PROSPECTS FOR DETECTING AND CHARACTERIZING ASTEROID SATELLITES WITH NASA'S HIGH-ALTITUDE BALLOON PROGRAM.

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Introduction: NASA's Balloon Program Office (BPO) regularly flies payloads weighing several tons at altitudes of 33 - 38 km, above 99.3% - 99.6% of the Earth's atmosphere, respectively. Balloon-borne telescopes operating in the stratosphere have four distinct advantages over ground-based telescopes with respect to detecting and characterizing asteroid satellites.

- The Fried parameter, *r0*, is thought to be larger than 4 meters at float altitudes, compared to 10-15 cm at good terrestrial sites. Balloon-borne telescopes should have diffraction-limited performance as a result, even at visible and UV wavelengths where ground-based adaptive optics (AO) systems typically have poor Strehl ratios. As an example, a one-meter aperture telescope in the stratosphere has a Point Spread Function (PSF) width of 0.12" at λ=0.5 µm, which enhances the signal-to-noise ratio (SNR) of a faint object observed next to a bright primary.
- Balloon-borne telescopes have access to most of the UV and IR spectrum (Figs. 1,2), with sky backgrounds dominated by zodiacal light and sky emission lines [1].

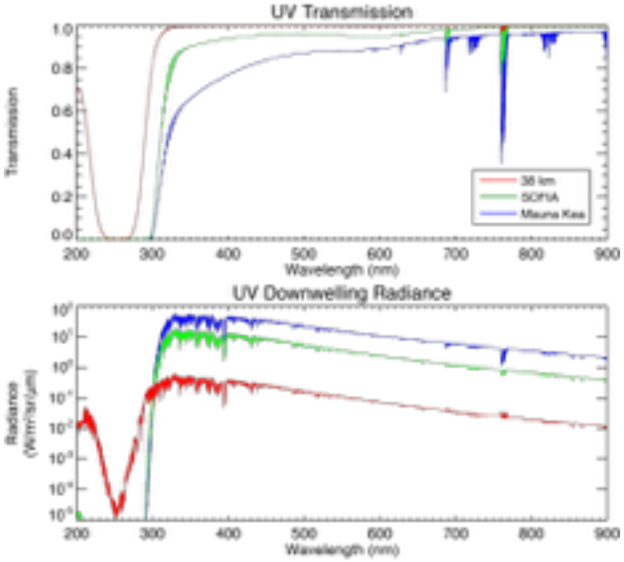

Figure 1a. Telluric transmissions and downwelling radiances in UV-Visible wavelengths (200 - 900 nm) at three altitudes, corresponding to the summit of Mauna Kea, SOFIA (40,000 ft) and a balloon platform at 38 km.

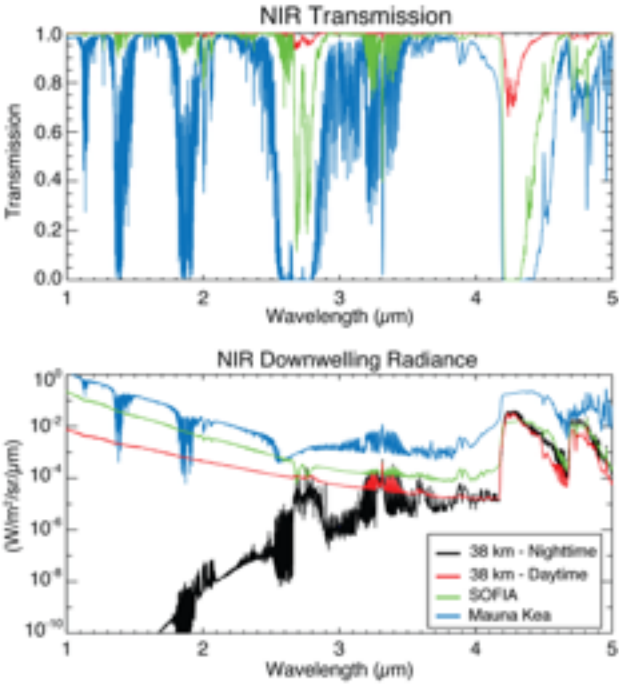

Figure 2. Telluric transmissions and downwelling radiances in IR wavelengths (1-5 µm) at three altitudes, corresponding to the summit of Mauna Kea, SOFIA (40,000 ft) and a balloon platform at 38 km.

- Balloon-borne telescopes should have better SNR of faint light curves compared to ground-based sites, for two reasons. First, there is virtually no scintillation noise at float altitudes. Second, the SNR benefits from a narrow PSF, allowing finer platescales and reduced areas of sky background.
- NASA has developed super-pressure balloons with nominal flight durations of ~100 days [2]. These platforms provide consecutive nights to help determine satellite orbits or asteroid light curves.

Ongoing Work: The THAI-SPICE Project: The THAI-SPICE balloon project (*Testbed for High-Acuity Imaging - Stable Photometry and Image-motion Compensation Experiment*) will study two of the main obstacles to obtaining sharp images from a balloon platform: motion of the focal plane and temperature-induced optical aberrations. In addition, it will carry a wavefront sensor that may eventually drive a deformable mirror to reduce wavefront aberrations.

Thermal gradients are a problem on balloon platforms. Heat transfer is dominated by radiation, as in space, but the ambient atmosphere is thick enough to thermally short-circuit the normal MLI (Multi-layer insulation) radiation blankets. Day-to-night temperature excursions on balloon payloads typically exceed 50 K, which can be devastating to carefully aligned optics. THAI-SPICE will fly a system of sunshields, earth-shields and telescope insulation to passively reduce thermal gradients to a few degrees (K).

Image motion on a balloon is produced by various pendulation modes in the flight train and by vibrations from mechanisms on the gondola, such as cryocoolers. Several balloon missions have demonstrated coarse pointing to stabilize the motion of their focal planes to less than 2” (rms). Additional stabilization is then required to reduce image motion from a few arc-seconds to a fraction of an arc-second (e.g., to 0.05” rms, or half the width of the PSF of a one-meter aperture at λ=0.5 μm). THAI-SPICE will demonstrate a solid-state fine-pointing device: an orthogonal transfer CCD (OTCCD) to move the image on the detector during exposures to compensate for tip-tilt pointing errors.

NASA’s GHAPS project (*Gondola for High-Altitude Planetary Science*) showed the difficulty in producing a diffraction-limited OTA (Optical Telescope Assembly): Catanzaro et al., 2018 [3] describe how a suite of factors (such as elevation sag, thermal distortions, mirror cell support structures) can blow the wavefront error budget. THAI-SPICE will measure wavefront errors in flight to determine whether relatively inexpensive telescopes – combined with deformable mirrors – can produce images of sufficient quality to be useful in finding asteroid satellites.

Conclusions: Balloon-borne telescopes are well-suited to making direct observations of binary asteroid systems, as they provide long time-baseline observations with good acuity at visible wavelengths and good telluric transmissions at IR wavelengths. We report on the THAI-SPICE experiment and its plans to address three problems: thermal gradients, image motion and wavefront errors.

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References: [1] Chanover et al., 2016. “Findings Report: Gondola for High Altitude Planetary Science Science Instrument Definition Team”, <**http://tinyurl/ghaps-sidt-report**>. [2] <**https://www.csbf.nasa.gov/balloons.html**>. [3] Catanzaro et al., 2018. “STOP modeling in support of a 1-meter aperture balloon based telescope. <**https://doi.org/10.1117/12.2312312**>.