Cubesats for Astrophysics

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Cubesats are small satellites build to multiples of a standard unit of 10 cm x 10 cm x 10 cm (1U). They are launched in rideshare agreements with larger missions. Because they are launched in isolated pods, they add little risk to the main payload. Standardization has created of a lively market for components, which has reduced prices and allowed small companies and universities to launch their own satellites. Within the first five months of 2015, 30 cubesats were launched into space. This was in line with the explosive growth of cubesat missions in the last few years (Figure 1).

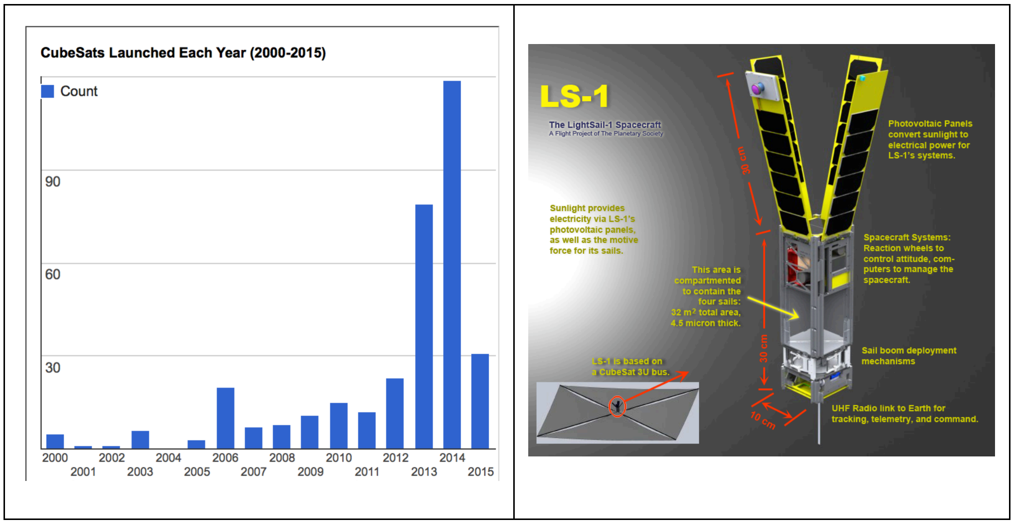

Figure1: (**Left**) Number of cubesats launched each year (as of June 3, 2015). The total number so far is 341 cubesats. Data and plot from M. Swartwout [1]. (**Right**) Example of a recent #U Cubesat, The Planetary Society's LightSail [2].

Most of these missions have been technology demonstrators, and hardly any of them has had astrophysics as its primary goal.[2] I would like to suggest that the technology that can fit in a cubesat volume has advanced enough that competitive astrophysics is possible.

For the purposes of this discussion, I focus on 3U or 6U cubesats. I will limit the discussion to the detection of photons: payloads used to detect cosmic rays, gravitational waves, or neutrinos are not considered here.

Observational Parameter Space

Telescope designs with apertures between ~10 cm to ~20 cm that would fit in 3U to 6U cubesats have been proposed for astrophysics missions [3]. These apertures

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[1] The opinions expressed here are not necessarily those of The Aerospace Corporation. This white paper does not contain any proprietary information.

[2] From my count, only the six 1U cubesats from the BRITE mission have primarily an astrophysics goal (http://www.brite-constellation.at/).

are small enough that it likely does not make scientific sense to pair them with a spectrograph in the focal plane, although narrow-band photometry may be competitive.

To assess the niches that a cubesat astrophysics mission may occupy I consider the following parameters:

- **Wavelengths:** Cubesats are not competitive in the visible, unless there is a particular application (i.e. high precision photometry) or instrumentation package that is difficult to do from the ground.
  Thermal IR observations requiring cryogen will likely not be possible, given the mass limitations of the cubesat standard (1.3 kg/U). Some near-IR applications may be competitive using thermocouples and miniature cryocoolers.
  In the UV the limitation is the relatively low throughput of typical optical systems. However, advances in δ-doping processes have increased the intrinsic QE of silicon detectors to values close to 100% [4]. This allows for better sensitivity with a smaller aperture, compared with previous generations of telescopes.
- **Survey vs. pointed observations:** All-sky photometric surveys have been performed at 0.1-2.4 keV (ROSAT) and at almost all wavelengths from 1516 Å (GALEX) to 100 μm (IRAS). A cubesat operating at any of these wavelengths will not be able to compete in sensitivity with previous facilities. However some X-ray and radio bands are good candidates for all sky surveys. At other wavelengths, cubesat science should center on specific objects or object classes.
- **Single epoch vs. time domain:** As with small observatories from the ground, cubesat telescopes cannot compete with larger telescopes when performing single-epoch observations. However, larger facilities, both on the ground and in space are generally not operated in a time-domain mode (e.g. "observe the same object once every three days for 3 months"). Time-domain observations are a unique niche that small telescopes (on the ground and in space) can exploit.

This analysis suggests that cubesats can be competitive if they carry specialized instrumentation and/or they perform time-domain observations of a limited class of objects in the UV or near-IR, or they perform all-sky surveys in the X-rays or the radio.

Other studies have also found these regions of the observational parameter space as potential cubesat niches. Under the sponsorship of the Keck Institute for Space Sciences (KISS), the workshop on "Small Satellites: A Revolution in Space Science" [5] resulted in three astrophysics concepts that fall within the constraints suggested above: (1) SoftX: An all-sky survey in soft X-Rays using two cubesats in a sun-synchronous orbit. (2) Relic: An all-sky, aperture synthesis survey, using ~30 3U cubesats in L2 observing at <30 MHz. (3) UVIP-UV: a fleet of 15 cm to 20 cm apertures observing young, active galaxies, at wavelengths between 912-2400 A.

Spacecraft Bus Limitations

In terms of the spacecraft bus capabilities, communications and pointing are generally seen as limiting factors for possible science. However for most applications communications are not an issue. Modern UHF radios can downlink ~5 MB per ground station pass, and optical systems being developed can downlink up to 1 GB per ground station pass [6]. For comparison, a 1k x 1k detector will produce ~2 MB images. Therefore, unless the application involves very dense sampling of large fields or infrequent passes, downlink technology will not limit the possible astrophysics activities.

Pointing is more problematic. Pointing jitter (high frequency attitude changes), coupled with flat-field errors and non-negligible dark current, imposes a hard limit on the achievable S/N. Current state-of-the-art attitude control systems for cubesats can provide jitter control to ~10" (see for example [7]). For a 10 cm (20 cm) aperture, this implies that the telescope should only be diffraction limited down to 5 μm (10 μm). Pointing remains the limiting factor in the achievable spatial resolution.

The time-domain and all-sky survey aspects of the astrophysics applications require lifetimes in excess of 1 yr, which in turn imposes requirements on the lifetime of components and their response to the space environment. These lifetimes are achievable, as demonstrated by the long-lived long-lived satellites like Aerospace's AeroCube4, launched in 2012 and still functioning normally. However, reaching them is not trivial and requires careful attention to component development and testing.

Funding

Within the NASA context, astrophysics cubesat missions are funded as part of the ROSES Astrophysics Research and Analysis (APRA) call. While cubesat technology development is funded by several program elements, the ROSES-APRA is the only element that explicitly requires a strong science component. APRA cubesats share the call with suborbital missions such as balloons and sounding rockets, perhaps because of the fact that they are Class D missions[3] . In 2013, the total awarded funding for suborbital missions was $5.7M.

Typical cubesat costs are difficult to gauge from public sources and accurate pricing models have not yet been developed. However, some estimates are possible. Procurement costs for typical buses are modest ($50K to $100K per U [8]). The actual cost of producing a cubesat, ready to be delivered for launch, depends on who builds it. Universities, depending primarily on students and labor not charged to the project, can develop and launch a cubesat for as low as $100K to $1M per U [9].

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[3] NASA missions are classified as A, B, C, or D, depending on their risk. Class D is low priority, low to medium national significance, low to medium complexity, low cost, short lifetime, few launch constraints, and alternative flight opportunities (NASA procedural Requirements 8705.4).

I believe that these very low costs are not representative of the development of a competed astrophysics mission. While cubesat form factors are standard, no two astrophysics applications are the same and a requirements-based mission involves the development or adaptation of reliable communications systems, high precision pointing, thermal control, development of qualification models, and integration and testing. These factors increase bus costs to ~$750K/U [10]. The development price of a state-of-the-art payload depends on its complexity but it will be comparable to the bus price. After including operations (~1 yr) but not launch, the mission price for a 3U is likely to be larger or equal than ~$5M.

While not all of the $5M required for a cubesat will be spent on one year, the amount is large enough that even funding one cubesat per APRA call will result in significant budgetary pressure on balloons and sounding rockets. Given these rough estimates, the funding amounts in the APRA call seem inadequate.

Conclusions

While it is possible to perform competitive science from a cubesat platform, these small satellites remain underexploited for astrophysics. There are unexplored regions of the observational parameter space that can be exploited with a cubesat. Possible applications include pointed observations of particular targets, time-domain science, UV and radio observations, etc. Pointing is currently limited to ~10”, but there are a number of applications that do not require higher resolution imaging. I suggest increasing the funding element in the APRA suborbital call to ~$10 M, or creating a completely new program element.

References:

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