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Astrochemistry VII: Through the Cosmos from Galaxies to Planets

Edited by

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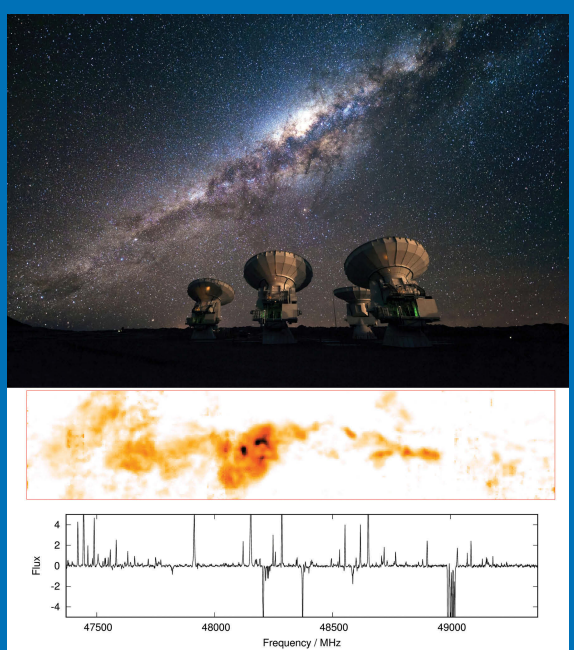
Tom Millar
Yuri Aikawa



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FROM GALAXIES TO PLANETS

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COVER ILLUSTRATION:

Top: ALMA antennas and centre of the Galaxy, credit: ESO/José Francisco Salgado (josefrancisco.org) Middle: The Central Molecular Zone (CMZ) in methanol (at 48.37 GHz) with the Mopra radio telescope. Bottom, spectrum of Sgr B2 LMH with the ATCA, around the methanol line showing the complex chemistry.

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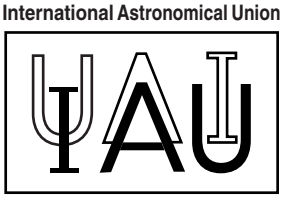

ASTROCHEMISTRY VII: THROUGH THE COSMOS FROM GALAXIES TO PLANETS

PROCEEDINGS OF THE 332nd SYMPOSIUM OF THE INTERNATIONAL ASTRONOMICAL UNION HELD IN PUERTO VARAS, CHILE MARCH 20–24, 2017

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Preface

The 7th IAU Symposium on Astrochemistry: Through the Cosmos from Galaxies to Planets was held on 19-24th March 2017 in Puerto Varas, southern Chile, a beautiful spot on the edge of Lake Lanquihue and overlooked by the snow-capped peak of the Osorno volcano. The location was chosen especially because of the influence that the Atacama Large Millimeter/submillimeter Array (ALMA) has had and is having on our discipline. ALMA, which is situated in the Atacama Desert at an altitude of 5000m, some 2500km north of Puerto Varas, has opened up almost the entire Molecular Universe with exquisite sensitivity and spatial resolution and is allowing us to probe the fundamental physical properties of stars, galaxies and planets and the material between them.

The astrochemistry community has come a long way in the years since the first IAU Symposium on astrochemistry in Goa in 1985 in understanding how molecules respond to local conditions and thereby how to use them to provide information on temperatures, densities, dynamics and ionization. Molecules are crucial to our understanding of the 'hidden' phases of both low-mass and high-mass star formation, the latter of which determine the properties of the massive stars that shape the evolution of galaxies, at all epochs, due to the energetic events that shape their births and deaths. Molecules are also key tools in exploring planet formation in low-mass protoplanetary disks and provide hints as to the type of molecular complexity that may have encouraged the beginnings of biology on Earth. Neglecting isotopologues, we have now detected some 200 different molecules beyond our Solar System, ranging in complexity from species such as methyl ethyl ether, $C_2H_5OCH_3$, and benzonitrile, C_6H_5CN, to the famous C_{60} and C_{70} 'buckyballs'. The nature of the detected species, including cations, anions, free radicals, unsaturated and saturated hydrocarbons, and their seeming propensity to exist in favoured types of regions, many at temperatures as low as 10-20K and in which collision time scales can be weeks or months, provides important information. They tell us immediately that the dominant chemistry must involve exothermic ion-neutral and radical-radical reactions together with a rich solid-state chemistry driven through the interaction of ultraviolet photons and cosmic-ray particles with ice-covered interstellar grains.

At the same time as new and re-instrumented observational facilities such as ALMA, NOEMA, APEX, SOFIA, Rosetta and the Herschel Space Observatory are revealing new views of our Molecular Universe, there has been a concerted effort among physical chemists to provide the large amount of fundamental data required to interpret these observations. This critical collaboration was reinforced at the XXIXth IAU General Assembly in 2015 by the creation of two new IAU Commissions - B5 on Laboratory Astrophysics and H2 on Astrochemistry - and this Symposium, IAU S332, is the first fruit of what we plan to be a close and fruitful engagement between us. Nationally, too, the importance of close collaboration between the chemical and astronomical communities has been recognised through, for example, the creation of the Astrochemistry Sub-Division of the American Chemical Society, the UK's Astrophysical Chemistry Working Group, a joint activity of the Royal Society of Chemistry and the Royal Astronomical Society, and the Dutch Astrochemistry Network in the Netherlands.

This synthesis of astronomical observation, laboratory experiment and theoretical modelling has driven a close and effective cooperation between the astronomical and chemical communities for over 30 years and the proceedings of this Symposium make it plain that it is vital to continue these efforts. Not only does such collaboration lead to a better understanding of astrophysical phenomena but also to advances in fundamental atomic and molecular physics and chemistry. The importance of tunnelling in both gas phase

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and ice mantle reactions at 10K and of spin chemistry in determining D/H ratios in molecules are just two of the ways in which microscopic quantum effects influence the macroscopic properties of our Universe.

It was thus with a degree of excitement and anticipation that some 169 scientists from 25 countries gathered at the Hotel Cumbres, Puerto Varas, where they were welcomed by an opening address from Ewine van Dishoeck in which she formulated some 14 challenges for astrochemistry in the coming decades. Following this, and inspired by some 21 keynote and invited speakers, participants undertook their own astrochemical journey through the cosmos.

At the Toledo Symposium, there was a panel discussion entitled 'On to ALMA'. In Puerto Varas, it was immediately clear that we are firmly in the ALMA Age with talks on how ALMA has provided new insights into high-redshift and ultra-luminous galaxies, dwarf galaxies such as the LMC and SMC, and photon-dominated regions in our own Milky Way. Here we were impressed by the ALMA detections of lines at redshifts up to $z = 7$ and its detections of thousands of molecular lines from the ULIRG, Arp 220.

There were several talks and posters on low-mass star formation including a talk on an ALMA study of the rotating, infalling envelope of IRAS 16293-2422 Source A that demonstrated the power of chemistry to trace different regions of the infall, in particular the position of the centrifugal barrier at which the gas composition appears to be dominated by the evaporation products of ice mantles. This work highlights the importance of ALMA to our field as the chemistry associated with protostellar collapse may be a useful tool to isolate important phases, such as the young disk. This work is still in its infancy and we can look forward to significant advances in the coming years.

The subject of ice mantles is a very active area of theoretical and experimental research worldwide and theoretical models of surface chemistry were summarised, in particular in relation to the formation of complex organic molecules (COMs). Laboratory astrophysics is playing an important role in understanding gas-phase chemistry as well as surface and bulk processes in ices and the Symposium featured many talks and posters on these subjects. The interaction of ices with soft X-rays was reviewed and it was shown that soft X-ray irradiation of cosmic ice mixtures induced a complex chemistry that resulted in the formation of the nucleobase adenine and peptide bonds, amongst others. One of the major challenges of ice chemistry is to identify the primary products of photolysis and to determine photodesorption yields. A new experiment was described in which the photolysis products of methanol ice were detected using gas-phase millimetre and sub-millimetre spectroscopy. This opens up an exciting new way in which yields can be measured directly and in which products that cannot be differentiated using conventional mass spectroscopic techniques can be identified. This is certain evidence that laboratory science is moving in directions that continue to be central to astrochemistry.

Molecules are also important in the formation of dust grains in supernovae, circumstellar envelopes and the interstellar medium (ISM) and we had talks on ALMA observations of late-type AGB stars. Here detections of species such as TiO, TiO_2, SiO, AlO and AlOH are aimed at understanding how dust precursors help nucleation and growth. Observations were complemented by laboratory evidence that SiO molecules could grow to nanoscale amorphous clusters in liquid He drops at 0.37K, giving experimental support to the hypothesis that most silicate dust must form in the ISM given its fast destruction time scale in supernovae explosions.

A significant part of the program was devoted to low-mass star formation and protoplanetary disks (PPDs) including the importance of molecules in tracing the dynamics in such regions. There were also several PPD talks on subjects such as the means to determine the water snowline, observations of COMs, gaps, and rings, grain growth and

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dynamics, disk masses and carbon depletion, dust in transition disks, and isotopic chemistry. One of the highlights of this session was the amazing images from ALMA where it is clear that the chemistry associated with planet formation is slowly being revealed.

Comets are an important part of our astronomical heritage and our journey through the cosmos took us to the fabulous and detailed results emerging from the Rosetta Mission, in particular, to the molecular 'zoo' detected at comet 67P/CG. A range of results were presented, from the observation that the comet does not have a solar Xe isotopic distribution, that its O_2 is likely inherited from interstellar ice, to the conclusion that comets did not supply the Earth's water. The audience was impressed at the vast array of molecules detected by Rosetta and we suspect that many will be keen to take advantage of the new research opportunities in this exciting field.

Exoplanet atmospheres are becoming of increasing importance in astronomy and there are now many groups using astrochemical techniques to interpret their observations. A major task identified for those interested in exoplanet atmospheres is to develop a community similar to that current in astrochemistry. The chemical composition of exoplanetary atmospheres is an area in which astrochemists will continue to make important contributions and we expect that this topic will play a larger role in future Symposia.

The programme explicitly included a number of invited talks on future facilities, including the JWST and ALMA Band 1, and concluded with an extensive and passionate debate on whether the C_{60}^+ ion was responsible for five of the diffuse interstellar bands, with arguments against suggesting that atmospheric contamination had not been effectively removed from the astronomical spectra and that non-LTE stellar lines were also blended with C_{60}^+ features.

In addition to the oral presentations, some 116 papers were presented as posters in two sessions and poster prizes awarded to six individuals, three from each session: Ko-Ju Chuang, Anna Miotello, Victor Rivilla, Richard Teague, Marie van de Sande and Merel van't Hoff.

Ewine van Dishoeck also gave a special presentation on 'Women in Astronomy', summarising the results of the recent IAU survey on this topic. She encouraged participants, as we do readers, to contact her with any ideas on how the IAU could grow the number of its female members.

The organisers would like to thank a number of institutions for providing organisational and financial support: in particular, the IAU for the award of travel grants to 34 young scientists, some 19 nationalities based in 16 countries; NRAO; ALMA; ESO; Queen's University Belfast; the University of New South Wales; the Universidad de Chile, and the journal Molecular Astrophysics.

The Local Organising Committee, which was ably chaired by Gautier Mathys, who brought his exceptional organisational skills and experience to this key role, comprised of Ann Edmunds, Maria Gomez, Natalia Inostroza, Paulina Jirón, Diego Mardones, Sergio Martin, Lars Nyman, and Ursala Throm. They performed their duties both before and during the Symposium in a highly effective manner and the fact that the Symposium ran so smoothly is a testament to their professional approach that ensured attendees had a stress-free experience.

Ted Bergin, Maria Cunningham and Tom Millar, as Co-Chairs, were greatly aided in their duties by the other members of the SOC and would like to express their thanks to them: Susanna Aalto, Yuri Aikawa, Jacob Bean, Dominique Bockelée-Morvan, Paola Caselli, Pierre Cox, Jes Jørgensen, Sun Kwok, Farid Salama, Stephan Schlemmer and Satoshi Yamamoto.

In closing, we are already looking forward to Astrochemistry VIII. At the time of the next Symposium, the Mid-InfraRed Instrument (MIRI) on the James Webb Space Telescope (JWST) will be making ground-breaking observations crucial for understanding the interstellar medium, including molecules, such as H_2 and CO_2, without permanent dipoles, and solid-state ices on dust grain mantles. These observations can only be taken from space. And by 2020, ALMA will be operating with full capabilities, including the ability to measure polarisation and hence magnetic fields in molecular gas. ALMA will also have a working 7-mm band, opening up a new, high-resolution window on the many complex molecules that have their fundamental frequencies within this band, helping solve the puzzle of how molecular complexity develops in star forming regions.

Maria Cunningham (University of New South Wales, Australia)
Tom Millar (Queen's University Belfast, UK)
Yuri Aikawa (University of Tokyo, Japan)
Editors
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CONFERENCE PHOTOGRAPH

Photo 1. Conference photo, show attendees at the conference venue, Hotel Cumbres, Puerto Varas, Chile.

Photo 2. Student prize winners for best talks and posters.

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Photo 3. IAU Commission H2 (Astrochemistry) President, Tom Millar, giving the after dinner speech at the conference dinner.

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