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The large and the small of interstellar dust

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Dust is an important component of the interstellar medium of galaxies. Dust dominates the extinction, hence also radiative transfer, of non-ionizing radiation and therefore the optical to sub-millimeter appearance of galaxies. The high dust extinction for energetic UV photons – associated with molecular clouds – also allows molecules to survive. Moreover, grain surfaces provide a catalytic agent for the drive towards molecular complexity in these environments. Small grains also play a major role in the energy balance of interstellar gas through the photoelectric effect, so they control the phase structure of the interstellar medium. Eventually, these small dust grains partake in the process of star and planet formation. In particular, this dust coagulates into larger "dust balls" and eventually cometesimals and planetesimals in the disks around young stellar objects in the first steps towards the formation of a new planetary system. It is clear that many of the key processes in the interstellar medium involve dust and, conversely, that the characteristics and physical properties of dust are key to our understanding of the Universe.

The presence of interstellar dust grains was first surmised from their extinction effects on starlight (Trumpler 1930), and for much of the last century most of our information on interstellar dust was derived from extinction studies supplemented by a smither of scattering and polarization data. Really what this data probed was the size distribution of interstellar dust and during the sixties and seventies – thanks to the opening up of the UV window by space-based observations – these studies culminated in the influential Mathis et al. (1977) dust model with steep (index –3.5) powerlaw grain size distributions ranging from 100 Å to 3000 Å. The field sort of stagnated at this point. Admittedly, at about any astronomical meeting in the next decade, there was much discussion on the composition, origin, and evolution of interstellar dust – aspects that were not well-constrained by the observations – but that was mainly driven by the force of personalities rather than by new developments.

In hindsight, this started to change dramatically in the late seventies, driven by the advent of infrared detector technology, which in many ways provided a new view of the dusty Universe. Some of this reflected the rise of infrared absorption spectroscopy as a very powerful way of probing the composition of solid compounds. Studies of infrared emission spectra, though, provided a much more dramatic revolution in our understanding of interstellar dust. In particular, airborne observations revealed that broad emission features dominate the mid-infrared spectra of many luminous objects. Subsequently, observations with the InfraRed Astronomical Satellite showed that widespread mid-infrared emission is a general characteristic of the diffuse interstellar medium. In a seminal paper in the mid-eighties, Kris Sellgren (1984) observed mid-infrared emission far from the illuminating stars in reflection nebulae and realized that it had to imply the presence of a ubiquitous and abundant family of small (50 C-atom) species that, because of their limited heat capacity, are transiently heated after absorption of a single ultraviolet photon and radiate the excess energy in mid-infrared while they are hot. Subsequently, these species were spectroscopically identified as large, polycyclic aromatic hydrocarbon molecules (Léger & Puget 1984; Allamandola et al. 1985).

The paper "Interstellar dust models for extinction and emission" by Désert, Boulanger, and Puget for the first time connected these two separate views of interstellar dust in a single model that explained the extinction characteristics and the infrared emission spectra of interstellar dust in an internally consistent way. Indeed, this paper provides a clear overview of the essential observational aspects that had to be part of any successful model. In that way, it focused on the overarching agreements rather than on the nitty-gritty differences that had bogged down previous discussions of synthesizing unified dust models. Also, in a way, the authors heralded the arrival of a new breed of young pundits to whom infrared astronomy held the key to the Universe and who were ready to storm the dusty towers of astronomical learning. As an aside, it also coined the terms "very small grains" and "big grains" that have now become standard in any astronomer's lexicon. Progress hardly stopped there. Observations with the European Infrared Space Observatory in the mid-nineties have revealed the incredible richness of the mid-infrared emission spectrum, while NASA's Spitzer Space Telescope subsequently showed the ubiquity of these emission components in sources near and far out to redshifts of ~3. These data have taught us much about the detailed characteristics of these dust components. Most important, we have learned that polycyclic aromatic hydrocarbon molecules and very small grains dominate the mid-infrared emission of the Universe, and I expect that the next space missions, the James Webb Space Telescope and SPICA, will reveal that they dominate the spectra of the first galaxies in the Universe.

Désert, Boulanger, and Puget realized that the extinction studies could be summarized by identifying three independent dust components responsible for the visible and near-ultraviolet linear, the 2175 Å bump, and the nonlinear far-ultraviolet rise. Similarly, the infrared emission spectrum contains three independent components: the mid-infrared emission features, the 25 and 60 μm cirrus emission due to fluctuating grains, and the far-infrared emission due to large grains in radiative equilibrium with the radiation field. They then linked the extinction and emission components – using laboratory data and common sense as a guide – and "Voilà!", a new and very heuristic dust model was born. Thus, the lauded paper presented a very elegant and simple model and identified a few, but essential, parameters. In that way, observers could translate their observations into two key parameters – the abundances of polycyclic aromatic hydrocarbon molecules and very small grains relative to that of big grains – and that allowed comparison of data from a wide variety of regions in a coherent and astrophysically relevant way. It is still being used that way. I think this key aspect explains some of the popularity of this paper over the years.

All of these points make this paper one of my most favored articles. The community agrees with this assessment: this paper continues to be widely cited some 20 years after its publication, and rightfully so.

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