Physical Properties of Asteroid Surfaces

Karri Muinonen[1,2]
Professor of Planetary Astronomy & Geodesy
[1]Department of Physics, University of Helsinki, Finland
[2]Finnish Geospatial Research Institute (FGI), Masala, Finland

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Lectures

1. Introduction to asteroid UV-VIS-NIR spectrometry,
Monday, November 7, 2016
2. Novel spectrometric modeling,
Tuesday, November 8, 2016
3. Hands-on application to asteroid observations,
Monday, November 14, 2016
4. Combining spectrometric, polarimetric, and photometric observations,
Monday, November 14, 2016

Lecture 1, Contents

- Introduction
- Polarimetry, photometry, and spectropolarimetry
- Asteroid Vis-NIR spectrometry
- Shkuratov radiative transfer model
- Monte Carlo radiative transfer for meteorite spectra
- Conclusions

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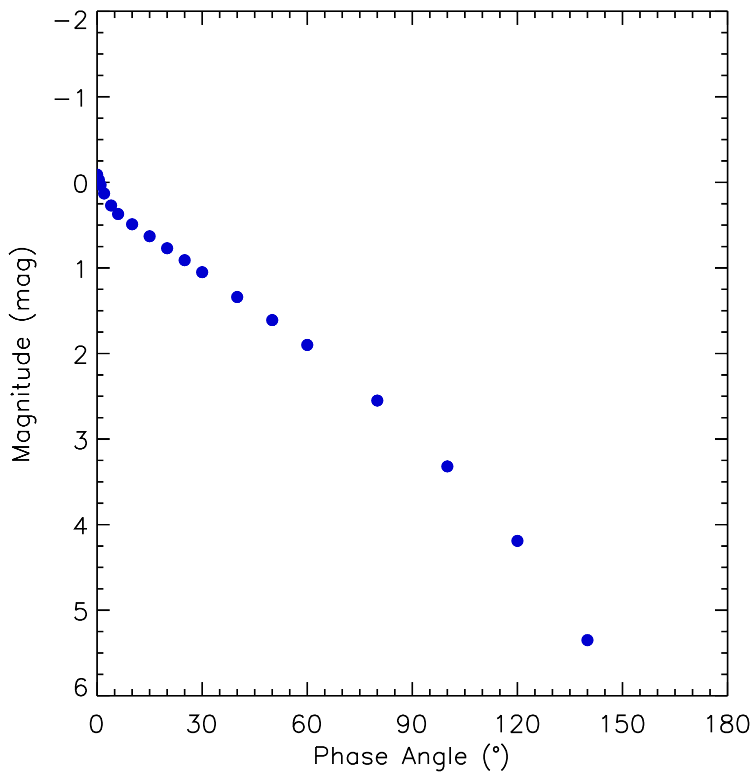
Introduction

- Physical characterization of small particles and particulate media in asteroid surfaces
- Direct problem of light scattering with varying particle size, shape (structure), and refractive index (optical properties)
- Inverse problem of retrieving physical properties of particles based on observations/measurements
- Plane of scattering, scattering angle, solar phase angle, degree of linear polarization

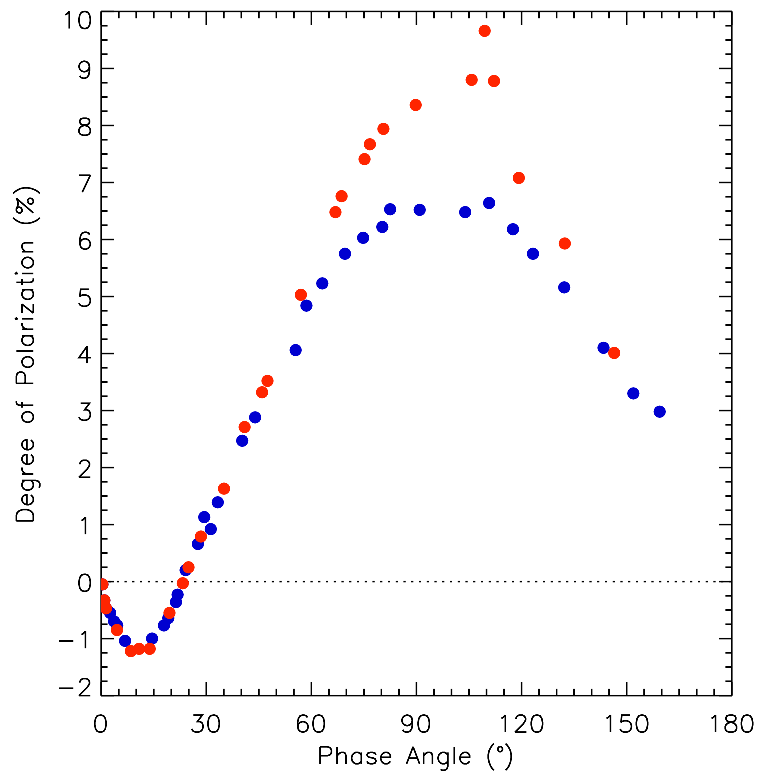
Polarimetric & photometric observations

Moon

Photometry



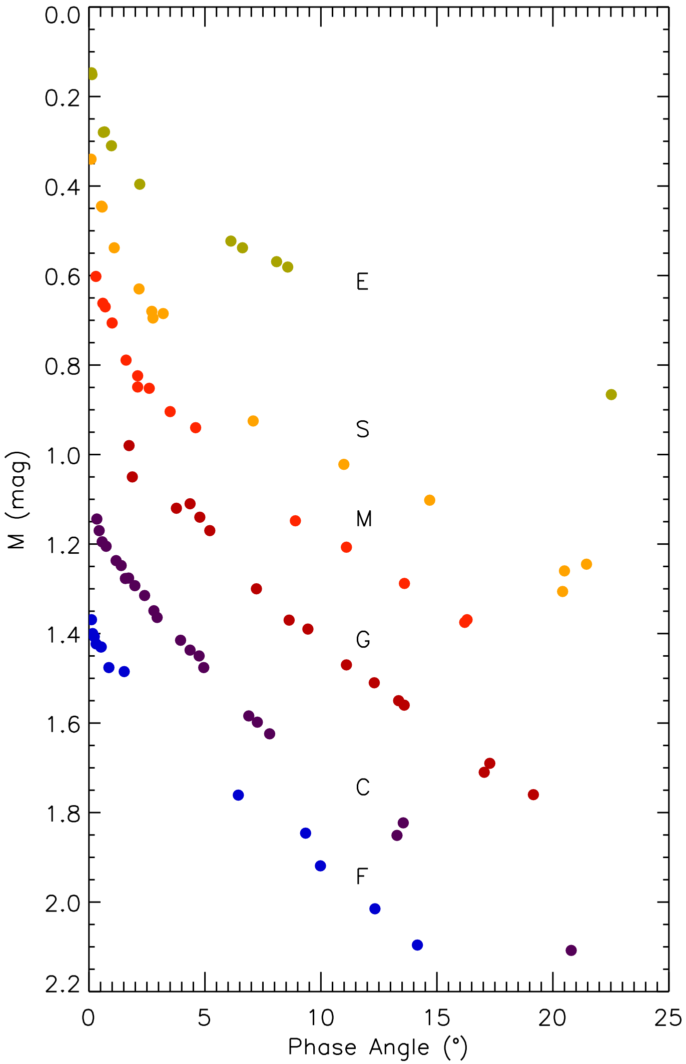
Polarimetry



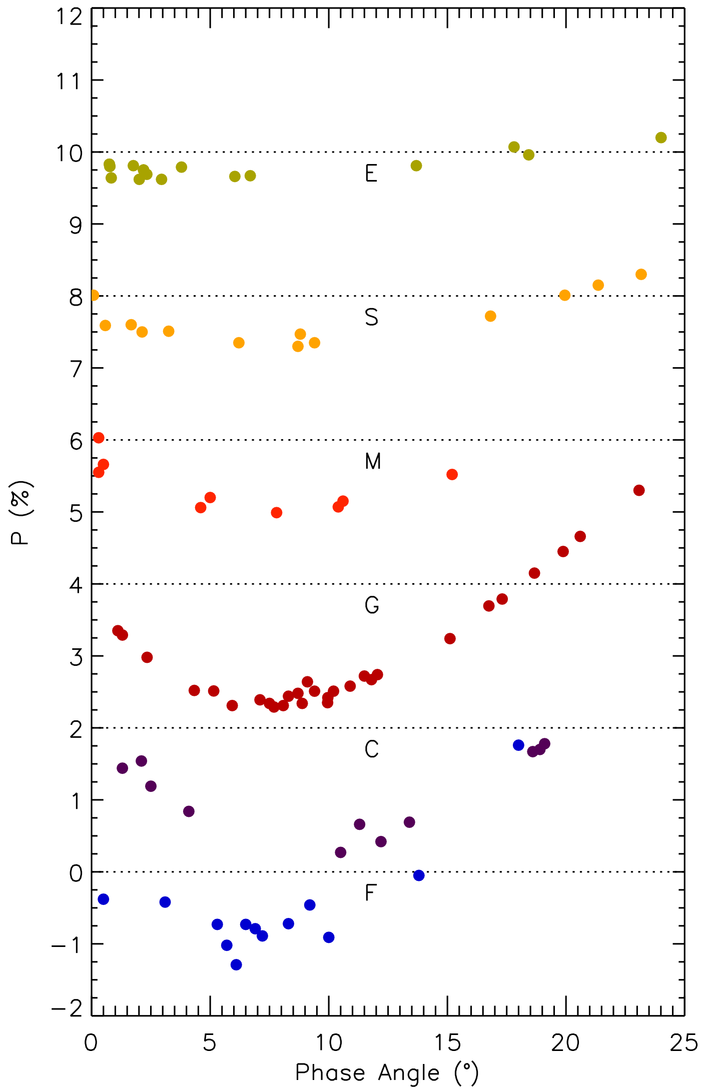
Muinonen et al., in Polarimetry of Stars and Planetary Systems, 2016 (obs. ref. therein)

Asteroids

Photometry

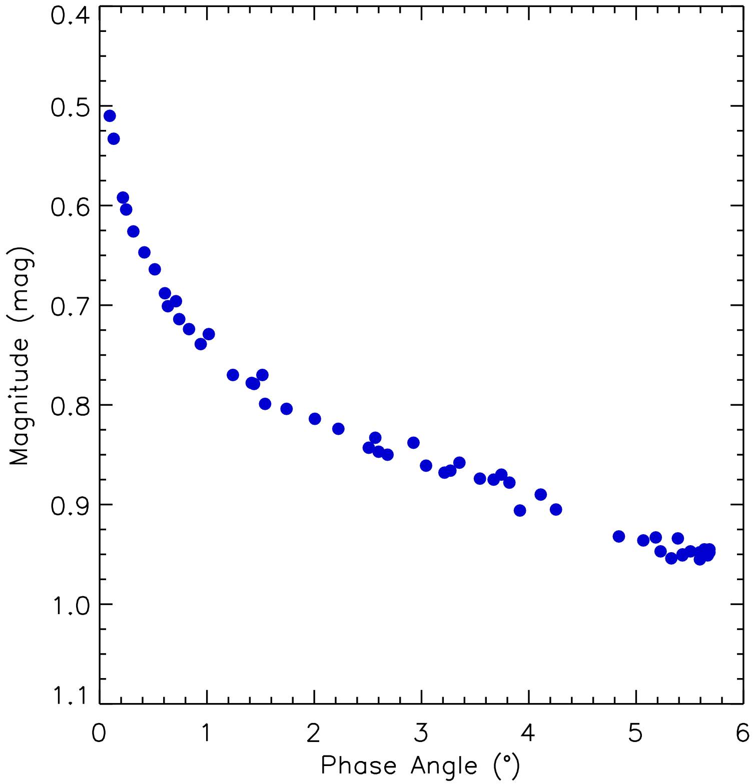


Polarimetry

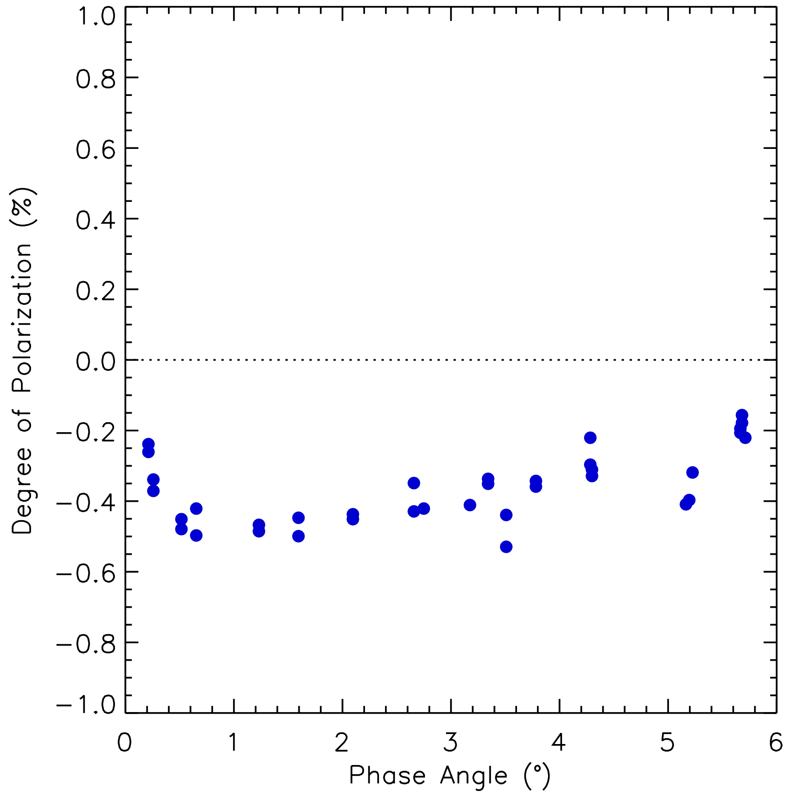


Saturn's Rings

Photometry

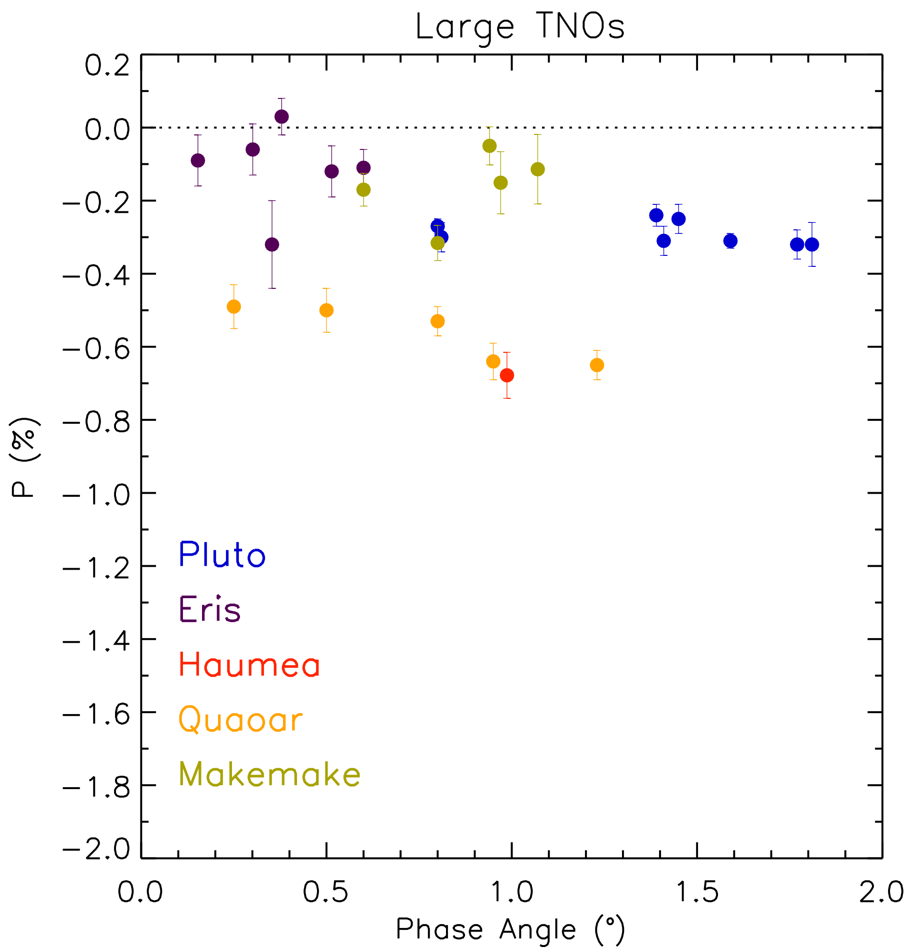


Polarimetry

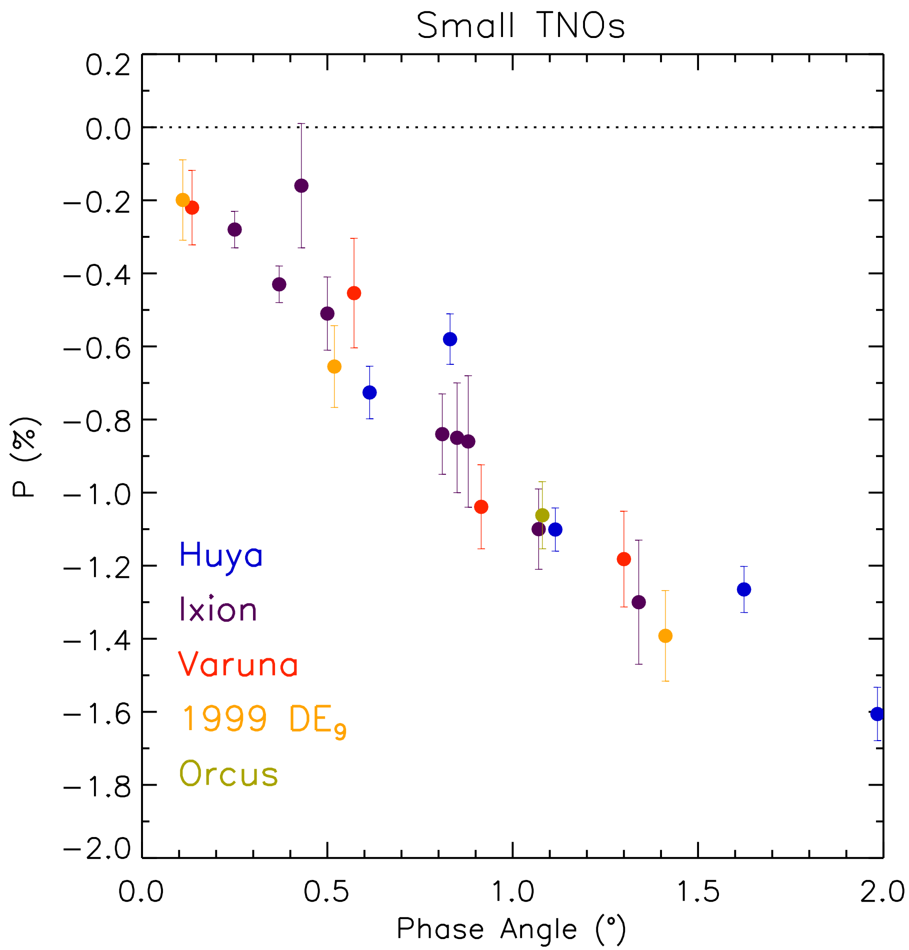


Transneptunian objects (TNOs)

Polarimetry for large TNOs



Polarimetry for small TNOs



Shkuratov Radiative Transfer Model

Shkuratov et al. 1999
Icarus 137, 235

Forward problem, albedo of a particulate medium:

$$A = \frac{1+\rho_\mathrm{b}^2-\rho_\mathrm{f}^2}{2\rho_\mathrm{b}} - \sqrt{\left(\frac{1+\rho_\mathrm{b}^2-\rho_\mathrm{f}^2}{2\rho_\mathrm{b}}\right)^2 - 1}.$$

$$\rho_\mathrm{b} = q \cdot r_\mathrm{b}$$

$$\rho_\mathrm{f} = q \cdot r_\mathrm{f} + 1 - q.$$

$$r_\mathrm{b} = R_\mathrm{b} + \frac{1}{2} T_\mathrm{e} T_\mathrm{i} R_\mathrm{i} \exp(-2\tau)/(1 - R_\mathrm{i}\exp(-\tau)),$$

$$r_\mathrm{f} = R_\mathrm{f} + T_\mathrm{e} T_\mathrm{i} \exp(-\tau) + \frac{1}{2} T_\mathrm{e} T_\mathrm{i} R_\mathrm{i} \exp(-2\tau)/$$
$$(1 - R_\mathrm{i}\exp(-\tau)).$$

Inverse problem, imaginary part of refractive index:

$$\kappa = -\frac{\lambda}{4\pi S} \ln\left[\frac{b}{a} + \sqrt{\left(\frac{b}{a}\right)^2 - \frac{c}{a}}\right],$$

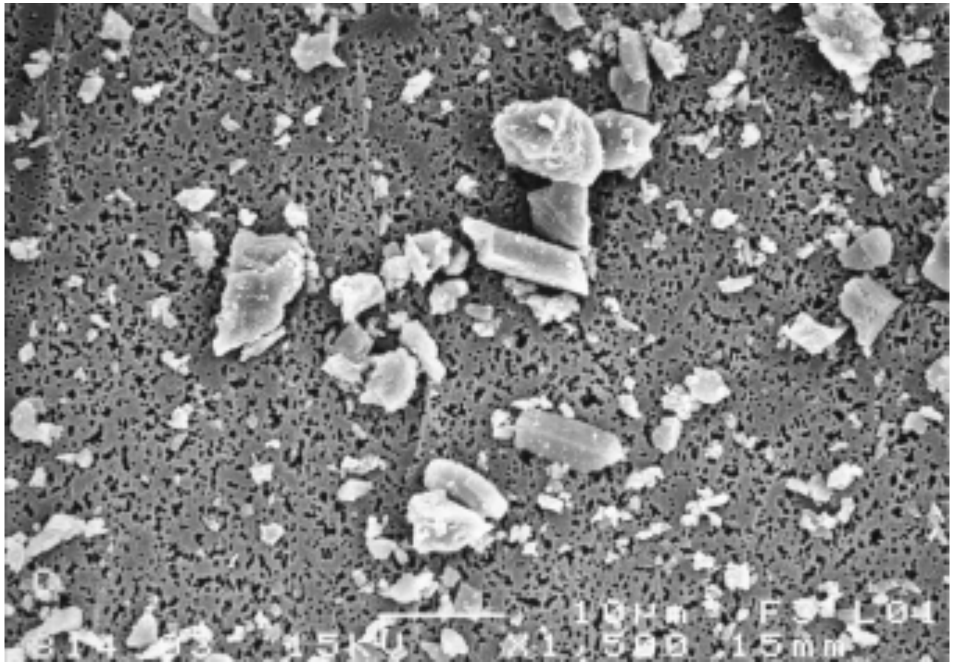
$$a = T_e T_i (y R_i + q T_e),$$

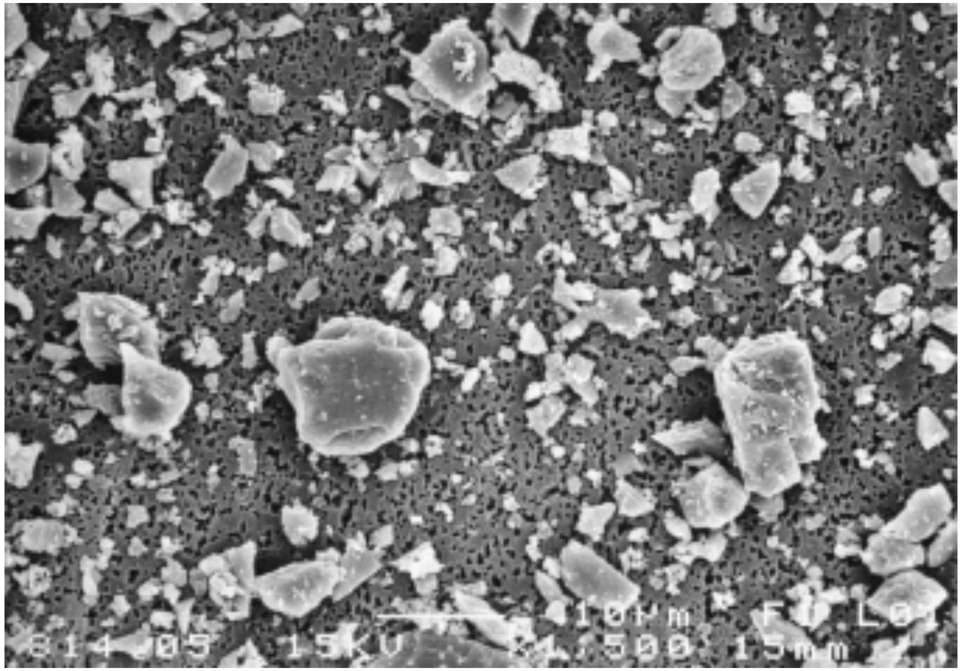
$$b = y R_b R_i + \frac{q}{2} T_e^2 (1 + T_i) - T_e (1 - q R_b),$$

$$c = 2y R_b - 2T_e (1 - q R_b) + q T_e^2,$$

$$y = (1 - A)^2 / 2A.$$

Monte Carlo Radiative Transfer for Meteorite Spectra





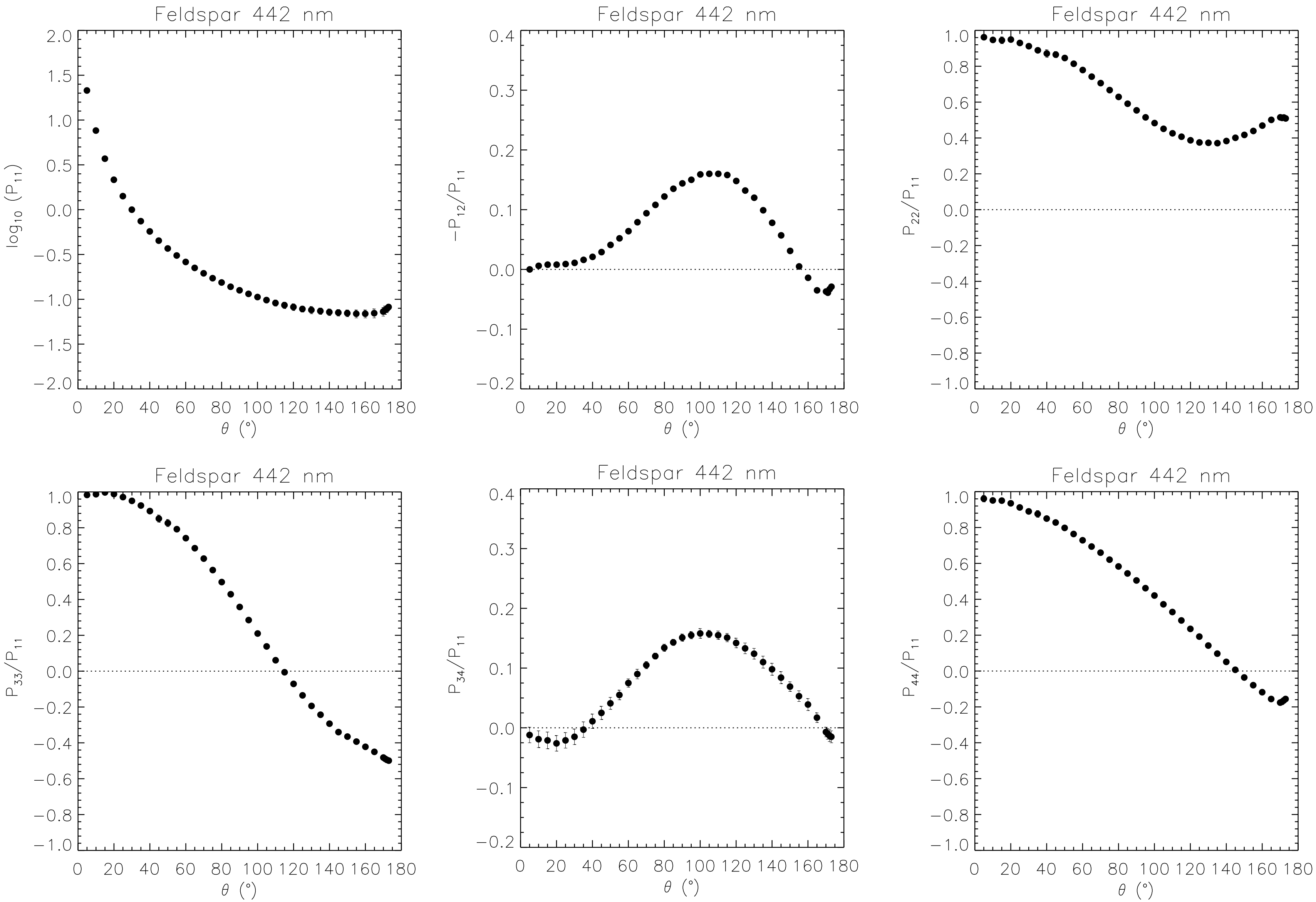
Laboratory measurements for feldspar particles:
Single scattering: Volten et al. 2001, Munoz et al. 2012
Multiple scattering: Shkuratov et al. 2004
Monte Carlo Radiative Transfer with olivine particles:
Multiple scattering, spherical medium: Pentikäinen et al. 2014

Feldspar at 442 nm

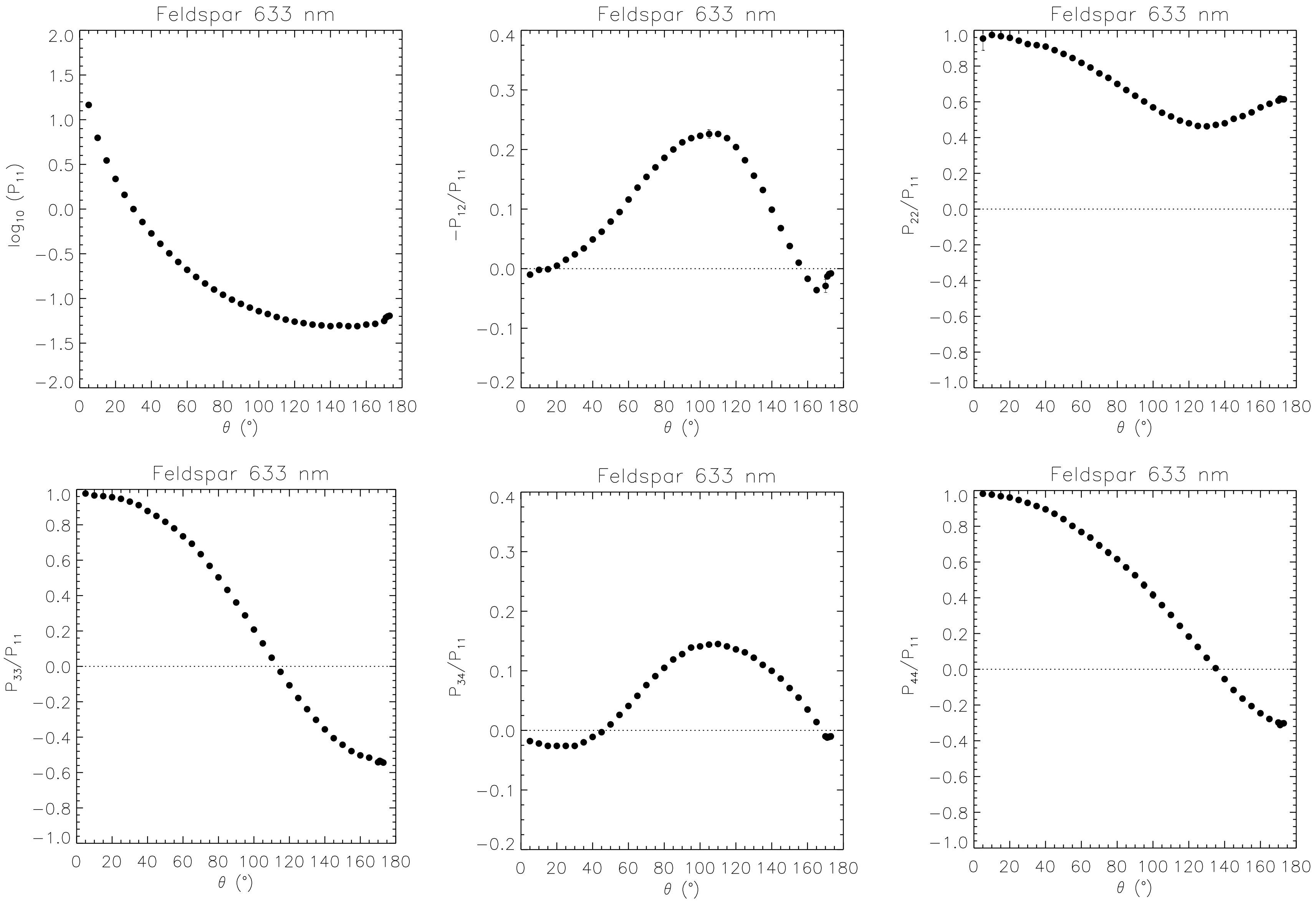
$$\boldsymbol{I}_{\mathrm{s}} = \frac{1}{k^2 R^2}\, \boldsymbol{S} \cdot \boldsymbol{I}_{\mathrm{i}}$$

$$\boldsymbol{I}_{\mathrm{i}} = (I_{\mathrm{i}}, Q_{\mathrm{i}}, U_{\mathrm{i}}, V_{\mathrm{i}})^T$$

$$\boldsymbol{I}_{\mathrm{s}} = (I_{\mathrm{s}}, Q_{\mathrm{s}}, U_{\mathrm{s}}, V_{\mathrm{s}})^T$$



Feldspar at 633 nm



Conclusions

- Asteroid photometry, polarimetry, and spectrometry: synoptic surface modeling from first principles called for
- How do particle size, shape, structure, and composition affect the spectrum?
- How does the viewing geometry affect the spectrum?
- Astronomical observations vs. laboratory measurem
- What are the prospects for successful inversion from first principles?
- How solid or fragile is our understanding of asteroid surface properties?