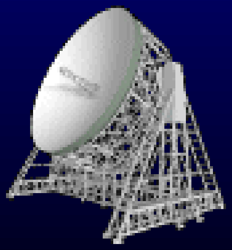
Hubble's Heritage

Ian Morison

Gresham Professor of Astronomy



MANCHESTER 1824
Jodrell Bank Observatory

GRESHAM COLLEGE

The Kepler Mission – first major results.

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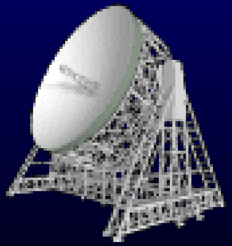
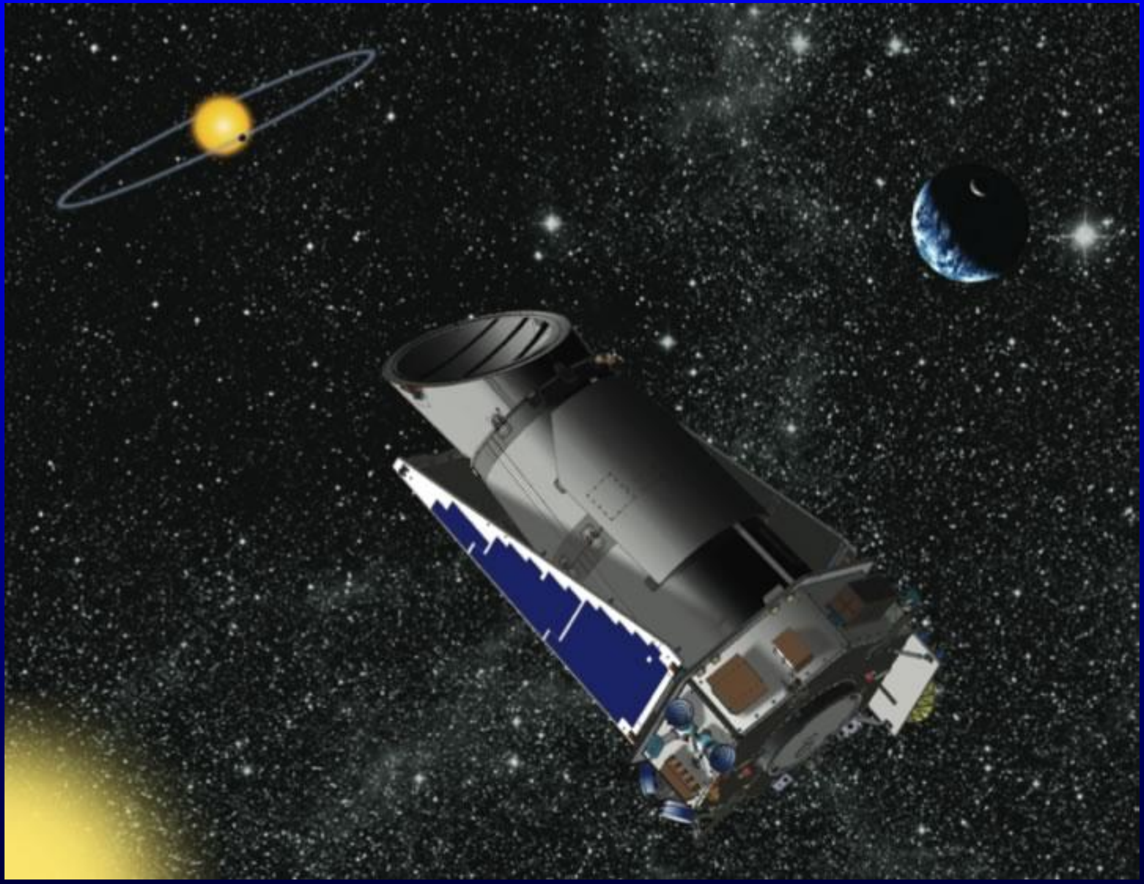
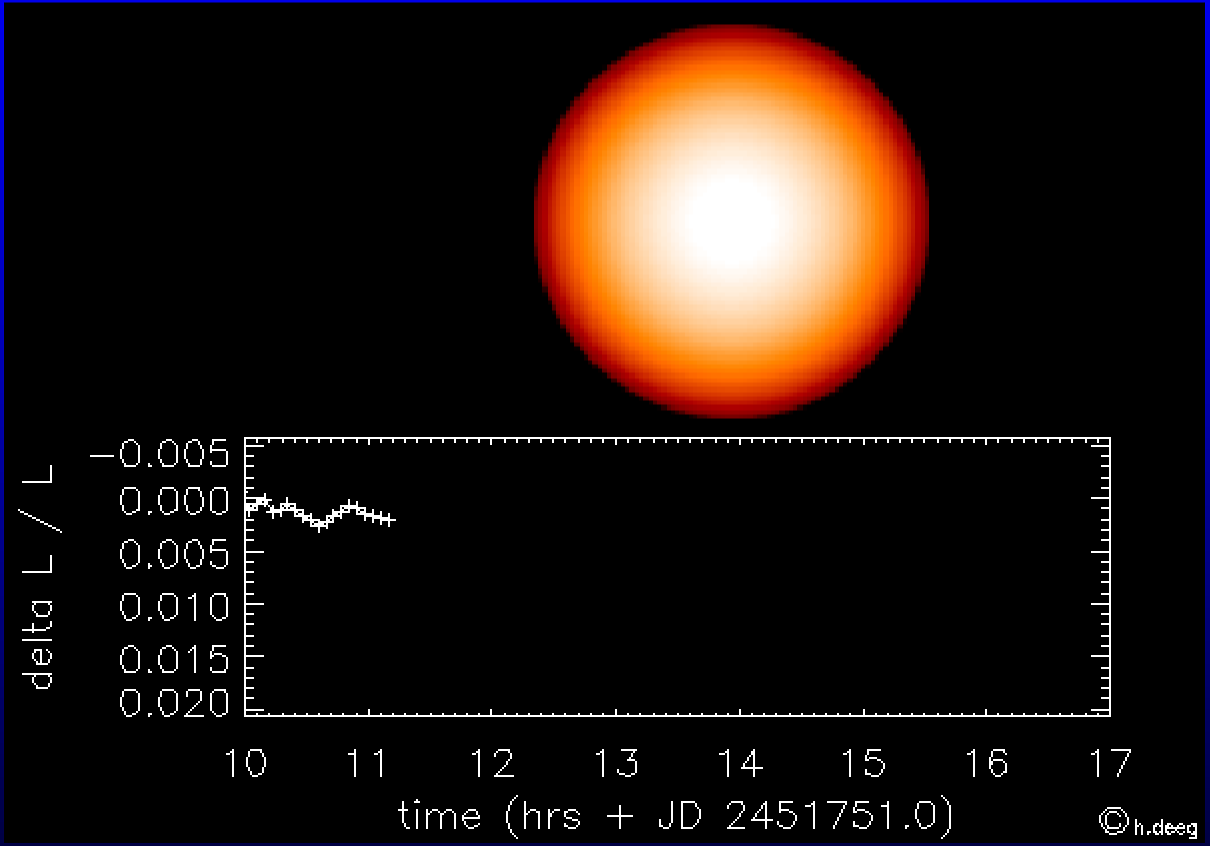


To detect planets transiting their star.



The Kepler Mission

- Will spend 3.5 years observing 10,000 stars.
- It is expected to find between 50 and 640 candidates with periods of roughly one year.
- It should be able to tell us how many planets of what type orbit stars in our galaxy.



delta L / L
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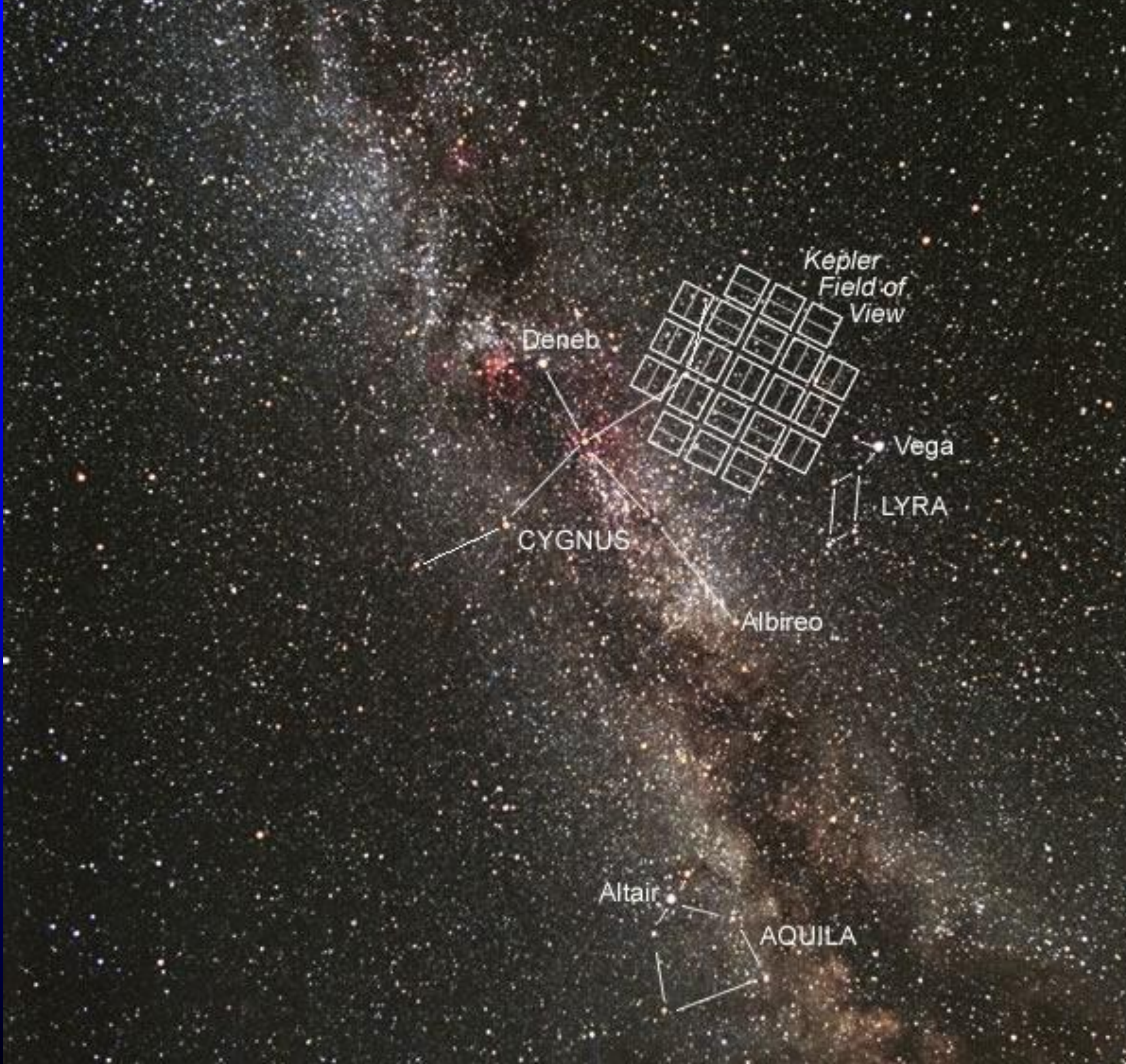
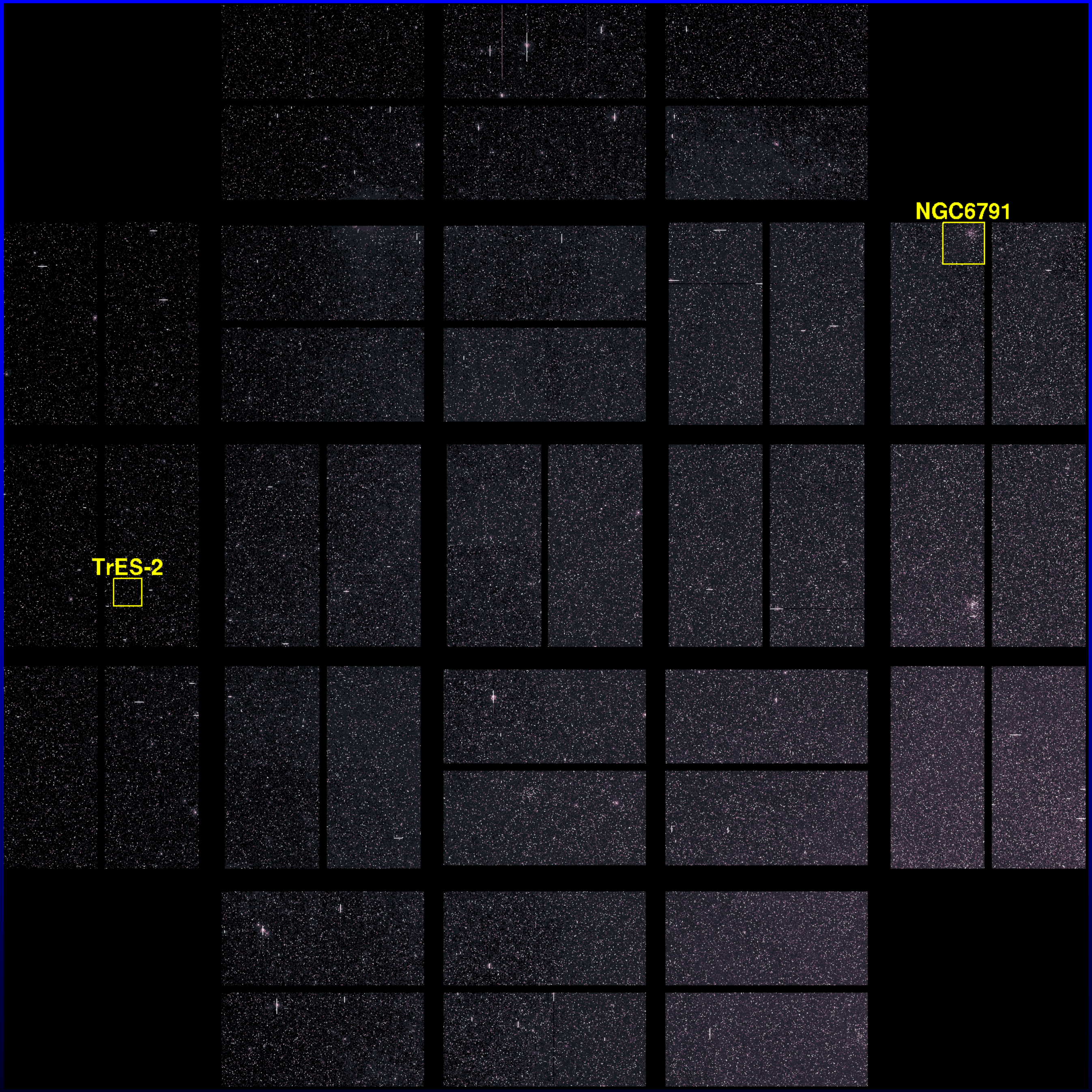
Cygnus search area

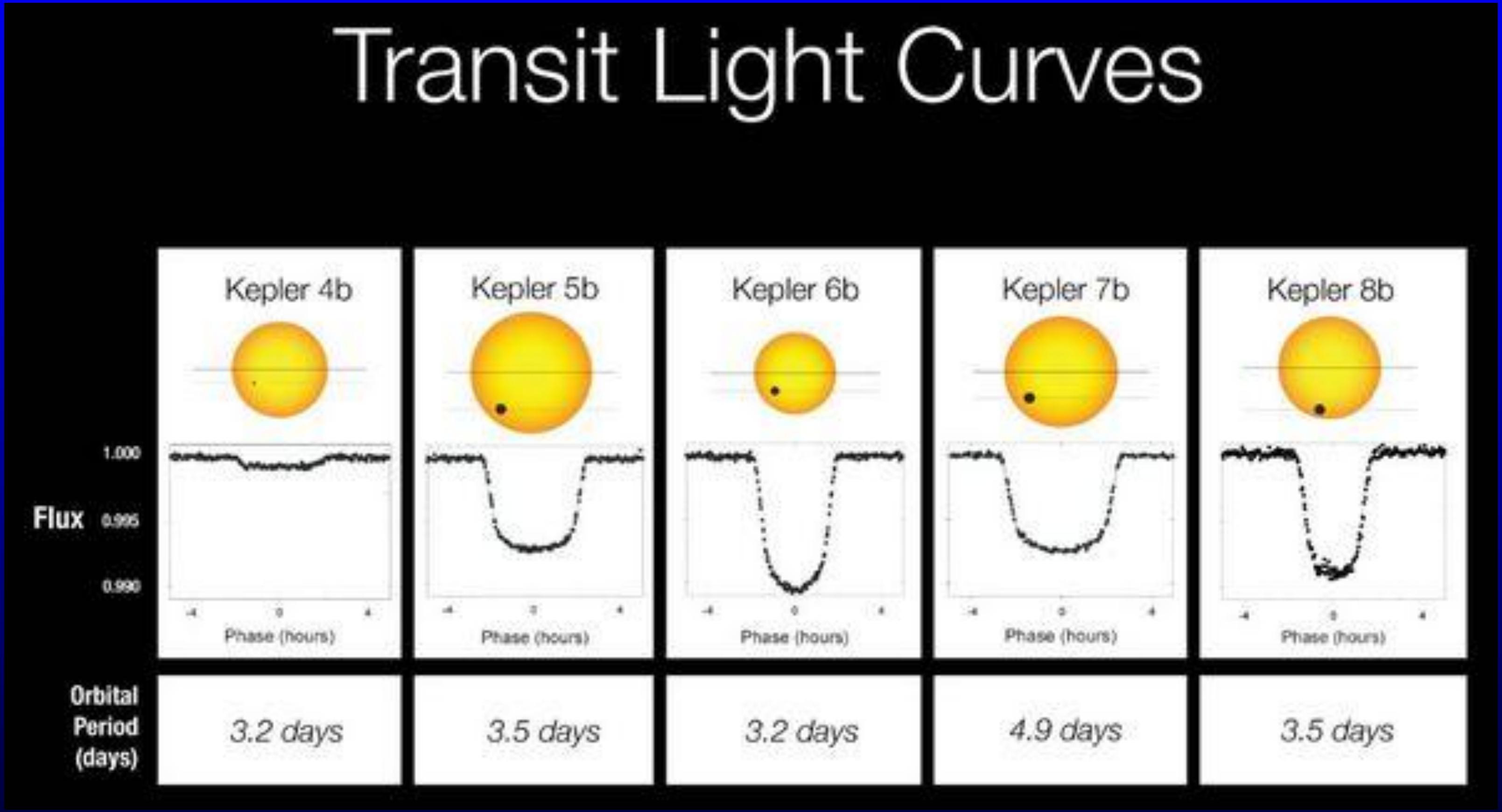



NGC6791
TrES-2

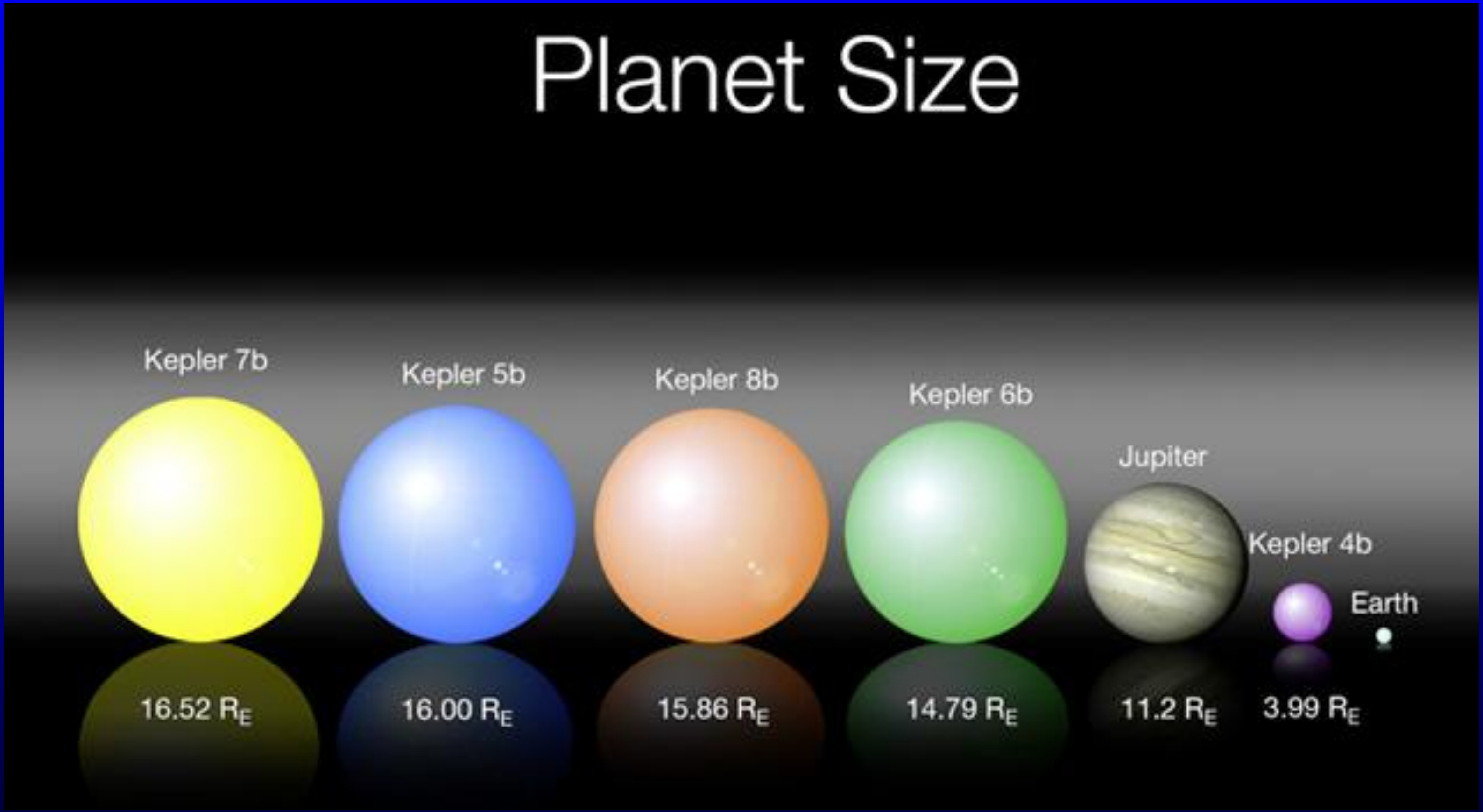
Began observations on May 2nd 2009

So 1 year and 9 months of observations so far.

First 5 detected planets



“Hot Jupiters”

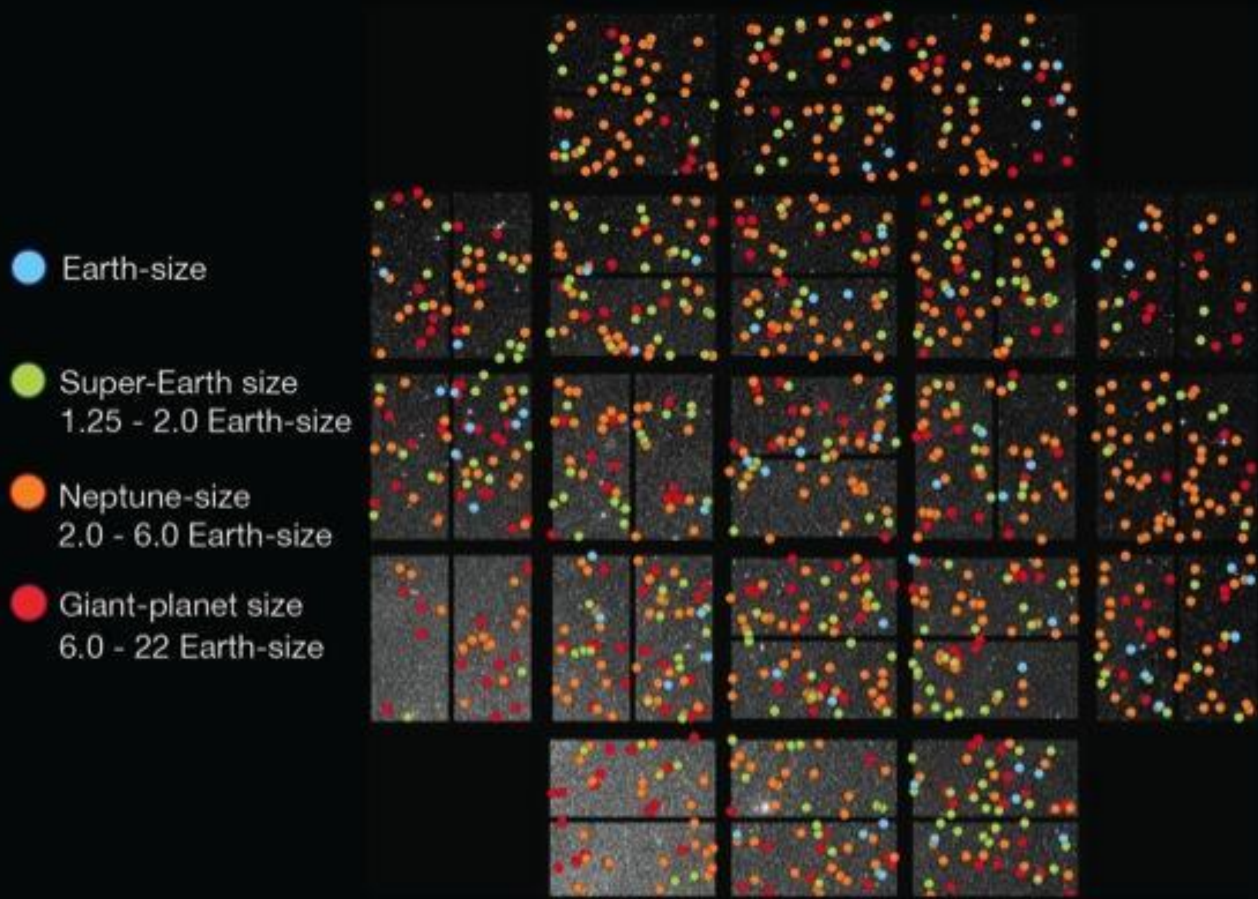


Earth-Sized Transit

Febuary 2nd 2011

- Kepler announced the discovery of 1200 potential planets.
- Based on observations made from May 2nd to Sept 17th 2009 - 137 days.
- 68 of them are potentially “Earth-sized”

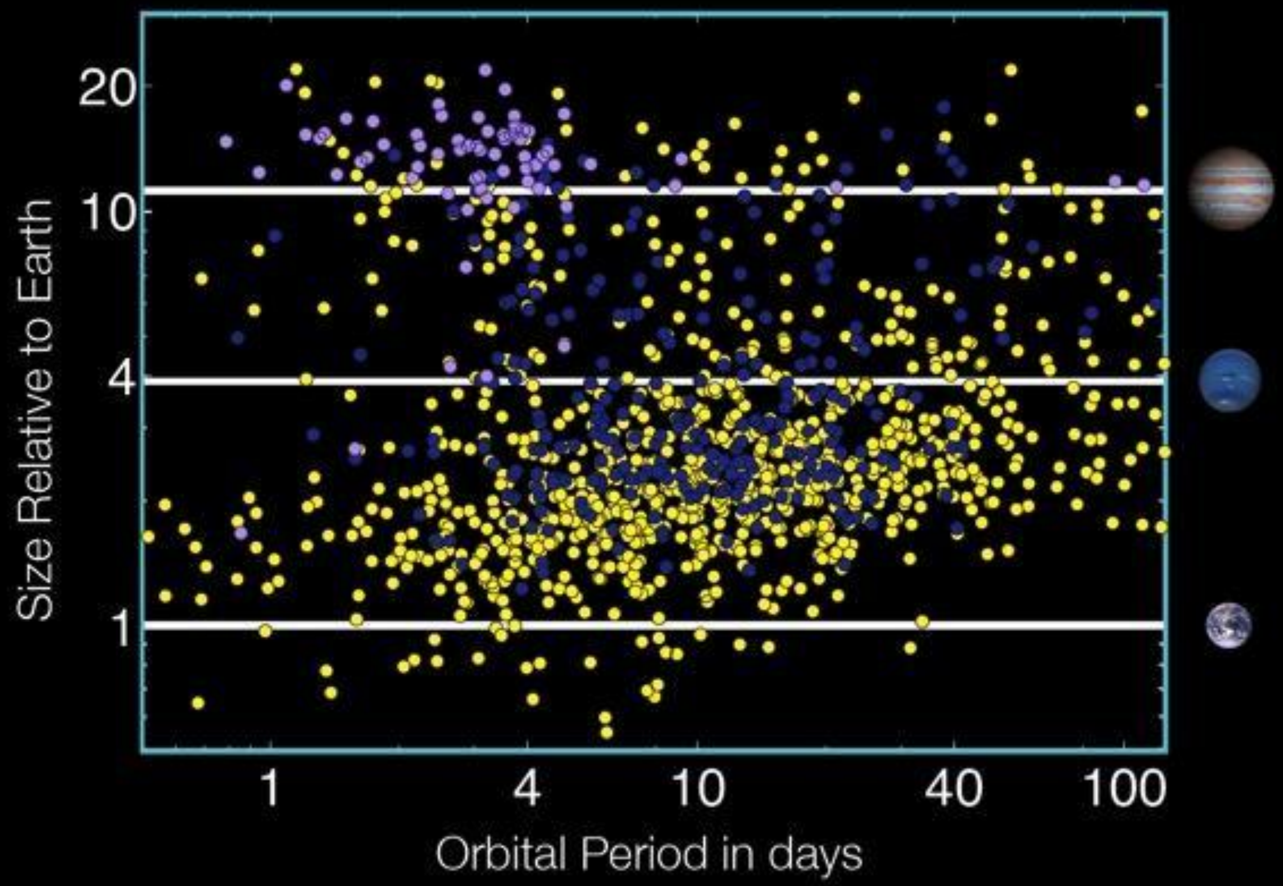
Locations of Kepler Planet Candidates



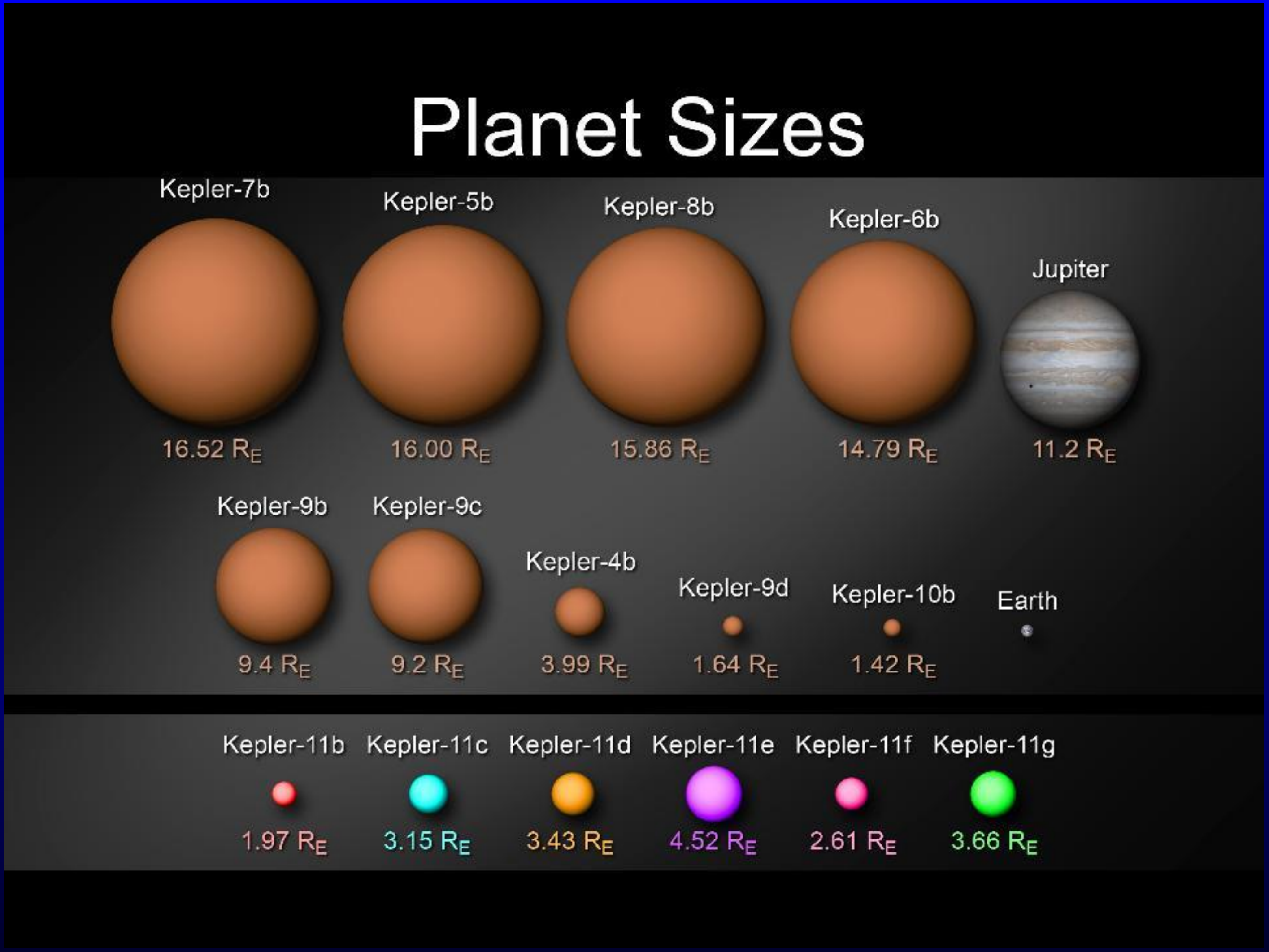
An important point.

- Observation period was 137 days.
- A planet must make at least two transits for a period to be found.
  - Preferably 3, as there could be more than one similar sized planet orbiting the star so two transits could be one each of two different planets.
- So, from this data, there cannot be planets with orbital periods greater than 137 days.

Kepler Candidates as of February 1, 2011



Confirmed Planets



- Habitable “Earth’s” will orbit their Sun-like stars at comparable distances to their star as the Earth does to our Sun.
- So they will have orbital periods comparable to that of our Earth.
- It will take at least ~1 year of data to be analysed to detect a “Goldilocks” planet.

We should not have to wait too long.

Kepler has the observational data in hand!

MANCHESTER 1824
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Hubble's Heritage

Ian Morison

Gresham Professor of Astronomy

Edwin Hubble

- Born 1889.
- Brought up in Wheaton Illinois.
- Excellent both in his academic studies and sports.
- Gained a scholarship to the University of Chicago in 1906.

A Superb Athlete

At Chicago he studied Physics, Astronomy and Mathematics.

But also excelled at sports.

A Rhodes Scholar at Queen's College Oxford

- Supported by Physics Nobel Laureate-to-be Robert Millikan who recommended him as "a man of magnificent physique, admirable scholarship, and worthy and lovable character."

Some Affectations on his return to the USA

- His sister described him: “dressed in a cape, knickers and sported a walking stick. A signet ring graced his little finger, and he was wearing a wristwatch he had won for high jumping”.

Yerkes Observatory

40 inch Alvan Clark Refractor

A Research Student

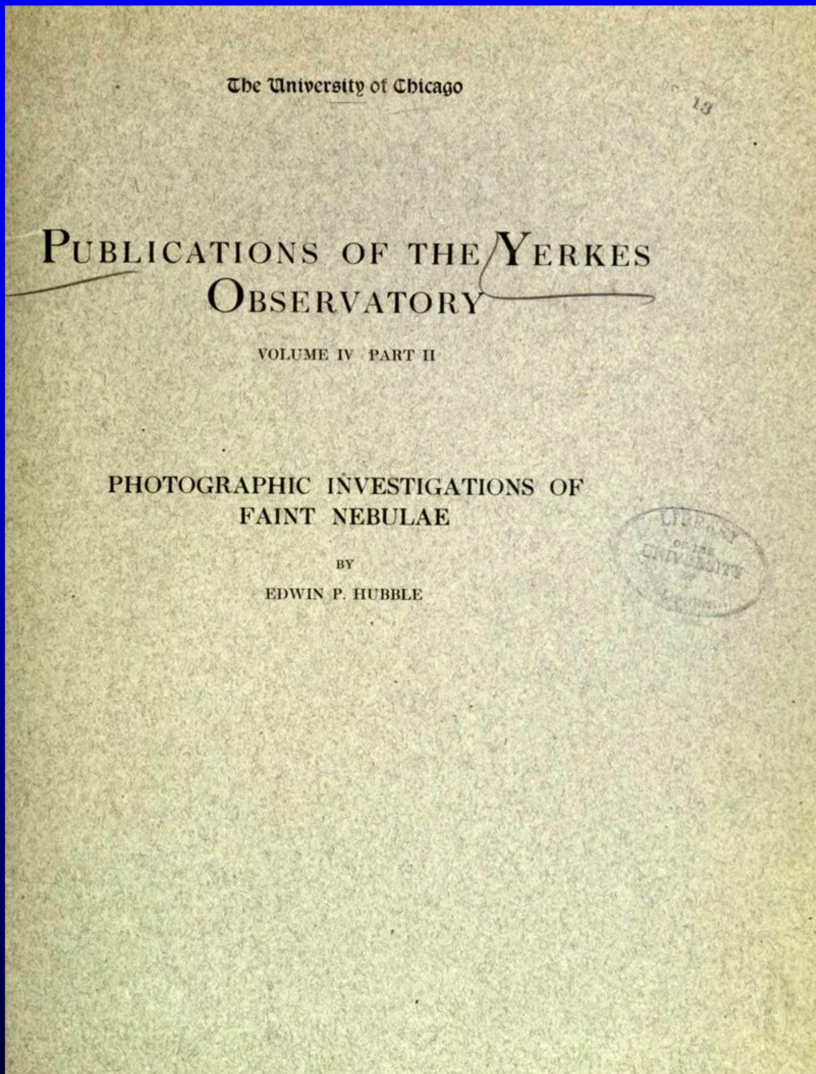
- He used the 24” reflector at Yerkes Observatory to make photographic observations of nebulae.

Hubble's Variable Nebula

- Hubble's first scientific paper was about a variable reflection nebula surrounding the star R Monocerotis.
- Also called Hubble's Cometary Nebula

- Many of the nebulae he studied were then called “White Nebulae” - which we now call galaxies.

Thesis



The University of Chicago

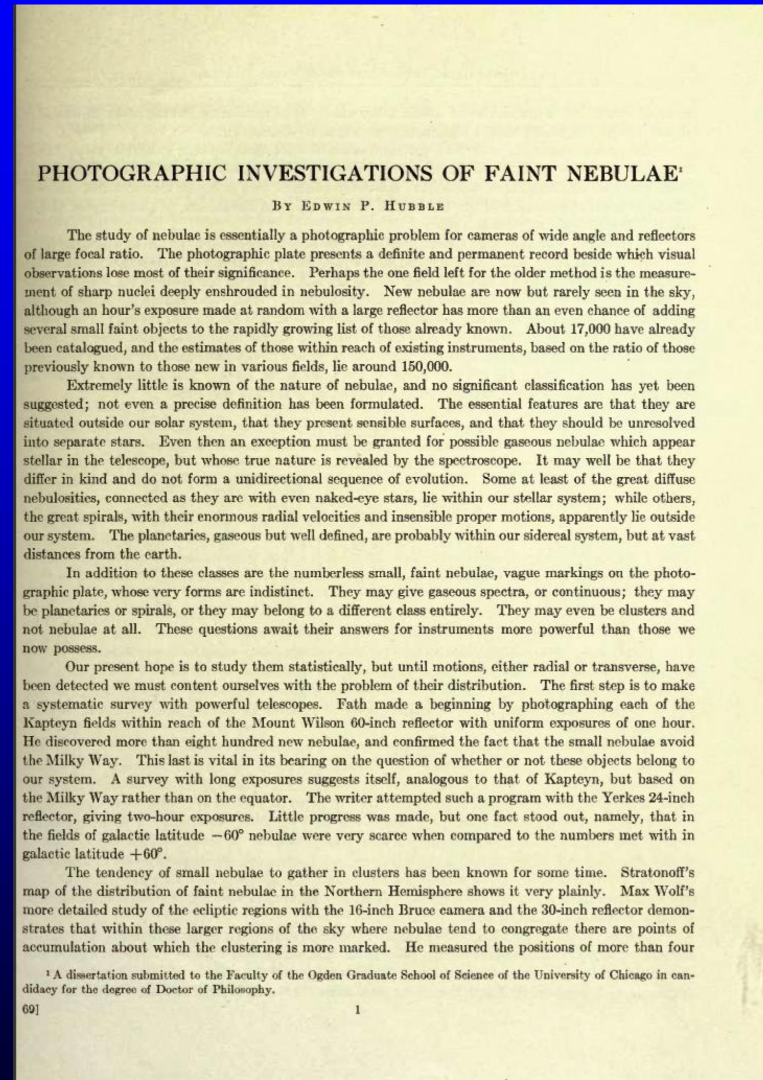
PUBLICATIONS OF THE YERKES OBSERVATORY

VOLUME IV PART II

PHOTOGRAPHIC INVESTIGATIONS OF FAINT NEBULAE

BY

EDWIN P. HUBBLE



PHOTOGRAPHIC INVESTIGATIONS OF FAINT NEBULAE[1]

BY EDWIN P. HUBBLE

The study of nebulae is essentially a photographic problem for cameras of wide angle and reflectors of large focal ratio. The photographic plate presents a definite and permanent record beside which visual observations lose most of their significance. Perhaps the one field left for the older method is the measurement of sharp nuclei deeply enshrouded in nebulosity. New nebulae are now but rarely seen in the sky, although an hour's exposure made at random with a large reflector has more than an even chance of adding several small faint objects to the rapidly growing list of those already known. About 17,000 have already been catalogued, and the estimates of those within reach of existing instruments, based on the ratio of those previously known to those new in various fields, lie around 150,000.

Extremely little is known of the nature of nebulae, and no significant classification has yet been suggested; not even a precise definition has been formulated. The essential features are that they are situated outside our solar system, that they present sensible surfaces, and that they should be unresolved into separate stars. Even then an exception must be granted for possible gaseous nebulae which appear stellar in the telescope, but whose true nature is revealed by the spectroscope. It may well be that they differ in kind and do not form a unidirectional sequence of evolution. Some at least of the great diffuse nebulosities, connected as they are with even naked-eye stars, lie within our stellar system; while others, the great spirals, with their enormous radial velocities and insensible proper motions, apparently lie outside our system. The planetaries, gaseous but well defined, are probably within our sidereal system, but at vast distances from the earth.

In addition to these classes are the numberless small, faint nebulae, vague markings on the photographic plate, whose very forms are indistinct. They may give gaseous spectra, or continuous; they may be planetaries or spirals, or they may belong to a different class entirely. They may even be clusters and not nebulae at all. These questions await their answers for instruments more powerful than those we now possess.

Our present hope is to study them statistically, but until motions, either radial or transverse, have been detected we must content ourselves with the problem of their distribution. The first step is to make a systematic survey with powerful telescopes. Fath made a beginning by photographing each of the Kapteyn fields within reach of the Mount Wilson 60-inch reflector with uniform exposures of one hour. He discovered more than eight hundred new nebulae, and confirmed the fact that the small nebulae avoid the Milky Way. This last is vital in its bearing on the question of whether or not these objects belong to our system. A survey with long exposures suggests itself, analogous to that of Kapteyn, but based on the Milky Way rather than on the equator. The writer attempted such a program with the Yerkes 24-inch reflector, giving two-hour exposures. Little progress was made, but one fact stood out, namely, that in the fields of galactic latitude $-60°$ nebulae were very scarce when compared to the numbers met with in galactic latitude $+60°$.

The tendency of small nebulae to gather in clusters has been known for some time. Stratonoff's map of the distribution of faint nebulae in the Northern Hemisphere shows it very plainly. Max Wolf's more detailed study of the ecliptic regions with the 16-inch Bruce camera and the 30-inch reflector demonstrates that within these larger regions of the sky where nebulae tend to congregate there are points of accumulation about which the clustering is more marked. He measured the positions of more than four

[1] A dissertation submitted to the Faculty of the Ogden Graduate School of Science of the University of Chicago in candidacy for the degree of Doctor of Philosophy.

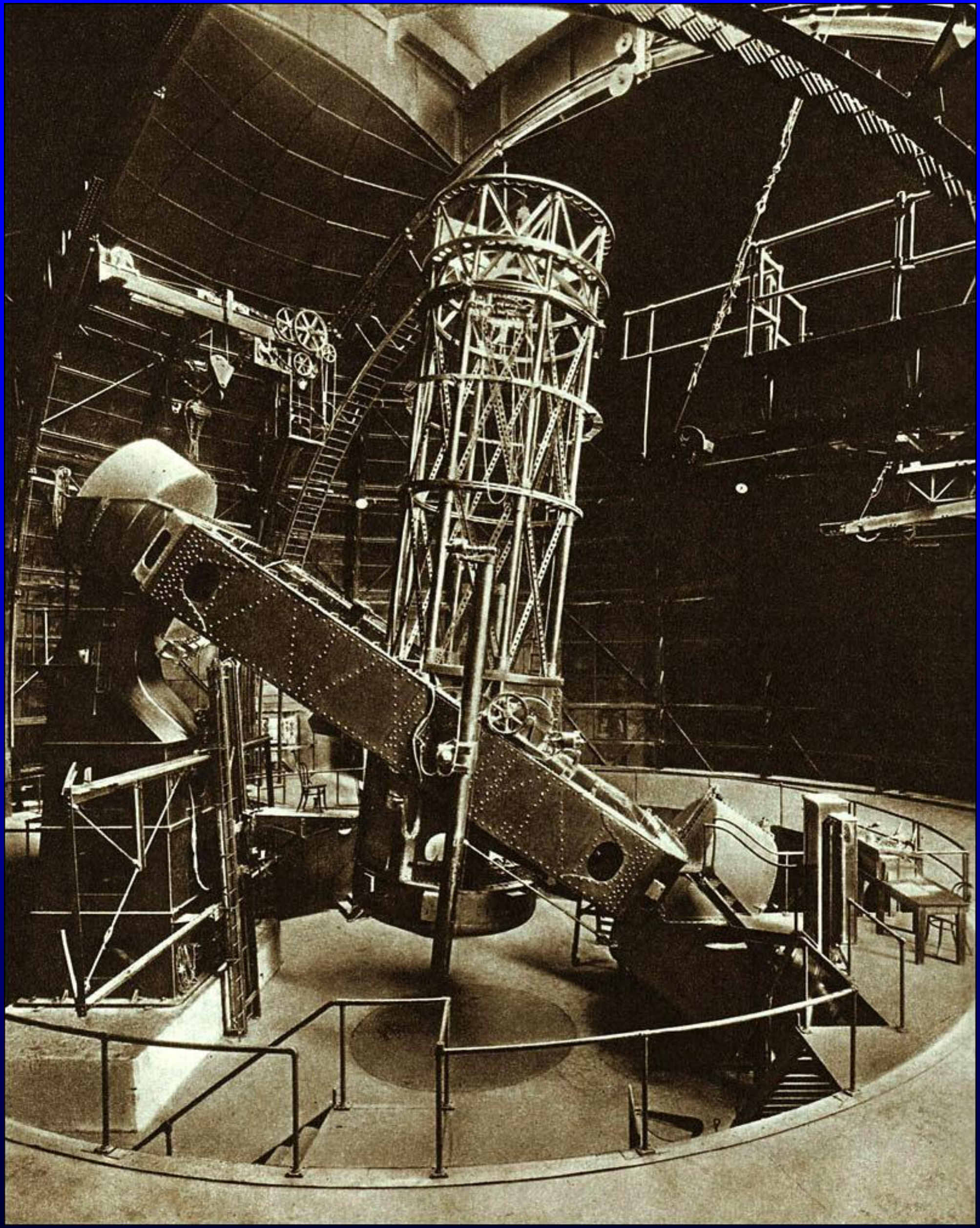
- Immediately following his PhD Viva he enlisted in the army and turned down an offer to join the George Ellery Hale at the Mt Wilson Observatory.

- His reply to Hale’s offer:

  "Regret cannot accept your invitation. Am off to the war."

The Hooker 100” Telescope at Mt Wilson

- Hubble joined Hale after his war service and stayed for the whole of his career.



A fundamental question of the time.

White Nebula – were they within or beyond our Milky Way?

Harlow Shapely

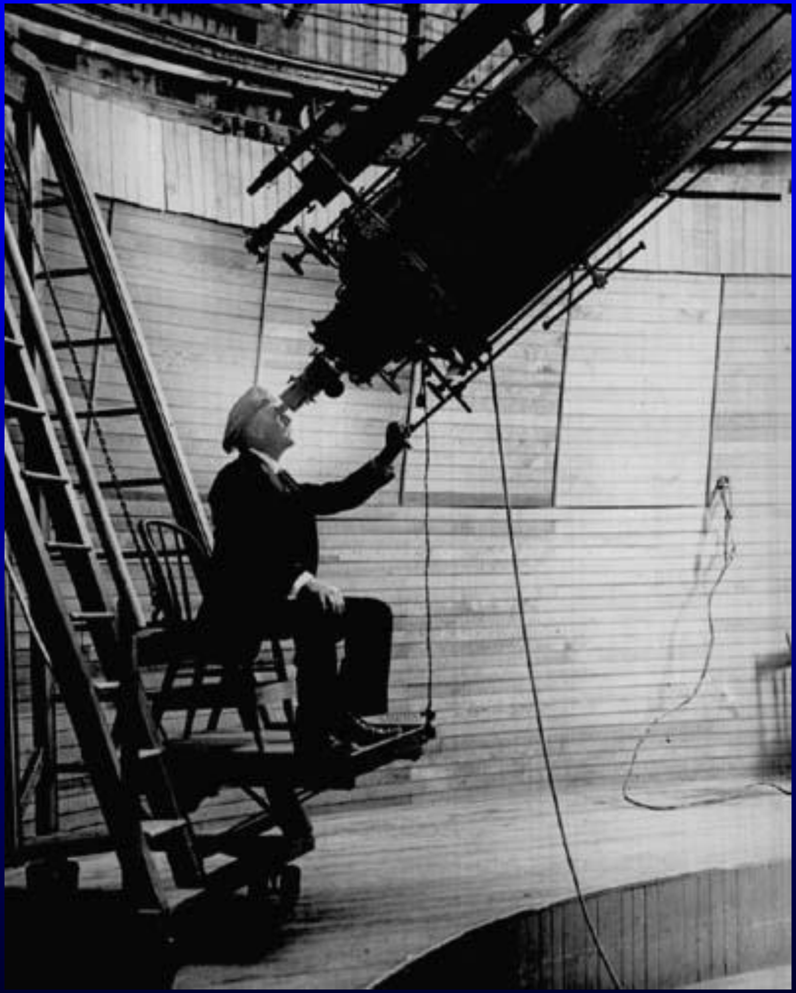
- Harlow Shapely was a highly respected astronomer who had measured the size of our Milky Way Galaxy and the location of the Sun within it.

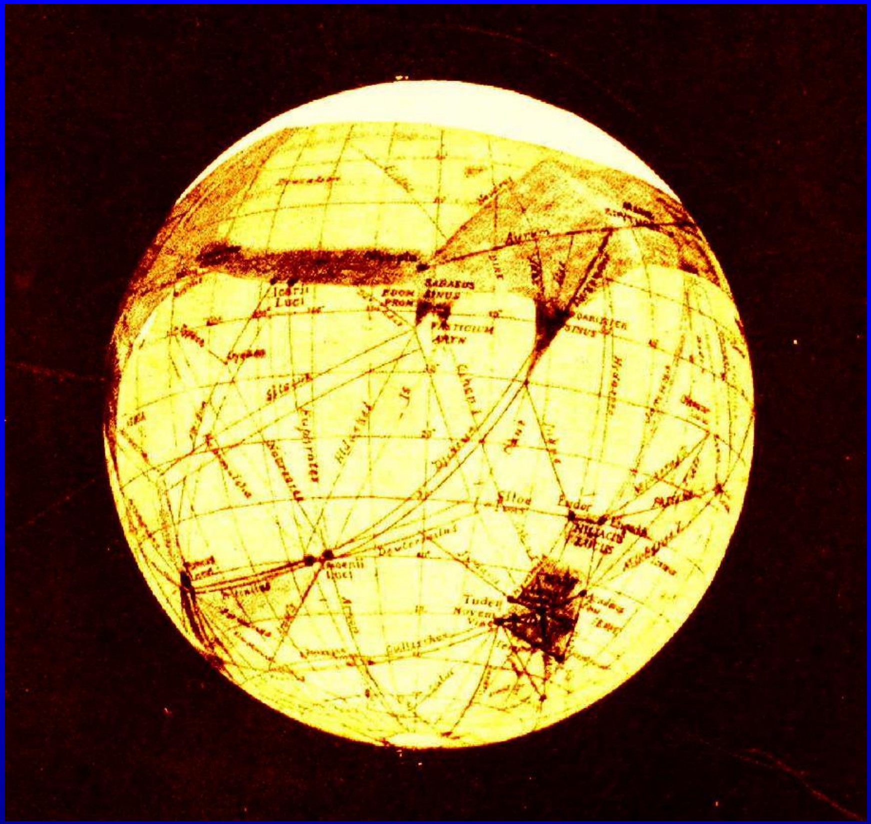
- He had observed novae in the white nebulae and pointed out that, if they were distant, the novae would have to be impossibly bright.

Lowell Observatory

24 inch Alvan Clark Refractor

Percival Lowell





Vesto Slipher

- Vesto Slipher had photographed the spectrum of M31, the Andromeda Nebula and found it to be approaching us at a speed of ~ 300 km/sec. (Assuming that the shift in the spectral lines was due to the Doppler shift.)

- This was far higher than any object known to be within the Milky Way.

A Dilemma!

- To resolve this problem what was needed was a direct measurement of the distance to one of these white nebulae.

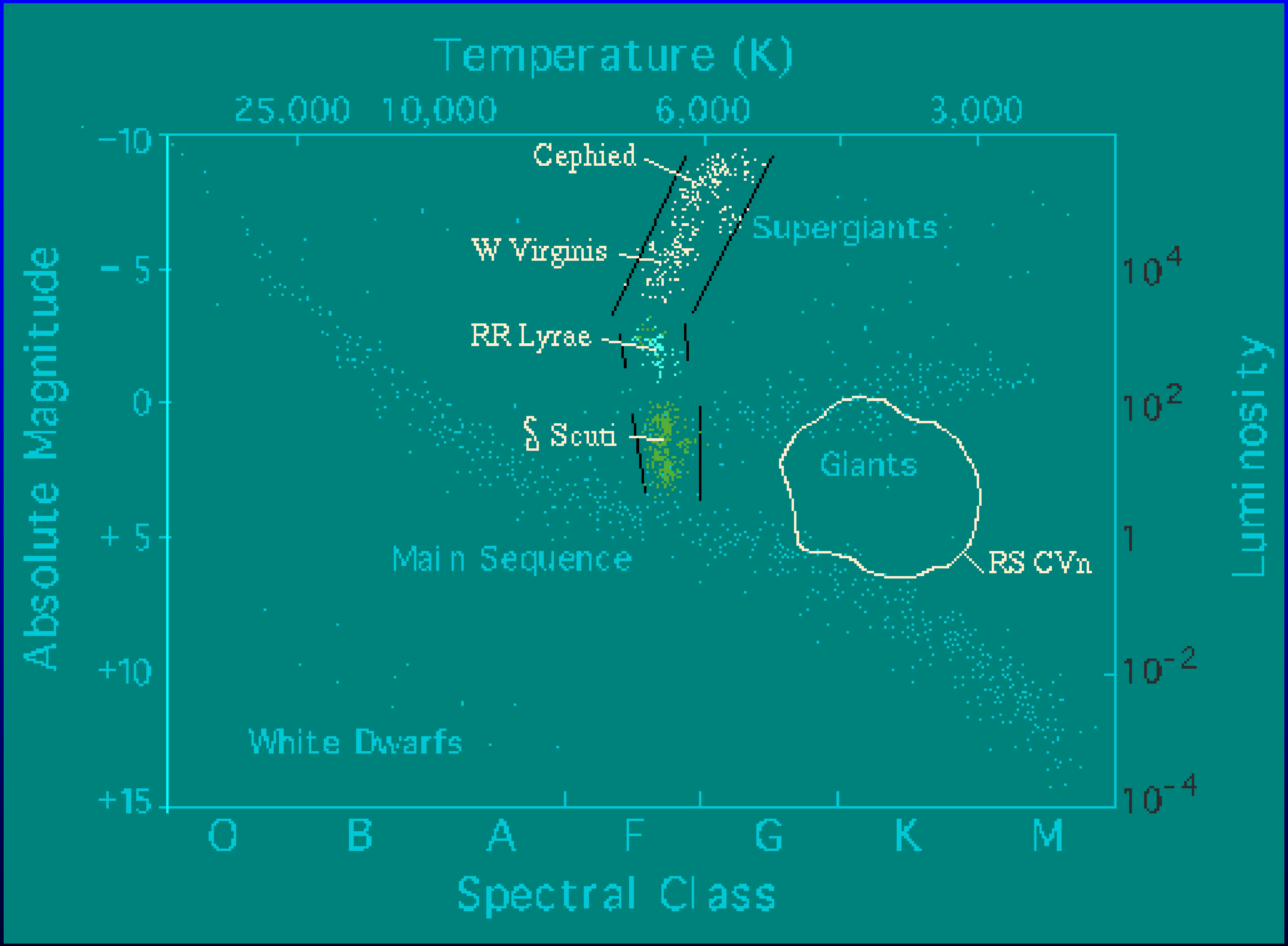
- How could this be done?

Delta Cepheus

- Nearly two hundred years ago, the English astronomer John Goodricke discovered a new type of variable star in the constellation Cepheus, called delta Cepheid.

- The star brightness varies regularly with period 5 days, 8 hours and 48 minutes.

Where they lie in the HR diagram

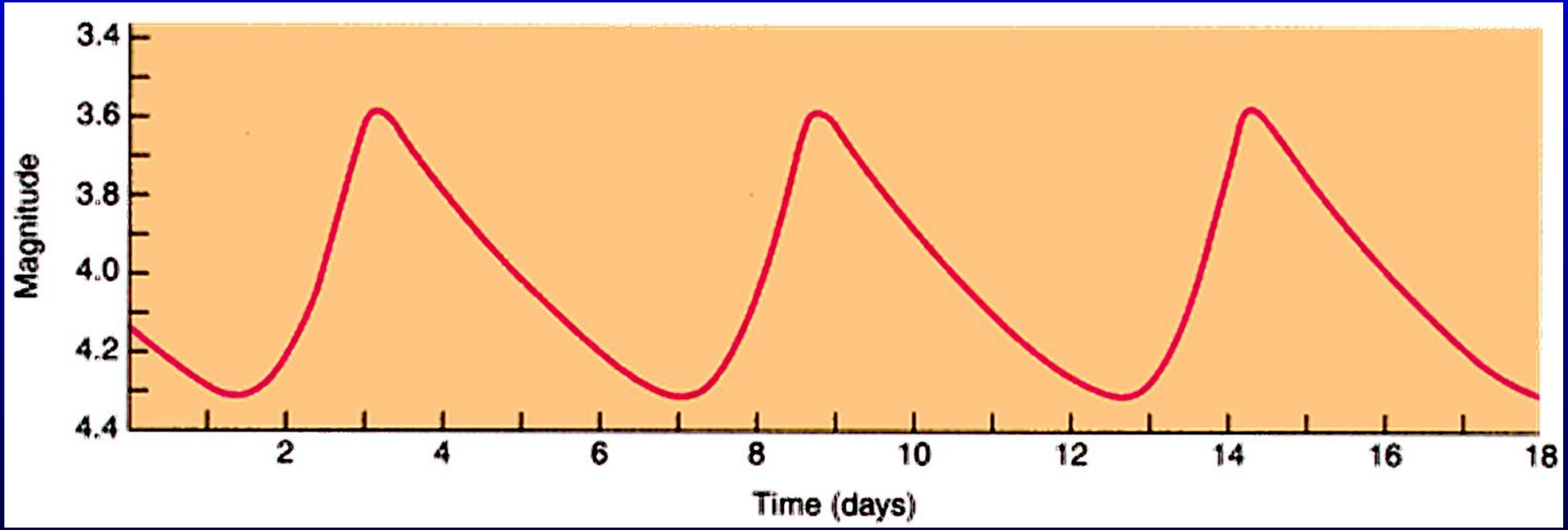


Henrietta Leavitt 1868 - 1921

- She joined the Harvard Observatory in 1895 – at 30 cents per hour - and became head of the stellar photometry department.
- Discovered 2400 variable stars – half of those then known.

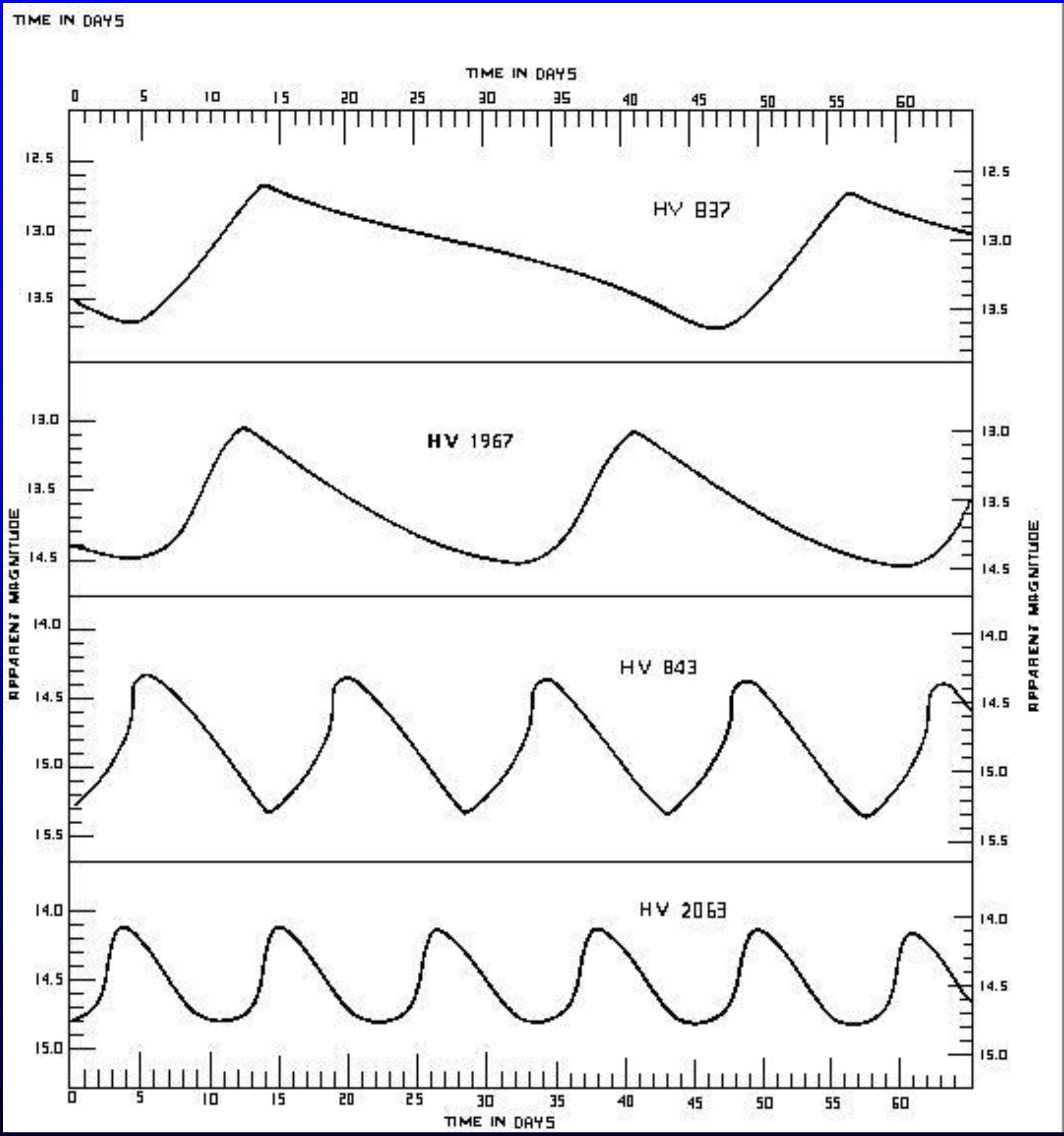
The Cepheid Variables

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



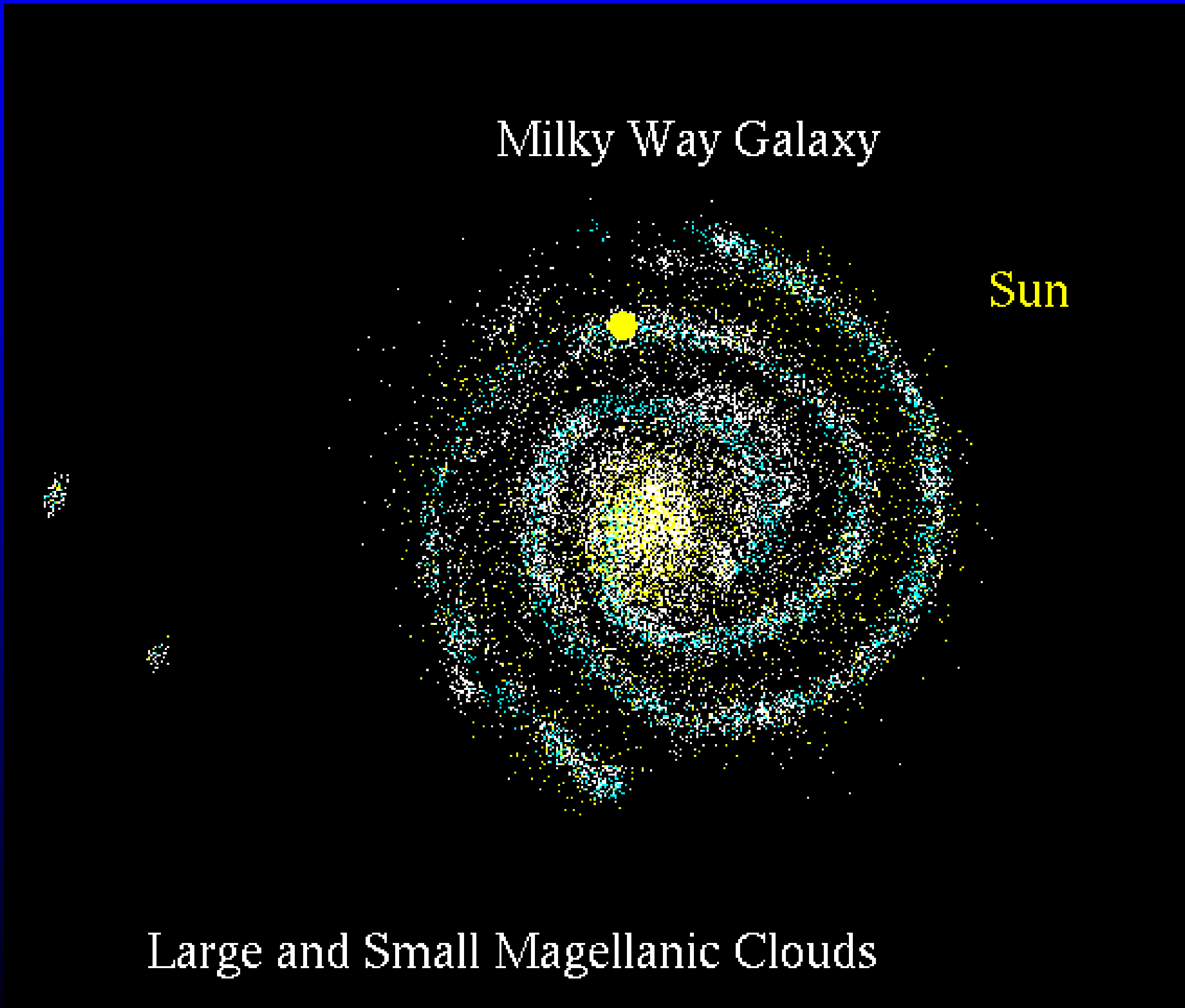
Some Lightcurves

- She plotted the light curves of these Cepheid variable stars.



The Magellanic Clouds

- Henrietta Leavitt observed many of these Cepheid variable stars in the Small Magellanic Cloud.
- These would all be at essentially the same distance.



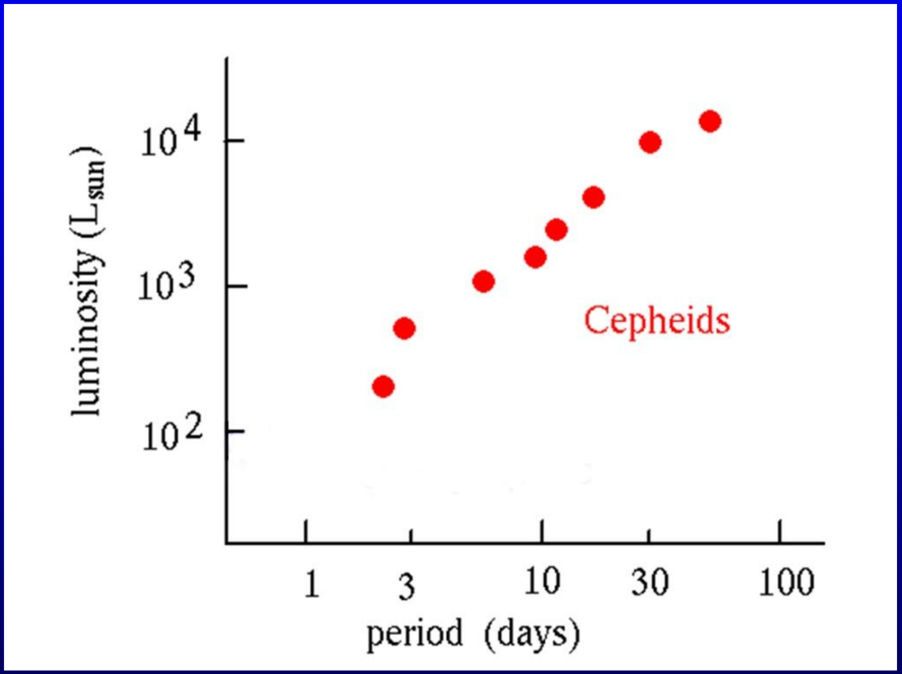
Arequipa Observatory, Peru

24" Bruce Refractor

The Period-Luminosity relationship

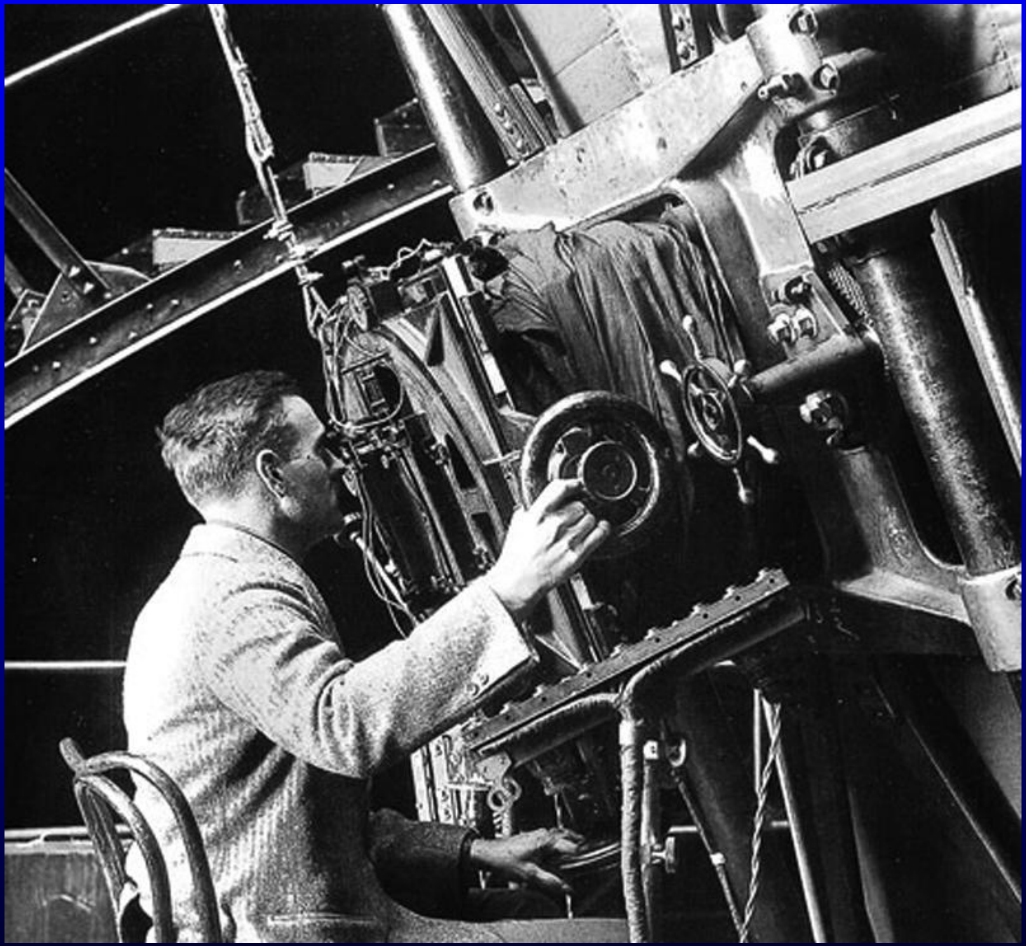
- She observed that the period was related to the luminosity.

- This gave a way of measuring distances to any “Nebula” in which a Cepheid variable could be seen.



M31, The Andromeda Nebula

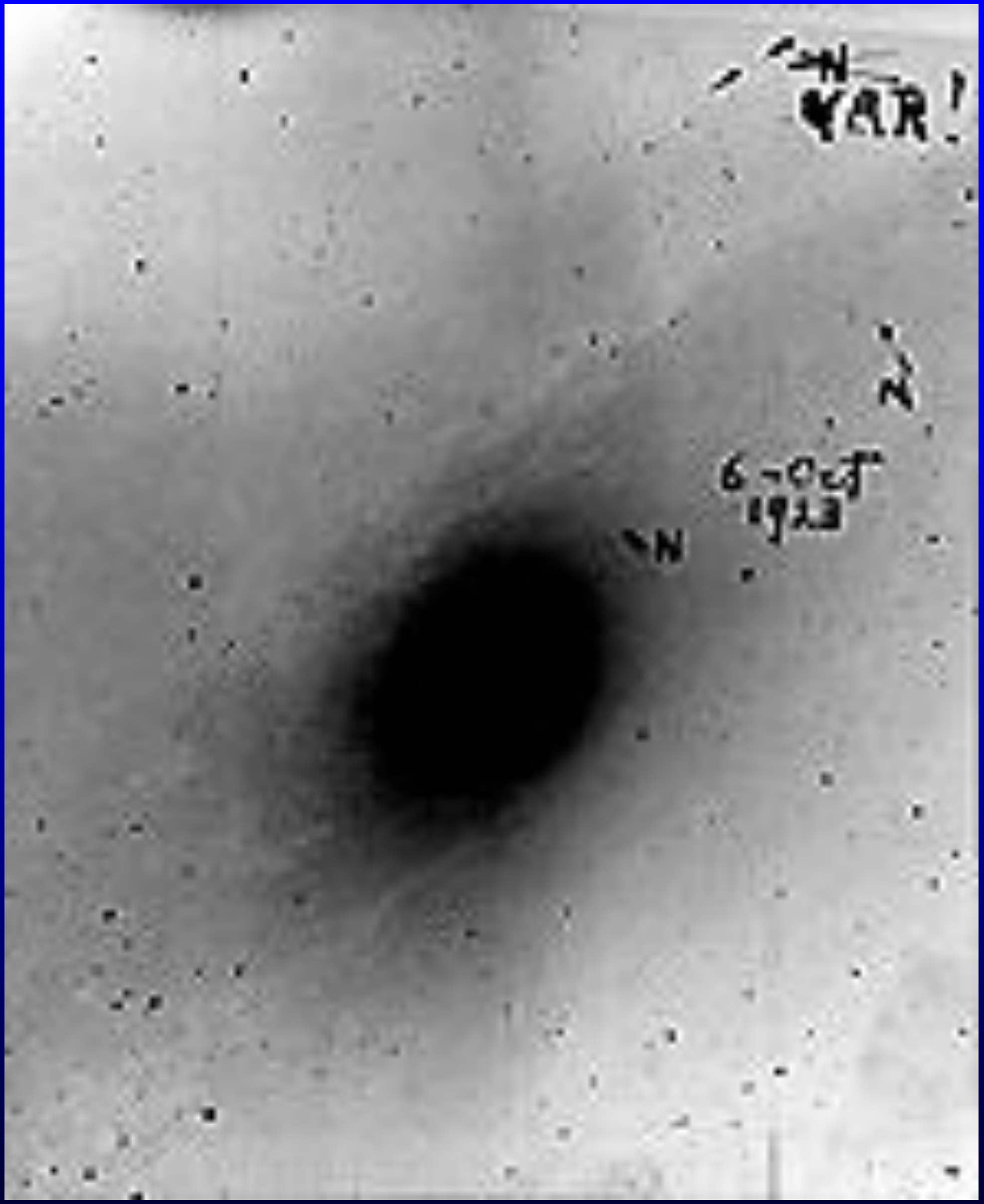
Hubble at the focus of the 100”



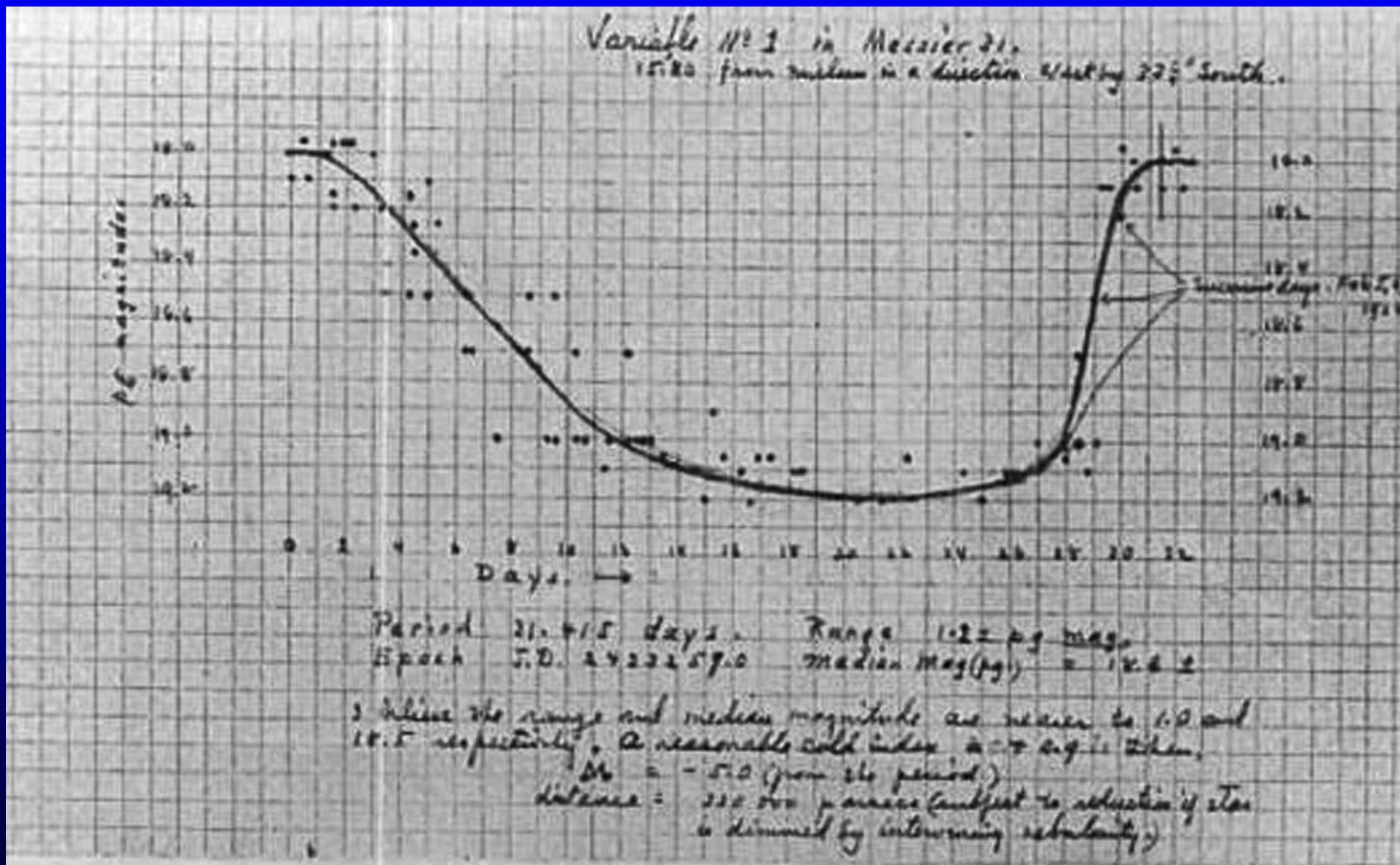
A Cepheid Variable in M31

- A photographic plate taken with the 100 inch Telescope.

- Hubble had discovered a Cepheid Variable.



Variable No1 Light Curve



White Nebula were Extra-Galactic

- Using the Cepheid Variable, Hubble was able to measure the distance to M31, the Andromeda Nebula.

- He derived a value of ~ 860,000 Light Years.

A letter to Harlow Shapley

- "Here is the letter that has destroyed my Universe!"

You will be interested to hear that I have found a Cepheid variable in the Andromeda nebula (M31). I have followed the nebula this season as closely as the weather permitted and in the last five months have netted nine novae and two variables.... The two variables were found last week ['confirmed' would be a better word here, rather than 'found' – A.S.]. No. 1 is roughly 16′ preceding the nucleus, but well within the borders of the arms, and is situated on a background of faint mottled nebulosity. Magnitudes were estimated rather hastily from a set of comparison stars and a light curve was constructed covering all available observations from 1909 down to date. The zero point in the comparison scale was extrapolated from your pg magnitudes, making what seemed to be a fair allowance for distance correction. I believe the range of the variable cannot be as much as 0.3 in error, nor the median magnitude more than 0.5.

Enclosed is a copy of the normal light curve, which, rough as it is, shows the Cepheid characteristics in an unmistakable fashion. Am I right in supposing it a typical cluster type curve? The period of 31.415 days corresponds to $M = -5.0$ on your period–luminosity curve. The medium sg magnitude of about 18.5 needs an uncertain correction for color index. Seares suggests 0.9 as a maximum, although your period–color curve for the Magellanic cloud calls for a higher value. With Seares' value, the median pv magnitude is 17.6 and the distance comes out something over 300 000 parsecs. If the stars were dimmed materially by shining through nebulosity, the distance would be correspondingly reduced... (see Figure 1).

Hubble had shown that the White Nebula were outside our galaxy.

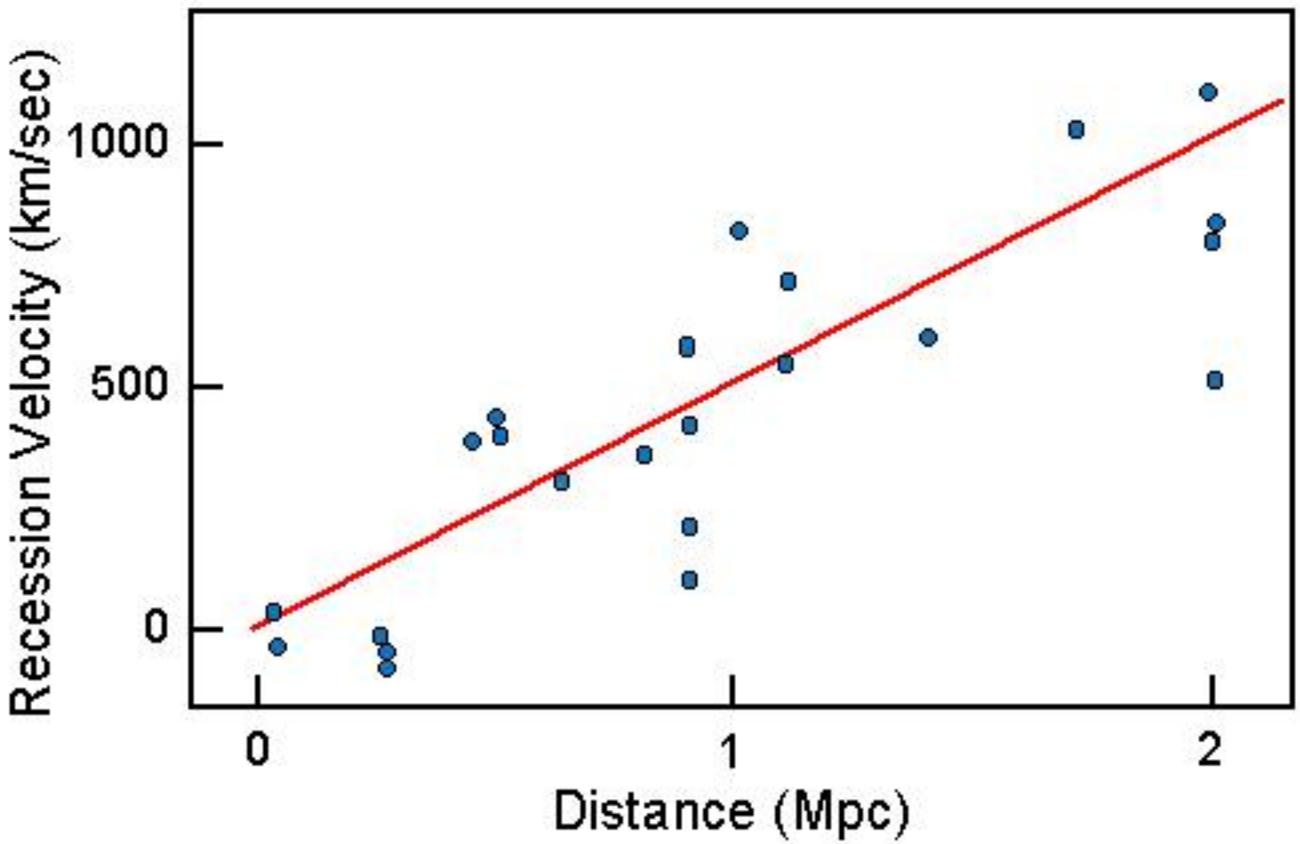
The Universe was far larger than many thought!

Vesto Slipher

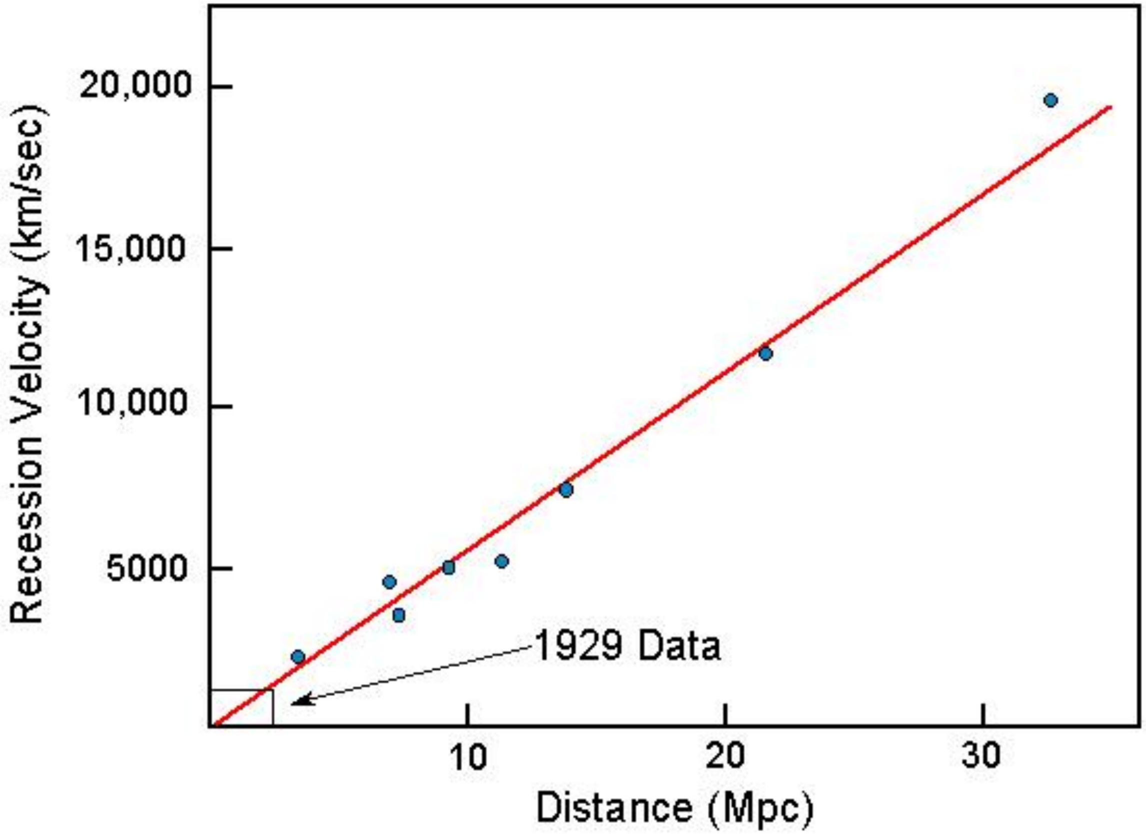
- Vesto Slipher measured the speeds of approach or recession of 14 galaxies by measuring the blue or red shifts in their spectra.

- Three nearby galaxies were approaching us whilst the remainder were receding.

Hubble's Data (1929)



Hubble & Humason (1931)



Hubble's Law

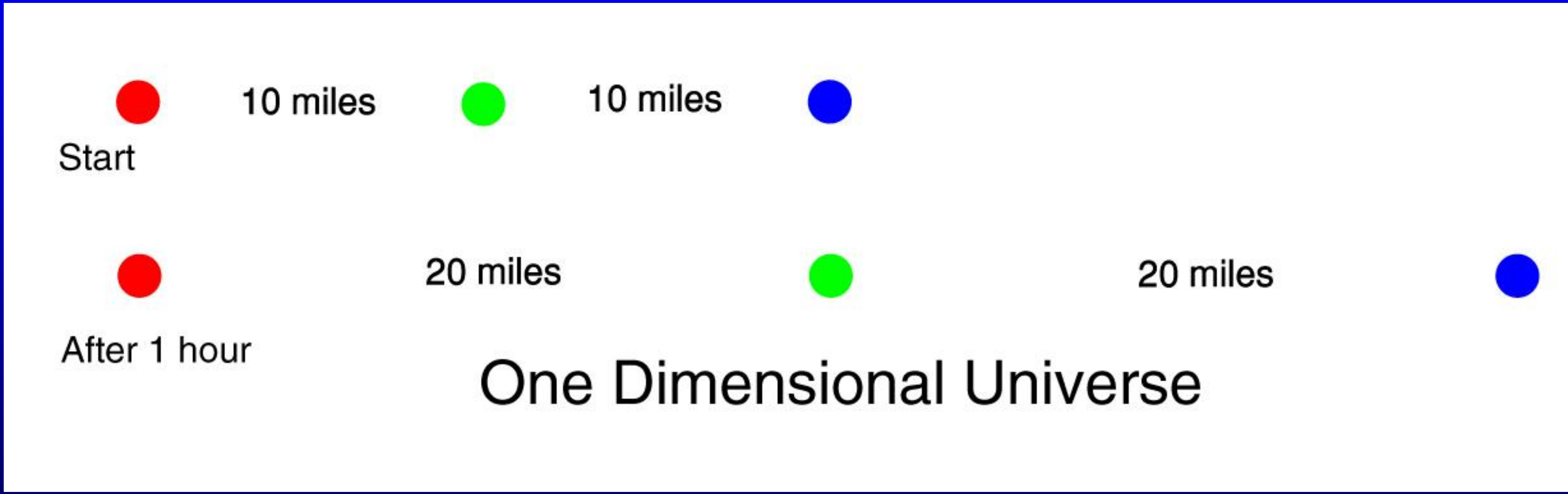
$$V = H_0 \times R$$

The Velocity of recession is proportional to the distance.

H_0 - Hubble's Constant - is the current constant of proportionality!

Hubble's Value ~ 500 km/sec/Mpc

An Expanding Universe



- The fact that the more distant galaxies were receding from us at a speed proportional to their distance implies that we live in an expanding Universe.

- One can backtrack to the time when the universe had no size.

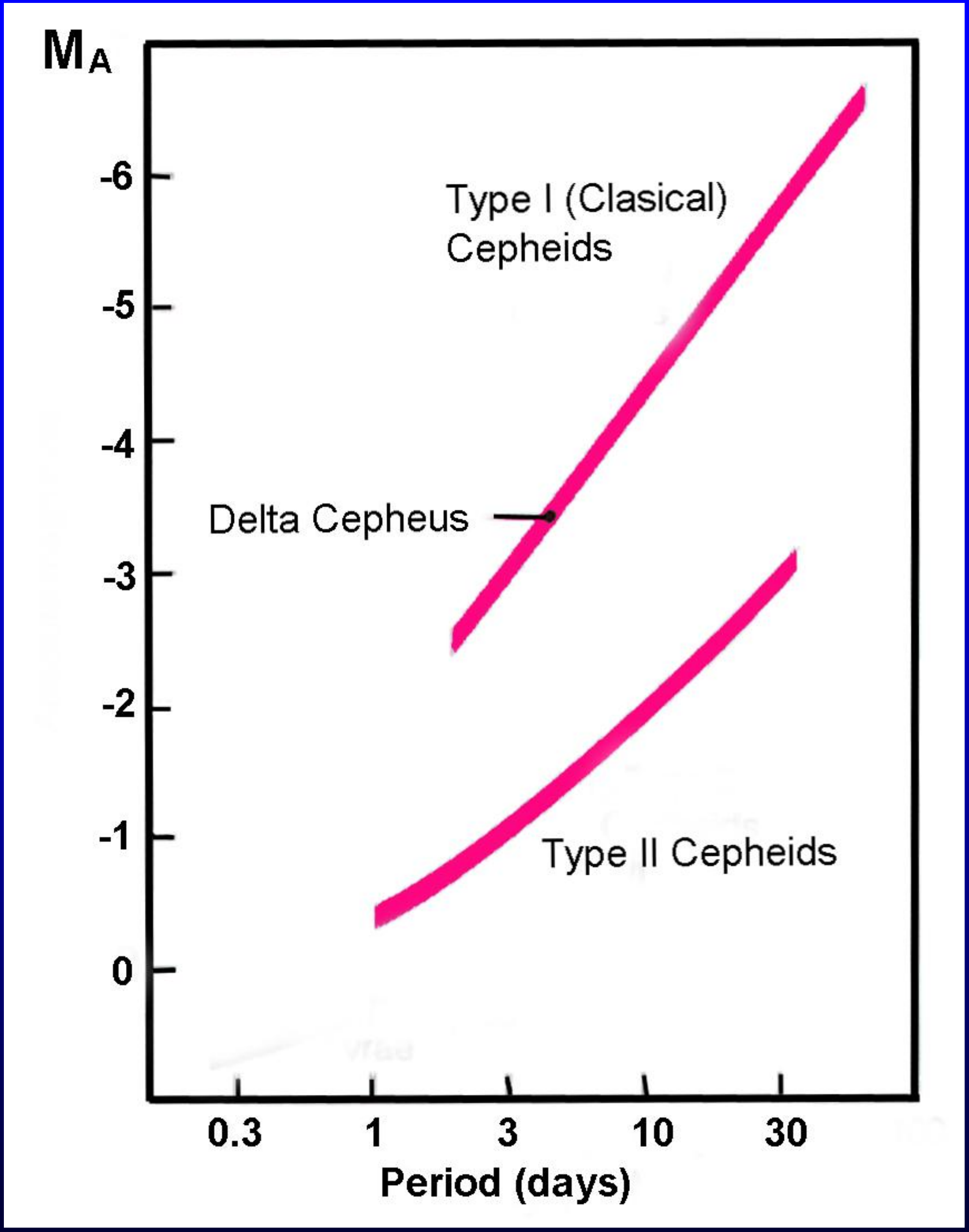
- This was $(1/ H_0)$ ago ~2000 million years.

This cannot be right!

- The Solar System is ~ 4.5 thousand million years old.
- Some stars appear to be ~ 12 thousand million years old.
- So what was wrong?

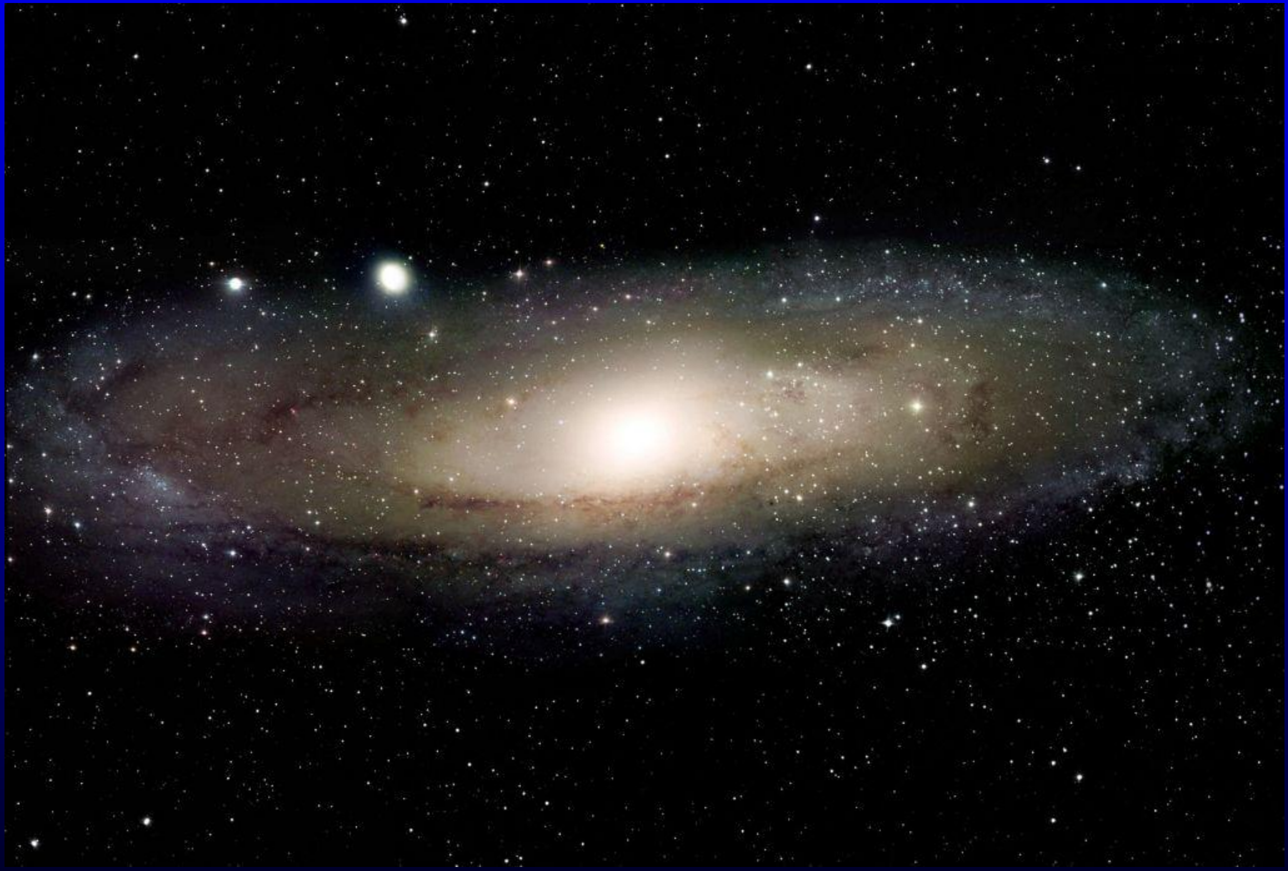
Two Types of Cepheids

- There were two types of cepheids.
- The Cepheid calibration data were incorrect.



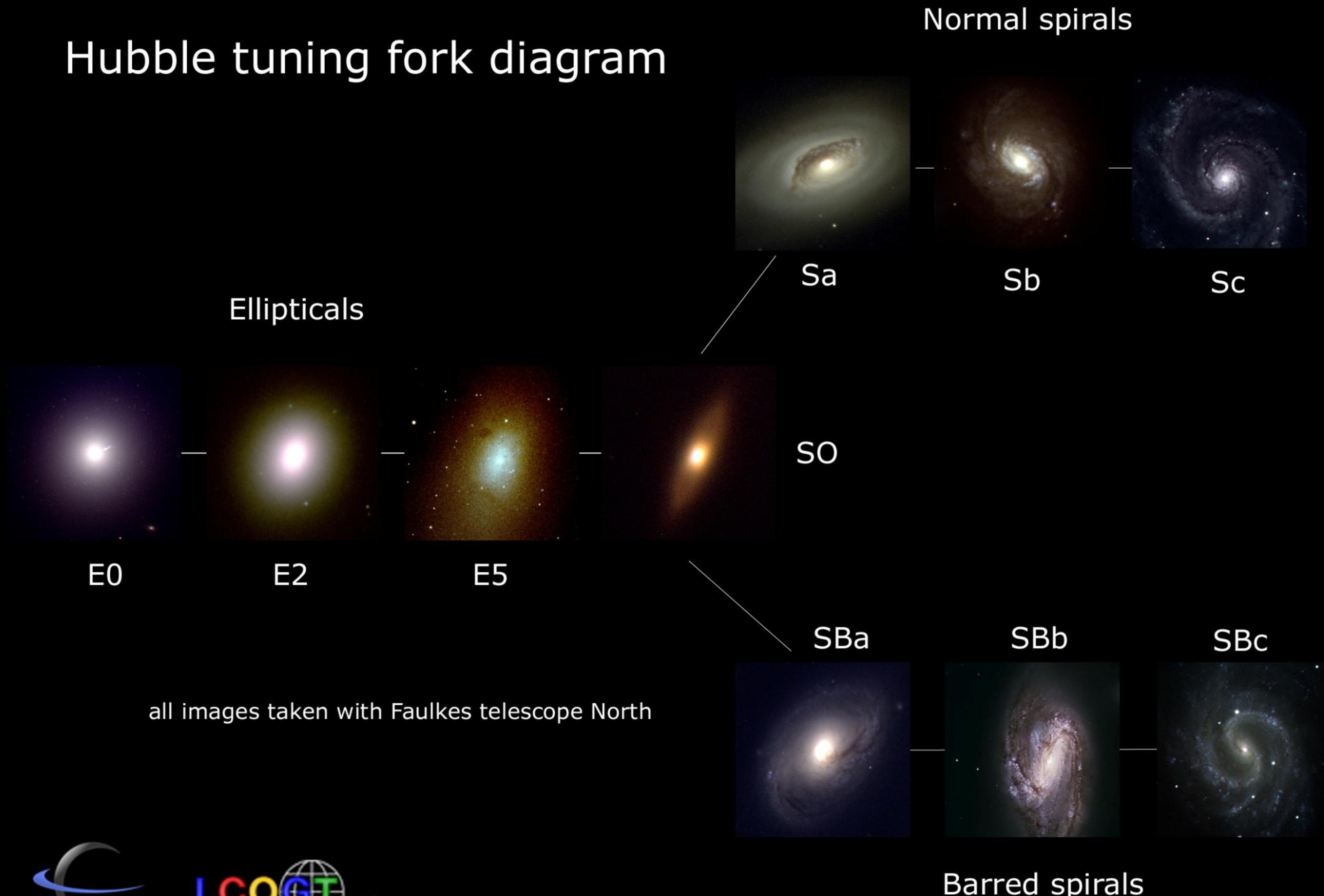
Walter Baade - 1952

His Value of H_0:
250 km/ses/Mpc



1936 - Hubble’s Galaxy Classification

Hubble tuning fork diagram



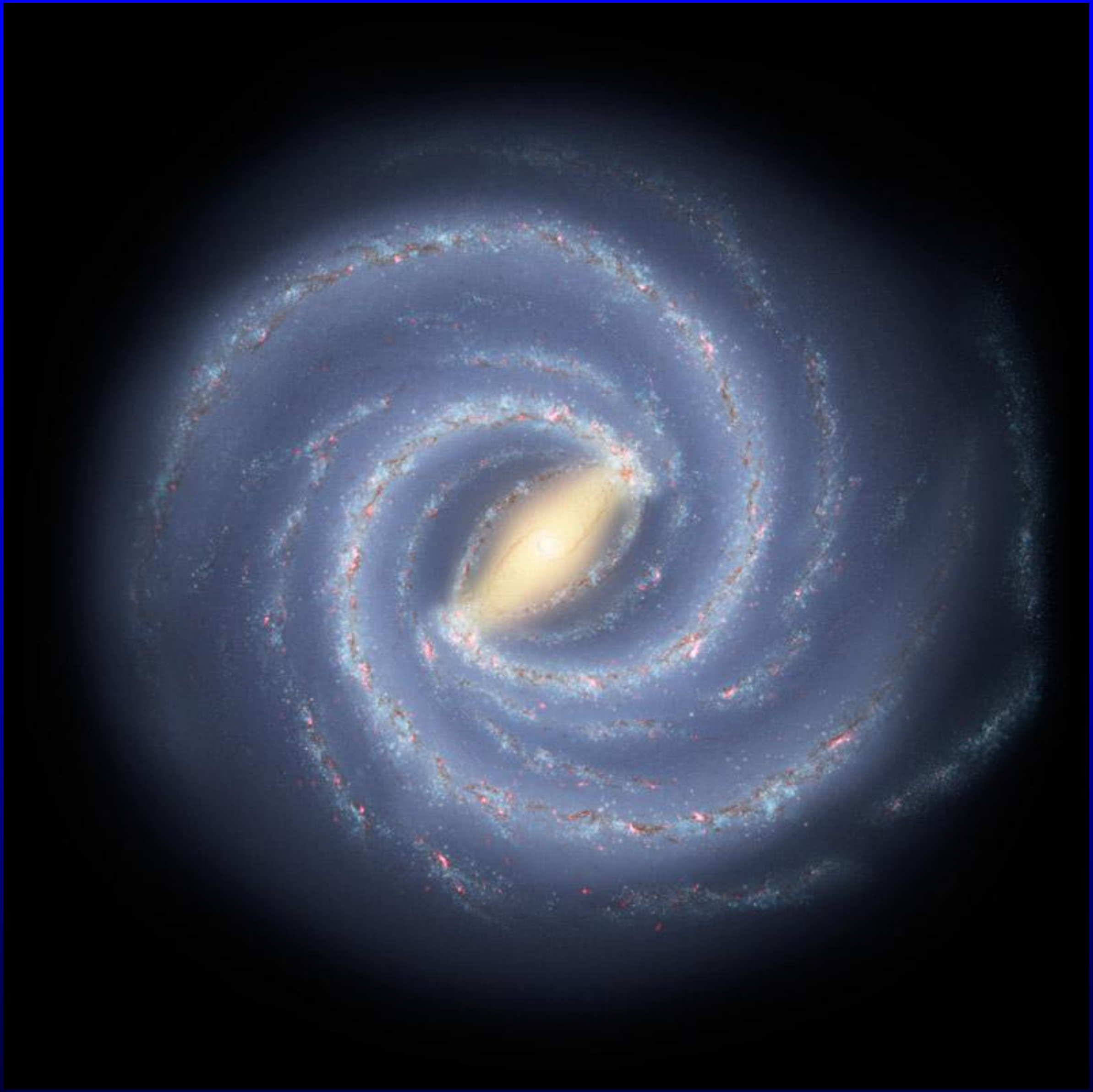
all images taken with Faulkes telescope North

FAULKES TELESCOPE

LCOGT.net

Our Milky Way galaxy

- A Barred Spiral – Type SBb.

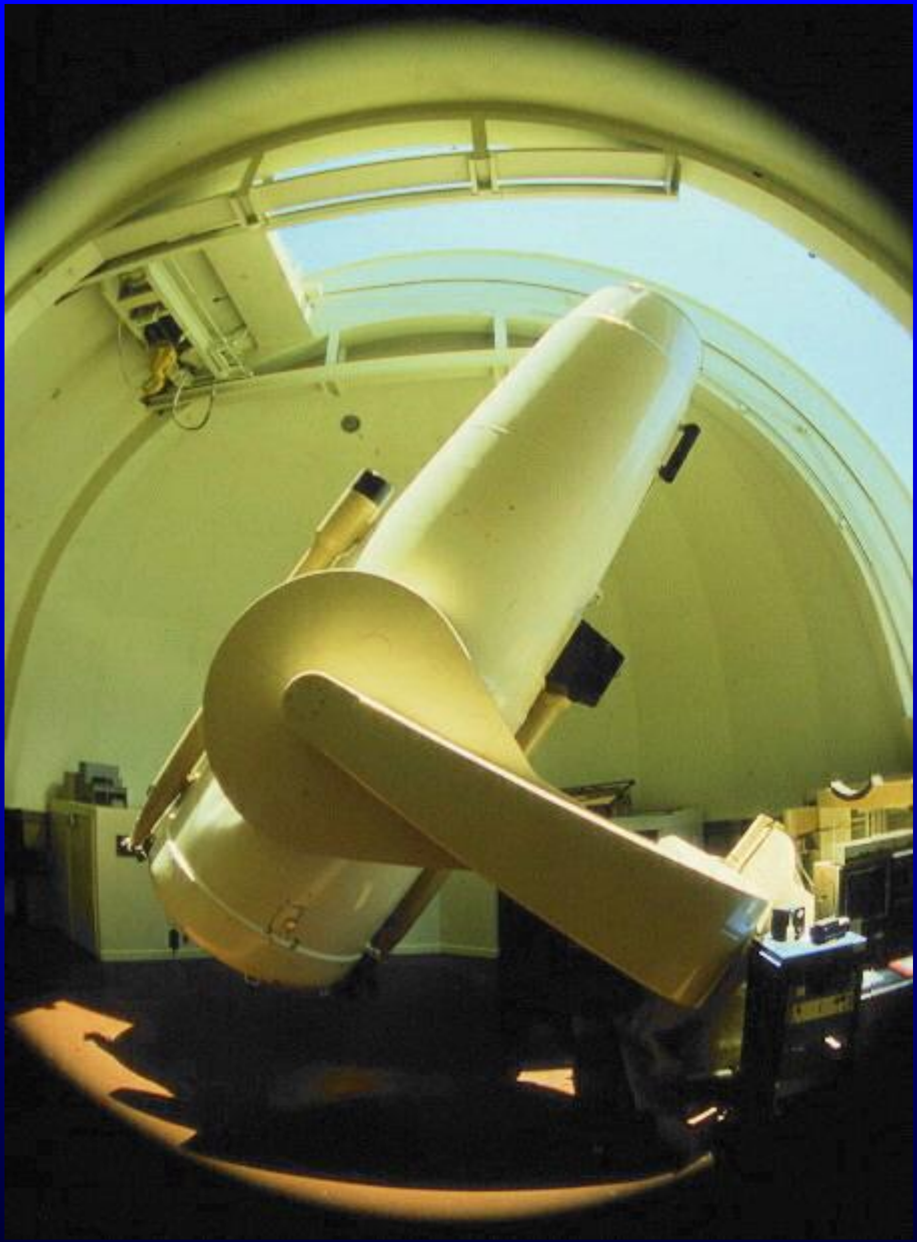


Mt Wilson Observatory

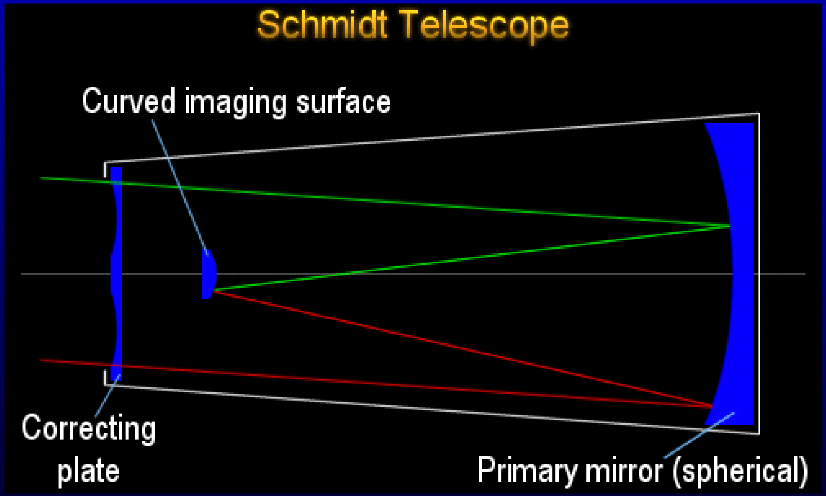

August 31st 2009

Mt Palomar Observatory

- At an elevation of 5,600 feet on Palomar Mountain, 100 miles southeast of Pasadena, California.



Mt Palomar 48” Schmidt

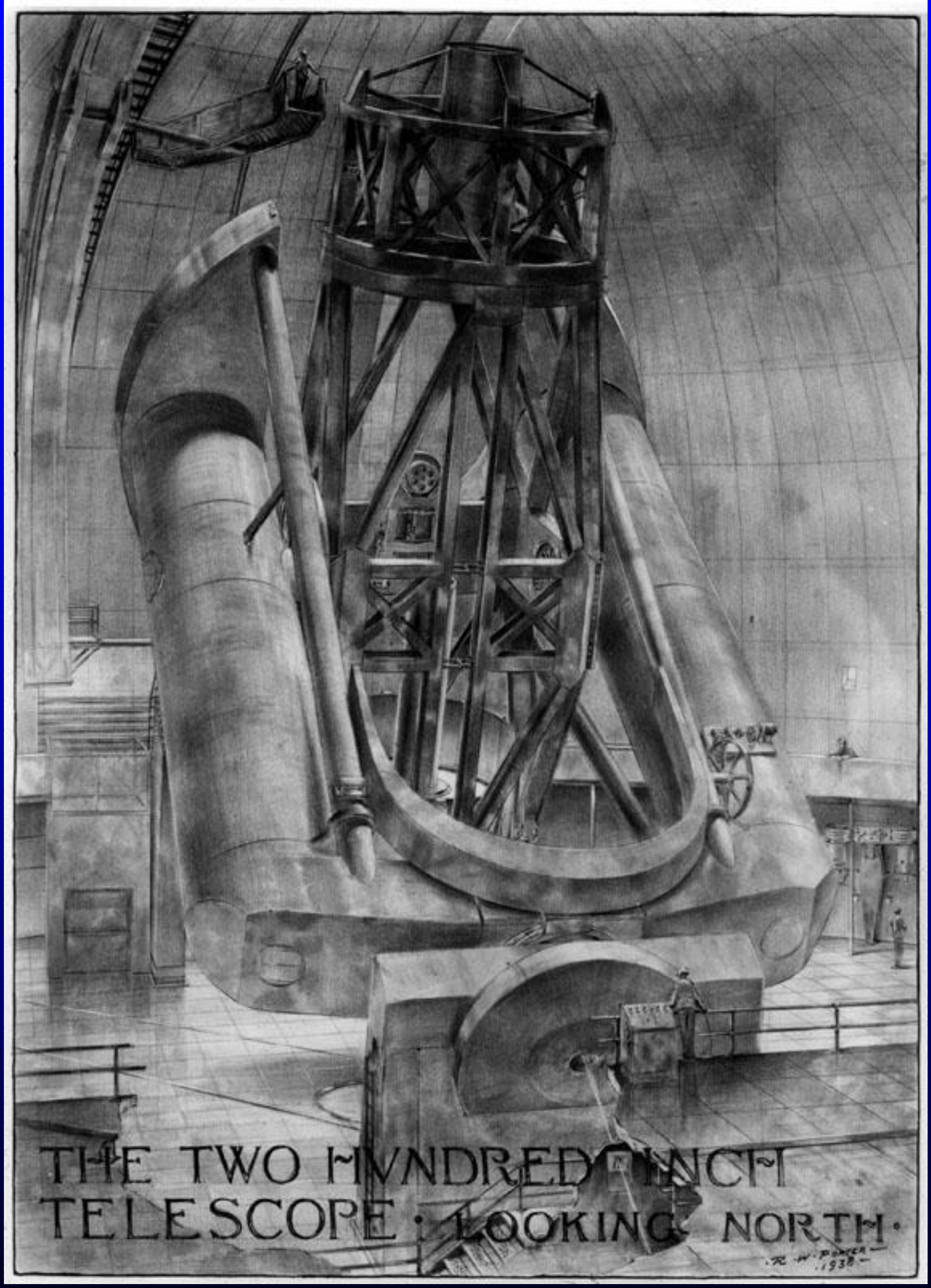


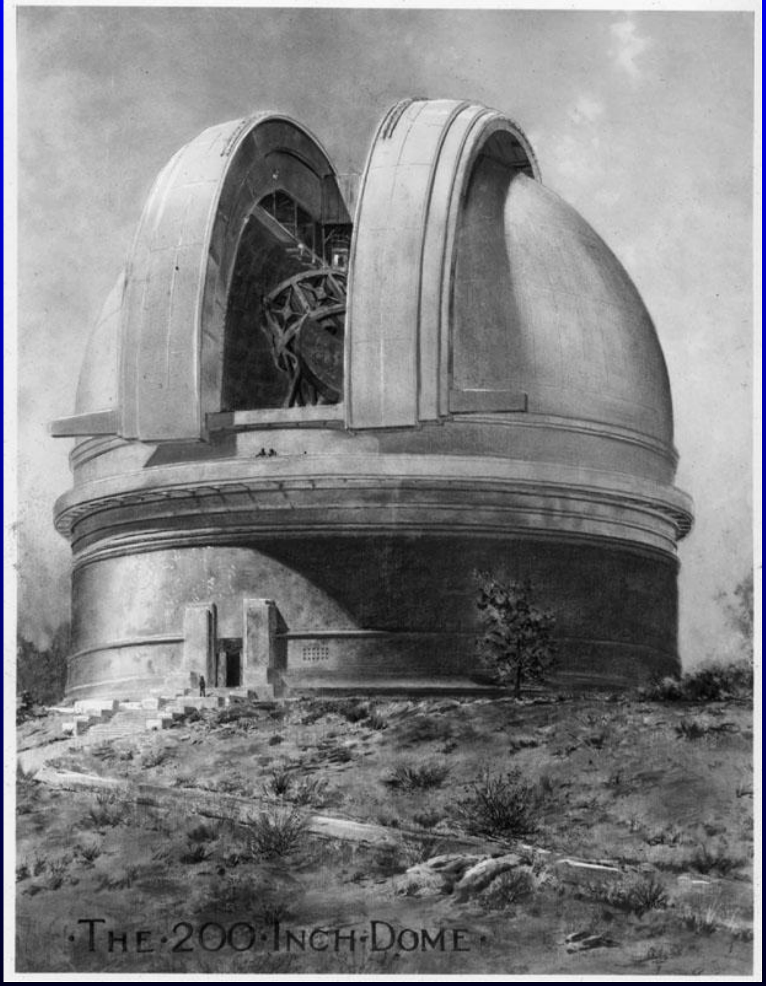
Hubble at the guide-scope of the 48” Schmidt.

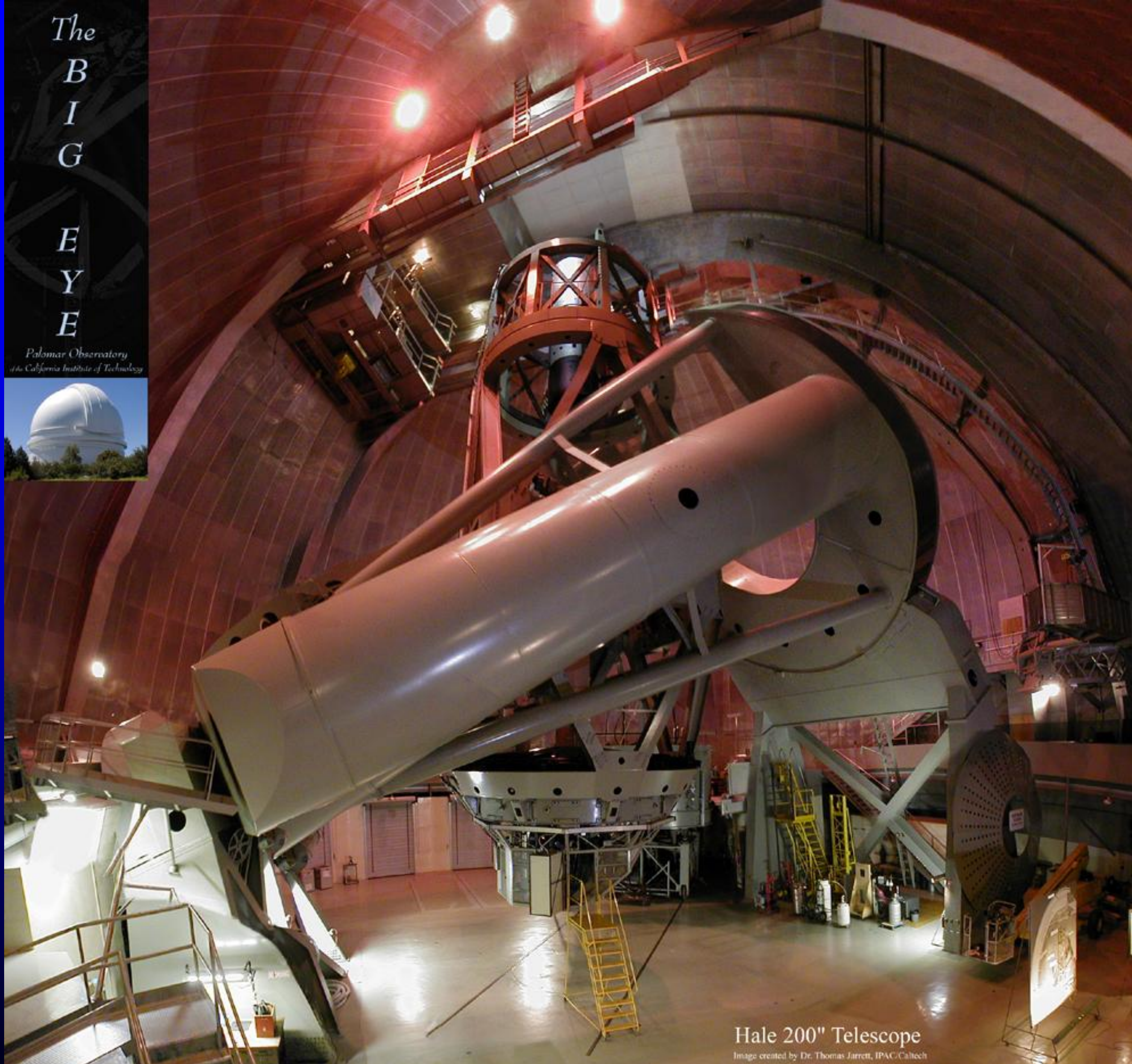
Hubble was deeply involved with the design and construction of the Mt Palomar Hale 200” Telescope

He had the honour of taking its “first light” image – that of the “Comet Nebula” he had first studied as a PhD student.

Russell Porter's Drawings



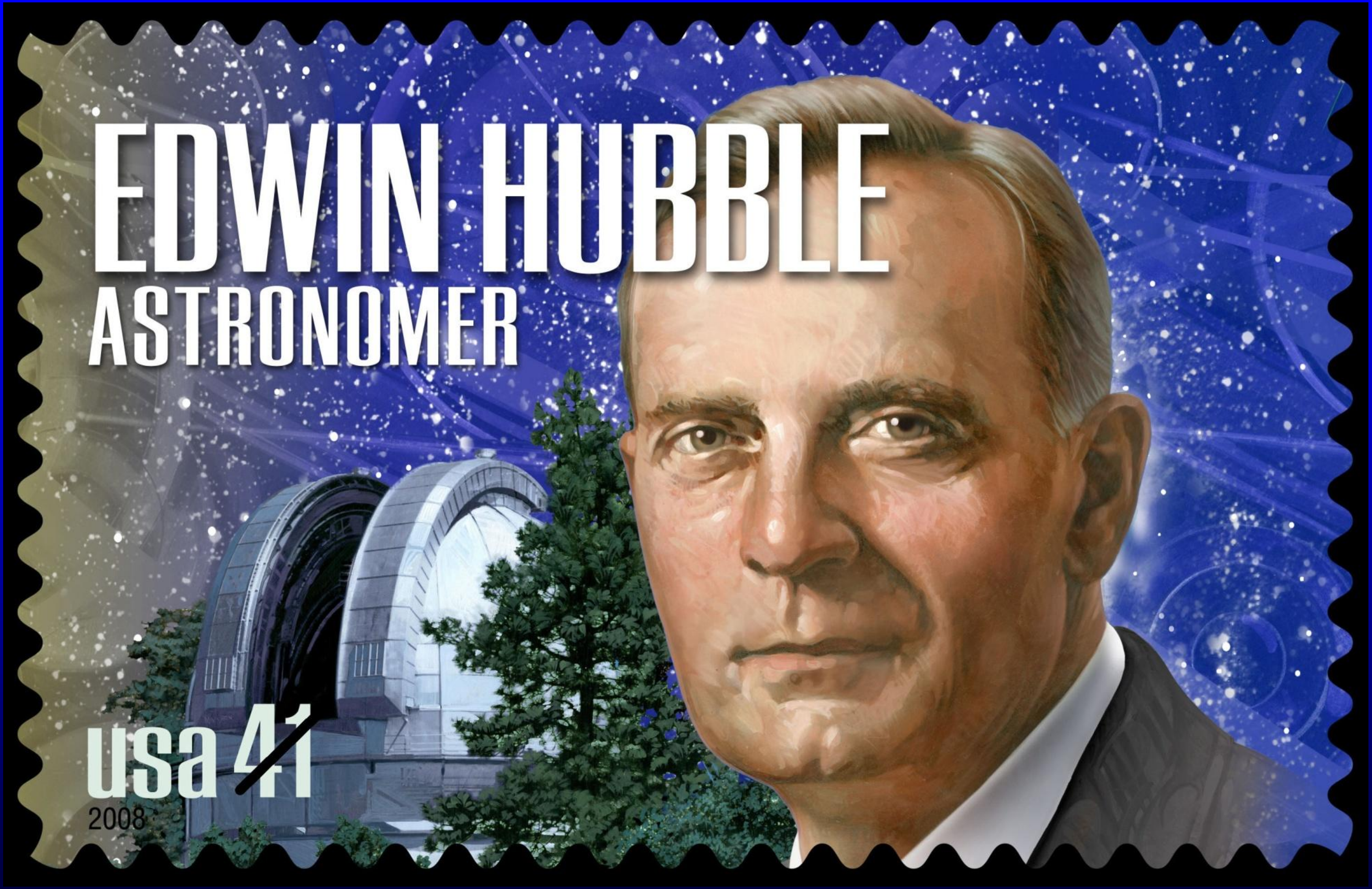



The BIG EYE
Palomar Observatory
of the California Institute of Technology
Hale 200" Telescope
Image created by Dr. Thomas Jarrett, IPAC/Caltech

Edwin Hubble at the Prime Focus of the Hale 200" Telescope

Hubble's Cometary Nebula

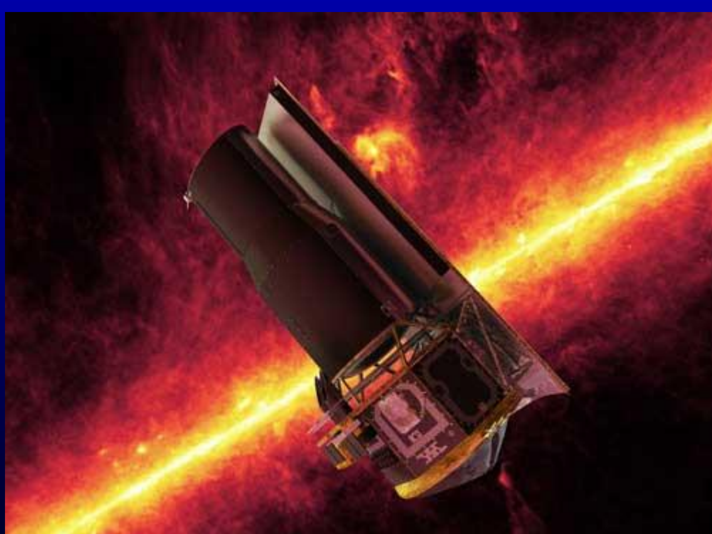
- Sadly, on September 28th 1953, at the age of 63 he died of a cerebral thrombosis.
- At that time Astronomers could not receive the Nobel Prize.
- Shortly after his death, they were able to receive the Nobel prize for Physics.
- But it cannot be given posthumously so he never receive the honour he so richly deserved.


EDWIN HUBBLE
ASTRONOMER
usa 41
2008

The Hubble Space Telescope

Lyman Spitzer

- 1946 – "Astronomical advantages of an extraterrestrial observatory"



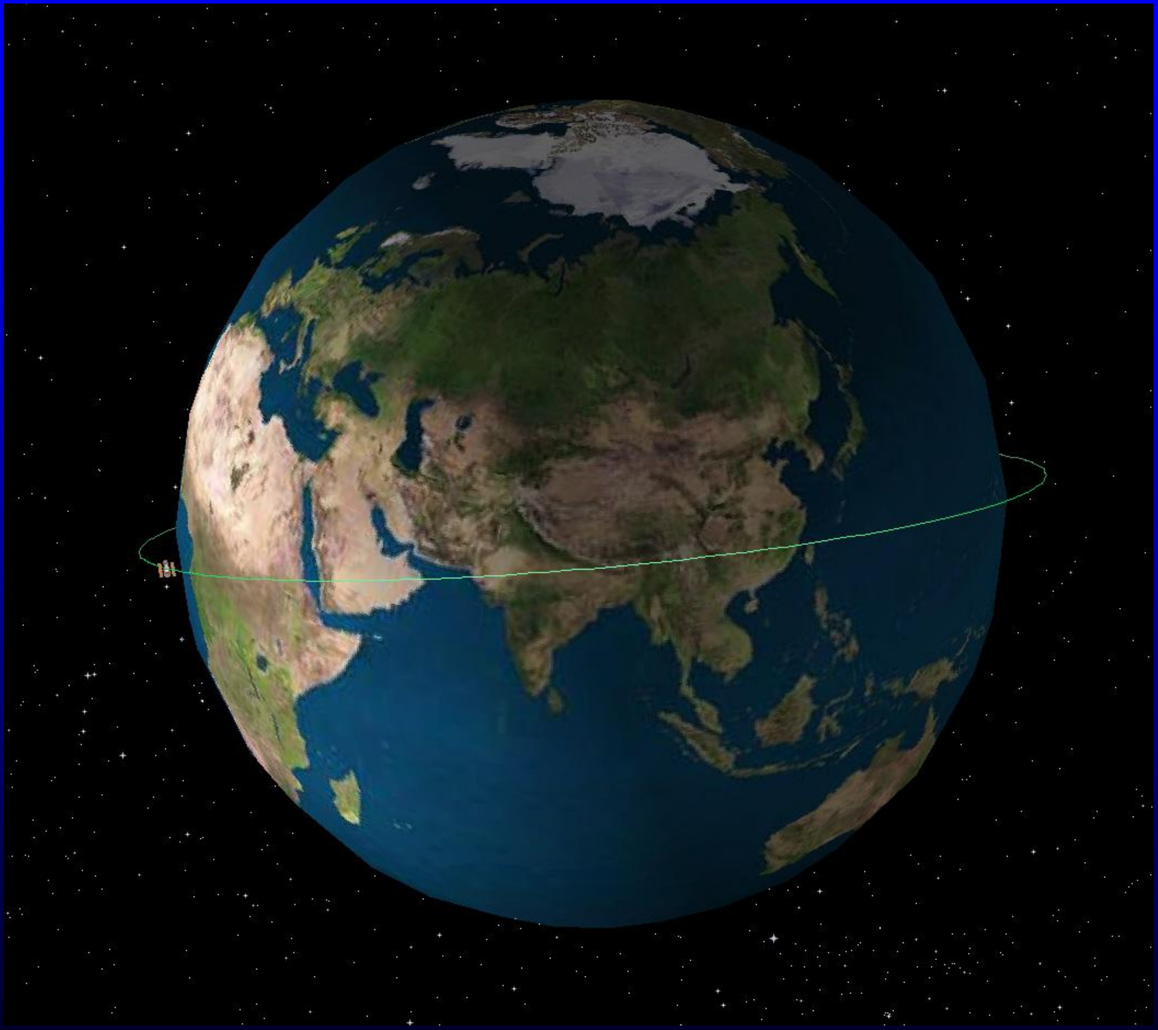
Two Main Advantages

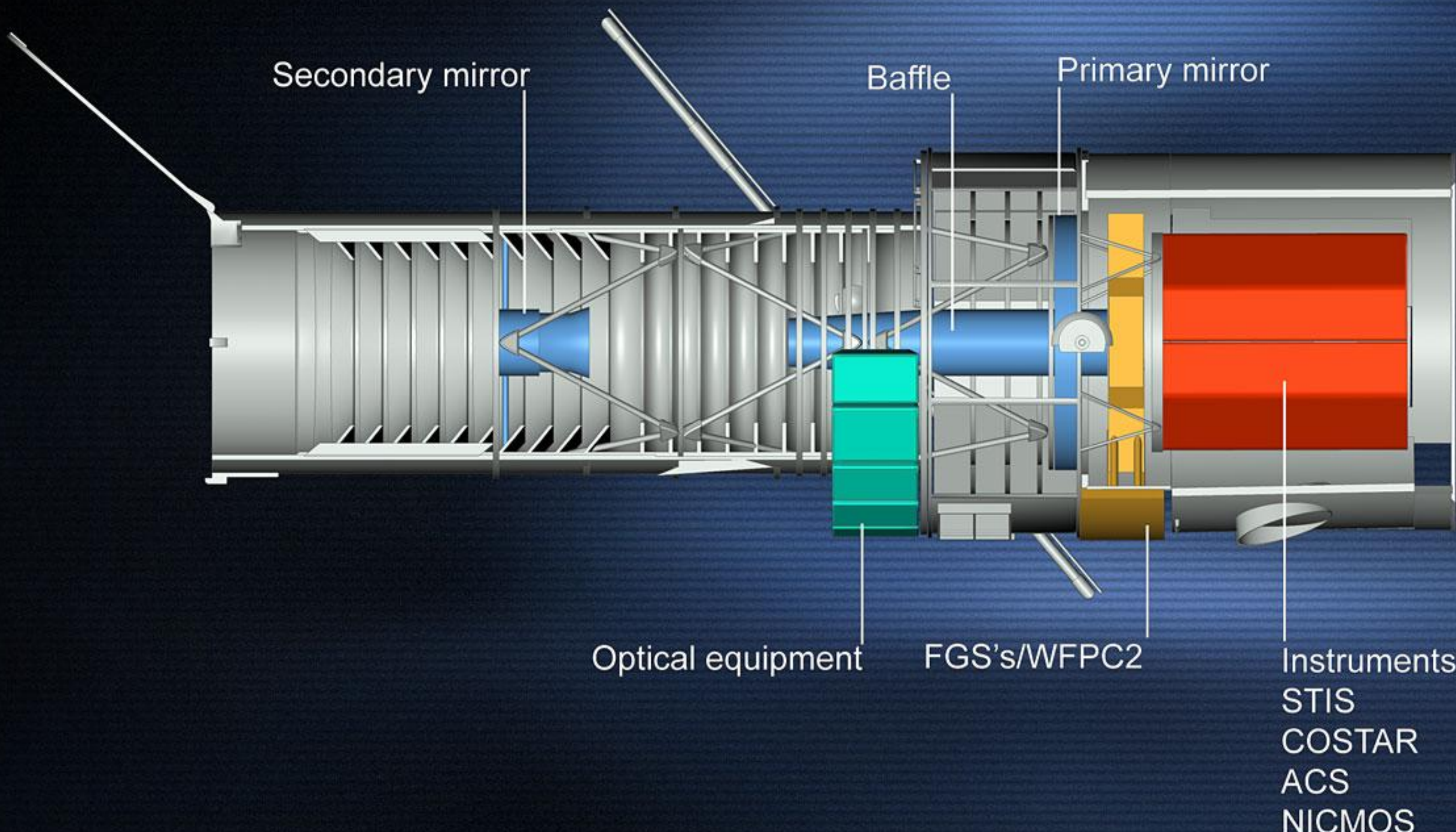
- 1) The angular resolution would be limited only by the size of the mirror (assumed to be optically perfect), rather than by the turbulence in the atmosphere.

- 2) A space-based telescope could observe in the infrared and ultraviolet light wavebands which are strongly absorbed by the atmosphere.

Deployed by Discovery in April 1990

In a very low orbit ~350 miles high

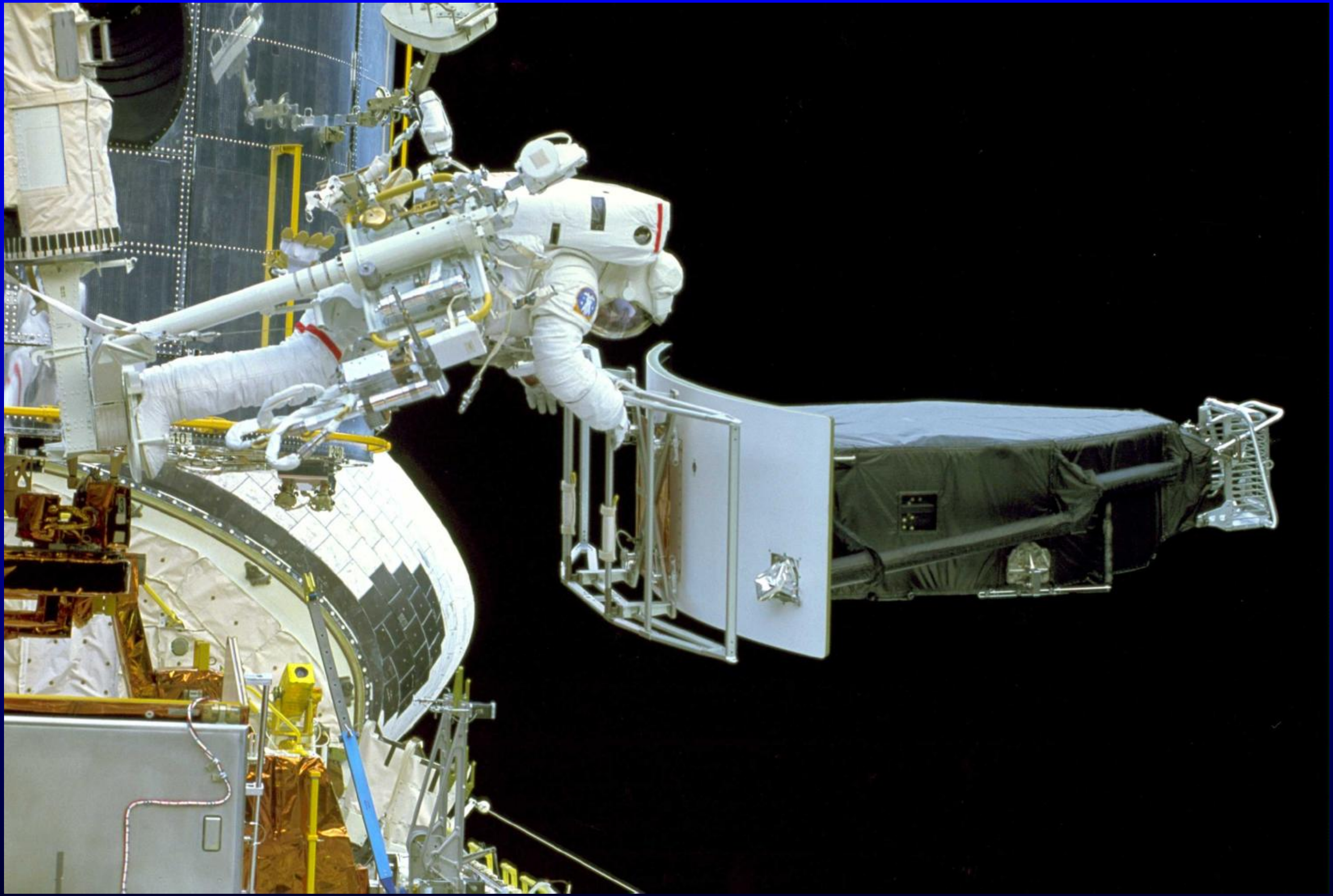



Secondary mirror
Baffle
Primary mirror
Optical equipment
FGS's/WFPC2
Instruments:
STIS
COSTAR
ACS
NICMOS

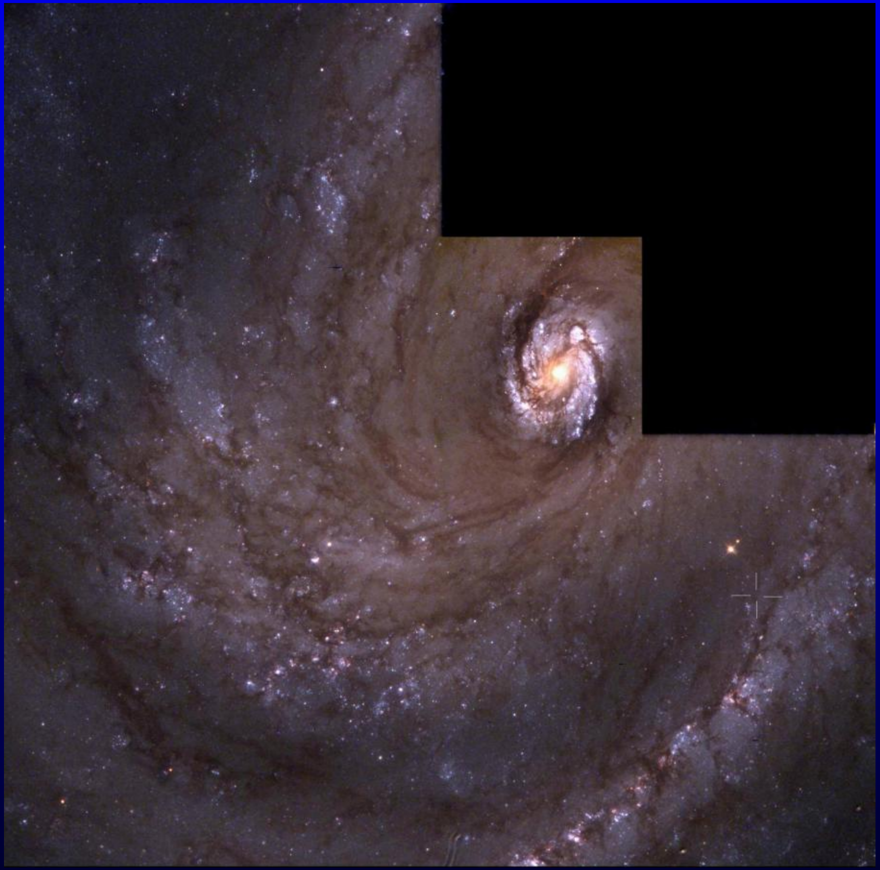
A problem with the mirror!

M100 - Quite an Improvement!

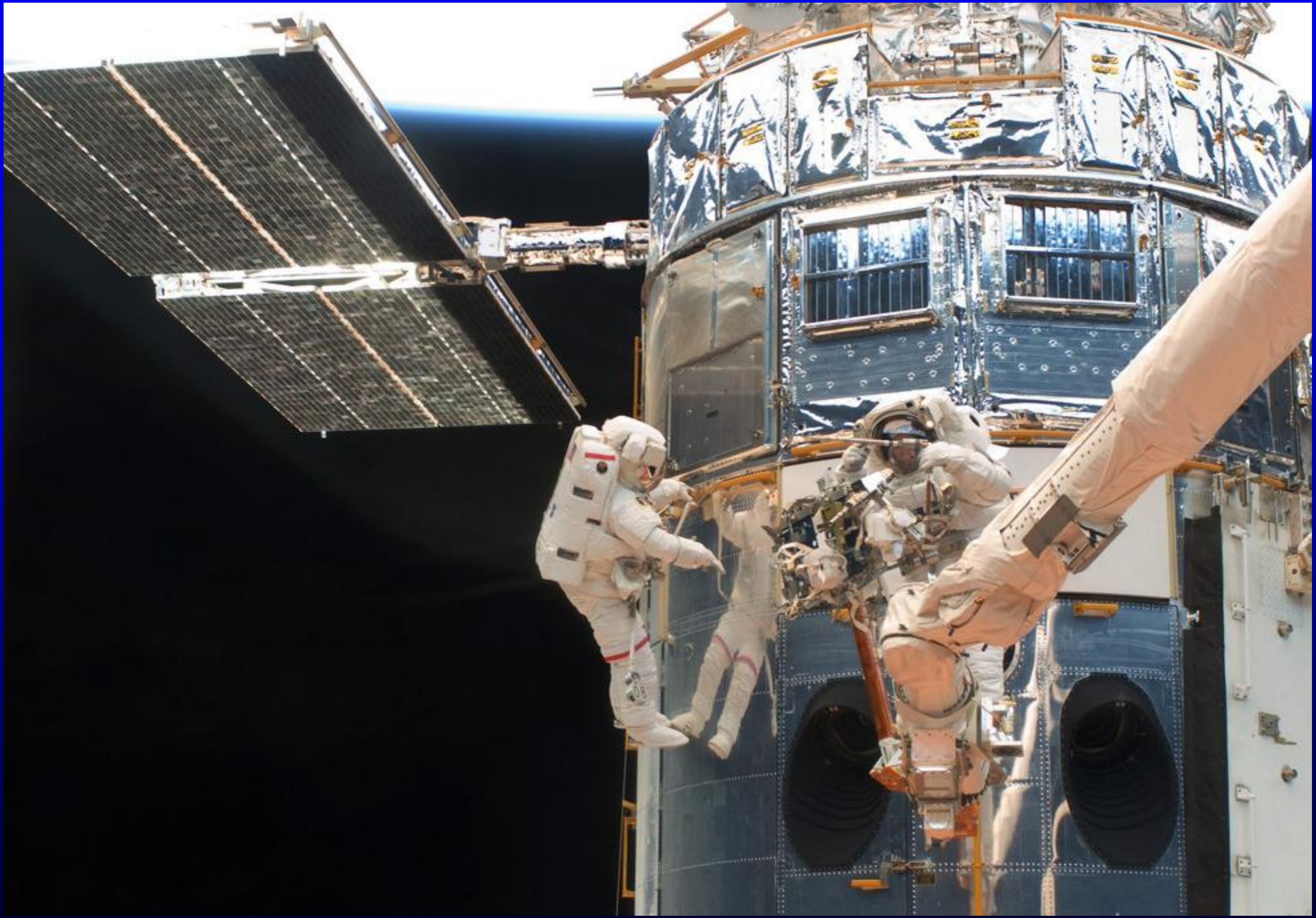
Replaceable Instrument Bays

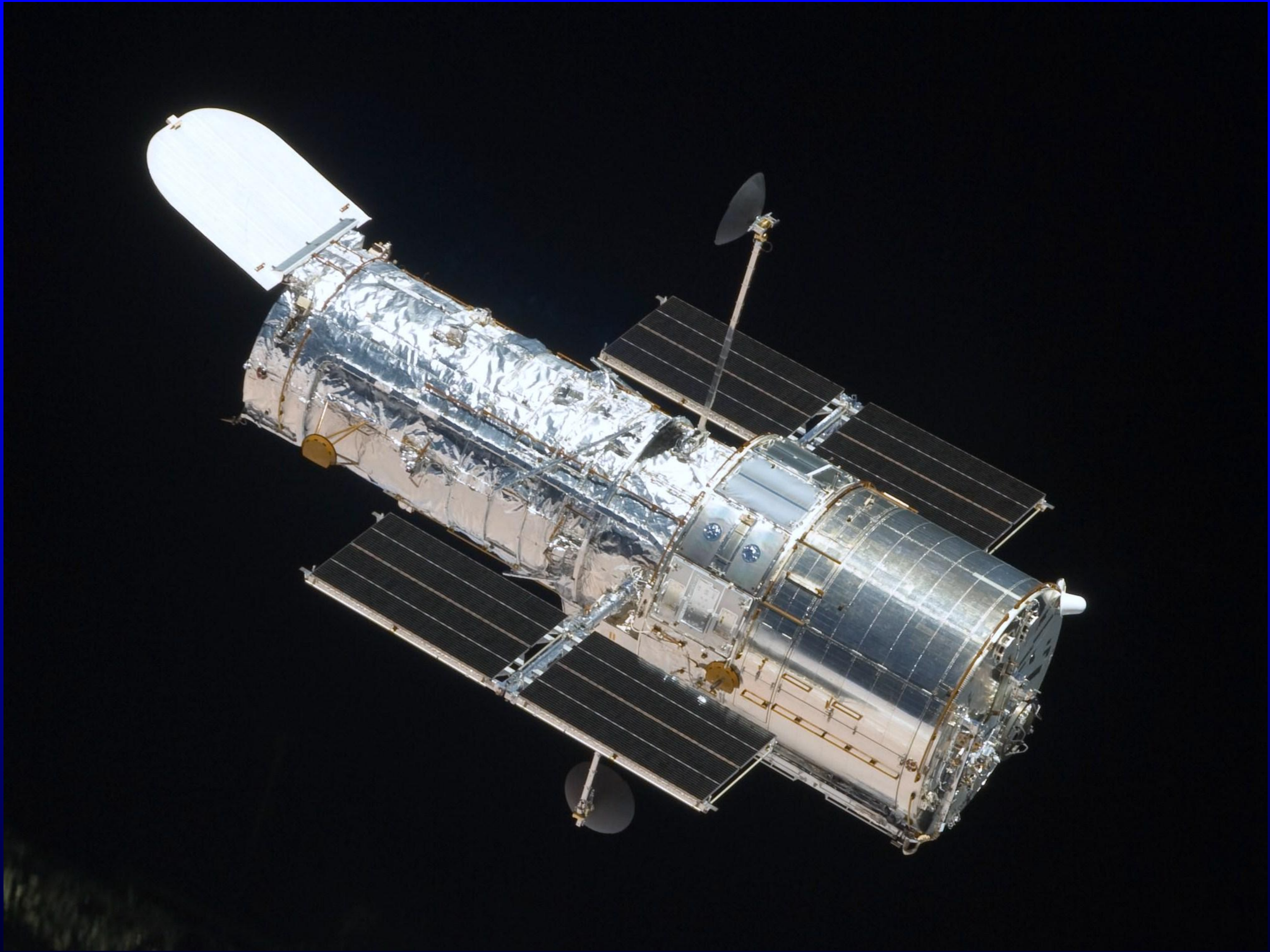


M100 – WFPC2



2002 - Smaller Solar Panels





2009 – Final Servicing Mission

Hubble Science

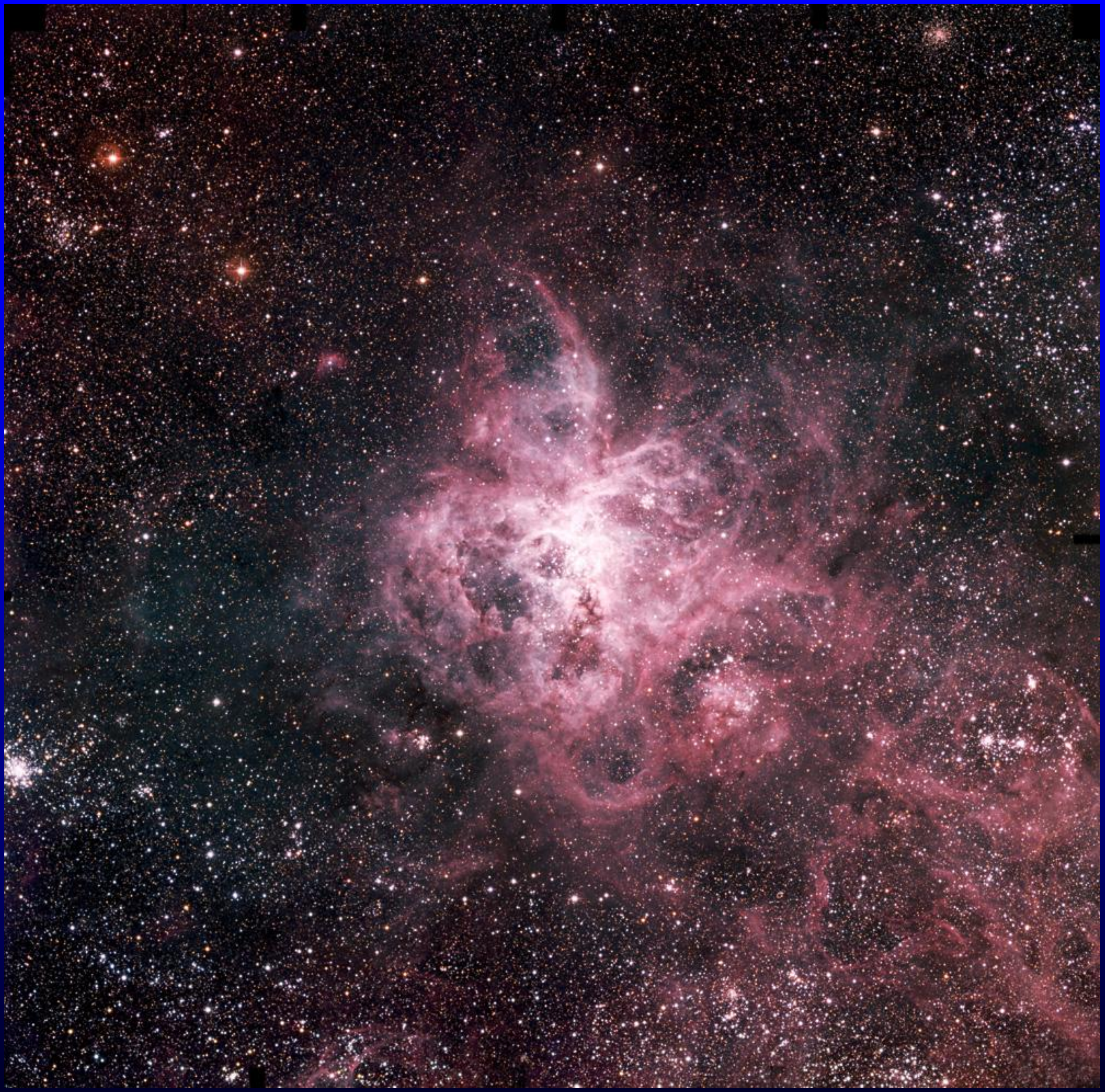
The Distance Scale of the Universe

A Hubble Key Project

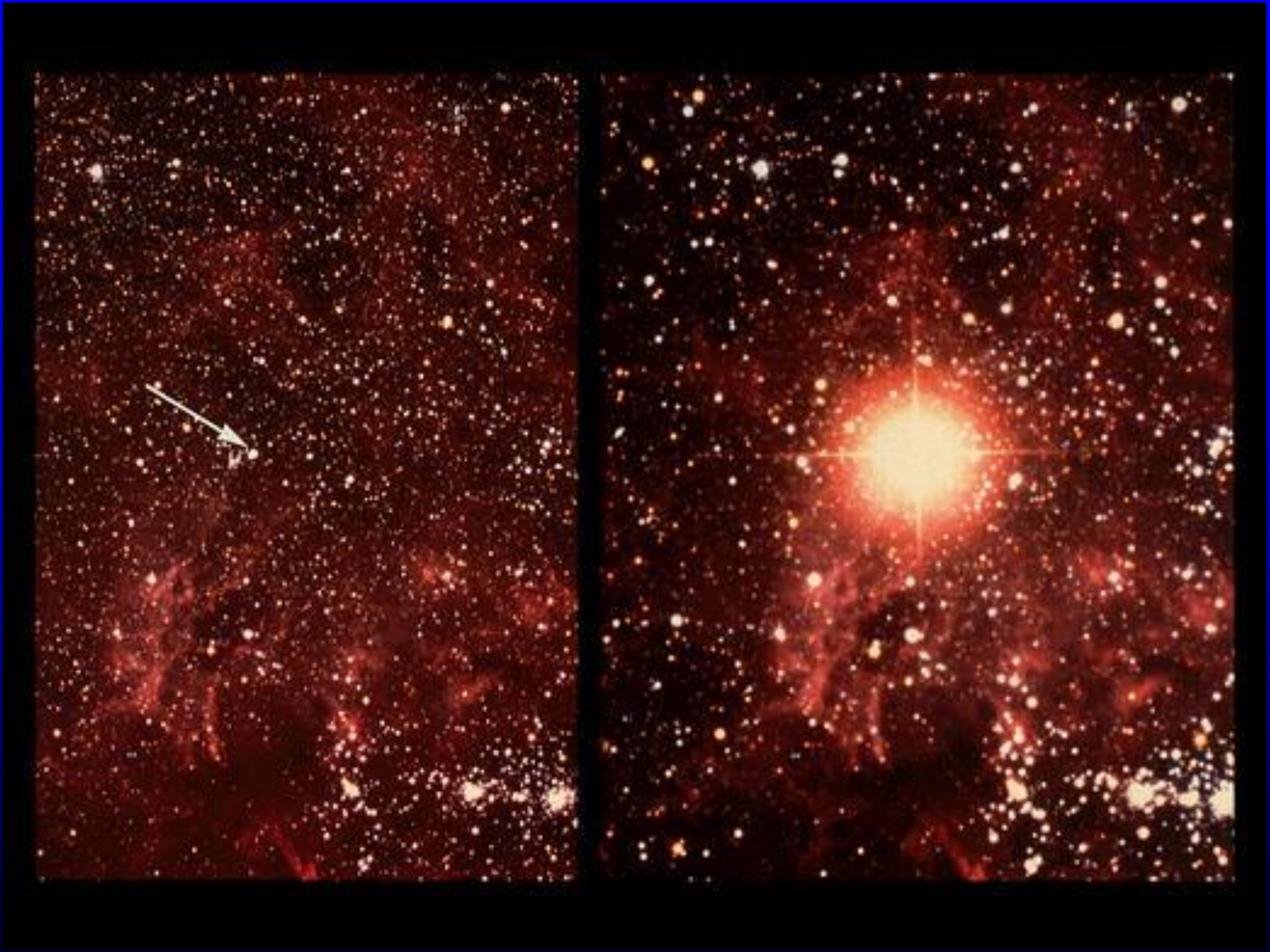
Milky Way and Magellanic Clouds

Large Magellanic Cloud Cloud

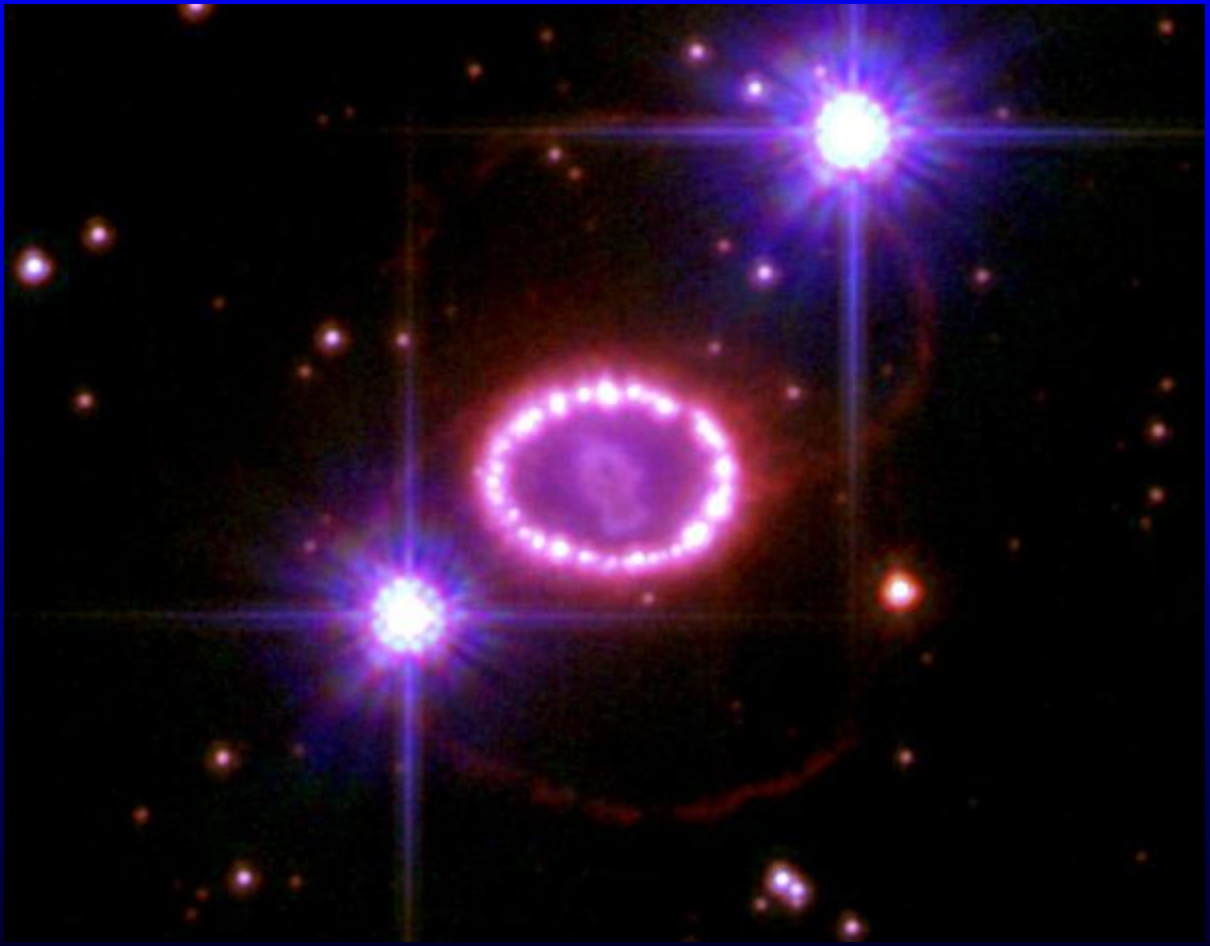
Tarantula Nebula



Supernova 1987A



Hubble Image December 2006



Radius of the ring in light travel time

= 232.5 days

= 6×10^{12} km

Angular Diameter of the ring as measured by the HST

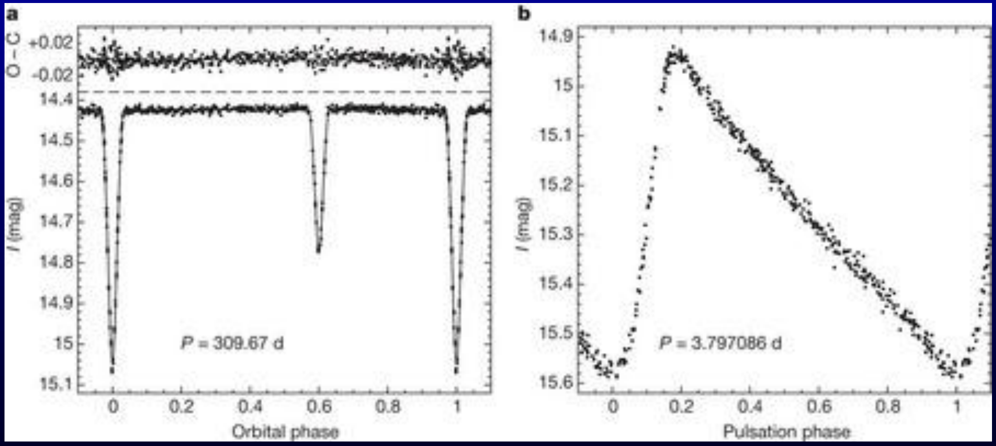
= 17.2 arc seconds

Simple Trigonometry gives a distance of

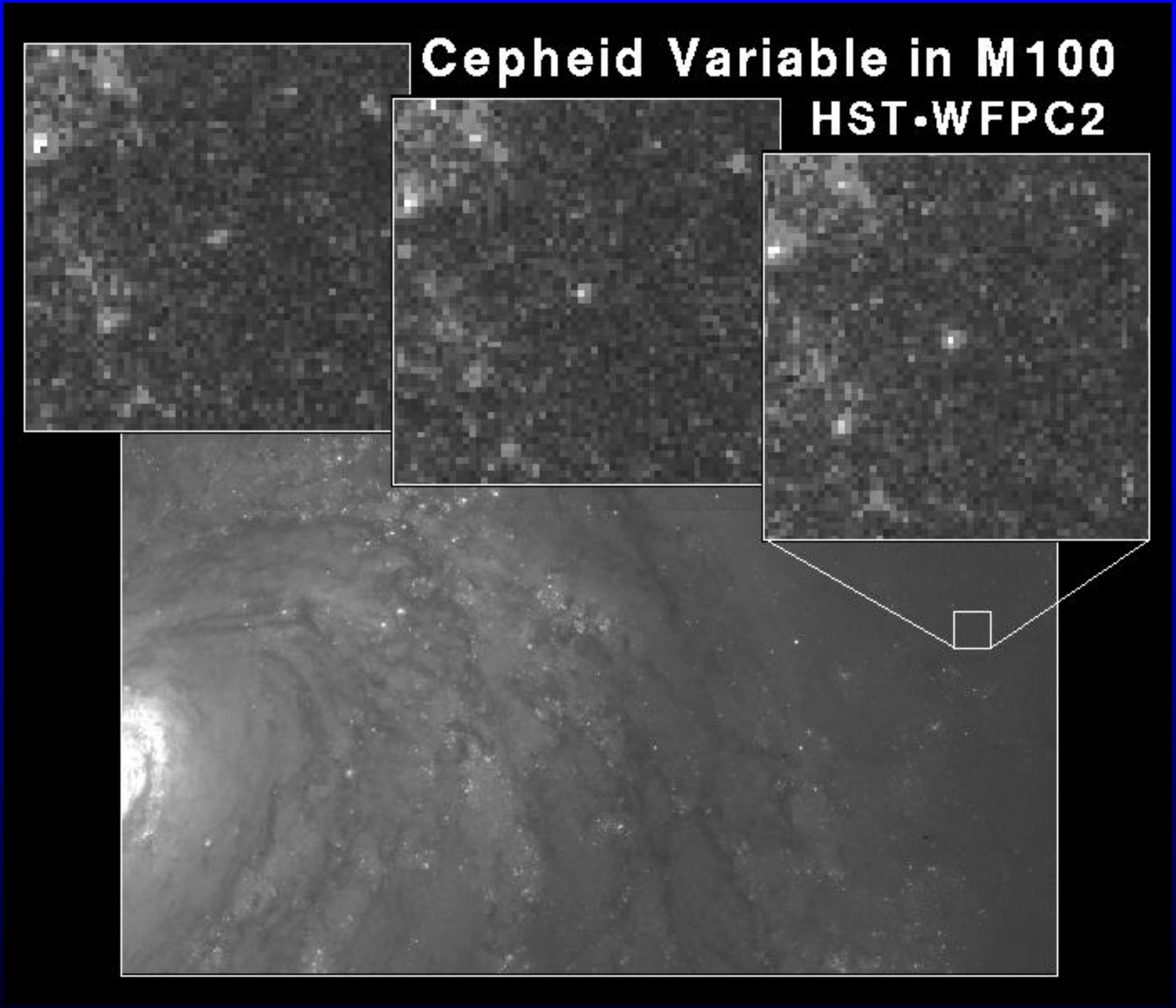
1.4×10^{18} km = 170,000 Light Years

A Cepheid Variable in the LMC

A Cepheid Variable in an Eclipsing Binary System

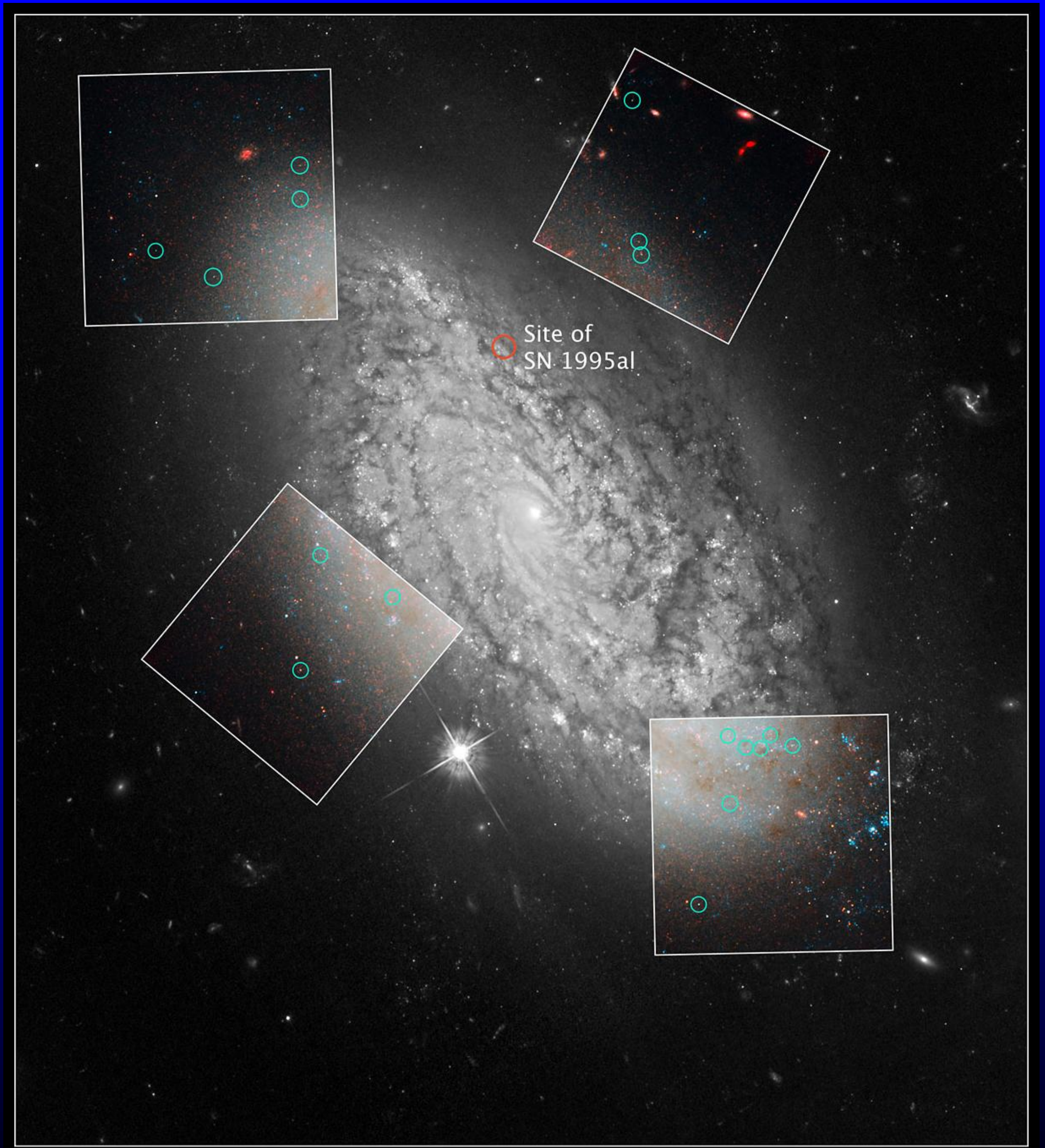


A Cepheid in M100

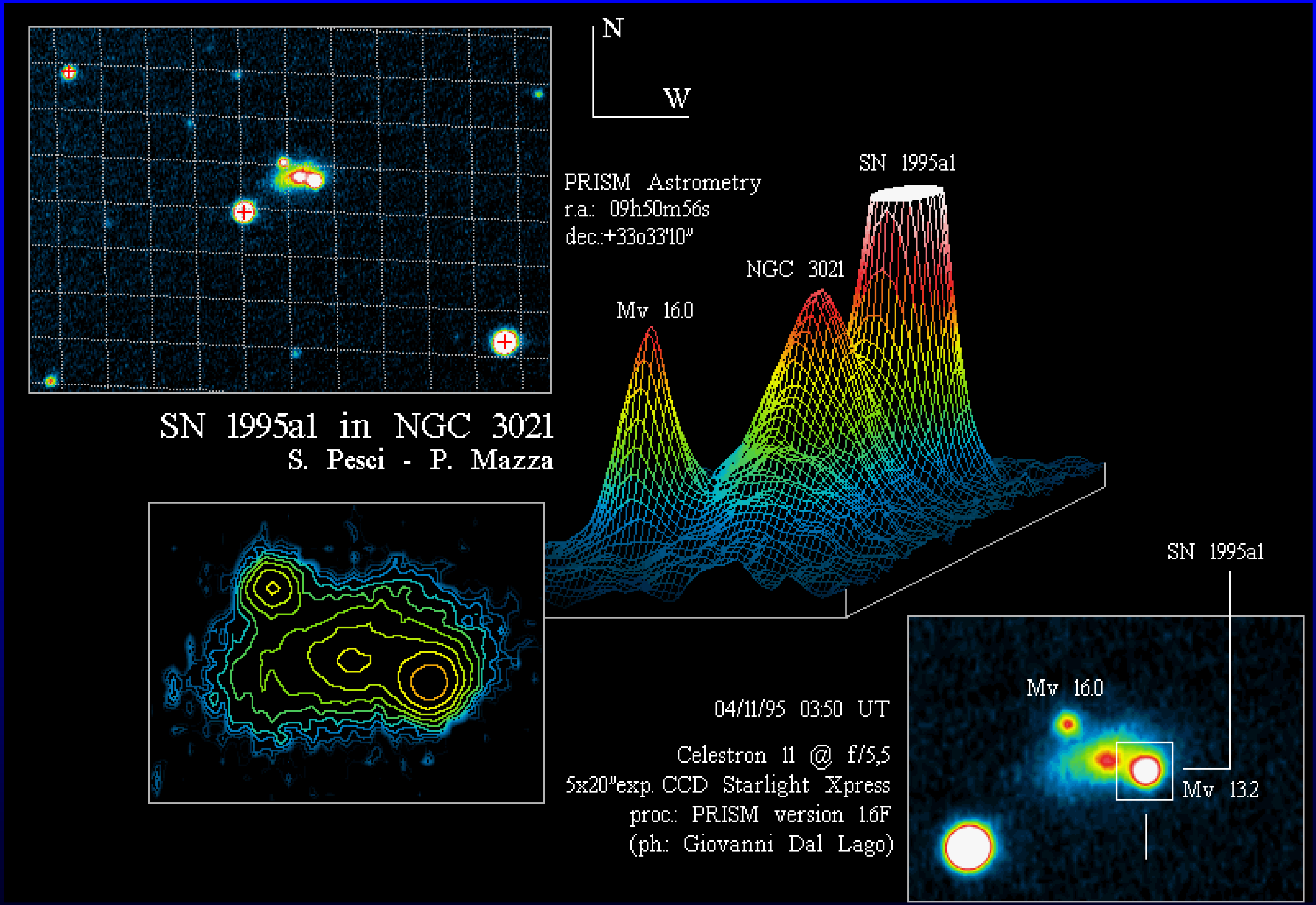


NGC 3021

- Cepheid Variables and site of a Type 1a Supernova observed in 1995.

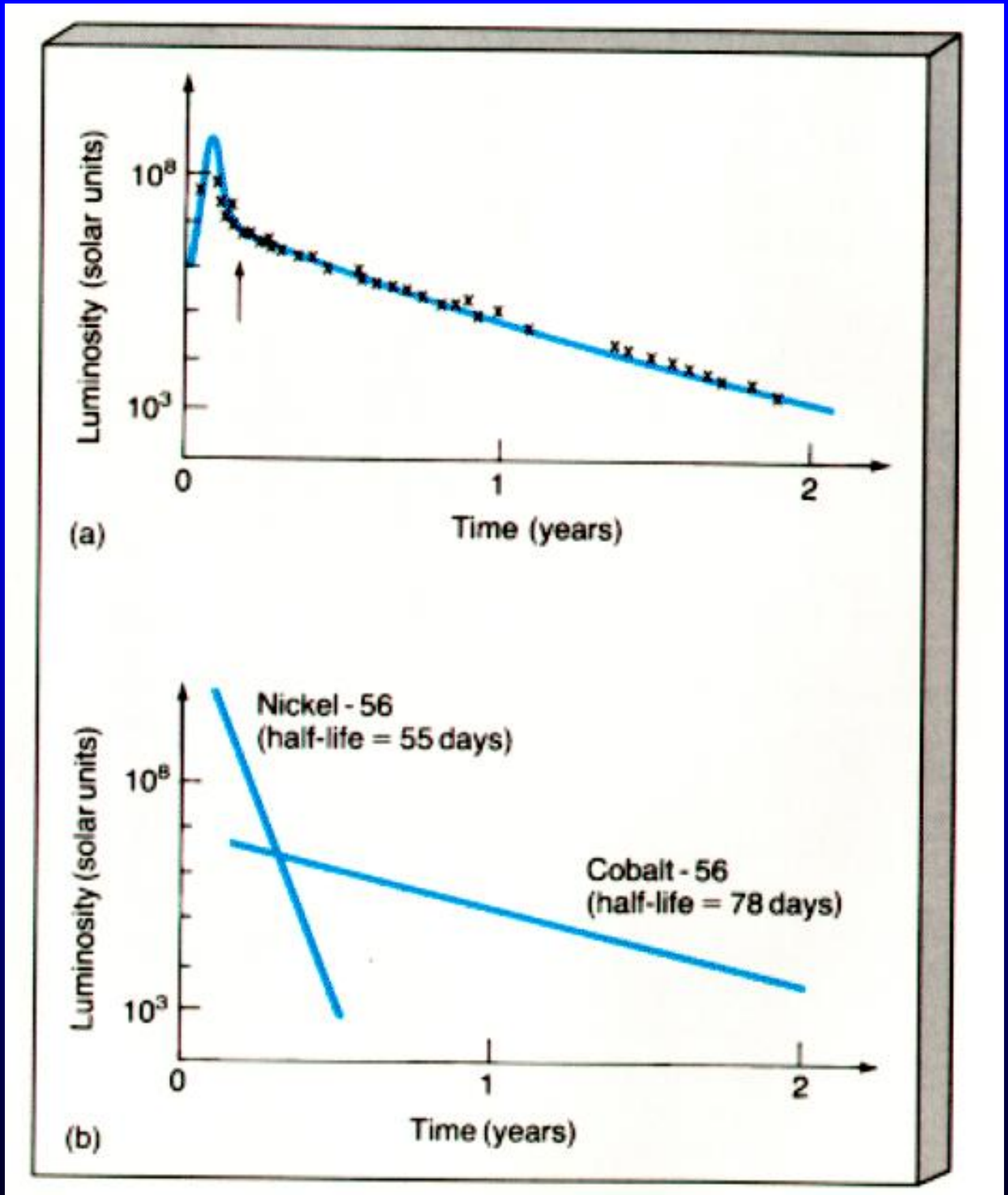


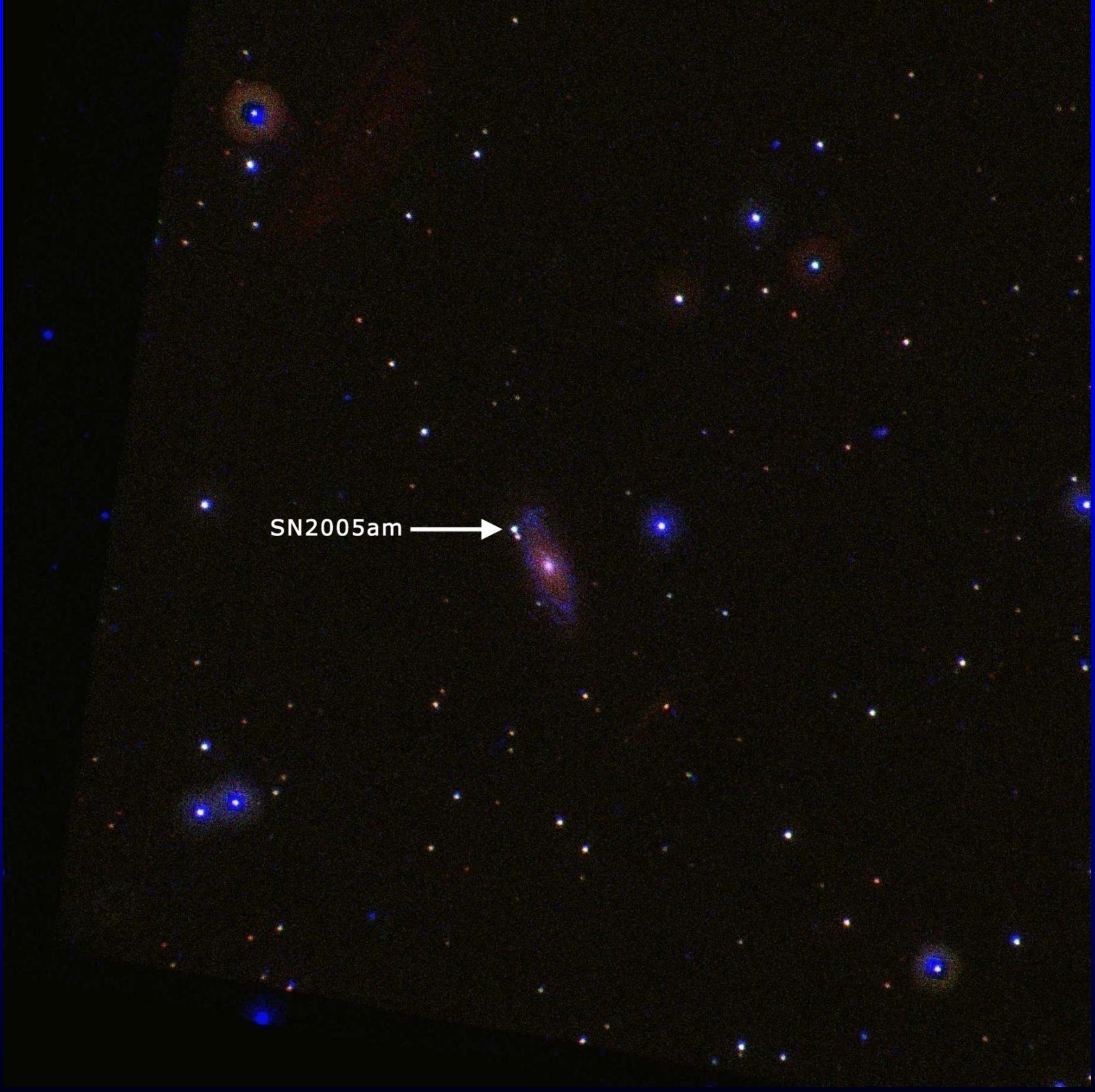
SN1995al

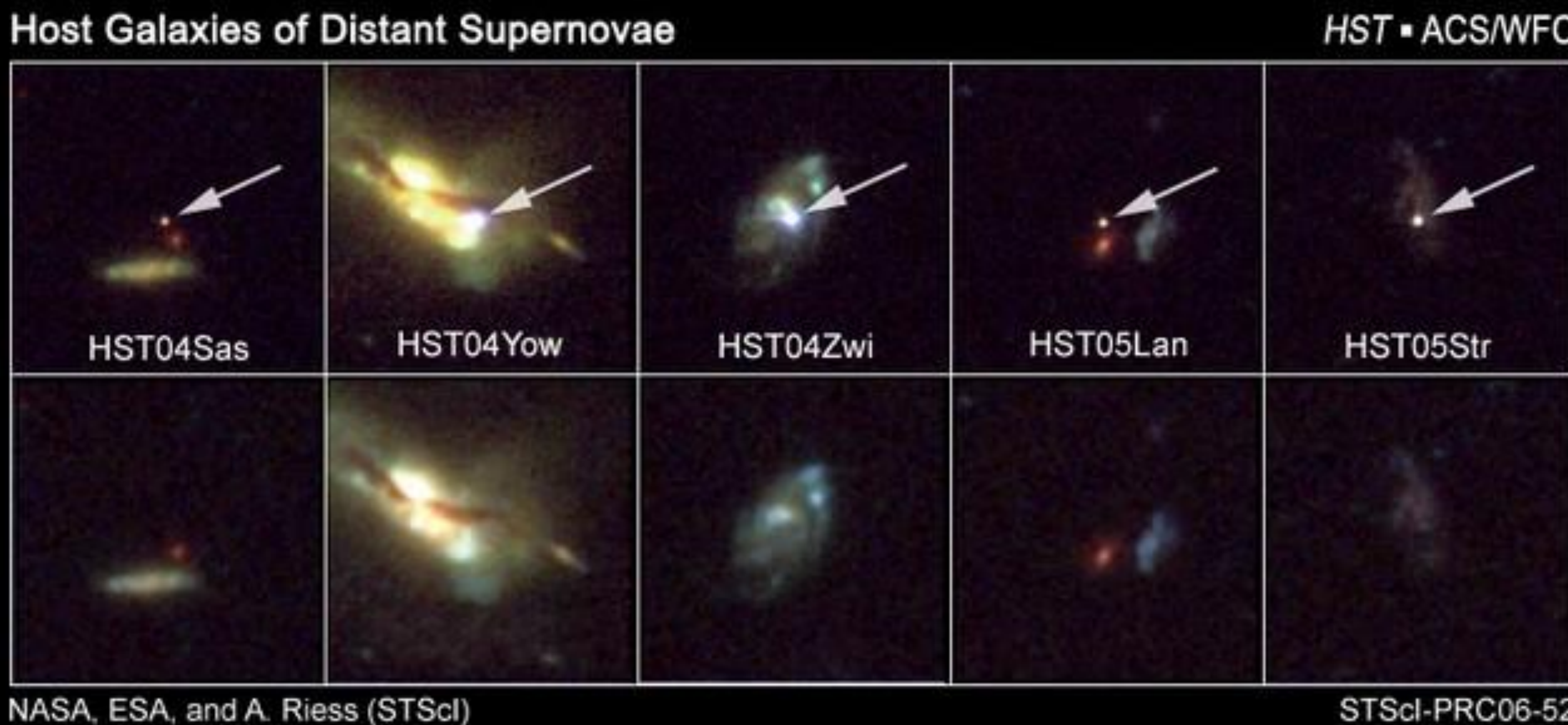

N
W
PRISM Astrometry
r.a.: 09h50m56s
dec.:+33o33'10"
SN 1995al
NGC 3021
Mv 16.0
SN 1995al in NGC 3021
S. Pesci - P. Mazza
SN 1995al
Mv 16.0
Mv 13.2
04/11/95 03:50 UT
Celestron 11 @ f/5,5
5x20"exp. CCD Starlight Xpress
proc.: PRISM version 1.6F
(ph.: Giovanni Dal Lago)

Type 1a

- Decay of Ni-56 followed by the decay of Co-56



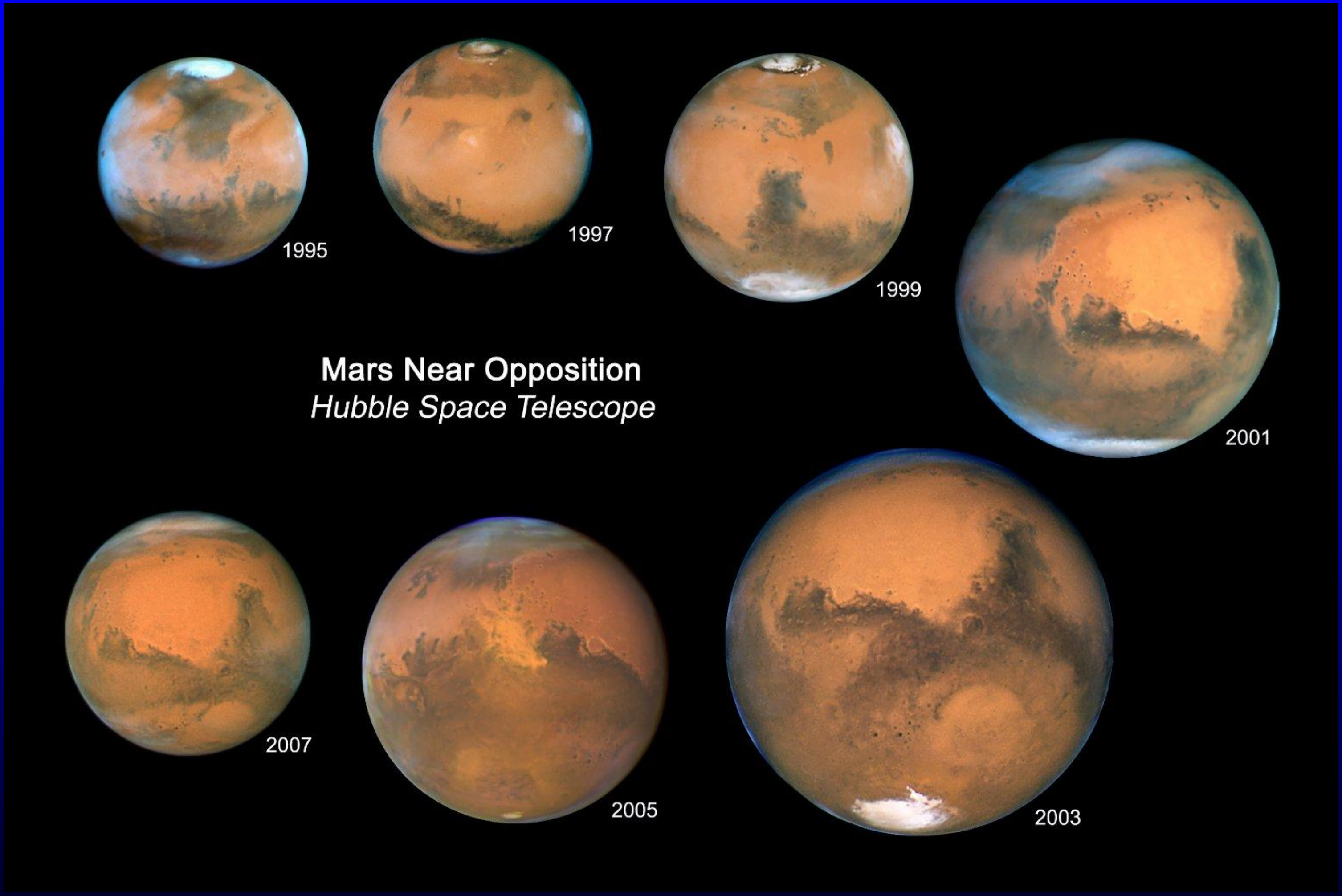

SN2005am

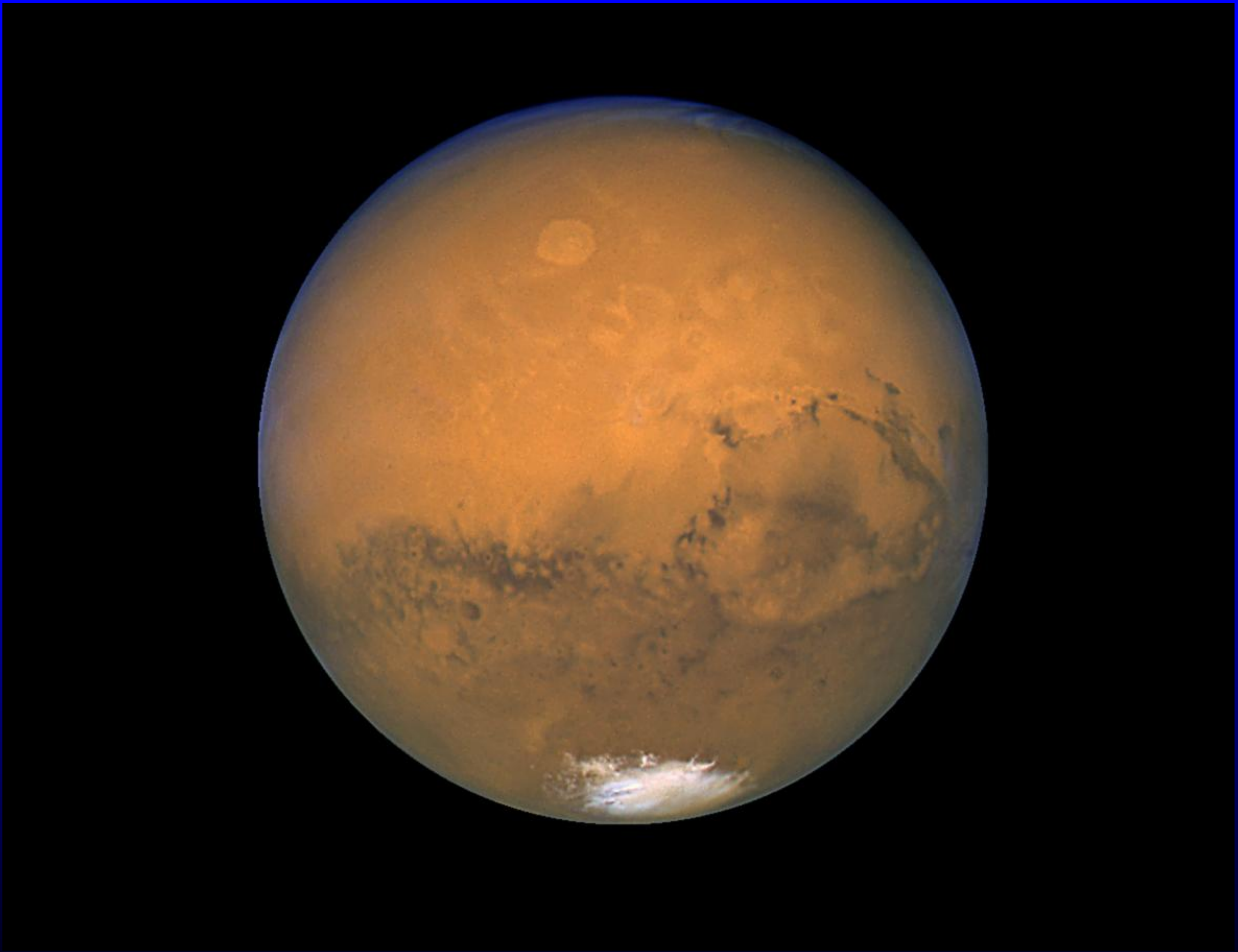

Host Galaxies of Distant Supernovae
HST ▪ ACS/WFC
HST04Sas
HST04Yow
HST04Zwi
HST05Lan
HST05Str
NASA, ESA, and A. Riess (STScI)
STScI-PRC06-52

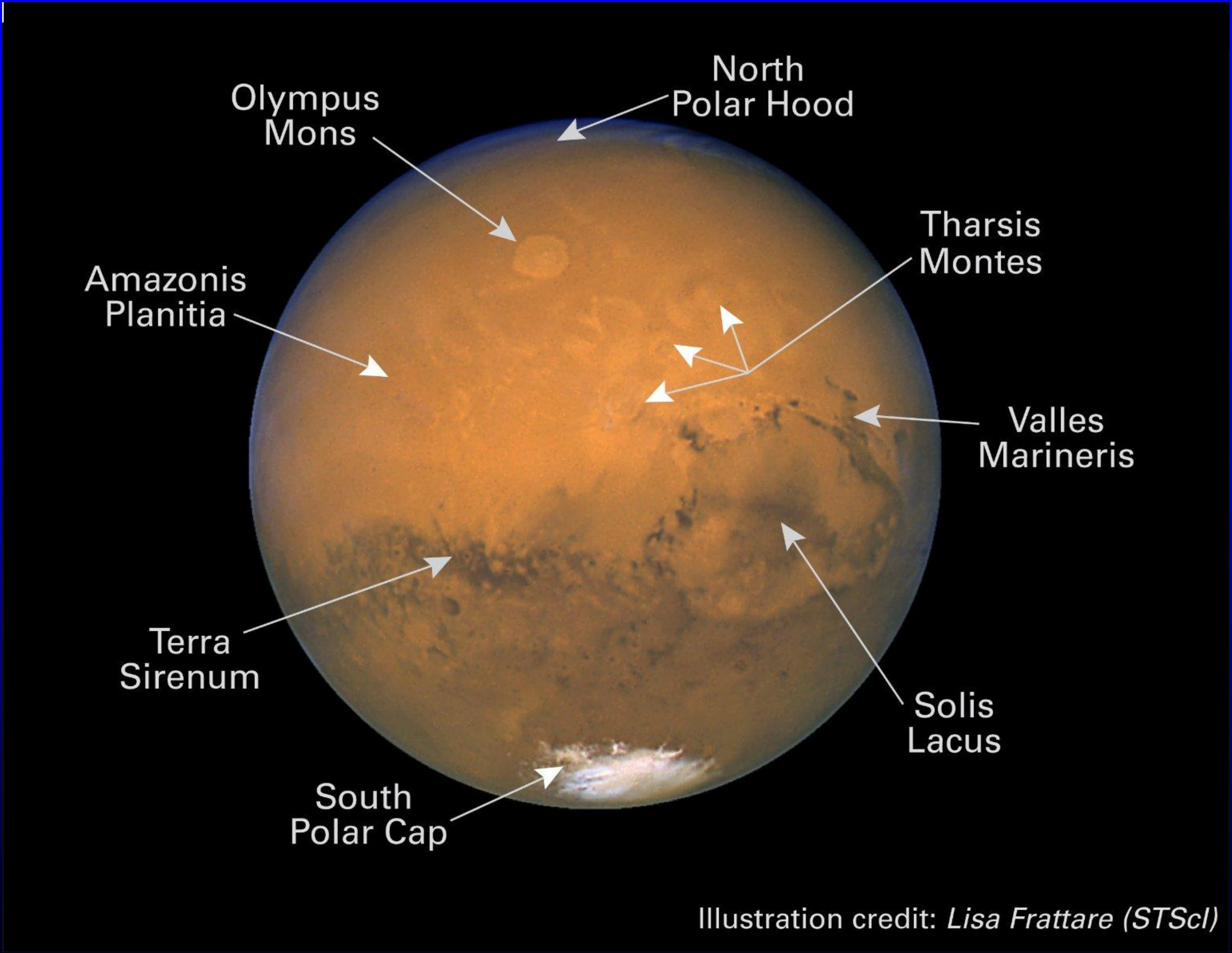
Our Solar System and Extra-solar Planets

1) Mars, Pluto and Comet Shoemaker-Levy 9

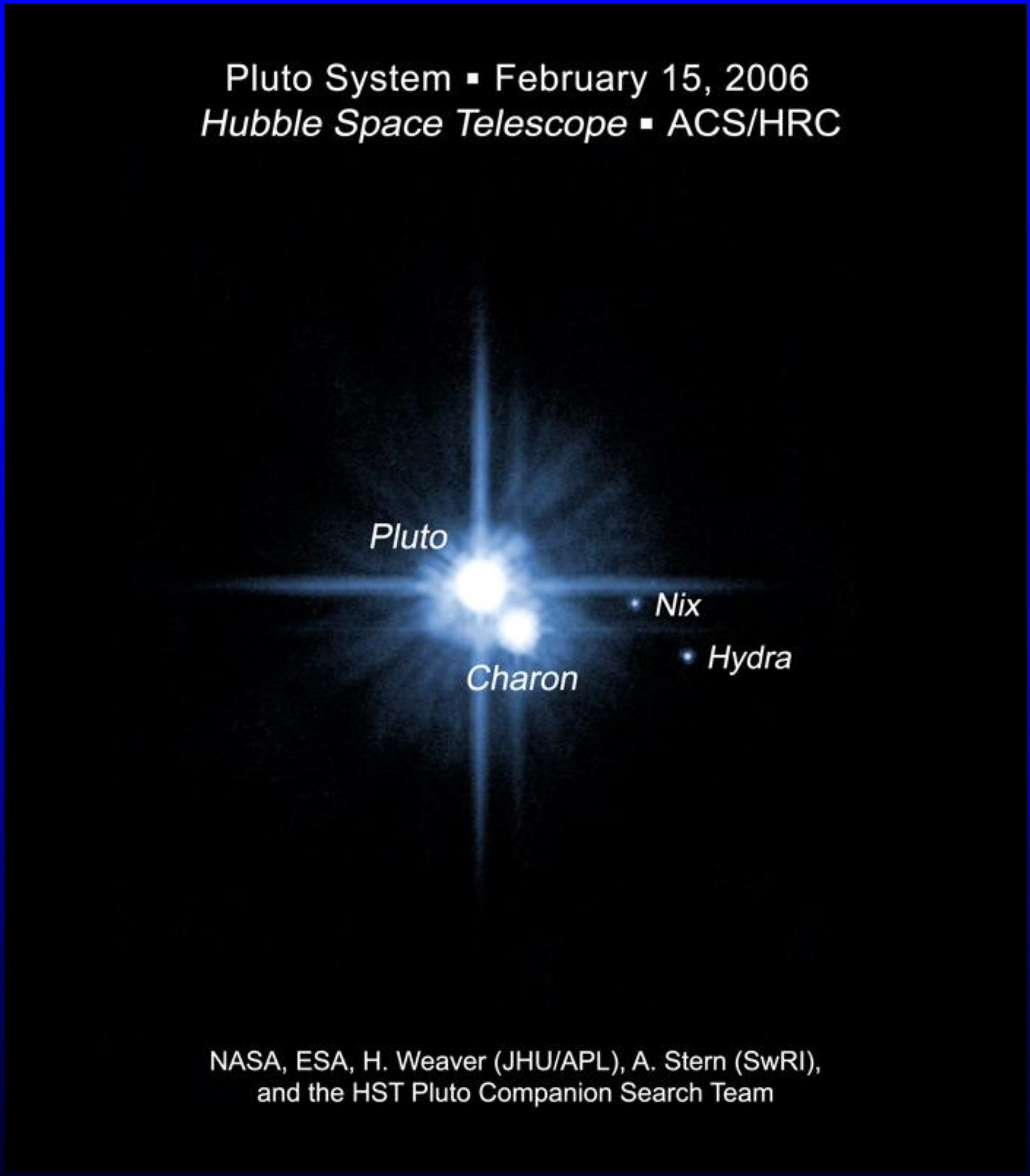
Mars at Closest Approach





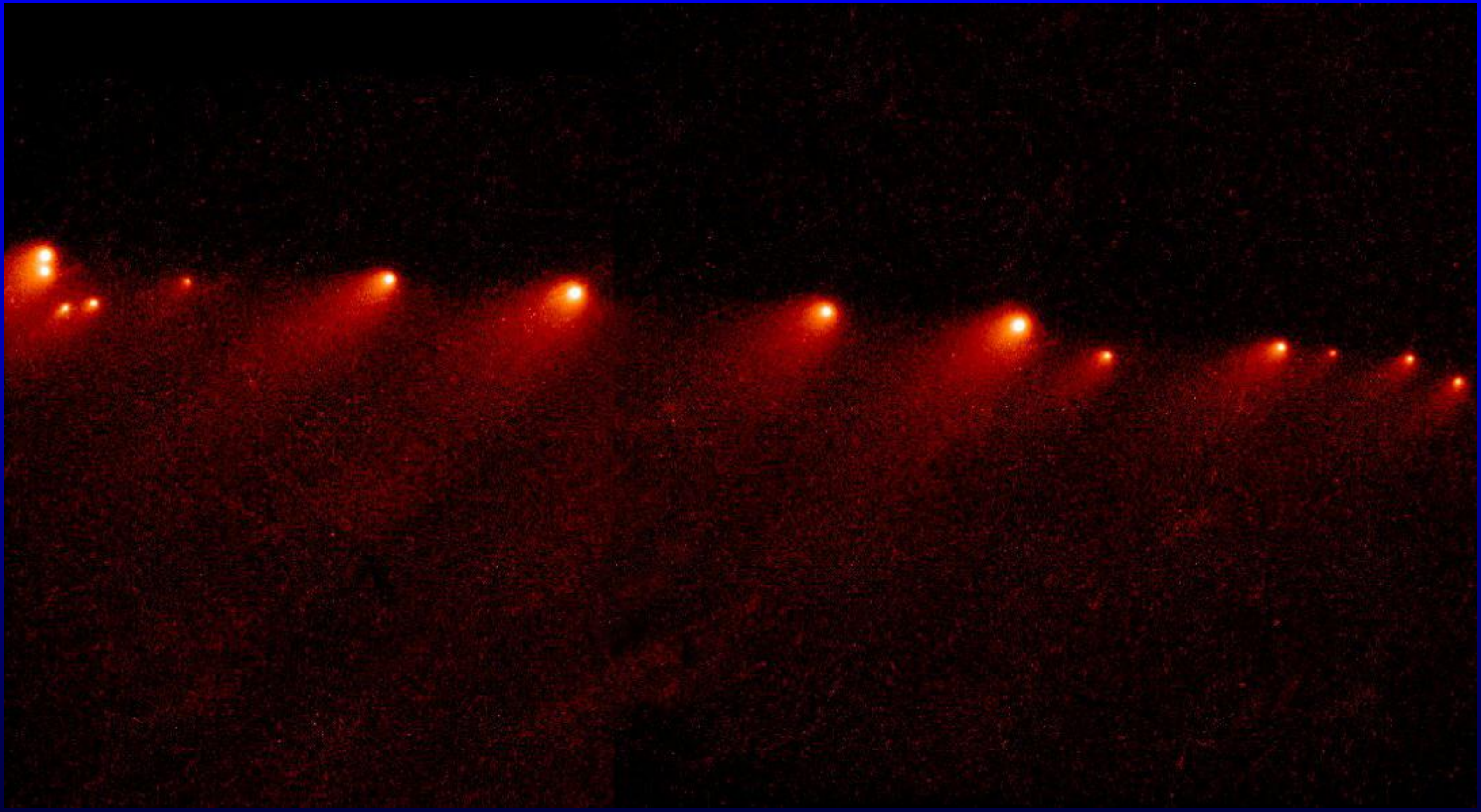

North
Polar Hood
Olympus
Mons
Tharsis
Montes
Amazonis
Planitia
Valles
Marineris
Terra
Sirenum
Solis
Lacus
South
Polar Cap
Illustration credit: *Lisa Frattare (STScI)*

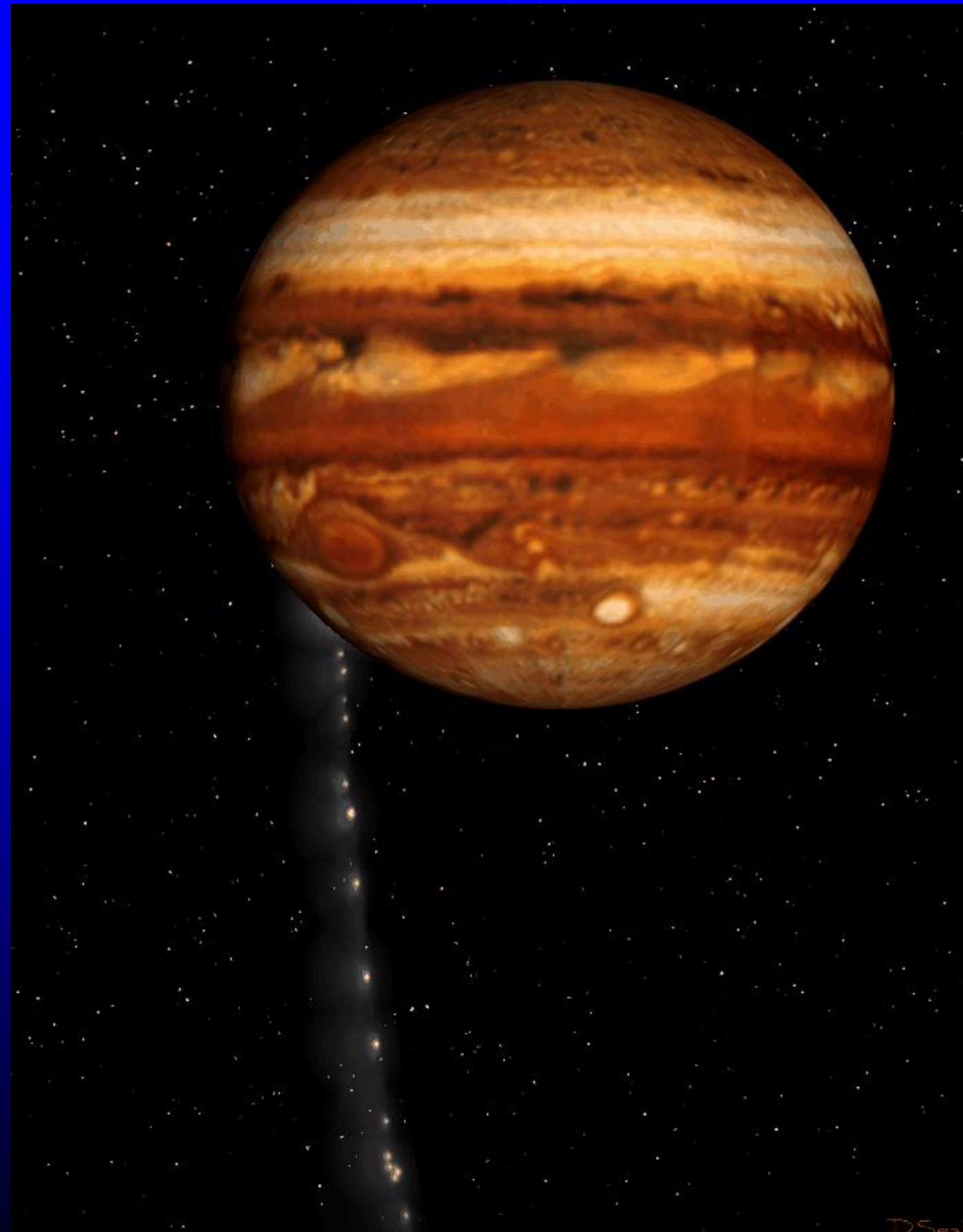
Pluto

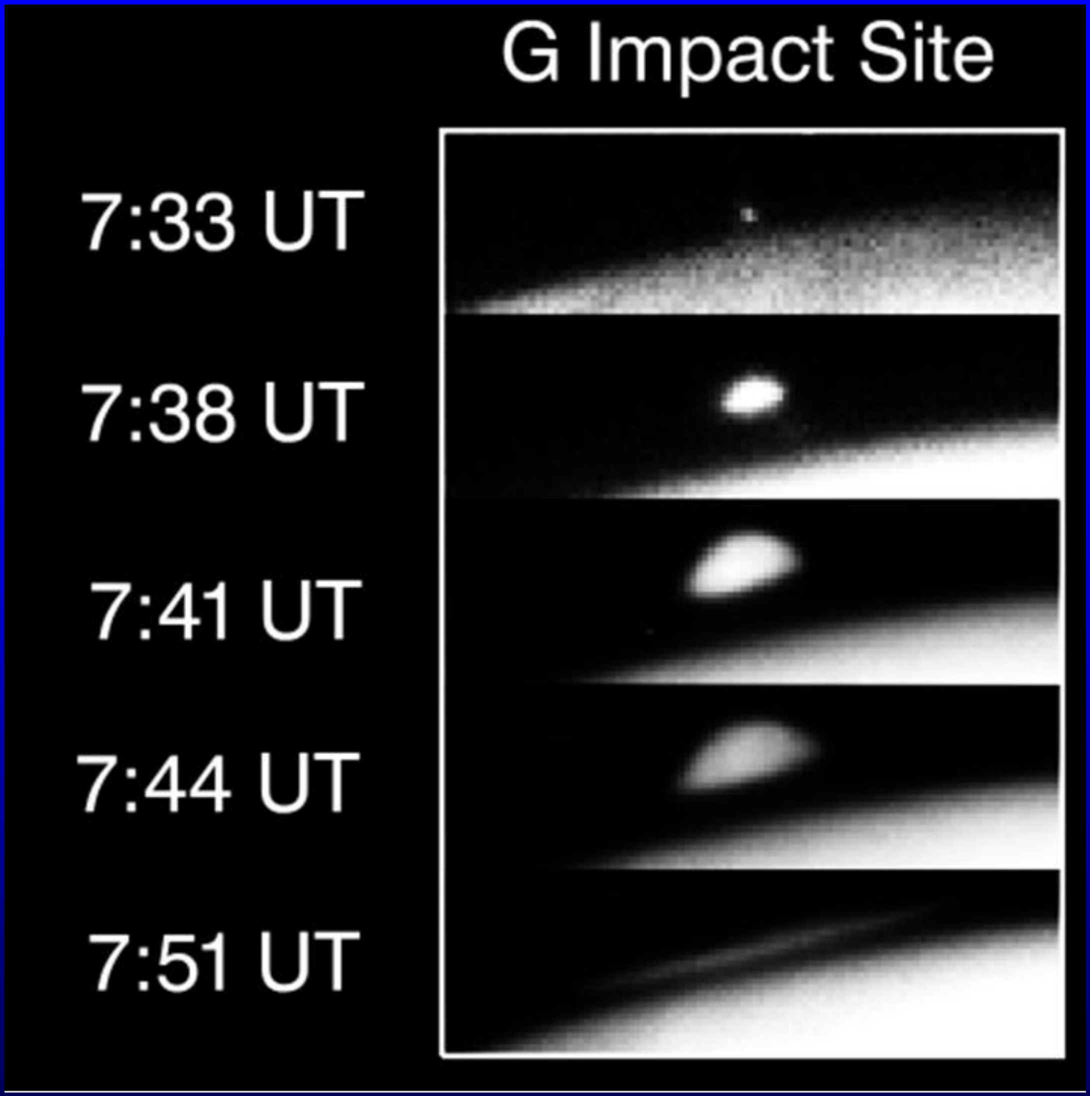


Pluto System ▪ February 15, 2006
Hubble Space Telescope ▪ ACS/HRC
Pluto
Nix
Hydra
Charon
NASA, ESA, H. Weaver (JHU/APL), A. Stern (SwRI),
and the HST Pluto Companion Search Team

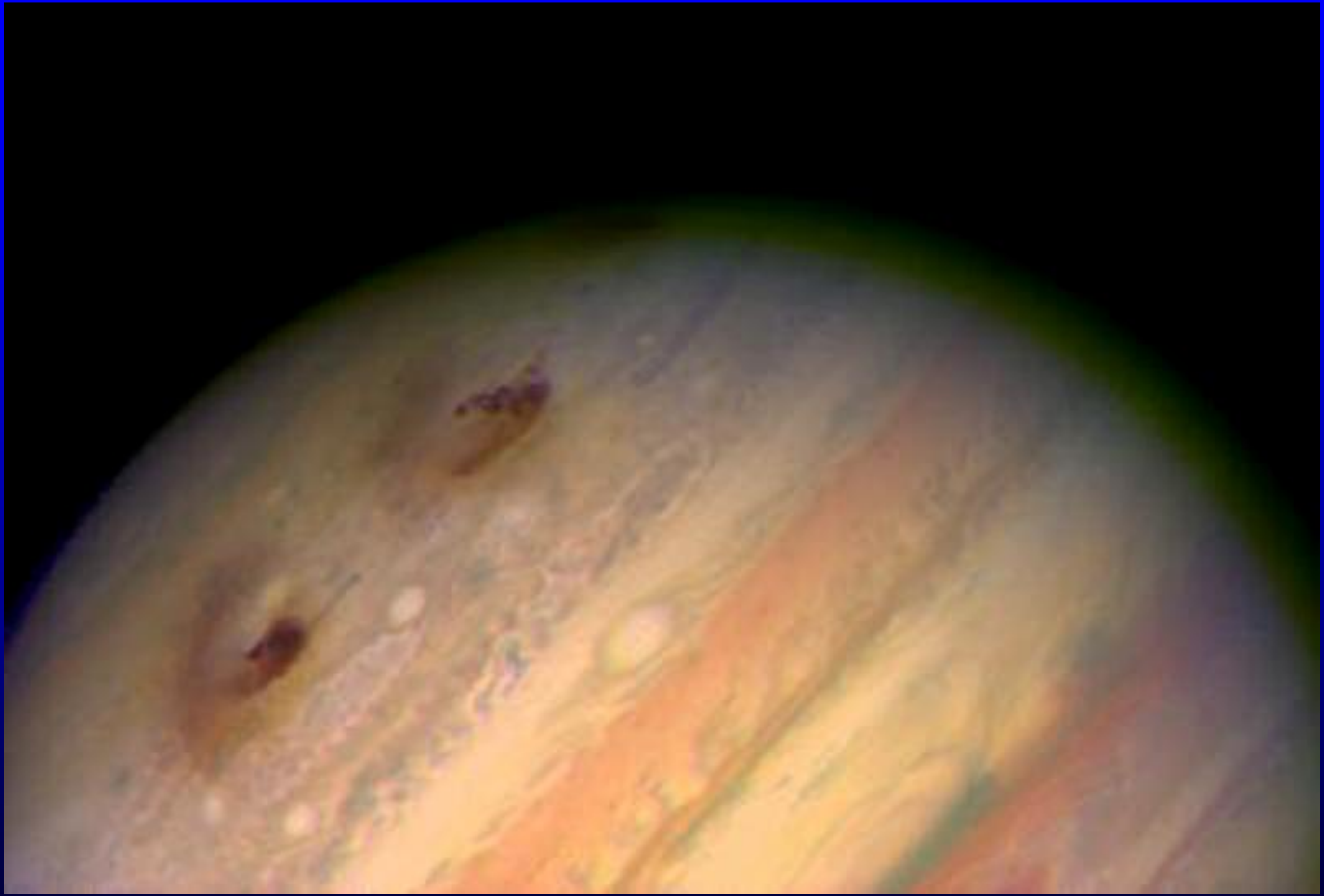
Comet Shoemaker-Levey 9




D Seal

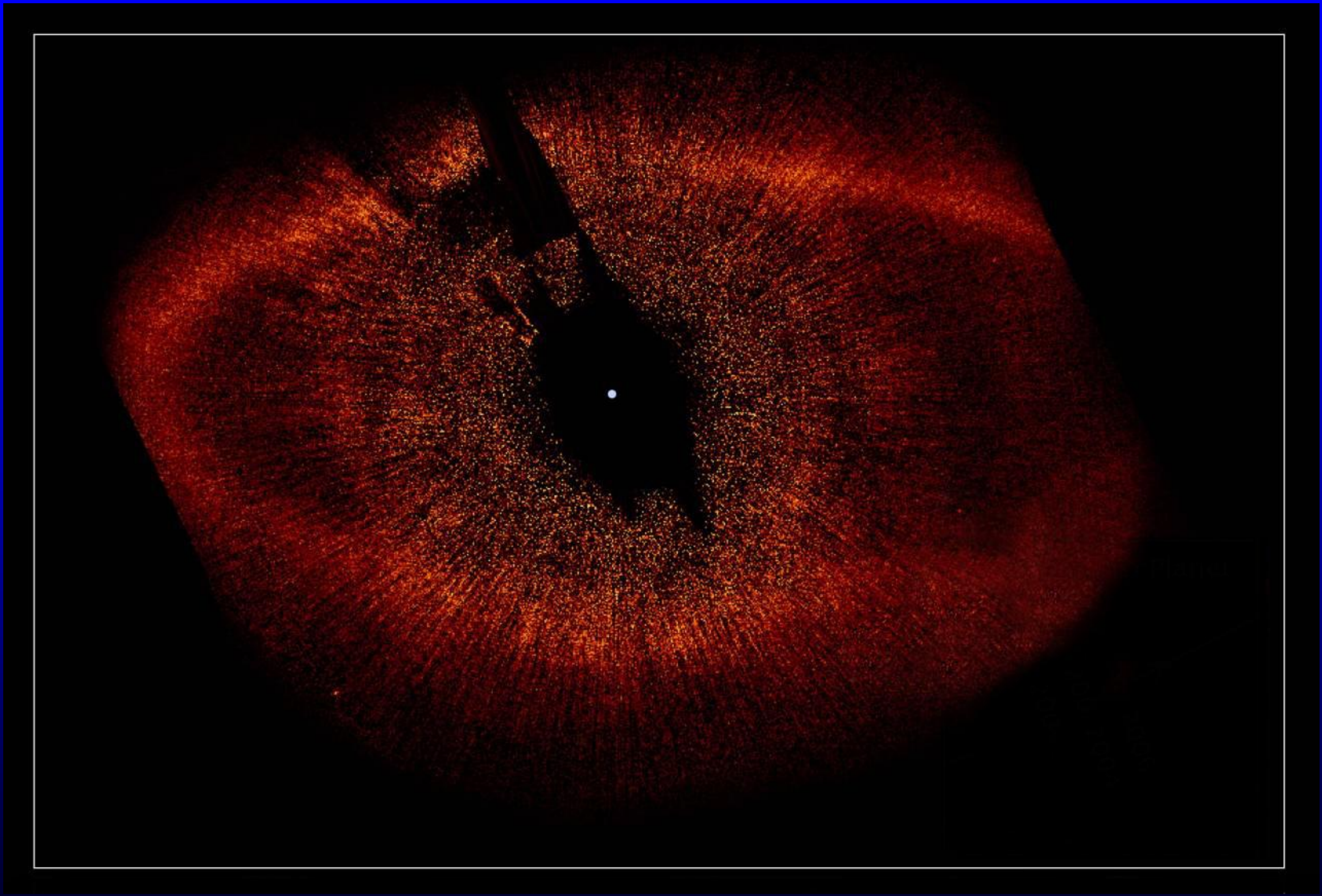


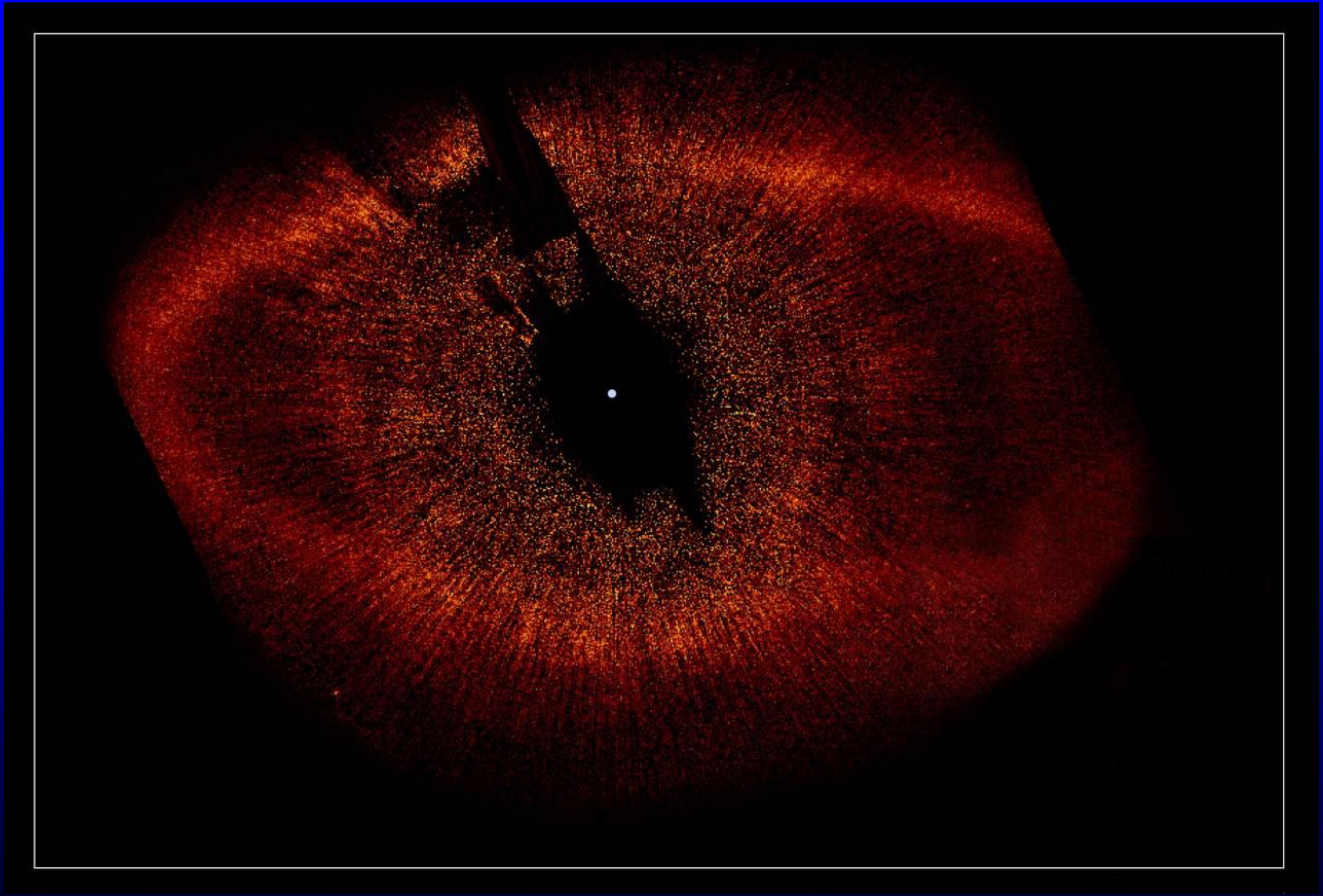
Hubble observed the fireball

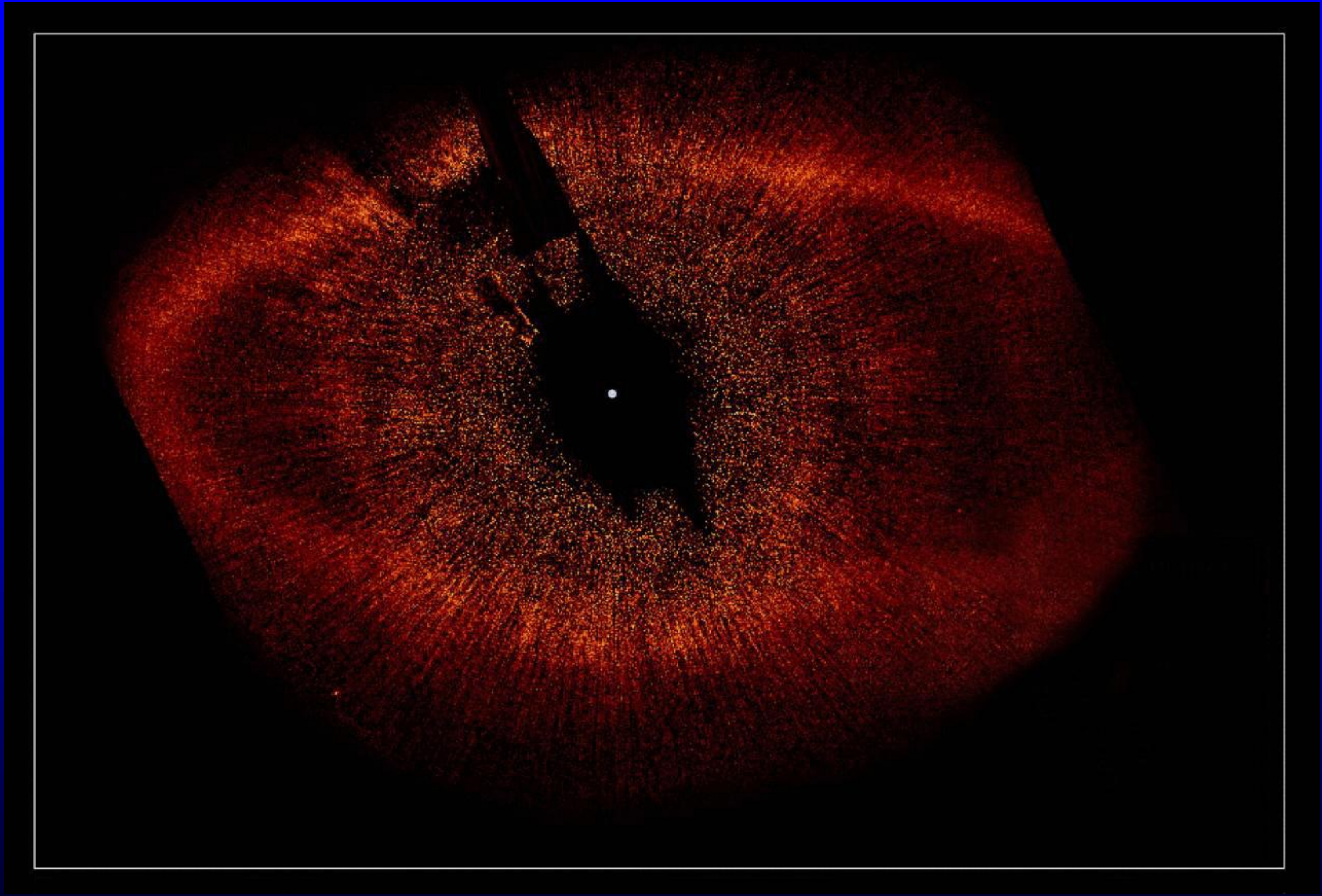


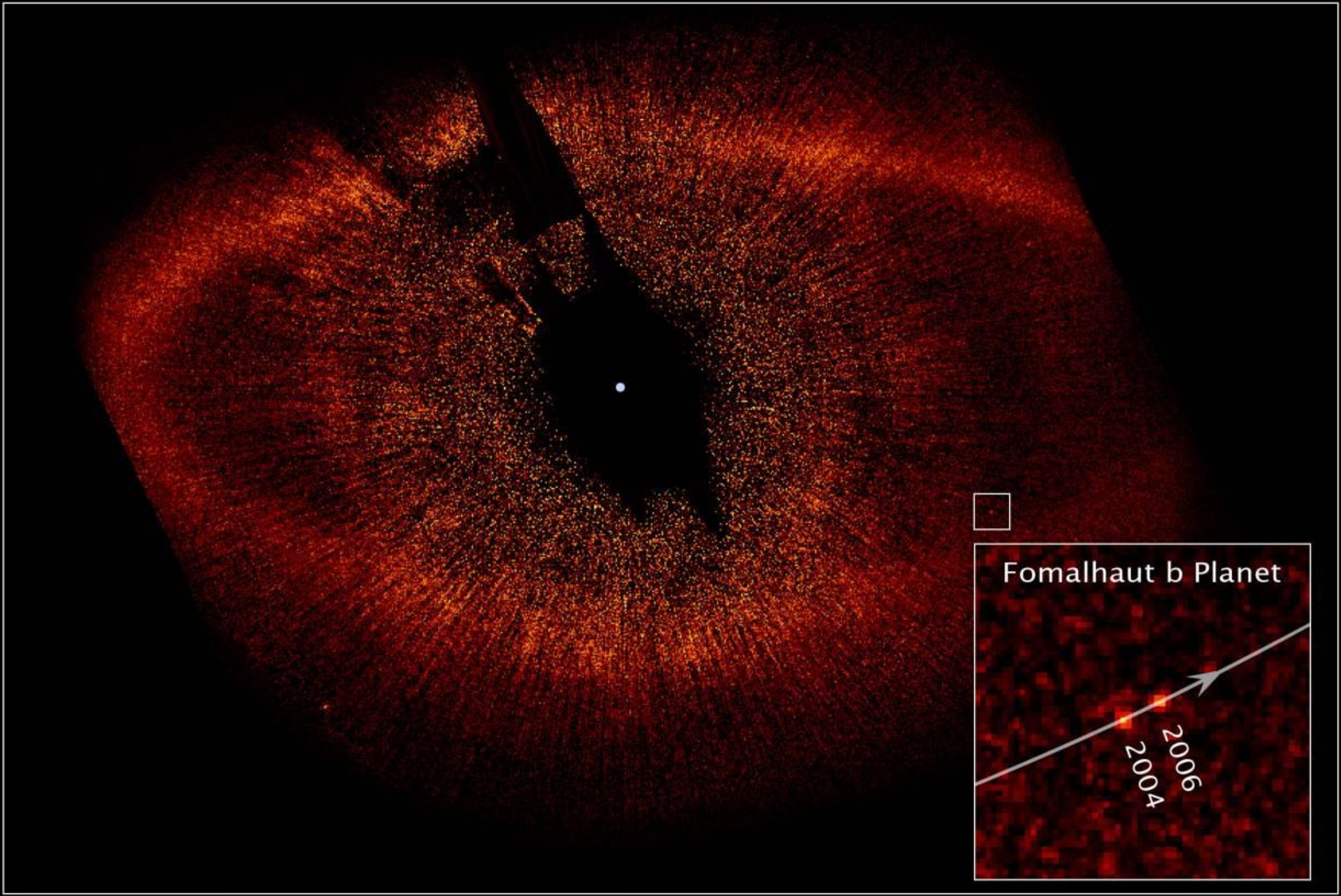
Our Solar System and Extra-solar Planets

2) Visual Discovery of the planet orbiting Formalhaut.








Fomalhaut b Planet
2006
2004

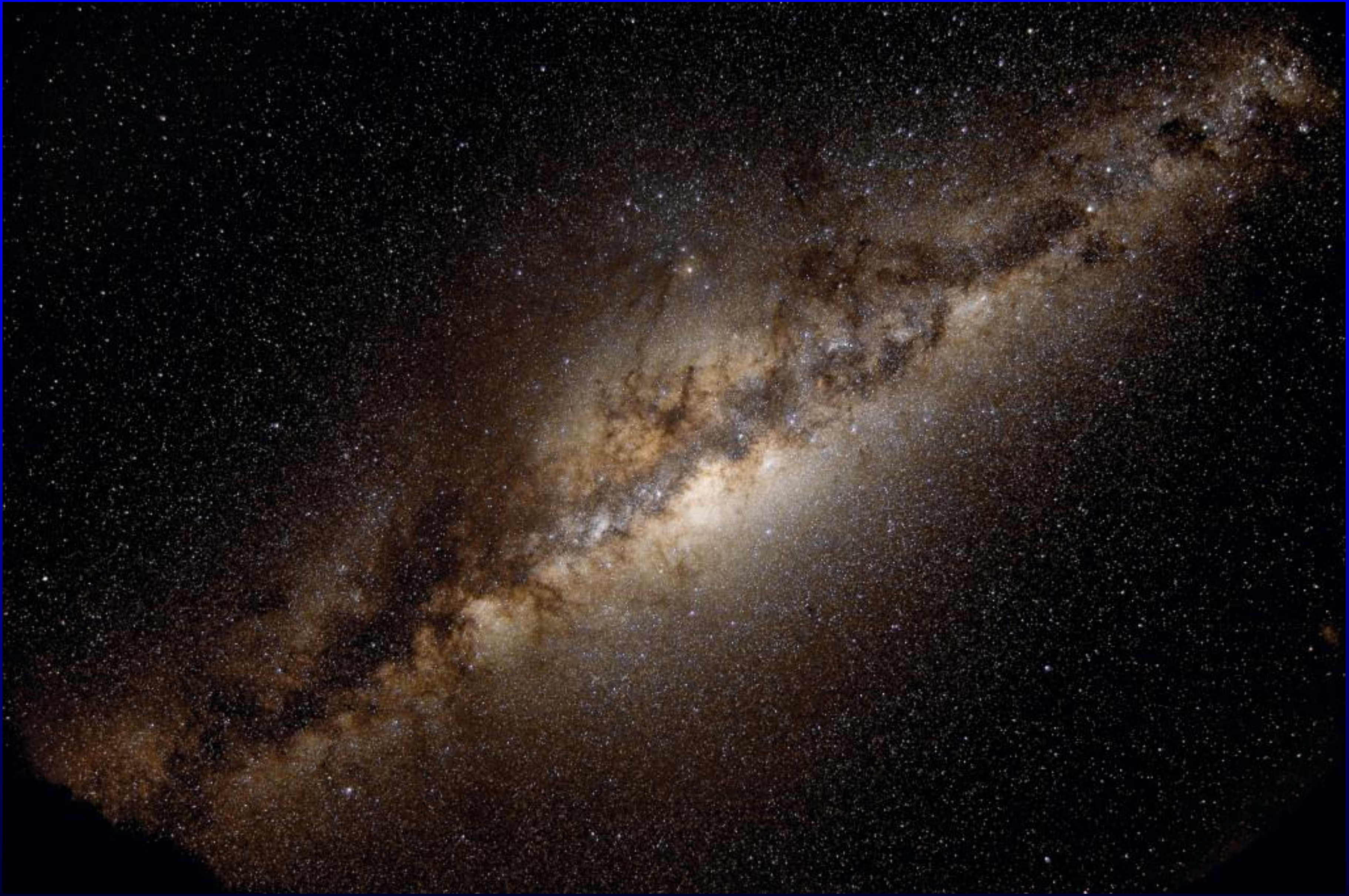
Our Solar System and Extra-Solar Planets

3) Discovery of 16 planets towards the Galactic Centre

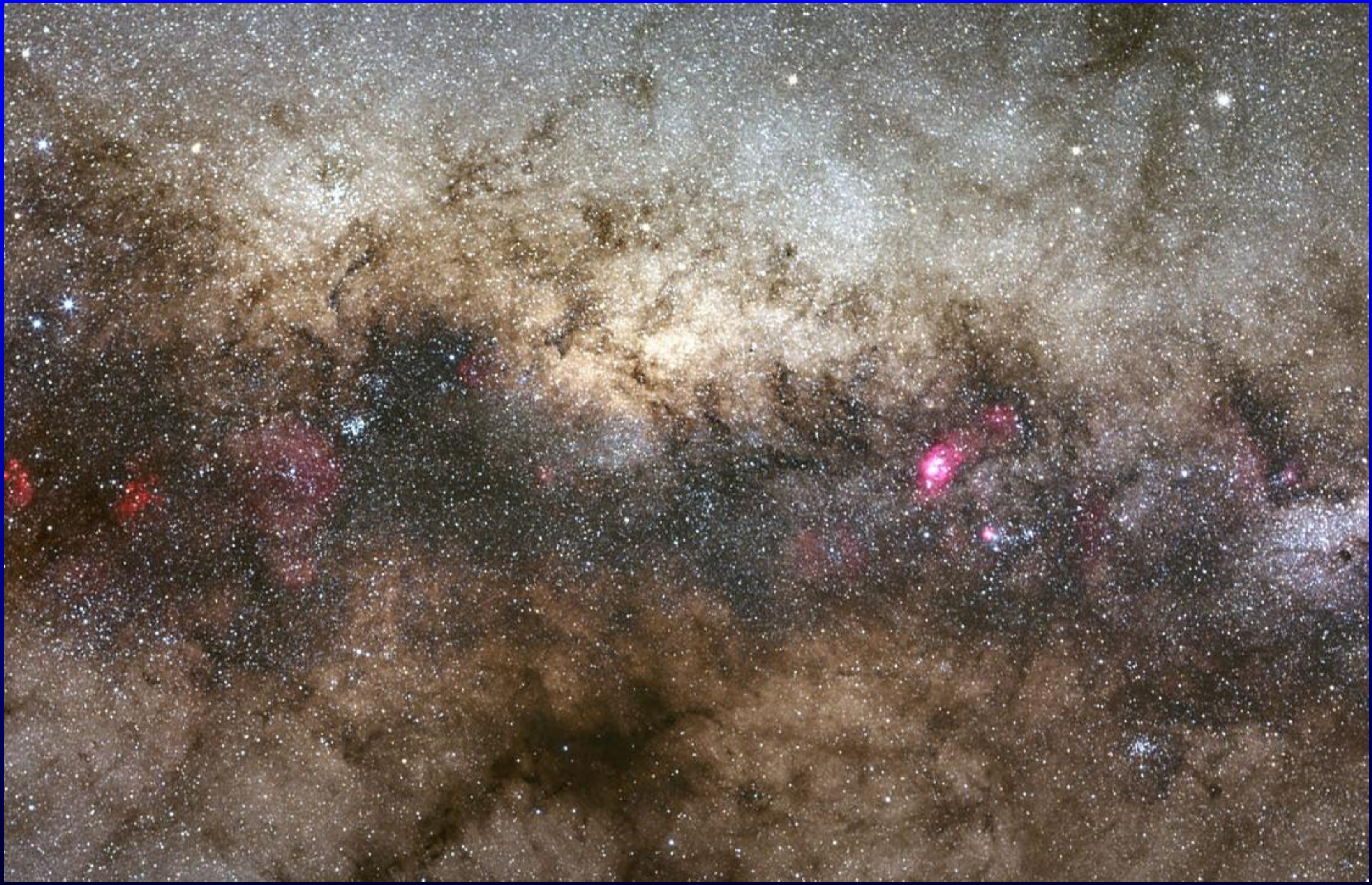
SWEEPS

Sagittarius Window Extra-solar Eclipsing Planet Search

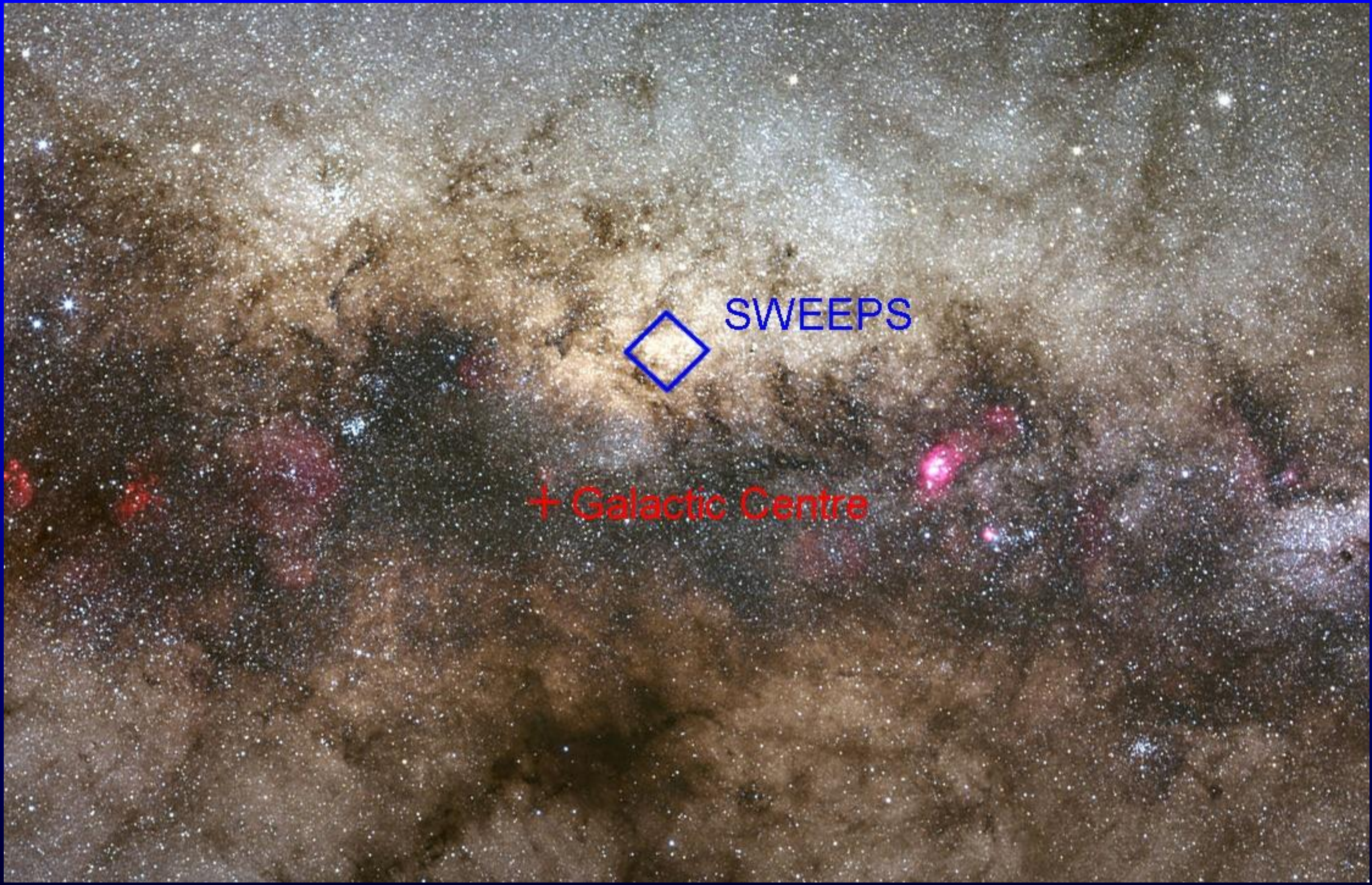
Astronomers wanted to find out if planets were also to be found orbiting stars near the centre of the galaxy.



A problem - Dust



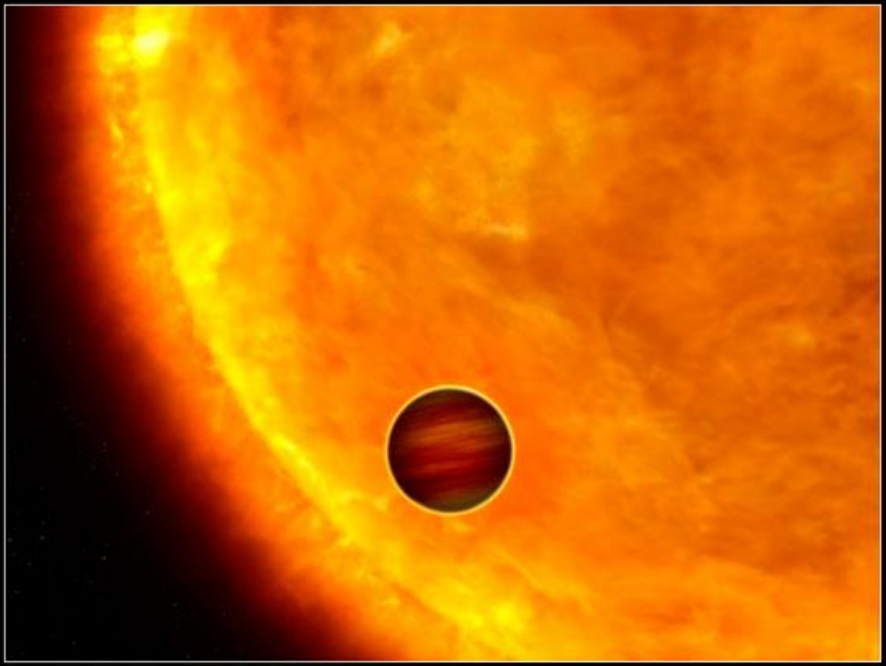
Baard's Window


SWEEPS
+ Galactic Centre

SWEEPS

- Hubble monitored 180,000 stars within Baard’s Window continuously for a seven day period in 2004 looking for the slight dimming of light due to planetary transits.

SWEEPS Movie

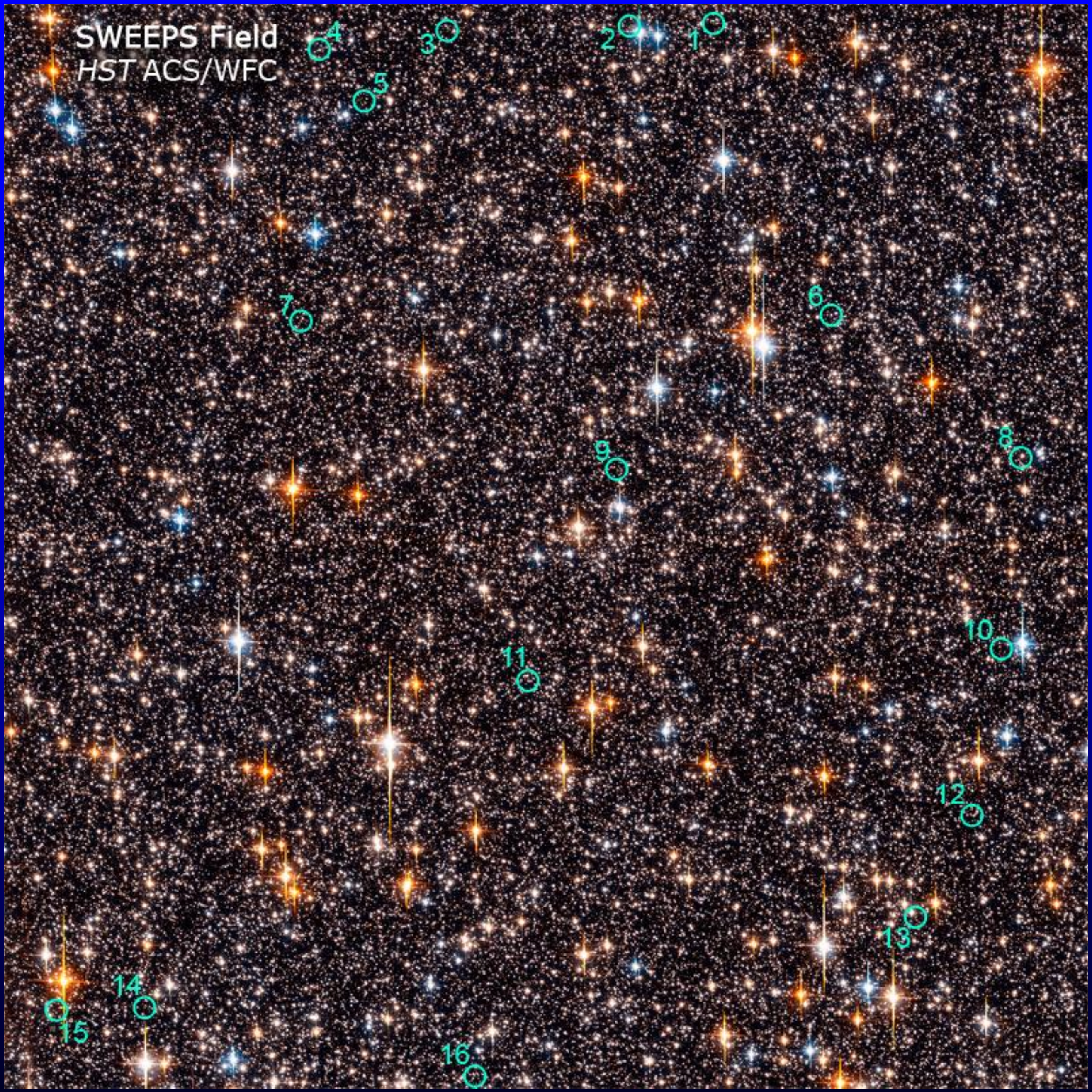


Artist's View of a Transiting Extrasolar Planet

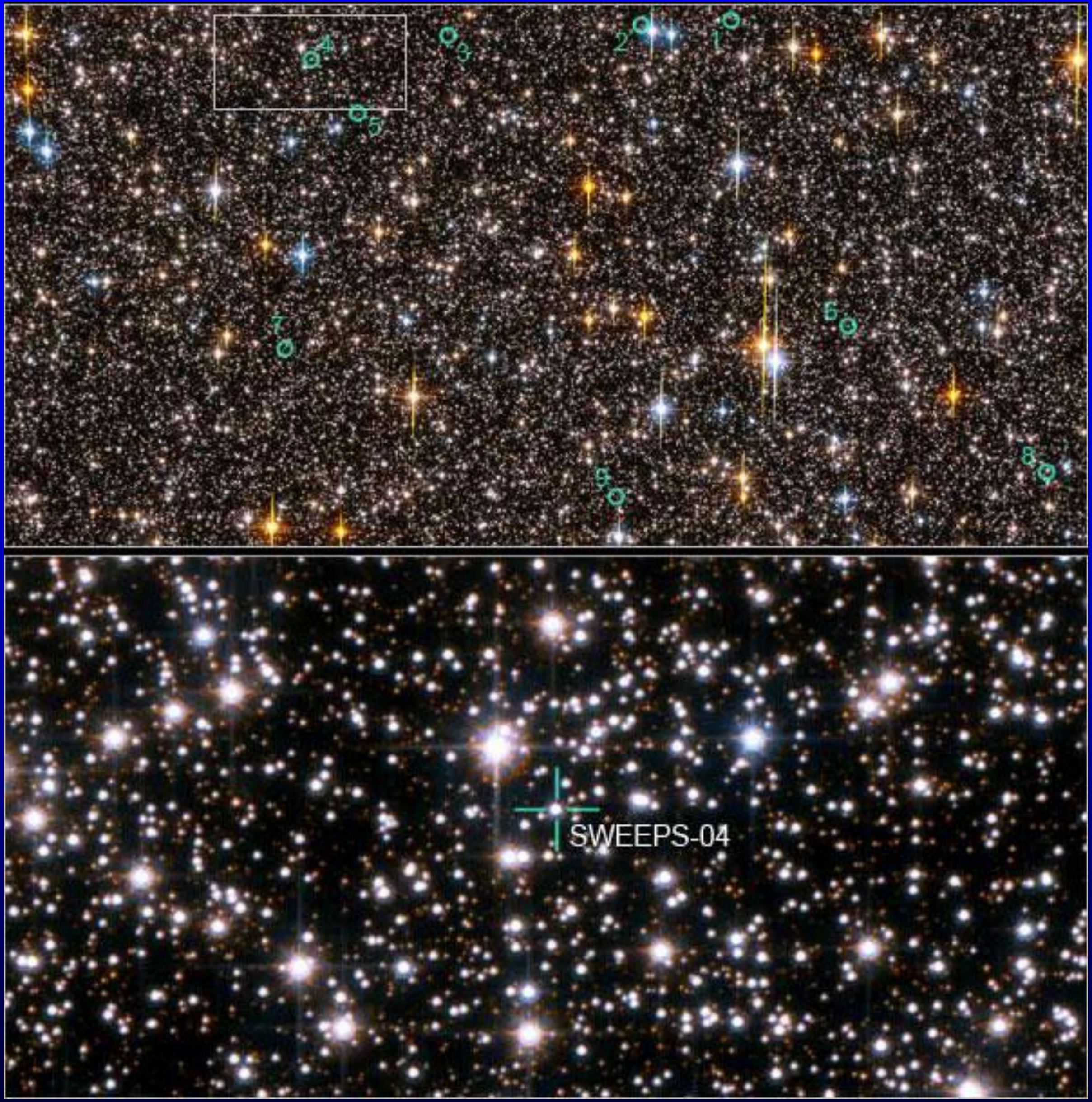
NASA, ESA, and G. Bacon (STScI) ▪ STScI-PRC06-34b

Artist's View of an Ultra-Short-Period Planet

NASA, ESA, and A. Schaller ▪ STScI-PRC06-34c

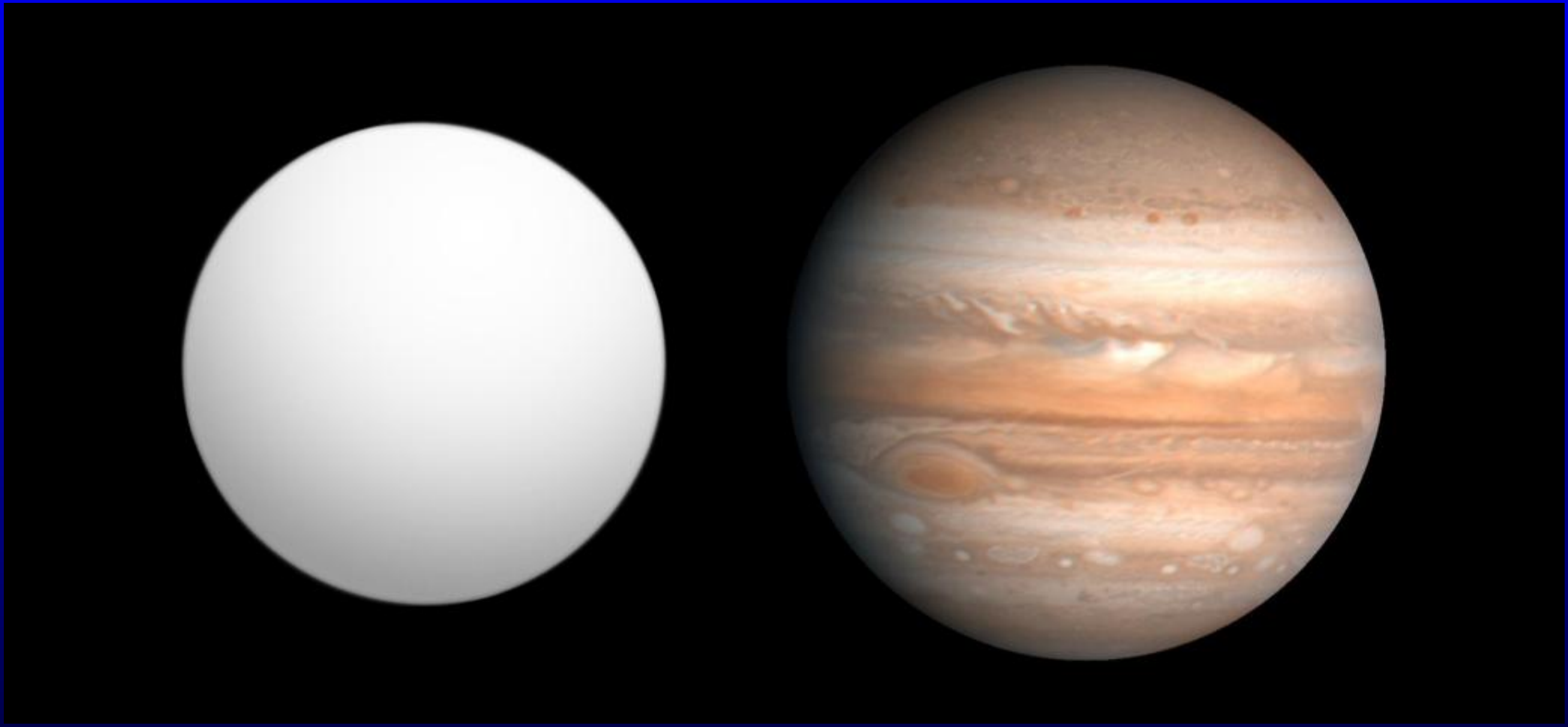

SWEEPS Field
HST ACS/WFC
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

- Two of the 16 observed planets have been confirmed by radial velocity measurements.

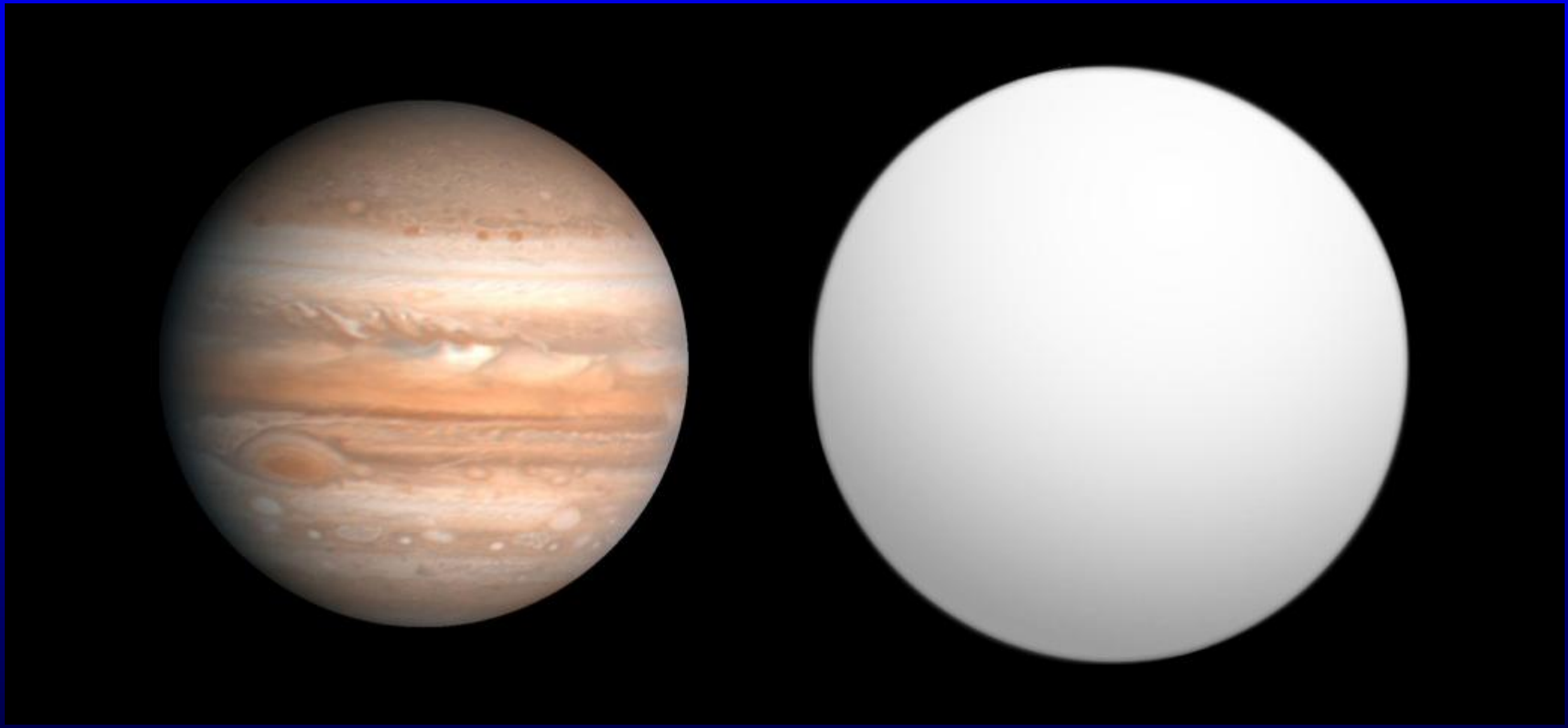


SWEEPS 4

Period ~4 days Mass ~ 3.8M_J



SWEEPS 11
Period ~1.8 days Mass ~ 9.7 M_J

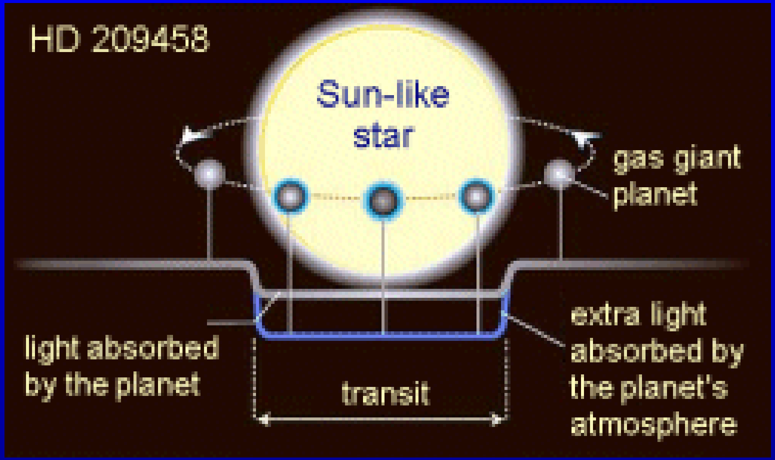


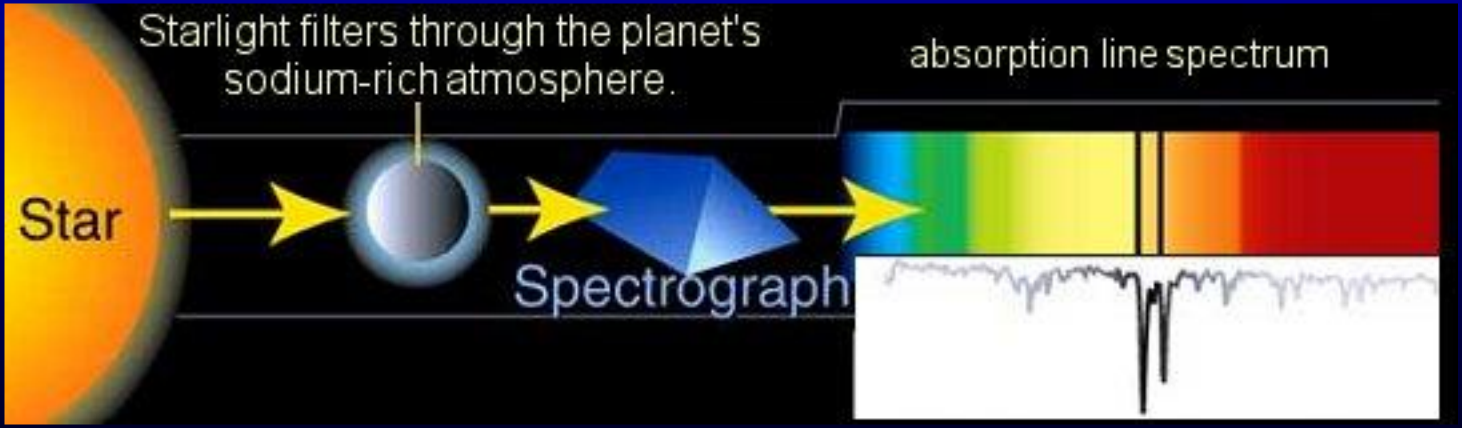
Our Solar System and Extra-solar Planets

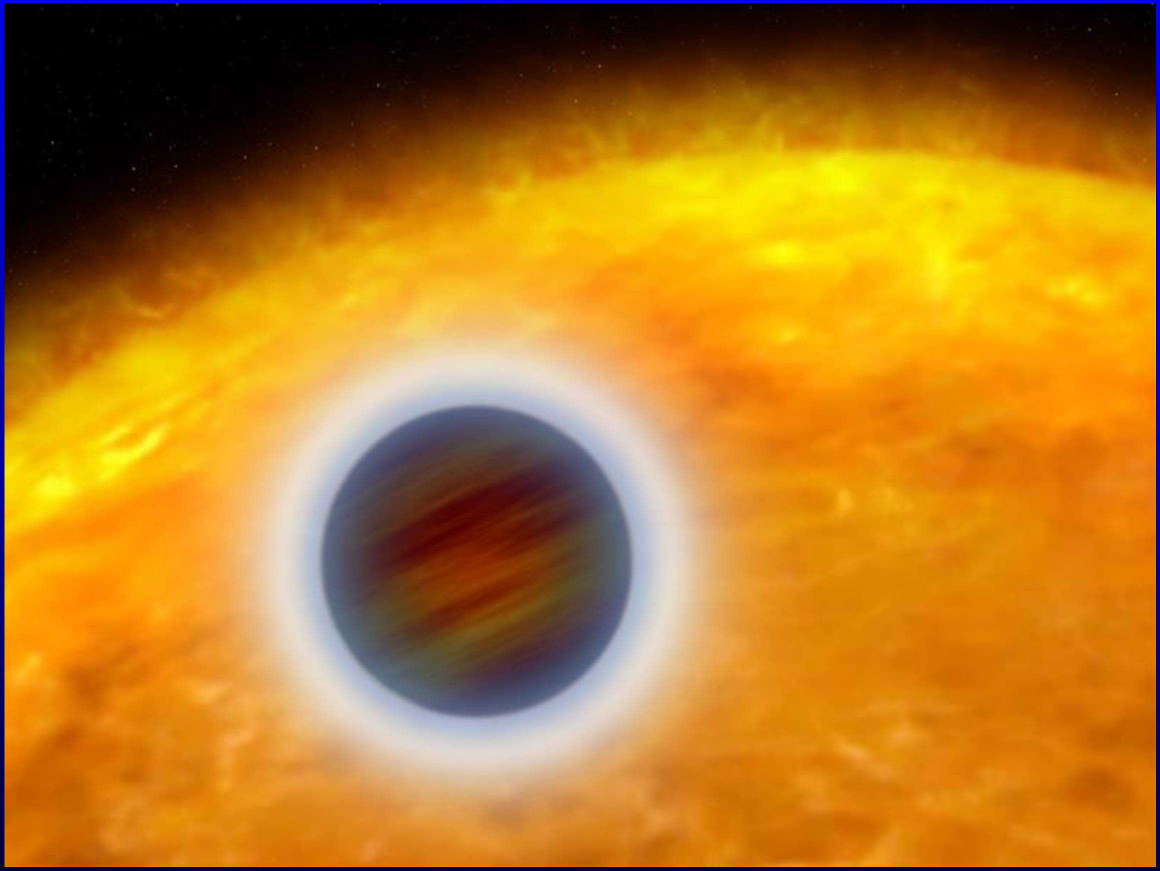
4) Investigating the atmospheres of exoplanets

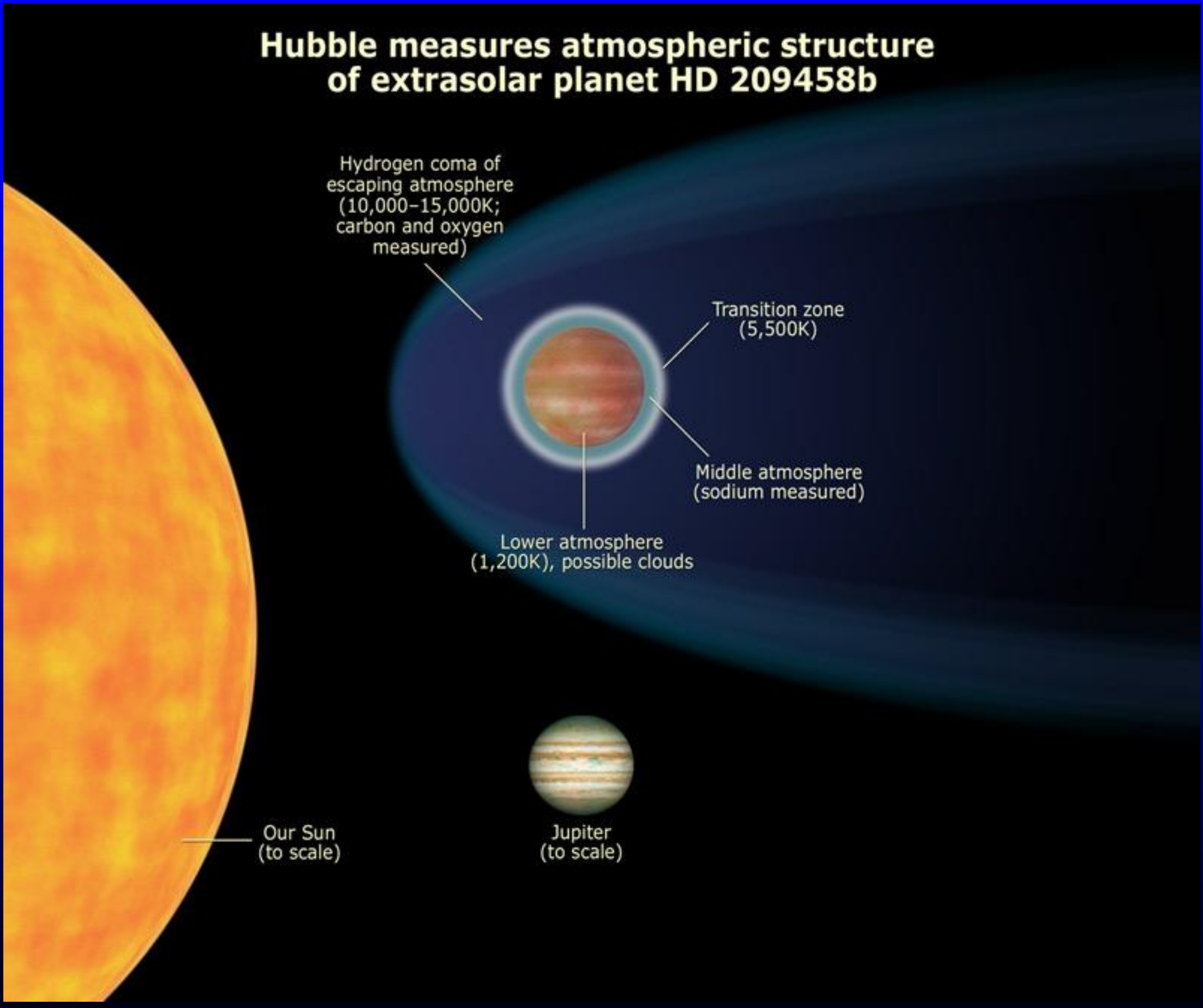
HD 20945b


Artist's View of Planet around the Star HD 209458
NASA and G. Bacon (STScI) • STScI-PRC01-38


HD 209458
Sun-like star
gas giant planet
light absorbed by the planet
transit
extra light absorbed by the planet's atmosphere


Starlight filters through the planet's sodium-rich atmosphere.
absorption line spectrum
Star
Spectrograph



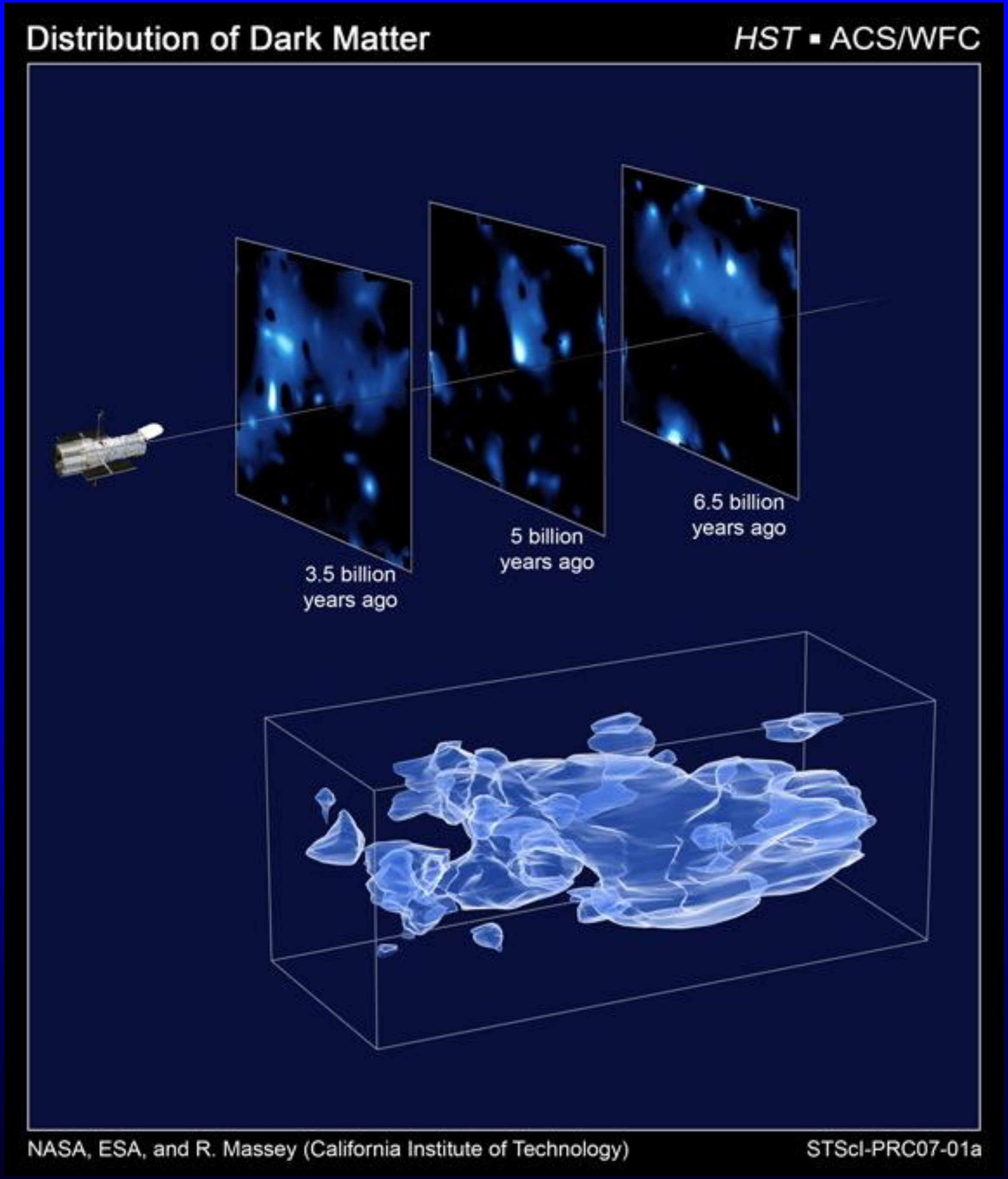

Hubble measures atmospheric structure
of extrasolar planet HD 209458b
Hydrogen coma of
escaping atmosphere
(10,000–15,000K;
carbon and oxygen
measured)
Transition zone
(5,500K)
Middle atmosphere
(sodium measured)
Lower atmosphere
(1,200K), possible clouds
Our Sun
(to scale)
Jupiter
(to scale)

Dark Matter and Dark Energy

Galaxy Cluster Abell 370
Hubble Space Telescope ▪ ACS/WFC

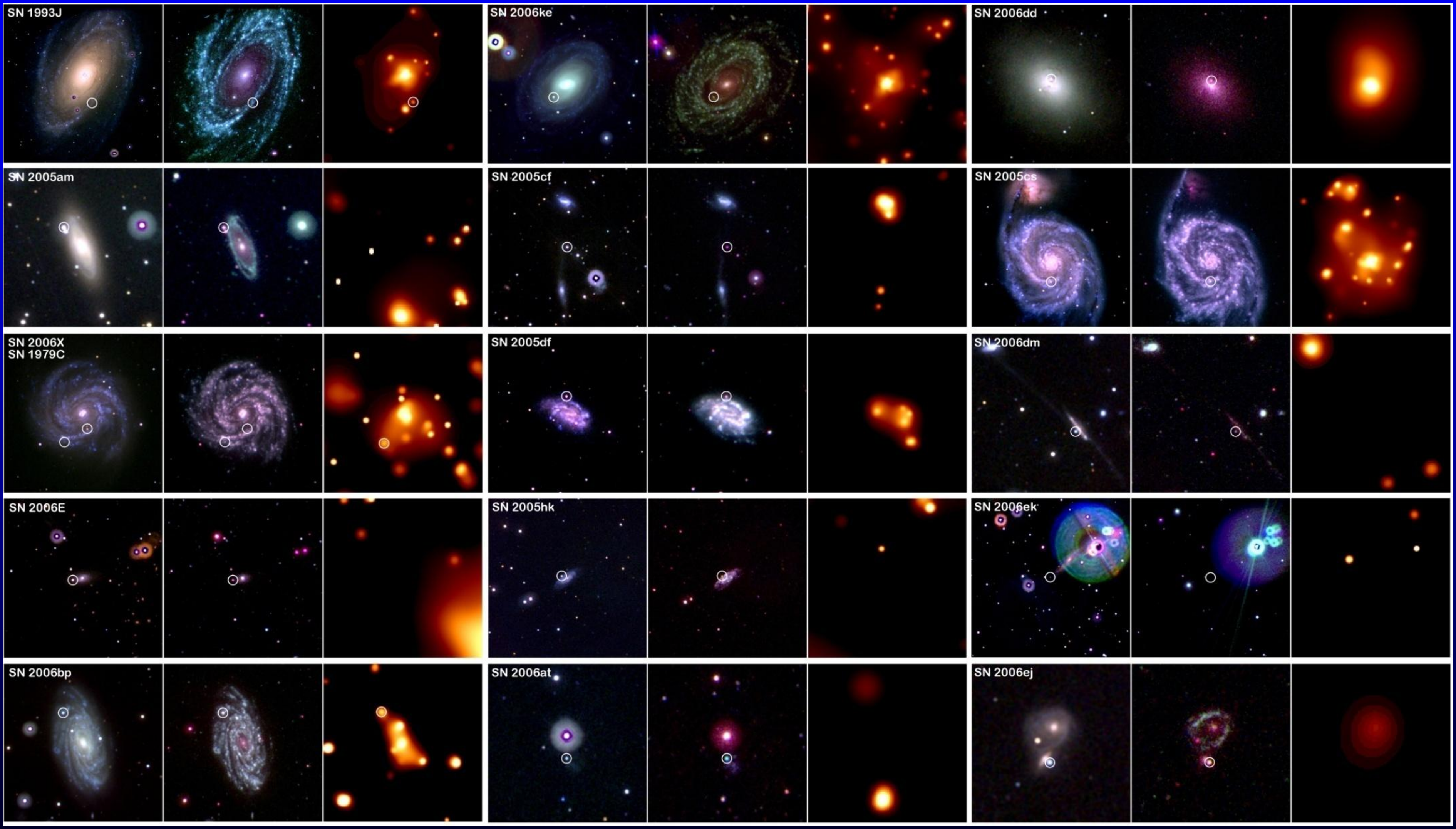
NASA, ESA, the Hubble SM4 ERO Team, and ST-ECF

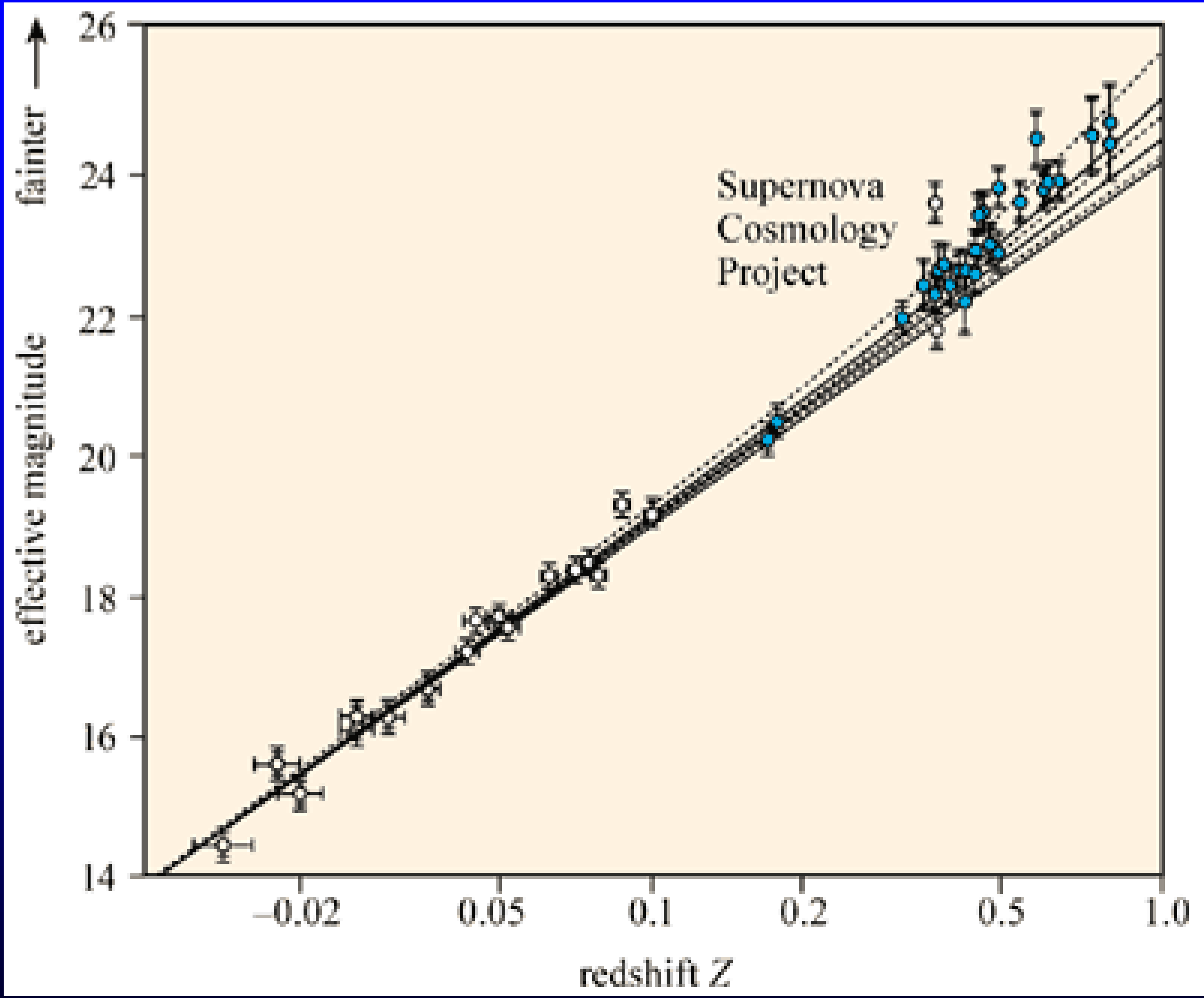
STScI-PRC09-25h


Distribution of Dark Matter
HST ▪ ACS/WFC
3.5 billion years ago
5 billion years ago
6.5 billion years ago
NASA, ESA, and R. Massey (California Institute of Technology)
STScI-PRC07-01a

Bullet Cluster

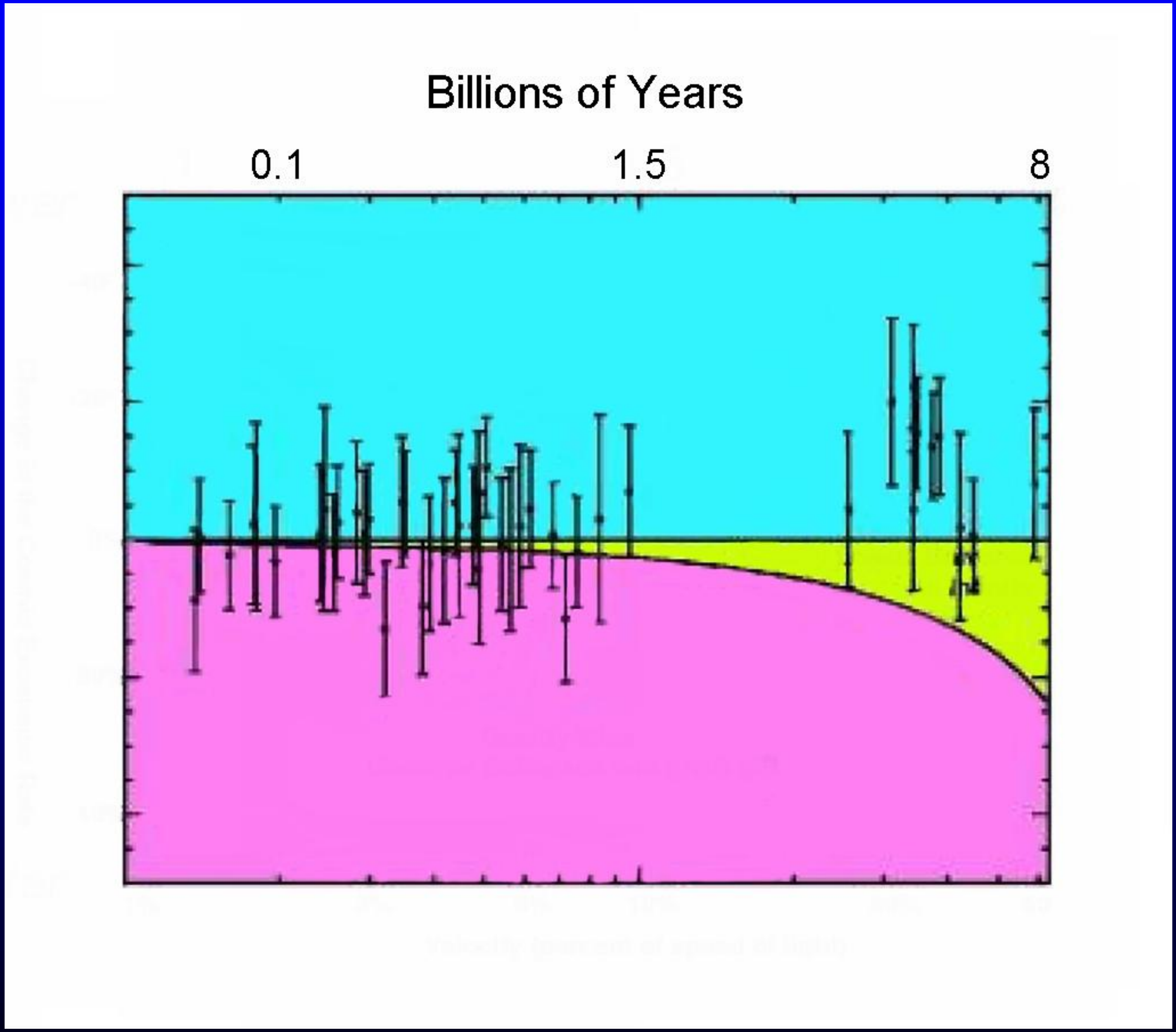
Probing the effects of Dark Energy





fainter
effective magnitude
26
24
22
20
18
16
14
Supernova
Cosmology
Project
-0.02
0.05
0.1
0.2
0.5
1.0
redshift Z

Not was expected!



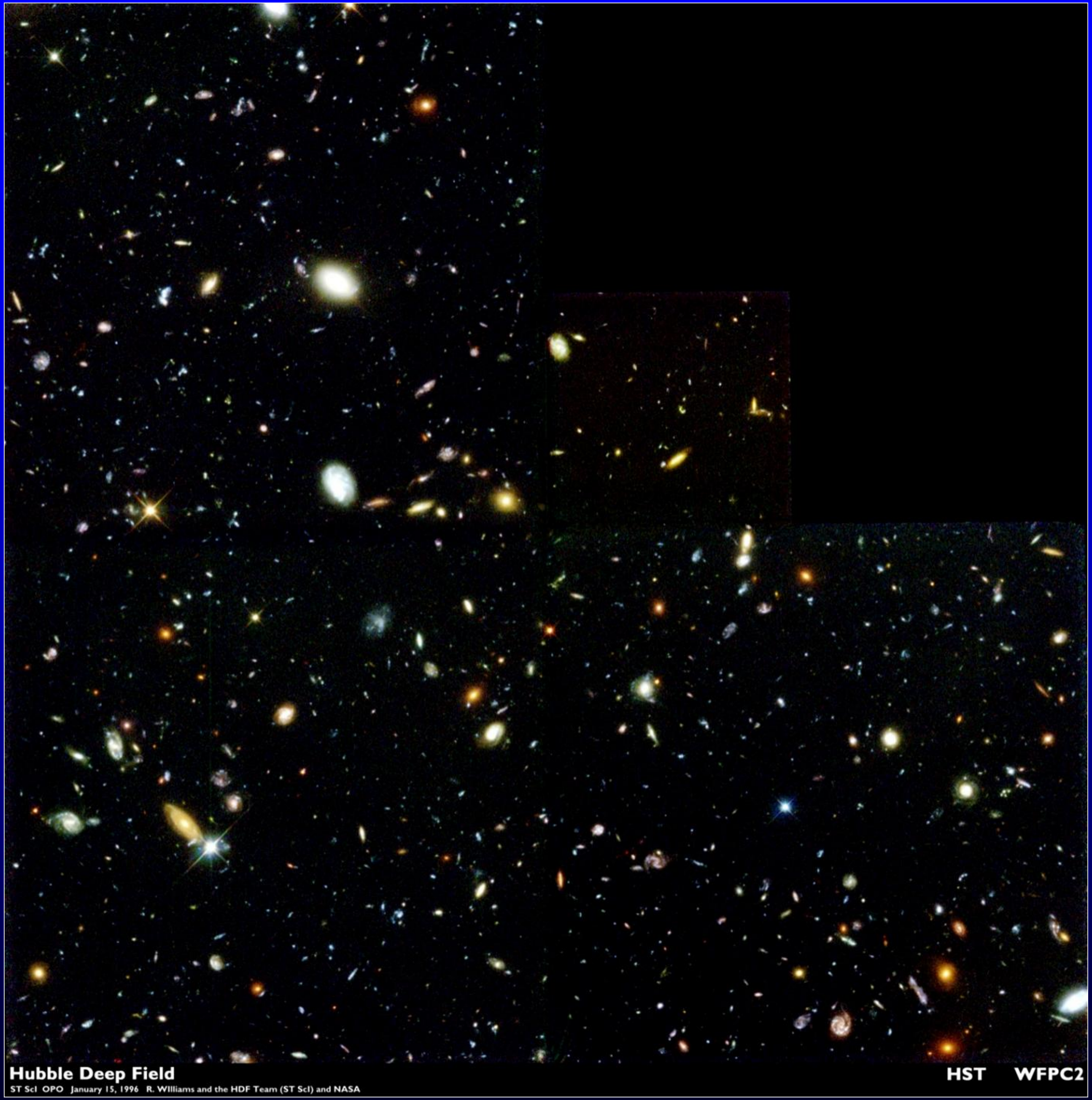
It appears that the rate of expansion of the Universe is increasing.

The effect we believe of "Dark Energy" - giving rise to a pressure exerted by the vacuum of space.

Galaxy Formation

The Hubble Deep Fields

Hubble Deep Field (North)



Hubble Deep Field (South)

Hubble Ultra Deep Field

1 million second exposure!

- The faintest galaxies gave 1 photon per minute!
- Galaxies in the distant past were smaller and more irregular than those we see nearby (and hence more recently).
- Star formation peaked some 9 billion years ago and has now dropped to ~ 1/10th its maximum value.

Helped our understanding of what is "Dark Matter"

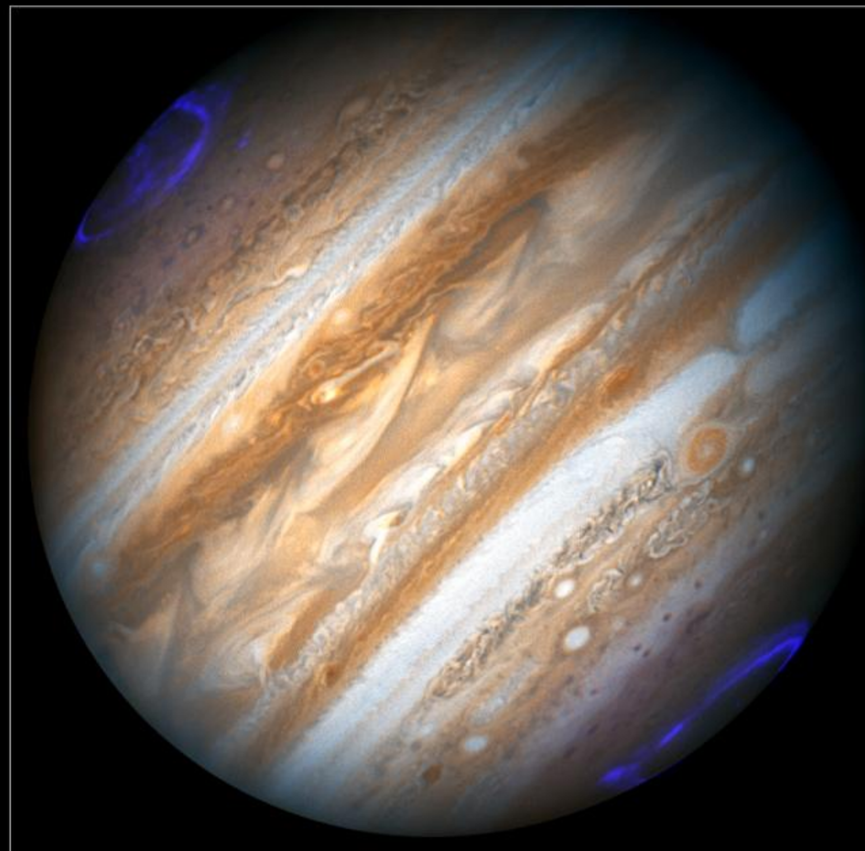
- It showed that red dwarfs were not common in the Galactic Halo – only 20 stars were observed in the field.
- It had been thought that faint stars might make up a substantial part of Dark Matter.

The most distant galaxy known – seen just 600 million years after the origin of the Universe.

Hubble Heritage Images

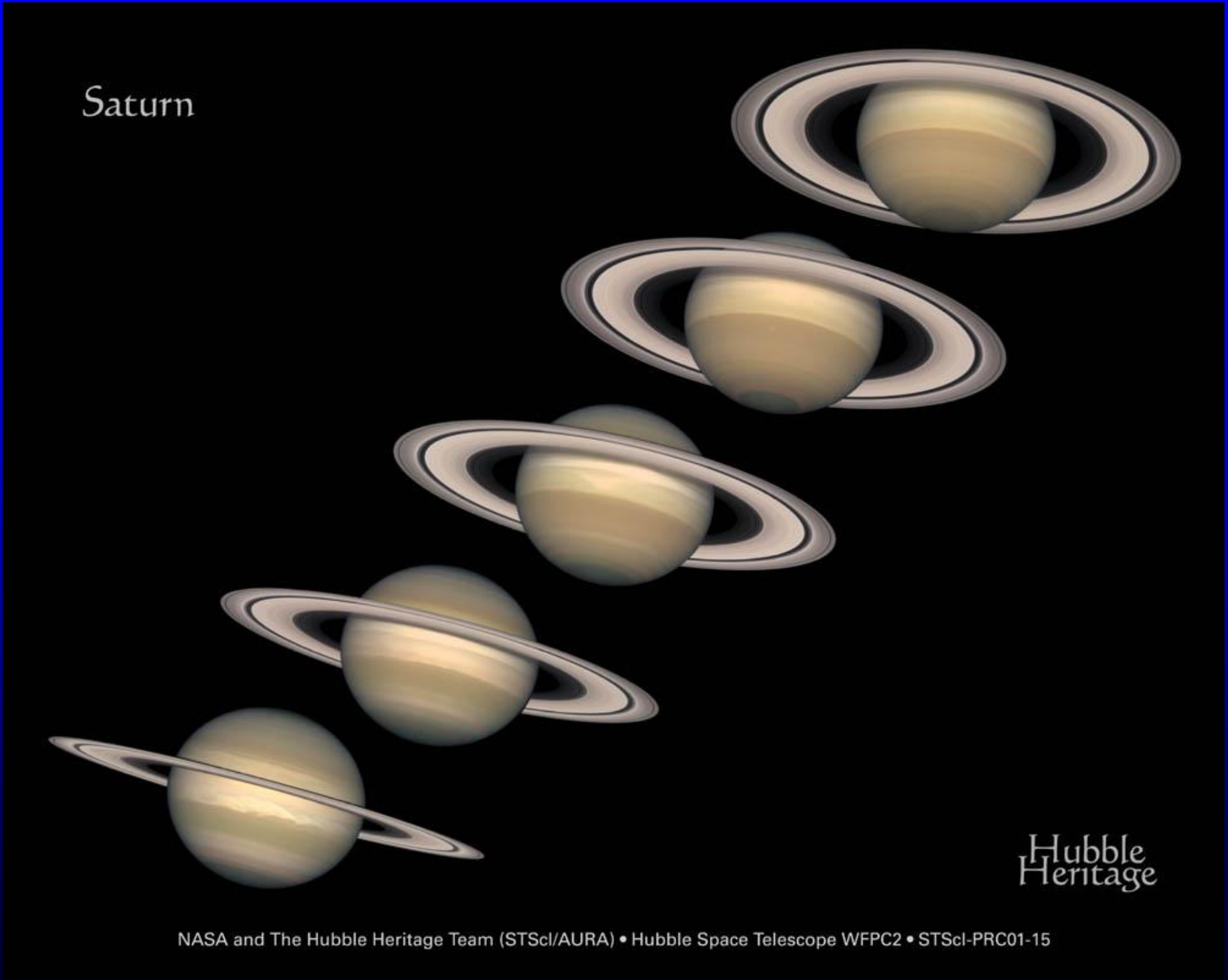
The Beauty of the Heavens

Jupiter Aurora

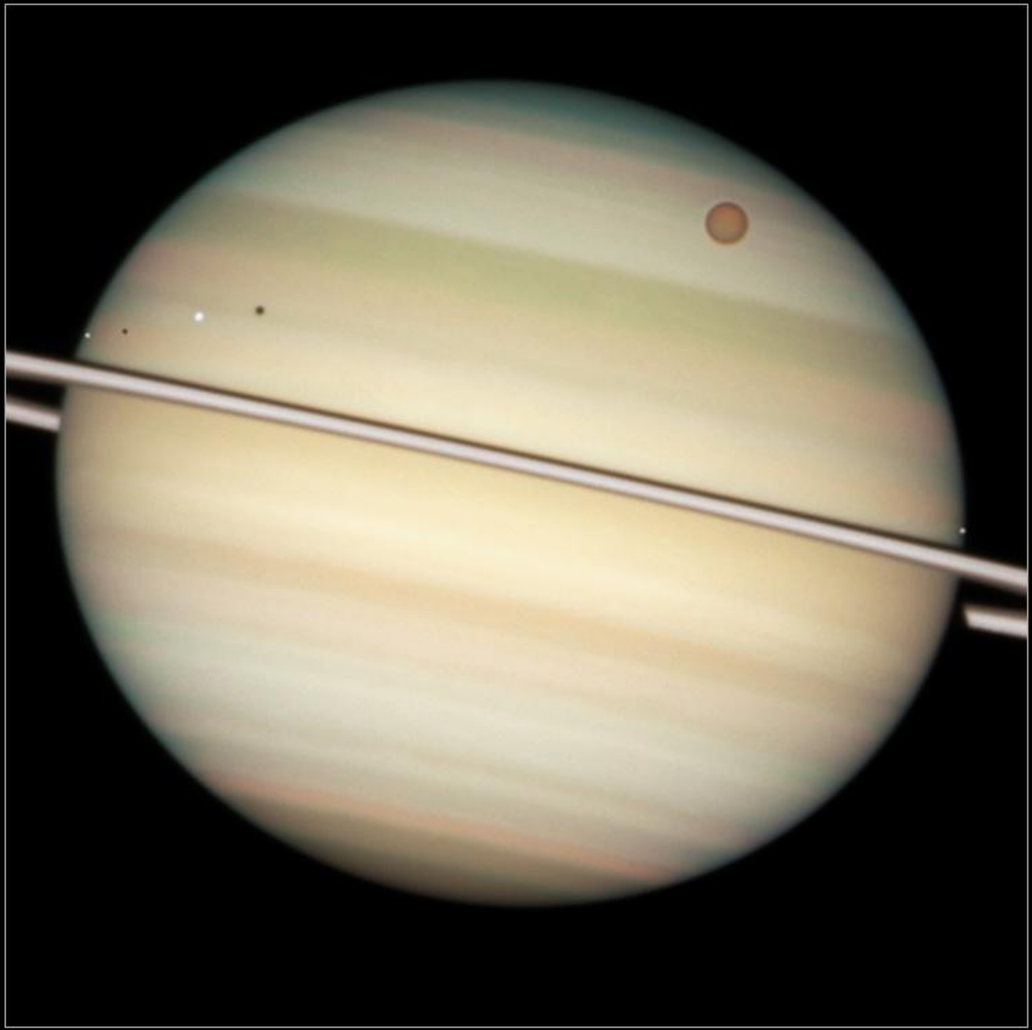


Hubble Heritage

NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • HST/WFPC2/ACS/SBC • STScI-PRC07-14

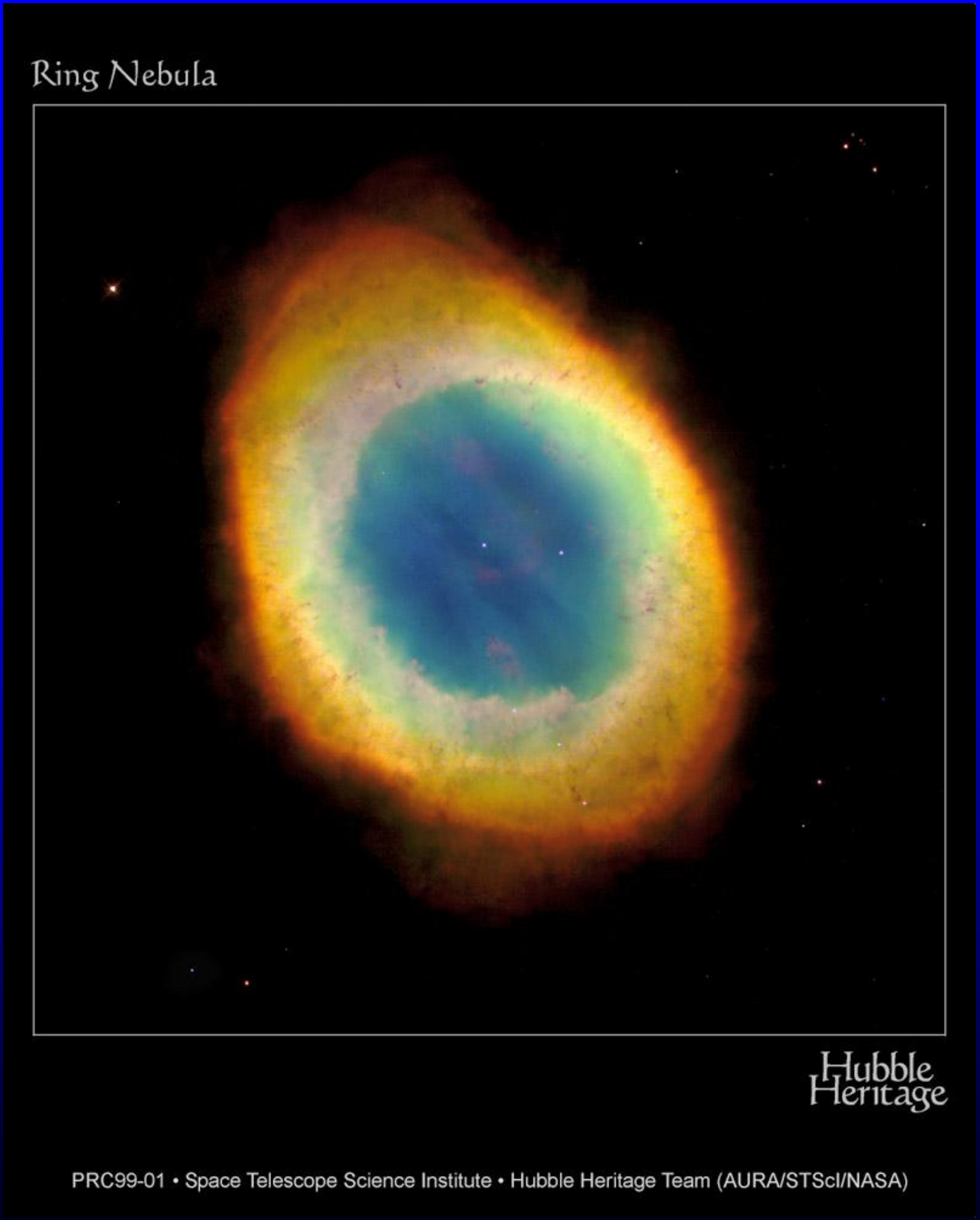

Saturn
Hubble Heritage
NASA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC01-15

Saturn • February 24, 2009



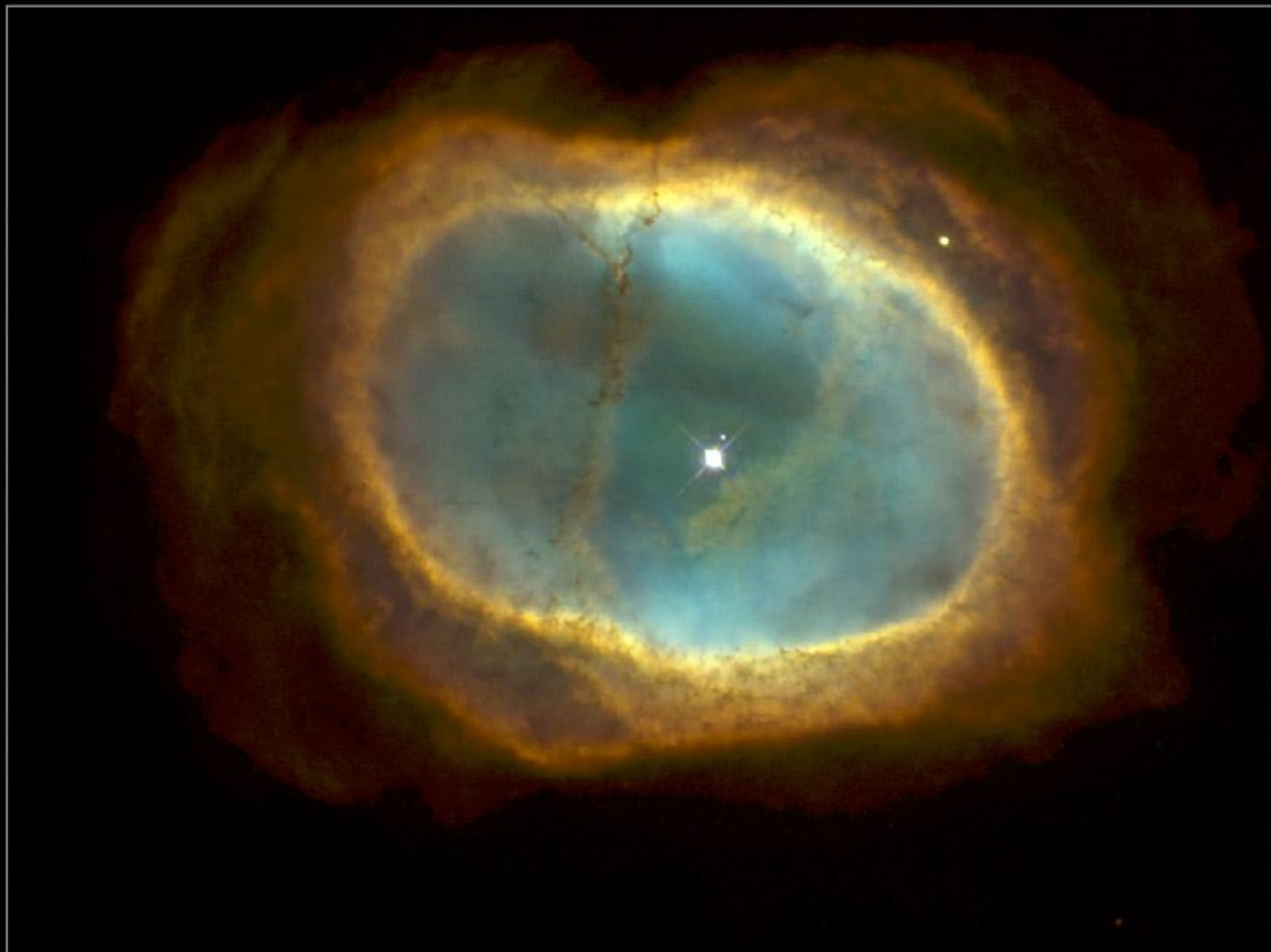
Hubble Heritage

NASA, ESA, and the Hubble Heritage Team (STScI/AURA) • *HST* WFPC2 • STScI-PRC09-12c



Ring Nebula
Hubble Heritage
PRC99-01 • Space Telescope Science Institute • Hubble Heritage Team (AURA/STScI/NASA)

Planetary Nebula NGC 3132



Hubble Heritage

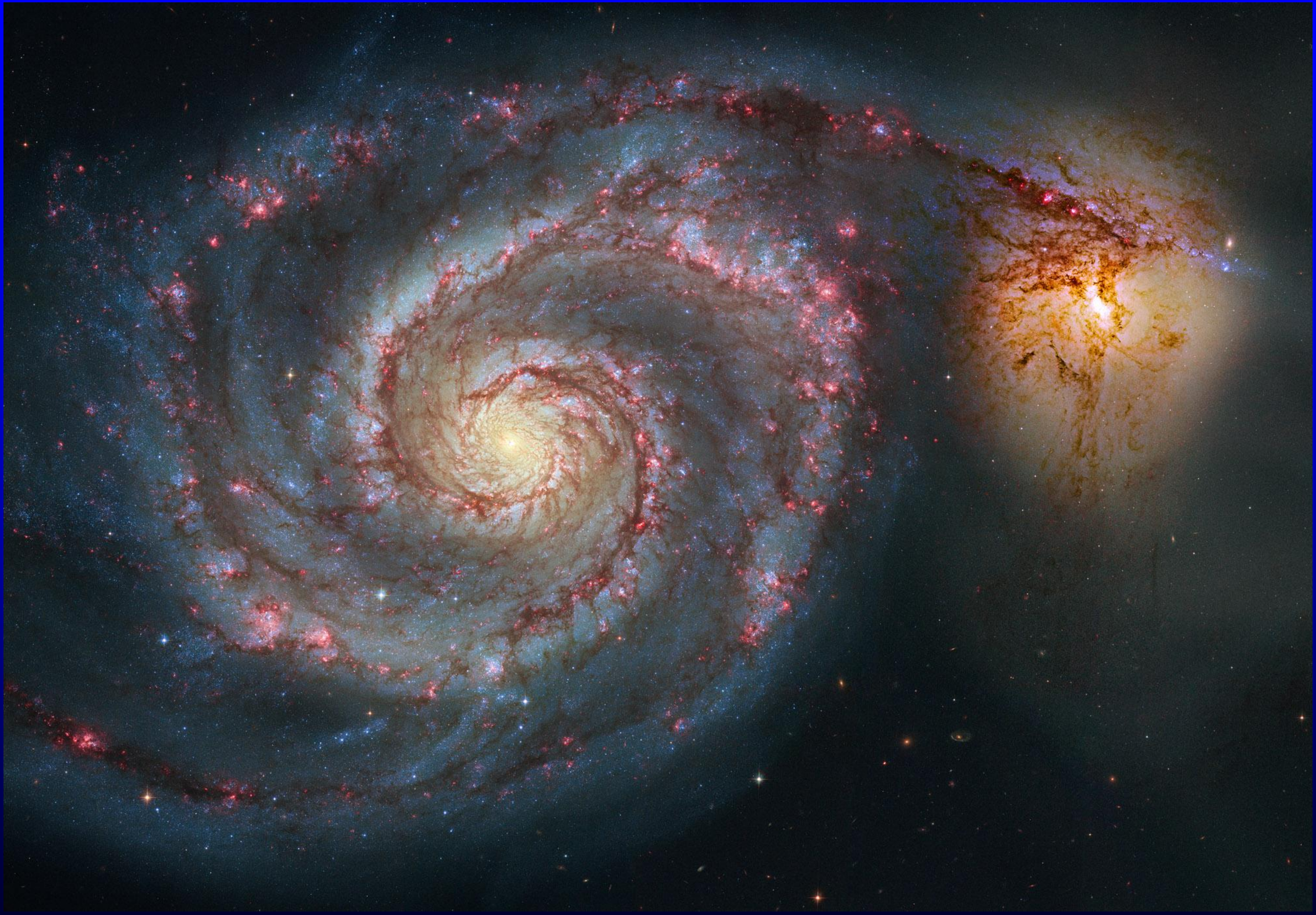
PRC98-39 • Space Telescope Science Institute • Hubble Heritage Team


Planetary Nebula IC 418
Hubble Heritage
PRC00-28 • NASA and The Hubble Heritage Team (STScI/AURA) • HST/WFPC2

Cat's Eye Nebula • NGC 6543

Hubble Heritage

NASA, ESA, HEIC and The Hubble Heritage Team (STScI/AURA)
Hubble Space Telescope ACS • STScI-PRC04-27



Barred Spiral Galaxy NGC 1672

Hubble Heritage

NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration • *Hubble Space Telescope* ACS • STScI-PRC07-15

Active Galaxy M82

Hubble Heritage

NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS/WFC • STScI-PRC06-14a

Sombrero Galaxy • M104

Hubble Heritage

NASA and The Hubble Heritage Team (AURA/STScI) • Hubble Space Telescope ACS • STScI-PRC03-28

Barred Spiral Galaxy NGC 1672

Hubble Heritage

NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration • *Hubble Space Telescope* ACS • STScI-PRC07-15

Galaxy Triplet Arp 274

Hubble Heritage

NASA, ESA, and M. Livio and the Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC09-14

Spiral Galaxy NGC 1376

Hubble Heritage

NASA, ESA, and the Hubble Heritage Team (STScI/AURA) • *Hubble Space Telescope* ACS

Coma Cluster of Galaxies

Hubble Heritage

NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • *Hubble Space Telescope* ACS • STScI-PRC08-24