Optical Interferometry and Astronomy

A brief historical perspective

Pierre Kervella

in·ter·fer·ence [ˌɪntəˈfɪərəns]

An effect caused by the superposition of two or more systems of waves

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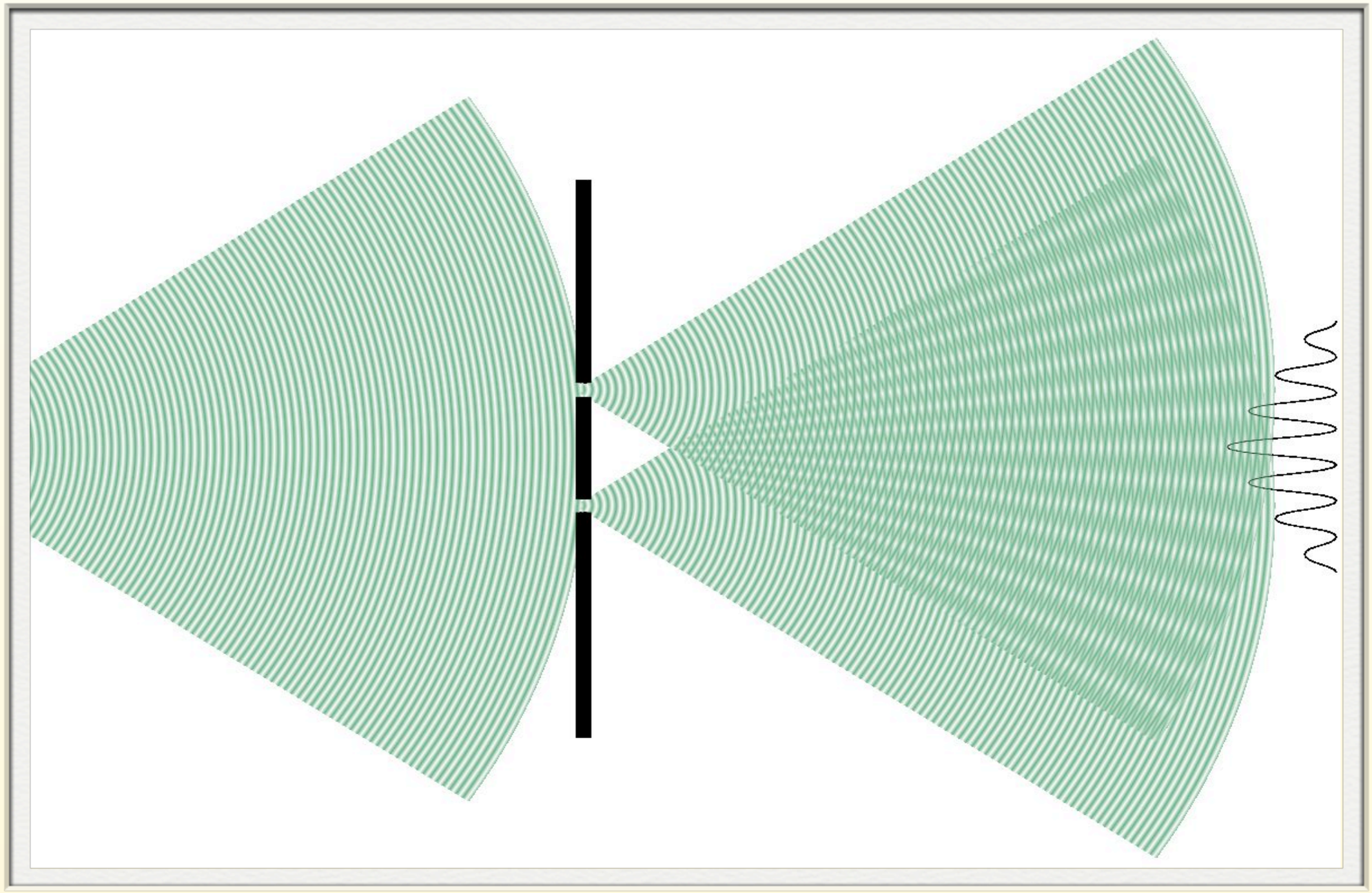
- The wave theory of light held until the early 20th century, when the particle theory and the wave theory joined into quantum optics

Young’s experiment



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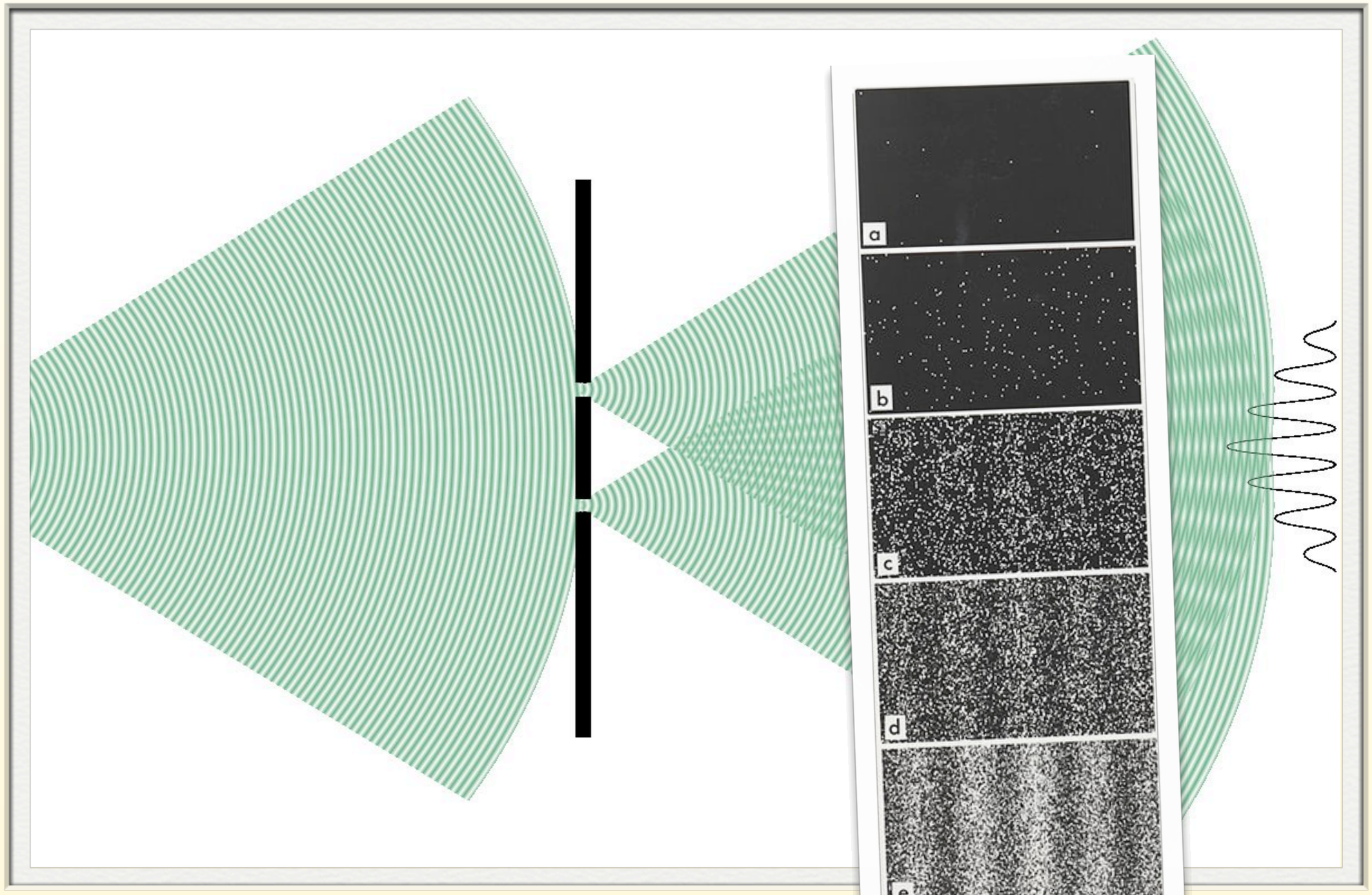

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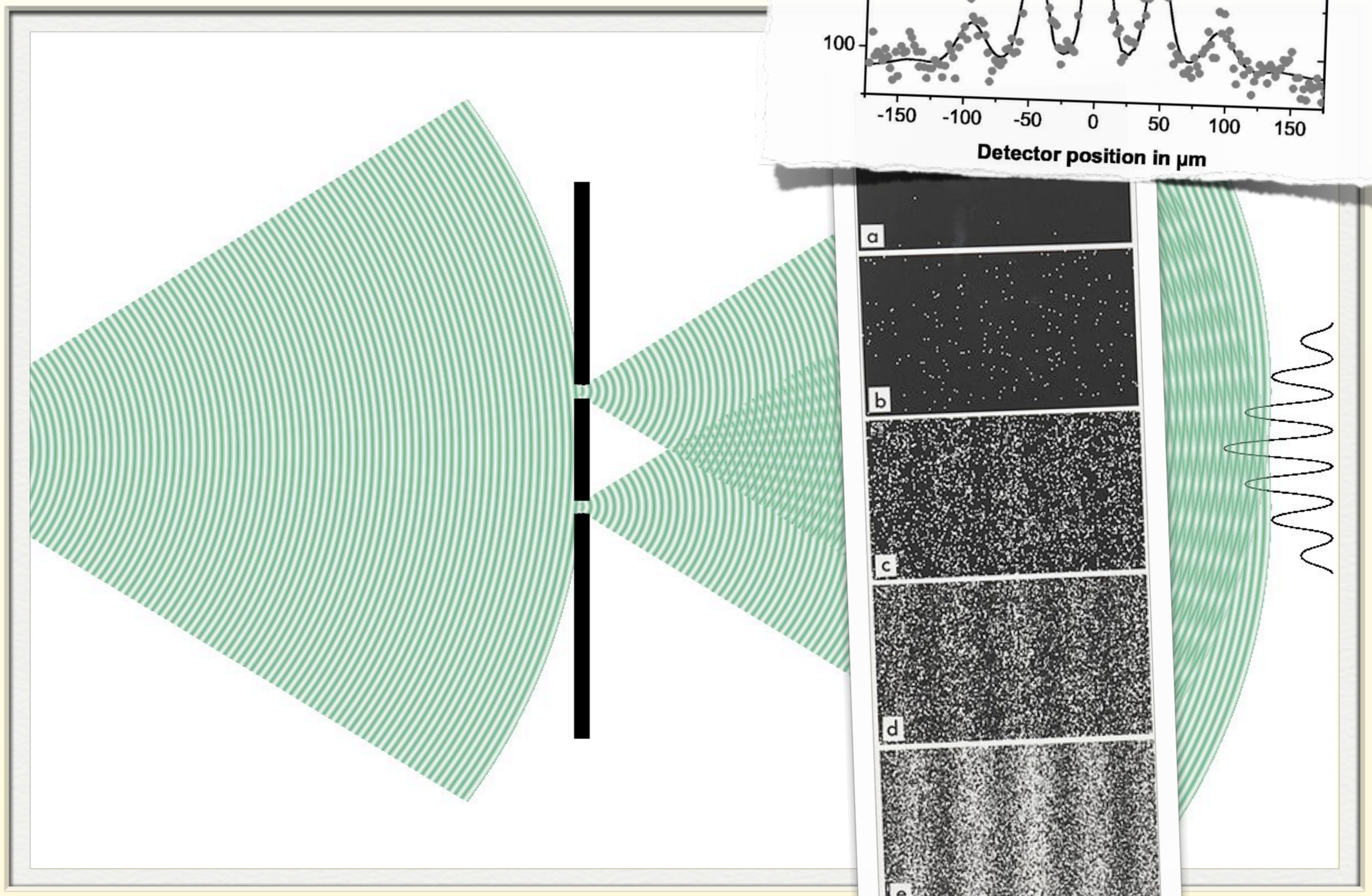
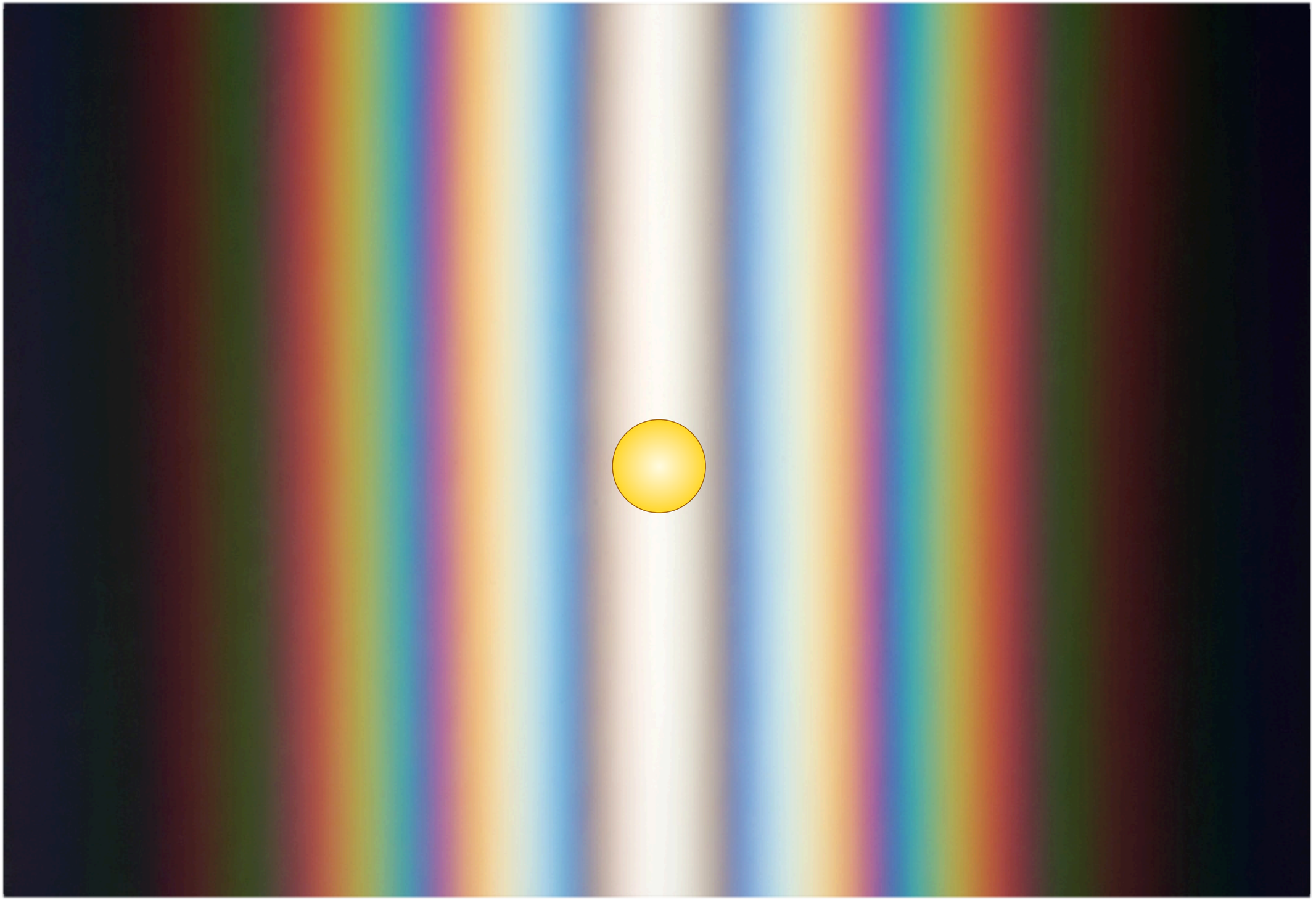
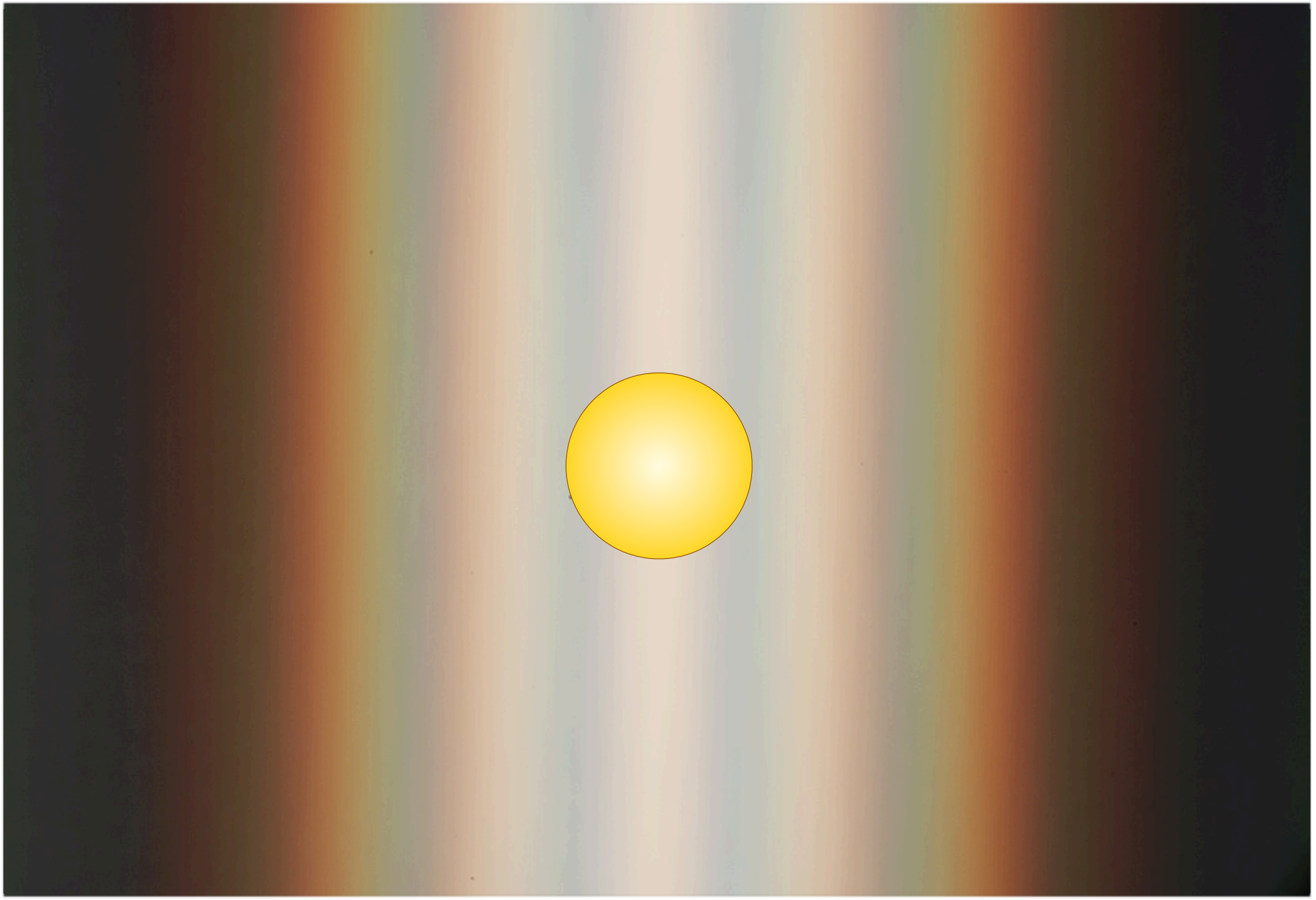
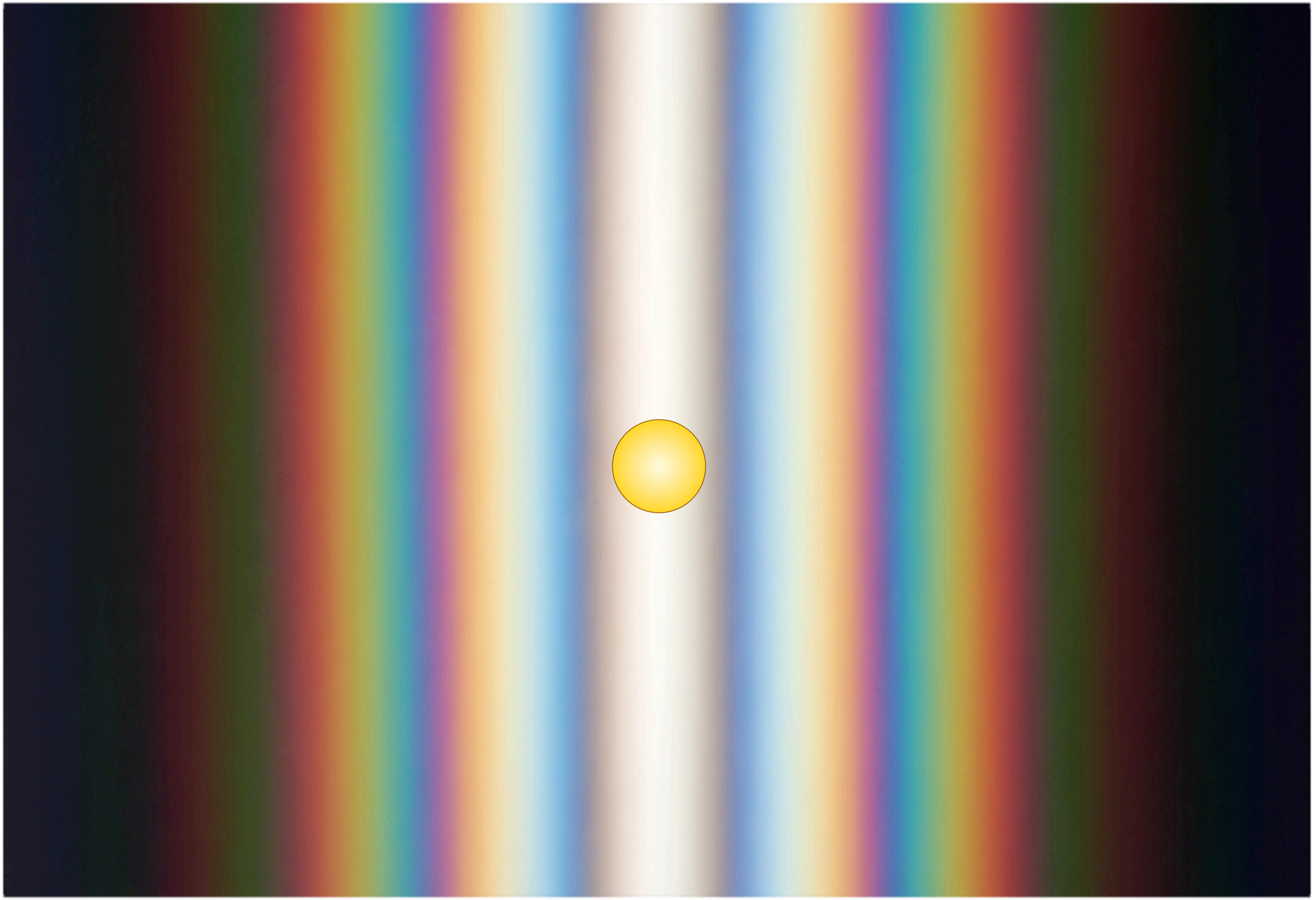
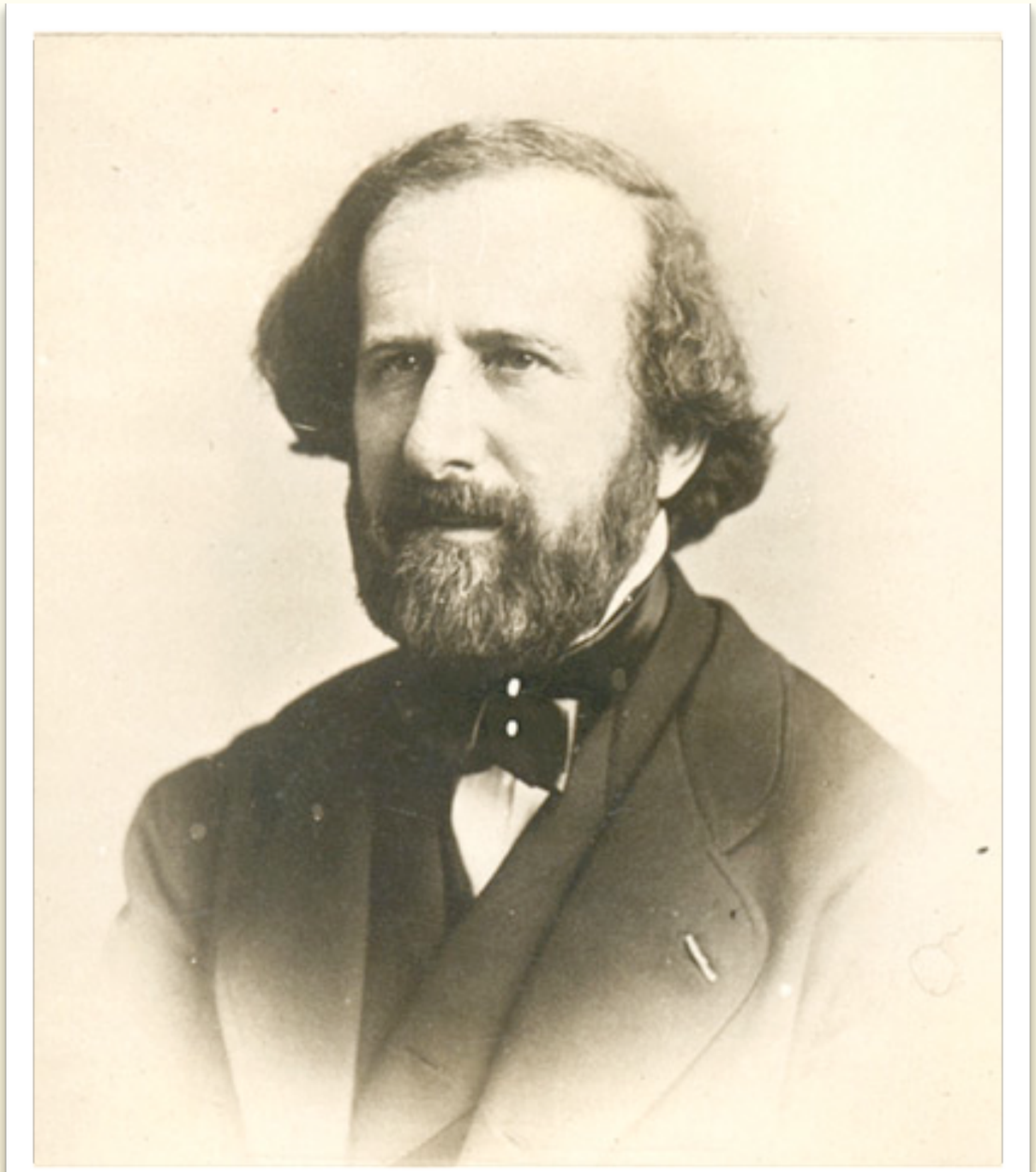








Armand Hippolyte Fizeau (1819-1896)



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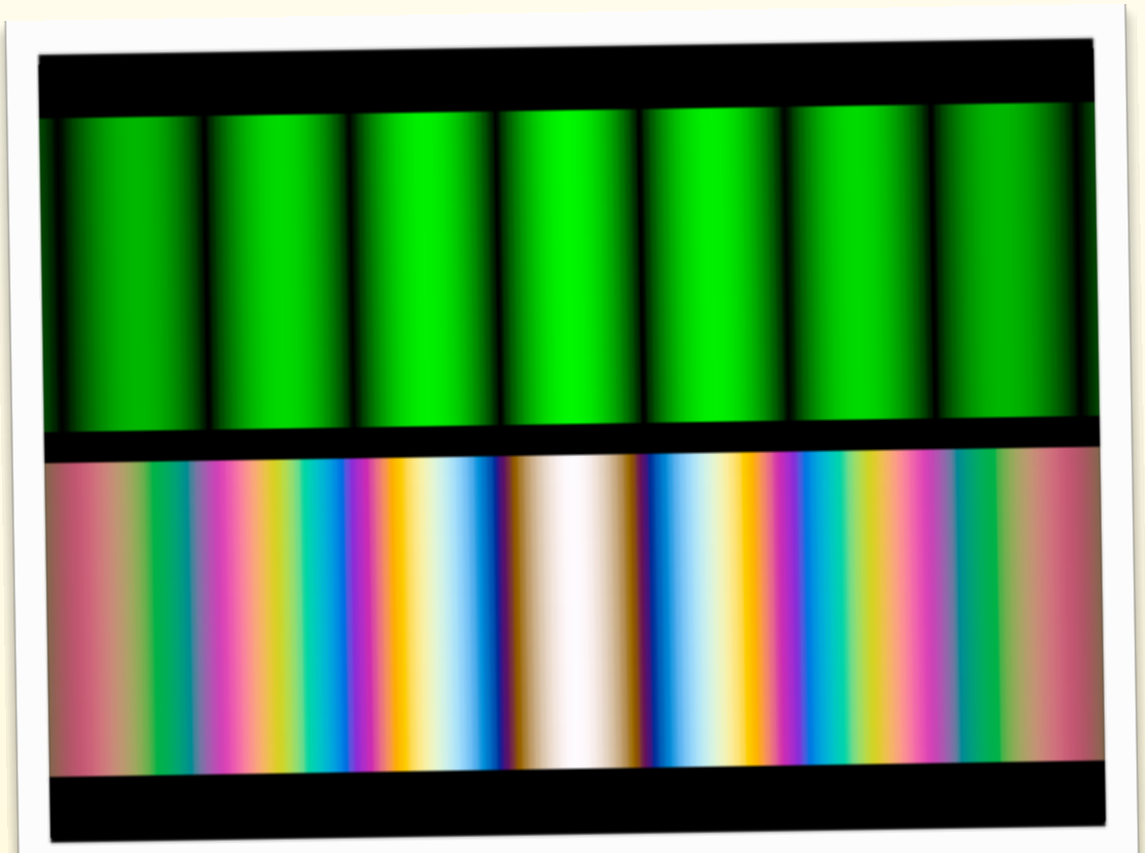
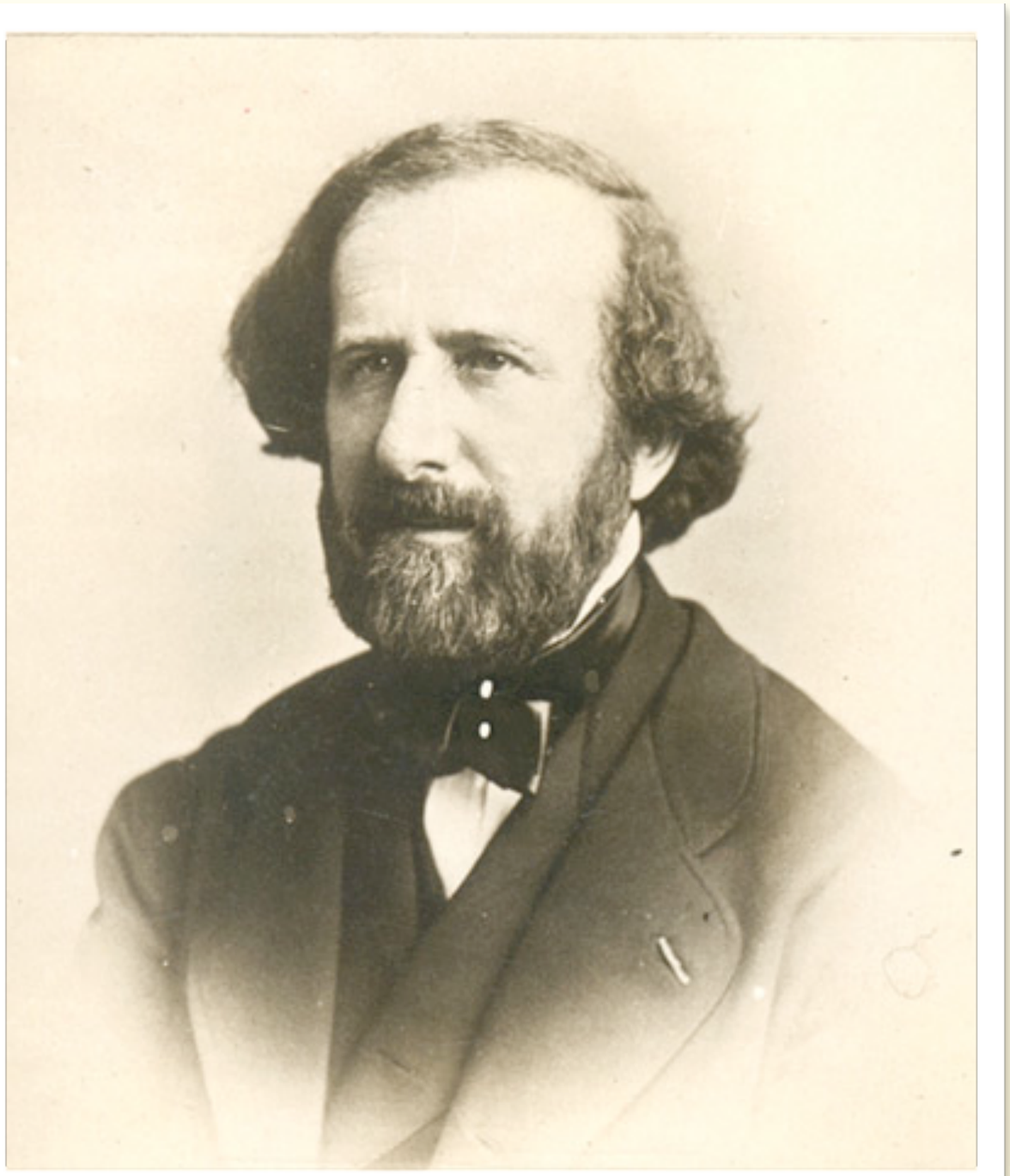
- Together with Foucault, Fizeau describes in 1845 interferences in dispersed light





Seminal idea: interferometry and Astronomy

PRIX BORDIN.

QUESTION PROPOSÉE EN 1865 POUR 1867.

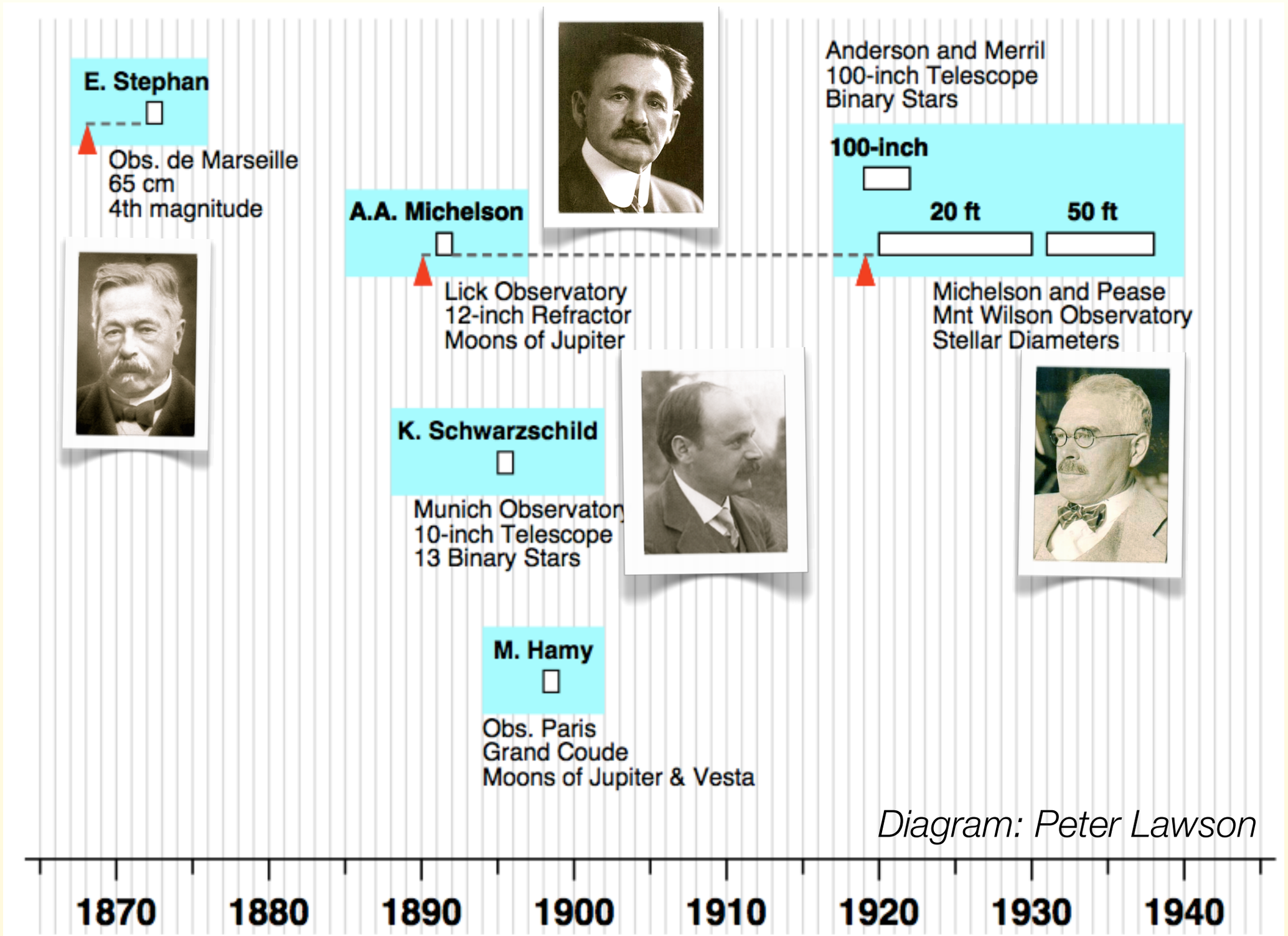
(Commissaires : MM. Duhamel, Pouillet, Regnault, Bertrand, Edmond Becquerel, Fizeau rapporteur.)

Rapport sur le Concours de l'année 1867.

« *Le prix sera décerné au savant qui aura exécuté ou proposé une expérience* » *décisive permettant de trancher définitivement la question déjà plusieurs fois* » *étudiée de la direction des vibrations de l'éther dans les rayons polarisés.* »

Il existe en effet pour la plupart des phénomènes d'interférence, tels que les franges d'Yung, celles des miroirs de Fresnel et celles qui donnent lieu à la scintillation des étoiles d'après Arago, une relation remarquable et nécessaire entre la dimension des franges et celle de la source lumineuse, en sorte que des franges d'une ténuité extrême ne peuvent prendre naissance que lorsque la source de lumière n'a plus que des dimensions angulaires presque insensibles ; d'où, pour le dire en passant, il est peut-être permis d'espérer qu'en s'appuyant sur ce principe et en formant par exemple, au moyen de deux larges fentes très-écartées, des franges d'interférence au foyer des grands instruments destinés à observer les étoiles, il deviendra possible d'obtenir quelques données nouvelles sur les diamètres angulaires de ces astres.

At the turn of the XXth Century: the Pioneers



Application to Astronomy: first results

ASTRONOMIE PHYSIQUE. — *Sur l'extrême petitesse du diamètre apparent des étoiles fixes.* Note de M. STÉPHAN.

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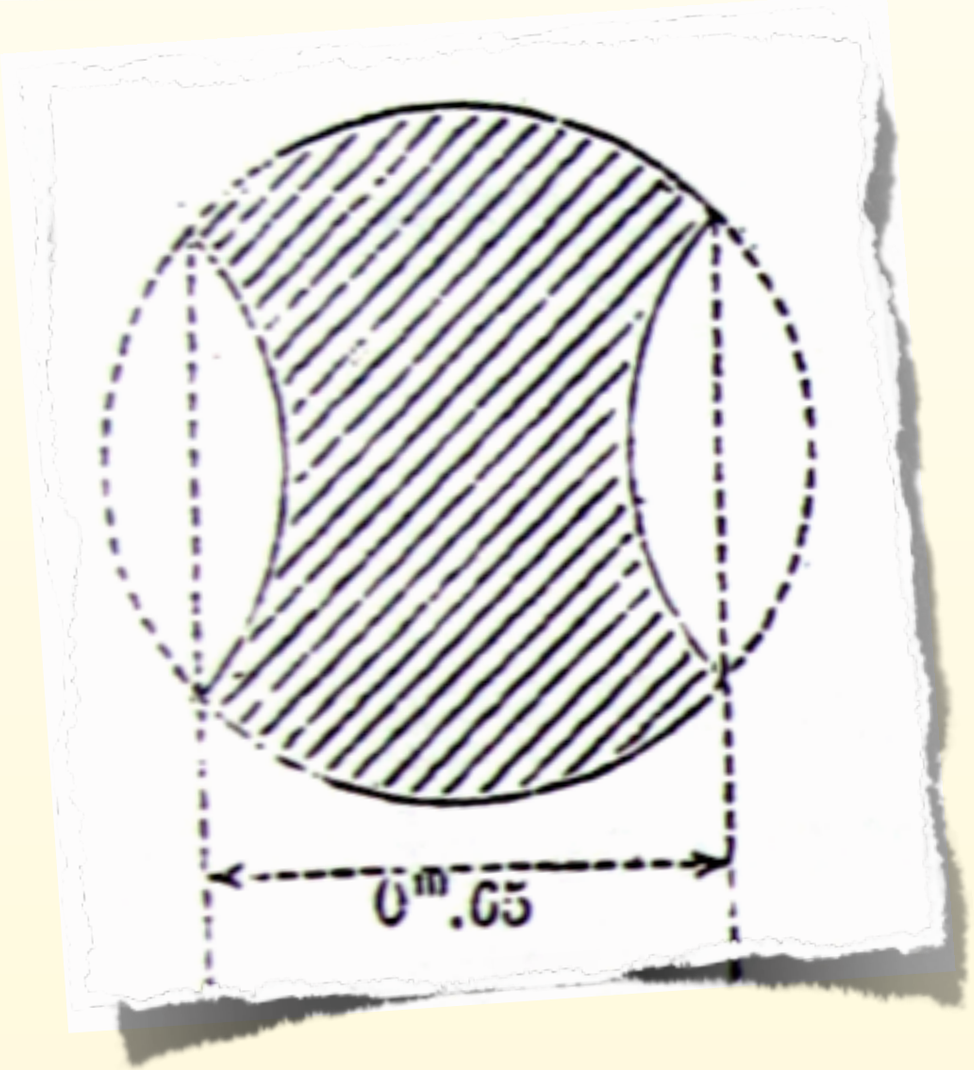

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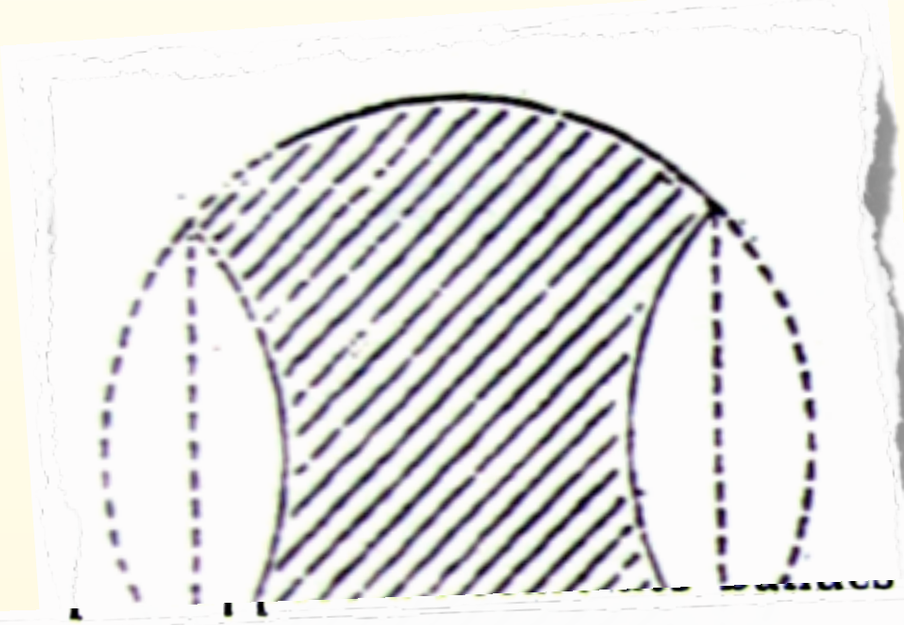

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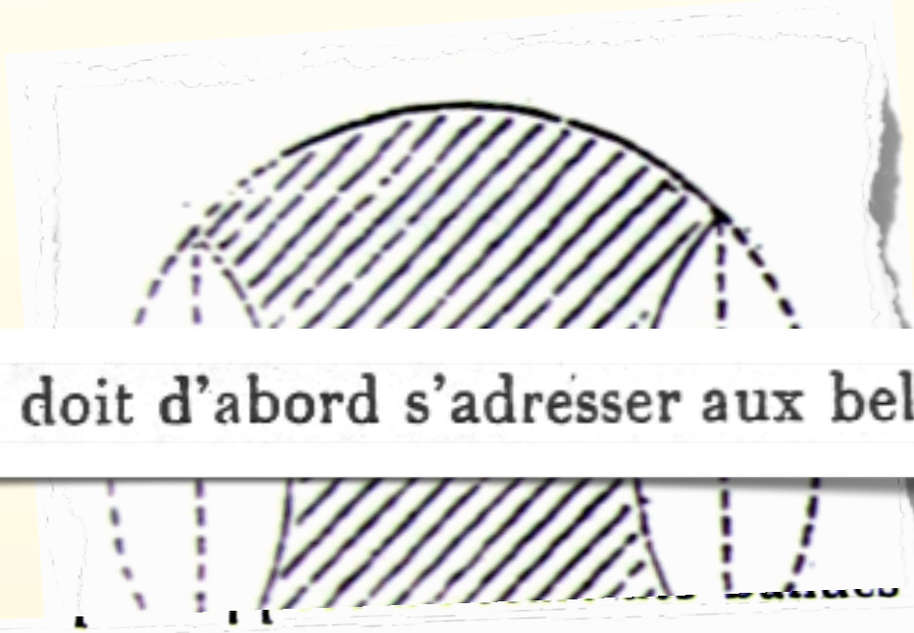

» Il est évident que l'on doit d'abord s'adresser aux belles étoiles.

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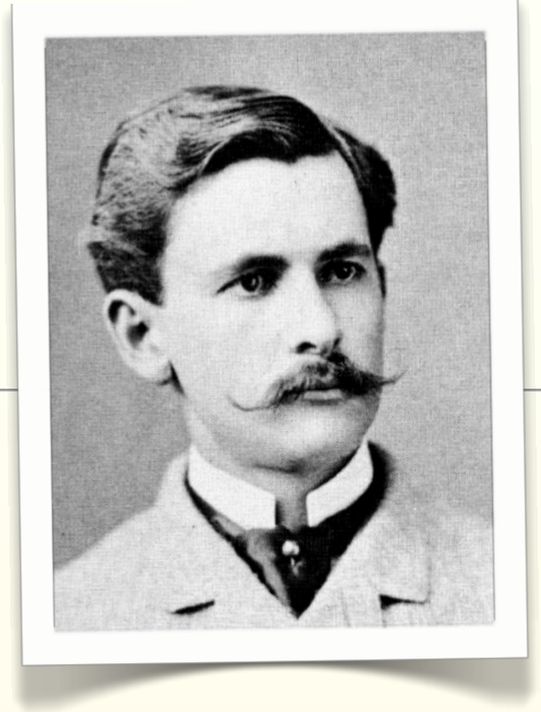

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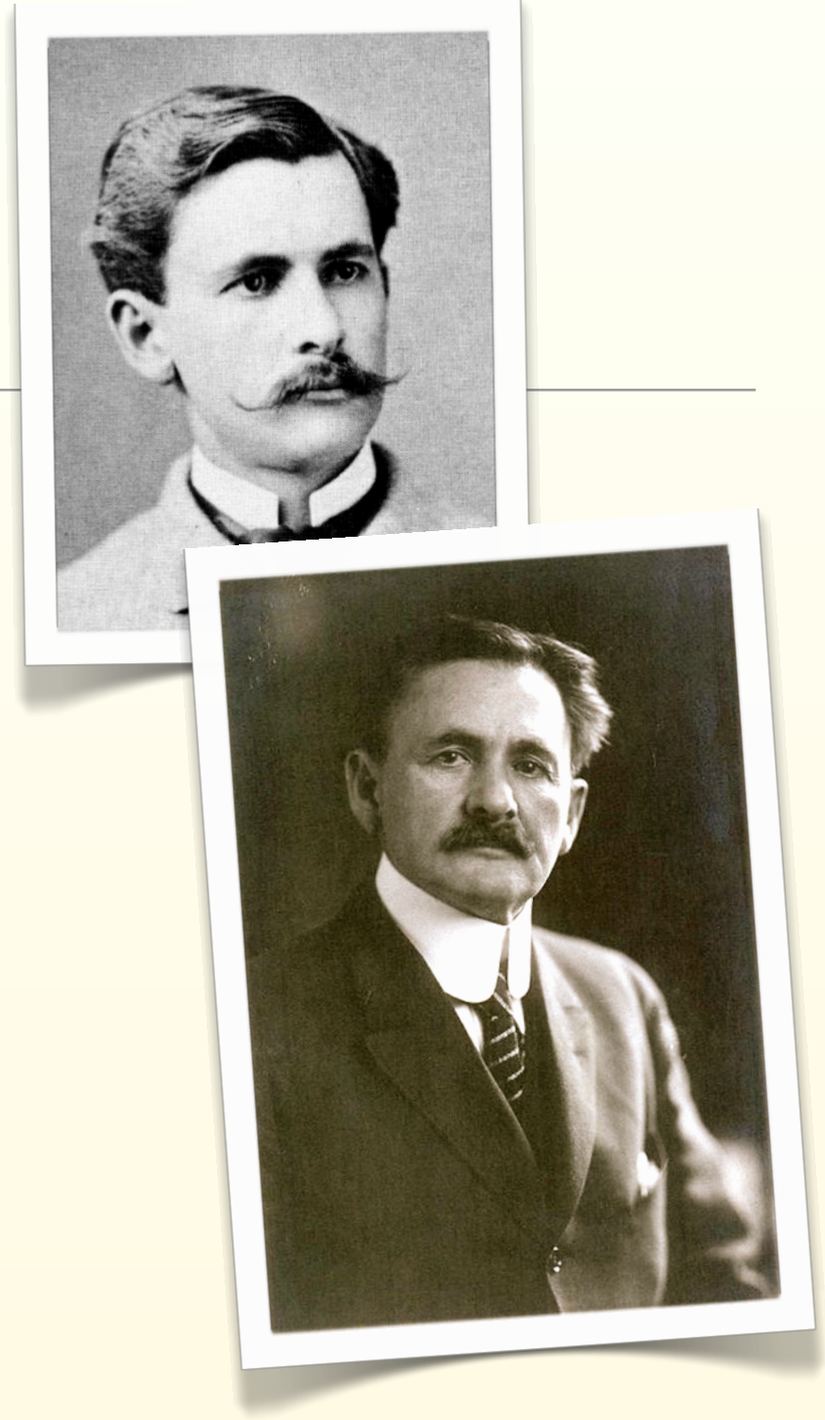

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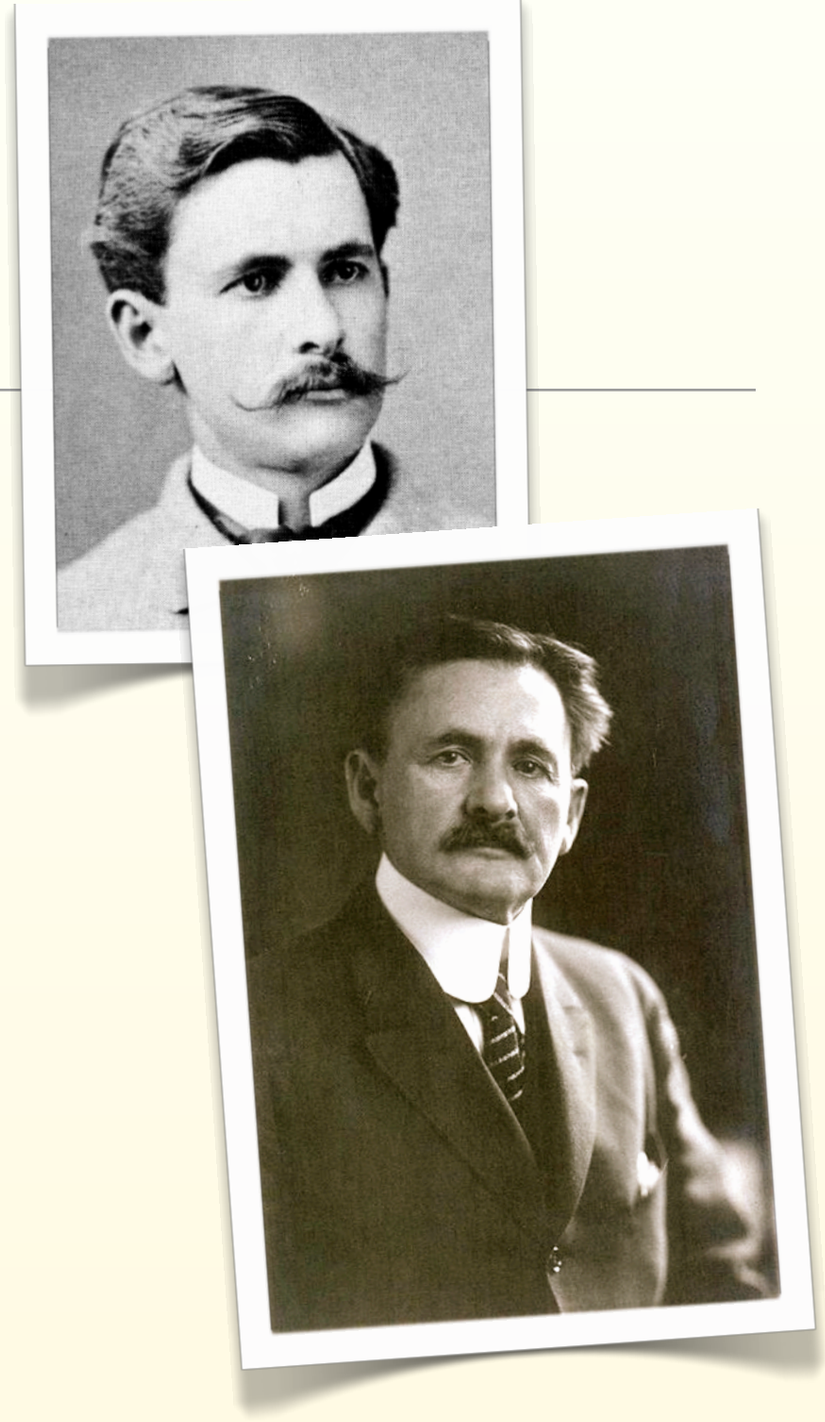

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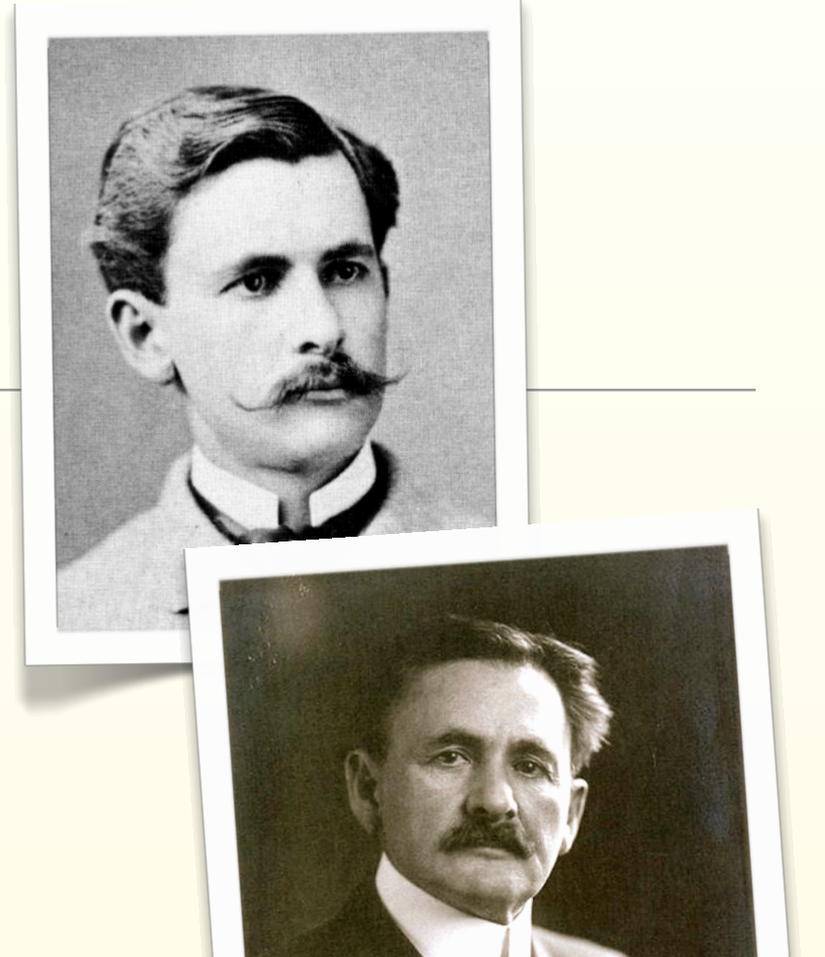
- After WW1, in 1920, Michelson & Pease measure the angular diameter of Betelgeuse and a few other bright stars



M. L. Humason · Edwin Hubble A. Einstein W. W. Campbell W. S. Adams

A step towards distant stars: the satellites of Jupiter

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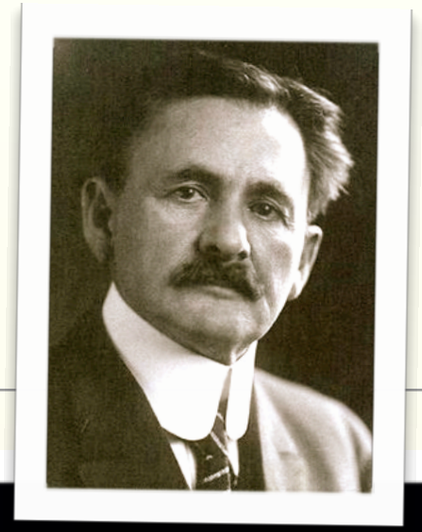

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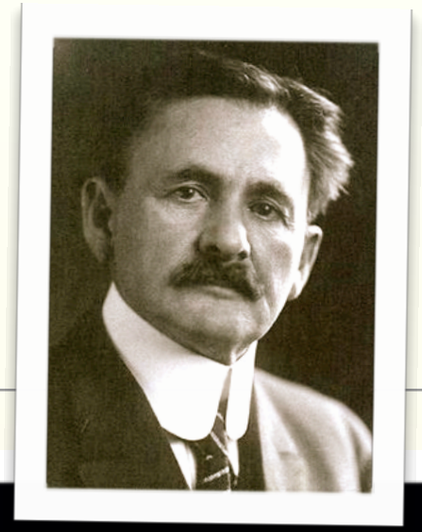

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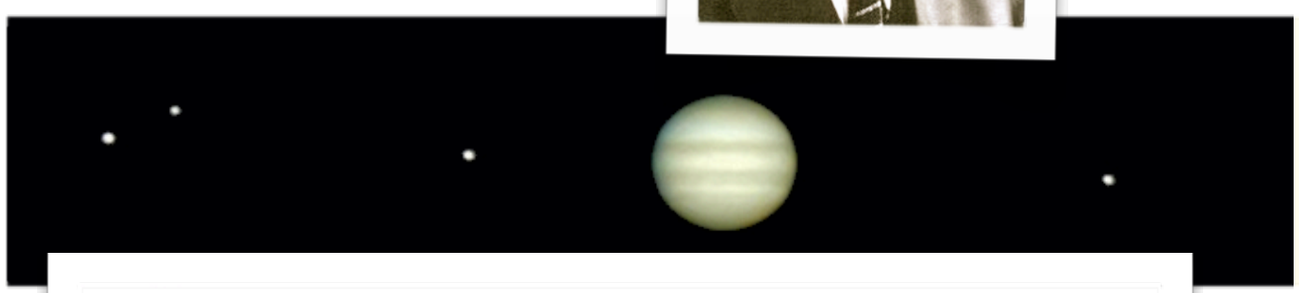

MEASUREMENT OF JUPITER'S SATELLITES BY INTERFERENCE.

IT has long been known that even in a telescope which is theoretically perfect, the image of a luminous point is composed of a series of concentric circles with a bright patch of light at the common centre. This system of circles can easily be observed by examining any bright star with a telescope provided with a circular diaphragm which diminishes the effective aperture. The appearance of the image is shown in Fig. 1, *a*. In the case of an object of finite angular magnitude the image could be constructed by drawing a system of such rings about every point in the geometrical image. The result for a small disk (corresponding to the appearance of one of the satellites of Jupiter as seen with a 12-inch telescope whose effective aperture

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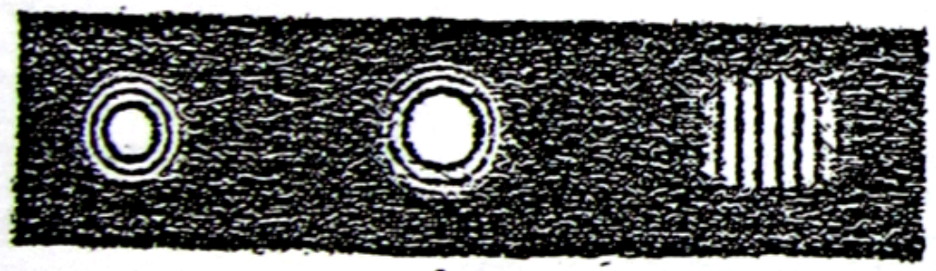

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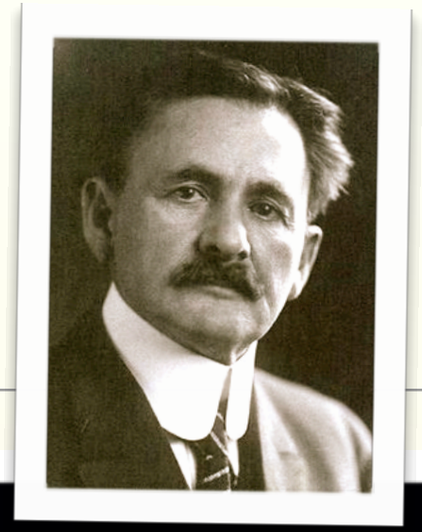

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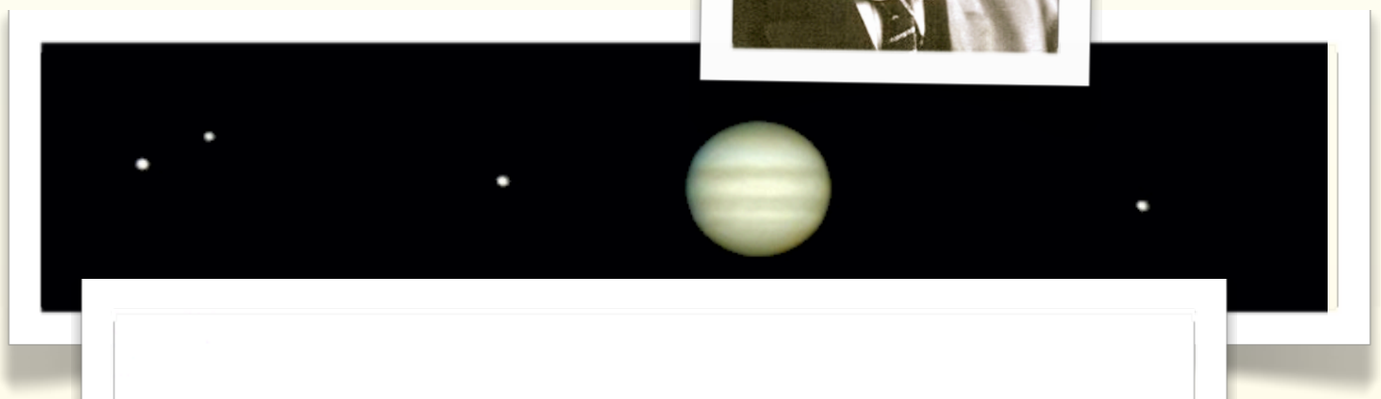

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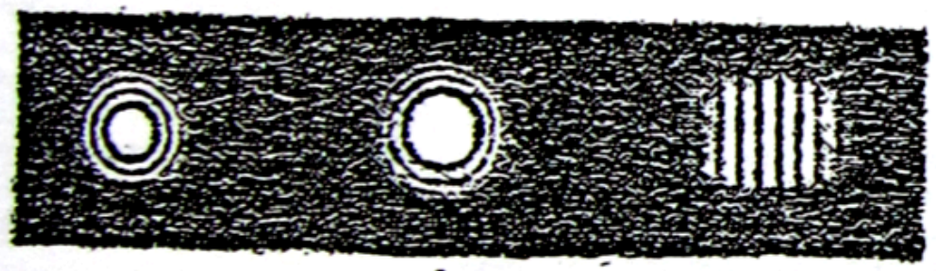

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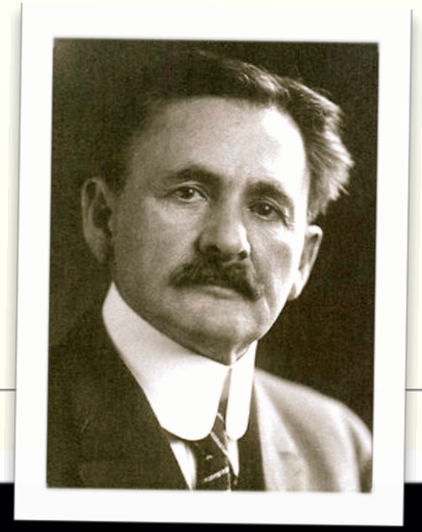

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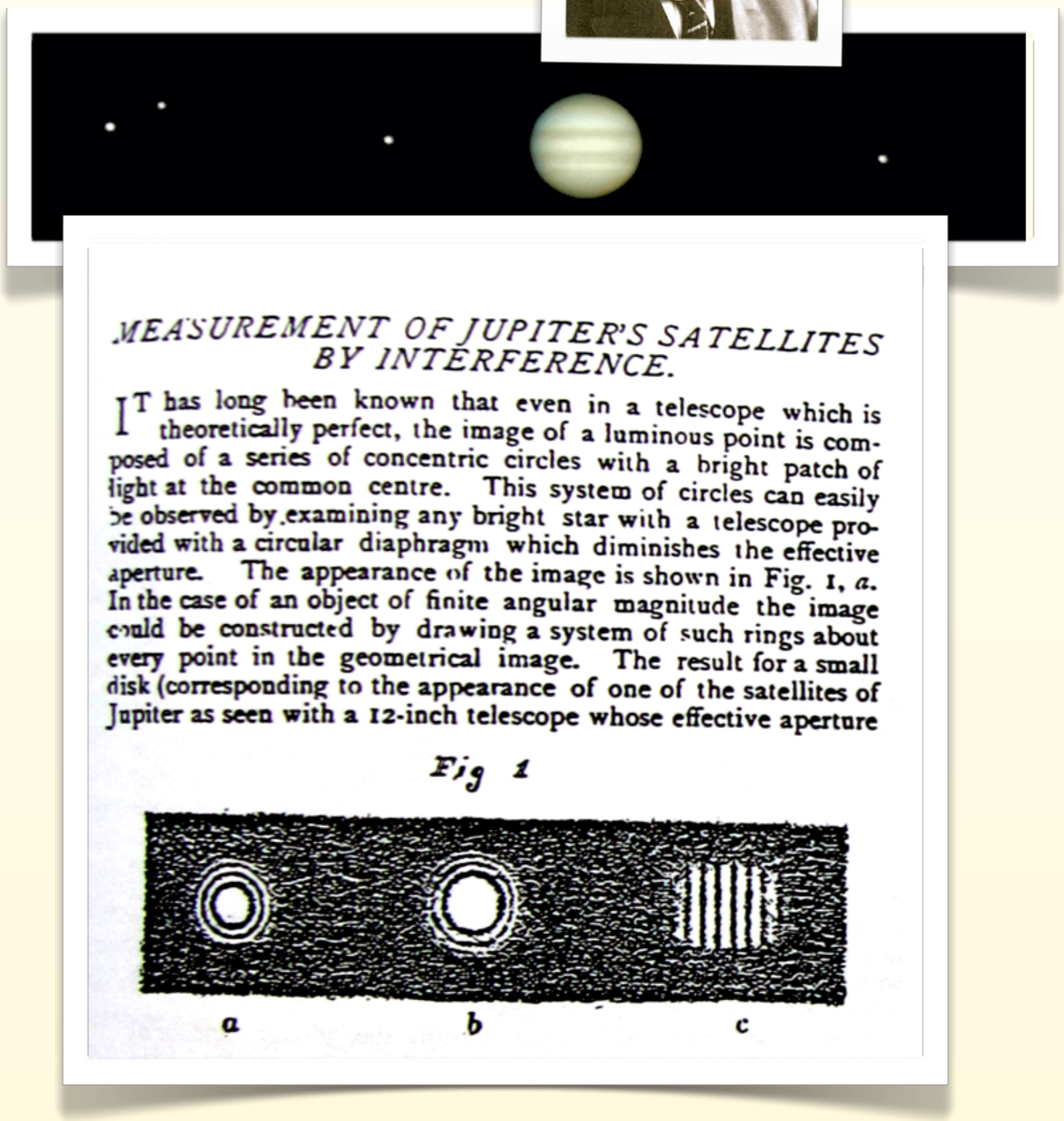

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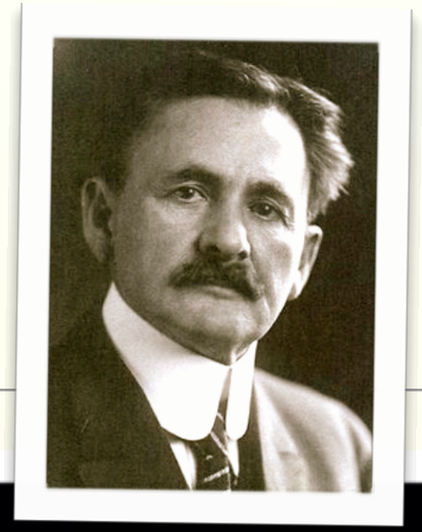

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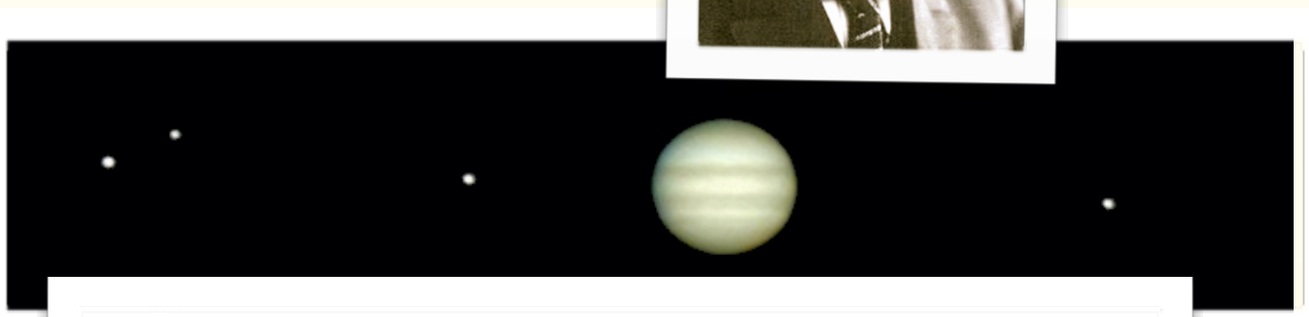
- First use of interferometry as a precision tool to estimate angular diameters



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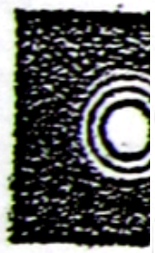


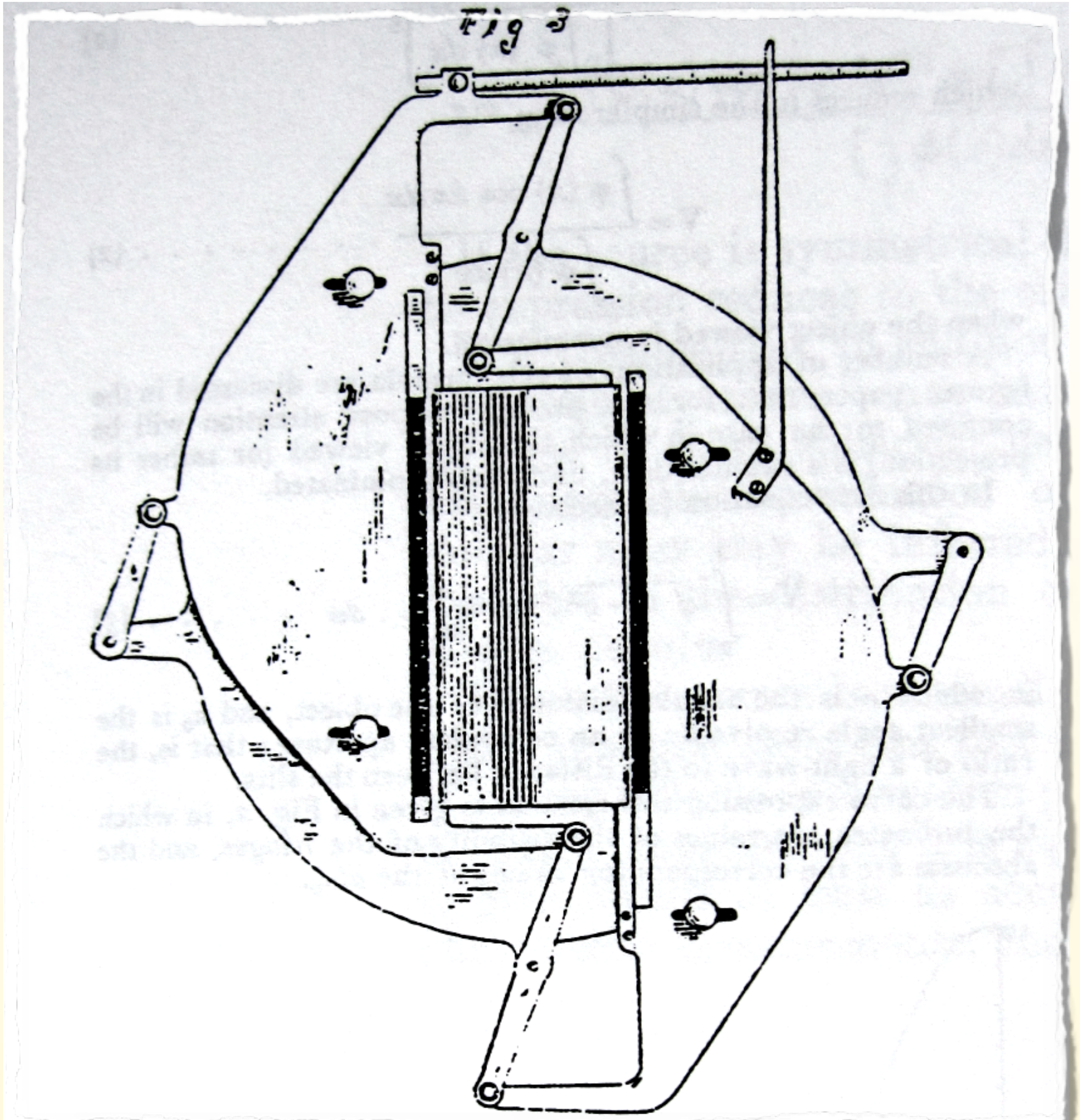
a

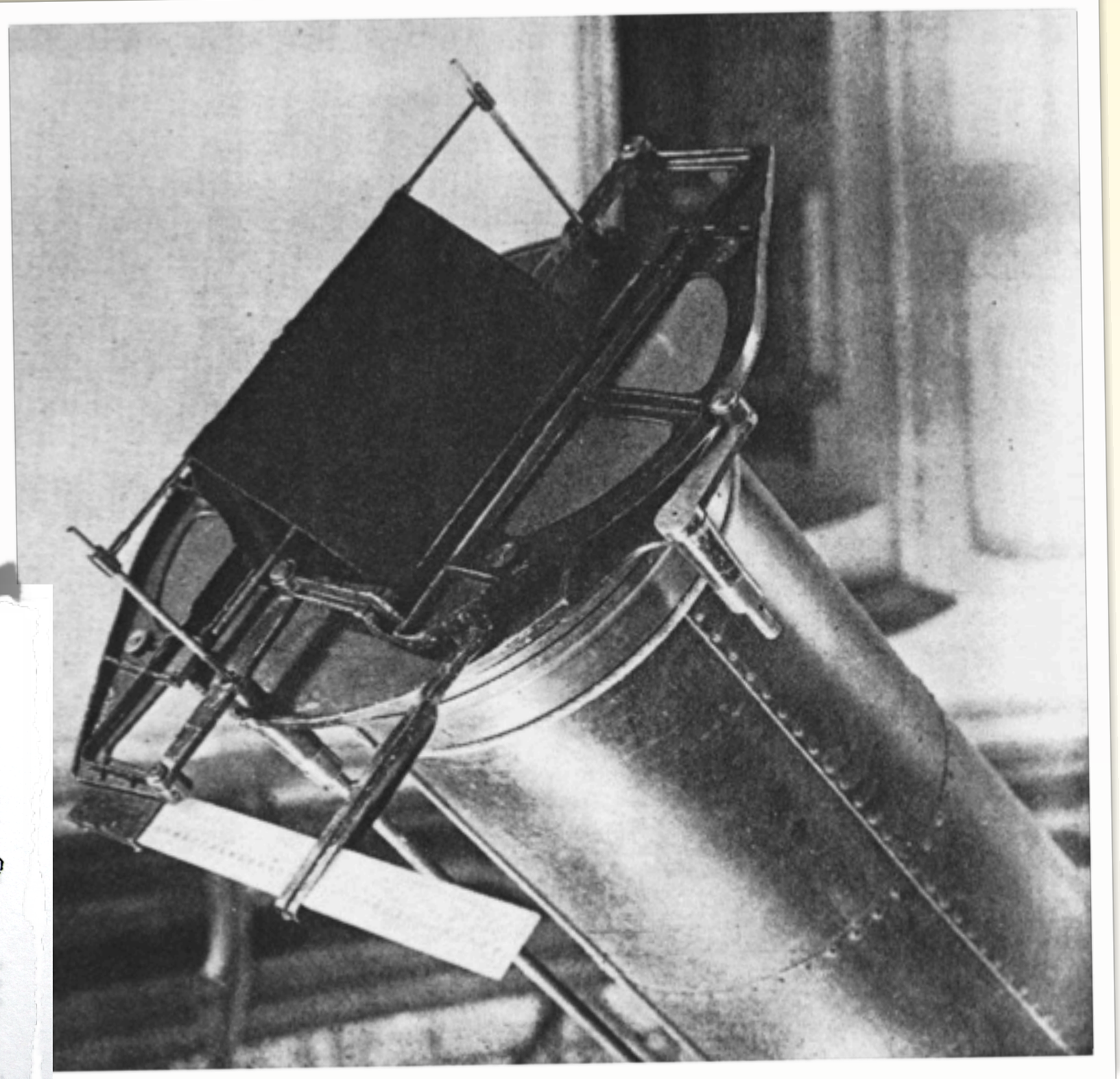
TABLE I.

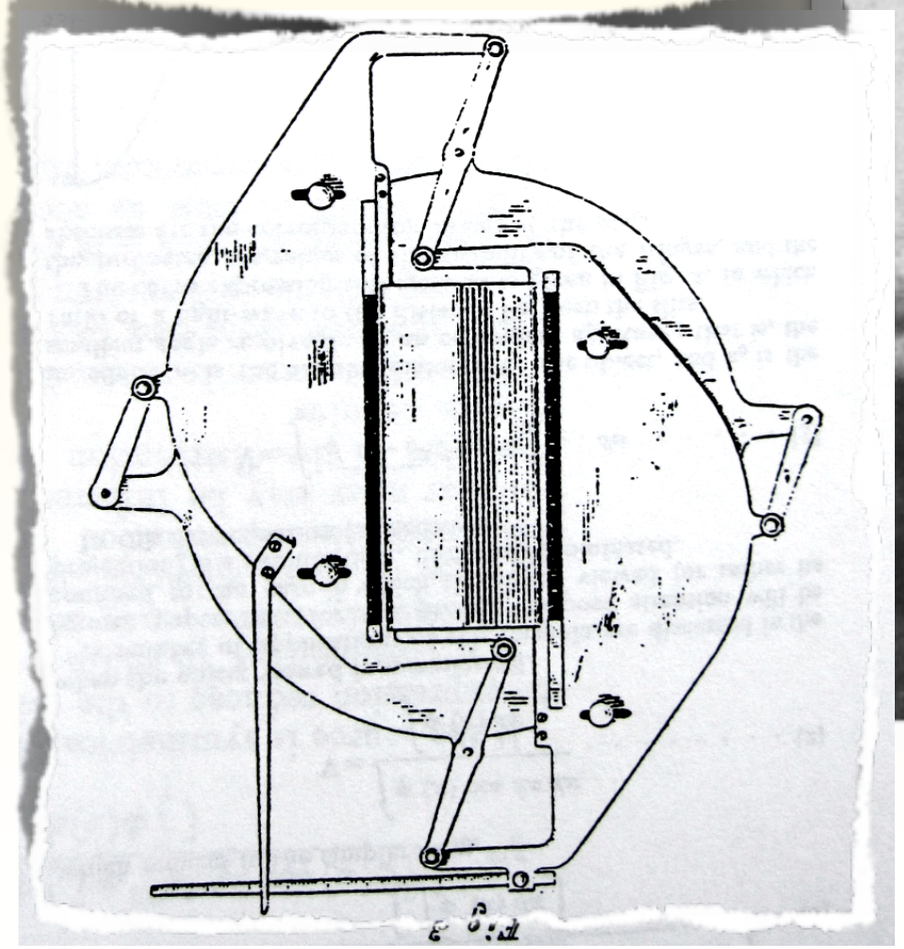
No. of Satellites.	I.	II.	III.	IV.	Seeing.
August 2 ...	1".29	1".19	1".88	1".68	Poor.
August 3 ...	1".29	—	1".59	1".68	Poor.
August 6 ...	1".30	1".21	1".69	1".56	Poor.
August 7 ...	1".30	1".18	1".77	1".71	Good.
Mean...	1".29	1".19	1".73	1".66	

1.22 1.05 1.76 1.61

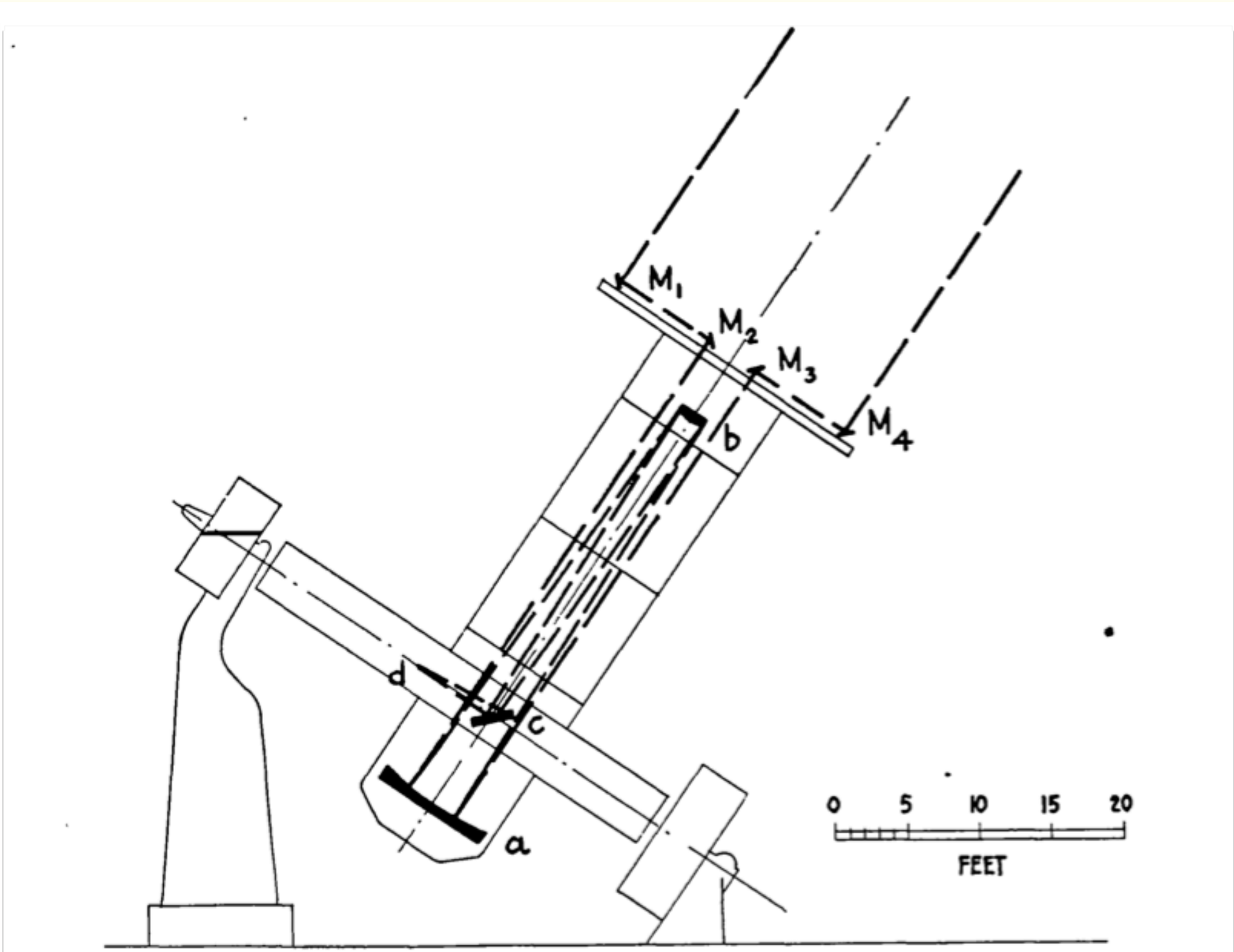
Fig 3







Really high angular resolution:
the 20-ft interferometer at the 100-inch Hooker



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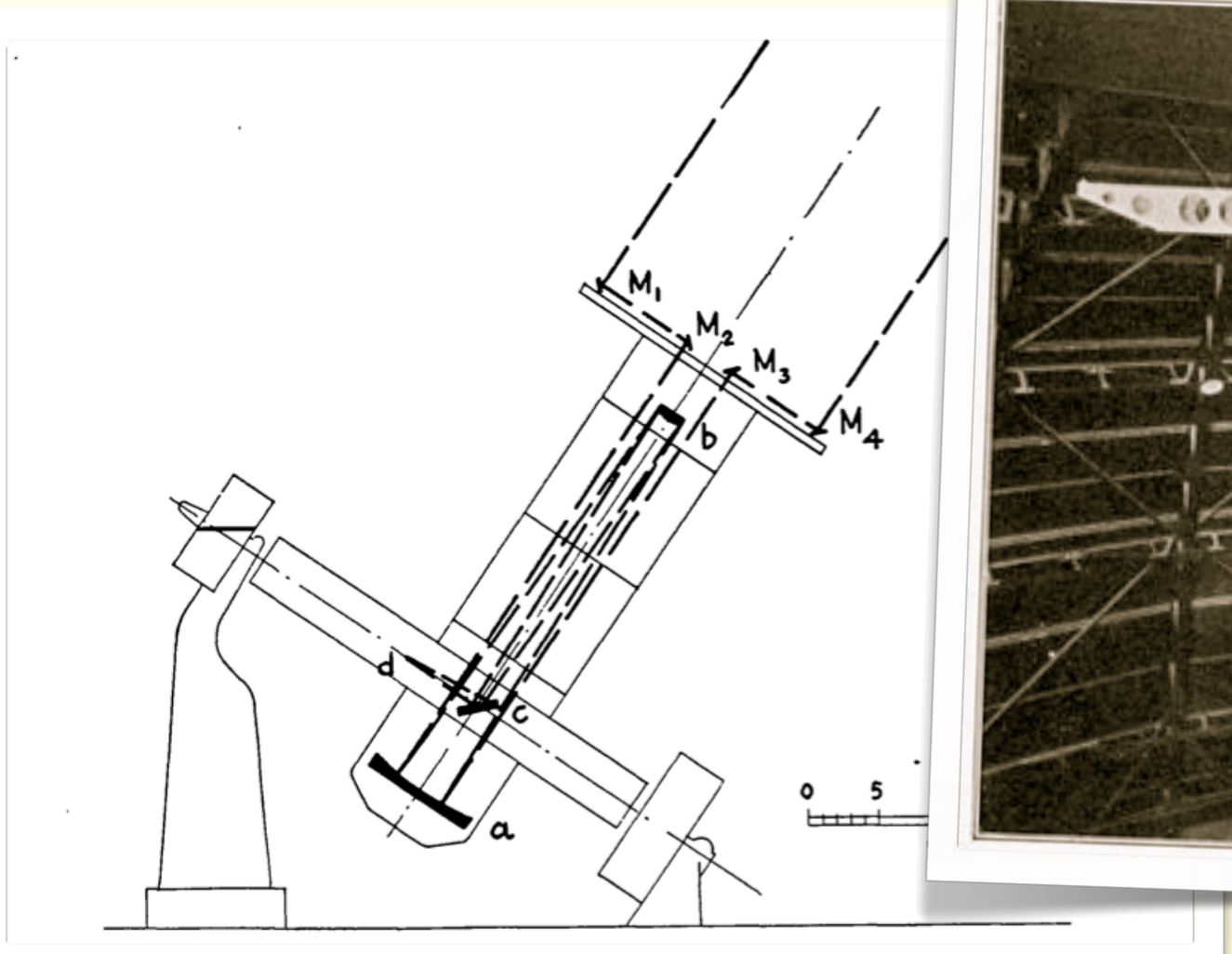

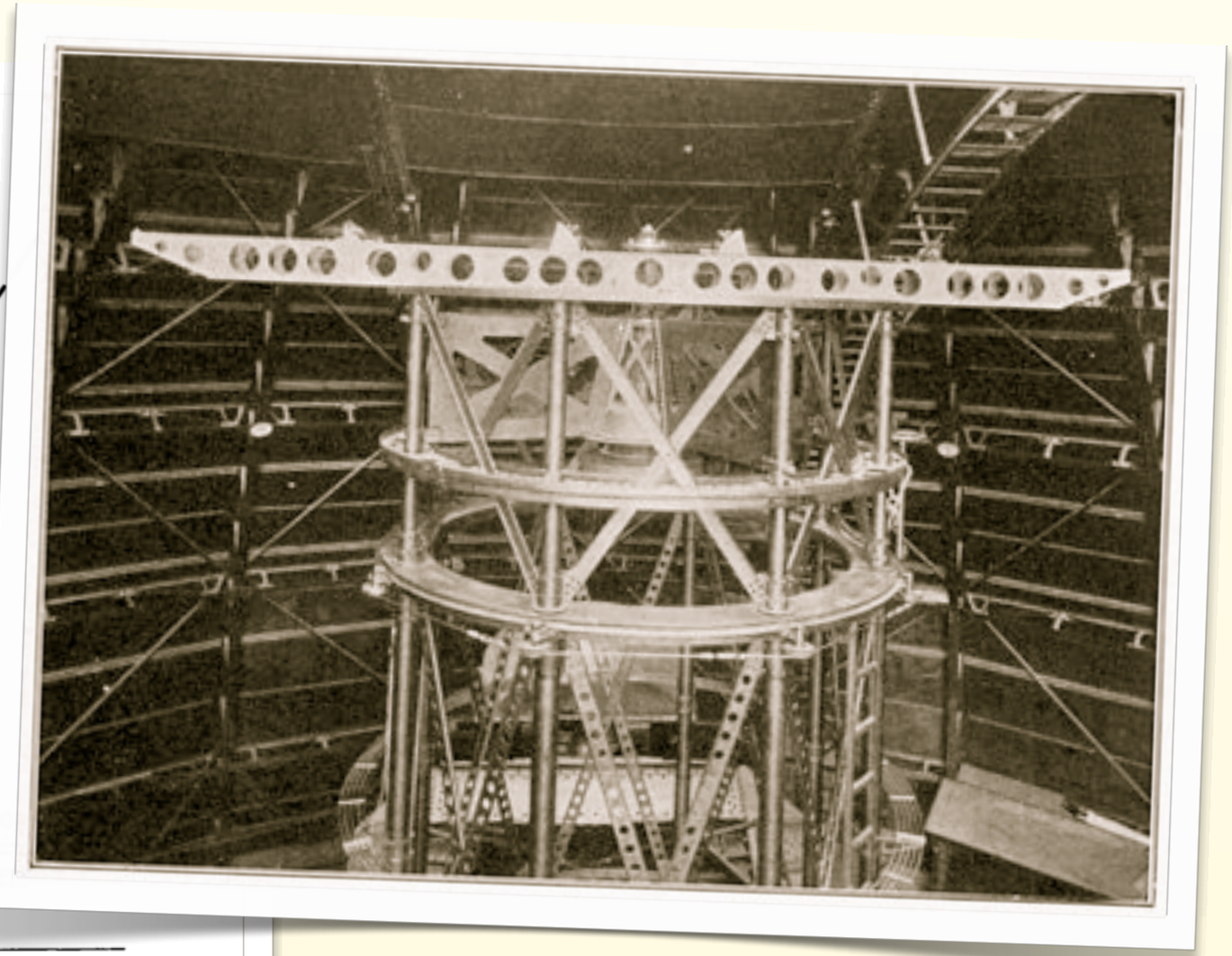

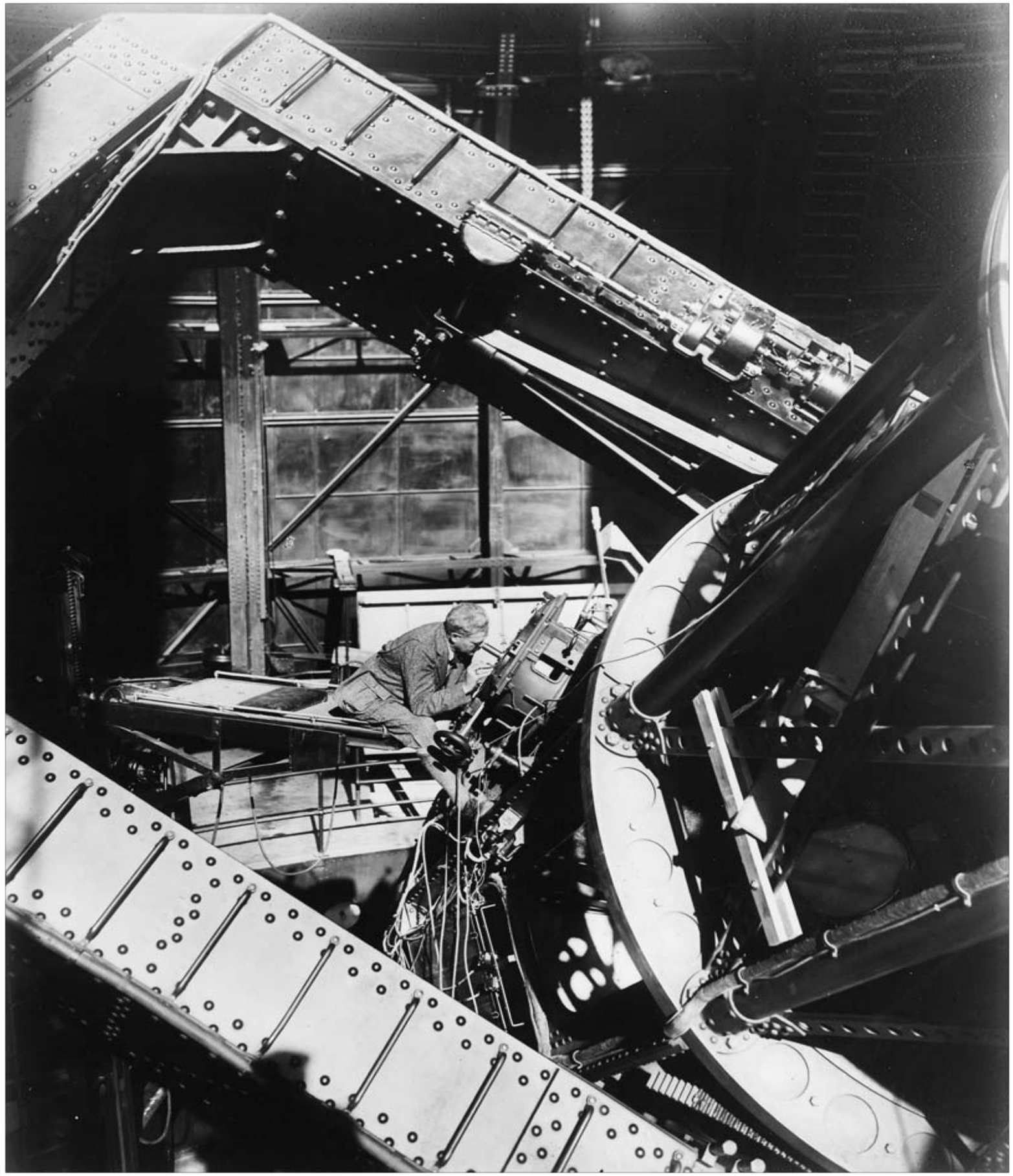

the value $F(k,n)=0$. A preliminary investigation by Merrill, with the apparatus used by Anderson[1] in the measurement of Capella, revealed in fact a definite decrease in visibility of the fringes of α Orionis for the maximum separation of the slits (100 inches). This was true, moreover, for all position angles, which indicated that the star is not a binary and that the decrease in visibility is to be attributed to a measurable diameter.

On December 13, 1920, after preliminary settings on β Persei with the mirrors separated 81 inches (229 cm) and on β Persei and γ Orionis with a separation of 121 inches, thus insuring that the instrument was in perfect adjustment, it was turned on α Orionis and fringes across the interferometer image were sought for some time, but could not be found. The seeing was very good, and the zero fringes could be picked up at will.

When next turned on α Canis Minoris the fringes stood out on both images with practically no adjustment of the compensating wedge, which furnishes a check on the disappearance of the fringes for α Orionis.

It is clear from these observations that the disappearance of the

Michelson & Pease 1921, ApJ, 53, 249

objects [illegible] diameter are being continued.

Assuming that the effective wave-length for α Orionis is λ 5750, its angular diameter from the formula $a = 1.22\ \lambda/b$ proves to be 0".047; and with a parallax[1] of 0".018 its linear diameter turns out to be 240×10^6 miles, or slightly less than that of the orbit of Mars. This value corresponds to a uniformly illuminated disk, while for one darkened at the limb, this result, as mentioned above, would be increased by about 17 per cent. The uncertainty of the measurement of the angular diameter is about 10 per cent.

Cordial acknowledgment is tendered to Director George E. Hale for placing the resources of the Observatory at our disposal and for his enthusiastic co-operation in furthering the investigation.

Mr. J. A. Anderson was present on several occasions and we wish particularly to acknowledge his valuable assistance in checking the measures on December 13.

MOUNT WILSON OBSERVATORY
February 1921

[1] The weighted mean of Adams' spectroscopic parallax, 0".012, and the trigonometric values of Elkin, 0".030, and of Schlesinger, 0".016.

Michelson & Pease 1921, ApJ, 53, 249

The Pease & Hale 50-ft interferometer

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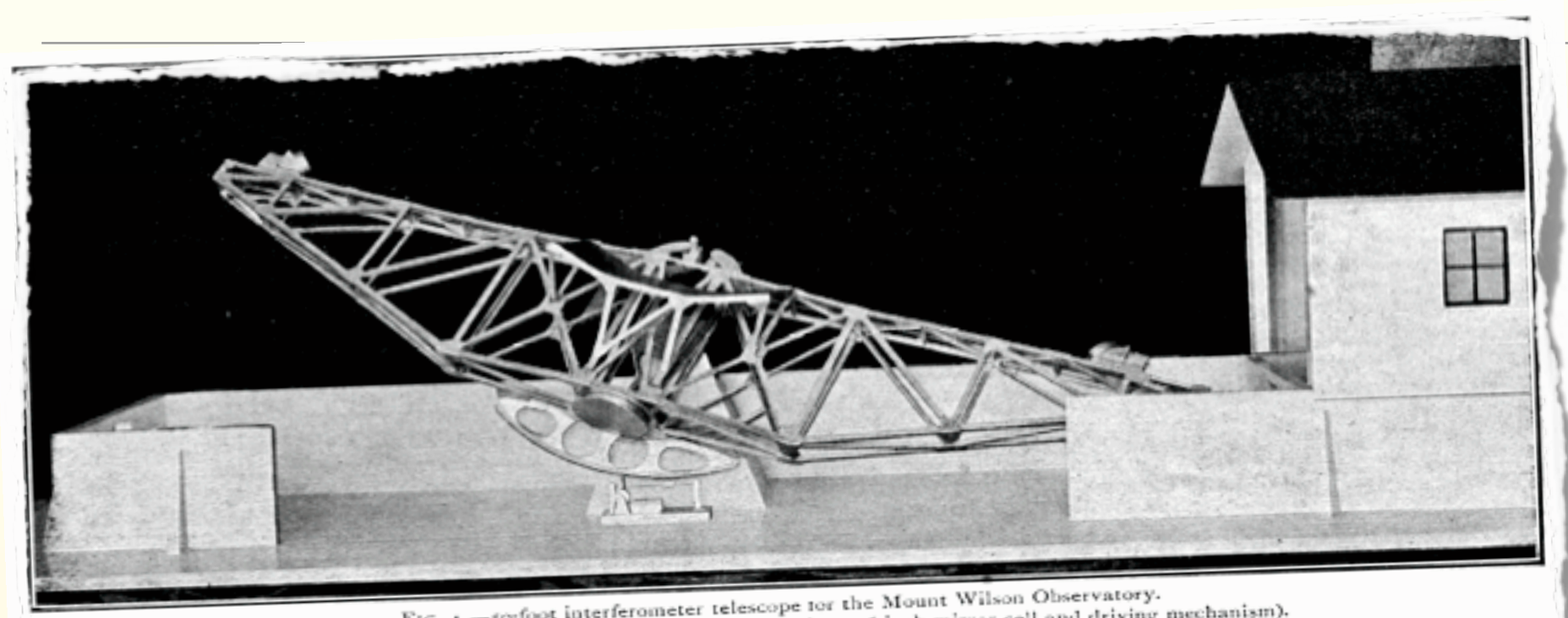

FIG. 1.—50-foot interferometer telescope for the Mount Wilson Observatory.
Model seen from the north (part of wall removed to show 36-inch mirror cell and driving mechanism).

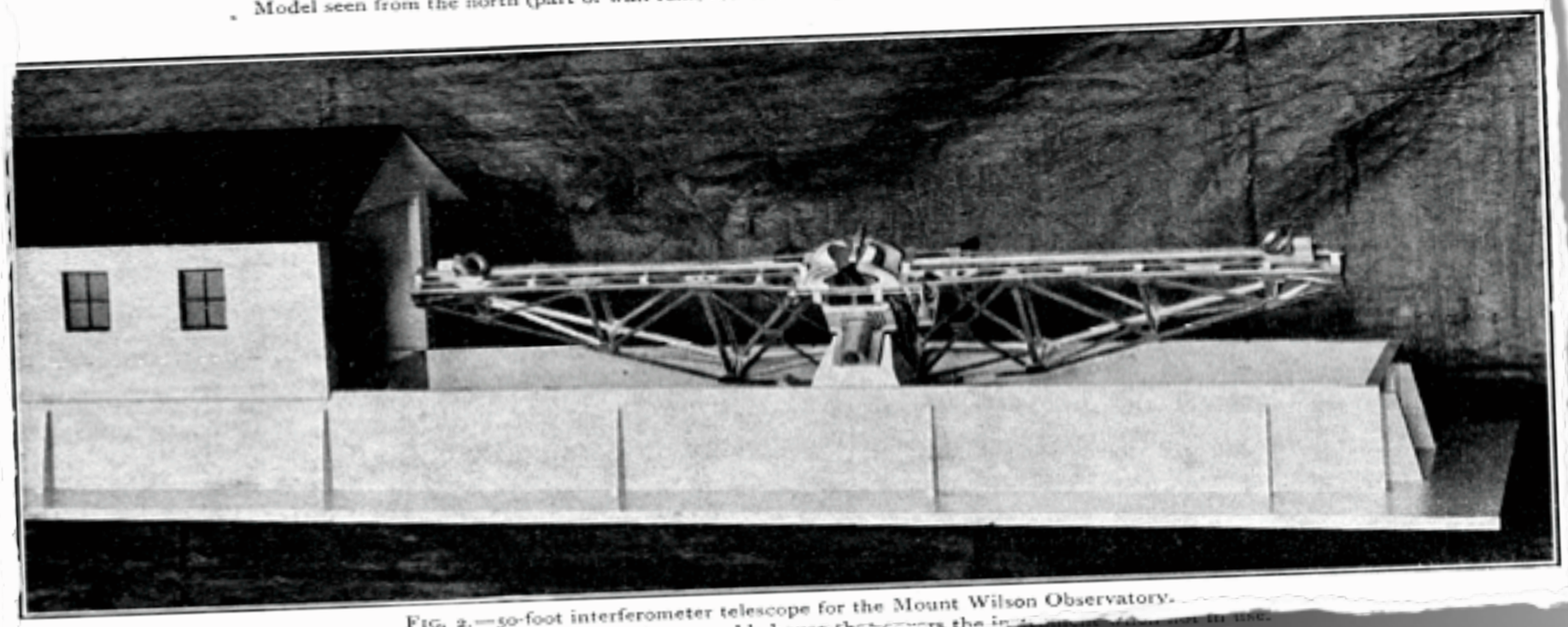

FIG. 2.—50-foot interferometer telescope for the Mount Wilson Observatory.

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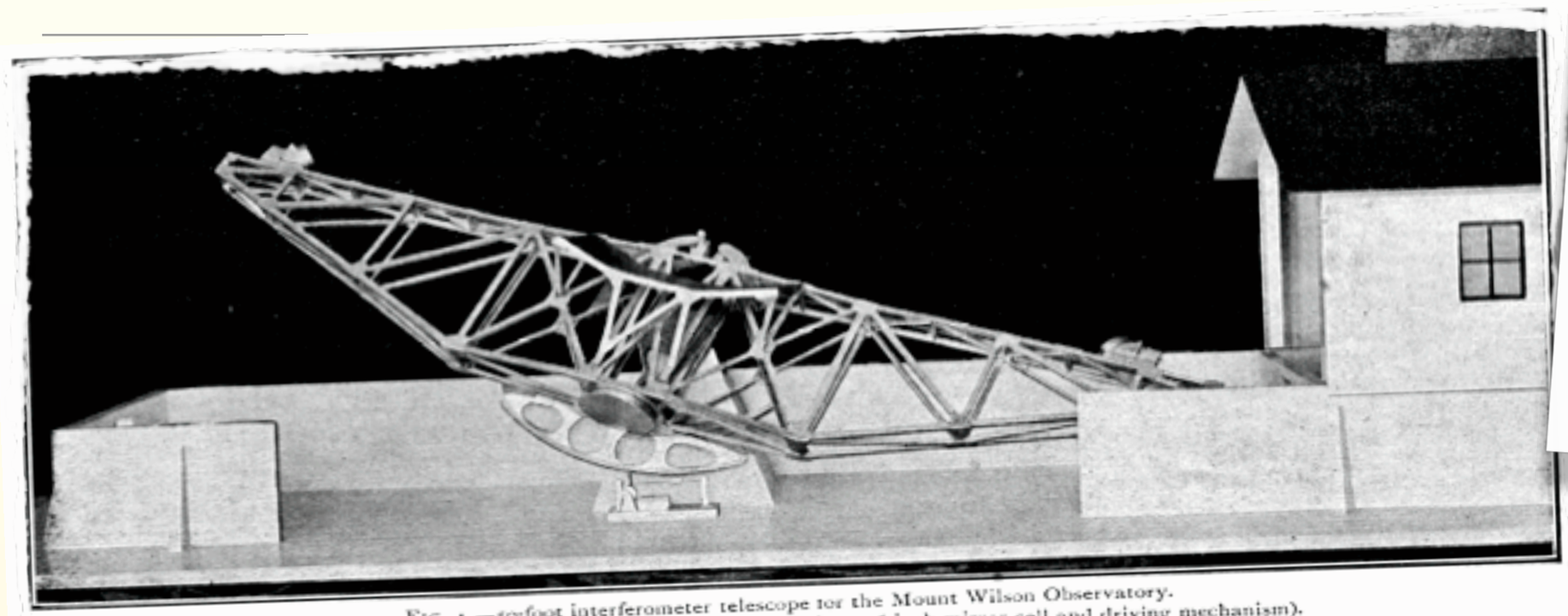

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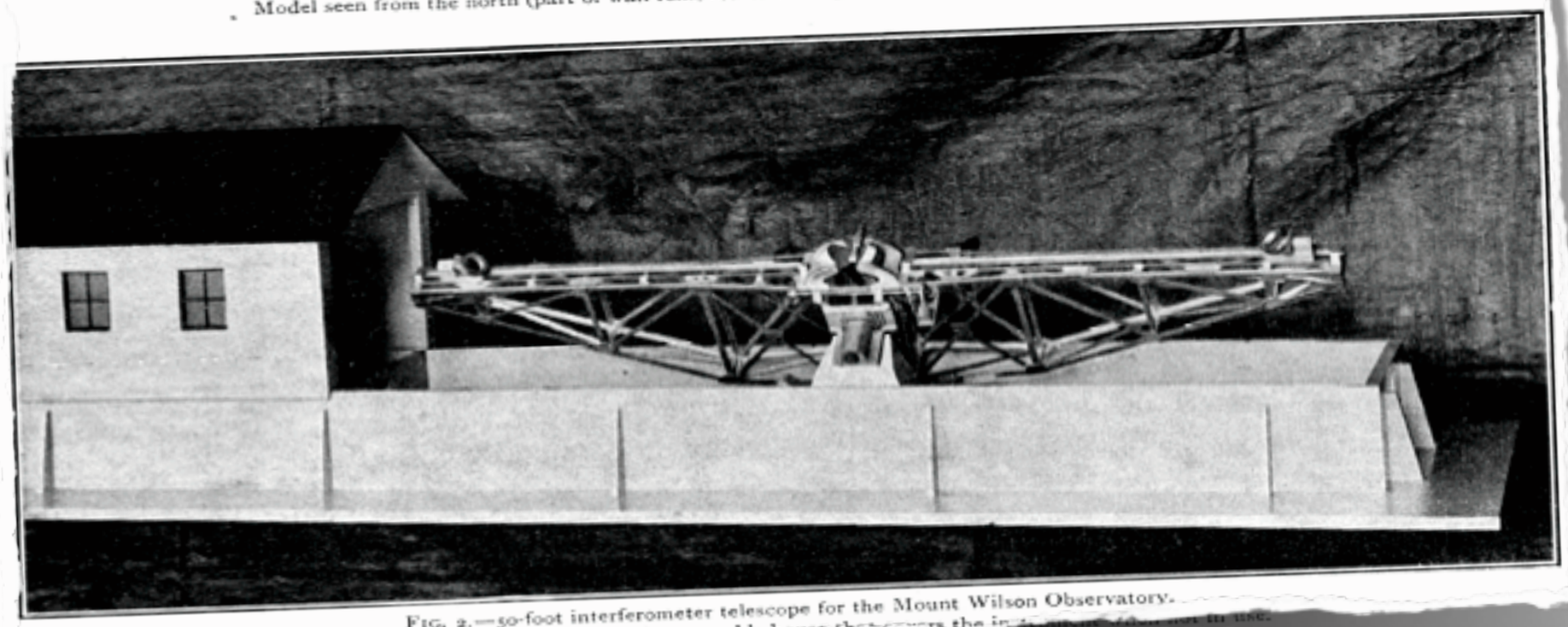

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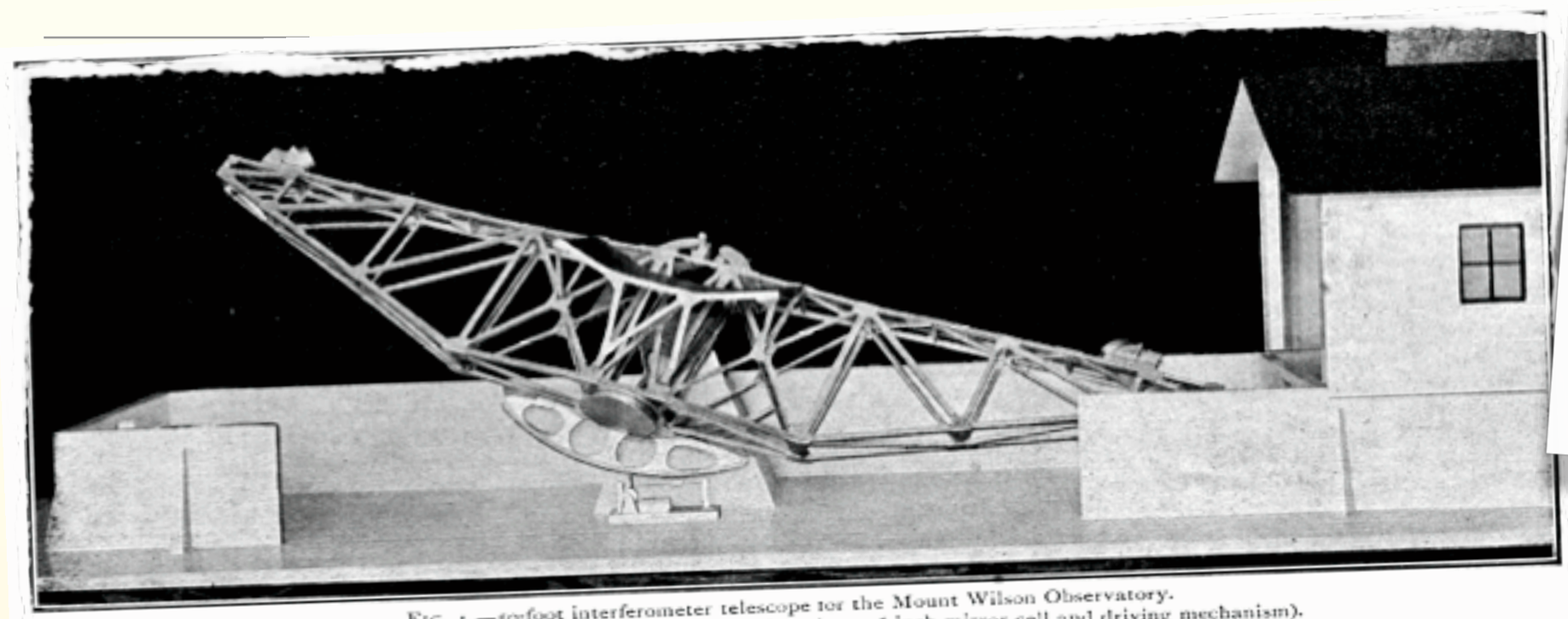

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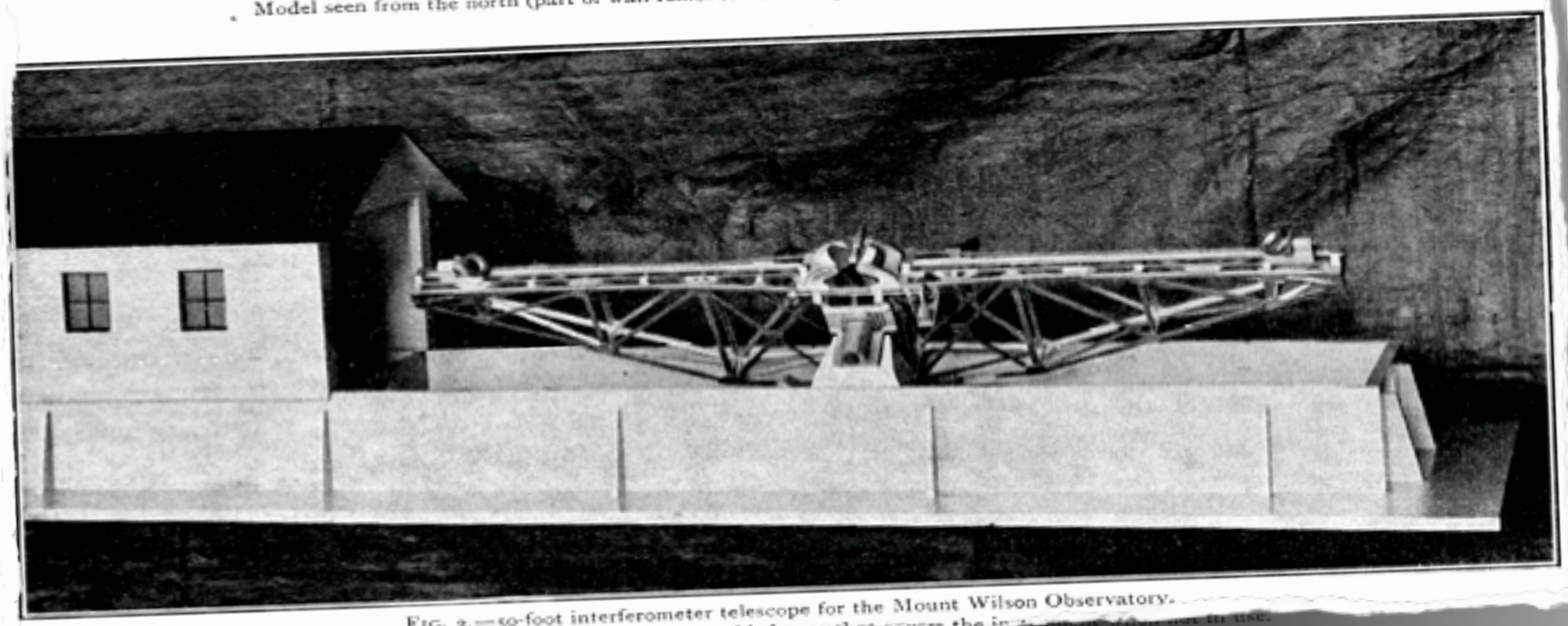

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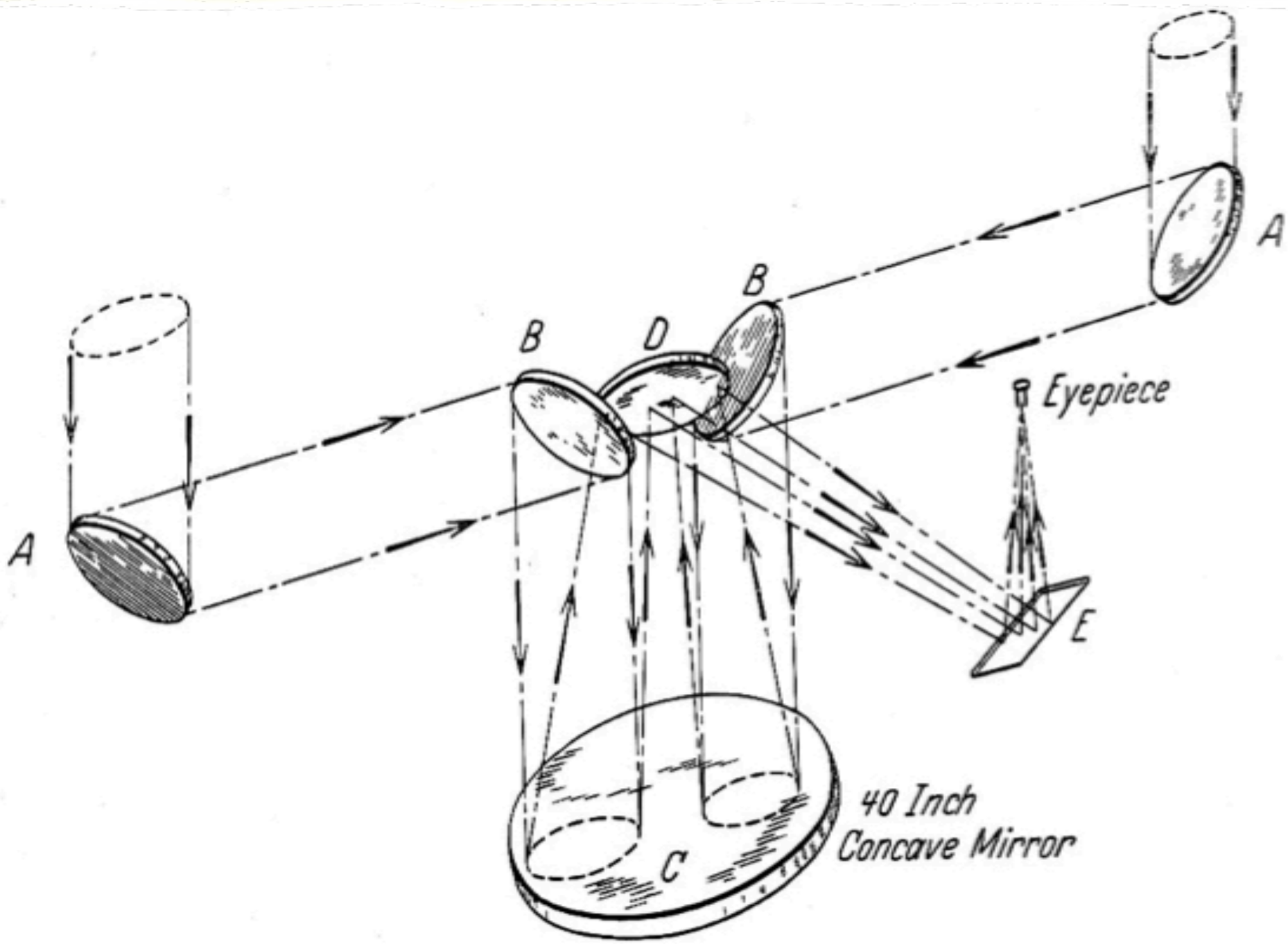
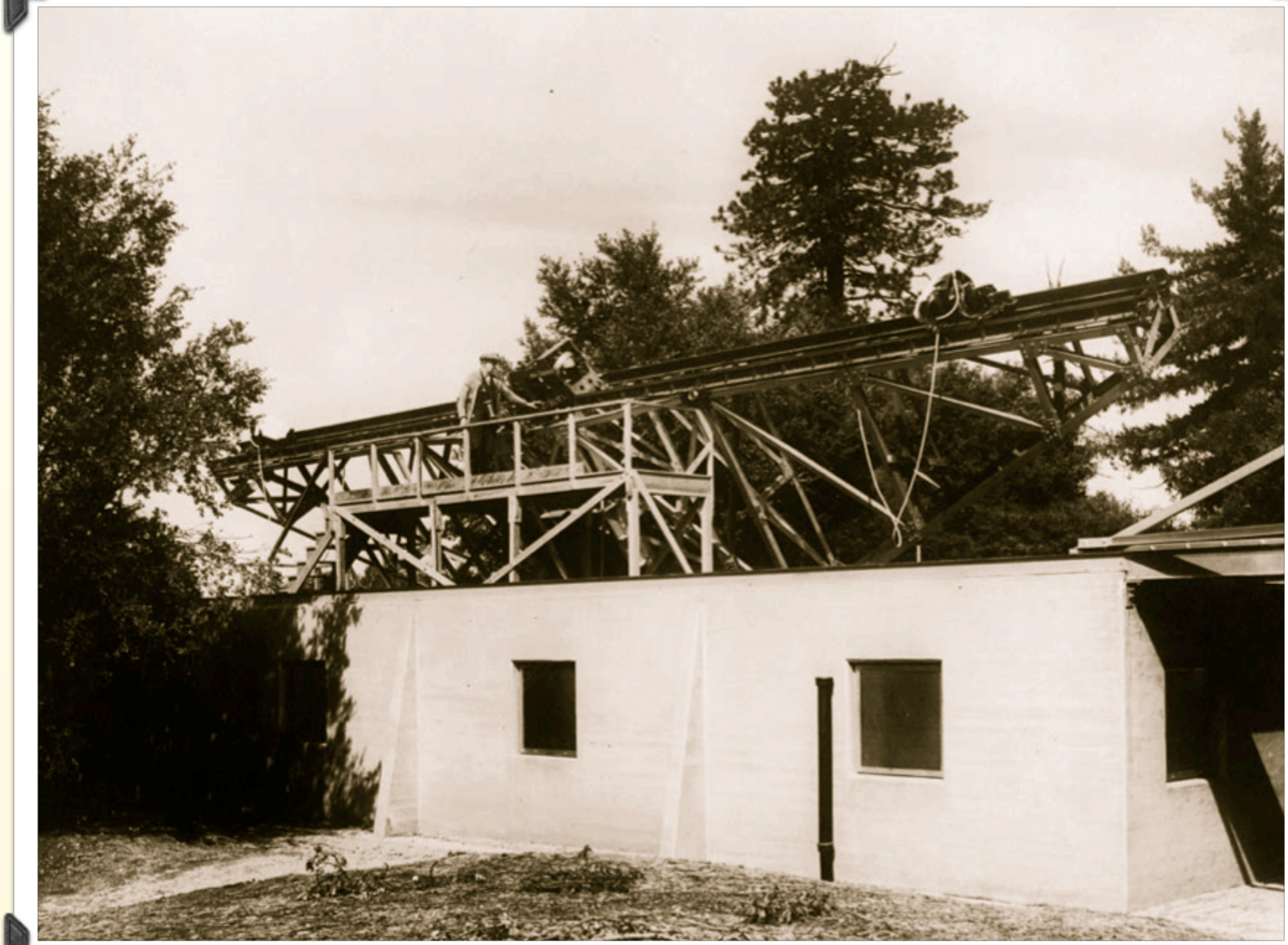
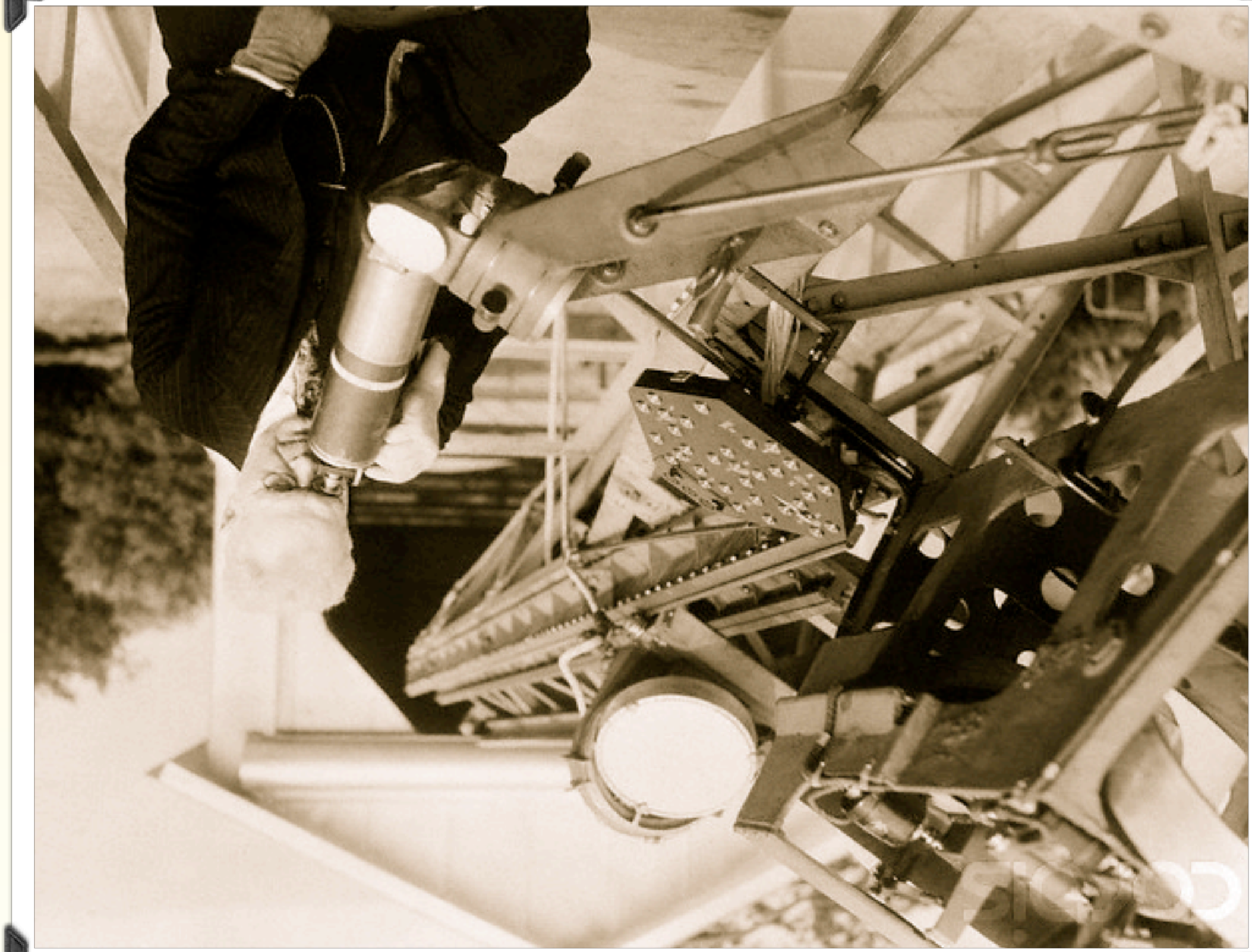
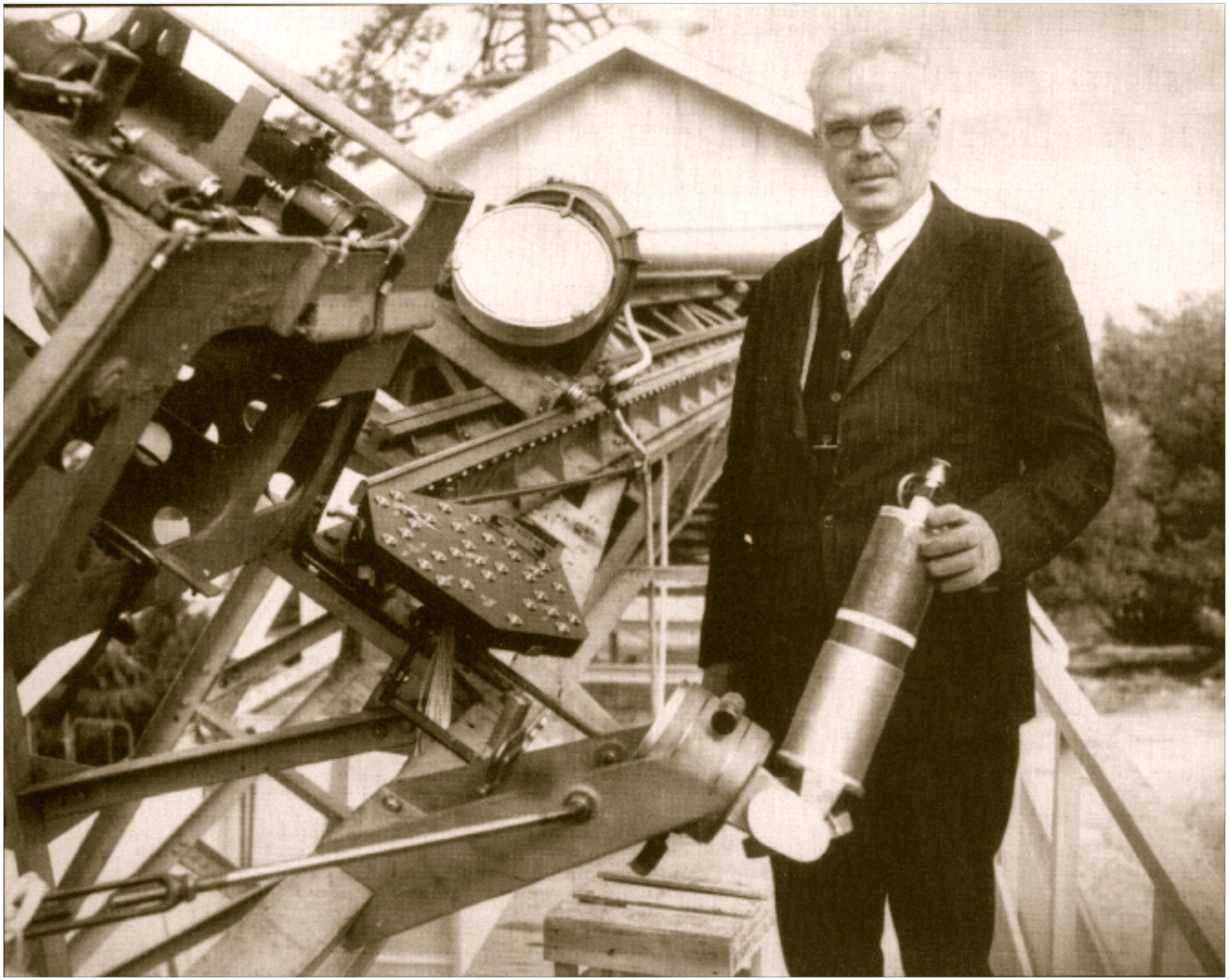
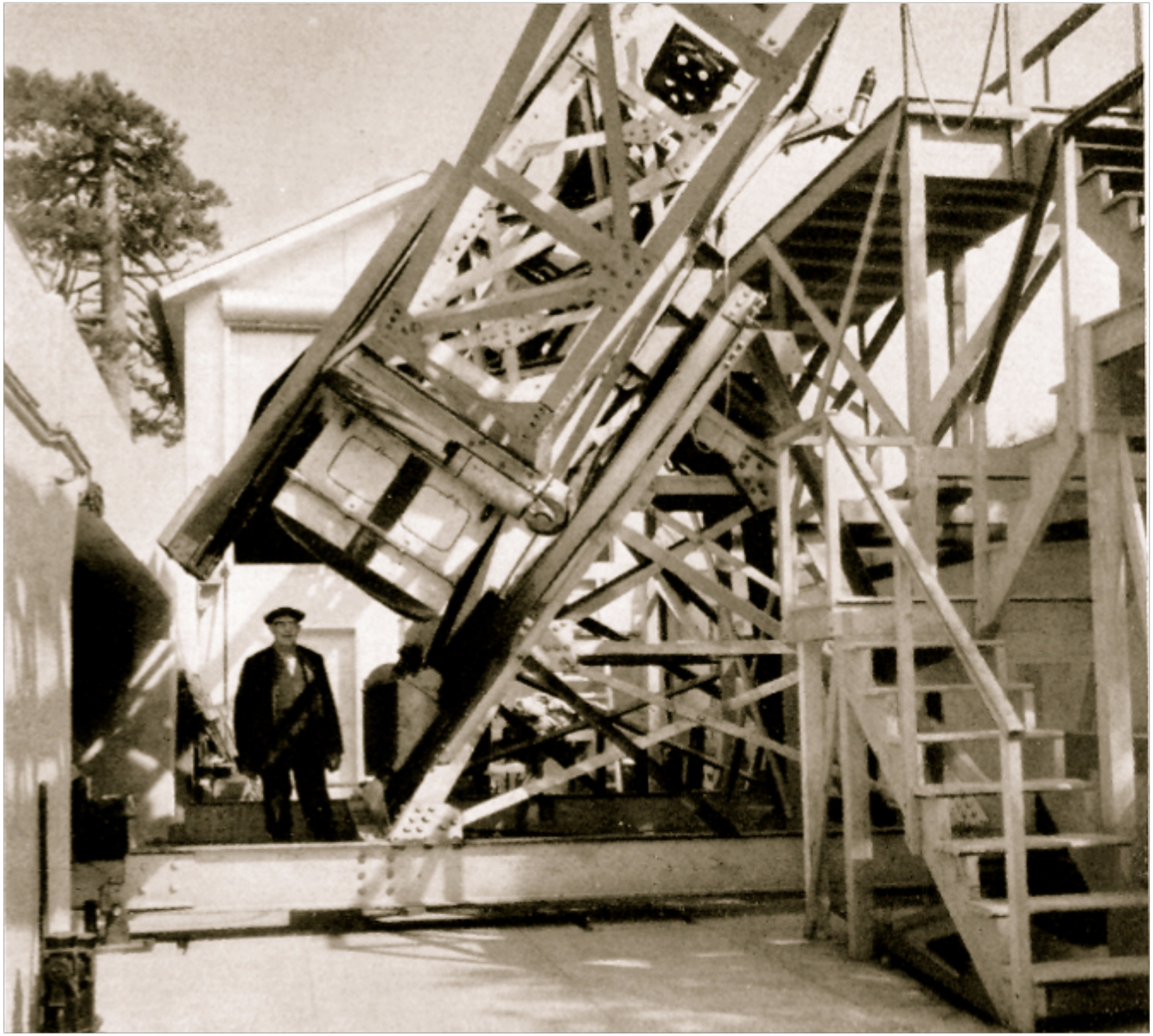


Abb. 8. Diagram of light path in 50 foot interferometer.









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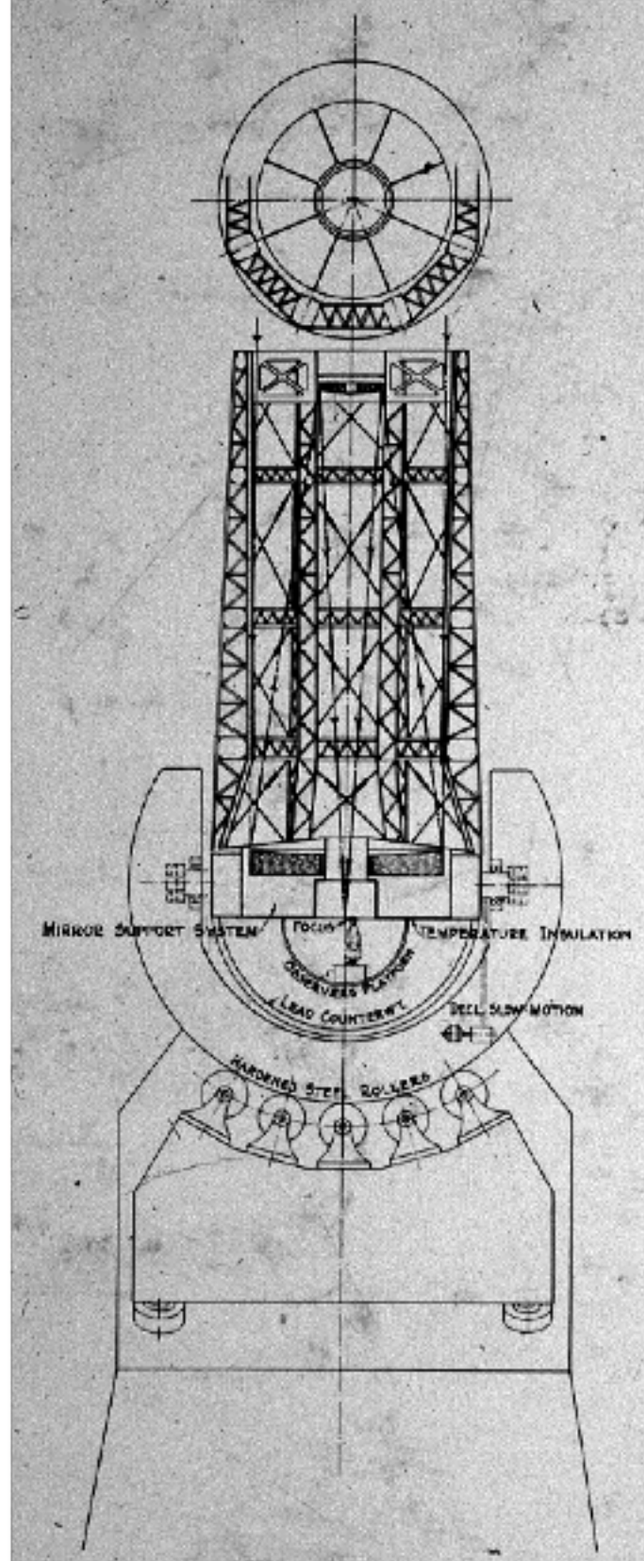
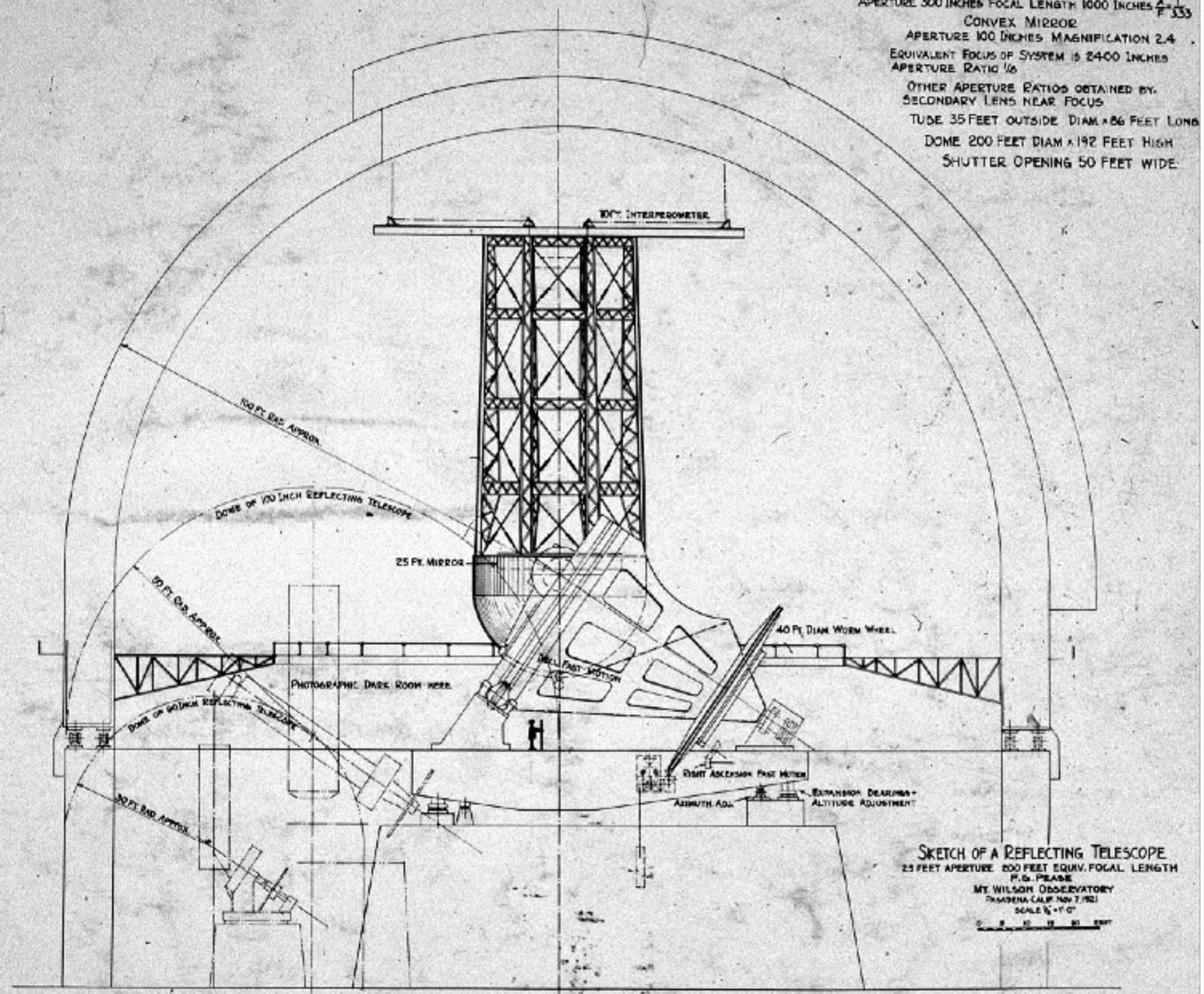
- In 1938, Pease died at age 57 and his interferometer was never used again. It was dismantled in 1978 (but the building is still visible on Mount Wilson).

LARGE MIRROR
APERTURE 300 INCHES FOCAL LENGTH 1000 INCHES $\frac{A}{F} = \frac{1}{3.33}$
CONVEX MIRROR
APERTURE 100 INCHES MAGNIFICATION 2.4
EQUIVALENT FOCUS OF SYSTEM IS 2400 INCHES
APERTURE RATIO 1/8
OTHER APERTURE RATIOS OBTAINED BY SECONDARY LENS NEAR FOCUS
TUBE 35 FEET OUTSIDE DIAM. × 86 FEET LONG
DOME 200 FEET DIAM × 192 FEET HIGH
SHUTTER OPENING 50 FEET WIDE



VIEW LOOKING DOWN POLAR AXIS



SIDE ELEVATION

SKETCH OF A REFLECTING TELESCOPE
25 FEET APERTURE 200 FEET EQUIV. FOCAL LENGTH
F. G. PEASE
MT. WILSON OBSERVATORY
PASADENA, CALIF. NOV. 7, 1921
SCALE 1/8" = 1'-0"

The «middle-ages» of astronomical interferometry

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- The 50-ft interferometer was a major investment, and its poor results led to a four decades long «desert crossing» period for optical interferometry.

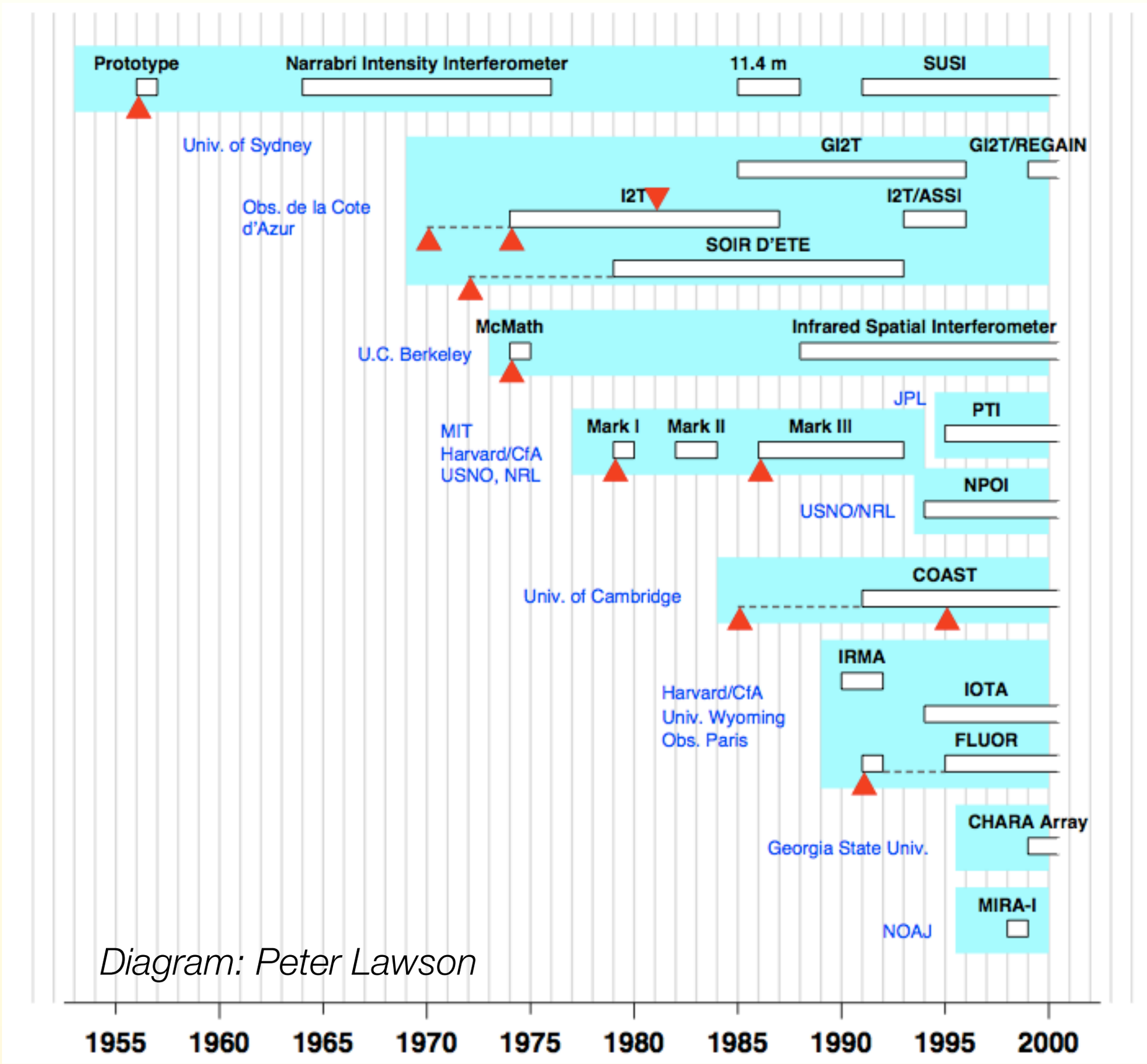
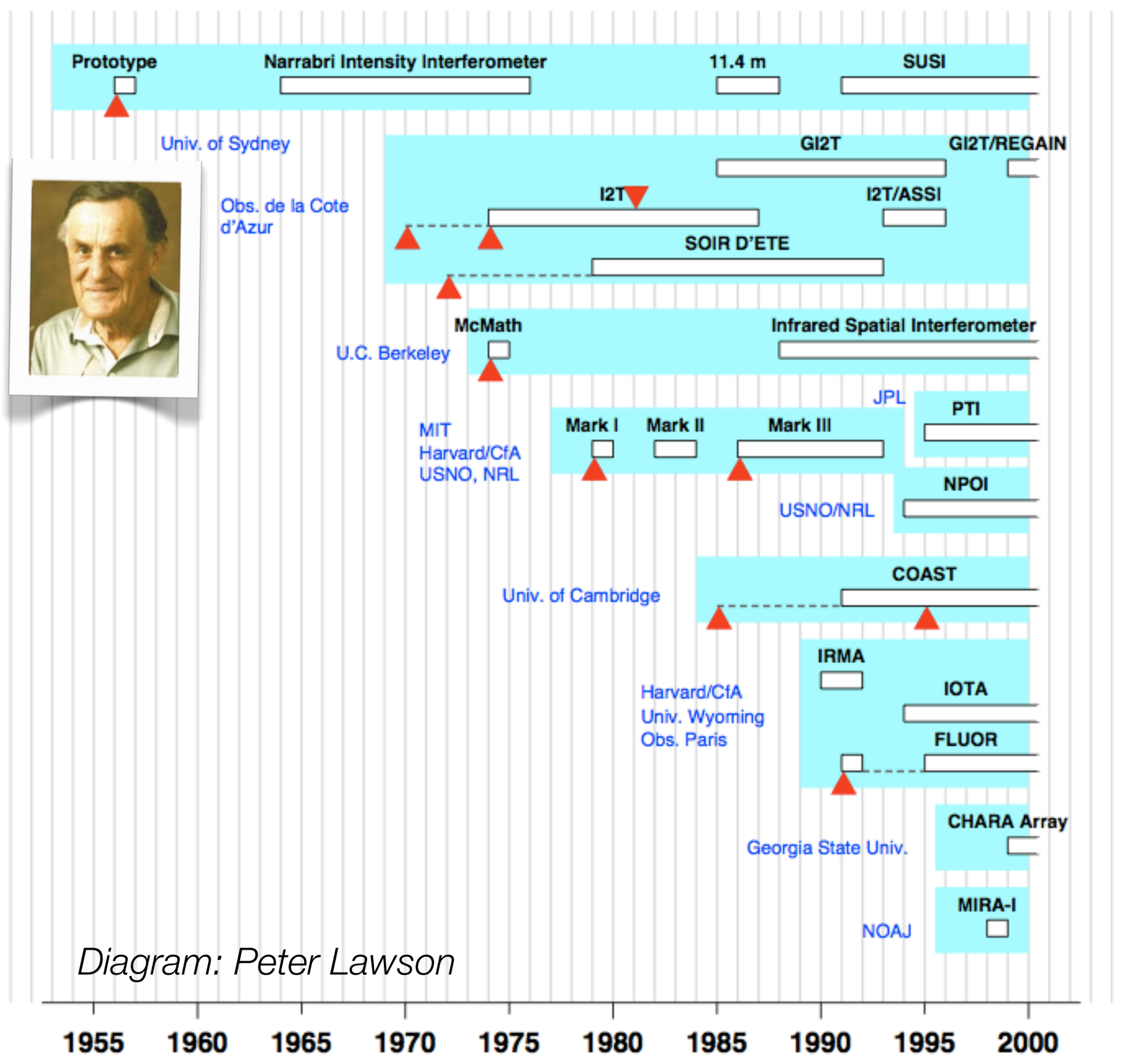


Diagram: Peter Lawson

- **After WW2**: from radio to optical: renaissance



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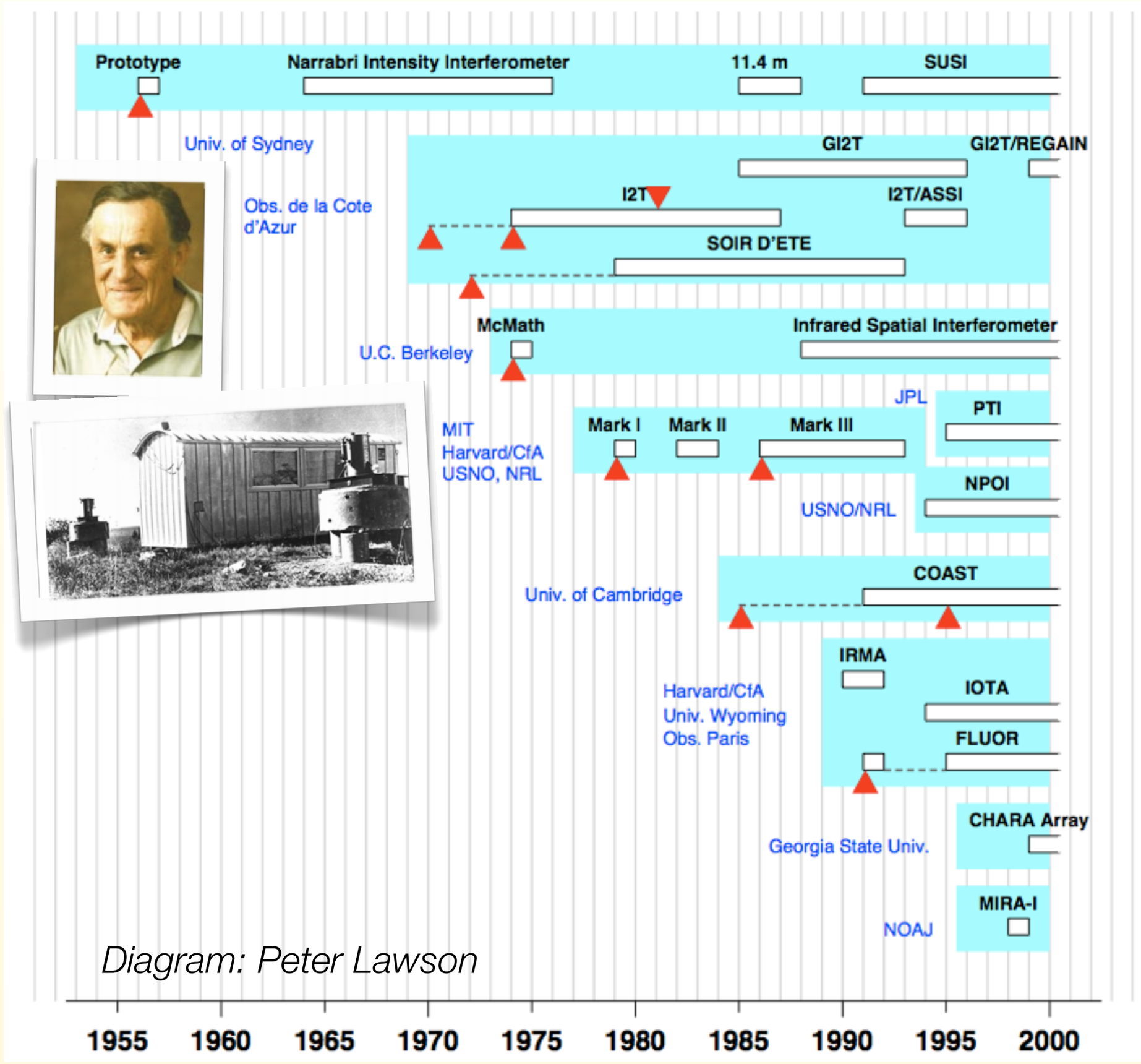

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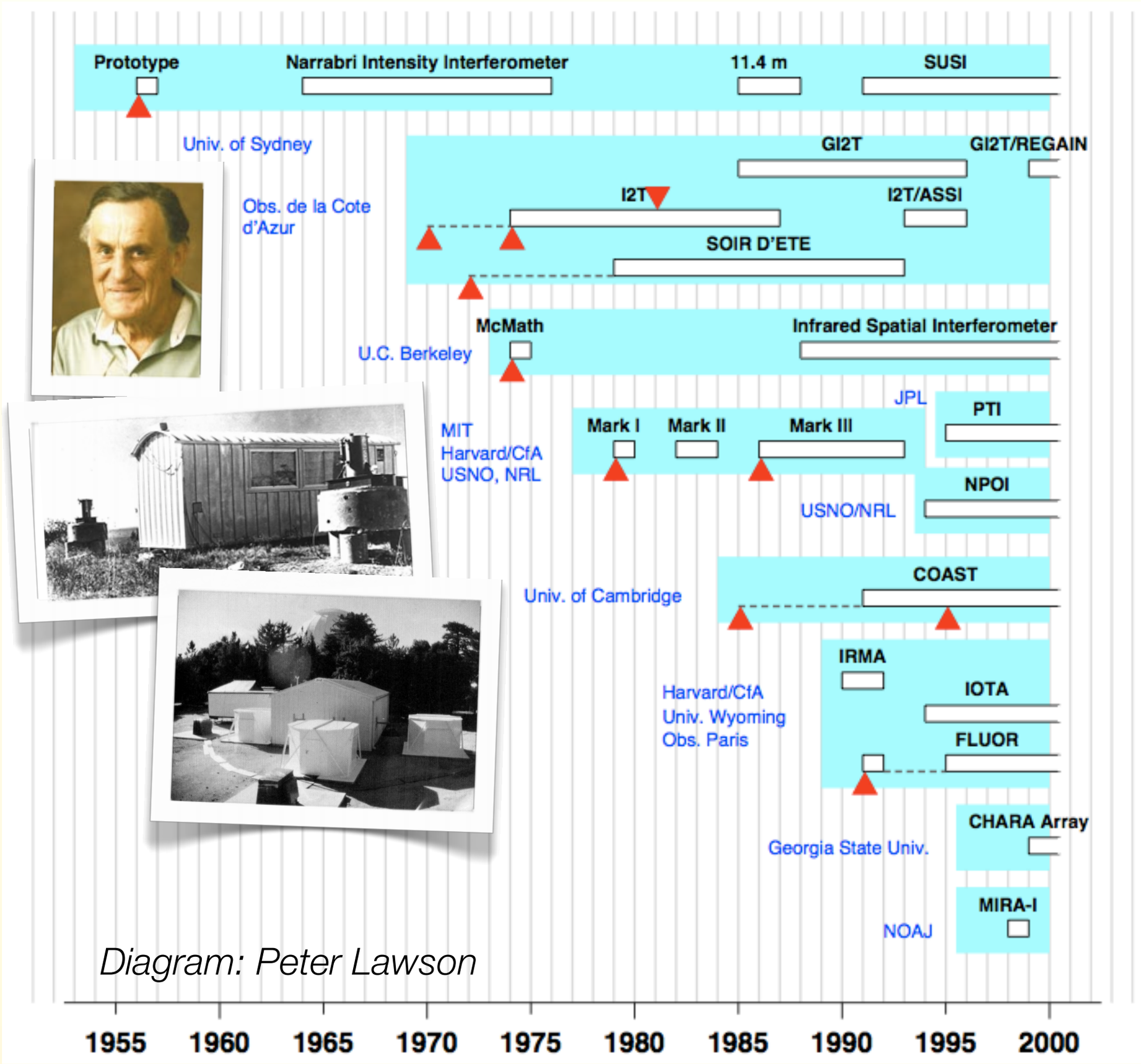

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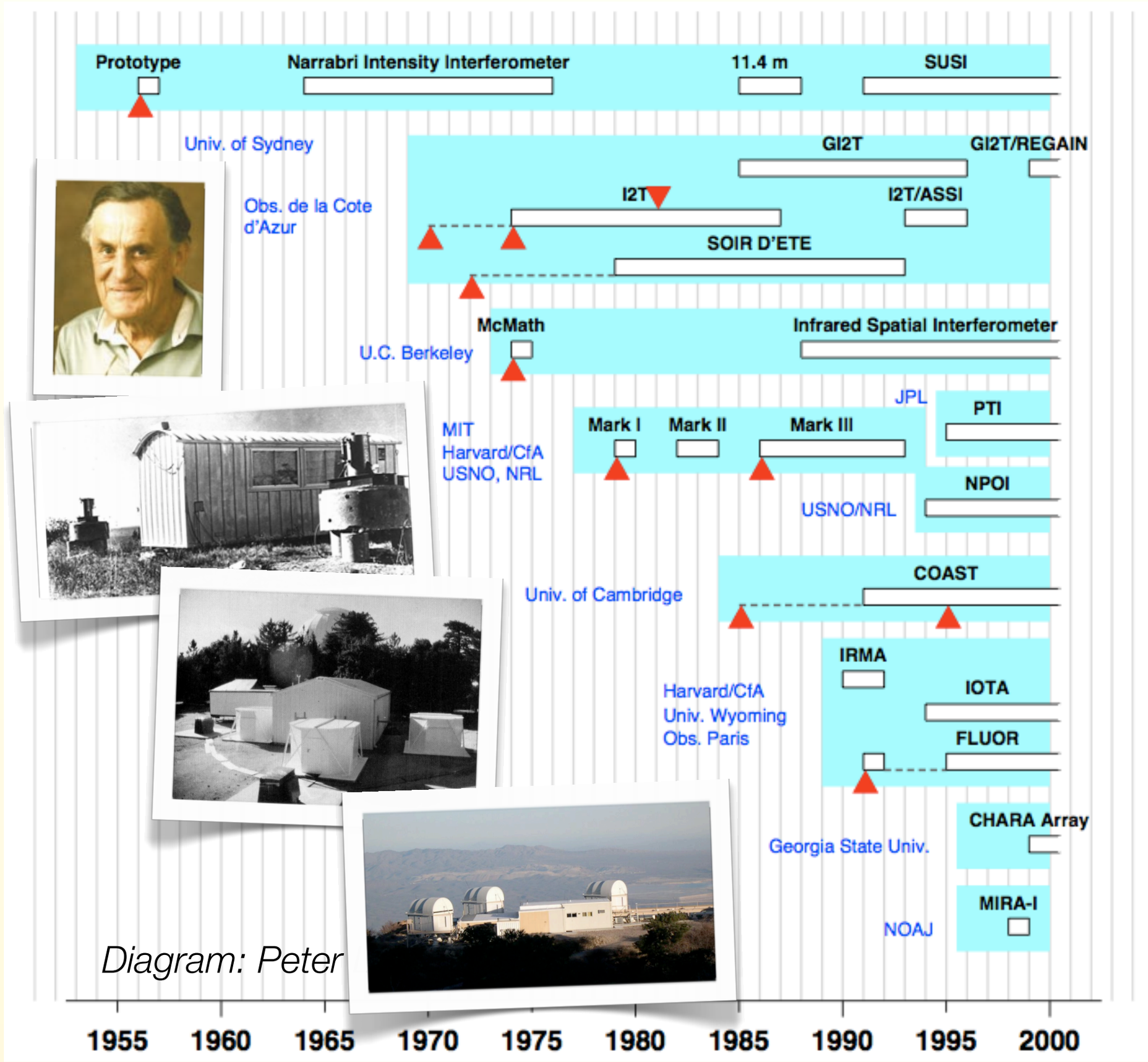

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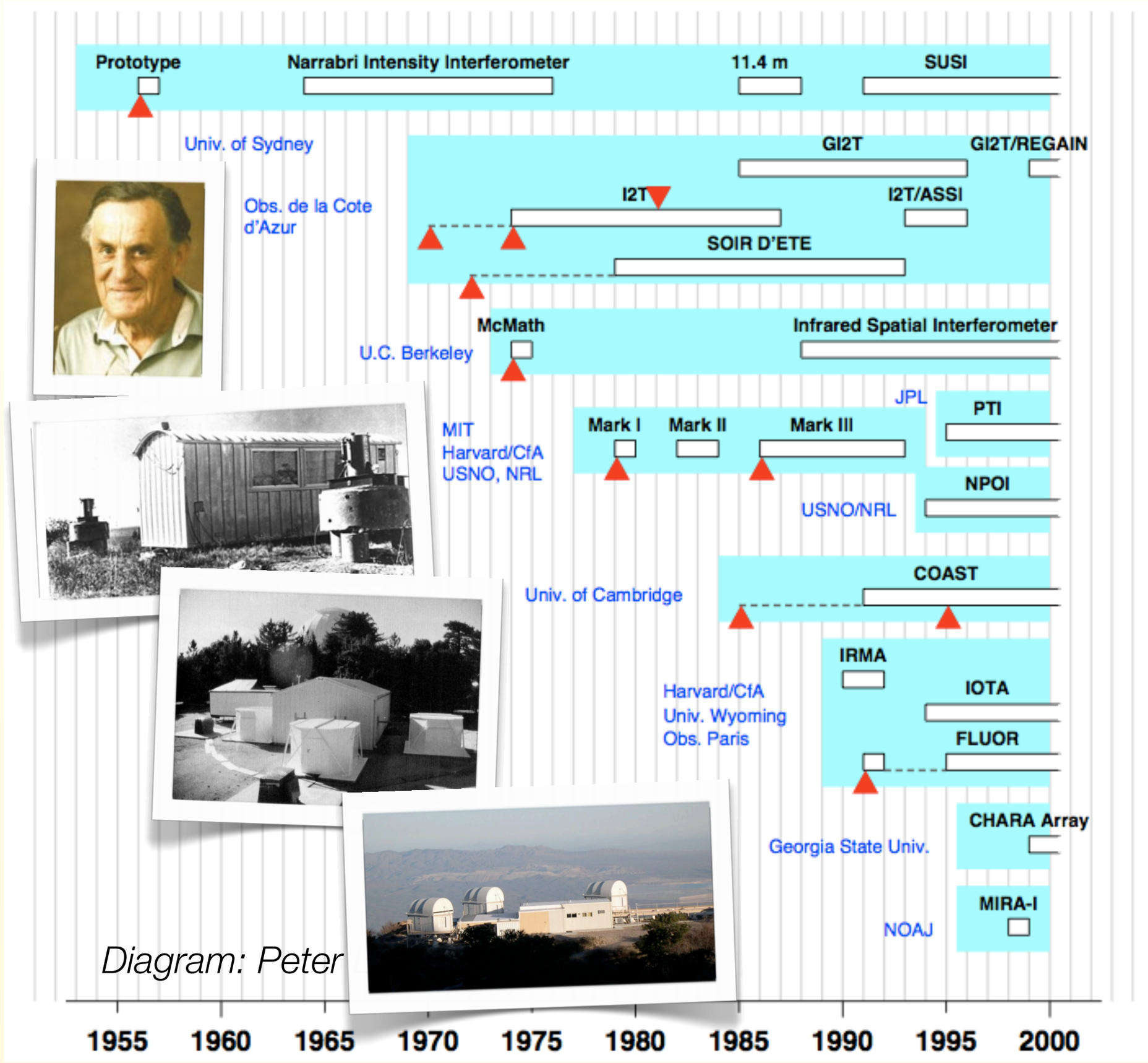

Renaissance: the Intensity Interferometer

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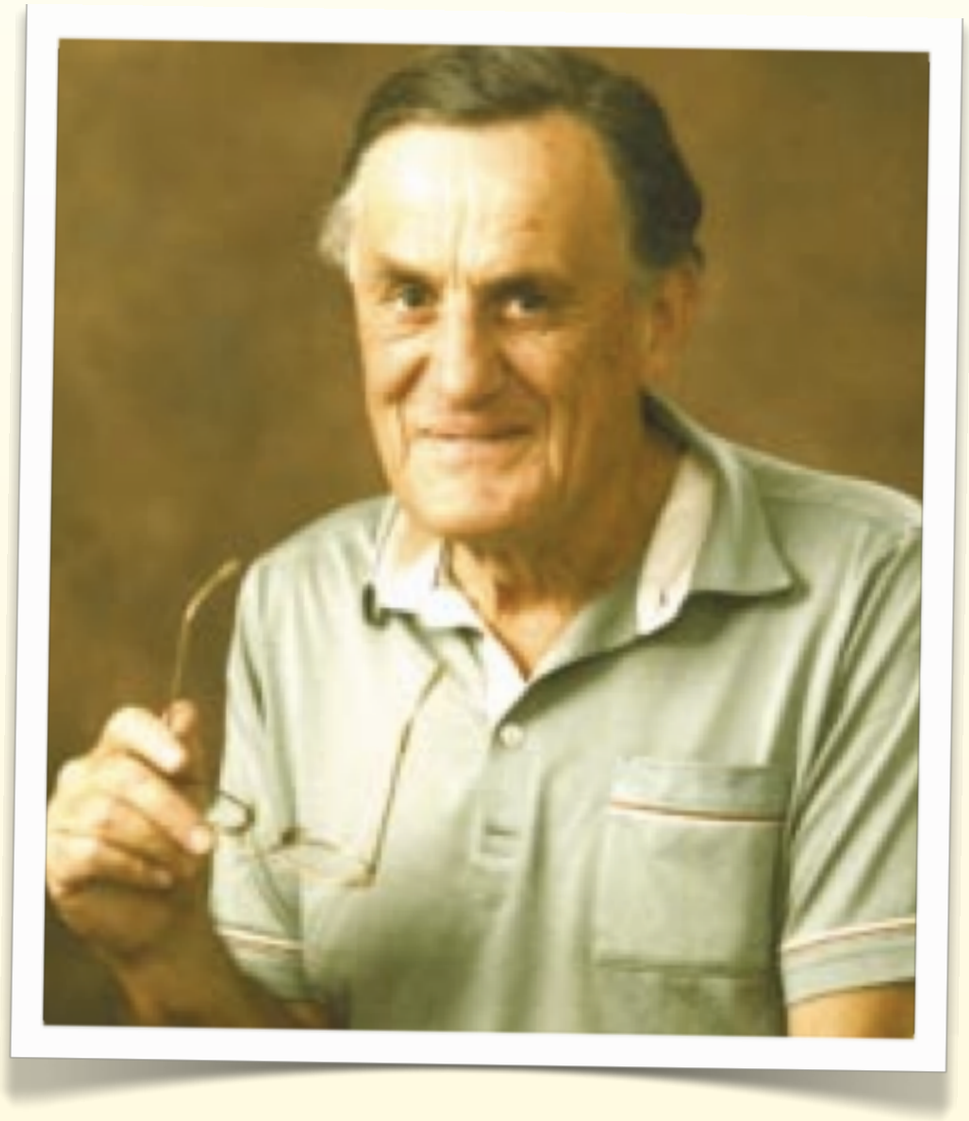

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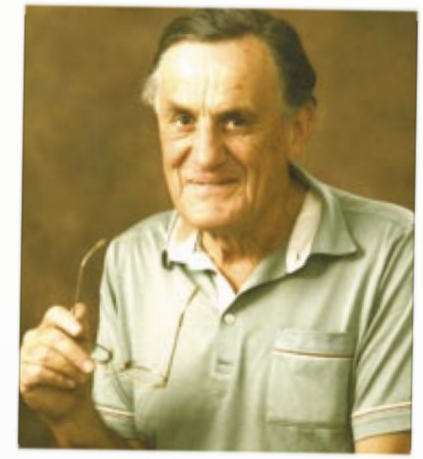

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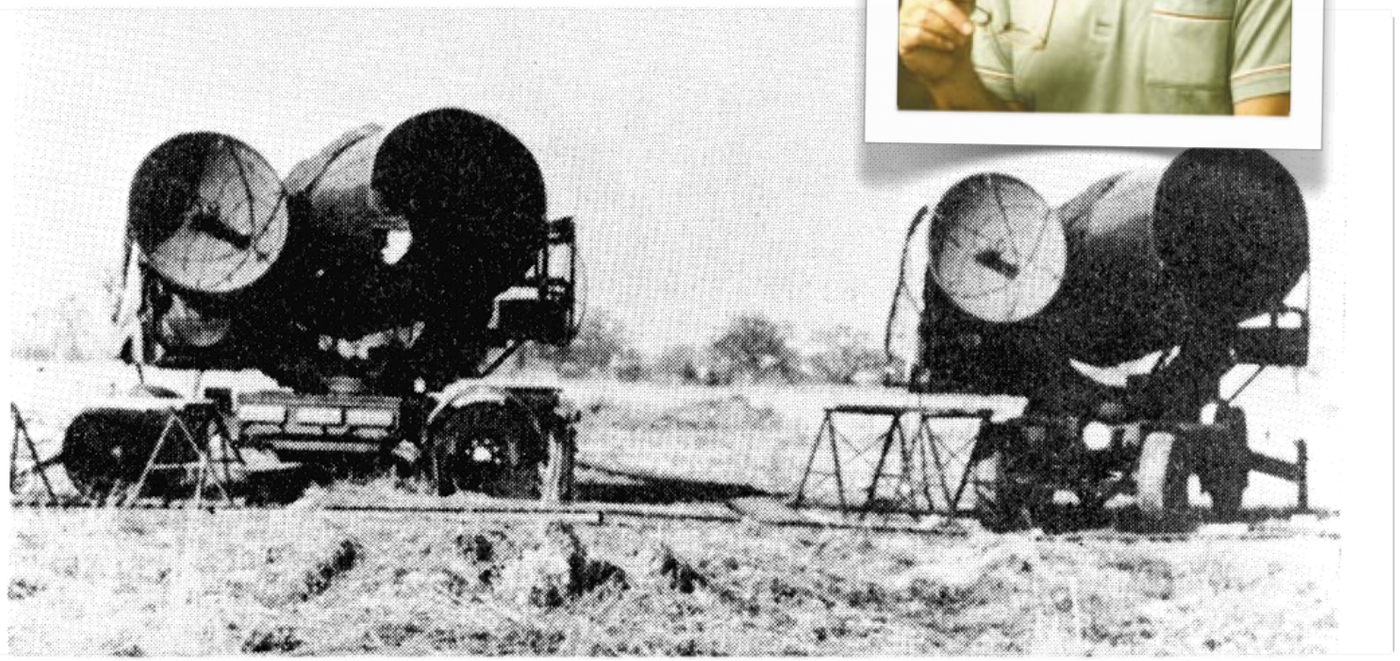

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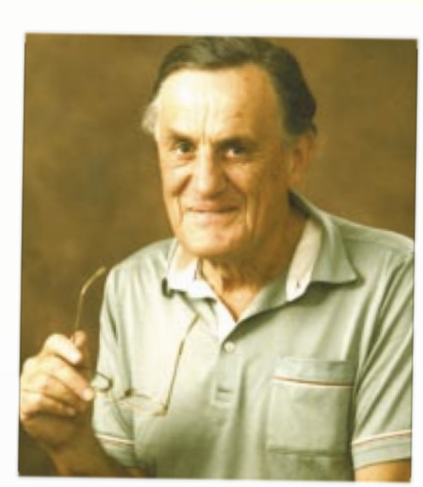

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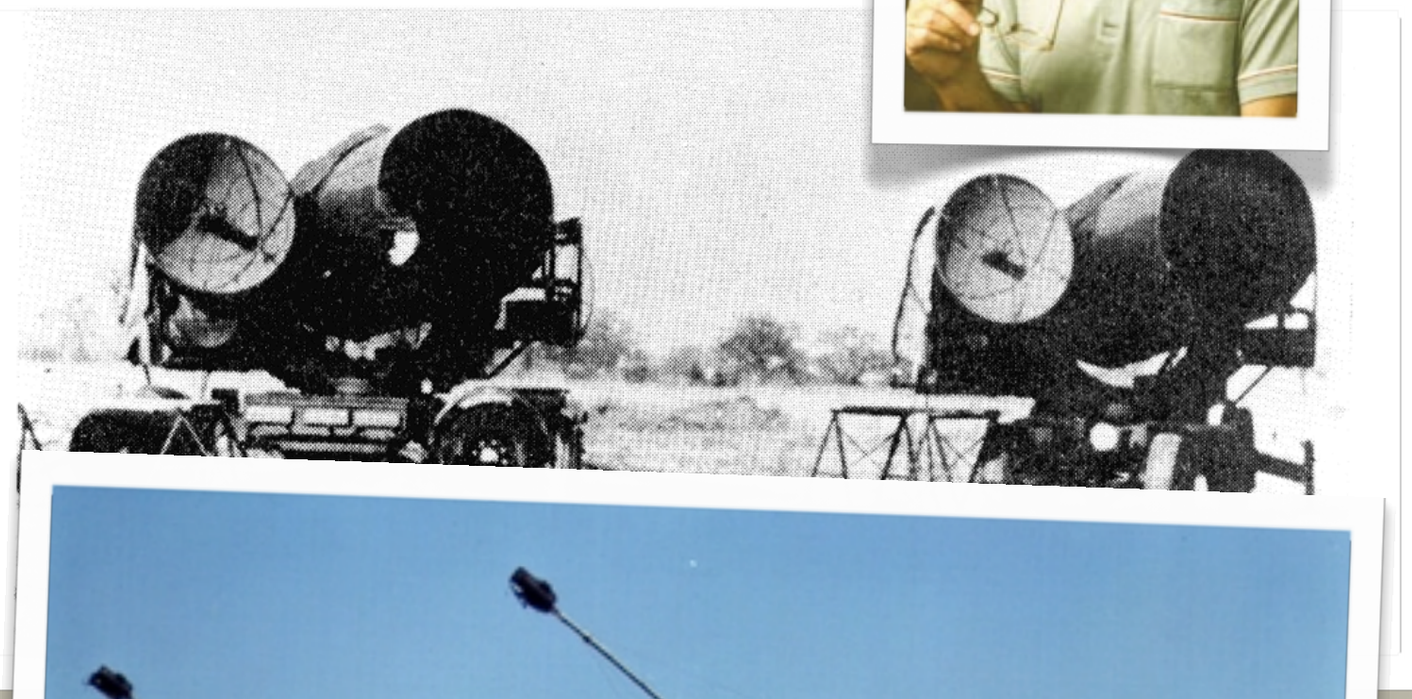

- Simple and reliable experimental setup, but limited to bright and blue stars

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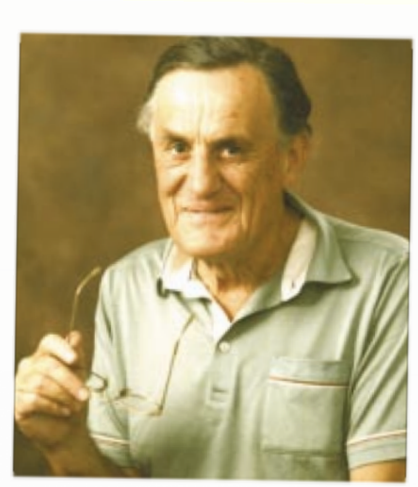

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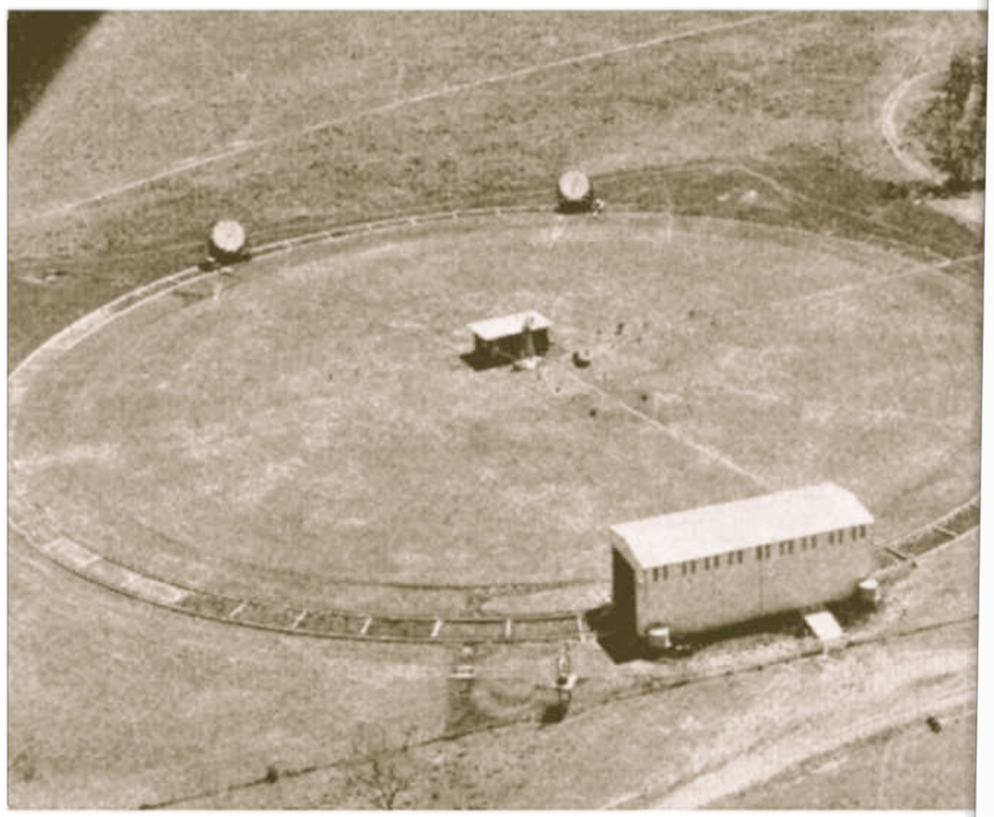
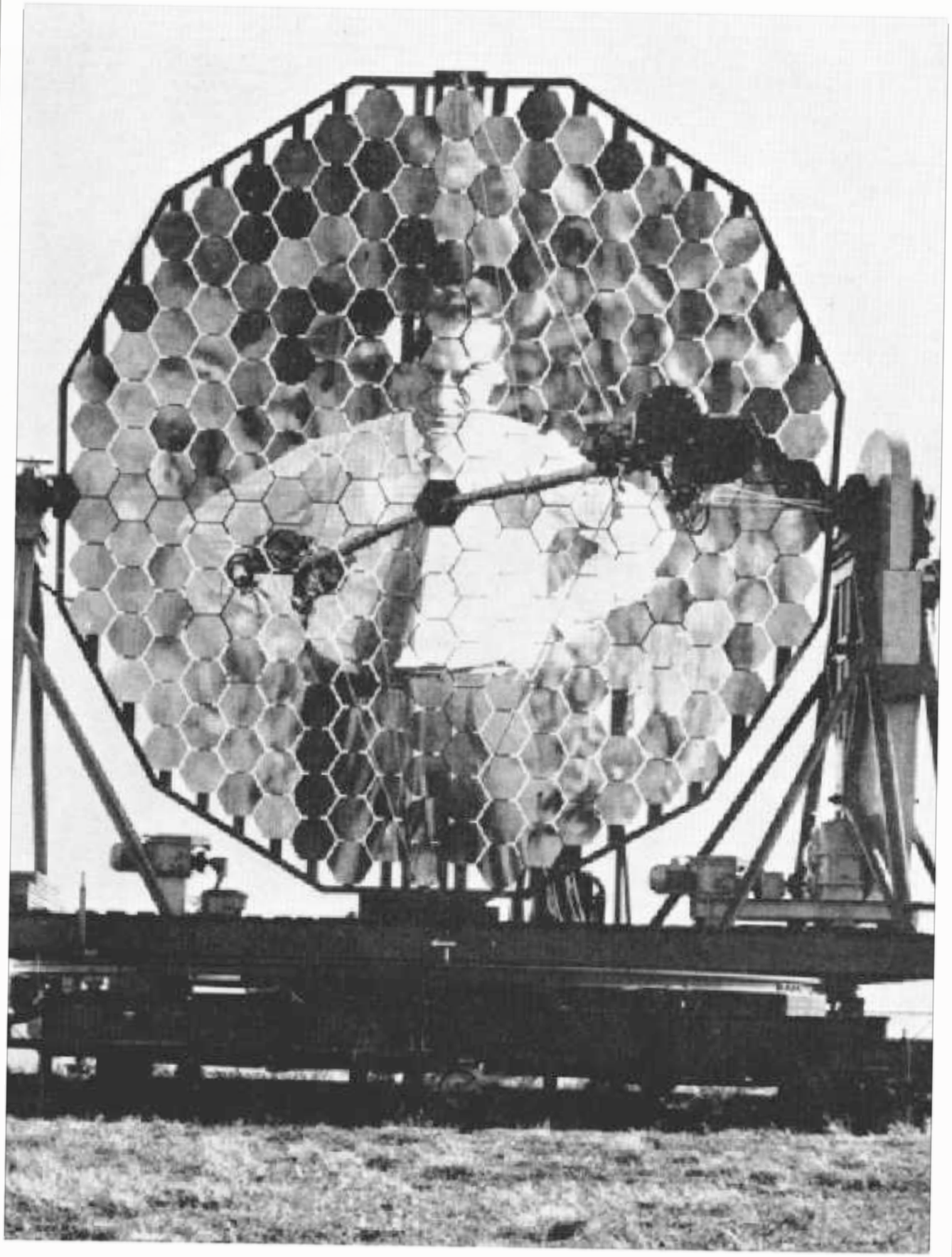
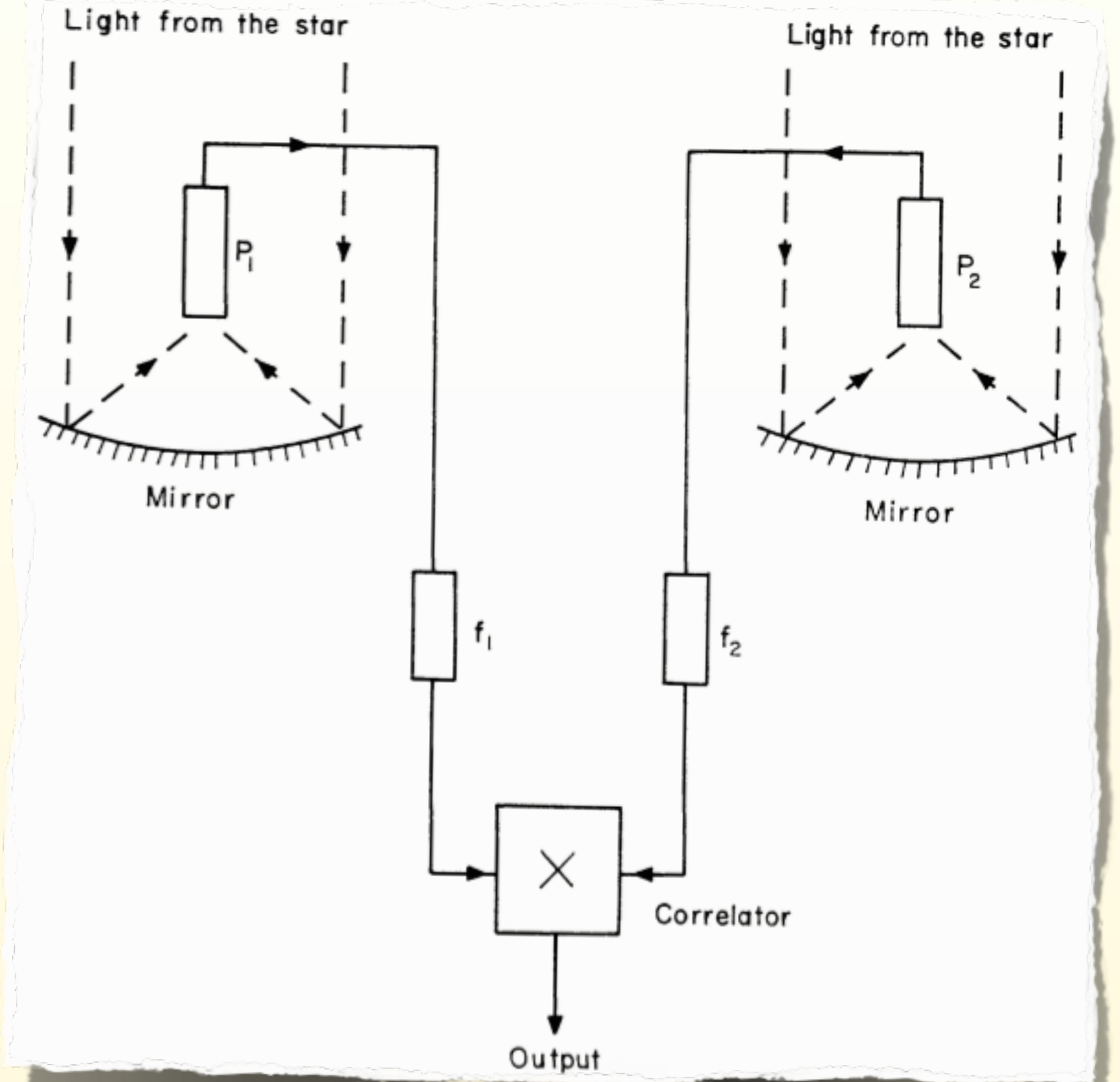
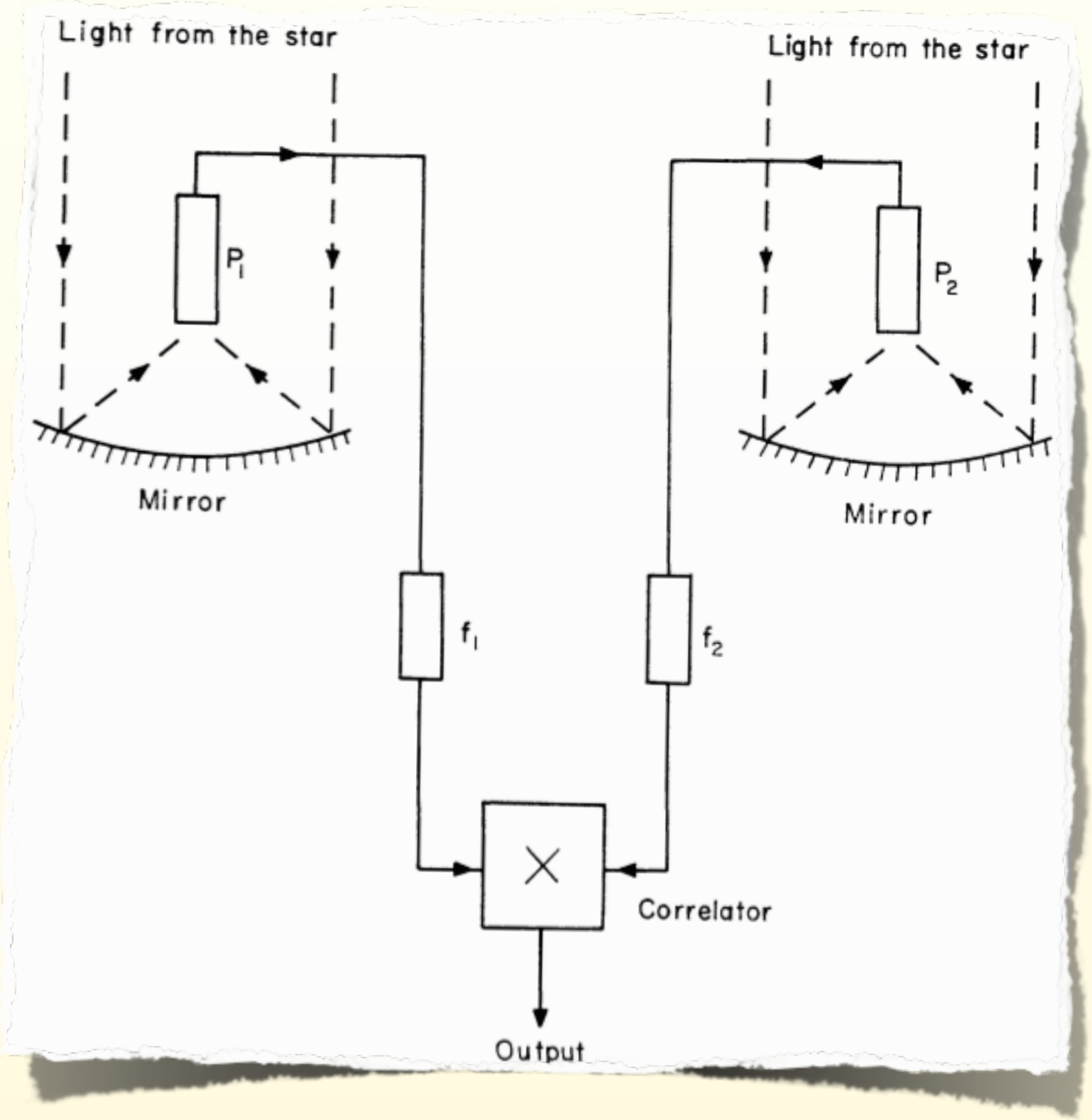
- Revival of intensity interferometry under study today for use with Cerenkov telescope arrays






Light from the star
Light from the star
P1
P2
Mirror
Mirror
f1
f2
Correlator
Output

- Photomultipliers P1 and P2 count the photons arriving on each of the two apertures



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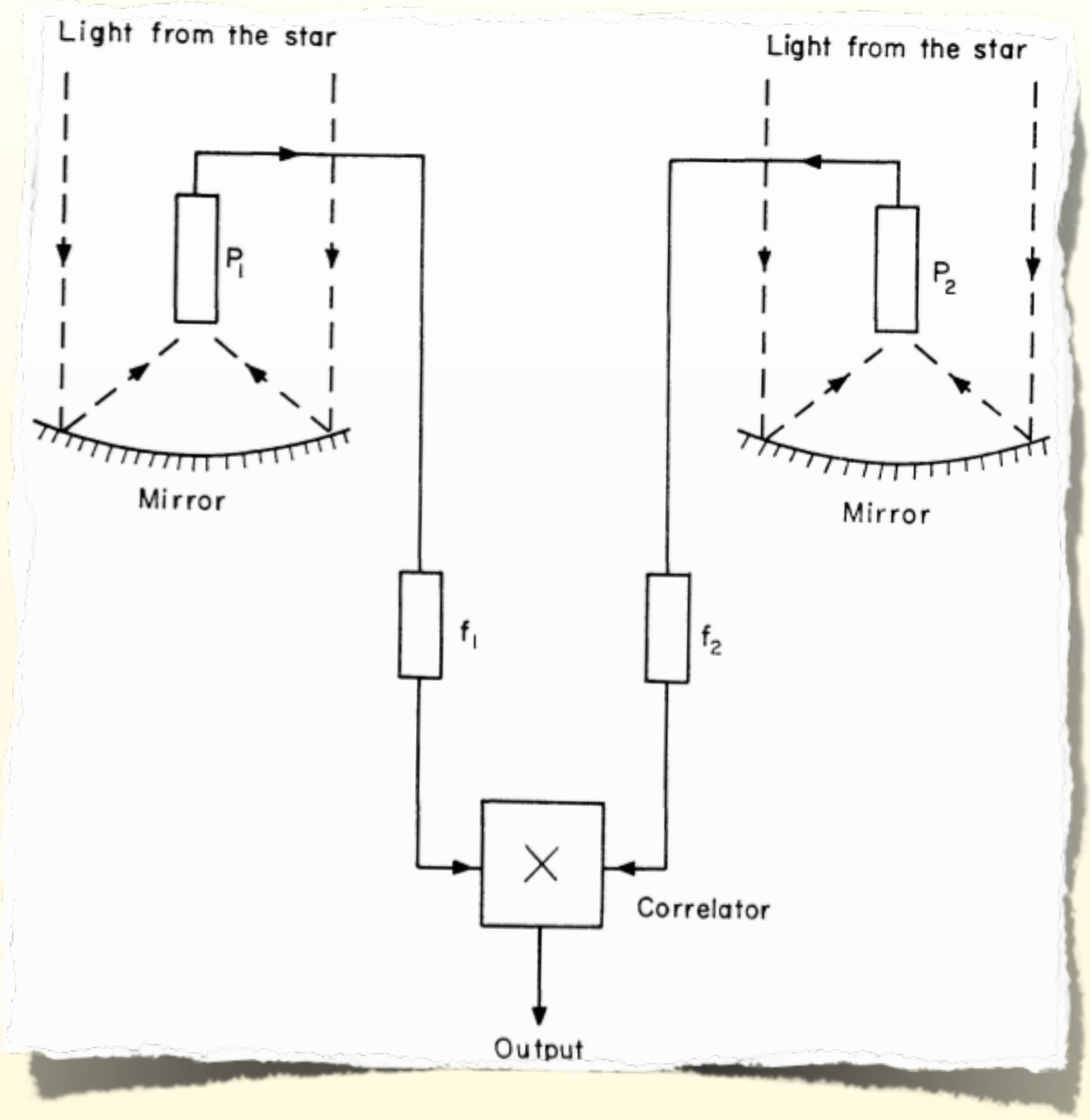

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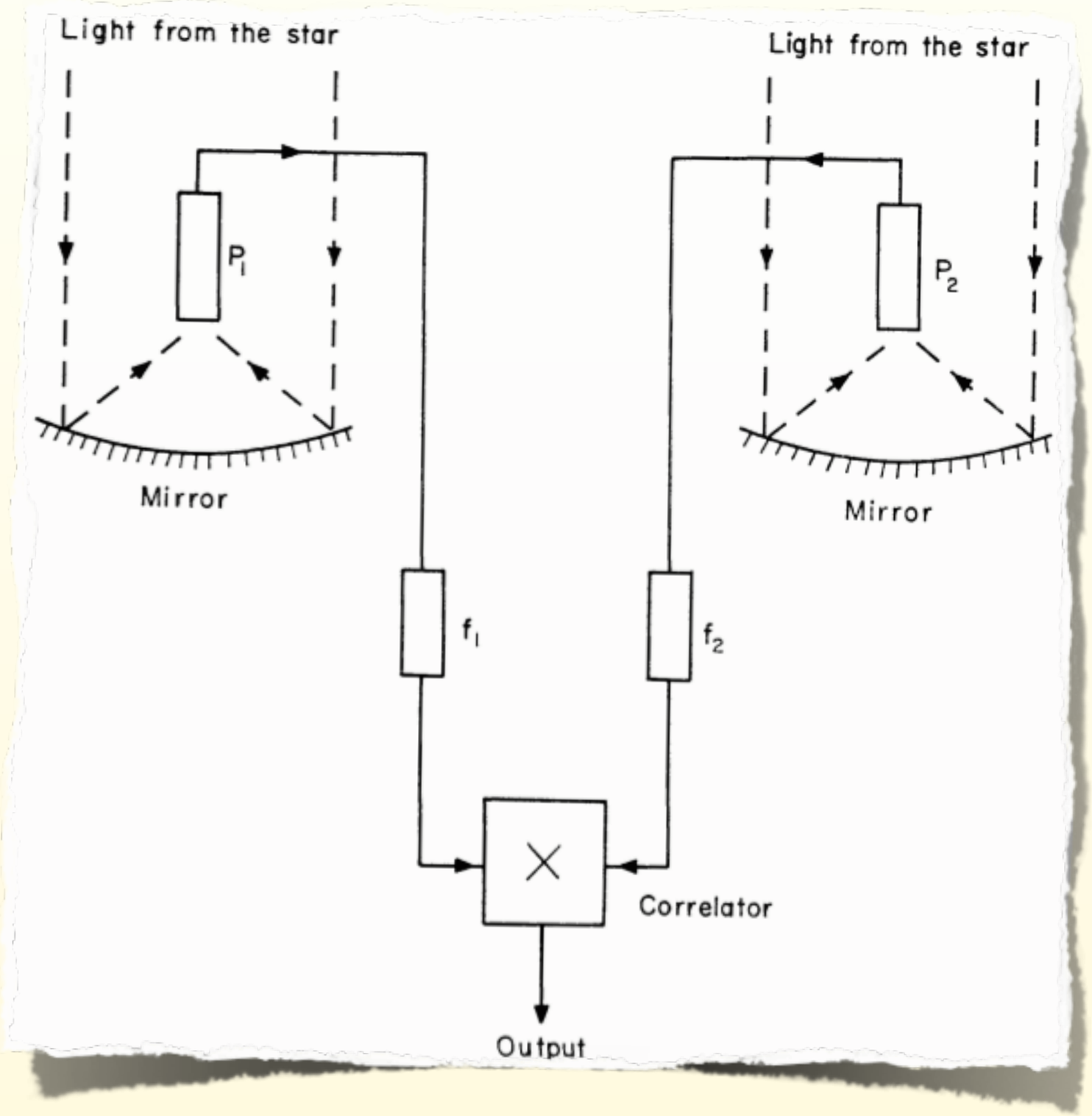

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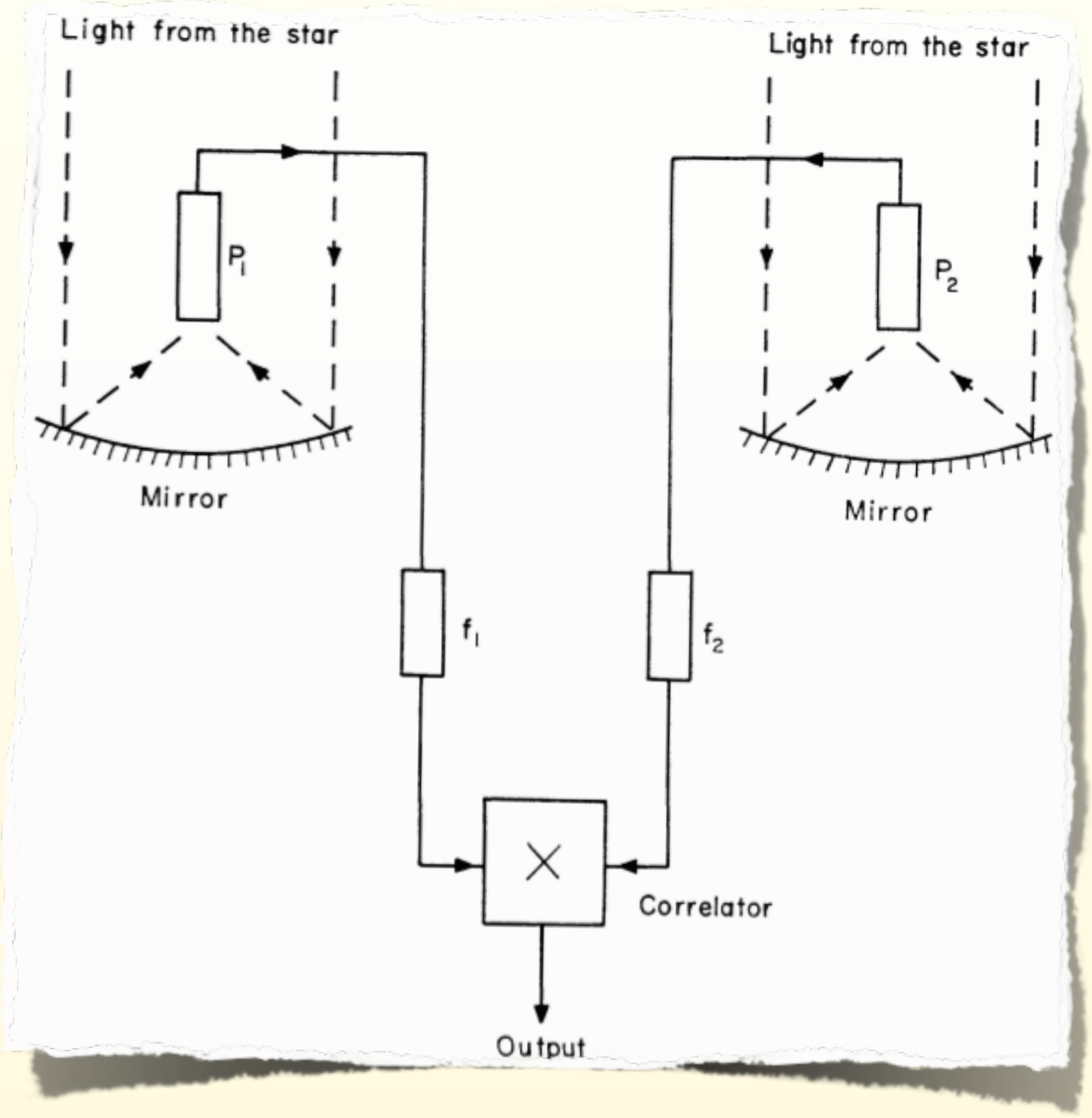
- Angular diameters of 32 stars measured with the NII (published in 1974)



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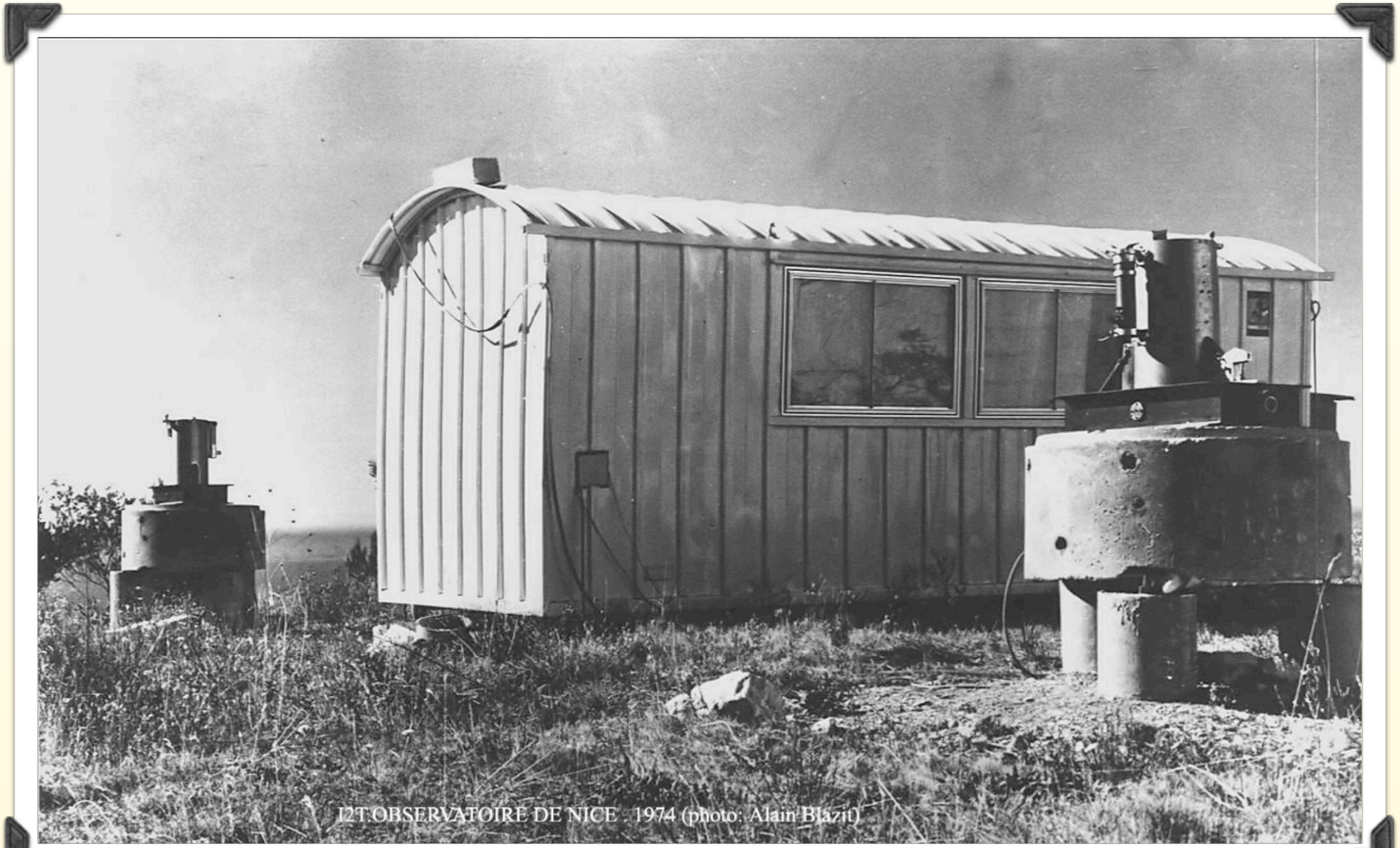
Labeyrie’s two-telescope interferometer



I2T.OBSERVATOIRE DE NICE . 1974 (photo: Alain Blazit)

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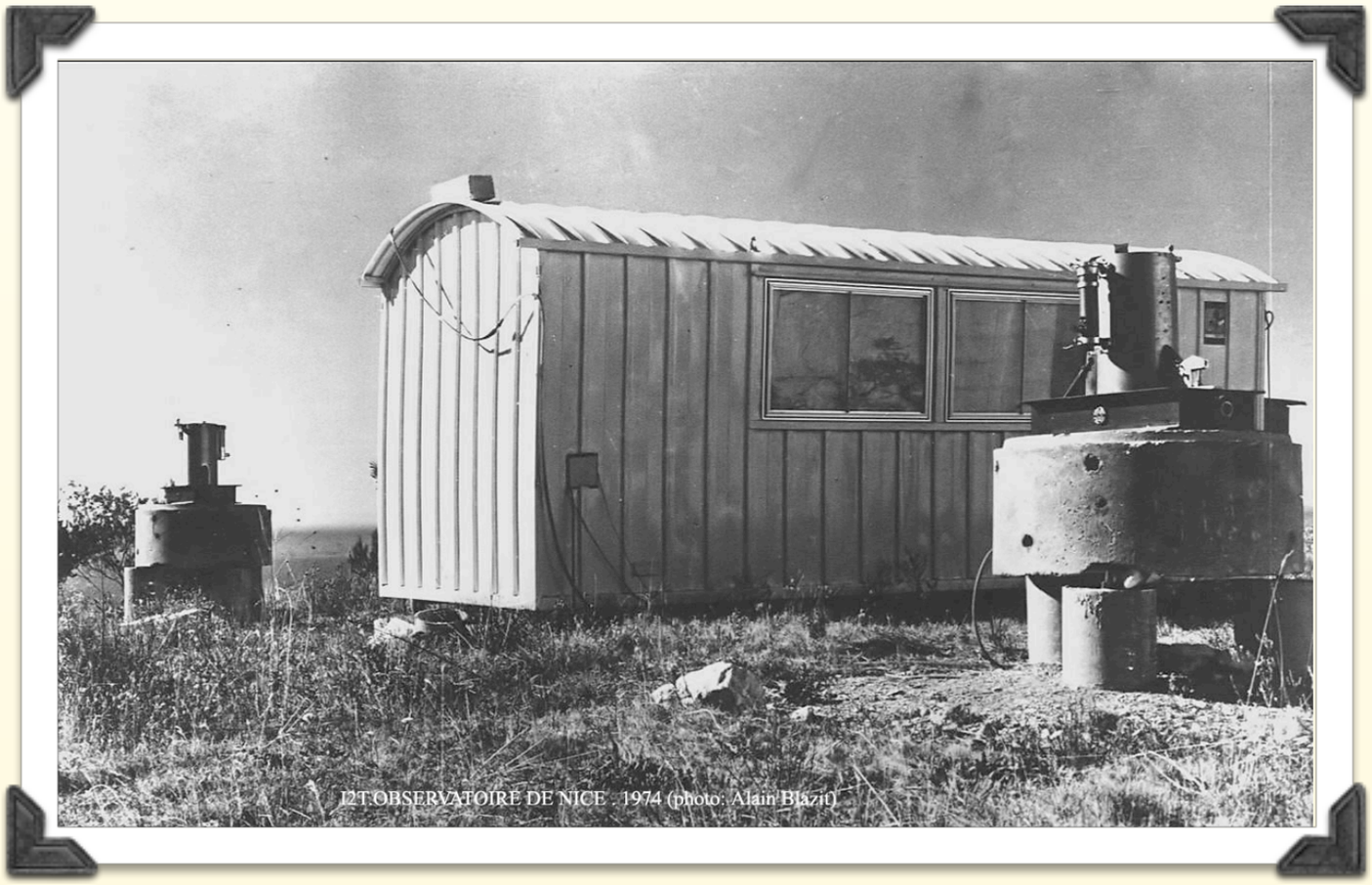

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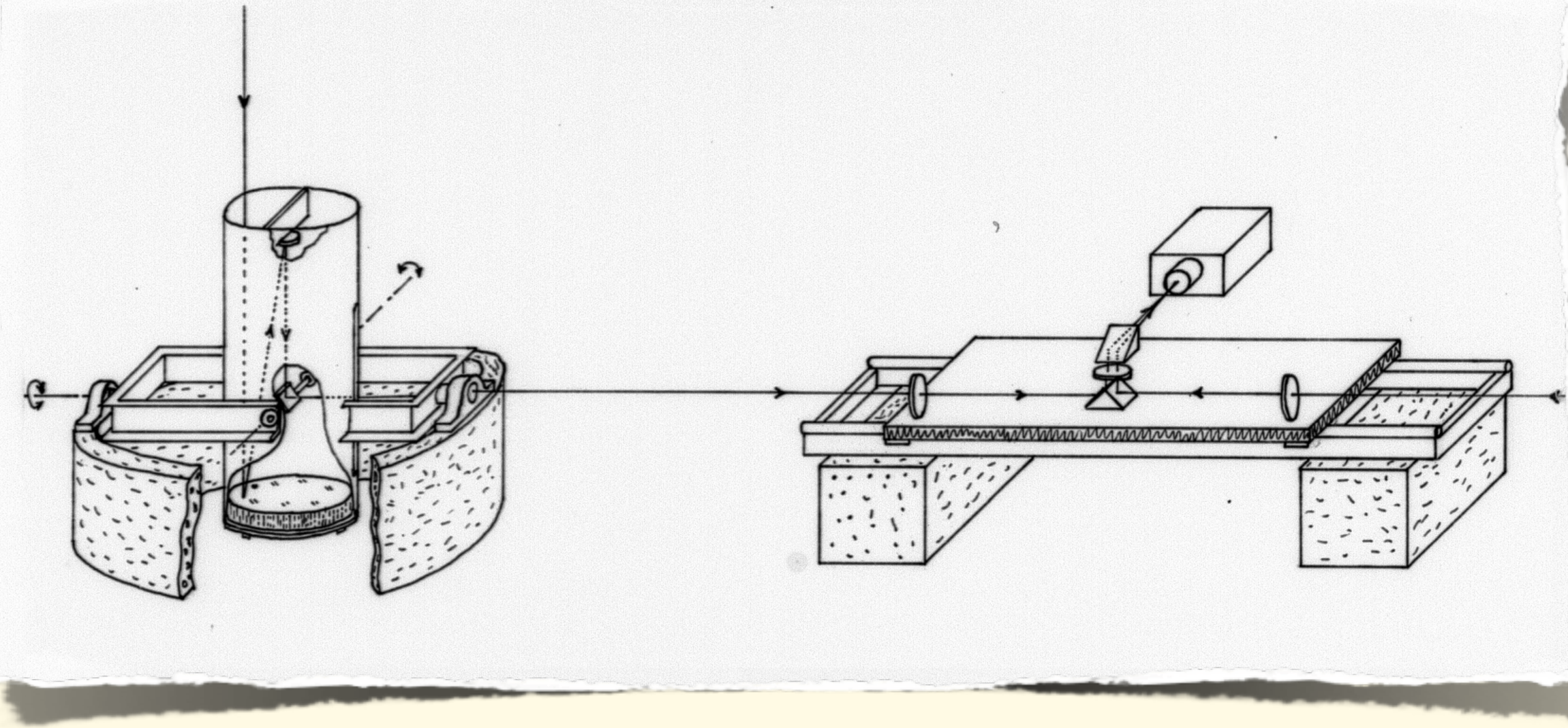
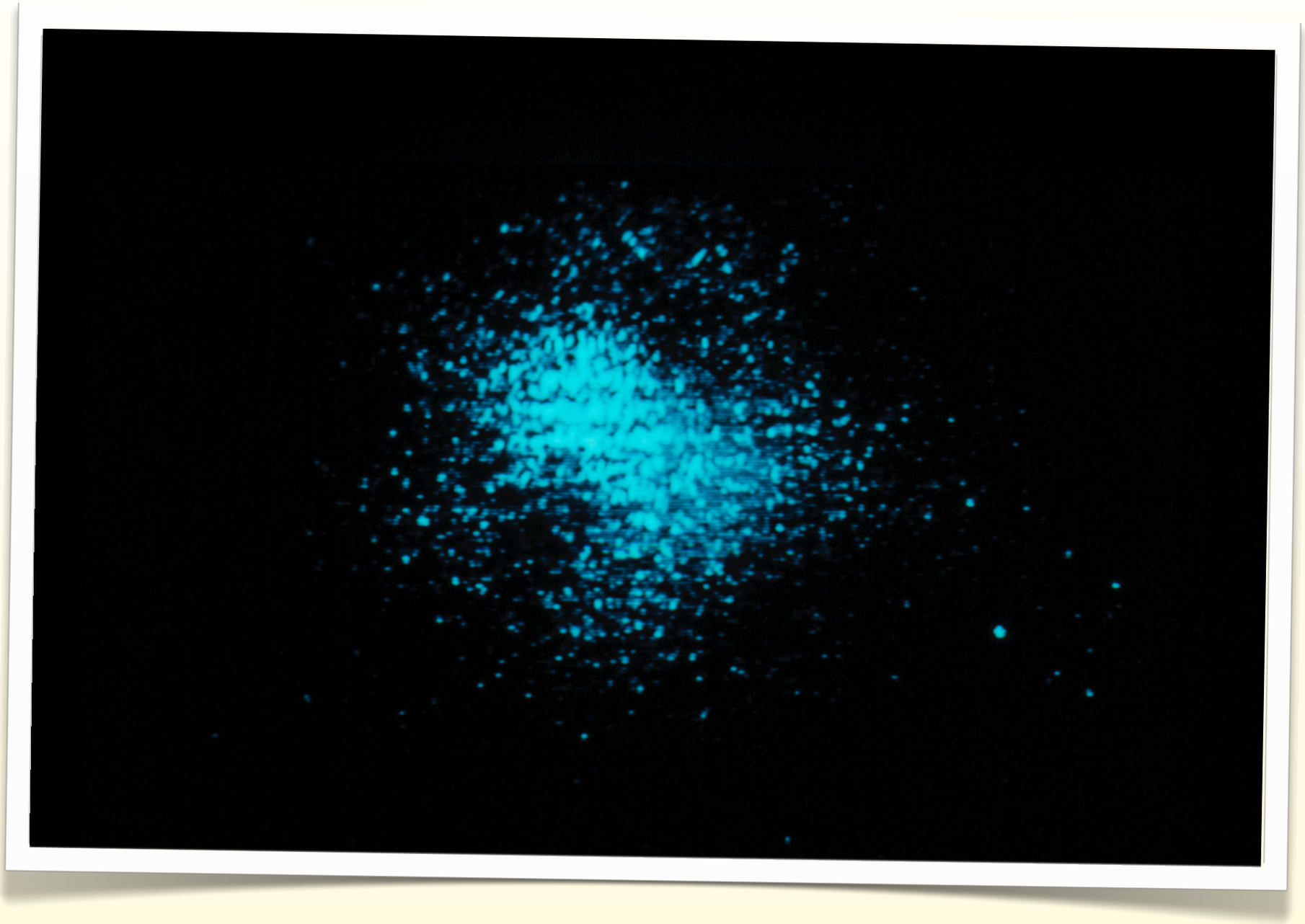
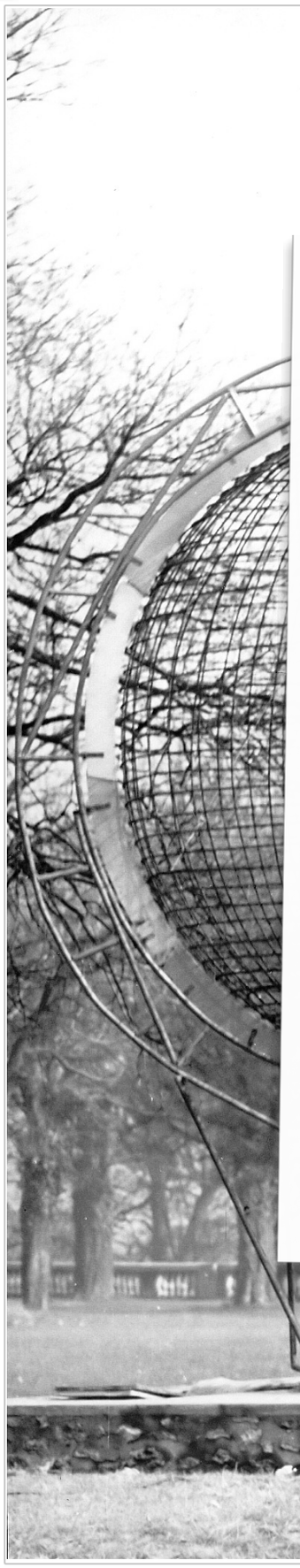



I2T
Photo: L. Koechlin

Photo: O. von der Lühe

First fringes with the I2T:
Amplitude interferometry... again at last !



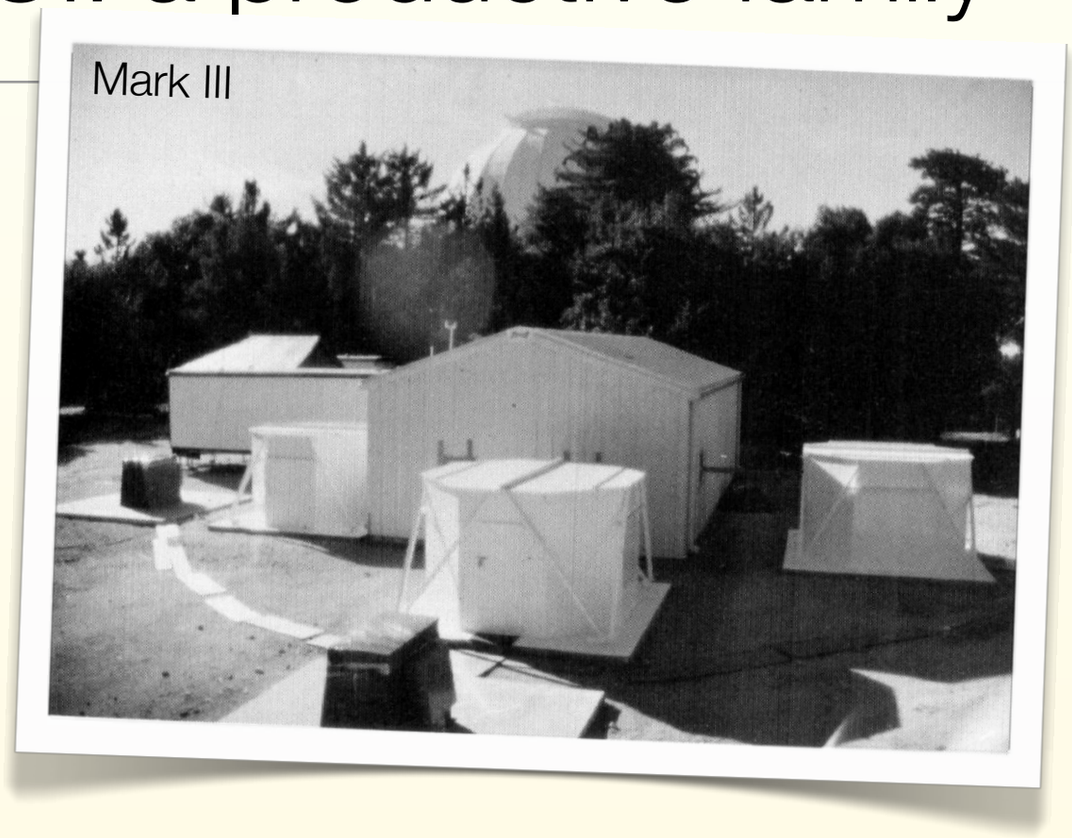


GI2T

credit: Peter Lawson.

Mk I, Mk II, Mk III, PTI & NPOI: a productive family

- This series of instruments served as a basis for the technology developments of the present large arrays



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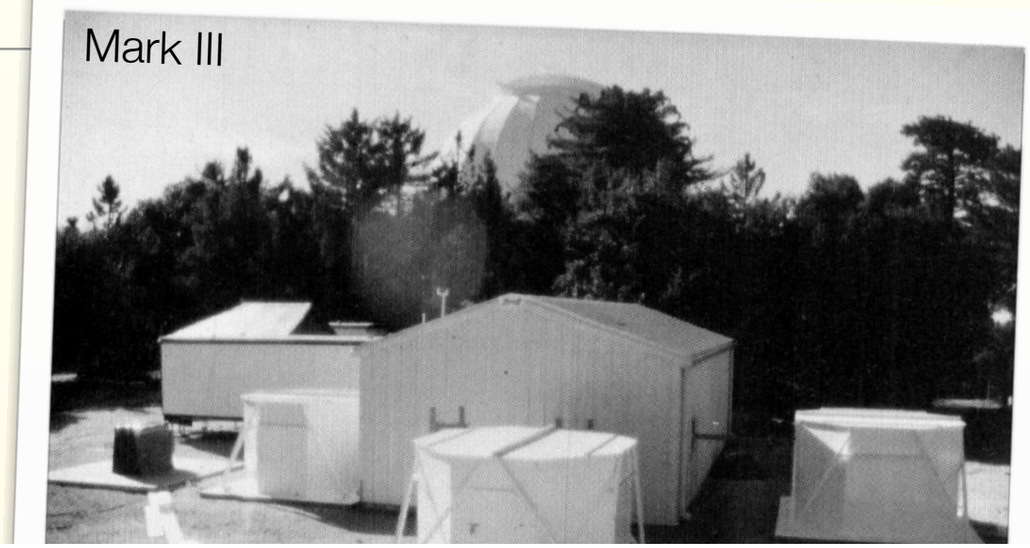

Mk I, Mk II, Mk III, PTI & NPOI: a productive family

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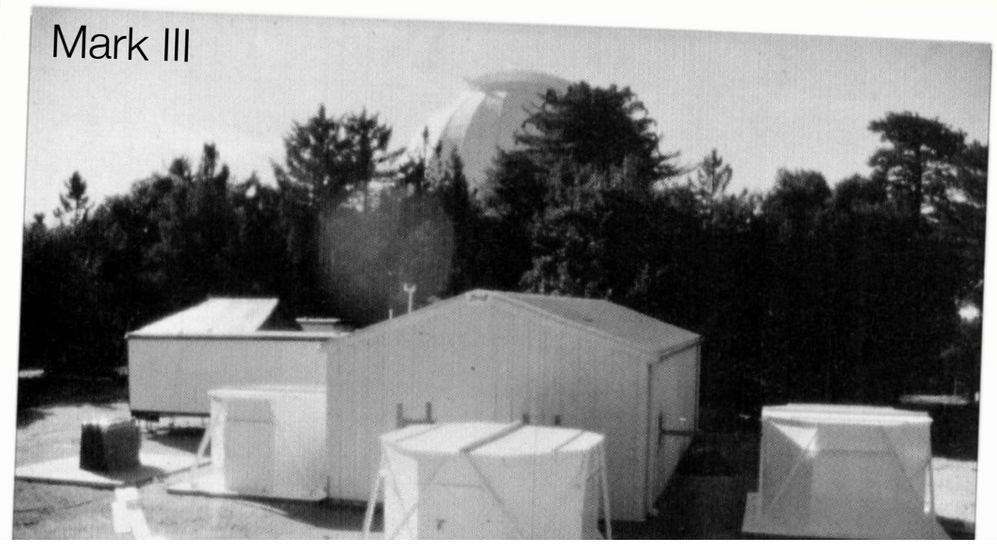

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The CHARA Array

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CHARA & 100 inch Hooker telescope - credit: G. van Belle

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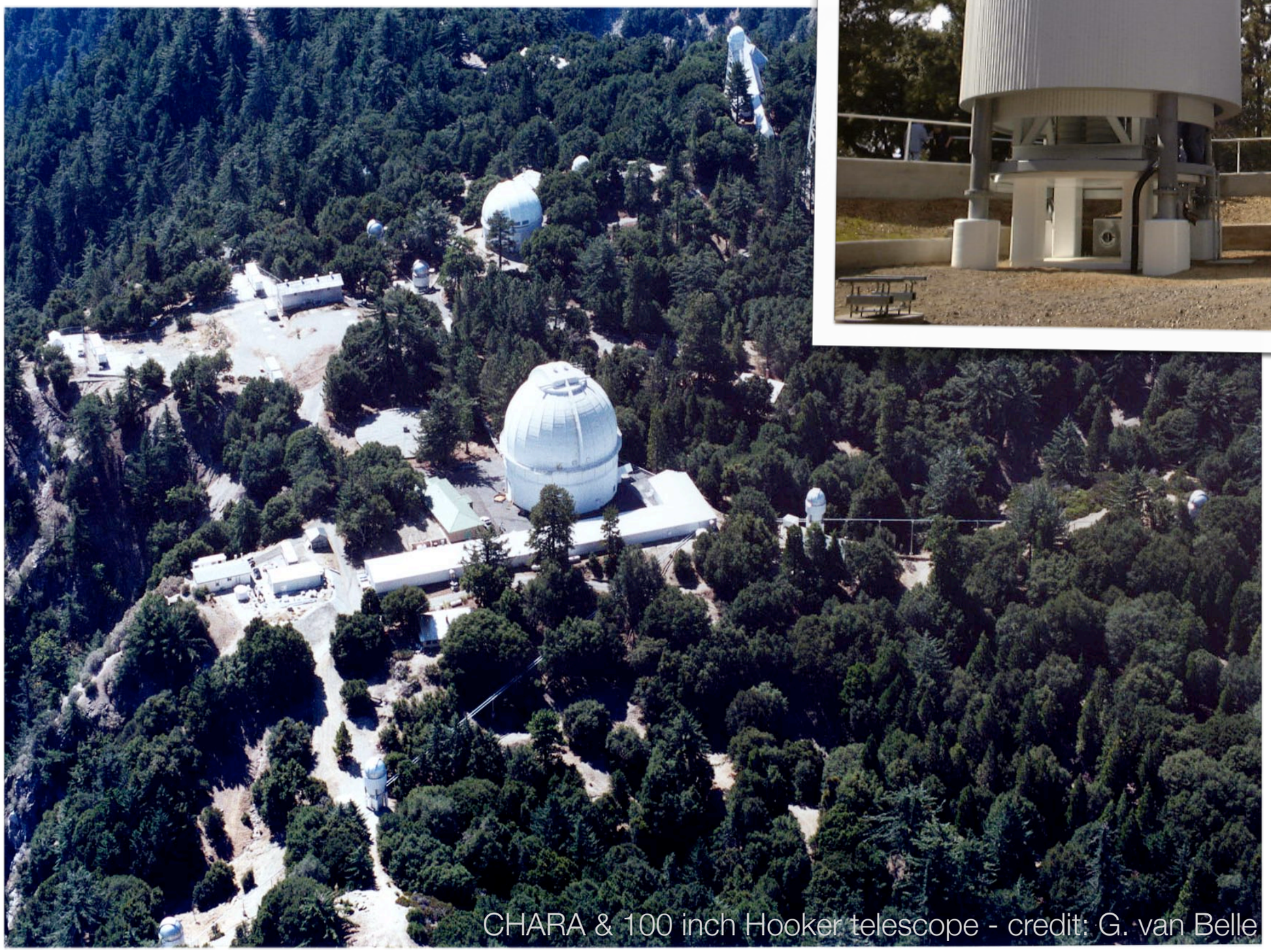

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The Giants: Keck Interferometer & VLTI

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- You will hear a lot about VLTI...

The Keck Interferometer

The VLT Interferometer: open to all astronomers

The VLT Interferometer

Conclusion

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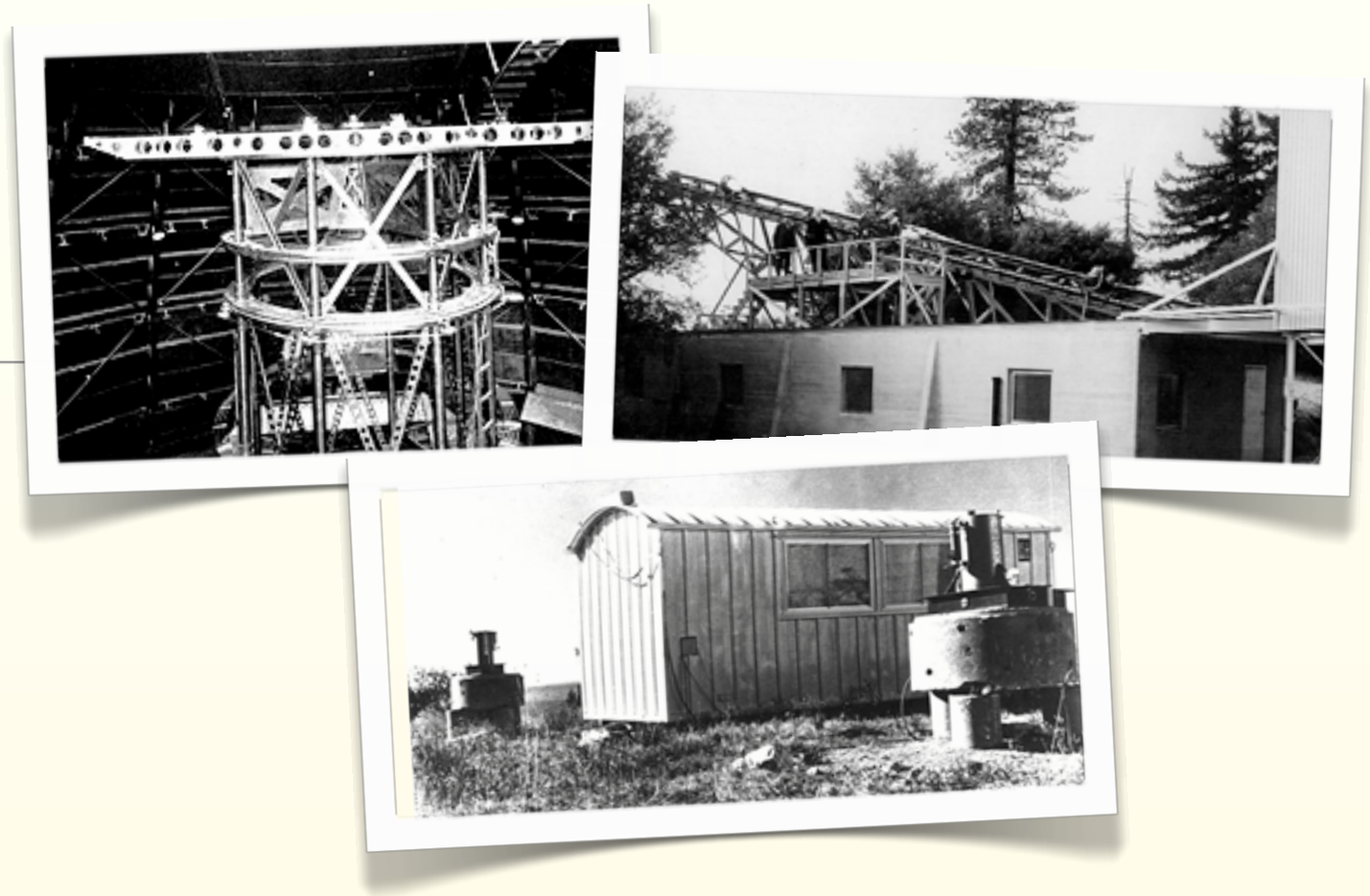

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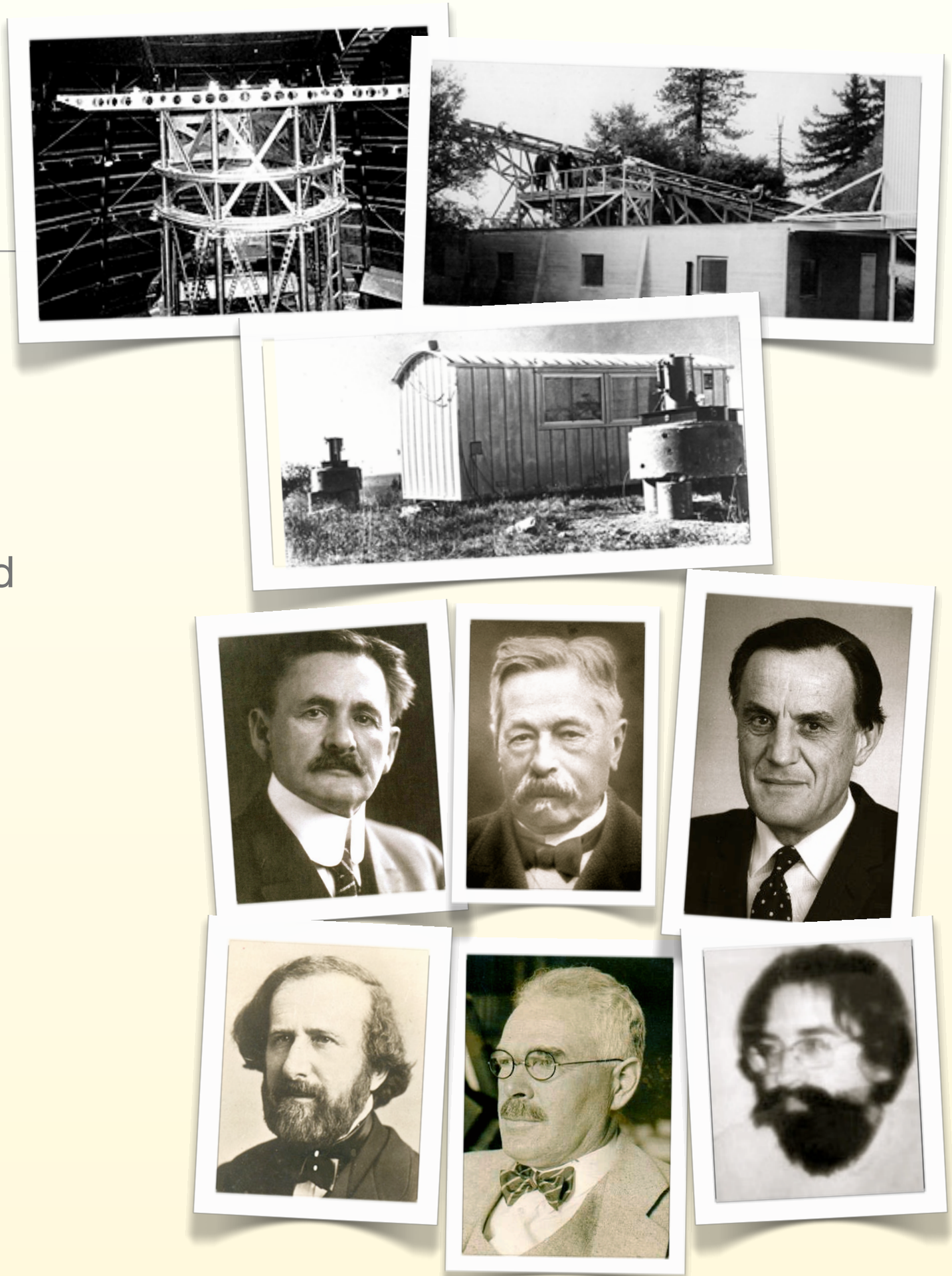

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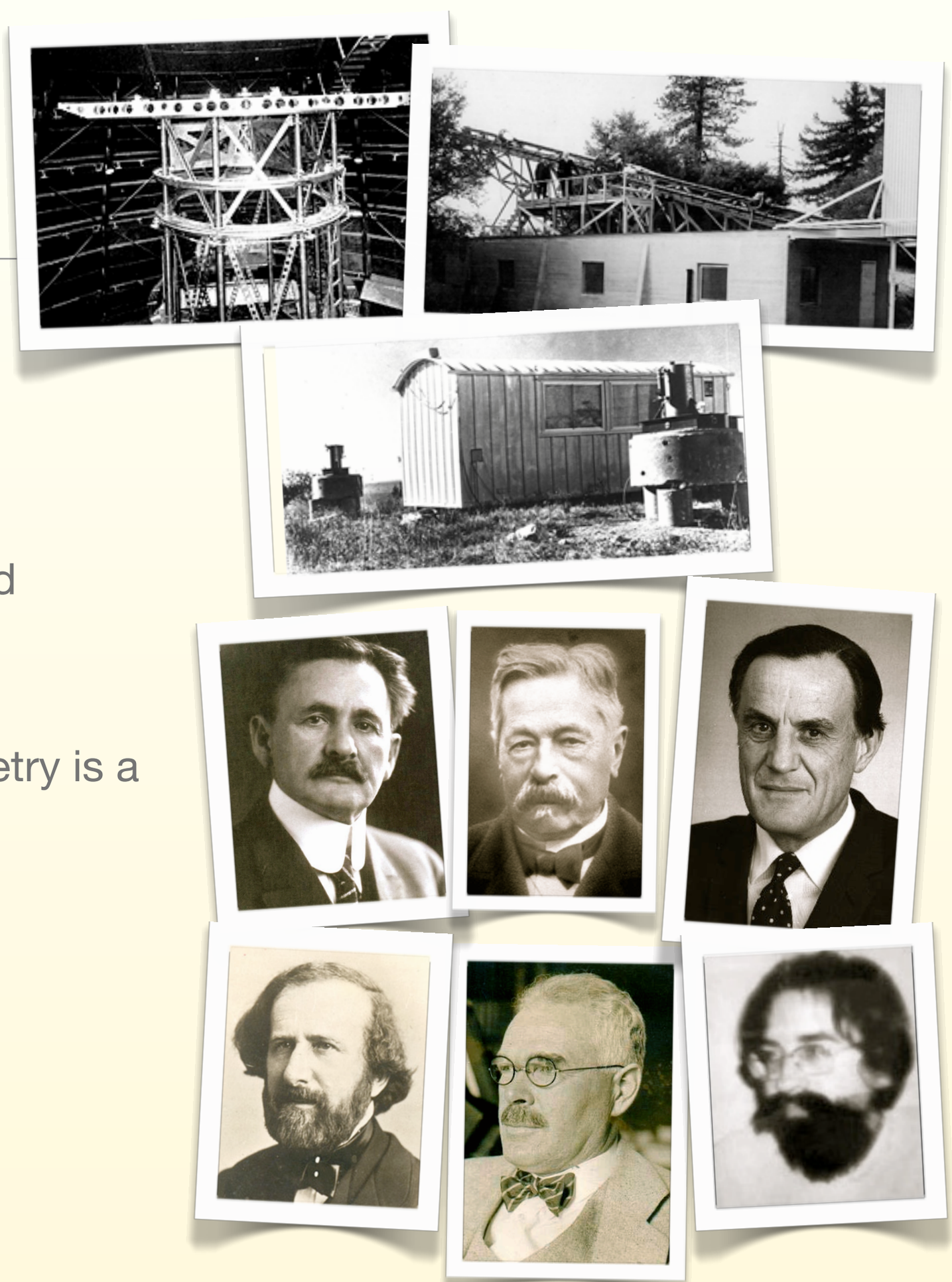

Conclusion

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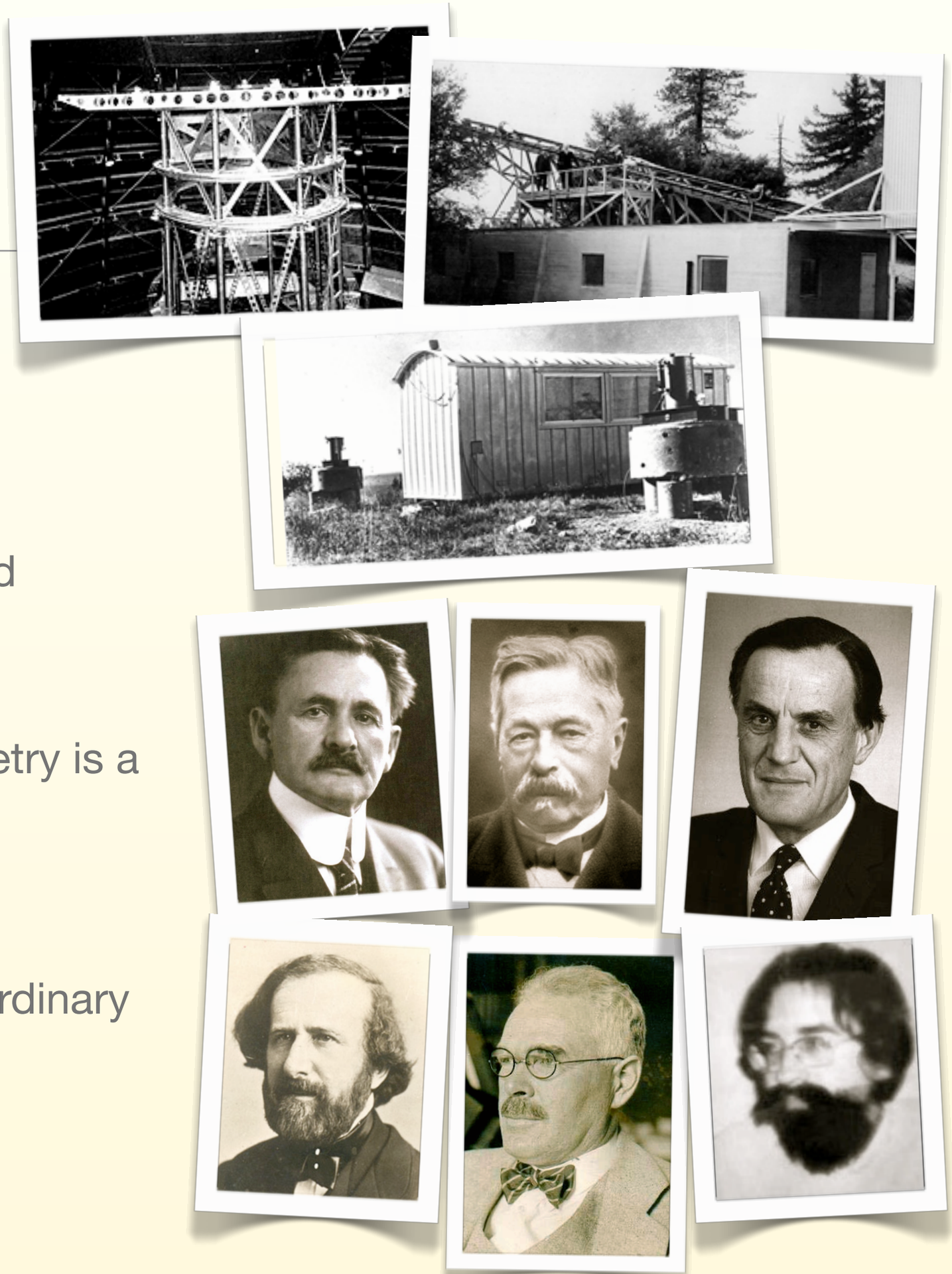
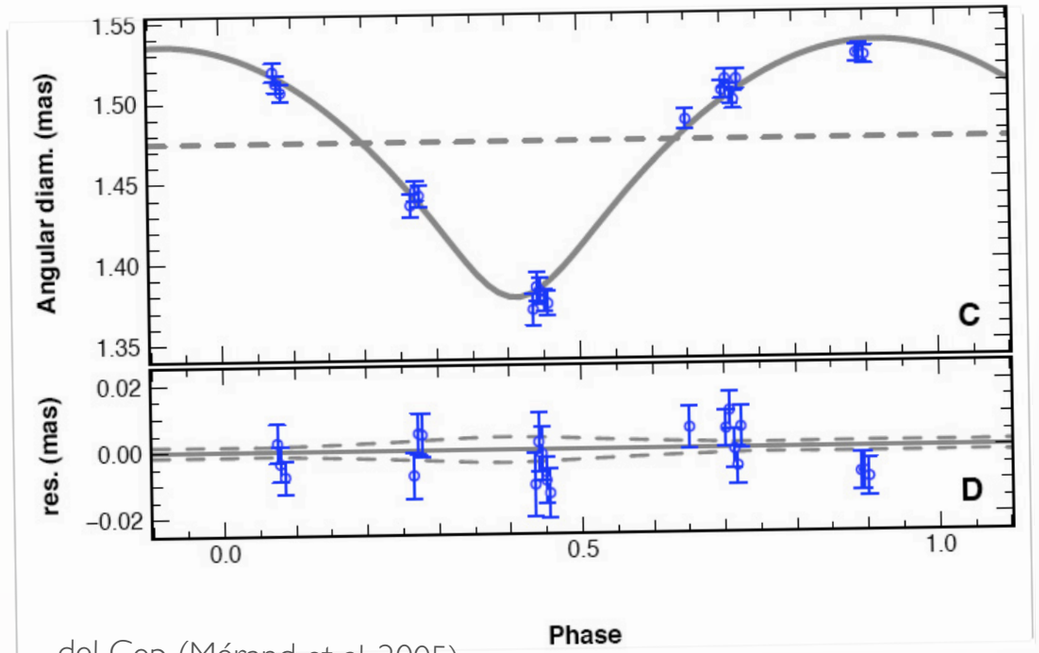
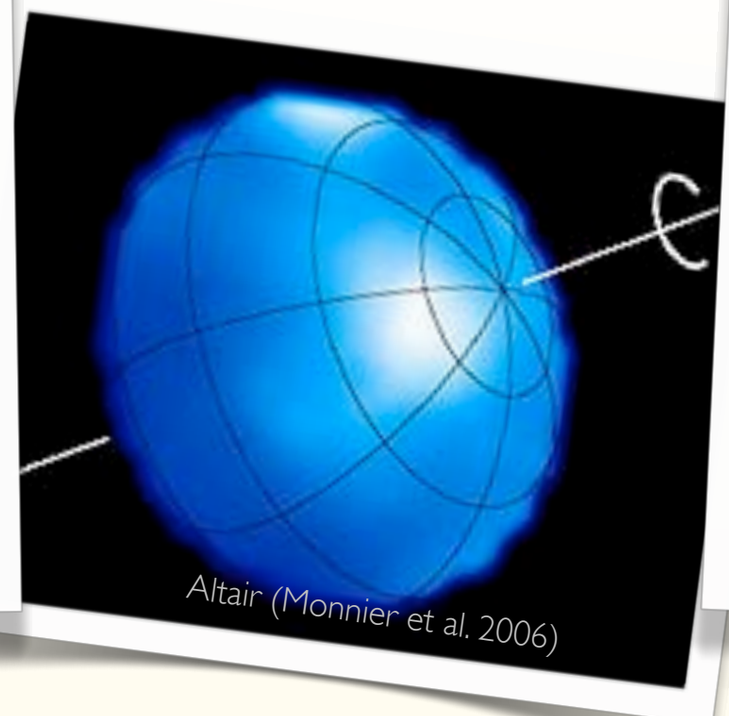
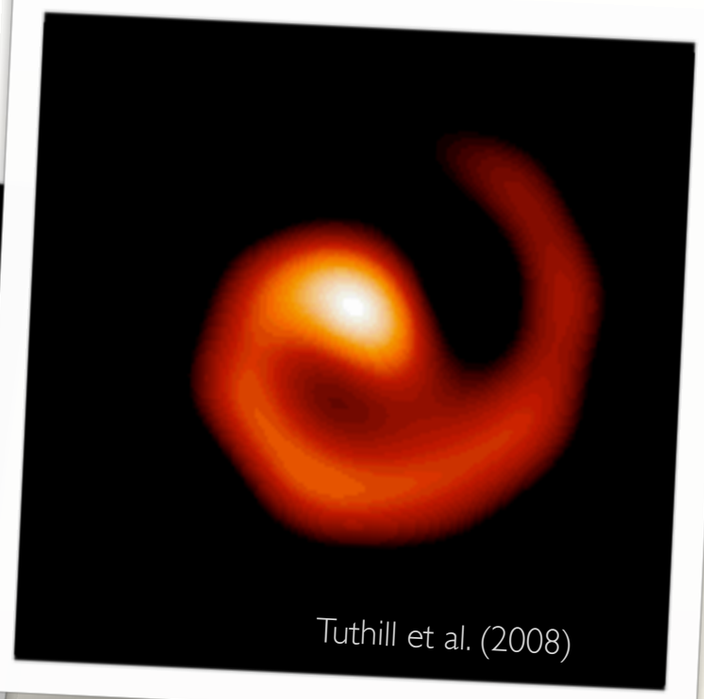




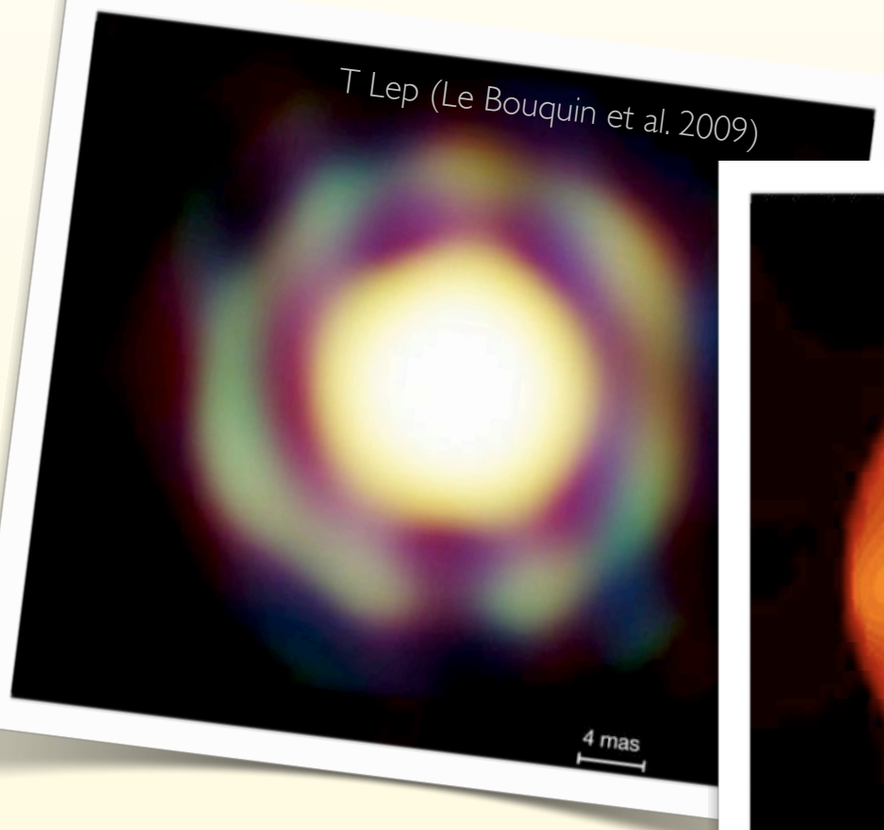
del Cep (Mérand et al. 2005)



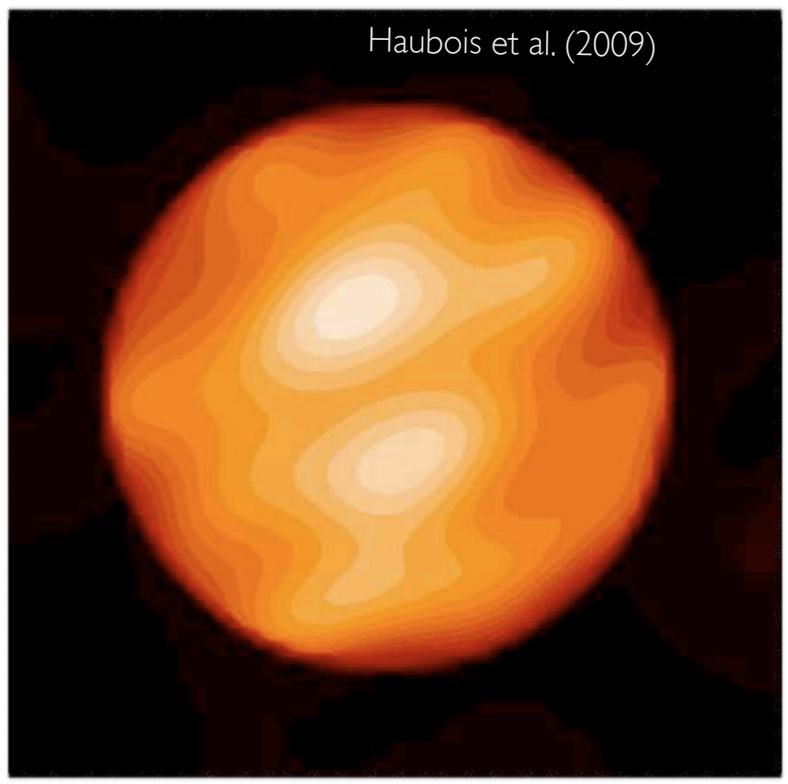
Altair (Monnier et al. 2006)



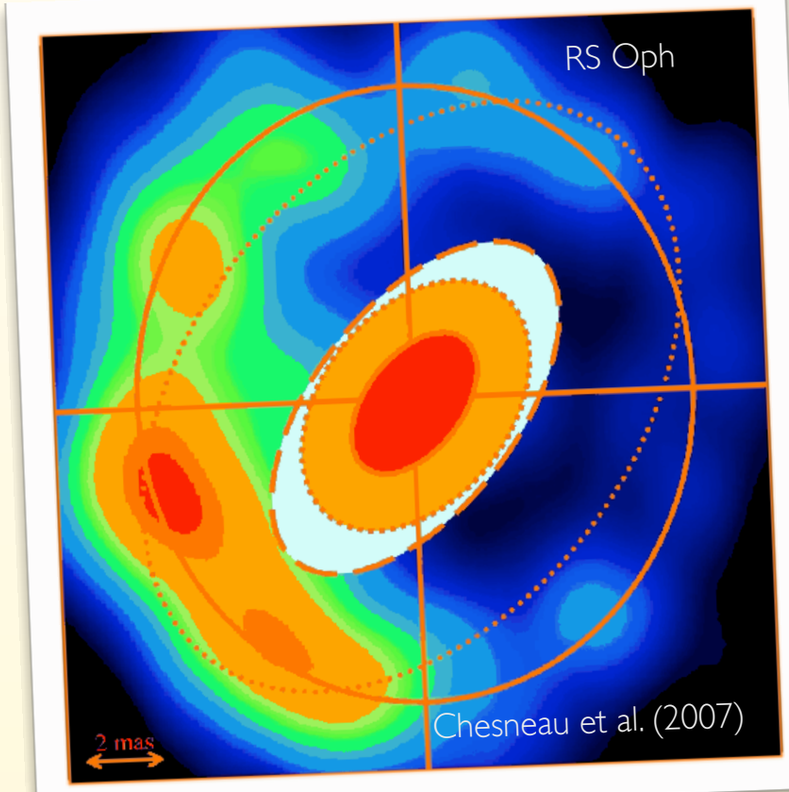
Tuthill et al. (2008)



T Lep (Le Bouquin et al. 2009)



Haubois et al. (2009)



RS Oph

Chesneau et al. (2007)

This presentation is based on the volume on the history of interferometry published by Peter Lawson (JPL) in 1997. The history of the 50-ft interferometer is based in part on the work of Larry Webster (CHARA/ Mount Wilson).

Selected Papers on Long Baseline Stellar Interferometry P.R. Lawson, editor (SPIE Press: Bellingham WA, 1997). SPIE Milestone volume of papers covering stellar interferometry from 1868 to 1996.

http://olbin.jpl.nasa.gov/