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Hard X-ray Vela supernova observation on rocket experiment WRX-R

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Abstract. This paper presents a hard X-ray telescope for the Vela nebula observation during a sounding rocket flight. The Water Recovery X-ray Rocket (WRX-R) experiment is organised by the Pennsylvania State University (PSU), USA with a primary payload of a soft X-ray spectroscope. The Czech team developed a hard X-ray Lobster-eye telescope as a secondary payload. The Czech experiments astrophysical object of study is the Vela pulsar in the centre of the Vela nebula.

Key words: Hard X-ray – Lobster Eye – Telescope – Vela Supernova

1. Introduction

The aim of the rocket experiment is to demonstrate newly developed technologies - the soft X-ray spectrometer and the hard X-ray telescope. The main payload of the mission is the soft X-ray spectrometer, developed at the Penn State University, which provides field of view (FOV) of $3.25\,\mathrm{deg} \times 3.25\,\mathrm{deg}$. This spectrometer will observe the upper part of the nebula. The Czech part of the rocket experiment is the hard X-ray telescope, respectively two of them, which will observe the lower part of the supernova remnant and the Vela pulsar. One telescope is a Lobster-eye providing a line focus, so called 1D optics. The second one is a Lobster-eye in the Schmidts arrangement, consisting of two sub-modules, which can create a 2D picture. The direct predecessor of this Czech payload is the CubeSat VZLUSAT-1 (Urban et al., 2016).

This small 2U satellite is carrying 1D Lobster Eye optics, a twin-piece of the 1D lobster on-board WRX-R. This kind of hard X-ray telescope is intended in the future for an all-sky photometric survey. In the past, several X-ray missions were launched, but most of them were not suitable for all-sky observation. Telescopes with X-ray optics were equipped with Wolter I shell optics, with a different number of nested shells and usually with cooled charge-coupled device (CCD) detectors. These telescopes, like Chandra (Weisskopf et al., 2000; Schwartz, 2014) with 4 nested mirrors or XMM-Newton (Gondoin et al., 2000) with 58 mirrors for each of three telescopes, were suitable for measurement with the angular resolution larger than 0.5 arcsec for Chandra and larger than 5 arcsec for XMM-Newton, but their FOV is only a number of arcminutes. Typically, the energetic range of observed objects was up to 10 keV.

2. The astronomical target of the mission

The rocket experiments object of interest is the Vela nebula. This supernova remnant has a size about 8 deg $\times$ 8 deg. In the centre of the nebula is the Vela pulsar. This pulsar has roughly the mass of the Sun, a diameter of about 20 km and rotates 11 times per second. It was observed by several missions and well investigated especially by Chandra, which measured the spectrum of the pulsar in the energy range of 0.25–8.0 keV. The spectrum of the pulsar does not contain any significant spectral lines. In the hard X-ray band, the Vela pulsar was observed by several missions. According to the data from these previous measurements, the expected flux in the REX band (3–60 keV) is 10^{-10} erg cm^{-2} s^{-1} (Pavlov et al., 2001; Willmore et al., 1992). After recalculation to counts per second we get approximately 0.01 counts cm^{-2} s^{-1} which corresponds to the medium value of the measured spectrum. The WRX-R maximum observation time is 298 seconds. It means approximately 90 photons for 2D REX and 18 photons for 1D REX at 10 keV for the expected observation time.

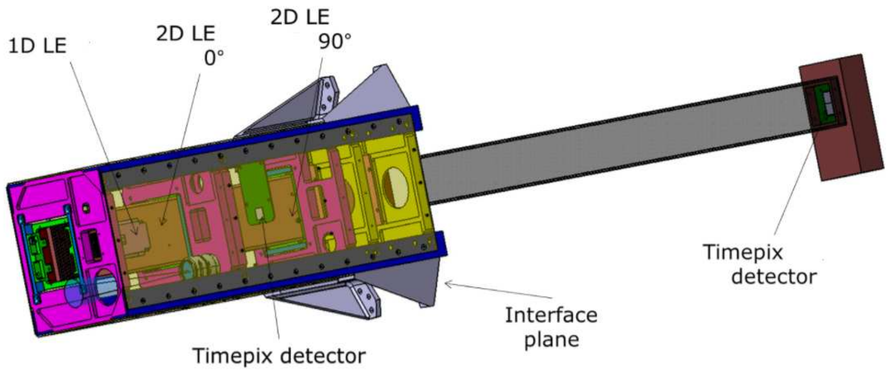

Figure 1. The arrangement of Hard X-ray payload

3. Optics and detectors

The WRX-R will carry two different Lobster-eye optics on board, the sketch of the payload can be seen in Fig. 1. The payload has three parts, the 1D optics, the 2D optics and a colour camera in the visible spectrum, which is not described here – it serves only as a star tracker for documenting the telescope orientation. The optics are built of planar glass mirrors, which are equipped with golden reflective layers, and both of them use the same type of detector – Timepix, a proportional counter. The 1D optics, the twin of VZLUSAT-1 optics, have a 25 cm focal length and a field of view of 3.5×4.5 deg. Its spectral range is 3–40 keV. The 2D optics are designed in Schmidt's arrangement (Schmidt, 1975); they consist of two sub-modules. The focal length of this layout is 1.2 m and its field of view is 1.5×1.5 deg. This arrangement is designed to operate in energy ranges of 3–60 keV (Blazek et al., 2017; Pina et al., 2015). The FOV of telescopes and the area of observation compared to the arrangement of the nebula is in Fig. 2.

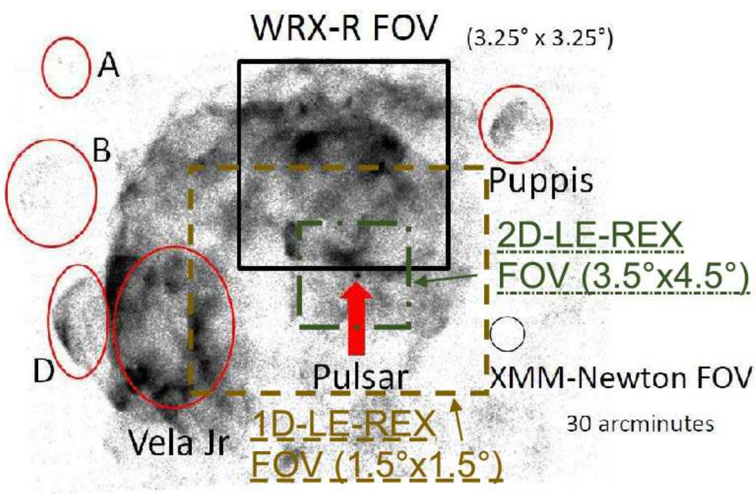

Figure 2. The field of view of all optics aboard the WRX-R compared to the FOV of XMM Newton (Dániel et al., 2017)

The Timepix is a non-cooled hybrid Complementary Metal-Oxide-Semiconductor (CMOS) pixel detector. This type of detector has already been used in space applications on board PROBA V (Francois et al., 2014) and on board the ISS (Turecek et al., 2011). The resolution is 256×256 pixels with 55 μm pitch, the active silicon layer has 300 μm thickness, physical size is $1.4 \times 1.4\,\mathrm{cm}^2$. The Timepix allows capturing photon in energy range 3–60 keV. The lower limit of the detectable range corresponds to the set threshold. This threshold can be individually set for each pixel. The detector eliminates thermal and readout noise by cutting off the signal in this manner. Each pixel is connected to its own amplifier and measuring electronics by bump-bonding. The ODROID-XU4 commercial computer is used as the evaluating device. The computer uses Linux software with a sort of real-time operating system. The computer is connected to the detector using a USB interface.

The arrangement of the rocket will have an isolated part, which will be waterproof, and a vacuum part, facing space. The optics are placed in the vacuum part, while the data-saving computers are placed in the protected part. After landing in the sea, the waterproof section will be recovered and the data downloaded. During the flight, no data from the hard X-ray payload will be streamed to the ground station.

4. Ground experiment

Pre-launch optics and detector ground experiments have already been performed. The first test of 2D optics took place at Pennsylvania State University. They were placed into a vacuum tunnel, and a radiation source of Fe-55 with a peak of 5.9 keV was placed at a 47 m distance. The flux was only 0.1 counts per sec per cm^2, but we got a reliable focus image, and this flux is ten times more intense, than the expected flux from the Vela pulsar. Since the facility was underground, there was a lot of visible noise and false signals in the resulting images, mainly paths of electron flights. To eliminate this effect, short exposures were used, and the pictures were filtered using an algorithm which saves only one-pixel events. Then, the pictures were stacked together to obtain a final image even with such low flux. A similar data post-processing strategy will be used on the rocket experiment data.

5. Summary

The Lobster-eye X-ray, built as a compact telescope consisting of two pairs of optics and Timepix detectors, will be launched as the secondary payload on the Water Recovery X-ray Rocket mission performed by the Pennsylvania State University. The astrophysical aim of the mission is to observe the Vela pulsar, located in the Vela nebula. This nebula has been well-described during previous missions; this fact makes it an ideal target for a demo mission proving a new technology such as WRX-R. The Lobster-eye will observe the Vela pulsar and its surroundings in the energetic band of 3–60 keV, and collect 1D and 2D images. The basic idea and main reason to launch the Lobster-eye payload, is to evaluate the Lobster-eye hard X-ray optics and the detector, as we are planning on proposing it for an all-sky monitoring mission in the future.

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