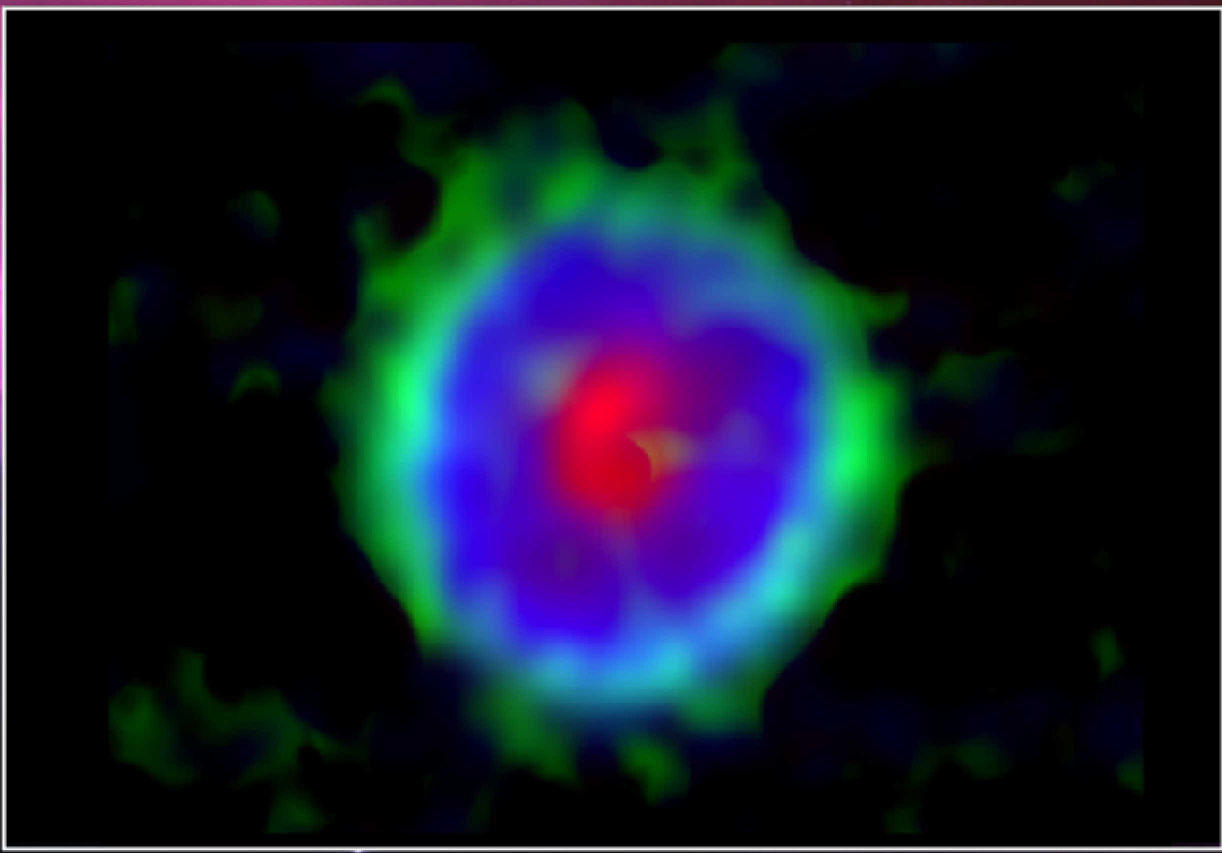
AstroPAH

A Newsletter on Astronomical PAHs

Issue 64 ● December 2019



Fullerenes in Planetary Nebulae

Editorial

Dear Colleagues,

As we wrap 2019, we are pleased to share with you our AstroPAH Issue 64! Once again, the rich PAH-related output has contributed to making this a fertile year for the community. We have also had recent changes in our Editorial Team, as we welcome Dr. Helgi Rafn Hróðmarsson from Leiden Observatory. Welcome, Helgi!

Our In Focus this month contains two parts. First, a summary of the Tc 1 and fullerene emission in planetary nebulae co-written by our Executive Editor Isabel Aleman, with a description of what it takes to get a better understanding of the physical conditions throughout Tc 1. We also feature our interview with Helgi, so be sure to read through that, too!

Finally, we also feature a recent publication about the thermal evaporation of pyrene clusters and a Postdoc position opportunity at the NASA Goddard Space Flight Center on the processing of amino acids from ice irradiation experiments.

We hope you enjoy reading our last newsletter of 2019, and we thank you for your dedication and interest in AstroPAH! Do not hesitate to send us your contributions, and if you wish to contact us, feel free to use our email: astropah@strw.leidenuniv.nl. We will have our annual January break, so the next AstroPAH issue will be in February. The Editorial Team wishes you happy and safe holidays!

The Editorial Team

Next issue: 20 February 2020.
Submission deadline: 7 February 2020.

Contact us:

astropah@strw.leidenuniv.nl

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PAH Picture of the Month

Tc 1 image showing the ionized gas emission in blue and the dust emission in red. The green ring is the C_{60} emission.

Credits: Cami et al. (2018)

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In Focus

Tc 1 and the Fullerene Emission in Planetary Nebulae

by
Isabel Aleman (UNIFEI, Brazil),
Jan Cami (UWO, Canada; SETI, USA),
Els Peeters (UWO, Canada; SETI, USA),
Stavros Akras (FURG, Brazil),
Marcelo L. Leal-Ferreira (Germany)

with the support of

Christophe Morisset (UNAM, Mexico),
Nick Cox (ACRI-ST, France),
Alexander Tielens (Leiden Univ., The Netherlands),
Roger Wesson (UCL, UK).

When low- and intermediate-mass stars reach the final stages of their evolution, they return much of their initial matter – enriched in nucleosynthesis products – back to the interstellar medium in the form of massive, but slow winds. In these outflows, the stellar gas cools down, forms molecules, and nucleates dust grains. When the hot stellar core becomes exposed, its ultraviolet (UV) radiation ionizes the atomic gas and processes the molecules and the dust in what is now a planetary nebula (PN). As a result of this mass loss, evolved stars are characterized by copious amounts of circumstellar gas and dust. The precise composition of this material depends on the stellar chemical abundances and the reigning physical conditions that govern the formation and further processing of these materials.

Molecules and dust grains in evolved stars are ideally studied at infrared wavelengths where they exhibit strong rotational and vibrational transitions. Infrared observations of PNe (especially of carbon-rich objects) have revealed a bewildering variety of spectral features (e.g., Beintema 1998; Hrivnak et al. 2000; Hony et al. 2001; Stanghellini et al. 2007; Joblin et al. 2008; Ruffle et al. 2015; Mishra et al. 2015). In addition to a plethora of ionic gas lines, many PNe show features due to aromatic carbonaceous molecules, SiC dust grains and features whose origin is still debated (e.g. the so-called 30 μm feature; Hony et al. 2002; Mishra et al. 2015).

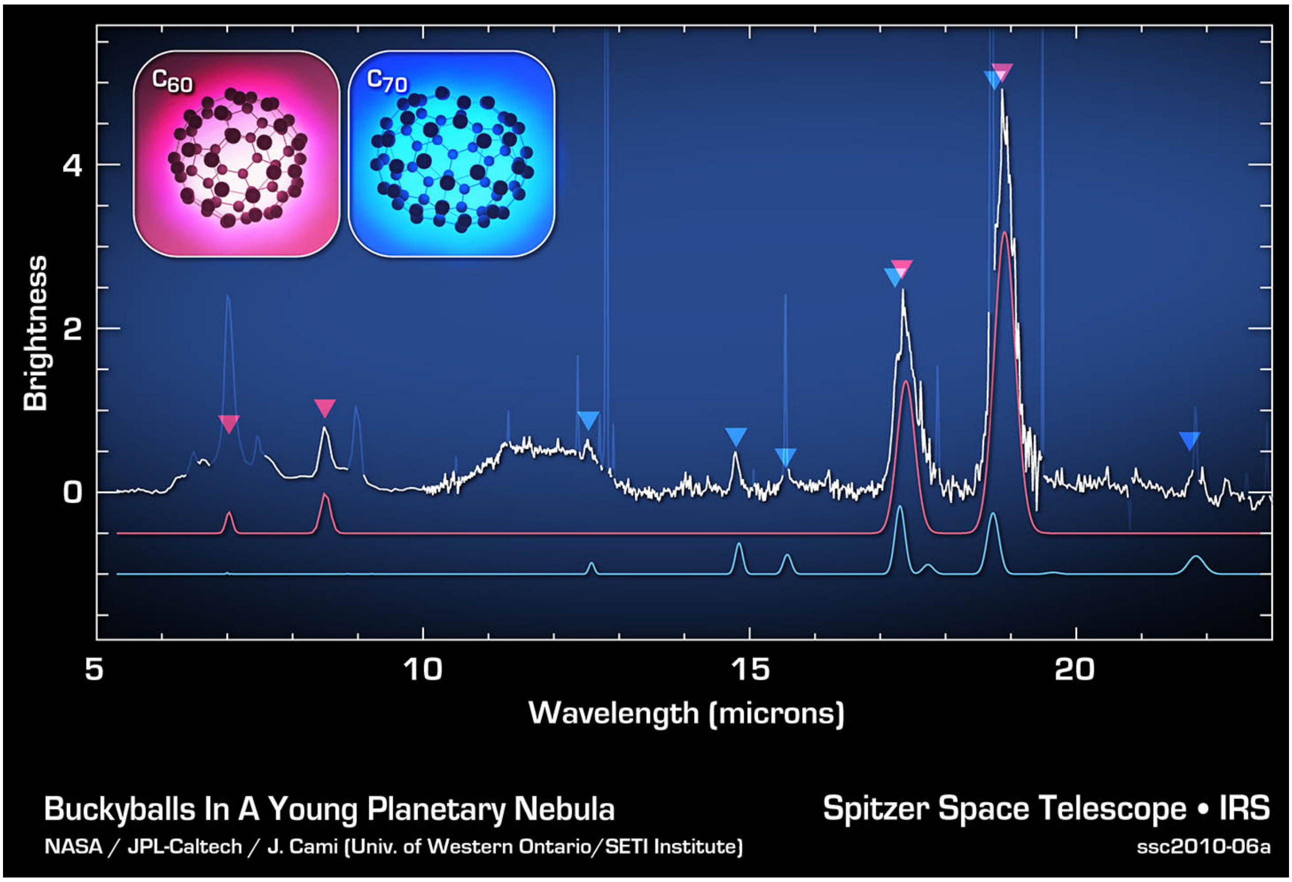

Figure 1: First detection of fullerenes in space. Tc 1 Spitzer Mid-IR Spectrum showing bright bands of C_{60} and C_{70} emission bands. Credit: NASA/JPL-Caltech/J. Cami (Univ. of Western Ontario and SETI Institute).

An exciting and fairly recent addition to the molecular inventory in C-rich PNe are fullerenes (Cami et al. 2010; Fig. 1). Fullerenes are a class of large carbonaceous molecules in the shape of an ellipsoidal or spheroidal cage (Kroto et al. 1985) with C_{60} ("buckyballs") the best known and most stable example of the class. In space, the IR emission features of fullerenes have also been detected in reflection nebulae (e.g., Sellgren et al. 2010; Peeters et al. 2012; Boersma et al. 2012), young stellar objects (Roberts et al. 2012) and, more recently, diffuse clouds (Berné et al. 2017). In the near-IR, a set of diffuse interstellar bands has been identified as due to C_{60}^{+} (Campbell et al. 2015; Walker et al. 2015). Fullerenes are thus widespread and abundant in space; however, as we will see below, many details about their formation and excitation in these environments remain unanswered to date. This is important, since PAHs and other abundant carbonaceous materials share many properties with fullerenes, including formation and processing pathways and excitation and relaxation processes. Our ignorance about fullerene formation in these environments, and the remaining issues in explaining the details of their observed emission and absorption properties thus point to important gaps in our understanding of the relevant processes that drive the carbon cycle rather than in our understanding of a single molecular species.

Combined theoretical and observational studies of spatially resolved PNe can be the key to unraveling these complex problems. Spatially resolved PNe offer great opportunities to map the local physical conditions in great detail. The parameters that describe the environment can then serve as input to theoretical models that include all the relevant fullerene processes at the molecular scale, resulting in clear predictions about where we should expect to see fullerenes and what that emission or absorption should look like.

Let's focus now on the population of PNe where the C_{60} emission was detected. The first thing to note is that fullerene emission is quite a rare phenomenon: only a small fraction ($\sim$3%) of the C-rich PNe shows the IR C_{60} bands. In fact, despite extensive searches, we know of only 24 PNe that exhibit fullerene emission bands (Otsuka 2019). All these objects are young, low-excitation PNe with fairly similar IR spectra pointing to similar conditions (Bernard-Salas et al. 2012; Otsuka et al. 2014). However, there is no obvious characteristic that sets apart the C_{60} objects from their non-C_{60} containing counterparts except perhaps in their colours: Sloan et al. (2014) noticed that fullerene sources tend to cluster in an IR colour-colour plot, and that the direct lines of sight to the central stars of C_{60}-PNe are the least obscured of all evolved objects they considered. This suggests that geometry may play a role in creating the right fullerene formation and/or excitation conditions.

Much of what we know about the formation of fullerenes is firmly rooted in laboratory experiments and detailed theoretical calculations. A key set of experiments describes bottom-up formation routes for large carbonaceous molecules starting from a simple carbon-rich seed gas (e.g. C_2H_2). At temperatures <1700 K, this results in PAH molecules and carbonaceous dust with a graphitic, PAH-like structure. At higher temperatures, the same experiments produce fullerene molecules and fullerenic dust – i.e. both the molecules and the dust carry the clear imprint of curved structures rather than the at PAH-like geometry (Jäger et al. 2008; Jäger et al. 2009). A second pathway derives from a similar set of experiments but in H-poor conditions. In such cases, fullerenes can form abundantly even at moderate temperatures ($\sim$1000 K; see Cherchneff et al. 2000). Finally, following suggestions from the astronomical community, laboratory experiments have revealed a top-down mechanism as well: stellar UV photons can process large PAHs to first strip the H's to form graphene flakes, which then curl up into closed carbon cages that are further processed into the specific fullerene structure (Zhen et al. 2015). Such a mechanism has been proposed to explain the formation of C_{60} in reflection nebulae (Berné & Tielens 2012).

To figure out which of these routes is responsible for the formation of fullerenes in PNe, or to establish if another route is required, we first and foremost need a detailed knowledge of the physical conditions throughout the circumstellar environments of C_{60}-PNe. With such knowledge, we can then evaluate which of the proposed routes are viable in these environments or propose alternatives based on these observational constraints. PNe are ideally suited for this. Not only are they the evolved star environments where we see fullerenes most frequently, PN researchers have a widely used set of tools available to determine the physical conditions in these environments to great detail. To make this work, we need to know the physical conditions spatially resolved throughout the nebula, in objects where there is no confusion with other species such as PAHs, and where we *know* where the C_{60} is located. There really is only one such object....

Enters Tc 1...

Following the detection of C_{60} in Tc 1, several authors have studied the properties of this object. Tc 1 is a young, low-excitation, Galactic planetary nebula. The nebula is carbon-rich (C/O > 1) with abundances typical for a low-mass PN progenitor (1.5-2.5 $M_\odot$; Pottasch et al. 2011; Otsuka et al. 2014; Aleman et al. 2019). The central star has an effective temperature in the range of 28 000-35 000 K and a total luminosity between 1 400-13 000 $L_\odot$ (e.g. Gorny, Stasińska & Tylenda 1997; Pauldrach, Hoffmann & Méndez 2004; Gesicki &

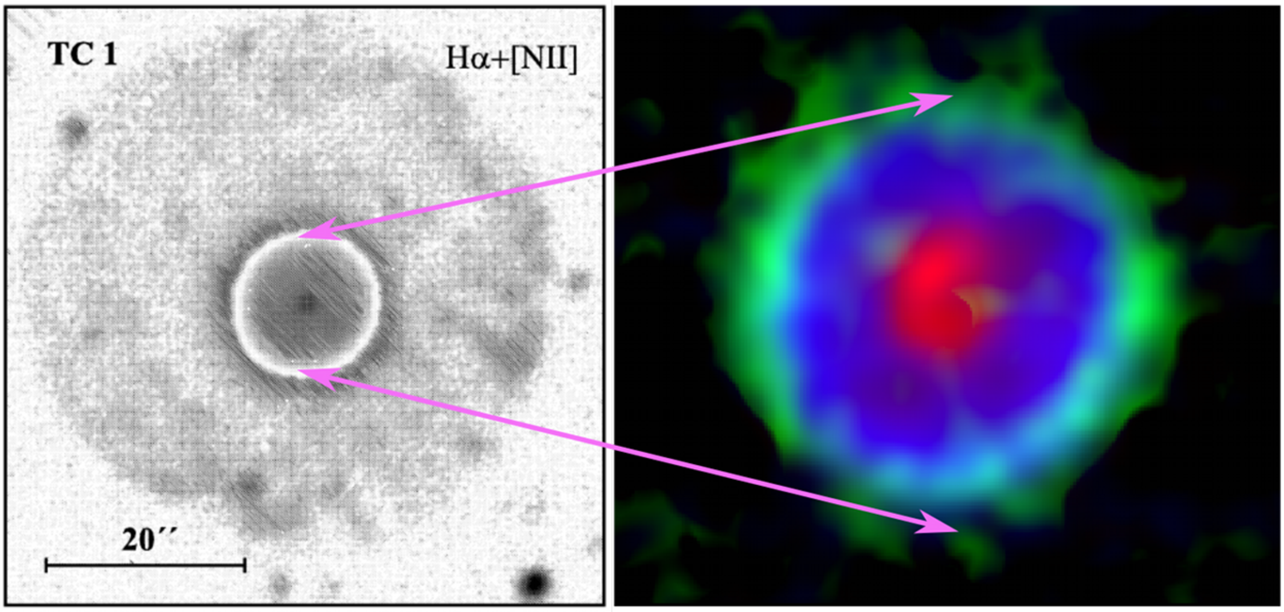

Figure 2: *Left:* Image taken in the Hα+[N II] filter (Reproduced from Corradi et al. 2003). The central and outer (halo) region are shown in different scales as the halo is much fainter than the main ionized shell. *Right:* In Tc 1, C_{60} emission is produced in a ring of $\sim$5 arcsec radius around the central star (green). The ionized gas and dust emission are shown in blue and red, respectively. Figure adapted from Cami et al. (2018).

Zijlstra 2007; Pottasch et al. 2011; Otsuka et al. 2014). The large ranges are partly due to its poorly constrained distance; in the literature, we find distances ranging from 0.6 to 4.1 kpc (a compilation of values can be found in Aleman et al. 2019).

Figure 2 shows Tc 1 optical and mid-infrared images. Optical images show that most of the nebular emission originates from a round nebula of $\sim$12″ in diameter, with a much fainter external halo of $\sim$52″ in diameter. This halo is a remnant of the progenitor asymptotic giant branch (AGB) star mass loss (Schwarz et al 1992; Corradi et al. 2003). In the center of the main shell, the nebula shows a 3″ diameter bright core. Mid-infrared images of the main shell reveal a horseshoe-shaped central structure of $\sim$3″ in diameter produced by continuum dust emission, surrounded by ionized gas and a ring of fullerenes 5″ away from the central star (Cami et al. 2018).

With the exception of the fullerene emission, all the characteristics listed for Tc 1 are fairly common, and there are tens of other PNe with very similar characteristics that do not show the C_{60} emission. The explanation for the C_{60} emission is thus not to be found in the overall properties of the object but must be in the details of the local physical conditions – present or in the past. Tc 1 is also by far the ”cleanest” fullerene source with very little (if any) contamination by PAHs, and it is also the only source for which we know *where* the fullerenes are emitting (a spatial study of the IR emission in IC 418 is less conclusive, see Díaz-Luis et al. 2018).

Improving What We Know About Tc 1

To get a better view of the physical conditions throughout the entire nebula, we carried out a detailed analysis of the optical/UV spectrum of Tc 1 obtained with the X-Shooter spectrograph mounted on the ESO Very Large Telescope (VLT). The main goals of the study were to determine key physical parameters such as elemental abundances, kinematics, and morphology of the main shell and investigate whether some of these parameters vary across the nebula. We summarize our results below; the full text can be read in Aleman et al. (2019).

The elemental abundances we determined show no surprises – the abundances of He, C, O, N, S, Ne, Si, Cl, Ar, and Fe are similar to values previously reported in the literature. The detected spatial variations of these abundances were not high enough to be attributed to real significant variations. With our high-resolution, deep spectrum we could identify one faint Krypton line. The abundance of this element is a proxy for the carbon abundance, and the abundance we inferred indicates a C/O ratio of 1.9 compatible with other (ours and previous) measurements (Sterling & Dinerstein 2008; García-Rojas et al. 2015).

From the emission lines, we could also extract information about the kinematics in the nebula, and in turn we used this information to study the three-dimensional (3-D) structure of Tc 1. Although Tc 1 seen through the telescope is fairly round, its 3-D morphology was still uncertain, as bipolar nebulae seen pole-on can also result in round (projected) images. Assuming a homologous expansion law ($v = K \times r$, where r is the distance from the central star and K is a constant; see e.g. Akras & Lopez 2012), we modelled its structure. Our best fit to the observations indicate that Tc 1 is a slightly elongated ellipsoid, with the long axis tilted at a small angle ($\sim$6 degrees) from the line of sight.

Armed with these diagnostics, we then constructed a detailed photo-ionization model for the nebula. The model shows, among other results, that the main shell of Tc 1 is matter bounded, meaning that the central ionizing star produces more photons than needed to ionize the main shell. Consequently, a fraction of the ionizing photons is escaping. Our calculations show that the leaking ionizing photons are enough to ionize the large and faint Tc 1 halo. Given that the fullerene emission is at about 5$''$ from the central star (Cami et al. 2018; Fig. 2), this indicates that the C_{60} emission originates close to the interface between the denser material that forms the main shell and the fainter halo remnant of the AGB gas. One would be tempted to conclude this must be from a Photo-Dissociation Region (PDR) around the main ionized shell. However, we did not find H_2 lines in the X-Shooter spectrum of Tc 1 and, in fact, Otsuka et al. (2014) reported that none of the C_{60}-PNe they studied showed any H_2 emission. There is also no clear evidence for PAH emission in Tc 1: if there are PAHs in this object, they would only reveal themselves through an extremely weak bump at 11.3 μm that is seen in the central structure and not where the C_{60} is emitting; all other usual PAH bands are absent in the Spitzer spectrum (Cami et al. 2018). The absence of PAH and H_2 emission in the fullerene-emitting zone of Tc 1 in addition to our result that the nebula is matter bounded are strong evidence that there is no *bona fide* PDR surrounding the main shell (although a PDR may exist outside the halo). We are currently studying SOFIA observations of PDR cooling lines in Tc 1 to shed more light on the nature of the circumstellar environment that lies beyond the ionized shell. The absence of a regular PDR around the main shell in this young PN indicates that this shell may be the star's fast wind, which is overtaking the AGB remnant halo, as suggested by Corradi et al. (2003).

This scenario is consistent with the suggestion by Cami et al. (2018) that the C_{60} formation and excitation is related to the fast wind overtaking the slow wind, or the development of an ionization front. In addition, the dust destruction process must be related to the transition from the AGB to the PN phases, as the fullerene bands are only detected in young PNe. Cami et al. (2018) suggest that fullerenes, produced in earlier phases (AGB), are released when dust is destroyed by the ionization front. Although this is a possible mechanism, further studies should be done to determine the C_{60} formation route in Tc 1.

Current and future studies will look in detail at spatially resolved kinematics in Tc 1 using integral field spectroscopy and at the PDR characteristics as discussed above. But we are particularly looking forward to the launch of the James Webb Space Telescope (JWST), which offers a unique opportunity to map out the location of *all* IR spectral components. Combined with our current detailed knowledge of the physical conditions throughout the nebula, such observations offer a great promise to solve many of the remaining mysteries related to fullerenes in PNe. And Tc 1 is the ideal target to do just that.

Acknowledgments

I.A. would like to thank CAPES/MEC (Brazil), and the Institute of Physics and Chemistry (IFQ) and the Laboratory of Computational Astrophysics (LAC), UNIFEI (Brazil) for the financial support. We also acknowledge the co-authors of the paper Aleman et al. (2019) who were unable to co-author this In Focus for the wonderful collaborative work that resulted in that paper.

In Focus

Interview with
Helgi Rafn Hróðmarsson
The New Member of the AstroPAH Editorial Team

Dr. Helgi Rafn Hróðmarsson is a Marie Curie fellow under the supervision of Prof. Harold Linnartz. He started his position in September 2019, after having spent 2 years as a postdoc in the group of Laurent Nahon at the Synchrotron SOLEIL. Before moving to France, he completed his PhD in chemistry at the University of Iceland under Prof. Ágúst Kvaran (finished 2016) and spent an additional year there as an adjunct working for Prof. Oddur Ingólfsson.

Welcome to the AstroPAH Editorial Board! Can you tell us how you got into PAH-related research?

HRH: I had been actively thinking about PAHs and especially large ones ever since my first visit to Prof. Harold Linnartz's group back in 2015 (while I was still pursuing my PhD). The aim was to write a Marie Curie proposal around a laboratory-based PAH study with the intention of going towards larger PAH species to study their photoionization and photofragmentation dynamics.

I think I can pinpoint the moment where my interest in PAHs was sparked. It was while Harold was showing me the different setups in his lab and on the wall I saw a mass spectrum exemplifying the photodegradation of the HBC cation. That one spectrum told an interesting story very elegantly. The hydrogen atoms were initially stripped off the edges of the PAH, revealing a graphene-like sheet. From there the photofragmentation continued in C2-losses and gave rise to several (presumably) closed-cage structures that were more stable to the continued onslaught of radiation than their predecessors. My interest in PAHs was thus piqued.

What are you working on right now?

HRH: My first two Marie Curie proposals written with Prof. Linnartz were rejected. A little over a year ago while I was doing a postdoc at the SOLEIL synchrotron we decided to try one more time and as they say, third time's the charm. So now I am finally pursuing the research project that has been in the back of my mind for several years now.

I am working towards using complementary radiation techniques (from IR to UV) to extract physical and chemical parameters of very large PAHs (containing more than 60 carbon atoms). These have been theorized to be omnipresent in space, but there has been practically no laboratory work dedicated to extracting information relevant to their radiation-induced behavior which is very important if we want to characterize the presence of these molecules in an astrophysical setting. I am particularly interested in the interstellar formation of fullerenes, but prior laboratory work has suggested they may form in interstellar environs from the photo-induced breakdown of very large PAHs.

Which open question in Laboratory Astrophysics would you like to see answered in the near future?

HRH: Woah, this is a tough one.

There are probably way too many mysteries (small and big) to mention that I am particularly interested in. I could point toward the aforementioned formation of fullerenes from PAHs in interstellar space. I could point toward the propensity for "anti-Arrhenian" chemical kinetics in space (i.e. CRESU-related research which reveals the extent to which quantum effects start to dominate the rates of chemical reactions at very low temperatures). There is still the open question of which molecules are DIB carriers, which by now remain a century-old spectroscopic mystery. And as prevalent and unquestionably important as it is, we still don't fully comprehend the complete formation mechanism of H_2 in space.

I am hesitant to answer which one I'd like to see answered in the near future. It would be nice at least to be a participant in unravelling a part of these cosmic enigmas. But if these questions still elude us, that shouldn't be discouraging though. It should be about the journey rather than the destination, right?

What does it mean for you to be part of the AstroPAH editorial team?

HRH: Obviously it means the world to me that I am being granted the chance to work with a lot of incredibly intelligent and talented researchers to sculpt this beautiful newsletter.

But the inverse of the question is more important to me personally – i.e. what me being a part of this editorial team would mean for others.

I have grappled with depression most of my life, and I went through a burn-out phase shortly after I finished my PhD. I also spent most of my adult life in the closet until I came out as bi/pan a few years ago. Being a metalhead on top of everything I have frequently found myself in a very niche and isolated Venn diagram. I hope that my being on the editorial team will bring hope to others who have been marginalized or find themselves outside the box, particularly in academia. There are others like you out there. You have allies, you are valued, and you can make it happen. Lots of love to you all. <3

What was the most important advice somebody gave you?

HRH: I am probably the most grateful for whatever algorithm it was that recommended me to start reading about stoicism. It turned out to be incredibly complementary to my therapy sessions and the course I took in cognitive behavioral therapy after my burn-out. At its core, stoicism sort of just strips down and helps you swipe away every single negative thought process that is slowing you down and leaves you with a concentrated drive for self-betterment. I find it very helpful in focusing on what matters in life and what doesn't.

I also take a lot of inspiration from media mogul RuPaul whose slogan is (famously, if you're a drag race fan): "If you can't love yourself, how in the hell are you gonna love somebody else."

I think it's also only appropriate that I mention some advice the editor in-chief, Xander Tielens gave me during a brief email communication between us as I voiced concerns about a single passage in the Marie Curie application program that could under a certain interpretation disqualify me as an applicant. He simply said to me: "To score you have to shoot first."

This really struck a cord with me when I was still a PhD student and ever since I've always taken it at heart. (It may be because I am an avid football fan – who knows?). Is something unlikely to go through? Well, go for it anyway! Take the shot! Otherwise, you'll never know.

What do you do outside of work?

HRH: Hmmm. I will have to answer this in two parts.

(Technically still work) I play the drums in two active black metal bands from Iceland called Misþyrming (https://misthyrming.bandcamp.com/) and Carpe Noctem (https://carpenoctem.bandcamp.com/). I also like to do some writing about science in Hollywood movies as well as write about my own research under the pseudonym "Cosmic Chemist" (https://cosmicchemist.com/).

(Definitely not work) I am a massive F. C. Barcelona fan so I try to catch as many games as possible. I read a lot as well. I enjoy literature from all over the world, and whether it's sci-fi, fantasy, drama, autobiographical, horror, suspense, I like it all. Music is among my deeply rooted passions, and my musical taste is very eclectic – Black metal to Björk. I am also a walking talking Eurovision encyclopedia. I used to be a much bigger movie buff than I am now, but I do love watching films with my girlfriend, Helena. Particularly horror films and 90's cheese.

Also tattoos. I have lost count of how many I have, but I still have space for lots more than I currently have. Also board games and chess.

How do you balance your professional and personal life?

HRH: I have absolutely no idea. Often I've paraphrased Heath Ledger's Joker and said: "I just... do... things."

But to give an example, while on tour with my band Misþyrming (Carpe Noctem plays less regularly and requires the stars to align so to speak), I manage to get a significant amount of work done in terms of reading and writing. Obviously, I can't be in the lab while on tour, so I try to plan my working schedule along those lines. E.g. I'm writing these answers whilst in Montréal, Canada for a Misþyrming show for the 2019 edition of the Messe des Morts festival.

I am very lucky to have the loving support of my girlfriend, Helena. We've been living together for a few months now, and she has always been incredibly supportive and full of love.

All my supervisors have also been very understanding of my musical obligations, and hence I have been very fortunate to have been able to come so far with these two concurrent careers.

I try to be well organized but a balance with hectic schedules is a bit like a chemical equilibrium. What seems to be this sort a stationary point where nothing happens anymore between reactants and products is in actuality a swirling vortex of natural chaos upon further inspection; only the total numbers of reactants and products are unchanged. I find that with the correct perspective you're already in balance.

Thermal evaporation of Pyrene clusters

Sébastien Zamith[1], Ming-Chao Ji[2], Jean-Marc L'Hermite[1], Christine Joblin[2], Léo Dontot[2,3], Mathias Rapacioli[3] and Fernand Spiegelman[3]

[1] Laboratoire Collisions Agrégats Réactivité (LCAR/IRSAMC) UMR5589, Université de Toulouse (UPS) and CNRS, 118 Route de Narbonne, F-31062 Toulouse, France

[2] Institut de Recherche en Astrophysique et Planétologie (IRAP) UMR5277, Université de Toulouse (UPS), CNRS, CNES, 9 avenue du Colonel Roche, F-31028 Toulouse, France

[3] Laboratoire de Chimie et Physique Quantiques (LCPQ/IRSAMC) UMR5626, Université de Toulouse (UPS) and CNRS, 118 Route de Narbonne, F-31062 Toulouse, France

This work presents a study of the thermal evaporation and stability of pyrene $(C_{16}H_{10})_n$ clusters. Thermal evaporation rates of positively charged mass-selected clusters are measured for sizes in the range $n = 3-40$ pyrene units. The experimental setup consists of a gas aggregation source, a thermalization chamber, and a time of flight mass spectrometer. A microcanonical Phase Space Theory (PST) simulation is used to determine the dissociation energies of pyrene clusters by fitting the experimental breakdown curves. Calculations using the Density Functional based Tight Binding combined with a Configuration Interaction (CI-DFTB) model and a hierarchical optimization scheme are also performed in the range $n = 2 - 7$ to determine the harmonic frequencies and a theoretical estimation of the dissociation energies. The frequencies are used in the calculations of the density of states needed in the PST simulations, assuming an extrapolation scheme for clusters larger than 7 units. Using the PST model with a minimal set of adjustable parameters, we obtain good fits of the experimental breakdown curves over the full studied size range. The approximations inherent to the PST simulation and the influence of the used parameters are carefully estimated. The derived dissociation energies show significant variations over the studied size range. Compared with neutral clusters, significantly higher values of the dissociation energies are obtained for the smaller sizes and attributed to charge resonance in line with CI-DFTB calculations.

E-mail: sebastien.zamith@irsamc.ups-tlse.fr

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Announcements

Postdoc Position in Processing of Amino Acids from Ice Radiation Experiments at NASA/GSFC

Advertised by Dr. Chris Materese

Deadline for application: January 31, 2020

The Cosmic Ice Lab at NASA Goddard Space Flight Center (Greenbelt, MD) is seeking candidates for a postdoctoral position in the field of astrochemistry. This research will involve a systematic study of the formation of prebiotic molecules through a combination of experimental ice radiation and aqueous chemistry. The successful candidate will perform high-vacuum ice irradiation experiments, aqueous chemistry in high pressure reaction cells, and will analyze the results using liquid chromatography coupled with mass spectrometry.

This research will focus on organic compounds of astrobiological interest formed by ice radiation chemistry. Additionally, it will examine the role of hydrothermal processing in modifying these organics, comparing the findings to organic materials previously detected in extraterrestrial samples (e.g., meteorites).

The applicants should have a PhD in chemistry or a related field at the start of the position and must be within five years of the receipt of their doctoral degree. Ideally, candidates will have experience with some or all of the following:
- cryo-vacuum apparatus
- radiation chemistry
- infrared spectroscopy
- ultrahigh-performance liquid chromatography with UV fluorescence and time of flight mass spectrometry detection(LC-FD/ToF-MS)
- high-pressure reaction cells

Applicants should provide **cover letter**, **curriculum vitae**, **3-page statement of research interests**, **publication list**, and arrange to have **one to three letters of recommendation** submitted. The deadline to apply is January 31, 2020. Late applications will be considered at the discretion of the committee.

To apply send all documents to:
Katherine McKee, CRESST II Program Coordinator
katherine.s.mckee@nasa.gov
(301) 286-3063
Mail Code 660.8 NASA/GSFC, Greenbelt, MD 20771

Salary and benefits are competitive, commensurate with experience and qualifications. Approximate start date around May 2020 is preferred; later start dates may be negotiated. For more information about the proposed research, contact Dr. Christopher Materese (christopher.k.materese@nasa.gov).

For information on CRESST II or Howard University, contact Dr. Marcus Alfred (maralfred@howard.edu). We are committed to building a diverse group and encourage applications from women, racial and ethnic minorities, individuals with disabilities and veterans.

Howard University is an Affirmative Action, Equal Opportunity Employer.

AstroPAH Newsletter

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