Ordinary Meeting, 2009 May 27

held at the Royal Astronomical Society, Burlington House, Piccadilly, London SE1

Roger Pickard, President

Ron Johnson, Hazel Collett and Nick James, Secretaries

The President opened the seventh meeting of the 119th Session and announced that the minutes of the previous meeting were on display at the back of the lecture theatre. He went on to announce that 47 new members were proposed for election, and those 57 new members who had been proposed at the previous meeting were approved by the audience and declared duly elected. Mr Nick James, Papers Secretary, reported that one paper had been approved for publication in the *Journal*:

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???, Nigel Longshaw

The President announced that the next Ordinary Meeting would be held as a part of the Association's Exhibition Meeting on Saturday June 27 at the Old Royal Naval College in Greenwich. The next meeting to be held in Burlington House would be the Association's Annual General Meeting on October 28. In the meantime, the Variable Star Section would be holding its Annual Meeting at the University of Cardiff on June 13 and there would be an *Out-of-London* weekend at the University of Leeds over the weekend of September 4-6. Announcing a change to the advertised programme, the President then introduced the evening's first speaker, Mr Fraser Lewis, a PhD student at the University of Cardiff working on the Faulkes Telescope Project. The President expressed his gratitude to Mr Lewis for agreeing to present this talk in place of his PhD supervisor at short notice.

Pro/Am Collaboration with Schools using Robotic Telescopes

Mr Lewis began by explaining that the two Faulkes Telescopes formed a part of the Las Cumbres Observatory Global Telescope (LCOGT) Network, whose construction had been funded largely by the philanthropic generosity of Dr Martin C. (Dill) Faulkes, who had contributed £10 million to the project. This funding had been supplemented by a £1 million grant from the Particle Physics and Astronomy Research Council (PPARC; subsequently merged into the STFC in April 2007), and a £600k grant from the Department for Education and Skills (DfES; subsequently broken in multiple departments in June 2007).

At its inception, the Telescope Network had been envisaged as a part of the Millennium Dome project, providing a platform for bringing live astronomy into the Dome during the hours of UK daylight with the help of internet communications. In the end, that plan had not come to fruition and project's aim had shifted to providing a means of bringing data from remotely-controlled robotic telescopes into school classrooms. This remained the project's central aim, for which purpose it now owned and operated two purpose-built two-metre telescopes – the *Faulkes Telescope North* in Haleakala, Hawaii, and the *Faulkes Telescope South* in Siding Spring, Australia. The geographic placement of these telescopes in opposite hemispheres and at longitudes well-separated from that of the UK made it possible to make live observations of both the northern and southern celestial hemispheres throughout much of the UK school day; typically at least one of the two telescopes was online at any time between 6am and 7pm UK time.

Turning to give an overview of the telescopes themselves, the speaker explained that both were housed in unusual clam-shell domes which completely retracted when opened to give a full view of the sky. This aspect of the design was partially historic, dating back to early plans to link the two telescopes up with the similarly-sized Liverpool Telescope on the island of La Palma to form a network of telescopes, given the provisional name *Robonet*, for performing follow-up observations of Gamma Ray Bursters (GRBs) detected by the *Swift* satellite. Given the transient nature of GRBs, follow-up observations had to be made as rapidly as possible after their initial detection, and the lack of any dome around the Faulkes Telescopes eliminated any delay that a slowly-rotating dome might cause when slewing to such objects at speed. Had Robonet come to fruition, its three telescopes would have provided 24-hour coverage of the night side of the sky, but in practice the network had never been funded. Nonetheless, the Faulkes Telescopes were kept on standby to make GRB observations during those hours when they were online.

Mr Lewis added that there were plans to imminently expand the LCOGT network, both to increase the amount of observing time available to schools, and to increase the number of hours of the day when at least one of its observatory sites would be online. It was hoped that LCOGT would soon provide its own 24-hour facility for making follow-up observations of GRBs in the place of Robonet. Whilst these plans would not involve the building of any more two-metre telescopes of the same class as the existing pair of telescopes, a large number of much smaller 0.4-metre telescopes would be added to the network within the next 12 months. These would be arranged with between two and four alongside each of the current two telescopes, and, subject to planning negotiations, similar numbers at each of five further new observatory sites: Cerro Tololo in Chile, Mauna Loa in Hawaii, Sutherland in South Africa, Exmouth in Australia, and Tenerife in the Canary Islands.

Looking further ahead, there were more ambitious plans to add a similar number of one-metre telescopes to the network by 2012. It was currently hoped that as many as eighteen might be installed in total, arranged with three side-by-side on each of six sites, though such plans were not yet definite.

Mr Lewis then turned to outline the optics of the telescopes. The current pair of two-metre telescopes each had two-metre f/10 research-grade primary mirrors, which had been built at a cost of £250k each. Each had a field-of-view of 4.6 arcminutes – rather smaller than that of most amateur telescopes – and was fitted with a professional-grade 2048×2048 CCD camera. Given the large apertures and small fields-of-view of these telescopes, they were best suited for deep imaging of small patches of sky, rather than wide-angle photography. Typically, the seeing at each of the sites varied between 0″75 at best to 2″ at worst. A wide range of different colour filters were available to observers, including the traditional BVR Bessel (similar to Johnson) filter set, the u′g′r′i′ filter set of the Sloan Digital Sky Survey (SDSS), z′ and y′ filters to match those available on the Pan-STARRS telescopes, and narrowband filters including Hα, Hβ and OIII. Both of the Faulkes telescopes were fully robotic – to reduce costs, the observatory sites were completely unmanned – and were able to open and close in response to automatic weather alerts.

The forthcoming 0.4-metre telescopes would bear a much greater similarity to standard amateur telescopes. The optical tubes would be standard Meade parts, yielding a field-of-view of 30′×20′ at a focal ratio of f/8. Nonetheless, professional-grade CCDs would be mounted on them, allowing 3-4 three-colour images to be taken in each of the 30-minute observing slots allocated to schools. A user-friendly pipelined interface would guide the schools through the process of taking three sequential exposures with different filters and then stacking them to produce colour images.

Turning to outline the scientific research for which the telescopes were being used, Mr Lewis explained that research projects had been developed with the aim not only that they should produce genuinely useful and interesting science, but also that schools should be able to contribute to them with a wide range of different levels of commitment. Furthermore, it was hoped that each project would provide as much interaction as possible between the schools and the professional researchers who were guiding the research to make new discoveries, whilst at the same time being accessible to schools which could not be expected to come to the project with much background expertise. The speaker thus explained that in the design of each project, considerable effort had gone into preparing training material for teachers so that they could get involved without needing to have any prior specialist knowledge; the detailed work of planning worthwhile observing campaigns was largely done for them. The speaker went on to remark that the two Faulkes telescopes were not well suited for observing many of the most obvious stereotypical astronomical objects – for example, the Moon and planets – because they had such large apertures and small fields-of-view. He explained that this was in many ways a deliberate choice: it provided a useful way of driving schools into participating in a more diverse and challenging set of scientific projects – with the end reward that genuine new discoveries could be made – than they might otherwise have devised themselves.

The speaker then outlined one particularly successful project which schools had been involved with, in which they had taken time-lapse images of asteroids. He explained that on the most basic level, a school which took a single image of an asteroid discovered the impossibility of distinguishing asteroids from stars in such images: both appeared as unresolved point sources. On the next level, when a few time-lapse images had been taken and made into a movie or otherwise animated, the motion of the asteroid relative to background stars became very apparent. The most committed schools could then go on to perform photometry and estimate the asteroid’s brightness, and over time construct a light-curve for it. Eventually, it might be possible to measure the asteroid’s rotation period.

In reality, this project had proven such a success, and some schools had been so committed to it, that a particularly notable first had been achieved. The speaker explained that for some time, professional astronomers had been hoping to detect a theoretically-predicted phenomenon called the Yarkovsky-O’Keefe-Radzievskii-Paddack (YORP) Effect, that the spin rate of non-spherical asteroids should change over time as a result of the pressure exerted on them by the sunlight falling on their surfaces. Einstein’s theory of special relativity predicted that even though photons of light had no mass, they still exerted a force – a very tiny force – when they collided with things; this was termed radiation pressure. Applying this theory to a non-spherical asteroid which might have, for example, a knobbly mountain sticking out of one side, it was possible that the mountain would present a disproportionately large surface area for sunlight to push against on one side of the asteroid, and by this means act as a lever with which sunlight could spin up the asteroid.

In practice, the effect was very small because sunlight only exerted very tiny forces, and hence it had never been successfully detected. However, observations of a small near-Earth asteroid by the name of (54509) 2000 PH5 by the Faulkes Telescope North, when combined with data from various other professional instruments, had revealed the rotation period of the asteroid to be decreasing by around a millisecond each year, in agreement with theoretical predictions of the magnitude of the YORP Effect for this object.[1,2]

The speaker moved on to discuss some of the science which had been made possible during the brief window in 2007 when Uranus' ring and moon system had passed through its edge-on orientation as seen from Earth. The speaker explained that this event had been analogous to the more readily observable ring-plane crossing which Saturn would shortly be undergoing in 2009 August. Just as Saturn's system of moons was presented in an edge-on orientation during its current 2009 apparition, and amateurs had been able to observe mutual occultations of its moons over the past few months, so the Faulkes Telescope had been able to image and obtain accurate timings for mutual occultations of Uranus' moons in mid-2007. For example, on 2007 May 5, an occultation of Umbriel (IV; 1,500-km across) by Oberon (II; 1,200-km across) had been observed by the Faulkes Telescope South. Interestingly, however, the event had occurred 10 minutes later than had been predicted by the best models of Uranus' moon system. This highlighted the surprising fact that our knowledge of the orbits of the moons of the outer planets often remained quite sketchy, and were often based on small numbers of observations.

Other projects with which schools were involved included making follow-up observations of candidate extrasolar planets as they were reported by the *SuperWASP* robotised search programme. These typically involved making photometric measurements of the parent star to build up a lightcurve over a moderately long period in the hope of finding any short and well-defined dips which might be attributed to the transit of a planet across the star's disk. On a similar theme, lightcurves could be constructed for a variety of variable star systems, including variable X-ray sources. All of these photometric projects required the collation of data collected over a period of days, and so encouraged collaboration between schools, each taking photometry for half an hour before passing on to the next.

The speaker closed by addressing the question of whether amateur astronomical societies could use the Faulkes Telescopes. He remarked that the enthusiasm of amateurs for the work of the telescopes was very pleasing to see, and that amateurs were very welcome to sign up with the project and make use of the data collected by the two telescopes. However, he explained that the principal audience for the project were young people who would not otherwise have access to telescopes, whereas most amateur societies had their own observing facilities. Thus, astronomical societies were generally not permitted to schedule their own observations unless there was a clear educational purpose to their work.

Following the applause, the President introduced the evening's second speaker, Dr David Walker, head of the Optical Science Laboratory at University College London (UCL) and technical director of a private optical engineering company, Zeeko Ltd.

The European Extremely Large Telescope – Fabricating the Mirror Segments

Dr Walker opened by explaining that his talk would outline some of the engineering challenges posed by the manufacture and maintenance large telescope optics. It would go on to look in detail at the work which was in progress to develop new techniques for fabricating mirror segments for the *European Extremely Large Telescope* (E-ELT), which was to be built in the mid-2010s.

Dr Walker first took a survey of the largest telescopes which were currently available to professional astronomers. The largest telescope ever to have been built was the *Gran Telescopio Canarias* (Gran TeCan), a 10.4-m telescope on the island of La Palma in the Canary Islands, which had taken over seven years to build and which was only just beginning to take its first observations. Behind it in the league table of size, there were around a dozen telescopes worldwide with apertures of between 8 and 10 metres, including the two American 10-m *Keck Telescopes* and the Japanese 8.3-m *Subaru Telescope* on the summit of Mauna Kea, 13,796-feet above sea level on the island of Hawaii. These were complemented by around a dozen more telescopes with 4- to 8-metre apertures, including the Anglo-European *William Herschel Telescope* (WHT) on La Palma.

The speaker remarked that it was interesting to compare this current generation of telescopes with those which had been in use in the 1930s, to see how things had changed in the intervening 70 years. In the 1930s, the available telescopes had included the 100-inch (2.54-m) *Hooker Telescope* at the Palomar Observatory on Mount Wilson, which been in operation since 1908, and work had been well under way on a new 200-inch (5.08-m) *Hale Telescope* at the same site. The mirror for this new telescope had been silvered in 1934, though it had not entered service until 1948 owing to delays brought about by the Second World War. So, perhaps rather surprisingly, the change was comparatively slight: telescope apertures had grown by a mere factor of two in the past 70 years.

Over that time, there had, however, been tremendous advances in the sensitivities of the detectors placed at the foci of these telescopes. In the 1930s, photographic plates with a typical light-collecting efficiency of 1% had been state-of-the-art, whereas modern CCD cameras were typically able to record 70-80% of the light which landed on their sensors. As a result, a modern photographic exposure could reveal equivalent detail in less than a seventieth of the time that it would have taken in the early twentieth century, and it was consequently possible to detect much fainter structures on the sky. But, putting these advances to one side, the lack of corresponding progress in the building of telescopes with ever-larger apertures seemed to beg an explanation. Astronomy was, after all, surely unique among the sciences in that the optics of telescopes such as the *Hale Telescope* remained among the best in the world over 60 years after their construction.

Dr Walker went on to explain that, in essence, large telescope mirrors were very difficult and expensive to manufacture and handle. Taking as an example the two 8.4-metre mirrors of the *Large Binocular Telescope* (LBT; completed 2002), he explained that in the accounts of such projects, the phenomenal cost of building and equipping a vacuum chamber which was large enough to use for silvering such a mirror was often exceeded only by the more-mundane-still cost of building a road which was good enough to use for the transportation of such a bulky mirror up to a good mountain-top observing site. Aside from these cost considerations, there were naturally hazards associated with handling such large and unwieldy mirrors: a single crack could render it entirely useless. For this reason, the 8.4-m mirrors built for the LBT were the largest *monolithic* mirrors ever to have been built: all larger telescopes used tessellating hexagonal mirror segments which could be manufactured individually and put together as tiles. For example, the primary mirrors of the two 10-metre *Keck* telescopes were built up from 36 segments, each measuring 1.8-m across.

The principles involved in the construction of segmented telescope mirrors had first been demonstrated in the 1990s with instruments such as the *Keck Telescopes*, but the task was not easy. Typically, a sophisticated computer system was needed to continuously monitor the positions of the segments and make corrections for any errors in the shape of the mirror using actuators placed behind each segment. Issues such as the thermal expansion of the telescope structure, and its flexion as the telescope slewed across the sky, introduced errors into the shape of the mirror which needed to be painstakingly corrected for. These challenges grew massively more difficult as telescope apertures got larger, owing to the increased weight of the mirrors which were having to be manipulated and kept in shape.

However, the speaker added that the scientific rewards for having a telescope with an aperture which was very much larger than anything which was currently available were potentially great. For example, in order to image Earth-like extrasolar planets around other stars it would be necessary to have a telescope with a tremendously high resolving power, but which was simultaneously able to detect an intrinsically very faint planet. Likewise, in order to see the formation of the first generation of galaxies out of the primordial gas which had been produced by the Big Bang, a telescope was needed which could detect objects which were not only at distances of billions of lightyears away from us, but also intrinsically rather small and faint.

In response to these challenges, designs for several very large optical telescopes had been proposed. In the US, plans were currently under way to build a *Thirty Meter Telescope* (TMT), whose primary mirror would be made up from 492 hexagonal segments, and which it was hoped would be operational by around 2017-8. In Europe, plans for a similar telescope had stemmed from two competing proposals, which had recently been merged into a plan for a single telescope, taking the most realistically achievable aspects from each of the earlier designs.

The first of these two earlier designs had been the 50-m *Euro50 Telescope*, which had been designed around an aspherical primary mirror made from 619 segments. The speaker explained that the aspherical shape of the segments required to build such a mirror was not insignificant. Spherical segmented mirrors were relatively easy to manufacture, because every segment was of the same shape and mass-production was possible. The segments of an aspherical segmented mirror, on the other hand, all needed to have different curvatures. Not only was mass-production impossible, but the fabrication of high-precision aspherical surfaces was costly and difficult. Many amateurs would be familiar with the difference in cost between Schmitt-Cassegrain telescopes with spherical mirrors and corrector plates, and more traditional Cassegrain telescopes with parabolic mirrors. The idea of building a 50-m aspherical mirror was thus highly ambitious.

The competing design, the *OverWhelmingly Large telescope* (OWL), was in one sense simpler: its 100-m primary mirror was spherical, made from 3,048 identical segments. However, to correct for the spherical shape of this primary mirror, a 25.6-m aspherical secondary mirror was required, which would itself be made from 216 segments.

Dr Walker explained that the merged proposal was to build a more realistic 42-metre telescope, called the *European Extremely Large Telescope* (E-ELT), which would have an aspherical primary mirror built from 984 hexagonal segments, each measuring 1.42-m across. In practice, a total of 1,148 mirror segments would need to be manufactured in order to ensure an adequate supply of spare parts. The resulting telescope would be configured with a field-of-view of around ten arcminutes and a focal ratio of f/1. Despite the move to a less ambitious aperture, the task of manufacturing the segments for the E-ELT remained a serious challenge, however. With the best technology currently available, each segment would take around six months to polish, at a cost of several million pounds, and so it was essentially that new techniques be developed.

The speaker explained that his own involvement with the project came through his company, Zeeko Ltd, which was pioneering a new way of polishing aspherical mirror surfaces. He explained that standard polishing tools worked rather poorly on aspherical mirrors because the target curvature of the mirror was not constant across its surface. Consequently, a polishing tip which had the right curvature to hug the surface of the mirror at one point would have the wrong shape to hug the surface of other parts of the mirror. The speaker's idea had been to use an inflatable membrane with abrasive surface in place of a traditional polishing tip. One simply needed to press down on the membrane by different amounts to change the pressure inside it and change its curvature to match the desired shape at any particular point on the mirror's surface. This inflatable membrane could be mounted on a computerised (CNC) polishing machine and controlled automatically.

The speaker explained that having patented his idea, he had formed a collaboration with OpTIC Glyndŵr Ltd in North Wales, and the partnership had accepted a contract a build seven full-size prototype segments for the E-ELT. To provide a fair test of the most challenging engineering which was needed for the E-ELT mirror, these prototype segments corresponded to the most extremely aspherical parts of its surface, around the edges. There was also a competitive element to the contract: a rival company in France had been contracted to independently manufacture a similar set of prototype segments.

The speaker closed by reporting that he was making good progress on his own contract: in a recent test he had polished a single mirror segment to the desired surface accuracy within 31 hours. Looking ahead, he hoped to be able to deliver his first two prototype segments in April 2010, and the remaining five in late 2010. If he completed the contract successfully, he hoped to form an industry consortium and be in a position to bid for the manufacture of all 1,148 of the E-ELT's segments when the time came.

Following the applause, the President invited Dr Richard Miles, Director of the Association's Asteroids and Remote Planets Section, to present Sky Notes.

The Sky in May

Dr Miles opened by showing a pair of time-lapse videos compiled by Gustavo Muler in Lanzarote, Spain, of the motion of comet C/2007 N3 (Lulin) relative to the background stars behind it. He went on to report that the Sun's period of quietness was continuing, and that although a small group of sunspots had been visible in the past month, these had now disappeared to leave the Sun's disk spotless once again. Modest prominences remained visible around the edge of the Sun's disk in Hα images. However, some astrophotographers had been finding some other uses for the Sun's disk: during the recent flight of the space shuttle *Atlantis* (STS 125; May 11–24) to service the *Hubble Space Telescope* (HST), French amateur astrophotographer Thierry Legault had captured the silhouettes of *Atlantis* and the HST against the solar disk as they approached one another on May 13 at 12:17 EDT.[3] This remarkable image was a testament to Legault's skill and determination: the low orbit of the HST meant that the transit had only been correctly aligned within a 5-km-wide corridor of visibility, and had only lasted 0.8 seconds. In order to ensure a sharp image, Legault had used an exposure of a mere 1/8000th second.

In late April, the Moon had formed a pleasing conjunction with Mercury and the Pleiades (M45). Nick James had captured an impressive image of the triplet on April 26 in conditions of remarkably transparency; Richard Fleet had also captured a notable image of the triplet from Wiltshire on the following evening.

The speaker reported that Jupiter was coming into view in the morning sky, now rising at midnight BST. However, it would not be well placed for UK-based observers in its coming apparition on account of its southerly declination in Capricornus – currently –13° and reaching –16° by September. Saturn was now setting at around 2.30am BST, and would disappear into evening twilight over the course of the summer.

Moving out to Pluto, Dr Miles reported that the Association's Asteroids and Remote Planets Section would be organising an observing campaign over the coming months to measure the dwarf planet's lightcurve as it approached opposition on June 23. He reported that similar work had historically secured Pluto's rotation period to be 6.4 days, but that as Pluto was now moving further away from the Sun having passed perihelion in 1989 and having passed outside the orbit of Neptune in 1999, its surface temperature would now be dropping fast and its albedo features may have changed if any components of its atmosphere had begun solidifying onto its surface.

The speaker congratulated Tom Boles upon the recent discovery of his 120th supernova, 2009es, in IC1525 on May 24 – his first discovery since January. He closed his talk with some images that he had captured himself using the Faulkes Telescope South on May 14, a few hours after the launch of the *Herschel* and *Planck* space observatories aboard an Ariane 5 rocket from the Guiana Space Centre. These images had been taken shortly after the two spacecraft had separated from the Sylda 5 payload dispenser which had packaged them in the launch vehicle, and clearly showed three point sources. From their relative motion and relative brightnesses, the speaker reported that he had been able to identify each of them.

Following the applause, the President adjourned the meeting until the Exhibition Meeting, to be held at the Old Naval College Greenwich on Saturday 27th June.

Dominic Ford

References

[1] Lowry S.C. *et al.*, Science, **316**, 272 (2007)
[2] Taylor P.A. *et al.*, Science, **316**, 274 (2007)
[3] NASA Astronomy Picture of the Day, 2009 May 16.