Ordinary Meeting, 2006 May 31

held at New Hunts House, Guys Hospital, London Bridge, London SE1

Richard Miles, President

Ron Johnson, Hazel Collett and Nick James, Secretaries

The President opened the sixth meeting of the 116th Session, and, in the absence of the Meetings Secretary, invited Mr Martin Morgan-Taylor to read the minutes of the previous meeting, which were approved by members and duly signed. Mr Ron Johnson, Business Secretary, reported that two presents had been received since the last meeting. [I have this in my notes, but left it rather late to get the details from Ron, who has no record of this, so we might not be able to list details…] The President announced that 13 new members were proposed for election. Council had met twice since the last meeting; in April, it had approved 84 new members, subject to confirmation by the present meeting, and a further 23 new members had been approved shortly before the present meeting. The meeting approved the election of these 107 individuals, and the President declared them duly elected.

Mr Nick James, Papers Secretary, announced that four new papers had been accepted by Council for publication in the *Journal*:

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Dr Miles reported that the next meeting of the Association would be the Variable Star Section's annual meeting, to take place at the Rutherford Appleton Laboratory in Didcot, Oxfordshire, on Saturday June 3. The next Ordinary Meeting would take place during the annual Exhibition Meeting on June 24, which would once again be hosted by the Cavendish Laboratory in Cambridge. The talks on that occasion would include Martin Mobberley's final Sky Notes instalment before he stepped down from the job; this was surely a show not to be missed.

The President then proceeded to introduce the evening's first speaker, Dr Arne Henden, Director of the American Association of Variable Star Observers (AAVSO). The President added that, in addition to sharing his expertise presently, Dr Henden would also be attending the Variable Star Section meeting on the following Saturday; he expressed his gratitude to Dr Henden for offering such keen support to the Association's observers.

Let's Collaborate! A Professional's Perspective

Dr Henden remarked in opening that he had always considered himself a professional astronomer, but had also always felt the line between amateurs and professionals to be a very grey one. After all, the word 'amateur' derived from the Latin verb '*amare*' (to love), and whilst he was a professional in the sense that he earned his livelihood by his work, was he not also an amateur if he loved doing it? With this thought in mind, he was keen for both astronomical communities to acknowledge the common passion that they shared.

In recent times he could think of many examples where amateur – in the traditional sense of the label – astronomers had made very valuable contributions to the work of professionals. One example was in the *SETI@home* project, founded in 1999 by a professional team at the University of California, Berkeley. The problem had been this: the Berkeley astronomers had wanted to search data from the Arecibo Radio Telescope for signals which were finely tuned to specific frequencies – too finely so to be of plausible natural origin – and which might thus originate from alien radio communication. The computational demands of such a search, however, were far more than could be met by their own hardware. Their solution had been to invite PC users from around the world to donate computer time. A software package had been devised which allowed users to set their desktop PCs to automatically detect whenever they were sitting idle, and to then switch to performing calculations for *SETI@home*. Motivated only by the excitement of wondering whether aliens might be seen, nearly a million computer users had taken part since the project's inception, contributing between them a total of two million CPU years since 1999. At present, *SETI@home* was able to analyse data at a rate of 50 Gb each day; the processing capability offered by their users was comparable to that of the world's fastest supercomputers.

Whilst *SETI@home* had not found any evidence for extra-terrestial intelligence, it had demonstrated a principle: if the public imagination was suitably caught by a project then so-called 'distributed computing' could offer a tremendous resource for data analysis. In the near future, another Berkeley team, *Stardust@home*, planned to start a similar project, this time analysing data from NASA's recently returned *Stardust* probe, sifting through high-resolution images of the probe's aerogel plates for evidence of dust grain impacts.

These projects required little skill on the part of the amateur, but there were other examples where the expertise of amateurs seemed to exceed that of professionals. An example would be the task of searching for comets in images returned by the LASCO solar coronograph on NASA's SOHO satellite. NASA had opted to publish all data from this instrument live on the web – a policy which had been well-rewarded: the dominance of amateur eyes in the art had grown so great that professionals now scarcely tried to compete. The coronograph had recently celebrated its thousandth comet discovery since its launch in 1995.

The rôle of amateurs in astronomy had a long history. The speaker recalled that when Percival Lowell had founded the *Lowell Observatory* at Flagstaff in 1894, he had done so at his own expense. Through the spectroscopic work of V.M. Slipher – a professional whom Lowell had employed – the Observatory had gone on to discover the expansion of the Universe. Here was a rare example of a professional employed by an amateur. A modern parallel to such philanthropy was being seen in the *Allen Telescope Array*, a SETI project in California, currently under construction, being part-funded by Microsoft co-founder Paul Allen.

Dr Henden now turned to give his personal perspective on amateur astronomy, and Lowell's Observatory provided a useful link, as he recalled how he had first been enthused into astronomy by the experience of viewing the planets through the 24" refractor there. He went on to recall the books which he had read through his teens, the planetary observations he had made with his first 3" instrument, and the 6" Dynascope through which he had observed Comet Bennett in 1970. By the time of his authorship of *Astronomical Photometry* (1978), he had been using a 16" Boller & Chivens Cassegrain. In time, his passion for astronomy had led him to obtain his Ph.D. from Indiana University in 1985.

Throughout these years, variable star observation had always been his passion, leading him to become involved with the American Association of Variable Star Observers (AAVSO), of which he had eventually become Director in 2004. The AAVSO would be the subject of the remainder of his talk.

Based in Cambridge, Massachusetts, its history stretched back to 1911. Today, it had 1,200 members, only 15% of whom were professional. The total number of observers who frequently submitted observations, however, was closer to 3,000. From them, around 600,000 observations were typically added each year to the 13 million which were already accessible from the AAVSO website. The speaker wanted to stress that visual observations remained as scientifically valuable to the AAVSO as those made with CCDs; around half of the data received remained in the form of visual observations. He also wanted to stress that the AAVSO was not a 'members only' organisation; in his view, true scientific enquiry knew no boundaries. Data was accepted from all, members and non-members alike.

At the other end of the website, the AAVSO's staff comprised ten paid workers, most of whom were graduate-level, though two held university positions, and one was a post-doctoral research scientist.

Dr Henden turned to outline some of the advantages which he perceived the amateur community to hold over professionals in the monitoring of variable stars. For one, the sheer number of amateur observatories around the globe made it possible to monitor very large numbers of objects. Their good geographic spread was of especial value when constructing light curves for objects which fluctuated on timescales of hours; a world-wide network effectively made 24-hour monitoring possible. Having so many distributed observing sites also alleviated the effects of local weather conditions, which professional survey instruments found hard to escape.

The long history of the AAVSO also brought its own advantages. The degree of continuity in its data archive was hard for professional surveys to rival, operating, as they did, typically for only a few years at a time. To study targets which exhibited variability over timescales of many years, this was invaluable; in some cases it allowed homogeneous light-curves to be constructed over nearly a century. Dr Henden added that perhaps it was also true, if under-appreciated, that amateurs were often simply more competent than professional observers, possessing a much greater degree of familiarity with their instruments.

The objects studied by the AAVSO ranged from classic variable stars to more exotic objects, including supernovae and Gamma Ray Bursters (GRBs), and the speaker discussed the diverse scientific cases for studying each class. He explained that the Association was often approached by research teams requesting data for specific objects, and that the increasing frequency of such approaches in recent times suggested a healthy appreciation of the amateur community among professionals. Observing campaigns were organised in response to such requests, aiming to achieve especially well-sampled light curves for these objects over a few months. Earlier in the year, for example, several campaigns had been run for targets which had been simultaneously being monitored by the *XMM-Newton* space-based X-ray observatory, in order to provide ground-based optical data to compliment the X-ray variability data.

To close, the speaker listed some of those amateurs who had made especial contributions to the AAVSO, including, perhaps most notably, Edgar Smith, founder of the Calypso Observatory on Kitt Peak, now home to a 1.2-metre instrument which could regularly monitor $\sim10^4$ targets. Smith hoped to be able to put this large aperture to use in the near future to discover exoplanets: the degree of photometric accuracy which could be achieved was potentially sufficient to detect the slight apparent faintening of stars as planets transited across their disks. This might open up a whole new avenue of research for the AAVSO. While such prospects were very exciting, the speaker also wanted to stress that they should not eclipse the work done by those with more modest equipment: the value of visual observers with binoculars was not to be forgotten.

Following the applause, the President thanked Dr Henden for providing such an authoritative account of the AAVSO's work and invited questions.

A member asked whether the AAVSO accepted spectroscopic observations from amateurs. The speaker replied that they did and that this was a growth area; good spectroscopic equipment was now quite readily available and amateurs could make well-calibrated observations. Mr Maurice Gavin, in the audience, queried this: he remarked that he had submitted some spectra to the AAVSO's website recently, and that they had not appeared in the online archive. In reply, Dr Henden explained that there were some outstanding technical issues with the online retrieval of spectra, but that the submission process was working and filing incoming data correctly.

The President then introduced the evening's second speaker, Prof. Steve Miller of University College, London. In addition to his work as a planetary scientist, Prof. Miller was also a very active communicator of science; he headed the Department of Science and Technology Studies at UCL. Tonight, he would be talking about observations of aurorae in the atmospheres of the solar system's gas giants.

Bright Lights on Giant Planets

Prof. Miller explained that his scientific background was in chemistry rather than astronomy, but that he had become involved with planetary science, and especially aurorae, through an interest in the chemical composition of planetary atmospheres. The various colours seen in aurorae were powerful probes of the chemical constituents of planetary atmospheres, and the speaker illustrated this with an image of the aurora borealis of our own planet. The deep red emission seen at the highest celestial altitudes could be attributed to atomic oxygen, and likewise the brighter green emission below it. Towards the lower edge of the aurora, closest to the horizon, reddy-pink emission stemmed from molecular nitrogen.

Not only were such aurorae revealing the chemical makeup of the Earth's atmosphere, but the dominance of different colours at different altitudes was also revealing its vertical structure. Above a certain point, the *homopause*, the atmosphere's various constituents ceased to be well mixed, being instead gravitationally stratified according to mass. Because molecules weighed more than atoms, the reddy-pink emission of molecular nitrogen was seen at lower altitudes than the emission of atomic oxygen.

Images taken from high-altitude aircraft presented compelling evidence that auroral emission arose high in the upper atmosphere, Prof. Miller explained – even from the highest-flying aircraft, one had to look upward to see it. Detailed study revealed it to emanate 70-200 km above the Earth's surface.

The speaker then turned to discuss the physical origin of aurorae. He began with a schematic of the Earth's magnetic field, which he compared to that of a bar magnet: field lines emanated from the Earth's surface at its north magnetic pole, wrapped longitudinally around the planet, and re-converged upon its south magnetic pole. However, they were permanently distorted from those of a bar magnet by their interplay with the solar wind – a continuous stream of high-energy charged particles, flowing outwards from the Sun through the solar system at around 400 km/s.

Michael Faraday had discovered in the 19th Century that when electric currents traversed circular paths, magnetic fields were generated – the principle behind the electromagnet. Conversely, he had also found that in the presence of magnetic fields, a force was exerted upon charge-carrying particles which caused them to follow circular paths around the field lines.

Thus, when solar wind particles came under the influence of the Earth's magnetic field, their paths were bent: they began to circle around the magnetic field lines. Broadly speaking, the Earth's magnetic field could be said to be an obstacle to their outward flow through the solar system.

This interaction also bent the Earth's magnetic field lines. On the sunward side, this distortion took the form of a compression, and at an altitude of around 70,000 km it exhibited an outer boundary called the *magnetopause*, outside of which the Sun's magnetic field dominated. It was upon impact with this boundary that solar wind particles came sharply into interaction with the Earth. More precisely, about 15,000 km upstream of it, compressed solar wind material piled up against the boundary to form a *bow shock*. In the anti-solar direction, the distortion had the opposite effect, stretching out the Earth's magnetic field into a long tail called the *magnetotail*, about 190,000 km in length.

Prof. Miller noted that the most profound consequence of this interplay between the Earth's magnetic field and the solar wind for the human species was that it shielded the Earth's surface from ionising solar wind particles: without such a shield, we could not survive. Aurorae were surely a secondary consequence. They arose when solar wind particles descended into the Earth's atmosphere and collided with one of the various atomic or molecular gas particles around them, dumping their energy into the gas, often leaving the particles ionised or in excited states. The visible light of the aurora arose when these gas particles subsequently de-excited via photon emission, but Prof. Miller added that the display of lights was not the only consequence of this process – it also effected a significant heating upon the atmosphere.

This descent of solar wind particles into the Earth's atmosphere was only possible in the Earth's polar regions, because these were the only places where magnetic field lines were directed up out of the surface of the Earth; these were the only places where the solar wind particles, spiralling around the field lines, could descend towards the Earth. More specifically, aurorae were actually most frequently observed slightly away from the pole, where the magnetic field lines were at a slight slant to the surface, in a circular region called the *auroral oval*.

During an auroral display, the solar wind might dump energy into the Earth's atmosphere with a power of around 100 GW, raising the temperature of the upper atmosphere by around 100 K. This effect was very significant, though somewhat less dramatic than it sounded for the fact that the absorption of solar UV radiation already heated this part of the atmosphere to around 1000 K. The change made by aurora was thus a significant but not overwhelming 10%.

The speaker then turned to discuss the aurorae of other planets, and first of all, of Jupiter. Infrared images from the United Kingdom Infrared Telescope (UKIRT), on the summit of Mauna Kea, Hawaii, revealed compelling evidence for a bright auroral oval, not dissimilar to our own, on Jupiter. Prof. Miller noted in passing that this was one of very few areas of work where ground-based telescopes could usefully be employed in planetary science; in the visible, the resolution of the Hubble Space Telescope (HST) ruled supreme. In addition to UKIRT, another ground-based infrared telescope, NASA's Infrared Telescope Facility (IRTF), also on the summit of Mauna Kea, provided a complementary facility to take high-resolution spectra of Jovian aurorae.

The emission seen in these images was arising high in Jupiter's atmosphere, at an altitude of 450-2000 km above the surface. At this altitude, the atmosphere was thin, having a particle number density less than 10^{18} particles per cubic metre, but also apparently incredibly hot, ranging between 900 and 1100 K. This compared with 400 K for Saturn's upper atmosphere and 500-750 K for that of Uranus. The speaker would return to the puzzle of how the Jovian upper atmosphere came to be so hot later.

The primary constituent of the Jovian atmosphere was hydrogen gas, and so narrow-band images centred upon the Lyman transition lines of atomic hydrogen produced detailed maps of the excited gas. These lines lay in the ultraviolet part of the spectrum, unobservable from the ground because of absorption from the Earth's atmosphere, but could be imaged by the HST. Such images contained a wealth of information, both about the auroral oval and its neighbourhood; for the present talk, the speaker concentrated upon the former, specifically upon the question of how it compared with the Earth's auroral oval. Were the aurorae of Jupiter similarly controlled by the solar wind?

To answer this question, Prof. Miller started by outlining what was known about the Jovian magnetosphere. It was a huge structure. Its magnetopause and bow shock lay a colossal 1-2 million km above Jupiter's surface, and if these were visible structures, their projection on the night sky would appear 2½ times the size of a Full Moon from the Earth. The magnetotail was larger still, stretching 750 million km in the anti-solar direction – so far that it stretched beyond Saturn's orbit; Saturn could indeed pass through it. The Jovian magnetosphere was arguably the second largest 'structure' in the solar system after the Sun.

Apart from its sheer size, it differed from the Earth's magnetosphere in one additional respect, which arose from Jupiter's interaction with its nearest moon, Io. Orbiting at a mere 350,000 km above Jupiter's surface – closer than the Earth-Moon distance – Io experienced extreme tidal gravitational forces, stirring up its internal structure. The resultant strain rendered Io the most volcanic body in the solar system, as had compellingly been seen in many images returned by the *Voyager* probes. Volcanic plumes spewed around a tonne of ionised material into the neighbourhood of Jupiter each second. This material spread out to form a thin circular sheet termed a *plasma torus*, extending out to a distance of a million km from Jupiter. When initially spewed from Io, this material would share its orbital period of 42 hours. However, because of its electrical charge, it interacted with the magnetic field of Jupiter, bringing about a rapid change in its rotation speed. For such a large planet, Jupiter was remarkably fast-spinning: in fact, it was not only the largest planet in the solar system, but also that with the shortest rotation period – a mere 9 hours. As Jupiter spun, it carried its magnetic field around with it, and the effect of the interaction between this rapidly-rotating magnetic field and the plasma torus was to spin up the ionised material, draining rotational energy from Jupiter at a rate of 10 TW – sufficient to completely halt Jupiter's rotation within 60 times the current age of the Universe.

The interaction was not quite strong enough, however, to completely bring the plasma torus into co-rotation with Jupiter, and the difference between the two rotation speeds was especially great at large radii. The resulting sheer in electric field produced a break in Jupiter's magnetosphere through which solar wind particles could break.

Prof. Miller noted in passing that the plasma torus also seemed to have another effect: in recent HST images, a clear 'footprint' of auroral activity could be seen beneath Io, suggesting that its volcanic activity produced a secondary source of ions, in addition to the solar wind, which produced their own aurorae. Rather curiously, Ganymede and Europa also had visible auroral footprints, despite not being appreciably volcanic; this remained unexplained.

Returning to the question of why Jupiter's upper atmosphere was so hot, the speaker discussed whether energy input from aurorae could be the answer. He explained that the effect of solar wind electrons upon the Jovian atmosphere was primarily to ionise hydrogen through the reactions:

$H_2 + e^- \rightarrow H_2^+ + 2e^-$ (1)
$H_2^+ + H_2 \rightarrow H_3^+ + H$ (2)

Emission lines, resulting from the rotational excitation and de-excitation of the H_3^+ ions produced on the right-hand side of Reaction (2), were responsible for producing the infrared emission seen in the UKIRT images discussed earlier. By contrast, it was the second product on the right-hand side of Reaction (2), the atomic hydrogen, which was responsible for the ultraviolet emission seen in the narrow-band Lyman-line images returned by the HST.

Across the whole planet, the energy input from the solar wind through these reactions could be calculated to be about 10^{14} W – more than two orders of magnitude in excess of the power absorbed by Jupiter from sunlight. Aurorae did thus seem a plausible mechanism for heating, although the situation was actually rather more complicated than suggested by this simple evaluation of power input alone. The bright infrared emission seen from H_3^+ ions demonstrated that they were very efficient at re-radiating absorbed energy, and thus much of the energy absorbed from solar wind particles seemed not to be retained by the planet's atmosphere.

Turning next to Saturn, the speaker explained that images of aurorae in its polar regions had been returned by the *Cassini* probe, but that they appeared to be rather modest as compared to those on Jupiter. It also appeared that those on Saturn were controlled exclusively by the solar wind, rather than any volcanism on its moons. Uranus showed signs of aurorae as well, perhaps contributing up to 20% of its total emission, but they were rather difficult to image on account of being spread very widely and thinly across the planet's entire disk. The lack of an auroral oval on Uranus was not well understood, but could perhaps be attributed to the planet's unusual axial tilt, at 98° to its orbital plane.

The speaker closed with a brief discussion of the possible effects of aurorae on extrasolar planets. He remarked that over 100 planets had now been discovered around stars other than our own, and that many of them seemed to be gas giants not unlike Jupiter, but in very close orbits around their parent stars – perhaps as close as 1/20th of an astronomical unit. Such discoveries raised many questions about how these planets came to be found so close to their parent stars. One especial problem was that models of planetary atmospheres predicted that planets in such hot environments would completely boil away within a timescale of 10^5-10^6 years. In astronomical terms, these were very short timescales, and so we would not expect to observe such planets so close to stars.

Prof. Miller argued that aurorae on these planets might have a rôle to play in extending their lifespans: the production of H_3^+ ions on their sunward sides could lead to very intense infrared emission in the H_3^+ rotational transitions. The cooling effect of this emission might have a thermostatic effect, preventing the atmosphere from boiling away. The speaker added that if this idea was correct, then the first direct detection of emission from exoplanets might well be in the form of H_3^+ emission lines in the spectra of their parent stars.

Following the applause, the President thanked Prof. Miller for his thorough account and invited questions. A member asked at what wavelength the UKIRT images of Jovian aurorae had been taken. The speaker replied that they were taken in the atmospheric window around the photometric L-band, specifically, at 3.42 and 3.53 μm.

The President then adjourned the meeting until the occasion of the Exhibition Meeting, to be held in Cambridge on June 24.

Dominic Ford