Laboratory Experiments on Rotation of the Analogs of Interstellar Dust Grains by Radiation Pressure;

Investigators: P.I.:Dr M.Abbas C.I. D. Tankosic Collaborators: Dr. J. Spann, Dr. P.Craven, E.West, R. Hoover

ROTATION OF INTERSTELLAR DUST GTAINS

- Surprising discovery of the polarization of starlight (Hall, 1949; Hall & Miskell, 1949; Hiltner, 1949).
- Physical and dynamical properties of interstellar dust grains were considered to be the primary source of the observed phenomenon. The selective extinction properties of dust grains determined by their size, configuration, and orientation were recognized to be responsible for the polarization.
- The first explanations of the observed polarizations based on alignment of rotating elongated interstellar dust grains were provided by Spitzer & Schatzman (1949) and Spitzer and Tukey (1949). The relationship between the existence of aligned dust grains and the polarization of starlight was concluded on the basis of a correlation in the degree of polarization with interstellar extinction.
- Polarization by the interstellar dust grains requires a suitable mechanism for rotation of non-spherical dust grains to sufficiently high speeds, and some process for alignment of the major axis of the grains along the Galactic magnetic field or with respect to some preferred direction.
- Understanding the processes and the mechanisms involved in the interstellar grain rotations and alignments is of great interest as it would provide a valuable and independent means of determining the morphology of the Galactic magnetic fields from observations of the polarization of starlight .

Rotation Mechanisms

Numerous processes capable of exerting rotational torques on interstellar grains have been proposed

(a) Collisional processes: These include: (i) *Thermal rotation* of grains induced by random collisions with interstellar gas atoms, as originally considered by Davis & Greenstein (1951). (ii) *Suprathermal rotations* induced by collision with the ambient hydrogen gas with formation and ejection of H_2 from non-spherical and irregular surface features of the grains, as considered by Purcell (1979).

(b) Radiation pressure induced torques:

(i) Torques due to radiation pressure on grains by radiation from the sun or the interstellar radiation field has been considered as an effective mechanism for spinning dust grains to high speeds (e. g., Paddack, 1969, 1975; Harwit, 1970; Dohnanyi, 1978; Misconi, 1993).

(ii) A detailed theory of suprathermal spin-up and alignment of interstellar dust grains by radiative torques induced by anisotropic starlight has been presented by Draine and Weingartner (1996, 1997) and Weingartner and Draine (2003).

Alignment Mechanisms

- **Davis-Greenstein Mechanism:** Involves paramagnetic dissipation in the grains and tends to ends to drive a grain to rotate along its principal axis of maximum moment of inertia, which then approaches alignment along the interstellar magnetic field (Davis and Greenstein, 1951) .
- **Direct Grain Alignment by Radiation:** Every photon carries an intrinsic angular momentum $h/2\pi$ (where h is Planck's constant) that makes the incident light an effective carrier of angular momentum (Harwit, 1970).
- **Charged Dust Grains**: The angular momentum of rotating charged charged dust grains would lead he the grains to precess about the magnetic field on a time scale less than the time scale of the D-G mechanism (Martin, 1971)
- **Barnett Dissipation:** Arises from the Barnett Effect that refers to a paramagnetic/ferromagnetic body rotating in a field-free medium spontaneously developing a magnetic moment along the axis of its rotation. The rotating body decreases its kinetic energy, while keeping its angular momentum constant, with some of the angular momentum taken up by the unpaired of electrons or nuclei in the grains (Landau and Lifshits, 1960; Dolginov and Mytrophanov, 1976; Purcell, 1979; Lazarian and Draine, 2000)
- **Viscoelastic Dissipation**: Arises from dissipation due to periodic alternating mechanical stresses by centrifugal (Purcell, 1979).

Experimental Setup for Rotation Measurements

- ***Power supplies***: Computer controlled electrical power supplies for the electrodes to provide AC voltage (V_{ac} ~ 100-2000V, at f_{ac} ~ 10-1000 Hz), DC voltage (V_{dc} ~ 0.01 to 100 V), and a high DC voltage (V_h ~ 0-1000V).
- ***Electrodynamic balance***: Top and bottom electrodes, and a ring electrode, of hemispherical configuration enclosed in a chamber with appropriate viewing ports.

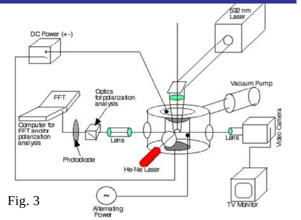


Fig. 3

- ***Particle injector*** : A device to inject an inductively charged particle (positive or negative) of known composition and density in the balance through a suitable port at the top (Spann et al., 2002 .

Particle imaging system: A He-Ne laser and an optical system to project a magnified image of the levitated particle on a monitor.

Experimental Results on Grain Rotations

Fig. 6. Variations in the rotation rates of a 3.9 μm SiC particle as a function of pressure.

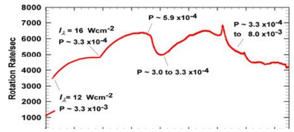
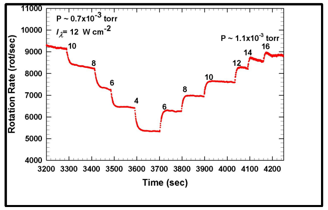


Fig. 7. Variations in the rotation rates of a x.x9 μm SiC particle as a function of radiation intensity.



Experimental Results on Grain Rotations

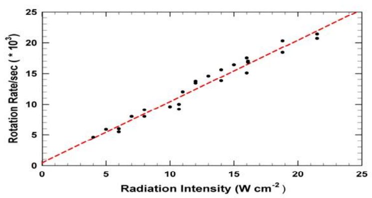


Fig. 8. Plot of the rotation rate of a 0.17 μm radius particle as a function of radiation intensity. The dotted line represents a linear fit to the observed data and permits evaluation of the torque correction factor C_{FT} as a measure of the atmospheric drag.

Experimental Results on Grain Rotations

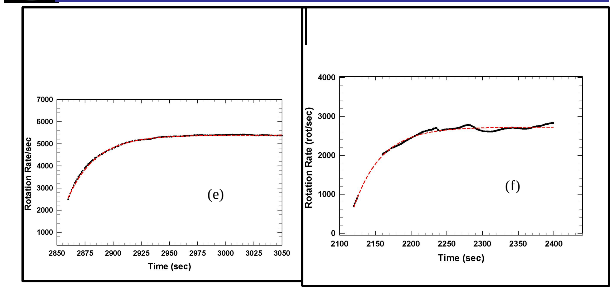


Fig. 8e-f. Plots of the rotation rates (dots) for SiC particles measured with (e) r_d = 3.3 μm, P=1.2x10^{-3} torr, I= 8 Wcm^{-2} and (f) r_d =8.25μm, P=4.9x10^{-4} torr, I= 4 Wcm^{-2}. The dashed line shows the calculated model values using the retrieving the rotational parameters with a, b, ω_{ss}, C_{FT}, , and r_{ma}.

Summary and Conclusions

•First laboratory measurements of rotation of the analogs of interstellar dust grains induced by radiative torques have been made

• The measurements were made on irregularly shaped SiC particles particles of ~ 0.17 to 8.2 μm effective radii levitated in an electrodynamic balance and illuminated with laser light at a wavelength of 5320 Å, at pressures of ~ 10^{-3} to 10^{-5} torr.

•The rotation rates with radiation intensities of ~ 4-30 Wcm^{-2} were observed in the range of 1,000-22,000 rot/sec.

•The grain rotation rates were observed to follow the expected functional relationships, being directly proportional to the incident radiation intensities and inversely proportional to the drag represented by the ambient pressure.

•Average values of the effective torque efficiency (Q_T), the torque correction factor *(C_{FT}) to* the atmospheric drag torque Γ_D, and effective moment arm ration or the asymmetry factor representing the irregular and non-spherical configuration of the particles were retrieved as a function of the Knudsen number from rotational measurements on SiC particles of ~ 0.2 to 8.2 μm radii.
The time scale for the Barnett effect for alignment of the dust grains along the Earth's magnetic field (~ 0.6 G) is calculated to be many years and may not be observed in the laboratory. However, the precession time scale arising due to the Barnett torque representing coupling between the Barnett magnetic moment of the spinning grains with an external magnetic field is much shorter, being ~ 2- 40 minutes and was observed in several cases as a low frequency modulation of the rotational spectrum.
The alignment time scales due to the Davis-Greenstein mechanism requiring paramagnetic dissipation, as well as the mechanism based on the magnetic moment due to charges on spinning grains are too long to be observed in the laboratory. However, the Davis-Greenstein mechanism could be observed in the laboratory by introducing an external magnetic field of ~ 20 – 100 G at the trap center, on time scales ~ a few seconds or minutes.

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