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Memorie della

The fine and transformational optics of Guido Horn d'Arturo

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1. Introduction

Astronomy is a field where challenges can be so desperately hard to deal with, that refinement of existing technology are often able to gain such a small step with respect to the required leap to appears pathetic. One of the reasons of this is probably due to the fact that the differences of length scales involved has no comparison to other sciences. Astronomers use microscopes to examine meteorites, or to study "in situ" other planets, and probes distances that are about the size of the known universe. The ratio of these length is of the order of 10^{32}. The energy of the carriers involved in the classical electromagnetically astronomy (a concept that is going to be abandoned in favor of multi-messengers like neutrinos or gravitational radiation) contemplates from the 21cm radio maps to the highest energy GRBs is "only" of about 10^{11}. Confining ourselves to the realm of the not so exotic exoplanets, of which we pretend to explore (although often indirectly) ocean and atmospheres, the thickness of the latest is, apparently speaking, confined to an angle that is 10^{15} times smaller than the naked eye capability, the only available till a few centuries ago. These ratios are so large that often only new paradigms can have the chance to erode them significantly. With these preconditions, transformational ideas have the chance to change the world. Or at least to change the world of astronomy. Sometime the idea is somehow wrong, but produces the seeds to get the right one, and sometime the idea is perfectly right, but still need the technology -or at least the investments of enough resources- to turn them into a proven reality.

It is in this framework that, I believe, we should see how the concept of segmented mirrors develop in the work by Guido Horn d'Arturo, in the foreground of an "age of the extremes", that makes his ideas a transformational one.

Transformational here is to be taken as literary as it depicts the meaning of a "first" and "after" the idea. A concept that would make, if properly applied, astronomy not anymore as it was before. It is nowadays widely accepted, and the technology allows from decades such achievement, that segmented mirrors, and more in general the concept of co-operative optics, can lead to infinite scalability. Such a theoretical limit is of course purely conceptual. A single large reflecting optical dish on the ground requires properties of the bulk materials that does not exists as soon as its size exceed a certain diameter. The exploitation of novel anisotropic materials, like Silicon Carbide, would allow to push further such limits, maybe beyond the boundaries of the reasonable amount of resources that one would allow to spend for studying the heavens, but still a limit would exists.

Heading back to the time when Guido Horn d'Arturo developed several concepts, including the segmented apertures, one should try to embark in the zeitgeist of the time, at least in the fied of astronomical instrumentation, in order to get a better insight on the relevance of his work.

Surely in the first half of the 20th century, and probably till the Labeyrie' speckles concepts, well before space telescopes or adaptive optics make their signature in the telescopes development, a "large" telescope only means a large collecting area. This is such an interesting fact (and hard to accept in current days) that we should elaborate further on this in a few lines. Before the image formation theory reached its refinement the magnification was considered a key parameter (and interesting to note this is still persisting in large area of common belief among non professionals) making the manufacturing of extremely long focal length telescopes a driving factor. The realization that extremely large magnifications make an illusory augmentation of the details recoverable on the image plane made clear that the potential resolution is only given by the telescope diameter. This is true for a perfect telescope that is not observing through a turbulent media. Ground based observatory can maybe fall in the first category but surely not in the second one. And it took further decades to reach a comparable degree of knowledge. The Fried parameter has been introduced more or less at the time when Guido Horn d'Arturo left this world, and surely much later than when he produced the stream of ideas related to segmented or cooperating optics. The concept of seeing was known, of course, but basically there was general consensus that for any realistically large professional telescope, resolution was dominated by our beloved atmosphere rather than to the effectiveness of the optical quality in the astronomical instrumentation. This paradigm would be briken, as mentioned earlier, only decades later than the Guido Horn d'Arturo times and it is just mentioned passing by that in X-ray astronomy we live together exactly the same condition, where the telescope image resolution is not being dominated by the famous λ/D ratio. Finally, let me remind that numerical optimization was way before to come, and engineers and scientists were used to solve problems with graphical or mechanical (we would today name them "analog" in contrast to digital) tools.

While this preamble is boring, I believe it is essential to define the framework where the work of Guido Horn d'Arturo deployed, and also to understand why it has been subsequently forgotten just to be re-invented at a time when the technology and the knowledge of the image formation through our atmosphere developed substantially.

A contributing factor for such an anomaly, it must be pointed out, it is represented by the fact that Guido Horn d'Arturo didn't publish in English language basically all of his works on astronomical instrumentation. While some of these, especially toward the last part of his admirable career, are mostly of descriptive nature, several are very sophisticated pieces of high order description of the image formation with, occasionally, new graphical techniques to solve high-degree polynomial equations. Although it is highly speculative this could have roots on the perception of the time toward engineering vs. scientific approaches, vaguely reminding the two cultures issues, later depicted by C.P. Snow, if not belonging to the Italian school system that, based upon a reform dating back in 1923, distinguish, basically placing on a lower grade on a scale of social relevance, practicalities from the knowledge.

Focusing on the pure optical side of the Guido Horn d'Arturo works, the adoption of cooperating optics, taking places in segments mimicking a common optical surface, is central in most of the Guido Horn d'Arturo production. In principle, the ideal manufacturing of an optical surface through perfectly built and aligned segments of various nature and shape (and in this we can easily spot an evolution from pieces of coronas to hexagonal segments, an ante litteram edition of the optimization process that is nowadays widely accepted) does not necessarily require the introduction of novel concepts in optics, especially if, as it is in the case of Guido Horn d'Arturo, confined to the ray-tracing approximation. In a real world, however, errors in the manufacturing and co-alignment of the various pieces compounding a conventional Newton, Cassegrain or Schwarzschild telescope, would play a role that has to be treated in the proper manner. We can clearly trace three approaches in the remarkable series of papers we have from Guido Horn d'Arturo, not necessarily uncontaminated between each other, that one can outline in the following:

i) Guido Horn d'Arturo realize that, with the electromechanical means available at the time, and within the framework of building a cheap telescope with the size of the largest available at his own epoch, the only viable way is the one to build some zenith fixed, transit telescopes; he will conceive the concept of having several of these devices scattered along different latitudes, and will identify specific location whose natural conformations, like caves, would naturally allow to deploy these kind of telescopes;

ii) Guido Horn d'Arturo recognize that the various segments will suffer from manufacturing error such that, for instance, they will not exhibits a common focal length. Further to budget such non conformance parameterizing to the overall aimed optical quality, ways to propagate them into different deterioration of the performance are sorted out, like balancing between lowering the overall optical quality or accepting a degradation toward the edge of the Field of View;

iii) Finally, ways to operationally co-align these kinds of segments in a proper fashion are described. It is interesting that, while this is usually treated in a very academic formal manner, one can always read behind the lines actual means to practically operate on the several screws supporting the segments, in order to make the whole set of optical segments to act in a cooperative manner.

In these approaches one can see predecessors of the modern approaches used to align large telescopes nowadays, and in the way the off-axis optics are corrected when dealing with fixed zenith telescopes, as depicted for the large liquid rotating mirrors proposed by Borra and collaborators more than half a century later.

In all these fine descriptions the pure geometrical approximation is always used. Within the seeing-limited regime where Guido Horn d'Arturo spawn in the realm of astronomical instrumentation this approach is fully justified as the Airy disk size, for the diameters considered, is negligible. The incorporation of physical optics appears finally for the first time in 1957 where the Babinet's principle (although without mentioning it explicitly) is used. In this work the description of the point spread function of an hexagonal segmented mirror with the six spikes around the central core is properly described, while, however, the problem that today would be listed as co-phasing is not even vaguely recognized. While this is routinely implemented in large astronomical telescopes is by no means implemented in Cherenkov collectors, where, however, the overall optical quality is worse by at least an order of magnitude of the limits imposed by the atmospheric turbulence.

In this period, apparently Guido Horn d'Arturo understand of the Michelson interferometry applied to a telescope in order to measure binary stars and immediately figure out a minimalistic version with just two segments located far away. Without taking into account the co-phasing problem fringes will unliekely be visibile and, furthermore, in case the segments could be located "as far as one wish" the fringes would wash-out, diluted into the large central portion of the Airy disk of a single segment. But these last findings occours when our hero is 87 years old and within short time will leave our world, with its envelope of turbulent atmosphere that justify the approach he follow just 30 years (and a world war) before.

I would like to finally add a short personal note. I had the lucky opportunity, when much younger, and when astronomical instrumentation was a passion fueled by amateur astronomy aim rather than a professional duty, to chat with Ferdinando Caliumi, one of the technician that worked with Guido Horn d'Arturo aligning manually the segments in the tower at the Bologna's specola. And I spent nights when the weather were not allowing to open the dome of the Asiago Astrophysical telescopes carefully

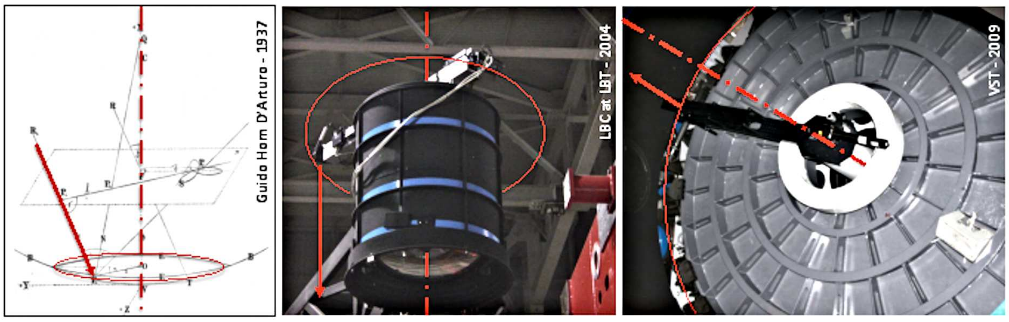

Fig. 1. Different epochs, different telescopes, with in common the same principle for their optical alignment. Guido Horn d'Arturo, in 1937, describe the behavior of starlight isolated through a screen with a circular hole mounted on a mechanism that allow it to explore a circular portion (the red circle) of the telescope optics coaxial to the symmetry line. Seventy years later a laser beam materialize in the same manner a similar circle in order to get the proper misalignment information on two among the most important telescopes (LBT and VST) belonging to a community, the Italian one, for which Guido Horn d'Arturo fight during WWI just one century away.

reading the vast and imaginative literature of Guido Horn d'Arturo in the local library. There was not piexoelectric precision actuators, neither electronic sensors or digital means of closing the loop between the aberrated optical image and the position of the segmented optics. There was rarely, in the Guido Horn d'Arturo papers, the willing to invest the amount of resources that more than half a century later people would invest into the Keck telescopes and their successors. More easily, he described approaches to make a country like the Italy after WWII, able to compete with smart and cheap approaches to the same kind of apertures deployed by much powerful country using the brute force of building large and expensive optics. I like to see the curious approach to avoid to write in English all these kinds of superb, visionary and transformational ideas in order to give to the Italian astronomical community that sort of advantage over their foreign collegues. A subtle way to give the opportunity to the country for which he risked his own life to ransom the names of Galileo, Secchi, of him and our "fathers".

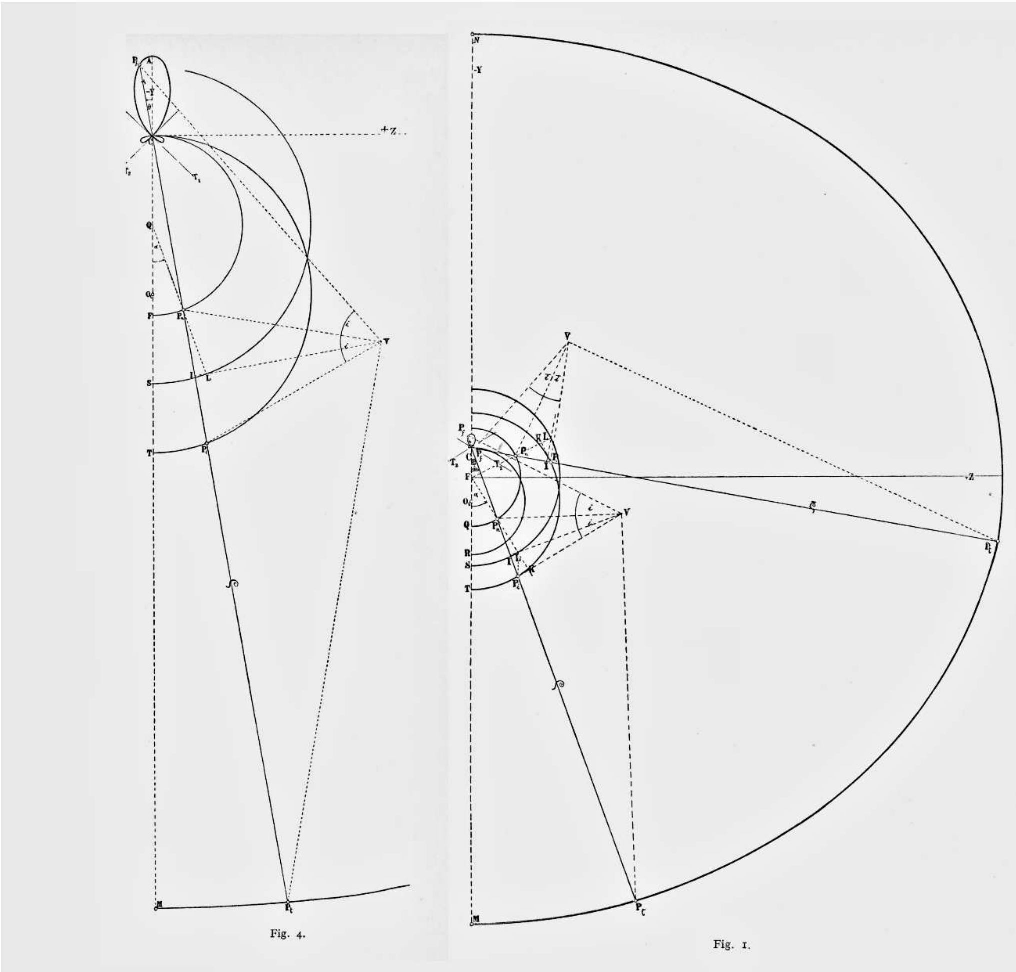

Fig. 2. Although the parallel is somehow overwhelming, Guido Horn d'Arturo, as most physicists in the golden age of relativity, have to work out his own mathematical methods with the tools of his own epoch. Here a way to solve graphically fourth order equations is depicted out.