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

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### Experimental Setup for Rotation Measurements

- **Power supply:** Computer controlled electrical power supply for the electrodes to provide DC voltage ($V_{dc} = 100-2000$ V), at $f = 10-1000$ Hz, DC voltage ($V_{dc} = 0-1000$ V), and a high DC voltage ($V_{dc} = 800$ V).
- **Electrodynamic Balance:** Top and bottom electrodes, and a ring electrode, of hemispherical configuration enclosed in a chamber with appropriate viewing ports.
- **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

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Rotation Rate (°/s)</th>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
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<tr>
<td>10</td>
<td>5</td>
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<td>20</td>
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<td>50</td>
<td>25</td>
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<td>60</td>
<td>30</td>
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### Summary and Conclusions

- The measurements were made on irregularly shaped SiC particles of $0.17$ to $8.2$ μm effective radii levitated in an electrodynamic balance and illuminated with a laser light at a wavelength of $5320$ Å, at pressures of $10^{-4}$ to $10^{-8}$ torr.
- The rotation rates with radiation intensities of $4-30$ W cm$^{-2}$ 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 radiation intensities and inversely proportional to the drag represented by the ambient pressure.
- Average values of the effective torque efficiency ($Q_{\nu}$), the torque correction factor ($C_{p}$), and the atmospheric drag ($D_{a}$) were calculated to be many years and may not be observed in the laboratory. However, the precision 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.

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### Rotation Mechanisms

#### (i) Thermal rotation of grains: Inertial rotation of grains heated by radiation.

#### (ii) Radiative pressure induced torques:

- Torques due to radiation pressure on grains by radiation from the sun or the interstellar radiation field. The radiation pressure results in a net force on the grains, causing them to rotate.
- The net force can be given by the radiation torque $\tau_{rad} = \frac{2\pi}{3} \rho C_{p} \frac{d^{3}}{d} \sigma \frac{d}{d} \mathbf{v}$, where $\rho$ is the density of the grain, $C_{p}$ is the specific heat capacity, $d$ is the diameter of the grain, $\sigma$ is the cross-sectional area of the grain, and $\mathbf{v}$ is the velocity of the grain.

#### Alignment Mechanisms

- **Davis-Greenstein Mechanism:** Involves paramagnetic dissipation in the grains and tends to drive a grain to rotate along its principal axes 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 $\hbar c$ (where $\hbar$ 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 to the grains to precess about the magnetic field on a time scale less than the Davis-Greenstein mechanism (Davis and Greenstein, 1952).
- **Barnett Dissipation:** A ring charged dust grain with a magnetic moment $\mathbf{M}$ in a uniform magnetic field $\mathbf{B}$ precesses about the magnetic field on a time scale much shorter than the Davis-Greenstein mechanism (Barnett, 1971).
- **Lazarian and Draine Dissipation:** A ring charged dust grain with a magnetic moment $\mathbf{M}$ in a uniform magnetic field $\mathbf{B}$ precesses about the magnetic field on a time scale much shorter than the Davis-Greenstein mechanism (Lazarian and Draine, 2000).