The Cosmic Cycle of Dust & Gas in our Galaxy: From Old to Young Stars
Abstracts

Solid matter: from ISM to protoplanetary disks (Review)

Dartois Emmanuel et al., *Institut des Sciences Moléculaires d'Orsay (France)*

The interstellar medium dust grains and their observed spectral signatures reveal a great diversity of allotropes. Astronomical observations give access to the molecular functionality of these solids, setting constraints on the composition of organic solids and molecules in the cycling of matter in the Galaxy. Some of them can be reproduced in the laboratory. Other signatures still await for their carriers definitive identifications and laboratory analogues help in constraining their physico-chemical composition and evolution under the harsh radiation environments. This talk will particularly focus on dust materials from the far space environments, from diffuse ISM to protoplanetary disks and in our neighbourhood (Solar System) extraterrestrial collected dust. One objective will be to draft some commonalities and differences between materials found in the Solar System, protoplanetary disks and interstellar dust.

Organic molecules in primitive small bodies: From meteoritic studies toward asteroid sample return missions (Invited)

Yabuta Hikaru et al., *Hiroshima University (Japan)*

Organic molecules in the early Solar System are one of important building blocks of planets, as their elements (C, H, O, N, and S) are very abundant in space. The first organic molecules were synthesized in interŋstellar clouds through photochemical reactions in the gas phase and on dust surfaces. The interstellar molecules were then involved in further synthesis and decomposition through various processes in the protoplanetary disk and planetesimals, which resulted in diversity in chemical compositions of asteroids (meteorites) and comets. These small bodies are thought to have supplied organics as life's building blocks to the early Earth during the Late Heavy Bombardment. Therefore, organic compounds in the primitive small bodies are 4.5 billion-year-old fossils to record the Solar System history. The most primitive meteorites are classified as carbonaceous chondrites. Carbonaceous chondrites contain 2 wt% total organic carbon that contains insoluble macromolecules (IOM) (> 1%) and soluble organic molecules (SOM). The chemical structure of IOM is complex and its exact compositions are still unknown, but a number of previous studies have suggested that it is composed of aromatic network crosslinking with short-branched aliphatic chains and various oxygen functional groups. The IOM in the primitive carbonaceous chondrites show variable D and 15N enrichments, indicating that precursor molecules of IOM were formed in extreme cold environments such as interstellar cloud or outer solar nebula. SOM has been historically well studied represented by a variety of compounds of biochemical interest, such as amino acids, carboxylic acids, hydrocarbons, etc., although there still exist more than 10000 unidentified molecules. Classification of meteorites is based on different asteroidal parent body and/or solar nebula histories, which include processes such as aqueous alteration, thermal metamorphism, and impact-induced dehydration. These chemical histories are recorded in the variations of elemental, molecular, and isotopic compositions of organic molecules in meteorites. Assuming that all the chondritic IOM had a common origin, any variations in the IOM composition within and across chondrite classes are reflected by the conditions of parent body and/or nebular processes. The advantages of small body exploration missions compared to the meteoritic studies are to link chemical compositions with the geology of the target bodies and to understand the intact compositions without terrestrial contamination. To date, there have been several successful missions, NASA's cometary dust sample return mission, Stardust: JAXA's stony asteroid sample return mission, Hayabusa, and ESA's comet rendezvous mission, Rosetta. Japanese carbonaceous asteroid sample return mission, Hayabusa2, will explore the near-Earth asteroid Ryugu. The primary scientific goal of Hayabusa2 is to investigate the interaction of organic molecules, water, and minerals on the primitive asteroid. The spacecraft will arrive at Ryugu around July 2018. During its 18-month stay, remote-sensing and lander observations will be carried out. Hayabusa2 is planned to collect asteroid samples from up to three sites. The third sampling site will be around the artificial crater created by the small carry-on impactor, which enables sampling of the asteroid interior. The collected samples will be returned to the Earth in the end of 2020.

The volatile composition of comet 67P/Churyumov-Gerasimenko (Invited)

Rubin Martin et al., *Physikalisches Institut, University of Bern (Switzerland)*

Comets belong to the most pristine objects in our solar system. The study of these small icy bodies reveals crucial information about the material present during solar system formation and the physical and chemical conditions at the time and location of formation. Investigating their composition is thus a crucial step in the understanding of our own origins. A few comets have been visited by spacecraft and many more have been observed from ground. The Stardust mission even brought a sample of cometary dust back to Earth for in-depth analysis. Recently, the European Space Agency's Rosetta spacecraft competed its mission. The spacecraft accompanied comet 67P/Churyumov-Gerasimenko along its trajectory past the sun from August 2014 to September 2016. Rosetta carried several instruments to investigate the comet's nucleus and surrounding neutral gas, dust, and plasma environment. In this presentation we will address some of the major findings of the Rosetta mission in terms of the composition of volatiles of 67P/Churyumov-Gerasimenko and discuss the implications on the formation and thermal evolution of the comet. We will review the results in the light of observations obtained at other comets and extend the comparison beyond our solar system to ices and volatiles detected around newly forming stars and in the interstellar medium.

The composition of interplanetary and cometary dust (Invited)

Engrand Cécile et al., *Centre de Sciences Nucléaires et de Sciences de la Matière (France)*

Small bodies are unique in the Solar System, as they have escaped planetary accretion and have best preserved the composition of the matter initially present in the solar nebula. Cosmic dust originates from these small bodies, asteroids and comets. Interplanetary and cometary dust can be collected on Earth in regions where there is a low accumulation rate of terrestrial dust, like the polar caps or the stratosphere. Interplanetary dust particles (IDPs) have been collected in the stratosphere by NASA for a few decades. A fraction of IDPs (at least) are proposed to be of cometary origin. Cosmic dust collection from the polar caps have yielded larger dust particles than from the stratosphere, and are called micrometeorites. The Concordia micrometeorite collection performed since 2000 at Dome C, near the Concordia station in Antarctica contain very pristine samples, including particles of very probable cometary origin. Spatial missions like Stardust (NASA), Hayabusa (JAXA) and Rosetta (ESA) also gave access to the structure and composition of asteroidal and cometary dust. Stardust brought dust particles from comet 81P/Wild 2 to Earth, but the collection occurred at high relative velocity (6 km/s) and the samples were altered during the collection. The Rosetta mission collected dust particles from comet 67P/Churyumov-Gerasimenko at much lower velocity (1-10 m/s), but the dust analyses had to be performed in situ by the dust instruments (GIADA, COSIMA, MIDAS) onboard the Rosetta orbiter. The Hayabusa mission returned samples from asteroid Itokawa, which is an asteroid related to ordinary chondrite meteorites. At least two future spatial missions are bound to bring back samples from carbonaceous asteroids: Hayabusa 2 (JAXA, asteroid Ryugu) et OSIRIS-REx (NASA, asteroid Bennu). The CAESAR mission is also currently under study to bring back a sample from comet 67P/Churyumov-Gerasimenko. The presentation will summarize the present knowledge on the composition of interplanetary and cometary dust, based on the results of laboratory analysis of dust particles collected on Earth, and of spatial missions.

Gas and dust in protoplanetary disks: their connection to materials in our Solar system (Invited)

Nomura Hideko et al., *Tokyo Institute of Technology (Japan)*

Protoplanetary disks are the natal place of planets and ALMA observations are now revealing the detailed physical and chemical structure of planet forming regions in the disks. Understanding chemical components of gas, dust and ice in the disks is essential to investigate the origins of materials in our Solar system and other planetary systems. As a first step of planet formation, dust grains are thought to grow through collisional sticking, and then drift radially and sometimes azimuthally to be piled up, depending on the gas distribution, which has been observed in some disks by ALMA. Also, spatially resolved observations of dust size distribution by ALMA give us information of detailed physical structure, such as possible planet formation in the disks. Meanwhile, protoplanetary disks are known as the object of chemical diversity because the physical structure dramatically changes, depending on the distance from the central star which is the main source of heating and UV radiation. ALMA is now revealing the detailed chemical structure in the disks. Also, ALMA enables us to detect complex organic molecules in the disks, CH3CN and CH3OH, which could lead to more complex organic compounds found in comets and meteorites in our Solar system. In this talk I will review some of our recent work of ALMA observations and modelling of gas and dust in protoplanetary disks. In addition, I will introduce our recent model calculations for studying the effect of possible carbon grain destruction on chemical structure in the disks. Elemental abundance ratio of carbon to oxygen (C/O) in gas is a fundamental parameter to control the chemical composition in the disks and then the materials in planetary systems. The abundance distributions of carbon-bearing and oxygen-bearing species dramatically change, depending on the C/O ratio, near the midplane of the disks where CO is not photodissociated. I will discuss the effect on the composition of gas and ice in the disks, and then possible observational probes to diagnose the C/O ratio, such as HCN and its isotopologues. References Nomura, Tsukagoshi, Kawabe et al. 2016 ApJ, 819, L7 Walsh, Loomis, Oberg et al. 2016 ApJ, 823, L10 Tsukagoshi, Nomura, Muto, Kawabe et al. 2016, ApJ, 829, L35 Notsu, Nomura, Walsh, Honda, Hirota, Akiyama, Millar 2018, ApJ, 855, 62 Nomura, Higuchi, Sakai, Yamamoto, Nagasawa, Tanaka, Miura et al. 2018, in prep. Wei, Nomura, Lee, Ip, Walsh, Millar 2018, in prep. Kim, Nomura, Tsukagoshi, Kawabe, Muto 2018, in prep.

Dying stars and their evolution (Review)

Zijlstra Albert et al., *University of Manchester (United Kingdom)*

Stars lose much of their original mass during their evolution. In the case of low and intermediate mass stars this happens during the red giant branch and subsequence asymptotic giant branch evolution. The mass loss is driven by different mechanisms over this evolution: the star switches between chromospheric mass loss, pulsation-driven mass loss and a dust-driven wind. Mass loss from lower-mass stars is important to the evolution of galaxies and stellar systems mainly at late times in their evolution. In this review talk I will discuss the observations of mass loss and of the dust production. The initial-final mass relation will be discussed, planetary nebula formation, and the evolution of globular clusters.

Supernovae and their impacts on surrounding environments (Invited)

Matsuura Mikako et al., *Cardiff University (United Kingdom)*

Supernovae (SNe) play multiple roles in the cycle of gas and dust of interstellar medium (ISM). Supernovae, the explosion of massive star, synthesise elements and eject them into the ISM. Some of these elements are condensed into dust in SN remnants, thus, now it is believed that SNe can be an important source of dust in the ISM. The role of SNe as a dust source is particularly highlighted towards high redshift (z>6) galaxies, where low- and intermediate-mass stars have insufficient time to evolve into the asymptotic giant branch (AGB) phase, when dust grains can be formed, thus, SNe can be dominant source of dust in high redshift galaxies. In contrast, historical picture of supernovae is dust destroyer: explosion of supernova ejects fast (1000-10000 km s-1) expanding gas, and the collision of the fast expanding gas with ambient ISM material triggers shocks, destroying existing ISM dust. I will review the current status of our understanding of these three aspects (elemental synthesis, dust formation and dust destruction) of SNe.

Dense Molecular Knots in the Crab Supernova Remnant (Oral)

Wootten Henry et al., *National Radio Astronomy Observatory (United States)*

Molecular emission was imaged with ALMA from numerous components located at or near bright H2-emitting knots and/or absorbing dust globules in the Crab Nebula. These observations provide insight into how energetic photons and particles produced in a young supernova remnant interact with gas, cleanly differentiating between competing models. The four locations targeted show contrasting properties. Our successful observations are contrasted with Cloudy models of these knots. We suggest that the Crab filaments present an exotic environment in which H2 emission comes from a mostly-neutral zone probably heated by cosmic rays produced in the supernova. We detect carbon monoxide emission from many clumps distributed throughout the regions imaged with characteristics consistent with predictions based on the CLOUDY photoionization model of one of the dust globules in the nebula. Emission from HCO+ (J=4-3), SiO (J=8-7), and SO (89-78) transitions was also observed from the strongest CO-emitting region. The molecular knots in the Crab present a novel very young phase of the ISM representative of many important astrophysical environments.

AGB stars and their environment (Invited)

Guelin Michel et al., *Institut de RadioAstronomie Millimétrique (France)*

During their late pulsating phase, AGB stars expel most of their mass in the form of dusty envelopes, an event that largely drives the chemical composition of interstellar matter. The envelopes, however, are distant and opaque to visible and NIR radiation: their structure remains poorly known and the mass-loss process poorly understood. Millimeterwave interferometry, which combines the advantages of longer wavelength, high angular resolution and very high spectral resolution, is the optimal investigative tool for this purpose. Mm waves pass through dust with almost no attenuation. Their spectrum is rich in molecular lines and hosts the fundamental lines of the ubiquitous CO molecule, allowing a tomographic reconstruction of the envelope structure. After a short description of the TP-AGB stage, we will focus on a few envelopes, recently studied by millimeter-wave interferometry, which teach us about the nucleosynthetic and mass-loss processes during this fairly short, albeit capital phase of stellar evolution. Emphasis will be placed on CW Leo/IRC+10216, the archetype of TP-AGB stars, whose simple, nearly spherical geometry allows a 3-D reconstruction of the envelope and of the recent mass-loss history.

On the circumstellar envelope of an AGB star EP Aqr (Oral)

Do Hoai et al., *Vietnam National Space Center (Vietnam)*

ALMA and IRAM observations of the CO millimetre emission of the circumstellar envelope of AGB star EP Aqr are presented and analysed. Possible interpretations in terms of different enhancements of the bipolar wind and equatorial effective emissivity are presented and critically discussed. Evidence is given for patterns of increased brightness possibly associated with accretion from a companion. A discussion of the morphology and kinematics in terms of temperature and density is presented.

Dust formation around old stars and its feedback on the dust forming system (Invited)

Winters Jan Martin et al., *Institut de RadioAstronomie Millimétrique (France)*

I will present the basic approaches currently in use to describe the formation of solid particles (dust) out of the gas phase in a circumstellar environment. Based on theoretical grounds, different species had been identified as promising candidates to form the primary condensation seeds. In order to quantitatively determine their nucleation rates, thermodynamic and energetic properties, like the Gibbs free energy of formation and the binding energies of the small clusters need to be known. Examples will be given of corresponding cluster structure calculations that allow to derive these data. Recent observations confirm the presence in the gas phase of some of the required molecules that had not been detected before in the circumstellar environment. On the other hand, high spatial resolution interferometric observations in the mm range seem to basically rule out some of the suspected candidates as being responsible to provide the primary condensate in oxygen-rich circumstellar shells. At the same time, chemical species are favored observationally, whose nucleation process is not yet well understood on the theoretical side. In the second part of the talk, I will give examples of the kind of nonlinear effects that in general have to be expected in the context of the dust formation process. In the framework of a consistent model for a pulsating, dust forming atmosphere, I will highlight the coupling between the dust component and the physical conditions in the dust forming circumstellar shell. The involved complex regulation circuits make it necessary to describe the dust formation process by a consistent approach that takes these interactions into account.

Molecular complexity around evolved stars (Invited)

Agúndez Marcelino et al., *Instituto de Física Fundamental, CSIC (Spain)*

The ejecta of evolved stars are excellent chemical laboratories where a large variety of exotic molecular species are formed in situ. Molecules are detected in the circumstellar material of almost every type of evolved star, no matter if it is a low-mass or massive star. These types of evolved stars comprise Asymptotic Giant Branch (AGB), post-AGB (planetary nebulae), red supergiant, yellow hipergiant, luminous blue variable, Wolf-Rayet, and supernovae. However, the largest variety and complexity of molecules is found in the nearly isotropic expanding envelopes around AGB stars. The gentle stellar wind developed during this phase possesses ideal conditions to trigger the formation of dust particles and favor the synthesis of different types of molecules. Carbon-rich stars AGB stars still surpass oxygen-rich AGB stars in the number and complexity of molecules detected, with IRC+10216 being the richest molecular laboratory among these types of objects and even among any type of astronomical source. Around half of the molecules known in space are observed toward this C-star envelope. Recent times are seeing a significant progress in this area because the increased frequency coverage and the improved sensitivity of telescopes is allowing to discover new circumstellar molecules, but also because the order-of-magnitude enhancement in spatial resolution of ALMA and NOEMA is making possible to pinpoint the exact chemical origin of each type of molecule in these environments. These observations are leading to a change of paradigm in our understanding of how the chemistry works in envelopes around AGB stars. In this talk I will review the status concerning molecular complexity around evolved stars, and I will also briefly discuss the prospects for the future.

Non-equilibrium chemistry of O-rich AGB stars as revealed by ALMA (Oral)

Wong Ka Tat et al., *Institut de RadioAstronomie Millimétrique (France)*

Chemical models suggest that pulsation driven shocks propagating from the stellar surfaces of oxygen-rich evolved stars to the dust formation zone trigger non-equilibrium chemistry in the shocked gas near the star, including the formation of carbon-bearing molecules in the stellar winds dominated by oxygen-rich chemistry. Recent long-baseline ALMA observations are able to give us a detailed view of the molecular line emission and absorption at an angular resolution of a few stellar radii. I am going to present the latest results from the ALMA observations of IK Tau and o Cet in late 2017, with a particular focus on HCN.

The Surprising Molecular and Isotopic Content of Planetary Nebulae (Oral)

Schmidt Deborah et al., *Department of Astronomy, University of Arizona (United States), 2 - Department of Chemistry & Biochemistry, University of Arizona (United States)*

Planetary nebulae (PNe) were once thought to merely be the realm of atomic material, as any molecules remaining from the AGB stage were expected to be rapidly photodissociated. Recently, however, polyatomic molecules of increasing complexity have been detected in PN envelopes, with structures as large as C60 and C70 having been identified in their ejecta. As PNe provide ~85% of their mass to the surrounding interstellar medium (ISM), elucidation of their chemical makeup is vital for understanding their contribution to diffuse clouds. Several recent surveys by Schmidt & Ziurys probing the molecular content of a set of PNe spanning a wide range of ages, sizes, and morphologies uncovered the presence of HCN, HCO+, HNC, and CCH in most of the observed nebulae, showing, strikingly, that polyatomic molecules are a common constituent of PN envelopes. Further, these works revealed that (1) the abundances of each molecule do not vary significantly with kinematic age, in contrast to the predictions of nebular models, and (2) the abundances of these molecules are approximately 1-2 orders of magnitude greater than those measured for the diffuse ISM, indicating that the molecular material from PNe disperses and seeds the surrounding ISM. Detections of HCO+, H2CO, HCN, HNC, CCH, and c-C3H2 at numerous positions across the Helix Nebula show that this material is well-mixed in the PN envelope. Targeted searches of several PNe revealed an even greater wealth of molecules. In particular, recent observations of the young PN K4-47 using the ARO 12-M and SMT and the IRAM 30-M Telescope uncovered the presence of a surprising array of molecular transitions, including several singly and doubly 13C-substituted isotopologues of HC3N and HC15N. Estimations of the 12C/13C ratio for K4-47 as well as several other PNe ranged from ~1-10, implying that these nebulae may have J-type progenitor stars. Furthermore, the 14N/15N ratio measured for K4-47 is an astounding 9, the largest enrichment of 15N yet observed, suggesting that J-type stars could be a significant source of 15N in the Galaxy. The results of the aforementioned works, as well as their implications for nucleosynthetic processes and the role that PNe play in providing the ISM with molecular material, will be presented. Additionally, recent CO, HCN, and HCO+ ALMA images of several PNe will be shown.

Carbon stars in the Magellanic Clouds: colours, properties and dust production rate (Oral)

Nanni Ambra et al., *Università di Padova (Italy)*

We employ newly computed grids of spectra reprocessed by dust to fit the spectral energy distributions (SEDs) of the entire sample of carbon-stars (C-stars) in the Small Magellanic Cloud (SMC). This procedure allows us to derive some important properties of these stars as well as their dust production rate (DPR). For the first time, the grids are calculated as a function of the stellar parameters, i.e. mass-loss rate, luminosity, effective temperature, current mass and carbon-excess, following a consistent scheme of dust growth coupled with stationary wind outflow. Our model accounts for the dust growth of various dust species formed in the circumstellar envelopes of C-stars, such as carbon dust, silicon carbide and metallic iron. The available grids are computed for different combinations of optical constants and grain sizes for carbon dust that have been shown to simultaneously reproduce the most relevant infrared colour-colour diagrams in the SMC. Differently from the other works in the literature, our approach allows for the direct estimate of the mass-loss and of the DPR of these stars, without the need of assuming the gas-to-dust ratio, the outflow expansion velocity and the dust chemistry. These latter quantities are indeed consistently calculated by in our dust growth scheme. The DPR provided by our method can be significantly different, of a factor between 2 and 5, from the ones available in the literature. The same kind of investigation is currently ongoing for C-stars in the Large Magellanic Cloud and we here show our preliminary results.

The interstellar medium: an observational review (Review)

Stanimirovic Snezana et al., *University of Wisconsin Madison (United States)*

The interstellar medium (ISM) is intimately related with star formation processes, being both the fuel for star formation and a place where star formation feedback strongly shapes the thermodynamics and morphology of various gas phases. In this talk, I will summarize the components of the ISM focusing largely on the key observational results and outstanding questions. I will then specifically examine the current status of our understanding of the neutral ISM and its connection with molecular gas, as the first step in the process of star formation. As numerical simulations of galaxy formation continue to include more detailed ISM physics, statistical comparisons between simulations and observations are essential for informing numerical simulations, as well as obtaining more in-depth observational constraints. I will highlight some resent results and point out potential future needs and advances.

The role of shocks in the ISM (Invited)

Lesaffre Pierre et al., *Laboratoire d'Etude du Rayonnement et de la Matière en Astrophysique (France)*

Throughout this talk, I will introduce shock physics and explore their role in the interstellar medium (ISM) thanks to observational, simulated and theoretical illustrations. Typical velocities in the ISM are within an order of magnitude of the sound speed. Shocks should therefore be a ubiquitous component of this turbulent gas. Ordered kinetic energy is converted into heat inside a shock's working surface, the thermal collisions excite the gas and the excitation energy is then radiated away in their wake. Shocks should then be one of the most efficient ways to probe dissipation in our galaxy. However, their unambiguous observational characterisation has remained elusive in the dilute ISM. Shocks compress the gas and the magnetic fields: they are in part responsible for the equipartition between the magnetic and kinetic energies, and may impact the relative density and magnetic structures as seen in Planck's foregrounds. Last but not least, the local temperature rise in shocks help to overcome energy barriers and open new chemical routes for the formation of molecules. Recent molecular observations in high-z galaxies may thus trace the dissipation of turbulent gas.

H2 emission from non-stationary magnetized bow shocks (Oral)

Le Ngoc Tram et al., *Laboratoire d'Etudes du Rayonnement et de la Matière en Astrophysique et Atmosphères (France)*

When a fast moving star or a protostellar jet hits an interstellar cloud, the surrounding gas gets heated and illuminated: a bow shock is born that delineates the wake of the impact. In such a process, the new molecules that are formed and excited in the gas phase become accessible to observations. In this paper, we revisit models of H2 emission in these bow shocks. We approximate the bow shock by a statistical distribution of planar shocks computed with a magnetized shock model. We improve on previous works by considering arbitrary bow shapes, a finite irradiation field and by including the age effect of non-stationary C-type shocks on the excitation diagram and line profiles of H2. We also examine the dependence of the line profiles on the shock velocity and on the viewing angle: we suggest that spectrally resolved observations may greatly help to probe the dynamics inside the bow shock. For reasonable bow shapes, our analysis shows that low-velocity shocks largely contribute to H2 excitation diagram. This can result in an observational bias towards low velocities when planar shocks are used to interpret H2 emission from an unresolved bow. We also report a large magnetization bias when the velocity of the planar model is set independently. Our 3D models reproduce excitation diagrams in BHR 71 and Orion bow shocks better than previous 1D models. Our 3D model is also able to reproduce the shape and width of the broad H2 1-0 S(1) line profile in an Orion bow shock.

Properties of diffuse clouds (Invited)

Liszt Harvey et al., *National Radio Astronomy Observatory (United States)*

The meaning of diffuse interstellar matter is imprecise and has changed over time. In its original sense it meant any gaseous matter outside the immediate environment of a star, but this has narrowed over time to imply gas that is easily penetrated by the galactic optical/UV radiation field. This is gas for which, locally, the attenuation of incoming radiation is not much greater than that for 1 magnitude of optical extinction. Diffuse gas is sometimes seen in isolation but it is also seen in directions having very high total extinction, for instance near the Galactic equator in the inner Galaxy. The outskirts of dark and molecular cloud complexes are diffuse gas. Diffuse clouds on the other hand are intended to be discrete neutral gas parcels having modest attenuation of the radiation field, for instance a classical Spitzer H I cloud or the gas producing optical absorption lines toward nearby stars. Such things exist quite widely but are seldom imaged, as only their shadows (absorption lines) are apparent, complicating their definition. In any case, a discussion of diffuse gas is not entirely the same as a discussion of diffuse clouds. In terms of the components of the ISM, diffuse gas is present as CNM (cold neutral medium) at temperatures below a few hundred Kelvin, WNM (warm neutral medium) and WIM (warm ionized medium) at 8000 K, and HIM (hot intercloud medium) at 10^6K. All of these are in rough thermal pressure equilibrium at p/k ~ 3000K/cc with volume filling factors ranging from a few percent for CNM to perhaps 20% for HIM+WNM, and 80-100% for HIM. Of course this interpretation, based on theoretical models of an ISM driven by supernovae explosions but traceable to Spitzer (1956), is an oversimplification that ignores molecular gas and molecular clouds even when they bear most of the mass. This talk will concentrate on the colder, denser CNM bearing most of the atomic mass. It dominates the ISM in the outer Galaxy and carries about half the gas locally. The presence of this gas in observations follows from noting that its hydrogen is mostly atomic with H2 as a minority constituent, ~1/3 of the total on average near the Sun. C+ is the dominant form of gas-phase carbon with neutral carbon and CO each having perhaps a few percent of the total. Despite this, CO emission and some molecular absorption can be quite strong, giving the false impression of observing denser, more opaque material. H3+ is wildly over-abundant, with implications for the cosmic-ray flux. To explain this it is necessary to consider the mechanisms of heating (mostly the photoelectric effect on small grains), cooling (CII and OI fine-structure transitions), ionization of carbon and metals (by photons) and hydrogen (cosmic-rays), atomic-ion recombination (radiative and assisted by small grains), formation of H2 (grain catalysis) and CO formation (recombination of HCO+), along with the thermal, chemical and ionization balance. I'll survey this all with a nod to understanding the diffuse molecular gas.

CH as a tracer for molecular hydrogen: forming synergies between its far-infrared and radio fingerprints (Oral)

Jacob Arshia Maria et al., *Max Planck Instiute for Radio Astronomy (Germany)*

Diffuse clouds form an essential link between the death and birth of stars which makes them ideal laboratories for the study of interstellar chemistry. But being completely exposed to radiation fields, the low density diffuse clouds were considered to be bereft of molecular species. But over time, a wide range of molecules have been detected with the advent of space borne observatories and telescopes. Much like H2 studies conducted in the dense regions, those in the diffuse regions were carried out using CO as the preferred chemical tracer. However, indirect observations by Blitz et al. (1990) have provided ample proof of diffuse molecular clouds containing volume densities of H2 that were too low to even excite the low lying rotational states of CO, motivating the search for alternative tracers for H2 in diffuse clouds. This search resulted in the use and establishment of interstellar hydrides such as HF, CH and OH as tracers for H2. CH stands out from its hydride counterparts HF and OH as a tracer for H2 because it possesses a tight correlation with H2, [CH]/[H2] = 3.5 Œ 1e8 in the low (H2) density limit (Sheffer et al. 2008). The CH spin-rotational transition near 2 THz obtained using GREAT onboard SOFIA is seen in deep absorption towards actively star forming regions W49 and W51. A rigorous tool was developed, to first fit and then derive the total column densities of CH using a minimum number of a priories. This tool utilizes the Wiener Filter and further deconvolves the hyperfine structure from the observed spectrum to reveal the underlying one. The column densities of CH that were derived from the deconvolved spectra establish this transition as a tool for ultimately measuring the column densities of molecular hydrogen. A wide array of observational techniques and instruments can be used to study line of sights (LOS) composed of diffuse clouds, it is hence important to be able to relate these different observational regimes. But interpreting the ground state radio lines of CH near 3 GHz are difficult as they are mainly found in emission (even against strong continuum sources), initiating weak level inversion and maser action. To form a quantitative understanding of these lines we took advantage of the fact that it shares a common lower level with the 2 THz transitions and further employed a non-LTE radiative transfer code RADEX to model the physical and excitation conditions of its surrounding regions.

Early results of the SIGGMA (Oral)

Liu Bin et al., *National Astronomical Observatories (China)*

Ionized gas is one of the primary components of the interstellar medium (ISM) and plays a crucial role in star formation and galaxy evolution. Radio recombination lines (RRLs) can directly trace ionized gas in HII regions and warm ionized medium (WIM) without being affected by interstellar extinction. Single-dish telescopes like Arecibo Observatory are sensitive to low surface brightness emission, and are therefore powerful tools for the study of HII regions and the WIM. We report here on a large surveys of RRL emission: The Survey of Ionized Gas in the Galaxy, Made with the Arecibo telescope (SIGGMA). It is the first large-scale fully-sampled RRL survey, and covers the whole observable inner Galactic plane by the Arecibo telescope (l = 32 - 70 deg). It is performed with the Arecibo L-band Feed Array (ALFA) receiver, whose bandpass covers twelve hydrogen alpha lines from H163alpha to H174alpha. By stacking the alpha-lines and smoothing to 5 km/s velocity resolution, the final SIGGMA spectra have a mean rms level of ~0.65 mJy per beam. Here, we report on early analysis of the SIGGMA data and present first scientific results.

Molecules in absorption at intermediate redshift (Oral)

Muller Sebastien et al., *Department of Earth and Space Sciences, Chalmers University of Technol ogy, Onsala Space Observatory, SE-43992 Onsala, Sweden (Sweden)*

I will present ALMA observations of molecules in absorbers at intermediate redshifts (z=0.68-0.89). The molecules can be used to probe the physical and chemical properties of the interstellar medium in the disk of these distant galaxies. In particular with hydrides, we can unveil the multi-phase nature of the absorbing gas, and estimate the molecular fraction and cosmic ray ionization rate. In addition, isotopic ratios are used to probe the ISM enrichment by stellar nucleosynthesis.

Fluorescent H2 Emission Lines from the Reflection Nebula NGC 7023 Observed with IGRINS (Oral)

Le Nguyen Huynh Anh et al., *Seoul National University (South Korea)*

We have analyzed the temperature, velocity, and density of H2 gas in NGC 7023 with a high-resolution near- infrared spectrum of the northwestern filament of the reflection nebula. By observing NGC 7023 in the H and K bands at R ~ 45,000 with the Immersion GRating INfrared Spectrograph, we detected 68 H2 emission lines within the 1”Œ15” slit. The diagnostic ratio of 2-1 S(1)/1-0 S(1) is 0.41-0.56. In addition, the estimated ortho-to-para ratio (OPR) is 1.63-1.82, indicating that the H2 emission transitions in the observed region arise mostly from gas excited by UV fluorescence. Gradients in the temperature, velocity, and OPR within the observed area imply motion of the photodissociation region (PDR) relative to the molecular cloud. In addition, we derive the column density of H2 from the observed emission lines and compare these results with PDR models in the literature covering a range of densities and incident UV field intensities. The notable difference between PDR model predictions and the observed data, in high rotational J levels of v=1, is that the predicted formation temperature for newly formed H2 should be lower than that of the model predictions. To investigate the density distribution, we combine pixels in 1”Œ1” areas and derive the density distribution at the 0.002 pc scale. The derived gradient of density suggests that NGC 7023 has a clumpy structure, including a high clump density of ~10ˆ5 cm-3 with a size smaller than ~5Œ10ˆ-3 pc embedded in lower-density regions of 10ˆ3-10ˆ4 cm-3.

Photodissociation fronts in star-forming regions as revealed by high angular resolution observations (JWST, Herschel, ALMA) (Oral)

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Massive stars disrupt their natal molecular cloud material by dissociating molecules, ionizing atoms and molecules, and heating the gas and dust. Much of this interaction occurs in Photo-Dissociation Regions (PDRs) where far-ultraviolet (FUV) photons of these stars create a largely neutral, but warm region of gas and dust (Hollenbach et al. 1999). PDR emission dominates the infrared and sub-mm spectra of star-forming galaxies and also provides a unique tool to study in detail the physical and chemical processes that are relevant for most of the mass in inter- and circumstellar media. I will review on recent high angular resolution observations in the far-infrared and sub-mm domains (Herschel, ALMA) that have challenged the traditional view of PDRs and unambiguously revealed a steeply varying interface between the molecular clouds and the ionized gas which betrays dynamic effects (e.g., Goicoechea et al. 2016, Joblin et al. 2018). Through some physical and chemical boundaries, one can start having access to the physical conditions and the chemical composition of a very structured medium with entangled dense molecular filaments and globules, and evaporation flows that advects material into the ionized region. Detailed analysis of the best spectral maps at small spatial scales in various tracers (high-J CO, H2, PAHs, dust) will be presented (e.g., Parikka et al. 2017, 2018, Schirmer et al. in prep.) and used to test the theoretical models (PDR Meudon code, DustEM/THEMIS). For prototypical PDRs with different excitation conditions (i.e., Horsehead, Orion Bar), how correlate the dust evolution with the changing physical conditions and vice-versa will be in particular investigated. In the very near future, the James Webb Space Telescope (JWST) will observe in the near- to mid-infrared domains (over the full 0.6-28 mum range) with a sensitivity and a spatial resolution better than one to two orders of magnitude than its predecessors. JWST will resolve and directly observe, for the first time, the response of PDR gas to the penetrating FUV photons in its key zones (i.e. the H/H2 photodissociation front and the ionization front), where the main radiative heating and photochemical feedback processes occur. Understanding the intricate combination of physical, chemical and dynamical processes at the origin of the extremely rich IR spectra of PDRs is a key objective for JWST. In this context and in order to guide the preparation of the future proposals on star-forming regions in our Galaxy and beyond, I will present the ERS (Early Release Science, http://jwst-ism.org) and GTO (Guaranteed Time) programs on local PDRs and underline the important JWST-Herschel-ALMA synergy.

Physical and chemical evolution from diffuse to dense clouds (Invited)

Ruaud Maxime et al., *NASA Ames Research Center (United States)*

The physical and chemical processes at work in the interstellar medium (ISM) play a central role in the regulation of the star formation process and thus on the evolution and shaping of galaxies. Conversely, stars, through their radiation fields, winds and supernova explosions profoundly affect the physical and chemical properties of the ISM and contribute to its evolution and composition. The ISM presents an extraordinary molecular richness: to date almost 200 molecules have been detected. These molecules range range from simple polyatomic species to complex molecules containing more than 10 atoms. The type of environments in which these molecules are observed cover a broad range of physical conditions, varying from low density and irradiated regions to very dense and opaque gas. Interstellar matter is thought to evolve from diffuse interstellar clouds to high density regions (i.e. dark clouds). The resulting increase in gas column density results in increased shielding from photodissociation, leading to the development of a rich molecular chemistry in both the gas phase and at the surface of the grains. Because molecules play an important role in the thermal balance of the ISM and because they give us a unique access to its physical conditions, understanding the chemistry at work is mandatory if we are to understand its physical evolution. In this talk I will review our current understanding on the physical evolution from the most diffuse to the densest part of the ISM. I will discuss the chemistry associated with this evolution for both the gas and at the surface of the grains. Finally I will discuss how physical conditions in the past can be important when establishing the molecular content of dense clouds.

Magnetic Fields in Molecular Clouds (Invited)

Koch Patrick et al., *Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) (Taiwan)*

The role of the magnetic (B-) field in the star-formation process is highly debated. How important is the magnetic field in the presence of gravity and turbulence? Conclusive observational results have been scarce due to both limited available data and due to the generally challenging measurements requiring very sensitive observations. We present observational results illustrating the role of the B-field on three representative scales in the star-formation process: (1) the filamentary-scale infrared dark cloud G34. Here, the local B-field correlates with the local velocity gradients on the largest scales. Based on a benchmark analysis that quantifies the various energy components we argue that a different relative importance between B-field, turbulence, and gravity leads to different observed fragmentation types on a next smaller scale, (2) the molecular-cloud-scale in the high-mass star-forming region W51. Here, increasingly higher resolutions from the SMA to ALMA resolve new B-field sub-structures. In particular, we see zones of symmetrically converging B-field lines, cometary-shaped satellite cores, local collapse features, and a possible new phenomenon of magnetic channelling, (3) the protostellar-source-scale in B335. Here, we provide evidence for magnetic braking from detailed high-resolution observations of the kinematics of neutral and ionized gas tracers. Besides these textbook cases on three different scales, we further present statistical resultsfrom a 50-source sample of molecular clouds that reveal generic B-field features and a systematically locally varying importance of the B-field versus gravity.

Molecular complexity in the interstellar medium (Invited)

Belloche Arnaud et al., *Max-Planck-Institut für Radioastronomie (Germany)*

The search for complex organic molecules (COMs) in the interstellar medium (ISM) has revealed chemical species of ever greater complexity in various types of environment, even in cold or UV-illuminated regions where they were initially not expected. This search relies heavily on the progress made in the laboratory to record and characterize their rotational spectra. Besides, our understanding of the chemical processes that lead to molecular complexity in the ISM builds on astrochemical numerical simulations that use chemical networks fed by laboratory and theoretical studies. On the observational side, the advent of the Atacama Large Millimeter/submillimeter Array (ALMA) and the expansion of the IRAM Plateau de Bure Interferometer now called NOEMA have recently opened a new door to explore the molecular complexity of the ISM. Thanks to the high angular resolution they can achieve, the spectral confusion of star-forming cores can be reduced, and their increased sensitivity allows astronomers to detect molecules of low abundance that could not be probed by previous generations of telescopes. The complexity of the molecules detected recently manifests itself not only in terms of number of their constituent atoms but also in their molecular structure. I will discuss results on molecular complexity in the ISM delivered by recent ALMA and NOEMA surveys.

The Emergence of Molecular Complexity in Solar-Type Star Forming Regions (Invited)

Lefloch Bertrand et al., *Université Grenoble Alpes (France)*

The conditions for planet formation and the emergence of life is one of the key-questions in modern astrophysics. Thanks to the recent spectacular progress in radioastronomical observations, we are now in position to address the question of our “chemical origins”, namely to understand the evolution of matter and molecular complexity during the long process that brought it from prestellar cores, to protostars, protoplanetary disks, and ultimately to the bodies of the Solar system. Spectral line surveys constitute the most powerful diagnostic tool to study the emergence of molecular complexity in the interstellar gas. Such surveys are now routinely carried out with the major (sub)millimeter facilities in the World and have brought a new perspective on the formation of organic molecules, which help us improve our understanding of chemical networks and the emergence of molecular complexity in star-forming regions. I will review the main results recently obtained in the domain thanks to ASAI, a Large Program of 400hrs dedicated to astrochemical surveys of solar-type star forming regions conducted at the IRAM 30m telescope. I will discuss the perspectives offered in this context with the advent of the large millimeter arrays ALMA and NOEMA.

Complex organic chemistry in solar-type protostars : new detections in the framework of the ALMA-PILS survey (Oral)

Coutens Audrey et al., *Laboratoire d'Astrophysique de Bordeaux (France)*

Complex organic molecules are detected in various astrophysical environments. They are particularly abundant in the warm inner regions of protostars, where planets, comets and asteroids are expected to form. These molecules may survive during the star formation process and be incorporated into asteroids and comets, which could deliver them to planetary embryos through impacts. This molecular delivery could favor the emergence of life. It is, therefore, important to understand how these molecules form and how they evolve towards more complexity.Thanks to the high spatial resolution and high sensitivity of the interferometers ALMA and NOEMA, new opportunities were offered to astronomers to characterize the molecular complexity in low-mass star-forming regions. In particular, several new detections of complex molecules were obtained in the framework of the PILS program, an unbiased spectral survey of the solar-type protostar IRAS 16293-2422 with ALMA (e.g., Jorgensen et al. 2016, Lykke et al. 2017, Ligterink et al. 2017). Isotopologues of several complex molecules (D, 15N, 13C) were also detected for the first time in the interstellar medium (e.g., Coutens et al. 2016, Jorgensen et al. 2016), which can help constrain formation pathways of molecules. In this talk, I will present some of the recent results obtained with the ALMA/PILS survey. I will especially mention the recent detection of cyanamide (NH2CN), one of the rare interstellar molecules with 2 Nitrogen atoms, as well as its deuterated form (Coutens et al. 2018) and I will discuss what these observations teach us regarding its formation. References : Coutens et al. 2016, A&A, 590, L6 Coutens et al. 2018, A&A in press (arXiv 1712.09548) Jørgensen et al. 2016, A&A, 595, A117 Ligterink et al. 2017, MNRAS 469, 2219 Lykke et al. 2017, A&A 597, A53

The chemical structure of the young pre-stellar core L1521E (Oral)

Nagy Zsofia et al., *Max-Planck Institute for extraterrestrial Physics (Germany)*

L1521E is a pre-stellar core in Taurus which was found to be in an early evolutionary state, and to have very little or no molecular depletion. We have obtained ~2.5x2.5 arcminute maps in transitions of key molecular species, including C17O, CH3OH, c-C3H2, CN, SO, H2CS, and CH3CCH, using the IRAM-30m telescope, to study the chemical structure of L1521E. We compared the results to those obtained toward the more evolved and better characterized L1544 core. Based on the IRAM-30m C17O map and N(H2) derived from Herschel/SPIRE data, CO depletion toward L1521E is more significant than suggested by earlier studies, with a lower limit of 4.9+/-1.8 on the CO depletion factor toward the dust peak. Comparing the abundances of species toward the two cores we found that sulfur-bearing molecules such as C2S, HCS+, C34S, C33S, SO, and H2CS are factors of 10 to 50 more abundant toward L1521E than toward L1544, suggesting that significant sulphur depletion is taking place during the dynamical evolution of dense cores.

Physical properties and evolution of GMCs in the Galaxy and the Magellanic Clouds (Review)

Onishi Toshikazu et al., *Osaka Prefecture University (Japan)*

Most stars are born as clusters in Giant Molecular Clouds (hereafter GMCs), and therefore the understanding of the evolution of GMCs in a galaxy is one of the key issues to investigate the evolution of the galaxy. The recent state-of-the-art radio telescopes have been enabling us to reveal the distribution of GMCs extensively in the Galaxy as well as in the nearby galaxies, and the physical properties and the evolution of the GMCs leading to cluster formations are actively being investigated. Here we present studies of spatially resolved GMCs in the Galaxy and in the Magellanic Clouds(LMC/SMC), aiming at determining the origins of the observed turbulence and assessing the role of gas interaction in triggering star formation by the observations spanning a range of scales and environmental conditions. We have carried out ALMA observations toward ~10 GMCs located across the LMC by using ALMA mainly in the CO isotopologue lines of J=1-0 and 2-1 and continuum bands. The typical angular resolution is 1~3 arcsecs, 1 arcsec corresponds to 0.24pc at the distance of the LMC. These clouds have different evolutionary stages spanning a wide range of star formation activity. The observations revealed the complex nature of the molecular gas in the LMC, full of filaments and clumps, we also quantify their density structure and velocity-size correlations. The comparison with the galactic GMCs indicates the similarity of multiple filaments entangled toward the region where high-mass stars are forming. Further high-resolution observations have been done toward N159, which is the most intense and concentrated molecular cloud as shown by the brightest CO J=3-2 source in the LMC. The spatial resolution is 0.06pc, which is high enough to spatially resolve high-density cores and narrow filaments. The observations revealed 0.1pc width filaments entangled as well as high density cores as the possible site of proto cluster formation. We have also carried out 0.3pc resolution observations of N83C, a high mass star-forming region in the SMC. The radiative transfer analysis suggests that the kinetic temperature is ~40K and the density is a few x 10^4cm^-3, which is consistent with the virial analysis. This high-density, implying a lack of lower-density envelope, and the high temperature indicates that UV radiation deeply penetrates into the clump and CO molecule is heavily photodissociated in the low-metalicity environment.

Recent progress in high-mass star-formation studies (Invited)

Hirota Tomoya et al., *National Astronomical Observatory of Japan (Japan)*

High-mass stars (with 8 Solar masses or larger) have strong impacts on various field of astrophysics and astrochemistry. However, their formation processes have been long-standing issues because of observational difficulties such as extremely large opacity of interstellar dust in high-mass star-forming regions except for centimeter to submillimeter wavelengths, larger distances and more complex structures in young high-mass clusters compared with low-mass star-forming regions, and smaller number of high-mass young stellar objects due to shorter evolutionary time scale. As a result, theoretical modeling is also challenging as basic properties of high-mass star-forming regions and newly born high-mass young stellar objects are still unclear. Very recent high resolution and high sensitivity observations with ALMA at millimeter/submillimeter wavelengths begin to overcome these observational difficulties. Number of infrared dark cloud cores and filaments, disks and outflows associated with high-mass young stellar objects have been observed at the highest resolution of 100-1000 au. These results provide initial condition, mass accretion and feedback processes, and chemical compositions in high-mass star-forming regions. I will review recent progress in high-mass star-formation studies in the ALMA era along with related observational and theoretical studies.

Molecular complexity in the star forming region W43-MM1 (Oral)

Molet Jordan et al., *Laboratoire d'Astrophysique de Bordeaux [Pessac] (France)*

The study of the distribution of molecules in star forming regions helps to constrain the chemical models. The "mini-starburst region associated to W43-MM1, located at a distance of 5.5 kpc, includes a number of massive cores from ~1M_sun to ~100M_sun with pre-stellar and proto-stellar cores candidates (e.g. Motte et al. 2018, Nony et al. in prep.). Hence, it is an important sample of molecular cores at various evolutionary stages and moreover, it may contain the most massive cold core known in the whole Galaxy. In this talk I will present the current state of our comparison of the molecular composition of the cores in W43-MM1. We used high spectral and spatial resolution data from ALMA Cycle 2 and Cycle 3 at 230 GHz, covering a total bandwidth of 4 GHz with a 0.5" (~2400 AU) spatial resolution. In addition we had a spectral survey obtained at the IRAM 30m telescope covering a total of 153 GHz at 1, 2 and 3mm. I will introduce the technique I developed to substract automatically the continuum in order to study weak emission lines, similar to the one presented by Jørgensen et al. (2016) and better adapted to large regions of molecular emission. Finally I will present the molecular content and the physical parameters of the different continuum sources identified in Motte et al.

On the dust and gas components of the z = 2.8 gravitationally lensed quasar host RX J0911.4+0551 (Oral)

Pham Tuan-Anh et al., *Vietnam National Space Centre (Vietnam)*

Observations by the Atacama Large Millimetre/sub-millimetre Array of the 358 GHz continuum emission of the gravitationally lensed quasar host RX J0911.4+0551 have been analysed. They complement earlier Plateau de Bure Interferometer observations of the CO(7-6) emission. The good knowledge of the lensing potential obtained from the Hubble Space Telescope observations of the quasar makes a joint analysis of the three emissions possible. It gives evidence for the quasar source to be concentric with the continuum source within 0.31 kpc and with the CO(7-6) source within 1.10 kpc. It also provides a measurement of the size of the continuum source, 0.76 ś 0.04 kpc full width at half-maximum, making RX J0911.4+0551 one of the few high-redshift galaxies for which the dust and gas components are resolved with dimensions being measured. Both are found to be very compact, the former being smaller than the latter by a factor of ~3.4 ś 0.4. Moreover, new measurements of the CO ladder CO(10-9) and CO(11-10) are presented that confirm the extreme narrowness of the CO line width (107 ś 20 km/s on average). Their mere detection implies higher temperature and/or density than for typical quasar hosts at this redshift and suggests a possible contribution of the central active galactic nucleus to gas and dust heating. The results are interpreted in terms of current understanding of galaxy evolution at the peak of star formation. They suggest that RX J0911.4+0551 is a young galaxy in an early stage of its evolution, having experienced no recent major mergers, star formation being concentrated in its centre.

Dust Properties in our Galaxy (Review)

Hoang Thiem et al., *Korea Astronomy and Space Science Institute (South Korea)*

Interstellar dust is an intrinsic component of the interstellar medium and plays an important role in many astrophysical processes, including gas heating and cooling, and the formation of planets and stars. Interstellar dust grains are present in a wide range of sizes, from Angstrom (e.g., big molecules) to micron. The alignment of dust grains with magnetic fields enables dust as a powerful tool to probe magnetic fields from the diffuse cloud to star-forming regions to protoplanetary disks. In this review, I will review our modern understanding of properties of interstellar dust, focusing on two important aspects, namely dust polarization and microwave emission from rapidly spinning dust nanoparticles (aka spinning dust emission). First, I will review observational properties of interstellar dust in our Galaxy, including dust extinction, emission, and polarization. Second, I will talk about astrophysics of dust polarization, including grain alignment theory and applications of dust polarimetry for dust properties, star formation and cosmic inflation studies. Finally, I will discuss microwave emission from spinning nanoparticles (polycyclic aromatic hydrocarbons, silicate and iron nanoparticles), and its implication for probing nanoparticles in the entire protoplanetary disks.

Dust evolution (Invited)

Ysard Nathalie et al., *Institut d'Astrophysique Spatiale (IAS Orsay) (France)*

Dust grains are ubiquitous in all astrophysical environments, from the Solar System and protoplanetary disks to interstellar and intergalatic clouds, and their influence on the radiative properties of all these very diverse media is always significant through the absorption, scattering, and (non-)thermal re-emission of starlight. They are also a major player in the determination of the interstellar gas temperature through photo-electric emission or gas-grain collisions. Similarly grains have a great influence on the chemical complexity in the interstellar medium: indeed, the role of grain-surface reactions is crucial to understand the formation of some very common molecules, such as H2, and of more complex molecules. The grain radiative properties and their catalytic efficiency are, at least, reliant on the grain size distribution, structure, and chemical composition, which vary throughout the dust lifecycle. Observations show that grain growth arises in dense molecular clouds and protoplanetary disks as traced by an enhancement of the dust far-IR emissivity, a change in the far-IR SED spectral index, and by the effects of cloud-/core-shine from the visible to the mid-IR. There are also more and more evidences for dust variations in the diffuse ISM both from cloud-to-cloud and within clouds. In the context of THEMIS (The Heterogeneous Evolution dust Model of Interstellar Solids), a core-mantle dust model, I will show how most of the variations in the observations of both diffuse and dense clouds are consistent with accretion and coagulation processes.

Dust reddening in the Taurus molecular cloud and modeling dust-scattered radiation (Oral)

Kuzhikkatt Sathyanarayanan et al., *Amrita University 690525 India (India)*

We present an analysis of the diffuse ultraviolet emission near the Taurus Molecular Cloud based on observations made by the Galaxy Evolution Explorer. We used a Monte Carlo dust scattering model to show that about half of the scattered flux originates in the molecular cloud with 25 percent arising in the foreground and 25 percent behind the cloud. The best-fitting albedo of the dust grains is 0.3, but the geometry is such that we could not constrain the phase function asymmetry factor (g).

Conflicting Measurements of the Dust Emissivity Index in OMC 2/3 (Invited)

Sadavoy Sarah et al., *Harvard-Smithsonian Center for Astrophysics (United States)*

Previous studies of the OMC 2/3 star-forming filament give conflicting values for the dust emissivity index, beta, on ~ 0.1 pc scales. One study used observations at 1 mm and 3 mm to find beta < 1, indicative of millimeter-sized dust grains found in protoplanetary disks, whereas another study used data from 160 um to 2 mm to find beta ~ 1.7-1.8, which is consistent with micron-sized dust associated with the diffuse cloud material. This discrepancy in beta may be caused by (1) the dust emissivity index flattening at long wavelengths, which is predicted by experimentation but has never been observed or (2) contamination at longer wavelengths from non-thermal emission. To explore this discrepancy, we are undertaking a multi-wavelength study of the entire OMC 2/3 filament from the far-infrared to the radio using observations from Herschel, JCMT, ALMA, GBT, and the VLA. These data will reveal the true shape of the dust spectral energy distribution on < 0.1 pc scales and provide the most robust characterization of beta in this nearby, high-mass star-forming region.

Dust opacity near 24 eV (Oral)

Roshi D. Anish et al., *National Radio Astronomy Observatory (United States)*

We investigate the possibility of selective absorption of ionizing photons of energy >= 13.6 eV by the dust in HII regions. Selective absorption could possibly produce the observed low helium ionization in the warm ionized medium (WIM) and in the diffuse ionized regions surrounding HII regions. New measurements of the singly ionized helium to hydrogen ratio (nHe+/nH+) toward diffuse gas surrounding three Ultra-Compact HII regions (G10.15-0.34, G23.46-0.20 & G29.96-0.02) were made near 5 GHz with the Green Bank Telescope. These observations show that helium is not uniformly ionized in the three observed sources and the upper limits of the nHe+/nH+ ratio obtained is 0.05. Our analysis indicates that the dust absorption cross section needs to be larger by a factor >= 1.8 for photons of energy 24.6 eV compared to that at 13.6 eV to account for the low helium ionization. We compare the estimated energy dependence of the absorption cross section with that given by the Weingartner & Draine (2001) dust model and discuss possible causes for the discrepancies.

Extraterrestrial Prebiotic Molecules: Photochemistry vs. Radiation Chemistry of Interstellar Ices (Review)

Arumainayagam Chris et al., *Wellesley College (United States)*

Energetic ice processing is thought to be the primary mechanism responsible for the interstellar synthesis of most saturated organic molecules that are considered to be precursors of prebiotic molecules. Because the gas and dust absorb most of the external UV radiation, the interiors of dark, dense molecular interstellar clouds reach temperatures as low as 10 K, ensuring the freezing of most molecules and the formation of ice mantles around dust grains. Interaction of these ices with cosmic-ray induced photons/electrons produces radicals whose diffusion at temperatures above 30 K results in radical-radical reactions that lead to the synthesis of complex organic molecules. In this presentation, I will explore the different underlying interstellar molecular formation mechanisms with specific emphasis on the fundamentals of photochemistry and radiation chemistry of cosmic ices. The recently installed laser-driven low-energy (< 7.4) photon source makes our laboratory the only one in the world with the capability to study the differences and similarities between condensed-phase reactions initiated by electrons and photons, each with energies below 10 eV, the approximate ionization threshold for a generic molecule. I will report on our recent studies of energetic processing of cosmic ice analogs of water, ammonia, and methanol, three molecular species which are found in relatively high abundance in interstellar ices.