

(NLTE) effects in the chromosphere into account, such as scattering of radiation and non-equilibrium hydrogen ionization. In the NLTE simulations, the average temperature of the prominence plasma is higher, and the temperature structure within the prominence becomes more inhomogeneous compared to the LTE case.

With the current setup, we plan to conduct more extensive parameter studies in order to gain a better understanding of the origin of the visible structures and dynamics. In the future, we intend to expand our simulation setup to include more sophisticated magnetic-field configurations, such as larger sheared arcades and magnetic-flux ropes. By calculating synthesised emission at different wavelengths, we will be able to make more detailed comparisons with observations.

The President. Questions for Lisa? I'm just amazed at the detail you are able to simulate. Some of the simulations look more like things from computer games. I was going to ask about the basis of the field model, but also the pattern of motions — are they prescribed from instrumentation or are they produced by other models?

Dr. Zeßner. The movement in general is produced by the models. You start out with a simple atmosphere and then the model gets heated so you put energy in which tries to match what energy comes out of the Sun and then you naturally get this hot-plate effect that creates granulation cells in the plasma when you heat it from below. You have to define a boundary condition because the convective zone is pretty deep — it makes up about 30% of the solar diameter. We cannot simulate all of that and also we have the problem that we don't really know exactly how the convection cells look deep-down. We simulate only the very top layer so we have to make assumptions.

The President. My question was biased because the movie didn't run. It looked as though the field was sitting within granulation cells. That is why I wondered if they were prescribed. I'm amazed at some of the things that you are able to simulate. Some of them look more like computer games.

Dr. Zeßner. That field was prescribed because it was put in by the initial magnetic-field configuration, but its shape is also affected by the turbulent convective motions.

The President. Are there any other questions? Thank you very much, that was lovely. [Applause.]

There are just two announcements before we close. The next meeting will be on Friday, March 13th and there are drinks next door in the library. Remember to write to your MP.

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2026 March 13 at 16^h 00^m
in the Geological Society Lecture Theatre, Burlington House

MIKE LOCKWOOD, *President*
in the Chair

The President. Welcome to today's meeting. This is a hybrid meeting. Questions can be put in the Q&A and they will be asked at the end of each lecture by Dr. Pam Rowell.

I have an unhappy job to do and that is to announce the death of Dame Carole Jordan. [Carole was an Editor of this *Magazine* 1968–1973. — Ed.] She was the first female President of the Society and served in that post from 1994 to 1996. I can tell you that the RAS was incredibly close to her heart. We would often talk both here at the meeting and afterwards

on the train to Oxford, and she would always ask about the Society. She was a genuine trailblazer in making her own way in what was a male-dominated field at the time. She made her name in particular in spectral studies of in the UV from the *IUE* mission and in X-rays. She analysed the spectra in terms of states of ionization and followed through that with work on cool stars. I was asked to talk about her for *Last Words* on Radio 4 and I was looking for a suitable anecdote. Fortunately Roger Davies came up with the perfect example: At a reception at Oxford, she was introduced as Professor Dame Carole Jordan and her response was “Dame Commander — I like the Commander bit”. Can I ask you to take a few moments to remember her? Thank you.

The bad news comes from STFC. There is a major funding crisis with 30% cuts to astronomy-grants projects and teams have been told to plan for 60% cuts. I want to tell you what the Society has been doing and my sincere thanks to Robert Massey, Marieta Lefort, Sam Tonkin, and Jess Shaper who have contributed enormously as has Jim Wild (our President-Elect), and Ian Russell.

They have been trying to improve the situation and I know we have made a definite impact. As soon as the announcement was put out in a press statement we talked to several national media outlets and Jim Wild and I spoke to a large number of journalists. We have created a template letter for Fellows to write to their MP, and if you haven’t already done so, please do help to keep the pressure on. I wrote to Lord Vallance the Science Minister for a meeting and we briefed ministers at the Science and Technology Committee. We hosted an emergency astronomy forum where STFC staff were in attendance. We have also talked to Michele Dougherty, Catherine Heymans, Peter Fortune MP, and the Shadow Science Minister. Ian, Robert, and I attended other sessions at advisory Town Hall meetings and the IoP Heads of Physics meeting.

The Society has tabled FOI requests on certain aspects on how this crisis came about and also what the plans are to end it. I’m pleased to say that MPs are now asking those same questions. We have also had an open letter from physics teachers with 120 signatures. They understand the aspirational value of astronomy and getting people into science and technology. RAS Council is doing what it can to help and I remind you that we have tripled the number of fellowships that we offer.

Max Alexander is presenting his ‘Fragile Earth’ exhibition on the growing threat of space debris. The exhibition started at Lloyd’s of London and has been to the United Nations, the European Parliament, and is now being hosted by us in the BH courtyard from March 19 to May 16.

The first speaker today is John Coxon who is an STFC Ernest Rutherford Fellow at Northumbria University and who won the Fowler Award in 2025. His research interests are primarily in terrestrial electrodynamics: he studies electric-current systems that flow at Earth, including the Birkeland currents. He has also contributed to the question of substorm physics, including work in how energy and currents are distributed before and after substorm onset. The title of his talk is ‘Hemispheric asymmetry in terrestrial electrodynamics’.

Dr. John Coxon. Kristian Birkeland produced an instrument called the terrella consisting of a giant magnetized metal ball and he fired electrons at it. He was occupied with the question of how the aurora occurs. It was located under one of the lecture theatres at the University of Oslo, and in 1899 he built an observatory in Norway to make studies of geomagnetic storms.

In 1908 he wrote in a paper “the knowledge gained in radioactivity since 1896 has favoured the view to which I give in that year namely the magnetic disturbances on the Earth and the aurora borealis are due to corpuscular rays emitted by the Sun.”

He built the terrella to test the theory that the aurora borealis was being caused by some sort of emanation of charged particles coming from the Sun. His idea was widely pilloried in Britain and he did not get anywhere near the recognition he deserved during his lifetime.

Birkeland discovered that current flows along the magnetic-field lines at Earth, and he found that by firing electrons at the terrella. The morphology of the Birkeland currents was

first established by Iijima and Potemra in 1978, 70 years later.

I would like to introduce to you the Dungey cycle. The magnetic-field lines are trapped in the solar wind. Effectively there is a circulation of field lines with reconnection and the solar wind drags the field lines around to the night side where reconnection occurs again and the Earth's magnetic-field lines go back to the dayside thus completing the cycle. There are large plasma flows because the plasma is trapped on the field lines and as the field lines move, the plasma moves with them. You have a mass movement of plasma in the Earth's magnetic field, so you end up getting an electric field as a result. If you have a vortex in the plasma flow you get the electric field pointing into the middle of one vortex and out of the middle of the other vortex. Because you have electric fields pointing inwards and electric fields pointing outwards, that implies you have some large-scale current flowing and the magnetic line currents are the currents that Birkeland hypothesized.

We can take snapshots of the current system using a megaconstellation of satellites called *Iridium*, a telecommunications satellite network. There are 66 satellites in six orbital planes and we get data in a ten-minute-long sliding window, evaluated every two minutes. We have 16 years of data at a resolution of 1200 spatial data per time-stamp. We pay the satellite operators for magnetic data and we can get the currents from that.

It turns out that if you look at the total current in the northern hemisphere and subtract the total current in the southern hemisphere you get a sinusoid. In the northern summer, currents are stronger in the north, and stronger in the south in the southern summer, because of the differences in insolation caused by seasons. We expected that the current flowing in each hemisphere during equinox would be equal. What we find is that at the equinox they are absolutely not equal in the two hemispheres. The northern current dominates at all times except during the southern summer and the northern-hemisphere currents are larger than those in the south. We had to decide if that difference was an artefact or was real. Other teams found the same difference in *Swarm* and *DMSP* [the U.S. *Defense Meteorological Satellite Program*] data which was very encouraging.

However, in my 2016 paper, I found that the northern-hemisphere currents were 27% stronger than the southern-hemisphere currents, whereas the asymmetry reported by *Swarm* was 12%, which are inconsistent with one another. In other data sets, Poynting flux and ionospheric conductivity are also asymmetrical whereas neutral winds do not seem to be. Asymmetrical neutral winds might cause an asymmetry in the current because plasma vortices drive vortices in the neutrals which end up counteracting the current you get. If you think about Antarctica and the ocean around it *versus* the Arctic circle, the northern-hemisphere magnetic pole is in the sea, surrounded by land, and in the south it is in a land mass surrounded by sea. A recent paper by Silva *et al.* in 2020 does not find a significant difference between the neutral winds in other hemispheres but that is a difficult observation to make. As such the leading theory for why we see asymmetries in the electrodynamics is that the Earth's dipole itself is asymmetrical.

We recently looked at a solar cycle's worth of data, plotting data *versus* the FACER model* parameterized by a simple consideration — if the plasma vortex results in currents I described earlier and is being driven by magnetic reconnection, you can parameterize the model of the vorticity with magnetic reconnection and estimate the current you should get. The model includes conductance and so it knows about seasons, because the zenith angle is part of the model and it changes with season.

The modelled currents vary with season and so are centred on zero as there is no systematic asymmetry in the model. Another important thing to note is that in 2018 the *Iridium* satellites were replaced. Older *Block-1* satellites were replaced with *Iridium NEXT* satellites, which

*The Field-Aligned Currents Estimated from Reconnection (FACER) model is a model of Birkeland current based on a few simple assumptions; the full model description is at <https://github.com/johncoxon/facer-model>.

carry science payloads and have different magnetometers on board compared to the *Block-1* vehicles. Also, the fitting process has been changed from the WORLD MAGNETIC MODEL to CHAOS 8.1, and now incorporates an extra spherical elementary current step.

In reality you can see that the *Iridium* satellite tracks in the northern hemisphere are much more constrained than they are in the south and you effectively end up with a change in coordinates in the south. That fitting tries to correct for issues with the southern-hemisphere maps, and leads to new maps.

The old fitting method gives a result which was 21% asymmetric for *Block 1* and 19% for *NEXT* whilst the new fitting method applied to *NEXT* data gives an asymmetry of 4% which is interesting because every other data set gives a value between 10% and 12%. The asymmetry has seemingly gone from being overpredicted to underpredicted. There is a problem because it is really hard to do conjugate studies of Earth, particularly if you want to do it from the ground. There are a lot of data in the northern hemisphere but in the Antarctic it is really hard to put magnetometers there because you have far less land mass. If you use spacecraft, even those giant constellations that span the Earth, you are at the mercy of the orbital mechanics and you are going to have to make assumptions as to how to do your fitting in either hemisphere. There is no way, at Earth, of making truly conjugate measurements except for one. We need a dual-hemisphere auroral imager. It has been about two decades since the last time we had an auroral imager taking images of the aurora from space and we've never had a dual-hemisphere auroral imager. Multiple missions have been proposed and all have failed, which is intensely irritating. We know the hemispheres are asymmetrical and we are finding out more and more that the asymmetry manifests itself in many ways.

I'd like to end by thanking all the people who have supported me.

The President. Thank you, John. Questions? Is Peter Cargill here? Peter, the student that we looked after together, Tim Stubbs, looked at polar-hemisphere work.

Professor Peter Cargill. I don't think it was ever submitted.

The President. After he left he went and joined Goddard.

A Fellow. A very intriguing presentation, particularly since most of us simply present saying "here are my results". That not only gives the results but presents the facts that there are questions still to be answered. That really leads us all on further. During the presentation I thought, because of the asymmetry, could it be that the northern hemisphere has far more surface land than the south, though you have suggested that it is the altitude of that land that plays a role.

Dr. Coxon. It's possible — it's not the favoured interpretation but it is something that I want to look at. Measuring neutral wind is very difficult and I haven't worked out how to do it yet. I thank you for your kind words. I don't want anyone to think that we have solved the problem, partly because we haven't but partly because I would like more money to work on this!

The President. One thing that you pointed out was that the poles had a different offset. That means that our magnetic field is not geocentric. It really imposes a big UT variation on everything we do and I think that is very related to all that you say. Let us thank John again. [Applause.] In my Presidential address in two months I am going to be producing evidence for the Dungey cycle on an exoplanet.

The next speaker is Mark Lester who is our Senior Secretary. The title of his talk is 'Chance observations with a meteor-scatter radar'.

Professor Mark Lester. Just a comment on John's talk — there will soon be a new auroral imager flying in space, at least providing that the launch of *SMILE* goes to plan next month.

I'm going to talk about some observations taken with a meteor-scatter radar. This is about work that my colleagues Alexander Kozlovsky (Sodankylä Geophysical Observatory) and Gunter Stober at the University of Berne have done in this respect. These are observations that we saw but could not have predicted in any grant proposal. The instrument that I will talk about, *SLICE* [Sodankylä–Leicester Ionospheric Coupling Experiment], has been

operational since 2008. It's not really an ionospheric experiment but a meteor-scatter radar which tends to make observations between 80 and 100 km — that is where meteors tend to leave the bulk of their ionization trail as they fall into the atmosphere. In that region we tend to get constant measures of neutral winds.

The first observation I will talk about was triggered by one of the largest volcanic eruptions since Krakatoa. It happened on the volcano of Hunga Tonga Hunga Ha'apai in the south Pacific and observations were made in Scandinavia where there are four radars at Tromsø, Andøya, Kiruna, and Sodankylä, and *CONDOR* (Chilean Observation Network De Meteor Radars) in Peru. We got five days of data and we have used a data-assimilation algorithm. We see an eastward gravity-wave arrival, followed 48 hours later by a westward one. In the Nordic cluster you see the arrival of eastward and westward gravity waves at the same time. We can then use the five sets of observations in more detail and include a worldwide network of radars. The westward wave moved at 165 metres per second and the eastward component at 240 metres per second. That tells us that the system is acting in a way that was not anticipated. I'm fascinated by the fact that the Nordic array can see both gravity waves. Previously, such southern volcanic events could be seen only in the southern-hemisphere sector.

The second study relates to from an effect which is known as the Tromsø spiral. It was caused by the controlled destruction of a Russian military missile in 2009 December. We know from other studies such as launches of the Space Shuttle that some 350 metric tons of water vapour can be injected between 100 and 115 km on each ascent. We did not have a handle on the neutral winds in that altitude range. You would not normally expect to see anything in the Sodankylä region but from 0900 UT there are extensive clusters of apparent meteor scatter, unusual in itself, but after about 30 minutes, the occurrence rate drops right down for about 2.5 hours. In the sporadic E-layer there are events at 15 MHz. We believe that that is not associated just with neutral winds on their own. We expect to see scattering from the debris of the missile launch. A meteor scatter has a delay of about 1 second. A rocket launch is much more long-lived, so we don't think it's aurora.

In summary, this event occurred in a period of extremely low solar and magnetic activity, so we don't think it's aurora. It's unlikely that the scatter has been moved by electric fields and the observed horizontal transport by neutral winds can't explain this either. There were some suggestions from the Shuttle launches that turbulence could play some role in this and the theoretical estimation suggests that this could be the case, but for me the quenching of the scatter is a real unknown that we still have to resolve.

So, two very different chance events, which we would not have seen were we not operating this system on a continuous basis. In one case, the response to the rocket explosion, the instrument is not well suited to the study due to the limited amount of data that has been saved for each echo, such that we have no idea of the full life history of the scattering bodies. The violent volcanic eruption caused wave activity across the globe in different local-time sectors and hemispheres, so something of that nature, a 1-in-100-year event, does have significant impact elsewhere. One last point, John mentioned constellations — one of the problems with that is that the satellites have to de-orbit and when they do they leave stuff in the mid- and upper atmosphere. That is something that has to be looked at in a great deal more detail.

The President. Any questions for Mark?

Professor Kathy Whaler. Going back to the Hunga Tonga eruption — did you see any evidence for the arrival of a second wave? Was there any evidence, therefore, in your observations for dispersion?

Professor Lester. We didn't see any evidence for the second arrival, and there is a question over the dispersion of the signal. The thing is we did a straight line and there probably is a dispersion of the signal.

The President. Kathy has stolen my question! We saw the tropospheric wave at Reading three times.

Professor Whaler. Yes, we saw that in some of the pressure observations.

Mr. Horace Regnart. A little bit of prehistory from my childhood. The Krakatoa explosion is said to have knocked people unconscious on top of a cliff where they were standing 30 miles away and the sound waves being detectable going three times around the world. A rather unsophisticated precedent to your sophisticated work.

Professor Lester. Kathy just made that comment about the pressure waves that you saw. I should say that we have evidence for a land wave as well but that is a different story.

Rev. Garth Barber. You mentioned the effect of exploding missiles and the Space Shuttle — could you comment on Elon Musk's plan to launch a million satellites to process his AI?

Professor Lester. Apart from the fact that I know all my astronomical colleagues will be very unhappy, I am genuinely concerned about the impact of such a proposal. I also take John's point that if there is a scientific instrument in there we would have a fantastic data set to work with, but it's the de-orbiting from a long-term perspective of the atmosphere; the impact on the atmosphere is still troubling and that needs to be studied in detail.

The President. I think that we can take some comfort in Musk's promise that one of his automatic cars was going coast to coast, and that we are going to have a city on Mars. Neither has happened.*

Dr. Quentin Stanley. You'll find in Max Alexander's photos some photos of debris that has landed and the impact of that is quite an eye-opener.

The President. 120 bits of debris a year fall out of space at the moment.

Professor Lester. And that could change as there is a variation in the number of bits that come in depending on the solar cycle and sunspot maximum.

The President. Strangely, the thing that is working in our favour is climate change. It's cooling the upper atmosphere and reducing the drag so they don't come down quite as quickly.

The President. The Eddington Lecturer today is Dr. Kareem El-Badry. He is an Assistant Professor of Astronomy at the California Institute of Technology. His research focusses on binary stars, black holes, and unusual outcomes of stellar evolution, combining large-scale surveys, targeted observations, and stellar modelling to understand how stars and compact objects form and evolve. He earned his PhD in astrophysics from UC Berkeley in 2021 and was a Junior Fellow at the Harvard-Smithsonian Center for Astrophysics before joining Caltech in 2023. He also holds an adjunct appointment at the Max Planck Institute for Astronomy in Heidelberg, where he has been a frequent visitor since 2016. The title of his talk is 'Black holes and revelations: unseen companions in stellar binaries'.

Dr. Kareem El-Badry. I'm going to talk about astrometry — the small motion of stars on the plane of the sky — and binary stars. William Herschel, along with his sister Caroline, at the end of the 18th Century made many observations of various types of objects and often made sketches. He particularly liked double stars and compiled a catalogue of new companions to single stars mostly of the 8th to 10th magnitude, and he also noticed the motion on the plane of the sky. He assumed that the pairs of stars were chance alignments of a distant star and a nearby foreground star, and he was searching for that in order to measure a parallactic shift which he argued they should exhibit if they were at different distances. Over 25 years he re-observed some of the pairs but found that many of the pairs were physical binaries and had the same parallax. He did discover that some companions moved in curved paths around the primary star.

*[Though not coast to coast, while editing the first version of this talk for publication, I read that astrophysicist Lawrence Krauss had recently completed his "[s]econd trip up the west coast 1k miles without touching steering wheel". I remain sceptical about the latter in the near future, though; see my review of *A City on Mars* in these pages: 144, 210, 2024. — Ed.]

In the 1830s Friedrich Bessel used a heliometer to measure small angles and he observed 61 Cygni. He knew that both components were at the same distance, and he measured both stars with respect to two distant field stars. That was a difficult observation for several reasons, including the effect of a turbulent atmosphere, so he increased the number of observations to beat down the measurement error. He measured a parallax of $0''.31$ with an error of $0''.02$, which corresponds to a distance of ten light years which is within 1.5σ of the result obtained by *Hipparcos*. Bessel noted that the position angle increased two-thirds of a degree per year and calculated that the period of the star was 540 years. Today's figure is around 700 years.

Bessel then looked at Sirius, and when he examined the positions over 50 years he found that the motion was not linear and the same was happening with Procyon. Bessel came up with the bold prediction that the motion was due to an invisible binary companion. Sirius and Procyon are both accompanied by white dwarfs that are much fainter than their bright companions; the latter, however, have masses comparable to the primaries.

Modern application of the method is carried out by *Gaia*, an astrometric satellite located at the L2 Lagrangian Point which has two cameras that scan the sky every six hours. The rotation axis precesses every two months so *Gaia* scans the whole sky. *Gaia* measures every star very precisely once a month and over a period of time the linear motion of the stars can be seen. The parallaxes are also measured along with gravitational effects from any companion. The precision of *Gaia* is 0.01 mas which is the angle subtended by a human hair at a distance of 1500 km, and is also four times smaller than the image of the event horizon of the supermassive black hole in M87.

Bessel had uncertainties of a fraction of an arcsecond and could measure positions in binary-star orbits a few parsecs away. *Gaia* can measure the distances to stars a few tens of kpc away so essentially it can measure orbits across the Milky Way galaxy.

Gaia finished operations last year but over its 11-year working life it measured each star about 120 times, but so far only the first three years of data has been published. The DR4 catalogue will appear in December and will contain six years of data.

The current data release, DR3, was the first to include astrometric orbits, 200 000 of them. The colour–magnitude diagram shows that most stars are like the Sun and also close to its mass. We found 5000 cases where the companion was most likely a white dwarf like Sirius, about 50 with a neutron star, and about five with a black hole. In the last five years we have been following up on those objects and trying to characterize them in more detail. We do that *via* radial velocity using telescopes with high-resolution spectrographs. The astrometry and radial velocities can be combined to produce a Keplerian orbit.

One object which we get excited about is an object called *Gaia* BH1. The visible star is similar to the Sun and the period is half a year and it lies at a distance of about 500 parsecs. The radial-velocity measures confirm the astrometry and we find that the star has a mass $0.9 M_{\odot}$ but the companion has a mass of $9.3 M_{\odot}$ — we think that it is a black hole. Black holes come from massive stars and this object originally had $40 M_{\odot}$. When it evolved into a red supergiant it became too large to fit inside the current orbit without interacting with the companion star. We suppose that the separation between the stars was greater and the progenitor black hole expands and spirals in, releasing gravitational potential energy which could be used to eject the envelope of the massive star. All the envelope gets blown away and the companion star survives next to the core of the progenitor black hole. That, however, works only if the star gets really close to the black hole and in that case the spiral has stalled so it is difficult to explain the current situation.

Several theories have been proposed. Perhaps the massive star remained compact but the mass transfer was stable. Another possibility includes a third star — there is a massive pair of stars which run into each other and there is no expansion which would save the distant star, or maybe the black hole formed on its own and later gathered up the star gravitationally, perhaps in a cluster.

We have found some more of them. In *Gaia* BH2 the star is evolving off the main sequence. The black hole mass is $9 M_{\odot}$, the period is 3.5 years and the separation is 5 AU. Those are the only two black holes in *Gaia* DR3 but there is another, *Gaia* BH3, which has a period of 11 years and it was found during preparations for DR4. The black hole has a mass of $33 M_{\odot}$ and the star is very metal-poor. We think that the star and the black hole formed at the same time and we can see the composition of the star from its spectrum so we can see what sort of star formed the black hole (BH). We are looking for more black holes in the *Gaia* data but we can also find BH binaries from the X-ray binary systems. Most of the X-ray binaries have abundances close to solar and masses around 9 to $10 M_{\odot}$, although Cyg X-1 has $20 M_{\odot}$.

Could we have two BHs in a binary system? We know that they exist from gravitational-wave observations. My student Pranav Nagarajan has modelled a system with a star and a pair of BHs but the motion is not strictly Keplerian and orbital precession is involved. We have used very precise radial velocities from *Keck* and *VLT* to test that model but even with the most precise velocities we find no evidence for non-Keplerian motion so it looks like a single BH. We cannot strictly rule out that BH-binary model as the two objects could be very close but they would merge if the period were < 1.5 days. Radial-velocity work is the only way to detect BH binaries.

The three *Gaia* BHs are the three closest BH systems that we know about. We infer that the non-accreting, non-interacting wide binaries are about ten to 100 times more common than the wide X-ray binaries. We expect to see ten X-ray-bright red giants in binaries and we are now looking at red giants associated with a radio source but most do not have a black hole associated with them.

In the case of neutron stars (NS) we have 30 nights of data to yield some orbits. We started with 50 candidates and in 21 cases we confirm the *Gaia* velocity and confirm that the companion is a neutron star based on its mass. The orbits are eccentric and the periods range from ten to 100 days. We have found that the companion stars are often enhanced in lithium (Li) and from that line we can measure the absolute abundances of Li. We don't know what produces the Li but it must be related to the neutron star. The stars must have formed co-evally. In the case of the wide star-NS binaries we think that the star will become a red giant and become X-ray bright and we compared the number of those systems with the number of X-ray-bright binaries. From the close bright X-ray systems 2 kpc away we can infer a space density and a formation rate and we find that the birth rates of the two populations are consistent. When we plot the mass distribution of NSs and BHs we find masses between 1.3 and $2 M_{\odot}$, a couple of BHs at $9 M_{\odot}$, one at $33 M_{\odot}$, and nothing in between. We are learning that those binary systems prefer to make NSs of $1-2 M_{\odot}$ or a BH which is much more massive. If we compare to other kinds of NS that we see such as radio pulsars and BHs to what we see in X-ray binaries then we find a mass bi-modality between BHs and NSs.

In December we will have *Gaia* DR4. We expect the number of binaries to increase and to have longer orbital periods. In DR4 we will be able to fit periods up to 2000 days. The orbit is consequently bigger and the binaries can be seen further away. In DR4 we simulate that we will get 30 BHs mostly at longer orbital periods. We are now writing proposals to get observing time in December mostly for high-resolution spectroscopy and hopefully we'll have lots of spectra of BH systems in DR4.

There is a mission called *Roman* which launches in September this year and also will be good at finding BHs. It is doing a Galactic-bulge survey and will find stars that are gravitationally lensed by BHs passing in front of them. The star gets brighter and deviates in position on the sky. It will also look at other parts of the sky and we will use it to extend the *Gaia* baseline. We think that combining *Roman* astrometry with *Gaia* astrometry will double the known number of BH binaries.

The President. Thank you very much. Questions?

Professor Richard Ellis. The mass gap between the neutron stars and black holes: I presume that we understand it at some level but recently there were some claims that there was an object within the gap. I think it is a neutron star. Do we understand that object?

Dr. El-Badry. It's debatable whether we understand the gap but there are some reasons why we should get a gap. At the end of the star's life you have a core collapse and then you have a supernova, or your supernova fails and a bit of material falls on the star and that is why you get a gap. There are objects that are $2\text{--}3 M_{\odot}$ stellar objects in a globular cluster and we have radio timing of the companion. It could be a massive neutron star or it could be a low-mass black hole. I guess it's a massive neutron star. From the gravitational waves we have a better-sampled mass function so the answer is probably not that there is nothing in the gap but just an order of magnitude fewer objects in the gap than there are on either side. Nature usually finds a way to make objects in all areas of parameter space, it's just that some parts work better than others.

Professor Phil Charles. I was most intrigued by the enhanced Li in some of your neutron stars. That happens to be related to the formation from the SN event but the Li will actually be absorbed and decay with time which implies that those are young objects. Have you looked for radio SN remnants or faint examples of that to support the idea of the recent production?

Dr. El-Badry. We have looked in the radio and not seen anything. We think that those are pretty old stars because they are metal-poor and we didn't find any young stars with those values. Because they are metal-poor they have very thin convective envelopes so anything you dump on the surface effectively stays on the surface, it doesn't get mixed in, and we think the Li will survive for a long time. You can produce Li in a SN in a super AGB star. Young NSs produce high-energy particles which will bombard the surface of the companion and those high-energy particles can make carbon and oxygen by spallation.

The President. Thank you again for a wonderful lecture. [Applause.] To close, nobody in Washington is measuring how thick your hair is! [Laughter.]

I give notice that the AGM will be here on May 8 and the next A&G meeting will be on April 10th in Bristol. Thank you again for the wonderful talks.

REDISCUSSION OF ECLIPSING BINARIES. PAPER 32: THE ECCENTRIC F-TYPE SYSTEM EY CEPHEI

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EY Cep is a detached eclipsing binary containing two Fo V stars in an orbit with a period of 7.97 d and an eccentricity of 0.440 . We determine the physical properties of the system using light-curves from the *Transiting Exoplanet Survey Satellite* and published spectroscopic measurements. We find masses of $1.523 \pm 0.008 M_{\odot}$ and $1.494 \pm 0.014 M_{\odot}$, radii of $1.491 \pm 0.004 R_{\odot}$ and $1.446 \pm 0.004 R_{\odot}$, and temperatures of 7070 ± 170 K and 6990 ± 150 K. We calculate the system's distance to be 300.3 ± 3.8 pc, in excellent agreement with the *Gaia* DR3 parallax, and estimate its age to be 220 Myr. We find no evidence for pulsations, but there are hints of variation in the eclipse times potentially attributable to a third body on a longer-period eccentric orbit.