On Development of a New Technique for Remote Measurements of Interplanetary Magnetic Fields

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Magnetic Energy and Field in the Heliosphere

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Historical Background

- The surprising discovery of the observed polarization of starlight in 1949-1950, was immediately attributed to the existence of micron- size dust grains in the intervening space environments.
- Rotation and alignment of dust grains: The mechanisms involved in the observed variable polarization of light from various sources have been related to the rotation and axial-alignment of the dust grains along the ambient magnetic fields.
- Determining magnetic fields in space-environments involves comparing observed polarized scattered light to models that take into account magnetic fields and knowledge of the dust properties in the intervening regions

Rotation of Interstellar Dust Grains

- The selective extinction properties of interstellar dust grains were considered to be the primary source of the polarization of starlight (e.g., Hall, 1949)
- The first explanations of the observed polarizations based on alignment of rotating elongated interstellar dust grains were provided on the basis of a correlation in the degree of polarization with interstellar extinction (e.g., Spitzer & Schwartzman, 1949)
- 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

Dust Grain Alignment Mechanisms

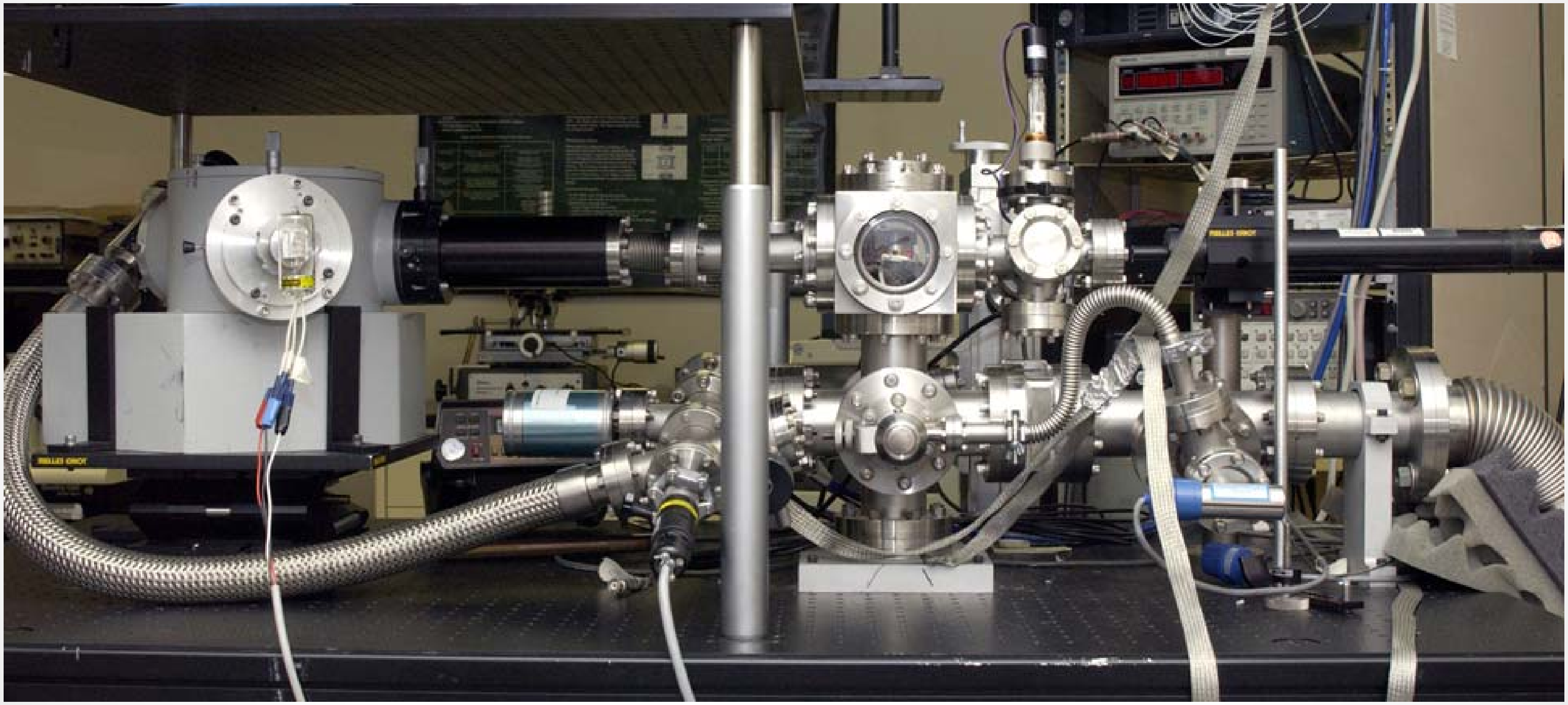
- Direct Grain Alignment by Radiation: Every photon carries an intrinsic angular momentum h/2p (where h is Planck's constant) that makes the incident light an effective carrier of angular momentum (Harwit, 1970)
  - Davis-Greenstein Mechanism: Involves paramagnetic dissipation in the grains that tends 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) .
  - Barnett Dissipation: The Barnett Effect refers to a paramagnetic/ferromagnetic body rotating in a field-free medium spontaneously developing a magnetic moment along the axis of its rotation.

The concept to measure IMF

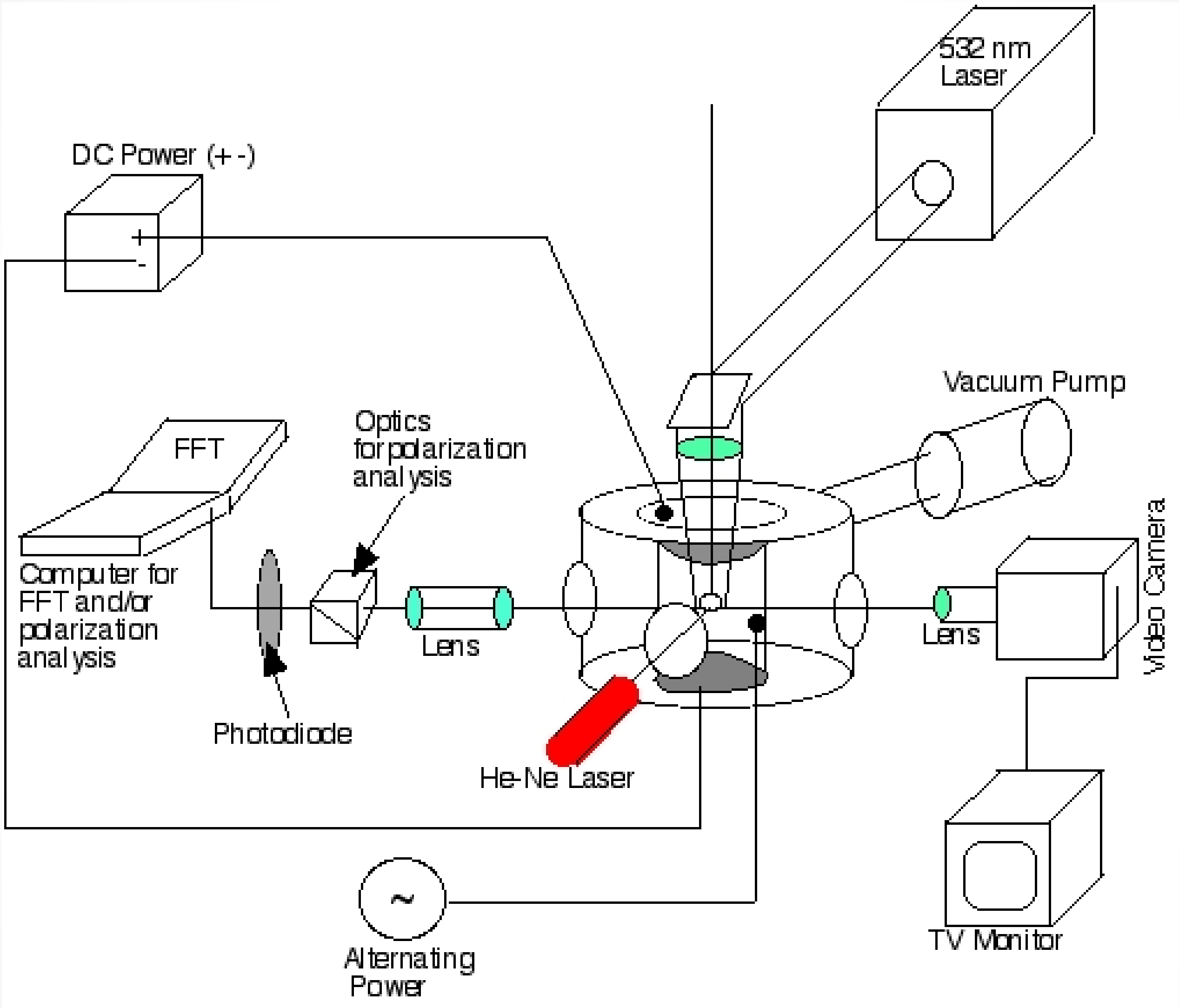
- Zodiacal light is scattered sunlight off interplanetary dust grains
- Dust grains rotate when illuminated, and become charged when exposed to UV and charged particles

- A rotating grain will align itself with the ambient magnetic field
- Alignment of a cloud of dust grains will produce polarized scattered light when illuminated
- Using polarimetry measurements and knowledge of the dust grain optical extinction coefficient, the magnetic field direction can be inferred

Grain Rotation Experiments



MSFC Experiment Schematic



Equations for grain rotation measurements

4. Dust Grains Rotation by Radiative Torque: Exp. Set-Up & Basic Eq

Basic Equations for Grain Rotation Measurements

$$\sum \vec{\Gamma} = \vec{F}_{rad} \times \vec{r} - \vec{\Gamma}_D = I\vec{\alpha} = I\frac{d\vec{\Omega}}{dt} = 2\pi I \frac{d\vec{\omega}_R}{dt}$$

$$\frac{d\omega_R(t)}{dt} + a\omega_R(t) = b$$

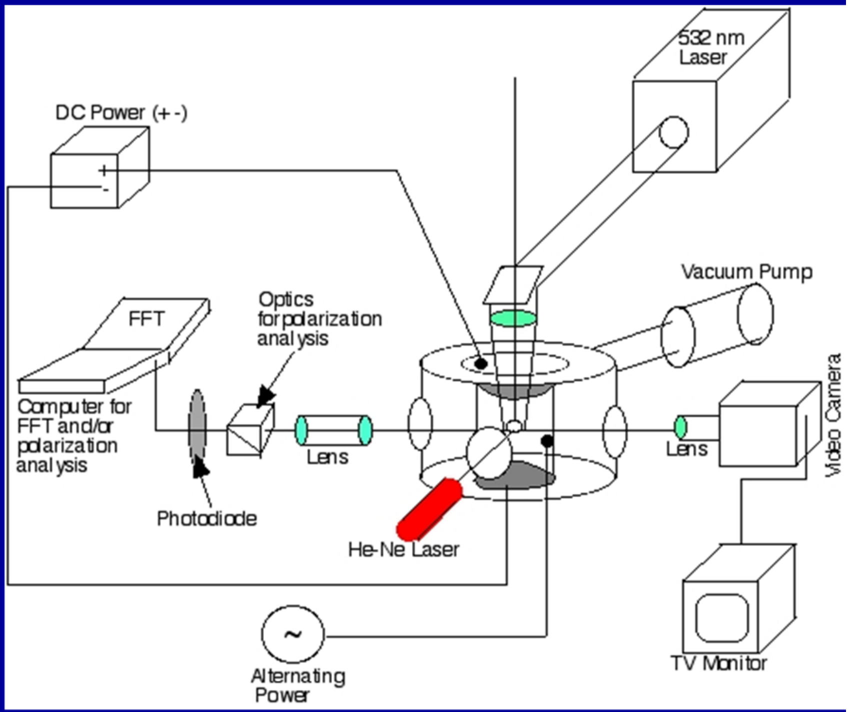
$$a = \frac{(1.81\times10^3)\,P_{torr}C_{FT}}{\rho D_{\mu m}} \qquad b = \frac{(7.9\times10^4)\,I_\lambda Q_T}{\rho D_{\mu m}^3}$$

$$\omega_R(t) = \frac{b}{a}\left(1 - e^{-at}\right)$$

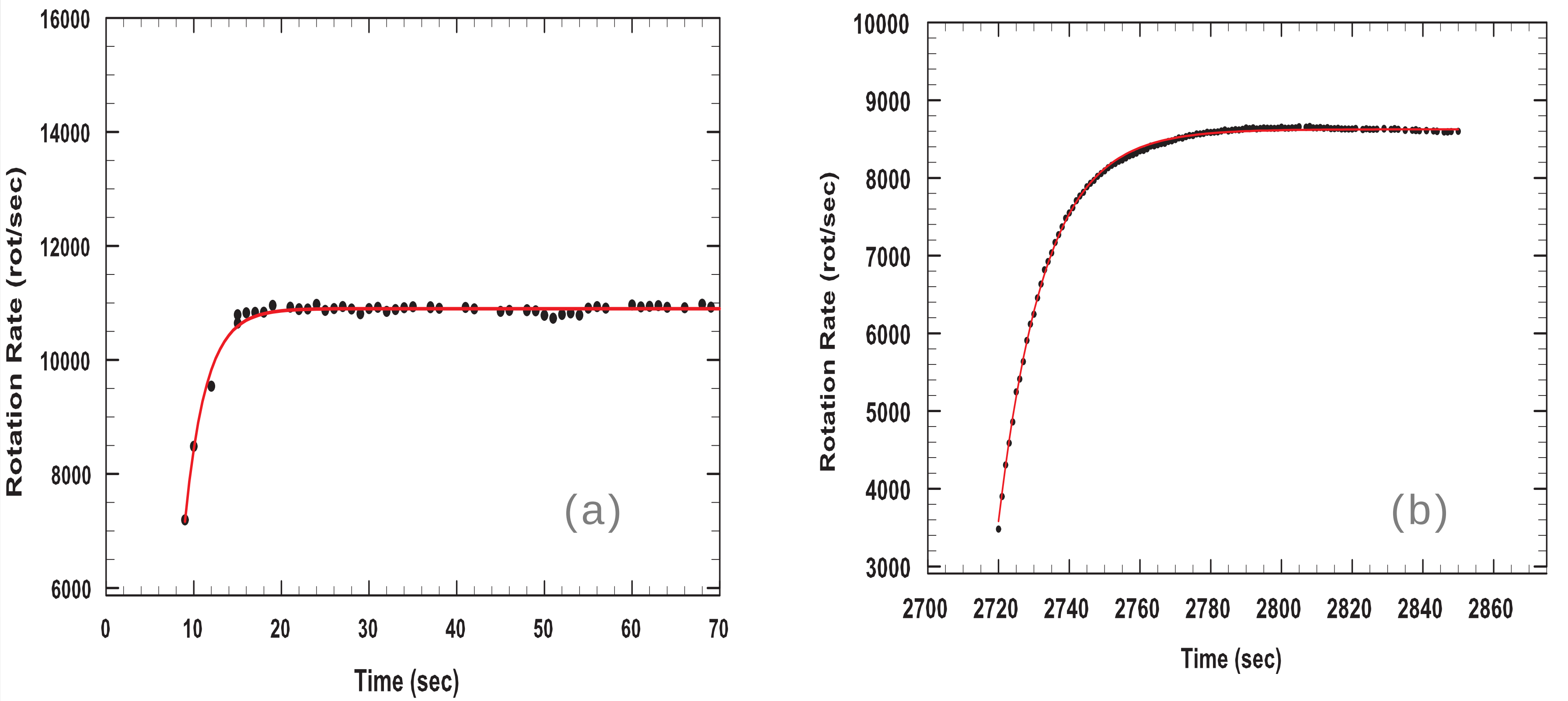
$$\omega_R(t) = bt \qquad a \to 0 \qquad \omega_R^{ss} = \frac{b}{a} = \frac{(43.6)\,I_\lambda Q_T}{D_{\mu m}P_{torr}C_{FT}}$$

$$C_{FT} = \frac{(5.52\times10^{-4})\,a\rho D_{\mu m}}{P_{torr}} \qquad Q_T = \frac{(2.3\times10^{-2})\,\omega_R^{ss}D_{\mu m}P_{torr}C_{FT}}{I_\lambda}$$

Experimental Setup for Rotation Measurements



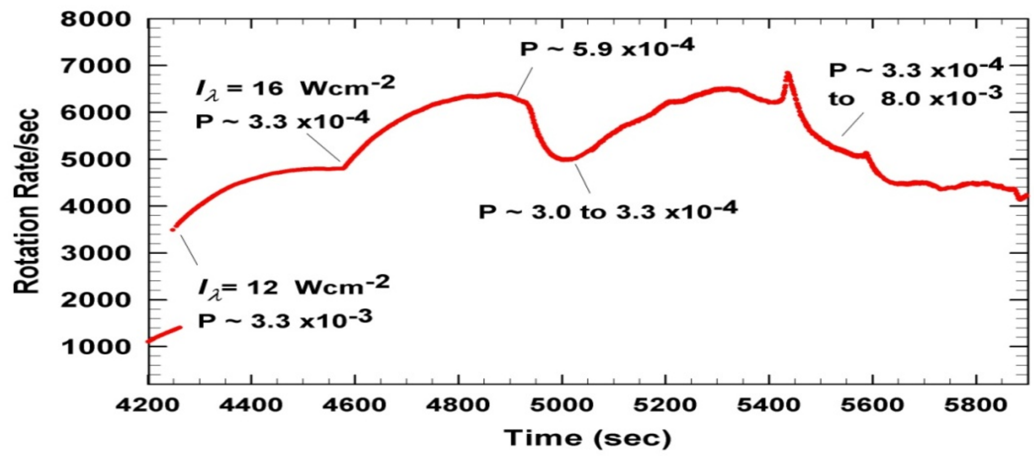
Dust Grain Rotation Results



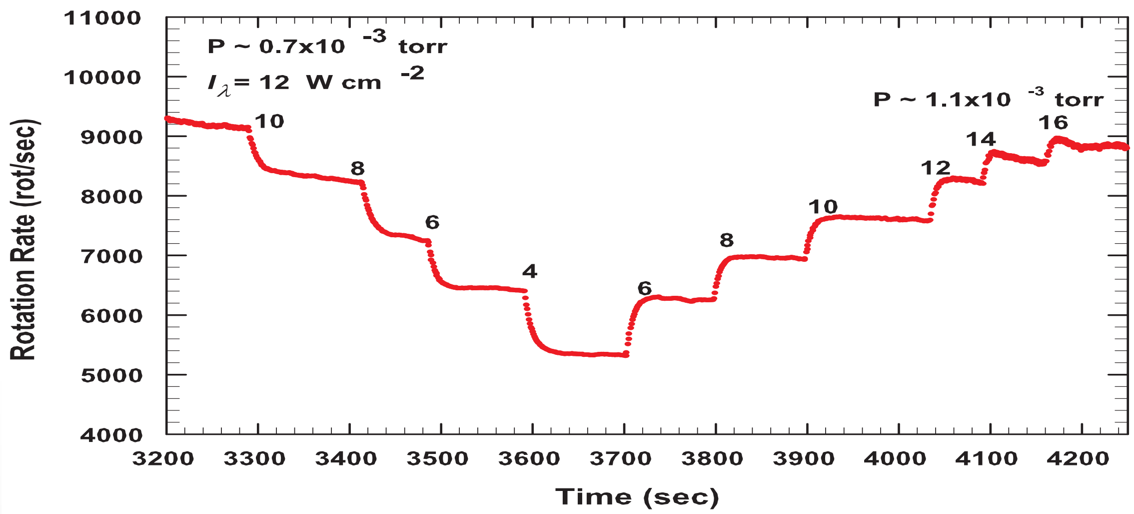
Plots of the rotation rates (dots) for SiC particles measured with (a) $r_d = 0.45\ \mu m$, $P=2.3\times10^{-3}$ torr, $I= 6\ Wcm^{-2}$ and (b) $r_d = 0.98\mu m$, $P=5.0\times10^{-4}$ torr, $I= 8\ Wcm^{-2}$. The dashed line shows the calculated model values using the retrieved rotational parameters with a, b, ω_{ss}, C_{FT}, , and r_{ma}.

Dust Grain Rotation Results

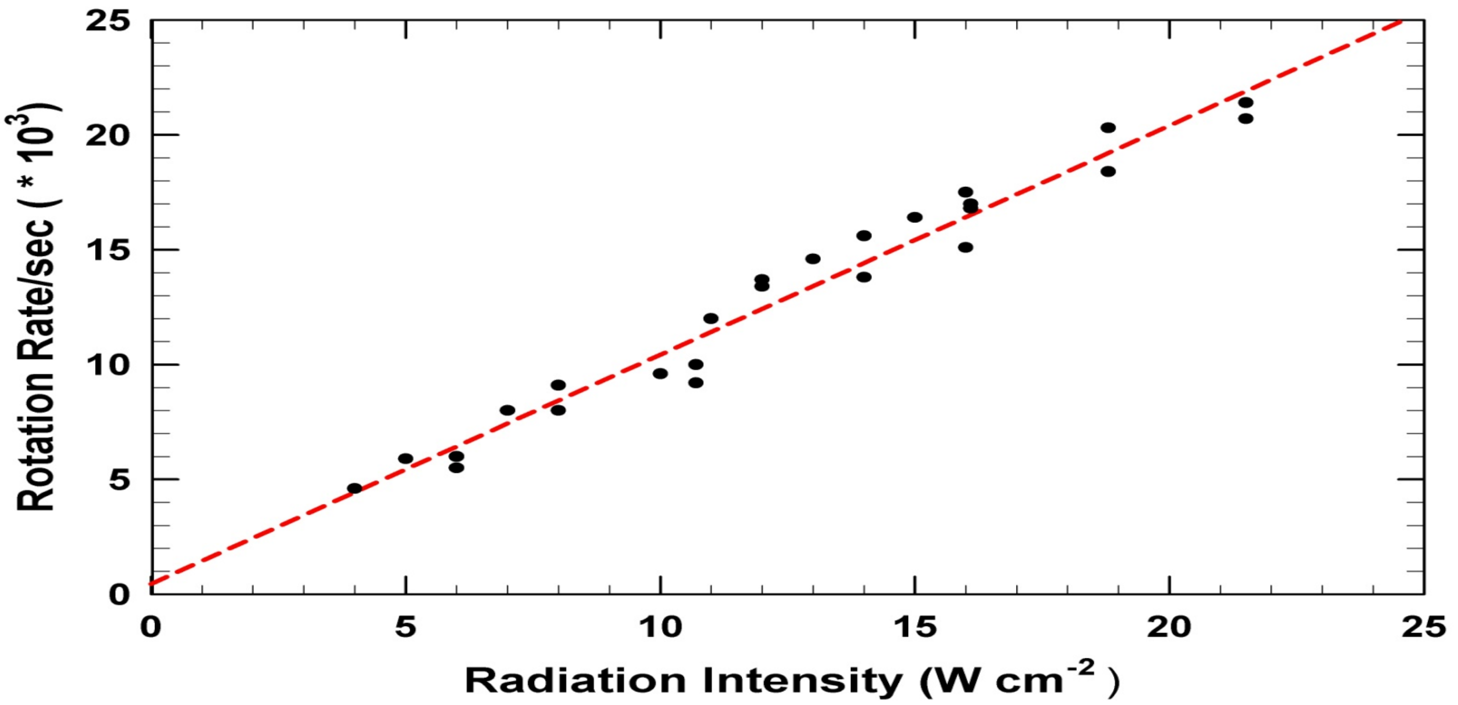
Variations in the rotation rates of a 3.9 μm SiC particle as a function of pressure



Variations in the rotation rates of a 0.98 μm SiC particle as a function of radiation intensity



Dust Grain Rotation Results



Rotation rates of a 0.17 μm radius particle as a function of radiation intensity, with Max rate of ~ 20,000 rot/sec. The dotted line represents a linear fit to the data and permits evaluation the atmospheric drag.

Lab Measurements and Modeling

- **Required Measurement Activities:** Following the techniques employed in the experiments discussed above, laboratory measurements of the following optical properties involving individual micron-size dust grains of various compositions, in variable magnetic fields:
  - Extinction & scattering from dust grains with incident radiation at selected wavelengths
  - Rotation and alignment of dust grains with variable ambient magnetic fields
  - Measurements of the polarization of the light scattered by the rotating/aligned dust grains in variable magnetic fields
- **Development of Analytical Models:** With the extensive detailed data obtained from the above experimental activities dealing with a large number of parameters, analytical models will be developed to compare with polarimeter observations