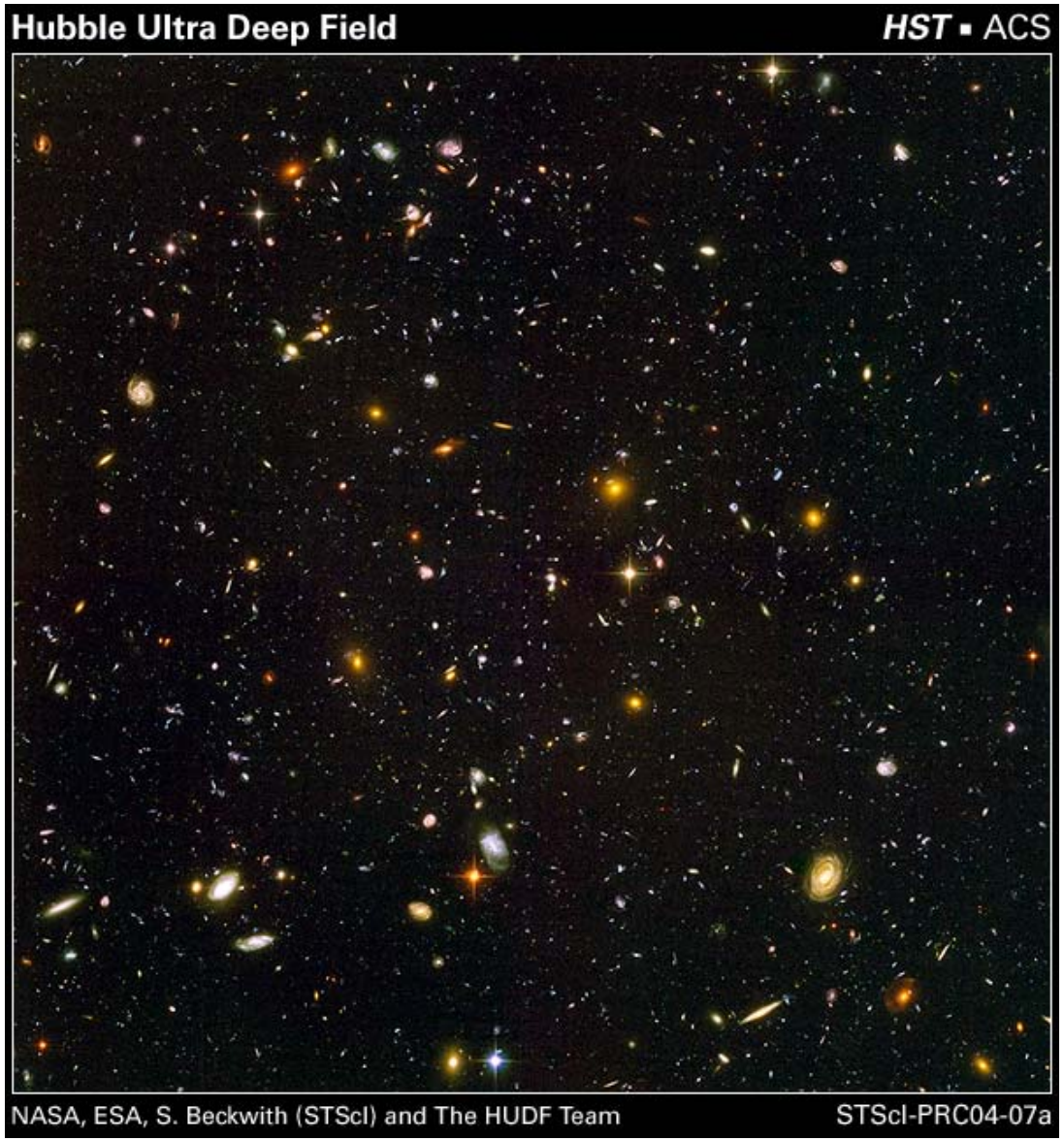
Galaxies and Active Galactic Nuclei

Bits of C&M Chaps. 23, 24 and 25

1995: Hubble deep field taken with WFPC2 on HST during 150 orbits. 2.5 arc minutes across. 3000 galaxies. 1/28,000,000 of the total area of the sky.

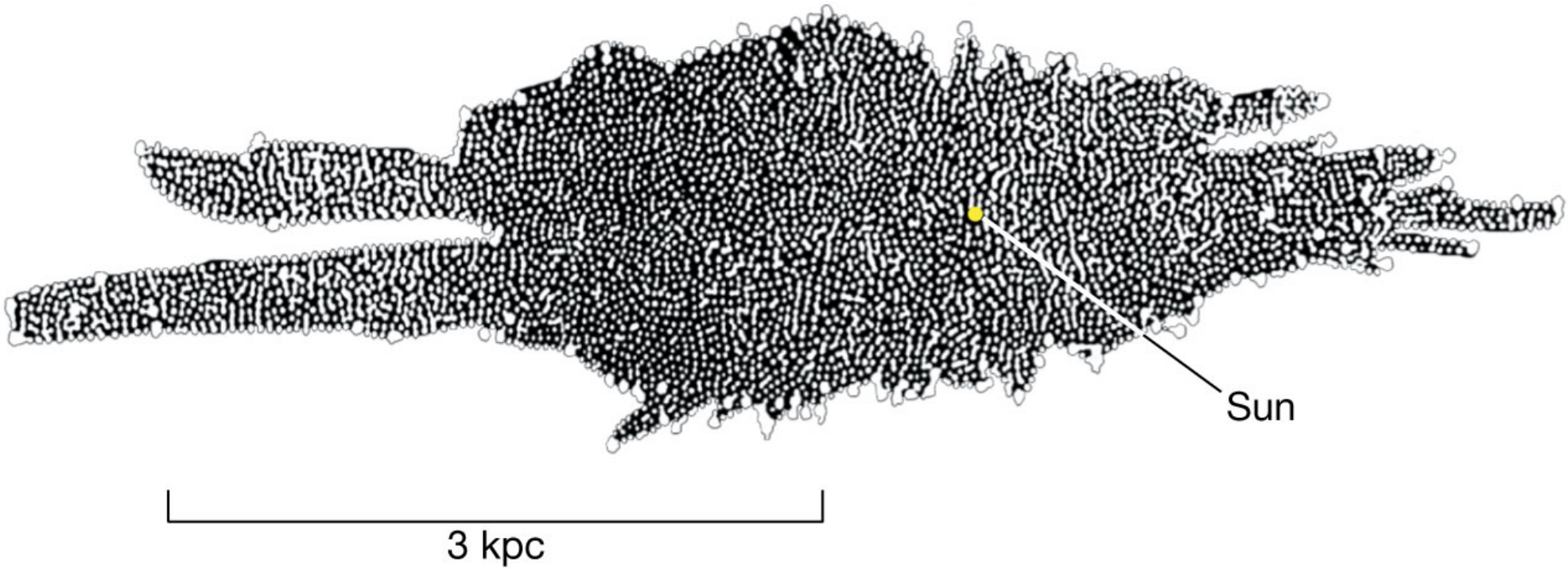


2004: Hubble Ultra Deep Field (1/10 moon's extent) taken with ACS on HST during 400 orbits. 3 arc minutes across. 10,000 galaxies => 1000 billion galaxies over entire sky.

Hubble eXtreme Deep Field (HXDF) image in Sept. 2012. 23 days in the centre of the HUDF, adding an extra 5500 galaxies

From 1920 to the present day we have gone from knowing only one galaxy, to identifying trillions.

From geocentrism to heliocentrism, Galileo showed (early 1600s) that the Milky Way is a blur of unresolved stars.

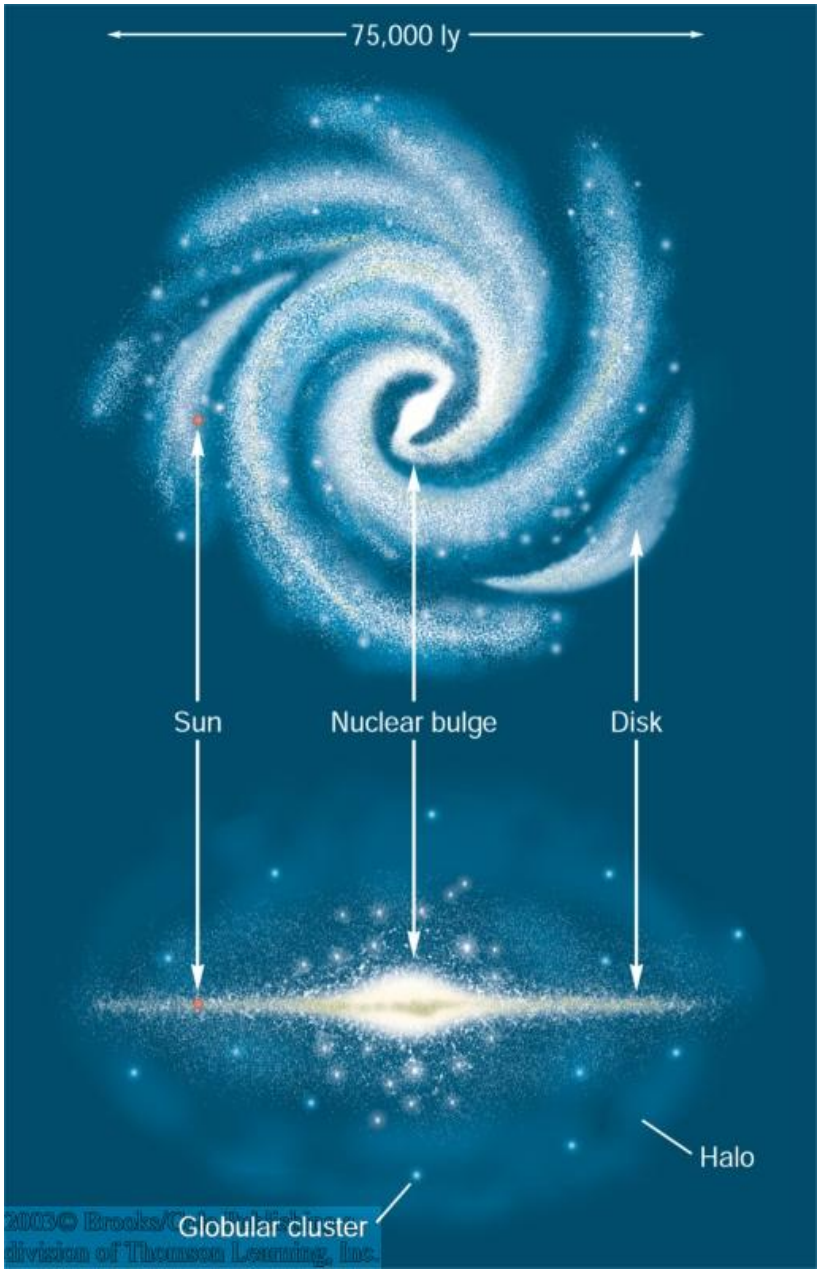


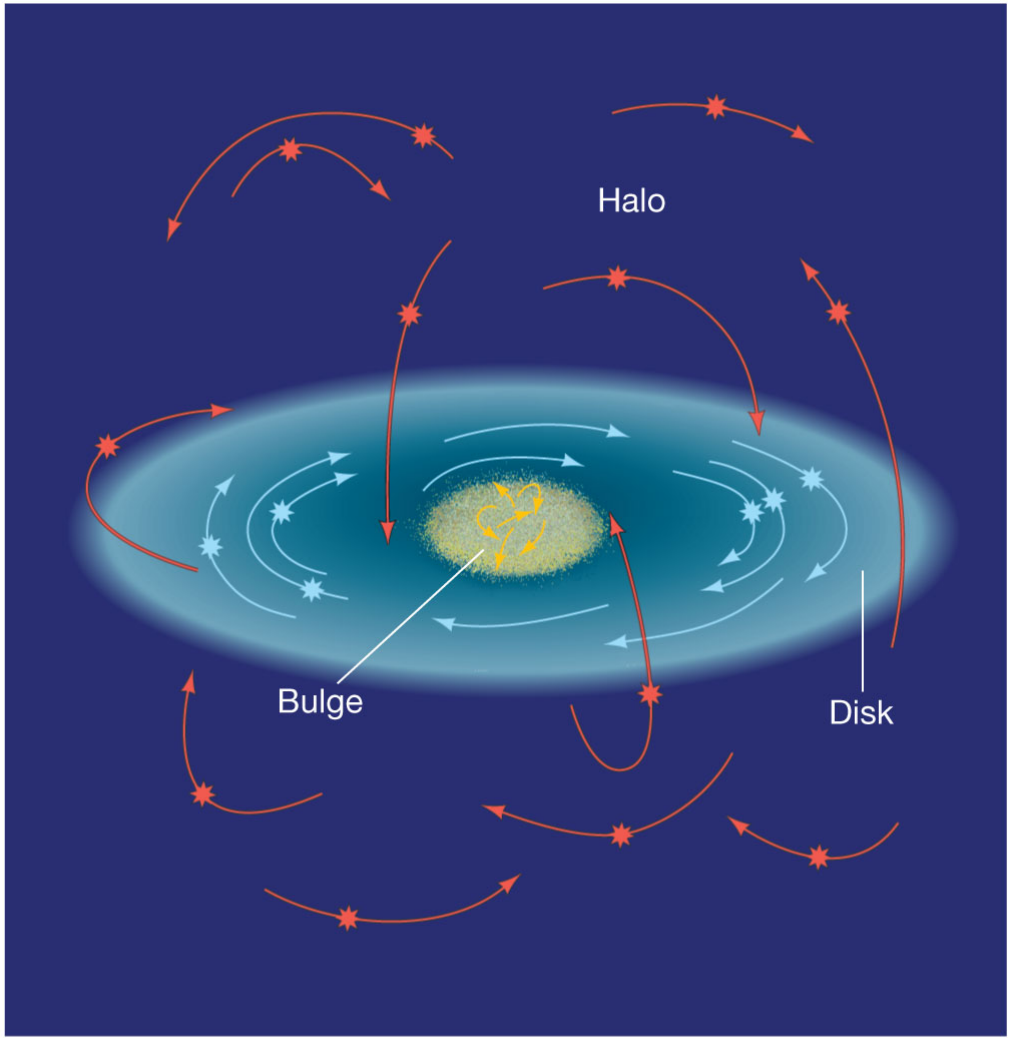
Mid 1800s, William Herschel counted stars to sketch the Milky Way. Put sun at the centre! Problem: dust blocks our view!


View from the inside!

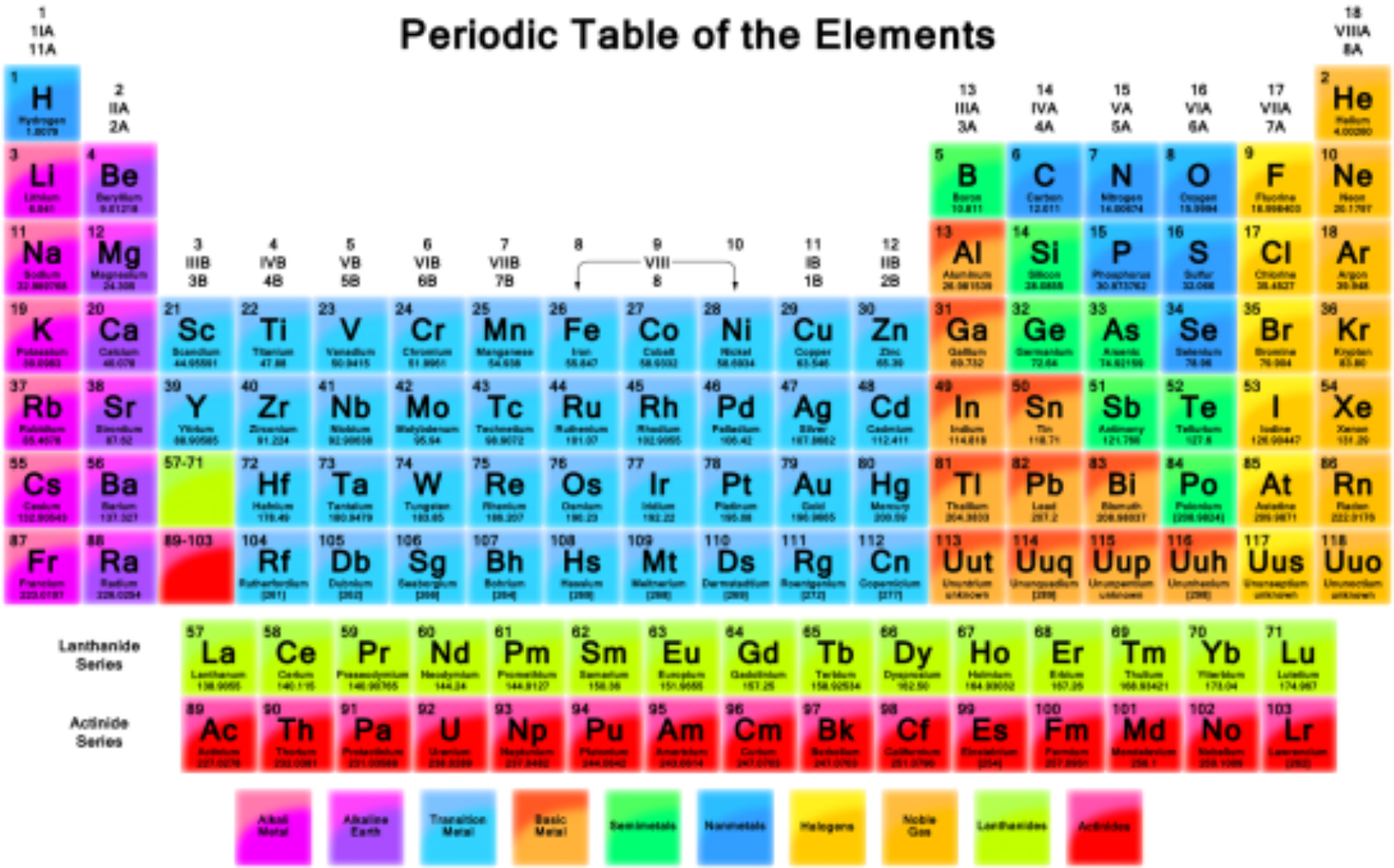

View from the outside?

The Structure of the Milky Way

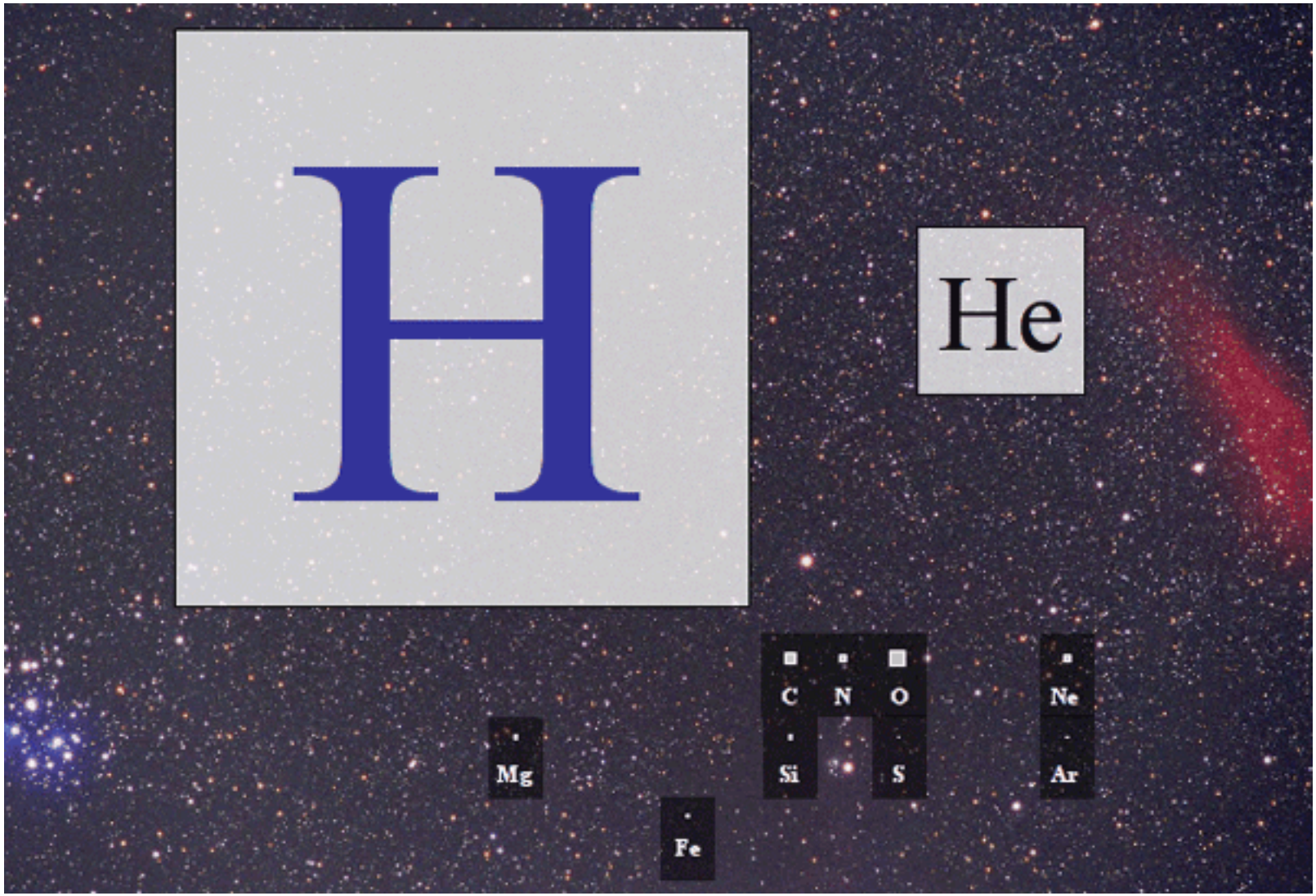




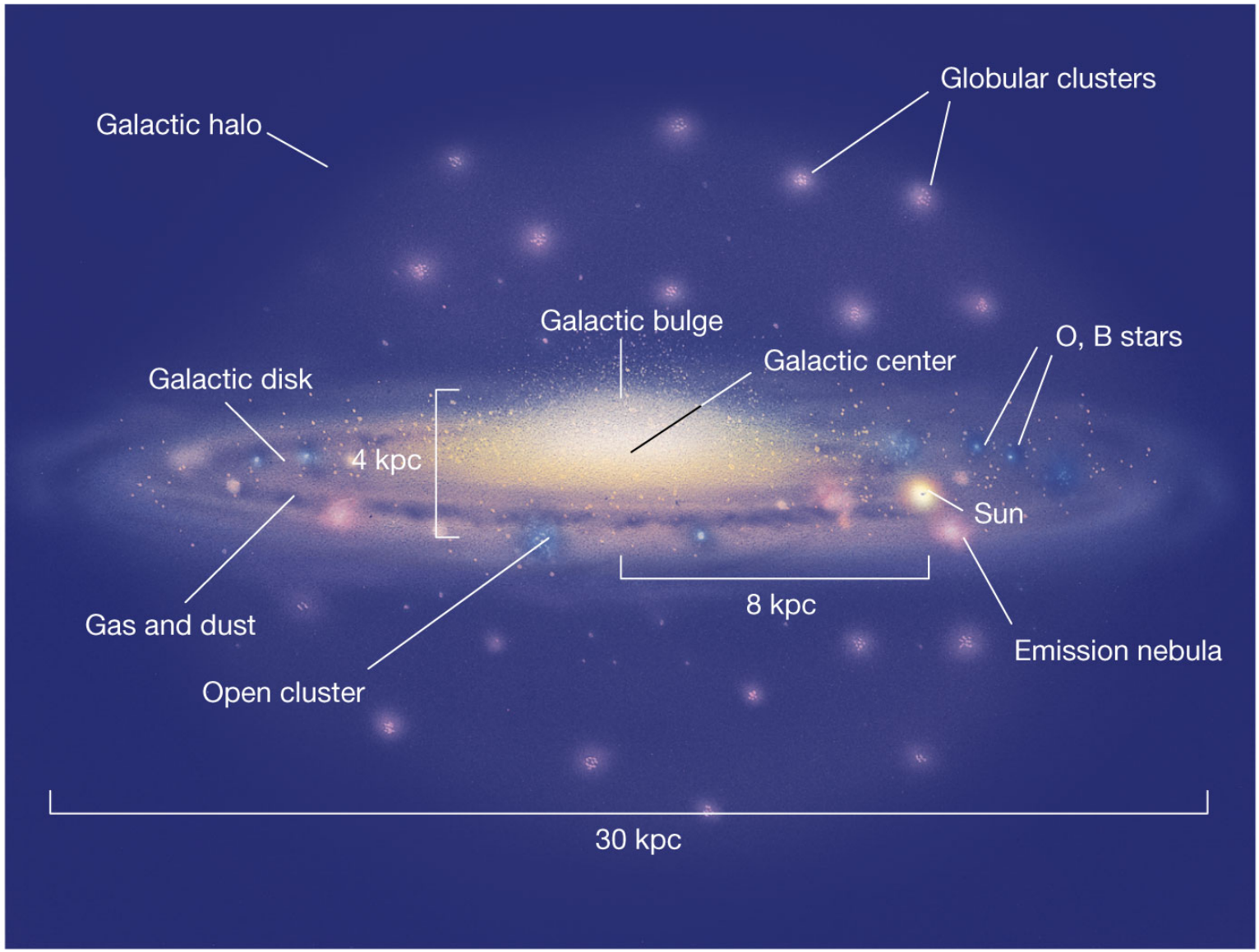
Aside: elements from a chemist's perspectrive



Aside: elements from an astronomer's perspectrive



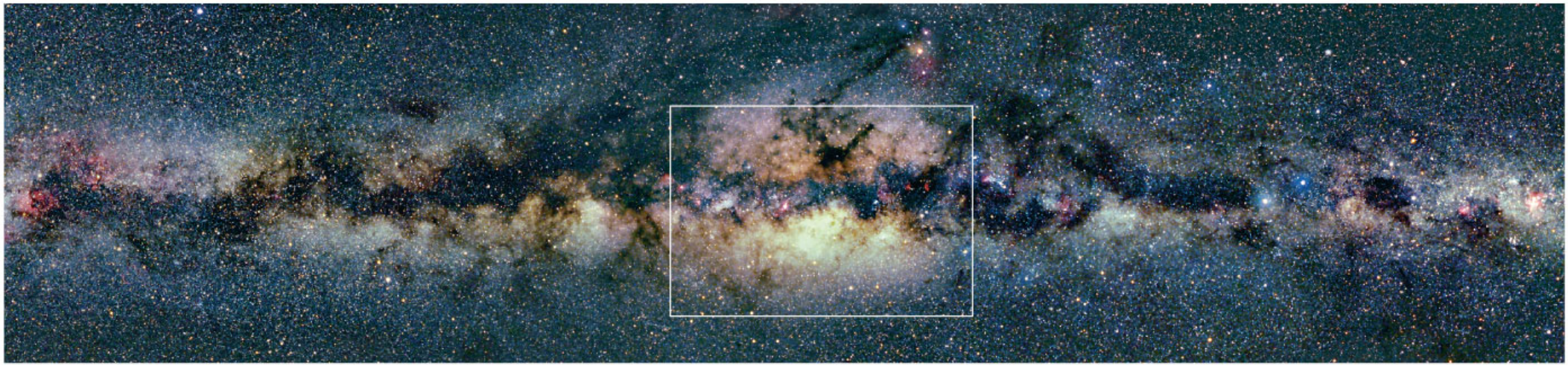
Stellar populations in the Galaxy:



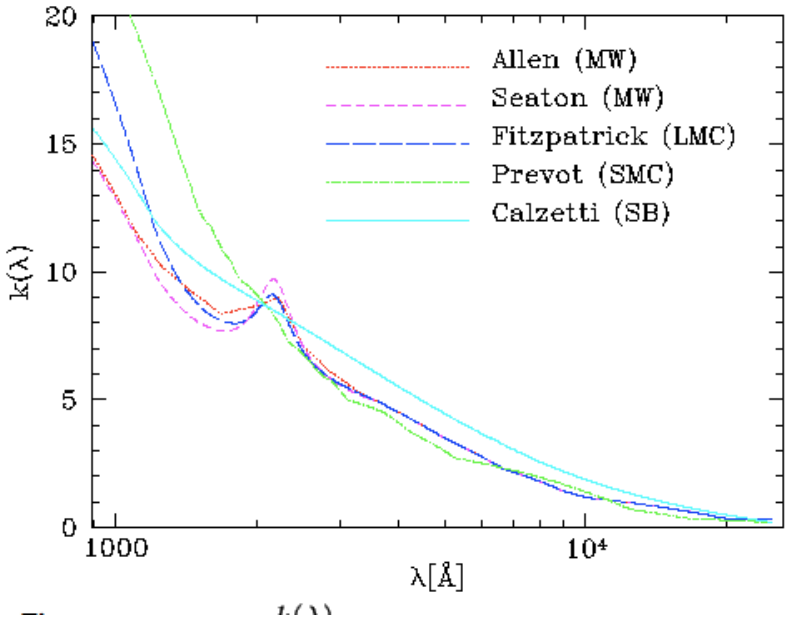
Mapping spiral arms: stars.

Nice and bright, but…

We live <u>in</u> the disk and it is dusty: we can only see about 1kpc.

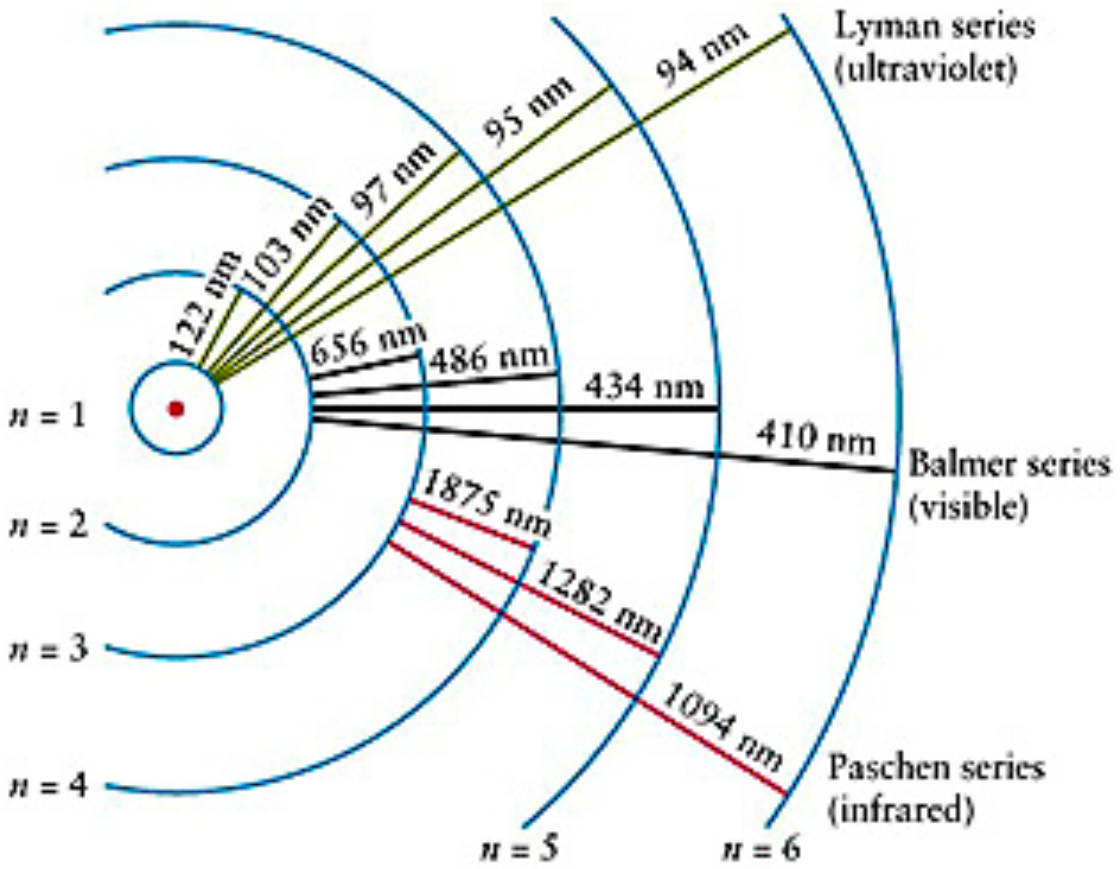


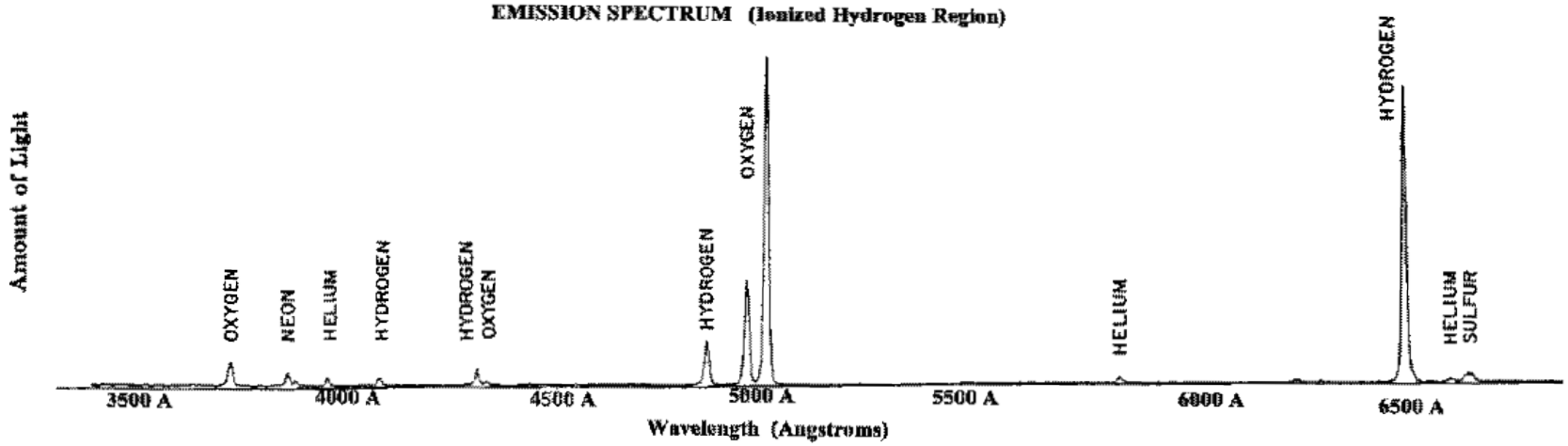
Galactic extinction laws:



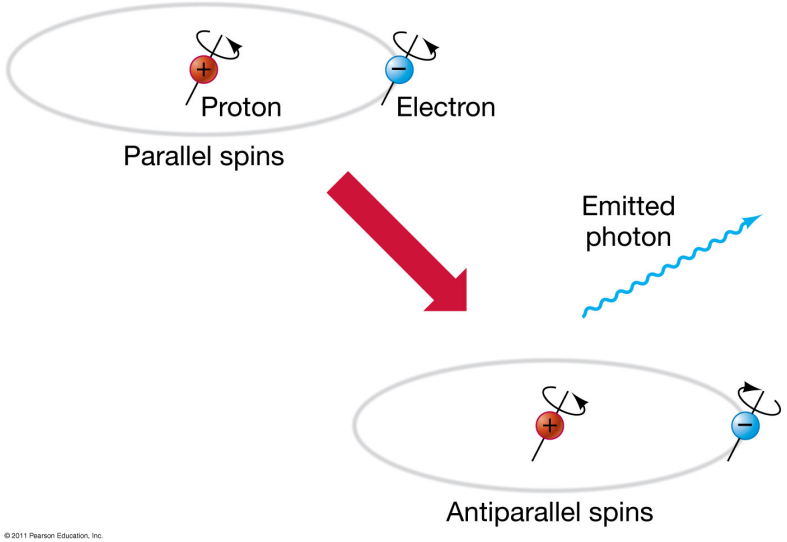
Mapping spiral arms: gas near hot stars.

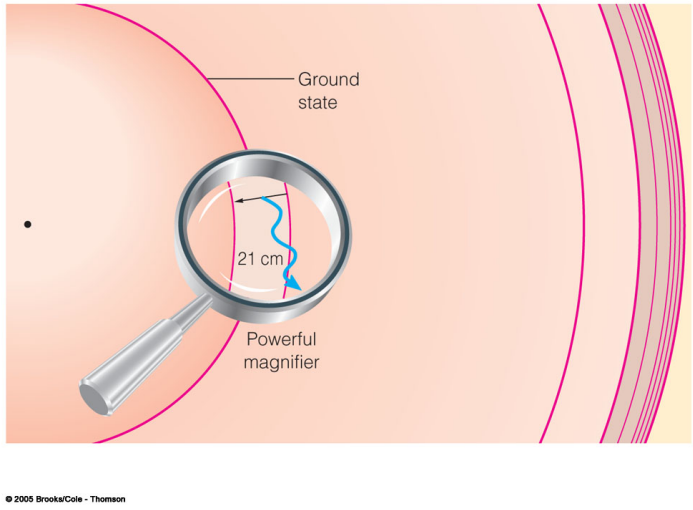
Strongest emission lines are in the optical, so still suffer from interstellar extinction.





Mapping spiral arms: gas. HI 21cm immune to dust.





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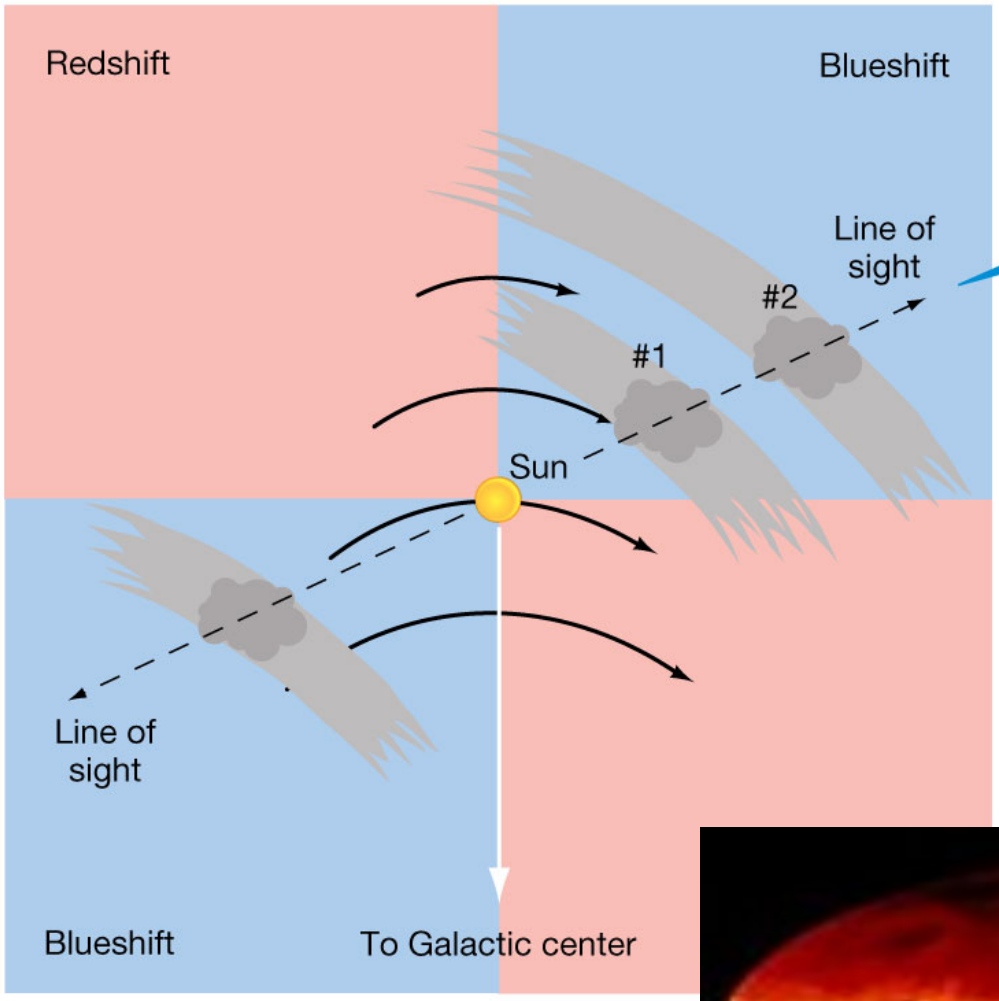
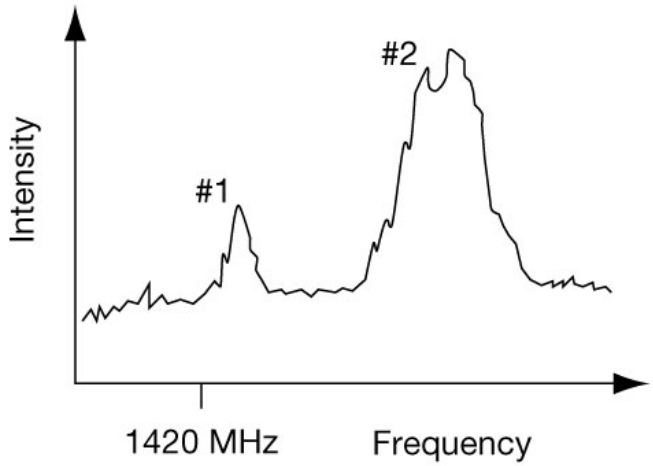
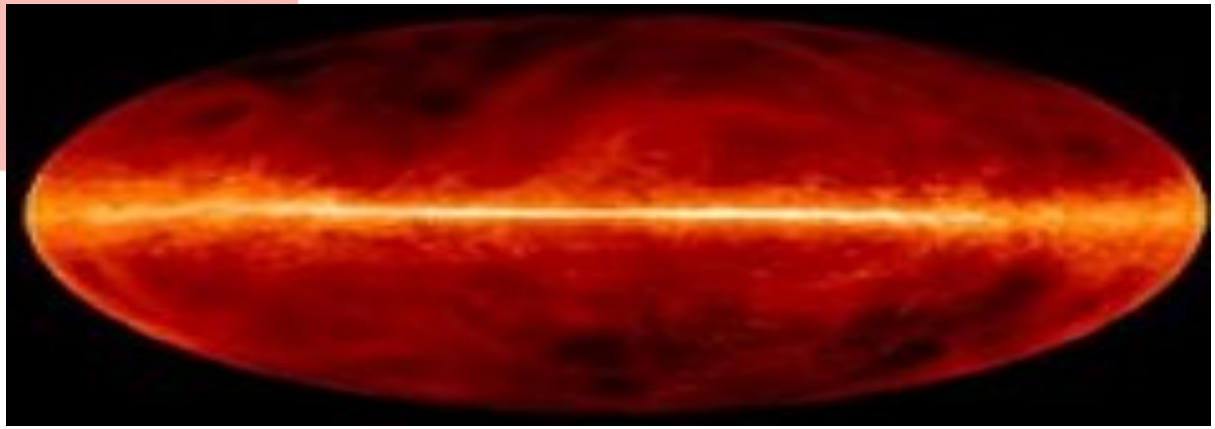
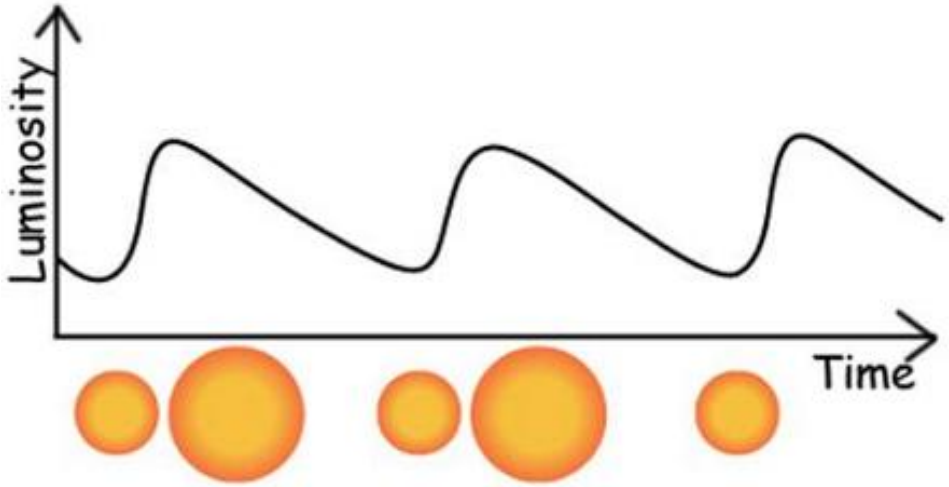






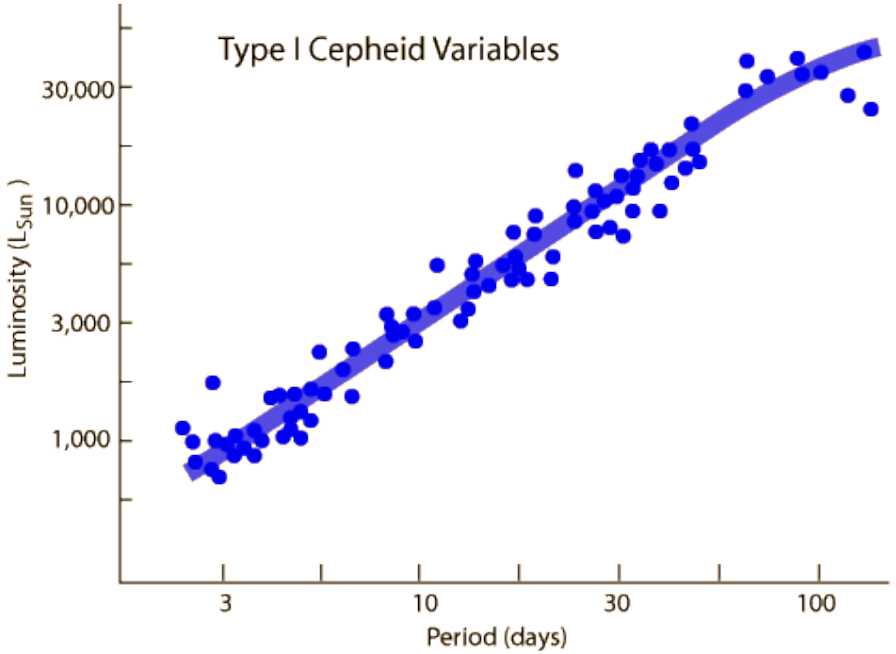
Can also map star-forming galaxies in the IR.

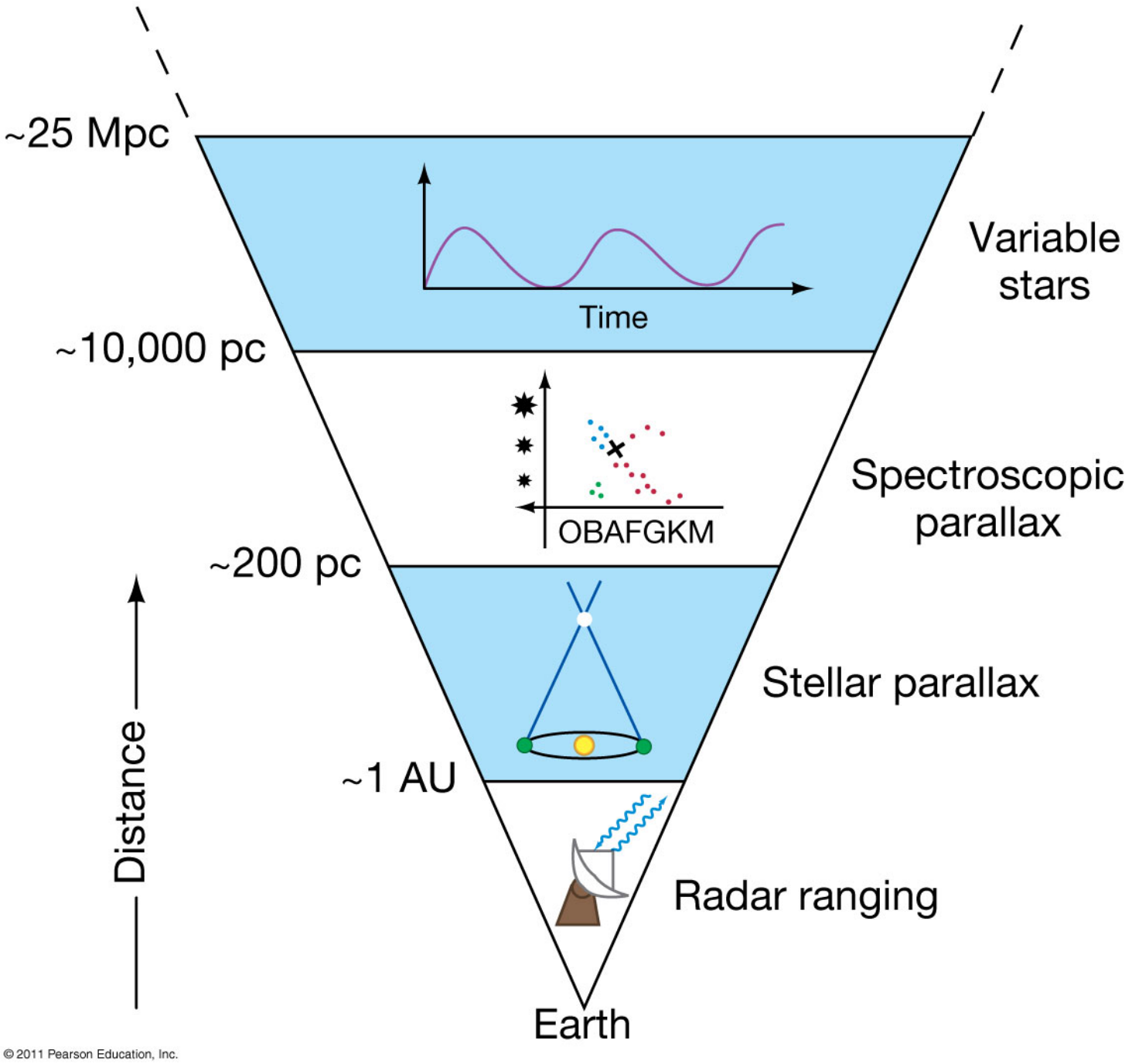
Measuring the size of the Milky Way



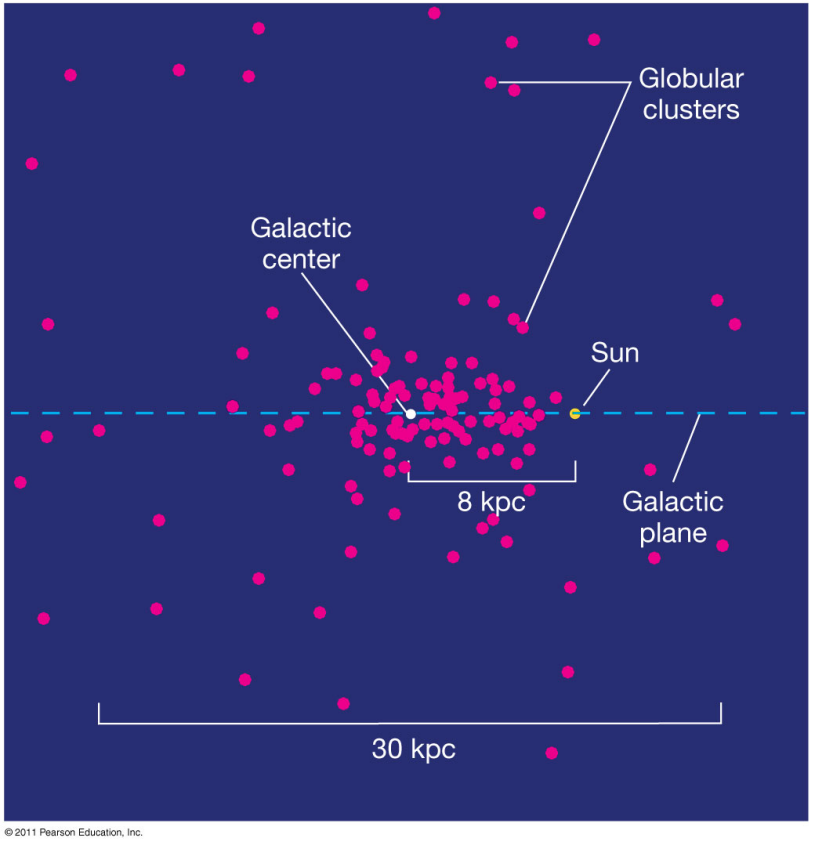
Cepheid variable stars pulsate.

Period-luminosity relation discovered by Henrietta Swan-Leavitt c 1910. Distance measure beyond parallax.





Early 20th century, the extent of the Milky Way determined by Harlow Shapley using distances to globular clusters. Spherically distributed over many kpc. Sun not at centre.



Weighing the Galaxy with Kepler's 3rd Law

$P^2 = a^3 / M$, where P in years, a in AU and M in solar units

Example: What mass is contained in the Galaxy within the radius of the sun's orbit if the sun's period around the Galaxy is 240 million years at a radius of 8.5 kpc?

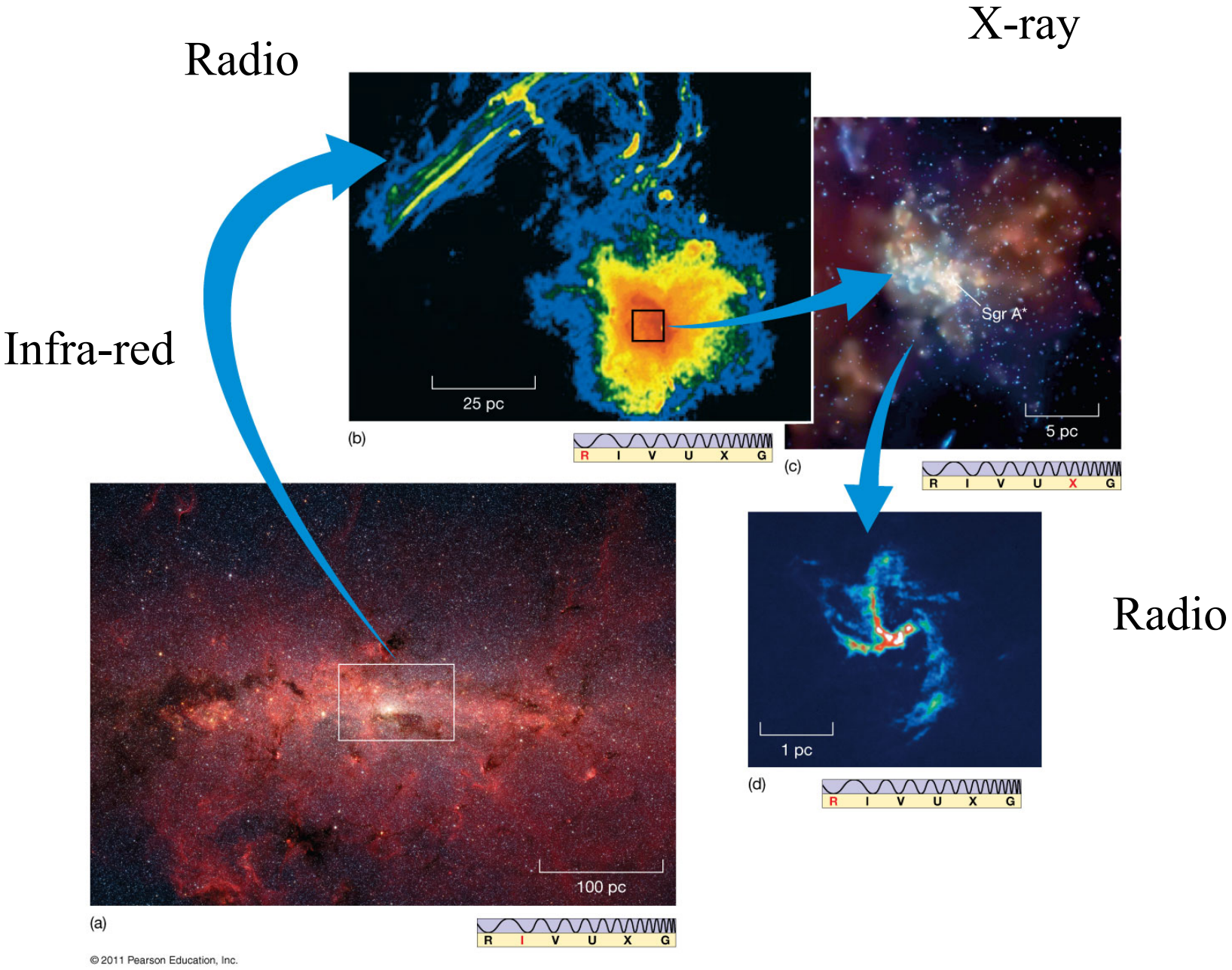
8.5 kpc= 1.75×10^9 AU.

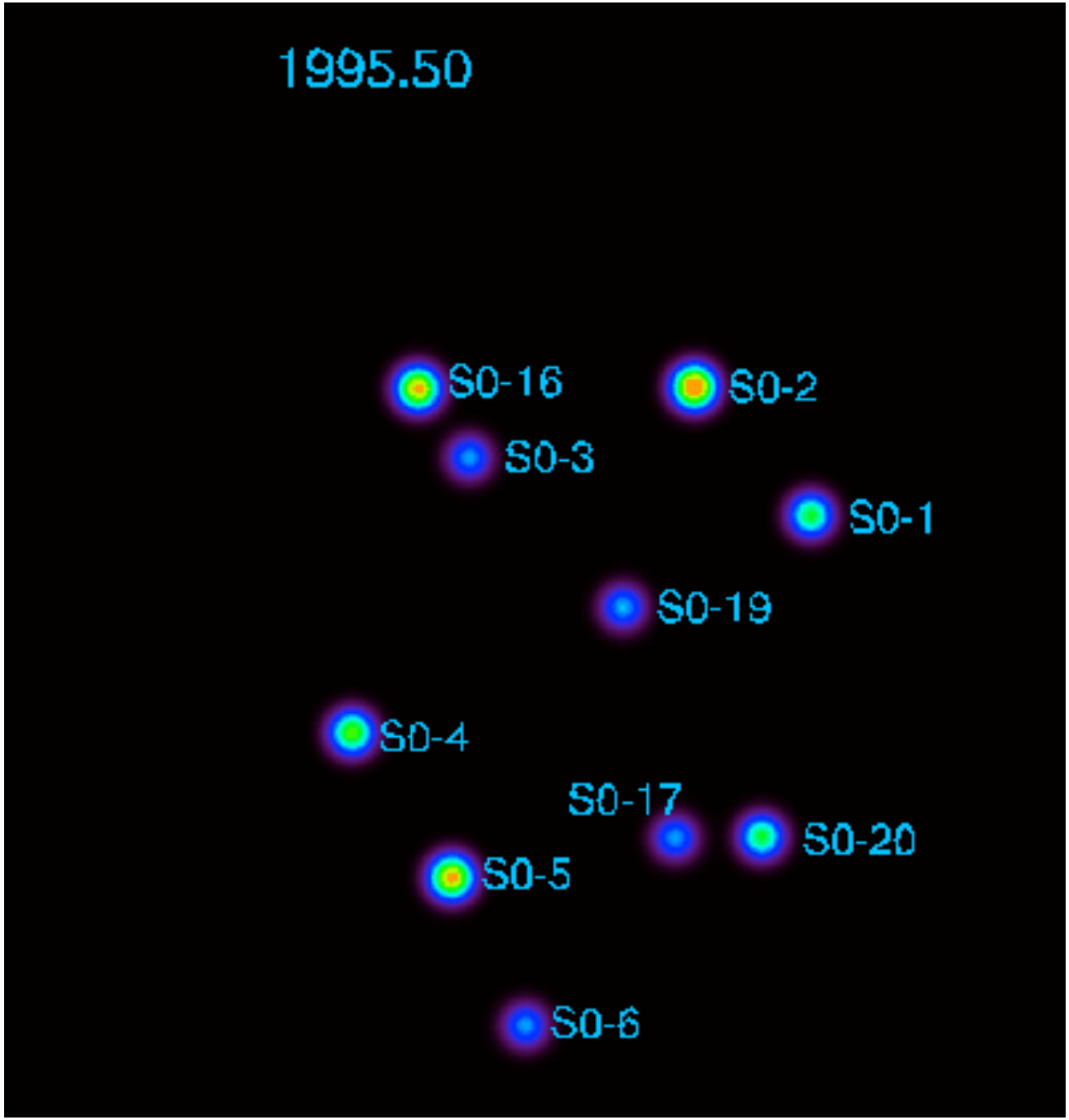
$M = a^3/ P^2 = (1.75 \times 10^9)^3 / (240 \times 10^6)^2$

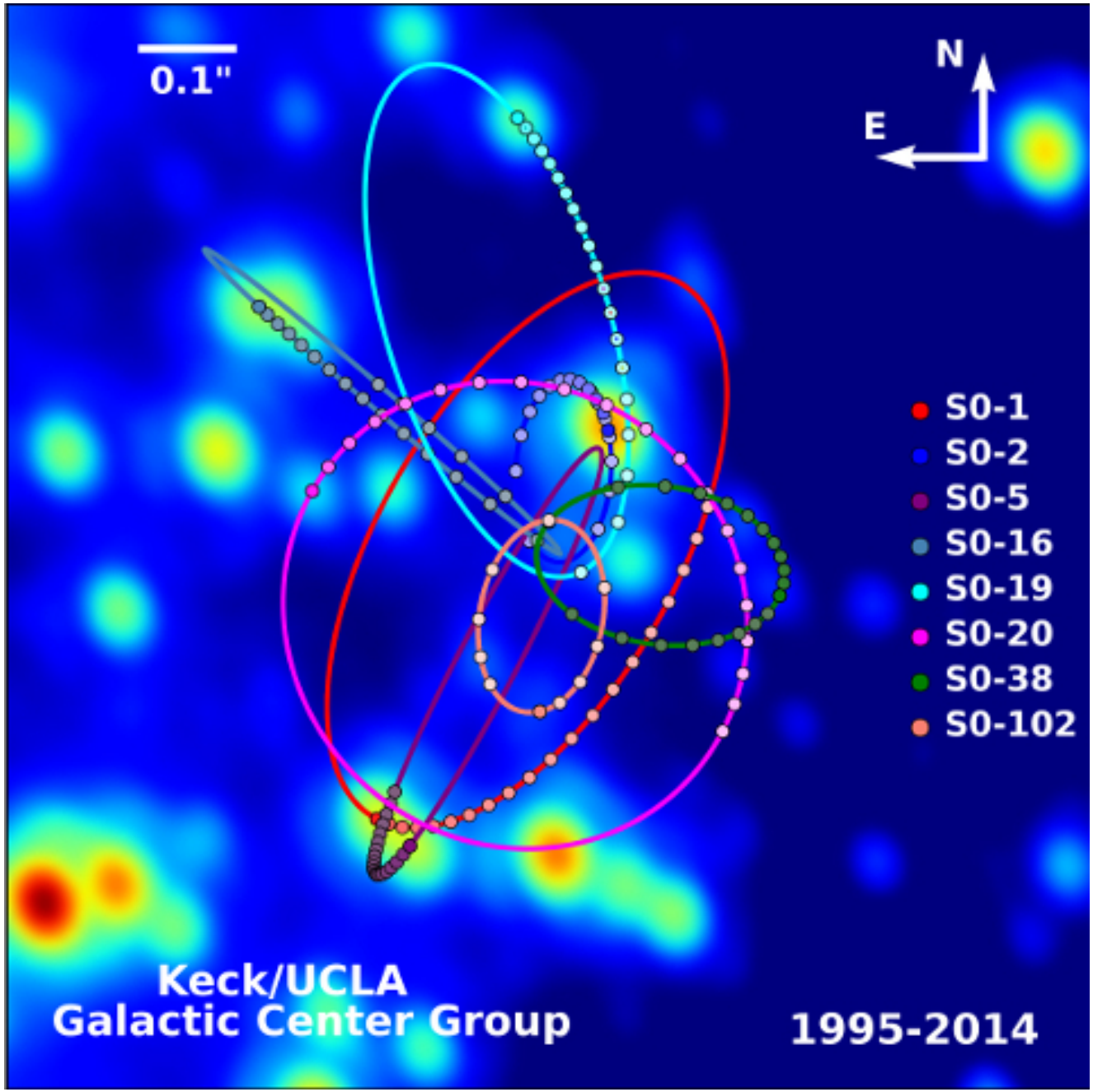
$= 0.9 \times 10^{11}$ solar masses

If we take into account the mass outside the sun's orbit, we would find a mass of at least 2×10^{11} solar masses, i.e. 200 billion solar masses.

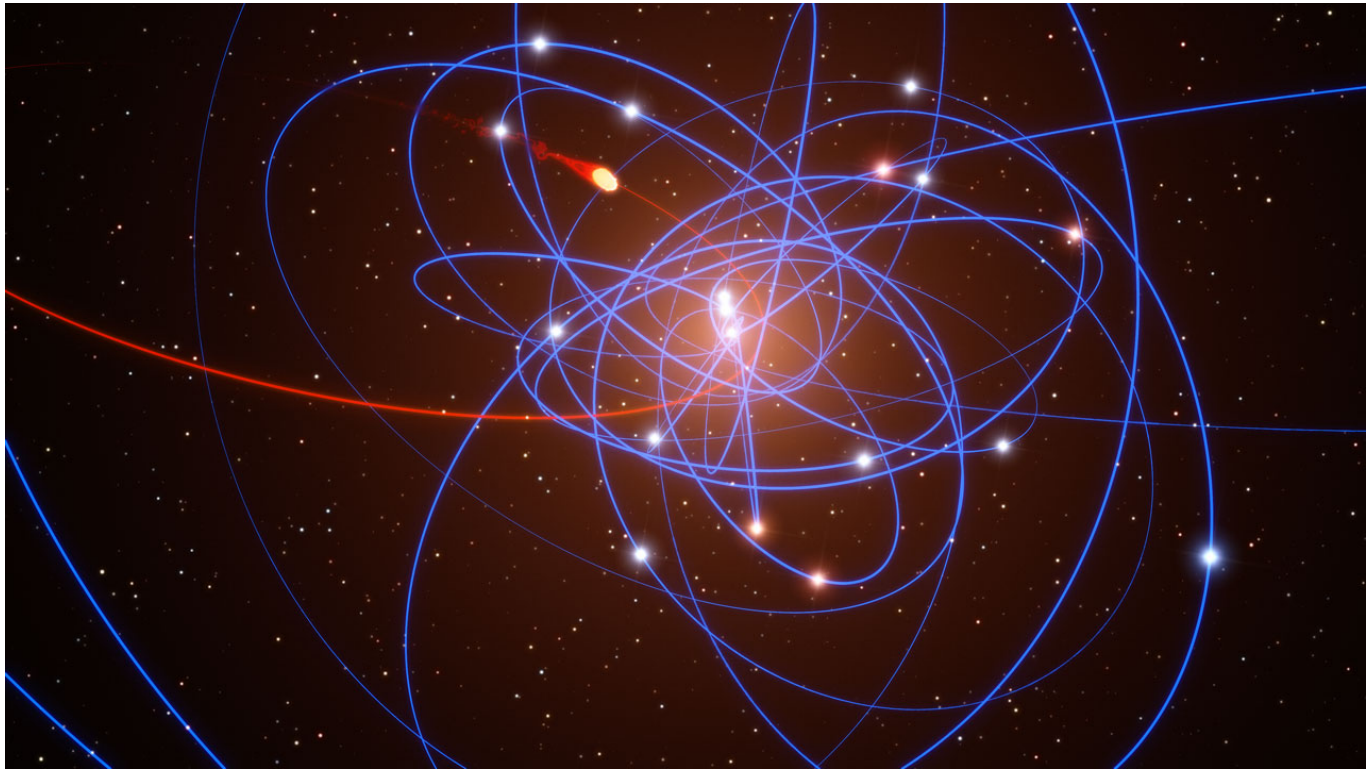
The Galactic Centre

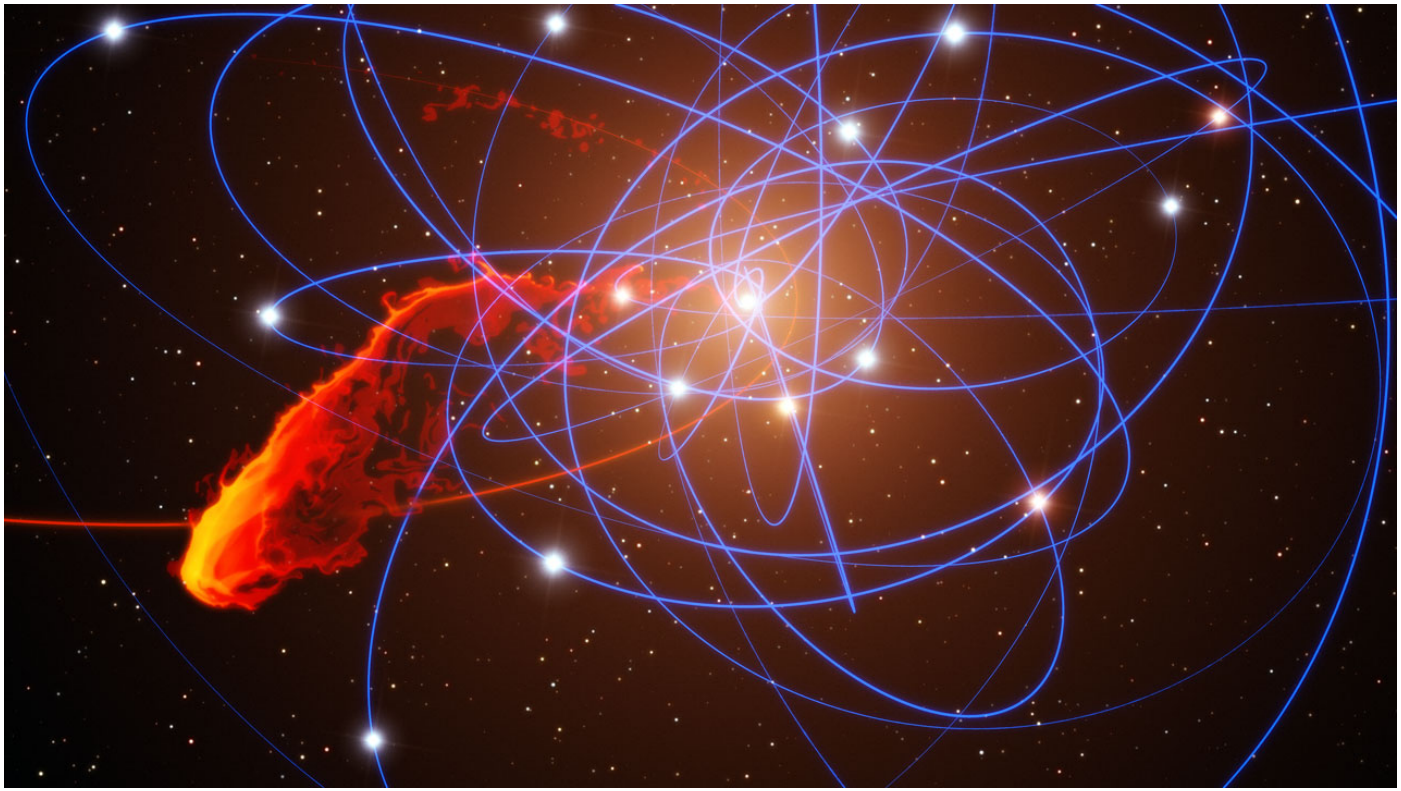



1995.50
S0-16
S0-2
S0-3
S0-1
S0-19
S0-4
S0-17
S0-20
S0-5
S0-6

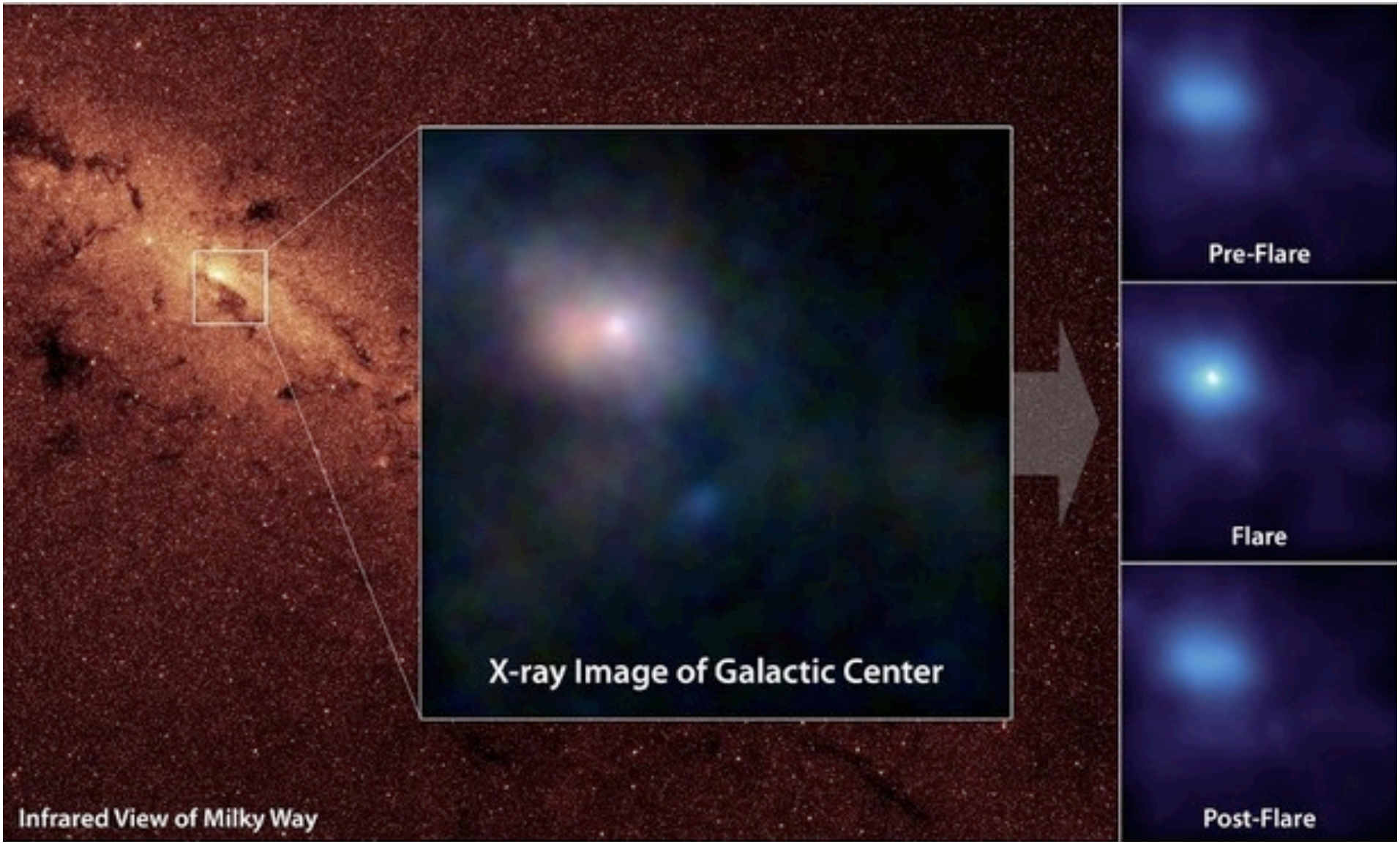


http://www.galacticcenter.astro.ucla.edu/

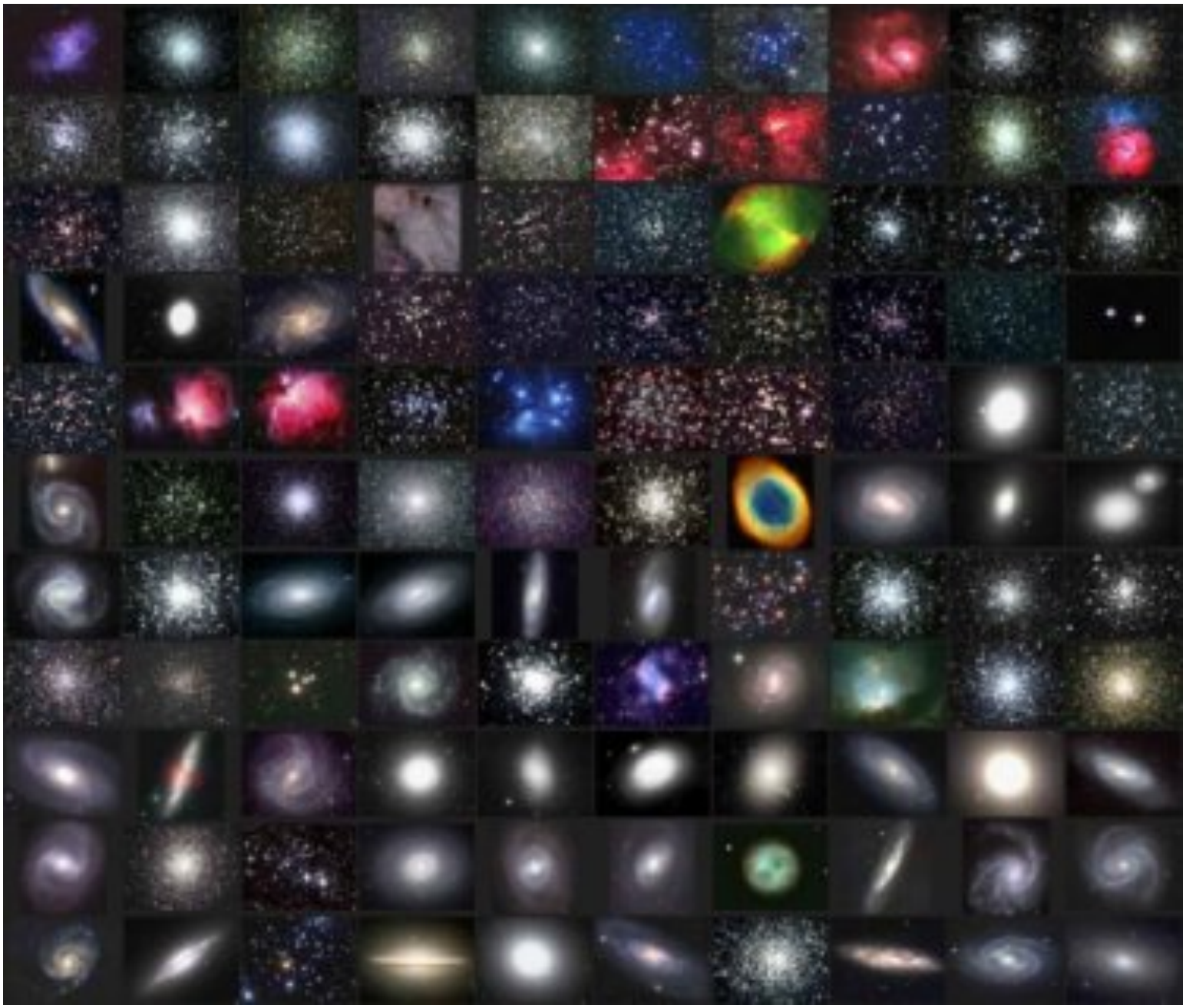




New NASA X-ray telescope, NuSTAR detects flares as the black hole “burps”.



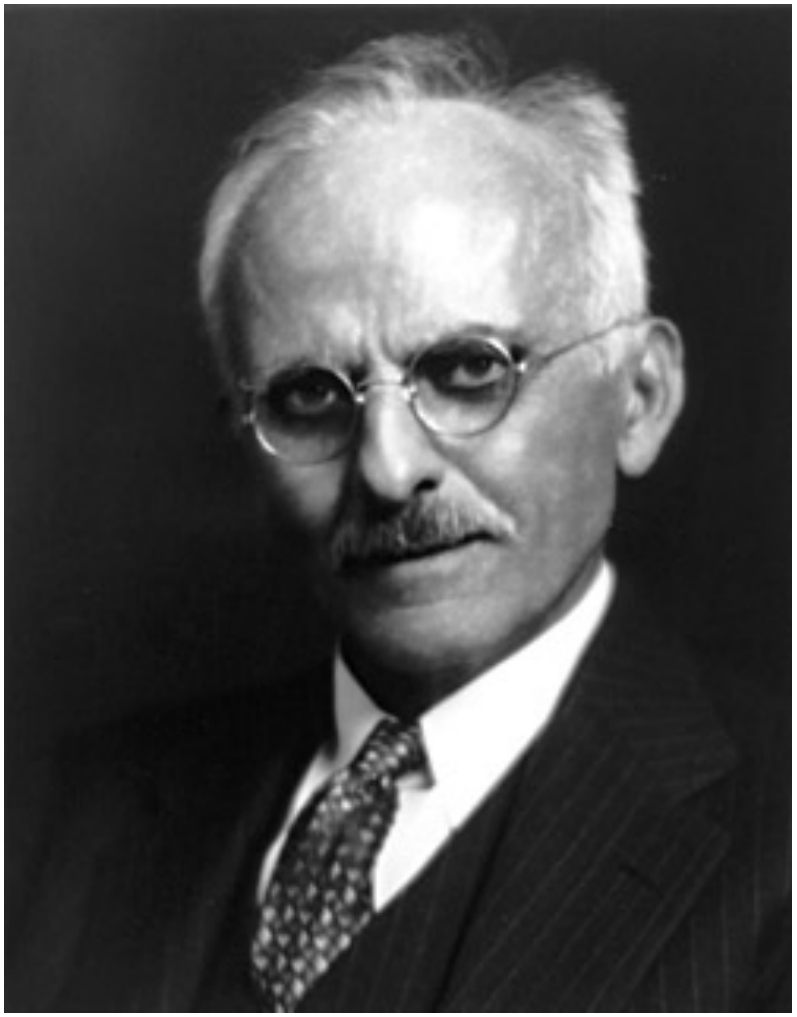
The first (unintentional) catalog of extra-galactic objects by Charles Messier in the mid 1700s: 100 fuzzy objects that were not comets!



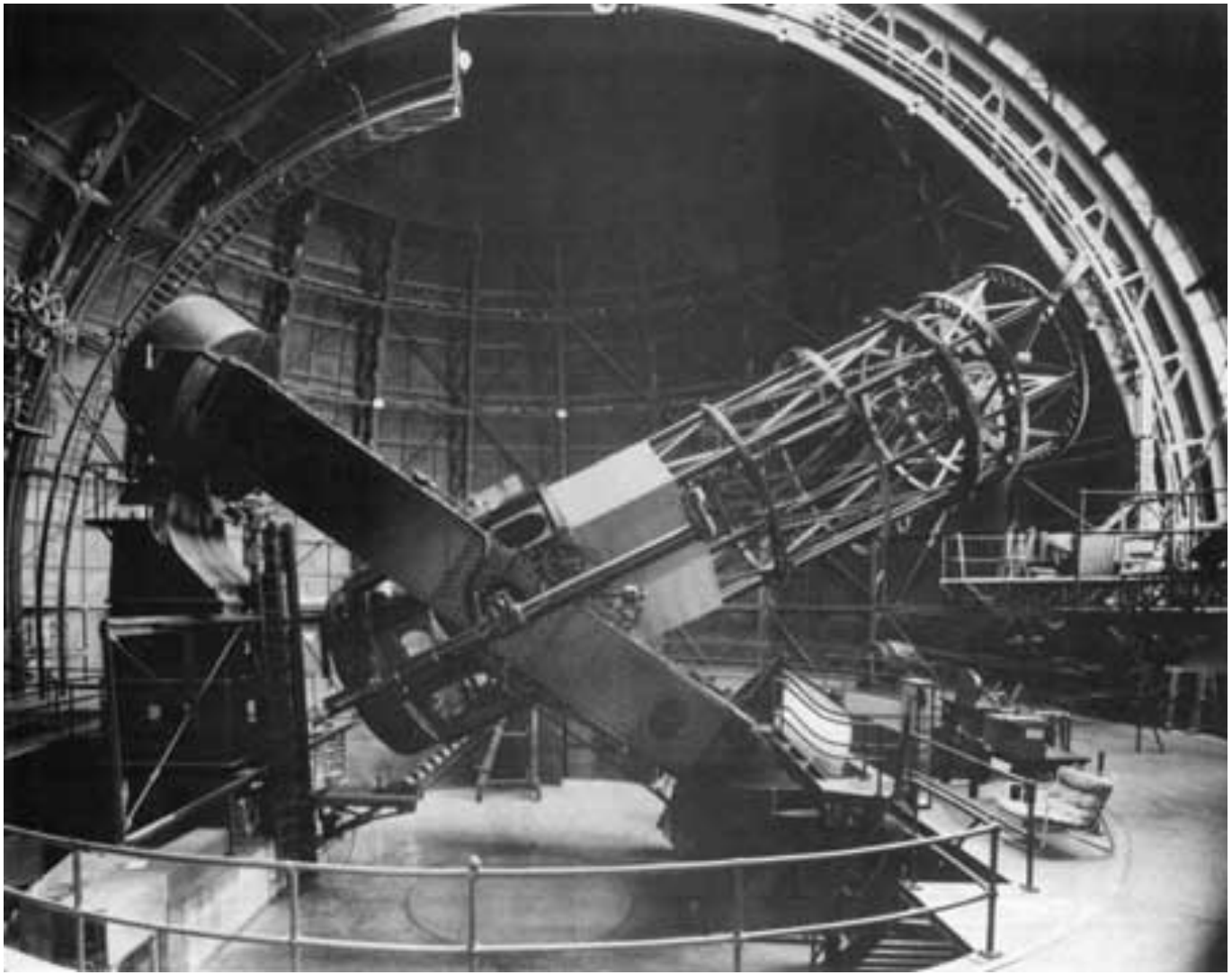
The Leviathon of Parsonstown

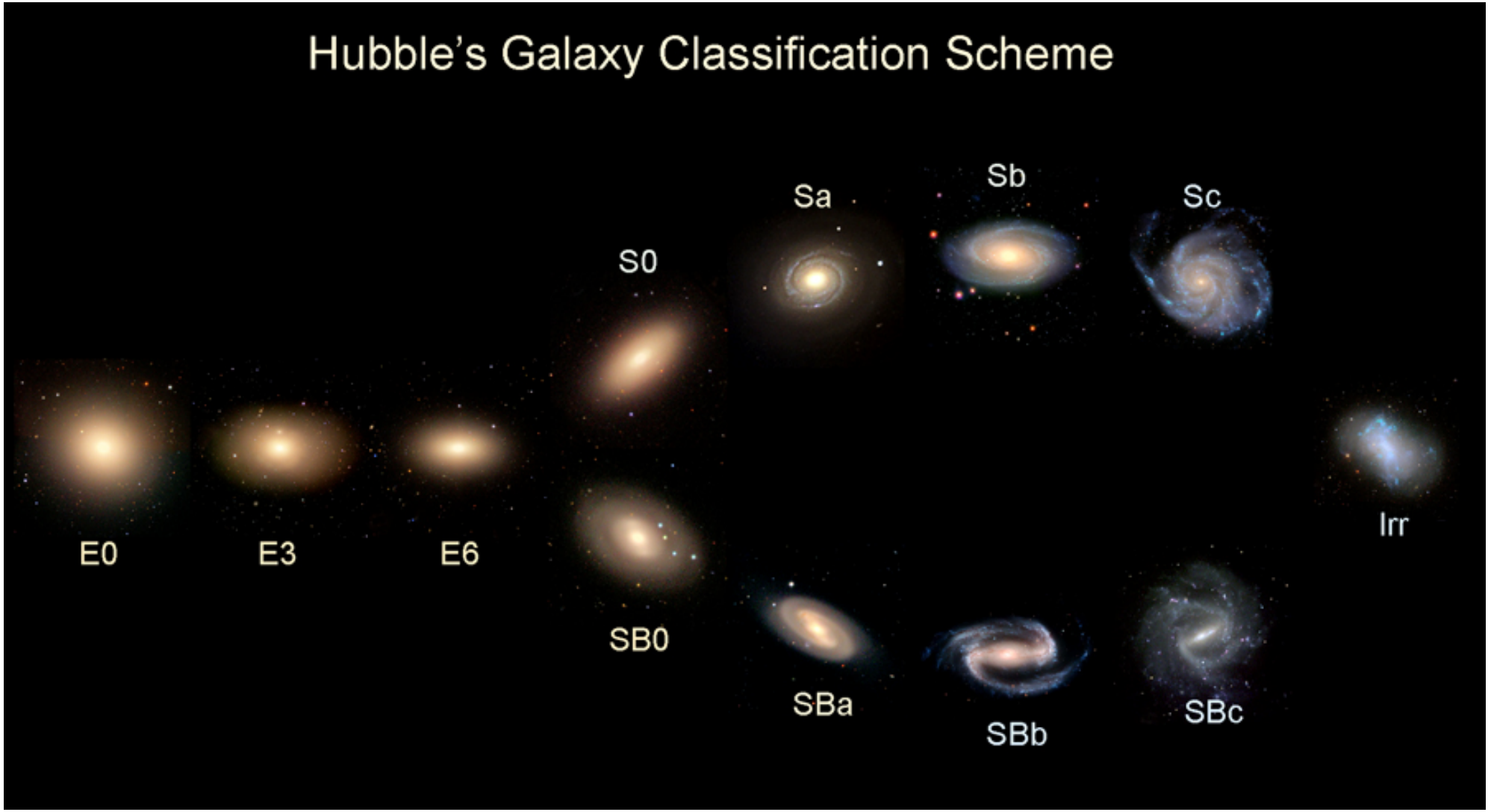

Astro
Cruise

The nature of nebulae: The Shapley-Curtis debate (1920)



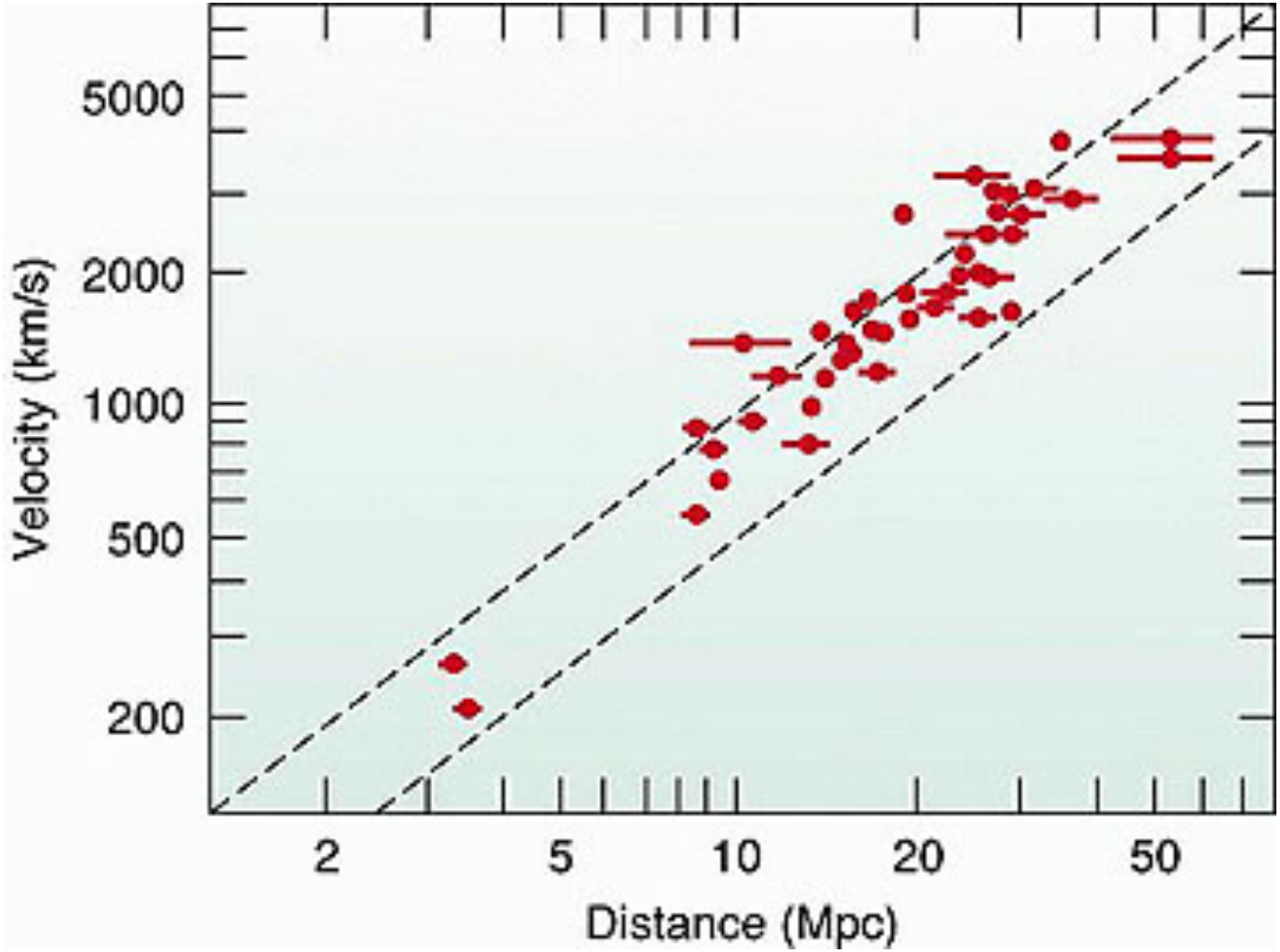
Edwin Hubble settled the Great Debate in 1923.



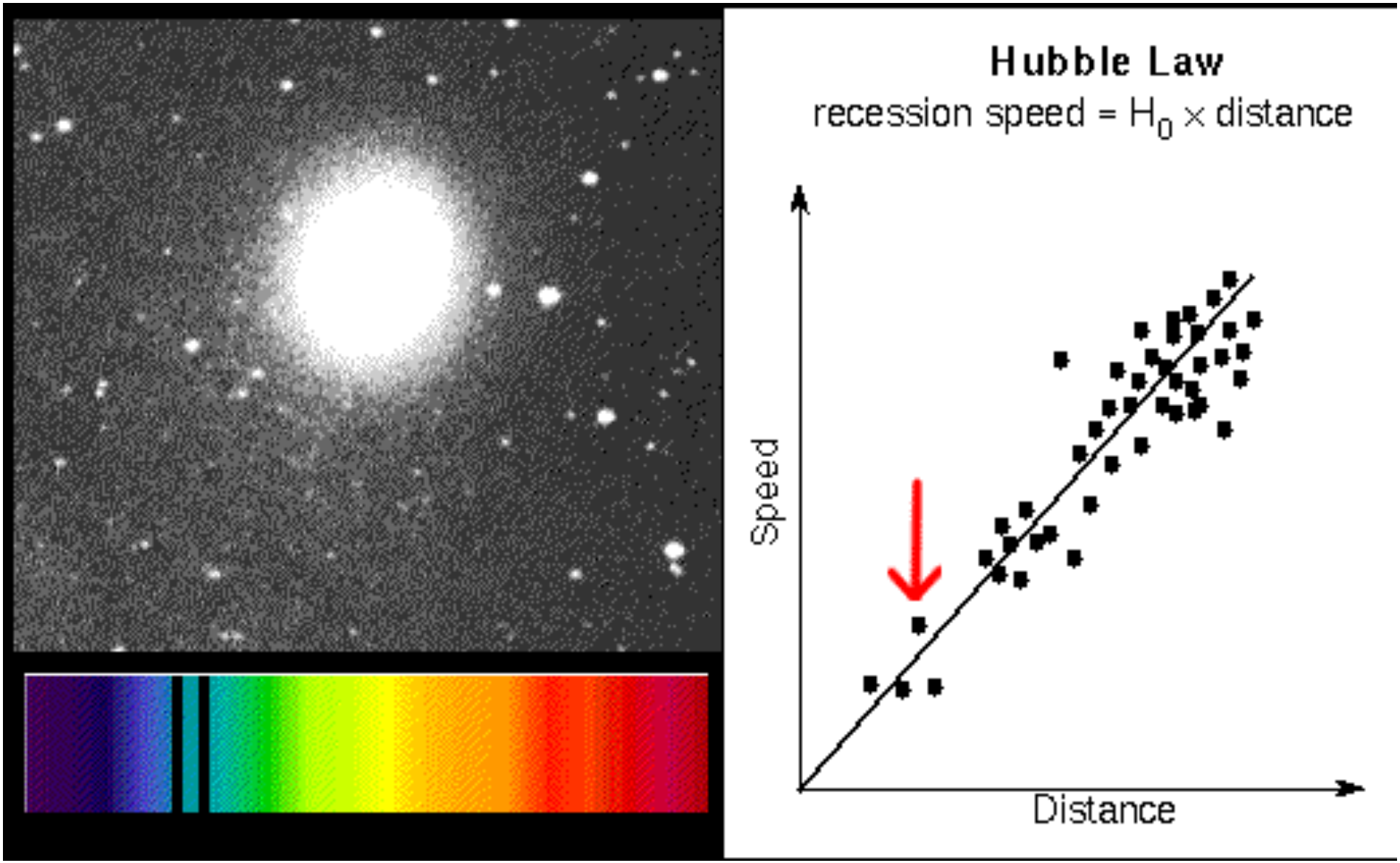

Hubble's Galaxy Classification Scheme
E0
E3
E6
S0
Sa
Sb
Sc
SB0
SBa
SBb
SBc
Irr

The Hubble Law

V (km/s) = H (km/s/Mpc) x D (Mpc)

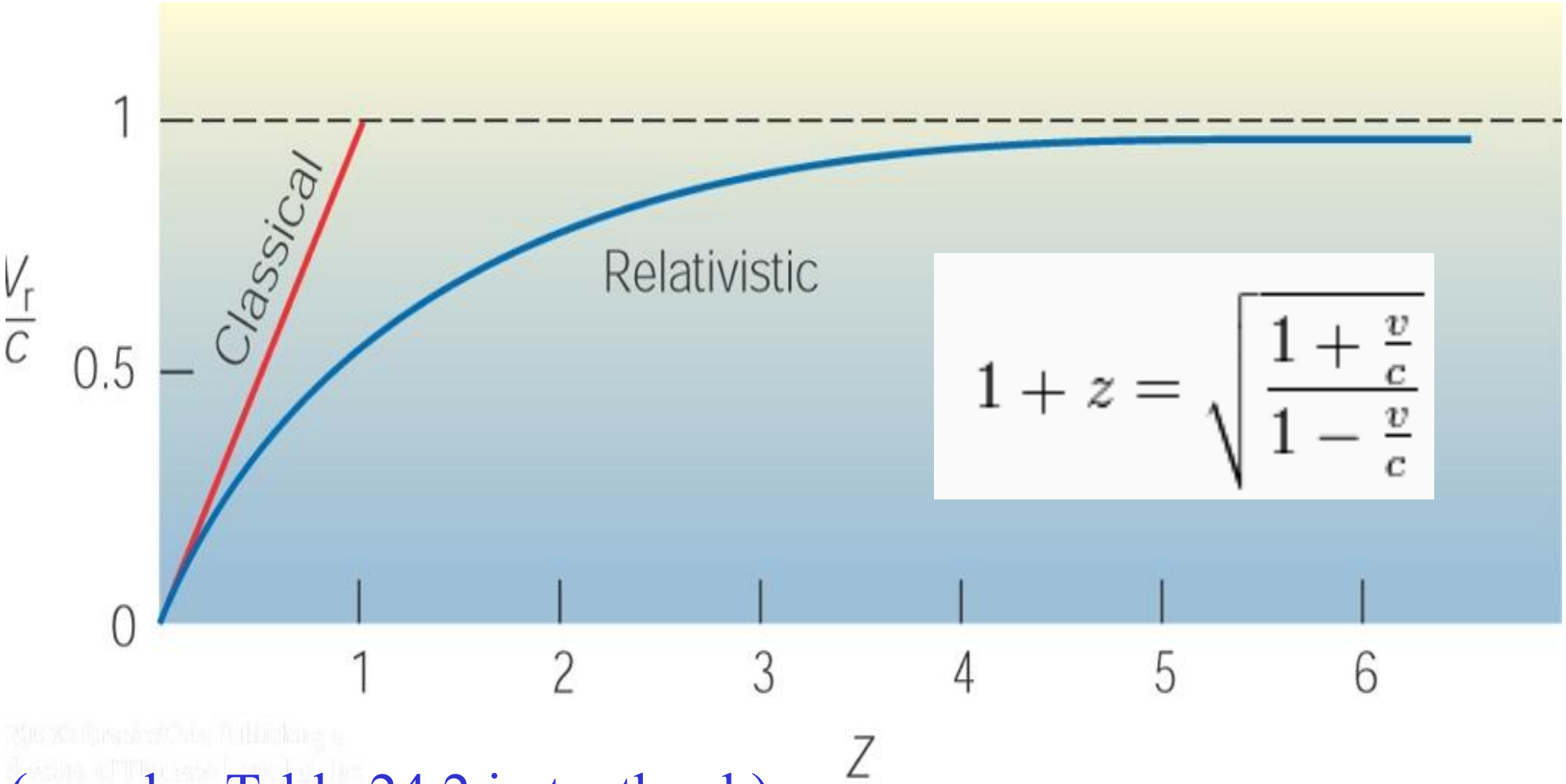


Where H is a constant that describes the gradient of the slope, and is called the Hubble constant (km/s/Mpc).


Hubble Law
recession speed = $H_0 \times$ distance
Speed
Distance

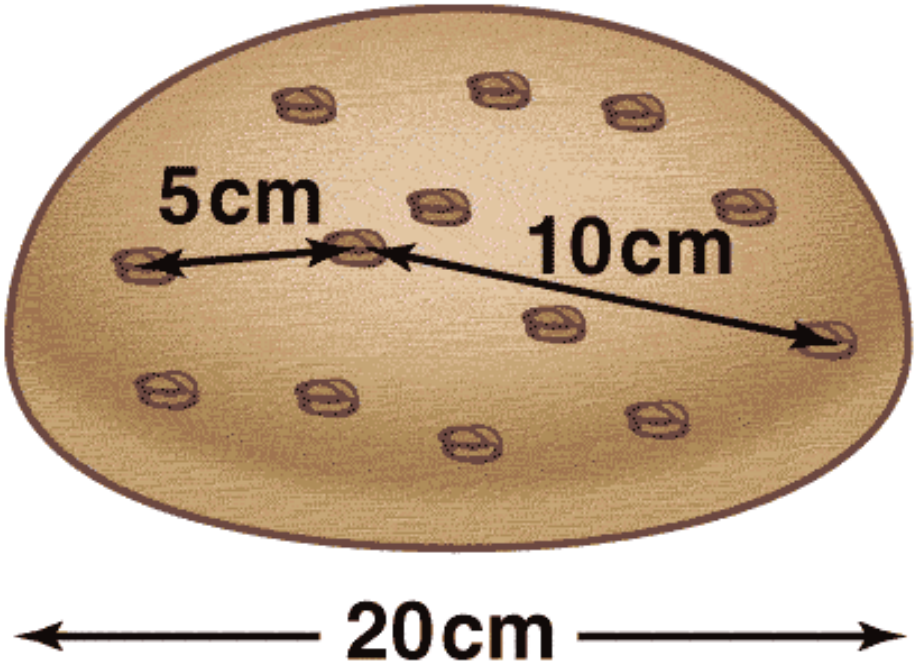
Redshift

$$\frac{\text{Change in wavelength}}{\text{Original wavelength}} = \frac{\text{velocity}}{\text{light speed}} = \frac{\Delta\lambda}{\lambda_0} = \text{redshift} = z$$



(see also Table 24.2 in textbook)

Implication of Hubble law - the Universe is expanding!



MAP990404

Example: A galaxy has its H alpha line shifted from 656 nm to 664 nm, what is the distance to the galaxy, assuming H = 70 km/s/Mpc?

Using Doppler equation: $\frac{v}{c} = \frac{\Delta\lambda}{\lambda_{rest}}$

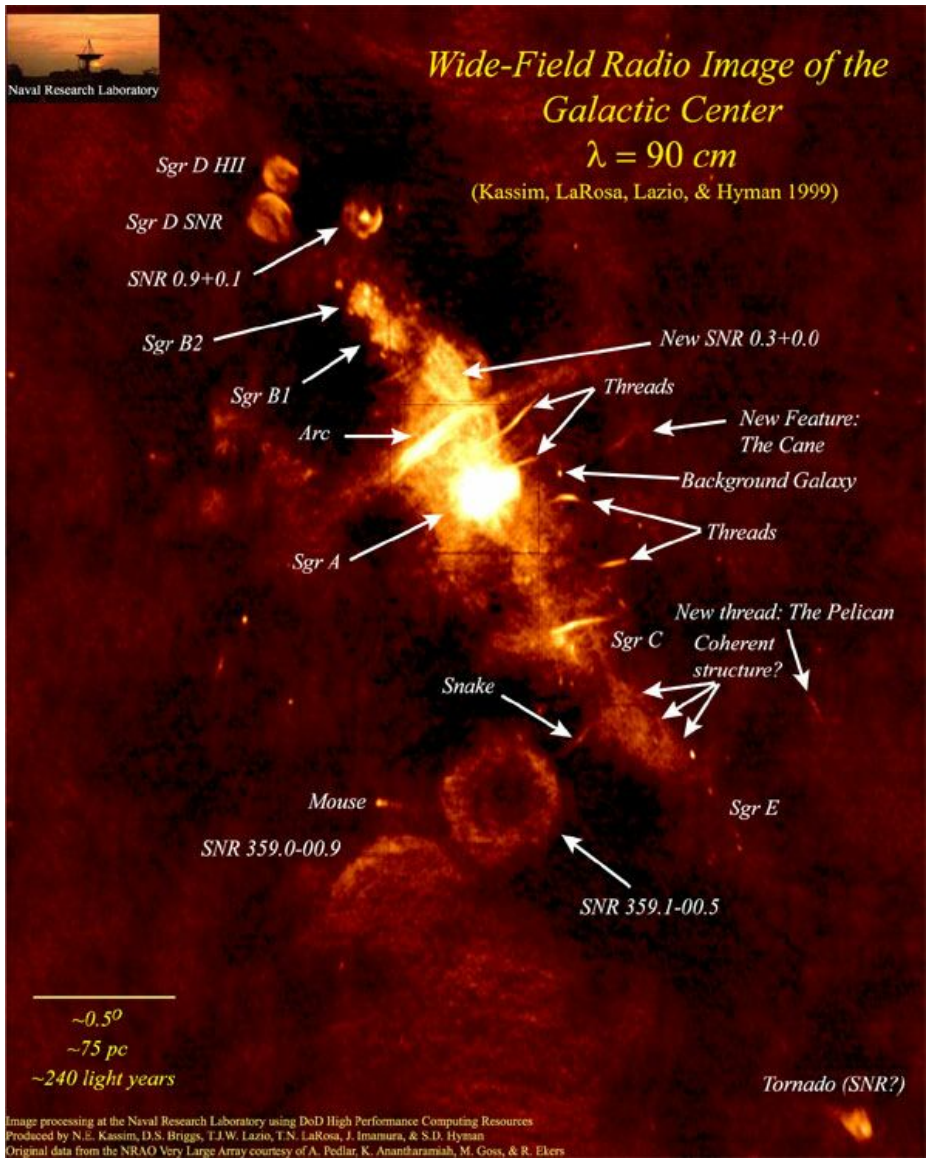
$\frac{664-656}{656} \times 3 \times 10^5 = 3.66 \times 10^3$ km/s

$V = Hd$

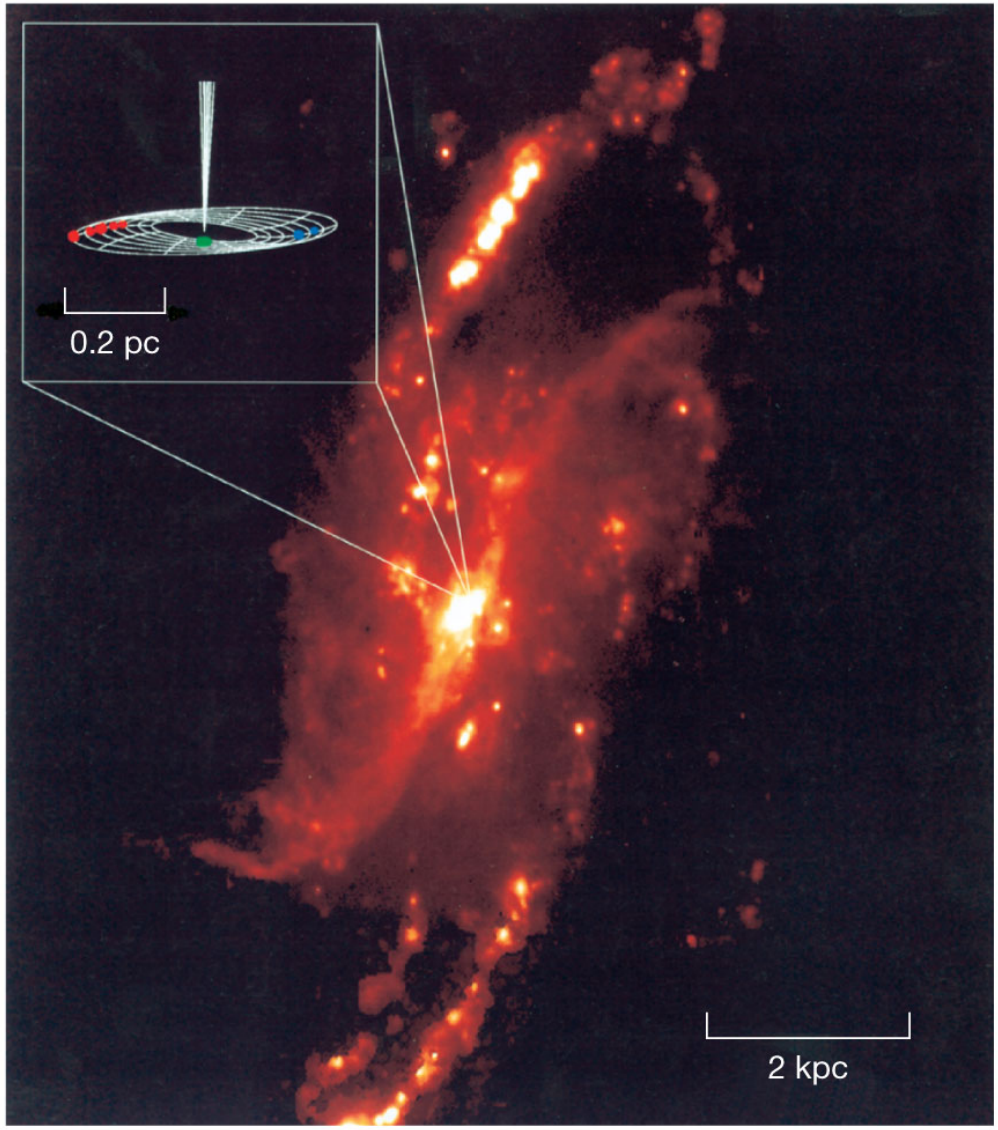
$D = 3.66 \times 10^3 / 70$

$= 52$ Mpc

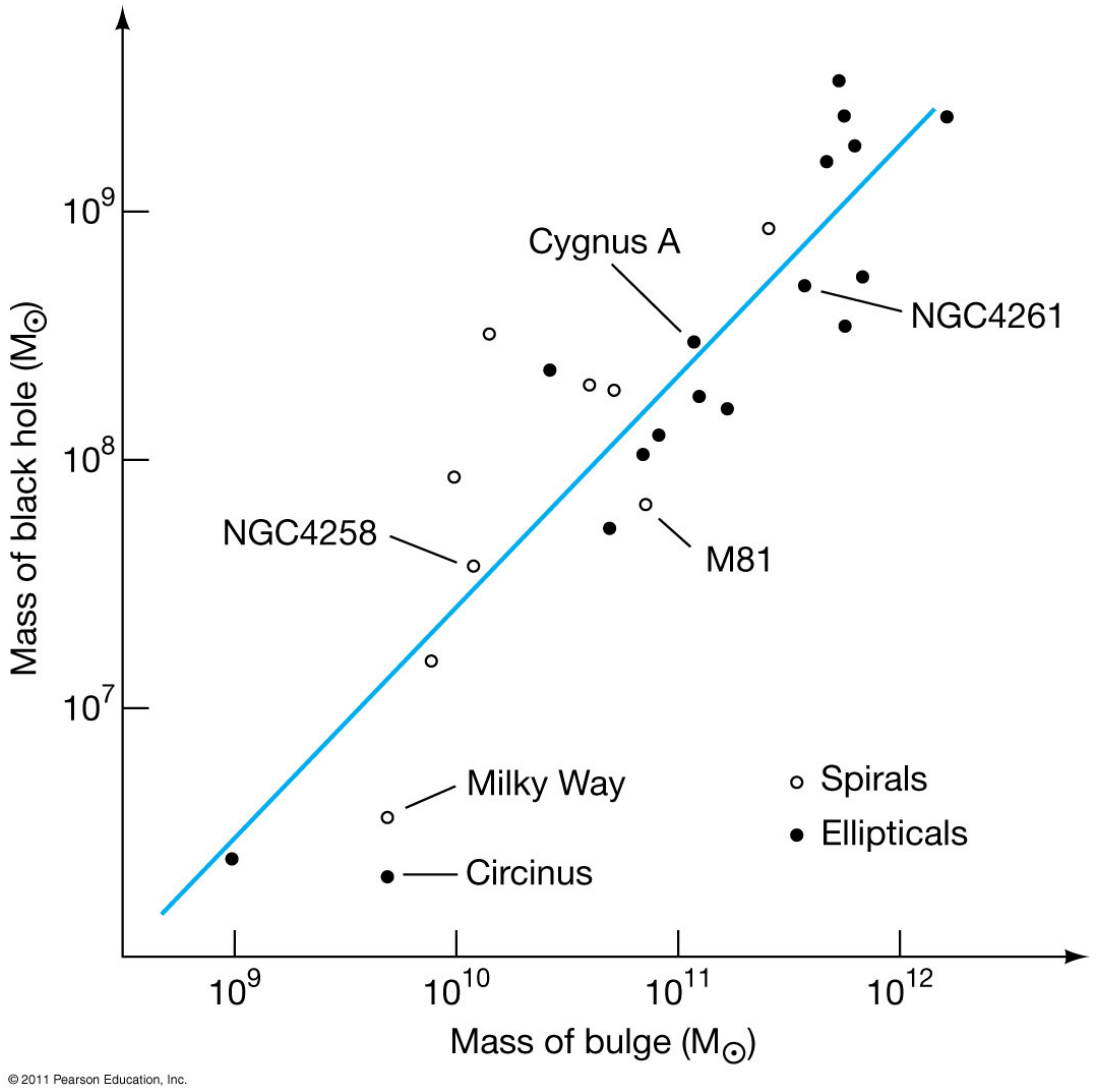
Central supermassive black holes



Structure around Galactic centre



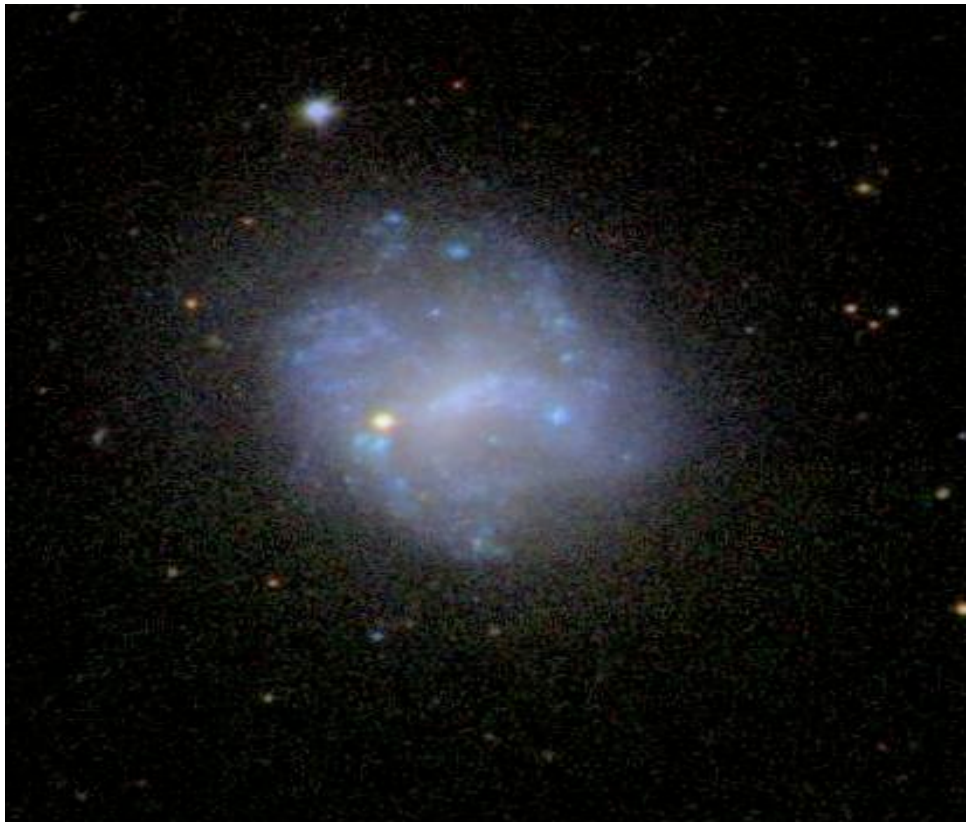
Gas disk at centre of spiral NGC 4258



All (massive) galaxies have central supermassive black hole whose mass is proportional to the mass of the stars in the bulge - remarkable!

Low mass galaxies which don't have bulges shouldn't have black holes, but…

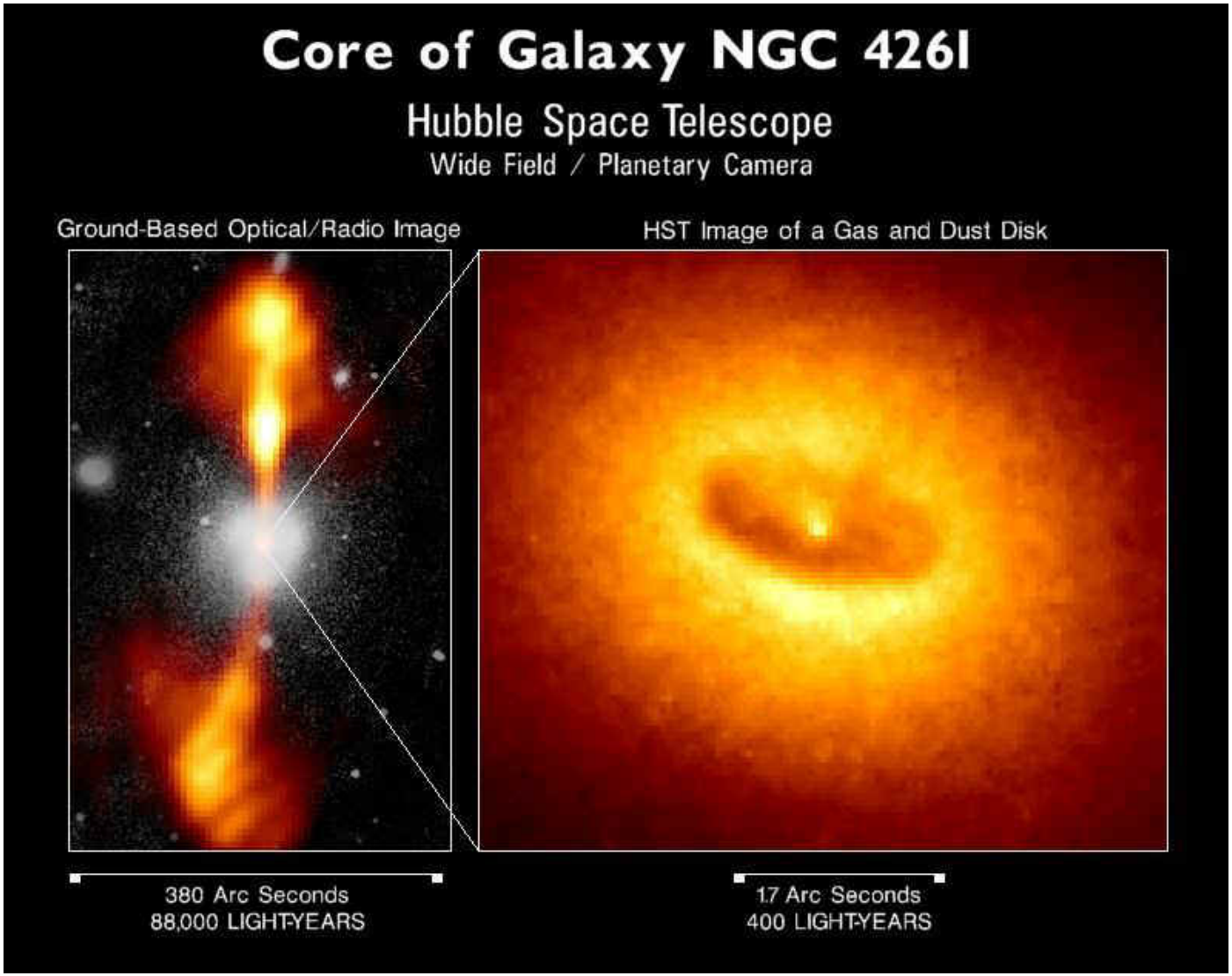
This dwarf has a 2 million solar mass BH.



This bulgeless galaxy has clear signs of nuclear activity.

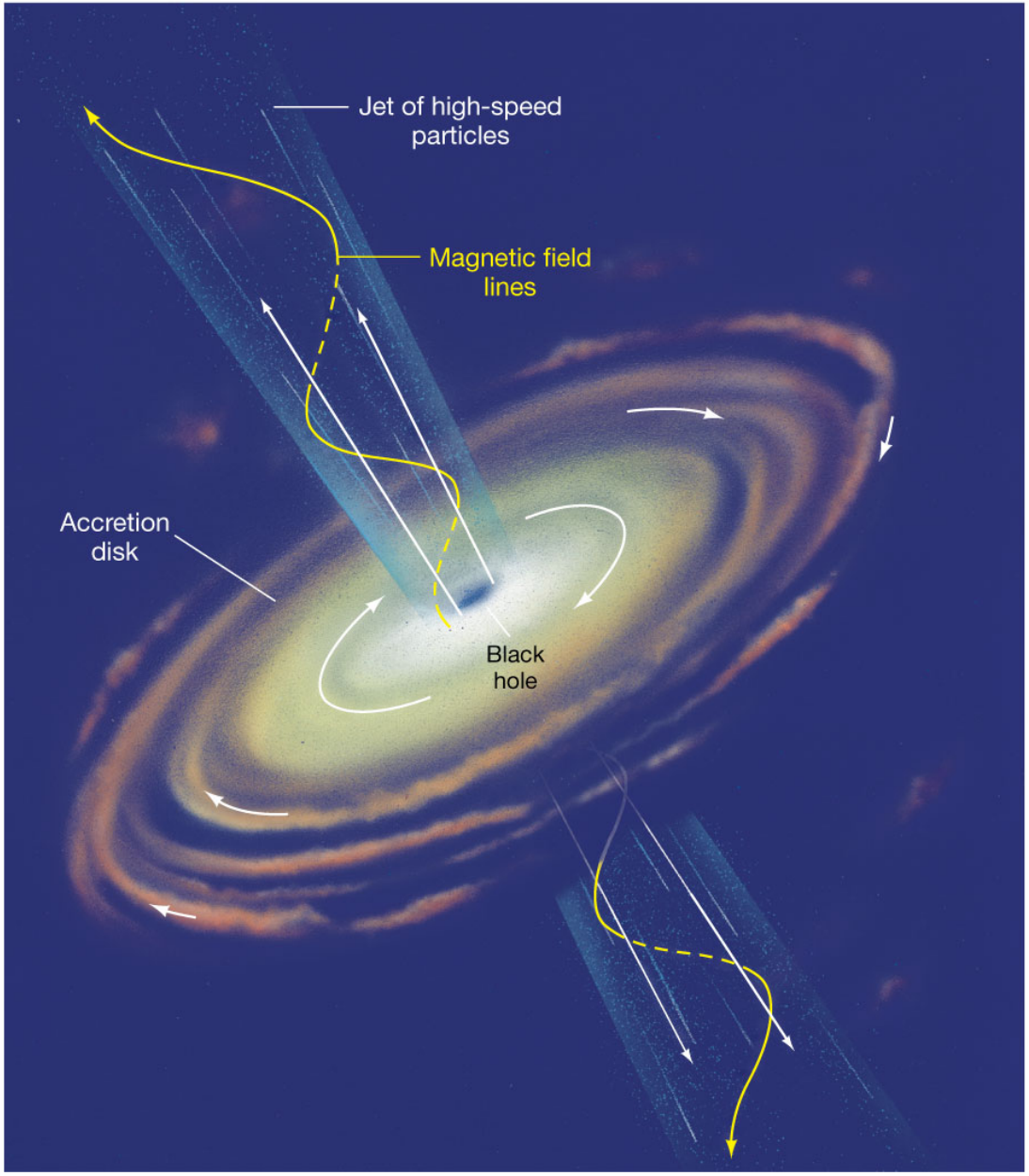
Nuclear star clusters as seed black holes?

Active galaxies - when the black hole gets fed

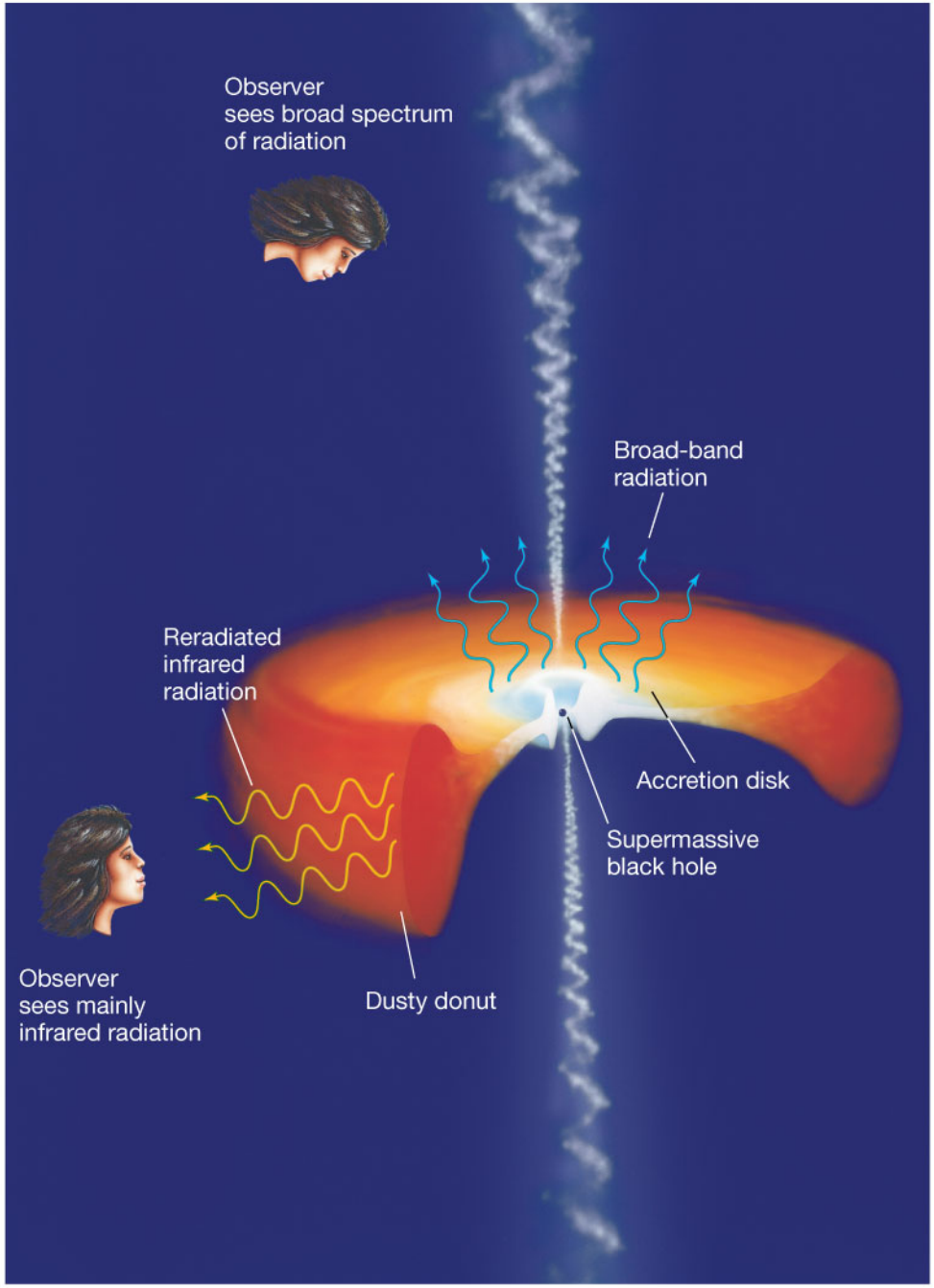


Galaxies in which the black hole is "switched on" and producing large amounts of energy are referred to as active galaxies, and the cores themselves are called active galactic nuclei (AGN).

AGN fuelling: accretion disks. Processes in the accretion disk/jet makes black hole "visible".

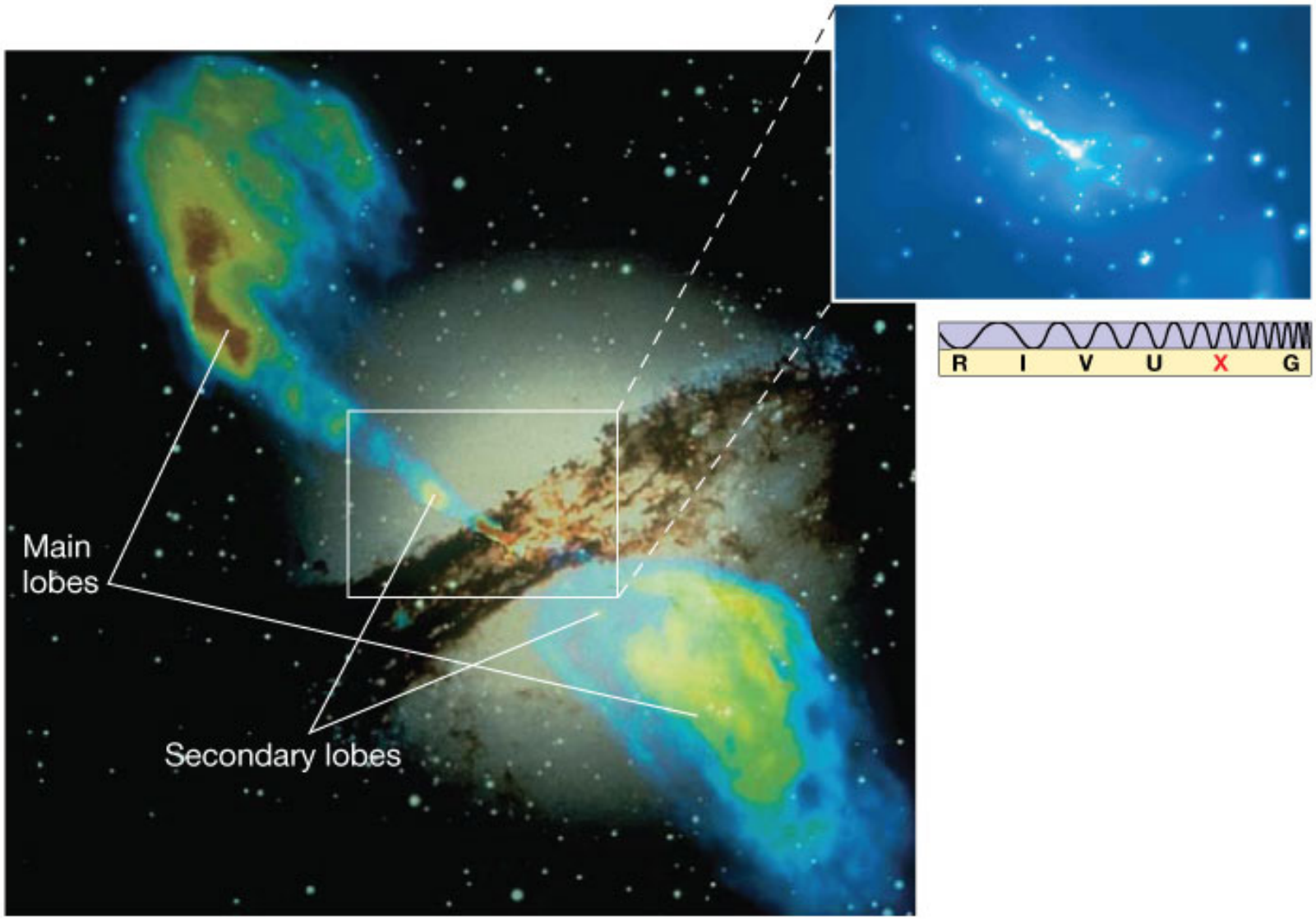


The “unified model”



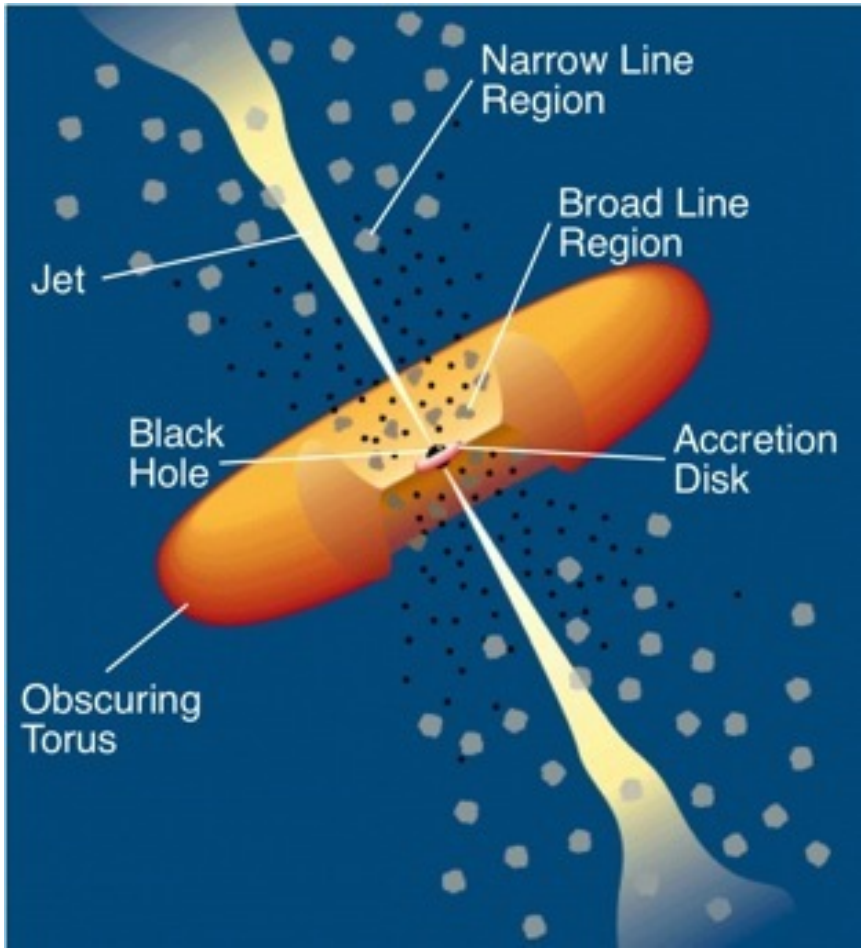
AGN detection methods: Radio jets, most common in massive ellipticals, “radio galaxies”.

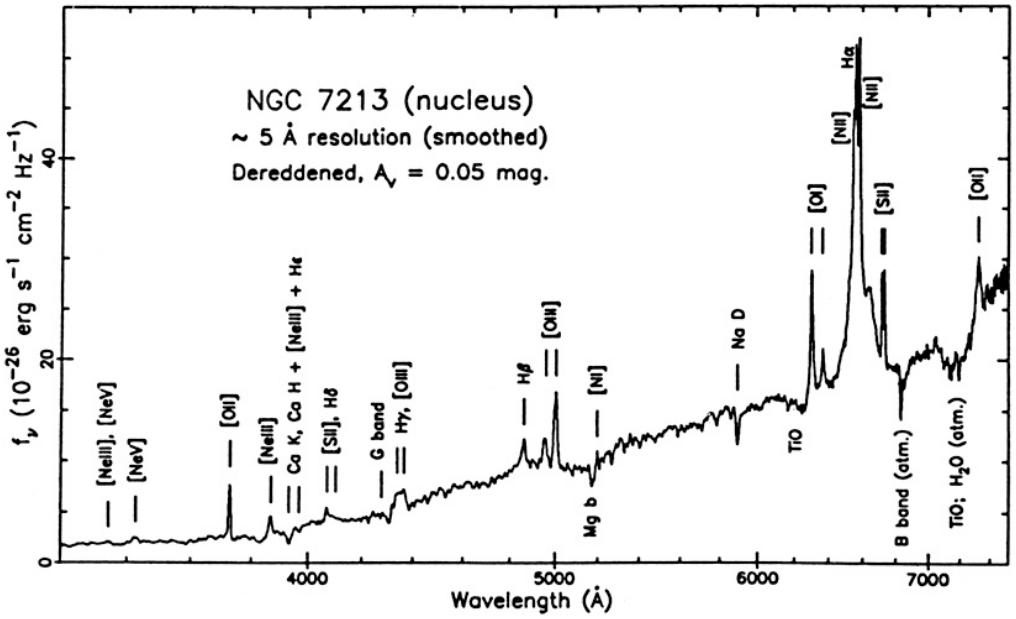
AGN detection methods: X-ray emission detected around accretion disk.



(b)

AGN detection methods: spectroscopy of broad emission lines:

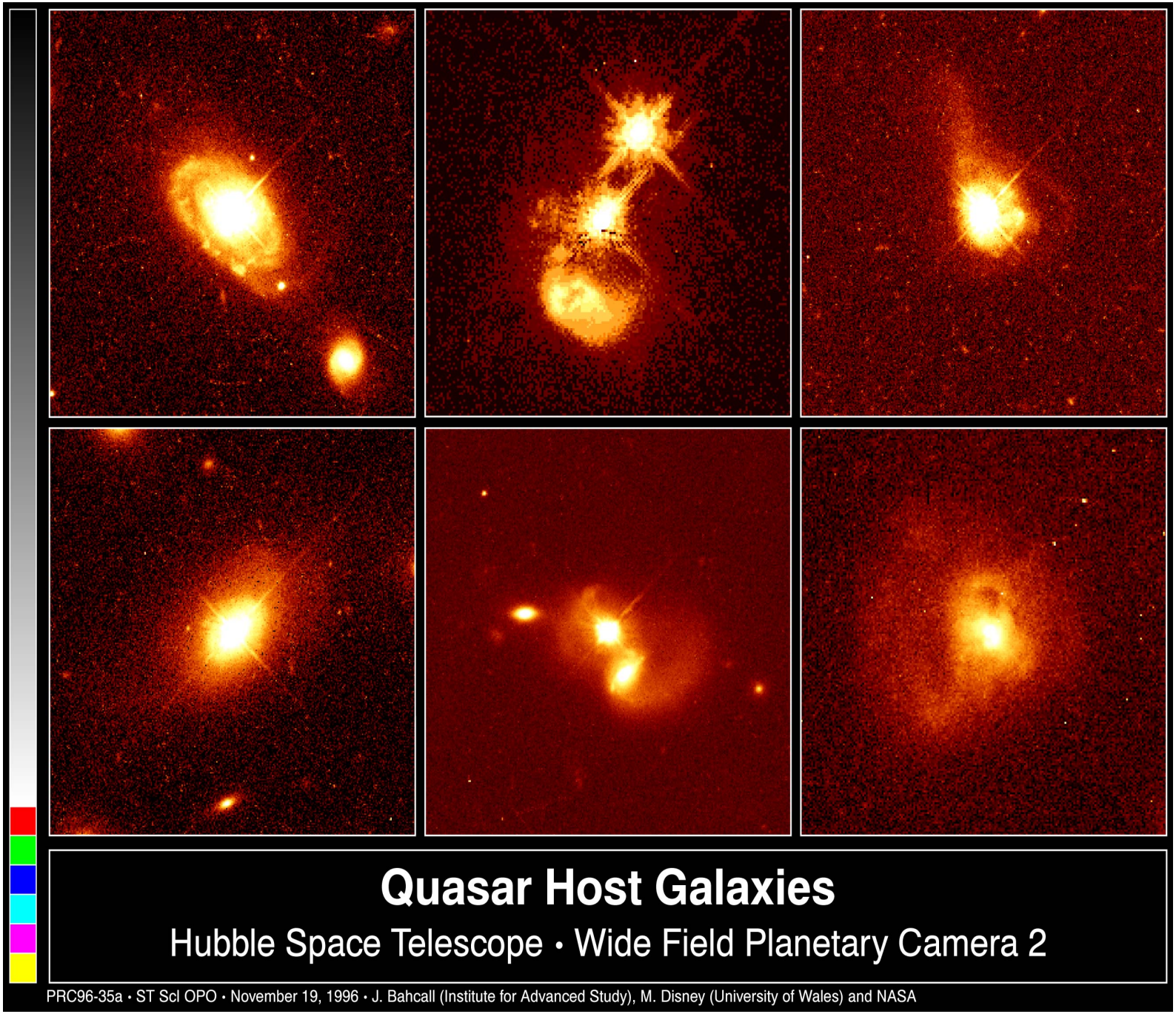


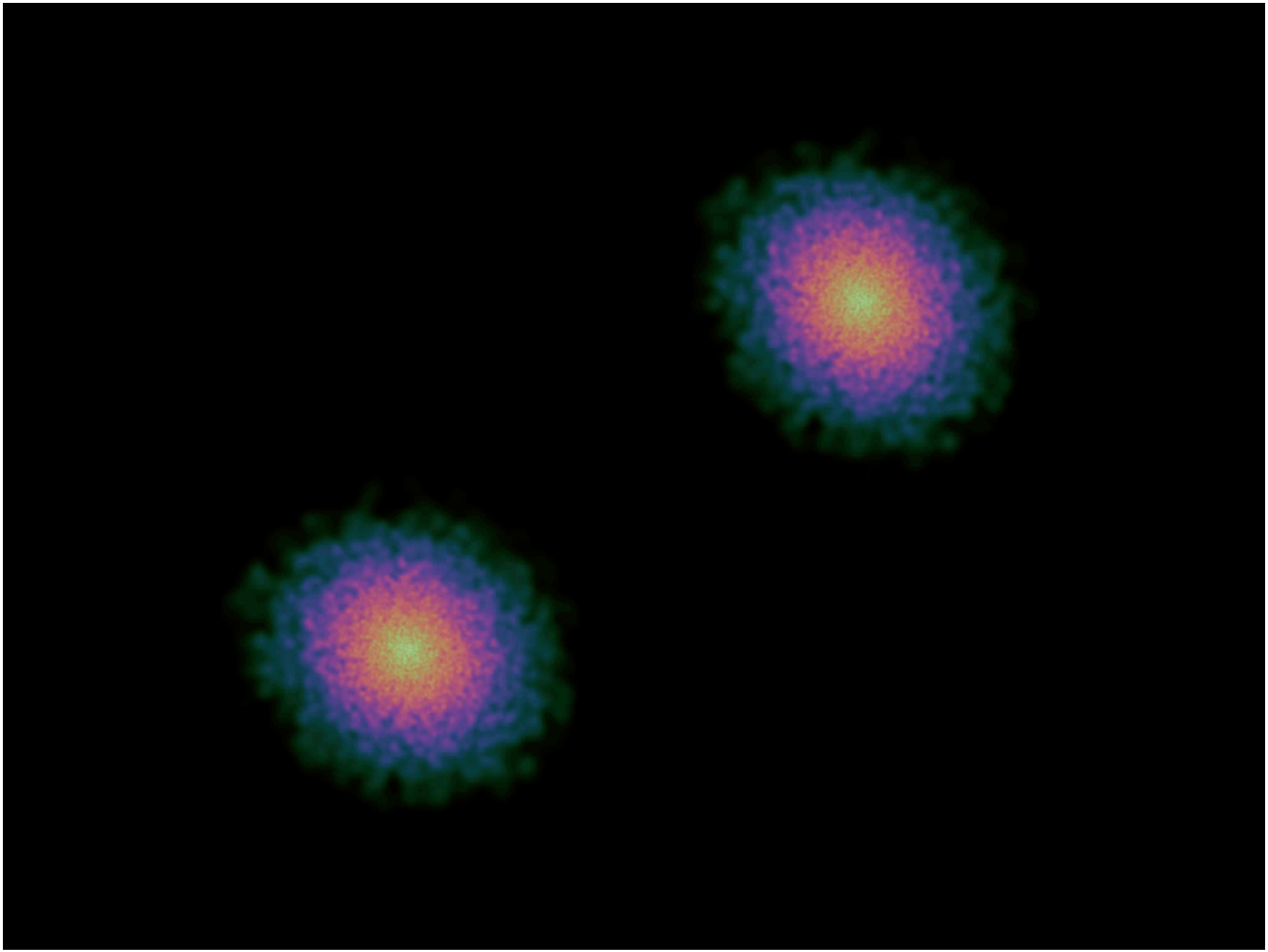


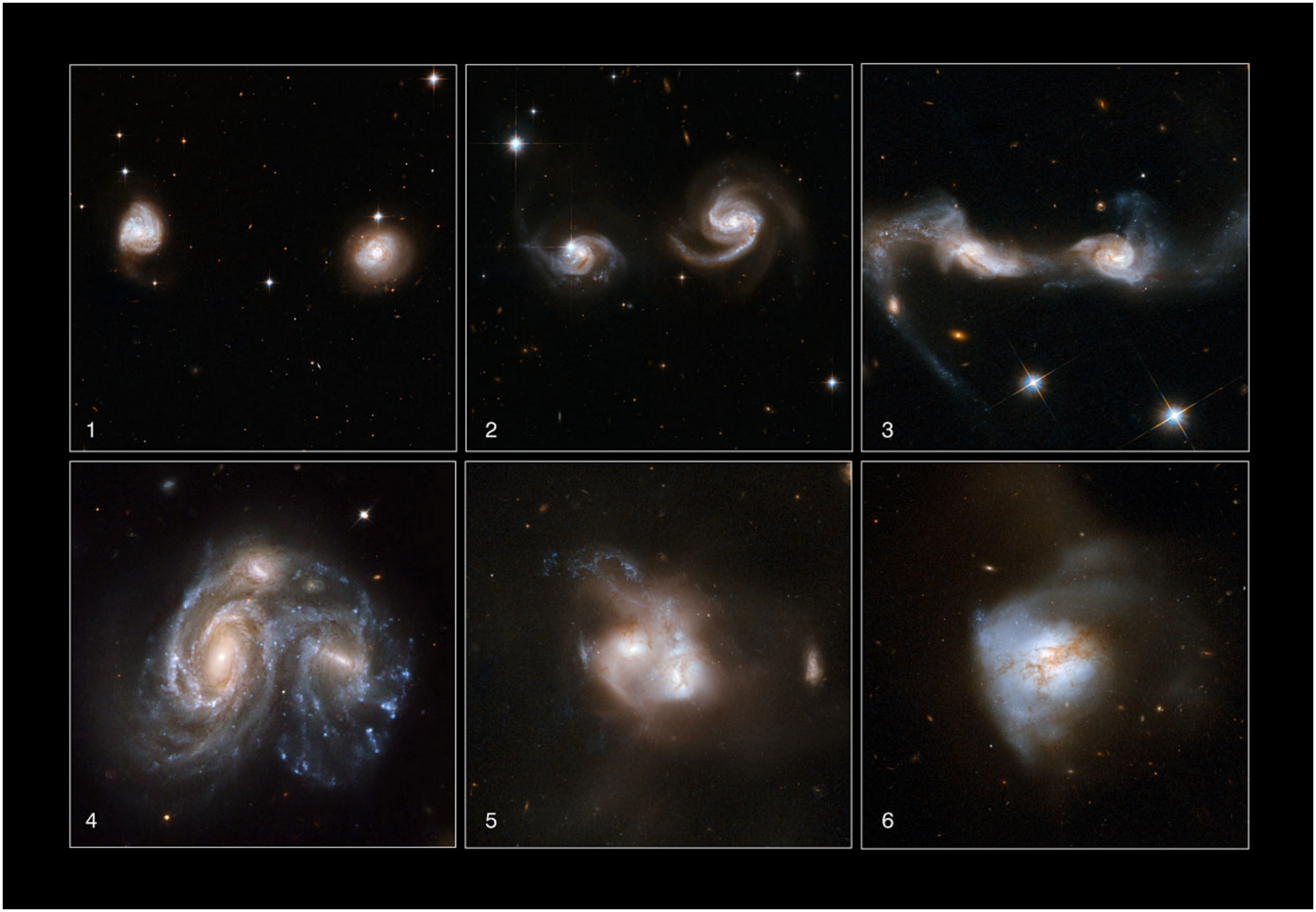
Why are lines broad in this region?

Not all AGN are in massive ellipticals, they can also be found in spirals, where they tend to be classified as lower luminosity Seyfert galaxies.

Quasars - a clue to what switches black holes on.



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2
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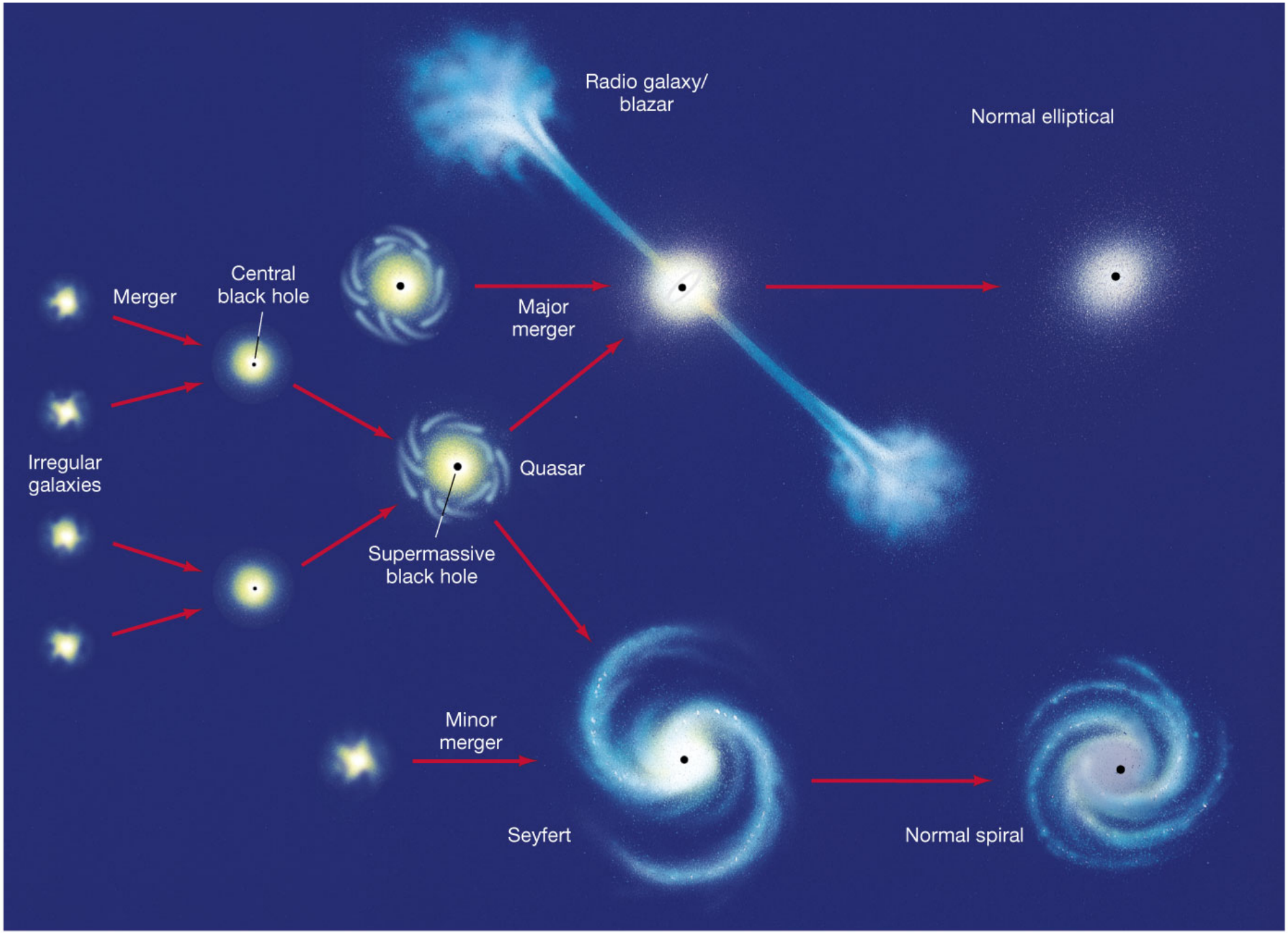
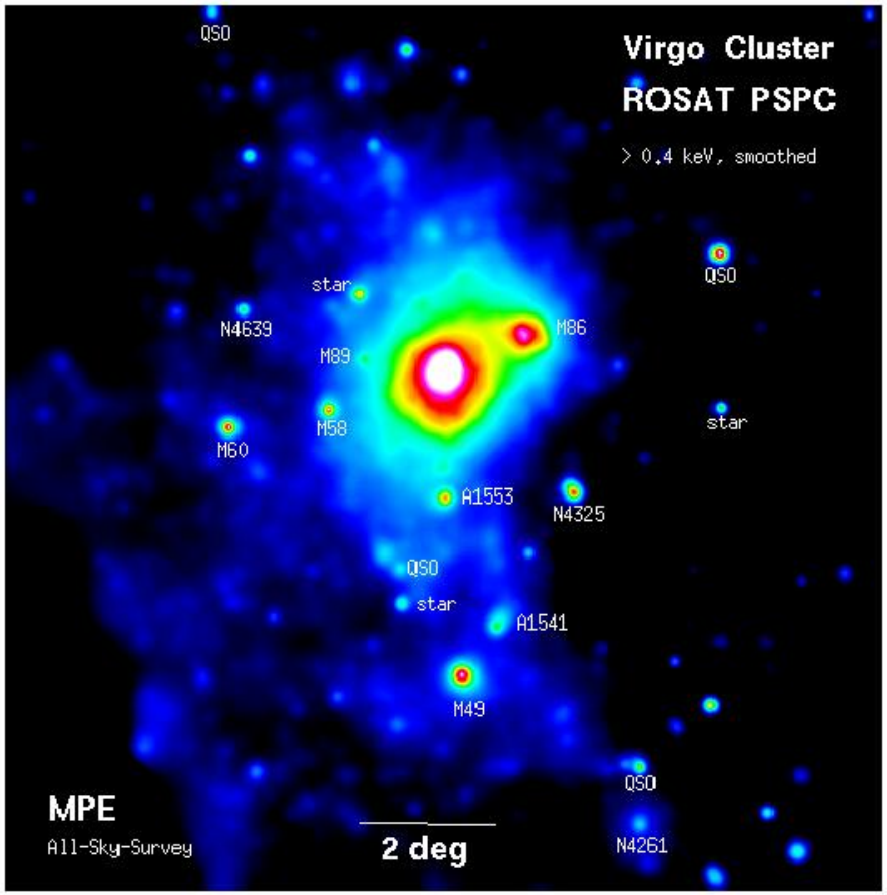
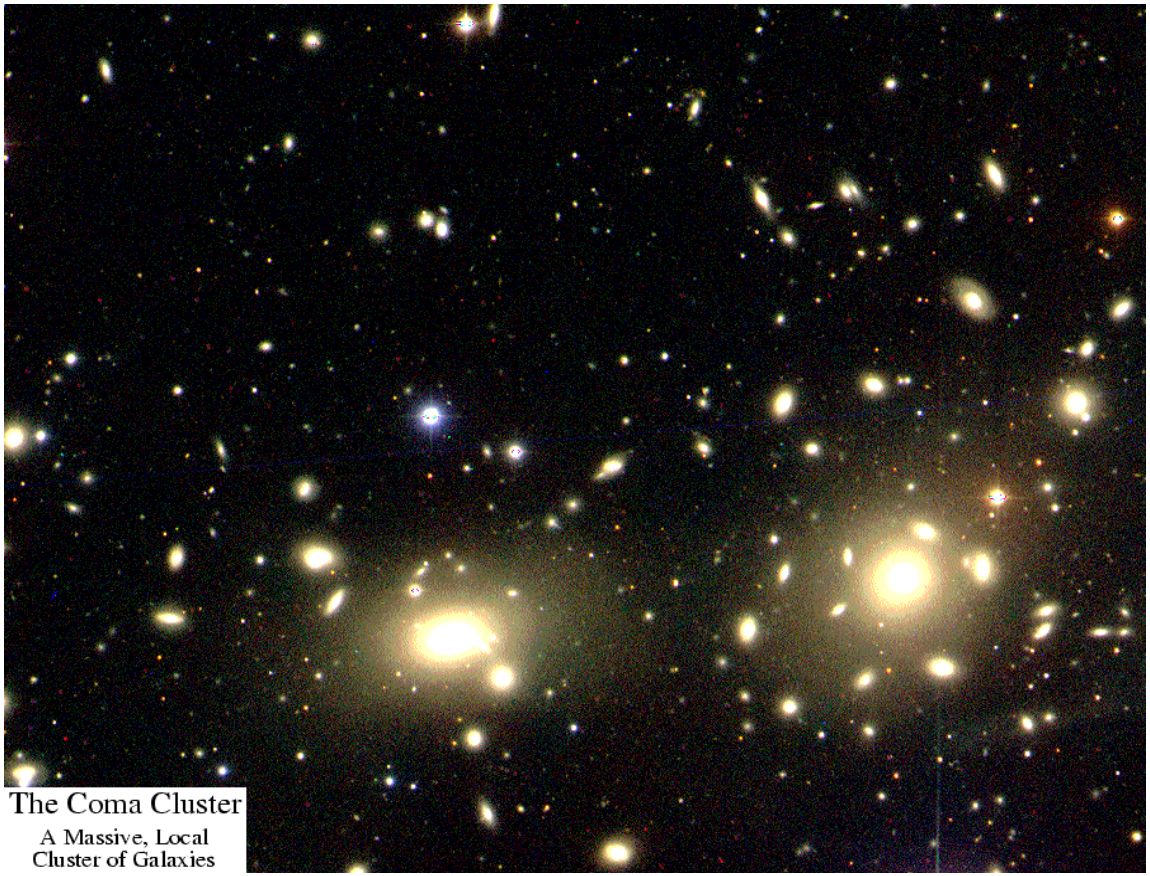


Galaxy Clusters and Large Scale Structure

Local Group of galaxies has 2 big spirals (Milky Way and Andromeda), the two Magellanic Clouds (Large and Small) and about 50 other galaxies spanning 10 million light years (3 Mpc).

Galaxy Clusters





The Coma Cluster
A Massive, Local
Cluster of Galaxies

Something fishy in the Coma cluster (Zwicky 1933)

Distance to Coma ~ 100 Mpc
Angular size ~ 0.5 deg.
Apparent mag ~ +9 mags

$$\text{Diameter} = \frac{0.5 \times 3600 \times 100}{206265}$$

Diameter ~ 1 Mpc

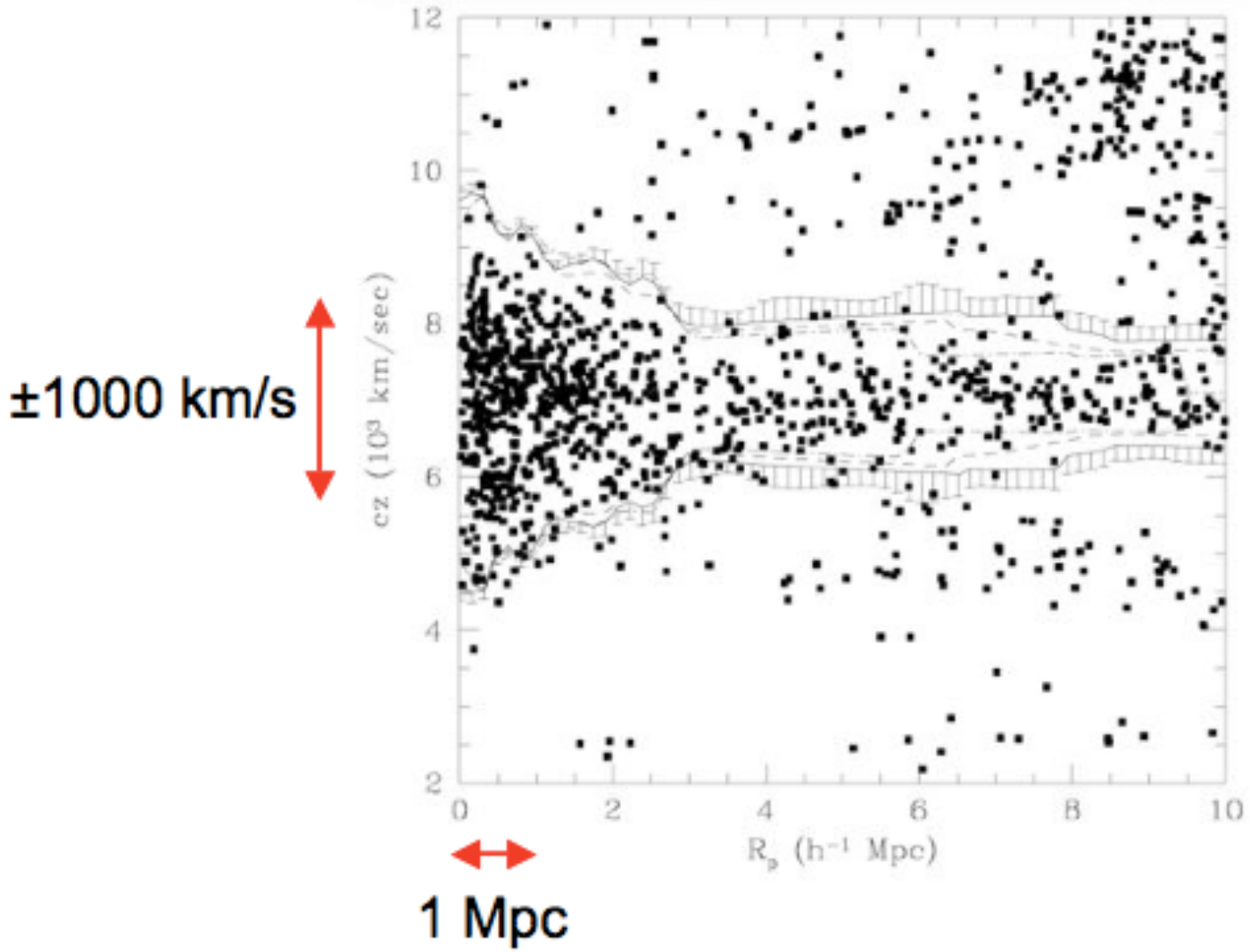
Absolute magnitude of Sun ~ 5 , so apparent mag of Sun at 100 Mpc:
$m = -5 + 5 \log(1e8) + 5 = 40$
Coma is 31 mags brighter than Sun: $2.5^{31} = 2.5 \times 10^{12}$ times brighter!

Luminosity of Coma cluster is ~ 2.5×10^{12} solar luminosities, so probably contains about 2.5×10^{12} stars (average stellar mass is about 1 solar mass).

Galaxy radial velocities in Coma have a dispersion (spread) about 1000 km/s within 1 Mpc.

$$\frac{GMm}{r^2} = \frac{mv^2}{r}$$

$$\rightarrow M \sim \frac{v^2 r}{G}$$



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$$\frac{GMm}{r^2} = \frac{mv^2}{r}$$

$$\rightarrow M \sim \frac{v^2 r}{G}$$

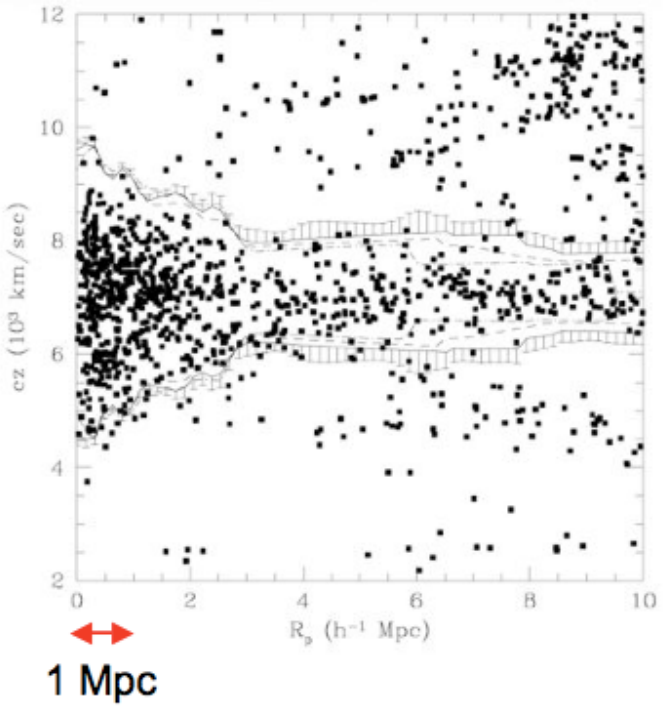
V (1000 km/s) in m/s

R (1Mpc) in m

$$M = \frac{(1e6)^2 \times 3.08e12}{6.67e\ -11}$$

$$= 4.6e44 \text{ kg}$$

$$\sim 2.5 \times 10^{14} \text{ solar masses}$$



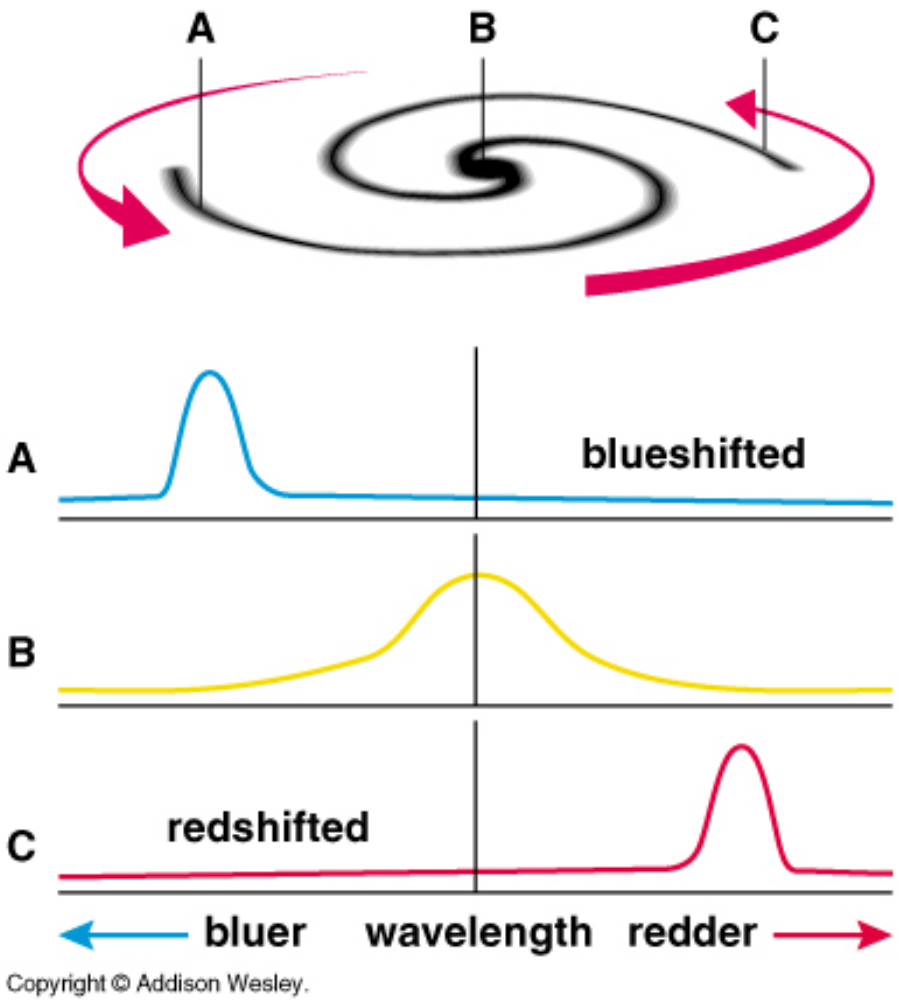
For each solar mass, expect a solar luminosity but for Coma:

$$\frac{2.5 \times 10^{14} \text{ solar mass}}{2.5 \times 10^{12} \text{ solar luminosities}}$$ = 100 times more mass than light!

(accurate virial theorem treatment gives x400)

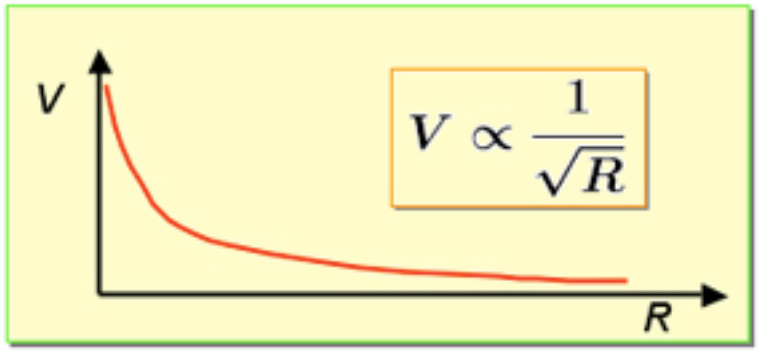
First evidence of dark matter largely ignored for 40 years!!

Dark Matter Inferred from Galaxy Rotation Curves



Measure velocity from Doppler shift as a function of radius. From equating gravity and centripetal forces:

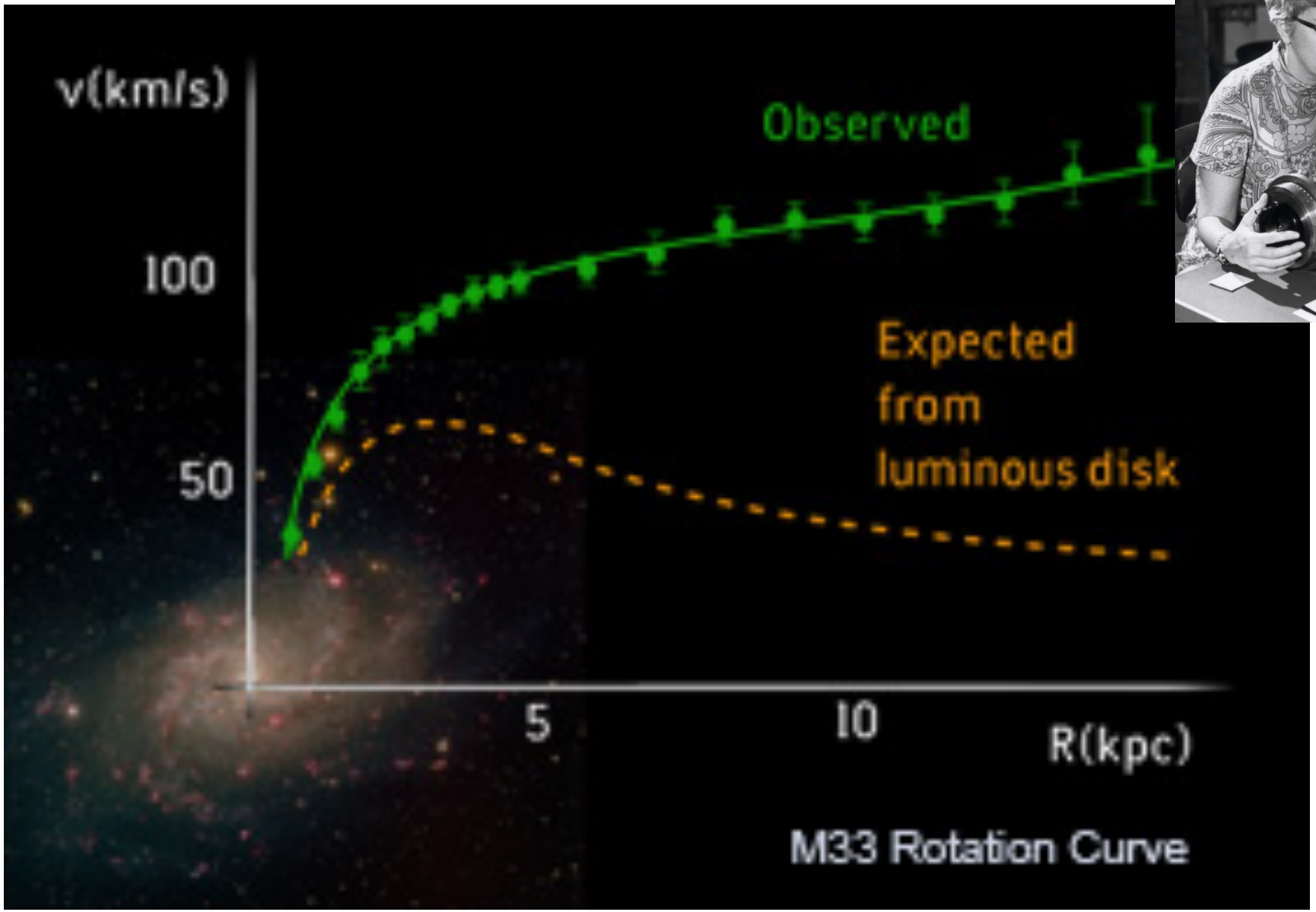
$V^2 = GM/R$

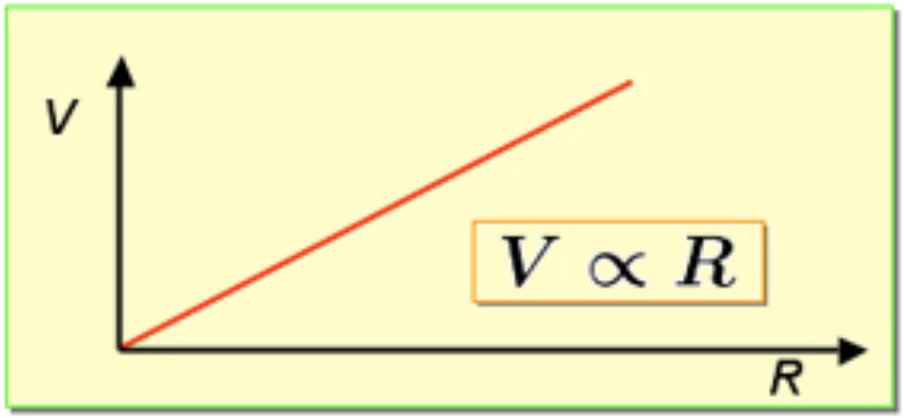


Kepler's 3rd law also predicts $V^2 \propto 1/R$

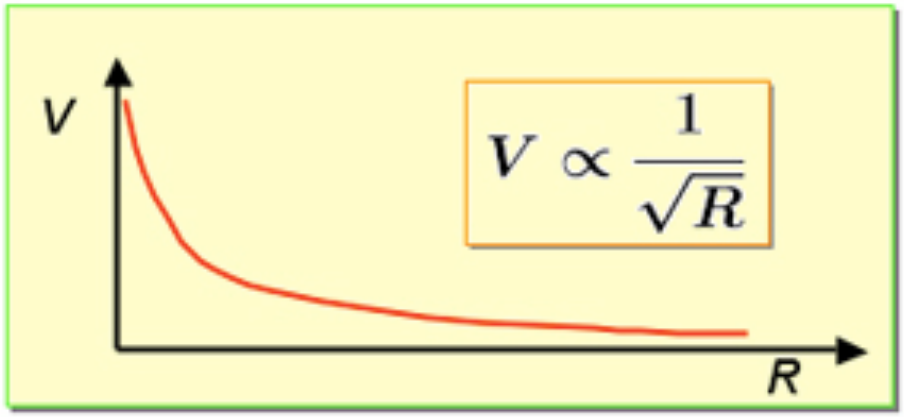
Actual rotation curves are flat (constant velocity beyond stellar disk), or even rising!!

Vera Rubin c1970

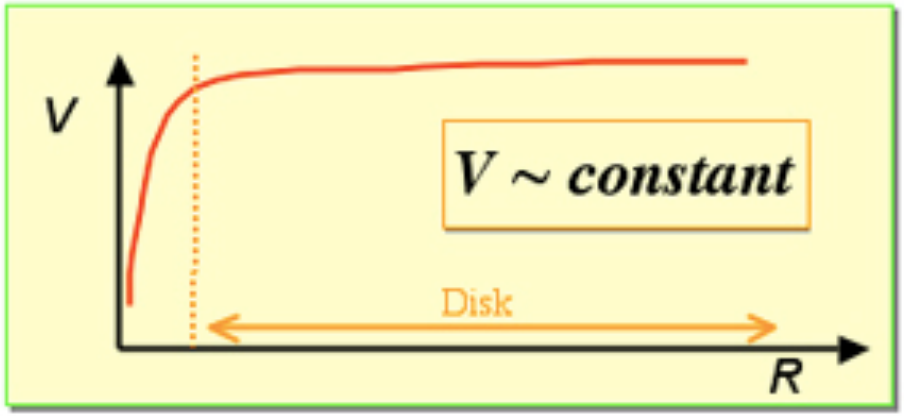




Solid Body Rotation



Keplerian Rotation



Galactic Rotation

What does it mean to have constant velocity at large R?

Let M_R = mass enclosed within R,

$\rho(R)$ = density at R

$$v^2 = \frac{GM_R}{R} = \text{constant - what does this mean?}$$

Answer: $M_R \propto R$

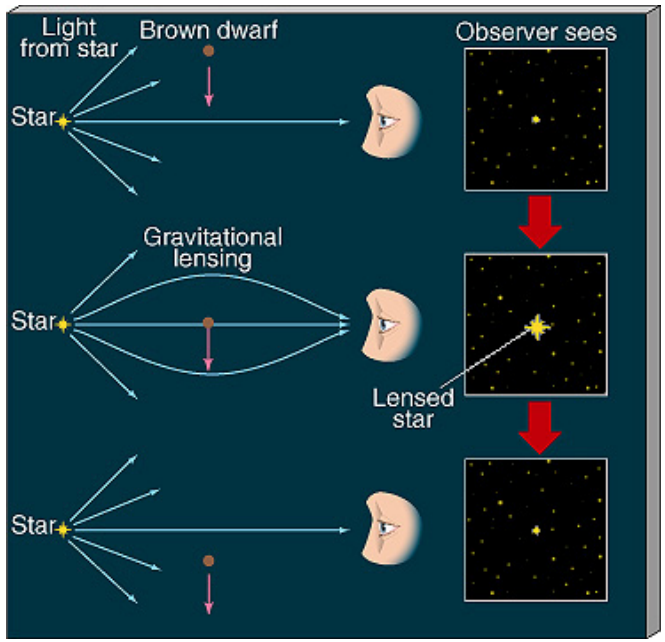
Mass keeps on increasing with radius!

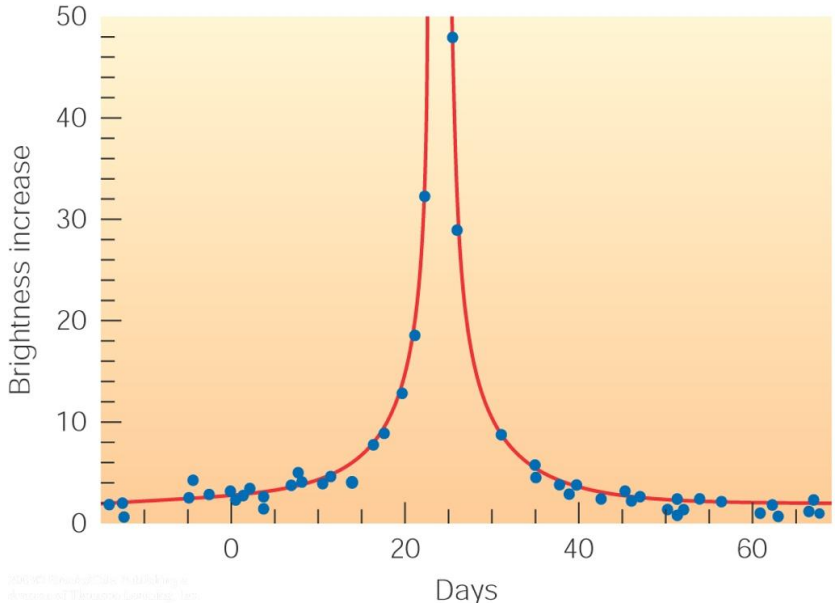
What is dark matter?

- Stars - No! Would be visible.

- Gas - No! Seen in emission (21cm, CO mm, Xray, etc.) and absorption.

- Stellar remnants (white dwarfs, neutron stars) - No! Microlensing experiments.





What is dark matter?

- Stars - No! Would be visible.

- Gas - No! Seen in emission (21cm, CO mm, Xray, etc.) and absorption.

- Stellar remnants (white dwarfs, neutron stars) - No! Microlensing experiments.

- Stellar mass BHs - No! Lensing.

- Massive BHs - No! Would see X-rays, gravitational effects.

- Exotic particles - probably, but not sure what!!

80-90% of matter in galaxies is dark!!!!