Il Colle di Galileo

Illuminating the Dusty Universe: A Tribute to the Work of Bruce Draine

Arcetri, October 10 – November 3, 2023

Organisers:
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Abstract. From catalyzing the formation of molecules, to building up planets, obscuring stellar light and tracing cosmic star formation rates, dust has an outsized impact on the astrophysics and observational properties of the Universe. Few have contributed more to illuminating our own understanding of the dusty universe than Prof. Bruce Draine of Princeton University. To celebrate the vision of Prof. Draine and assess our current view of astrophysical dust from different perspectives, including laboratory astrophysics, meteoritics, astrochemistry, optics and observational astronomy across the electromagnetic spectrum, 90 scientists from 18 countries spanning five continents gathered last autumn at the Garbasso Institute. The conference was an opportunity to highlight Prof. Draine's past and ongoing work in this field as well as the enduring collaborations and friendships formed along the way. Arcetri has hosted Prof. Draine many times, over a period of almost 40 years, and he has spent many sabbaticals here, also writing part of his textbook "Physics of the Interstellar and Intergalactic Medium."

Conference logo. Image: Roberto Baglioni (University of Florence), Leslie Hunt (INAF-Arcetri Observatory), Spitzer Infrared Array Camera.

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Selected conference highlights

Dust in the Solar System

The importance of dust begins in the Solar System, where samples can be collected and directly studied in the labs. Primitive extraterrestrial materials, such as meteorites, interplanetary dust particles (IDPs), returned asteroidal and cometary samples, contain preserved dust grains from our protoplanetary disk. A study presented by Prof. Larry Nittler (Arizona State University, USA) suggested the presence of presolar organic grains in the Ryugu meteorite. Astrochemical analysis of primitive Solar-System rocks has also revealed pre-biotic molecules, shown in the talk by Dr. Paola Caselli (Max Planck Institute for Extraterrestrial Physics, Garching, Germany).

Dust, Clouds, and Planet Formation

Dust is central to planet formation: There are currently (10/4/2024) 5,602 confirmed extrasolar planets found around 4,299 stars, with hundreds of planetary systems with more than one planet detected. Many of these planets lie within the debris disks surrounding the central star, where the coagulation of dust grains forms the initial planetesimals. Because the temperatures are so cold, the dust grains are enveloped in an icy mantle that stores molecules for the subsequent stages of planet formation (Draine 2003). Several studies of astrochemistry in debris disks were presented at the conference, including detections of micron-sized grains in dense clouds by JWST (Dartois, Noble, Caselli et al. 2024), and the JWST detection of acetylene, methanol, complex organic molecules, water vapor and other molecules, as described by Dr. Ewine van Dishoeck (Leiden Observatory, Netherlands).

Dust in Galaxies

Since the IRAS satellite was launched in the 1980's, we have known that dust emission can dominate the spectral energy distribution (SED) of galaxies. The SED captures important diagnostics for how grains are heated, their dust size distribution and their distribution within a galaxy. As shown by Prof. Daniela Calzetti (Univ. Massachusetts, Amherst, USA), models are very successful at reproducing dust SEDs of galaxies and separating different grain populations. With the launch of JWST, it is now possible to image warm dust emission at parsec scales as shown in the talk by Dr. Francesco Belfiore (INAF-Osservatorio di Arcetri, Florence), where it was shown that emission of Polycyclic Aromatic Hydrocarbons in the mid-infrared is a sensitive probe of the overall interstellar medium (ISM) in galaxies (Lee et al. 2023).

The Optics of Dust

Although dust grains are frequently modelled as spheres, their shape is much more complicated. In fact, IDPs from comets are "fluffy" grains, indicative of high porosity. On the other hand, interstellar dust grains must be good polarizers of light, so possibly tending toward spherical shapes, rather than fluffy conglomerates. Dr. Bruce Draine presented results of a new approach (see Draine & Hensley 2021a, 2021b) that constrains dust grain shape in the ISM by assessing the polarization capacity of a given grain. Results suggest that ISM grains tend to be more compact than fluffy (with high porosity), because they have a greater capability to polarize radiation, consistent with observations.

Dust Grain Formation, Growth, and Destruction

Dust grains are formed in the winds of evolved stars (Asymptotic Giant Branch) and the ejecta of supernovae (SNe), but also through grain accretion in dense clouds in the ISM. They can be destroyed by shocks from SNe, but also through grain shattering, as illustrated in the talk by Dr. Hiroyuki Hirashita (ASIAA, Taiwan, Taipei). Dr. Caleb Choban (Indiana University, Bloomington, USA) presented new state-of-the-art models of this lifecycle that are consistent with the wide observed range of elemental depletion patterns onto grains, the dust-to-metals ratio, and predict the conditions necessary for the transition from "stardust" to grain accretion in the ISM (Choban et al. 2024).

Dust Through Cosmic Time

Most of the metals (elements heavier than Helium) produced by stars from the beginning of the Universe are found in neutral gas; but the amount of metals residing in dust grains needs to be accounted for. Prof. Chris Howk (Univ. of Notre Dame, Indiana, USA) presented new results that showed that a long-standing problem in "missing metals" over cosmic time is, in truth, an artefact of methodology. Dust content over cosmic time is closely linked with the rise and fall of metals and star formation.

Acknowledgements

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Figure 1. Group photo in front of the Garbasso building, Thursday 2 November 2023.