MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2024 March 9 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 chat facility. The questions will be read out by the Assistant Editor of *Monthly Notices*, Dr. Pamela Rowden. I hope that many of you will have had an e-mail today or seen the headlines in the press — I'm really pleased to announce that we have obtained a new deal on the accommodation arrangements at Burlington House. Last week, with the other courtyard Societies, we signed a 999-year lease at a peppercorn rent, which means that we don't have to pay rent in future. It basically transfers ownership of Burlington House from the Government to the Societies. It does mean that we have to pay money to look after the building in return, but we can afford this from our reserves. We can now plan for the future and work more closely with the other courtyard Societies to plan outreach events and so on [applause].

On to today's programme. I'm very pleased to welcome Dr. Ravindra Desai. He is an Assistant Professor at the University of Warwick. His research into astrophysical plasmas incorporates both particle-scale kinetic physics and system-scale phenomena, to pursue blue-skies research into how plasma dynamics govern astrophysical systems across the Solar System and beyond. He is also interested in how astrophysical plasma processes can intersect with, and pose dangers to, our increasingly technology-dependent society through the phenomenon collectively known as space weather, and, no doubt, particularly bad in the UK as it always is [laughter]. The title of his talk is 'Extreme space-weather events'.

Dr. Ravindra Desai. Space weather is influenced by phenomena operating across a multitude of scales, from the large-scale expulsion and evolution of coronal mass ejections from the solar corona, to particle-scale interactions within the radiation belts. My interests within plasma simulations focus on both large-scale fluid physics and kinetic processes and the interplay between them to try to understand holistically space weather and the extreme physical regimes that this can produce. I want to start with Sun-to-Earth studies of coronal mass ejections and review some of the largest geomagnetic storms on record and examine under what conditions 'Carrington-scale' events are possible.

Coronal mass ejections (CMEs) are eruptions of vast amounts of magnetized material which erupt from the Sun at high velocities, and are the primary cause of severe space weather. When they reach Earth, these solar storms trigger amazing auroral displays, but can disrupt power grids, satellites, and communications. I first introduce the large CME that occurred on 2012 July 23 and which narrowly missed Earth by just two weeks. The CME was estimated to travel at around 2250 km s^{-1}, and is thought to be comparable to the Carrington event in 1859. We used a state-of-the-art magnetohydrodynamic model of the inner heliosphere, driven by time-dependent boundary conditions at the solar surface, to model this event and examine whether a prior CME on July 19 might have influenced this CME and enhanced its characteristics. We found that by the time of the July 23 event the solar wind had largely recovered from the July 19 event, so the previous event had little impact. However, our model showed that if the latter CME had occurred earlier, closer to the 19 July event, then it would have been even more extreme — reaching speeds of up to 2750 km s^{-1}. Hopefully here I have shown how two CMEs can combine to produce an even more severe space-weather event.

I then discuss a following study where we examined the interaction of two magnetized CMEs between the Sun and the Earth to see how these can combine to enhance their impacts at Earth, their 'geo-effectiveness'. We used magnetohydrodynamic flux-rope models to simulate pairs of CMEs and determine the strength of the resultant storm. For idealized conditions we explored three factors: the tilt of the CMEs with respect to Earth's magnetic field, the twist of the magnetic fields, and the delay time between two successive erupting CMEs. To quantify the strength of the storms, we used a measure of how compressed Earth's simulated magnetic field was and calculated the commonly used Disturbance Storm Time (DST) index. A significant finding here was that the handedness of the CME had a significant effect on the geo-effectiveness of the resultant storm through magnetic reconnection, or lack thereof, between the two interacting CMEs.

How do these impulsive injections of energy flow through the coupled Sun–Earth system and present an imminent danger to our increasingly technology-reliant society? In 1991 March, a large interplanetary shock struck the magnetosphere, at the leading edge of a CME. This rapidly accelerated a new radiation belt into the normally depleted slot region — a region considered safe by many satellite operators. To model this we use ensembles of test-particles embedded within global magnetohydrodynamic simulations which are able to reproduce this rapid energization process for radiation-belt electrons. We consequently examine a variety of shock impacts and examine the results and find that shocks of greater than 1000 km s^{-1} pose a significant space-weather risk. We are taking these results forward to be implemented at the UK Met Office for space-weather-forecasting purposes.

In summary, I have shown using a series of Sun-to-Earth simulation studies how severe and extreme space weather events can unfold. Thank you for your attention.

The President. Thank you very much. Questions?

Reverend Garth Barber. Is it possible to compare these recent extreme events with the Carrington event? Was that similar to or greater than these?

Dr. Desai. That is something that I am interested in. So far the modelling capabilities have extended Sun to Earth at the radiation belts. If you want to compare to the Carrington event the only data we have is from magnetometers on the ground. For that there is too much detail — we need a model of the Earth's ring current. If you have a model like that you can reproduce the signatures on the graph, so yes, I think there is a lot of potential for going back, and that is something that is on the agenda.

Dr. Paul Wheat. Is there any impact at all on the pressure waves in the atmosphere when these things hit? Is there anything that came back down and you get a bounce either in pressure or density changes in the physical atmosphere? As a rider to that is there much we can do either with satellites or on the ground if we know what is coming, because we don't get a lot of warning, do we?

Dr. Desai. In answer to the first part of your question, absolutely. There is an effect on the neutral atmosphere. When you compress the magnetosphere you get all those velocity shears, you get currents, which close along the field lines and these produce a phenomenon called Joule heating which heats the whole atmosphere. The ions collide with the neutrals which heats the whole atmosphere and modifies satellite drag. It's a big problem for satellite operators and for producing conjunction warnings between satellites and satellite debris. For extreme events there might not be too much warning. You might see something on the Sun that will arrive a day later. That is probably enough time to galvanize observations on the ground. There are lots of facilities on the ground that are constantly observing, such as radar systems and ground magnetometers which are perfectly active and provide a valuable resource. Space-weather forecasting requires ten or 100 times more observations from stations before it can compete with terrestrial forecasting.

The President. One last question.

Professor Mike Cruise. You mention the 'f' word a few times in the talk, *i.e.*, forecasting. Do you see a really big improvement in the ability to forecast the trigger event or will we always be just waiting for the front edge of this and then you will forecast what's going to happen next?

Dr. Desai. At the moment I think it is a case of watching the Sun, and if you see a large active region rotating on the solar disc there is an increased likelihood that something will erupt from that. It is very difficult to predict whether active regions are about to erupt. In the last few days there has been a very large active region which is pointed towards the Earth and has produced loads of flares but hasn't produced CMEs and people don't know why.

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

We now move on to a talk entitled 'Massive black holes during the first billion years with the *JWST*' and I'm delighted to welcome Dr. Hannah Übler who is currently a Newton-Kavli Fellow at the Kavli Institute for Cosmology and the Cavendish Laboratory at the University of Cambridge. She obtained her Doctorate (PhD in Astronomy) in 2019 from the University of Munich, Germany, working at the Max Planck Institute for Extraterrestrial Physics in Garching on galaxy kinematics during the peak epoch of cosmic star formation. Hannah also holds a Magister Artium in Philosophy from the University of Munich. Her research focusses on the formation and evolution of galaxies and massive black holes, most recently using the *NIRSpec* instrument on board *JWST*, as part of the *NIRSpec* GTO team and as co-lead of the *NIRSpec-IFS* GTO survey.

Dr. Übler. It is my pleasure to present to you today results about massive black holes in the first billion years detected with the *James Webb Space Telescope* (*JWST*). The majority of the work I will present has been done in collaboration with the *NIRSpec* Guaranteed Time Observations (GTO) team surveys GA-NIFS and JADES, the latter a joint effort with the *NIRCam* GTO team.

We have learned much about the properties of distant galaxies through large survey efforts over the past decades. We know that there has been a peak epoch of cosmic star formation around redshifts $z \sim 1-3$, leading to a build-up of stellar mass, while the winding-down of star formation has been accompanied by a decline in molecular gas in galaxies. Much of the spatially-resolved properties of these galaxies have been revealed through ground-based spectroscopy. However, ground-based studies of the rest-frame optical properties of galaxies are limited to $z \sim 4$ due to the Earth's atmosphere. With *JWST*, we can observe these wavelengths at $z > 4$ for the first time, facilitating detailed studies of galaxies during the first few billion years of cosmic history, and of course also of their black holes.

Supermassive black holes have been observed in all massive galaxies in the local Universe, and the experimental proof for a supermassive black hole at the centre of our own galaxy, the Milky Way, has been awarded with the Nobel Prize in Physics in 2020. Observational evidence suggests that there exists a tight link between the growth and properties of galaxies and their supermassive black holes. Yet, we still do not understand how these black holes managed to grow so massive so quickly, even though the key pathways for forming massive black holes were identified already 40 years ago. Through *JWST*'s ability to push observational studies of galaxy evolution into the first billion years, we may now start to constrain some of these predicted formation pathways for the first time.

Before I discuss some of our exciting results on this topic, a few more words about the telescope. *JWST* has been developed over several decades, and is the largest telescope currently in space. It has gold-coated mirrors to reflect infrared light, a large sunshield to keep the instruments cool, and a huge improvement in sensitivity and sharpness compared to previous missions in the infrared. On board *JWST* are four superb instruments, *NIRCam*, *NIRISS*, *NIRSpec*, and *MIRI*, and I will focus mainly on discoveries with the *NIRSpec* instrument. The *NIRSpec* GTO team is following two complementary strategies to study galaxies in the early Universe. The GA-NIFS survey uses the *NIRSpec Integral Field Spectrograph* (*IFS*) to get detailed and spatially-resolved views on carefully-selected individual galaxies. The JADES survey uses the multi-shutter array to observe up to 200 objects at a time through single slits, thus providing statistical information, while *NIRCam* provides imaging.

Through these observing programmes, it became clear early on that there are many more active black holes in the early Universe than previously expected. I show here an example from GA-NIFS of the first spatially-resolved spectroscopic study of a galaxy and its massive black hole one billion years after the Big Bang. In the spectrum of this object, GS 3073, you can appreciate the superb data quality we can achieve with *JWST*. We see clearly the broad-line region associated with gas clouds orbiting at high velocities around the accreting black hole in the helium and hydrogen lines, and we also observe emission lines of highly ionized atoms, indicative of the radiation field from an active galactic nucleus (AGN). This rich spectrum allows a detailed investigation of many important physical properties of the galaxy and its black hole, such as kinematics, dynamical mass, metallicity, excitation, electron density, black-hole mass, and outflow properties. Interestingly, although the AGN lies in the deepest *Chandra* field, it is not detected in X-rays.

Also in JADES we found several of these broad-line AGN. Interestingly, they all appear to be over-massive with respect to the stellar mass of their host galaxies, when compared to galaxies in the local Universe. There is also some indication that we see dual AGN, that is, two broad-line regions within our slit observations. This is not trivial to interpret in the JADES spectra. The spatial resolution of the *IFS* is a great advantage here. I show here another example from the GA-NIFS survey, where we were extremely excited to find an off-centre AGN in the system ZS 7 only 740 million years after the Big Bang. Our observations indicate an on-going galaxy and massive-black-hole merger. The final stages of such massive-black-hole mergers in the early Universe will be detectable with future gravitational-wave missions like *LISA*.

Finally, I want to show you the highest-redshift black hole found to date, in the galaxy GN-z11 at $z = 10{\cdot}6$, identified here through emission lines tracing extremely high ionization, high densities in the broad-line region around the black holes, and fast outflows. With measurements of black-hole masses so early in cosmic history, we can finally start to put constraints on theoretical models of massive-black-hole growth in the early Universe.

I hope I have shown you how *JWST* is pushing the redshift frontier and our understanding of early galaxy evolution. Within the *NIRSpec* GTO team we follow a two-tier approach to get both statistics and very detailed studies of the earliest galaxies and their black holes. We are also very excited for the years to come, just having been awarded an open-time Large Programme to characterize massive black holes and their host galaxies in the first billion years with the *NIRSpec IFS*. And, of course, we are looking forward to many unexpected discoveries that lie ahead. Thank you very much for your attention.

The President. You have two black holes, 600 pc apart — how long would it take for them to merge?

Dr. Übler. We can make back-of-the-envelope calculations on what would be the dynamical-friction time-scale — between 100 and 200 million years. However, if we also consider the stellar-hardening timescale, *etc.*, the real time to merge might be longer. The final stage of the merger will be detectable with *LISA*.

Professor Phil Charles. On that same system you must have some idea of the rough size of the black holes from your data.

Dr. Übler. From the broad-line region we can estimate the mass at about $10^{7 \cdot 7}$ solar masses. This is fairly massive but not as massive as some of the black holes that have been detected at similar redshifts. For the other source we don't see a broad-line region and so we don't have a direct way to estimate the black-hole mass. We can do some estimates but this gets really difficult. We can, of course, use the local relation between the black holes and the host properties so we have an estimate of the stellar mass of the system, but then we also see that many of the sources that are discovered are way off, by two or three orders of magnitude. In our JADES data the secondary black holes are estimated to be less massive by about two orders of magnitude or so.

Dr. Robert Fosbury. The hypothesis of the black hole — is that based solely on the line width or are the emission-line spectra consistent with normal black-hole ionization rules?

Dr. Übler. We see these broad-line regions in the hydrogen line, and also in the helium lines. We have the broad lines but we don't see them in the forbidden lines. This is an indication about the origin of the emission and it's consistent with black holes; however, there are diagnostic diagrams that are used for local AGNs, for instance, the so-called BPT diagram where you compare specific line ratios, and this tells you what the prominent ionization mechanism is in the source — is it star formation or AGN? The issue with these diagrams for the high-z sources is that due to the lower metallicity of these galaxies in the early Universe, galaxies shift their position in this diagram such that at $z = 4$ or so star-forming and AGN-dominated systems start to overlap in these diagnostics. The development of alternative diagnostic diagrams takes a lot of effort, and several groups are working to identify new diagnostic diagrams that can be used to identify, based on narrow lines, what is dominated by black holes and by star-formation feedback. Some promising diagrams are those that include the He II line which requires relatively high ionization. For many sources we don't have deep-enough spectra to detect these lines and so we have people working on alternative diagnostics such as the UV lines. This is also done for galaxies in the local Universe. Also, for the auroral lines, there is a project on which a student is currently engaged to find new diagnostics to help identify, in addition to those features like the broad lines, what could be an AGN or not. In the local Universe, people look for X-ray emission, and also, as I said earlier, in higher-

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redshift objects. We do not see X-ray emission for the AGN I showed, even in very deep integrations, so this is something that people are trying to understand now.

Mr. Horace Regnart. How does the central Milky Way black hole compare in size to those central black holes for similar-sized galaxies? Is there a hint of anomaly, and if so, is there a hint of an explanation?

Dr. Übler. Regarding the Milky Way, I will refer you to Frank Eisenhauer in the audience who knows everything about the black hole in our own galaxy. In terms of these high-redshift sources, if you remember the diagram showing the black-hole mass *versus* stellar mass, this would suggest to us that actually these black holes are, compared to the galaxy size, bigger than what we have in the Milky Way. There are some uncertainties that we need to take into account both in terms of how the black-hole masses are derived, but also how the stellar masses are measured. If we look at other properties of the galaxies, for instance, the integrated velocity dispersion that can be used as an estimator of the total mass of the system, we see that we are closer to the local relation, and potentially this would suggest that the baryonic mass corresponding to a black hole in the local Universe is already present here, but has not yet converted into stars, and these are things that we try to pin down with the programme that we have upcoming. With these imaging-spectroscopic data we hope to get much more accurate estimates of the stellar masses and also the black-hole masses to understand what the systematics are in the plots I showed, and also measure the kinematics.

The President. Thank you very much [applause].

It is now my pleasure to introduce the Eddington Lecture for this year, to be given by Dr. Stephen Taylor who is a Northern Irish astrophysicist and Assistant Professor at Vanderbilt University in Nashville, Tennessee. He has an undergraduate degree in physics from the University of Oxford in 2010, followed by a PhD from the University of Cambridge in 2014 where he worked with Dr. Jonathan Gair at the Institute of Astronomy. After postdoctoral fellowships at NASA's Jet Propulsion Laboratory and Caltech, he joined Vanderbilt University as faculty in 2019. Stephen Taylor is the recipient of the US National Science Foundation's prestigious CAREER award, and was recently named as the 2024 Kavli Plenary Lecturer by the American Astronomical Society. He co-led the North American Nanohertz Observatory for Gravitational Waves analysis campaign that resulted in the first evidence for an all-sky background of gravitational waves at light-year wavelengths, and currently serves as the Chair and spokesperson of the NANOGrav collaboration. We look forward very much to your talk which is entitled 'The dawn of galaxy-scale gravitational-wave astronomy'.

Dr. Stephen Taylor. Thank you very much for the warm invitation to deliver this year's Eddington Lecture.

The first direct detection of gravitational waves (GWs) was by ground-based instruments like *LIGO* (the *Laser Interferometer GW Observatory*) in 2015. The field has blossomed from that first detection of two black holes coalescing in 2015, to the amazing 2017 multi-messenger observation of two neutron stars merging and radiating not just GWs but pan-spectral electromagnetic (EM) waves, to a growing catalogue of mergers that has recently almost doubled in number with a new on-going observation run. But as we know from the history of EM astronomy, new discoveries await as we expand into heretofore inaccessible or unexplored regions of phase space.

On 2023 June 29, the global pulsar-timing-array community announced

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strong evidence for an all-sky background of gravitational waves at nanohertz frequencies, almost eleven orders of magnitude lower in frequency than had previously been seen by *LIGO*. This discovery was made with approximately 3·5–4 sigma significance by NANOGrav, a collaboration that I currently chair. But in a remarkable day for the field, the *European Pulsar Timing Array* (*EPTA*), the *Indian Pulsar Timing Array* (*InPTA*), the *Parkes Pulsar Timing Array* (*PPTA*), and the *Chinese Pulsar Timing Array* (*CPTA*), all announced their own evidence with varying levels of significance.

The radio telescopes used by these collaborations are really only the Earth-based portion of the detector, with the crucial other portion being the pulsars themselves. Discovered in 1967 by Dame Jocelyn Bell-Burnell while a graduate student at Cambridge, pulsars are rapidly spinning neutron stars that emit radiation along a magnetic-field axis that may be misaligned from its rotational axis. This creates a lighthouse effect, such that, if we are fortunate to be in its path, we measure a radio pulse from these objects every time they rotate. This allows us to time the arrival of these pulses, and to use their timing accuracy to construct predictive models. Differences between predicted and observed pulse-arrival times can be ascribed to a variety of processes, including some intrinsic and astrophysical sources of noise, and GWs.

When a GW transits between a pulsar and the Earth, it induces a change in the proper separation between those bodies, causing radio pulses to arrive earlier or later than expected. While one may be tempted to try GW detection using only the few best-timed pulsars, the presence of noise due to pulsar rotational instabilities and ionized-interstellar-medium effects makes the confident attribution of timing residuals to GWs impossible. Hence GW detection with pulsar timing is predicated upon the unique correlation signature of timing residuals induced between pairs of pulsars across angular scales by GWs. This correlation signature is called the Hellings & Downs curve, and is predicted under the assumption of an isotropic GW background signal described by GR.

The distinctiveness of this correlation signature, being predominantly quadrupolar in structure, is why it plays a central role in our GW detection statistics. It also underlies the NANOGrav observing strategy since the collaboration's founding in 2007, wherein more pulsars have been added to the array in addition to continued monitoring of the original pulsars. The array has steadily expanded since NANOGrav's earliest work consisting of five years of observations of 17 to the most recent 15-year dataset of 68 pulsars. The timing of many pulsars allows for many distinct cross-correlation values to be measured between pairs across a distribution of angular separations, ensuring that the Hellings & Downs correlation signature is well mapped.

With strong evidence established for a nanohertz-frequency background of gravitational waves, we are now interested in its properties, and ultimately its origins. It certainly appears to have a steep, red spectrum. When the power-spectral density of its induced timing residuals is fitted to a power-law model, the exponent appears to be approximately –3·5 or steeper. This characterization is broadly supported by the independent analyses of NANOGrav, the *EPTA*, *InPTA*, and *PPTA*. However, the posterior probability distribution of the recovered parameters does have some support for a power-law exponent of –13/3, a value that holds special significance. A model with this steepness is the average GW spectrum predicted to derive from a population of inspiralling binary compact objects. Thus our attention turns to a cosmic population of supermassive black-hole binary systems as the most plausible origin for the measured GW background signal. These are the naturally expected by-product

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of hierarchical galaxy growth, in tandem with most galaxies harbouring a central massive black hole. Yet we do not want simply to assume and fix the shape of the spectrum to analytical expectations; we want to measure it since, at lower frequencies that correspond to wider orbital separations, there are a variety of interactions that these binaries may have with their broader galaxy environments. Whether these be scattering interactions with stars, or coupling to discs of gas, such mechanisms can impart a low-frequency turnover in the shape of the spectrum.

Our analyses show that a population of supermassive black-hole binaries can plausibly produce a background of GWs consistent with what we've found. The constrained amplitude of the GW background is consistent with previous literature, although favouring the high end of the range of those predictions. What is obvious though is that we are sensitive to the very-high-mass tail of the distribution of black holes in the Universe, with typical masses for contributing systems being greater than a billion solar masses, and with redshifts nearer than one. As we look to the future, our next scientific milestone is to resolve individual binary systems out of the confusion of signals from the entire population. One way this may initially be achieved is through measuring anisotropy in the intensity of the GW background (similar to characterizing anisotropy in CMB temperature fluctuations), perhaps observing excess power in a certain direction that indicates the presence of binary signal. While we have no evidence of GW anisotropy yet, we could expect to find anisotropy within the next five years if the origin of the GW background signal is truly a population of binary supermassive black holes, and as further leverage we also expect the level of anisotropy to increase with GW frequency. Yet we do also currently conduct searches for individual binary systems based on modelled templates for the GW signal as it would appear in pulsar-timing residuals. Again, we have no evidence of a single binary system in our GW searches yet, but we have charted the distance out to which we can exclude the presence of a binary, which, for a billion-solar-mass system at a GW frequency of 27 nHz, varies from approximately 160 Mpc where we have the most pulsars on the sky to approximately 30 Mpc in the part of the sky with the sparsest pulsar coverage.

While a population of supermassive black-hole binaries may be the most prosaic origin of the GW background, they are by no means the only one. Processes in the early Universe such as inflation and phase transitions, or topological defects like cosmic-string networks and domain walls, could all produce GWs which may lie within the frequencies to which pulsar-timing arrays are sensitive. This is an area of rapid growth within our field, as new researchers join us in a bid to test their new early-universe models against our data. While there is as yet no evidence of such signals, constraints on some models (*e.g.*, of ultralight dark matter) are competitive with other experiments. This is really only the beginning of the tremendous science to come from this field. There are many questions remaining to answer, among which are the origin of the GW background signal, the time to detection of individual binary signals, and the nature of tests of fundamental physics and early-Universe cosmology that complement other observations. Within the next few years, the key regional pulsar-timing collaborations will be combining their datasets to form an international array with more than 100 pulsars, offering exciting prospects for stronger detection of the all-sky background and perhaps even individual sources. There are also mid-term prospects for new radio facilities in the US such as the proposed *DSA-2000*, an array of 2000 × 5-m dishes that would have a sizable portion of time dedicated to NANOGrav observations.

And of course, the *Square Kilometer Array* will be a huge leap forward in radio astronomy, providing the potential to carry the field of pulsar-timing-array GW searches further into the future.

For now, I would like to conclude by thanking you all for your attention and acknowledging the tremendous efforts of my collaborators in NANOGrav and the International Pulsar Timing Array community in this recent breakthrough.

The President. Thank you very much indeed. I'm sure that Mr. Eddington would have been fascinated by that lecture. Can I invite questions?

Professor Chris Lintott. I just wondered whether there were things that we could learn about pulsars that would improve your measurements.

Professor Taylor. Indeed yes. Something that would help us tremendously with measuring individual supermassive black-hole-binary signals is improving our knowledge of the distance to the pulsars and that is because we have to track back the phase of the gravitational-wave signal to the pulsar, and in order to do that well we would need to know the distance of the pulsar within a gravitational wavelength. That would be sub-parsec precision on the distance and we don't have that at the moment for more than just one or two pulsars. We know the pulsar distances to about 10% and they are at kiloparsec distances. I was talking to some folks yesterday at the IoA, Cambridge, about potential ways to do that, which would help tremendously.

Dr. Guy Morgan. Pulsars glitch. The ones you observe have presumably not glitched yet, but if you get a glitch does that destroy the data from that pulsar?

Professor Taylor. Yes. Milli-second pulsars that we use are less glitchy than the canonical pulsars and so for that reason and several others, we use millisecond pulsars. Some of them have glitched and that shows up in our timing behaviour and something distinctive in a way that could not be explained by GW signals. Obviously it is the sudden change in spin of the pulsars — timing offsets look like a ramp as it's an integrated step function, so that is a very clear signature. Interestingly, if you had some other GR effects, you could have ramp features as well correlated across different pulsars. That's called the GR memory effect — it is very rare and very difficult to find but it would be very clear and easy, we think, to separate from actual glitch behaviour.

Professor Charles. You talk about the individual sources and there are a few known binary-black-hole systems with known recurrence times. I am thinking here of OJ 287 which has something like a ten- or eleven-year outburst time-scale which I think is now fairly well established as its period. Is there any chance of something like that?

Professor Taylor. OJ 287 was one of the candidates on the map that I showed. Unfortunately in the fits to those flares, the theory being that the secondary black hole is plunging through the accretion disc of the primary creating flares, the implied dynamics of the system would give a mass ratio that disfavours GW detection; the secondary black hole is just very light in comparison to the primary which diminishes the chirp mass in the GW signal. We can still search for it but the prospects are slim for that particular candidate.

The President. Can I particularly thank the Eddington Lecturer, and also the other two speakers as well? Interesting that each of them mentioned the other which is indicative of just what these meetings are supposed to do. Thank you very much indeed. [Applause.]

Let me remind you that in the Council Room we will be celebrating the news about the new lease on the premises. I'd like to say that this development has been due to many people in the Society over many years — at least ten years — some might say 30 years. It has involved people such as Phil Diamond, members of his staff, past and present Treasurers of the Society, past Presidents, Council members, and so on. It has been a long haul so a good celebration is certainly called for. I give notice that the next A & G Highlights meeting will be on Friday, April 12th.

Editorial Note: The Editors wish to record their gratitude to Dr. Quentin Stanley for his invaluable help in compiling this report.

THE STRUCTURE OF THE GALAXY AS DESCRIBED IN BRITISH PROFESSIONAL JOURNALS 1820–1920 PART 1: 1820–1905

By Steven Phillipps

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When the Royal Astronomical Society was formed in 1820, the prevailing view of the structure of our Galaxy (also known as the Milky Way, the 'sidereal system', or even 'the universe') was that of William Herschel[1], derived from his 'star gauging', counting stars in different telescopic fields of view. As neatly summarized a little later by Alexander von Humboldt in his *Cosmos*, "The cluster of stars, to which our cosmical island [the Solar System] belongs, forms a lens-shaped, flattened stratum, detached on every side, whose major axis is estimated at seven or eight hundred, and its minor one at a hundred and fifty times the distance of Sirius." In addition there were the nebulae, which might be part of the galactic system, in which case it would encompass the entire Universe, or could be external 'island universes', the argument not being settled in favour of the latter until Hubble's work in the 1920s. A previous article[2] considered pre-Hubble papers in British professional journals (primarily *Monthly Notices of the Royal Astronomical Society* and *The Observatory*) which turned out to be about external galaxies (whether the original authors thought so or not). Here we similarly consider papers on the structure of our own Galaxy across approximately the same time period to explore what British readers could discover about the structure of the sidereal system (generally omitting papers merely describing, without interpreting, the appearance of the Milky Way on the sky). We take the end point as 1920 to cover papers up to the culmination of Harlow Shapley's series of contributions[3] from Mount Wilson which demonstrated essentially the modern view of the Galaxy. Given the rush of papers towards the end of the period, we split the time range into two very unequal parts; in this first part we cover the years up to 1905.

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