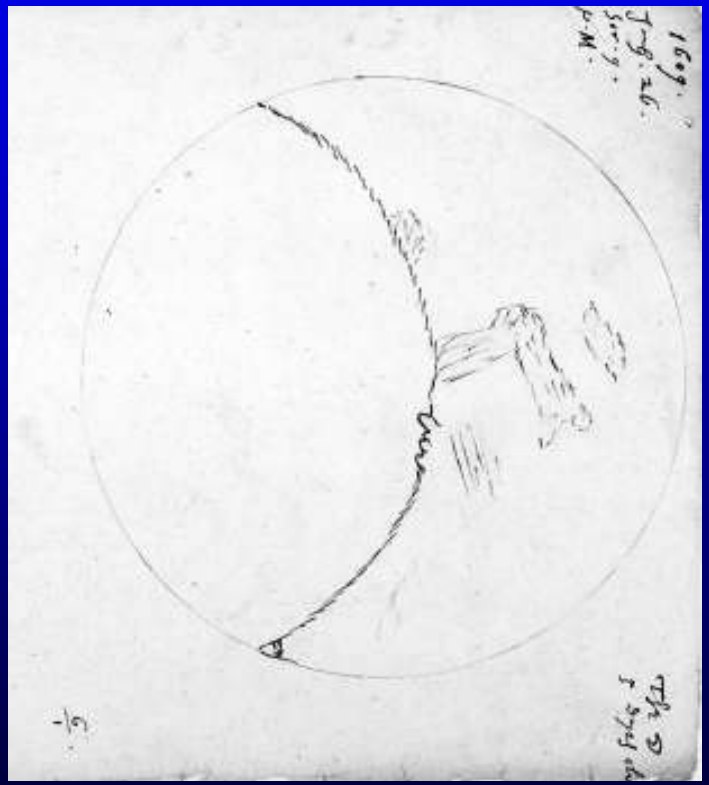
GRESHAM COLLEGE

400 years of the Telescope

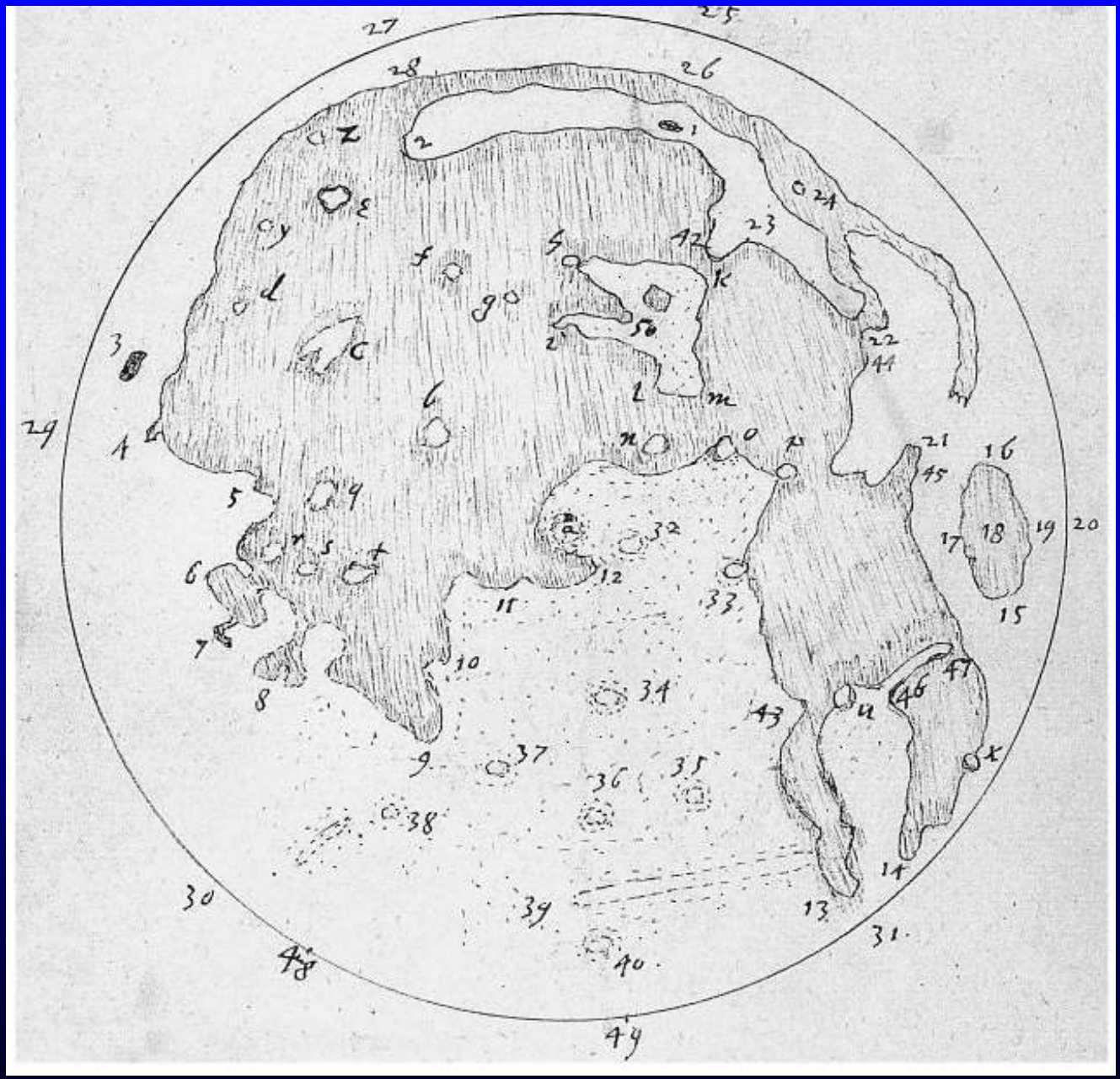
Ian Morison

Gresham Professor of Astronomy

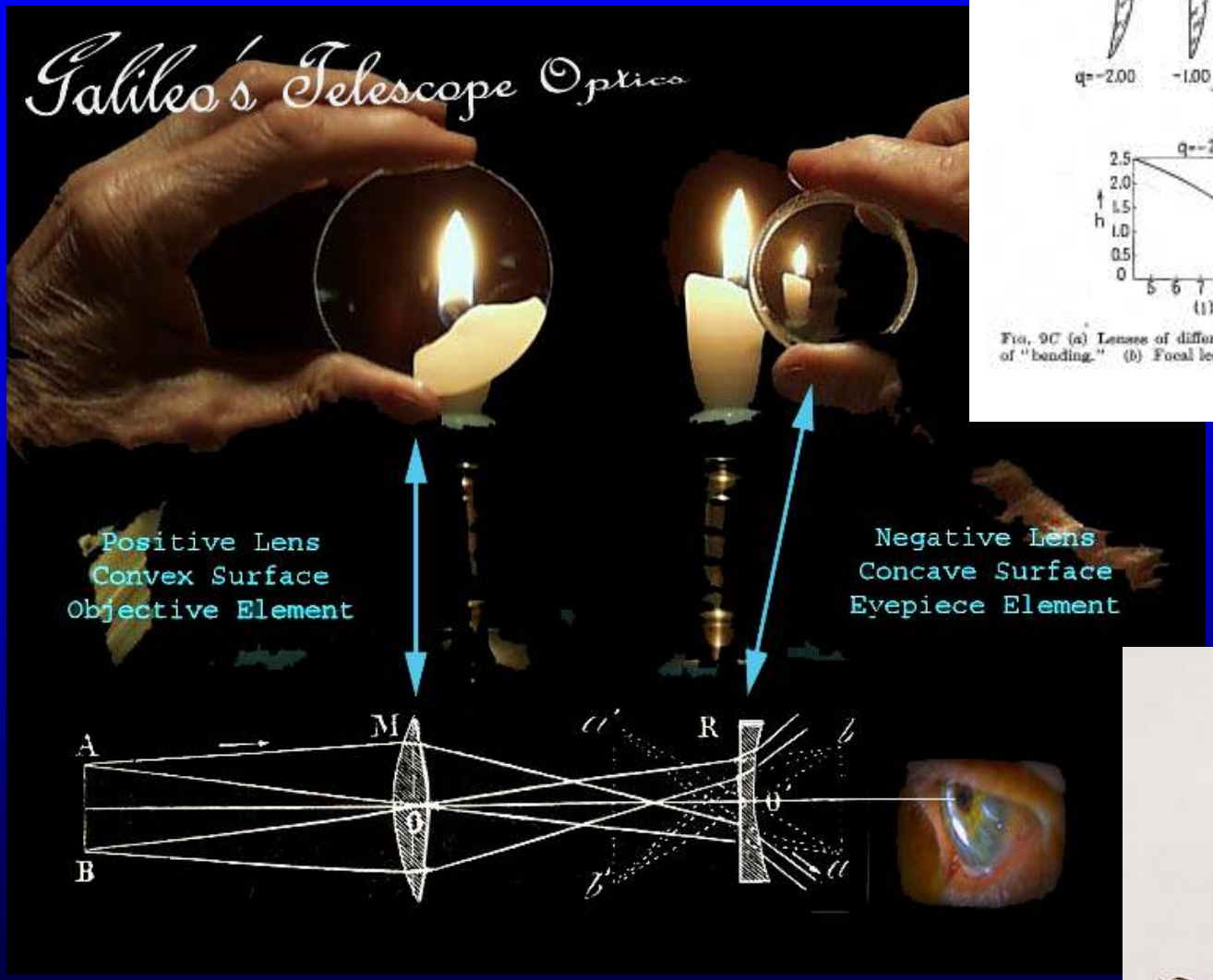
Thomas Harriot



Theophilus, Cyrillus and Catharina


27
25
28
26
2
1
24
23
22
44
29
4
5
6
7
8
9
10
11
12
32
33
34
37
36
35
38
39
40
30
48
49
31
13
14
43
42
46
47
45
21
16
17
18
19
20
15
3
a
b
c
d
e
f
g
h
i
k
l
m
n
o
p
q
r
s
t
u
x
y
z

Galileo Galilei



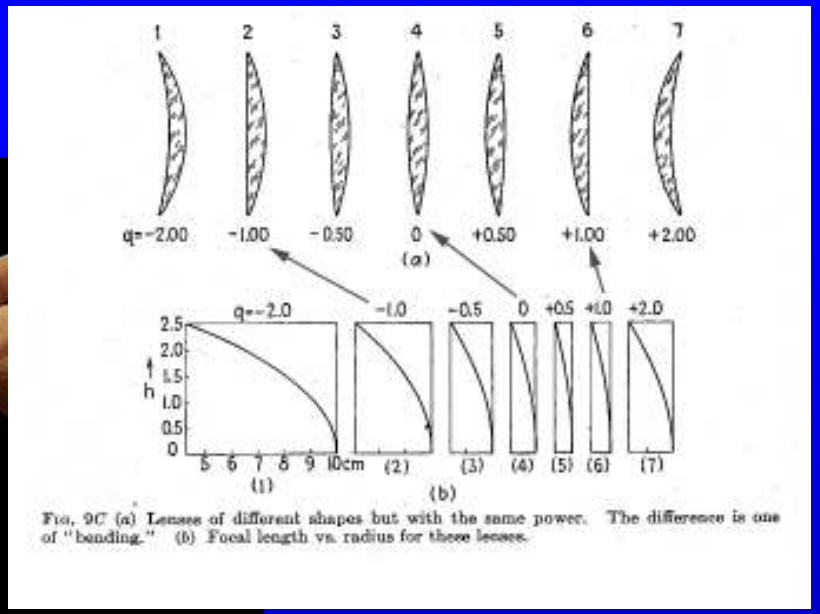
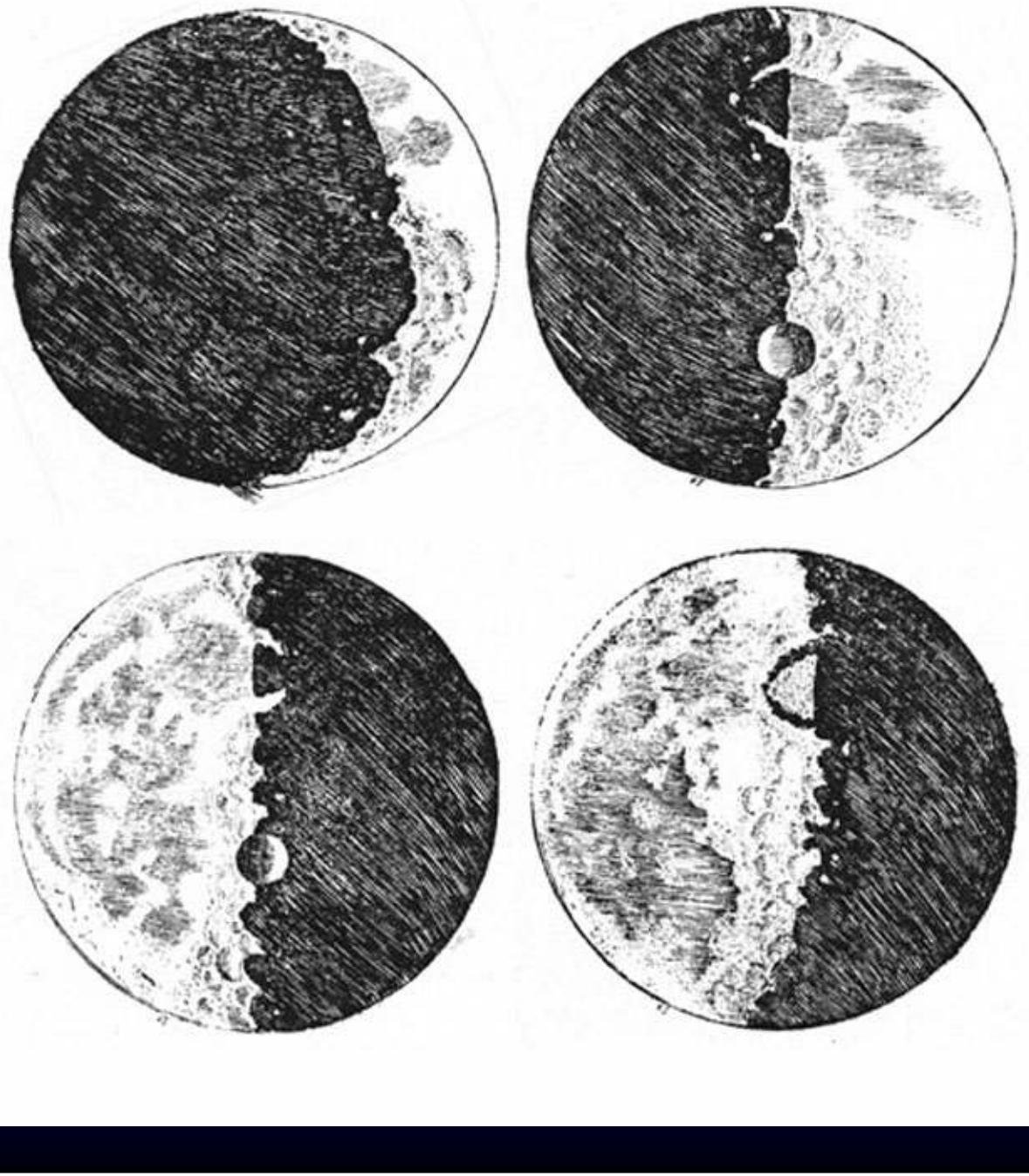
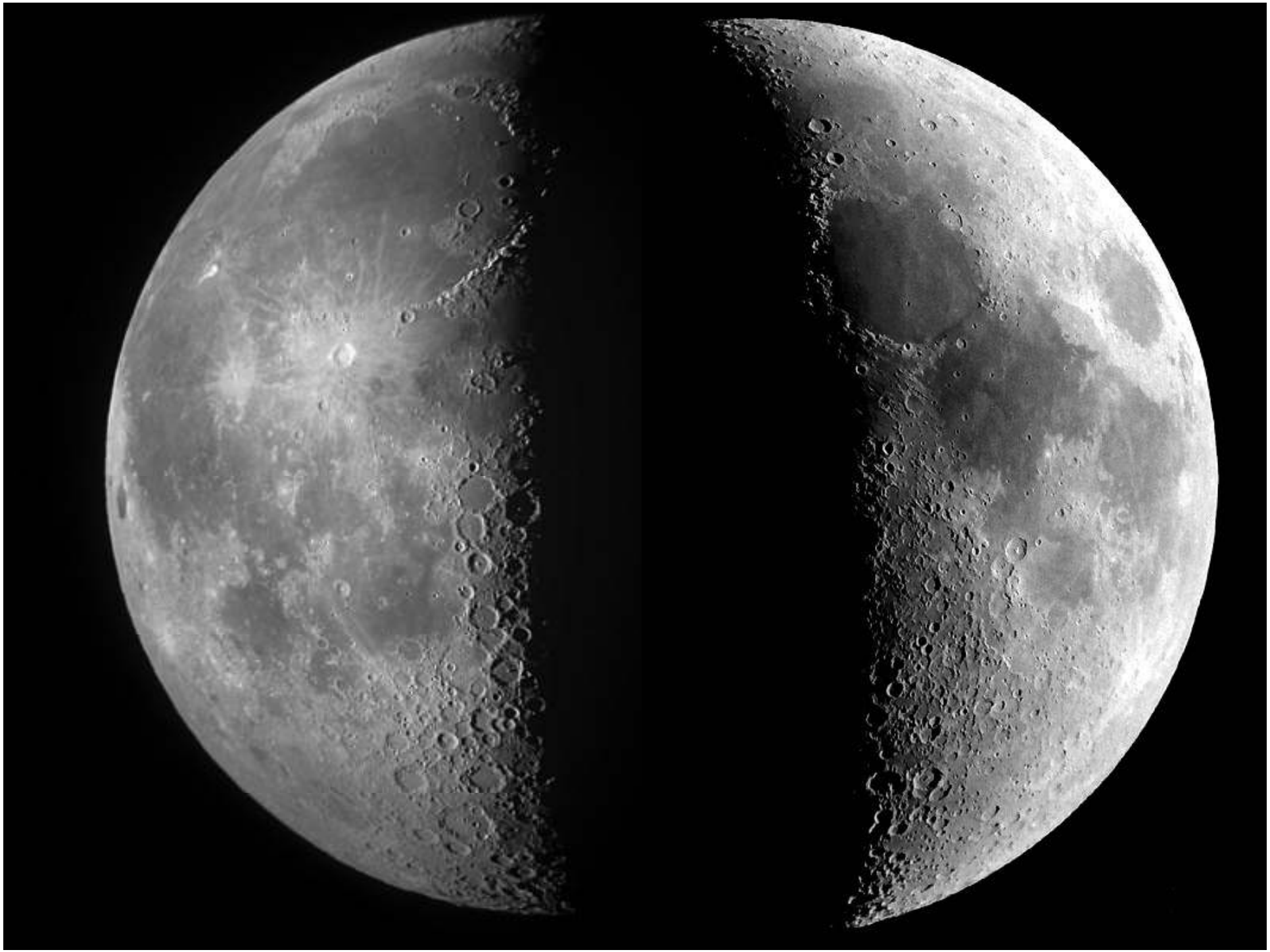
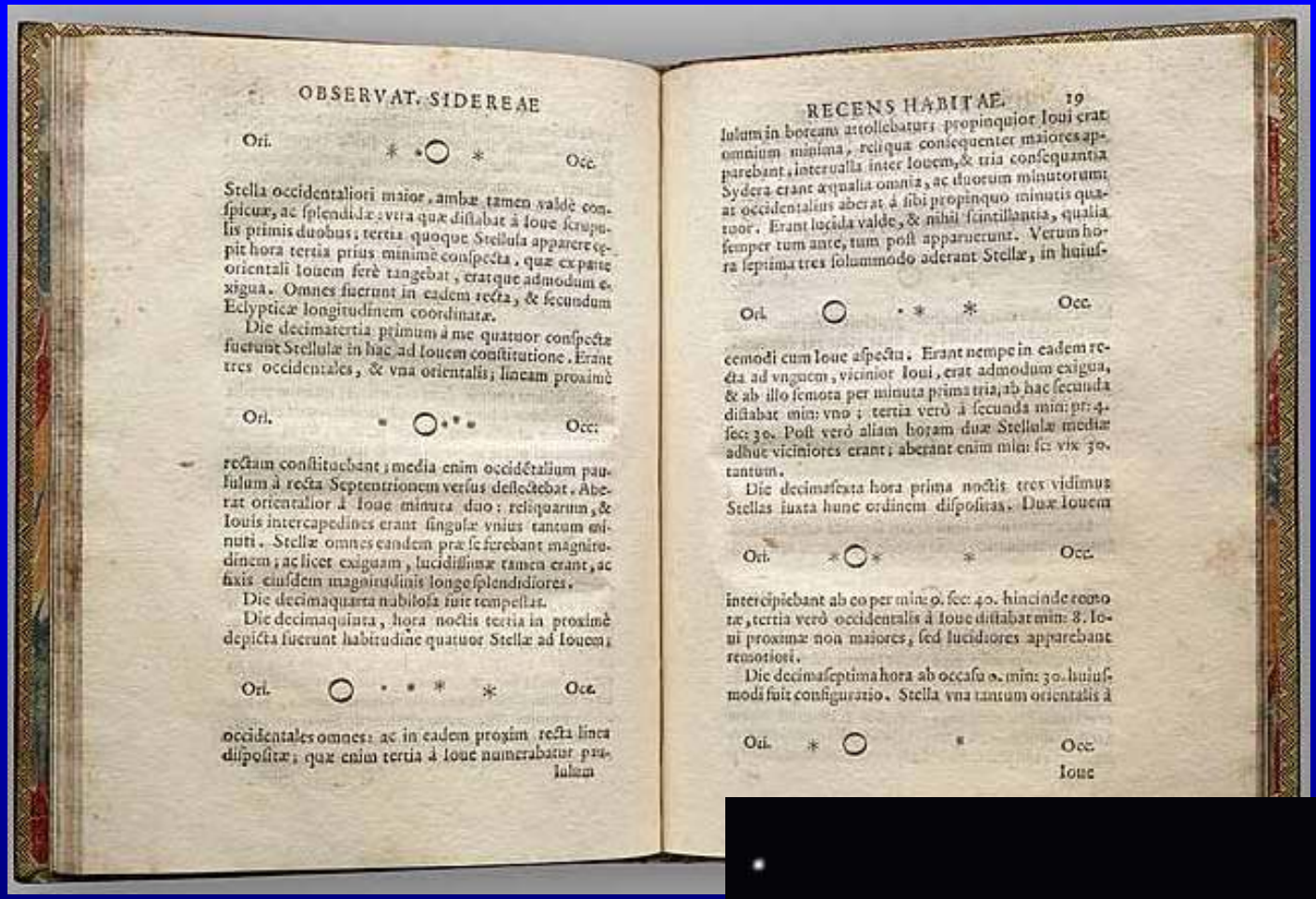


FIG. 9C (a) Lenses of different shapes but with the same power. The difference is one of "bending." (b) Focal length vs. radius for these lenses.





The Moons of Jupiter



OBSERVAT. SIDEREAE

Ori. * *○ * Occ.

Stella occidentaliori maior, ambæ tamen valdè conspicuæ, ac splendidæ: vtra quæ distabat à Ioue scrupulis primis duobus; tertia quoque Stellula apparere cepit hora tertia prius minimè conspecta, quæ ex parte orientali Iouem ferè tangebat, eratque admodum exigua. Omnes fuerunt in eadem recta, & secundum Eclypticæ longitudinem coordinatæ.

Die decimatertia primum à me quatuor conspectæ fuerunt Stellulæ in hac ad Iouem constitutione. Erant tres occidentales, & vna orientalis; lineam proximè

Ori. * ○ * * Occ.

rectam constituebant; media enim occidentalium paululum à recta Septentrionem versus deflectebat. Aberat orientalior à Ioue minuta duo: reliquarum, & Iouis intercapedines erant singulæ vnius tantum minuti. Stellæ omnes eandem præ se ferebant magnitudinem; ac licet exiguam, lucidissimæ tamen erant, ac fixis eiusdem magnitudinis longe splendidiores.

Die decimaquarta nubilosa fuit tempestas.

Die decimaquinta, hora noctis tertia in proximè depicta fuerunt habitudine quatuor Stellæ ad Iouem;

Ori. ○ * * * Occ.

occidentales omnes: ac in eadem proxim recta linea dispositæ; quæ enim tertia à Ioue numerabatur paululum

RECENS HABITAE. 19

Iulum in boream attollebatur: propinquior Ioui erat omnium minima, reliquæ consequenter maiores apparebant, intervalla inter Iouem, & tria consequentia Sydera erant æqualia omnia, ac duorum minutorum; at occidentalius aberat à sibi propinquo minutis quatuor. Erant lucida valde, & nihil scintillantia, qualia semper tum ante, tum post apparuerunt. Verum hora septima tres solummodo aderant Stellæ, in huiusmodi cum Ioue aspectu. Erant nempe in eadem recta ad vnguem, vicinior Ioui, erat admodum exigua, & ab illo semota per minuta prima tria; ab hac secunda distabat min: vno; tertia verò à secunda min: pr: 4. sec: 30. Post verò aliam horam duæ Stellulæ mediæ adhuc viciniores erant; aberant enim min: sc: vix 30. tantum.

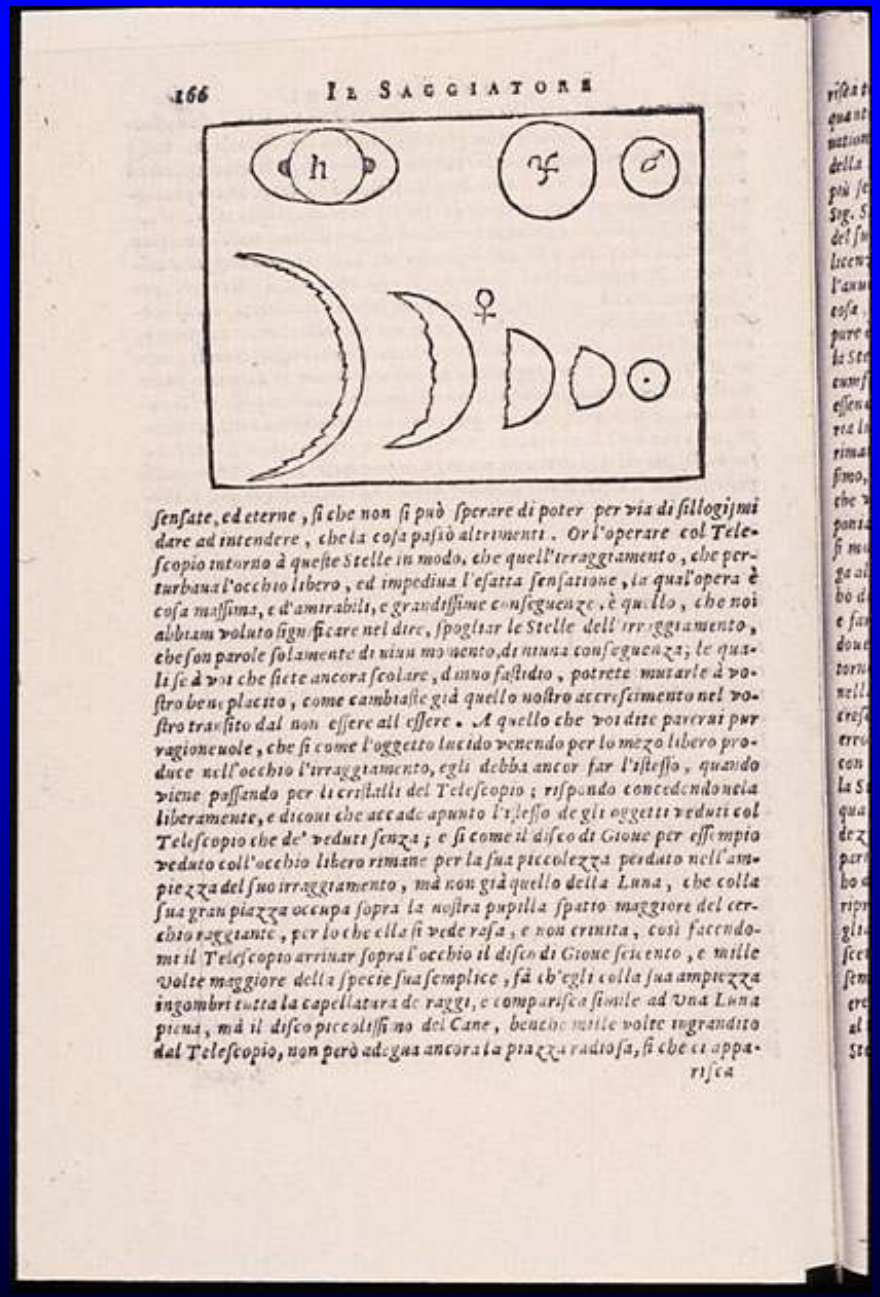
Ori. * ○ * * Occ.

Die decimasexta hora prima noctis tres vidimus Stellas iuxta hunc ordinem dispositas. Duæ Iouem intercipiebant ab eo per min: 0. sec: 40. hinc inde remotæ, tertia verò occidentalis à Ioue distabat min: 8. Ioui proximæ non maiores, sed lucidiores apparebant remotiori.

Die decimaseptima hora ab occasu 0. min: 30. huiusmodi fuit configuratio. Stella vna tantum orientalis à

Ori. * ○ * Occ.

Ioue



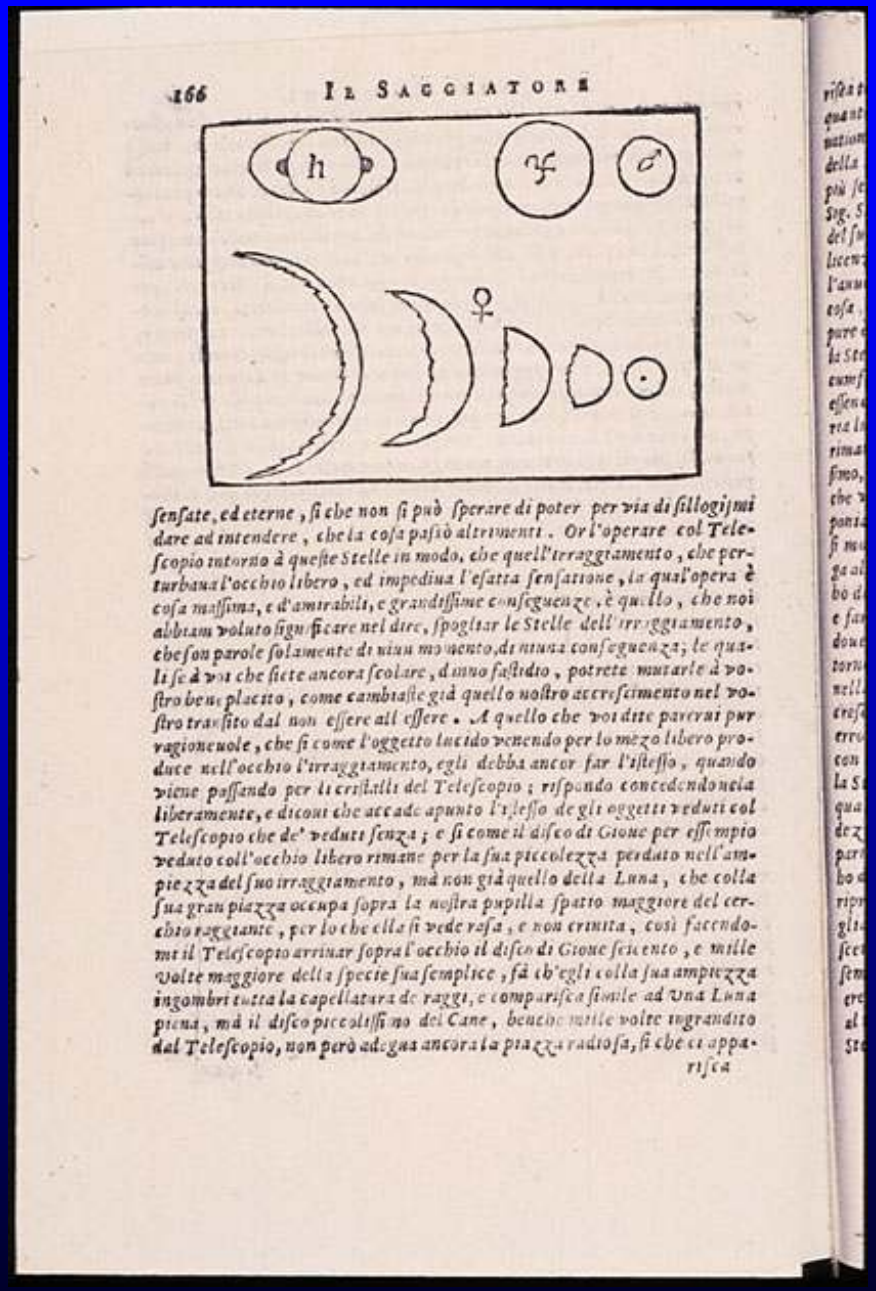
166 IL SAGGIATORE

senſate, ed eterne, ſi che non ſi può ſperare di poter per via di ſillogiſmi dare ad intendere, che la coſa paſsò altrimenti. Or l'operare col Teleſcopio intorno à queſte Stelle in modo, che quell'irraggiamento, che perturbaua l'occhio libero, ed impediua l'eſatta ſenſatione, la qual'opera è coſa maſſima, e d'amirabili, e grandiſſime conſeguenze, è quello, che noi abbiam voluto ſignificare nel dire, ſpogliar le Stelle dell'irraggiamento, che ſon parole ſolamente di niun momento, di niuna conſeguenza; le quali ſe à voi che ſiete ancora ſcolare, d'inno faſtidio, potrete mutarle à voſtro beneplacito, come cambiaſte già quello noſtro accreſcimento nel voſtro tranſito dal non eſſere all eſſere. A quello che voi dite parevi pur ragioneuole, che ſi come l'oggetto lucido venendo per lo mezo libero produce nell'occhio l'irraggiamento, egli debba ancor far l'iſteſſo, quando viene paſſando per li criſtalli del Teleſcopio; riſpondo concedendouela liberamente, e diconi che accade apunto l'iſteſſo de gli oggetti veduti col Teleſcopio che de' veduti ſenza; e ſi come il diſco di Gioue per eſſempio veduto coll'occhio libero rimane per la ſua piccolezza perduto nell'ampiezza del ſuo irraggiamento, mà non già quello della Luna, che colla ſua gran piazza occupa ſopra la noſtra pupilla ſpatio maggiore del cerchio raggiante, per lo che ella ſi vede roſa, e non crinita, così facendomi il Teleſcopio arrivar ſopra l'occhio il diſco di Gioue ſeicento, e mille volte maggiore della ſpecie ſua ſemplice, fà ch'egli colla ſua ampiezza ingombri tutta la capellatura de raggi, e comparisca ſimile ad Una Luna piena, mà il diſco piccoliſſimo del Cane, benche mille volte ingrandito dal Teleſcopio, non però adegua ancora la piazza radioſa, ſi che ci appa-

riſca

Saturn

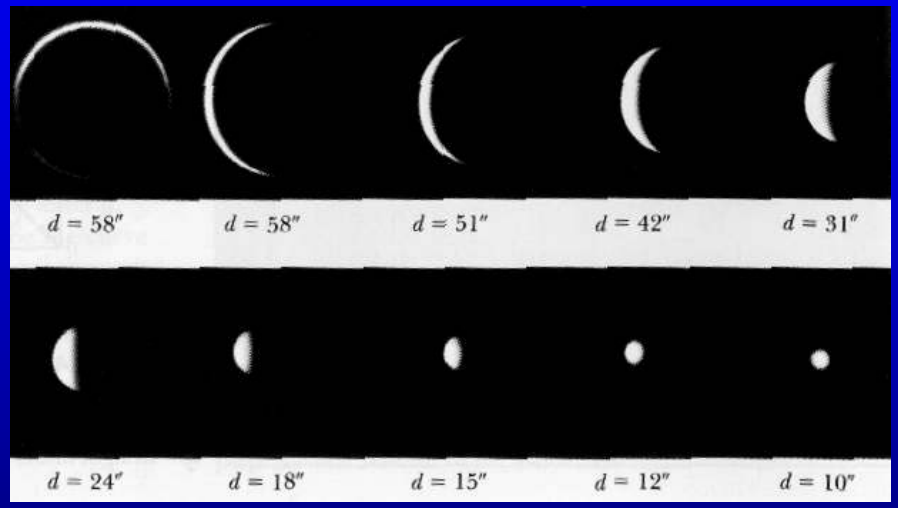
Venus



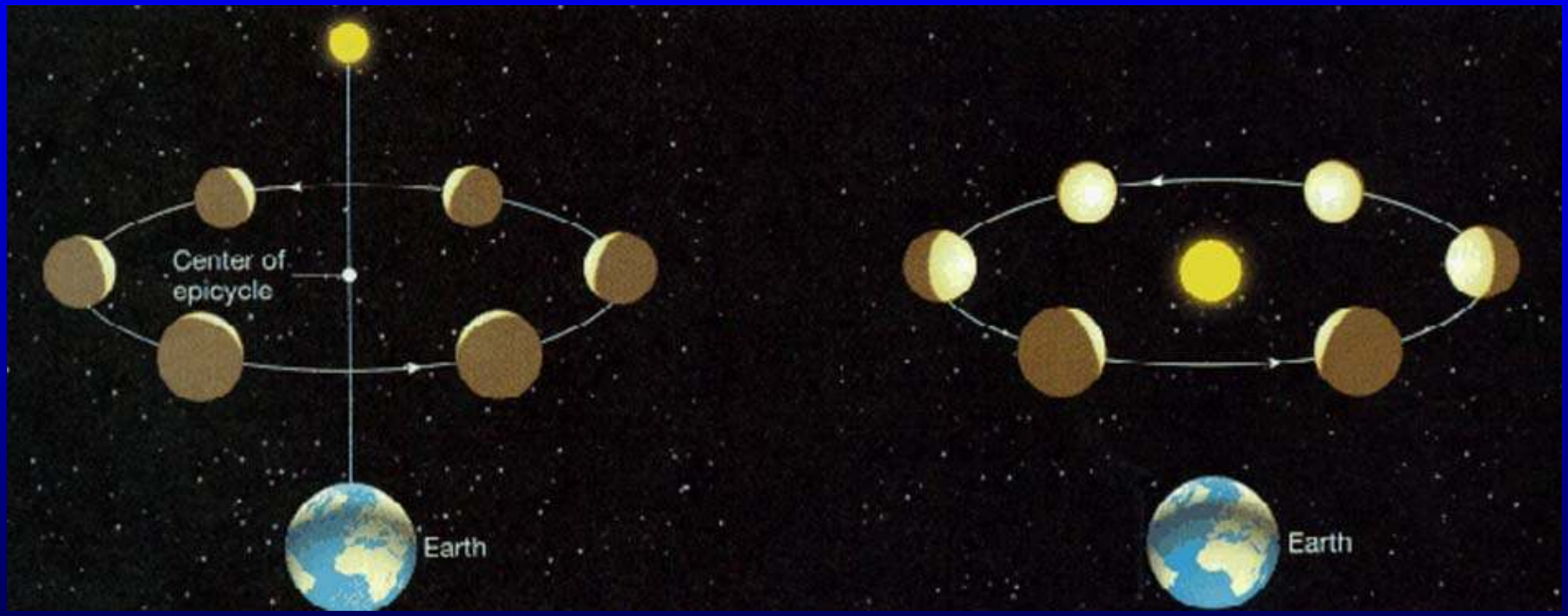
166 IL SAGGIATORE

ſenſate, ed eterne, ſi che non ſi può ſperare di poter per via di ſillogiſmi dare ad intendere, che la coſa paſsò altrimenti. Or l'operare col Teleſcopio intorno à queſte Stelle in modo, che quell'irraggiamento, che perturbaua l'occhio libero, ed impediua l'eſatta ſenſatione, la qual'opera è coſa maſſima, e d'ammirabili, e grandiſſime conſeguenze, è quello, che noi abbiam voluto ſignificare nel dire, ſpogliar le Stelle dell'irraggiamento, che ſon parole ſolamente di niun momento, di niuna conſeguenza; le quali ſe à voi che ſiete ancora ſcolare, d'alcun faſtidio, potrete mutarle à voſtro beneplacito, come cambiaſte già quello noſtro accreſcimento nel voſtro tranſito dal non eſſere all'eſſere. A quello che voi dite parerui pur ragioneuole, che ſi come l'oggetto lucido venendo per lo mezo libero produce nell'occhio l'irraggiamento, egli debba ancor far l'iſteſſo, quando viene paſſando per li criſtalli del Teleſcopio; riſpondo concedendouela liberamente, e dicoui che accade apunto l'iſteſſo de gli oggetti veduti col Teleſcopio che de' veduti ſenza; e ſi come il diſco di Gioue per eſſempio veduto coll'occhio libero rimane per la ſua piccolezza perduto nell'ampiezza del ſuo irraggiamento, ma non già quello della Luna, che colla ſua gran piazza occupa ſopra la noſtra pupilla ſpatio maggiore del cerchio raggiante, per lo che ella ſi vede roſa, e non crinita, così facendomi il Teleſcopio arriuar ſopra l'occhio il diſco di Gioue ſeicento, e mille volte maggiore della ſpecie ſua ſemplice, fà ch'egli colla ſua ampiezza ingombri tutta la capellatura de raggi, e comparisca ſimile ad vna Luna piena, ma il diſco piccoliſſimo del Cane, benche mille volte ingrandito dal Teleſcopio, non però adegua ancora la piazza radioſa, ſi che ci appa-

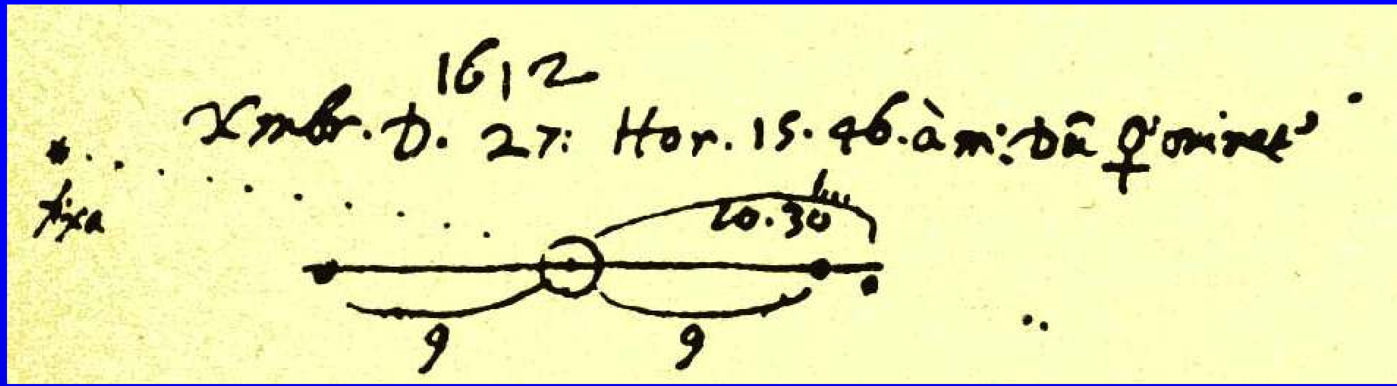
riſca



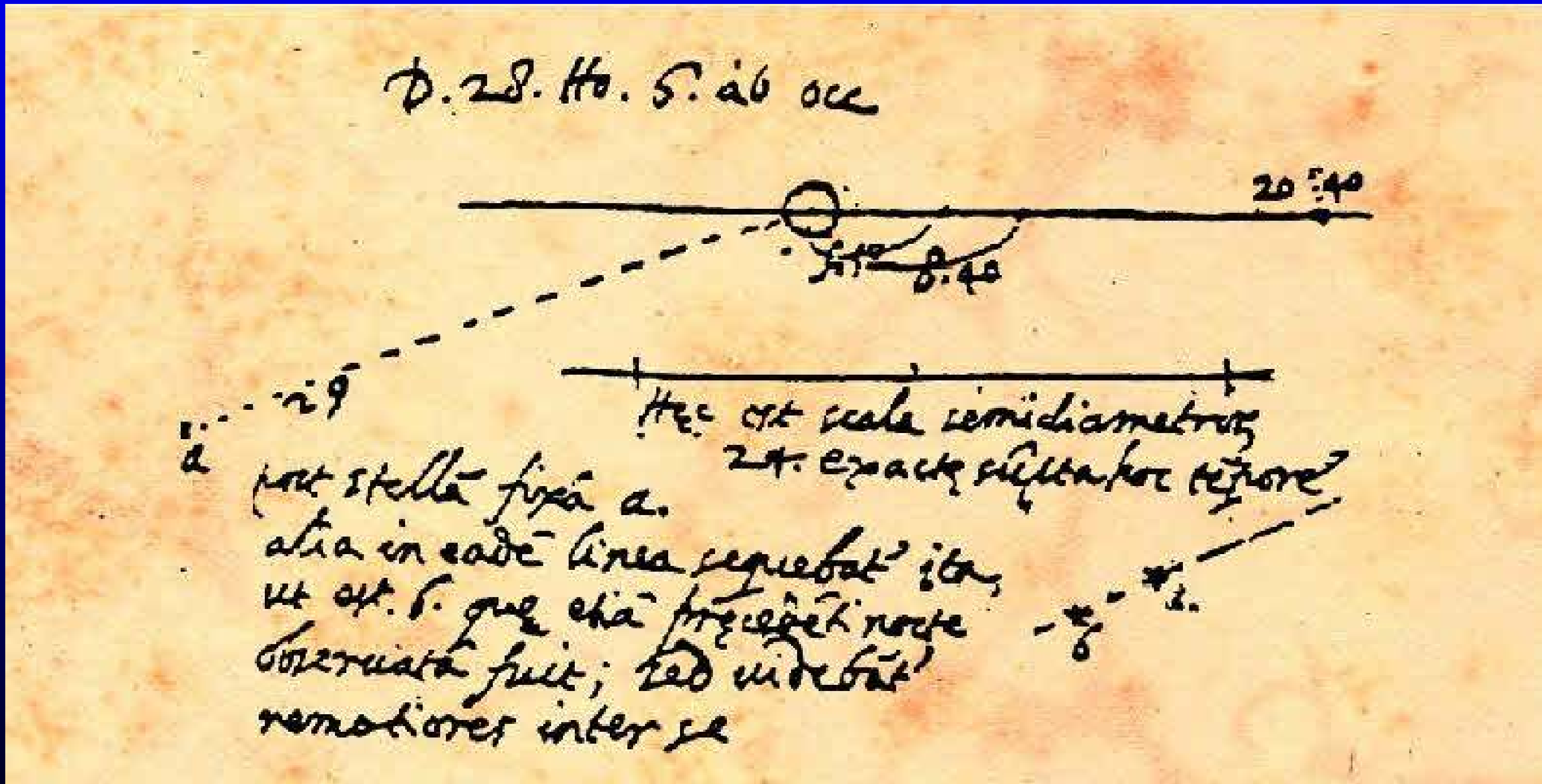
Venus must orbit the Sun



Neptune



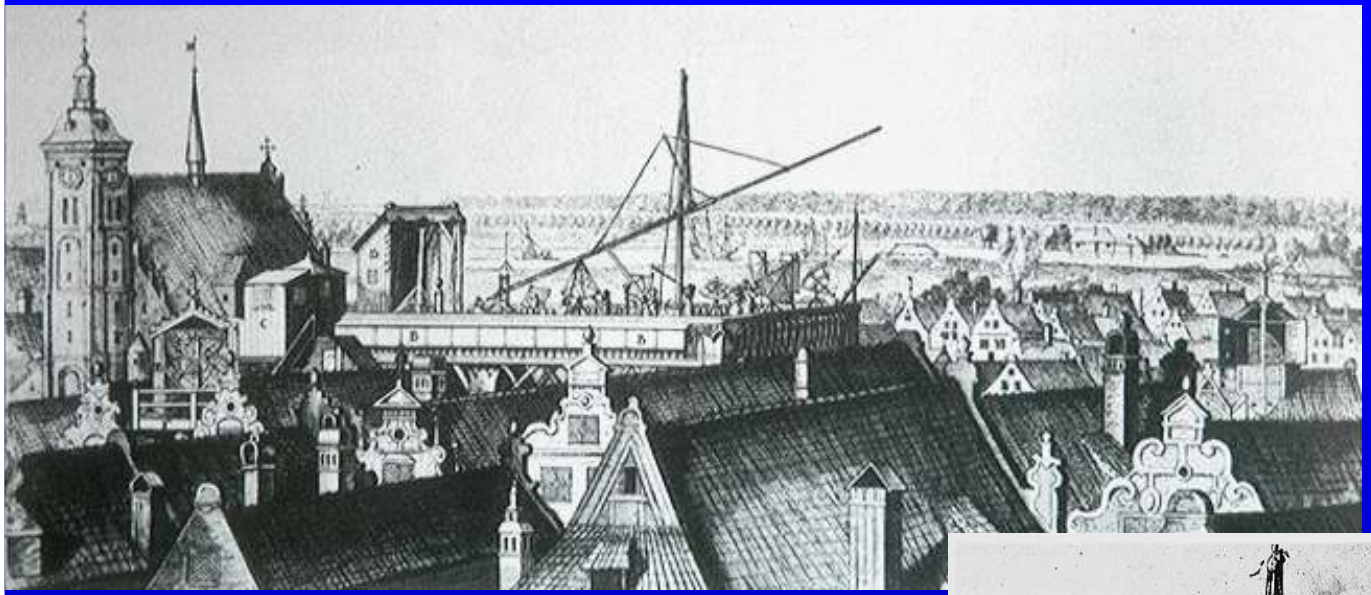
1612
fixa
20.30
9
9

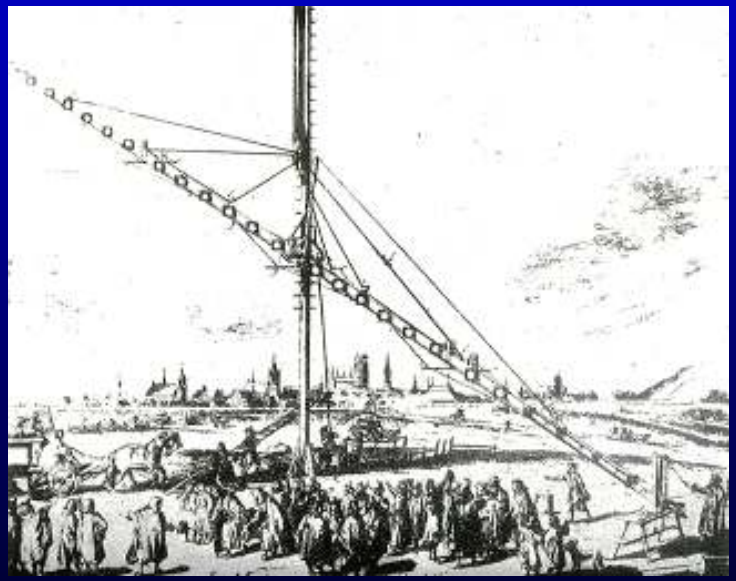


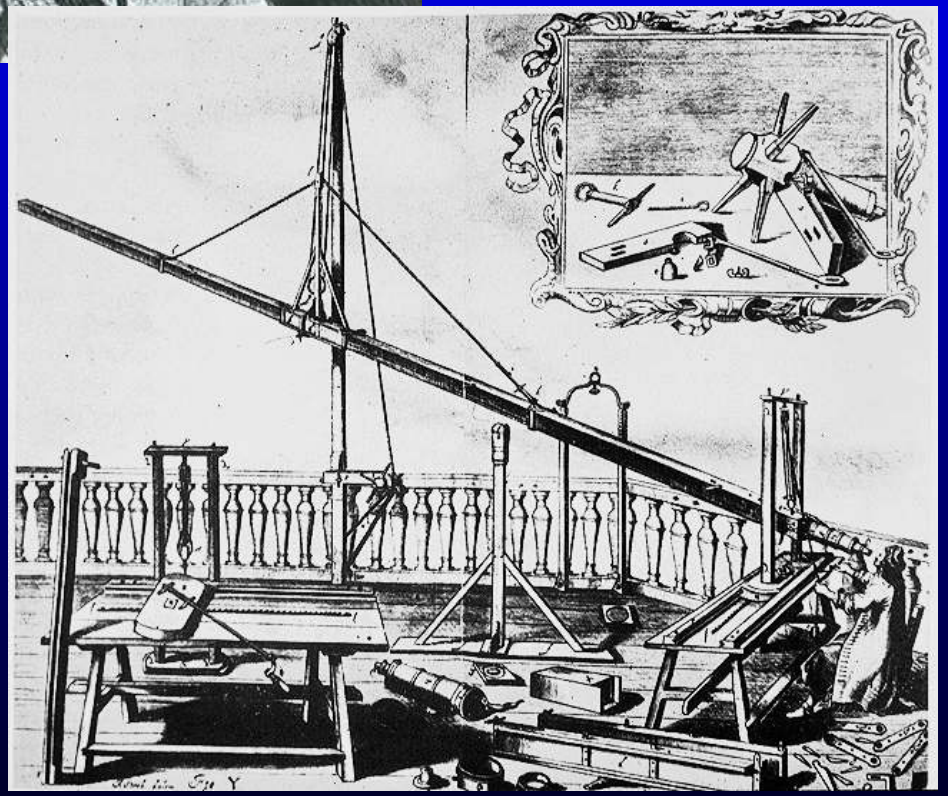
D. 28. Ho. 5. ab occ
20 :40
a
post stellā fixā a.
remotiores inter se


Callisto
Io
Jupiter
Ganymede
Neptune
Earth, Manchester, 41m
FOV 0.401°
15.7 FPS
1612-12-28 04:27:40

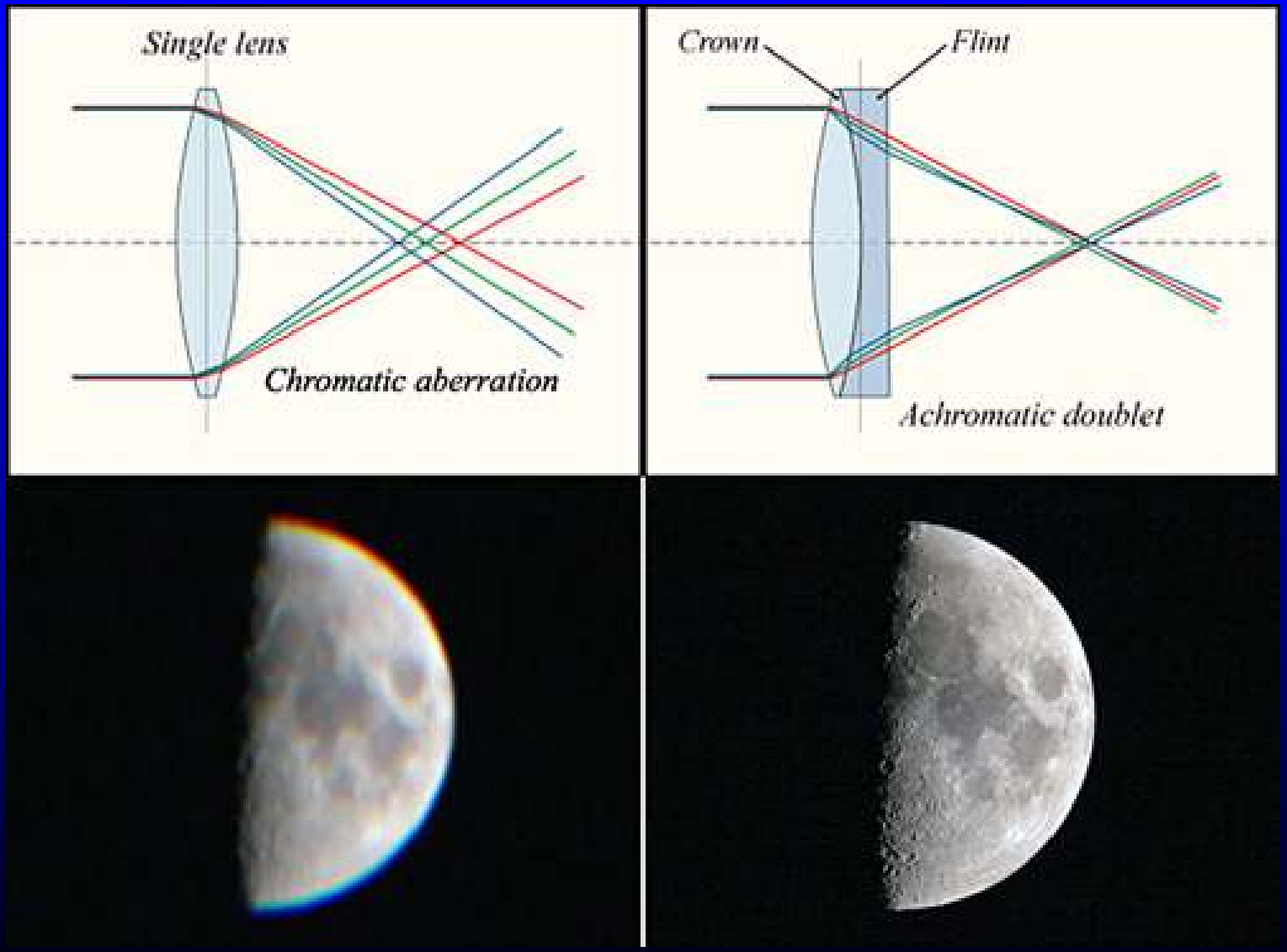
Helvelius



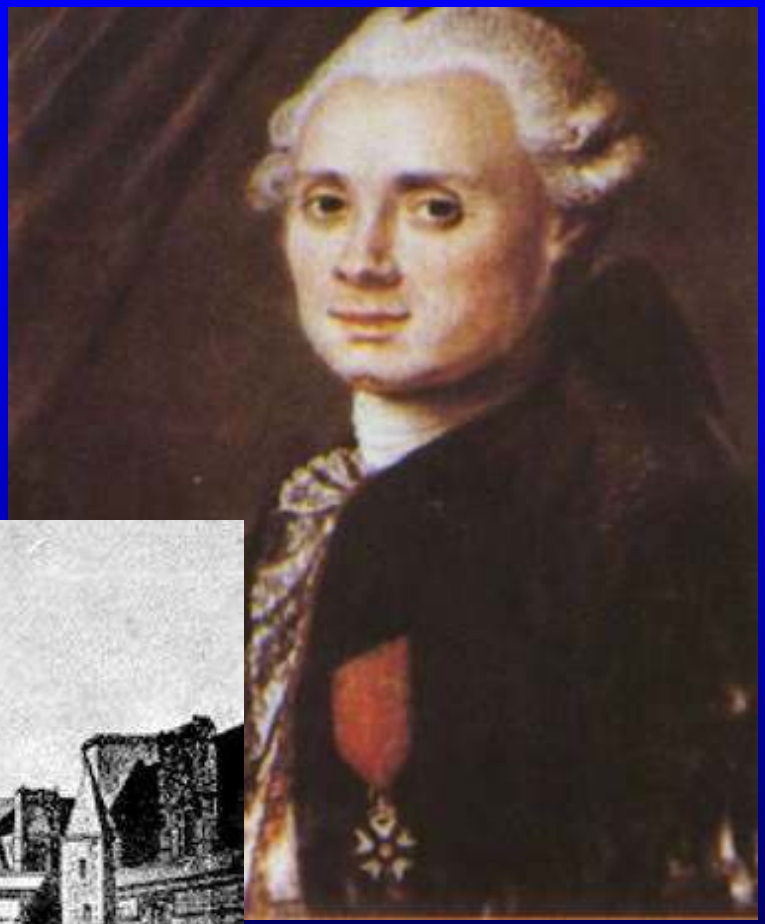


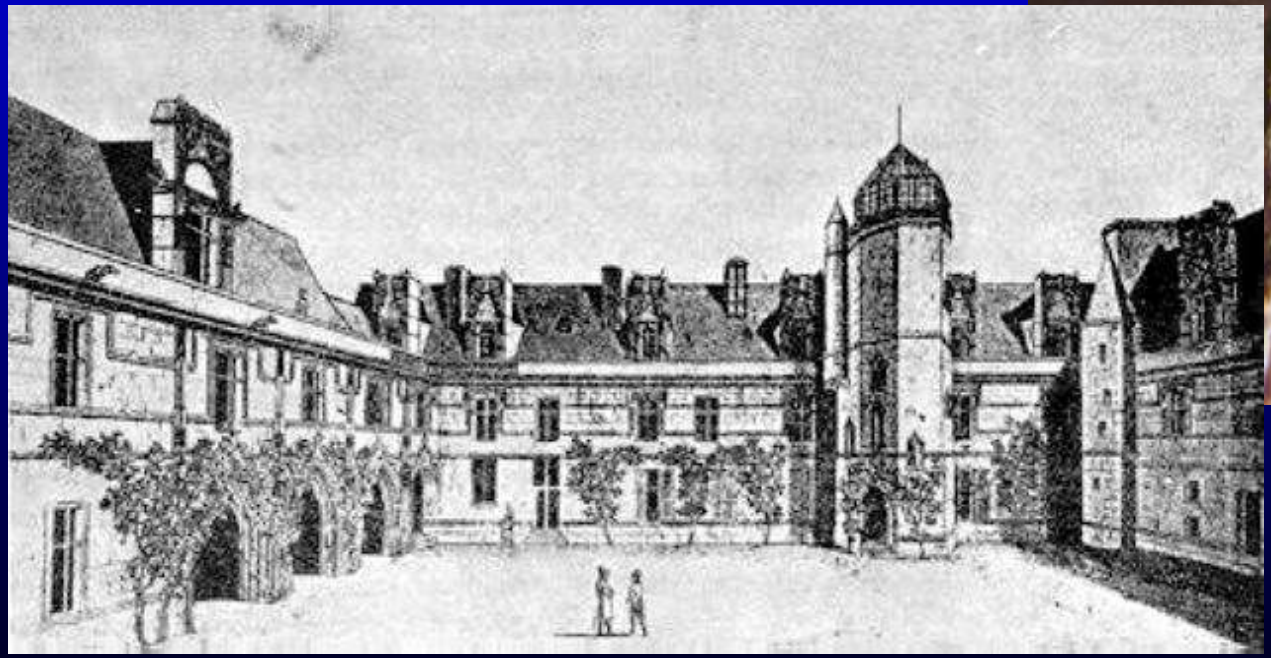


Achromatic Doublet



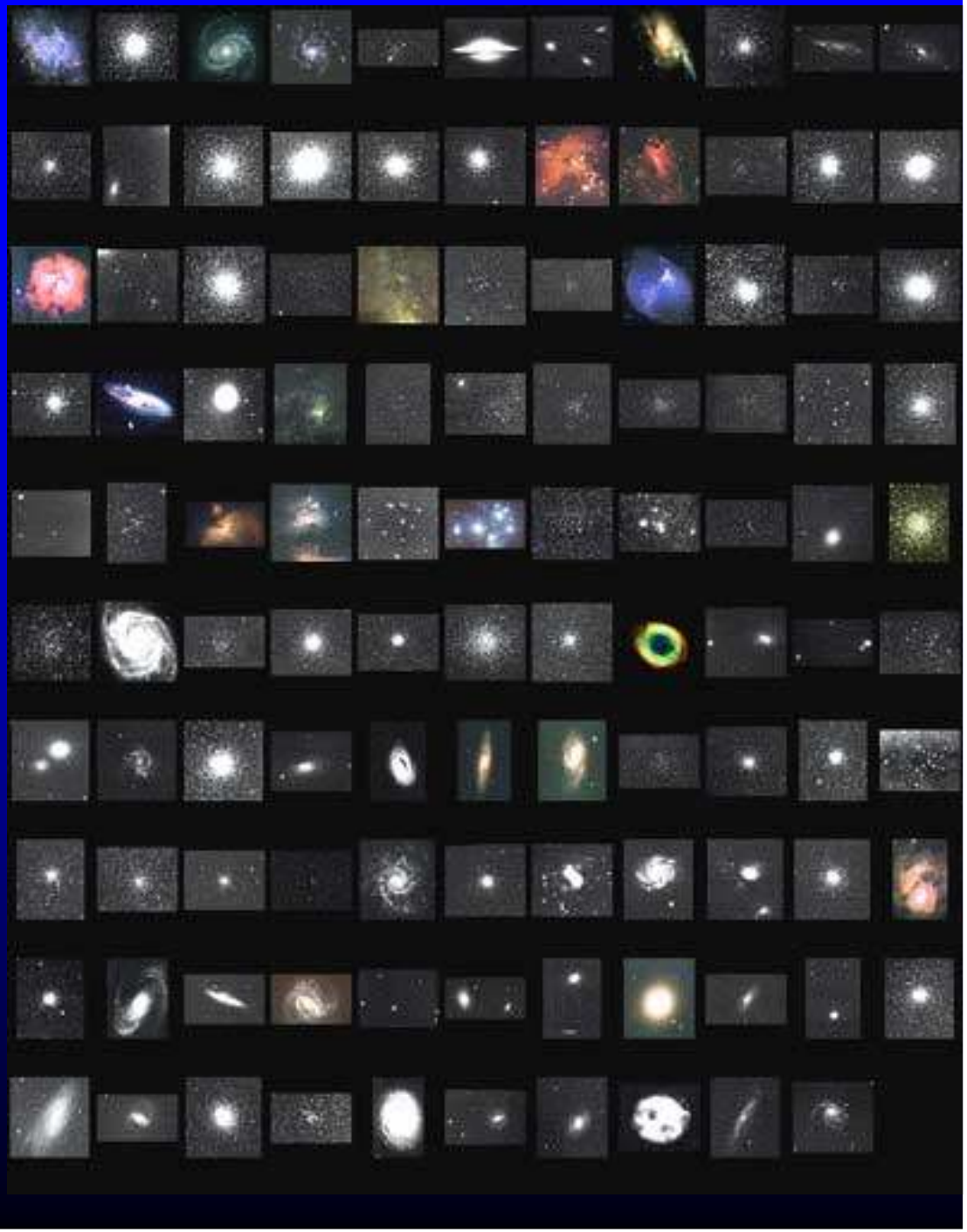
Charles Messier



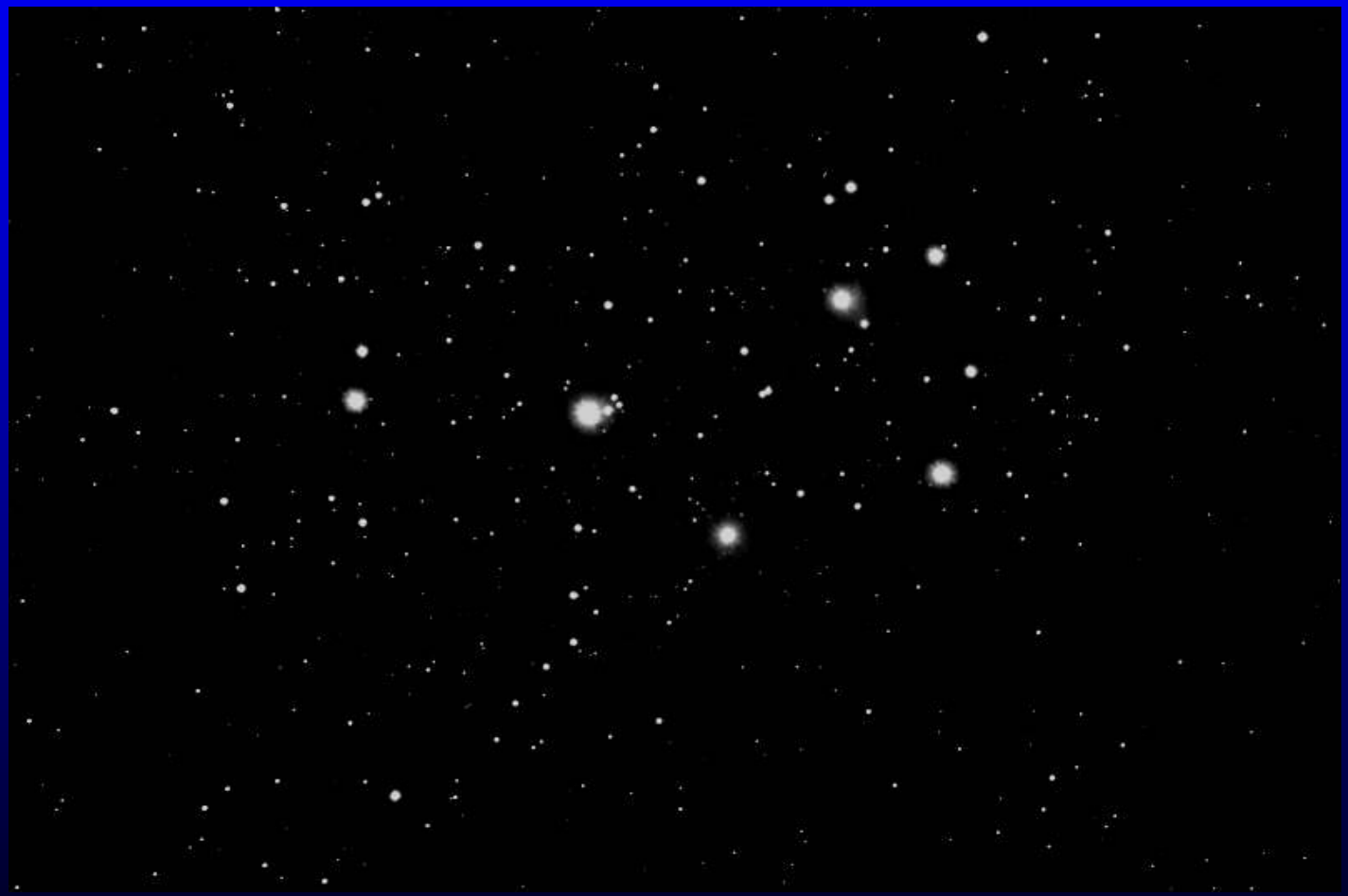


Messier's Catalogue

- Finally included 110 objects
  - Open Clusters
  - Globular Clusters
  - Planetary Nebulae
  - Galaxies



M45 – The Pleiades Cluster

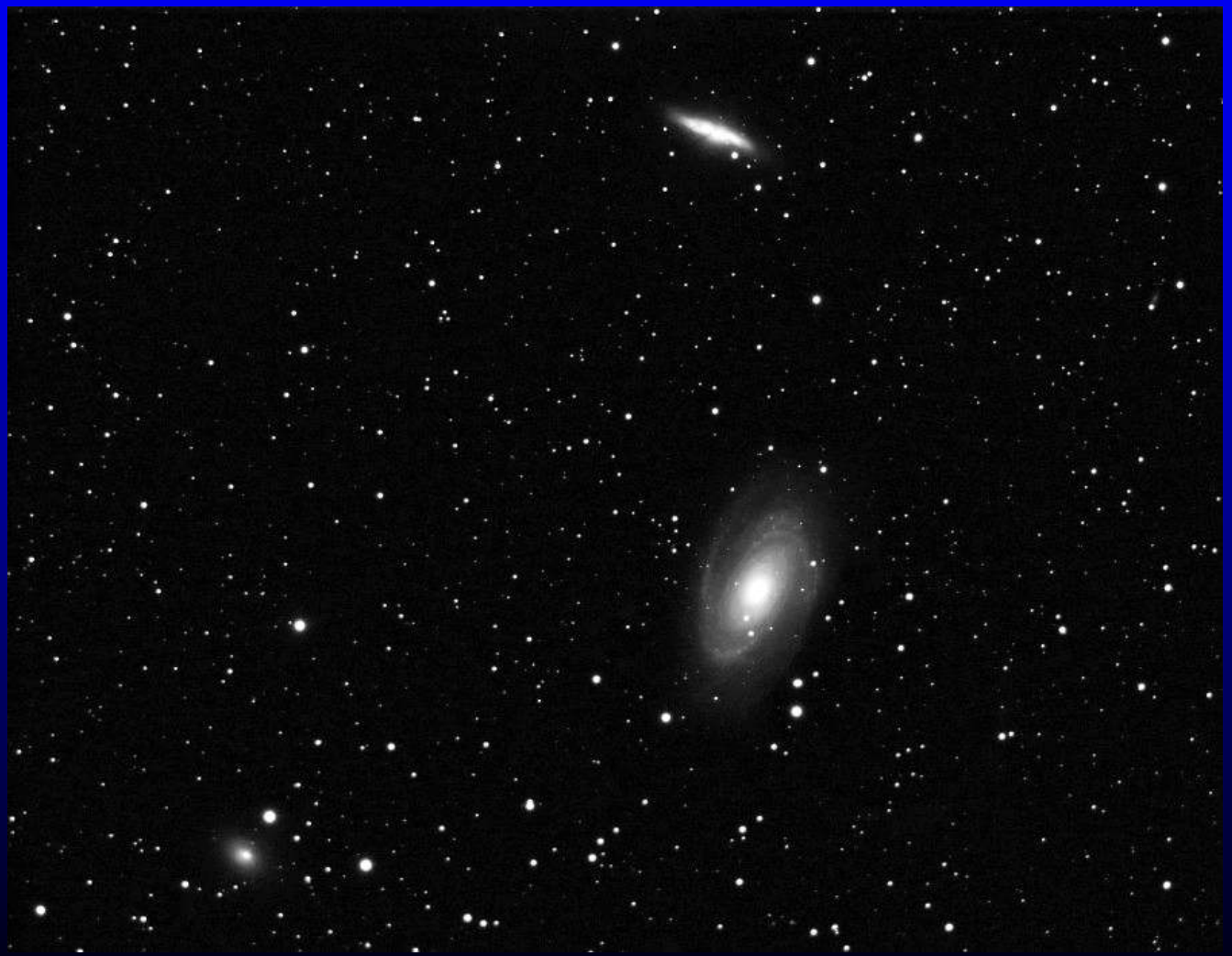


M13 – Globular Cluster

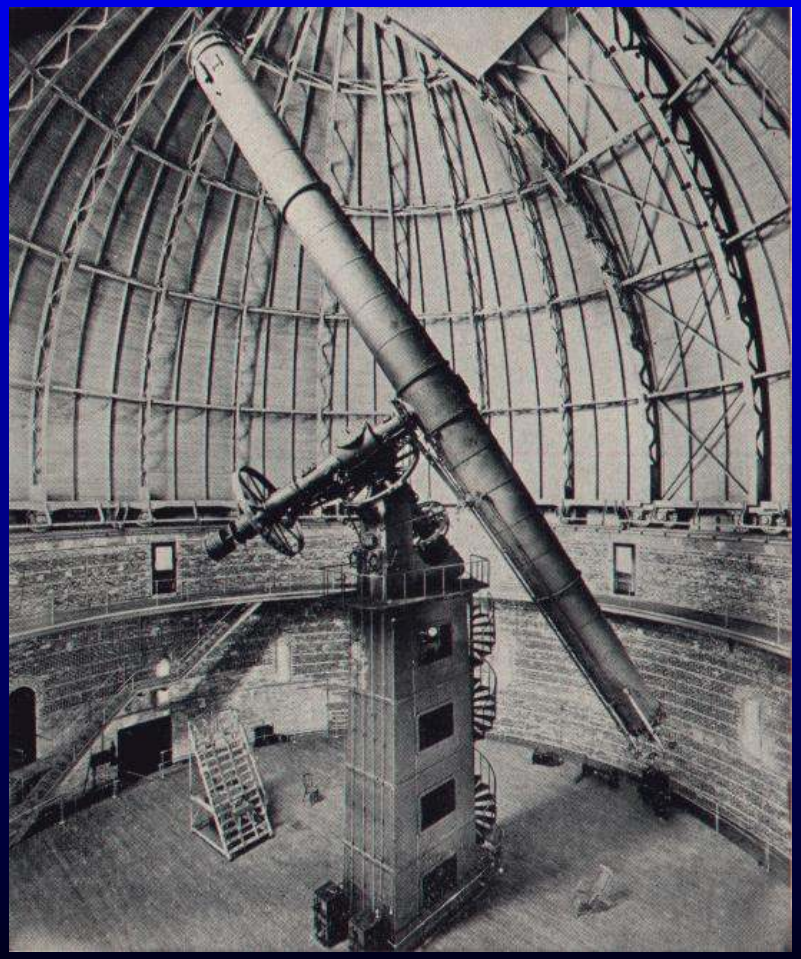
M27 - Dumbbell Nebula

M31 – The Andromeda Galaxy

M81 and M82

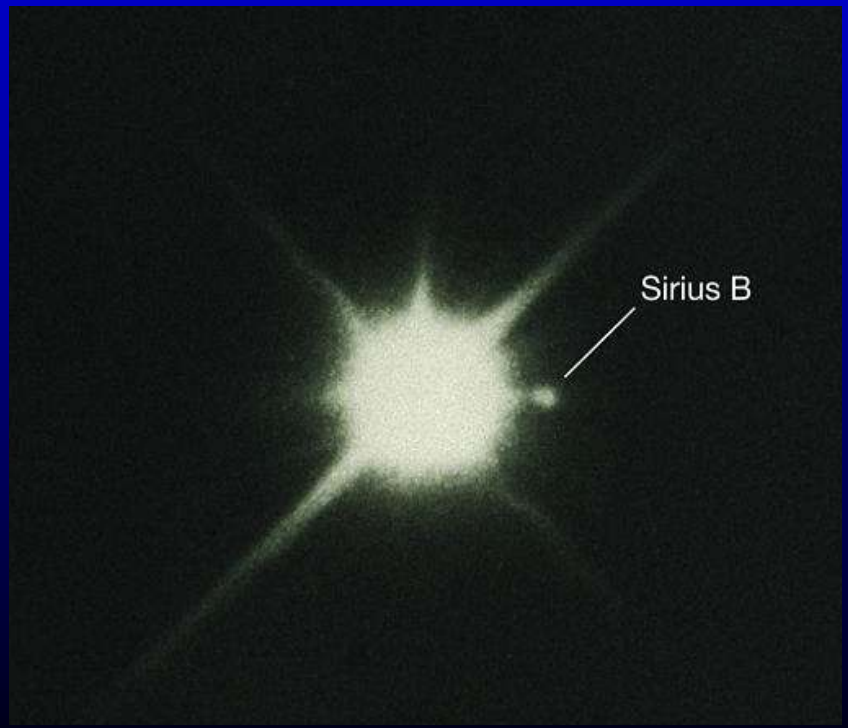


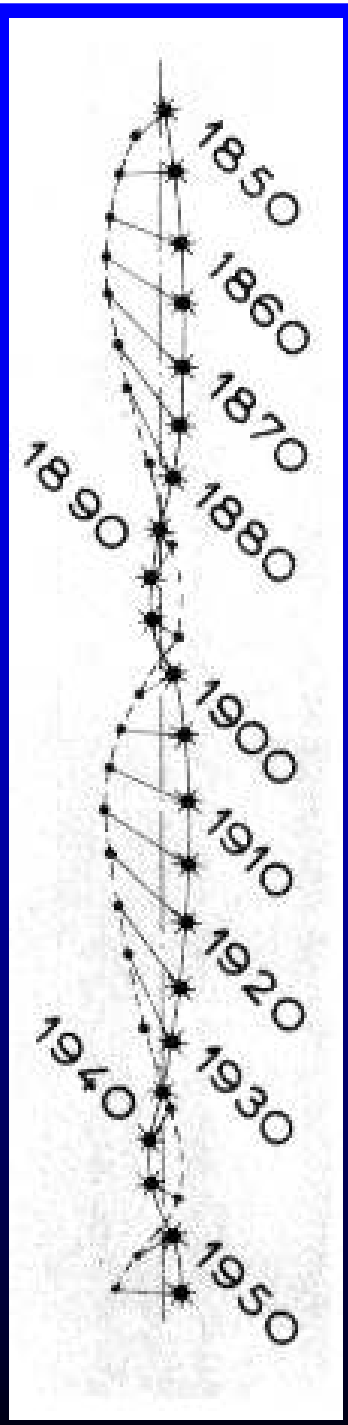
Giant Refractors



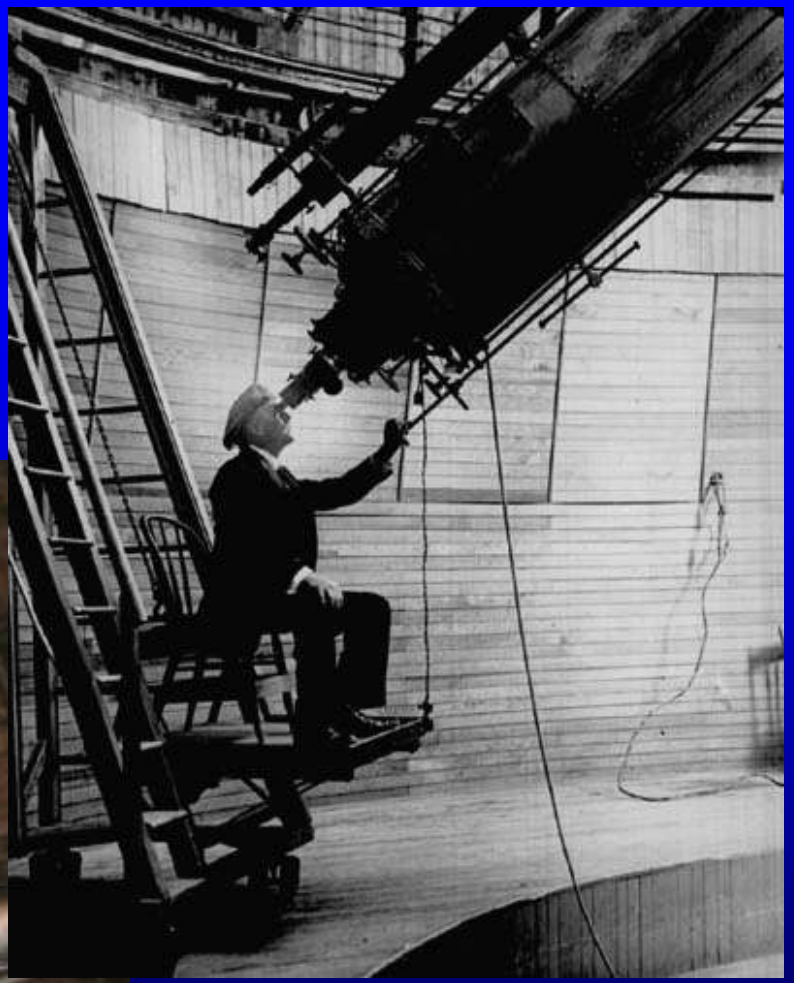
Sirius B

Clarke
Brothers



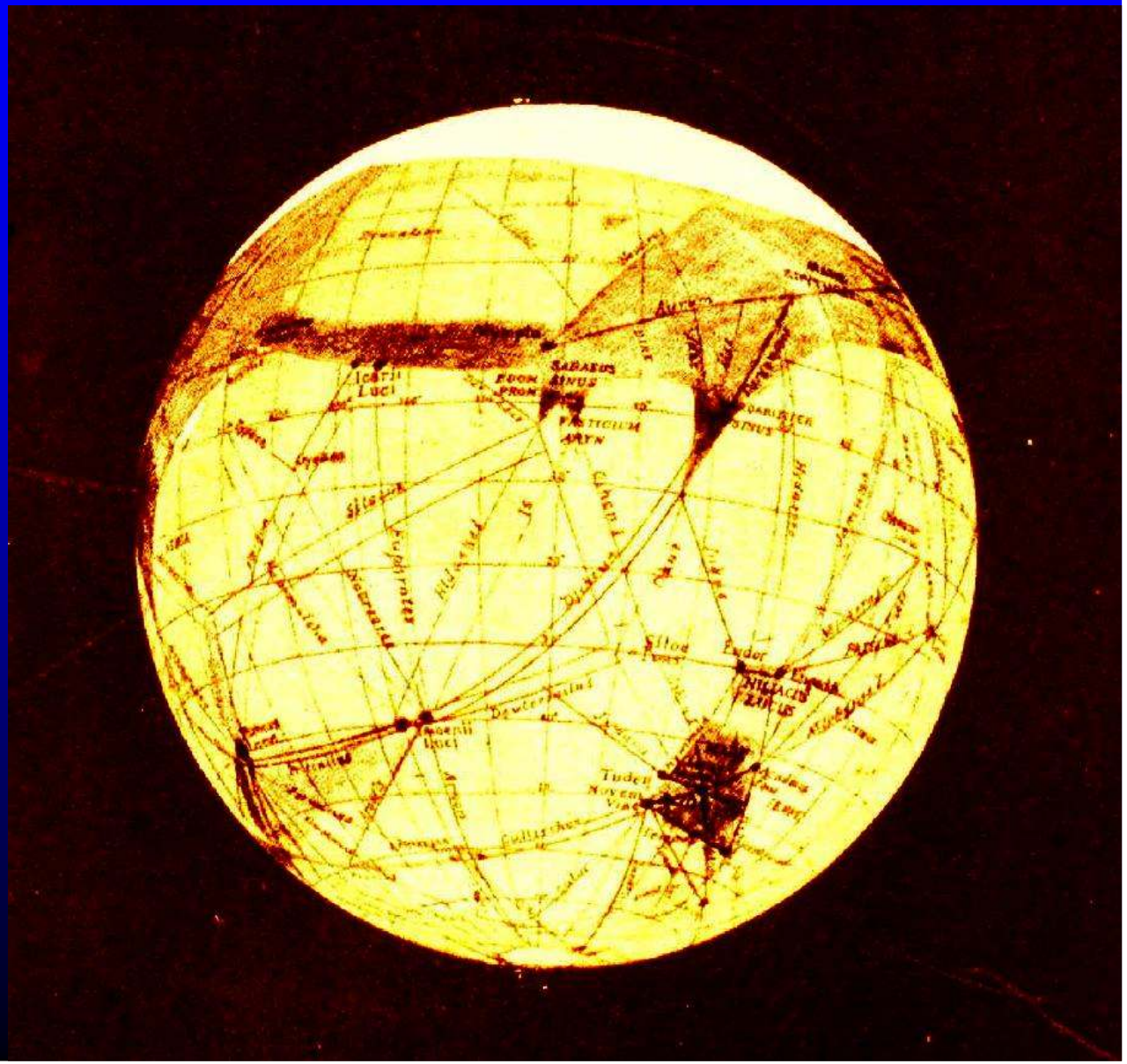


Lowell 24 inch



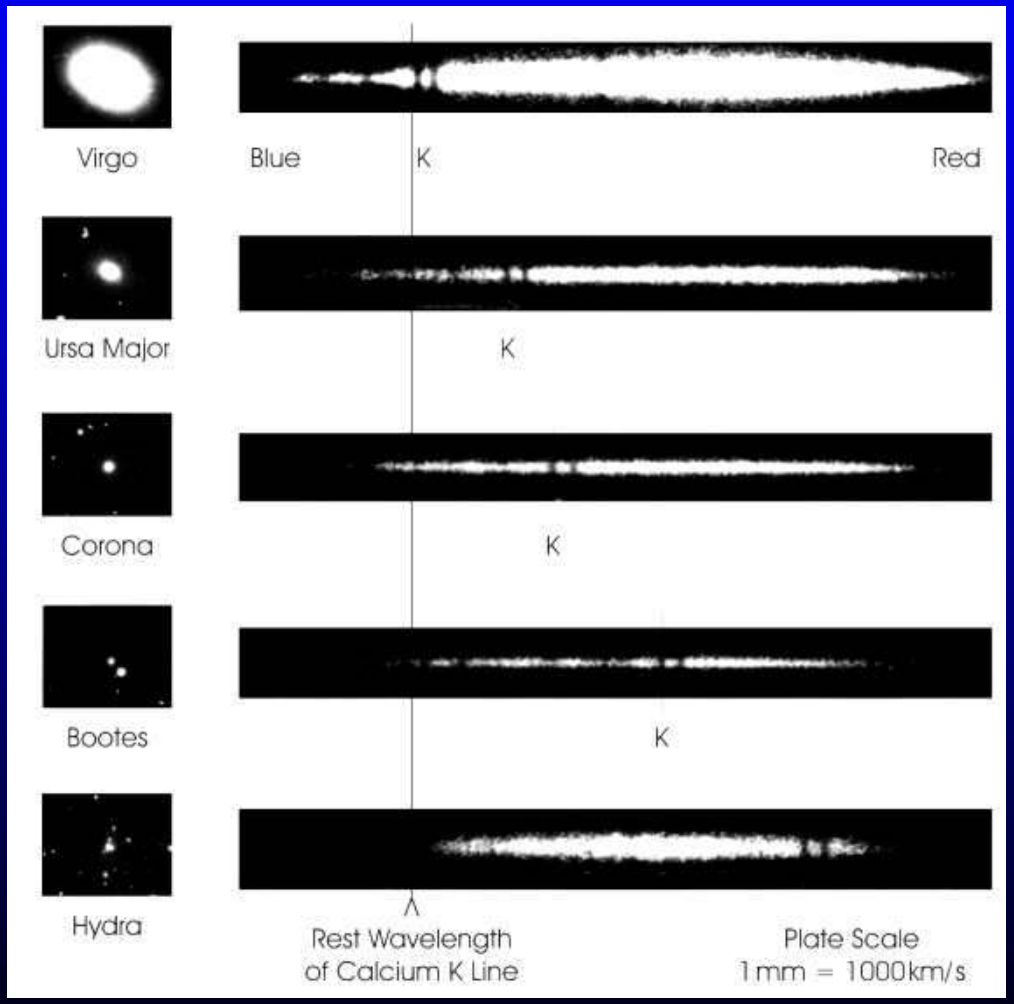
Percival Lowell
observing Mars

Canals on Mars?

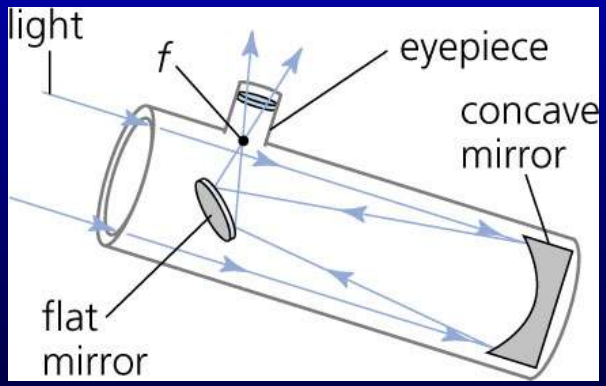


Vesto Melvin Slipher

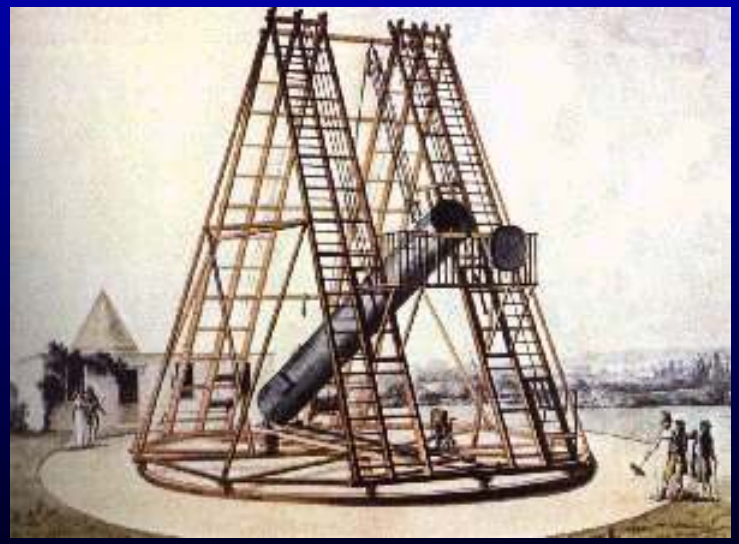
- Used the Lowell 24” refractor to measure the speeds of approach or recession of galaxies



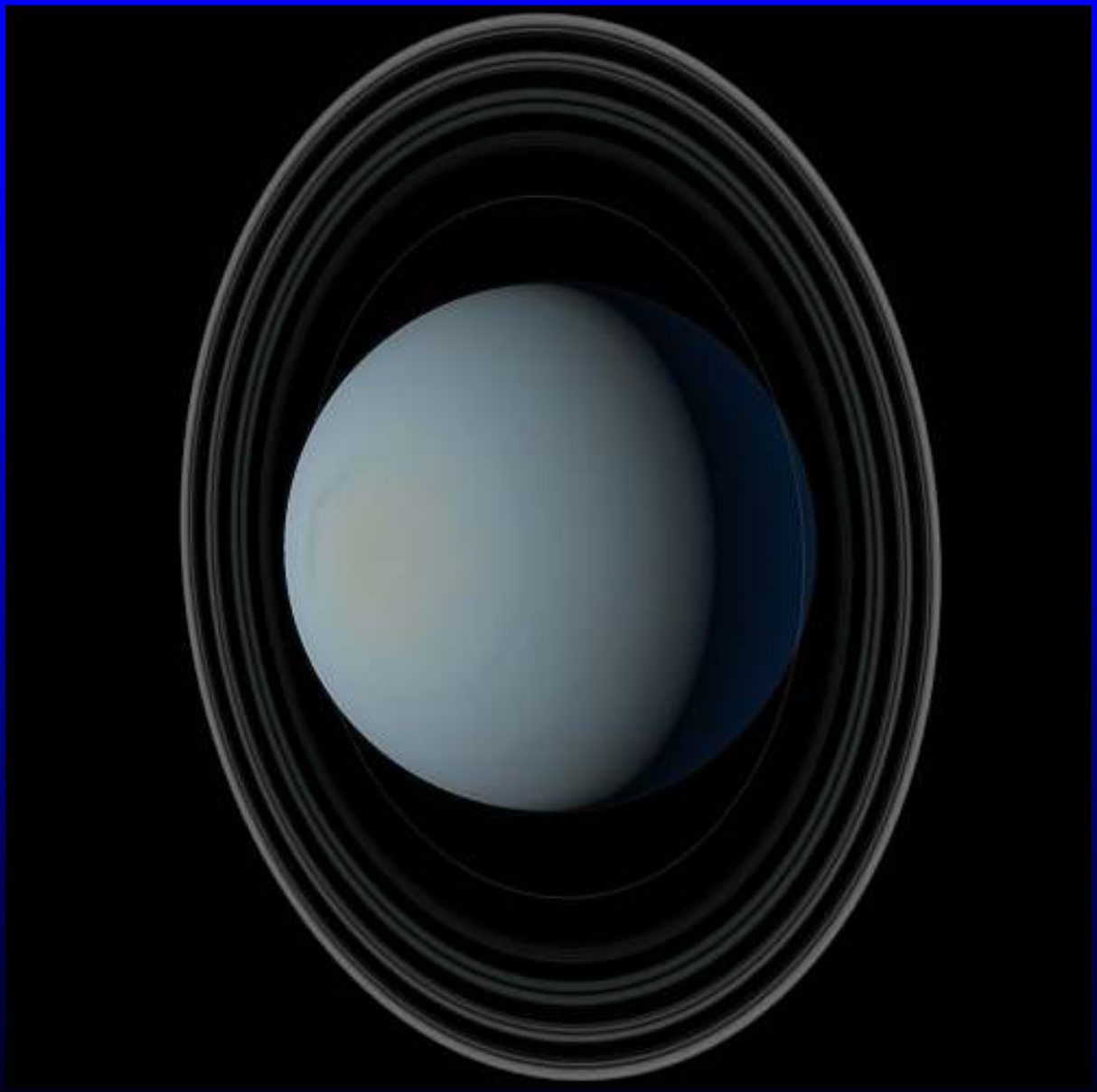
Newton's Reflecting Telescope



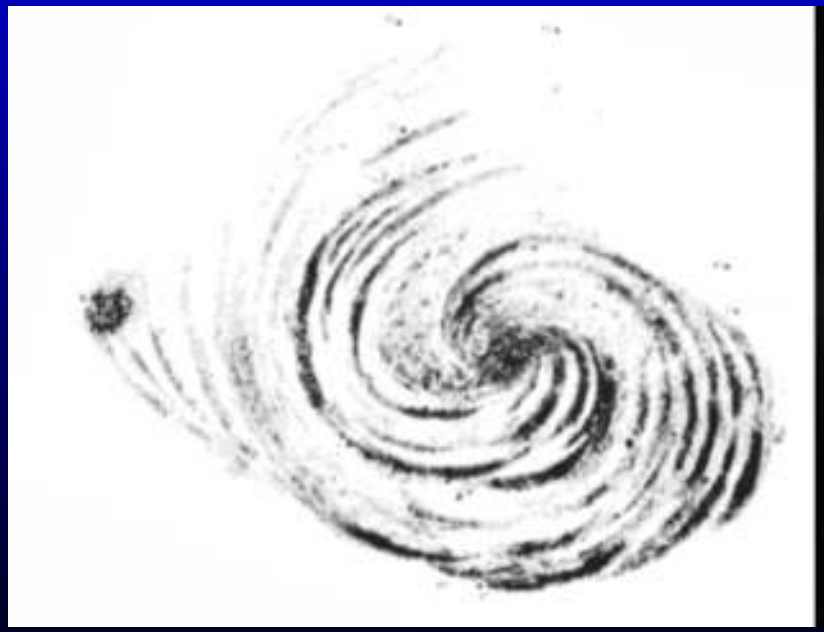
William Herschel and his Telescope

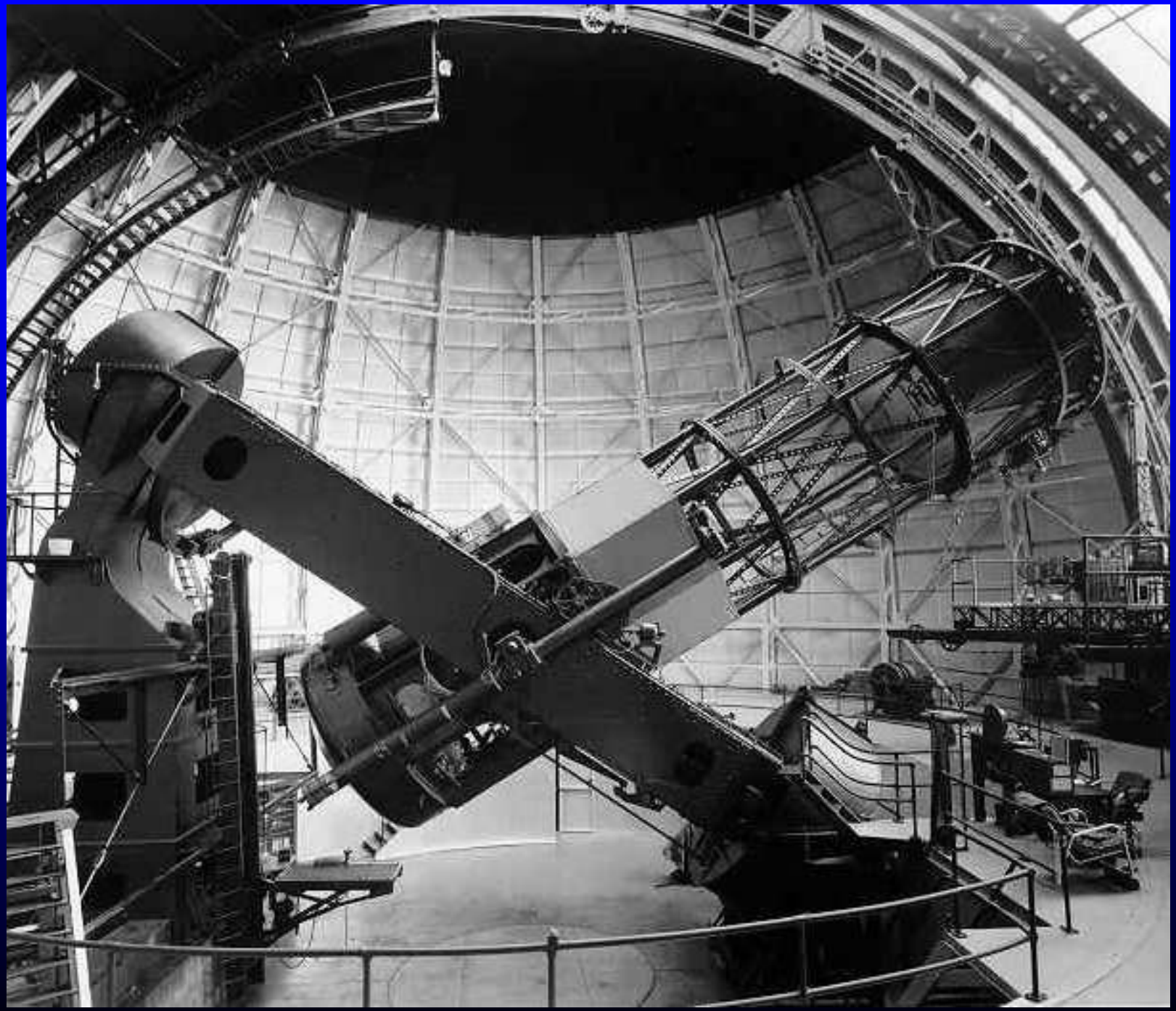


Uranus



The Leviathon of Birr Castle



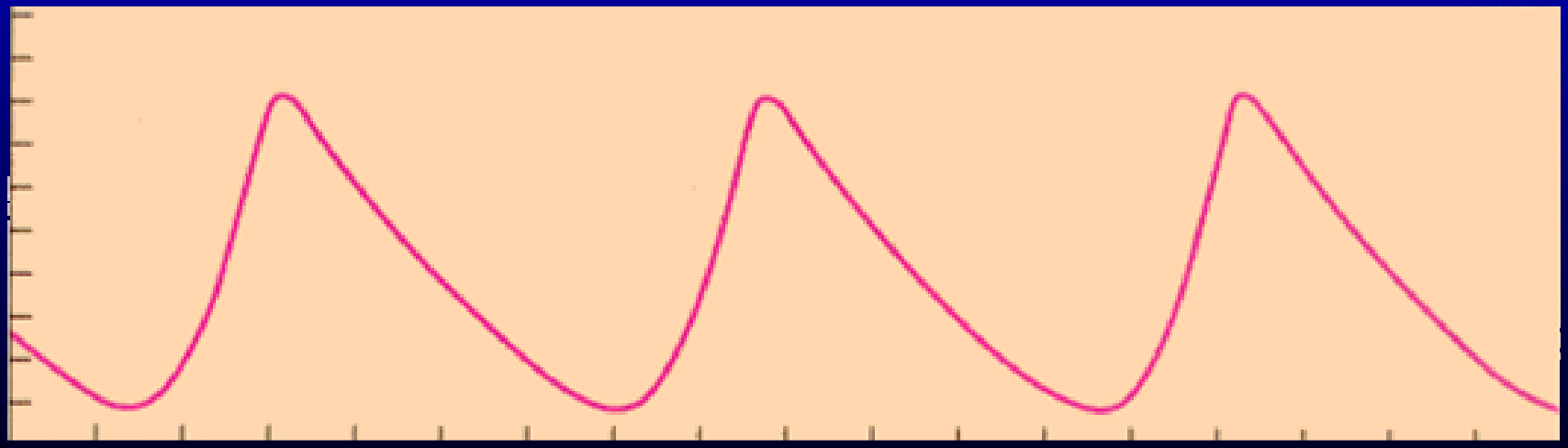


Edwin Hubble

Showed that the Universe was expanding.

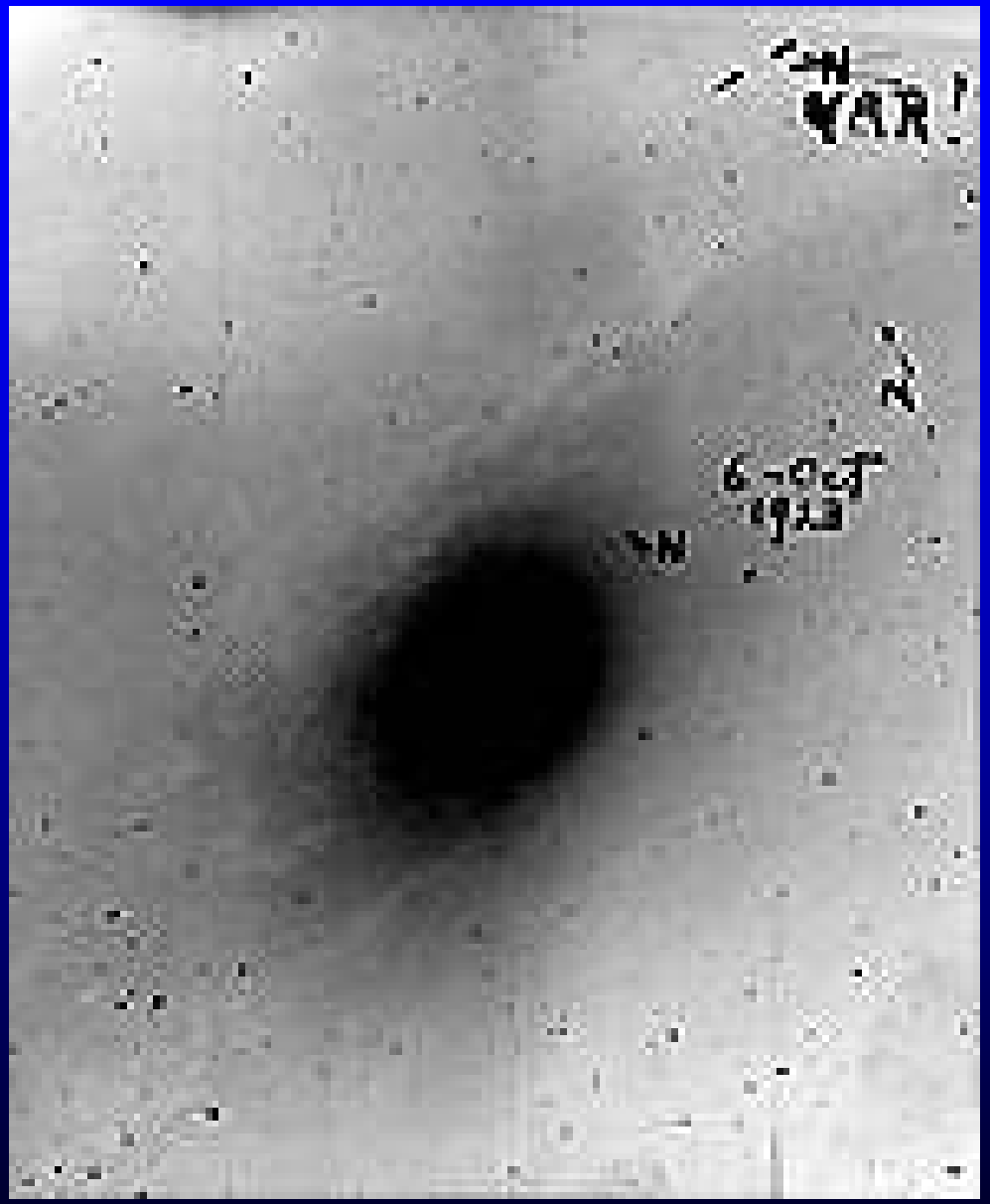
Cepheid Variables

- Henrietta Leavitt observed that Cepheid Variable Stars had a very regular variation in brightness.
- Their brightness was a function of their period

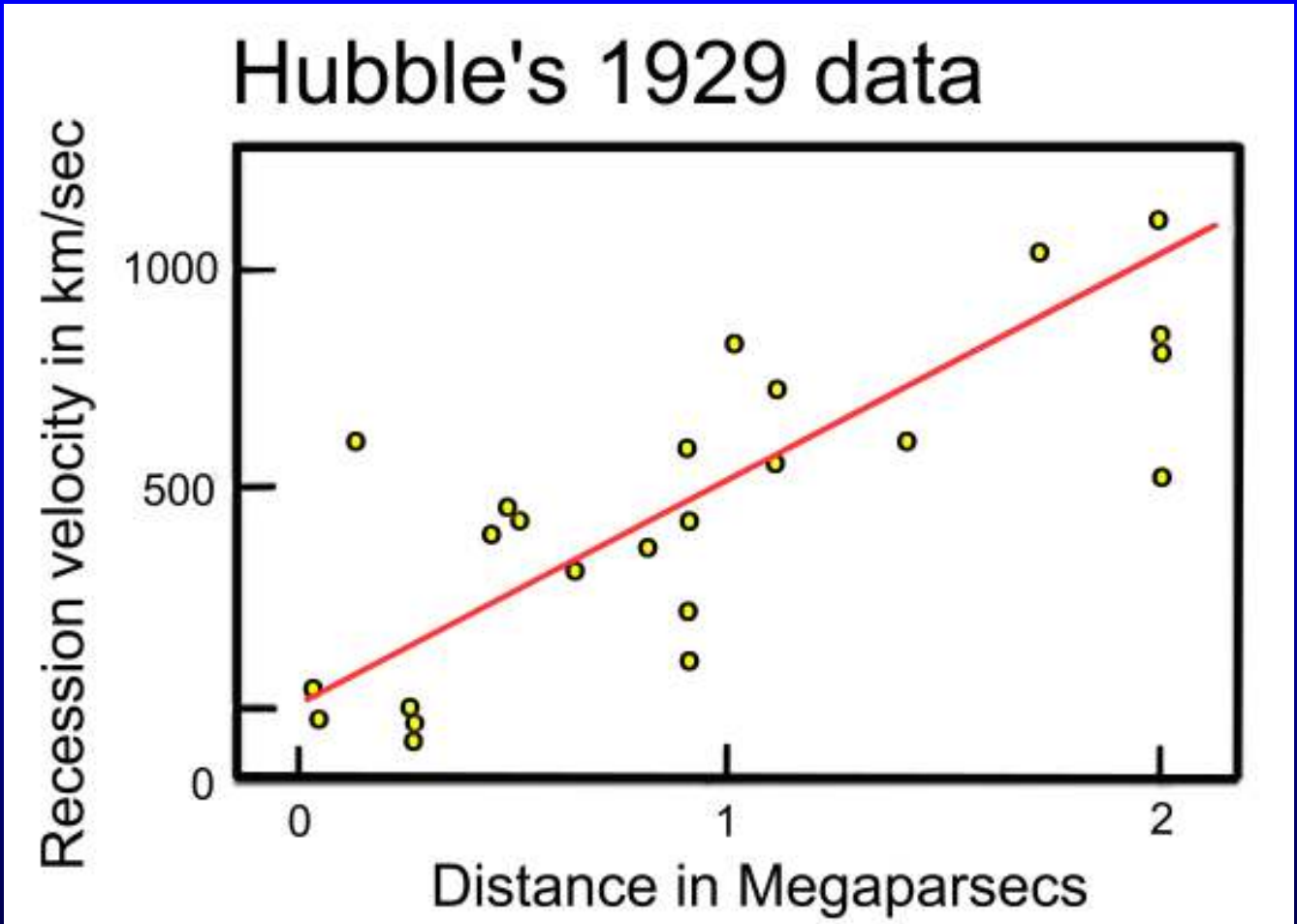


A Cepheid Variable in M31

- A photographic plate taken with the 100 inch Telescope.
- Hubble had discovered a Cepheid Variable.

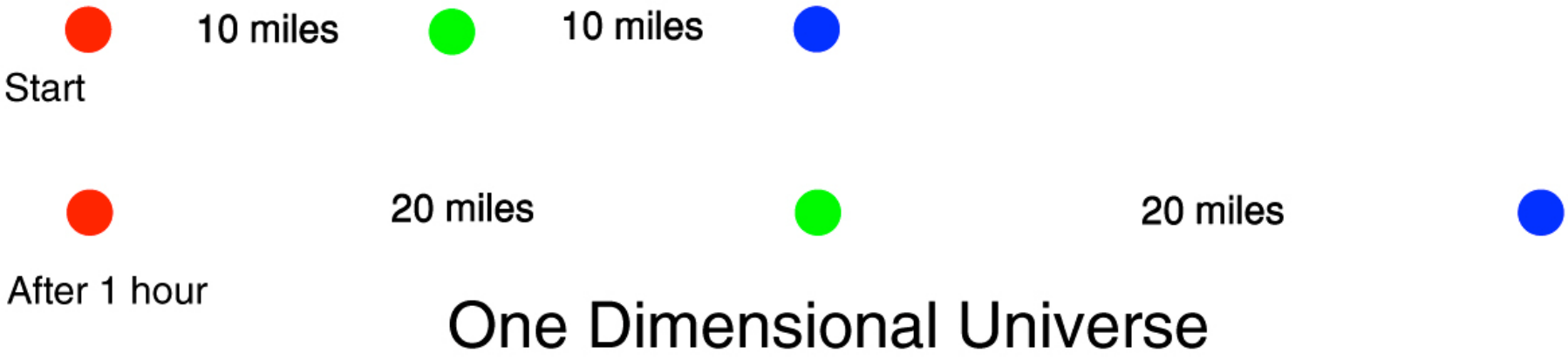


Hubble Diagram

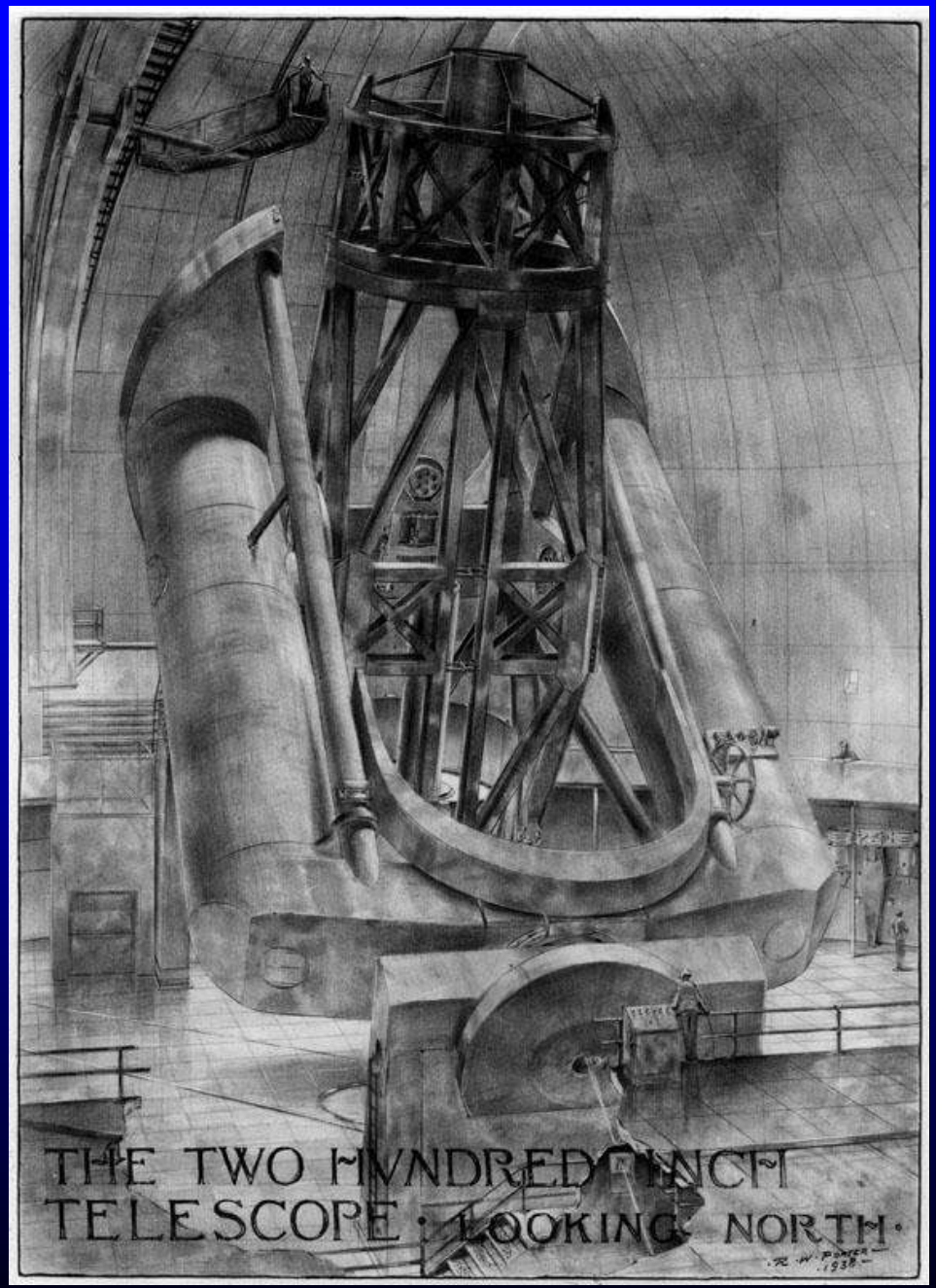


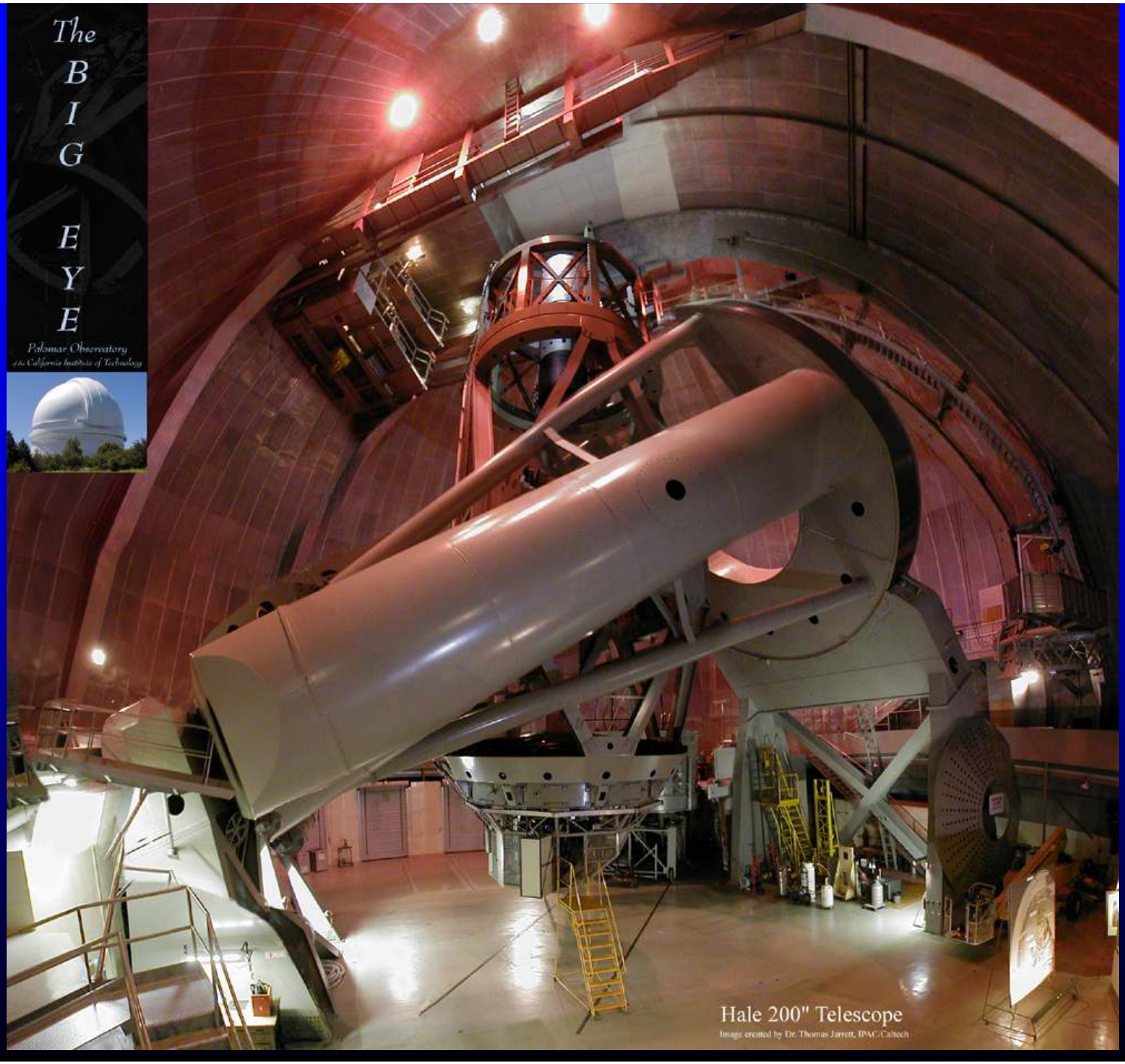
$V = H_0 x\ R$ where H_0 = Hubble's Constant

An Expanding Universe



Russell Porter's Drawings

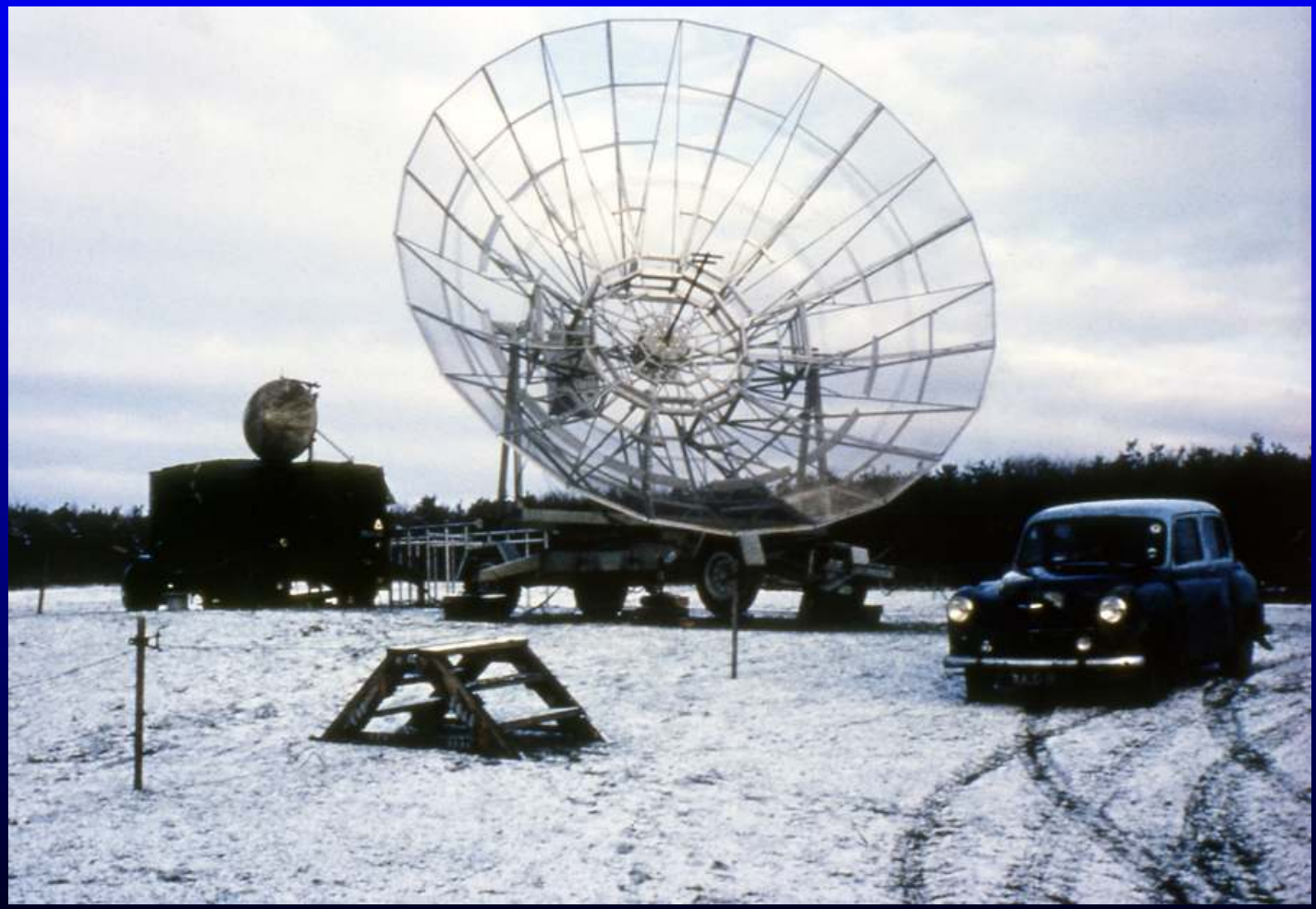



The
B
I
G
E
Y
E
Palomar Observatory
of the California Institute of Technology
Hale 200" Telescope
Image created by Dr. Thomas Jarrett, IPAC/Caltech

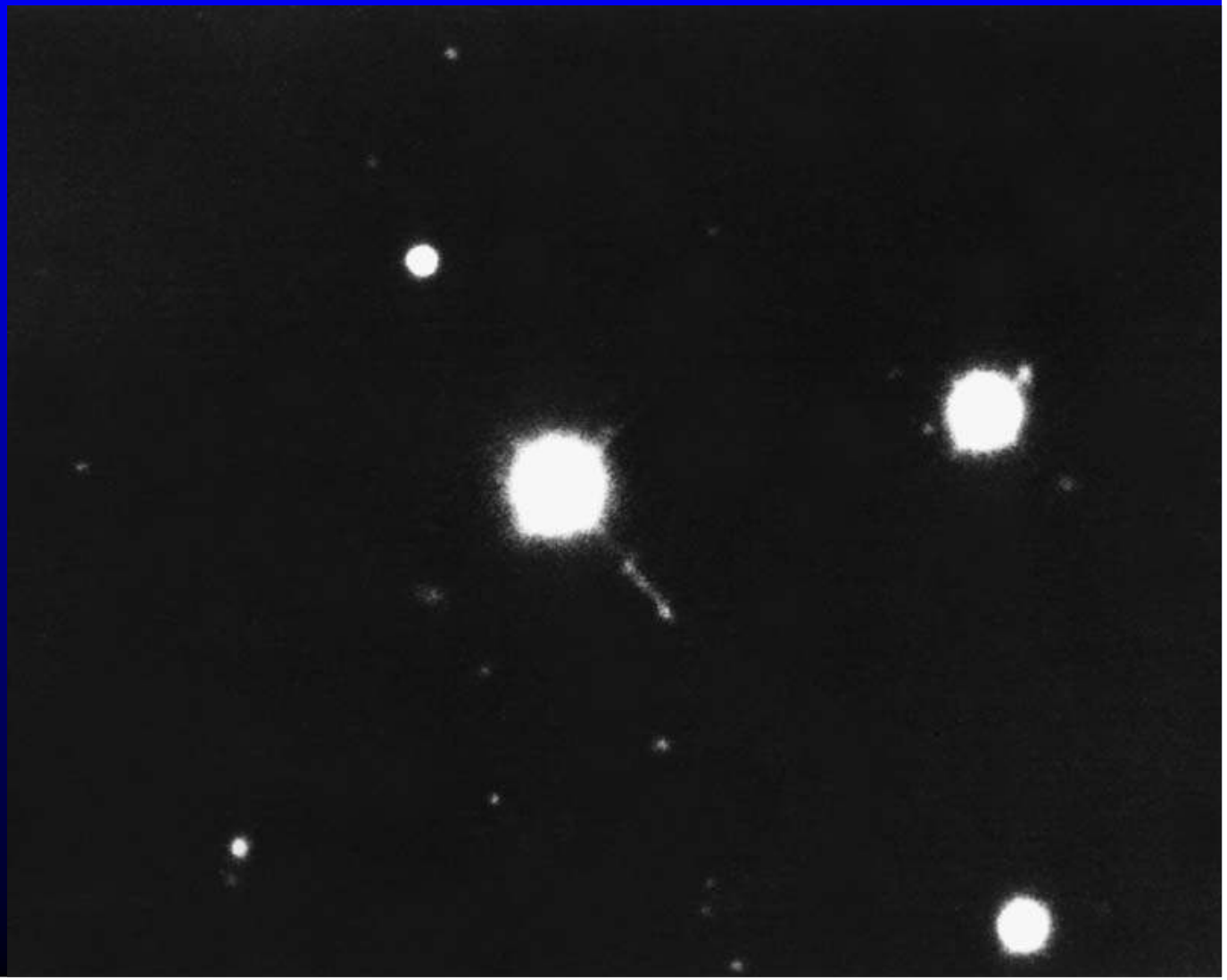
The MK 1 Radio Telescope

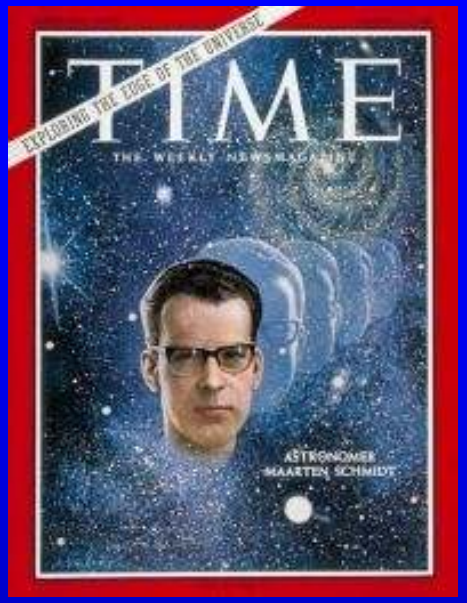
Linked to a small Telescope

- Signals from a remote telescope were brought back to Jodrell Bank by a microwave radio link

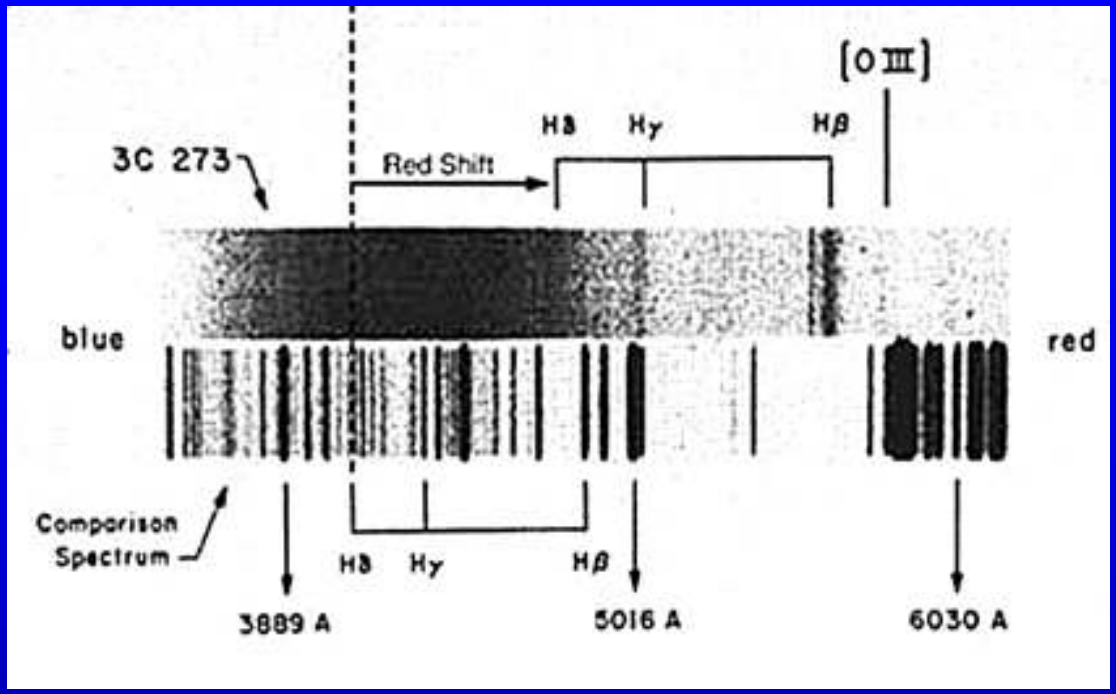


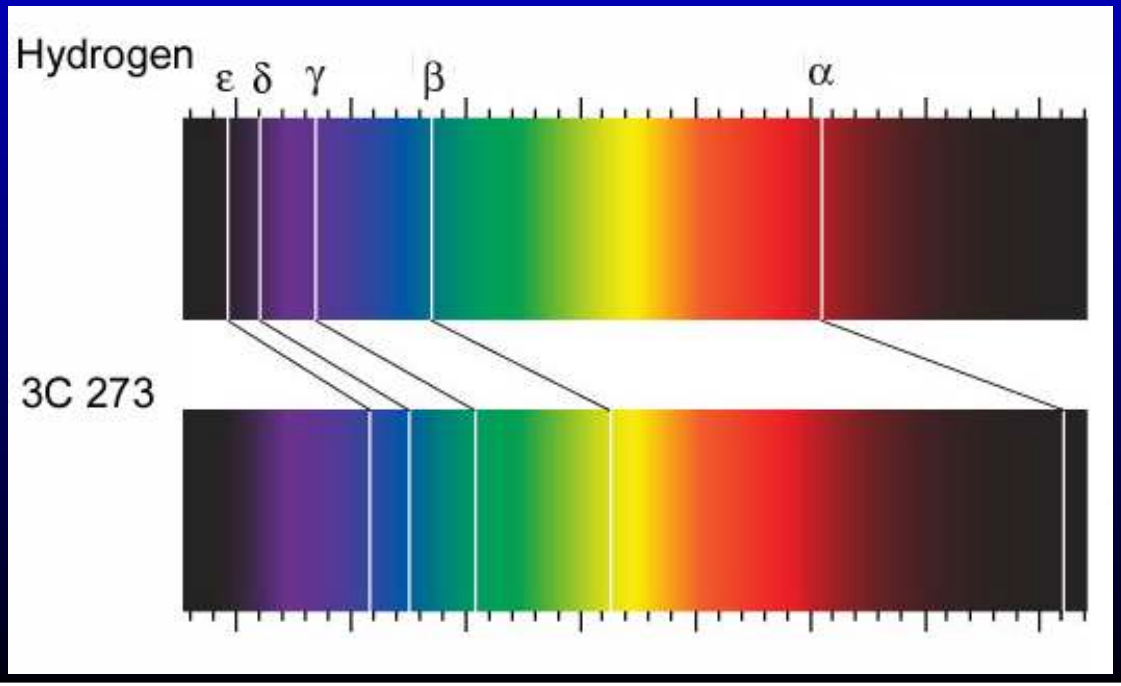
The Quasar 3C 273





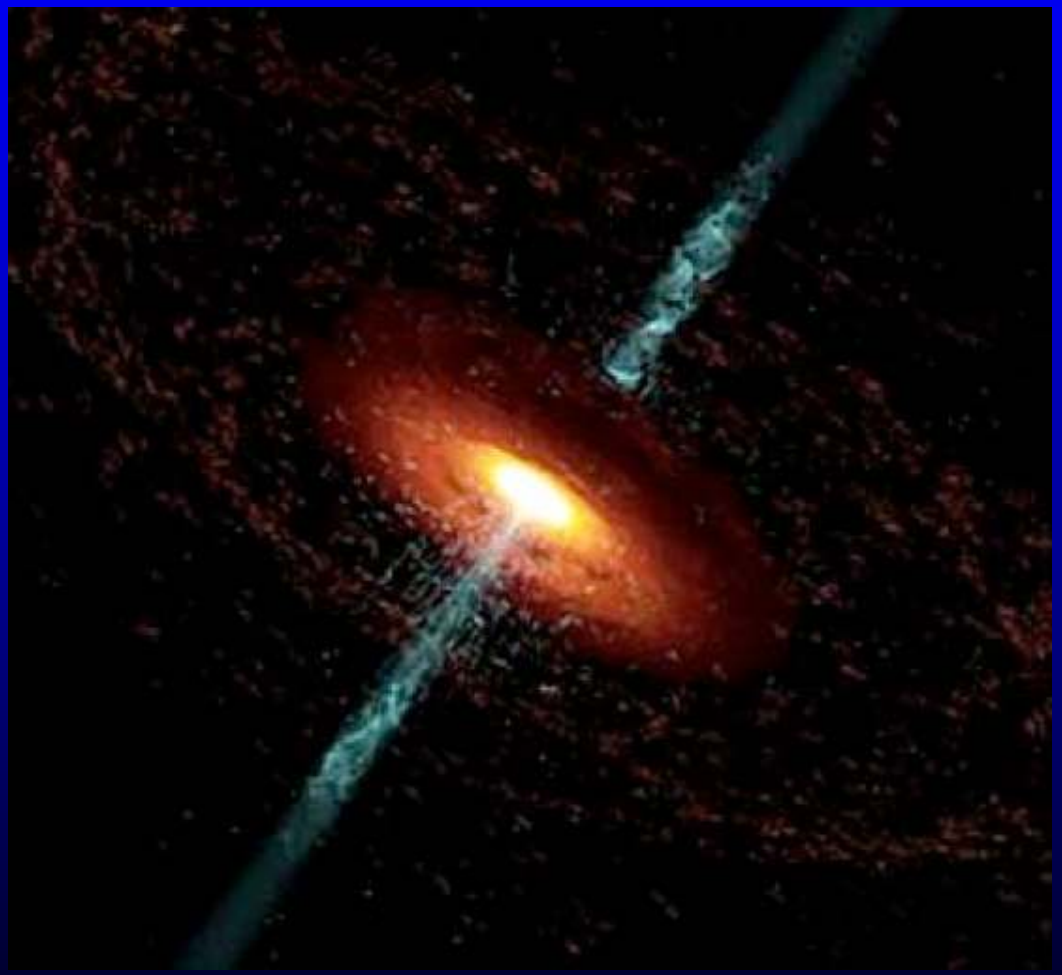
Maarten Schmidt

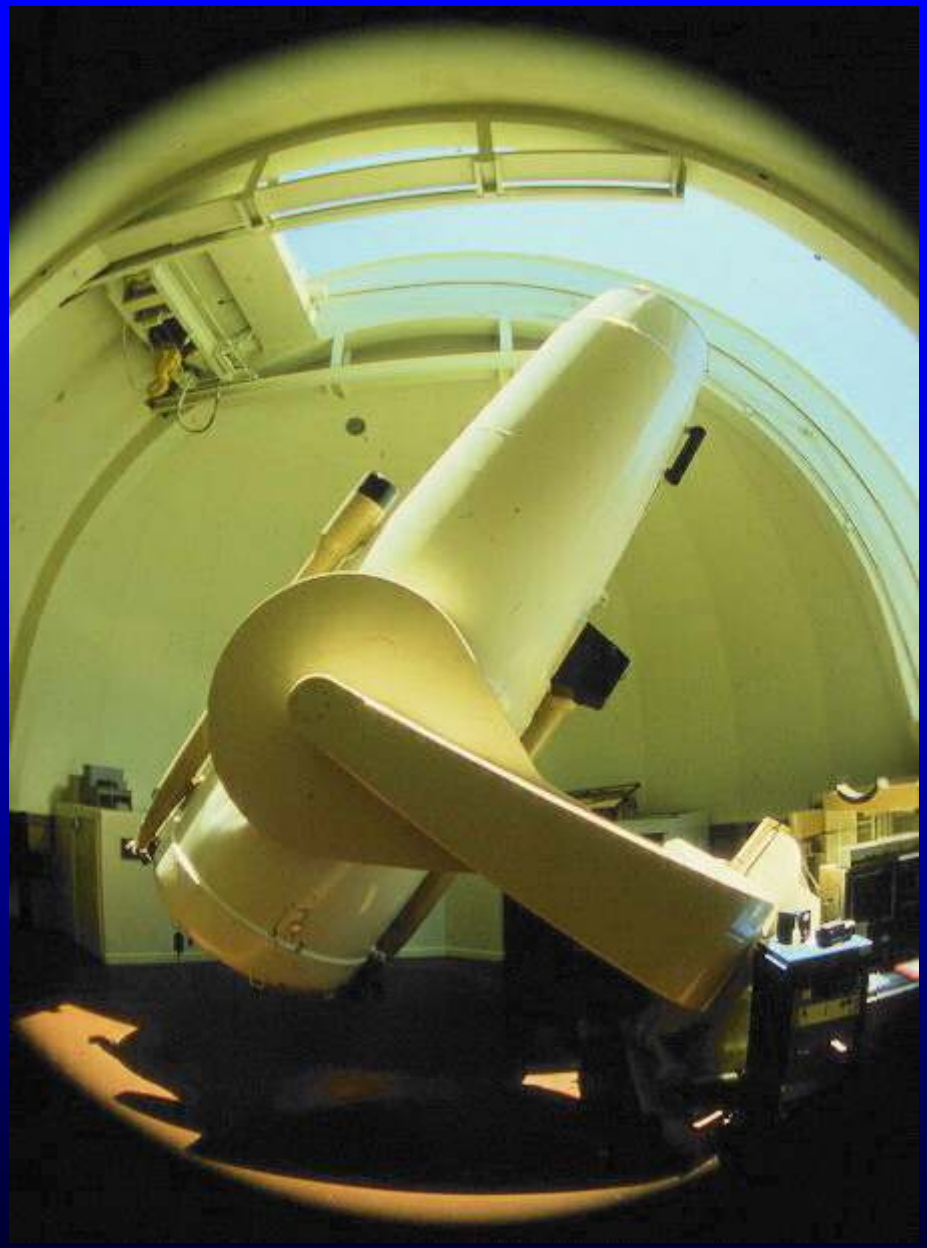




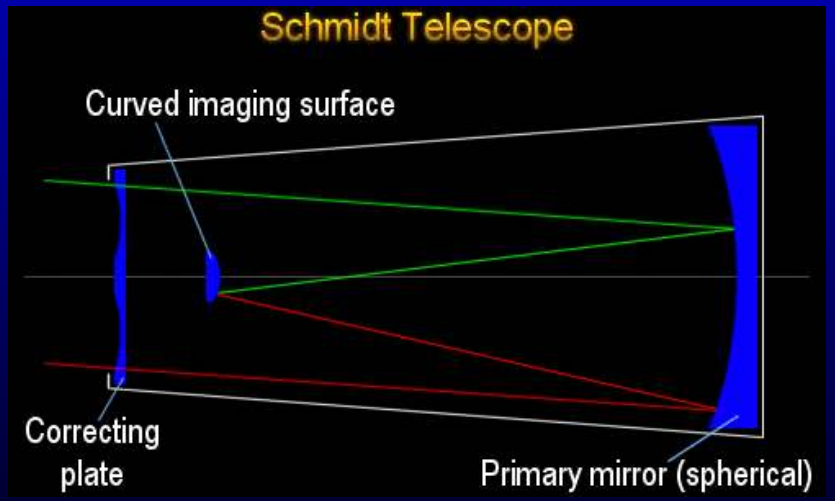
3C273 Redshift

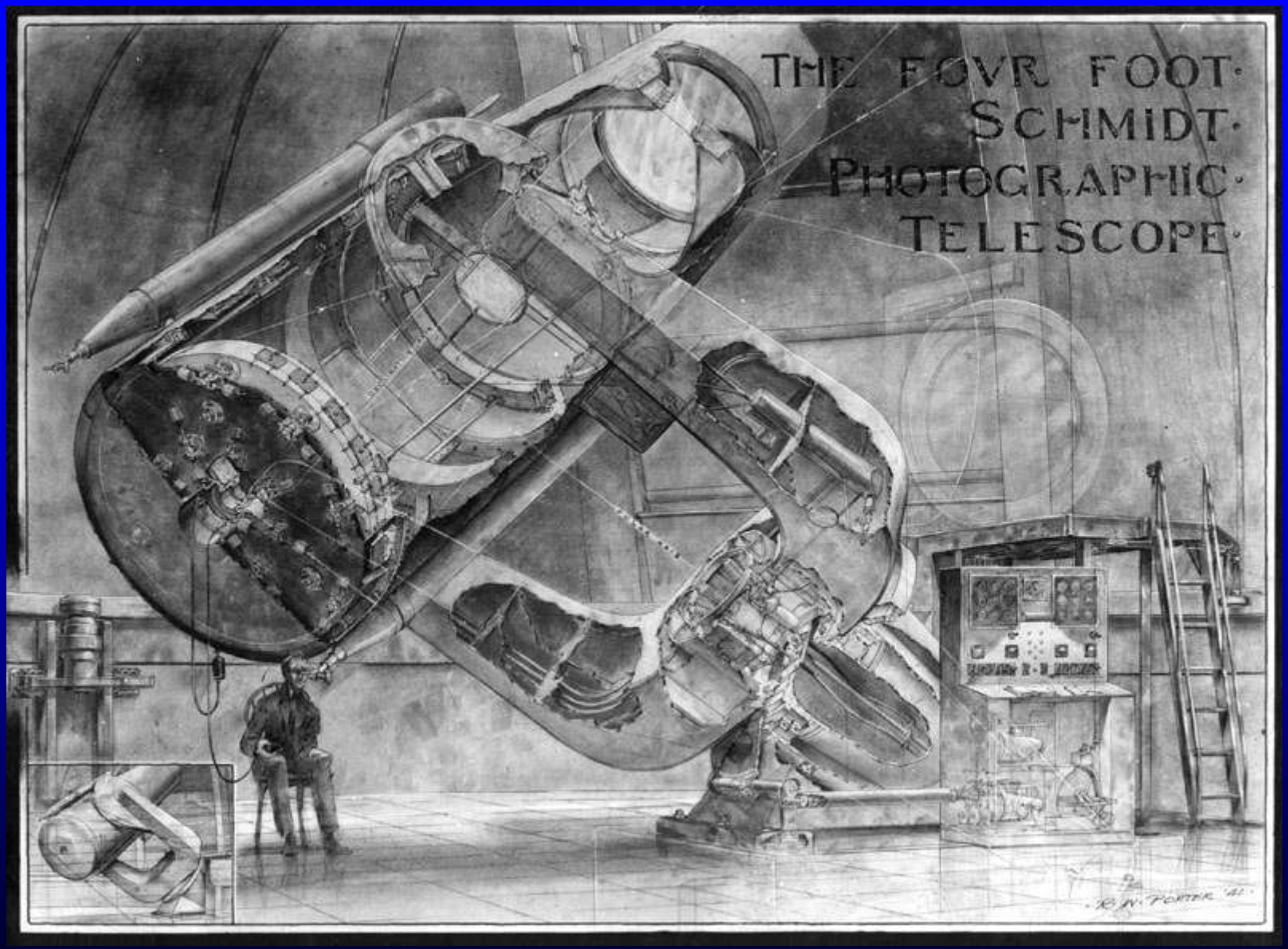
What powers these objects?





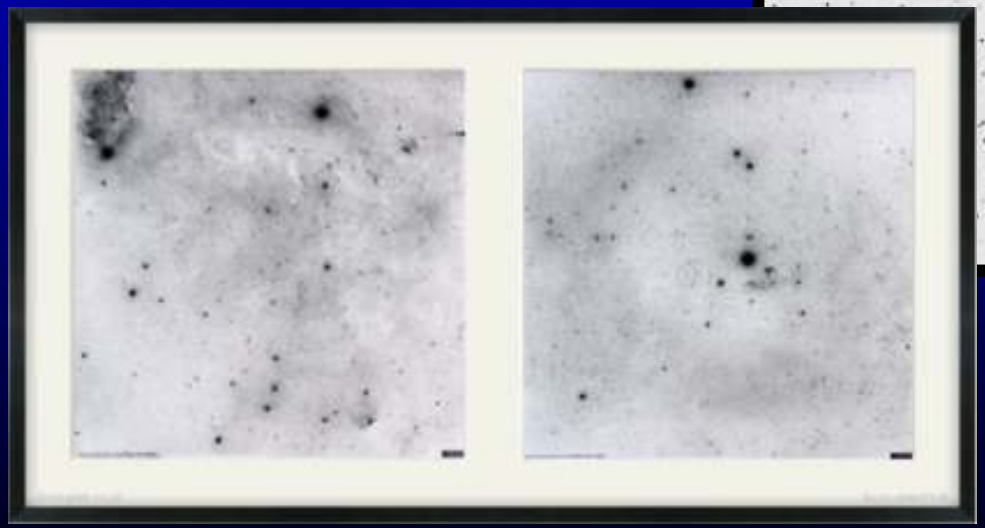
Mt Palomar 48” Schmidt

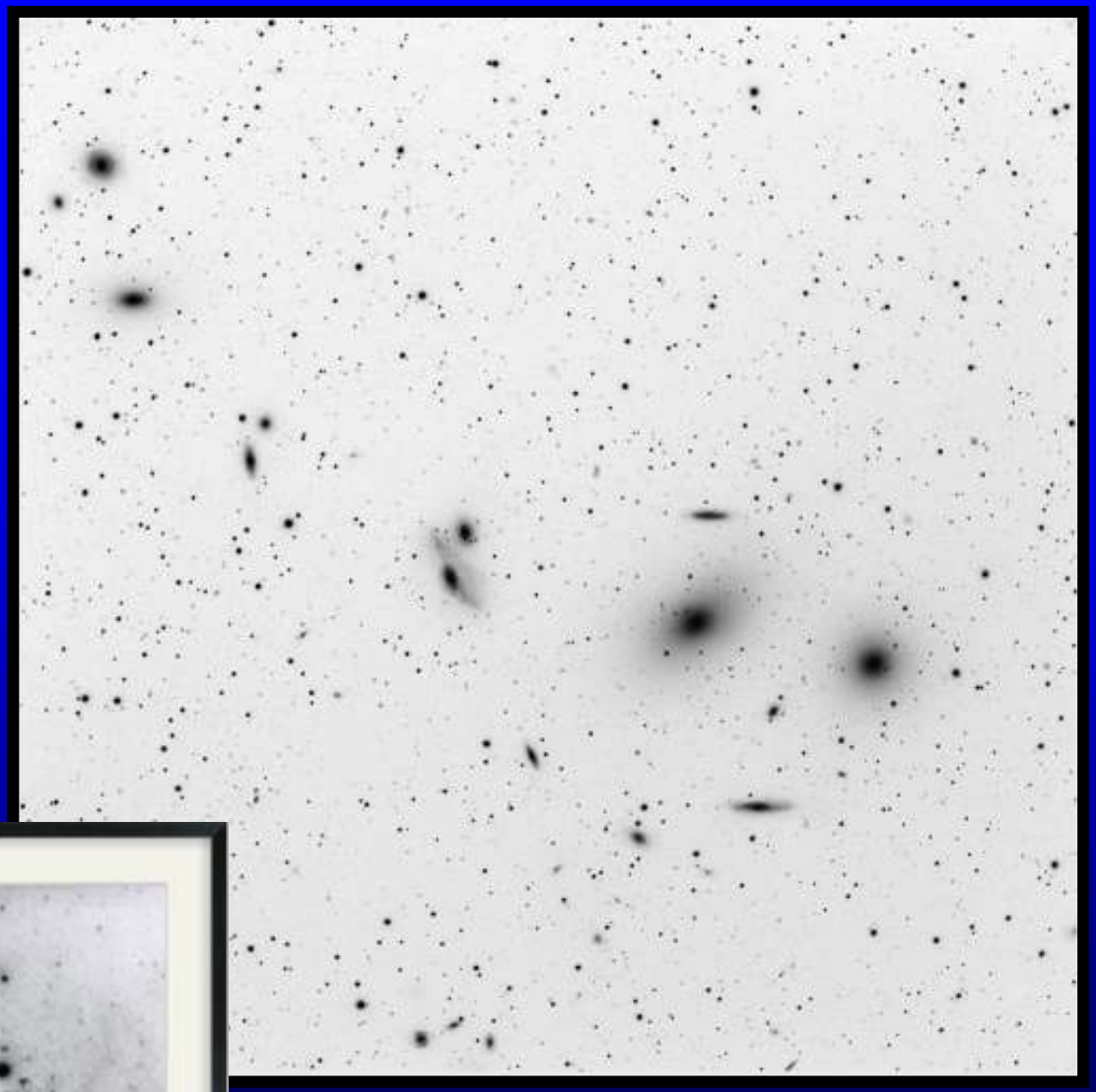



THE FOVR FOOT·
SCHMIDT·
PHOTOGRAPHIC·
TELESCOPE·

Plates are 7” square

5 degrees on a side



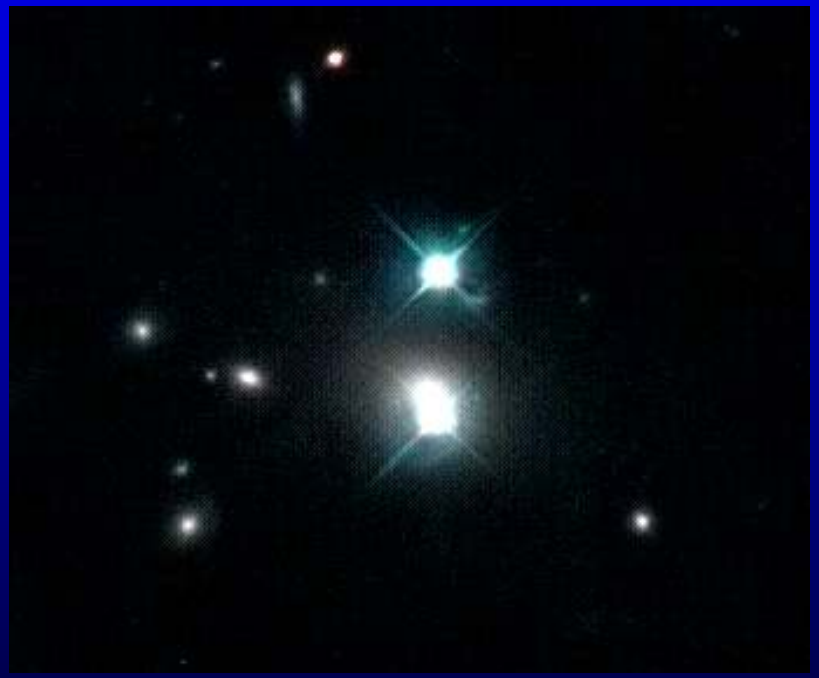


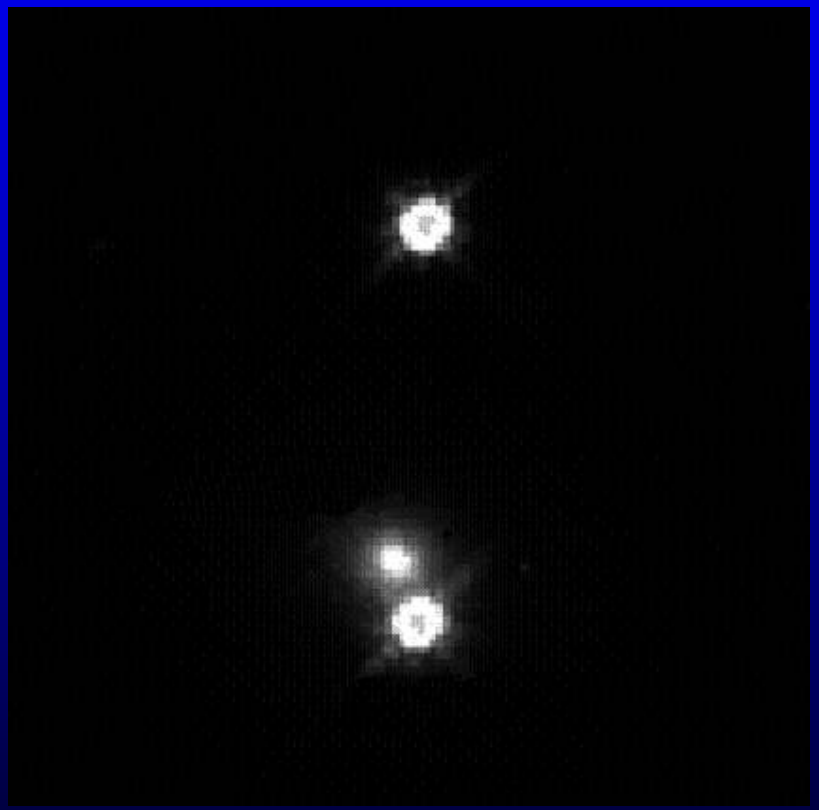
Virgo Cluster

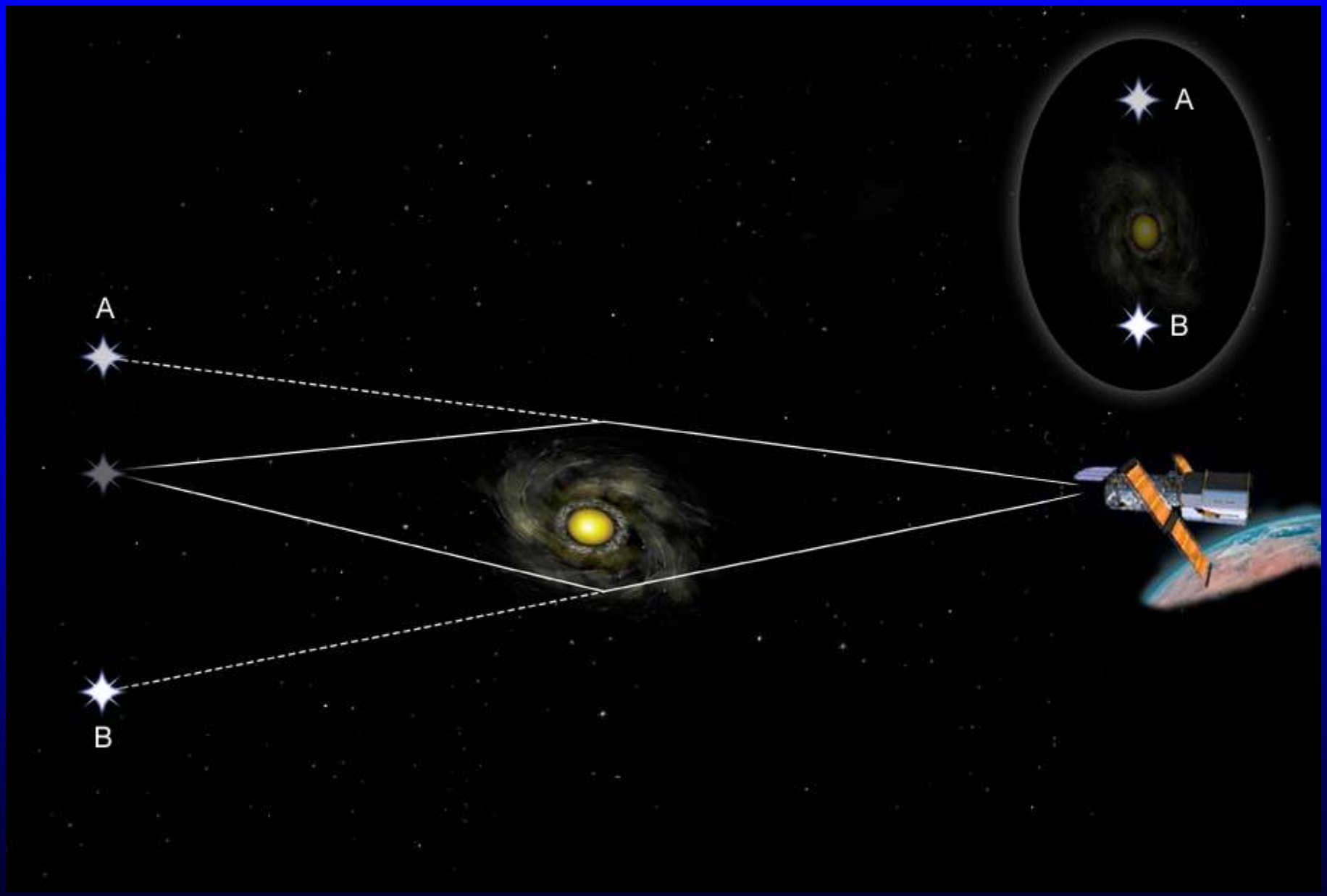

November 1972: 966 MHz Survey

National Geographic Sky Survey

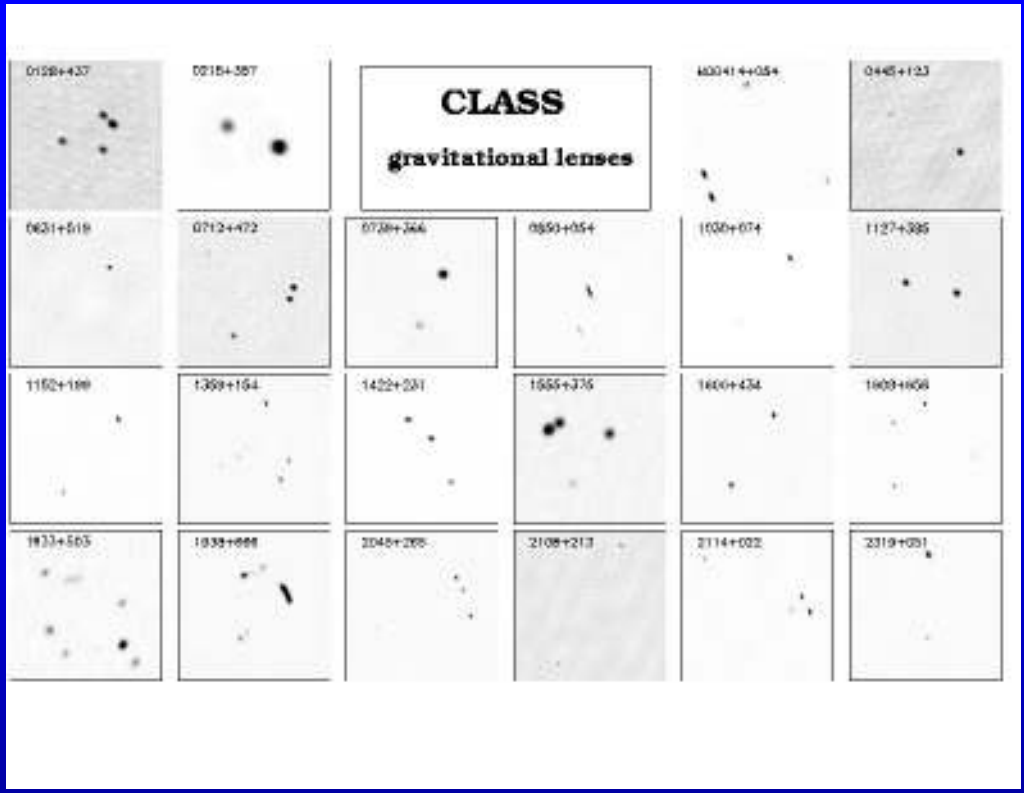
“Two” Quasars and a Galaxy






A
B
A
B

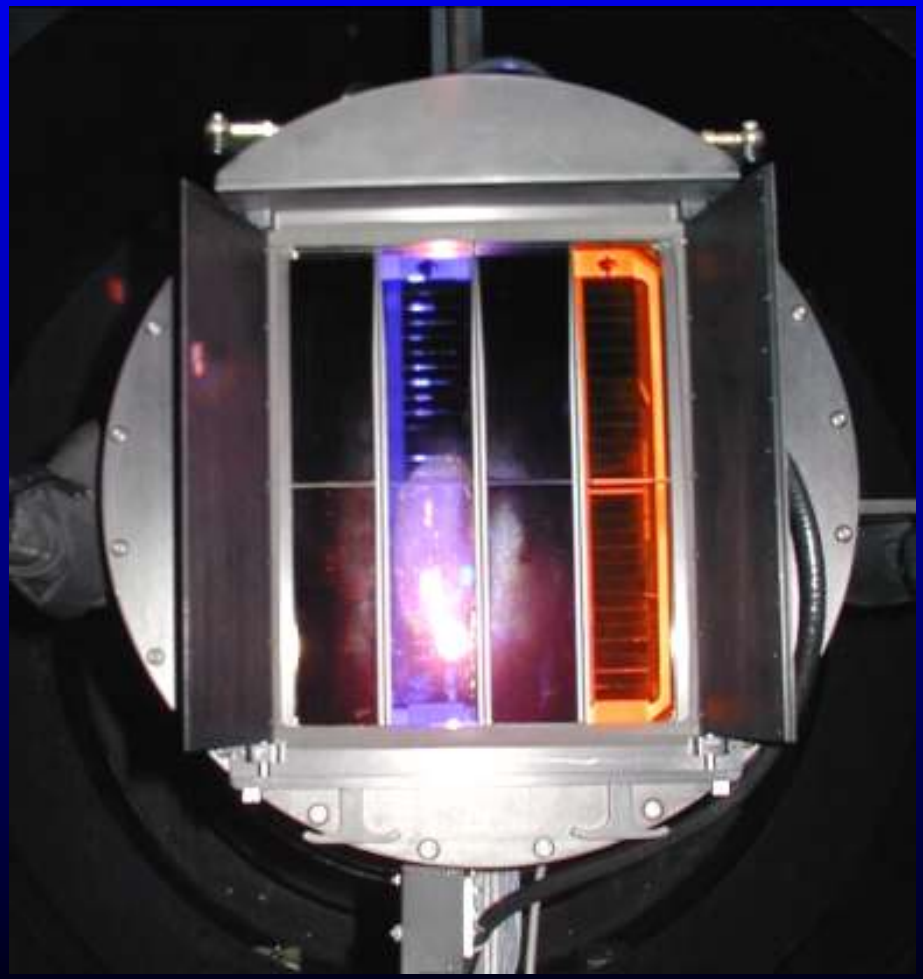
Hubble's Constant



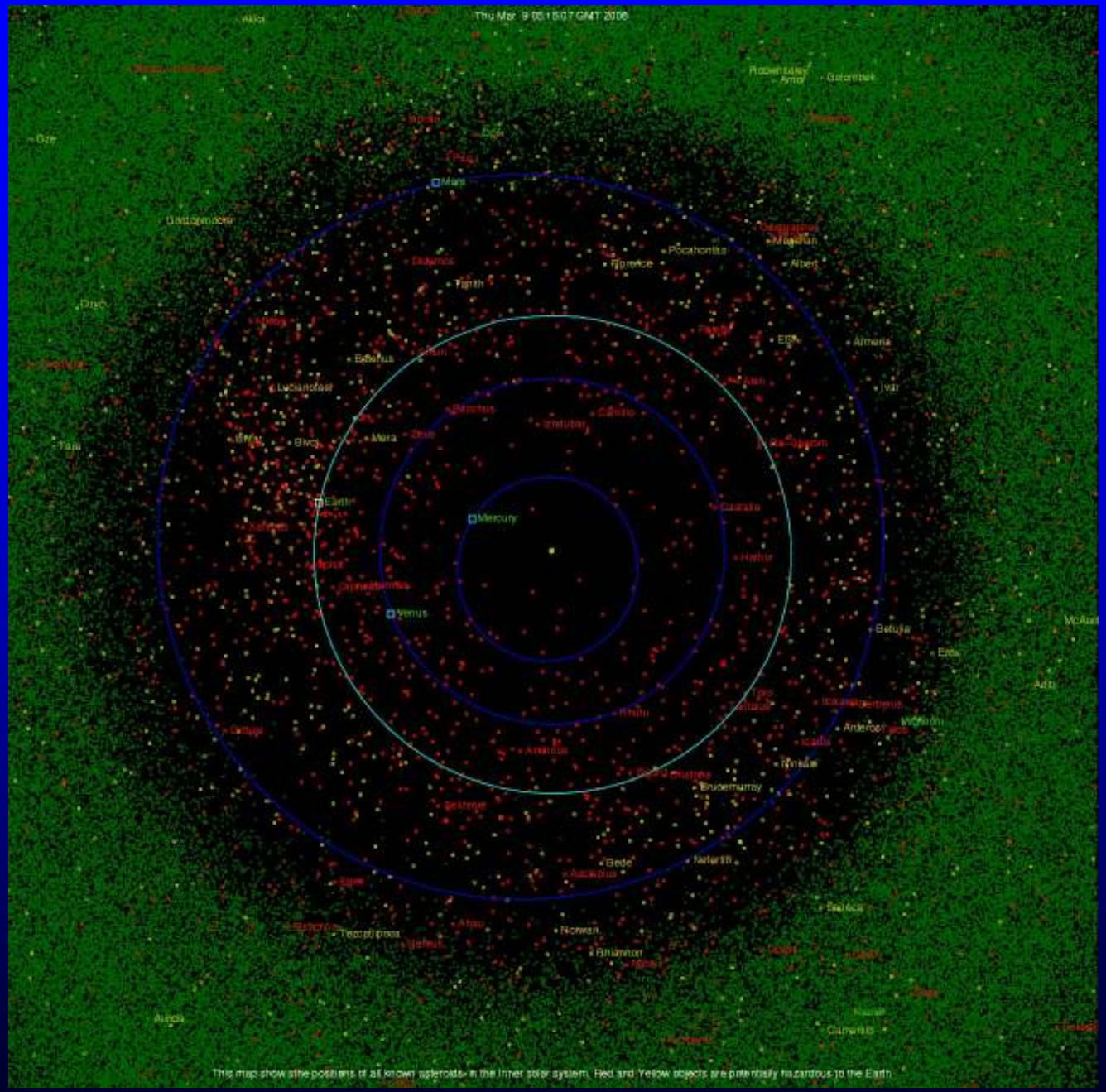
- Jodrell Bank Observations of Gravitational lenses have enabled an accurate measurement of Hubble's constant to be made:
  - 71 +/6 km/sec/Mpc

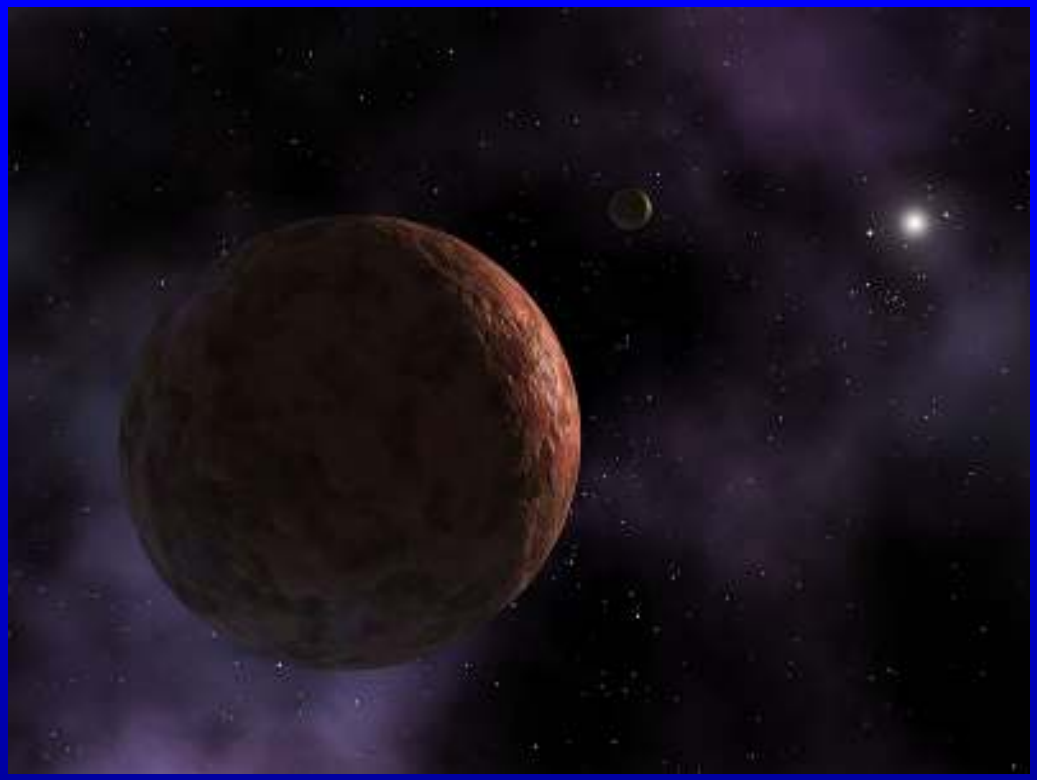
QUEST 161 Mpixel CCD

- Each area of sky is observed three times at 1.5 hours intervals



NEO's


Thu Mar 9 00:15:07 GMT 2006
Mars
Earth
Mercury
Venus
This map show sthe positions of all known asteroids in the inner solar system. Red and Yellow objects are potentially hazardous to the Earth

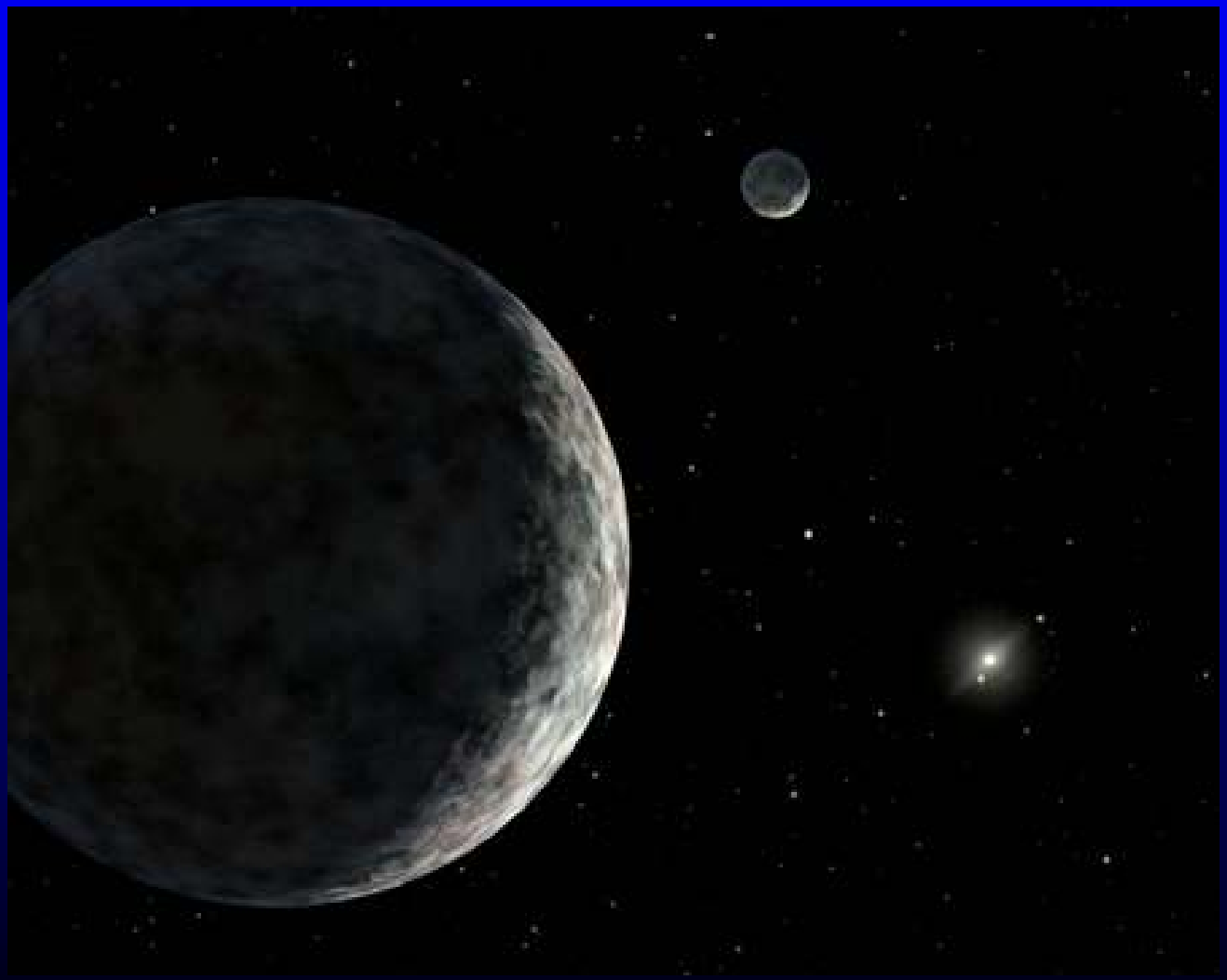


Sedna

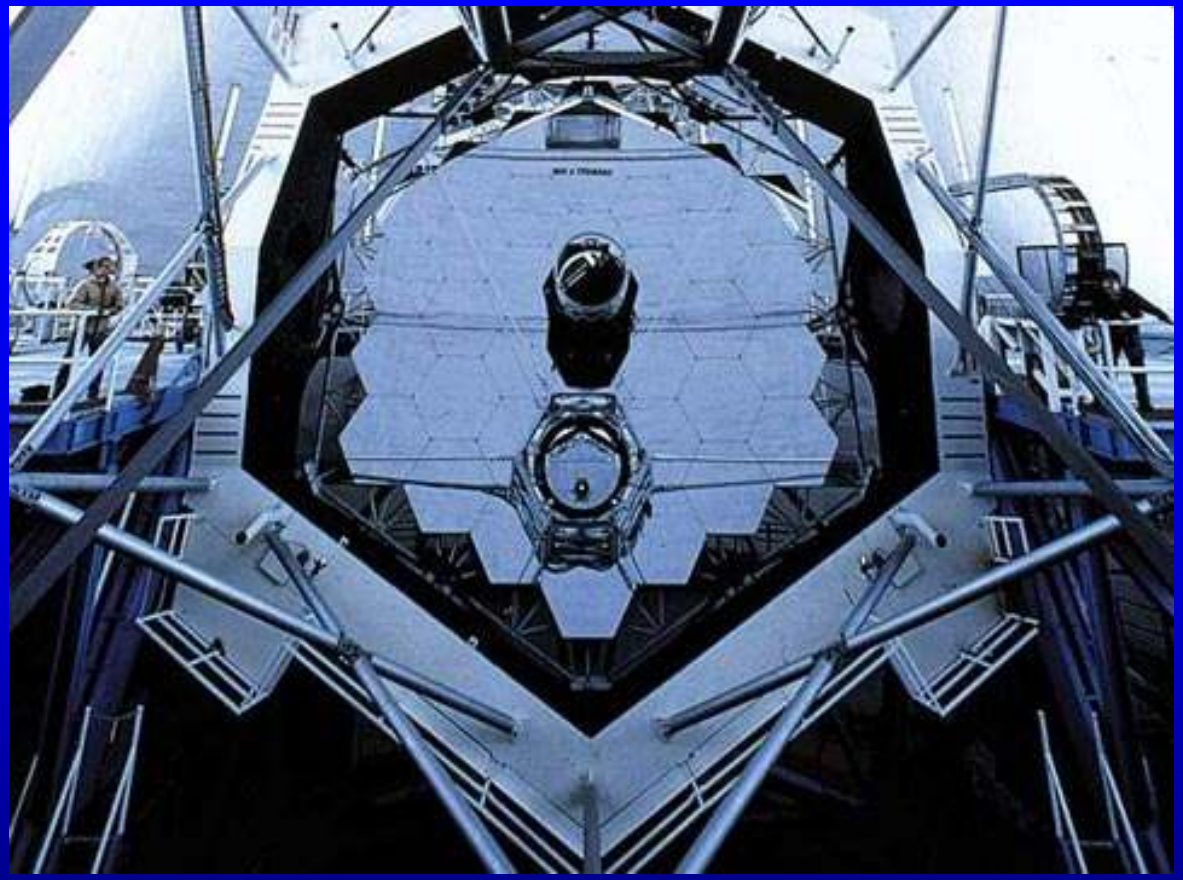
An Ice Dwarf at 88 AU – 3 times further away than Pluto.

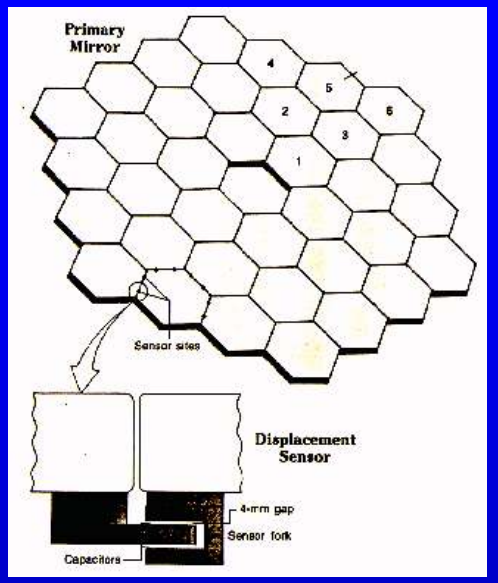
~1,600 km in diameter

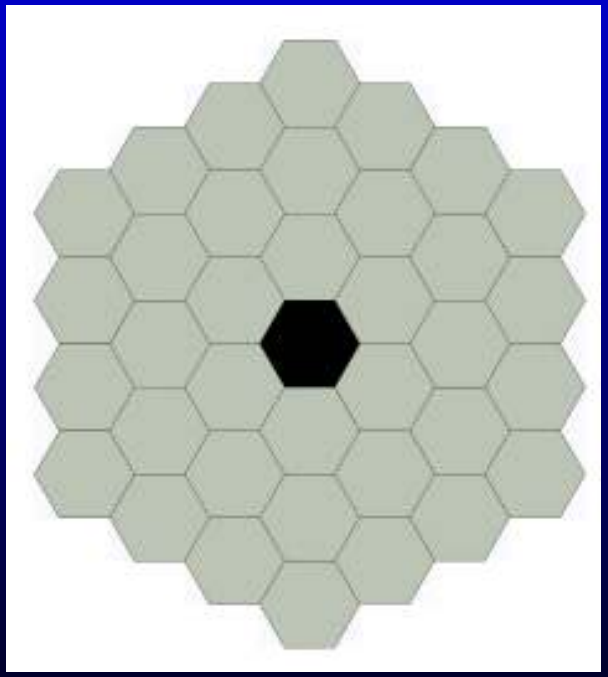
Eris and Dysnomia



10 m KECK Telescopes





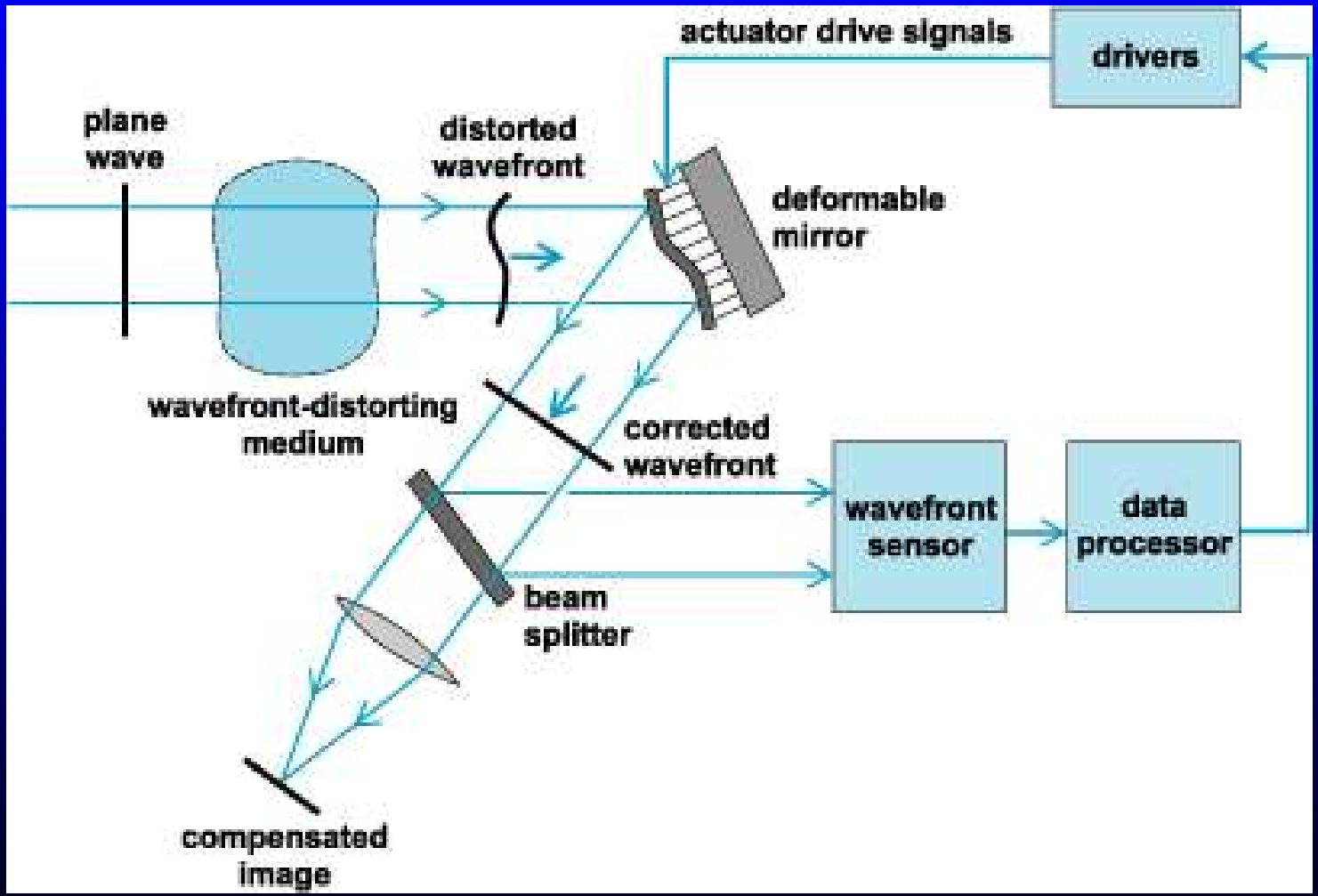


- Segmented Mirror using ACTIVE Optics

Other Solar Systems

VLT

Adaptive Optics

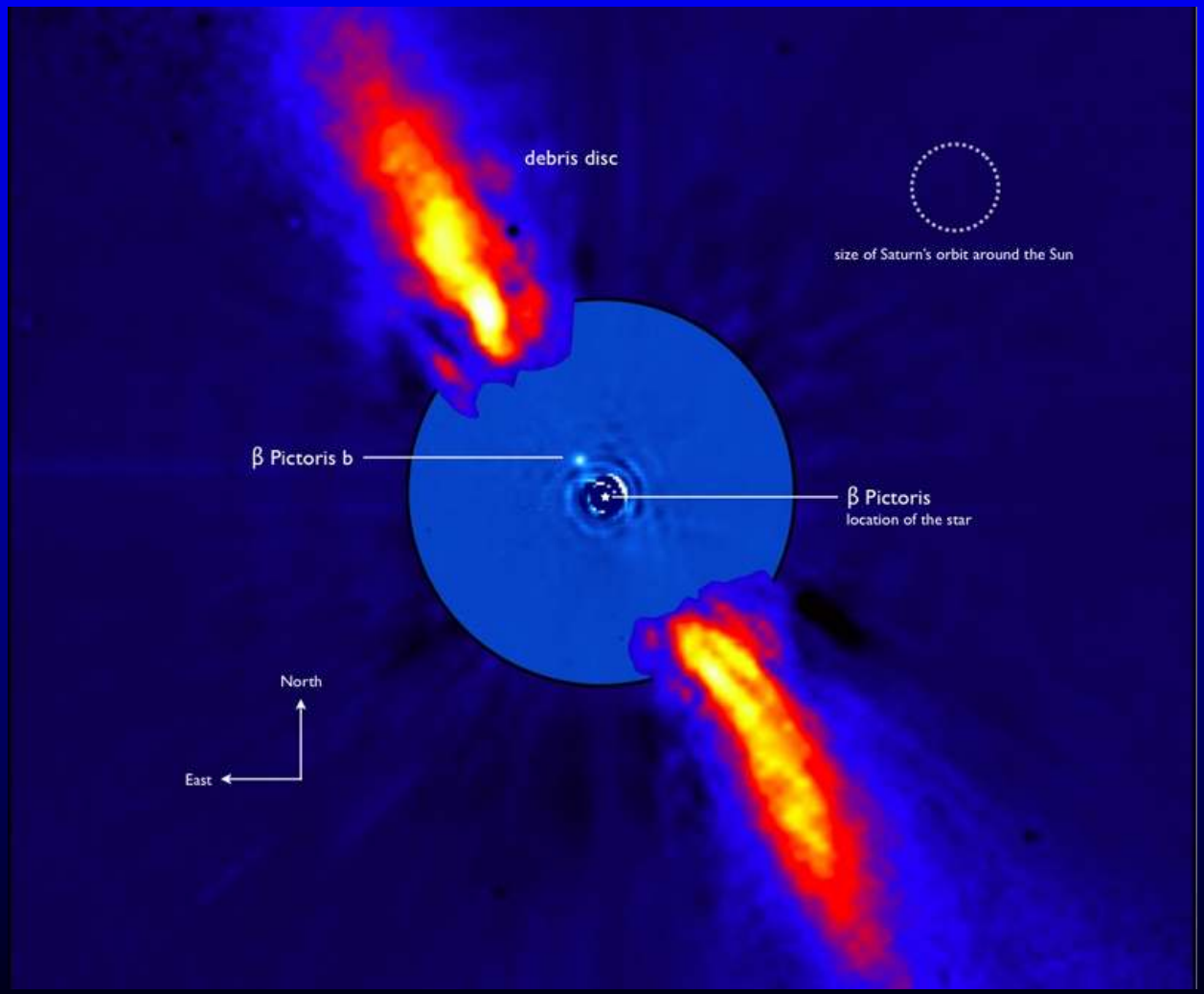


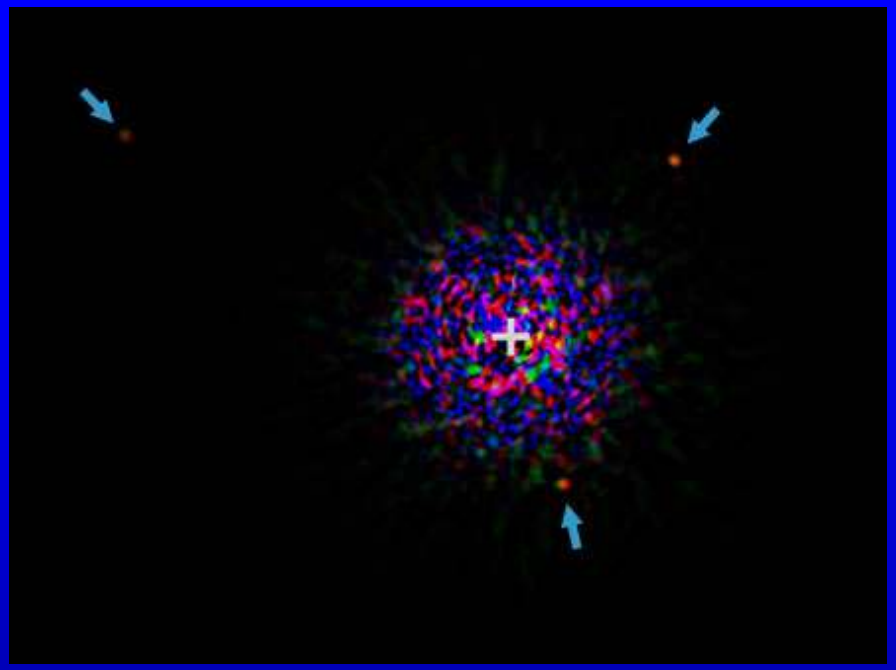
Laser Stimulated Artificial Star

Direct Detection: A planet in orbit around a "Brown Dwarf"

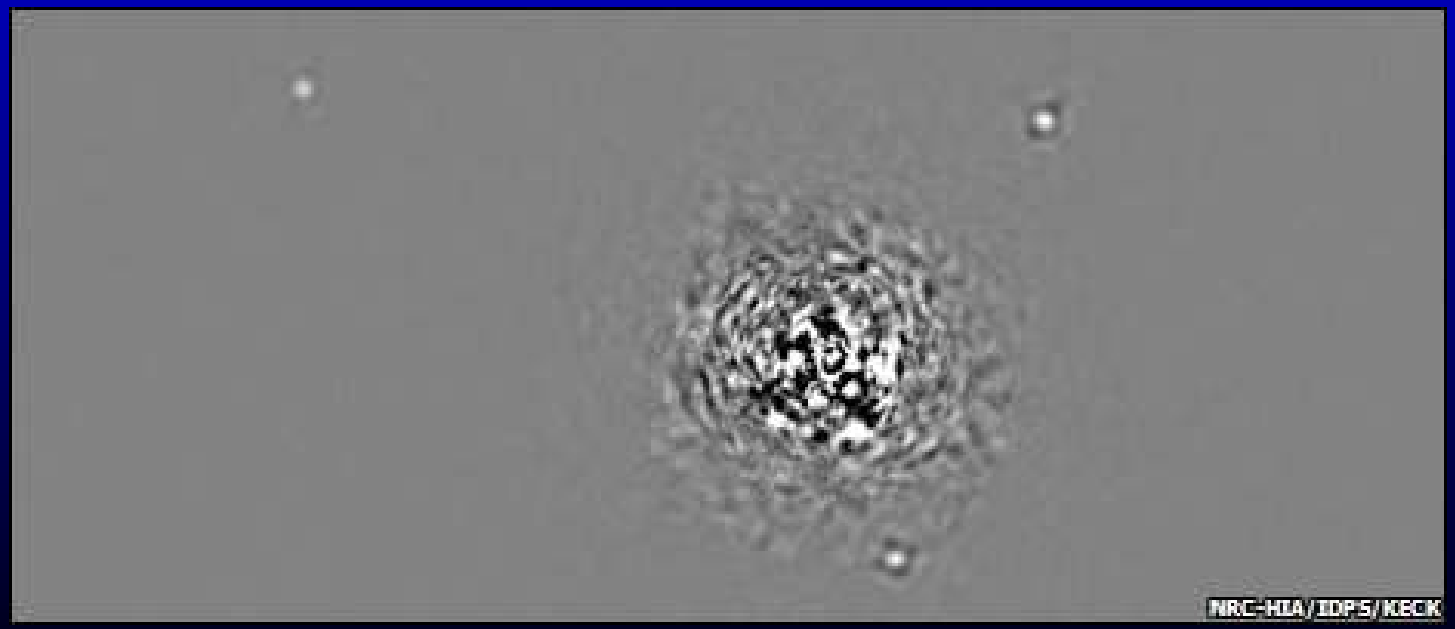
- Observed by the VLT in Chile in the infrared using adaptive optics.
- 5x Jupiter mass at a distance of 55 AU from brown dwarf.

β Pictoris b


debris disc
size of Saturn's orbit around the Sun
β Pictoris b
β Pictoris
location of the star
North
East

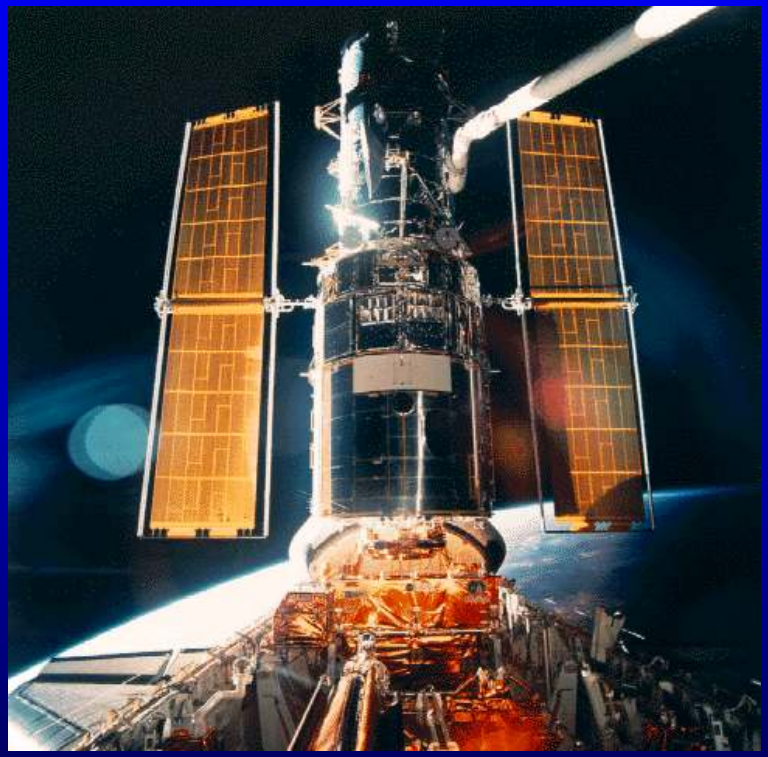


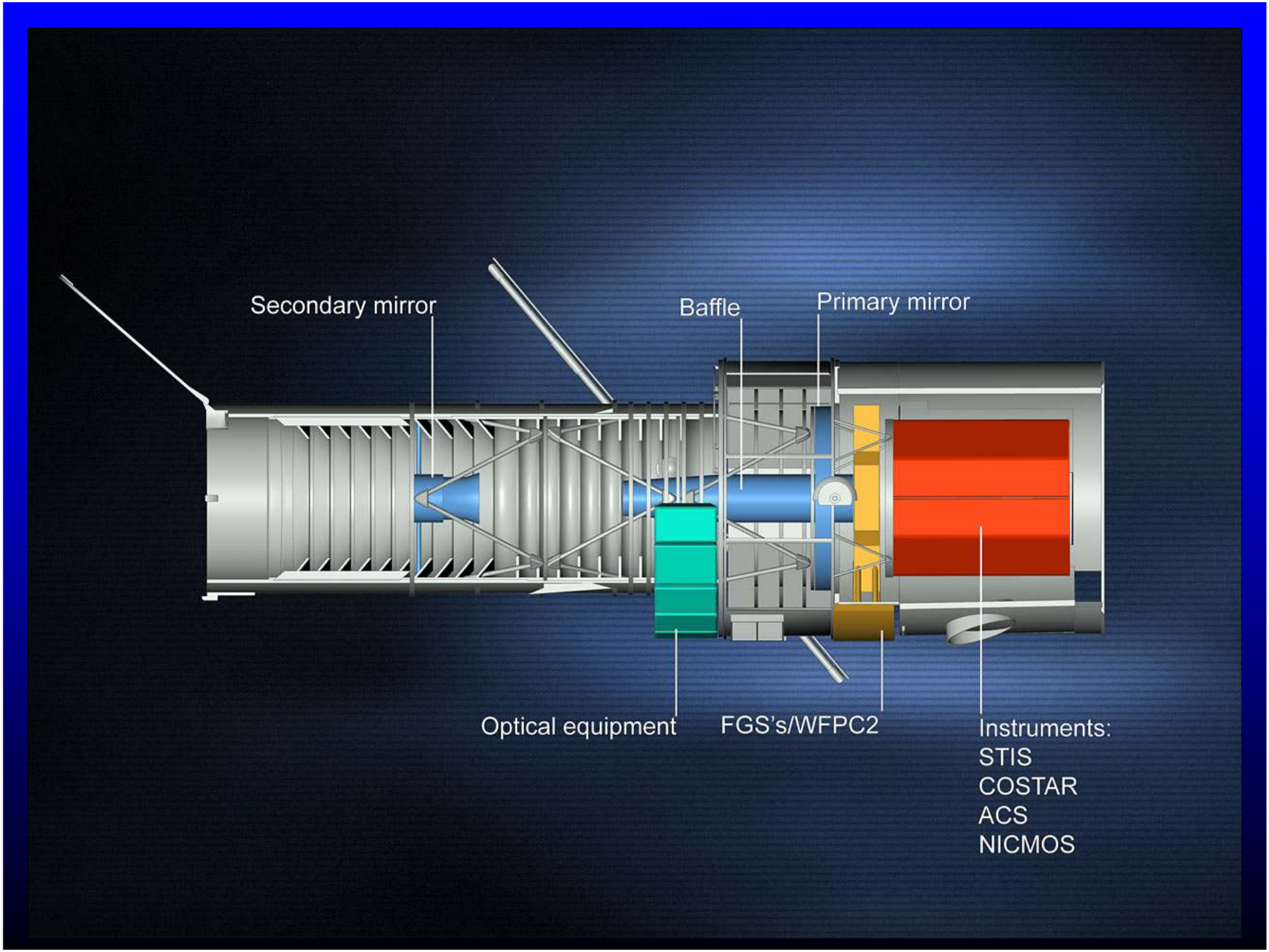
HR 8799 with three planets imaged by the Keck Telescope



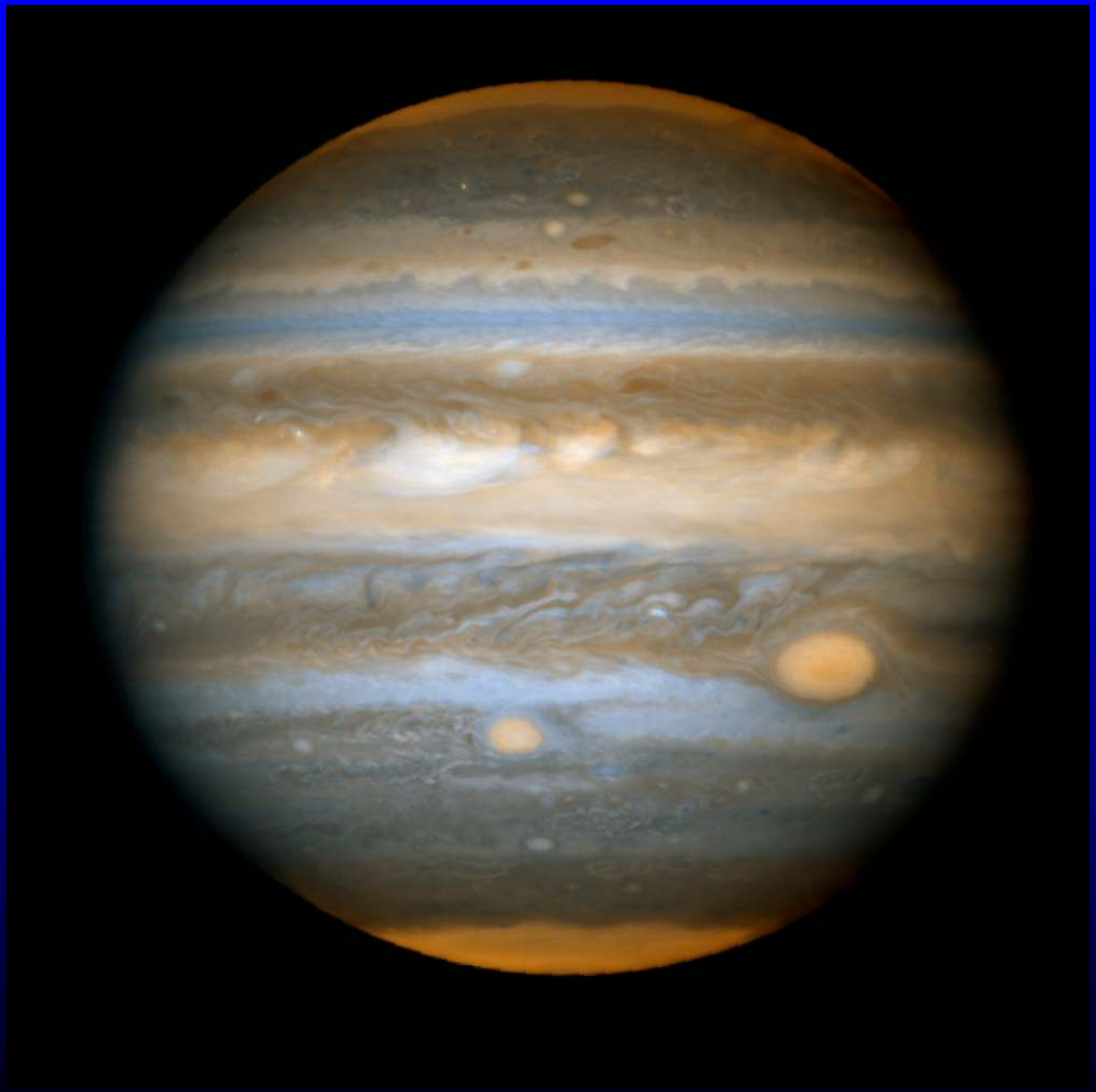
Hubble Space Telescope

Hubble Space Telescope

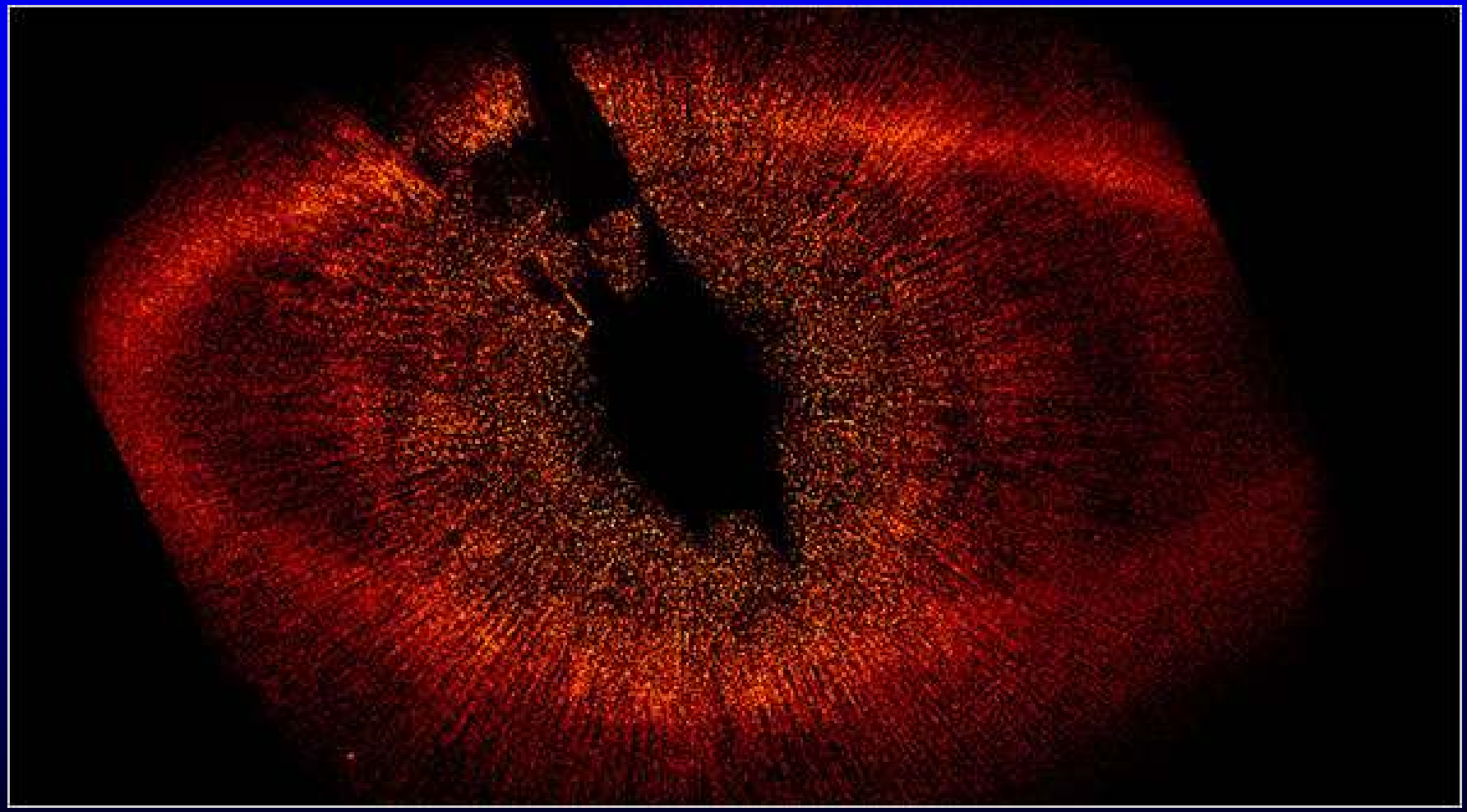


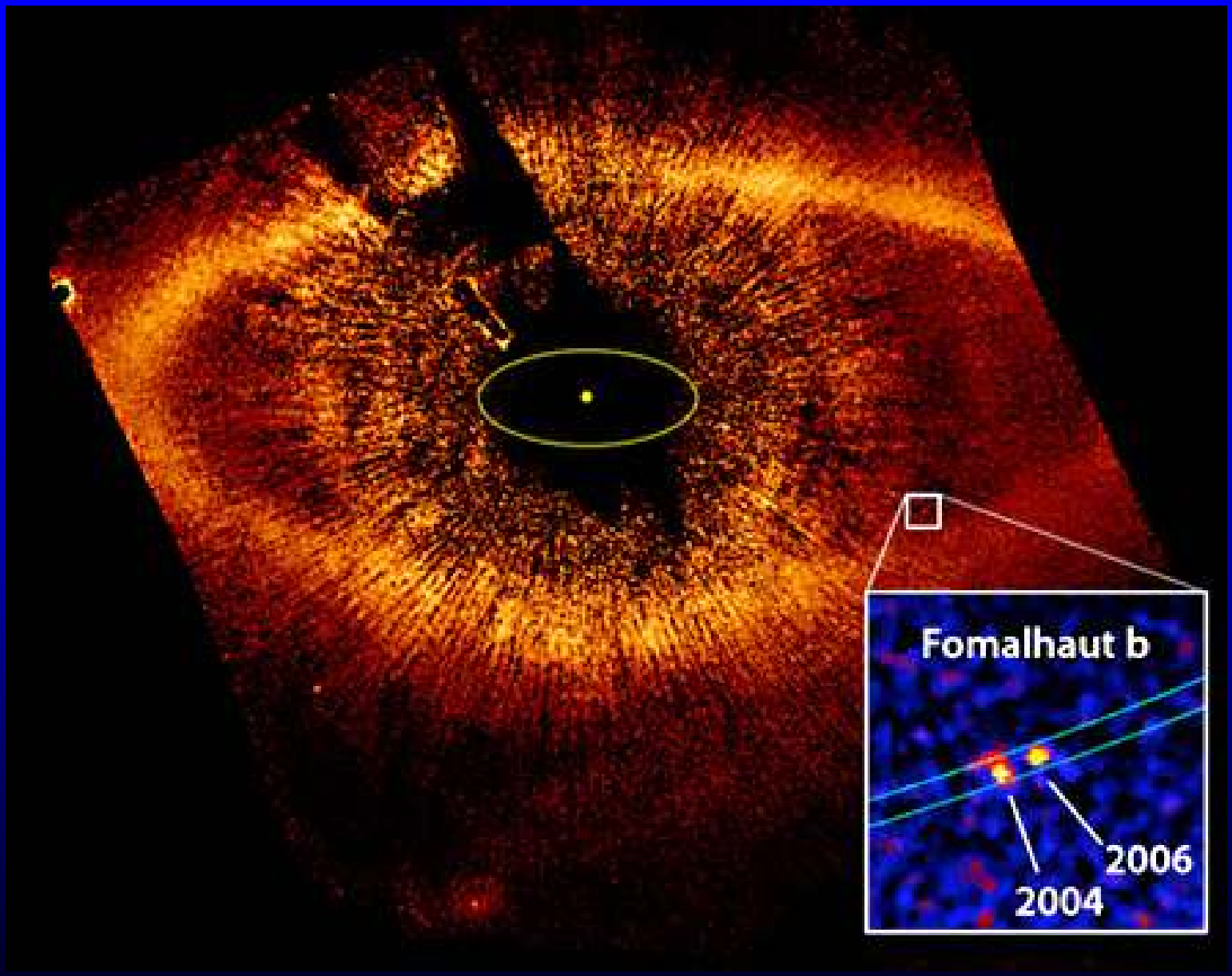

Secondary mirror
Baffle
Primary mirror
Optical equipment
FGS's/WFPC2
Instruments:
STIS
COSTAR
ACS
NICMOS

A problem with the mirror!

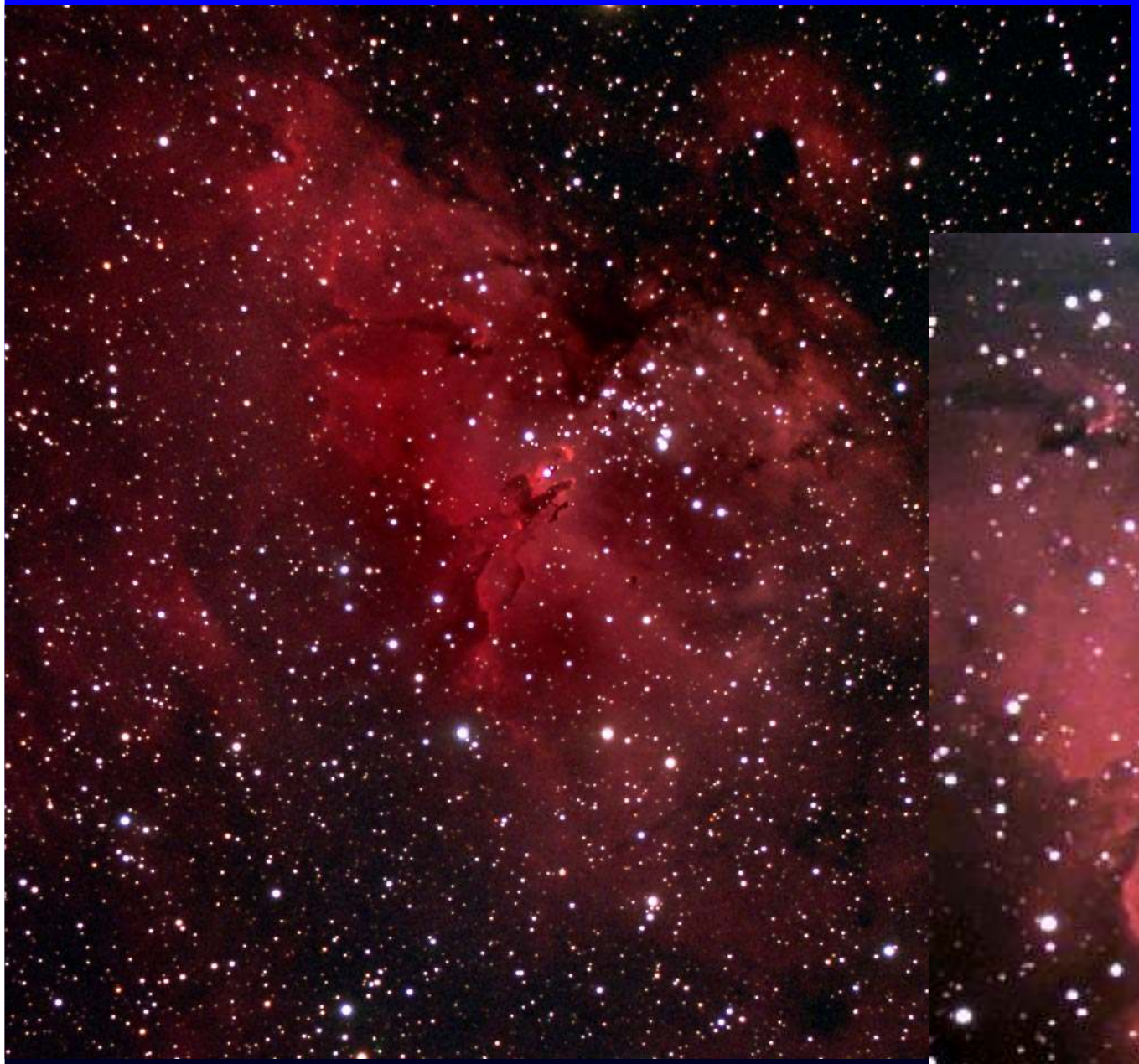


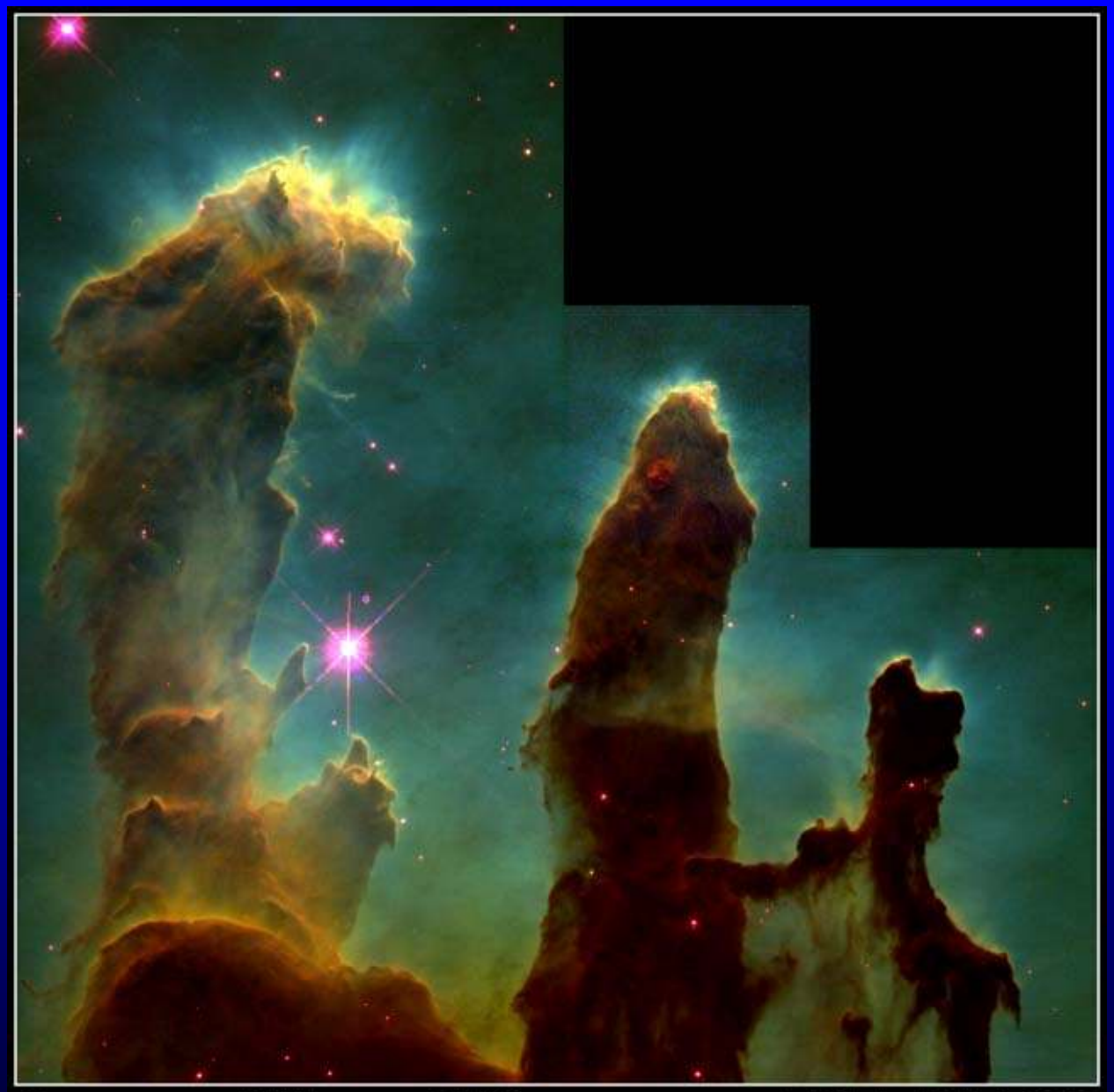
Hubble Visible Image of Formahaut b




Fomalhaut b
2006
2004

M16

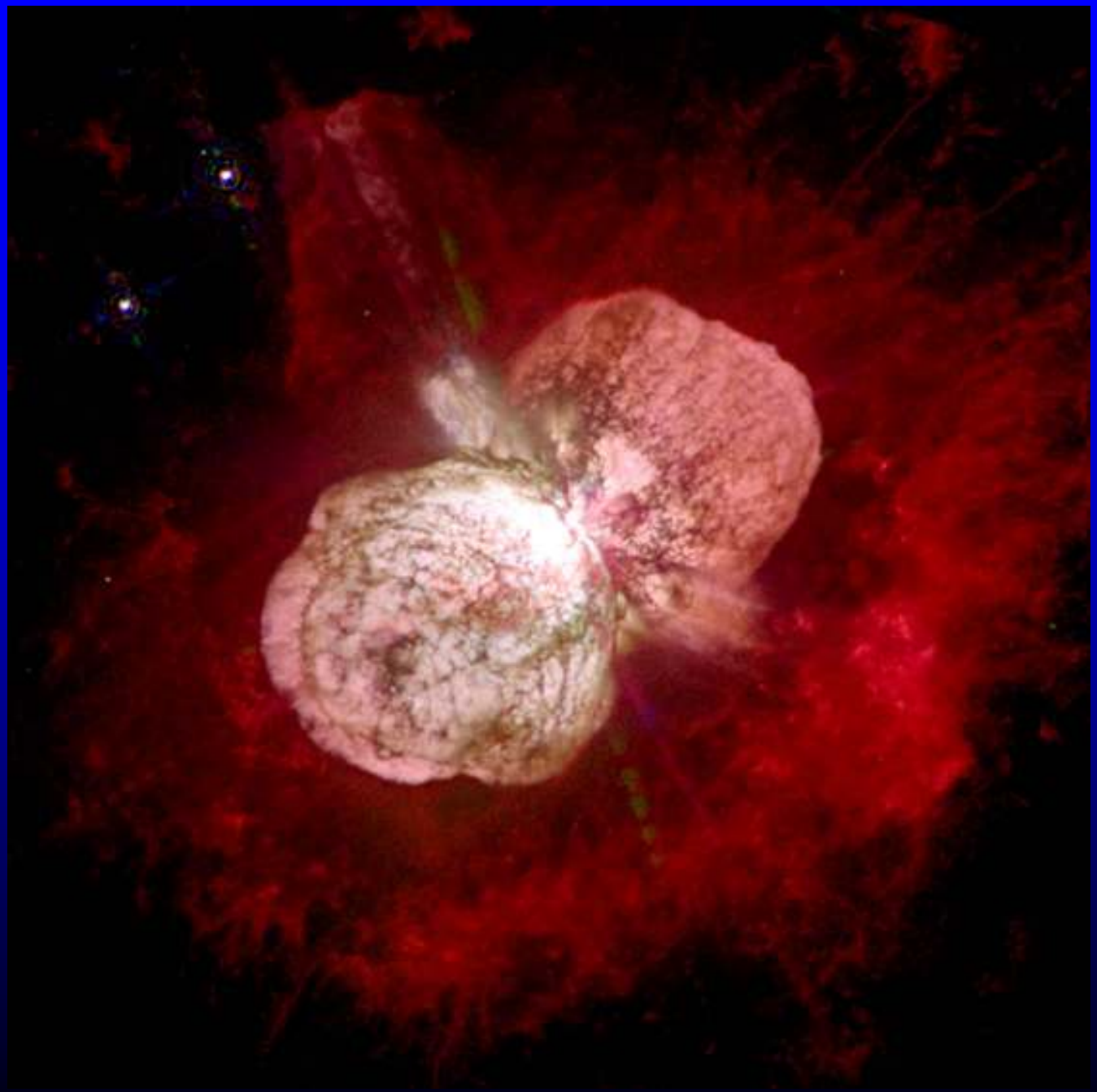




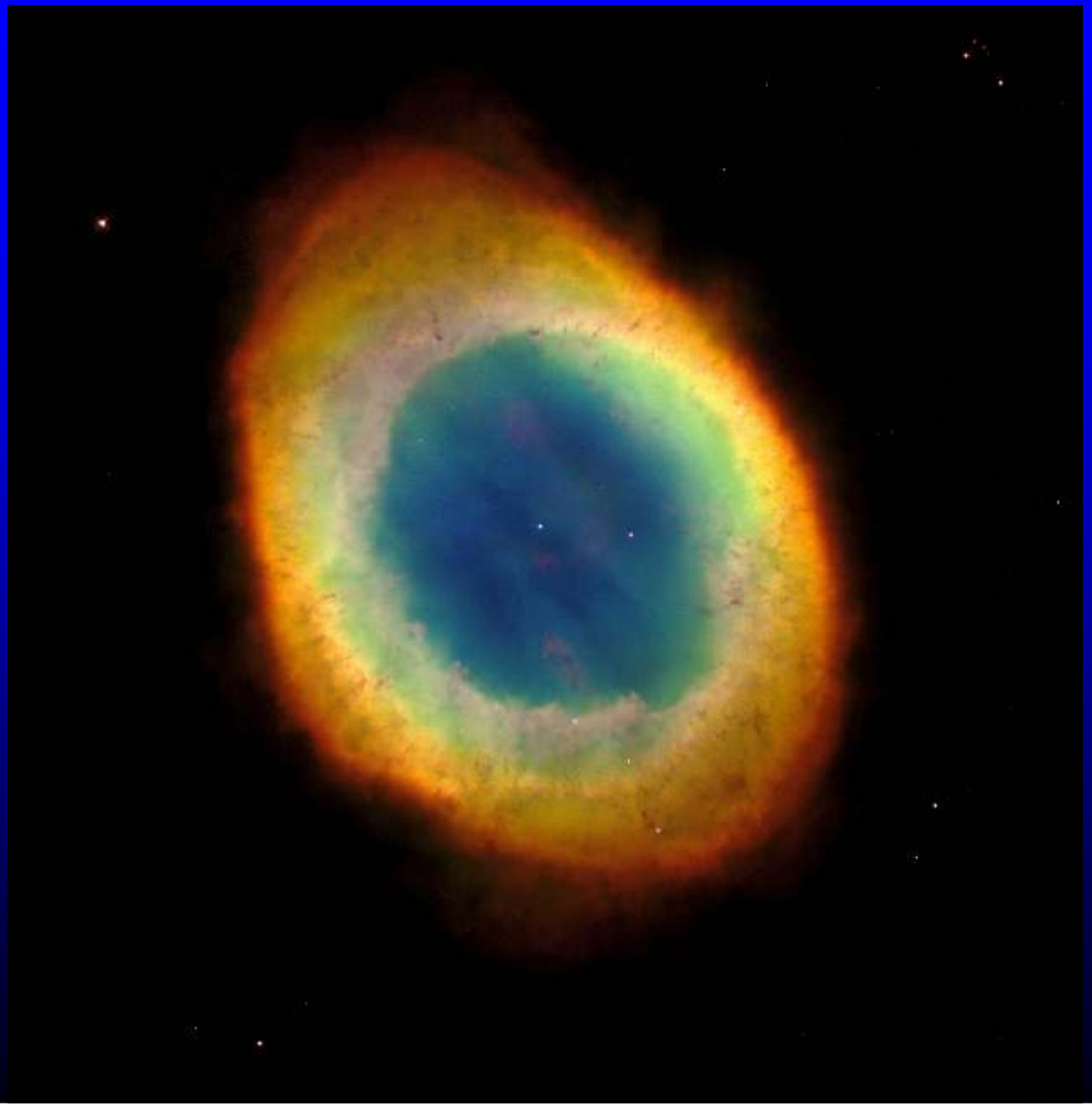
Gaseous Pillars · M16 HST · WFPC2

PRC95-44a · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

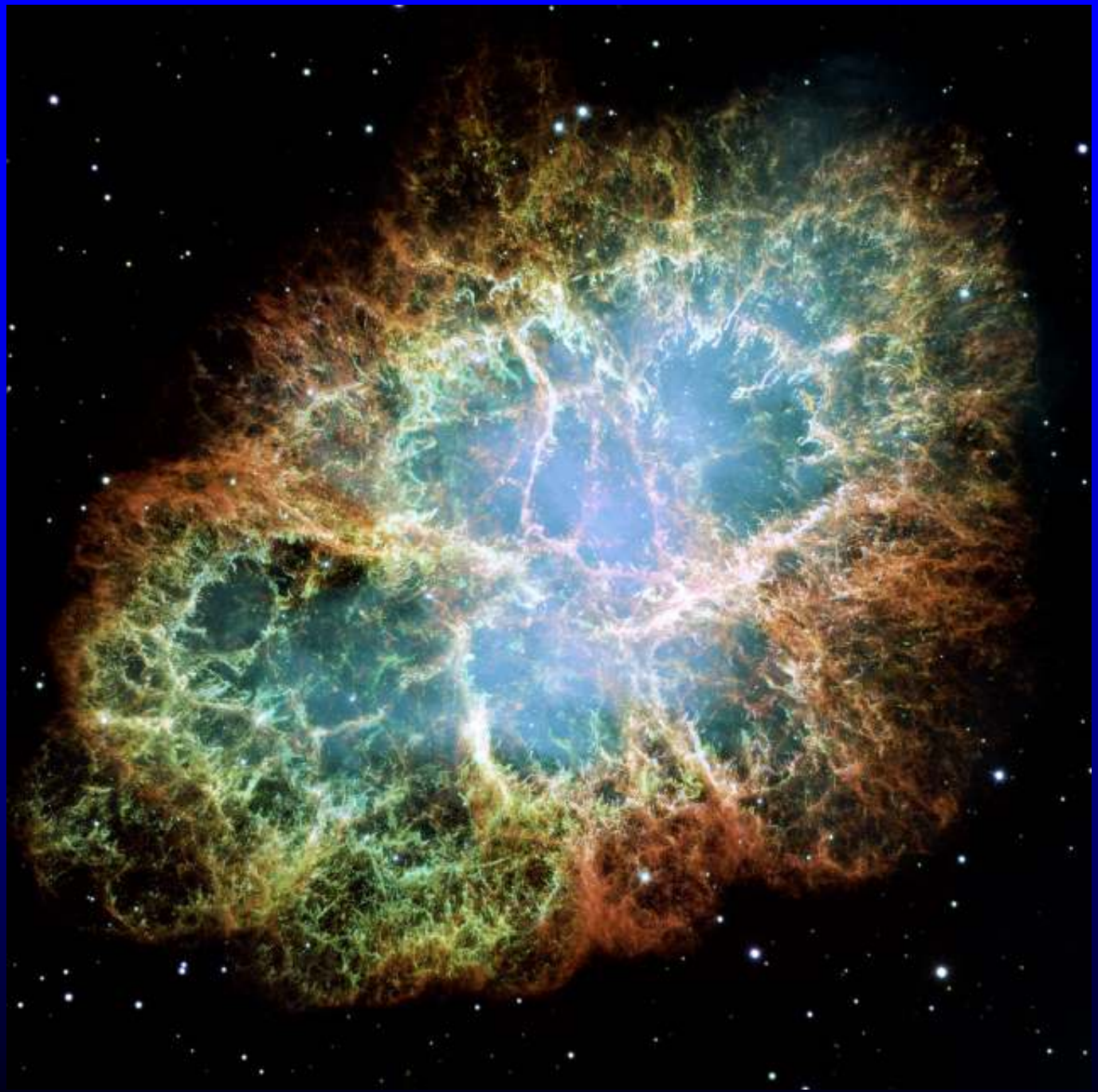
Eta Carina



Ring Nebula

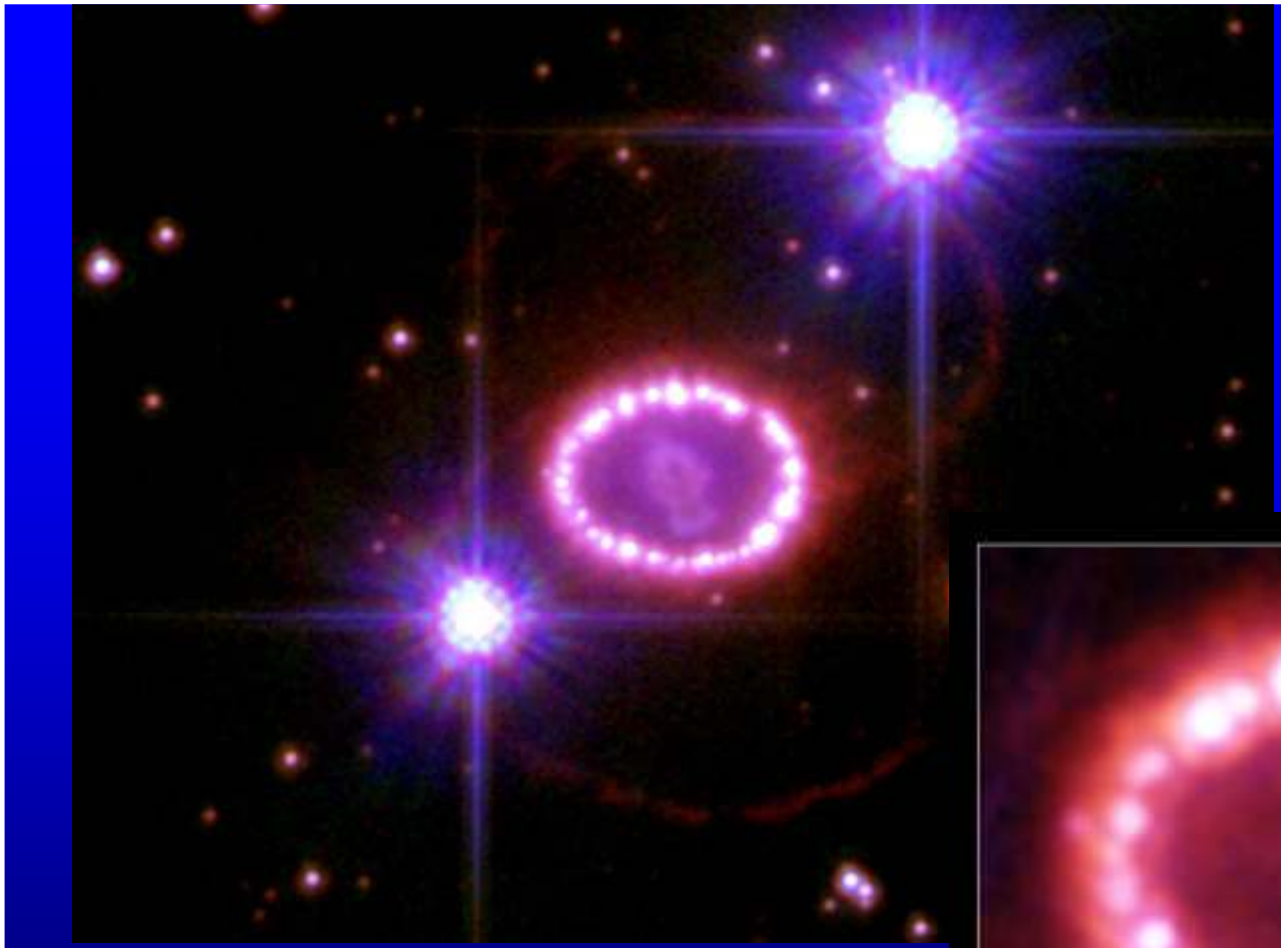


Crab Nebula



LMC

SN1987A



Supernova 1987A • November 28, 2003
Hubble Space Telescope • ACS

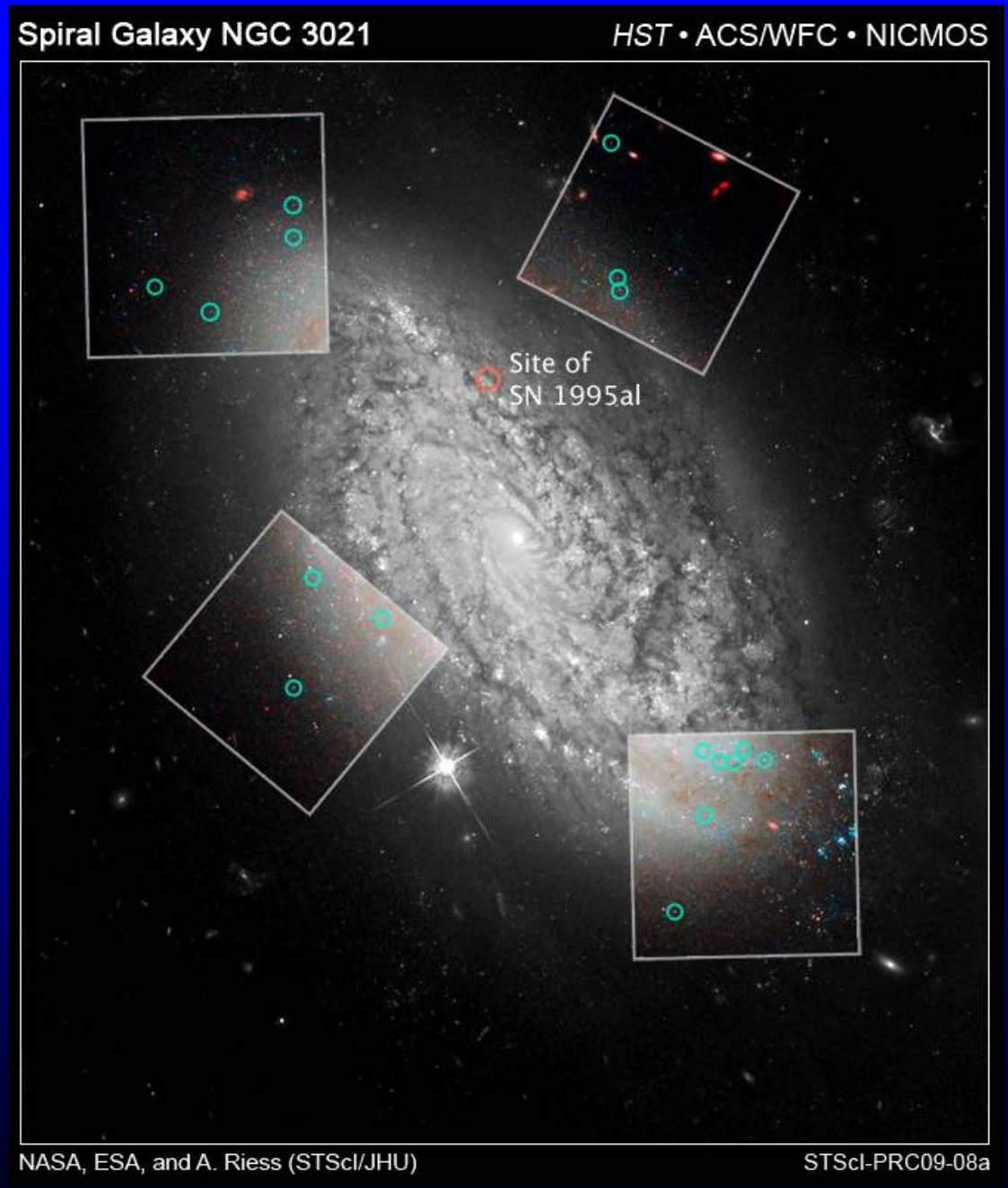
NASA and R. Kirshner (Harvard-Smithsonian Center for Astrophysics) STScI-PRC04-08a

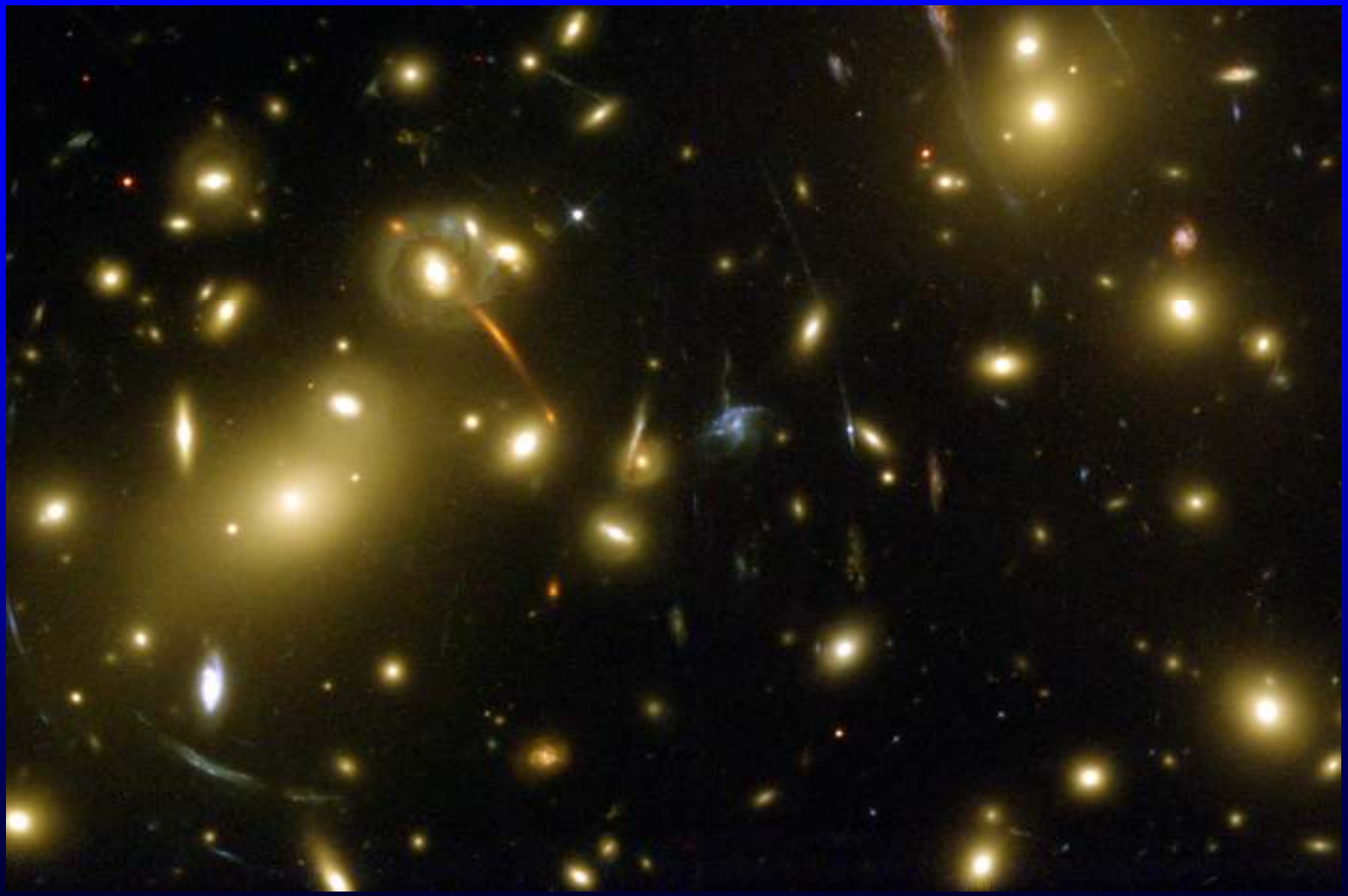
Hubble's Constant

- Observations of Cepheid Variables have provided what is perhaps the very best value:

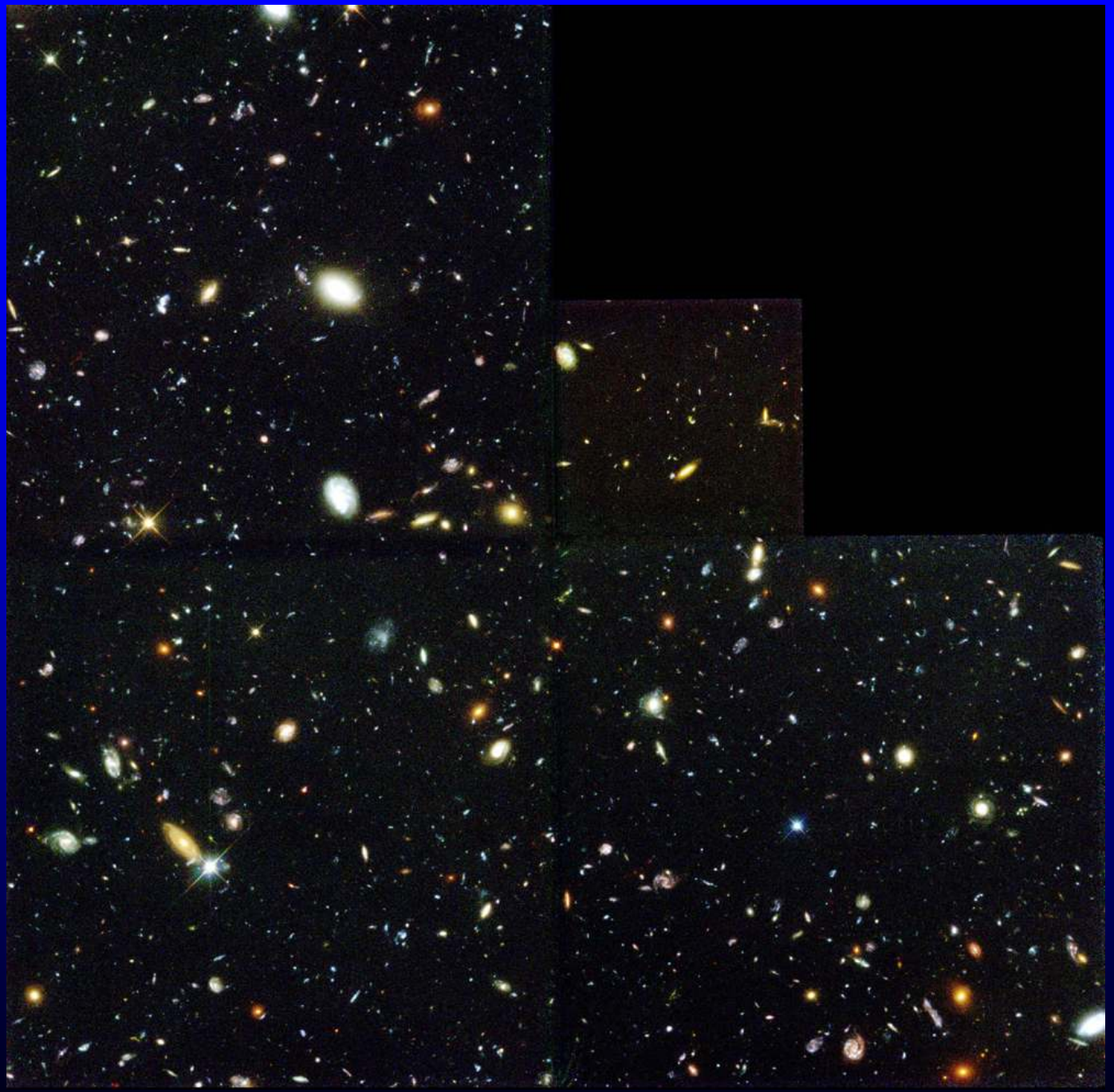
  74.2 km/sec/Mpc

  +/- 3.4 km/sec/Mpc

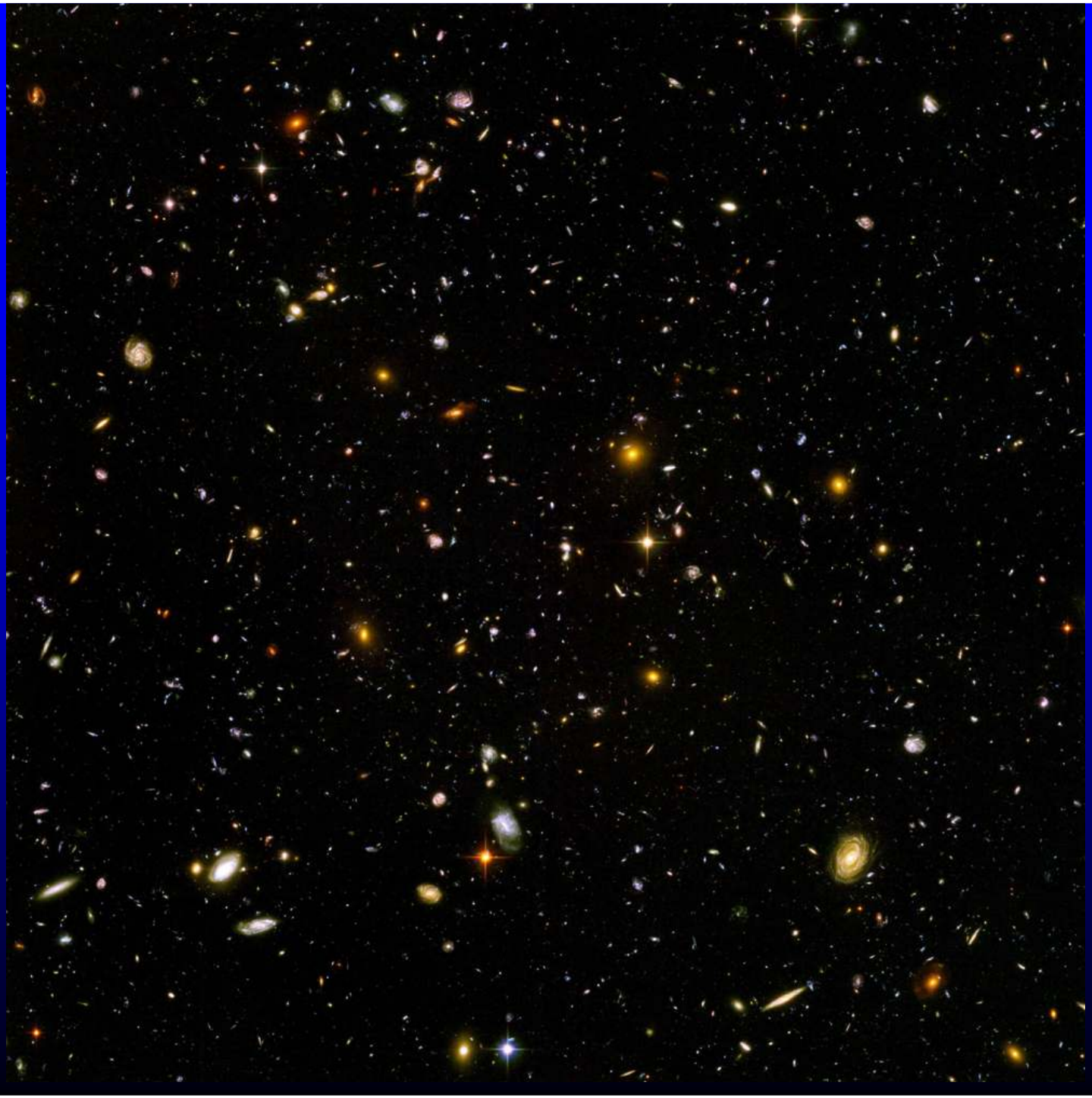




Hubble Deep Field



Hubble Ultra-Deep Field



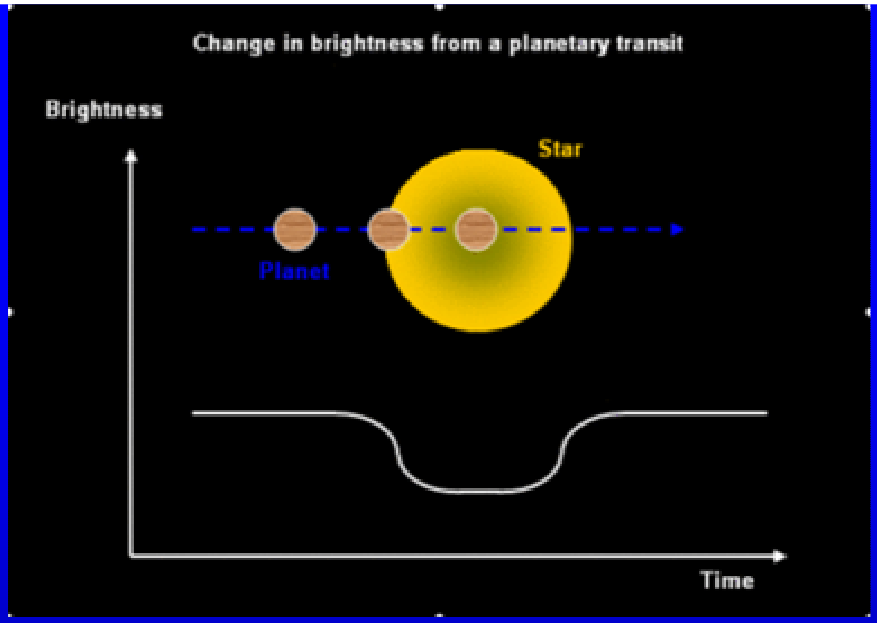
Robotic telescopes

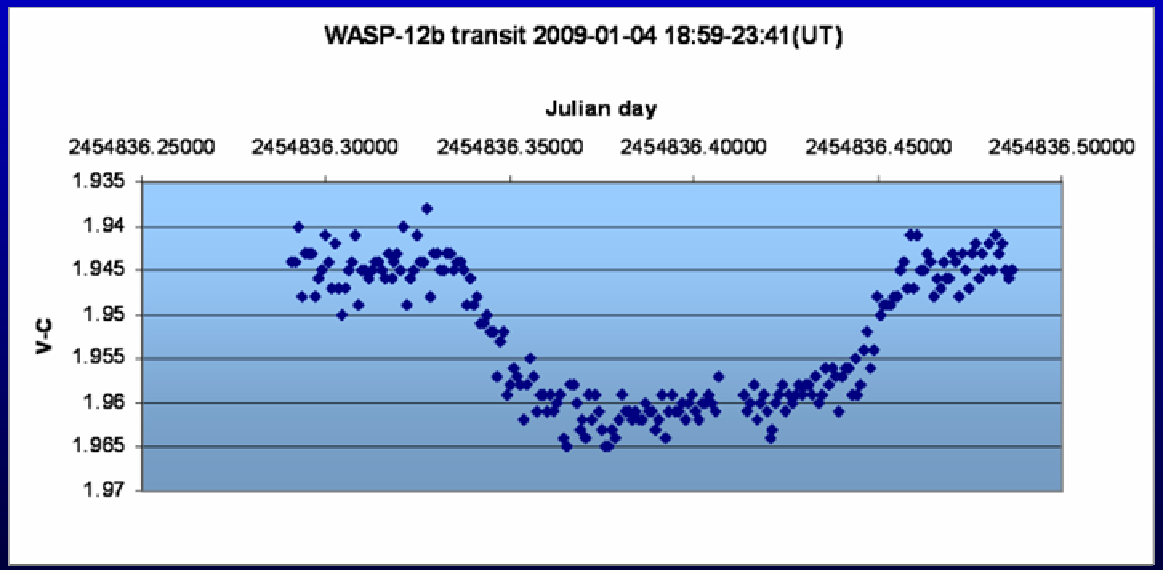
1) Small wide field telescopes to detect planetary transits

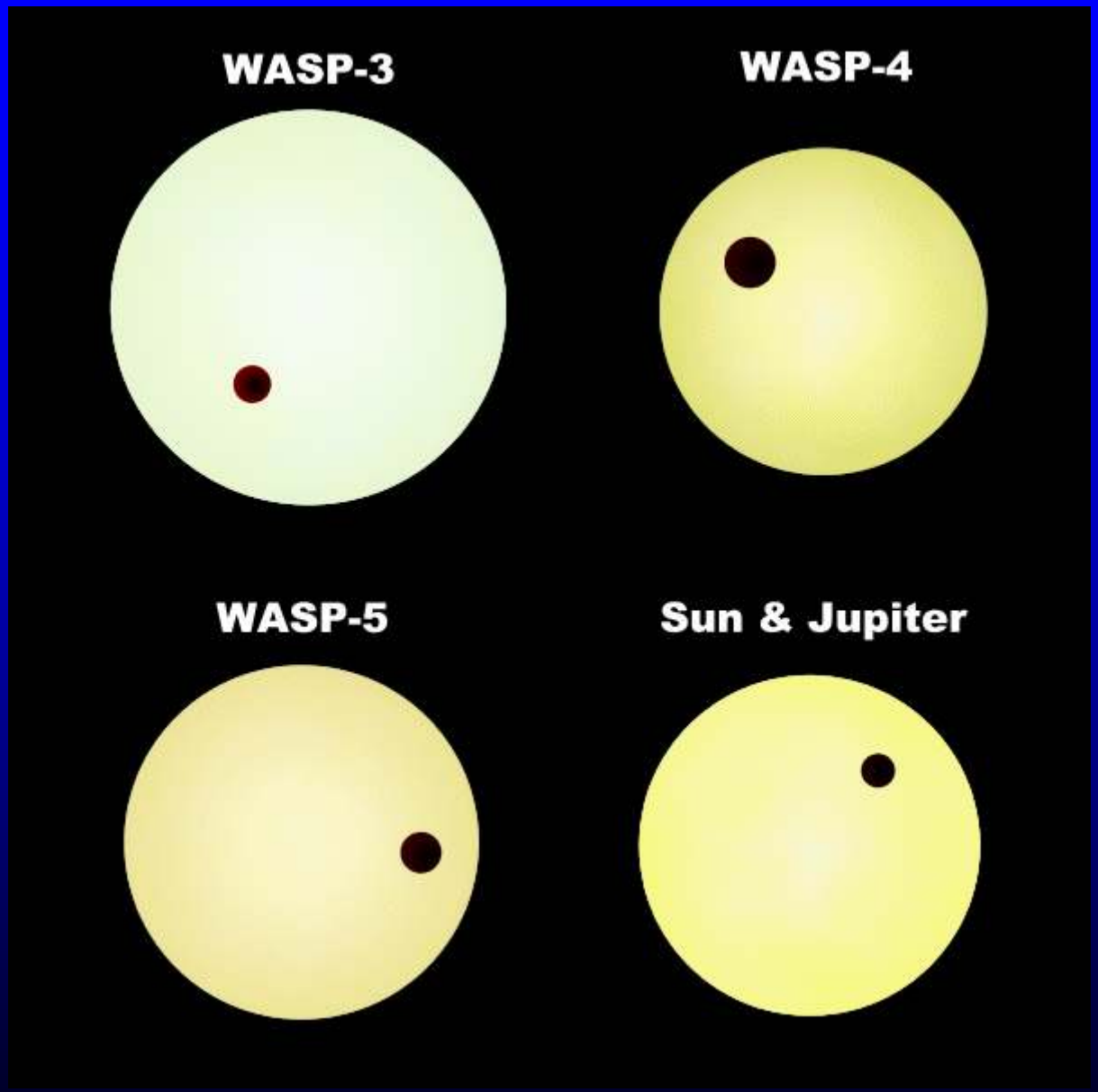
WASP

Super-WASP

Planetary Transits



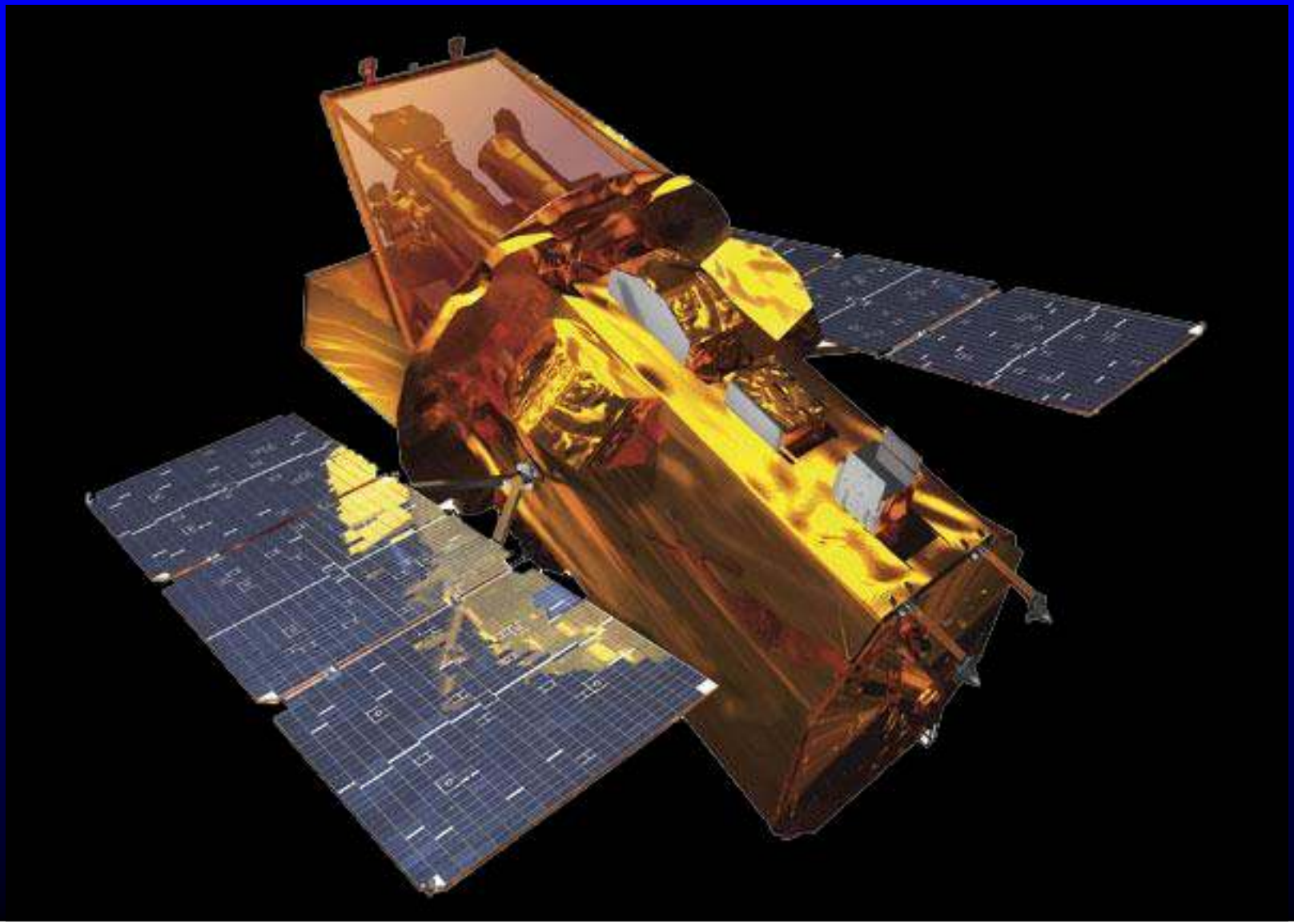



WASP-3
WASP-4
WASP-5
Sun & Jupiter

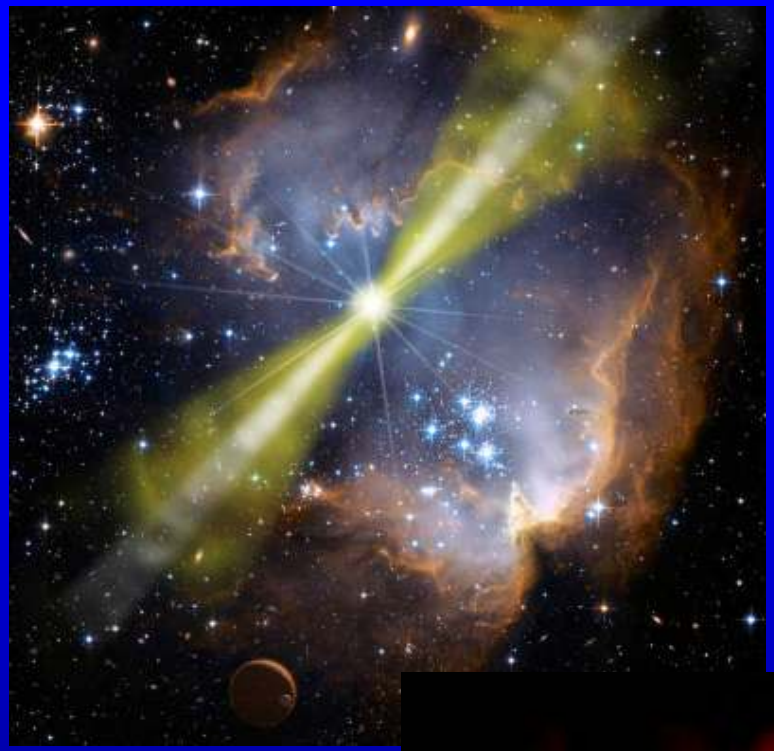
Robotic telescopes

2) High slew rate telescopes to detect transient events such as Gamma Ray Bursts

Swift Spacecraft



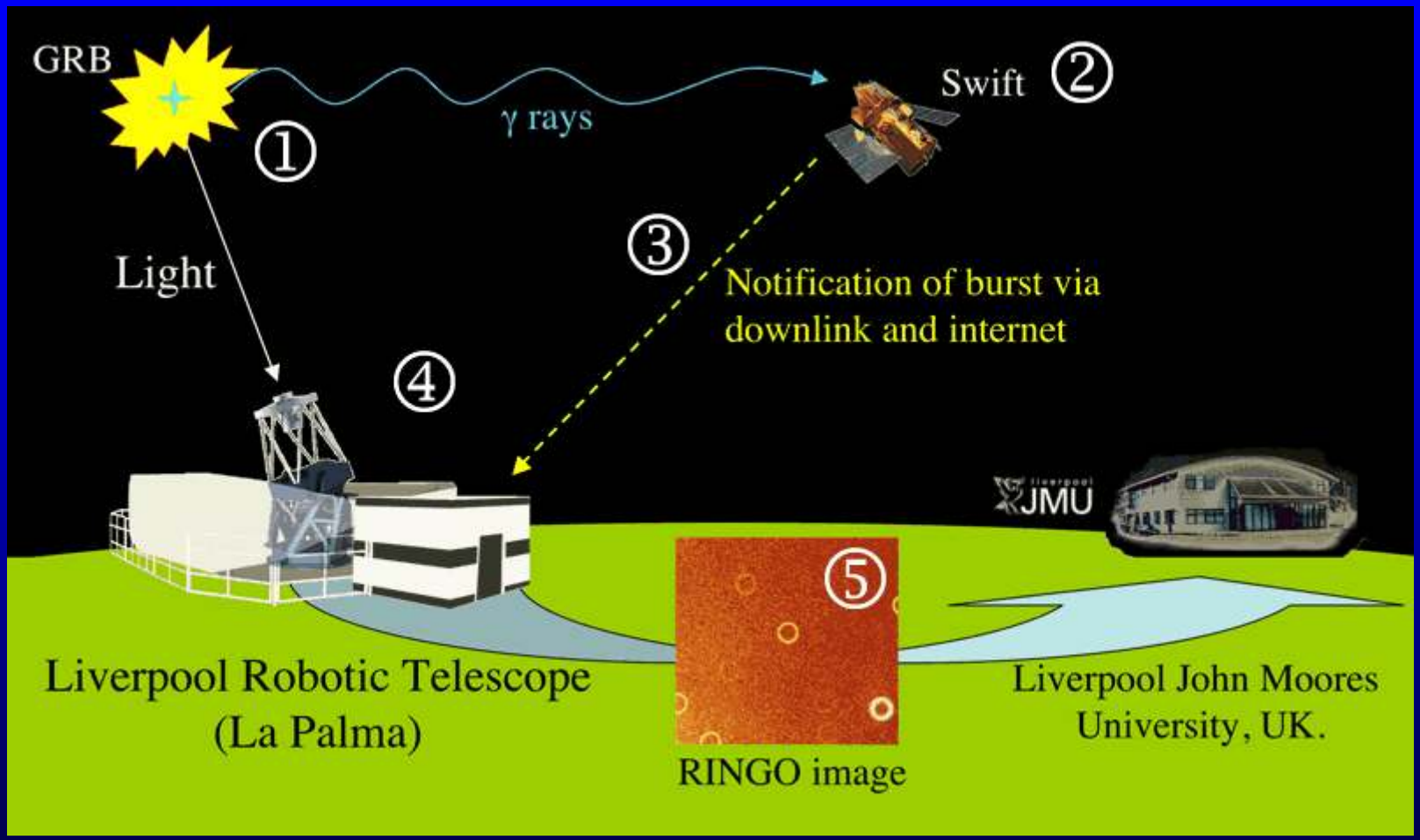
Gamma Ray Bursts



High Speed Slew Rate Telescopes

Robotic telescopes

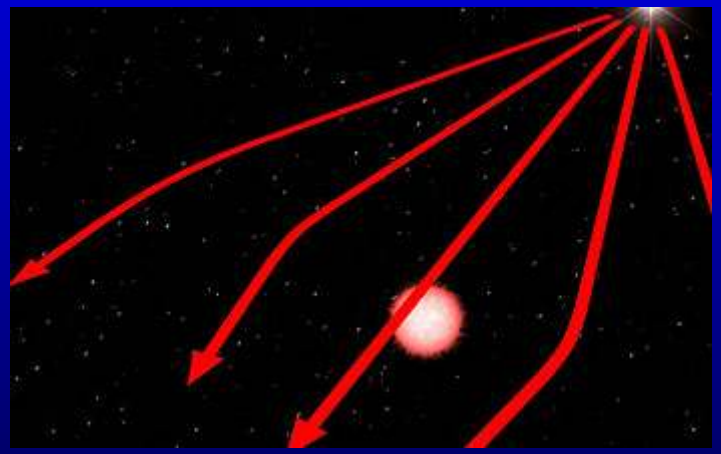
3) Two metre class telescopes to detect longer gamma ray bursts and find planets by gravitational microlensing

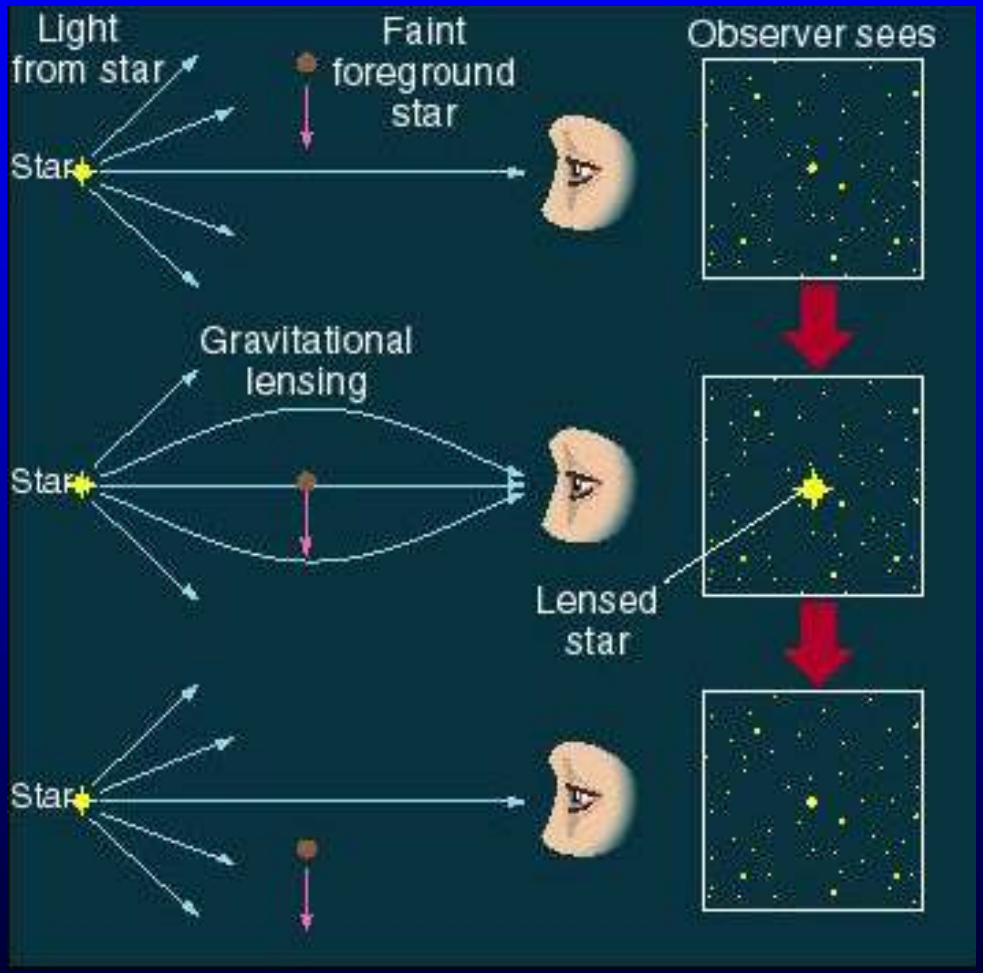

GRB
γ rays
Swift ②
①
③
Light
Notification of burst via
downlink and internet
④
JMU
⑤
Liverpool Robotic Telescope
(La Palma)
RINGO image
Liverpool John Moores
University, UK.

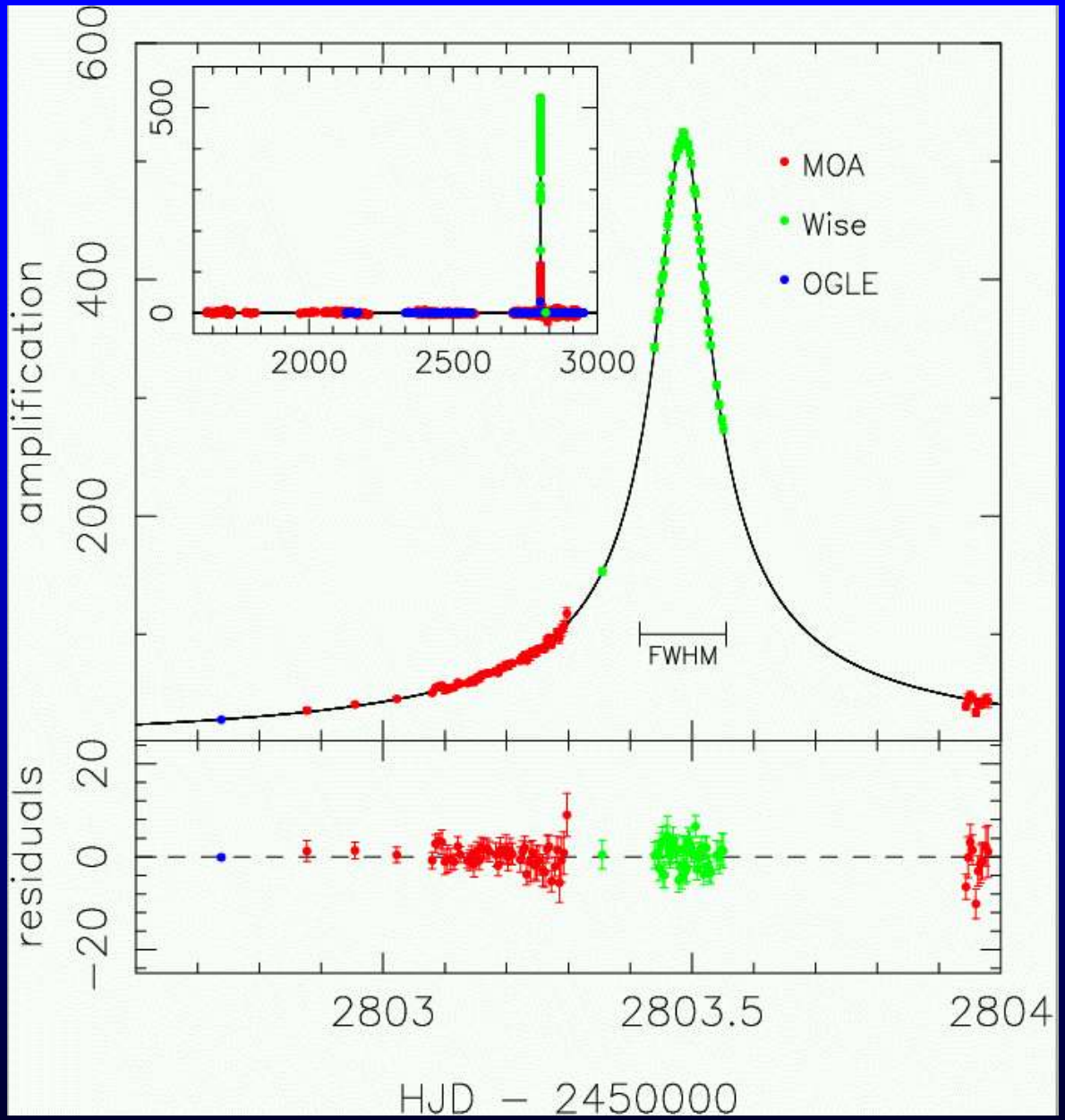
Faulkes Telescope: Siding Springs

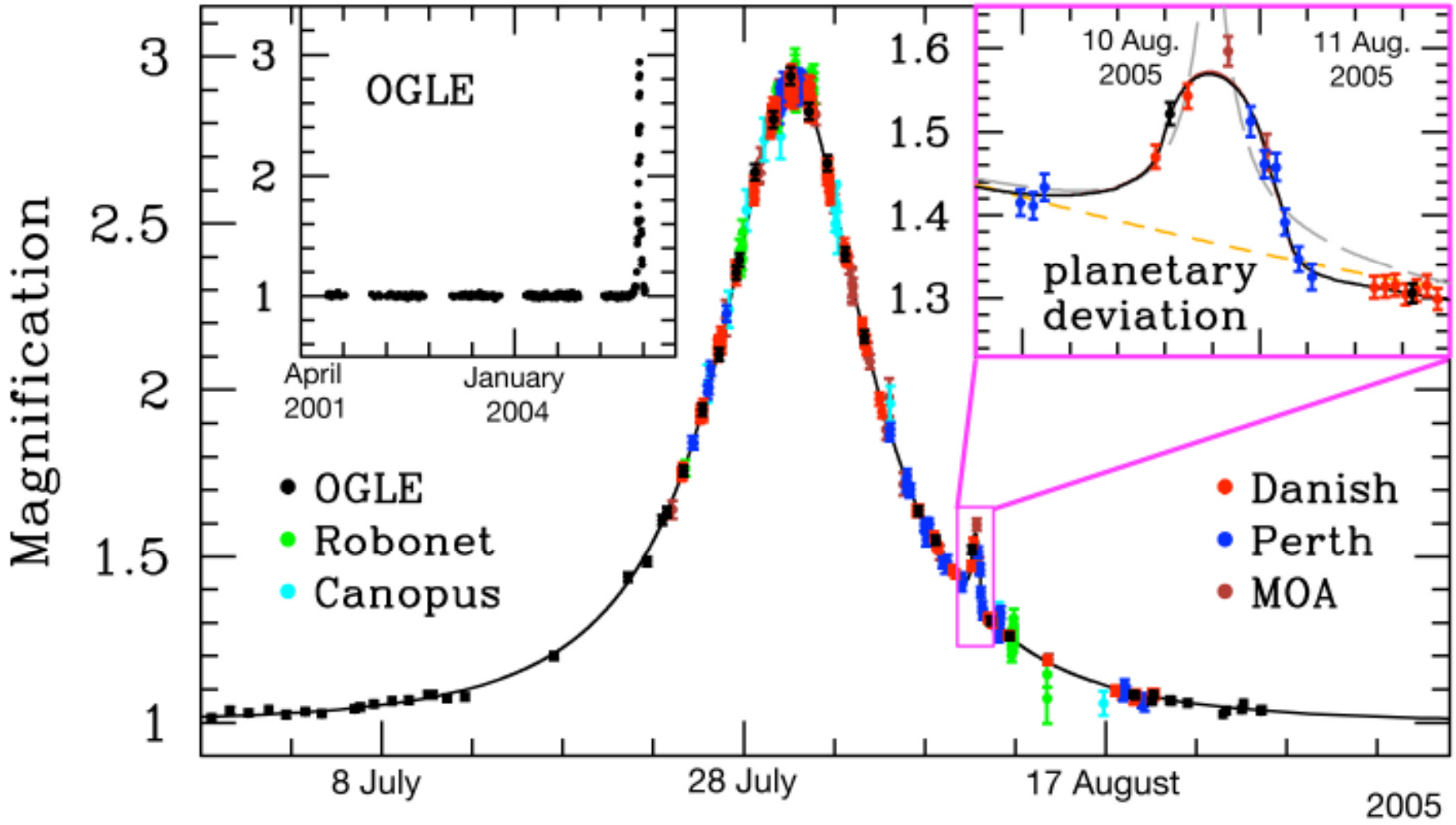
Faulkes Telescope: Hawaii

Gravitational Micro-lensing



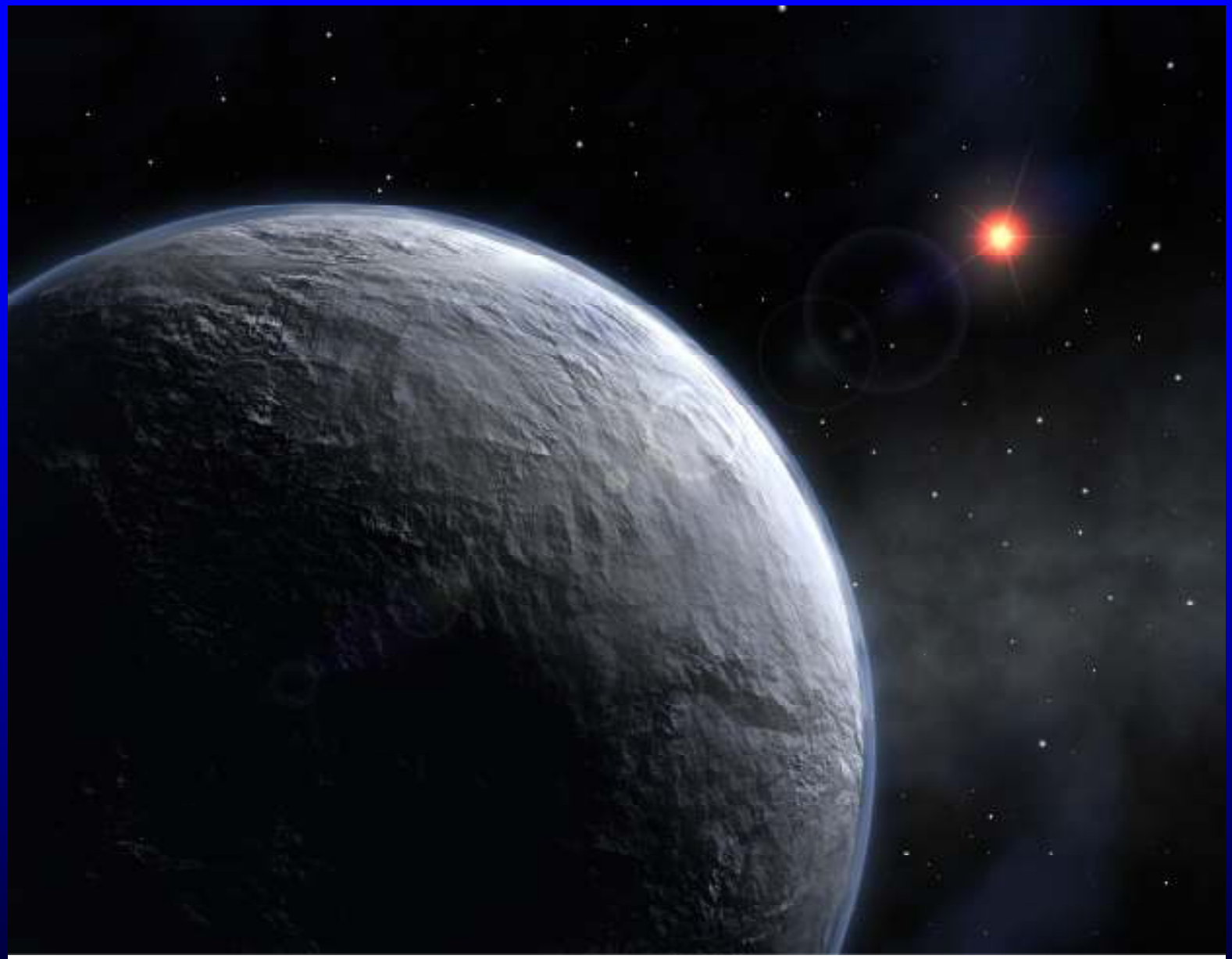



amplification
600
400
200
500
0
2000
2500
3000
MOA
Wise
OGLE
FWHM
residuals
20
0
−20
2803
2803.5
2804
HJD − 2450000



Light Curve of OGLE-2005-BLG-390

ESO PR Photo 03b/06 (January 25, 2006)

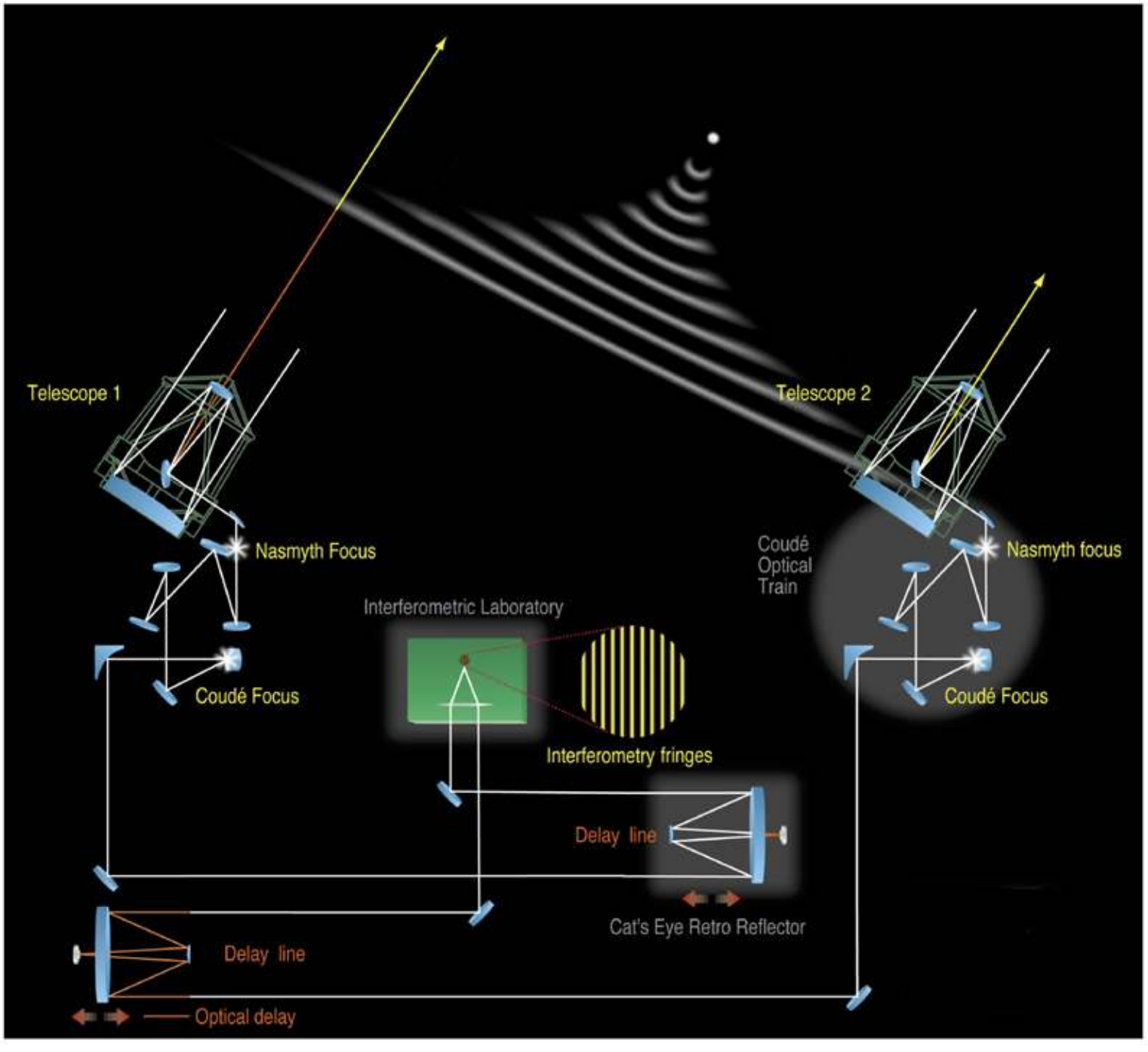


Five Earth Masses Icy Extrasolar Planet
(Artist's Impression)

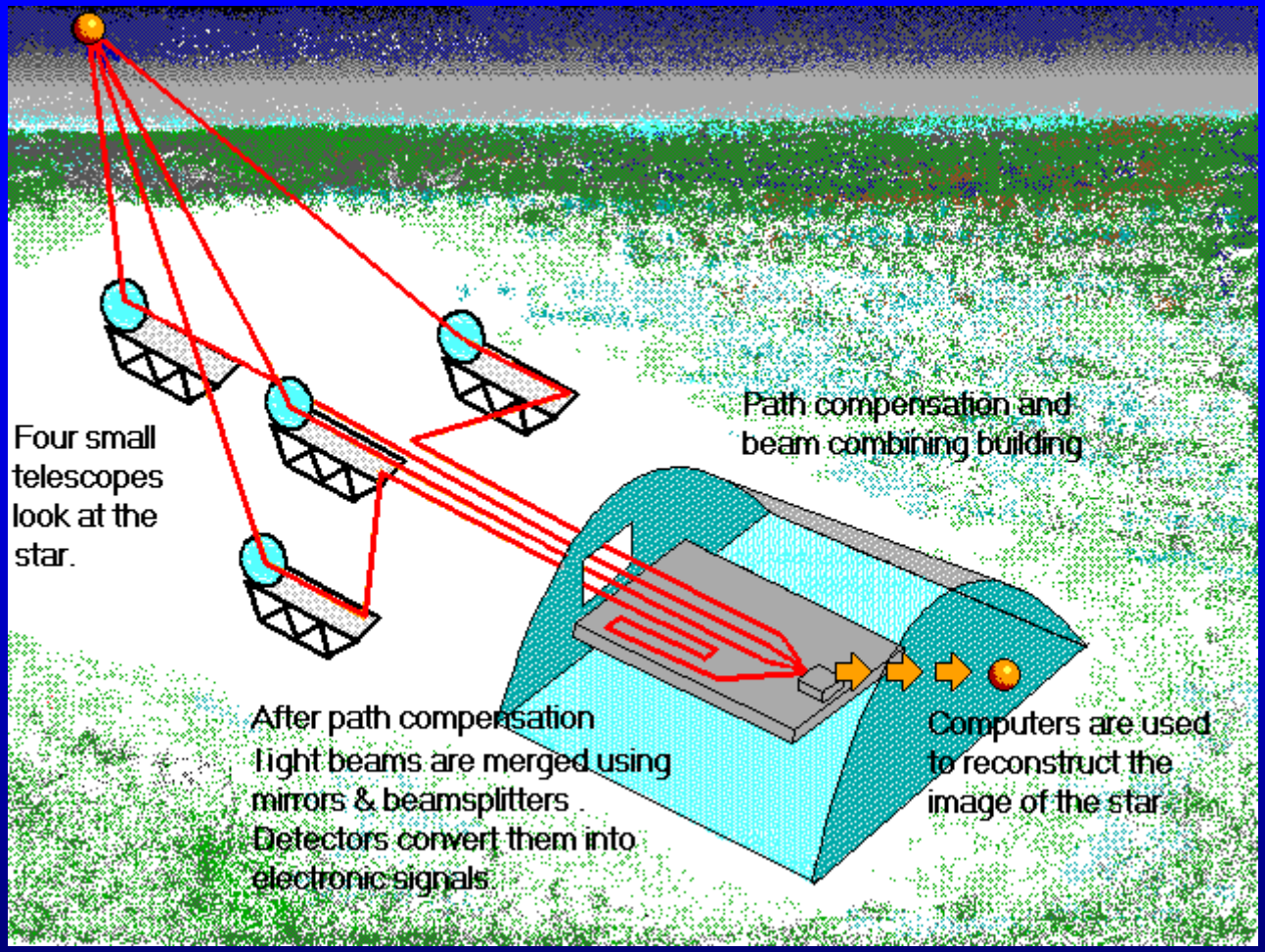
ESO PR Photo 03a/06 (January 25, 2006)

Interferometric Arrays

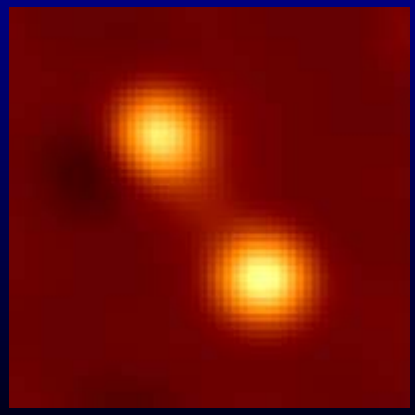
Combining multiple telescopes to
give ultra-high resolution


Telescope 1
Telescope 2
Nasmyth Focus
Coudé Focus
Interferometric Laboratory
Interferometry fringes
Coudé Optical Train
Nasmyth focus
Coudé Focus
Delay line
Cat's Eye Retro Reflector
Delay line
Optical delay

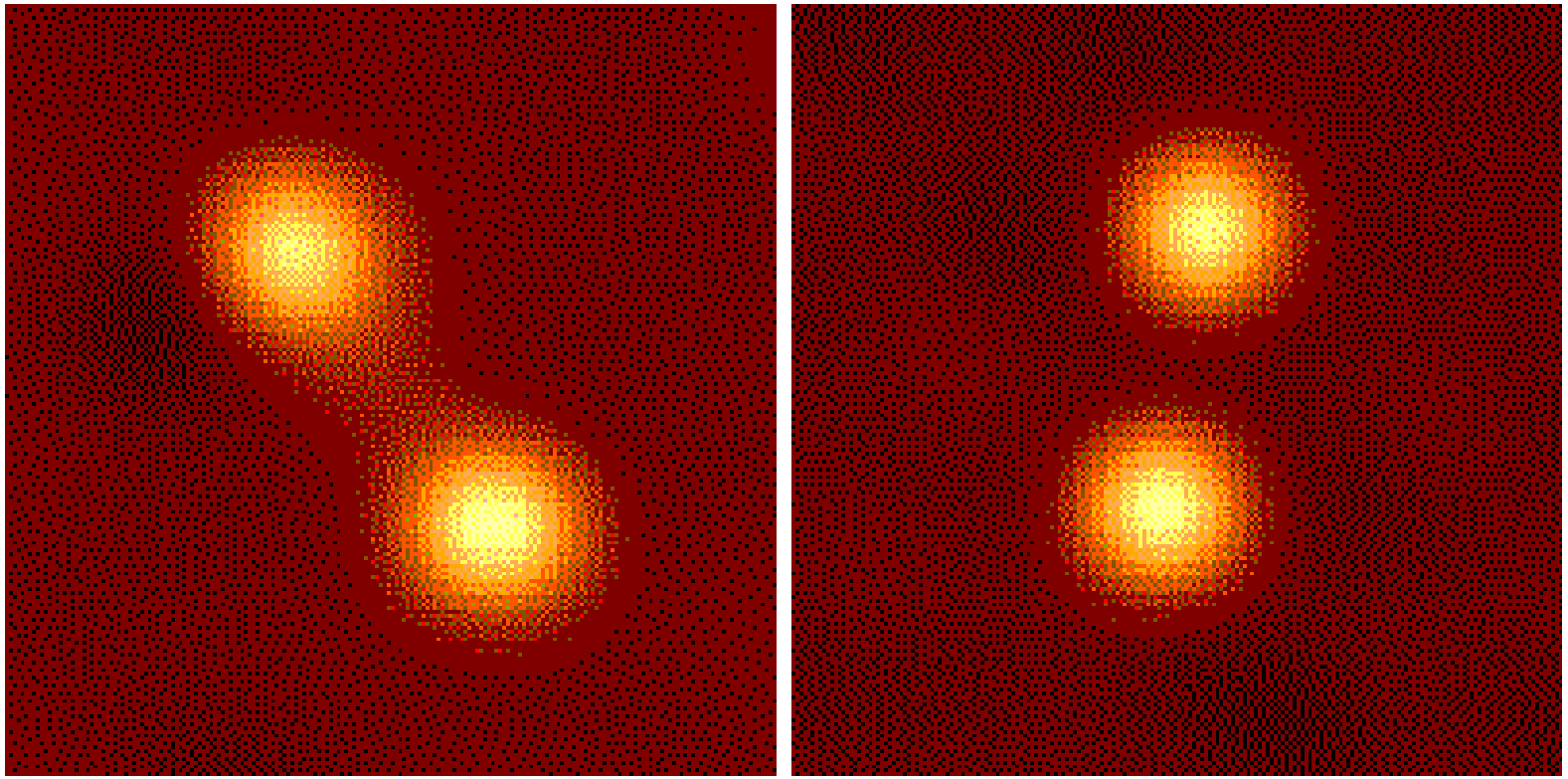
COAST at Cambridge



Capella binary:



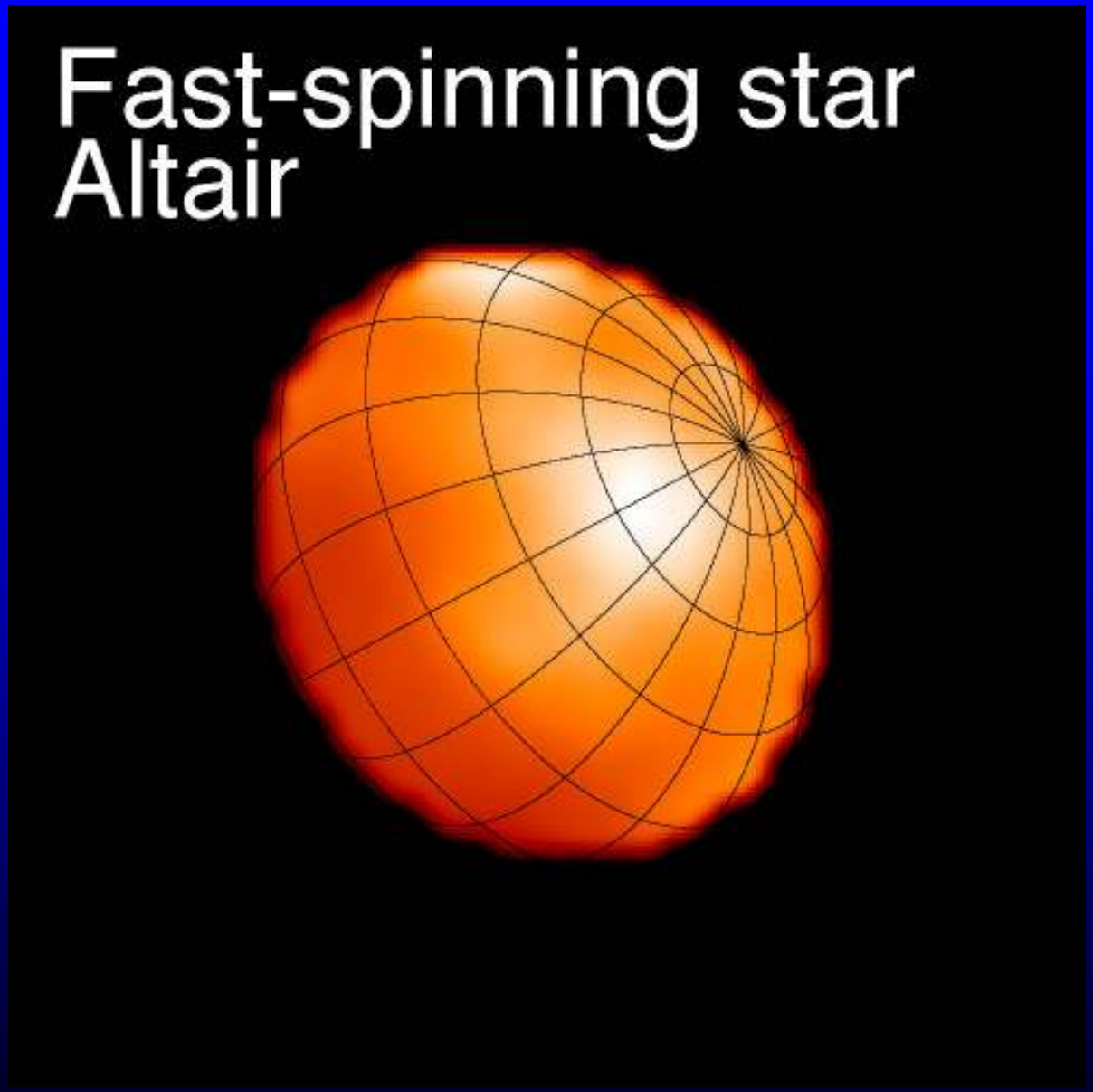
Binary Star System



Images of Capella taken on the 13th (left) and 28th (right) September 1995. The separation between the stars is 55 milli-arcsec.

Mt Wilson CHARA Interferometer

CHARA Image of a star!

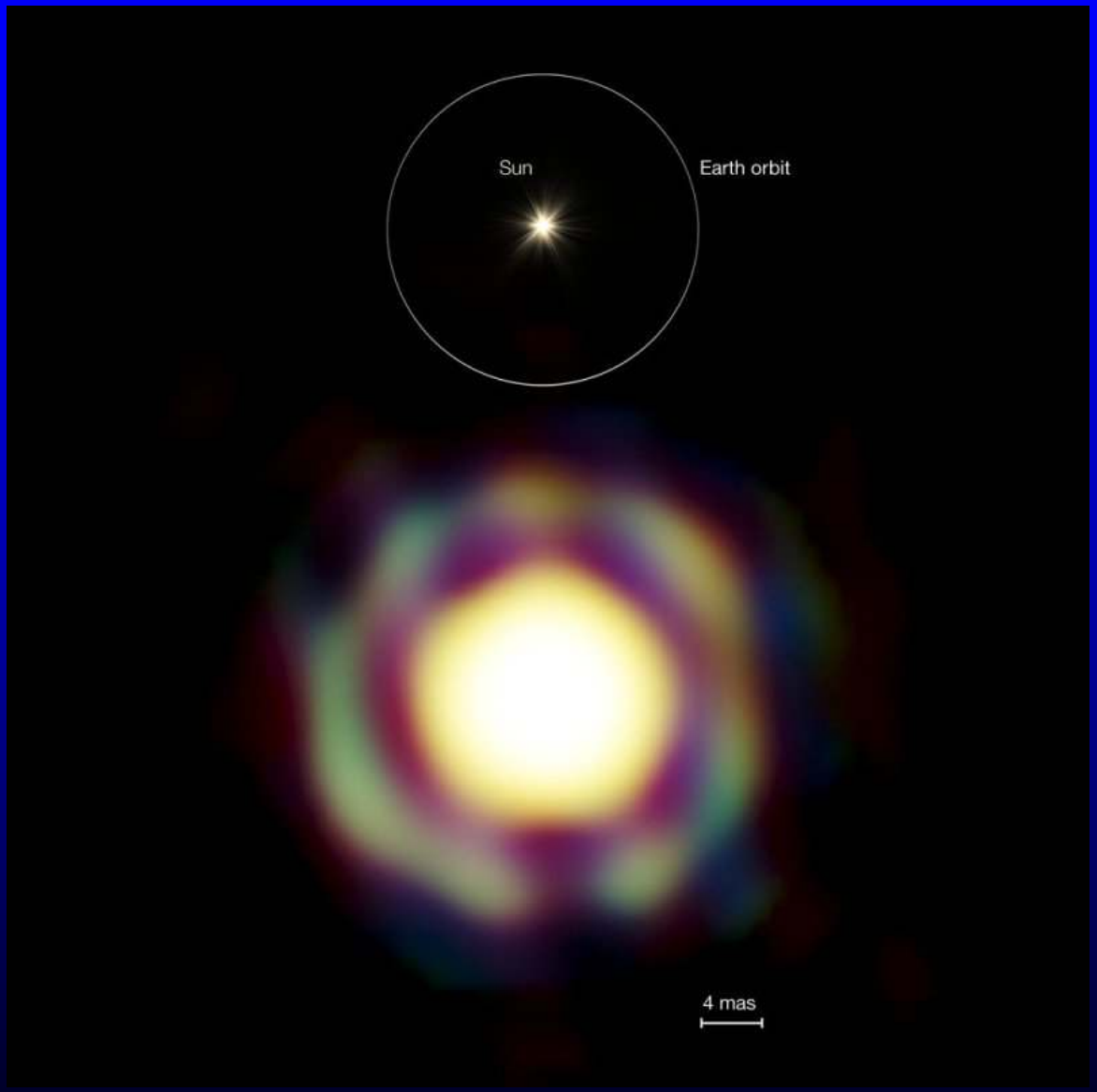


VLT Interferometer

- Equivalent to a 100 metre aperture telescope

t Leptoris

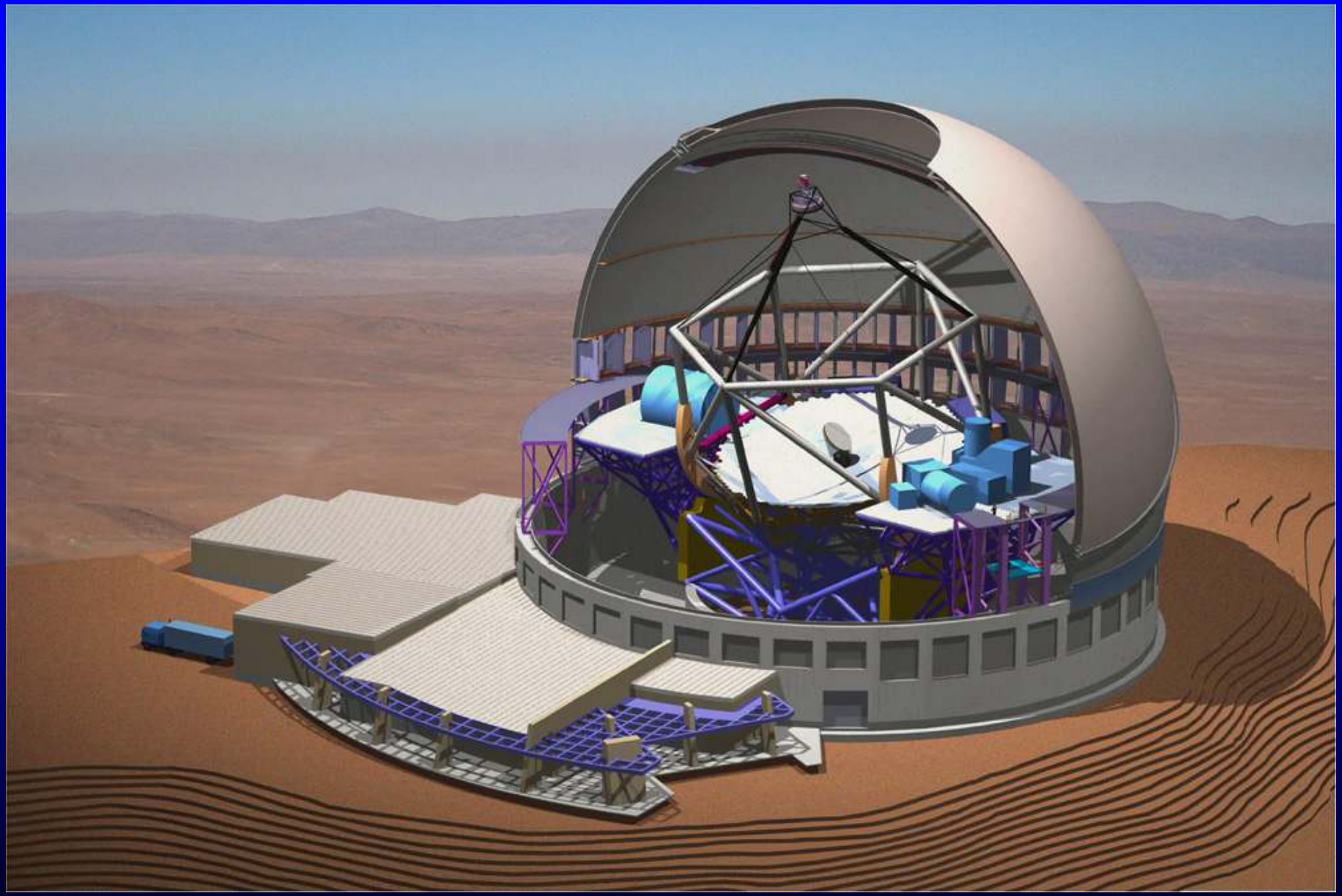
- 500 Light years from us.
- 100 times the size of the Sun.

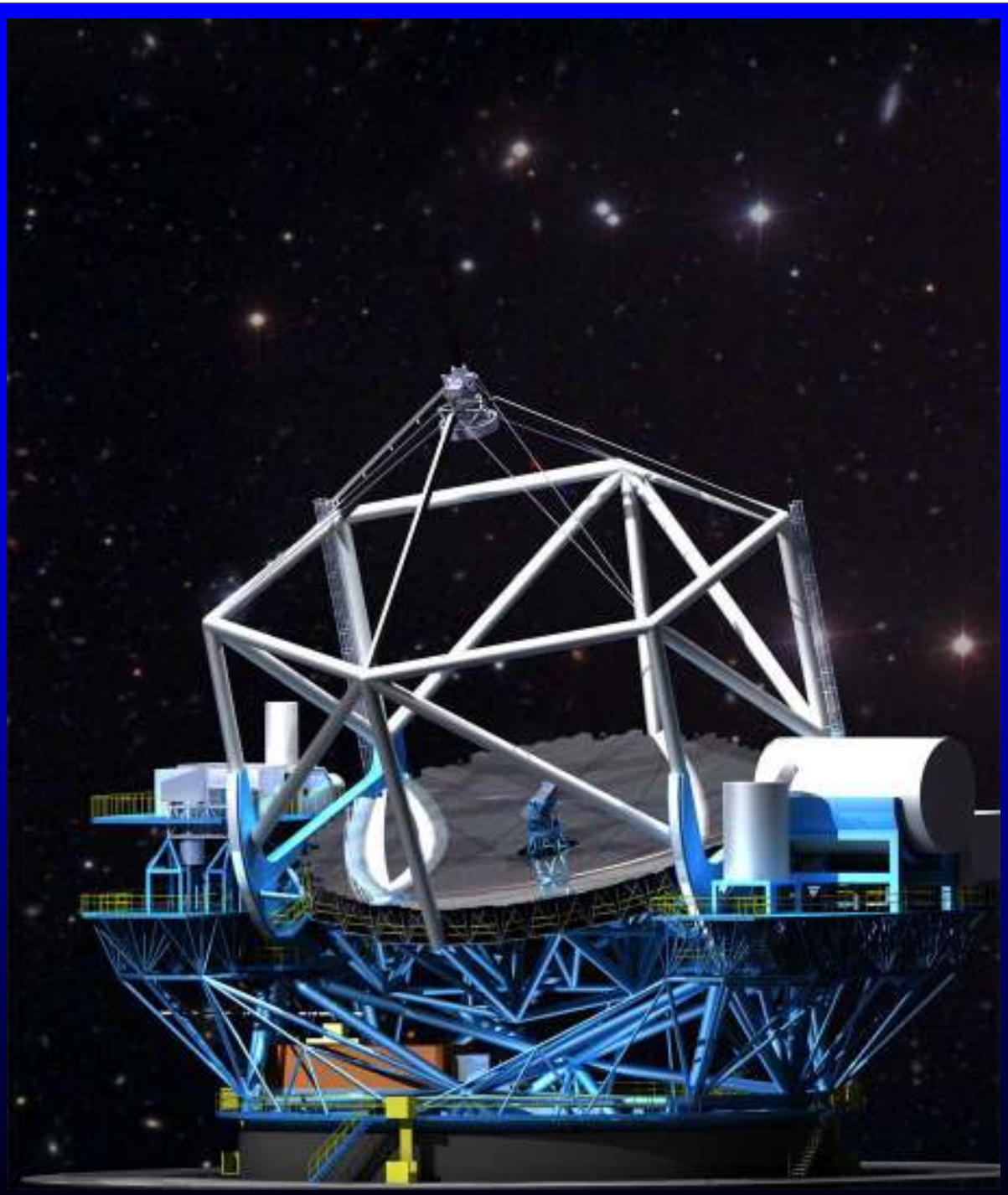


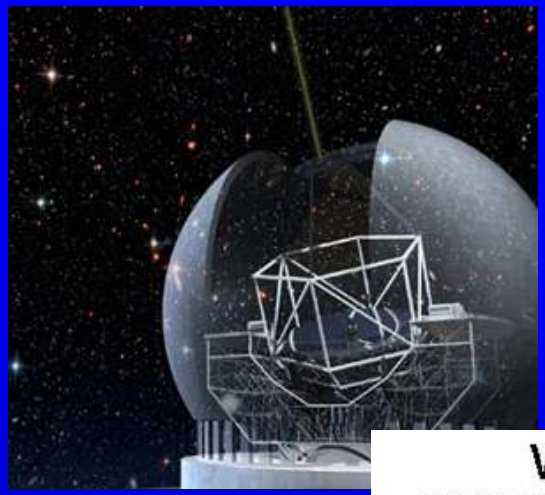
The Future

30 and 40m diameter telescopes

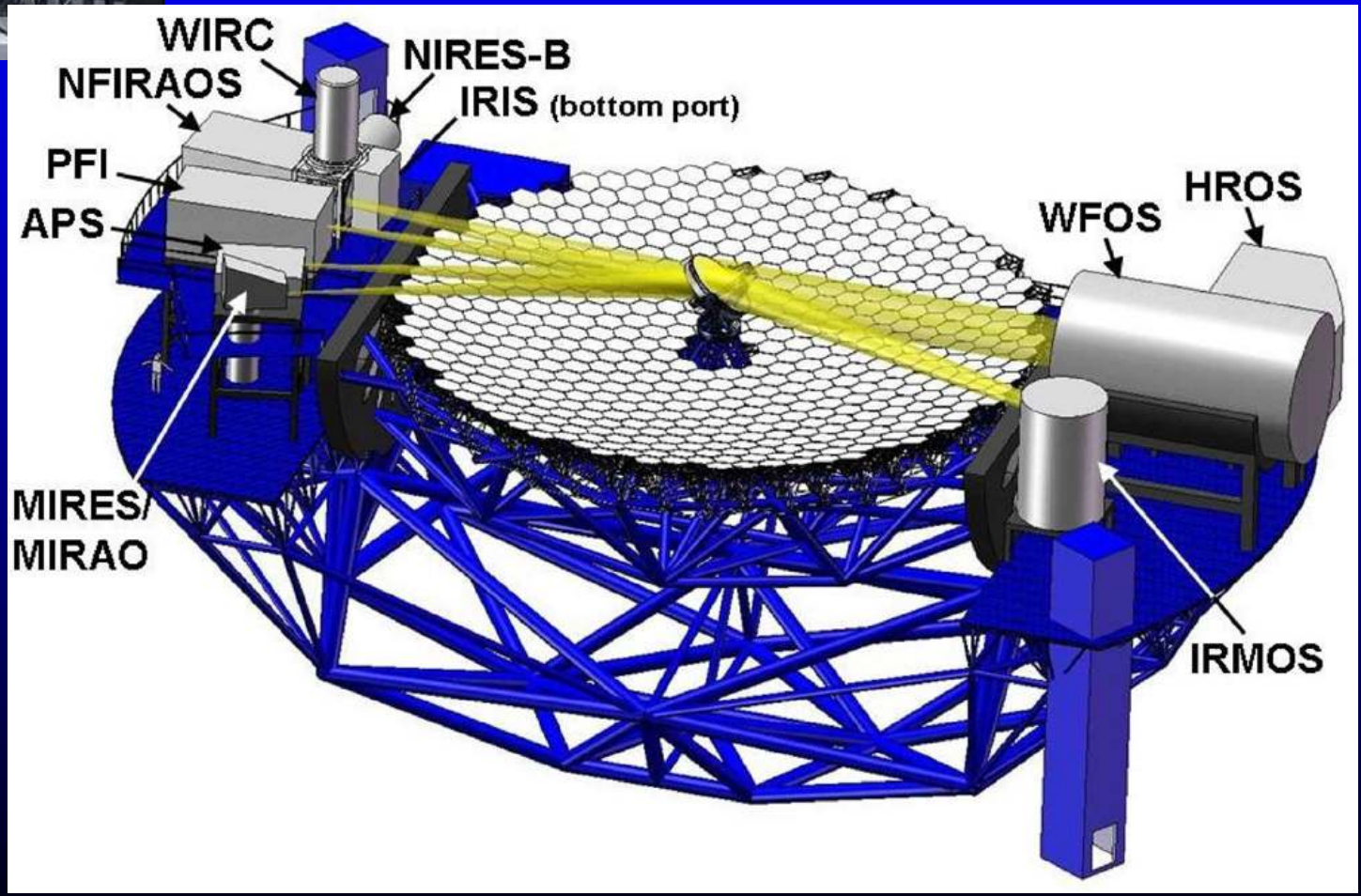
Thirty Meter Telescope

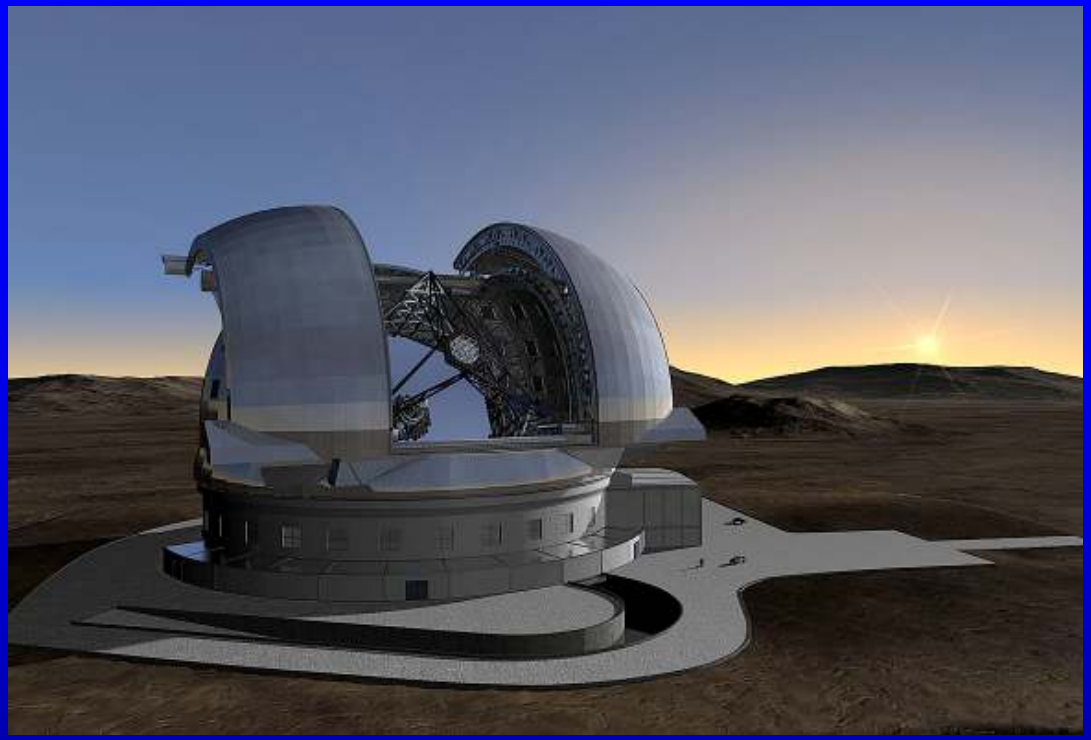




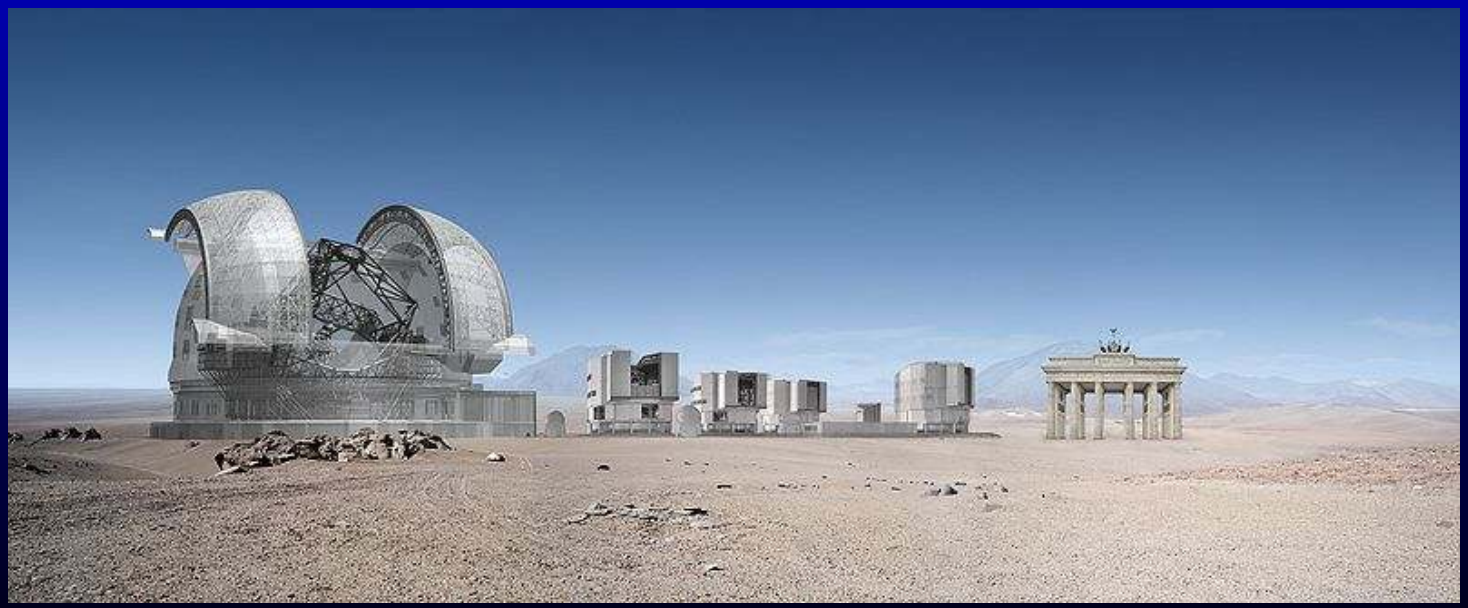


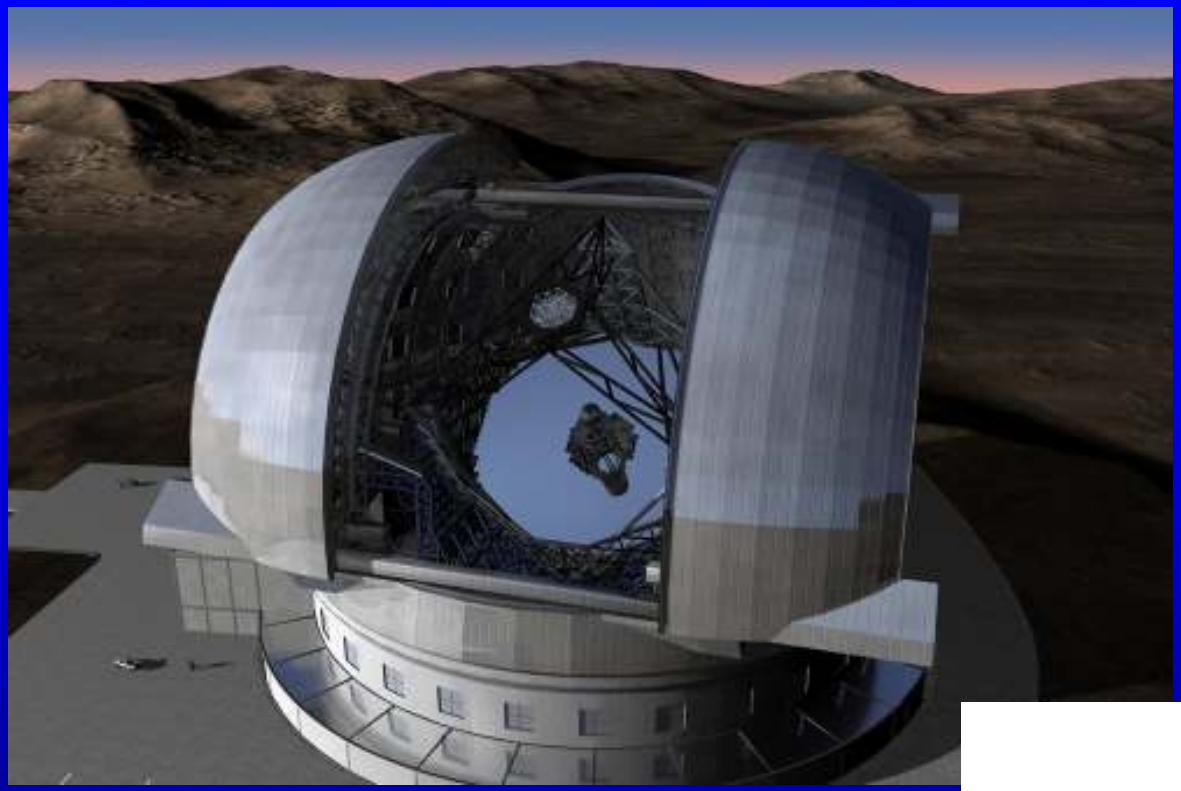
Bring light to many instruments.

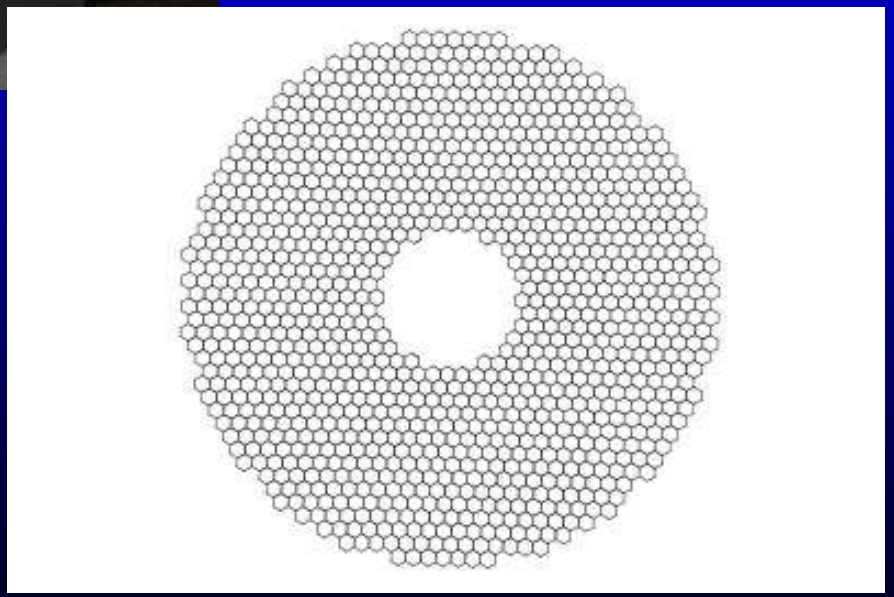




E-ELT







Segmented Mirror

Optical astronomers have an exciting future!