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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2025 February 14 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

MIKE LOCKWOOD, *President*
in the Chair

The President. The first speaker today is Dr. Chris Smith from Huddersfield New College and his talk is called 'Searching for Saturn's periodicities in the upper atmosphere'. Chris Smith graduated from Cambridge University with an MSci in 2002 and completed a PhD in atmospheric modelling in 2006 at UCL. He then trained to be a secondary science teacher at Newcastle University and between 2007 and 2022 worked with 11 to 18-year-olds. He currently teaches physics and maths at A level at Huddersfield New College in West Yorkshire.

Dr. Chris Smith. I would like to talk about my work to try to explain the 'planetary period oscillations' (PPOs) in Saturn's magnetosphere using models of the neutral atmosphere. To understand the problem, we first need some context around the structure of Saturn's magnetosphere. An important feature is the equatorial plasma disc, which rotates more slowly than the deep atmosphere of the planet. The disc is continually loaded with mass from the moons and rings, and is then spun up towards co-rotation by the transfer of angular momentum from the planet. This transfer is mediated by electric currents flowing along magnetic-field lines. The result is that the magnetosphere rotates much more slowly than the deep planet, and the connected neutral upper atmosphere — the thermosphere — where the currents flow also rotates significantly more slowly than the deep planet.

Given this context we can explain what the PPOs are and why they are such a puzzle. The PPOs are ubiquitous signals observed in the magnetosphere in various phenomena including magnetic-field perturbations and radio emissions. The majority of our information about these signals was gathered by the *Cassini* mission. The period of these signals is close to the rotation period of the planet, but they show several puzzling features: the period varies by a few percent on a time-scale of months; there are distinct periods in the northern and southern hemisphere; and these periods became locked together for about a year in 2013–2014. Given the context of a sub-corotating magnetosphere, the presence of the signals themselves is difficult to explain: how can there be planetary-period signals in a system that does not rotate anywhere close to the planetary period? The neutral atmosphere is an excellent candidate to resolve some of these problems.

Before I go on to talk about my work, I should mention that there is now good evidence that the PPOs are indeed driven from the neutral atmosphere by twin-vortex flows in the polar regions. Driving an MHD model of the atmosphere with these types of flows reproduces many of the observations. A twin-vortex has also been observed in infrared Doppler observations of the ionosphere, and the features of this vortex are consistent with a driver in the neutral atmosphere.

My work has been on constructing the nature of this twin vortex using numerical modelling and theory. My initial approach was to use a global circulation model of the thermosphere to produce a twin vortex that could explain the observed currents. To produce something approximating the observations required the model to be forced by an artificially imposed heat source. There were two key problems with this approach. First, a plausible source of the heating required is difficult to find. Second, and more critically, the thermosphere itself does not rotate close enough to the planetary period to be the origin of the signals.

A possible solution to the second problem is to push the location of the twin vortex deeper in the atmosphere. The thermosphere sub-corotates largely due to the coupling currents that transfer angular momentum to the magnetosphere. However, the stratosphere is sufficiently close to corotation that it could be the source of the PPOs. For this to be the case there needs to be a mechanism to extract sufficient field-aligned currents from the Hall conductivity that dominates this region of the upper atmosphere.

To investigate this mechanism I have explored various atmospheric-wave models to describe the required neutral flows. The first of these adapted a terrestrial model of circumpolar waves to develop a three-dimensional model of slowly westward-propagating Rossby waves. A problem with this model was that it was able to produce large enough currents only by invoking aurorally enhanced conductance. However, the prediction of waves propagating westward at a few percent of the planetary angular speed fits perfectly with the PPO periods being slightly longer than the likely deep planetary period.

The nature of Rossby waves also provided a possible heuristic model of the locking together of the northern and southern periods. Rossby waves are able to propagate westwards only with a small range of speeds. If the northern and southern Rossby waves each have their own range of possible propagation speeds, which vary independently, then it would be possible for them to lock together only when these ranges happened to overlap. This model qualitatively reproduces the observed locking behaviour, although the actual mechanism for them to lock together is not yet clear.

My most recent refinement to the Rossby-wave model has been to extend the beta-plane concept to ionospheric conductance. A beta-plane is an approximation in atmospheric-wave theory that represents the variation of the Coriolis parameter with latitude in a linear way. I applied the same approach to the variation of Hall conductance with latitude. This led to an explicit coupling equation between magnetospheric plasma flows and quasi-geostrophic Rossby waves, allowing me to investigate energy flow between the atmosphere and magnetosphere in a quantitative way: essentially, the magnetosphere can drive atmospheric waves, and *vice versa*.

Overall then, I have had some success in applying atmospheric-wave theory to this novel context. The next step is to try to build the physics of the centrifugal interchange instability into the magnetospheric component of the model, in the hope that this can provide an energy source for the Rossby waves that make up the twin-vortex. If successful this could provide an explanation, rather than just a description, of this fascinating and puzzling phenomenon.

The President. Thank you very much [applause]. Our next speaker is Professor Leah Morabito. She is UKRI Future Leaders Fellow at Durham University. Her work focusses on studying active radio galaxies at sub-arcsecond imaging with *LOFAR*, the low-frequency array. Recently, in the US, Leah won a military scholarship to fund her undergraduate studies and spent six years in the United States Air Force as an Air Battle Manager. During this time she was an MSc student at the University of Oklahoma when she worked with others on electromagnetic spectra and X-ray observations of quasars. Leah then went to Leiden University and hence to Durham, *via* Oxford. The title of her talk is 'The highest-resolution imaging at the lowest frequencies — sub-arcsecond imaging with *LOFAR*'.

Professor Leah Morabito. Thank you for the invitation to talk to the RAS and for the Rosemary Fowler Award for the work which I am going to talk about today.

If you took a picture with a very sensitive optical telescope, you would see hundreds to thousands of faint, distant galaxies. There are so many that they crowd each other in the picture: spiral galaxies next to elliptical galaxies, merging galaxies, irregular galaxies (and the occasional nearby star). However, if you looked at the same patch of the sky with a radio telescope, you would see something completely different. Radio images reveal the imprint of supermassive black holes in the form of radio-emitting jets of relativistic plasma. These jets are launched from supermassive black holes at the centres of massive galaxies, which are actively feeding on material in their host galaxy. Only about one in every one hundred galaxies has radio jets, so the radio sky is much emptier when compared to the optical sky, but radio provides us with important information on active supermassive black holes.

To study fully these radio-emitting jets, we must be able to study them in detail. This is where the *LOw Frequency ARray* (*LOFAR*) comes in. *LOFAR* is a radio telescope that is made up of hundreds of thousands of dipole antennae (similar to those in a car), which are located in eight different countries in Europe. These antennae are grouped into 'stations' of 96 dipoles each, and we can correlate the information recorded from each station to create images of the radio sky. Most of the stations are located in the Netherlands. By combining the signals from just these stations, we get *LOFAR*'s 'standard' resolution, which is poorer resolution than optical telescopes, but we can survey an area about eighty times larger than the Moon in a single image. If we include all European *LOFAR* stations, which span Ireland to Poland, we get a much bigger effective 'lens' for our telescope, and we can improve our resolution by a factor of 20 (see Fig. 1).

Combining signals from radio antennae up to 2000 km apart is technically and logistically challenging. The biggest challenge is correcting the data for distortions caused as the incoming radio waves pass through the ionosphere. What effect does this have on our images? Imagine that you're lying at the bottom of a swimming pool, looking up at the clouds. There might be a little gentle swaying as the water moves above you, distorting the image. Now, imagine that someone jumps into the pool right next to you. It would be incredibly difficult to describe the exact shape of the clouds above you if that happened. This is similar to what the ionosphere does to low-frequency radio waves. Sometimes, it is nicely behaved, and we need only small corrections — but sometimes we need many corrections in many different directions in the image to reconstruct what the radio sky looks like.

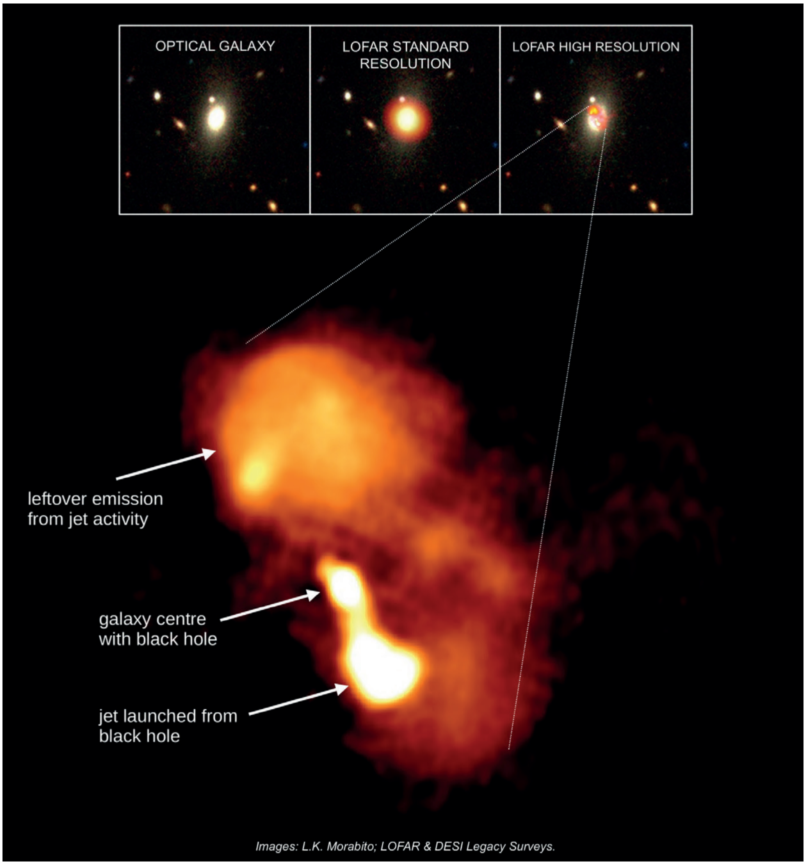

FIG. 1
An example of the resolving power of *LOFAR*.

Over the past decade, I have led efforts to develop a strategy for correcting the data. We have gone from doubt that it would ever work to huge successes — breaking the record for the highest-resolution images made using low radio frequencies! Today, high-resolution imaging is becoming routine thanks to our efforts to create a user-friendly data-processing pipeline that produces high-quality results. *LOFAR* is an exceptional instrument with major advantages that make it unique even in the era of next-generation radio telescopes like the *Square Kilometre Array* Observatory. High-resolution imaging with *LOFAR* can be done across a wide field of view, enabling blind and statistical studies. To get a similar resolution with other radio telescopes, one must go to higher frequencies at the cost of a drastically reduced field of view. *LOFAR* also matches the resolution of instruments at other wavebands, like optical, near-infrared, and X-ray, which is crucial for understanding how the emission at these different wavebands is related. The low-frequency coverage with high spatial resolution also enables studies of how the spectral-energy distribution changes across a wide range of radio frequencies; the information provided by *LOFAR* is necessary to constrain the initial injection index of the radio-emitting plasma. And finally, *LOFAR* can uniquely image a wide range of spatial scales from the same dataset, simply by choosing which stations to include. No other radio telescope is capable of simultaneously measuring diffuse degree-scale radio emission and compact sub-arcsecond-scale radio emission (and all spatial scales in between). All of these advantages make *LOFAR* uniquely capable of achieving science goals where other radio telescopes would struggle to compete.

Now that high-resolution imaging with *LOFAR* is routine, we are planning and enacting wide-area high-resolution surveys by post-processing current data, as well as deep images of selected 'famous fields' in the sky that are well-studied at non-radio wavebands. One of these fields is the *Euclid* Deep Field North. This field will have exceptional matched-resolution coverage from *Euclid* and *LOFAR*, providing a first-rate dataset to study star formation and supermassive-black-hole activity using a combination of spectroscopy and radio emission, all the way back into the early ages of the Universe.

The President. Thank you very much, Leah. Questions?

Professor Richard Ellis. If I have got this right, you said that you were finding more AGN through these high-resolution images?

Professor Morabito. Yes. This is quite technical but you can identify AGN using brightness-temperature measurements. There is an upper limit to star formation, the radio emission you produce in star formation. You really need high resolution to be able to detect high-surface-brightness sources because those high-surface-brightness sources are going to be your AGN. This is just a comparison in the GOODS North Field where they found 31 AGN, and the Elias N1 field where we find over 1500 using brightness temperature. Basically you predict what you get from star formation and if you get something above that as radio emission in terms of surface brightness it has to be due to AGN. That is frequency dependent so you need milli-arcsecond resolution to do this, *i.e.*, by using GHz frequencies, but at 144 MHz you can do it with 0·3-arcsecond resolution.

Professor Ellis. JWST is finding these puzzling little red dots so it would be wonderful if there is any overlap between your survey and these paradoxical little red dots.

Professor Morabito. I think that we will probably find things like this in the *LOFAR 2·0* Ultra Deep Observations (LUDO) survey because at present our deep fields are not deep enough to see these higher-*z* things, but LUDO should be able to see these kind of objects over the next few years.

The President. We are now experimenting by having a remote question for a remote speaker!

Dr. Pamela Rowell. Ian Robson has asked a question. "Great talk. In terms of data extraction and analysis what is the key lesson to be learned for the *SKA*?"

Professor Morabito. I would say that international *LOFAR* data processing is probably as close as we will get to *SKA* data processing in terms of what you are doing with the processing and the data volumes. I think that the key lesson is that we are going to have to be more efficient in how we process data. We have done very well in getting to a solution but for *SKA* and even now for LUDO when we are trying to process a lot of data at once, if you do a calculation based on the fact it takes 250 000 hours to make one wide-field image; it doesn't take that long now, but if you want to do this across the entire sky, it will take 75 years, which is not feasible. What we are really learning is how to process data efficiently in a large-scale non-interactive manner but I think although we have learned that we still have a long way to go.

The President. I have a question which I would ask over a glass of wine if you were here. You mentioned S/N problems early on. Have they got worse for any particular reason in recent times?

Professor Morabito. Because the ionosphere is impacted by the solar cycle and we are reaching a maximum, it has been an issue and we have seen that the data quality has decreased. *LOFAR* is currently off-line for an electronics upgrade which fortuitously coincides with the solar maximum. It does not mean that the data is not able to be calibrated, it just means that it has been a little more difficult.

The President. I was thinking about satellite-constellation noise but that may need several hours of discussion so let's leave it at that. Thank you very much again, Leah [applause].

We now come to the James Dungey Lecture to be given by Dr. Gabby Provan of the University of Leicester. She obtained a BSc Honours degree in Physics in 1993 and followed this with a PhD. She helped construct the *SuperDARN* radar in Iceland and I admire her courage in doing that. I tried to climb one of the antennae, got half way up and had to come down. Since her PhD she has worked on planetary aurorae, the magnetospheres of Earth, Saturn, and Jupiter using, in particular, the *Cassini* and *JUNO* spacecraft, and particularly looking at field-line currents associated with those aurorae. She also contributes greatly to the University of Leicester by looking after staff, so time pressures are high. She serves on the University Senate and Council. The title of her talk is 'The Northern Lights on Earth and other planets'. [It is expected that a full report will appear in a forthcoming issue of *Astronomy & Geophysics*.]

Dr. Gabrielle Provan. It's a real pleasure to be here today and to give the James Dungey Lecture, not least because James Dungey was one of the founding fathers of ionospheric physics, and it is a field which I have had the pleasure to work in for many years.

[The Northern Lights, or aurora borealis, rank among nature's most awe-inspiring light displays. For centuries, they have captivated those fortunate enough to witness them, inspiring myths, legends, and scientific curiosity. Despite their enigmatic beauty, it wasn't until the late 19th Century that scientists began unravelling the complex mechanisms behind these luminous phenomena.

The speaker began by examining Earth's aurorae in detail, showcasing stunning images and dynamic visualizations to illustrate their behaviour and variability, and continued by exploring the underlying processes that produce these dazzling lights, from the acceleration of charged particles in Earth's magnetosphere to their energetic collisions with atmospheric gases. How energy is transferred from the Sun to the Earth's system during auroral displays and the possible effect of this space weather on Earth was also discussed.

The speaker then extended the talk beyond Earth, exploring auroral displays observed on other planets within our Solar System, and considered the vivid ultraviolet aurorae of Jupiter, driven by the interplay of the planet's immense magnetic field and its volcanically active moon Io, as well as Saturn's auroral emission, and its temporal variability, followed by the more enigmatic aurorae observed on Uranus and Neptune.

Throughout the lecture the speaker focussed on using aurorae as diagnostic tools for understanding planetary magnetic fields, the properties of stellar winds, and the interactions between stars and planets. By studying aurorae on other planets, we gain critical insights into the habitability of exoplanets and the potential for magnetic fields to shield atmospheres from stellar radiation.]

The President. Thank you very much, Gabby. Questions? I have one. People often say that the last signal you can detect from Earth as you went away would be the auroral kilometric radiation (AKR). I am wondering if people are making predictions from the point of exoplanetary science on the difference between AKR, SKR, and JKR in terms of detecting what sort of planet we are talking about?

Dr. Provan. I do know that people are using radio signals to look for aurorae for different planets and extrasolar sources.

The President. These differences in the field-line-current systems for those sources are so fundamental that I think we should use that.

Dr. Stanley. We would have had some fantastic storms like the Carrington event that the ancient cave dwellers, in France, for instance, would have seen.

Dr. Provan. That is interesting when you look at the Northern Lights in myths and stories. That must also have occurred to the Romans and the Greeks given their latitude.

Dr. Stanley. Regarding the Carrington event, if you read his actual diary, rather than *Monthly Notices*, he did not continue his observations because he got back to cutting his trees. If you see the actual diary entry you will see that his arboreal interest supercedes his interest in astronomy.

A Fellow. I was looking to the future instead of the cave paintings. The *JUICE* mission is on its way to Jupiter and Ganymede now and I wondered what thoughts you might have both about what *JUICE* might discover about Ganymede and also Jupiter's aurora?

Dr. Provan. I had wanted to talk about Ganymede's aurora in this talk because it is the lack of wobbling of Ganymede's aurora that demonstrated that Ganymede has a salty, subsurface ocean. I'm looking forward to *JUICE*.

The President. Can I ask for a last round of applause for our James Dungey Lecturer. [Applause.] Thank you to Gabby and our other speakers tonight.

REDISCUSSION OF ECLIPSING BINARIES. PAPER 26: THE F-TYPE LONG-PERIOD SYSTEM HP DRACONIS

By John Southworth

Astrophysics Group, Keele University

HP Dra is a well-detached eclipsing binary containing two late-F stars on an orbit with a relatively long period of 10·76 d and a small eccentricity of 0·036. It has been observed in 14 sectors using the *Transiting Exoplanet Survey Satellite* (*TESS*).