Introduction

Radiation emitted and reflected by a planet:
Photometric & Spectroscopic Studies of Planets

1. **Photometry** - low resolution, absolute flux measurements (visible and IR)
   - Albedo at zero phase angle
     → constraint on "surface" composition & texture
   - Brightness variation with
     1. phase angle → surface texture/particle sizes
     2. posn on disk (limb darkening)
        → atmos. cloud properties
   - Albedo (geom.) + phase function → net solar energy input
Photometric & Spectroscopic Studies of Planets

2 Spectroscopy
   a) Reflected sunlight
      • identify atmos. or surface constituents by selective absorption
      • atmos. composition (quantitative) of "active" species
      • Doppler shifts → atmos. rotation rates
      • Polarization studies → cloud particle properties

b) Thermal emission
   • retrieve temperature profiles (atmos and sub-surf.
   • identification of atmos. constituents
   • infer wind velocities (geostrophic flow)
   • study overall energy balance of planet
Fig. 9. Emitted and reflected planetary radiance levels shown schematically for indicated brightness temperatures and albedos. The estimated NER for the baseline (IRIS) interferometer and the modified (MIRIS) interferometers are indicated; the measured noise equivalent radiance (NER) for the Mariner Mars (1971) interferometer is also shown for comparison. The MIRIS NER curves are shown for the intermediate gain setting. The dependence of the noise levels on apodization, mode and gain settings are given in Table III. Dashed NER values apply to individual spectra and will improve in proportion to the square root of the number of spectra used in any averaging process. Such averaging will be required for Uranus, and in some instances, for Saturn and Jupiter as well. For example, dotted curves show NER for 12 hour averages at high resolution MIRIS spectra.
Reflection and Emission

The solar flux $\pi F_0$ that is incident on a planet at a distance $r$ from the sun is given by:

$$\pi F_0 = \frac{L_\odot}{4\pi r^2}$$  \hspace{1cm} (11)

The power intercepted by unit area $da$ is:

$$P_{in} = \pi F_0 da$$  \hspace{1cm} (12)

The reflected power is given by:

$$P_{out} = \int_{2\pi} I(\theta) \cos \theta d\Omega da$$  \hspace{1cm} (13)

with $I(\theta)$ the radiance reflected in direction $\theta$
Without absorption, $P_{in} = P_{out}$, which gives:

$$\int_{0}^{1} I(\theta) \cos \theta d\cos \theta \equiv \frac{1}{2} F_0$$

(14)

For a Lambert surface (or atmosphere), the reflected radiance is independent of $\theta$, thus:

$$I(\theta) = F_0$$

(15)

For an arbitrary surface (or atmosphere), the reflected radiance is usually expressed as:

$$I(\theta) / F_0$$

(16)

or as:

$$I(\theta) / \cos \theta_0 F_0$$

(17)

with $\theta_0$ the local solar zenith angle
When observing a planet of radius $R$, at a distance $r$ from the observer, the received flux is:

$$F_\lambda^0 = I(\alpha)\Omega = I(\alpha)\frac{\pi R^2}{r^2} \quad (18)$$

Define the phase function of the planet by:

$$\phi(\alpha) = \frac{I(\alpha)}{I(0)} \quad (19)$$

then:

$$F_\lambda^0 = I(0)\phi(\alpha)\frac{\pi R^2}{r^2} \quad (20)$$
Geometric albedo $p$:

This albedo is defined as:

$$ p = \frac{I(0)}{F_0} \quad (21) $$

For a Lambert surface, $p = 1$ by definition

Bond albedo $A$:

This albedo is defined as:

$$ A = \frac{\text{total reflected power}}{\text{total incident power}} $$

$$ = \frac{\pi R^2 \int_{4\pi} I(\theta) d\Omega}{\pi R^2 \pi F_0} $$

$$ = \frac{2}{F_0} \int_0^\pi I(\theta) \sin \theta d\theta $$

$$ = 2p \int_0^\pi \phi(\theta) \sin \theta d\theta $$

$$ \equiv pq \quad (22) $$

with the phase integral $q$:

$$ q = 2 \int_0^\pi \phi(\theta) \sin \theta d\theta \quad (23) $$
by the comparison object ξ UMa, which approximates the solar spectrum in the infrared quite closely. They were then matched to published photometric results, in the region of overlap from 0.9–1.1 µm. Our spectral data are displayed as solid lines in the figures.

The photometric data were derived from a number of sources. For Uranus we employed the data of Younkin (1970) but corrected to the diameter of 51,800 km obtained by Danielson, Tomasko, and Savage (1972). It is shown as the dashed line in Figure 2a. For Uranus we have also plotted Trafton's (1976) observations as a dotted line. This data set is not totally independent since Trafton normalized to Younkin's numbers in regions of high transmission. Trafton's data should, however, be more accurate in the bottoms of the strong methane bands where he
took particular care to obtain accurate measurements. Our own spectrum, when matched to Younk’s data in the transmission window at 1.06 μm, agrees well with Trauton’s residual intensity in the 1.9 μm CH₄ complex and thus lends support to this statement. Our spectrum also tracks the detailed fine structure of Trauton’s data in the bottom of this band.

The data of Wamsteker (1973, 1975) are shown as crossed circles connected by long dashes in all the figures. They are the only narrow-band photometric data that we could find for Saturn and Neptune. When fitting our spectra to his data points, the difference in resolution was taken into account. For Titan we have plotted Younk’s (1974) albedos divided by a factor of 1.5 to correct for a different radius and solar constant (Younk 1978, private communication). The resultant curve agrees well with Wamsteker’s measurements.

Comparison of the albedos of Neptune, Uranus, Titan, and Saturn yields additional information not apparent from inspection of Figure 1 alone. Now Neptune and Uranus appear quite similar with respect to the absolute albedo levels and the general shapes of the curves. They have a relatively high albedo in the visible which drops off rapidly toward the infrared. The drop in reflected intensity for both planets can be
Some examples:

**sphere with uniform surface brightness:**

\[ \phi(\alpha) = \frac{1}{2}(1 + \cos \alpha) \quad (24) \]
\[ q = 2 \]
\[ p = A/2 \]

**(metallic) sphere with perfect reflection:**

\[ \phi(\alpha) = 1 \quad (25) \]
\[ q = 4 \]
\[ p = A/4 \]

**Lambert sphere:**

\[ \phi(\alpha) = \frac{1}{\pi}[(\pi - \alpha) \cos \alpha + \sin \alpha] \quad (26) \]
\[ q = 3/2 \]
\[ p = 2/3 \quad (A \equiv 1) \]
Some Phase Functions:

Some values for phase integrals:
Earth:  $q = 1.05$
Venus:  $q = 1.2$
Jupiter:  $q = 1.25$
Voyager observations (clear filter)

Phase functions

- Rhea $q = 0.7$
- Dione 0.8
- Tethys 0.75
- Enceladus 0.85
- Mimas 0.80
- Moon 0.62
- Europa 1.1
- Callisto 0.6
- Ganymede 0.8
- Uniform brightness $(1 + \cos \alpha)/2$

Disk Integrated Brightness

Phase Angle

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Magnitudes.

Remote disk-integrated measurements are usually reported as astronomical magnitudes:

\[ m_\lambda = -2.5 \log_{10} (f_\lambda) + C_\lambda \]

\( C \) depends on \( \lambda \), and is chosen by convention such that \( m = 0.0 \) for the A0 star Vega = \( \alpha \) Lyrae.

\[ f(\Delta, \theta) = \frac{L_\odot R^2}{4\pi r^2 \Delta^2} \cdot p \phi(\theta) \]

\[ m(\Delta, \theta) = -2.5 \log \left( \frac{L_\odot}{4\pi r^2 \Delta^2} \right) = -2.5 \log m_\odot + C \]

The observed magnitude of the Sun at \( r_0 = 1 \) AU:

\[ m_\odot = -2.5 \log \left( \frac{L_\odot}{4\pi r_0^2} \right) + C \]

\[ m(\Delta, \theta) = m_\odot + 5 \log \left( \frac{R_\odot}{r_0 R} \right) - 2.5 \log p \phi(\theta) \]

(<NB: in a standard V filter (\( \lambda = 0.55 \mu m \)) \( m_\odot = -26.74 \))

To compare the intrinsic brightnesses of different objects, we calculate their magnitudes at \( \theta = 0 \)

and \( r = \Delta = r_0 = 1 \) AU:

\[ m(1, \theta) = m_\odot + 5 \log \left( \frac{r_0 R}{R} \right) - 2.5 \log p \]

- depends only on \( R \) and \( B_\lambda \)
- this is analogous to an ABSOLUTE MAGNITUDE for a star.

So we then have:

\[ m(\Delta, \theta) = m(1, \theta) + 5 \log \left( \frac{\Delta^2}{r_0^2} \right) - 2.5 \log p \phi(\theta) \]
Note: Light scattering by "small" particles (e.g., atmospheric aerosols, ring particles, etc.)

Particle extinction cross-section $Q_{\text{ext}}$ (dimensionless)

Intercepted power, $P_I = \pi F Q_{\text{ext}} \cdot \pi r^2$

$Q_{\text{sc}}$ (scattered) $Q_{\text{abs}}$ (absorbed)

The scattered power, $P_S = \pi r^2 \int I(\theta) d\Omega$

$= \bar{\omega}_0 P_I$

where $\bar{\omega}_0$ is the single scattering albedo

$\therefore \int I(\theta) d\Omega = \bar{\omega}_0 Q_{\text{ext}} \pi F$

$= Q_{\text{sc}}$

It is conventional to normalize $I(\theta)$ to its average value over $4\pi$ steradians:

$I(\theta) = \bar{I} P(\theta)$ with $\frac{1}{4\pi} \int P(\theta) d\Omega = 1$

$\therefore \bar{I} / F = \bar{\omega}_0 Q_{\text{ext}} / 4$
\[
I(\theta) = \frac{\tilde{\omega}_0 \Omega_{ext} \rho(\theta)}{4}
\]

In general, \(\Omega_{ext}\) depends on particle radius, composition, and wavelength \(\lambda\). For spherical particles, \(\Omega_{ext}\) depends on \(x = 2\pi r / \lambda\)

and the refractive index (complex):

Figure 8. Efficiency factor for scattering, \(\Omega_{scat}\), as a function of the effective size parameter, \(2\pi a/\lambda\). The standard size distribution (2.56) was used with four values of the effective variance \(b\). For the case \(b=0\), \(2\pi a/\lambda = 2\pi r/\lambda\). The refractive index is \(n_x = 1.33, n_i = 0\).

Hansen & Travis (1974)
For $x << 1$ (the Rayleigh scattering limit),
\[ \tilde{\omega}_0 Q_{\text{ext}} \propto x^4 = \left(\frac{2\pi r}{\lambda}\right)^4 \]

and
\[ Q_{\text{abs}} \propto x \cdot \text{Im}(n). \]

For $x >> 1$ (macroscopic particles), $Q_{\text{ext}} \to 2$ (50% of the light removed is confined to a forward-scattering diffraction cone of angular width $\delta \sim \lambda/2r$).

If we neglect the diffracted light, $Q_{\text{ext}} \approx 1$ and we have
\[ \tilde{\omega}_0 = A, \] the “Bond albedo at $\lambda$”

and
\[ I(0)/F = \beta = \frac{1}{4} \tilde{\omega}_0 P(0). \]
Some scattering functions $P(\theta)$ for macroscopic and wavelength-sized spherical particles:

![Graph showing phase functions for various macroscopic bodies.](image)

FIG. 4. Phase functions of various macroscopic bodies, real and imagined. The plot includes two satellites—Callisto and Europa, and three theoretical phase functions—a Lambert sphere, the phase function of a “planet” covered with a semi-infinite, isotropic-scattering atmosphere, and the “naive” phase function, which is proportional to the illuminated area of the sphere. In general, darker satellites are more strongly backscattering; nonetheless, all known atmosphereless satellites are significantly more backscattering than a Lambert sphere, the prototype for smooth macroscopic bodies. All phase functions have been scaled to unity at exact backscatter.

from Done et al. (1993)

![Graph showing phase functions for microscopic particles derived from Mie theory for spherical particles with the refractive index of pure ice ($m = 1.313 - 1.910 \times 10^{-5} i$ at $\lambda = 0.5 \mu m$, from Warren 1984), and the observed phase function of zodiacal light particles. The three narrow size distributions assume a Hansen–Hovenier law $n(r) \propto r^{1/8} \exp(-r/\alpha b)$, where $n(r)dr$ is the number of particles per unit area with radii between $r$ and $r + dr$, with mean radii of 0.1, 0.5, and 2.5 $\mu m$ ($x = 1.3, 6.4$, and 32.1), and with $b$, the variance in units of the mean particle size, equal to 0.1 (Hansen and Travis 1974). The broad distribution is a power-law $n(r) \propto r^{-\rho}$ with $\rho = 3$ between limits $r_{\text{min}} = 0.01 \mu m$ and $r_{\text{max}} = 5 \mu m$. For particles much smaller than the wavelength of light ($x \ll 1$), the phase function is rather isotropic. For much larger particles ($x \gg 1$), the phase function contains a narrow forward scattering lobe.

FIG. 6. Phase functions for microscopic particles derived from Mie theory for spherical particles with the refractive index of pure ice ($m = 1.313 - 1.910 \times 10^{-5} i$ at $\lambda = 0.5 \mu m$, from Warren 1984), and the observed phase function of zodiacal light particles. The three narrow size distributions assume a Hansen–Hovenier law $n(r) \propto r^{1/8} \exp(-r/\alpha b)$, where $n(r)dr$ is the number of particles per unit area with radii between $r$ and $r + dr$, with mean radii of 0.1, 0.5, and 2.5 $\mu m$ ($x = 1.3, 6.4$, and 32.1), and with $b$, the variance in units of the mean particle size, equal to 0.1 (Hansen and Travis 1974). The broad distribution is a power-law $n(r) \propto r^{-\rho}$ with $\rho = 3$ between limits $r_{\text{min}} = 0.01 \mu m$ and $r_{\text{max}} = 5 \mu m$. For particles much smaller than the wavelength of light ($x \ll 1$), the phase function is rather isotropic. For much larger particles ($x \gg 1$), the phase function contains a narrow forward scattering lobe.
Light scattering from a particle layer:

Define the optical depth of the layer by

$$\tau = \int_0^d n(z) \pi r^2 Q_e (r, \lambda) \, dz$$

where $n(z) = \# \text{ of particles} / \text{vol.}$

For a particle size distribution $n (r, z)$ we have:

$$\tau = \int_0^{r_{\text{max}}} \int_{r_{\text{min}}}^{r_{\text{max}}} \pi r^2 Q_e (r, \lambda) n (r, z) \, dr \, dz$$

In terms of the individual particle phase function $P(\alpha)$ and single-scattering albedo $\bar{\omega}_0$, the reflected intensity due to single scattering only is given by:

$$\frac{I (i, \alpha)}{F} = \frac{\bar{\omega}_0 \mu'}{4 (\mu + \mu')} P(\alpha) \left( 1 - \exp \left[ -\frac{\tau (\mu + \mu')}{\mu \mu'} \right] \right)$$

where $\mu' = \cos i$ and $\mu = \cos \Phi$

For contributions from multiply-scattered light see Chandrasekhar, S. (1960) "Radiative Transfer."

Limits:

$$\tau \to 0 : \quad \frac{I}{F} \to \frac{1}{4} \bar{\omega}_0 \tau / \mu P(\alpha)$$

(e.g., Jovian rings)

$$\tau \to \infty : \quad \frac{I}{F} \to \frac{1}{4} \frac{\bar{\omega}_0 \mu'}{\mu + \mu'} P(\alpha) \quad \text{(e.g., thick cloud)}$$
Light scattering from airless bodies:

Light scattering from solid surfaces is complicated further by surface microstructure (→ shadowing of soil particles) and by macroscopic (topographic) shadowing. Several quasi-empirical relations have been developed, such as:

Minnaert's "law": \[ \frac{I}{F} = B_0(\alpha) \mu_0^k \mu^{k-1} \] (1)

- developed for the Moon, where \( k = 0.5 \) @ \( \alpha = 0 \)
- at zero phase, \( \mu = \mu_0 \Rightarrow \frac{I}{F} \sim \mu^{2k-1} \)

⇒ the Moon shows no limb darkening!

Lambert "law": \[ \frac{I}{F} = B_0(\alpha) \mu_0 \]

- \( I \) is independent of \( \mu \)
- corresponds to Minnaert \( k = 1 \)

see JVeal Fig. 15, 14

Buratti's relation: \[ \frac{I}{F} = \frac{Am_i}{\mu + \mu_0} f(\alpha) + (1-A) \mu_0 \] (2)

- linear combination of \( S + L \); usually \( A \gtrsim 0.6 \)

see JVeal Fig. 11

- for icy spheroids

Hapke's theoretical formulation:

\[ \frac{I}{F} = \frac{1}{4} \mu_0^2 \frac{\mu^\prime}{\mu + \mu_0^\prime} \left[ 1 + B(\alpha) \right] P(\alpha) + \frac{\mu_0^\prime}{\mu_0} H(\mu_0^\prime) - 1 \]

Table VII

\[ \mu^\prime, \mu_0^\prime = "effective" \mu_s \]

- multiple scattering terms à la Chandrasekhar

- \( B(\alpha, h) = \frac{B_0}{[1 + tan(\beta)/h] \}

\[ P(\alpha, g) = \frac{1 - g^2}{(1 + g^2 + 2g \cos \alpha)^{\frac{3}{2}}} \quad \sigma_{-1} \leq g \leq 1 \]

\( \alpha = \text{phase angle} \)

\( \mu_0 = \bar{\mu} = \text{call} \)

\( \mu = \cos \epsilon \)

(1) For real bodies \( k(\alpha) \) (2) see JVeal Fig. 11 in "Satellites"
Asteroid phase curves:

- Usually only disk-integrated photometry is available
  \[ \Rightarrow \ \Phi (\phi) \text{ measured} \]
  - A standard analytic approximation which works quite well was adopted by the IAU in 1985:

1. Compute "reduced mag." \( V_0(\phi) = V_{\text{obs}} - 5 \log \Delta \)

2. Fit curve to data:
   \[ V_0(\phi) = H - 2.5 \log \left[ (1-G)\Phi_1(\phi) + G \Phi_2(\phi) \right] \]
   where
   \[ \Phi_i(\phi) = \exp \left\{ -A_i \left[ \tan(\phi/2) \right]^{B_i} \right\} \]

   and
   \[ A = (3.33, 1.87) \quad B = (0.63, 1.22) \]

3. G \approx 0 \text{ for steep phase curves} \quad \text{(low albedo objects)}
   \[ G \approx 1 \text{ for shallow """" (high """""" )} \]

**Note:**

- Expression reasonably valid for \( 0 \leq \phi \leq 120^\circ \)
- See "Asteroids II" (1989), pp. 1090–1138 for a table of \( H \) and \( G \) for \( \sim 3300 \) asteroids.
- See Chapter by Bowell et al., p 549 for discussion.
- Earlier work involved the phase function, \( \beta \)
  \( (dV(\phi)/d\phi \text{ for } 6^\circ \leq \phi \leq 20^\circ) \) and various definitions of the opposition surge at \( \phi < 6^\circ \).
- Typically, \( \beta \approx 0.03 \text{ mag/deg} \ (\pm 0.01) \)
- Note that the absolute magnitude, \( V_C(1, \phi) \)
  by convention excludes the opposition surge,
  so \( V_C(0^\circ) < V(1, \phi) \) by \( \sim 0.32 \text{ mag} \).
Fig. 10. Scans along the photometric equators of the five medium-sized Saturnian satellites at the lowest phase angle observed by Voyager. Fits of the empirical photometric law described by Eq. (5) are shown and the derived values of the parameter $A$ indicated (figure from Buratti 1984).

Buratti model fits

Minnaert model fits

Fig. 14. A photometric scan across Europa (Voyager 1 orange filter) at a small phase angle ($\alpha = 2.9^\circ$) showing a significant degree of limb darkening. The fitted curve corresponds to a limb darkening parameter $k = 0.70$. For a lunarlike surface, there would be almost no limb darkening ($k = 0.5$), while a Lambert surface would give $k = 1$ (figure from Buratti and Veverka 1984).
TABLE VI
Minnaert Parameters for the Saturn Satellites

<table>
<thead>
<tr>
<th>Object</th>
<th>$\alpha$</th>
<th>Bright areas</th>
<th>Dark areas</th>
<th>$B_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rhea</td>
<td>5.5</td>
<td>0.54 ± 0.01</td>
<td>0.59 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Dione</td>
<td>7.1</td>
<td>0.56 ± 0.02</td>
<td>0.55 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Tethys</td>
<td>9.9</td>
<td>0.63 ± 0.02</td>
<td>0.64 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>Enceladus</td>
<td>13.4</td>
<td>0.78 ± 0.04</td>
<td>1.06 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>Mimas</td>
<td>16.8</td>
<td>0.65 ± 0.07</td>
<td>0.63 ± 0.02</td>
<td></td>
</tr>
</tbody>
</table>

*Voyager clear filter; effective passband centered near 0.47 $\mu$m. Table from Buratti (1984).

TABLE VII
Values of $\omega_0$, $h$, $g$, and Mean Slope Angle for Hapke’s Theory

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Single Particle Scattering Albedo $\omega_0$</th>
<th>Hapke Compaction Parameter $h$</th>
<th>Asymmetry Factor $g$</th>
<th>Slope Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moon</td>
<td>0.25 ± 0.02</td>
<td>0.4 ± 0.1</td>
<td>-0.25 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>Europa</td>
<td>0.97 ± 0.01</td>
<td>1.0 ± 0.2</td>
<td>-0.15 ± 0.04</td>
<td>23$^\circ$</td>
</tr>
<tr>
<td>Mimas</td>
<td>0.93 ± 0.03</td>
<td>0.7 ± 0.2</td>
<td>-0.30 ± 0.05</td>
<td>30$^\circ$</td>
</tr>
<tr>
<td>Enceladus</td>
<td>0.99 ± 0.02</td>
<td>0.4 ± 0.2</td>
<td>-0.35 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Rhea</td>
<td>0.76 ± 0.03</td>
<td>0.4 ± 0.1</td>
<td>-0.35 ± 0.05</td>
<td></td>
</tr>
</tbody>
</table>

*Table from Buratti (1983,1985).

---

Fig. 15. Plot of Minnaert $k$'s of the Saturnian satellites and Europa compared with the lunar $k$. Bright satellites have values for $k$ significantly higher than the Moon's, whereas the moderately bright Rhea and Dione closely follow lunar behavior (figure from Buratti 1984).
Fig. 5. Fitted V-band phase curves for 24 Themis, using (a) Hapke’s model, and (b) Lumme and Bowell’s model.

Fig. 6. As Fig. 5, for 44 Nysa.

Fig. 4. Fitted phase curves for (a) Mercury, using Hapke’s model, and (b) the Moon, using Lumme and Bowell’s model.

Fig. 11. As Fig. 5, for 1862 Apollo.
Figure 1. Observations of 1 Ceres (Tedesco et al. 1983) and 4 Vesta (Gehrels 1967) compared with predicted phase curves from Hill et al. (1984) and Hapke parameter fits (Table 1) using two different values of $\theta_0$ and $4\theta_0$. (a) Predicted curve for Ceres plotted to large phase angles; (b) enlarged Ceres plot for $\theta > 4\theta_0$; (c) phase curve for Vesta plotted to large phase angles; (d) enlarged Vesta phase.
Fig. 17. Near-infrared opposition brightness surges of Ariel, Umbriel, Titania and Oberon. Also plotted are the visual opposition surge data for Saturn’s rings from Franklin and Cook (1965). The data for the Uranian satellites contain an arbitrary offset to facilitate comparison to the data for Saturn’s rings (figure from Brown and Cruikshank 1983; also Fig. 6 in the chapter by Cruikshank and Brown).

### TABLE IV

Hapke’s Model: Parameters for Fitted Phase Curves

<table>
<thead>
<tr>
<th>Body</th>
<th>w</th>
<th>$B_0$</th>
<th>$h$</th>
<th>$b$</th>
<th>$\bar{\theta}$</th>
<th>rms Residual (mag)</th>
<th>Geometric Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 Themis</td>
<td>0.048</td>
<td>1.6</td>
<td>0.060</td>
<td>0.40</td>
<td>5°</td>
<td>0.011</td>
<td>0.061</td>
</tr>
<tr>
<td>44 Nysa</td>
<td>0.58</td>
<td>0.6</td>
<td>0.0055</td>
<td>0.40</td>
<td>27</td>
<td>0.014</td>
<td>0.492</td>
</tr>
<tr>
<td>69 Hesperia</td>
<td>0.154</td>
<td>0.94</td>
<td>0.036</td>
<td>0.40</td>
<td>35</td>
<td>0.017</td>
<td>0.147</td>
</tr>
<tr>
<td>82 Alkmen</td>
<td>0.183</td>
<td>1.4</td>
<td>0.047</td>
<td>0.28</td>
<td>5</td>
<td>0.017</td>
<td>0.138</td>
</tr>
<tr>
<td>133 Cyrene</td>
<td>0.204</td>
<td>1.19</td>
<td>0.022</td>
<td>0.383</td>
<td>10</td>
<td>0.012</td>
<td>0.21</td>
</tr>
<tr>
<td>419 Aurelia</td>
<td>0.204</td>
<td>0.47</td>
<td>0.030</td>
<td>0.60</td>
<td>25</td>
<td>0.011</td>
<td>0.044</td>
</tr>
<tr>
<td>1862 Apollo</td>
<td>0.28</td>
<td>0.98</td>
<td>0.026</td>
<td>0.325</td>
<td>2</td>
<td>0.042</td>
<td>0.21</td>
</tr>
<tr>
<td>Mercury*</td>
<td>0.21</td>
<td>1.85</td>
<td>0.030</td>
<td>0.40</td>
<td>20</td>
<td>0.12</td>
<td>0.14</td>
</tr>
</tbody>
</table>

*A three-term Legendre polynomial was used for \( p(\alpha) \) [cf. Eq. (5)] with \( c = 0.4 \).