Towards an Understanding of Dust Grain Alignment in the Interstellar Medium

John E. Vaillancourt and B-G Andersson; SOFIA Science Center, Universities Space Research Association, NASA Ames Research Center; jvaillancourt@sofia.usra.edu

The polarization of optical/infrared light in the interstellar medium is the result of dust grains that are aligned with magnetic fields. The aspherical grains are responsible for dichroic extinction of background starlight at ultraviolet, optical, and infrared wavelengths as well as thermal emission at far-infrared through millimeter wavelengths. These polarization measurements are used to study the structure of interstellar magnetic fields, the physical properties of the dust, and the interactions between the magnetic-fields and grains. Observations spanning wavelengths from the ultraviolet to millimeter have the potential to expand our knowledge of the alignment mechanism, dust composition and size distribution, three-dimensional molecular cloud structure (i.e., temperature, density, magnetic-field strength and orientation), and foregrounds to the cosmic microwave background (CMB).

Magnetic fields are ubiquitous in astrophysics and are believed to have an influence on structures of all sizes, from galaxies to planets. For example, whether large-scale fields significantly influence star-formation or whether turbulence plays a stronger role is currently a hotly debated question. The relative strength of these two mechanisms can be measured by mapping magnetic fields using polarization and applying the Chandrasekhar-Fermi method. Also, polarization is currently being used to study the dust and magnetic environments around YSOs, early in the evolution of the protostar and proto-planetary disk. Polarization as revealed via grain alignment is one of the few observational techniques for studying these phenomena. Doing so requires an observationally supported grain alignment theory to link the polarization observations to the magnetic fields. Without such a model in place, the interpretation of ISM magnetic field observations using polarimetry remains highly uncertain.

The "textbook" physical mechanism by which grain alignment occurs is "paramagnetic dissipation", including important updates incorporated over several decades. However, recent theoretical and observational results cast serious doubt on the ability of this mechanism to provide the necessary alignment, to do so on timescales faster than the alignment is disturbed by any number of damping mechanisms. A new theoretical paradigm has emerged in which the interaction of photons with dust provides the necessary torques to align the grains the magnetic field. This radiative alignment torque (RAT) model makes a number of observational predictions, some of which it has successfully passed and others which still require further testing. In the near-term our goal should be identifying and carrying-out the remainder of these tests in order to more deeply probe the underlying assumptions and physics within the RAT model.

Longer-term goals should be to expand both the RAT model and observational tests to different environments within the ISM. Current observational tests focus on the diffuse ISM ($A_V \sim 5$) but RAT also makes predictions for denser clouds. The model is only just beginning to incorporate the influence of individual stars/clusters embedded in molecular clouds. Preliminary tests in such clouds have been carried out at FIR-MM wavelengths but more precise tests require increased better spatial and spectral resolution as well as model refinements. For example, the role of plasma damping and far-infrared emission damping on the rotation rate of the grains has not been fully explored.

Once a well-tested grain alignment model is in place we can see our way forward to use it for other key studies. A non-exhaustive list would include:

- Removal of CMB foregrounds typically involves extrapolation of the measured foreground into a frequency band relevant to the CMB. The behavior of Galactic dust polarization in these bands is currently unclear; extraction of the polarized CMB and subsequent study of cosmological B-modes will benefit from a better understanding of grain alignment.
- Magnetic field studies via polarization in the ISM suffer from line-of-sight integration that limits the production of full three 3-D magnetic field maps. However, a grain alignment model, along with ancillary observations such as extinction mapping and/or spectral energy distributions, can partially break this degeneracy. This can also allow for improved studies of magnetic field strength and turbulence via the Chandrasekhar-Fermi method.
- The wavelength dependence of interstellar polarization (from both optical extinction and far-infrared emission) to constrain the grain-size distribution in the ISM. This could address questions such as: Is grain growth observed in denser regions? Are there size variations with temperature or radiation field? Since the RAT model depends on the radiation field one may also be able to strength and color of the radiation field in different environments.