Dust Grain Alignment in the Interstellar Medium

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The first observations of interstellar polarization at visible wavelengths over 60 years ago were quickly attributed to the net alignment of irregular dust grains with local magnetic fields. This mechanism provides a method to measure the topology and strength of the magnetic field and to probe the physical characteristics of the dust (e.g., material, size, and shape). However, to do so with confidence, the physics and variability of the alignment mechanism(s) must be quantitatively understood. The description of the physical alignment mechanism has a long history with key contributions spanning decades; the last 15 years have seen major advances in both the theoretical and observational understanding of the problem. For example, it is now clear that the canonical process of paramagnetic relaxation, in which grain rotational components perpendicular to the magnetic field are damped out, is inadequate to align grains on the necessary timescales (compared to damping via collisions) for typical interstellar medium conditions. However, the more modern theory of radiative alignment has been more successful; in this theory grains are aligned with respect to the magnetic field via photon-grain interactions that impart the necessary torques to the grains' rotation axes.

Here we highlight key observational tests of these alignment mechanisms, especially those involving spectropolarimetry of both dust extinction at near-optical wavelengths and dust emission at far-infrared through millimeter wavelengths. Observations in both these regimes can place limits on such grain aspects as their size and temperature. To date, most observations of the polarized emission have been in the densest regions of the interstellar medium where interpretation in terms of grain alignment models is complicated by regions containing embedded stars and a wide range of temperatures. Additionally, direct comparison of the optical extinction polarization ($A_V \lesssim 10$ magnitudes) with dust emission polarization ($A_V \gtrsim 25$ magnitudes) has not been possible. We briefly review future observations with the increased sensitivity and spectral coverage in the far-infrared which may reach much lower extinction levels and thus allow more definitive tests of grain alignment models.