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Small satellites - Useful tools for multifrequency astrophysics

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The very small satellites, recently in development at many institutes and universities worldwide (e.g. Schmidt et al. 2009 and Schilling 2006), represent, apart from growing commercial applications, a challenge for multifrequency astronomy and astrophysics, as they can provide valuable data even with miniature payloads. We present and discuss some ideas with emphasis on the developments at the CTU in Prague.

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1. Introduction

While the large scientific satellites in general and astronomical satellites in particular are extremely difficult to fly due to funding limitations and huge competition especially at major space agencies such as ESA and NASA, the small and very small satellites represent nowadays promising alternative based on recent technological developments. The miniature satellites are recently in development at many institutes and universities, in numerous cases with a participation of students so that there is an essential educational aspect as well. The fast development of the related techniques and technologies enables the growing commercial applications, but also to consider scientific applications of these small satellites. In addition, fast progress in related control engineering aspects allows to consider tandem cubesats flights as well as fleets of cubesats, meeting some particular scientific aspects.

2. Pico and nanosatellites for multifrequency astrophysics

In this paper, we focus on application of pico and cubesatellites in X-ray and UV astrophysics, with emphasis on the recent developments at the CTU in Prague. It is however evident that also payloads for other energy ranges e.g. visible light and IR can be considered as well. Also employable structures can be applied in some specific cases in order to achieve larger apertures in orbit.

In general, the motivation for application of picosatellites in X ray and UV astrophysics is as follows.

- The recent situation in experimental satellite high-energy astrophysics is not very promising
- E.g., LOFT was not selected as ESA M3 mission
- In the past, large projects such as ESA XEUS, NASA Cons X, ESA/NASA/JAXA IXO were canceled
- A hope remains with Athena+ but that is a distant future
- QUESTION: IN WHAT EXTEND MAY THE VERY SMALL SATELLITES FILL THE GAP?

The picosatellite missions represent a cost effective solution for space astronomy and astrophysics and also less strict requirements for space qualification of used components if compared to larger satellites developed by space agencies. However, there are still the following strict requirements for the scientific payload for picosatellites. (i) The scientific payload must fit into a small volume, typically $30 \times 10 \times 10$ cm or less (3U, i.e. 3 cubesat modules), (ii) it must be of low weight, less than 1 kg, (iii) with low power consumption of about 10 Watts or less.

Apart from scientific goals, the picosatellite missions can be used for technological tests such as TRW (Technology Readiness Level, a method for estimating the maturity of technologies during the acquisition phase of a program, developed at NASA during the 1970s and nowadays used by space agencies including ESA) increase, flight demonstrations, etc.

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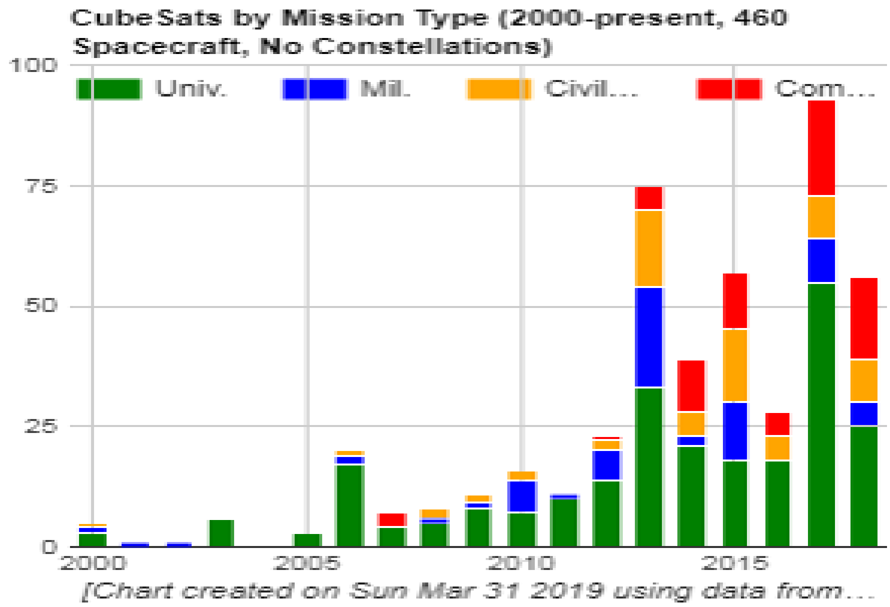

Figure 1: Cubesatellites by mission type. https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database.

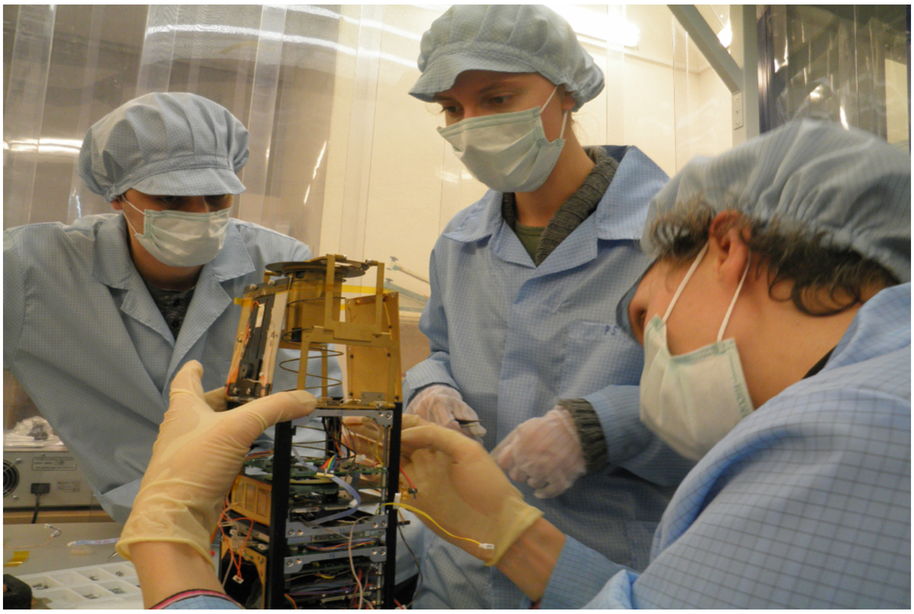

Figure 2: Assembly of Czech cubesatellite VZLUSAT-1 with miniature Lobster Eye X-ray telescope on-board (Urban et al., 2017, Baca et al., 2016).

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In this paper we give and discuss some upgraded and recent ideas for picosatellites astrophysical X ray and UV applications, i.e. scientific payloads, with emphasis on developments at the CTU in Prague. It is not describing any particular space mission hence no details about the real space

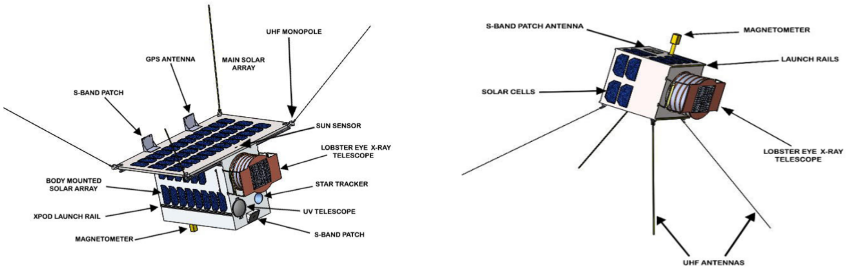

Figure 3: The configuration of 16U cubesatellite with both X-ray telescope as well as UV telescope on board (left) and 8U cubesatellite with UV camera (right).

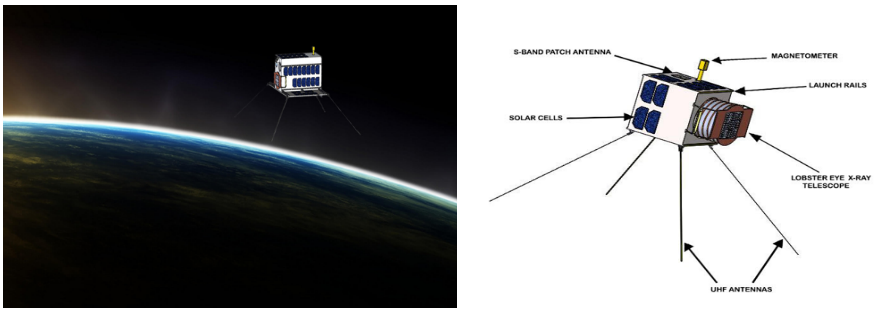

Figure 4: The picture illustrating the small 16U cubesatellite for X ray and UV astronomy (left) and design of 8U cubesatellite for X-ray astronomy with Lobster Eye X-ray telescope onboard (right).

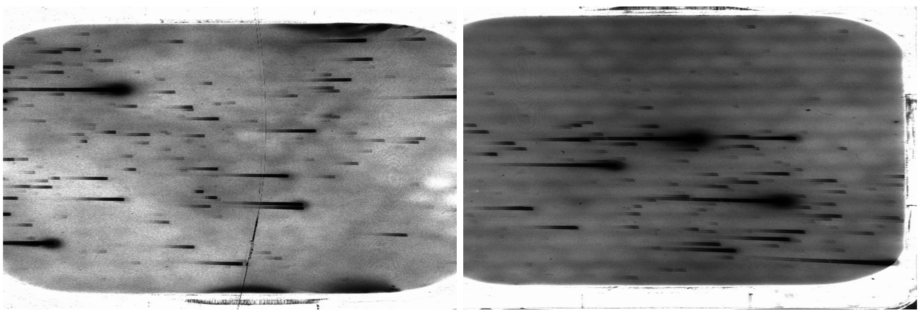

Figure 5: The newly digitized photographic negatives from the Skylab UV telescope (Skylab ultraviolet stellar astronomy experiment S019). Modified design could be used for 8U or 16U cubesatellite for stellar low resolution UV spectroscopy.

mission such as processing resources, ground support system and TTC (Telemetry, Telecommand and Control), orbit, temperature requirements of detectors and their qualification plan, etc., are addressed in this contribution.

3. Miniature payloads for X–ray and UV astronomy and astrophysics

Some astrophysical X–ray instrumentation can be successfully miniaturized for cubesat appli-

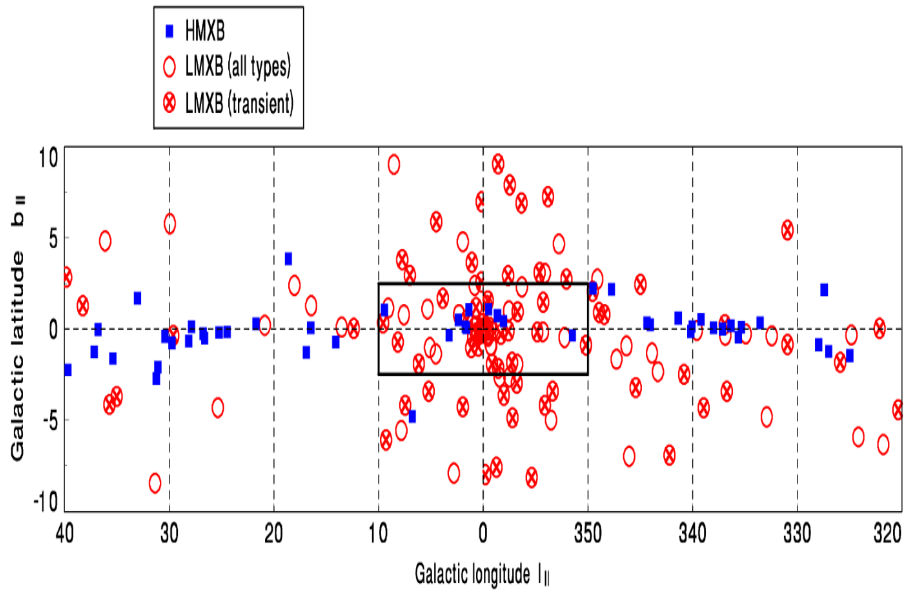

Figure 6: The field of the center of the Galaxy (20 x 80 deg). The positions of known LMXBs and HMXBs are marked. The field proposed for the monitoring by lobster is marked by the oblong – it contains a number of the already known objects.

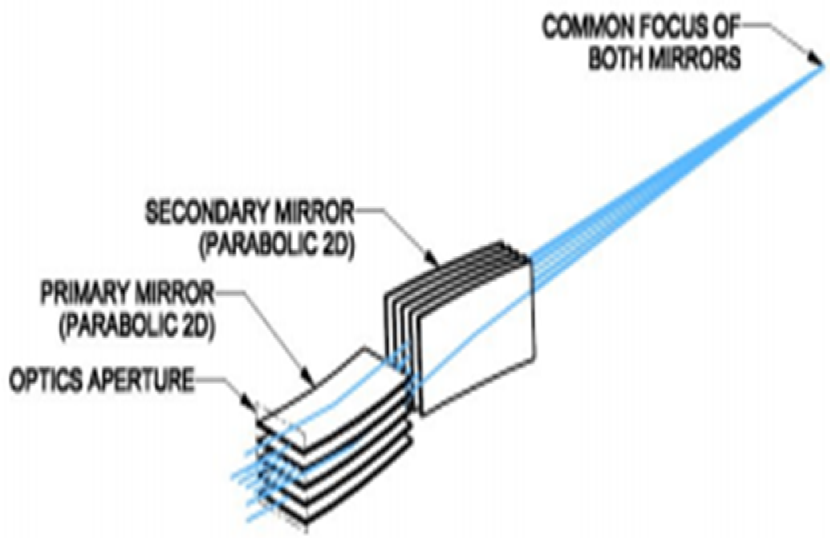

Figure 7: The schema of the Kirkpatrick Baez X-ray mirror module suitable for tandem flight on cubesatellites because of long focus when compared with Wolter lenses.

cations. The most promising application area is represented by wide field X–ray lenses. The Lobster Eye (LE) X-ray optics was originally proposed by Schmidt (1975) and Angel (1979). Since then, numerous test specimens of Lobster Eye telescopes were designed and tested (e.g. Inneman et al. 1999; Hudec et al. 2000, 2003, 2004; Tichý et al. 2009, 2011). The Lobster-Eye (LE) X-ray telescope can be miniaturized for an application in picosatellites. The LE telescopes are novel wide field X-ray telescopes with the field of view (FOV) of 100 sq. deg. They are more easily possible (a classical X-ray optics has the FOV of only 1 deg or less) and are based on a real analogy with the lobster eyes.

The miniature X–ray telescopes requires miniaturized focal detectors as well. The one of best available options is the detector Medipix (Timepix). Medipix is a family of photon counting pixel detectors developed by an international collaboration, hosted by CERN. The CTU in Prague is a member of this cooperation. The Medipix detector represents a suitable imaging detector for a use in space LE telescopes, as it is a pixelated photon counting semiconductor detector which features adjustable energy thresholds allowing multispectral X-ray imaging. These detectors offer several different working modes for X–ray imaging applications (e.g. Procz et al., 2012): (i) Single pixel mode (SPM): one threshold with a large 24–bit counter providing a high dynamic range or two thresholds with separate 12–bit counters providing two energy channels. This enables dual channel X–ray imaging with a single acquisition, and (ii) Charge summing mode (CSM): to reduce the influence of charge sharing effects, in this mode charge deposited to adjacent pixels will be summed up and assigned to the pixel featuring the highest signal. The space application was demonstrated recently e.g. onboard the VZLUSAT1 cubesatellite (Baca et al., 2018).

Additional possibilities are provided by more advanced solutions such as cubesatellite tandem flights and fleets. Some types of X–ray lenses are especially suitable for tandem flights (Fig. 7).

Wide field X-ray monitors of Lobster Eye type were demonstrated to play an important role in modern astrophysics (e.g. Hudec et al. 2007; Švéda et al. 2004). The most important scientific cases, apart from regular all sky monitoring, are briefly summarized below. (i) A long-term (months) measurement of the light curves of bright persistent X-ray binaries in the direction toward the center of the Galaxy in the soft X-ray band (Fig. 6). and (ii) Detection and measurement of the light curves of bright transient events of X-ray binaries in the direction toward the center of the Galaxy in the soft X-ray band (Fig. 6).

The LE telescopes can typically serve in two basic operation modes as follows. (i) Starrying (pointed) mode – only for satellite with pointing, and (ii) Scanning mode (no satellite pointing and/or stabilization required).

The LE application on cubesat was demonstrated on the VZLUSAT minisatellite (Urban et al., 2017, Baca et al., 2016). The spectral energy range can be extended toward higher energies up to 30 keV aby application of 1D (one dimensional) LE arrangement (Pina et al., 2016). This is based on the fact that there is only one reflection in 1D systems, compared to the two reflections in the full LE (2D) system..

4. Conclusions

The recent fast progress in cubesats technologies allows picosatellites with extended lifetime as excellent platforms for cost effective astrophysical payloads providing reasonable scientific results to be considered. The proposed mission designs for X-ray and UV astronomy can acquire scientifically important data for a low price, if compared to large satellite missions.

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