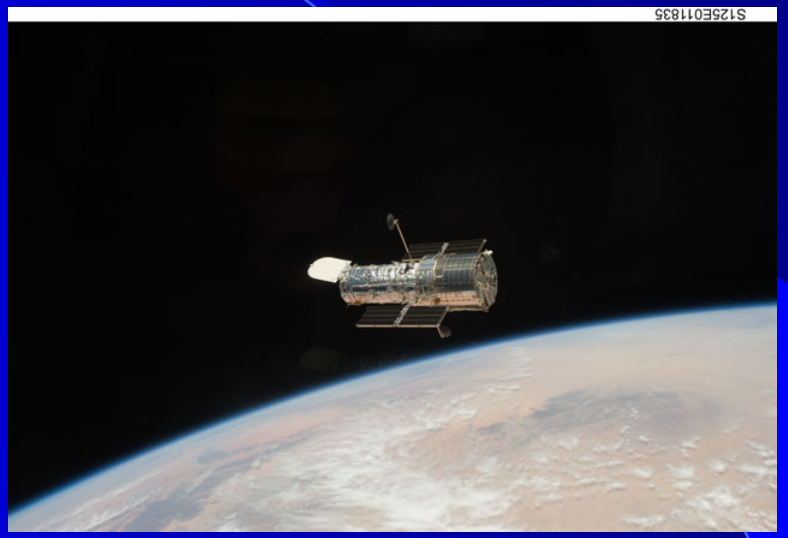
The Hubble Space Telescope and the Hubble Constant



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THE UNIVERSE YOURS TO DISCOVER

INTERNATIONAL YEAR OF ASTRONOMY 2009

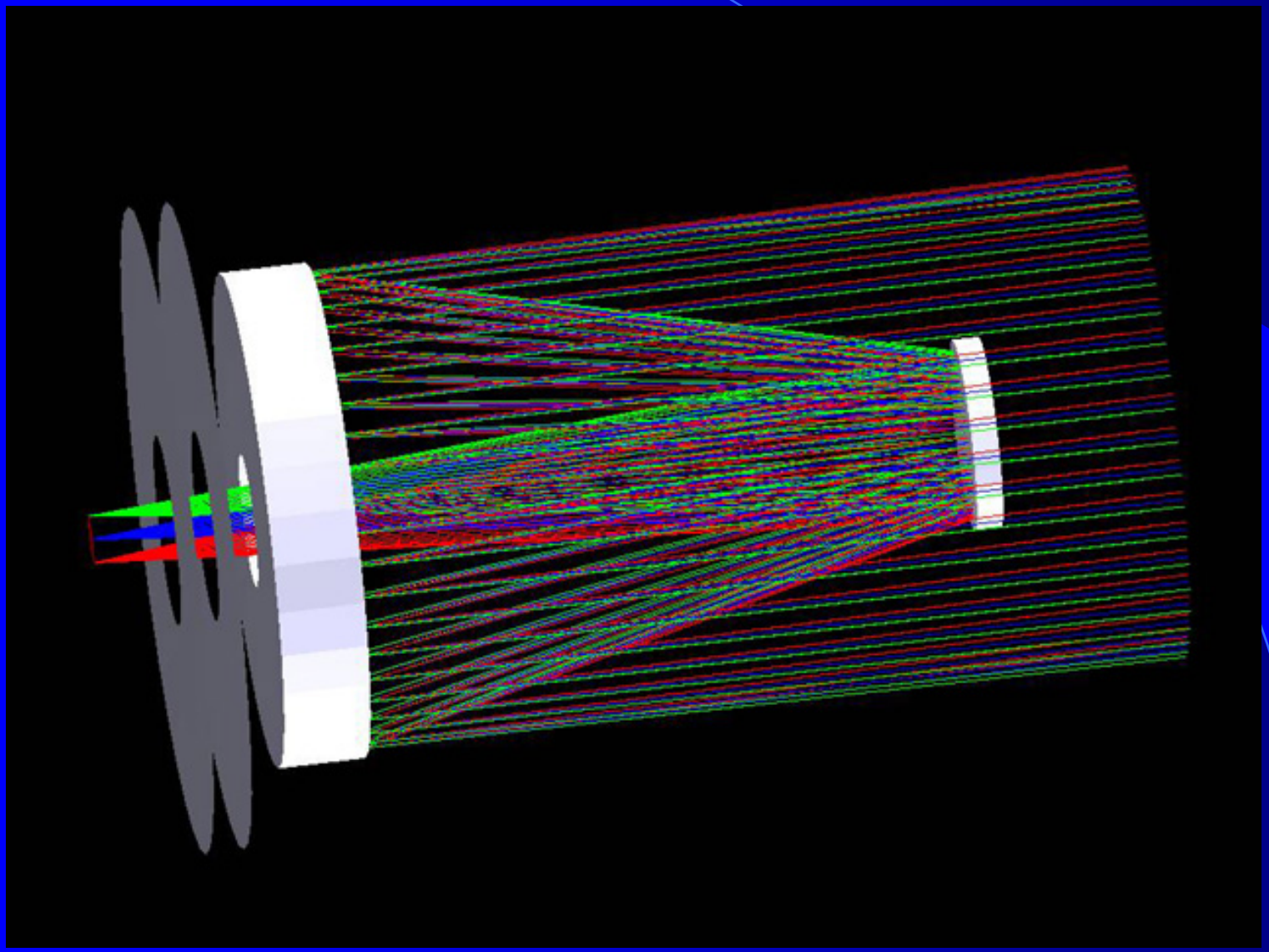
SWINBURNE UNIVERSITY OF TECHNOLOGY

Telescope resolution

Due to the wave nature of light (diffraction) the optical resolution of a telescope or camera is λ/D

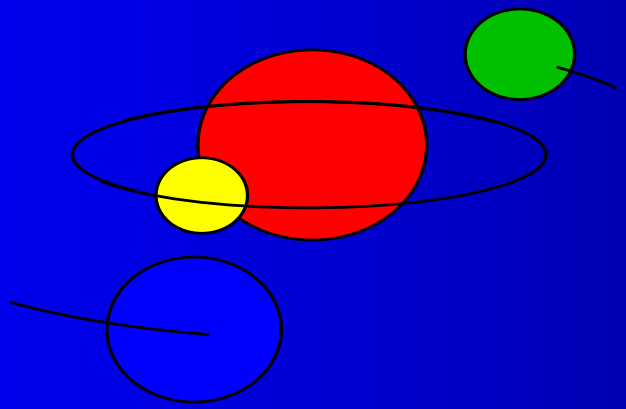
- The human eye: 20 arcsec
- Galileo's telescope: 3.8 arcsec
- Hubble Space Telescope 40 milliarcsecs

Ritchey Chrétien optical design



Introduction

- Subject today is the Expanding Universe
- The Expanding Universe model describes the motions of galaxies
- Just like the model of Copernicus describes the motions of the planets



Outline

- Hubble's evidence for an expanding Universe
- How fast is the Universe expanding now ?
  (the Hubble Constant)
- Variation of the expansion rate over time
- How long is it since the Big Bang ?

Edwin Hubble

1889

-

1953

Hubble's evidence

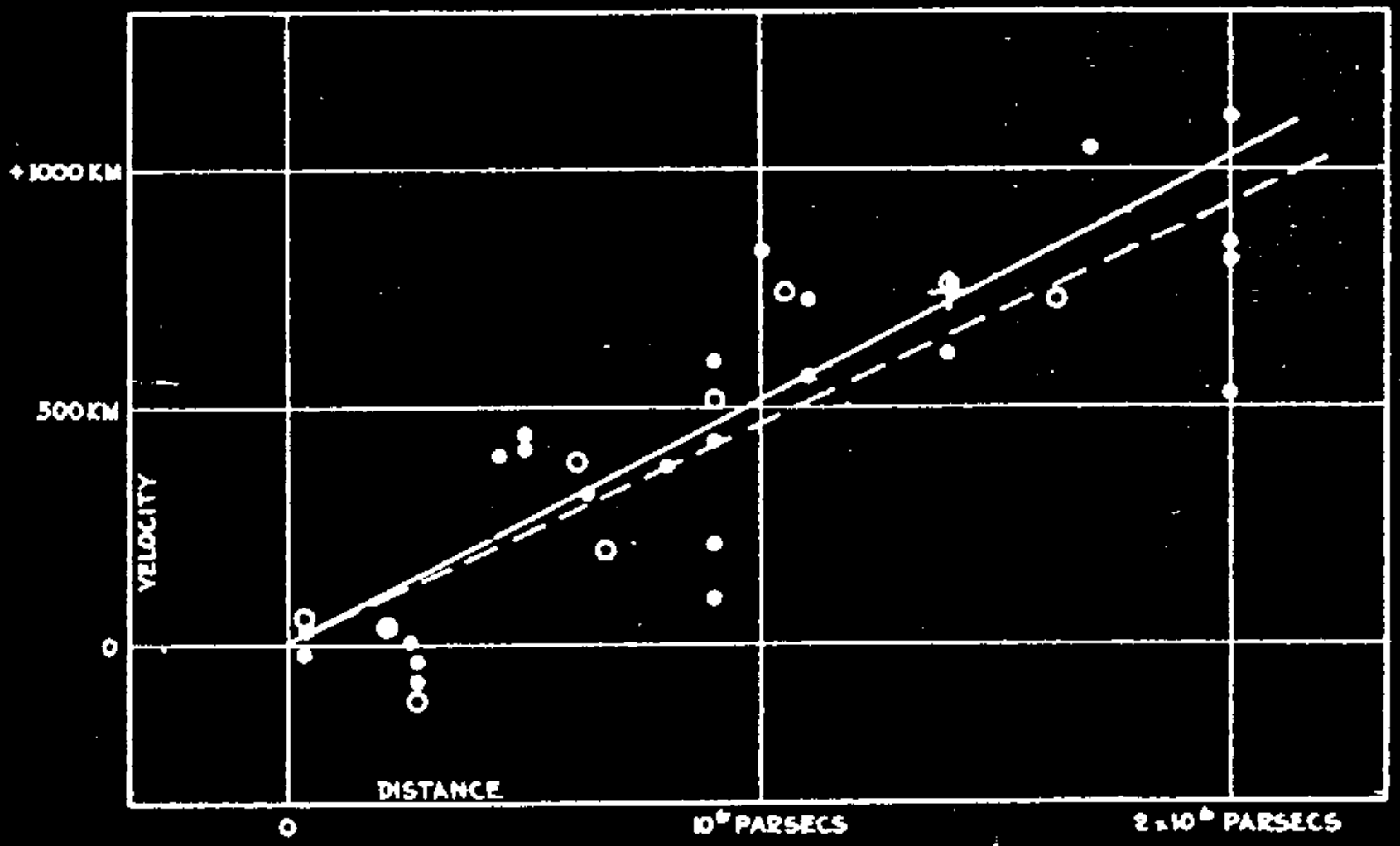
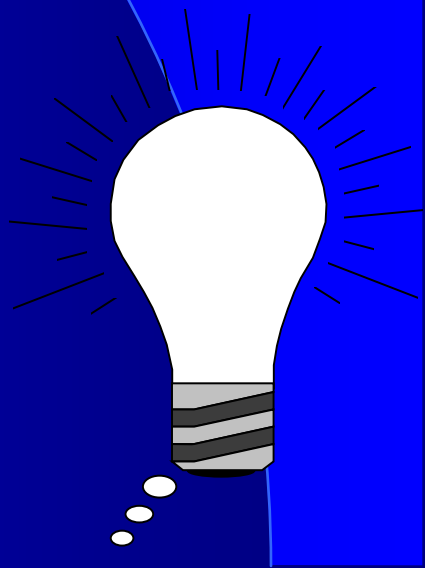


FIGURE 1

Overview on the Hubble Constant

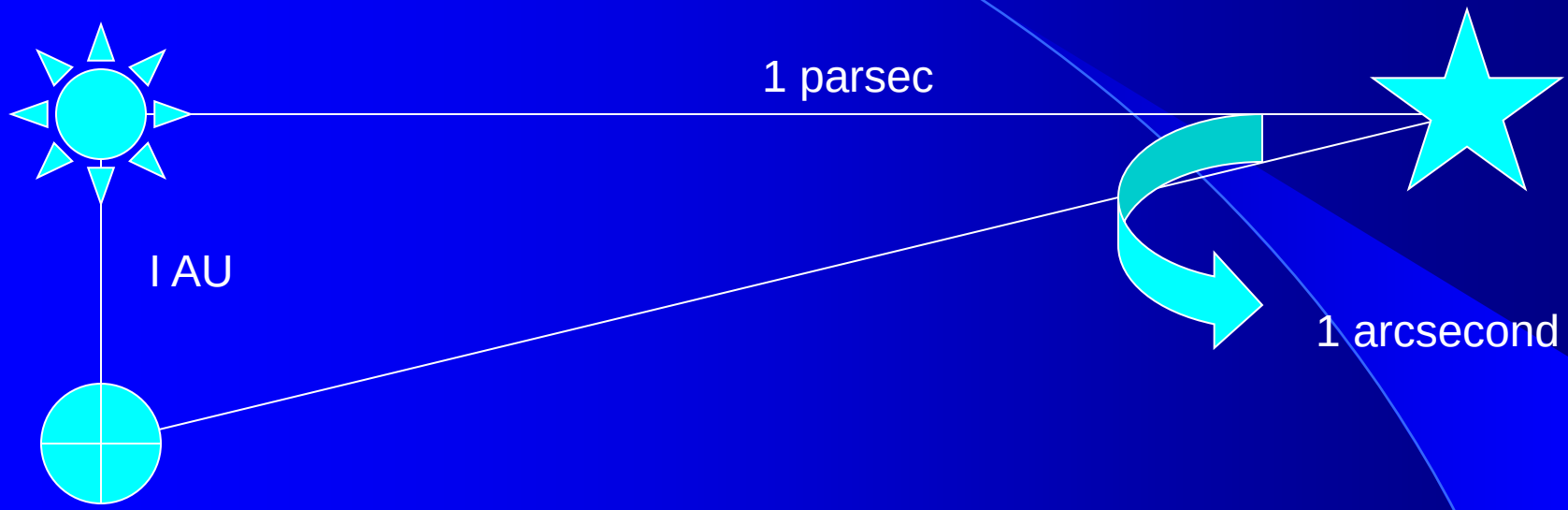
- what is redshift ?
- measuring distances geometrically
- we start with the Large Magellanic Cloud
- the Hubble Space Telescope Key Project
- Cepheids as standard candles
- Supernovae as standard candles



REDSHIFT

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c} \qquad c = 3 \times 10^5 \text{ km/sec}$$

Parallax distance measurement



Also: 1 AU at 1 kiloparsec subtends 1 milliarcsec

1 AU at 1 megaparsec subtends 1 microarcsec

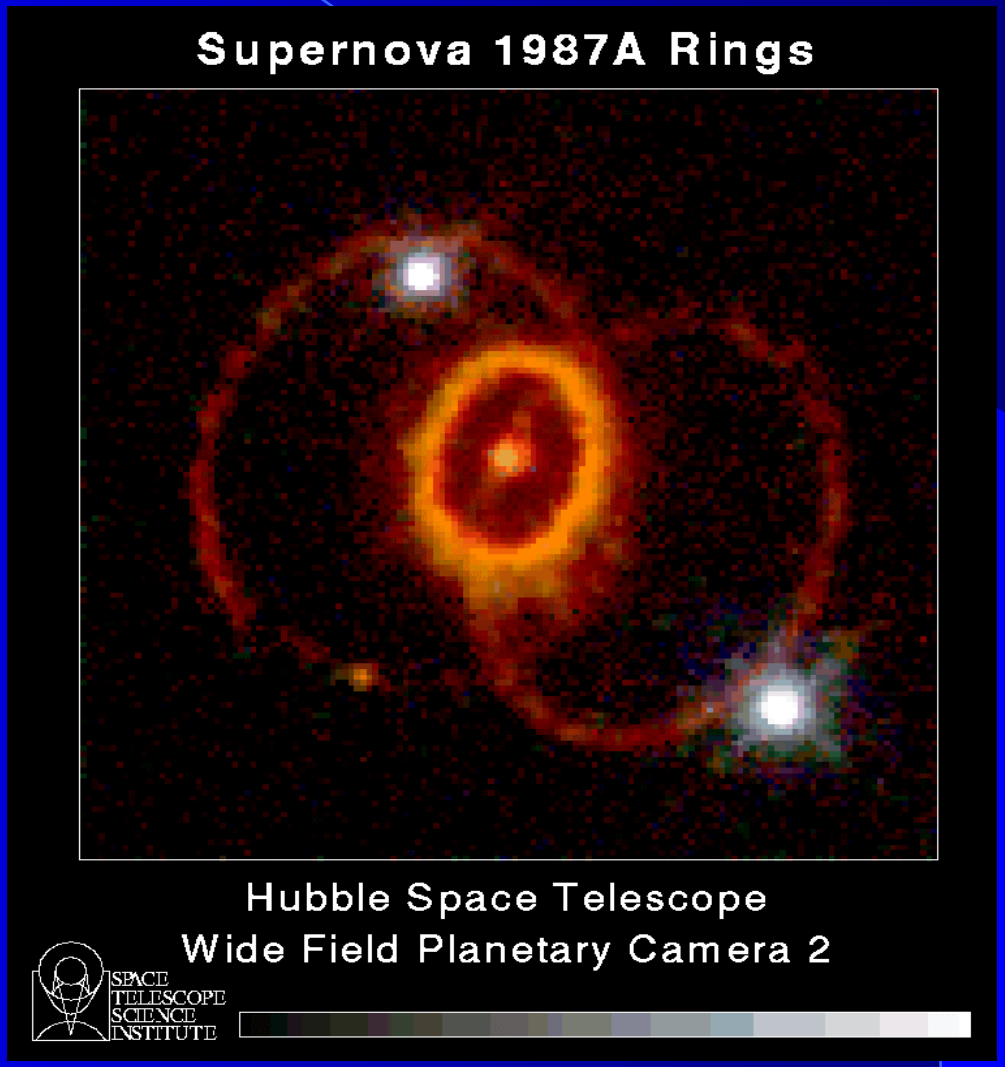
1 parsec is 3×10^{13} km;
if we can measure the angle, we can get the distance

Supernova 1987A

- a massive star exploded in the LMC
- February 1987
- the LMC is our nearest neighbour galaxy
- in fact, it's a satellite

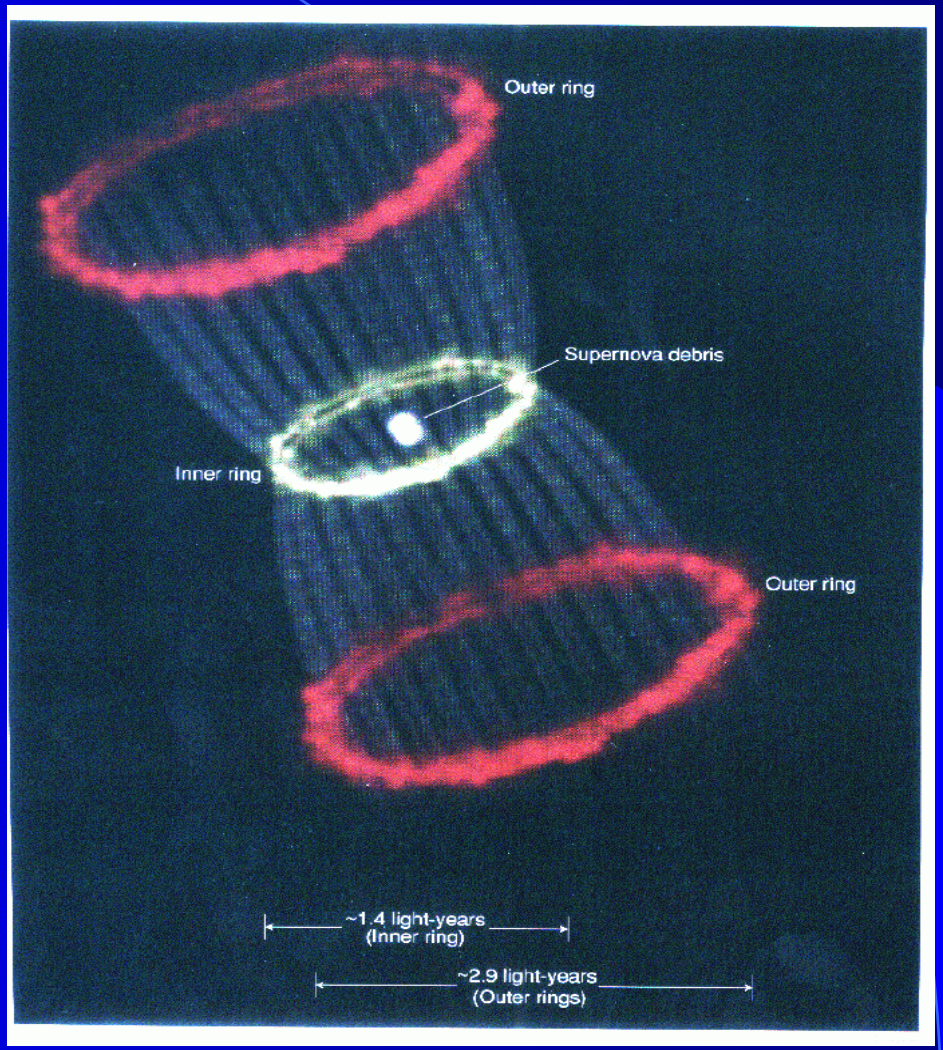
SN1987A

- the ring lit up 250 days after the supernova
- radius known
- angle known
- => distance



SN1987A

Schematic of SN1987A



The Hubble Constant Key Project

Goal:

Measure how fast the Universe is expanding

to 10% accuracy

The HST Key Project

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Barry Madore
Nancy Silbermann
Shoko Sakai
Randy Phelps
Robert Hill
Abi Saha
Peter Stetson
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Laura Ferrarese
Holland Ford
Garth Illingworth
Dan Kelson
John Graham
John Hoessell
Lucas Macri
John Huchra
Anne Turner
Paul Harding
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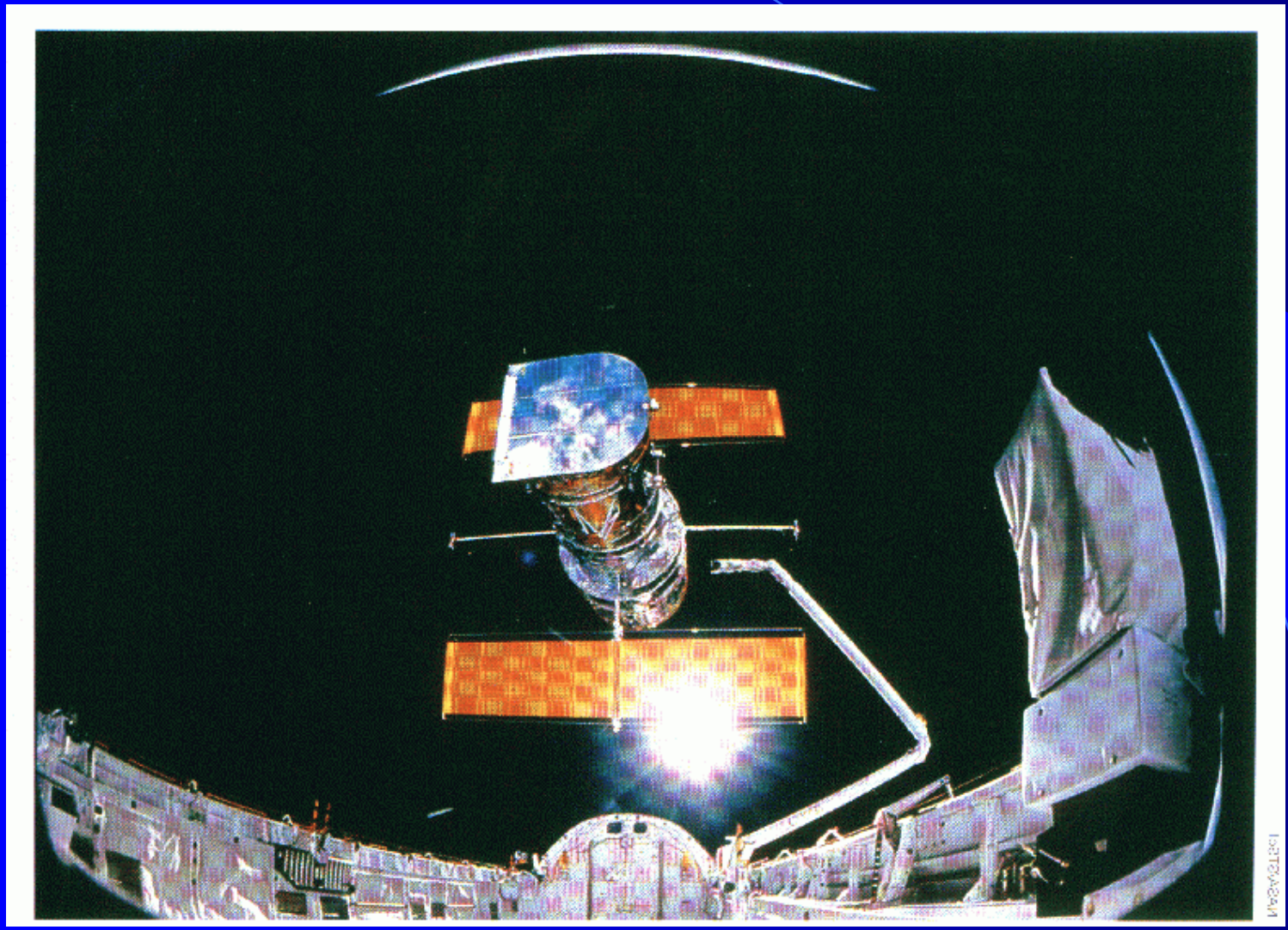
servicing mission

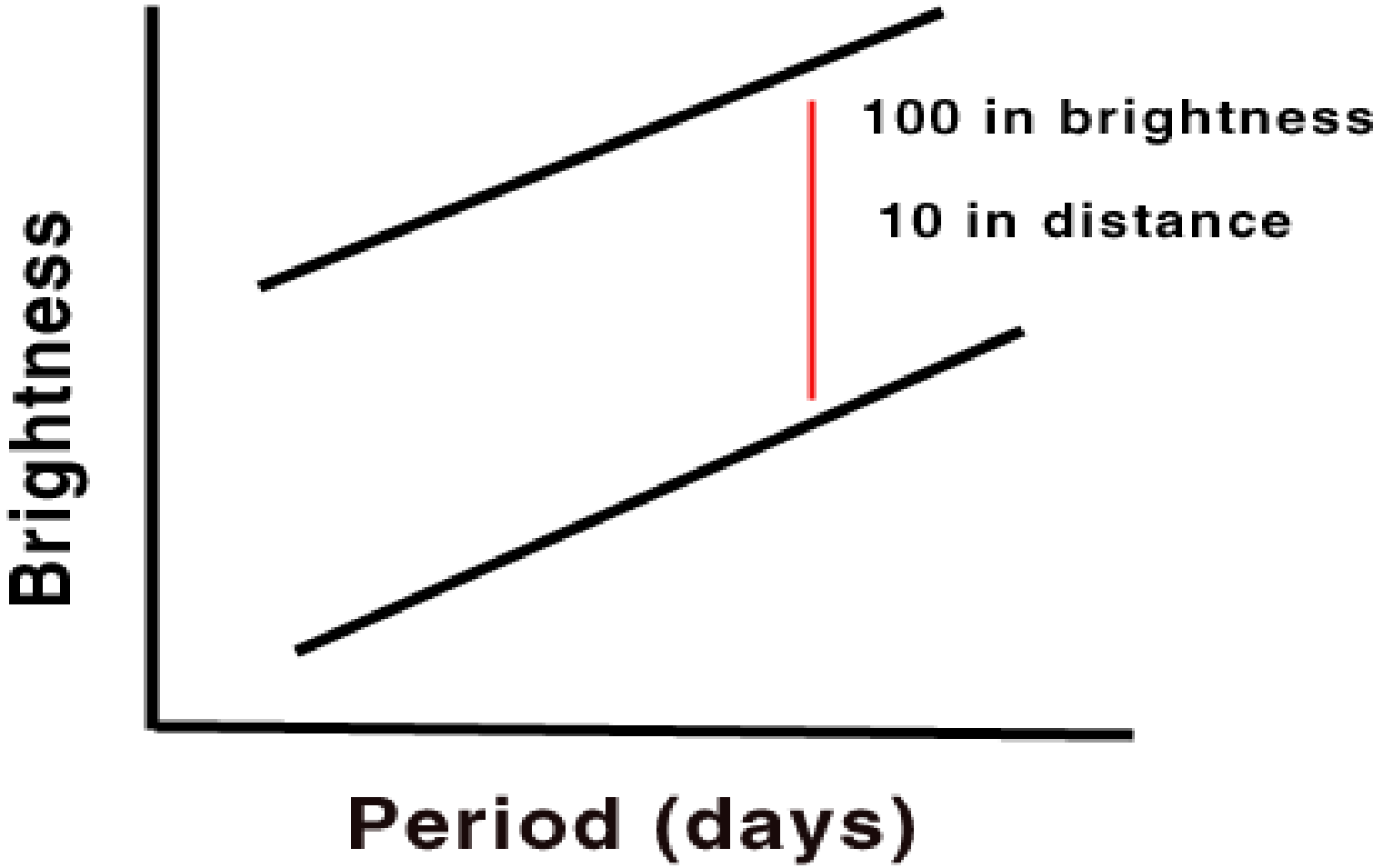


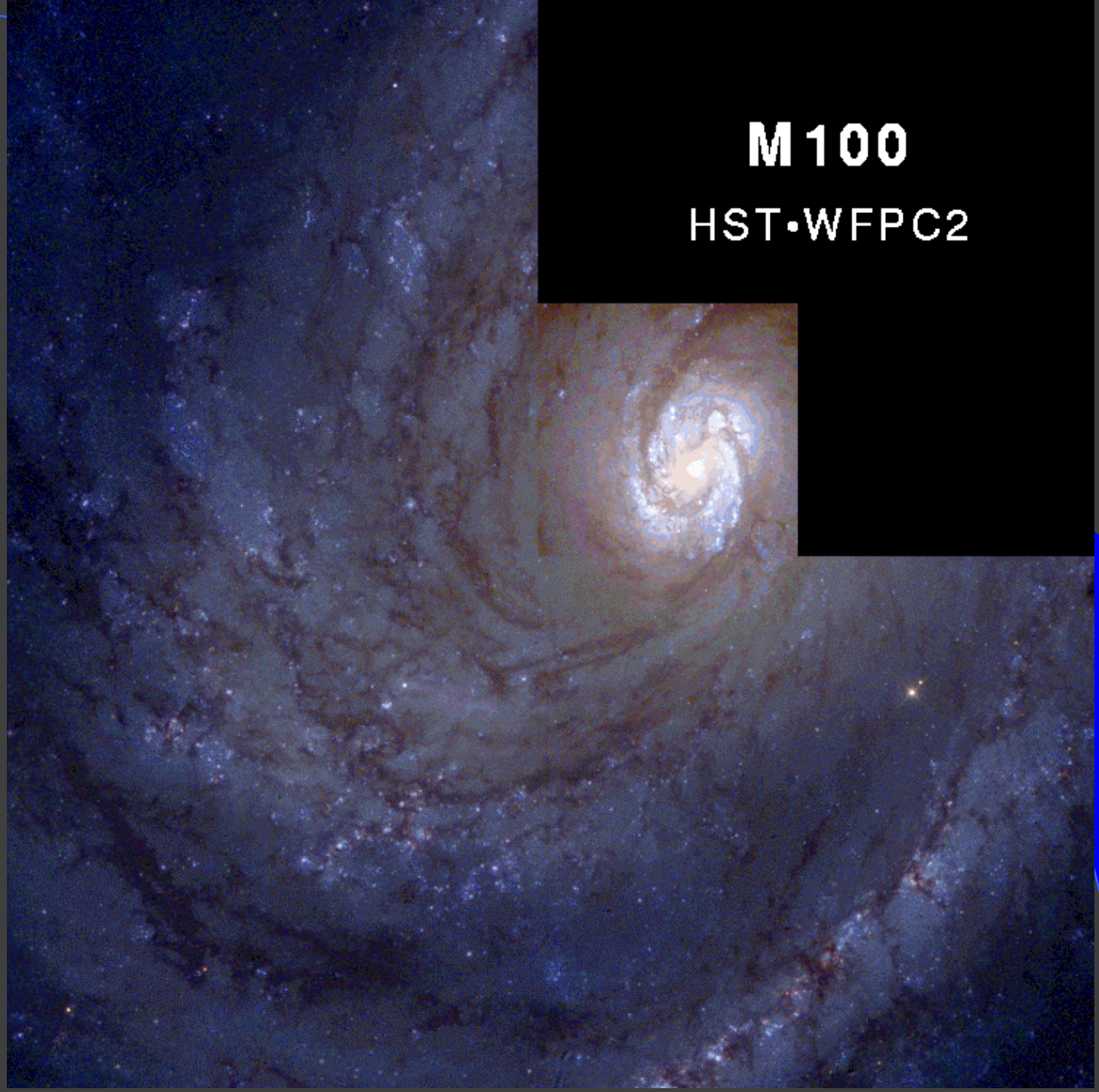
The first servicing mission replaced the WFPC with WFPC2 in December 1993, thus remedying spherical aberration

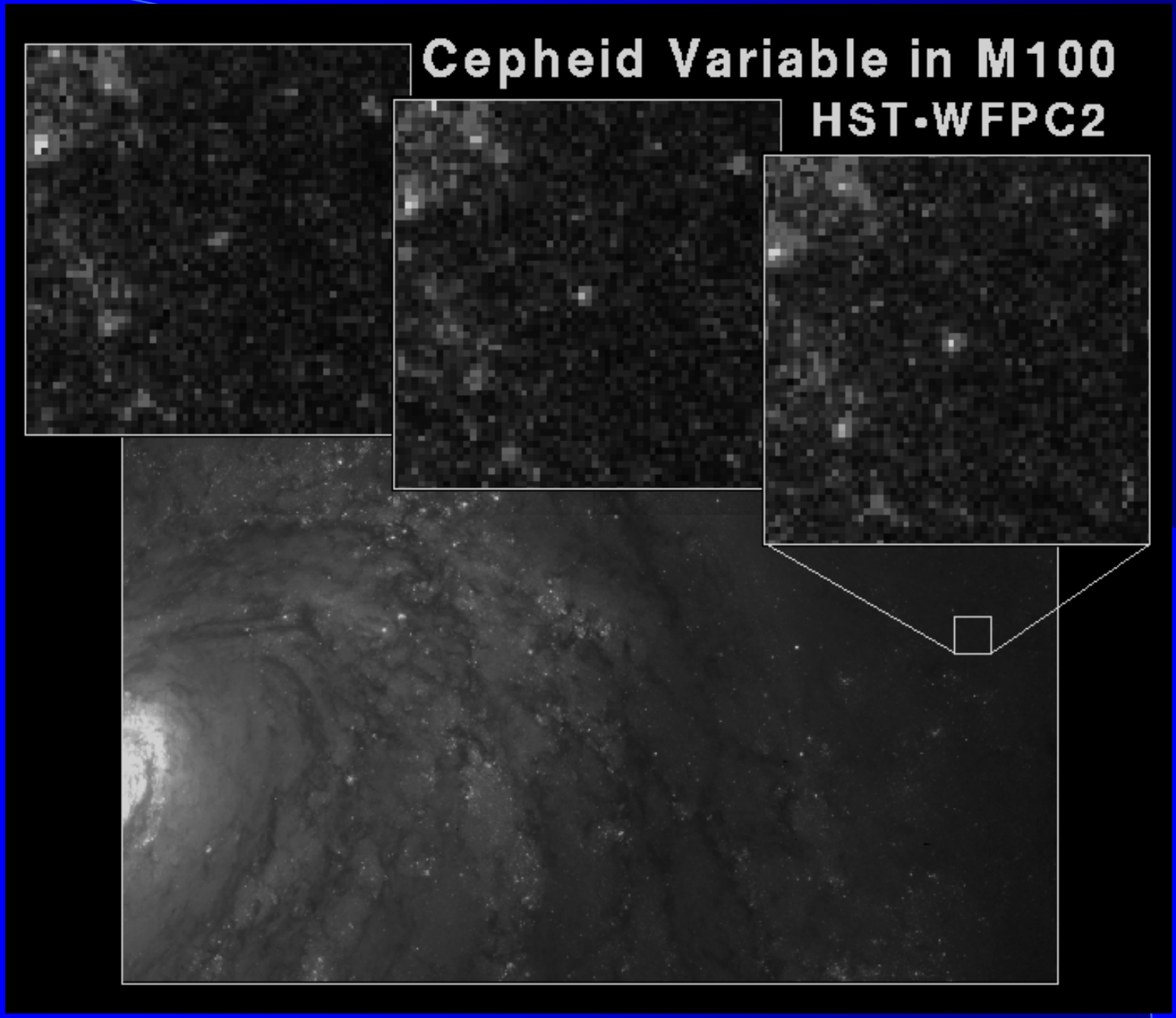
The power of the Hubble Space Telescope

- From the ground we can resolve galaxies up to 2 or 3 Mpc away
- HST was designed to have ten times the resolution of ground based telescopes
- The project to find Cepheids up to 20 Mpc away was designated a Key Project for HST

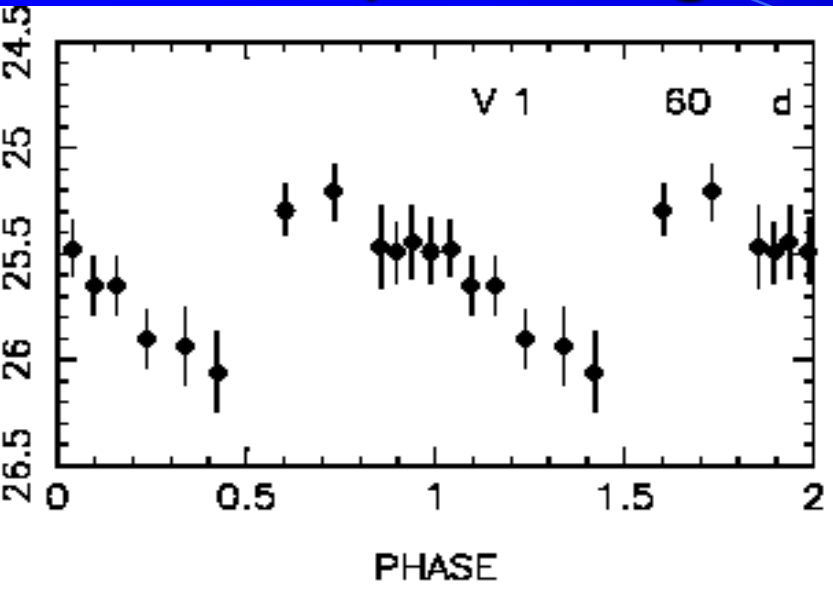
The Cepheid period luminosity relation

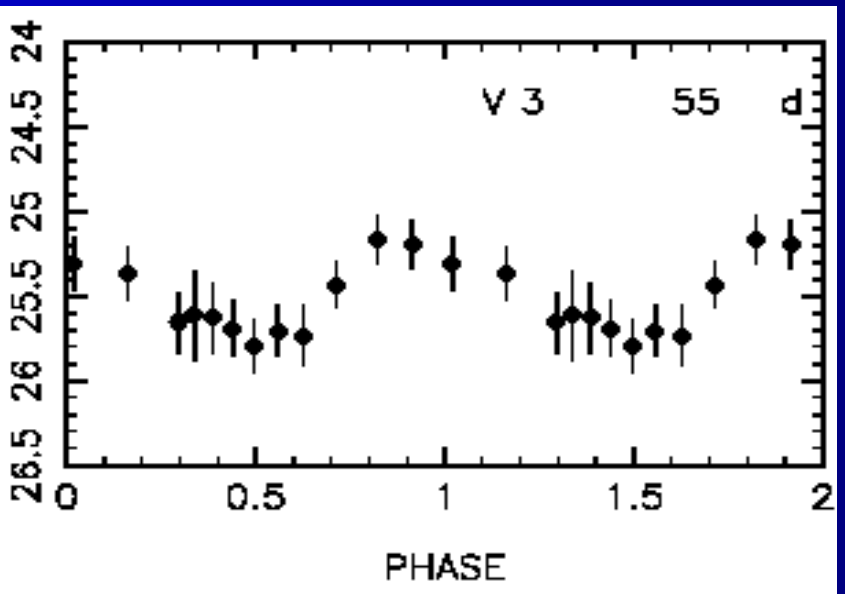


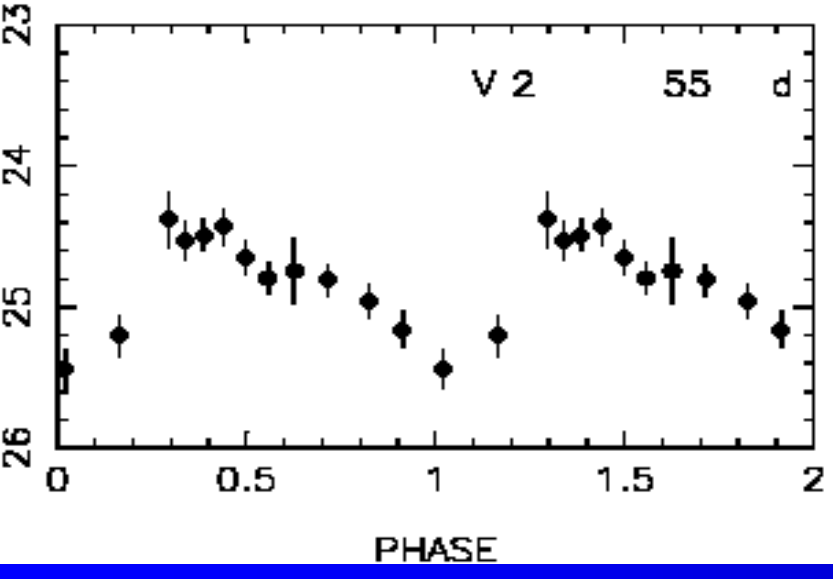

M100
HST•WFPC2

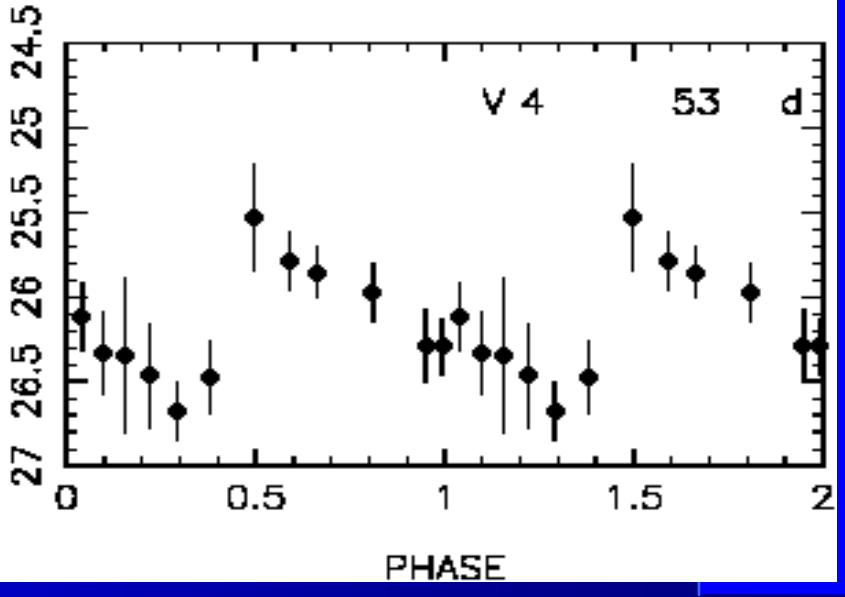

Cepheid Variable in M100
HST•WFPC2

Cepheid light curves in NGC 1365





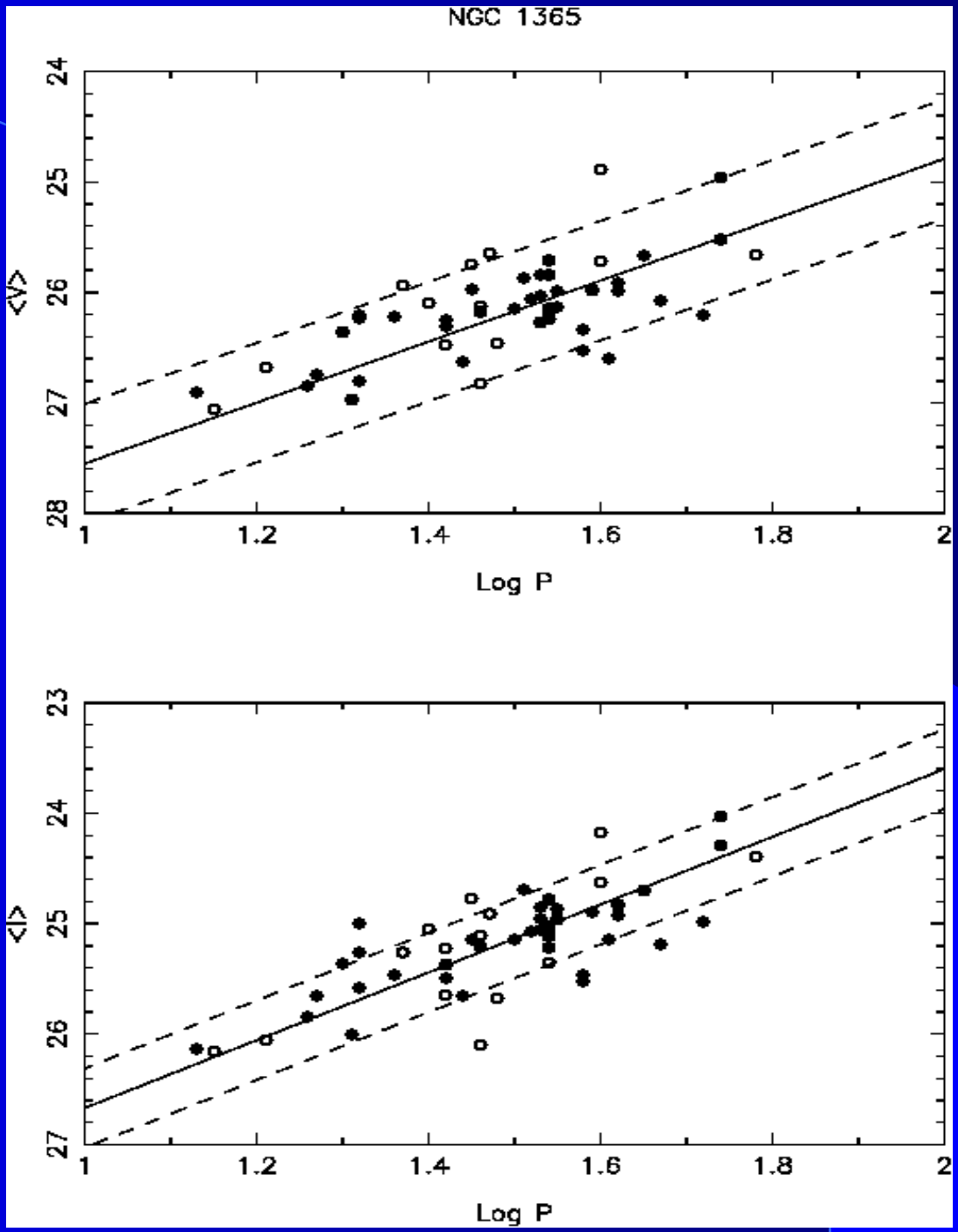


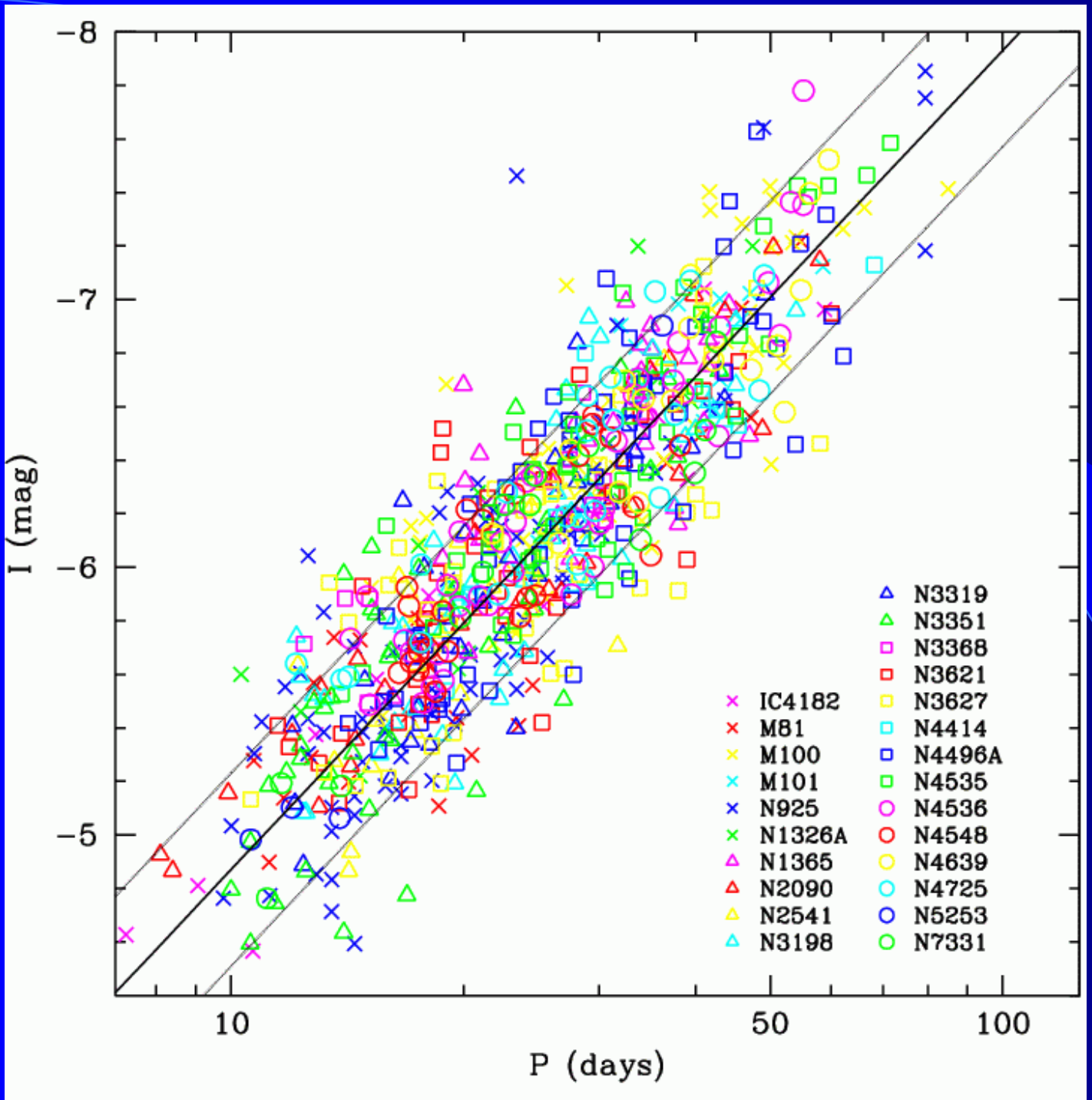


top: visual

The PL relation in NGC 1365

bottom: infrared



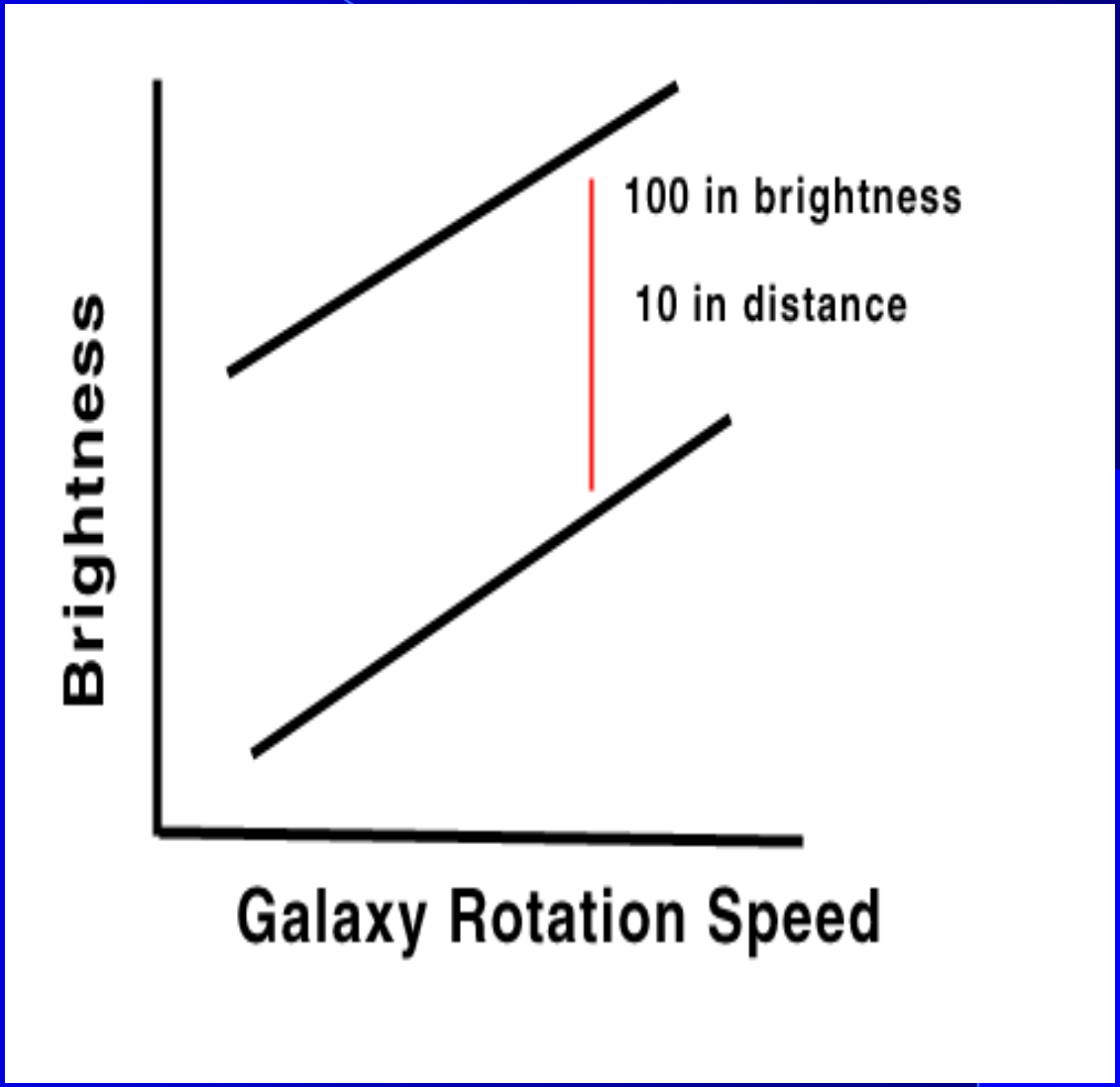

−8
−7
−6
−5
I (mag)
10
50
100
P (days)
IC4182
M81
M100
M101
N925
N1326A
N1365
N2090
N2541
N3198
N3319
N3351
N3368
N3621
N3627
N4414
N4496A
N4535
N4536
N4548
N4639
N4725
N5253
N7331

Beyond the Cepheids

- Beyond 20 Mpc even HST has difficulty resolving Cepheids
- We use four other standard candles to measure distances a further factor of ten
- The Tully Fisher relation for spiral galaxies
- Supernovae of type Ia
- Surface brightness fluctuations = resolvability
- The fundamental plane for elliptical galaxies

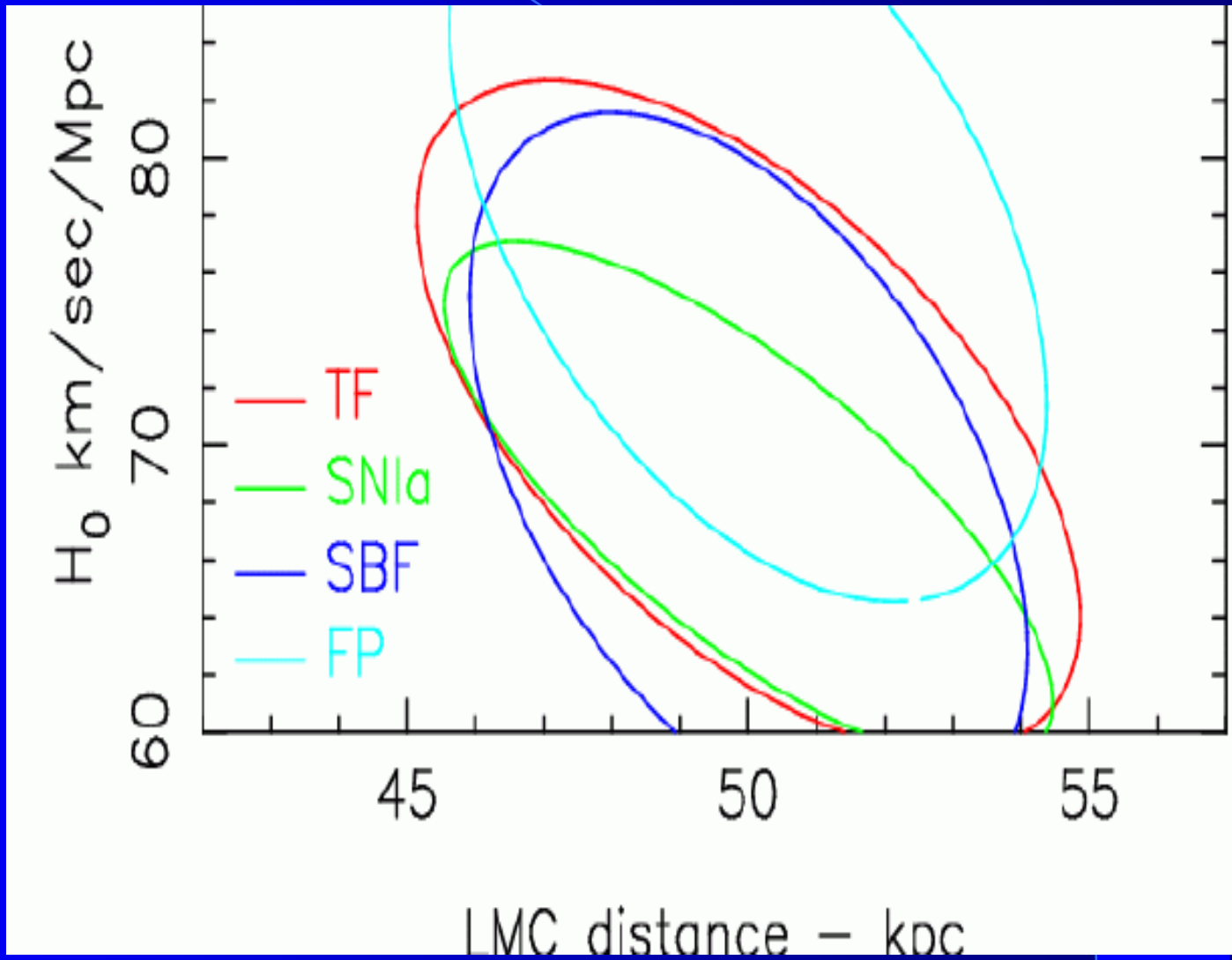
Tully Fisher relation

- big galaxies rotate faster
- a galaxy with a given rotation speed is a standard candle



The Hubble Constant

- All 4 standard candles agree
- H lies in the range 65 to 77 km/s/Mpc



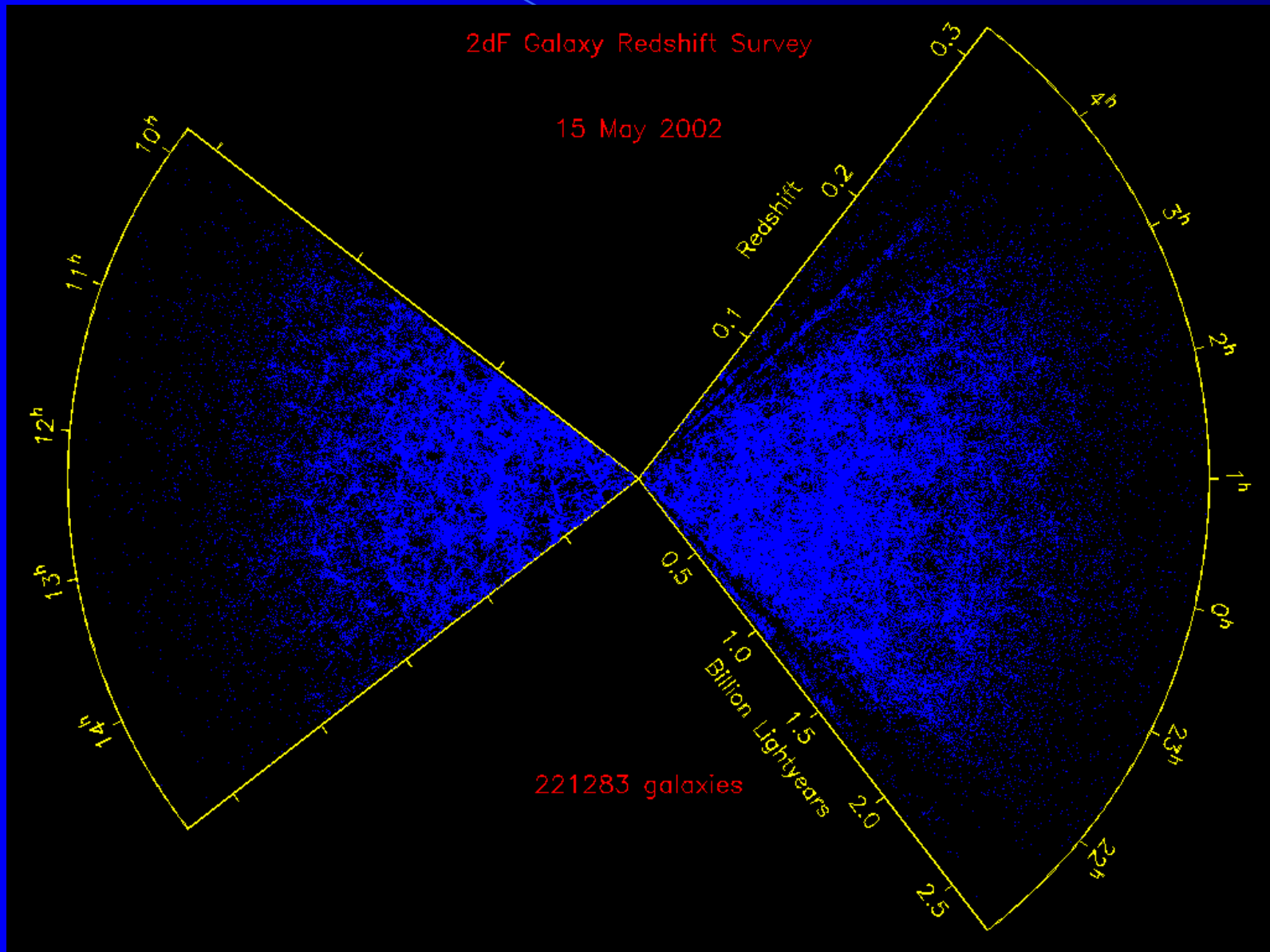
How standard are standard candles ?

- most stars have a chemical composition like that of the sun
- but there are some variations....
- Cepheids with different chemistry pulsate differently
- accounting for this changes our distances a few percent

What is the density of the Universe ?

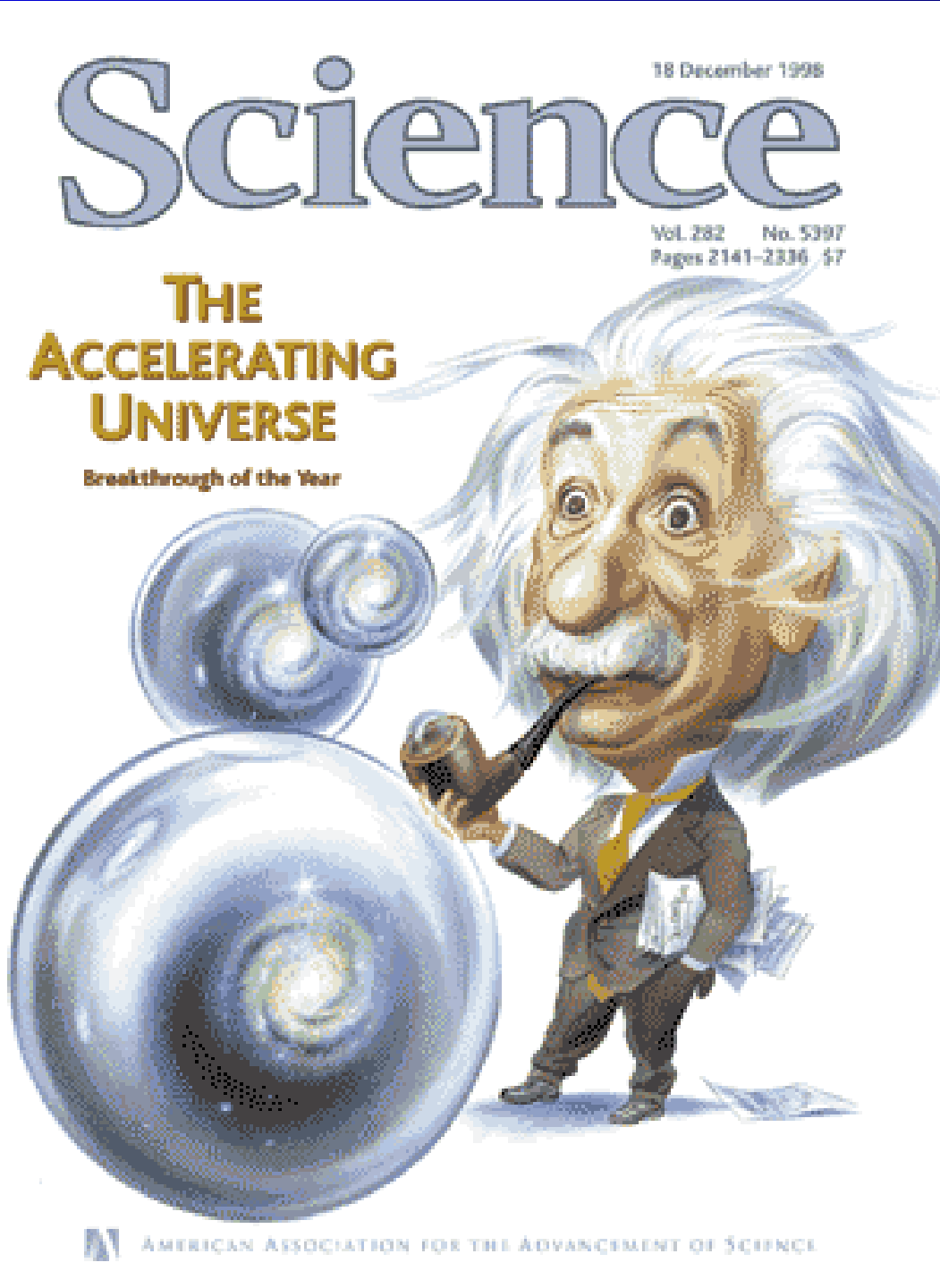
2dF map of the 3d density of the local few billion light years

Colless and team

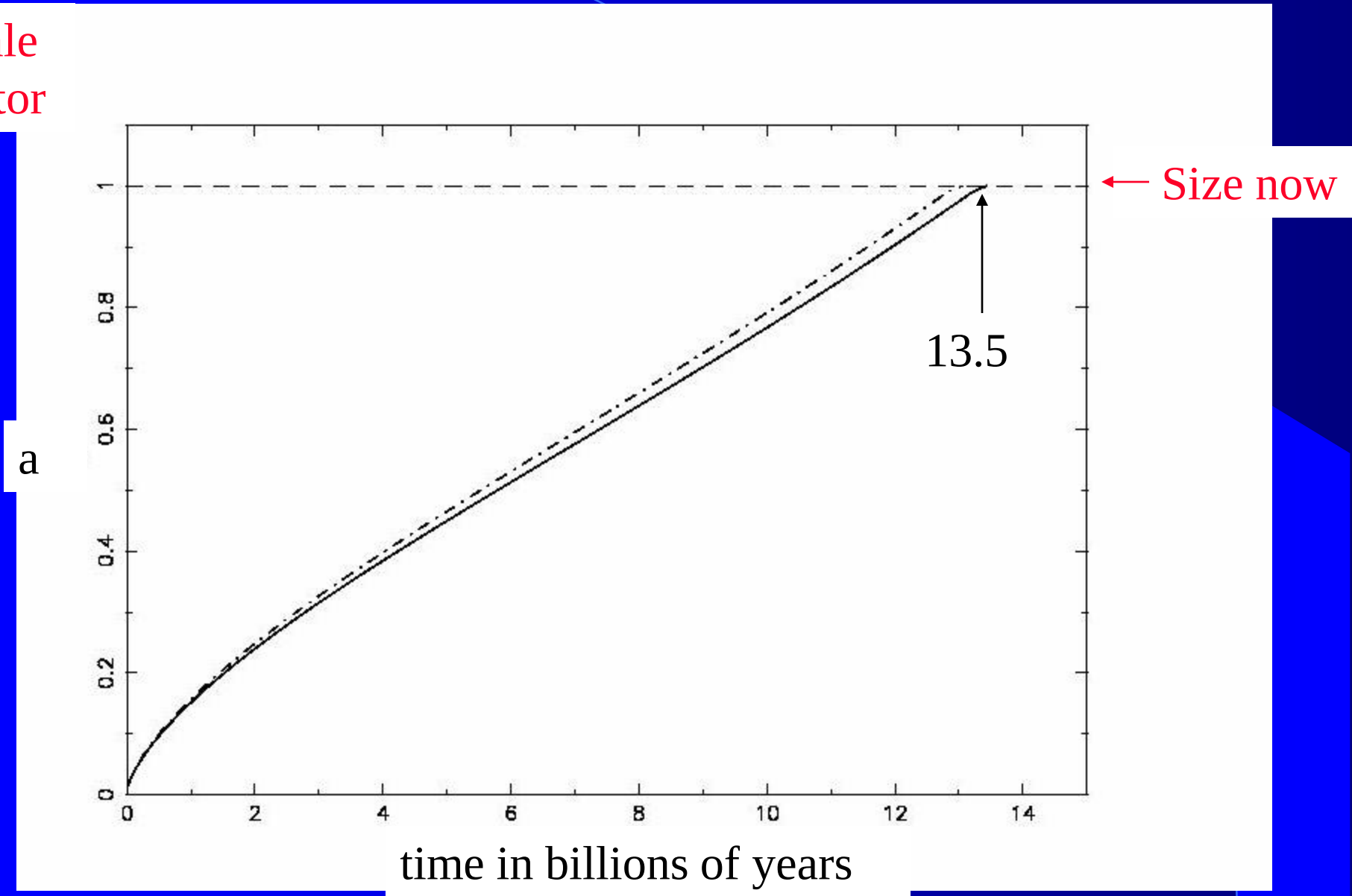


Rediscovery of Λ

See
www.mso.anu.edu.au/~brian



Measuring the age



Summary

- we start with the distance of the LMC
- a Cepheid of period P is a standard candle of luminosity L
- HST maps the Cepheids out to 20 Mpc
- Four other standard candles map the expansion out to 200 Mpc
- H_0 = 72 +/- 7 km/sec/Mpc
- Universe is 13.5 +/- 1.5 Gyrs old

Oldest stars

- globular star clusters
- parallaxes with SIM or GAIA
- measure ages to half a billion years

Where to get more information

- ‘Measuring the Universe’ by Stephen Webb

- www.stsci.edu (Hubble Space Telescope)
  http://oposite.stsci.edu/pubinfo/1999.html