Low Cost Camera System for Short Term Sounding Rocket Experiment

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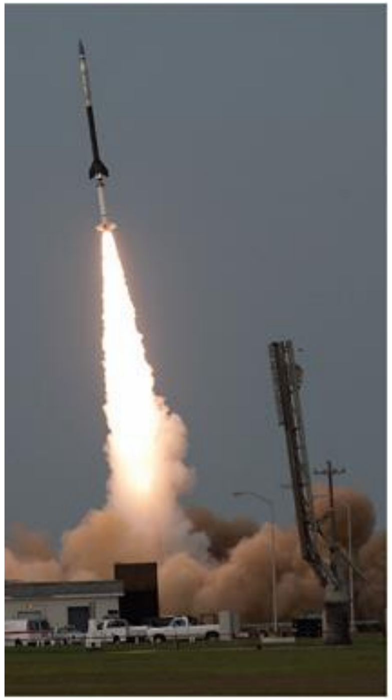
WRX-R sounding rocket mission

- Experiment of Pennsylvania State University
- Observing of Vela Supernova Remnant in X-ray
- Usage of Black Brant IX sounding rocket
- Launched 2018/04/04 from Kwajalein, Marshall Islands
- Parachute controlled landing into ocean



Czech teams involved in experiments

- 1D and 2D lobster eye roentgen optics with Timepix detector
- Camera system for pointing confirmation of Czech telescopes
- Test of infrared array, accelerometer and gyroscopes

Our camera part of mission

- Czech roentgen telescopes had slightly different target of observation
- Only small amount of particles expected to be detected by Timepix detector
- Certainty of right pointing is necessary requirement for roentgen optics validation

…. Preparation of low cost camera system for confirmation of right pointing
…. Camera selected with consideration of possible future usage in CubeSat

Camera requirements

- Small size and low power (suitable also for small satellites)
- Metal structure (good heat transfer to rocket body, no outgassing)
- Standard mount for lens (wide availability of suitable lens)
- Standard interface and wide driver support (simple programming)
- Low cost in comparison to star trackers (suitable for short one-time usage)
- Unprocessed image data support (allows special signal post-processing)
- Manual control of camera exposure (optimizing for mission objectives)

Selected camera and lens

Ximea MQ013CG-E2 – industrial camera, 1.3 Mpx resolution, USB3 interface, Robotic operating system driver, 1/1.8" CMOS sensor, max. 0.9 W of power consumption, aluminum body with dimensions 26 mm x 26 mm x 26 mm, C-mount lens interface, price 350 Euro.

ThorLabs MVL50M23 – lens with 50 mm fixed focal length, manual iris and focus with lock mechanism, 9.8° field of view with used camera, metal body, 110 g mass, price 180 Euro.

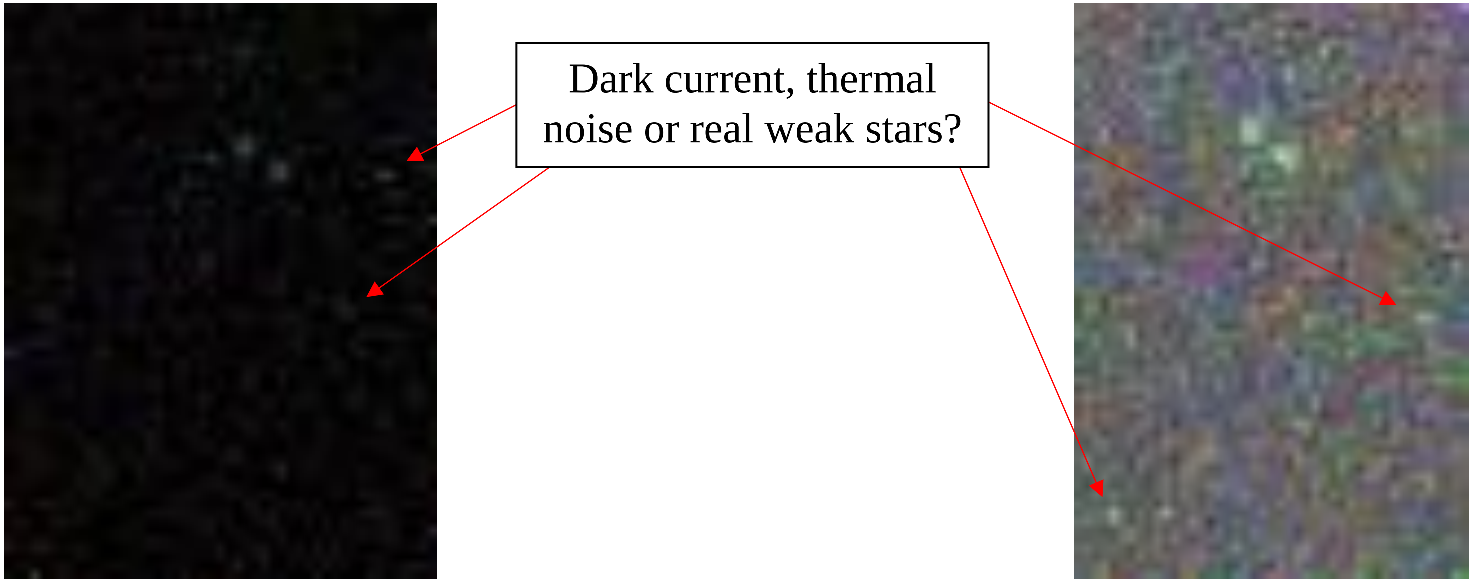
Low cost camera instead of space qualified star tracker?

- absence of radiation hardened devices not important for short term experiments outside polar region or South Atlantic anomaly
- absence of optical filters or mechanical shutter as a protection against Sun light not important, Sun irradiation eliminated by active pointing of sounding rocket
- absence of active thermal management could be a serious problem, limiting the usage of common industrial cameras in space due to noise of CMOS sensor


Captured unprocessed images during ground test of camera with exposure time 900 ms and sensor gain 5 dB (left image) and 18 dB (right image), sensor temperature was approx. 27°C. Unprocessed images are affected by thermal noise and by the dark current, allowing to recognize only bright stars (Vega, Double Double and Nasr Alwaki in figures).

Dark current and thermal noise issue

- Dark current (signal generation without incident photons) is caused by crystallographic defects in CMOS structures.
- Dark current has a relatively static character for images captured with the same exposure settings, dependent on the image sensor temperature.
- Thermal noise of image sensor has a random character even for images captured with the same exposure settings and with the same sensor temperature.
- Both effects create small point artefacts in images, masking the real captured signal of weak stars when the sensor is not actively cooled.



Post-processing image compensation proposed for rocket experiment

- Dark current is removed from each captured image by subtracting the dark frame (image captured with the same exposure settings and sensor temperature as original image, but with closed shutter) from original images.
- Thermal noise is removed by combination of spatial domain and temporal domain averaging filters applied on the time-series of compensated images.

Optimal exposure setting for unknown temperature during mission?

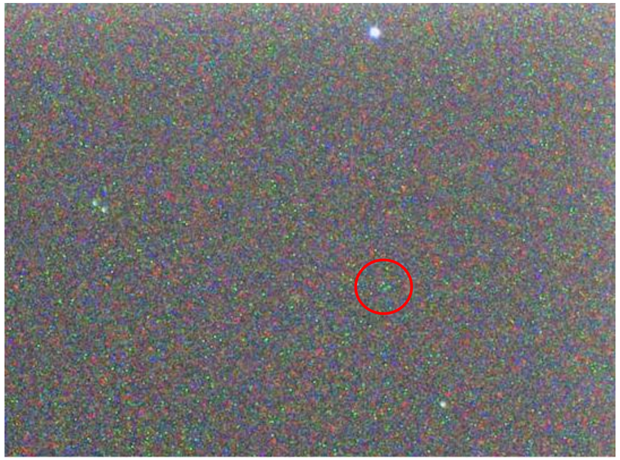
- High gain of camera sensor could capture weaker stars, but also increases the problem of dark current and thermal noise during high sensor temperature.
- Longer exposure times allow to capture weaker stars, but also increase the issue of dark current and in the case of attitude control system drift the image could be blurred.

→ we use several different exposure settings in the loop during all phases of mission to avoid improper exposure setting due to temperature effect.

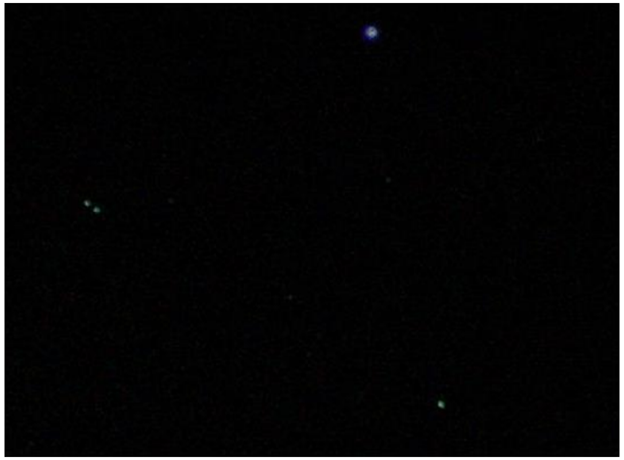
→in this case the dark frames are captured during mission before door opening in right altitude and after door closing before rocket landing for all exposure settings and with the real camera temperatures.

Results of ground camera test and signal processing development

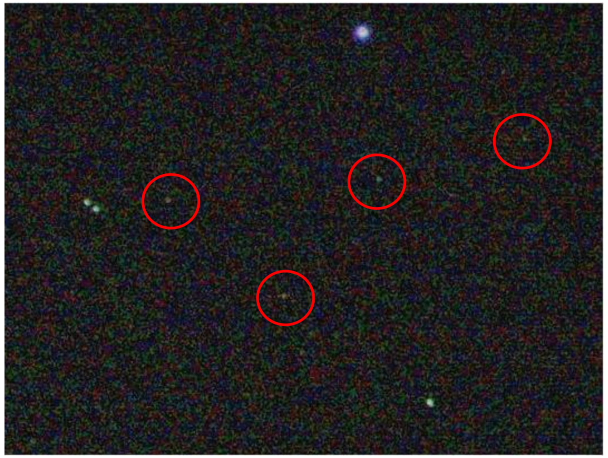
- During the ground test of camera system many dark frame exposures as well as the real star exposures were realized with different exposure settings.
- One star with apparent magnitude 9.15 was identified from processed images, many stars with magnitude between 7 and 8 were identified without any problem.



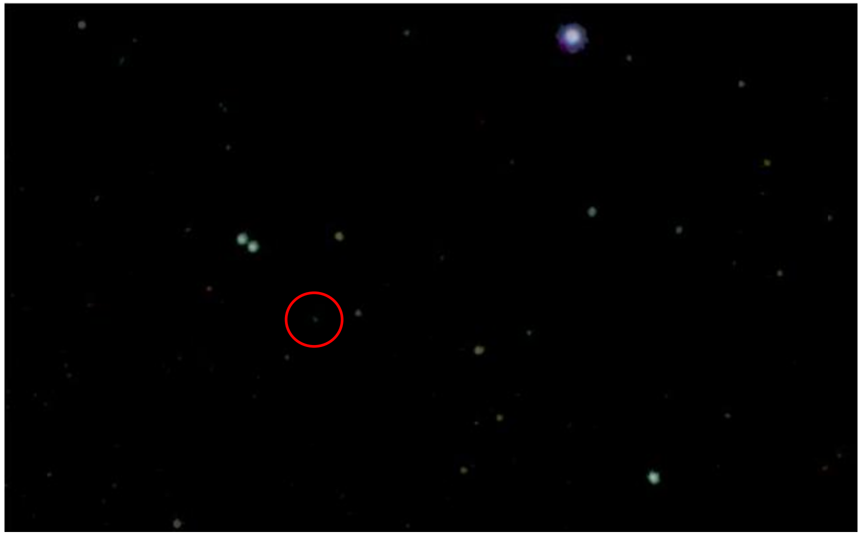
Cut-out of original captured image during ground test with exposure time 900 ms and gain 18 dB. Red circle shows hot pixels caused by the dark current, easily confusable with stars.



Cut-out of processed image with applied dark image compensation. Thermal noise and other recognizable stars are in image presented, but not visible due to brightnes scaling.



Gamma correction of previous image for better visualization of other recognized stars and residual thermal noise. Red circles show the newly recognized stars.



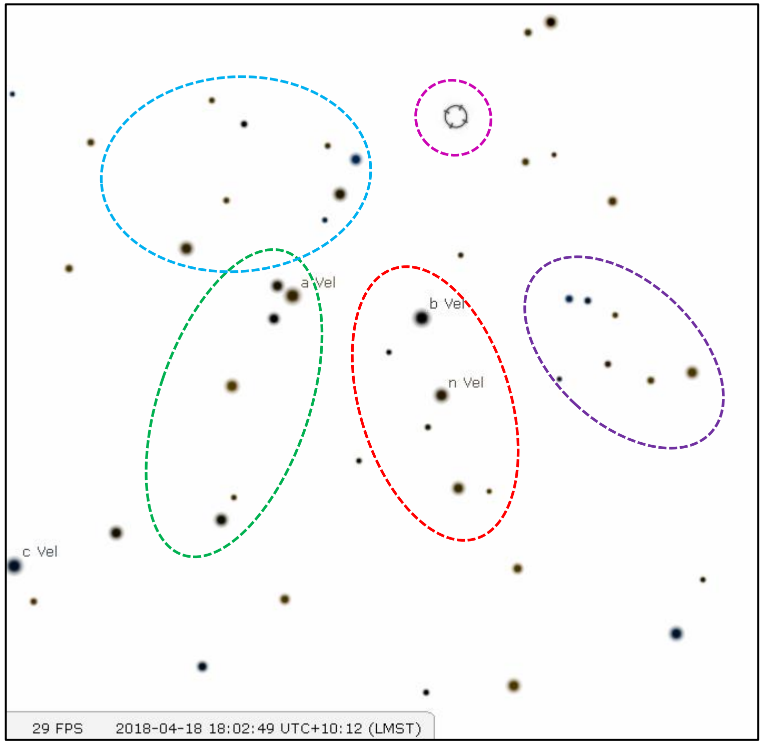
Result of image processing from Ximea camera during ground test. Red circle shows the weakest star with magnitude 9.15, recovered by post-processing from time series of noised images.

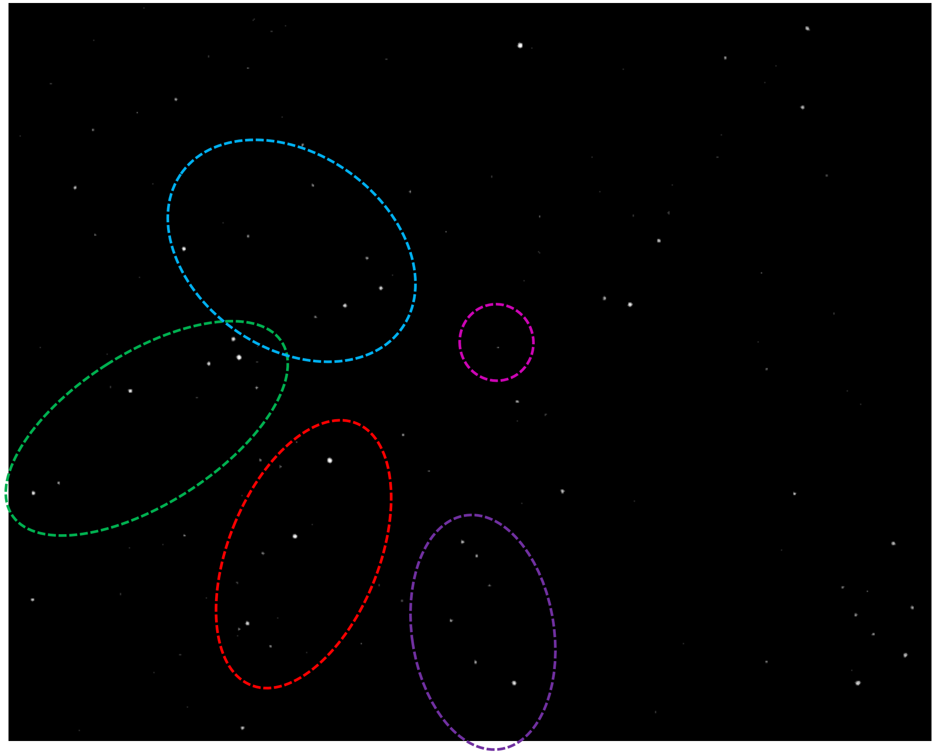
Sky map from Stellarium software with the area of interest. Processed images with identified stars are in consensus with Stellarium sky map.

Ground camera tests give us the promising results of sensitivity, even under the atmospheric effects and with light pollution from near Pilsen city.

Preliminary results from sounding rocket mission

- Rocket mission was realized few days ago - 4th of April, 2018.
- We get data late night 16th of April, more than 7.5GB of images was captured.
- All image data still not fully post-processed, but stars successfully recognized.





Even low cost and not space qualified camera could fulfil the sounding rocket mission requirements with proper signal processing and camera properties compensation.

Thank you for your attention.

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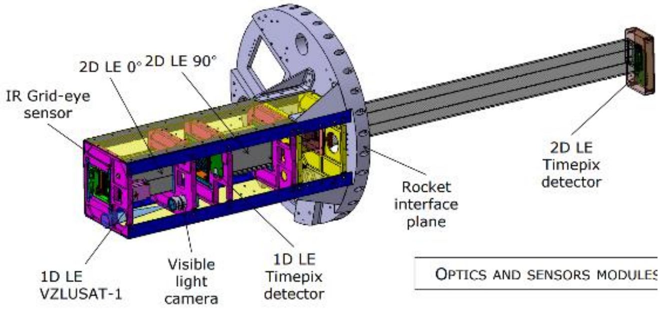

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