A&G

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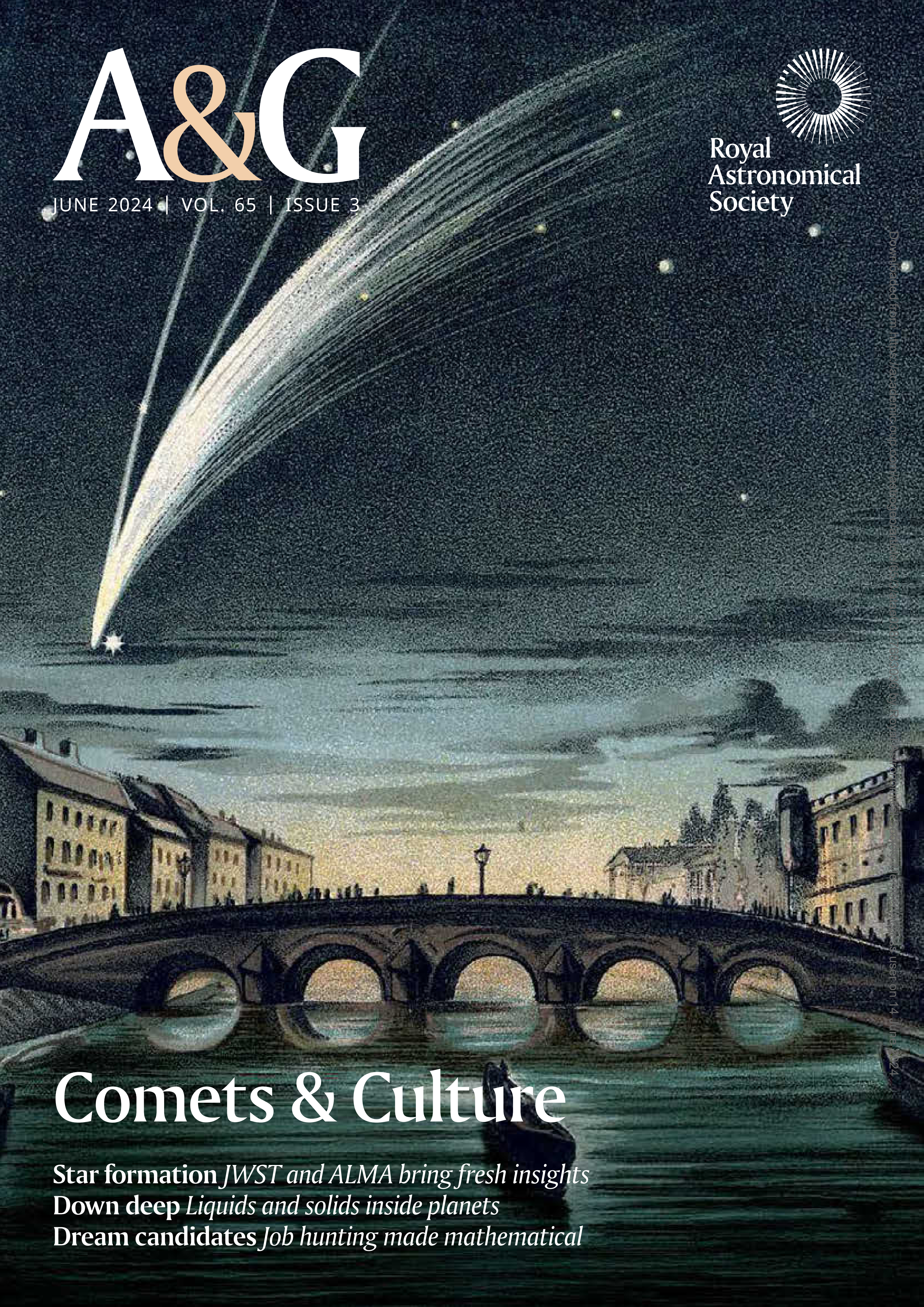
Royal Astronomical Society



Comets & Culture

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Dream candidates *Job hunting made mathematical*

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Get in touch

Astronomy & Geophysics publishes news, reviews and comment on topics of interest to astronomers and geophysicists. See academic.oup.com/astrogeo for more details or contact the editor:

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On the cover

Comet C/1858 L1 (Donati) on 5 October 1858. In 1858 September it reached magnitude ~1. Perihelion, 0.58 AU, was at 1858 on 30 September, with closest approach to Earth (0.5 AU) on 9 October. Around this time the comet showed a prominent curved dust tail resembling a scimitar.

(From E. Weiß's *Bilderatlas der Sternenwelt* (1888); lower portion under cover text extended using AI)

Royal Astronomical Society

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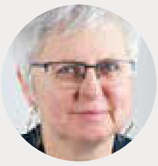
News

Editorial
Back to the future
Sue Bowler, Editor



This issue of *A&G* feels a bit historic – not least because we mark the start of a new chapter in our time at Burlington House, 150 years after we arrived. But we also celebrate the life of Astronomer Royal for Scotland, John Brown, with the first of the lectures to be given in his memory. John had wide interests, and Randall Stevenson ably highlighted one of them: the intersection of science and wider culture. Here he discusses the impact the great comets of the 19th century had on literature and society, taking the novels of Thomas Hardy as a striking example.

Science still matters in wider culture; consider the impact of images from the Hubble Space Telescope – and now JWST. But science has its own culture, and aspects of that need to change. Career-boosting awards go to disproportionately more men and white people than are found in our science community – and the RAS is exploring how to change this. Spoiler alert: more people should nominate more people. Take a moment to read Jasmine Sandhu's article and think about who to nominate for RAS medals and awards later this year.

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Caroline Herschel Medal awarded

Linda J Tacconi, recipient of the 2024 Caroline Hesrchel Medal

The 2024 Caroline Herschel Medal was presented to Linda J Tacconi of the Max Planck Institute for Extraterrestrial Physics in Garching, Germany, in a ceremony at the British Embassy in Berlin on 21 March. Dr Tacconi was recognised for her "world-leading observational studies of the cosmic evolution of dense, star-forming molecular gas in galaxies" as well as her "unique contributions to international leadership in astronomy and service to the European astronomical community".

The award is run by the RAS and the Astronomische Gesellschaft (German Astronomical Society) whose president Professor Stefanie Walch-Gassner commented: "Linda Tacconi has made ground-breaking contributions to our understanding of how galaxies form and evolve over cosmic time, exploring these objects with detailed observations paired with impressive dedication. She is an outstanding and inspiring leader and mentor." **tinyurl.com/3xmmrp7j**

Sealing our future at Burlington House

After protracted negotiations about our premises in Burlington House, the Royal Astronomical Society's future there is now secure. On 21 March 2024 the RAS President Mike Edmunds (second from left in the Council photo) signed an agreement on a 999-year lease. With the agreement comes stability, but also new responsibilities, including upkeep of the building, and a committment to future activities including enhanced public outreach for the Society itself and with our neighbours in the Burlington House Courtyard.

International collaboration boost

Phase 2 of the International Bilateral Fund has awarded £13 million to 11 projects partnering UK institutions and companies with groups in other countries. The award is supported by funding from the Australian Space Agency, arising from the UK-Australia Space Bridge agreement.

Projects include work on developing space nuclear power: Rolls-Royce will work with US company BWXT and, in a separate project, the University of Leicester will work with UK, US and Japanese partners. The company Virtual Future is developing a robotic space farm and X-ray imaging of the aurora, and Surrey Satellite Technology is developing water quality monitoring and forecasting in the UK, Australia and beyond. There's even a high-accuracy nanosatellite magnetometry project, collecting data in support of the World Magnetic Model. **tinyurl.com/ay2b4nxn**

Space Agency spreading out

The UKSA is setting up national headquarters at the Harwell Science Campus Space Cluster, Oxfordshire – together with new regional offices – in order to boost collaboration with UK space industry.

The HQ will open in June and take advantage of the roughly 100 research organisations based at Harwell; offices at William Morgan House in Cardiff and at Space Park Leicester opened in April and the Edinburgh office, at Queen Elizabeth House, will open later this year. "This will place the UK Space Agency at the heart of the space sector we serve", said UKSA CEO Paul Bate, "boosting growth, improving relationships with regional organisations and supporting a strong, diverse and connected sector." The UKSA will retain its existing offices in London and Swindon. **tinyurl.com/mr3payr9**

Is this a lazy quasar?

Not much is known about how much influence quasars in galaxy clusters have on their surroundings. But a new study of quasar H1821+643, using NASA's Chandra X-ray Observatory, shows it has relinquished much of the control imposed by more slowly growing black holes. The black hole's appetite is not matched by its influence. The research team, led by Helen Russell (University of Nottingham), describe it as 'underachieving'. A paper appears in *The Monthly Notices of the Royal Astronomical Society*. **tinyurl.com/mryxrvby** (NASA/CXC/University of Nottingham/H. Russell et al./NSF/NRAO/VLA/SAO/N. Wolk)

Baby star sneezes during formation

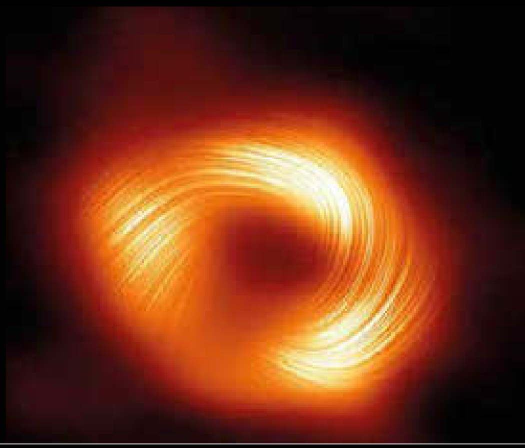
Astronomers have found that infant stars 'sneeze' plumes of magnetic energy during formation. Kazuki Tokuda (Kyushu University) and colleagues used ALMA to study MC 27; a stellar nursery located about 450 light-years distant. They found spike-like structures extending from the proto-stellar disk. Interpreting these as 'interchange instabilities', the team suggest these 'sneezes' result in a high-speed outward expelling of magnetic energy. The study appears in *The Astrophysical Journal*. **tinyurl.com/mszu73ps**

Extremely violent and catastrophic ends

In a new study, Amornrat Aungwerojwit (Naresuan University) and colleagues have investigated what happens to asteroids, moons and planets that pass close to white dwarfs. The team analysed oddly shaped, chaotic and disorderly transit data for a small sample and found the fate of these bodies is likely to be extremely violent and catastrophic. The team present their findings in *The Monthly Notices of the Royal Astronomical Society*. **tinyurl.com/29xcjjsn**

On the edge of the eclipse

People living or travelling to the path of totality in North and Central America on 8 April had the chance of imaging the Sun's corona – and even taking part in data collection for Sunseeker. A partial eclipse was visible in north-western parts of the UK; astrophotographer Callum Potter captured this image from Rousay, Orkney, Scotland. (starlightnights.com)



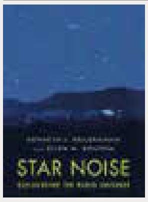
Sgr A* in polarised light

The EHT team have produced the first polarised light image of the Milky Way's central black hole, Sagittarius A* (Sgr A*). The results show strong, twisted, and organised magnetic fields near the object. The structures are strikingly similar to that of the monster black hole at the centre M87, despite being more than a thousand times less massive and significantly smaller, suggesting that strong magnetic fields may be common to all SMBHs. The EHT Collaboration has published two papers in *The Astrophysical Journal Letters*. tinyurl.com/6fr9vesh (EHT Collaboration)

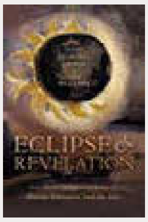
Tellurium tracked

Using multiple telescopes, researchers have found the signature of the element tellurium in the spectrum of gamma-ray burst GRB230307A. This breakthrough discovery puts astronomers one step closer to solving the mystery of the origin of elements that are heavier than iron. Tellurium, one of the rarest elements on Earth, should be made by these so-called 'kilonovas'. Andrew Levan (Radboud University) and team report the findings in *Nature*. tinyurl.com/4mzmnd4k (Luciano Rezzolla, University of Frankfurt)

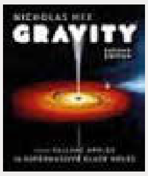
RAS Library
New books



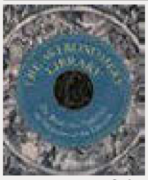
Kellermann, Kenneth I, and E Bouton. *Star Noise: Discovering the radio universe.* Cambridge: Cambridge Uni Press, 2023.



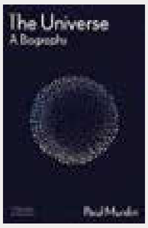
Lange, Henrike C., ed, and Tom McLeish, ed. *Eclipse and Revelation: Total solar eclipses in science, history, literature and the arts.* Oxford: Oxford Uni Press, 2024.



Mee, Nicholas. *Gravity: From falling apples to supermassive black holes.* 2nd ed. Oxford: Oxford Uni Press, 2022.



Masters, Kate. *The Astronomers' Library : The books that unlocked the mysteries of the universe.* London: Ivy Press, 2023.



Murdin, Paul. *The Universe: A biography.* London: Thames and Hudson, 2022.

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Antarctic meteorites on the way out

The Antarctic is a valuable source of meteorites that stand out on the icefields. But they are disappearing beneath the ice – and the culprit is global warming. This alarming picture is reported by Veronica Tollenaar (Université libre de Bruxelles) and colleagues in Nature Climate Change. Using artificial intelligence, satellite observations, and climate model projections, the team calculated that for every one-tenth of a degree of increase in global air temperature, an average of nearly 9000 meteorites disappear from the surface of the ice sheet. At the present rate of global warming, the loss is about 5000 meteorites a year – outpacing efforts to collect them by a factor of five. **tinyurl.com/ydfxxxaf** (Veronica Tollenaar, Université Libre de Bruxelles)

Global warming buys time for negative leap second

The tricky prospect of removing a leap second from Universal Coordinated Time (UTC) has been delayed by some three years as a result of the increased rate of ice melting in Greenland and Antarctica. Satellite data shows that Present Day Mass Transfer arising from ice melt has decreased the angular velocity of the Earth more rapidly than before. But analysis of the data suggests that the angular velocity of the liquid core has also been decreasing at a steady rate, with a corresponding increase in the angular velocity of the rest of the planet; the ice melt has slowed this increase overall, according to Duncan Agnew (University of California San Diego) publishing in *Nature*. The analysis also makes a negative leap second likely in the next decade.

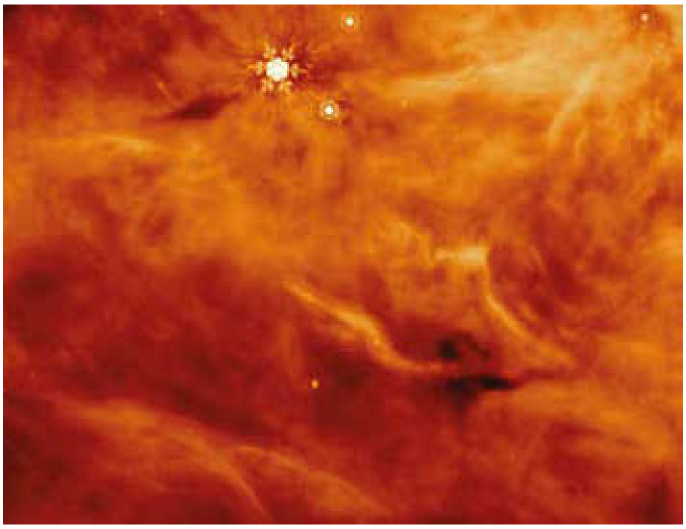
Leap seconds have been added at intervals over the past half century, but in that time, the world has become more reliant on precise timekeeping. However, the synchronised global infrastructure may not be able to accommodate the loss of a second. Global warming may have bought a little time, but a looming negative leap second may need significant changes to the way we mark time. **tinyurl.com/4hfrstp5**

100 at 100

The RAS has produced a booklet called *100 influential papers from Geophysical Journal International*, a compilation of 100 key papers from the first 100 years of geophysics publishing by the RAS. The papers were chosen by *Geophysical Journal International* (*GJI*) editors in their subject areas; each section is introduced by an essay on the development of the subject. The booklet is free to download from the RAS website and the papers themselves are part of the entire archive, now free to access. **tinyurl.com/yc3wjv72**

Icy COMs from protostars

Using the JWST, researchers report the robust detection of acetaldehyde, ethanol, methyl formate, and likely acetic acid, in the solid phase, in early-stage protostars. The team, led by Will Rocha (Leiden Observatory), also detected simpler molecules, including methane, formic acid, sulphur dioxide, and formaldehyde. These complex organic molecules (COMs) can become part of comets and asteroids and eventually new planetary systems when the icy material is transported inward to the planet-forming disk. A paper appears in *Astronomy & Astrophysics*. **tinyurl.com/3berk6wc** (ESA/Webb, NASA, CSA, W. Rocha et al. (Leiden University))

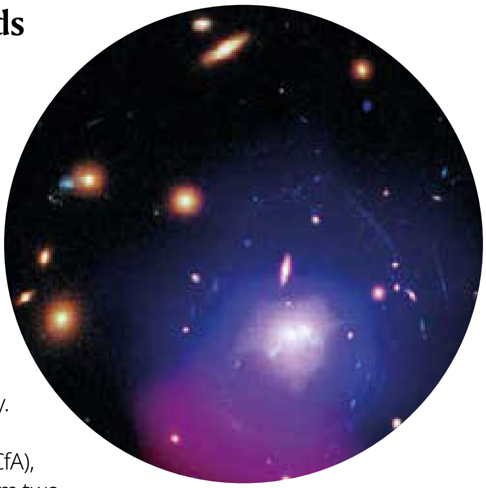


String of pearls

The mechanism that breaks up aircraft contrails may explain the 'string of pearls' surrounding SN 1987A. That's the conclusion of a study by Michael Wadas (University of Michigan, Ann Arbor), and colleagues, appearing in *Physical Review Letters*. The researchers argue that the 'Crow instability' does a better job of explaining the phenomenon than the 'Rayleigh-Taylor instability'. The mechanism accurately predicts the number of clumps seen around SN 1987A. **tinyurl.com/3yb3v948**

(NASA, ESA, CSA, M. Matsuura (Cardiff University), R. Arendt (NASA's Goddard Spaceflight Center & University of Maryland, Baltimore County), C. Fransson (Stockholm University), J. Larsson (KTH Royal Institute of Technology), A. Pagan (STScI).)

String of beads



Multi-wavelength observations of massive galaxy cluster SDSS J1531 have provided evidence for an ancient, titanic eruption, probably resulting from a powerful jet from a black hole at the core of a large galaxy. The researchers, led by Osase Omoruyi (CfA), think tidal effects from two merging galaxies compressed the gas along curved paths, leading to the star clusters forming in the 'beads on a string' pattern around a distinctive cavity. A paper appears in *The Astrophysical Journal*. **tinyurl.com/4yv3hkvm** (X-ray: NASA/CXC/SAO/O. Omoruyi et al.; Optical: NASA/ESA/STScI/G. Tremblay et al.; Radio: ASTRON/LOFAR; Image Processing: NASA/CXC/SAO/N. Wolk.)

Europa's modest oxygen

Jamey Szalay (Princeton University) and colleagues report on the direct measurement of charged oxygen molecules in the atmosphere of Europa. The source of these molecules is thought to be water ice on Europa's surface. The data puts a narrow constraint on the total oxygen production at Europa; currently at around 12kg per second. The findings unambiguously demonstrate oxygen is continuously produced at the surface, although at a much lower rate than previously thought. A report appears in *Nature*. **tinyurl.com/2xmd9f3u**

(NASA/JPL/University of Arizona)

The RAS New Fellows

The following were elected fellows of the RAS in March 2024:

Matthew Allcock, London
Giulia Ballabio, London
Thomas Bickle, Southampton
Shannon Bohle, Lima, Ohio USA
NovaProton Bucknall, Marlborough
Alexander Byrne, Cambridge
Richard Cannon, Edinburgh
Brian Chapman, Cumbernauld
Jerric Chong, Oxford
Jake Clark Brown, Abbots Langley
Fraser Cowie, Oxford
Catherine Cuddy, Dublin Ireland
Adriana Dias, Staines-upon-Thames
Dilan Diyalanthonige, Mitcham
Josh Dury, Compton Martin
Mattia Emma, Egham
Samuel Farr, Berkeley
Silvia Giuliatti Winter, Guarantingueta Brazil
Emily Grant, Leeds
Ferdinand Hollaf, Dundee
Hallie Hudson, Leeds
Heather Johnston, Leeds
David Jones, Southampton
Ardra Kozhikottuparambil, Coventry
Tanya Kushwahaa, Cardiff
Anne Laas, Epsom Downs
Ewelina Lawrence, Edinburgh
Cindy Lim, Bristol
Vikram Lingamgunta, Paisley
James McPartland, Bedlington
Bijas Najimudeen, Manchester
Helen Norman, Coventry
Joshua Perkins, Ashbourne
Alicja Polanska, London
Joshua Pollin, Belfast
Andres Ponte Perez, Birmingham
Toby Rodel, Belfast
Gyan Singh, Nagpur India
Georgina Stroud, Manchester
Sofia Vasieva, West Kirby
Thomas Wakefield, London
Jamie Wickham-Eade, Stanmore
Wendy Williams, Macclesfield
Dawei Xi, Manchester

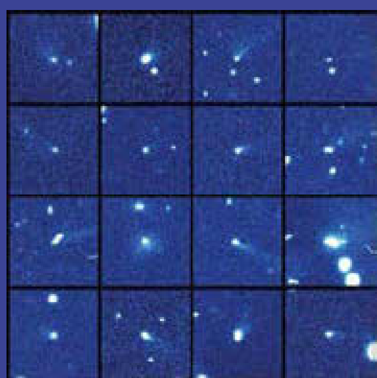
Earliest SMBH?

Roberto Maiolino (University of Cambridge) and colleagues have found evidence that GN-z11, one of the youngest galaxies ever observed, hosts a 2-million-solar-mass black hole. It is the most distant active supermassive black hole ever found, and it explains why the galaxy is so luminous. **tinyurl.com/mupa3334**

Trace of cannibalism

Evidence of a cannibalistic white dwarf swallowing its planets has been discovered. Using VLT data, Stefano Bagnulo (Armagh Observatory) and colleagues found a unique concentration of metals, a 'scar', imprinted on the surface of WD 0816-310. They originate from a planetary fragment possibly larger than Vesta, which is about 500km across. A paper appears in *The Astrophysical Journal Letters*. **tinyurl.com/yc2kyk6s**

Citizen science in the solar system



Citizen scientists have managed to find rare solar system objects in a collaborative study. Some 8300 volunteers examined more than 430 000 DECam images from the Victor M Blanco telescope in Chile. The results show previously unknown activity in 15 asteroids and one Centaur. Colin Chandler (University of Washington) and team report on the findings in *The Astronomical Journal*. **tinyurl.com/32ze642t** (H. Hsieh/PSI)

Echoes inside the Crab Nebula

JWST image of the Crab Nebula in Near and Mid infrared light, coloured to show gaseous elements in orange, dust (yellow and green) and light from accelerated particles in white.
NASA, ESA, CSA, STScI, T Temim (Princeton University)

The Crab Nebula is the most active of the known supernova remnants, observed as a continuous cloud of synchrotron radiating plasma, while the neutron star at its centre is a spectacular pulsar, writes Francis Graham-Smith. Optically, the nebula appears as a crab-like network of filaments of unclear origin, but recent radio observations of the pulsar are giving us a more detailed picture of their structure.

Near daily observations from the 42ft (13m) radio telescope at Jodrell Bank have monitored the rotation of the pulsar and its pulse shapes over several decades and have shown the remarkable phenomenon of echoes, appearing as copies of the characteristic double profile of the pulses. The echoes have delays of around a millisecond and persist for days or weeks, during which time the delay diminishes to zero following a parabolic time sequence. The parabolic delay of the extra pulses is just what is expected if the echoes are bouncing off an object that is moving steadily across the line-of-sight to the pulsar. A recent paper by Nadeau *et al.* 2024 (*Ap J* 962, 57) has studied the occasional 'giant' pulses emitted by the pulsar and these have allowed a more detailed study of the phenomenon.

This duplication of the radiation route from the pulsar to the observer is attributed to a reflection from a sheet of ionisation which is seen at a glancing angle that changes as the pulsar moves, much like the single glint of light from the surface of a shiny ball illuminated by a lamp. The ionised sheet may be a shock front, a small version of the optically observed filaments. The physical size need only be a few light seconds across, in contrast to the light-year scale of the nebula itself.

The 42ft Telescope at Jodrell Bank was originally used in Australia as a radar antenna at the Woomera rocket test range, but it has proved to be the ideal telescope for continuous monitoring of the Crab pulsar.

Martian formaldehyde

New simulations suggest that the ancient atmosphere of Mars could have provided a continuous supply of formaldehyde which could have led to the creation of organic compounds. This raises the intriguing possibility that organic materials detected on the martian surface could have originated from atmospheric sources, particularly during the planet's two earliest geological periods. Shungo Koyama (Tohoku University) and colleagues present the findings in *Scientific Reports*. **tinyurl.com/mv7emhd9**

'Hubble tension' persists in JWST

A comparison of HST and JWST measurements of Cepheids has confirmed that the 'Hubble tension' remains a conundrum. Despite improved accuracy, the new JWST results have not diminished the discrepancy with cosmological predictions. This furthers the case that something else – not measurement errors – is the cause of the controversy. Adam Riess (STScI) and team discuss the latest results in *The Astrophysical Journal Letters*. **tinyurl.com/m4xp9snu**

No dark matter, no problem?

New research suggests that the universe does not need dark matter to exist. Rajendra Gupta (University of Ottawa) combines the ideas of 'covarying coupling constants' and 'tired light' to question the existence of dark matter. The theory eliminates the need for dark matter while still being consistent with key cosmological observations. The study appears in *The Astrophysical Journal*. **tinyurl.com/2xn7zumd**

Many happy… oscillations?

A fresh look at red giant stars offers key insights into cosmic distance measurement. The study, led by Richard Anderson (Observatoire de Sauverny), has shown that red giant oscillations can be used to distinguish stars by age, offering a more nuanced approach to standard candle techniques. The analysis appears in *The Astrophysical Journal Letters*. **tinyurl.com/363sf3ad**

KBOs age with icy volatility

A new study suggests that many Kuiper Belt Objects (KBOs) could still retain their original volatile ices, challenging previous notions about the evolutionary path of these ancient objects. Based on an analysis of KBO 486958 Arrokoth, the research could help explain phenomena such as the intense outburst activity of comet 29P/Schwassmann–Wachmann. A paper by Samuel Birch (Brown University) and Orkan Umurhan (SETI Institute) appears in *Icarus*. **tinyurl.com/8vtdyfuv**

Young star offers T Cha-ble moment

T Chamaeleontis (T Cha) is a young star enveloped by an eroding disk notable for its vast dust gap, approximately 30 AU in radius. Naman Bajaj (University of Arizona) and colleagues have detected winds coming from an extended region of the disk, which indicates it is at the end of its evolution, and the planet-building phase of T Cha appears to have ended. A report of the findings is found in *The Astronomical Journal*. **tinyurl.com/mw9as3as**

Ancient star

Anirudh Chiti (University of Chicago) and colleagues believe they have found an example of a rare second-generation star in the Large Magellanic Cloud. Using data from Gaia and the Magellan Telescope in Chile, the team found a candidate with extremely low metallicity generally and depleted carbon and iron specifically. It was probably formed in the wake of the first generation of stars in the universe. The research appears in *Nature Astronomy*. **tinyurl.com/yct7kcyp**

Take the rest of the day off

Marcin Glowacki (ICRAR) and colleagues were trying to find star-forming gas in a single radio galaxy, but instead discovered 49 new galaxies. The discovery was made using the MeerKAT array of radio dishes in South Africa. Surprisingly, the haul of new galaxies was contained in less than three hours of observations. A paper appears in *The Monthly Notices of the Royal Astronomical Society*. **tinyurl.com/yckh7nk5**

Who ate a planet?

Are the chemical compositions of stellar binary pairs always the same? In new research, Fan Liu (Monash University) and team found that in 8% of 91 examples, they were not. Publishing their results in *Nature*, the researchers suggest this is evidence that one of the stars in some pairs has swallowed planetary material and changed composition. And these are main sequence stars, not red giants. **tinyurl.com/39z6r83u**

Brown dwarf formation

Are giant planets and brown dwarfs born like stars? Basmah Riaz (University Observatory Munich) and colleagues observed the extremely young brown dwarf Ser-emb 16 with ALMA. Modelling of the data showed a dynamic brown dwarf formation process is most likely, similar to Sun-like stars. A paper appears in *The Monthly Notices of the Royal Astronomical Society* **tinyurl.com/mzm5a5jm**

Bigger black hole breaking records

A newly discovered black hole is breaking all records. It resides at the centre of quasar J0529-4351, 12 billion light-years distant. Christian Wolf (Australian National University) and colleagues estimate the black hole has a mass of roughly 17 billion solar masses and appears to be devouring about one solar mass every day. A paper appears in *Nature Astronomy*. **tinyurl.com/2p9h8knv**

No trace of quantum gravity

Coherence loss in neutrino propagation has not been seen in 300 000 atmospheric neutrinos detected by the IceCube Neutrino Observatory. The measurements thereby provide no evidence for quantum gravity. Researchers, the IceCube Collaboration, writing in *Nature Physics*, say that much longer propagation distances may be needed to reveal quantum gravity effects. **tinyurl.com/4xdcp9pe**

Lunar overturn

Weigang Liang (University of Arizona) and colleagues have been investigating events after the creation of the Moon. They compared simulations of a sinking ilmenite-rich layer to gravity anomalies detected by NASA's GRAIL mission. The analysis shows that ilmenite migrated to the near-side and then sank, before 4.22 billion years ago, in sheet-like cascades. The Moon literally turned itself inside out. The research appears in *Nature Geoscience*. **tinyurl.com/4uk8mudt**

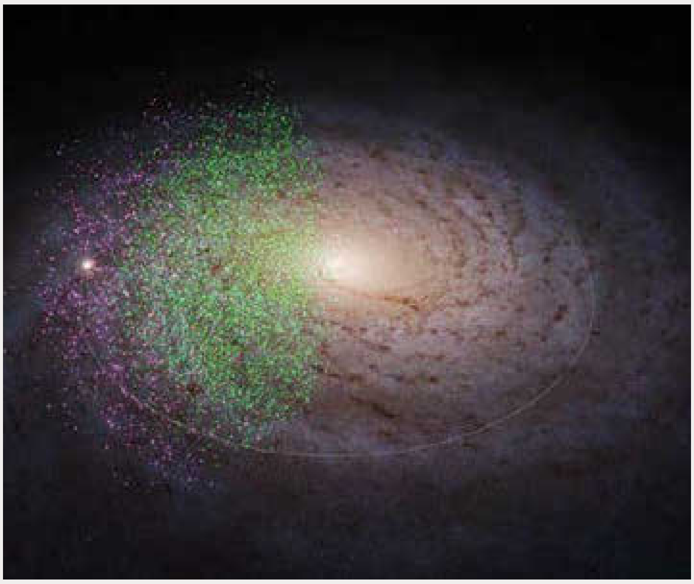
Exoplanet glory

Astronomers have discovered a 'glory'; a luminous phenomenon similar to a rainbow, in the atmosphere of exoplanet WASP-76b. Olivier Demangeon (Universidade do Porto) and colleagues believe a glory can explain a brightening from the east terminator of the exoplanet compared to the west. The phenomenon occurs if the light from the host star is reflected by clouds of perfectly uniform long-lived material. The analysis appears in *Astronomy & Astrophysics*. **tinyurl.com/ydu6bhse**

Northern hitch

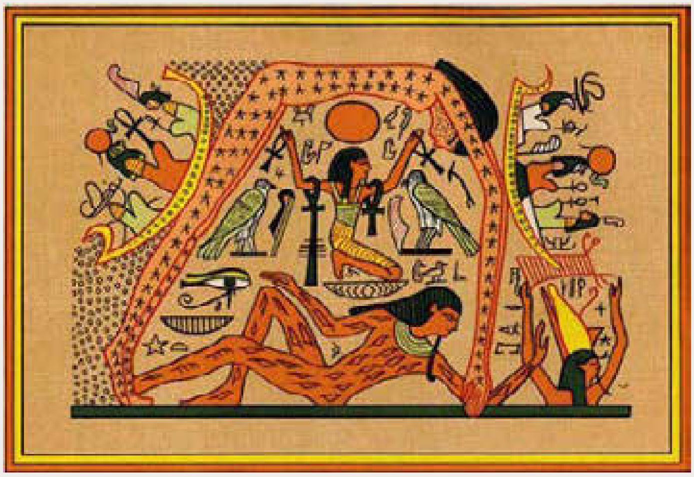
In the April issue of A&G, we mistakenly located new Fellow Bobby Manoo in Nottingham, whereas he is based in Mottingham, London.

Shakti and Shiva made the Milky Way?



Khyati Malhan and Hans-Walter Rix (Max-Planck-Institut für Astronomie Heidelberg) have identified what could be two of the Milky Way's earliest building blocks. Using data for nearly six million stars from Gaia and the Sloan Digital Sky Survey (DR17), the researchers found that, for a certain range of metal-poor stars, stars were crowded around two specific combinations of energy and angular momentum. The implied proto-galactic fragments probably merged with an early version of the Milky Way between 12 and 13 billion years ago. The components have been named 'Shakti' and 'Shiva', the latter one of the principal deities of Hinduism and the former a female cosmic force often portrayed as Shiva's consort. The study appears in *The Astrophysical Journal*. **tinyurl.com/m65mskp**

(S. Payne-Wardenaar/K. Malhan/MPIA)

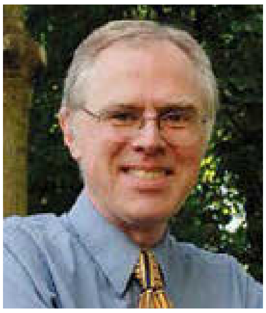


Nut and the Milky Way

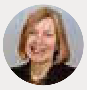
Or Graur (University of Portsmouth) has shed light on the possible relationship between the Milky Way and 'Nut', an Egyptian sky-goddess. The study draws on ancient Egyptian sources including the *Pyramid Texts*, *Coffin Texts*, and the *Book of Nut*, and compares them to simulations of the Egyptian night sky, to argue that the Milky Way might have shone a spotlight, as it were, on Nut's role in the sky. Graur proposes that, in winter, the Milky Way highlighted Nut's outstretched arms, while in summer, it traced her backbone across the heavens. The study appears in *The Journal of Astronomical History and Heritage*. **tinyurl.com/yedzp26p**

(E. A. Wallis Budge, The Gods of the Egyptians, Vol. 2 (Methuen & Co., 1904))

Obituary



AUTHOR
Belinda Wilkes (pictured), Steven Phillipps and Malcolm Bremer were colleagues of Mark Birkinshaw at the University of Bristol, UK; Roger Davies, University of Oxford, UK.



FURTHER READING

Sunyaev-Zel'dovich effect detection
Birkinshaw M, Gull S F & Hardebeck H 1984 *Nature* **309** 34B

Sunyaev-Zel'dovich effect review
Birkinshaw M 1999 *Phys. Rev.* **310** 97
Roy. Astron. Soc. 227 1
Kaiser N 1992 *Astrophys. J.* **388** 272

Deaths of Fellows

Nicholas Aresti
Born 5 January 1959
Elected 8 September 1995
Died 12 October 2023

Tazal Azim
Born 8 November 1931
Elected 10 May1963
Died 18 October 2023

John Dowthwaite
Born 7 July 1961
Elected 10 March 2023
Died 16 July 2023

Petros Florides
Born 16 February 1937
Elected 10 January 1963
Died 31 December 2023

Phillip Gething
Born 22 August 1929
Elected 12 November 1948
Died 31 July 2023

Reuben Margerison
Born 20 May 1991
Elected 10 February 2017
Died 1 October 2023

Mark Birkinshaw (1954–2023)

Belinda Wilkes and colleagues remember a clear and incisive thinker, a light-touch leader and, above all, an inspirational collaborator

Mark Birkinshaw, William P Coldrick Professor of Cosmology and Astrophysics in the School of Physics, University of Bristol, died on 23 July 2023 after a brief illness, with his wife and long-time collaborator, emeritus professor Diana Worrall, at his side.

Mark was born in London in December 1954, the eldest of three children. The family later moved to Hampshire where he attended Portsmouth Grammar School. He won a scholarship at St. John's College, Cambridge in 1973 and went on to a PhD at the Mullard Radio Astronomy Observatory (MRAO) of the Cavendish Laboratory between 1976 and 1979. He completed nine papers from his thesis work, several with Steve Gull, all as first author. He subsequently spent two years as a Miller Research Fellow at the University of California, Berkeley, before returning to Cambridge as a research fellow of Gonville and Caius College.

Back at MRAO, he established his reputation as a world leader in studies of the Cosmic Microwave Background (CMB). He observed for hundreds of hours with the Owens Valley Radio Observatory in California, and in the early 1980s published the first solid detections of the Sunyaev-Zel'dovich (SZ) Effect, the lower CMB temperature observed when CMB photons pass through foreground clusters of galaxies en route to Earth. His application of the SZ-effect to determine the scale of the universe subsequently founded a new (and still thriving) field of study. Mark's most highly cited paper is a beautifully written and comprehensive, 137-page, review of the SZ effect.

In 1982 Mark had met fellow British astrophysicist Diana Worrall, then working in California; they married two years later. Mark crossed the Atlantic again to join the Department of Astronomy at Harvard University, where for part of the time he was also an Alfred P. Sloan Foundation research fellow. He joined the Smithsonian Astrophysical Observatory in 1992. Mark continued to publish widely, often in collaboration with Diana, on radio, optical and X-ray observations of galaxies and clusters and on the physics of radio jets, also adding theoretical work and papers on gravitational lensing.

Mark was appointed the inaugural William P. Coldrick Professor of Cosmology and Astrophysics at the University of Bristol in 1995, becoming head of the Astrophysics Group in the Department of Physics. Combining his research with undergraduate teaching, post-graduate supervision and the administration of the group, particularly the acquisition of research grants, he oversaw the significant increase in size and prestige of the Bristol group and was for a time joint head of the Physics Department. Mark was a very impressive, light-touch leader, running the group with the minimum of fuss and formal meetings, while ensuring that his colleagues were fully consulted, informed and involved as necessary. He was assiduous at shielding the team from a great deal of the administration, allowing them to concentrate on teaching and research. His unwavering enthusiasm for science made him an inspirational colleague and leader.

Mark was highly respected, known as a fair and professional reviewer and greatly in demand to serve on national and international research committees and boards. He served on multiple committees at any given time, often as chair. He forged connections with scientists and students abroad, including Sweden, South Africa, Korea and beyond, often supervising students either remotely or in person at Bristol. Despite all of this, he and Diana still found time to spend part of their summers back at the Harvard-Smithsonian Center for Astrophysics, working with multiple colleagues in the High Energy Astrophysics and Radio Astronomy divisions.

Mark *loved* astrophysics. His enthusiasm was infectious, and the significance of his contributions was huge. He brought energy, enthusiasm, deep knowledge and clarity of thought to all aspects of his work, encompassing broad and exciting topics including extreme conditions around black holes and the energetic jets they power, the hot gas that permeates rich clusters of galaxies, gravitational lensing, and the role of magnetic fields. His knowledge of radio galaxies was encyclopaedic, with an ability to immediately provide key parameters and properties of any radio source mentioned in passing. He was a gifted mathematician and teacher; his challenging General Relativity course was very popular. Mark was an inspiring and exacting collaborator whose input was always insightful and constructive, and a dedicated and supportive supervisor and mentor. He loved interacting with colleagues and was always generous with his time and ideas.

Mark also had a thirst for knowledge and experiences beyond science. He travelled the world, taught himself the language of many of the countries he visited, including China and Sweden, where since 2019 he held an affiliated professorship at Chalmers University and was a Hasselblad guest professor at Onsala Space Observatory. He was extremely well-read, and in spare moments he enjoyed a round of golf, demonstrating significant talent with an impressive handicap. He and Diana were regular bellringers for their local church.

Mark was a leader in his field, both in the UK and worldwide. He was hugely valued by his colleagues and students in the School of Physics in Bristol, and they feel his loss acutely. His collaborators at the CfA will miss his annual visits, and injection of energy and ideas. Beyond research, his broad contributions and dedication to advancing UK science have been invaluable. Mark's early and unexpected death represents a huge loss to his university and to the UK and worldwide astrophysics and science community.

Comets and culture in the 19th century and beyond

In the first of the Society's John Brown Memorial Lectures, **Randall Stevenson** explores the effects of comets on literature, art, and popular culture, and on the development of cometary science itself

To begin at the beginning… The tenth Astronomer Royal for Scotland, and Regius Professor of Astronomy in the University of Glasgow, John C. Brown, dated the origin of his career to a moment, early in 1957, when his Uncle Joe showed him Comet Arend-Roland through a pair of binoculars. Further encouragement for astronomical interests soon followed. The first of many *Sky at Night* programmes was broadcast on BBC television on 24 April that year, featuring information about Comet Arend-Roland. Jodrell Bank's largest radio telescope began observations in the summer – soon tracking Sputnik 1, launched in October, attracting world-wide interest, and inaugurating the space age. Perhaps the most fortunate feature of 1957, though, for a nascent astronomer, was simply the sight of a comet in the skies above Scotland. By 1957, bright comets had scarcely appeared in the northern hemisphere for nearly half a century.

Things were very different 100 years earlier – indeed, the 19th century was described by the astronomer Jay M. Pasachoff as "comet-crazed" (Olson & Pasachoff 1998). Dazzling comets crossed the skies during the century frequently enough not only to catch the attention of astronomers and scientists, but to enthral poets, novelists, artists, and the population generally. This makes it an outstanding period in which to follow John Brown's interest in what he calls "the arts-science interface": the intimate interconnection between disciplines often mistakenly supposed divergent. This interest extends throughout his recent book titled *Oor Big Braw Cosmos: A Cocktail of Cosmic Science, Imagery and Poetry* (Brown & Wilson 2019). Accordingly, this first John Brown Memorial Lecture will offer another 'cocktail' – a collection, anyway – of cosmic and cometary science, images, some poetry, and a good deal of fiction.

The 19th-century fascination with comets began as early as the opening of its second decade, with the arrival of Comet Flaugergues. Visible to the naked eye from around May 1811, eventually shining at magnitude 0, and brandishing a longish tail, it remained in the skies for more than eight months and was often referred to as 'Napoleon's Comet'. Ever the opportunist, Napoleon claimed it as a good omen: a shining star promising the success of his Russian campaign, begun in June 1811. To his Russian adversaries, it inevitably took on an opposite significance, as a portent of doom – a role before long, of course, also ascribed to it by the French themselves, after their long retreat from Moscow.

Naturally, it figured in Leo Tolstoy's epic account of the period of the Russian campaign, *War and Peace* (Tolstoy 1869). At a key moment in Tolstoy's novel, his hero, Pierre Bezukhov, spots the comet in: "an immense expanse of dark starry sky… almost in the centre of it… surrounded and sprinkled on all sides by stars but distinguished from them all by its nearness to the earth, its white light, and its long uplifted tail, shone the enormous and brilliant comet of the year 1812 – the comet which was said to portend all kinds of woes and the end of the world. In Pierre, however, that comet with its long luminous tail aroused no feeling of fear. On the contrary he gazed joyfully… at

1 *The Great Comet of 1843, pictured over Table Bay, Cape Town, where Charles Piazzi Smyth was working in the Royal Observatory.* (National Maritime Museum, Greenwich, London)

this bright comet… having travelled in its orbit with inconceivable velocity through immeasurable space."

Since he has just realised – and partly declared – his love for Tolstoy's heroine Natasha, the brilliant comet and its "long uplifted tail" might at this point be considered principally representative of Pierre's own feelings and rising emotions.

But his reflections also illustrate a wider shift in contemporary attitudes. Thinking of the comet not as a portent of woe or the world's end, but rather in terms of its orbit and velocity, Pierre's attitudes are typical of late-18th and early-19th century movements from superstition towards science and rationality. Particularly since the return in 1758, as Edmond Halley had predicted, of the comet eventually named after him, comets had begun to shed their long-standing role as mysterious harbingers of doom, and to be understood instead as celestial bodies subject to the understanding of scientists. This change in role was nevertheless far from complete – in popular apprehension at any rate – by the early 19th century, as indicated by the negative reactions to Comet Flaugergues Pierre considers. Older superstitions, moreover, were often merely replaced, or extended, by fears that comets – if they were understood to be celestial bodies – might collide with the Earth. At the start of the century, in other words, and to an extent throughout, comets continued to occupy a sometimes-disturbing or at least ambivalent place in the mind of the public, as we'll see again later.

"Superstitions were often replaced, or extended, by fears that comets – if they were understood to be celestial bodies – might collide with the Earth"

Common comets

First, though, it is worth simply stressing how extensively comets impinged on public attention and popular imagination during the period. By the time Tolstoy completed *War and Peace* in the 1860s, three comets as bright as any in the past millennium had bristled across the skies of the northern hemisphere, and there were more to follow. The first of these, the Great March Comet of 1843, extended a tail longer than Comet Flaugergues's, at 70°, and shone far more brightly. Reaching magnitude –10, as bright as a full Moon, it was easily visible in daylight, even when quite close to the Sun, appearing in this way in a contemporary oil painting by Charles Piazzi Smyth, one of John Brown's predecessors as Astronomer Royal for Scotland (figure 1).

Piazzi Smyth is one of the Scottish astronomers whose work John Brown celebrates in *Oor Big Braw Cosmos*, and the subject of two of Rab Wilson's poems included in that volume. The two Astronomers Royal – Piazzi Smyth the second, John Brown the tenth – had further aspects of their careers in common. Like Piazzi Smyth, John Brown was interested in photography, in painting, and in what he calls "cosmic graphic art" generally (Brown & Wilson 2019). Smyth's talents as an astronomical artist were already evident in drawings he made of Halley's Comet, on another of its returns in 1835, and they continued to develop during his years as Astronomer Royal in Edinburgh, evident in his view of Coggia's Comet, depicted above the city in 1874 (figure 2). By including some of the city's lights in its lower right-hand corner, his painting also indicates an early awareness of the effects on astronomy of light pollution – a concern John Brown shared with all astronomers in the 21st century, and discussed in *Oor Big Braw Cosmos.* Piazzi Smyth also recorded that he viewed Comet Coggia on 15 July at 10.30pm, but that it was soon engulfed in 'haar' – indicating something all Scottish astronomers have in common: the likelihood of their objects of interest either being invisible or soon vanishing behind copious clouds.

Comets nevertheless remained copious in the skies of the mid-19th century, with the Great Comet of 1843 followed by Donati's Comet in 1858, and a still brighter one three years later. Shining at magnitude –1, with a fine, 40°, scimitar-shaped tail, Donati's was one of the most beautiful of all the century's comets, and accordingly one of the most frequently represented by artists – such as James Poole, whose painting shows it in close proximity to the star Arcturus. It made an equally strong impression on writers – on Thomas Hardy, as we'll see, and on Alfred, Lord Tennyson. His son Hallam recorded that Tennyson interrupted a dinner party in the autumn of 1858 to observe the comet, witnessing "Arcturus shining brightly over the nucleus" and seeming to "dance as if mad when it passed out of the comet's tail" – an impression he evidently long remembered (Tennyson 1908).

2 *Detail from a watercolour of Coggia's Comet by Charles Piazzi Smyth.* (The Charles Piazzi Smyth archive at the Royal Observatory Edinburgh)

Published in 1876, Tennyson's play *Harold* begins with characters uneasily observing a comet that "glares in heaven" and "a star/That dances in it as mad".

Enter photography

Often the subject of drawings and paintings, Donati's Comet also figured in a new stage in the representation of celestial objects: it was the first ever to be photographed. The results were not wholly successful: only the nucleus was bright enough, and only just, to register on a photographic plate. Techniques soon improved, and were more successfully applied, in 1881, to the second discovery made by John Tebbutt, an Australian amateur astronomer whose comet searches originally relied only on a small marine refracting telescope, of around 1.5in aperture. His first discovery, the Great Comet of 1861, eventually outshone Donati, at magnitude –3, with an immense, 120° tail. Though less bright, Tebbutt's Comet of 1881 nevertheless appeared spectacularly in northern skies that summer, as shown in Etienne Trouvelot's depiction of it, shining over Harvard College Observatory on the night of 25 June (figure 3). The creator of numerous vivid illustrations of astronomical objects, Trouvelot believed – albeit at an early stage of photography's development – that the camera could never entirely replace the artist's eye. As his view of Tebbutt's Comet suggests, artistic representation could still have some advantages over the more objective mode of photography, at any rate in accentuating and drawing attention towards specific details. As some of John Brown's own 'cosmic graphic art' shows, painting and drawing long continued, too, to allow ample opportunity for inventive imagination and abstraction.

Reactions to Tebbutt's Comet offer an opportunity to assess the kind of attention accumulated, by the later 19th century, by the brilliant comets gracing the skies in 1812, 1843, 1858, 1861, 1874 and 1881. Its scale is demonstrated by the volume of commentary in newspapers in the early summer of 1881, when over 2000 articles about Tebbutt's Comet appeared in the press in Britain. As many of them recorded, in an age of relatively little public spectacle – obviously long preceding the thrills of cinema and television – such celestial wonders inevitably made a huge impression on the population generally. As the *Edinburgh Evening News* straightforwardly remarked on 24 June, "a large comet… easily visible with the naked eye, is one of those 'sensations' which affect all". The next day, the *North and South Shields Daily Gazette* described the sensation the comet was causing in London, noting that it was: "leading to a dangerous decivilisation of the social habits of the Londoner. Sitting up at night is becoming universal, and between midnight and one in the morning, when the comet makes its appearance over the horizon, the streets affording point of view are nearly as crowded as at noontide. The principal grand stands are the bridges, from which an excellent view is obtained."

Three days later, the *Glasgow Herald* quoted a New York correspondent's claim that "the new comet… is the principal topic of conversation in the United States". Its appeal was evidently equally extensive in France – the Paris correspondent of the *Illustrated London News* remarking on 2 July that "for the moment, the great subject of interest is the comet".

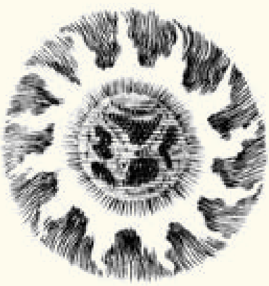
Newspaper reports on 23 July indicate how far comets and speculation about their nature had passed into popular discourse and imagination. The *Western Daily Press*, along with several other papers, described how, in the House of Commons the previous evening, a fellow MP had designated Lord Randolph Churchill as "a Parliamentary Comet". "The noble Lord," this MP suggested, "pursues in Parliament a course almost as elliptical and erratic as the comet which has been visiting us lately. Nor is this the only point of resemblance between the two… Astronomer[s] tell us that the heavenly comet is entirely without substance; is mainly composed of gas; and is of a levity inconceivable to ordinary mortals."

Ascribing the same extremely lightweight nature to "the noble Lord", the MP goes on to hope that, like the comet, he might soon be "speeding rapidly from the space we inhabit, to be seen by men of this generation no more".

Comets naturally made as firm an impression, or a firmer one, on literary imagination, likewise providing authors with a convenient source of metaphor. In Thomas Hardy's *Far from the Madding Crowd* (Hardy 1874), views of women held by the gauche farmer Boldwood are summed up through an analogy not unlike the one applied to Lord Randolph Churchill. For Boldwood: "women had been remote phenomena… comets of such uncertain aspect, movement, and permanence that whether their orbits were as geometrical, unchangeable, and as subject to laws as his own, or as absolutely erratic as they superficially appeared, he had not deemed it his duty to consider."

Comets would have been familiar objects to Hardy, who had been attentive to the sky from childhood. Born in 1840, he might just have been old enough to see the Great Comet of 1843. He almost certainly witnessed Donati's Comet in 1858, reflecting on the experience,

3 *The great comet of 1881 (Comet C/1881 K1) observed on the night of 25 June (Plate XI from The Trouvelot Astronomical Drawings 1881).* (MLibrary Digital Collections)



and on the comet's 2000-year orbital period, in one of his 1860s poems, *The Comet at Yell'ham* (Gibson 1991):

It bends far over Yell'ham Plain,
And we, from Yell'ham height,
Stand and regard its fiery train,
So soon to swim from sight.

It will return long years hence, when
As now its strange swift shine
Will fall on Yell'ham; but not then
On that sweet form of thine.

In her foreword to *Oor Big Braw Cosmos,* Dame Jocelyn Bell Burnell even describes Hardy as an amateur astronomer: his interests in the subject were certainly deepened during the 1870s through reading *Essays on Astronomy* (Proctor 1872), by Richard A Proctor, a contemporary astronomer, author, and populariser of astronomical knowledge and theories. At the end of the decade, too, in the course of a long illness, Hardy discussed astronomy while being treated by Sir Henry Thompson, a distinguished surgeon whose private observatory was equipped with instruments good enough eventually to be passed on to the Royal Observatory at Greenwich.

Perhaps the key moment in the deepening of Hardy's astronomical interests occurred at a very particular moment in his private life, when he moved with his wife Emma to a new house at Wimborne, in Dorset. On one of their first evenings there, 25 June 1881, when walking out into their new garden, they found Tebbutt's Comet hanging bright in the northern sky, near the constellation of Auriga – much as depicted by Etienne Trouvelot, above Harvard Observatory, on the same night. Hardy, at any rate, went on that summer to plan a novel on an astronomical theme – also drawing on the Transit of Venus due in December 1882 – and to seek further information from Greenwich Observatory. Permission to visit the Observatory required accreditation in those days: presumably, this was granted readily to Hardy, who had Alfred, Lord Tennyson and Thomas Huxley among his referees.

The result was *Two on a Tower* (Hardy 1882), in which a brilliant comet plays several key roles. "Visible in broad day" – while at night its "fiery plume… filled so large a space of the sky as to completely dominate it" – it proves as spectacular and as much of a "sensation", for Hardy's rural characters, as Tebbutt's comet had been for Londoners. It also saves the impecunious young astronomer Swithin St Cleve, the novel's hero, from serious – perhaps mortal – illness. Having long regretted that Comet Flaugergues will not reappear for 3000 years, when he hears that a new comet is approaching he is endowed with "a strenuous wish to live and behold the new phenomenon". As indeed he does, in the company of his patroness Lady Viviette Constantine, with whom he embarks on a tangled romance, initiated on the night they meet in his observatory tower to observe the new comet through the powerful telescope she has helped him acquire.

Two on a Tower was topical enough on publication in October 1882, when memories of Tebbutt's Comet were still fresh. Hardy could scarcely have anticipated how much more so it quickly became. In the autumn of 1882, the skies were dominated by yet another brilliant comet – even more spectacular than any of those mentioned above. Shining at magnitude –17, the Great September Comet of 1882 may have been the brightest in history. Its appearance, coinciding with the publication of Hardy's novel, can hardly fail to have boosted sales. That potential, and the usefulness of the comet in the novel's plot, suggest that Hardy's interest in the sky led to an altogether fortunate outcome in *Two on a Tower.*

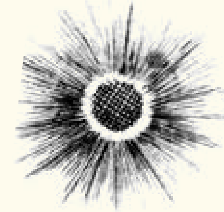
Comets and dark thoughts

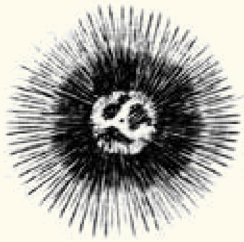
Yet Hardy's work is generally informed by a sense of melancholy and adverse fate, and *Two on a Tower* is no exception. Its darker feelings figure principally in what Jocelyn Bell Burnell describes as Hardy's "brilliant description of the scale of the Universe in *Two on a Tower*" (Bell Burnell 2019). Descriptions involved are brilliant, but also disturbing and vertiginous. Swithin regularly warns Viviette about "human insignificance" in the context of "yawning spaces" in the heavens and the "immensities… [of] the stars and their interspaces". "Void and waste places of the sky" offer "monsters of magnitude": "deep wells for the human mind to let itself down into", suggesting a universe of unknowable immensity; "a vast formless something… infinitely great".

This sense of universal darkness and emptiness extends into the work Hardy began planning during the 1870s: *The Dynasts* (Hardy 1904-08), his huge poetic drama of the Napoleonic wars, eventually published in three parts early in the 20th century. It offers an overwhelmingly bleak view of history, presided over by an "Immanent Will", utterly and remorselessly indifferent to human affairs, and described as ruling over:

… ghastly gulfs of the sky…
Monsters of magnitude without a shape
Hanging in deep wells of nothingness.

Reference to "deep wells" and "monsters of magnitude" show Hardy reprising in *The Dynasts* not





"Hardy's young astronomer embarks on a tangled romance with his patroness, initiated on the night they meet in his observatory tower to observe the new comet through the powerful telescope she has helped him acquire..."

only the bleak views of the cosmos outlined in *Two on a Tower*, but even some of the phraseology the novel had used to deliver them. Though probably not his best novel, the comet-inspired *Two on a Tower* was clearly a pivotal one, leading towards the deepening pessimism of Hardy's later career. It may have contributed more widely, too, to late 19th- and 20th-century conceptions of a godless, lonely, unimaginably immense universe: too vast to "cope with, even as an idea", as Swithin and Viviette find.

Two on a Tower also illustrates the 19th century's shifting understanding of comets and their natures, mentioned earlier. Old superstitions are seen still to survive – though in a rather dilute, even comic form – when one of Hardy's rural 'work-folk' asks uneasily: "What do this comet mean?… That some great tumult is going to happen, or that we shall die of a famine?" He is reassured swiftly, though bleakly, by a fellow farm-labourer's explanation that celestial portents of doom are unlikely to have much to do with the poor. Perhaps unconsciously following the view Shakespeare records in *Julius Caesar* – that "when beggars die, there are no comets seen" (II, ii) – he suggests that famine "only touches such as we, and the Lord only concerns himself with born gentlemen. It isn't to be supposed that a fiery lantern like that would be lighted up for folks with ten or a dozen shillings a week."

Fears of collision with the Earth are taken more seriously, Swithin reflecting of comets that: "these dazzling and perplexing rangers, the fascination of all astronomers, rendered themselves still more fascinating by the sinister suspicion attaching to them of being possibly the ultimate destroyers of the human race."

Swithin nevertheless considers comets "desirable visitors", and by Hardy's time the "sinister suspicion" of their threat to the Earth – like earlier fears of their dire portentousness – had been substantially displaced by scientific enquiry. Less disturbing views had developed even by Napoleonic times, in the first years of the 19th century, through the work of contemporary astronomers and mathematicians – in particular Pierre-Simon Laplace. From careful calculations – particularly regarding the movements of Lexell's Comet – Laplace deduced that comets exert minimal gravitational influence on the orbits of other celestial bodies, and are therefore of relatively insignificant mass. Hitherto, it had often been supposed that they were as massive as planets, and that any collision with one would in consequence be apocalyptic. Though acknowledging that a cometary impact might still be expected to have serious effects, Laplace greatly diminished fears that it would be an "ultimate destroyer of the human race" (Laplace 1809). He remarks instead that: "the appearance of comets, followed by these long trains of light, has for a long period terrified mankind ... The light of science has dissipated these vain terrors, which comets, eclipses and many other phenomena inspired in the ages of ignorance."

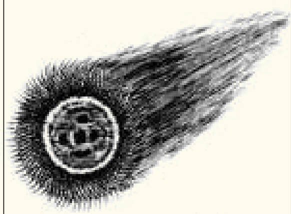
Science in later decades continued to dissipate terrors, and to confirm Laplace's conclusions, particularly through observations of Comet Biela – along with Halley and Encke, one of the earliest comets to be recognised as periodic, reappearing roughly every seven years. In 1846, it was observed to have split into two pieces, and these remained apart when they returned in 1852, suggesting their mass was insufficient to exert gravitational attraction strong enough to draw them back together. On the basis of this kind of evidence, popular astronomy after mid-century was inclined to describe comets as flimsy, lightweight,

entirely innocuous objects, probably gaseous or nebulous in nature. As that satirical MP remarked of Tebbutt's comet in 1881: "astronomers tell us that the heavenly comet is entirely without substance; is mainly composed of gas" – views of a kind widely emphasised in newspapers that summer. The *Alnwick Mercury*, for example, reassured its readers on 2 July that comets offered "no more reason to apprehend any danger… than there is to fear from a collision between a mountain range and the mist which the wind drives against its summits" – a risk no more serious than "smoke from the pipe of a labourer in a neighbouring field" might offer to "a Great Western broad gauge express".

From the point of view of later years – particularly in the 21st century, once again troubled by dangers posed by comets and near-Earth objects – such conclusions might seem almost too comfortable. It was after all only a quarter-century or so later, in 1908, that a comet, or possibly an asteroid, struck or exploded over Tunguska, in a remote region of Siberia – an occurrence that interested John Brown at an early stage of his career. Though no human casualties seem to have resulted, the Tunguska event devastated forests over hundreds of square miles, suggesting that the object responsible might have been composed of something a good deal more substantial than only gas, or material as lightweight as a mountain wind.

Contrary to contemporary newspaper opinion, views of this kind had begun to be shared at least among some astronomers, even before the 1880s, partly as a result of the later fate of Comet Biela. After its 1852 passage, still in two parts, Biela failed to reappear, though at the time it was due, in 1872, a spectacular meteor shower radiated from the area of sky in which it had been predicted to return (figure 4). The comet was presumed to have broken up much further, into smallish individual fragments, but evidently of a solid rather than gaseous nature. The resulting meteor shower, peaking in early December – the Bielids, or Andromedids – continued to appear for many years, though nowadays are much diminished.

4 *The shower of shooting stars of 27 November 1872, known as the Bielids, or Andromedids. From Amédée Guillemin's Le Ciel: Notions Élémentaires d'Astronomie Physique (1877). (credit: Wellesley College Library)*



Blinded by theories

Further evidence of a connection between meteors and comets had continued to accrue during the late 1860s and in the 1870s. Richard Proctor, for example – author of those essays on astronomy Hardy read during the decade – firmly identified the orbit of Comet Temple-Tuttle with the Leonid meteors, or "the November meteors" as he called them, in 1869. Yet theories of the gaseous nature of comets proved so tenacious – perhaps reflecting the depth of astronomers' determination to dispel the "vain terrors" they had so long occasioned – that Proctor was unable to recognise their true relations with meteor showers. "No reasonable doubt can exist that the meteors and the comet form a single system", he remarks in his *Essays on Astronomy*: "but what connection there may be between the gaseous comet and its solid attendants… has not hitherto been explained. It may be regarded indeed as one of the most mysterious facts ever discovered by astronomers that any association whatever should exist between bodies seemingly so different in their natures."

The mystery began to be resolved during the 1870s by suggestions, such as the science writer Amédée Guillemin's in *The World of Comets* (Guillemin 1877), that the two bodies might *not* be so different in nature. Following "very recent researches", by the Italian astronomer Giovanni Schiaparelli and others, Guillemin reported that it was "highly probable" that cometary nuclei were part-solid, made up of a "granulated structure… of isolated particles". Views of this kind led eventually to Fred Whipple's 1950s designation of comets as "dirty snowballs", though some astronomers remained unconvinced – at least until the Giotto probe encountered rocky particles when approaching Halley's Comet in 1986, or, finally, the Rosetta mission reached Comet 67P Churyumov-Gerasimenko in 2014.

Although 19th century science encouraged – even entrenched – a benign view of comets and their flimsy nature, the threatening aura they had earlier maintained in popular imagination never entirely disappeared. On the contrary, it was sometimes actually renewed by fresh theories of comet composition – by fears that their gaseous nature might somehow exercise a remote, malign influence over the weather, or even poison the atmosphere altogether. In an early Edgar Allan Poe short story, *The Conversation of Eiros and Charmion* (Poe 1839), characters acknowledge that "reason had… hurled superstition from her throne", leaving comets no longer assumed to portend doom, nor to threaten catastrophic collision with the Earth. They note that: "the very moderate density of these bodies had been well established. They had been observed to pass among the satellites of Jupiter, without bringing about any sensible alteration either in the masses or in the orbits of these secondary planets. We had long regarded the wanderers as vapory creations of inconceivable tenuity, and as altogether incapable of doing injury to our substantial globe."

Yet Poe's story goes on to describe how, as a huge comet approaches the Earth, "the atmosphere was radically affected" by its "impalpable gaseous character": so much so that the air itself eventually catches fire, in an immense global conflagration which entirely destroys humanity.

Apocalyptic imaginings of this kind were sometimes countered in the 19th century by an alternative superstition, construing cometary effects on the atmosphere as entirely benign, and particularly beneficial for vineyards and the production of wine. Such views were early evident in the century, in response to the appearance of Comet Flaugergues in 1811–12. Hailed as a portent by Napoleon, it was also supposed responsible for an outstandingly good vintage that year, long celebrated as 'Comet Wine'. Similar tributes were paid to the vintage of 1858, the year of Donati's Comet. Recalling its appearance in his play *Harold*, Tennyson has one of his characters seek to allay fears of the comet which "glares in heaven" by mildly suggesting that "perhaps our vines will grow better for it" (Tennyson 1908). At the time of Tebbutt's Comet in 1881, *The Era* reminded its readers that "in wine-growing countries comets are always welcome. A comet vintage is sure to be appreciated". Paris correspondents of several other newspapers reported during the summer that *gourmands* were already licking their lips in anticipation of the excellent vintage that would surely follow the comet's passage.

Such notions of affirmative cometary influences – perhaps intoxicating ones – extend in a way into H. G. Wells's novel *In the Days of the Comet* (Wells 1906). Like Hardy, Wells may have been influenced by the appearance of Tebbutt's Comet in 1881, or the Great Comet the following year. He records in his autobiography (Wells 1934) being at a "most receptive age" at the time, and having recently reassembled an astronomical telescope, using it to observe Jupiter and its moons, and the "starry heavens" more widely. *In the Days of the Comet* is in any case as concerned as *Two on a Tower*, at times, with cosmic "deeps… the immensities, and the mysterious possibilities that might float unlit in that unplumbed abyss" – or, occasionally, be discovered "rushing upon us out of the inhuman void". Yet despite

6 *Le Vin de la Comète ('Comet Wine'), c.1818. The inn sign – presumably "A La Comète" – is half-visible at top right.*
(British Museum, CC BY-NC-SA 4.0)

such passages, the comet which the novel describes rushing out of "the inhuman void" functions less as an object of astronomical attention than a convenient plot-device, mysteriously improving human life much as newspapers in the 1880s and earlier construed beneficent influences on wine. Narrowly missing the Earth, it creates in the atmosphere a strange gas, very far from being poisonous or incendiary. It induces instead a kind of euphoric intoxication on a global scale, leading to the transformation of politics and institutions into the kind of utopian society Wells often advocates and explores elsewhere in his work.

Enter spectroscopy

Despite Wells's novel, and the optimistic superstitions of oenophiles, the sinister aura surrounding comets still lingered influentially – and was even reinforced – in the closing decades of the 19th century and the early years of the 20th. Tebbutt's Comet was the first to be photographed entirely successfully, in 1881 – nucleus, tail and all. It was also among the first to be analysed spectroscopically. As techniques of spectroscopy grew more sophisticated, they suggested the presence of poisonous cyanogen gas in comets' tails, and orbital calculations suggested that the Earth would pass through the tail of Halley's Comet when it returned in 1910. Transits of this kind had occurred previously – the Earth passing through the tails of Donati's Comet and of the Great Comet of 1861 – and entirely without adverse effects, or confirmed effects of any kind. Fears about the 1910 encounter with Halley were nevertheless widely disseminated, and amplified by several figures, notably the French astronomer, artist and author Camille Flammarion.

Flammarion's novel *La Fin du Monde* or *The End of the World* (Flammarion 1893) had already contributed to fears of cometary apocalypse, describing – rather like Poe in his short story – how the close passage of a giant comet exercises a fiery, destructive effect on the Earth's atmosphere, almost destroying humanity. As the date of Halley's arrival grew closer, fears of this kind were greatly augmented – though partly inadvertently

– by articles Flammarion contributed to the press. These stressed that no danger was likely to accrue from passage through the tail of Halley. In terms similar to those employed by the *Alnwick Mercury* in 1881, Flammarion described the comet, when encountered by the Earth, resembling "a fog through which a locomotive was dashing at full speed". Nevertheless, he did also note some eventualities which *might* lead to "universal death with short shrift" (Goodrich 2023). These were carefully indicated as "improbable", or even entirely hypothetical. But they were enough for the contemporary press. Remarks by Flammarion and other commentators were seized upon by newspapers and amplified far enough to create some panic, particularly in the United States – sales of 'Comet Pills' and of oxygen supplies, for example, and the digging of supposedly comet-proof shelters. No ill-effects, of course – apart from the anxieties fostered by the newspapers – were occasioned when Halley duly returned in 1910.

Why the sheer volume?

The whole phenomenon – the panic and its sources – was recently surveyed by Richard J Goodrich in his facetiously entitled *Comet Madness: How the Return of Halley's Comet (Almost) Destroyed Civilization* (Goodrich 2023). That title, *Comet Madness*, may recall Pasachoff's description of the 19th century as "comet-crazed", inviting a couple of concluding questions: in particular, regarding the scale and origin of cometary influences on the period – on its authors and artists, as well as its press and its popular imagination generally. Why *did* so many dazzling, unforgettable comets appear at the time – in 1812, 1843, 1858, 1861, 1881, and 1882? Might some form of the "Immanent Will" that Hardy describes have *sent* this cascade of comets earthwards to extend recognition of its darkling powers, or to further the sense of cosmic emptiness and agnostic pessimism so evident in Hardy's work, and more widely in his age? Or – maybe more plausibly – might some passing star have stirred sunwards, aeons earlier, out of the Oort cloud of comets in the remote reaches of the solar system, more than usually abundant celestial visitors to its inner regions?

Or might some of the comets mentioned, possibly those of 1843 and 1882, belong together in a kind of family? Specifically, as members of the group of Kreutz 'sungrazers' which interested John Brown, some of whose work centred on solar astrophysics. He discusses Kreutz comets in *Oor Big Braw Cosmos,* and in a paper he wrote for the *Astrophysical Journal* in 2015 (Brown *et al.* 2015). According to some theories, many or most of these closely sun-skirting objects might be relics of a single, huge, originary comet – one which may have fractured into separate smaller bodies in 372 BC, though other dates have been suggested. A common origin – and, consequently, comparable orbits – might explain why 19th-century comets sometimes followed each other after relatively brief intervals, like buses assigned to the same route. More surely, though, that coincidence of bright 19th-century cometary visitations might need to be construed as only that: a coincidence or "statistical fluke" as Pasachoff calls it (Olson & Pasachoff 1998).

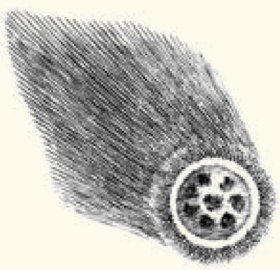
Yet the coincidence does seem stranger in the light, or rather darkness, of what has followed. If it is challenging, in the 21st century, to appreciate the scale of wonder and excitement comets generated in the 19th, it is largely because so little of equivalent size and brilliance has turned up since. After Halley and the Great January Comet of 1910, nothing even nearly as bright

"If it is challenging to appreciate the scale of wonder and excitement comets generated in the 19th century, it is largely because so little of equivalent size and brilliance has turned up since"

appeared in northern skies until Arend-Roland visited in 1957 – just in time, as mentioned earlier, to help inspire John Brown towards his career in astronomy.

After 1957, in the latter half of the 20th century and in the 21st, bright-ish comets appeared more regularly, including Ikeya-Seki, Hyakutake, West, Hale-Bopp, Holmes, Lovejoy, Panstarrs, and, more recently, Neowise and Nishimura. Yet only Hale-Bopp came close to the size and brilliance of cometary spectacles on view in the 19th century. Views of all those comets, and of the sky in general, were in any case much attenuated by levels of light-pollution greatly increased since Piazzi Smyth's time – at any rate for the city-dwellers who make up an ever-larger majority of the population. By the 21st century, urban environments had long ceased to provide the kind of 'grand stands' contemporary newspapers reported London's bridges still offering in the summer of 1881.

The period since the 1950s has of course maintained and extended, in other ways, the relations between science and culture John Brown advocated. As he shows throughout *Oor Big Braw Cosmos*, recent developments in astronomy and cosmology have extended the excitement of a universe more than Big and Braw enough to fascinate artists and the population generally. Yet that comet-crazed 19th century – when celestial objects were so often a 'sensation' and a public spectacle, night after night – offers another ideal context in which to explore connections between the arts and science, especially as interfaces between them were so regularly traversed in *both* directions. It is hardly surprising that the period's dazzling comets – and astronomical theories about their nature – contributed widely to the work of artists and of writers, and to culture and popular imagination generally. What seems more surprising, at least to a non-scientist, is the extent to which those astronomical theories were themselves shaped by popular culture – by a determination to dispel the menacing aura long surrounding comets, and to insist instead, despite mounting evidence to the contrary, on their flimsy, innocuous nature. Recognising mutual influences of astronomy and culture working in such ways helps remove the "groundless and damaging divide between arts and science" which John Brown warns against (Brown & Wilson 2019). It opens up fuller, freer appreciation of what he calls "the wonder and beauty of our colossal cosmos" – wonder and beauty which his own work did so much to celebrate, comprehend, and extend. ●



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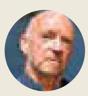
The Society's annual John Brown Memorial Lecture honours Prof John C. Brown, who was Regius Professor of Astronomy at the University of Glasgow and served as Astronomer Royal for Scotland for 14 years from 1995. The author would like to thank the RAS – in particular, Philip Diamond, Sheila Kanani, Sue Bowler, and Mike Edmunds – for organising the lecture, and Professor Graham Woan for his excellent arrangements on the day it was delivered at the University of Glasgow, 5 December 2023.

AUTHOR

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Solid-Liquid Interactions in Deep Planetary Interiors

Alfred Wilson, Andrew Walker, Dario Alfè and Chris Davies report on a meeting bringing together experimental, theoretical, and observational studies of the deep mantles and cores of terrestrial bodies

On 14 October 2022 the RAS Specialist Discussion 'Solid-Liquid Interactions in Deep Planetary Interiors' took place as the first in-person meeting of its kind at Burlington House following the pandemic. The meeting aimed to bring together experimental, theoretical, and observational studies of the deep mantles and cores of terrestrial bodies, with a particular emphasis on their mutual interactions. Solid-liquid interactions deep in the interiors of terrestrial planets shape their evolution and dynamics, the exchanges of mass and energy between cores and mantles, defines the crystallisation sequence of primordial magma oceans, and the power supplies that might sustain magnetic fields. Recent work has suggested that deep solid-liquid regions may be widespread (e.g. Davies & Greenwood 2023), arising at the top and bottom of Earth's core and in the cores of Mars, Mercury, the Moon and Ganymede. Non-equilibrium thermodynamic processes have also been identified as important despite often being ignored in models of core-mantle evolution. The meeting was divided into two halves, first focusing on the metallic cores of terrestrial bodies and the second exploring processes in silicate mantles and magma oceans.

Metallic cores

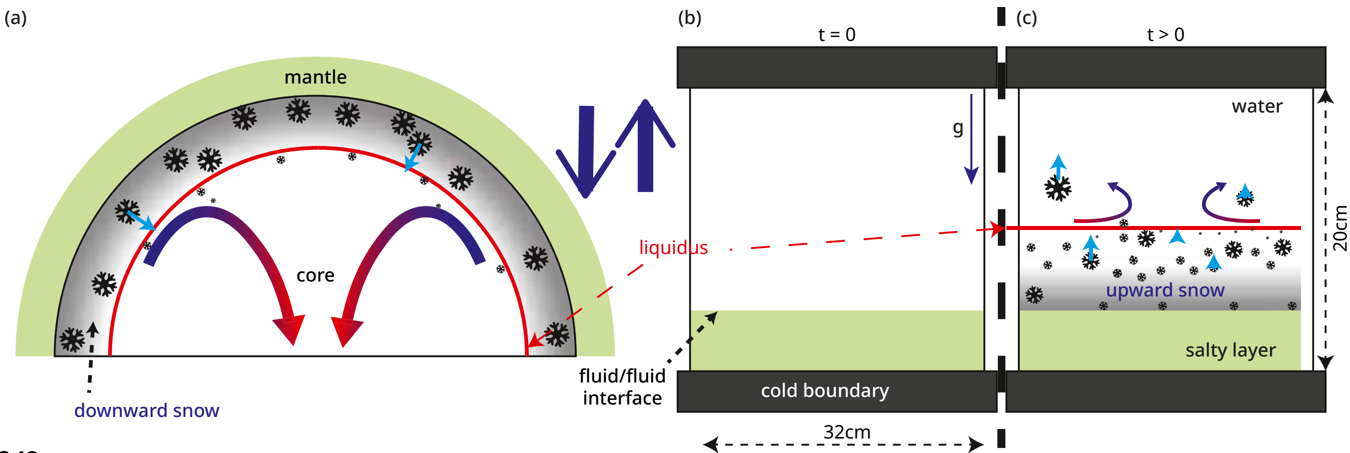
The morning session began with an invited talk from Tina Rückriemen (DLR) entitled 'Freezing metallic cores: Where do all the solids go?' which gave an excellent introductory walkthrough of the various processes by which planetary cores freeze and the ongoing research in the area.

While Earth's liquid core is slowly freezing heavy (compared to the liquid) material from the bottom upwards, core freezing in small planetary bodies such as Mars, Mercury, Ganymede, the Moon and planetesimals might proceed very differently. The direction of freezing depends on the relative gradients of temperature profile and melting temperature in a planet's core. Because of a significant pressure dependence of both quantities, larger planets such as Earth freeze from the inside out whilst the metal cores of small bodies likely solidify from the top to the bottom. Different top-down freezing scenarios can be envisioned depending on the type of solid material and its density compared to that of the liquid.

If the solid forming is heavier than the surrounding liquid, it may evolve as free crystals and 'snows' which fall into the deeper, entirely liquid core (Rückriemen *et al.* 2015). If the solid is lighter it may create a compact, floating solid layer directly below the core mantle boundary. For example, at low pressure, sulphur partitions strongly to the liquid iron, meaning that solid iron is relatively pure when it freezes. This means that as these dense solids sink into the core, they heat up and remelt, creating a dense iron-rich liquid which can drive compositional convection. Ganymede, Mars, the Moon and Mercury all offer unique geodynamo outputs which can each be explained by a snow zone, showing that these processes are powerful and potentially widespread features in planetary evolution.

Ludovic Huguet (CNRS) then presented 'A laboratory model for iron snow in planetary cores', the first talk on an experimental study, where a chilled tank of salt-water forms ice crystals as an inverted analogue for iron snow in planetary cores (Huguet *et al.* 2023; figure 1).

Whilst we can learn a great deal from the 1D thermal evolution of planets, this does not allow us to glean the details of dynamic processes which are providing convective power. In particular, we do not yet understand how iron snows come about in planetary cores, much less how they generate flow on the small scale. To answer these questions we can turn to analogous experiments (e.g. Bergman *et al.* 2005), in this case the freezing of salt water. In the case of iron the solid is always dense compared to the liquid, however, for water ice the opposite is true.



1(a) *Schematic view of an iron snow regime in a planetary core. Iron crystals solidify in the liquid bulk close to the core-mantle boundary, and settle into the hotter and deeper part of the liquid core, where they melt.* (b) *The experimental setup is inverted, with a chilled interface at the base of a tank, producing crystals which detach and float up into the liquid and remelt.* (Ludo Huguet)

For this reason, Huguet's experiments are inverted, with a chilled interface at the base of a tank, producing crystals which detach and float up into the liquid and re-melt. The experiments take several days to run and require a fine control of temperature to balance the supercooling (12°C below freezing point) needed to overcome the nucleation barrier (Huguet *et al.* 2018) and form crystals against freezing the entire system. Perhaps most surprising, and important for planetary processes, is the episodic nature of freezing events where a period of intense nucleation and high solid fraction near the base of the tank is followed by relatively low activity. This is due to crystals forming and releasing latent heat on one part of the experiment before floating up and re-melting in a different area.

Andrew Walker (University of Oxford) followed next with 'A non-equilibrium model of slurries in planetary cores'. This talk addressed iron slurries close to the growing inner core of Earth and how we can learn from a theoretical model outside of thermodynamic equilibrium.

Slurry zones are domains in planetary cores with modest fractions of solids crystallising from stably stratified liquid. In the Earth, the F-layer (a region at the lowermost outer core, characterised by a reduction in compressional wave velocity) has been suggested to be a slurry layer (Wong *et al.* 2021). Here, the growth of particles in the F-layer is examined, without the requirement that they are in equilibrium. An Fe-FeO system is considered, with a thermodynamic model defining melting temperature, solid fraction and growth of particles. Classical nucleation theory defines the formation of new solids, and fluid dynamics informs the sinking of particles and the boundary layer with which they interact. Falling time and particle size are calculated, revealing that the dynamics of the system are most strongly controlled by the viscosity of the liquid and the diffusion rate of O (which slows particle growth with increasing composition). Using the solution from individual particles in a multi-particle case, falling velocity and nucleation rate define the vertical separation of particles. Continued development of this model will provide a description of conditions which can support slurry layers and the thermo-chemical effects that they might have on the evolving core.

Kathryn Dodds (University of Cambridge) presented 'Inwards core crystallisation: Insights from analogue experiments', which was the next of our experimental analogue studies focusing on iron snow. She investigates how fluid flow from sinking crystals might drive convection in small planets.

Studies of snow zones in planetary cores have shown how snows can provide power to geodynamo action (Davies & Pommier 2018). However, this does not translate efficiently to smaller bodies where pressure gradients are low. In these cases, inward crystallisation is expected, however, as crystals fall, they may not re-melt until deep in the liquid core, if at all, greatly reducing potential for compositional convection. This presents a conundrum for asteroids derived from small planetesimals which have palaeomagnetic records suggesting strong magnetic fields (Dodds *et al.* 2021).

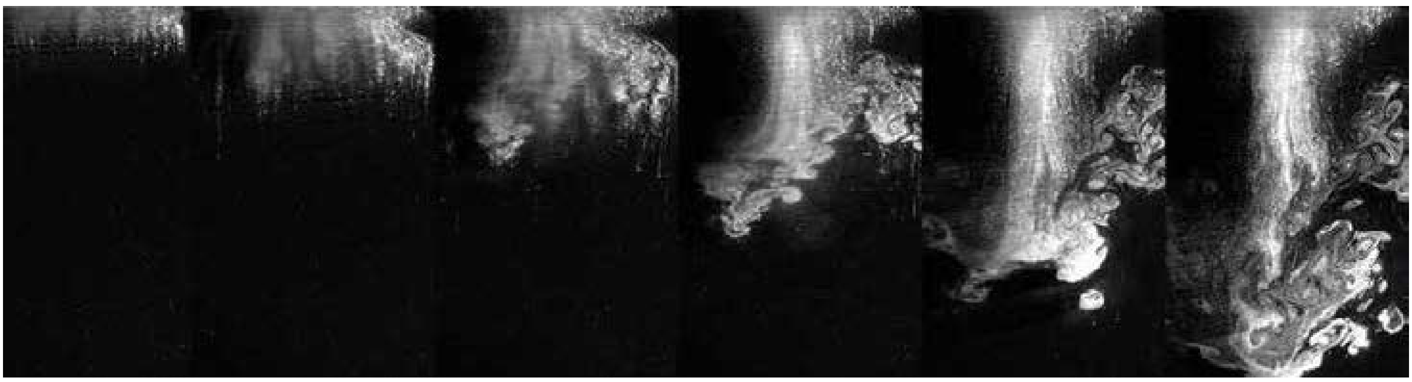
So how else can snow zones generate convection in small cores? Dodds performs experiments of super-eutectic NH_4Cl liquids, cooled (by a chill plate at the top of the experiment tank) to the point where they will spontaneously nucleate ammonium chloride crystals, which then sink into the remaining liquid and form a cumulate at the base of the tank. When a snow regime is entered, crystals form and entrain liquid as they sink, developing downwelling plumes. A test where crystals are not formed, but thermal convection remains, confirms that the crystals are driving greater flow velocities. In an asteroid or small planet, it is therefore reasonable that crystals might form in a layer at the top of the liquid core before detaching as plumes which help drive convection. An evaluation of the magnetic Reynolds number suggests that cores greater than 70km in radius might be able to generate a magnetic field via this process.

Quentin Kriaa (IRPHE) gave the final experimental talk of the morning; 'Compositional convection from iron snow: laboratory modelling with dissolving sugar'. Here, he also studies the overall fluid flow in the presence of dense sinking crystals but does so exclusively with compositional convection.

Thus far, we have considered either that falling snow melts and then drives compositional convection through dense liquids, or that sinking crystals can entrain flow and drive convection in doing so without re-melting. There is, of course, an important region between these extremes, where some of the crystals have remelted and are now sinking as dense liquids, and others (particularly large ones) continue to sink as solids (Kriaa *et al.* 2022).

Kriaa uses experiments to explore the influence of this regime and the effect on the dynamics of downwelling plumes. Dyed sugar crystals are dropped through a sieve into a laser illuminated tank of water with neutrally buoyant tracer markers (figure 2). Because they do not dissolve instantaneously, if a constant mass flux into the experiment is maintained, a steady state region is established where solids are sinking through the water column. As the downward flux of sugar begins, Rayleigh-Taylor instabilities organise the flow of particles into a single plume. Despite the difference in geometry and forces for a planetary core, one would expect the development of downward plumes which periodically exhaust the

"Data from the now-retired NASA InSight mission has found that the Martian core is both larger than previously thought and perhaps entirely molten"



2 *Sugar crystals (with rhodamine tracer) of mean initial radius 169 microns, sieved with an average mass rate of 0.57g/s, are dropped into water and dissolve to create a dense liquid. The dissolving sugar creates a coherent dense plume which exceeds the falling velocity of the remaining crystals in isolation. The particle size of the sugar defines the dynamics of suspension and entrainment in the system. The width of each snapshot is 16.5 cm and the time interval between snapshots is 3.24s.* (Quentin Kriaa) supply of new crystals at the top of the liquid core and are perhaps more efficient at driving convection than the dense liquids typically considered.

The morning session was concluded by Jac van Driel (UCL), presenting 'Composition of the Martian Core'. He uses a new class of multi-component equation of state, powered by density functional theory calculations, to decipher recent InSight data of the martian interior.

All talks in the morning session highlighted the important role that composition plays in defining the dynamic processes which are at play in planetary cores; despite this even for Earth's core, composition is poorly constrained. Data from the now-retired NASA InSight mission has found that the martian core is both larger than previously thought and perhaps entirely molten (Stähler *et al.* 2021).

Furthermore, inversion of the new findings gives estimates of the core density and seismic properties, allowing this study to estimate composition. Mars is smaller than Earth, meaning the pressures of its core are significantly lower and largely below the spin transition of iron. This means that whilst calculation of the Earth's core properties can negate the influence of spin states and magnetic entropy, it is imperative that these are considered for Mars.

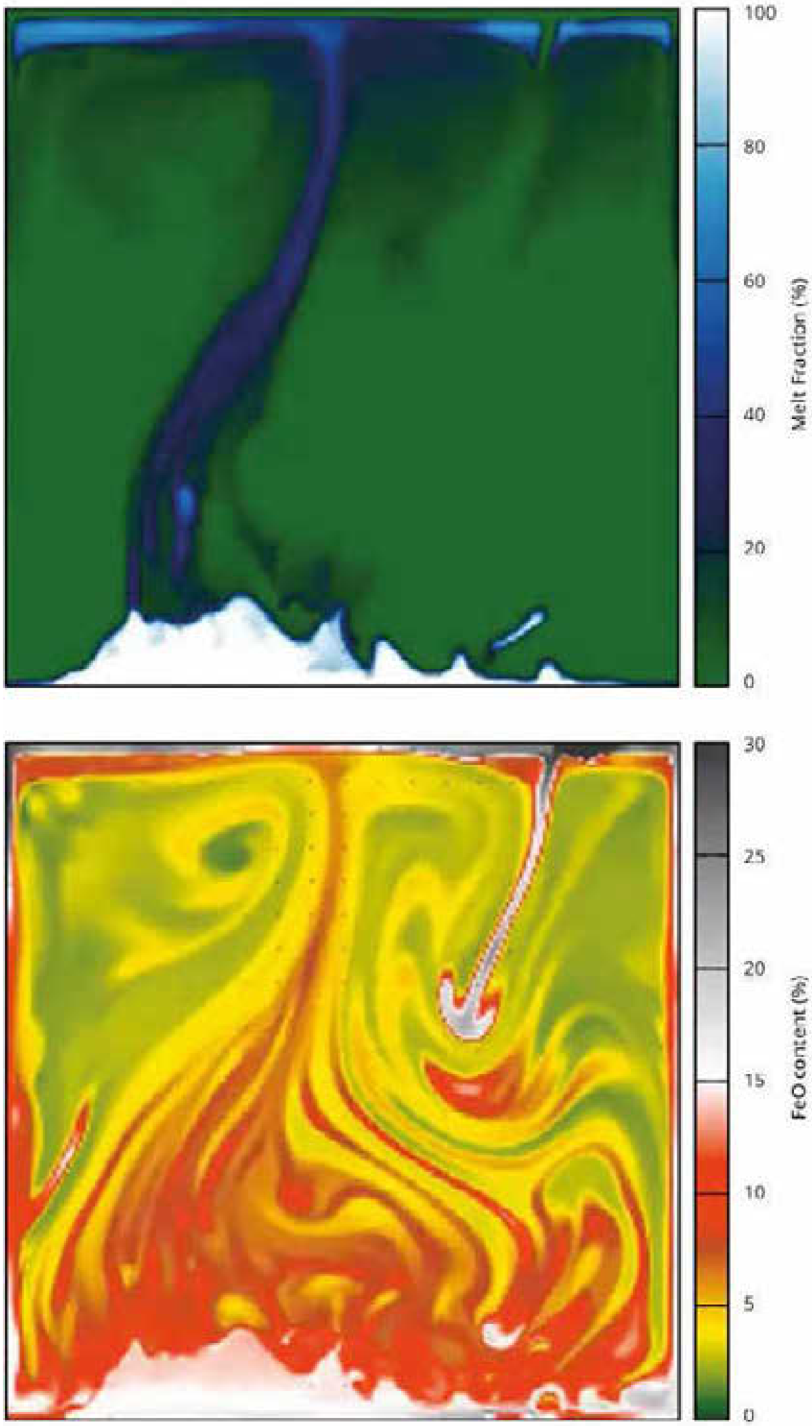
This study employs density functional theory calculations to calculate the free energy difference between different spin states of the materials being investigated. Once the thermodynamically favoured states are found, properties of individual compositions can be calculated and compared with experimental results. A gaussian regression approach allows the construction of self-consistent equations of state which can estimate the properties of untested compositions. The model finds that a core with 15 wt% S, 3.6 wt% O and 1 wt% H is most compatible with the inverted data.

Mantles and magma oceans

The afternoon session of talks on mantle and magma ocean processes began with an invited talk from Charles-Édouard Boukaré (IPGP) titled 'Beyond 1D magma ocean models'. He studies multiphase flow processes to understand how the Earth's early magma ocean evolved into the present day mantle.

The magma ocean is a widely accepted early state of Earth's silicate mantle, thought to arise from a giant impact, perhaps that which formed the Moon (Nakajima & Stevenson 2015). At high pressures, a non-linearity in the melting temperature of mantle silicates means that it is possible for the magma ocean to freeze from the middle outwards, potentially separating surface, and basal magma oceans (Labrosse *et al.* 2007). The dynamics of this process are not well understood as models will typically study only the 1D evolution of the liquid regime, or the 2D evolution of the solid regime, neither capturing this crucial time where both phases are present.

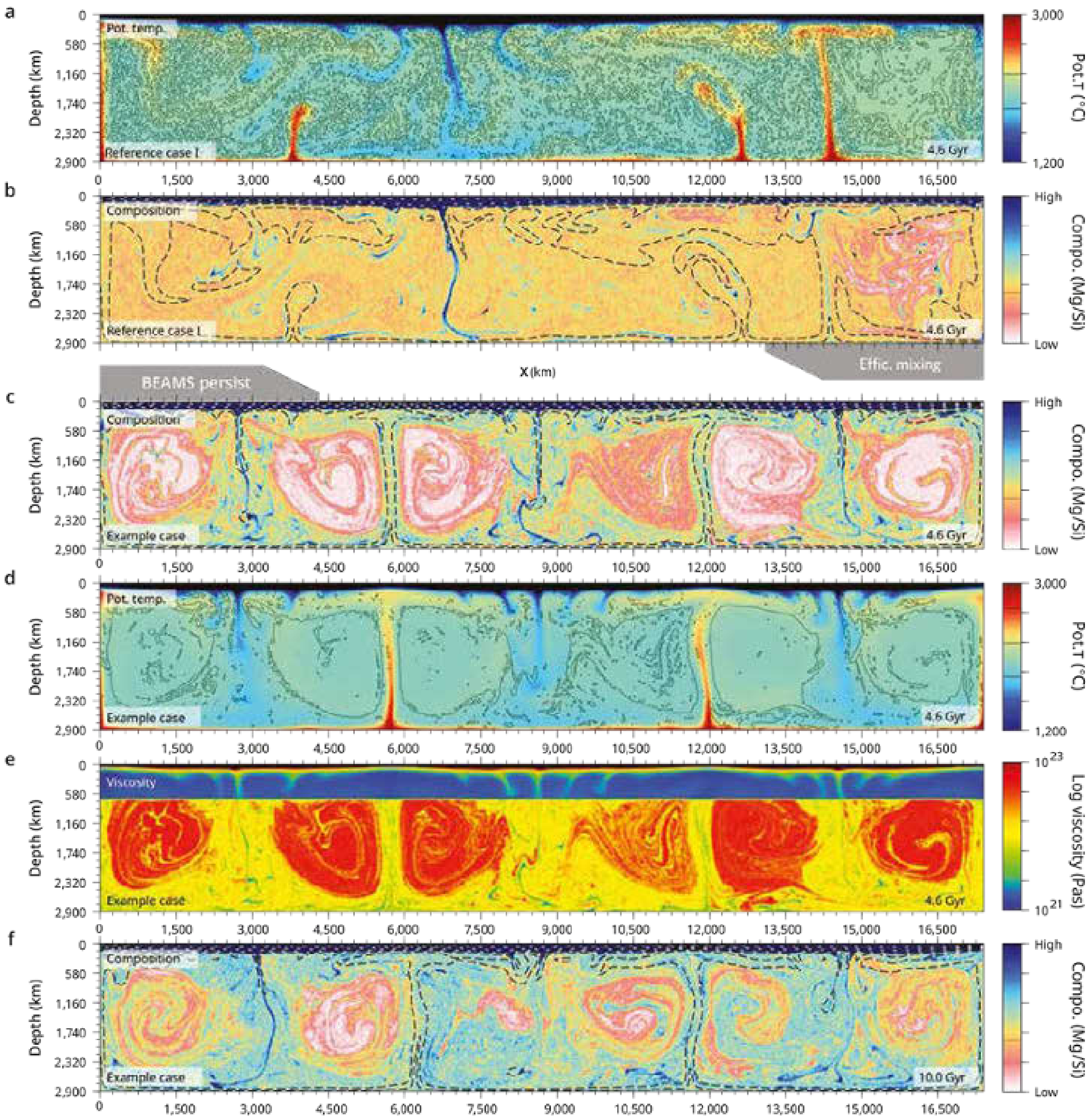
Boukaré uses multiphase physics to model 2D systems where convection is driven by thermal and chemical density contrasts as well as allowing crystals to grow and remelt (figure 3). The latter effect also introduces latent heat and chemical fractionation. The main finding is that the melt mobility in these models has a strong effect on the final state of the mantle. When melt mobility is low, the system remains well mixed with crystals and liquids entrained in the same flows. When mobility is high, liquids can be expelled from slurry layers and more strongly fractionate the magma ocean. At an extreme, this produces mantle stratification too strong to be mixed by convection, and structures that are incompatible with seismic observation of the deep Earth. In an intermediate case, a basal magma ocean is generated via fractionation, without the need for a mid-depth crystal barrier, and features similar to those observed atop the present day core mantle boundary can be preserved. In the future, constraints from geochemical tracers will be included to elucidate a range of plausible melt mobilities.



3 *A multiphase 2D convection model of Earth's mantle which includes both thermal and chemical convection alongside phase changes. The long term stability and growth of solid lower-mantle features depends primarily on the melt mobility of the system, which controls how a dense cumulate can expel trapped liquids. Features which share characteristics with seismically observed lower mantle features can be produced and destroyed by tuning this melt mobility.* (Charles-Édouard Boukaré)

Maxim Ballmer (UCL) followed with a complimentary talk: 'Reactive Crystallisation of the Basal Magma Ocean: Consequences for present-day mantle structure'.

The previous talk highlighted the importance of the evolving structure of the magma ocean on the subsequent features of the mantle. However, the evolution of the late stages of the magma ocean, where a basal magma ocean is present, can be



challenging to reconcile with the present-day structure and dynamics of the mantle. It has been suggested that stable features at the base of the mantle are derived from the fractional crystallisation of the basal magma ocean which enriches liquids, and therefore late stage solids, in iron (Labrosse *et al.* 2007). The issue is that when this is modelled, the effect is too great. Thick layers with extremely high densities are formed and would surely be observed today, but they are not. This work studies the ongoing interactions between the basal magma ocean and overlying young mantle. These interactions both promote freezing, through reactive crystallisation, and also reduce the density of the solids destined to be at the base of the modern mantle. If subducted from the planet's surface early crustal material is also able to interact with the basal magma ocean and a range of mantle features become possible. Lower mantle features become more reasonably dense and neutrally buoyant mid mantle structures can be generated (Ballmer *et al.* 2017; figure 4). If reactive crystallisation is a necessary part of Earth's thermochemical evolution, it could also explain properties of other planets. Venus has had large-scale resurfacing events, which might have exhausted its magma ocean, whilst the stagnant lid regime of the Martian crust might suggest a basal magma ocean is extant and very dense.

Helen Williams (University of Cambridge) then offered a logical progression from the previous two talks with 'Iron isotopes trace primordial magma ocean material in the Earth's upper mantle'. Williams asks if the preserved isotopic signatures of the rock record can describe the differentiation of the Earth's mantle.

The possibility of geochemical tracers for tracking differentiation of the magma ocean and mantle is an exciting prospect. Stable isotopes are often fractionated by processes in nature including in the deep Earth. Mantle plumes which reach the Earth's surface as hot spots deliver material from as deep as the core and give a glimpse into the deep interior as well as the past. Unfortunately, modern samples

4 *Predicted evolution of the mantle for two regimes of mixing. Results for a reference case (a, b) and an example case (c–f) show efficient mixing and persistence of large-scale heterogeneity, respectively. This difference in mantle-mixing efficiency between cases highlights the role of compositional rheology.* (Maxim Ballmer)

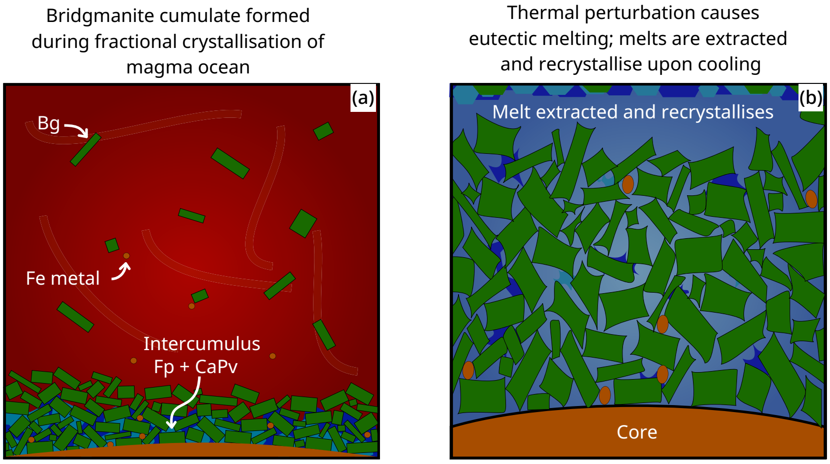
feature many signals that are challenging to untangle and so it is helpful to focus on ancient rocks when studying the differentiation of the Early mantle. The 3.5+ billion year old rocks of Canada and Greenland feature a variety of isotopic anomalies, one of which is elevated m182W and d57Fe (Williams *et al.* 2021). This signature indicates that the residual melts of a cooling magma ocean equilibrated at moderate pressure with high pressure, oxidised magnesium silicate. This reveals both that the mantle was likely to be oxidised 3.7 billion years ago and that the advection of crystals was active during the freezing of the magma ocean (figure 5). Whilst these high-pressure silicates are not expected to have melted when transported to the upper magma ocean, the lower pressures of smaller planets (e.g. Mars, Vesta and Mercury) would mean that they would melt, making the process impossible.

The final presentation of the meeting came from Hannah Rogers (Grenoble): 'Investigating regional heterogeneity at the core-mantle boundary and its impact on outer core flow'. Rogers uses satellite data of the Earth's magnetic field strength to understand how mantle structure may alter the field.

The Earth's geodynamo is generated by the churning of liquid iron in the outer core. The turbulent convection of the core makes this a process which has significant secular variation, with reversals, polar wander, and anomalous patches (Glatzmaier & Roberts 1995). Models of convection in the core suggest that the magnetic field should be far more complex than the largely dipolar field we observe at the surface. This means that the mantle, and potentially stratified layers at the outermost core, have a filtering effect on the field. Rogers uses the secular variation of the Earth's magnetic field, as recorded by the SWARM network of geomagnetism observing satellites, to understand how large structures in the lowermost mantle might provide lateral variation to this filtering effect. LLSVPs (large low-shear-velocity provinces), the origin of which is the focus of both Charles-Édouard and Maxim, are two continent sizes regions extending above the core mantle boundary around 1000km in height. Because they are thermally, and possibly chemically, distinct from the surrounding mantle, they could present different magnetic filtering qualities. Models which simply hope to capture the observed lateral variation in secular field strength are required to have different magnetic filtering qualities inside and outside of these regions. Additionally, whilst results are still emerging, there seems to be a significant correlation between these regions and periods of rapid magnetic field change.

Conclusions

The meeting offered a most welcome coming together of colleagues who had scarce opportunity to do so in the prior two-and-a-half years. The quality of presentations and surrounding discussion was outstanding, and many remarked on how satisfying it was to discuss our common interests in person. The talks only reinforced how important, diverse, and challenging the interactions of solids and liquids are for the evolution of planets. With more focus than ever on experimental analogues, nuanced simulations of two-phase systems and the observable outcomes from these interactions, the field is advancing at tremendous pace. ●



5 *Schematic demonstration of how the mantle component sampled by Isua basalts may have been formed.* **(a)** *the formation of the initial bridgmanite (Bg) cumulate with a small amount of interstitial calcium perovskite (CaPv) and ferropericlase (Fp).* **(b)** *the chemical effects after a eutectic melt is extracted from the cumulate before recrystallising as a new assemblage in the lower mantle.* (Helen Williams)

"Modern samples are challenging to untangle so we focus on ancient rocks when studying the differentiation of the Early mantle"

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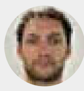
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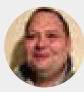
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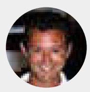
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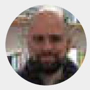
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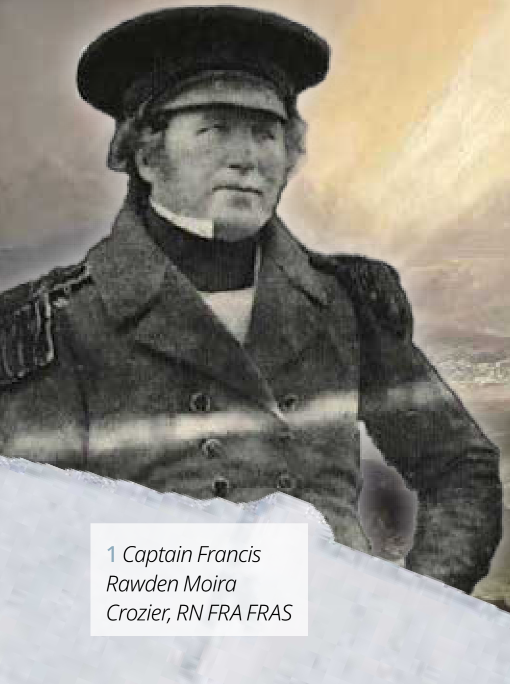
Cold and calculating

Angus Wardlaw writes about his ancestor, the explorer and sailor Francis Crozier, lost on Franklin's 1845 expedition in search of the Northwest Passage



1 *Captain Francis Rawden Moira Crozier, RN FRA FRAS*

2 *'Erebus and Terror in the Antarctic', by James Wilson Carmichael, 1847*

Francis Rawden Moira Crozier, born 1796 in Banbridge, Ireland, was a remarkable Fellow of the Royal Astronomical Society, whose last appointment was as second-in-command of the 1845 expedition led by Sir John Franklin to find a direct link from the UK to the Far East via the top of the world: a Northwest Passage.

The Northwest Passage had long been a goal of polar explorers. Back in 1821, as a 25-year-old midshipman, Crozier had become a protege of the legendary Sir Edward Parry during his second expedition to find a route westwards through the ice-choked seas of the Arctic Circle. Doubtless, Parry would have relied on juniors like Crozier to do much of the painstaking legwork for the expedition's many scientific tasks: cutting their teeth on precise magnetical, meteorological, or tidal readings, and trudging out on to the tundra for days on end so that they could listen for any sounds that the aurora borealis might emit.

Crozier's dedication was demonstrated one day when he failed to return to the ship after a terrible squall blew up. A search party, led by a promising young officer called James Clark Ross, was sent out in search of him. Ross eventually found his shipmate sitting cross-legged on a snow- and wind-strafed rock recording tidal variations. Crozier looked up at the relieved faces of his rescuers, only to send them away again so that he could continue his work. Here then was the start of a brotherhood and mutual admiration between Crozier and Ross that would endure for the rest of their lives.

These two tough, but very different, characters must have impressed Admiral Sir Edward Parry enough to land them places on his next two polar expeditions in 1824 and 1827. One of these was Parry's attempt to reach the North Pole. Instead of being part of the glorious final foray across the ice, Crozier remained onboard HMS *Hecla* to carry on with his astronomical and magnetical observations. Ultimately, Parry failed to reach the North Pole but his farthest north record, at 82° 45′ N, wouldn't be beaten for another 50 years (when the redoubtable AH Markham would trudge past by a geographical whisker of 17.25 miles). Crozier's contributions to astronomy and magnetism during his three expeditions under Parry were greatly appreciated by the RAS who elected him a Fellow in 1827.

> *"Crozier's contributions to astronomy and magnetism were greatly appreciated by the RAS who elected him a Fellow in 1827"*

Stars in their ascendency

At this time in the 19th century, just as Crozier and Ross were becoming arctic legends in their own lifetime – Ross had personally planted his Union Jack at the North Magnetic Pole in 1831 – but then there followed something of a moratorium in polar exploration. Queen Victoria's Navy were redeploying ships to the wars that were raging around Europe and Crozier found himself patrolling the coasts of Spain and Portugal.

In 1834, relief came when his old friend Ross, needed a second-in-command on a perilous mission to come to the aid of an 11-strong fleet of whalers that were lost in the great ice floes of Baffin Bay. All but one of the whalers eventually made it home safely, by which time James Ross at least, had caught the beady eye of Sir John Barrow.

Barrow was a powerful player in the politics of polar exploration; this cunning mandarin of stellar talents had seen in the swashbuckling Ross a hot ticket for helping him achieve what he hoped would be his own great legacy: Sir John Barrow, the great administrator who extended the influence of the

3 *Commander James Clark Ross: "The Handsomest Man in the Navy." By Wildman, John R. (1785)*

British Empire through knowledge and discovery. He could see that Ross and Crozier in combination were formidable: Crozier's gruff, stoic dedication to detail sat well alongside the somewhat racy glamour of Ross, the Royal Navy's ideal poster boy for exploration. Theirs was a rare polar double-act that would go on to produce what was arguably one of the most astonishing achievements since the Age of Navigation: the Ross Antarctic expedition of 1839.

What Ross and Crozier would achieve in their four-year circumnavigation of Antarctica in the Royal Navy's sturdiest bomb ships, HMS *Erebus* and HMS *Terror,* would change the understanding of our planet forever. Thousands of miles of coastline was added to maps and the first definitive charts on magnetic declination, dip and intensity were drawn as they established observatories at St. Helena, Cape Town and Hobart. The expedition's other achievements were equally impressive: the founding of a new branch of science called glaciology; the discovery of Victoria Land, the Ross Sea, the Great Ice Barrier (the Ross Ice Shelf as it is known today); the Transantarctic Mountains, and the presence of two volcanoes (which they named after their beloved ships). Throughout all of this, their young botanist, Joseph Hooker, just 22 at the start of the expedition, was able to produce six illustrated volumes bursting with descriptions of over 3000 new species. And, while refitting in the Falklands, Crozier surveyed a new, more suitable staging post for ships girding their loins or licking their wounds before or after negotiating the fearful Magellan Straits. It was Crozier's recommendation to move the capital from Port Louis, as it then was, to an inconveniently rain-lashed slope that had the advantage of a deeper harbour; what we now know as Port Stanley. In short, the Ross expedition was a glittering success. It would also have the distinction of marking the end of discovery expeditions performed entirely under sail.

Icebergs, love and other near misses

Another port of call that had proved crucial to the Ross expedition was Hobarton: the capital of Van Diemen's Land (as Tasmania was then known). The lieutenant governor of this torrid penal colony was an affable, middle-aged commodore called Sir John Franklin. His Excellency and Jane, his tireless wife, had been posted there after what had become something of a poor career record. During his Coppermine Expedition overland from Hudson Bay, Canada (1819–22), not only did Franklin stumble over an icy waterfall and into the river, he later managed to lose 11 of his 20 men to starvation as a result of logistical difficulties. British society, typically choosing to hide their embarrassment, laughed off Franklin's antics by referring to him as "the man who ate his boots", although he did get a knighthood for his troubles.

The spectacle of the famously glamorous Ross and his impressive exploration vessels dropping their anchors in their harbour brought a much-needed frisson to the Franklins' lives, so much so that they used Ross and his discovery squadron as the perfect excuse to throw parties. Crozier even allowed himself to fall in love with the Franklins' niece but alas, the charming but slick young lady only had eyes for the far more dashing (and already betrothed) Ross.

In advance of their arrival, the Admiralty had requisitioned Sir John to facilitate preparations for the construction of Ross's next observatory, so that work could begin as soon as his ships touched at Hobarton. Franklin approached the project with a touching eagerness by conscripting 200 convicts as well as procuring the necessary building materials – he even went as far as suggesting four possible locations, all of which were rejected by Ross. Eventually, it was down to Crozier to install his tricky, sensitive instruments (as well as his hammock) in an observatory christened 'Rossbank' by Lady Franklin (as she preferred to be addressed).

But it wasn't all parties and plain sailing for the Ross expedition. After leaving Antarctica for the Falkland Islands, *Erebus* and *Terror* had been caught in a tempest so fierce that it broke up the ice pack and sent colossal icebergs cavorting about the Southern Ocean. Tossing around in the pitch-black seas, one such beast, which was reckoned to be the size of a cathedral, loomed out of nowhere in the path of *Erebus*. Ross, a brilliant sailor with superb instincts, could only turn away sharply – but moved straight into the side of *Terror* which had every stitch of sail out and was on a decent run under Crozier's hand. The appalling crunch of *Erebus*'s bowsprit, entire foretop and half a dozen spars left the two ships snagged in a deadly game of seesaw as the massive swell rose and fell between them. At one point, *Terror* was tossed up so high that the crew of *Erebus* could only watch her triple-plated keel looming above them. At that moment, with miraculous timing, the rigging of the two ships untangled so that *Terror* could bear away. Now it was Crozier's turn to dice with the colossal hulk of ice now before him, threatening to smash the two ships to pieces. As soon as *Terror*'s catheads slammed down into the seething water, Crozier swung towards a dark fissure he had spotted in the middle of the iceberg. Could it possibly be a gap? Was the iceberg breaking up?

On Crozier's crisp orders, the men flew to the lines as he steered *Terror* through the impossibly narrow gap. Not in their wildest dreams would most skippers dare to guide a fully laden 325-ton warship with a beam of 27 feet into such a dire strait. With the sheer white cliffs rising above them for at least 200 feet on either side, the men could do nothing but hold their breath. One seaman, in a fit of horror, was only just caught by another matelot as he attempted to leap over the taffrail. Throughout all the mayhem, Crozier was observed to be serenely composed as he issued his perfectly measured commands. Once clear, he immediately ordered blue lights to be lit as a beacon for *Erebus* to follow them through. Afterwards, when asked about his actions throughout their ordeal, Crozier confessed that he couldn't recall much about the incident, either from the adrenaline that must have been pumping through his veins, or just out of old-fashioned modesty.

New partnerships, old challenges

On their return, Ross was the toast of England and nobody was impressed more than Barrow, now Second Secretary to the Admiralty. So much so that what the old man now saw in Ross was the opportunity to achieve his obsession and his swansong: the Northwest Passage. But by the time Ross returned to England, both he and Crozier were very likely to have been suffering from what we would now call Post Traumatic Stress Disorder: they were spent. Those who knew Ross were shocked to see that his hair was no longer shiny, lustrous or raven but had rather turned a fluffy white. Doubtless, the same would have happened to Crozier's hair if he'd had any left and both of the men's hands shook uncontrollably as they swigged from what were probably far too many flasks of whisky. The weight of responsibility of doing their all for their ships and their souls in the treacherous Southern Ocean had evidently taken its toll.

The search for the Northwest Passage had famously defeated the cream of Royal Navy: from Frobisher to Raleigh, Cook, Nelson, Parry… Ross let Barrow down with the excuse – more palatable perhaps for a naval hero – that his new wife was carrying his first child. Then, Barrow did an extraordinary thing: rather than approach Crozier, the next-most qualified man for the job, he suggested to the Board that he had found the perfect leader in the form of Commander James Fitzjames.

Fitzjames was a charming and well-respected gunnery officer but his closest encounter with the polar regions had been Shanghai and his only sea command was an uneventful cruise around the Persian Gulf. Historians have revealed that Fitzjames had been involved in saving Barrow's son from some sort of scandalous indiscretion in Singapore and that Barrow senior had, at best, felt that he had owed the young buck a favour. At worst, and a more sinister notion, was that a perilous mission in the Arctic was just the ticket to ensure that any dirt on his son would sink to the bottom of an ice-choked sea.

In all events, the Admiralty Board had ideas of their own. They had a chap in mind whom they now wanted to see shine at least once during his lengthy career. Sir John Franklin was now aged 59, overweight and not in the greatest of health; he was a very unlikely prospect indeed but perhaps, with a solid, capable man supporting him, it was a gamble that the Board were willing to take. At the very least, it would get Lady Franklin off their backs with her constant lobbying on behalf of her husband.

Crozier, like Ross, had been all in. But, perhaps on the tacit understanding that Franklin's niece could be persuaded into a union with him on his successful return, he raised his quivering, nail-bitten hand and volunteered. By this time, so much groundwork for the charting of the Northwest Passage had been done by so many intrepid explorers that the pen-pushers in Whitehall could have imagined that its completion was now mere formality: ink-in the last inch or so missing from their charts and prove the existence of the fabled route.

At this time, it must be remembered that the Suez and Panama Canals were nothing more than pipe dreams. As far as England was concerned,

The Magnetic Crusade

In the 19th century, measurement of the Earth's magnetic field was the goal of the British Magnetic Scheme, sometimes called the magnetic crusade, an early example of big science. In 1838, a group of powerful scientists – including astronomer and polymath John Herschel, lobbied the British government to add surveys of the Earth's magnetic phenomena to the voyages of exploration being undertake by the Royal Navy. Other European powers, notably Germany, were already developing international magnetic records. James Clark Ross's Antarctic expedition (1839–43), tested equipment and techniques for the British campaign. Crozier's work was essential to the success of the survey, both in his diligence in taking readings at sea and in establishing new magnetic observatories on land, in Saint Helena, Cape Town, now South Africa, and Hobart, Australia.

The magnetic field is close to horizontal over much of the Earth's surface. Its orientation was noted in terms of its declination, the difference between magnetic and geographic north (determined from the stars). Near the poles, the field is not horizontal; the inclination – the vertical angle of the field vector below horizontal – is measured with a 'dipping needle', a magnetised bar able to pivot in a vertical plane. And the intensity of the field was measured at this time by deflecting the needle and adding weights to return it to the original position (a method set out in John Herschel's *Manual of scientific enquiry*, 1849). None of these measurements are easy to carry out reliably on board ship. One of the goals of the British Magnetic Scheme was to use standardised instruments wherever data was collected. On the 1839 expedition, Crozier and Ross used a dipping needle made by Cornish instrument maker Robert Were Fox, which was later adopted by the Scheme. The extreme inclinations recorded during the Antarctic expedition allowed Ross to locate the south magnetic pole.

"Not in their wildest dreams would most skippers dare to guide a fully laden 325-ton warship with a beam of 27 feet into such a dire strait"

the far more achievable pursuit would be to find and claim the Northwest Passage: a notional White Silk Road that could be reserved on behalf of the British Empire and her interests in the Far East. Not only would the passage give England a huge commercial advantage, but it would avoid the loss of the many ships that the perilous Capes of Good Hope and Horn could be depended upon to take each year. With the best ships and equipment, and the right officers in support, Sir John Franklin would be the perfect name to attach to the final conquest of the Northwest Passage.

In order to achieve the Board's subsequent 23-part instructions, Franklin was handed control of the two greatest discovery ships in the world. Newly modified and further reinforced, *Erebus* and *Terror* were now bristling with the most advanced technology of the day – innovations such as retractable screw propulsion (via George Stephenson's Planet-class steam engines), desalinators, removable rudders and 6000-volume libraries, including signed copies of the novels of Charles Dickens. Even Franklin's provisions were state-of-the art with 13 tons of patented cans of delights such as ox tongue and cheeks in gravy and mock turtle soup (using a recipe favoured by Lady Franklin). So white-hot was the technology of their tinned goodies, that it would be another 10 years before something more elegant than a hammer and chisel would be invented for opening the tins.

In short, the Sir John Franklin expedition of 1845, with its two indestructible ships filled with technology, provisions and hand-picked men, was the Victorian equivalent of a manned mission to Mars. *Terror*, the bomb ship that had become so closely associated with Francis Crozier over the years, was aptly named. At the Battle of Baltimore, she had inflicted so much damage during the bombardment of Fort McHenry that one eyewitness was moved to pen an anthem which he eventually called 'Star Spangled Banner'.

During *Terror*'s illustrious career she would be nearly wrecked twice but no one had ever handled this tricky ship better than Crozier. He had taken her to the top of the world…as well as the bottom of it. She had been the spouse he never had and the home and family he must have longed for since he was a child. *Erebus*, which had meant the same to Ross, was the bigger, newer and better of the two bomb ships and would now be Franklin's flagship.

So it was then, that on 19 May 1845, the Sir John Franklin expedition set off on a Thames that was thick with a flotilla of well-wishers while the banks of the great river rippled with flag waving Victorians. After stopping off at the Isles of Sheppey, Stromness and Disko, Sir John's two ships and his 129 men were spotted by a whaler as they entered Baffin Bay's gates to the Passage at Lancaster Sound. It was the last time any Europeans would see them alive.

"Sir John's two ships and his 129 men were spotted by a whaler as they entered Baffin Bay's gates to the Passage at Lancaster Sound. It was the last time any Europeans would see them alive. "

The great race north

Two years later, with no word back from the expedition and reports from whalers of uncommonly severe winters, Crozier's oldest friend, Ross, could sit on his hands no longer. From Blackwall Docks in London, he refitted and provisioned two ships: HMS *Investigator* and HMS *Endeavour,* in record time and followed Sir John into Lancaster Sound – only to return a year later with most of his own people sick and broken by the appalling conditions they had endured.

The first significant news of Franklin's fate wouldn't come for another ten years when a snow-shoeing stalwart, Dr John Rae, filed an earth-shattering report of what he had found in the Arctic in 1854. This tough, resourceful Orcadian, who lived off the land and had adopted the ways of the native people of the Arctic, had incontrovertible evidence of what was to be one of the Royal Navy's greatest disasters. Part of Rae's subsequent report made for grim reading indeed: "From the mutilated state of many of the bodies and the contents of the kettles, it is evident that our wretched countrymen had been driven to the last dread alternative – cannibalism – as a means of prolonging existence."

The British Establishment responded by shooting the messenger. Rae's news ignited such public outrage that even Lady Franklin's great friend, Charles Dickens waded in with a racist tirade that dismissed Rae's testimony as "the lies of savages". He even went on to accuse the native people to whom Rae had spoken of cannibalising Franklin and his men.

The truth, according to Rae's gathering of Inuit testimony, was that a group of them had met with 30 to 40 starving *kabloonat* (white men) struggling across the ice at Washington Bay. These poor souls were led by a man whom they said was already familiar to them called *Aglooka*. Historians now believe that Aglooka was Captain Crozier. Though starving themselves, these 'savages' (as Dickens would have them be known) handed the sailors all they had: a small fur seal. Probably in fear of their own lives and knowing what armed and desperate men are capable of, the Inuit left the starving sailors as soon as they could.

Some 14 years after Franklin's ships had swung north out of the Thames Estuary, William Hobson, a young search party leader from the McClintock expedition, found a note buried in a pile of stones on an island the same size as Northern Ireland. It was laconic, to say the least:

"25th April 1848 HMShips Terror *and* Erebus *were deserted on the 22nd April 5 leagues NNW of this having been beset since*

12th Sept 1846. The officers and crews consisting of 105 souls under the command of Captain F. R. M. Crozier landed here—in Lat. 69°37′42″ Long. 98°41′ This paper was found by Lt. Irving under the cairn supposed to have been built by Sir James Ross in 1831—4 miles to the Northward—where it had been deposited by the late Commander Gore in May 1847. Sir James Ross' pillar has not however been found and the paper has been transferred to this position which is that in which Sir J. Ross' pillar was erected—Sir John Franklin died on the 11th of June 1847 and the total loss by deaths in the Expedition has been to this date 9 officers and 15 men.— James Fitzjames Captain HMS Erebus F. R. M. Crozier Captain & Senior Offr And start on tomorrow 26th for Backs Fish River."

Over the years, this rust-stained scrap of paper, now known as the Victory Point note, has been the only solid evidence about the fate of the Franklin expedition that thousands of historians, amateur detectives, professional detectives, explorers and scientists have had to go on. Most assumed that the two ships, having become beset in the ice and then 'deserted', would have been crushed into matchsticks 26 miles off King William Island before being sprinkled over the seabed 600 feet below. Over the following 170 years or so searchers contented themselves with scant bone fragments and naval bric-a-brac found scattered along the western shores of King William Island with each thaw.

Terror revisited

But in 2014, something incredible happened: *Erebus* was found, readily accessible in just 17 metres of water and in a condition that was beyond everyone's wildest dreams. Most of her deck's planking had been removed by years of storms and growling ice, but she was clearly definable. If the story had ended there, it would have been a jaw-dropping result. But then, two years later, like some sort of cruel, tasteless joke, HMS *Terror* was found in Terror Bay.

The expense and effort of all her reinforcement and over-engineering had evidently paid off: though 13 years her elder, *Terror* was in even better shape than *Erebus*. Since the two ships had been found, Parks Canada have explored *Terror* and *Erebus*, with breathtaking results. The cameras of their underwater drones have revealed a snapshot of Victorian life aboard a warship preserved in an aspic of seawater and silt: shotguns still on their racks, willow-pattern plates seemingly drying on shelves.

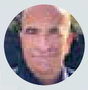
But then, perhaps leaving the most exciting discovery till last, the new Canadian owners of HMS *Terror* managed to manoeuvre their remotely operated vehicle's cameras into Crozier's Great Cabin. There, through the soup of phytoplankton, is Crozier's writing bureau – standing like a mahogany catafalque in the middle of a tomb. And what viewer can't help but contemplate its dark drawers, assuming, hoping, that Crozier would have interred the anatomy of a tragedy so that the latest in a long, long line of searchers can finally find the answers from the charts, logs and diaries of a doomed enterprise.

Then, the camera hovers, and perhaps echoing its pilot's excitement it moves towards something else: Crozier's inner sanctum – his last bastion: his bunk… door closed tightly… as if to keep the cold out in preparation for his return. But there, the mysteries will have to remain just until the barrier of silt that has done so much to preserve everything has been painstakingly removed by the new guardians of this ghostly vessel. Until this happens, we will all just have to read up from some of the many excellent text-books and novels that can only imagine the dreadful privations that Sir John and his poor men must have endured.

Written out of history?

And finally, it is interesting to note that Sir John Barrow, in the opening pages of his last book, *Voyages of Discovery and Research Within the Arctic Regions From the year 1818 to the Present Time* (1846) painstakingly listed Franklin's officers. In his list, Barrow promoted Sir John and all of the senior officers of *Erebus*. He also made the unprecedented point of singling out Commander Fitzjames with praise worthy of a favoured son – even referring to him as a "universal favourite in the navy". As for the officers and crew of HMS *Terror,* their ranks remained utterly unchanged. And, just to make it absolutely clear that this was some sort of snub, he referred to Franklin's second in command, the Captain of *Terror,* as Captain *Richard* Crozier. ●

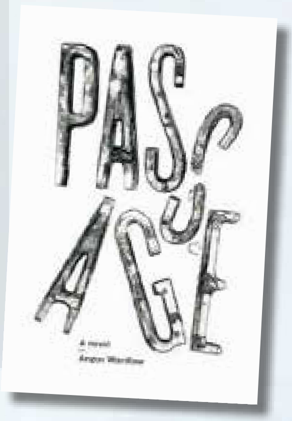
AUTHOR



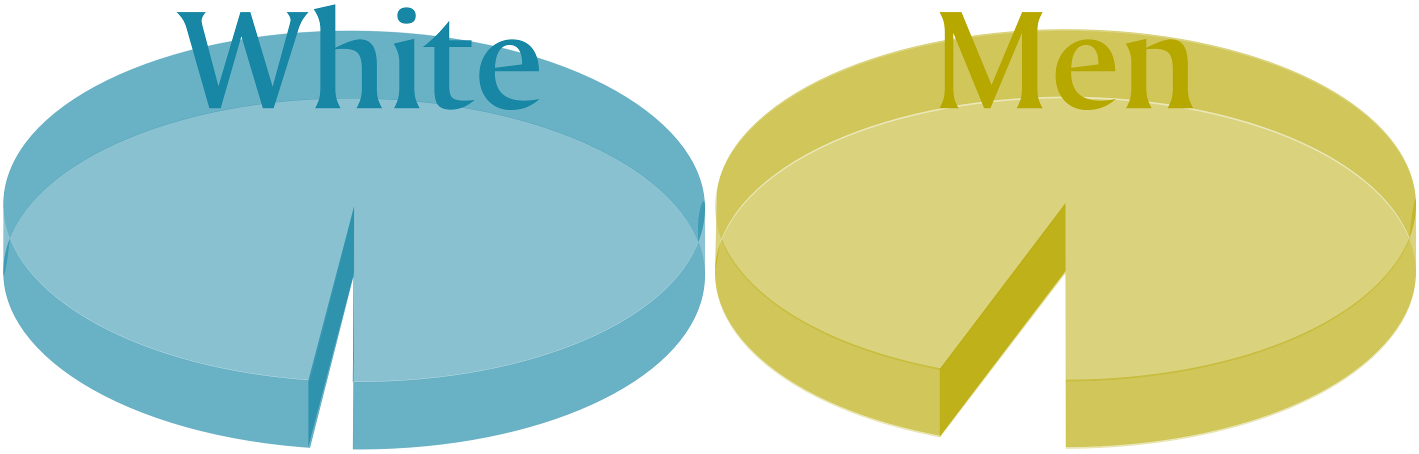
Angus Wardlaw, debut novelist and descendent of Crozier. *Passage* is published by Daredevil Books.

FURTHER READING:

Edward J Gillin has written about the *Magnetic Crusade in An Empire of Magnetism* (Oxford University Press, Oxford, 2023) and about the challenges of replicating the measurements with an original Fox dipping needle on a modern voyage in *Notes and Records: the Royal Society Journal of the History of Science* 76(3) 2022



And the award goes to...



Well, that's what the data says. Jasmine K Sandhu sifts the facts and identifies some glaring (and some rather less glaring) issues to address regarding diversity and inclusion in scientific awards.

In 2021 I was elected as an RAS councillor and have enjoyed contributing to the society's work on diversity and inclusion as part of the Committee on Diversity in Astronomy and Geophysics (CDAG). One area that I am particularly interested in is increasing inclusion in the scientific awards process. CDAG is driven by the long-standing and severe inequity across demographic identities, including gender, ethnicity, disability and LGBTQ+ identities present in the UK astronomy and geophysics community. Reports show under-representation across the community, with those from minority groups at higher risk of experiencing hostile environments and barriers in career progression (e.g. Massey *et al.* 2017, Rollock 2019, RAS Bullying and Harassment Survey). This exclusion and stark lack of diversity permeates our community, including science awards and prizes.

One prime example is Dame Jocelyn Bell-Burnell, with her ground-breaking discovery of pulsars in 1967. Although her work has deservedly received commendation (e.g. 2021 RAS Gold Medal), most controversially, Bell-Burnell was omitted for the 1974 Nobel Prize in Physics for her work, with the prize instead being awarded to her colleagues (Tesh & Wade, 2017). This is a particularly well-known example, but it is far from unique. Quantitative assessments show entrenched disparities in scientific prize recipients across awarding bodies, both nationally and internationally. Bell-Burnell, when eventually president of the RAS, addressed the issue (Bell-Burnell 2004) noting that it took the Society 167 years to award another medal to a woman after Caroline Herschel won the Gold Medal in 1828. An audit by Wade (2020) on previous RAS award winners estimated that only 6% of award winners were women, and that an overwhelming 98% of award winners were white. The records estimated zero winners who were non-binary, and zero Black winners. This is not a historical issue – the Institute of Physics reported that 8% of their 2022 award winners are from a minority ethnic background, well below the 19% of UK academic physics staff (tinyurl.com/kvdxpuzy).

It is clear that the awards process is not representative of our scientific community, and does not equitably celebrate success and achievements across astronomy and geophysics. People from all backgrounds and identities should be recognised and celebrated for their accomplishments. This clearly calls for an assessment at all stages of the process. However, panels can only select from those that are nominated, so a major step in an equitable awards process is at the nomination stage, and relies on the community nominating deserving members of the community. A lack of diversity exists at this early stage.

Analysis by the European Geophysical Union shows that the proportion of nominations for women compared to men falls significantly below the community membership, such that women are less likely to be nominated by their peers (EGU, 2022). This disparity increases with the career stage of nominees. There are a multitude of reasons why those from underrepresented demographics are less likely to be nominated. Our own biases mean that we are more likely to associate success with harmful, restrictive stereotypes and we can overlook colleagues who do not fit this, or that we are biased to favour those with a similar demographic profile to our own (Lincoln *et al.* 2012, Storage *et al.* 2020). The use of traditional markers of success (such as the H-index, citations, or number of publications) can exacerbate this exclusion, where these demonstrably biased metrics cannot always capture the quality or transformative impact of research outputs (Caplar *et al.* 2017, Davies *et al.* 2021).

Teachings from a taskforce

Over the past few years, I have been a member of a community initiative targeted at improving diversity in nominations. The MIST Awards Taskforce (Walach *et al.* 2021) was formed in 2019, and comprises a small group of scientists in the UK MIST (Magnetospheric, Ionospheric, and Solar-Terrestrial) community, that is formally affiliated with the RAS and a subset of the RAS Geophysics community. Our taskforce has three aims: to actively contribute towards more equal representation and diverse range of MIST nominees for national and international awards; to recognise and promote the work of overlooked members of the MIST community; and to provide a means for students and early-career researchers to gain experience in preparing an effective nomination package. The taskforce continues to evolve and grow, and we are proud of the number of successful nominations

Above: *An audit by Dr Jess Wade on previous RAS award winners found that 6% of award winners were women, and 98% of award winners were white. Zero winners were non-binary, and zero were Black.*

"It is clear that the awards process is not representative of our scientific community, and does not equitably celebrate success and achievements across astronomy and geophysics"

it has submitted and supported. Since joining the Taskforce, I have learnt a few lessons along the way:

- **The majority of awards processes, including those of the RAS, welcome nominations from anybody in the community at any career stage.** The diversity of career stages from PhD students to professors in the taskforce has been invaluable at allowing us to better identify deserving colleagues. It has also been a great opportunity to be mentored by those with more experience and has vastly increased my skill set – now I am confident in writing successful award nominations, as well as writing grant proposals and job applications.
- **It is essential to dive deep into a nominee's achievements.** It is often these less obvious achievements that help a nomination stand out from the crowd. Mention the public engagement, EDI, teaching, or community work that they are involved in. I love this graphic from UKRI which illustrates all the 'invisible' achievements that can be highlighted in an award nomination.
- **Get in touch with close colleagues of the nominee to see if they are able to support the nomination.** They will have a good sense of all the nominees achievements and latest work that may not be included on potentially outdated CVs. Even better, you might want to consider getting in touch with the nominee directly and let them know you are preparing a nomination for them. In my experience, nominees are honoured to be nominated regardless of the outcome, and the quality of the submission undoubtedly benefits from the nominee's input. Be careful to check the award criteria first though, as some awards (e.g. those from the RAS) mandate that nominees must not be notified.
- **Be critical of your own work.** Evaluate how the language you use could be coded, make sure you identify what your nominee's pronouns are and be consistent with them throughout the nomination statement. You can use gender bias calculator tools, and I recommend the excellent guide by Burrell *et al.* (2023) to reducing bias in your nomination statements.

Being part of the MIST Taskforce has been incredibly rewarding and is an avenue for me to contribute to real change in the community. This is just one example of nomination work within the RAS community – it's also important to recognise that the RAS community has numerous individuals with vast nomination experiences and skill sets, who actively promote their colleagues. I hope that my thoughts here encourage conversations with your colleagues and perhaps encourage some to make their first award nomination!

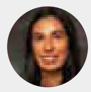
Although diversity in nominations can lead to diversity in award winners, the nomination process is one step in the system, and equity in how excellence is recognised is shaped by a multitude of factors. For example, what medals and prizes are being awarded, who selects winners from the pool of nominations, and how that selection takes place. Promisingly, recent years have seen conscious changes being implemented across awarding bodies. The Institute of Physics recently simplified its process to reduce barriers to nomination (e.g., self-nominations are allowed and referee letters are no longer included in the nomination package).

The Royal Society of Chemistry commissioned an independent review of its awards process resulting in a number of recommendations (RSC, 2020). The review highlighted that awards typically fail to recognise the role of collaborative work and calls for more awards to allow team nominations. Furthermore, it recommended that award portfolios should also better recognise the wider activities of researchers, such as work in public engagement and mentoring.

Most relevant here, the Royal Astronomical Society conducted a review of its awards process. Building a better awards process relies on accurate data collection to identify where biases exist in the system. This is an active area of ongoing work by the RAS, to improve what data is collected and increase collection where possible. The system is evolving and there is a community effort to drive and push for change in the right direction. So play your part in that community, keep nominating and keep the conversation going! ●

Left: *Visible versus invisible skills and experience*

AUTHOR



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Star Formation in the Milky Way and Beyond in the Era of JWST and ALMA

Star formation is much studied, but not thoroughly understood. However, a new generation of instrumentation promises an explosion of delicious data. Kate Pattle and Derek Ward-Thompson report.

Although the process of star formation has been studied for decades, many important aspects of the astrophysics involved remain unclear. The last decade has provided a wealth of information on the dynamics, kinematics and magnetic fields of molecular gas and dust on all size scales, from the detailed physics of individual star-forming cores (e.g. Pineda *et al.* 2023; Pattle *et al.* 2023) to resolved observations of molecular cloud complexes in nearby galaxies (e.g. Saintonge & Catinella 2022).

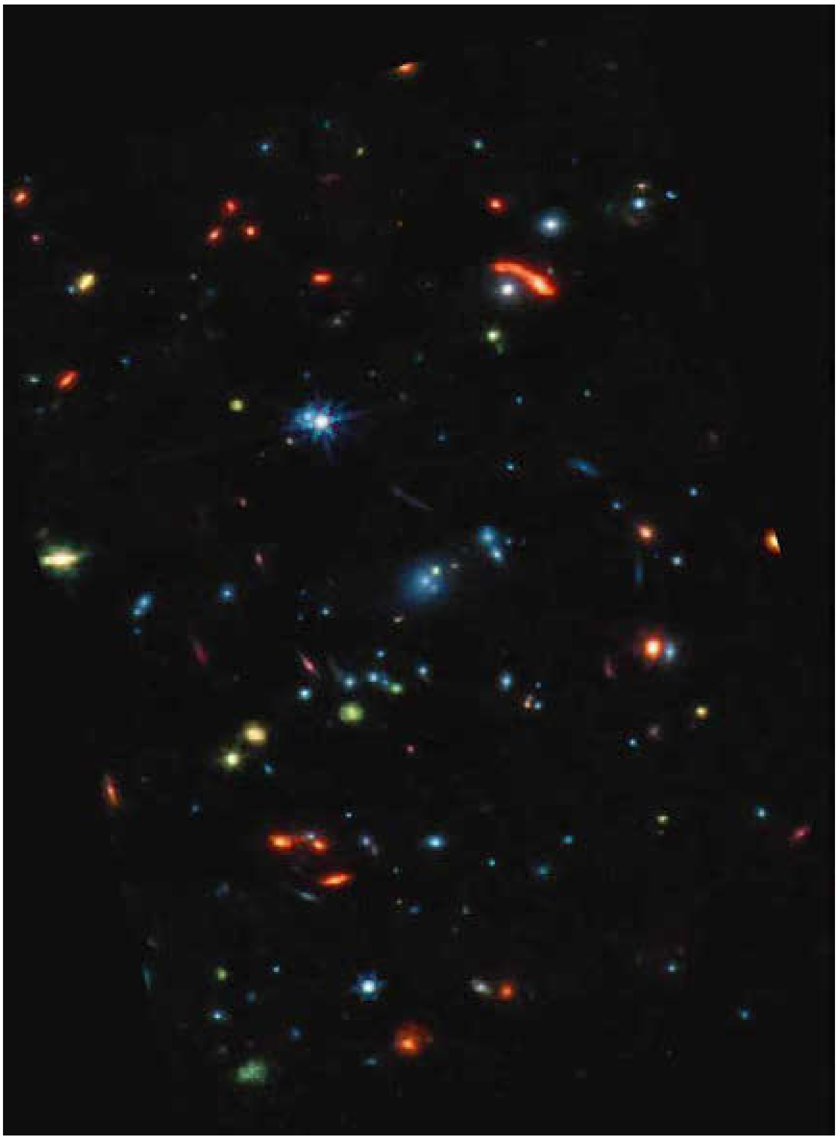
Many advances have been driven by observations made with far-infrared and submillimetre instrumentation, particularly interferometric arrays such as the Atacama Large Millimeter/submillimeter Array (ALMA) and the NOrthern Extended Millimetre Array (NOEMA), and large mm/submm single-dish telescopes such as the James Clerk Maxwell Telescope (JCMT) and the International Radio Astronomie Millimetrique (IRAM) 30m telescope. Data archives from telescopes that have ceased operations, or are winding down, are still yielding new results. These include the Hubble, Herschel and Spitzer Space Telescopes, the Infrared Space Observatory (ISO), the Planck Observatory and the Stratospheric Observatory for Far Infrared Astronomy (SOFIA).

Now, the JWST's near- and mid-infrared spectroscopy and photometry are revolutionising our understanding of young protostars, their environments, and the effects of their feedback on molecular clouds. Simultaneously, significant advances in simulations, including the development of zoom-in simulations and the integration of realistic astrochemical networks, have allowed star formation to be modelled from galactic scales (~10–100kpc) down to core and circumstellar disc scales (~10–100AU). In this meeting we heard about some of the latest advances from these telescopes and simulations.

JWST – more than just a pretty picture

The invited guest speaker was Klaus Pontoppidan (NASA Jet Propulsion Laboratory), who explained that his research project had begun as an outreach programme with JWST, by having the telescope make eye-catching images of some star-forming regions, eventually concentrating on the core of Ophiuchus.

The outreach project had subsequently evolved into research when it was realised how much science could be gleaned from the images. Pontoppidan began by showing figure 1, Mid-Infrared Imager (MIRI) pictures of galaxies at z=0.5 to 1.5, where the detected mid-IR images are actually rest-frame emission from Polycyclic Aromatic Hydrocarbons (PAHs), large interstellar molecules (Pontoppidan *et al.* 2022; Langeroodi & Hjorth 2023). The first 'local' star-forming region that the JWST imaged (with the Near Infrared camera, NIRcam) was the 'Cosmic Cliffs' of Carina (figure 2), closely followed by the 'Pillars of Creation' (of course). Then the JWST first anniversary image was of the core of the Ophiuchus molecular cloud (figure 3). The amazing data of this region show absolutely unprecedented detail. Pontoppidan discussed each aspect of this latter image in turn.



1 *'Skittles' – galaxies dominated by PAH emission at z=0.5–1.5 – observed with MIRI at 7.7–18 mm (Pontoppidan et al. 2022).* (NASA, ESA, CSA, STScI, Webb ERO Production Team)

2 *The 'Cliffs of Carina' are actually the edges of a nearby, young, star-forming region in the Carina Nebula. Captured in infrared light by JWST, this image reveals for the first time previously invisible areas of star birth. (credit: NASA, ESA, CSA, STScI, J. DePasquale)*

The brightest structure in the image is the photon-dominated region (PDR) seen here in yellow , driven by the B-star simply known as 'S1', that was so named because it was the brightest source to be discovered in the first near-infrared survey of the region (Grasdalen *et al.* 1973). It can be clearly seen in the lower centre of figure 3. This has previously been detected by many studies, most recently in polarised far-IR emission by the High Altitude Wide-field Camera plus polarimeter (HAWC+) on SOFIA (Lee *et al.* 2021). However, none have seen it in the detail of the JWST image. Structure on the edges in particular is incredibly detailed. Future studies of these features will undoubtedly yield new insight into PDRs and how they form and grow.

Also visible in the JWST image is the location of the radio source VLA1623 (right, upper), which was the first ever recognised 'Class 0' protostar (André *et al.* 1993), and which drives powerful jets and outflows. The jet details visible in the JWST data shed fascinating light on the driving mechanism of the jet, as well as the interaction between the jet and the surrounding medium. The multiplicity of VLA1623 is also apparent in JWST data, as well as in ALMA data. There appears to be a close binary star in the centre, one component of which is the origin of the outflow. Then there is at least one other component in a wider orbit. This is just one example of the advances that can be made in this field in the era of JWST and ALMA (figure 4).

Nearby galaxies as seen by JWST and ALMA

Elizabeth Watkins (University of Manchester) introduced the concept of super-bubbles in nearby galaxies, using the Physics at High Angular resolution in Nearby GalaxieS (PHANGS) project on the ALMA telescope (Leroy *et al.* 2021).

This gives resolution at 100-pc scales in 90 nearby galaxies. The first PHANGS-JWST observations of nearby galaxies unveiled a rich population of bubbles. Watkins found that the super-bubbles are consistent with Supernova Remnants (SNRs). As the bubbles expand, they sweep up the local Interstellar Medium (ISM) (Barnes *et al.* 2023).

Then Watkins moved on to the large-scale and the JWST image of NGC628 at high resolution (12pc), which appeared to have bubbles everywhere. She counted approximately 1700 bubbles in this one galaxy alone, with radii between 6 and 550pc (Watkins *et al.* 2023). Of these, 31% contain at

3 *The first-anniversary JWST image of the brightest part of the Ophiuchus star-forming region, known as Oph A.* (NASA, ESA, CSA)

4 *JWST views of the reflection nebula around S1 (the bright star at the centre of the top left image), some incredibly fine detail of the PDR (top right column), and the structure of the VLA 1623 outflow (lower three panels), all rotated by about 90 degrees relative to figure 3.* (Klaus Pontoppidan)

least one smaller bubble at their edge, indicating that previous generations of star formation have a local impact on where new stars form.

To quantify the feedback energetics on the star-forming gas, Watkins presented the largest molecular super-bubble catalogue found to date within nearby galaxies using ^{12}CO (J=2–1) observations. Using 18 PHANGS-ALMA galaxies at resolutions of ~50–100pc, a catalogue was produced of 325 super-bubbles with radii between 30 and 330pc and expansion velocities of around 10km/s. By focusing on a subset of these that have clear super-bubble signatures (unbroken shells etc.), the kinematic information available with ^{12}CO helps to constrain the feedback processes. Most are found to be supernova-driven, and rather than dispersing, molecular clouds are swept-up into a shell that grows over time. Therefore, these super-bubbles can potentially form stars in their shells, matching what is observed in the higher-resolution JWST bubble catalogue.

Helena Faustino Vieira (Cardiff University) used dust extinction to trace the star-forming gas in M51 with a view to understanding the initial conditions of star formation and dependencies on local environment within galaxies (Faustino Vieira *et al.* 2024).

For this, it is vital to study the cold molecular phase of the interstellar medium, traced by the cold dust, at the small scales of molecular clouds. Faustino Vieira presented an innovative dust extinction technique for obtaining high-resolution (sub-arcsecond or parsec-scale) maps of the ISM of nearby disc galaxies, using archival Hubble data in the optical (Faustino Vieira *et al.* 2023).

This technique does not compute the extinction of individual stars, but instead measures the attenuation caused by dust against a modelled, smoothly varying stellar distribution, along each individual line-of-sight. The estimates of dust mass were calibrated using lower-resolution dust emission observations from the Herschel Space Telescope.

Faustino Vieira specifically used the results of the application of the extinction technique to M51, which correlated well with previous independent dust and CO studies of the galaxy at lower resolution. The physical resolution achieved (5 parsec) is roughly a factor of 8 higher than the resolution achieved by the current best-resolved CO survey of M51, the Plateau de Bure Interferometer Arcsecond Whirlpool Survey (PAWS; Schinnerer *et al.* 2013).

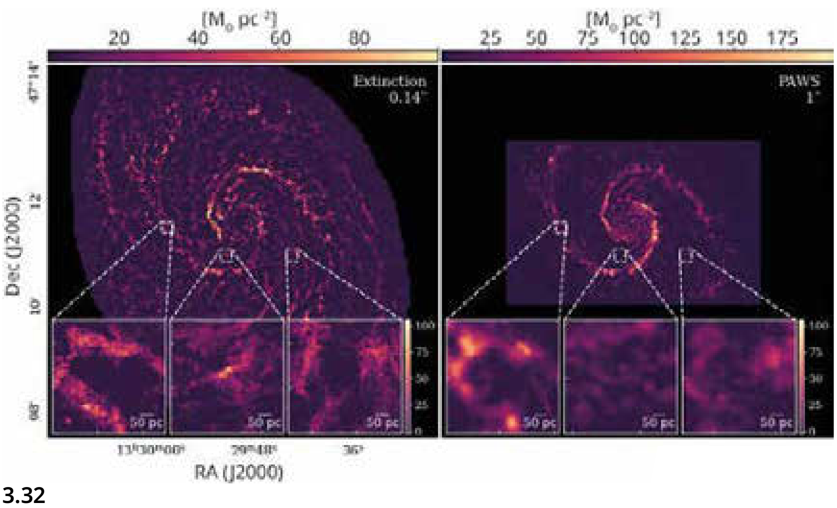
Faustino Vieira investigated the impact of large-scale environment and dynamics by analysing the distribution and properties of molecular clouds across the galaxy, which were extracted from the extinction-derived map of M51. The results showed that large-scale dynamical features (i.e. bar and spiral arms) have a strong influence on the organisation of gas across M51. In regions less affected by strong shearing motions, molecular clouds are allowed to grow and develop into higher masses (figure 5).

Additionally, there is a clear difference in average cloud surface densities within spiral arms in the inner galaxy versus the outer galaxy, a behaviour that is not present in the inter-arm regions. Helena hypothesised that this behaviour is caused by the tidal interaction between M51 and its companion. This study highlights the power of larger number statistics on resolved cloud populations (as a result of wider galactic disc coverage) in unravelling the potential effects of environment on molecular clouds, and consequently star formation.

Andrew Blain (University of Leicester) introduced the interactions between Gamma-Ray Bursters (GRBs) and the ISM in galaxies.

Blain mentioned that graduate student Miti Patel (University of Leicester) had first brought his attention to this topic. The recent possible (or at least plausible) detection of ultra-high energy photons from GRBs offers the prospect to read out the conditions in the circumstellar environment from arrival time measurements, and to understand features of the astrophysics of acceleration. Even with ALMA and JWST, the time domain offers finer effective resolution, and potential access to first light on giant molecular cloud scales.

The timescales on which GRBs vary are of order hours, corresponding to light travel times of less than 100au. Furthermore, the energies involved generate peta-electron-volt (PeV) photons! This can destroy the ISM along a very long but very narrow track. It is then interesting to see how a track such as this might interact with an SNR.



5 *Two methods of extracting molecular clouds from M51 from Faustino Vieira et al. (2023) and Schinnerer et al. (2013).* (Helena Faustino Vieira)

Chemistry of galactic and extra-galactic star-forming regions

Janet Bowey (Cardiff University) discussed carbonates (chalk dust) and ices in stellar nurseries within the Milky Way and beyond.

Bowey introduced a pair of bands at 6.0 (H_2O-ice) and 6.9µm taken with the spectrometers on ISO and Spitzer. These are observed in Milky Way molecular clouds and YSOs and in the z = 0.886 rest-frame of a molecule-rich spiral galaxy obscuring blazar PKS 1830–211. The 6.9mm band carrier(s) are uncertain, but CH_3OH (methanol) ice is thought to contribute. Previous observers ruled out carbonates, even though carbonates produce the band in meteoritic samples.

Bowey (2023) fits ISO and Spitzer observations with new carbonate spectra (Bowey & Hofmeister 2022) and CH_3OH ice. Four of the five observations require a carbonate component. CH_3OH abundances relative to H_2O are 10 times higher in the galaxy-absorber (~40%) than in three of the four Milky Way sources (<7%, outlier 35%), but the carbonate ($-CO_3$) abundance is ~33% of the Milky Way abundances. Carbonates match the Jones & Ysard (2019) abundance model in which solids with a C:O ratio of 1:3 explain the disappearance of atomic oxygen at the diffuse-medium-to-molecular-cloud interface. All of this is consistent with high rates of massive star formation, again illustrating why we need to better understand this process.

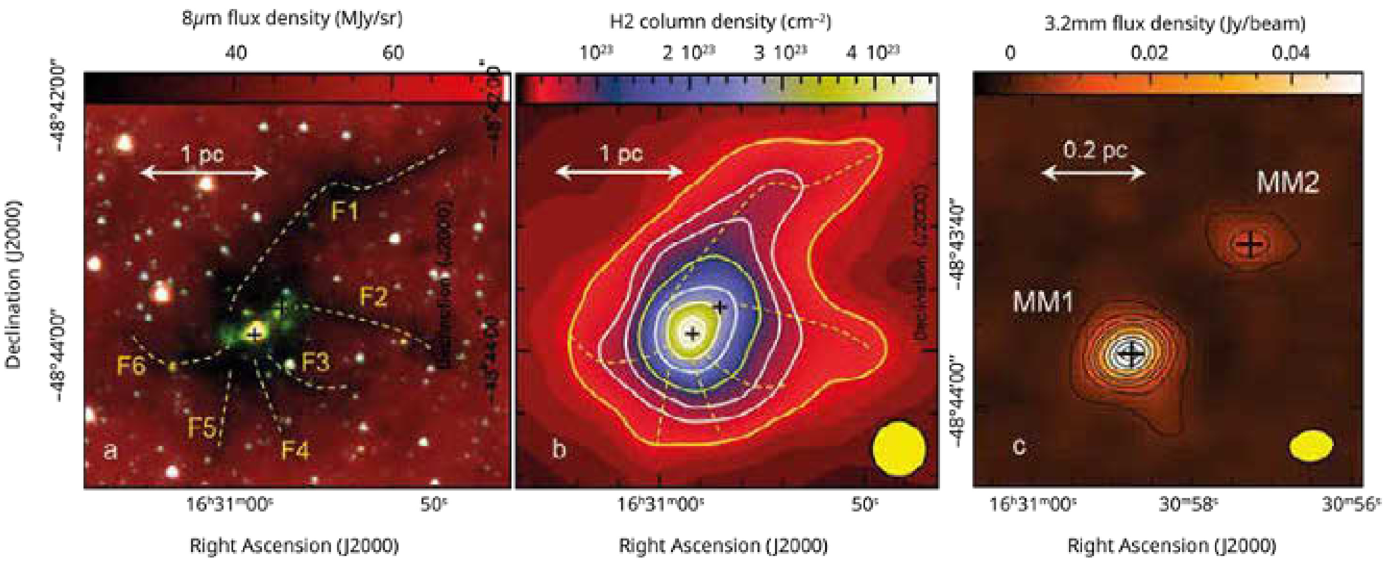
NOEMA and the IRAM 30m Telescope, he examined the links between the core populations identified at 2.8mm, the kinematics of the dense gas within which they are embedded, and the properties of the clump-scale environment (Rigby *et al.* 2024).

N_2H+ spectra of the sample of IRDCs appeared to show multiple velocity components. Distributions of N_2H+ (J=1–0) linewidths – tracing dense gas – within the most massive IRDCs are similar to the ambient clump gas, suggesting that they are not dynamically decoupled from the wider clump environment, but are similarly chaotic. These results support a picture of clump evolution in which globally collapsing clumps become more like hub-filament systems over time as gravity draws in nearby filamentary structures, driving an increasing accretion rate on to a central region of collapse, where the core population grows within a highly dynamic environment. This hub-filament collapse mechanism could be the primary route by which high-mass stars form (figure 6).

Zacariyya Khan (University College London) also stressed the importance of high-mass stars on the ISM, and specifically presented a study of magnetic fields in the hub-filament system G34.26+0.15, which falls under the influence of HII region feedback.

Khan pointed out that hub-filament systems are molecular clouds that play host to massive star-formation, often containing multiple high-mass stars within their central hubs. However, the physics of the fragmentation and collapse of hub-filament systems is poorly understood at present, especially the role played by magnetic fields.

G34.26+0.15 is a molecular cloud at a distance of 3.3kpc and is part of the W48 complex. It is clearly composed of the characteristic long filaments extending out from a dense central hub. This hub contains multiple ultra-compact HII regions which have been extensively studied, indicative of massive star formation. Khan presented an analysis of the magnetic field structure across the region, inferred from observations of polarised dust emission at 850µm, taken using the Submillimetre Common-User Bolometer Array-2 (SCUBA-2) and its polarimeter, POL-2, mounted on the JCMT. By considering the alignment of the magnetic field to the filaments of G34.26+0.15, Khan showed that, although some filaments appear to be undergoing gravitational in-fall towards the central hub as would be expected in a hub-filament system,



6 *The earliest stages of massive star formation shown in the infrared dark cloud SDC335, which has a mass of 5500 solar masses. Images from Peretto et al. (2013), using Spitzer, Herschel and ALMA data respectively.* (Nicolas Peretto)

Observations of the dynamics and kinematics of galactic star-forming regions

Andrew Rigby (University of Leeds) gave a description of infrared dark clouds (IRDCs) studied with NOEMA and the New IRAM Kinetic inductance detector Array-2 (NIKA2) camera on the IRAM 30m Telescope.

Rigby was a part of the Galactic ASTronomy On NIKA2 (GASTON) survey (Rigby *et al.* 2021) that found numerous candidate IRDCs that have been followed up with NOEMA. IRDCs are where high-mass stars form, and high-mass stars (greater than 8 solar masses) have a disproportionate effect on the ISM and on the evolution of galaxies. Hence a deep understanding of the formation and evolution of such stars is crucial to an understanding of the evolution of galaxies. Within this context, Rigby showed images of the central parsec of a sample of seven IRDCs with a range of masses and morphologies. Using high-resolution combined observations from a substantial portion of the cloud appears to have been altered by an expanding HII region. This intense form of feedback appears to have both reshaped the magnetic field in the cloud and affected the structure of the material surrounding the HII region, potentially even triggering further massive star formation.

David Eden (Armagh Observatory) has been using the Massive Active JCMT-Observed Regions of Star formation (MAJORS) survey which is observing over 100 of the highest-mass star-forming regions observable from the JCMT in the HCN and HCO+ (J=3–2) transitions.

This survey is designed to determine the role that dense gas plays in star formation. Eden is attempting to test the various scaling relations. The strongest correlation is found between the column density of the dense gas and the near-infrared luminosity, which is believed to be the best tracer of star formation. This holds over many orders of magnitude.

The work used the W49 complex as an example of high-mass star formation – a 'star-burst' star-forming region, as it is arguably the most active region of star formation in the Milky Way. Eden presented the first-look observations and analysis from this region and gave a demonstration of the science that can be done on individual regions within the MAJORS survey.

Janik Karoly (University of Central Lancashire) presented some preliminary results from the B-fields In STar-forming Region Observations 3 (BISTRO-3) survey using SCUBA-2/POL-2 on the JCMT.

This third round of observations of the BISTRO surveys is nearing completion and Karoly shared some of the preliminary results. The third round of observations has focused on two extremes in star formation: cold and dense nearby isolated cores, and massive distant star forming regions such as the Central Molecular Zone (CMZ) in the Galactic Centre. These observations fill out the three parameter axes of star formation that BISTRO set out to investigate, namely the age, distance and mass axes.

A large mosaic of the CMZ traced the magnetic field in most of the Galactic Centre clouds, including Sgr A, B2 and C, as well as the so-called 'Brick' and the 30km/s clouds. A great wealth of detailed structure was observed that astronomers are still trying to disentangle.

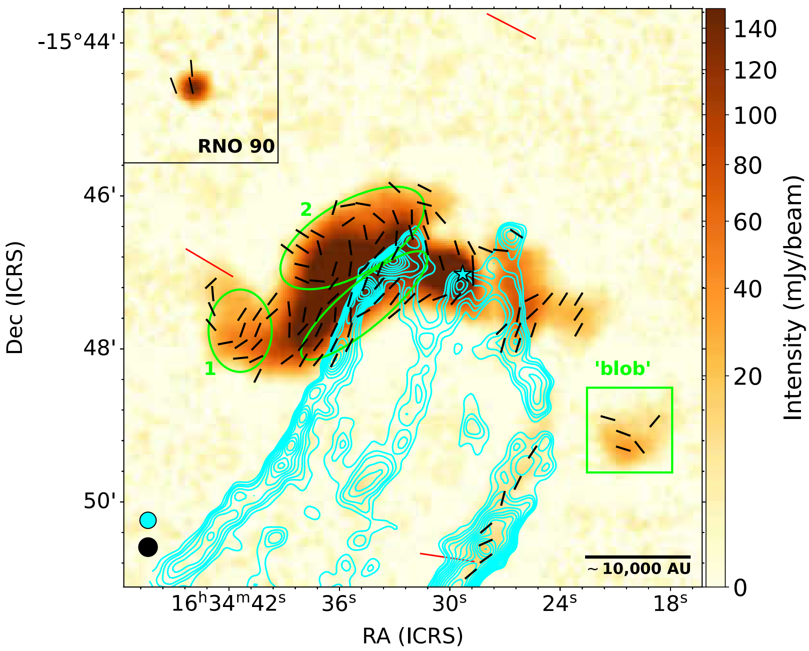
At the other end of the mass axis lie the Lynds dark clouds. BISTRO-3 has targeted a number of these, especially those that have not formed protostars yet (the starless cores with no embedded near-infrared sources), and Karoly described what has been learnt about a few of them:

L43 (Karoly *et al.* 2023; figure 7)**:** this core is brighter than the others because it lies adjacent to the protostar RNO91, which is driving an outflow, although L43 itself does not contain a protostar. The edge of the outflow lies along the edge of the L43 core, and BISTRO-3 shows that the magnetic field also lies along the edge of the outflow cavity. This also explains an earlier BISTRO result that magnetic fields generally lie at ~30° to the outflow axis (in projection) in protostars (Yen *et al.* 2021). The fields tend to lie along outflow cavity walls, and the cavity opening angles are typically ~30°.

L1498: this object is the faintest of the BISTRO-3 sample of cores and high levels of polarisation have yet to be detected from it, although not all the data have been taken yet. However, the polarisation that has been detected indicates a magnetic field lying perpendicular to the long axis of the core, as predicted by many models.

L1495 (Ward-Thompson *et al.* 2023)**:** this region is part of a filamentary complex that contains a number of cores. It is hypothesised to be in a state whereby the early magnetic field-dominated phase gives way to the matter-dominated phase of evolution of dense cores.

Karoly is continuing to study a larger sample of these cores, to produce an overall picture of what factors affect their evolution, and in what way. By the time the BISTRO-3 survey is complete, this should be the largest sample of such cores, whose magnetic fields have been observed at high resolution and sensitivity.



7 *The magnetic field following the outflow cavity in the L43 molecular cloud, as observed by JCMT SCUBA-2/POL-2.* (Janik Karoly)

Simulating star formation in the era of JWST and ALMA

To determine how global galactic processes might regulate how molecular clouds are formed, shaped, and are ultimately able to form stars, it is essential that we understand the evolution of the gas as it travels through a galaxy, experiencing a wide range of conditions, densities and processes, at different scales.

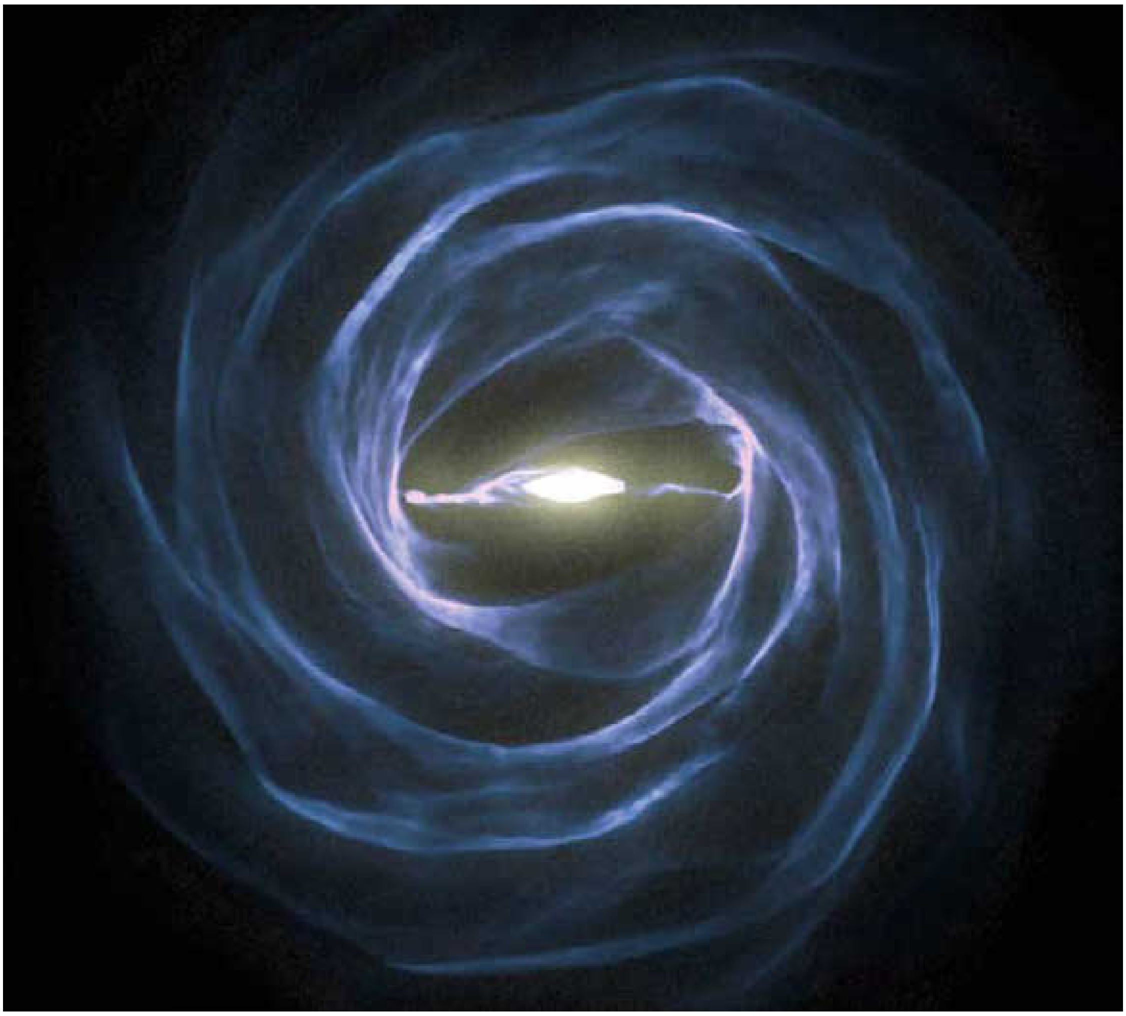
With this in mind, Ana Duarte-Cabral (Cardiff University) introduced the FFOGG project (Following the Flow Of Gas in Galaxies) to study star formation in nearby galaxies, and in particular to understand the evolution of the gas as it travels through a galaxy.

Using the AREPO (Weinberger *et al.* 2020) moving mesh model code (named after the enigmatic word AREPO in the Latin palindromic sentence *sator arepo tenet opera rotas*, the 'Sator Square') the project aims to determine how global galactic processes might regulate molecular cloud evolution.

Duarte-Cabral takes a sample of face-on galaxies so as to unambiguously separate material from the spiral arms and inter-arm regions, focusing particularly on the numerical modelling of the evolution of the ISM and star formation in specific nearby spiral galaxies using tailored AREPO simulations with live stellar potentials and sophisticated ISM physics. Ultimately, the FFOGG project aims at determining whether star formation self-regulates, or whether it might be influenced or controlled by the global dynamics of the spiral/bar structures of spiral galaxies. Models such as these will be essential to understand the complex data being generated by the latest telescopes.

Eva Durán-Camacho (Cardiff University) talked about self-consistent modelling of the Milky Way using live potentials.

Durán-Camacho is aiming to investigate the role of the large-scale dynamics of the Galaxy on



8 *Simulation of the Milky Way galaxy using the hydrodynamical AREPO moving-mesh code.* (Eva Durán-Camacho)

"Understanding the role of magnetic fields in controlling the large-scale dynamics of the ISM has proven a difficult challenge"

star formation, using the hydrodynamical AREPO moving-mesh code to perform numerical simulations of Milky Way-type galaxies using a live dark matter halo, stellar disc, and stellar bulge. Durán-Camacho has generated a set of 15 isothermal models whose parameters have been observationally constrained, to investigate the structure and dynamics created by the stellar potential and followed by the gaseous disc. She finds that the overall galactic structures are very sensitive to the initial stellar distribution, with some models developing long bars whilst others create none. She ultimately finds the best fit of the Milky Way by comparing the models to observations via longitude-velocity plots of the projected gas surface densities, from which is extracted the skeletons of the main features (arms, etc.), as well as the contours defining the terminal velocities of the gas. Combining all these results, Eva selects an overall best fit which serves as the Milky Way template.

Durán-Camacho presented details of distinctive features, such as the spiral pattern, the 3-kpc expanding arm and the CMZ (figure 8). The final model acts as the basis for inclusion of more physical processes, such as chemistry, feedback, magnetic fields, and increased resolution of individual regions. Those models can then be compared to observations using radiative transfer codes to mimic dust continuum and molecular line emission from the interstellar medium. These will be essential for testing the validity of the models and the physical processes behind the observables.

Kamran Bogue (University of Manchester) has carried out simulations that used the cutting-edge high-resolution, three-dimensional AREPO code of an isolated galaxy.

Bogue ran near-identical simulations with only one difference – the addition of a magnetic field! This was to investigate how a dynamo-generated field can shape the alignment of dense structures in the ISM and their subsequent star formation.

Understanding the role of magnetic fields in controlling the large-scale dynamics of the ISM has historically proven to be a difficult challenge. By running models of both a hydrodynamic and magneto-hydrodynamic case, the work specifically interrogates the impact of the field in star forming environments. Kamran compared the global properties of isolated galaxy disc models, studying differences in morphology and vertical extent, dense gas fractions, and star formation rates. One of the most interesting – and potentially controversial – results is that adding a magnetic field seems to lower the star-formation rate.

Conclusions

This meeting has shown tantalising evidence of what JWST is already bringing to studies of star formation. It has also demonstrated the power of interferometers like ALMA, and the ongoing importance of large, ground-based single-dish telescopes like the JCMT. Above all, it has shown that to make progress in any field of astronomy in the modern era, it is necessary to put together the findings from many telescopes, both old and new, as well as state-of-the-art model simulations.

One other question captured the attention: why does Derek Ward-Thompson think that the JWST image of Ophiuchus looks like a monster fighting a jellyfish? ●

AUTHORS

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Derek Ward-Thompson (DWard-Thompson@uclan.ac.uk) is the director of the Jeremiah Horrocks Institute at the University of Central Lancashire, where he carries out research and teaches on the undergraduate degree schemes. He has written a text-book on the formation of stars and has taught one of Doctor Who's children.

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A match-making metric

Getting a job in astronomy can be a fraught process. Institutions vie to select from a pool of candidates, who are in turn vying to select from a pool of institutions. Phillip Helbig has come up with a plan to make it all rather easier.

Astronomy is a field in which there are few specialist jobs. Other branches of physics offer jobs outside of academia, including permanent jobs at a relatively early age, while essentially all astronomy jobs are within academia. If one considers the high degree of specialisation, it is clear that the number of potential jobs for a given astronomer is very low. Indeed, most astronomers with a doctorate in the field never get a permanent job and eventually leave academia. (To first order, each professor with students will, on average, have one student who goes on to become a professor with students.)

There are more applicants than jobs on offer and a typical job might attract, say, a few dozen applicants (though there is a wide range). The oversubscription is not that high, though, as applicants typically apply for several jobs. The usual scheme is that jobs are advertised, mostly in the autumn, people apply, applicants are ranked, and offers are made for each job until a candidate accepts. Good applicants will have several initial offers from desirable institutes. Lesser applicants could have offers from lesser institutes or offers from better institutes after others have declined. Many will get no job offer at all.

The scheme seems on the surface of it to work quite well: institutes rank applicants, good candidates might be able to negotiate if they have more than one offer, and eventually all jobs are filled. Most jobs are advertised in the autumn so that competing offers can be compared without applicants being forced to accept a less desirable job only because it has an earlier deadline. This can be avoided with a common deadline, as is exercised in high-energy physics, where most offers adhere to a decision deadline of 7 January. However, there are many other things that could be improved.

First, good applicants will have several offers. Although good for such candidates, that has disadvantages both for some other applicants and for some institutes. Consider an applicant who is very good, but not at the top of most lists, perhaps not at the top of any – because an excellent, high-profile candidate occupies the top positions. The absolute difference in quality might be quite small. Nevertheless, in the first round the best applicant will get several offers and the second-best perhaps none, at least not from good institutes. Usually, because most jobs are advertised at approximately the same time, decisions must also be made within the same time frame. A good candidate, especially considering the possibility of negotiating on the strength of having more than one offer, might take essentially the entire allowed time to accept. That means that the second-ranked applicant will not get an offer from any institute which ranked the high-profile candidate first, unless the high-profile candidate declined some offers before finally accepting one. That would not be in the interest of the high-profile candidate and probably rarely happens. The second-ranked will then, at best, have an offer from a lesser institute to which the high-profile candidate did not apply (perhaps one to which the second-ranked applicant applied for personal reasons). Being forced to accept such an offer, the second-ranked applicant is no longer available to all the other institutes who ranked the high-profile candidate first, and such institutes are forced to make an offer to a candidate lower down on the list. So while multiple offers are good for the top-ranked candidate, they are bad for good though lower-ranked candidates and for almost all institutes which ranked the high-profile candidate first. It is also arguably a worse situation for the institute chosen by the high-profile candidate since that candidate might have negotiated some advantages which would otherwise not have been offered.

Ranking the Rankers

My suggestion to improve the situation would be that applicants rank jobs just as employers rank applicants. Such rankings could be given to a neutral, trusted third party in order to match the candidates: all candidates with an offer from their top-ranked institute are obliged to accept that offer and are removed from the pool. The lists are then updated, i.e. entries on lists from which a candidate or a job have been removed are moved up to fill the gaps, and the process repeated. Although not essential, candidates who have applied to a given institute could be informed when that position has been filled by another candidate, and institutes could be informed when one of their applicants has accepted a job elsewhere. The former usually happens eventually via rejection notifications. The latter usually happens only when a candidate has more than one offer and declines all but one; applicants don't always notify institutes to which they have applied but from which they have no offer that they have accepted an offer elsewhere. The process is repeated until a round in which no applicant/job pair is removed, or until all jobs have been filled.

A deadlock situation could occur in which no pair is removed but there are still candidates without jobs and jobs that are still open. For example, candidate 1 might prefer institute A and candidate 2 institute B, but institute A has ranked candidate 2 the highest and institute B candidate 1. Obviously, some compromise must be made. My suggestion is that in such cases it favours the applicants, because in practice the difference between candidates will be small, perhaps even within the noise, and any institute should have no problem accepting a candidate one position lower on the list. However, the difference between institutes, even of the same quality, could be much greater for candidates, primarily for personal reasons, perhaps because an institute is nearer, more familiar, or colleagues work there. It would be obvious to candidates if such a deadlock exists: they would have neither received an offer nor been informed that the position is filled. Thus, a match to a candidate's first-ranked institute would be welcomed, even if the candidate isn't the institute's first choice.

"Instead of the chaotic results of the current system, which might take several months to play out, a transparent algorithm maximises the overall good, optimally matching candidates to jobs"

An additional advantage of such a scheme is that it levels the playing field. With the current scheme, if the candidates involved in a deadlock are well connected, they could mutually agree to decline their offers, resulting in new offers from their preferred institutes. Those not well connected cannot take advantage of such an opportunity. In practice, there might be some risk, though well connected candidates might be aware of the shortlists involved.

An initial offer from a candidate's preferred institute is best for both the candidate and the institute although, as noted above, in the current system it could be associated with disadvantages for other applicants and other institutes. How should other combinations of candidate and institute be ranked? A simple function would be C^2+J^2, where C is a candidate's rank for a certain job and J an institute's rank for a certain candidate. In contrast to, say, $C+J$, such a function favours similar ranks. Good institutes want good candidates, not just candidates who ranked the institute highly; good candidates want good jobs, not just jobs at institutes that rank them highly. So when a deadlock occurs, such functions could be calculated for all possible pairs of jobs and candidates and those with the best (lowest) value would be matched and removed from the pool. (The case discussed above with $C=1$ and $J=2$ is a special case.) The lists are then updated and the process then repeats. The entire process could be based entirely on that function, because a candidate being ranked first by the candidate's first-ranked institute – 1^2+1^2 – is the minimum of such a quantity, 1^2+2^2 describes the deadlock situation, and so on. In cases where the function value is the same, preference should be given to the cases with $C < J$, giving more weight to a candidate's job preference than an institute's candidate preference.

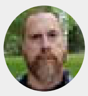
Usually, applicants rank jobs in such a concrete way only when there is more than one offer. Offers are usually preceded by interviews, which can influence the order in which institutes are ranked by the applicants. Institutes usually make an initial rough ranking to decide which subset of applicants should be interviewed. Under my proposed scheme, institutes' and applicants' rankings would be sent to the trusted third party only after the interviews, which, after the common application deadlines, should take place in a common time range. The main difference is that after the interviews, the process of matching applicants to jobs is automatic, quick and results in an optimum solution. That should be contrasted with months of waiting, tactical manoeuvres, efforts to obtain information (of uncertain veracity), and a less-than-optimum outcome, not to mention good candidates leaving academia because they couldn't afford to wait another month.

In some sense, my scheme is similar to stable-marriage algorithms, which are used in some similar circumstances, for example, for matching graduating medical students to their first hospital appointments. The 2012 Nobel Prize in Economics was awarded for work on such algorithms. However, for astronomy jobs in which there are more applicants than jobs, a given applicant is neither interested in nor qualified for all jobs, and time-consuming interviews are an essential part of the process, I suggest that my scheme is more effective.

One difference from the current system is that there is no possibility for negotiation after an offer has been made and a candidate and a job have been matched. In practice, unless a candidate has more than one offer, such negotiations achieve little overall. A top candidate might have several offers and thus negotiate a substantial improvement, which is good for that candidate but brings an overall loss in efficiency. Also, in a field where chance and contingency play a large role, such non-linear effects should be avoided. A reasonably good candidate might have several offers from lesser institutes; the loss of the possibility of negotiation in such cases is more than made up for by such a candidate getting a job at a good institute and good institutes getting good candidates, both of which, under the current system, don't always happen.

The suggested changes are few. Everything up until the end of the interview stage would be the same as now (except that all interviews should be within the same time frame): ads, applications, search committees, making short lists, interviews. But then, instead of the chaotic results (depending on who makes the first offer to whom) of the current system, which might take several months to play out, a transparent algorithm maximises the overall good, in the sense of the optimal matching of candidates to jobs. Candidates and jobs could be matched within seconds once the institutes and candidates have submitted their interview-based rankings, which could be just a week or two after the end of the interview phase. It is probably not even necessary for there to be a consensus that such an algorithm should be used to match candidates to jobs; once a few institutes set up such a scheme, including a neutral trusted third party to do the rankings-based matching, other institutes will probably follow. ●

AUTHOR



Phillip Helbig was a student of Sjur Refsdal at the University of Hamburg, where he obtained his master's degree in physics and astronomy. He has a PhD in astrophysics from the University of Liège and has also worked at Jodrell Bank and the Kapteyn Institute in Groningen.

FURTHER READING

The high-energy physics approach, with a common deadline
tinyurl.com/5p6k9uzt

The stable marriage problem
tinyurl.com/yc377dyf

The 2021 Nobel Prize in Economic Sciences
tinyurl.com/ys454ht9

A bigger broader Autumn MIST

Beatriz Sanchez-Cano, Emma Woodfield, Sam Rennie and Diego Moral Pombo report on a big meeting reflecting a thriving community

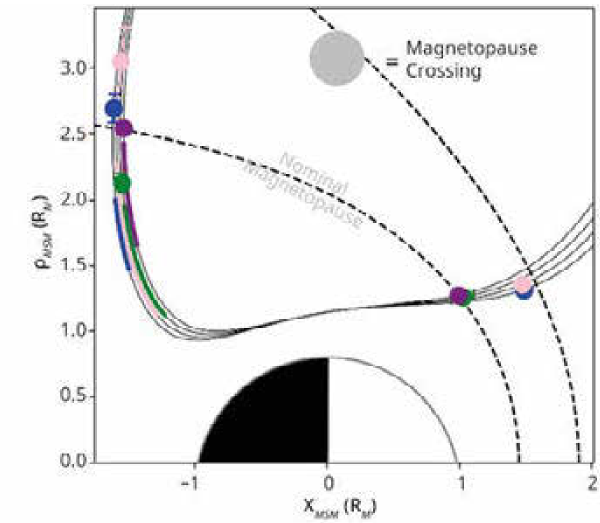
The Magnetosphere, Ionosphere and Solar-Terrestrial (MIST) community met in person at their annual Autumn MIST meeting at the Geological Society building on Tuesday 28 November 2023. It was the largest in-person attendance at a MIST meeting in London, with 122 attendees in the room and 10 online. The meeting was split into three sessions of talks, focusing on planetary, solar and Earth-based science, respectively, plus two poster sessions to accommodate the very large number of abstract submissions, together producing a packed meeting to reflect a thriving community.

Planetary patterns

The opening session for this Autumn MIST meeting encompassed talks on planetary science, showcasing some of the varied research carried out by groups across the UK on the magnetospheres of different planets of our solar system.

The meeting kicked off with a statistical analysis of Mercury's magnetotail lobe by Charles Bowers (Dublin Institute for Advanced Studies), who used data from the MErcury Surface, Space ENvironment, GEochemistry and Ranging (MESSENGER) plasma spectrometer and magnetometer to constrain the crossings of the spacecraft with the magnetotail lobes.

He developed a new expression to describe the fall-off of the lobe field strength with radial distance from the planet and, based on four years of data, showed evidence that the solar wind pressure directly influences the response of the lobe magnetic flux, presenting enhanced lobes when the magnetosphere is compressed by the upstream dynamic pressure (figure 1, Bowers *et al.* 2024).



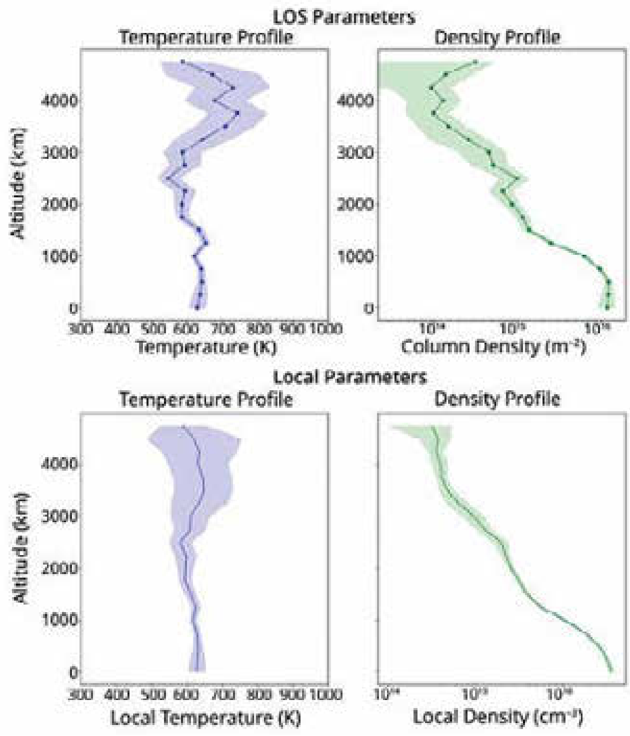
1 *Mercury's Lobe field strength and magnetopause boundary both vary from orbit-to-orbit compared to their nominal state. Diminished lobe in blue and pink, enhanced lobe in green, and nominal state in purple.* (Modified from Bowers *et al. Journal of Geophysical Research*, 2024 CC BY 4.0 DEED)

Staying focused on Mercury, Sophia Zomerdijk-Russell (Imperial College London), presented newly published results on the location of magnetic reconnection in Mercury's magnetosphere, using both modelling and MESSENGER data.

The results, besides the expected high-magnetic shear regions, show that in some cases the reconnection occurs at low shear angles (<70°). This supports the idea that symmetric reconnection dominates at Mercury's dayside magnetopause and could imply a smaller influence of the diamagnetic drift in the reconnection processes than, for example, Earth, where reconnection is restricted to sites of maximum shear.

Moving outward in the solar system to Mars, Dikshita Meggi (University of Leicester), presented work comparing ionospheric variability to the presence of crustal magnetic fields in the Southern hemisphere of Mars.

Through 12 years of data from Mars Express, the ionosphere response is correlated to the crustal magnetic fields; strong crustal magnetic fields and near-vertical magnetic field inclinations on the dayside result in extra ionospheric layers, while



2 *Comparisons between JWST line-of-sight profiles (top panels) and local profiles (bottom panels) from from JWST Programme #3665.* (From talk by P.I.Tiranti)

near-horizontal fields contribute to significant and long-lasting reductions of the topside density.

Moving away from the rocky planets to Jupiter, Gabrielle Provan (University of Leicester), presented model fits to proton and heavy ion densities from the Jovian Auroral Distributions Experiment (JADE) on the Juno mission.

The model shows that changes in magnetospheric conditions impact the magnetosphere-ionosphere coupling parameters; for example, the hot plasma index K_h increases with total magnetodisc current. These results suggest that the plasma pressure carried by the hot plasma population is the cause of the increasing total magnetodisc current.

The final talk in the planetary session was again about Jupiter, exploring the upper atmosphere of this gas giant. By combining novel data from the JWST Near Infrared Spectrograph (NIRSpec) with Juno Jovian Infrared Auroral Mapper (JIRAM) vertical profiles, Paola Ines Tiranti (University of Leicester) used new model (H3PPY) to fit $H3^+$ ion spectra, allowing the analysis of vertical density and temperature profiles up to 1000km for JIRAM data and 5000km for JWST data.

She derived local parameters from line-of-sight profiles and extended the analysis to different local times, allowing the evolution of the profiles across all dayside regions to be explored (figure 2).

Solar and solar wind science

The second session began with a presentation from Nawin Ngampoopun (Mullard Space Science Laboratory, University College London) on the evolution of coronal hole boundaries.

Using Solar Dynamics Observatory (SDO) data and the Differential Emission Measure analysis technique to track the dynamics of coronal hole edges, he showed that the leading edge of a coronal hole can have a higher temperature and magnetic flux than the trailing edge. These measurements will contribute to the debate over where exactly the solar wind comes from.

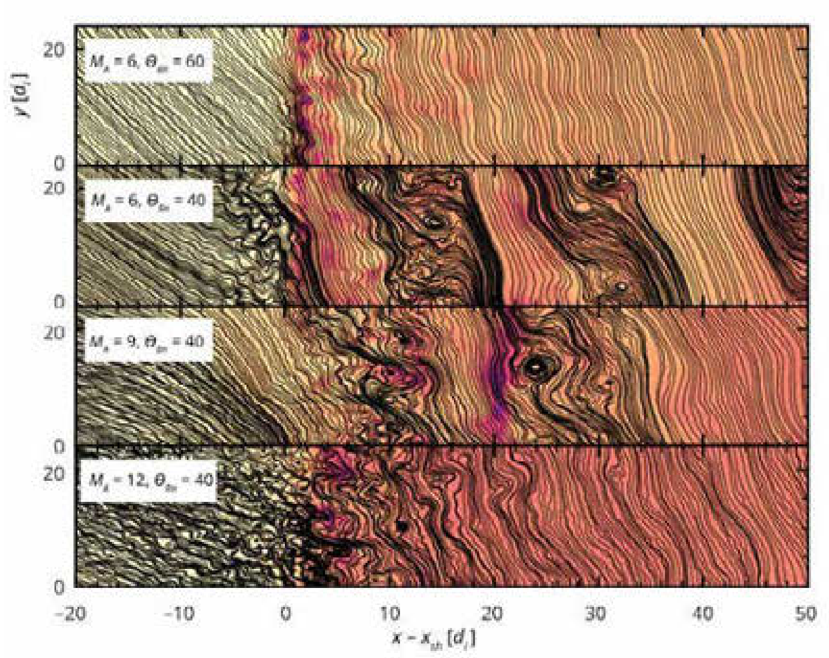
From the source of the solar wind the session moved on to plasma measurement. Georgios Nicolaou (MSSL, UCL) presented work on how plasma is measured by the Solar Wind Analyser's Electron Analyser System (SWA-EAS) on Solar Orbiter.

A simplified formula is often used to construct the 3D electron velocity distribution function, but Nicolaou presented a new, more accurate method to calculate it, and the resulting velocity moments (i.e., temperature, density, etc.). This new method helps particularly with relatively cold and fast electron distributions in which errors in the temperature can be overestimated by 60% as well as density in some cases by 40%.

Pauline Simon (Queen Mary University of London) continued the solar wind theme with a presentation on turbulence in a magnetised, collisionless plasma.

Using a model based on the generalisation of Kolmogorov's 4/5 law for an incompressible fluid applied to the case of a bi-adiabatic magnetised fluid with Hall effect, Simon investigated the compressible gyrotropic-pressure exact law in Hall-model simulations, finding that the anisotropic pressure makes a significant contribution to the total turbulent cascade rate. This is important to understand how heat is distributed in the plasma through turbulent processes.

Next, James Plank (University of Southampton) discussed the downstream influence of shock-driven turbulence.



3 Simulation for quasi-parallel, quasi-perpendicular and high-low Mach of shock-driven turbulence. (From talk by J. Plank)

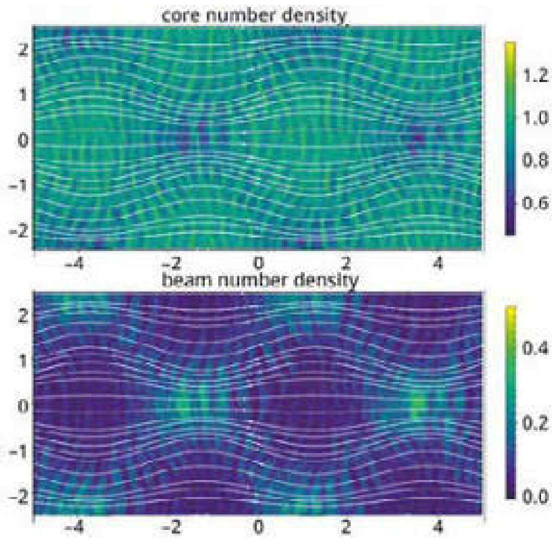
Using a variety of hybrid and full particle-in-cell simulations, Plank investigated the behaviour of the magnetic spectrum, kurtosis and correlation length with distance from the shock for a wide variety of shock conditions. His work showed that shock-driven turbulence is effective at cascading away small-scale structures, but the larger structures seem to persist a long way downstream (figure 3).

Laura Vuorinen (University of Turku, Finland), presented new work on the effect of solar wind conditions and solar cycle phase on enhancements of dynamic pressure in Earth's magnetosheath, known as magnetosheath jets.

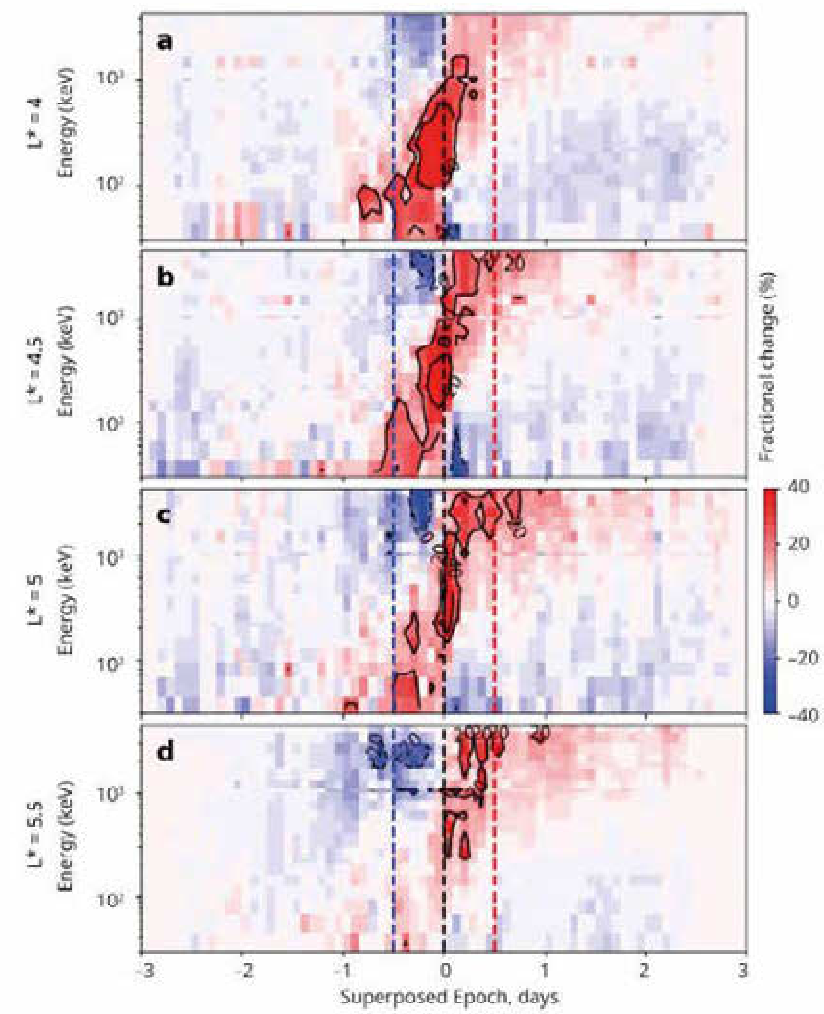
Vuorinen used data from the Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission to show that jets downstream of quasi-perpendicular shocks are much more sensitive to solar wind parameters. After careful removal of orbital bias in the THEMIS observations of these jets, the dependence of jet occurrence on solar cycle phase was shown to be weak.

Wrapping up the solar wind session, Jingting Liu (MSSL,UCL) spoke about Langmuir waves associated with magnetic holes in the solar wind.

These magnetic holes are small-scale, short-duration reductions in the amplitude of the interplanetary magnetic field. She showed simulations of magnetic bottle particle-in-cell simulations with an electron beam, that show that



4 This figure illustrates the result of particle-in-cell simulations of an electron core-beam distribution in a magnetic bottle structure. The white lines represent the magnetic field lines. The top panel displays the core number density, the bottom panel displays the beam number density. The inhomogeneous background leads to a spatially inhomogeneous triggering of beam-driven kinetic instabilities. The unstable waves share properties with electrostatic waves observed by Solar Orbiter near magnetic holes in the solar wind. (From talk by J. Liu).



5 *This figure shows the relative changes in electron flux at different energies in a superposed epoch study of 70 isolated storms observed by the Van Allen Probes. The storm recovery phase starts at 0 days, the main phase starts at the blue dashed line and chorus wave power is enhanced between the blue and red dashed lines.* (Chakraborty *et al.* submitted to *Geophysics Research Letters*)

Langmuir waves in different parts of the magnetic hole have different wavenumbers (figure 4).

Down to Earth

The third and final session of talks explored work on Earth's environment. Samuel Greess (QMUL) presented research undertaken using Terrestrial Reconnection EXperiment (TREX) laboratory observations of magnetic reconnection processes in plasmas along with specialised kinetic, particle-in-cell simulations to study asymmetric reconnection in low-density space environments such as Earth's magnetopause.

He reported observation-simulation agreements, finding that reconnection rates increase for decreased system sizes, suggesting a shift to an electron-dominated regime, and a spreading of layer widths that can be attributed to a toroidal instability developing in the current layer.

Looking to data closer to the planet's surface, Rosie Hodnett (University of Leicester), presented work on the ionospheric Alfvén resonator: the structure in which magnetohydrodynamic waves are partially reflected at ionospheric boundaries and drive ionospheric Alfvén resonances (IAR).

To complement IAR harmonic frequencies extracted from observations from the Eskdalemuir induction coil magnetometer dataset, Hodnett modelled IAR harmonics in an ionosphere with a non-uniform Alfvén velocity profile. Good agreement between observed and modelled harmonics was observed, and she concluded that the non-uniformity of the ionosphere is significant in controlling harmonic phase.

Suman Chakraborty (Northumbria University) then took the meeting off the surface and into the heart of Earth's outer radiation belt.

Chakraborty used measurements from the Van Allen Probes to correlate chorus wave power with the fractional change of relativistic electron fluxes during 70 isolated geomagnetic storms. The results showed that intense chorus waves are responsible for reducing net losses of relativistic electrons during the main phase of geomagnetic storms, which is important for capturing the complex chorus wave activity for accurate radiation belt modelling (figure 5).

Radiation belt modelling relies on realistical capture of the interactions between high-energy particles and magnetospheric waves. But the physical processes are highly variable, introducing uncertainties. Sarah Bentley (Northumbria University), explained ways in which ensembles – collections of model results obtained using varied input parameters – are ideal for addressing such uncertainties.

Bentley explored the impact that initial particle distributions and outer-boundary conditions have on modelled radial diffusion in the radiation belts; she used the time it takes to reach monotonicity, akin to the time for radial diffusion effects to be interesting, and an energy-like density distribution to investigate changes in mass and energy. This analysis revealed multiple key considerations, including the importance of the outer-boundary properties in modelled diffusion.

Staying in the Earth's radiation belts, Dovile Rasinskaite (Northumbria University), presented a method using number density and temperature description of the outer belt to understand how plasma populations evolve through heating and transport.

Using Van Allen Probe measurements from the Energetic particle, Composition, and Thermal plasma (ECT) Suite, Rasinskaite investigated the response of outer-belt particle populations during substorms (previously only done at geosynchronous orbit using lower-resolution data). This work indicated that both number density and temperature are highly variable, with temperature and density enhancements occurring mostly on the nightside at lower energies, a result postulated to be due to particle injection.

Next, Martin Cafolla (University of Warwick) presented work on space-time correlated enhancements in the ionosphere with respect to seasonal variations and Geomagnetic Activity.

The work is based on 18 years of Total Electron Content (TEC) observations from Global Position Satellites and 100–200 ground stations, from which global TEC maps are retrieved every 15 minutes. By analysing the most extreme TEC values in these maps, Cafolla showed the evolution in time and space of these enhancements, as well as their trajectories over the surface of Earth.

The last part of the session focused on electrodynamics of the Earth's system. Cara Waters (Imperial College London) applied machine learning techniques together with a 2.5D particle-in-cell simulation to show how energy is distributed during magnetic reconnection, combining the results with data from the Magnetospheric Multiscale (MMS) Mission.

Waters showed that regions are distinct in their energy partition signatures, meaning that different energy transfer mechanisms may be playing a role. Moreover, she demonstrated a new way of identifying different regions of reconnection, by determining the spacecraft location relative to the reconnection site and attributing energy flux densities to different regions.

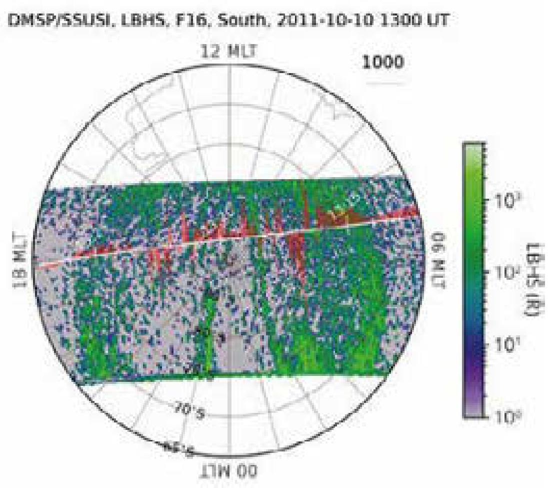
Following on this topic, Michaela Mooney (University of Leicester) described how a northward interplanetary magnetic field (IMF) can undergo magnetic reconnection at higher latitudes tailward of the cusps and simultaneously in both hemispheres.

The process can result in an almost entirely closed magnetosphere and has been linked to cusp-aligned arcs (an auroral signature). By using cusp-aligned arc observations from the electrostatic analyser on-board ARTEMIS, together with Cluster-II observations of plasma densities, Mooney *et al.* (2024) found that precipitation of trapped plasma into the polar region may produce the cusp-aligned arc signatures (figure 6).

The final talk of the session – and of the day – was by Patrik Krcelic (University of Southampton), who presented work on the variability in the electrodynamics of the small-scale auroral arcs.

He used three distinct wavelengths from the narrow-field Auroral Structure and Kinetics (ASK) camera to cross-correlate electric field measurements, separating its normal and tangential components; he compared these data with a modelled auroral source for 23 auroral arcs in order to understand the mechanism and connections in auroral electrodynamics, as well as to comprehend the source of high auroral variability.

MIST council would like to thank the Geological Society for hosting Autumn MIST 2023 and for the continued support for MIST from the Royal Astronomical Society. Furthermore, we thank all attendees and presenters for contributing to an engaging and enjoyable meeting. The next MIST community meeting will take place at the upcoming NAM 2024 meeting and we look forward to another vibrant meeting! ●



6 *DMSP/SSUSI observation of cusp-aligned arcs observed in the southern hemisphere during a prolonged period of Northward IMF* (Figure produced by Michaela Mooney using the Python geospacelab module)

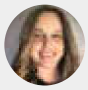
The posters

In addition to the excellent oral presentations we had 41 posters split across two sessions, which led to a vibrant atmosphere of discussions that once again demonstrates the power of an enthusiastic group that gathers together year after year to informally discuss and engage with the latest cutting-edge MIST science being developed in the UK.

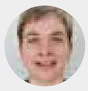
Author	Institution	Title
Martin Archer	Imperial College London	*Magnetosonic ULF waves with anomalous plasma – magnetic field correlations*
Ravindra Desai	University of Warwick	*ROARS: Revealing Orbital and Atmospheric Responses to Solar activity – A multi-spacecraft mission to Low Earth orbit*
Gareth Dorrian	University of Birmingham	*Tracking asymmetric quasi-periodic oscillations within a travelling ionospheric disturbance from Poland to the North Sea with LOFAR*
George Greenyer	Lancaster University	*Implementing the Boris Method in a jovian middle-magnetosphere plasma simulation*
Charalambos Ioannou	University College London	*Polytropic analysis of ion-acoustic waves in the solar wind observed by Solar Orbiter*
Nawapat Kaweeyanun	University of Southampton	*In-situ observations of interaction between the closed magnetic field of Earth's transpolar auroral arcs and the magnetopause*
Adrian LaMoury	Imperial College London	*Operational modelling of space weather ground effects with the GorgonOps simulation suite*
Zoe Lewis	Imperial College London	*Constraining ion transport in the diamagnetic cavity of comet 67P*
Sophie Maguire	University of Birmingham	*Large-scale plasma structures and scintillation in the high-latitude ionosphere*
Jack McIntyre	Queen Mary University of London	*Observations of the turbulence transition range as evidence for the helicity barrier*
Sam Rennie	University of Leicester	*Modelling of ULF waves in SuperDARN backscatter*
Joshua Ruck	University of Birmingham	*On the use of SuperDARN ground backscatter measurements for ionospheric propagation model validation*

Beatriz Sanchez-Cano	University of Leicester	*From the Sun to Mars's surface: How solar energetic particles affect Mars's atmosphere and ionosphere*
Jasmine Sandhu	Northumbria University	*How do plasmaspheric plumes impact ULF waves?*
Audrey Schillings	University of Leicester	*Space weather on Earth: how could we better preserve our technologies from space weather events?*
Julia Stawarz	Northumbria University	*Distributed Receivers for Electron Astrophysics Measurements (DREAM): A CubeSat*
Konrad Steinvall	University of Southampton	*The influence of rotational discontinuities on magnetic reconnection in the shock transition region*
Katerina Stergiopoulou	University of Leicester	*Ionopause detections in the martian ionosphere*
Maria-Theresia Walach	Lancaster University	*Introducing TiVIE: a new model of the Time-Varying Ionospheric Electric field*
Xueyi Wang	University of Warwick, University of Tromsø, International Space Science Institute	*Wavelet determination of magnetohydrodynamic-range power spectral exponents in solar wind turbulence seen by Parker Solar Probe*
Nicholas Brindley	University of Southampton	*Intermittent turbulence in fine-scale auroral structure*
Gemma Bower	University of Leicester	*Identification of geomagnetic disturbances*
John Coxon	Northumbria University	*A geomagnetic storm case study of Birkeland current timescales*
Tom Daggitt	British Antarctic Survey	*Chorus wave power at the strong diffusion limit overcomes electron losses due to strong diffusion*
Rowan Dayton-Oxland	University of Southampton	*Pc1 measurements of EMIC waves are not significantly linked to the acceleration of auroral protons in the cusp*
Kendra Gilmore	Northumbria University	*How important is magnetospheric time history for predicting auroras?*
Shannon Killey	Northumbria University	*Mapping the evolution of relativistic electrons during geomagnetic storms*
Patrik Krcelic	University of Southampton	*Local Joule heating profile near small scale auroral features estimated from high resolution electric fields*
Adrian LaMoury	Imperial College London	*Magnetic reconnection in Earth's turbulent magnetosheath: Exhaust structure and heating*
Andrea Larosa	Queen Mary University of London	*On the relation between switchbacks and turbulence in the inner heliosphere for different types of solar wind*
Christian Lao	UCL Mullard Space Science Laboratory	*On the robustness of a new global index of solar wind-magnetospheric coupling*
Georgios Nicolaou	UCL Mullard Space Science Laboratory	*Determining electron plasma properties from solar orbiter observations*
Jonathan Nichols	University of Leicester	*Jovian magnetospheric injections observed by the Hubble Space Telescope and Juno*
Utsav Panchal	Northumbria University	*An investigation of the helicity barrier effect using Parker Solar Probe*
Abid Razavi	University College London	*Investigating electron energisation across interplanetary shocks in the solar wind*
Natalie Reeves	University of Birmingham	*Understanding the sensitivity of TIE-GCM's forcing parameters*
Andrey Samsonov	UCL Mullard Space Science Laboratory	*Magnetospheric response to a southward IMF turning in the dayside and nightside magnetosphere*
Jasmine Sandhu	Northumbria University	*Results from the survey of bullying and harassment in the MIST community*
Hannah Trigg	University of Birmingham	*Highly detailed observations of symmetrical quasi-periodic oscillations with LOFAR*
Domenico Trotta	Imperial College London	*Observations and modelling of accelerated particles at interplanetary shocks in the inner heliosphere*
James Waters	Aix Marseille Univ, CNRS, CNES, LAM, Marseille, France	*Evaluating remote auroral kilometric radiation observations as a classification and predictive tool for substorms*

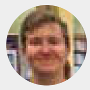
AUTHORS



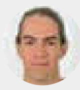
Beatriz Sanchez-Cano is an STFC Ernest Rutherford Fellow and lecturer at the University of Leicester and member of MIST council, working on planetary space physics mainly Mars and Mercury space weather.



Emma Woodfield is a member of MIST council working as a Radiation Belt Modeller at the British Antarctic Survey investigating these extremely energetic regions on Earth and the outer planets.



Sam Rennie is a PhD student at the University of Leicester studying the occurrence and spatio-temporal characteristics of ultra-low frequency waves in Earth's magnetosphere.



Diego Moral-Pombo is a PhD student at Lancaster University studying magnetospheric and auroral dynamics at Jupiter.

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Q&A

Kate Bond Assistant archivist, RAS Library

Sue Bowler talks to Kate Bond, new assistant archivist, who casts a fresh eye over the RAS collections

What do you like about your role at the RAS?

I am thrilled to work for an organisation that has learning as its ethos. I pinch myself every day I walk through the gateway of Burlington House. To work for a Society that is at the centre of astronomical research and to come into contact with the Fellows, their work and achievements is pretty special. I do not come from a scientific background and need to learn a huge amount to understand the context and history of the items I handle, something that I am enjoying. A world where there isn't the capacity to learn anymore would be a very boring place. I am also struck by how friendly and welcoming everyone here has been to me and really appreciate working for such a happy place. Most importantly, the collection is fascinating and I don't think I will ever stop feeling excited when I turn over a letter and realise whose signature is at the bottom of it. You have such a wealth of material here and it is a privilege to work with it.

What are you working on at the moment?

As I write, an actor is in the library researching the life of Sir John Herschel for the RAS 'Eyes on the Universe' schools workshops at Slough Museum. I'm also getting out Sir John's letters as foreign secretary for the RAS in preparation for an exhibition at the Royal Society in June. As this year is the 150th anniversary of the RAS arriving at Burlington House, we would like to fully catalogue that year of correspondence to see exactly what we've got. There are so many letters from interesting people, and not all of them are from astronomers. I recently found a letter from Cumberland Clark, aka the Bard of Bournemouth, widely considered Britain's second worst poet of all time! In an ideal world we would like to digitise the collection to allow access for a global audience – it would be great for research across so many disciplines.

Do archives matter in the modern world?

An archive isn't just an historical entity that fits a heritage brief but has a real job in supporting the modern-day functions of societies and organisations. Digitisation appears to bring information within everyone's grasp, but it does in fact leave it in far greater danger of loss, either through easy deletion, or technological obsolescence.

"Digitisation appears to bring information within everyone's grasp, but it does leave it in greater danger of loss, either through easy deletion, or technological obsolescence"

Tell us about your career so far...

It hasn't taken a straight line. I was a history student at Durham University, but serious illness completely scuppered me for about five years. When I recovered, I did a few jobs just to get back to working, before moving to France with my then-husband. After five years, my job moved to the USA, I moved back to the UK and he moved to Ireland! I started from scratch again, volunteering at Wandsworth Heritage Services and at Putney Library. I did library shift work, while also working at an art gallery, on market research and occasionally in a pub. I so enjoyed volunteering in the archive at Wandsworth, I wanted to make a career out of it. I started with full-time work at Bromley Central Library in Historic Collections, which gave me experience handling documents and working with the public. While working, I began post-graduate studies to train as an archivist with Dundee University. I was completely ruthless with my time, spending holidays completing my coursework and studying eight hours a day on my days off. This was hard, but worthwhile; I was promoted to archivist after I had qualified. The main museum collection at Bromley comprised the papers of Lord Avebury (Sir John Lubbock), the son of the RAS Fellow, Sir John William Lubbock. I had a great fondness for Lubbock, mainly because of his lobbying to create bank holidays and for trying to teach his dog to read. I get very excited when I see letters from his father in the RAS collection, even though it seems most are about leaving personal belongings behind or not returning items from the library.

What did you want to do when you grew up?

I wanted to be an air hostess when I was very small! Those were different times, when flying seemed very glamorous. The archivist's trolley could be the link; subconsciously I could be giving out metaphorical 'snacks and drinks' to the thirsty minds of researchers. But no actual gin and tonic in the library, I'm afraid.

What's the best thing you've ever found in an archive?

When you have a researcher who needs to find a definitive answer and an item from the collection provides this, it's a wonderful feeling. I've danced round the room when some uncatalogued material I've dug out provides the data or evidence that is needed.

And the worst?

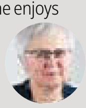
Water coming though the roof! In second place, I once found a rat's jaw in a box of slides brought in by a member of the public. Luckily the jaw did not come with the rest of the rat.

What careers advice would you give to a young person?

Not to panic! If you asked me what I was going to do when I was 18, I wouldn't have known. Do a degree that you will be good at and that you enjoy. Do not be downcast if the only job you get initially isn't what you dreamed of doing – use it for money, experience and gaining confidence. In your spare time, volunteer or study in something that you are interested in and you will soon find a job that suits you better. You are also networking by volunteering, meeting the right people who can offer guidance and who will mentor you. I am forever thankful to the wonderful Emma Anthony at Wandsworth Heritage Services who had me as her volunteer not so long ago. ●

AUTHOR

Kate Bond is the newly-appointed assistant archivist in the RAS Library. She enjoys outdoor swimming, walking, exploring museums and art galleries, and has



been trained in plumbing and use of semi-automatic weapons. **Sue Bowler** is Editor of *A&G*, and will in future be on her best behaviour when in the Library.