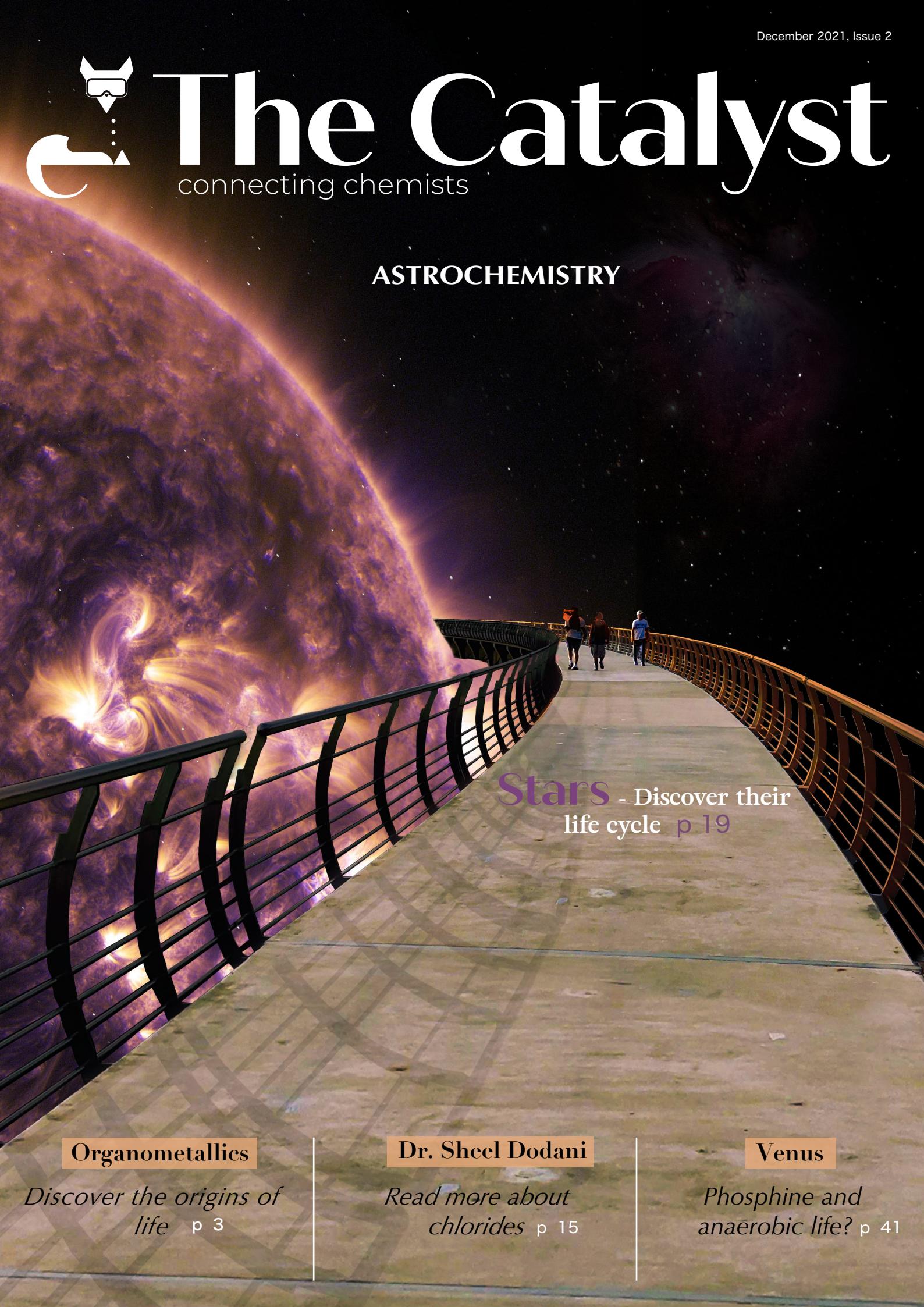




The Catalyst

connecting chemists

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Note from the Co-Founders

Our second edition of The Catalyst is centred around astrochemistry: from the sky we see, to the composition of planet surfaces we cannot see. You will learn about the birth and death of stars, the essential molecules that make up the universe, the possibility of life on a neighbouring planet, and a lot more. If the wonders of space weren't enough, you can delve into the world of plastics and how it has been affected by the pandemic or read about our exclusive interview to Dr. Dodani, a chemical biology expert who is involved in cutting edge research. This issue also features a special collaboration with the King's College London Space Society who have contributed with an intriguing article on the future of mining. We want to thank our writers and proofreaders for making this issue possible with their dedication and curiosity; our editors for bringing lights and colours to each article and our marketing team for constantly promoting us. Finally, we want to thank you, our dear readers, for keeping our dream alive.

Enjoy!

The Founders



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Author: Matt Dagwell

Do we owe our lives to ORGANOMETALLICS?

The theories of the origins of life (abiogenesis) on Earth have been disputed for years, with seven different hypotheses being proposed to date. All of these theories attempt to explain how we came to be on the planet, but are yet to be proven as 100% true. One of the more accepted hypotheses is that of the primordial soup. This was the hypothesis tested in the infamous Miller-Urey Experiment, where the conditions of the early Earth atmosphere - as envisioned by Oparin and Haldane - were tested to see if the building blocks of life such as RNA and amino acids could form. A key molecule thought to be involved in the process of amino acid formation and RNA synthesis is hydrogen cyanide (HCN). HCN, formed from a hydrogen atom covalently bonded to a nitrile group, is believed to have reacted with many of the components found in the atmosphere in the early years of Earth's existence to form the amino acids we know today. This occurs via the Strecker synthesis. Within this synthetic pathway, gaseous HCN and aldehydes react and then condense with ammonia to form an aqueous solution of aminonitriles. These aminonitriles can then be hydrolysed to form the full amino acid, with the variation of amino acid side chains being dependent on the structure of the original aldehyde.

However, one of the main questions asked is where these cyanide molecules came from, with the answer potentially lying in organometallic compounds. Organometallics are compounds containing at least one metal to carbon bond, where the carbon atom is part of a larger organic group. A study published by Smith et al. in 2019, in the popular scientific journal 'Nature' suggested that organometallic compounds found in primitive meteorites could be a place of origin for cyanide molecules bound in organometallic structures. The study looked at the abundance of cyanide compounds in CM chondrites (a class of carbonaceous chondrites), finding that these ranged from 50 ± 1 to 2472 ± 38 nmol/g, whilst also finding that the abundance of these cyanide molecules is influenced by the processing of the parent meteorite. Further analysis of a specific meteorite named 'Lewis Cliff 85311' within this study found the key evidence of the organometallic origin of cyanide molecules primarily in the form of two iron cyanocarbonyl complexes: $[\text{Fe}(\text{CN})_5(\text{CO})]^{3-}$ and $[\text{Fe}(\text{CN})_4(\text{CO})_2]^{2-}$. These two complexes are of particular interest due to their incredibly similar structure to the iron moieties found at the centre of iron and nickel-iron hydrogenases, that are believed to be some of Earth's earliest enzymes and are responsible for the reversible oxidation of hydrogen.

These enzymes - [NiFe] and [FeFe] hydrogenases - are believed to have been found in the early forms of bacteria and archaea; they were used as the first energy producing enzymes on the early Earth and are thought to have played a fundamental role in the evolution of bacteria to the first eukaryotic single cell organism. They function in similar ways by using the metal centre and organometallic moiety of the enzyme redox potentials to both oxidise and reduce hydrogen molecules to produce energy. In both enzymes, structure is imperative for function. Within the [FeFe]-hydrogenase enzyme there are two catalytic moieties that allow for the redox reactions to occur. The structure of the organometallic centre of these catalytic sites allows for these reactions to happen as the CN⁻ ligands bound to the Fe centres form numerous hydrogen bond contacts which stabilise the orientation of the catalytic site. Some evidence also suggests that these ligands contribute to the focussing of the highest occupied molecular orbital (HOMO) at the catalytic site, consequently allowing for the fast electrochemical communication between iron subclusters within the enzyme and thus efficient catalysis.

The carbonyl ligands present on the organometallic centre are able to switch during the catalytic cycle and contribute to the spin state of the iron metal centre, in addition to a bridging carbonyl ligand between the two metal centres allowing for the stabilisation of the low oxidation state of the catalytic site, thus aiding in its redox potential. All allow for this enzyme to produce energy for its host by the redox reactions involving hydrogen.

Overall, the understanding of the role of organometallics in the origins of life is one that requires more in-depth research. Organometallics often play a key role in enzymatic activity due to their incredibly versatile metal centres being able to adopt a variety of oxidation states, thus making them the preferred choice for redox reactions. However, the origins of life on Earth are a heavily debated area of all sciences and have been for many years, but hopefully with future advances in analytical and computational chemistry we will become ever closer to finding the reality behind how we as a species and all other species on the planet came to be.

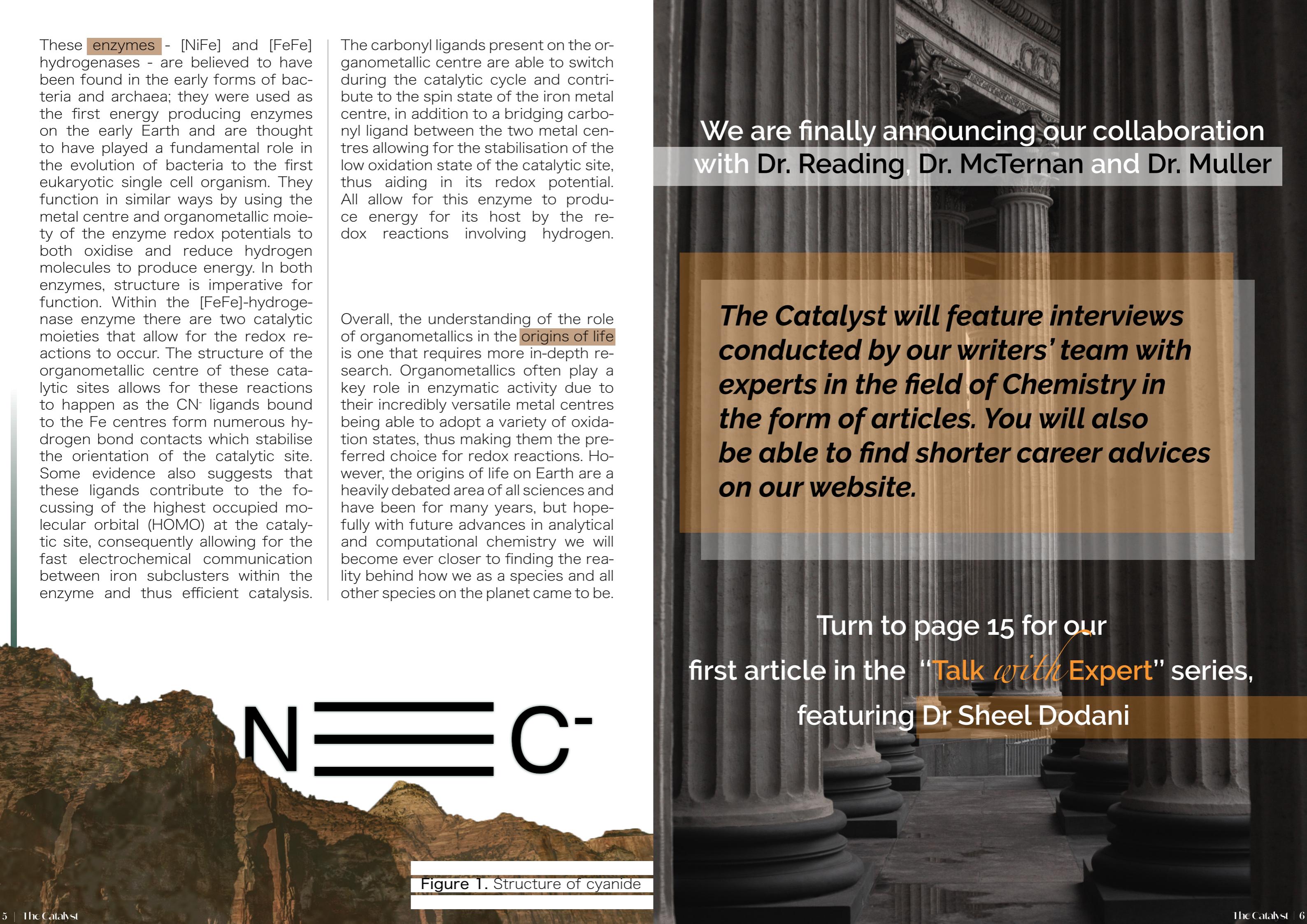


Figure 1. Structure of cyanide

We are finally announcing our collaboration with Dr. Reading, Dr. McTernan and Dr. Muller

The Catalyst will feature interviews conducted by our writers' team with experts in the field of Chemistry in the form of articles. You will also be able to find shorter career advices on our website.

Turn to page 15 for our first article in the “Talk with Expert” series, featuring Dr Sheel Dodani



THE COVID-19 PANDEMIC PLASTIC SHORTAGE:

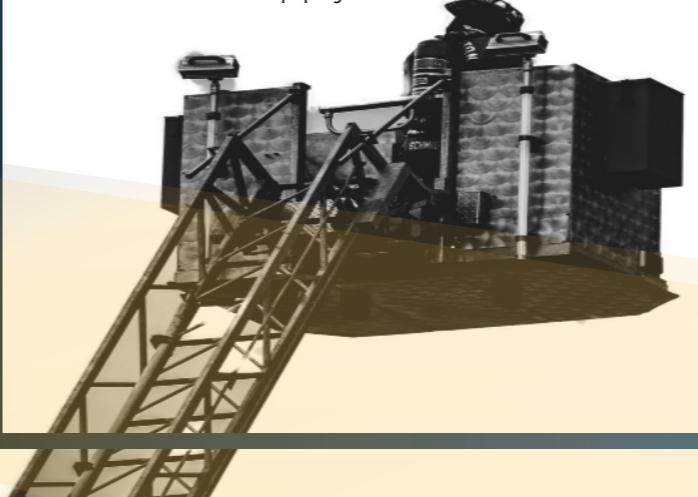
How the Pandemic has Triggered *Demand* for Development of New Plastic Catalysts.



Author: Louis Weiss

With a pandemic battering supply chains and complicating manufacturers and consumers lives, another shortage is complicating our lives even further: plastics. Plastic bags, plastic packaging, plastic medical and lab equipment (among others) are all suffering as a consequence. However, a new chemical catalyst involving the intermetallics of platinum and gallium could change the production of the primary resource of the world's 2nd most used plastic, propylene. This is used to make more than 100 million tons annually, with 4% annual growth, of the plastic polypropylene. Thus, the demand for polypropylene in the food packaging and medical applications market increased during the COVID-19 pandemic, particularly in the US and the UK, who are both large consumers of plastic medical supplies.

During the summer 2020, Covid-19-related lockdowns caused inventory levels to fall. This was followed by Hurricane Laura which shut down a number of petrochemical factories in Louisiana and Texas; overnight, between 10 to 15% of U.S. polyethylene (PE) and polypropylene (PP) production stopped. There followed a plethora of force majeures (unforeseeable circumstances that prevent business from fulfilling their contracts) from big polymer giants, including LyondellBasell in Louisiana and Chevron Phillips Chemical in Texas. By declaring force majeure, these suppliers were relieved of certain supply-delivery



commitments due to circumstances outside their control.

Simultaneously, Covid-19 safety precautions slowed production at many workplaces and caused labour and trucking shortages at ports. The US defence production act, passed in May 2020, allowed the government to tell manufacturers to prioritise selling to those in the industry who are making covid testing kits first (each testing kit using four pipette tips on average with millions produced daily). Add to that the strong economic recovery in Asia, especially China which aims to become self-sufficient in propylene production, and medical/research companies are at pains to secure supplies. Thermo Fisher Scientific, a manufacturer of plastic lab supplies, revealed that since demand started spiking it has invested more than \$150 million in new capacities. Despite this, it still couldn't keep up with the demand as it can take up to a year to start production of a new product! Bringing this all together, the cumulative effect is monumental.

Conventionally, propylene is obtained by cracking petroleum-derived naphtha and is a by-product of ethylene production. To ensure adequate propylene production, an alternative is needed, and non oxidative propane dehydrogenation (PDH) is considered the most interesting process. In literature, the catalysts that have shown the best performance in the dehydrogenation reaction are Cr-based and Pt-based. Chromium has the non-negligible disadvantage of toxicity, while on the other hand, platinum shows several advantages, such as a higher reaction rate and stability. PDH produced 13.6 million metric tons of propylene in 2019, accounting for nearly 11% of global propylene production.

Commercial PDH processes utilize either chromium (Cr)-based (Catofin process) or platinum (Pt)-based catalysts [Olefex and steam-activated reforming (STAR) processes]. This endothermic reaction operates at a relatively high temperature between 550° and 700°C, and atmospheric pressure which increases the equilibrium conversion.

Cracking shale gas to produce propylene by non-oxidative dehydrogenation is inefficient because current catalysts require adding hydrogen to the process. The production also requires harsh temperatures of more than 600°C to obtain sufficient propylene yields, and severe catalyst deactivation is inevitable due to carbon deposition (coke) and/or sintering which renders the catalyst unusable. This can lead to replacement of the catalyst occurring up to every 12 minutes. Catalysts in practical use must therefore be regenerated either continuously or in cycles, making the process inefficient and costly.

A study led by Associate Professor Shinya Furukawa at Hokkaido University's Institute for Catalysis, focuses on the intermetallics of platinum (Pt) and gallium (Ga), which have unique properties and structures. PtGa has a high thermal stability and its structure does not change, even under high temperatures. It is also known to have two kinds of catalytic sites on its surface: a site with three Pt atoms (Pt3 site) and one with single-atom-like isolated Pt (Pt1 site).

The group hypothesised that if the Pt3 sites—which facilitate carbon deposition in addition to producing propylene—are disabled to allow only the Pt1 sites to function, the catalyst shows incredibly high stability and prevents

carbon deposition. The group tried various metals and catalyst synthesis methods to preserve only Pt1 site function.

The newly developed catalyst (PtGa-Pb/SiO₂), which is silica-supported and made by adding lead (Pb) to the surface of PtGa, exhibits no deactivation when dehydrogenating propane at 600 °C. The catalyst maintained the initial conversion rate of 30% for 96 hours after the reaction started, which is significantly more stable than conventional catalysts. Propylene selectivity is as high as 99.6% with few side reactions, including carbon deposition. These results showed that this catalyst produced the world's best performance at temperatures of 580 degrees °C or higher! In particular, its life span is more than twice as long as the previously reported record for longevity with such catalysts. Furthermore, the catalyst can be produced as cheaply as conventional ones. Their structural analysis confirmed that only Pt3 sites were covered and disabled by Pb, as they expected.

The findings could lead to a more efficient and cheap industrial process to produce propylene from propane without the need for catalyst regeneration, by using a new catalyst which is far superior in selectivity and stability than current, conventional catalysts. Moreover, this method could be applied to dehydrogenation of other lower alkanes such as ethane and isobutane, thus contributing to the development of the petrochemical industry at a time when it is needed most!





Author: Sofia Schönauer



Back in the early days of spaceflight, the team at the Jet Propulsion Laboratory (JPL) was searching for the best materials to build its crafts. With a solid background in rocket propulsion and missile building, the way to success was nonetheless through testing and re-testing. Although the JPL scientists weren't uncreative with the stresses and different testing conditions they exposed their work to, hiccups were bound to happen. The goal was to reach where no one had ever been, after all.

Nowadays, there are different methods of ensuring the viability of a rocket or vessel. Not only is there cutting edge technology that wasn't available in the 20th century, but a multitude of space agencies now have access to a satellite in low Earth orbit. The International Space Station (ISS) is the largest man-made satellite in our orbit and has been continuously inhabited since 2000. It serves as a laboratory under special conditions, accessible for scientists of a range of disciplines. Here the microgravity, often mislabeled as "zero gravity" that exists on the ISS allows for experimentation close to Earth. One of the tools available for data collection is an Electromagnetic Levitator, shortened to ISS-EML. It's been used to study a variety of super alloys and semiconductors, with applications in future aircraft engines and industrial processes for aerospace manufacturing amongst others.

The ISS-EML melts and helps investigate the cooling and solidifying properties of metals in various shapes and compositions under different influences such as under vacuum or another gaseous atmosphere. A system of coils generates electromagnetic fields that heat and control the movement of the sample. The name "Levitator", rather unconventional for an analytical tool, comes from the effect microgravity has on liquids, comparable to incredibly high cohesion between the particles, to not flow away but rather stay put. The EML therefore eliminates the need for a container that would capture molten components. A levitating, molten material can give much more accurate data sets for its physical properties, as disturbance factors like standard gravity as well as contact to the container have been eliminated.

Several experiments on specific heat capacities of nickel based superalloys conducted on the ISS-EML attribute higher accuracy to these microgravity results, as well as less measurement uncertainty in comparison to being conducted within the container on the ground under standard conditions. This comparison alone hints at the advantages chemistry has by collecting more accurate data, even if it's just on minor physical properties.

DID YOU KNOW?

The International Space Station orbits the earth 16 times in 24 hours, witnessing 16 sunrises and sunsets.

Data on the material's behavior is also very important. Measuring viscosity or surface energy subject to temperature changes of these superalloys used in craft engines could not only fortify the producer's confidence in his product if his materials ran no danger of changing phase. Another useful application of these properties is the improvement of the additive manufacturing process: building up the material instead of taking away from bulk. As materials can behave very strangely subject to specific triggers, the more data is collected, the sooner and better behavior can be predicted and explained based on precedents. As a result, this could directly improve the design of bottom-up synthetic routes, for example avoiding steps requiring too much energy.

Additionally, these predictions would likely be leading us towards synthesizing new and improved superalloys with viscosity more suited towards the successful and accident-free casting of engine parts.

The conditions on the ISS allow for more grounded theories on life and science in space, which greatly improves space travel, safety, survival rates as well as efficient fund usage. Especially chemistry in space has tremendous potential to be explored to a much greater extent, starting from innovating space travel materials to completely uncharted research limited only by our imagination.



Have you read our first issue yet?

September 2021, Issue 1

September 2021, Issue 1

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THERAPEUTIC CHEMISTRY

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Gases

Discover risks in the household p 7

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Did lockdown help us? p 37

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Talk with Experts

Dr. Sheel Dodani

Assistant Professor at
The University of Texas at Dallas



Author: Paul Amar



Interview WITH DR SHEEL DODANI

The Catalyst, in association with the KCL Chemistry Department Seminar Series 2021/2 is delighted to present the first of an ongoing series of **Talks with Experts**. In this series we sit down with researchers working on the front lines of scientific advancement to delve deeper into their cutting-edge research and gain insight into how they have successfully attained the distinguished positions they hold today. Now, grab a chair and join us on a journey through today's technology and incredible research.

We've all once added NaCl (table salt) to our food to make it taste better, but did you know that there are approximately 115 g of chloride (Cl^-) in your body? Biological receptors that selectively detect and position sodium (chloride's cationic counterpart) have been extensively studied in cell biology. However, anions such as Cl^- are scarcely understood, despite also serving as essential nutrients for life. Dr. Dodani's interest lies in understanding "the who, what, when, where, and why of what anions are doing in living cells." This has wide therapeutic implications because dysregulation of anions is implicated in a plethora of diseases from cystic fibrosis to neurological disorders. To address this and "accelerate biological insights with molecular technologies", the work of Dr. Sheel Dodani is crucial.

Dr. Dodani is an Assistant Professor at The University of Texas at Dallas (UT Dallas), where in addition to teaching various (bio)chemistry courses, she leads the Dodani Lab. Her highly skilled research team is focused on building a chemical biology toolkit, based on engineering turn-on, fluorescent protein-based biosensors for halides (specifically chloride) and oxy-anions. These imaging tools would provide spatial and temporal resolution to help us understand the exact role, location, and mechanisms of anions within our body. On a fundamental level, her research aims to shed light on the thermodynamics and kinetics of anion-protein interactions. Crucial work which Dr. Dodani enjoys because "[...] you never know what you will learn. We do not talk about anions

in our biochemistry classes beyond ATP – my team and I will change that.”

Prior to the inception of the Dodani Lab, the curiosity of Dr. Dodani was piqued in the final year of her PhD, when coincidentally encountering “phosphate being mentioned in a disease”. For her postdoc, she decided to work with anionic modifications. “I studied nitration enzymes [...] and anions kept coming back to me [somehow]! So, I started learning about how you bind an anion in water using molecular tools [...] and I realised that there weren’t many applications inside a living cell.” She and her team have explored small molecule, polymer, and protein-based approaches. “To better design small molecules that can recognize anions in water, we must learn how biological supramolecular hosts or proteins do it!

We use natural laboratory guided evolution to learn about the coordination chemistry of anions and proteins to build functional tools that we can apply in living systems to image anions with fluorescence microscopy.”

Dr. Dodani was next asked for her opinions and advice to students approaching the stage of their careers where they may look to specialise. “You have to be excited and figure how to explore that space somehow. You need to be proactive about seeking out opportunities.” She wished for aspiring chemists to follow their curiosity, find papers that fascinate them, get in contact with fellow chemists and never hesitate to ask questions. She followed with:

“What unifies all the students that join my lab is that they’re fearless and curious.”



Most importantly, she advises “sometimes you just have to jump and not second-guess yourself”. “You’re not going to get every opportunity, but there’s always another door that will open,” is her encouraging advice when faced with adversities. “But if you’re looking for an opportunity and don’t know where to start, think interdisciplinary, [it’s] where we’re going to solve some of the more challenging problems that face the world”.

To conclude the talk, Dr. Dodani elaborated on why she chose an academic career over one in industry and if there was anything she wished she would have known: “I actually got an offer [to go to industry] [...] but I wasn’t ready. I like being around students and academic research,

and wanted to keep exploring. [...] [I asked myself] What do I want to change about the world?

How do I want to make a positive impact on the world and people around me? [...] So, I wrote my proposals and it worked out for me! [...] I’m very lucky to now have the opportunity to do what my professors did for me! I get to work with an awesome team, teach [bio]chemistry and talk about science with students; [...] that’s the best part of my job!” The researcher finishes the interview, sharing some of her wisdom: “You are [constantly] learning on the job. [...] You can’t predict what your path will be versus someone else’s, we all have different challenges [...] and you go through the experience. But I always say two things to my students:

“You need to be *fearless* and you need to be a *sponge*,
but you’re also drinking from a *fire hydrant*. ”

Could we have finally developed a MALE contraceptive?

Many social and political changes to increase women's rights occurred throughout the 20th century. What was once a taboo subject - even illegal to discuss publically in some countries 70 years ago - is now a topic that has been well researched. It's even led to the development of several different methods of contraception with very high success rates of over 99%. However, these methods do not come without their contraindications and effects on their takers. A significant proportion of women who are on contraception nowadays experience many different adverse effects, ranging from headaches over nausea to an increased risk of blood clots to name but a few. So, could it now be time to introduce a form of contraception that men can use?

Before reporting the most recent developments in male contraception it is first important to understand the male reproductive physiology. In men, the production of sperm cells (spermatogenesis) is regulated by the hypothalamic-pituitary-testicular axis which regulates the production of both testosterone and sperm. Many different hormones are released: first is the gonadotropin-releasing hormone that stimulates the pituitary gland to secrete the luteinizing hormone (LH) and follicle stimulating hormone (FSH). The LH then stimulates the Leydig cells found in the testes to produce testosterone whilst the FSH stimulates the Sertoli cells which are necessary in the production of sperm cells. The testosterone produced is then able to

bind to the androgen receptors in the pituitary gland to suppress the release of LH and FSH in a regulated feedback loop, which can then be exploited by scientists to produce contraceptives.

The Most Recent Developments

Led by the University of Washington School of Medicine alongside UCLA, the most recent development in male contraception went into phase one clinical trials in 2019 and showed some promising results. The chemical is called 11- β -methyl-19-nortestosterone dodecylcarbonate (11- β -MNTDC) and functions by mimicking testosterone. It therefore hinders the release of LH

and FSH, thus inhibiting the regulated feedback loop associated with the hypothalamus-pituitary-testicular axis. For the phase one trials, 40 men from across the University of Washington Medical Centre and Los Angeles Biomedical Research Institute took a pill once a day for 28 days. Ten men randomly received a placebo, 14 were given a 200 mg dose of 11- β -MNTDC and 16 were given a 400 mg dose. It was found that within the test cohort, the levels of two hormones required for sperm production dropped greatly compared to the placebo. However, it was also found that due to spermatogenesis taking around 72 days to occur, the pill must be taken for 60-90 days to be effective, with these effects being reversible once administration stopped.

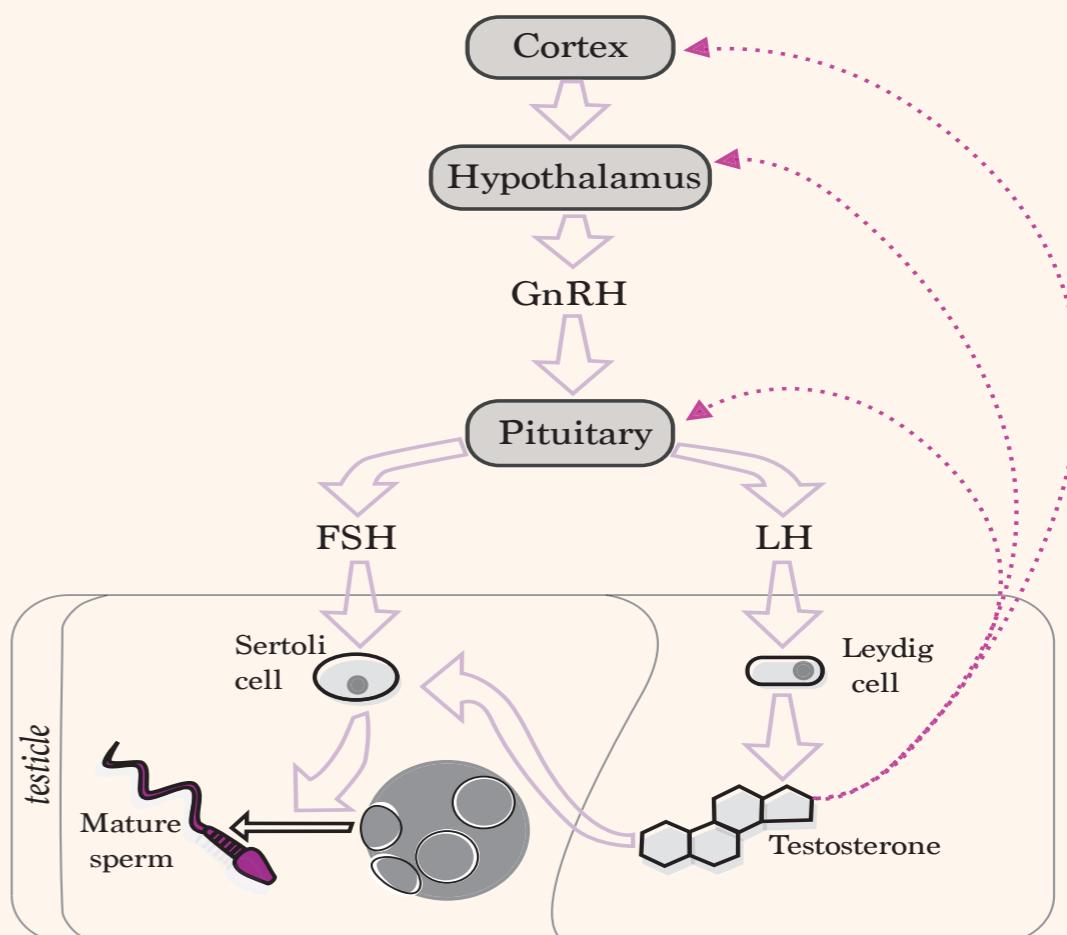


Figure 1. Diagram representing a simplified schematic of spermatogenesis. The dashed lines represent the feedback loop.

Is it safe?

In the case of 11- β -MNTDC a small study carried out by the same institutions on 12 male participants saw them receiving escalated single oral doses of 11- β -MNTDC (100, 200, 400, and 800 mg). They found that the drug was well tolerated without serious adverse effects and that administration with food increased the average 11- β -MNTDC serum concentrations, compared to the serum concentrations in men who were fasting, thus supporting that this drug could be both safe and effective. Furthermore, the side effects reported ranged from fatigue, headaches, acne and weight gain to decreased libido and decreased erectile/ejaculatory function - similar to the side effects often reported by women who use the contraceptive pill as their preferred method of contraception.

So, could this be the future of contraception?

Whilst it is still in the early stages of trials the results for 11- β -MNTDC are promising when looking at its efficacy, safety, and tolerability in healthy male participants. However, it is still very early days in the development of these new male contraceptives. It is yet to be seen how the advancement of these drugs may change in the future and if they will ever reach a large-scale trial or even the pharmaceutical market. So for now, we must sit by and watch with a keen eye, hoping to witness more progress in this field.

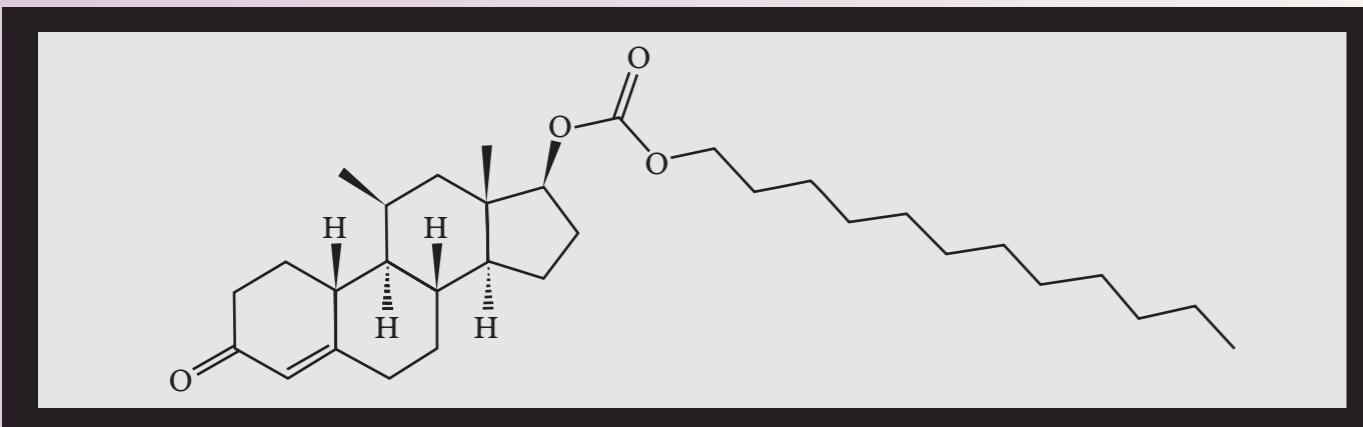


Figure 2. 11- β -methyl-19-nortestosterone dodecylcarbonate



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Life Cycle of a Star

Every star goes through three distinct life stages: birth, nuclear fusion and death. Stars are grouped together by their mass, which determines the types of nucleosynthesis and sudden changes happening throughout their life cycle. We separate small, medium and massive stars to discuss in detail.

The Proton-Proton Cycle

The reaction process that occurs in all stars from their beginnings is the fusion of hydrogen to helium, also known as the proton-proton cycle. Two hydrogens are fused together to give deuterium, with a positron and an electron neutrino produced alongside. Hypothetically the deuterium could fuse with one another, but as the D:H ratio is lower than 10-18, a reaction of deuterium with a proton is much more likely. This fusion releases gamma radiation, which can carry off some of the exothermic energy yield, as well as ^3He . Lastly, the burning helium fuses two ^3He to synthesise ^4He , and regenerates two protons. Each cycle generates roughly 25 MeV of energy. The fusion stage of small-mass stars such as Proxima Centauri, consists of the proton-proton cycle only.

Next Door Neighbour

Proxima Centauri – part of the triple star system called Alpha Centauri – is currently known as the closest star to the solar system, at 4.25 light years distance. It is categorized as a red dwarf, with relatively low mass and dimmed, red light. The red color indicates a much slower burning of fuel, making the nuclear fusion stage last trillions of years. As the hydrogen it runs on is being used up, Proxima Centauri will likely turn into a blue dwarf, similar in size but much brighter and hotter, hence the blue color. There aren't any blue dwarfs to date, as the universe is yet quite young. The death stage will see Proxima Centauri become a white dwarf, retaining its mass, and mainly consisting of helium. Although there are no reactions happening anymore, residual energy from previous nucleosynthesis reactions gives the star its thermal radiation. Presumably, this will fade over time to give a black dwarf, although it too, doesn't exist yet.

one month. The low biodegradability



Did you know?

The pair of Alpha Centauri A and B are quite close together, with Proxima Centauri orbiting them at a large distance.

The Sun

Hydrogen-Low

Massive Stars

The most important medium-mass star in our lives is the Sun. It shines brighter than Proxima Centauri due to the increased mass. The Sun also burns its fuel at a faster rate, lasting about 10 billion years "only" until the hydrogen is used up. When our Sun nears the end of its reserves (in 5 billion years' time), the reactions move to the outer layers while expanding, so it shines brighter and cooler. The increase in size along with the changing color puts stars at this stage in the red giant classification. In contrast to small-mass stars, the Sun can start to fuse helium atoms to carbon and oxygen amongst others, but it too will one day become a white dwarf, losing a lot of mass as plasma through a process called planetary nebula.

Helium fusion happens through the triple-alpha process once the star starts collapsing from the core, to accompany the transition from red giant to white dwarf. During this process, two alpha particles (helium core) fuse together to form ^{8}Be . The beryllium is immediately fused with another alpha particle to give a ^{12}C core, alongside some gamma radiation. This carbon core can fuse with another helium core to give oxygen too. Once the helium is used up, the white dwarf is likely also going to stop radiating from residual energy over time, slowly becoming a black dwarf.

Massive stars have life stages akin to medium-mass ones, going through similar nuclear fusion cycles at the beginning. Their mass is at least eight times that of our Sun, which results in a much hotter and faster burning star. Stars at temperatures over 14 million Kelvin use the carbon fusion cycle, rather than the proton-proton one. This process sees a ^{12}C capturing a proton to fuse to an unstable ^{13}N (as well as gamma rays). This decays to ^{13}C via beta emission. ^{13}C fuses with another proton to give ^{14}N . The same step is repeated to produce ^{15}O , which subsequently becomes ^{15}N via beta decay. Lastly, ^{15}N takes on another proton, producing a helium nucleus and restoring the ^{12}C . After having consumed all hydrogen in about one billion years, the massive star becomes a red supergiant,

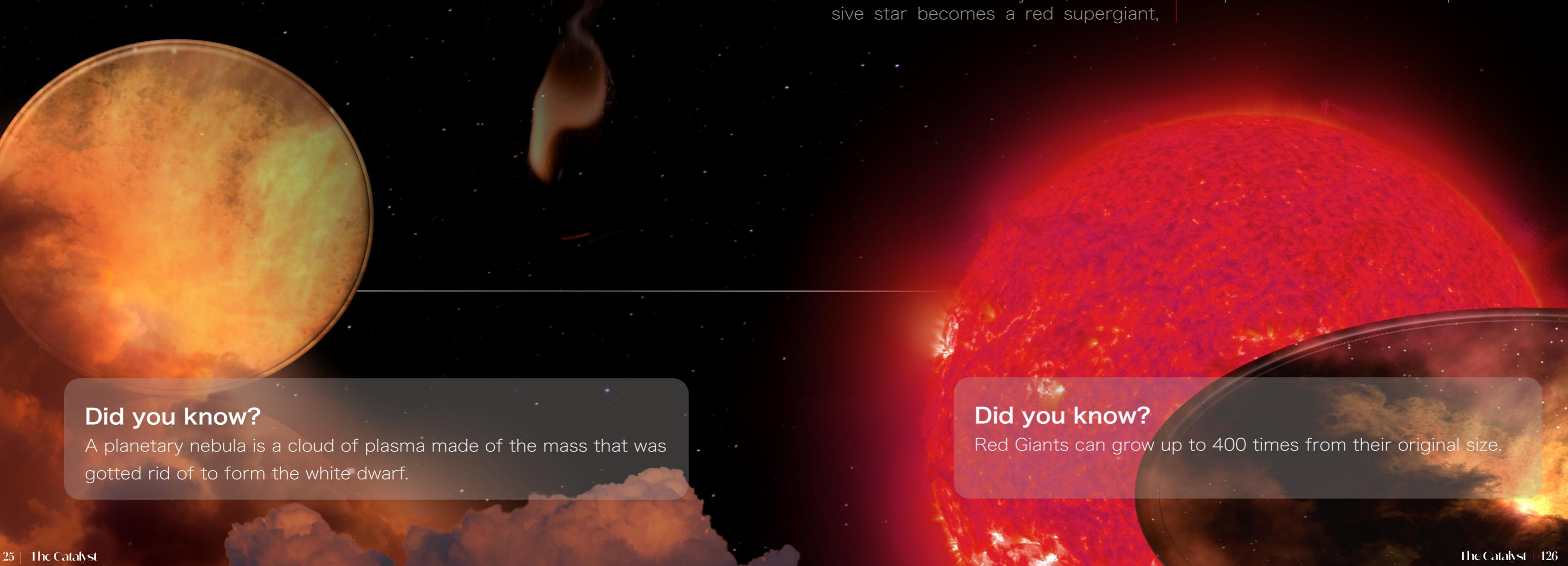
in the same way our Sun will become a red giant. With more mass, the star can reach bigger gravitational pressure, allowing the core to burn at even higher temperatures. This sees not only carbon and oxygen, but many heavier elements up to iron, as well as a few heavier natural elements being produced in the hotter core regions. When the red supergiant ultimately runs out of fuel and nucleosynthesis halts, heat and pressure decrease outwards from the core, and the stellar mass is pulled towards the center by its gravitational force to form a so-called neutron star. This sudden collapse of the core triggers the explosion of the outer part of the star through shock waves set off by compressing and rebounding of that neutron star: a phenomenon called supernova.

Did you know?

A planetary nebula is a cloud of plasma made of the mass that was gotten rid of to form the white dwarf.

Did you know?

Red Giants can grow up to 400 times from their original size.



Supernova 2008D

Iron releases no energy when being fused, while fusions of smaller nuclei are exothermic and bigger nuclei only release energy during fission. It makes iron the most stable of all nuclei, and would be the natural endpoint for fusions in red supergiants. The largest stars can produce heavier nuclei through a process of successive neutron capture. Neutrons taken from interactions between helium and neon can be captured to make heavier nuclei than iron. This usually occurs during a supernova explosion, where the high temperatures and incredible force cause collisions with successful neutron capture. Unstable isotopes of heavy elements are created, which decay to some natural, stable elements - a process that would not have been possible before the explosion, without melting the nuclei in the process of further fusing iron with helium. The first supernova that was observed during the explosion through serendipity, was called SN 2008D.



A Live Universe

The remains of any supernova can present themselves in different shapes. One is the neutron star, which only retains a fraction of its original mass - comparable with that of a small or medium heavy star, while having a diameter of a few kilometers. Alternatively, if the neutron star's mass exceeds about three-fold that of the Sun, the mass becomes too great to resist its gravity, and collapses into itself. This collapse continues until a point where the speed of light would be needed to escape the pull of gravity: the event horizon. Light past it travels too slowly to escape, thus it wouldn't be visible. This forms a black hole. As the event horizon is approached, it is also theorized that time passes slower relative to the rest of the universe. The resulting mass of SN 2008 D after explosion is estimated at 1.6-1.8 suns, meaning the remains are very likely a neutron star.

Planetary nebulae and supernovae are actually quite similar in their purpose within the universe's life cycle. Both have particles dispersed as a cloud. These clouds are where new star systems are formed; particles that a dying star has gotten rid of, cluster together, and a new star is born. This is how the loop closes, as dictated by the conservation of matter. As all atoms within the solar system were once part of the cloud that formed the Sun and planets, there's a point to make about us humans being made of stardust. Notably, a fusion product of medium and massive stars towards their death is carbon, also known as the universal building block of life.

Alongside oxygen, magnesium and iron are also some of the more crucial elements involved in making our bodies work, from basic processes such as respiration, allowing oxygen uptake, up to more complex functions like bone structure and strength.

It is fascinating and scary to think about how intricate life is, as minute changes in nuclear or electric force would impede the successful fusion of carbon or oxygen completely, abolishing any chance of life as we know it. Thankfully we do exist, and can perceive not only the visual wonders of the universe, but can analyze and try to understand the logic behind it as well.

Did you know?

Iodine, Xenon, Gold and some natural, radioactive elements are produced only during supernovas.

Ruthenium-based catalysts could be a solution to our plastic crisis

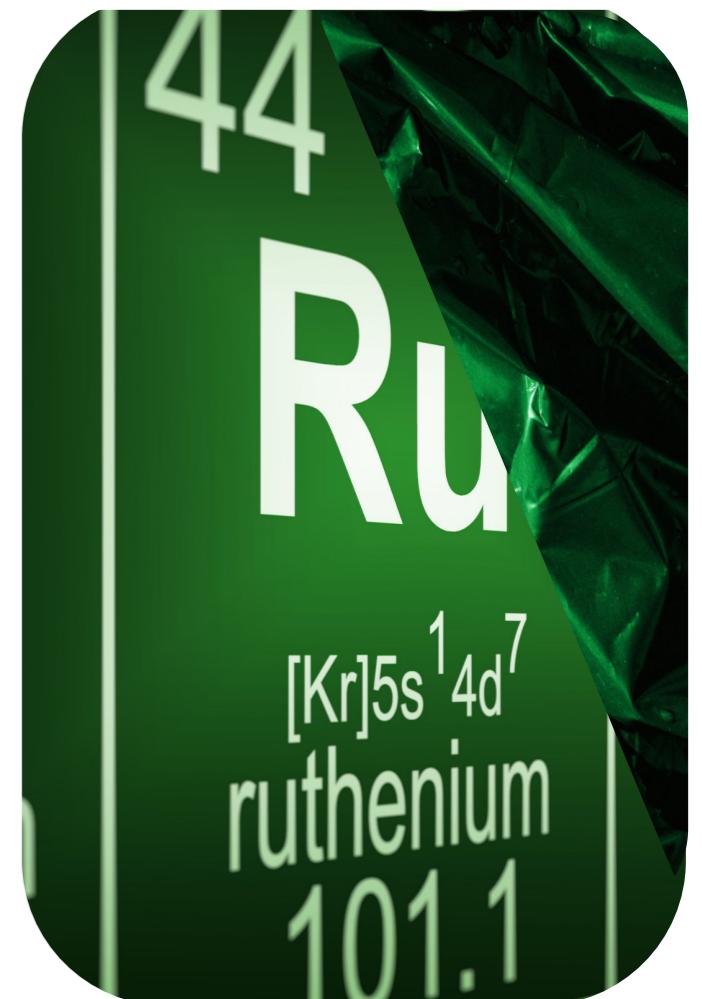
Plastics are polymeric chains of organic compounds which have useful properties including durability, low electrical conductivity, inert reactivity, low cost; and they can even be lightweight. Therefore, they have many uses in numerous industries such as healthcare, agriculture and electrical appliances. Most of the plastics are made of polyvinyl chloride (PVC), polyethylene, polypropylene or polystyrene; these materials have many uses in industry. Their life spans unfortunately are very short and they are often discarded after one month. The low biodegradability of plastics, staying behind as remains in the environment for hundreds of years, makes disposability of these compounds very difficult. In fact, this a growing problem and plastics will often end up in landfill sites or will be disposed of in the oceans, which significantly damages the environment. While there are current methods of dealing with plastics,

many of them suffer from problems such as high costs and high energy input, most of which comes from fossil fuels therefore exacerbating the issue of pollution.

One of the methods for disposing plastics is through incineration: around 30% of plastics are disposed of this way in Europe. The problem with this technique is that it is very energy intensive, as it requires very high temperatures to crack the plastics into smaller compounds and it often releases toxic compounds such as nitrous and sulfurous oxides, furans and dextrins. Recycling and turning the plastics into other useful materials may be a better option. Tertiary recycling is a very attractive alternative to scientists, because the products obtained from the cracking of the plastics can be used to make other petroleum chemicals.

Hydrocracking involves the use of hydrogen to break down large polymeric plastic compounds into smaller polymeric organic compounds. This technique bifunctional catalysts which can crack the plastics, but also have a hydrogenation - dehydrogenation function. However, the problem with these breakdown processes is the harsh conditions used, therefore using milder conditions for the process is more favourable to reduce adverse environmental effects. Scientists have screened many different transition metals including Pt on Al_2O_3 surface, Ni on C surface, however none of them could match the high yields and mild conditions achieved by a Ru catalyst. This article will focus on this compound and its future prospects in solving the plastics crisis.

Scientists have found that using a ruthenium catalyst on carbon support can carry out the hydrocracking process in milder conditions of lower temperature and pressure without the need of a solvent. This reduces the large environmental pollution from organic solvents. 5% wt of Ru/C was added to octadecane at 200 °C and the alkane products monitored. It was determined that after two hours the alkanes had chain lengths between C_7 - C_{18} , however as the reaction proceeded, even shorter chained alkanes started to be produced. If the organic compound is heated long enough all the products become gaseous and there is 100 % yield. This shows that the catalyst not only cleaves terminal C-C bonds. This is important in industry because it means that plastics can be selectively cleaved to produce alkanes of desired size, which can be further processed into useful products.



Another group of scientists have monitored and investigated a Ru/ CeO_2 catalyst. They have found that the catalyst has 90% selectivity for waxes but only ~10% selectivity for gases. It is important to minimise the amount of gas produced during the reaction because the gas cannot be used to produce petroleum products and is therefore lost. When compared to a Pt/zeolite catalyst standard which is used in plastic breakdown, it was seen that the Ru/ CeO_2 catalyst had a higher selectivity for C_{10} - C_{21} alkanes as opposed to the zeolite catalyst (only 2.2%). This selectivity can be explained from the Lewis acid-base properties of the catalyst. Hydrocracking over the acidic zeolite catalysts occurs through the addition of H^+ or abstraction of H^- . When a

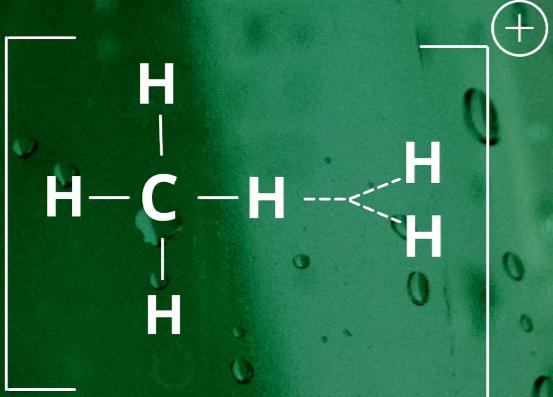


Figure 2. Carbonium ion of methane structure (CH_5^+). This is an example of pentacoordinated carbonium ion.



It can be concluded that ruthenium-based catalysts show promising results in the breakdown of plastics. Results have shown that the Ru catalyst performs even better than the Pt/zeolite catalyst producing alkane products with chain length between $\text{C}_{10}\text{-C}_{21}$, which are more useful and can be converted to petrochemical products. It seems that the way forward is not only to do with ruthenium-based catalysts, but with the broader class of heterogeneous catalysts. It has been found that homogeneous catalysts are difficult to use in industry for various reasons; the difficulty in separating between the reaction mixture, products and catalysts to be reused lowers their stability. However, while heterogeneous catalysts appear to be the most prominent option, solving issues such as price of raw materials and duration for catalysis reaction need to be considered.

hydrogen ion is added, a pentacoordinated carbonium ion is formed as an intermediate, which is decomposed to form carbonium ions. Some of these carbonium ions are primary, which are energetically very unstable and as a result undergo skeletal isomerization and beta-scission to become converted to stable alkanes. As mentioned previously, the problem with the standard zeolite catalyst is the formation of a large number of isomerized products which may not all be good fuels. On the other hand, the CeO_2 in the Ru catalyst is basic and therefore does not have strong Bronsted-Lowry acid sites to result in the donation of H^+ or abstraction of H^- .

Interested in OFF-WORLD MINING?

Do you know what BIOMINING is?

Turn to PAGE 40 to read more on our collaboration with the SPACE SOCIETY at King's College London

Is this the first sign of extraterrestrial life... on Venus?

Phosphine on Venus



Author: Louis Weiss



Venus is our nearest and most similar planetary neighbour. Its surface roasts at an enormous 426 °C,

with an atmospheric pressure ninety times that of earth, mainly composed of carbon dioxide. The outer stratospheric clouds, whilst much cooler at potentially life-supporting temperatures, contain clouds of concentrated sulphuric acid up to 60 km thick, bombarded by heavy UV radiation. So how is one led to believe that these are the ripe conditions to support life as we know it? It could have been a possibility 4 billion years ago during an earlier era where, like Mars, it once supported a more moderate climate with oceans. Now, Venus remains far too hostile for any probe to enter the atmosphere. It was ruled out as a site of possible extraterrestrial life many years ago, until 2017, when a certain molecule called phosphine (PH_3) was discovered there by a group of scientists at the University of Cardiff.

It has been proposed that phosphine is a feasible biosignature (a compound suggestive of biological processes that are, by virtue, indicative of life), when detected in a rocky planet's atmosphere. Its abundance on earth is plausible, yet PH_3 is elsewhere only found in the reducing atmospheres of giant planets in our solar system, where it is produced in deep atmospheric layers at high temperatures and pressures. Solid surfaces of rocky planets present a barrier to their interiors, and PH_3

would be rapidly destroyed in their highly oxidized crusts and atmospheres. Thus, PH_3 meets most criteria for a biosignature-gas search, but is challenging as many of its spectral features are strongly absorbed by Earth's atmosphere.

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The detection and role of phosphine in the phosphorus cycle on Earth was first discussed in 1988. It was examined that the phosphorus cycle in open-air sewage treatment plants involved a gas being released from sediments of 1-2-meter-deep water, which was found to be phosphine in minute amounts (5g released from 200m³ of sewage). In 2014, however, a thermodynamically feasible redox reduction method was proposed via a disproportionation reaction from phosphite and hypophosphite:

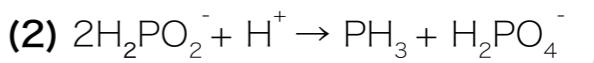
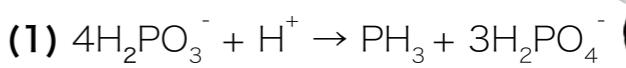
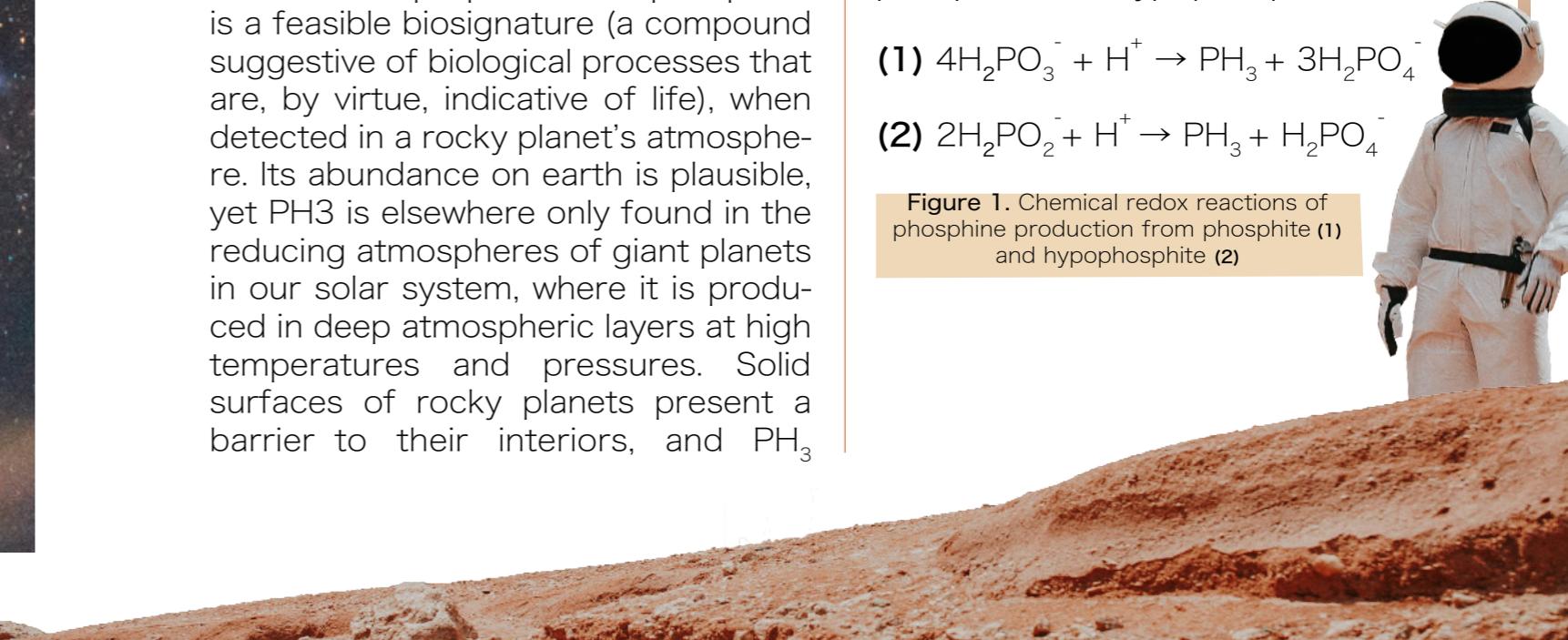


Figure 1. Chemical redox reactions of phosphine production from phosphite (1) and hypophosphite (2)



No other common reducing agent can produce phosphine at the concentration at which it is observed in nature, as reduction from phosphate is energetically unfeasible unless phosphite/hypophosphite ions are present in the environment – both important molecules in the phosphorus cycle.

A group of astronomers, led by Jane Greaves, discovered the presence of the molecule in the clouds of Venus but could come up with no reasonable explanation for its formation.

Greaves was using Venus as a negative control in a search for biosignatures, believing no signs of life there were possible. Using the James Clerk Maxwell Telescope (JCMT), she looked for a dip in the light from Venus at 1 millimetre (mm) wavelength.

In essence, the telescope utilises spectral-line observations to identify molecules in molecular clouds, and study their chemistry and distribution. Light recorded with a wavelength of 1 mm contains photons with the energy equal to approximately 1.2 milli-electron volts. This can frequently be seen from earth as they are produced by most warm forms of life. However, these photons were produced by the heat of Venus' clouds. Greaves was investigating this wavelength as the phosphine molecule absorbs light at this wavelength.

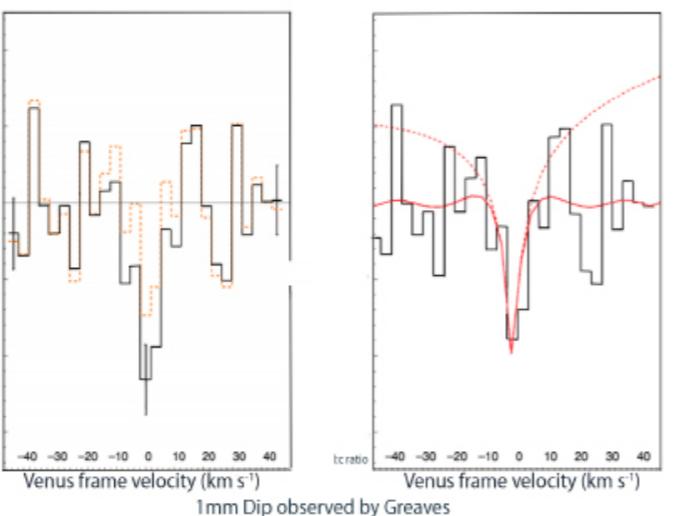


Figure 2. Wavelength of the phosphine molecule absorbing light. (Taken from Greaves, J. S., Richards, A.M.S., Bains, W. et al. Phosphine gas in the cloud decks of Venus)

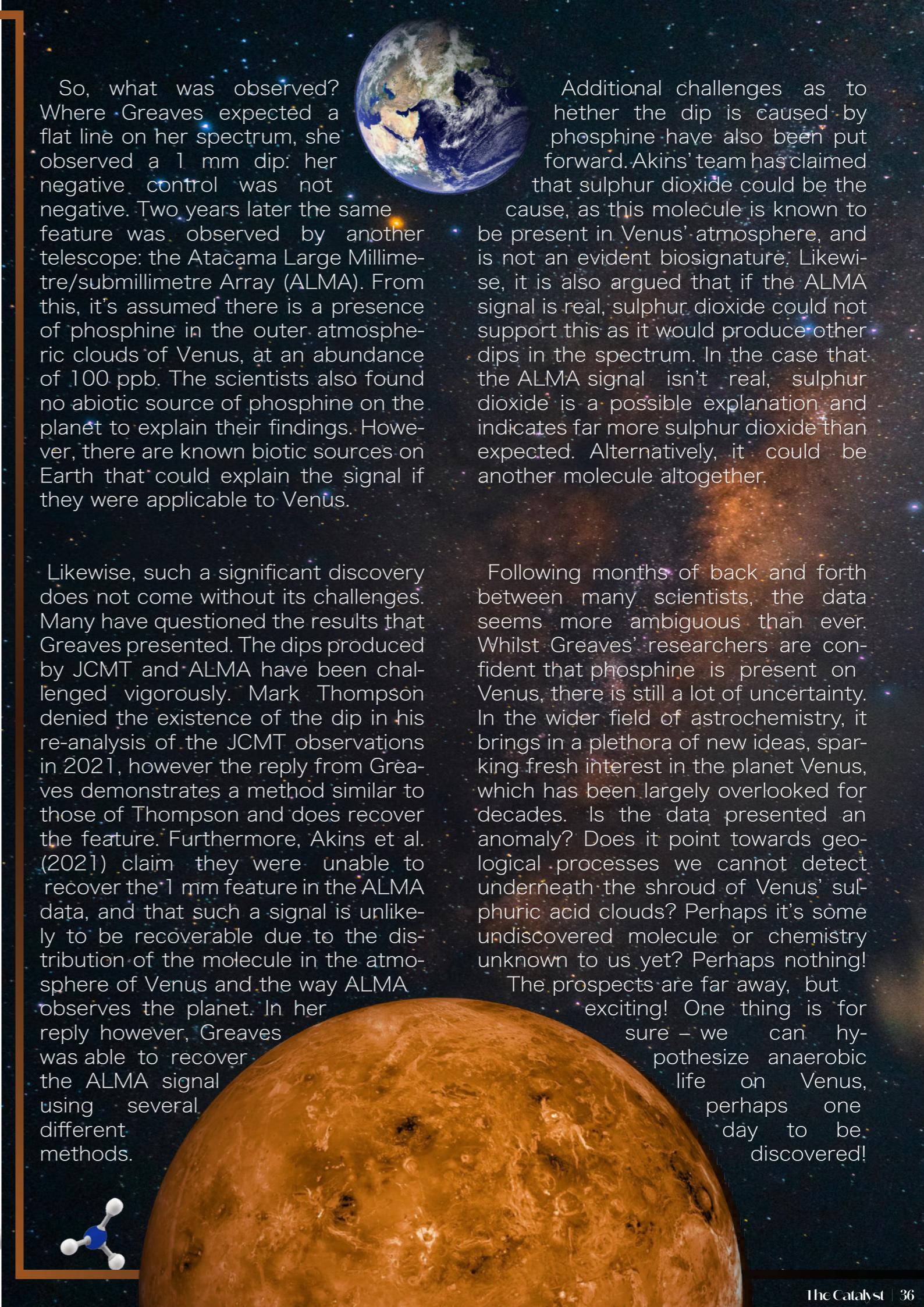
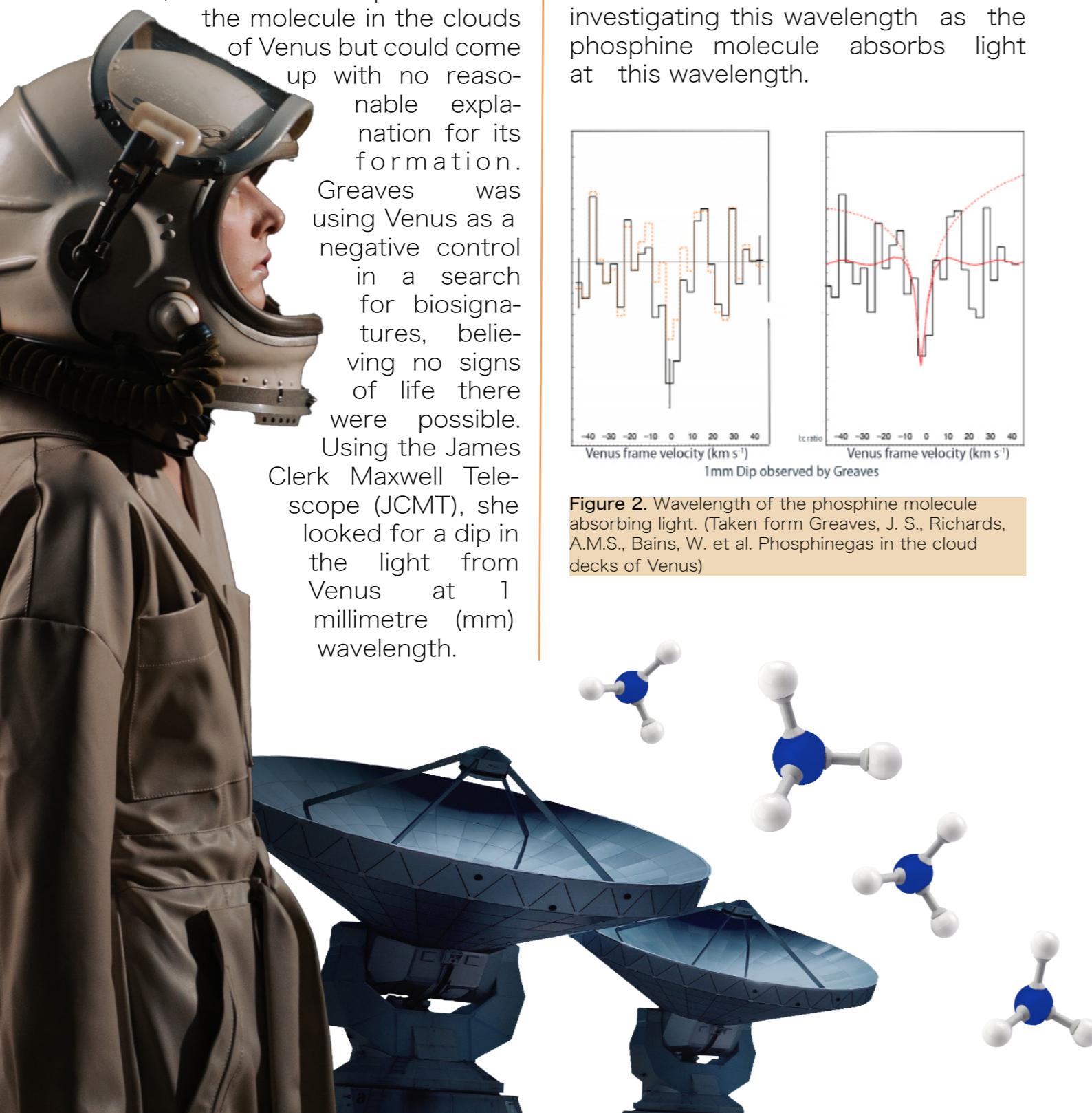
So, what was observed? Where Greaves expected a flat line on her spectrum, she observed a 1 mm dip: her negative control was not negative. Two years later the same feature was observed by another telescope: the Atacama Large Millimetre/submillimetre Array (ALMA). From this, it's assumed there is a presence of phosphine in the outer atmospheric clouds of Venus, at an abundance of 100 ppb. The scientists also found no abiotic source of phosphine on the planet to explain their findings. However, there are known biotic sources on Earth that could explain the signal if they were applicable to Venus.

Likewise, such a significant discovery does not come without its challenges. Many have questioned the results that Greaves presented. The dips produced by JCMT and ALMA have been challenged vigorously. Mark Thompson denied the existence of the dip in his re-analysis of the JCMT observations in 2021, however the reply from Greaves demonstrates a method similar to those of Thompson and does recover the feature. Furthermore, Akins et al. (2021) claim they were unable to recover the 1 mm feature in the ALMA data, and that such a signal is unlikely to be recoverable due to the distribution of the molecule in the atmosphere of Venus and the way ALMA observes the planet. In her reply however, Greaves was able to recover the ALMA signal using several different methods.

Additional challenges as to whether the dip is caused by phosphine have also been put forward. Akins' team has claimed that sulphur dioxide could be the cause, as this molecule is known to be present in Venus' atmosphere, and is not an evident biosignature. Likewise, it is also argued that if the ALMA signal is real, sulphur dioxide could not support this as it would produce other dips in the spectrum. In the case that the ALMA signal isn't real, sulphur dioxide is a possible explanation and indicates far more sulphur dioxide than expected. Alternatively, it could be another molecule altogether.

Following months of back and forth between many scientists, the data seems more ambiguous than ever. Whilst Greaves' researchers are confident that phosphine is present on Venus, there is still a lot of uncertainty. In the wider field of astrochemistry, it brings in a plethora of new ideas, sparking fresh interest in the planet Venus, which has been largely overlooked for decades. Is the data presented an anomaly? Does it point towards geological processes we cannot detect underneath the shroud of Venus' sulphuric acid clouds? Perhaps it's some undiscovered molecule or chemistry unknown to us yet? Perhaps nothing!

The prospects are far away, but exciting! One thing is for sure – we can hypothesize anaerobic life on Venus, perhaps one day to be discovered!





THE FUTURE OF MINING: **THE USE OF OFF-WORLD RESOURCES**

(In collaboration with KCL Space Society)

Authors: Ahlam Abdi & Ellen Oudkerk-Sodia

Mining is the process of the extraction of materials, usually variable minerals, from the Earth's crust. It has been central to human civilization for over 43,000 years and is now used for the production of anything from jewellery to electronic components. However, this process has many flaws - from the socio-economic, environmental and political impacts that come along with it, to the scarcity of our resources.

Mining processes are known to cause severe consequences, including loss of biodiversity in many ecosystems, soil erosion, and water and air pollution. Mining sites can often cause leakage of chemicals, which poses a great danger to the environment surrounding the mining site. A landscape affected by mining takes a very long time to heal, or may never fully recover. Remediation efforts do not always ensure that the biodiversity of the area is restored, making the consideration of alternative ways to traditional mining crucial. The two processes discussed in this article have been at the forefront of research that aims to reduce the negative impacts of traditional mining.

One process is biomining, which uses microorganisms to extract certain metals from rock ores or mine waste. As humans plan expeditions deeper into space, biomining offers a way to obtain materials on other planets instead of transporting them from Earth. The benefits: a cost efficient and environmentally friendly way to obtain metals. The primary biomining technique uses microbes to oxidize metals within solid minerals, allowing them to dissolve in water. Another technique uses microbes to break down the surrounding minerals, allowing a direct recovery of the metal from the rock. Current biomining operations target valuable metals that are commonly found in sulfidic minerals, such as copper, uranium, nickel, and gold. With its wide range of processes and target metals, there have been many significant experiments, including an experiment from the European Space Agency (ESA) Biorock investigation in

2019 aboard the International Space Station (ISS).

This investigation conducted an experiment using **vanadium** aboard the ISS, which demonstrated how microbes can extract rare Earth elements from basalt in space.

To test if microbes could mine vanadium in altered gravitational conditions, the team filled a KUBIK incubator on the space station with liquid growth media to support the replication of microorganisms. The team then grew selected microbes which were known to break down rocks under microgravity. Those were able to grow to their maximum concentration, meaning that different gravity conditions did not influence biomining processes.

The team showed that microbes can not only mine elements in space, but also get **better results** under such altered gravitational conditions. Vanadium biomining on the ISS showed a 283% performance increase, showing that this process may be possible in space just as well as on Earth. Although showing great potential, environmental risks associated with biomining are related to the leakage and treatment of the acidic, metal-rich solution created by the microbes. This risk can be managed by enforcing controlled conditions with proper sealing and waste management protocols.

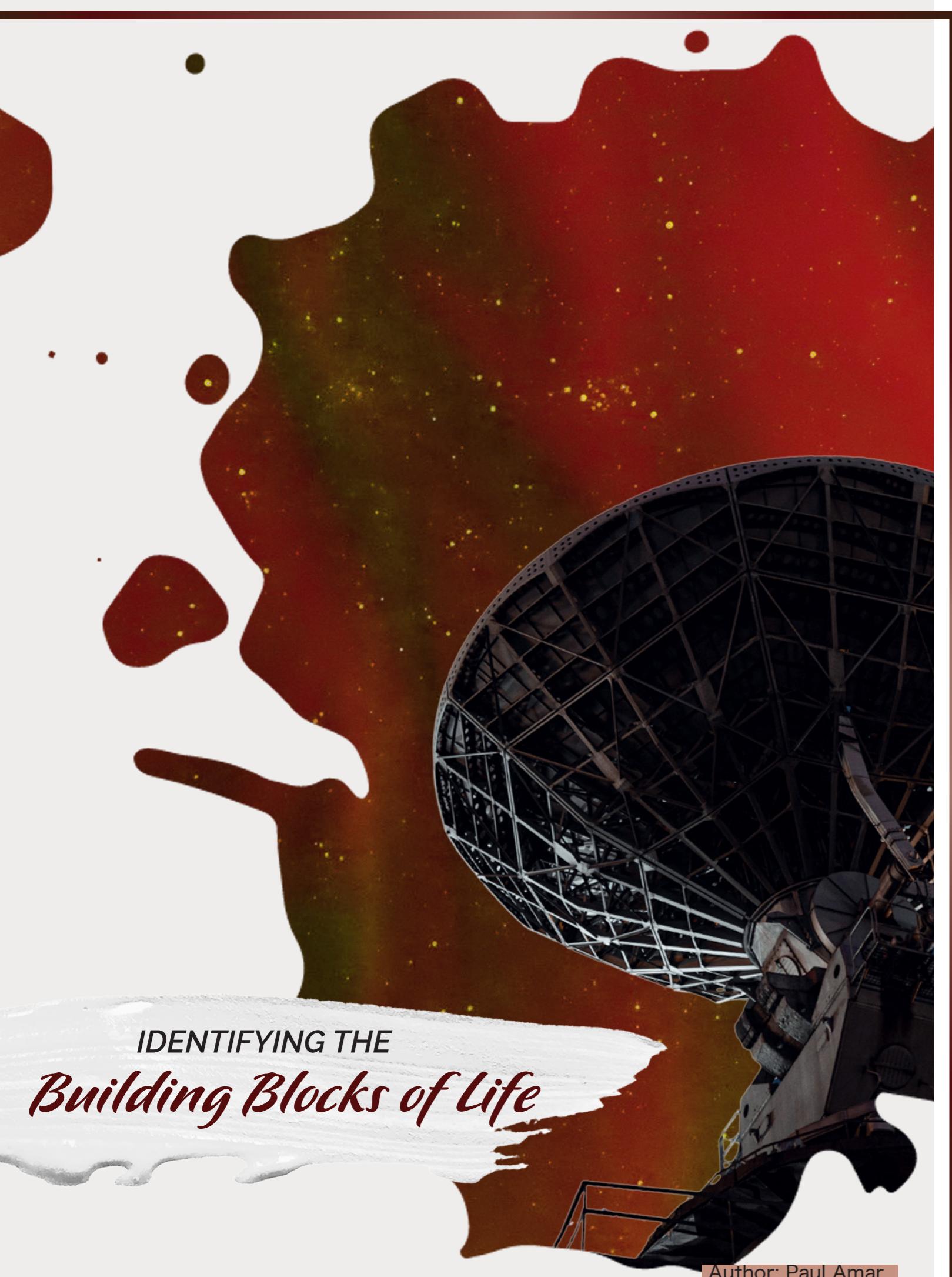
The second process on the frontline of current research is **asteroid mining**, which is the extraction of materials from asteroids, minor planets and near-Earth objects. Currently, there are many methods to do this. This includes the use of magnetic rakes, surface mining and the vaporisation of rock. However, the real challenge lies with transporting this to Earth. The most supported method is pushing the asteroid into the Earth's orbit and then having reusable spacecraft bring the extracted materials back to Earth. The benefit of asteroid mining over other processes is that it would give our environment a chance to recover from all the aforementioned issues. Furthermore, the research required to achieve asteroid mining would incentivise other areas of innovation, having the side effect of bringing down the cost of spaceflight. Current research in this area aims to start mining by 2023.



ASTEROID MINING

They hoped to return four space modules to Low Earth Orbit for mining by the end of the decade. The final project currently being developed is by the TransAstra Corporation, which hopes to utilise three classes of spacecraft to harvest asteroids of different sizes up to 40m in diameter. Some factors are however still restricting the progress within this sector. These include the current high cost of spaceflight, the lack of technology to accurately identify the composition of asteroids as well as that of the creation of an environment to extract materials in space.

Currently, biomining is a small part of the mining industry. It is usually used when the percentage of the metal in a rock is small, or to extract remaining metals from waste rock. As metal-rich ores are depleted worldwide with advances in microbial research and engineering, biomining may become more common in the future. The process of asteroid mining will also become possible in the future as the use of current technologies would make the process financially unfeasible. However, there is progress currently towards reducing the cost of spaceflight by private companies such as SpaceX and the development of new technologies by NASA and Deep Space Industries. Hopefully, with these, humans can transition away from current techniques of mining will pose a great benefit to the environment and the population.



Author: Paul Amar

It should not be a surprise to any of us that atoms and molecules are present all around our universe. However, it may be more surprising to learn that some of these molecules are rather more complex than we once believed possible. For a long time, it was the view of most astrophysicists and chemists that the interstellar medium (ISM) had conditions too harsh for complex molecules to form. Yet this was all put into question in 1968 when Charles Townes (Nobel laureate) and his colleagues detected the first of three molecules, ammonia (NH_3), near the centre of our galaxy by its inversion transition, resulting in a microwave emission. This essentially gave birth to the field we know today as:

Astrochemistry.

Since this first discovery, nearly 200 gas-phase molecules have been detected in the ISM or circumstellar shells, with some even being detected from extragalactic sources. These molecules range greatly in complexity, from diatomics to species containing up to thirteen atoms. Most are found to be organic, with all species detected containing more than six atoms being organic. These have been dubbed complex organic molecules (COMs), but how have we managed to detect these?

Let us start at the beginning. Most of the interstellar matter in the universe resides in the form of clouds,

which are composed of gas and tiny silicate and carbonaceous dust particles. These clouds are where interstellar chemistry begins; they originate from old stars which eject the gas and dust either gently through their expansion, or more explosively, in supernovae. These gases congregate under the force of gravity and form progressively denser clouds (10^{1-4} cm^{-3}), comprised mostly of elemental and molecular hydrogen, until a critical limit is reached and a “cold” prestellar core is formed. As the temperature of these cores is approximately 5-10K, this means that only binary reactions without activation energies may occur, specifically ion-neutral exothermic reactions. They occur due to cosmic rays; high energy nuclei travelling near the speed of light. This leads to a variety of molecules being formed, from terrestrial molecules such as CO (the second most abundant molecule after H_2) to more exotic molecules, such as, molecular cations & anions (H^{3+} , HCO^+), unsaturated long carbon chains (C_8H), metastable isomers (HNC), and radicals (C_8H). The prestellar core eventually collapses on itself as the density of the gas increases, leading to the formation of a protostar. The ensuing collapse causes the region to heat up the matter within it, eventually allowing the star to reach temperatures of 100K-300K, known as a “hot core”. At this stage, the chemistry of the star changes drastically as many more reactions may now occur. Various common organic molecules have been formed, namely methanol (CH_3OH), propionitrile ($\text{CH}_3\text{CH}_2\text{CN}$) and dimethyl ether (CH_3OCH_3). These molecules are ejected into space periodically through violent explosions as the star evolves. At the same time, a protoplanetary disk is formed around

the young star, as some of the ejected matter congregates due to the effect of gravity, eventually leading to the formation of comets and meteorites.

All the while this occurs, from the initial cloud to the ejection of molecules due to the fusion reactions occurring within the hot core, surrounding stars emit radiation in the form of photons which cause excitation of the molecules in the ISM. These photons, being of different energies, can hence cause varying transitions; some being electronic (residing in the UV-Vis portion of the electromagnetic spectrum), but it is mainly found that they cause rotational and vibrational transitions (residing in the millimetre-wave region going to the infrared). For this reason, the study of interstellar molecules is principally done through rovibrational spectroscopy of the emission and absorption spectra of the COMs, coupled with quantum mechanical simulations, as we will see later.

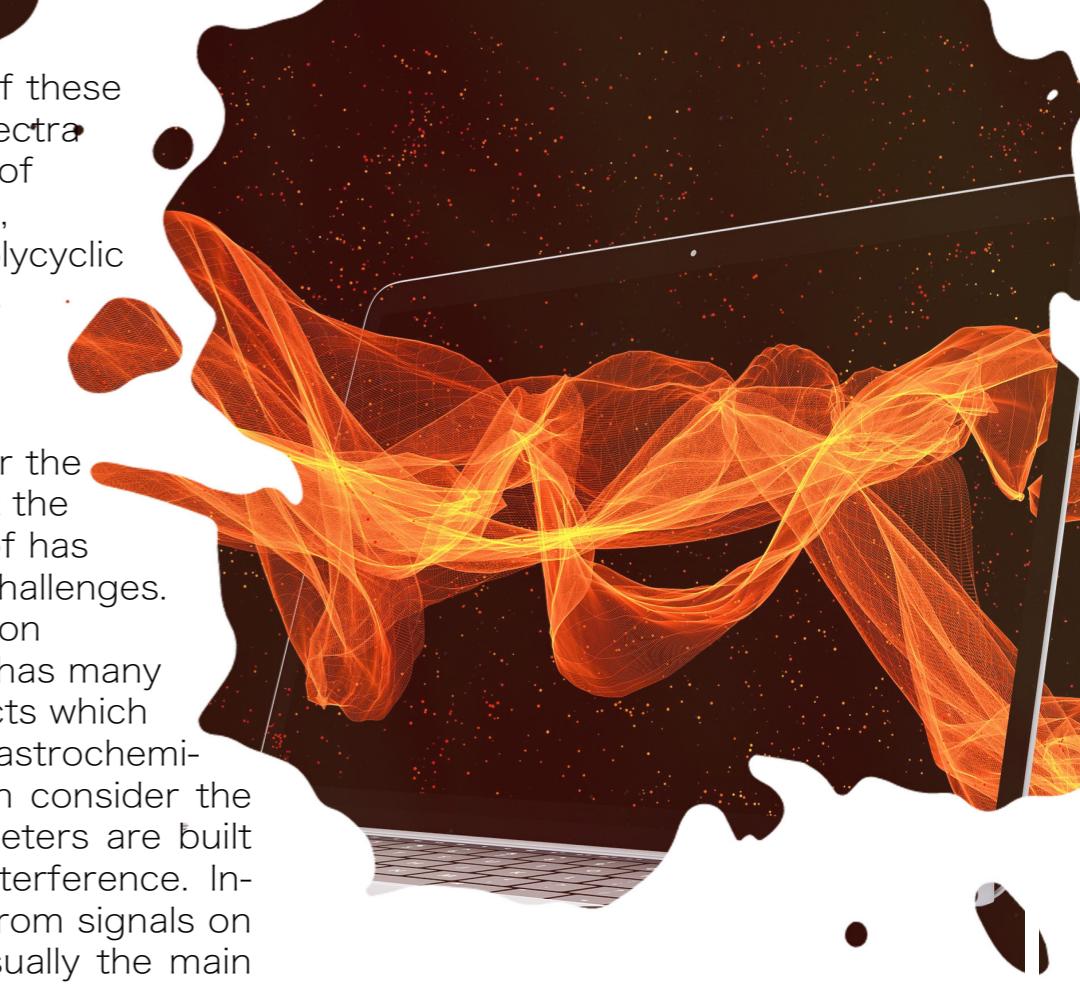
Chemists have been able to study the rovibrational signatures of these molecules due to the incredible technological advancements made over the past 53 years.

We have built astoundingly sensitive and accurate, ground-based radio-telescopes (telescopes which detect radio-waves, hence rotational transitions) such as the Atacama Large Millimetre Array (ALMA). They have enabled the detection and identification of most of these COMs in the colder regions of the universe. We have also embarked spectrometers onto the Stratospheric Observatory for Infrared Astronomy (SOFIA), and even in space on the Herschel Space Observatory, which have permitted infrared spectroscopy (studying rovibrational transitions) to also flourish in this field, mapping the warmer, star-forming regions.

Let us then get into the nitty-gritty of rovibrational spectroscopy. First, we must consider that two spectrums exist: absorption and emission. The absorption spectrum is often most considered for the infrared radiation detected, by the use of background stars as lamps. The dips in intensities are used to probe the density and temperature of the gas, the population of the various quantum vibrational states and the ratio of adhered molecules to dust particles. Meanwhile, the emission spectra, both microwave and infrared, have been used to try and

elucidate the identity of these COMs, with infrared spectra revealing the presence of giant carbon structures, fullerenes (C_{60}) and polycyclic aromatic hydrocarbons.

However, our pursuit for the comprehension of what the universe is composed of has faced many challenges. As spectroscopy relies on quantum mechanics, it has many uncertainties and aspects which have made the lives of astrochemists difficult. Let us then consider the reason these spectrometers are built in remote locations: interference. Interference may occur from signals on land, but that is not usually the main problem (anymore); it lies with interference from other molecules in the ISM which also have rovibrational transitions within the frequency range recorded by the instrument. This interference leads to spectra from these machines containing more than one molecular signature, but potentially tens if not more. This problem is then coupled with the fact that many of the COMs may also be exotic, and hence the possibility of isotopologues being detected must also come into play. This has caused debate over the proper identification of certain molecules, not omitting the fact that the analysis of these spectra requires rigorous quantum mechanical calculations. Determination of the proper Hamiltonian operators to physically describe the quasi-rigid rotational motion, which is coupled with higher frequency vibrational motion is involved amongst others. The need for these calculations often means that larger molecules are harder to properly interpret, as their spectra are denser, caused by their



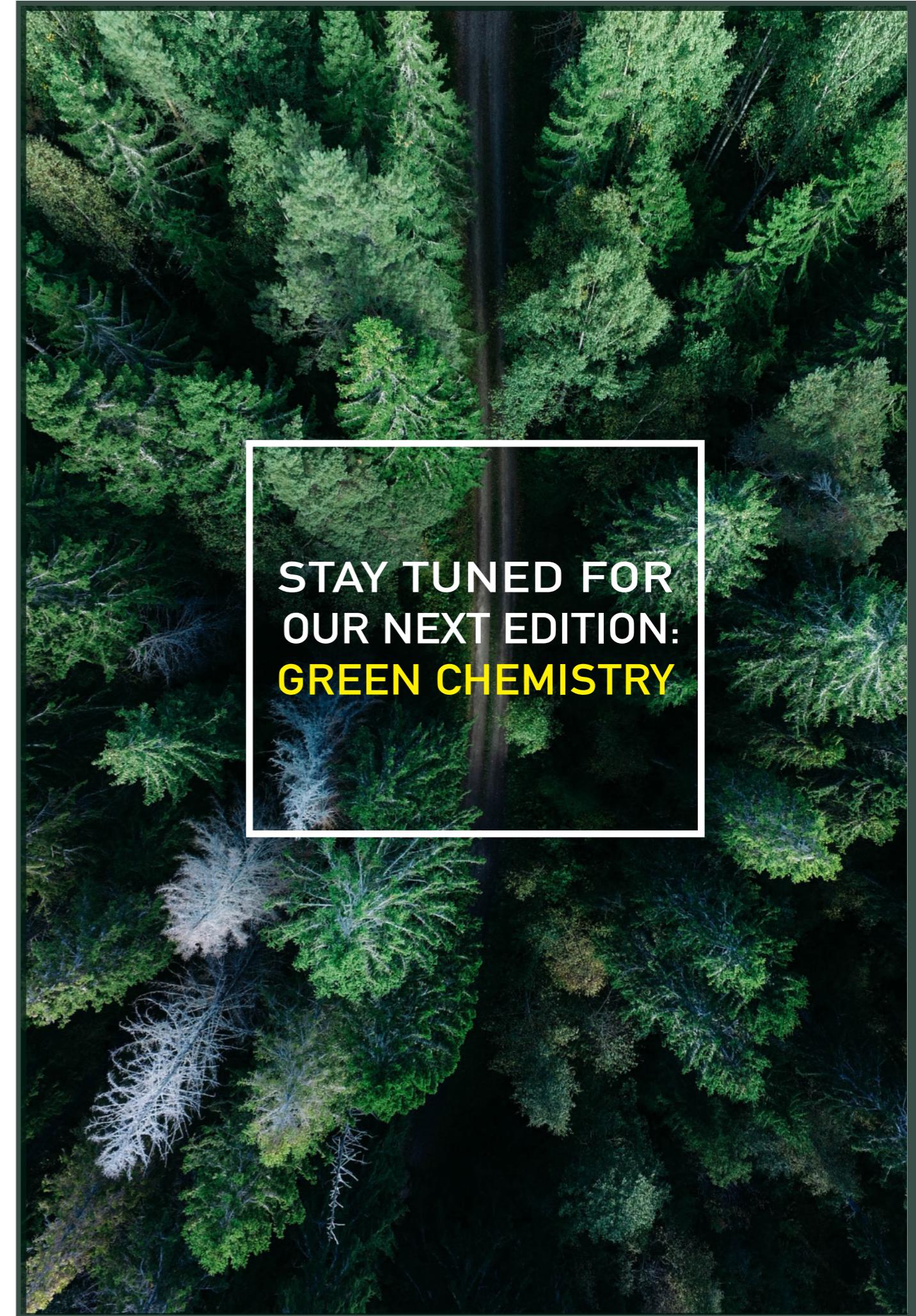
increased moment of inertia which in turn decreases the rotational constants. Not only this, but the increase in frequency of detection also implies higher energy transitions. These may be higher order transitions of smaller molecules, as well as first/second-order transitions of larger COMs, which does not also include molecules with large amplitude motion. Let us then finally remember that the origin of the photon emitted by the molecule, and the path it has travelled to reach our telescopes must be carefully considered. Not only will the radiation be subject to the Doppler effect, but to relate the observed intensities to physical parameters (density/temperatures/etc.), careful assumptions must be made to allow for the formulation of a quantum mechanical expression. These are unfortunately, only a fraction of the challenges faced by the community today.

None of this is helped by the relatively low abundance of COMs in the unimaginably large area that is space. We have nonetheless come up with methods of better understanding the data we are receiving, specifically through the constant improvement of our quantum computation and simulation techniques, allowing for faster and more cost-effective results. These have been an irrefutable help in accurately analysing the spectral lines. Theoretical chemists around the world have developed incredible methods using quantum chemistry as a tool for producing acceptably accurate theoretical spectra. These methods have included extensive computation of equilibrium properties with the inclusion of anharmonicity and other effects by way of density functional theory (DFT), but also more recently the Best Theory + Reliable High-Resolution Experiment (BTRHE) strategy has been proposed. BTRHE functions by way of ab-initio quantum mechanical methods to determine a potential energy surface (PES) and dipole moment surface (DMS). After refinement using reliable high-resolution experimental data, the PES obtained can yield energy-level predictions with comparable accuracy to the expected interpolated energy

levels, calculated through the empirical measurements, allowing for the construction of a spectrum. The accuracy of these levels however degrades with increasing extrapolation. Yet, as the degradation is slow, it has been shown that the technique can potentially prove useful to assign higher order transitions from new experiments, which when refined can then be used to predict even larger transitions. I describe here a mere fraction of the astounding research taking place.

All of the above goes to show that astrochemistry is still within its infancy, and will have many hardships to overcome, but that the men and women dedicated to this fascinating field are probing frontiers which we never even dared believe existed. Their research has allowed for the potential detection of glycine (although this remains heavily debated), an amino acid precursor to the molecules that make up our DNA. As we delve ever deeper into the void that is our vast universe, we inch closer to discovering the building blocks of life, and maybe even one day answering our impregnable question:

How did we get here?



**STAY TUNED FOR
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