**The Atsa Suborbital Observatory: using crewed suborbital spacecraft for a low-cost space-borne telescope.**
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**Introduction:** We discuss a human-tended suborbital flight program supporting NIR observations, suitable for a variety of Solar System targets. A suborbital platform gives an observatory two distinct advantages over a ground-based system. First, a suborbital telescope, at ≥100 km altitude, is above telluric water in the Earth's atmosphere, allowing access to the complete IR spectrum of an object, as well as other wavelengths (e.g. UV). Second, an inexpensive telescope can observe inside the solar exclusion angles of robotic orbital telescopes. For example, the solid angle excluded for the Hubble Space Telescope is $50^{o}$[1]; for Spitzer Space Telescope, it is $82.5^{o}$[2]. Observations of inner-Earth asteroids, Sun-grazing comets, comets reaching perihelion at heliocentric distances < 1 AU, and the planets Mercury and Venus, all must be made in the vicinity of the Sun. Human-tended suborbital missions could also have significant advantages over sounding rockets currently in use: flights are less expensive, allowing for more observations in a campaign; the payload is recovered without damage, allowing for a much longer operational lifetime.

**Instrument Concept:** For this initial concept, the Atsa Suborbital Observatory ("atsa" is the Navajo word for eagle) would be an infrared system consisting of a Schmidt-Cassegrain telescope with an aperture of 356 mm and a focal length of 3.97 m ("telescope"), along with a commercially-available infrared camera at the focal plane ("camera"). The camera would accomodate a filter wheel, and be sensitive to the spectral range of 0.8-2.5 µm with a quantum efficiency over 70%. The telescope is attached to a gimbal system and drive motors. The exact configuration will depend on the vehicle used: in the case of Virgin Galactic's SpaceShip2, the gimbals might be attached to the front aperture of the telescope, and attach, via a frame or bracket, to the SS2 porthole. Gross telescope steering would be provided by the spacecraft; fine steering is provided through the gimbal system. This telescope would have diffraction-limited resolution of about 2.6 km/pixel on the Moon near 2.0 µm for lunar observations. Actuation might be motor-driven, potentially with a steadicam-like system to track the target through perturbations of the spacecraft (similar systems currently fly on Air Force Predator and Reaper drones). The initial target acquisition would be done manually by the operator. Control of the telescope, including data acquisition, would be done with a ruggedized laptop computer. Later versions of the observatory might use a UV or X-ray instrument, with as much common hardware as possible.

*Heritage and development status:* For the initial IR concept, the telescope and focal plane components are all commercially available. The parts that must be custom fabricated include the interface between the telescope and the camera, the mounting system (gimbals, bracket, etc.), the drive system, and specified filters.

*Size, mass, power, data:* The notional telescope diameter is 14 in, length is 31 in. The tube weight is 45 lb. The camera is ~ 6.5 lb, and ~ 8 in long. The computer is 5.1 lb. Truss and drive motors are loosely estimated here at 50 lb. Total mass is ~ 100 lb. The camera uses a power source that accepts 80-240V AC, and would either need a power from the spacecraft, or an on-board battery. The flight is short enough that battery power could be sufficient for both devices. The gimbal drives might similarly be battery-powered, but this is subject to power availability on the vehicle and current draw of the gimbal drives. All data would be stored on the computer. There would be no real-time data streaming from the instrument, and no data storage requirements levied on the vehicle.

**Solar System Study Example:** Target acquisition and tracking for faint, moving point sources represents the greatest observational challenge. Solar System targets that could benefit from the scientific data provided by human-tended suborbital spacecraft, and the design challenges presented by them, illustrate the utility of these types of observations. As an example, consider an inner-Earth asteroid:

From ground-based telescopes, these asteroids require twilight observations through high atmospheric air masses for both asteroid searches and photometric or spectral characterization. These objects are also point sources. These asteroids are, however, compelling to observe and study both scientifically and operationally. They are likely representative of daughter asteroids that moved to near-Earth space following the collisional destruction of a main-belt asteroid, but could be extinct comets or comet fragments. Near-Earth asteroids do not have stable orbits; they survive a few Myr before crashing into the Sun, a terrestrial body, or being ejected from the Solar System [3], [4]. We benefit scientifically from observing these objects as they represent asteroids that were disrupted during recent Solar System history, and can be windows into the interior composition and formation conditions that occurred in the inner main asteroid belt, much less affected by surface alterations due to exposure in space ("space weathering").

The near-Earth asteroids also represent the population of objects most likely to produce the next major impacting body to the Earth. Designing an effective mitigation capability requires an inventory of the number and physical characteristics of NEAs.

Most NEAs have reflectance spectra similar to those of iron-bearing mafic silicates (e.g., olivines, pyroxenes, plagioclases), consistent with the S-class asteroids that dominate the inner main asteroid belt. Other NEAs, however, have characteristics similar to the C-class asteroids that dominate the outer main belt, many of which have reflectance spectra similar to aqueously-altered rocks (e.g., phyllosilicates, iron alteration materials). Physical properties of these different minerals vary, suggesting important differences among asteroids of these classes. Two properties of particular importance are mineralogical composition, which can determine grain density (and constrain the NEA's bulk density [5]), and the geometric albedo, which can determine the NEA's size. Visible photometry provides one means of estimating geometric albedo through assumptions about absolute magnitude, H, from photometric measurements [6]. Thermal IR radiometry coupled with visible photometry provides an extremely accurate measure of the albedo.

Visible and NIR spectral region photometry should include filters to define the existence of iron-bearing silicates and phyllosilicates, and the overall trend of the slope of a featureless spectrum. Thermal infrared radiometry requires mid-IR observations made at a wavelength near 10 µm. Measuring temperature from observations at two different thermal IR wavelengths permits a measurement of albedo. Background signal for thermal IR observations is greatly reduced, and affords better detection of a faint NEA. All could be achieved as part of a human-tended suborbital flight.

**Requirements on a suborbital spacecraft:** Use of a suborbital spacecraft for astronomical observations could impose new requirements on vehicles that might be planning for tourist flights. Some targets could require a night launch, which might require upgrades to the craft's avionics to allow for night flight. It might be necessary for a single experiment to take up an entire launch: in the case of SpaceShip2, instruments would be restricted to looking out of portholes, and unless the instruments are looking at the same target (and are in coplanar portholes), it is unlikely that two different instruments could be accommodated on the same flight. An observatory flight would likely not be suitable for flying tourists. On the one hand, the spacecraft may have to fly in an attitude which is disadvantageous for Earth viewing in order to accommodate pointing at the target; on the other hand, pointing stability requirements of the telescope will likely necessitate all participants remaining seated, and not hitting the side of the spacecraft (as they would do if free-flying), even if the telescope were isolated from passengers.

*Flight planning and training requirements*. As the period of time above the atmosphere is mere minutes, effective time management is critical to mission success. This will require choreographing the mission beforehand, and understanding the timing of critical events, such as maneuvers and deployments, to the second. Flight training for the crew should include NASA-like practice of the mission profile, with plenty of simulated missions run before the real thing.

*Window*. The ideal location for an instrument would be on the exterior of the spacecraft to avoid all issues with window tranmissivity. Any window must have good transmissivity across the desired spectral range (tentatively, 0.8 – 2.5 µm for the infrared telescope concept). A purpose-built window might be needed (as is planned for XCOR's Mk 2 Lynx vehicle [7]).

*Stray light*. Accommodation for stray light issues will depend on the spacecraft configuration. In the case of SpaceShip2, this may include essentially turning off all lights inside the cabin to avoid reflections from the window, and optically shielding the data acquisition station from the telescope. Scattered light from the spacecraft exterior must also be accounted for: this may mean using a certain attitude to put the telescope in the spacecraft shadow, or even altering the spacecraft exterior to minimize reflected light. Given that one of the great strengths of a low-cost suborbital system is its ability to observe close to the Sun, thorough understanding of and planning for light reflected from the spacecraft will be critical to mission success. Accomodation issues should be worked with spacecraft designers early in their process.

*Pointing requirements*: Spacecraft pointing control needs to be within the field of regard of the telescope, which will depend on the window size versus the telescope diameter, etc. If we are using a pre-existing window, which ostensibly has a constant thickness, we will want to limit the movement of the telescope so that we do not see time-dependent effects due to seeing a changing transmission coefficient at different angles.

**References:**

[1] HST Primer for Cycle 17, 2.3 Pointing Constraints (2007). [2] Gerhz, et al., Rev. Sci. Instrum. 78, 011302 (2007). [3] Morbidelli, A., et al. (2002), in Asteroids III, pp. 409- 422, U. Az Press. [4] Bottke, W. F., Jr., et al., (2002) Icarus 156, 399 – 433. [5] Britt, D., et al. (2002), in Asteroids III, pp. 485 - 500, U. Az Press. [6] Harris, A. W., and Lagerros, J. S. V., (2002) Asteroids III, pp. 205 - 218, U. Az Press. [7] Greason, J., personal communication.