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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2025 January 10 at 16^{h} 00^{m}
in the Geological Society Lecture Theatre, Burlington House

MIKE LOCKWOOD, *President*
in the Chair

The President. Welcome everybody and thanks for braving the cold weather today. This is a hybrid meeting. Questions can be asked at the end of the meeting by putting them in the Q and A, and then they will be read out by Dr. Pam Rowell.

I now move on to the announcement of the winners of the RAS awards for 2025. The Gold Medal (A) goes to Professor James Binney, Oxford University, and the Gold Medal (G) to Professor Jonathan Tennyson, University College London. The Eddington Medal is awarded to Emeritus Professor Douglas Heggie, University of Edinburgh, and the Chapman Medal goes to Dr. Nigel Meredith, British Antarctic Survey. The Herschel Medal is awarded to Emeritus Professor Ian Smail, Durham University, and the Price Medal to Dr. Paola Pinilla, University College London. The Jackson-Gwilt Medal goes to Professor Anna Moore, Australian National University. The Fowler Award (A) is awarded to Dr. Hannah Wakeford, University of Bristol, and the Fowler Award (G) goes to Dr. John Coxon, Northumbria University. An Early Career Award (A) is awarded to Dr. Steve Cunnington, University of Manchester, and Dr. Niall Jeffrey, University College London. The Early Career Award (G) goes to Dr. Giulia Magnarini, Natural History Museum, London. The Group Achievement Award (A) goes to the European Pulsar Timing Array, and the (G) Award has been given to the Met. Office Space Weather Operations Centre. The Service Award (A) goes to Professor Francis Keenan, Queen's University Belfast, and the (G) Award goes to Dr. Dmitry Storchak, International Seismological Centre. The Secondary Education Award goes to Dr. Alex Calverley, Surbiton High School, whilst the Higher Education Award is given to Professor Andrew Norton, The Open University. The Annie Maunder Medal is awarded to Amelia Jane Piper. The following 'named' lectures will be delivered at a meeting of the Society: The George Darwin Lectureship goes to Dr. Dimitri Veras, University of Warwick, whilst the James Dungey Lecture will be given by Dr. Ryan Milligan, Queen's University Belfast. The Harold Jeffreys Lectureship goes to Dr. Andrew Valentine, Durham University. Honorary Fellowships have been awarded to Professor Caitriona Jackman, DIAS Dunsink Observatory, and Professor Francesca Matteucci of the University of Trieste. Many congratulations to all the award winners [applause].

BepiColombo has arrived at Mercury and the separation of the craft into two will take place later this week. It was launched in 2018 and has already generated a lot of scientific data.

Moving on to today's programme. Nilanjan Choudhury is a Bangalore-based theatremaker and novelist. He has written two plays on science history, *The Square Root of a Sonnet* and *The Trial of Abdus Salam*, which have received wide critical acclaim and have been staged across several cities in India, the UK, and the USA. He is currently working on a new play about India's first woman particle physicist, Bibha Chowdhuri. He has been a part of over 300 stage performances with Bangalore's leading theatre companies including the Centre for Film and Drama and others. Mr. Choudhury's most recent novel is *Song of the Golden Sparrow* — a fictional retelling of the story of free India. His previous novel *Shillong Times* is a coming-of-age story set against the ethnic conflict in the hill town of Shillong during the 1980s and was nominated for the Indian Sahitya Akademi Award in 2023. His earlier novels include a mythological thriller and a contemporary detective caper set in Bangalore. Mr. Choudhury is a postgraduate in Physics from the Indian Institute of Technology, Kanpur.

Mr. Nilanjan Choudhury. I should explain what *The Square Root of a Sonnet* is all about. It is a play which we performed at the Royal Institution, London, in July last year. It is about two giants of modern astrophysics: Sir Arthur Eddington and Subramanyan Chandrasekhar. Eddington, of course, was the most renowned astronomer of his time in the early to mid-1900s and Chandrasekhar was awarded the Nobel Prize for Physics in 1983 along with William Fowler for his work on white-dwarf stars. I believe that the reason that I have been asked to present this today is because of a significant date. Tomorrow is the 90th anniversary of a fairly remarkable incident that happened at the RAS on 1935 January 11. Chandra presented his paper called 'The maximum mass of ideal white dwarfs'. The audience included Jeans, Hardy, R. H. Fowler, Stratton, who was in the Presidential chair, as well as Eddington.

While he was travelling from Bombay to Dover to take up a research studentship at Cambridge under the guidance of Eddington and R. H. Fowler, Chandra spent the three months of the voyage working on the evolution of white dwarfs. He found that white dwarfs nearing the end of their lives, those which have a mass greater than 1·44 solar masses would start contracting and collapsing under their own gravitational forces, becoming very small, and eventually they turned into neutron stars and, in some cases, black holes. This was a remarkable piece of work for a 19-year-old as it involved analysing theories of quantum dynamics, along with Special Relativity. It had to do with electron degeneracy as the star shrinks into a small volume. The idea that a star with the mass of the Sun could become such a tiny thing was something that his mentor could not quite grasp. There was a conflict between the young Chandra and the eminent Eddington at the RAS AGM in 1935, and this was a brutal public humiliation of the younger man. It not only took Chandra by complete surprise, because Eddington had been encouraging him all the while, but it affected him deeply for several years and he left the study of gravitational collapse of stars and worked on other topics. It was only when he was 63 that Chandra returned to the study of black holes.

However, during that period despite the opposition and conflict with Eddington, there was a strange relationship between the two of them especially from Chandra's side. This was a form of hero worship which lasted throughout Chandra's life although the hero turned out, in certain ways, to have feet of clay, by completely dismissing a theory which later on became known as explaining the first critical step to the formation of a black hole.

The title of the play *The Square Root of a Sonnet* is actually paraphrased from one of Eddington's own statements where he says "human personalities are not measurable by symbols, equations, or logic, any more than you can extract the square root of a sonnet", which means we don't often act in rational ways when we are doing rational work in science and mathematics. The interface of the rational world of science and mathematics with the irrational world of the human mind comes together in this play. What follows is a brief seven-minute scene from the play and it enacts a scene at the 1935 January RAS meeting when Chandra was presenting his paper on the maximum mass of ideal white-dwarf stars. Many of the words and sentences used in the clip are quoted verbatim in the sense in that they represent what Eddington said. They are not what Chandra said because this is an imaginary setting. He did not retaliate against some of the things said at the meeting itself but many of the words that you hear Eddington speaking I am quoting verbatim from the meeting report [Ed. — see these pages **58**, 33, 1935].

[There followed a seven-minute extract from the play in which Chandrasekhar was played by Nilanjan Choudhury and the part of Eddington was taken by Sal Yusuf.]

The President. Would you take some questions?

Mr. Choudhury. If you have the time I have the inclination [laughter].

Professor Steve Miller. Are there plans for bringing the play back to the UK? I think you are in discussion with the Murty Trust about doing something in Cambridge that maybe the RAS can be involved with as well.

Mr. Choudhury. First of all Steve, if you are in the room, I am glad to see you up and about. Yes, we would love to come back and we are in talks with the Murty Trust. They have an interest in maybe doing something with the RAS. We will try and see how we can make this financially feasible.

The President. I must just make the point that what made Eddington's behaviour all the more remarkable was that the man was a Quaker and had been known for his kindness, and I just don't understand where it came from. I do know that a lot of people wrote to Chandra afterwards saying that he (Eddington) had got this wrong. The reality and the truth came out in the end but it was a remarkable outburst.

Ms. Gail Campbell. Thank you very much indeed for that wonderful play, and if it does come to Cambridge I will certainly come and see it. There is a huge interest in the lives of scientists and as you know, for example, Srinivasan Ramanujan had a wonderful play about him turned into a film. Do you have any plans to address any other scientists in your artistic work?

Mr. Choudhury. As we speak we have started rehearsals on my second science play. It is called *The Trial of Abdus Salam*. He was the first Pakistani and, in fact, the first Muslim to win a Nobel Prize in Science. This play involves his complex relationship with his country, and that also has a very strong British connection because he did a lot of his work at Imperial College London. We open on March 29 and as mentioned before I have also finished the first draft of a third play I wanted to call *Invisible Particles* which concerns India's first woman particle physicist, a lady called Bibha Chowdhuri who has been completely lost from history, and her life intertwines very closely with another woman physicist, Marietta Blau, whose work on nuclear emulsions finally led to the discovery of the meson.

The President. Thank you very much, Nilanjan. Briefly, do you think that the reference to 'the square root of a sonnet' was by way of some sort of apology from Eddington?

Mr. Choudhury. Not really. As you know Eddington was a very gifted writer and orator and was very fluent with his language and words. This statement had nothing to do with Chandra. In fact, he never apologised. If I may, there is one quote worth repeating — in 1939 Chandra wrote a book which summarized all his work; Eddington had read it and said "How nice to get everything wrong in one place".

The President. Sometimes one can be cursed by having a good wit.

Mr. Choudhury. If someone wants to read the play I would be happy to share a script with them. Please contact me *via* nilanjanpc@gmail.com or www.nilanjan.net. The play really explores the potential reasons why this thing happened. This is Eddington's very strong view on how nature should work, how God should have constructed the world.

The President. Thank you very much, Nilanjan [applause].

We now move on to the Harold Jeffreys Lecture. It will be given by Jessica Irving and the title is 'Hearing planetary hearts: seismology of the cores of Earth and Mars'. Jessica Irving received her MSci in 2005 and PhD in 2009 from the University of Cambridge, where she was also a Postdoctoral Researcher. She was an Assistant Professor at Princeton University and is now Associate Professor in Global Seismology at the University of Bristol. Her research encompasses Earth's core, mantle, and oceans, as well as Mars and other planetary bodies.

[The Harold Jeffreys Lecture explored what seismology has revealed about the structure of the cores of Earth and Mars — a topic on which Jeffreys spent considerable time. A full account is expected to appear in *A&G*.]

Dr. Jessica Irvine. Our understanding of Earth's core has evolved from early ideas of an inaccessible central kernel of seismically slow material, through the discovery and measurement of the inner core, to present investigations into the properties of the dynamic heart of our planet. Seismological data from the *InSight* (*INterior exploration using Seismic Investigation Geodesy and Heat Transfer*) geophysical mission were the first to probe the deep Martian interior, which is now the second planetary core to be seismically detected.

The President. Thank you very much, that was beautifully clear.

Reverend Garth Barber. One of the first surface features on Mars is the apparent appearance of ocean features and yet where has all the water gone? Is there any seismic evidence that there may be sub-surface water in the Martian structure?

Dr. Irving. There are certainly people who could speak better to the surface-related story than I as a seismologist could. I would say, first of all, that there are a number of models about what might be happening directly under the *InSight* lander — some relatively short-scale structure. Some of these models have a small amount of hydrated material present, others do not. The history of Mars is very different to the history of our planet, primarily due to the absence of whole-planet plate tectonics as we understand it. What we do see from the seismic results, and it doesn't directly answer your question, is that we have some small amount of hydrogen and oxygen in the core, and I want to be clear that these are primordial features. That is not where the ocean would have drained to. That water would not have gone the whole way through the mantle of the planet although people may have sometimes suggested it. We have a really complex body that we are seeing, where clearly the nature of water storage must be different to that on the Earth because on Earth we do believe it could be possible for the hydrated material to travel very deep. Indeed, on Mars, we think that is slightly different.

Professor John Zarnecki. I did not understand how, in the case of the Mars event, you were able to locate the origin except in the case of the impact, of course.

Dr. Irving. If you take an undergraduate class in seismology then they will tell you that you need multiple seismic stations to detect the location of an event and I just told you that it was done with one. What you can do is actually use the polarization of the energy to try and determine its back azimuth, *i.e.*, the direction from which the energy is coming. We know that the P wave is a compression and we understand the polarization of those. You can use these P waves to tell you the direction the energy is coming in from and you can use the time separation seismic phases to tell you the distance. We do this by looking at the vertical motion, the east–west and north–south motion of each individual seismic phase and then you can have a go at estimating back azimuth and get a full location, contrary to what any undergraduate lectures might have taught you. This is not easy but only for a few events was the amazing Mars Quake service able to do this sort of work. There are many more events where a full location could not be developed because it was not possible to do the technical calculations. The short answer is that it is super-hard but with a lot of seismic processing you can get a decent idea.

The President. I can see other hands up, but we are beginning to overstay our tenure of the room so please ask your questions to Jessica at the wine reception afterwards. Thank you very much [applause].

Dr. Christopher Lovell is a Dennis Sciama Fellow at the University of Portsmouth. His research focusses on numerical simulations of galaxy evolution, in particular how to model the electromagnetic emission from galaxies, whilst also leveraging the latest statistical and machine-learning methods. He received a PhD in Astronomy from the University of Sussex in 2019, supervised by Professor Peter Thomas and Dr. Stephen Wilkins. He has held postdoctoral roles at the University of Hertfordshire and the University of Tokyo. Recently he was awarded the 2024 Winton Award from the Royal Astronomical Society for his work on forward-modelling extreme-star-forming galaxies. He is a member of the *Euclid*, Learning the Universe, CAMELS (Cosmology and Astrophysics with MachinE Learning Simulations), and FLARES (First Light And Reionization Epoch Simulation) international collaborations. His talk is entitled 'Accelerated modelling of the entire observable Universe'.

Dr. Christopher Lovell. [The latest space-based telescopes, such as the *James Webb Space Telescope* and *Euclid*, are now regularly probing the earliest galaxy populations, formed less than a billion years after the Universe formed. Numerical simulations are a key tool in the astrophysicists' toolbox that allow us to understand the complex processes occurring in those distant galaxies. But how do we compare our theoretical models to actual observations? And what can we learn about both galaxies and cosmology from these sophisticated models?

The talk also reviewed how we model galaxies using numerical simulations, with a particular focus on how we model the light they emit across the whole electromagnetic spectrum. Some of the exciting new methods from statistics and machine learning that are helping to accelerate our models, and provide new insights into both astrophysics and cosmology, were described.]

The President. I'm sorry to hurry you there, but that was absolutely fascinating. We can take a couple of quick questions.

Dr. Q. Stanley. You are taking one of the larger models as the initial conditions for FLARES and that is where you are looking at. Are you finding that it is certain assumptions that you are taking that lead to errors in the areas that you are looking for, or is it other assumptions that you are finding through SPI which leads to those things? It is a very complex situation.

Dr. Lovell. To first order it is the environment. These FLARES regions are large enough that they are capturing cosmological representatives of populations of galaxies. They are rare enough that they are producing rare galaxies but you are right, for a given over-density there is still a lot of scatter in the predicted properties when you add in the galaxy attributes. For certain regions that you think will be very rare there is actually a spread in the rarity of these objects. Otherwise, as you add in the forward modelling that also increases the variance as well so it's not a case of a very simple one-to-one mapping on just the over-density.

The President. One more question.

Reverend Barber. Can you model the very early objects we see with the *James Webb Space Telescope* — the massive black holes, *etc.*?

Dr. Lovell. Yes, is the short answer. We essentially stop the simulations at a redshift of five, so FLARES is very much focussed on *JWST* and early galaxies and it has already been used to explore and place some limits on those very early galaxies. FLARES seems to do quite well at matching some of these early results that suggested attention with our previous understanding of abundances and masses of galaxies. FLARES does slightly better than some other models and we believe that part of that is due to our simulation approach — we are actually catching these rare objects that *JWST* is seeing and other models are able to probe but they don't have the volume to do it. With that said, there have been a few papers in the past few weeks where FLARES is still struggling to produce enough of these very massive things. FLARES is not the end of the story but it is an important contribution.

The President. With that I fear I have to wrap up. Everything you have heard today was beautifully presented and absolutely fascinating and I think we should give a big round of applause to all our speakers [applause]. I should say that Dr. Siân Prosser has produced an exhibition in the Library about Chandrasekhar and Eddington. The next meeting will be on the second Friday of February (14th).

REDISCUSSION OF ECLIPSING BINARIES. PAPER 25: THE CHEMICALLY-PECULIAR SYSTEM AR AURIGAE

By *John Southworth*

Astrophysics Group, Keele University

AR Aur is a detached eclipsing binary containing two late-B stars which are chemically peculiar, on a circular orbit of period 4·135 d. The primary is a HgMn star which shows temporal changes in its chemical abundances and spectral-line profiles, whilst the secondary is a likely weak Am star. Published analyses of the system have used spectroscopic light ratios to constrain