Clementine Observations of the Zodiacal Light and the Dust Content of the Inner Solar System

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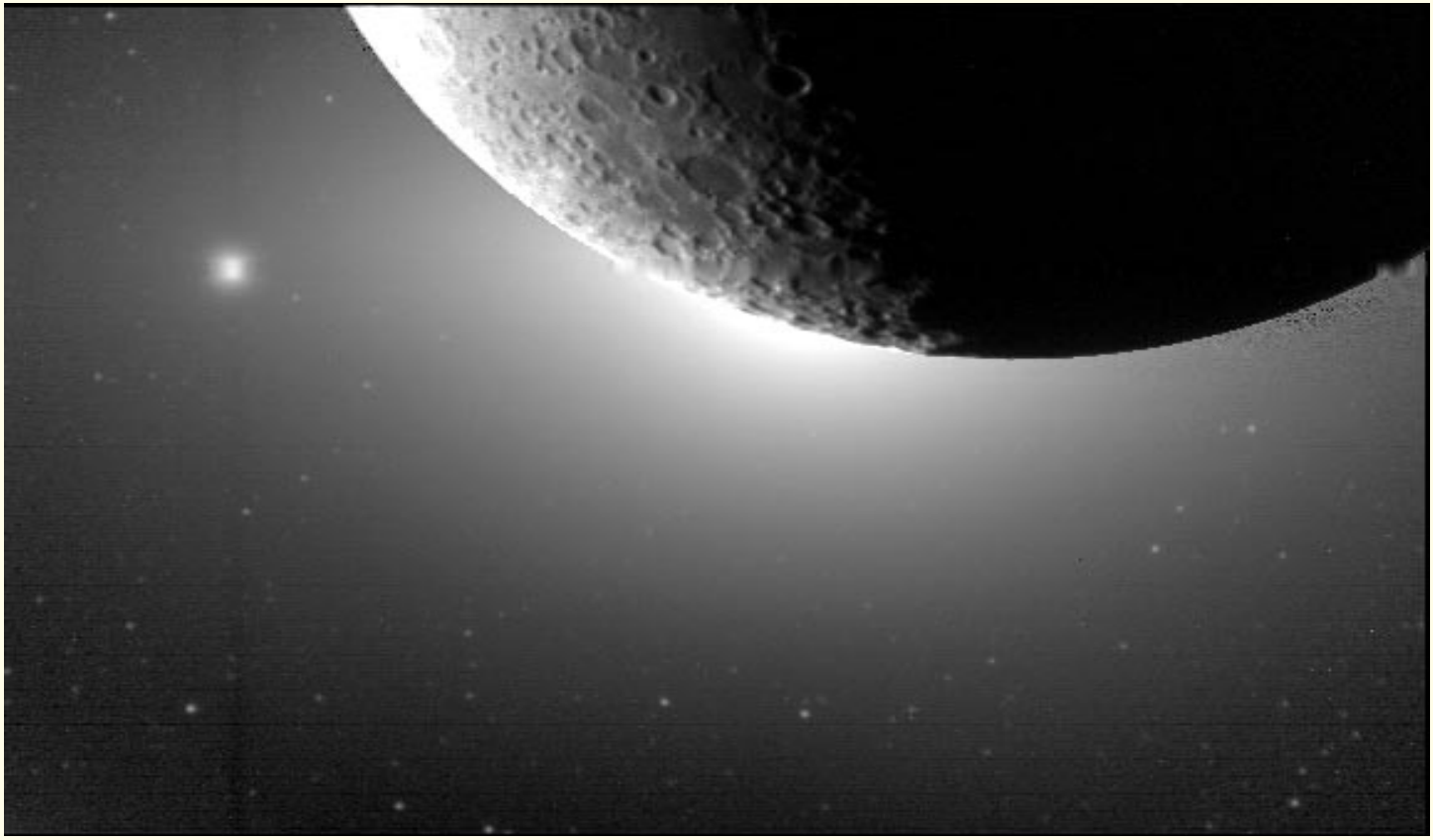
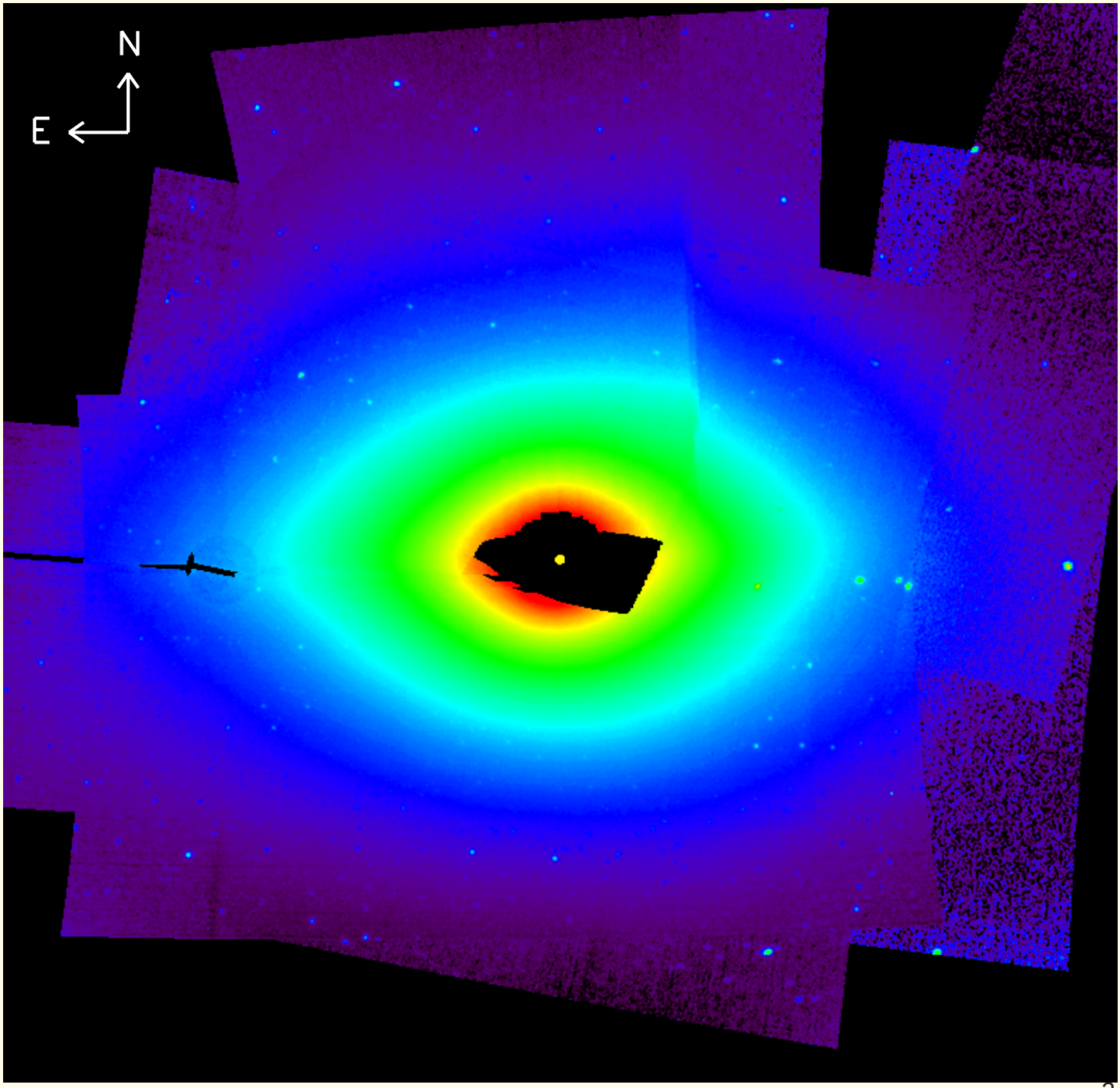
November 19, 2001



The Clementine spacecraft orbited the Moon in 1994. With the Moon occulting the Sun, the spacecraft used its navigation camera to acquire hundreds of wide–angle images of the inner zodiacal light at optical wavelengths over elongations $3 \lesssim \epsilon \lesssim 30^\circ$.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Apply Model $\Rightarrow$ Abundance of Asteroidal & Cometary Dust

Assume density of dust cross section varies as

$$\sigma(r,\beta) = \sigma_1 \left(\frac{r}{r_1}\right)^{-\nu} h(\beta).$$

The ZL surface brightness Z is (Aller *et al.* 1967)

$$Z \propto \frac{a\sigma_1}{\sin^{\nu+1}\epsilon} \int_{\epsilon}^{\pi} \psi(\varphi) h(\beta_\varphi) \sin^{\nu}\varphi d\varphi$$

where

a = dust albedo,

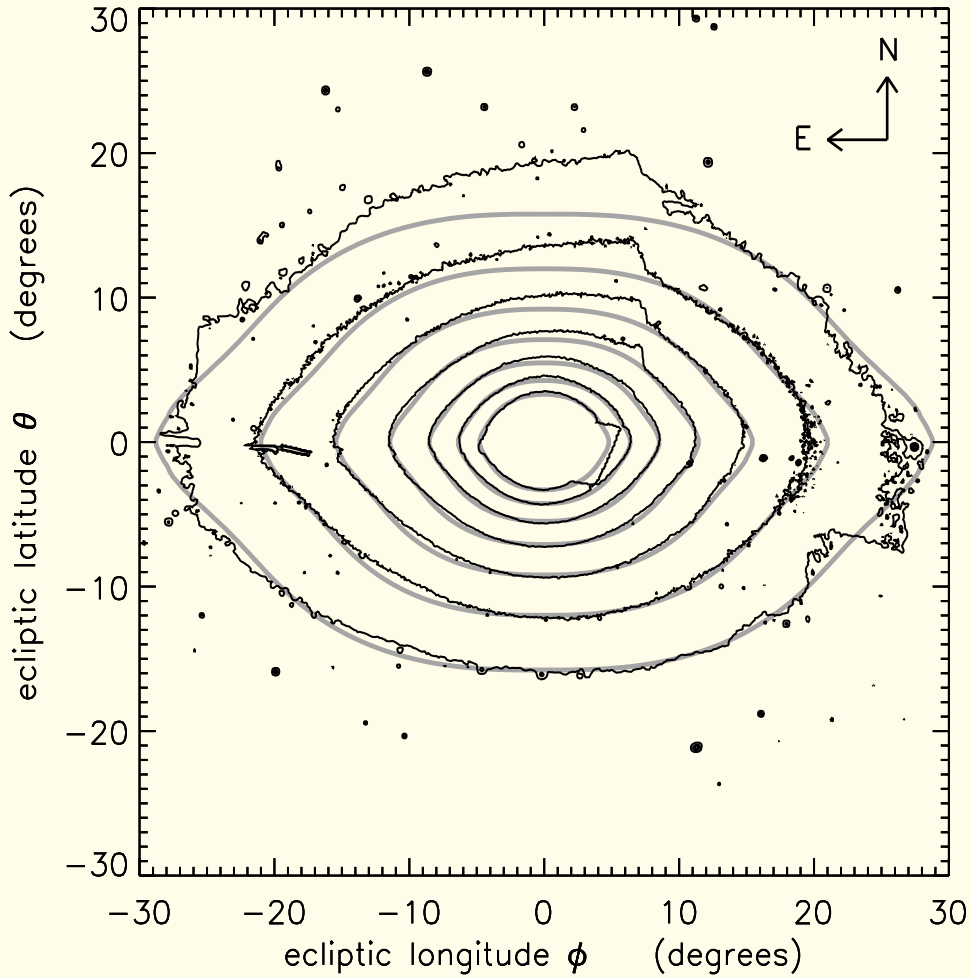
σ_1 = dust cross section density in ecliptic at 1 AU,

ψ = empirical phase law (Hong 1985), and

$h(\beta)$ = dust latitude distribution.

Note that the dust latitude distribution $h(\beta)$ depends on the inclination distribution $g(i)$.

- Assume that the dust have a $g(i)$ identical to that of their sources (e.g., asteroids and comets).
- Assume each dust–source j has a gaussian distribution of inclinations: $g_j(i) \propto \sin i \times e^{-(i/\sigma_j)^2/2}$.
- the asteroidal dust source has $\sigma_{ast} \simeq 6^\circ$.
- the cometary dust sources have 3 distinct subpopulations:
  - Jupiter–Family comets have $\sigma_{\mathrm{JFC}} \simeq 8^\circ$.
  - Halley–Type comets have $\sigma_{\mathrm{HTC}} \simeq 33^\circ$.
  - the isotropic Oort Cloud comets have $g_{\mathrm{OCC}}(i) \propto \sin i$.



Fractional contribution by each population to the *ecliptic dust cross–section at 1 AU*:

- $f_{\text{ast + JFC}} = 45 \pm 13\%$
- $f_{\text{HTC}} = 50 \pm 2\%$
- $f_{\text{OCC}} = 5 \pm 2\%$

Summary of Findings

- at most 45% of the ecliptic dust cross section is contributed by sources in low–inclination asteroid–like orbits.
  - extrapolate out to the asteroid belt: $M_{ast} \lesssim 2 \times 10^{18}$ gm $\Rightarrow 12$ km asteroid.
- when considering within a 1 AU radius sphere, *at least 90%* of the dust cross section is in high–inclination cometary orbits.
- observed asymmetries of $\sim 10\%$ in the ZL surface brightness:
  - North–South asymmetry is consistent with the zodiacal cloud's tilt wrt. the ecliptic (Leinert 1980).
  - East–West asymmetry is likely due to giant planets secular gravitational perturbations, aka pericenter glow.