THE OBSERVATORY

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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2025 December 12 at $16^{h}\ 00^{m}$
in the Geological Society Lecture Theatre, Burlington House

Mike Lockwood, *President*
in the Chair

The President. Good afternoon, everybody. This is a hybrid meeting for those of you who are on-line and using Zoom. Questions will be taken at the end of the lecture, but you'll be muted on Zoom, so please use the Q&A facility. We'll read out your question to the meeting.

For today's programme we start with Dr. Louise Devoy, who's Senior Curator at Royal Observatory Greenwich, our once great Observatory, and you might see a rather wonderful pamphlet and some rather wonderful-looking books that she's going to tell us about, I'm sure. Over the past five years Louise has delved into the archives and museum stores to choose 100 objects and their stories for her book *The Royal Observatory Greenwich: A History in Objects*, published to celebrate the Observatory's 350th anniversary in 2025. Louise has a background in astrophysics and the history of science and has worked at various museums in the UK and abroad. Her research interests encompass astronomical instruments, women in astronomy, and networks of knowledge exchange between historic observatories.

Dr. Louise Devoy. Today, I have been tasked with the seemingly impossible challenge of trying to condense 350 years of astronomy, navigation, and timekeeping at Greenwich into just 20 minutes, so bear with me as I try to make this happen and give you a flavour of this unique site in our special anniversary year.

To help me do that, I'm going use my book, *Royal Observatory Greenwich: A History in Objects*, which came out in 2025 October and has all those narratives in much greater detail. It's based on the stories of 100 objects, mostly from RMG [Royal Museums Greenwich] collections, arranged in chronological order from our origins in 1675, with each object described in around 350 words. I wanted to ensure that it wasn't just the famous clocks and telescopes but a whole range of objects, many of which have never been photographed or displayed before. I hope you will enjoy the diversity of objects, both familiar and new.

As you'd expect, it starts with our founding story, at the height of the so-called 'quest for longitude', which began centuries before the Observatory itself. Astronomers and mathematicians had long realized that we could measure longitude at sea using the Earth's rotation. By comparing local times and their associated longitude differences between locations, mariners could make trade routes quicker, safer, and more profitable. Two key ideas emerged: comparing astronomical events as seen simultaneously from two locations, or else taking a timekeeper to sea and comparing local time against the known time elsewhere. Those two challenges shaped the Observatory's work for the next three centuries and form the backbone narrative of the book as we see how astronomers, mathematicians, clockmakers, and instrument makers persevered to make it work.

I also wanted to show that the Observatory is not just about instruments, it's about people, and so you'll encounter a wide range of characters, from the Astronomer Royal and his family to the assistants, teenage human 'computers', and the wider London community of clock and instrument makers. Their endeavours were made possible by objects such as an insulated observing suit [Fig. 1], calculation templates, a hole punch for assembling papers, and even a fork for extracting spider silk for creating micrometer wires! Many objects also bear witness to the Observatory's involvement with various eclipse and transit-of-Venus expeditions, along with Nevil Maskelyne's pioneering experiment in 1774 to measure the density of the Earth by observing the stars either side of a Scottish mountain.

Another objective in writing this book was to highlight the Observatory's growing remit and widening expertise in the 1800s as it became a research centre for measuring terrestrial magnetism, meteorology, and solar activity. Like many other observatories, Greenwich became part of the movement towards astrophysics with the adoption of spectroscopy in the 1860s, albeit with limited results. In the 1890s, the Observatory became a participant in the global International Astrographic Survey (*Carte du Ciel*) that created the first professional roles for women at Greenwich.

The book also highlights the Observatory's continuing use of new technologies to ensure the distribution of accurate Greenwich Mean Time (GMT). In 1833, Astronomer Royal John Pond installed a roof-top time-ball to provide mariners waiting on the Thames with a visual time signal to rate their chronometers before heading out to sea. In the 1850s, accurate GMT was made more widely available *via* electric impulses from the Observatory's Shepherd Motor Clock [Fig. 2]. Those time signals were transmitted *via* telegraph networks that shadowed the country's growing railway network, making GMT an essential part of daily life. By the 1920s, accurate GMT was made available *via* radio signals, firstly as the BBC's 'six pips' broadcast and later as the 'GBR' long-wave transmission from Rugby in Warwickshire.

On a global scale, the Observatory was becoming increasingly important as a reference for 0 degrees longitude. By the 1880s, politicians and business leaders were calling for consensus among the 11 meridians in use, leading to the International Meridian Conference in October 1884. My object in focus here is the Airy Transit Circle [Fig. 3], which was one of the most advanced instruments at the time and helped sway the decision to adopt the Greenwich Meridian as Prime Meridian of the World and as the starting point of the Universal Day.

As we enter the 1900s, we find the Observatory having to cope with the effects of the First World War, leading to diminished staffing and a focus on military priorities such as increased chronometer testing for the Admiralty and a decrease in astronomical research. The story of a pair of binoculars serves as reminder of the secret testing programme in which Greenwich astronomers restored and tested over 3 000 pairs of donated binoculars for military use.

In the 1920s we return to horology with three objects that chart the technological changes in defining time standards in the 20th Century. We start with the Shortt free-pendulum clock: a two-part system consisting of a primary clock with a pendulum suspended in a partial vacuum tank connected to a secondary pendulum clock that were synchronized *via* electric impulses every 30 seconds. That created a very stable and consistent pendulum swing that revealed tiny variations in the Earth's rotation — previously measured as constant — that heralded the end of our 250-year dependence on pendulum clocks for timekeeping standards. The narrative continues with an early experimental quartz frequency standard to represent the transition away from astronomical to laboratory methods of timekeeping and then culminates with an atomic clock from the 1970s that became a standard feature of many observatories worldwide.

A set of lantern slides depicts the relocation of the Observatory's Magnetic Department to Abinger in Surrey as the London site suffered electrical interference from nearby railway lines. Similarly, a slitless spectrograph that saw limited service on the 36-inch Yapp Tele-

Fig. 1

Trousers and jacket, once belonging to 5th Astronomer Royal Nevil Maskelyne, composed of a silk outer layer with lining from linen and wool and with additional cotton wadding to create a quilted effect. This and other images as well as more information are available at `https://www.rmg.co.uk/collections/objects/rmgc-object-534404`. © National Maritime Museum, Greenwich, London.

Fig. 2

From 1852 to 1893, this motor clock sent time signals *via* telegraph wires to many cities in the British Isles and by 1866 even to Cambridge, Massachusetts, *via* the new transatlantic submarine cable. This and other images as well as more information are available at `https://www.rmg.co.uk/collections/objects/rmgc-object-79636`. © National Maritime Museum, Greenwich, London.

FIG. 3

Airy's transit circle. This and other images as well as more information are available at `https://www.rmg.co.uk/collections/objects/rmgc-object-11153`. © National Maritime Museum, Greenwich, London.

scope during the early 1930s helps us appreciate the deteriorating observing conditions at Greenwich as the astronomers battled against air pollution and vibrations from surrounding industries.

After the Second World War, the rural location of Herstmonceux Castle, East Sussex, was chosen as the new home of the Observatory's departments with the staff and instruments gradually relocated over the course of a decade. The historic site at Greenwich became part of the National Maritime Museum and continues to attract over 600 000 visitors each year. We're proud to celebrate 350 years of pioneering science, incredible engineering, and remarkable people at Greenwich and we're excited for our future project, First Light. Over the next few years, we will transform the site to make those objects and their stories even more accessible and engaging for future generations — come and visit!

Dr. Quentin Stanley. It's a wonderful book and thank you for signing my copy. [Laughter.] The actual honour of manning the last observing run of the Airy Transit Circle fell to the late Fellow of the Society, Gilbert Satterthwaite, and he was very much part of the RO's history there. It was a great loss to the Society when he passed away. The timing ball where the mechanism failed: there was the observer at the time who was using a clock in the city to set the time to drop the ball, and the person in the city was using the timing ball to set the clock so you had this recursive drift in time. What will be the next thing we will see that can bring that back to life for us in the changes you're working on at the moment?

Dr. Devoy. We've had to close the south part of the site at the moment which includes our planetarium and our education centre. The historic north part of the site is still open and hopefully will be for another year or so. Then I think we will have to close the site completely at some point, but we're hoping to re-open around 2028. There will be new galleries, and we will have our usual stories, of course, and our Meridian objects as well. We're trying to weave in new elements to bring the objects to life, whether that's using projection, sounds, or digital effects, because at the moment some of the spaces can feel quite sterile, particularly in the Meridian building. We really want to bring those spaces to life a lot more as well. There is also a general trend across many museums that have slightly fewer objects on display, but to tell their stories in a slightly more interesting way, so we're definitely working on those principles as well.

Mr. Horace Regnart. The tragedy of Admiral Shovell and the development, both financially and controversially, of the Harrison clocks, the best of which was accurate to a second both here and in the Caribbean. Is that outside the ambit of your work?

Dr. Devoy. No, it's very much part of our Longitude gallery. The Shovell disaster less so, but Harrison, absolutely. Harrison is a pivotal moment in the stories. They will still be on display, don't worry.

Mr. Regnart. So another time can you come back and give us a lecture about that?

Dr. Devoy. Potentially.

Mr. Regnart. Please! Thank you.

The President. Sir Cloudesley Shovell reminds me of how far we've come, as does Annie Maunder, because she got her first from Cambridge; she sat the exam but couldn't be given a degree. I'm afraid it's to the shame of this Society that Edward had to present the papers because she wasn't allowed to. It just reminds me how far we've come.

Dr. Devoy. Yes, she had a lot of support as well, and, at least, she had her name on the sunspot catalogue, which is great.

The President. She was a big friend of Everett, wasn't she? One more question please.

Mr. Geraint Day. The National Maritime Museum itself doesn't charge for visitors but the Observatory does which seems to be rather unfortunate. It may not be within your remit, but it could be good idea if it is.

Dr. Devoy. It has always been charging since I've joined but I believe yes, it was free at one point. I think when it was free, there was a question around wear and tear on the site because there were over 1 million people [per year] trying to squeeze through Flamsteed

House. It was doing huge amounts of damage; it's an ancient scheduled monument. It has the the highest status in the land, so it's a difficult balance between trying to make it accessible and engaging for everyone, but also generating some income to pay for the maintenance because there is just literally so much wear and tear on the site. We feel we have to charge, but it's difficult, I agree.

The President. I think we should thank Louise again. [Applause.] The next speaker is Go Murakami. Murakami Sensei is an Assistant Professor working at Institute of Space and Astronautical Science (ISAS) in Japan Aerospace Exploration Agency (JAXA). He is the Project Scientist of the ESA–JAXA joint mission *BepiColombo* for the *Mercury Magnetospheric Orbiter*, *Mio*. His science expertise is solar–terrestrial physics, plasma physics, and planetary atmospheric science. He got his PhD from The University of Tokyo in 2011. Then he worked at JAXA/ISAS as a research fellow between 2011 and 2017 for developments and observations of Japanese ultraviolet space telescope *Hisaki* and the *BepiColombo* mission. In 2017 he got the current position at JAXA/ISAS. The title of his talk is '*BepiColombo* — the ESA-JAXA joint mission to Mercury'.

Dr. Go Murakami. In today's era of intensifying planetary exploration by various nations, Mercury remains a planet shrouded in mystery. Beyond the inherent difficulty of placing a spacecraft into Mercury's orbit, the intense solar radiation experienced in orbit and the powerful albedo and thermal radiation reflected from Mercury's surface make it an extremely challenging planet to explore. Consequently, the only previous orbiter successfully to enter Mercury's orbit was NASA's *Messenger* spacecraft in 2011. *Messenger*'s numerous discoveries fundamentally changed Mercury's status in planetary science, establishing it as a unique observational target. However, limitations on the instruments that could be carried by a single spacecraft and the constraints of an orbit confined to the northern hemisphere left many unresolved questions. The *BepiColombo* mission aims to tackle Mercury's remaining mysteries through comprehensive observations by its two spacecraft *Mio* and *MPO* [*Mercury Planetary Orbiter*]. It seeks to advance our understanding of the Solar System's planets, particularly the terrestrial planets, focussing on their 'origin', 'evolution', and 'environment'.

One of Mercury's most striking features is its massive metallic core, which occupies approximately 80% of the planet's diameter. That is significantly larger than the cores of Earth, Venus, or Mars, which range from 40 to 50%. Furthermore, despite being the closest planet to the Sun, *Messenger* discovered that Mercury's surface mineral composition contains far more volatile elements than expected. While various proposals have been made regarding its unique planetary-formation process, none can explain all those features, leaving them still unexplained. Conversely, that indicates that unravelling the formation process holds a crucial key to understanding planetary formation, including Earth's. Even on Earth, the nature of the original solid rocky material remains unclear. The answer may not lie on Earth, which has been profoundly altered by planetary evolution, but rather on Mercury, which strongly retains traces of its primordial state. By deciphering Mercury's geological and compositional information through *MPO* observations, we can approach the mystery of the origin of terrestrial planets.

Another major feature of Mercury is its magnetic field. Mercury possesses a magnetic field believed to originate from its fluid metallic core, with a strength approximately one-hundredth that of Earth's. Among the terrestrial planets, only Earth and Mercury currently possess intrinsic magnetic fields. Prior to that discovery, the prevailing theory held that "the interior of Mercury, the smallest planet in the Solar System, had long since cooled and solidified, and thus possessed no intrinsic magnetic field like Earth's". Why has Mercury managed to retain its magnetic field? That major mystery in the planet's 'internal' evolution process fundamentally changed the significance of Mercury as an exploration target. Furthermore, *Messenger* observations revealed that the magnetic equator is shifted northward by about 20% of Mercury's radius. However, due to orbital constraints, no data exists for the southern hemisphere, making that a projection based solely on observations from the northern hemisphere. Simultaneous multi-point observations by both *Mio* and *MPO* can eliminate solar-wind–induced disturbance components. Furthermore, their north–south symmetric orbits enable more precise measurements of Mercury's intrinsic magnetic field than *Messenger*, encompassing the southern hemisphere. By capturing the information leaking out from Mercury's interior *via* its magnetic field, we can decipher the evolutionary process of that enigmatic solid planet.

Mercury, the closest planet to the Sun, exposed to intense solar wind and possessing a weak magnetic field, forms the most dynamic magnetosphere in the Solar System. Furthermore, its small size and weak gravity result in a thin atmosphere, creating a stage for complex physical processes unique to Mercury where gases from the solid planetary surface directly interact with outer space. In such an 'enironment' how much does Mercury, which forms a barrier called a magnetosphere, actually suffer from solar-wind effects? That perspective has become a crucial issue not only for traditional magnetosphere and space-plasma physics but also for the search for 'a second Earth' especially now that numerous exoplanets orbiting very close to their stars have been discovered. Japan has consistently led the world in Earth magnetosphere exploration. Applying those observational technologies, the *Mercury Magnetospheric Orbiter (Mio)* is the first spacecraft dedicated specifically to observing the Mercury environment. It has the potential to advance dramatically our understanding of how stellar winds affect planetary environments *via* the magnetosphere.

The President. Thank you very much. Questions?

Professor Kathy Whaler. Thank you, really interesting talk. What's the nominal lifetime of the mission once it's started the science phase?

Dr. Murakami. The nominal science period is one year, after eight years' cruise, but of course, we are already planning to extend it.

Dr. Bob Barber. A question about that diagram that you gave, the core, the outer region of the mantle, and you talked about impact. It seemed that the ratio of the diameter of the core to the outer region, was normal. What was missing was the mantle, which is consistent with an impact.

Dr. Murakami. In order to make such a huge core, if we assume the same origin of the materials as Earth's, then we need also a similar size of the planet as Earth. Then after the generation of the core there should be some kind of impact to remove the amount of surface materials.

Professor John Zarnecki. A comment rather than a question. When *Bepi* was originally selected by ESA, which I think was around 2000, it still had a small lander. It's always painful when I see it like that because I had a small instrument on the lander. Sadly it was for financial and technical reasons that it was de-selected.

Mr. Stewart Coulter. It's often said that a minority of astronomers both professional and amateur have seen Mercury. I saw Mercury a couple of months ago. At an early-morning swimming I saw the pre-separation from Australia very easily. I just wonder if I might add to those anecdotes by inviting the audience to put their hands up if they have ever seen Mercury. [About 65%.] Thank you, and if you have not? [About 35%.] Right. So it is the majority of this audience who have seen it. That's interesting. Thank you very much.

The President. Our next speaker is Dr. Lina Hadid from the Observatoire de Paris. Since 2020, Lina has been an astrophysicist and research scientist at the Laboratory of Plasma Physics (LPP), École Polytechnique / CNRS, in France. Her research focusses on studying the microphysical and macrophysical plasma processes in the solar wind and planetary magnetospheres. She analyzes wave and particle measurements in a variety of planetary environments, including Mercury, Earth, Venus, and Saturn, as well as in the solar wind, adopting a comparative-planetology approach. She is the lead of the *Mass Spectrum Analyzer* (*MSA*) onboard the ESA/JAXA *BepiColombo* mission to Mercury. She is also the PI of the Mars *Mass Spectrum Analyzer* (*MSA*) for ESA's M7 mission *M-MATISSE* (*Mars Magnetospheric ATmosphere Ionosphere and Space-weather SciencE*), a multi-point mission to Mars currently in Phase A (2026). In addition to her role in *BepiColombo* and *M-MATISSE*, she has contributed to several international space missions, including the *Cassini* mission and the *JUICE* and *Solar Orbiter* missions. Lina earned her MSc from Paris-Saclay University in 2013 and her PhD in astrophysics from the Laboratory of Plasma Physics at the École Polytechnique in 2016. She was a postdoctoral research fellow at the Swedish Institute of Space Physics in Uppsala (2019) and later at ESA's European Space Research and Technology Centre (ESTEC) in the Netherlands in 2019, before joining CNRS as a permanent research scientist at LPP in 2020. Lina is going to tell us about 'The ESA/JAXA *Bepi Colombo* mission on its way to Mercury: initial plasma observations during the cruise phase'.

Dr. Lina Hadid. Thank you much for that very nice introduction and thank you as well to the organizing committee for the invitation. I'm very honoured to be here and very happy to share with you some of the initial observations from *BepiColombo* during its cruise phase. I will be focussing mainly on the plasma observations, but also on the ion observations. Of course, the results I will show are results of collaborations among many instrument teams.

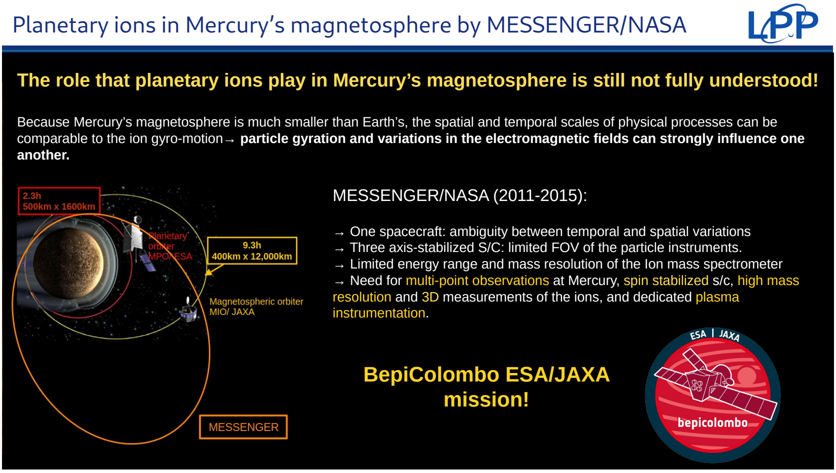
Mercury is the innermost planet in our Solar System, and it's the only planet other than Earth that has an intrinsic magnetic field; however, it's weaker than Earth's but also, unlike Earth, Mercury has an extremely thin exosphere. It is composed mainly of hydrogen, helium, oxygen, sodium, potassium, and other metallic species and originates from the surface of the planet. Those exospheric neutrals get ionized under the effect of the solar EUV radiation, and subsequently they are trapped along the magnetic field around the planet and form those ions that circulate in the magnetosphere of Mercury. Those ions can escape to the solar wind, but some of them return to the surface in the process called ion recycling. The very close proximity of Mercury to the Sun and the weak magnetic field lead to a very dynamical and highly compressed magnetosphere in comparison to Earth, and, in addition, the lack of an atmosphere leads to a much more direct space weathering of the surface, especially under extreme solar-wind conditions. There is very tight coupling between the solar wind, the magnetosphere, the axis, and the surface of the planet.

The first observations of the ion compositions in the magnetosphere of Mercury were performed by the mass spectrometer *FIPS* on board the NASA Orbiter *Messenger* (*MErcury Surface Space EnviroNment GeochEmistry and Ranging*). That identified the presence of light ions, such as protons and He^+, in the magnetosphere, but also the presence of heavier ions, maybe oxygen-group ions and sodium-group ions, and *FIPS* also showed the spatial distributions of those ions. It revealed that the He^+ ions have a more even distribution around the planet, implying probably a much more uniform source of those species *via* evaporation. However, the heavier ions, maybe the sodium-group and the oxygen-group ions, showed a non-uniform distribution around the planet with distinct peaks around the planet.

Despite those very important observations, *FIPS* could not really distinguish the detailed ion composition within those sodium-group ions because of the low mass resolution. So the sodium-group ions included sodium ions, magnesium ions, potassium, and calcium. It was not possible to measure the cold ions below 100 eV per charge.

We still have a lot of unanswered questions and mysteries to solve. For example, the detailed ion composition around Mercury and the link of those ions to the surface, and also the role that those planetary ions play in Mercury's magnetosphere — especially since, as I mentioned, Mercury's magnetosphere is much smaller than Earth's, and so the spatial and the temporal processes at Mercury can be compared to the ion gyro-radius, and the particle gyration and variation in the intermagnetic fields can strongly influence each other.

NASA's first orbiter *Messenger* was only one spacecraft, so it was impossible to disentangle the spatial from the temporal effect. It was also a three-axis stabilized spacecraft, so we have a very limited field of view of the particles, naturally because the spacecraft is not spinning. In order to understand in detail the coupling between the solar wind and this highly dynamical magnetosphere and also to understand the feedback of the surface, we need to have at least two-point measurements. We need to have spin-stabilized spacecraft as well to be able to



Planetary ions in Mercury's magnetosphere by MESSENGER/NASA

The role that planetary ions play in Mercury's magnetosphere is still not fully understood!

Because Mercury's magnetosphere is much smaller than Earth's, the spatial and temporal scales of physical processes can be comparable to the ion gyro-motion→ **particle gyration and variations in the electromagnetic fields can strongly influence one another.**

MESSENGER/NASA (2011-2015):

→ One spacecraft: ambiguity between temporal and spatial variations
→ Three axis-stabilized S/C: limited FOV of the particle instruments.
→ Limited energy range and mass resolution of the Ion mass spectrometer
→ Need for multi-point observations at Mercury, spin stabilized s/c, high mass resolution and 3D measurements of the ions, and dedicated plasma instrumentation.

BepiColombo ESA/JAXA mission!

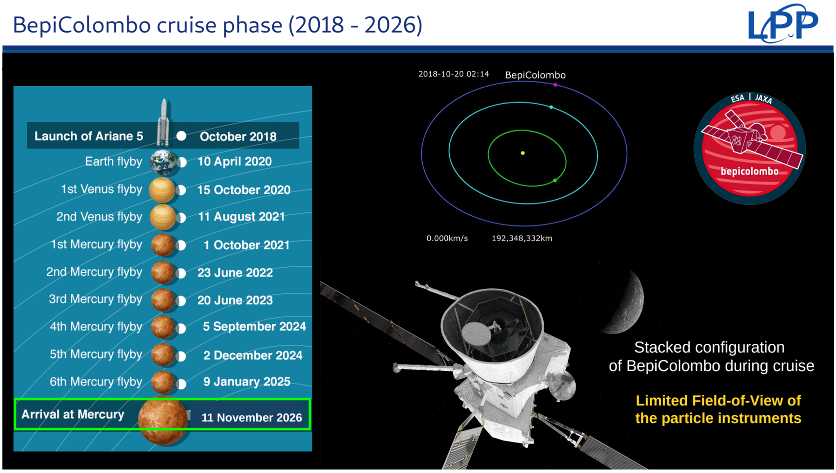
Fig. 4
Orbits of *MPO* and *Mio*.

have a 3-D distribution of the particles and we also need to have high mass resolution for the spectrometer to distinguish the heavy ions from each other, and, of course, we need to have a dedicated plasma instrument to understand in detail the plasma processes in Mercury's magnetosphere and the effect on the atmosphere and the surface, and *vice versa*. That is the goal of the *BepiColombo*, ISAS/JAXA mission.

This is just a sketch here [Fig. 4] showing the orbits of *MPO* (*Mercury Planetary Orbiter*), ESA's contribution, and the magnetospheric orbiter's (*Mio*) contribution. And just for comparison, I added here the *Messenger* orbit, which has a much larger eccentricity, and so with *Messenger* we could observe more closely, for example, the northern pole, but we could not really observe the southern pole and the southern hemisphere.

With those two orbiters, we hope to understand and characterize this coupling between the solar-wind magnetosphere and the surface of the planet. As Go has mentioned, we are currently ending the cruise phase and we are preparing for the orbit insertion in November next year [2026]. During those eight years, *BepiColombo* has performed nine fly-bys, first one around Earth, two around Venus, and six around Mercury, the last one being earlier this year [2025] in January. During that cruise phase the configuration of the spacecraft is very particular: it's in a so-called stacked configuration. So you can see here [Fig. 5] the *Mio* spacecraft inside the *MOSIF* sunshield attached to the planetary orbiter *Mio* and both of them on the *Mercury Transfer Module*; despite that very particular configuration and despite the fact that some of them are not operational, most of them have a lot of opportunities for nominal observations. For example, the particles instrument onboard the magnetospheric orbiter has a field of view which is very limited and we are looking into the sky within just one or two windows. Despite those constraints, we have very interesting observations that give us a preview of the very exciting results that we will get after orbit insertion.

This is just the trajectory of only the Mercury fly-bys here [Fig. 6], in the meridinal x–z plane and in the azimuthal x–y plane. So here you see only five fly-bys — in fact the fifth one actually does not appear here because the closest approach was further away from Mercury. The first three fly-bys were equatorial and they were extremely important for us because in the nominal phase, as I showed earlier, the orbits of *MPO* and *Mio* are polar, so those were



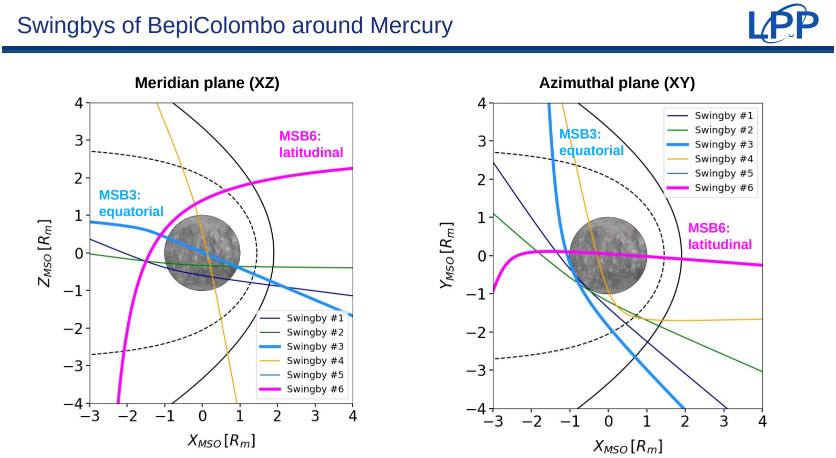
BepiColombo cruise phase (2018 - 2026)

Launch of Ariane 5	October 2018
Earth flyby	10 April 2020
1st Venus flyby	15 October 2020
2nd Venus flyby	11 August 2021
1st Mercury flyby	1 October 2021
2nd Mercury flyby	23 June 2022
3rd Mercury flyby	20 June 2023
4th Mercury flyby	5 September 2024
5th Mercury flyby	2 December 2024
6th Mercury flyby	9 January 2025
Arrival at Mercury	11 November 2026

Stacked configuration of BepiColombo during cruise

Limited Field-of-View of the particle instruments

FIG. 5
Configuration during cruise phase.

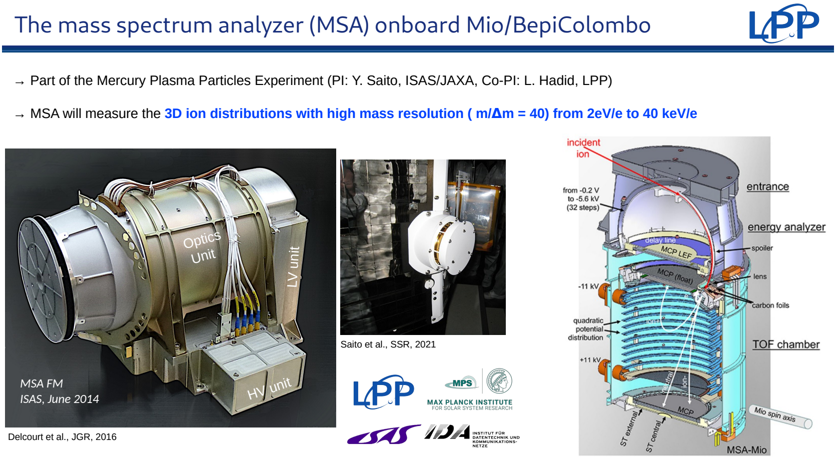


Swingbys of BepiColombo around Mercury

FIG. 6
Swing-bys of *BepiColombo* around Mercury.

the only kind of opportunities that we could have on an azimuthal cut of the magnetosphere of Mercury. On the fourth fly-by and the sixth fly-by, they were highly polar as you can see in the meridian plane, but different. The sixth fly-by, for example, crossed from the day side to the night side. And what I will be showing later are the observations from one equatorial fly-by, the third one, and one highly polar fly-by, the sixth one.

I will show you mainly observations from the *MSA* onboard the magnetostatic orbiter *Mio*. It's part of a particle consortium, and *MSA* is a time-of-flight spectrometer and the goal is



The mass spectrum analyzer (MSA) onboard Mio/BepiColombo

→ Part of the Mercury Plasma Particles Experiment (PI: Y. Saito, ISAS/JAXA, Co-PI: L. Hadid, LPP)

→ MSA will measure the **3D ion distributions with high mass resolution (m/Δm = 40) from 2eV/e to 40 keV/e**

Delcourt et al., JGR, 2016

Saito et al., SSR, 2021

FIG. 7
The MSA aboard *Mio*/*BepiColombo*.

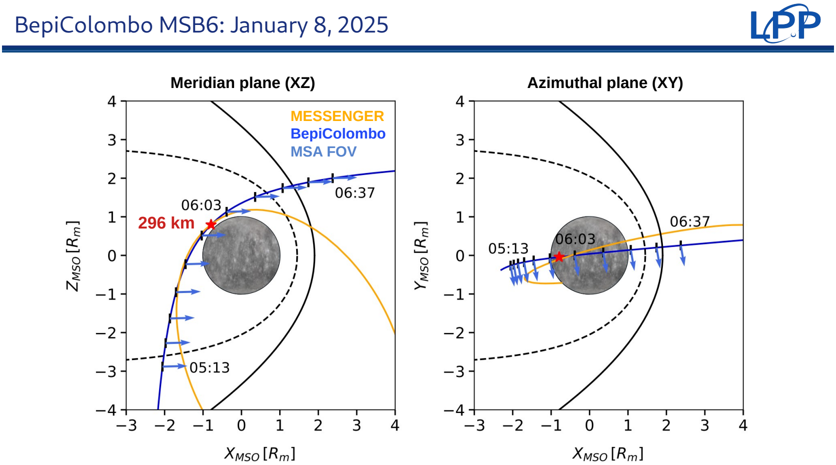
to measure the 3-D distribution functions of the ions with a very high mass resolution and between a few eV and 40 keV; it can actually can be seen as a mini consortium because it's an international collaboration between different institutes. In LPP we have developed the optics unit and then Max Planck Institute provided the high-voltage power supply, ISAS/JAXA provided the detector-electronic units inside the low-voltage box here, whilst IDA provided the DPU.

This is just a sketch [Fig. 7] here showing the cut, and you can see the inside of the optics in it, which consists of an electrostatic analyser that filters the ions with specific energies. And then we have a time-of-light chamber with a very particular design that allow us to have Dirac functions for the ion species and distinguish between sodium and magnesium, for example. We have two electron analysers, one ion analyser, and the mass-spectrum analyser. I will show you observations from those four, but also we have a high-energy–ion detector, a high-energy–electron detector, and an energetically neutral analyser as well. The PI is Yoshifumi Saito from ISAS/JAXA.

The third Mercury fly-by occurred on 2023 June 19. During that fly-by *BepiColombo* crossed the magnetosphere of Mercury from the night side to the day side and from dusk to dawn. And the closest approach was about 235 kilometres. What was particular about that fly-by is that it offers a synoptic view of the large-scale structure and ion composition of Mercury's magnetosphere.

As expected, the energy–time spectrograms for ions and electrons are very similar; then we have the electron observations. I do not have time to go into all the details here, but, by looking at the particle data and the ions, we could distinguish the boundary crossings as *BepiColombo* flew by Mercury. We could actually see the inbound bowshock crossing.

Looking at the very narrow-band signature due to the outgassing of the spacecraft, we could see a small jump at the inbound bowshock crossing. But we also see a clear boundary which is the inbound magnetopause crossing, after which we see a clear dispersion signature in the ions ranging from a few tens of eV per charge up to 40 keV, and we interpreted that region as the low-latitude boundary layer. Then as *BepiColombo* approached Mercury around the closest approach, the ion detectors observed a very clear signature of about 20-keV ions.



BepiColombo MSB6: January 8, 2025

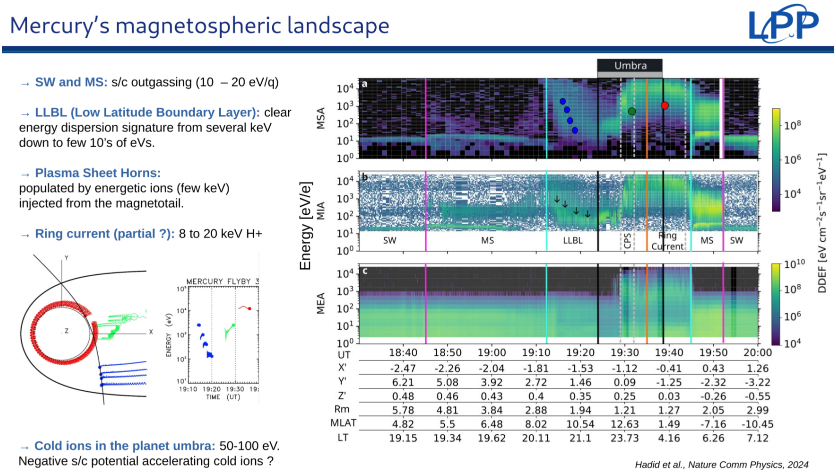
Fig. 8
Sixth Mercury fly-by.

We interpreted those as the detection of a partial ring of a ring current; whether it's partial or full, it's very hard to tell, and it is still debated. We need to wait until we get the nominal phase to study that in detail.

Now in addition to this large-scale picture of Mercury's magnetosphere and different regions, the goal of *MSA* we also want to pursue is to characterize the ion composition, but during the cruise phase we are operating in low mode, so we have that information integrated over only about 17 minutes and so we have the information of the ion composition but integrated along six segments.

And along those 17 minutes or so after the low-latitude boundary layer inside the magnetosphere, *MSA* detected cold ions about few 100 eV/e, mainly protons but also alpha particles, and also some signatures of heavier ions including sodium, and a very weak signature of potassium or calcium ions. After this closest approach here the instrument detected signatures of energetic atoms, about a few KeV protons and He^+, but also sodium ions and some heavier ions. Now this was actually for the third fly-by, which was more of an equatorial view of the magnetosphere. Here I want to show you observations from the fly-by which occurred earlier this year in January [Fig. 8]; the trajectory was completely different; it was highly polar. *BepiColombo* crossed dawn to dusk and from night side to day side.

This slide [Fig. 9] shows a latitudinal-cross-section observation of Mercury's magnetosphere, specifically the centre of its plasma-sheet region, where we clearly detected cold protons and ions down to 10 eV per charge for the first time cold potassium and sodium ions very clearly and with distinct distributions along the central plasma-sheet region. But we also see that the plasma is highly dynamic and what I want to show here is that we do observe this kind of dispersion signature in the ion data. In the first panel, we observe heavy elements and protons recorded while *BepiColombo* was connected to closed magnetic-field lines; these specific signatures are consistent with those typically observed at Earth. They represent bouncing ion clusters, so ions that bounce back and forth on the closed magnetic-field line while drifting around the planet. And it's the first time that we could see them at Mercury. So in the end, similar processes are induced in the terrestrial planets and those actually reflect some injections from the tail towards the polar latitudes of the planet.



Mercury's magnetospheric landscape

→ **SW and MS:** s/c outgassing (10 – 20 eV/q)

→ **LLBL (Low Latitude Boundary Layer):** clear energy dispersion signature from several keV down to few 10's of eVs.

→ **Plasma Sheet Horns:**
populated by energetic ions (few keV) injected from the magnetotail.

→ **Ring current (partial ?):** 8 to 20 keV H+

→ **Cold ions in the planet umbra:** 50-100 eV.
Negative s/c potential accelerating cold ions ?

UT	18:40	18:50	19:00	19:10	19:20	19:30	19:40	19:50	20:00
X'	-2.47	-2.26	-2.04	-1.81	-1.53	-1.12	-0.41	0.43	1.26
Y'	6.21	5.08	3.92	2.72	1.46	0.09	-1.25	-2.32	-3.22
Z'	0.48	0.46	0.43	0.4	0.35	0.25	0.03	-0.26	-0.55
Rm	5.78	4.81	3.84	2.88	1.94	1.21	1.27	2.05	2.99
MLAT	4.82	5.5	6.48	8.02	10.54	12.63	1.49	-7.16	-10.45
LT	19.15	19.34	19.62	20.11	21.1	23.73	4.16	6.26	7.12

Hadid et al., Nature Comm Physics, 2024

FIG. 9
Mercury's magnetosphere.

I mentioned ions, but we also have the electron observations. Those are the time spectrograms for all the five. With five different fly-bys, we can say that we have five different magnetospheres.

The *BepiColombo* cruise phase was not limited to the planetary fly-bys; it also it contributed to heliospheric science. And we showed the importance of the cruise science and we could study the evolution of the properties of the solar wind taking advantage of the presence of operational spacecraft in the inner heliosphere with *Parker Solar Probe* (*PSP*) and *Solar Orbiter*. *BepiColombo*, and other L1 probes and so we could study, for example, the evolution of turbulence as a function of the Sun as observed by *BepiColombo* and then *Solar Orbiter*. We had a recent paper, an overview of all the solar energetic-particle events, CME events observed by multiple spacecraft including *BepiColombo* and that's another very important example. It seems that it's the strongest SEP event for the solar cycle 2025 detected by *PSP* and *BepiColombo* and other spacecraft further away from the Sun.

During the cruise phase, we had exciting observations around Earth, Venus, and Mercury. We have at least 50 publications from the fly-bys alone. Not only has *BepiColombo* showed the importance of cruise science to be able to perform measurements in the solar wind when there is no dedicated mission at those distances, and it's important not only for calibration purposes of the instrument, but those observations gave us a tantalizing preview of all the exciting science that could be done during the normal phase, so we are ready now to explore Mercury. Thank you.

The President. Steven, your hand is up before I even ask!

Professor Steve Miller. The light species hydrogen and helium. Are they being captured from the solar wind or are they breakdown of molecules from the surface of Mercury?

Dr. Hadid. It's very difficult to distinguish the origin of the protons, whether it's the solar wind or the surface. We know that there's hydrogen on the surface, but it's very difficult to distinguish the He$^+$; it can evaporate from the surface, but it can come from the interstellar medium.

Professor Monica Grady. Just to follow up on that question from Steve, can you detect deuterium?

Dr. Hadid. I don't think so with *MSA* because we don't distinguish the charges of the ions. We assume it's a singly charged ion.

Professor Grady. But it would have a mass of two. You're measuring ^{2}H then, are you?

Dr. Hadid. Good question!

The President. I wondered if with the cold ions that you see, is the lower limit set by the spacecraft potential?

Dr. Hadid. Yes, actually it will be very challenging for us to observe a few eV per charge. It's a big question.

The President. I just wondered if the appearance of cold ions in certain regions was actually a spacecraft-potential modulation.

Dr. Hadid. In the first fly-by in the shadow region, the spacecraft potential got very low and then it was very interesting because of the change of the potential of the spacecraft; it became negative. So we could actually start tracking. In the end they are accelerated.

The President. Ultimately, I love the boundary-layer dispersion, that there's all sorts of information you can get out of that. Thank you very much indeed. That was lovely. [Applause.]

Our last speaker today is Dr. Paola Pinilla from Mullard Space Science Laboratory. She obtained her BSc and MSc in her country of origin, Colombia. She did a PhD at Heidelberg University in Germany and held several positions before joining UCL, including: a post-doctoral researcher at Leiden Observatory, a NASA Hubble Fellowship at the University of Arizona, and an independent group leader at the Max Planck Institute for Astronomy. Her research interests focus on understanding the first steps of planet formation using theoretical models and observations of young stars. Paola also enjoys working on topics related to equality, diversity, and inclusion. She was recently awarded an ERC starting grant, the 2024 New Horizons in Physics Prize, and the 2025 Royal Astronomical Society Price Medal. So I think you're going to tell us about 'How planets are made of star stuff'. Thank you.

Dr. Paola Pinilla. Thank you so much for the invitation. It's a great honour for me to be here and thank you so much also from the planet-formation community for giving us the Price Medal. Today I'm going to tell you about what I have been working on in 15 years of research since I started my PhD.

It was only three decades ago that the only planets that we knew were those in our Solar System. The Solar System is actually a quite well-organized system; it has the terrestrial planets inside, then the giant planets and the ice giants. It was in 1995 that we discovered the first exoplanet around a solar-type star and that was 51 Pegasi b. That really opened our eyes to a new world because that planet is as massive as Jupiter, but much closer to the star than Mercury to the Sun, so it's a hot Jupiter. We don't have such planets in our Solar System and since then, the number of planets that have been discovered has increased enormously.

In 2009 the campaign was launched with *Kepler*, and by 2016 we already had more than 1000 exoplanets discovered. In 2018 we had the launch of *TESS* (*Transiting Exoplanet Survey Satellite*), another space mission using the transit method to discover exoplanets. Now in 2025, we have more than 6000 exoplanets. Many of those exoplanets don't have a representative in the Solar System, such as hot Jupiters. There are planets like mini-Neptunes and super-Earths that also are very common but we don't have such planets. We believe that, at least in our Galaxy, every star hosts a planet. Nevertheless, we still don't know how planets form. I like to think about planets like like human beings: we are very diverse and our properties and who we are probably depends our infancy. We are trying to do that in the field of planet formation and to understand where they're born, how they are born, and how the properties and the physical processes of those first steps of planet formation impact the diversity that we see in the exoplanets.

Everything starts with a molecular cloud and in those molecular clouds some regions can become very dense and that happens when there is a gravitational collapse, so the molecular cloud cannot be pressure-supported any further. As a result of that collapse, a protostar is formed and in that process, thanks to the conservation of angular momentum, the disc remains around that new star. Those are called protoplanetary discs and it is in those discs we believe planets are formed. The lifetime of that disc is around one to ten million years and after it dissipates we have a planetary system like our Solar System. The star will continue evolving, and eventually, for example, it might end in a supernova explosion that will enrich the interstellar medium and complete the cycle.

We cannot reverse the clock of our Solar System, so to help us to understand our planets and other planets we need to study young stars that are a million years old that have those discs. We believe that initially they have the properties of the interstellar medium, so 99% of it is molecular hydrogen and 1% of that material is dust and it should be cosmic dust. That consists of sub-micron-sized particles that collide and then grow to pebbles, millimetre- then centimetre-sized particles, and then eventually to planetesimals, asteroids, and planets.

That disc dissipates by different mechanisms and observations have shown us that they live between five and ten million years and that the giant planets like Jupiter should form before the disc is gone, so before all the gas is accreted onto the star. Other planets form also within that time, but they still have time to form later after the discs dissipate. Observations have shown us that those discs can have a diverse range of sizes up to 1000 astronomical units (AU) whilst the most common ones are around hundreds of AU and because of that, they span a large range of temperatures, from thousands of kelvins when close to the star to a few kelvins at the edge. Because of that we can observe in a large range of wavelengths from optical to centimetre wavelengths; that's one of the very cool things about the first steps of planet formation, because actually we can see those interstellar dust particles and those dust patterns because the dust dominates the disc opacity and most of the information that we have from planets forming in those days comes from the dust emission.

A disc is shaped like a piece of cheese: it's not completely flat, but it's wedge-shaped. What we believe is that small grains and micron-sized particles are everywhere following the gas. They can be in the surface of the disc because turbulence pushes those grains up to the surface and the light that comes from the star will reach the surface and the particles that are there, that are small, will scatter. We can actually see the distribution of micron-sized particles through the optical wavelengths to the near infrared from scattered-light observations.

Observations of protoplanetary discs with the *Very Large Telescope* with an instrument that is called *SPHERE* (*Spectro-Polarimetric High-contrast Exoplanet Research*) show beautiful structures in these discs such as spiral arms and rings and gaps and some shadows. On the other hand, we can also observe the patterns in the disc. They are expected to be settled to the mid-plane and for that we need to observe the disc at millimetre and centimetre wavelengths and therefore we use radio telescopes. The *Atacama Large Millimeter Array* (*ALMA*) in Chile has revolutionized the field. There are observations with *ALMA* of these protoplanetaries showing that they are not smooth, but they also have quite a lot of sub-structures. Because we can observe those processes of planet formation, those first steps of planet formation from the growth of micron-sized particles to millimetres, we can actually test our models with the observations.

I have been working on modelling: how do particles grow and move in a disc? We model together the transport of the grains and the collisions of those particles, because when particles move in the disc, they can meet other particles, and depending on the relative velocities between particles, they will stick, they will fragment, or they will bounce. There are different physical processes that can move the particles in a disc such as Brownian motion, like here in this room we have small particles that are moving randomly. That happens also in discs but it affects only the very small grains. Then we have turbulence and the grains can move vertically and radially due to that turbulence. We have the effect of gravity that moves the grains towards the mid-plane of the disc and then we have a very important physical phenomenon that is called radial drift. That comes from the fact that the gas is pressure-supported while the dust is not. So while the dust is moving or trying to move in

Keplerian velocity, the gas doesn't move, and as a consequence of that there is a constant head-wind that particles feel and they lose angular momentum and move towards the star.

That was known as the radial-drift barrier in planet formation because the drift time-scales are much faster or they are much shorter than the times that the particles need to grow to pebbles or planetesimals, so we didn't know how planets actually form or how to overcome the radial-disc barrier. And just to show you how that looks, what you will see in this calculation is a particle that starts small in the interstellar medium, 80 AU from the star.

This particle grows due to collisions, it grows in the disc, but once it reaches a certain size, it goes to the star very fast. That was the drift problem and we didn't know how to solve it and in 2012 I was trying to solve that barrier. We propose that the disc, instead of having a smooth pressure gradient, because it's the pressure that changes, that produces variations, we have variations in the pressure that can retain particles, and this is a simulation of gas evolution. It's the grain size and then it's distance from the star, but now we have a lot of grains. So we have a dust density and we have a disc that is not smooth, but it has variations of pressure and in that case, those variations of pressure comes from the interaction of the disc with the magnetic field from the star, and at million-year time scales, we do have grains trapped in those regions of high pressure. We propose that if we have high angular resolution at millimetre and sub-millimetre wavelengths of that type of structure, we will see rings and gaps around the young star, and as I showed you before, that is what we observe now with *ALMA*.

Another thing that can create those pressure pumps is that we have already planets in the disc. If a planet is very massive, it will create a huge gap in the gas surface density. Probably this one is. The planet located at 28 AU is a giant planet and we have a huge gap in the gas surface density that creates a gigantic pressure trap outside. As before, we created synthetic images of that type of simulation and we predicted that if a giant planet was there in the disc we would see a ring-like structure around the star. In observations with *ALMA* one can see how similar they are. We use so-called transition discs that have large cavities to look for baby planets that are forming in those discs.

You can imagine how excited I was in 2018 when we actually discovered the first protoplanet inside a disc and that was in the system called PDS 70. The *ALMA* observation of that disc shows a ring-like structure with two giant planets and emission from a circumplanetary disc. It is at this point where moons are forming. We are still looking for baby planets because they give us the chance to look at planet formation in action.

In summary, what I have explained so far is that we have been focussing on understanding the first steps of planet formation. The initial conditions of the disc are that particles start with micron-sized particles which then collide and grow to bigger objects. We know that we have disruptive collisions and small grains are replenished continuously in the disc and we see from scattered-light observations that we have plenty of small grains in those discs. The ones that grow are expected to drift very quickly toward the star, unless we have a particle trapped in the disc that can come from different regions and we study in detail what those physical phenomena can be that can create those pressure traps. It could be planets, but it could be other phenomena. We came from giant planets by the agglomeration of those objects: if a giant planet is formed, then it can itself be a particle trap because it can create a gap in the disc and help with the formation of the next planet.

I'm going to give you two beautiful examples of that. One comes from recent observations of the *James Webb Space Telescope* and that gives us amazing spectra of the inner regions of protoplanetary discs in the mid-infrared where water emits a different frequency, so we can actually observe the amount of water that is inside the first AU of these protoplanetary discs. One of the amazing results that we have obtained with these data from *JWST* is that there are compact discs that don't have a structure, don't have traps which show high water abundances in the inner disc. That agrees with the fact that if pebbles that are ice-coated are drifting towards the star, once they reach the snow line — that is the region where the water evaporates — they enrich the inner part of the disc with water and we are observing that. On the other hand, discs that show traps and that are extended show low water emission, consistent with the idea that pebbles are being retained in the outer parts of the disc. So those pressure traps have a direct impact on the composition of planets that are forming in regions where the Earth was formed.

Another result is that those traps can also help for the formation of macro-molecules that is very important for matter that is needed for hosting life. What happens is that in those traps fragmentation of particles also happens and those small grains can go to the surface of the disc because they have direct irradiation from the start, they have the right temperature to form those complex molecules. Observations have shown that there is a correlation with the emission of complex molecules and the locations and the existence of those traps. It seems that they really play a role also in the conditions for hosting life.

I'll finish with a short description of a couple of large programmes that I have been involved with in the last years. One is the *ALMA* large programme AGE-PRO which consists of more than 100 observations to trace systematically the evolution of the gas, its mass and size throughout the lifetime of protoplanetary disc. Gas is the main component of discs and is very important for the formation of giant planets, but it's very difficult to observe directly. The reason is because the main component is molecular hydrogen, but it's very difficult to excite at the temperatures of discs and because it lacks a dipole, we cannot really directly observe it. We rely on other molecules that are also abundant like CO_2 to understand how the gas is distributed in the disc, but there are a lot of chemical reactions happening in that disc. We need to observe different molecules to be able to reconstruct how much gas emission there is.

Why is gas so important? Many of the processes that I mentioned before affect the dust; the transport and the collisions depend on the gas distribution because all the dynamics of the particles is dominated by the gas. We need to know how much gas there is in those discs to understand all of those dynamics that I showed you before. In addition, it tells us if we can form gas-giant planets, ice giants, super-Earths, or other type of planets in that disc.

For that we selected 30 protoplanetary discs that are in different star-forming regions that have different ages. We selected ten in Ophiuchus that are younger than one million years, ten in Lupus that are between one and three million years, and ten in Upper Scorpius that are the latest phases of protoplanetary discs. We narrowed the spectral type down to solar-type stars between 0·3 and 0·8 solar masses, so those stars will evolve. We didn't have any binaries in the system to bias our sample. Some young discs in Lupus have masses that are higher than the minimum solar nebula, meaning that they can form systems like our Solar System and several of the Ophiuchus and Lupus areas have masses between Jupiter and the minimum-mass solar nebula, meaning that they have the potential to form planets like Jupiter and also some in Lupus, but they don't have any masses as high as Jupiter.

In this year we got another large programme with *ALMA*. It's called DMOST and is focussed on understanding the discs around M dwarfs as those are very important because they are the most common stars in our Galaxy. The frequency of Earth-sized planets in habitable zones appears to be higher in M dwarfs, so it's very interesting to understand also what are the first steps of planet formation around those objects. What is also very interesting is that some giant planets have been found around those objects, even though it's very difficult to explain the formation from models. In this project we are going to observe 14 protoplanetary discs; that is a small number but it's because they are very small and faint. What we want to do is to measure the gas and dust disc size and compare with models of the vertical structure. That type of information will tell us what kind of planets can also form in that disc. We will also measure the gas mass and are looking forward to getting those observations. We just got the *ALMA* proposal accepted, so it will take some time to get the observations.

The exoplanet field is growing; we have so many space missions that will increase our knowledge about exoplanets. The UK is highly involved with missions like *PLATO* and *Ariel*, and *Gaia* also will give us DR4 next year. That will supply astrometric information and will perhaps be enough to detect thousands of cool giant planets. The future for exoplanets is very bright in the next decade.

We have more than 6000 exoplanets with a large range of properties and so far we really don't know what is the range of that diversity. We want to understand the first steps of planet formation to see if that has an impact on what we observe in exoplanets. One of the main results is that those are not smooth and there is sub-structure and those sub-structures are also diverse. So they can meet even later with the diversity that we see also in exoplanets. Those sub-structures have actually a key impact on the composition of the inner disc where planets like Earth are being formed, and also the origin of micromolecules in discs that are essential for the formation of life.

The President. Questions for Paola?

Dr. Daniel Heyner. I thought the gas at the mid-plane of the protoplanetary disc wouldn't be ionized, so I was surprised to hear that magnetic fields would be responsible creating pressure variations. Could you elaborate on that?

Dr. Paola Pinilla. I know there is no answer to that. It is related also to the dust because the dust can transport ions in the disc, especially very small dust and that can help to reionize the disc. So that's why it's important to understand the fragmentation process of particles because depending on that you have different small grains within the disc that can change the disc ionization. So yes, ionization, especially because of the transport of ions to the small grains, can create pressure variations.

Dr. Ted Parton. Thank you. Excellent talk. Is it possible that you think that between stars there are small gas and dust clouds that are capable of forming planets, the cold planets that we may never see? You know *JWST* has seen some JUMBOs [JUpiter-Mass Binary Objects] which are warm. But is it possible that there's lots of material out there which is never big enough to form a star and so it's never going to get hot enough for us to detect?

Dr. Pinilla. That's an interesting question. That is something that we have observed too, there are free-floating planets with masses of five or ten Jupiters and we believe they form like stars and they can actually be gravitationally bounded to a system. That would be a way to form those very cold giant planets very quickly. They would need to be very massive for that to happen and we don't see in those observations of the gas that the discs are so massive. I would say that, if it's possible, it is likely the same process as star formation by which they form. They are ejected and potentially again bounded to a system.

Professor Richard Ellis. It's possibly a related question. This age programme sounds very exciting, but how accurately are you estimating the ages and what's the method, once you get down to ages of less than two million years? You need very precise ages — are you assuming the age of the star?

Dr. Pinilla. Yes, that's a very important question. So we calculate the ages for each system, but there is a large uncertainty. It could be of the order of a million years but because we observe different star-forming regions and we see the accretion rate of that fraction in that star-forming region changing. So we know that there are young star-forming regions and intermediate star-forming regions — the whole cycle.

Professor Phil Charles. There was one comment in one of the slides which I was intrigued by, which is that you said that Earth-sized planets are more common in the habitable zone in the lower-mass stars, and the implication then is that it's less in the case of higher-mass ones like for instance our own. Would you like to speculate on what might be causing that and why it's so different?

Dr. Pinilla. That's a good question; I would need to think about that. It could be biassed, but I understand that that argument is corrected by completeness. Yes, we are biassed by planets that are closer to the stars by the transit method or the velocity method.

Professor Charles. Just a quick follow-up on the related question. This is not my field at all, but the one thing that I did believe happened is that those gas clouds don't just nicely produce one star with a planetary system, that we see many multiple-star formations and huge interactions with them, and yet you have those lovely systems coming out. Things are a lot more complicated than that, aren't they?

Dr. Pinilla. Observations have shown us that binarity increases with the stellar mass. So we expect multiple systems to be more common for stars that are more massive than our Sun, and less common for solar-type stars and for that reason we try to avoid binaries because they actually affect a lot of planet formation. But it's an interesting topic in itself to try to understand how planets form around circumbinary discs. We do all suspect interactions and when we see what you see here is dust, so you don't see it so clearly, but when we see the gas, we can see a lot of potential interaction with encounters in the star-forming regions. Now with *Gaia* that we know locations and velocities with high precision, we can try to go back in time and see how many interactions have happened in this business.

The President. I look forward to the Pinilla–Charles correction to the Drake equation. [Laughter.] Thank you so much. Just a couple of announcements. The licensing situation is not getting solved but it is close to being. It turns out that all our neighbours in the courtyard have a licence, they just didn't tell us, so we're on it, but it's taking time. The next Open Meeting will be on Friday the 9th of January. You are all welcome to attend. I think we should just end with applause for a wonderful set of talks today. [Applause.] Thank you everybody, I look forward to the next meeting.

THE REORGANIZATION OF THE UK ASTRONOMICAL OBSERVATORIES — 'OBSERVATORY WARS'

By Ian Robson

One of the key events in the history of UK ground-based astronomy was the closure of the Royal Greenwich Observatory (RGO) and the Royal Observatory Edinburgh (ROE), to be replaced by the UK Astronomy Technology Centre (UKATC) located on the site of the ROE on Blackford Hill Edinburgh. Although that took effect in the late 1990s, the discussion surrounding the status of the two Royal Observatories had been raging for over a decade beforehand. This is a personal compilation of the history and the reasoning behind that major upheaval, using archival records of the time where available, open-source data, input from colleagues, and personal involvement. I have striven to ensure it is as accurate as I can determine.

Introduction

As we will see, funding, or lack of it, lies at the heart of all the decision-making regarding current and future astronomy developments and as such, there has always been pressure on financial budgets. My introduction to the management side of supporting UK astronomy