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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2023 October 13 at $16^h\ 00^m$
in the Meeting Room of the Linnean Society, Burlington House

Mike Edmunds, *President*
in the Chair

The President. Good afternoon and welcome to this A & G Highlights meeting for October. This is a hybrid meeting. Those on-line will be muted and should use the chat facility to ask questions. These will be read out at the end of each talk by Dr. Sue Bowler.

It is my great pleasure to introduce our first speaker, Dr. Tim Lichtenberg, winner of the Winton Award in Geophysics for Early Achievement. He got his PhD in 2018 in the Department of Earth Sciences at ETH in Zurich. From 2018–2022 he was SNSF and Simons PDRF in the Atmospheric, Oceanic and Planetary Physics Department at the University of Oxford. Since 2022 he has been Assistant Professor at Kapteyn Astronomical Institute at the University of Groningen. I invite him to give his talk on 'Molten exoplanets as a window into the earliest Earth'.

Dr. Tim Lichtenberg. One of the greatest unsolved questions with regard to our origins and the diversity of life in the Universe is what the environment of nascent Earth looked like after planetary formation. Prebiotic synthesis in lab environments has made enormous strides in the past years uncovering chemical conditions that seem suitable to birth life as we know it *via* chemical means. These emergence paths rely on relatively stable atmospheric settings with a surface ocean and an atmosphere rich in feedstock molecules such as hydrogen cyanide. At the same time, exoplanet science has undergone a tremendous expansion in the number of detected planets, reaching the realm of high-density worlds potentially similar to the Earth in some aspects.

However, given that most exoplanets detected *via* the transit method orbit very close to their star, they receive intense stellar irradiation — seemingly disconnected from the planetary environment that we envision for the early Earth. However, those planets, in fact, enable us to probe key physics and chemistry of the earliest episodes of atmospheric formation of rocky planets in general. In particular, a key constraint on the origin of life is the apparent detachment of nitrogen and carbon oxidation states in extant biomolecules — nitrogen feedstocks are preferred in highly reduced forms, but carbon oxidation states of biomolecule precursors are preferred in neutral to mildly oxidising redox states. This places chemical constraints on the transition from the primary to secondary atmosphere on the early Earth.

Rocky planets are born from magma — the high-energy environment of planetary accretion vaporizes and melts new-born planets, similar to the long-term molten states of rocky exoplanets that orbit close to their primary star. By observing and characterizing the chemical redox environment of these atmospheres we can thus gain an understanding of the diversity of atmospheric regimes, and the likelihood for prebiotic chemical environments suggested by laboratory experiments. A key factor in the distribution of atmospheric volatiles is the internal chemical differentiation of planets — these set the distribution of redox-active elements such as iron, and thus drive atmospheric chemistry to first order. On the Earth we have evidence that internal processes strongly altered the atmospheric composition by redistributing core-forming metal and hydrogen during the early Hadean, together with loss of the primary atmosphere by atmospheric escape. The amount of change of atmospheric composition alters the greenhouse forcing of the planetary atmosphere. By studying atmospheric composition of exoplanets we can thus gain a first-order insight into the primary redox state of the planet.

Importantly, however, the planetary phase state has a first-order control on the fractionation of atmosphere-forming volatiles, such as nitrogen and carbon. These elements are distributed between core, mantle, and atmosphere. If the atmosphere is in equilibrium with a highly molten mantle, such as the magma-ocean epoch on Earth, for example, different atmospheres than for solid planets are expected. In the next few years there will be two primary means of obtaining access to this phase: detailed atmospheric characterization of individual planets that orbit inside the orbital runaway-greenhouse threshold, and demographic studies of the bulk densities and thus global compositions of exoplanets. Insight into both of these will be crucial for obtaining a better understanding of whether the chemical composition and distribution of volatile elements on Earth is rare or frequent among high-density planets. In the upcoming years, we will gain a better sense of the distribution of solid and largely-molten planets, and the effects of mantle phase state on planetary differentiation and atmospheric distribution, paving the way towards a more detailed exploration of wider-orbit planets. Understanding the time evolution of rocky planets and their outgassing atmospheres will be central to obtaining knowledge on the earliest atmospheric states of rocky planets in general, and thus being able to conclude back on our own world, and the nascent environment of the origins of life as we know it.

The President. Thank you very much for a fascinating talk. Can I, first of all, invite questions in the room?

Dr. Quentin Stanley. In the development of the planet there seemed to be the oxidation of the magma at the same time as the atmospheric escape. They seemed to be in conflict but I take it that it is much more complex than that?

Dr. Lichtenberg. There are multiple effects in the interior of the atmosphere that are happening at the same time, and this is exactly the point I want to make. In this particular case actually the internal processes and the atmospheric processes tend to oxidize the planet over time and especially with regard to these two mechanisms that are here, they both work in the same direction. There is a process which is called iron disproportionation in the interior, and atmospheric escape, both typically tend to oxidize the planet but on different time-scales and to different magnitudes. I think it will be an important challenge of the upcoming ten years or so to start trying to tear apart these processes, and understand which ones are overwhelming which other processes.

Mr. Horace Regnart. Do you agree that some or all of the numerous hypotheses as to the formation of life, when the time comes, may all be accurate postdictions?

Dr. Lichtenberg. I think, ultimately, that I am the wrong person to answer that question [laughter] but I can speculate.

The President. Speculate!

Dr. Lichtenberg. I think that you are probably right in that everything that we think at the moment is based on the fact that we have this one instance and one example and we try to make it work, given the facts that we have. I'm half-astronomer, half-geoscientist, and from my perspective what would be very interesting to see is whether there are any global biospheres within 10–20 pc. If there is something like this, we can actually empirically test whether other chemical signatures of other planets behave similarly to our own and then, I think, we are in a very different game. Then we can start to distinguish different postdictions from each other; so I think that you may be right that the origin-of-life hypotheses are postdictions. But I think they have very different origins and different evolutionary aspects that they bring in, and I think at some point there is a chance that we will distinguish at least some of them from each other, so I am an optimist.

The President. Have we any more questions on-line or in the room? No? Then can we thank Tim again for a fascinating talk. [Applause.]

Now we move on to the Fowler Award for young, promising geophysicists. Dr. Oliver Allanson is Assistant Professor in Space Environment in the Space Environment and Engineering Group in the School of Engineering at the University of Birmingham. He is also an Honorary Senior Lecturer in Mathematics at the University of Exeter. He holds a UKRI NERC Industrial Research Fellowship to understand better and improve our modelling of space science and space weather (2021–2026). He is particularly interested in the importance of non-linear physics in radiation-belt modelling, and his current work considers the fundamental theory, modelling, and observation of high-energy charged-particle dynamics in the plasma of Earth's radiation belts which he will now greatly simplify for us. The title of his talk is 'Understanding the Earth's radiation belts — our local, super-scale, relativistic particle accelerator'.

Dr. Oliver Allanson. It's an honour and a privilege to be able to talk to you today about the radiation belts, and I'd like to thank the RAS for the opportunity to do so. I'm giving quite a broad talk, and I know that there is a diverse audience today, so I really want to hammer home the point that science is a collective endeavour. I am and have been a part of the UK Space Science (MIST and UKSP) communities, which probably totals around 250 people. My specialism in terms of this talk is in the final few slides. So I'm giving a shout out to some colleagues and mentors that I have been lucky enough to work with. We are greater than the sum of our parts, and have had a lot of success in recent years building strong networks. Long may that continue.

Our story begins in the late 1950s which represents the beginning of the space age, with the successful launch of a series of *Sputnik* satellites by the Soviet Union and *Explorer* satellites by the United States. A team led by James Van Allen of the University of Iowa discovered one of the Earth's radiation belts. It was unexpected and not understood at the time, since the team were in fact looking to measure something called cosmic rays. However, the team measured an amount of radiation very much higher than expected at an altitude of approximately 1200 km, so much so that the instrument broke down. The discovery of the radiation belts has become synonymous with this now famous quote by Ernest Ray, a colleague of James Van Allen: “My God, space is radioactive”. The discovery could have been heralded as one by the Soviet Union. But recorded history tells us that the former Soviet Union refused Australian colleagues the opportunity to analyse the data, and thus they missed this opportunity. So we now have our first piece of information. Space is not empty — it is full of radioactive material! This radioactivity is referring to energetic particles. And when we talk about radiation belts we are specifically talking about particles with velocities that are significant fractions of the speed of light, maybe even very close to the speed of light.

There is a fascinating history to tell regarding the early studies of the radiation belts, a sequence of at least two space-based nuclear tests by the USA, and three by the former Soviet Union, and no doubt a web of geopolitical concerns. However, that is not our story today. Instead I will tell you of the history of photons, electromagnetic forces, and charged particles that eventually become the radiation belts. In so doing I hope to give an appreciation of what a space scientist is considering, and contending with, and to convince you that the radiation belts are fascinating, complex, and rich with fundamental physics questions. We are lucky to be able to call it our laboratory.

The Sun is a very hot and very large body of gas, and overwhelmingly composed of hydrogen and helium. It is approximately 1·5 million km wide, meaning that over a million Earths would fit inside the Sun. Temperatures reach 15 million degrees in the core. For some context, the temperature of a gas stove on high might reach approximately 1000 degrees. Now, atoms and molecules very much prefer to remain neutral, which means that the sub-atomic charged particles that make them up love each other very much. It takes an enormous amount of energy to separate an electron from a hydrogen nucleus, which is a proton. However, the temperature of the Sun is sufficient to do this, above around 100 000 degrees. This means that electrons can escape the protons, and move more freely, which means that we have moving charged particles. A gas composed of freely moving charged particles behaves very differently to a neutral gas, and therefore deserves a special name — which we call a plasma. As some of my family will know, I very much like to tell people that overwhelmingly, the Universe is plasma — so it’s probably important.

So we have this enormous object making this plasma. What does that mean for us on Earth? Specifically, everything within what we call the magnetosphere? Well, the most energetic particles in the Sun have enough energy to escape the gravitational field and stream out to fill the Solar System. They do this at around 400 km sec^{-1}. To put that into perspective, Concorde travelled at roughly 600 m sec^{-1}. So, once you do the maths you’re talking about something moving at over 600 times the speed of Concorde. So we certainly have light, and we have established that we have plasma. Which gets there first? Well, plasma is fast but nothing is faster than light. It takes approximately eight minutes for light to travel the 150-million km to reach the Earth, and about three to four days for typical solar wind speeds. So let’s start with light.

As I mentioned, it takes light from the Sun approximately eight minutes to reach the Earth. Light carries energy (and you can think of that as being bundled up in a wave or a photon), which can be transferred to material particles in Earth’s atmosphere. As discussed earlier, this can lead to the charged particles that make up atoms to break free from their bonds. This happens on the day-side of the Earth, and leads to the production of plasma to make an ionized layer called the ionosphere, reaching several-hundred km altitude. Some of the more energetic particles from the ionosphere leak further out and up along magnetic-field lines. This creates a much larger body of plasma called the plasmasphere, extending out to approximately 20–30 000 km, but this is highly variable. Let's talk about temperatures. Are we reaching the radiation-belt energies? No!

The next important source of energetic plasma has a direct origin in the solar wind. There is a universal process called magnetic reconnection that enables this plasma to enter the magnetosphere (the Dungey Cycle). Magnetic-field lines carried by the solar wind impinge on the geomagnetic dipole field, and become stressed at the node of the magnetosphere. Under stress, the field lines reconfigure at the day-side of the Earth in a process analogous to that of bar magnets reordering themselves, and drag solar-wind plasma towards the night-side of the Earth. A similar process then occurs again on the night-side, which pushes plasma (originally solar wind in origin) towards the Earth.

So we've learned about the cold plasmasphere and we've learned about a way in which solar-wind plasma can eventually find its way into the magnetosphere. And we call this population the ring current. However, we are still a factor of 10 or 100 below the radiation-belt energies. The main ingredient missing is the one that I myself study, namely electromagnetic-wave–particle interactions. That is what we need to give the missing energy boost to the particles.

System-scale 'ultra-low' frequency waves generated by the interaction of the solar wind with the magnetosphere, and small-scale 'very/extremely-low' frequency waves generated by the injected plasma from the night-side of the Earth can resonantly interact with the charged particles that are otherwise trapped. These interactions can raise energetic electrons in the radiation belts to relativistic energies. This happens *via* processes analogous to a surfer riding a wave in the sea. Therefore it is a selective mechanism, as not all surfers manage to ride a wave!

To conclude, radiation-belt science is relativistic particle acceleration, transport, and loss. It is measurable in our Solar System lab 'before' (solar atmosphere and solar wind), 'during' (*in situ*), 'remotely' (ground-based), and 'after' (precipitation). The energy in the radiation belts is a manifestation of the energy emitted by the Sun, but enhanced. It is very important for space-weather risk — satellites, astronauts. It was the first scientific discovery of the space age, but as full of open questions as ever.

The President. Thank you very much. What is the main risk to humanity?

Dr. Allanson. I think the main threat is power outages. Energetic particles in space end up impacting on power networks, the result of which is very expensive. What I would add is that we are in the golden age of data collection on the one hand but the last solar cycle has been relatively benign so we have built up this understanding of what is going on with space weather. The possibility that we may have become a little complacent is an interesting question.

The President. The next one could be much worse?

Dr. Allanson. I hope not, but it's possible.

Mr. Steve Cookson. I have a similar question with a name on it — the Carrington event. There have been similar events recently where whole sections of hardware on the eastern seaboard of the USA went down because of space-weather events, and I wondered if you could speak more generally about space-weather events? Does this occur at the peak of the solar cycle, for instance?

Dr. Allanson. The most intense activity occurs on the declining phase of the solar cycle because we have a high solar wind.

The President. The Carrington event happened in 1859 — how likely is it that there will be another one? Are the statistics roughly known or not?

Dr. Allanson. I'm not the best person to ask that.

Dr. Annelies Mortier. The strength of the solar cycle is not predictable so it's difficult to know.

Dr. Paul Wheat. A lot of this is magnetic shielding we are getting from the Earth but with lots of micropollutants high in the atmosphere, such as plastics, jet fuel, *etc.*, and the ozone problem. Is that changing the protection we are getting at all? Are more particles coming in now and causing space-weather effects because of chemical changes in the upper atmosphere due to man-made effects?

Dr. Allanson. Most of what I have spoken about today is happening at far higher altitudes than the micropollutants that you mention. However, the effects that you mention are certainly important. Atmospheric and ionospheric density and composition affect signal propagation and satellite drag at lower altitudes. Some of my colleagues at Birmingham do work on that.

The President. Any questions on-line? None at the moment.

Dr. Jaqueline Mitton. You haven't mentioned the aurora. I have two questions. Firstly, is the study of the aurora from the ground contributing anything useful to research, and secondly could you comment on what causes aurorae because most people do not seem to get that quite right?

Dr. Allanson. There are definite links between the radiation belts and the aurora. The chorus waves, the whistler-mode waves — they are one cause of the aurora. The chorus waves scatter particles and make them more field-aligned, then precipitate into the atmosphere. Chemistry happens and we get an aurora. The aurora also occurs because of the process happening on the night-side of the Earth bringing particles back towards the Earth. That sends a whole bunch of plasma along the field lines; they will then be sufficiently energetic to propagate into the atmosphere and we get an aurora. There is a definite link between the things I have mentioned today and aurorae.

Dr. Mitton. From the point of view of serious research does the study of aurorae from the ground contribute anything?

Dr. Allanson. It is absolutely real science.

The President. It is a distance thing. The auroral phenomenon happens much closer to Earth than the bulk of the radiation belts but is one feeding into the other?

Dr. Allanson. It is true that the radiation belts do not generate much current but they do precipitate and this does cause changes in the atmosphere.

Mr. Leonard Mann. Do cosmic rays have any effect on the radiation belts or are they swamped by the Sun's radiation?

Dr. Allanson. They will go straight through and collide with the atmosphere. The number density in the radiation-belt environment, what we call the plasma trough, is of the order one electron per cubic centimetre.

Professor Mike Cruise. I notice you have the Cabinet Office Risk Register there and at the top of the list is the pandemic. It had been there for eight years before 2019. The point of this register is that you identify the risks and do something to mitigate them, which is something the Government never did with respect to the pandemic. Is the Government doing anything to mitigate these radiation effects?

Dr. Allanson. We have been quite fortunate in the radiation-belt community to secure quite chunky amounts of funding.

Professor Cruise. That's not what I asked [laughter].

Dr. Allanson. What we have done with that is to take our results to the Met Office to aid in forecasting — that is one aspect. The Met Office also engages with industry. It doesn't just engage with scientists and the public.

Mr. Regnart. Thank you for your fascinating irradiation of my ignorance on this subject. In your drawing-it-together slide you mention the ring-current temperature going up from 100 million to one billion K. Just to check, is that a milliard (a thousand million) or a mathematical billion (a million million).

Dr. Allanson. The first one.

The President. No further questions? Then thank you very much [applause].

The next speaker is Dr. Annelies Mortier. This is the continuation of a Specialist Discussion Meeting held earlier today. She is going to talk about 'Weighing exoplanets through a telescope network'. Annelies is Assistant Professor at the University of Birmingham and an observational astronomer. Her undergraduate studies were done at the Universities of Ghent and Leiden. She obtained her PhD from Porto. Before moving to Birmingham in 2022 she was a postdoc at the University of St. Andrews and a Senior Kavli Fellow at the University of Cambridge. We look forward to your talk.

Dr. Annelies Mortier. Ever since the discovery of the first exoplanet in the 1990s, we have witnessed an exponential rise in the number of known exoplanets with over 5000 exoplanets discovered so far. In the past five years, this exponential rise has noticeably slowed down. This is partly due to a shift towards in-depth characterization of known exoplanets, but partly due to detection genuinely getting harder.

Exoplanets are typically detected and characterized *via* two methods. The photometric transit method uses the dip in stellar flux when an orbiting planet passes between the star and the observer to measure precisely the orbital period and planet radius. This technique can successfully be done from space using satellite missions such as *Kepler* or *TESS*. The second method, and indeed the method that was used to find the first exoplanet orbiting a solar-type star, is the spectroscopic radial-velocity (RV) method. An orbiting planet exerts a gravitational pull on its host star, changing the radial velocity in a periodic manner. The semi-amplitude of that periodic signal is then related to the planet mass.

I am part of the *HARPS-N* Collaboration which aims to characterize terrestrial planets *via* radial-velocity measurements. *HARPS3* is a high-resolution optical spectrograph, installed at the *Telescopio Nazionale Galileo* on La Palma. What makes the instrument capable of finding exoplanets is its long-term stability below the metre-per-second level. Earth-like exoplanets have RV semi-amplitudes well below 10 m s^{-1} and a true Earth twin only induces a variation of 10 cm s^{-1} on its solar-type host star. One of the main science goals of the *HARPS-N* Collaboration is to measure planet masses of small transiting exoplanets that were discovered *via* photometric space missions. With both a planet radius and mass, we then get a bulk density of the small planets, allowing for studies of their possible compositions. With our collaboration, we have contributed greatly to the mass measurements of small exoplanets.

While thousands of small exoplanets are known, only about 100 exoplanets smaller than Neptune have both their mass and radius measured precisely. Furthermore, almost all these exoplanets orbit their star within the orbit of Mercury. This is due to the bias of the transit method towards shorter periods since planets orbiting further away from their host star will have less probability to transit from our point of view. This is easily shown through a geometric argument. The RV technique, however, has no such bias. While the semi-amplitude of the signals will decrease with increasing orbital distance, gravity will always be there and an RV signature is thus always detectable, unless the planetary system is exactly face-on.

Can RVs thus more easily be used to detect Earth twins? When looking into the semi-amplitudes of exoplanet signals, we find that the first detected exoplanets had semi-amplitudes of 50–100 m s^{-1}. This gradually lowered with instrumentation and computational methods improving. However, for the past decade, there is seemingly a barrier of 1 m s^{-1} below which we struggle to detect planetary signals. Current instrumentation is stable below that level, so there is something else holding us back.

The main barrier in finding the small signals is the star itself, generating signals intrinsic to their surface features that can drown out or even mimic the signals of genuine exoplanets. These stellar signals happen on different time-scales, from seconds to years, and easily have amplitudes well above 1 m s^{-1}. While some stellar effects, such as oscillations or spots, are well understood, others, such as supergranulation, are not well understood yet. For these purposes, we use Sun-as-a-star telescopes coupled with planet-hunting spectrographs to study the variations of solar activity in our data, where the *HARPS-N* Collaboration was the first to start this back in 2015.

But even with excellent instrumentation and better understanding of the physics and nature of these stellar signals, what we need most of all is more overall observing time. Due to the stellar signals happening on all time-scales, it is crucial that we have well-sampled data, preferably nightly, if we want to find the signal of a true Earth twin or indeed any small long-period exoplanet. Simulations have shown that thousands of measurements will be required over a decade to find confidently a true Earth twin. The *Terra Hunting Experiment* on the newly-built *HARPS3* spectrograph, seeing first light in 2025, will be the first of its kind where a handful of solar-like stars will be observed nightly for 10 years in a hunt for the smallest and longest-period exoplanets.

As this experiment will only be able to study 40 stars at most, we need more of its kind. Going to bigger telescopes does not take away the need for the thousands of data points that will always be required to find the planetary signals, regardless of the telescope size. As such, there is an opportunity to use 2–4-metre-class telescopes and outfit them all with stabilized spectrographs. We (Annelies Mortier and Heather Cegla) are currently gathering support to get such a network realized and have just held an RAS Specialist Discussion Meeting on the topic. A network of stabilized spectrographs will unlock the ability to get firm statistical samples on the small-exoplanet population and will finally allow us to answer the question: how unique is our Solar System?

The President. Thank you very much. Two to four-metre telescopes, six of them, and half the observing time for ten years — who is going to fund it?

Dr. Mortier. The *JWST* is more expensive still!

The President. Is this an international programme?

Dr. Mortier. We are not the only country which is interested in this, but the UK currently leads on stellar variability as well as the design and calibration of stability in spectrographs, but there is interest from other countries to do this. We would like a lot more than six telescopes in a worldwide international network.

Professor Miller. Where does *ARIEL* help with all this?

Dr. Mortier. *ARIEL* is very interested in this. This is an ESA mission to look at exoplanet atmospheres, particularly on small planets. The problem with doing exoplanet atmospheres, especially for small planets in order to interpret the data, is that they need to know the scale height of the atmosphere which is related to mass, so we need to have precise masses at the 20% level for all the planets. If they don't actually know the scale height, which they don't, they can't know the atmospheres, so they need the mass which we can give them.

Dr. Stanley. Further to the comments about extra value from this project, you can obviously measure stellar oscillation in stars such as Betelgeuse, so perhaps you could sell telescope time to other scientists and answer the President's questions at the same time as raising funds which could offer a broad advantage to a large section of the astronomical community.

Dr. Mortier. And not just to the astronomical community, but also to the solar community. You can easily invest in several solar telescopes because you already have your spectrograph. *PLATO* will do stellar observations as well but there is much more you can do from a stellar as well as solar perspective.

Dr. Stanley. So low cost, high benefit.

Dr. Mortier. The entire team is not really low cost! Super benefit!

The President. You mentioned *Gaia* and that you are waiting for them to release their astrometric data. How much difference will that make?

Dr. Mortier. What *Gaia* has released already has changed a lot. Thanks to the *Gaia* parallaxes we have really precise radii for all of our stars which obviously helps in getting a better stellar mass and hence planetary mass. In terms of their planets, while *Gaia* is preparing to release thousands of exoplanets, they will all be long-period Jupiters; they can't do small planets at all.

The President. When will those data be released?

Dr. Mortier. The last date I heard was 2025.

The President. Any further questions? I'd like to comment that this afternoon has been fascinating to me. I'm old enough to remember when we had no idea whether there were any other planets. To come along and hear that you are actually beginning to think of Earth twins and the technical ability required to do that. The temperature and pressure controls on the spectrograph were just not possible 20–30 years ago. It is a very interesting and exciting story and it worries me that it might be ten years of observing before you find out — can you hurry up please?

Reverend Garth Barber. Could you comment on Proxima b? It seems that next door we might have what might be termed a twin Earth?

Dr. Mortier. It's not just Proxima Centauri b. As you know Earth-sized planets in the temperate zone of a star abound. I wouldn't call Proxima Cen b Earth's twin because of the nature of its star, which is cooler and actually is why we found it in the first place. There have been studies on the nature of Earth twins and possible life. Everything we think we know about life is based on one data point but what we do know about life on Earth is that it needs UV energy to kick-start it. This is something you can test in a lab and from the experiments it has been shown that the star is simply too small and not powerful enough to give that UV energy, even if the planet is close in.

The President. It's the life but not as we know it that might be even more interesting!

Mr. J. Penston. Can I ask a follow-up question? If we are looking for Earth twins should we not find a solar twin first?

Dr. Mortier. We are thinking long and hard about the kind of stars we will be looking at with *HARPS3*, so there is interest in a solar twin. The definition of an Earth twin is an intriguing one — some say you can find an Earth twin around an M dwarf but I disagree. We are currently looking at stellar parameters and abundances in the solar neighbourhood, so that we can make an informed decision.

Professor Miller. I wonder if I can make a comment and a slight reminiscence? I can remember the RAS meeting when Michel Mayor came and first announced his discovery of an exoplanet. Ironically, the people who gave him the hardest time were the proponents of the space mission called *Eddington*. *Eddington* is now called *PLATO*.

Dr. Mortier. Back in the day this was a really hard sell. In Europe, we found that the Americans were technologically ahead of us and were searching for a long-period Jupiter with their spectrographs. In Europe they were looking for short periods and that is when they found it. It only took the Americans a couple of months to find another six more hot Jupiters that were in their data all along.

Dr. Wheat. I know that *Kepler* looked at stars which are quite distant. It seems to me that we should be looking in the zone within 25 to 50 light years of the Sun. Is there any prioritization of that particular zone?

Dr. Mortier. The biggest downside of *Kepler* is that these stars are all too faint for us. For thousands of Earth-size planets that they found we can't get masses at all. *PLATO* has been re-designed to focus on bright stars, *TESS* and *CHEOPS* also. However, there is such a thing as being too bright from space, so it's a matter of finding a balance. With *HARPS3* from the ground we are definitely going to look close by, but that is purely from a photon perspective. The *HARPS3* sample is limited to stars brighter than *V* magnitude 7·5 whilst the space missions have looked at magnitude 7 and fainter.

The President. Watch this space over the next ten years. Thank you very much again [applause]. May I remind you that there is a drinks reception about to begin in the RAS Council Room. The next A & G Highlights meeting will be on Friday, November 10th. I look forward to seeing all of you then.

LETTERS FROM DUN ECHT: A NETWORKED OBSERVATORY

By Peredur Williams
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The Archives of the Royal Observatory Edinburgh preserve the out-going letters of Lord Lindsay's private observatory at Dun Echt, providing a detailed picture of its development and operation during its twenty-year (1872–1892) existence. Nearly all were written by the two astronomers in charge, David Gill until mid-1876, followed by Ralph Copeland until the observatory's merger with the Royal Observatory. Here we look primarily at their communications with other astronomers to consider how the observatory maintained its connections with the astronomical world through correspondence and the exchange of telegrams using the Science Observer code devised in Boston, as well as the publication of the *Dun Echt Circulars* and *Copernicus*. Also quoted are some letters which fill the gaps in the published accounts of the observatory to round out our picture of its operation.