Title: Dust in debris disks, from exo-Kuiper belts to exozodis

Author: Virginie Faramaz (Steward Observatory, University of Arizona)

One of the most prominent goals of astronomical sciences is to unravel whether we are alone in the Universe or not. In its recently issued decadal survey, the whole astronomical community identified future space missions dedicated to this endeavor as an utmost priority. As a result, the next decade of the field of exoplanetary sciences will be focused on developing the technology and instruments that will allow for the direct observation of exoplanets in the so-called Habitable Zone (HZ) of their host stars. As these exoplanets orbit where water could exist in liquid form, they seem at first to be excellent candidates to search for biomarkers in their atmospheres. However, the early stages of planet formation often lead planets forming there to undergo extreme radiations from their host star, leading them to be sterile.

This means that it takes more than orbiting in the HZ to make a given planet a relevant target for the search for exolife. The actual best candidate systems are those in which we have indications that water and volatiles frozen beyond the iceline have been transported towards the HZ. Beyond the ice-line, the mass of km-sized bodies that make up reservoirs analogues to the Solar System's Kuiper Belt and Asteroid Belt -- called "debris disks -- is essentially dominated by water and simple organic molecular ices. It is through interactions between planets and these reservoirs that seeds for life can be transported to the innermost parts of a system, under the form of exocomets. These in turn can also deliver dust in the HZ as they sublimate, generating analogues to the Solar System's Zodiacal Cloud, an exozodi.

I am a global specialist of planets and debris disks interactions, and of the dynamical production of exocomets and exozodis. In this talk, I want to take you through a tour of exoplanetary systems from their outermost icy comet belts to the star's sublimation radius. I want to brush for your a broad picture of how planets, comets, dust grains are interconnected, how the study of dust is central to this picture, and what techniques I use to get informations on this dust (ALMA, LBTI).

Infrared absorption of dust of meteorites from the Atacama Desert

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Dust particles are the dominant source of opacity at infrared and (sub)millimeter wavelengths. While accurate dust opacities are crucial for modeling disks properties, their estimation is highly uncertain in this regime: dust opacities values used in models are mostly extrapolations in wavelength and grain sizes. In order to tackle this problem and resolve these caveats to help the astronomical community to make the most of the revolutionary JWST and ALMA observations, we have established the UDP Cosmic Dust Laboratory, the first one of its kind in Chile and Latin-America. We have started operations working on infrared measurements of meteorites from the Atacama Desert, planning to extend our opacity measurements to the submillimeter regime.

Meteorites are the best analogs of the type of dust expected in protoplanetary and debris disks, and the most accessible samples from the Earth to study in the laboratory. The semiarid to hyper arid climates of deserts allows preservation and accumulation of meteorites. Being the driest desert in the world, the Atacama Desert shows an exceptional meteorite concentration per km^2 that has remained hyper-arid for several Myr and has preserved meteorites for a long time with a very low erosion rate and slow chemical weathering.

In this first study, we present the measurements of absorbance spectra and dust opacities of 23 meteorites, 3 carbonaceous and 20 ordinary chondrites (types H, L and LL) from the Atacama Desert. We correlated their infrared spectra (2-23 microns) with chemical composition and the grain size distribution (Batalla-Falcon et al., to be submitted to Icarus).

Dust around evolved stars
Ambra Nanni (National Centre for Nuclear Research, Poland)

It is well established that dust formation around evolved stars plays a fundamental role in their evolution, being in large part responsible for the development of stellar winds and mass-loss, and in shaping their emerging spectra by absorbing photons from their photosphere and re-emitting them at longer wavelengths. Evolved stars are also important dust factories in the Universe that enrich the interstellar medium with dust grains. Despite the importance of dust build-up around evolved stars, many questions related to this process and the dust properties remain unanswered. In this talk I will review what we learned from spatially resolved observations of evolved stars, and recent advancements in theoretical modelling and the challenges that lie ahead.

Systematic Laboratory Study on Chemical Composition of Circumstellar Amorphous Silicate Dust

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Amorphous silicate is a major component of circumstellar and interstellar dust [1, 2]. Infrared spectra of oxygen-rich asymptotic giant branch (AGB) stars, the most prevalent circumstellar dust suppliers in the galaxy, show features at ~10 μm and ~18 μm deriving from amorphous silicate dust. Their peak positions and strength ratios vary among stars, which are explained by (1) optical constants depending on the chemical compositions and structures, and (2) physical parameters such as particle size, temperature, and shape. Artificial materials called "astronomical silicate" [3, 4], have been widely used to interpret observed dust spectra. However, astronomical silicate cannot be used to discuss chemical compositions of observed dust and dust formation processes. Various dust analogues have been produced in laboratories [e.g., 5, 6, 7] yet cannot explain observations better than astronomical silicate. This is partly because the relation between optical constants and chemical compositions of amorphous silicate is not fully understood. Previous experiments are mainly conducted in the system of Mg-Fe-Si-O and experiments regarded in elements, that can change the structure of SiO_4 network (such as Al, Ca, and Na), are limited [8]. Also, the effects of physical parameters such as particle size are poorly considered.

We conducted condensation experiments using an induction thermal plasma (ITP) system (JEOL TP-40020NPS [8]). The chemical compositions of the starting materials were systematically changed from the CI chondritic composition in the systems of Al-Mg-Si with Al/Si ratios of 0.08–0.64 and Al-Ca-Mg-Si with Ca/Mg ratios of 0–1. The condensed particles were analyzed by XRD (Rigaku RINT-2100), EPMA (JEOL JXA-8530F), and TEM (JEOL JEM-2800). IR absorption spectra of the products dispersed in KBr pellets and the reflectance spectra of pressed sample pellets were measured with FT-IR (JASCO FT/IR-4200, Thermo Scientific Nicolet 6700).

The products were mainly spherical amorphous nanoparticles (10–100 nm) and showed little change in the bulk chemical compositions from the starting materials. Optical constants for five samples were determined from absorption and reflectance spectra using the Lorentz oscillators model with/without the KBr medium effect. No set of optical constants replicated both absorption and reflectance spectra, probably because the pressed grains were agglomerated and deformed. Dielectric constants at high frequency determined from the reflectance spectra at ~7000 cm^{-1} (1.4 μm) were used to fit the absorption spectra to obtain optical constants between 390–2500 cm^{-1} (4–26 μm) Absorption spectra of the amorphous silicates without KBr medium effect were calculated with the optical constants determined in this study assuming the spherical-shaped grain of 0.1–10 μm in diameter. We compared the calculated spectra with observed dust emissions of Z Cyg [9]. The 10 μm peak position of Z Cyg was longer than any of the products and the 18 μm peak was located between those of the products with Ca/Mg ratios of 0 and 1. The higher Al and Ca contents than the CI chondritic composition can explain the dust spectra of Z Cyg. These results suggest that circumstellar dust cannot be explained by pure Mg-Fe-silicate dust but by silicate dust enriched in Al and Ca.

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Mass-loss Rate of Highly Evolved Stars in the Magellanic Clouds

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Asymptotic giant branch stars (AGBs) and red supergiant stars (RSGs) exhibit evident mass loss phenomena and are considered important sources of interstellar dust. However, the mechanism of mass loss is still unclear, and the mass-loss rate (MLR) of evolved stars requires further research and precise evaluation. To address this, we utilized an updated and complete sample of over 40,000 evolved stars in the Magellanic Clouds (MCs) and employed the 2-DUST radiation transfer model and spectral energy distribution fitting approach to determine the dust-production rates (DPRs) and dust properties of the AGBs and RSGs. Our results reveal that the total DPR of the Large Magellanic Cloud is approximately $1 \times 10^{-5}\, M_{\odot}\,\mathrm{yr}^{-1}$, while the total DPR of the Small Magellanic Cloud is around $2 \times 10^{-6}\, M_{\odot}\,\mathrm{yr}^{-1}$, with a few stars significantly contributing to the total DPR. We explored relations between stellar parameters (luminosity, infrared color, period, amplitude) and MLR for evolved stars. A prominent turning point locating $\log{(L/L_{\odot})} \approx 4.4$ appears on the luminosity-MLR diagram of RSGs in MCs, potentially related to the mass loss mechanism of RSGs. The MLR of AGBs show a clear change with the pulsation period and amplitude, that the MLR of the AGBs with pulsation period of approximately 300 days and I band amplitude greater than 0.5 mag show a drastic increase. The metallicity has some impact on the DPR of RSGs, with lower metallicity seems to result in lower DPR and higher optically-thin proportion. Based on the new samples of Local Group, studying the influence of metallicity on DPR is our next plan.

PAH Emission in the Andromeda Galaxy: Probing its Dependence on Starlight Spectrum

Bo Yang and Aigen Li

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Polycyclic aromatic hydrocarbon (PAH) molecules exhibit distinct emission bands across various wavelengths in the infrared, revealing their prevalence throughout the Universe. Their excitation is dependent on the spectrum or “hardness” of the illuminating starlight.

The Andromeda galaxy (M31), of which the nucleus, bulge, active star-forming rings, and quiescent inter-ring regions are characterized by different starlight “hardnesses”, provides an ideal laboratory for studying the excitation of PAH emission by starlight of various spectral shapes.

Utilizing data from Spitzer/IRS, alongside GALEX and SDSS broadband photometry, we construct the starlight spectrum for each region from the far ultraviolet (UV) to the near infrared (IR). We then explore how PAH excitation in M31 varies across different environments, from the UV-bright star-forming rings to the UV-poor bulge and inter-ring areas. Our findings support the earlier studies of Li & Draine (2002) and Mattioda et al. (2005) that the excitation of PAHs does not require UV photons and PAHs can be excited sufficiently to emit in the IR by 'soft' photons. By comparing the model emission spectra of PAHs in various regions of M31 with the astronomical spectra observed by ISO and Spitzer, we determine the size and charging properties of PAHs and examine how they vary across M31. This study sheds light on the nuanced relationship between PAH excitation and starlight spectrum, offering insights into the broader understanding of the physics and chemistry of PAHs in galaxies.

Exploring comet dust through advanced numerical modeling of scattered and emitted light

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Scattered solar and thermally emitted light by cosmic dust particles can reveal important information on their physical properties such as size, morphology and composition. Interpreting remotely observed light poses a non-trivial challenge, and it requires solving an inverse problem for Maxwell's equations coupled with a thermopysical model. This is possible only for particles that are small or the same size compared to wavelength and, for practical problems where particles can be much larger that the wavelength, some approximations are needed. Furthermore, a solution to the inverse problem for Maxwell's equation is not unique, thus relying solely on one observable for fitting may result in a misleading interpretation.

In this talk, I will present some recent developments of the approximate and numerically exact solvers for different types of dust particles, and discuss their capabilities and applicability ranges. Further, I will show examples on how to better constrain comet dust properties using multi-instument observations and self-consistent numerical modeling together with dust dynamical modeling.

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The Properties and Evolution of the Dust Ejecta Produced by the DART Impact

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NASA's Double Asteroid Redirection Test (DART) mission successfully impacted asteroid Dimorphos on September 26, 2022. This event marked the first-ever opportunity to directly observe both the excavation and the subsequent evolution of dust ejecta resulting from a planetary-scale impact on an asteroid. The data collected from this collision will not only enhance our understanding of asteroid impact mechanics, but also provide insights into the nature of dust emissions from active asteroids.

The DART impact ejecta contains three components: a fast jetting material expanding at ~15 km/s, a plume moving at ~1.5 km/s, and the dust and boulders ejected at speeds up to a few 100s m/s. Here we focus on the results about the dust ejecta, including the m-sized boulders, as observed by Hubble Space Telescope and ground-based telescopes. The dynamics of the dust ejecta is dominated by the particle size, ejection speed, and direction under the influence of solar gravity, the gravity of Didymos, and solar radiation pressure (SRP). The dust and boulders ejected at speeds exceeding a few m/s directly escape the binary system, maintaining their initial trajectories and forming a cone-shaped morphology. In contrast, slower ejecta with speeds under ~1 m/s is appreciably influenced by the gravity of Didymos, resulting in curved and rotating features a few days post-impact – a unique characteristic of ejecta from the satellite in a binary system. Additionally, SRP push the ejecta toward the antisolar direction, continuously modifying the cone morphology, leading to a wing-like structure with overlapping striae. The slowest dust forms a long, narrow tail starting from ~T+3 hours and lasting over 9 months after the impact. Modeling indicates μm- to cm-sized particles in the tail with a broken power law size frequency distribution with slopes of -2.6 and -3.7 for dust <~3 mm and larger, respectively. Observation also suggests possible temporal and spatial variations in the color and polarimetry of the ejecta and tail. Further analysis is needed to fully understand additional features, including the circular features and arc-like features in the ejecta, the double-tail, and the dust cloud to the south of the main tail observed ~4 months after the impact.

Two groups of m-sized boulders are observed in the ejecta. One group is embedded in the ejecta cone, with diameters of a few meters and moving at 20 – 30 m/s, primarily clustered in two directions. Another group is observed to distribute around the asteroid in the deep exposure acquired two months after the impact, indicating slow speeds of a few m/s and diameters of 3 – 7 m. The detection of m-sized boulders suggests a broad size distribution of the dust in the ejecta.

The morphological characteristics of the ejecta from Dimorphos differ significantly from those observed from Comet 9P/Tempel 1 during the Deep Impact mission, likely due to the different volatile compositions, dust sizes, and surface and subsurface conditions of the two bodies. Notebly, the tail morphology of Dimorphos resembles those seen in certain active asteroids that are believed to result from impulsive dust release triggered by impacts, rotational instability, or binary interactions, This similarity clearly supports the hypothesis that impacts are an important mechanism for activating asteroids.

Dust in Active Asteroids

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Some asteroids exhibit activity, manifesting a comet-like appearance with the development of a coma and a tail due to material being released from their surface or interior. This activity commonly arises from the presence of volatile substances in their composition or as a consequence of collisions with other asteroids.

In this presentation, we consider photometric and polarimetric observations of active asteroids, specifically focusing on asteroid (248370) QN173, for which we have quasi-simultaneous data on the distribution of color and polarization along the asteroid tail. We apply computer modeling to these data to recover the dust characteristics. We consider irregular solid particles, consisting of material similar to that for C-type asteroids, and use the surface-integral-equation (SIE) method for the PMCHWT formulation for particle sizes $r \leq 3$ micron, and SIRIS4 code based on the geometric optics approximation using inhomogeneous plane waves for particles larger than $r > 3$ micron. The modeling allows us to determine the size distribution of particles and their change with the distance to the asteroid and with phase angle.

One more object of our interest is the dust, ejected by asteroid Dimorphos as a result of impact by the DART spacecraft. We are combining the observations of polarization (FORS2, VLT) and color (MUSE, VLT) with the HST WFC3/UVIS imaging data for the same dates. As this was done for (248370) QN173, we model the DART ejecta dust as irregular solid particles, although in this case the composition is taken to be typical for S-type asteroids. The observations showed an absence of any trends in color and polarization with the distance from the impact, thus, limiting our capability to study the variations in the dust properties along the observed tail and indicating that the ejecta dust was dominated by large particles that scatter light in the geometric optics regime. To extract more information about the ejecta particles, we considered several dates of observations, thus, exploring the change in the dust with the time after impact. The characteristics of the size distribution obtained from the modeling were applied to the HST images, enabling estimation of the dust column density at different distances from the asteroid and for different dates.

We also present radiative transfer modeling of the DART ejecta images acquired by the camera LUKE onboard LICICube CubeSat in close proximity to the impacted asteroid.

Electrodynamics of dust on airless bodies

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Airless bodies, such as the Moon, asteroids, Martian moons, and dormant comets, are mostly covered by a layer of fine dust. Due to direct exposure to the solar wind and solar radiation, dust particles on the surfaces of these airless bodies are charged and may be mobilized, lofted, and transported due to electrostatic forces. Several observations have been related to this physical process, including the lunar horizon glow, the dust ponds on Eros, and the radial spokes in Saturn's rings. However, the underlying physics stood unsolved for more than five decades. A series of recent laboratory studies made an important milestone towards ultimately solving these observation mysteries, providing us further insights about how this physical process would change our view on understanding the surface evolution of airless bodies and asteroid dynamics, and how it may affect human exploration to the Moon and other airless bodies. In this talk, I will walk through the important discoveries of recent studies on electrostatic dust dynamics and instrument ideas for in situ measurements on the Moon and other small airless bodies.

Cosmic dust interactions with the solar wind

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Key-words: interplanetary dust, interstellar dust, plasma-dust interaction, spacecraft dust impacts, data analysis

Dust in the solar system originates from various sources within the solar system or the Interstellar medium. Such dust is affected by the Sun, especially from the solar wind plasma. Indeed, on top of the particle-to-dust contacts that push the dust or possibly destroy the dust grains, the solar wind shapes the interplanetary magnetic field and therefore bends the motion of the electrically charged dust grains. These plasma-dust interactions take place at the heliopause (~100 au, only for the interstellar dust entrance in the solar system), or closer to the Sun, in the interplanetary medium (from fractions of au to a few au).

Dust and its motion in the solar system can be studied by spacecraft specifically designed for its study or by other spacecraft impacted by dust grains. These impacted spacecraft, whose plasma wave antennas record a signal, essentially serve as unexpected dust grain detectors. One such example is the Wind/WAVES instrument. The Wind/WAVES dust impacts database (Malaspina & Wilson 2016) offers more than 25 years of data, however not calibrated or without detailed information on dust properties (velocity, electric charge, etc.).

We use this Wind/WAVES dust impacts database to study the dust-plasma interaction in the interplanetary medium, with a particular focus on Interstellar dust.
First, long-term variations – from months to years - of dust impact counts provide insights into the origin of the dust and its response to solar cycles.
Second, a frequency analysis in the dust impact counts highlights a solar rotation signature – 27 days and harmonics - (see Baalmann et al., submitted). This solar rotation signature is possibly linked to the Corotating Interaction Regions (CIRs) created by the solar wind.
Third, such effect of solar plasma on dust impacts is corroborated by a study that crosses Wind/WAVES dust impact data with solar events like Coronal Mass Ejections (CMEs) and Stream Interaction Regions (SIRs) catalog to look for short-term – a few days – effects. A statistically significant depletion of dust counts during such solar events is visible (see Péronne et al., in preparation).
Both studies show increased solar signatures on Interstellar dust and give new information on the cosmic dust interactions with the solar wind.

The interpretation of the data analysis from the Wind/WAVES instrument benefits from numerical simulations, especially for Interstellar dust trajectories within the heliosphere. Such simulations complement our understanding of how the Interstellar dust can reach the interplanetary medium, and how the properties of such grains make them particularly sensitive to the solar events mentioned before.

In-Situ Mass Spectrometry for Interstellar Dust in Space Missions: A Novel Approach to Study the Physical and Chemical Properties of the Local Interstellar Cloud

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Remote-sensing high-resolution spectroscopic observations of interstellar absorption lines towards nearby stars provide us the opportunity of inferring the chemical elements in the solid phase of the Local Interstellar Cloud (LIC) from the depletion of the elements in the gas phase. In contrast, in-situ mass spectrometry for dust particles streaming into the inner Solar System from the LIC is a promising technique to directly measure the elemental abundances of dust in the LIC. Therefore, in-situ mass spectrometric measurements of the elements in the solid phase and remote-sensing spectroscopic observations of the elements in the gas phase are complementary to each other with regard to the determination of elemental abundances. We show that the chemical composition of interstellar dust measured in situ acts as a powerful tool to constrain the gas-phase abundances and ionization states of the elements undetectable by spectroscopic observations. The isotopic composition of iron in the LIC dust, particularly the magnitude of ^{60}Fe excess, is of great importance for estimating the age of the dust, while laboratory analyses of radioactive isotopes originating from the LIC and collected on the Earth could compensate for a low mass resolution of spectra if measured at Earth's orbit. The elemental abundance of sulfur in the solid phase is the key to determining the ionization fraction of hydrogen in the LIC, although a significant reduction in the baseline noise of in-situ mass spectrometers, compared to previous space missions, is a requisite for the detection of sulfur. Identification of the smallest LIC dust inside the heliosphere gives insights into not only the strength of interstellar magnetic fields, but also the thickness of the heliospheric layer. To probe the coagulation growth of dust in the interstellar medium, the dynamics of dust in the heliosphere could be better simulated with the chemical composition of LIC dust derived from in-situ mass spectrometric measurements. In the light of forthcoming space missions with a state-of-the-art time-of-flight mass spectrometer, we will demonstrate how in-situ mass spectrometry for interstellar dust in space missions is a novel approach to study the physical and chemical properties of the LIC.

Photophysics of PAHs in the Atmosphere of Titan

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Titan is the largest satellite of Saturn and the second largest satellite in the solar system. It is the only satellite in the solar system that has a dense atmosphere. Its atmosphere is dominated by N_2 (98% by volume), with a small amount of CH_4 (2% by volume) and tiny amounts of other organic molecules. The *Visual-Infrared Mapping Spectrometer* (VIMS) on board the *Cassini* spacecraft detected in the atmosphere of Titan the 3.28 μm emission feature which is believed to arise from the C-H stretching mode of polycyclic aromatic hydrocarbon (PAH) molecules. PAHs are thought to be a major constituent of the Titan haze. As the atmosphere of Titan is about 250 times more N-rich (relative to C) compared to the interstellar medium, we would expect the PAH molecules in the Titan atmosphere to be doped by one or more N atoms.

In this talk we will present our recent results on the vibrational excitation simulation of N-rich PAH molecules in the Titan atmosphere illuminated by the Sun and calculate their infrared emission spectra. We will compare the computed PAH emission spectra with that observed by *Cassini/VIMS* and derive the PAH abundance and its spatial distribution in the upper atmosphere of Titan.

Collisional evolution of dust in planet formation

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Planets were believed to form via the accretion of planetesimals generated from dust grains in protoplanetary disks. However, the growth of planets is much slower than their migration due to disk-planet interaction. Comparably rapid growth via pebble accretion was then proposed, which requires very massive protoplanetary disks because most pebbles fall into the central star. Although planetesimal formation, planetary migration, and planetary growth have been studied with much effort, the full evolution path from dust to planets was uncertain. We have investigated full collisional evolution from dust to planets. For collisional evolution, collisional outcomes are not simply characterized as fragmentation, bouncing, etc. The impact simulations for dust aggregates showed the detailed outcomes. According to the outcome model, the growth of dust grains are not prevent from collisional fragmentation. We thus perform the full simulations (DTPSs) for collisional evolution from dust to planet in whole protoplanetary disks. Dust growth with high porosity allows the formation of icy planetesimals in the inner disk ($\leq 10\,\mathrm{au}$), while pebbles formed in the outer disk drift to the inner disk and there grow to planetesimals. The growth of those pebbles to planetesimals suppresses their radial drift and supplies small planetesimals sustainably in the vicinity of cores. This enables rapid formation of sufficiently massive planetary cores within 0.2-0.4 million years, prior to the planetary migration. However, such porous pebbles are unlikely to reproduce the polarized millimeter wavelength light observed from protoplanetary disks. We thus investigate gas-giant core formation with non-porous pebbles via DTPSs. Even non-porous bodies can grow into planetesimals and massive cores to be gas giants are also formed in several 10^5 years. The rapid core formation is mainly via the accretion of planetesimals produced by collisional coagulation of pebbles drifting from the outer disk. The formation mechanism is similar to the case with porous pebbles, while core formation occurs in a wider region ($5-10\,\mathrm{au}$) than that with porous pebbles. Although pebble growth and core formation depends on the disk temperature, core formation is likely to occur with disk temperatures in typical optical thick disks around protostars.

Sublimation and recondensation of ice in a protoplanetary disk

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Icy dust aggregates migrate in both radial and vertical directions in a protoplanetary disk. The icy components sublime when the aggregates pass the snow line or a heating event occurs. The sublimed molecules recondense if they pass again the snow line or the temperature decreases after the heating event. The size and the number of the recondensed particles are critical in the growth of the icy dust aggregates and temperature distribution of the protoplanetary disk. If the size of the particles is large, the mechanical strength of an aggregate composed of the particles is low because the number of contact points decreases as the particle size increases. In addition, the formation of small particles increases the opacity, and the temperature distribution of the disk can be changed.

The sublimed molecules recondense in two ways, including homogeneous and heterogeneous nucleation. In homogeneous nucleation, the molecules form nuclei by themselves and the nuclei grow through the sticking of the sublimed molecules. If the amount of the leftover dust aggregate (silicate component + unsublimed ice molecules) is large, the sublimed molecules recondense onto the leftover aggregate. Thus, the outcome of recondensation strongly depends on the size of the icy aggregates before sublimation. If the aggregate size before sublimation is large, the total surface area of the leftover aggregates is small, and heterogeneous nucleation is suppressed.

Simulation of recondensation of H_2O molecules after a heating event has shown that the size of the recondensed particles is larger than $0.16\,\mu$m if the cooling timescale is longer than 0.1 yr and the initial aggregate size is larger than $0.07\,\mu$m. When the size of the composing grains in an icy aggregate is larger than $0.16\,\mu$m, continuous collisional growth of the aggregate is impossible because of the low mechanical strength. Because heating events such as FU Orionis outburst frequently occur in a protoplanetary disk and the cooling timescale is much longer than 0.1 yr in a global heating event, this result strongly suggests that the icy planetesimal formation through the collisional growth of icy dust aggregates is not probable.

The second simulation is the recondensation of various icy molecules after passing the snow line above the midplane of the disk. If the size of the aggregates before the sublimation is larger than $10\,\mu$m, H_2O, NH_3, and H_2S molecules recondense by homogeneous nucleation and form small particles, leading to a substantial increase in the total surface area of the particles compared to that before sublimation. The region with the increased total surface area is limited by the sublimation temperature of the icy component and the temperature distribution of the disk. The opacity due to the recondensed particles can substantially change the temperature distribution of the disk. In summary, sublimation and recondensation of the ice component can affect both the growth of the dust aggregates and the temperature distribution of the disk.

JWST and PAHs in Protoplanetary Disks: Placing Constraints on the PAH Properties and Disk Structures

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The 3.3, 6.2, 7.7, 8.6 and 11.3 μm emission features of polycyclic aromatic hydrocarbon (PAH) molecules have been detected in protoplanetary disks (PPDs) around Herbig Ae/Be stars and T Tauri stars. PAHs are present at the disk surfaces and even in the cavity or gaps from which large grains are missing. They play an important role in the thermal budget and chemistry of the gas in PPDs, by providing photoelectrons for heating the gas and large surface areas for chemical reactions. Stochastically heated by a single UV/visible photon, PAH emission is spatially more extended than large grains and therefore, PAH emission can resolve PPDs more easily and is a powerful tracer of the disk structure.

Due to their limited sensitivities, it was not possible for ISO or Spitzer to spatially resolve PAH emission in PPDs. Indeed, so far almost all spatially-resolved observations of PAH emission were made by ground-based telescopes. Also, the low detection rate of PAH emission in T Tauri disks is probably related to their faintness. With its unprecedented sensitivity, JWST is expected to detect and spatially resolve PAH emission at all the major bands in a much larger sample of Herbig Ae/Be and T Tauri disks. This will enable far more detailed band analysis than previously possible.

To facilitate the analysis, interpretation and modeling of the incoming JWST data of PAH emission in PPDs, we develop a PAH spectral and band-ratio (i.e., $I_{6.2}/I_{7.7}$, $I_{11.3}/I_{7.7}$) library. This library will serve as a quantitative diagnostic tool for determining the PAH size and ionization fraction from the observed band ratios of the PAH emission features at 6.2, 7.7 and 11.3 μm.

We calculate the IR emission spectra of both neutral and ionized PAHs of various sizes, located at various radial distances (from the central star) in PPDs around stars of a wide range of spectral types and of several representative luminosities. We create a library of PAH model emission spectra and model band ratios and generate a series of diagrams of $I_{6.2}/I_{7.7}$ vs. $I_{11.3}/I_{7.7}$. To demonstrate the effectiveness of this diagnostic tool, we apply the model $I_{6.2}/I_{7.7}$ vs. $I_{11.3}/I_{7.7}$ diagrams to infer the PAH size and ionization fractions of a number of PPDs of representative properties (for all of which PAH emission has been detected and spatially resolved).

Dust in active galactic nuclei

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From the formation of stars and planets to the evolution of galaxies, dust plays a crucial role in many astrophysical processes. Each field of astrophysics approaches the problem in a unique manner. In active galactic nuclei (AGN), the geometry and distribution of the component conformed by dust historically controls much of the observational properties of AGN classes. For decades, scientists studying AGN have focused on determining the geometry and distribution of dust within the first few tens of parsecs. This historical reason left behind important questions related to dust composition and grain size distribution. However, the harsh environment of AGN provides an ideal laboratory to understand dust processes such as coagulation or accretion. Recently, we discovered that both the chemical composition and dust grain sizes differ significantly from those of the ISM. During this talk, I will provide an overview of the extensive research conducted in the field of AGN, as well as recent and future prospects, thanks to high-quality MIR observations obtained with JWST.

Aromatics in Merging Galaxies Involving Active Galactic Nuclei and Starburst Cores as Probed by the James Webb Space Telescope

Charles E. Mentzer and Aigen Li

University of Missouri

The merging of galaxies presents a dynamic laboratory for studying the interplay of molecular species within evolving cosmic environments. In this presentation, we delve into aromatic molecules amidst the tumultuous process of galactic mergers, particularly those involving active galactic nuclei (AGN) and starburst cores, with special attention paid to VV 114, NGC 3256 and J0749+3256. Leveraging the cutting-edge capabilities of the James Webb Space Telescope (JWST), particularly its Mid-Infrared Instrument (MIRI) and Near-Infrared Spectrograph (NIRSpec) equipped with Integral Field Unit (IFU) capabilities, we unravel the chemical intricacies within these cosmic collisions. The emission of polycyclic aromatic hydrocarbon (PAH) molecules, which is clearly seen in the JWST/NIRSpec and MIRI data of galaxy mergers, offers a nuanced lens into the physical conditions within merging galaxies. Due to the sensitivity of the PAH emission bands to PAH size and charge as well as the aliphatic fraction of the molecules, the JWST/NIRSpec and MIRI spectra of merging galaxies allow us to probe the unique environmental characteristics of the regions responsible for the emission. We derive the spatial distribution of the size and charge and chemical structure of the PAH molecules present within these stellar laboratories (VV 114, NGC 3256, and J0749+2255) and discuss the implications.

Far-UV to far-IR emission from Dusty SAGE: a galaxy evolution model with self-consistent dust treatment

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We introduced a semi-analytic galaxy evolution model with a detailed dust prescription, Dusty SAGE. The model includes condensation of dust in the stellar ejecta, grain destruction by supernovae shocks, and removing dust from the interstellar medium by star formation, reheating and outflows. These dust- related processes are combined with the usual prescriptions in a galaxy evolution model, including gas infall, star formation, and feedback from supernova and active galactic nuclei. Here, we use dust and stellar properties from the model to generate the far-UV to far-IR emission self-consistently. The model reproduces the z=0 far-UV to far-IR luminosity functions from observation but is less successful at higher redshift. We found that the far-UV emission is sensitive to the dust processes and AGN feedback. Altering these parameters improves the agreement of the far-UV luminosity function at z=2 and z=3. However, further study of how these parameters behave during galaxy evolution is needed to consistently reproduce the far-UV to far-IR emission across a wide redshift range.

A Coherent Model of the Amount and Emission of Dust in Galaxies at Various Redshifts

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Dust influences the physical properties of galaxies, depending on the quantity and its size distribution. Therefore, a proper understanding of dust evolution is crucial to understand the formation and evolution of galaxies. Recently, a large amount of dust has been discovered in galaxies at very high redshifts. Surprisingly, the dust-to-stellar mass ratio of such galaxies is as large as that of nearby galaxies. This is not easy to explain by current theories of dust production and evolution in galaxies, leading to a problem known as "the dust budget crisis". To explain the dust amount in these galaxies, it is necessary to supply a tremendous amount of dust at a very early stage of the galaxy. In the series of previous studies, we established a model of dust formation and evolution based on the chemical evolution of galaxies, with a closed-box assumption. With this model, we discovered that the dust accretion in the dense interstellar matter is crucial for the dust evolution. However, as we mentioned above, there remain some unsolved problems such as the origin of huge dust amount at high redshifts ($z > 8$).

In this work, we developed an extension of the previous dust evolution model, implementing an inflow of gas from the intergalactic medium. Recently, gas infall is regarded as one of the fundamental processes in galaxy evolution. We found that even if the gas is significantly consumed to form stars, dust can grow in the interstellar matter infalling from outside of a galaxy. In such a case, the dust mass compared with the stellar mass becomes larger than that predicted from a closed-box model. Therefore, a galaxy can have a sufficient amount of dust at a young galaxy age when the stellar mass is quite small. We consider the new framework to be able to explain a broader range of physical properties and observations. Particularly, some modifications are necessary to reproduce their observed spectral energy distribution (SED). Very high-z galaxies are known to be much more luminous than expected. Since distant galaxies are typically compact, the density in dense molecular clumps should be higher than that in nearby galaxies. We discovered that if we adjust the radius of clumps to have a higher mass density, we could reproduce the luminous dust SED of high-z galaxies. We will present the details of this new theoretical model.

Probing the Spatially Resolved Characteristics of Interstellar Dust with the z0MGS Dataset

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We present the spatially resolved studies on interstellar dust using data products from the z=0 Multiwavelength Galaxy Synthesis (z0MGS). The z0MGS program aims to create a large, uniform database of resolved measurements of gas and dust in nearby galaxies. The key data products includes: (1) WISE & GALEX: we have released WISE infrared (IR) and GALEX ultraviolet (UV) maps of $\sim 15,750$ local galaxies at matched resolutions (FWHM $7.''5$ and $15''$). These maps can be utilized to derive surface densities of star formation rate (SFR) and stellar mass as ancillary data for dust sciences. (2) *Herschel* and Dust: In a sub-sample of ~ 900 galaxies, we uniformly reduce their *Herschel* data. We then fit their dust properties with WISE and *Herschel* IR data and the Draine & Li (2007) model at SPIRE 250 μm resolution ($\sim 21''$). The data product includes the dust surface density, PAH fraction and properties of interstellar radiation field. (3) H I 21 cm: We conduct new H I 21 cm observations with the VLA for galaxies with *Herschel* data but missing in previous H I surveys (e.g. THINGS, HALOGAS). Around 40 galaxies have science-ready H I cubes.

The z0MGS data offer unprecedented insights into the resolved properties of interstellar dust and how dust interacts with the interstellar medium. One of the projects we conduct utilizing this catalog is to study the properties of dust temperature in terms of local environmental quantities at kpc scale, using a sub-sample where CO (1–0) or CO (2–1) is available. We find that the dust temperature correlates well with the SFR surface density, which traces the radiation from young stars. The dust temperature decreases with increasing dust-to-gas ratio (D/G) at fixed SFR surface density as expected from stronger dust shielding at high D/G, when SFR surface density is higher than $2 * 10^{-3}$ $M_\odot\,yr^{-1}\,kpc^{-2}$. These measurements align well with the dust temperatures predicted by our proposed analytical model. We also use a subset of nearest galaxies to examine how resolution affects the fitted temperature. We observed a systematic increase of approximately 2 K in the dust temperature as we degrade the resolution of IR maps from ~ 10 pc to ~ 1 kpc.

We also use the z0MGS-*Herschel* dust data to trace other quantities in the interstellar medium. For instance, we utilize the fitted dust surface density and an assumed D/G(Z) relation to trace the gas mass surface density to study the environmental dependence of the CO-to-H2 conversion factor. We found that the CO-to-H2 conversion factor scales with the stellar mass surface density as a power law in the high-surface-density regime. The power-law index is ~ -0.5 for CO (2–1) and ~ -0.2 for CO (1–0), and it is invariant of assumed D/G(Z) relation. The derived conversion factor also shows anti-correlation with local CO (2–1) linewidth, consistent with observations made with CO isotopologues. The above findings underscore the significant potential of the z0MGS dataset in advancing our understanding of interstellar dust and its role in galactic chemistry.

An analysis of interstellar medium and star-formation scaling relations in nearby galaxies

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We present a detailed analysis of dust, star-formation and interstellar medium (ISM) scaling relations - pivotal when trying to understand the ISM evolution or the star-formation and the lifecycle of dust and gas - done on a representative sample of nearby galaxies, as a proof-of-concept study for a new alternative method to derive more accurate, dust-corrected star-formation rates (SFR) and related dust/ISM and star-formation quantities. Hα images are analysed in order to derive the integrated galaxy luminosity, known as a more instantaneous and accurate star formation rate tracer, and the required photometric and structural parameters. Dust- and inclination-corrected Hα luminosities, SFRs, and related quantities are determined for the analysis of the scaling relations, using a self-consistent method based on previous work prescriptions. The main advantages of the method are: a) only Hα fluxes / luminosities are needed; b) easy to use based on a few equations and numerical corrections; c) no Balmer decrements (or other hydrogen recombination lines) needed or the assumption of a certain attenuation curve; d) other dust models can be easily considered in the equations; e) dust masses, opacities and dust temperatures are determined along the way; f) more instantaneous dust-free SFRs can be derived; f) it can be applied for normal low- to intermediate redshift spiral, elliptical, and lenticular galaxies and used in larger scale studies of galaxy and ISM evolution.

To investigate which star-formation or ISM related quantity best traces dust temperature, we analyse relations between the dust temperature and surface densities of SFR, dust and other related quantities.

We also show how the diffuse dust distribution in the stellar disc compares with the extent of star-formation distribution and the stellar continuum emission one, and their evolution with stellar mass.

Processing of hydrocarbon dust in a wide range of interstellar environments in nearby galaxies revealed by AKARI near-IR spectroscopy

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Hydrocarbon dust is one of the dominant components of interstellar dust, which mainly consists of polycyclic aromatic hydrocarbons and aliphatic hydrocarbons. While hydrocarbon dust is thought to be processed in interstellar radiation fields or shocks, detailed processing mechanisms are not completely understood yet; there are few statistical studies on the relationships between the aromatic and aliphatic components for a large number of objects with different interstellar environments.

Based on the luminosities of the aromatic hydrocarbon feature at 3.3 μm ($L_{\rm aromatic}$) and the aliphatic hydrocarbon feature at 3.4–3.6 μm ($L_{\rm aliphatic}$) estimated with the AKARI near-infrared (IR) 2.5–5 μm spectra, we have studied the relationships between $L_{\rm aromatic}$ and $L_{\rm aliphatic}$ for 299 nearby galaxies at redshifts lower than 0.3. The sample includes 138 star-forming galaxies at redshifts $0.01 < z < 0.3$, which are point-like sources with the AKARI resolution. The other 161 galaxies are very nearby ones at redshifts $z < 0.01$, most of which are spatially-resolved sources, with 961 spectra in total. As a reference sample, we also analyzed AKARI near-IR spectra of star-forming regions in our Galaxy, and obtained $L_{\rm aromatic}$ and $L_{\rm aliphatic}$ from 31 regions with 232 spectra in total.

As a result, $L_{\rm aliphatic}/L_{\rm aromatic}$ shows wide variations among the 299 sample galaxies. Overall, our sample galaxies systematically possess higher $L_{\rm aliphatic}/L_{\rm aromatic}$ than the star-forming regions in our Galaxy. Several spectra show unusually high $L_{\rm aliphatic}/L_{\rm aromatic}$ (> 1). On the other hand, for the IR-luminous galaxies, we find that galaxies with higher IR luminosities tend to exhibit lower $L_{\rm aliphatic}/L_{\rm aromatic}$. We also find that the galaxies with low $L_{\rm aliphatic}/L_{\rm aromatic}$ are dominated by merger galaxies.

Our results suggest that aliphatic hydrocarbon is highly processed by strong radiation fields and/or shocks due to galaxy mergers, while the degree of the processing of hydrocarbon dust may be significantly different from galaxy to galaxy. In this presentation, we discuss the causes of the variations in the processing of hydrocarbon dust for our sample galaxies, focusing on $L_{\rm aliphatic}/L_{\rm aromatic}$ in different interstellar environments.

Systematics in the determination of dust mass from far-infrared SEDs: the role of temperature-dependent opacity

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One of the most powerful tools in the study of the interstellar medium is the spectral energy distribution (SED) of thermal dust emission, which is mainly observed at far-infrared and submillimeter wavelengths (~100–1000 μm). Using a dust emission model such as a modified blackbody, this SED can be fit to reveal the dust temperature, as well as its column density, which can be converted to a gas column density via a conversion factor. The dust SED is therefore a tracer of the structure and local conditions of the interstellar medium, and plays a key role in topics such as star formation and galactic chemical evolution.

One caveat regarding SED fitting is that its results depend strongly on the adopted value for dust opacity. This is especially important in view of recent experimental findings which suggest that our previously adopted values for far-infrared dust opacity, extrapolated from shorter wavelengths, may be systematically biased. These experimental results suggest that dust opacity is higher than previously thought and, crucially, dependent on temperature: as temperature increases, the opacity of dust analogues tends to increase and its dependence on wavelength becomes shallower. It is therefore essential to understand how this new understanding on dust opacity changes our interpretation of dust emission SEDs.

We are working on quantifying the effect of temperature-dependent dust opacity in SED fits results. This effect has been identified as a possible source of bias in fit results for some time, but has not yet been studied quantitatively. We use optical data on several candidate dust materials, collected by multiple laboratories, to model dust opacity as a function of wavelength and temperature. We then produce a grid of synthetic galaxy SEDs for various temperature distributions and redshifts. By fitting these synthetic observations with a fixed-opacity model we can then recover the bias in the fit results. We find that the dust masses recovered by the fit can be underestimated or overestimated depending on the target's temperature and redshift, as well as the choice of photometric bands.

Finally, we exploring the relevance of our findings for the determination of dust abundances in the early Universe, where dust mass estimates pose a challenge to dust formation models (the so-called "dust budget crisis").

Dust polarization as a tool to study magnetic fields in the core of the starburst galaxy NGC253

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The interstellar space contains a complex mixture of gas and dust, along with cosmic rays and magnetic fields (B-fields), which exert a significant impact on the physical characteristics of the interstellar medium (ISM). Each of these components emits electromagnetic radiation across a broad range of wavelengths, making it essential to compare different tracers to gain a comprehensive understanding of their influence on the structure and evolution of galaxies. B-fields, which cannot be directly detected, are especially challenging to study, but they play a crucial role on different spatial scales, such as affecting the global rotation of gas, driving gas mass inflows into galactic cores, and regulating the collapse of molecular clouds where star formation occurs.

The observation of cosmic dust polarized emission is one of the most effective tools to study B-fields in the cold phase environment of external galaxies. This method relies on the fact that elongated dust grains can be oriented with their major axis perpendicular to the interstellar magnetic field lines by paramagnetic or radiative torque alignment and emit thermal linearly polarized radiation in the FIR and millimeter wavelength range with their E-vector pointing perpendicular to the field. From the polarization angle of the measured radiation rotated by 90° it is possible to infer the B-field lines in the plane of the sky. Unlike the traditionally used synchrotron radio polarimetric observations, dust polarized emissions can map the B-field characteristics in the cold, dense areas of the ISM in galaxies, such as molecular clouds, where star formation occurs. To understand the crucial role of B-fields in star formation processes, investigating dust FIR and millimeter polarimetric emissions is a critical step.

We present the analysis of ALMA polarization observations in band 7 (~ 350 GHz) of the central regions of the galaxy NGC253, a well studied nearby starburst galaxy, with resolution up to 8 pc in physical scale. This galaxy's central area exhibits a complex structure characterized by 14 dense clumps of molecular gas, likely hosting young super starclusters. Starting from the Band 7 observations we computed a detailed parsec-scale map of dust-traced B-field and polarization fraction distribution in the galaxy, exploring their relationship with the super starclusters and the several structures in the molecular gas observed in the region. The findings highlight a tight correlation between local minima of polarization fraction structures of the galaxy and the presence of super starclusters, alongside a more general anti-correlation between dust column density and polarization fraction. One of the physical origins which could explain these correlations is the disruption of large dust grains in dense regions of the ISM where the star formation is high, with consequent lowering of fractional polarization.

Mapping dust extinction curve variation in 3D

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Despite the vital importance of interstellar dust to many areas of astronomy, its composition and properties are highly uncertain. The dust extinction curve (the relation of extinction vs. wavelength) depends on both the grain-size distribution and the chemistry of the dust, and is therefore a probe of dust properties. The dust extinction curve is typically characterized by $R(V) \equiv A(V)/E(B-V)$, with higher $R(V)$ indicating a flatter extinction curve. Using low-resolution optical "XP" spectra from the *Gaia* space telescope, we have measured $R(V)$ for 130 million stars in the Milky Way and Magellanic Clouds, nearly two orders of magnitude more than have previously been available.

We present a three-dimensional map of interstellar dust $R(V)$ within a few kiloparsecs of the Sun, as well as two-dimensional maps of $R(V)$ in the Magellanic Clouds. We find relatively high $R(V)$ in the diffuse interstellar medium (ISM), with $R(V)$ first decreasing as density increases into the translucent ISM, before increasing again in the dense cores of clouds. This suggests that at intermediate densities in the ISM, accretion from the gas phase is the dominant mechanism for grain growth, while coagulation comes to dominate at higher densities. We find a strong correlation between star formation and high $R(V)$ – two possible explanations are the cycling of large grains formed by coagulation in dense molecular clouds back into the diffuse ISM, and preferential destruction of large grains by supernova shocks.

Such a large volume of precise $R(V)$ measurements will both place constraints on theories of grain chemistry and evolution, and allow the development of "next-generation" dust extinction maps that take extinction-curve variation into account, and which therefore deliver more accurate observational corrections for the effects of dust.

The dust population in PDRs: impact on PDR structure and observable gas tracers

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Dust grains play a key role in the physics and chemistry of the Interstellar Medium. They heat the gas through the photo-electric effect, and therefore influence the thermal structure of the ISM. They absorb the UV radiation of stars that dissociate molecules. They also act as catalysts of the formation of molecules like H_2. All these processes depend on the dust population: chemical composition (carboneous, silicates etc.) and size distribution. Multiple dust population models have been proposed (Mathis et al. 1977, Zubko et al. 2004, Draine & Li 2007, Compiegne et al. 2011, Jones et al. 2013). These dust population models propose a various range of grain compositions and size distributions. They have been constrained by dust IR-emission and UV-extinction in the diffuse ISM but, up to now, the impact of these new distributions on the chemistry and the excitation of the gas has never been tested. Our goal is to find a comprehensive model of both, able to explain consistently the gas and grain tracers in various environments.

Our goal is to study the link between the dust population and the thermal and chemical structure of PDRs, traced by gas emission lines. We have updated the treatment of dust physics in the Meudon PDR Code (Le Petit et al. 2006) to allow a wide range of possible dust populations to be used in the model, and refined the treatment of photoelectric effect to account for the effect of grain composition. The Meudon PDR code simulates the physics and chemistry of PDRs, solving the chemistry of hundreds of species, the radiative transfer, the thermal balance and the excitation of main species. With this new version of the code, we compare the THEMIS dust population model (Jones et al 2017) with former models (Mathis et al. 1977, Draine & Li 2007), and its impact on the chemical and thermal structure of various environments : diffuse ISM, dense and highly illuminated PDRs such as the Orion Bar, and less excited PDRs such as the Horsehead Nebula. In particular, for PDRs like the Orion Bar, our models show that gas tracers like CO are highly sensitive to the small grains abundance and to their evolution through the PDR.

The Role of Amorphous Physics in Radio Dust Emission

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Most interstellar dust is known to be composed of amorphous material, not crystalline. Constructing a dust emission model that considers the amorphous properties is imperative to understand dust emission better and extract information on the physical properties of dust from observations.

Some previous studies have proposed a model of interstellar amorphous dust radio emission [1, 2], which applies the two-level systems (TLS) model introduced to explain the universality of the low-temperature dependence of the heat capacity and thermal conductivity of amorphous materials to the optical properties of interstellar dust. It is shown that the amorphous dust radio emission model can explain observed features such as the anti-correlation between the spectral index and dust temperature and the anomalous microwave emission (AME) with a peak around 30 GHz [3, 4]. On the other hand, the TLS model has the following problems. First, the TLS model can explain the temperature dependence of physical quantities in amorphous materials below 1 K but not around 10 K. Second, the assumption in the TLS model that the TLS eigenenergies and transition energies are independent parameters is not self-evident. These two problems indicate there is room for theoretical improvement in the TLS model.

We propose a new amorphous dust emission model adapted from a physical model that extends the TLS model, called a soft potential (SP) model [5, 6], and verify whether the characteristics of amorphous dust emission expected from the TLS model are reasonable. The SP model explains the temperature dependence of the thermal properties of amorphous materials over a wider temperature range than the TLS model by simultaneously considering two effects derived by assuming that the atoms comprising the amorphous material are trapped in a fourth-order potential: the TLS originating from the double-well potential, and the anharmonicity given by higher order terms. In this study, based on the SP model, we have developed a scheme to calculate absorption cross-sections of amorphous dust by solving the ab initio of the interaction between atoms and electric fields in amorphous dust.

We showed that the SP model can reproduce observed trends such as AME and the temperature dependence of the spectral index, like the TLS model. On the other hand, we showed that the absorption coefficient of amorphous dust is not equal between the two models, even when the same physical properties are set. We performed SED fitting for some objects with pronounced AME to validate the model further. We showed that the amorphous dust emission based on the SP model reproduces the observations with comparable or slightly better accuracy than the TLS model. In this presentation, we are going to discuss the impact of applying the SP model and the physical properties of amorphous dust expected from the SP model.

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Aromatics and Aliphatics at Cosmic Dusk as Probed by JWST

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The so-called "unidentified" infrared emission (UIE) features at 3.3, 6.2, 7.7, 8.6, 11.3 and 12.7 μm, commonly attributed to the stretching and bending vibrations of polycyclic aromatic hydrocarbon (PAH) molecules, are ubiquitously seen in a wide variety of astrophysical regions in the Milky Way and nearby galaxies as well as distant galaxies at redshifts $z \geq 4$. The 3.3 and 3.4 μm features which are commonly respectively attributed to aromatic and aliphatic C—H stretches have been used to explore the chemical structure, and therefore then the properties of the environment of the UIE carriers. While the 3.3 and 3.4 μm PAH emission bands are frequently seen in Galactic sources, their detections in extragalactic sources are rare and limited to only several nearby galaxies. We report the serendipitous detections of the 3.3 and 3.4 μm emission bands in over two dozen galaxies at redshift z~0.2-0.5 with JWST NIRCam in the GOODS-S and GOODS-N. The aliphaticity of the emitter is quantitatively derived from the 3.3 and 3.4 μm emission. We found that the aliphaticity does not appear to evolve with redshift, and the aliphaticity exhibits no correlation with the star formation rates (SFRs) and galaxy metallicity.

Optical to Infrared studies of dust extinction revealed by JWST and the implied dust physics

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A precise interstellar dust extinction law is critically important to correctly interpret observations and infer the properties of interstellar dust grains. The ultraviolet (UV) to optical extinction curves of the Milky Way are known to be characterized as a one-parameter function of R_V, however, the precise needs to be updated. Besides, how does it vary with the environment, and can it be applied to the Magellanic Clouds? More importantly, what are the properties of dust grains in different environments?

In this talk, we will introduce our recent works of combining photometric, spectroscopic, and astrometric data to derive high-precision color excess ratios (reddening laws) and extinction ratios (extinction laws) of the Milky Way and the Magellanic Clouds. Based on these results, we adjust the parameters of the R_V-dependent extinction law. The adjusted R_V extinction curves agree with the observations with less than 3% deviations. Further, we investigate the distribution and variation of the R_V-dependent extinction law throughout the Milky Way, especially in molecular clouds.

In addition, we also investigate the infrared extinction curves using JWST data. The reddening and extinction curves of 0.6–5.3 μm are measured with much-improved precision. The potential variations of reddening or extinction curves are also investigated. These results also help us imply the properties of micron-sized dust grains in different environments.

Anharmonic IR Absorption and Emission Spectra of Polycyclic Aromatic Hydrocarbons

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In order to provide a foundation for the analysis of new high-fidelity JWST data, computational tools have been developed at NASA Ames to produce fully anharmonic IR absorption and cascade emission spectra of PAHs. The computational spectra are validated and benchmarked with new and existing laboratory measurements. Gas-phase polycyclic aromatic hydrocarbons (PAHs) are ubiquitous throughout the universe, and their emission dominates the near- and mid-infrared (IR) spectrum of various astronomical sources such as molecular clouds, protoplanetary disks, and galaxies. This emission is used as a tracer for the temperature, density, and radiative characteristics of the local chemical and physical environment. These data are then utilized as input for astrochemical and astrophysical models that are integral to understanding the lifecycle (or evolutionary) dynamics of these sources. Focusing on astrochemistry, PAH molecules provide a rich source of accessible carbon while PAH clustering and stacking provide precursors of carbonaceous dust grains that participate in the subsequent growth of pebbles, boulders, and ultimately planets. Carbon based dust also acts as the medium on which interstellar ices composed of H_2O and CO_2, among other molecules, accumulate. Chemistry within these ices produces new molecules, seeding the chemical complexity that is found in geological features on Earth. This work sets the stage for future implementation of the code as a tool for populating the NASA Ames PAH IR Spectroscopic Database (PAHdb) with anharmonic spectra of vast numbers of PAHs for use in the interpretation of astronomical PAH data from missions such as JWST, Spitzer, ISO, and RST.

The Impact of Dust Dynamics and Grain Properties on Star Formation: Insights from Radiation-Dust-MHD Simulations

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Cosmic dust is integral to the evolution of giant molecular clouds (GMCs) and star formation. Conventional models often overlook the intricate dynamics and variations in dust properties, assuming a constant dust-to-gas ratio (DTG) and canonical Mathis, Rumpl, & Nordsieck grain size distribution (GSD). However, the DTG likely fluctuates locally within star-forming regions and the GSD likely significantly varies across environments. Crucially for star formation, these variations have non-linear impacts on interstellar medium (ISM) thermochemistry, dynamics, and radiative transfer.

In this presentation, I introduce radiation-dust-magnetohydrodynamic (MHD) simulations of star formation within the STARFORGE project, advancing previous models by explicitly modelling the dynamics of a diverse size spectrum of live dust grains. These simulations incorporate radiation, drag, Lorentz forces, and dust heating and cooling. I also investigate how changes in the GSD, while maintaining fixed dynamic range and dust mass, affect star formation.

My findings emphasize the significant impact of the GSD on GMC thermochemistry. Specifically, when increasing grain size at fixed dust mass, the dominant effect is a reduction in opacity. As the maximum grain size increases from 0.1μm to 10μm, photons penetrate deeper through the cloud, heating the gas and reducing star formation efficiency by an order of magnitude. Furthermore, I find that radiation-dust interactions strongly influence the properties of gas surrounding and accreting onto massive stars. As stars exceed a critical mass ($\sim 2 - 5\mathrm{M}_{\odot}$), radiation expels dust, forming $\sim$ 100 AU dust-evacuated zone surrounding by a "dust shell". This leads to a reduction in the DTG by up to 1-2 orders of magnitude within circumstellar environments, consequently impacting the composition of massive stars and their circumstellar discs.

In summary, this presentation highlights the essential role of detailed dust modeling in enhancing our understanding of the processes governing the ISM and star formation.

Bubble-Filament Paradigm of Star Formation and Dust Evolution in Disk Galaxies

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Recent observations of NGC628 and other face-on disk galaxies by *JWST* have revealed outstanding chains of bubbles on spiral arms in those galaxies, which seem to justify "the bubble-filament paradigm" for the formation of molecular clouds and stars studied for our Milky Way Galaxy. This paradigm emphasizes the importance of the formation and evolution of magnetized filamentary molecular clouds on the bubbles in the processes of star formation. Theoretical and observational investigations have provided convincing evidence for the formation of molecular cloud cores by the gravitational fragmentation of filamentary molecular clouds on the bubble. The paradigm self-consistently explains the origins of the stellar initial mass function and the angular momenta of astronomical objects in addition to the other basic properties of star formation process such as the star formation rate and efficiency. On the other hand, *Herschel HiGAL* survey has shown that all the luminous star cluster forming clouds are exclusively identified as hub-filament systems where the central roundish hub region consists of numerous short filamentary clouds. Thus, the formation and evolution of hub-filament systems determines the formation of massive stars and star clusters in our Galaxy. Using these findings, we can create a framework to describe the evolution of dust grains in our Galaxy and other disk galaxies where heavy chemical elements in the halos play important roles.

Simple analytic expressions for the opacity of highly conducting materials

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Infrared spectra have been used to probe the mineral composition of dust in cosmic space. It is commonly accepted that silicate dust is responsible for mid-infrared features. However, pure silicates are much more transparent at near-infrared wavelengths and do not account for the near-infrared emission common to a variety of astronomical objects such as AGB star circumstellar dust, white dwarf circumstellar dust disks, and protoplanetary disks (e.g., Draine & Lee 1984; Reach et al. 2009; Varga et al. 2024). Potential sources of the near-infrared opacity are metallic iron and/or carbon with high refractive indices. However, the opacities of such conducting dust are poorly understood from an analytical standpoint.

In this study, we investigate if the analytical expressions for the opacity of insulating materials (Kataoka et al. 2014) are also applicable to conducting materials with refractive indices much higher than unity. The expressions by Kataoka et al. (2014) are based on Mie calculations and show the opacity can be well approximated by the combination of three distinct closed-form expressions. When the particle size is larger than the wavelength, geometric optics applies, and the optical properties of the grains can be understood by tracing the ray inside the material. Within the geometric optics regime, there are optically thin and optically thick regimes depending on the absorption of incident light within the particles. For conducting particles, we find that the larger refractive indices make the wavelength inside the particles become shorter, causing the particles to enter the geometric optics regime at smaller particle sizes. Therefore, the Rayleigh regime only applies to very limited conditions. Furthermore, we find that because light rays are reflected many times within the sphere due to a higher refractive index, most of the geometric optics regime is characterized by the optically thick regime.

Presentation Title: Carbonaceous dust formation via gaseous CO disproportionation reaction in hydrogen-poor outflows
School: University College London
Student Level: PhD
Presentation Type: Poster Presentation
Authors: Wafaa Omarouayache, Jonathan Rawlings.

Abstract:

Carbonaceous dust grains are most commonly thought to form in relatively cool regions with high hydrogen densities. In these conditions hydrocarbon precursors can form and subsequently polymerise, producing larger aliphatic and aromatic structures - dust grains. Yet how do we observe such efficient dust formation in hotter hydrogen-poor areas (Wolf Rayet stars, Nova outflows, red supergiants) with extreme and opposite conditions?

We propose a gas phase reaction that can produce solid deposits of carbon which can act as the nucleation sites for dust formation.

The CO disproportionation reaction also known as the Boudouard reaction (1) is well studied in terrestrial environments in industry and catalysis but has not yet been considered in astronomical environments.

$$CO_{(g)} + CO_{(g)} \rightarrow C_{(s)} + CO2_{(g)} \qquad (1)$$

Large activation energy barriers (11.6eV) comparable to the CO bond energy (11.2eV) are associated with the Boudouard reaction. To overcome this CO has to be highly vibrationally and electronically excited. These reaction conditions can be achieved through shocked gas.

To model this reaction as the main driver of dust formation we chose a shockwave scenario occurring after a nova outburst. Nova ejecta contains material from inside a white dwarf, a degenerate body that lacks hydrogen. The shock creates high temperatures (>10,000 K) and exposes molecules to UV and optical radiation, allowing for CO to get highly vibrationally and electronically excited.

Our results indicate that it is not only possible to create solid carbon but it is abundant enough to achieve successful dust formation as the fractional abundance of nucleation sites > 2 x 10^{-14} (J. Rawlings & D. Williams 1989)

Experimental study on the effect of filling factor and internal structure of sintered porous materials on their mechanical properties

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Planets are thought to have formed by collisions between planetesimals. For collisions in the strength-dominated regime, the filling factor and tensile strength of planetesimals are important parameters that determine the collision outcome (Jutzi et al., 2010). The filling factor of the planetesimal is considered to have been increased by the sintering process during the thermal evolution (e.g., Gail et al., 2015). The formation of inter-particle necks by sintering changes the mechanical properties of the granular material (Poppe, 2003). Therefore, an understanding of the mechanical properties of sintered porous materials in relation to their internal structure and filling factor is necessary to elucidate the physical phenomena associated with planetesimals and porous primitive bodies. In this study, we prepared sintered samples with different filling factors. We investigated the changes in the mechanical properties of the sintered samples, in particular longitudinal wave velocity and bending strength, with the filling factor.

We used four types of soda-lime glass particles with a softening point of 730℃: monodisperse and spherical glass beads with a median diameter of 94 μm, monodisperse and spherical glass beads with a median diameter of 55 μm, polydisperse and spherical glass beads with a median diameter of 22 μm, and polydisperse and irregularly shaped glass powder with a median diameter of 34 μm. We heated these particles in an oven at 620-650℃ and prepared sintered samples. Electron microscopy images show that heating at temperatures near the melting point of irregularly shaped particles not only forms necks between the particles but also changes the particle morphology by rounding the corners and smoothing the surface. The filling factor, longitudinal wave velocity, and bending strength of these samples were measured.

We show that the longitudinal wave velocity of the sintered glass particles increases in proportion to the filling factor, irrespective of the particle size, particle size distribution, initial internal structure, and particle shape. The increasing trend observed in this study is similar to that observed in the measurement of sintered ice aggregates (Shimaki and Arakawa, 2021) and Greenland snow (Smith, 1965). The bending strength of the sintered samples increases according to two trends. One is a power law increase, which is consistent with the measured tensile strength of sintered ice aggregate (Shimaki and Arakawa, 2021). The other is a sharp increase in a narrow range of the filling factor, which is not observed in sintered ice aggregates. This increase asymptotically approaches the power-law increase with increasing filling factor. The latter increase in strength is mainly due to neck growth between particles, while the former is thought to be due to changes in particles alignment.

Molecular dynamics simulations of rolling motions between two contacting dust monomers

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The first step of planet formation is the dust growth due to collisional sticking. It is considered that the dust is an aggregate composed of monomers, whose size is submicron. The aggregates collisions have been investigated by powder simulations (e.g., Wada et al., 2013; Hasegawa et al., 2021), which calculate the interactions between the monomers in contact when calculating the monomer motion. In the powder simulations, a physical model is used that gives the interactions between the elastic spheres to the monomer interactions (Johnson et al., 1987). However, the physical model assumes elastic spheres and therefore does not include viscous effects. It has been suggested that this viscous effect is due to the molecular motion, and such a microscopic effect is considered to be particularly well represented at submicron sizes (Tanaka et al. 2012). Therefore, the physical model needs to be revised for accurate powder simulations.

We use molecular dynamics (MD) simulations, a method of studying the physical processes of a system by solving for the molecular motion. In the previous Cosmic Dust meeting, we showed the MD simulations of head-on collisions and the normal forces. This presentation will focus on rolling motion. Roling motion significantly affect the collision results since it causes the most energy dissipation in aggregate collisions among four interactions. In the model of rolling motion, there is an important physical parameter called the critical displacement, which gives the threshold of displacement at which the two spheres begin to roll. However, the value of the critical displacement is not yet agreed upon: 0.2 nm theoretically (Dominik & Tielens, 1995), 3.2 nm experimentally (Heim et al., 1999), and 0.8 nm used in powder simulations. This study investigates the value of the critical displacement.

In MD simulations, we treat monomers consisting of 0.1 - 100 million molecules. For initial conditions, two monomers are prepared in contact and given opposite angular velocities of spin rotation about a certain tangential direction to the contact surface. We check that the angular velocity decreases with time due to a resistive torque and quantify the magnitude of the resistive torque by comparing the MD simulations to the model. In particular, we analyze the critical displacement from the magnitude of the resistive torque and show that its magnitude is about 0.2 nm, which is consistent with the value predicted by theory and smaller than the value used in previous powder simulations. This suggests that the monomers are more likely to roll among themselves than in previous studies, indicating that the compressive strength of the aggregates is lower. Therefore, it is conceivable that the dust density could be greater than previously thought, e.g., due to ram pressure due to the low compressive strength. We will present the above results.

A study on the properties of dust in clouds extended in the halo of the radio galaxy Centaurus A

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Centaurus A (Cen A) is the nearest galaxy hosting an active galactic nucleus (AGN), which produces powerful radio and X-ray jets extending to hundreds kpc from the center. At 15 kpc northeast (NE) and 12 kpc southwest (SW) in the halo along the jet from the nucleus of Cen A, dust clouds are detected in the far-infrared (IR) with Herschel, which are accompanied by the Hα emission. The far-ultraviolet (UV) emission extended along the jet, which is apparently associated with the halo clouds, is also detected with GALEX. For both clouds, since the Hα emission is detected, it is suggested that star formation may have been induced through interactions between the AGN jet and the clouds in the halo of Cen A.

In this study, we aim to investigate the properties of the dust in the NE and SW halo clouds and the possibility of jet-induced star formation in those clouds. In order to obtain the emission properties, we have performed dust model fitting to the near- to far-IR spectral energy distributions of Cen A created from the archival data of WISE, Spitzer and Herschel. We have also compared the IR emission properties of the dust clouds with the far-UV emission extended along the jet using the archival data of GALEX/FUV. Moreover, we have performed Paβ narrow-band imaging of the Hα-emitting regions in the halo clouds with the IRSF telescope in South Africa.

As a result, we find that the NE cloud shows significantly higher dust temperature than the SW cloud. We also find that the local far-UV intensities in the NE cloud are significantly higher than those calculated from the far-UV flux originating from the central region of Cen A. These results consistently support that the jet-induced star formation have indeed occurred in the NE halo cloud. On the other hand, for the SW cloud, there is no evidence supporting for the star formation therein; the local far-UV intensities detected in the SW cloud can be explained by scattering of the far-UV flux from the central region by the dust in the SW cloud. The Paβ emission is not detected from either the NE or SW clouds. Based on the dust-scattered far-UV intensities and the upper limits of Paβ/Hα, we derive the constraint on the dust size distribution, which indicates that the dust in the halo cloud may be abundant in the very small grains. Finally, we have found that the PAH emission is associated with both NE and SW halo clouds. The mass abundance ratios of the PAH to the dust for both clouds are significantly lower than that in the central region of Cen A.

In this presentation, we summarize the properties of the halo dust in Cen A obtained in the IR and far-UV observations. We discuss the origins of the halo clouds and their relationship with the jet-induced star formation.

Thermal States of HI gas and Dust properties in The Galactic Halo: Towards Understanding Circum-Galactic Medium and Cosmic Star Formation in The Galaxy

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The star formation rate in our Galaxy has been maintained at the level of several $M_\odot$ yr^{-1} for about 10^{10} yr. However, if star formation continues at the current rate, the current amount of gas in the galactic disk should be depleted in less than 10^9 yr. Recently, large amounts of metal-enriched gas, exceeding $10^{10} M_\odot$, have been observed in the halo. From these observations, it is expected that the gas supply and circulation between the disk and the halo are responsible for long-sustained star formation. The gas transport mechanism from the disk to the halo has been re-examined by Shimoda & Inutsuka (2022). Their detailed theoretical calculations have shown that cosmic ray heating suppresses radiative cooling, allowing the gas to be transported out of the disk over 100 kpc. In contrast, the gas supply mechanism from the halo to the disk, including the thermal condensation process in the halo and the infall process from the halo to the disk, remains to be studied, which is the purpose of this work. This line of work should include the analysis of Intermediate- and High- High-velocity clouds (IVCs / HVCs), which are the HI gas objects in the halo whose origins are still under debate.

On the other hand, a map of the dust-to-HI ratio in the whole sky is recently provided by Hayakawa & Fukui (2024). They show that the metallicity of IVCs/HVCs is universally less than several $Z_\odot$ in our Galaxy. However, the properties of dust grains in the halo are still unknown, so there are many open questions. For example, it is unknown whether dust can survive in hot regions such as Circum-Galactic Medium.

In this study, we analyze the thermal state of the halo gas in detail. We have performed a linear stability analysis of the thermal gas in the halo that is gravitationally stratified and in thermal equilibrium, considering thermal instability, gravitational dynamics, and the effect of cosmic rays. One of our results shows that the lower layer of the halo is thermally and convectively unstable, which may correspond to the mixing layer of multi-phase gases. We also compare the expected condensations in the halo as a result of the present analysis with observations of HVCs/IVCs.

Cosmic very small dust grains as a natural laboratory of mesoscopic physics

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In this presentation, we present a model of interstellar dust emission that incorporates mesoscopic-scale physics.

The number of atoms contained in cosmic very small dust grains (VSGs) ranges from 100 to 10,000 atoms. Therefore, the VSGs belong to the mesoscopic scale --- an intermediate scale between microscopic and macroscopic. At the mesoscopic scale, the finiteness of the grain size brings non-negligible effects on their physical properties. In particular, the models describing properties of bulk materials cannot be applied mainly for the following reasons. 1. The longest wavelength of lattice vibration modes is limited by the grain size. The number of thermal excitation modes becomes a few, making it difficult for VSGs to hold thermal energy by vibration modes, especially at low temperatures [1]. 2. Since VSGs are expected to have irregular shapes, the degeneracy of the energy levels is broken. Furthermore, the VSGs exhibit various shapes, leading to a diverse distribution of energy levels among them.

We have constructed a model describing the thermal and optical properties of graphite VSG [2], which have free electrons, with the above mesoscopic properties taken into account. A method of energy level statistics, devised by Kubo (1962) [3], was applied for the first time to model the thermal properties of the free electrons in cosmic graphite VSGs. It is impossible to ascertain the energy level distribution of individual grains, but since what we observe is emission and absorption by an ensemble of grains in interstellar space, considering their statistical features is sufficient. Furthermore, because VSG's shape distribution is anticipated to take various forms, the energy levels of free electrons around the Fermi level are considered randomly distributed. This allows the graphite VSGs to effectively have a large number of thermal excitation modes even in a cold VSG.

The SED of thermal emission from graphite VSGs calculated using these models predicts that the graphite VSGs not only produce the mid-infrared excess emission but also emit a significant amount of energy in the millimeter and submillimeter wavelengths.

In this presentation, we further apply this model to polycyclic aromatic hydrocarbons (PAHs) and demonstrate their thermal emission SED. Although their absorption cross-section is different from graphite, essentially the same model can be applied since the molecular structure of PAHs is similar to graphite, and possesses free electrons. We will then provide the total SED of thermal emission from carbonaceous grains and silicate by superposing their thermal emission with a size distribution [4], assuming that large carbonaceous grains are graphite and small carbonaceous grains are PAHs. Comparisons between the model prediction and the observed SED of the interstellar dust grains are shown.

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Modelling molecular cloud scattering using dust aggregates

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Mid-Infrared (MIR) observations and scattering models of molecular clouds have shown the existence of micrometer-sized particles in molecular clouds that are responsible for the so-called coreshine. Coreshine has been explained as the scattering of stellar radiation by micrometer-sized particles in molecular cloud cores and is a probe for the largest size population of dust particles in the interstellar medium. Since dust grains stick together to form aggregates of the grains which have inevitably different optical properties than the individual grains, it is important to model the MIR scattering using aggregates of different sizes. Here, we consider a simple spherical geometry of a molecular cloud consisting of dust aggregates, illuminated by an embedded source in order to predict the scattered intensities for different density distributions. Using freely available radiative transfer codes such as radmc3d and SKIRT, we also model the polarised intensities associated with such a model and study the dependence of polarisation in different dust distributions.

PAHs and 2175 Å Extinction Bump at the Cosmic Dawn

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The 2175 Å extinction bump, first detected in 1965, is the most prominent spectroscopic feature of the interstellar extinction curve. Widely seen in the interstellar medium (ISM) of the Milky Way (MW) as well as several nearby galaxies, this bump was recently detected by JWST/NIRSpec in JADES-GS-z6-0, a distant galaxy at $z \approx 6.71$ (Witstok et al. 2023). Although it is generally attributed to carbonaceous dust grains, specifically polycyclic aromatic hydrocarbons (PAHs) or nano-sized graphite, the exact carrier of the bump remains unknown. We calculate the electronic absorption spectra of a large number of PAH molecules by means of TD-DFT and meticulously examine the absorption peaks attributed to $\pi^* \leftarrow \pi$ transitions of each molecule near 220 nm in terms of central wavelength, width, and intensity (Lin et al. 2023). It shows that the absorption bumps tend to peak at slightly longer wavelengths for larger PAH molecules, while their bump widths are randomly distributed around $\gamma = 1.0\ \mu m^{-1}$ regardless of size. By assigning proper weights for different molecules, both the Galactic 2175 Å extinction bump and that at $z = 6.71$ can be closely explained by mixture of PAH molecules. The derived total PAH abundance in JADES-GS-z6-0 is $\eta_{PAH} = 2.34 \times 10^{16}$ cm^{-2}, which is about ten times smaller than that of the MW. On the other hand, JADES-GS-z6-0 appears to favor larger PAHs (with a mean size of $N_{carbon} = 53$) compared to those in the MW ($N_{carbon} = 39$), indicating that active star formation at Cosmic Dawn may have preferentially destroyed smaller PAHs.

Anomalous Interstellar Extinction Curves: HD 93222 and HD 29647

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Cardelli, Clayton, & Mathis (1989; CCM) proposed an analytical formula which only involves one parameter—R_V, the total to selective extinction ratio – to parametrize the interstellar extinction curves from the near infrared (IR) to the far ultraviolet (UV). While the CCM parametrization satisfactorily approximates most of the observed extinction curves in the Milky Way, a number of interstellar lines of sight exhibit anomalous extinction curves which appreciably deviate from the CCM representation. We perform a systematic investigation of the anomalous extinction curves, aiming at gaining insight into the properties of the dust responsible for the unusual extinction curve and its relation to the physical and chemical conditions of the region where the extinction curve is found.

Here we report our first results on the sightlines toward HD93222 situated in the southern region of the Carina Nebula, and HD29647 in the Taurus dark cloud. We employ the IUE data and the Kurucz stellar atmosphere model to determine their extinction curves. It is found that for both lines of sight the extinction curves are peculiar. HD 93222 has a large R_V of 4.76, characteristic of dense regions, while its extinction curve shows a sharp 2175 Å bump and a steep far-UV rise, which are typical of diffuse regions with $R_V < 3.1$. In contrast, HD 29647, a highly reddened late B HgMn star, has a relatively smaller R_V of 3.6, but its extinction curve exhibits a weak hump which is more typical of dense regions with a larger R_V. While the extinction curves of both HD 93222 and HD 29647 differ substantially from what are expected from the CCM parametrization, they can be closely explained by mixtures of silicate and graphite grains or silicate core-carbon mantle grains combined with nano-sized carbon dust.

Extinction Map Construction and Extinction Law Calculation of M31 and M33

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Interstellar extinction refers to the absorption and scattering of starlight by dust. The multi-band extinction laws are crucial to recover the intrinsic energy distribution of celestial objects and infer the characteristics of interstellar dust. Meanwhile, extinction maps of galaxies contribute to the dust distribution in galaxies and the structure of galaxies and are essential tools to study the stellar population and the star formation history in galaxies.

The current studies of extinction in nearby galaxies are limited to a few galaxies. As a result, there is large uncertainty about the nature and dust distribution, stellar population, and star formation history of nearby galaxies. By introducing the dust model to simulate the effect of dust on stellar radiation innovatively, we: (1) calculate the multiband extinction laws toward more sight lines in M31, M33, and other nearby galaxies with blue supergiants as extinction tracers, and analyze the dust properties in different interstellar environments; (2) construct dust extinction maps of M31 and M33 with member stars as tracers, and analyze the dust distribution in different galaxies; (3) predict the multiband extinction toward different sight lines in nearby galaxies by combining the obtained extinction maps and extinction laws and provide extinction corrections for the observation of the Chinese Survey Space Telescope (CSST) and related scientific objectives.

Infrared dust extinction law of the Milky Way with JWST NIRSpec

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Although infrared (IR) extinction is much weaker than optical extinction, accurate infrared extinction is essential for high-precision distance measurement and detection of the properties of dust grains. In contrast to the optical extinction law, the IR extinction law is not well understood and remains controversial. For example, whether the near-IR extinction curve of 0.9–3 μm can be approximately characterized by a general power-law $A_\lambda \propto \lambda^{-\alpha}$, and how the power-law index varies with sight lines or the optical extinction.

In this talk, we will present our recent work on the 0.6–5.3 μm interstellar dust extinction law based on the 993 prism/CLEAR spectra from the James Webb Space Telescope (JWST). We propose a pair method to obtain the reddening curves based only on JWST observed spectra and find that the infrared 1.0–5.3 μm reddening curves agree with the power law $A_\lambda \propto \lambda^{-\alpha}$ well. We determine an average value of $\alpha = 1.98 \pm 0.15$, which is consistent with the average value of the Galaxy. We find that α may be variable and independent of R_V. With the derived α, we convert the reddening curves into the extinction curves and establish the nonparameterized α-dependent extinction curves in the wavelength range of 0.6–5.3 μm. At λ<1μm, the derived extinction law is not well described by the parameterized power-law-type curve. Our nonparameterized α-dependent extinction curves are suitable for the extinction correction of JWST-based photometry and spectra measurements at 0.6–5.3 μm. With more results from different regions, it will help to study dust growth in dense environments.