

DIVISION VI INTERSTELLAR MATTER

MATIÈRE INTERSTELLAIRE

Division VI provides a focus for astronomers studying a wide range of problems related to the physical and chemical properties of interstellar matter in the Milky Way and other galaxies.

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DIVISION VI COMMISSIONS

Commission 34	Interstellar Matter
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DIVISION VI WORKING GROUPS

Division VI WG	Astrochemistry
Division VI WG	Planetary Nebulae

TRIENNIAL REPORT 2009-2012

1. Introduction

Division VI, consisting of one Commission (Commission 34) and two Working Groups (Astrochemistry WG and Planetary Nebulae WG), has 972 members whose theoretical, observational, and experimental research interests cover a wide spectrum of activities associated with the study of the interstellar medium (ISM) in the Universe. As such, the Division has close links with Division VIII, IX, and X. The ISM and stars, the two major visible components of a galaxy, are coupled to each other through star formation, stellar feedback, and gravitational potential; thus, the Division is also closely linked to Division VII.

Our report on activity since 2009 is divided into four sections, covering our view of past and future developments of the Division, important meetings and conferences, relevant proceedings and monographs, and a list of important review articles published in the reporting period. Reports of the Working Groups are provided separately.

2. Developments

2.1. *Scientific advances*

Recent advances in observing facilities have made it possible to study the physical structure and processes of the interstellar medium in the Galaxy and nearby galaxies with higher angular resolution in a wide range of wavelengths. Most notably, the dust component of the interstellar medium can be studied with unprecedented sensitivity and angular resolution in mid- to far-infrared by the Spitzer Space Telescope, the Herschel Space Observatory, and the Planck Satellite. Numerous surveys were made for the Galactic plane, e.g. Spitzer's GLIMPSE and MIPS GAL, and Herschel's Hi-GAL, and for the Magellanic Clouds, e.g. SAGE and S³C. These surveys have been used to analyze the abundance and distribution of polycyclic aromatic hydrocarbons, very small grains, and big grains. Planck, in addition to its mission goal in cosmology, mapped the coldest dust in the Galaxy. Besides these large-scale mappings, Spitzer and Herschel observations have been used to discover molecules, e.g. fullerenes, and study astrochemistry.

From the ground, the International Galactic Plane Survey (IGPS) combines many radio telescope surveys from around the world to map the interstellar gas and dust in the galaxy, while the HI Nearby Galaxy Survey (THINGS) maps out the interstellar gas in nearby galaxies. The Bolocam Galactic Plane Survey (BGPS) and the APEX Telescope Large Area Survey of the Galaxy (ATLASGAL) are mapping out the colder dust in the Galaxy. The Atacama Large Millimeter Array (ALMA) will provide a clear view of dust and star formation in the Galaxy and nearby galaxies. The polarimetric capabilities of Institut de Radioastronomie Millimetrique (IRAM) in lines, Planck in continuum, and the upcoming ALMA in mm-submm wavelengths are opening a new window to probe magnetic fields. The Wisconsin H α Mapper (WHAM) has mapped the distribution and velocities of warm ionized gas in the Galaxy from the north and is extending to the south.

At the high-energy end, Chandra and XMM-Newton Observatories have been used to investigate the distribution and physical properties of the 10⁶ K hot ionized gas in star forming regions, such as the Carina Nebula, as well as diffuse fields in the Galaxy, Magellanic Clouds, and nearby galaxies. The Far UV Spectroscopic Explorer (FUSE) and the Hubble Space Telescope (HST) STIS and COS have been used to probe the 10⁵ K hot gas at interfaces and in the Galactic halo. The Fermi Gamma-Ray Observatory has resolved the gamma-ray emission and revealed the sites of cosmic-ray production in the Galaxy as well as the Magellanic Clouds, and revealed the existence of huge bubbles in the Galactic Center of mysterious origin.

Progress has also been made in the numerical modeling of local and global conditions of the ISM, its morphology and its time-dependent evolution, owing to a rapid development of suitable hard- and software. It is now possible to follow the full non-linear evolution of a plasma by solving the hydro- or MHD equations in high resolution simulations with adaptive mesh refinement. One of the key results of the past years was to recognize, and quantitatively describe, the role of compressible turbulence in the ISM and its impact on the distribution of gas into phases, the mixing of chemically enriched material, the volume and mass filling factors of the ISM plasma, and its heating and cooling history, amongst others.

Advances have also been made in the treatment of magnetic field in star formation. To address the magnetic flux problem in the collapse of a molecular cloud to form stars, the ambipolar diffuse mechanism was suggested. Recently, an alternative mechanism to transport magnetic flux in the early stage of star formation is proposed – magnetic reconnection in the presence of turbulence. 3-D MHD simulations of ISM clouds with consideration of a gravitational field provided by embedded stars and introducing tur-

bulence indicate that magnetic reconnections can indeed reduce the magnetic field built up at the center. It has also been shown that, with the considering of effects of the self-gravity in the clouds, the turbulent reconnection transport may be efficient enough to make an initially subcritical cloud that becomes supercritical and collapse. 3-D MHD simulations show that turbulent magnetic reconnection can also transport magnetic flux to the outskirts and form a protostellar disk. (Contributed by E. M. de Gouveia Dal Pino.)

To promote scientific communications and collaborations, the Division has supported or organized several Symposia and Special Sessions, covering topics of ISM in general, star formation, and magnetic fields in the IAU General Assembly at Beijing in August 2012. These Symposia and Special Sessions are listed in Section 3.

2.2. Restructuring of Divisions and Commissions

The Division members are mostly in favor of restructuring the IAU Divisions. It is logical to merge Division VI Interstellar Matter and Division VII Galactic System into Division H. The general concern is the title of Division H. Among the responses, the majority think that the title “Interstellar Matter & Local Universe” can be fine-tuned to better represent the constituents of Division H.

It has been noticed that Laboratory Astrophysics is conspicuously absent in the IAU structure. Laboratory work has made essential contributions to, for example, astrochemistry and plasma astrophysics that are particularly relevant to Commission 34. While there is no specific commission on Laboratory Astrophysics, it should at least be mentioned in “Note b” that states what Division B will cover.

There is also concern that some Commissions in other Divisions are very narrowly focused and may continue to exist for historical purposes. It is questioned whether some small Commissions with similar focus could be merged into a reasonably sized Commission. The draft document for the IAU Restructuring did not provide sizes of membership for the Commissions, making it difficult to judge whether some Commissions might benefit from mergers.

Scientists working on space infrared missions identify themselves more strongly with Division B, and question why Division D is not included in Division B.

Finally, the two Division Working Groups, Astrochemistry and Planetary Nebulae, have both proposed to change their status from Working Group to Commissions. Both Working Groups have organized successful IAU Symposia every ~ 5 years, and both have large numbers of active researchers in the subjects. The Division Organizing Committee fully support these initiatives to convert Astrochemistry and Planetary Nebulae Working Groups to Commissions.

3. Meetings and conferences

Many conferences devoted in whole or in part to the scientific interests of Division members were held in the reporting period. Below, we list some of the most significant meetings:

- *Assembly, Gas Content and Star Formation History of Galaxies*, 21 – 24 September 2009, Charlottesville, Virginia, USA
- *Ten Years of Science with Chandra*, 22 – 25 September 2009, Boston, Massachusetts, USA
- *Planetesimal Formation*, 28 – 30 September 2009, Cambridge, UK
- *Herschel Space Observatory: Discovering the Cold Universe*, 2 – 4 October 2009, Thessaloniki, Greece

- *Interstellar Matter and Star Formation - A Multi-Wavelength Perspective*, 8 – 10 October 2009, Hyderabad, India
- *Reionization to Exoplanets: Spitzer's Growing Legacy*, 26 – 28 October 2009, Pasadena, California, USA
- *2009 Fermi Symposium*, 2 – 5 November 2009, Washington, DC, USA
- *From Circumstellar Disks to Planetary Systems*, 3 – 6 November 2009, Garching, Germany
- *5th Korean Astrophysics Workshop on Shock Waves, Turbulence, and Particle Acceleration*, 18 – 21 November 2009, Pohang, Korea
- *Plasmas in the Laboratory and in the Universe: Interactions, Patterns, and Turbulence*, 1 – 4 December 2009, Como, Italy
- *Infrared Emission, Interstellar Medium and Star Formation*, 22 – 24 February 2010, Heidelberg, Germany
- *Multi-Phase Interstellar Medium and Dynamics of Star Formation*, 28 February – 2 March 2010, Nagoya, Japan
- *Starbursts Near and Far*, 12 March 2010, London, UK
- *From First Light to Newborn Stars: A Science Symposium Celebrating 50 years of our National Observatory*, 14 – 17 March 2010, Tucson, Arizona, USA
- *Galaxies and their Masks - KC Freeman 70th birthday fest*, 11 – 17 April 2010, Namibia
- *Herschel First Results Symposium (44th ESLAB Symposium 2010)*, 4 – 7 May 2010, Noordwijk, The Netherlands
- *Rotation Measure Analysis of Magnetic Fields in and around Radio Galaxies*, 10 – 14 May 2010, Riccione, Italy
- *Magnetic Fields on Scales from Kiloparsecs to Kilometres: Properties and Origin*, 17 – 21 May 2010, Krakow, Poland
- *Magnetic Fields: From Core Collapse to Young Stellar Objects*, 17 – 19 May 2010, London, Ontario, Canada
- *Science with ALMA Band 5 (163 - 211 GHz)*, 24 – 25 May 2010, Rome, Italy
- *IAU Symposium 270: Computational Star Formation*, 31 May – 4 June 2010, Barcelona, Spain
- *PAHs and the Universe: A Symposium to Celebrate the 25th Anniversary of the PAH Hypothesis*, 31 May – 4 June 2010, Toulouse, France
- *Ultraviolet Universe - 2010*, 31 May – 4 June 2010, St. Petersburg, Russia
- *The Dynamic ISM: a celebration of the Canadian Galactic Plane Survey*, 6 – 10 June 2010, Naramata, BC, Canada
- *Cosmic Magnetism - From Stellar to Intergalactic Scales*, 7 – 11 June 2010, Kiama, Australia
- *A Universe of Dwarf Galaxies*, 14 – 18 June 2010, Lyon, France
- *EPoS 2010 The Early Phase of Star Formation*, 14 – 18 June 2010, Ringberg Castle, Germany
- *Asymmetrical Planetary Nebulae V*, 20 – 25 June 2010, Lake District, UK
- *The Multi-Wavelength View of Hot, Massive Stars (39th Liège International Astrophysical Colloquium)*, 12 – 16 July 2010, Liège, Belgium
- *The Infrared/X-ray Connection in Galaxy Evolution*, 12 – 15 July 2010, London, UK
- *New Insights into the Physics of Supernova Remnants and Pulsar Wind Nebulae. 38th COSPAR Scientific Assembly 2010 Event E19*, 18 – 25 July 2010, Bremen, Germany
- *IAU Symposium 272 - Active OB Stars: Structure, Evolution, Mass Loss and Critical Limits*, 19 – 23 July 2010, Paris, France

- *Molecules in Galaxies*, 26 – 30 July 2010, Oxford, UK
- *Astronomy & Astrophysics in Antarctica*, 16–20 August 2010, Xi'an, China
- *Immersion Grating Infrared Spectrometer Science Workshop*, 26 – 27 August 2010, Seoul, Korea
- *25th Summer School and International Symposium on the Physics of Ionized Gases*, 30 August – 3 September 2010, Donji Milanovac, Serbia
- *IAU Symposium 274: Advances in Plasma Astrophysics*, 6 – 10 September 2010, Giardini-Naxos, Italy
- *Herschel and the Formation of Stars and Planetary Systems*, 6 – 9 September 2010, Gothenborg, Sweden
- *Great Barriers in High Mass Star Formation*, 13 – 17 September 2010, Townsville, North Queensland, Australia
- *Conditions and Impact of Star Formation: New Results with Herschel and Beyond*, 19 – 24 September 2010, Zermatt, Switzerland
- *Charge Exchange Meeting*, 29 September 29 – 1 October 2010, Madrid, Spain
- *WittFest: Origins & Evolution of Dust*, 10 – 12 October 2010, Toledo, Ohio, USA
- *Science with the Hubble Space Telescope - III*, 11 – 14 October 2010, Venice, Italy
- *Galaxy Evolution: Infrared to Millimeter Wavelength Perspective*, 25 – 29 October 2010, Guilin, China
- *Stormy Cosmos: The Evolving ISM from Spitzer to Herschel and Beyond*, 1 – 4 November 2010, Pasadena, California, USA
- *Spiral Structure in the Milky Way: Confronting Observations and Theory*, 7 – 10 November 2010, Copiapó, Chile
- *Kinetic Processes in Plasma: Instabilities, Turbulence and Transport*, 8 – 11 November 2010, Bochum, Germany
- *Massive Galaxies Over Cosmic Time 3: The Role of Gas and Dust*, 8 – 10 November 2010, Tucson, Arizona, USA
- *The Submillimeter Universe: The CCAT View*, 12 – 13 November 2010, Ithaca, New York, USA
- *Observing with ALMA: Early Science*, 29 November – 1 December 2010, Grenoble, France
- *Star Formation under Extreme Conditions: the Galactic Center*, 6 – 9 December 2010, Besancon, France
- *The Millimeter and Submillimeter Sky in the Planck Mission Era*, 10 – 14 January 2010, Paris, France
- *ALMA: Extending the Limits of Astrophysical Spectroscopy*, 15 – 17 January 2011, Victoria, BC, Canada
- *Herschel and the Characteristics of Dust in Galaxies*, 28 February – 3 March 2011, Leiden, Netherlands
- *2nd CARMA Symposium*, 28 February – 3 March 2011, Berkeley, California, USA
- *Star Formation across Space and Time: Frontier Science with the LBT and Other Large Facilities*, 31 March – 3 April 2011, Tucson, Arizona, USA
- *Assembling the Puzzle of the Milky Way*, 17 – 22 April 2011, Le Grand-Bornand, France
- *The 5th Korea-Mexico Joint Workshop*, 20 – 22 April 2011, Goheung, Korea
- *A Decade of Exploration with the Magellan Telescopes*, 25 – 28 April 2011, Pasadena, California, USA
- *IAU S280: The Molecular Universe*, 30 May – 3 June 2011, Toledo, Spain
- *Frontier Science Opportunities with the James Webb Space Telescope*, 6 – 8 June 2011, Baltimore, Maryland, USA

- *Star Formation Summer School*, 15 – 18 June 2011, Taipei, Taiwan
- *Cosmic Ray and their Interstellar Environment*, 26 June – 1 July 2011, Montpellier, France
- *Multiwavelength Views of the ISM in High-Redshift Galaxies*, 27 – 30 June 2011, Santiago, Chile
- *From Dust to Galaxies*, 27 – 30 June 2011, Paris, France
- *The X-ray Universe 2011*, 27 – 30 June 2011, Berlin, Germany
- *Recent Advances in Star Formation : Observations and Theory (Part of the Silver Jubilee celebration of the Vainu Bappu Telescope)*, 28 June – 1 July 2011, Bangalore, India
- *EWASS2011 - Special Session SPS2: Massive Stars Formation*, 4 July 2011, Saint-Petersburg, Russia
- *Sixth NAIC/NRAO School on Single Dish Radio Astronomy*, 10 – 16 July 2011, Green Bank, West Virginia, USA
- *Four Decades of Research on Massive Stars: A Scientific Meeting in the Honour of Anthony F.J. Moffat*, 12 – 14 July 2011, Lanaudière, Québec, Canada
- *Galaxy Formation*, 18 – 22 July 2011, Durham, UK
- *IAU Symposium No.283: Planetary Nebulae: An Eye to the Future* 25 – 29 July 2011, Tenerife, Spain
- *The 11th Asian Pacific Regional IAU Meeting*, 26 – 29 July 2011, Chiang Mai, Thailand
- *32nd. International Cosmic Ray Conference*, 11 – 18 August 2011, Beijing, China
- *Magnetic Fields in the Universe: from Laboratory and Stars to Primordial Structures III*, 21 – 27 August 2011, Tatra Mountains, Poland
- *Jan65: Magnetic Fields and the Cosmos*, 24 – 26 August 2011, Nijmegen, The Netherlands
- *IAU Symposium 284: The Spectral Energy Distribution of Galaxies (SED2011)*, 5 – 9 September 2011, Preston, UK
- *The Starburst-AGN Connection under the Multiwavelength Limelight* 14 – 16 September 2011, Villafranca del Castillo, Spain
- *FIR2011: Star Formation and Feedback in Galaxies as Revealed by Far Infrared and Submillimeter Wavelengths*, 14 – 16 September 2011, London, UK
- *6th IRAM 30m Summer School, Star formation - Near and Far*, 23 – 30 September 2011, Sierra Nevada, Spain
- *Through the Infrared Looking Glass: A Dusty View of Galaxy and AGN Evolution*, 2 – 5 October 2011, Pasadena, California, USA
- *Formation and Early Evolution of Very Low Mass Stars and Brown Dwarfs*, 11 – 14 October 2011, Garching, Germany
- *A Workshop on the Emerging, Multi-wavelength View of the Galactic Centre Environment*, 17 – 20 October 2011, Heidelberg, Germany
- *Midwest Astrochemistry Meeting 2011*, 21 – 22 October 2011, Urbana, Illinois, USA
- *Galaxy Mergers in an Evolving Universe*, 23 – 28 October 2011, Hualien, Taiwan
- *Science with Parkes at 50 years Young*, 31 October – 4 November 2011, Parkes Telescope, NSW, Australia
- *High Energy Astroparticle Physics 2011 - Gamma-Ray Universe: Fermi to CTA*, 13 – 15 November 2011, Tsukuba, Japan
- *6th Korean Astrophysics Workshop: Fundamental Processes of Astrophysical Turbulence*, 16 – 19 November 2011, Pohang, Korea
- *IAU Symposium 287: Cosmic Masers: From OH to H₀*, 29 January – 3 February 2012, Stellenbosch, South Africa

- *The Second AKARI Conference, Legacy of AKARI: A Panoramic View of the Dusty Universe*, 27 – 29 February 2012, Jeju island, Korea
- *Circumstellar Dynamics at High Resolution*, 27 February – 2 March 2012, Foz do Iguaçu, Brazil
- *IAU Symposium 279 - Death of Massive Stars: Supernovae & Gamma-Ray Bursts*, 12 – 16 March 2012, Nikko, Japan
- *From Atoms to Pebbles: Herschel's View of Star and Planet Formation*, 20 – 23 March 2012, Grenoble, France
- *Cosmic-ray Induced Phenomenology in Star-Formation Environments (2nd Workshop of the Sant Cugat Forum on Astrophysics)*, 16 – 19 April 2012, Sant Cugat, Barcelona, Spain
- *RTS 2012- Resolving The Sky - Radio Interferometry: Past, Present and Future*, 18 – 20 April 2012, Manchester, UK
- *First Stars IV - From Hayashi to the Future*, 21 – 25 May 2012, Kyoto, Japan
- *The Physics of Feedback Processes and their Role in Galaxy Evolution*, 10 June – 1 July 2012, Aspen, Colorado, USA
- *The Labyrinth of Star Formation*, 18 – 22 June 2012, Crete, Greece
- *Ultraviolet Astronomy: HST and Beyond*, 18 – 21 June 2012, Kauai, Hawaii, USA
- *7th International Conference on Numerical Modeling of Space Plasma Flows - ASTRONUM-2012*, 24 – 29 June 2012, Big Island, Hawaii, USA
- *Centenary Symposium 2012: Discovery of Cosmic Rays*, 26 – 28 June 2012, Denver, Colorado, USA
- *PoS 2012 The Early Phase of Star Formation - Assembling Pieces of the Missing Paradigm*, 1 – 6 July 2012, Tegernsee, Germany

The Division is supporting a number of Symposia and Special Sessions and is the coordinating Division for Special Sessions 12 and 16 at the IAU XXVIII General Assembly in Beijing, August 2012.

- *IAU Special Session 3: Galaxy Evolution Through Secular Processes*, 12 – 16 August 2012, Beijing, China
- *IAU Symposium 288: Astrophysics from Antarctica*, 20 – 24 August 2012, Beijing, China
- *IAU Symposium 292: Molecular Gas, Dust, and Star Formation in Galaxies*, 20 – 24 August 2012, Beijing, China
- *IAU Special Session 4: New era for studying interstellar and intergalactic magnetic fields*, 20 – 23 August 2012, Beijing, China
- *IAU Special Session 8: Calibration of star-formation rate measurements across the electromagnetic spectrum*, 27 – 30 August 2012, Beijing, China
- *IAU Special Session 12: Modern views of the interstellar medium* 27 – 31 August 2012, Beijing, China
- *IAU Special Session 16: Unexplained spectral phenomena in the interstellar medium*, 27 – 28 2012, Beijing, China

4. Proceedings and monographs

4.1. Conference proceedings

- *The Magellanic System: Stars, Gas, and Galaxies*. Proc. IAU Symposium No. 256, Eds. J. Th. van Loon & J. M. Oliveira (Cambridge: CUP), 2009

- *Cosmic Magnetic Fields: From Planets, to Stars and Galaxies*. Proc. IAU Symposium No. 259, Eds. K. G. Strassmeier, A. G. Kosovichev & J. E. Beckman (Cambridge: CUP), 2009
- *AKARI, a Light to Illuminate the Misty Universe*. Eds. T. Onaka, G. J. White, T. Nakagawa, & I. Yamamura (San Francisco: Astronomical Society of the Pacific Conference Series, vol 418), 2009
- *The Dynamic Interstellar Medium: A Celebration of the Canadian Galactic Plane Survey*. Eds. R. Kothes, T. L. Landecker, & A. G. Willis (San Francisco: Astronomical Society of the Pacific Conference Series, vol 438), 2010
- *Asymmetric Planetary Nebulae 5*. Eds. A. A. Zijlstra, F. Lykou, I. McDonald, & E. Lagadec (Jodrell Bank Centre for Astrophysics), 2011
- *Computational Star Formation*. Proc. IAU Symposium No. 270, Eds. J. Alves, B. Elmegreen, & V. Trimble (Cambridge: CUP), 2011
- *Active OB stars: structure, evolution, mass loss, and critical limits*. Proc. IAU Symposium No. 272, Eds. C. Neiner, G. Wade, G. Meynet, & G. Peters (Cambridge: CUP), 2011
- *The multi-wavelength view of hot, massive stars*. Eds. G. Rauw, M. De Becker, Y. Nazé, J.-M. Vreux, P. Williams (Liège: Société Royale des Sciences de Liège, Bulletin, vol. 80), 2011

4.2. Research monographs

- *Physics of the Interstellar and Intergalactic Medium*. Bruce T. Draine (Princeton: Princeton University Press), 2011

5. Review articles

Recent invited reviews on interstellar matter published in the Annual Reviews of Astronomy and Astrophysics or the Publications of the Astronomical Society of the Pacific have included:

- Kalberla, P. M. W., & Kerp, J. 2009, *ARA&A*, 47, 27, *The HI Distribution of the Milky Way*
- Zweibel, E. G., & Yamada, M. 2009, *ARA&A*, 47, 291, *Magnetic Reconnection in Astrophysical and Laboratory Plasmas*
- Herbst, E., & van Dishoeck, E. F. 2009, *ARA&A*, 47, 427, *Complex Organic Interstellar Molecules*
- Churchwell, E., et al. 2009, *PASP*, 121, 213, *The Spitzer/GLIMPSE Surveys: A New View of the Milky Way*
- De Marco, O. 2009, *PASP*, 121, 316, *The Origin and Shaping of Planetary Nebulae: Putting the Binary Hypothesis to the Test*
- Calzetti, D., & Kennicutt, R. C. 2009, *PASP*, 121, 937, *The New Frontier: Galactic-Scale Star Formation*
- Henning, T. 2010, *ARA&A*, 48, 21, *Cosmic Silicates*
- Adams, F. C. 2010, *ARA&A*, 48, 47, *The Birth Environment of the Solar System*
- Mann, I. 2010, *ARA&A*, 48, 173, *Interstellar Dust in the Solar System*
- Dullemond, C. P., & Monnier, J. D. 2010, *ARA&A*, 48, 205, *The Inner Regions of Protoplanetary Disks*
- Bastian, N., Covey, K. R., Meyer, M. R. 2010, *ARA&A*, 48, 339, *A Universal Stellar Initial Mass Function? A Critical Look at Variations*
- Fukui, Y., & Kawamura, A. 2010, *ARA&A*, 48, 547, *Molecular Clouds in Nearby Galaxies*

- Smith, I. W. M. 2011, *ARA&A*, 49, 29, *Laboratory Astrochemistry: Gas-Phase Processes*
- Williams, J. P. & Cieza, L. A. 2011, *ARA&A*, 49, 67, *Protoplanetary Disks and Their Evolution*
- Kotera, K., & Olinto, A. V. 2011, *ARA&A*, 49, 119, *The Astrophysics of Ultrahigh-Energy Cosmic Rays*
- Armitage, P. J. 2011, *ARA&A*, 49, 195, *Dynamics of Protoplanetary Disks*
- Frisch, P. C., Redfield, S., & Slavin, J. D. 2011, *ARA&A*, 49, 237, *The Interstellar Medium Surrounding the Sun*

You-Hua Chu
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**DIVISION VI / COMMISSION 34 / WORKING GROUP
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TRIENNIAL REPORT 2009-2012**6. Introduction**

The study of molecules in space, known as astrochemistry or molecular astrophysics, is a rapidly growing field. Molecules exist in a wide range of environments in both gaseous and solid form, from our own solar system to the distant early universe. To astronomers, molecules are indispensable and unique probes of the physical conditions and dynamics of regions in which they are detected, especially the interstellar medium. In particular, the many stages of both low-mass and high-mass star formation are better understood today thanks to the analysis of molecular observations. Molecules can also yield a global picture of the past and present of sources. Moreover, molecules affect their environment by contributing to the heating and cooling processes that occur.

Molecular observations are currently being used to study the interstellar gas and dust in diffuse interstellar clouds, dense molecular clouds, protostellar objects, maser and star-forming regions, envelopes of evolved stars, protoplanetary disks, (exo-)planetary atmospheres and comets. In addition to our own Milky Way Galaxy, molecules and solid-state features are routinely detected in interstellar regions of external galaxies ranging from the nearby Magellanic Clouds to distant starburst galaxies at redshifts of more than 6. Indeed, the role of molecules in the study of the early universe, including the formation of the first stars, is a critical one. Molecules are also key probes of galactic assembly processes, e.g., mergers vs. smooth accretion, and molecular gas provides the fuel for star formation and black hole activity. The role of molecules in astronomy has grown to such an extent that it is no longer an exaggeration to refer to a sizable portion of the universe as ‘The Molecular Universe’.

To chemists, the synthesis of molecules from simple atoms to complex species is of increasing interest. The distant goal of learning about the onset of pre-biotic processes is coming closer to home through studies of cometary samples and meteorites, as well as of circumstellar disks, which are the precursors of planets. The processes that produce

these species are unusual and exciting since interstellar space provides a laboratory with conditions not readily simulated on Earth. Thus, astrochemistry attracts scientists from a number of different disciplines. Astrochemistry directly connects with even newer fields such as astrobiology and the study of exoplanets and their atmospheres. As a result, astrochemistry has many adherents throughout the world, and the potential for huge growth as new and more powerful telescopes search the sky for molecules. Large-scale international cooperation occurs in the construction and exploitation of expensive telescopes, such as space-based Herschel and JWST, air-borne SOFIA, and ground-based ALMA, for which the initial scientific cases were largely driven by astrochemists.

The IAU working group (WG) on Astrochemistry in Division VI (new Division H), Commission 34 (Interstellar Matter) was established about 30 years ago by Alexander Dalgarno and led by him for the first two IAU Symposia. From 1991–1999, the WG was chaired by David Williams, with Ewine van Dishoeck as vice-chair. From 1999–now, the WG is chaired by Ewine van Dishoeck with Eric Herbst as vice-chair.

The current WG members come from 13 countries and represent different disciplines (see <http://www.strw.leidenuniv.nl/iau34/> for overview). The WG is responsible for fostering interest in the subject and ensuring the continuation of meetings on the subject under the auspices of the IAU. So far, six IAU-sponsored meetings have been held, roughly every 5-6 years: IAU Symposium 120, in Goa, India 1985 on ‘Astrochemistry’; IAU Symposium 150 on ‘Astrochemistry of Cosmic Phenomena’ in Brazil 1991, attended by 120 scientists from 19 countries; IAU Symposium 178, ‘Molecules in Astrophysics: Probes and Processes’ in Leiden, The Netherlands 1996, with 231 participants from 27 countries; IAU Symposium 197 ‘Astrochemistry: From Molecular Clouds to Planetary Systems’ in Sogwipo, Korea 1999, with 262 participants from 25 countries; IAU Symposium 231 ‘Astrochemistry: Recent Successes and Current Challenges’ in Asilomar, USA in 2005 with 300 participants from 26 countries, and IAU Symposium 280 ‘The Molecular Universe’ in Toledo in 2011 with 440 participants from 30 countries. Worldwide, the number of astrochemists is expected to be at least double this number. The activity and growth of the field is further illustrated by a number of other international meetings and workshops around the world, including numerous meetings having to do with planning for the Herschel and ALMA telescopes, as well as dedicated networks on astrochemistry on a regional and continental basis. The purpose of the IAU symposia has been to ensure that the many aspects of astrochemistry are reviewed, and that the entire community (both astronomers and chemists/physicists) is brought together.

7. Developments within the past triennium

During the 2009-2012 triennium, the WG concentrated on the proposal, planning and organization of IAU Symposium 280 on ‘The Molecular Universe’ in beautiful Toledo, Spain, which took place from 30 May - 3 June 2011 at the newly renovated Technological Campus of the University of Castilla-La Mancha. The IAU WG acted as the Scientific Organizing Committee of the symposium. The Local Organizing Committee, chaired by J. Cernicharo, organized both the scientific and structural aspects of the meeting very well, including a delightful banquet and preceding concert. The cultural mecca that is Toledo added a sense of awe and excitement to the symposium. The large size of the meeting did not interfere with the proceedings in any way. A large number of questions were asked of speakers, who, given their relative youth and diversity, brought many different viewpoints to the proceedings. The three dedicated 2.5-hr. poster sessions were very well attended and enriched the experience of the participants. The sessions were enlivened by tapas and by a variety of beverages. Informal conversations at intermissions and during

the poster sessions were many and spirited. The large number of younger scientists at the meeting was quite impressive, and confirmed that the field of Astrochemistry is entering a period of rapid growth led by new and exceedingly powerful telescopes.

The scientific program of the symposium consisted of 41 invited and review talks, 32 contributed talks, and 323 poster presentations. The SOC democratically proposed and elected the speakers. In the oral program were three sessions on new results from the Herschel Space Observatory labeled 'Herschel hot results', as well as a panel discussion entitled 'On to ALMA'. Three awards were given to the best posters in each of the three sessions from personal funds by Ewine van Dishoeck, as well as a prize for the best proposal in the ALMA session. During the third poster session, there were also computer demonstrations of databases. The abstracts for all contributions to the symposium can be found on the NASA Astrophysics Data System and on the conference website: http://www.cab.inta-csic.es/molecular_universe/show-abstracts.php, where actual poster presentations have been uploaded. A number of video interviews and highlights of the poster sessions can be found on the IAU Symposium 280 YouTube Channel (<http://www.youtube.com/user/IAUsymposium280>). Invited and review talks will appear in the symposium volume, edited by J. Cernicharo and R. Bachiller.

The symposium started with a session on star formation. This field has become broader since the last astrochemistry symposium, and observational talks concerning stages of both low-mass and high-mass star formation were given, as was a theoretical talk on a new class of models that combines hydrodynamics with chemical simulations. The first session of hot results from Herschel emphasized observations of water vapor, molecules in protostellar shocks, and a wide spectral survey toward Orion KL.

Astrochemistry certainly extends to planetary studies. This session started with a review talk on the chemistry of the solar system, including the origin of water on Earth, which was followed by talks on comets, meteorites, and the atmospheres of Titan and Saturn. The power of sample return missions to solar system bodies was emphasized.

The second day started with a session on evolved stars, in which supernova chemistry was also discussed. Talks on the molecular evolution from AGB stars to planetary nebulae, the role of time-dependent anionic chemistry (involving negatively-charge molecules) in IRC+10216, and the detection of fullerenes in assorted environments rounded out the session. Complex molecules were subsequently discussed in a variety of objects, along with current gas-grain simulations as well as possible future simulations involving the use of stochastic methods to improve the surface chemistry occurring in icy mantles.

Astrochemistry is based on the laboratory and theoretical study of basic atomic and molecular processes, and two sessions were held on this subject. The first concerned gas-phase processes, where a review talk was given on gas-phase reactions as a function of temperature, followed by a talk concerning the theory of low-temperature reactions, and one on experimental studies on the rates of reactions involving anions and how they relate to the observations of such species in various sources. Surface processes in the laboratory and in space were discussed in the second session (on day 3). Much progress has been made during the last decade, but there is still a great need for further laboratory studies before robust interstellar chemical simulations including surface processes can be constructed. The second day of the meeting ended with another Herschel hot topic session, highlighted by the report of an unambiguous detection of interstellar O₂.

The topic of protoplanetary disks on day three demonstrated vividly the phenomenal developments in observations at a variety of wavelengths ranging from the millimeter to the far-UV and an emphasis on interferometry. Modeling was also discussed, as was the chemical history of molecules from the hot core to the disk stage.

Although most of astrochemistry still revolves around galactic sources, the field of ex-

tragalactic astrochemistry will receive a big boost with the onset of ALMA observations. So, it was quite appropriate to have a session on extragalactic astrochemistry, which was held on day 4, including talks on the early universe chemistry and on extragalactic line surveys. It is impressive to now see spectra of extragalactic sources with similar complexity to those found in galactic star-forming regions three decades ago!

Next in line was the explosive topic of exoplanets and their atmospheres. Talks on observations, atmospheric models and their chemistry, as well as biomarkers of habitable worlds were included. The final session on day 4 concerned the tools of analysis and databases, including how to reduce the problem of unidentified lines in hot cores, on various analysis tools for spectral surveys, and on database uses.

The last day started with a session on diffuse clouds and photon-dominated regions (PDRs). The role of turbulence in diffuse clouds was discussed. Overview talks on both PDRs and XDRs as well as diffuse interstellar bands were given. A number of aspects of the PAH hypothesis were touched upon. Finally, the complex nature of the central molecular zone of our galaxy, as seen through H_3^+ , was explored. Next came the third of the Herschel sessions, which included talks on observations of diffuse clouds in the spiral arms of the Milky Way, and carbon chemistry in translucent clouds. The detection of the reactive ions OH^+ and H_2O^+ in a variety of sources was an exceptionally interesting topic. The oral program was concluded with a thoughtful summary of the field, past, present, and future, by John Black.

8. Closing remarks

Based on the growth of the field, the sustained activity of the working group for over 25 years, and exciting future prospects, the WG proposes to elevate Astrochemistry to a proper commission under Division VI (new Division H). Among the activities that can be enhanced as a full-fledged commission are broader advertising of the role of astrochemistry and its multiple uses in astronomy; emphasizing the large amount of new spectra coming from new telescopes and the need for improved molecular data; expanding the training of astrochemistry among astronomers; and stimulating further interdisciplinary activities. By the time of the next astrochemical symposium, planned for 2017, much progress will have been made thanks to Herschel and ALMA, and the field will have grown both in size and, we trust, in understanding.

Ewine F. van Dishoeck
chair of Working Group

Eric Herbst
vice-chair of Working Group

References

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**DIVISION VI / COMMISSION 24 / WORKING GROUP
PLANETARY NEBULAE**

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	Albert Zijlstra

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9. Introduction

The aims of this Working Group are:

- To ensure that scientific symposia on planetary nebulae take place regularly, ideally every 5 years. These symposia would preferably be sponsored by the IAU;
- To organize and coordinate the Joint Discussions on the subject at the IAU General Assemblies. These discussions should address topics of interest not only to our Division VI but to other Divisions as well; and
- To maintain a Web page with general information about the WG, the activities related to planetary nebulae, and the future meetings and symposia.

10. Meetings and Conferences

- IAU Symposium 283, “Planetary Nebulae: an Eye to the Future” Puerto de La Cruz, Tenerife, Spain, 25-29 July 2011, <http://www.iac.es/congreso/iaus283/>
- “Asymmetric Planetary Nebulae V”, Lake District, United Kingdom 20-25 June 2010, <http://www.jodrellbank.manchester.ac.uk/meetings/APN5/>
- “Towards understanding Asymmetric Planetary Nebulae: strategic research collaboration”, Rochester NY 17-19 June 2009, http://www.pas.rochester.edu/~afrank/Pn_Meeting_Page.htm
- “Legacies of the Macquarie/AAO/Strasbourg H α Planetary Nebula project”, February 16-18th 2009, Sydney, Australia <http://www.physics.mq.edu.au/astronomy/mash-workshop/>

11. Proceedings and Monographs

11.1. *Conference Proceedings*

- IAU Symposium 283, “Planetary Nebulae: an Eye to the Future”, 2012, (ed. A. Manchado, L. Stanghellini, D. & D. Schönberner, eds.) (in press)

- Asymmetric Planetary Nebulae V, ed. A. Zijlstra, F. Lykon, E. Lgadec and I. McDonald <http://www.jodrellbank.manchester.ac.uk/meetings/APN5/proceedings.html>

12. Developments within the past triennium

The Working Group on Planetary Nebulae (PNWG) planned and organized the IAU Symposium 283, “Planetary Nebulae: an Eye to the Future”, <http://www.iac.es/congreso/iaus283/> that took place on July 25-29 2011 at Puerto de la Cruz of Tenerife in the Canary Islands, Spain. One hundred and fifty seven participants from 26 countries from the five continents interacted and discussed the many different aspects and facets of the planetary nebulae field. This meeting followed the time-honored tradition of having an IAU symposium on planetary nebulae every 5 years. The symposium proceedings are edited by A. Manchado, L. Stanghellini and D. Schoenberner. The main topics of the Symposium were: new results from observations; the stellar evolutionary connection; aspects of the planetary nebula phase; the central stars; the population of Galactic, extragalactic, and intra-cluster planetary nebulae; and future endeavours in the field.

Some of the PNWG members have been organizing interim meetings in the field of planetary nebulae. Albert Zijlstra, Romano Corradi and Alberto López organized the “Asymmetrical Planetary Nebulae V” conference, in June 2010, held in Bowness-on-Windermere, UK. (<http://www.astrophysics.manchester.ac.uk/apn5.html>)

Adam Frank organized the workshop “Towards understanding Asymmetric Planetary Nebulae: strategic research collaboration”, in June 2009, in Rochester, NY, USA http://www.pas.rochester.edu/~afrank/Pn_Meeting_Page.htm

Quentin Parker, organized the workshop “Legacies of the Macquarie/AAO/Strasbourg H α Planetary Nebula Project”, in February 2009, in Sydney, Australia <http://www.physics.mq.edu.au/astronomy/mash-workshop/>

The SFWG webpage (<http://www.iac.es/proyecto/PNGroup/wg/index.html>) is maintained and updated with links to past and forthcoming meetings on PNe, and useful databases related with the PN field can also be found there. It has recently been updated with the “Kinematic Catalogue of Galactic Planetary Nebulae” consisting of high-resolution (6 – 11.5 km s⁻¹) spectra for about 600 planetary nebulae.

13. IAU reorganization

During the last IAU Symposium 283, the PNWG held a business meeting, where the members voted in great majority to request an upgrade to an IAU Commission. The reasons are as follows: Our WG has been very active over the last 44 years, having organized eight IAU Symposia. Research on PNe has undergone vigorous growth in recent years, the number of published papers has more than doubled in the last 5 years. There has been an impressive diversity in scientific topics and observational techniques in PN research. In addition, PNe consist of material ejected by intermediate- and low-mass stars. The formation of PNe is in many ways similar to the formation of ring nebulae around massive stars, such as Wolf-Rayet (WR) stars and luminous blue variables (LBVs). Both PNe and ring nebulae around WR stars contain hot, X-ray-emitting plasma originating from shocked fast stellar winds. In fact, researchers who study WR ring nebulae and LBV nebulae frequently study PNe as well, as the study of these objects leads to a better understanding of their formation and physical conditions.

These objects represent the stellar material returned into the ISM, yet they are still

closely associated with their central stars. Researchers of circumstellar nebulae have very little overlap with Commission 34 members who study the ISM in general.

Therefore, the PNWG proposed to upgrade the PNWG to an IAU Commission of “Circumstellar Nebulae” to include both PNe and ejecta nebulae around massive stars within the current Division VI or future Division H of the IAU.

Arturo Manchado
Chair of the Planetary Nebulae Working Group