A new optical design for dismountable and portable catadioptric telescope.

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ABSTRACT

A dismountable and portable telescope with a primary mirror of 250 mm in diameter and a numerical aperture of 5.6, is presented. The telescope has a all-spheric catadioptric optical design, consisting of a spherical primary and a group of spherical lenses, where the last surface is aluminized, as a secondary mirror.

The group of lenses corrects all the optical aberrations, including the spherical introduced by the primary and the chromatic ones. The telescope has a very compact design, with a physical length of 600mm. This fact, joint with the all-spherical design, make it a ligth portable and easy to align instrument: when dismounted it can be contained in a suitcase sizing 580x440x140 mm and the spherical surface for all the mirrors and lenses makes easy the final alignment of the optical train.

We discuss here in detail the optical design and the realized prototype and will show the results, both in terms of theoretical and effective performances.

1. INTRODUCTION

Portable telescopes in the class of 250-300 mm aperture are market required and the better solution seems not yet found at now. The main requirement for a such class of telescope has to be its easy alignement, which must be done “in the field”, and that’s lead directly to a wide as possible optical tolerance, expecially in the secondary mirror alignement. A second design parameter must be driven by the compactness of the instument, which is bound to the secondary mirror support trusses.

Our target is to realize a 250 mm aperture telescope with a fast relative aperture (F/5.6) with a wavelength working range from UV (400 nm) up to NIR (900 nm), a back focal distance of 150 mm for facilitate the mounting of focal plane instrumentations, and a distance between the primary and secondary mirrors on the order of 400 mm or less, for compactness and a low as possible weight.

Classical Schmidt–Cassegrain system, may be the most popular configuration for telescopes in the class, are not able to fit the two constrains above. The aspheric plate decentration tolerances are extremely narrow for high aperture ratio and that lead to a bad transportability without damage the optical quality. Also the chromatic aberration, always present in this configuration, precludes covering the required wavelength range.

We individuate in the solution described by Klevtsov[1] the good one for meet our requirements above. This system is designed starting from the classical Cassegrain scheme using the Popov[2] and Argunov[3] approaches. It use all-spheric components and fit well our contraints: it have a small dimensions, an absence of aspherical surfaces that complicate the “on the field” alignement, a fast relative aperture and the correcting lenses have a relative small diameter, about 0,35 of the primary aperture.

In the Klevtsov solution a quasi-afocal meniscus lens placed in the double ray path near the secondary mirror has two free parameters (the thickness is fixed): the curvature and the difference between radii. The two parameters are used by Klevtsov for correcting the spherical and coma aberrations. The lenses group consist of a meniscus and a Mangin mirror, which act as a secondary mirror in the classical Cassegrain design, and introduces small chromatism into the system. The Mangin mirror makes possible the correction of the residual chromatism and, since its value is small, the difference between the curvatures of the surfaces is also small. Thus the mirror not introduce monochromatic aberrations much different from those introduced by a convex spherical mirror and the aplanaticity is preserved.

In the Klevtsov described solution the tolerance in primary-secondary alignement is declared to be about 1.7-2 broader than in the Cassegrain design, due to the absence of aspherical surfaces.

Thus, in comparison to popular telescopes of the same class as the Schmidt–Cassegrain or Maksutov-Cassegrain design, the Klevtsov design has potentially the capability of providing higher image quality, a larger spectral range, a higher relative aperture, a relatively broader tolerances which are all coherent for meet our constraints.

2. OPTICAL DESIGN

We choose to built a telescope with a 250 mm diameter primary mirror and an all-spheric configuration described by Klevtsov[1]. The other fixed parameters are the back-focal distance of 150 mm, the numerical aperture of F/5.6 (that lead to a focal length of 1400 mm), a field of view of 18 arcminutes and a spectral range from 400 up to 900 nm.

The all-spheric Klevtsov solution described above is able to fit our main requirements (compactness and easy alignement). We calculate the alignement tolerances for a Cassegrain-type equivalent telescope able to resolve the above required parameters. We describe those in the next paragraph.

2.1 The quasar-Klevtsov telescope

The found parameters following the Klevtsov description have been optimized using a commercial ray tracing code (Zemax). A sketch of the telescope is reported in the figure 1. The (spheric) primary mirror have a diameter of 250 mm and its curvature is 1160 mm. Both the two lenses composing the secondary mirror catadioptric group are made in BK7. All the optical surfaces (mirrors and lenses) are spheric.

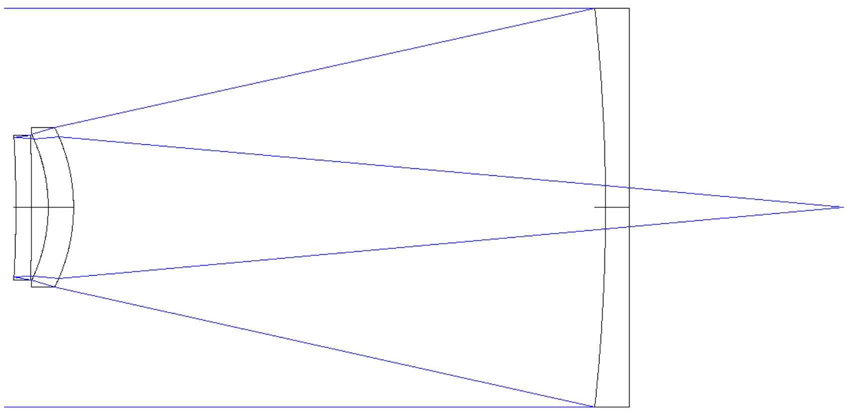

Figure 1. The sketch of quasar-Klevtsov telescope.

The curvatures of the meniscus surfaces have a small difference (110 mm vs. 105 mm) and its thickness is of 16 mm. The Mangin mirror has a very slow curvature and introduces few monochromatic aberrations. Its thickness is 10 mm. The distance between the primary mirror and the Mangin reflecting surface is 370 mm. The obstruction ratio is 0.4 and the back focal distance 150 mm. The performances, in terms of spot size (geometrical) dimensions, are shown in the figure 2. The figure shown the polychromatic performances, from 400 up to 900 nm. The field if view is of 18 arcmin and the spot results always down the 5 μm in r.m.s. radius at all fields and wavelengths.

Great relevance has to be pointed to the alignement tolerances, in particular the primary mirror-lens group alignement. The figure 3 shows the deterioration of the performances due to a lens group tilt and decentering, with respect to an aligned telescope. The performances are shown as polychromatic fraction of encircled energy for the on-axis point.

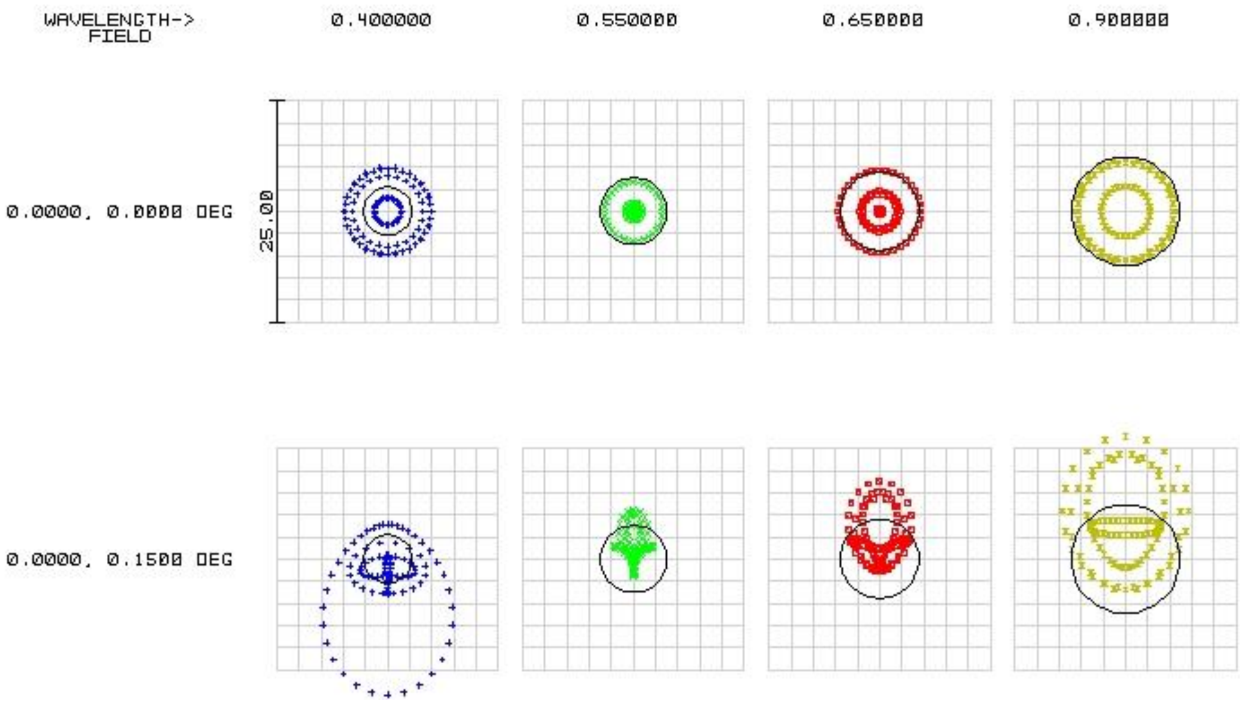

Figure 2. The simulated spots size.

The continuous bold line shows the diffraction limit curve, while the dotted-line one that of an aligned telescope, which is almost diffraction limited on axis. The dotted- and the continuous lines show the performances for, respectively, a tilt of 0.05 degrees and a shift of 0.75 mm of the lenses group with respect to the primary mirror. Those show as 80% of the energy fall inside a circular region of 10 μmin radius also for a relatively bad alignement. That must be compared with the performances of an equivalent Cassegrain that will be reported on the next paragraph.

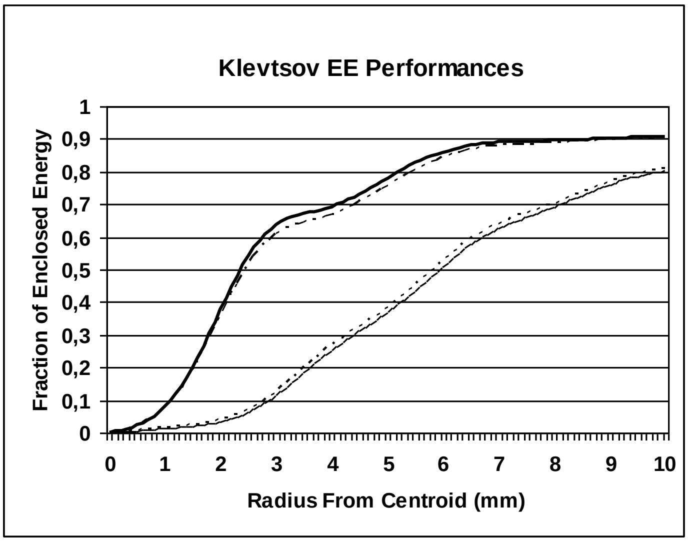

Figure 3. Tolerances as loss in encircled energy fraction for a Quasar-Klevtsov telescope.

2.2 The equivalent Cassegrain solution

In order to compare the tolerances of the proposed telescope, we design a Cassegrain telescope with equivalent properties. A sketch of the main optical parameters for a such configuration is depicted in the figure 4. For details about the parameters derived here the reader may refer to the Schroeder[4] book on astronomical optics.

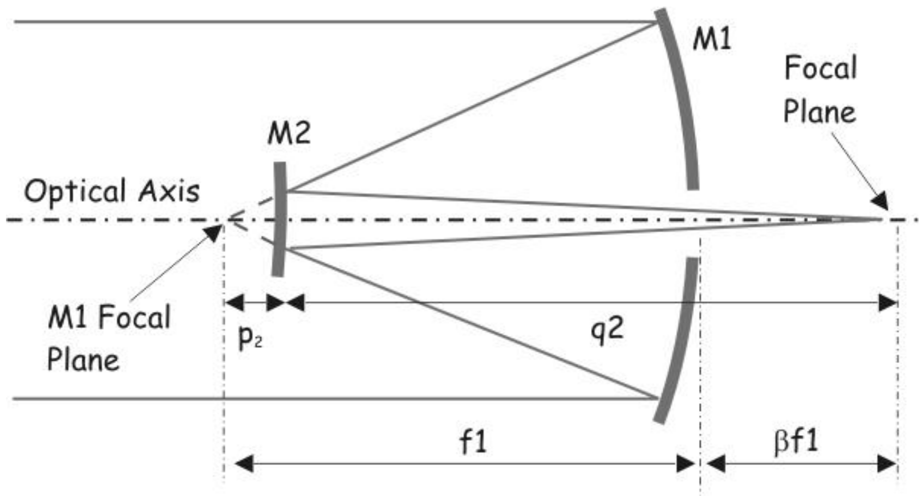

Figure 4. Cassegrain main optical parameters.

The constraints (initial) parameters are: the Diameter of the primary mirror (M1) D1= 250 mm, the telescope focal length f = 1400 mm (F/5.6), the back focal distance βf1 = 150 mm (with f1 the focal length of M1) and the distance between M1 and the secondary mirror (M2) D12 = 370 mm. As sketched in the figure D12 is f1-p2 (with p2 the distance from the M2 vertex and the M1 focal plane.

From those initial parameters we can calculate (see Schroeder[4]) the other construction parameters. The obstruction ratio will be ε = q2/f = (370 + 150) / 1400 = 0.37, with q2 the distance between the M2 vertex and the telescope focal plane. The diameter of M2 results D2 = ε D1 = 92.5 mm. From similar triangle (p2+D12)/D1 = p2/D2 and p2 results 217 mm. The primary mirror focal length f1 become f1 = D12 + p2 = 587 mm and its radius of curvature R1 = 2 f1 = 1174 mm. The adimensional back focal length β is 150.0/f1 = 0.255. The telescope magnification is m = f/f1 = 2.38. The adimensional parameter ρ defined as R2/R1 is also (see Schroeder[4]) mε/(m-1) = 0.638 and R2 become R2 = ρ R1 = 749.0 mm. Finally the conic constant of the hyperbolic secondary mirror is K2 = - [(m+1)/(m-1)]2 = -6. The conic constant of the primary mirror is obviously K1 = -1 (Cassegrain).

Once optimized we calculate the tolerances for M2 decentration and tilt with respect to the optical axis (defined by the primary mirror as in figure 4). Note that the equivalent aplanatic Cassegrain have exactly the same parameters above but the conic constants K1 and K2. The reader may try by himself this configuration by changing the conic constants into:

$$K1 = -1 - \frac{2(1+\beta)}{m^2(m-\beta)} \qquad \textit{and} \qquad K2 = -[\frac{m+1}{m-1}]^2 - \frac{2m(m+1)}{(m-\beta)(m-1)^3}$$

Anyway the equivalent aplanatic configuration will be also more sensible to the mirrors alignement and so we compare the Klevtsov configuration with the classic Cassegrain only. The tolerances of the equivalent Cassegrain designed here are summarized in the figure 5. Here the diffraction performances of an on-axis point is shows as continuous bold line. The optical performances of an on-axis point is perfectly superimposed to the bold curve, because the Cassegrain design is diffraction limited for that point. The fraction of the encircled energy falling inside a circular region of 10 μm in diameter for a decentered secondary is shown as a dotted and a dashed line. The latter line show that the 80% of the energy fall inside the region when the secondary is tilted by 0.013 degrees or decentered by 0.05 mm. Those values are much smaller than the designed Quasar-Klevtsov above (see figure 3) showing that, in the latter configuration, the secondary has a tilt tolerance about 3 times larger and a decentering tolerance of about 15 times larger! That is mainly due to the spherical design of the its optics.

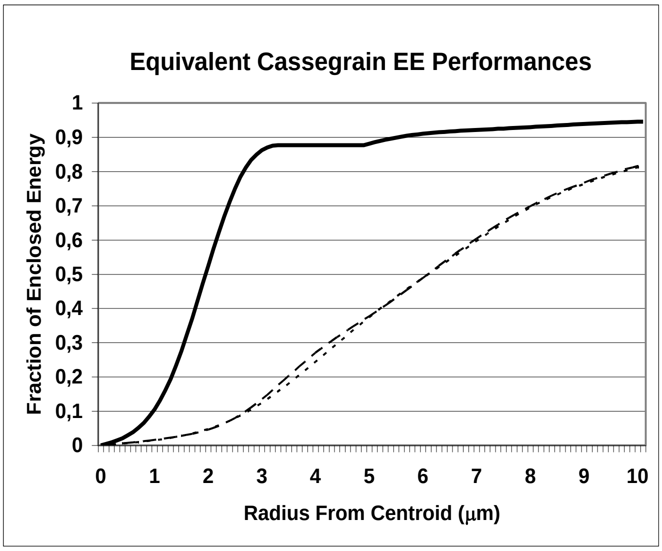

Figure 5. Tolerances as loss in encircled energy fraction for an equivalent Cassegrain telescope.

3. MECHANICAL MOUNTS AND ASSEMBLY

The optics and the opto-mechanical elements have been built and assembled. A 3D mechanical layout is shown in the figures 6a - 6d. The structure of the telescope consists of:

- the primary-holder cell (fig. 8, 6), in aluminium alloy, that also is the bearing element of the structure;
- a steel central tube, integral with the cell, on which the primary mirror, the focusing system and the primary baffle are fixed;
- the primary baffle (fig. 8,7), in Al alloy;
- the secondary-holder cell (fig. 8,8), in Al alloy, carrying the optical correction elements, besides the secondary mirror; the cell can be axially adjusted, to compensate optical and mechanical tolerances;
- the secondary baffle (fig. 8,9), in Al alloy;
- 3 steel rods (fig. 8,10) which connect the secondary cell to the primary cell through hinge-joints, are anchored to the primary cell on steel blocks fixed on the cell (fig. 8,11); these blocks have anti-rotation housings and axial lock; the axial position of the rods can be adjusted through screw-sleeves and blocked by threaded knobs (fig. 8,15); an adjusting group (fig. 8,12), incorporating extractor and collimator, is mounted at the end of each rod;
- a focusing device group (fig. 7, 3 and 8, 13), fixed through a flange to the rear side of the primary cell, that enables to mount an eyepiece holder (fig. 8, 14) or a photographic extension tube, both fixed by the same ring nut; the focusing is achieved by axially moving the eyepiece holder, or the camera, through a rapid thread screw (fig.8,13), that covers the full range in approx. 1.5 turns; the couple screw / female screw is axially loaded by springs and balls, so removing the play and reducing the friction resistance;
- the primary cell is provided with radial threaded holes to fix accessories, such as: dovetail bracket to fix the telescope to an equatorial mount (fig. 9, 15);
- bracket for the finder scope (fig. 9, 16);
- bracket for the guide telescope (fig. 9, 17);
- bracket for a pointing laser;
- brackets and accessories are positioned once and for all and can be left on the cell even when the telescope is dismounted (fig. 9A, B).

The telescope fits in a suitcase with internal dimensions of 580x440x240 mm. The weight is approx. 10 kg.

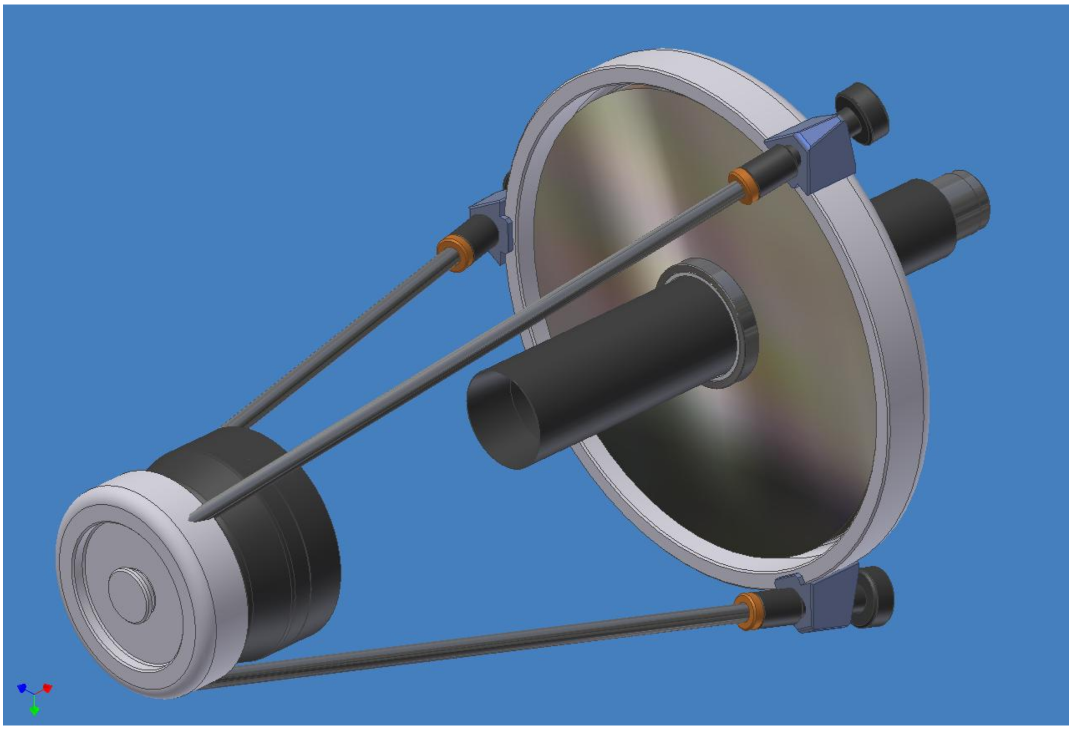

Figure 6a: 3D axonometric front view of the telescope.

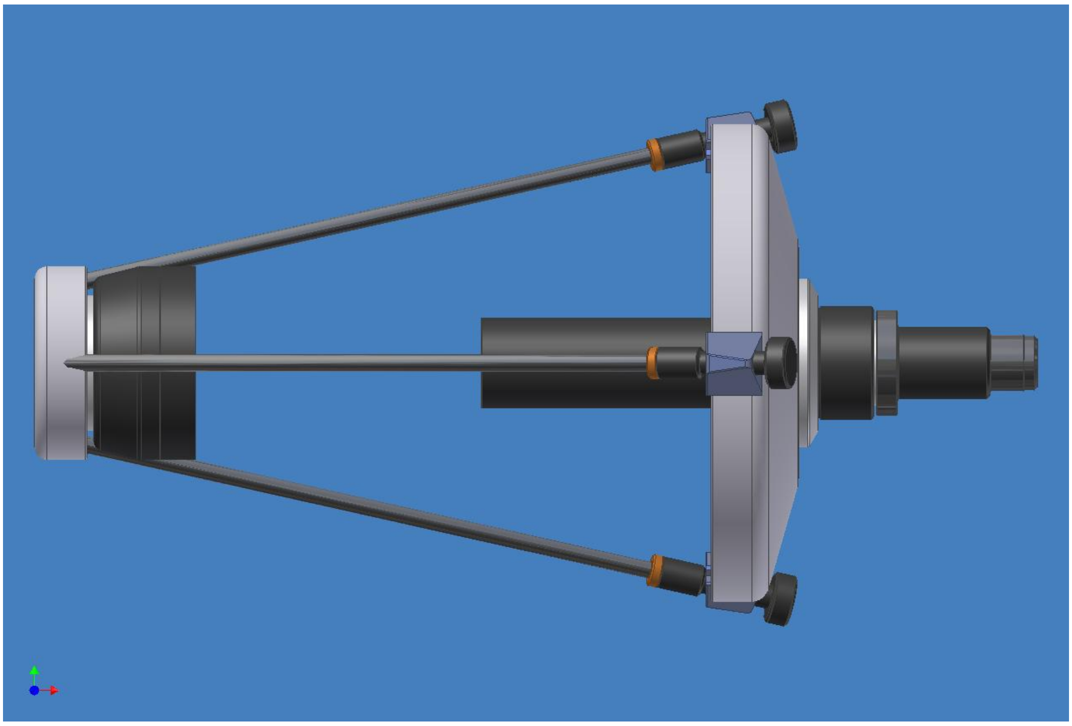

Figure 6b – 3D side view of the telescope.

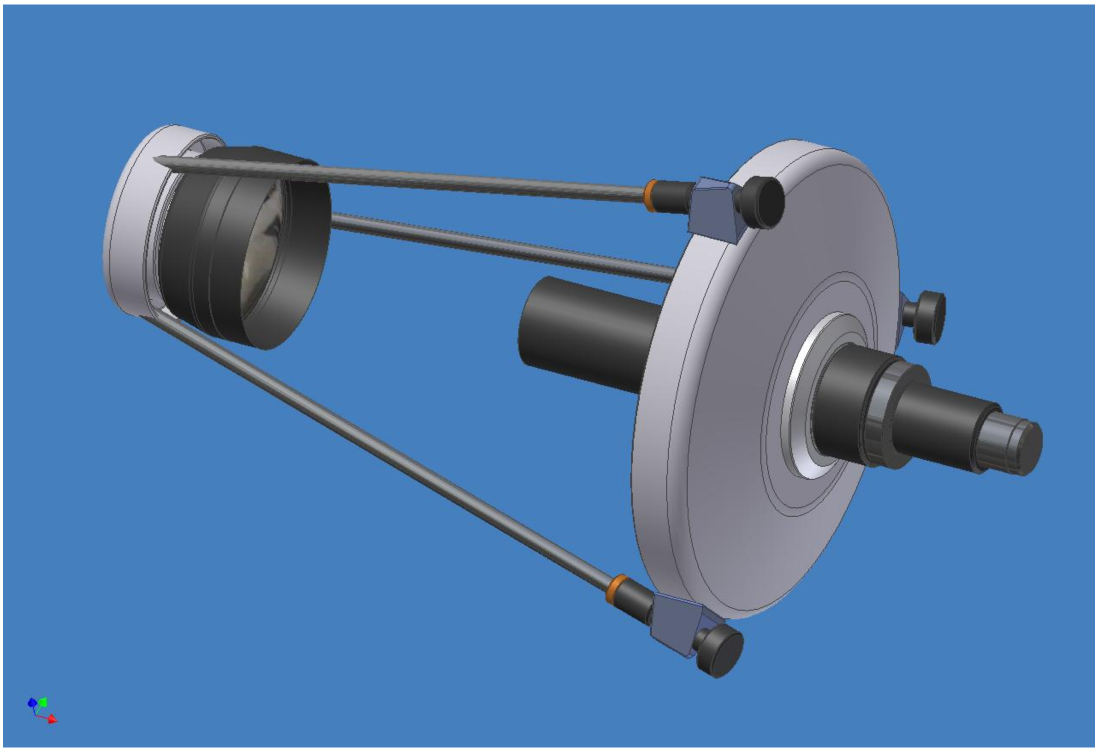

Figure 6c - 3D axonometric rear view of the telescope.

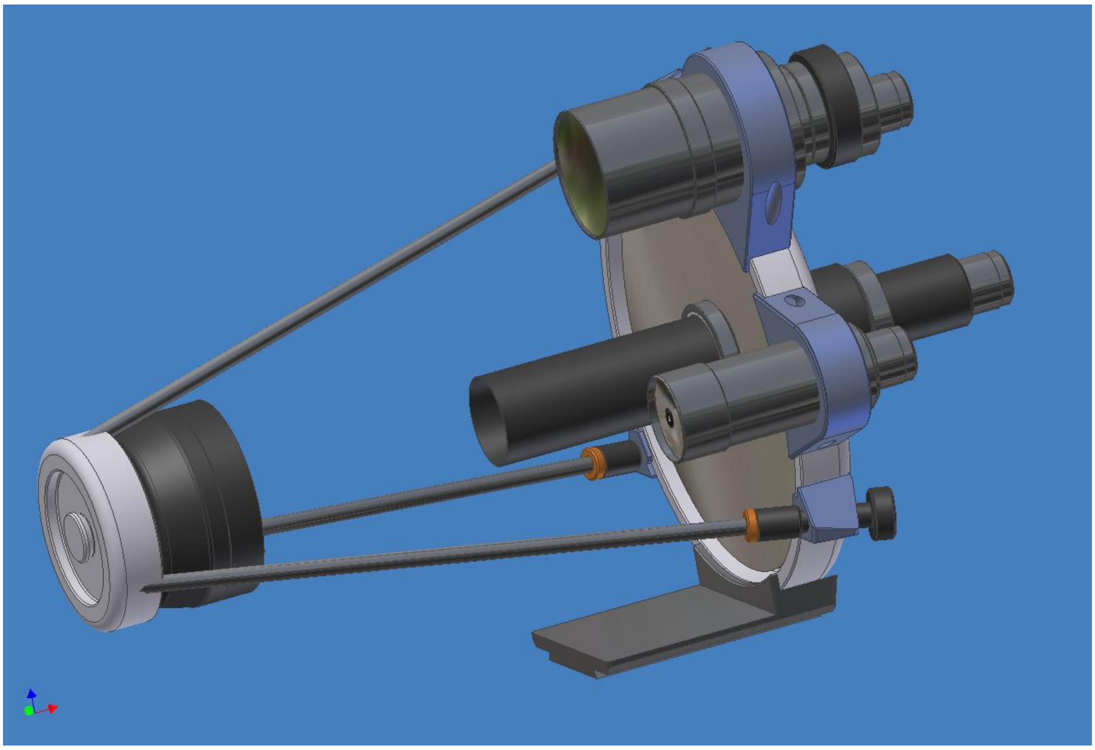

Figure 6d – A possible configuration of the telescope with some accessories, in this case a finder scope and a guide telescope.

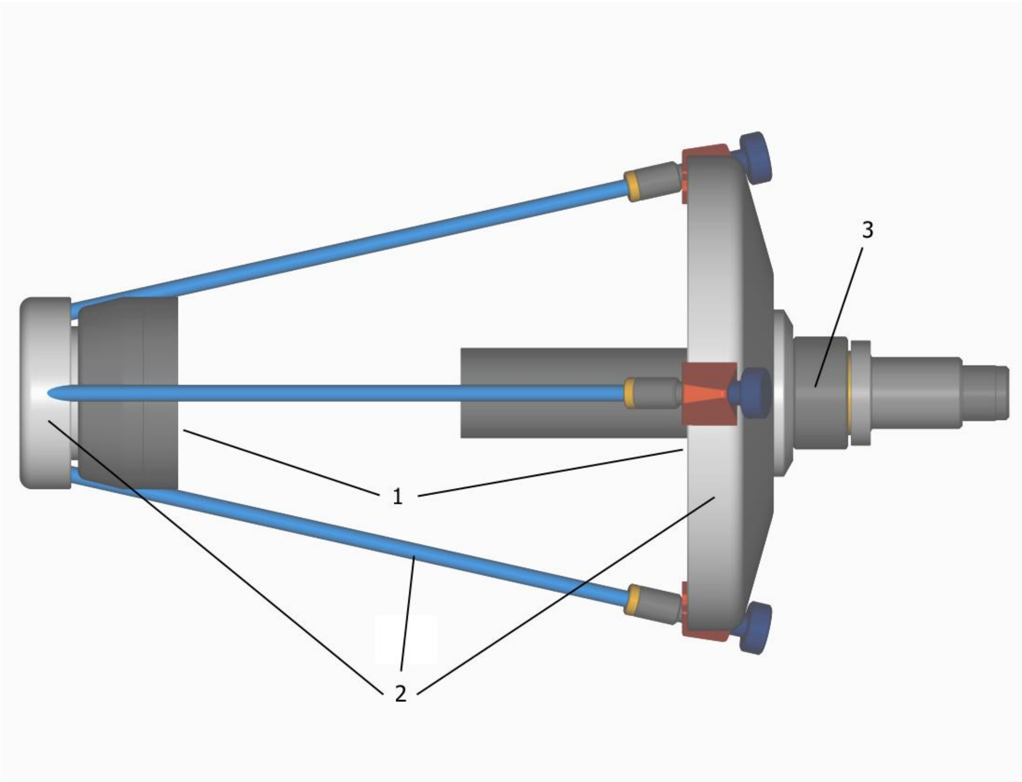

Figure 7 – Assembled telescope. 1 are the optical elements; 2 and 3 the mechanical structure.

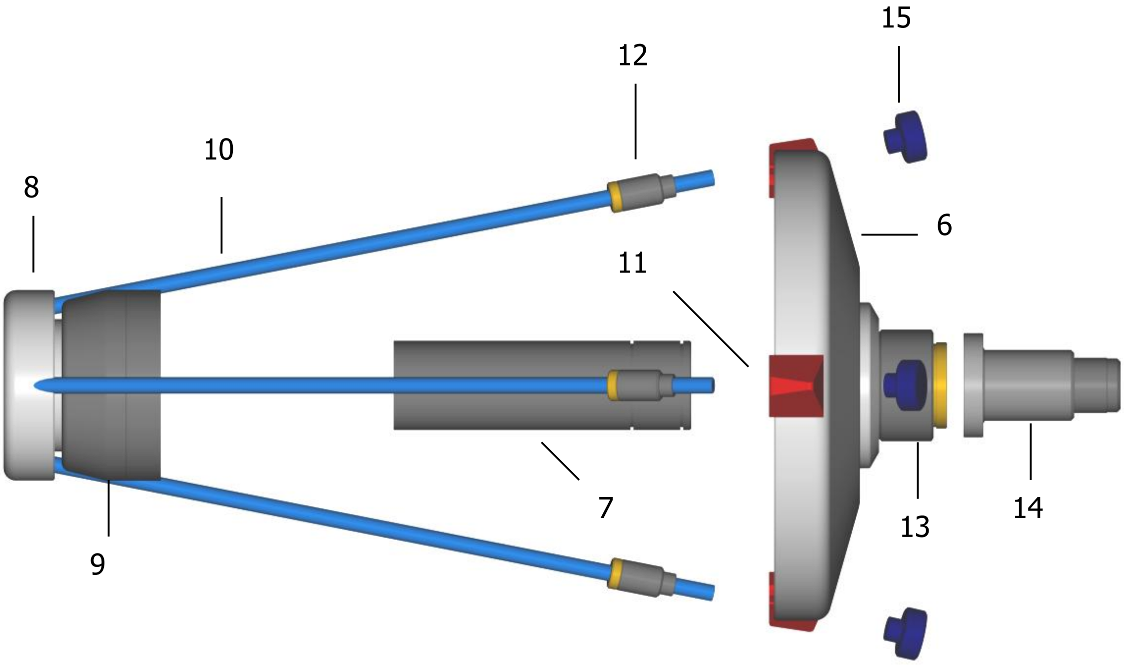

Figure 8 – Disassembled telescope. References 1 ÷ 15 are shortly explained below.

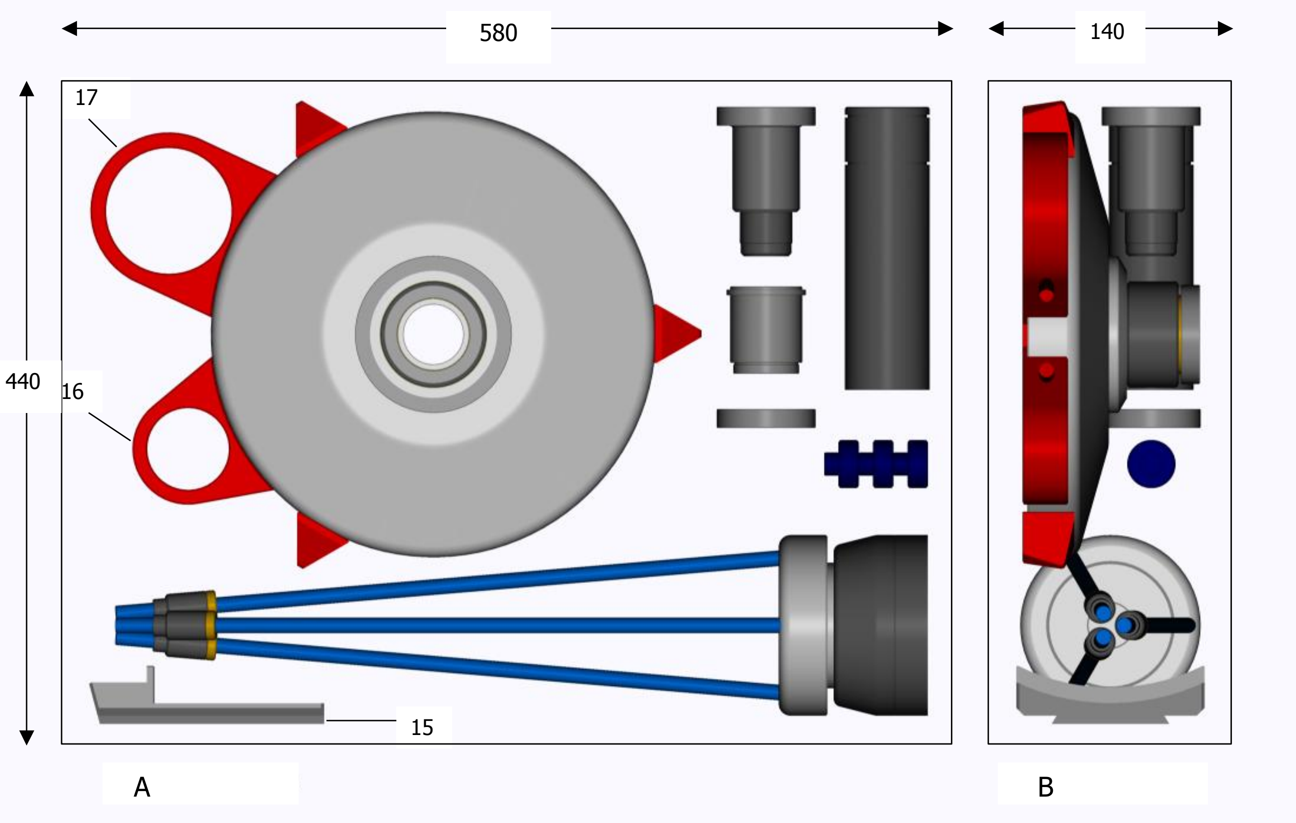

Figure 9 – The telescope carried in a 580x440x140 suitcase (internal dimensions).


Figure 10 – Photo of the assembled telescope (Pic du Midi).

Figure 11 – Photo of the dismounted telescope.

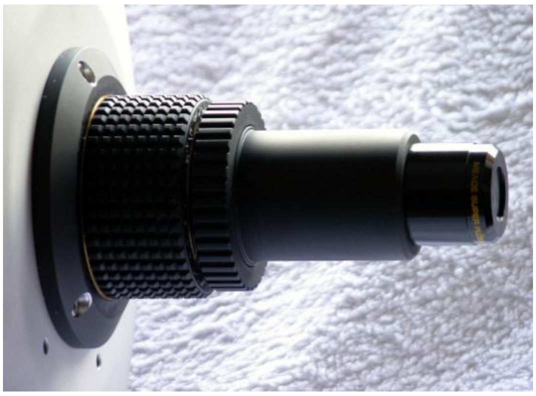

Figure 12 – Detail of the focusing device group.

Figure 13 – Detail of the blocking and collimation systems.

4. CONCLUSION

A dismountable and portable telescope with a primary mirror of 250 mm in diameter and a numerical aperture of 5.6 has been designed and built. The telescope has a all-spheric catadioptric optical design, consisting of a spherical primary and a group of spherical lenses, where the last surface is aluminized, as a secondary mirror. The telescope has a very compact design, with a physical length of 600mm. This fact, joint with the all-spherical design, make it a ligth portable and easy to align instrument: when dismounted it can be contained in a suitcase sizing 580x440x140 mm and the spherical surface for all the mirrors and lenses makes easy the final alignment of the optical train. Extensive on-sky test are planned for the next few months.

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