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Engineering a whole sky one meter class telescope: MezzoCielo as a patrol of transients

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ABSTRACT

MezzoCielo is a project of a monocentric optical system with a spherical glass envelope built up by meniscus arranged onto a Platonic or Fullerene-like structure filled with industrial liquid characterized by high transparency and low refractive index. Optical design of the cameras, implying the choice between large multiplexing and moderate individual field of view vs. a limited amount of cameras aiming to correct a much larger individual field of view is discussed, along with the current status of the engineering aspects of its design. A case study for such a telescope as a patrol of GW telescope in order to allow almost real-time pinpointing of the associated multimessengers potential sources is given, showing its capability to explore a unique science.

Keywords: Wide Field Telescopes, Large Optical Telescopes, Monocentric optical system, Liquid optics.

1. INTRODUCTION

Schmidt telescopes [1,2] are the kind of telescopes producing the larger astronomical information on large Field of View, although in short time the Vera Rubin Observatory [3] will redefine this paradigm with an 8m class aperture although through a somehow smaller Field of View. Significantly larger Field of Views are obtained by apertures two orders of magnitude smaller with single optical systems [4] or by apertures one order of magnitude smaller through the assembly of a significant number of conventional wide field very small telescopes [5,6,7] a sort of direct multiplexing. Multiplexing after a very small monocentric optical system [8,9] or at the focus of a world class size large telescope [10,11,12,13] are two extremes of the classes of optical solutions that one can conceive in this hybrid world where an initial common optical system is followed by an array of cameras that actually produce the multiplexing required to attain to certain science capabilities. The “FlyEye” [14,15,16] is a first attempt to combine a relatively large monocentric aperture with a moderate array of correcting cameras. MezzoCielo [17,18,19] is the extension of such a concept using as a monocentric device an hollow sphere build up by tessellating meniscus of feasible size [20,21] filled by low refractive index, high transparency liquid [22,23]. In the following we list some of the activities that are planned or being carried out in order to engineer a one meter class aperture telescope with a Field of View that can attain the whole observable sky at a given point from a location on the Earth. As this corresponds to half of the whole available sky on the celestial sphere, the nickname “MezzoCielo” stands for “Half of the sky”. Actually, some practical problem to avoid vignetting and to achieve high performance suggests some purely astrophysical solutions would reach optimality with a sky coverage of the order of ten thousands of square degree (that is actually a quarter of the whole celestial sphere), however most of the discussions reported here belong to a class of solution in the range 0.2m to 2m class aperture and FoV of 5000 to 20000 square degrees.

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2. ON THE OPTICAL DESIGN

While the optical problem behind the optical design described by the MezzoCielo concept is known for small apertures[23] for larger aperture and with a monocentric refractive sphere with low refractive index the field is somehow unexplored. In order to get an idea we compare the level of spherical aberration that is to be accounted for by the compensating camera with respect to the FlyEye where a spherical mirror is presented. The figures of course scales with the filling factor, i.e. the ratio between the actual aperture of the telescope and the diameter of the monocentric sphere (see Fig.1).

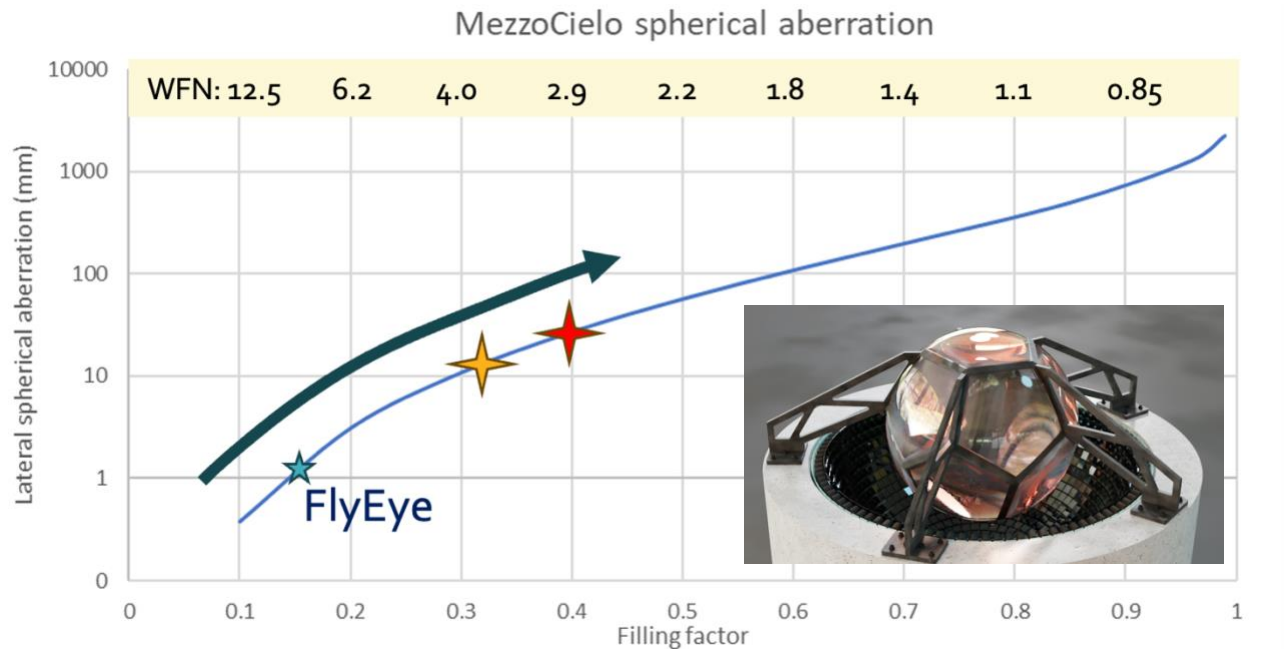


Figure 1: the filling factor for MezzoCielo (depicted in rendering in the image on the lower right part of the diagram) vs. the spherical aberration to be accounted for in the compensating cameras. As a comparison the FlyEye figures is quoted along with a couple of solutions briefly summarized in the text. On the upper part of the figure the equivalent focal number of the monocentric system is given as a reference.

Solutions for filling factors up to 40% have been found for monochromatic system (see also Fig.2) with optical quality compatible or exceedingly better the one required by a seeing limited optical system. These designs often use relatively large thickness optical components that are likely part of the ingredients to introduce spherical aberration to compensate the monocentric one.

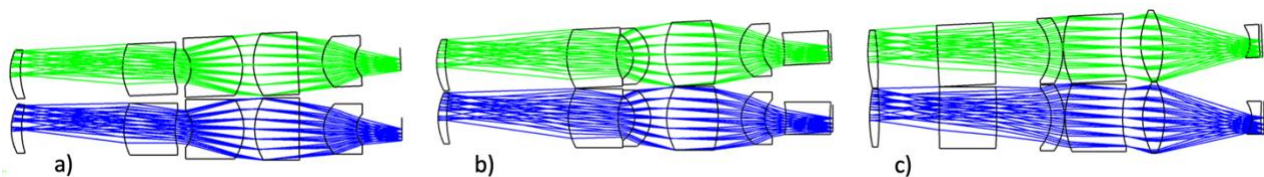


Figure 2: Three examples of monocentric optical design as an illustrative means of how cameras are supposed to be coupled to the monocentric system. The light is focused on the entrance field lens that is the first on the left for each of the three designs. All designs exhibit an overall focal ratio F/2 with filling factors of a: 0.31, b: 0.38 and c: 0.40. All the three solutions can mechanically be accommodate with some minimum clearance between each others.

In order to achieve a finalized optical design the following issues are being explored:

- Trade off between more cameras, each with a limited FoV, and less camera, each with a larger FoV;
- Compensation of chromatism assuming a certain range of wavelength is being explored for scientific purposes and assuming possible refocusing (or filter dragging compensation) if standard (e.g. UBVRI Johnson) astronomical filters are being used;
- Large individual Field of View in order to tackle light scattered at the edges of two adjacent cameras because of the initial large spherical aberration;
- Tolerancing on the tiles of the monocentric system (and possible activation of their positioning and/or shape) to achieve scale errors to avoid mis-superimpositions of beams passing through adjacent tiles on the monocentric sphere;
- Use of aspherical surfaces on the camera compensator, or use of liquid as interfaces between successive lenses.

We are also exploring the possibilities to retain monocentric the central optical system but using double meniscus in order to achieve a smaller spherical aberration and chromatism to be injected onto the array of cameras. We also look into the option of splitting the monocentric system into two hemispherical design, each monocentric. This would not allow for scaling up to the full exploitation up to 20 thousands square degrees but it looks doable with the 10 thousands square degree options. This approach could have two advantages: the first is to have a smaller second hemispherical part, lowering the cost of the monocentric system (or allowing, for a given budget, to achieve a larger aperture) and to have more degrees of freedom to achieve a pre-compensation of spherical and chromatic aberrations. The number of parameters one can play with are, of course, rather large, and we are in the process of exploring different roadmaps to finalize one or more classes of optical solutions.

3. ON THE MECHANICAL DESIGN

In principle the design of a MezzoCielo system is somehow simplified with respect to a conventional telescope because no moving parts (other than adjusting, refocusing or bandwidth selection) are required with the noticeable possible exception of rotating around the Earth axis the whole assembly of the cameras (an option that could be avoided with electronic tracking on the detectors, at least to some extent). However tolerancing and hydraulic issues requires to design to be somehow non conventional. While Finite Element Analysis [25] is being carried out to get figures of all the possible values of stresses on the various components and especially on the tiles building up the monocentric sphere (see also Fig.3) a number of considerations are required.

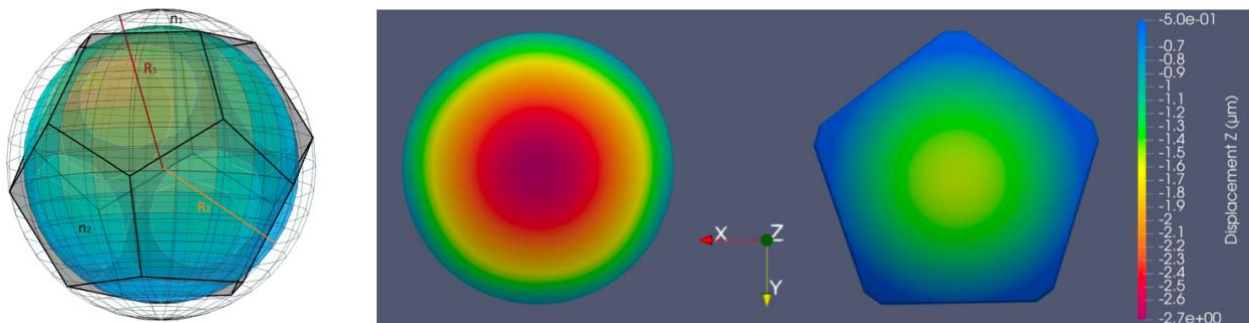


Figure 3: from right to left: the modelling of four of the several meniscus lenses arranged onto a platonic solid to mimic a spherical hollow sphere; Displacement and stress of a tile with both static gravitational and hydraulic load.

Issues to be considered in the design are at least:

- Static and hydraulic loads for each tiles;
- Deformation of the structure and consequences for the tightness and the tolerancing of the optical elements;

- Effects on the birefringence of the material;
- Fluid tightness of the tiles;
- Eventual activation (i.e. lateral and radial movements of the tile retaining the fluid tightness);
- Effects of wind load on the structure
- Ways to achieve larger rigidity with no or minimum impact on the overall throughput (for example with wires mounted onto diametral opposed points on the monocentric optical system);
- Detailed computations of overall throughput and trading off with thicker interfaces between optical and structural elements;
- Trade off between smaller number of tiles and their larger size and vice versa, with obvious effects on the mechanical structures (from smaller faces platonic figures to fullerene-like designs).

Most of these issues are being attacked in a variety of ways, including small scale experiments to learn by hands-on on some aspects of the structural design that are not obvious because of their unconventionality.

4. ON THE SCIENCE CASE

Transient and unpredictable phenomenon are the obvious target of a telescope with a significant aperture and a complete sky coverage. Kilonova [26] and counterparts of Gravitational Waves events [27] are among the ones that does not necessarily requires the aperture offered by the current largest 8m class telescopes and they are attainable by a one meter class telescope. In fact, several scientific cases are sketched or seriously carried out for much smaller apertures or for covered Field of View that are much more limited. While a limited coverage of electromagnetic counterparts can be effective into finding anyway a few interesting counterparts, a statistical analysis of the overall phenomenon would requires a telescope like MezzoCielo. In other words it is true that a modest aperture and a relatively large Field of View is capable to assure a handful of cases, biased toward the brightest magnitudes, that could deserve important follow-up in order to specifically study such cases, it is only through an un-biased analysis that a coherent description of the populations lying behind these event can be described. Because of limited efficiency due to weather and to the geographical and inaccessibility of the sky close to the Sun, even an array of extremely wide field telescopes will be unable to fully cover counterparts of events with no a-priori preferred position in the sky. The fraction of the sky that can be fulfilled is however close to a significant fraction of it with only one of such telescope in an average site. It is also interesting that limited (and probably prototypal) versions of MezzoCielo with limited apertures (like a 20..50cm monocentric sphere, with filling factors around 0.5) would be competitive to current versions of the largest sky coverage patrols.

An incomplete list of further cases also of scientific interests includes, and not necessarily limited to:

- Exoplanets transiting;
- Variable stars;
- Novae and SuperNovae;
- Minor planets;
- Near Earth Objects;
- Space debris;
- Unknown transient phenomenon.

5. FURTHER ISSUES AND (PRELIMINARY) CONCLUSIONS

The case for the data acquisition, handling, storing and mining is not being considered in the limits of this initial work. The full available sky coverage would allow, in principle, to make any a posteriori analysis of transient phenomenon's. However this would requires a large efforts in terms of data management. Assuming ten thousands square degrees with a

resolution of the order of one arcsec, a single “frame” of MezzoCielo corresponds to about 260 Gbytes, making a night at one minute cadence a data flow of the order of 150TBytes per observing night. Front end electronics and pipelining is hence one further issue to be seriously attacked in the near future and wireless or fiber optics connections could become a mandatory options for a number of practical reasons. Energy-resolving capabilities, translating into tessellated filtering, the adoption of energy capable detectors, or the use of arrays of spectrograph couple with fibers or through a fiber taper are of course fascinating but beyond the limits of the current level of the study. It is also unclear which could be the practical limitation in size of this approach and the eventual adoption of a double sphere with only the inner part filled by liquid could allow for a limited filling factor but for high quality imaging and a trade off for a more complex option with respect to a plain hollow sphere should be carried out in due time. Discussions to adopt such a kind of telescope as a prototype for demonstration purposes in connection with the Einstein Telescope as a Gravitational Wave sensors to be built in the Sardinia region are currently underway.

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