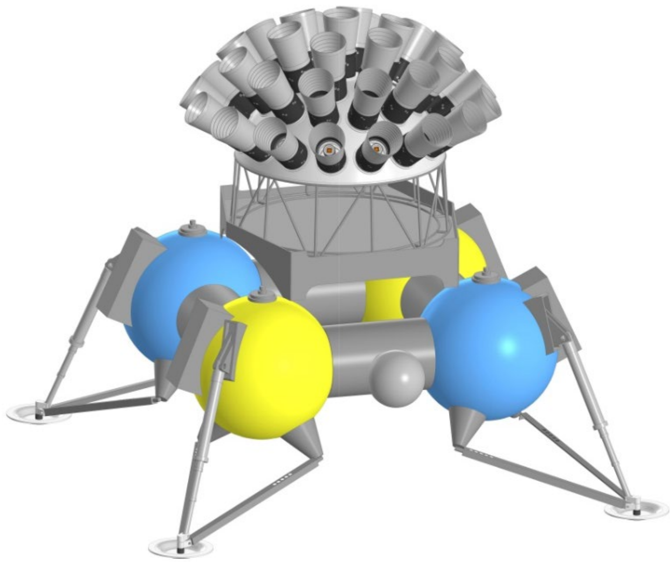
V NUVA Workshop 2022
Basque country University, Vitoria-Gasteiz (Spain) 3rd-7th October 2022



Prospects of Moon-based UV survey to study transients and variables

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High-cadence UV survey

One of the most ambitious and promising tasks of modern astronomy is to study transient events and variables with wide-field time-domain surveys.

In particular, high-energy transients have relatively high temperatures (>10000 K) at the earliest stage of the explosion/flare, and most of them have strong UV radiation.

Sky background in UV is a few magnitudes darker than in optical, making it possible to use a set of UV extra-wide small-aperture UV lenses in Space to monitor the whole sky in UV with high cadence and without interruptions to detect transients and variables.

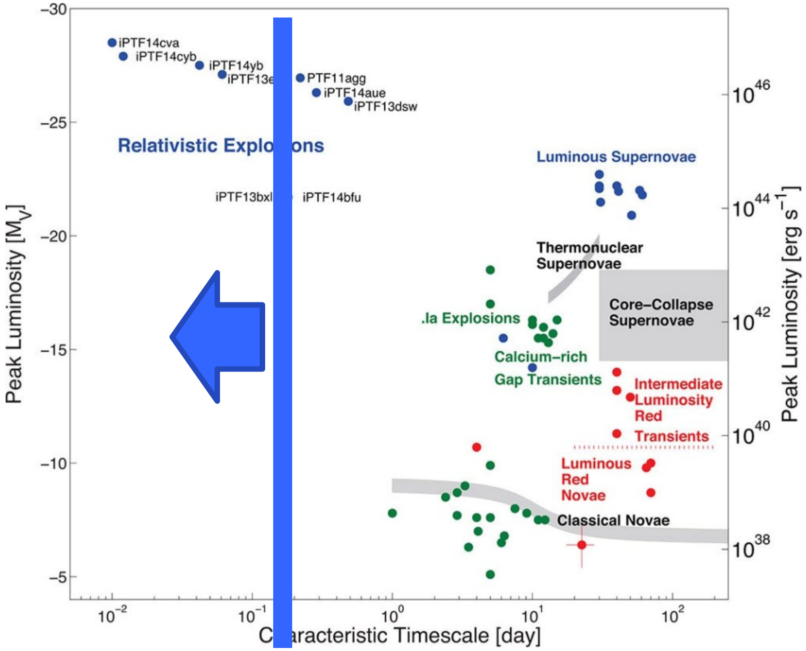
Such a UV survey will be significantly more efficient than existing similar systems that operate on the ground in the optical wavelength range.

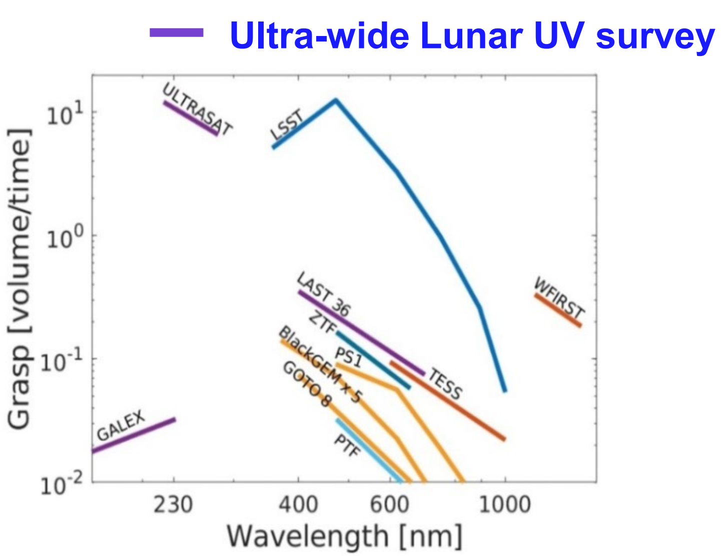
We are motivated to study the prospect of deploying a network of wide-field, small-aperture UV telescopes on the Moon by taking advantage of its unique environment.

The Moon-based multi-lens array with ~10,000 deg^2 field of view will make it possible to obtain the world's first all-sky “movie” of transients/variables in UV with high time resolution on the order of ~10 min.

Scientific objectives

- Complete samples of nearby supernovae of all types (SNe Ia and core-collapse supernovae) in UV. The high-cadence observations could detect shock breakout emissions for core-collapse supernovae (i.e., UV radiations within a few hours of the explosion), which can provide important observational clues on the unknown explosion mechanism for supernovae and enable direct measurements of the sizes of progenitors and the circumstellar environment.
- A complete sample of tidal disruption events (TDEs) in the local Universe to make a unique probe of dormant supermassive black holes (SMBHs) in nearby galaxies. The high-cadence observations could capture the UV emission at early rising stage, which is poorly explored yet crucial for understanding TDEs.
- Obtaining valuable early-time (~hr) UV information of the merger of neutron star – neutron star and neutron star – black hole, constraining the physical models.
- Potentially probing an uncharted parameter space of short and hot transients to discover hitherto unknown high-energy explosions in the Universe.

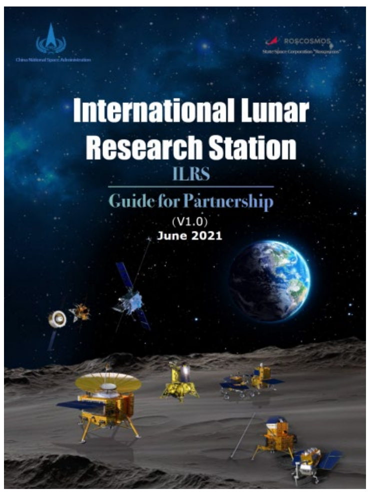




International Lunar Research Station (ILRS) Guide for partnership V 1.0, June 2021 (CNSA, ROSCOSMOS)

The first Chinese Moon-based telescope LUT (Chang'E 3 mission) demonstrated its efficiency in the near-UV wavelength range.

In 2021 China and Russia signed an agreement to build a future International Lunar Research Station, which provides new exciting opportunities for Moon-based astronomy.



ILRS-5 Telescope

Astronomical observation from the Moon

Advantages to put the telescope on the Moon

- No atmosphere – makes UV and IR observation possible (inaccessible from the Earth)
- Located outside of the main layers of geocorona (important for UV observation)
  – advantage over low Earth orbit telescopes
- Longer continuous observation time from the Moon south pole
  – advantage over ground based and low Earth orbit telescopes
- The surface of the Moon is relatively stable
- The Moon rotates much slower than the Earth – omit the mount for short focus telescopes
- Possibility to share ILRS transportation system and other facilities (data transmission, etc.)

Points of consideration

- No full sky availability from the south pole of the Moon
- To protect optics from the Moon surface dust
- Scattering light from the Moon surface, Sun, Earth
- Field rotation for long focus high resolution telescope with alt-az mount

The International Lunar Research Station (ILRS) on the Moon surface gives us a unique opportunity to install step by step a lot of small telescopes on different landers.

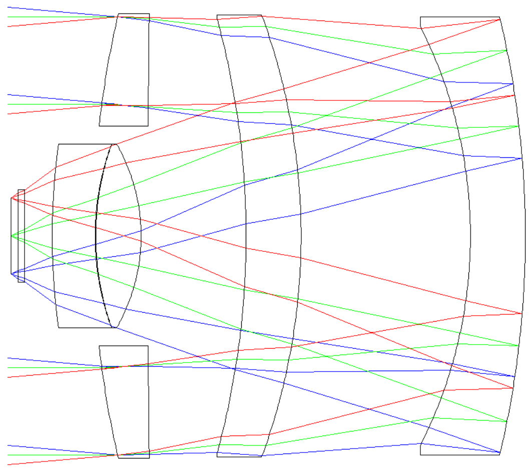
A dedicated mission (ILRS-5) can install up to 50-100 telescopes at ones.

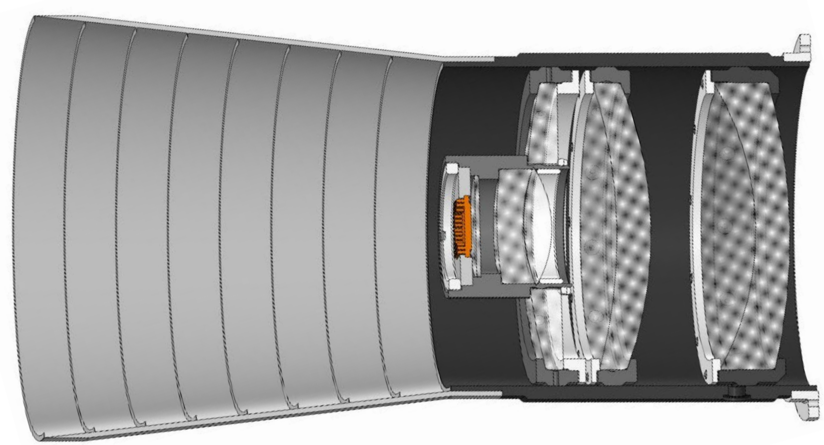
Draft optical scheme (proposed by INASAN)

A combination of optical lenses made of UV-transparent materials (fused silica, CaF_2, BaF_2), modern UV AR coatings allows us significantly improve the efficiency of small aperture wide field UV lens.

The main benefit of the proposed reflector design in comparison to the full refractive design is the length of the system. The main disadvantage – high central obscuration.

Telescope aperture	160 mm
Spectral range	180-280 nm
Central obstruction	50%
F-Number	F:1
Field of view on detector	67 sq. deg
Detector	~ 2×2 k
Pixel scale (11 μm pixel)	~ 14 arcsec/pix
Image quality (D80)	25-50 μm
Typical exposure	60 s
Optical elements mass	2.7 kg
Telescope mass	6-8 kg



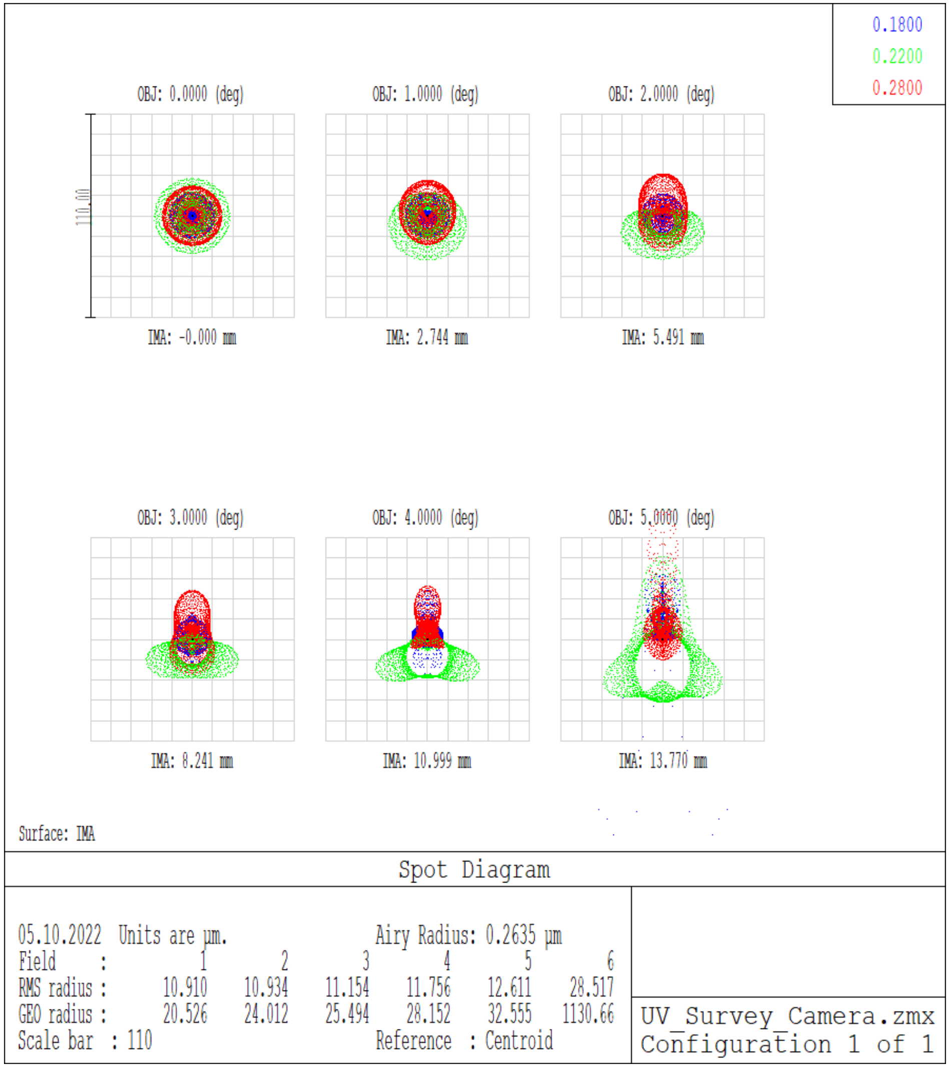


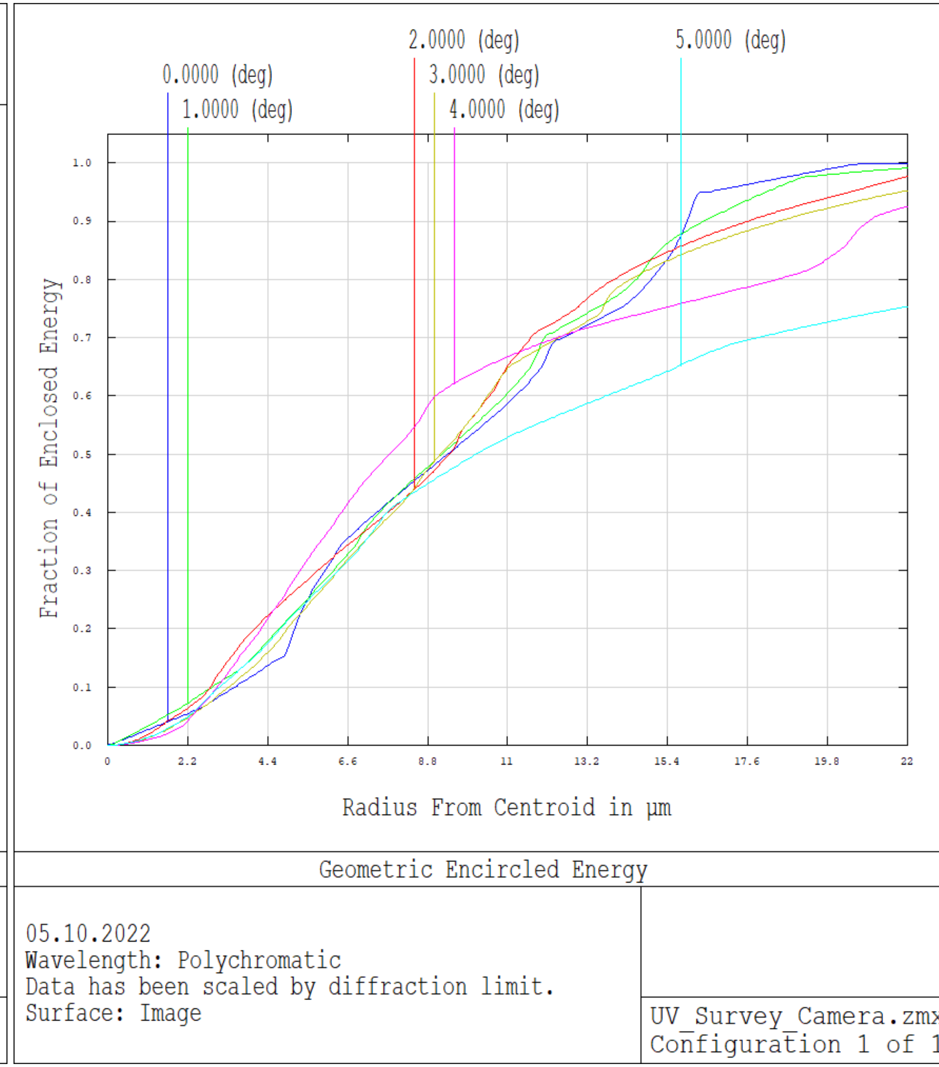
There is no space for a filter wheel, if needed the filter should be deposited on the detector.

Accurate focusing of the telescope can be carried out by controlled heating of some structural elements.

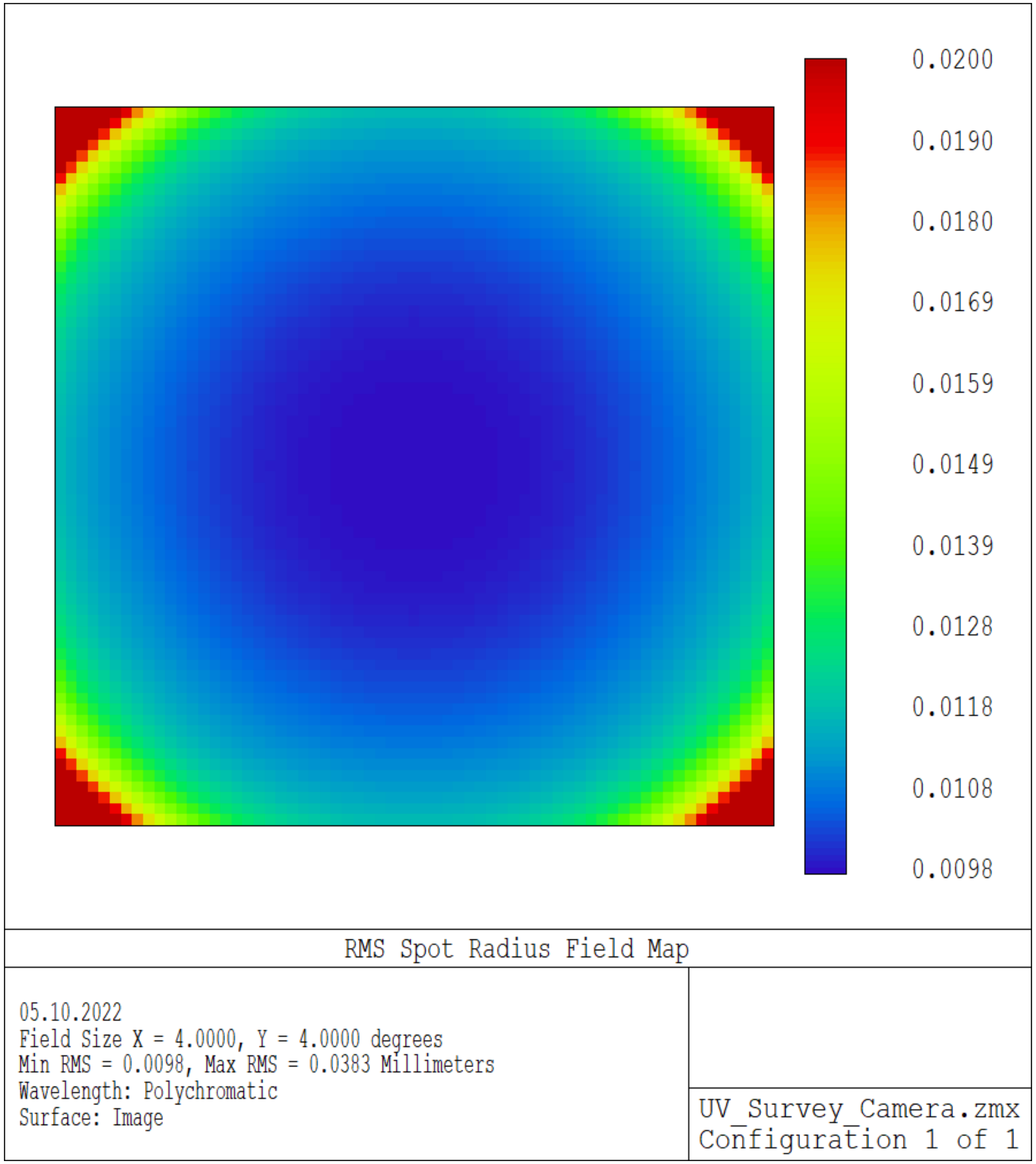
To improve the image quality curved CMOS option can be considered.

Optical scheme





Optical scheme

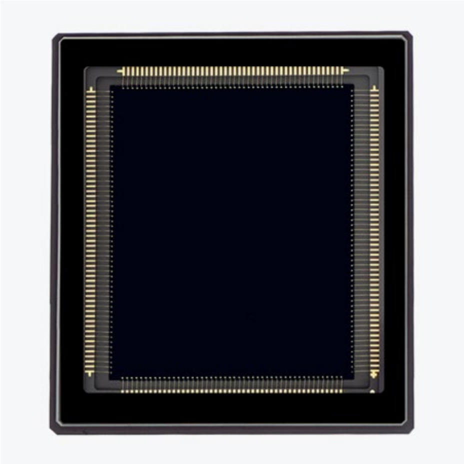


UV detector

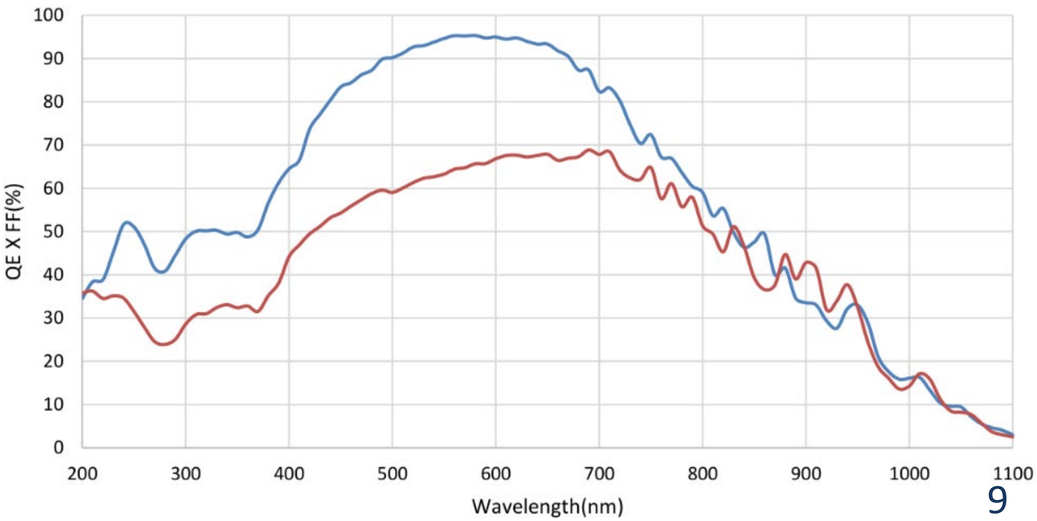
Observation in UV with CMOS and CCD faces two challenges – quantum efficiency in UV and red leak of UV filters.

The advanced UV coatings with high red leak suppression (E-5) were developed for modern space UV missions (ULTRASAT, DORADO).

We hope that technology of multilayer UV coating can be applied for GPIXEL's back illuminated CMOS to improve QE in UV and out of band suppression.



Detector	CMOS GSENSE400BSI
Detector size	22.5×22.5 mm
Detector format	2048×2048
Pixel size	11 µm
Shutter type	Rolling
Temporal noise	~ 1.6 e- RMS HG ~ 40 e- RMS LG
Full well capacity	90 ke- LG 2 ke- HG
On-chip ADC	12 bit
Quantum efficiency in UV	~ 40%



CMOS with a smaller pixel (3-5 µm) potentially can improve the angular resolution of the telescope.

We need to study the option of curved CMOS.

Lunar UV lens array

- Array total field of view 10000 sq.deg
- Single camera mass 6…8 kg
- Total amount of cameras 50-200

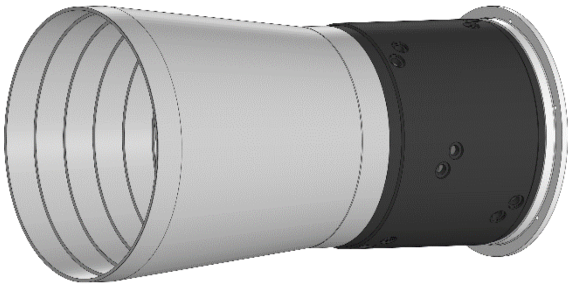
To cover the whole visible sky from the ILRS we need about 100-200 telescopes.

We can use a dedicated Moon-lander to accommodate up to 50-100 telescopes.

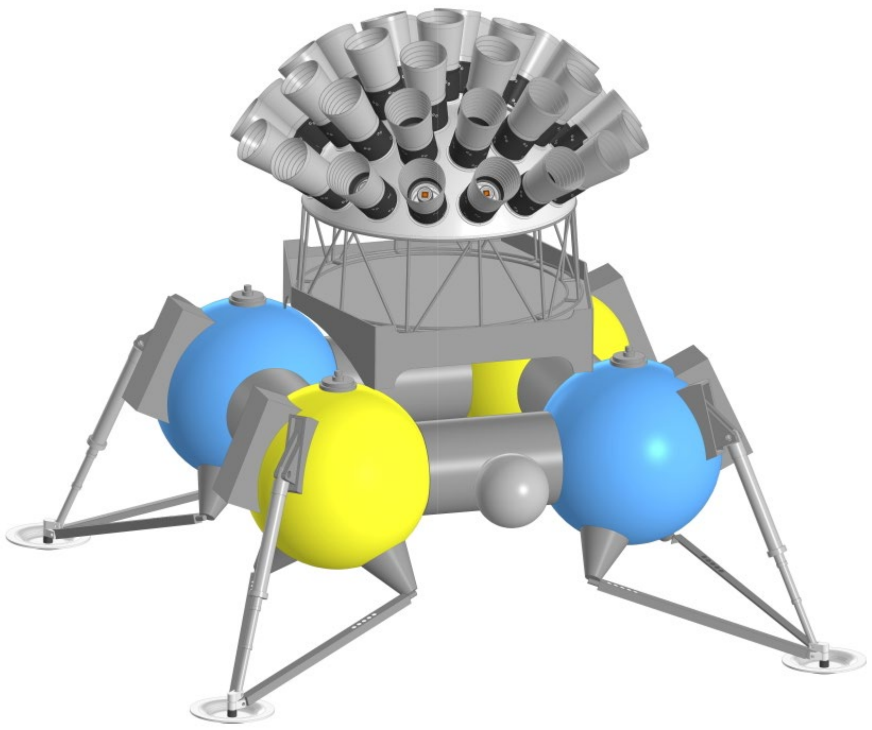
Also we can distribute telescopes across different landers.

UV telescope (6…8 kg) also can be installed on other spacecraft at any orbit (not on the Moon) as an additional payload. It is a simple instrument without moving parts and repointing system.

Potentially a single-lens prototype of the proposed multi-lens array can be installed on upcoming LUNA or Chang'E missions.



Single camera 6…8 kg



Dedicated Moon mission, 50-100 cameras
Total mass up to 1000 kg

UV extra wide field lens array operation on the Moon

Pointing and guiding options

- No repointing and no guiding
  Due to the sampling (14 arcsec/pix) and slow rotation of the Moon potentially we can avoid any telescope movements for pointing and guiding.
  In such a case the telescope should operate with short exposures with digital image co-adding.
  Thanks to a very low readout noise of modern CMOS and sky background, image co-adding probably will not affect the sensitivity of the telescope.

- Single-axis guiding within an exposure(s). After exposure(s) the telescope quickly returns back to its initial position to be ready for the next exposure(s).

- Limited-range 2-axis mount for a set of telescopes.

Data processing

- Severe downlink radio channel limitation (traditional radio link channel)
  Each frame must be processed on-board in order to detect all variable souses, etc.
  Cropped images of detected objects of interest will be transmitted to the Earth.

- High-speed (laser link for example) downlink channel allows to transmit all raw data or part of raw data on demand from internal buffer.

Conclusion

A network of UV telescopes with ~10,000 deg^2 field of view on the Moon allows us to obtain the world's first all-sky “movie” of transients/variables in UV with high time resolution of ~10 min.

A Moon based UV lens array will be an important research tool for astronomers for many astrophysical tasks. The expected signature discoveries are:

- Complete samples of nearby supernovae of all types in UV.
- A complete sample of tidal disruption events (TDEs) in the local Universe to make a unique probe of dormant supermassive black holes (SMBHs) in nearby galaxies.
- Obtaining valuable early-time (~hr) UV information of the merger of neutron star – neutron star and neutron star – black hole, constraining the physical models.
- Potentially probing an uncharted parameter space of short and hot transients to discover hitherto unknown high-energy explosions in the Universe.

Potentially, we can build a single-lens prototype of UV array to install it on upcoming LUNA or Chang’E missions.

It will be a very simple instrument, like a “UV star tracker” with a special data processing algorithms.

The instruments main parts: a UV-optimized wide field lens, fixed UV filter (option) and CMOS detector. No moving parts, no pointing system. The lens will always be pointed to zenith.