# MILLIWATT LUNAR VLBI BEACONS: SURVIVING THE LUNAR NIGHT

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**Introduction:** The exploration of the Solar System can be enhanced by the use of femtospacecraft, small autonomous units which can be used to provide multiple observation points or in hazardous environments where there is a strong risk of loss of individual nodes. In order to meet the more demanding requirements of operation in deep space and to create true spacecraft swarms to meet various operational goals we are developing the Pixie femtospacecraft [1] (see Figure 1). A Pixie is 80 x 40 x 9 mm with a mass $<$ 80 grams. These small units can act as autonomous spacecraft, or as modular nodes attached to or integrated with other spacecraft, rovers and equipment send to or near the Moon.

**Lunar VLBI Networks:** Low power ($<$ 1 milliW) Pixie transmissions could be used as a source for differential Very Long Baseline Interferometry (VLBI) observations from Earth [2, 3] using the new VGOS VLBI system [4]. The scientific goals would be to provide nanoradian accuracu astrometry and transverse positions with a single-observation accuracy of $/sim$50 cm. Each Pixie would broadcast a unique code-multiplex signal so that same beam interferometery could be performed with multiple beacons on and off the lunar surface.

These measurements would meet a number of scientific goals, including improvements in the Lunar ephemeris (transverse VLBI measurements of lunar rotation would nicely complement the on-going program of radial measurements from Lunar Laser Ranging). These beacons would serve as geodetic control points on the Lunar surface, directly tying the Lunar, planetary and extra-galactic reference frames and also allowing for differential position measurements of rovers and smallsat lunar orbiters.

**Surviving the Lunar Night:**

The scientific and programmatic goals of a lunar geodetic VLBI network would be best met with beacons able to survive the Lunar night. EThe Pixie would provide a battery, solar power and also computer control of beacon broadcasts (either on a regular schedule, or in response to local conditions or uplinked commands).

The minimum sustained power consumption of a Pixie beacon would be order 10 milliWatt. This amount of power can be provided from a roughly 1 gm Americium-241 battery [5] which, with an ultracapcitor for short term power needs, should suffice to power a continuous permanent VLBI network on the lunar surface for decades to come. This deployment would also serve as a test of small nuclear batteries likely to become increasingly important for small spacecraft missions into the outer solarsystem and interstellar space [6, 7].

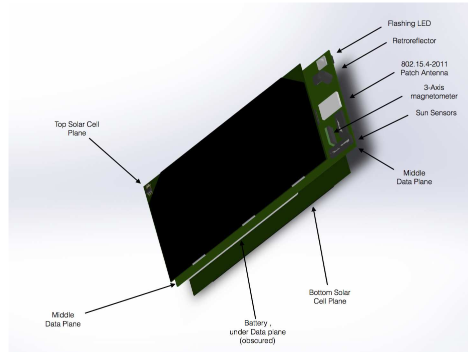


Figure 1: The Asteroid Initiatives Pixie Asteroid Instrumentation set (without insulation).

**References:** [1] T. M. Eubanks, et al. (2017) in *Lunar and Planetary Science Conference* vol. 48 of *Lunar and Planetary Science Conference* 1577. [2] G. Klopotek, et al. (2017) in *EGU General Assembly Conference Abstracts* vol. 19 of *EGU General Assembly Conference Abstracts* 433. [3] S. V. Pogrebenko, et al. (2004) in *Planetary Probe Atmospheric Entry and Descent Trajectory Analysis and Science* (Edited by A. Wilson) vol. 544 of *ESA Special Publication* 197–204. [4] R. Haas, et al. (2015) *IAU General Assembly* 22:2257511. [5] L. Cordingley, et al. (2011) in *9th European Space Power Conference* vol. 690 of *ESA Special Publication* 130. [6] A. M. Hein, et al. (2017) *ArXiv e-prints* (1711.03155). arXiv:1711.03155. [7] A. M. Hein, et al. (2017) *ArXiv e-prints*. arXiv:1708.03556.