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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

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

Mike Edmunds, *President*
in the Chair

President. Good afternoon. This is a hybrid meeting. Questions can be asked at the end of the lectures, but you will be muted so please use the Q and A facility. The questions will be read out by the Assistant Editor of *Monthly Notices*, Dr. Pamela Rowden. The AGM will be held on May 10 and will be for Fellows only. Our auditors this year are Professor Yvonne Elsworth and Professor Lorraine Hanlon.

The first talk today is 'Continental break-up along the East African Rift' and it's going to be given by Dr. Rita Kounoudis. She is a Postdoctoral Research Associate at the University of Oxford. Her research centres on understanding the evolution of plate tectonics using a diverse range of seismic techniques to map the structure and dynamics of the Earth's crust and mantle. She completed her PhD at Imperial College London in 2023 which focussed on understanding the process involved in continental break-up by imaging the subsurface along part of the volcanically and seismically active East African Rift. I look forward to the talk.

Dr. Rita Kounoudis. Plate-tectonic theory describes the evolution of Earth's rigid outer shell over geological time. However, precisely how continental plates break apart, or 'rift', to form new oceans is debated because there are few places on Earth where this process is currently active. Rifted continental margins, such as those along the coasts of Africa and South America, hold valuable information on the processes that once acted to rift them apart. However, these processes ceased long ago, and their remnants have been buried under thick ocean sediments and lava flows. In this talk, I will take you on a journey to an active continental rift that has captured the attention of numerous researchers — the East African Rift. Here, seismically and volcanically active narrow rift valleys cut through the elevated Ethiopian and Kenyan Plateaus, the highest topographical points on the African continent. Rifting has been on-going in East Africa for the last 20 million years, showcasing various stages of the rifting process, from incipient rifting in the south near Tanzania, to full-blown seafloor spreading towards the Red Sea in the north, where a new ocean floor is currently being born.

While much of the East African Rift has been well-studied through the years, an intriguing segment of the rift — the Turkana Depression — has remained largely unexplored. Located between East Africa's two uplifted plateaus, the Turkana Depression stands out for its subdued topography and unusual breadth, contrasting the narrower rift segments elsewhere. It also has a unique history, having hosted a previous failed rifting episode 50–80 million years before the formation of the East African Rift.

We first set out to investigate the cause for the Turkana Depression's low elevation compared to the adjacent plateaus. Early studies have speculated that the plateaus are each underpinned by buoyant, hot, mantle 'plumes' rising from deep within the mantle. Plume material might be absent below the Depression resulting in its lower topography. Alternatively, some studies have asserted the presence of a single unified African 'superplume' residing beneath the whole of East Africa. In this case, the Turkana Depression's lower elevations would instead be the result of a thinned plate, developed during its previous failed rifting episode. To distinguish between competing hypotheses, we require detailed images of the subsurface, where hot mantle plumes can be detected as slow-wavespeed material.

Mantle plumes below Ethiopia not only uplifted the plate, but they also gave rise to widespread magmatism, creating the world's youngest flood-basalt province on the surface. This significant magmatism altered plate structure to such an extent that it is no longer distinguishable above the seismically slow asthenosphere on which it sits. Whether this is the case below the Turkana Depression is uncertain and is another key to unravelling the region's tectonic evolution.

To address these questions, we require detailed imaging of the plate and deeper mantle facilitated by seismograph networks. These networks detect distant earthquakes, allowing us to analyse seismic waves that traverse the deep Earth geology *en-route* to the station. Despite nearly four decades of seismological deployments along the East African Rift, the Turkana Depression remained a critical gap, hindering a comprehensive understanding of the region. However, this changed in 2019 with a new US–UK–Ethiopian–Kenyan collaboration that installed the first temporary seismograph network in the Turkana Depression. We placed 34 seismometers in 1-m-deep holes, spread across a vast 200 × 300-km area of arid Ethiopian and Kenyan soil, for a two-year period.

Using a technique called seismic tomography, we first evaluate the cause of Turkana's low-lying nature. Our models reveal slow wavespeeds below the Turkana Depression and surrounding parts of East Africa, suggesting that the hot, buoyant material that is currently propping up the Ethiopian Plateau also exists below the Turkana Depression. The entire region is therefore underlain by a single unified 'African Superplume'. At the shallowest depths we find that the Turkana Depression does indeed have a significantly thinned crust (one that is at least 10 – 15 km thinner than its surroundings) the likely culprit for its subdued topography.

Next, we investigated whether voluminous plume-related magmatism has altered plate structure in the Turkana Depression. Surprisingly, the Depression retains a clearly discernible fast-wavespeed plate atop a slow-wavespeed asthenosphere, unlike the Ethiopian Plateau, where magmatism obscured this distinction. Despite their proximity and similar geodynamic 'superplume' setting, these two regions appear to have experienced markedly distinct magmatic histories, leading to profoundly contrasting plate structures.

To understand why these two regions are so different requires peering into greater depths in the mantle and appreciating the African plate's northward motion through geological time.

At depths of 410 km and 660 km below the Earth's surface lie two key mineral phase transitions: olivine-to-ringwoodite and ringwoodite-to-waldslyite, respectively. Together, these transitional depths define the boundaries of the mantle-transition zone. However, hot mantle temperatures, such as those from a mantle plume, alter these depths, suppressing the 410 km and elevating the 660 km, thereby reducing mantle-transition-zone thickness. Seismically mapping this thickness across East Africa reveals that the mantle transition zone is thinnest below the Turkana Depression, suggesting this may be where the African Superplume first reached the upper mantle. However, the African Plate has been moving northwards over time, and the Turkana Depression has only recently assumed its position above the thinnest transition zone. When Ethiopia's flood-basalt province formed 30 million years ago, the African Plate was located 500 km further south, lingering over the hottest part of the mantle. In contrast, the Turkana Depression spent much of its history above cooler regions, preventing the development of extensive magmatic systems.

The President. Can I invite questions? Did I gather that a new continent is going to split off from this? How long will it take?

Dr. Kounoudis. Tens, if not hundreds, of millions of years, but that is assuming there are no changes to the plate system.

The President. It's not definite that it will happen, but most likely?

Dr. Kounoudis. Yes. At the very north of Ethiopia, the Afar Depression is actually experiencing the very first signs of ocean development. The very southern bit of East Africa is just starting to rift in the last five to ten million years. Afar is where people go to understand the very last stages of breakup.

The President. This is quite a difficult area politically to work in, isn't it?

Dr. Kounoudis. In some cases, yes. We have not had to be accompanied by people with rifles but there have been conflicts in this part of the country. Where we were on the border between Ethiopia and Kenya, at a town called Moyale, the buildings showed lots of bullet holes only six months before we got there.

The President. Astronomy is much less dangerous!

Professor Mark Lester. Is it possible that those two boundaries get so close together such that the material in the bottom region gets pushed all the way through?

Dr. Kounoudis. The Turkana Depression is not completely melt-poor. There has definitely been volcanism on the surface and there are volcanoes on the top today, but it is nowhere near as significant as further north. I don't think that the boundary is necessarily extremely sharp but it does reach a point where it starts to erupt less on the surface. Maybe other parts of the rift may retain more melt in their deeper structure as opposed to it finally making its way to the surface. That is on-going research and people are trying to look at that transition.

Professor Lester. At the University of Leicester we have to fill in a risk-assessment form for international travel. I wondered how you managed to get it through your institution?

Dr. Kounoudis. Luckily for me, I had only just started my PhD when the proposal went through. My supervisor had to deal with that. At the time it was fine, there was not much unrest.

Mr. Horace Regnart. Are you able to do something to bring individuals and communities into your research for their benefit and bring them into the scientific community? Secondly, your research is very worthwhile in itself but is it telling us anything useful about the availability of specific elements which may be useful and necessary for generating and using renewable energy?

Dr. Kounoudis. In answer to your first question, there is a lot of work trying to collaborate with communities out there. We have done lots of outreach and we have tried to help the community in different ways. As you can imagine, the very remotest parts of Ethiopia don't have access to many educational resources such as books and pens so we contibuted as much as we could to that. There is a lot of collaboration with the community and we also bring researchers over here and help them work towards a PhD, for example. That is part of the proposal to work in East Africa.

Mr. Regnart. The use of geothermal energy and hot water might be relevant to that.

Dr. Kounoudis. Geothermal energy in particular, is very big in East Africa. It is a very hot part of the Earth and a lot of heat makes its way to the surface, especially where the plates are rifting. In Kenya and Ethiopia there are lots of projects on at the moment, trying to understand geothermal energy, in particular, in specific volcanoes along the Rift, and we are collaborating with them to see if we can tap into that energy. In places like this where you get magmatism, you also find critical metals, such as copper, which eventually precipitate.

The President. Thank you very much. [Applause.]

The next talk is on-line. It will be given by Dr. Christopher Berry the awardee of the Fowler 'A' Award. His research focusses on the origins and properties of black holes and neutron stars; he also has a keen interest in public engagement and informal education. He studied at the University of Cambridge, obtaining his PhD from the Institute of Astronomy. He was a Postdoctoral Research Fellow at the University of Birmingham, where he worked on analyzing the first observations of gravitational waves. He moved to the Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) at Northwestern University where he was the CIERA Board of Visitors Research Professor in 2018, and then moved back to the UK to join the University of Glasgow in 2020, where he is currently a Senior Lecturer in the Institute for Gravitational Research. He has won the International Union of Pure and Applied Physics Young Scientist Prize in General Relativity & Gravitation and the Royal Astronomical Society's Fowler Award for Early Achievement in Astronomy.

Dr. Christopher Berry. Each time we observe the Universe in a new way we make discoveries — new aspects of familiar objects are revealed, and new systems are observed for the first time. Throughout the 20th Century, astronomy expanded by using more of the electromagnetic spectrum. Discoveries included radio pulsars, X-ray binaries, and gamma-ray bursts, each of which gave a new insight into the end-points of stellar evolution. On 2015 September 14, astronomy expanded to include the gravitational-wave spectrum, with the measurement of GW150914 by the twin *LIGO* observatories.

GW150914 came from a binary-black-hole coalescence. The physics of its source is encoded within the measured signal. Matching waveform templates to the data we may infer source parameters such as the black-hole masses. GW150914's source consisted of two black holes, each around 30 $M_\odot$, the first time such a system had been observed.

Gravitational-wave astronomy has progressed rapidly since 2015. The increasing sensitivity of the *LIGO–Virgo–KAGRA* (*LVK*) detector network has enabled a rapid growth in observations. By the end of their third observing run, the *LVK* Collaboration had 90 probable gravitational-wave candidates in their third *Gravitational-Wave Transient Catalog* (*GWTC-3*). The sources include binary black holes, binary neutron stars, and neutron-star–black-hole binaries. We have seen a diversity of sources, with black holes ranging in mass from below 5 $M_\odot$ to around 100 $M_\odot$, with the 30 $M_\odot$ of GW150914 being common.

These masses are different from the masses of black holes previously discovered in X-ray binaries. Part of the reason is observational selection effects. Higher-mass sources produce larger-amplitude gravitational waves, and so can be seen to greater distance. We can calculate the sensitivity of our gravitational-wave detectors, and correct for their selection effects. Doing so reveals a distribution that peaks at lower masses (around 10 $M_\odot$, similar to X-ray-binary black holes), a secondary bump around 35 $M_\odot$, and a tail to higher masses. This mass distribution extends to higher masses than other observations.

The key to understanding the difference between X-ray and gravitational-wave masses is considering evolutionary selection effects in addition to observational selection effects. Only a small fraction of X-ray binaries would go on to become merging binary black holes (preferentially those at higher masses). Furthermore, gravitational-wave sources are observed at higher redshift (typically around 0·1); allowing for the delay time between formation and merger, the progenitor stars were born at even higher redshift. This means that gravitational-wave observations probe stellar evolution at much lower metallicity than X-ray observations. As stellar winds increase with metallicity, it is expected that black holes from lower-metallicity stars are bigger. Therefore, the difference between the two observed populations does agree with our current understanding of binary evolution, and highlights how, by combining multiple observations, we can gain a more in-depth understanding of astrophysical sources.

Does this mean that we understand everything about black-hole masses? Not yet, as demonstrated by the most recently announced gravitational-wave observation GW230529_181500 (GW230529 for short). GW230529 is the first announced discovery from the currently on-going fourth *LVK* observing run. Its source is probably a neutron-star–black-hole binary. The black hole sits within the 3–5 $M_\odot$ range where there is a dearth of X-ray observations. To explain these observations, it had been proposed that the way supernovae explode produced a mass gap. The detection of GW230529 adds to the growing evidence that the proposed mass gap is not empty, and black holes can form in this range. This leaves the question as to why no X-ray binaries have been observed to have masses in this range (the absence cannot be fully explained by selection effects).

We do not measure just masses, but also spins and merger redshifts. The properties of these systems encode the fingerprints of their formation — details of binary evolution that are currently uncertain. Given a set of input physical assumptions, we can make population-synthesis predictions for these properties. By considering a range of input physics, we can see how each fits the observations, and map out the most probable values for these properties. This requires considering multiple formation channels, as omitting a relevant channel will lead to biassed inferences of the input physics. As the catalogue of gravitational-wave observations continues to grow, we will be able to reconstruct more precisely the underlying astrophysical population, and more precisely measure the uncertain input physics of coalescing compact-object binary formation.

The uncertainty on population inferences typically scales inversely with the square root of the number of observations. With the currently planned series of observing runs, we will soon go from of order 10^2 to 10^3 gravitational-wave observations. Hence, binary evolution will soon become a high-precision science.

Key parameters such as stellar-mass-loss rates could be constrained to a few percent. Adding in complementary information from other observations, such as the population of X-ray binaries, will further tighten constraints on possible binary-evolution physics. The coming decade will reveal many mysteries of black-hole formation.

The President. I'll invite questions from the audience.

Dr. Berry. I have been asked a question on-line. The *LISA* mission has recently been adopted. How awesome is *LISA* going to be? *LISA* was the subject of my PhD so I am very attached to it. *LISA* will look at lower-frequency gravitational waves, around millihertz frequencies. It will primarily see massive black holes in the range 10^5 to 10^7 solar masses, but also those stellar-mass black holes in wide binary systems. It will be fantastic — we'll get a complete census of the Galaxy for stellar-mass binaries, and see massive black-hole binaries back to the early Universe!

The President. It's a shame that we have to wait so long.

Mr. Christopher Taylor. If the 50–60 solar-mass black holes are single-star stellar remnants, what sort of original main-sequence masses are we talking about, and are there stars that massive in the present day Universe, or are these things remnants of the earlier stages of star formation?

Dr. Berry. Stars should not leave behind black holes with masses between 40–60 and 120–140 solar masses because of pair-instability supernovae. Therefore, from single-star evolution they do not make much sense. However, we are seeing systems in this mass range! We can potentially have stellar mergers or mass transfer in binaries. Then you can get a larger hydrogen envelope for a core below the pair-instability limit.

Another possibility is that black holes seen in this mass range could be second-generation black holes. We know that black holes merge and form bigger black holes, so in a globular cluster or nuclear star cluster they may go on to merge again. This is something I have investigated with my student Chase Kimball. We have performed a population inference and found that there are some promising candidates for hierarchical mergers among our observations.

I have also been asked: can you comment on the no-hair theorem? This is something that we are looking to test with our observations. We perform a variety of consistency tests that check if we do have black holes described by relativity. One we would really like to do is measure the spectrum of ring-down frequencies. This is often called black-hole spectroscopy. If we can measure the various frequencies, we can measure the mass and spin of the final black hole and check if these are consistent. There have been some claims that this is possible with GW150914, but there are many subtleties in the analysis, particularly around the time of the signal. We want a loud signal, where we can measure the ring-down, so a binary that is relatively high mass. As our detectors continue to improve, the prospects of getting this improve.

Professor Phil Charles. It's fantastic to see the final link between the observed emerging black holes with your work down towards the high-mass X-ray binaries and the low-mass X-ray binaries that we know about. In terms of high-mass black holes, the only one I can think of that can fit on these as a current system is Cyg X-1, but it's a very short-lived system with another very high-mass star. From your calculations and simulations here do you have any idea of how many high-mass black holes like in GW150914 that we can expect to find in our own Galaxy? That has been a source of great debate with the only black-hole systems that we know about in detail being the low-mass ones — we only have about 20 accurately constrained. How many are there?

Dr. Berry. On Cyg X-1 there have been some recent studies done by the COMPAS team. They found a very small probability that Cyg X-1 would go on to form a merging binary black-hole system. In terms of our own Milky Way, Camille Liotine and I have not looked yet at that question specifically. The good news is that we would definitely expect to see any with *LISA*.

[Editors' Note: Dr. Berry informs us that shortly following this talk, detection of *Gaia* BH3 was announced, showing that there are 30-solar-mass black holes in our Galaxy.]

The President. I hope you get to see it, Phil! Thank you very much indeed [applause].

Moving on, the next talk is by Dr. Ziri Younsi. Ziri's research focusses on testing gravity and fundamental physics, with his work helping to enable interpretation of the first images of supermassive black holes from the *Event Horizon Telescope* (*EHT*). He is also an active science communicator. He has studied at Cambridge and UCL, later working as a Humboldt Fellow at the University of Frankfurt, before moving back to the UK to join Mullard Space Science Laboratory as a Leverhulme Fellow and subsequently as a Stephen Hawking Fellow. He is a member of the *EHT*'s Science Council and co-leads the consortium's Gravitational Physics Working Group. Since 2014, he has worked within the *EHT*, developing and performing supercomputer simulations of black holes and horizon-scale black-hole imaging. He is a co-recipient of the National Science Foundation's Diamond Achievement Award, the 2020 Breakthrough Prize for Fundamental Physics, and the Royal Astronomical Society's 2021 Group Achievement Award.

Dr. Ziri Younsi. The *Event Horizon Telescope* (*EHT*) has produced images of supermassive black holes in both the galaxy Messier 87 (M87), and in our Milky Way, Sagittarius A* (Sgr A*). These images, which resolve material in the vicinity of the event horizon, showed the total intensity of the radio emission. Just a fortnight ago, in late March of this year, the *EHT* published the first-ever polarized images of Sgr A*, providing new insights into the magnetic-field properties of black-hole systems.

The first polarized images of the M87 black hole were published in 2021, revealing the magnetic structure of the accretion disc and its connection to the galaxy's prodigious relativistic jets. These new 230-GHz measurements of the polarized synchrotron radiation from the Galactic Centre black hole were more challenging to acquire, in part due to Sgr A* being more than one thousand times smaller in mass than M87, meaning structural variability occurs on time-scales of minutes rather than days or weeks. Through careful calibration of the data, together with consideration of interstellar refractive and diffractive scattering effects, these data were finally ready to be published, almost seven years after they were first recorded.

These polarized images of M87 and Sgr A* present the first polarimetric observations of material circulating around the event horizons of black holes. The 'swirly' pattern we observe indicates the orientation of the electric-vector position angle (EVPA) of the light. Since magnetic fields are responsible for producing the polarization we see in these data, the magnetic field is everywhere perpendicular to the streamlines seen in these images, indicating that the magnetic field is orientated towards and threads the event horizon (the dark central region in the image).

It is remarkable that, in spite of these two black holes differing in size by a factor of about 1400, they present morphologically similar polarization patterns.

One of the most exciting aspects of these new measurements is their ability to serve as a tool for discriminating between physical models of black-hole accretion. Prior measurements, which provide total intensity alone, are not able to discriminate clearly between models with different physical models, *e.g.*, for the plasma electron distribution function or magnetic-field topology. With these new data we are already able to exclude many physical models of Sgr A*, providing much more stringent constraints on the strength and orientation of the magnetic field around the event horizon, as well as the temperature of the radiating electrons in the accretion plasma. These measurements reveal a spiral polarization structure which is robust to all image-reconstruction methodologies, and strongly favour an accretion disc which is magnetically arrested. We also find that internal Faraday rotation alone cannot replicate the observed rotation measure: models and data favour the presence of an external Faraday screen which de-rotates the EVPA.

These are the first measurements of polarization on event-horizon scales, and we are already working on measurements at different epochs, at higher frequencies (where opacity is higher and scattering effects are weaker), and are working towards dynamical images (*i.e.*, movies) of the accretion onto the black hole. Upcoming observations of the polarization properties of radiation produced near black-hole event horizons will reveal how these mysterious objects interact with their surroundings, how they power and sustain some of the most energetic outflows in the Universe, and will help to clarify the foundational role magnetic fields play in extracting energy from their enormous gravitational potentials.

The President. Thank you very much. Questions?

Professor Charles. Those are absolutely fantastic images and the structure that you are getting out of them is glorious. When I first saw that image a couple of weeks ago, I was starting to get worried. I'm not a radio astronomer but in undergraduate lectures one of the things that we state is necessary for VLBI to work is that the object should not vary when the Earth is rotating. In my naïve fashion, you have already admitted that isn't true and I know that from the X-ray variability you have seen from Sgr A* and lots of other wavelengths. How do you get around that? You've admitted that some of the structure requires a large pinch of salt and when I saw that fabulous fine structure there, is that solid or just a best-fitting model with all kinds of assumptions about variability or lack of it?

Dr. Younsi. With Earth-rotation aperture synthesis the primary assumption is that the source is not changing on the time-scales on which we are making the measurements. There is some fudging but essentially you have calibrator sources and you know each of these separate telescopes in the array based on their gains, and so on, what the time variability is and you know from independent measurements what the time variability is of a given source at each different telescope. You have a noise-injection model in which you inject the temporal variability of each telescope for that given day, for the various atmospheric effects in such a way that it makes the source quasi-stationary. It turns out that this has been calibrated against other sources such as quasars and it seems to work quite well. This is also something that is tested with five or six different image-reconstruction algorithms and the one that we have seen today seems to be pretty robust as well. The only way we are going to get around this is to have a better understanding of how that material along the line of sight is diffracting and scattering the light, because you have all this material moving across the line of sight and changing. There is a periodic structure to this but there is also a stochastic element as well. Periodic structures are something that are well-modelled and that we can mitigate for. The stochastic component is more difficult and it is that component that we are not able to remove that accounts for the first blobs being effectively artefacts of the reconstruction. It is no coincidence that those blobs are also aligned with the major axis of the beam. It is not an easy thing to do and requires a lot of calibration and self-consistency checks.

The President. Are you satisfied with that?

Professor Charles. I'm going to be using lots of salt!

Mr. Taylor. Could this be the origin of the global galactic magnetic field?

Dr. Younsi. I have no way to comment on that using the data we have right now. If we think about it all as a dynamo and this thing is rotating, you can have a battery-type mechanism where you can induce the rotation that generates and sustains a magnetic field — that's possible. I think that one would first have to look at wider-field studies. *MeerKat*, for instance, a couple of years back showed some very beautiful images of magnetic fields in the plane of the Milky Way moving out into the nuclear region and the disc, and you can see lovely vertical magnetic fields as well as turbulent eddy structures; understanding the connection of that with the central region is one of the million-dollar questions. Theory would tell us that they are connected; large-scale simulations that we perform up to the Bondi radius or larger seem to show that they are connected. The question is always what is happening in the region in the transition between the smaller scales and the larger scales. That is really tricky to model, so I would say that theory tells that they are connected, but being able to understand the detail of what is happening on different scales as you move from plasma kinetic scales to MHD scales to much larger scales is something that is very poorly understood right now.

Mr. Regnart. Is there any known explanation for the huge mass discrepancy between the Milky Way's black hole and that in M87? Is this to do with differential methods of growth, accretion that is circular rather than infalling, or repulsion and regrowth from seed?

Dr. Younsi. M87 is a giant elliptical which is very far away — 16 or 17 Mpc. We think it's older and the question I suppose is "are black holes primordial and born with 1 billion solar masses or is there some mechanism or channel through which, let's say, a stellar-mass black hole can reach the size of Sgr A* and potentially grow even larger?" There is no single channel which can account for everything that we see. This is why it is so important to look at proto-galaxies with the *JWST* at very high z and see whether the cores of those proto-galaxies in the early Universe really are supermassive black holes at millions or billions of solar masses. This would indicate that they have a primordial origin either from the Big Bang or from some enormous collapse of gas and dust when the galaxies were first forming, although even that is tricky to explain. It could be galactic mergers — it is very hard to say. This is why galactic archaeology and understanding the origin of our Milky Way with *Gaia* is allowing us to reverse integrate and understand what is happening in the past, and that is also why I showed these Fermi bubbles to say that there was some violent activity in the past; the truth is that we don't know for sure. I would love to know but I think the whole community is very aware of this and is striving to understand it.

The President. I think that it's true to say that there is a correlation between galaxy mass and black-hole mass. That implies something, but what?

Dr. Younsi. Yes, indeed.

The President. Can we thank you again for a very interesting talk. [Applause.] It's fascinating to get close to the black holes in a safe way. There is a drinks reception in Burlington House to which you are all invited. Next month is the AGM for Fellows only, followed by the Presidential Lecture which will be open to all on-line and that will be on Friday, May 10th.

REDISCUSSION OF ECLIPSING BINARIES. PAPER 21. THE TOTALLY-ECLIPSING B-TYPE SYSTEM IQ PERSEI

By John Southworth

Astrophysics Group, Keele University

IQ Per is a totally-eclipsing binary system containing a B8 V star and an A6 V star in an orbit of period 1·744 d with eccentricity and apsidal motion. We use new light-curves from the *Transiting Exoplanet Survey Satellite* (*TESS*) and published spectroscopy from Lacy & Frueh[1] to measure the physical properties of the component stars, finding masses of $3{\cdot}516 \pm 0{\cdot}050\ M_{\odot}$ and $1{\cdot}738 \pm 0{\cdot}023\ M_{\odot}$, and radii of $2{\cdot}476 \pm 0{\cdot}015\ R_{\odot}$ and $1{\cdot}503 \pm 0{\cdot}016\ R_{\odot}$. Our fit to the light-curve is imperfect, with a small sinusoidal trend in the residuals *versus* orbital phase and a slight mismatch in the depth of secondary eclipse, but the total eclipses mean the system is still well-characterized. The distance to the system from its masses, temperatures, apparent magnitudes, and bolometric corrections is in agreement with the parallax distance from *Gaia* DR3. Theoretical models cannot adequately match the measured properties of the system, and new spectroscopy to confirm the temperatures and determine the chemical compositions of the stars would be useful. A Fourier analysis of the residuals of the best fit to the light-curve shows many peaks at multiples of the orbital frequency, and one significant peak at 1·33 d^{-1} which is not. This pulsation and the properties of the primary component are consistent with it being a slowly-pulsating B star.

Introduction

This work continues our series of papers[2] presenting analyses of detached eclipsing binaries (dEBs) with a significant observational history and available radial-velocity (RV) measurements, based on new high-quality light-curves from the *Transiting Exoplanet Survey Satellite* (*TESS*[3]). Our aim is to increase the number of stars, and the precision of their measured properties, in the *Detached Eclipsing Binary Catalogue*[4] (*DEBCat**), which lists all known dEBs with mass and radius measurements to 2% precision and accuracy. These results represent

* https://www.astro.keele.ac.uk/jkt/debcat/