



# Galaxies

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# What are galaxies?

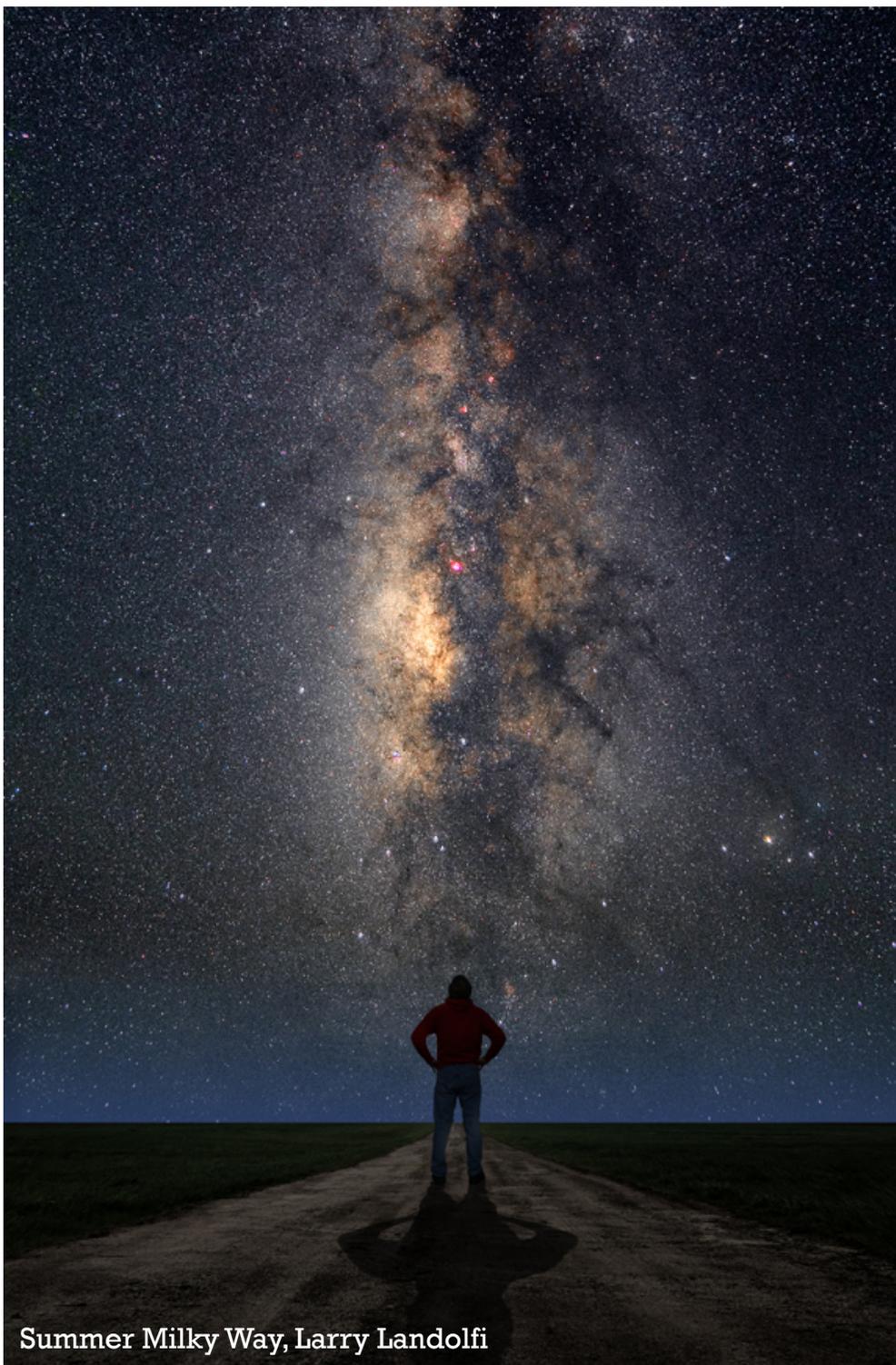
- gravitationally bound system of stars, gas, dust and dark matter;
- $10^{11}$  galaxies;
- $10^7$  to  $10^{12}$  stars;
- 10.000 to a few 100.000 lyr in size;
- usually millions of light-years apart
- elliptical, spiral, lenticular, irregular

Claudius Ptolemy  
(83-161): "... band, white as  
milk..."

"galaxias" = milky: Milky  
way

in Slovenian: Rimska cesta

Galileo Galilei (1564 – 1642)  
in 1610 with a telescope saw  
individual stars in Milky Way



Summer Milky Way, Larry Landolfi

# Great debate

- Washington, 1920 – on the size of our Galaxy



Heber Doust Curtis (1872-1942)

“other galaxies”

“Island universe hypothesis”:

- how far are spiral nebulae?
- are they made of stars or gas?
- why they avoid the plane of Milky Way?



Harlow Shapley

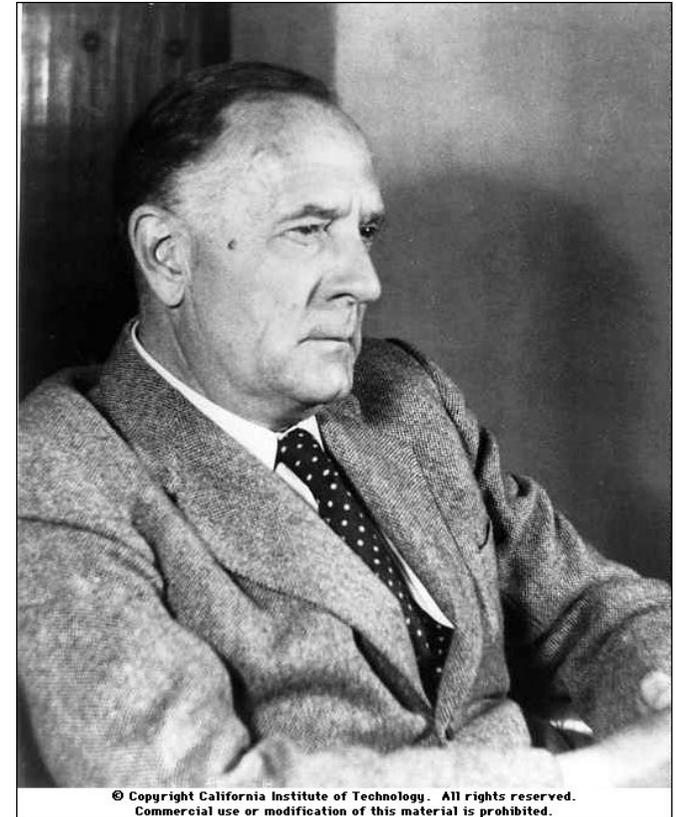
“nearby gas clouds”

# Edwin Powell Hubble (1889-1953)

1924 – used Cepheids and measured distance to Andromeda galaxy



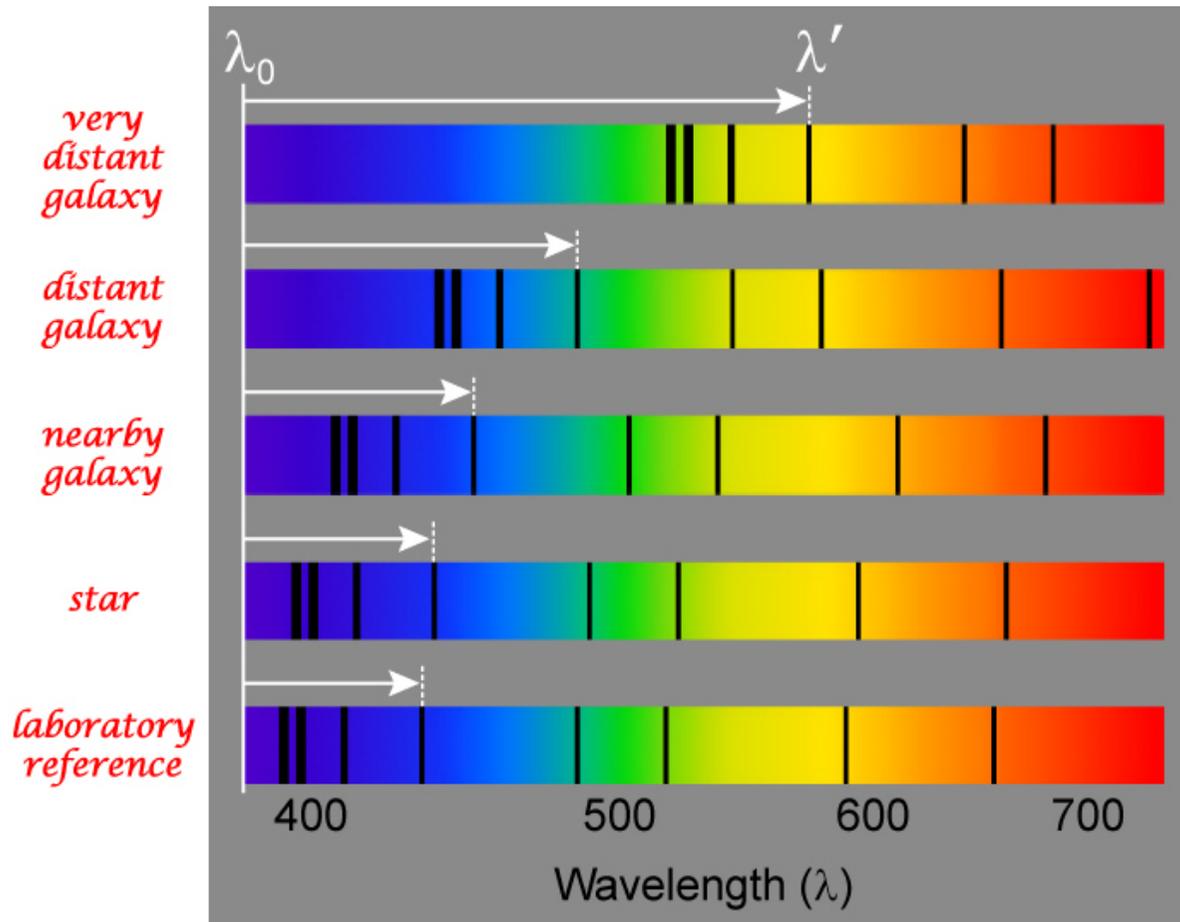
Andromeda – 2 million light-years



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other galaxies!

# spectra of galaxies

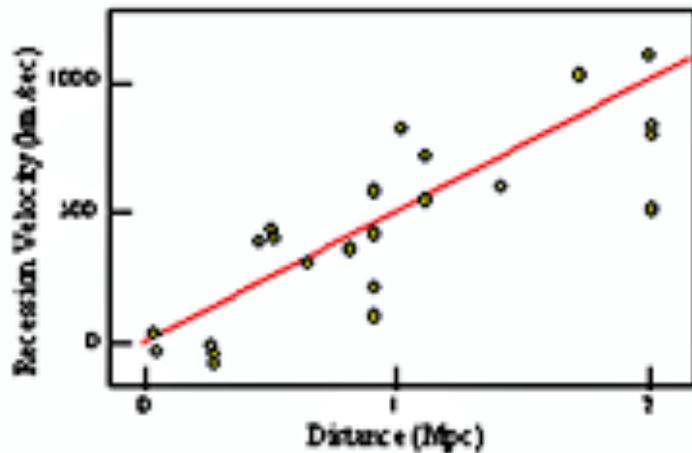


$$\frac{\lambda_{obs}}{\lambda_{em}} = \frac{\lambda_{em} + \Delta\lambda}{\lambda_{em}} = 1 + \frac{\Delta\lambda}{\lambda_{em}} = 1 + z$$

$$z = \frac{\Delta\lambda}{\lambda_{em}}$$

# Hubble's law

Hubble's Data (1929)



expansion of the  
Universe

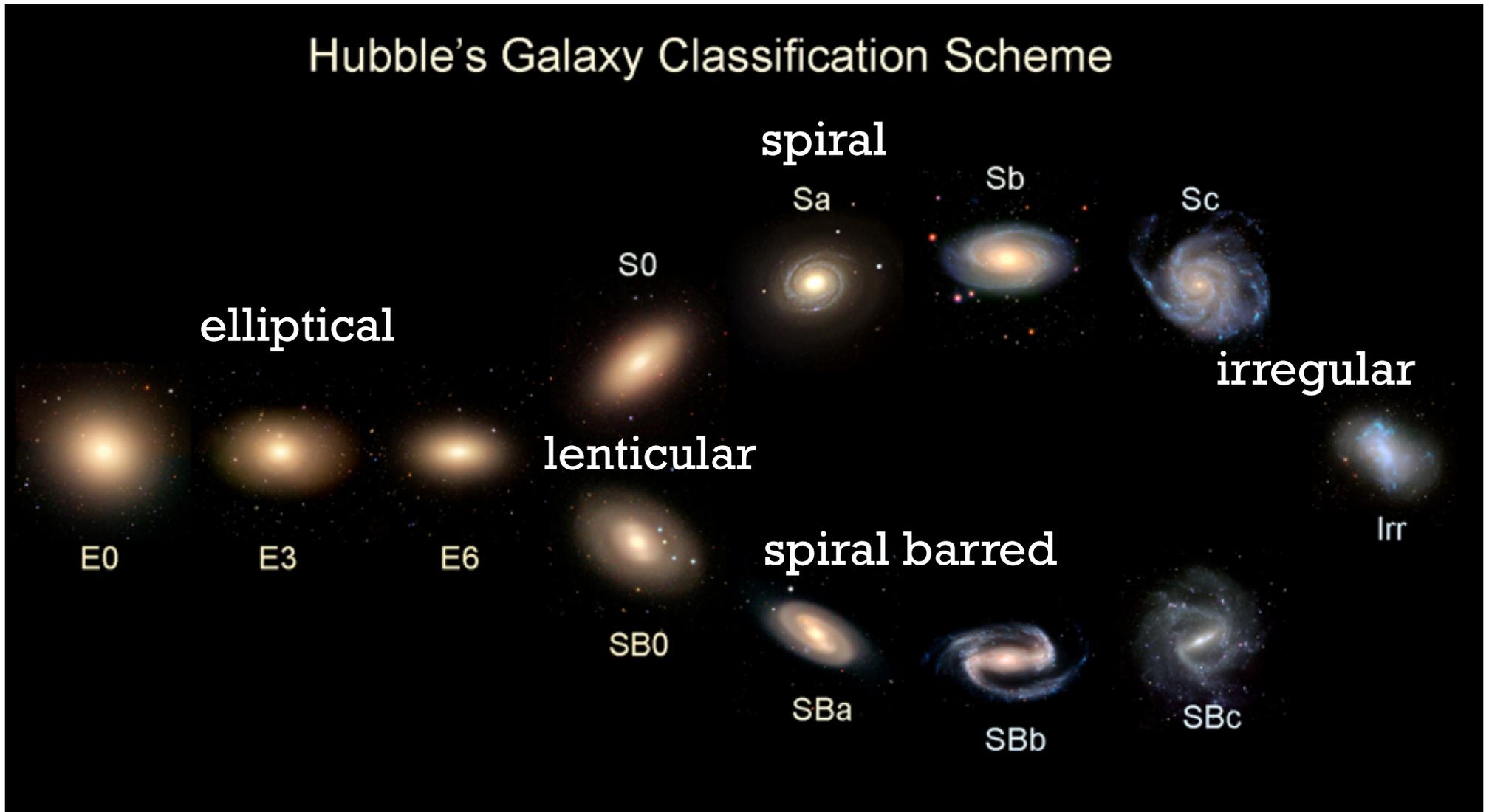
Big Bang

$$z \propto d$$

$$z = \frac{H_0}{c} d$$

# types of galaxies

Hubble's classification does NOT show evolution of galaxies!



# Spiral galaxies – with and without bar

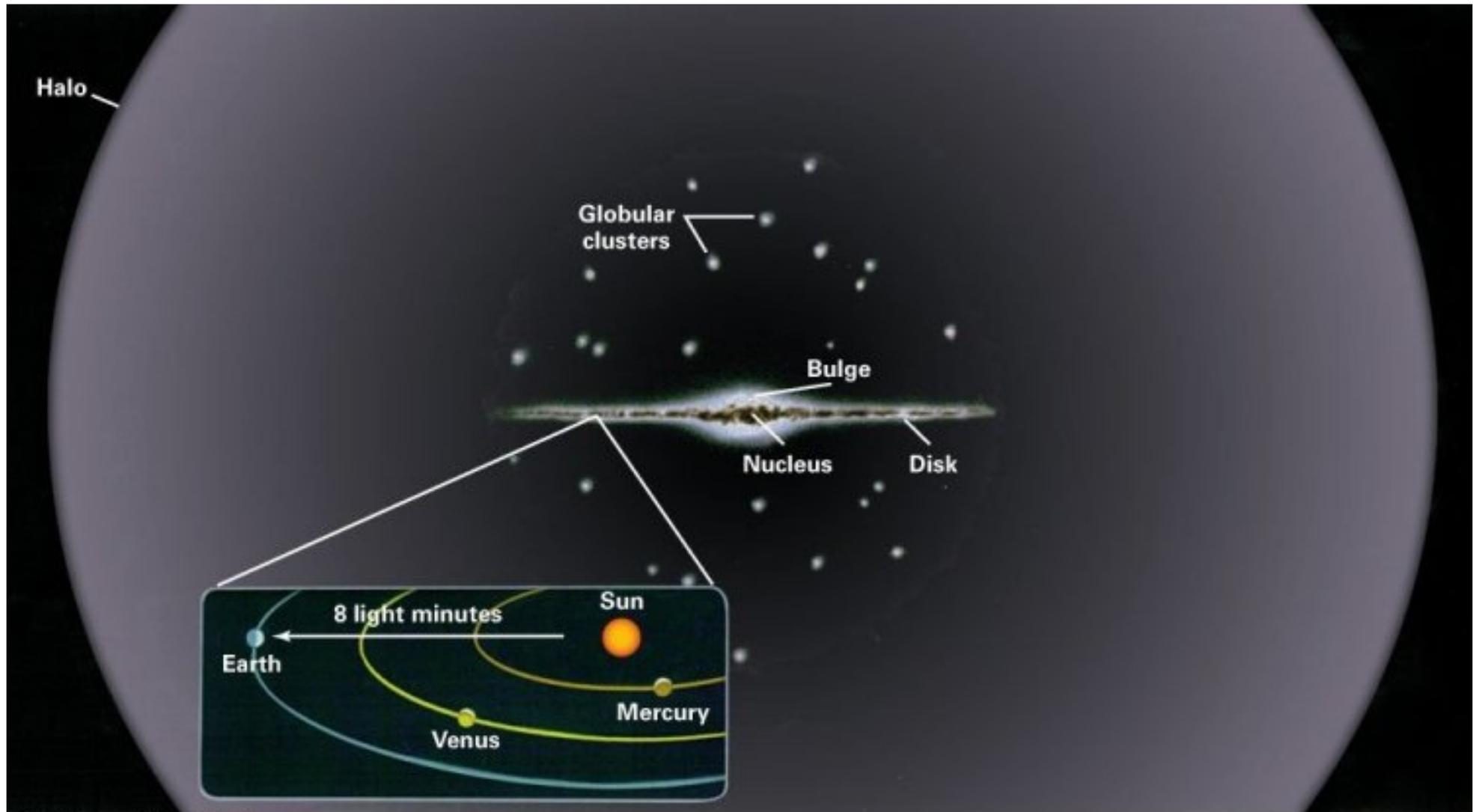
- spiral arms and central bulge
  - designation: ratio of luminosity from bulge and disk:
    - Sa, SBa – prominent central bulge, tight spiral arms
    - Sb, SBb - ...
    - Sc, SBc – less prominent central bulge, wide spiral arms;
- <30 % spiral (60% barred)

# spiral galaxies

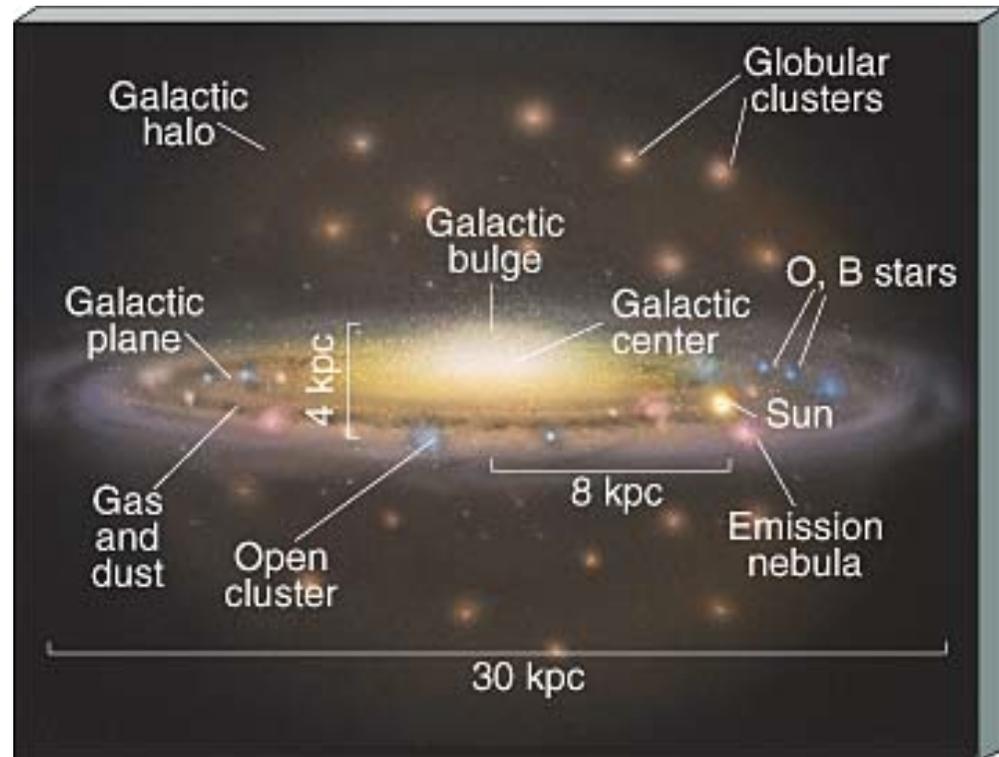
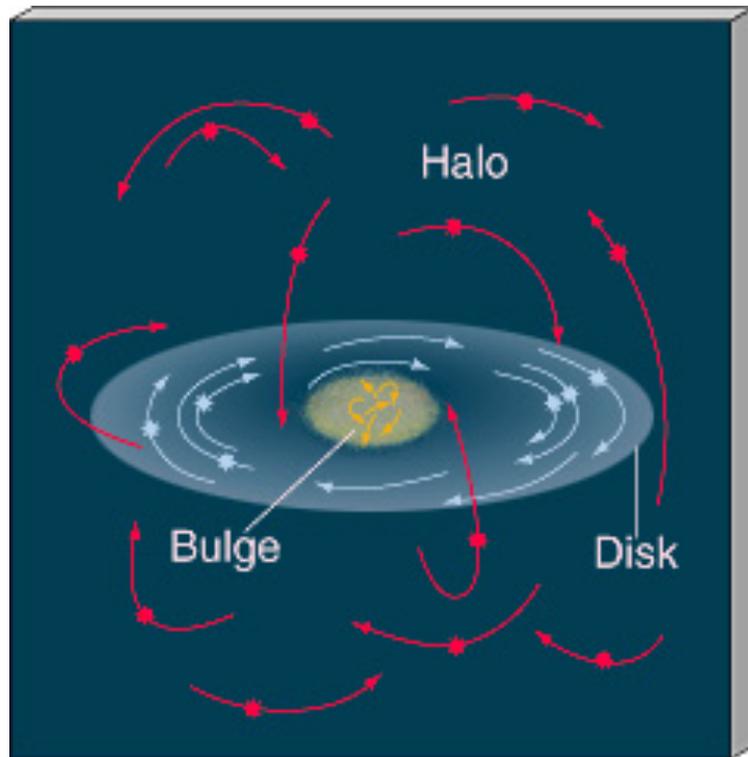
contain:

- gas and dust in the disk,
- star formation in spiral arms
- central bulge of reddish colour – made of old stars
- dark matter

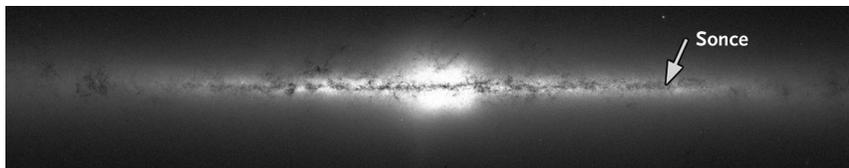
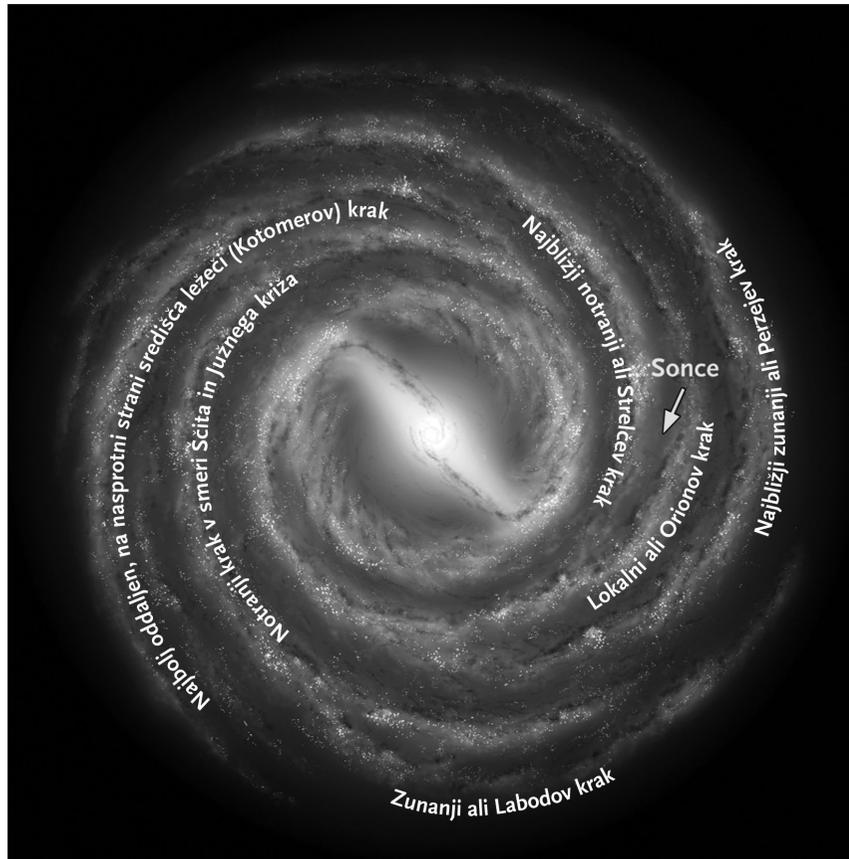
Stellar motion: ordered in disk, in all directions (not ordered) in central bulge and halo



# Galaxy - halo and bulge



# example: our Galaxy



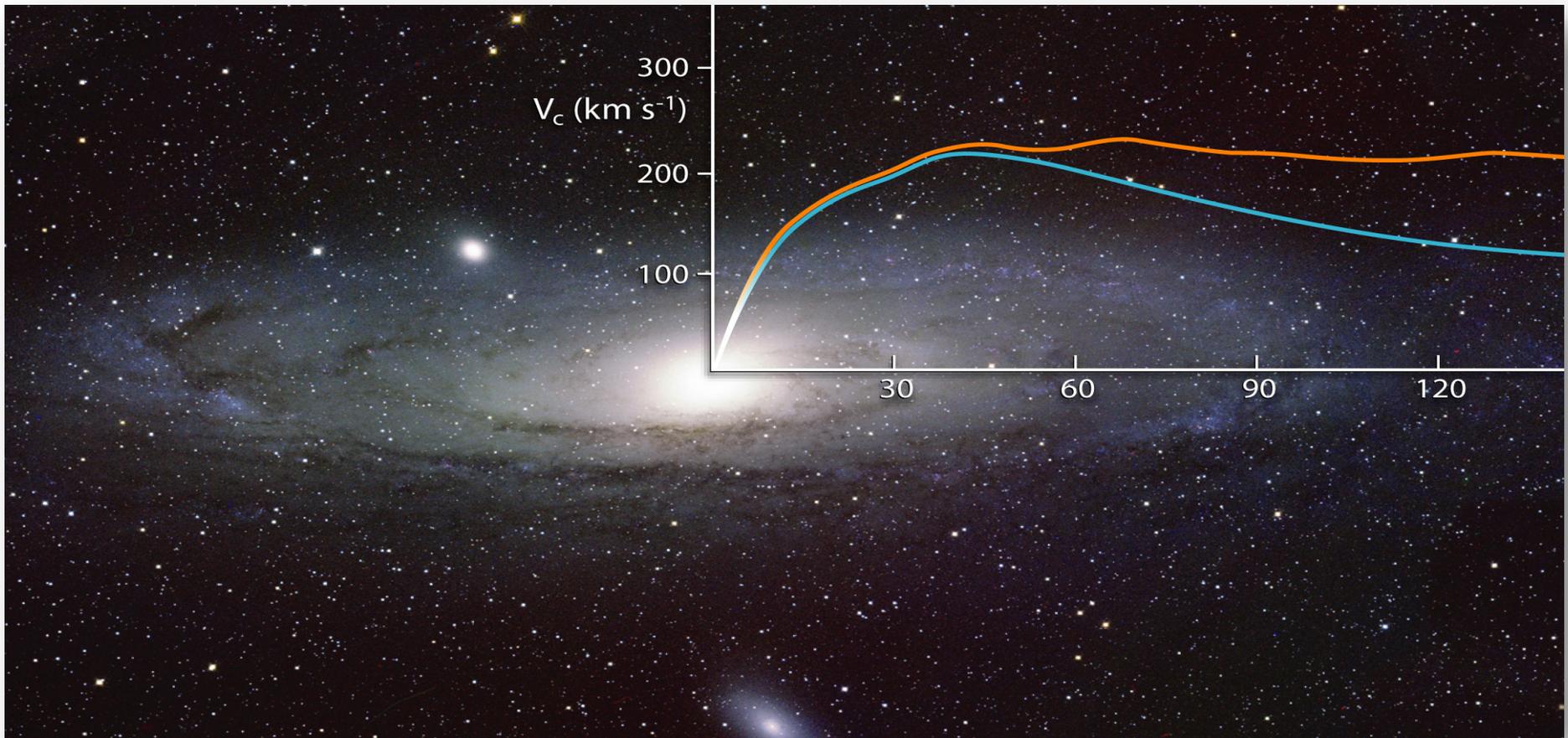
- spiral galaxy with bar
- diameter: 100.000 light years
- Sun: 26.000 lyr from center

## Mass:

- stars:  $10^{11}$  Solar masses
- gas: 10% mase zvezd
- dust: 0.1% mase zvezd
- dark matter:  $10^{12}$  Solar masses

# mass of spiral galaxies

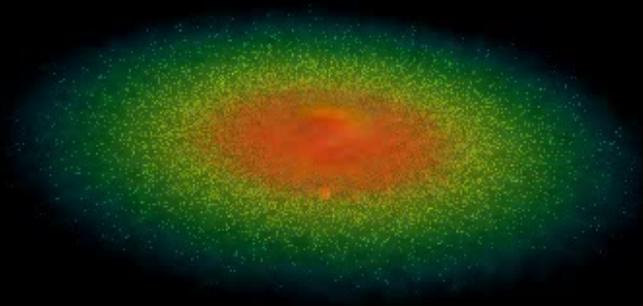
- rotation curve  $v(r)$ : 
$$v(r) = \sqrt{\frac{GM(r)}{r}}$$
- **dark matter halo: 90% mass**

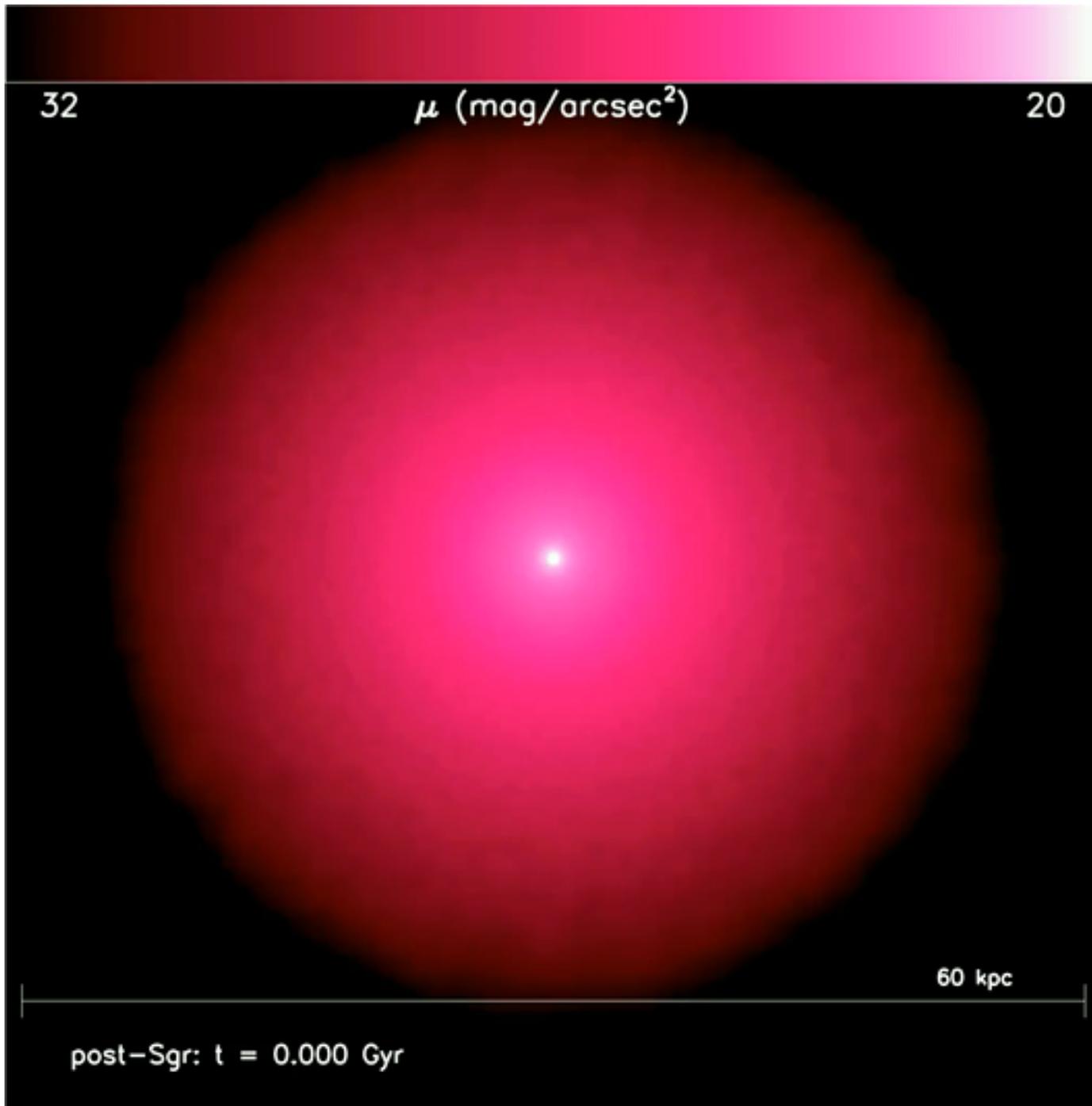


# origin of spiral arms

- density waves
- perturbations due to other (dwarf) galaxies

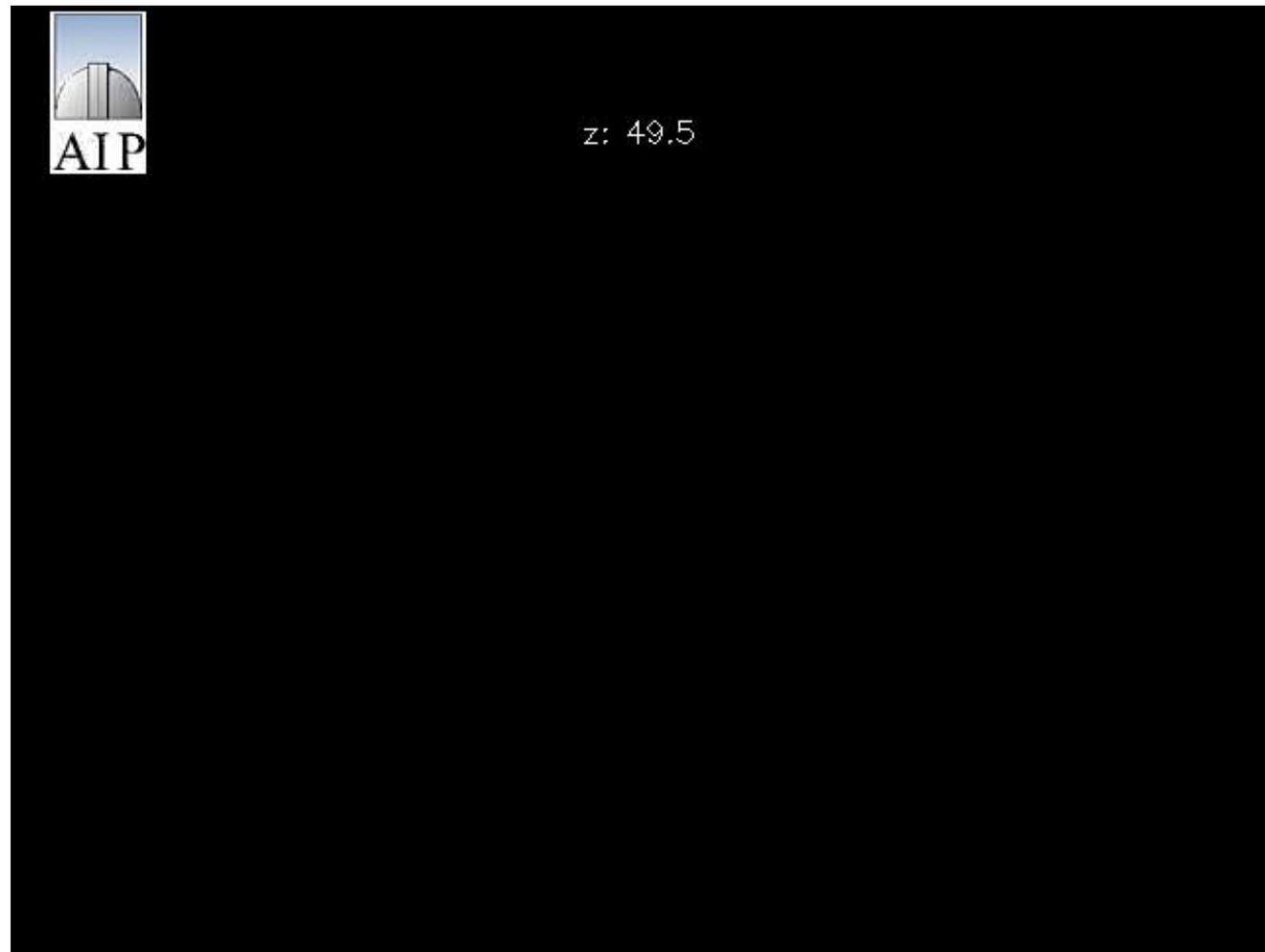
-2.65 Gyr





Purcell et al. 2011, Nature

simulation of  
cannibalistic  
evolution of our  
Galaxy –  
ordinary matter  
(barions)  
dark matter  
necessary!



view from above

side view

# Elliptical galaxies

Shape: ellipse (E0 – round, E7 – flattened):  
due to intrinsic shape and orientation

Contain:

- little gas and dust, therefore no star formation.
- reddish colour due to presence of red giants
- old stars
- dark matter

# elliptical

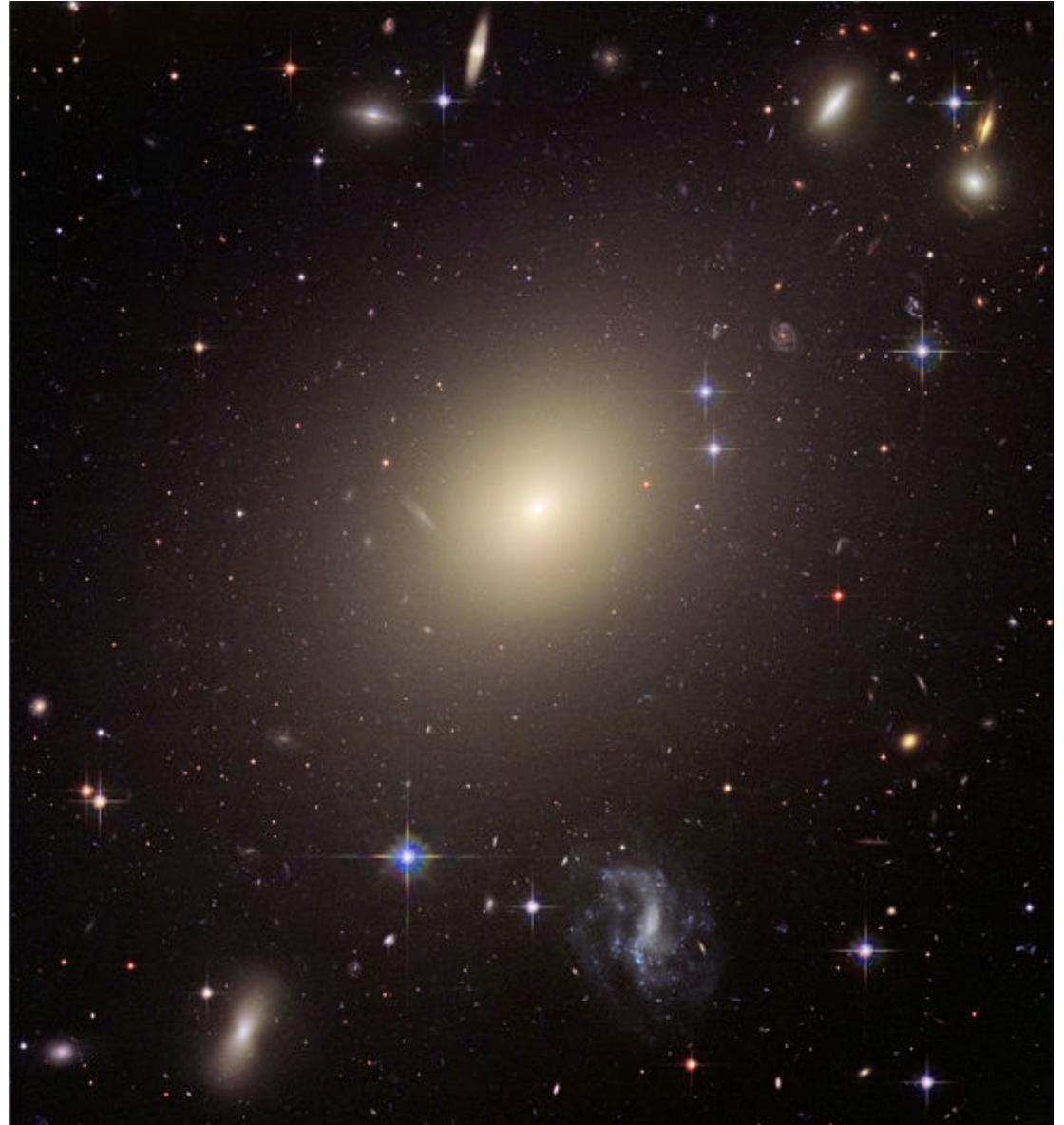
Stellar motion:

- in all directions (not ordered)

Mass:

dwarf galaxies (20x smaller than Galaxy) to cD galaxies (with 10x more stars).

>60% elliptical (most dwarf elliptical)



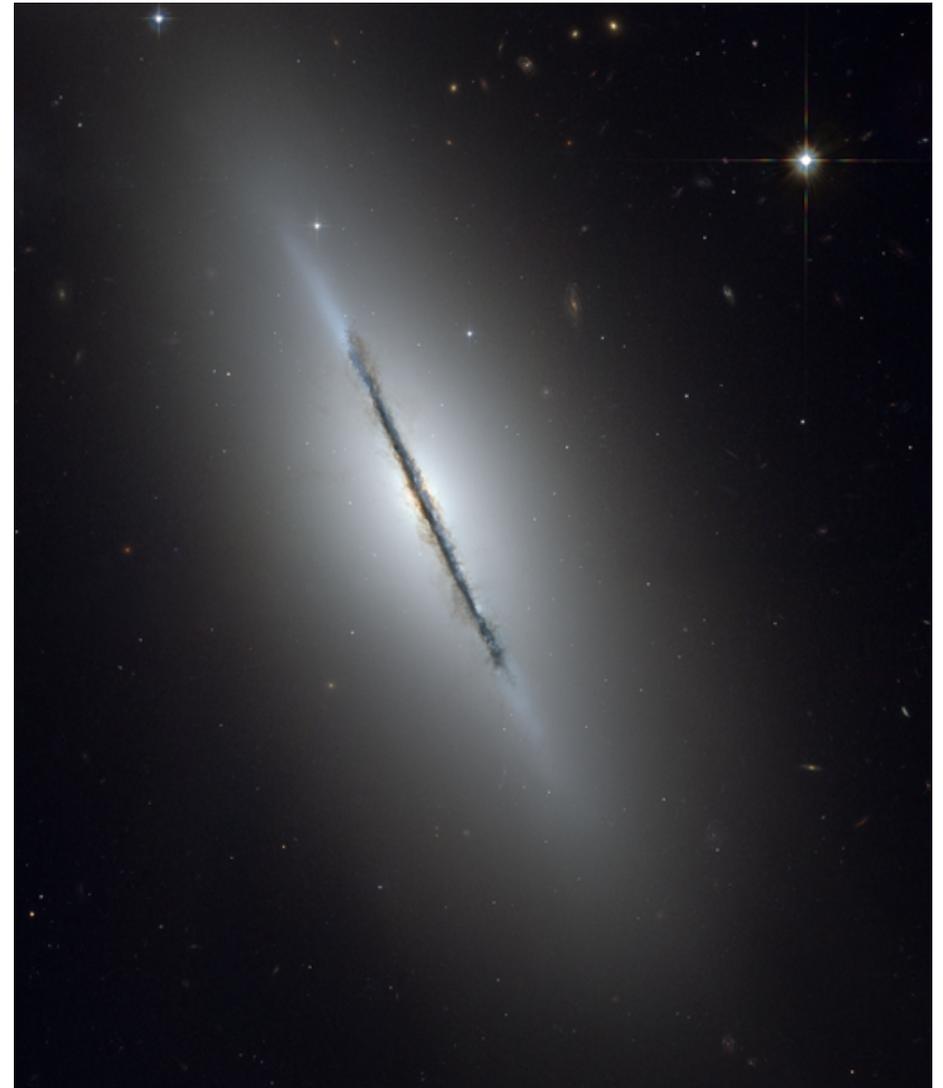
# Lenticular galaxies

Shape: galaxies with disk, no spiral arms

Contain:

- some gas and quite some dust
- very little star formation, mostly old (red) stars.

Characteristics: most characteristics shared with elliptical galaxies, although can have a bar and disk (made of dust)



# Irregular galaxies



<15% Irregular

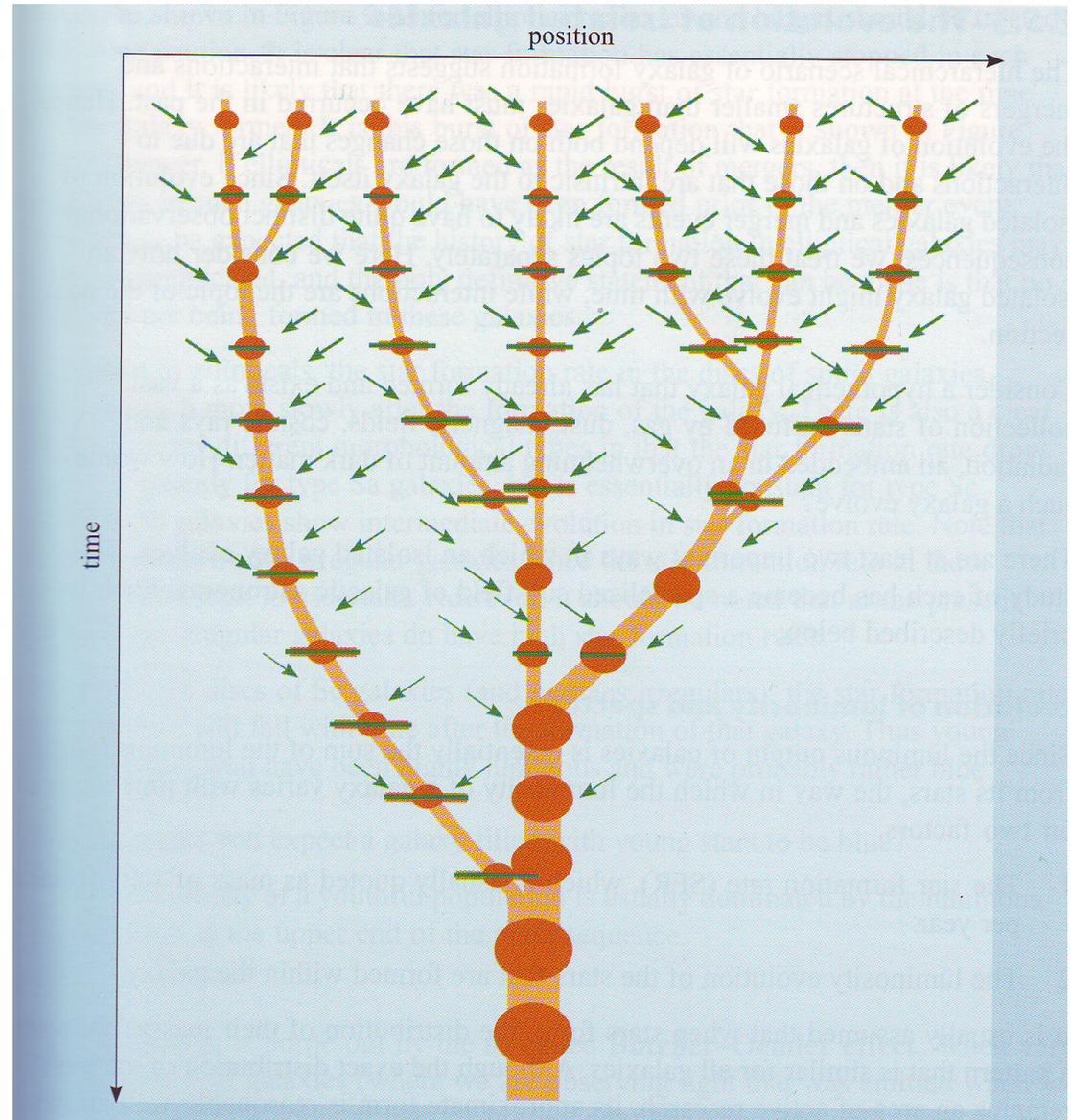


# collisions of galaxies



# evolution?

- bottom-up
- in a collision: elliptical forms
- between collisions: spiral
- more E, S0 and SB0 in dense regions of clusters
- in most dense S, SB and Irr almost not present
- bias!



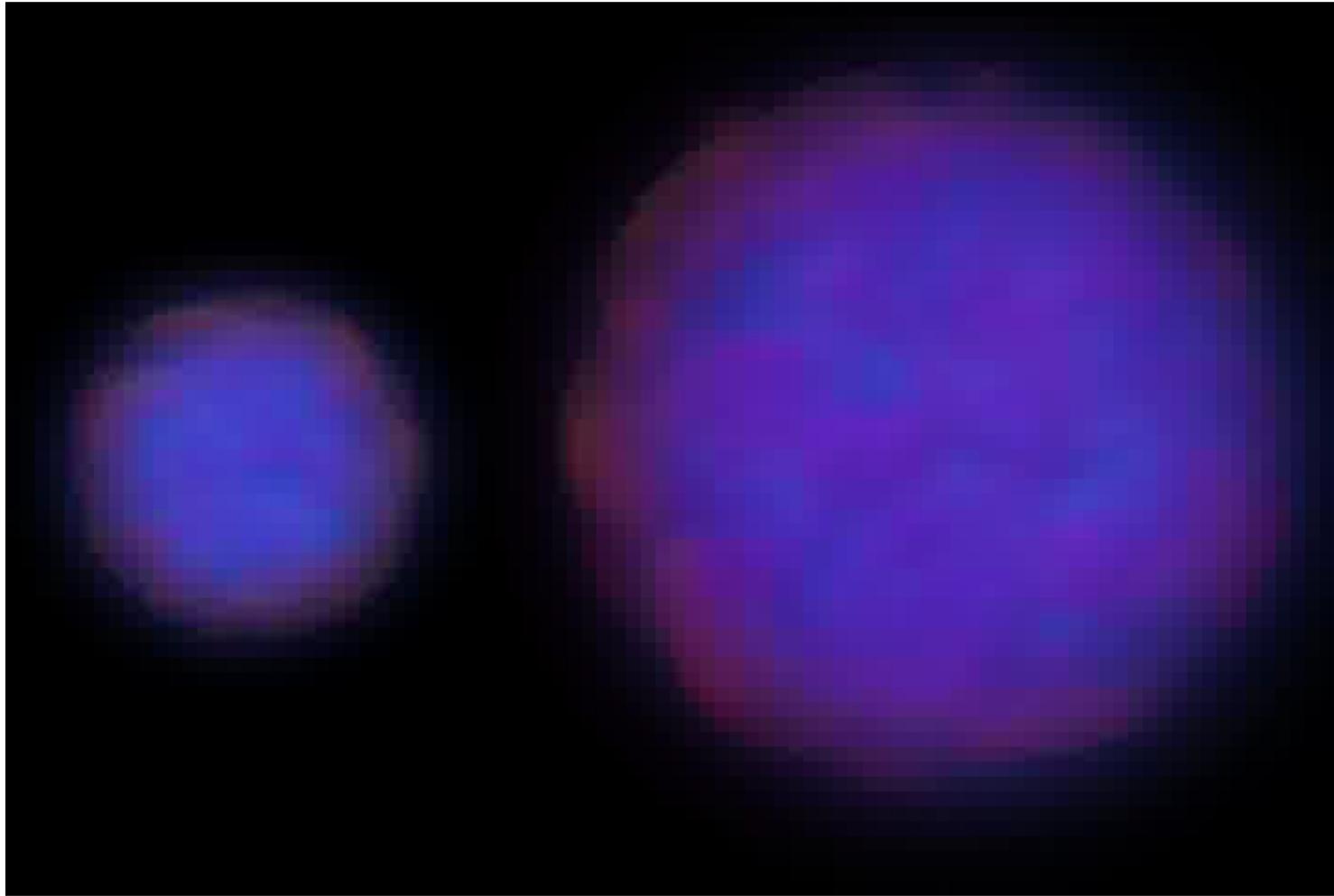
# galaxy clusters



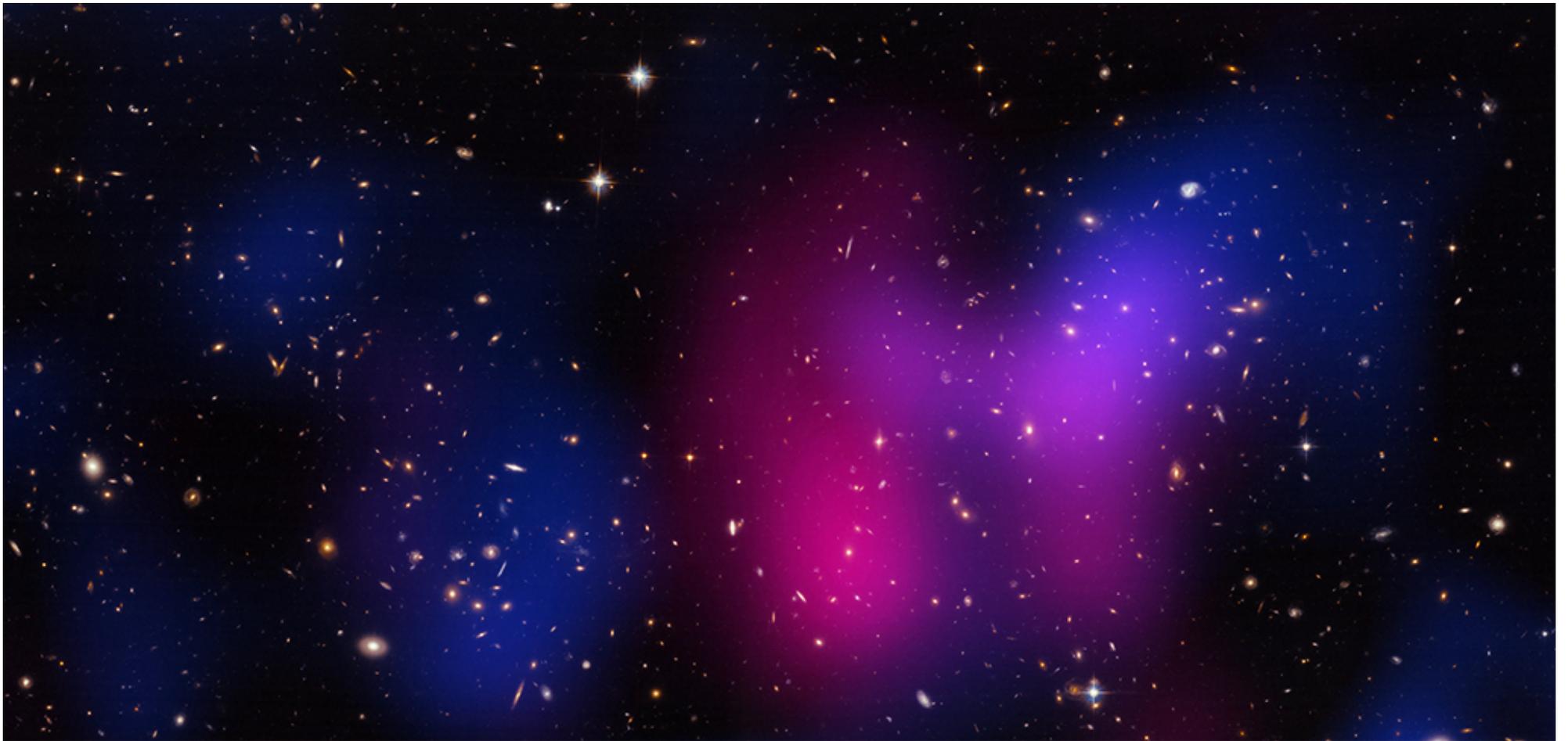
Coma cluster



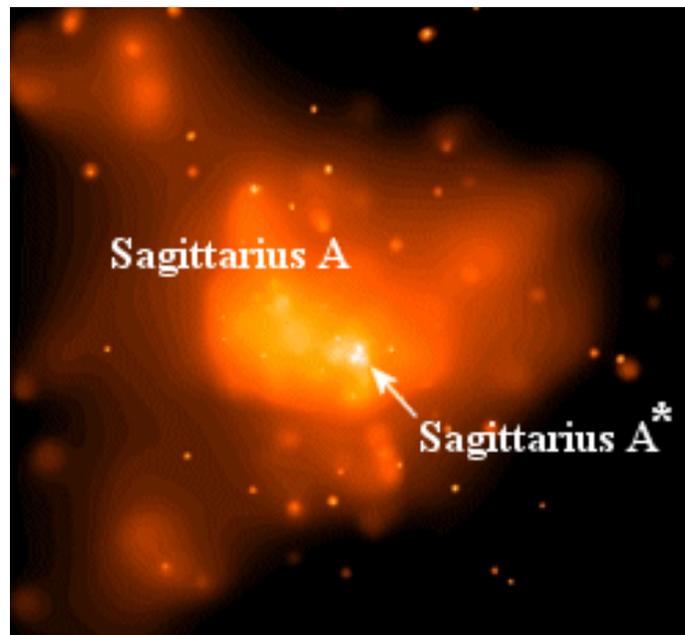
Virgo cluster

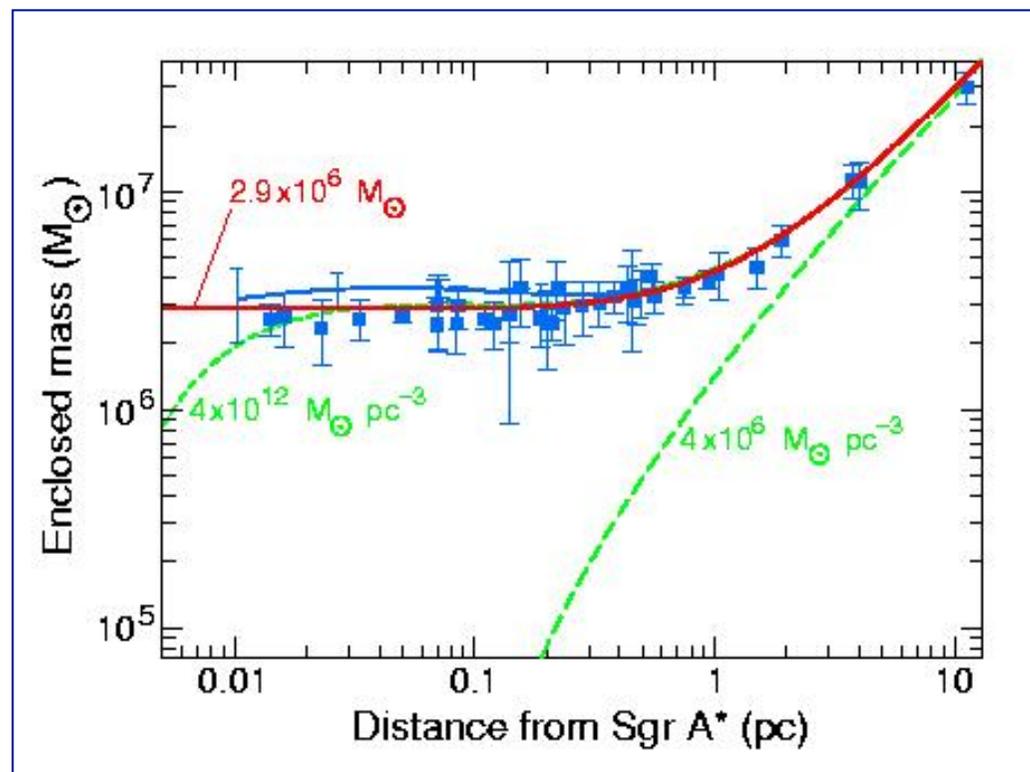


## Musket Ball cluster

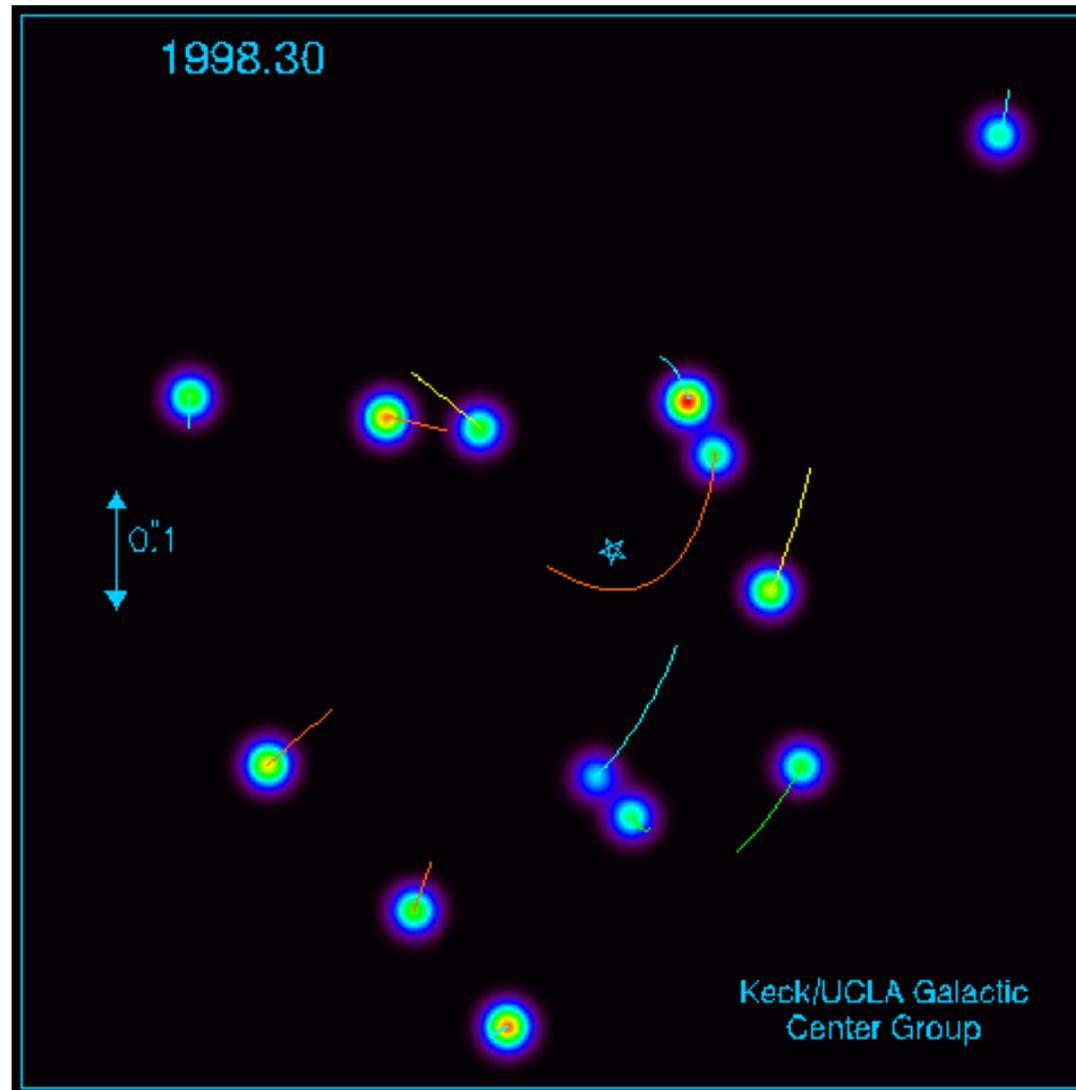


# what is in the Galactic center?



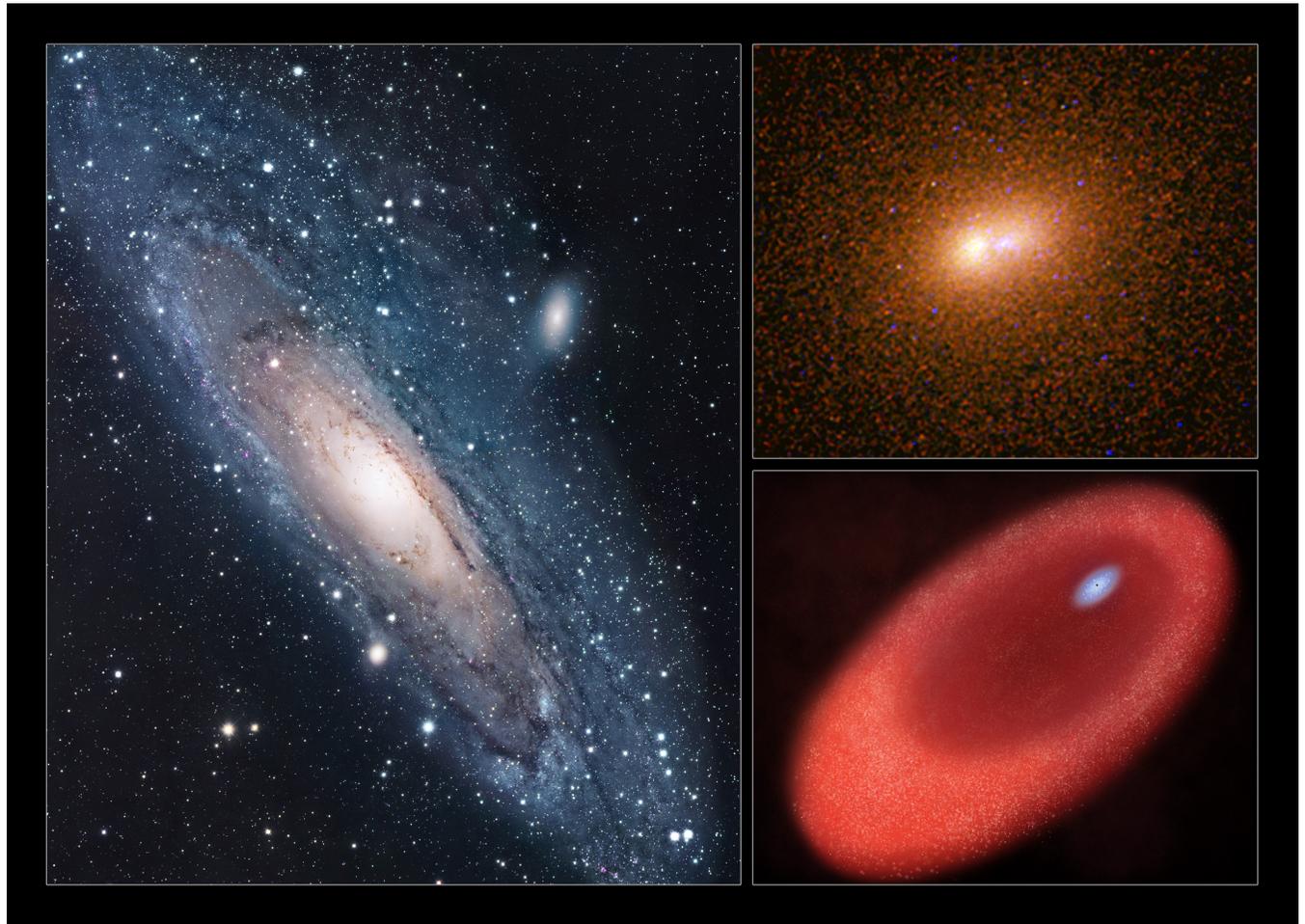


# black hole



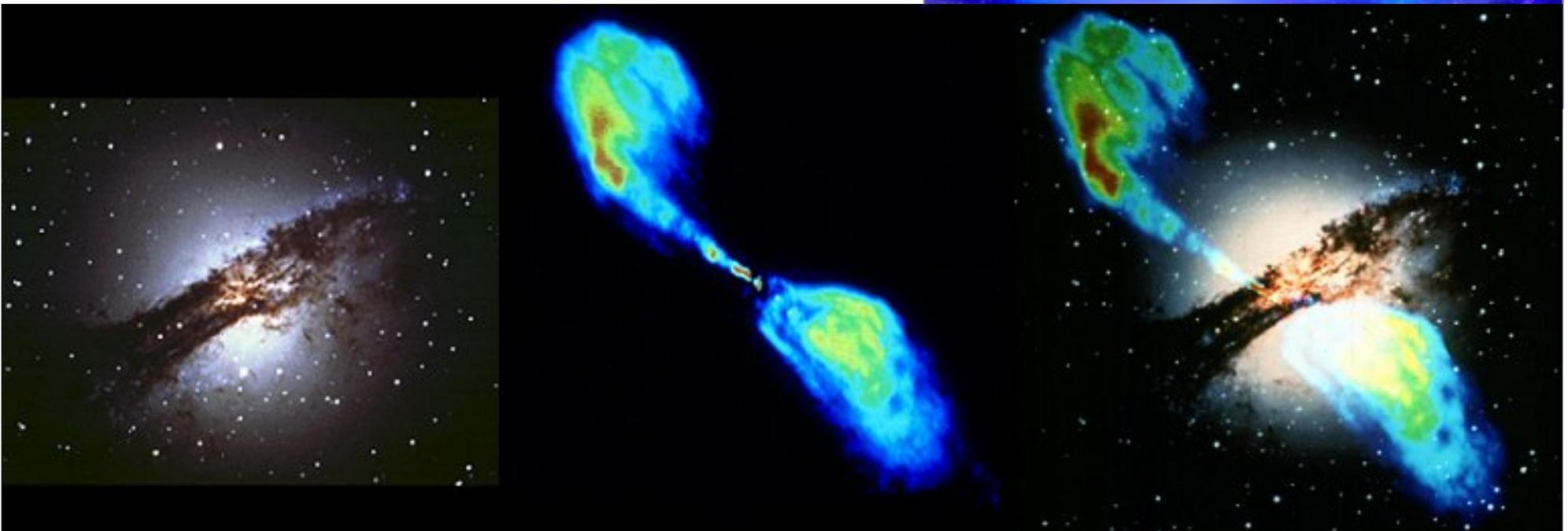
# black holes in centers of (all?) galaxies

- in M31, ...  
and  
others
- from  
million to  
few billion  
of Solar  
masses

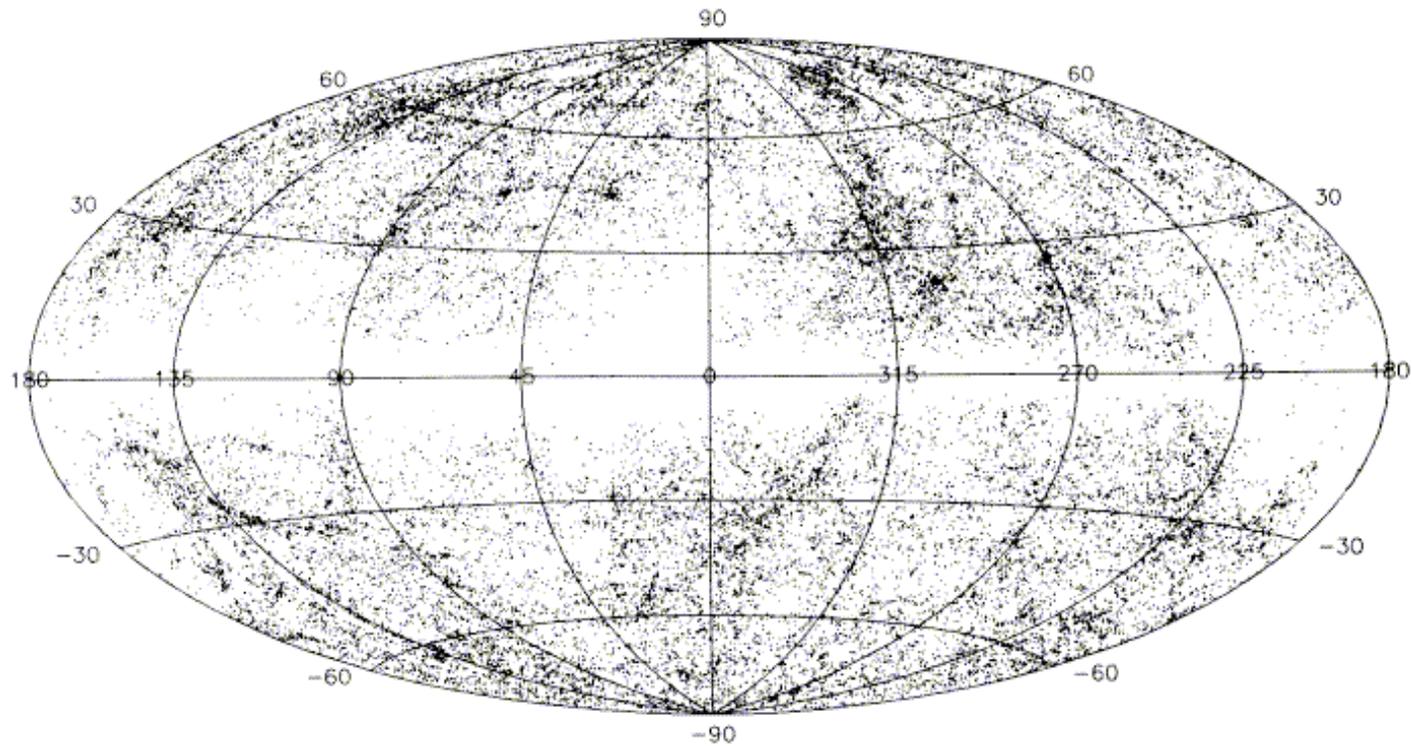


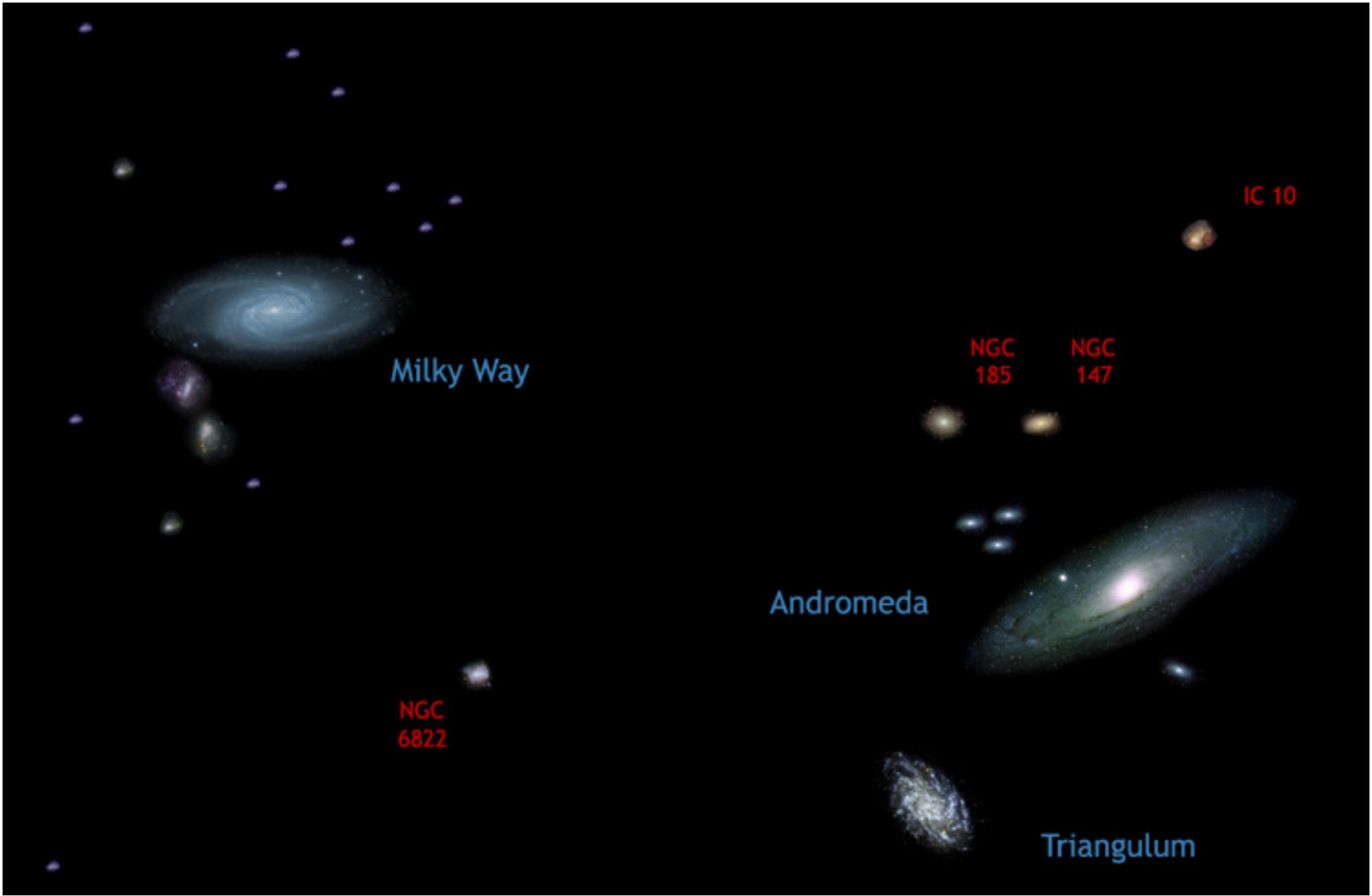
# in some - active

- galactic nuclei emits 100-times more energy than the rest of galaxy
- active galaxies



# galaxies on larger scales





Milky Way

IC 10

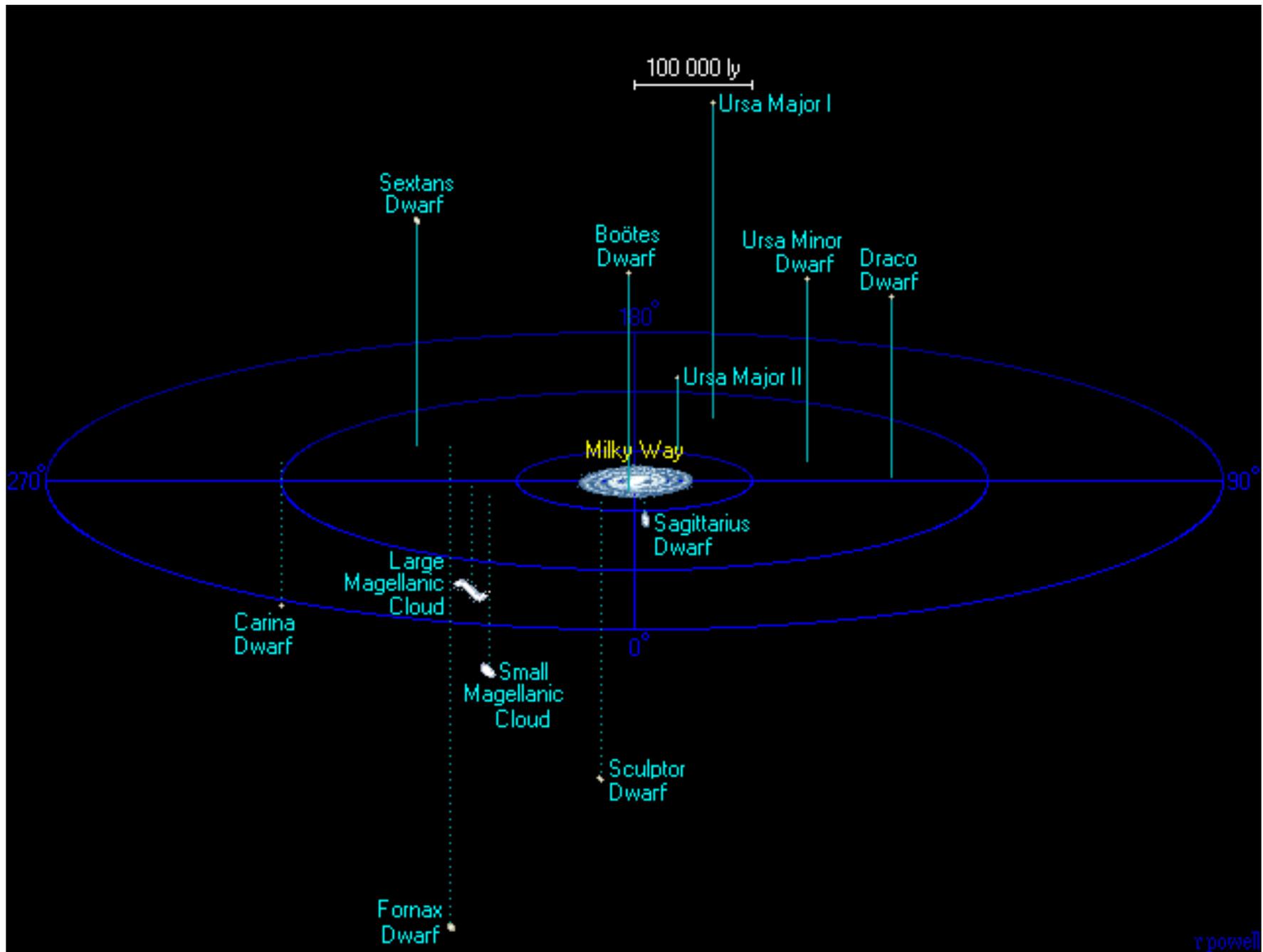
NGC  
185

NGC  
147

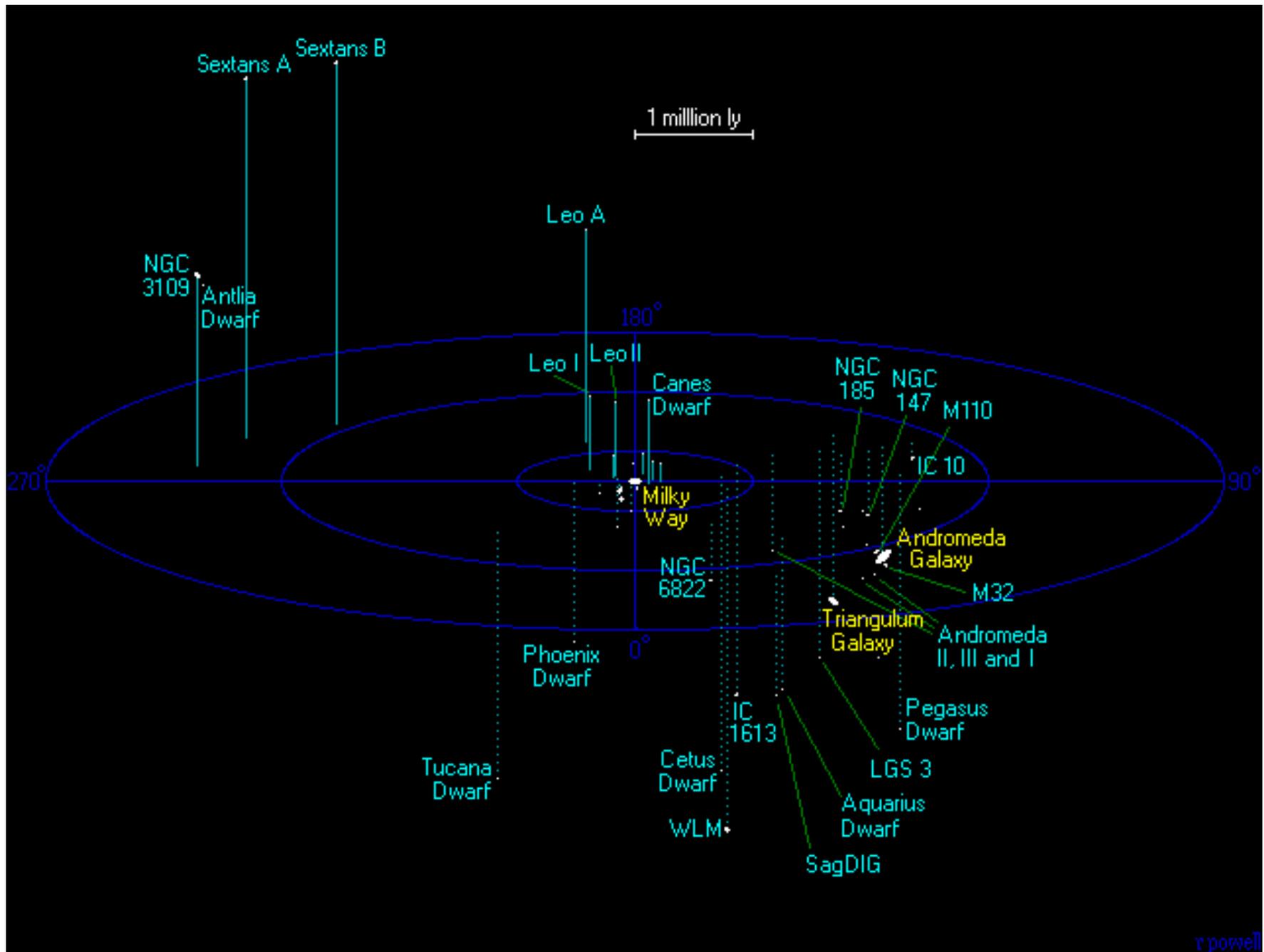
Andromeda

NGC  
6822

Triangulum



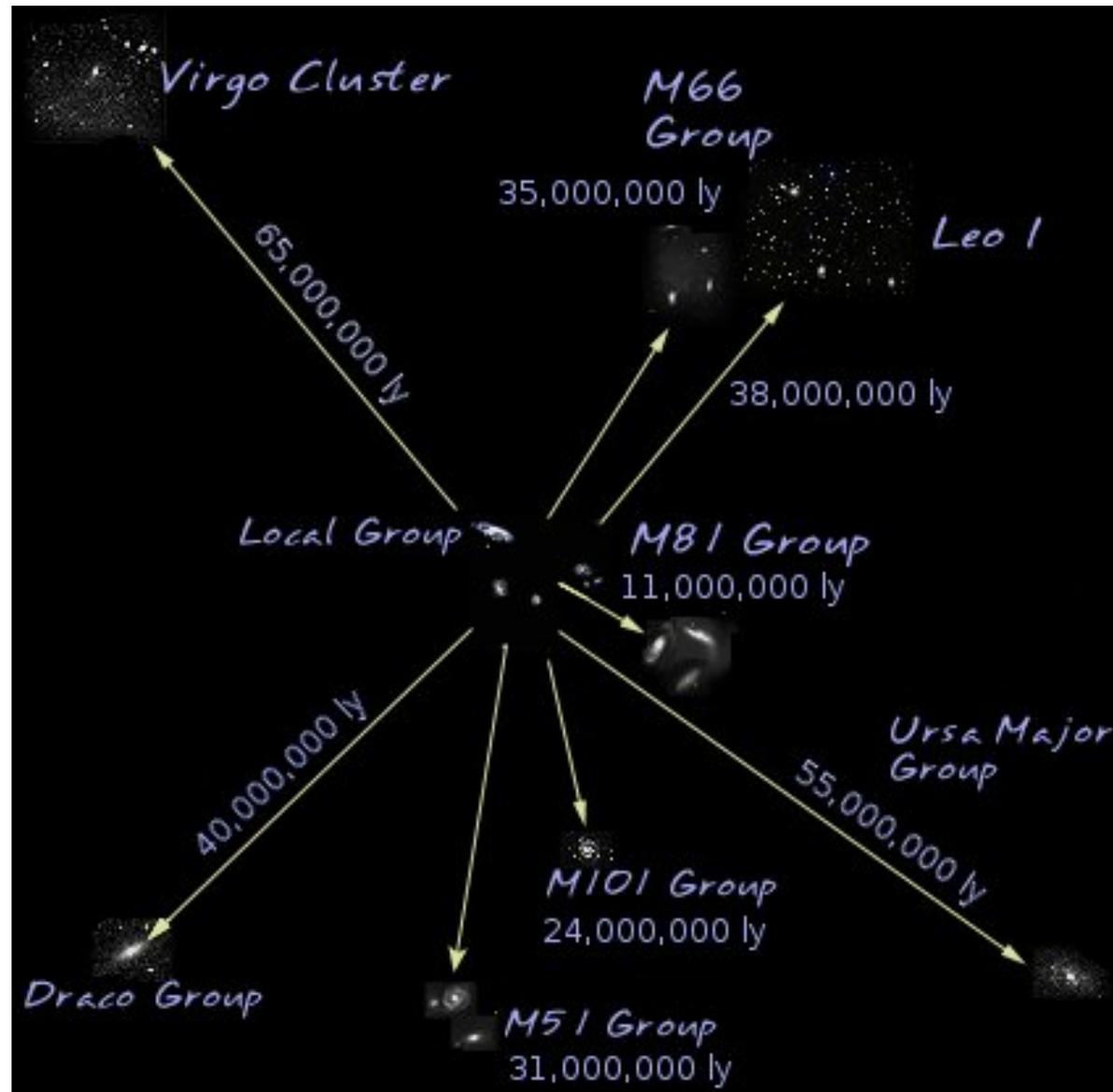
0.5 Mlyr



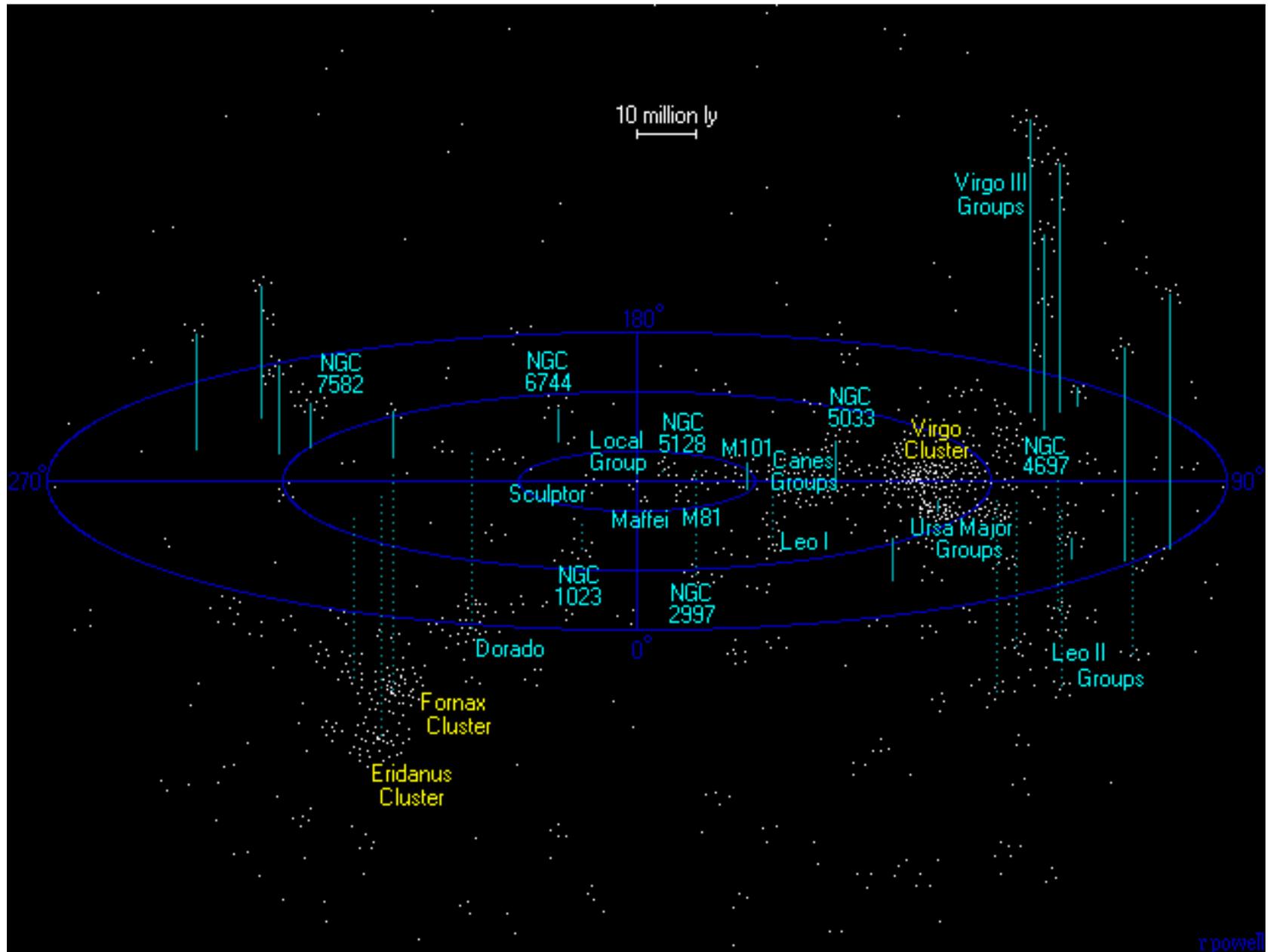
r powell

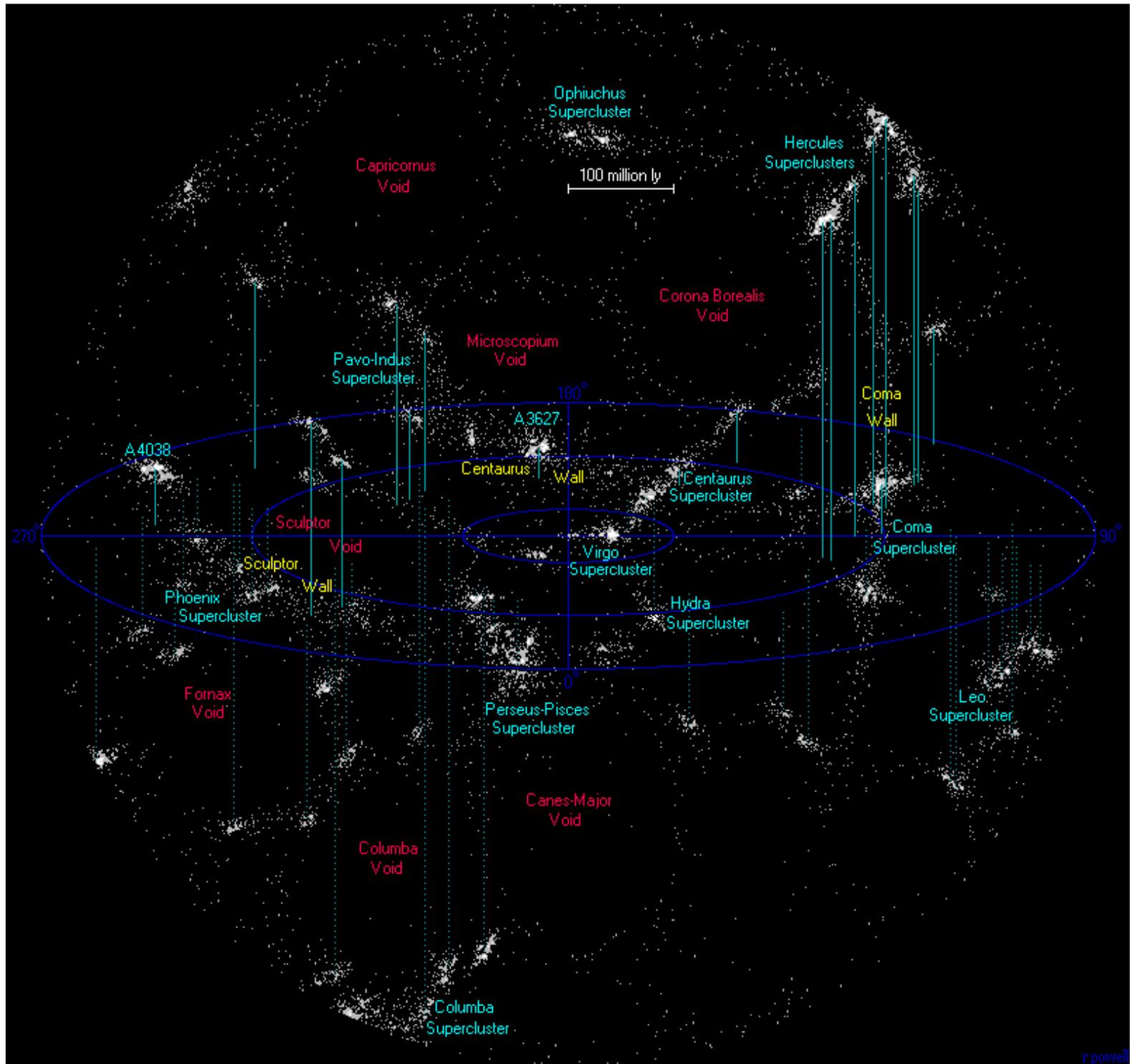
5 Mlyr

# Local group of galaxies



size about 30 Mpc or 100 Mlyr

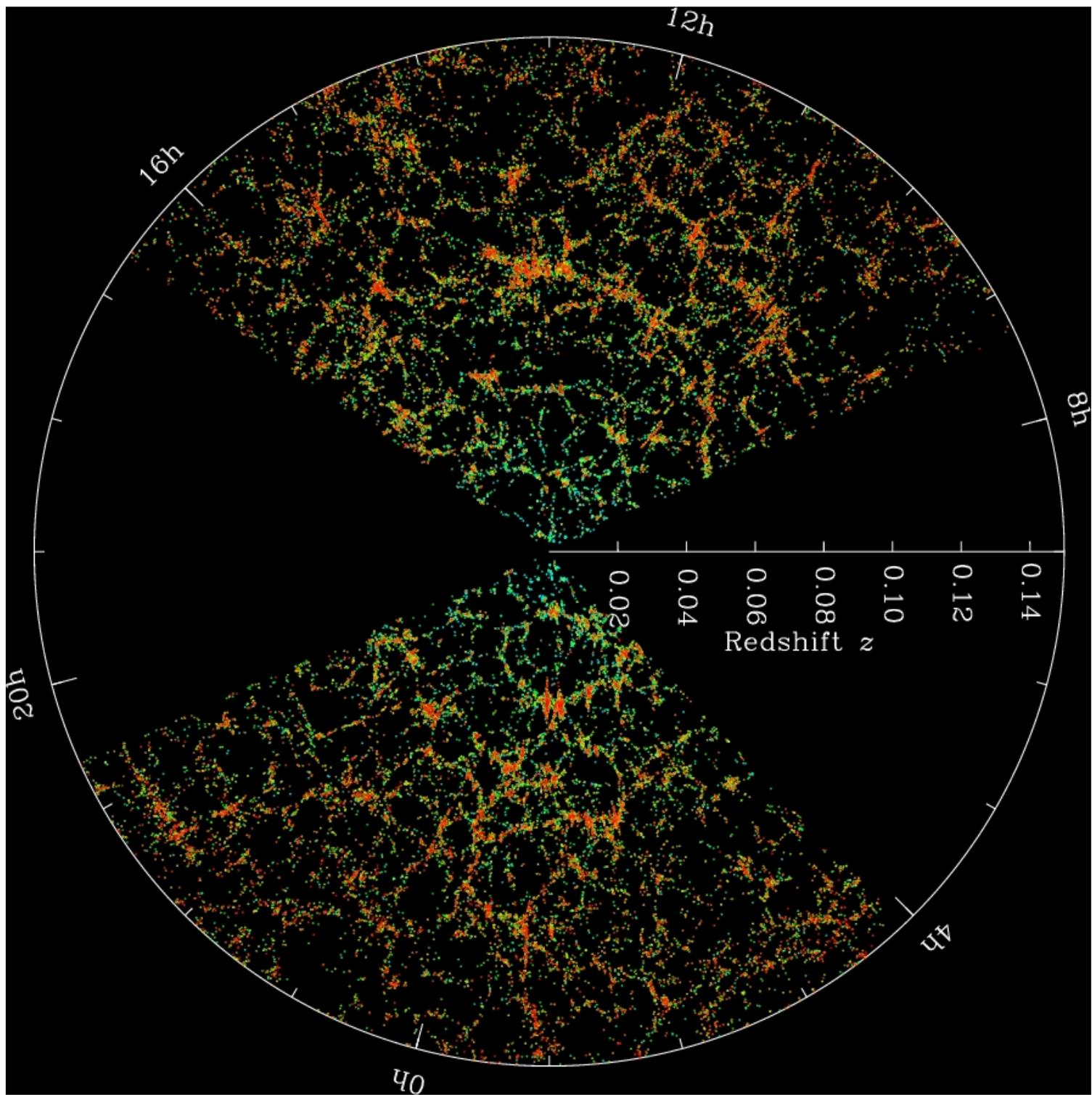




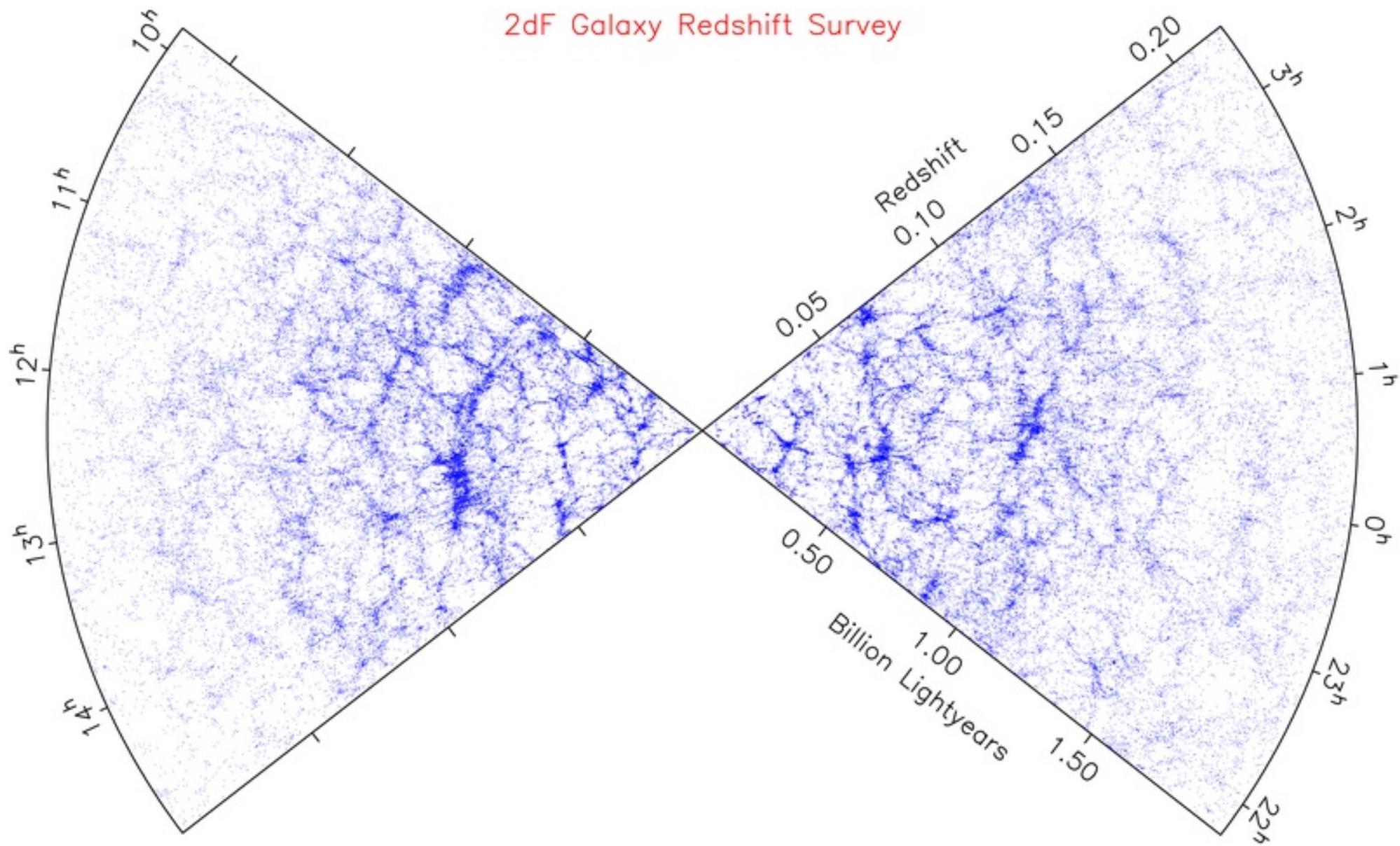
1 Glyr

3D

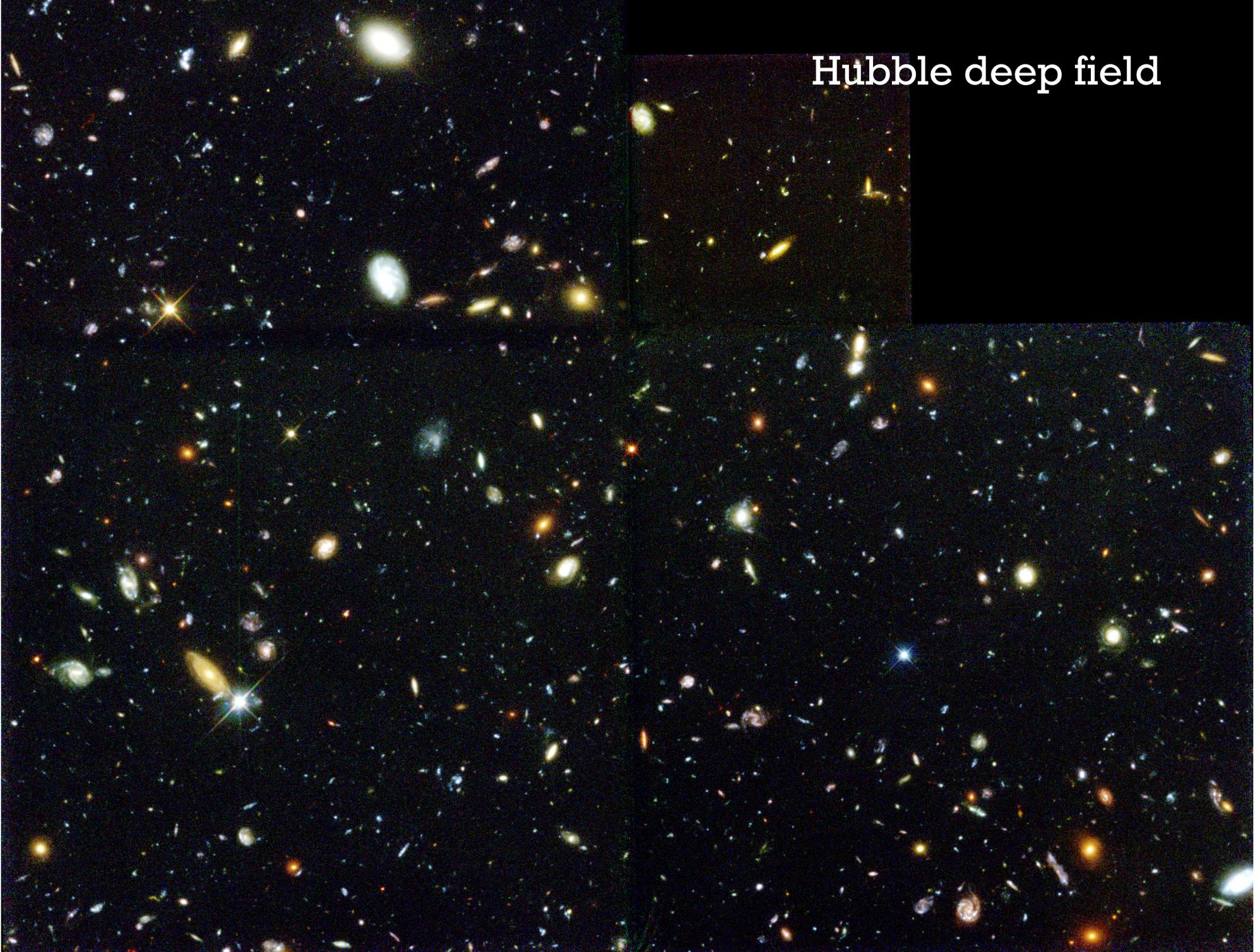
SDSS



# 2dF Galaxy Redshift Survey



# Hubble deep field



**Hubble Deep Field**

ST ScI OPO January 15, 1996 R. Williams and the HDF Team (ST ScI) and NASA

**HST WFPC2**

Hubble ultra deep field



Hubble extreme deep field- 2012

