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Astrophysical payloads for picosatellites

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Abstract. The recent progress in cubesatellite technology allows to consider scientific applications of these minsatellites including astrophysical research. Miniature X–ray and UV–payloads may serve as an example.

Key words: cubesatellites – picosatellites – X-ray monitoring– UV–astrophysics

1. Introduction

The miniature satellites are recently in development at many institutes and universities, mostly with a participation of students. The fast development of the related techniques and technologies enables to consider small scientific payloads for these satellites. Below we give a small summary of pico (cube) and nanosatellites.

– CubeSat standard size is 1 Liter Volume, i.e. 10×10×10 cm, and a typical weight is 1.3 kg.

– Multiple modules are possible, i.e. 3U = 3 modules/units, i.e. 10×10×30 cm, typically up to 12U.

– The typical masses are as follows: femtosatellite 10 to 100 g, picosatellite 0.1 to 1 kg, nanosatellite 1 to 10 kg, microsatellite 10 to 100 kg.

– Recent technological progress allows to consider a use in astrophysics,

2. Scientific payload for pico and nanosatellites

In this contribution, we focus on application of pico and cubesatellites in high-energy astronomy and astrophysics. The motivation for application of picosatellites in high-energy astrophysics is as follows.

– The recent situation in experimental satellite high-energy astrophysics is not very promising.

– LOFT was not selected as ESA M3 mission.

– ESA XEUS, NASA Cons X, ESA/NASA/JAXA IXO were canceled.

– A hope remains with Athena but that is a distant future.

Obvious question is: TO WHAT EXTEND MAY THE VERY SMALL SATELLITES FILL THE GAP? It is obvious that also some lower energy astrophysical payloads may fit the picosats volume, e.g. UV and/or optical (visible light) payloads. However, there are the following strict requirements for the scientific payload for picosatellites.

– It must fit a small volume, typically 30 × 10 × 10 cm or less (3U, i.e. 3 cubesat modules).

– It must be of low weight, less than 1 kg.

– The low power consumption of about 10 Watts or less.

– Technological tests: TRW increase, flight demonstration, etc.

– Reasonable science.

– It is not easy to find such an instrumentation, especially not in high–energy astrophysics.

The purpose of this paper is to present and discuss idea for picosatellites scientific payload. It is not describing any particular space mission hence no details about the real space mission such as processing, resources, ground support system and TTC, orbit, temperature requirements of detectors and their qualification plan, etc., are addressed here.

3. Miniature X-ray/telescope monitor

The Lobster Eye (LE) X-ray optics was originally proposed by Schmidt (Schmidt, 1975) and Angel (Angel, 1979). Since then, numerous test specimens of Lobster Eye telescopes were designed and tested, e.g. (Hudec et al., 2015). The Lobster–Eye (LE) X-ray telescope can be miniaturized for an application in picosatellites (Pina et al., 2014). 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 (Hudec, 2010; Sveda et al., 2009). The LE payload for picosatellites also requires miniaturized focal detectors. The best available option for miniature telescopes is the detector Medipix (Timepix). Medipix is a family of photon counting pixel detectors developed by an international collaboration, hosted by CERN (http://medipix.web.cern.ch/MEDIPIX/). 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 (Baca et al., 2016). These detectors offer several different working modes for Xray imaging applications: (i) Single pixel mode (SPM): one threshold with a large 24bit counter providing a high dynamic range or two thresholds with separate 12 bit counters providing two energy channels. This enables dual channel Xray 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. However, the following items are important: (1.) The detector is not yet space qualified; (2.) Its spectral coverage starts only in energies above 3 keV, while the spectral coverage of the LE optics in the Schmidt arrangement is typically from the visible light up to the energies of 8 or 10 keV.

The small LE Telescope for a picosatellite can be represented e.g. by the following example:

- Energy of 4.5 keV = 7.2 x 10^{-6} erg.
- Focal length 250 mm, h=30 mm.
- Weight less than 1 kg (optics: 50 g, detector: 50 g).
- FOV 2 deg x 2 deg, gain=820.
- Daily minimal flux: 9.2 x 10 $^{-10}$ erg s $^{-1}$ cm $^{-2}$

However, a more suitable spacecraft is a 6U CubeSat as it allows to accommodate several LE modules to increase the final FOV. We elaborated a design of a new SLE prototype as follows. More mirror plates (thin glass gold coated foils in Lobster Eye optical module in Schmidt arrangement) : 333 per set, a larger input area (10 × 10 cm) and hence higher gain, a special coating to increase the reflectivity at higher energies, a better manufacturing technology, the focal length kept at 250 mm, larger FOV (approximately 10 × 10 degrees).

3.1. Science objectives

Wide field X-ray monitors of Lobster Eye type were demonstrated to play an important role in modern astrophysics. The most important scientific cases are briefly summarized below.

- 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
- 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.

3.2. Modes of Operation

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

4. VZLUSAT–1

VZLUSAT–1 cubesatellite represents example of 2U cubesatellite with advanced astrophysical payload onboard (Dániel et al., 2016). The mail payload is represented by one dimensional (Pína et al., 2016) miniature X–ray telescope (Pina et al., 2015) with Widepix detector in its focal plane (Baca et al., 2016). The main mission goal is technological verification of the system but scientific outcome is also expected for bright celestial X–ray sources (Urban et al., 2016; Daniel et al., 2016).

Figure 1. LE 1D optical module of the VZLUSAT1 miniature X–ray telescope (left) and the Widepix pixel detector (right). Widepix is pixel detector from the MEDIPIX family with 256 x 256, 55 m pixel size, 14 mm x 14 mm area

5. Future plans

We have elaborated proposals for future 8U and 16 cubesatellites as X–ray and UV counterparts of successful project BRITE (Pablo et al., 2016). Albeit the project was not selected for funding, we plan to further evaluate the proposal for potential future submissions.

For future, we plan to include miniature UV LDS (Low Dispersive Spectroscopy) Camera as Picosatellite Payload (UV BRITE). This study addresses the question, namely Does one can miniaturize UV telescope/camera as payload for small satellites? Miniature but still providing usable scientific results? For comprehensive review of UV astronomy with small satellites we refer to (Brosch et al., 2014).

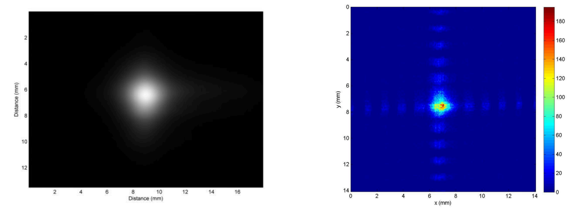

Figure 2. Image of point like source by 2D LE test module developed for NASA rocket experiment (Dániel et al., 2017) in optical light (left) and 8keV X–rays (right). The X–ray measurements were performed at the PenState X–ray test facility and the measured FWHM was 1.7 arcmin.

In these studies, the UV-BRITE payload is the miniature UV spectrographic camera, significantly upgraded camera system which was used by NASA in Gemini 10, 12 (Henize et al., 1968) and Skylab UV experiments (Henize et al., 1975) led by Prof. Karl G. Henize.

The objective of the experiment is to obtain line spectra in the wavelength 2200 to 4000 A of stars. The system will be represented by a UV camera with a UV lens with a 30-mm aperture, 100-mm focal length and a field of 30 degrees in diameter (preliminary values). CMOS or cooled CCD detector will be used as an image detector in the focal plane. As an alternative, an objective grating will be used to produce a dispersion of 180 Angstroms per mm at 2000 A. In addition, the quartz objective prism which produces a dispersion of 1400 Angstroms per mm at 2500 A is considered to be used.

Here, the proposed configuration represents 3U to 8U cubesat (or 16U in the case of installing together with X–tay instrumentation). The main features are: Deployable mechanismus to extend length, UV lens or folded reflector, Aperture 3 to 10 cm, Focal detector sCMOS detector e.g. e2V1 CIS101-00-*-M05 chip. This device has 1415 (H)1430 (V) pixels each 14.81 micron 11.53 micron in size, and Objective prism or grating for spectroscopy.

As for the UV lens, there are some options to be considered for further study on the market e.g. (TBC) UV-VIS 105mm CoastalOpt SLR Lens JENOPTIK's CoastalOpt 105 mm UV-VIS SLR Lens is a alternate to the Nikon 105/4.5 UV Nikkor lens. The lens has color corrected performance in the range from 250 nm - 650 nm. Crisp images covering this entire bandwidth can be captured without focus adjustment or compensation.

The instrumental design was expected to be optimized during the first epoch of the project. Then the final detector selection will be made as well as optimized optical design (lens objective versus mirror system, dispersive element optimization, etc.) Planned parameters are mass 2kg, power 2W, data 2MB per day, volume: 80 x 80 x 150 mm. For the astronomical observation we required

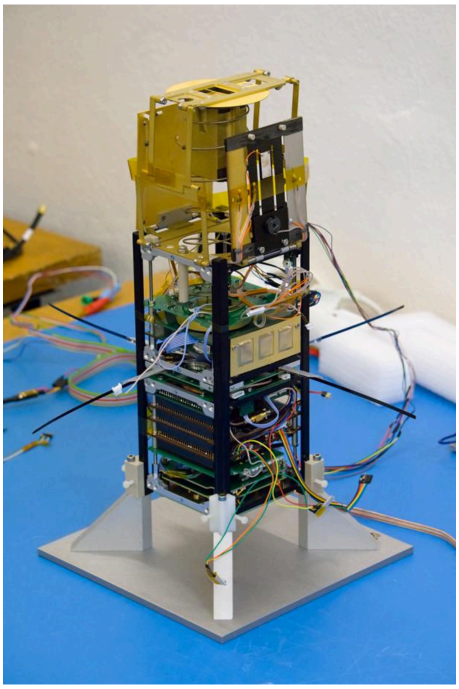

Figure 3. VZLUSAT1 2U cubesatellite with miniature X–ray telescope/monitor (in space extendable to 3U)

pointing knowledge better than 30 arcsec.

One promising possibility for miniature UV astrophysical payload is the low dispersive UV camera.The LDS (Low-Dispersion Spectroscopy) astrophysics was evolved and performed at numerous observatories (many in US) between ca 1909 and 1980. Mostly LDS with Schmidt telescopes (plates with objective prism) were used for various projects e.g. QSO, emission line and Halpha surveys, star classifications, etc. but little used after 1980, with today knowledge among astronomers very limited. Note the terminology: Objective prism spectra = Slit less spectra.

The considered exxperiment could represent some upgraded analogy of Gemini UV spectroscopic experiments, i.e. UV lens aperture 22 mm, f =73 mm, f/3.3, FOV 30 degrees, spectral region 2300 – 5000 A, Grating 184 A/mm at 2000 A, 600 lines/mm (Gemini X, XI and XII), and/or Prism 1400 A/mm at 2500 A (Gemini XI, XII), this instrumentation was operated during EVA (outside spacecraft), or Henize Skylab UV experiment namely f/3 Ritchey-Chretien telescope with aperture 15 cm and FOV 4 x 5 deg, with prism dispersion 64, 365 and 1281 A at 1400, 2000, and 2800 A and spectral resolution 2, 12, and 41 A.

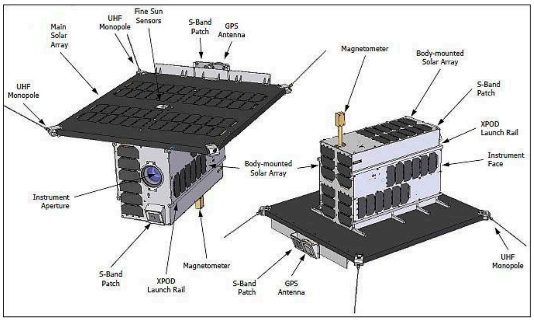

Figure 4. Small scientific satellite BRITE CZ with payload UV-BRITE and X-BRITE

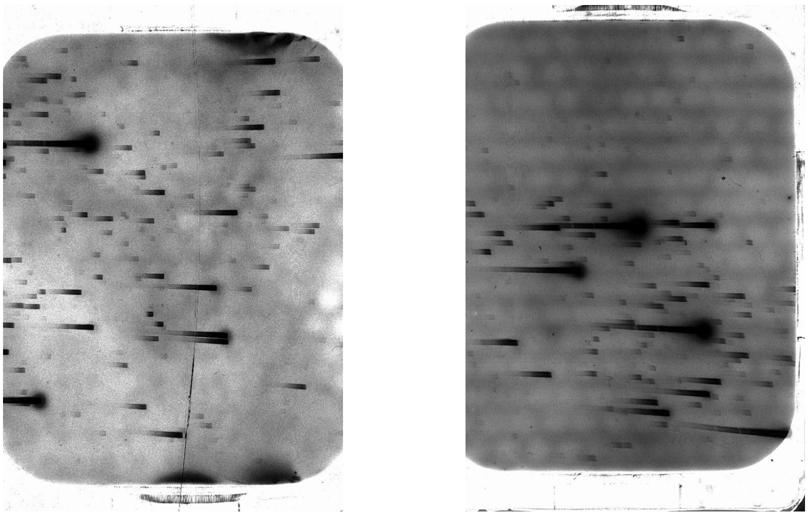

Figure 5. Original Henize Skylab film located at PARI, NC, USA, and digitized recently

The differences Gemini/Skylab vs. BRITE are as follows. (i) Recording medium will be CMOS instead of film, hence (ii) Essential increase in sensitivity, e.g. Skylab 9 mag lim. mag., BRITE 12 mag,

6. Conclusions

The recent progress in cubesats technology allows to consider astrophysical payloads. The mission of VZLUSAT1 2U cubesatellite (with miniature LE X-ray telescope/monitor) can acquire scientifically important data for a low price. The optics for this and similar missions is feasible. The scientific justification is strong, including several perspective areas of modern astrophysics. Another example is miniature UV instrumentation under study for future cubesats missions.

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