

How astronomy changed our view of the cosmos

Joseph Silk

March 6 2019



Pieter Breugel, 1590

Fall of Icarus

Adoration of the Magi
Giotto di Bondone, 1305

Halley's comet



Edmond Halley

1656-1742



SECOND ASTRONOMER ROYAL
FELLOW AND SECRETARY OF THE ROYAL SOCIETY
SPONSOR OF SIR ISAAC NEWTON'S PRINCIPIA
EDITOR OF PHILOSOPHICAL TRANSACTIONS
SAVILIAN PROFESSOR OF GEOMETRY OXFORD
OCEANOGRAPHER METEOROLOGIST GEOPHYSICIST
INVENTOR NAVIGATOR AND FAMED FOR
HIS RESEARCHES IN DETERMINING LONGITUDE
HE LAID THE ACTUARIAL FOUNDATION OF LIFE ASSURANCE

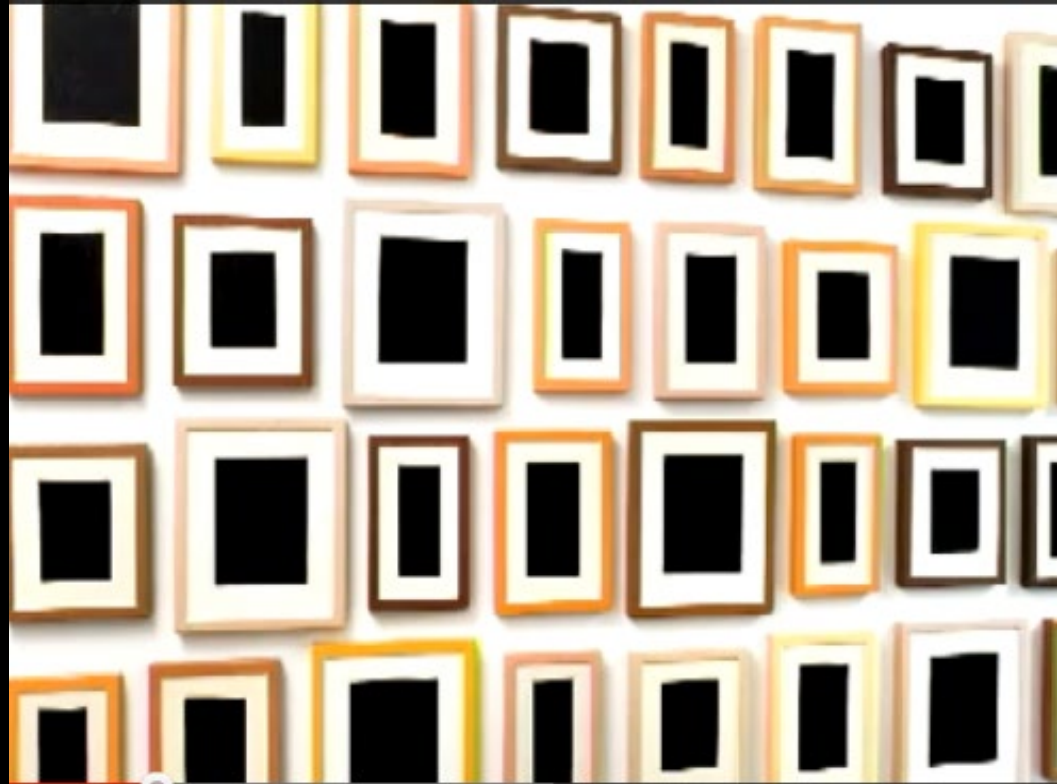
Halley's observatory
In Oxford

Dark Matter, the most mysterious substance in the universe

Alan MacCollum 1990
Dark Matters



Cornelia Parker 1991
Cold Dark Matter



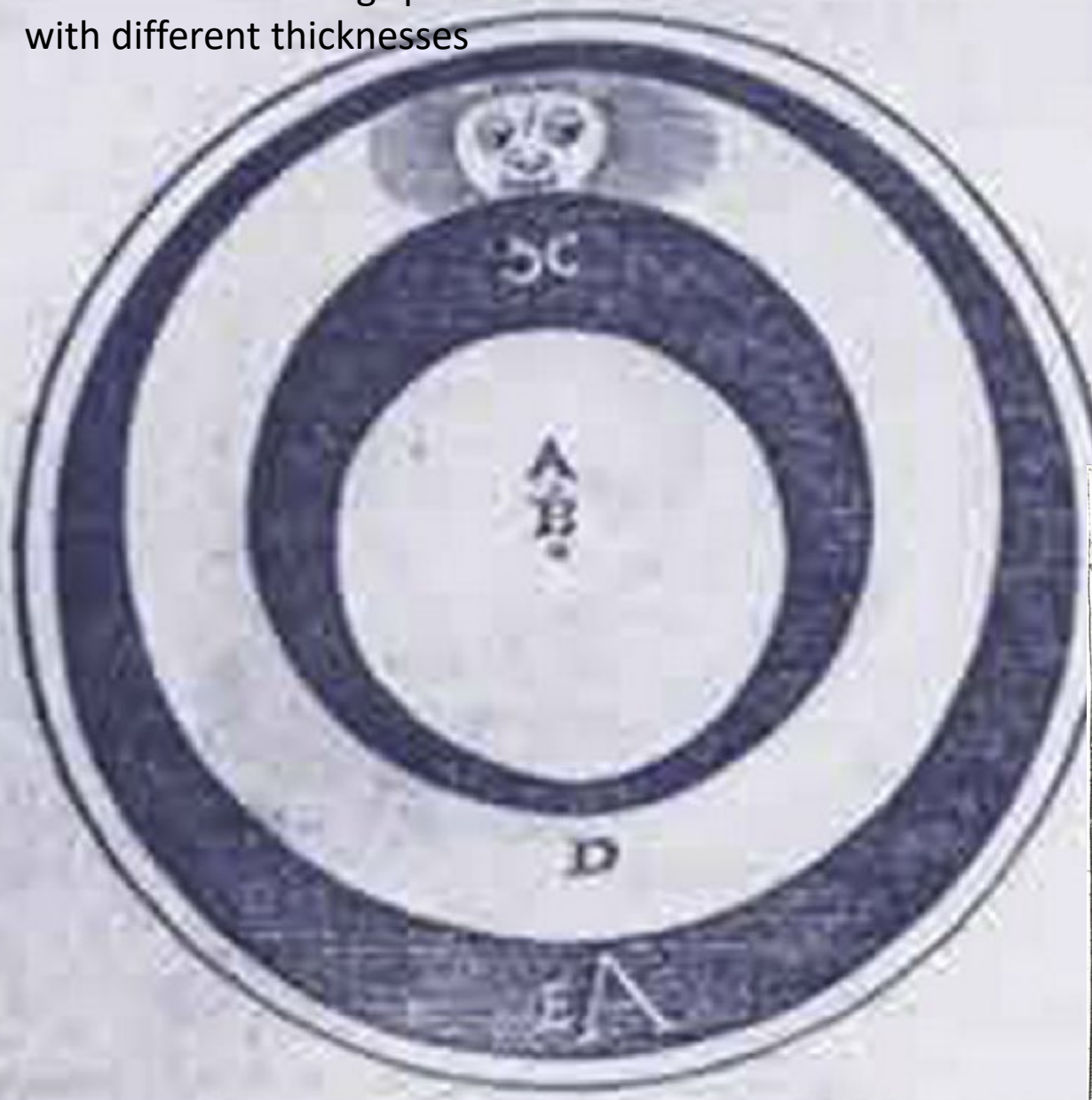
Earth rise

viewed from the Moon



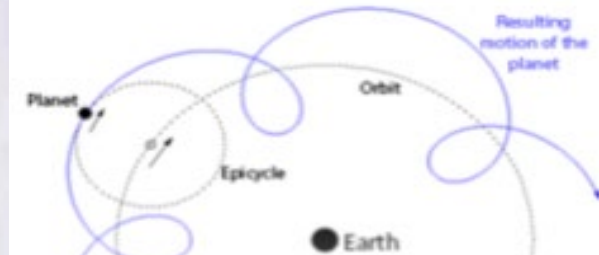
THEORICA TRIUM orbium Solis.

Concentric rotating spheres
with different thicknesses



Planetary hypothesis

Claudius Ptolemy 90-168 AD

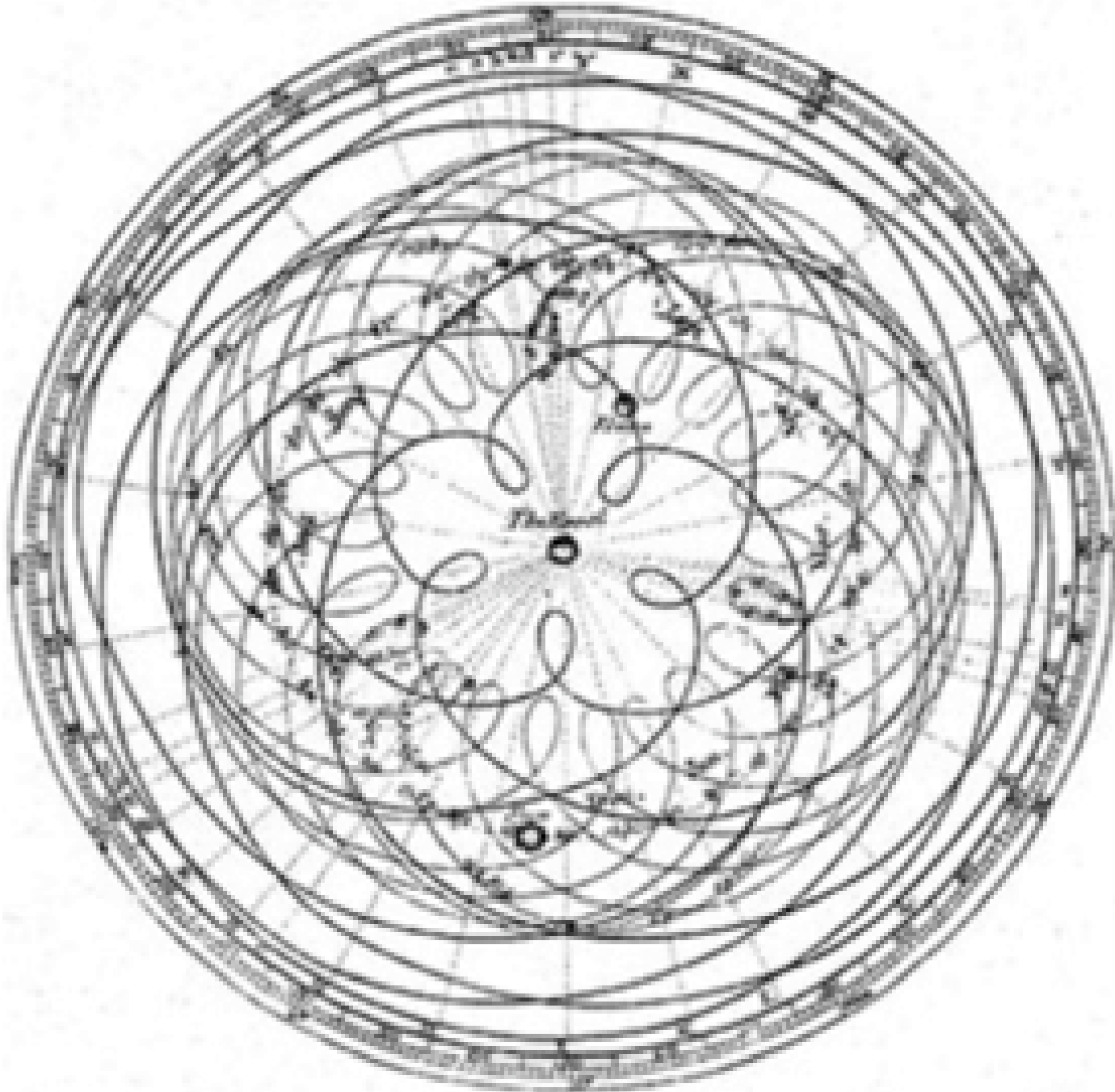


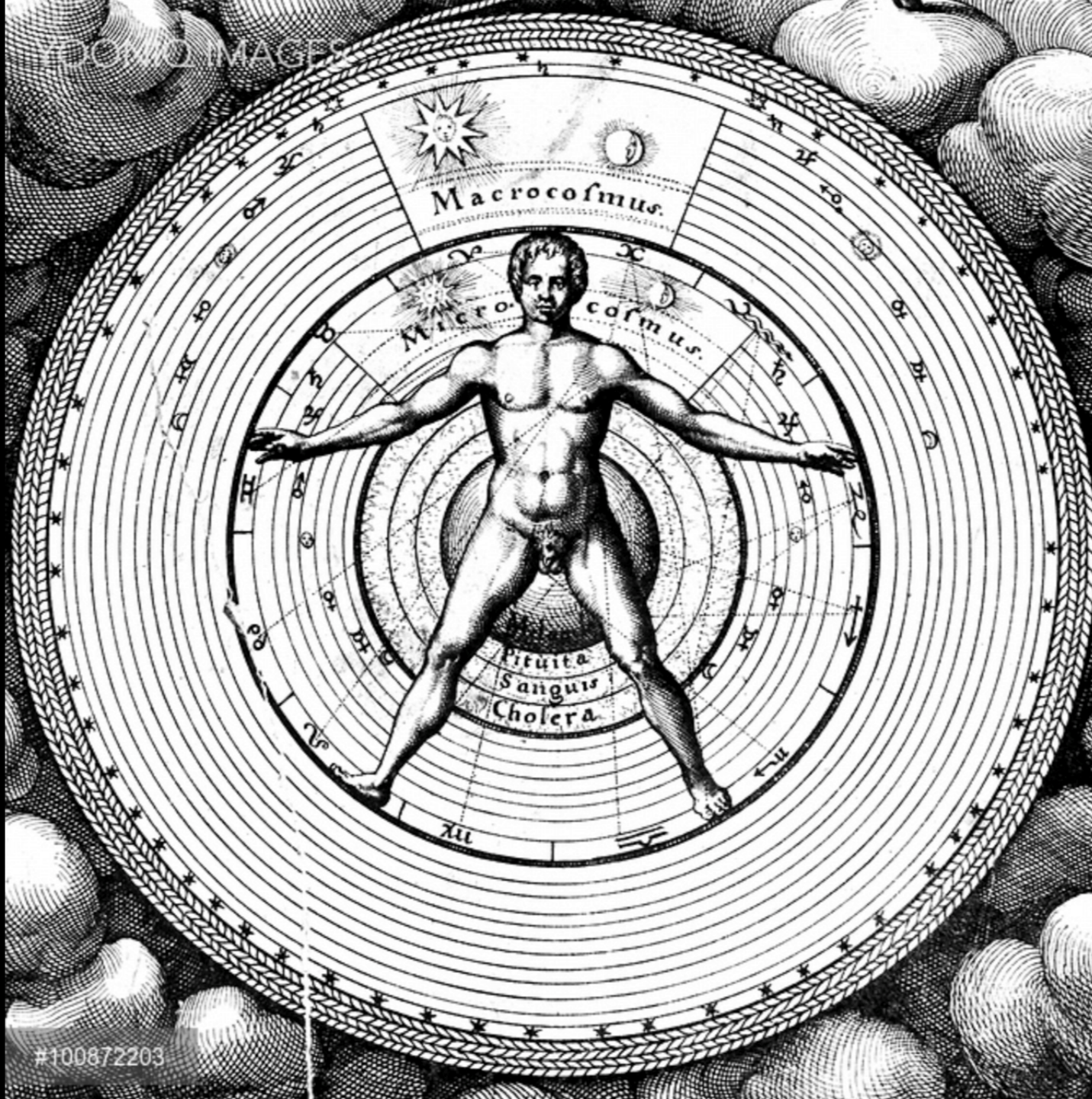
Epicycles: brightness variations
retrograde motions of planets

theory survived 1400 yrs till 1543



Epicycles became very complicated as observational precision improved





Robert Fludd
1574-1637

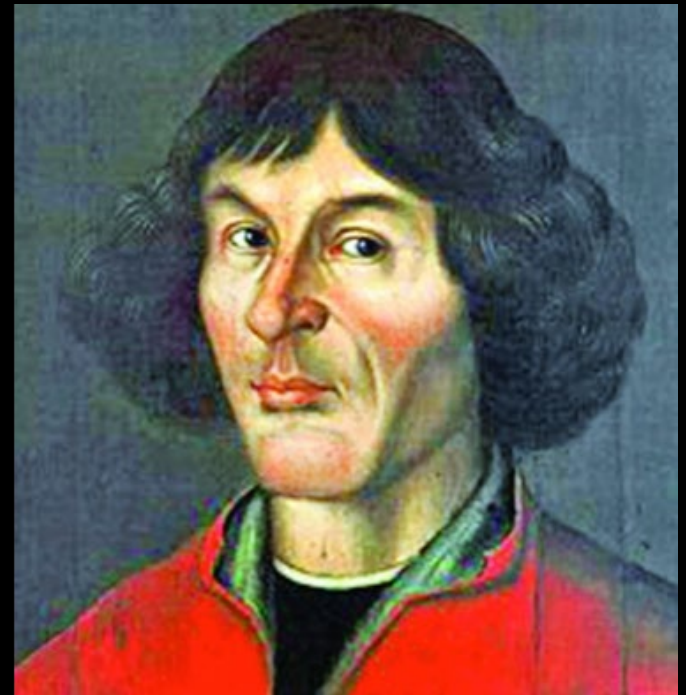
NICOLAI COPERNICI

net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum deniq; locum Mercurius tenet, octuaginta dierum spacio circū currentes, in medio utro omniū relidet Sol. Quis enim in hoc



pulcherrimo templolampadem hanc in alio uel meliori loco poneret, quā unde totum simul possit illuminare. Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uocant. Trimegistus uisibilem Deum, Sophoclis Electra intuentē omnia, ita profecto tanquam in solio regali Sol residens circum agentem gubernat Astrorum familiam. Tellus quoq; minime fraudatur lunari ministerio; sed ut Aristoteles de animalibus ait, maximā Luna cū terra cognationē habet. Concipit interea d. Sole terra, & impregnatur annuo partu. Inuenimus igitur sub

On the revolutions of celestial orbits
Nicolaus Copernicus 1473-1543



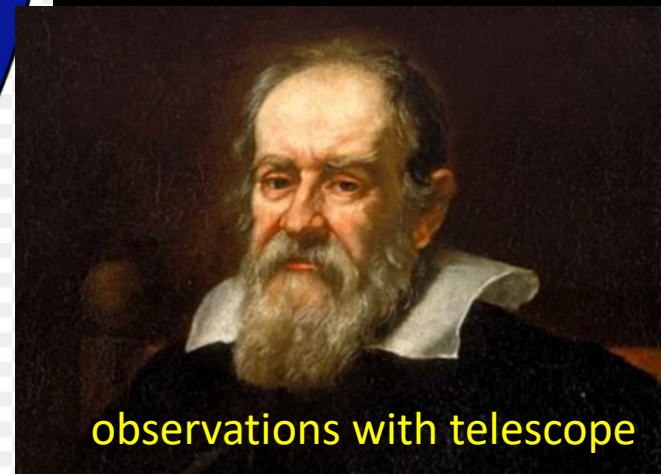
Retained circular orbits, needed epicycles

Tycho Brahe 1546-1601

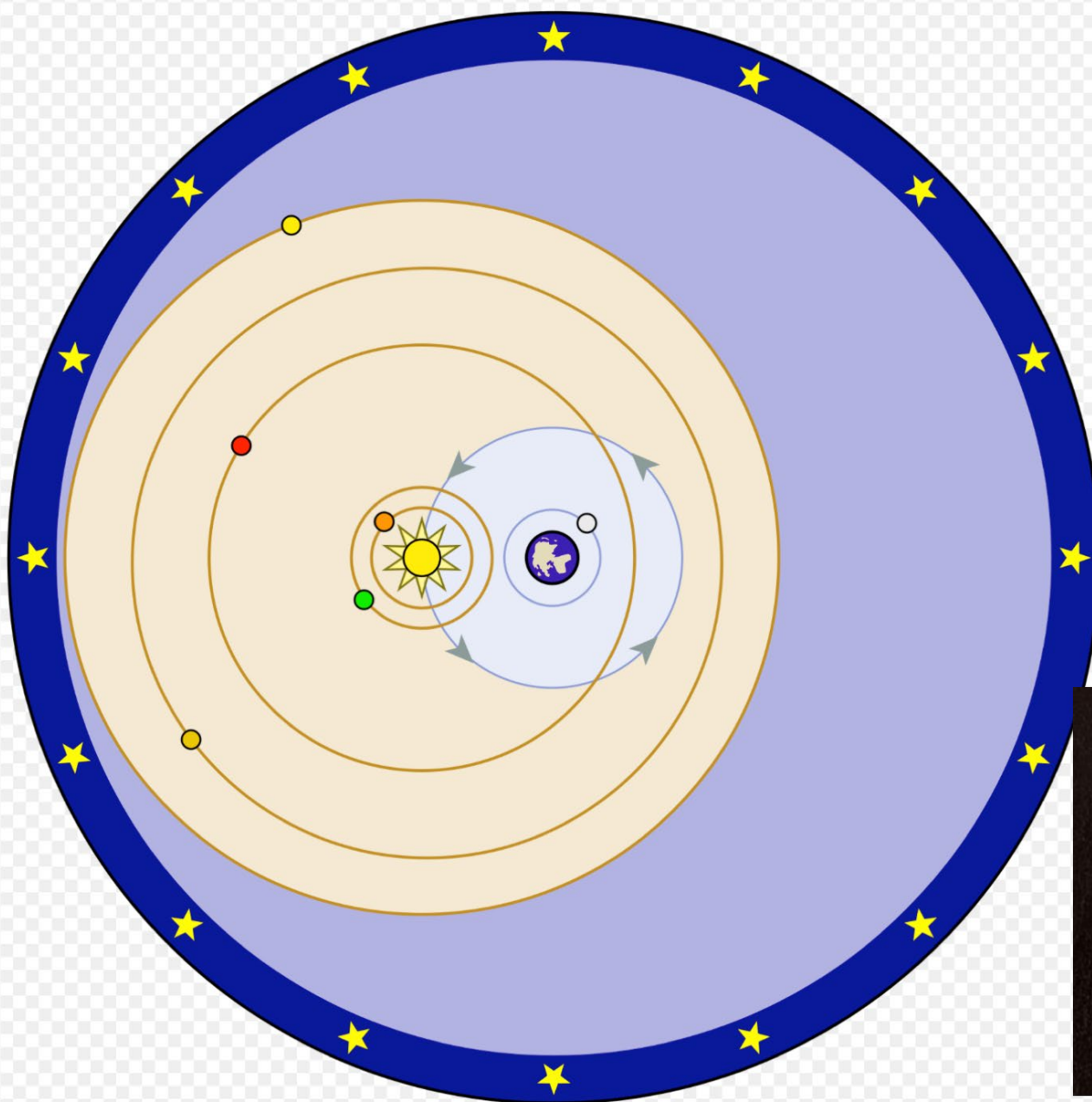


Comets, supernovae

Galileo 1564-1642



observations with telescope



The final heroes of classical astronomy

- Johannes Kepler (1571-1630)
- Isaac Newton (1642-1727)

Elliptical orbits

Theory of gravitation



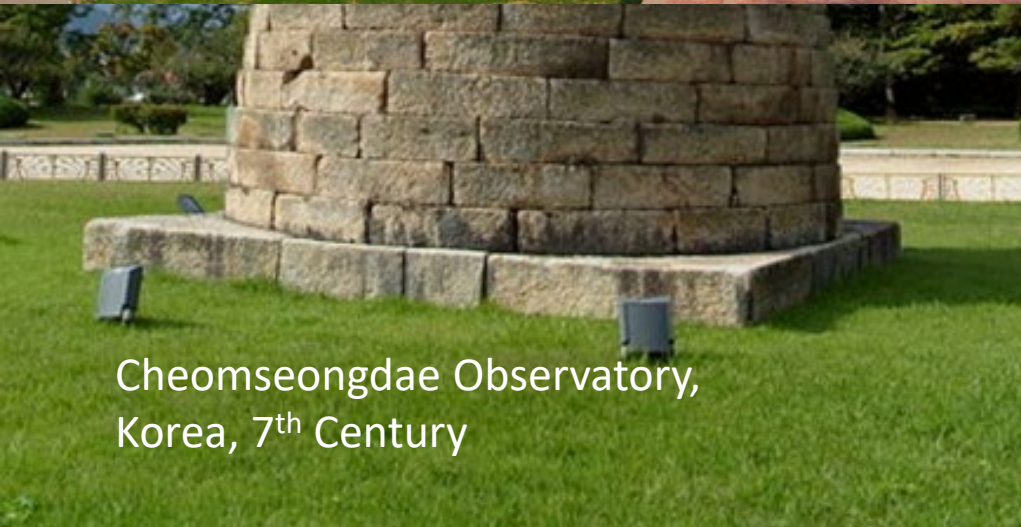
Precision astronomy, without telescopes



Jaipur Obs, 1734



Mayan Observatory, Chichen Itza
06



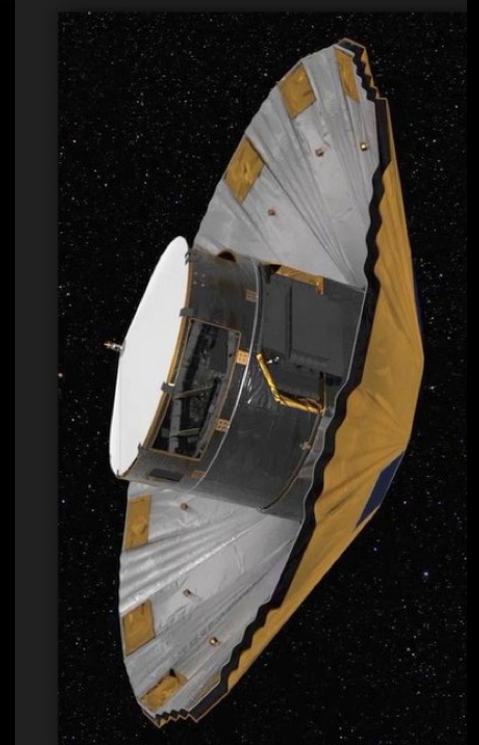
Cheomseongdae Observatory,
Korea, 7th Century



Guguk Observatory, 1276

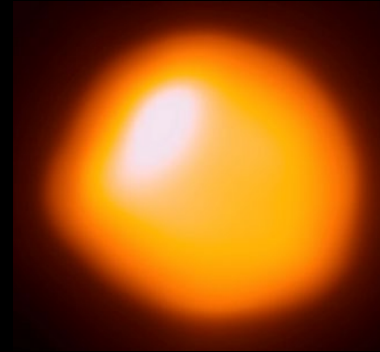
parallax

- Friedrich Bessel 1838
- 0.3 arc sec to 61 Cygni, 10.3 lt yrs
- GAIA 2018: parallaxes of a billion stars



Stellar radii

- Arthur Eddington
- Albert Michaelson

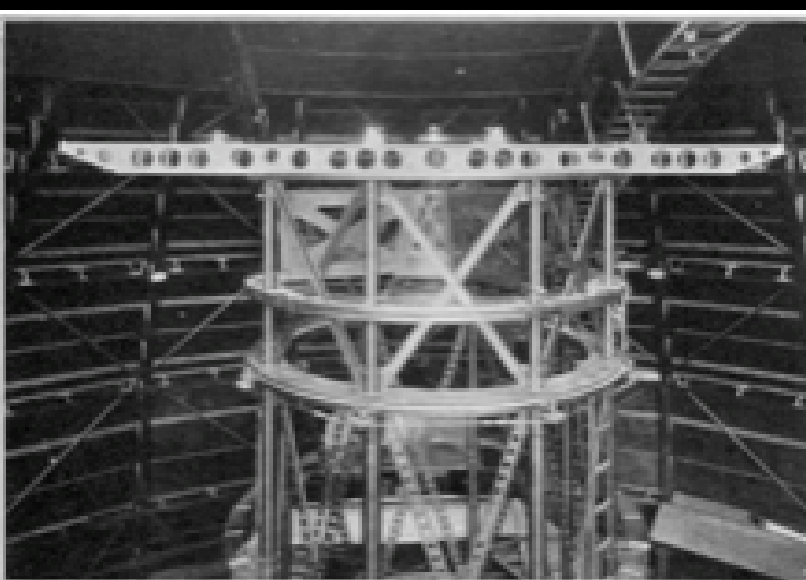


Probably the greatest need of stellar astronomy at the present day, in order to make sure that our theoretical deductions are starting on the right lines, is some means of measuring the apparent angular diameters of stars. At present we can calculate them approximately from theory, but there is no observational check. We believe we know with fair accuracy the apparent surface brightness corresponding to each spectral type; then all that is necessary is to divide the total apparent brightness by this surface brightness, and the result is the angular area subtended by the star. The unknown distance is not involved, because surface brightness is independent of distance. Thus the estimation of the angular diameter of any star seems to be a very simple matter. For instance, the star with the greatest apparent diameter is almost certainly Betelgeuse, diameter $0.051''$. Next



Betelgeuse, 1000 solar radii or 3 au, 0.05 arcsec: 1920
220 pc distance

Michaelson's stellar interferometer



Mirrors at both ends of interferometer gather starlight

Mirrors in middle reflect starlight into telescope

Interferometer

starlight

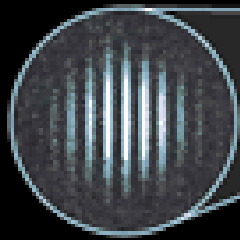
starlight

mirror

Image observed

Two star images are combined into one

Combined light signals create a striped interference pattern, which carries information about the star



The New York Times

NEW YORK, THURSDAY, DECEMBER 30, 1920.

GIANT STAR EQUAL TO 27,000,000 SUNS LIKE OURS

As for Our Little Earth, Betel-
geuse Is as Big as Trillions
of Globes Like It.

DIAMETER 280,000,000 MILES

Michelson Measures Colossus
of the Skies Whose Light
Comes to Us in 150 Years.

Operate On Caruso to Check Pleurisy; Resting Comfortably, Physicians Say

Enrico Caruso was operated on at his apartment in the Hotel Vanderbilt yesterday for an acute condition resulting from the attack of pleurisy which he suffered during the week. His physicians said the immediate difficulty was relieved and the patient was resting favorably. An earlier bulletin declared the famous singer "must be considered seriously ill," though there had been some improvement, attributable to his strong constitution.

Last evening's report of the doctors said:

"Mr. Caruso has developed suppurative pleurisy, necessitating a surgical operation. This has been successfully performed, and he is now resting comfortably."

The morning statement said:

"Mr. Caruso passed a comfortable

night. His condition this morning shows a slight but distinct improvement, but he still must be considered seriously ill."

Both announcements were signed by the five attending physicians—Dr. Lambert, Evans, Stalla, Murray and Moretti.

Some alarm was caused early in the evening by a report that several cans of oxygen had been taken to Caruso's apartment and that he had become worse. It was explained that the oxygen had been given at intervals since last Saturday, not because of a crisis in his condition but merely to aid in his fight against the disease. There was no reason for alarm, it was said, and those in his apartment, including Mrs. Caruso, were not apparently worried.

LABOR CHALLENGE ON IRISH REPLY MADE TO C

Parliamentary Party
to Disprove Charges
Crown Forces

WANTS THEM WITH

Immediate Election of
ent Assembly to Settle
Future Also Proposed

STRIKE AFTER TEST OF SLIDING SCALE

CITY TRANSIT TIE-UP DELAYS A MILLION

Much more depends on other conditions, especially those of climate, the kind of work to be done and, more than all, the man behind the gun. The case is not unlike that of a battleship. Would a thousand feet always sink one of five hundred feet?... we must hope for the next improvement in some other direction...we have nearly reached the limit of size of telescopes...
Edward Pickering 1909



the undertaking of large pieces of routine work, and the employment of numbers of inexpensive assistants, whose work is in a great measure mechanical, such as copying and routine computing



in co-operative scientific work, special importance should be attached to the encouragement of individual initiative, no less than to the accomplishment of big projects for routine work.
George Ellery Hale 1904



Fund raising

- Philanthropy
- State

George Ellery Hale and Andrew Carnegie

This led to the era
of big telescopes



Galileo and
Doge of Venice
Giuseppe Bertini, 1858

Size counts

telescope diameters

- Galileo, 2 inch, 1610
- Earl of Rosse, 72 inch, 1845
- Mt Wilson, 100 inch, 1917
- Mt Palomar, 200 inch, 1949
- TMT, Mauna Kea, 30 m, 2027
- ELT, Cerro Amazonas, Atacama, 39 m, 2025



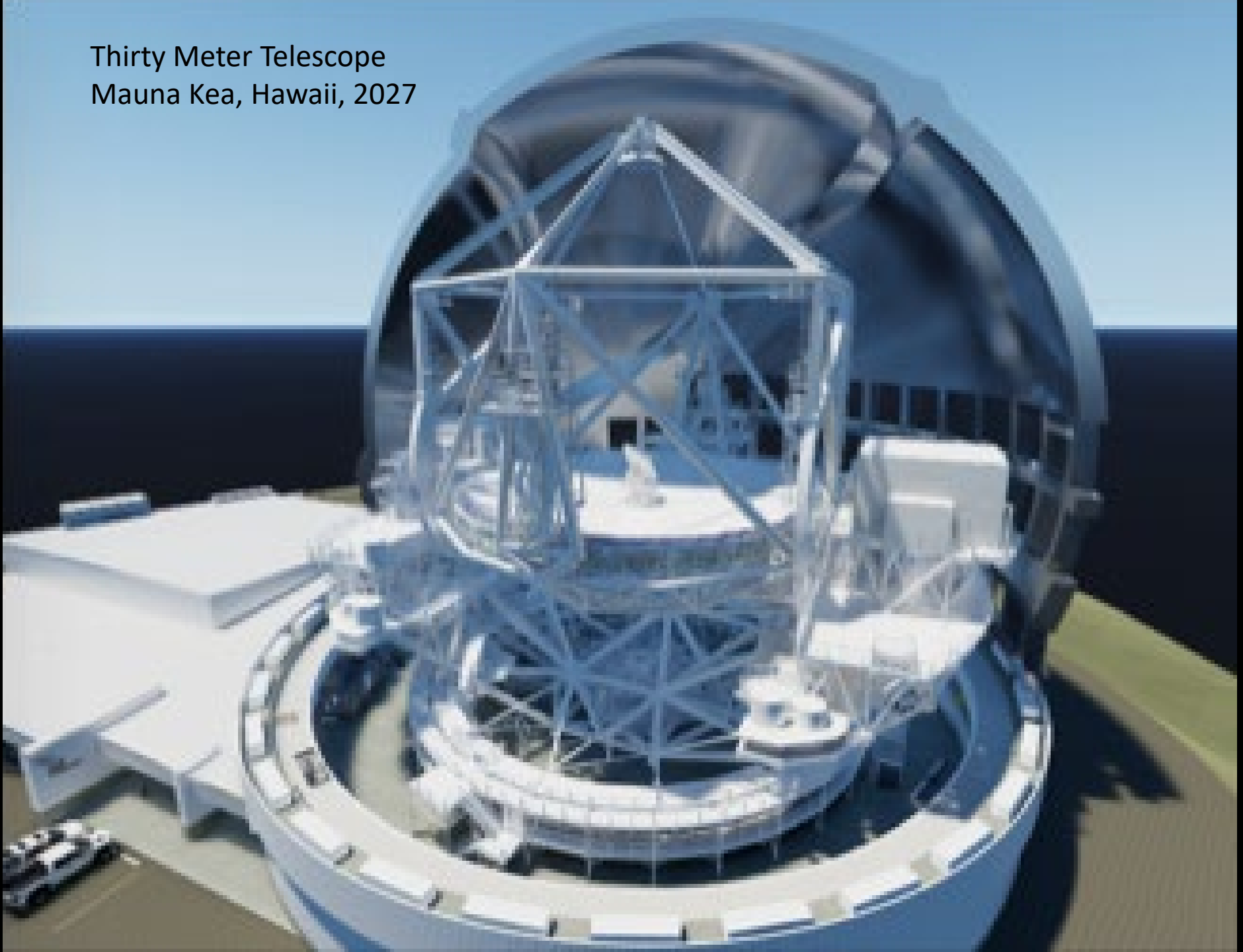
Earl of Rosse's
72inch refractor, 1845
Ireland





200 inch telescope, Mt Palomar, 1949

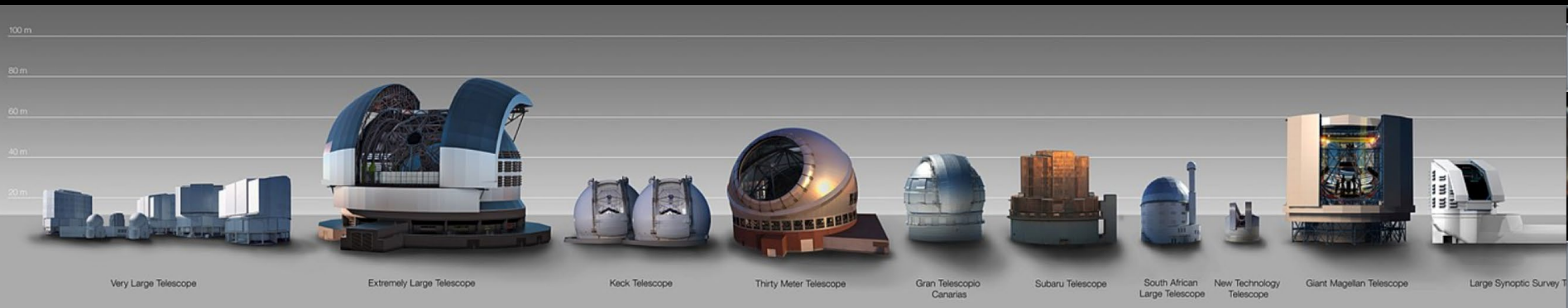
Thirty Meter Telescope
Mauna Kea, Hawaii, 2027



Extremely Large Telescope
39m
Atacama 2025



The world's largest telescopes

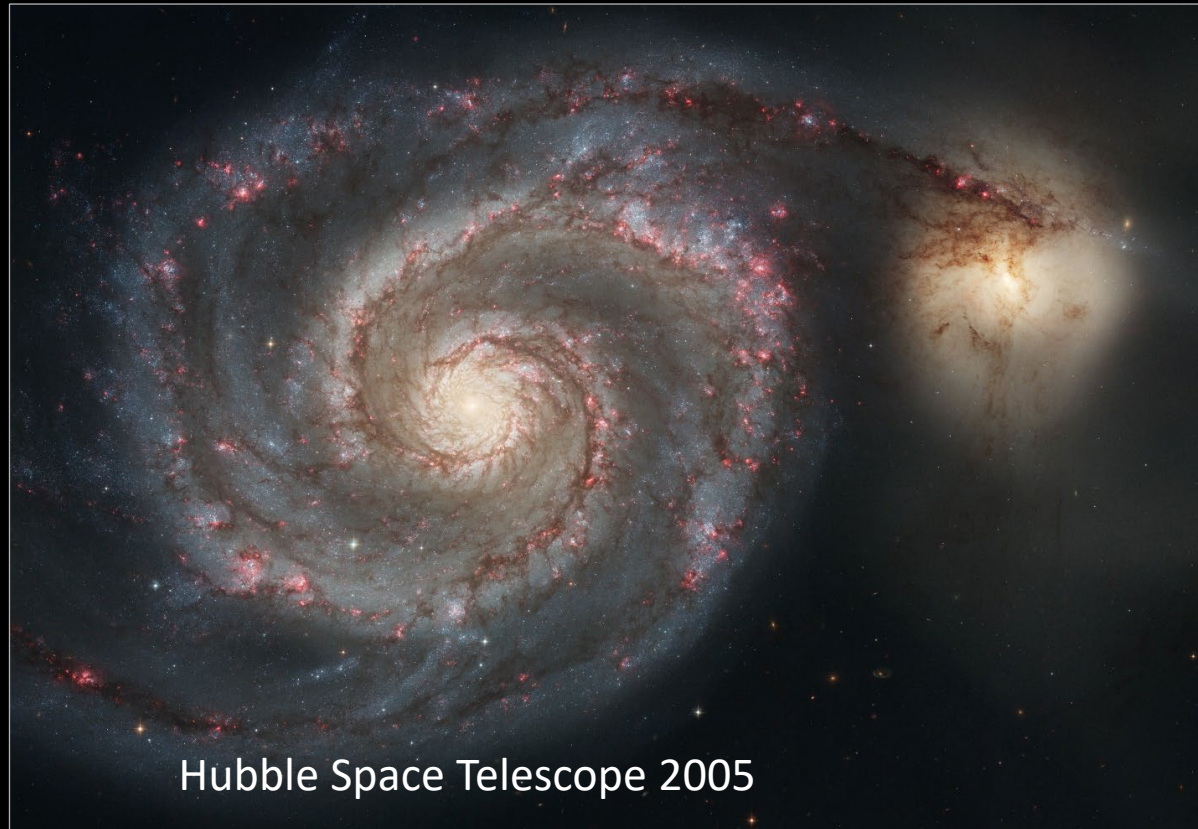


Technology



Earl of Rosse
1845

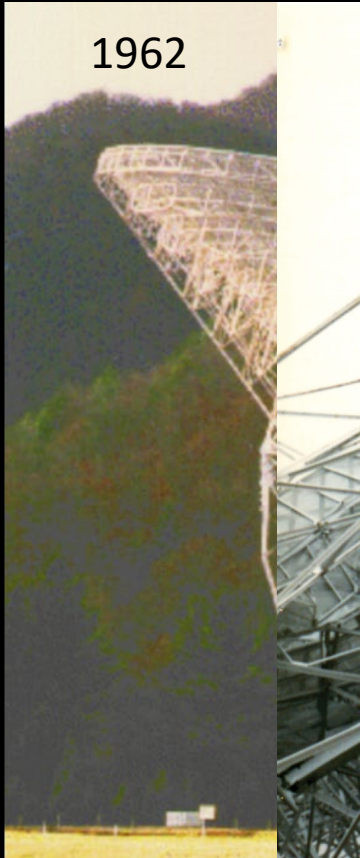
Whirlpool Galaxy - M51



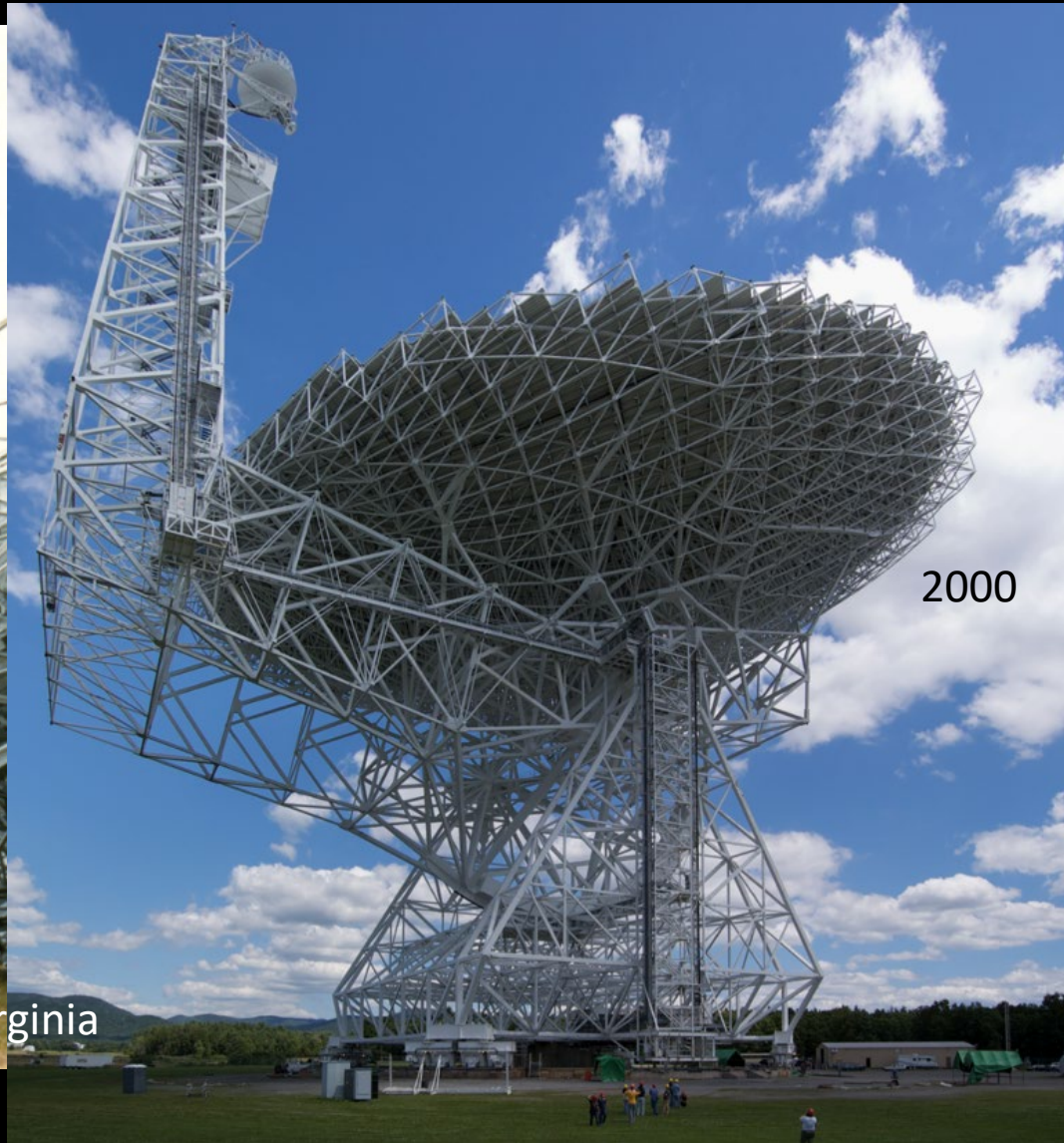
Hubble Space Telescope 2005

Radio telescopes

1962

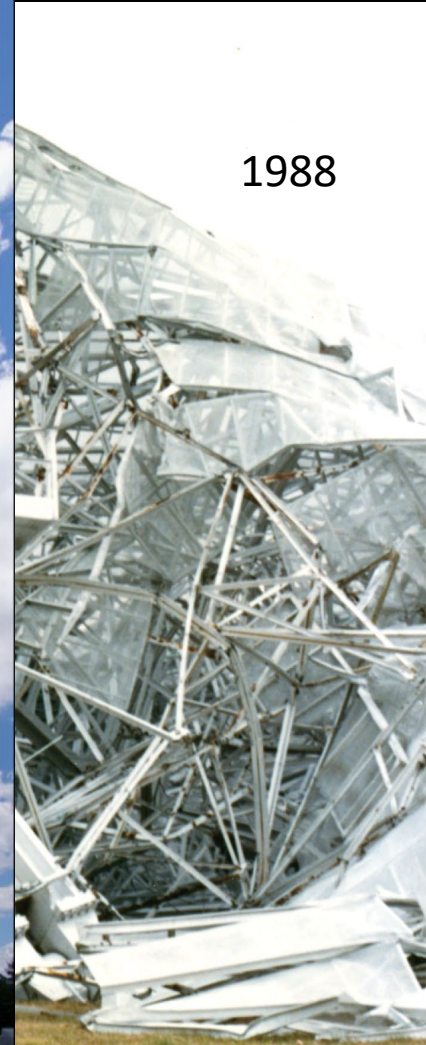


300 ft radio dish
Greenbank, W. Virginia



2000

1988





Arecibo
305m, Puerto Rico
1963



FAST 500m China 2016

Chandra x-rayspace telescope
1.2m, 1999

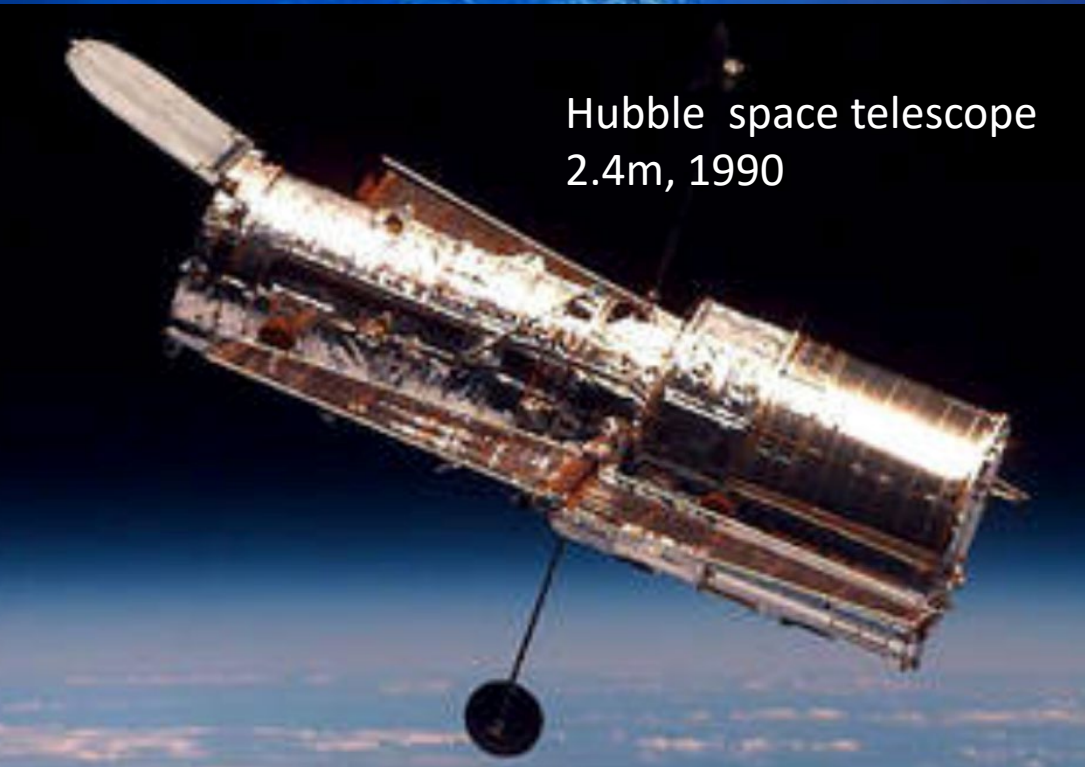


Space telescopes

Herschel infrared space telescope
3.5m, 2009



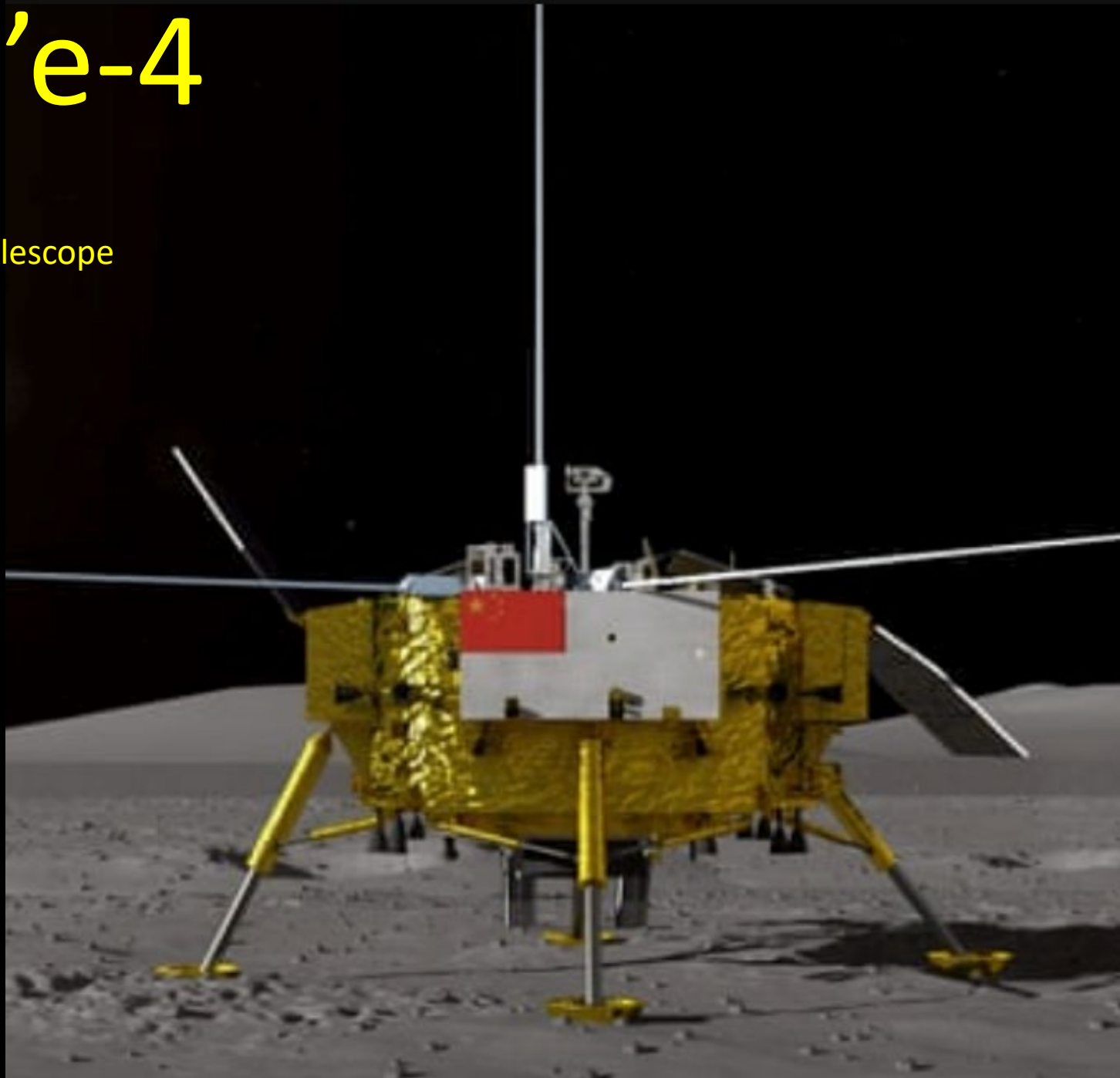
Hubble space telescope
2.4m, 1990



Chang'e-4

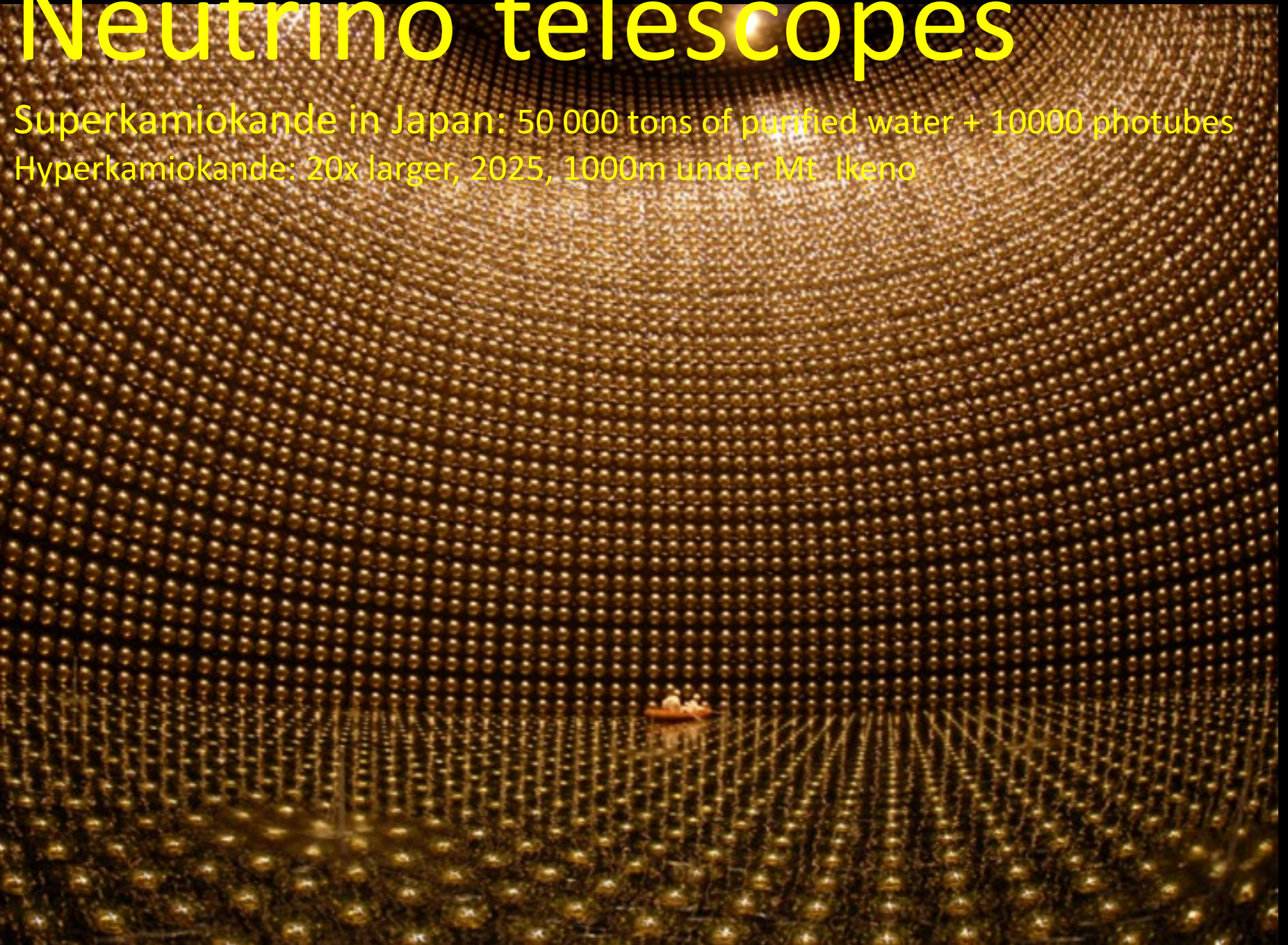
Jan 3, 2019

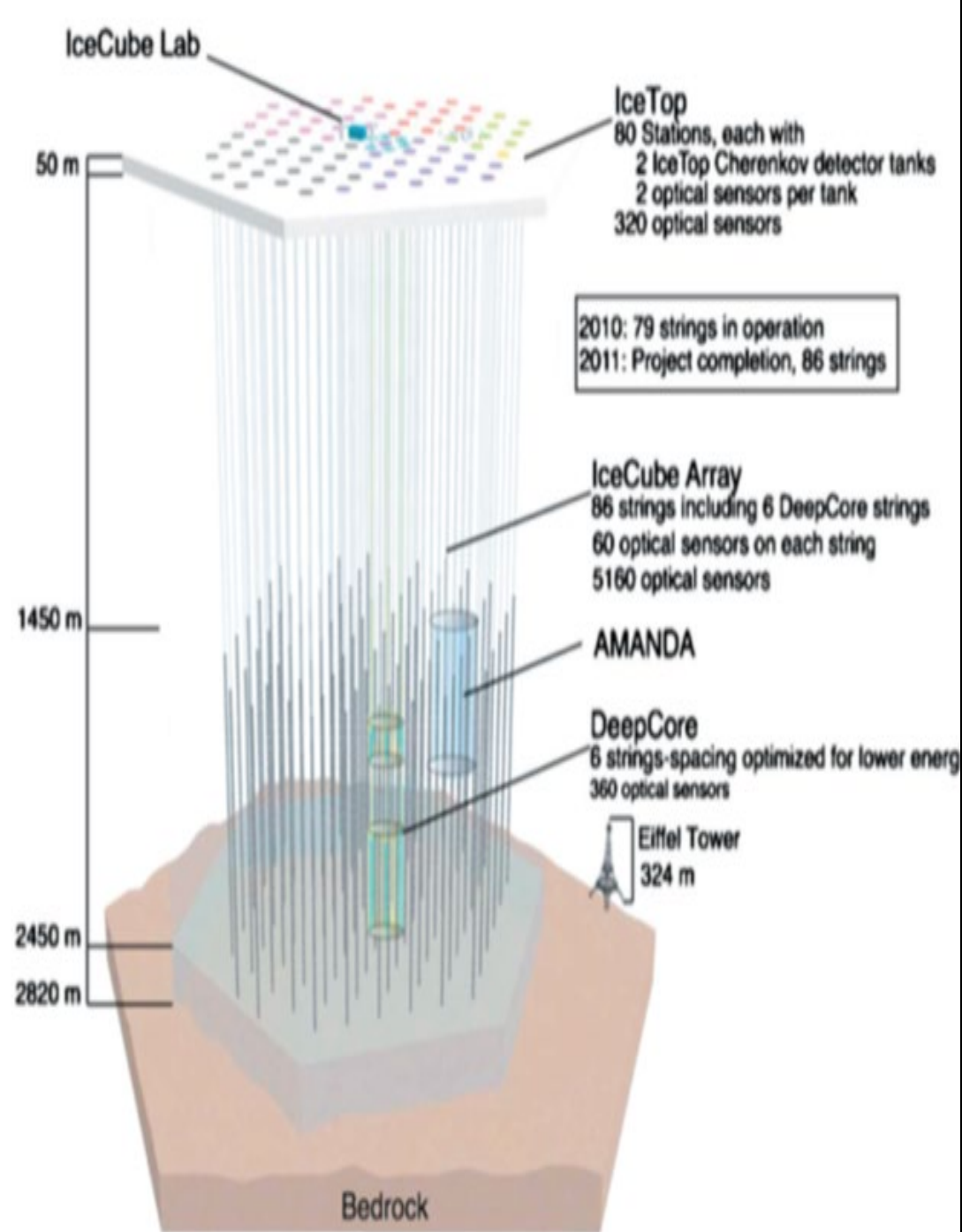
Low frequency radio telescope



Neutrino telescopes

Superkamiokande in Japan: 50 000 tons of purified water + 10000 phototubes
Hyperkamiokande: 20x larger, 2025, 1000m under Mt. Ikeno



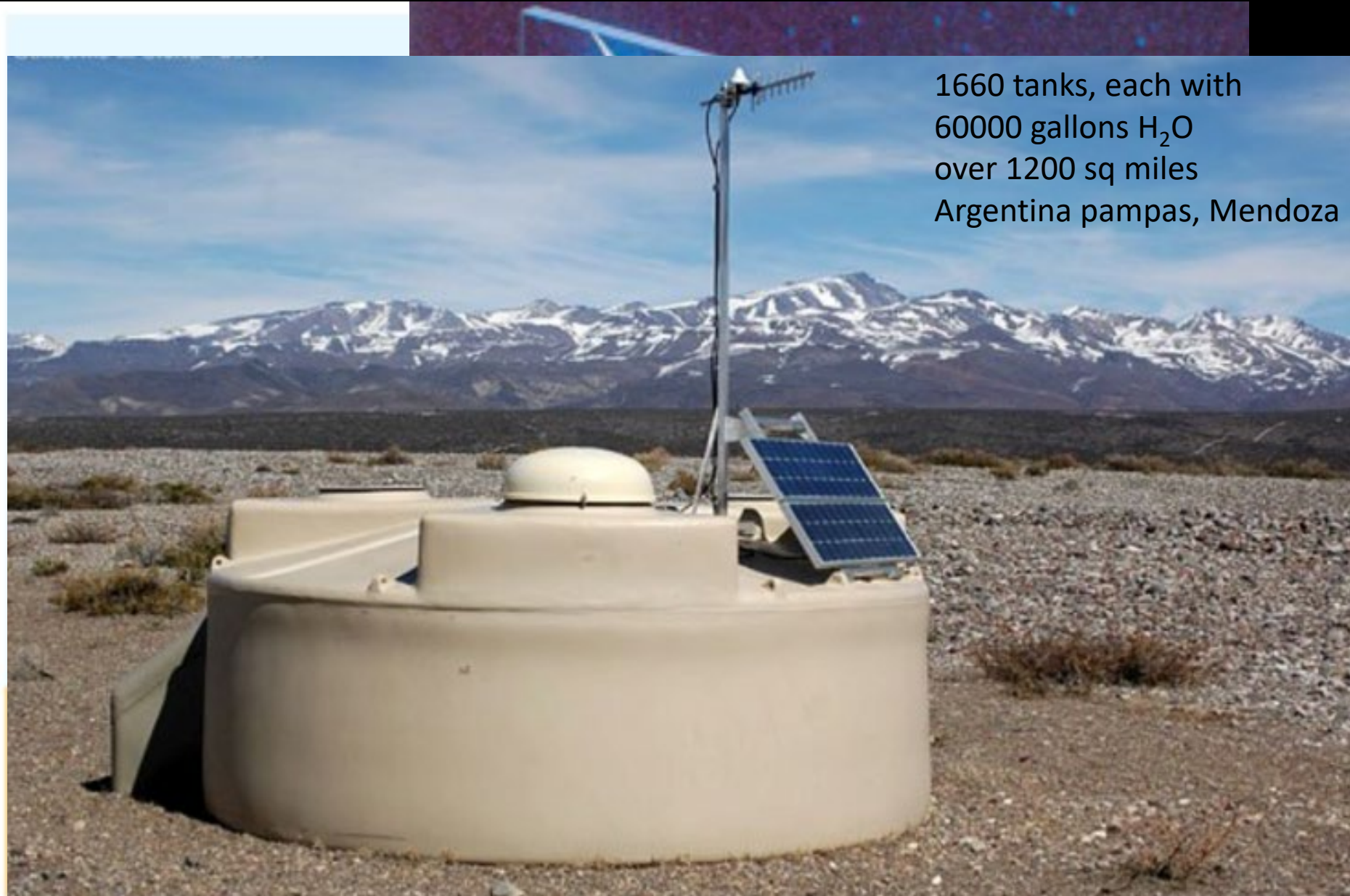


ICECUBE

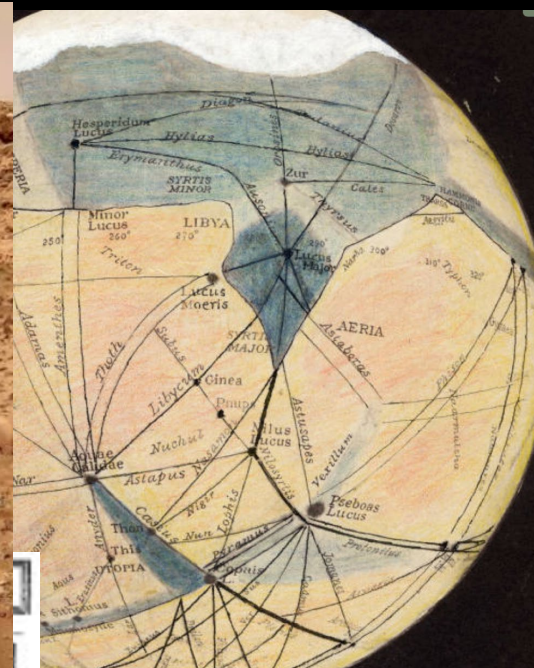
2.5 km under South Pole, 5000
 photosensors in 86 hot water-drilled
 holes: use Earth to filter upcoming events
 It's a km-size neutrino telescope!



Ultrahigh energy cosmic ray telescope



1660 tanks, each with
60000 gallons H_2O
over 1200 sq miles
Argentina pampas, Mendoza



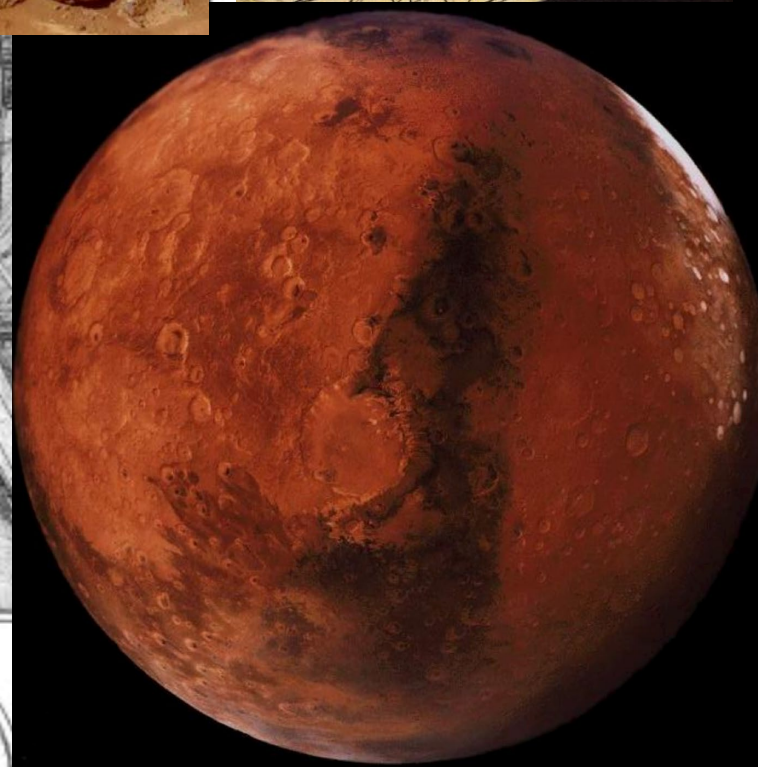
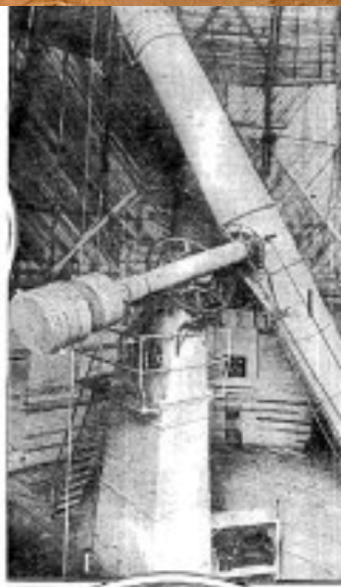
Wonders of the September Sky.

By Mary Stewart.

[illegible]

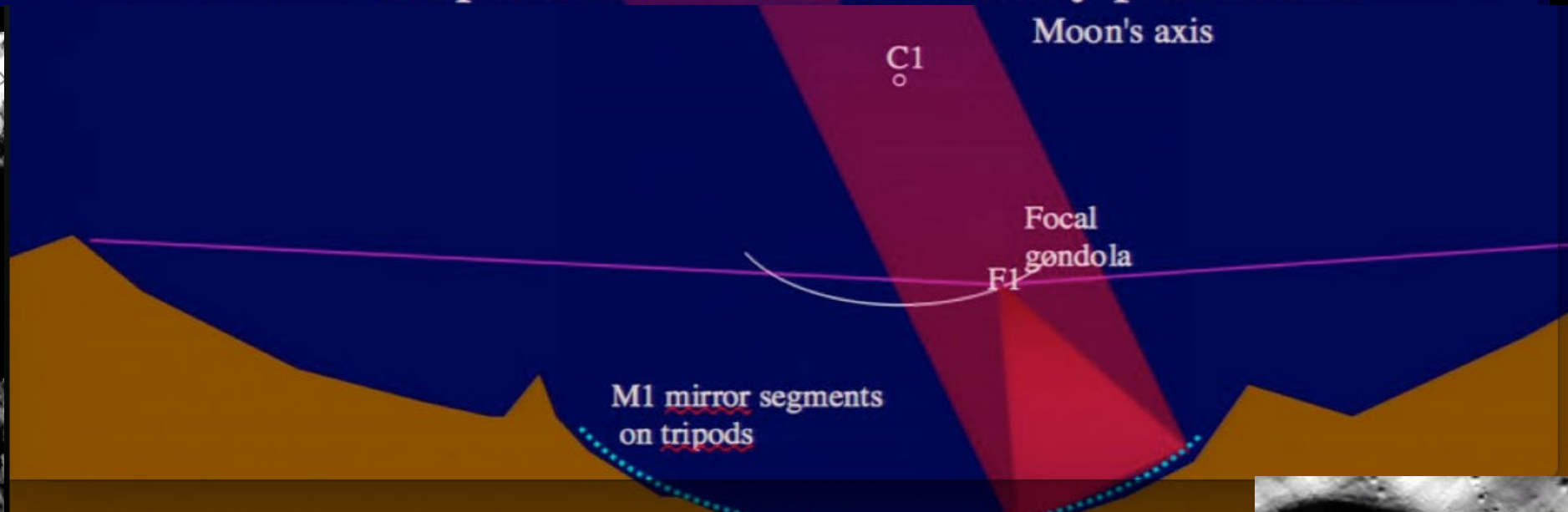
Wash. Post, Carroll and Paul, B. G. *Washes Show the New Course Just Observed*

NY Times 1911

[illegible]

A 5 km hypertelescope on the Moon

- Fixed segmented primary mirror, 5-10 m size
- Meta-aperture size: 5 km, limited by crater depth
- Focal camera suspended from cable, actively pendulated



TRAPPIST-1 System First images of exoplanets by 2040

40 lt yrs away

