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Guido Horn d'Arturo and the first multi-mirror telescopes: 1932-1952

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Abstract. In the late 1920s, the project of the big 5 m telescope on Mount Palomar was starting in the USA: an enterprise absolutely unapproachable for Italy at the time. In 1932, Guido Horn d'Arturo - Director of the Astronomical Observatory of the University of Bologna from 1921 to 1954, with a dramatic interruption due to the Fascist racial laws conceived first a reflecting telescope made with many small mirrors instead of a large monolithic mirror. After a 1 m diameter prototype, in 1952 Horn d'Arturo made a 1.8 m diameter telescope, assembling 61 hexagonal mirrors, each of which was aligned and focused by three underlying screws. Less than thirty years later, the Multiple Mirror Telescope in Arizona was the first of a long series of telescopes developed with the same technique devised by Horn d'Arturo, until the under construction European Extremely Large Telescope in Chile, with about 800 hexagonal mirrors for a total of about 40 m diameter, and the James Webb Space Telescope, with 18 hexagonal mirrors for 6.5 m diameter, which will be launched in the coming years. The tessellated telescope made and used by Guido Horn d'Arturo is undoubtedly the forefather of the new large multi-mirror telescopes with active optics, although his merit has never been recognized until November 2018, when the astronomical community has decided to name after him the modern telescope ASTRI-CTA on Mount Etna, dedicated to the observations of very high energy radiations from space.

Key words. History of astronomy: Guido Horn d'Arturo – History of astronomy: segmented telescopes – History of astronomy: racial laws – Astronomical instrumentation: multi-mirror telescopes

1. Introduction

Our aim is to summarize here a number of researches done on Guido Horn d'Arturo (1879-1967; Fig. 1), on his works and his correspondence kept in the Historical Archives of the Department of Astronomy of the University of Bologna (AABo),[1] in particular in the *Fondo Guido Horn d'Arturo*.[2] This fund mainly consists of 10 boxes with the private correspondence of the astronomer, *Epistolario privato 1912-1939*, donated by his grandnephews Maria Delia, Patrizia and Mario Horn, for a total of about 7000 documents. More documents found afterwards in the Department of Astronomy have been added and a large part of

[1] The Historical Archives of the Department of Astronomy (hereafter AABo), currently at the Department of Physics and Astronomy, completely reordered and inventoried and to a large extent digitized, are available on the network at: http://archiviostoricoastronomia.unibo.it/.

[2] Hereafter *Fondo GHd'A*, see http://archiviostoricoastronomia.unibo.it/serie/fgh.

his institutional correspondence can be found in the *Serie storica Specola*.

Thanks to this vast material, we have been able to follow the human and scientific path of a 20th-century scientist who has had a great influence on astronomy in Bologna (and not only), and to reconstruct the history of his project of segmented telescopes, forerunner of today's multi-mirror telescopes.

Fig. 1. Guido Horn d'Arturo; the signature of the author of the painting is not recognizable. (private collection)

2. Guido Horn d'Arturo

Elhanan Gad, named Guido, was born in Trieste on February 13, 1879,[3] corresponding to the *Schewat* 20, 5639, from the Jewish family of Dutch origin of Arturo Horn and Sabina Melli (Fig. 2).[4] Guido was the third in four children: Sara (she died shortly after birth), Mario, Guido and Arrigo. His father died when he was just two years old, and Guido and the brothers grew up in the house of the maternal grandfather, Raffaele Sabato Melli, rabbi and authoritative person of the Jewish community of the city of Trieste.

Born Austrian subject, Horn performed his university studies in Graz - four years of Mathematics, Physics and Astronomy - and then in Wien, where he obtained the PhD on July 19, 1902, with a thesis discussed with J. Von Hepperger, on the study of Comet 1889 IV, work published in 1904 on *Denkschriften der Kaiserlichen Akademie der Wissenschaften* (74, pp. 265-335), on *Astronomische Nachrichten* (165, pp. 327-330) and on *Memorie della Società degli Spectroscopisti Italiani* (33, pp. 95-99).

These synthetic biographical data emphasize the Middle-European cultural context in which Horn got his education. At first, in the Trieste *fin de sicle*, Habsburg but profoundly Italian, homeland or seat of personalities (Horn contemporary or almost) such as Italo Svevo, Umberto Saba, Scipio Slataper, Giani Stuparich, James Joyce, Rainer Maria Rilke; later, in the *felix* Wien, so described few years later by Karl Popper, Jew and Austrian subject as Horn:[5]

"Vienna really was an incredible city, characterized by unparalleled creativity. It was a fertile mixture of almost all European cultures: the regime encouraged freedom of expression and the meeting of these different traditions."

All this left a strong imprint on Horn's personality, making him an intellectual with several interests, open to new and various dis-

[3] For detailed information on the life and works of Horn d'Arturo, see Bonoli (2003 and 2007, and references within) and Picazzi, Bonoli (2017). Official academic documentation on Horn d'Arturo is located in the Historical Archives of the University of Bologna, *Serie dei professori ordinari*, f. 244. For a complete bibliography of the works of Horn d'Arturo, see M. Zuccoli, *Bibliografia delle opere di Guido Horn d'Arturo*, www.bo.astro.it/~biblio/Archives/Galleria/hornbib.html.

[4] Guido Horn, grandnephew of Guido Horn d'Arturo, kindly provided us with a copy of a page of a booklet of Hebrew prayers and meditations on which Arturo Horn, father of Guido Horn d'Arturo, had annotated the date of the marriage and the dates of birth of the children with their respective Hebrew names and some comments; *Elhanan* means "kindly donated by God" and *Gad* means "luck, good fortune": both names refer to Biblical characters.

[5] Popper (2004, p. 58).

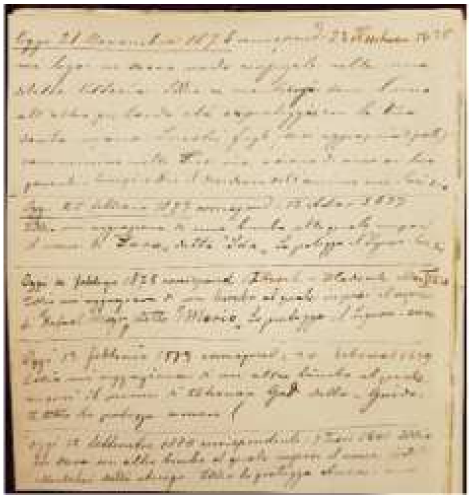

Fig. 2. A page of the Hebrew prayers and meditations book by Arturo Horn, father of Guido, in which the date of the marriage and the birth dates of the children are write down with their respective Hebrew name. (courtesy Mario Horn)

ciplines, not only scientific, as evidenced by friendships with Italo Svevo - with whom he took some private English lessons by Joyce -, Umberto Saba, Arturo Castiglioni, Franco Savorgnan, Enrico Morpurgo and, later, in Bologna, with the famous painter Giorgio Morandi.

In 1903, after military service in the Austrian Army, Horn was hired at the I.R. Maritime Observatory in Trieste, but its deeply Italian feeling pushed him to ask to be hired as first assistant at the Astrophysical Observatory in Catania in 1907. There he dealt with comets, positional astronomy, solar observations and variable stars, and collaborated in the great international project *Carte du Ciel*, for photographic mapping and cataloging of stars. In 1910 he moved at the Observatory in Turin, as an adjunct astronomer, but he was forced to go away for violent disagreements with the director Giovanni Boccardi, moving the following year to the Astronomical Observatory of the R. University of Bologna, directed by Michele Rajna, pupil of Giovanni Schiaparelli, where, in 1912, he was appointed to the professorship of Astronomy, looking ahead at a successful career.

But on May 29, 1915, barely a week after Italy entered the Great War, he enlisted as a volunteer in the Italian Army. In order to escape reprisals as "deserter", having already performed military service in the Austrian Army, Horn replaced his surname with that of "d'Arturo", named after the father. On March 6, 1919, he acquired Italian citizenship and in 1921 he obtained permission to add the *nom de guerre* "d'Arturo" to his own surname "Horn", thus officially becoming Guido Horn d'Arturo.[6]

By the end of the war, he resumed service in Bologna, but in 1920 he was transferred to the Astronomical Observatory of the Collegio Romano in Rome, where he stayed for just over a year. After the death of Rajna, in February 1921 he was again called in Bologna in charge of teaching Astronomy and of the direction of the University Observatory. In 1925 he won the competition for the Chair of Astronomy.

Horn d'Arturo could now attend to the scientific recovery of the Bolognese astronomical institution he directed until December 13, 1938, when he was "released from service in response to the measures on the basis of race". In 1945, after having escaped persecutions, he regained the Direction and the Chair.[7]

Among other activities, Horn d'Arturo started the *Pubblicazioni dell'Osservatorio Astronomico della R. Università di Bologna*, he dealt with positional and statistical astronomy, stellar variability, spatial distribution of nebulae, instrumentation, optics and physiology of vision, in which last disciplines he was particularly expert. He organized and directed two expeditions for observations of solar eclipses, obtaining important results: in 1926 in Jubaland and in 1936 in the Peloponnese.

In the same 1936, he succeeded in completing the project, started by Rajna, to bring astronomical observations far from the city cen-

[6] Letter by Guido Horn to the Rector of the R. Università di Bologna, in AABo, "Serie storica", b. 52, 1.27, 9/07/1921.

[7] For an history of the Italian astronomers persecuted by racial laws, see Bonoli, Mandrino (2015).

ter. He managed to build the Observational Station of Loiano (40 km from Bologna), with an excellent 60 cm Zeiss telescope, the second largest in Italy at the time, thanks to the endowment by Bianca Montanari, widow of a Horn d'Arturo's friend, Adolfo Merlani, mathematician and keen on astronomy.

Among others, he was member of the *Commission des notations, des unitłs et de l'conomie des publications* of the International Astronomical Union chairman M.F. Schlesinger, Director of Yale Observatory which on July 13, 1928, defined the boundaries of the constellations, as the Belgian astronomer E.J. Delporte had proposed.

His already mentioned extensive cultural interests led him to take care of updating the Observatory library, buying many important and rare historical texts as well, and to make the first reorganization of the Archives, which collect more than 100,000 documents since the middle of the seventeenth century, so being an important source for the study of the development of astronomy in the last three hundred years.

He was also interested in history of astronomy, translating from Latin the Igino's *Poeticon Astronomicon*, compiling the *Piccola Enciclopedia Astronomica e Vita e opere degli astronomi: dai primitivi al sec.* xix, and some historical entries on the *Enciclopedia Italiana*, including "Copernico" and "Astrology". The latter entry, however, was "unsigned" by his express will, because of a disagreement with the same director of *Enciclopedia*, Giovanni Gentile, due to some additions, imposed by the editor, that could have distorted the clear condemnation of astrology by Horn d'Arturo as an absolutely unscientific discipline, albeit historically important.[8]

In 1931, he started to publish the magazine *Coelum*, devoted to dissemination of astronomy - a high disclosure, by his own choice - which would have had great diffusion also abroad and will cease the publications in 1986.

Horn d'Arturo retired on November 1st, 1954: his last astronomical observations at the tessellated telescope were just made in the previous night, October 31! He continued, however, to actively attend the Specola, carrying on both the direction of *Coelum* and the care of the library and the archives. In February 1955 he was appointed Professor Emeritus of the Faculty of Mathematical, Physical and Natural Sciences; he got the nomination to Commendatore of the Italian Republic in 1957 and was awarded the I Class Diploma with gold medal for services to School, Culture and Arts in 1958. His pupils donated him a commemorative gold medal in 1965, on the occasion of the 9TH Conference of the Italian Astronomical Society.

Death reached him in Bologna on April 1st, 1967: he is buried in the Jewish section of the Verano cemetery in Rome, next to his mother.

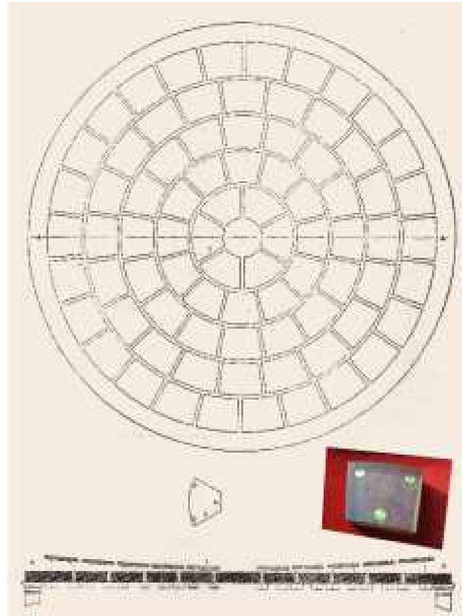

Fig. 3. At the top: design of the prototype of the tessellated mirror from the 1932 patent application. Bottom: the section shows the adjusting screws underneath the small mirrors. The overlapped not-in-scale photograph of an original non-aluminated tile allows to see the three supports on which the adjusting screws were acting. (AABo, "*Fondo GHd'A, Specchio a tasselli*", Fh5.1.3, 21/06/1932)

8 Cf. Bonoli (2015).

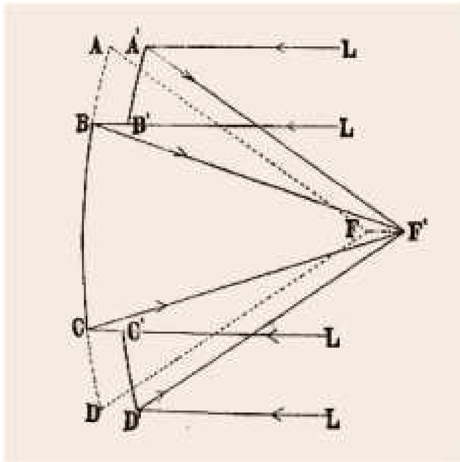

Fig. 4. The drawing shows the path of the luminous rays without the correction for spherical aberration (dashed lines) and with the correction due to the raising of the external rings, indicated by the letters with apex. CB represents the central tile, AB and CD are the tiles of the first ring, elevated in A'B' and C'D' to eliminate spherical aberration. (Horn d'Arturo 1935)

3. The Thirties: the project of the tessellated telescope

The Rockefeller Foundation allocated six million dollars in 1928 for the 200-inch telescope on Mount Palomar. The large telescope will only be completed in 1949, because of the enormous, mainly technical difficulties encountered. Horn d'Arturo knew right away that the difficulties especially were in the casting of the glass (in fact it had to be done twice), in the polishing of the parabolic surface at a fraction of the wavelength of the visible light (50 nm), in the mirror sagging under its weight, in the great thermal inertia of the glass and in its overall fragility, in the handling of the heavy mechanical parts of the instrument and, more than anything else, in the enormous costs:[9] costs that were utterly unthinkable in the Italy of the time, while the Great Depression was at its worst.

[9] Horn d'Arturo (1932a).

And so, at the beginning of the Thirties, Horn d'Arturo had the brilliant idea: instead of using a large mirror as a reflective surface of a telescope, why not assemble smaller mirrors to form a light collecting surface of great size? They cost much less and it is easier to cast and polish them, to put them together as in a mosaic, to place them appropriately and to make them work as if it were a single mirror.[10]

This was the beginning, in 1932, of the project of the tessellated (or segmented) mirror: 80 small trapezoidal mirrors ("tasselli" in Italian, i.e. tiles), approx. 10x10 cm, with a spherical section, having 1 m total diameter, in fixed azimuth mount (Fig. 3). Three screws were underneath each mirror to move and align it. A detailed and complex study on the generation of images by composite mirrors accompanied the project,[11] to demonstrate, among other things, that

"The shape and dimensions of the theoretical images of the tessellated mirror are practically identical to those generated by a circular paraboloid, when its parameter is equal to the radius of curvature of the spherical tiles."

Moreover, the system allowed to change the height of the different tile rings to eliminate the overall spherical aberration, appropriately raising external rings; it was also possible to partially correct astigmatism and coma aberrations (Fig. 4). Bearing in mind the differences due to the technological development over almost ninety years, we can say that the possibility conceived by Horn d'Arturo, to concentrate the images from small mirrors in the same focal plane, so obtaining a composite image corrected for some aberrations, is today called "active optics".

[10] Horn d'Arturo (1932b). The documents of the Historical Archives of the Department of Astronomy (see here Note 1) allowed to follow with great detail the development of the project and the problems of realization, from its birth to the actual astronomical observations and the scientific results: see the thesis for Master Degree in Astrophysics and Cosmology by V. Picazzi (2017); see also Bonoli, Picazzi (2019). The most significant papers on the tessellated telescope by Guido Horn d'Arturo are collected in Zuccoli, Bonoli (1999).

[11] Horn d'Arturo (1936).

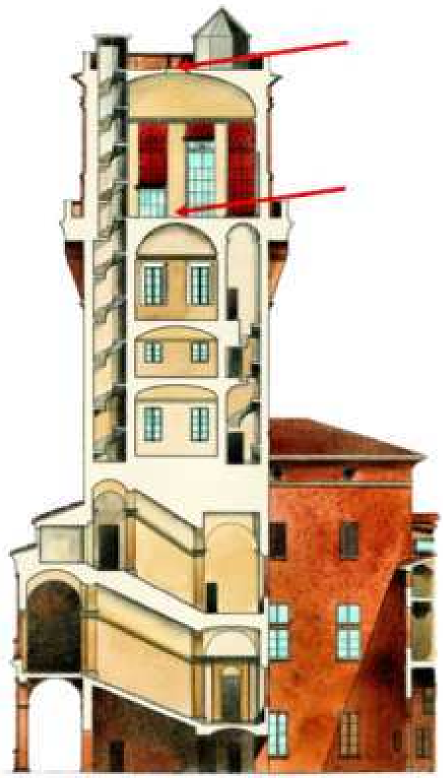

Fig. 5. Section of the Specola tower in Bologna. The lower arrow indicates the expected position of the prototype of the tessellated mirror; the higher arrow indicates the focal plane of the instrument.

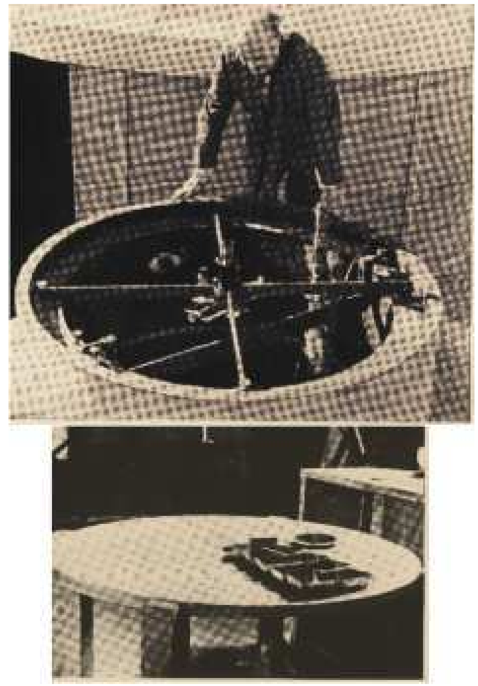

Fig. 6. At the bottom: the first ten 1935 tiles for the 1 m telescope are shown in the turret room of the Specola. Top: Horn d'Arturo overlooks the opening in the focal plane of the mirror on the Specola terrace; the mobile plateholder and the eyepiece for the guide during the exposure are mounted on the iron cross. The collimator to control the alignment of each tile is on the movable bar placed obliquely at the opening. (Horn d'Arturo 1935)

The great upper hall of the eighteenth-century tower of the Specola was suitable for positioning the mirror: the 10.4 m height was comparable with the focal length of the optical system, and an opening already used for zenithal observations with ancient, long aerial telescopes was also available in the vault (Fig. 5).

The main difficulties arose with the need to obtain tiles having the same focal length and the same radius of curvature along the two axes. In addition to contacting the optician Angiolo Ciabilli, from the "Premiato Laboratorio di Ottica Scientifica e Commerciale" in Florence, and the engineer Angelo Salmoiraghi, from the Filotecnica in Milan, Horn d'Arturo proposed the construction of the first tiles at Zeiss, on the occasion of a voyage to Jena to check the construction status of the Loiano telescope, in May 1932.

The first tests performed in Jena by the German firm did not provide satisfactory results, but the tenacity of Horn d'Arturo and, above all, his great expertise in optics convinced first Salmoiraghi and then the director of the Zeiss section of astronomical instruments, Walter A. Villiger, of the feasibility of the idea and to continue the tests, and at last they made the tiles.

Moreover, on the occasion of his trip to the United States to attend the 4th General Assembly of the International Astronomical Union, held in September 1932 in Cambridge (MA), Horn d'Arturo had the opportunity to discuss the project with Harlow Shapley and Frederick Stratton, and with George Willis Ritchey and Henri-Jacques Chrtien, fathers of the Ritchey-Chrtien optical system, currently the most widespread for the large telescopes.[12] He went also at the Lick Observatory, where, together with director Robert Aitken, performed some tests on the mirror of the 90 cm "Crossley" telescope, properly obscured with a cardboard mask to simulate the tiles. Test plates were successfully taken by Robert J. Trumpler on the stellar field around NGC 7092, showing how the diffraction effects due to the intersections between the individual parts were, all in all, negligible.[13] "My idea has found much acclaim in America" Horn d'Arturo enthusiastically wrote to Carlo Gobessi, from Milan Lehmann-Mechanoptica, a Zeiss representative in Italy, even hoping to be able to present "a mirror of 5 meters in diameter (with tiles) to the Chicago Exposition of the coming year! [i.e. *The 1933 Chicago World's Fair*]".[14]

Meanwhile, he applied for a patent on the segmented mirror, hoping even to sell it to Zeiss. He had already obtained a patent on "the synchronization of pendulum clocks" in 1911,[15] and two patents on instruments able to speed up the beating on typewriters in 1922: "the commutator pedals" and "the knee-brace". In June 1932 he sent an "Application for industrial rights" to the Ministry for Corporations in Rome. The Ministry replied one year later, asking him to fill out the application on new forms and in a different style. Horn d'Arturo answered few months after, on February 1934, to withdraw the application, but without advancing justifications. The archival documents do not offer any explanation, but one can imagine that the difficulty of obtaining satisfactory tiles still left some doubts on him: the first tiles, made by the Florentine optical instrument maker Ciabilli, were indeed poorly constructed and completely unusable.

At last, the project could be realized thanks to 10 Filotecnica tiles: the first, partial, composite mirror was assembled and, on June 19, 1935, the first tests were done checking the quality of the optics and the complicated alignment procedures. The total time needed to adjust the instrument was even 3-4 hours, but it was already possible to reach 10.5 magnitude with an exposure time of $3^{m}35^{s}$. Since the mirror was fixed on a marble table and could not be moved, the plateholder had to be shifted along a guide to follow the motion of the zenithal sky on the focal plane. At first the movement was manual and difficult, but later a motor was used to shift the plateholder with the appropriate speed (FIG. 6). Ten new tiles from Zeiss were added to the previous ten from Filotecnica and the telescope started to be used for astronomical observations.

But in the fall of 1938 the racial laws took effect: Horn d'Arturo was removed from the direction and the chair, and dismissed. He desperately tried to continue the work at the tessellated mirror and at his beloved *Coelum* magazine, as a long and sad correspondence shows. But the director who had replaced him, Francesco Zagar, and the Rector of the University, Alessandro Ghigi, refused to grant him any chance. He wrote to Vito Volterra,[16] to try to be hired by the Cairo Observatory, at Helwan, "I know that the entrance to Egypt is prohibited (while thirty-three centuries ago we were forbidden to get out of it!) but the Egyptian government might be doing an exception", and then also tried to be housed by the Vatican Observatory, but without success in both cases.

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[12] Letter to Ritchey in AABo "*Fondo GHd'A*, *Epistolario privato*", Fh1, b. 7, No. 188, 28/06/1932, and in "*Fondo GHd'A, Specchio a tasselli*", Fh5.2.1, /06/1932; Letter to Chretin in AABo "*Fondo GHd'A*, *Epistolario privato*", Fh1, b. 9, No. 679, 7/07/1937.

[13] HORN D'ARTURO G. (1935).

[14] AABo "*Fondo GHd'A*, *Epistolario privato*", Fh1, b. 7, No. 242, 9/10/1932.

[15] HORN D'ARTURO (1912).

[16] AABo "*Fondo GHd'A*, *Epistolario privato*", Fh1, b. 10 (498), 24/01/1939.

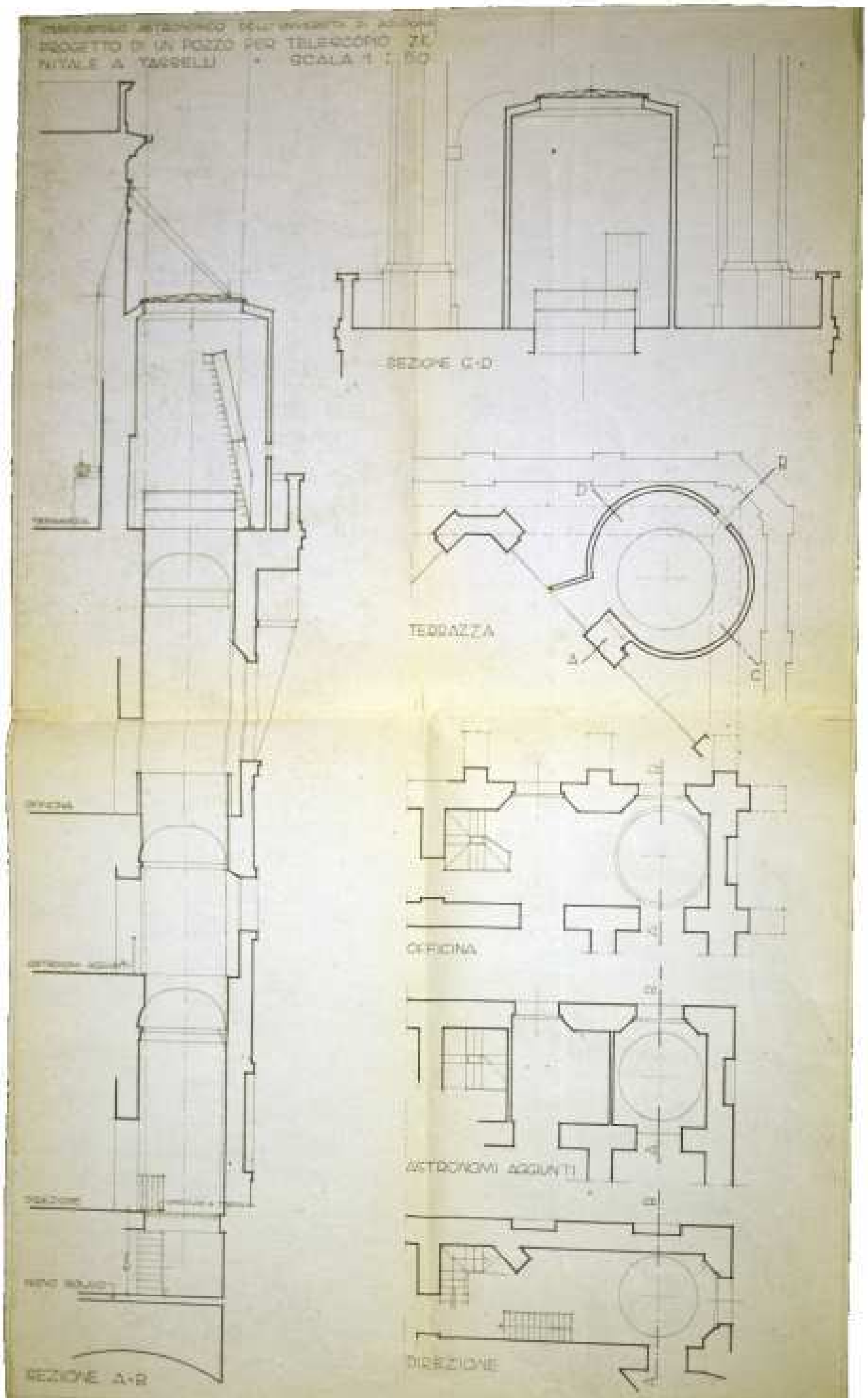

Fig. 7. The project of the well to be made in the tower to house the 1.80 m telescope shows the drilling through four floors in section and in plan. The center of curvature of the tiles is in the oval room at the top. (AABo, "*Fondo GHd'A*, *Specchio a tasselli*", Fh5.3, 1951)

He could at least remain in Bologna for a while, but then he was forced to take refuge in Faenza, helped by the friend and colleague Giovanni Battista Lacchini, and later to hide in the neighboring countryside.[17] Right after the war, in the spring of 1945, he could definitely come back to Bologna and he was restated in his position, even if forced to a difficult sharing of the chair for a few years with the one who had replaced him, Zagar, until this last was appointed Director of the Observatory of Brera, in 1949.

4. The Fifties: the 1.80 m tessellated telescope sees the first light

After the war, Horn d'Arturo found the Observatory in a terrible state - as all Italy and Europe as well - and he was in the need to start over the previous works from the beginning. The Loiano Observational Station had been severely damaged by the passage of the front and partially shelled, the premises and the workshop looted, the telescope engines stolen (the mirror had been put in a safe place in Bologna), and there was no power. The magazine *Coelum* had suspended publications in 1943, the library was severely in arrears.

He also resumed the work at the tessellated mirror which was completed to reach the planned overall dimensions of 1 meter in diameter, thanks to 60 tiles polished in the workshop of the Observatory and added to the previous 20.

In the years of exile, the astronomer had not ceased to think about how he could develop the project: the tiles had to be larger and hexagonal to be better assembled (10 cm apothem and 3.5 dm^2 each, versus 1 dm^2 of the previous ones), so reducing the diffraction effects in the interstices. Moreover, not fully satisfied with the optical polishing of the prototype tiles, he independently worked them in the observatory workshop, with the help of the expert technician Aldo Galazzi: the glorious Zeiss, hard hit by the war, was going to be divided between the two Germanies. It was also expected that the mirror was larger, but there was not enough space in the Specola tower. In 1950, Horn d'Arturo obtained funds from the *Consiglio superiore dei lavori pubblici* so that four floors in the western edge of the tower were drilled by the Engineer Corps (Fig. 7).

At last, in 1952, the large mirror was completed with 61 tiles and 1.8 m (71 inches) total diameter (Fig. 8).[18]

A small room for handling the 183 adjusting screws had been obtained under the large marble holding the mirror and a new much quicker technique was devised to adjust the whole system from the center of curvature and not from the focal plane: compared to the previous 3-4 hours about 45 minutes were now "enough". This operation, however, had to be performed at the beginning of all the nights and often during the observations, because of the thermal variations that the optics underwent.

The mirror focal length was 10.4 m and the aperture ratio was f/5.7. The telescope useful field was 1.3, with 20"/mm scale. Plates 9x24 cm were used, thus covering a 30 arcmin field in right ascension and 80 arcmin in declination. The resolving power of each single piece was 0.5"/mm, while the total, theoretical resolution, was 0.05"/mm. Horn d'Arturo was well aware that the overall resolving power was limited by that of the single tile - much lower than that of a monolithic mirror of the same size - and that this was a limitation for the tessellated mirror. As early as December 1935, in fact, he had written to a "dearest friend" not better identified, perhaps Lacchini:[19]

"More serious is the question of resolving power which depends on the size of the tiles and not of the entire mirror, so that the "definition" of the images is ruled by the area of a square decimeter [he is obviously speak-

[17] A "vivid" summary of his vicissitudes during the persecutions and the war and immediately after his return to Bologna is in a letter to G.B. Lacchini of July 9, 1945, kindly provided us (with others) by his nephew Maria Vittoria Lacchini, who has ordered the correspondence of his grandfather - one of the founders of the American Association for Variable Stars Observers (AAVSO) - and which here we thank for her courtesy and helpfulness.

[18] Horn d'Arturo (1955).

[19] AABo "*Fondo GHd'A*, *Epistolario privato*", Fh1, b. 8, No. 882, 02/12/1935.

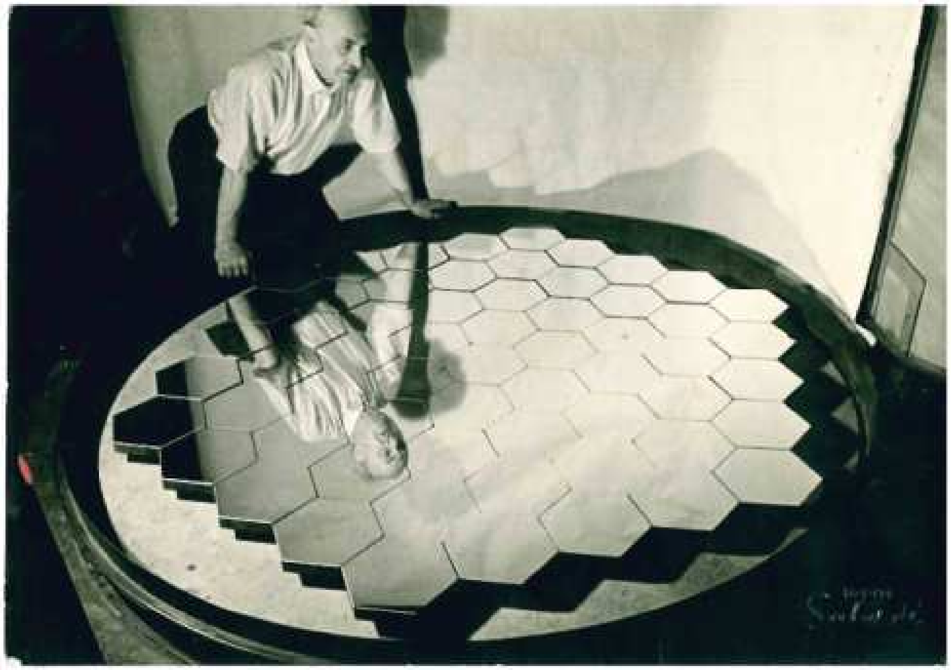

Fig. 8. Summer 1952: Horn d'Arturo admires the completed 1.80 m tessellated mirror. (Horn d'Arturo 1955)

ing of the first model of the Thirties with small trapezoidal tiles]. In larger mirrors, the tiles can be larger, e.g. in a diameter of five meters, the tiles will have sides of fifty centimeters and so on [this is just what happens in the modern multi-mirror telescopes]. But I affirm that even in the large monolithic mirrors the definition is not that expected from the diameter, because the deformations produced by the temperature are such that it makes illusory the theoretical definition."

He was also well aware that even in the monolithic mirrors the theoretical resolving power was mainly limited by the seeing. "In fact, little could be theoretically predicted on the dot-likeness of the images and it was much better to directly run the experiment; which is encouraging." The experiment basically consisted in measuring the minimum angular separation between two stars. It was about 5 arcseconds, a quarter of a millimeter on the photographic plate, for the 1.8 m mirror. In this respect, we report what the Irish physicist Edward H. Synge, expert in microscope and telescope design (we will talk about him later), wrote in 1930:

"It seems that 6" may be taken as the minimum angular diameter of the photographic image of a star, which can be obtained by any of the large telescopes in the United States ... This limit is imposed by the minimum of atmospheric disturbance over the area."[20]

The plateholder was shifted by a 12-volt DC engine, with a step of 1 mm per 1.852 s (sidereal time). Because of the sky motion and the useful field available, and to prevent the traveling plateholder from straying too far from the optical axis, the maximum exposure was $6^{m}45^{s}$, using *Cappelli Ultrasensibili* plates (Kodak plates were still too expensive), spe-

[20] Synge (1930).

cially made by Ferrania for the Bologna telescope in the 9x12 cm and 9x24 cm formats:

"Time must be short (the astronomer wrote in the previous quoted 1935 letter) in order the plate not to go in that part of the field where the "coma" aberration is too much high."

The faintest magnitudes measured in good sky conditions were about 18.5, which looks a surely excellent result, keeping in mind that the instrument was placed in the center of the city with a lot of atmospheric and luminous pollution (Fig. 9).

A telescope is clearly made for astronomical observations and these could now start. All the Bologna zenith sky had been photographed over six years, from 1952 to 1957, on more than 17,000 plates, now stored in the *Museo della Specola* of the University of Bologna. Together with Giovanni Battista Lacchini and some collaborators, Horn d'Arturo observed, among other things, many variable stars, discovering 11 new variables of magnitude between 14 and 16, for which they obtained elements and light curves.[21] This demonstrated the efficiency of the ingenious instrument, built cheaply thanks to the local technical staff and without the tools of verification and control available at large optical industries: only with Horn d'Arturo's vast optical and instrumental competence.

Another disadvantage was the horizontal immobility of the mirror; this limit is today exceeded by technological improvements. Already in the Thirties he had thought of how to obviate it by building many tessellated telescopes in several places at various latitudes, to observe wider areas of the sky.[22] He proposed to locate a dozen of them all over Italy, from north to south, spaced out about 150 km in geographic latitude, each able to cover 80 arcminutes in celestial latitude, thus observing all the sky over Italy, and even more. For the same old problem of lack of funds, Horn d'Arturo thought of exploiting some already existing places, suitable to host the telescopes. He examined, among others, the *Pozzo di San Patrizio* in Orvieto, the *Torre dei Francesi* in Brescia and the *Grotte di Castellana* in Puglia. For the latter, recently discovered, Horn d'Arturo even planned a majestic instrument he called "the largest reflecting surface of the world", with a mirror made up of 217 tiles and a total diameter of 5.10 m, larger than the Mount Palomar telescope.[23] The project, however, never started, despite the support of the local Apulian institutions, for reasons that still remain to be clarified.

Not content and with great anticipation on the times, Horn d'Arturo also considered to use two large mirrors, spaced apart from each other by at least ten meters, as a stellar interferometer.[24] Furthermore, in 1966 he had occasion to read an article on *Missiles and Rockets*, where the possibility of launching in space a 3 m telescope with a Saturn v, even in 1979, was presented.[25] NASA, Perkin-Elmer, Boeing and American Optical were studying an active optics that acted on a mirror composed (of course) of hexagonal tiles (Fig. 10). Beller, author of the article wrote:

"The surface of an active optical mirror is made up of a number of "tiles", much like those on a bathroom floor."

And so, a few months before death, Horn d'Arturo could write in his latest paper on *Coelum* (I guess with great satisfaction, but also with sure regret not to have ever seen mentioned his name):

"The impossibility of obtaining better defined images as long as one remains inside the atmosphere of the Earth ... pushes the astronomer to bring the optical instruments out of the atmosphere; ... Being the great weight of the monolithic mirror one of the obstacles ... it ends up using the tessellated mirror ... relatively little heavy."[26]

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21 Horn d'Arturo, Lacchini (1955a, 1955b). For a description of the observations made with the tessellated mirror, see Picazzi (2017, pp. 95-106 and in particular Tab. 5.3, where the variable stars observed are shown, with their elements and the modern classification from Simbad database).

22 Horn d'Arturo (1932b).

23 Horn d'Arturo et al. (1957).

24 Horn d'Arturo (1965).

25 Beller (1966).

26 Horn d'Arturo (1966).

Fig. 9. The plate No. 2996, October 10, 1953, shows the region of the sky north to the star 56 Cygni, which is visible at the lower margin and whose regular figure of the diffraction image can be appreciated. Star images are circular and completely coma free up to the edges of the field. 1 arcmin = 3 mm at the scale of the original 9x24cm plate.

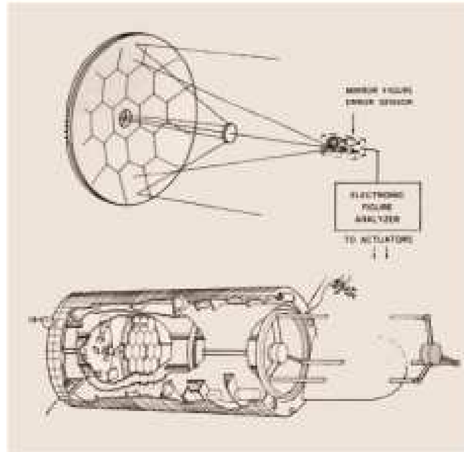

Fig. 10. At the top: mid-Sixties sketch of the active optics system for a space telescope equipped with "self-adjusting tiles". Bottom: exploited design of the large multi-mirror space telescope with active optics. (Beller 1966)

5. The modern developments of the tessellated telescope

Others will present here in more detail the modern developments of Horn d'Arturo's idea, so we just stress that we had to wait more than twenty years from the first light of the 1.8 m tessellated telescope, and almost fifty from the birth of the project, before finally a large telescope was built with the technique of the mosaic of mirrors: the *Multiple Mirror Telescope* (MMT) on Mount Hopkins saw it first light on 1979. It operated till 1998 with six circular mirrors, each with a diameter of 1.8 m, providing an equivalent area of a 4.5-meter telescope.

Time passes and the idea of Horn d'Arturo to increase the size of the primary mirror by assembling smaller surfaces became the construction technique of most of the large modern multi-mirror telescopes. In 1993-97 the *Keck I* and *Keck II* twin telescopes were built on Mauna Kea in Hawaii, with a 10 m primary mirror, each made by 36 segments. In 1997 the *Hobby Eberly Telescope* of the McDonald Observatory started to operate with 91 segments and a 10 m overall diameter. The 2005 *Southern African Large Telescope* in South

Africa, with a mirror made by 91 hexagonal segments for a total diameter of 9.2 m, was similar to the latter. We just still mention the 2007 *Great Canary Telescope* in La Palma, Canary Island, with 36 segments and a diameter of 10.4 m, and the *Large Sky Area Multi-Object Fibre Spectroscopic Telescope* of the Chinese Academy of Sciences, composed of a primary mirror with 24 segments for a total of 5x4 m, and a secondary with 37 segments for 6 m total, to form a very complex optics for spectroscopic observations.

More giant multi-mirror telescopes are now being built or planned: the *Thirty Meter Telescope*, with 30 m diameter and 492 hexagonal segments, and the ESO *European Extremely Large Telescope* (E-ELT), with an important Italian presence, 39.3 m diameter and 798 segments, expected to see first light the next few years in Chile: it will be the largest telescope in the world and, needless to say, will be made according to the project developed about ninety years ago by Guido Horn d'Arturo.

As if all this were not enough, the last of the futuristic dreams of Horn d'Arturo, a tessellated telescope even in space, will be realized with the launch of the *James Webb Space Telescope*, made up of 18 mirrors (obviously hexagonal) for a total diameter of 6.5 m, in an advanced phase of construction.

Modern technology has today developed alignment systems of the single mirrors (active optics) and even control of the optics to remove the effects of distortions caused in images by the atmospheric turbulence (adaptive optics) operating in micro- or nano-seconds, so greatly reducing those laborious 45 minutes needed to Horn d'Arturo and his collaborators.

In short, even from a simple visual comparison with the primary mirrors of many built and planned multi-mirror telescopes, it is impossible not to see the direct lineage of the new instruments from that built and scientifically used in the Bologna University Observatory.

6. Why hasn't the merit of Horn d'Arturo been recognized so far?

In 1978, shortly before the MMT became into operation, Luigi Jacchia[27], a pupil and friend of Horn d'Arturo, forced by the racial laws to escape in USA, where he became an important astronomer at the Smithsonian Astrophysical Observatory, wrote an article on *Sky and Telescope* with a significant title: *Forefathers of the MMT*. Jacchia rightly gave Horn d'Arturo credit for the primogeniture of the idea of a composite mirror for large telescopes and concluded by stating:[28]

"All things considered, the MMT on the eve of completion in Arizona must be considered a descendant, along a cadet line, of Bologna telescope."

It follows that the original idea was to be attributed to the Italian astronomer since the time of construction of the first modern multi-mirror telescope; so, how did it happen that very few references to his "tessellated telescope" are in the astronomical literature?

The "mental" process that leads to a scientific or technical discovery and consequently "the *if*, *who* and *when*" the primogeniture can be with greater or lesser certainty attributed has always been, and continues to be, a source of discussion in the environment of historians and philosophers of science. The history of science is full of assigned, debated and then challenged attributions. It can be said, in general and very synthetically, that a new scientific theory or a new technological development comes to light in a context of beliefs, knowledge, experiences and evaluations that are not merely scientific or only "personal", but, broadly speaking, entirely "cultural"; so it may not be coincidental that two or more people are at the same time able to formulate the same assumptions or to develop the same tools. This means that similar ideas can bloom at the

[27] SALADYGA (2007); see also the recent thesis by GIUSEPPE PISANA (2019) for the Master degree in Astrophysics and Cosmology, Università di Bologna, a.y. 2017-18, where Jacchia's human events and successful scientific career in the United States are discussed in detail.

[28] JACCHIA (1978).

Fig. 11. The 1.80 m tessellated mirror is relocated in its original seat inside the Museo della Specola in the ancient tower. (photo: F. Bonoli)

same time, or almost, when the environment is "hot" and the *humus* fertile.

Among the many examples, one can mention the interminable affair concerning the invention of the telephone between Antonio Meucci and Alexander Graham Bell, ended (perhaps) in favor of the Italian only in 2002, with a Resolution of Congress of the United States of America. Not to mention the controversies that with a certain frequency arise when awarding the Nobel prizes in different disciplines. To remain in the astronomical field, it is possible to remark the still unresolved dispute about the invention of the telescope between Hans Lippershey, Jacob Metius and Zacharias Janssen (and why not Giovanbattista Della Porta as well?), or those between Galileo and Simon Mayr (Marius), for the priority of the discovery of the satellites of Jupiter, and between Galileo and Christoph Scheiner, concerning the observation of sunspots, or the long controversy between Angelo Secchi and

Lorenzo Respighi on the priority of a particular use of the objective prism. A very recent example is the decision taken by the International Astronomical Union to change the name of the universally known "Hubble Law" in that of "Hubble-Lematre Law", thus acknowledging the coincidence in time of the discovery of the relationship between distance and recession velocity of galaxies; all this has happened with a wide debate and after a vote expressed by IAU members in October 2018.[29]

Therefore, beyond our certainty in crediting to Guido Horn d'Arturo the priority in conceiving, building and using a multi-mirror telescope - which was substantiated, as we have seen, by the authoritative opinion of an astronomer as Luigi Jacchia - it can be interesting to see if and how the idea of Horn d'Arturo circulated, has been discussed, accepted or rejected, or even ignored, in the international specialized literature. Without going too much into detail, we here propose to chronologically and synthetically retrace what we have found in astronomical magazines or books.

The first testimony appeared in 1951 on *Scientific American* by Albert Graham Ingalls, expert on astronomical instruments.[30] The work that Horn d'Arturo had already begun in 1932 and which was near to be completed in the old Specola of Bologna was presented by comparing it with contemporary projects of development of monolithic telescopes, highlighting how it could have been a solution to problems presented by the other telescopes and stressing its low cost. Ingalls still wrote about it three years later on the same magazine, discussing other similar projects of segmented mirrors: those by Y. Visl, director of the Turku Observatory, Finland,[31] by J.P. Hamilton, of the Astronomical Society of Victoria, Australia, and by L.T. Johnson of La Plata in Maryland. The same Horn d'Arturo frankly wrote about them in his papers, stressing that his own telescope had been built, it was operating and it was obtaining scientific results, while the other projects had remained only at the level of a schematic design or of a small prototype as the one by Visl.

Jacchia still mentioned the tessellated telescope in the 1967 obituary of Horn d'Arturo on *Sky and Telescope*,[32] and Giorgio Abetti, director of the Astrophysical Observatory of Arcetri, did the same in the relative entry on *Dictionary of Scientific Biography*, though, seemingly, without too much enthusiasm.[33] One must remember how the project of Horn d'Arturo has not enjoyed wide recognitions among the Italian astronomers, as bitterly Jacchia emphasized in his article on MMT, claiming that:

"In Italy Horn d'Arturo was considered an eccentric, and mention of his "specchio a tasselli" almost invariably caused shrugs and smiles."

A few years later, in 1972, Cesare Barbieri, of the University of Padua, adding as author the name of Guido Horn d'Arturo in parentheses (certainly with courtesy and affection) to his own, presented the *Tessellated mirror* on *Optical Sciences Center Newsletter*; a magazine, however, not very widespread in the astronomical community.[34]

It was just the construction of the *Multiple Mirror Telescope* that allowed the memory of the previous projects of segmented mirrors to return a little "fashionable". In a 1981 book on the telescopes of the Eighties, a wide paper by Jacques M. Beckers et al. presented in detail the new MMT and traced an accurate history of the early multiple objective telescopes, dividing them into two types, shown in two separate tables:[35]

"Table 1 summarizes the literature describing devices that were constructed and tested. Some of these consist of arrays of single mirror segments, which combine to form effectively a single objective in the sense that a single image is formed (Type A). Others, like the MMT, form

29 Cf. www.iau.org/static/archives/announcements/pdf/ann18029e.pdf; www.iau.org/news/pressreleases/detail/iau1812/?lang. For critical discussions on the IAU resolution, see KRAGH (2018) and ELIZALDE (2016), and the references therein.

30 INGALLS (1951, 1954).

31 VISL (1949).

32 JACCHIA (1967).

33 ABETTI (1981).

34 (D'ARTURO), BARBIERI (1972).

35 BECKERS (1981).

initially separate images, which are combined by means of relay optics or electronics into one final image (Type B). Table 1 excludes multiple aperture devices aimed at interferometric studies only."

The segmented mirror in Bologna is presented in the table as the only one that had been actually built and that had observed the sky, among all the previous projects discussed. In mentioning the pioneering work by Horn d'Arturo, the authors recognized that:

"By far the greatest early effort was that by Guido Horn d'Arturo who, as the director of the Bologna Observatory in Italy, pursued the construction of the so-called "tessellated mirror" from 1932 to 1953 with major interruptions caused by the Second World War."

For the sake of truth, the major interruptions had been caused mainly by the racial laws, but let's skip it.

A short mention of the tessellated telescope is found in a 1990 picture book, *The visible universe*.[36] It appears only in the caption of a photograph showing Horn d'Arturo stooped on the 1.80 m mirror:

"A little-known forerunner of modern segmented telescope mirrors was the mosaic-like reflector conceived in 1932 by Italian astronomer Guido Horn d'Arturo ... Screws attached to the underside of each tile allowed the astronomer to tilt the mirrors ... eliminating spherical and other types of optical aberrations."

Few words, but extremely clear in describing the advantages of the instrument and in declaring it forerunner ... and certainly little-known.

At last, only a quick hint to the telescope of Horn d'Arturo is in a 2017 book on modern telescopes by David Leverington.[37]

That's all, not that much. But then again is Jerry Nelson to be widely credited as inventor of the segmented-mirror primary telescope mirror and father of the large segmented telescopes. We read in the 1992 Berkeley-Lab Research Review Magazine:

"Instead of a single, gigantic reflecting mirror, Nelson proposed constructing a parabolic or bowl-shaped reflecting surface out of many thin mirror segments. He argued that if the technology of a segmented mirror could be mastered, there would be no inherent limit to the size of a reflecting surface."[38]

We don't want to absolutely minimize the merit of Jerry Nelson, pioneering project scientist of *Keck* telescopes and adaptive optics, among others. It is nevertheless curious that the way the Nelson idea is above mentioned sounds very similar to the words used by Horn d'Arturo in presenting the advantages of a mosaic of mirrors compared to a monolithic mirror in his 1932 paper.

7. Someone else before Horn d'Arturo?

Going back to the pioneering works on combining more mirrors to form a unique image, it may be interesting to take a step back in time, as both Lord Rosse, in the far 1828, and Edward H. Synge, in 1930, were sometimes presented as forerunners of this technique.[39]

William Parsons, 3rd Earl of Rosse and Baron Oxmantown, was an Irish astronomer who does not need any presentation, because he was one of the most famous telescope makers of the 19th century, in particular of the 1845 gigantic 72-inch reflector, known as "the Leviathan of Parsonstown", the world's largest telescope until the early 20th century. In 1828, Lord Rosse presented a project of a new telescope reflector on the *Edinburgh Journal of Science*, where he described how to decrease the spherical aberration and discussed the limits of the two methods in use at the time.[40] The first method consisted in working the spherical surface to make it parabolic or almost: a work extremely delicate and difficult for those who had to manually ground and polish the *speculum*, as it was called the copper and tin alloy (sometimes with small amounts of lead,

[36] *The visible universe* (1990), p. 112.
[37] Leverington (2017), p. 71.
[38] Yarris (1992).
[39] See e.g. Tables 1 and 2 in Beckers (1981).
[40] Oxmantown (1828); the paper is signed "Lord Oxmantown".

Fig. 12. The complex mechanism of 183 screws to regulate the 61 tiles can be seen on the ceiling of the small room placed under the 1.80 m mirror. (photo: F. Bonoli)

silver and arsenic) then constituting the objective of reflectors before moving to the use of silvered optic glass. The second method was to increase the focal length in proportion to the aperture, so making an extremely complicated to use and cumbersome telescope. The new method, tested by Lord Rosse on a 6-inch brass prototype, was to assemble a ring of the same material and the same spherical section around the mirror: the central mirror rested on three screws and could be lowered so that the image obtained on the focal plane, 2 feet away, was free of spherical aberration. Lord Rosse was planning to make later a 20-inch diameter mirror: as far as we know, it was never built.

Horn d'Arturo was aware of the Lord Rosse experiment and extensively discussed it with the Zeiss engineer Villiger.[41] But, while the idea of the Irishman was only aimed at correcting the spherical aberration through a single reflecting surface surrounded by a reflecting ring, the idea of the Italian foresaw a mosaic of much thinner and lighter and easier to build mirrors, with all the advantages we have described. In fact, the before quoted Beckers presented the idea of Lord Rosse stating that "Goal was not large size but elimination of spherical aberration".

The second figure we cited is the Irish physicist Edward H. Synge who in 1930 presented a proposal for a very large telescope on the *Philosophical Magazine and Journal of Science*.[42] In this case too, the idea of Synge is not entirely comparable with that of Horn d'Arturo. Beckers does not indeed put it in the same table of the Bologna tessellated mirror, because the Synge instrument was not made up of a mosaic of mirrors combined to form a single objective and a single focal image, but of a set of real telescopes, whose images are collected and combined by appropriate and complex secondary optics, preferably lenses, as described by the same Synge:

"The design consists essentially in the assemblage of a number of similar reflecting telescopes pointed in the same direction, the images from which are ultimately superimposed in the focal plane of another reflector or lens, the resultant image containing the aggregate light of all ... The whole assemblage forms a sort of "battery " of 1-meter telescopes, all pointing in the same direction [where there] is a large lens, or reflector, of, say, 1 meter in diameter."

It comes therefore out that both ideas - by Lord Rosse in 1828 and by Synge in 1930 - were substantially different from that of a segmented mirror by Horn d'Arturo, and, above all, that no one else had ever built and scientifically used a multi-mirror telescope before him.

One last aspect should be added: all of Horn d'Arturo's accurate works on optics and on his project were in Italian, except for a note on the *Journal of the British Astronomical Association*, a surely widespread magazine, but certainly not among the most relevant in astronomy, and two short articles in German on *Optik* and *Sterne*.[43] This certainly did not contribute to spreading his ideas, though, as we have just seen, interested people could have had absolute knowledge about them up from the articles by Ingalls and Jacchia.

8. Conclusions

While there is still regret that the Italian astronomical community of the time made "shrugs

41 AABo "*Fondo GHd'A*, *Epistolario privato*", Fh1, b. 7, No. 154, 14/5/1932.

42 Synge (1930).

43 Horn d'Arturo (1953, 1956, 1957).

and smiles" in hearing about the tessellated mirror, as Jacchia bitterly recalled, so forgetting the name of its author as time passed, we should today congratulate those who have at last recognized his merit and pioneering skills, deciding to name the modern telescope ASTRI after Guido Horn d'Arturo.

In particular, I want to thank Giovanni Pareschi of the Osservatorio Astronomico di Brera, who first suggested it, and the president of Italian Astronomical Society, Ginevra Trinchieri, who has addressed the proposal at the National Institute of Astrophysics, interpreting the wish of the Italian astronomical community. Moreover, a big thank you to all those who have stimulated researches on the works and on the archival documents of the scientist, within the project born a couple of years ago for the realization of an exhibition at the Jewish Museum of Bologna on occasion of the fiftieth anniversary of the death of Horn d'Arturo: Vincenza Maugeri, director of the Jewish Museum Foundation in Bologna, Caterina Quareni of the Jewish Museum, Sandra Caddeo, of the Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, Nicola Stefano Sinicropi, of the Dipartimento di Storia e Culture of the University of Bologna.

And finally, special thanks to the big Horn family that has always been a great help to our researches and has made available all the material they had on their ancestor Guido.

I would like to finish by recalling the words used sixty six years ago by Horn d'Arturo to conclude his sole article in English on the subject:[44]

"We think the tessellated-mirror system will find its most useful employment not with mirrors two or three metres in aperture, which can be effectively constructed in single pieces, but with much greater mirrors, and perhaps a day will come in which tessellated mirrors five metres in diameter will be counted among the small ones."

We can say that ever words were more forgotten, but more prophetic.

[44] Horn d'Arturo (1953).

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