Space born wide field telescope with full aperture slewing mirror to detect decameter size NEOs (the SODA mission)

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We describe technical features of the SODA project (System of Observation of Day-time Asteroids) aimed to detect "all" NEOs (larger than 10 m) approaching the Earth from the day sky. Special attention is given to the updated optical issues. These include a new telescope optical design, pre-aperture slewing mirror design and new CMOS detector with small pixels. The combined area of observation by few telescopes from one spacecraft is presented.

About the SODA project

The System of Observation of Day-time Asteroids (SODA) is a concept for a future space mission, aimed to observe asteroids approaching the Earth from the daytime sky. The SODA system includes one (in optimal variant two) spacecraft (SC) in a halo orbit around the L1 point of the Sun-Earth system (in the case of two SC they will be located approximately in an opposite phase). Each SC will be equipped with 30 cm aperture telescopes . The minimal requirement is 2 telescopes on a SC, whereas the optimal option is 3 telescopes.

The top-level SODA project goals are:

- to detect "almost all" bodies larger than 10 m approaching the Earth at a distance of less than 10^6 km from the Sun direction;
- to quickly identify a body of special interest (e.g. an asteroid at collisional orbit) and to characterize it, i.e. perform an accurate orbit determination and a body mass estimation;
- in the case of a collisional orbit, the system should ensure a warning time of about 10 hours and determine coordinates of the atmospheric entry point with the best possible accuracy.

The SODA telescopes should provide two modes of operation:

- discovery of new asteroids coming from the Sun direction;
- target mode to define the orbit of dangerous asteroids with highest possible accuracy.

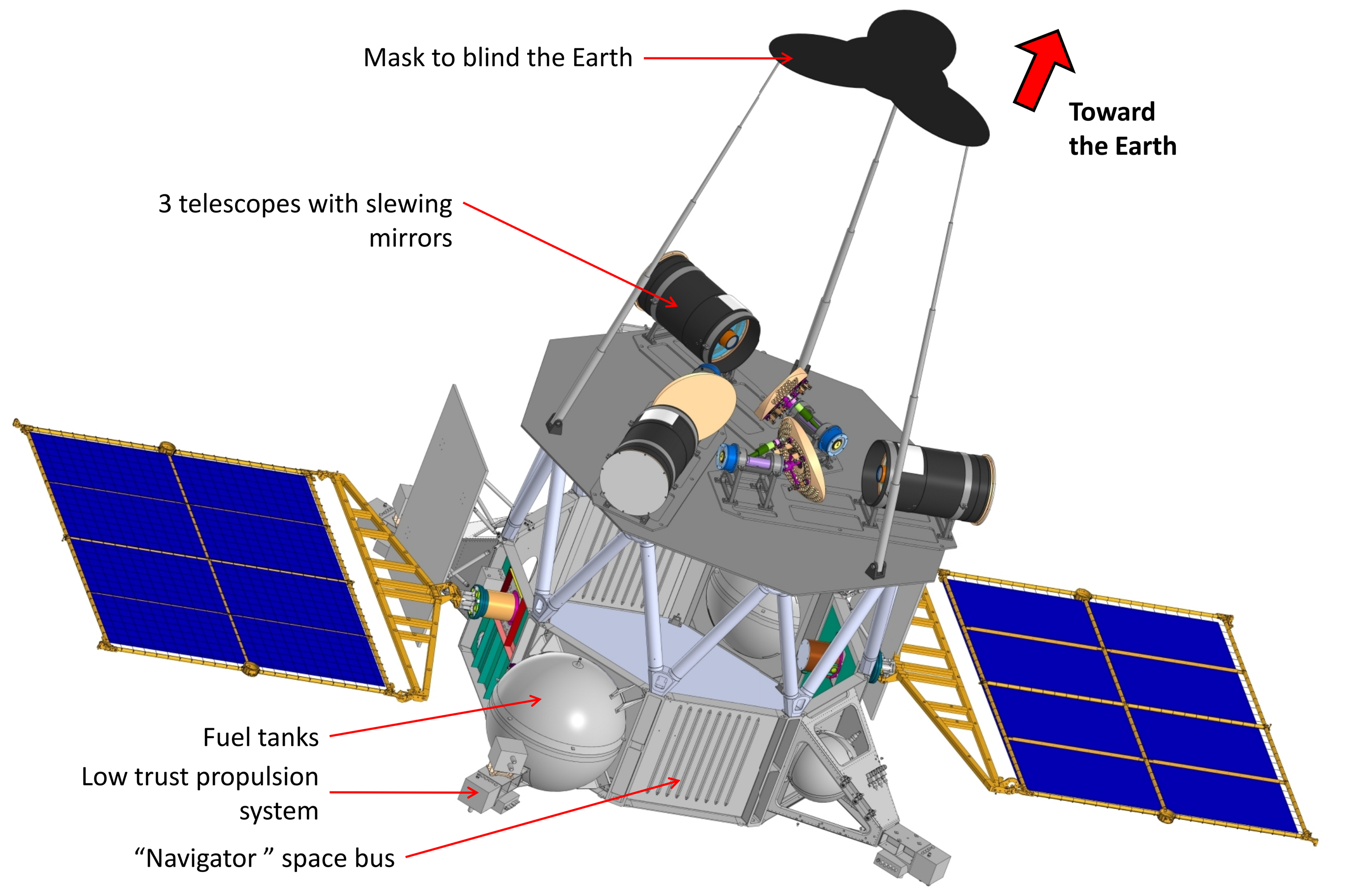

Fig. 1. SODA spacecraft concept with "Navigator" space bus.

Telescope optical features

The optical scheme of the SODA's telescope (Fig. 2) is based on the Sonnefeld camera and consists of a two-lens aperture corrector, the inner element of which operates in a double beam path, a Mangen mirror and a two-lens corrector near the focal plane. The slewing mirror provides a 50×120 deg area of observation with a single telescope. The concept of the telescope with a slewing mirror is illustrated in Fig. 3.

Optical scheme	Prime focus lens corrector	Pixel scale	2.3 arcsec/pixel
Telescope aperture	300 mm	Typical exposure	2 - 4 s
Optical assembly length	1325 mm	Limiting magnitude	17^m
Spectral range	450-900 nm	Single observation accuracy	0.5 arcsec
Field of view, diameter	3.75 deg 29.5 mm	Repointing mirror size	480×340 mm
D80	4 µm	Slewing angle	Pitch +20° …+50° Roll -60° …+60°
Central obscuration	33 %	Area of observation by each telescope	50°×120°
Pixel size	5 µm	Time of repointing	3 s

Table 1. SODA's telescope main parameters.

The main properties of the 3 telescope option:

- Observation time of the whole barrier 3.5 min
- Number of observations of the NEO crossing the barrier * 6

** For the NEO with a transversal speed of 10 km/s at distance of 0.25 million km from the telescope*

Performance of the SODA system can be improved by using a modern off-axis TMA optical design or by freeform optics which provides more parameters for optimization. Because of the absence of vignetting and in combination with a small pixel size CMOS detector with an enhanced NIR sensitivity, this approach potentially allows us to decrease the telescope aperture down to 20-25 cm without impacting the system efficiency. A smaller aperture results a reduction of the overall mass of the payload as well as the total cost of the project.

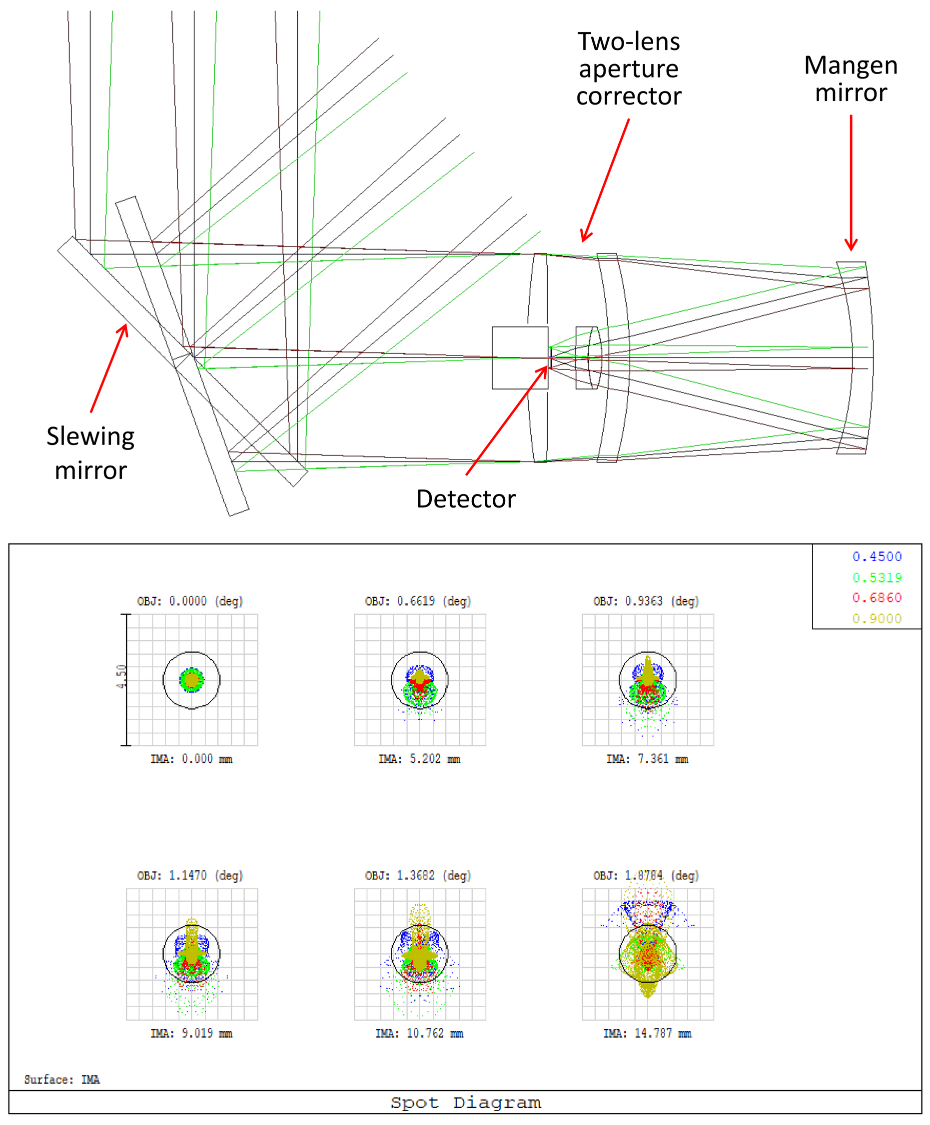

Fig. 2. SODA's wide field telescope optical scheme and image quality.

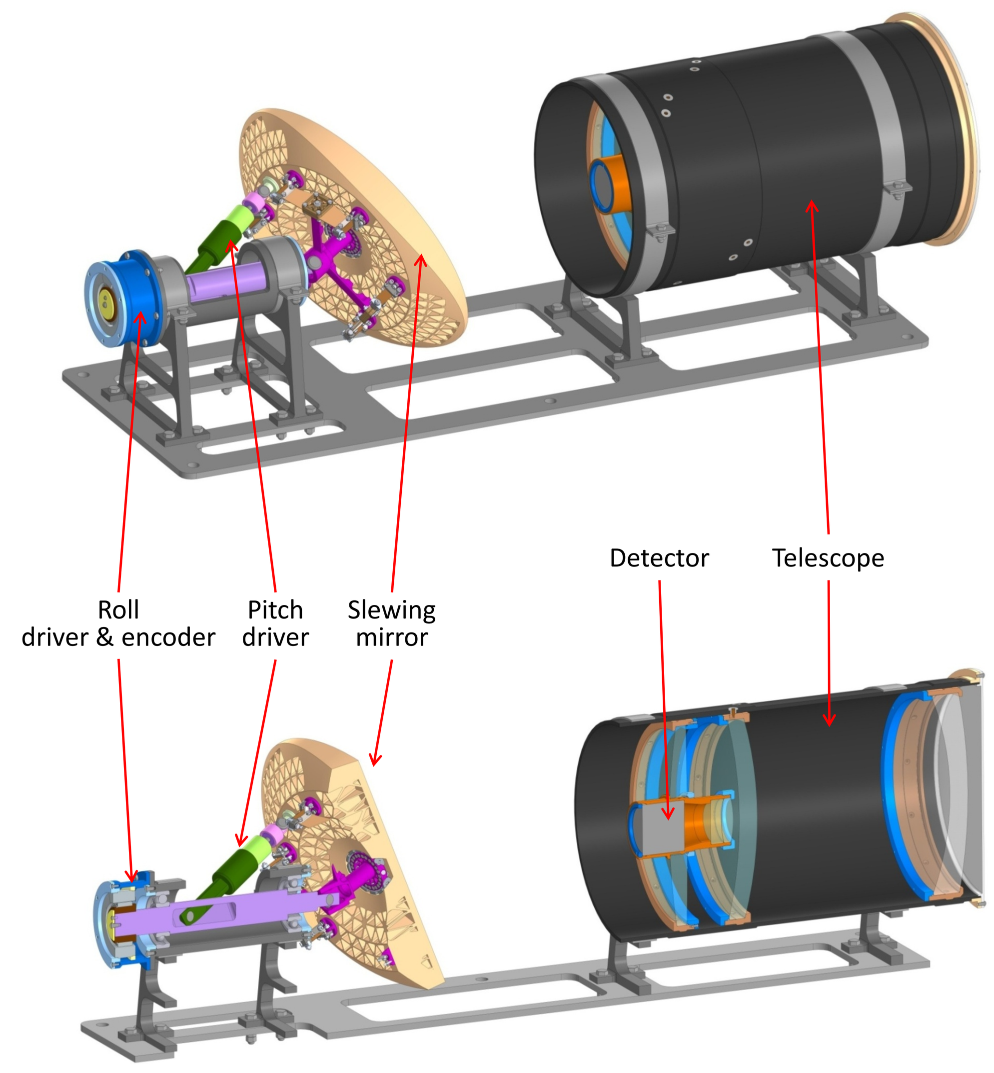

Fig. 3 The concept of SODA's wide field telescope with a slewing mirror.

Area of observation

To solve the problem of mass detection of asteroids flying from the Sun using the optical barrier technique, one needs at least two telescopes capable to monitor 50×120 deg observable area each. The combined field of view of the two telescopes provides a full angle of 100...120 deg at the apex of the cone of the optical barrier (Fig. 4) which is enough for the SODA project.

In the 3 telescope option, about 50 % of the total monitored sky area can be simultaneously observed by two telescopes. This will increase the reliability of the system, if one telescope fails only 17 % of the observable area will be lost. The other benefit of the 3 telescope option is a possibility to observe potentially hazardous bodies in the tracking mode synchronously with two telescopes from one SC, which will increase the astrometric accuracy.

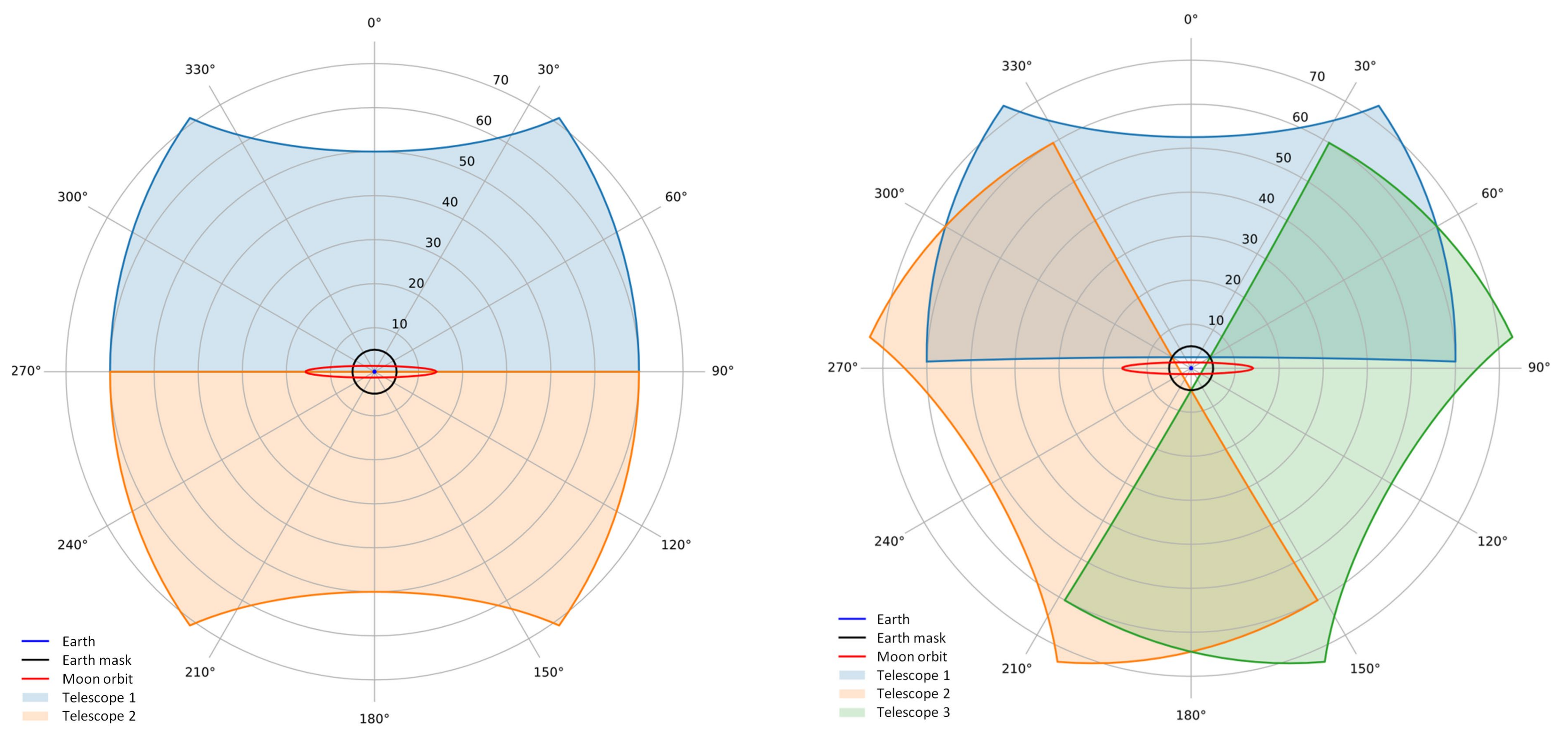

Fig. 4. Area of observation of the SODA project with 2 and 3 telescope options.

Slewing mirror as a critical technology for the SODA project

The slewing mirror technology is becoming more commonly used. A good example is the two-coordinate optomechanical scanning device BSKR-T (Fig. 5) for the multi-zone scanning device onboard the meteorological satellite Electro-L. This mirror has worked in continuous mode for 10 years together with a 220 mm aperture IR telescope, performing a line and frame scanning to obtain images of the Earth every 30 minutes. The scanning angle is 10°. The number of repointing of the SODA's telescope over 10 years is estimated as 50 million, which is similar to the BSKR-T and seems realistic.

Another example of the usage of a pre-aperture slewing mirror is the European Meteosat Third Generation (MTG) project that used Scan Assembly (SCA) developed by the SENER company (Fig. 6). The two axis gimbaled scanner is controlled in a closed-loop and provides both excellent pointing accuracy and high flexibility allowing fast Earth scanning, deep space view and very stable pointing for on-ground characterisation. The SODA's requirements are very similar to the main SCA parameters, which are:

- Supporting a 300 mm aperture mirror;
- Mirror slope: 30º for FCI instrument and 45º for IRS instrument;
- To scan East/West up to 2deg/s speed, and then perform a 180° U-turn in less than 0.8 s;
- In-flight Line of Sight absolute pointing accuracy of 170 µrad including control error and encoder noise;
- On-ground point-to-target stability at the level of 0.6 µrad max half-cone over 10 s;
- Launch lock and release mechanism;
- Damping system to keep the required performance in the event of disturbances from the platform.

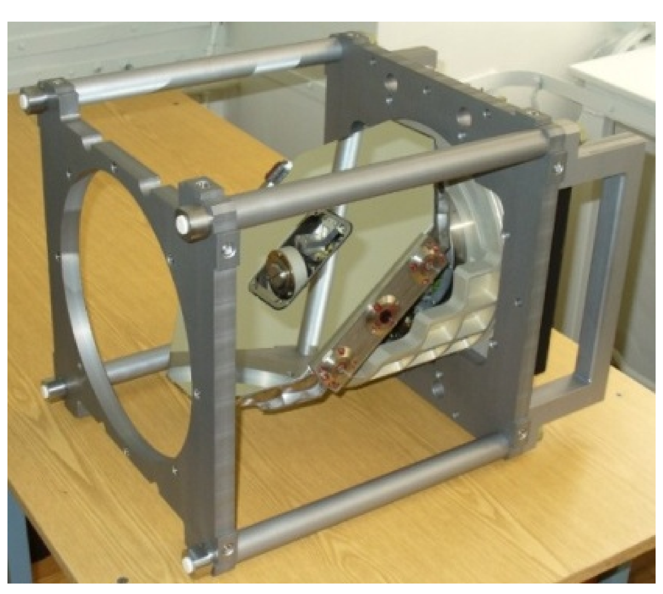

Fig. 5. Two-coordinate optical-mechanical scanning device BSKR-T, meteorological satellite Electro-L.

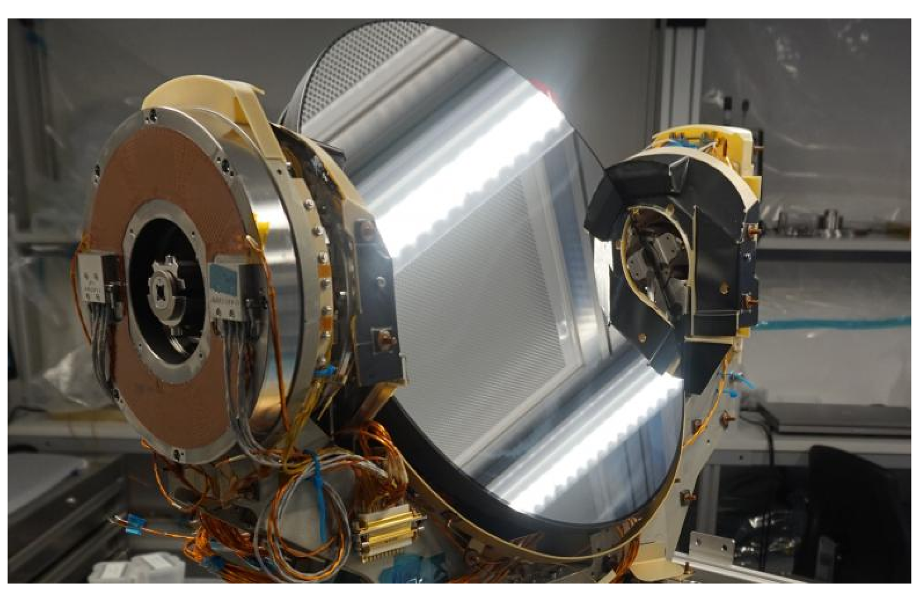

Fig. 6. The Scan Assembly (SCA) of the Meteosat Third Generation (MTG) satellite.

CMOS detector with small pixel

In recent years due to the rapid development of CMOS technology, it has become possible to produce a very small pixel with a size of 3-5 µm with reasonable performance. Using such CMOS will, on the one hand, reduce the size of the optical system using faster optics, and on the other hand, will allow to maintain necessary image scale to ensure astrometric accuracy.

The requirements for CMOS detector for the SODA telescope seem to be realistic:

- Size of 30×30 mm;
- Format of 6×6 k;
- 5 µm pixel;
- Enhanced NIR sensitivity (if possible);
- Both rolling and global shutters are acceptable.

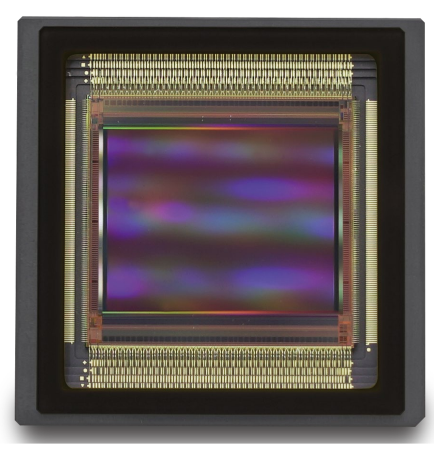

Fig. 7. An example of small pixel size 5×4 k CMOS detector with global shutter (GPIXEL GSPRINT4521).

One of the examples to mention is the modern CMOS GSPRINT4521 with a photosensitive area of 23×18.4 mm, pixel size of 4.5 µm with capacity of 30000 e^- and readout noise of 3 e^- RMS (fig. 7).

The operating exposure in the SODA project will not exceed a few seconds, so the acceptable operating temperature of the CMOS detector could be about 0...-20 °C, i.e. a small passive cooling radiator attached to the telescope tube is sufficient.

Using a detector with "very small" pixels (3 µm) will slightly improve the accuracy of astrometric measurements, especially in the mode of tracking of hazardous asteroids. If the other parameters of CMOS with the "very small" pixels don't have a negative effect on the "detection on the barrier" mode, this type of CMOS could be recommended for the SODA project.

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