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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2023 December 8 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

Mike Edmunds, *President*
in the Chair

President. This is a hybrid meeting. Questions may be asked at the end of each lecture but you will be muted so please use the chat facility. Questions on-line will be monitored by Professor Steve Miller, RAS Council member. Moving on to the first presentation, the first talk is the RAS Diary talk and this will be given by Dr. Daniel Belteki: 'The making of an observatory — the early years of the Cambridge Observatory'. Daniel Belteki is a Research Fellow on the Congruence Engine Project at the Science Museum. His work explores the application of digital tools to the history of 19th-Century science, technology, and industry. His previous work focussed on the history of astronomy during the 19th Century, with a specific focus on the history of the Royal Observatory at Greenwich.

Dr. Daniel Belteki. I would like to start by thanking Mark Hurn, Librarian at the Institute of Astronomy at Cambridge, for many amusing conversations and also the Cambridge University Archives. I am also grateful to Dr. Roger Hutchins who has written what is, so far, the only modern history of the Cambridge University Observatory (CUO), and to Dr. Siân Prosser, Librarian of the RAS.

The CUO was not established in a vacuum. There had been prior observatories at Cambridge but they were not major institutions; they were attached to different colleges. One was set up at Trinity College around 1704, another at St. John's College which is actually associated with Thomas Catton. Pembroke College also had one which was associated with the Lowndean Professorship of Astronomy and established in 1749. There is a brief mention of the establishment of an observatory in 1790 but the idea died out.

In 1816 a proposal was made which would re-ignite the passion for a university observatory. Around this time the Analytical Society (AS) was founded; it was trying to convince the University, as well as the scientific network, that the analytical approach in mathematics coming from France needed to be taken up in order to make progress in astronomy. At the same time there were discussions between astronomers on how Greenwich Observatory and its publications were not as accurate as desired. *The Nautical Almanac* was based on Greenwich observations which were not accurate enough for quick and efficient navigation and transport on the sea. This group of astronomers came together and the result was the formation of the Astronomical Society of London which later became the Royal Astronomical Society (RAS).

In Cambridge there was the establishment of the Cambridge Philosophical Society, again recognizing a new venture taking place in science and the need for institutionalization — the qualification of these new ventures, and which helped to pave the way for what was to become the Cambridge University Observatory. The proposal in 1816 came from George Peacock, a mathematician and Fellow of Trinity College who later on became the Dean of Ely. He was a member of the AS and a Fellow of the RAS and was very much engaged in the reforms taking place within the University. He saw the Observatory as a tool to reform science alongside reforms in the exam system, in textbooks, and in the rules themselves. When new ideas and reforms were introduced there were counter effects. The opposition was mounted by men such as James Wood, the Master of St. John's College, and so there followed arguments which raged back and forth between the reformers and members of the establishment.

In 1817 Thomas Catton and John Haviland prepared estimates for how much it would cost to fit out the Observatory with instruments. They hoped that having the costing and the figures would persuade the University to do something. Also in 1817 a Grace was passed which accepted the need to produce a report about the value of the addition of the Observatory to the University, but there was a caveat.

The report states that it shouldn't be a university observatory — it should be funded by the Government and should not be for the benefit of the University, but for the benefit of the nation. The projected cost was no more than £10 000 of which £2 500 would be for instruments. The University recognized that it could not fund the entirety of this, but it could cover half the fund with the remainder coming from public subscription, and there was a suggestion that the Government should appoint and pay for two assistants. These would be nominated by the heads of the Senate, so this was aimed not at the reformers but at the establishment. It was rejected. Then there was a re-examination of the founding documents of the Plumian Professorship, and amongst the duties were publishing observations, and furnishing instruments as well as the assistants. Now there was a justification for the money to come from the Plumian Professorship, *i.e.*, from the University through endowment.

In 1820 a new proposal was put forward saying there should be new regulations for the Plumian Professorship, that there should be an observatory, and two assistants who are University graduates should be appointed by the Senate. It estimated the costs of salaries and emphasized a focus on meridional observations. This was in line with the motivation of the RAS and it was also stepping on the toes of Greenwich Observatory. The observations should be published annually and they should be distributed to most of the European observatories, with some small instruments available for teaching purposes. This was accepted and the work quickly gathered pace. Note that the Professor was not the observer but the manager of the Observatory.

The Grace was passed on 1820 May 5 and in the next three months more than £5 000 was received from Government funds or through subscriptions — a little later the instruments were ordered and in 1820 December a site was selected and once again there was a gap for the buildings. In 1822 a tender to complete the work was issued with completion in 1824.

In 1824 also it was realized that the cost would be double that of the initial estimate. The Senate did not agree to increase the funding but following negotiations another £4000 was agreed, with another £3000 granted in December. The final cost was £19241.

The Plumian Professor in 1821 was Samuel Vince but he died that year and was succeeded by Robert Woodhouse. He was an important figure — he taught George Peacock and also propagated the analytical method to his students. Unfortunately, before Woodhouse could do much more he died, in 1827, but managed to install the main transit instrument and to make some observations with a Dollond refractor.

At this point George Biddell Airy appeared on the scene. He was very much seen as a member of the new movement and this put him in a very strong position to become Plumian Professor. He was appointed and began by asking the Senate to increase his salary. He argued that he would be paid less than the Chief Assistant at Greenwich and got an increase. His role involved three main duties: lecturing, maintaining and managing the Observatory, and to continue publishing the observations. He wanted to have an assistant but the amount being offered did not cover expenses so he set up a syndicate that reported to the University Senate. The syndicate was packed with members of the AS, the RAS, and the Cambridge Philosophical Society. In 1829 he hired Andrew Baldrey, a retired lieutenant, who was pointedly not a Cambridge graduate, and Airy was empowered to set the Assistant's salary.

Did Airy fulfil the duties of Plumian Professor? Yes, he managed the Observatory and also made observations during the first year of operation. In 1833 a new instrument, a mural circle, was set up and James Glaisher was appointed as a second Assistant, and subsequently made observations with it. Airy also saw it as part of his job correcting the meridional observations made by Greenwich as identified by the RAS. He also rejected the use of *The Nautical Almanac* and adopted the Paris observations.

The Observatory was seen as a tool for radical reform at Cambridge rather than as a scientific establishment. The operation was just catching up with the promoted vision for the Observatory in its early years.

The President. Thank you very much. Mr. Airy was a poacher turned gamekeeper presumably because he wanted to be Director of the Greenwich Observatory.

Dr. Belteki. Yes, if you'd like to invite me for a second talk [laughter].

The President. Questions from the floor? The Analytical Society was John Herschel and Charles Babbage?

Dr. Belteki. Yes.

The President. So, two of our founder members.

Professor Alex Schkochihin. Four hundred pounds per year? What is it in current money? This is important for the record. I want the answer minuted! [Laughter.]

The President. It's quite good! [Laughter.]

Dr. Jacqueline Mitton. At around the time you are talking about, one of the drivers in setting up observatories, particularly in the United States, was the observation of comets. It appears that this wasn't anything that drove the enthusiasm of Cambridge?

Dr. Belteki. The best way to describe it is that cometary observations don't bring in any money whereas if you are correcting the positional or the meridional observations used in *The Nautical Almanac*, which in turn gets used by ships for navigation, there is plenty of vested interest, not just from business, but from the Navy, to improve that, so the monetary interest lies mainly with the star catalogues. There is always a miscellaneous section at the end of the published observations that includes some comet observations but they are very rare.

Professor Lord Martin Rees. Just a couple of footnotes to this lovely talk. First, Airy, before he became Plumian Professor, was Lucasian Professor which was a chair held by Newton, and he wrote a pleading letter saying that he should have double the salary because he had to work at night as well as day [laughter]. The Observatory, which was located on top of Trinity's gatehouse, was put up for Newton's successor, Cotes, and had lapsed into disuse by the end of the century. Science did not really exist as a respectable subject until after this time and it was Whewell who was Master of Trinity and a great scholar who coined the word scientist. At the time he thought that science should not be taught to students, that it was transient — they should just learn the eternal truths of mathematics and theology [laughter].

The President. I assume that as a theoretician you only get half the salary [laughter].

Professor Steve Miller. There is a comment on-line from David and Kenneth Walter James. "I have just looked on-line and £500 in 1828 would be worth about £67 000". So just small change for you, Mike. [Laughter.]

The President. I wish! [Laughter.]

Professor Roger Davies. It is 2% of the capital cost of the telescope, so that tells you that it was a lot of money.

The President. Yes, if you could become Director of the *European Extremely Large Telescope*, you would do really well! [Laughter.]

Dr. Guy Morgan. When was the *Northumberland* refractor built?

Dr. Belteki. In 1834 — and Airy left the Observatory the following year; the installation of the telescope didn't happen until after he left, so it is interesting that he was writing a description of the telescope from Greenwich, even though it was back in Cambridge under a different Director.

The President. Thank you very much indeed [applause]. Note the large numbers that are talked about in the Society are salaries and not distances! [Laughter.]

Now we move on to the Group Achievement Award from the last year awarded to *MeerKAT*. This is going to be a double act. Rob Fender is going first and Ian Hayward second. Rob Fender is head of Astrophysics at the University of Oxford, and has a long history of working in radio astrophysics, with a focus on astrophysical transients in general and black-hole jets in detail. He was awarded the 2020 Herschel Medal of the Royal Astronomical Society. Rob is also a visiting Professor at the University of Cape Town. Ian Heywood is a senior researcher in radio astronomy at Oxford, a visiting Professor at Rhodes University in South Africa, and an honorary associate of the South African Radio Astronomy Observatory. His work encompasses all aspects of cutting-edge radio interferometry, including developing new and automated ways to process the huge volumes of data that characterize radio astronomy in the 21st Century.

Professor Rob Fender. The *MeerKAT* radio telescope arose from the South African bid in 2005 to host the *Square Kilometre Array* (*SKA*). The final *SKA* site decision in 2012 allocated the mid-frequency array (*SKA1-MID*) to South Africa and a low-frequency one (*SKA1-LOW*) to Australia. The *KAT-7* test array was complete by 2009 and was, to our knowledge, the first radio array on the African continent. *MeerKAT* is the first-phase *SKA-MID* and comprises 64 13·5-m dishes with UHF (0·6–1·1 GHz), L-band (0·9–1·7 GHz), and

S-band (1·8–3·5 GHz) receivers. The baselines extend to around 8 km, with a dense core containing a large fraction of the dishes, only 1-km across. The large number, and good distribution, of the dishes and hence baselines provides very good imaging on short snapshot.

MeerKAT was inaugurated on 2018 July 13 and began observations mainly across eight approved Large Survey Programmes (LSPs), tackling a very wide range of science. In the field of pulsars, *MeerKAT* is now providing the best timing accuracy, with an arrival-time accuracy better than seven nanoseconds. In the globular cluster NGC 1851 the first pulsar–black-hole binary may have been found. The *MeerTRAP* project, which piggybacks on regular observations, and is led by the University of Manchester, is detecting fast radio bursts in real time. The *ThunderKAT* LSP is tracking the power and evolution of relativistic jets within our Galaxy, arising from stellar-mass black holes and neutron stars in X-ray binary systems (XRBs). Particular examples include MAXI J1848, precisely tracked relativistic jets in a globular cluster XRB, and Circinus X-1, a neutron-star XRB where jets are punching a hole through the boundary of its nascent supernova remnant. In the remarkable case of the XRB Vela X-1, *MeerKAT* observations of the target system revealed both the first radio detection of a bow shock associated with the binary, as well as the serendipitous discovery, in the field, of the slowest-known radio pulsar.

Dr. Ian Heywood. A substantial fraction of *MeerKAT*'s LSP programme is devoted to observations of the neutral hydrogen (H I) gas in and around galaxies. Observed by means of its 1420-MHz (rest-frame) emission, observations of H I have been a valuable tool for radio astronomy for over seven decades. Serving as the raw fuel from which stars are born, the velocity of the gas can be measured by the Doppler shift of the line, allowing it to be used to trace the motion of gas in and around galaxies. The H I emission line is extremely faint, and the diffuse nature of the hydrogen clouds result in very low surface brightness; however, the imaging capabilities along with its extremely sensitive receivers are facilitating many new insights. Unprecedented views of the H I in nearby galaxies are being obtained through the *MHONGHOOSE* LSP, and an intensive study of the nearby Fornax galaxy cluster is revealing the role that H I plays in the life cycle of galaxies as they collide, with tidal streams containing a billion solar masses of H I being torn from galaxies in the process, seen with *MeerKAT* for the very first time.

A principal driving goal for the *SKA* since its inception has been to detect the faint H I emission at cosmologically significant distances, and *MeerKAT* is making inroads into this main scientific driver of its eventual successor. Surveys such as MIGHTEE and LADUMA are targeting the very distant Universe using deep radio-continuum, spectral-line, and polarimetric observations to provide information on the magnetic fields in and between the galaxies. These surveys are observing fields with unprecedented optical and infrared imaging to look back billions of years to determine the physical processes and environmental conditions that govern how galaxies have formed and evolved over cosmic time.

As *MeerKAT* celebrates the completion of five years of full operations with a conference in Stellenbosch, South Africa, we conclude by returning to our own Galaxy, and revisiting the image that was used to introduce the telescope to the world at its inauguration in 2018 July. The inaugural image of the centre of the Galaxy revealed the chaotic environment around the four-million-solar-mass supermassive black hole that lurks at the centre of our Galaxy with never-before-seen clarity and depth. The image was a fitting demonstration of the capabilities and potential of *MeerKAT*, and that it was produced so soon in the life of the telescope stood as testament to the ingenuity of our South African colleagues who designed and built it. Since then the Galactic-centre data has been used to shed light on the decades-old mystery of the origin of the population of mysterious magnetized filaments that are only seen in that region, as well as having provided the serendipitous discovery of the giant 1400-light-year bubbles of radio-emitting gas, driven by an explosive event in the heart of our Galaxy several million years ago. It is this latter result amongst others that were cited in the Group Achievement Award for *MeerKAT*, and we look forward to many more ground-breaking discoveries with the telescope in the years to come.

The President. Thank you very much for a beautifully illustrated talk. I can't help thinking that some of those images should be in the Royal Academy across the road. May I invite questions in the room to both speakers?

Dr. Arvind Parmar. Is there any evidence on the evolution of these filaments with time?

Dr. Heywood. Not to my knowledge. We have a time baseline of 30 years. I could estimate the resolution you would need to detect motion given the speed. It's probably worth looking at. They are hundreds of light years long and lots of them have compact sources embedded in them. In fact, a lot of the theories about the origin of these features invoke a compact object or a stellar source with a magnetic field and particles. It's not unreasonable to start to detect proper motion in those if they are in the Galactic centre given high enough resolution.

Professor Miller. I have a question from Zaid. Why is Sgr A called a star but is a black hole?

Professor Fender. I think that it is more properly called Sgr A*. The brightest radio source in the constellation got the label Sgr A as is traditional but once they began to resolve that source they realized that it was a very bright extended source with an extremely compact feature in the middle so it became Sgr A*.

The President. Any more questions? If not, we'll thank our speakers again [applause].

We now move on to David Hosking who won the 2022 Michael Penston Thesis Prize. He is going to talk about 'Cosmic voids filled with reconnecting magnetic fields from the early Universe'. David is a Postdoctoral Fellow at the Princeton Center for Theoretical Science (PCTS) and a Research Fellow at Gonville & Caius College, Cambridge. He uses a combination of analytical theory and numerical experiments to study waves, instabilities, and turbulence in astrophysical fluids and plasmas. Dr. Hosking earned his Masters in Mathematics and Theoretical Physics in 2018 and his DPhil in Astrophysics in 2022, both from the University of Oxford. He was awarded the 2022 RAS Michael Penston Prize for his DPhil thesis, which proposed a theory of the decay of magnetohydrodynamic turbulence that combined new statistical invariants with a view of magnetic reconnection as the dominant dynamical process mediating decay.

Dr. David Hosking. According to some theories of cosmology, magnetic fields were generated during inflation or phase transitions in the early Universe. It is widely hypothesized that the relics of these primordial fields (PMF) might still exist today, within the voids of large-scale cosmic structure. This idea suggests the remarkable possibility that measurements of the magnetic fields in voids could be combined with a theory of the evolution of PMFs to provide constraints on early-Universe physics.

Although precise measurement of the magnetic fields in voids is not yet possible, a lower bound on their strength can be deduced from gamma-ray observations of blazars (active galactic nuclei with jets that point towards Earth). If present, extragalactic magnetic fields (EGMFs) in voids would scatter the electrons produced in the electromagnetic cascades of TeV gamma rays emitted by blazars, thus suppressing the number of secondary (GeV) gamma rays received at Earth. Such suppression is indeed observed by the *Fermi Gamma-ray Space Telescope*, and has been used to argue that the fields in voids can be no weaker than around 10^{-17} Gauss (assuming a coherence length of 1 Mpc). Although this lower bound is extremely small by usual standards (magnetic fields in galaxy clusters are 100 billion times stronger, for example), early attempts (using ideas from the theory of decaying turbulence) to estimate how strong the primordial magnetic fields would have needed to be in the early Universe to leave a relic of this strength today found that they would have needed unreasonably large energy, even larger than the radiation density of the Universe (specifically, under the scenario that they were generated at the electroweak phase transition without strong parity violation).

On the other hand, significant evidence emerged in the mid-2010s from numerical simulations of decaying magnetic turbulence that the canonical models did not describe the evolution well. For example, these simulations showed that magnetic fields have a tendency to increase their characteristic size as they decay, a phenomenon that became known as 'inverse transfer'. My PhD thesis provided the first theoretical understanding of these effects, showing that they follow from the requirement that decay conserves the fluctuation level of magnetic helicity (a topological quantity related to twists and linkages of magnetic-field lines) that arises in large volumes. Furthermore, I argue that a corollary of this topological constraint is that the time-scale for decay is not set by ideal dynamics, as had previously been assumed, but the time-scale on which magnetic fields reconnect (changing their topology, but, crucially, preserving their helicity). The electrical resistivity of the primordial plasma was large compared to its viscosity (because it was hot and rarified) so reconnection of primordial magnetic fields would have been a slow process. The decay of primordial fields would therefore also have been slow: the relics of any given initial state would today be stronger by several orders of magnitude than was previously expected. In my thesis, I show that these results restore consistency between a magnetogenesis scenario at the electroweak phase transition and the observational constraints. As the observational constraints on relics of the primordial fields improve (particularly with the next generation of CMB experiments, which will produce improved upper bounds on their strength), the theory that I have derived in my PhD thesis will provide a means to use them to constrain the physics of the early Universe.

The President. Time for a question or two. Any questions in the room?

Dr. Quentin Stanley. Are you able to observe any differences with the magnetic fields depending on which parts of the void you are looking for? Are you expecting them to be homogeneous? If it goes against that will it modify your theory?

Dr. Hosking. I emphasized in my talk a particular region of parameter space where the fields in the voids are small scale. That the fields will be small scale is a prediction of the theory, provided that magnetogenesis occurred at a phase transition. There are other ideas based on magnetogenesis during inflation that lead to homogeneous fields: in that case, the theory of decay has to be revised. We do have some ideas about how to do that, although I didn't have time to speak about them today.

The President. One last question.

Professor Eric Priest. Nice talk, very interesting. One of the problems with using magnetic helicity is that a lot of the MHD-turbulence experiments cannot use a well-defined expression for magnetic helicity because they are periodic. Do you have a periodic system? Magnetic helicity is not well defined. One way around that is to use a sophisticated invariant called field-line helicity. I wonder if you had considered that?

Dr. Hosking. I know about this idea. I don't know exactly how one would construct a theory like the one in my thesis using field-line helicity, but it would be interesting to look into how that would work. Your question, I think, drives at the issue that magnetic helicity is only well-defined if one restricts attention to a closed volume; otherwise, it depends on the choice of gauge. In our case, the volume is not closed, but we find that rapid decay of correlations in space, which we do have, also allows one to prove that the theory is gauge invariant.

Professor Priest. Well, I have lots of other technical questions.

The President. I think you should meet up afterwards. Thank you very much indeed. [Applause.]

Just a couple of things. At the railway station this morning I noticed that the Moon and Venus were in a very nice conjunction which is supposed to be even better tomorrow morning. John Zarnecki has alerted me to the fact that the aphelion of Comet Halley should occur at 1 am on Saturday morning, in other words, in about nine hours' time. He has checked previous perihelia and aphelia which have occurred since we were founded in 1820 and he reckons this is the closest occurrence of any aphelia or perihelia to any RAS meeting. Halley is about 35 AU away and is starting to come back in. It should be visible again in 2061. I give notice that the next A&G Highlights meeting will be on Friday, January 12th, 2024. I remind you of the drinks reception to be held in the RAS Council Room and I also have great pleasure in wishing you a very happy Christmas and a productive New Year.

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2024 January 12 at $16^{h}\ 00^{m}$
in the Geological Society Lecture Theatre, Burlington House

MIKE EDMUNDS, *President*
in the Chair

President. Good afternoon. Welcome. This is a hybrid meeting. Questions can be asked at the end of the lecture but as you will be muted please use the chat facility. Your questions will be read out by the Assistant Editor of *Monthly Notices*, Dr. Pamela Rowden. A list I don't mind is the list of awards. In the New Year's Honours list the following Fellows of the Society received honours: Professor Emma Bunce (former President) is awarded an OBE, Professor Mike Cruise (former President and current Treasurer) an OBE, Dr. Maggie Aderin-Pocock a DBE, and finally a CBE has been awarded to Professor Philip Diamond, Head of *SKA* at Manchester. Very well done to all [applause].

I am now going to announce the RAS Awards for 2024. This is the 200th anniversary of the first award of the Gold Medal, which in 1824 went to