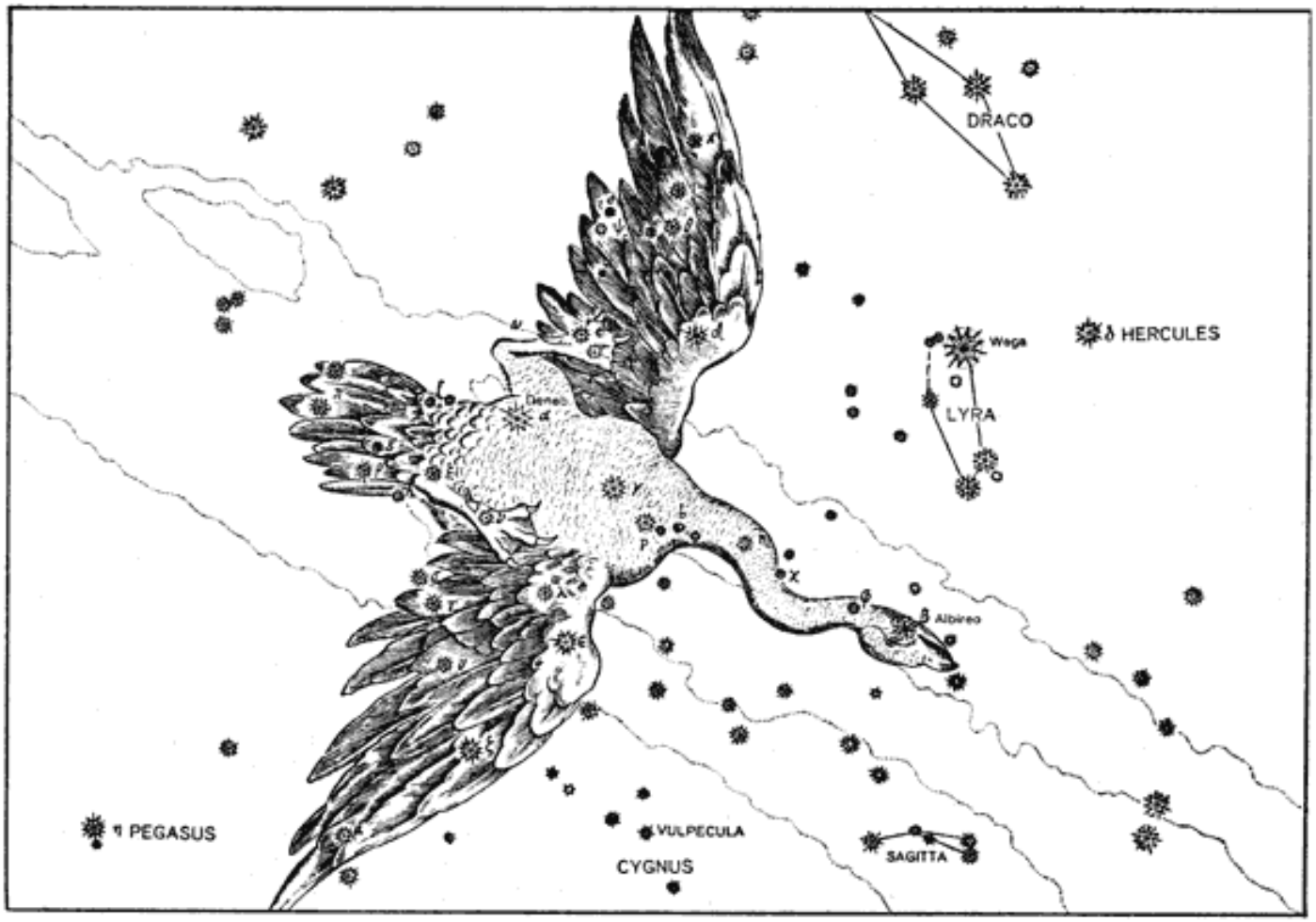
GRESHAM COLLEGE

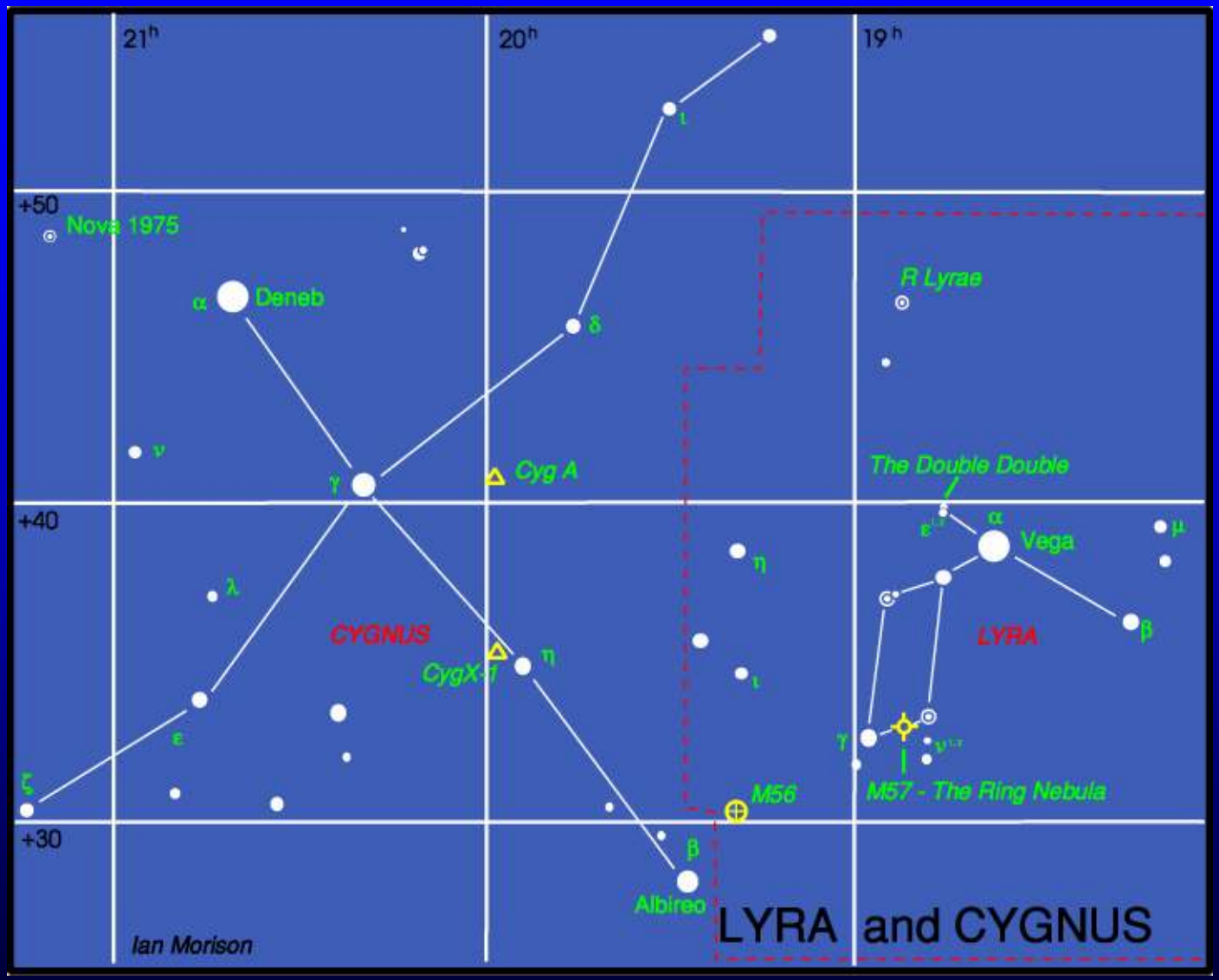
Watchers of the Skies

How our knowledge and understanding of the Universe has increased over the Centuries.

Ian Morison


©1997 by F. Espenak


DRACO
Vega
δ HERCULES
LYRA
Deneb
β Albireo
¶ PEGASUS
VULPECULA
CYGNUS
SAGITTA


21h
20h
19h
+50
+40
+30
Nova 1975
α Deneb
ν
γ
δ
ι
Cyg A
R Lyrae
The Double Double
ε1,2
α Vega
μ
η
λ
CYGNUS
CygX-1
η
ι
β
LYRA
ε
ζ
γ
ν1,2
M56
M57 - The Ring Nebula
β
Albireo
Ian Morison
LYRA and CYGNUS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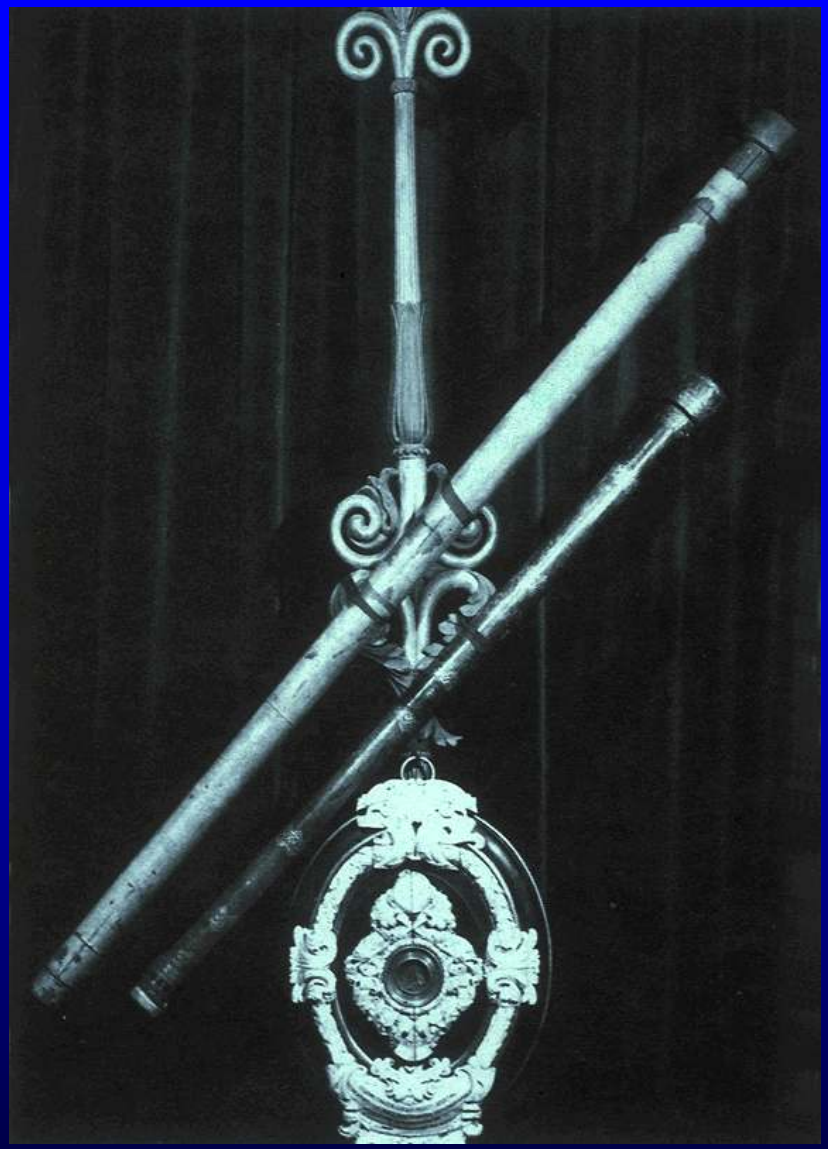
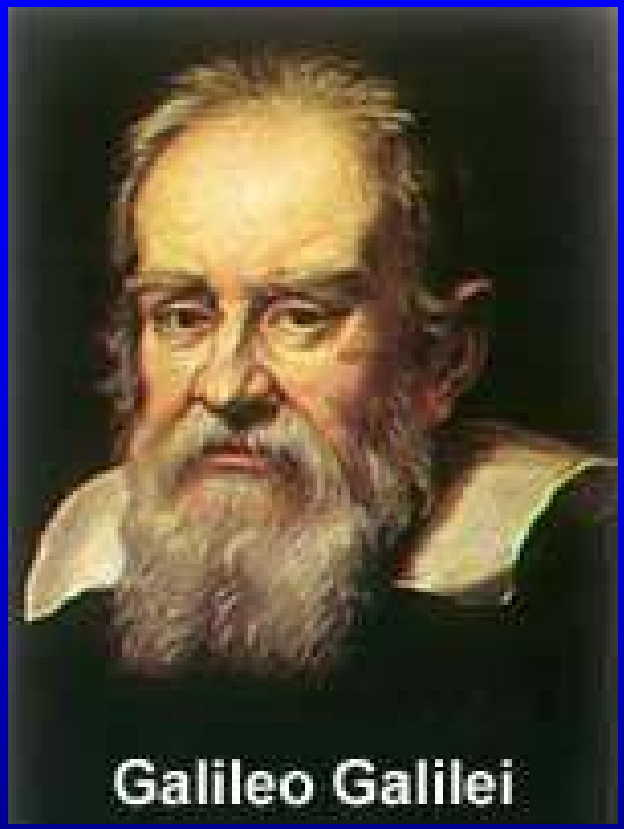
Our Understanding of the Universe

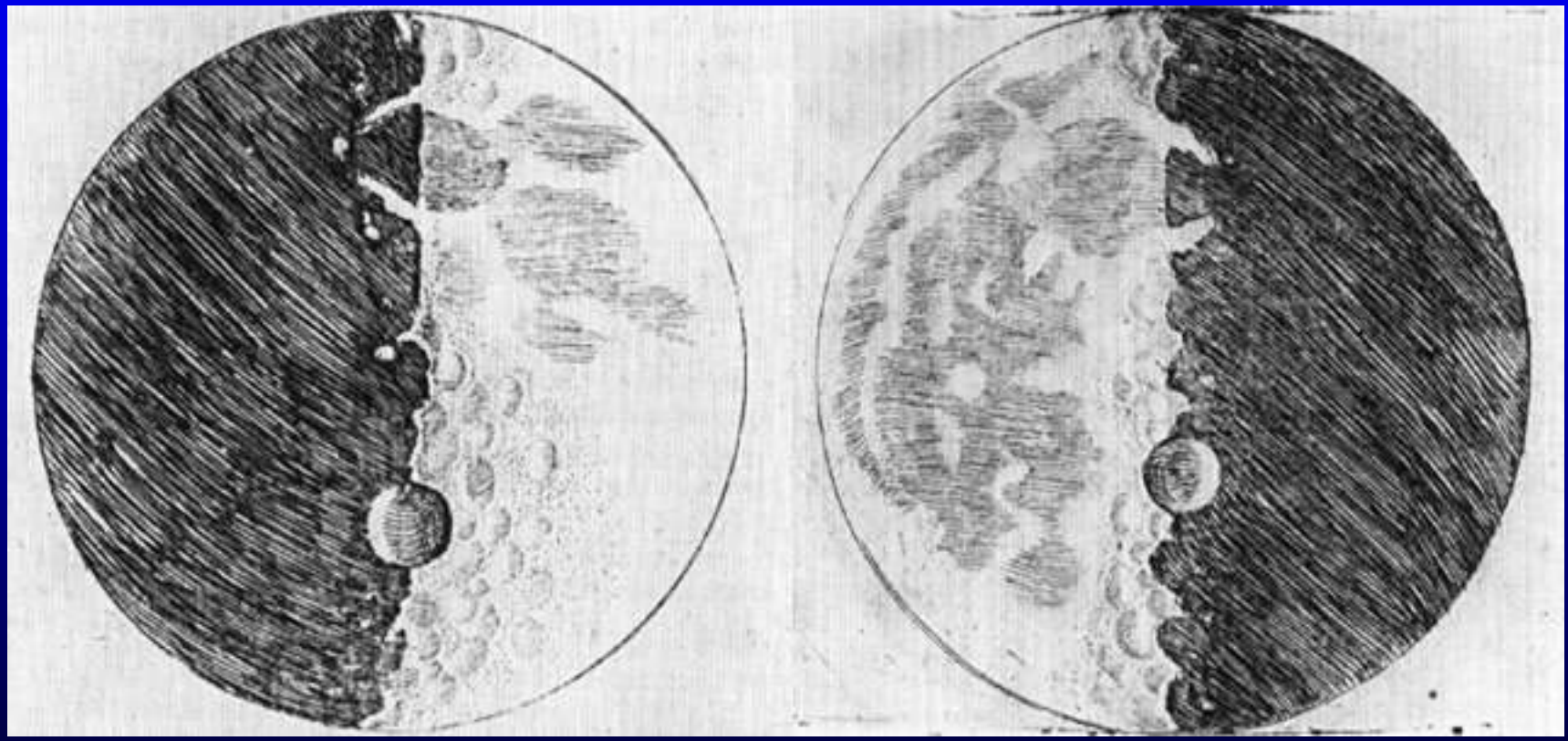
Is the Earth the Centre of the Universe?

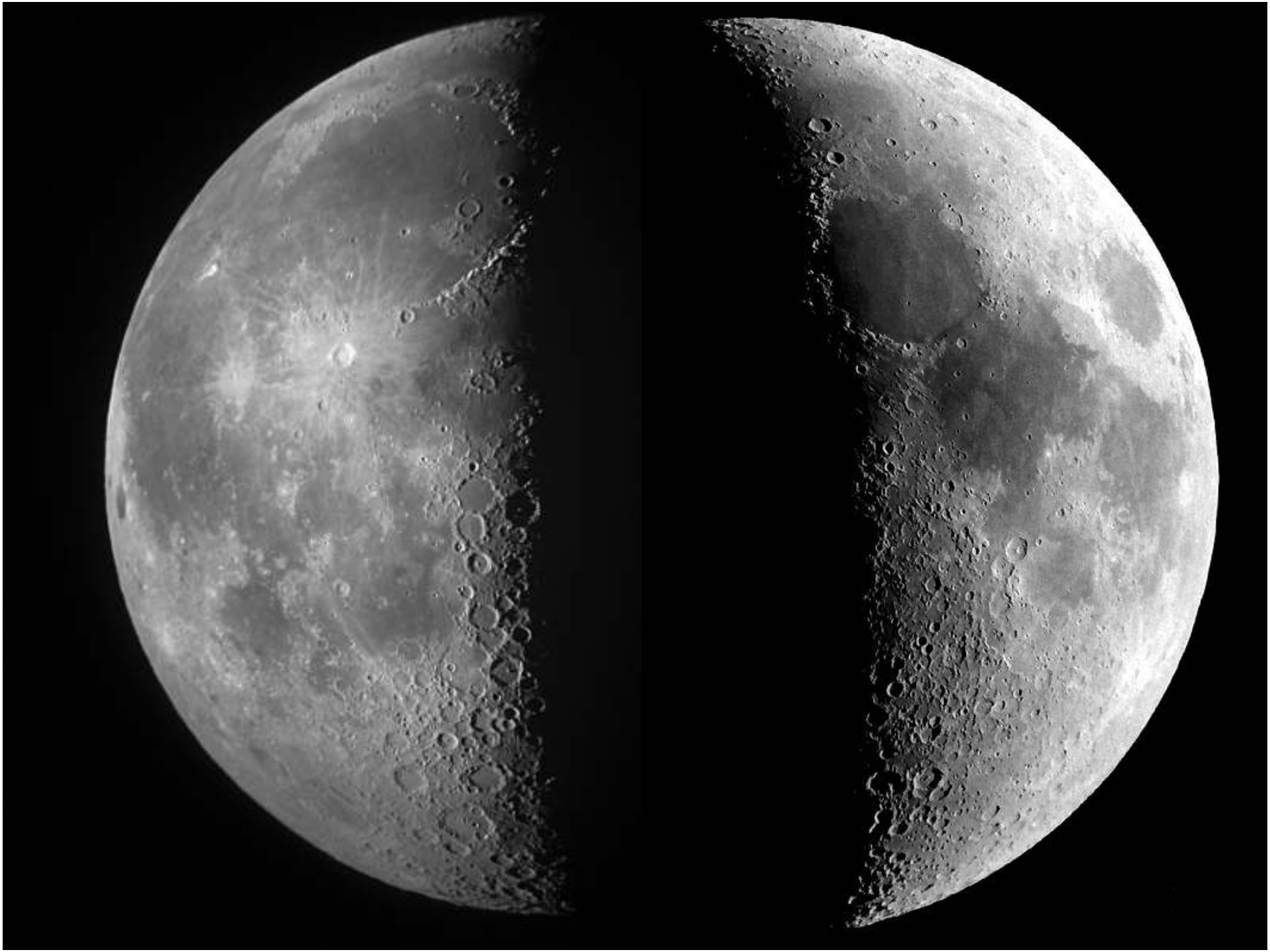



Galileo Galilei

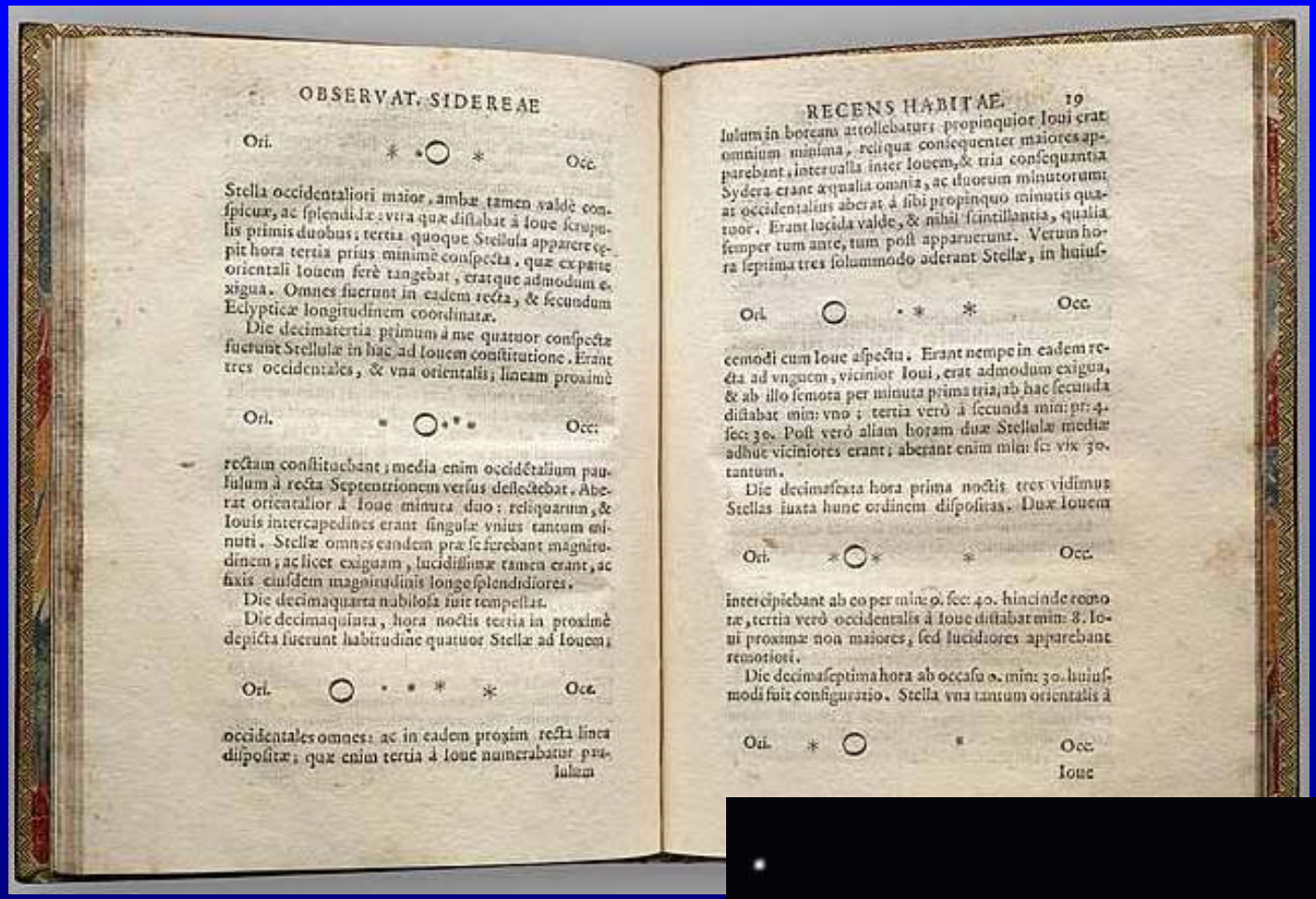

©INAF-Firenze

The Moon





The Moons of Jupiter



OBSERVAT. SIDEREAE

Ori. * ◯ * Occ.

Stella occidentalioti 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

lulum 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 huiuſ-

Ori. ◯ * * Occ.

cemodi 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.

Die decimaſexta hora prima noctis tres vidimus Stellas iuxta hunc ordinem diſpoſitas. Duæ Iouem

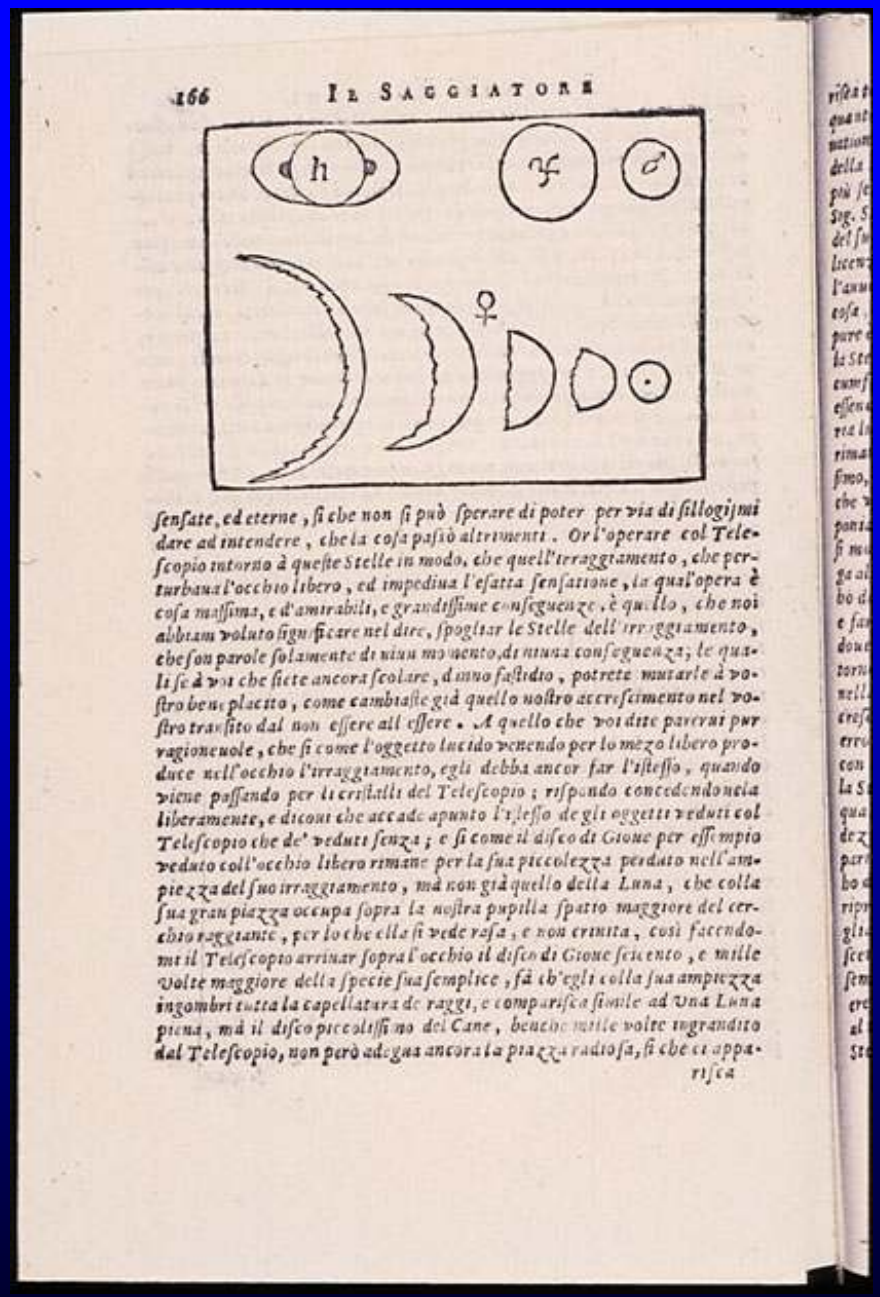
Ori. * ◯ * * Occ.

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

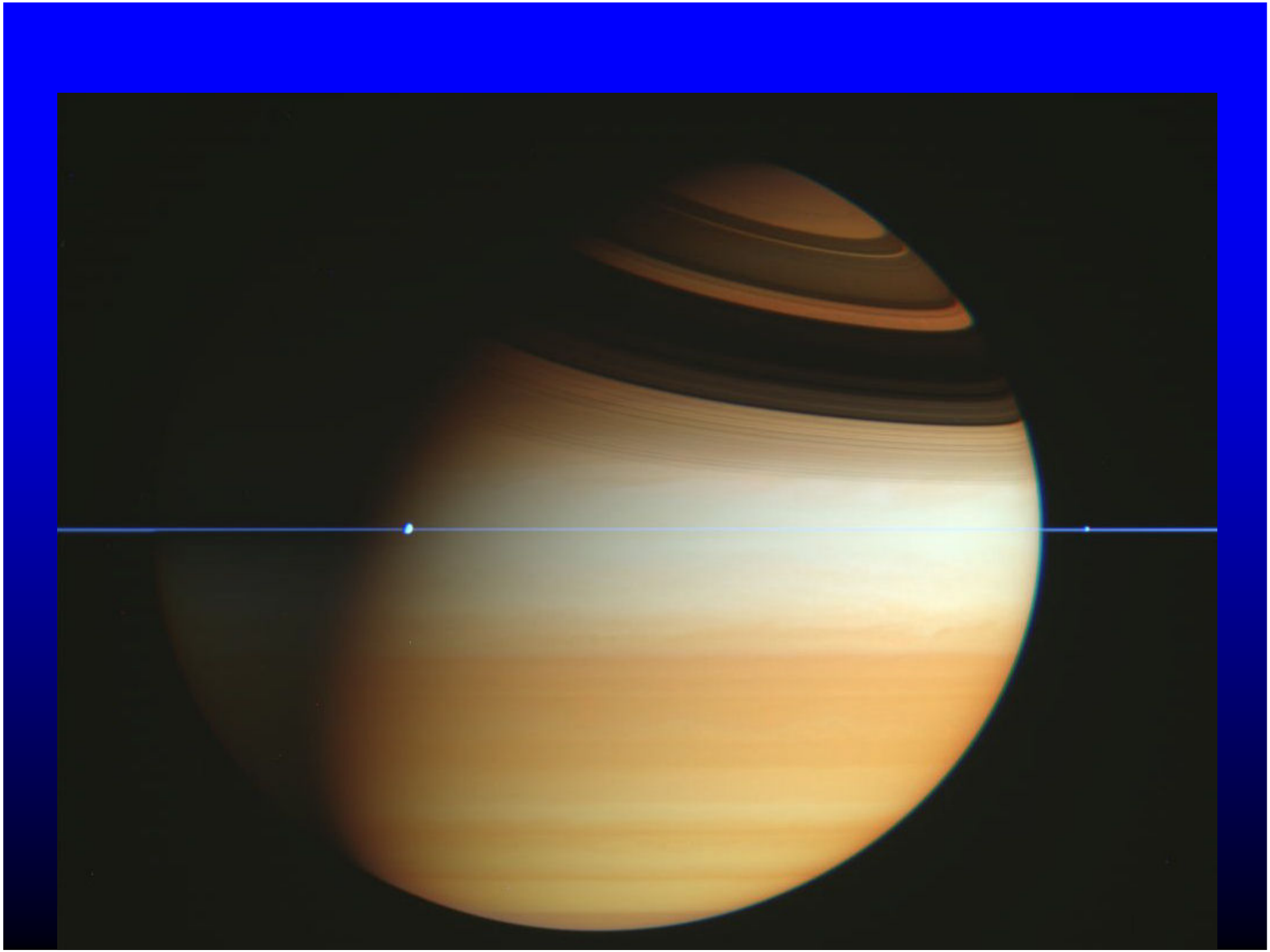


166 IL SAGGIATORE

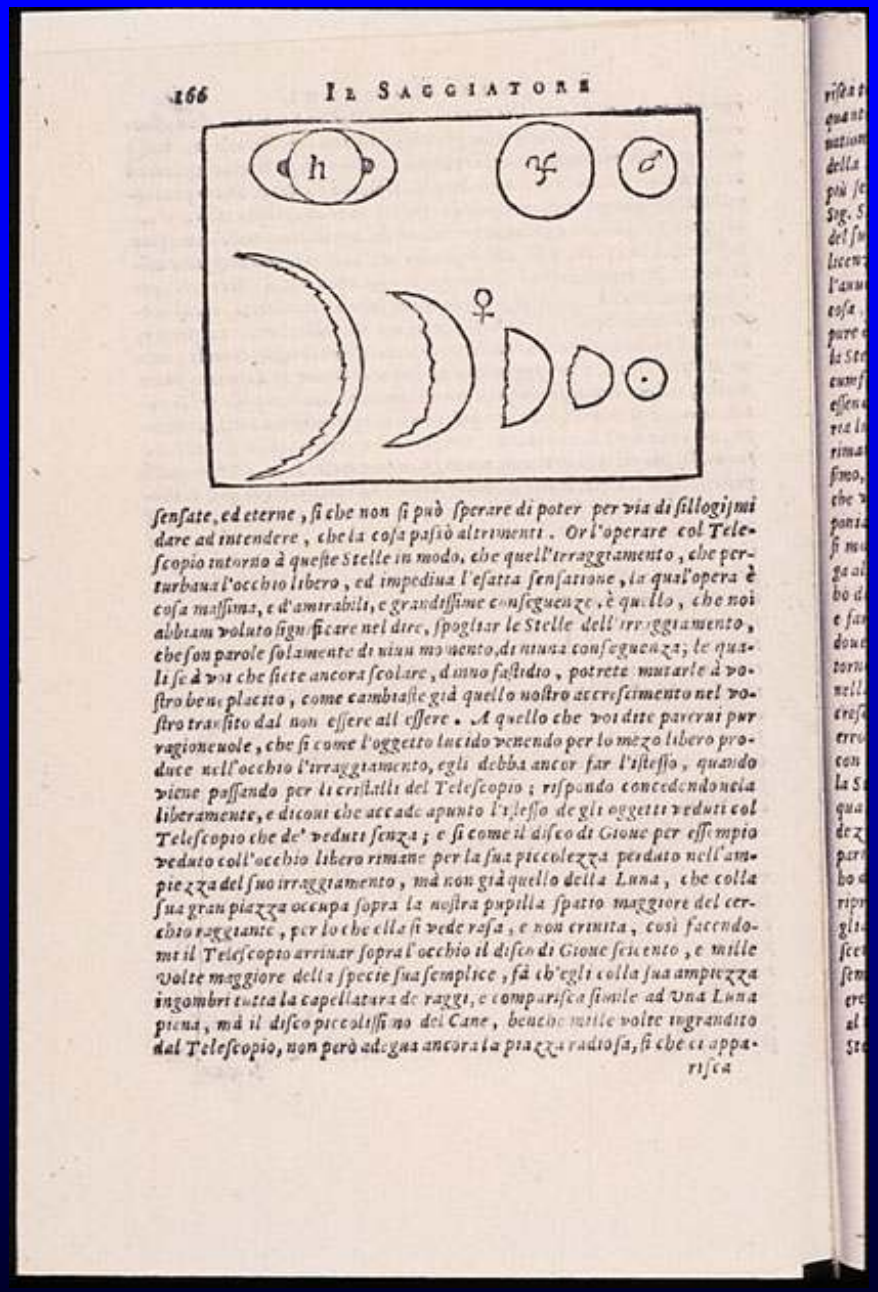
ſenſate, ed eterne, ſi che non ſi può ſperare di poter per via di ſillogiſmi dare ad intendere, che la coſa paſsò altrimenti. Or l'operare col Teleſcopio intorno à queſte Stelle in modo, che quell'irraggiamento, che perturbaua l'occhio libero, ed impediua l'eſatta ſenſatione, la qual'opera è coſa maſſima, e d'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'vno 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 concedendoui la 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, 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 vna 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

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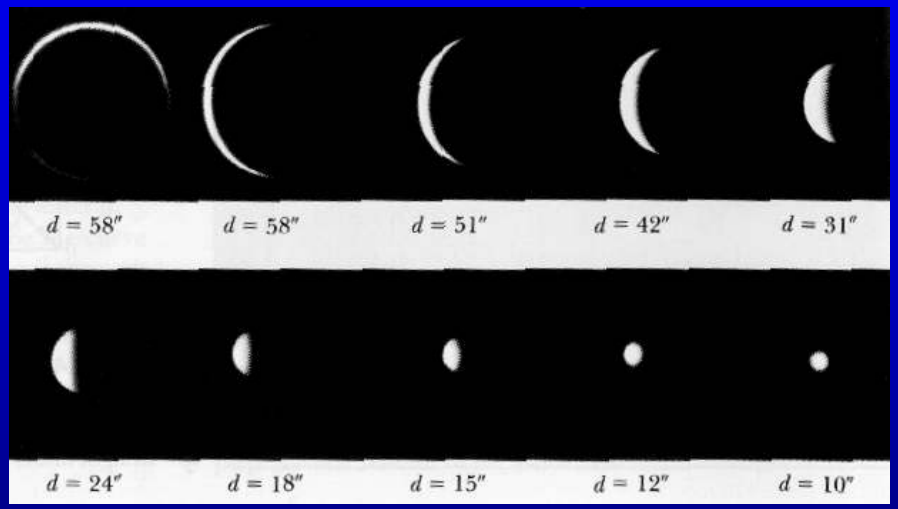
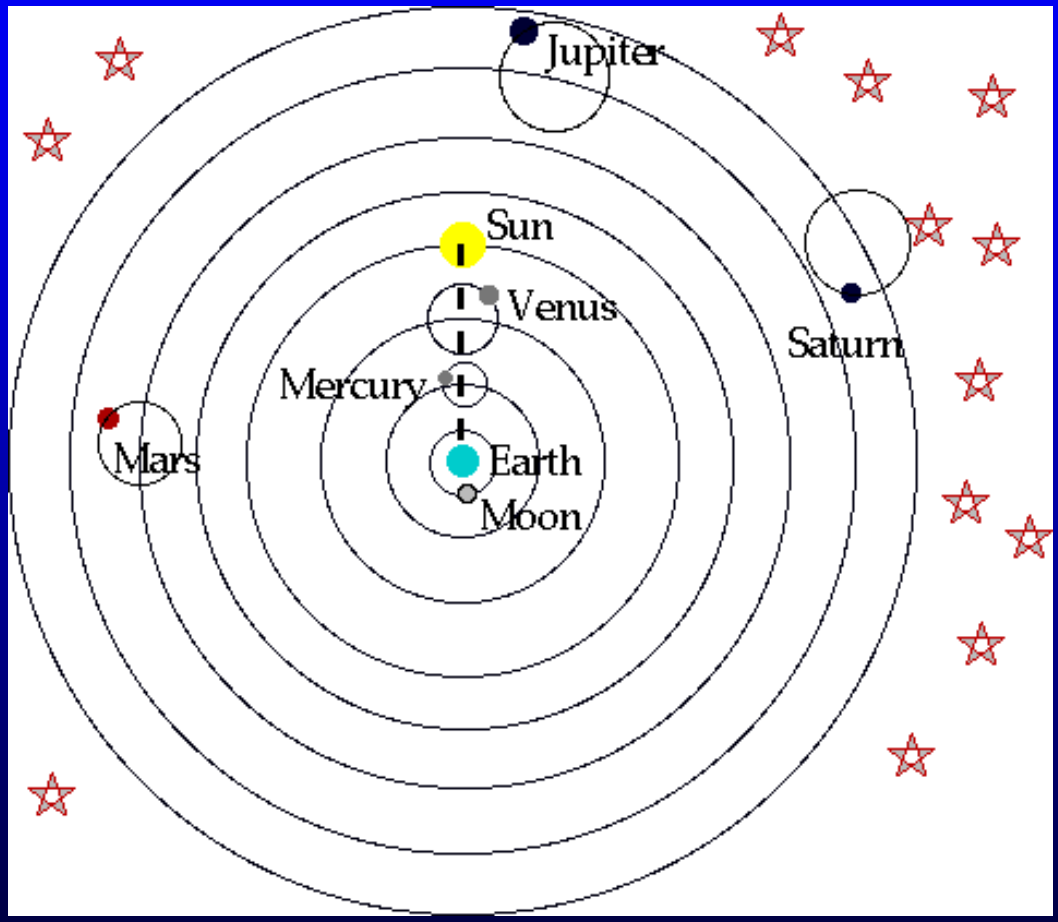
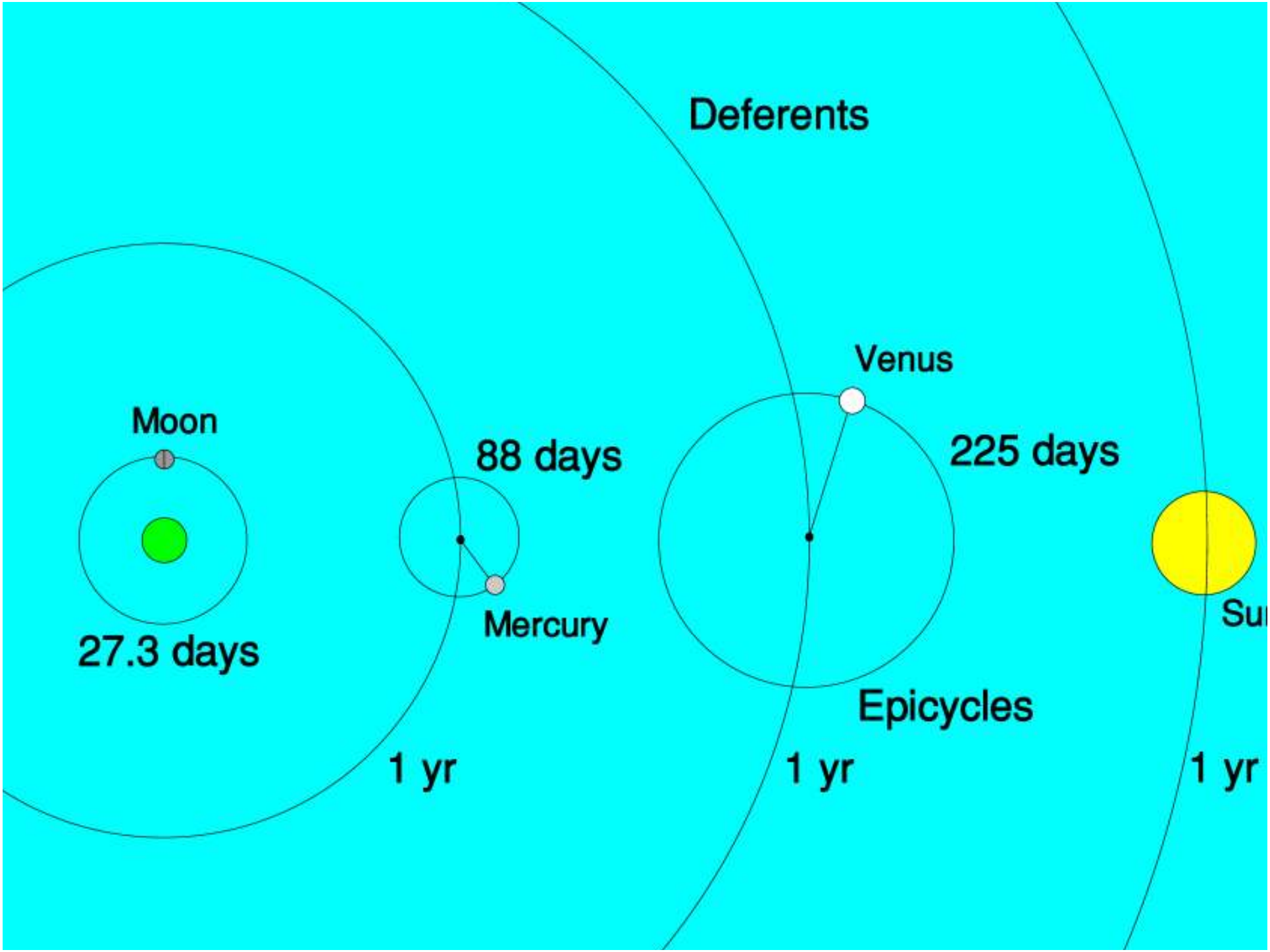
riſca

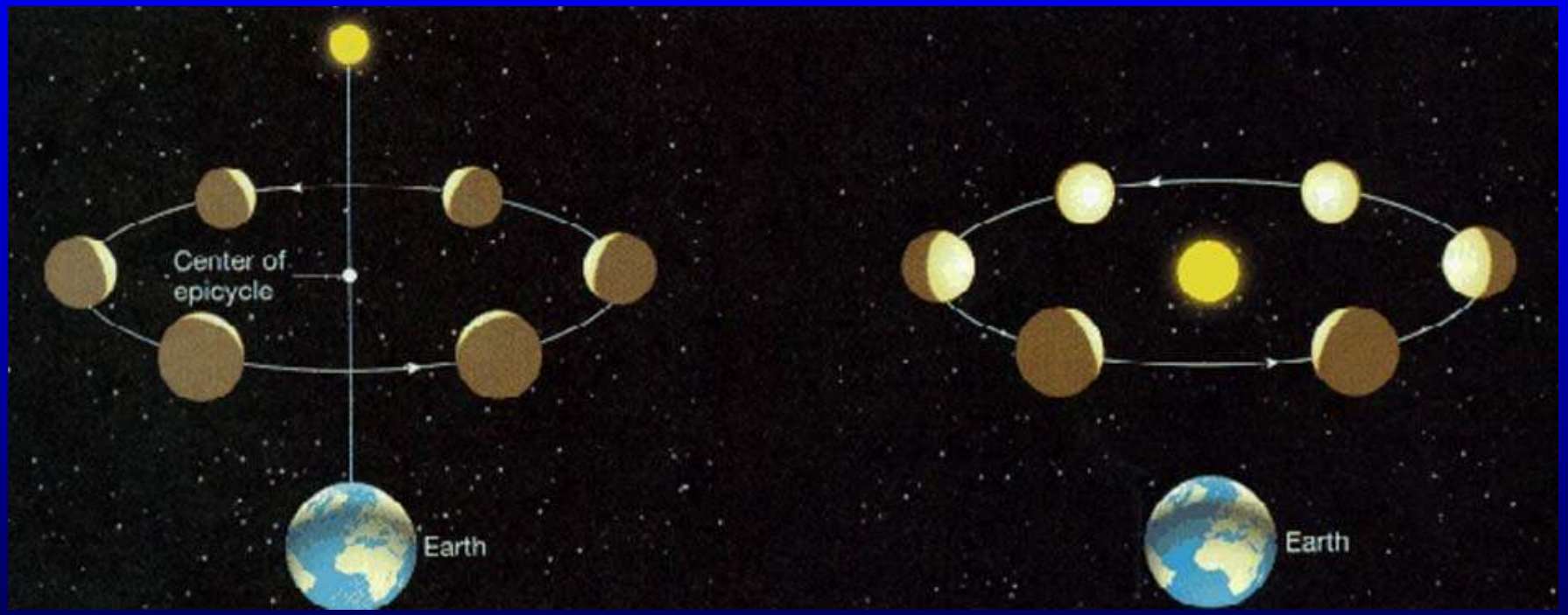


Potolemy's Geocentric Model

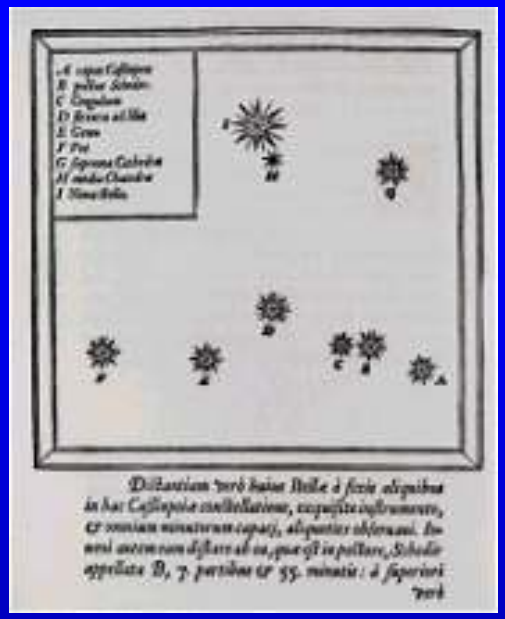


Notice Mercury nearer than Venus!

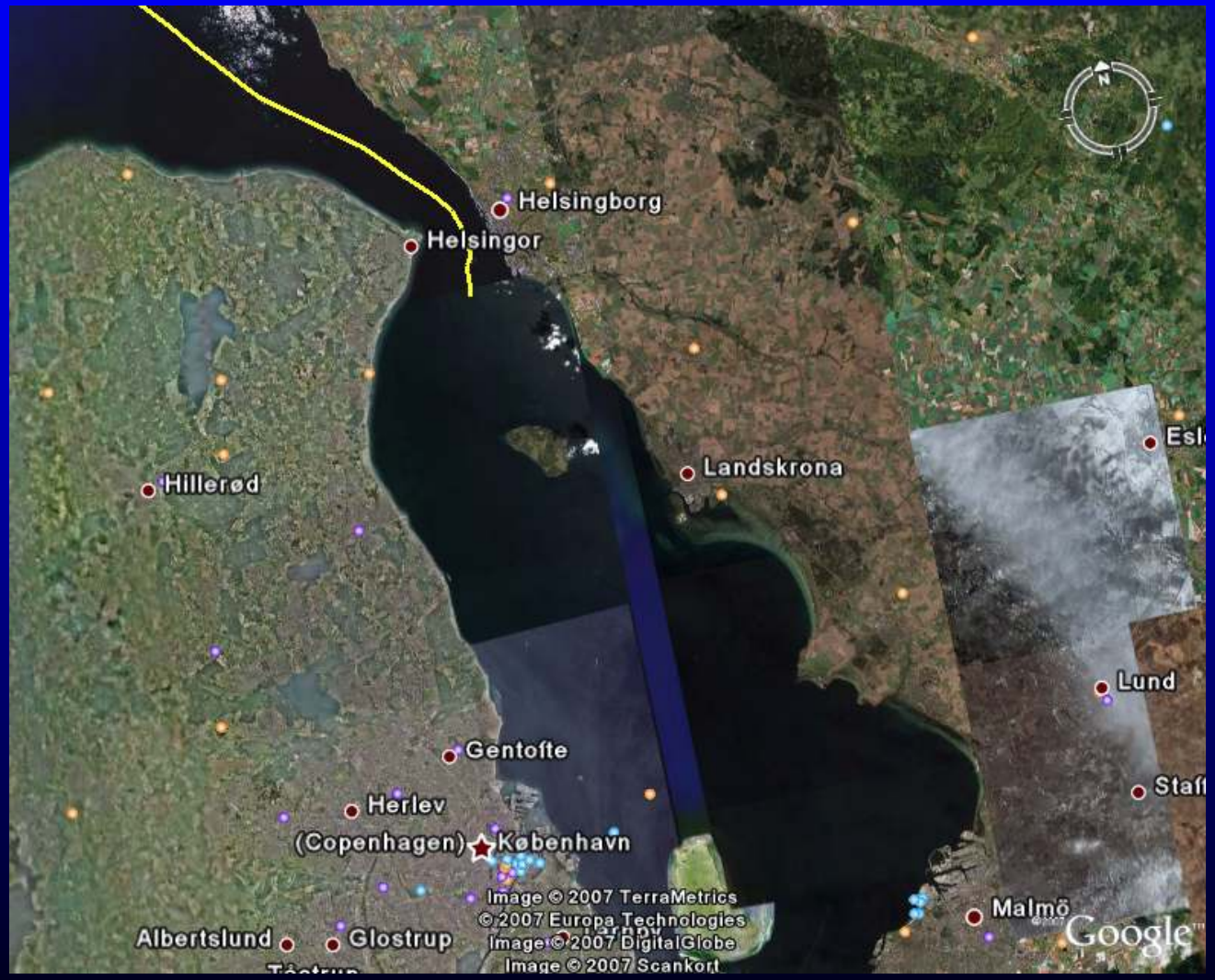

Deferents
Moon
27.3 days
1 yr
88 days
Mercury
Venus
225 days
Epicycles
1 yr
1 yr

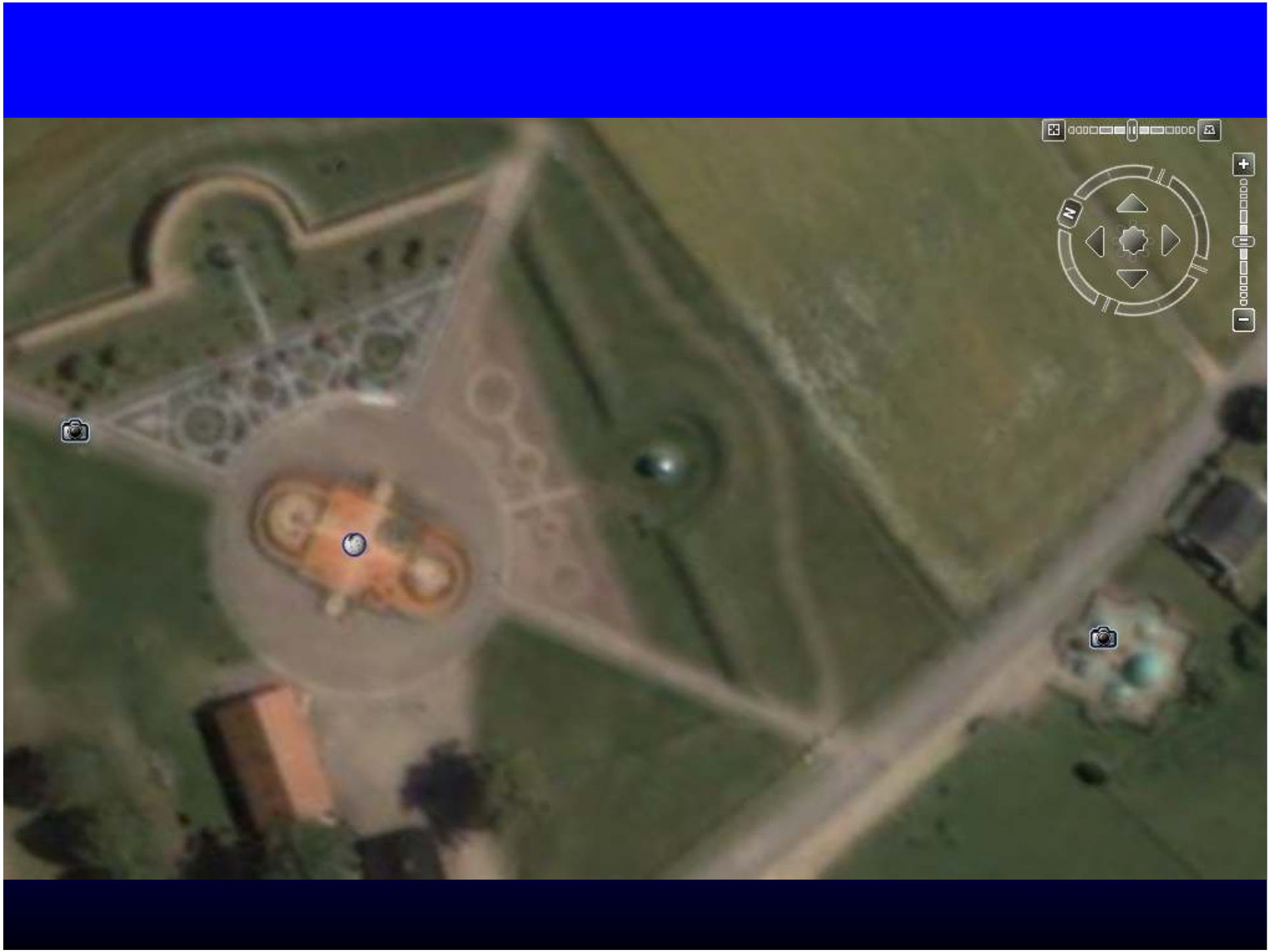

Center of
epicycle
Earth
Earth

1572: Tycho's Supernova



The Isle of Hveen

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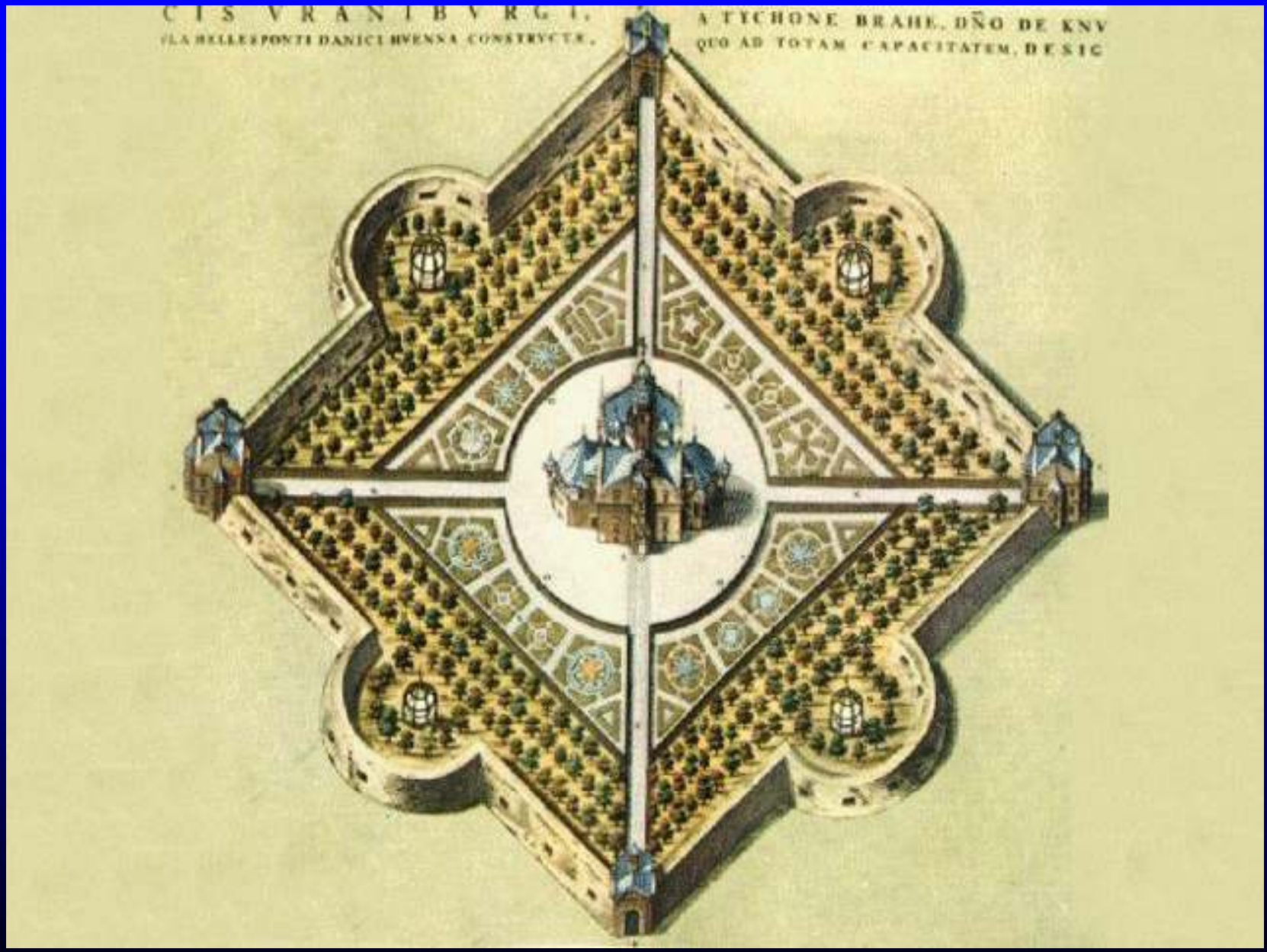
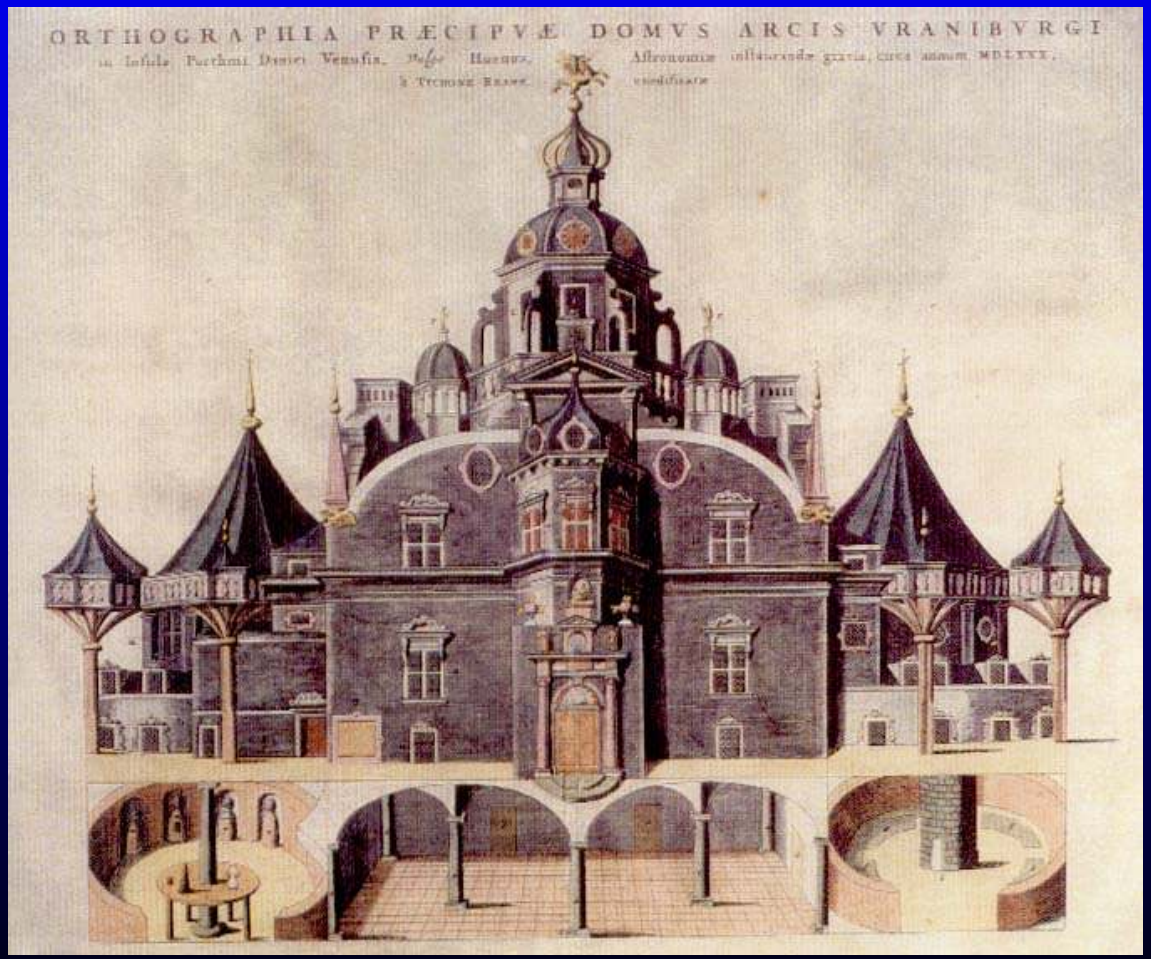
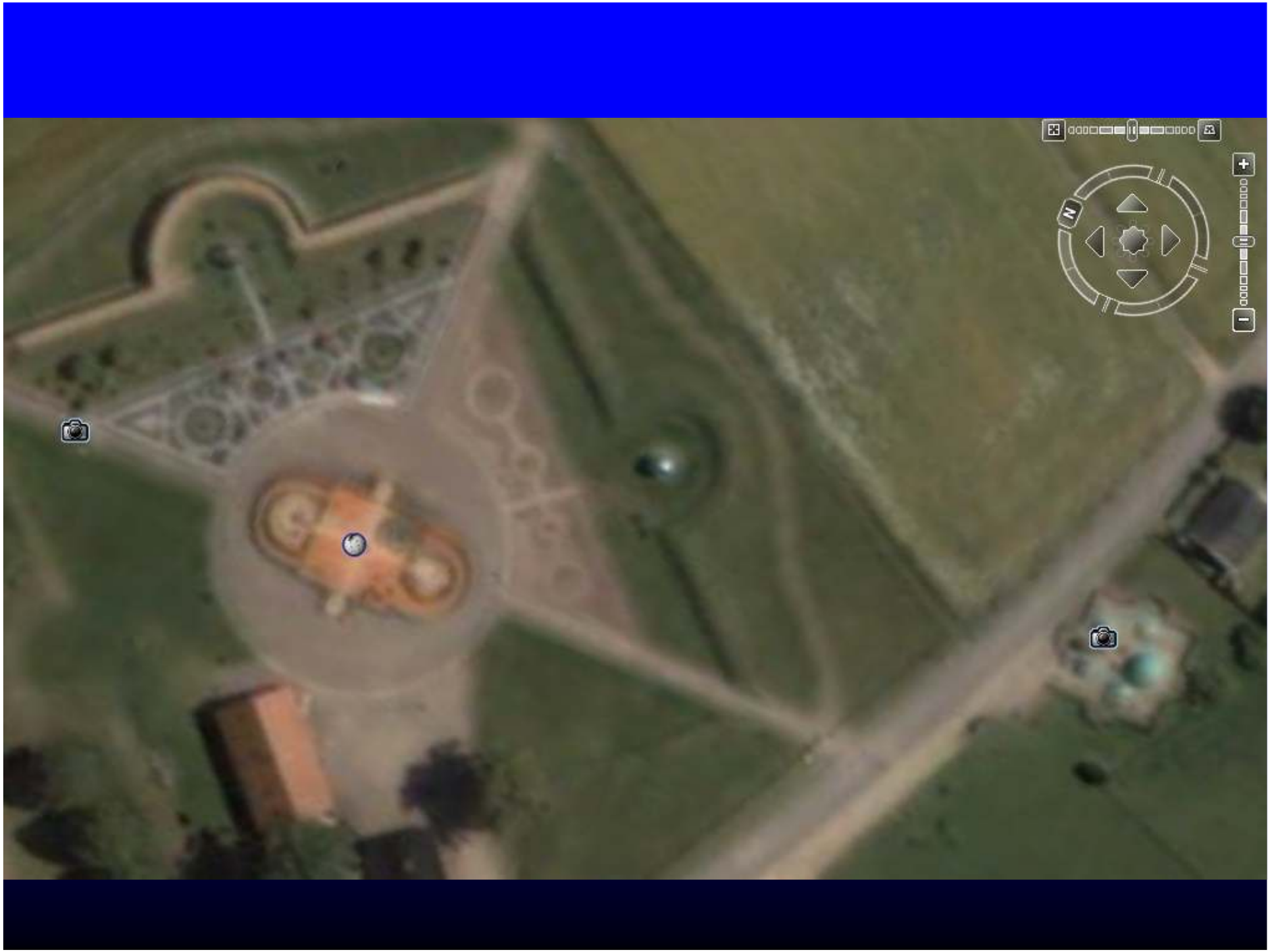
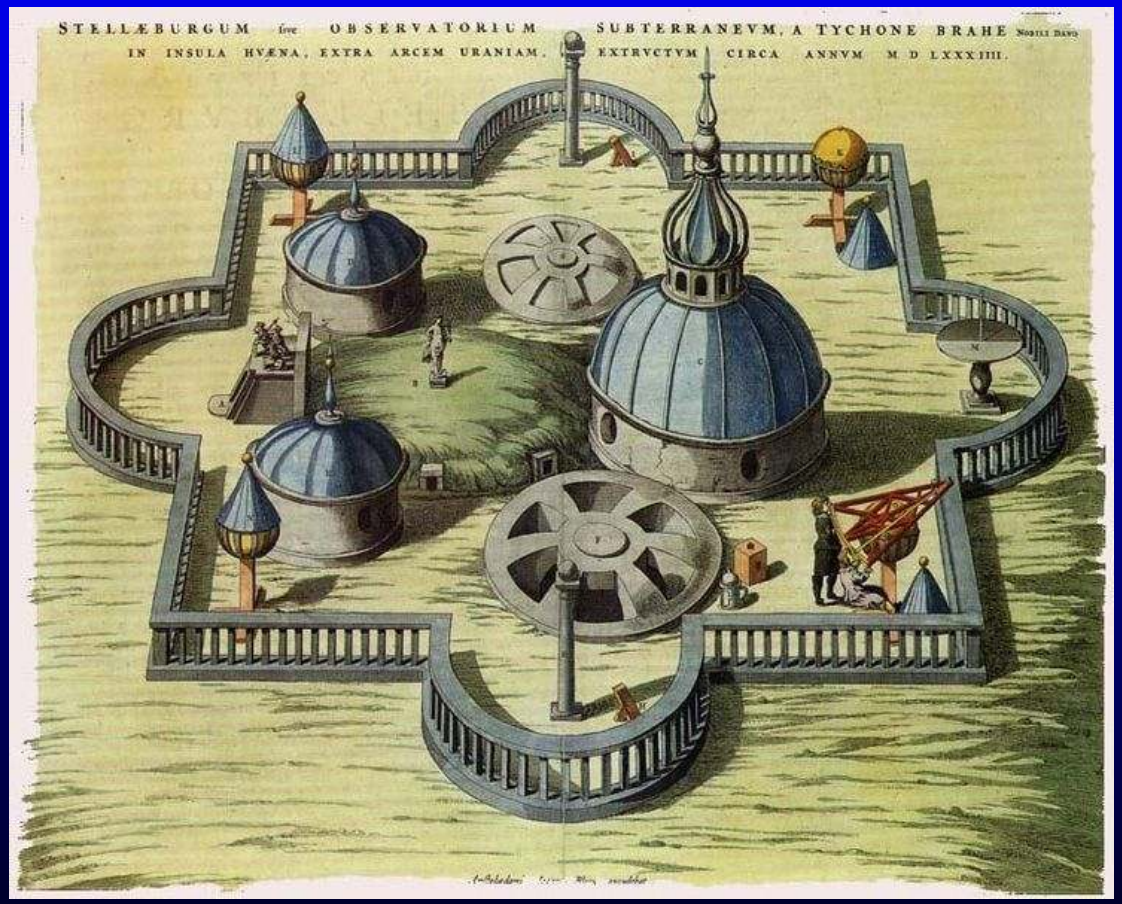

CIS VRANIBVRGI.
A TYCHONE BRAHE, DÑO DE KNV
QUO AD TOTAM CAPACITATEM, DESIC

Tycho's Castle - Uraniborg



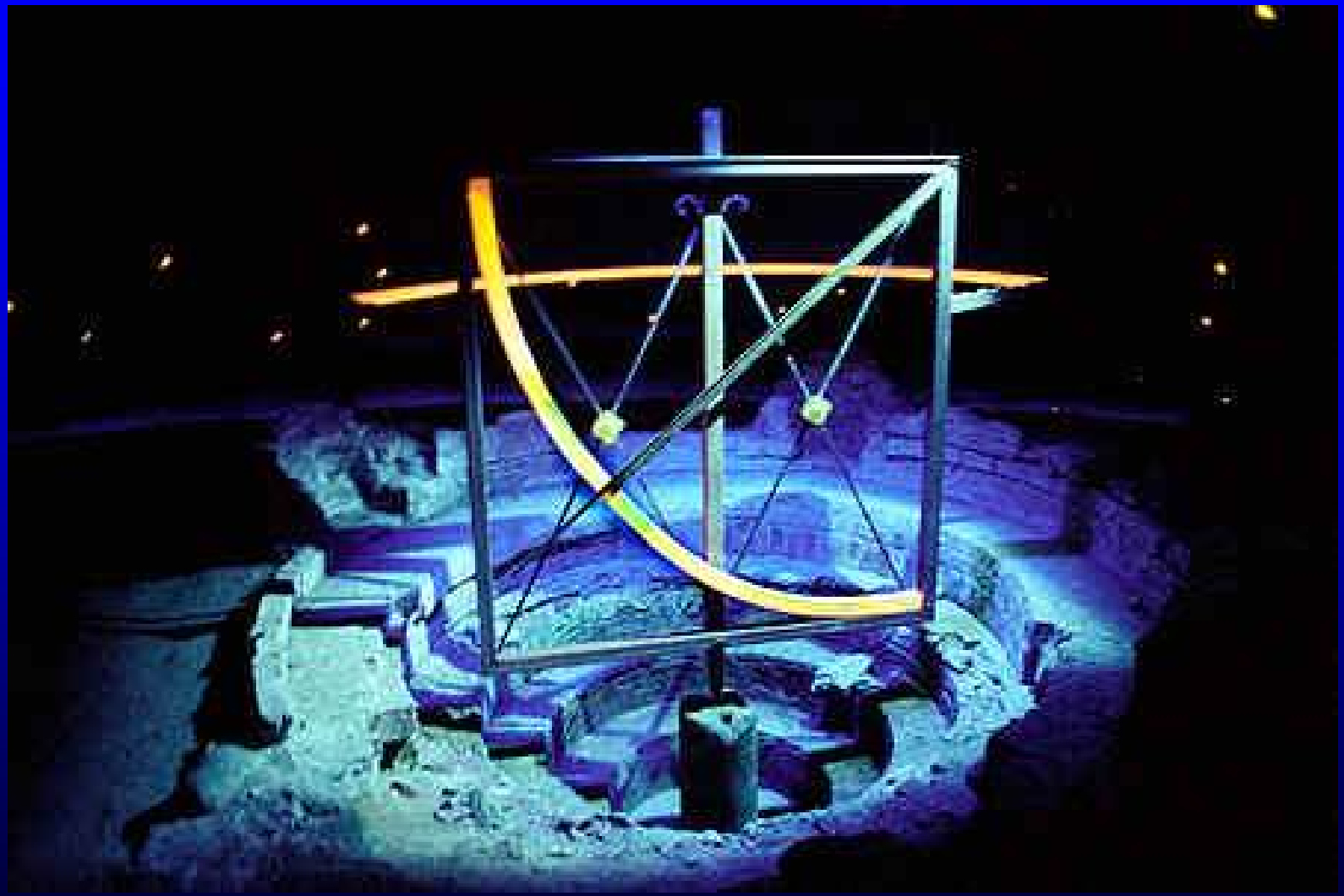

N

Tycho's Observatory Sternberg



Quadrant

Can find a star's position in the sky



But, for 20 years, he also observed the positions of the Planets

- He observed the heavens from ~ 1577 to 1597 and plotted the motion of the planets against the fixed backdrop of the stars

Jupiter and Venus below the Moon

Tycho's final years

- Tycho left Hven in 1597 and in 1599 was appointed Imperial Mathematician to Emperor Rudolph II.
- He was given a choice of castles (!) and chose Benakty Castle 40 km north of Prague

Johannes Kepler

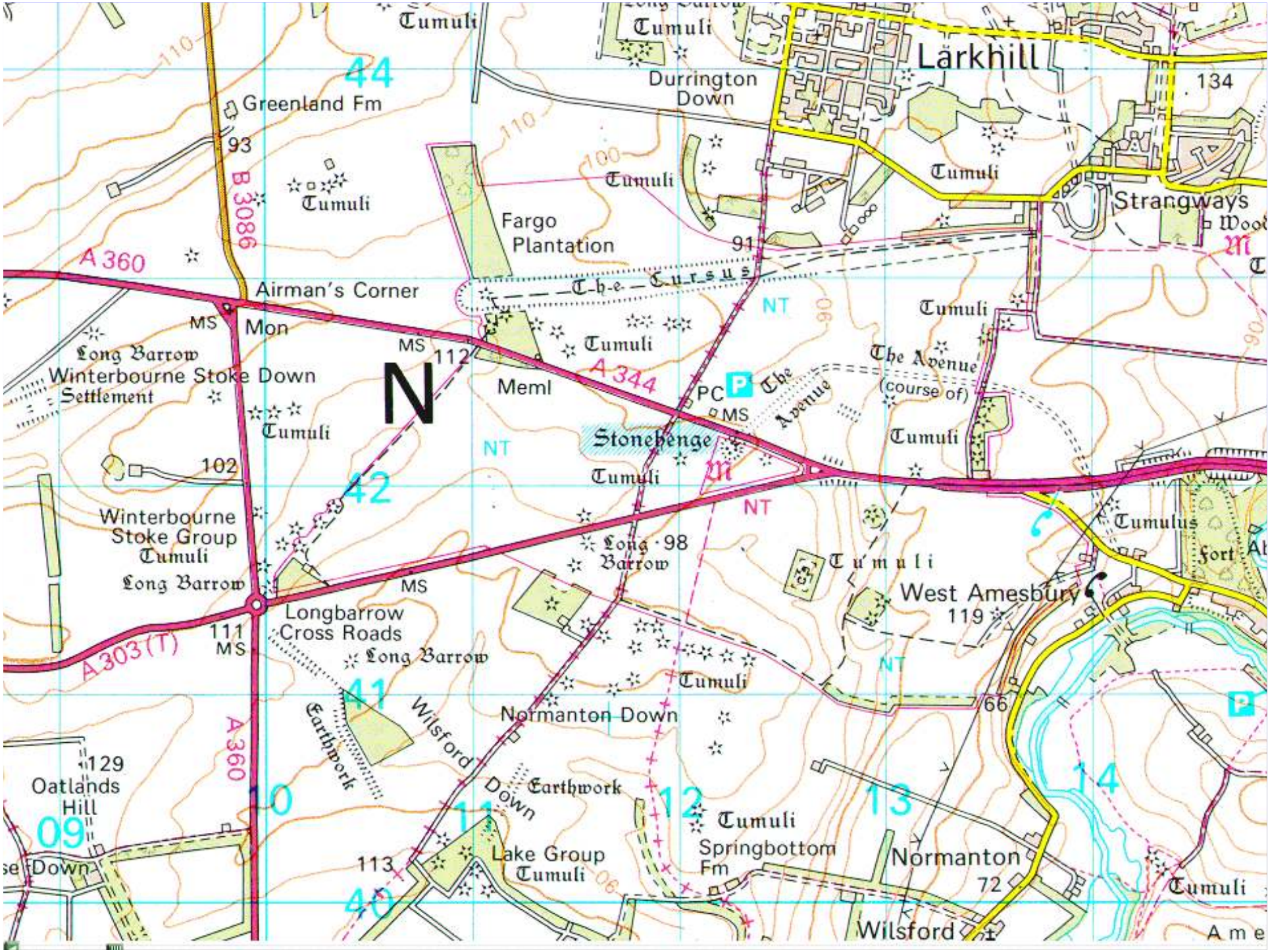
- Joined Tycho Brahe in 1600.
- He became Imperial Mathematician after Tycho's death in 1601
- From Tycho's Observations of the movement of the planets Kepler deduced the laws of Planetary Motion.

Third Law

The square of a planet's period around the Sun is proportional to the cube of its distance from the Sun

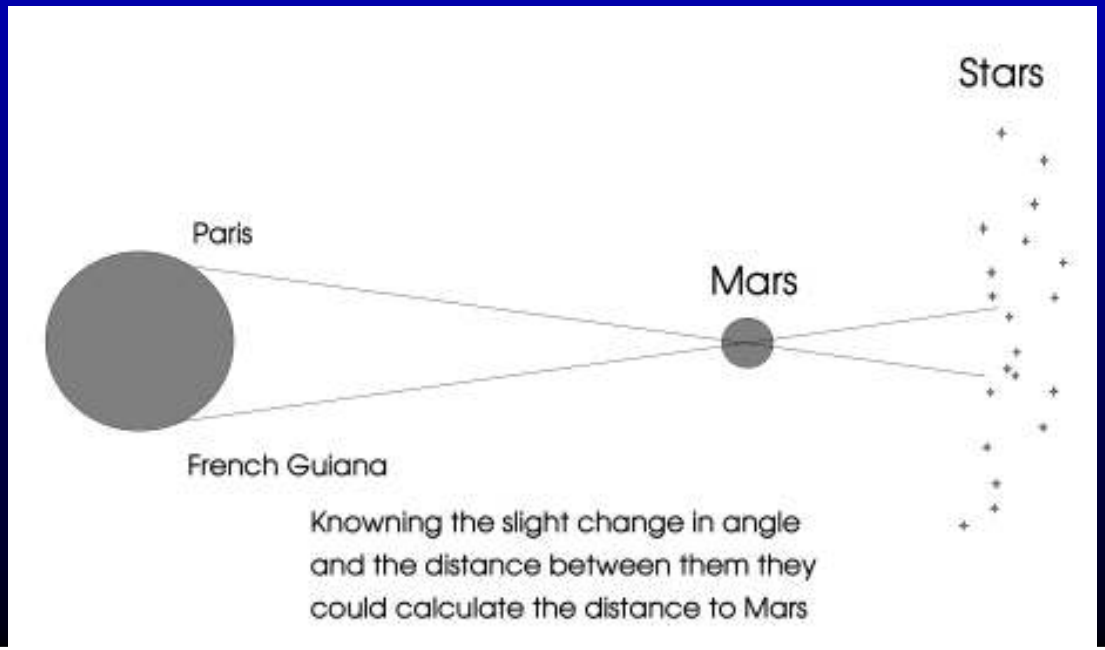
The Size of the Solar System

- Kepler's Third Law enables us to make a superb map of the Solar System –
- BUT it cannot give us a scale.
- If we could find one distance accurately then we could give the map a scale.


Tumuli
Larkhill
Durrington Down
134
Greenland Fm
93
B 3086
Tumuli
Fargo Plantation
91
Strangways
A 360
Airman's Corner
The Cursus
NT
Tumuli
MS
Mon
Long Barrow
Winterbourne Stoke Down Settlement
MS
112
A 344
Meml
PC
The Avenue
(course of)
Stonehenge
Tumuli
102
Winterbourne Stoke Group Tumuli
Long Barrow
Long Barrow
98
Tumulus
Fort
MS
Longbarrow Cross Roads
111
MS
A 303 (T)
Long Barrow
Tumuli
West Amesbury
119
Earthwork
Wilsford Down
Normanton Down
66
A 360
129
Oatlands Hill
Earthwork
Tumuli
Springbottom Fm
Normanton
72
113
Lake Group Tumuli
Wilsford
09
10
11
12
13
14
40
41
42
44

Measurement of the Astronomical Unit

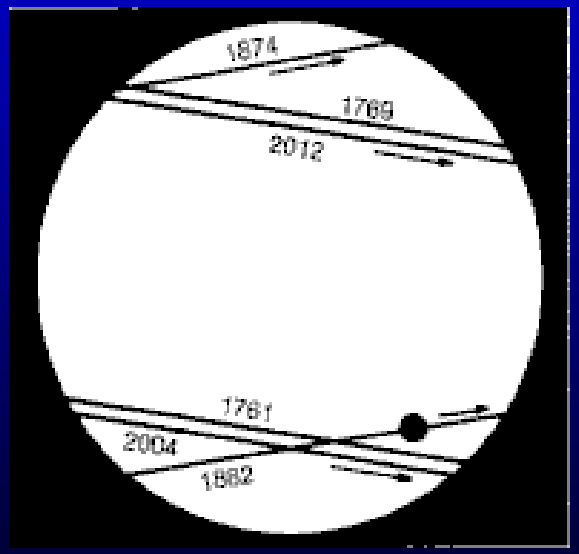
- In 1672 Cassini observed Mars from Paris whilst a colleague observed it from French Guiana in South America. They were thus able to measure its parallax, and hence measure the Earth-Mars distance. Using Kepler's third law they were then able to calculate the Earth's distance from the Sun.
- Cassini got 140 million km – low but not at all bad.



Transits of Venus

- By timing, from locations all over the Earth, when Venus first entered the Sun's limb and then just before it left, one can measure the parallax of Venus and hence find its distance.

- Enke analysed both 18th century eclipses and derived a value of 95.25 million miles. (152 million km)



Transits of 1789 and 18th Century

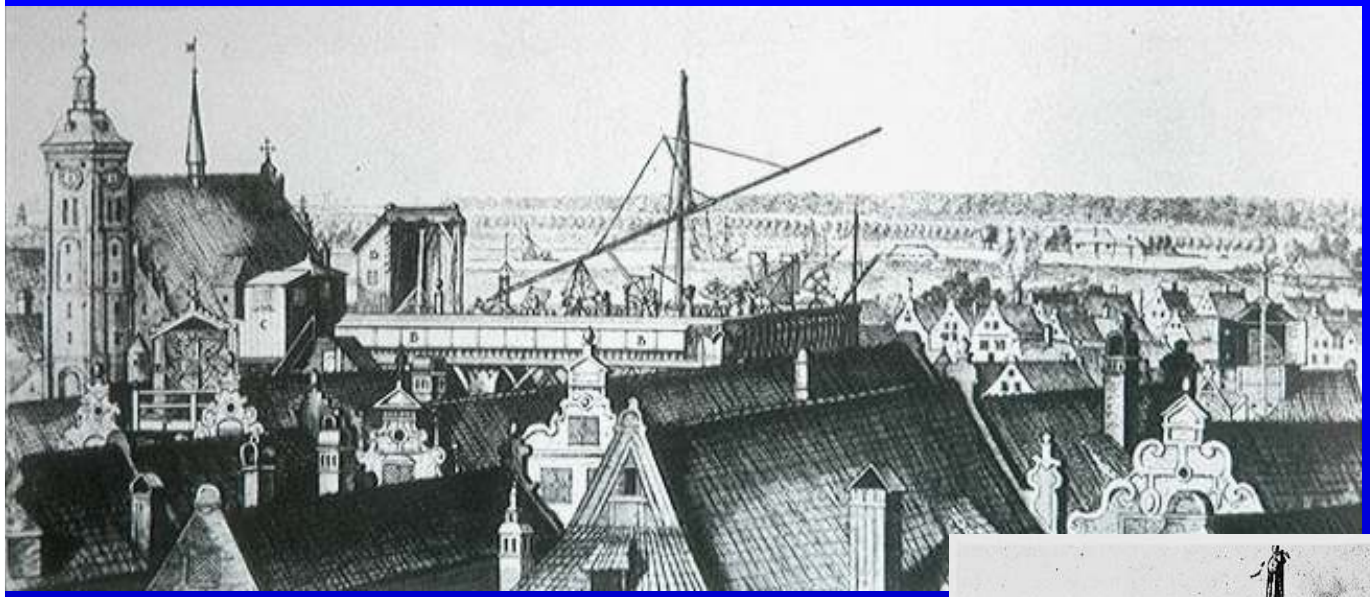
- Value deduced from 1789 transit was between 93 and 97 million miles. (149 to 155 km)
- Enke analysed both 18th century eclipses and deduced 95.25 million miles. (152 km)

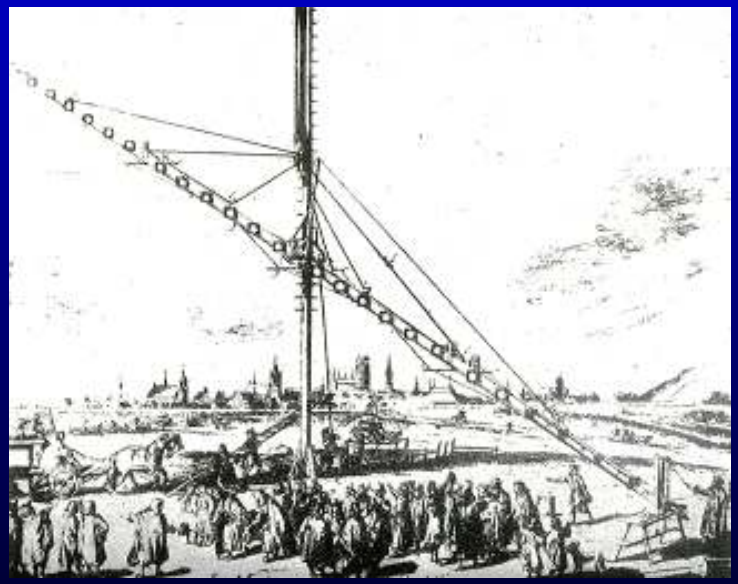
Distance by Radar

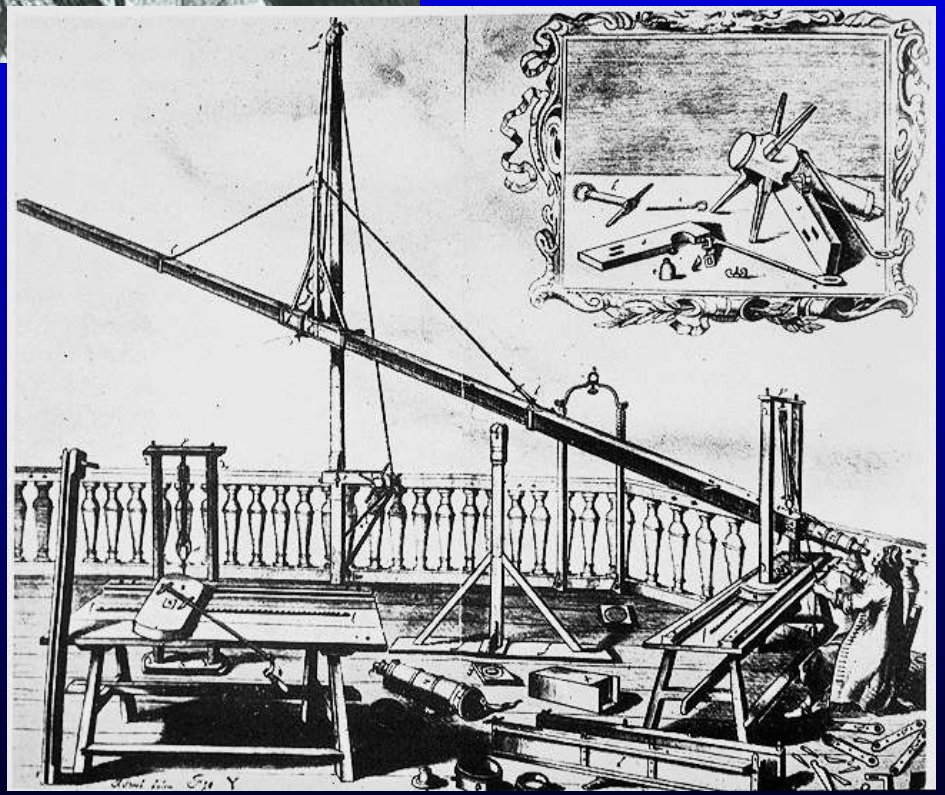
- The AU was finally found to high precision by Planetary radars in the US, USSR and UK (using the MK1 Radio-Telescope).
- The result was:
  - 149,597,870.691 km
- So just less than 150 million km or 93 million miles.

Giant Refractors

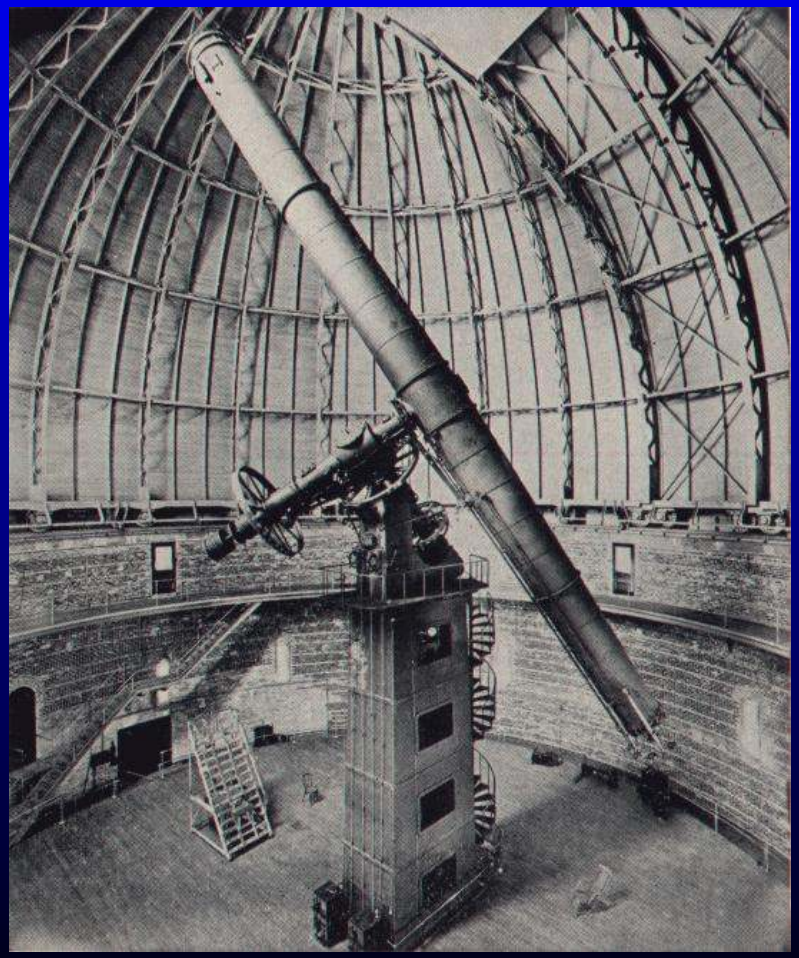
Helvelius



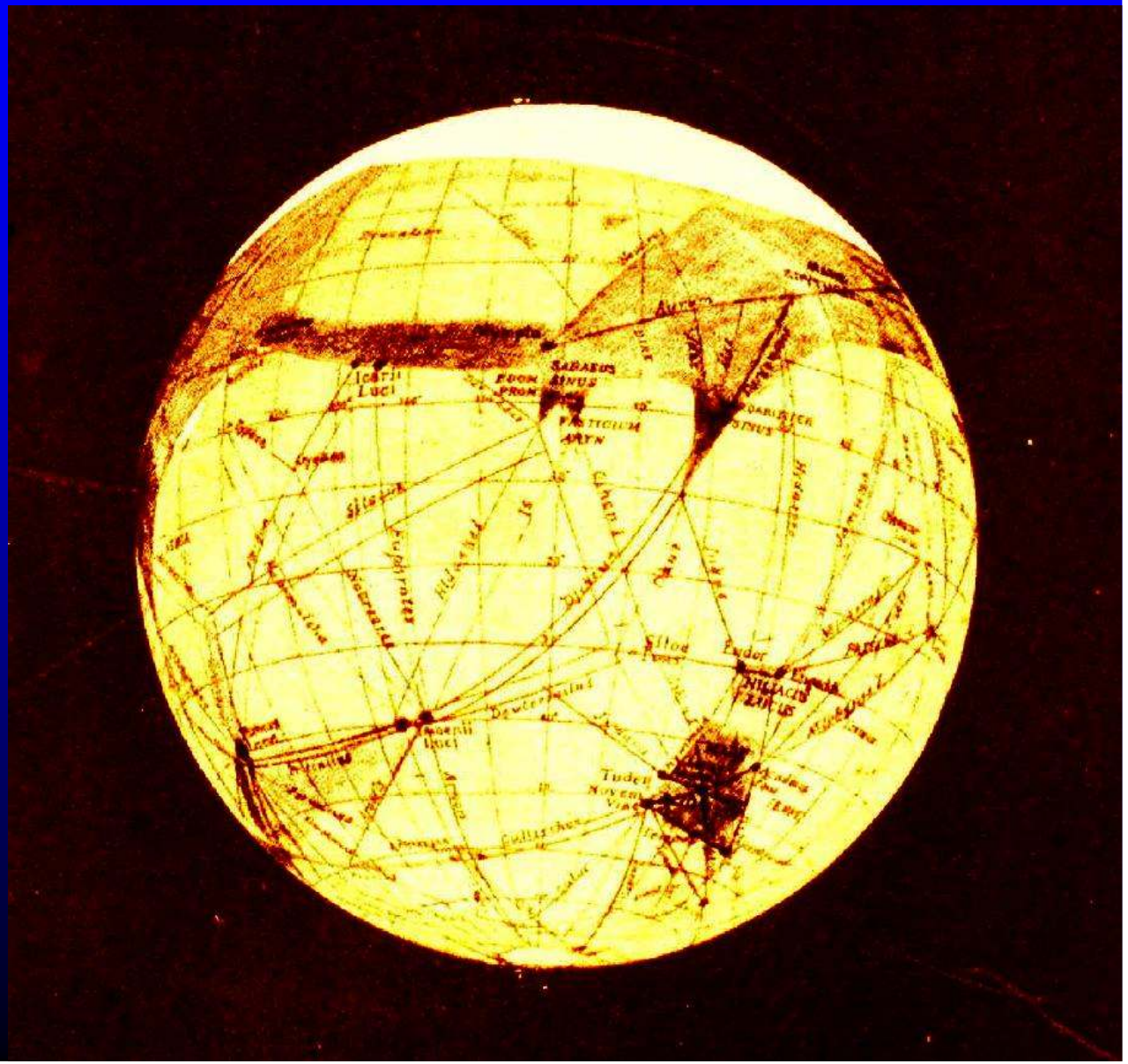


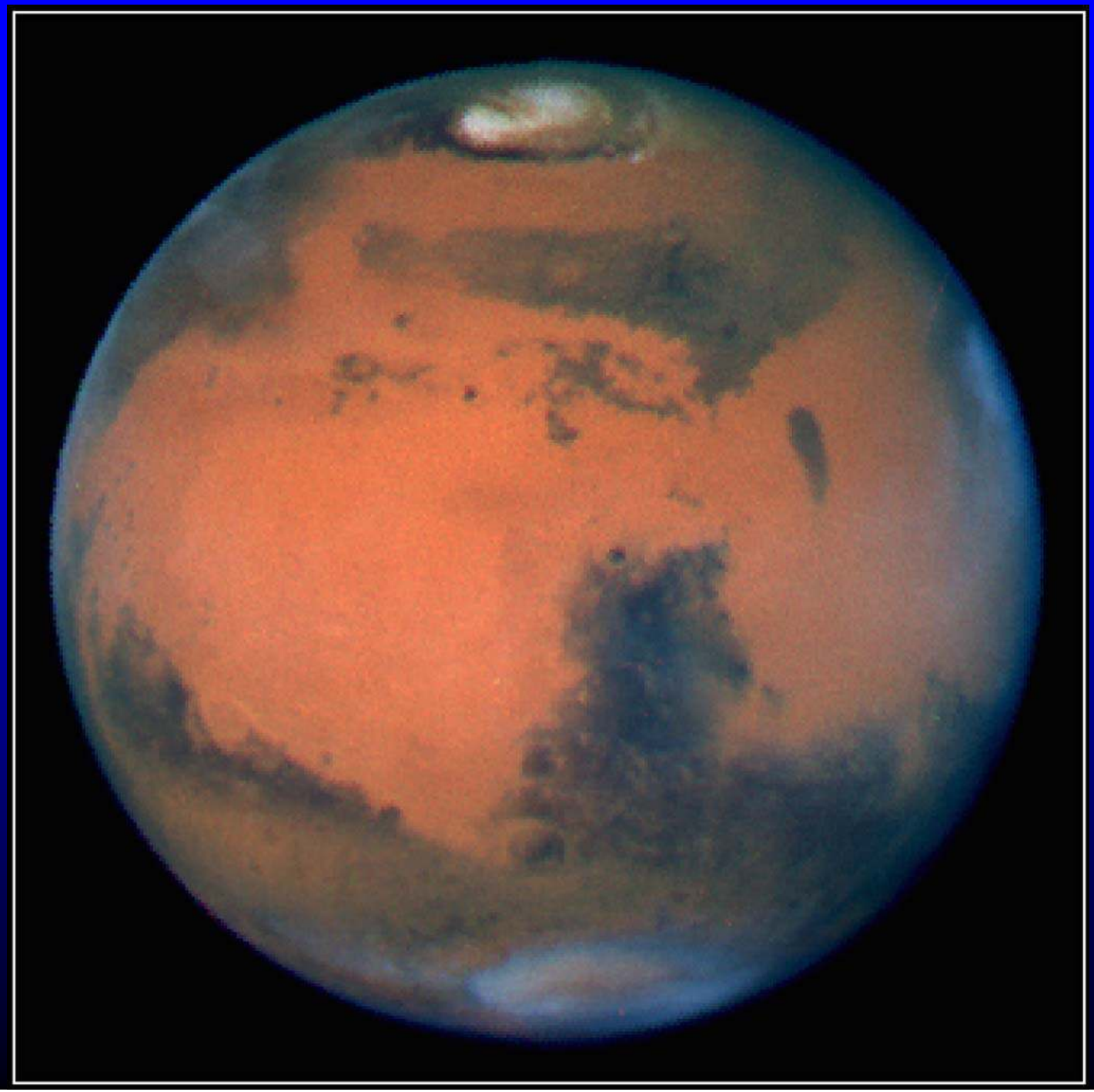


Giant Refractors

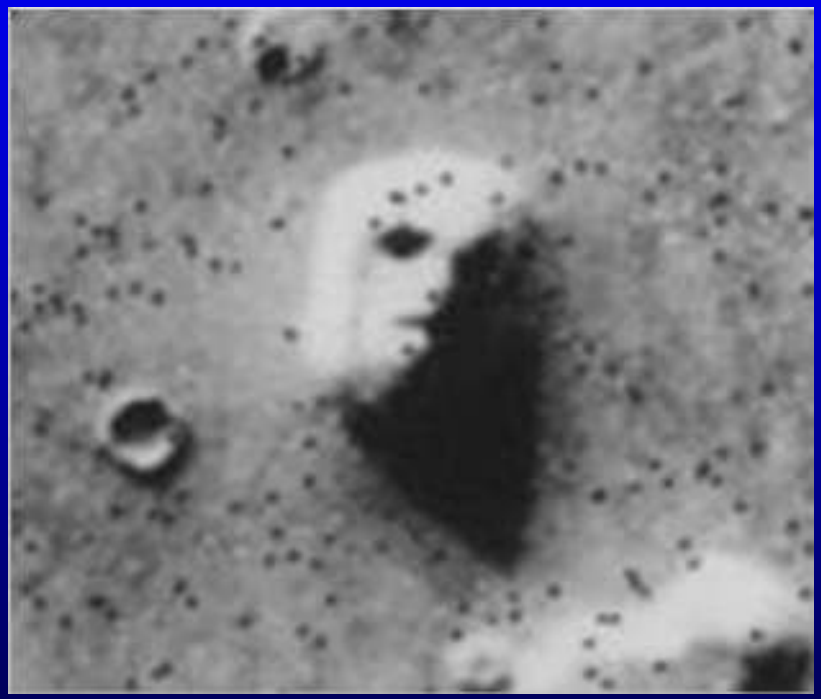


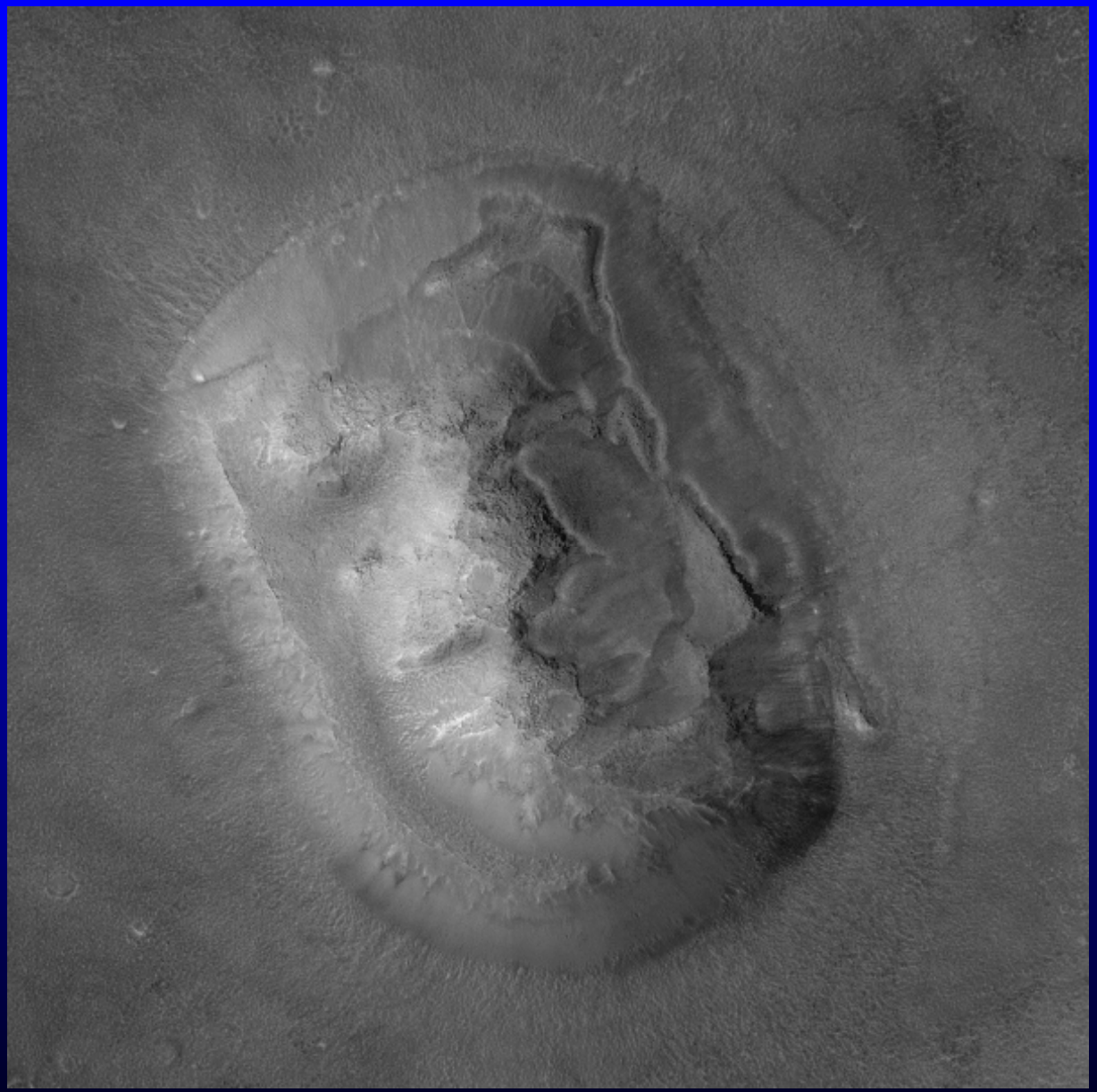
Canals on Mars?





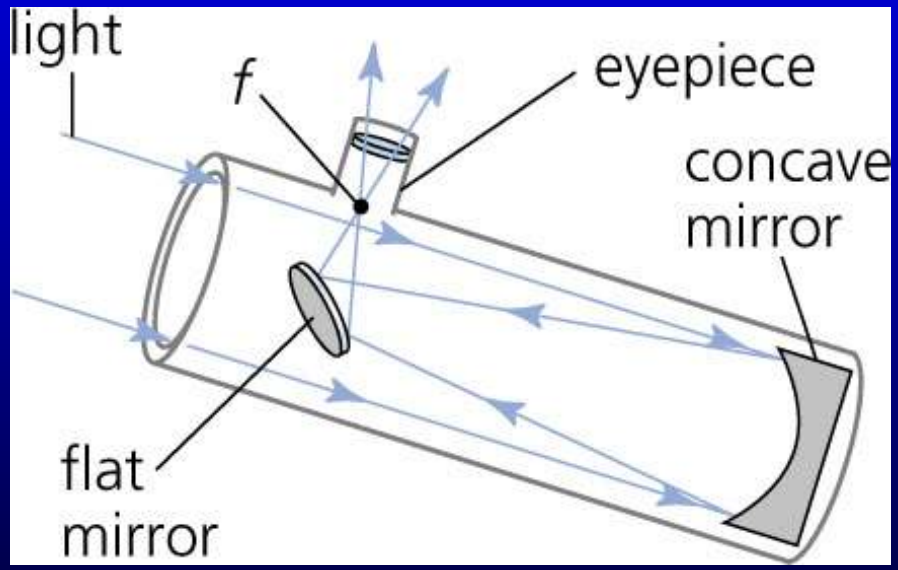
The Face on Mars!



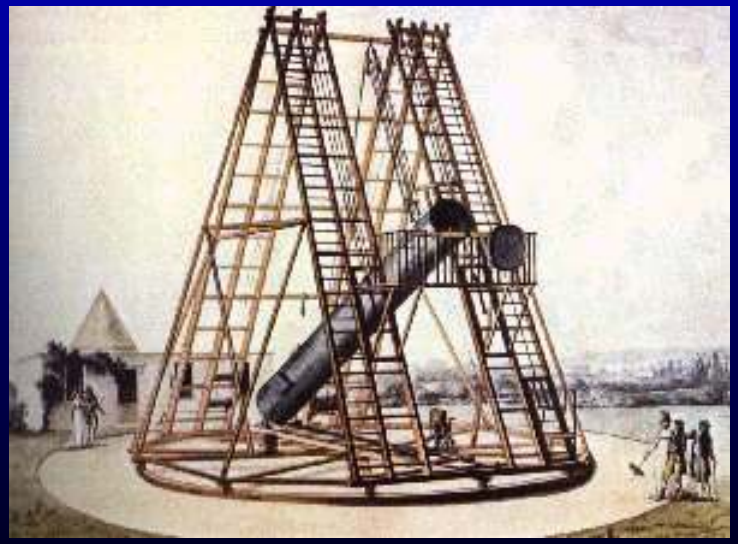


The Reflecting Telescope

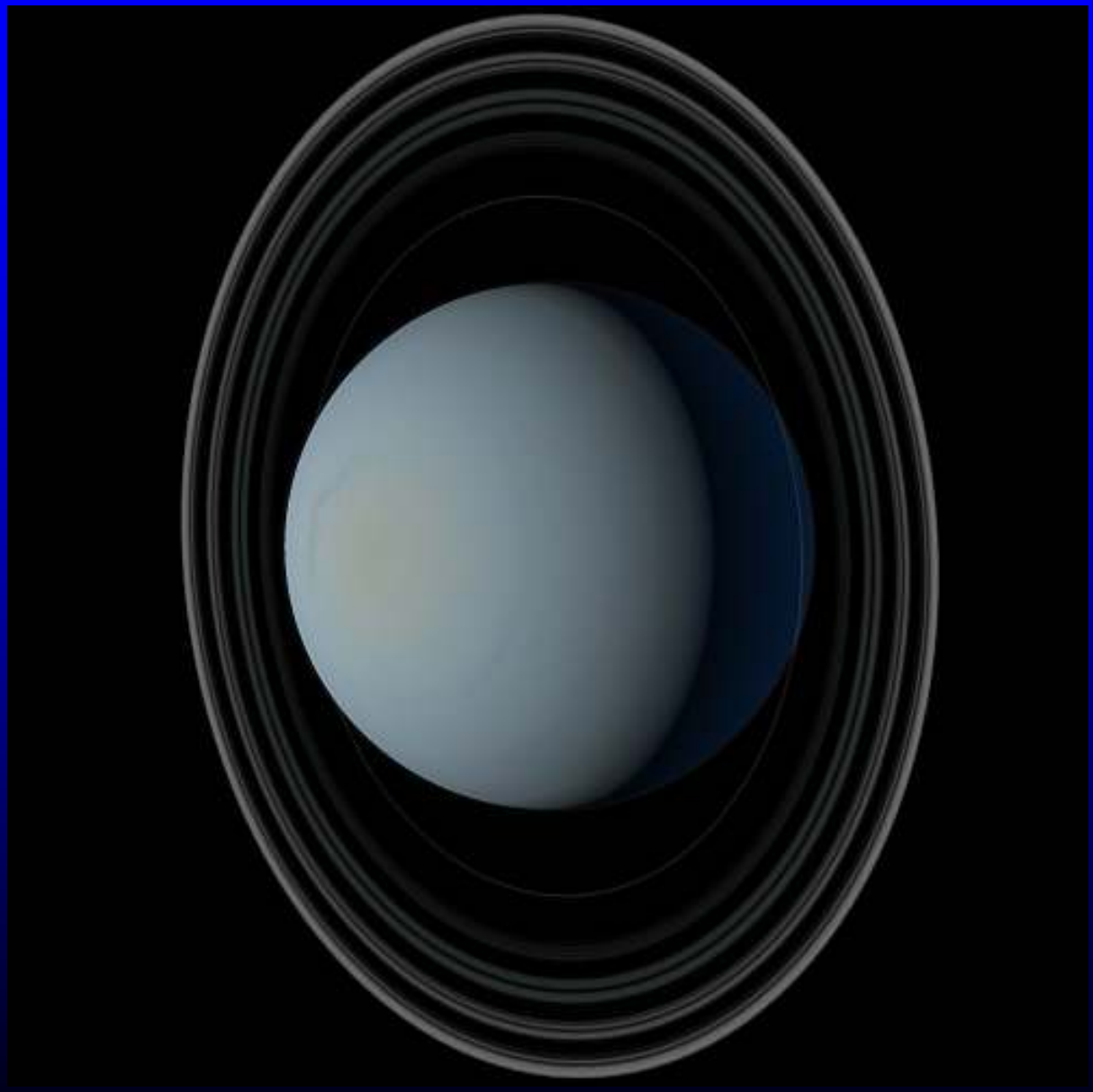
Newton's Reflecting Telescope



William Herschel and his Telescope



Uranus

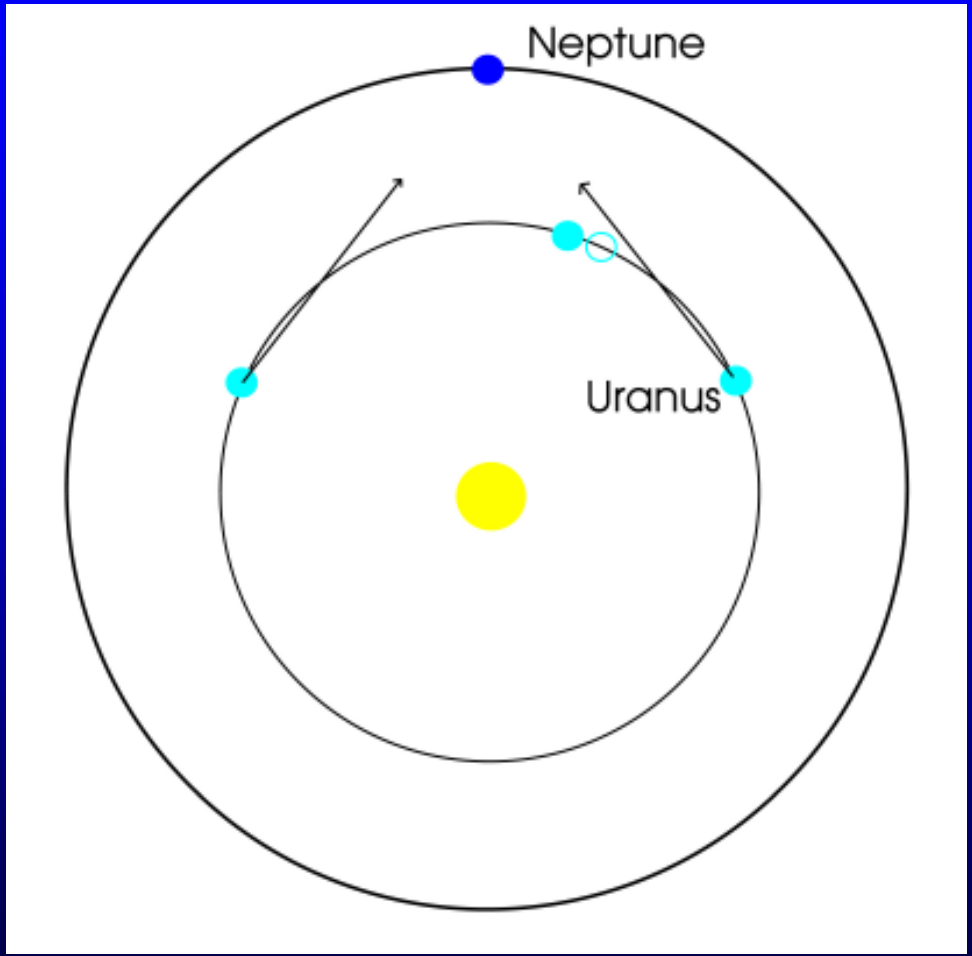


The discovery of Neptune

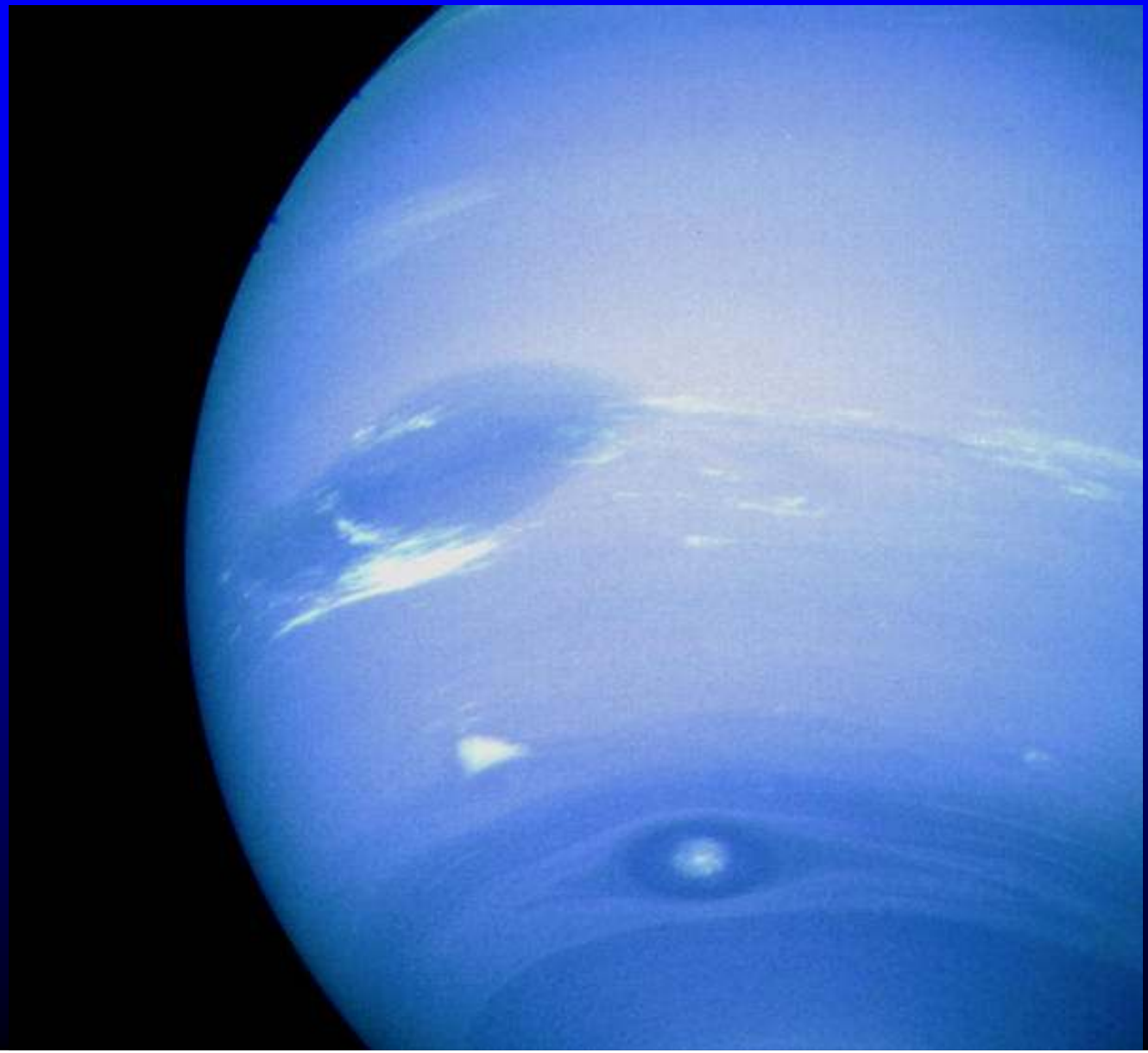
- *John Couch Adams*

- Urbain Le Verrier

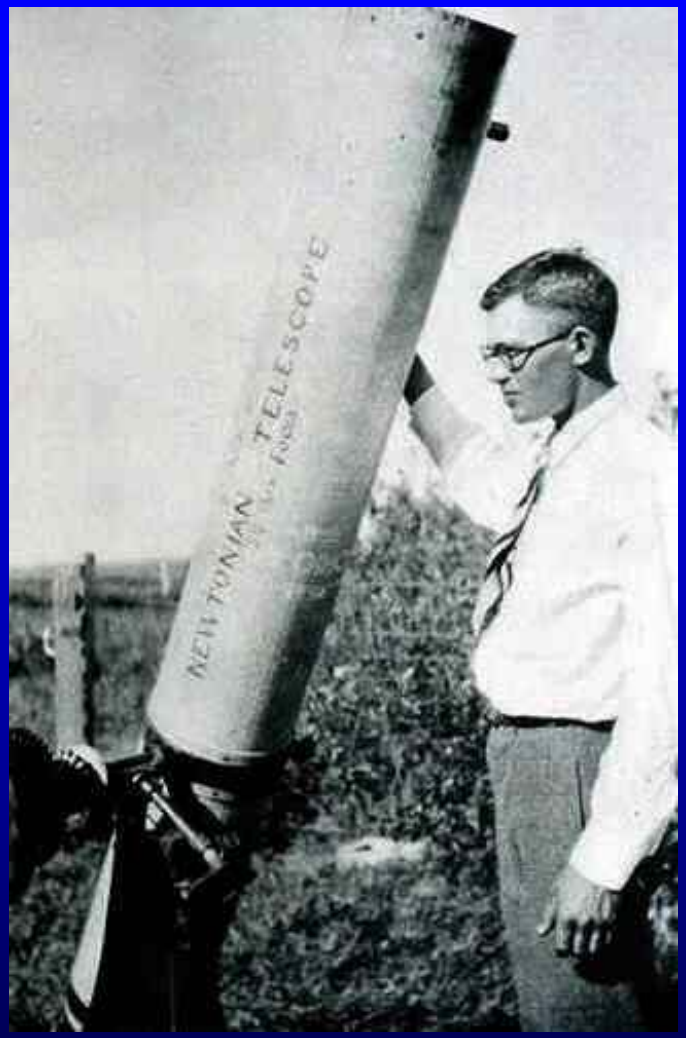
- As Uranus approached Neptune, their joint attraction ADVANCED the position of Uranus in its orbit.
- As it receded from Neptune, their joint attraction RETARDED the position of Uranus in its orbit until it was back where it would have been without the presence of Neptune.
- Neptune lay beyond the point where where Uranus was most ahead of its predicted track.



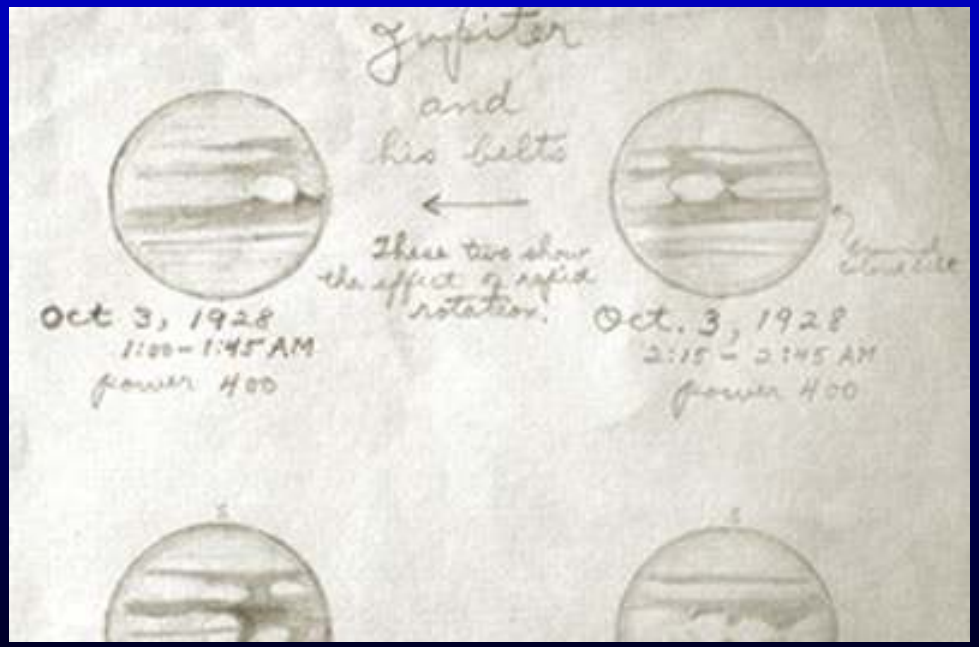
Neptune



Neptune with Triton



Clyde Tombaugh

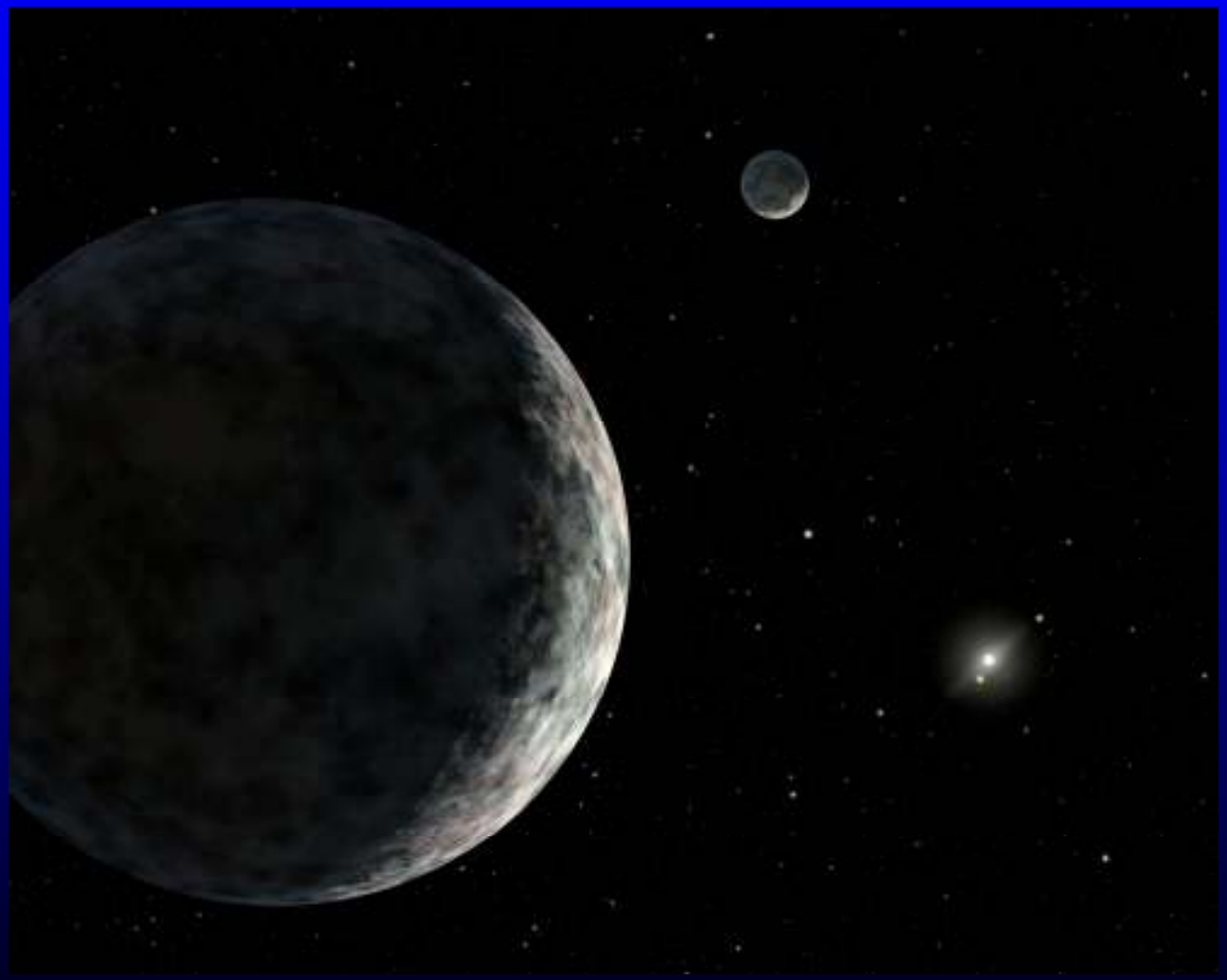


Pluto and Charon

A Planet no more!

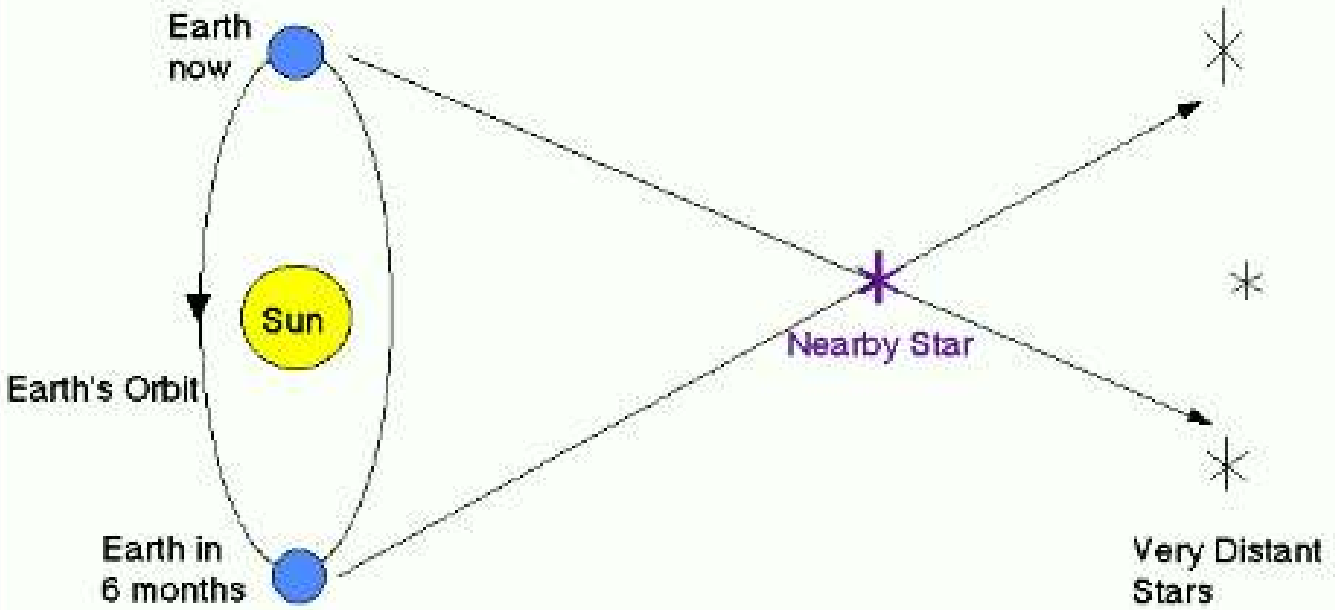
- Now given the classification of a “Dwarf Planet”
- Along with
  - Eris - discovered in 2003
  - Ceres – the largest body in the asteroid belt

Eris with its moon

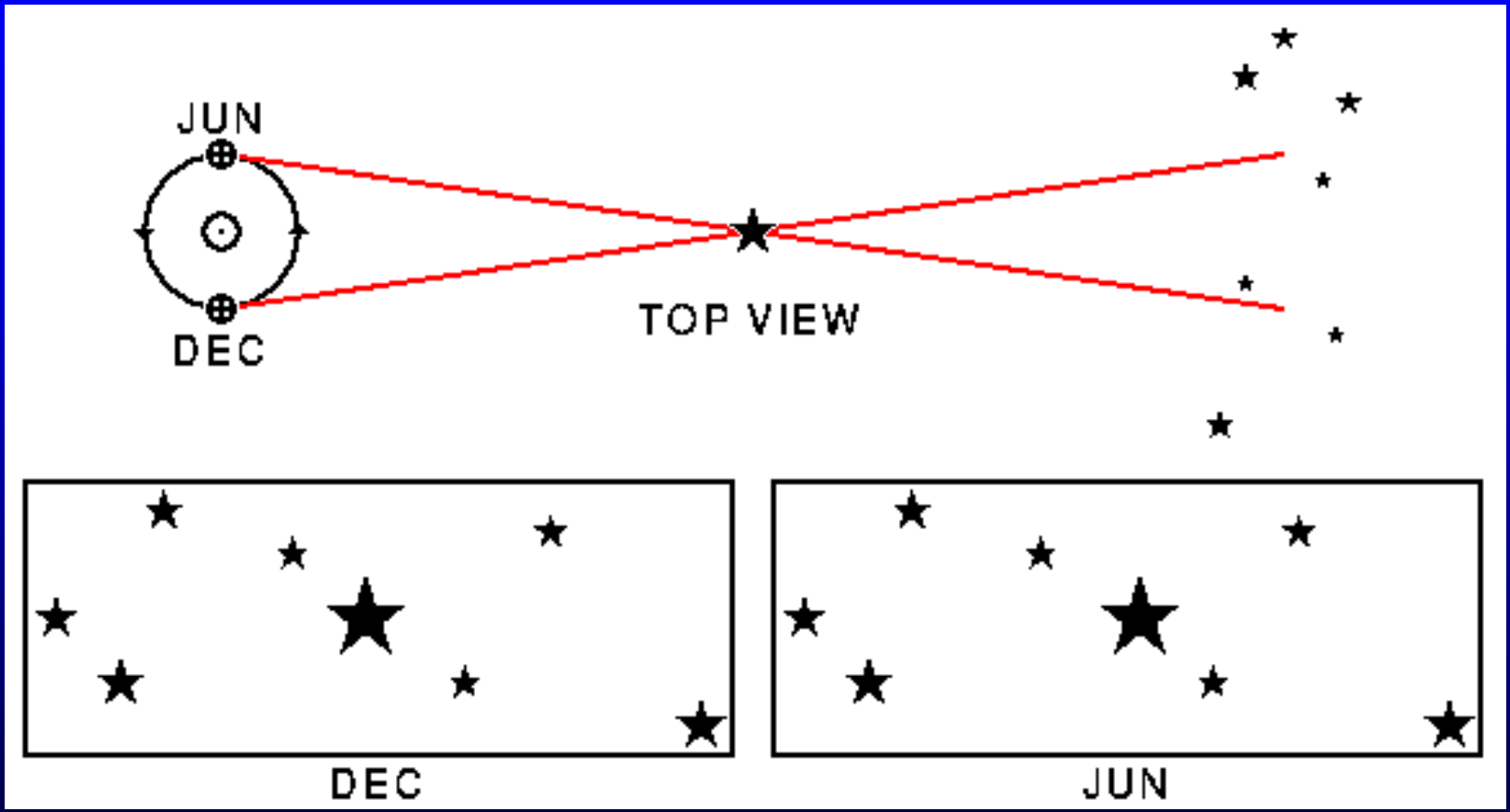


Distances to the Stars

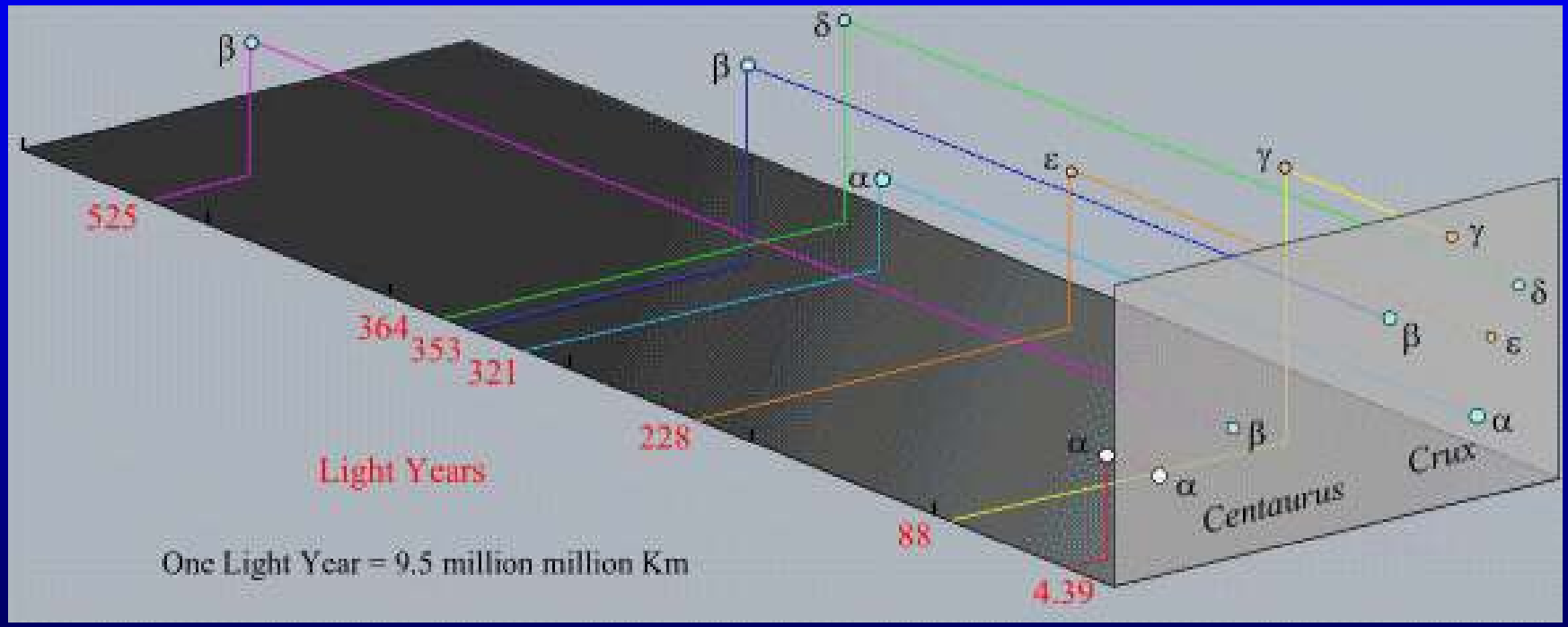
Large Baselines : Earth's Orbit



- A very large baseline is need to measure the parallax of stars

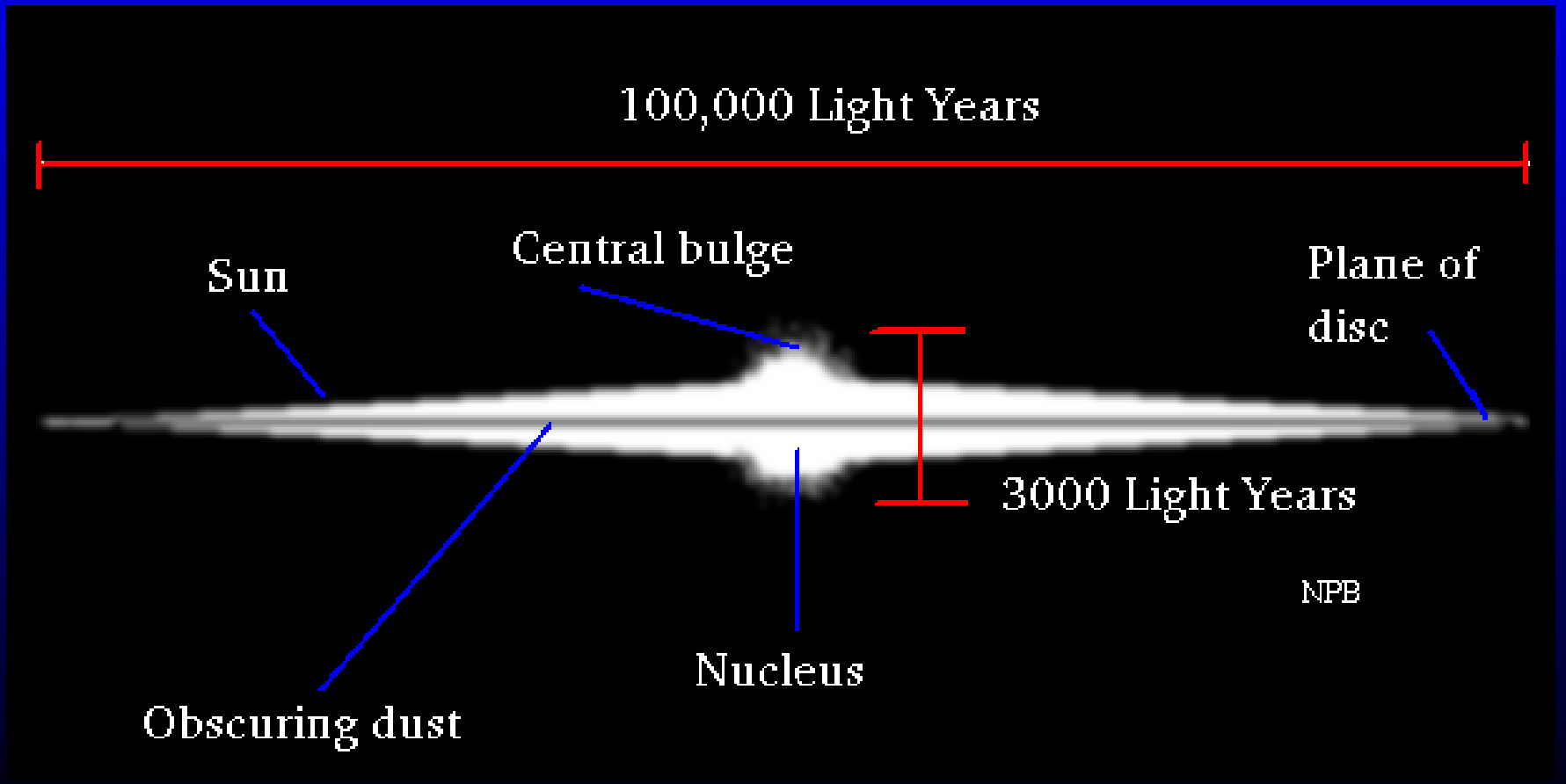

JUN
DEC
TOP VIEW
DEC
JUN

The Southern Cross


β
β
δ
ε
γ
α
525
364
353
321
228
88
4.39
Light Years
One Light Year = 9.5 million million Km
α
α
β
Centaurus
Crux
γ
δ
β
ε
α

The Deep Sky

Our Galaxy
The Milky Way



Beyond the Milky Way Galaxy

Birr Castle

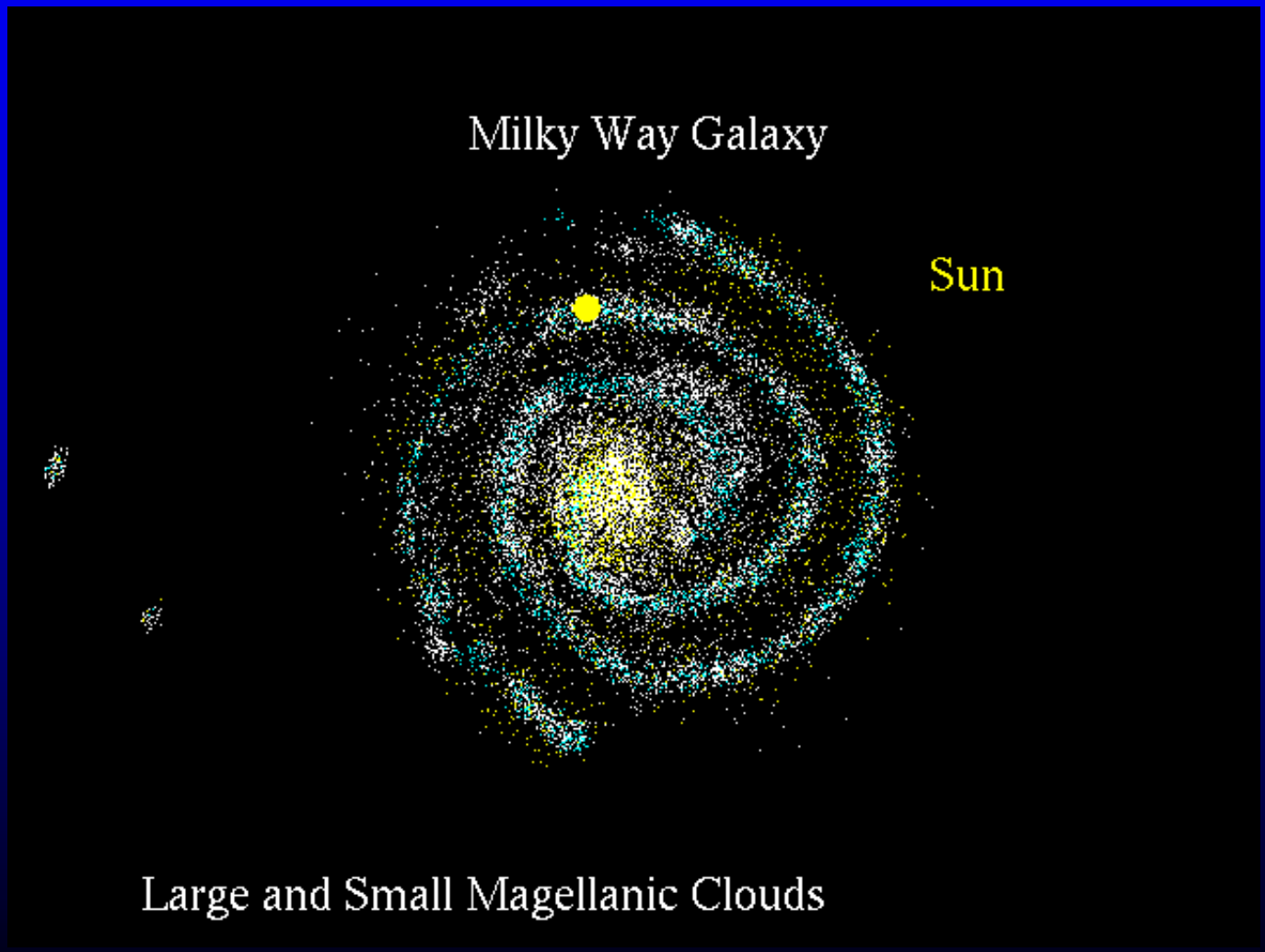
M51 – The Whirlpool Galaxy

How far are the Galaxies?

Step 1:

The distance to the Large Magellanic Cloud

The Magellanic Clouds



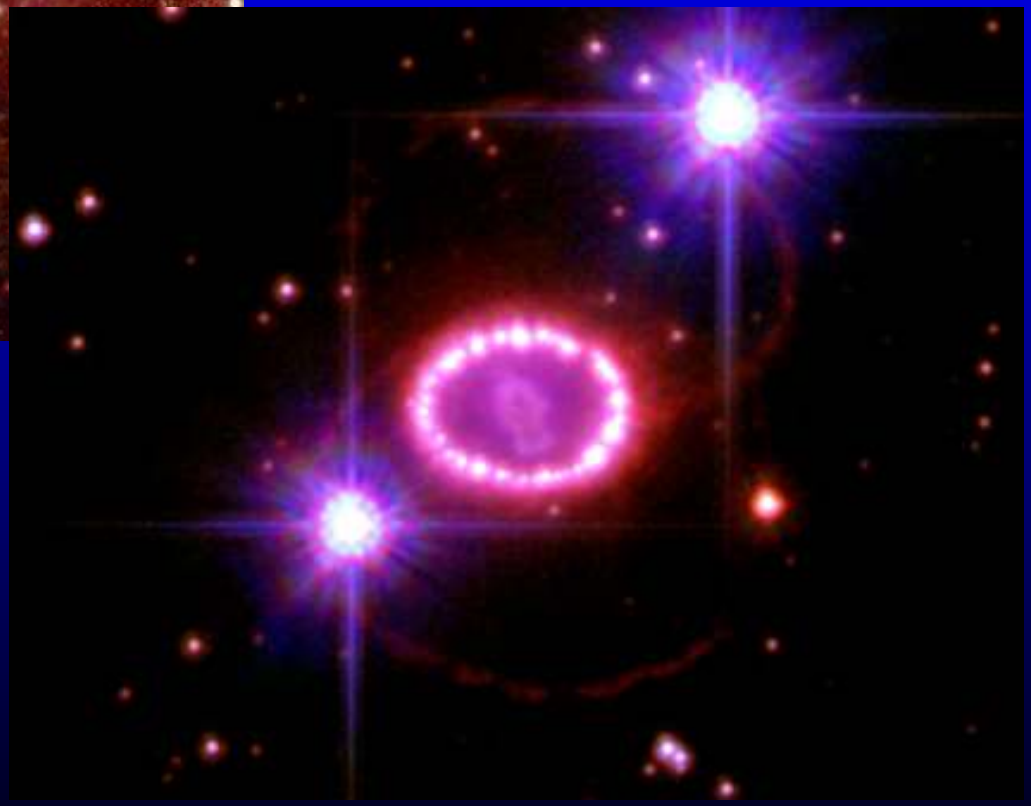
Large Magellanic Cloud

Tarantula Nebula

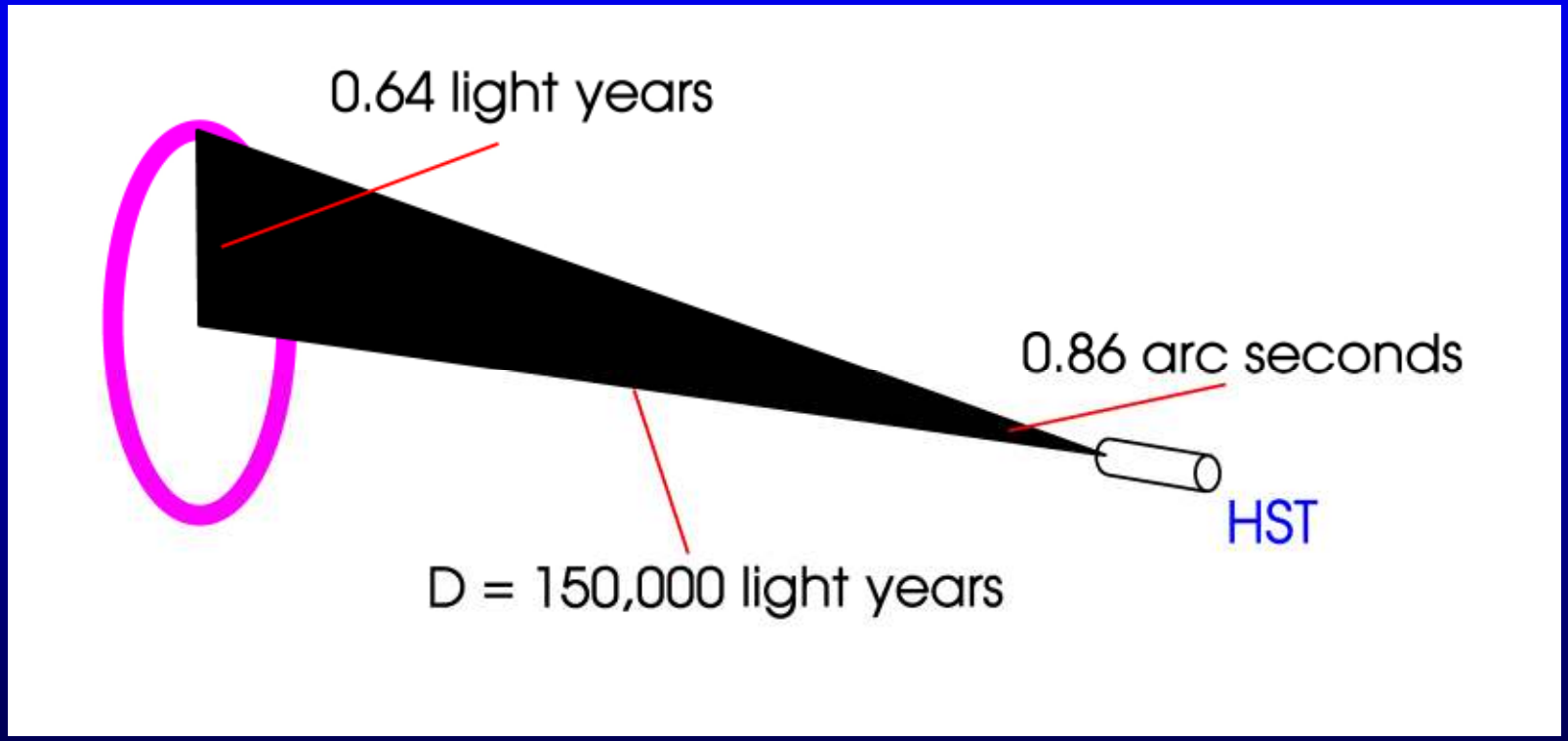
SN 1987A

Hubble Space Telescope

SN 1987A



- The ring lit up 230 days after the supernova exploded


0.64 light years
0.86 arc seconds
HST
D = 150,000 light years

How far are the Galaxies?

Step 2:

Using Cepheid Variables

Delta Cepheus

- Nearly two hundred years ago English astronomer John Goodricke discovered a new type of variable star in the Cepheus constellation called delta Cepheid. The star brightness varies regularly with period 5 days, 8 hours and 48 minutes.

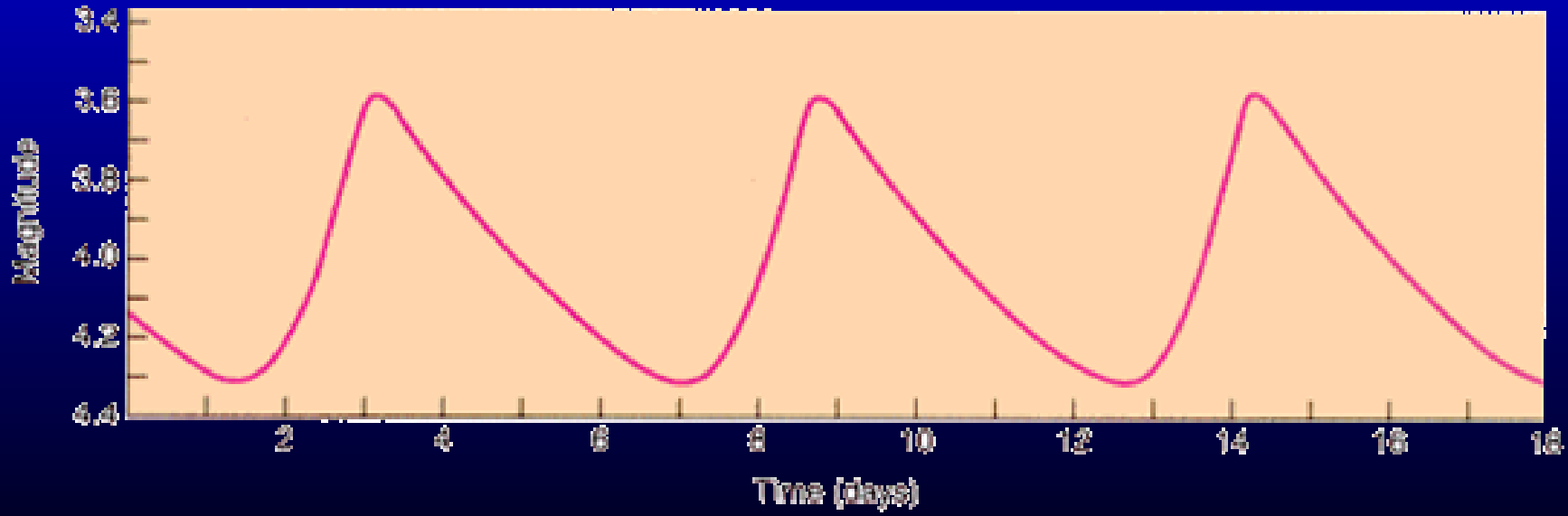
- Delta Cepheid stars are rhythmically breathing in and out, becoming alternately brighter and dimmer in the process.

Henrietta Leavitt 1868 - 1921

- Born in Cambridge Mass, she studied Astronomy at Radcliffe College.
- Illness left her very deaf.
- She joined the Harvard Observatory in 1895 and became head of the stellar photometry dept.
- She discovered 2400 variable stars – half of those then known.

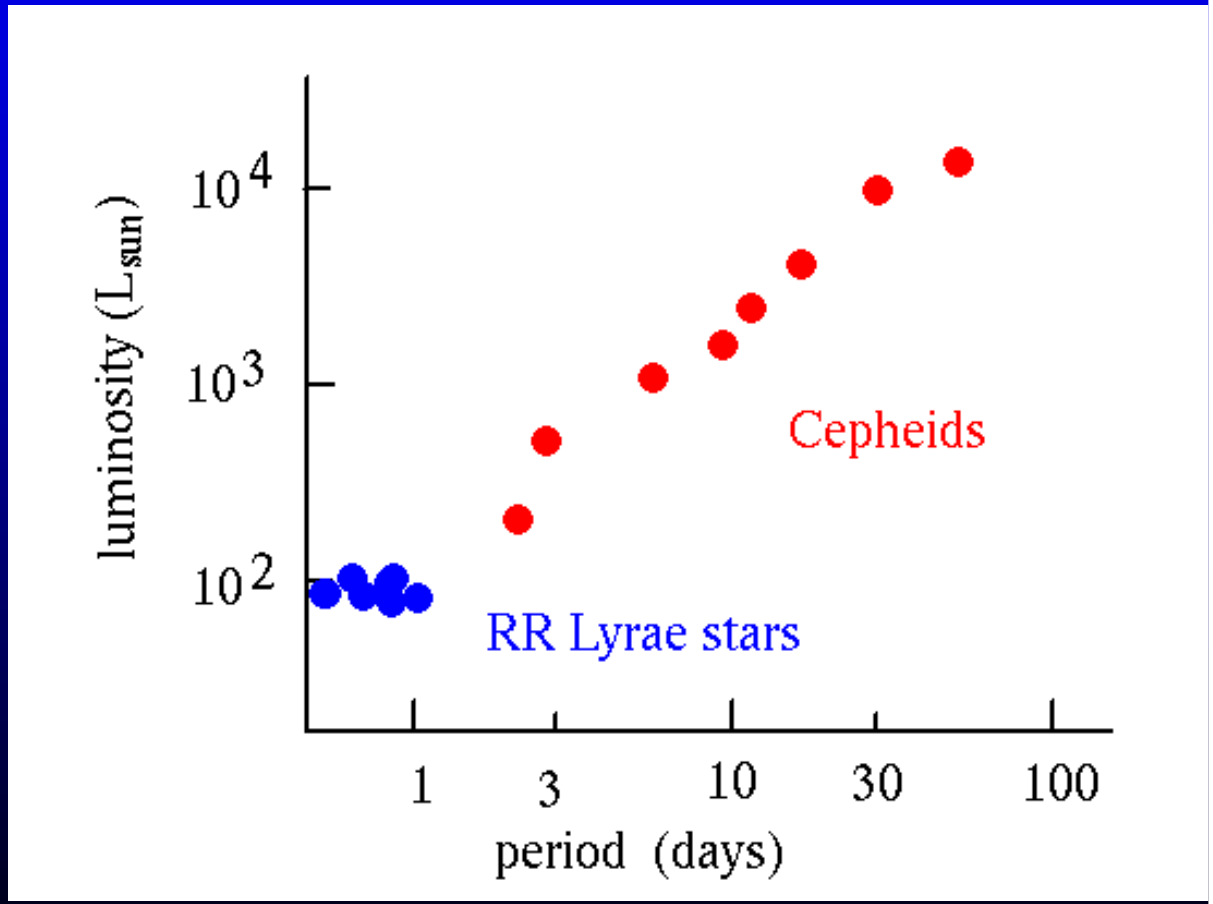
The Cepheid Variables

- Miss Leavitt observed that the Cepheid Variables had a very regular variation in brightness.

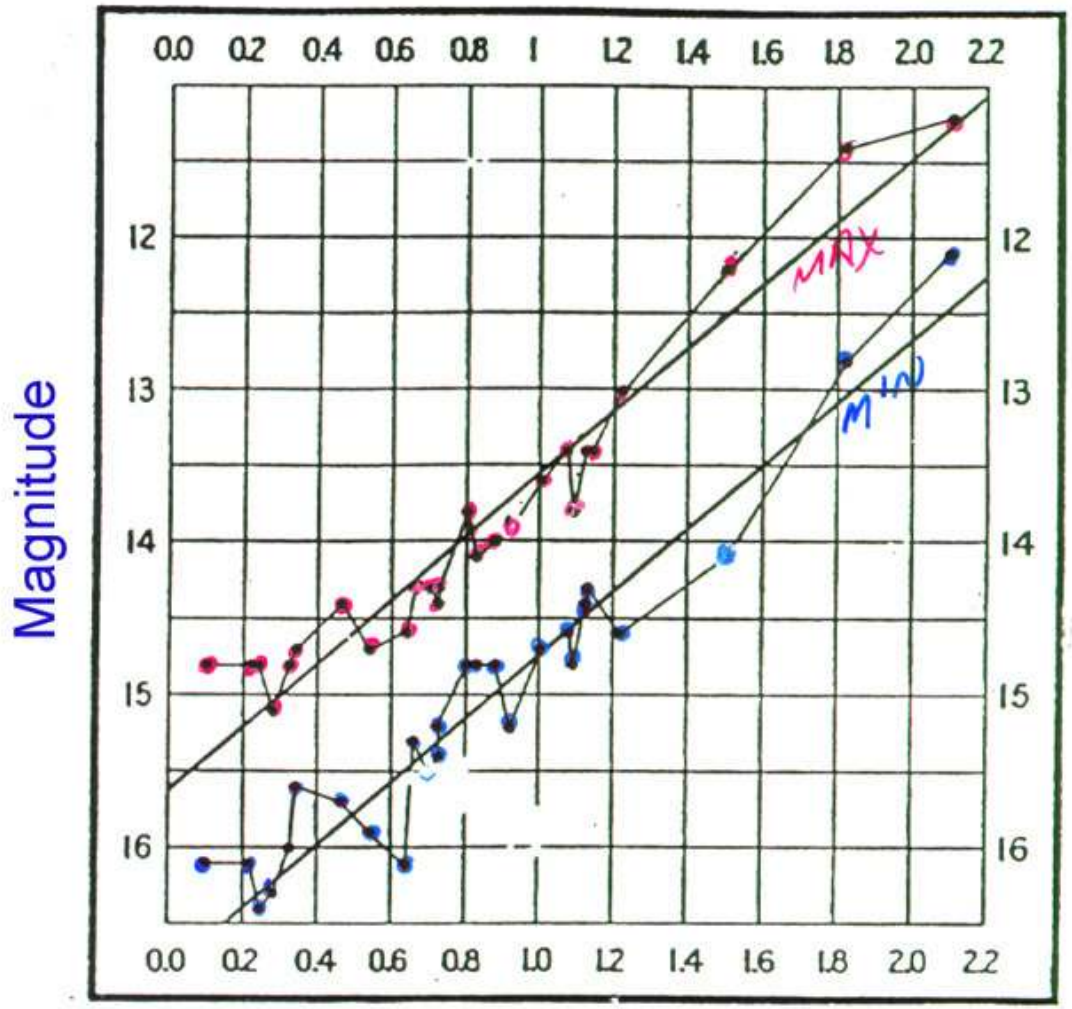


The Period-Luminosity relationship

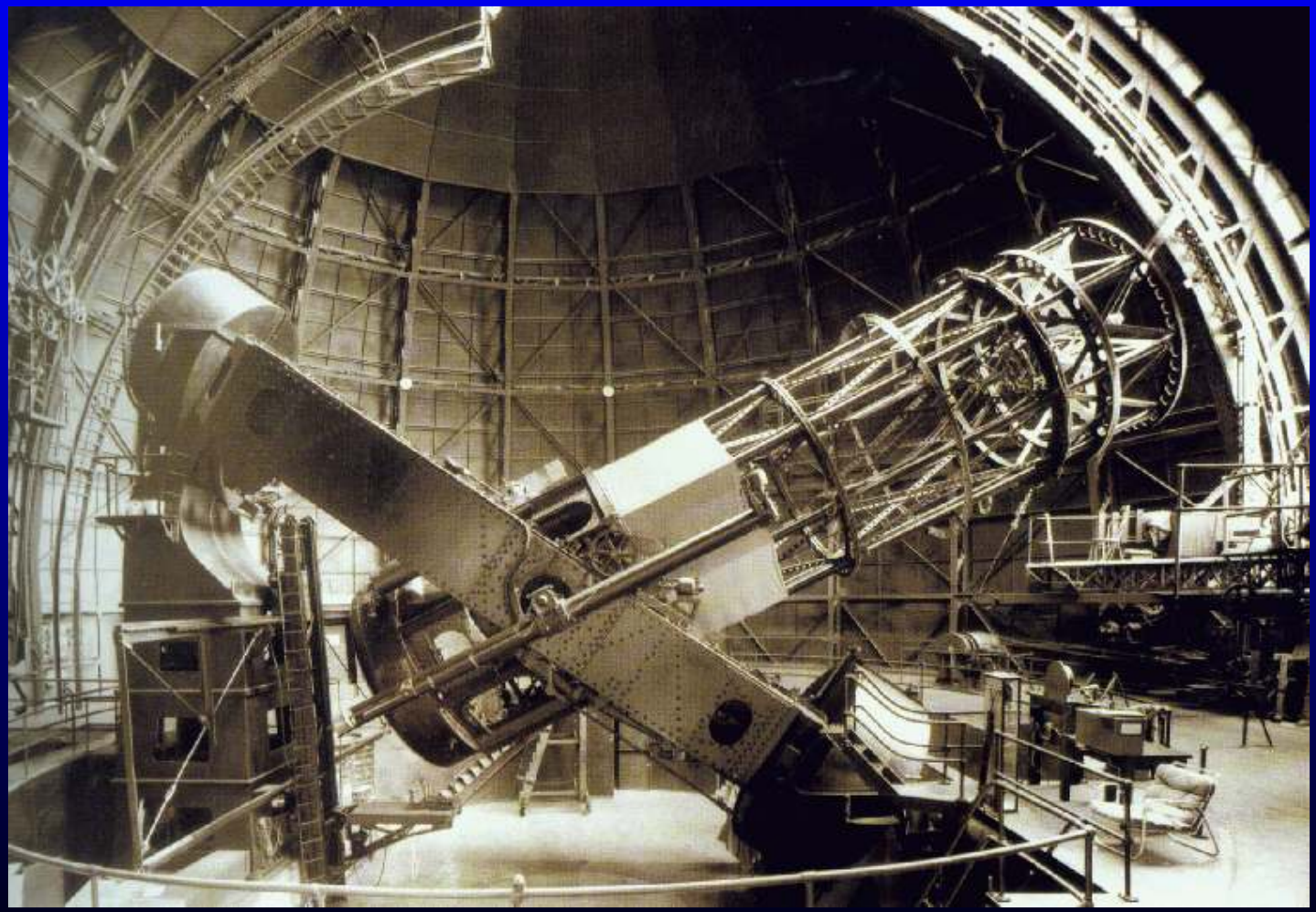
- She noticed that the period was related to the luminosity.
- The more luminous stars had longer periods.
- This gave a way of measuring distances to any galaxy in which a cepheid variable could be seen.



P-L Relation for Cepheids in Large Magellanic Cloud Henrietta Leavitt, 1908



Mt Wilson: Hooker 100” Telescope



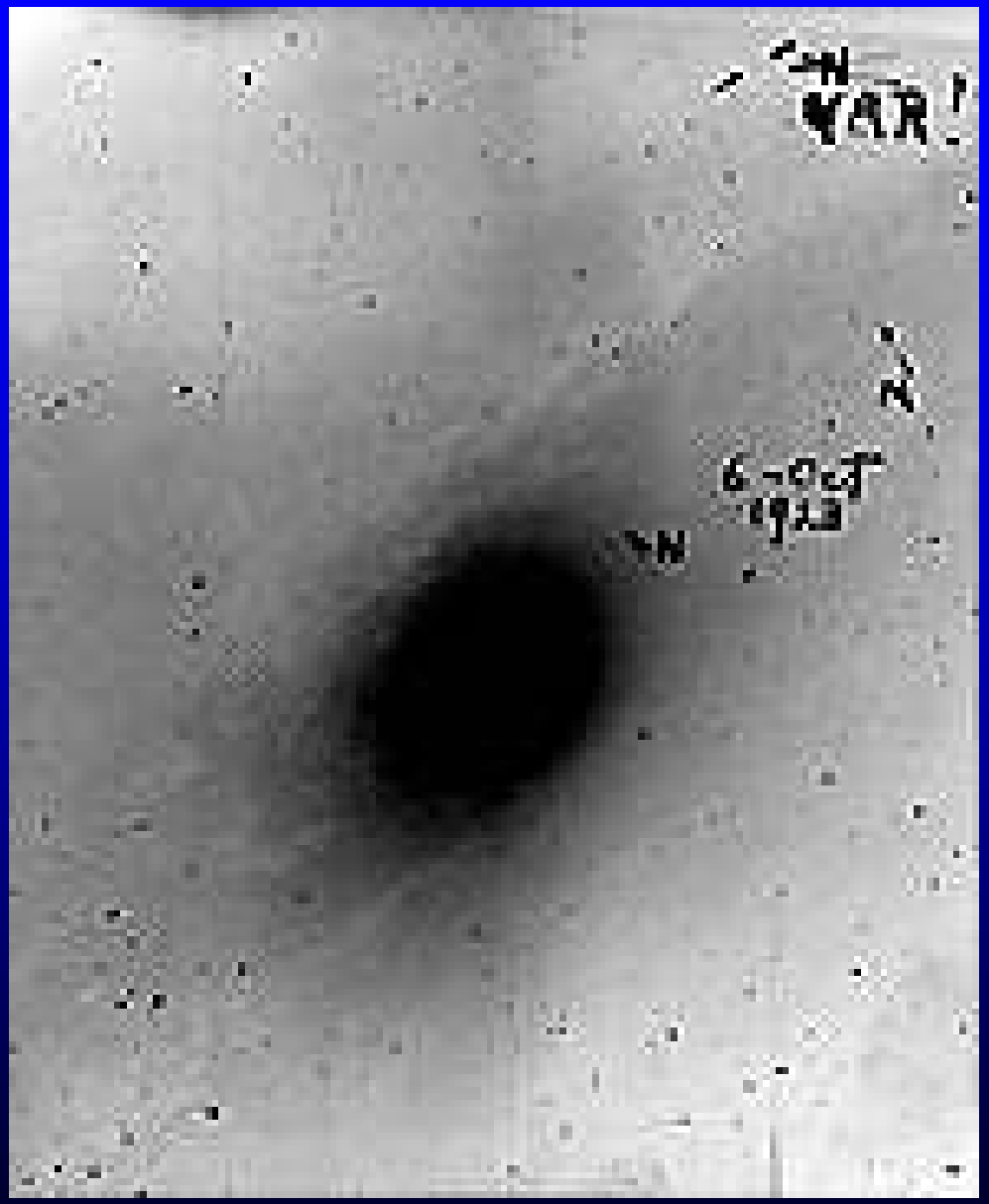
Edwin Hubble

- Using this telescope Edwin Hubble made one of the most important discoveries of the 20th Century

The Andromeda Galaxy

A Cepheid Variable in M31

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



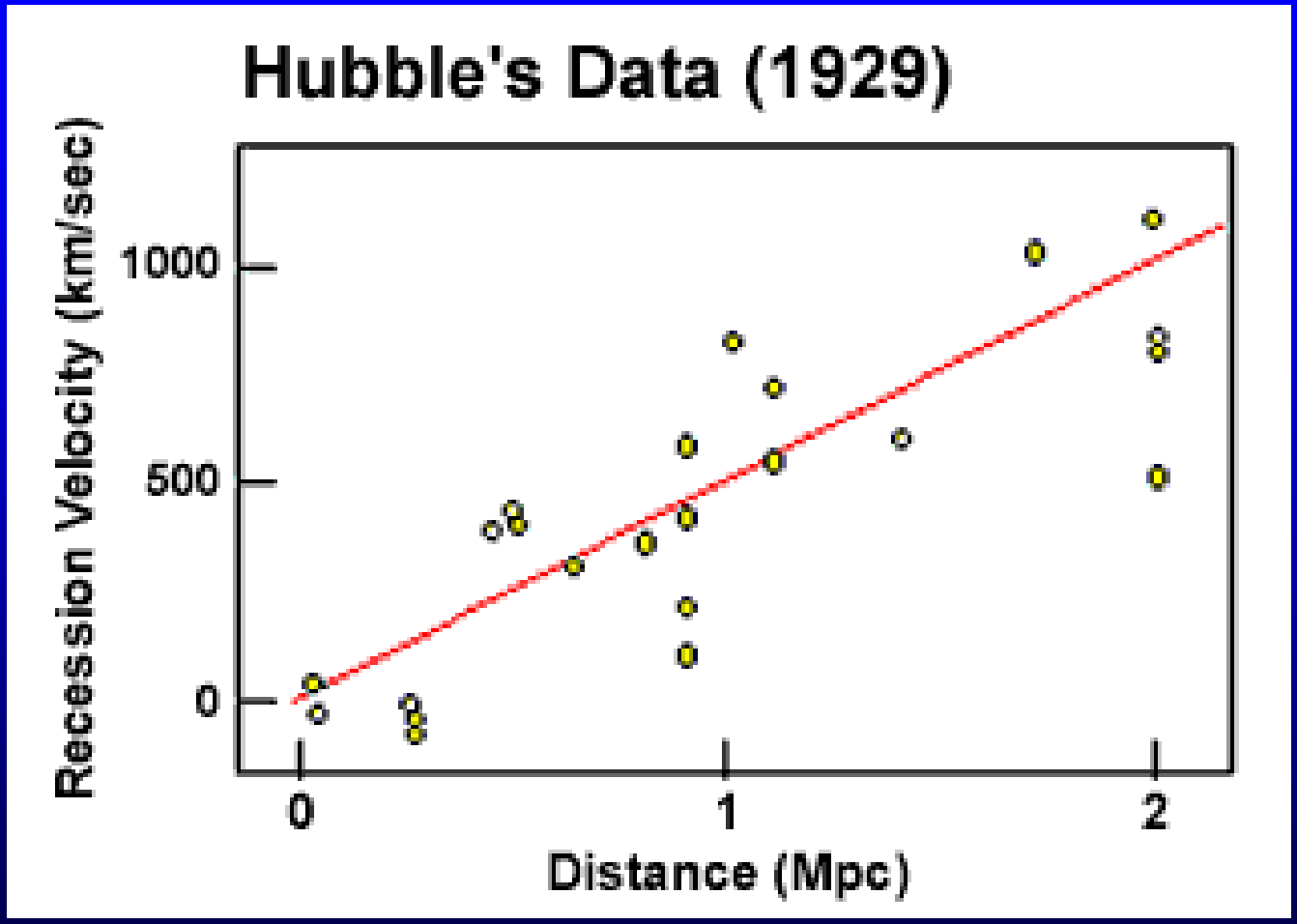
- He was able to show that the Andromeda galaxy was far beyond our own Milky Way galaxy.

Velocities of recession

- Slipher had measured the speed at which 23 galaxies were moving away (they showed a redshift) or towards us (they showed a blueshift)
- Most were moving away from us.

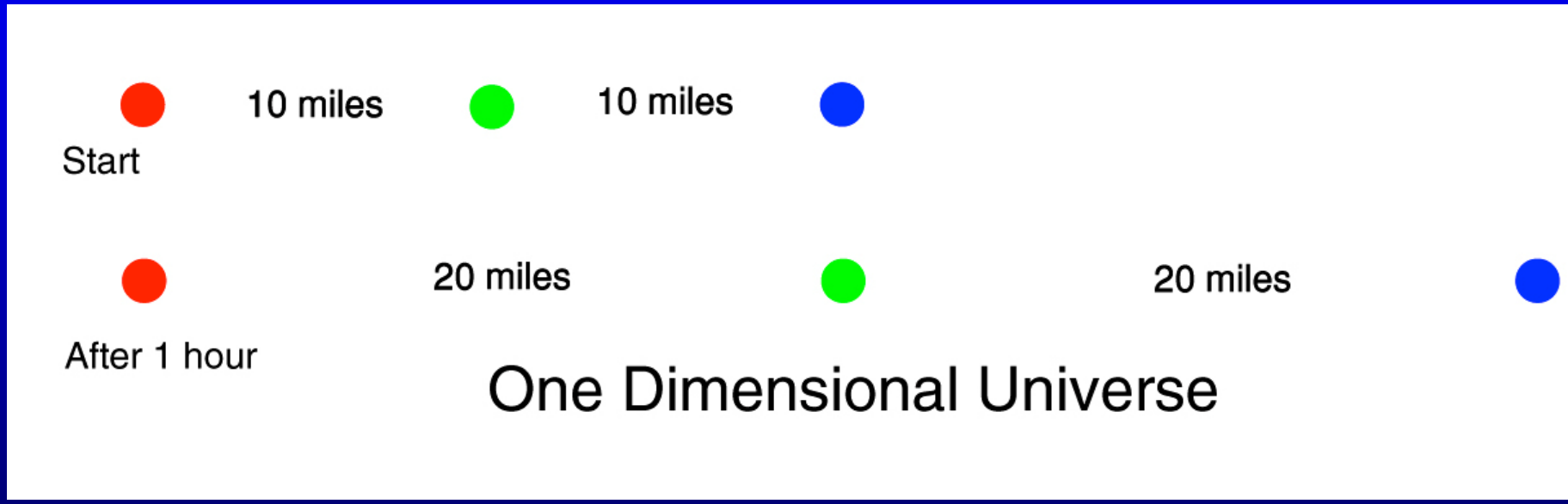
- Hubble combined these data with his distance measurements

Hubble Diagram



V = H x R where H = Hubble's Constant

An Expanding Universe



- Hubble had showed that the universe was expanding

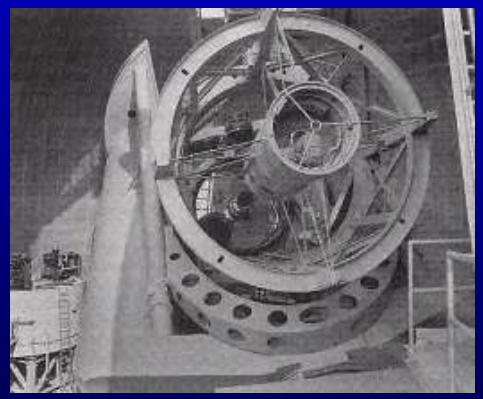
The Age of the Universe

- If the universe is increasing in size with time, then it would have been smaller in the past.
- If we assume that the expansion has been linear we can back track to the time when the universe had no size.
- Its origin in the Big Bang!

The Age of the Universe

- Given the value Hubble got for his constant:
  - 500 km/sec/Mpc
- The age is ~ 2,000 million years
- This worried people!

Hale 200”
at
Mount Palomar



Walter Baade

His Value of H:
250 (km/sec)/MPc

Very Large Telescope

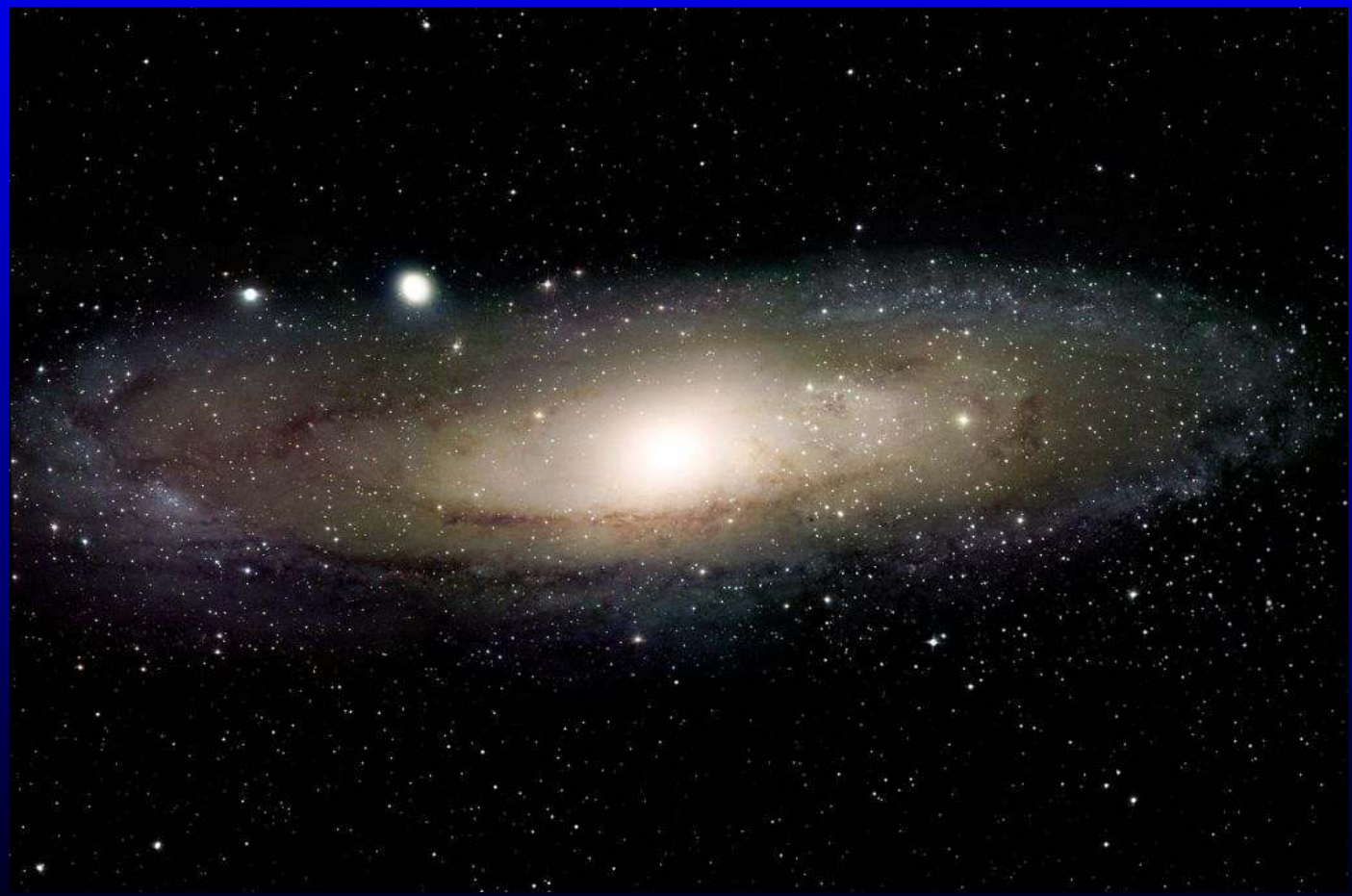
Spiral Galaxy Messier 83 (VLT ANTU + FORS1)

Barred Spirals

The Universe

Groups and Clusters of Galaxies

The Andromeda Galaxy of our Local Group of Galaxies



M33

Magellanic Clouds

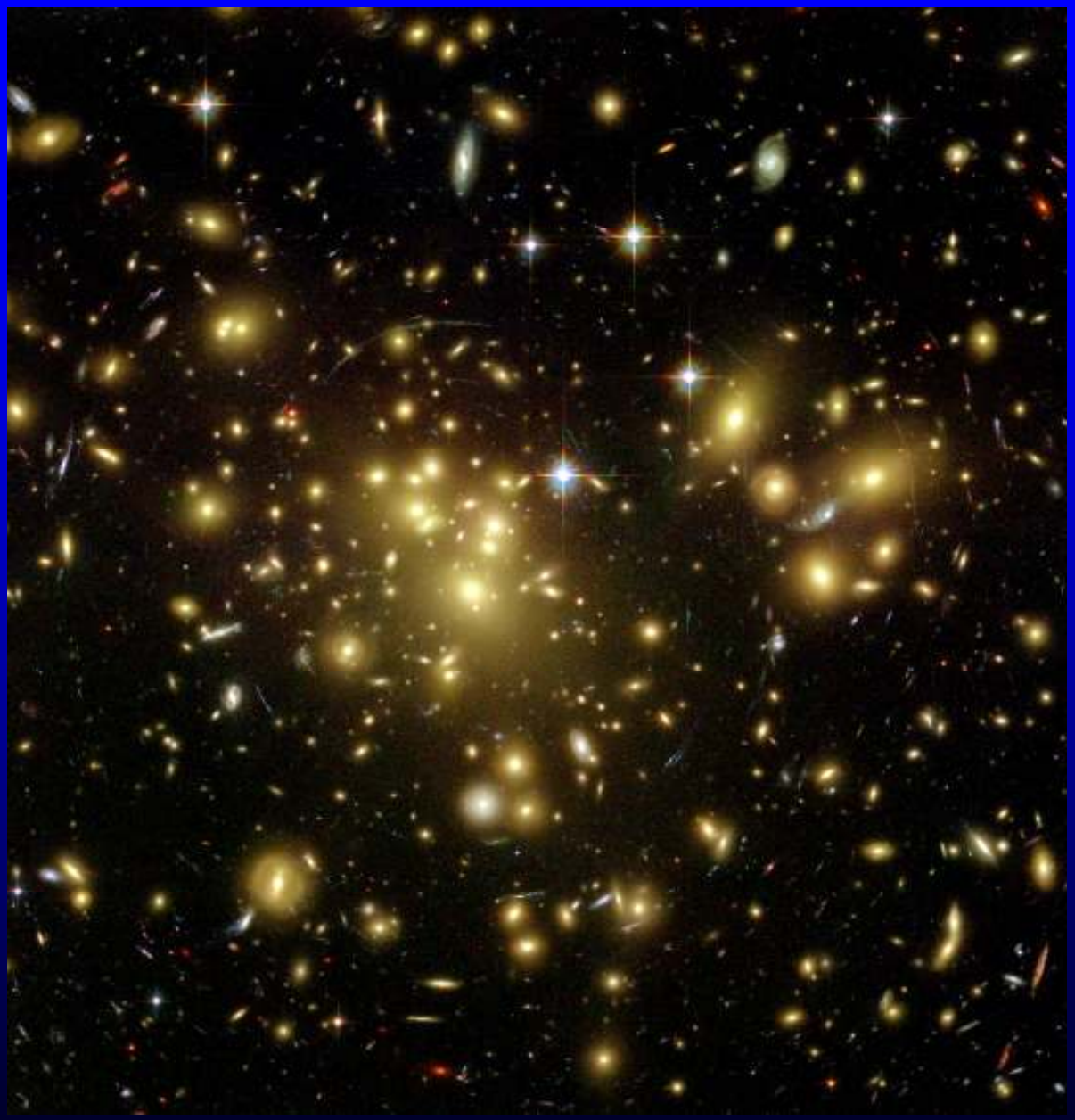
Hercules Cluster

Coma Cluster

Dark Matter

- Fritz Zwicky observed that the cluster must contain several times more mass that could be observed in the stars.
- No one believed him!
- But he has since been proven to have been right.

Galaxy Cluster Abell 1689



How can we measure distances beyond the range of Cepheid Variable Stars?

Beyond ~64 million light years we need to observe brighter “standard candles”

Observations of Distant Type Ia Supernovae

Type 1a Supernovae

- Matter falling onto a “white dwarf” star gradually increases its mass.
- It cannot support a mass of more than ~1.4 solar masses.
- When it reaches this mass it explodes!


HARDY

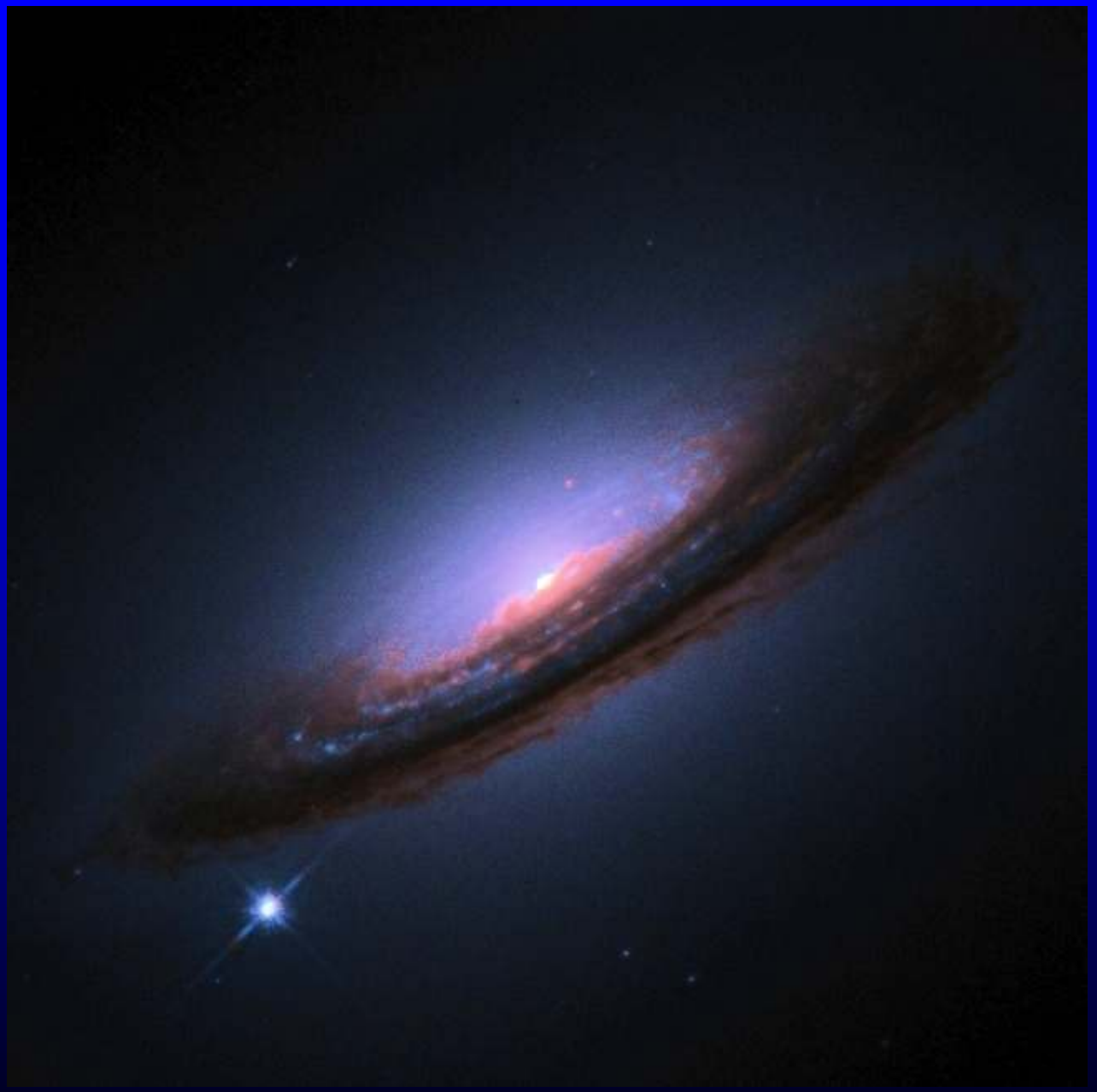
Type Ia Supernova

As they are very bright we can see them at very great distances.

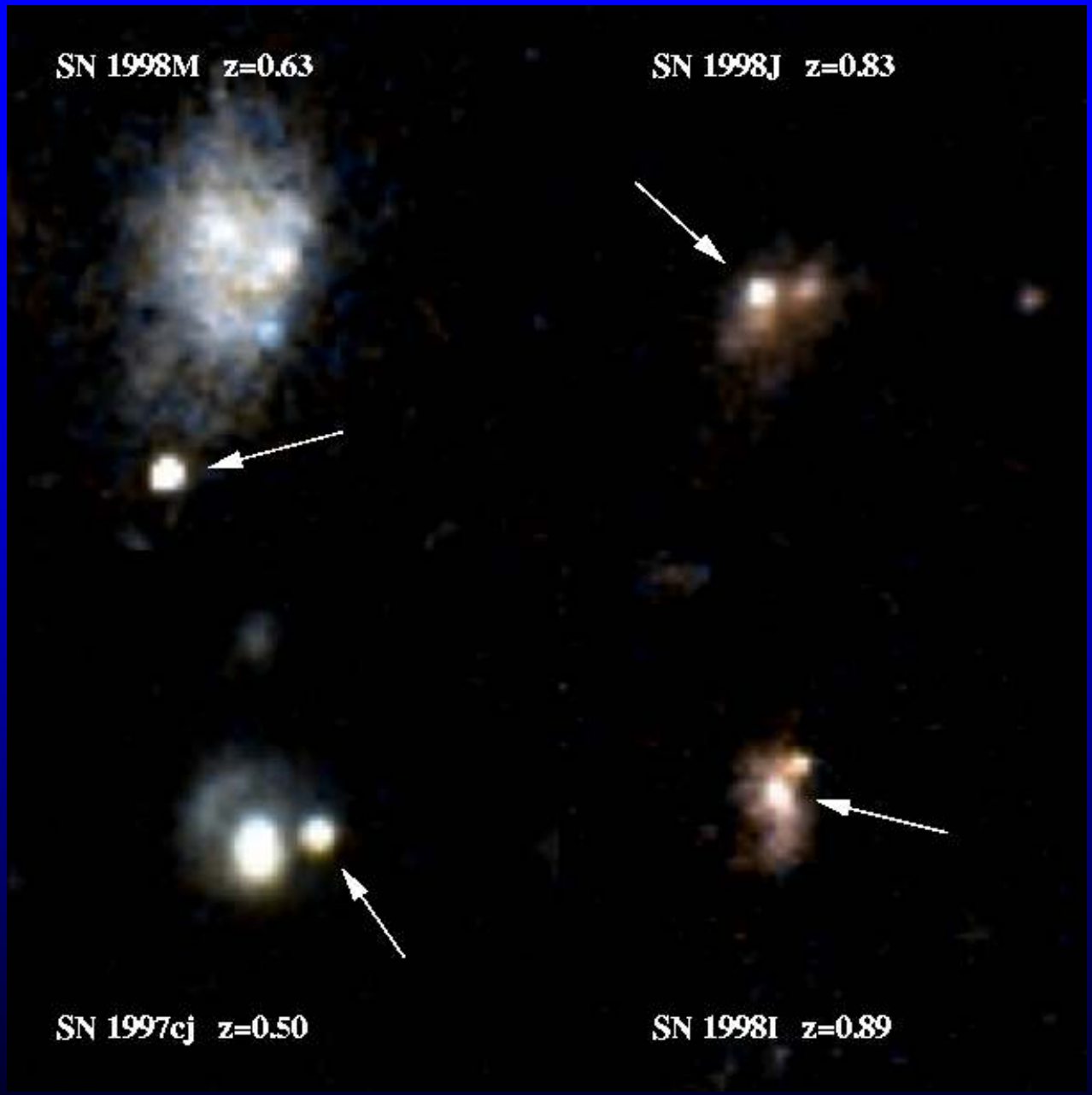
We believe that they all will have the same peak brightness.

So we can use them as “standard candles”.

These enable astronomers to extend distance measurements out to far greater distances

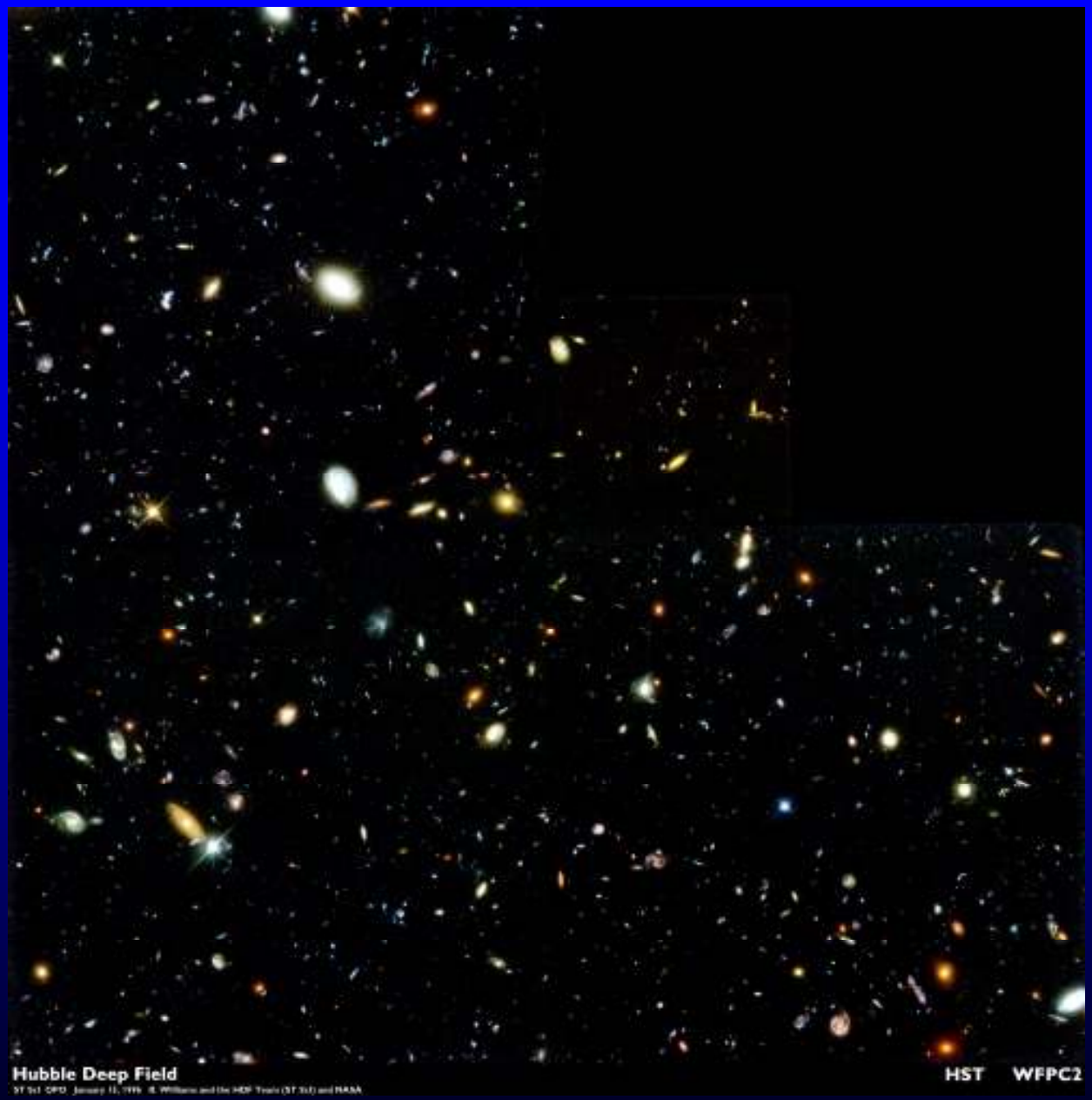


Distant Galaxies



Dark Energy

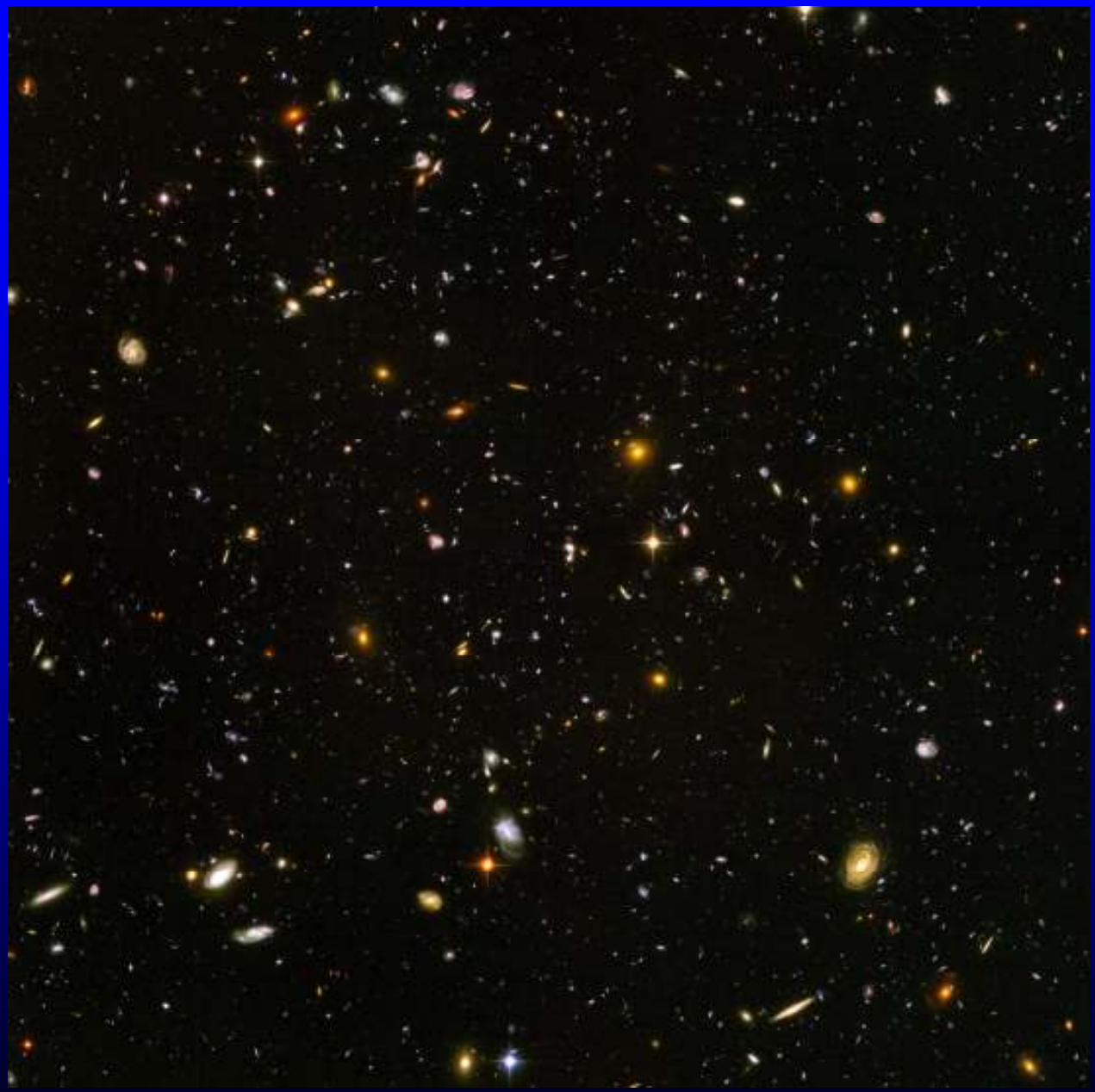
- These observations showed that the Universe is bigger than was expected.
- It appears that some “pressure” called dark energy is making the Universe expand at an ever faster rate!

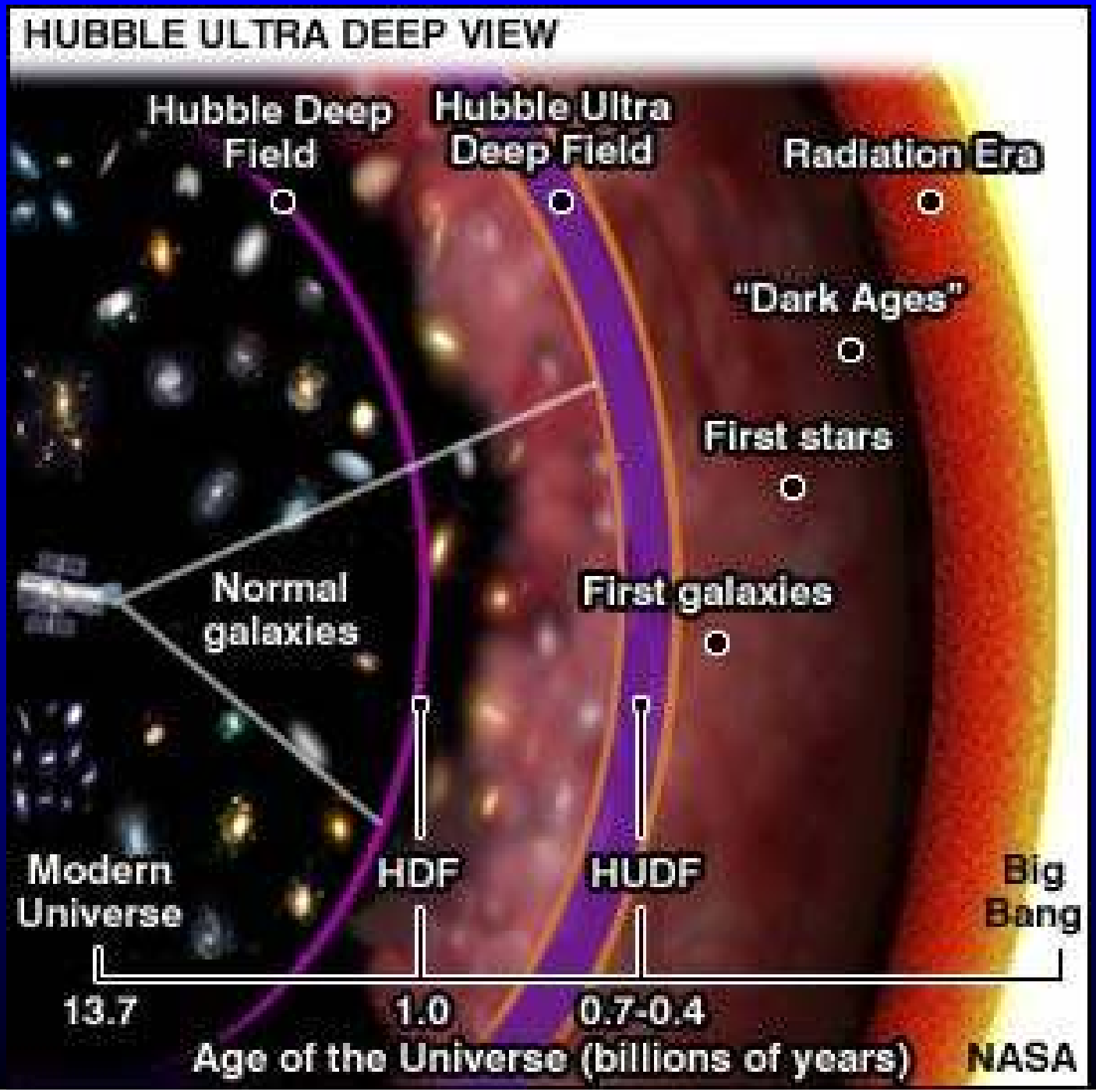


Hubble
Deep Field

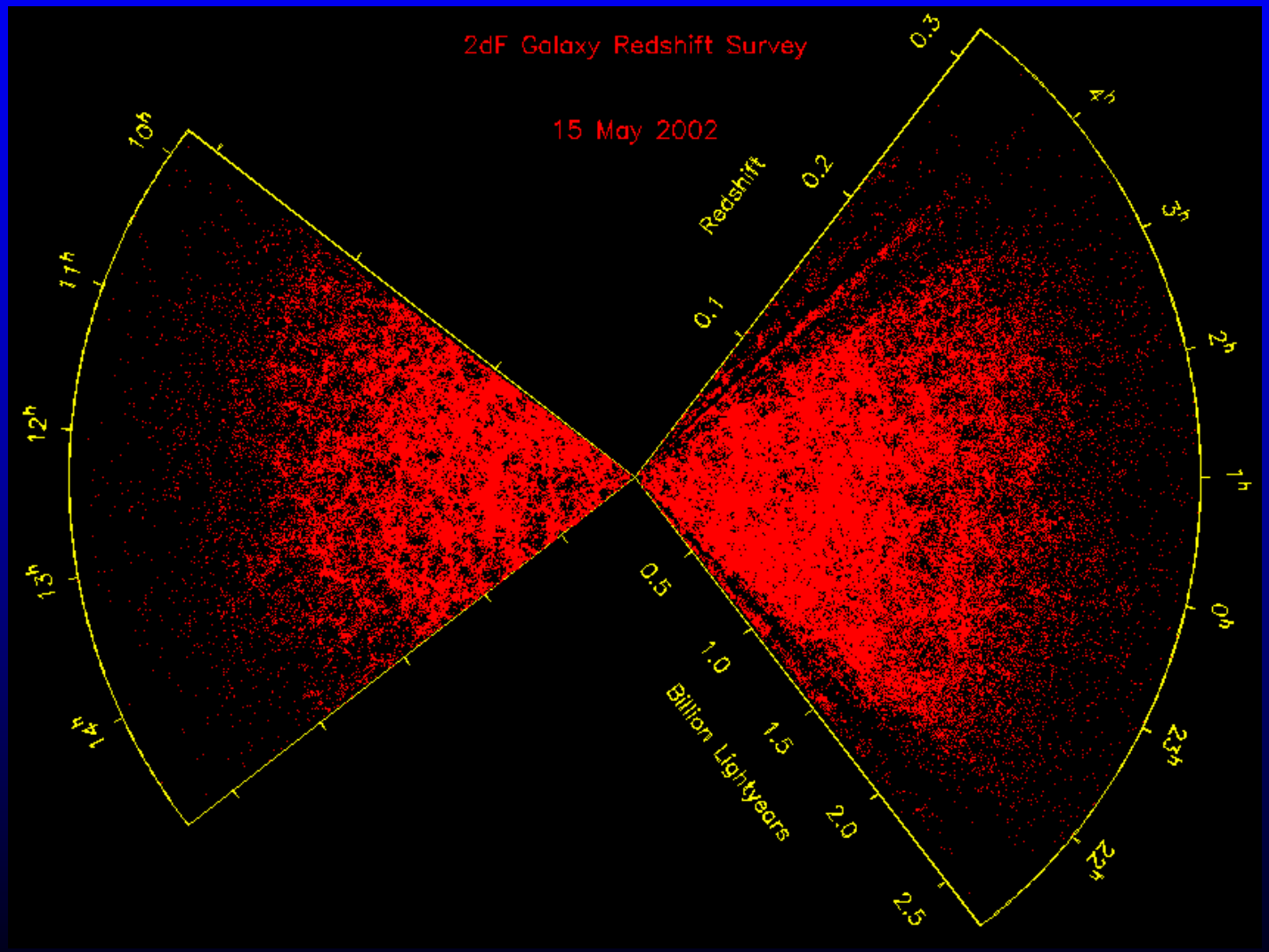
Hubble

Ultra-Deep Field




HUBBLE ULTRA DEEP VIEW
Hubble Deep Field
Hubble Ultra Deep Field
Radiation Era
"Dark Ages"
First stars
First galaxies
Normal galaxies
Modern Universe
HDF
HUDF
Big Bang
13.7
1.0
0.7-0.4
Age of the Universe (billions of years)
NASA

Galaxy Distribution Map

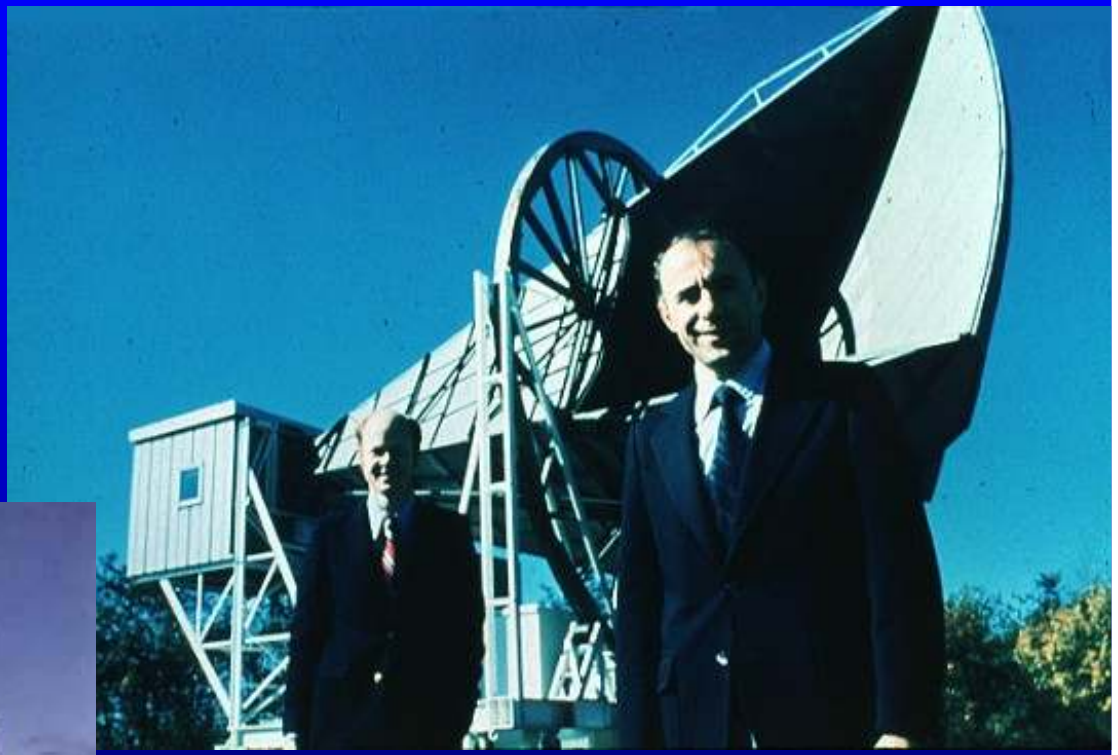


How Far Back in Time can we see?

Observations of the

Cosmic Microwave Background

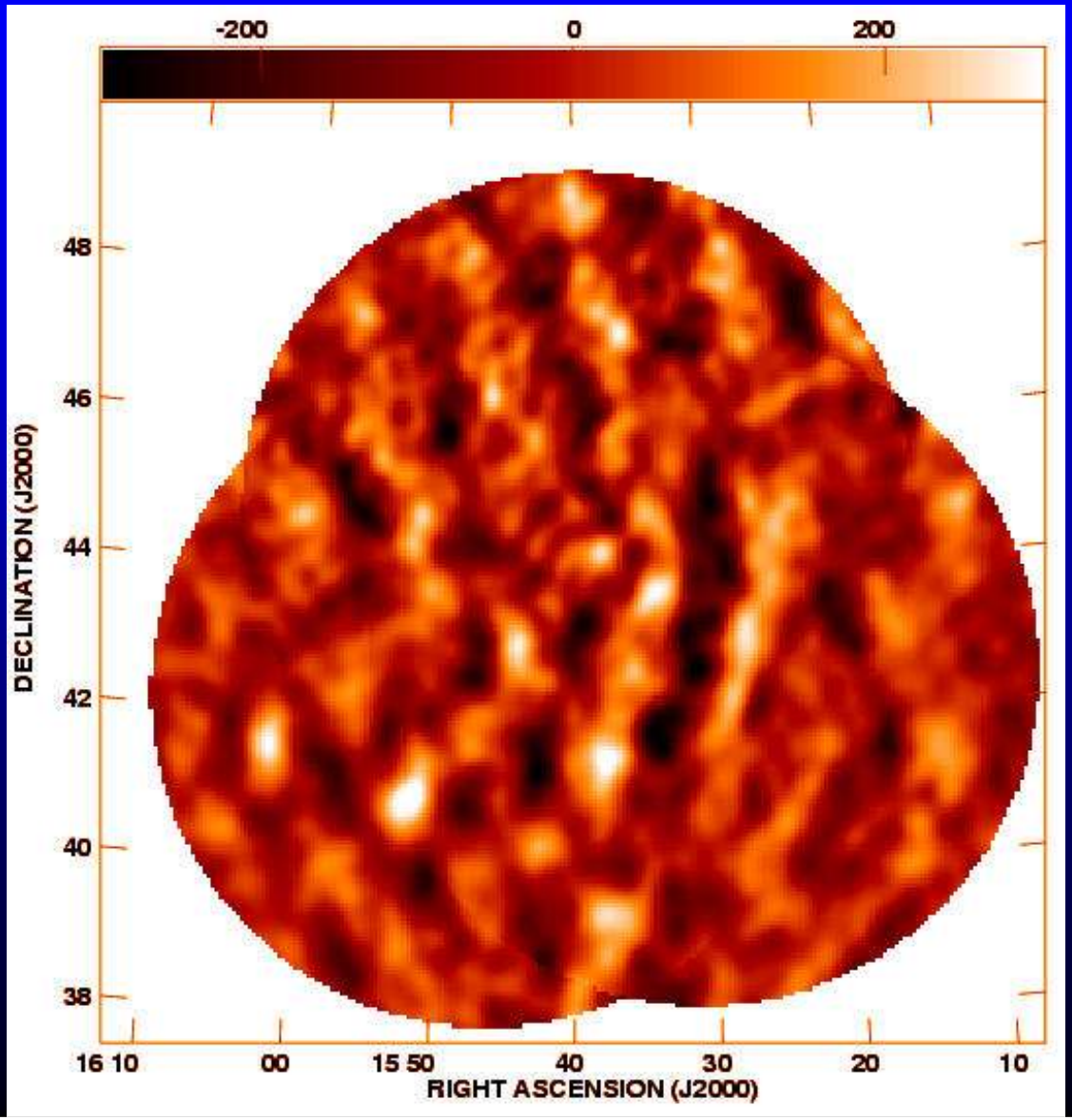
Penzias and Wilson



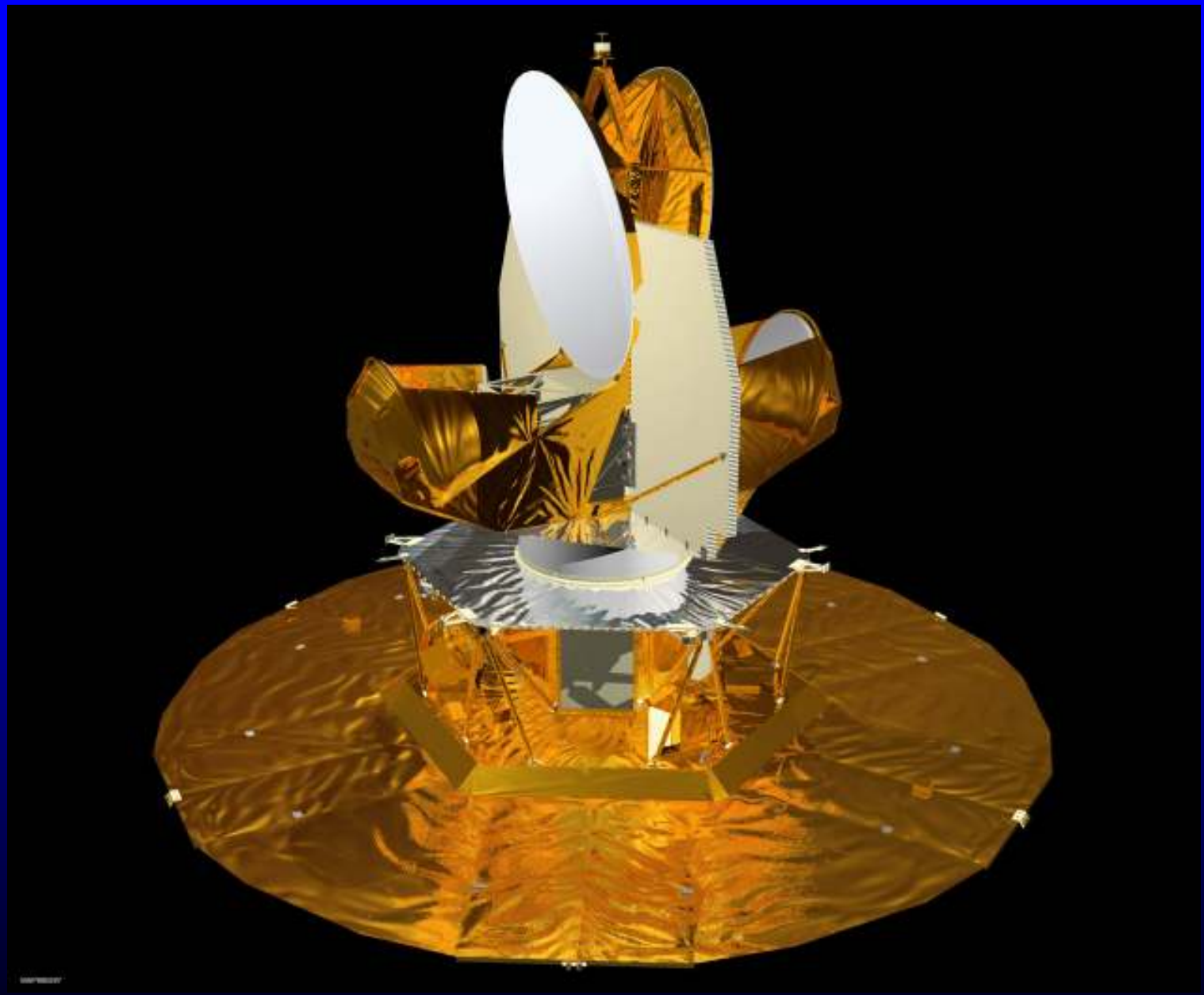
Pigeon Trap

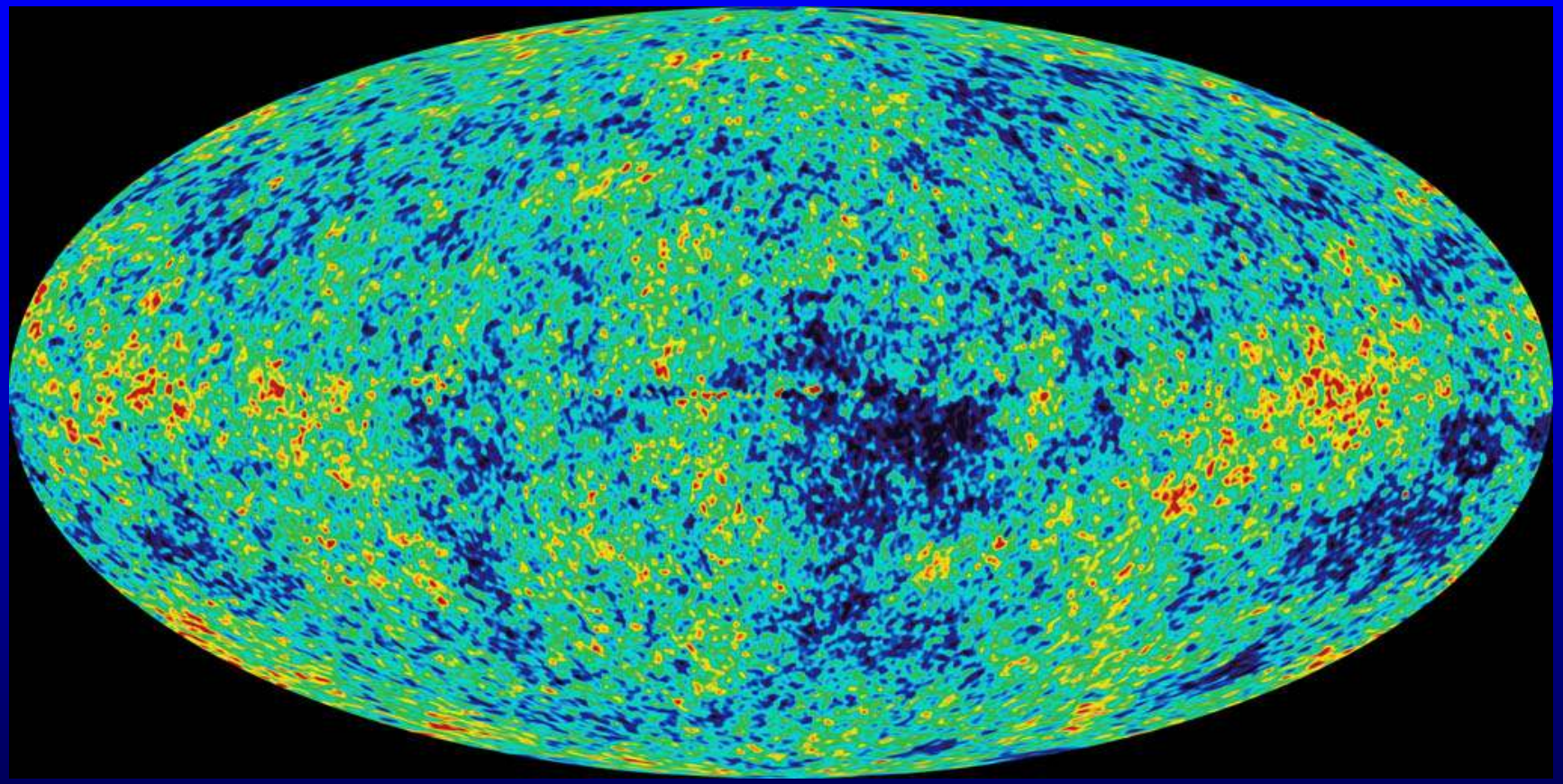
VSA on Mount Teide

VSA Map


-200
0
200
48
46
44
42
40
38
DECLINATION (J2000)
16 10
00
15 50
40
30
20
10
RIGHT ASCENSION (J2000)

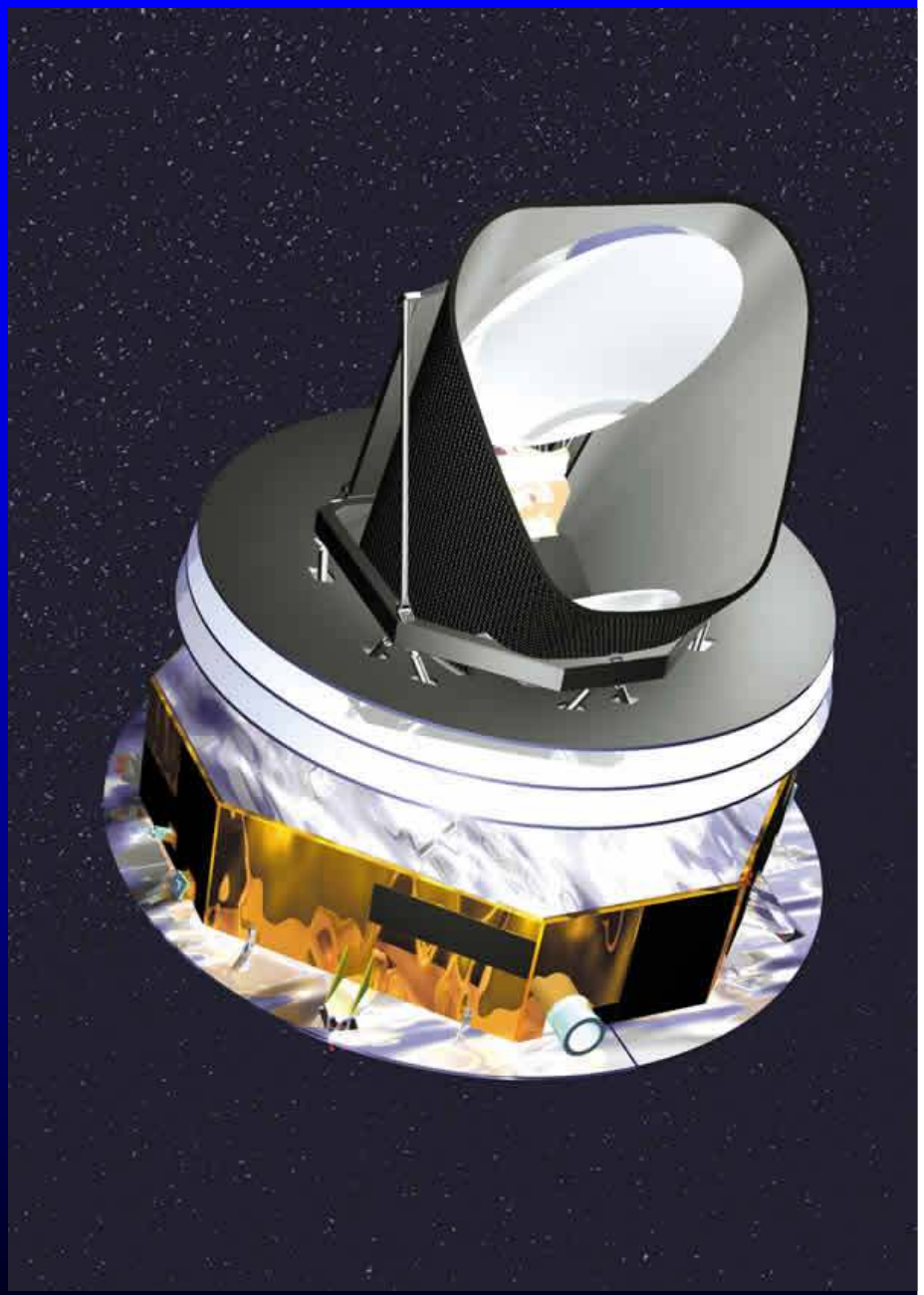
WMAP





Planck Spacecraft

- Launch August 2008

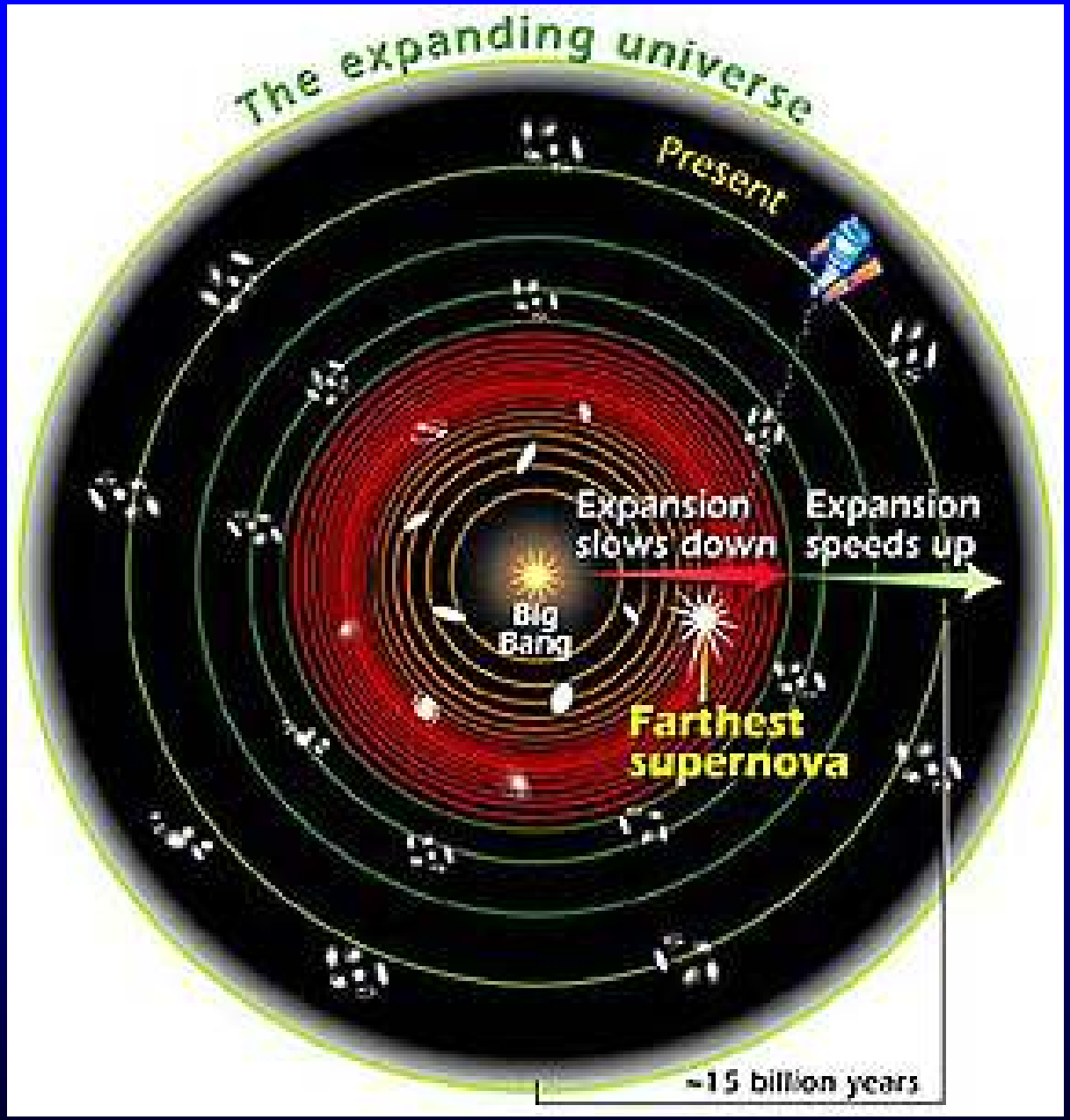


We get a consistent model

- ~4-5 % Normal Matter
- ~23% Dark Matter
- ~73% Dark Energy

- Age of Universe: ~ 13.7 Billion Years

- The pressure produced by the Dark Energy is now making the expansion rate of the Universe INCREASE with time.


The expanding universe
Present
Expansion slows down
Expansion speeds up
Big Bang
Farthest supernova
~15 billion years

The Far Future

- As the clusters of Galaxies move further apart carried ever faster by the expansion of the space between them there will be less and less for astronomers to see.
- We live at the best possible time to learn about the Universe
- I do hope that you will join me in this quest over the next three years.