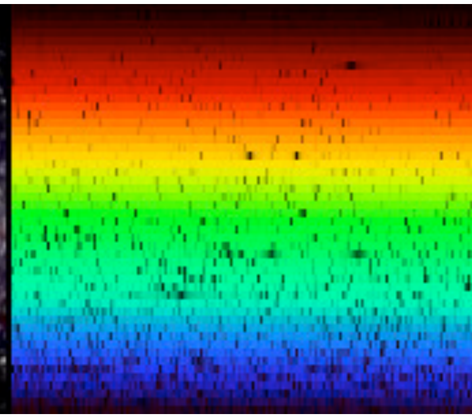
ASTR/PHYS 3070: Foundations Astronomy



Week 15 Tuesday

Today's Agenda

- Milky Way structure
- Evidence for dark matter
- Galaxy types
- Extragalactic distances

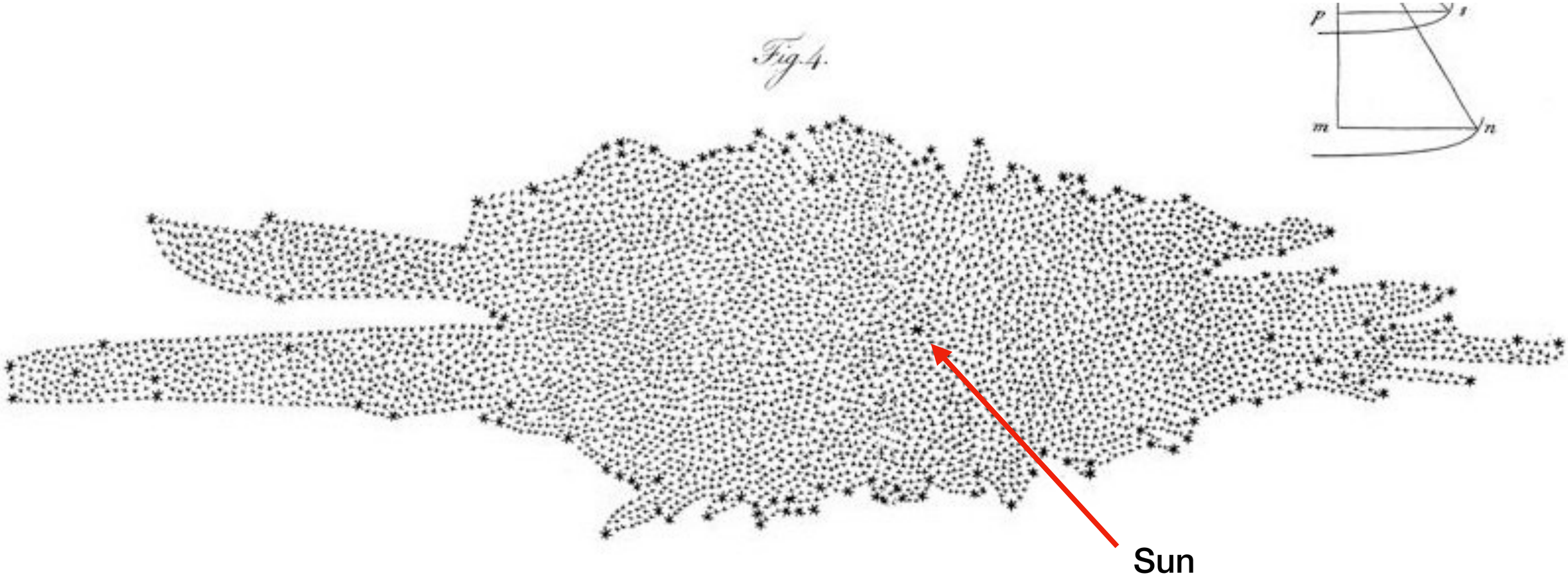
Announcements / Reminders

- HW 10 due this Friday @11:59pm
  - HW 11 also available, due next week
- Read Chapters 20 & 23.0-3 (& 24)

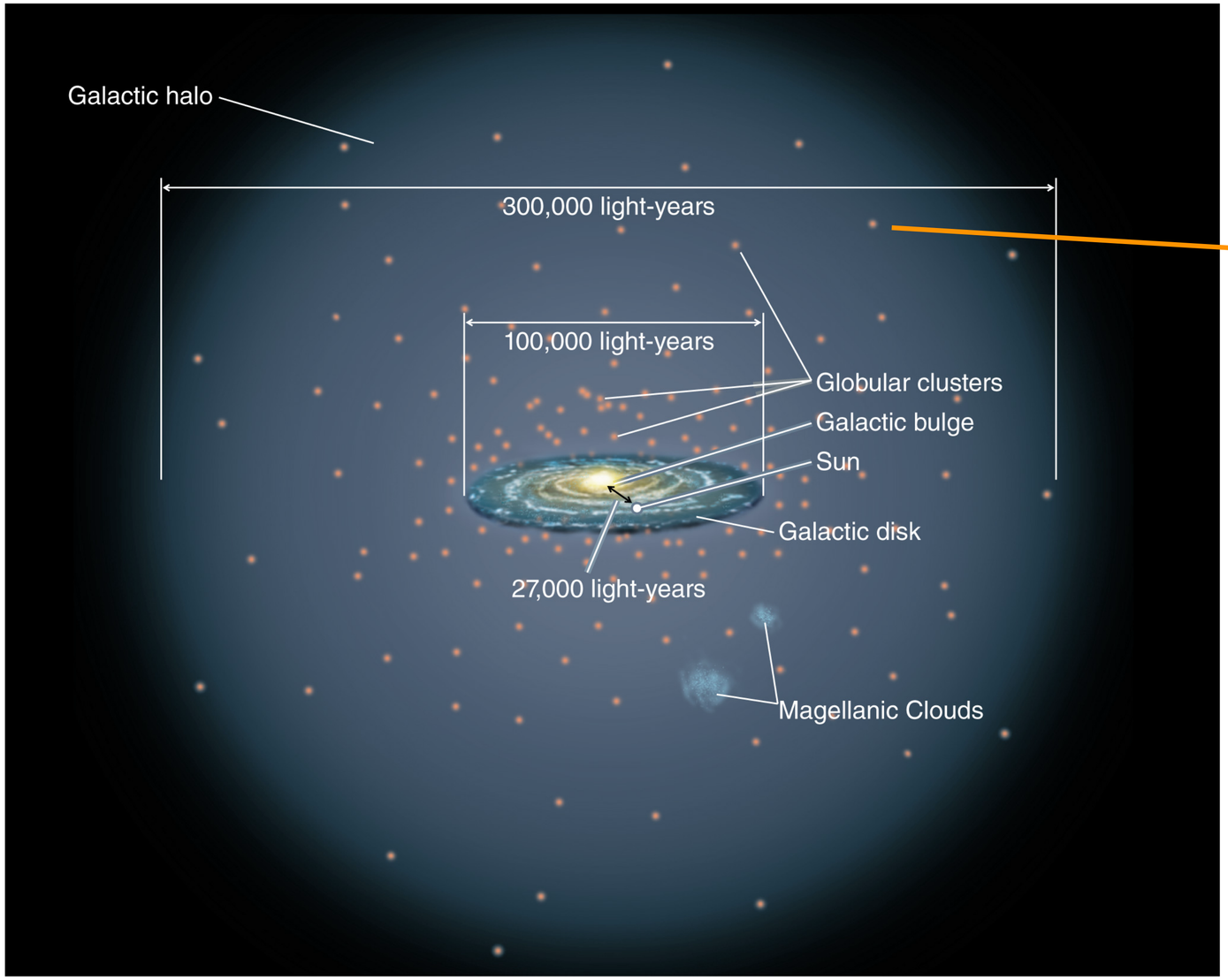
- HEAP TODAY @ 3pm AND tomorrow @ 8am
  - Neutrino detectors & neutrinos from blazers
- Colloquium Friday @ 2pm
  - Intercellular Communication & Drug Delivery

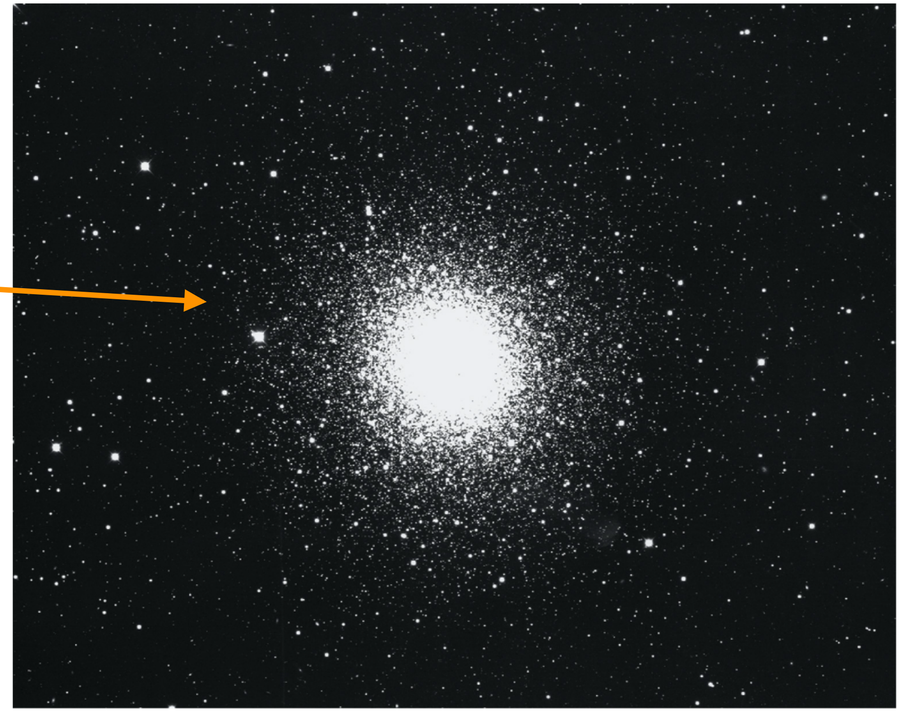
Our Galaxy, the Milky Way

Star counts: William and Caroline Herschel (1785)



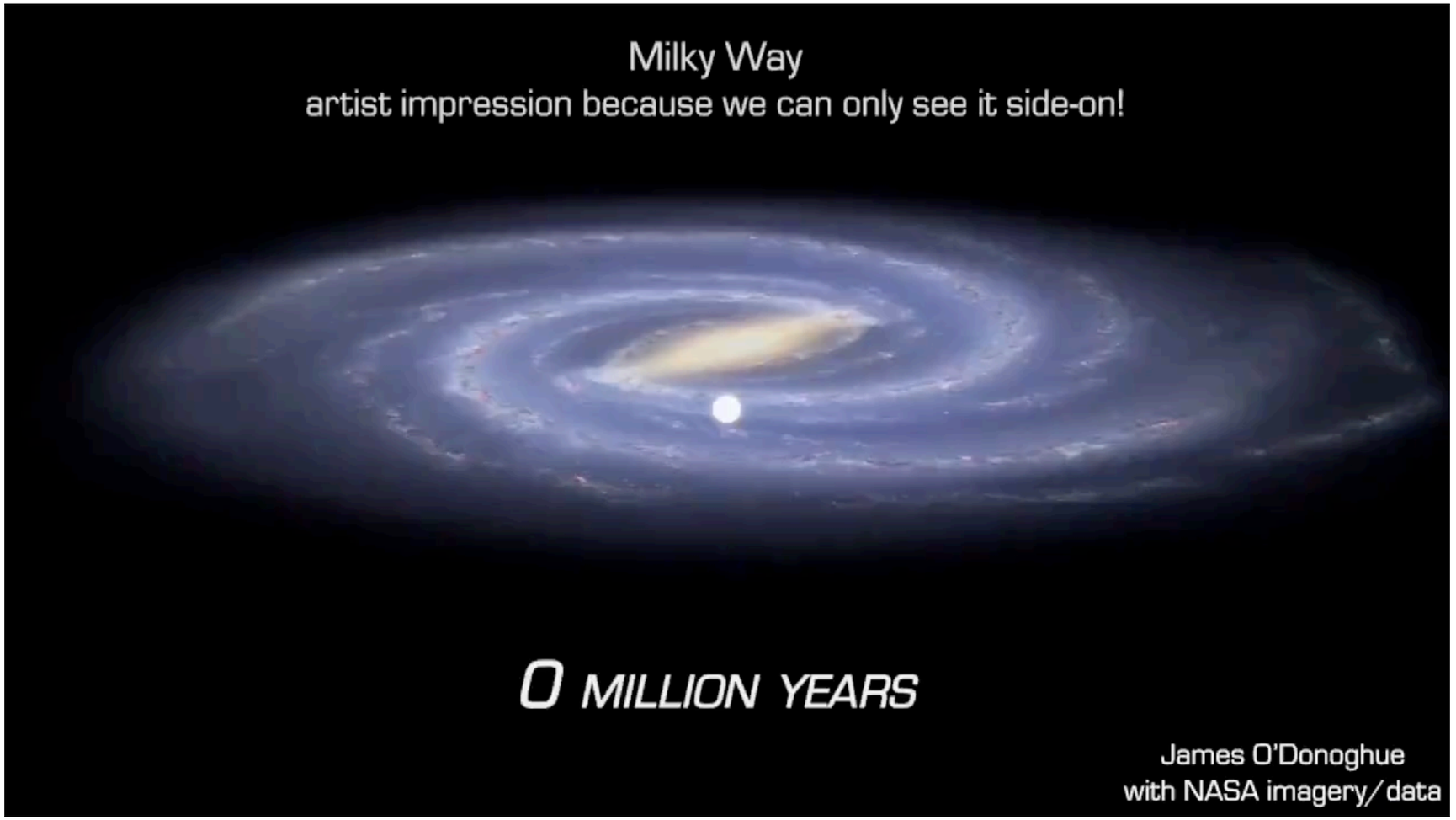
Globular clusters revealed the scale of the MW



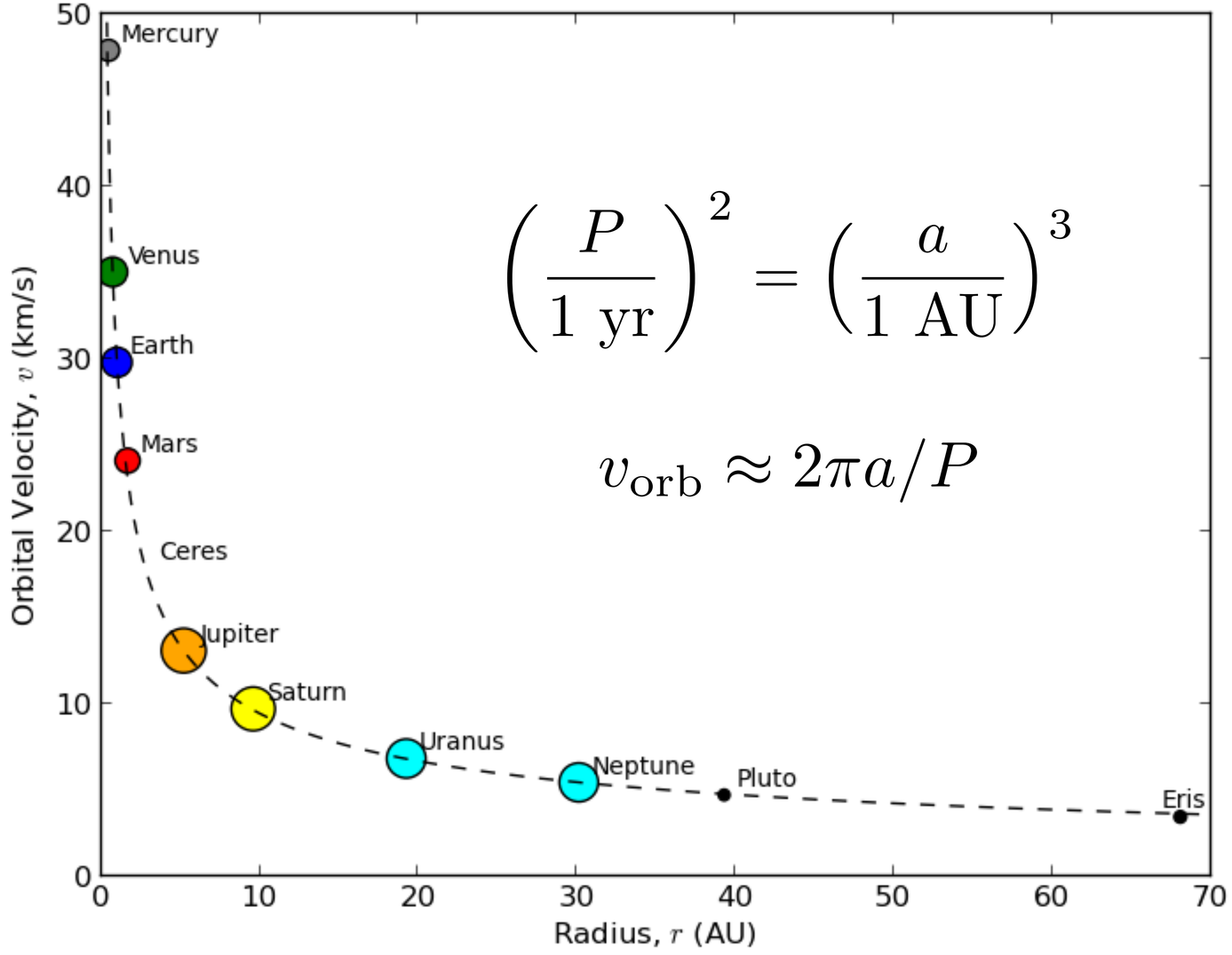


Variable stars like Cepheids (called RR Lyrae stars) were used to estimate the distance to globular clusters, which were assumed to be distributed uniformly around the center of the MW

Sun's Motion through the Galaxy



How do stars move in the Galaxy?



$$\left(\frac{P}{1\ \mathrm{yr}}\right)^2 = \left(\frac{a}{1\ \mathrm{AU}}\right)^3$$

$$v_{\mathrm{orb}} \approx 2\pi a/P$$

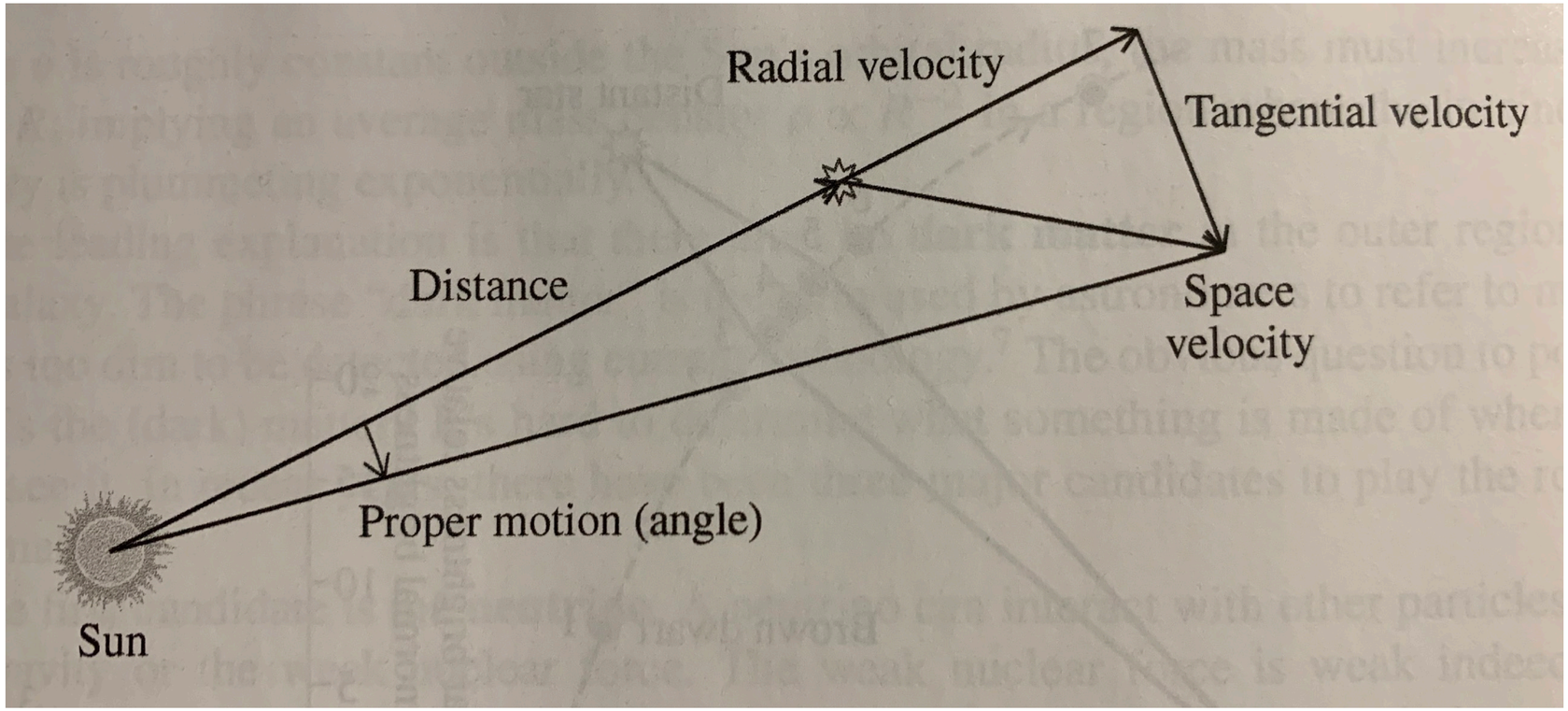
Kepler's 3rd Law in the Galaxy

$$M_\odot + M_G(< r) = \frac{(a/1\ \mathrm{AU})^3}{(P/1\ \mathrm{yr})^2}$$

Mass inside Sun's orbit

How do we get 3D star velocities?

Radial Velocity: $$v_r = \frac{\Delta\lambda}{\lambda} c$$

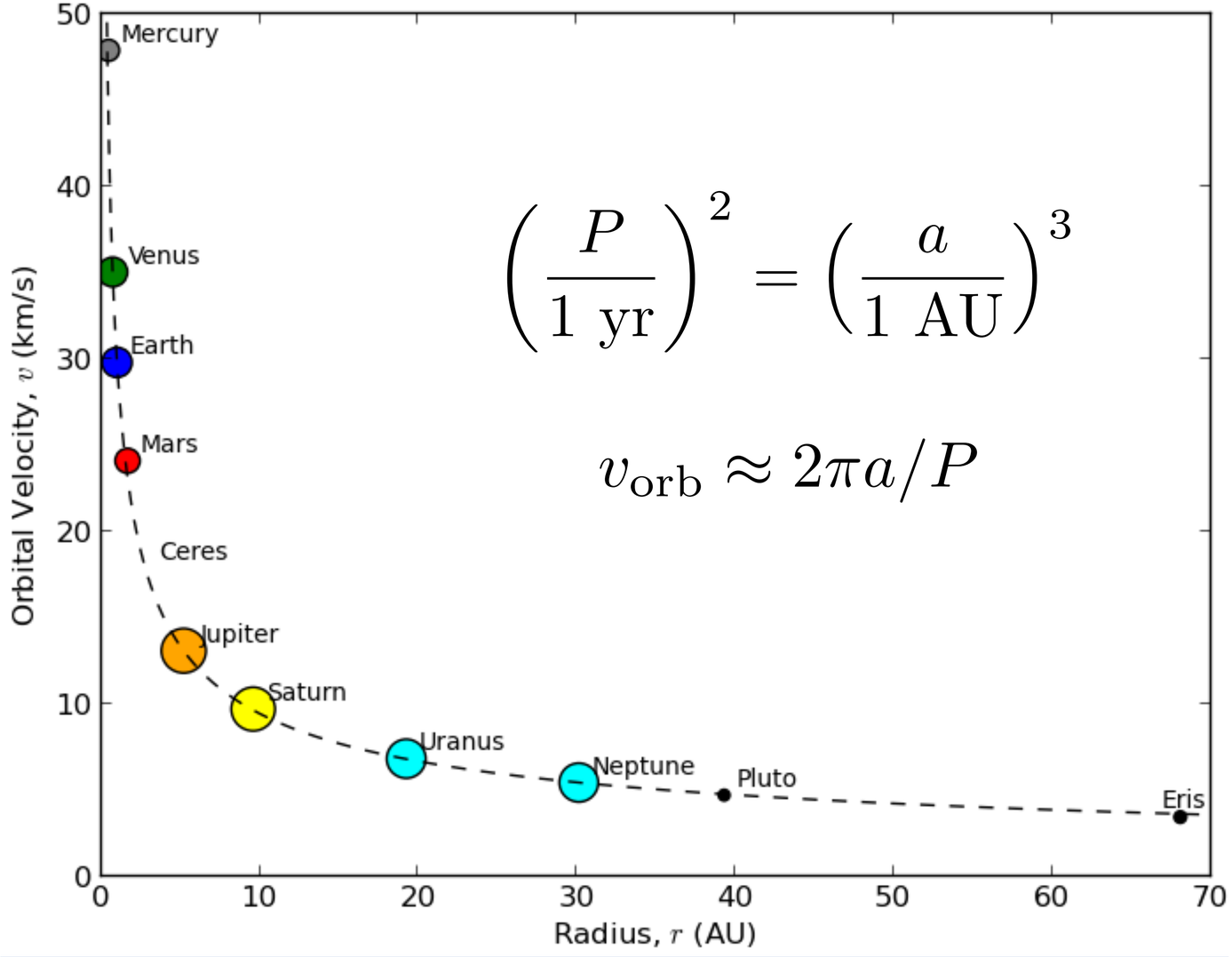


Proper Motion:

$$\mu = \frac{v_t}{d}$$

$$v = \sqrt{v_r^2 + v_t^2}$$

How do stars move in the Galaxy?



$$\left(\frac{P}{1\ \mathrm{yr}}\right)^2 = \left(\frac{a}{1\ \mathrm{AU}}\right)^3$$

$$v_{\mathrm{orb}} \approx 2\pi a/P$$

Kepler's 3rd Law in the Galaxy

$$M_\odot + M_G(<r) = \frac{(a/1\ \mathrm{AU})^3}{(P/1\ \mathrm{yr})^2}$$

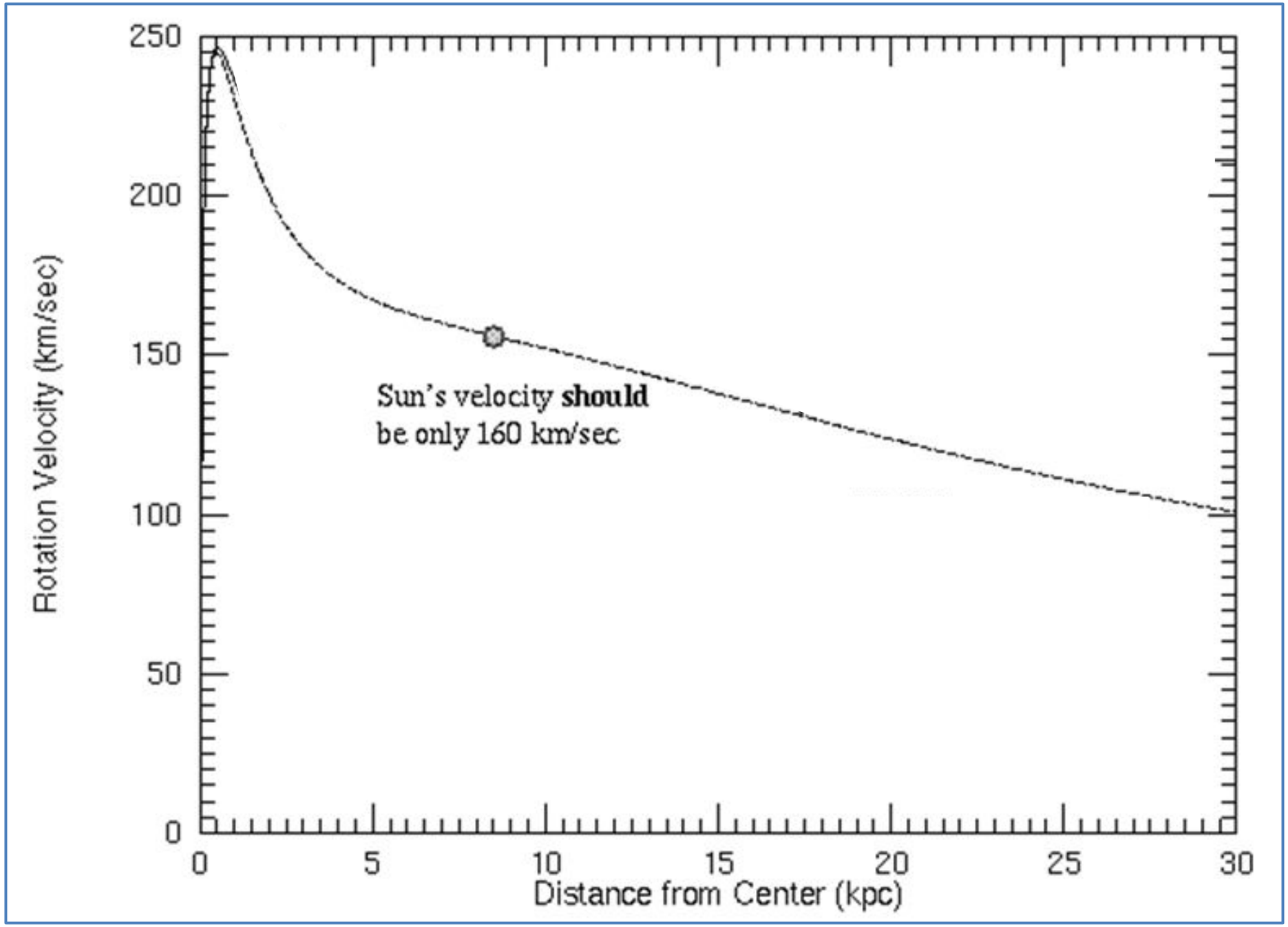
Mass inside Sun's orbit

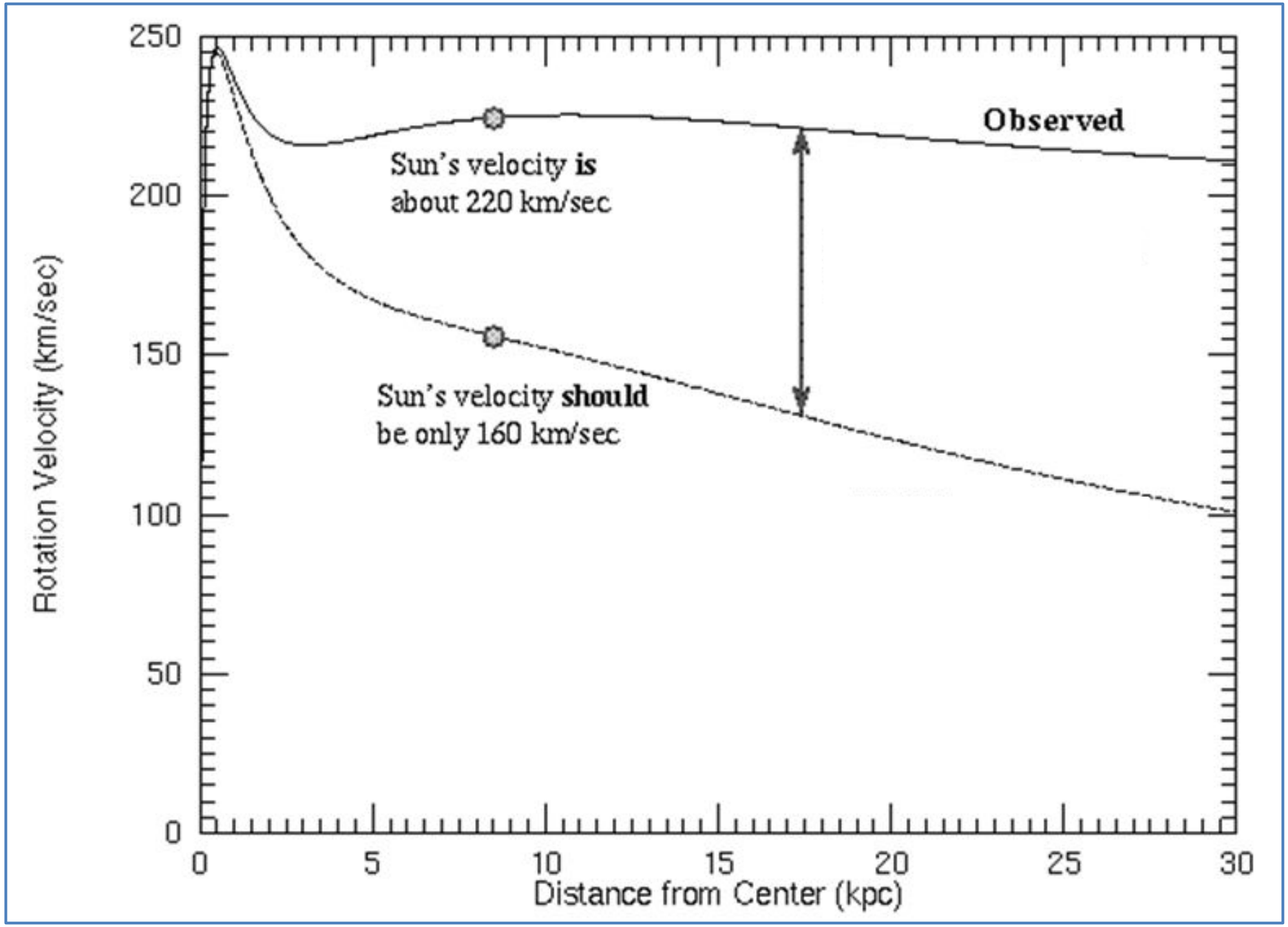
$$a \approx 8\ \mathrm{kpc}$$
$$P \approx 220\ \mathrm{Myr}$$

$$M_G(<r) \approx 9.3 \times 10^{10}\ M_\odot$$

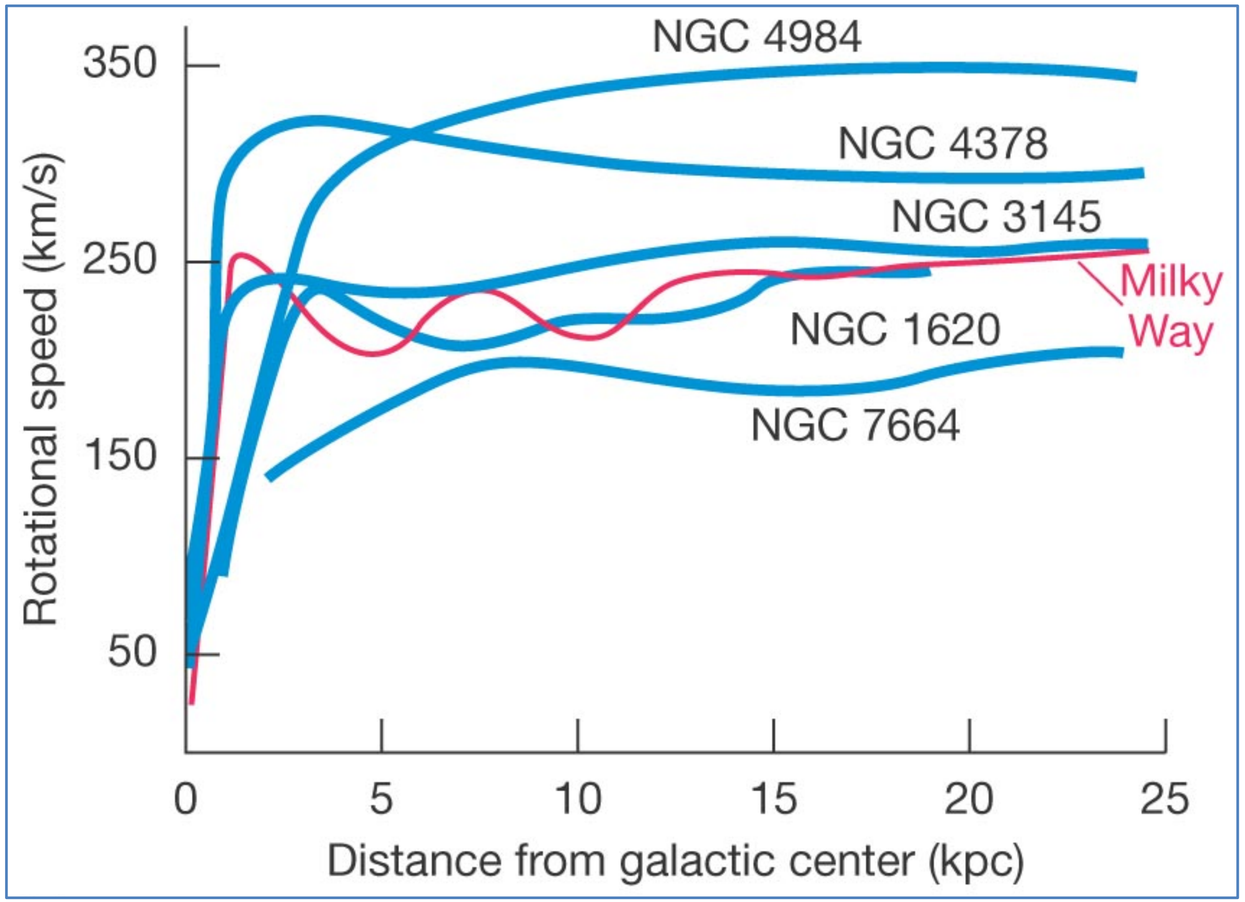
$$\frac{v(R)^2}{R} = \frac{GM_G(<R)}{R^2}$$

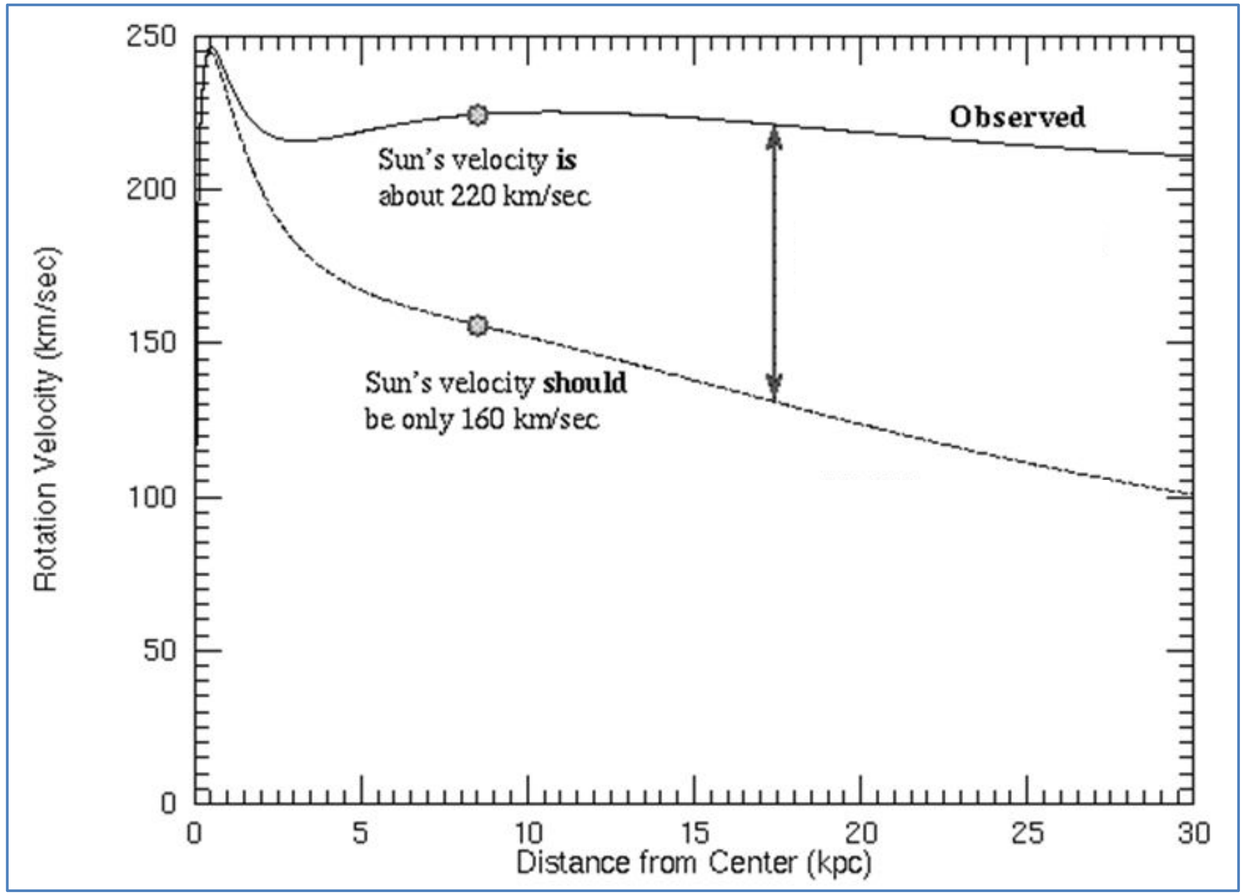
$$v(r) \propto \left(\frac{M_G(<R)}{R}\right)^{1/2} \propto R^{-1/2}$$

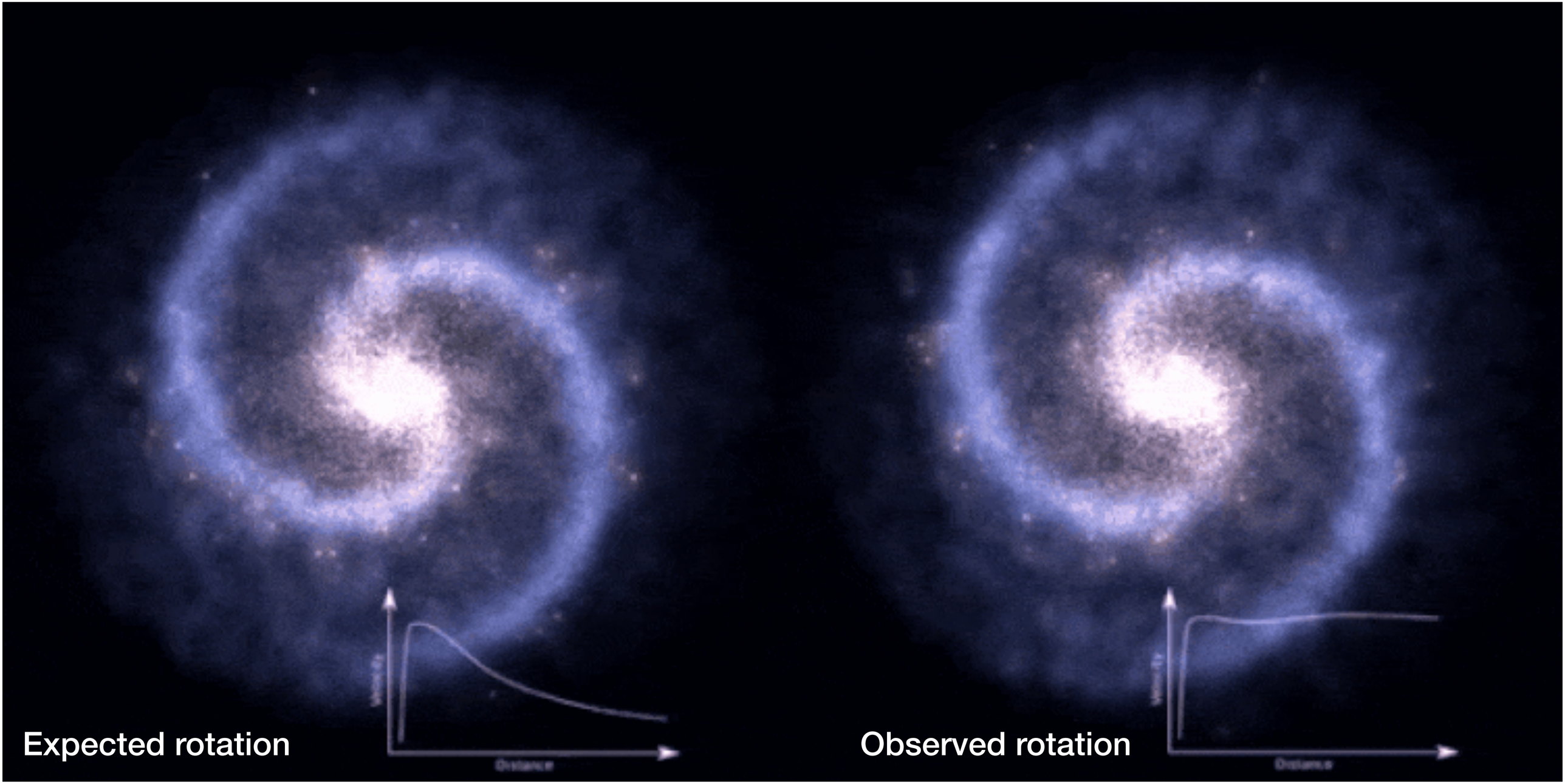

250
200
150
100
50
0
Rotation Velocity (km/sec)
Sun's velocity **should**
be only 160 km/sec
0
5
10
15
20
25
30
Distance from Center (kpc)


Observed
Sun's velocity is
about 220 km/sec
Sun's velocity should
be only 160 km/sec
Rotation Velocity (km/sec)
250
200
150
100
50
0
0
5
10
15
20
25
30
Distance from Center (kpc)

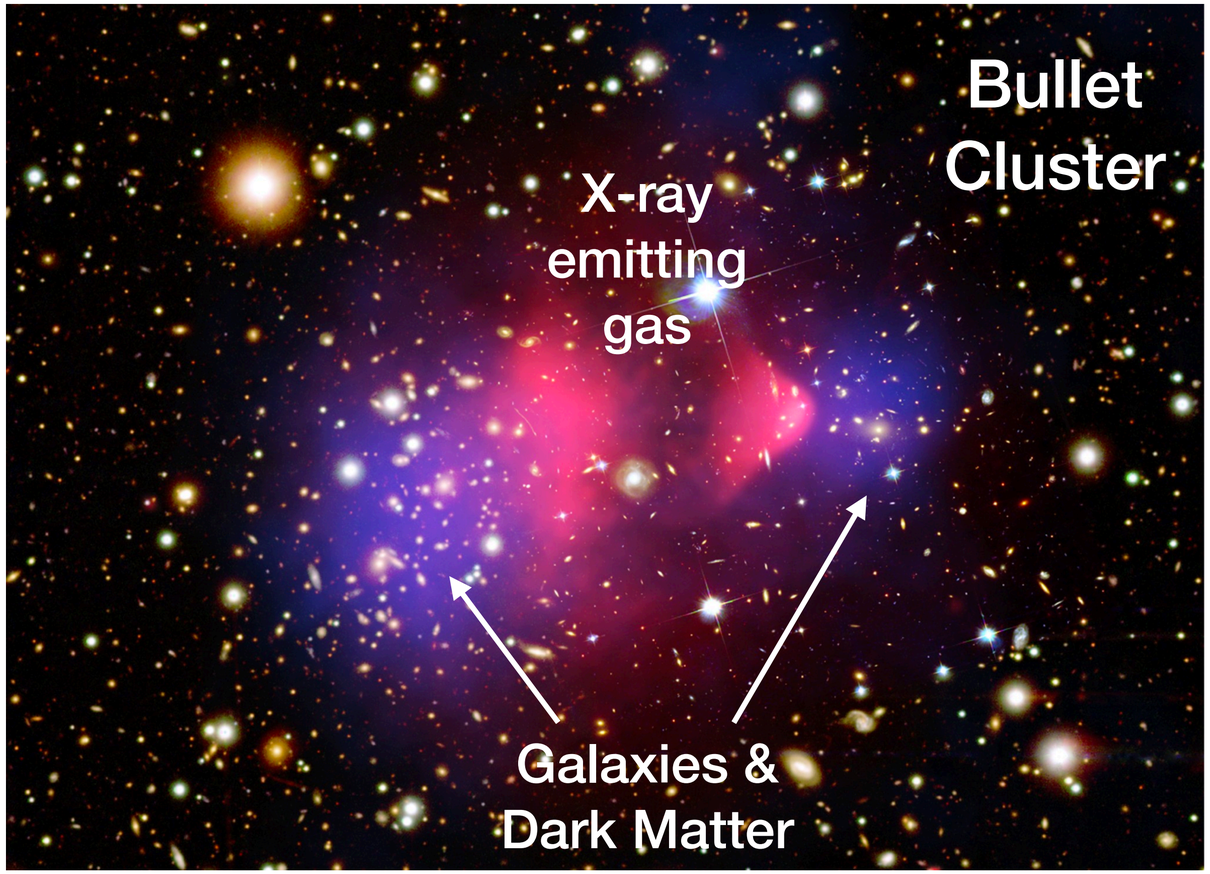
Milky Way is not alone — there is extra, non-luminous matter in galaxies: “dark matter”



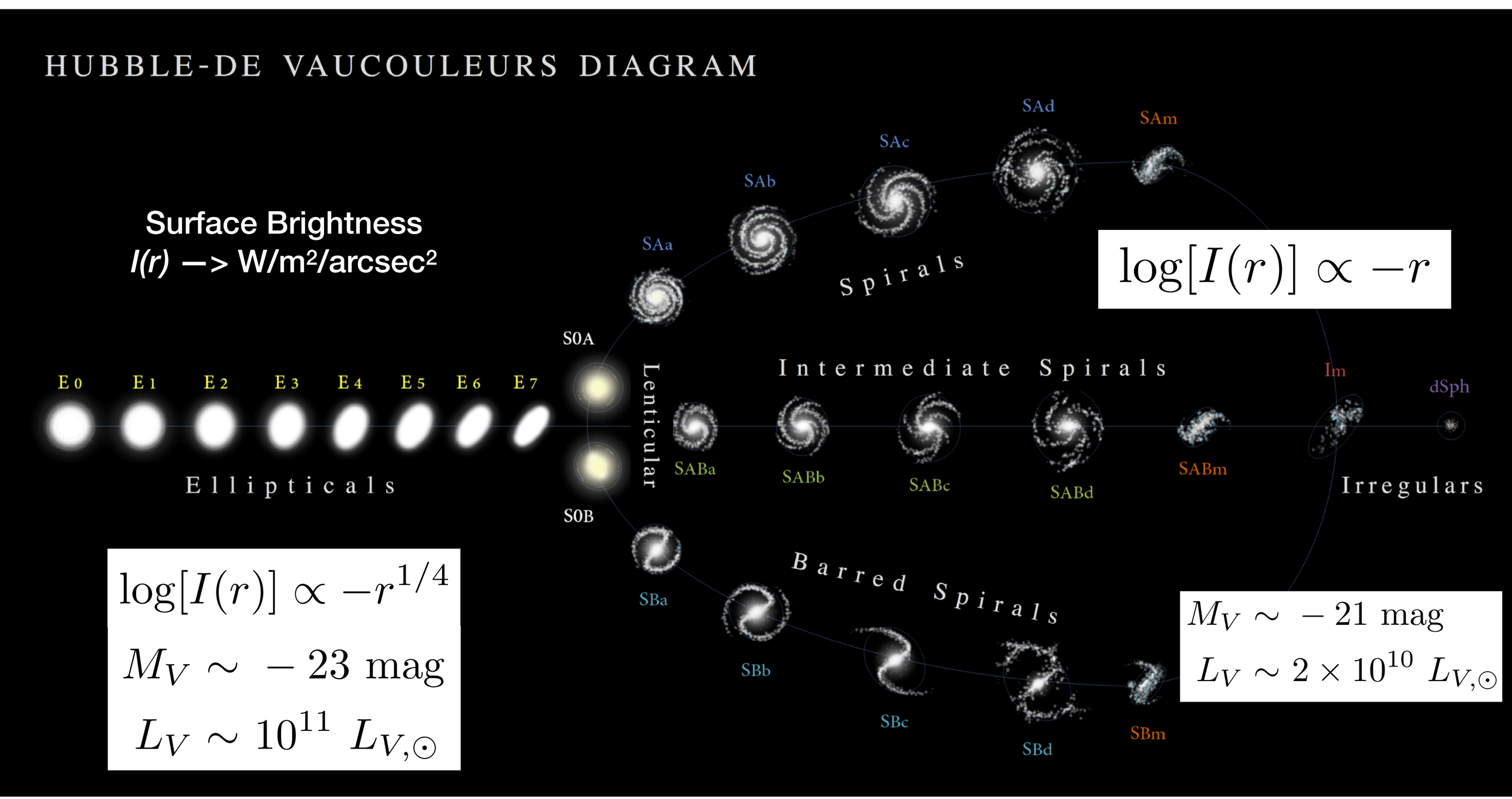


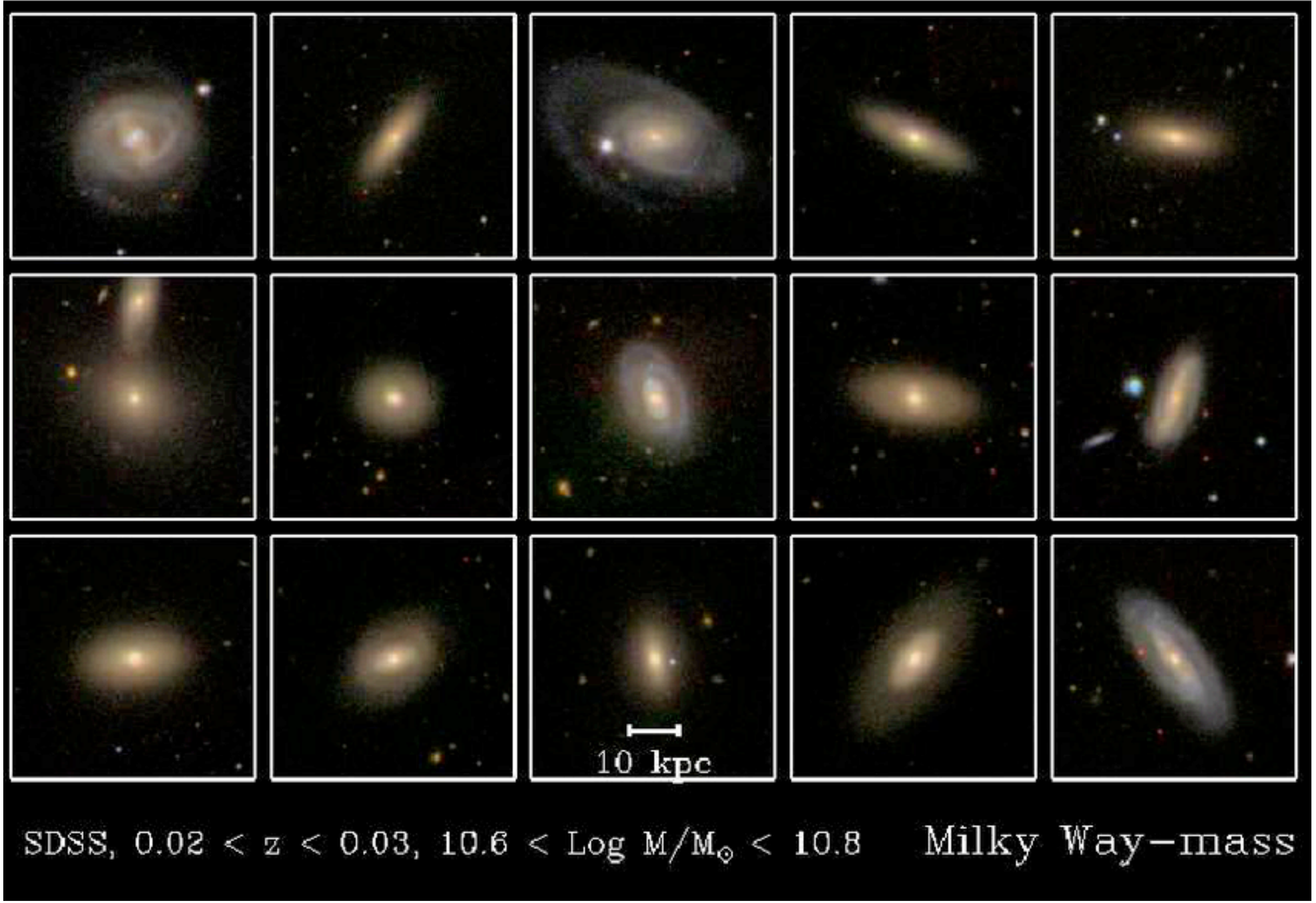

Expected rotation
Observed rotation

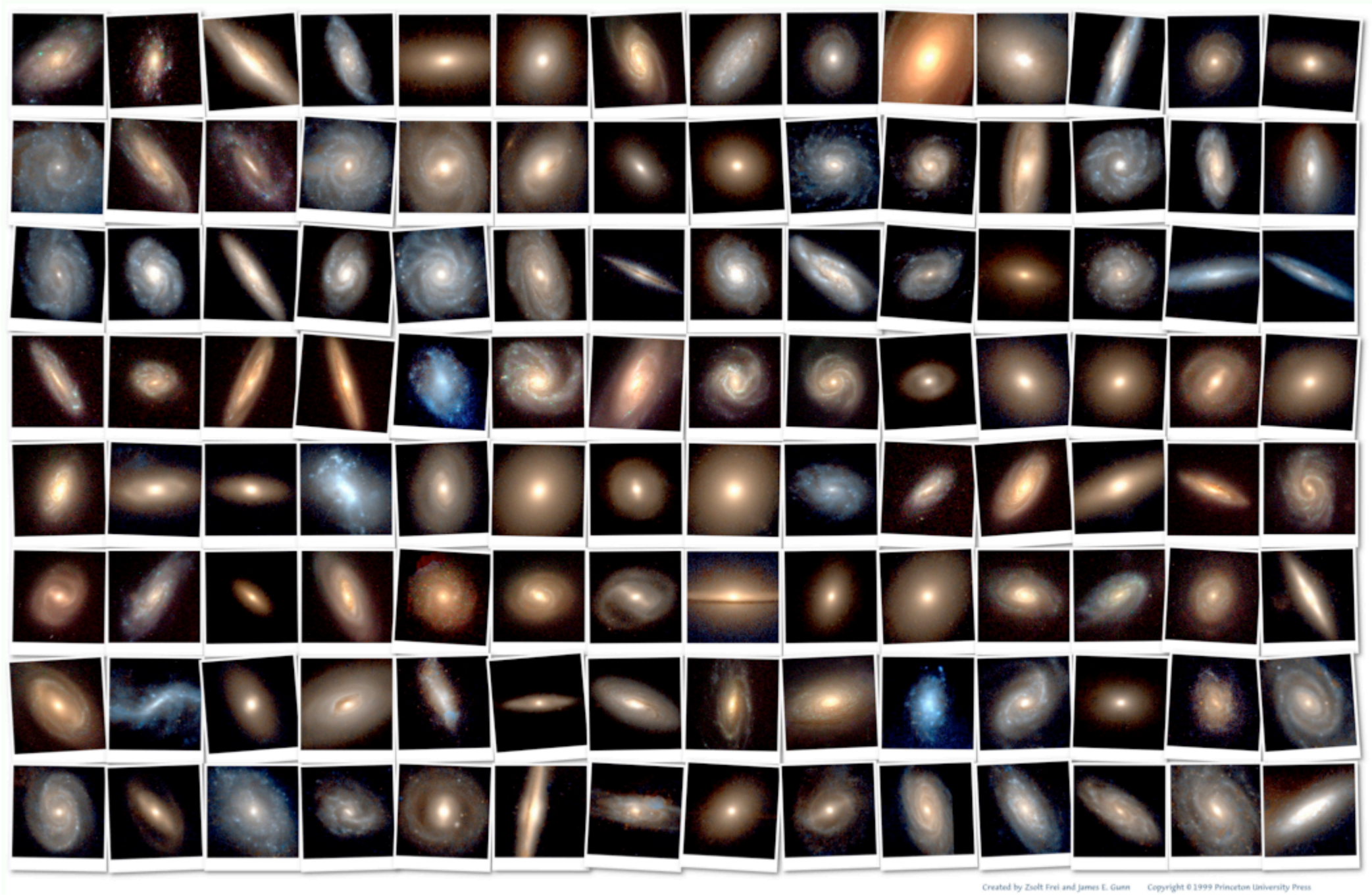
Dark Matter: what is it?



- Neutrinos (like those produced in fusion
  - Have mass, but not enough
  - New kind? Sterile Neutrino
- WIMP (Weakly Interacting Massive Particle)
  - Direct detection searches have failed
  - “WIMP miracle” not miraculous
- MACHO (MAssive Compact Halo Object)
  - WDs, NSs, BHs roaming around
  - Can detect via gravitational lensing - ruled out
- Theorists are clever - can invent other options!
- Modified Gravity (explains galaxy rotation, but…)


HUBBLE-DE VAUCOULEURS DIAGRAM
Surface Brightness
I(r) —> W/m²/arcsec²
$\log[I(r)] \propto -r$
E0 E1 E2 E3 E4 E5 E6 E7
Ellipticals
S0A
S0B
Lenticular
SAa SAb SAc SAd SAm
Spirals
SABa SABb SABc SABd SABm
Intermediate Spirals
Im
dSph
Irregulars
SBa SBb SBc SBd SBm
Barred Spirals
$\log[I(r)] \propto -r^{1/4}$
$M_V \sim -23$ mag
$L_V \sim 10^{11}\ L_{V,\odot}$
$M_V \sim -21$ mag
$L_V \sim 2 \times 10^{10}\ L_{V,\odot}$


10 kpc
SDSS, 0.02 < z < 0.03, 10.6 < Log M/M$_\odot$ < 10.8
Milky Way−mass


Created by Zsolt Frei and James E. Gunn
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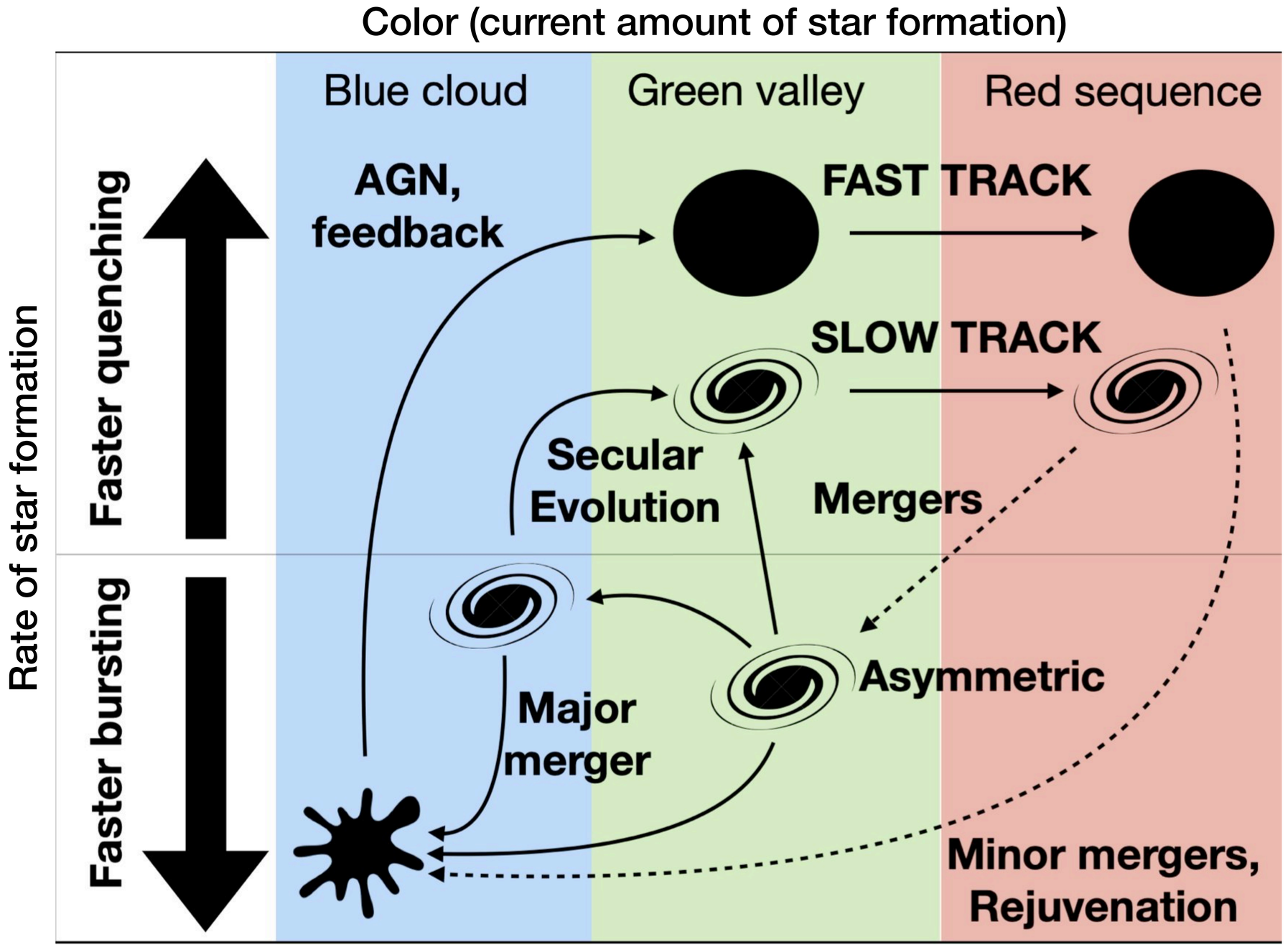
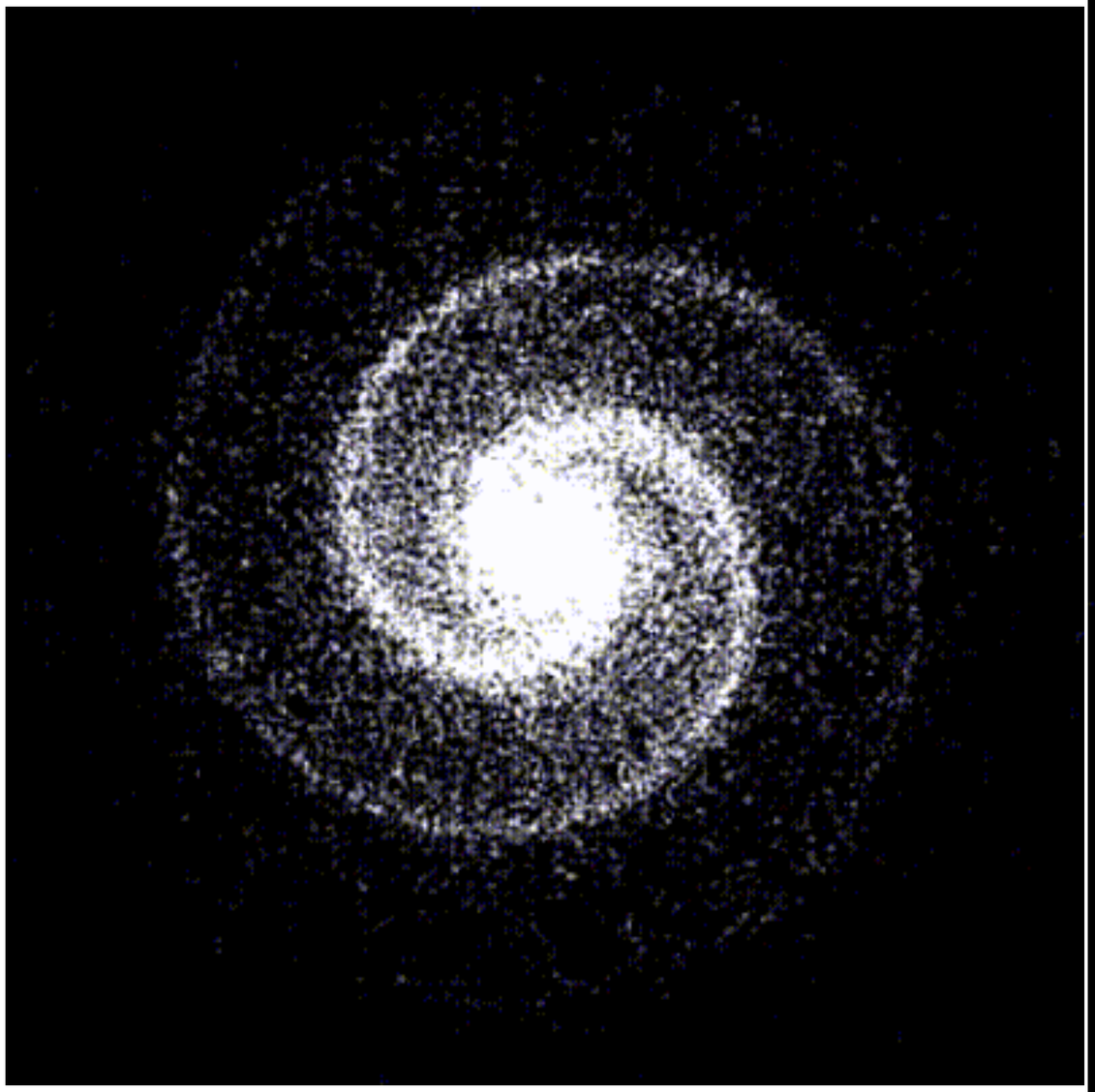
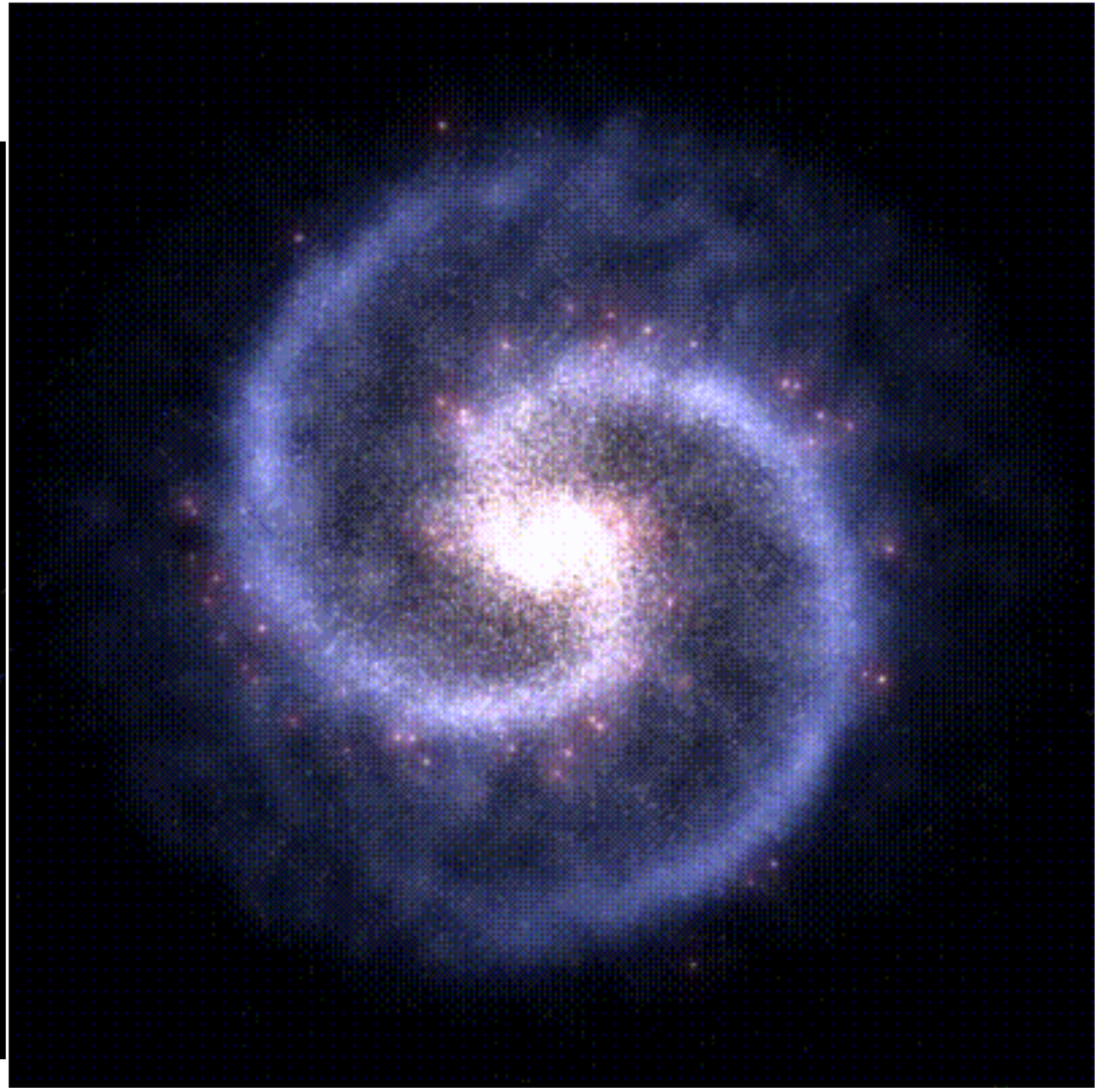


Growth / Evolution of Galaxies

Spiral Arms





Galaxies are not isolated

and R frames. After sky subtraction, the coadded frames were then normalized to their respective exposure times, resulting in pixel values in ADUs/second.

Figure 1.1

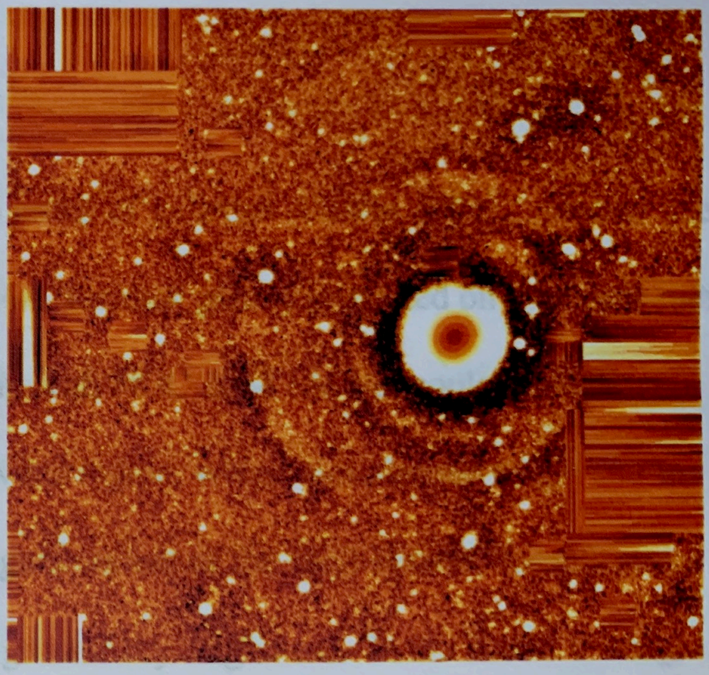
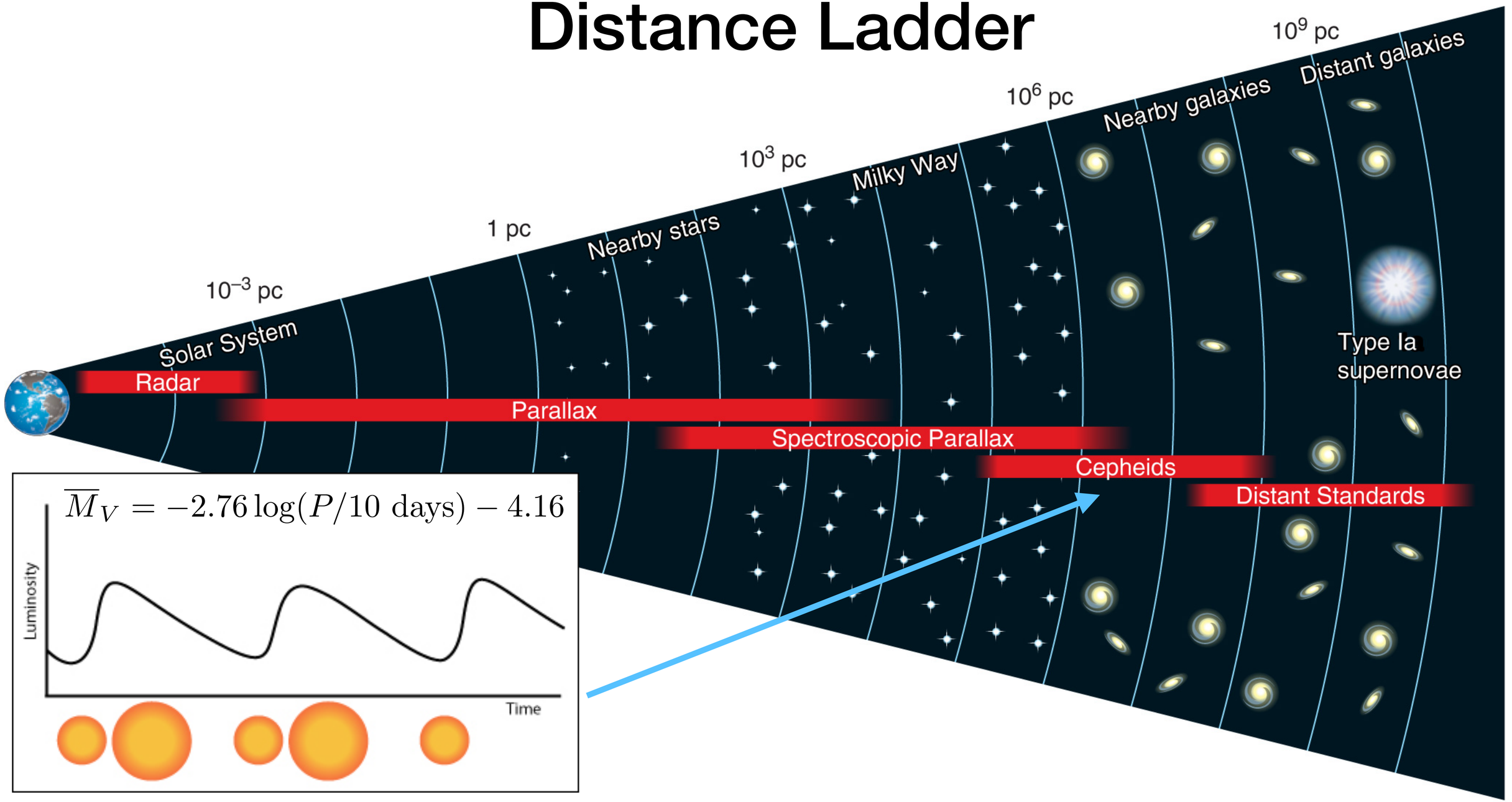
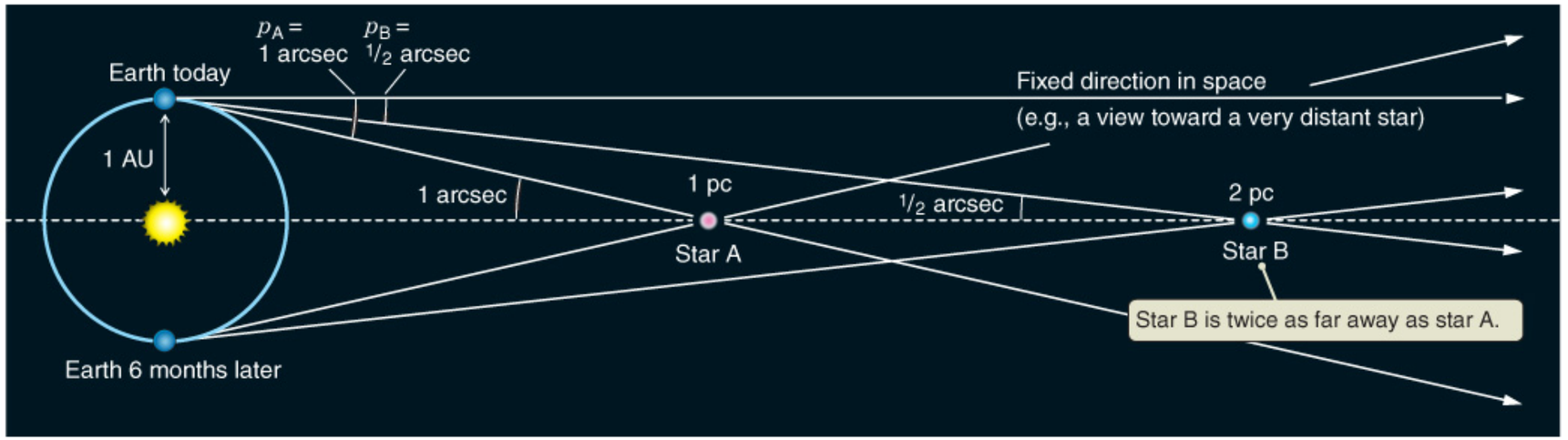


Figure 1.2

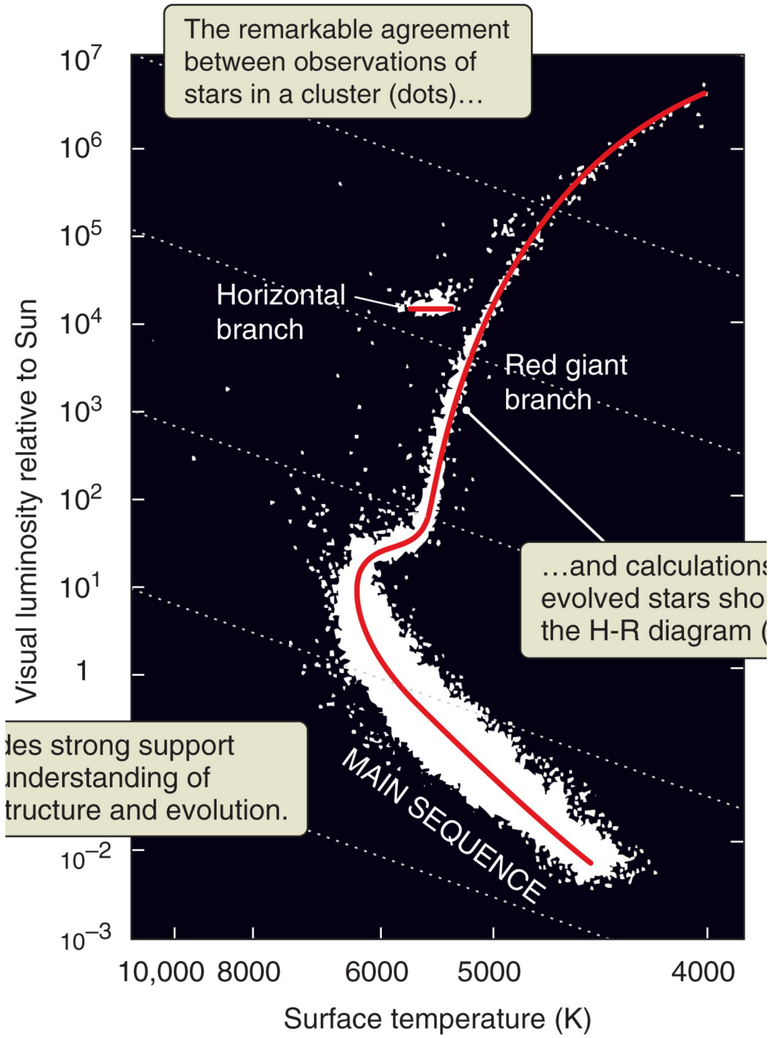
Distance Ladder



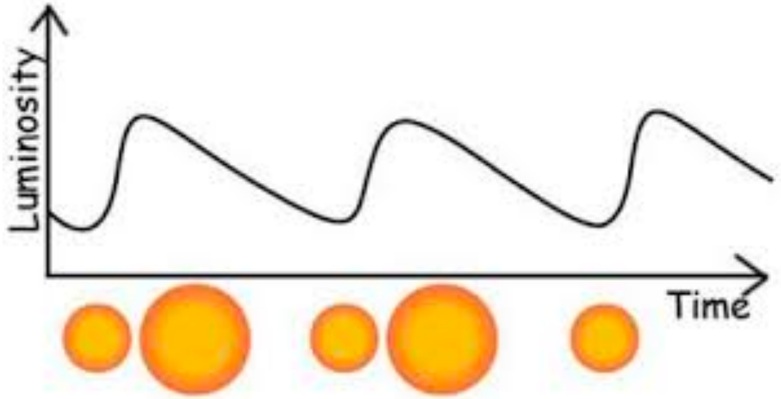
Parallax



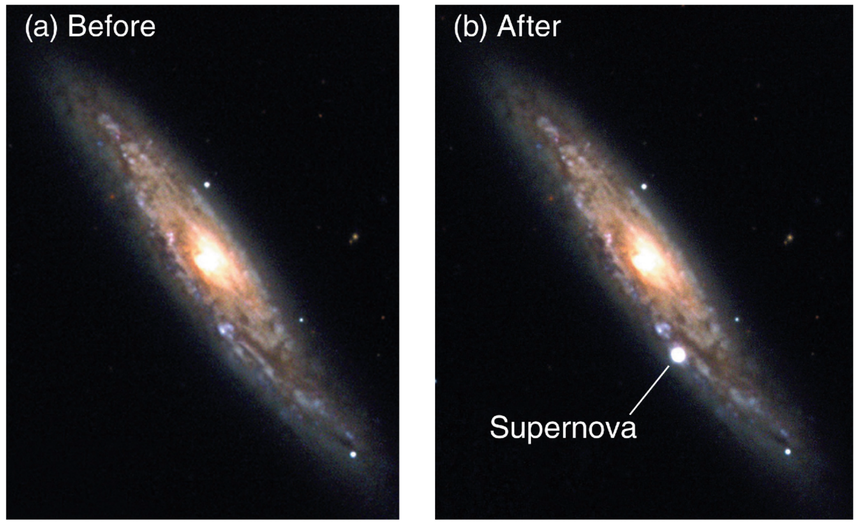
Spectroscopic Parallax



Cepheid Variables

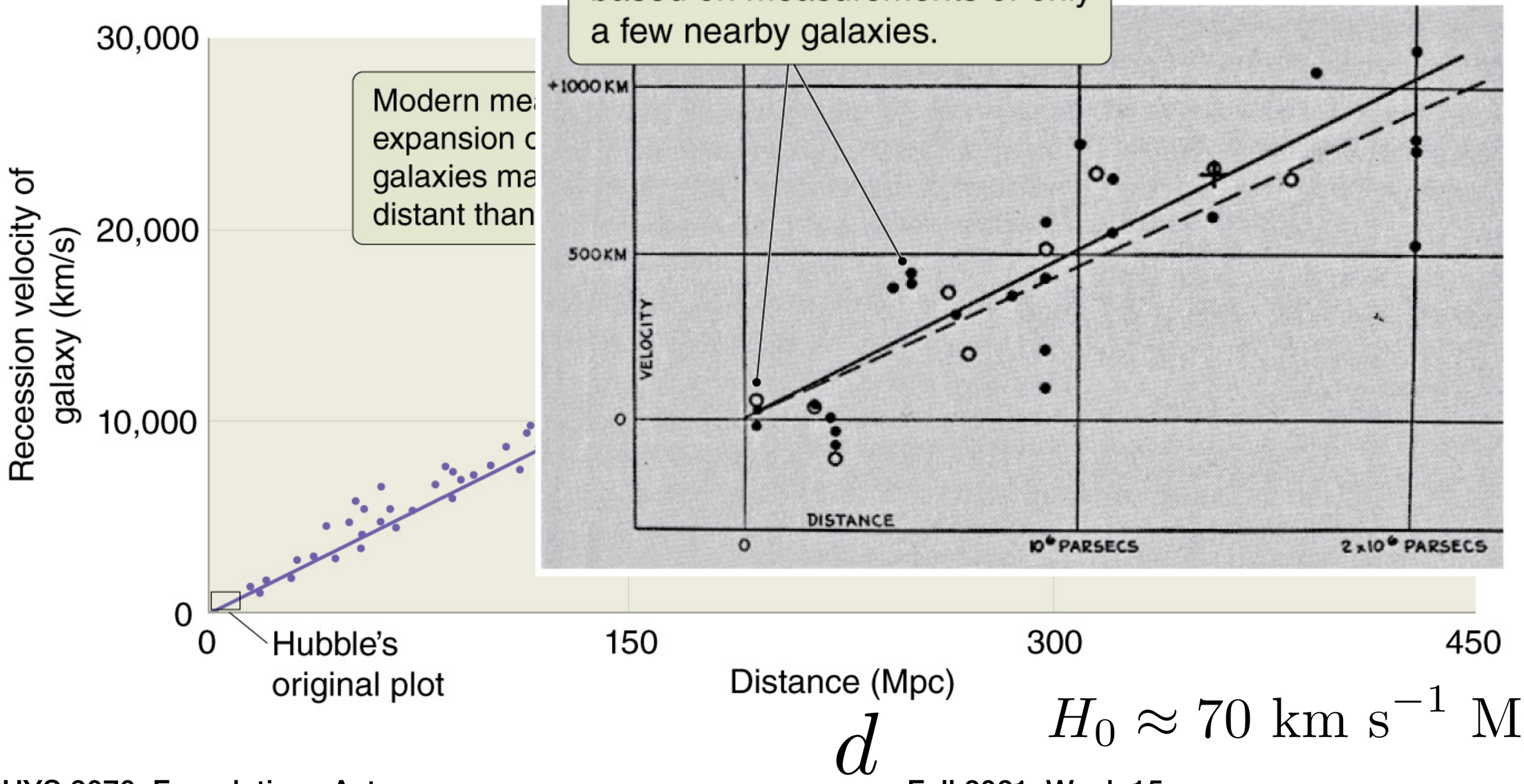


Type Ia SNe



Hubble's Law

$$cz = H_0 d$$

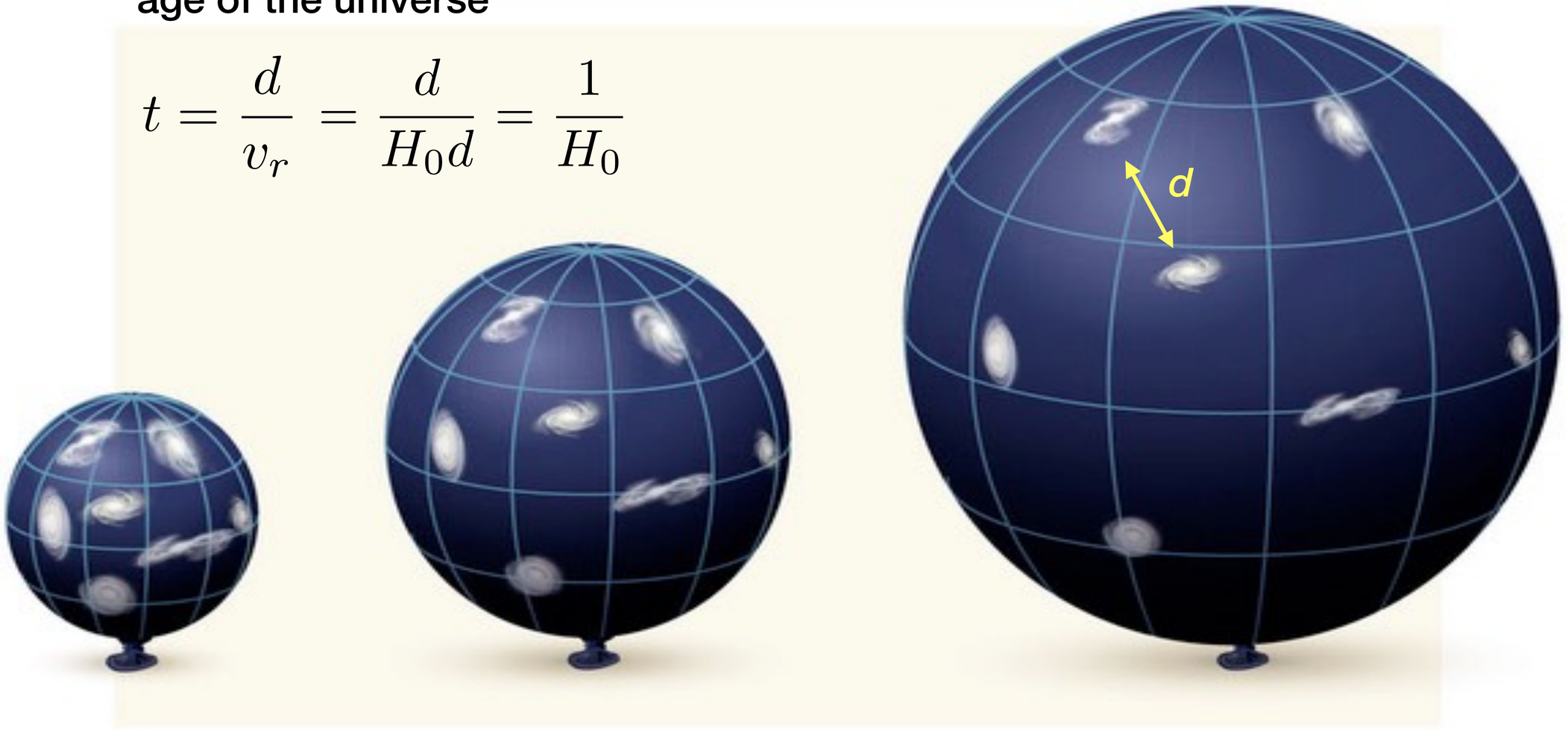


$$H_0 \approx 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

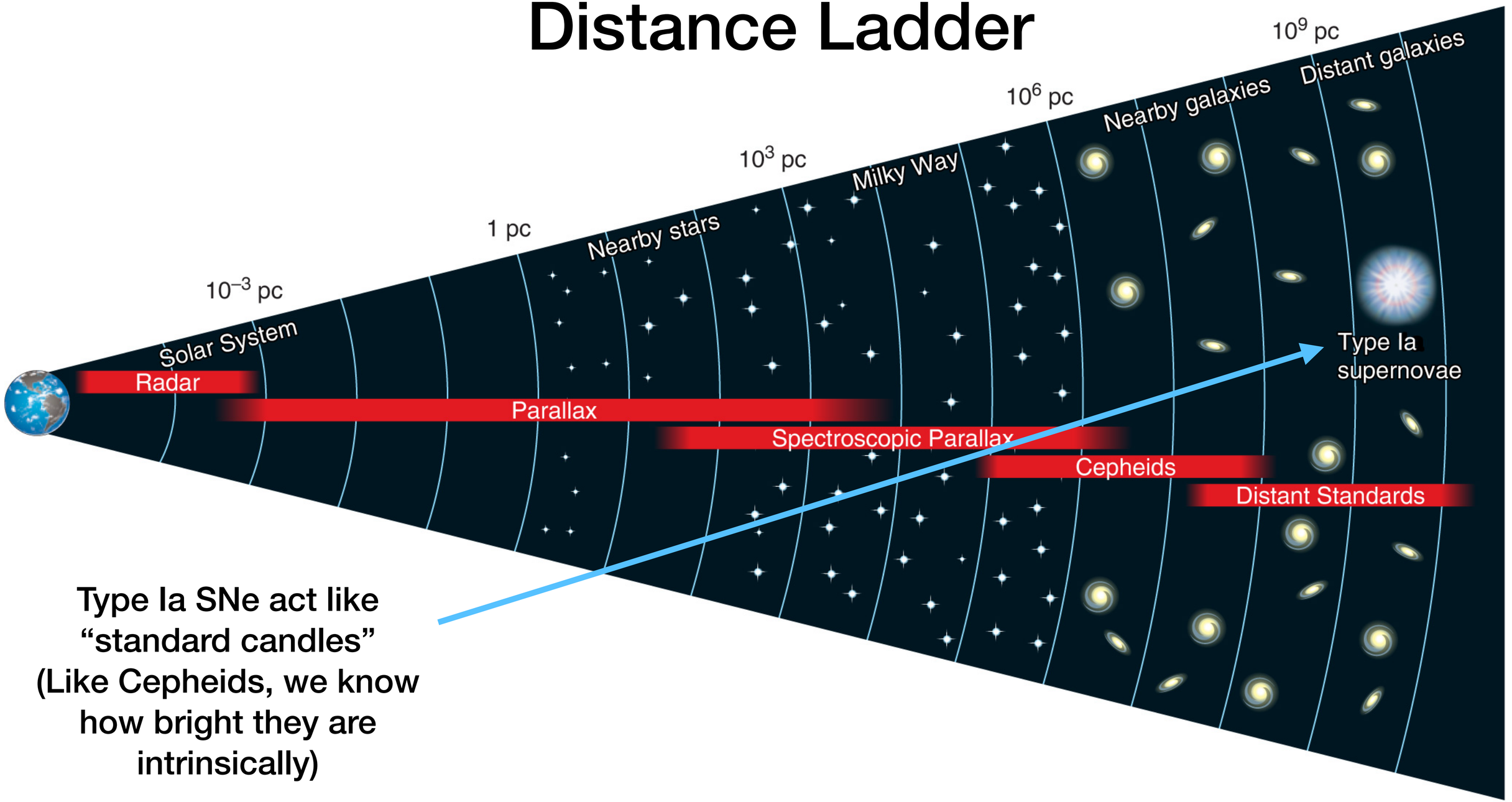
We live in an expanding “balloon universe”

If expansion constant, then can estimate the age of the universe

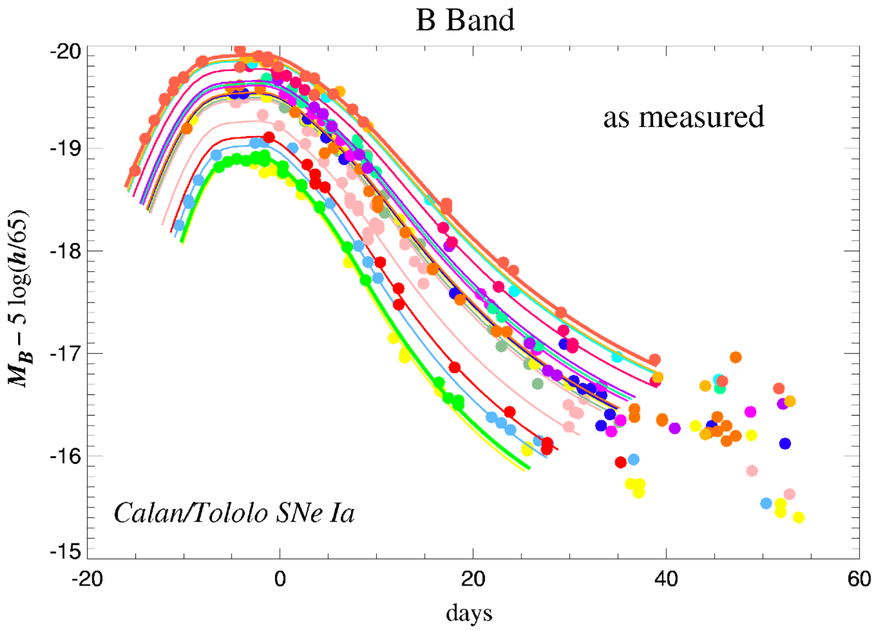
$$t = \frac{d}{v_r} = \frac{d}{H_0 d} = \frac{1}{H_0}$$



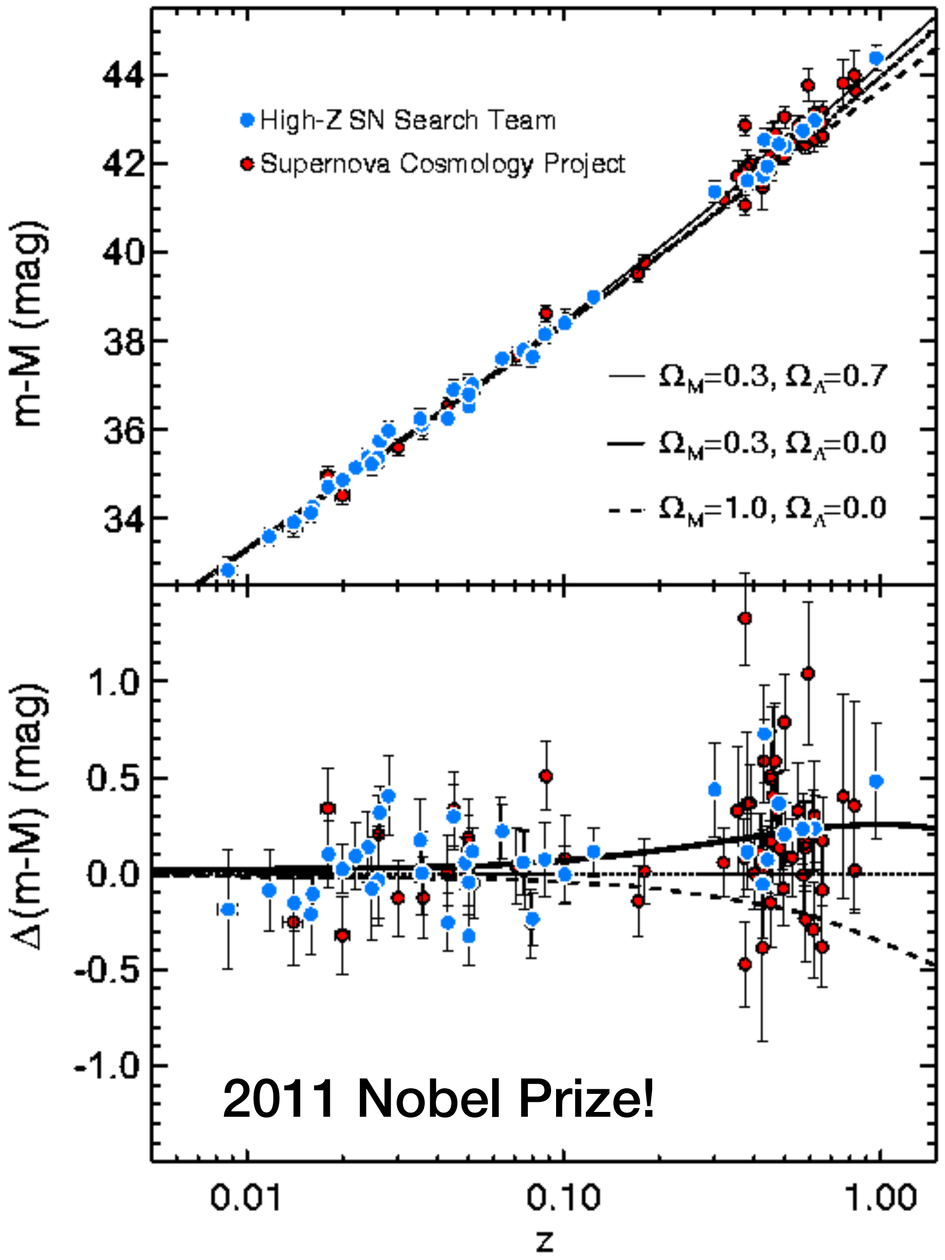
Distance Ladder



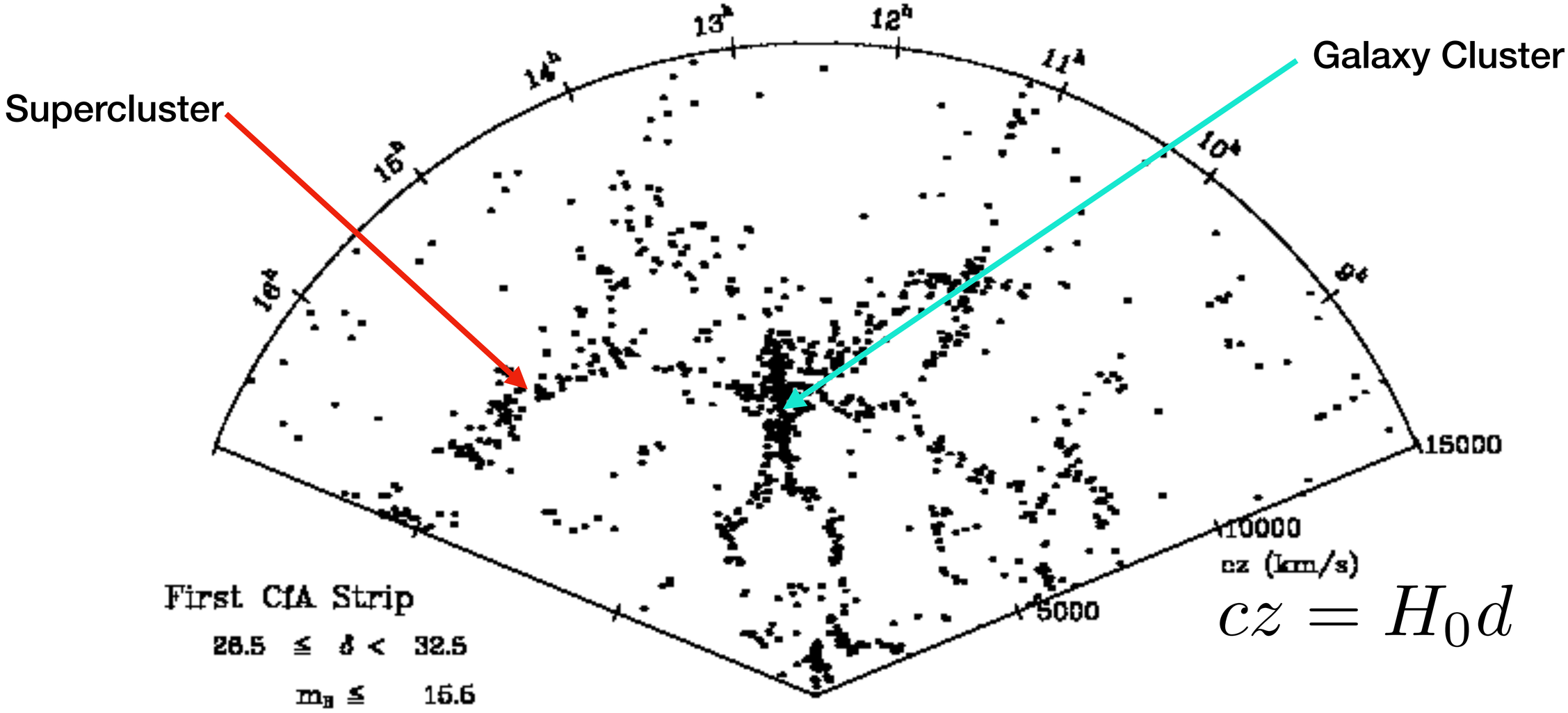
Type Ia SNe act like "standard candles" (Like Cepheids, we know how bright they are intrinsically)



Kim, *et al.* (1997)



Finger of God: the Coma Cluster



$$cz = H_0 d$$

Galaxy Surveys

Why does the pattern look different at high redshifts?