Schmidt type optical system for the KLYPVE-EUSO UHECR detector

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1- INTRODUCTION
The Schmidt telescope provides a wide field of view (FoV) and a fast relative aperture F/# with a simple layout consisting of few optical elements. Thus it is the preferred solution for wide FoV imaging telescopes. The classic layout of the Schmidt telescope consists of a spherical mirror, of a corrector plate and of a focal surface. A remarkable advantage of the Schmidt telescope consists in having the image surface not facing the object plane avoiding the radiation from out-of-field sources (e.g. scattered out-of-field Earthshine) to directly impinge on the image surface. This feature, combined with the low number of optical elements, results in a particularly efficient suppression of the stray light both in-field and out-of-field. The poster reports the optical design of a compact Schmidt telescope covering a FoV of 40° with an entrance pupil diameter of 2.5m, a 4m diameter mirror and a focal length of 1.7m optimized both for image quality and throughput. The relative aperture is F/ = 0.7.

2- REQUIREMENTS
The fluorescence detector of ultra-high energy cosmic rays (UHECRs, energies >500EeV) of the KLYPVE-EUSO project will be installed on the Russian Segment of the International Space Station and will operate at an orbit H = 450 km approximately from the Earth’s surface. The requirement for each detector pixel, with size p = 3mm, of the multi anode photo multipliers is to cover an atmosphere portion corresponding to a ground sampling distance GSD on Earth between 0.5km and 1km. The required entrance pupil diameter is 2.5m and the focal length results: f = \frac{H}{4p} = 1750 mm for GSD = 750 m. The relative aperture is F/# = 0.7 and the required FoV 40° with an operating spectral range from 337nm to 391nm (Table 1).

3- BASELINE SOLUTION
We started from a classic layout and we used a merit function for RMS spot radius performing an optimization by using as variables the shape of the corrector with both surfaces set as even aspheres, the radius of curvature of the mirror, the distance between the corrector and the mirror and the back focal length. The material of the corrector plate is PMMA-000 a special Grade UV-transmitting poly methyl methacrylate (by Mitsubishi Rayon Co. LTD, Japan). The layout is in Fig. 1. The ground resolution in Fig. 2.

The throughput is optimized by compacting the axial length of the telescope and by optimizing the position of the aperture stop. The diameter of the corrector plate is 2.6m with a mass of 76.6kg. The corrector plate has a central hole with diameter 10cm which simplifies the manufacturing process. The plate can be conceived as composed by many identical radial slices (e.g. 12) moulded on a cast and then assembled together with a mechanical holder or through cementing. The central hole in the corrector might also represent the access for other instruments, e.g. a Lidar. The central hole in the corrector plate has no impact on the RMS spot (Fig. 2).

4- ADVANCED SOLUTION
The large dimension of the mirror requires that it is deployable in order to fit the limitation of the launcher fairing diameter and for this reason the mirror can be conceived as segmented. This allows to optimize the shape of mirror (Fig. 3) to achieve a better correction of the aberrations (Fig. 4) and an easier shape of the corrector. The throughput of the baseline and advanced solution is in Fig. 5.

The mirror is spherical for a diameter up to 3m with an outer corona with slightly aspheric petals. The profile of the corrector results much less bendened at the edges. The aperture stop is placed in front of the corrector plate.

5- CONCLUSIONS
The progress reached in the construction of deployable and active mirrors makes the telescope feasible.

Two ESA projects have recently explored the possibility to develop large lightweight and deployable space mirrors:

1- ALC (Advanced Lidar Concept) studied a deployable, lightweight, 4 m aperture space born telescope for Lidar applications
2- LATT (Large Aperture Telescope Technology) extended the study producing a breadboard of a 400mm active mirror, 1mm thick, in Schott Zerodur coupled to a carbon fibre reinforced plastic backplane by 19 actuators controlling the optical surface.

The presented baseline (Fig. 1) and advanced (Fig. 3) solutions of the telescope for the KLYPVE-EUSO instrument allow for a remarkable exposure in the detection of ultra-high energy cosmic rays covering both hemisphere thanks to the orbit of the ISS. Fig. 6 compares the exposure of the two presently operating observatories, the TA in Utah and the Auger in Argentina, with the expected exposure of EUSO based on Fresnel lenses and on a Schmidt camera, and with the exposure of JEM-EUSO.

Table 1. Requirements of the Schmidt camera for the KLYPVE-EUSO.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of view</td>
<td>60°</td>
</tr>
<tr>
<td>Entrance pupil diameter</td>
<td>2.5 m</td>
</tr>
<tr>
<td>Effective focal length f</td>
<td>1750 mm</td>
</tr>
<tr>
<td>Spectral range</td>
<td>337-391 nm</td>
</tr>
<tr>
<td>Fraction of unvignetted rays</td>
<td>Maximum value ≥ 0.75; Minimum value ≥ 0.67</td>
</tr>
<tr>
<td>Diameter of corrector</td>
<td>2.5 m ≤ d ≤ 2.6 m</td>
</tr>
<tr>
<td>Shape of the mirror</td>
<td>Baseline: spherical mirror</td>
</tr>
<tr>
<td>Diameter of the mirror</td>
<td>6 m</td>
</tr>
<tr>
<td>Polychromatic RMS spot</td>
<td>&lt;3 mm for all the FoV</td>
</tr>
<tr>
<td>Ground sampling distance</td>
<td>0.5 km ≤ GSD ≤ 1 km</td>
</tr>
</tbody>
</table>

Fig. 1. Layout of the Schmidt camera (baseline).
Fig. 2. Spot radius and half ground resolution (baseline).
Fig. 3. Layout of the Schmidt camera (advanced).
Fig. 4. Spot radius and half ground resolution (advanced).
Fig. 5. Vignetting curve as a function of FoV.
Fig. 6. Exposure comparison.