
# Guido Horn d'Arturo: the inventor of segmented mirrors

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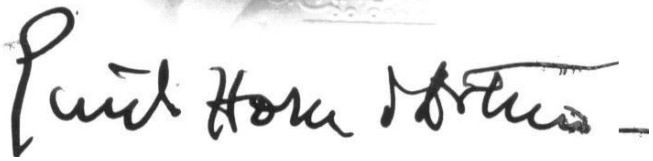
ALMA MATER STUDIORUM - UNIVERSITÀ DI BOLOGNA

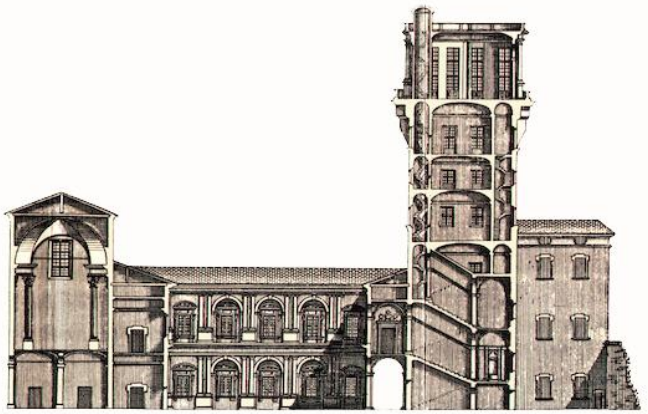
IL PRESENTE MATERIALE È RISERVATO AL PERSONALE DELL'UNIVERSITÀ DI BOLOGNA E NON PUÒ ESSERE UTILIZZATO AI TERMINI DI LEGGE DA ALTRE PERSONE O PER FINI NON ISTITUZIONALI

# What will we talk about?



- ✓ **A person**: Guido Horn d'Arturo (1879-1967)
- ✓ **An invention**: the segmented-mirror telescope, a brilliant and innovative idea anticipating modern astronomical optical technology

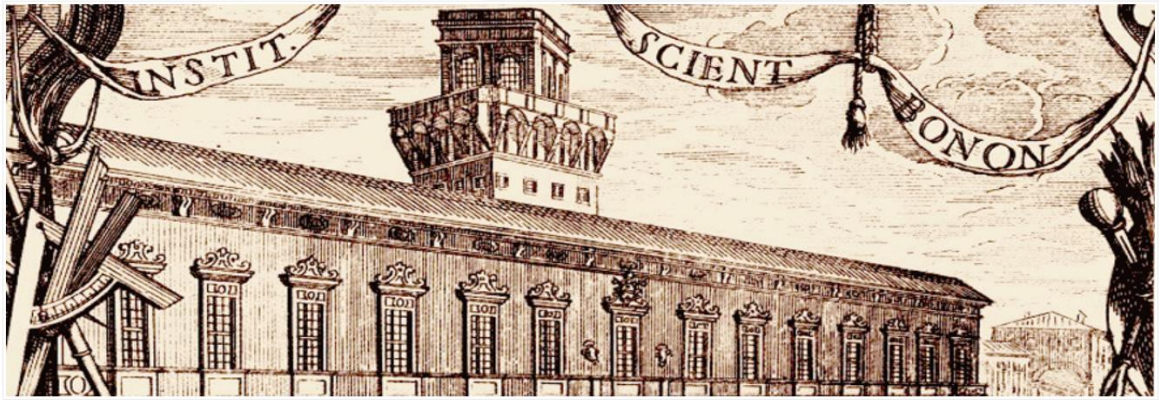
A history reconstructed mainly from documents kept at the **Historical Archives of the Department of Astronomy**, now preserved at the Department of Physics and Astronomy, University of Bologna.



*Spaccato del Palazzo dell'Istituto delle Scienze, in veduta del Cortile e della Specula*

# *Fondo Guido Horn d'Arturo*

HOME BRIEF HISTORY CONSULTATION CONTACTS




SERIE

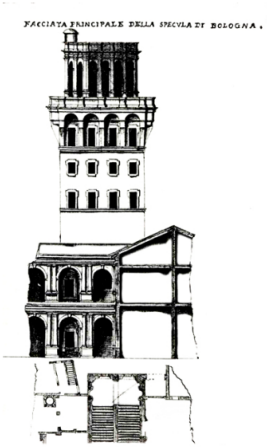
Osservazioni Astronomiche

Osservazioni Meteorologiche

Serie Storica Specola XVII-XIX sec.

Serie nuova Specola XVII-XXI secolo

Fondo Guido Horn d'Arturo




**Obi-Wan Kenobi**:
*I'm looking for a planetary system ... It doesn't show up on the archive charts.*
**Archivist**:
*Are you sure you have the right coordinates? ... It looks like the system you're searching for doesn't exist.*
**Obi-Wan Kenobi**:
*... perhaps the archives are incomplete ...*
**Archivist**:
*If an item does not appear in our records, it does not exist!*

*(From: **Star Wars: Episode II - Attack of the Clones**)*

The Historical Archives of the Department of Astronomy (AABo, Astronomical Archives Bologna) are kept at the Department of Physics and Astronomy of the University of Bologna.
They collect documents related to astronomy in Bologna since the end of 17th century, so being the most ancient collection of documents of a not private Italian astronomical institution.

The Archives are completely reorganized and inventoried and a large part of them is digitized.

The online Archives can be accessed sequentially or searched with the form.

To access the Archives see "Contacts"

FONDO GUIDO HORN D'ARTURO

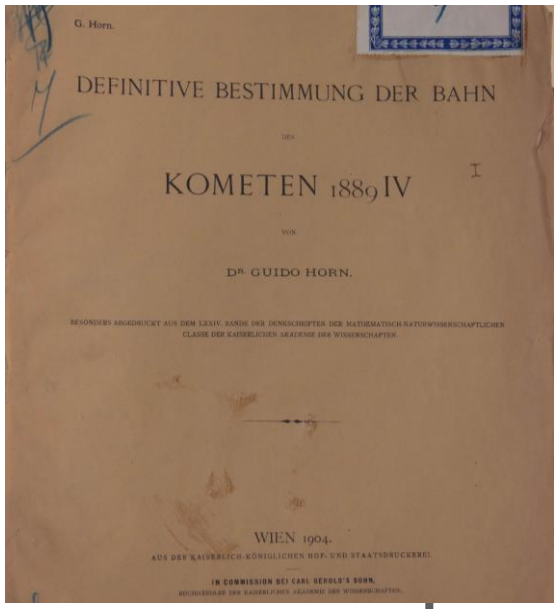
- Fh1: EPISTOLARIO PRIVATO
- Fh2: DOCUMENTI AGGREGATI ALL'EPISTOLARIO PRIVATO
- Fh3: MATERIALI DI SCRIVANIA: RICORDI DELL'ATTIVITÀ SCIENTIFICA
- Fh4: MINUTE SCIENTIFICHE
- Fh5: SPECCHIO A TASSELLI
- Fh6: PUBBLICAZIONI A STAMPA - 1904-1965
- Fh7: FOTO
- Fh8: CARTE GEOGRAFICHE

# Guido Horn (Trieste 1879 – Bologna 1967)

**Guido Horn** was born in **1879**, in Trieste (Austro-Hungarian Empire) to a Jewish family, the third of four children of Arturo Horn and Vittoria Melli.

**1881** – his father dies, he is raised by his maternal grandfather, Raffaele Sabato Melli, Chief Rabbi of Trieste

**1902**: After completing his studies in Austria, a four-year course in Mathematics, Physics and Astronomy at the Karl-Franzens University in Graz, he defends his thesis in Wien


G. Horn.

DEFINITIVE BESTIMMUNG DER BAHN

DES

KOMETEN 1889 IV

VON

Dr. GUIDO HORN.

BESONDERS ABGEDRUCKT AUS DEM LXXIV. BANDE DER DENKSCHRIFTEN DER MATHEMATISCH-NATURWISSENSCHAFTLICHEN CLASSE DER KAISERLICHEN AKADEMIE DER WISSENSCHAFTEN.

WIEN 1904.

AUS DER KAISERLICH-KÖNIGLICHEN HOF- UND STAATSDRUCKEREI.

IN COMMISSION BEI CARL GEROLD'S SOHN.

# Guido Horn: the first years of his career

**1903:** military service in the Austro-Hungarian Army

**1903:** volunteer then permanent assistant at the Royal Imperial Maritime Observatory in Trieste

**1907**: first assistant at the Royal Observatory in Catania

**1910**: public examination for assistant astronomer, assigned to the Turin Observatory

**1911:** he moves to the Observatory in Bologna

**1913**: he is appointed professor of Astronomy at the University of Bologna

# From Guido Horn to Guido Horn d'Arturo


**23 May 1915:** Italy enters the war

**29 May 1915:** he enlists in the Italian Army and **changes his surname from Horn to d'Arturo** to avoid being identified as a deserter

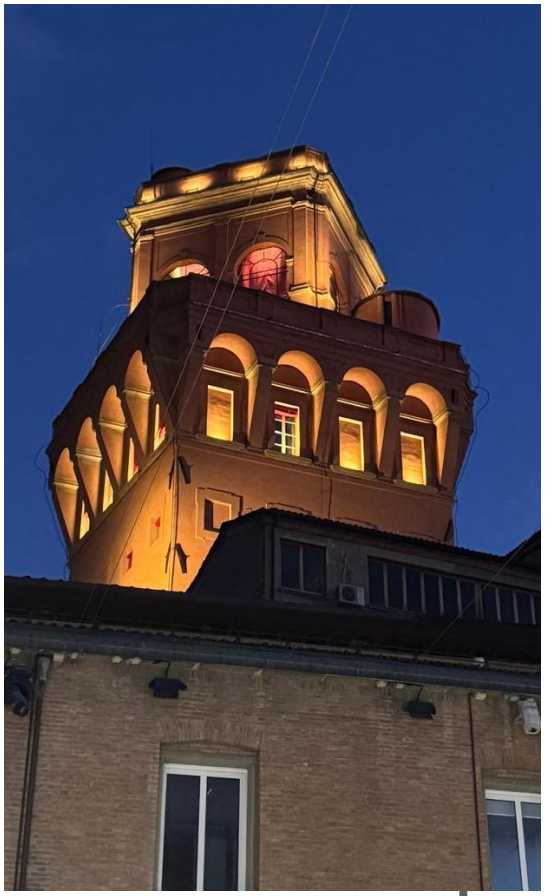
**1918:** he resumes service in Bologna and is granted Italian citizenship on 6 March

**1920:** he is appointed to the Observatory of Rome

**1921:** he resumes his work in Bologna and **officially adopts the name Guido Horn d'Arturo.** He becomes director of the Observatory in Bologna following the death of Michele Rajna (1854-1920)

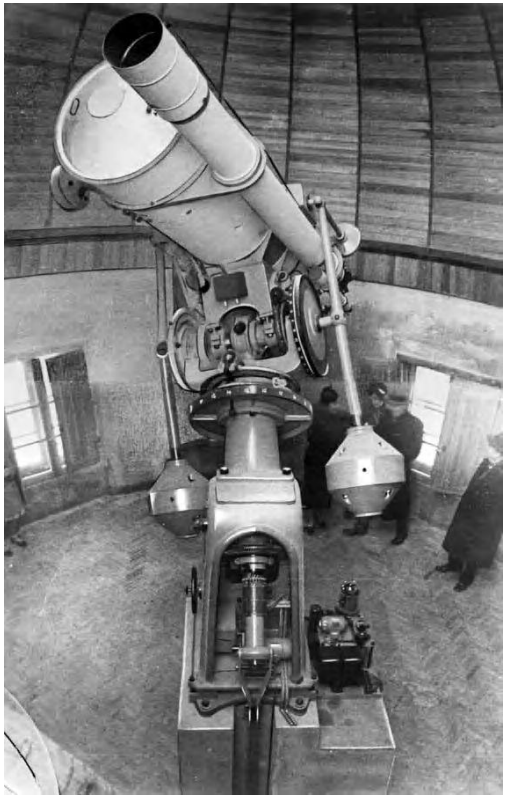
# The Specola tower

https://sma.unibo.it/it/il-sistema-museale/museo-della-specola

# A new telescope for a new Observatory (1936)

Horn promotes the construction of a new Observatory at Monte Orzale (Loiano), equipped with a **reflecting telescope** with a **60 cm monolithic mirror** (**Zeiss** factory in Jena) F/3.5



It is the **second largest telescope in Italy** after the 1 m - Zeiss in Merate
→ **Bologna's return to the forefront of astronomical research**

# An expedition for a solar eclipse

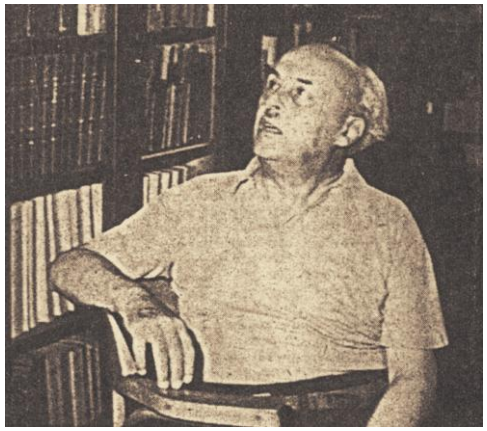
Horn d'Arturo plans and leads a **scientific expedition** to **Oltregiuba**, in present-day Somalia, to document the **total solar eclipse** of **14 January 1926**. The Ministry of Education supports him with a grant of 50,000 lire.

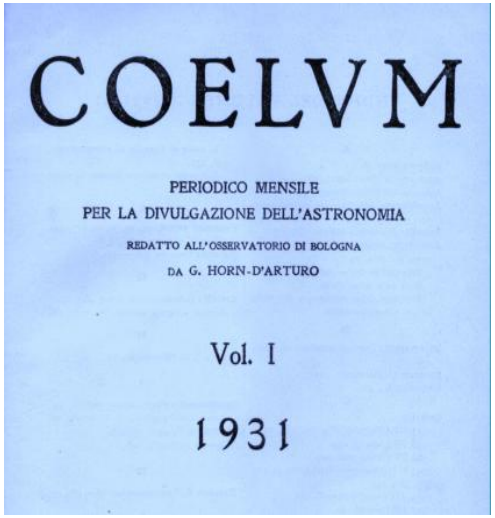

**100 years!**

He focuses on optical phenomena called the 'black drop' and 'flying shadows'

# Not only ‘science’

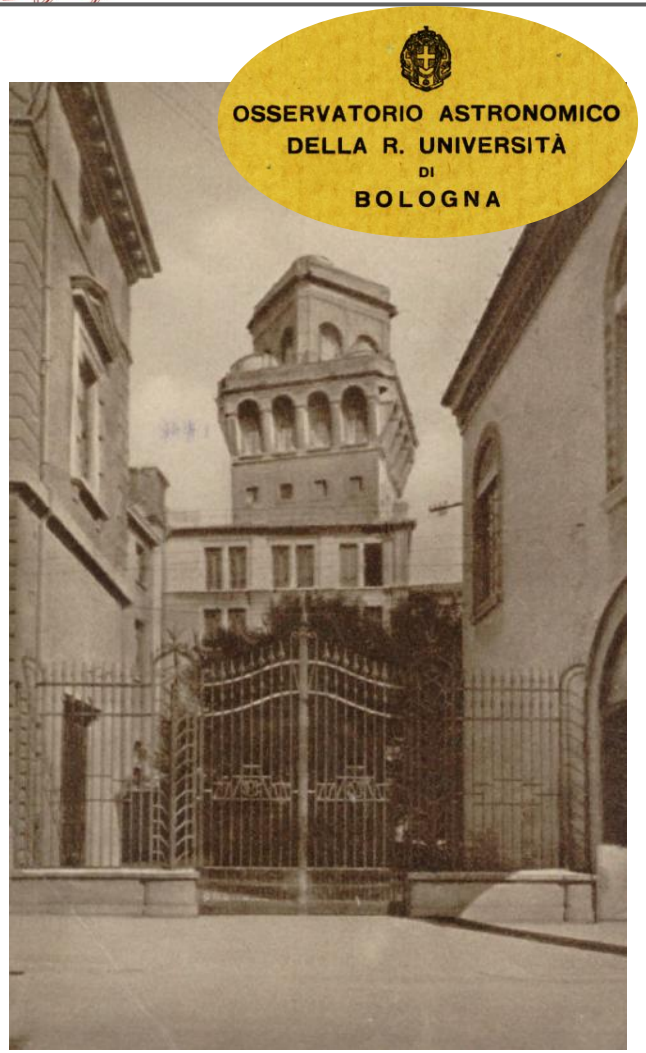
– **modernization of the astronomical instrumentation**
– promotion of the **revival of the Observatory** from its decline in the 19th century (journal *Pubblicazioni dell’Osservatorio*)
– **enrichment of the Specola library** (in 2021, the DIFA History Library was named after him)
– first systematic **reorganization of the historical archive**






– in 1931, under the patronage of the Italian Astronomical Society, **he founded *Coelum***
– translation of *Poeticon Astronomicon* by Hyginus
– numerous **entries for the *Enciclopedia Italiana***, including **Copernicus** and **Astrology** (1927; still anonymous today)
– author of *Piccola Enciclopedia Astronomica* and *Life and Works of Astronomers*

# Director of the Bologna Observatory (1921-1954)



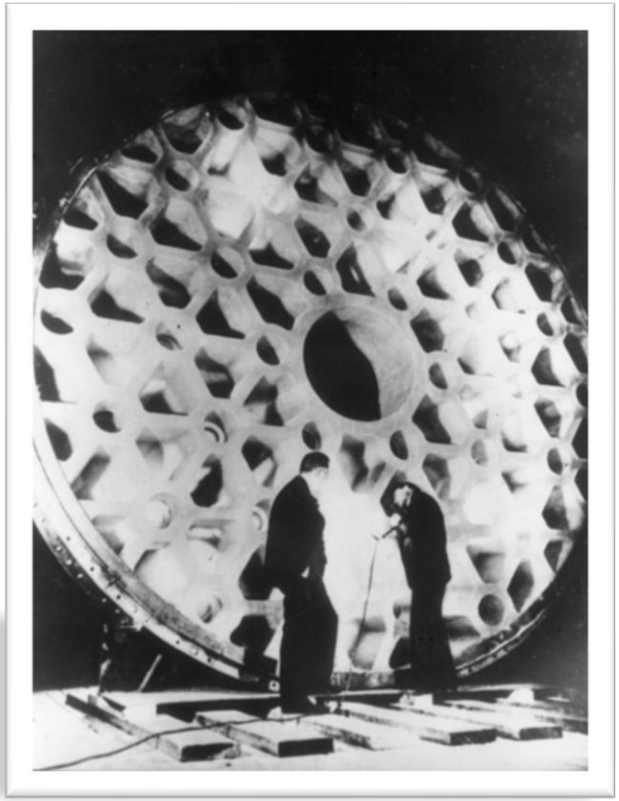

**1938** – Racial laws: he is "dismissed from service"
**1945** – he regains his professorship and directorship

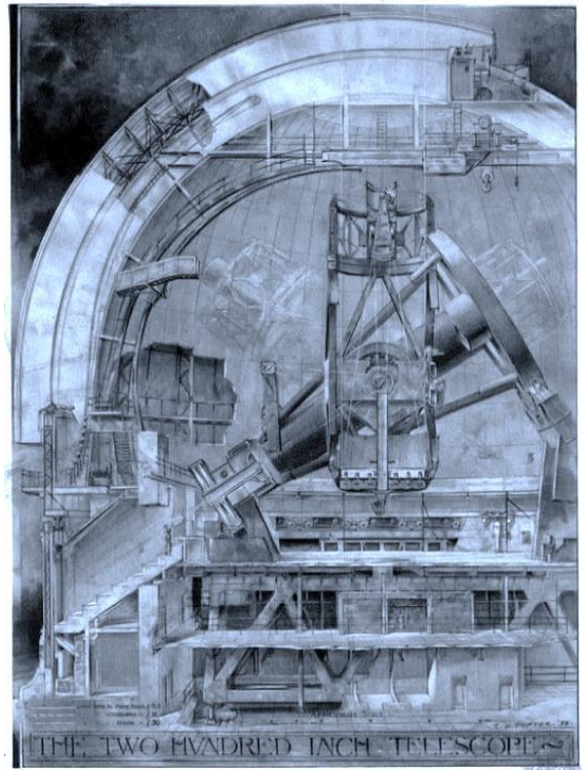
**1957** - he retires
**1958** – he is appointed Professor Emeritus of the Faculty of Mathematics, Physics and Natural Sciences at the University of Bologna


**1965** - he receives the commemorative medal from the students of the Italian Astronomical Society (SAIt)
**1967** – he dies in Bologna

# The brilliant idea

**1928 -** The Rockefeller Foundation allocates $6 million for the construction of the 200" Palomar telescope (completed in 1949)



# The brilliant idea

**1932 -** Horn predicts the technical challenges in building the large mirror:

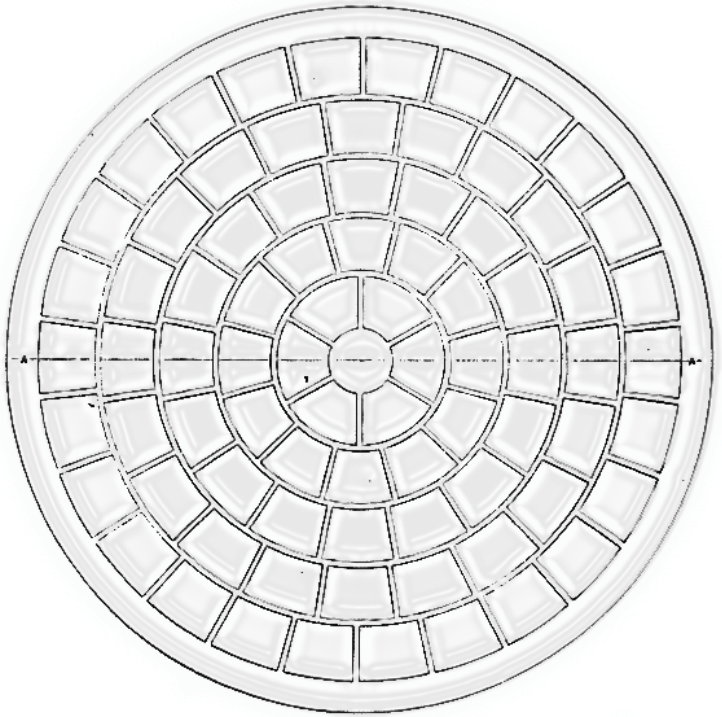
1) glass casting (will need to be done twice)
2) precise polishing of the parabolic surface
3) difficulty in moving mechanical parts due to the telescope's weight
4) costs !!!!

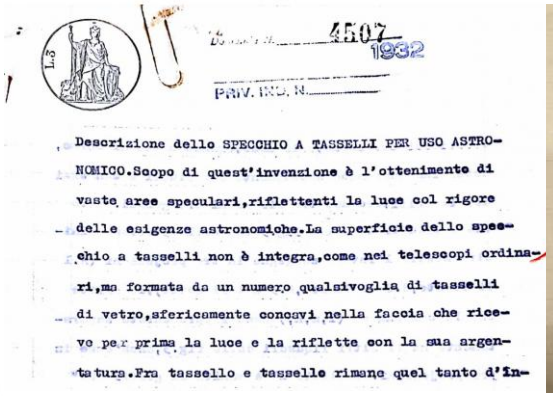
**NOTHING LIKE THIS EXISTS IN ITALY AT THE TIME!**

He begins to work on a solution that would occupy him for the next two decades → **revolutionary idea of replacing a single mirror with a mosaic of small tiles** of identical shape and size, assembled and precisely aligned to form a continuous reflective surface.

# 1932: the TESSELLATED MIRROR (a patent request)

21 June: Horn applies for a patent for a telescope made of **spherically concave glass tiles** (silvered). The Ministry of Corporations requests **new drawings and detailed descriptions**.

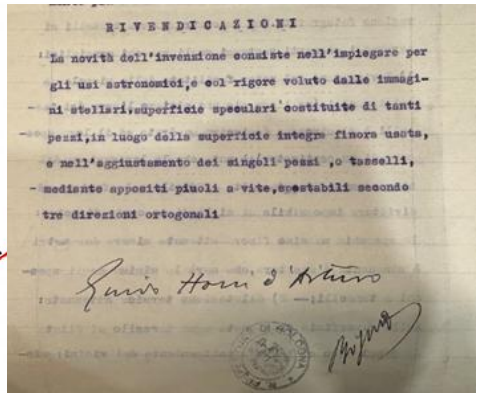




4507
1932

PRIV. ING. N.

Descrizione dello SPECCHIO A TASSELLI PER USO ASTRONOMICO.Scopo di quest'invenzione è l'ottenimento di vaste aree speculari,riflettenti la luce col rigore delle esigenze astronomiche.La superficie dello specchio a tasselli non è integra,come nei telescopi ordinari,ma formata da un numero qualsivoglia di tasselli di vetro,sfericamente concavi nella faccia che riceve per prima la luce e la riflette con la sua argentatura.Fra tassello e tassello rimane quel tanto d'in-



RIVENDICAZIONI

La novità dell'invenzione consiste nell'impiegare per gli usi astronomici,e col rigore voluto dalle immagini stellari,superficie speculari costituite di tanti pezzi,in luogo della superficie integra finora usata, e nell'aggiustamento dei singoli pezzi ,o tasselli, mediante appositi piuoli a vite,prestabili secondo tre direzioni ortogonali

Guido Horn d'Arturo

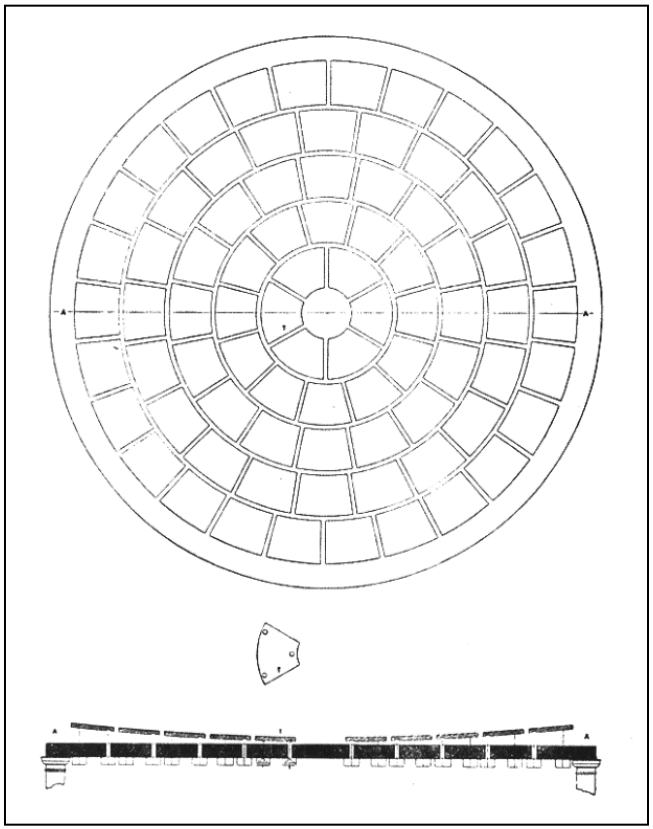
*«Settore e **tassello** sono la stessa parola; soltanto la prima è dotta e deriva da "secare" la seconda è volgare e **viene da "talea" tagliare** donde regolarmente tassello. […] Sempre **più espressiva la parola volgare** e perciò l'ho preferita.»*

Fondo Guido Horn d'Arturo, B07.215 (1932)

# 1932: the TESSELLATED MIRROR (the telescope design)

**80 trapezoidal mirrors** with **spherical curvature**
Total diameter: **1 m**
Mount: fixed azimuthal

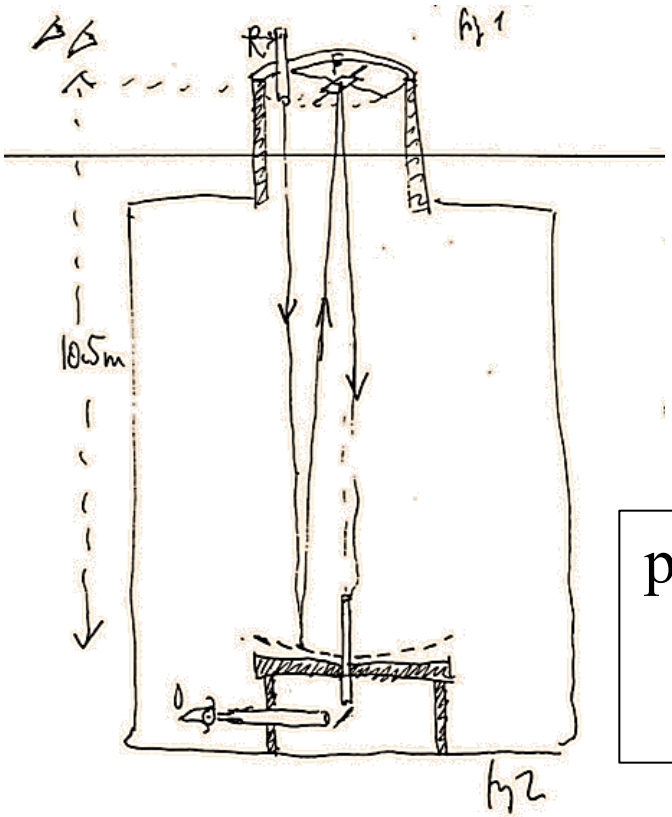
~ 10x10 cm



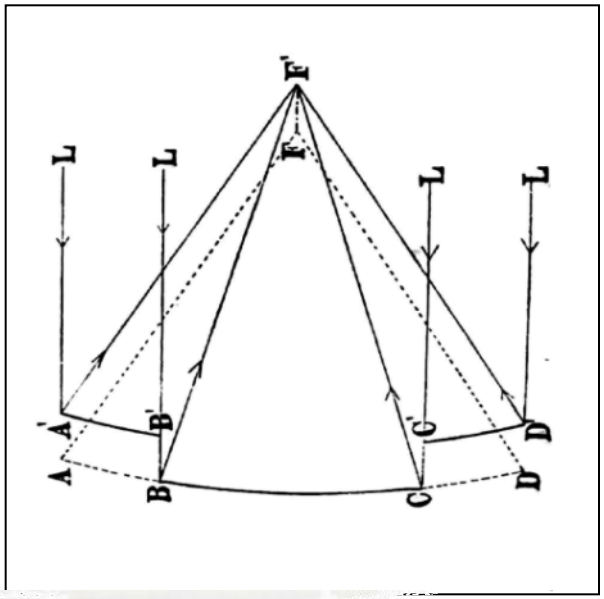
Each tile is adjusted with **3 screws** to align all mirrors to the same focus and **correct optical aberrations**

ACTIVE OPTICS (!):
-eliminates spherical aberration
-partially corrects coma and astigmatism

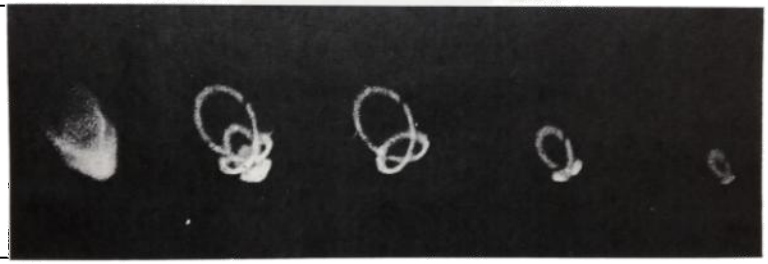
# 1932: the TESSELLATED MIRROR (the telescope design)




eliminates spherical aberration




partially corrects coma and astigmatism



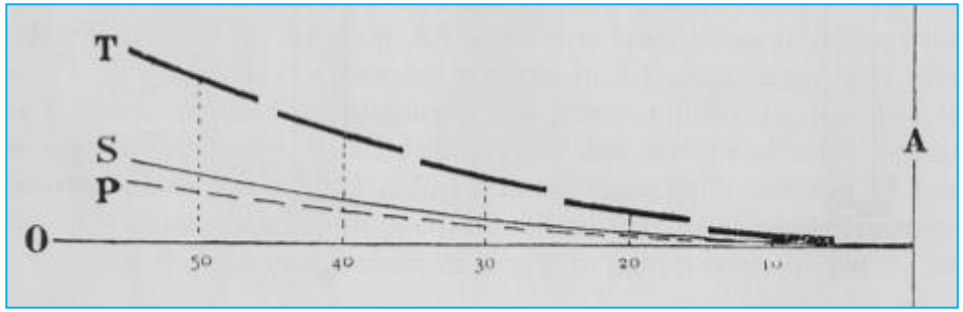
# 1935: the TESSELLATED MIRROR (the theory)

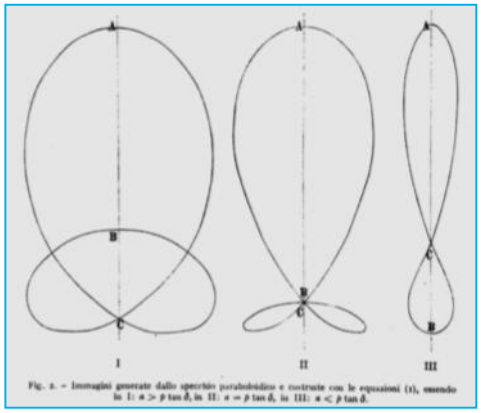
*«…ora mi preme mostrare che* ***la forma e le dimensioni delle immagini ottenute teoricamente con lo specchio a tasselli sono praticamente identiche a quelle generate da un paraboloide rotondo****, quando il suo parametro sia uguale al raggio di curvatura dei tasselli sferici…»*

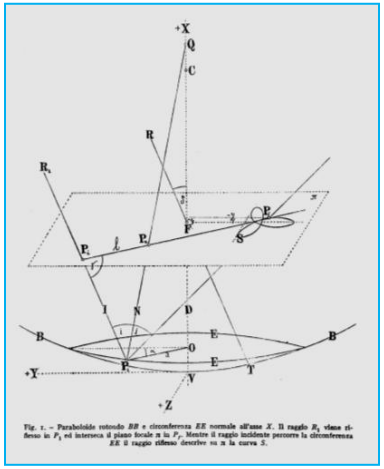
G. Horn d'Arturo: *Immagini stellari extrassiali generate dagli specchi parabolodici, sferici ed a tasselli*, in *Pubblicazioni dell'Osservatorio Astronomico della R. Università di Bologna*, 1936

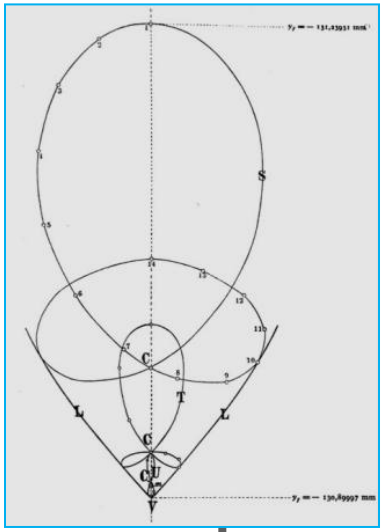
$$y_f = (a+A)\cos\alpha + D_1\tan\delta - \frac{\frac{2D_1}{\cos\delta}(a\cos\alpha+\sqrt{r^2-a^2}\tan\delta)\ (\sqrt{r^2-a^2}\cos\delta-a\cos\alpha\ sen\ \delta)}{2(\sqrt{r^2-a^2}\cos\delta-a\cos\alpha\ sen\ \delta)^2-r^2+2(\sqrt{r^2-a^2}\cos\delta-a\cos\alpha\ sen\ \delta)N}$$

$$z_f = (a+A)\sin\alpha - \frac{\frac{2D_1}{\cos\delta}a\sin\alpha\ \ (\sqrt{r^2-a^2}\cos\delta-a\cos\alpha\ sen\ \delta)}{2(\sqrt{r^2-a^2}\cos\delta-a\cos\alpha\ sen\ \delta)^2-r^2+2(\sqrt{r^2-a^2}\cos\delta-a\cos\alpha\ sen\ \delta)N}$$



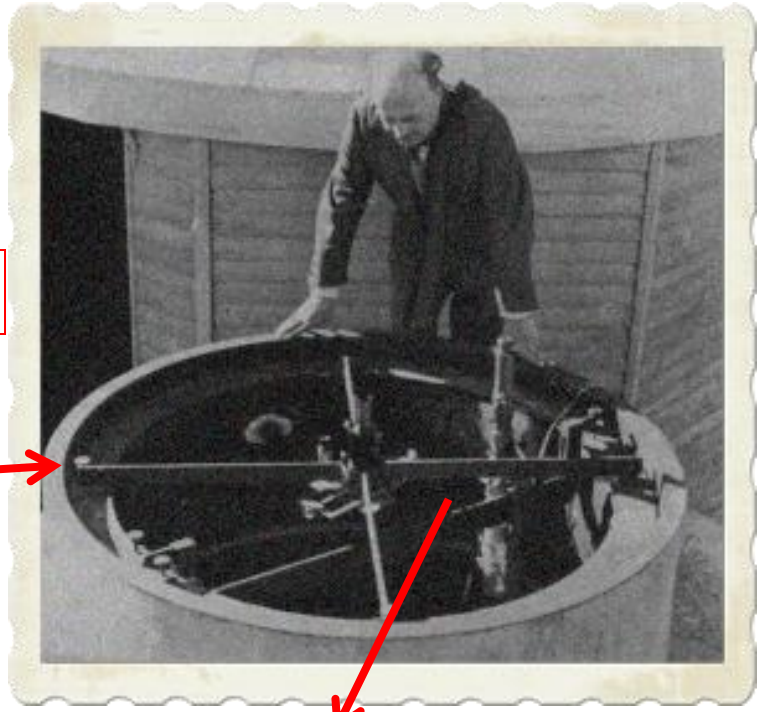



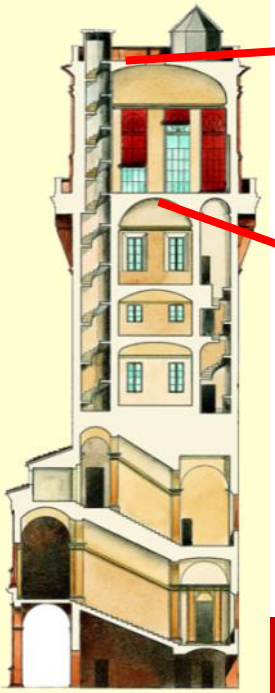



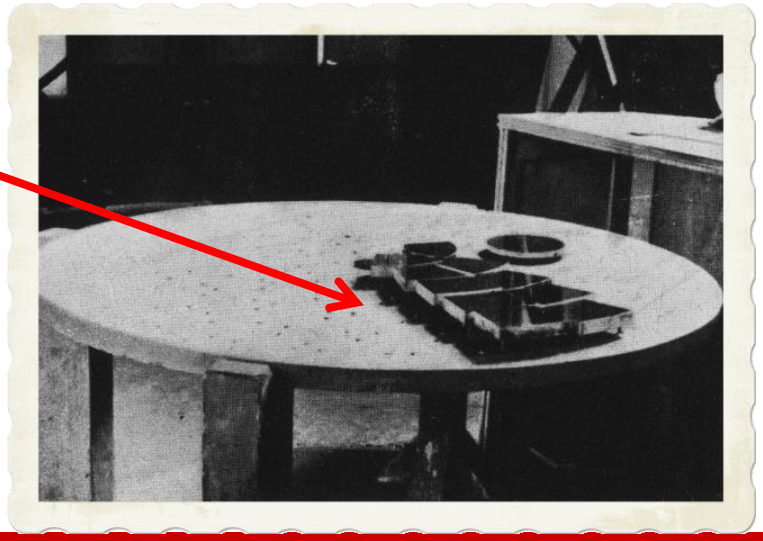


# 1935: the TESSELLATED MIRROR (the first observations)

**f = 10,4 m**



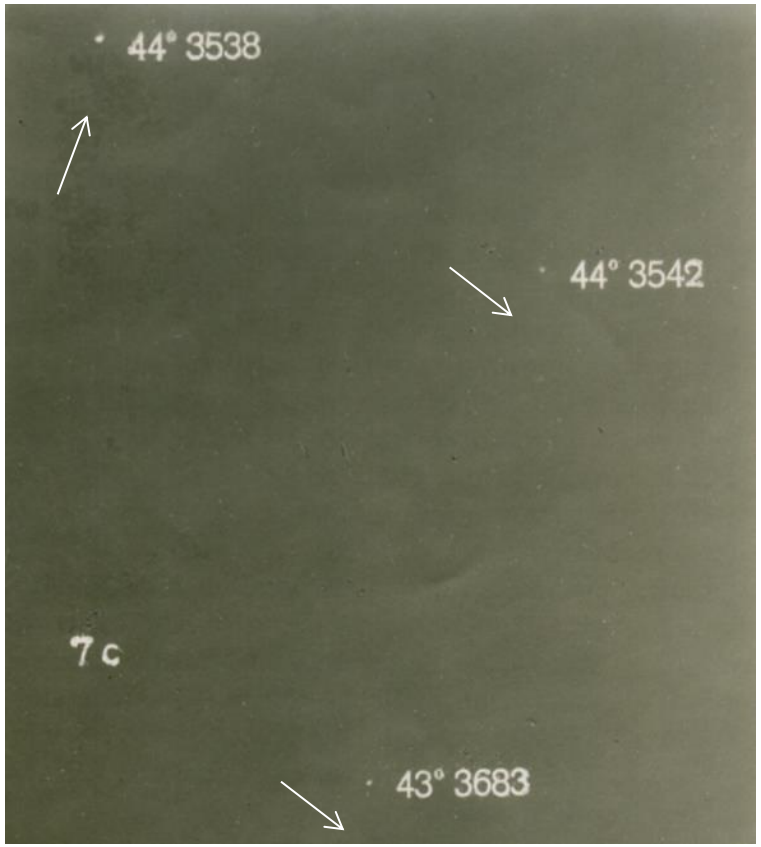


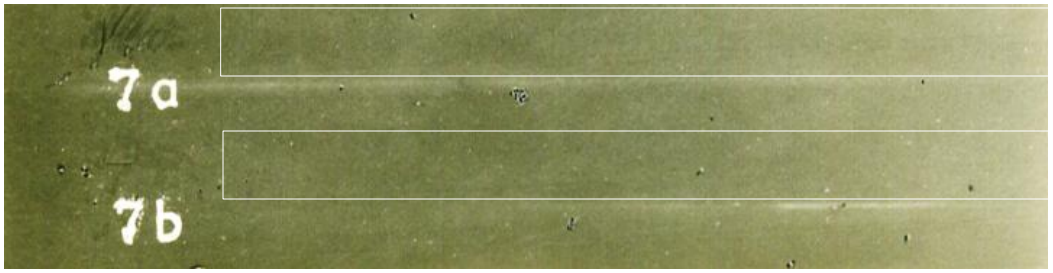


A viewer for adjusting the tiles and a motorized plate holder

**Adjustment time: 3-4 hours !!**

# 1935: the TESSELLATED MIRROR (the first observations)




1 to 8 tiles, the plate remains stationary

10 tiles, the plate moves with a 3 min 35 s exposure time (magnitude 10.5)

**BUT…**

# 1938-1945: the TESSELLATED MIRROR (the interruption)

In 1938, the racial laws come into force…


CORRIERE DELLA SERA

Le leggi per la difesa della razza approvate dal Consiglio dei ministri

I matrimoni misti sono proibiti - La definizione di «ebreo», le discriminazioni e l'annotazione allo Stato Civile - L'esclusione dagli impieghi statali, parastatali e di interesse pubblico - Le norme concernenti le scuole elementari e medie e gli insegnanti

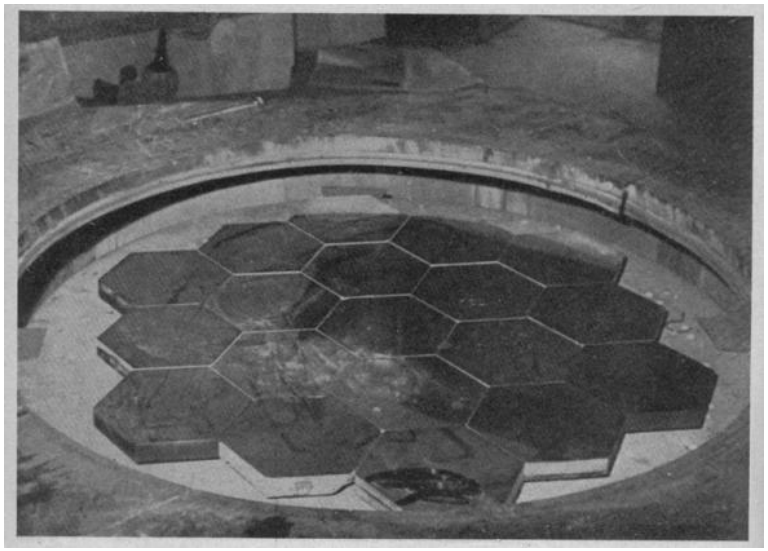

…Horn is dismissed from the Observatory

# 1945: the TESSELLATED MIRROR (a technical evolution)

With no financial support from the University, Horn decides to polish the missing tiles himself in the Bologna Observatory. But a **TECHNICAL EVOLUTION** is required.

Trapezoid → **Hexagon**

1 $dm^2$ → 3.5 $dm^2$

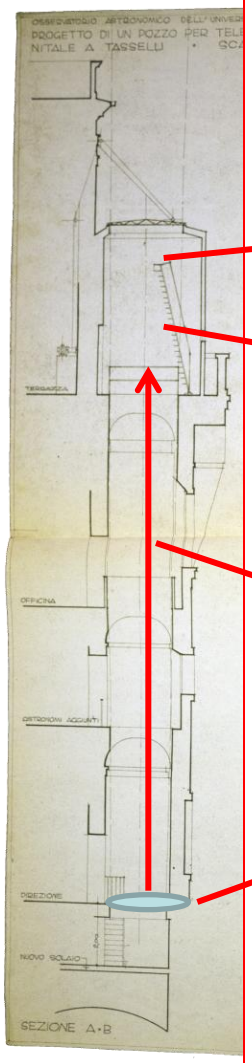


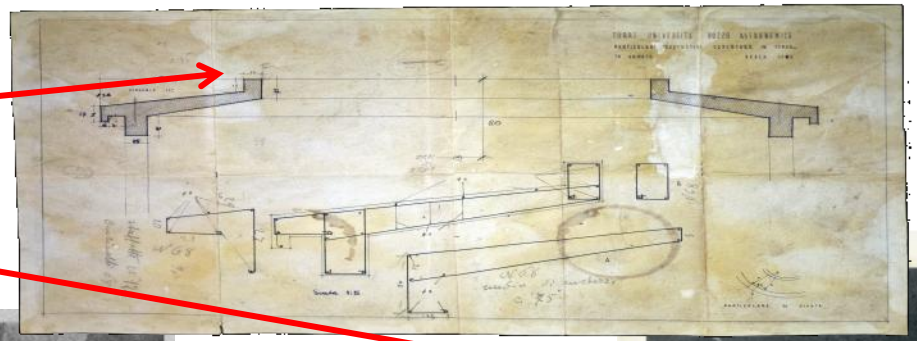
**1949**: the **first 19 tiles** (~1 m diameter) are mounted on **marble table**, 7th floor of the Specola

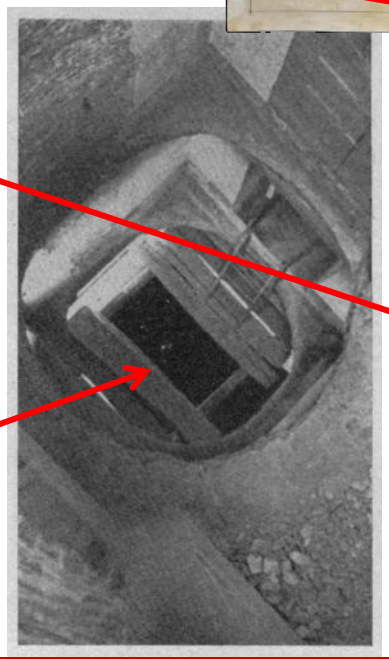
# 1950: the TESSELLATED MIRROR (a new location)

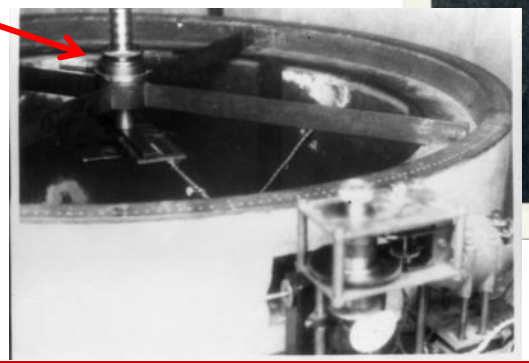
**Horn d'Arturo opens a section in the floors of the tower**

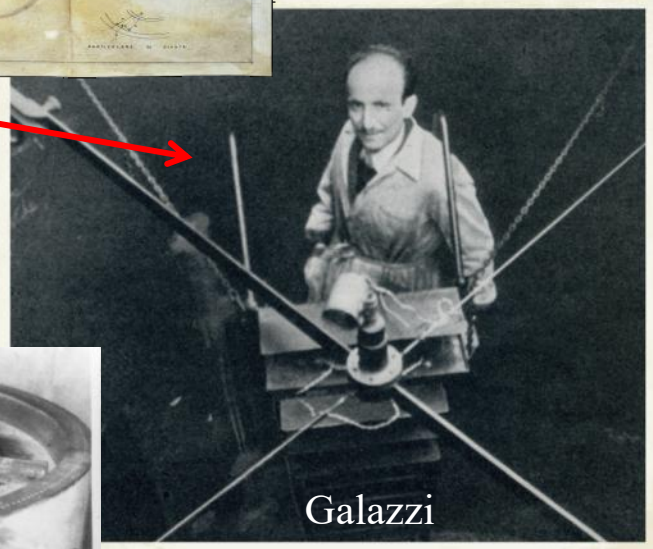
He places the mirror 10 m lower; 37 tiles, diameter 1.4 m



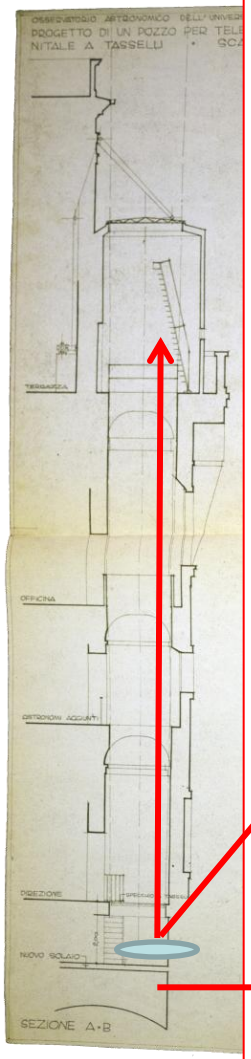



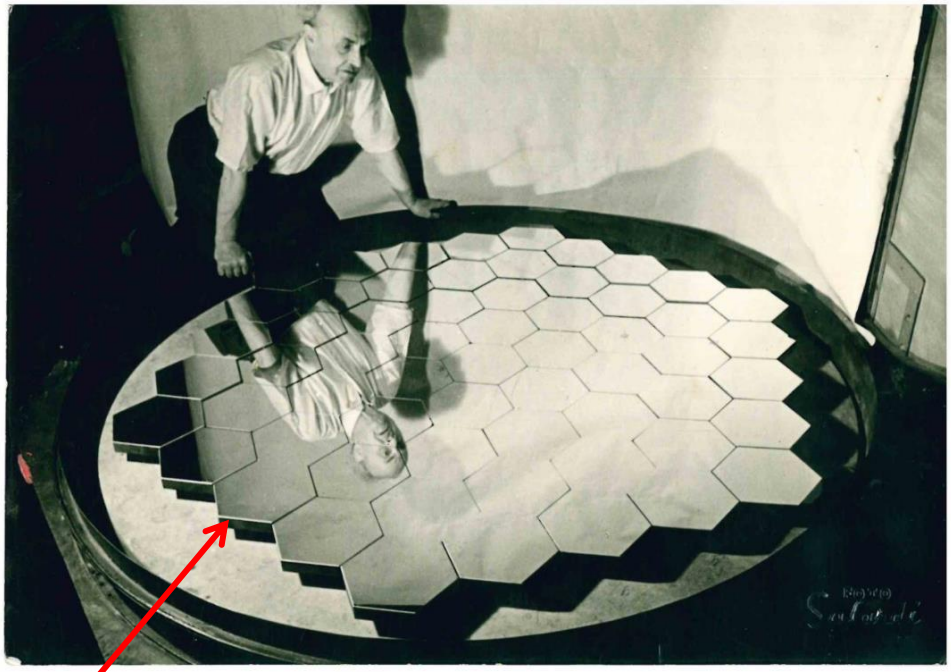






# **1952**: the TESSELLATED MIRROR (the final adjustments)



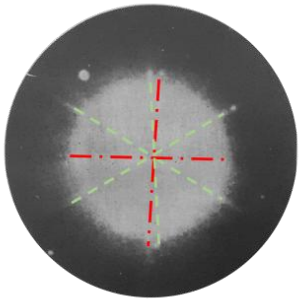



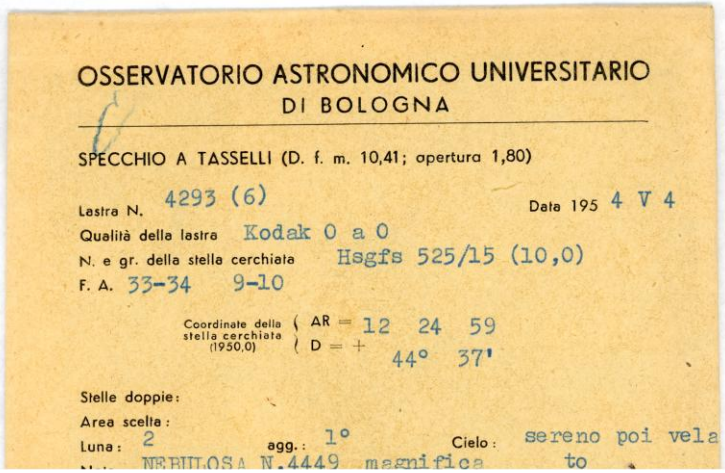
**61 hexagonal mirrors**
Total diameter: **1.80 m**
Mount: fixed azimuthal

**183 screws**
**adjustment time: 45 minutes !!**

# 1952: the TESSELLATED MIRROR (the photographic plates)

- Maximum exposition $6^m45^s$
- **Magnitude limit ~ 18**
- Scale 20"/mm
- Field ~ 1.3°
- **Min angular resolution measured ~ 5" (¼ mm)**
- $pr_{tile}$ 0.5"/mm ($pr_{monolitic\ 1.8\ m}$ 0.05"/mm)





OSSERVATORIO ASTRONOMICO UNIVERSITARIO
DI BOLOGNA

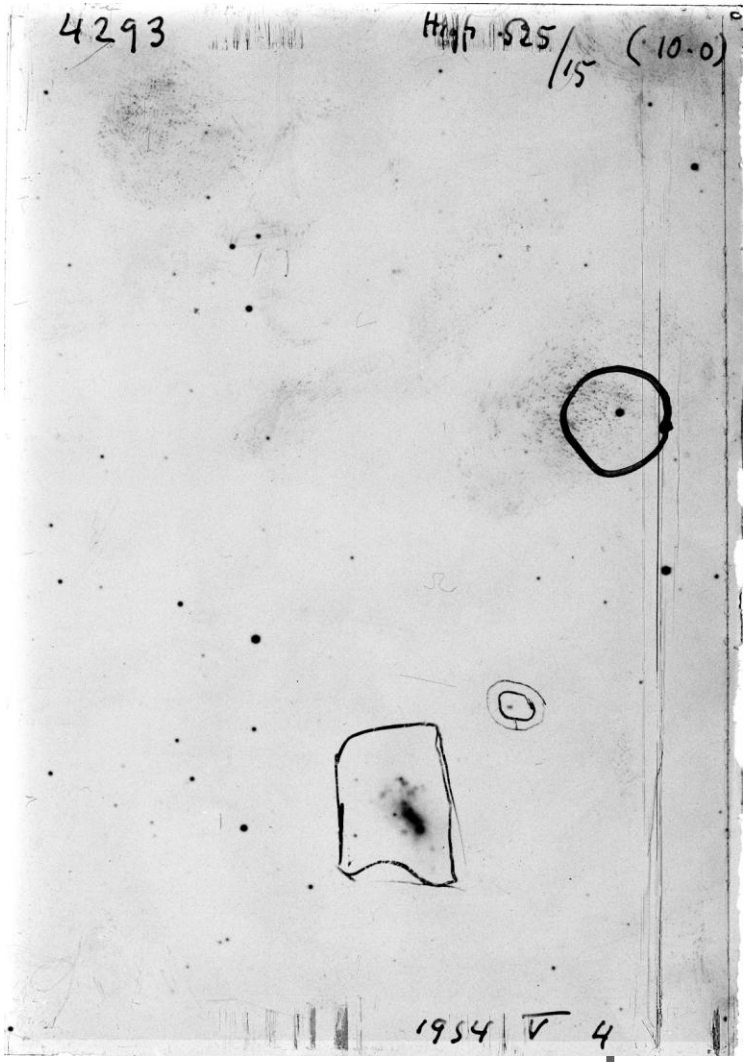
SPECCHIO A TASSELLI (D. f. m. 10,41; apertura 1,80)

Lastra N. 4293 (6) Data 195 4 V 4
Qualità della lastra Kodak 0 a 0
N. e gr. della stella cerchiata Hsgfs 525/15 (10,0)
F. A. 33-34 9-10

Coordinate della stella cerchiata (1950,0) AR = 12 24 59
D = + 44° 37'

Stelle doppie:
Area scelta:
Luna: 2 agg.: 1° Cielo: sereno poi vela
NEBULOSA N.4449 magnifica to

17,000 photographic plates

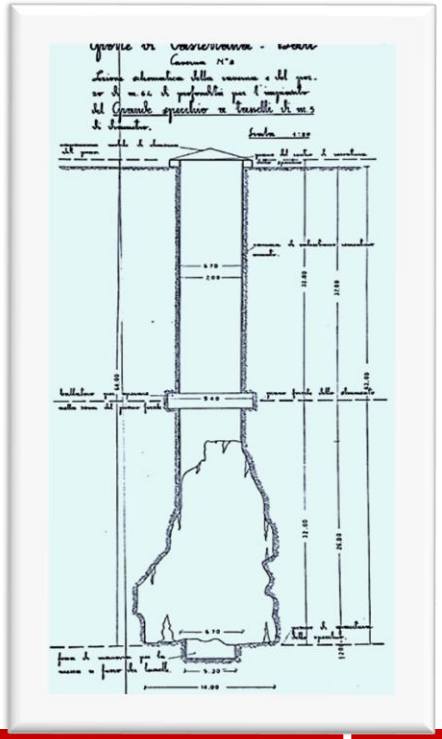


# More tessellated mirrors

**A dozen segmented telescopes throughout Italy,**

**in existing structures**

Ex.: pozzo di San Patrizio (Orvieto);  Torre dei Francesi (Brescia):
Grotte di Castellana (Bari)



# Horn d'Arturo's legacy

"*S'intende che sarà sempre più pratico confezionare specchi di un metro, come il nostro, in un solo pezzo; ma, volendo spingersi a diametri grandissimi, è evidente la necessità del frazionamento in tasselli, e* ***la fantasia può trasferirci in un futuro, forse non molto lontano****, in cui si scaveranno pozzi di centinaia di metri di profondità, per collocarvi* ***specchi a tasselli di centinaia di metri quadrati***."

Guido Horn d'Arturo, "Altri esperimenti con lo specchio a tasselli", *Pubblicazioni Dell'osservatorio Astronomico Di Bologna*, volume III, n. 1, 1950.

"*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***."

Guido Horn d'Arturo, "The tessellated mirror", *Journal of the British Astronomical Association*, 63/2, 1953, p. 74.

# Horn d'Arturo's legacy

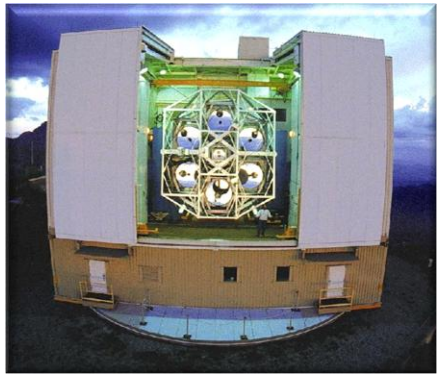
*«Saranno dunque a tasselli i **telescopi dell'avvenire?**»*

L. Rosino: *Sapere*, 1952


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

L. Jacchia, *Sky and Telescope*, 1978

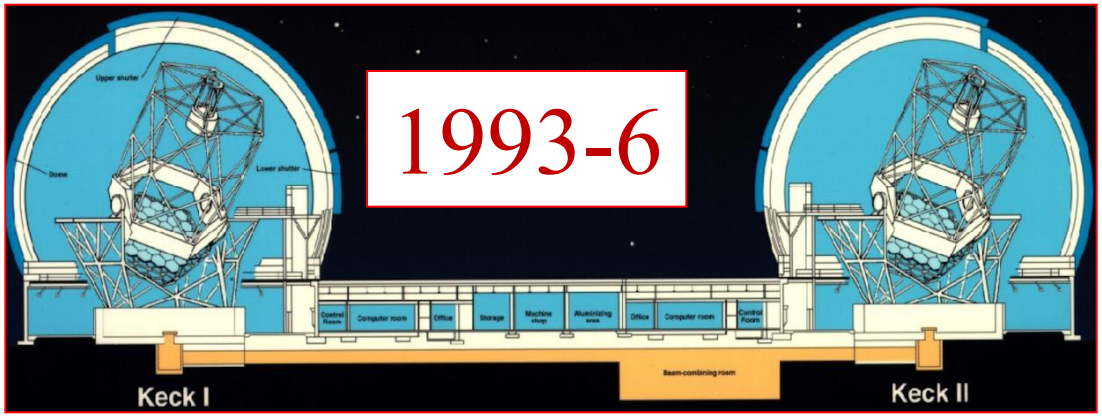
# Horn d'Arturo's legacy

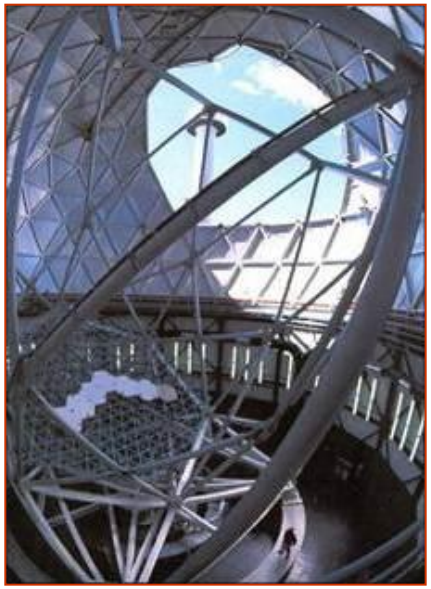


1979

**Multiple Mirror Telescope** (Arizona), 6 circular mirrors (1.82 m each, 4.45 m in total)

**Keck I & Keck 2** (Hawaii), 36 hexagonal mirrors (each telescope, 10 m in total)



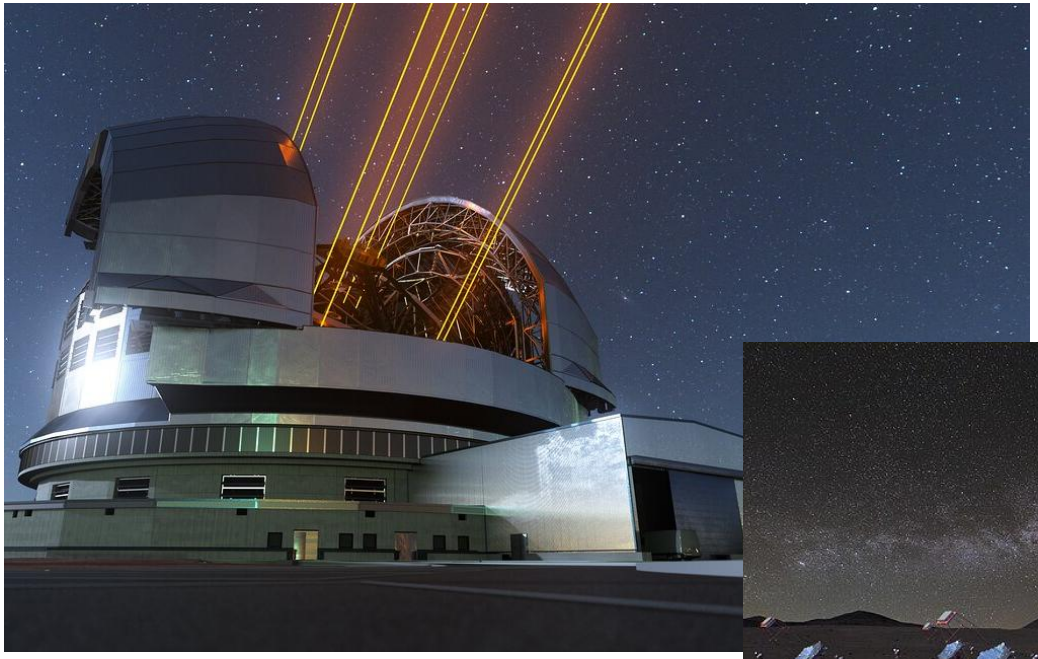



**Hobby-Eberly Telescope** (Texas), 91 hexagonal mirrors (11,1 m each, 9.8 m in total)

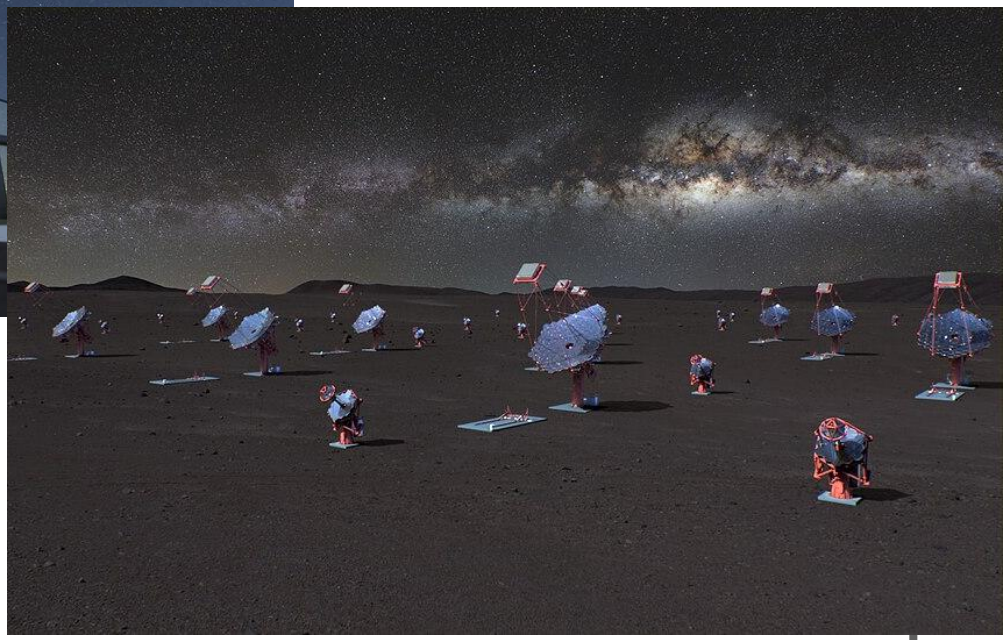
1997

# Horn d'Arturo's legacy… on earth

Extremely Large Telescope



Cherenkov Telescope
Array Observatory



# Horn d'Arturo's legacy… in the space

«L'impossibilità di ottenere immagini meglio definite, finché si rimane dentro l'atmosfera, **spinge l'astronomo a portare i mezzi ottici fuori dell'atmosfera**. Essendo uno degli ostacoli il gran peso dello specchio, si finisce per ricorrere allo specchio a tasselli che con il piccolo spessore di ciascun tassello permette di ottenere grandi superfici riflettenti relativamente poco pesanti.» *Coelum*, 1966

transl. "The impossibility of obtaining better-defined images, as long as observations are carried out within the atmosphere, leads astronomers to move optical instruments beyond it… ultimately, this results in the adoption of tessellated mirrors that are relatively lightweight.»

# Horn d'Arturo's heritage

## Specola Museum of Astronomy

(Exclusive guided tour tomorrow!)

# *Thank You !*

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