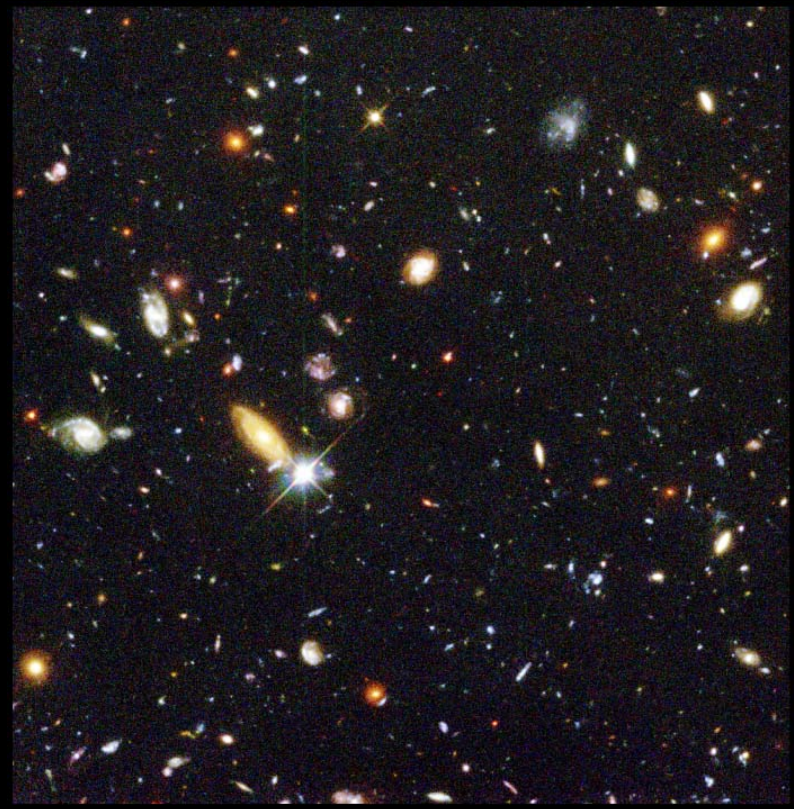
A1Y Introduction to Cosmology

10 lectures, exploring the development of cosmology, and some of the key ideas of Big Bang theory



Access course website via A1Y website, or at

http://www.astro.gla.ac.uk/users/martin/teaching/

username = 'aone'; password = 'aone'

What is Cosmology?...

Cosmology is the study of the properties of the Universe as a whole: its

- Origins
- Evolution
- Eventual Fate

Summary of Course Contents

I: Galaxies and their Properties

- Structure of the Milky Way galaxy
- Rotation curves and dark matter
- Classification of normal galaxies
- Active galaxies and quasars

II: Large Scale Structure of the Universe

- Measuring cosmological distances and redshifts
- Mapping the Local Group and Supercluster
- Distribution of clusters and superclusters

Summary of Course Contents

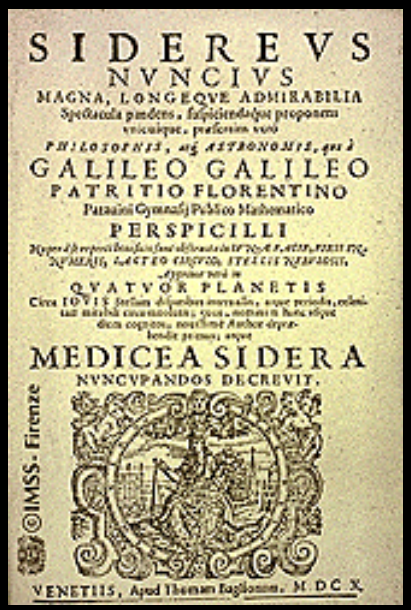
III: The Expanding Universe

- The Hubble expansion
- The cosmological principle
- Cosmological models: open, closed and flat Universes
- Weighing the Universe: evidence for dark matter

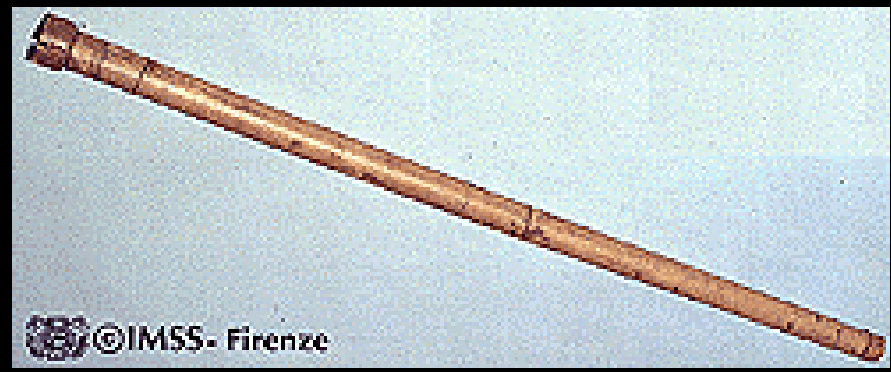
IV: The Early Universe

- Radiation and matter dominated eras
- The cosmic microwave background radiation
- From the CMBR to galaxy formation

Galileo Galilei:
1564 – 1642 AD


SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
unicuique, præsertim vero
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
QVATVOR PLANETIS
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M. DC X.

Galilean Moons: 1610



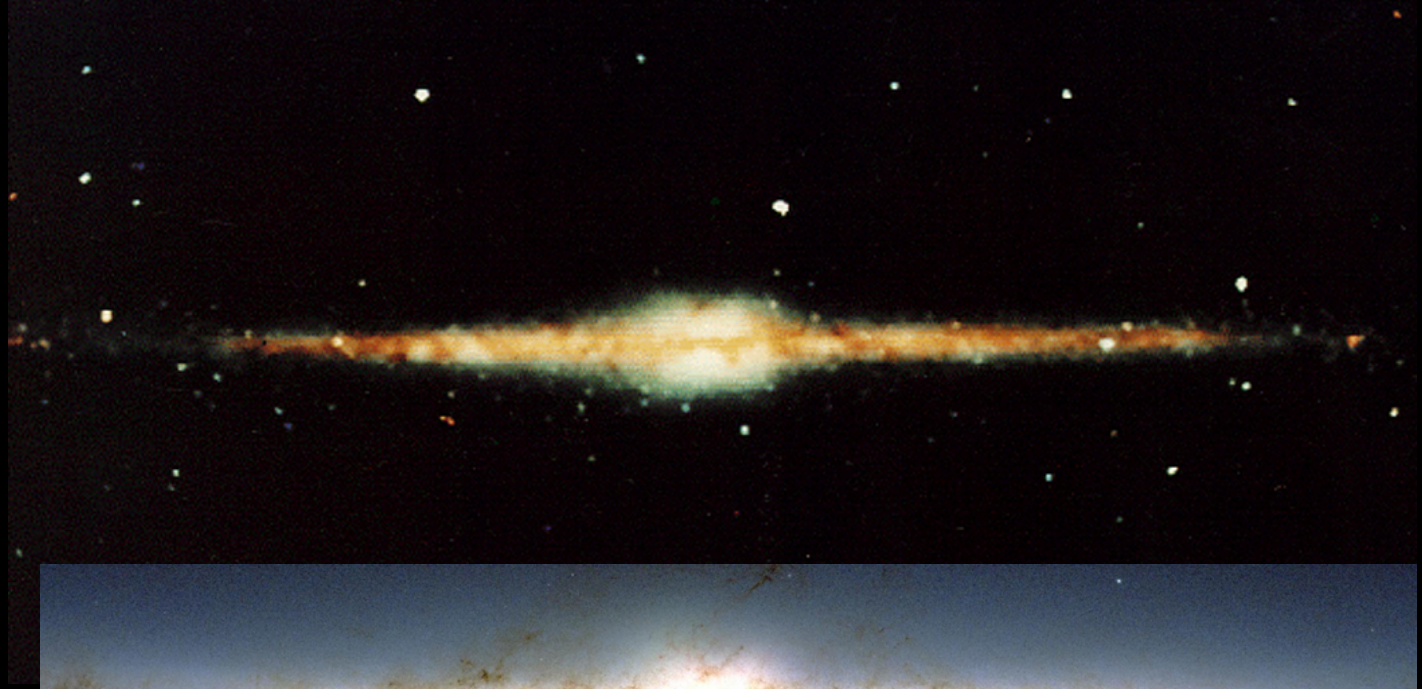
Galileo Galilei:
1564 – 1642 AD

"I have observed the nature and the material of the Milky Way. With the aid of the telescope this has been scrutinized so directly and with such ocular certainty that all the disputes which have vexed philosophers through so many ages have been resolved, and we are at last freed from wordy debates about it.

The galaxy is, in fact, nothing but a collection of innumerable stars grouped together in clusters. Upon whatever part of it the telescope is directed, a vast crowd of stars is immediately presented to view. Many of them are rather large and quite bright, while the number of smaller ones is quite beyond calculation."

from The Starry Messenger (1610)

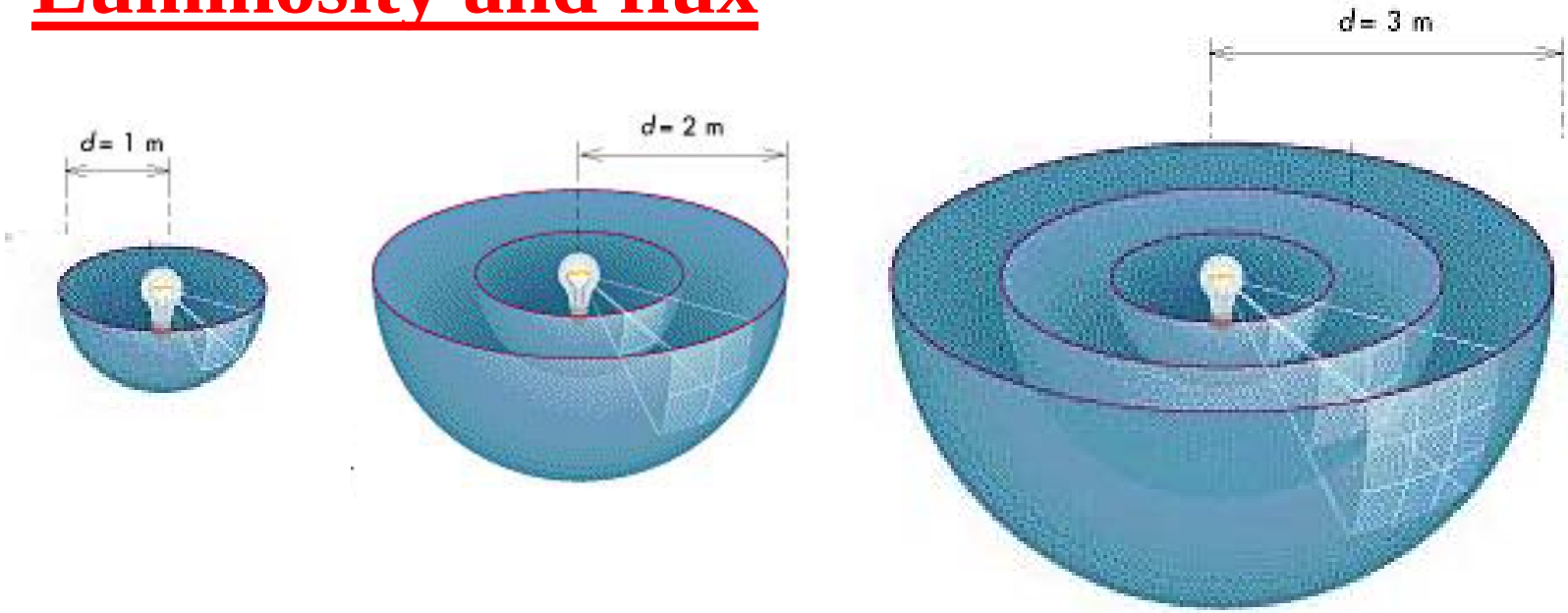
Microwaves
(CoBE)



Infra-red
(2MASS)

Visible light

Luminosity and flux



Apparent brightness, or flux, falls off with the square of the distance, because the surface area of a sphere increases with the square of its radius

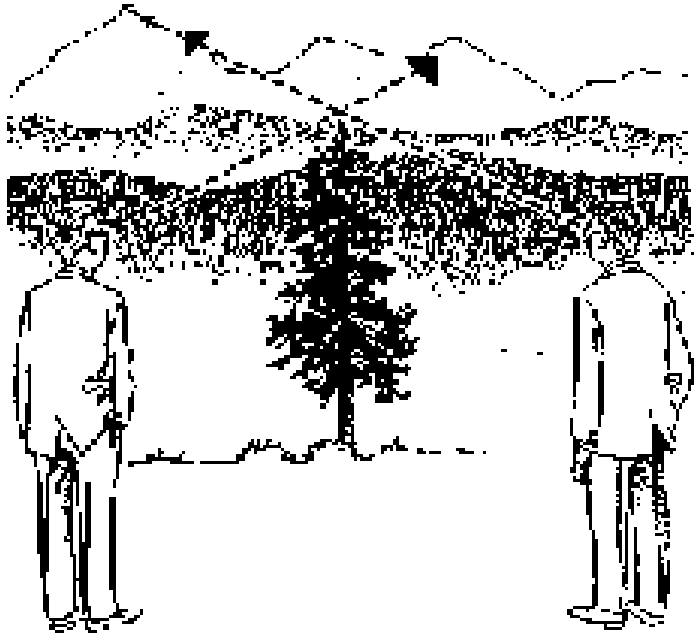
Distance, (metres)

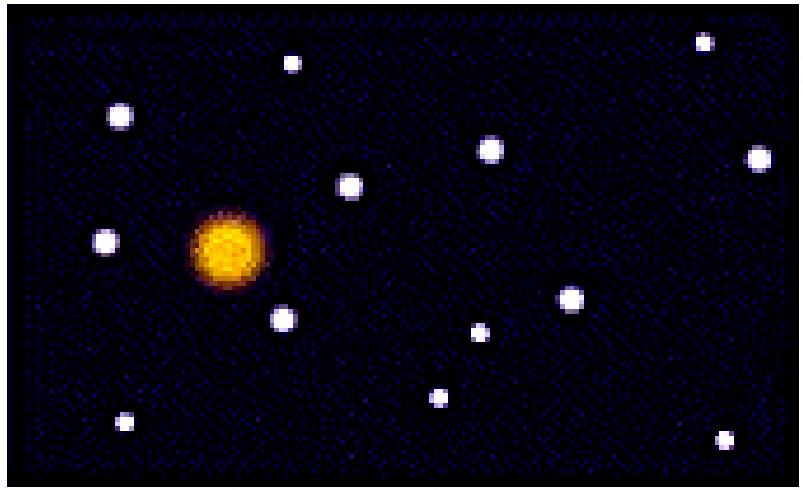
$$L = 4\pi D^2 F$$

Luminosity, (watts)

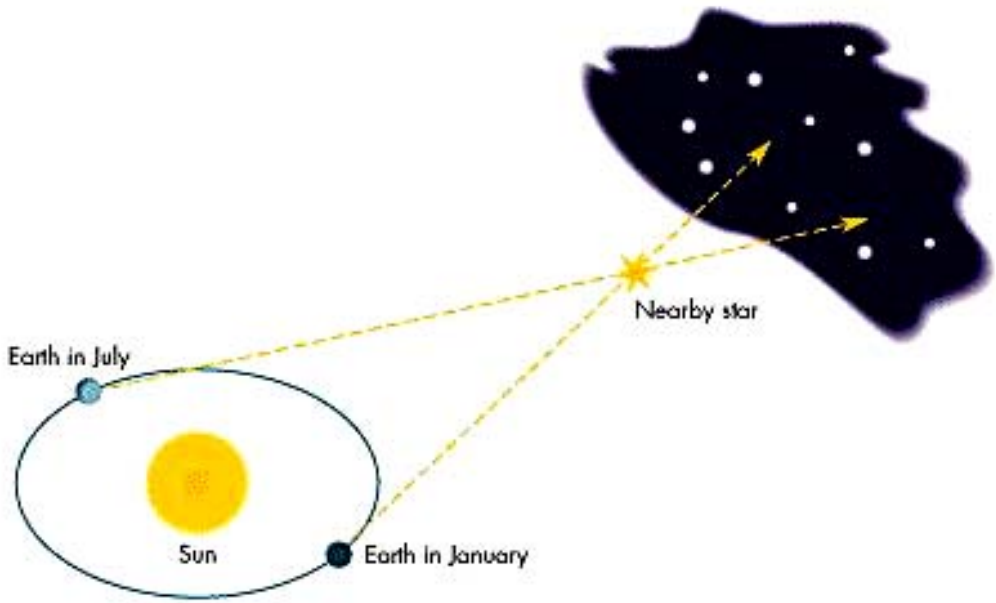
Flux, (watts / square metre)

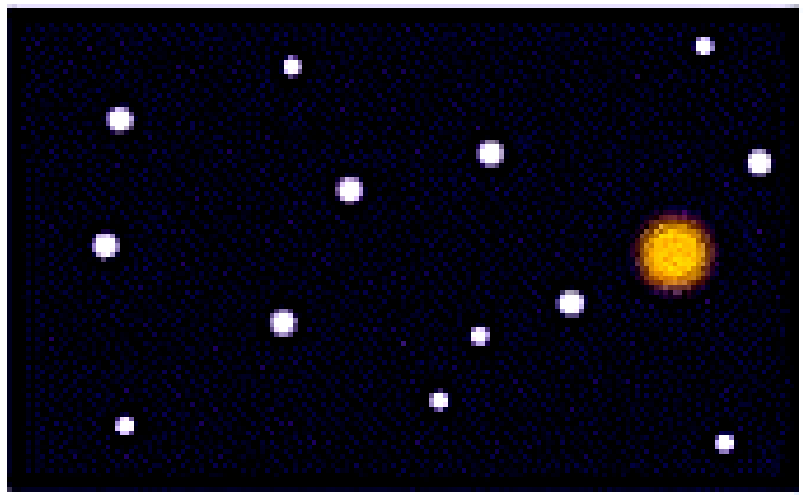
Measuring Astronomical Distances: Parallax





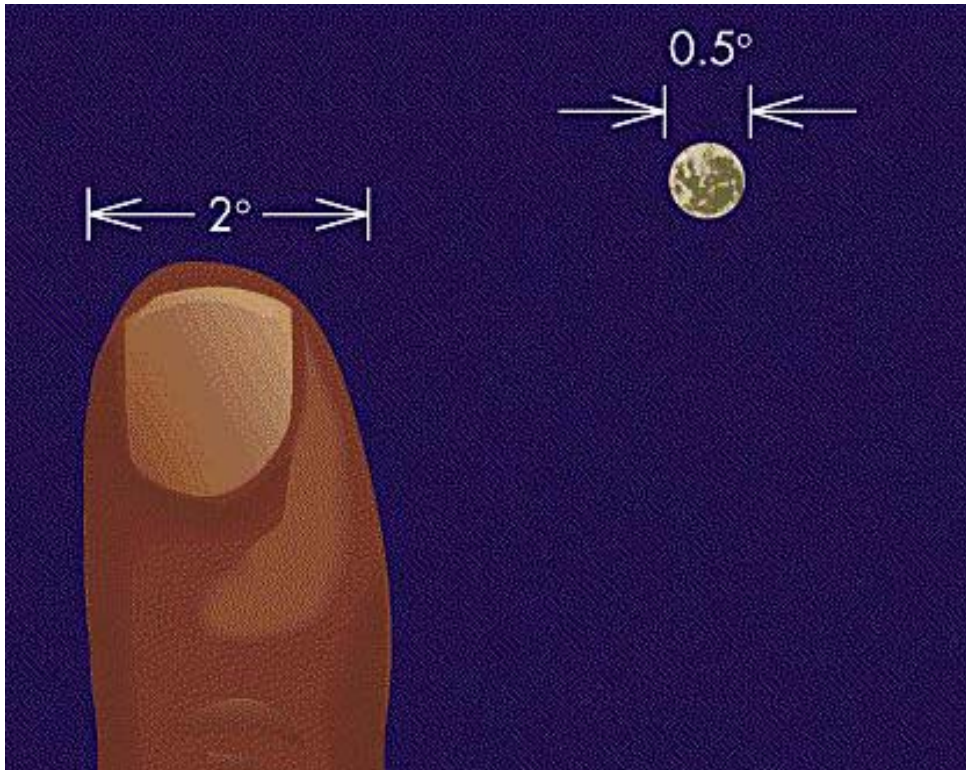
View from the Earth in January

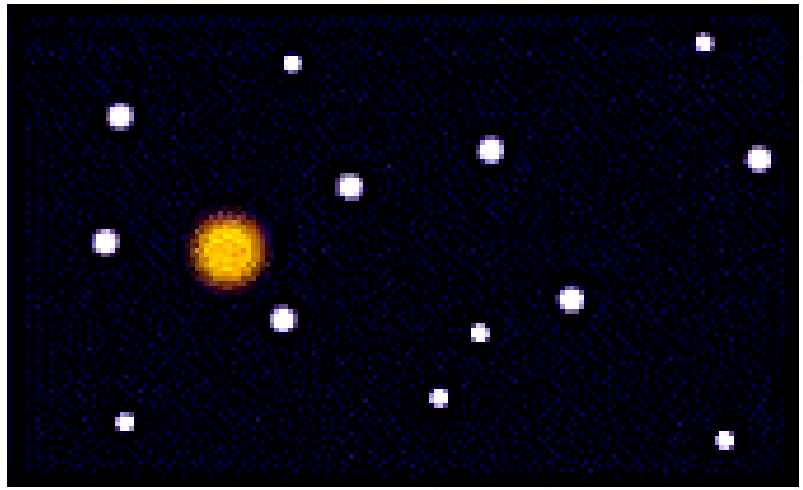




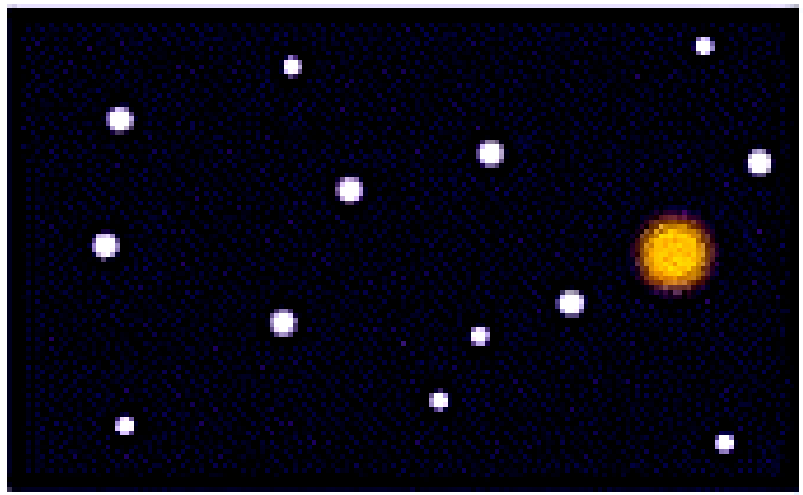
View from the Earth in July

Measuring Astronomical Distances: Parallax





View from the Earth in January



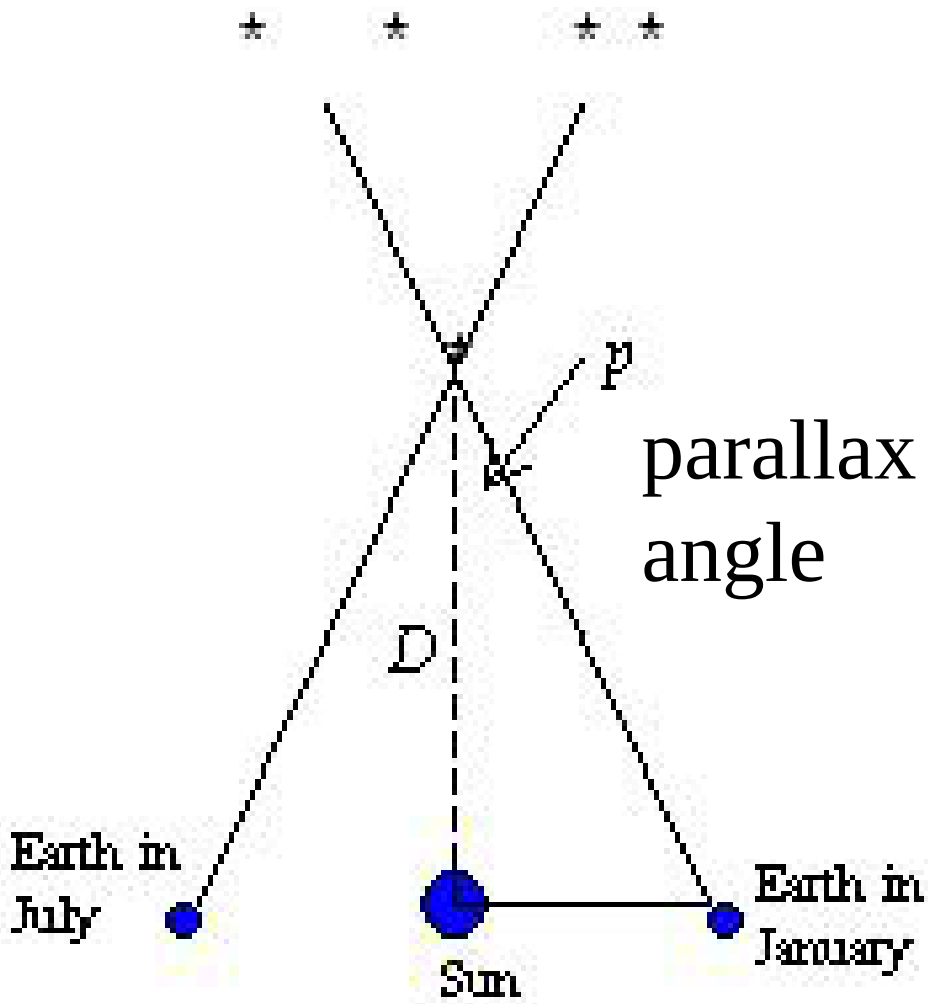
View from the Earth in July

Even the nearest star shows a parallax shift of only 1/2000th the width of the full Moon

Measuring Astronomical Distances: Parallax

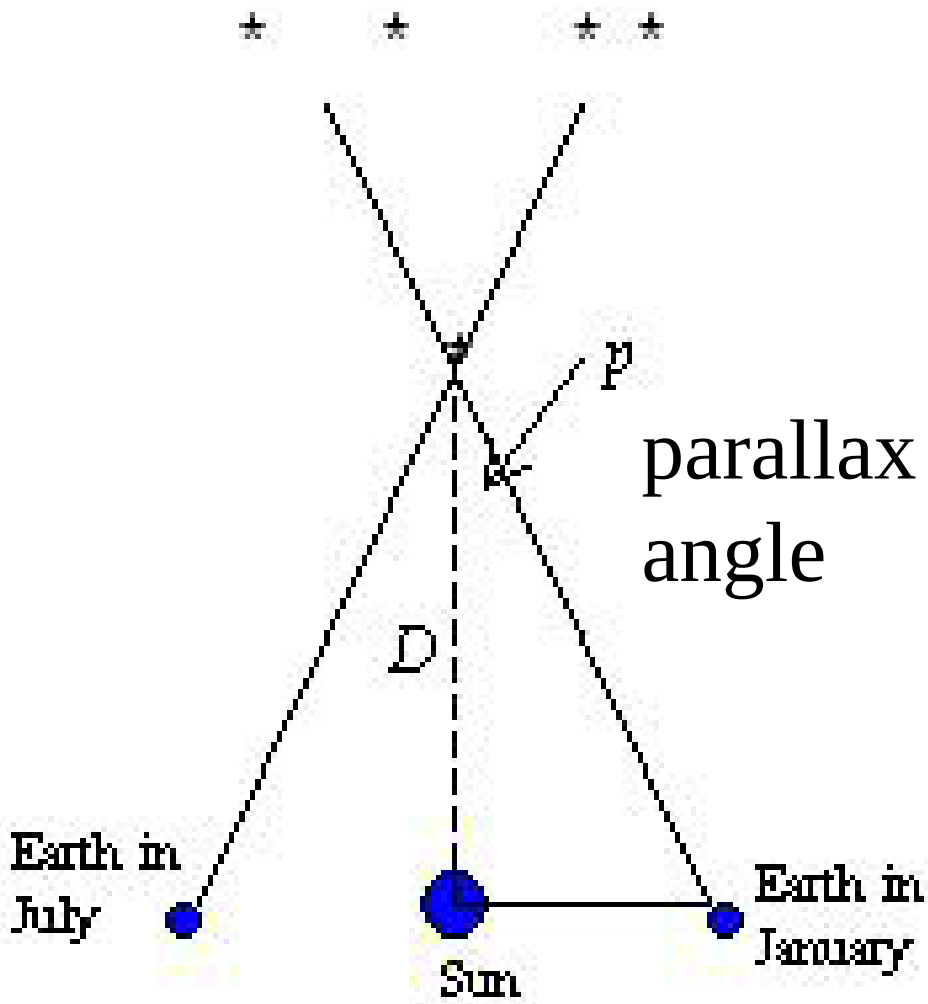
$$D = \frac{1}{\tan p} \cong \frac{1}{p} \text{ A.U.}$$

$$D = \frac{206265}{p''} \text{ A.U.}$$



A star at a distance of 1 parsec shows a parallax angle of one arc second

Measuring Astronomical Distances: Parallax



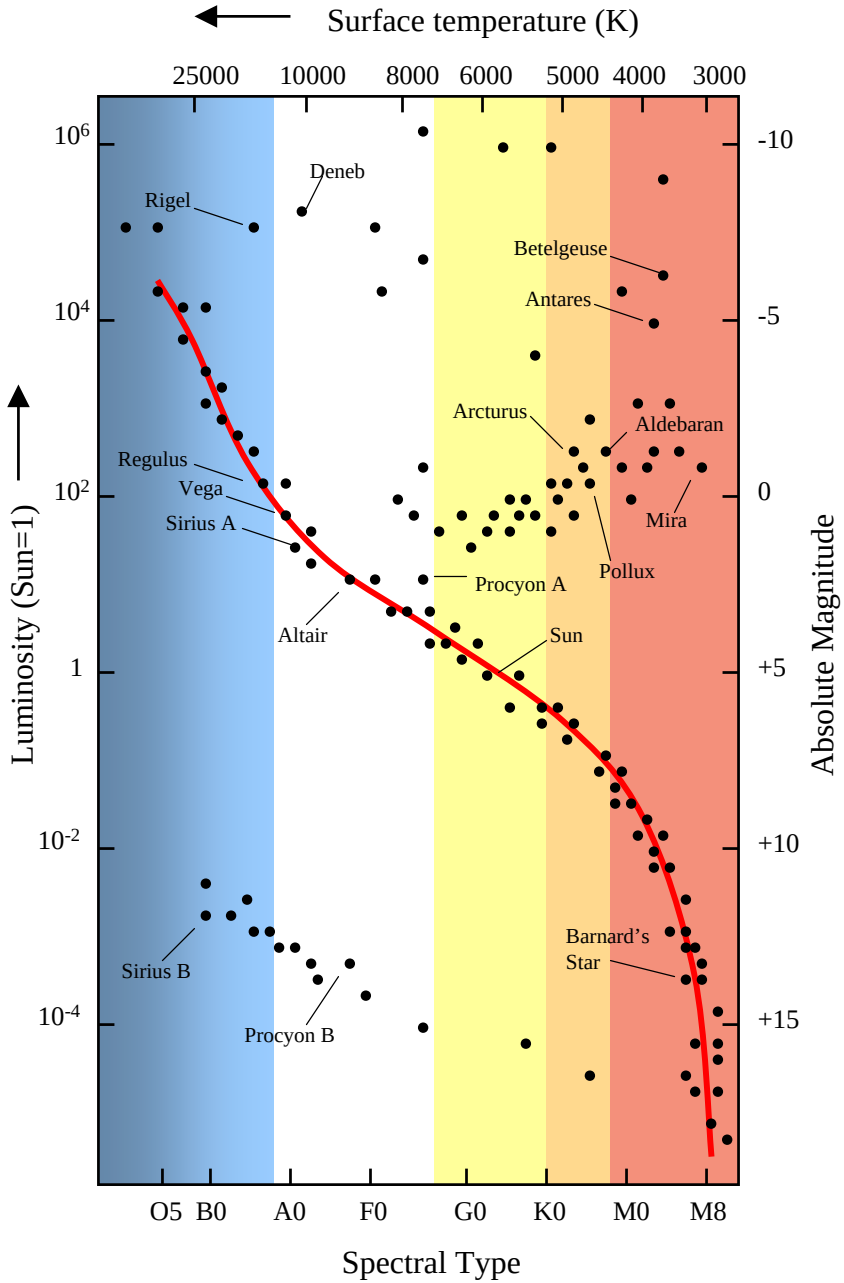
$$D = \frac{1}{\tan p} \cong \frac{1}{p} \text{ A.U.}$$

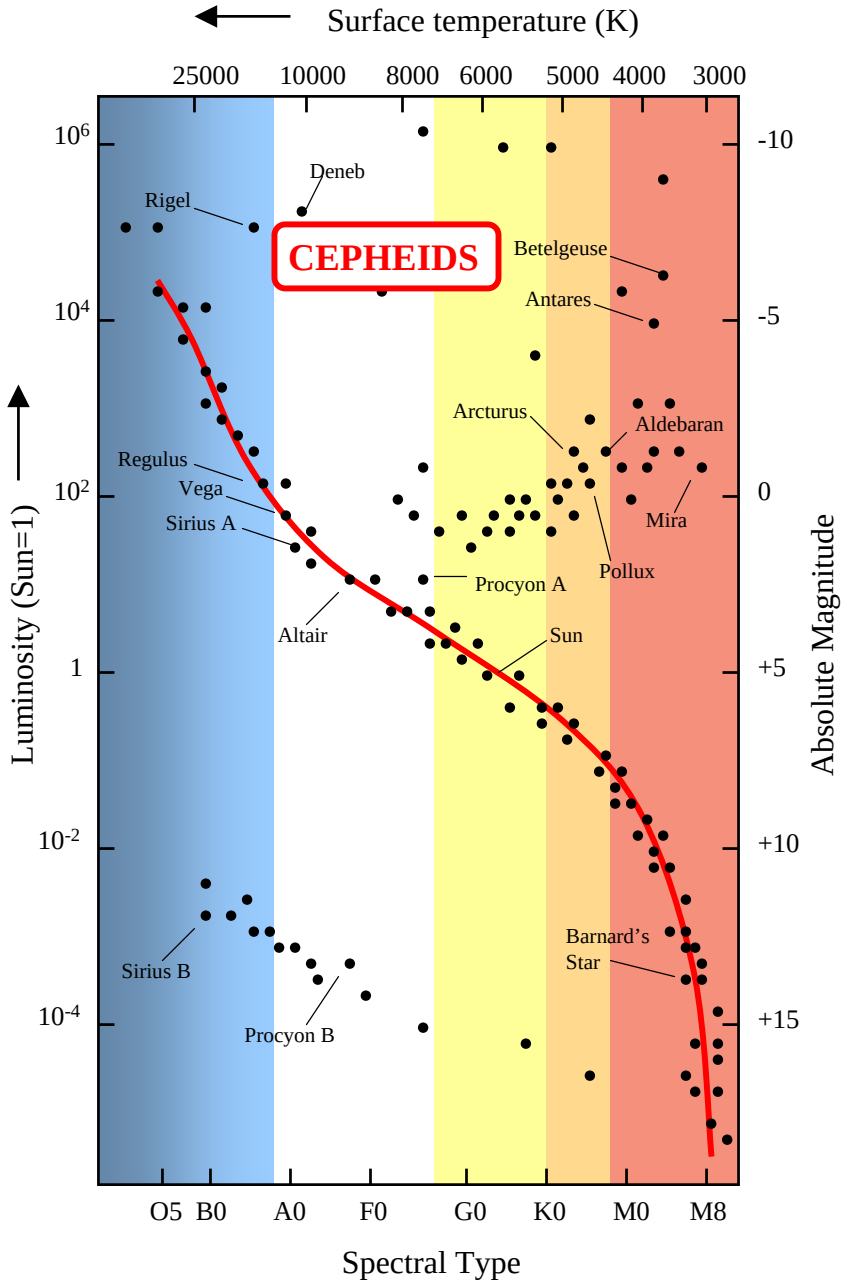
$$D = \frac{206265}{p''} \text{ A.U.}$$

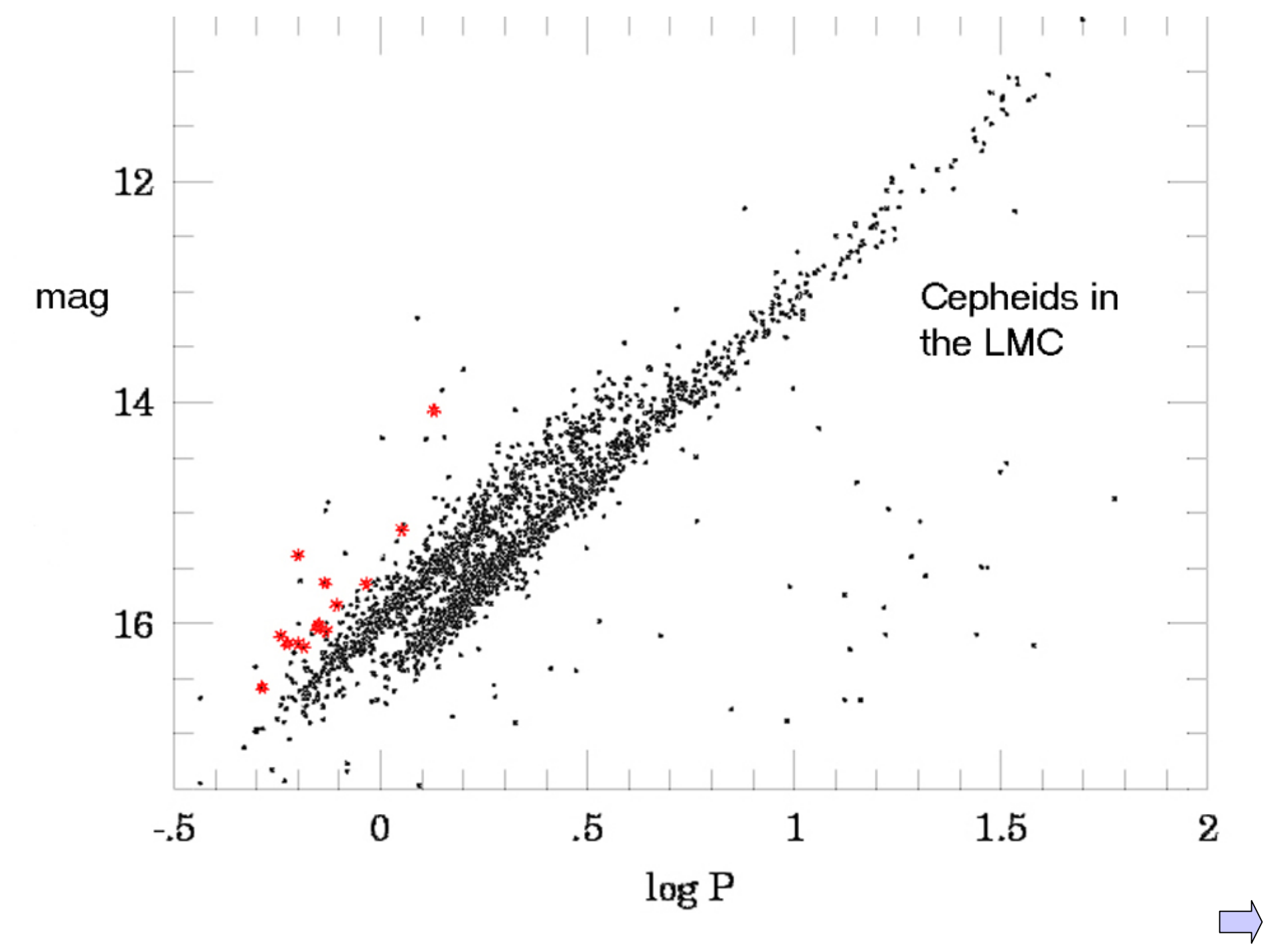
$$1\,\text{pc} = 206265 \text{ A.U.}$$

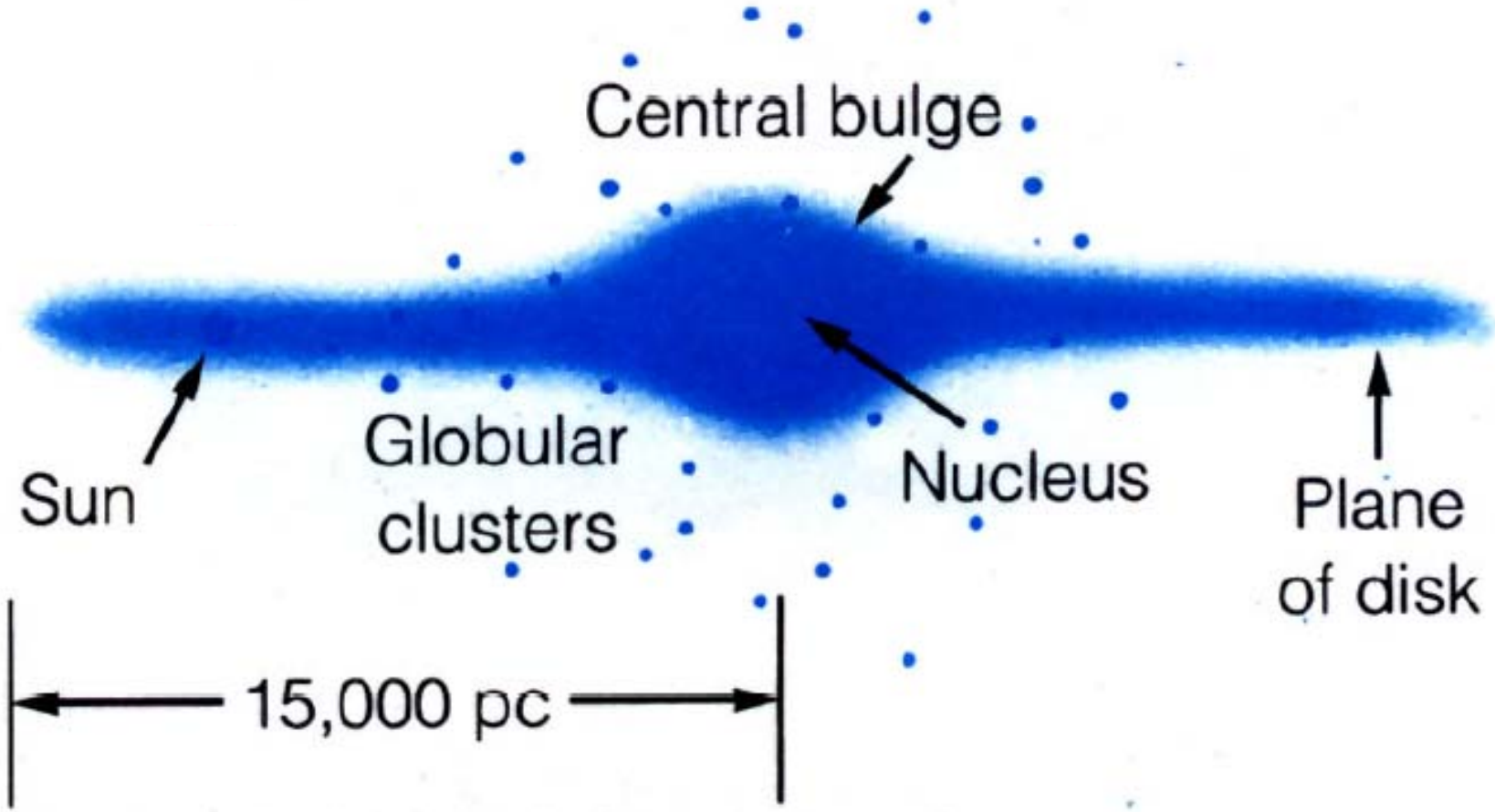
$$= 3.086 \times 10^{16} \text{ m}$$

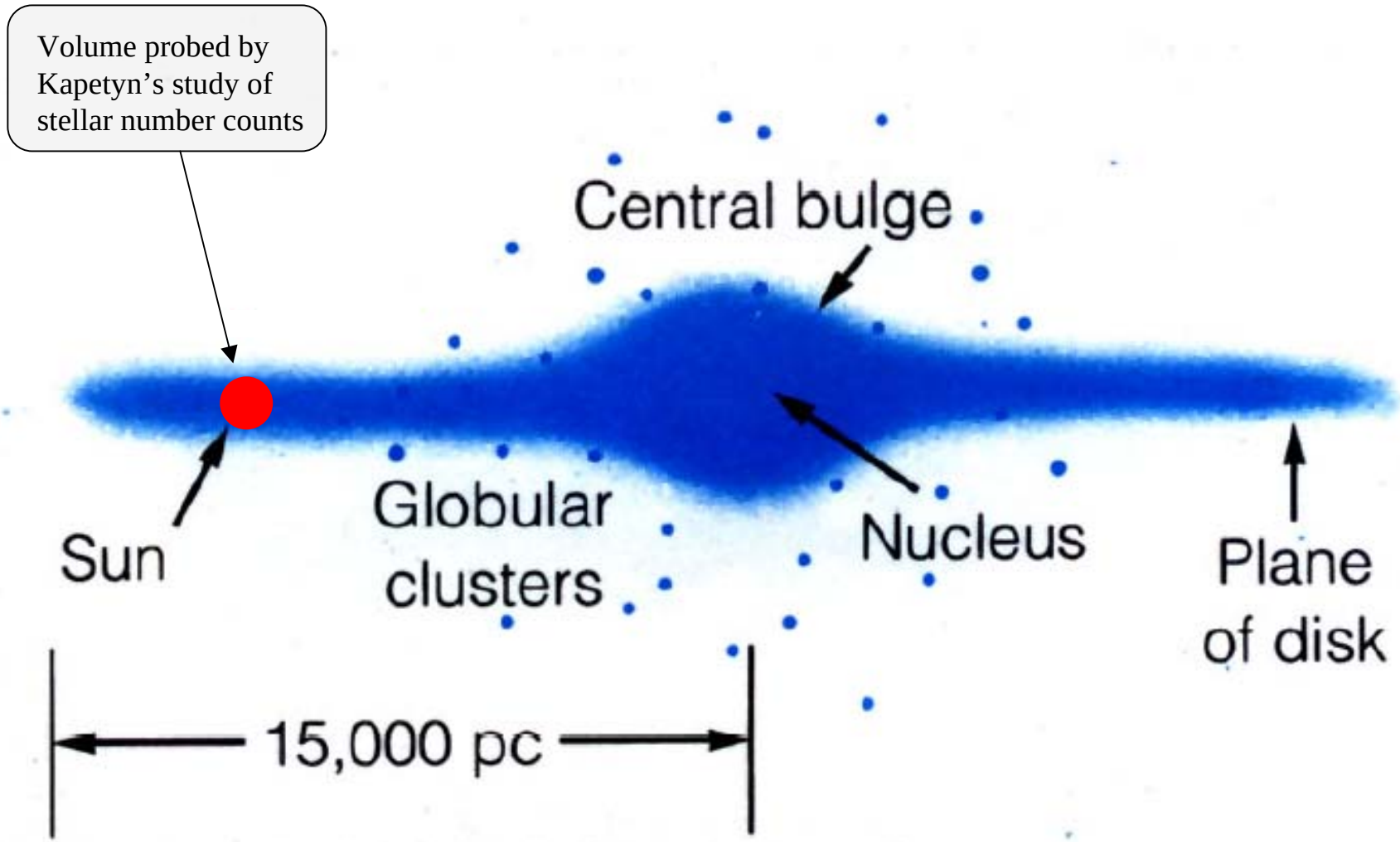
$$= 3.262 \text{ light years}$$


Surface temperature (K)
25000
10000
8000
6000
5000
4000
3000
Luminosity (Sun=1)
10^6
10^4
10^2
1
10^{-2}
10^{-4}
Absolute Magnitude
-10
-5
0
+5
+10
+15
Deneb
Rigel
Betelgeuse
Antares
Arcturus
Aldebaran
Regulus
Vega
Sirius A
Mira
Pollux
Procyon A
Altair
Sun
Barnard's Star
Sirius B
Procyon B
O5
B0
A0
F0
G0
K0
M0
M8
Spectral Type

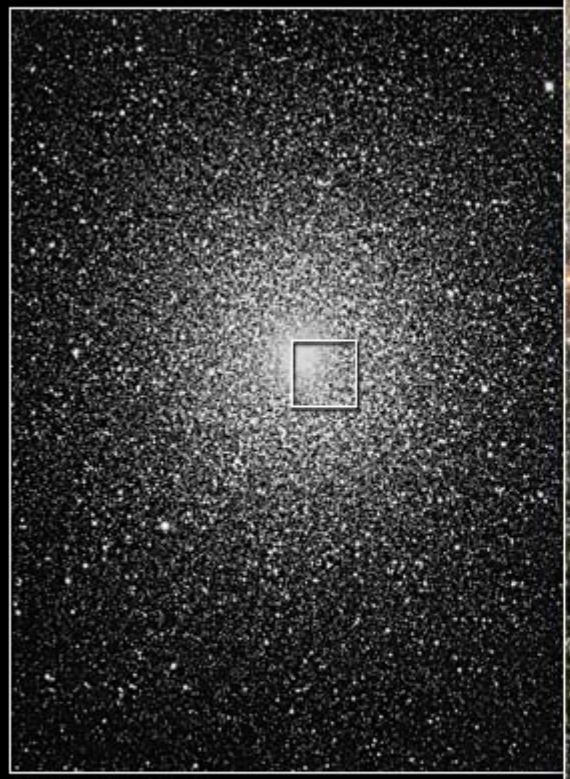

Surface temperature (K)
25000
10000
8000
6000
5000
4000
3000
Luminosity (Sun=1)
10^6
10^4
10^2
1
10^{-2}
10^{-4}
Absolute Magnitude
-10
-5
0
+5
+10
+15
CEPHEIDS
Deneb
Rigel
Betelgeuse
Antares
Arcturus
Aldebaran
Regulus
Vega
Sirius A
Mira
Pollux
Procyon A
Altair
Sun
Barnard's Star
Sirius B
Procyon B
O5
B0
A0
F0
G0
K0
M0
M8
Spectral Type


12
14
16
mag
Cepheids in
the LMC
-.5
0
.5
1
1.5
2
log P

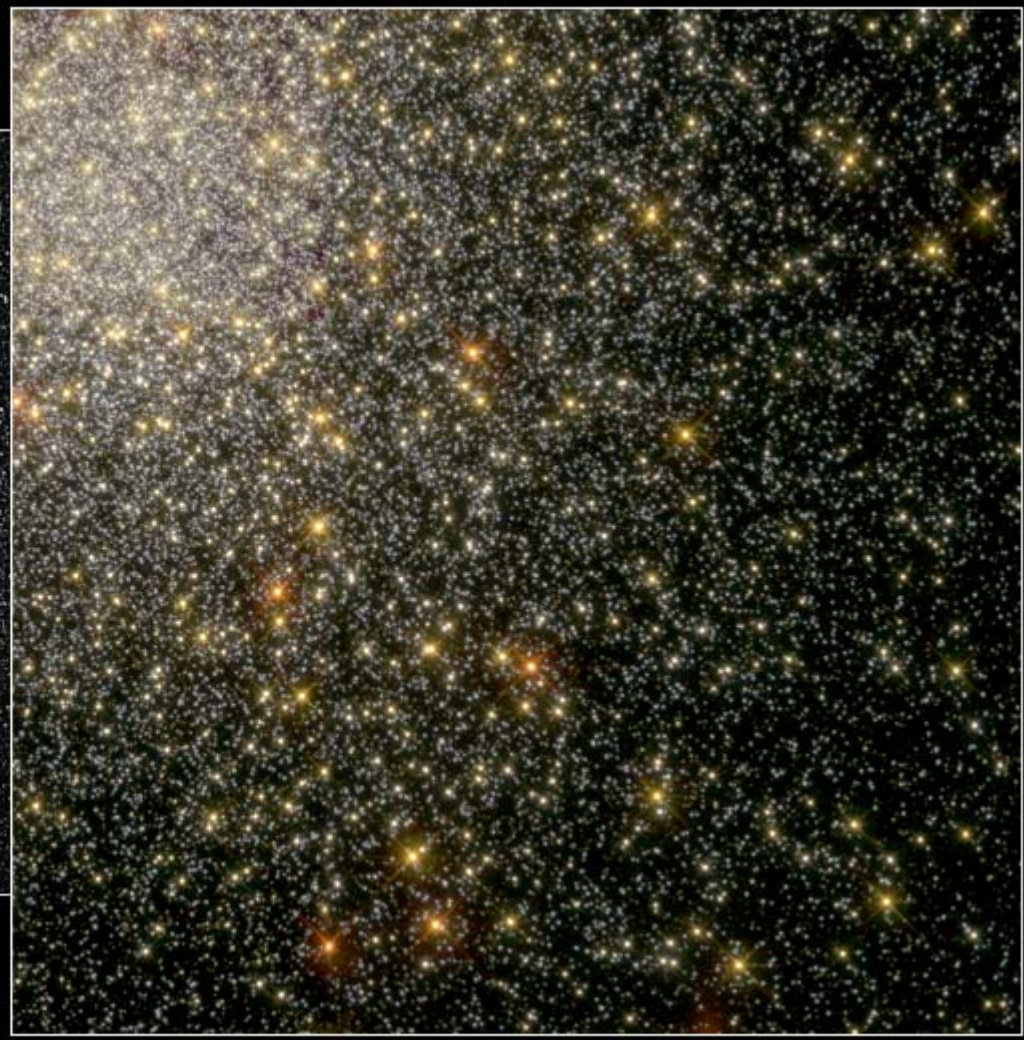

Central bulge
Sun
Globular clusters
Nucleus
Plane of disk
15,000 pc


Volume probed by Kapetyn's study of stellar number counts
Central bulge
Sun
Globular clusters
Nucleus
Plane of disk
15,000 pc

Globular Cluster 47 Tucanae

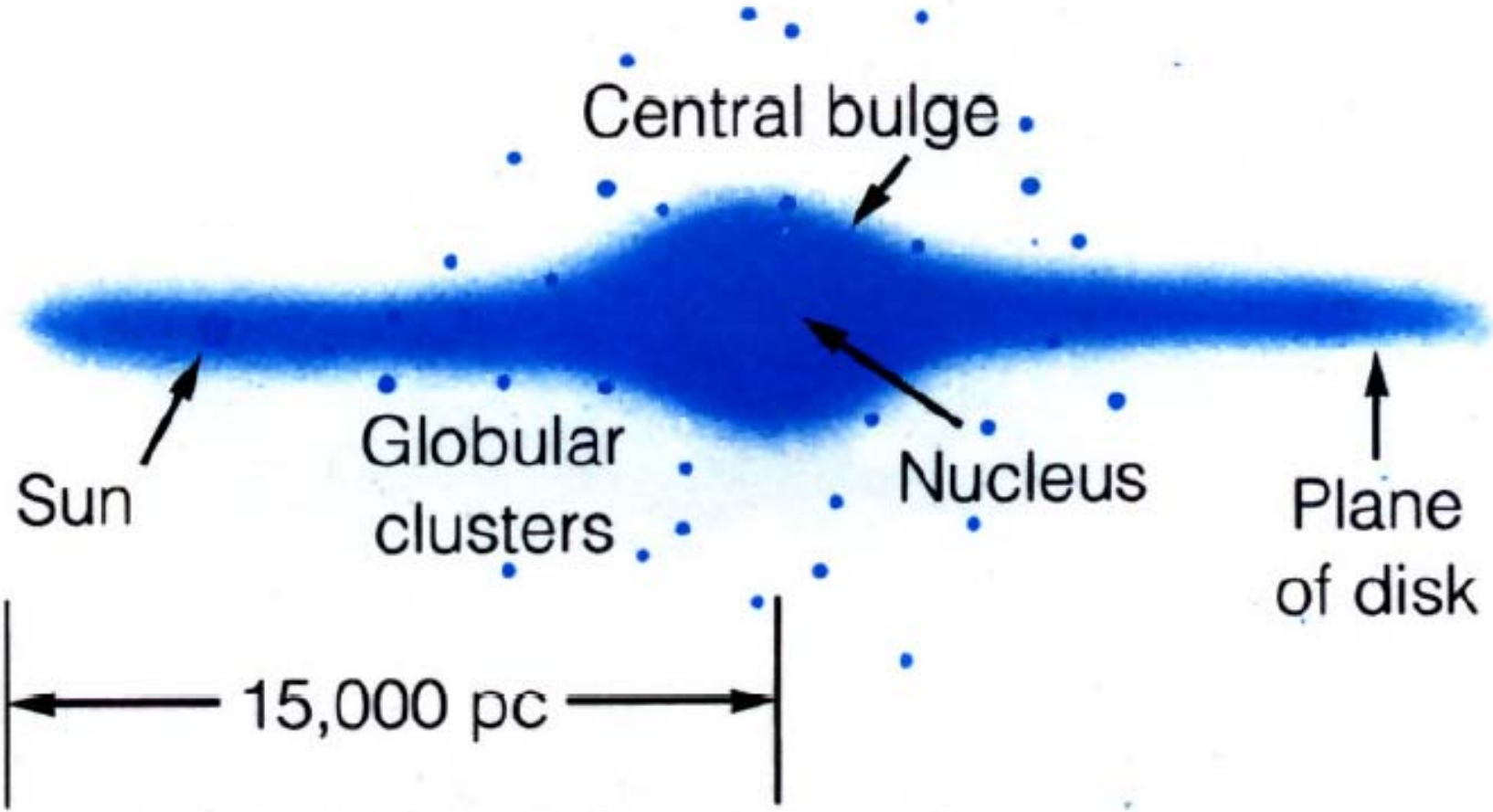


Ground • AAT



Hubble Space Telescope • WFPC2

NASA and R. Gilliland (STScI)
STScI-PRC00-33


Central bulge
Sun
Globular clusters
Nucleus
Plane of disk
15,000 pc

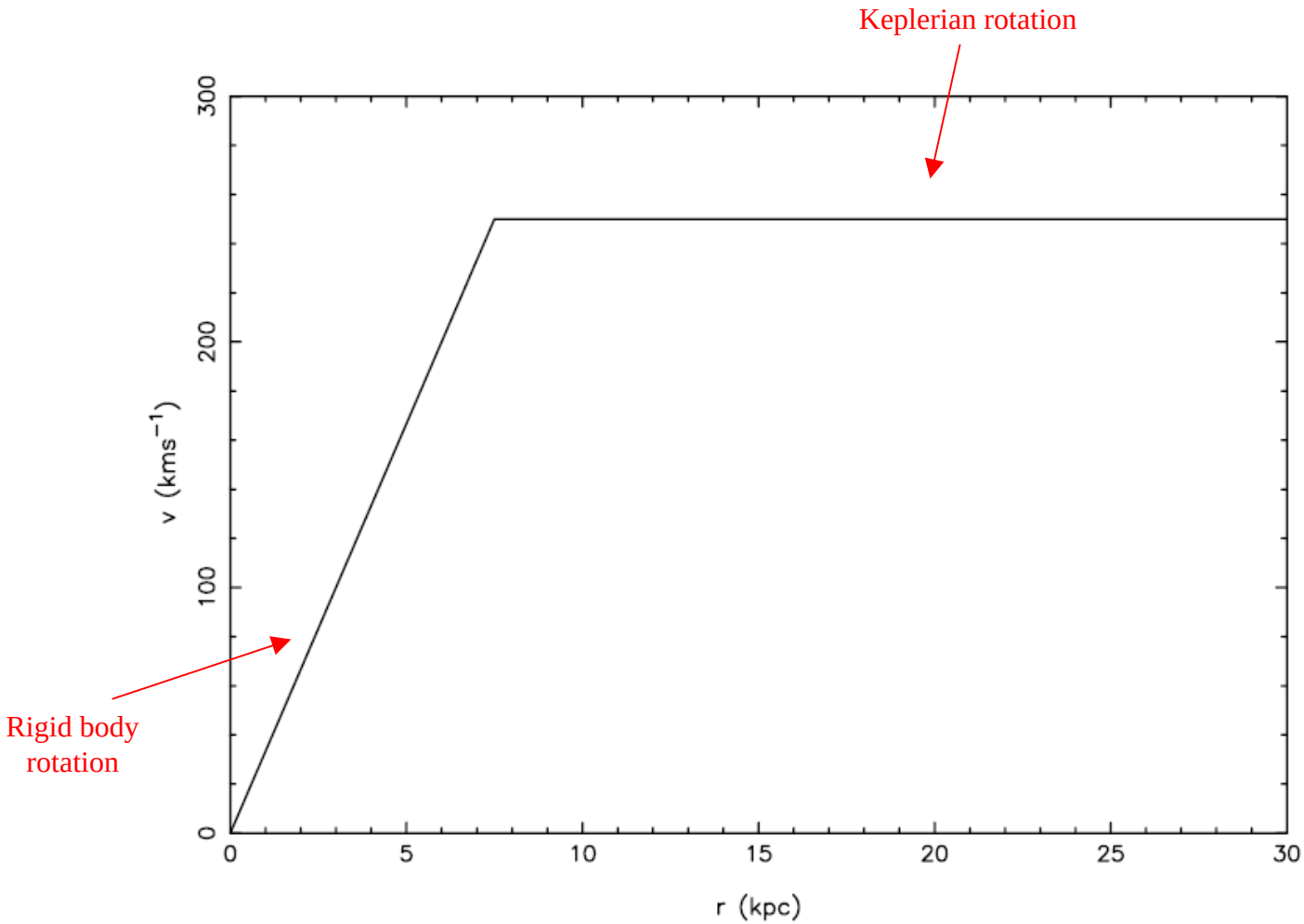
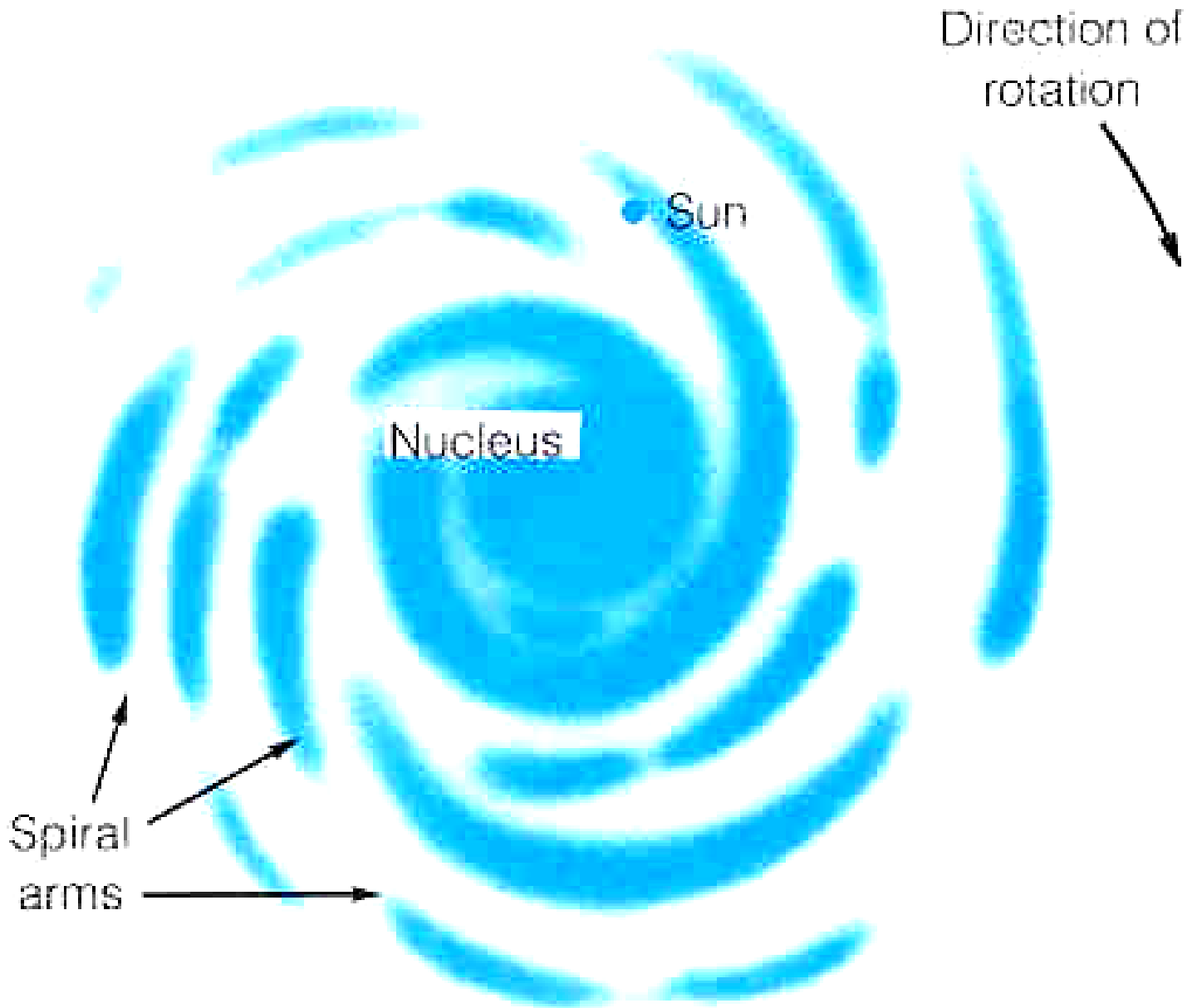


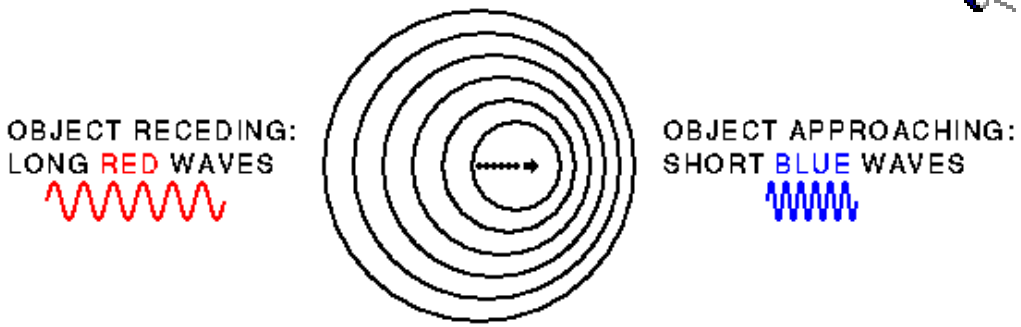
Figure 1: A schematic galaxy rotation curve.

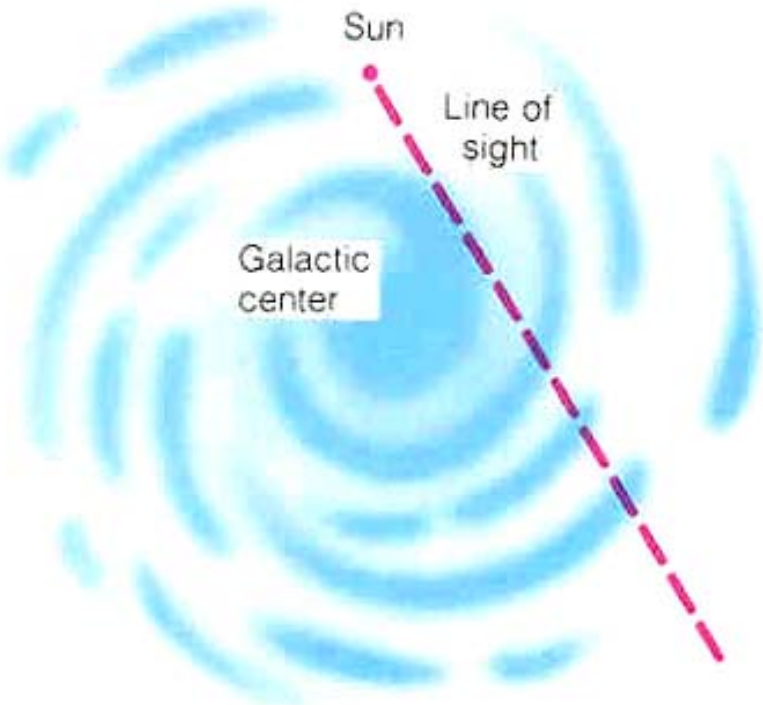

Direction of rotation
Sun
Nucleus
Spiral arms

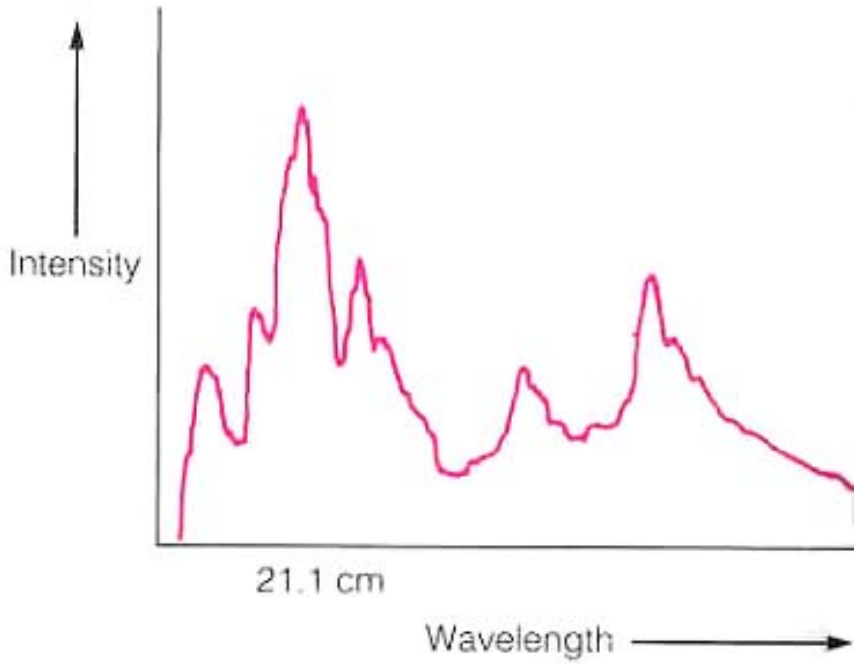

© CFHT

In the Milky Way, Doppler analysis of HI 21cm radio emission, has revealed the *spiral structure* of the Galaxy

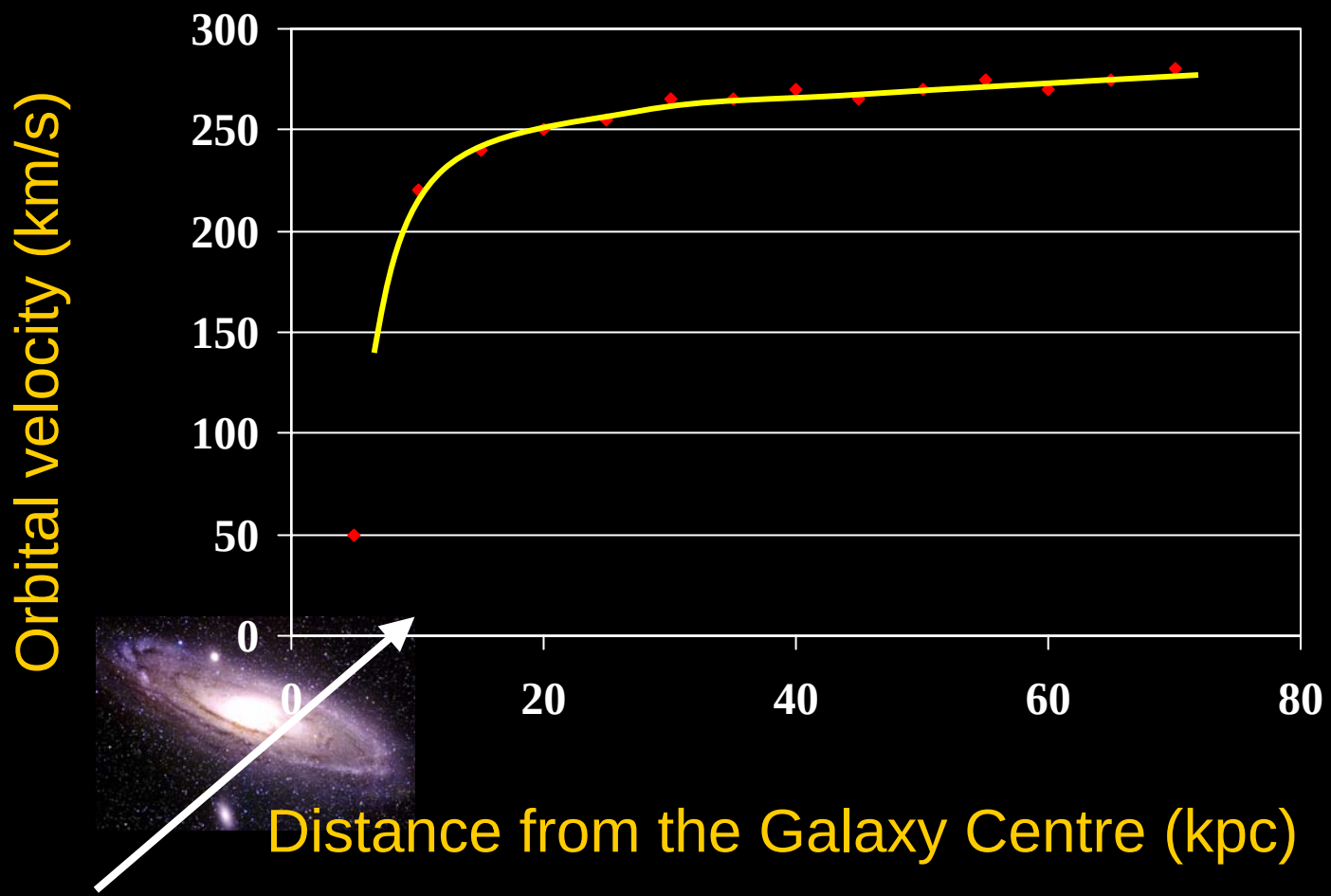
Doppler Shift







Around Galaxies



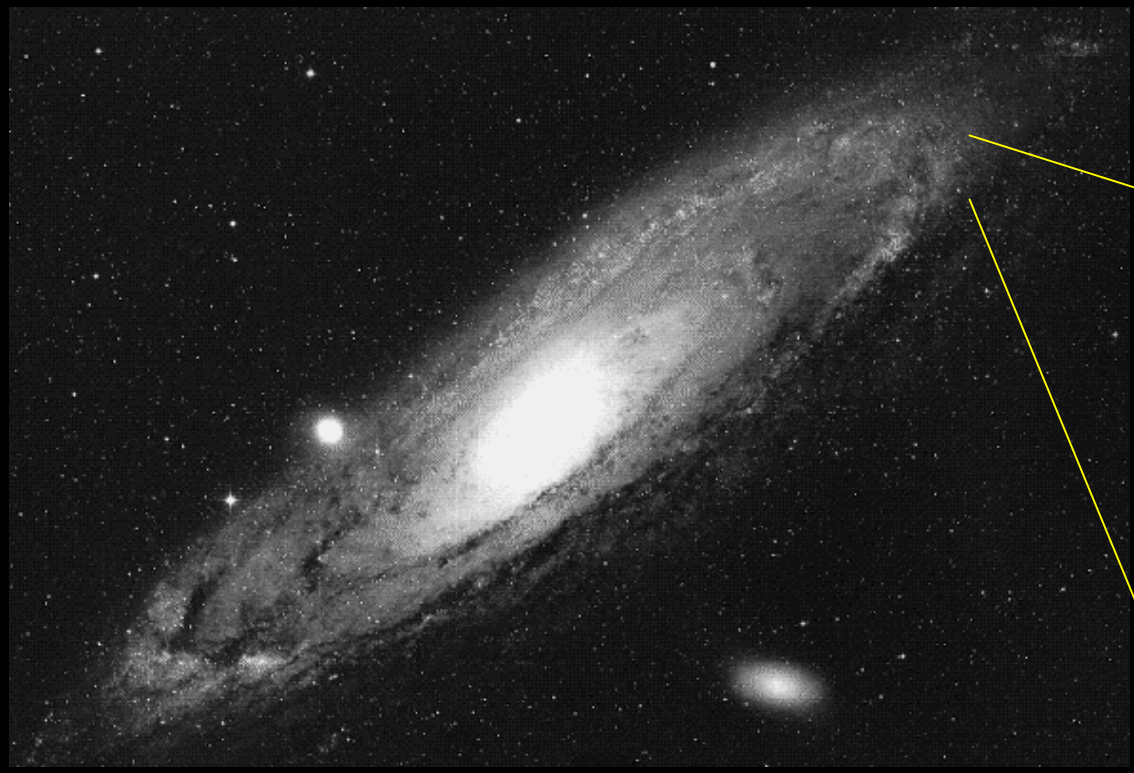
Typical size of galaxy disk

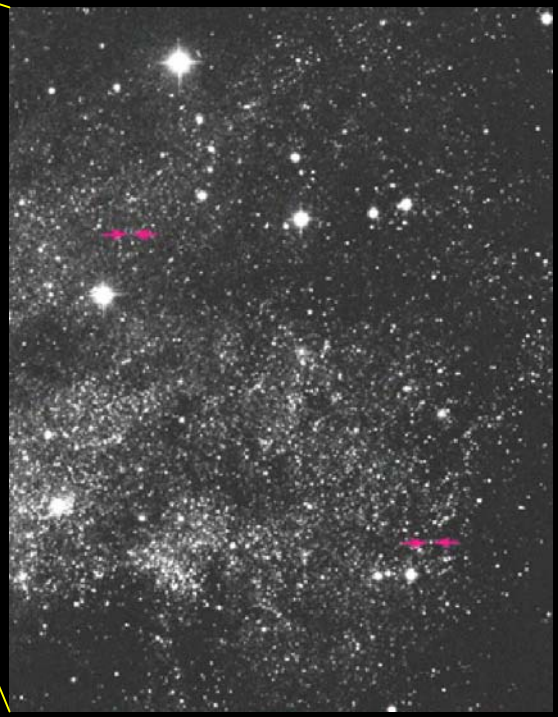
What we see

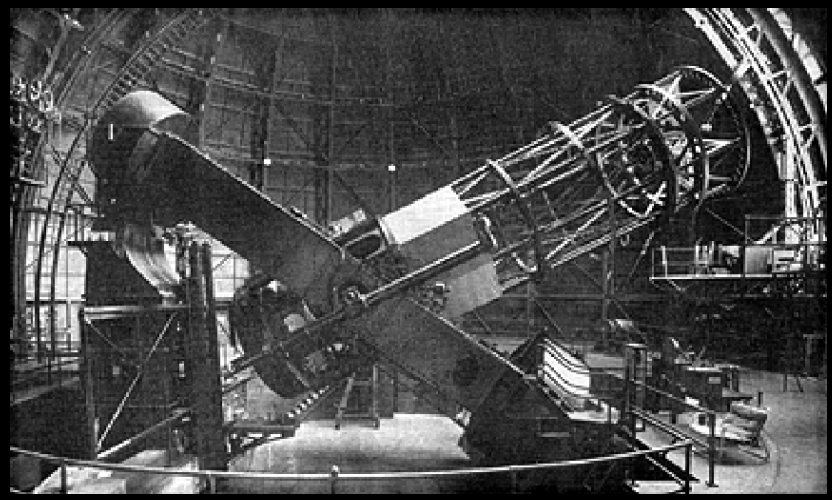
What is really there.

Early 1920s

Edwin Hubble tried to measure the distance of the Spiral Nebulae



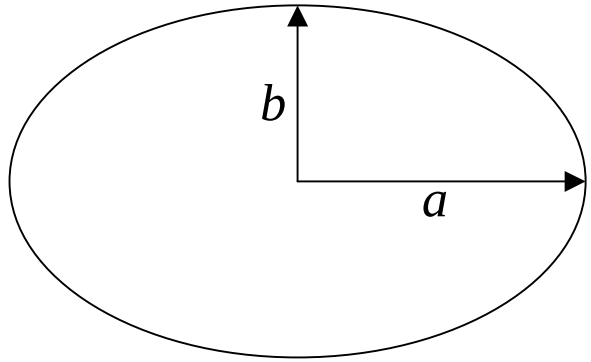


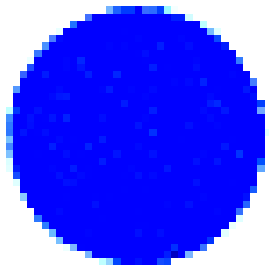


1924: Hubble finds Cepheids in the Great Nebula in Andromeda

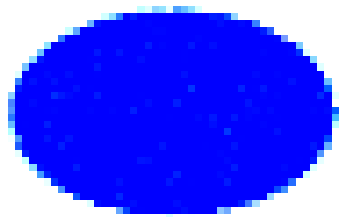
Elliptical classification

$$En \quad ; \quad n = 10(1 - b/a)$$

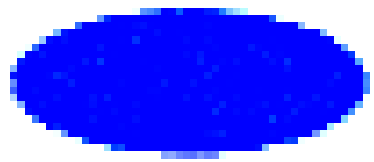




E0

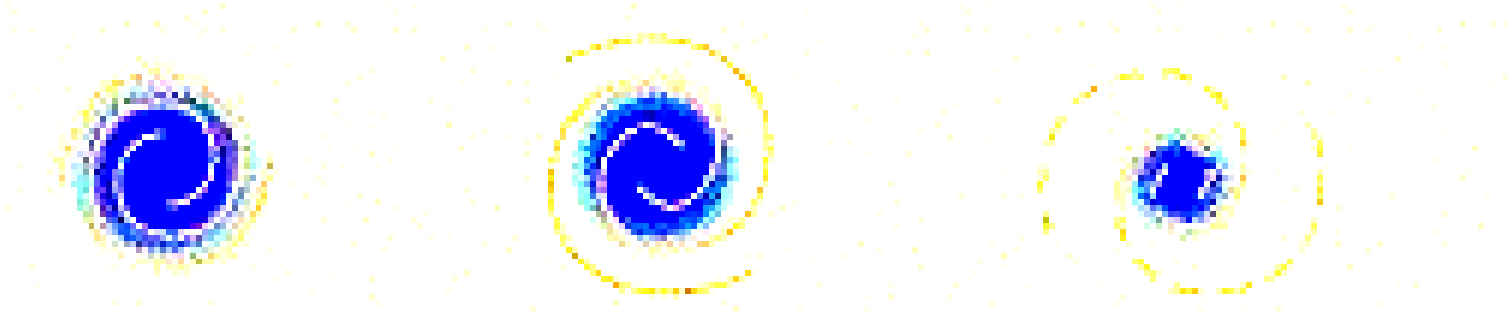


E3



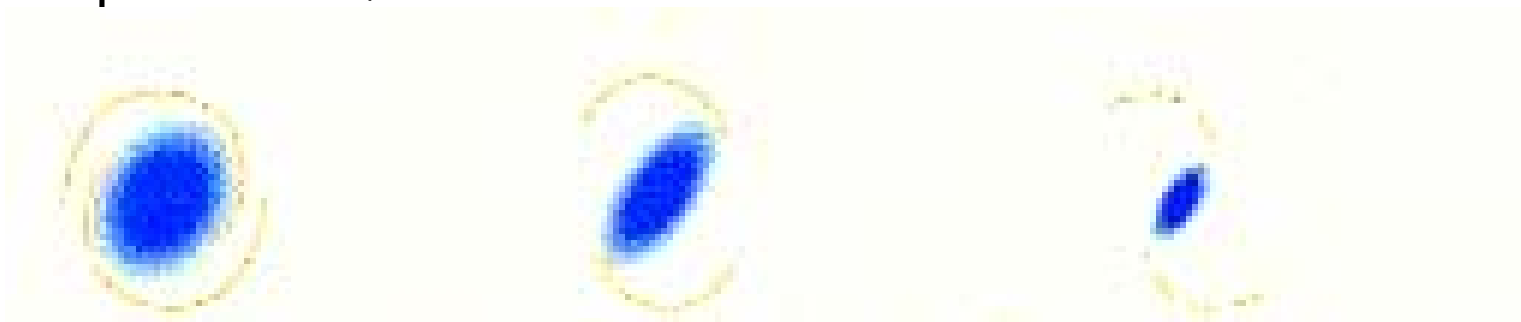
E7

Spiral classification



Sa **Sb** **Sc**

Barred spiral classification



SBa **SBb** **SBc**

An Sa galaxy has a large central bulge and small, tightly wound spiral arms. An Sc galaxy has a small central bulge and wide, open spiral arms.


M31

M51

M100

NGC4414

NGC2997


M32

M87


Large Magellanic Cloud

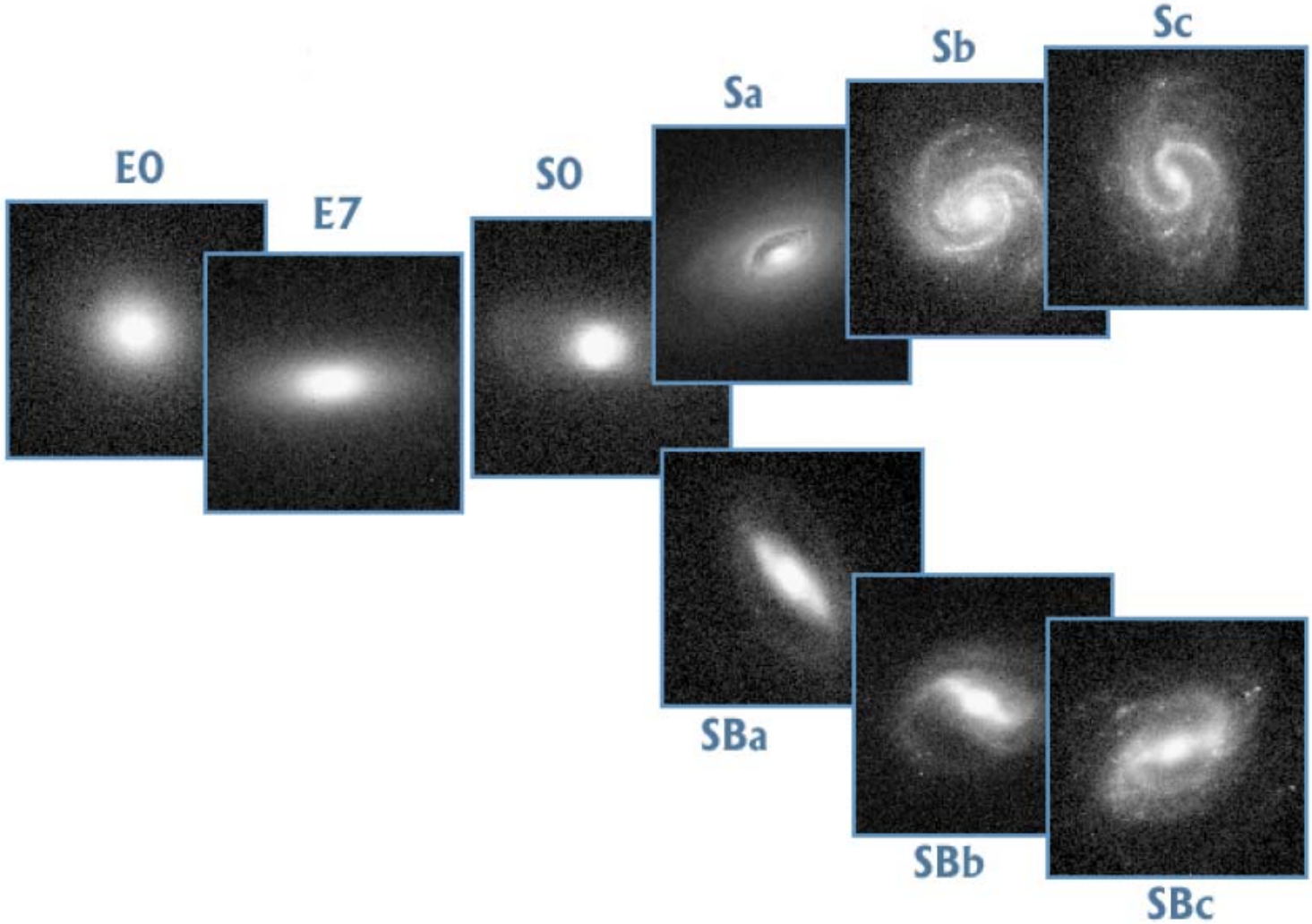
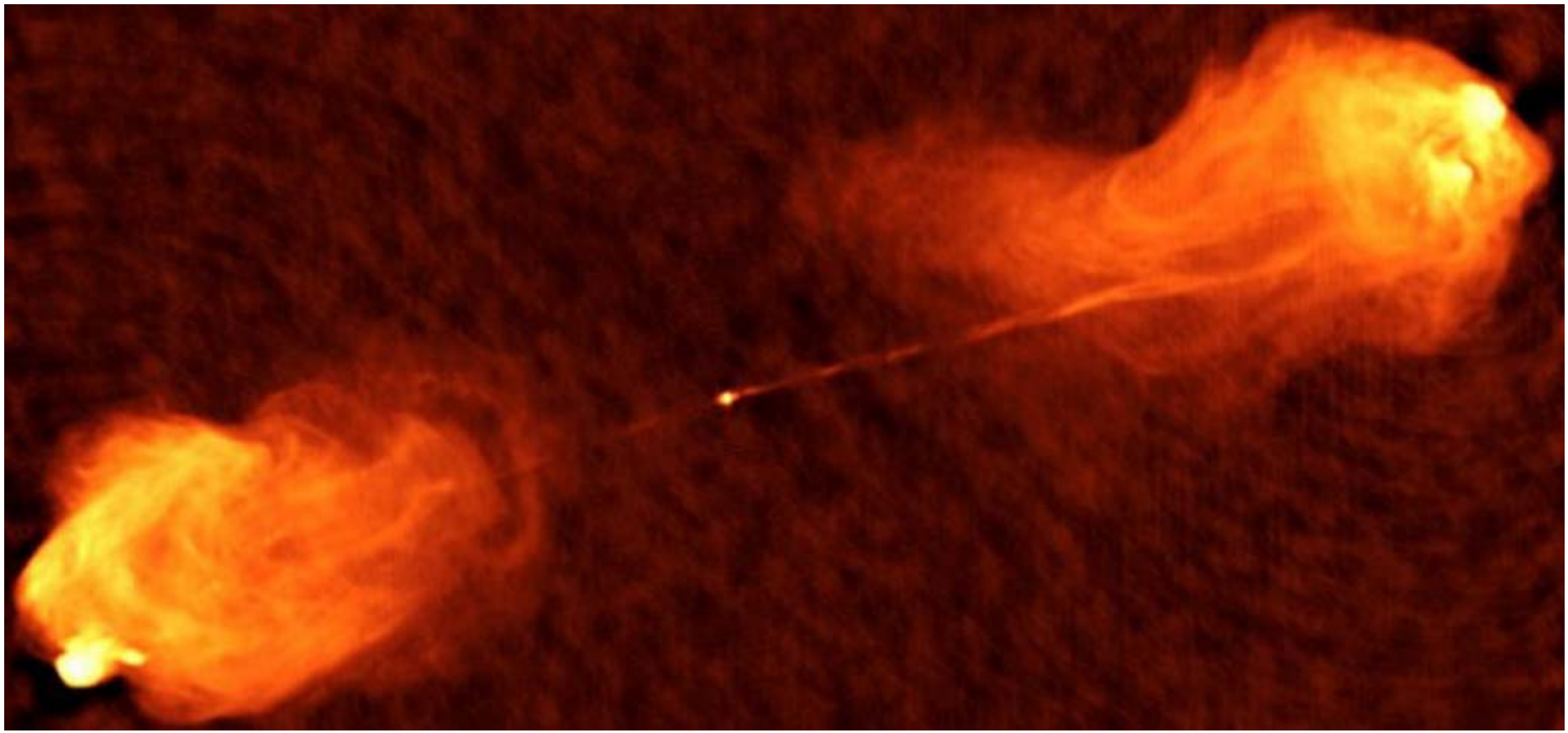
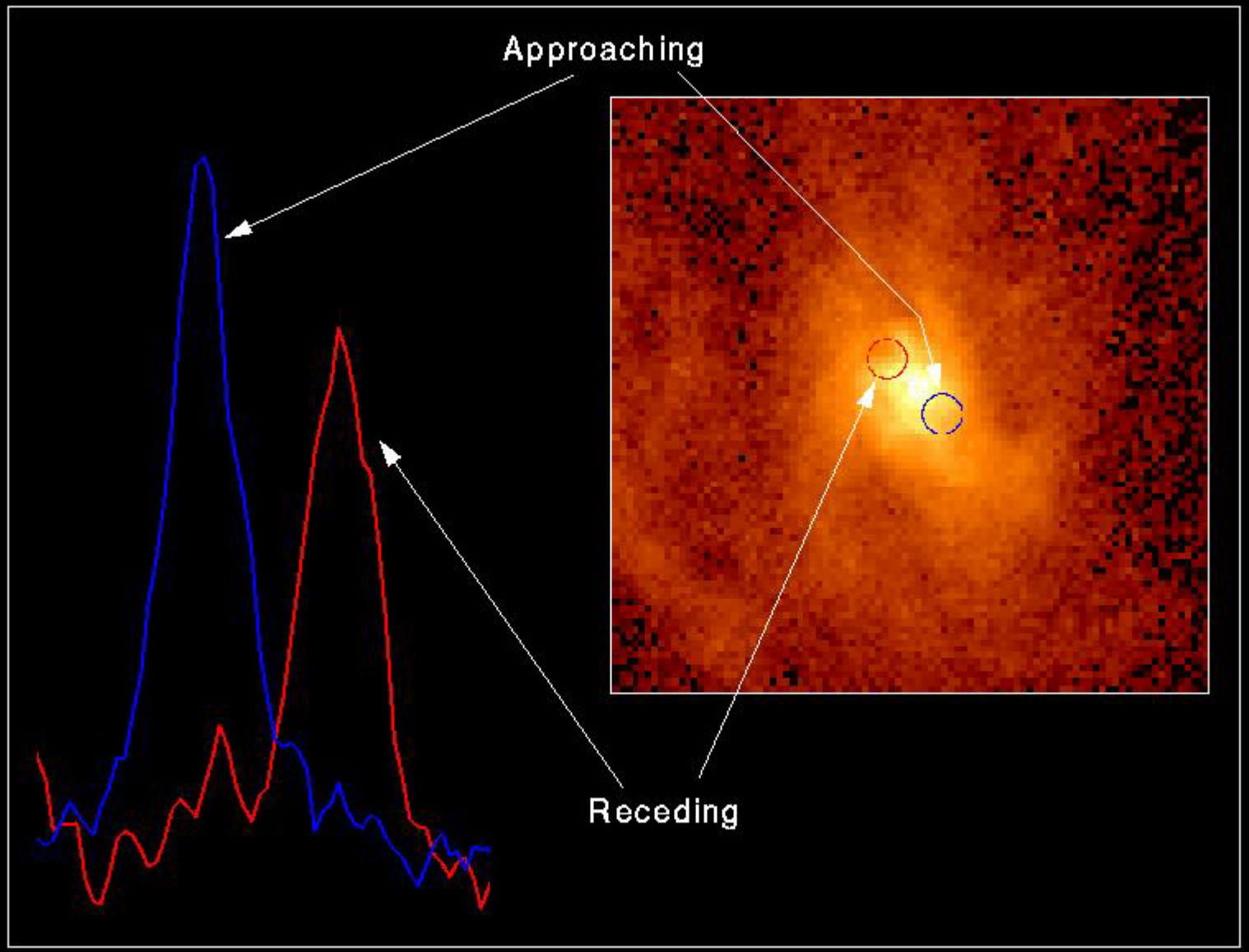


Figure 4: Hubble's tuning fork galaxy classification.

Cygnus A: radio map

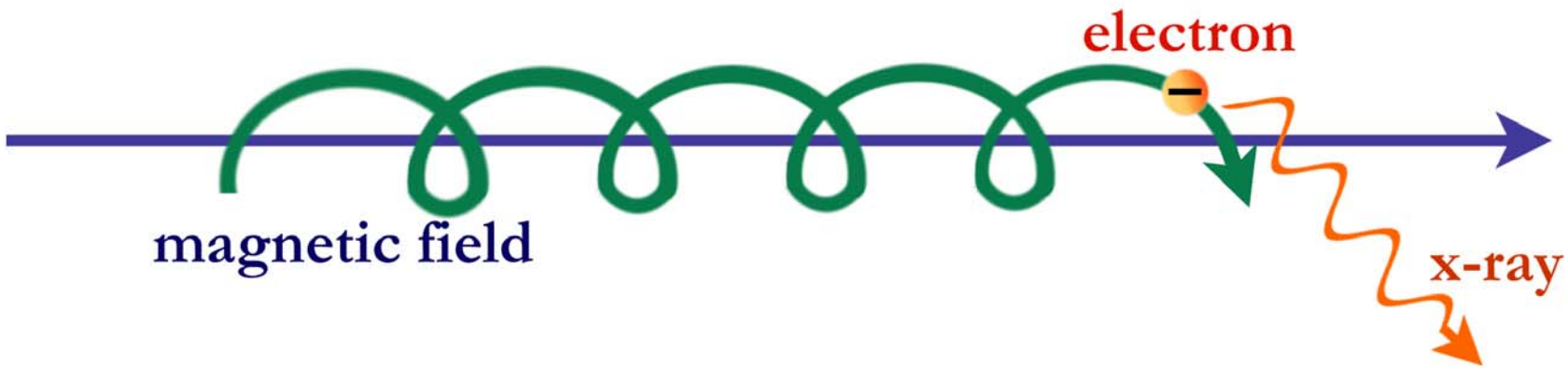


Spectrum of Gas Disk in Active Galaxy M87

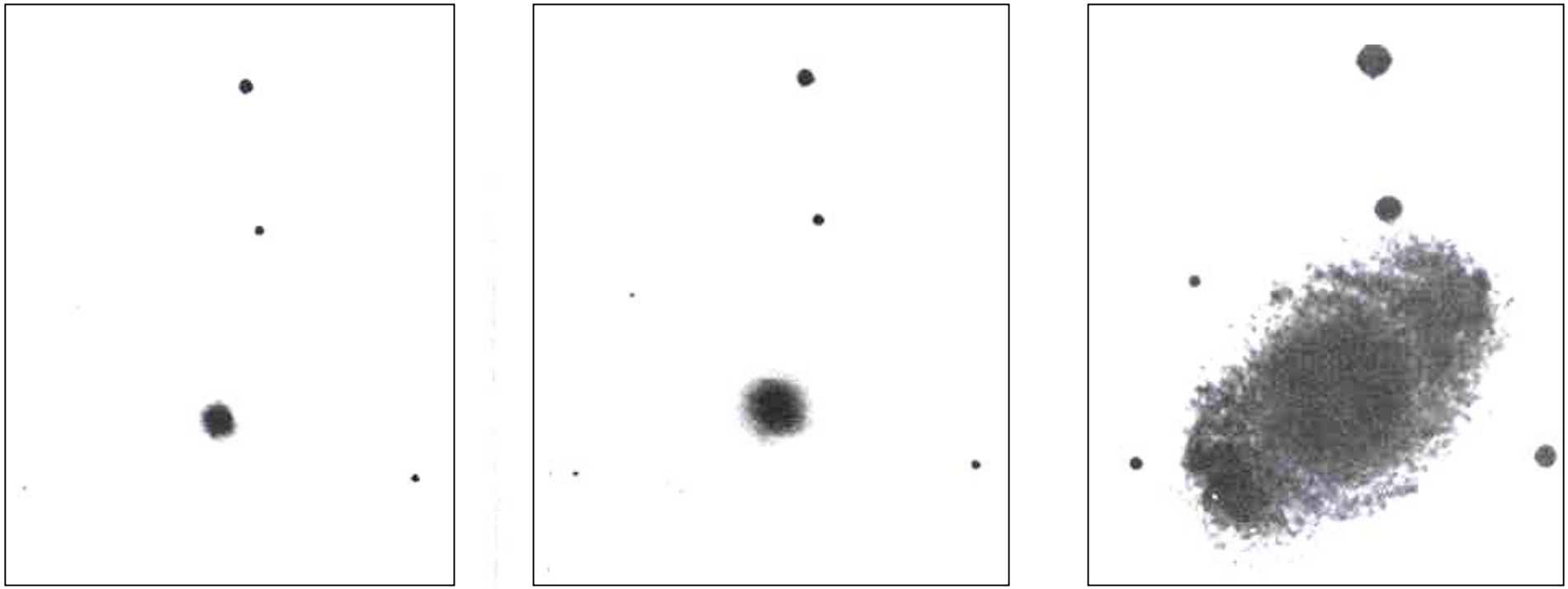


Hubble Space Telescope • Faint Object Spectrograph

Synchrotron radiation

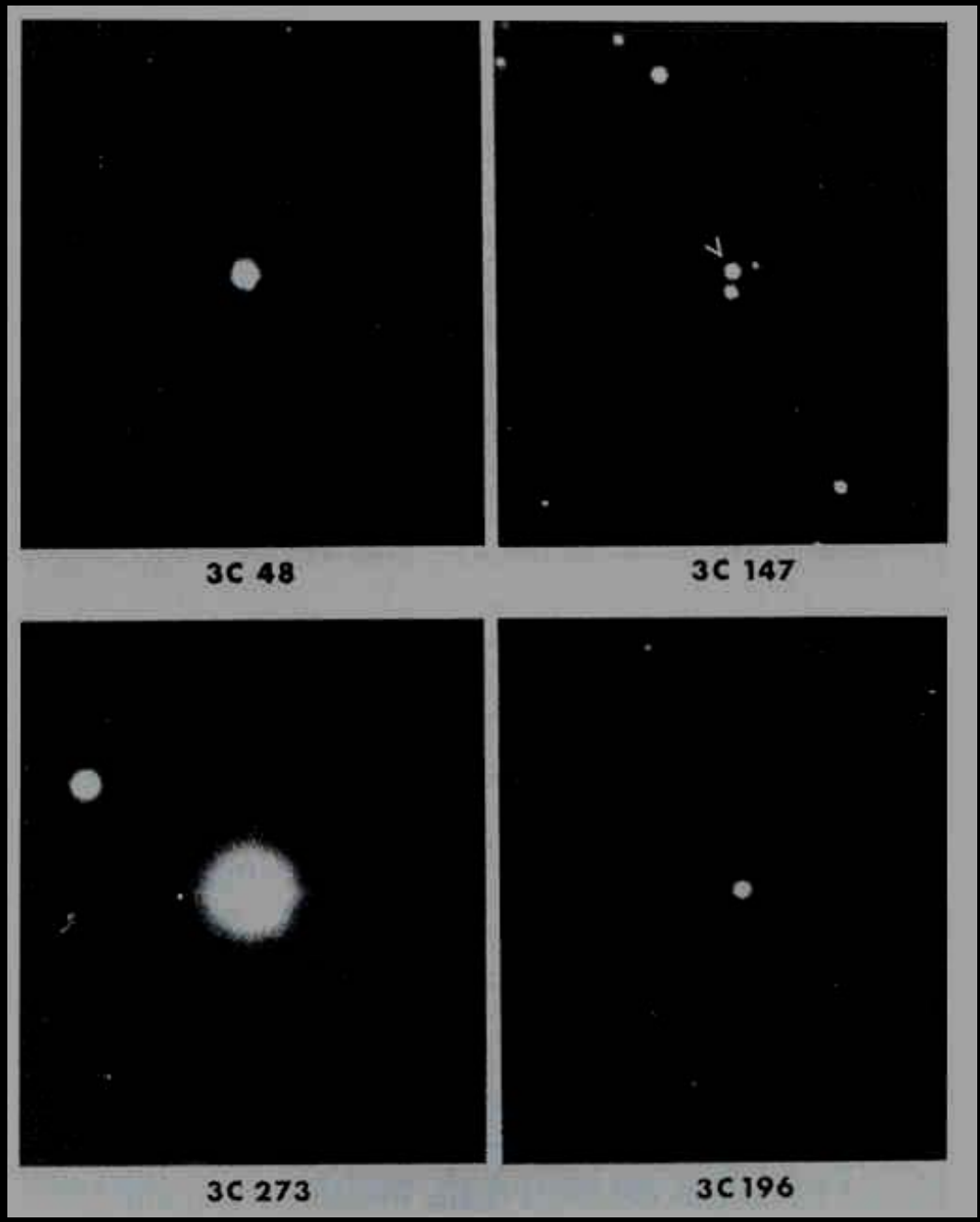


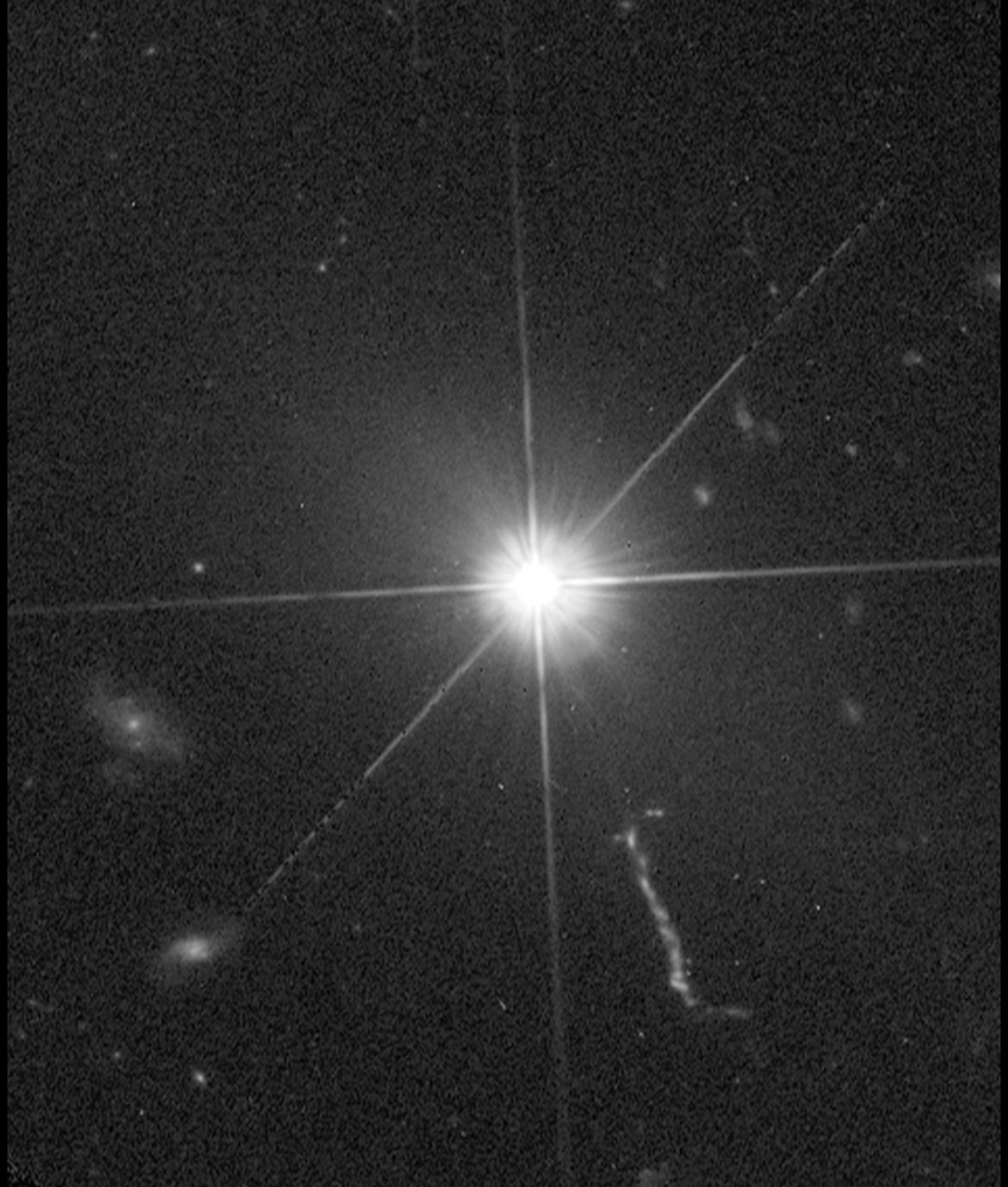
Seyfert galaxy nuclei

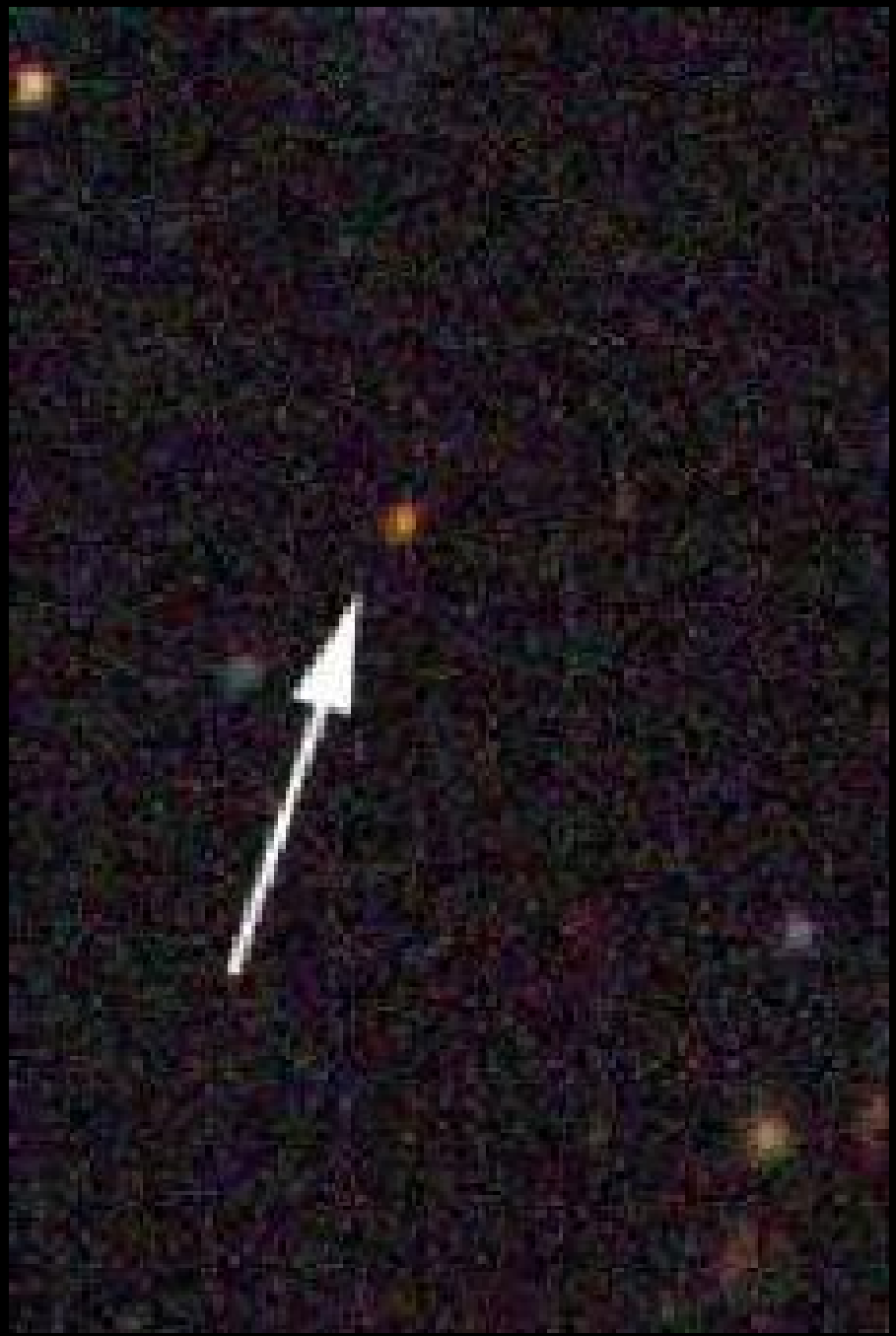


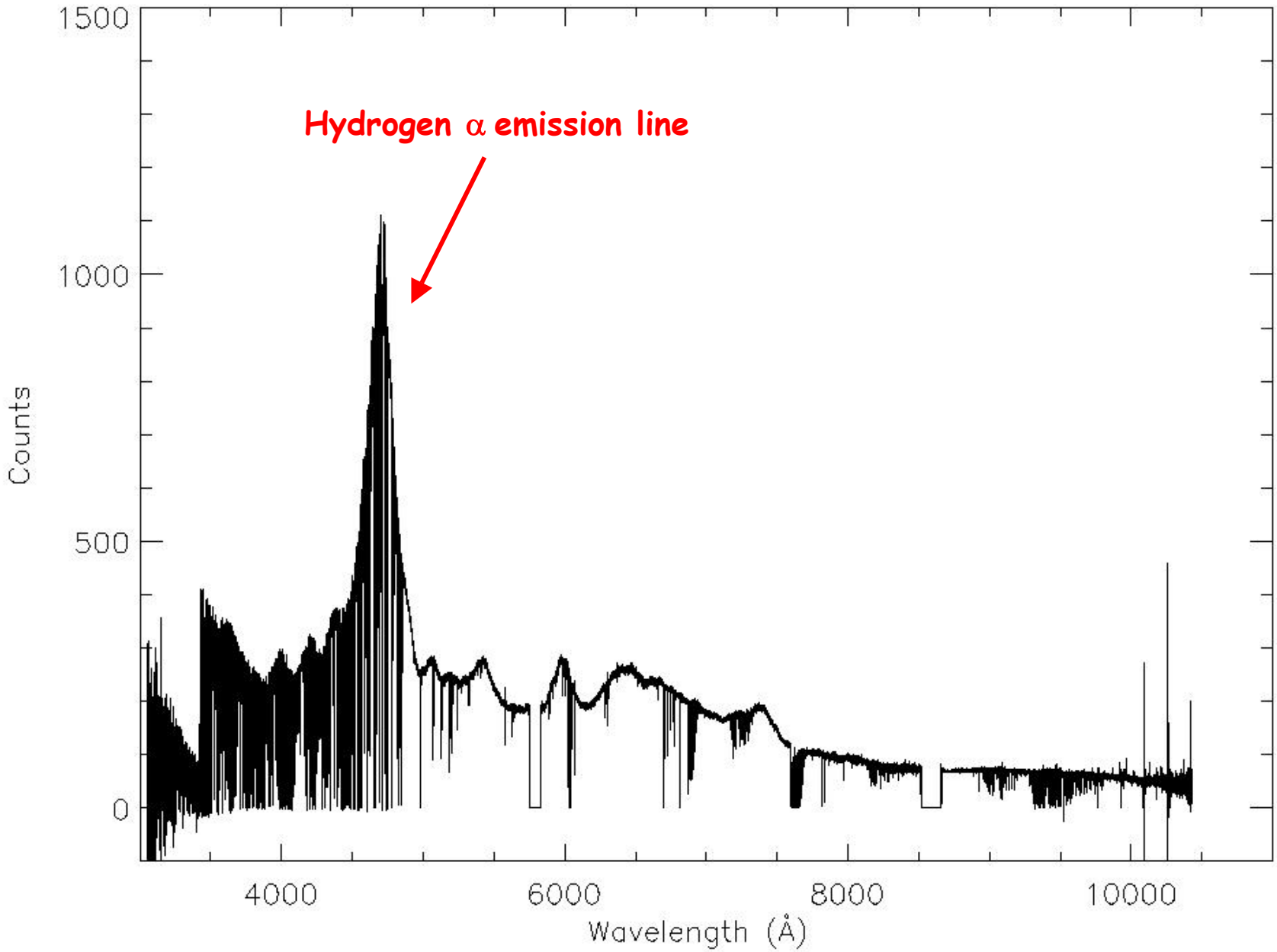
Increasing exposure time

NGC7742

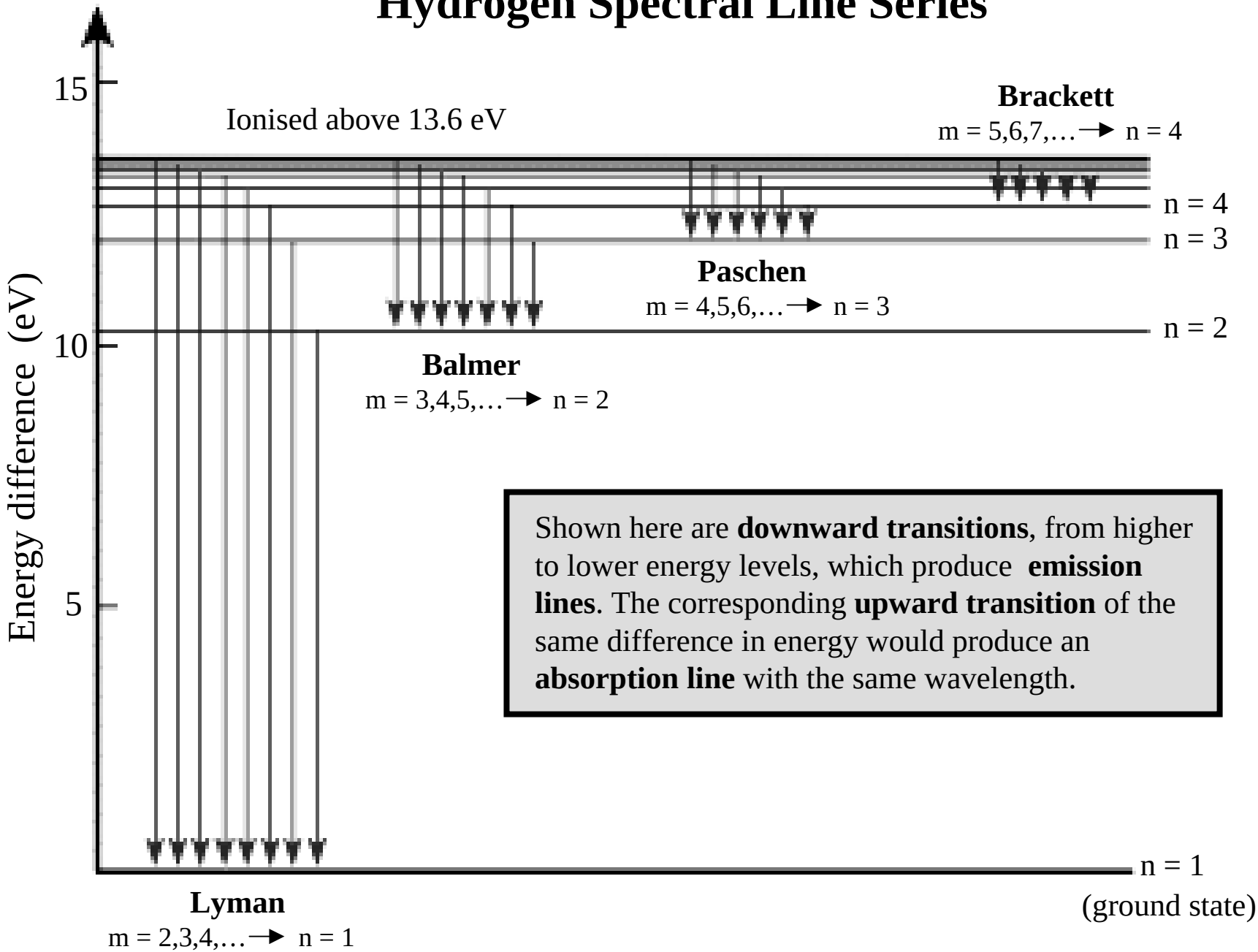

3C 48
3C 147
3C 273
3C 196



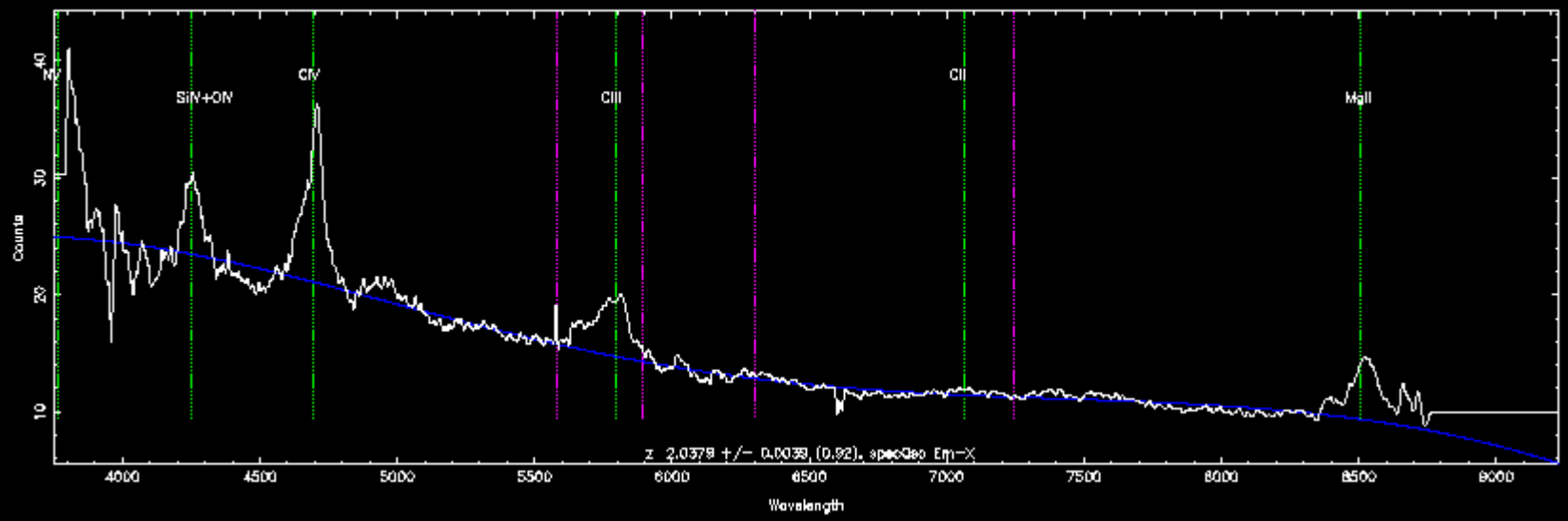



Hydrogen α emission line
1500
1000
500
0
Counts
4000
6000
8000
10000
Wavelength (Å)

Hydrogen Spectral Line Series

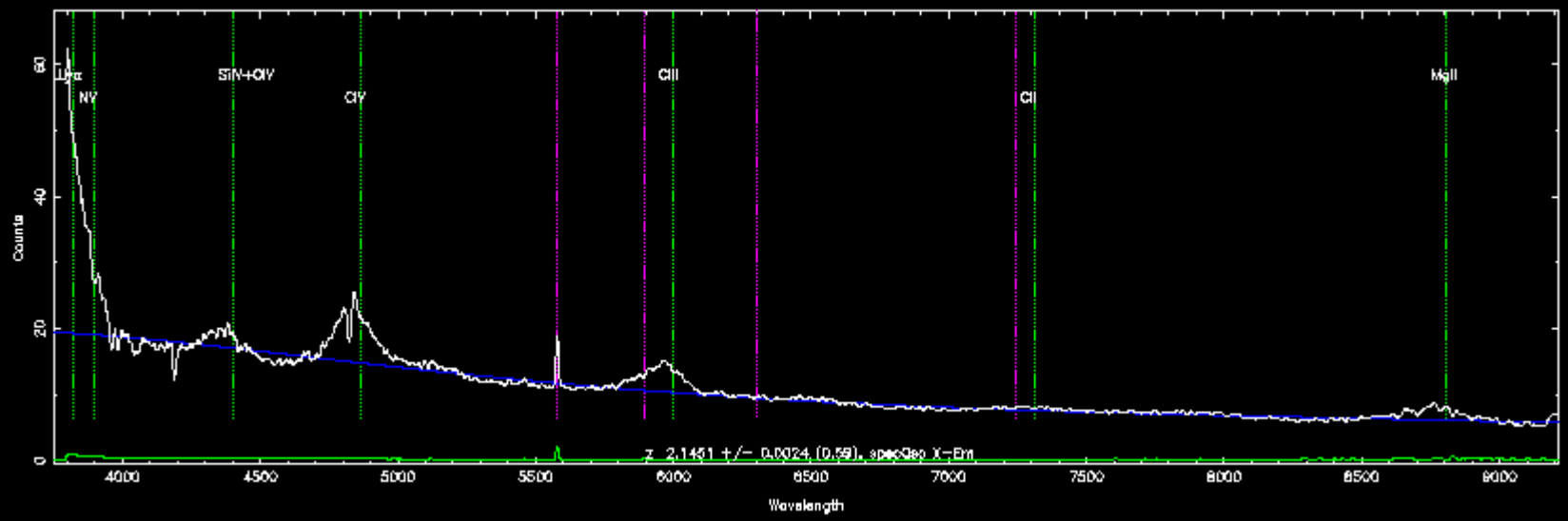


Shown here are **downward transitions**, from higher to lower energy levels, which produce **emission lines**. The corresponding **upward transition** of the same difference in energy would produce an **absorption line** with the same wavelength.



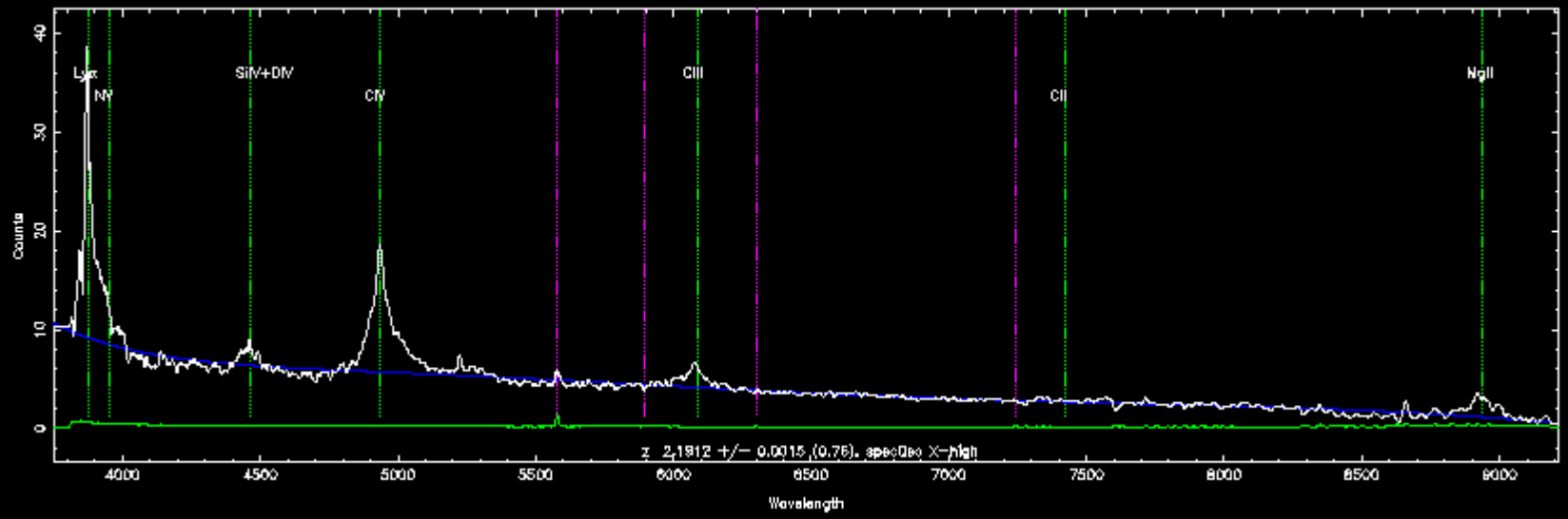
z = 2.0

Light travel time =
10.3 billion years



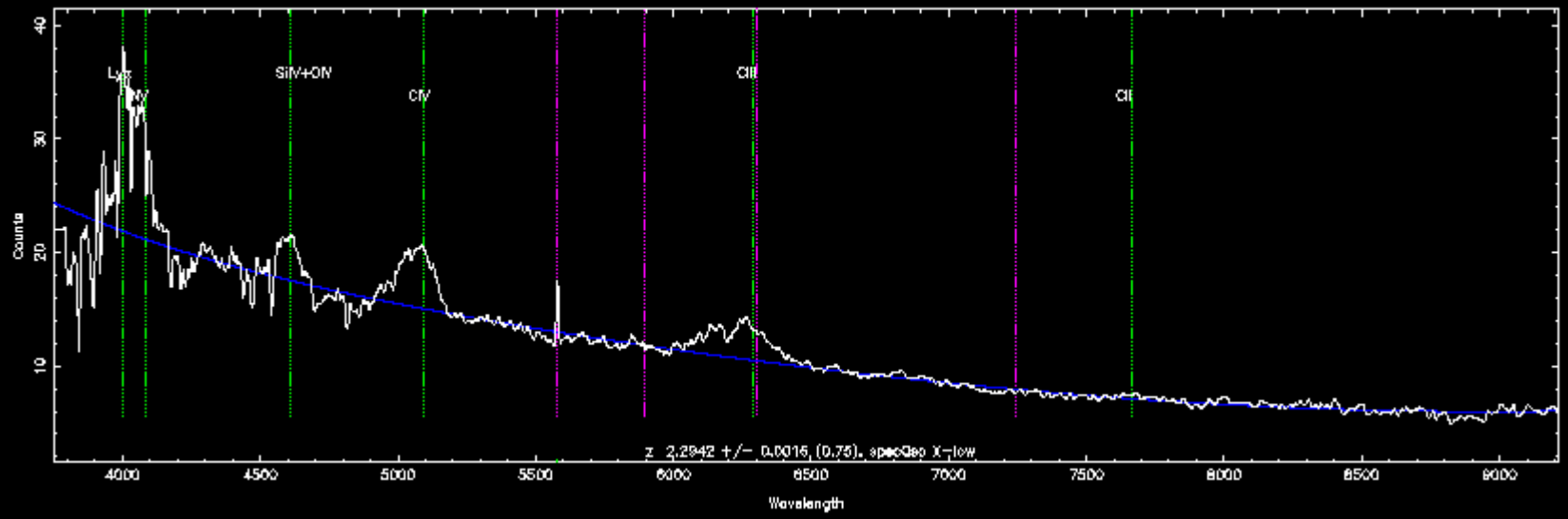
z = 2.1

Light travel time =
10.5 billion years



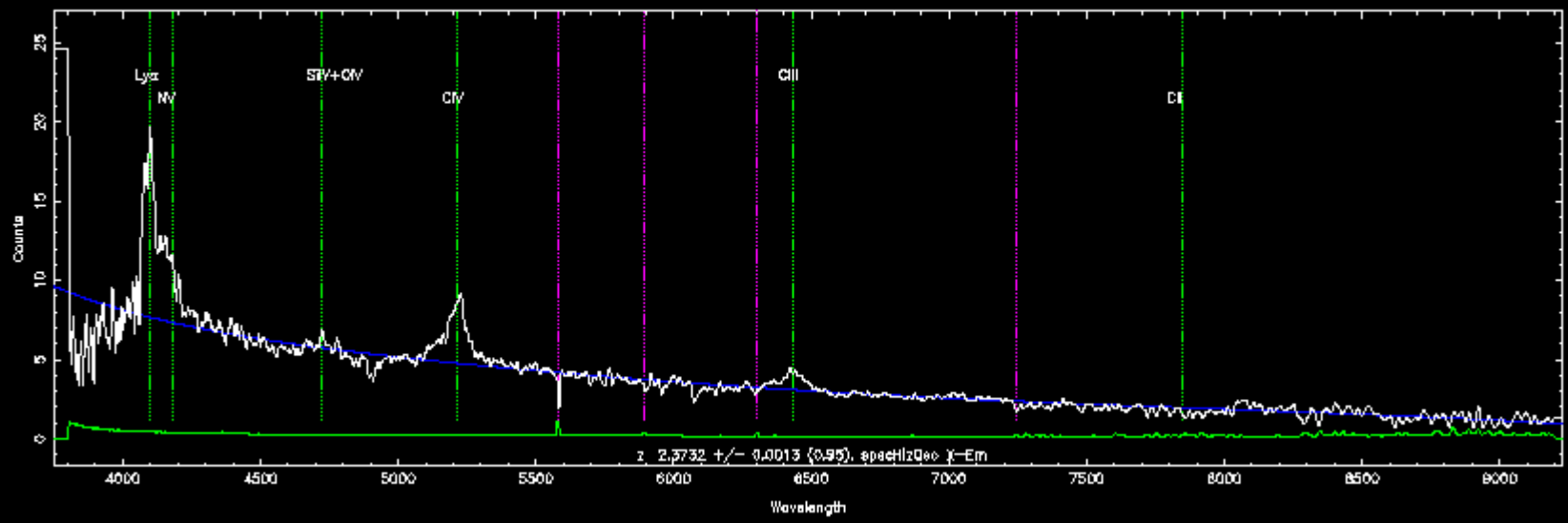
z = 2.2

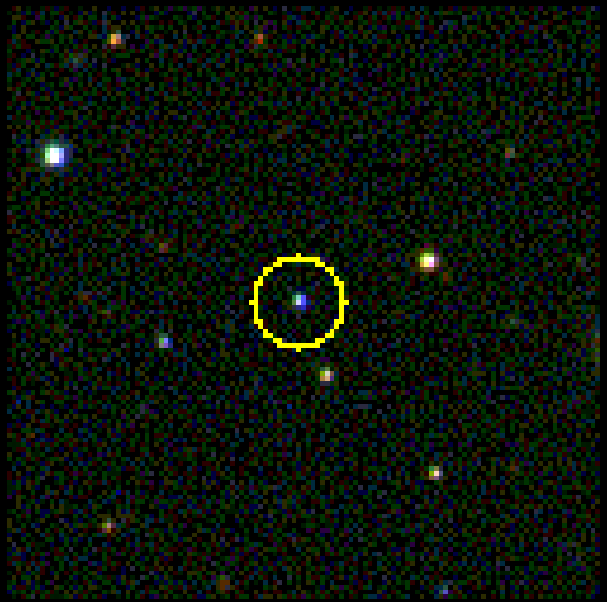
Light travel time =
10.6 billion years



z = 2.3

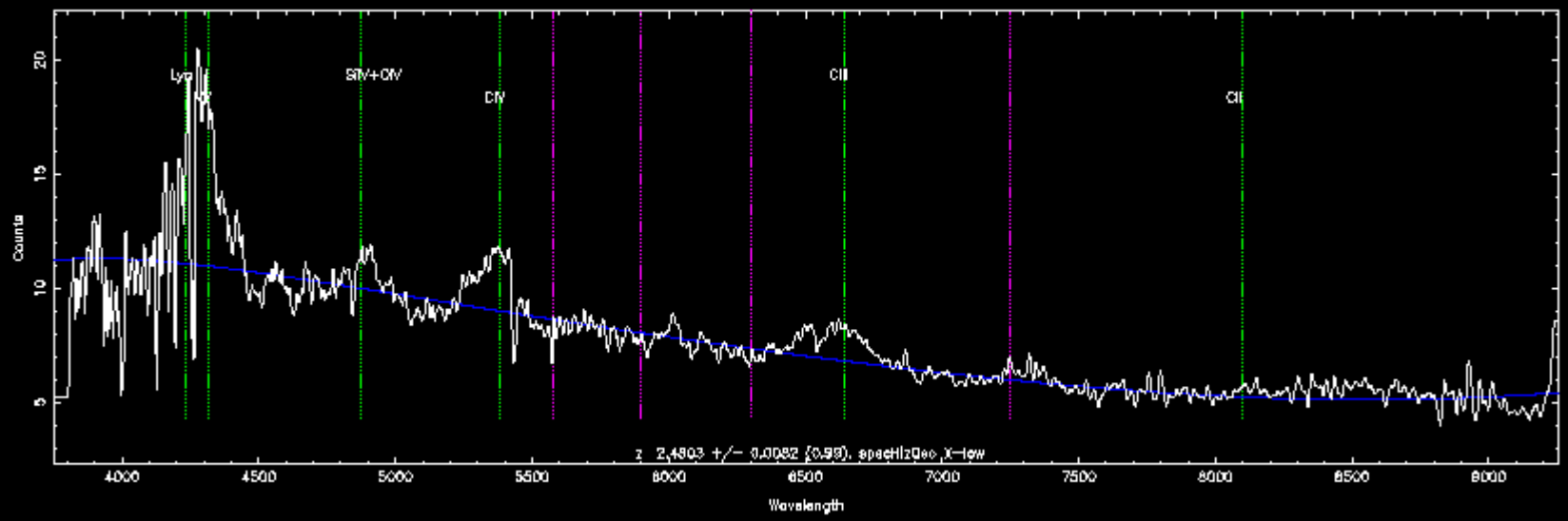
Light travel time =
10.8 billion years

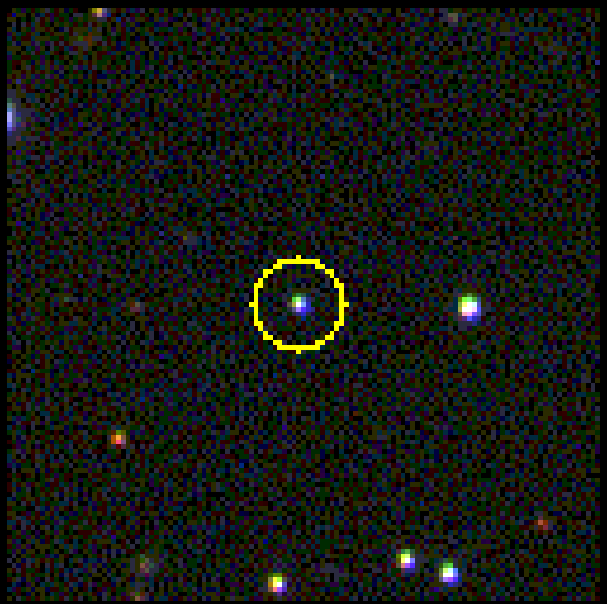




z = 2.4

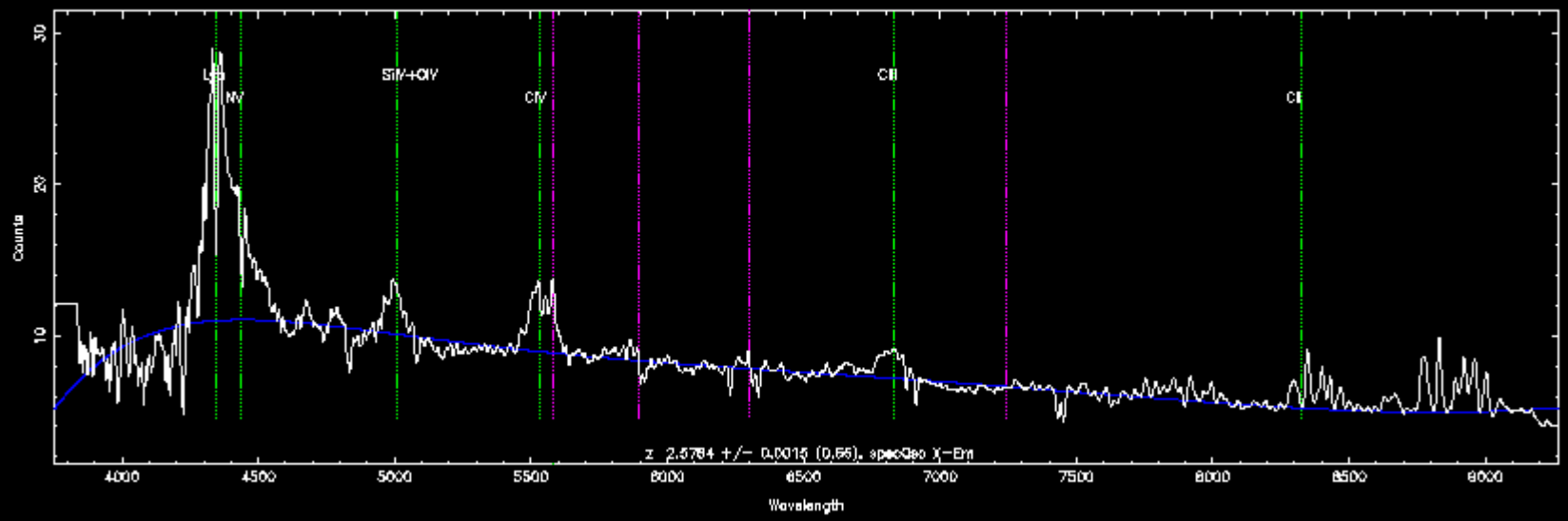
Light travel time =
10.9 billion years





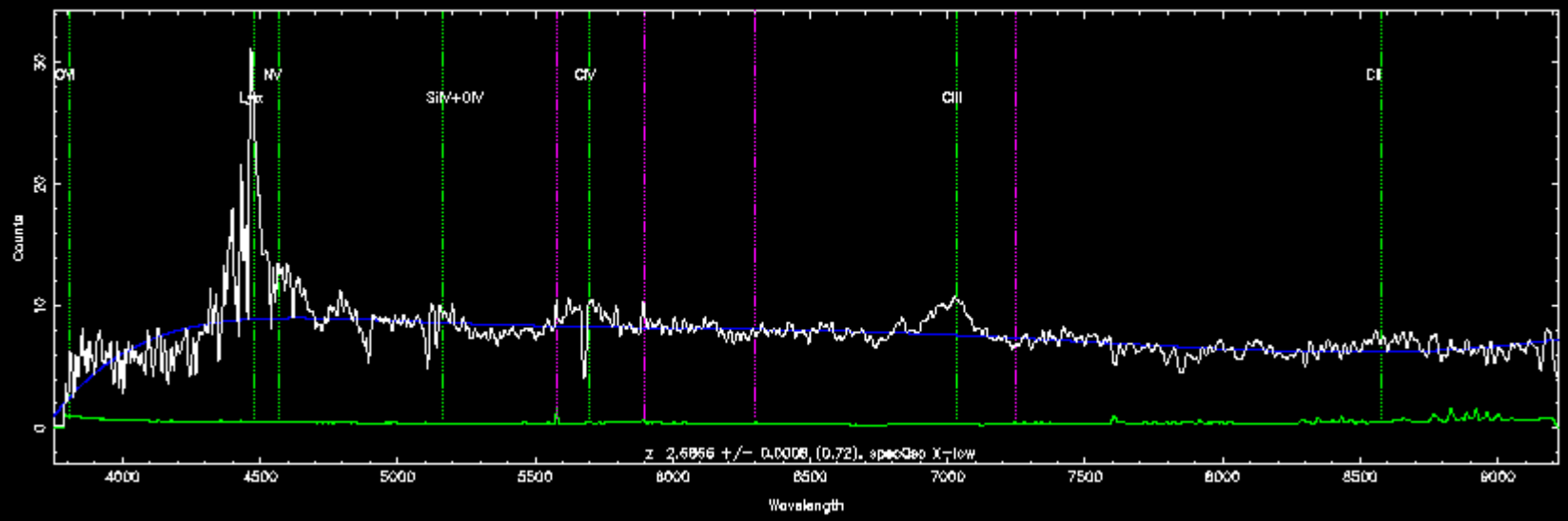
z = 2.5

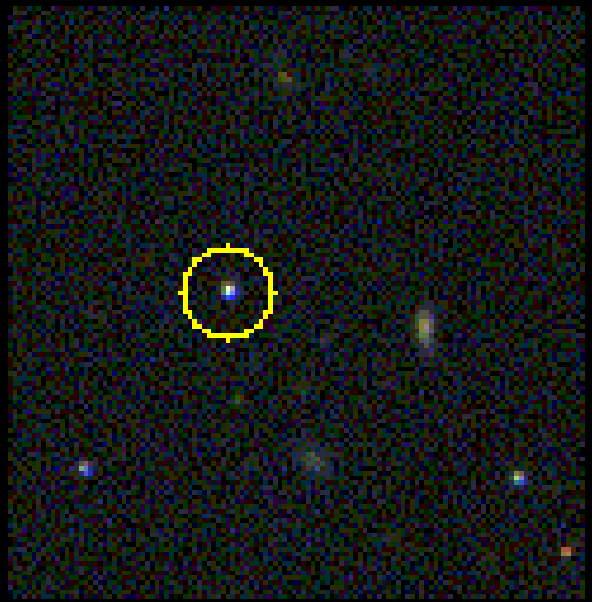
Light travel time =
11.0 billion years



z = 2.6

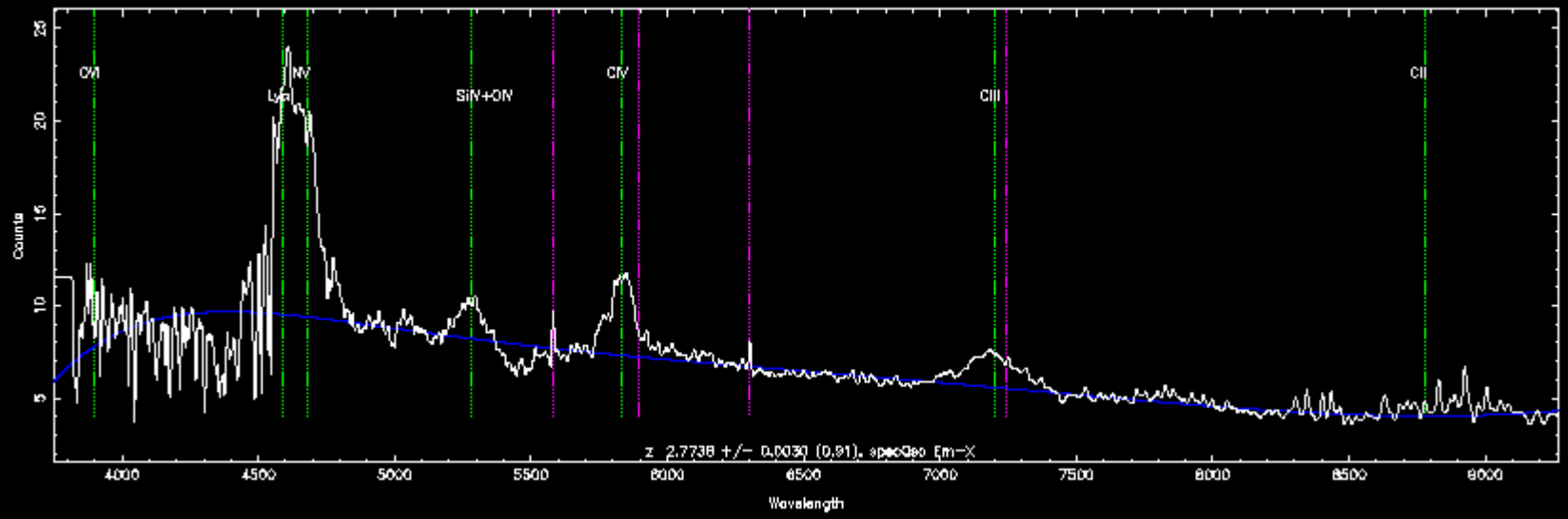
Light travel time =
11.1 billion years





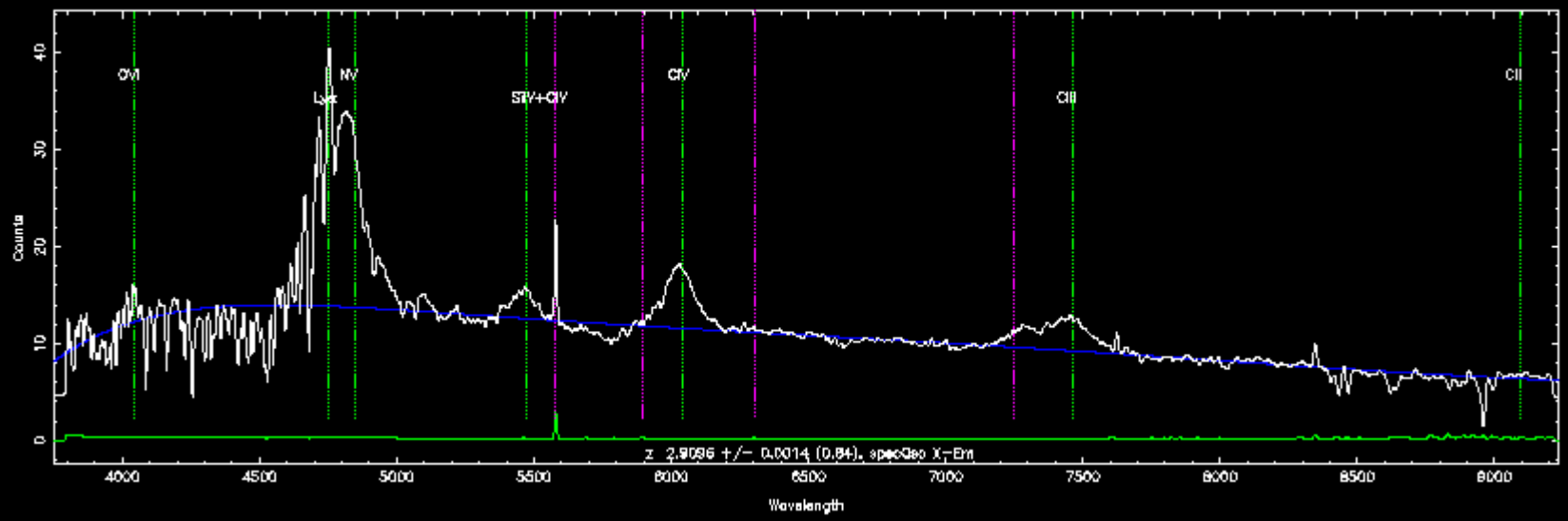
z = 2.7

Light travel time =
11.2 billion years



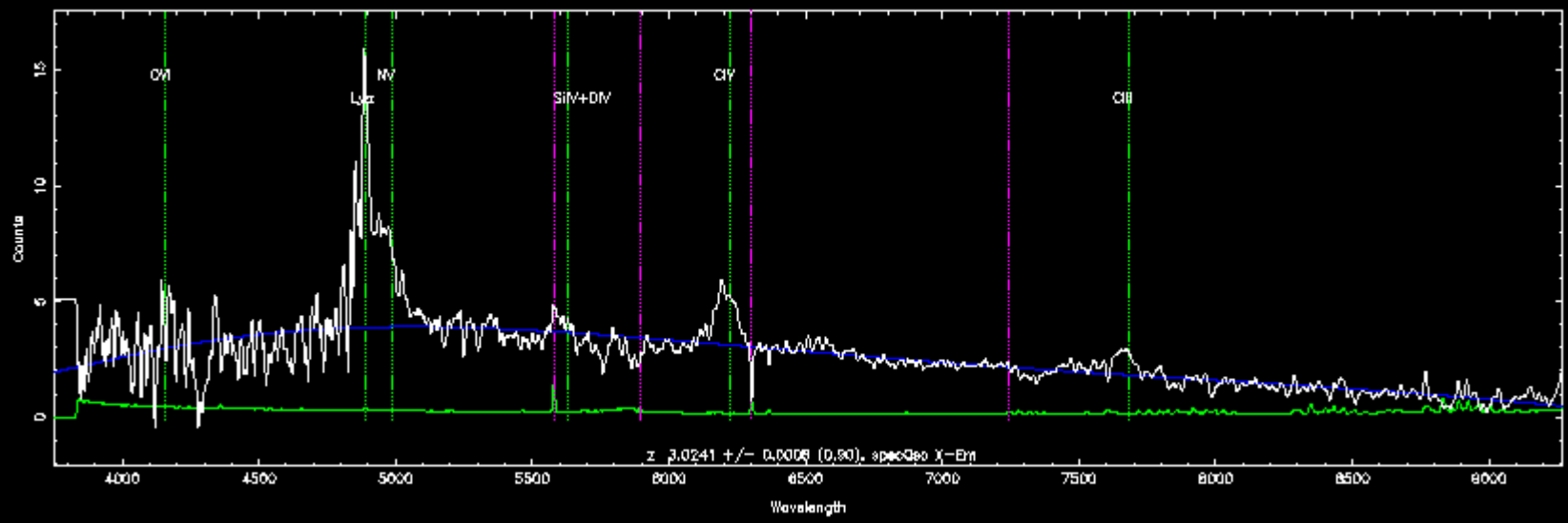
z = 2.8

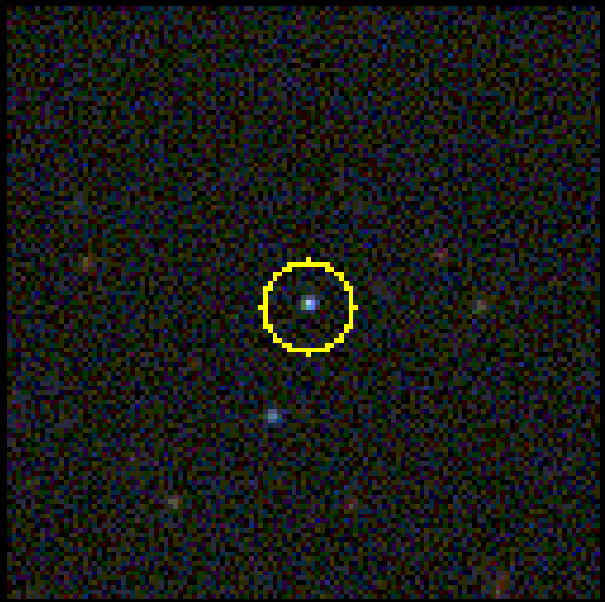
Light travel time =
11.3 billion years



z = 2.9

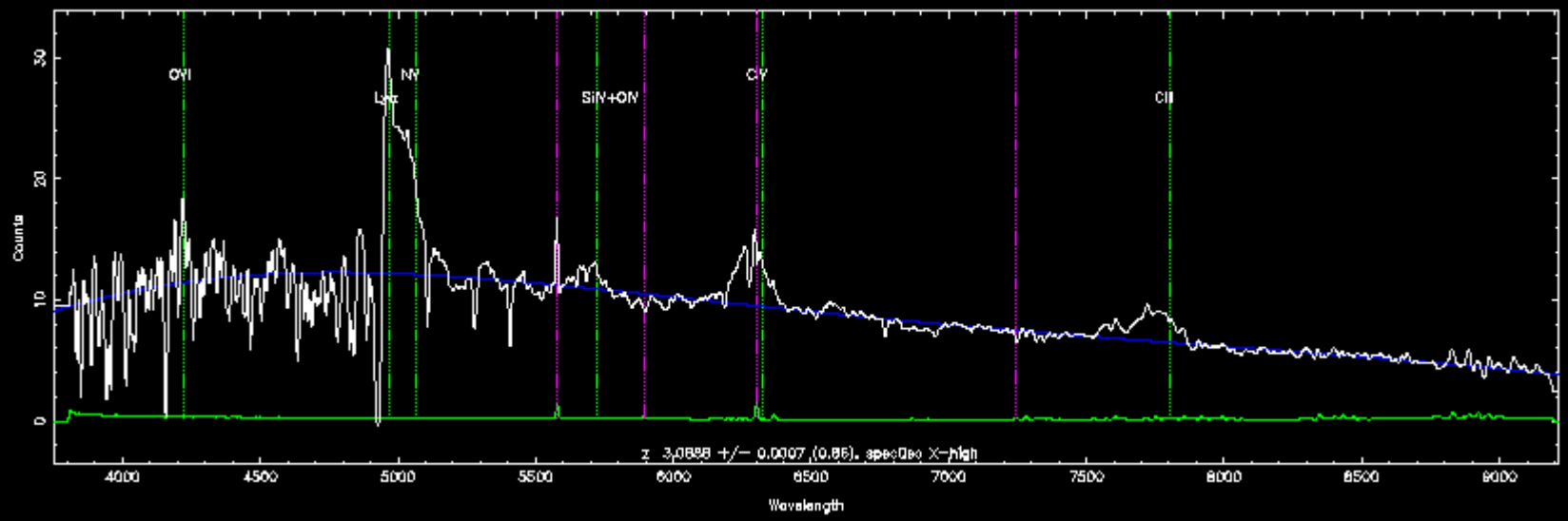
Light travel time =
11.4 billion years





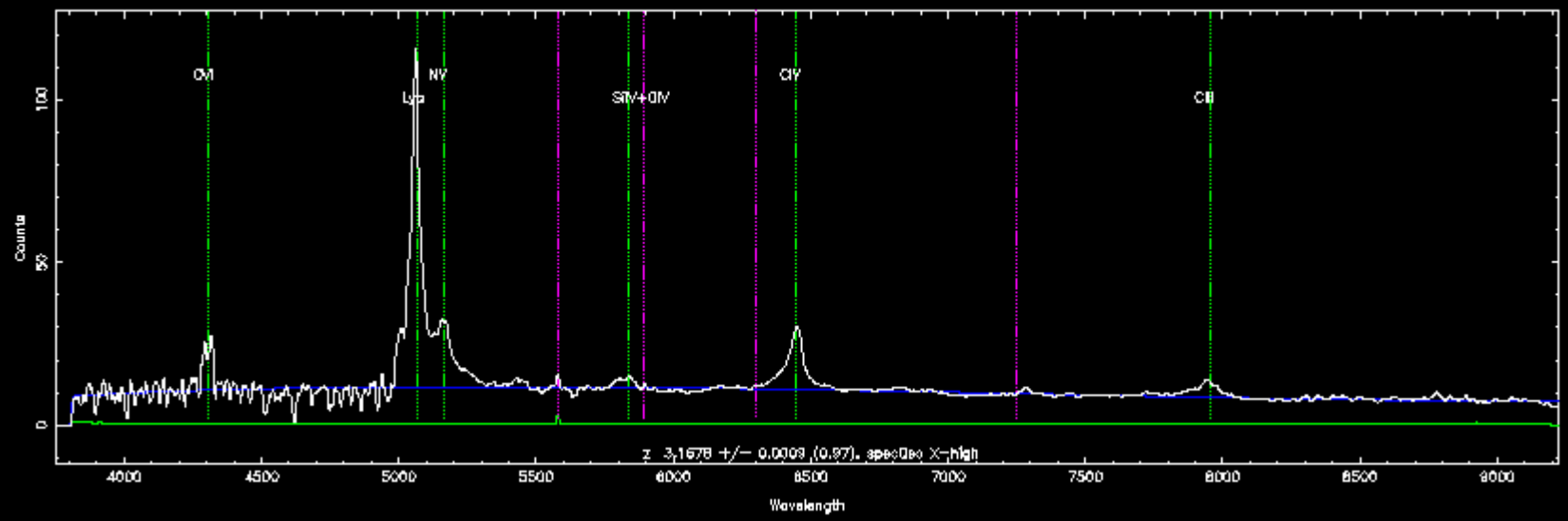
z = 3.0

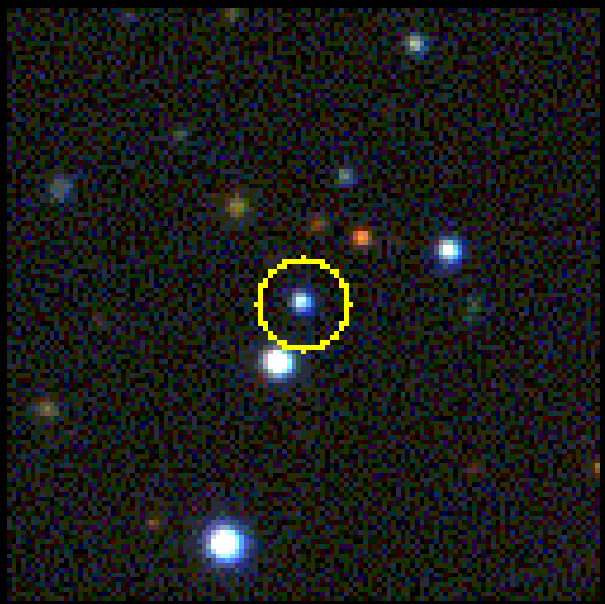
Light travel time =
11.5 billion years



z = 3.1

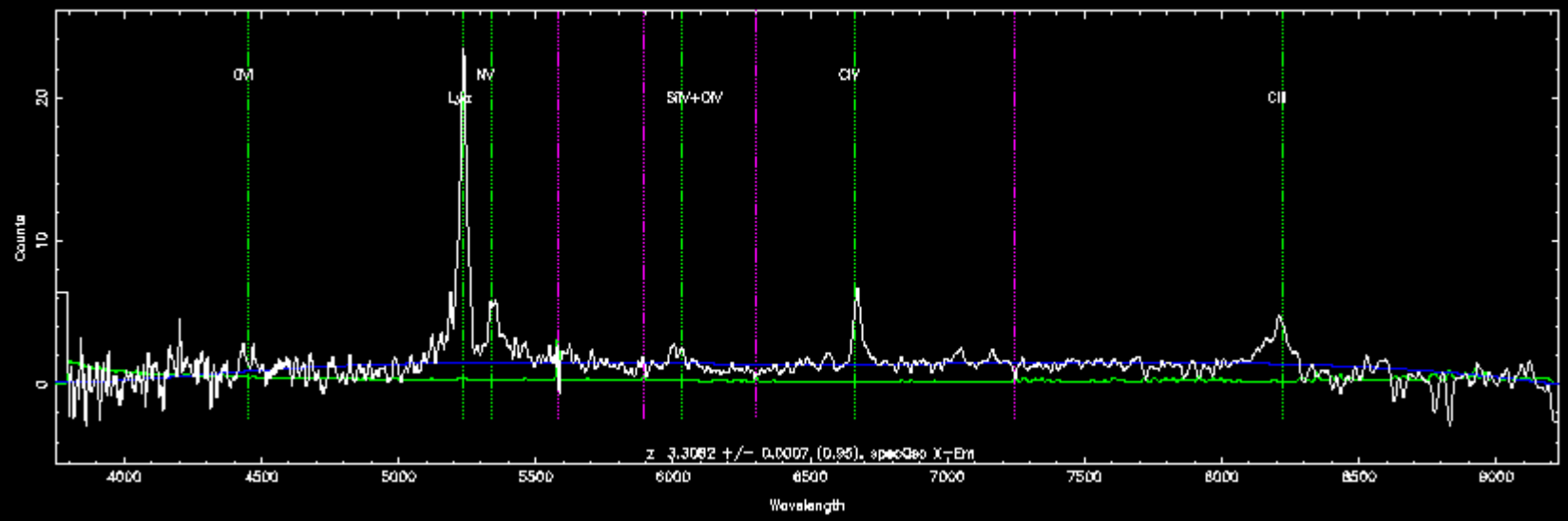
Light travel time =
11.6 billion years





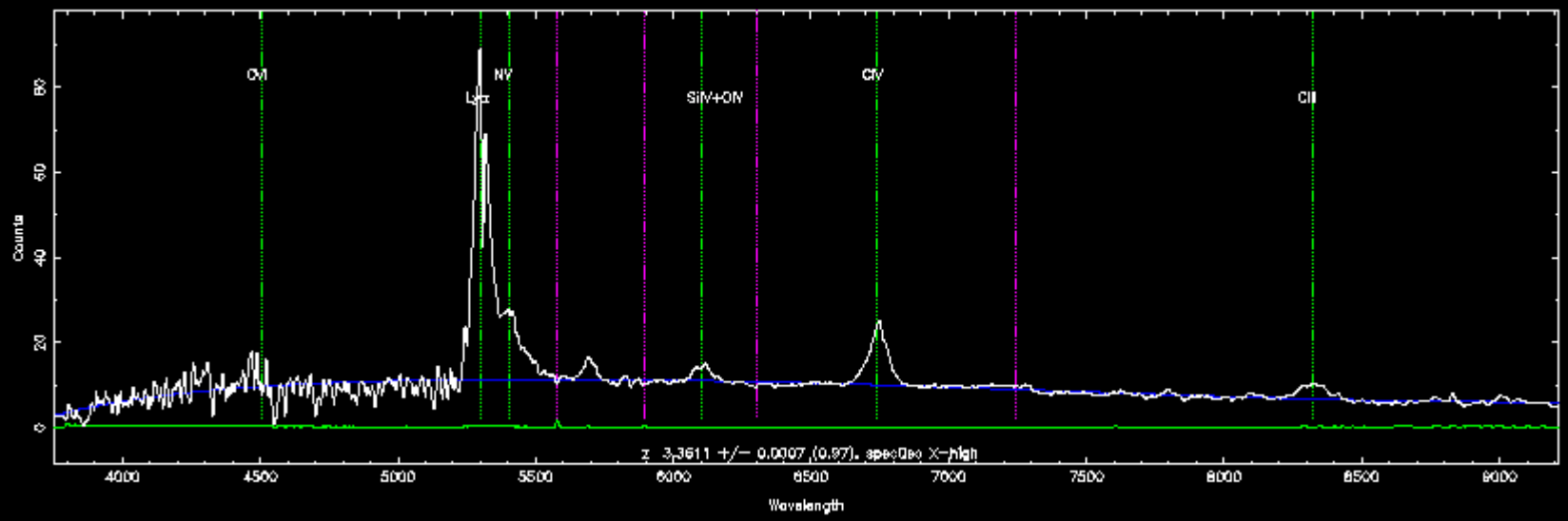
z = 3.2

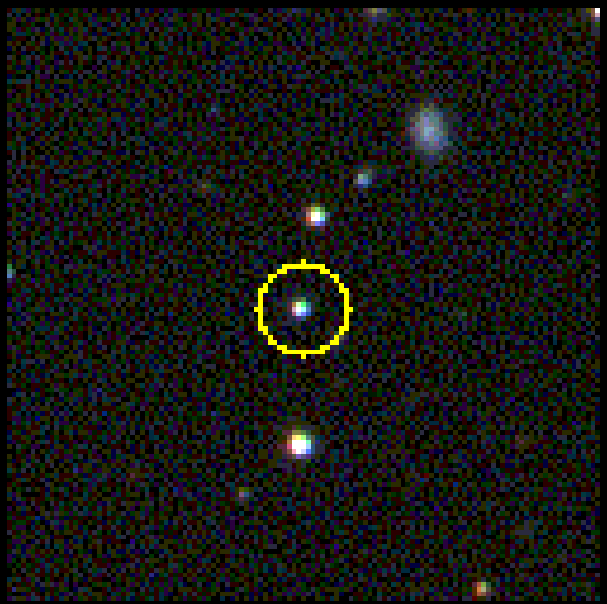
Light travel time =
11.6 billion years



z = 3.3

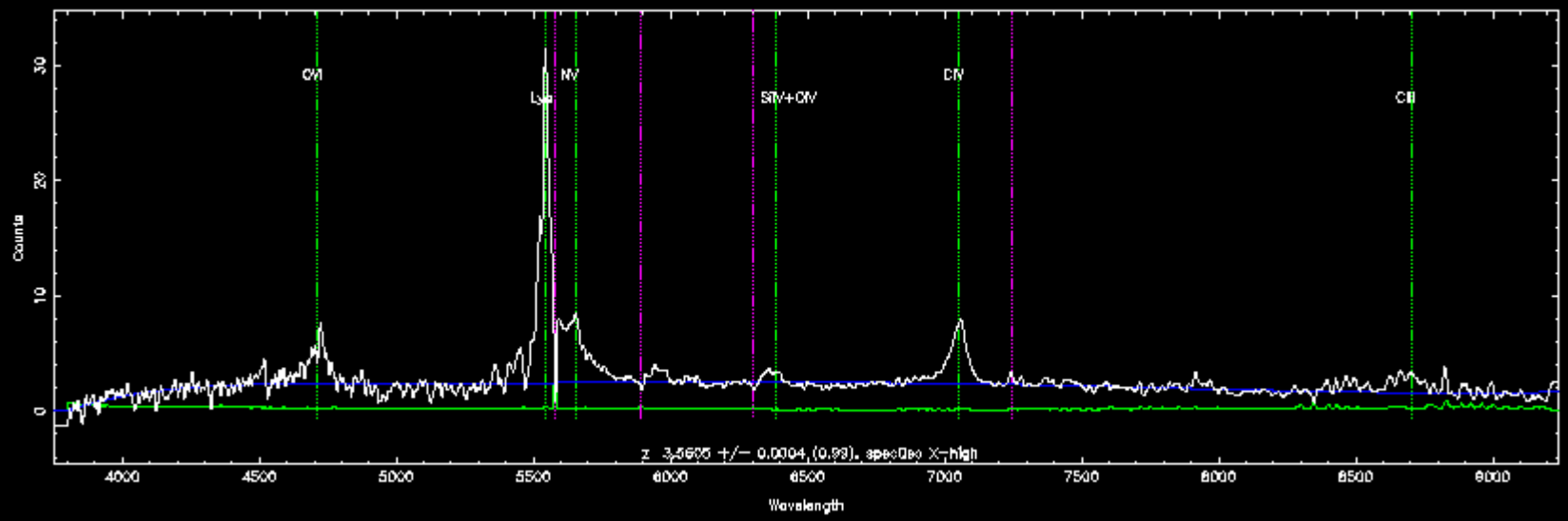
Light travel time =
11.7 billion years





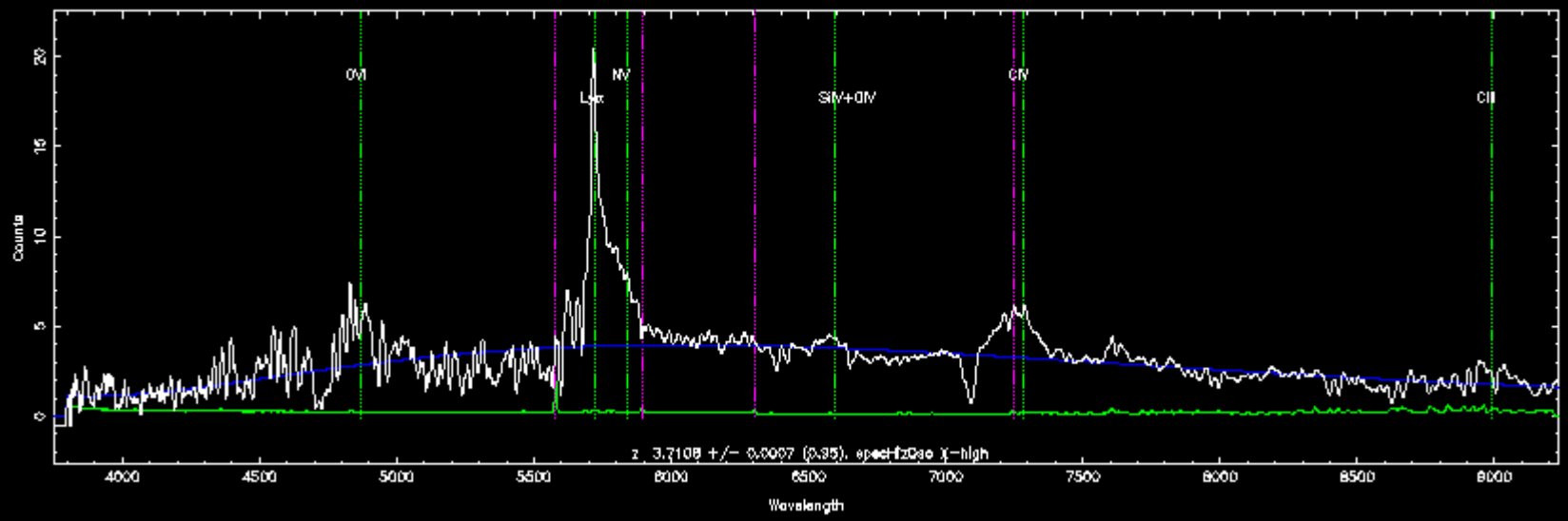
z = 3.4

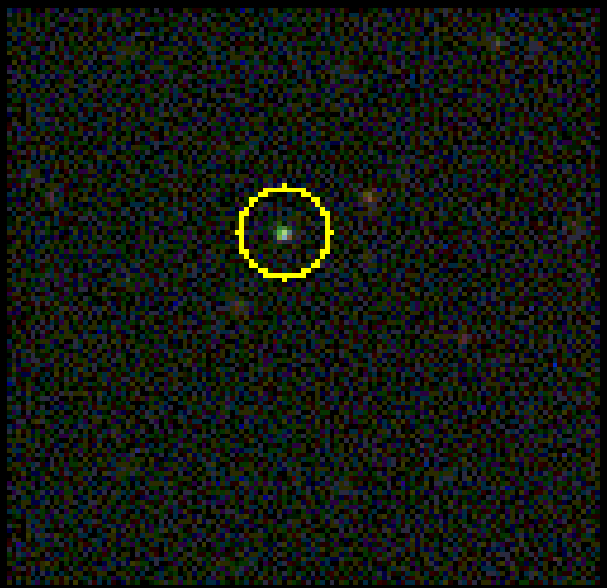
Light travel time =
11.8 billion years



z = 3.6

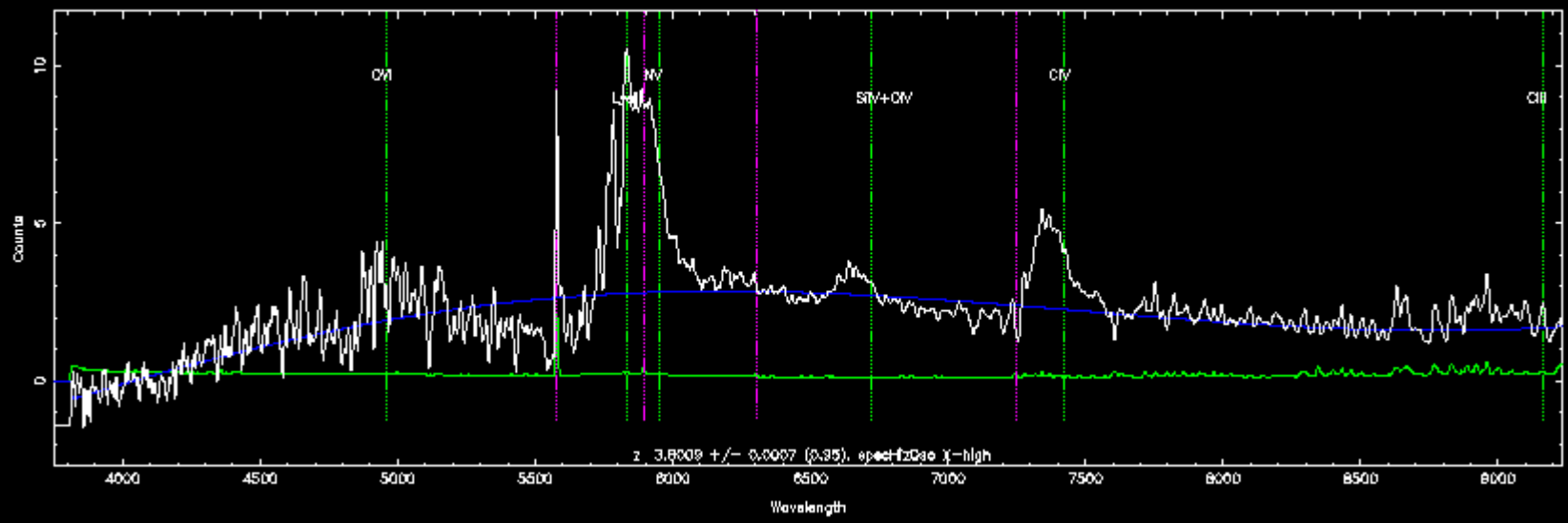
Light travel time =
11.9 billion years





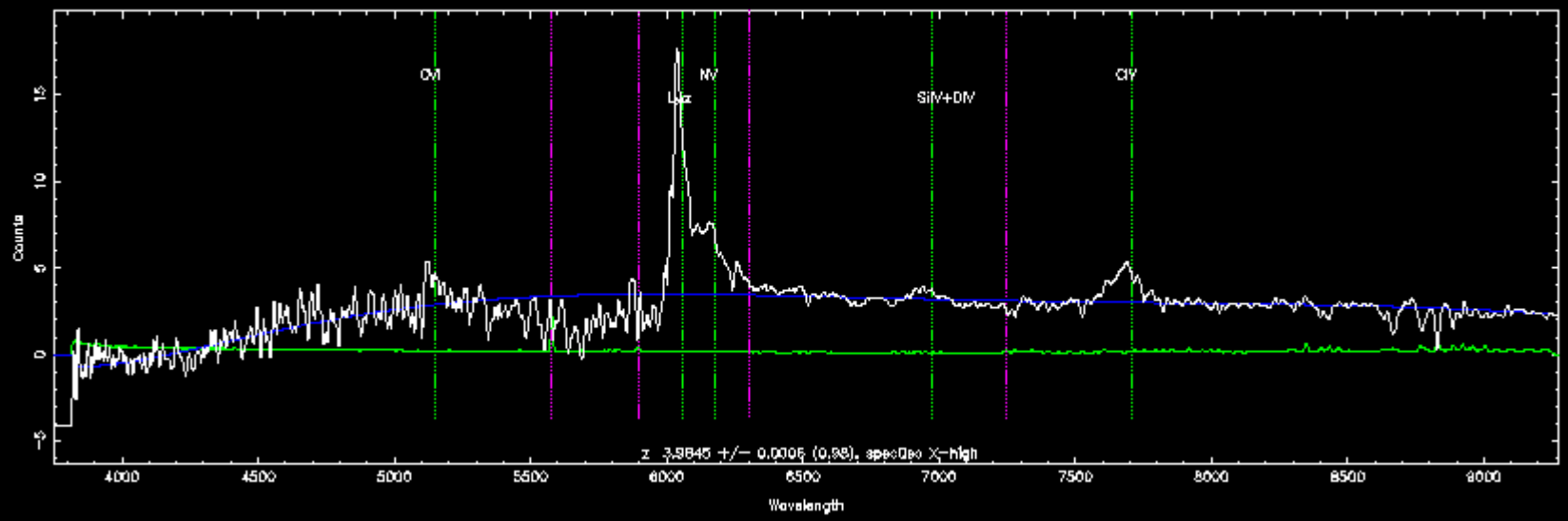
z = 3.7

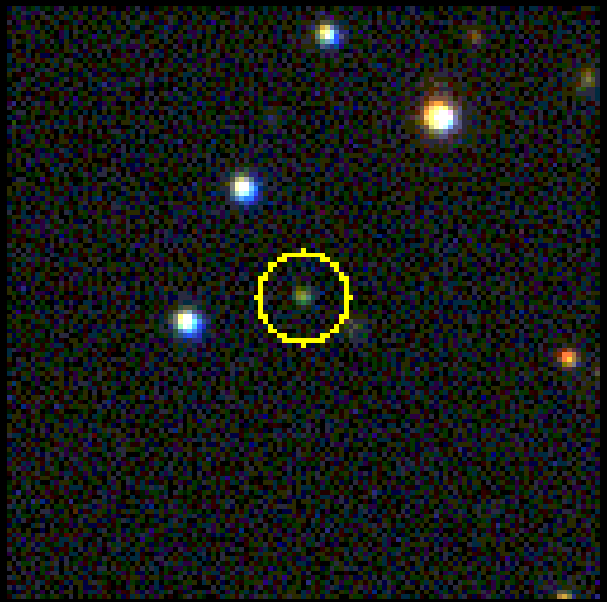
Light travel time =
11.9 billion years



z = 3.8

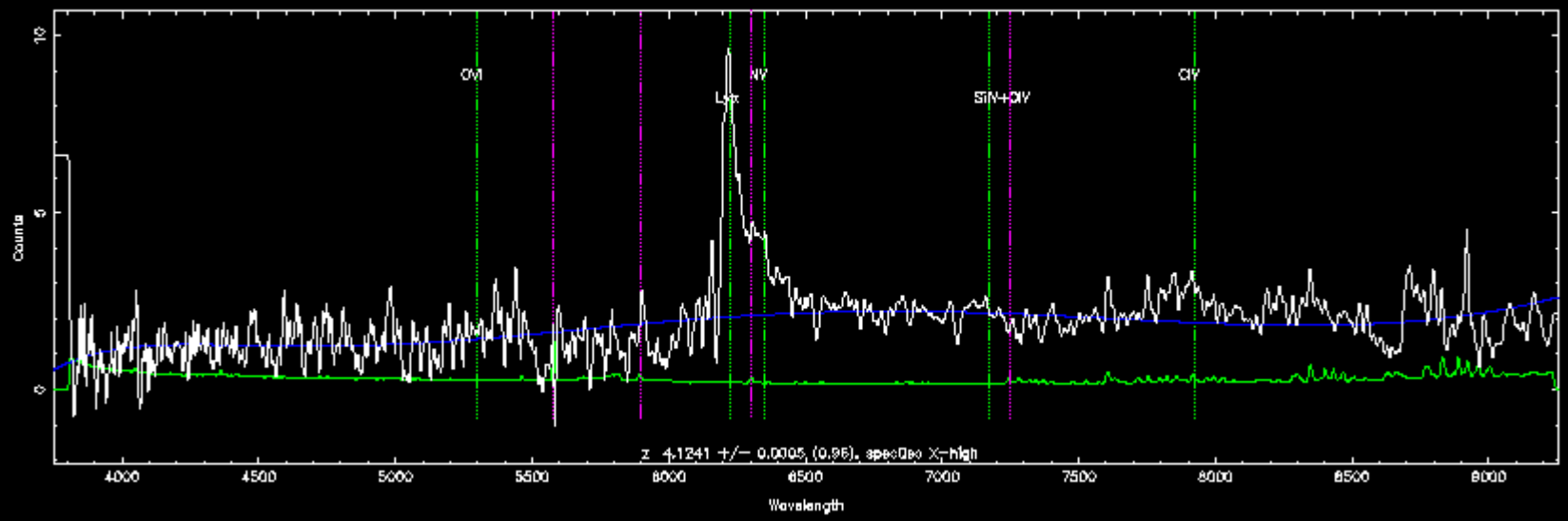
Light travel time =
12.0 billion years





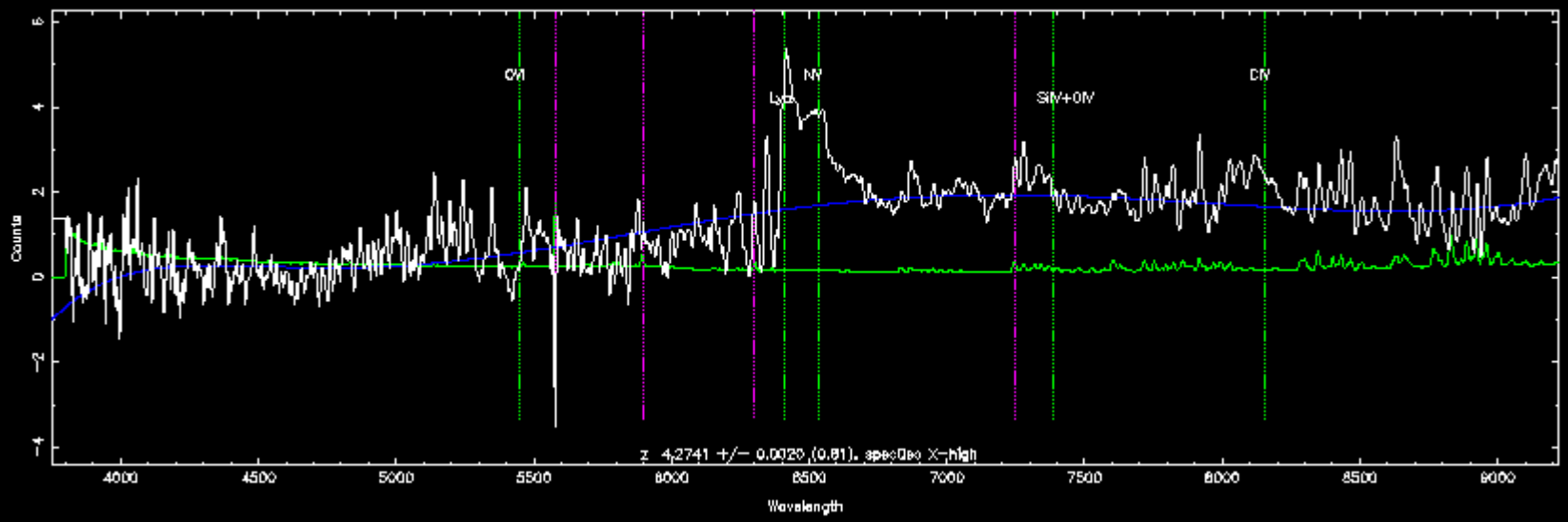
z = 4.0

Light travel time =
12.1 billion years



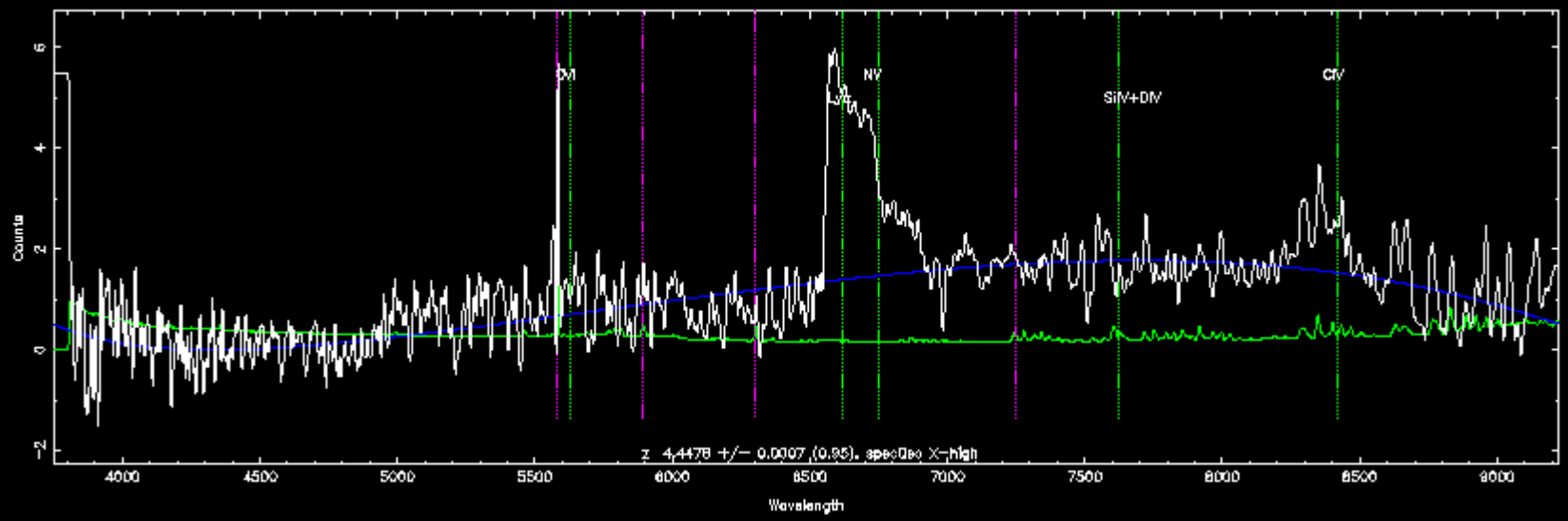
z = 4.1

Light travel time =
12.1 billion years



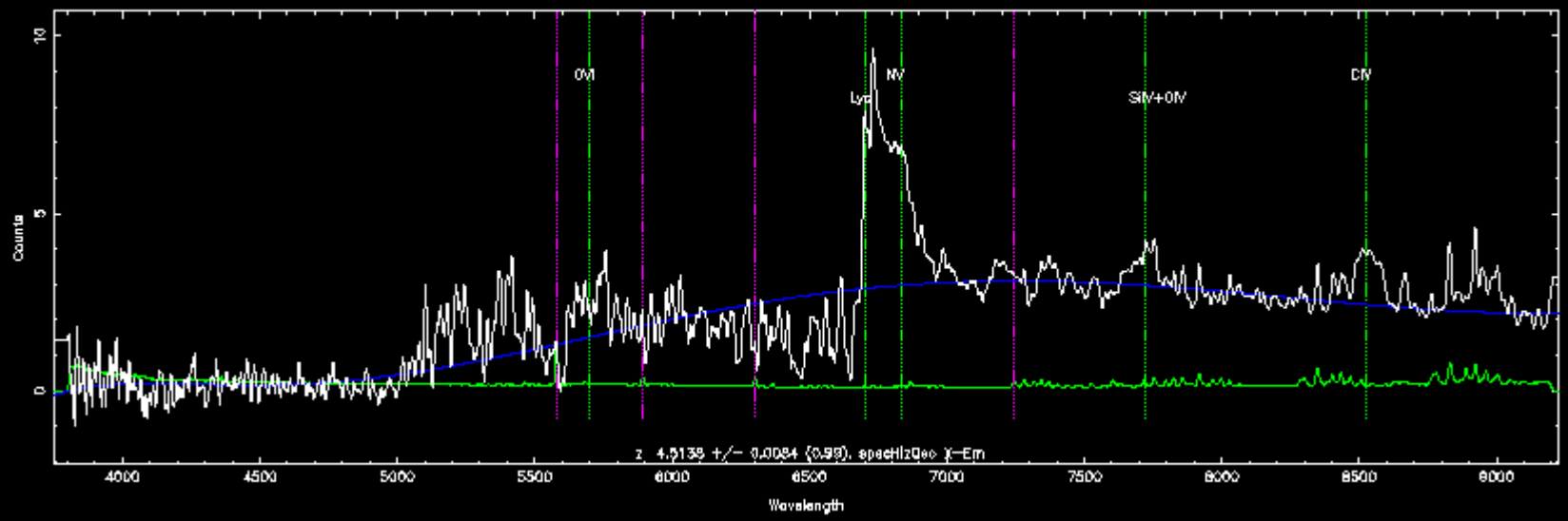
z = 4.3

Light travel time =
12.2 billion years



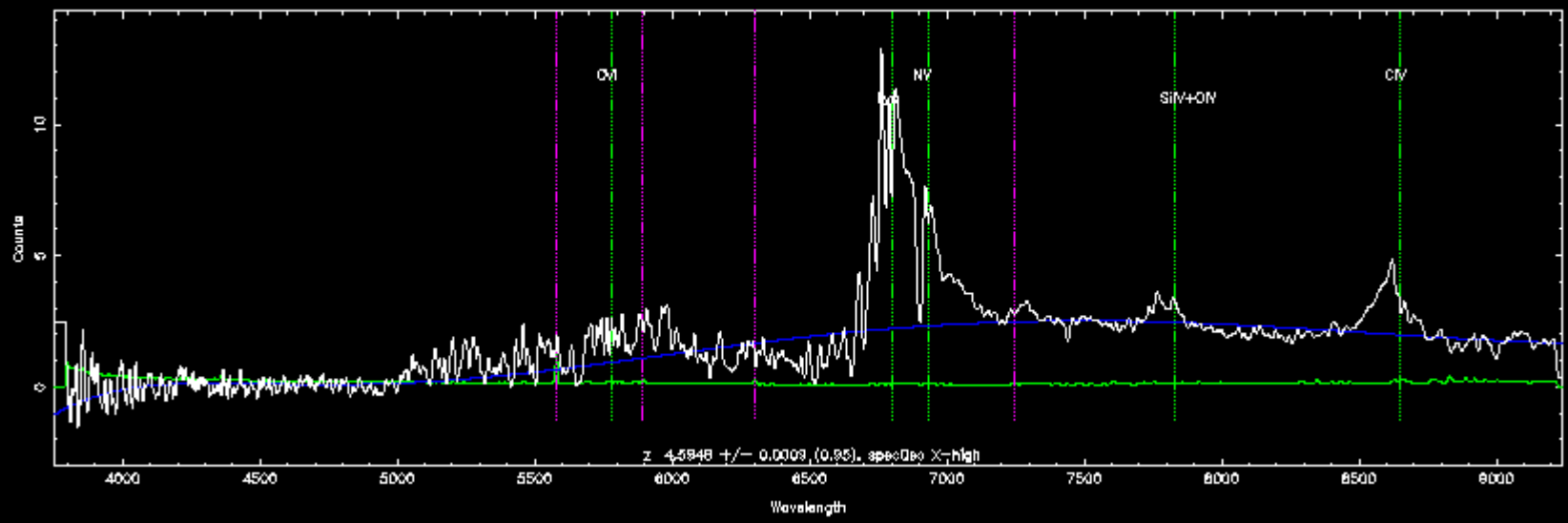
z = 4.4

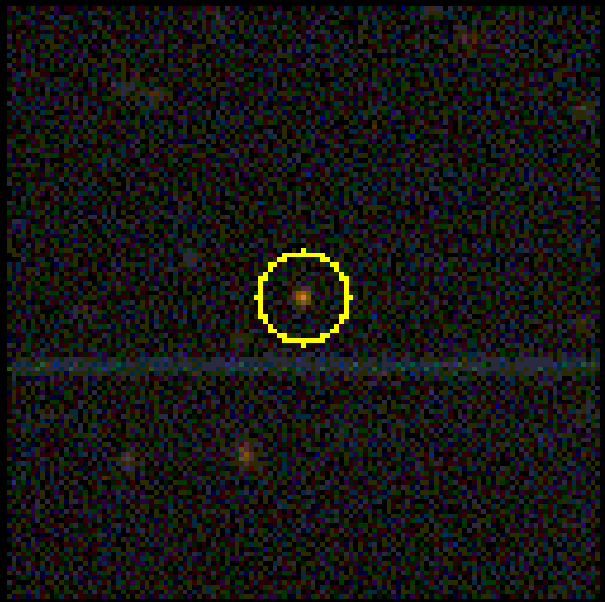
Light travel time =
12.2 billion years



z = 4.5

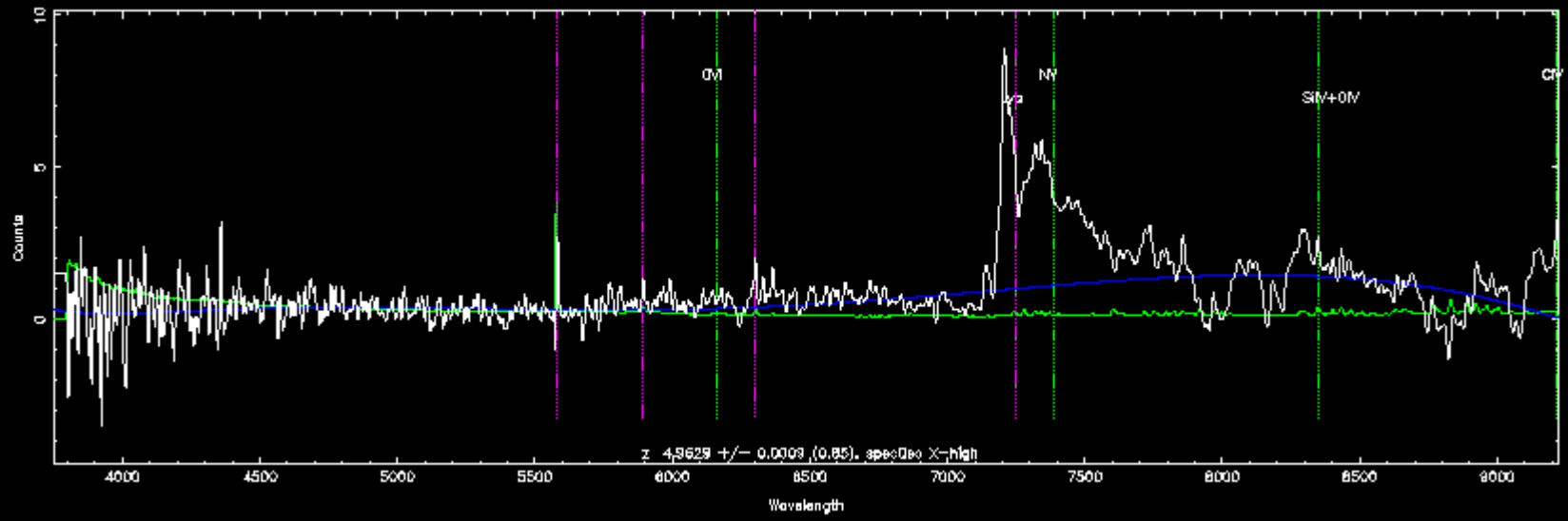
Light travel time =
12.3 billion years





z = 4.6

Light travel time =
12.3 billion years



z = 5.0

Light travel time =
12.5 billion years

Re-run

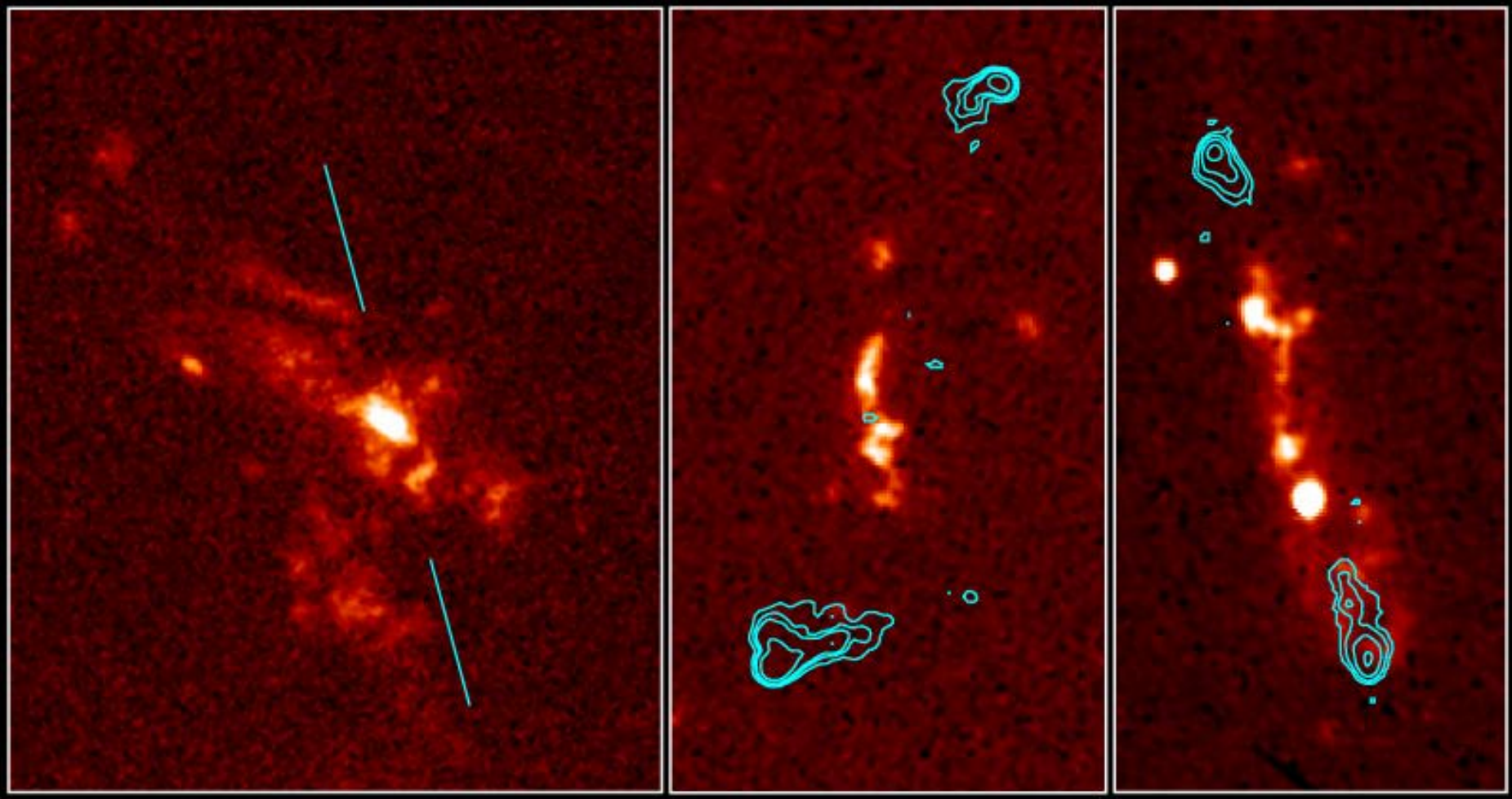
Exit

Quasar Host Galaxies

HST • WFPC2

PRC96-35a • ST ScI OPO • November 19, 1996

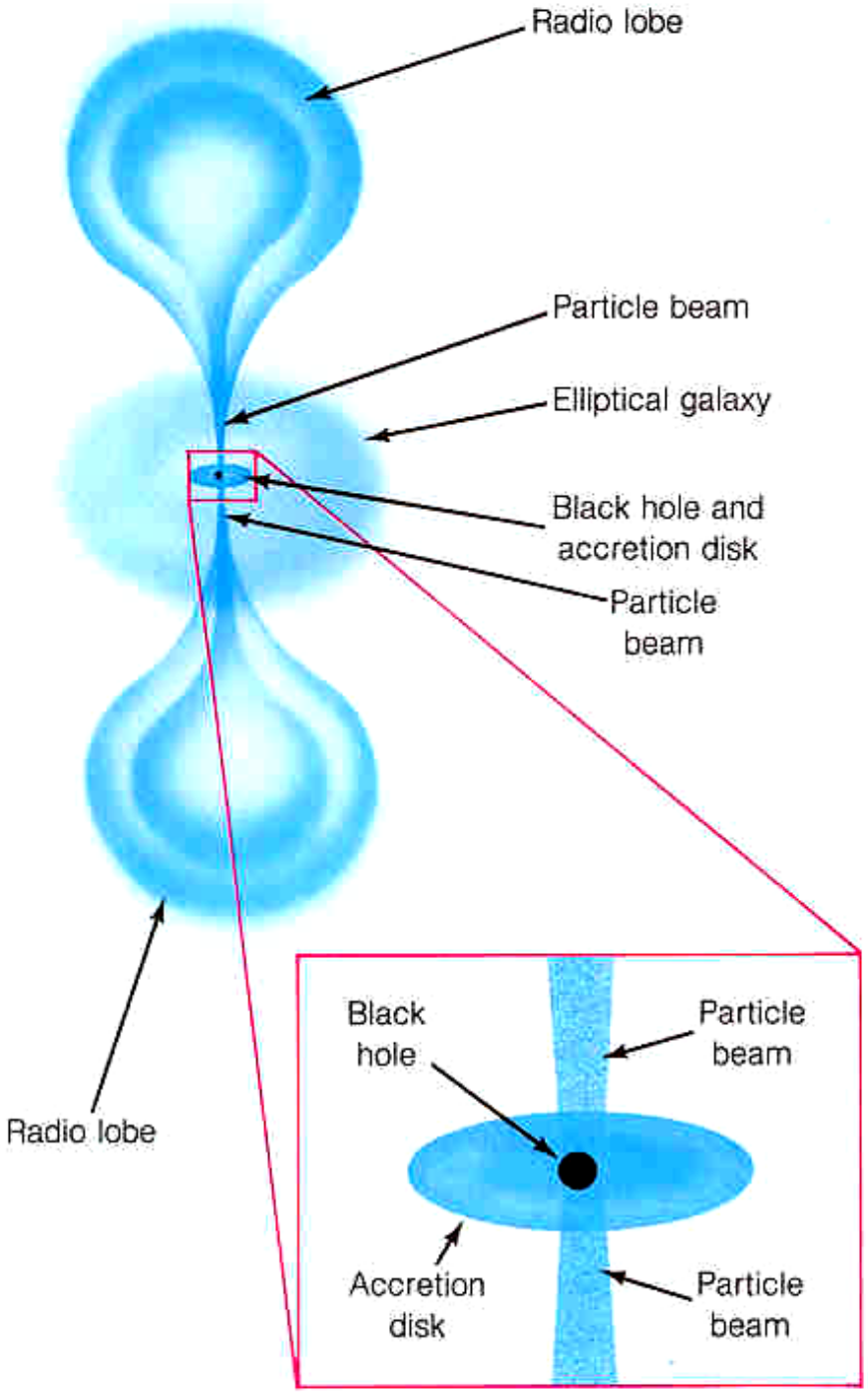
J. Bahcall (Institute for Advanced Study), M. Disney (University of Wales) and NASA

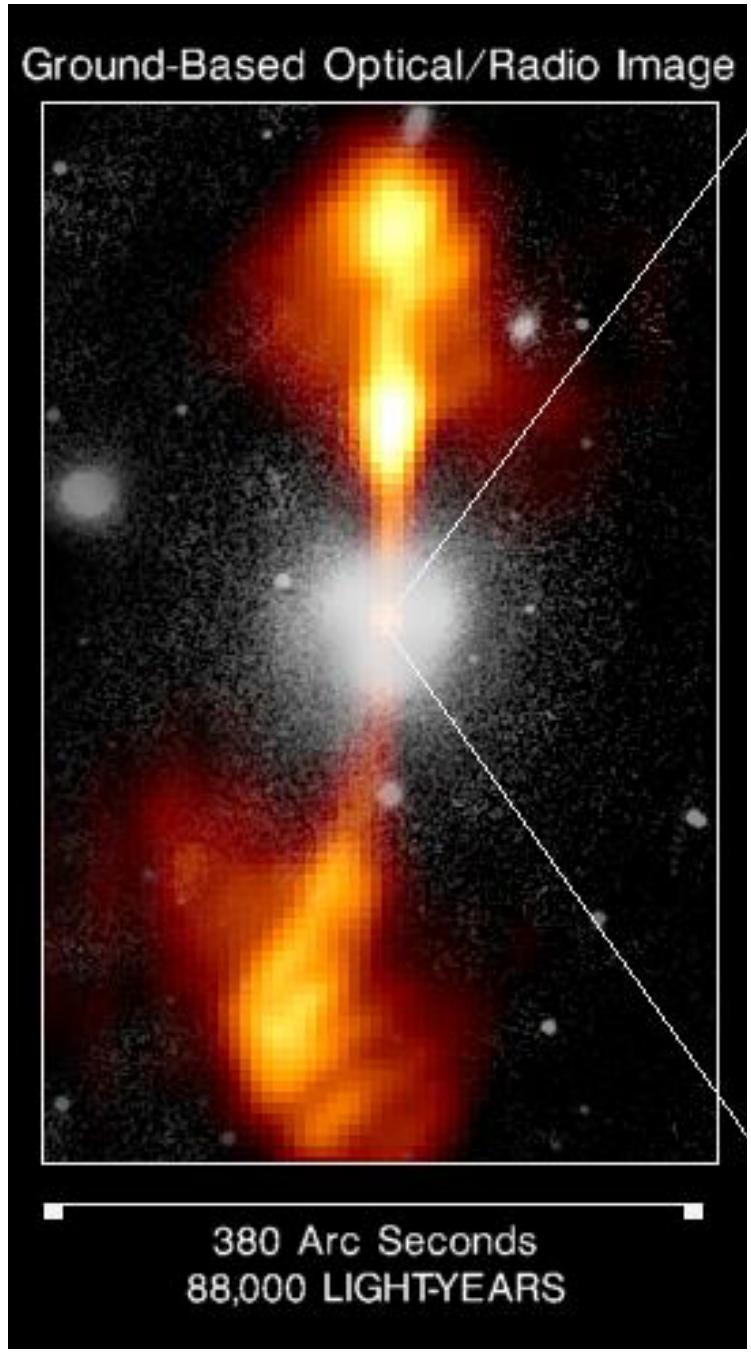


HST Observes Radio Galaxies

HST • WFPC2

PRC95-30 • ST ScI OPO • August 7, 1995 • M. Longair (Cavendish Lab.), NASA

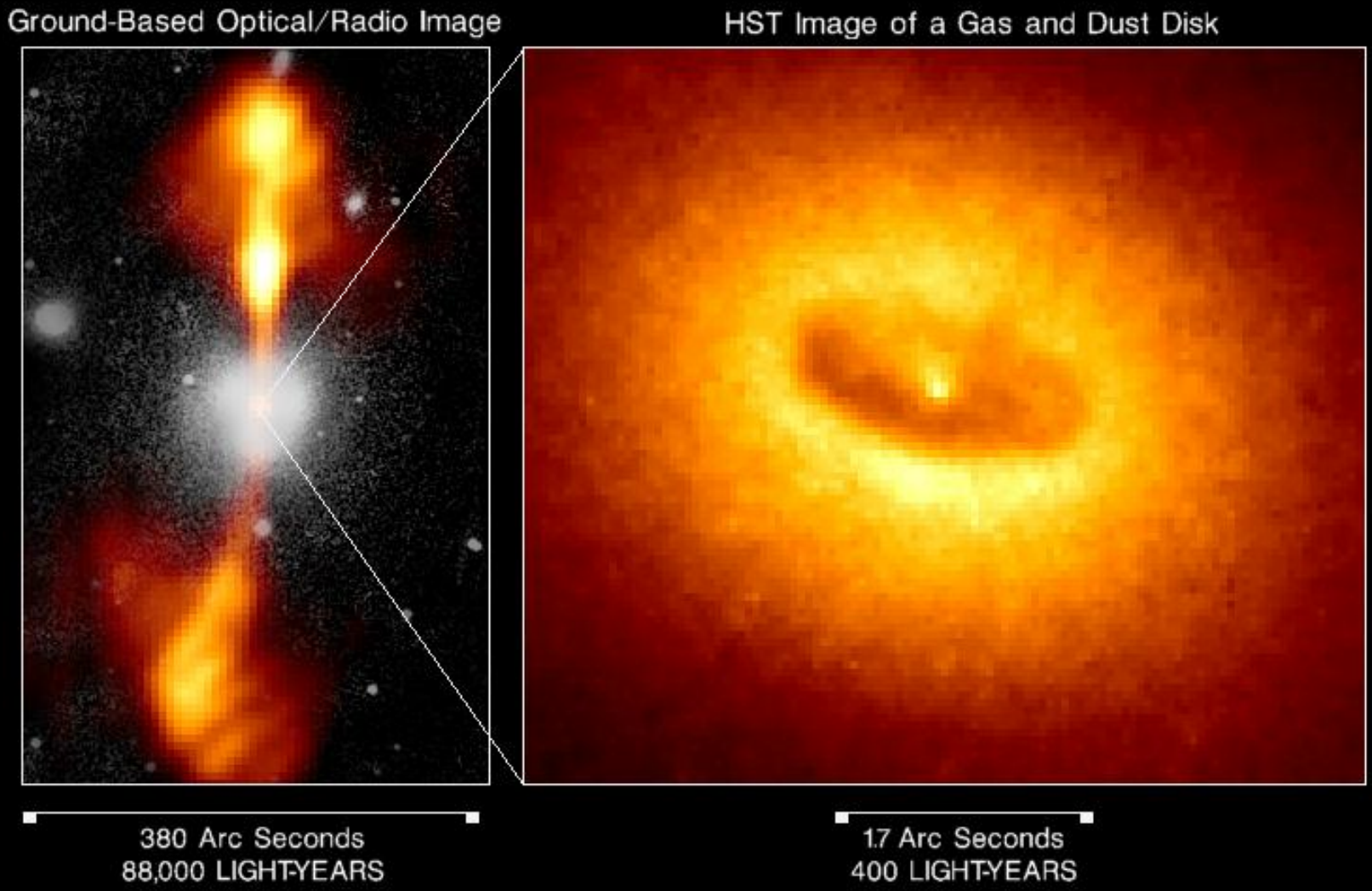

Radio lobe
Particle beam
Elliptical galaxy
Black hole and accretion disk
Particle beam
Radio lobe
Black hole
Particle beam
Accretion disk
Particle beam

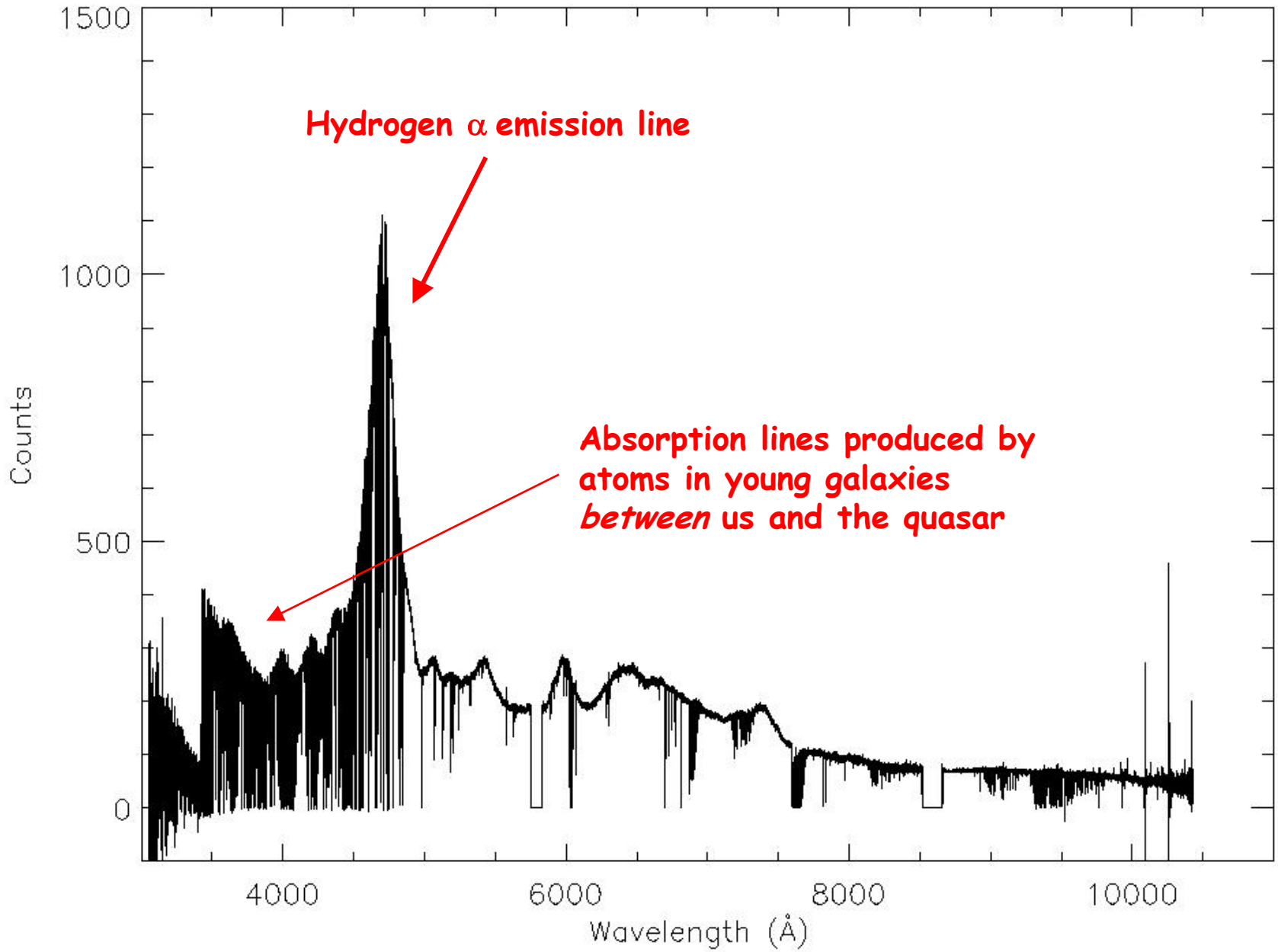

Ground-Based Optical/Radio Image
380 Arc Seconds
88,000 LIGHT-YEARS

Core of Galaxy NGC 4261

Hubble Space Telescope

Wide Field / Planetary Camera




Hydrogen α emission line
Absorption lines produced by atoms in young galaxies *between* us and the quasar
1500
1000
500
0
Counts
4000
6000
8000
10000
Wavelength (Å)