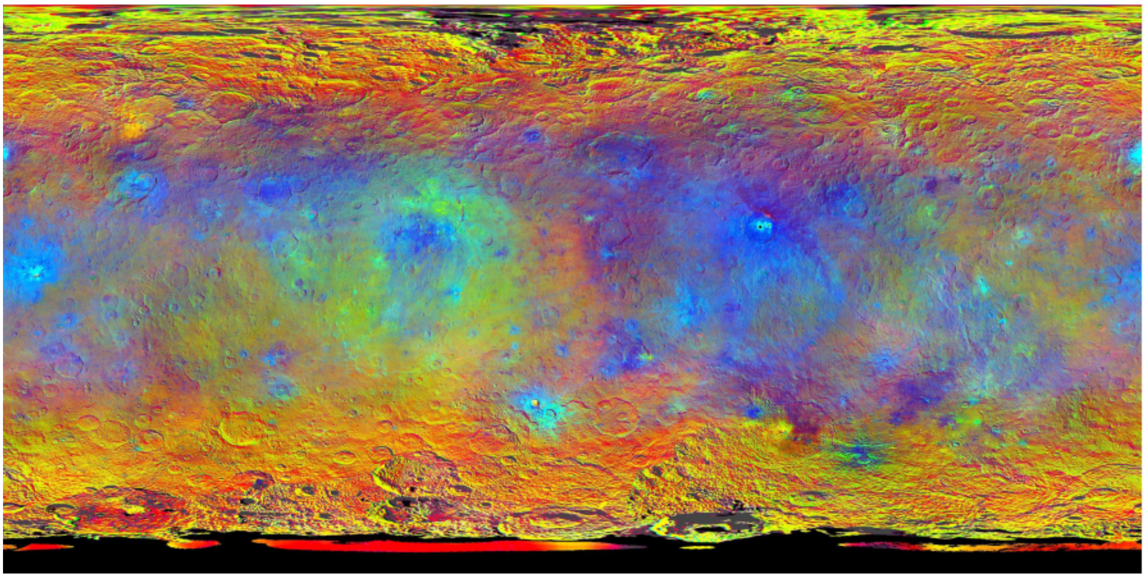
Vesta and Ceres Geological Maps





Vesta Top. This high-resolution geological map of Vesta is derived from Dawn spacecraft data. Brown colours represent the oldest, most heavily cratered surface. Purple colours in the north and light blue represent terrains modified by the Veneneia and Rheasilvia impacts, respectively. Light purples and dark blue colours below the equator represent the interior of the Rheasilvia and Veneneia basins. Greens and yellows represent relatively young landslides or other downhill movement and crater impact materials, respectively.
Ceres Bottom, is a false colour image taken using infrared (920 nanometers), red (750 nanometers) and blue (440 nanometers) spectral filters were combined to create this false-color view. Redder colours indicate places on Ceres' surface that reflect light strongly in the infrared, while bluish colours indicate enhanced reflectivity at short (bluer) wavelengths; green indicates places where albedo, or overall brightness, is strongly enhanced. See Rendezvous with Comets and Asteroids, page 4. NASA images.

CONTENTS

I think you can tell by the title of this article how long I've been thinking about writing it…

You Cannot be Sirius

By Mike Frost

Twenty years ago, there was a newsagent shop called Martin's in Rugby Town Centre – it closed a long time ago, Boots the Chemist now occupies the shop. The newsagent used to have a table full of remaindered books on sale at a discount. One day in 1993 copies of a title of interest to me appeared, *"The Colours of the Galaxies"* by David Malin and Paul Murdin, and of course I bought one.

It was a wise investment. *"The Colours of the Galaxies"* was a lovely book - I remember recommending it to people at the time; such a pity (though not for me!) that it had to be sold off at a discount price; the book was a reprint of the 1984 first edition, perhaps the publishers over-estimated the demand for a reprint. David Malin was the photographic scientist at the Anglo-Australian Observatory, Coonabarabran, NSW, and was widely regarded as the finest astro-photographer of his generation – he trained as a chemist and understood how to get the most out of film, yet pioneered a number of techniques which have continued to flourish in the digital era. Paul Murdin was head of the Head of Optical Telescopes at the UK Observatory in the Canary Islands.

"The Colours of the Galaxies" was full of fascinating information. There was a tremendous amount of astrophysics, explaining the reasons why stars and galaxies behaved the way they did. David Malin spent a lot of time explaining his photographic techniques. Both these strands were copiously illustrated with beautiful pictures, many taken by Malin at the Anglo-Australian Telescope.

Perhaps the book's technical content was too ambitious for the general public, even if almost anyone would have appreciated the illustrations. For me personally, Malin and Murdin's book has had quite a profound influence on my astronomical activities, triggering several lines of enquiry that I have been pursuing doggedly ever since. For example, the book's discussion on atmospheric scattering came in useful when I was preparing my ever-popular lecture on the green flash, and the paragraphs on refraction within raindrops informed my talk on rainbows.

One particular section has stuck in my memory to such an extent that, twenty plus years after reading it, I am finally going to tell you about it. Chapter five of *"The Colours of Galaxies"* is entitled *"The changing colours of stars"*. There is a fascinating discussion of the evolution of stars, onto then on and then off the main sequence of the Hertzsprung Russell diagram, and how this can be used, for example, to determine the age of star clusters such as the Pleiades.

Interesting though this chapter is, the portion of it that has stayed in my memory for so long is the closing section, *"The Colour of Sirius"*. This presents evidence for an extraordinary claim – that the observed colour of Sirius, the brightest star in the night sky, has changed at some time in the last two thousand years.

What leads us to this conclusion? In Ptolemy's star catalogue, the Almagest, he described six stars as being "hypokirros". These six stars are Arcturus, Aldebaran, Pollux, Antares and Betelgeuse, which all have reddish, orangish or yellowish tints … and Sirius, which most observers would describe as being white. Ptolemy's exact meaning of "hypokirros" is not clear – Malin and Murdin suggest "yellowish".

Ptolemy's anomaly was first pointed out by Thomas Barker in 1780, and discussed by, among others, Sir John Herschel, Schiaparelli and Simon Newcomb. But the person who really brought the issue to public attention was one of astronomy's more colourful characters – TJJ See.

Thomas Jefferson Jackson See was born and educated in Missouri, took a Ph.D. at Berlin, became an instructor at the University of Chicago, a member of the staff at Lowell Observatory, Flagstaff, and then took successive posts at the US Naval Observatories in Washington D.C., Annapolis and finally Mare Island, California. His was a career that started with great promise; he was an outstanding visual observer, and may even have glimpsed craters on Mercury. But illness blighted his career and he never achieved the heights that he thought himself capable of reaching. Instead, bitter at being overlooked by the astronomical establishment, he took to arguing increasingly controversial theories in popular newspapers – for example, he never believed in relativity.

On the subject of Sirius, See took up the baton in two articles; one in 1892, the other, not substantially different, in 1927. See had certainly done research. He produced 20 classical references which he claimed backed Ptolemy's observation of a red Sirius. Some of these were obscure, many were open to interpretation.

Most writers on the subject think that the resolution to the Sirius mystery is comes in a misinterpretation of what Ptolemy said. Perhaps "hypokirros" refers to the overall brightness of Sirius, or perhaps to the sometimes vivid flashes of colour due to twinkling when Sirius is at low altitude in the sky. It's even been suggested that "hypokirros" is a mis-transcription of "Sirius", which makes sense in the context of Ptolemy's text, where the name of the brightest star in the sky doesn't otherwise appear. However, the two words don't look similar, and See was particularly dismissive of this possibility. Unless further historical texts turn up, we'll never know exactly what Ptolemy intended to say.

But can modern day astrophysics come to our assistance? Is it physically possible that Sirius might have changed colour over the course of the last 2000 years? Sirius is a main sequence star, of which we now know the physics well – such stars remain stable for billions of years at a time. Besides which, we can see so many similar stars, that we'd stand a reasonable chance of catching a few such stars "in the act" of changing colour, and we haven't seen any examples.

There is one other possibility. Sirius is part of a double star system. In 1970 D. Lauterborn presented two papers on the evolution of such a double star system, starting as two stars of two solar masses and five solar masses. The more massive star reaches its red giant state, so that the binary system appears red at great distances. But the red giant rapidly loses mass to its companion, hastening its demise to a white dwarf, and boosting the previously less massive star to six solar masses, becoming the brighter star of the two, and intensely white in colour. This fits the current observed state of the Sirius system, and gives a possible reason why Sirius may once have appeared red. Unfortunately, it's not currently possible to model a transition which settles down in mere millennia. There are certainly binary star systems in which mass is transferred from one star to the other – but the transitions between stellar types still take millions of years to happen. Inconveniently for See and others, modern day astrophysics doesn't offer a solution.

What I like about this story are the layers of historical perspective. The theories of Barker, See and others rely on the interpretation of the exact meaning of phrases written two millennia previously. Malin and Murdin added their own perspective of a century; adding twentieth century astrophysics to the mix, and providing a historical perspective on See's extraordinary career. The fact that See was proven historically wrong on many other issues such as relativity doesn't mean that he was wrong about Sirius, of course, but it certainly calls into question his judgment.

And now with another thirty years of perspective we can make further judgements. First of all - David Malin and Paul Murdin, I'm pleased to say, are still going strong. Malin retired to run his own website, www.davidmalin.com, which manages his superb library of astronomical images. Paul Murdin is still very active at the Institute of Astronomy, Cambridge.

Does twenty-first century physics have anything further to say about the colour of Sirius? Unfortunately for See and company, there is still no realistic model for any way in which Sirius can have changed colour over the last two millennia. Astrophysics may be wrong, of course, but the evolution of main sequence, "bog-standard" stars such as Sirius is no longer a subject of much argument – we know how such stars behave, and it doesn't include changing colour.

But there is one person whose reputation might benefit from a historical re-evaluation, and that is TJJ See. In See I see (no pun intended) shades of a figure from half a century later – Fred Hoyle. There are similarities in their career trajectories and willingness to take their arguments directly to the public. Hoyle was certainly the more important of the two astronomers – his work on nuclear fusion chains with Burbage, Burbage and Fowler was one of the central achievements of twentieth-century astrophysics, and goes a long way toward disproving the Sirius colour change thesis. But in later years Hoyle espoused a number of very provocative theories, which he often pitched directly to the public by books and television programs rather than through standard academic routes.

So, See argued that Sirius had changed colour since antiquity – and was probably wrong. Hoyle argued that outer space is full of microbial life – and is also probably wrong. Probably. But it's interesting that Hoyle's panspermia conjecture doesn't seem to be going away right now, rather mutating – I don't think there are many scientists who now don't accept that microbial life could travel, say, from Earth to Mars or vice versa, even though travel over interstellar distances is still beyond the pale.

My point, really, is that for science to advance, we need people like See and Hoyle, talented people who are not afraid of arguing contrary points of view even though doing so might hurt their careers. Geniuses who are sometimes in error, but seldom in doubt.

A bit like John McEnroe, actually. . .

Sources:

"Colours of the Galaxies", David Malin and Paul Murdin (Promotional Reprint Company, 1993; original edition Cambridge University Press, 1984). The section on the colour of Sirius acknowledges correspondence with Robert Temple, author of *"The Sirius Mystery"*, which I haven't read.

"A Career of Controversy: The Anomaly of T.J.J.See", Sherill, T.J. (Journal of the History of Astronomy, 1999, p.25)

See's papers on Sirius (which I haven't read) were:

"History of the colour of Sirius", See T.J.J., Astr. & Astrophys., 11, 269-274, 372, 457, 550 (1892)

"Historical researches indicating a change in the colour of Sirius, between the epochs of Ptolemy, 138, and of al Sufi, 980 AD", See T.J.J., Astr. Nachrichten, 229, 245-72 (1927)

Lauterborn's paper: *"Evolution with mass exchange of Case C for a binary system with total mass 7 solar masses"*, Lauterborn, D., Astr. & Astrophys.,7, 150-9 (1971)

Rendezvous with Comets and Asteroids

By Paritosh Maulik

Human kind has been always fascinated by comets with their fleeting visits. By the eighteenth century astronomers had learned to predict the appearance of planets. In 1781 William Herschel discovered Uranus in the expected location. Astronomy community were convinced that there must be planets between Mars and Jupiter and continue to look for them. Then in 1801, Giuseppe Piazzi discovered a "missing planet", it was named Ceres. Subsequent observations suggested the size of Ceres to be 940km (smaller than Pluto, which is 2300km). So Ceres was classified as a minor planet. By 1845 more similar objects were discovered; astronomers classified these objects as asteroids and began to look for more such objects. For a brief history, see `http://www.esa.int/About_Us/Welcome_to_ESA/ESA_history/Asteroids_The_discovery_of_asteroids`

Eventually it was realised that asteroids and comets were made from the same material which formed the Solar System and have remained almost unchanged during the last nearly 4.5 billion years. By learning about these objects, we get a better understanding of the early Solar System. As the technology improved, space scientists wanted direct encounters with comets and asteroids to analyse dust from these objects in-situ and/or bring back samples to the Earth for further analysis. The European Gitto mission was the first mission to meet comet Haley and since then there has been one Japanese and one US mission to asteroids with the Europe's ESA Rosetta probe the latest.

Asteroids and Comets a brief Introduction

Asteroids

As the Solar system began to form, dust particles cooled down and formed planets. Some of these did not quite make the grade planet, their mass was too small and weak gravity did not form a near spherical object. A majority of the asteroids orbit between Mars and Jupiter. From time to time, these get a knock from other astronomical bodies and leave their usual place of residence.

Comets

Like asteroids, comets are also made from dust and ice, but these are much smaller with sizes varying from hundreds of metres to a few kilometres. These orbit the Sun in highly elliptical orbits. As the comet approaches the Sun, the heat melts the ice and the Solar wind causes the evaporating materials to travel away from the Sun. This appears as the tail of the comet. We have discussed some these points in an earlier issue of MIRA Number 90, 2011.

We only see the nucleus of the comet. It is solid and is a mixture of ice, rock and dust. Perhaps comets contain less of ice and more of rocky material and are very dark. A typical size of a comet is about a few km across.

As the comet moves nearer to the sun, the heat causes the ice to evaporate. The water vapour and the dust are released from the surface and covers the surface of the comet which forms a cloud like feature around the nucleus of the comet. Light from the Sun makes it visible and this is the coma.

As the comet moves closer to the Sun, water vapour and dust particles form the tail behind the comet, making it visible to us. The UV rays and the charged particles from the Sun causes ionisation of some particles; ionisation makes the particles electrically charged. These electrically charged becomes magnetic. Under the influence of solar wind these charge particles get defected and forms a separate stream called an ion tail. Thus a comet has two tails, one an ion tail made of charged particles and the other a dust tail made up of silicate dust from the surface of the nucleus of the comet. After observing comets for many years, the next obvious step was direct contact with a comet.

The Giotto Mission

European Giotto mission was the first attempt to fly through the tail of a comet. The comet was Halley's comet. It was the first European Deep Space Mission. It attempted to image the nucleus of two comets and to analyse the composition of comets. Although Edmund Halley was not the first to observe the comet named after him, by using Newton's calculations, he predicted the periodic nature of the comet. Halley also predicted the orbit of several other comets. Italian painter Giotto included the comet in his painting The Adoration of the Magi in 1300.

The Giotto mission was originally planed as a joint ESA – NASA mission in 1980. But due to financial constrains NASA pulled out of the mission and ESA decided to go alone. The encounter with comet Halley consisted of a total of five probes. Two Japanese probes to carry out the long distance measurements and two Soviet probes to located the nucleus of the comet. Giotto used this information to attempt a flyby close to the nucleus of the comet.

Giotto was launched on 2 July 1985 aboard an Arian Rocket. Russian probes Vega 1 and Vega 2 took images of the nucleus of comet Halley in early March 1986. The closest Vega 1 came to the nucleus was 8,889 km and on 14 March 1986, Giotto flew past the nucleus at a distance of 596 km. taking linages of the nucleus and carried out analysis of dust and gasses. Giotto was hit by a particle, probably a fragment of the comet weighing between 0.1–1g. This changed the controlled spinning of the probe, but the spinning was restored quickly. It continued to gather data till 15 March 1986 and then it was turned off. Another collision put the Halley Mulitcolour Camera out of action, however the data was sent back to the mission control.

The probe was switched off and then it flew by Earth to encounter a second comet, Grigg-Skjellerup in 1992.

What we learnt about comet Halley was the size of the nucleus, about 16x8x8km. The nucleus surface is very irregular, with hills and depressions. The density was estimated to be around $0.3 kg/m^3$ and the ejected mass was 3 tonne/sec. Average density of the Earth is around $5514 kg/m^3$.

The mass of the dust was in the range of 1×10^{-18} to 4×10^{-1}g. There were predominantly two major classes of dust particles. One was consisted of lighter elements like carbon, hydrogen, oxygen and nitrogen and the other was rich in mineral containing elements like sodium, magnesium, silicon, iron and calcium. Water content about 80%, carbon monoxide about 10%, methane and ammonia about 2.5%, other hydrocarbons, iron and sodium were also detected. The nucleus was very dark, this suggested a thick covering of dust.

Water on Earth

The temperature of the early Earth was too hot to retain water. Now the question is how did the water get on the Earth? It was suggested that water was carried to the Earth by comets. But the Deuterium – Hydrogen (D/H) ratio of the terrestrial water does not match to those of comets Halley, Hyakutake and Hale–Bopp. It may be that these three comets are odd ones out and there are other Kuiper belt objects with D/H ratio similar to terrestrial water. Water associated with carbon-rich chondrites meteorites have similar D/H ratio as that of the terrestrial water. These meteorites have their origin in the primordial Solar System dust cloud which formed the planetesimals and eventually the planets. The D/H ratio of the Lunar rock is also similar to that of the Earth. Hence water was already present on the Earth when the Moon was formed, so the water source of the terrestrial and Lunar is the same. A theory based on these observations goes like this. Jupiter temporarily moved into the inner Solar System or Jupiter formed much closer to the Sun and later on moved to the present position. This destabilised the orbit of water rich meteorites (asteroids) and bought water to the Earth. The ESA Herschel mission detected the presence of water in the asteroid Ceres. NASA's mission Dawn went into orbit around Ceres on 6 March 2015. It has sent some images from a distance of 46,000km (9,000 miles).

So better understanding of the comets and asteroids would help us to understand the origin of the Solar system.

Hayabusha

Mission to comet Itokawa, by the Japan Aerospace Exploration Agency was launched in 9 May 2003 from Japan to drop a lander on the surface of comet Itokawa. It was also to collect dust from the comet and return to Earth. The mission used ion propulsion and since the communication from the control centre was prohibitively long, it deployed an Autonomous Optical negation method. Once the spacecraft arrived near the comet, it did not go into the orbit around the comet, but surveyed the comet from a heliocentric orbit. After another survey from 20km away from the surface, the craft was lowered further down. The final aim was to land a probe weighing 591g (12cm diameter x 10cm high) with a collection device. According to the original plan, the spacecraft was to fire pellets onto the surface of the comet and the lander would collect the dust; the lander would then be flown back to the space craft and eventually the dust would be retuned to the Earth. The lander was also to image the surface of the comet.

But due to some some technical glitch the lander was released from a higher altitude; it did not touch the surface of the comet and flew into the space. From the ground the mission appeared to be failure, however the orbiting spacecraft did collect some dust and managed to return the dust to the Earth. The landing site was in the outback of Australia on 13 June 2010.

What was the message from Hayabusa?

Asteroid Itokawa appears have two distinct types of surfaces. A smooth zone with layer of sand and gravel (called regolith) and and an area with lots of rocks. The combination of minerals in the Itokawa is typical of extraterrestrial chondrites. Such mineral combination does not occur in terrestrial minerals.

The formation of the asteroid Itokawa from dust and gas from the original solar medium formed the asteroid. Its original size was about 20 km. The highest temperature of the original mass was around 800°C and then it cooled down slowly. Eventually collisions with other astronomical objects occurred, and then gravity of some of the larger bodies pulled together to form the asteroid Itakawa. Its present size is about 540x270x210m and the largest rock seen was about 50m.

Some ground based observations suggest that the the density of the asteroid is not uniform. The density of one side is 2.850kg/m^3 and the other side is 1.750kg/m^3. These observations also found that the brightness of the asteroid changes as it rotates. The rays from the Sun is reflected from the surface as heat. If the surface is not uniform, the heat radiated from the surface is also not uniform. This non-uniform heat radiation introduces a torque and affects the spin. Currently Itokawa is loosing its spin by about 0.045 second/year.

The presence of noble gasses in the minerals suggests that the asteroid is being bombarded with solar wind on the surface and and the asteroid is undergoing space weathering. Evidence of bombardment by galactic cosmic rays is not evident. The asteroid is loosing its surface by about 20–30cm per million years by space weathering. The current size of the asteroid about 500m, and if this depletion rate continues, it is estimated that the asteroid may eased to exist in one billion years.

Chondrites

Chondrites are some of the most primitive rocks in the solar system. These 4.5-billion-year-old meteorites have not changed much from the asteroid these came from. Since these have never really got hot, these have not melted and as a result chondrites have a very distinctive appearance made from droplets of silicate minerals, mixed together with small grains of sulphides and iron-nickel metal. This structure of millimetre-sized granules also gives chondrites their name, which comes from the Greek for sand grains 'chondres'.

NASA missions to Asteroids and Comets

STARDUST

This was aimed to collect dust from comet Wild 2 and also interstellar dust and return to Earth. The mission was launched in February 1999, followed by a gravity Earth bypass, it encountered comet Wild2 in January 2002. On it way, it images asteroid Annefrank. The dust was returned to Earth in January 2006.

Comet Wild2 is less dusty than comet Halley. So it was hoped that a better quality of image of the nucleus and the source of the dust could be obtained. The dust was collected by an Aerogel plate. Aerogel is a very low density sponge like ceramic material. The spacecraft travelled at a velocity of 6.1km/sec. Laboratory experiments have shown that, at this the collision speed, the dust would not suffer any collision damage and would retain their identity. After it has collected the cometary dust the collection plate was encapsulated in a container for return to the Earth (the conical clam shaped object at the lower left hand corner).

Interstellar Dust Collection

Another aim of the mission was to collect interstellar dust. The velocity of the interstellar dust entering the heliosphere is about 30 km/s. Its direction of entry with respect to the ecliptic latitude is known. Interstellar dust is affected by solar pressure, solar gravity and the interplanetary magnetic field. The orientation of the spacecraft required for the optimum collection of interstellar dust is reasonably flexible. The dust was collected for period of six months. The reverse side of the Aerogel panel which collected the cometary dust, had another panel to collect the interstellar dust.

The spacecraft also had a spectrometer to analyse the dust in-situ. Analysis of the retuned dust showed the presence of a protein. This protein is also found on Earth. The terrestrial protein is based on carbon 12 isotope, but the retuned dust sample contained carbon 13, which has extraterrestrial origin. Presence of the carbon 13 isotope confirmed the extraterrestrial origin of the protein. This is first time presence of protein, building block of life, has been found in comets.

In the returned dust sample polycyclic aromatic hydrocarbons (PAH) were found. These compound occurs in interstellar dust and also in soot from burning on Earth. Some of the compounds were novel and are believed to be have been synthesised in the dust, that formed the solar system.

Minerals found in the dust samples of comet Wild2 suggests that these minerals formed under different conditions. This indicates that different compounds formed in different locations in its life. The chemistry of these minerals do not seem to have much altered by water, in other words these mineral had very little contact with water. Some iron–nickel alloy and iron–nickel sulphides have also detected in the dust.

NASA DAWN

Dawn mission left Earth in September 2007 and studied asteroid Vesta for 14 months from July 2011 to September 2012. Then it headed for dwarf planet Ceres. The spacecraft carries optical and infrared cameras and a spectrometer, gamma ray and neutron spectrometer. There are other instruments as well to monitor other physical properties of both Vesta and Ceres.

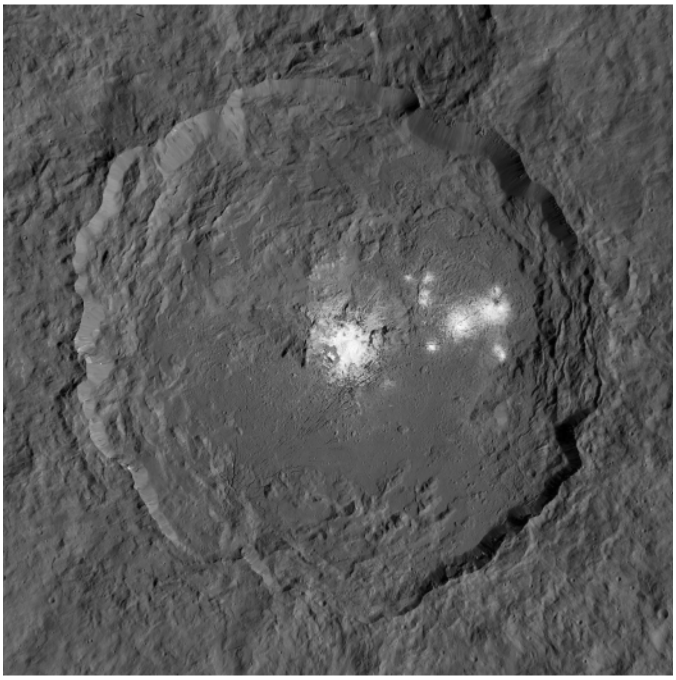
Perhaps Ceres and Vesta are the last two remaining large proto-planets. Vesta accreted material from the dust cloud for about only 5-15 million years, whereas Mars and the Earth continued to accreted for 30 and 50 million years respectively. It is suggested that formation and relocation of Jupiter perhaps stopped the accretion process of bodies in the asteroid belt. It is also likely that some of the asteroid belt objects collected materials from the comets.

Unlike Ceres, Vesta has seem many changes, basaltic lava flows similar to that of the Moon and the surface contains a lot of craters. It is believed that we have meteorites on Earth originated from Vesta. Minerals on Vesta have undergone changes due to the bombardment of cosmic rays. These changes have occurred at least five times in the last 50 million years. Vesta is about 573x560x450km in size and is nearly spherical. It rotates once in 5hr 20m. Its mass is 2.6×10^{20}kg (0.00002 of Earth's mass). There is a massive crater near the south pole.

Hydrogen was detected by gamma ray and neutron detectors on board the spacecraft. This hydrogen is likely to be associated with minerals near the equator rather than as free water. Free water is not expected to survive near the equator, but water ice can exist near the poles, where there is highest concentration of hydrogen.

These are some of the conclusions from the Dawn mission. It is surprising that Ceres and Vesta are relative close to each other, yet Ceres remain dry and cool while Vesta retained sufficient heat from its origin to undergo melting. These are some of the early findings of the Dawn mission. Both of these asteroid belt objects are in ecliptic plane and their orbits are near circular. Hence the one mission to cover both of these objects for the next phase of a future exploration.

After leaving Vesta, Dawn went into orbit around Ceres on 6 March 2015 and sent some images from a distance of 9,000 miles (14,500km). When the very early images came in, there was an area with a white spot. Now we have a 3D image of Ceres with the spot: the location is Occator crater, its diameter is about 90km (60 miles). The walls of the crater are generally smooth, but there are several surface features near the centre. Images taken with different filters suggest that this bright feature is due to different mineral distribution, such as salts and highly reflective material.



By imaging with different filters, there appears to be evidence of water bearing minerals, a very weak atmosphere and frost on the surface of Ceres, The surface has undergone very little modification since its formation. Spectroscopic analysis indicate that the surface of Ceres is covered with clay like minerals and perhaps that is why we have not received any meteorites originated from Ceres.

Ceres measures 965x961x890km, (606x565 miles) with a mean radius of 470km, and rotates in 9 hs, 4.5 minutes. Its mass is 9.4×10^{20}kg (0.00015 of Earth's mass).

The lower front cover image is a map-projected view created from images taken during its high-altitude mapping orbit, in August and September, 2015. Images taken using infrared (920 nanometers), red (750 nanometers) and blue (440 nanometers) spectral filters were combined to create this false-colour view. Redder colours indicate places on Ceres' surface that reflect light strongly in the infrared, while bluish colours indicate enhanced reflectivity at shorter (bluer) wavelengths; green indicates places where albedo, or overall brightness, is strongly enhanced.

Scientists use this technique in order to highlight subtle colour differences across Ceres, which would appear fairly uniform in natural colour. This can provide valuable insights into the mineral composition of the surface, as well as the relative ages of surface features.

Since December 2015 until September 2016 Dawn orbited Ceres at 375km, now it is at 20,000km where it will

Some Thoughts on my Articles and Talks

By Mike Frost

I have now been giving talks and writing articles for over thirty years. I thought that people might be interested in how I came up with ideas. (If you're not at all interested, feel free to skip this article. I won't mind).

My first ever astronomical talk was a short presentation to the department of astronomy at the University of Sussex, where I studied for an M.Sc in astronomy between 1984 and 1985. The department held a weekly seminar, which all were encouraged to attend, and towards the end of our course all the M.Sc students were required to give a five minute talk, featuring one or two overhead transparencies, outlining the progress of our M.Sc project. My project was an analysis of the star field in the direction of the Galactic Centre.

I thought seriously about going on to do a doctorate in astronomy, but I was also looking at jobs in industry. I met a lot of very good people with Ph.D.'s who seemed to be trapped in a never-ending series of PostDocs, and so when I was offered a job with GEC in Rugby, I jumped at the chance (the CEGB in London also offered me a job, but I didn't fancy a daily commute into central London). I moved to Rugby and pretty quickly joined a number of groups, including the Coventry and Warwickshire Astronomical Society; also Rotaract, the junior Rotarian group in Rugby (my father had been a Rotarian).

Almost the very first talk I attended at C&WAS (who met at the time in Coventry Technical College) was a talk by Doctor Allan Chapman about Edmond Halley, in anticipation of the arrival of Halley's Comet later in 1986. As I have written elsewhere, Allan's talk was a revelation. I realised that the history of astronomy was rich and fascinating. I also found out what an extraordinary character Edmond Halley was. Next month the speaker for my Rotaract group dropped out and I was asked, at short notice, to give a talk about Halley's Comet. I cherry-picked the juicier bits of Allan's talk (for example, Halley getting drunk at Greenwich with the future Peter the Great and pushing him through a hedge in a wheelbarrow) and added some science I picked up from the papers. After the talk we all piled outside and I attempted to find the comet in binoculars. Fortunately it was cloudy.

For C&WAS, I wanted to try to tell the society about my researches in my M.Sc. I think that I gave a slightly extended version of my M.Sc presentation to a members' evening. But I also wanted to talk and write about some of the tidbits that I had picked up during the course of my studies – things that were peripheral to the course, but which I found interesting. For example, our introductory course included an explanation of how the epicyclic theory of planetary motion was replaced by heliocentric (sun-centered) circular orbits and then by heliocentric elliptical orbits. But later on, when we learnt about galactic structure, we were told that the motion of stars around the galactic centre, under the combined gravitational attraction of billions of stars, was actually epicyclic. It amused me that a "discredited" theory of planetary motion turned up in a rather different context, and so I gave a short talk about this at another C&WAS members evening.

For my first full-length talk to the Coventry Society, I stayed with thoughts on the theory of gravity. I was lucky that Sussex University's astronomy department had on its staff at the time Professor John Barrow, who went on to join the Institute of Astronomy in Cambridge and become Gresham Professor in London. John was forever dropping interesting mathematical facts into his lectures and conversations. I particularly liked it when he pointed out how Isaac Newton had produced a geometric proof of the gravitational pull produced by a spherical shell of matter. From the outside, the shell has the same pull as single point, of the same mass, at the centre of the sphere. But on the inside of the sphere, anywhere at all on the inside, there is no gravitational pull at all – everything cancels out.

This was mathematically interesting – to me, at least – and actually quite an important technical problem for Newton to solve on his way to the Universal Law of Gravity. But how could I make this interesting for a talk to an astronomy society? Then I remembered a splendidly demented book I had read when I was a teenager: *"Secret of the Ages – UFOs from inside the Earth"* by Brinsley le Poer Trench (who later inherited the title of Earl Clancarty and spoke in the House of Lords on UFO matters). Mr le Poer Trench seemed not to be aware that there would be no gravity in the centre of a hollow Earth, instead asserting that this had to be the original location of the Big Cats who turn up every summer in Britain (usually on a slow news day). Thus was born *"Isaac Newton and the Surrey Pumas"*, a perennially popular talk. Although it has migrated from overhead projector to slide projector to Powerpoint presentation, it is still a vehicle for me to tell audiences about interesting things I have found out about Newtonian Gravity. In its early incarnations, I used to talk about space elevators; these days it's figure-of-eight orbits and Earth's pseudo-Moons.

One thing I did figure out from *"Isaac Newton and the Surrey Pumas"* was the importance of a good title; preferably one which piques the curiosity of the audience. What are the Surrey Pumas and what possible connection do they have to Isaac Newton? You have to listen to the first twenty minutes of the talk to find out the answer (but I once gave the talk to Liverpool AS, and Erich Strach, the great solar observer, a wartime refugee to Britain, asked at the end "Vot is a puma?"). Likewise – what on Earth are *"The Arms of Buddha"*? What does Mata Hari have to do with astronomy? Wasn't *"The Accidental Death of an Anarchist"* a political farce by Dario Fo? Indeed it was - so why am I using it as the title of a talk? In each case, the title is, eventually, explained.

A title that didn't work was the one I used for my second full-length talk to CAWAS – "Damp Squibs". I wanted to tell the society about a fascinating course I had done at Sussex on Dwarf Novae. These, it turns out, occur in binary systems, where material from one star is falling onto an accretion disk around the other star. Every so often, a thermonuclear explosion occurs in the accretion disk, triggering an outburst which we can observe from Earth. Great stuff, and really interesting physics. But at the same time we were also studying quasars, where a supermassive black hole powers mind-blowing outbursts of energy in powerful jets, which can be seen from billions of light years away. By comparison, mere atom bomb explosions on binary stars seemed rather piddling – so I re-christened the dwarf novae course "damp squibs", and this was the title I gave my talk. Not a good idea. The C&WAS chair at the time, Barry Merrikin, had this verdict – "enjoyable talk, but who's going to come to something called 'Damp Squibs'?" Point taken – so I tried to come up with better titles after that.

Although I found my stride fairly quickly giving talks, I felt it took a little longer to find my style in print. C&WAS's excellent journal, MIRA, was in its early days in 1986. My first contributed article was a short piece on a NASA mission to comet Schwassmann-Wachman, a kind of consolation prize for not going to Halley, based on articles I had read in New Scientist. Interesting, perhaps, but it didn't really add anything to the original New Scientist article. I felt I did better with a longer article on *"Astronomy at University"* in which I gave my personal experience of studying.

I think I began to produce better articles when I traveled away with work. I spent ten months working at a steel works in Wollongong, Australia, in 1987-88, and then the best part of two years in Cleveland, Ohio, in the States between 1989 and 1991. Australia in particular was good for my astronomical career. First, it's a wonderful country, the best one I've ever worked in. Second, it is of course in the Southern hemisphere, so there was a whole new sky for me to explore. Third, the Wollongong astronomical society was a very friendly and welcoming society. I even gave them the Surrey Pumas talk. The pumas, of course, travelled to Australia through the holes in the Poles and their home in the centre of the Earth – I had to take the long way round, unfortunately. I wrote an article on astronomy in Australia for Mira during my stay,

My stay in America was not as successful, astronomically. I never found an astronomical society to join in Ohio. However, I did take a very successful holiday to Arizona, during which time I visited Barringer Meteor Crater, and the Lowell Observatory on Mars Hill, Flagstaff. I wrote an article called *"Flagstaff Arizona and the Outer Solar System"* which I was very pleased with. It opened with a quote from The Eagles song *"Take it Easy" ('I was standing on a corner in Winslow Arizona, such a fine sight to see. It's a girl, my Lord!, in a flatbed Ford, slowing down to take a look at me…')* and I felt the article captured something of the essence of my Arizona trip.

Ivor Clarke had just taken over the editorship of MIRA, and was worried that he wouldn't get contributions. I promised to try to write an article for every edition of MIRA. I haven't quite managed to do that – you won't find anything by me in MIRA 55, 77, 78, 81, 83, 89, 90 or 97 – but on the other hand there are plenty of MIRAs with more than one article by me, so my average is above one article per edition, I don't think that I have done too badly. My job has taken me all over the world over the last thirty years, and I have been able to visit and write about astronomical sites in many of these places: South Africa, Chicago, Pittsburgh, Port Talbot…

One unexpected place I found a new astronomical site was Brighton. I'd already spent a year there studying at Sussex University, so when I went to visit my sister, who'd settled in Hove, I wasn't expecting to visit somewhere I didn't know about. But she took me to see the camera obscura at Foredown Tower, Portslade. I got on very well with the curator, Mike Feist, and was able to help him over the next few years with researches into camera obscuras the world over; this has fuelled many articles and a talk.

By this time I was looking to present more talks, but wasn't sure how to develop a distinctive style of my own. I remember ordering a whole series of slides on planetary images from Rosemary Naylor at the Earth and Sky astronomical bookshop. The slides were great, but I wasn't able to think of a way of using them to tell stories no-one else was telling.

The solution to my dilemma actually came from Mike Feist at Foredown Tower. *"Why don't you talk about atmospheric phenomena?"* he asked, *"we observe them all the time from Foredown, and no-one ever talks about them."* I was intrigued. To research the topic, I bought a copy of Robert Greenler's *"Rainbows, Haloes and Glories"*. It turned out to be possibly the most influential book I have ever read – a mixture of very accessible physics and the most outrageous legends and mythology. Just as important was the note just inside the front cover, informing me that the illustrations and colour plates in the book were available as a slide set. I ordered slides from the United States, not an easy task in pre-internet days, and the slides which eventually arrived have been a mainstay of several of my talks ever since (I scanned them in for Powerpoint presentations during the early 2000s).

There was a moment as I read Rainbows, Haloes and Glories that I just knew I had a new talk. It came when I came across Greenler's quotes from Jules Verne's novel *"The Green Ray"*, and the *"Old Scottish Legend"* that Verne outlines. When I came to read The Green Ray, I realised that I could let the characters from the novel outline their own, incorrect, theories for why a green flash occasionally accompanied the setting sun; then take the audience through the correct physics; and finish with the extraordinary sequence of setting Sun pictures in Greenler's book, taken by Pekka Parvainen. The resulting talk premiered at the Easter star party of the Astronomy Centre, Todmorden and has been repeated many times since; it's my favourite talk.

The Astronomy Centre is close to where I grew up and for many years I'd visit my parents every Easter and give a talk to the Star Party. The year after the Green Flash I was researching another topic from Greenler's book, the glory or Spectre of the Brocken. Greenler recounts a story about a related phenomenon, the Heiligenschein, from *"The*

Autobiography of Benvenuto Cellini" which I thought I could hang a talk on – then I read a paper about the Glory in Scientific American which begins with Henry Miller's astonishing quote about *"The Arms of Buddha"*. At that instant I knew I had a talk for that year's Easter Star Party. The next year after that I gave a talk on Rainbows – I never quite came up with "the killer quote" for a rainbows talk, but the science of rainbows is so strong and so accessible that it didn't need a outrageous legend. Thus *"Rainbows Haloes and Glories"* has inspired three of my most enduring talks. There's even a fourth talk, *"The Battle of the Three Suns"* which I've never quite managed to extend to a full hour. Maybe one day…

I was continuing to produce a stream of articles for MIRA. For example, an astronomical pop quiz was followed by an astronomical music quiz. But I was always on the lookout for an angle to illustrate some obscure astronomical or mathematical fact that caught my fancy. As an example — escape velocity. This is how fast you have to fire a projectile, straight up, neglecting air resistance (which you can't, but that's another story), for it to escape from Earth's gravitational pull and enter the gravitational domain of the Sun. But you don't have to travel at escape velocity to do this. When we get round to building a space elevator, we could travel up it at walking pace and arrive at geostationary orbit many weeks later, fit and ready to blast off for the Solar System.

All very interesting (or not, according to taste). But is the same true for a black hole? If you read popular science books or articles you might come across a statement to the effect that escape velocity from a black hole is greater than the speed of light, and so it's impossible for anything to escape, because nothing can travel faster than light. All very well, but as we've just established, you don't have to travel at escape velocity to escape Earth's gravitational well.

To put it another way: why can't you abseil into a black hole, take a few pictures, and then climb back out again? The mathematical answer is to do with closed geodesics – but that doesn't really make for an easy article. I struggled to figure out how I could write interestingly about why it was impossible to abseil into and out of a black hole, until I had a flash of inspiration. Who would be stupid enough to try? I realised that I had known any number of people at university who would be daft enough to give it a go. And so was born the Interplanetary Dangerous Sports Club, a series of tales about my good friend Clive (an amalgam of my university friends) and his wild adventures around the universe.

The Dangerous Sports Club stories were very popular, and tested my imagination. Quite often, I would let Clive decide what happened next. At the end of the second story Clive was about to surf a supernova shock wave to the other end of the observable universe. What could possibly stop him from undertaking this suicidal endeavour? A girlfriend, of course, and so Clarissa also came on the scene (she was based on one of my more terrifying girlfriends – I won't tell you her real name, just in case she ever reads this). The stories were of uneven quality, but I was very pleased with the best of them, in particular *"Because it isn't there – the ascent of the anti-Matterhorn"* and *"Tying the Knot"* in which Clive and Clarissa's wedding is interrupted by the news that Clive already had a previous wife, who inconveniently fell into a black hole. But is he still married? Well, that rather depends on your frame of reference. . . My favourite title was for the episode where Clive rescues Clarissa from a curiously antipodean prison on Mercury – *"Prisoner Cell Block Hg"* of course. I wrote nine Dangerous Sports Club Stories, and then ran out of inspiration. I like to think that this was because Clive grew up and matured. I see him and Clarissa these days as a bickering middle-aged couple; kids off to university; Clive wishes he was back there himself. . .

Another suggestion for material came from a C&WAS member, who told me they'd love to read something about how's Earth's gravitational field varied across the planet. The person concerned, who I haven't seen in years, was a little bit overweight, so I wrote an article on *"How to Lose Weight"* with some unconventional ideas which don't usually appear in diet books – go to the top of a mountain, or the equator, or a smaller planet. . . *"How to Lose Weight"* eventually developed into a full length talk, which I gave at the British Science Festival in 2010; and a three-minute talk, which got me into the regional final of the Famelab science speaking competition. In the Famelab final I spoke for three minutes on Rainbows, but regrettably it wasn't enough to get me into the national final – I've seen several of the finalists on TV subsequently.

In 1995 I started submitting articles to *"Practical Astronomy"*, a magazine established by Patrick Moore in opposition to Astronomy Now, who he had fallen out with. The editor of Practical Astronomy, Adrian Ashford, was very encouraging, and printed my articles on Flagstaff, Camera Obscuras, the Celestial Police and Twinkling. Unfortunately the magazine then folded, so I never got paid for any articles (I'm not blaming Adrian for this). In the meanwhile I'd attended my first total solar eclipse at Fatipurh Sikri, India, in October 1995. There I met Pam Spence, the then editor of Astronomy Now, who invited me to contribute to her magazine. Over the next few years I wrote for ANow on the Green Flash, the 1927 eclipse, How to Lose Weight, the anarchist attack on the Royal Greenwich Observatory, the Tswaing Meteor Crater in South Africa, and on Tidal Bores.

It's interesting that the last time I offered an article to Astronomy Now, the editor said that, whilst he enjoyed it, he felt the content was too complicated for ANow readers. Perhaps I have managed to unlearn how to write articles on popular astronomy.

A pivotal moment in my astronomical career occurred in 1997, when C&WAS held an event in Rugby. Vaughan Cooper told me that he was going to visit the birthplace of the Victorian solar astronomer Norman Lockyer. Where was that? I wondered. It turned out to be a house in Sheep Street, central Rugby, and I had walked past it approximately twelve hundred times without once ever noticing the plaque commemorating his birth. This shows how good an observer I am.

I decided to find out more about Norman Lockyer. There are two biographies of him, but neither covered his early life in great detail. I worked with friends in Rugby's local history group to find out more about his life and times in Rugby. This research resulted in a paper in the journal of the society for the history of astronomy (SHA), and another popular talk. The SHA was founded at the start of the 2000s. I missed the inaugural meeting because I "got detention" and had to stay the week-end at Port Talbot to fix some technical problem. Had I attended that very first meeting I suspect that I might have ended up on the SHA council rather than my eventual route to becoming BAA historical section director.

I was actually very busy with work through the early years of the new millennium. This was in part because we had a series of contracts in America, Canada and South Wales, but also because I was doing a part-time M.Sc in engineering at Coventry University. I did still produce astronomical articles and talks during this period, but perhaps not as frequently as usual. As I came toward the end of my M.Sc thesis, I began to envisage the "creative explosion" which would happen once I turned back to astronomy full-time.

The creative explosion did happen – but not quite in the way I expected. The catalyst turned out to be one of the great days of my astronomical life, the transit of Venus in June 2004. I wrote a series of articles for MIRA about the history of transits, which were later published in the BAA journal. On transit day itself, I was in Cambridge, with fellow alumni and alumna of Emmanuel College, to celebrate the achievements of our compatriot Jeremiah Horrocks, first Venus transit observer (with appropriate nods to astronomers of other cultures who may have glimpsed a transit before Jeremiah). Among the celebrants was Peter Aughton, who had just published a biography of Horrocks, *"Transit of Venus: the brief, brilliant career of Jeremiah Horrocks"*. This very enjoyable popular history has been a fertile source of research for me.

One single line in the book that led to multiple papers and talks was a quote from Jeremiah Horrocks. In the letter in which he alerted William Crabtree to the possibility of a Transit, Horrocks also writes *'If this letter should arrive sufficiently early, I beg you will apprise Mr. Foster of the conjunction [Transit of Venus], as, in doing so, I am sure you would afford him the greatest pleasure.'* Who was Mr Foster? He turned out to be Samuel Foster, Gresham professor in London – but he spent his formative years in Coventry, at the grammar school, and at New Hall, Keresley. He observed a lunar eclipse from New Hall in December 1638, in the company of his friends John Palmer and John Twysden, and perhaps a precocious whippersnapper called Nathaniel Nye, who later wrote that he too had observed eclipses from Coventry at the time.

One of the great thrills of doing historical research is the moment that you realise that you are exactly the right person to be researching a particular topic. Jeremiah Horrocks and I are both astronomers, both Lancastrians, both graduates of Emmanuel College Cambridge – we even both had/have relatives in Rhode Island. How weird is that? If a co-incidence like this happens to you, make the most of it! Emmanuel College have been supportive of my researches into Horrocks, Foster and Palmer (all Emmanuel graduates). My Rhode Island relatives have been invaluable in helping me find out about Horrocks's correspondents among the colonists in the early days of the Rhode Island colony.

With Samuel Foster and his friends, a similar series of serendipities – perhaps synchronicities – happened. Every time I looked, a new, promising, line of enquiry opened up. Until one day I was sitting in Cambridge University library reading an almanac by the aforementioned Nathaniel Nye – and came across his claim that he too had seen the 1639 transit of Venus, making him one of only three people (along with Jeremiah Horrocks and his fellow Lancastrian William Crabtree) to have seen that very first transit. I have written elsewhere about how I had to turn away from the screen (it was a scanned copy of the book) and go for some lunch, just to calm myself down. This was my big discovery! Alas, when I came back from lunch, I realised that Nye's account was deeply flawed (for example, he gets the date wrong by one day), and is I think most likely a garbled re-hash of Horrocks's own account.

The story of Nathaniel Nye forms just a few paragraphs, little more than a footnote, in the long paper I wrote about Samuel Foster for the SHA's journal *"The Antiquarian Astronomer"*. On the other hand, it makes for a really good talk – I can tease the audience throughout as to whether Foster or Nye, or someone else, actually saw the 1639 transit. What comes across as wild speculation in an academic paper (did the teenaged Nye see the 1639 transit but not realise what he had seen until years later?) works much better in the informal setting of a talk.

So, most of the talks I was producing through the 2000s were related to my astronomical researches – to Horrocks, Foster and his circle, Lockyer, and other astronomers whose lives I have researched, including the Hanoverian polymath Henry Beighton and Revd William Pearson, co-founder of the Royal Astronomical Society. I wrote about these researches for the BAA Journal in an article on *"Getting started in the history of astronomy"*, which was reproduced in MIRA, so I won't bore you by repeating detail on the talks and articles which my researches have inspired.

In 2010 I was offered, to my complete surprise, the directorship of the BAA's historical section. This has been a great source of satisfaction to me, but has somewhat curtailed my original research, as I have too much routine section work, such as organising section meetings, to do. On the other hand I contribute articles to the bi-annual section newsletter, which seems to have re-kindled an interest in general articles on the history of astronomy – perhaps I'll try again for Astronomy Now before too long.

Also in the late 2000s I became a fellow of the Royal Astronomical Society. The RAS has also been an inspiration to me, but I do feel the need to act with the decorum that being a fellow of a learned society implies. Before joining the RAS, I wrote a number of articles for MIRA in which I tried to investigate controversial topics – *"Maunder Minimum"* discussed whether long-term solar cycles can affect climate (I think yes, but that doesn't let us off the hook for man-made global warming). *"Receding Moon"* took a swipe at young-earth creationists, *"Prediscovery"* supported Jocelyn Bell for a much-deserved Nobel prize, and *"What's in a Name"* suggested that we might auction off naming rights to extra-planetary objects as a way of funding science. I have now retreated to less provocative topics. In fact, in recent years, I have been completing a bucket list of articles I've been meaning to write for years, such as *"an Inventory of the Solar System"* or *"You Cannot be Sirius"*.

My talks, needless to say, have headed in yet another unexpected direction. I have been on many astronomical holidays all round the world, but, as those who know me will testify, I am not an imager. So I've been reluctant to incorporate my holidays into talks. I think that articles for MIRA suit the material better, and I can often shape the holiday experience into a story – for example, the scary night-time journey to observe the 2001 Leonids, which concluded with one of my friends becoming a minor Polynesian deity. Or visits to fascinating and quite often scary places – Mongolia, Libya, Mozambique, Zimbabwe. . .

Then in 2015 I joined the Totally Insane Travel Society on their trip to Svalbard to observe the solar eclipse and see the northern lights. The holiday was wildly successful on several counts. First, the eclipse was observed in perfect skies, albeit with temperatures below minus twenty degrees C. Second, the extraordinary things we saw – shadow bands, fata morgana, beautiful aurorae. Third, the superb imagers whose company I enjoyed on that holiday, and who were happy for me to share their work with a wider audience. Fourth, my Microsoft Surface Tablet, which enabled me to shoot video up to and just after totality, capturing the atmosphere of a unique day (a tablet is useless for recording fine detail on an eclipsed sun, but great for recording the sudden onset of frostnip in the cameraman). Fifth, the number of memorable things that happened inside the Arctic Circle – TV interviews, polar bear attacks, French girls taking their clothes off. All these made for a memorable talk which has been popular ever since. My trip the next year to Indonesia wasn't quite so bonkers, but *"Gerhana Mata Hari"* has also been well-received. Perhaps starting with ten minutes about the famous exotic dancer, courtesan and spy, the other Mata Hari, is a good way of getting the audience onside.

So what of the future? I have a longish list of articles I'd like to write, and I'm sure I'll make my way through them. I'm also sure that unexpected things will happen to me which demand that I write about them. I intend to go and see some more eclipses, aurorae and meteor showers and visit astronomical sites around the world, both natural and man-made, and these will find their way into MIRA, or talks, I'm sure. Some specific projects are on my agenda. The RAS is 200 years old in 2020, so a renewed focus on its co-founder, William Pearson, the rector of South Kilworth, is very likely. And there are several astronomers with links to Warwickshire who I haven't yet got round to researching.

Then again, the Interplanetary Dangerous Sports Club might decide to re-form, to revisit the crazy activities of their youth, paying little attention to mortgages and middle-aged spread. And then I'll have to tell you about their adventures!

Measuring the Earth

By Mark Edwards

Some years ago some of us from the society visited Newton's birthplace in Woolsthorpe and had our pictures taken in front of his famous apple tree. The story goes that Newton saw an apple fall from the tree and realised that it was falling directly towards the centre of the Earth and that the force acting upon it was the same force that kept the Moon in orbit. This was the force of gravity.

What you might not realise is that we can use that simple observation to get an estimate of the Earth's radius.

If instead of letting the apple fall we were to throw it sideways at just the right speed (and also removed the Earth's atmosphere) it would not hit the ground, but instead it would orbit the Earth staying at the same height above it. In both cases the force of gravity towards the centre of the Earth would be the same and hence the acceleration that the apple experiences would also be the same.

We can calculate the apple's acceleration as it falls off the tree by knowing the height of the branch it was attached to and timing how long it takes to hit the ground from the equation:-

$$a = 2s/t^2$$

s = height of the branch
t = time taken to fall

If now we equate that acceleration to the one the apple would experience towards the centre of a circular orbit, given by:-

$$a = v^2/R$$

v = velocity of the apple
R = radius of its orbit

As the orbit is a circle the distance travelled in one orbit

$$= 2\pi R$$

so:-

$v = 2\pi R/T$

T = time to complete one orbit

Substituting for v gives us:-

$a = (2\pi R/T)^2/R$

therefore:-

$a = 4\pi^2 R/T^2$

We know this is equal to the acceleration of a falling apple, so:-

$a = 4\pi^2 R/T^2 = 2s/t^2$

or:-

$2\pi^2 R/T^2 = s/t^2$

Rearranging gives us an equation for our estimate of the Earth's radius:-

$R = (s/2\pi^2)(T/t)^2$

In principle we could time the apple as it falls (t) and time it as it passes overhead in its orbit (T) and we would have our measure of the radius of the Earth. Unfortunately, there aren't many orbiting apples!

However, there is an object visible in the night sky from time to time that we can use as a substitute. This is the International Space Station (ISS). As the ISS is in a very low orbit we can as an approximation assume that it is in a circular orbit whose radius is equal to that of the Earth's.

If now an astronaut performing a space walk on the ISS were to lose an apple from their pocket it would follow the same orbit as the ISS, so giving us our orbiting apple!

This then gives us a very simple way of estimating the Earth's radius from our own back gardens with a stopwatch and an apple. Just drop the apple over a known distance and time it with the stopwatch. Then time how long it takes for the ISS to reappear after it has already passed overhead, put it into the equation and there is your answer.

As an example, if you let an apple fall for 5m it will take about 1s and one orbit of the ISS takes about 90mins.

So we have:-

s = 5m
T = 5400s
t = 1s

Using the equation gives R = 7386km which is not a bad estimate as the real figure for the Earth's mean radius is 6371km.

Now we have an estimate of the Earth's radius, can we use that to determine the distance to that other half of Newton's musings, the Moon?

To do this we can use Newton's theory of gravitation, which says that the acceleration due to gravity experienced by the Moon towards the Earth is given by:-

$a = GM/R_M^2$

G = gravitational constant
M = mass of the Earth
R_M = distance between Moon and Earth

As with the apple in orbit we can equate this acceleration to that towards the centre of a circular orbit, so:-

$a = GM/ R_M^2 = 4\pi^2 R_M /T_M^2$

T_M = time for Moon to complete one orbit

or:-

$GM/4\pi^2 = R_M^3/T_M^2$

This equation is the same as for an apple in orbit, so:-

$GM/4\pi^2 = R^3/T^2$

We can then combine these two equations to give:-

$GM/4\pi^2 = R_M^3/T_M^2 = R^3/T^2$

(This is Kepler's third law of planetary motion)

Rearranging gives us:-

$R_M^3 = R^3 T_M^2 /T^2$

So using our previously calculated value for R (the Earth's radius) and timing the ISS (T) and the Moon (T_M) we can calculate the distance to the Moon (R_M).

Again, as an example, the Moon takes about 27 days to complete one orbit.

So we have:-

R = 7386km
T_M = 2332800s
T = 5400s

Using the equation gives 422,000km which compared to the Moon's mean distance of 385,000 is not a bad estimate.