# BAA / RMetS Joint Meeting, 2004 November 27
## held at The Geological Society, Burlington House, Piccadilly, London W1

### **Tom Boles**, President

### **Ron Johnson, Nick Hewitt and Nick James**, Secretaries

Opening the Meeting, Mr Jonathan Shanklin welcomed members to this innovative joint venture between the British Astronomical Association (BAA) and the Royal Meteorological Society (RMetS). As organiser of the day's talks, he hoped they would prove interesting, and invited members to give him feedback; short questionnaires were provided for this purpose. It was explained that the morning session would be chaired by Mr Tom Boles, President of the BAA. Prof Chris Collier, President of RMetS, would preside over the afternoon session, whilst Dr Brian Marsden would chair the George Alcock Memorial Lecture. Mr Shanklin then handed over to the morning's chair.

With apologies to those members of RMetS for whom it was not relevant, Mr Boles requested five minutes for BAA business. This was the second meeting of the 115th session of the Association, and Dr Hewitt was invited to read the minutes of the first, which were duly accepted and signed. The 24 new members proposed at the previous meeting were also accepted and declared elected, subject to ratification at the Meeting of Council later in the day. Mr Nick James, papers secretary, announced that one new paper had been approved to appear in the Journal, also subject to Council's acceptance:

*The Mean Density of the Earth*, by Prof David Hughes.

The next Ordinary Meeting would be held on December 18 in the newly refurbished English Heritage Lecture Theatre, formerly the Scientific Societies' Lecture Theatre, at 14:30, but would be preceded by the Christmas Lunch at 13:00, for which places were still available. The Christmas Lecture would this year be delivered by Prof David Hughes, entitled *Comets, and their Exploration by Spacecraft*. There being no further business, Mr Boles introduced the first speaker, Dr John Mason, a founder of the *South Downs Planetarium*, former BAA President, and frequent contributor to the *Sky at Night*.

## Meteors

Dr Mason opened expressing his thanks to Messrs Bob Marriott and Gordon Rogers for filling in at such short notice at the previous BAA meeting, since train delays had prevented him from presenting his scheduled talk. He remarked that the words 'meteor' and 'meteorology' had a common root in the ancient Greek adjective *meteoros*, meaning 'up in the air', which had referred to all phenomena in the atmosphere, from rain and snow to clouds and meteors. The first known scientific study of meteors was contained within Aristotle's *Meteorologica* (350 BC), which essentially summarised humanity's complete knowledge of weather and climate of the time. However, despite the subject's long history, the reaction of astronomers to meteor showers had changed considerably in the space of only the past thirty years. Whereas in the past they had been thought fully understood – they started, a few days later they peaked, and then they stopped – it was now realised that there were often surprise changes in rate, multiple peaks, and a whole host of other phenomena to be explained.

The speaker first introduced *meteoroids*: the progenitor interplanetary particles behind meteor storms, which created the observed streaks of light when they collided with the Earth's atmosphere. These were typically found to weigh between $10^{-9}$-$10^{3}$kg, and, in total, an average of around 16,000 tonnes of such material entered the atmosphere per year. In terms of physical composition, it was important to realise the low physical density of meteoroids, typically between that of water (1g/cm$^3$) and one-tenth that density, averaging around 0.3g/cm$^3$. This unusually low density could be explained by their structure: silicate rods with large spaces between them, originally occupied by water ice, which would over the course of time have sublimated.

Moving onto the trails themselves, Dr Mason showed an image of Taurid meteors, remarking that each varied: there were often multiple brightenings, and whilst some ended in a terminal burst, others simply faded away. The speaker also added that the height at which they were at their brightest was found to correlate with the collision velocity of the meteoroid, typically in the range 70-120km, most commonly at 95-100km. Those which peaked highest were the fastest moving, whilst slower meteors penetrated deeper into the atmosphere. The distribution of velocities was itself found to be very large – it had to be remembered that the Earth orbited the Sun at a speed of 30km/s, and so there was a difference of 60km/s between the observed speed of meteors colliding head-on as compared to those which the Earth had just caught up with from behind. Typically, velocities between 11-72 km/s were observed. There was some variation between showers, for example Leonid meteors were faster than most, and typically very close to 72km/s.

Upon collision with the atmosphere, the speaker explained that meteoroids transferred their kinetic energy to the atoms and molecules around them in a process called *ablation*. The result was that the surrounding molecules became excited, and often ionised. They would subsequently de-excite with the emission of light, giving rise to the observed glow. The speaker also remarked that ionised material reflected radio waves, and so meteor trails could be observed not just in visible light, but also from the radio waves they scattered. In the past, this had been quite popular among amateurs – a way to observe meteors even in cloudy conditions.

At optical wavelengths, meteors could appear at brightnesses of up to mag –16 or –18 – one-hundred times the brightness of a Full Moon. Some observers chose to use a wide-angle lens to photograph the whole sky when looking for meteors: this ensured no part of the sky was left unobserved, but did come with the downside that only the very brightest meteors were generally detected. The speaker felt this technique was only really useful for recording bright fireballs, from progenitor particles the size of grapes or oranges. By contrast, for fainter meteors, the use of intensified video cameras was recommended. Video photography with such instruments had been pioneered by Andrew Elliot and Steve Evans, who had used it to obtain orbits and estimate the heights of meteor trails. In the past, such calculations had also been done by installing a rotating blinking shutter of known speed on a camera, chopping up the observed trails, or by triangulation from observations at different locations.

The speaker explained that the trails could remain visible for several seconds, or up to 30-minutes in extreme cases. However, as they hung in the atmosphere, they were observed to distort from their initial straight line, as they were carried in the wind. It was found that the dispersion rate depended upon altitude – the shortest lived trails were at 90km, whilst those higher or lower decayed more slowly. This was particularly useful to radio observers, who could use the measured dispersion rate of their radio signal to estimate the altitude of each meteor they observed.

Dr Mason went on to explain that there were two distributions of observed meteors: showers and sporadics. The latter group arose from randomly distributed progenitors, and could be seen at any time of year, in any part of the sky. By contrast, showers resulted when objects, often comets, left streams of debris lying behind then, strewn across particular parts of the solar system through which the Earth passed at various times of year. Most of the very brightest meteors were sporadics, including most *fireballs*, defined as those brighter than mag –5, and *bolides*, meteors so brilliant that they generated an audible sound. In the most extreme cases, very massive meteors might make it all the way through the atmosphere to leave rocky debris on the ground, *meteorites*.

The number of meteors seen was found to vary both with the time of day and time of year. The speaker first explained the daily variation, which was due to the direction of the Earth’s spin with respect to its orbit around the Sun. At local dawn at any point on the Earth, the zenith pointed close to the direction in which the Earth was travelling through space as it orbited the Sun. Thus, any meteors above the horizon at this time made head-on collisions with the Earth, and as a result there were many of them and they had higher than average impact velocities. By contrast, at sunset, the zenith pointed away from the direction in which the Earth travelled: any meteors observed would be just catching up with it from behind, and so there would be few of them and they would have slower-than-average velocities with respect to the Earth. As a result, four times more meteors were seen just before dawn than just after dusk.

With regard to seasonal variations, the speaker returned to his division of meteors into two distributions. As comets approached the Sun, their surfaces were thought to crack, spewing fountains of dust grains into the interplanetary medium, leaving behind them streams of such material stretching through the solar system. As the Earth cut through these streams in its orbit around the Sun, brief showers of meteors were observed on the ground. All the meteors in the shower would appear to radiate from a common point in the celestial sphere, because all the dust grains were in near-identical orbits, similar to that of the parent comet. Some showers had a fairly steady rate from year to year, such as the Orionids, implying the dust stream to be fairly uniform. Others, such as the Bootids, had more erratic rates, indicating some bunching of the dust. Perhaps one of the most closely studied examples was the November Leonid shower, which Asher and McNaught had modelled as a series of fine filamentary clouds of particles, from which they had been able to accurately predict when there would be good Leonid displays, often correctly expecting several successive peaks in rate, each only around an hour in duration.

To close, the speaker recalled a story illustrating his earlier assertion that small-field cameras were often better than wide-field lenses for meteor observation. He explained that the Very Large Telescope (VLT) in Chile had been taking the spectrum of a supernova event, when a mag –8 meteor had passed through its field of view. This serendipitous accident probably seemed intensely frustrating at the time, but the result had been the highest resolution spectrum of a meteor trail ever recorded.

Following the applause, a member asked whether the increased use of Scramjets by the US military would make it more difficult to observe meteors by their radio signatures. Dr Mason replied that it was already very difficult to select frequencies which were not affected by a number of sources of noise, and he could only see this problem getting worse. Mr Boles then welcomed Dr Pat Espy of the British Antarctic Survey to present the second talk.

## Noctilucent Clouds

Dr Espy opened with a gallery of images of the clouds he would be talking about: strikingly beautiful silvery blue streaks which appeared across the night sky at high latitudes at certain times of year. These particular images were from Scandinavia, and he explained that despite the unusual colours of the clouds, they were in fact composed of the same water ice as many more familiar clouds, though in this case the ice crystals were very small – smaller than the wavelength of light – and at high altitude. The small size of the crystals gave them the same Rayleigh scattering properties as the particles which gave the atmosphere its characteristic blue hue, hence the clouds' similar apparent colouration, the speaker added. They appeared to glow in the night-time as a result of their high altitude: after sunset at ground level, the upper atmosphere might remain outside the Earth's shadow for some time, and the noctilucent clouds (NLC) thus remain illuminated by the Sun.

The exact altitude of NLCs had been known to be very high for some time: images from research aircraft flying at 37,000ft, for example, showed the clouds to be still very much higher above the plane. Their exact height had recently been measured using ground-based laser radar (LIDAR), which reflected laser beam pulses from them and timed the travel time before a return pulse was detected. The average derived altitude was 82.5km, high in the mesosphere, and much higher than more familiar clouds at altitudes of only a few kilometres.

The discovery of clouds at such altitudes was somewhat surprising: the speaker explained that the mesosphere was very dry, and so very cold temperatures would be required for any condensation to occur. Yet the mesosphere was originally thought to be as warm as the lower atmosphere, and that would have required much more water vapour than available. In addition, as it was above the ozone layer it would be bathed in ultraviolet solar radiation energetic enough to break apart water molecules, and so the existence of clouds implied some mechanism to continuously replenish this large supply of moisture. It was not until the 1960s, when the mesosphere was discovered to be extremely cold during the summer months, that a suitable formation mechanism was suggested.

Whilst the actual details of this mechanism were somewhat complex, the speaker proceeded to summarise our current understanding. The two essential ingredients were two air movements: firstly gravitationally-supported vertically-propagating waves through the atmosphere, generated by the movement of air masses over mountains and the jet streams, and secondly the circulation of the stratosphere around the poles, driven by the warming effect of the absorption of solar ultraviolet radiation by the ozone layer, and the rotation of the Earth. In the summer months, these interacted to produce substantial vertical motion into the mesosphere, both injecting moisture into it from the lower atmosphere, and, less intuitively, influencing the thermodynamics of the mesosphere to produce a cooling effect, yielding temperatures around 130-140K. At this temperature, the ~6ppm water concentration in the mesosphere would be well saturated. In winter, the interaction was reversed, and the mesosphere thus around 60K warmer.

The speaker explained that whilst NLCs might be present at any time of day, they were only visible when the Sun was between 6-12° below the horizon. When the Sun was higher, the clouds were lost in the sky's own blue glow, but when the Sun sank too far beneath the horizon, they themselves entered the Earth's shadow and faded from view. For this reason, there were long observing windows from Scotland and Scandinavia in the summer, when the Sun remained not far beneath the horizon long after setting, but much shorter windows for observers further from the poles. Satellites could also observe them close to the Earth's day-night limb, though in this field they were generally referred to by the alternative North American term, *Polar Mesospheric Clouds* (PMCs).

The speaker explained that there were many outstanding puzzles: for example, what atmospheric dynamic processes gave rise to their small-scale, filament-like structure. There was also evidence of solar-cycle dependence, as well as differences between the NLCs observed in the two hemispheres, possibly attributed to the near-alignment of the southern hemisphere's summer with the Earth's perihelion, and the corresponding aphelic northern summer. Curiously, the first records of NLCs dated back to 1884: they appeared to have been absent before this time – interesting in view of recent modelling, which suggested NLC activity to correlate closely with the $CO_2$ content of the atmosphere. An increase in greenhouse gases was thought to retain heat in the lower atmosphere, but reduce the upward heat flow, resulting in a cooling of the upper atmosphere. A doubling of the $CO_2$ concentration might reduce the mesosphere temperature by 10K, helping to satisfy the temperature requirement for NLC formation.

However, whether they truly were the miners' canary for climate change remained a matter of intense debate. Amateur reports of NLC sightings from Scandinavia were becoming more frequent, but the speaker was unsure how scientific this was: the region's population was also increasing, and the number of people looking for NLCs on any given night difficult to determine. For example, one apparent dip in the number of sightings correlated remarkably well with the period during which one of the more dedicated observers had been on military service. Further questions also remained over the distribution of sizes of the ice crystals, and the nature of their nucleation sites.

Following the applause for Dr Espy's talk, a member remarked that these images might not be so useful for raising environmental awareness, as without global warming, we might not see these beautiful structures. In response to a question concerning the nature of the mechanism behind the solar-cycle dependence of the phenomenon, the speaker replied that it was thought to be primarily that the enhanced flux of ultraviolet radiation broke up water molecules in the mesosphere more rapidly when close to solar maximum. Mr Boles proceeded to introduce the morning's final speaker, Mr Mike Pinnock, Head of the Physical Sciences Division of the British Antarctic Survey.

## The Aurorae

Mr Pinnock opened with a video of the northern lights, filmed from Alaska, which served both to introduce the phenomenon as well as to illustrate two features which were often not well appreciated: the fine structuring of the light, and its dynamic nature – the rippling structures changing from one second to the next. The speaker explained that whilst the altitude of aurora varied between a hundred and a few hundred kilometres, the image in question, a rare red aurora, was known from its colour to be at around 100-110km. It was also explained that whilst the physical mechanism producing the light was essentially understood, the structuring was not yet well understood.

Historically, aurorae had fascinated humanity for thousands of years, and the speaker recalled an excellent recent article by Stevenson et al.[1], which reported the discovery of a late Babylonian astronomical table, interpreted to contain the earliest known record of auroral observation, dating from 567 BC. The phenomenon was now understood to be triggered by the collision of charged interplanetary solar wind particles, primarily electrons and protons, with the Earth's atmosphere. Upon reaching the outer layers of atmosphere, such particles would typically be absorbed, resulting in the excitation of the absorbing particle. The energy would subsequently be re-emitted in the form of light of a colour characteristic to the material of the absorber – the same radiation mechanism used in television tubes. Mr Pinnock explained that there was considerable scientific interest in the effect, as it was a probe of many other processes which were much more difficult to measure. In addition, it was also known that enhanced solar activity posed a range of hazards to technology, especially satellites in orbit, but in extreme cases also on the ground, and so understanding the underlying processes was seen as a high priority.

It was now well-established that aurorae were primarily seen in two oval circumpolar belts, at latitudes 65-75° N/S, called the *auroral ovals*. This had first been realised in the analysis of data collected in the International Geophysical Year of 1957-8, but deeper investigation essentially had to await satellite technology, for example NASA's *Dynamics Explorer* probes, launched in 1981. Though many of the brightest aurorae were associated with the enhanced solar wind following coronal mass ejection (CME) events on the Sun, the speaker wished to make clear that there was always some background activity – the so-called *quiet-time auroral oval*. However no activity was visible at latitudes as low as the UK's 52° without the impact of solar features such as CMEs with the Earth's magnetic field.

The speaker showed images of a CME taken from the SOHO solar observatory – huge eruptions of solar material, often taking no more than an hour to develop. As the erupted particles travelled out through the solar system, they suddenly impacted with a shock front upon reaching the Earth's magnetic field, compressing it on the day side. Most of the charged particles in the solar wind were deflected by the Earth's magnetic field, but some penetrated the outer limits of the geomagnetic field and were then guided by it towards the polar regions, where they triggered aurorae. However, wishing to clear up one common misconception, the speaker emphasised that during storms as many as 90% of the plasma particles in the Earth's magnetosphere actually originated from the ionosphere, not the solar wind. Whilst the solar wind triggered the phenomenon, for the most part the visible glowing was caused by excited *atmospheric* material. Mr Pinnock explained that after the impact of CMEs, the auroral oval was observed to enlarge, both towards the poles and the equator. A series of "substorms", each lasting perhaps an hour, might extend the oval a few degrees in latitude, and thus several in succession were required to generate any visible effect in Scotland, and even more for London.

Returning to the subject of the technological hazards of solar wind phenomena, the speaker recalled that in recent years a handful of satellites had been lost to the damaging effects of solar storms. The collision of high-energy particles with the semiconductors used in the electronics of satellites tended to destroy small regions of it, and so the collision of such a particle with a satellite's on-board computer could easily result in the loss of the spacecraft. Such particles did not reach the ground, but there were still other hazards. The speaker recalled in particular the geomagnetic storm of 1989 March, which had blacked out much of Toronto. In this case, surging ionospheric currents had induced current surges in a power line, causing the dramatic explosion of a transformer. The hazards of such currents had to be considered in the design of any large metal structures at auroral latitudes, the speaker added, pipelines being another example.

Reviewing future plans, the speaker discussed proposals to study artificially-induced aurora, using huge antenna arrays to deliver 2MW of radio power into the ionosphere, exciting it at an altitude of 230km. Mr Pinnock also remarked that aurorae had been observed on other planets: the *Galileo* probe had detected polar brightenings on Jupiter caused by a similar phenomenon, however the formation mechanism had been shown to be rather different from its terrestrial equivalent, and so in the process, we had come to understand a new way in which aurora could arise.

To close, the speaker remarked that there was sadly little UK amateurs could usefully do in the observation of aurorae – the UK was not far enough north – but those who were interested were encouraged to sign up for the Lancaster University e-mail alert system[2], whereby they would receive regular updates on current space-weather activity.

Following the applause for Mr Pinnock's talk, the meeting broke for lunch. After the break, Prof Chris Collier, President of RMetS, took the chair, and welcomed the first speaker of the afternoon session, Dr Damian Wilson of the Meteorological Office.

## Tropospheric Clouds

Moving down in the atmosphere from the high altitudes of the previous two talks, Dr Wilson recalled that a previous speaker had already remarked that "one man's signal is another's noise". For amateur astronomers, this was certainly true of the present talk. Before starting, he wished to credit those who had contributed to the RMetS Cloudbank, an online image library from which many of his images were borrowed, and which was freely available for all to browse.[3]

The speaker first explained that clouds were all composed either of water droplets, as in the case of cumulus or stratus, or ice droplets in the case of higher altitude clouds such as cirrus and altostratus. The simplest explanation for their existence was that the atmosphere contained water vapour, but could only contain a certain amount before becoming saturated, whereupon it condensed. The exact concentration corresponding to saturation depended upon the physical conditions: for example, warmer air could hold more water before reaching saturation. Clouds formed whenever water-laden air exceeded its saturation point, when it became favourable for the vapour to undergo a phase change to form water droplets or ice crystals. It was already clear that one mechanism by which this might come about in an air mass was cooling: as its temperature lowered, the saturation water-content lowered, so that previously unsaturated air might condense into clouds.

But the speaker added that it had been known since the 18th century that the rate at which air could hold more water with rising temperature itself rose with temperature. In other words, a profile of the saturation water-content against temperature was not a straight line, but it curved upwards. A very familiar demonstration of this was the rapid condensation of exhaled breath on a cold day. As the moist breath mixed with surrounding air, both its temperature and water content would average towards that of the surroundings, traversing a straight line across a water concentration vs. temperature plot. Given that the exhaled air did not start out saturated at its initial warm temperature, and that the surrounding air was similarly unsaturated, the two ends of this straight line lay below the saturation limit. Yet as the exhaled air travelled along the line, it was observed to condense – a sign that it had exceeded saturation – demonstrating the saturation limit to be curved. This itself was of profound importance in cloud formation: the mixing of two bodies of air at different temperatures and with different water contents could lead to cloud formation, even if neither was itself initially saturated.

Dr Wilson went on to discuss various other mechanisms by which clouds might form. The fog seen on the floors of Martian valleys, for example, was caused by the radiative cooling of the surface during the night-time, and the subsequent cooling of the layers of air directly above them. By contrast, the sea-smoke seen in Arctic regions – not strictly smoke, but rather fog – resulted from the mixing of cold dry air with warmer moist sea air. As with an exhaled breath, the mixing of these unsaturated air masses caused condensation.

However, one of the single most important mechanisms was the rising of air masses. In this case, as the altitude of the air increased, its pressure dropped to equal that of its surroundings, and it expanded. But because the air evolved adiabatically – without heat input – this expansion also caused it to cool. It turned out there were many mechanisms by which vertical air motions might be induced, for example by convection, or the pushing of air masses over the windward side of mountains.

As well as these orographic considerations, cloud formation also varied with latitude as a result of the uneven heating of the Earth. Pressure was found to decrease more rapidly with altitude in cold regions, generating horizontal pressure gradients at high altitudes, and in turn air flows toward cold regions. To balance this out, counter-flows were required at low altitudes toward warm regions, as well as vertical flows to connect the two and complete the circulation cycle. This effect culminated in falling air in the cold polar-regions, and rising air at the equator, with roughly three circulation cells in between, each spanning 30° latitude. The speaker remarked that the size of each cell was limited by the rotation of the Earth, the consequent Coriolis forces drawing each flow out of the latitudinal direction, and into the longitudinal direction. Whilst the details were complex, the rich latitudinal banding of the Jovian winds provided illustration of this: on a larger planet, the rotational forces were more significant, and each circulation cell was consequently constrained to a smaller range in latitude.

To close, the speaker discussed where might be the best site for a telescope. Broadly speaking clouds formed where air was rising, and so latitudes 30° N/S, where the prevailing flow was downwards, were best. However, this was not universally true: the Canary Islands were at this latitude, but were very often cloudy because of boundary layers where moist air mixed with dry. But the speaker remarked that at high altitudes, above these mixing layers, the skies were generally good, hence the choice of location of so many professional observatories on the mountains of Tenerife and La Palma. In addition, the Sahara region was also poor for another reason: because of dust storms. Further complication arose in the selection of sites, because thus far the talk had only been concerned with transparency: by contrast, seeing conditions depended upon the mixing of air masses of differing temperatures and refractive indexes in the jet stream, bending rays of light. Atmospheric turbulence was therefore also a matter of concern, quite aside from avoiding cloud.

Following the applause, a member asked, given that water vapour was always in the atmosphere, why it only prevented the passage of light when condensed. The speaker replied that vapour was composed of particles much smaller than the wavelength of light, and thus which had little effect upon it. By contrast, condensed water droplets were significantly larger than this wavelength. Prof Collier then proceeded to welcome Mr John Nayler, a former physics teacher with a long interest in amateur astronomy, and author of the recent book *Out of the Blue* on his present subject.

## Rainbows

Mr Nayler remarked that of all meteorological phenomena, rainbows attracted perhaps the most interest. As well as scientists, they had also caught the imagination of many poets and philosophers over the centuries. From an astronomical prospective, Mr Nayler made the curious assertion, to be justified later, that whilst clouds were observed on many other planets and Moons in the solar system, with the possible exception of Titan, the same was not true of rainbows. Over the next half hour, he explained, he would be taking a historical approach, examining how humanity had come to understand their formation.

The first truly scientific study had been that of Aristotle, nearly 2500 years ago, but there were many basic facts which had been known since prehistoric times. A rainbow is an arc of many different colours, red on the outside, blue on the inside. The outside edge of the bow tends to be more brilliant than the inner edge. Sometimes a secondary bow can be seen just outside the first, with colours reversed. In the gap between the two bows, the sky is often noticeably darker than elsewhere, giving rise to the name *Alexander's Dark Band,* after Alexander of Aphrodisias who first noted the phenomenon in 200 AD. It had also been known since prehistoric times that certain conditions were necessary for a rainbow to be seen: the Sun had to be behind the observer, and there had to be clouds and rain in front. Finally, the speaker noted that rainbows were personal phenomena: the position of the bow was determined by the line between the observer's eye and the Sun behind him, and so everyone saw their own bow. And, contrary to popular myth, it was impossible to see a bow directly above oneself.

Aristotle's attempt to explain the formation of rainbows, around 350 BC, had been somewhat hampered by the untenable theory of light and colour within which he was trying to cast his theory: he essentially thought the eye sent out a ray, which interacted with the Sun's radiation. He had, however, been able to explain the circular shape of the bow by asserting that for all points on it, the distance to the observers' eye was in some constant ratio to the distance to the Sun. Despite the flawed theories upon which it was based, this work was to stand essentially unchallenged for nearly two millennia until the 17th century.

Aristotle had thought it was the entire cloud which gave rise to the bow. It was not until 1304 that it had first been proposed, by German monk Theodoric of Freiberg, that it was refraction within water droplets that caused the bow, though sadly this work was to be forgotten, and only uncovered in the 1830s. He backed up his argument by demonstrating the refraction of light through a circular flask of water. In 1266, Roger Bacon had also contributed to the field, by observing that the angular diameter of rainbows was always the same: 42° for the primary bow, and 51° for the secondary. Nowadays, it seemed curious that no one appeared to have made this measurement earlier.

However, the father of the modern understanding of rainbows was René Descartes, who in 1637 used his law of refraction, now known as Snell's Law in honour of its independent discoverer, to trace the paths of rays through spherical water droplets. Whilst most of the light would pass straight through the droplet, he realised a small proportion would undergo total internal reflection from the back surface of the droplet. He considered different rays of sunlight, entering the droplet at different angles to the surface, and calculated the angle at which they left the drop. It was found that all of these rays left the droplet going back in the direction they had come, at a slight angle to the original direction of travel. He further found that there was a maximum deflection from the original direction of 42°, and that at this angle there was a bunching together of the light rays – that is to say, many rays, having initially struck the droplet at different angles of incidence, all left it with nearly the same deflection. Rays at this angle, now known as Cartesian or caustic rays, added together to give the bright bow, circling 42° around the line connecting the Sun to the observer's eye. The formation of secondary bows was entirely analogous, but with two reflections within the drop, giving rise to a maximum deflection of 51°. The darkness of Alexander's Dark Band could also be explained: because no rays were deflected further than the caustic ray, none of the water droplets in the part of the sky outside the bow deflected light into the observer's eye.

However, the speaker remarked that Descartes' work still did not explain the colouration of the rainbow: it was monochromatic. This problem would have to wait until Newton's treatment in 1667. Around this time, Newton spent 18-months at Woolsthorphe, fleeing the plague, during which time he had realised that white light was not, as previously thought, pure. It was coloured light which was pure: white light was an impure mixture of colours. Whilst he had no particular interest in the phenomenon of rainbows, it provided a remarkably good test of his new theory. In particular, he realised that if the refractive index of the water droplets varied for different colours, as indeed he had experimentally found it to, the 42° radius of the rainbow would also be different for each colour, causing the observed splitting of the component colours in the Sun's light.

To close, the speaker remarked that it was theoretically possible to observe not just arcs of rainbows, but complete circular bows. To demonstrate this, he showed a rare instance of such an image, taken in Hawaii, with a complete circular primary bow, and near complete secondary. He remarked that this could not normally be observed, as the horizon normally truncated the bow. He also remarked that when the Sun was at an altitude above 42° in the sky, the entirety of the bow would be below the horizon, and so at most latitudes, no rainbows could be seen in the middle of the day in the summer months. Finally, in explanation of his initial assertion that no other planet had rainbows, he remarked that Descartes' calculation of the angular size of the rainbow depended finely upon the refractive index of water. For different refractive indexes, the resultant bows were of different sizes, as the caustic bunching of rays appeared at different deflections. But for refractive indices greater than around two, it was found that there was no caustic ray, and hence no rainbows. Therefore, on planets where the only droplets in the atmosphere would be of organic compounds, there would be no possibility of rainbows.

Following the applause for Mr Nayler's talk, Prof Collier introduced Mr Martin Mobberley to present his regular round-up of amateur astronomical news.

## The November Sky

The last few weeks had not been at all good for observing: even by British standards it had been an exceptionally cloudy month. Indeed Mr Mobberley doubted if anyone had managed to glimpse the stars in recent days. However, he started his round-up by discussing lunar observation: first of all, the total eclipse of October 28. Though most observers had been clouded out, a few resourceful Association members had caught glimpses of it through cloud gaps, including Peter Lawrence in Selsey, Sussex, and Jamie Cooper.

Continuing on a lunar theme, the *SMART-1* probe, launched by ESA on September 27, had arrived in its initial polar orbit of the Moon on November 15. Primarily a mission to evaluate new technologies, SMART-1's main scientific aim with regard to the Moon was to provide detailed surface maps to help understand how features had developed and evolved. The speaker remarked on the incredibly long travel time, due to the use of an ion-propulsion engine, being tested in flight for only the second time, and which provided no more force than the weight of a postcard, an acceleration of $0.2 \text{mm/s}^2$ and an average speed towards the Moon of 20mph.

A key question, useful if humans were ever to establish colonies, was whether surface water deposits existed. This focussed particular attention on the craters of the south-polar region, the bottoms of which were believed to be in perpetual darkness, the Sun being at such a low altitude in the sky as to never rise above the sides, creating cold conditions under which ice might survive for millions of years without sublimation. For this reason, considerable time would be invested in looking for the spectral signature of water-ice deposits in such places, particularly the Aitkin basin, the largest known impact crater in the Solar System.

The UK's supernova hunters had, as always, been hard at work, finding 20 events between them since June, leaving the UK total now standing at 162 discoveries. Of these, some of which were shared, 15 were Ron Arbour's discoveries, 70 by Mark Armstrong, and 82 by Tom Boles. Notable among recent non-UK discoveries was 2004et in NGC 6946, which had already hosted seven previous supernovae starting in 1917. The spectra of the most recent event revealed it to be of Type II. On November 20, Tago and Sakurai had discovered a new mag 7.6 nova in Puppis, the eighth in the constellation since 2001. At declination –27°, a further 10° south than Sirius, it was close to the southern limit of the UK observable sky, but despite this, Nick James claimed to have obtained an image the previous night at 3:17 UT, when it had been at altitude 10°.

The next big comet looked set to be C/2004 Q2, an amateur discovery by Dan Machholz on August 28. Undoubtedly one of the 20th Century's leading comet hunters, Machholz had accumulated nine discoveries between 1978 and 1994, when his success had come to an abrupt halt with the switching on of the automated searches of LINEAR and NEAT. However, not deterred, he had continued to search, though this discovery had been the first fruit of his labours since that time. The speaker noted that the discovery location, in Eridanus, had been exceptionally close to the Sun at the time. In December and January, C/2004 Q2 would be in a familiar part of the sky, passing from Eridanus into Taurus on December 27, possibly peaking around mag 4 shortly thereafter, and passing into Perseus on January 11. It would be around mag 5 as it passed into Cassiopeia on January 27. Mike Holloway, in Van Buren, had already produced a number of fine images, revealing dust and ion tails. The speaker noted that its orbit was orientated such that it would remain a northern-visible object for many years to come.

Moving onto fainter comets, the speaker apologised to those in the audience who found it difficult to get excited about mag 13 comets, only visible, after all, with CCDs, but he explained that they were all that comet-enthusiasts had to observe much of the time. Comet 2004 Q1 (Tucker) would spend December and January passing northwards through Andromeda at around mag 13, ~10° north of the Square of Pegasus. Tongue-twister 29P/Schwassmann-Wachmann presently lay on the Pisces-Pegasus border, a couple of degrees south of the Square, in almost permanent outburst at mag 12. 78P/Gehrels, presently in Aries, would pass into Taurus around January 15, moving through into Orion in the latter part of April, gradually fading from its present mag 11. C/2003 T4, presently in Draconis, would pass through Taurus and move into Lyra around New Year, edging around five degrees south-east of Vega on January 6, and hopefully brightening to around mag 9 by the end of that month. 32P/Comas Sola would spend the next couple of months taking a circuit around Aries, ~10° west of Hamal, remaining close to mag 12. 62P/Tsuchinshan, presently a little over 5° west of Regulus, would pass into Virgo in early January, before spending the remainder of the spring in Coma Berenices. The speaker remarked that it would pass close by several of the Virgo cluster of galaxies. Finally, C/2001 Q4, the big northern comet of 2004, remained a northern object, presently in Draco, moving into Cepheus on December 12, and into Cassiopeia in late January, whilst fading at around mag 11. Last of all, for asteroid enthusiasts, 2004 RZ164, a rock of around 700m diameter, would pass within two million miles of the Earth on December 9, perhaps reaching mag 11.8 in the Perseus region.

Moving onto the planetary scene, the speaker remarked that here transparency was often of secondary importance to seeing: planetary imagers wanted the sky to be as steady as possible, but their targets were so bright that a little cloud didn't worry them. It was found that high-pressure systems often provided the best seeing, because they deflected the 40,000ft jet stream, and turbulence brought with it, away from the UK. For this reason, the misty, foggy conditions often associated with high pressure was the favoured weather for planetary work. Saturn was now up for most of the night, transiting at 3am. Its north polar region was slowly emerging from beneath the rings. The speaker showed some fine images by Dave Tyler, using Damian Peach's old Celestron-11, having taken some lessons from that Great Master. Briefly commenting on the *Cassini* mission, the speaker looked forward eagerly to the separation of the *Huygens* probe at 02h00 UT on Christmas Day, later to plunge into the atmosphere of Titan on January 14. Larger than Mercury, Titan was the only moon in the solar system to have its own atmosphere, although it was not known whether its observed cloud-like structures were composed of liquid or gas. Mr Mobberley noted with some amazement that the atmosphere had been discovered in 1908 by the prolific Spanish planetary observer Josep Comas i Sola, on account of his observations of limb-darkening – how this observation had been possible by visual means on such a small body baffled him.

Jupiter now transited at 8am, and so was still largely lost in dawn twilight, but would soon be rising earlier in the night. Observers were urged to watch out for the Geminid meteor shower between December 7-16, predicted to peak December 13/14. As this coincided with New Moon, conditions were particularly favourable. By coincidence, the progenitor of the shower, 3200 Phaethon, was visible at around mag 15 in December, making closest approach to the Earth at 0.22 AU on 22nd.

Finally, Mr Mobberley urged anyone who might be in the southern half of France the following day to observe the occultation of mag 8.48 star HIP 30327 by mag 12.43 minor planet 238 Hypatia. By combining timings of such occultations from widely spread geographic locations, including negative observations, it would be possible to constrain the size of the minor planet. In this instance, the occultation would take place around 22:46.5UT (or 2-3 minutes earlier over Poland and Germany), for a maximum duration of up to 16.5 seconds. A previous occultation by the same minor planet of TYC 0158-01520-1 on November 11 had provided an estimated size of 159.8km by 148km. Another imminent occultation was that of mag 11.5 star TYC 1163-00239-1u by 1712 Angola at 18:08 – 18:21UT on November 29, passing over northern England at 18:12.5UT, around 2° from Markab in Pegasus. To close, the speaker wished to record his warmest congratulations to Sir Patrick Moore upon the 70th anniversary of his joining the BAA, on 1934 November 28.

Following the applause for Mr Mobberley's lively instalment, the meeting broke for tea, after which Mr Tom Boles invited Dr Brian Marsden, who had delivered the first annual BAA George Alcock memorial lecture last year, to introduce this year's speaker.

## The George Alcock Memorial Lecture

Dr Marsden opened, explaining that he had been travelling from his Boston home to a conference, and thought it very fortuitous that he had coincidently found himself in London on the day of such an enjoyable meeting. He announced that the 2004 Alcock Memorial Lecturer would be Dr Bill Livingston of the Kitt Peak Observatory, whose talk would be entitled *Glorious Visions – Colour and Light in the Landscape*. After spending time as a graduate student at Berkeley, Livingston had gone on to work for a time at the Mount Wilson Observatory, before becoming a Staff Astronomer at Kitt Peak, working primarily on image tubes as an engineer. However, with time he had made the transition, and become increasingly involved with his own scientific pursuits. Perhaps most notably, he had been President of *IAU Commission 9 (Instruments)* 1982-5. Dr Marsden recalled that Dr Livingston, always a keen amateur astronomer, had also taken part in many eclipse expeditions over the years.

Finally, before handing over to this year's speaker, Dr Marsden recalled some time ago a conversation he had had with writer Kay Williams concerning the possibility of writing a biography of the great observer to whose memory the following lecture was dedicated, George Alcock. Ms Williams, present in the audience, had thought this an excellent idea, and the fruits of her research had now been published under the title *Under an English Heaven*. In handing over to Dr Livingston, it gave Dr Marsden great pleasure to present him with a copy of this fine book.

Following applause, Dr Livingston recalled that George Alcock had always wanted to be remembered first and foremost as an observer, and so in the following talk, he explained that he would be describing many of the unusual atmospheric phenomena which he had observed around the site of the Kitt Peak Observatory. He opened with a discussion of a range of effects caused by shadows, ranging from the small, such as that of oneself projected forward onto mist on a foggy day, to some of the largest known, such as the dark blue band seen across the Eastern sky shortly after sunset, caused by the Earth's own shadow. He also remarked that shadows appeared unusually sharp when the Sun was only visible through a tiny crevice in the landscape. As a result, at sunset, there was a discernable difference between how horizontal and vertical features appeared, as the Sun's disk was truncated in one direction but not the other. Showing an image of the shadow of Kitt Peak onto neighbouring mountains, the speaker remarked that the shadow appeared triangular, with a sharp peak, even though in reality Kitt Peak was a relatively flat-topped mountain. This was a matter which had baffled him for some time, but he had eventually realised it was a general phenomenon: the shadows of all mountains appeared sharply-peaked.

Moving on to discuss rainbows, the speaker showed a range of unusual specimens, for example a pair of bows with different centres, one arising from direct rays from the Sun, and the other from its reflection in a lake. He also showed two rainbows of different sizes, coming about from the combination of freshwater rain and seawater spray, which, having differing refractive indices, produced bows of differing sizes.

Dr Livingston also discussed mirages – most often seen close to the ground on hot days, producing the familiar illusion of wetness. But he also explained that mirages could be seen next to any hot surface, and showed an example of the effect produced by an intensely hot concrete wall on a summer day, where a thin layer of very warm air had accumulated next to the surface. He also explained that if a temperature inversion layer formed in the atmosphere, where very warm air lay above much colder air, the familiar "wet-road" mirage might be inverted, and parts of the landscape appear in the sky. He showed an example of a mountainous horizon which appeared in double as a result of this effect.

The speaker has kindly provided a paper detailing the many other phenomena he discussed in his lecture, and for more detail the reader is referred to page ???.

Following the applause for Dr Livingston's discussion of such a curious range of phenomena, Mr Boles thanked him for giving a talk which was so relevant to Alcock's own interests, and so relevant also to the theme of the day's meeting: he had successfully combined physics, optics, astronomy and meteorology into a single talk. The meeting was opened to discussion, and a member pointed out, with reference to the speaker's earlier assertion that the shadows of mountains always appeared sharply peaked, that this was especially clear when observing peaks along the lunar terminator.

Mr Tom Boles then announced, on the subject of George Alcock, that the BAA had for some time been hoping to install a plaque to his memory in Peterborough Cathedral. Such a plaque had now been engraved, and had met the approval of the cathedral, and so it was hoped that it would be installed during the course of 2005 January. The meeting was then closed.

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Dominic Ford

## References

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