PIGGYBACK INSTRUMENTATION ON LUNAR ORBITAL SURVEYORS FOR CHARACTERIZING ZODIACAL DUST WITHIN 1 AU OF THE SUN.

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Introduction: Zodiacal dust ("zodi") is a tenuous but important component of our solar system that originates from ablation of cometary material, and from collisions between asteroids that orbit primarily between Mars and Jupiter. Zodi material is subject to perturbative forces, primarily Poynting-Robertson drag and photon pressure, which cause particles larger than a few microns to migrate towards the sun and ejects very small particles from the Solar System [1]. The larger, migrating particles will pass through the inner solar system and be subject to interactions with the inner planets, the Sun and nearby environment. In fact, the Earth collects about 40,000 tons of this interplanetary dust each year.

Measuring the spatial distribution of zodi dust grains, the temporal changes in that distribution, the specific chemical constitution, and the physical dimensions of the grains are all important for understanding the formation and evolution of our solar system. Such knowledge also enables us to better place our solar system in context with the growing number of planetary systems being discovered around other stars (e.g. [2],[3],[4]). Unfortunately, the evolutionary processes and composition of zodi grains in various zones within our solar system are still not understood in detail (e.g., [5]). Furthermore, many specific questions have barely been addressed, including the destruction of grains near the sun (they should evaporate when their equilibrium temperatures reach ~1200-1700K), perturbations and wakes caused by the inner planets, and the interaction between the inner zodi and the solar corona.

Observing Zodi: Zodi dust scatters and polarizes sunlight, and is visible on the horizon of an Earth-based observer just after sunset and before sunrise. The sun's UV light also heats the dust, which then reradiates this energy at infrared wavelengths. The Infrared Astronomical Satellite (IRAS) illustrated this well with images of thermal infrared emission from dust bands associated with known asteroid families and with comet trails (e.g., [6]).

While the zodiacal dust in our solar system has been characterized to some extent beyond 1 AU using space- and ground-based observations, the nature of grains and their detailed spatial distribution inside the earth's orbit is not well constrained. This deficiency is primarily due to the difficulty of observing the emission from zodi dust against the overwhelming glare of the sun and, on the ground, the overwhelming brightness of the daylight sky. High-altitude airplane and balloon missions or space-based platforms can reduce or eliminate the skylight, respectively, but cannot eliminate the solar glare. In principle, this difficulty can be overcome by blocking the sun with a space-based coronagraphic imaging system or by observing during a solar eclipse [7]. Tracking a solar eclipse with a high-altitude, aircraft-borne system is possible, but atmospheric scattering still imposes sensitivity limits that can only be overcome by observing from space. Therefore, a space-based platform is the best option.

The Clementine Mission: The lunar orbit of the Clementine spacecraft provided a unique opportunity to observe the inner zodi light. While the spacecraft was in lunar umbra, the solar glare otherwise contributing to the sky background was virtually eliminated Using Clementine star-tracker images obtained in lunar shadow, Hahn et al. [8] measured the optical intensity of the zodiacal light between 10 solar radii and 0.7 AU (Figures 1 & 2). These data provided important constraints on the spatial distribution, and on the particle albedos within the inner zodiacal cloud. However, the spatial resolution is very low, and the measurements do not allow the color or the polarization properties of the zodi light to be measured; this information is vital for constraining the sizes and shapes of the grains.

Here, we present the possibility of extending the method pioneered by the Clementine experiment by piggy-backing simple, dedicated instrumentation on future lunar surveying missions. Such instruments could provide multi-wavelength polarization observations with moderate spatial resolution, permitting assessment of the particle sizes and spatial distributions within the inner zodiacal cloud.

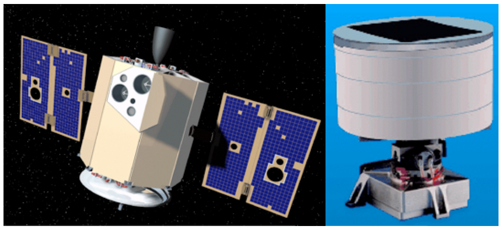

Figure 1. Clementine (left) carried two star trackers (right). Each weighed less than 290 gm; had dimensions of 12 x 12 x 14 cm; and required 4.5 W. Each used silicon CCD technology with a 384 x 576 pixel array sensitive to wavelengths between 0.4 and 1.1 µm, and had a wide field of view (29° x 43°).

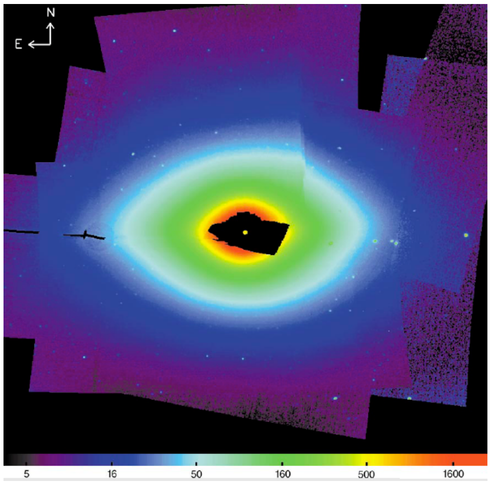

Figure 2. A mosaic of seven fields of the inner zodi light observed by the Clementine star tracker cameras. The color bar indicates surface brightness in units of 10^{-13} B_{sun}. Ecliptic north is up and east to the left in this Mercator projection; the field of view is 60° × 60°. The Sun is drawn to scale at the mosaic center. Black indicates gaps in the data. Regions beyond ~10° northwest of the Sun are polluted by scattered light, and the "dimple" 20° east of the Sun is a lower signal/noise patch that was polluted by Venus [8].

The Piggy-Back Concept: Many space-based missions have reserve payload capability that often goes unused. Instead of flying "dead weight," this reserve could be exploited by small instruments such as we propose here. Piggy-backed instrumentation on existing missions has recently been lauded as an economical way to provide space-based, astronomical instrumentation [9][1], and a recent example is the Lunar CRater Observations and Sensing Satellite (LCROSS), selected in April 2006 to piggyback on the Lunar Reconnaissance Orbiter in 2008.

A Proposed Instrument for Investigating the Inner Zodi: A simple instrument, piggy-backed onto a lunar orbiting surveyor mission, would provide multi-band polarimetric imaging at optical and near-infrared wavelengths. Additionally, longer wavelength imaging to capture thermal infrared emission would be very desirable to uniquely specify particle sizes and albedos, though trade-off studies for particular spacecraft architectures would be required given the cooling requirements for longer wavelength observations. The capability to measure linear polarization provides crucial information on the scattering phase functions of the dust, and thus the internal structure of the grains [5]. However, this capability could add complexity in a single instrument package that might be better implemented as two separate instruments, which could be flown in a separate bay, or on a separate mission.

Science Operations: Science operations could be supported by existing infrastructure. One example might be the capabilities already in place that support the Cassini imaging team (CICLOPS) at the Space Science Institute.

Conclusions: Piggy-backed instrumentation could provide important data about the inner zodiacal dust cloud for a small increment in payload mission cost and minimal risk. The data would complement existing and future measurements of the outer zodiacal cloud such as provided by the upcoming WISE infrared space mission, constrain models of the evolution of dust within our solar system, and provide insight into dust-disk mechanisms in other planetary systems.

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