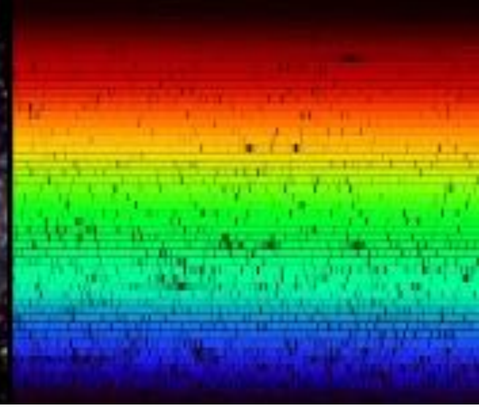


Week 10: Milky Way & Active Galaxies

HW9 due Thursday

Read Ch. 19.1-3, 19.7 for next week

Midterm 2 next Thursday

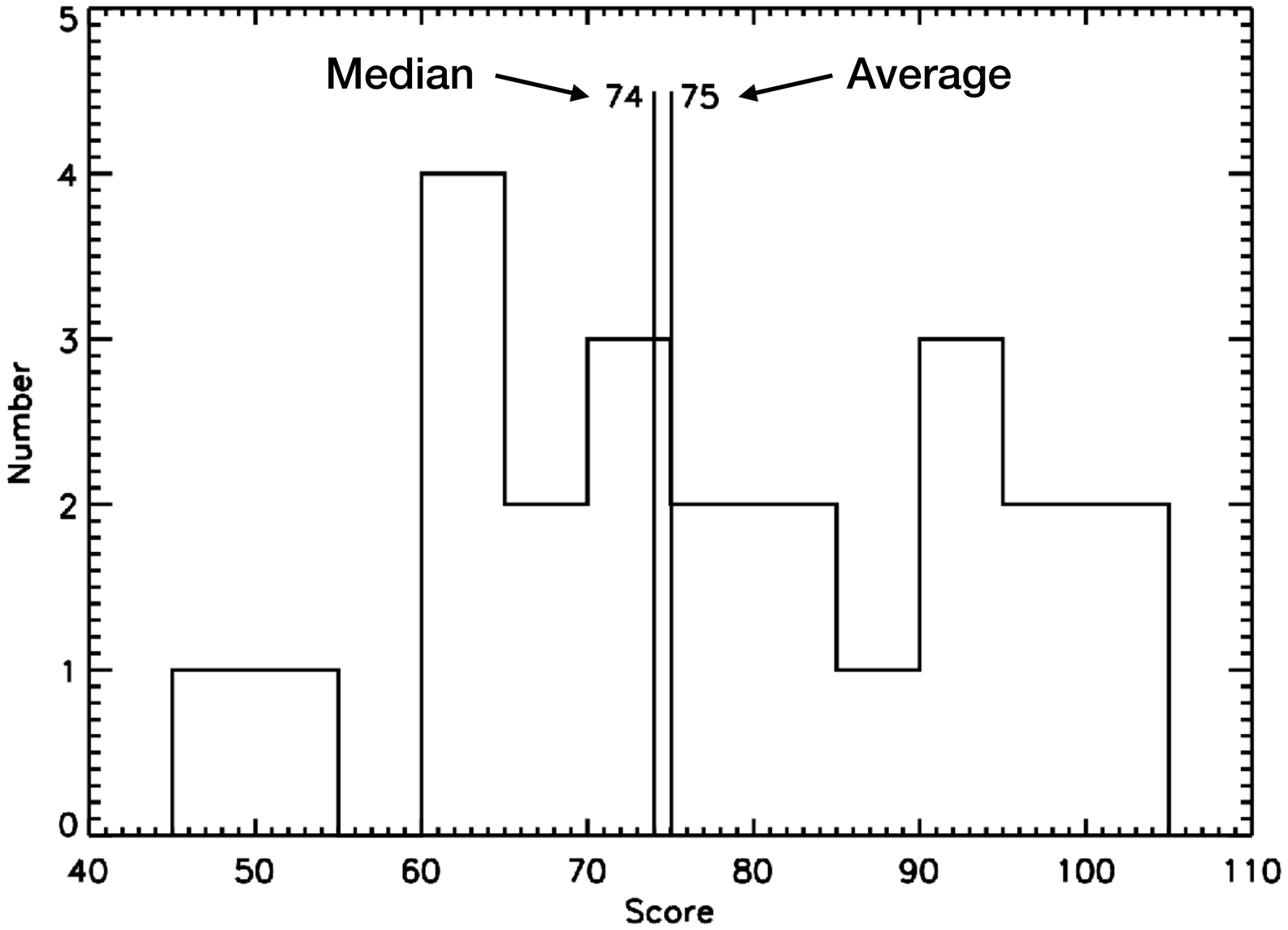
Workshop for Senior Undergrads planning to apply for graduate school

Monday, Nov. 9th 5:30-6:30pm?
The topics will be: (1) how to pick what schools to apply to, (2) choosing & contacting letter writers, and (3) preparing your written application.

Sample Retrieval from Asteroid Bennu

https://apod.nasa.gov/apod/astropix.html

Midterm 1 Results



No curve for now
(Any curve will be to your benefit)

Worth 10% of your grade
(Equivalent to 2.5 HWs)

Time a bit of an issue it appeared, but not overly so. I plan to make Midterm 2 shorter. Need to know the material though, or questions will be hard to parse.

Review the exam and make sure you understand what you missed. You will see that material again!

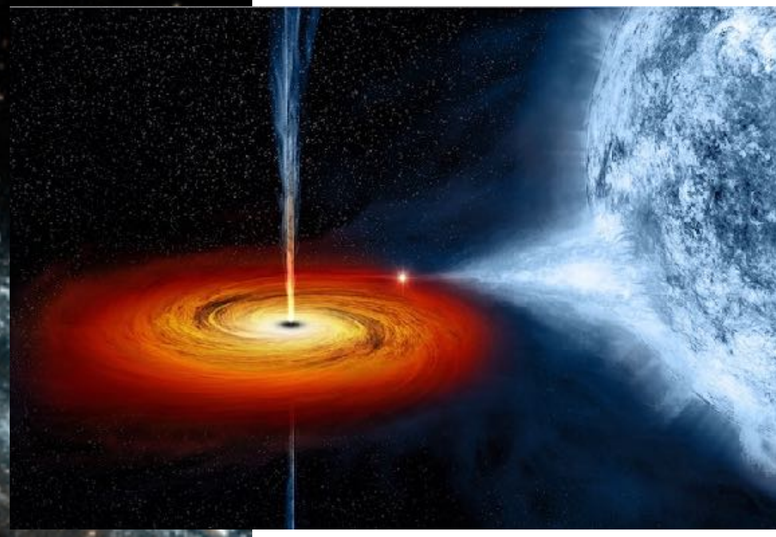
Observing real NSs and BHs

X-ray

Optical / UV

Andromeda Galaxy
(M31)

<u>X-ray Binaries</u>
Close binary stars where 1 star has exploded and is now accreting matter from its companion



Star's life determined mostly by its initial mass

White Dwarf:

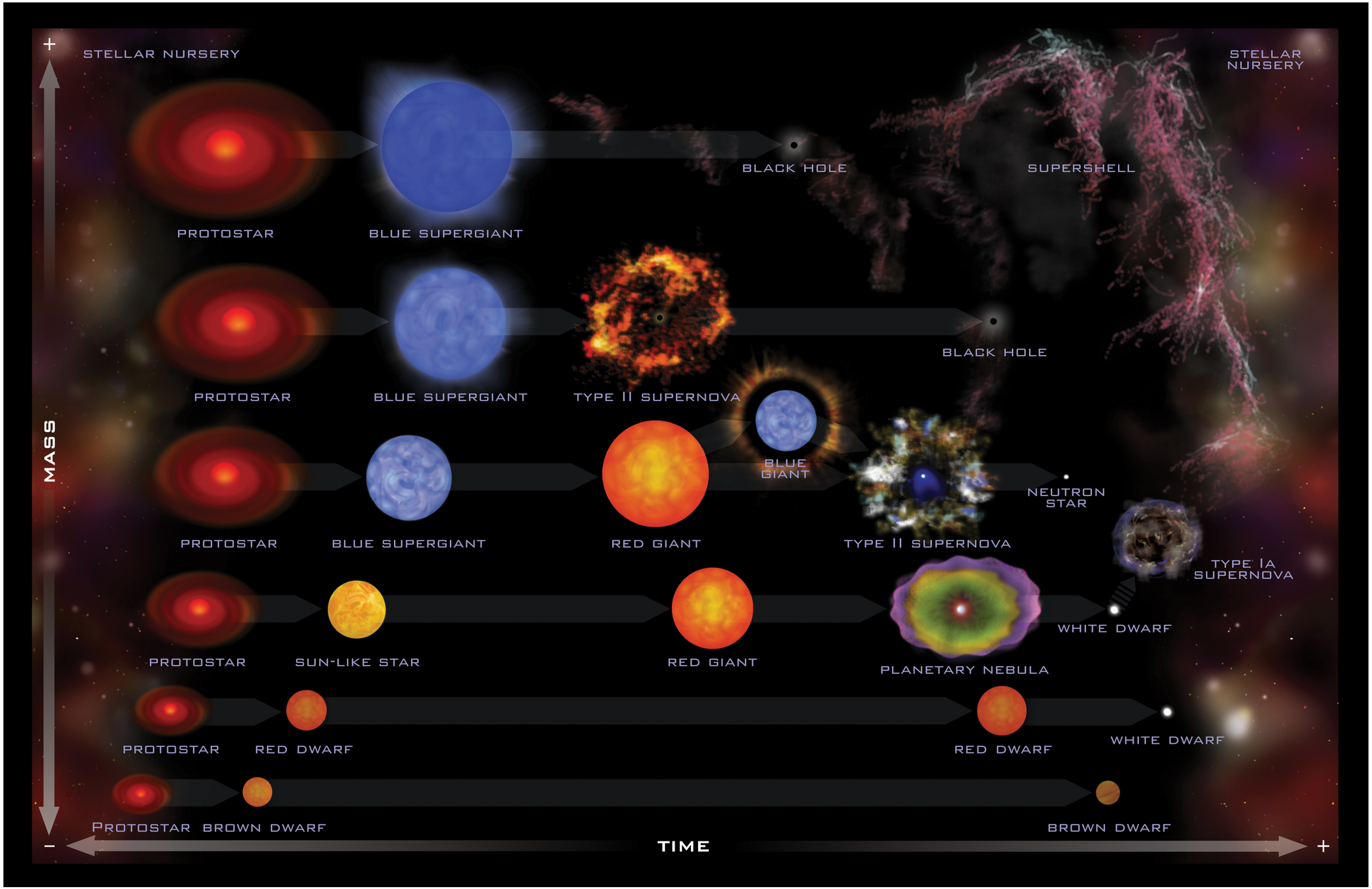
$$M < 7M_\odot$$

Neutron Star:

$$7M_\odot < M < 18M_\odot$$

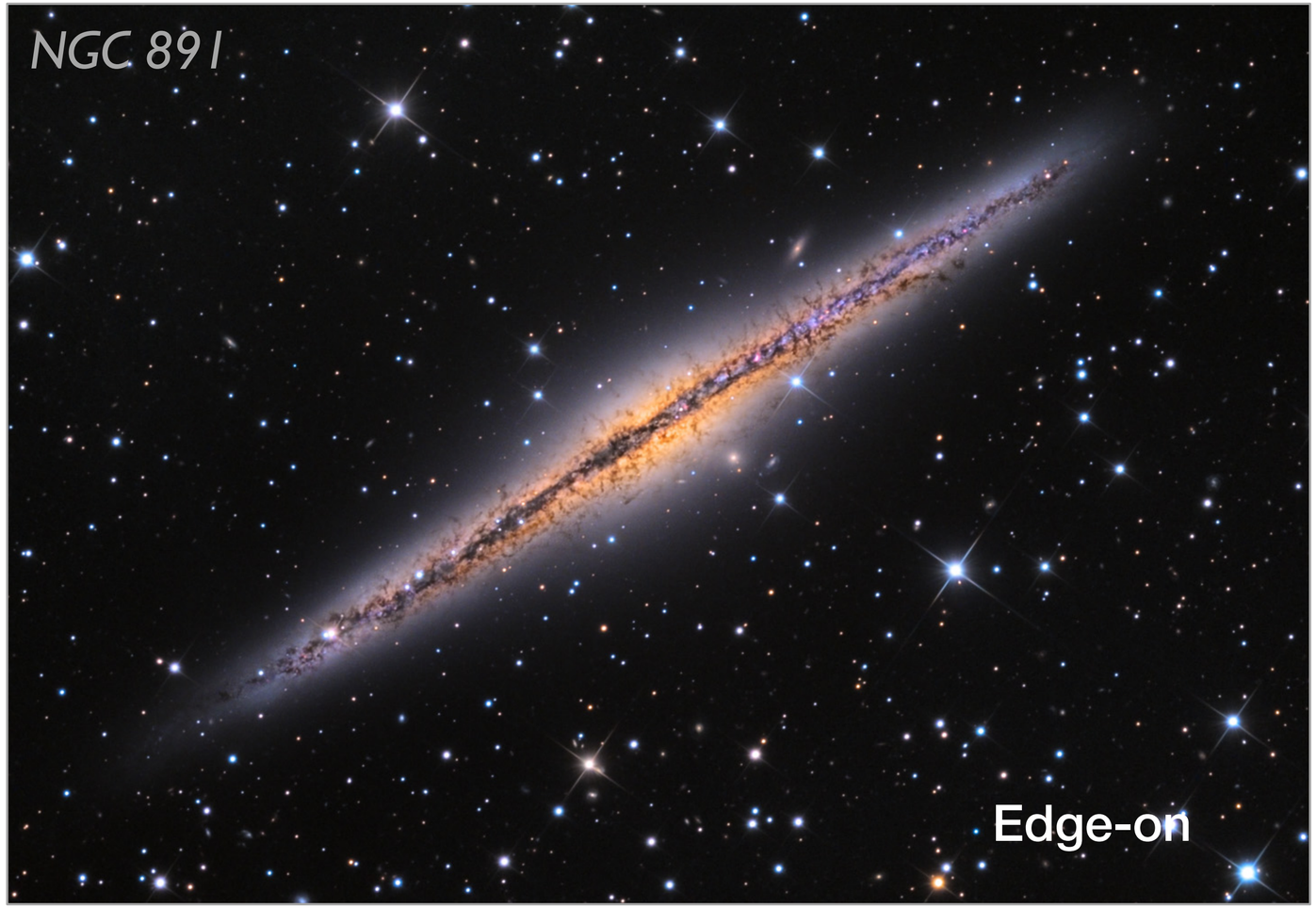
Black Hole:

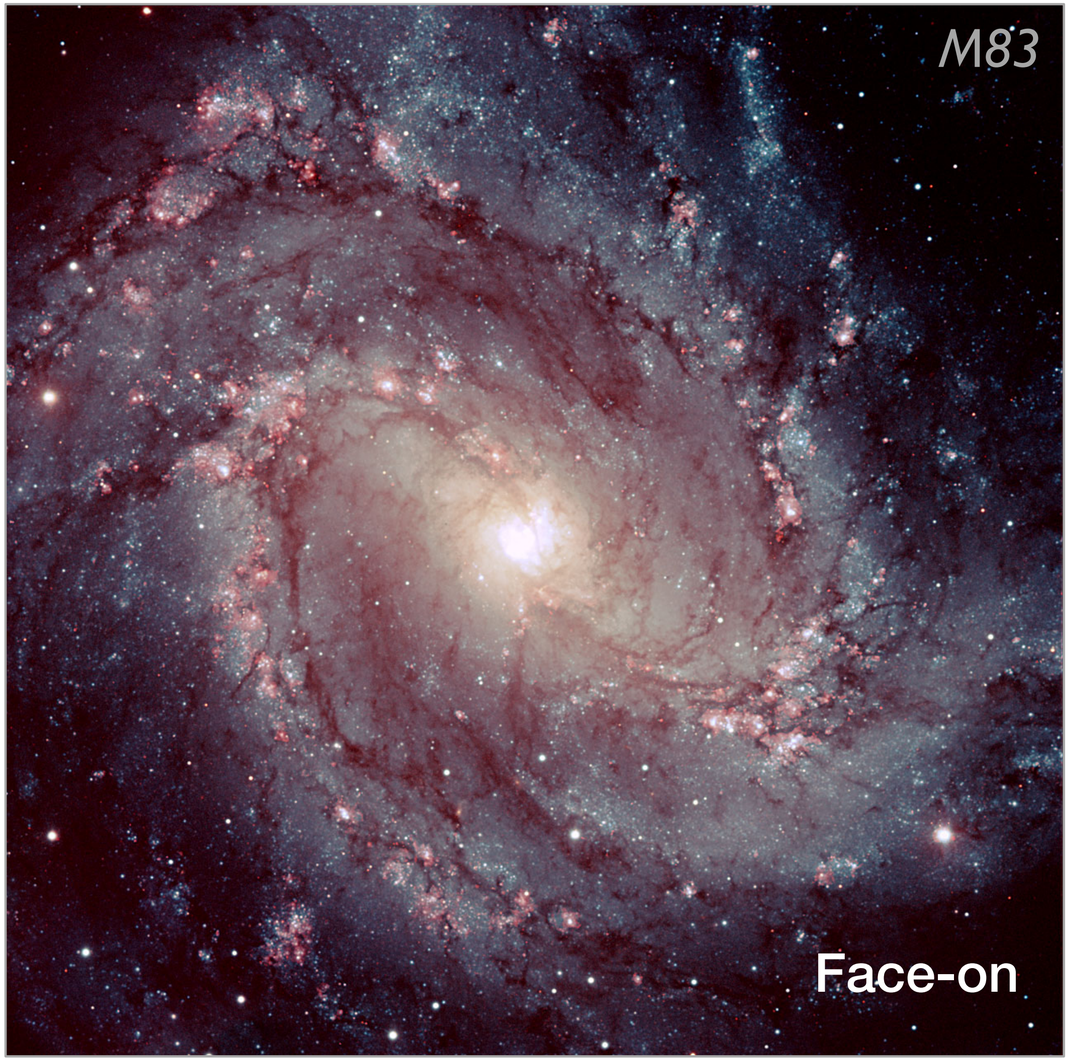
$$M > 18M_\odot$$



Our Galaxy, the Milky Way

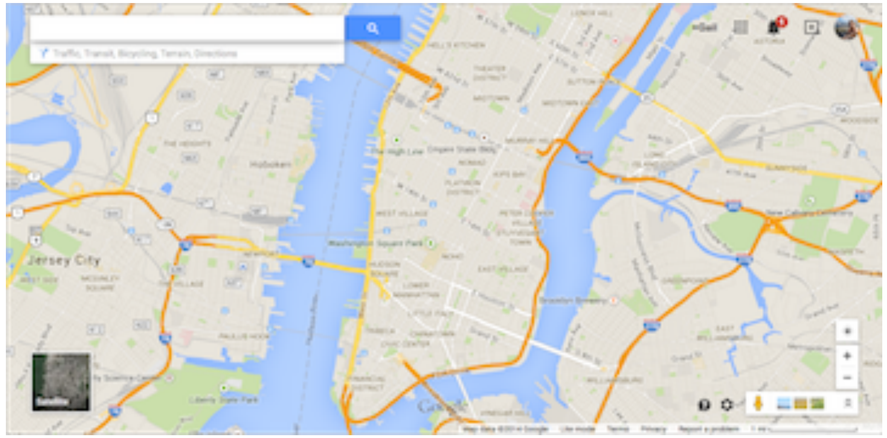
What it may look like from the outside



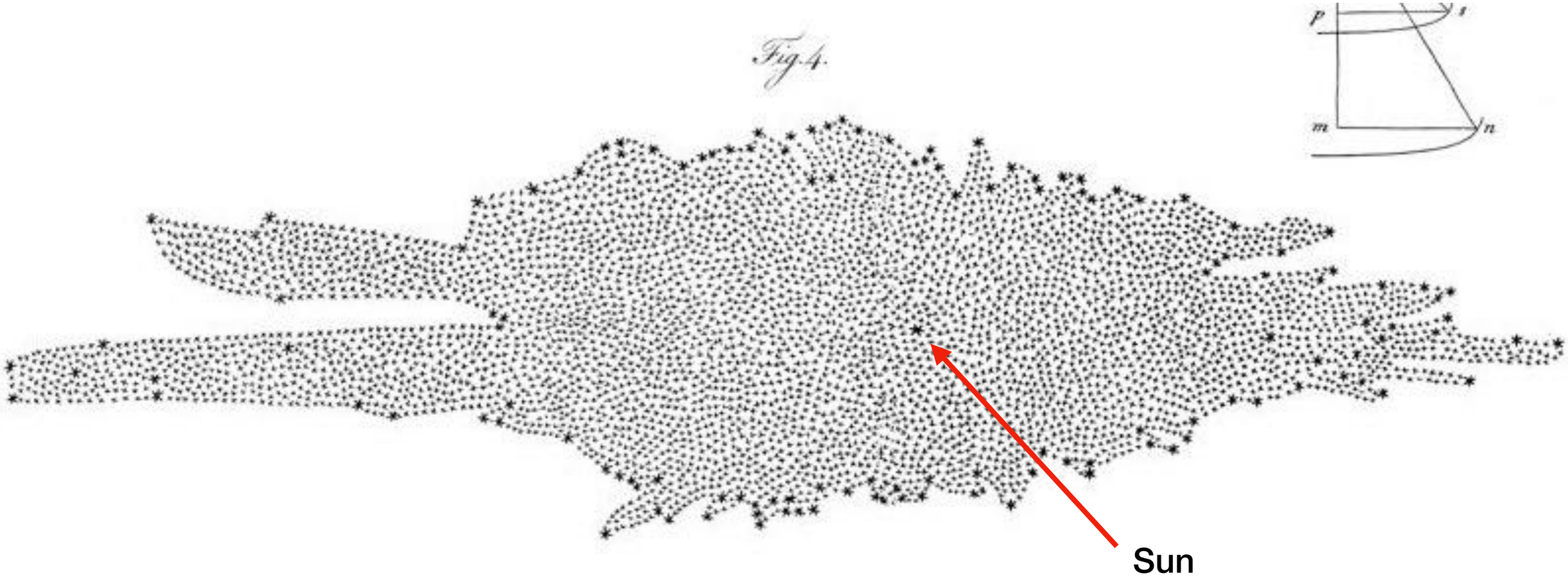


Our Galaxy, the Milky Way

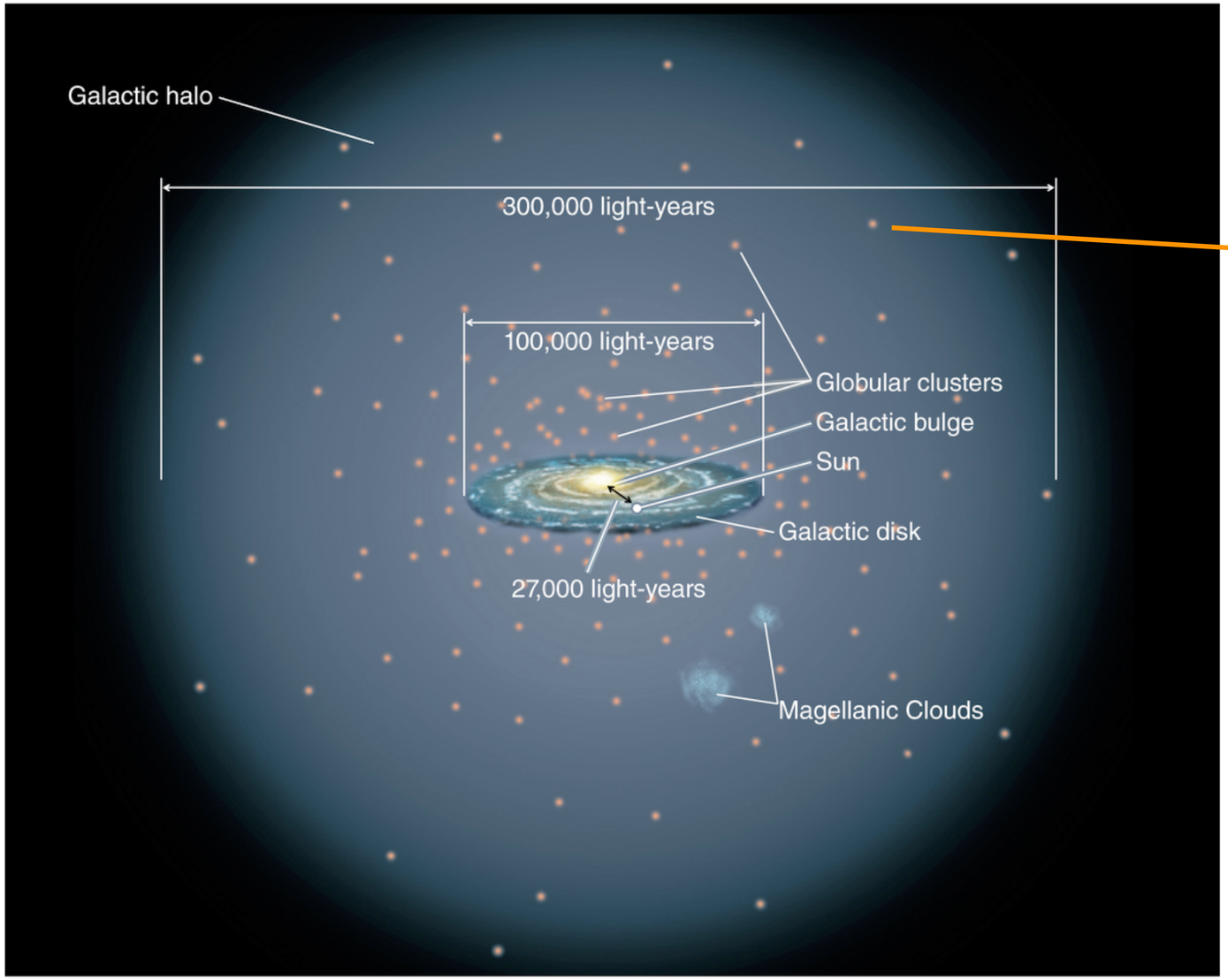
Can’t see the forest for the trees…

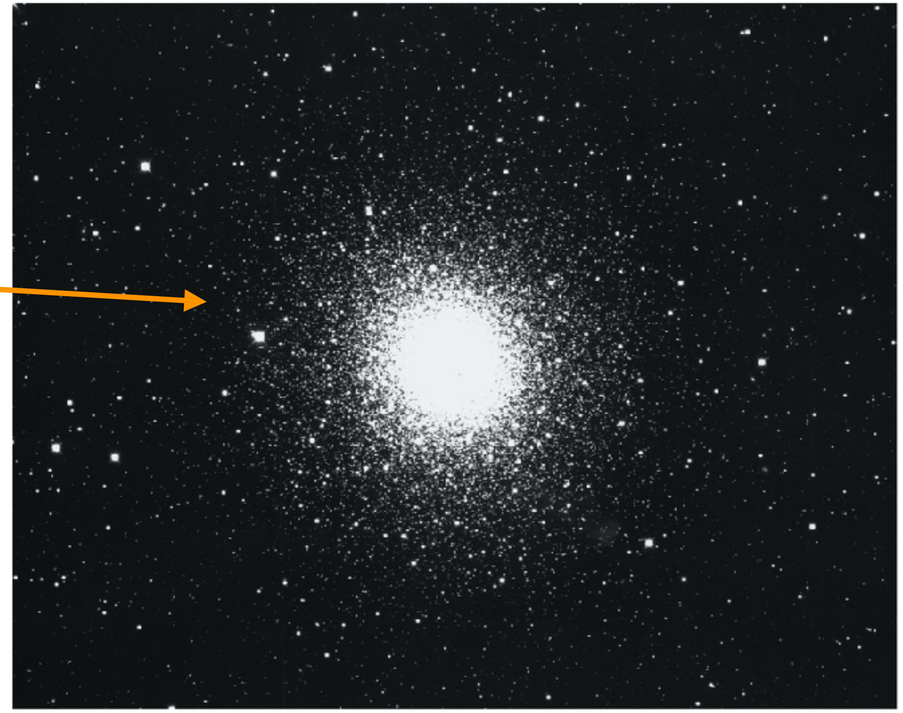


Star counts: William and Caroline Herschel (1785)

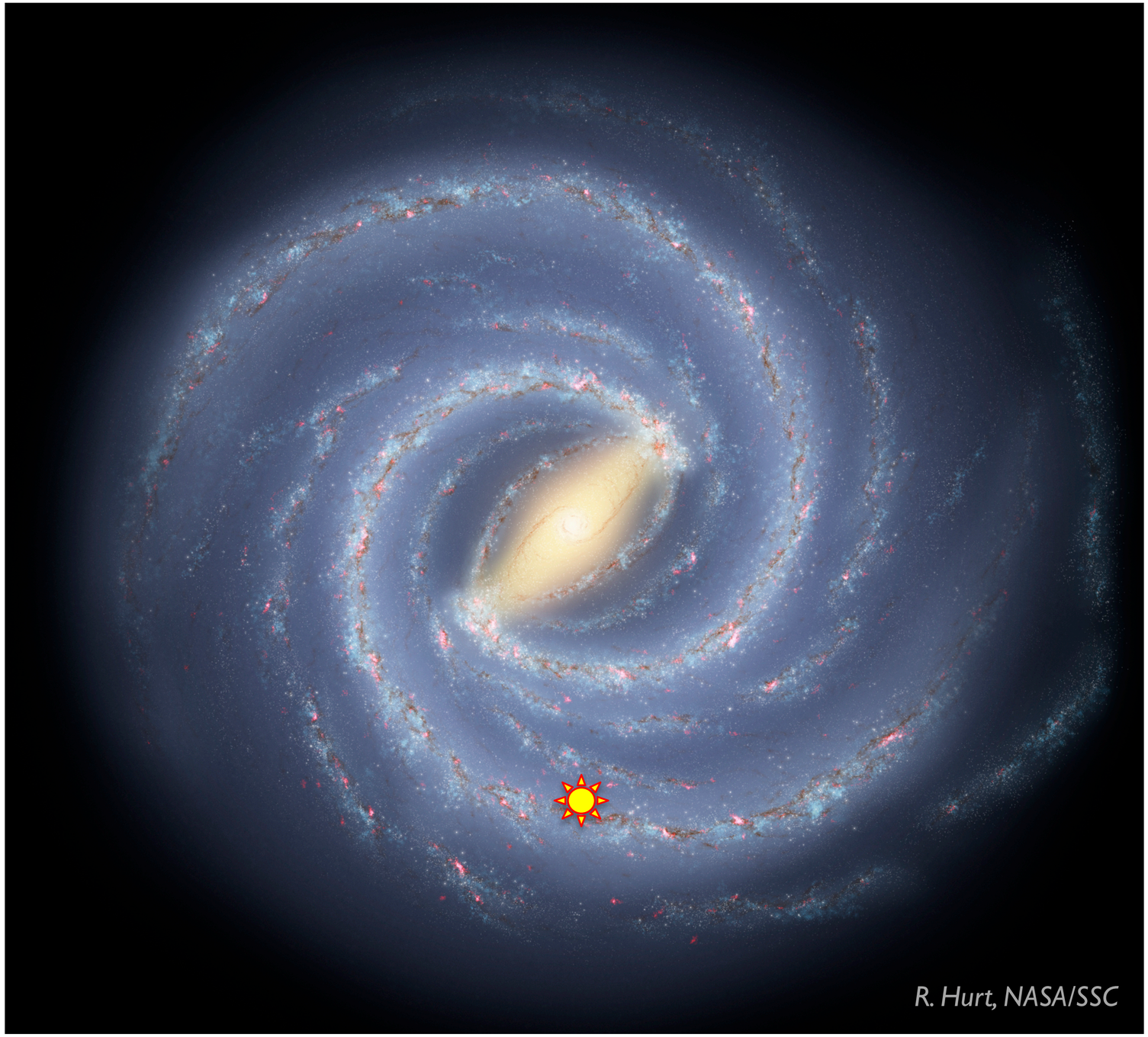


Globular clusters revealed the scale of the MW

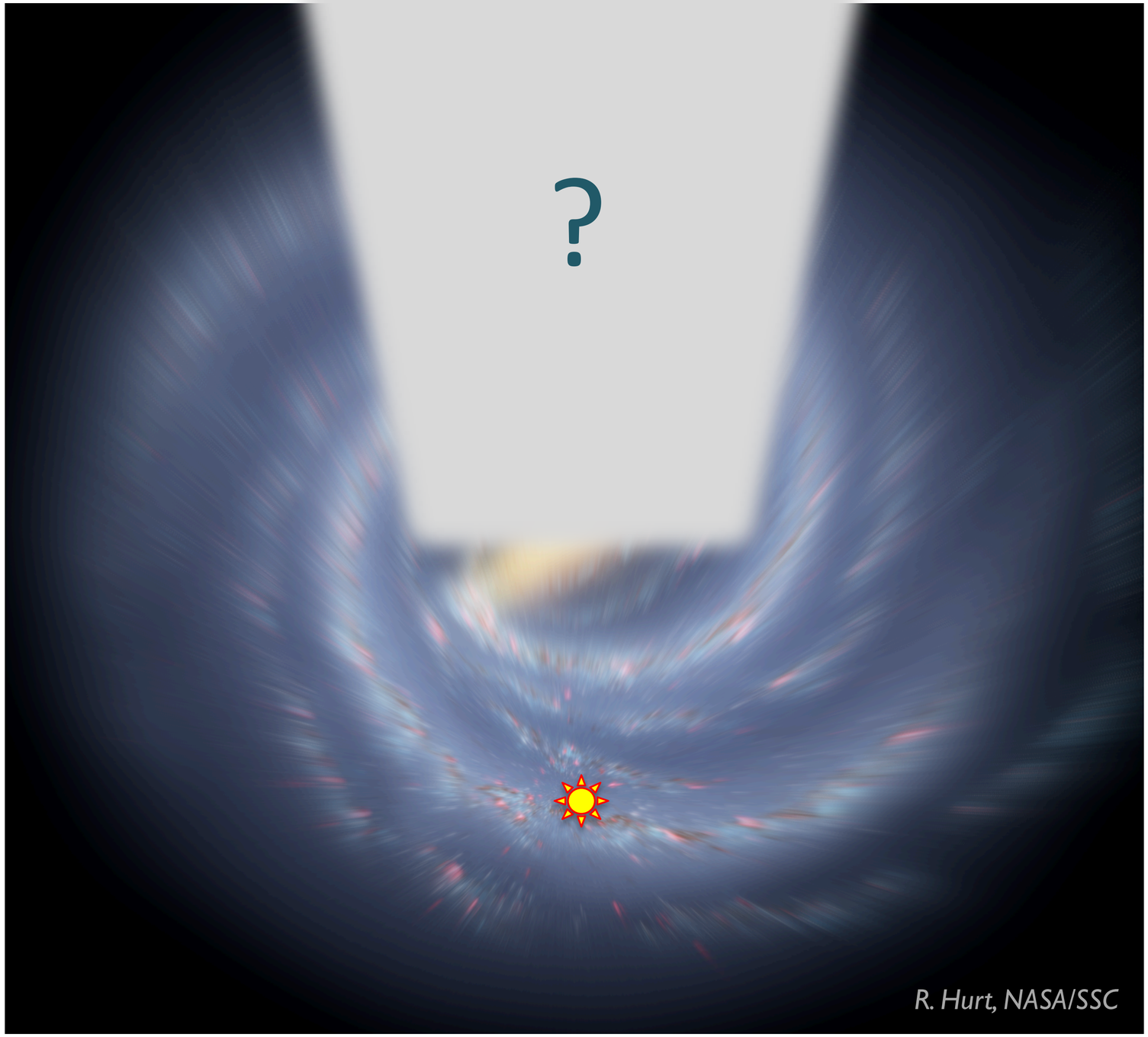




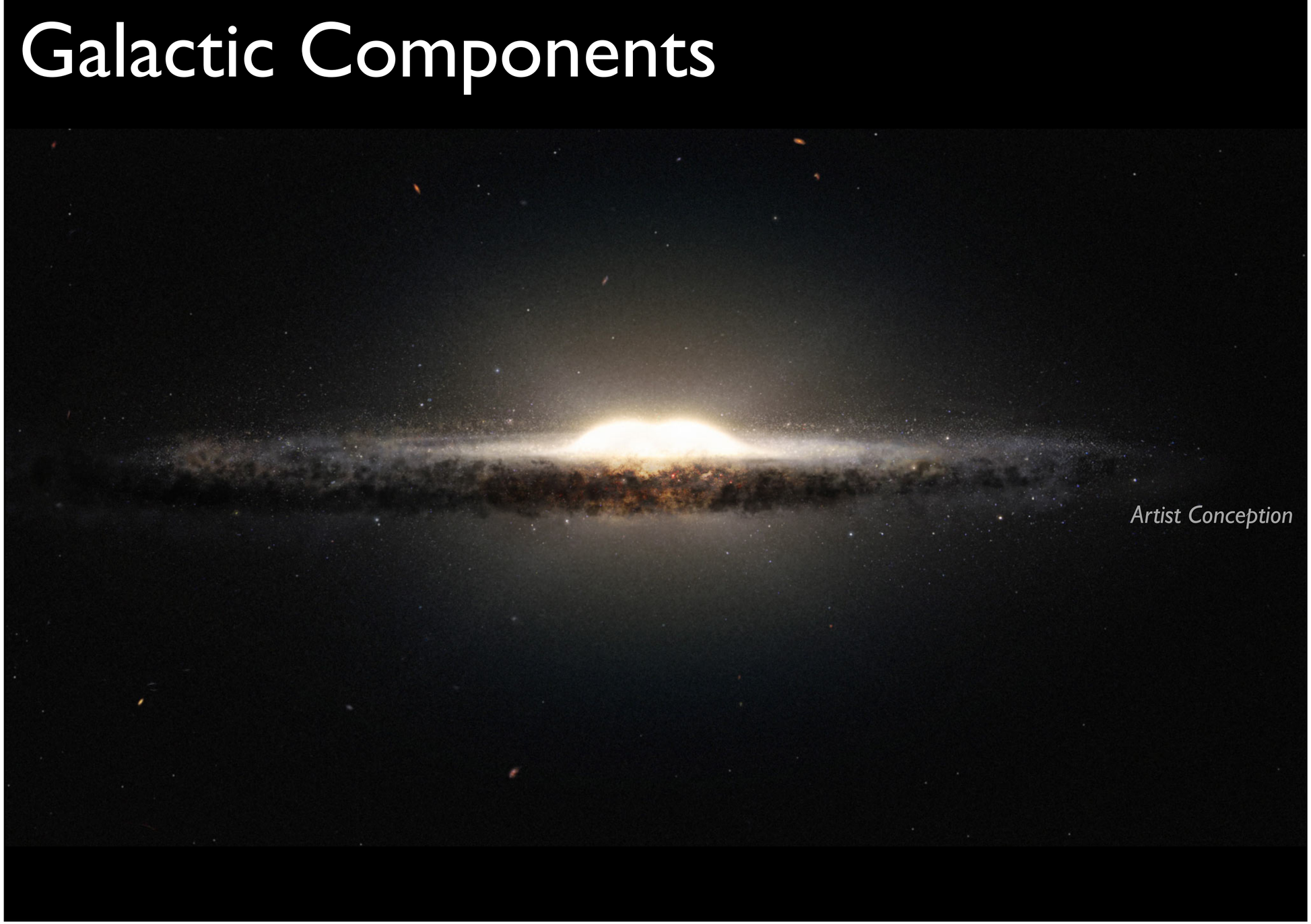
Variable stars like Cepheids (called RR Lyrae stars) were used to estimate the distance to globular clusters, which were assumed to be distributed uniformly around the center of the MW



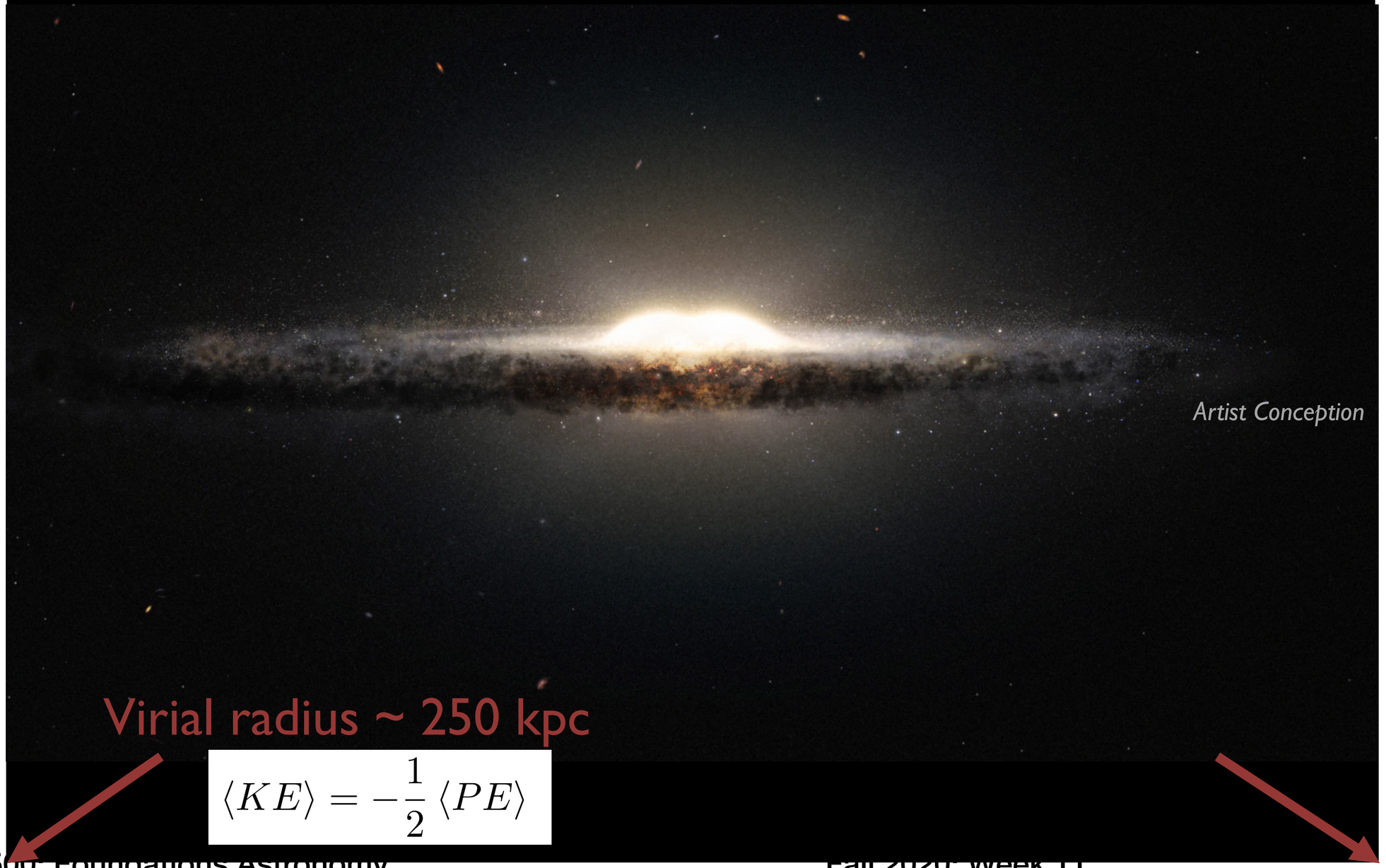
8 kpc


?
R. Hurt, NASA/SSC

Galactic Components

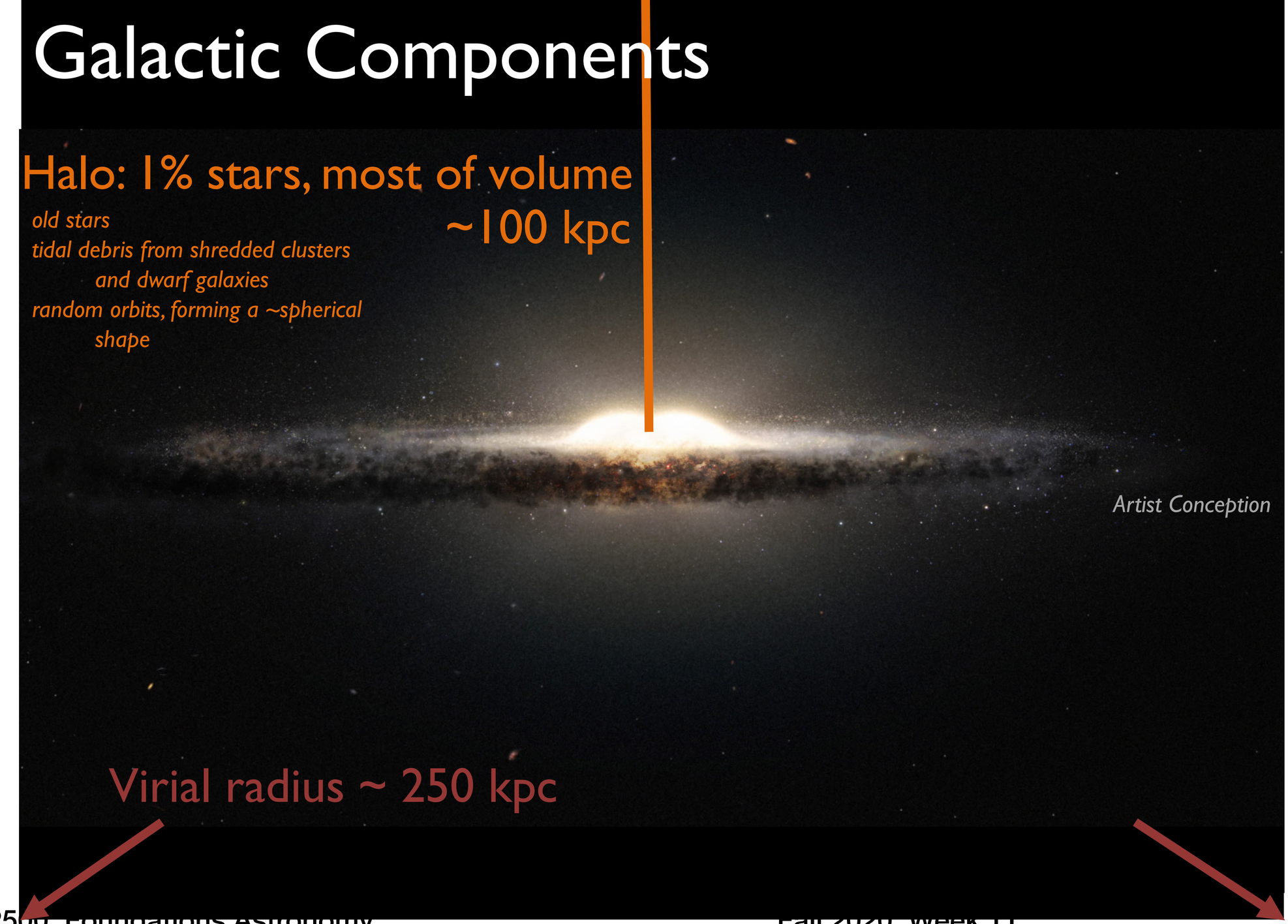


Galactic Components

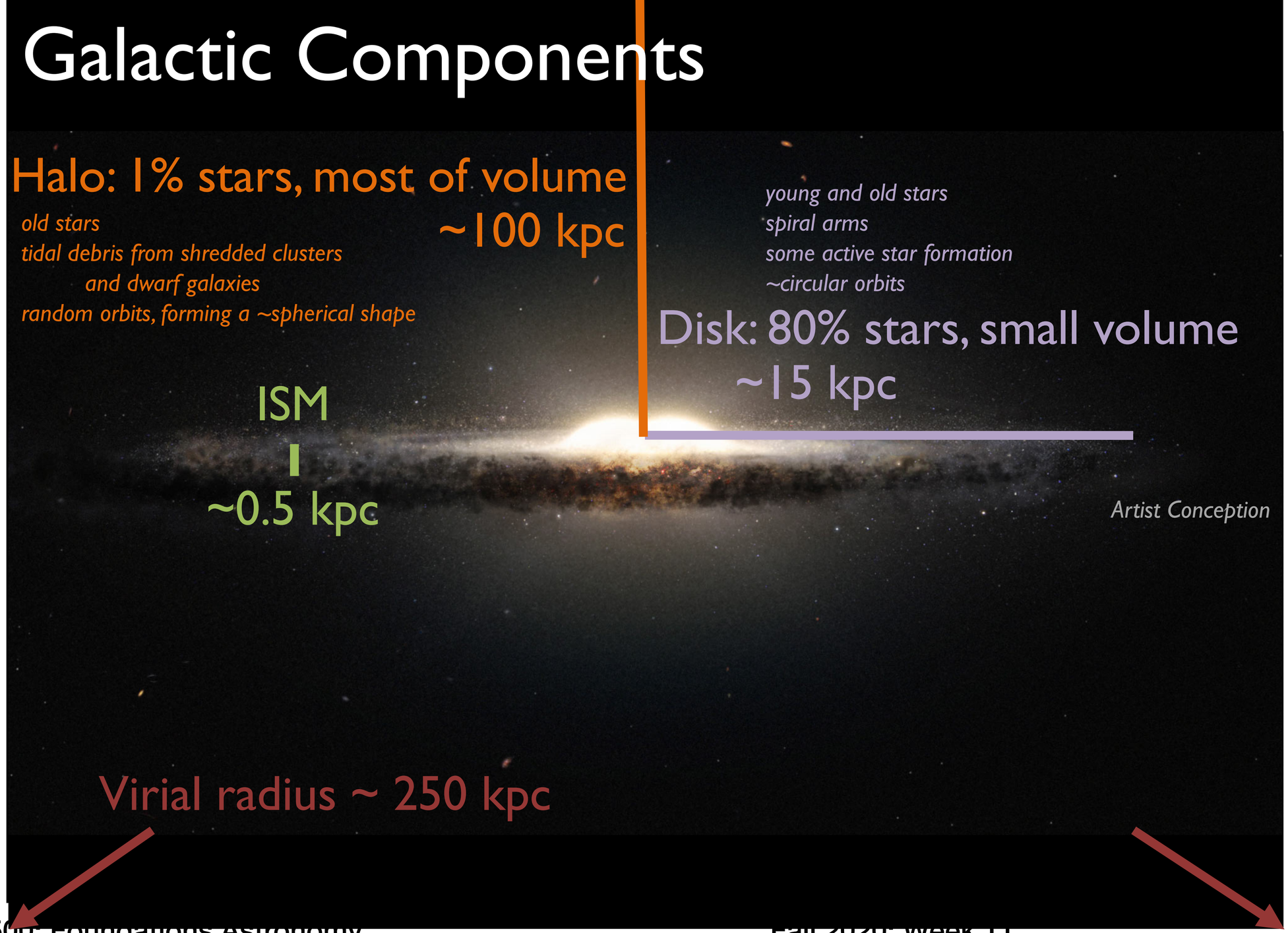


$$\langle KE \rangle = -\frac{1}{2} \langle PE \rangle$$

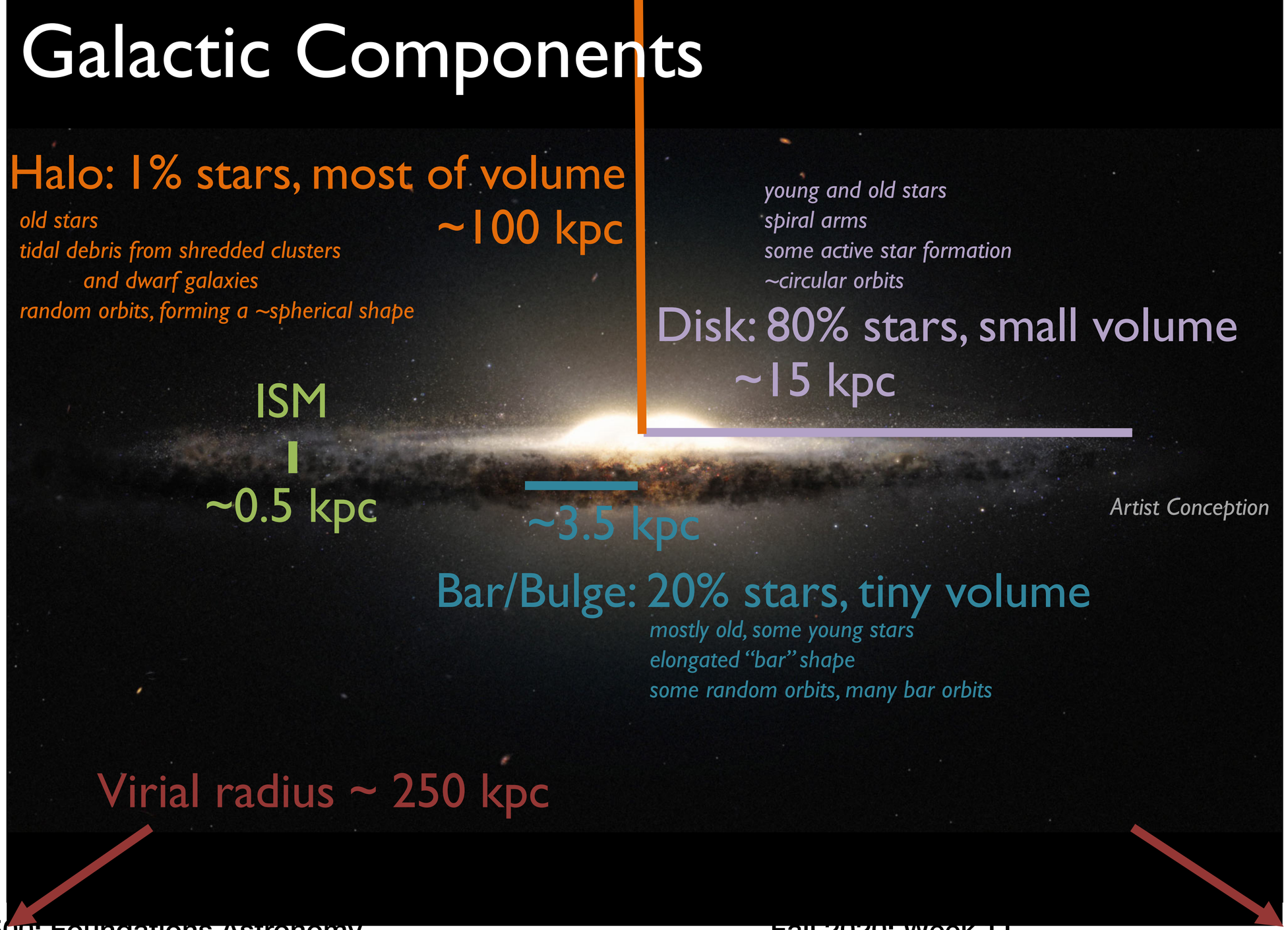
Galactic Components



Galactic Components



Galactic Components



Bulge/Bar

Optical Light

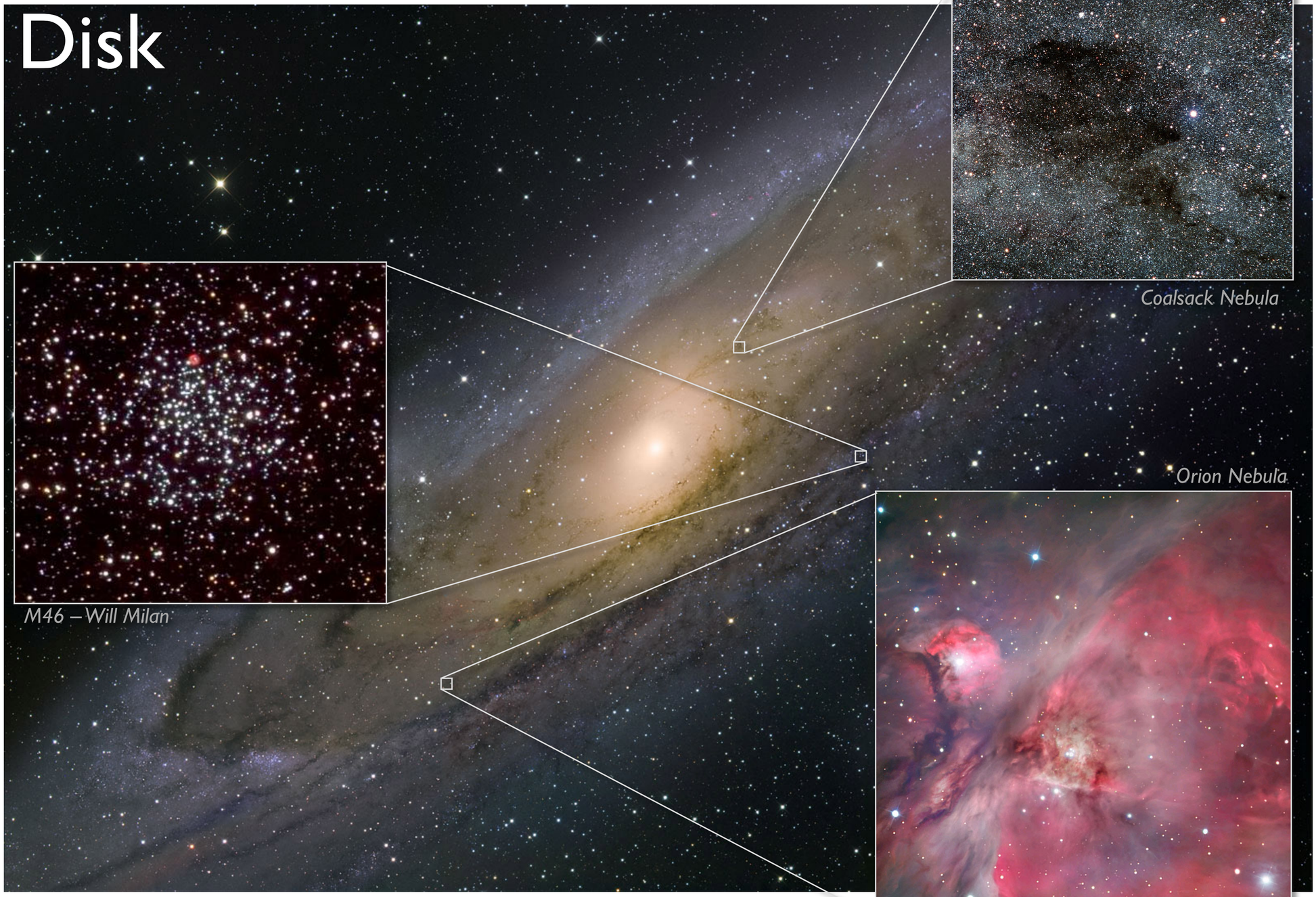
Infrared Light

Bulge/Bar

Disk

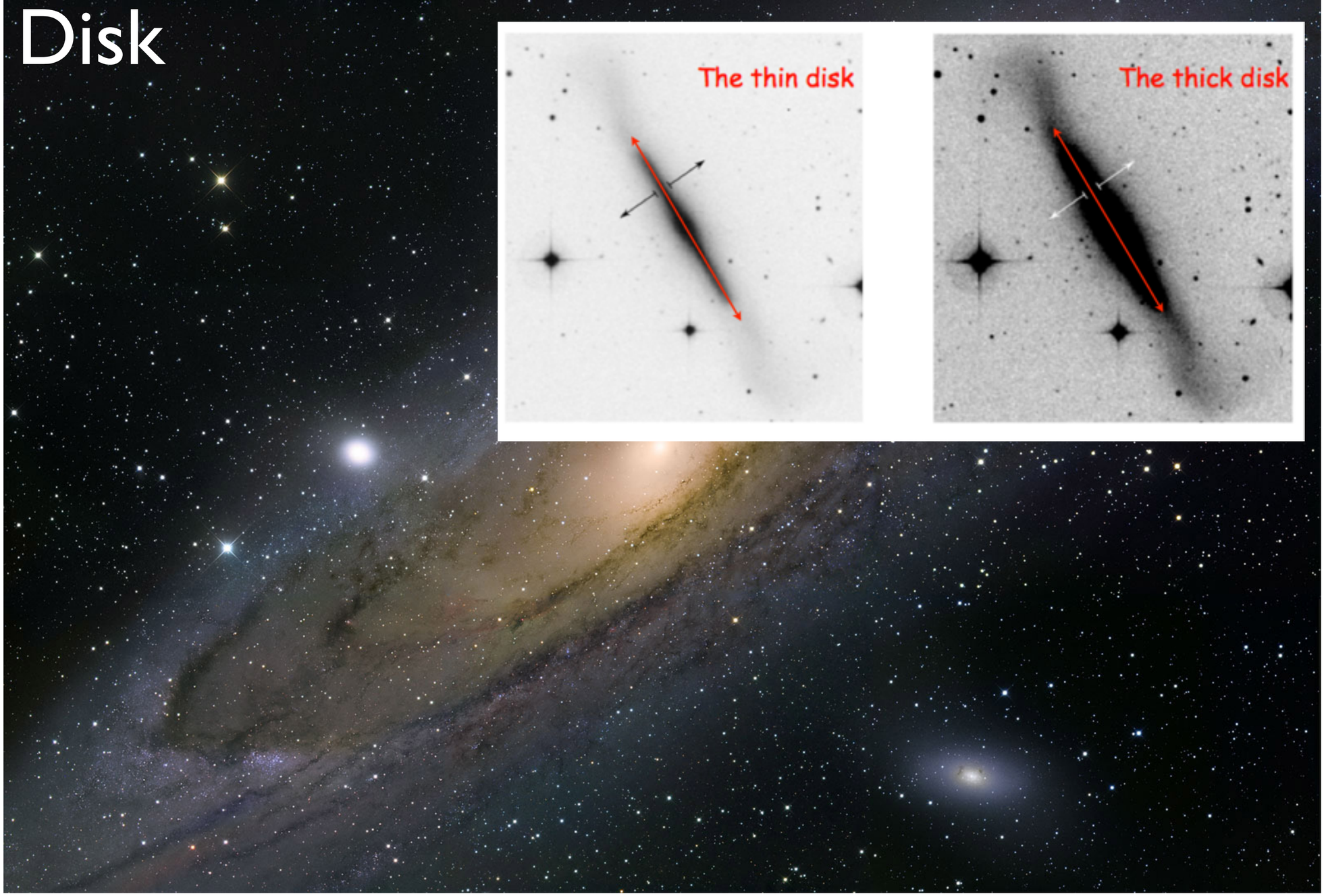
M31, kindly standing in for the Milky Way

Disk



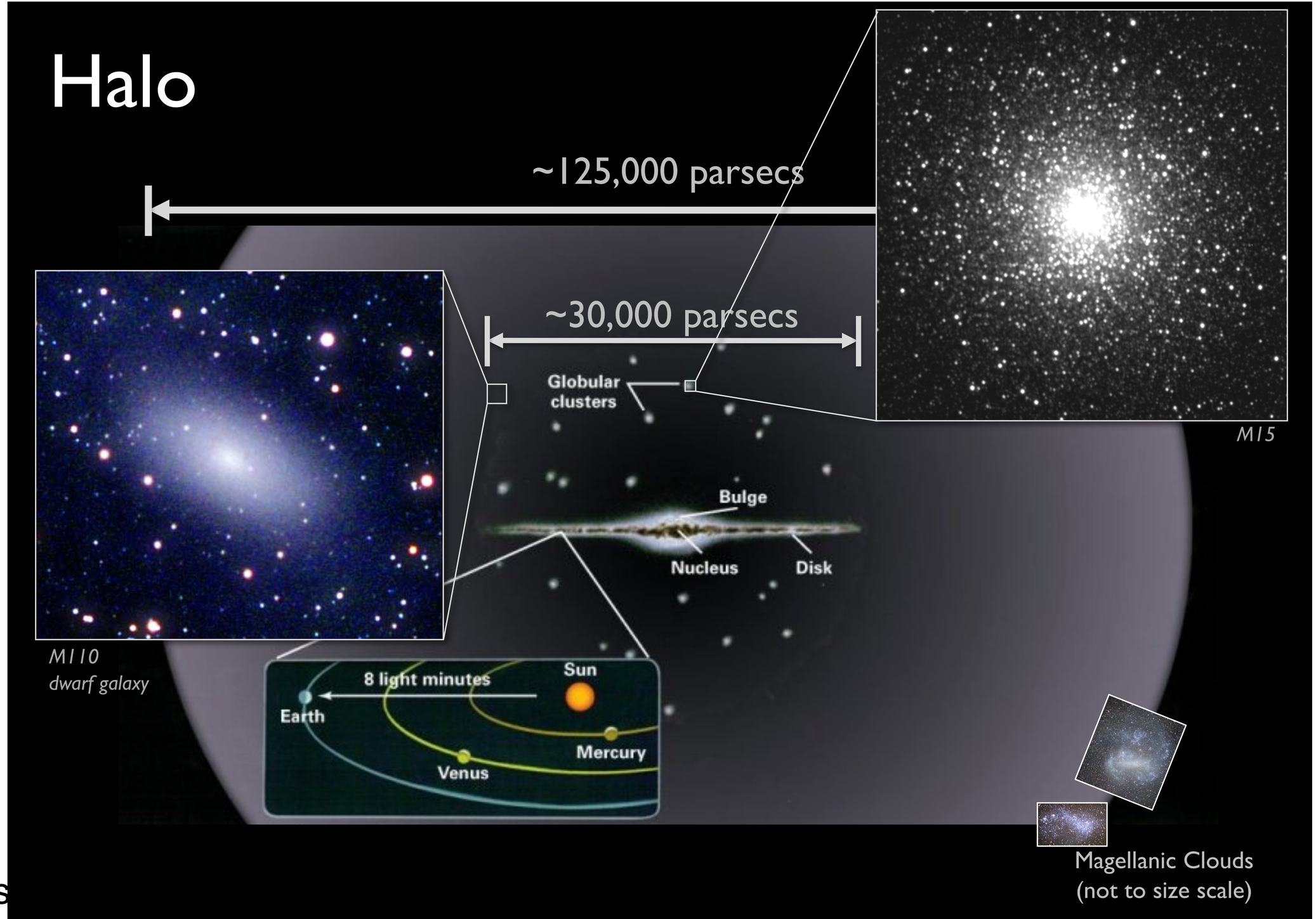
M31, kindly standing in for the Milky Way

Disk

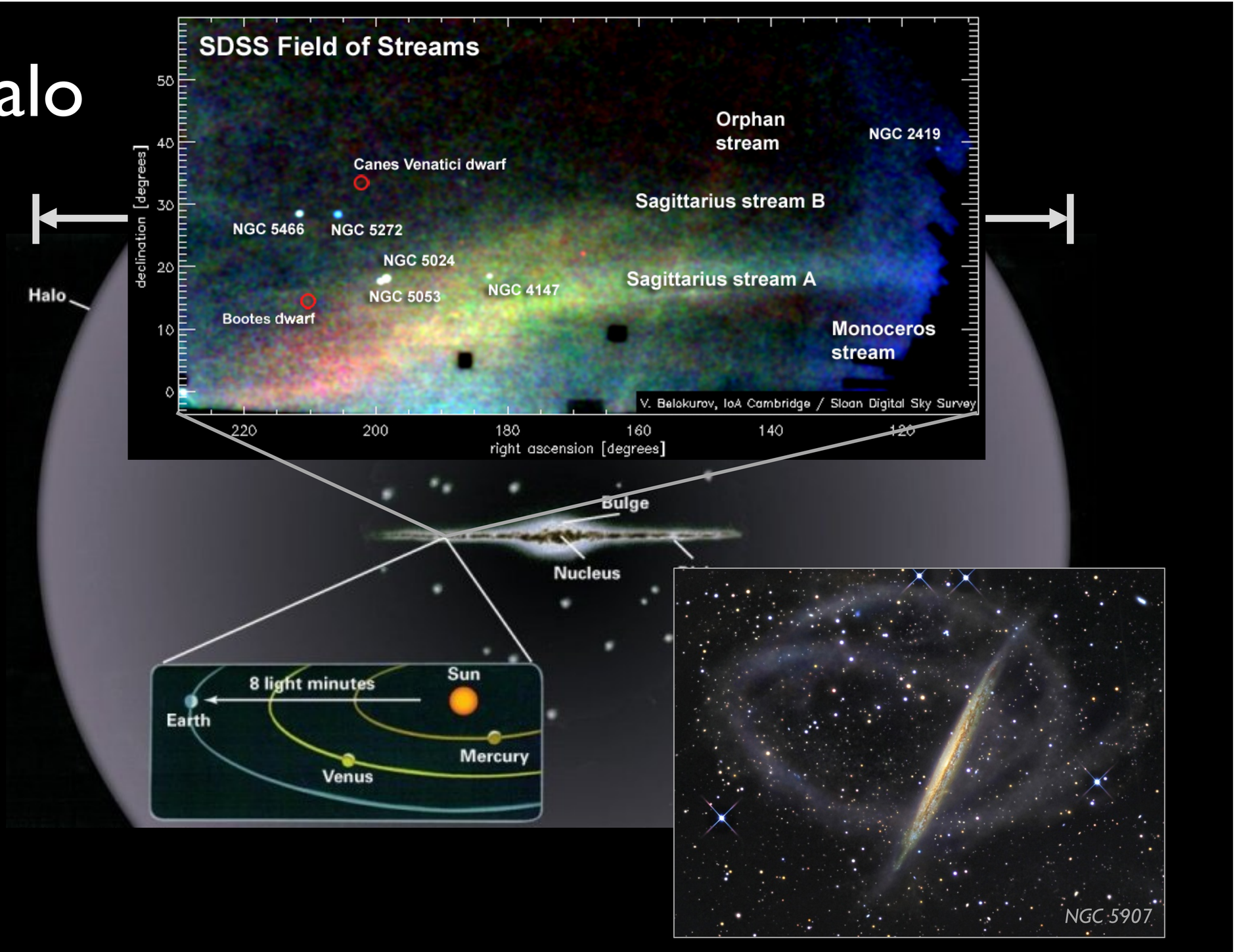


M31, kindly standing in for the Milky Way

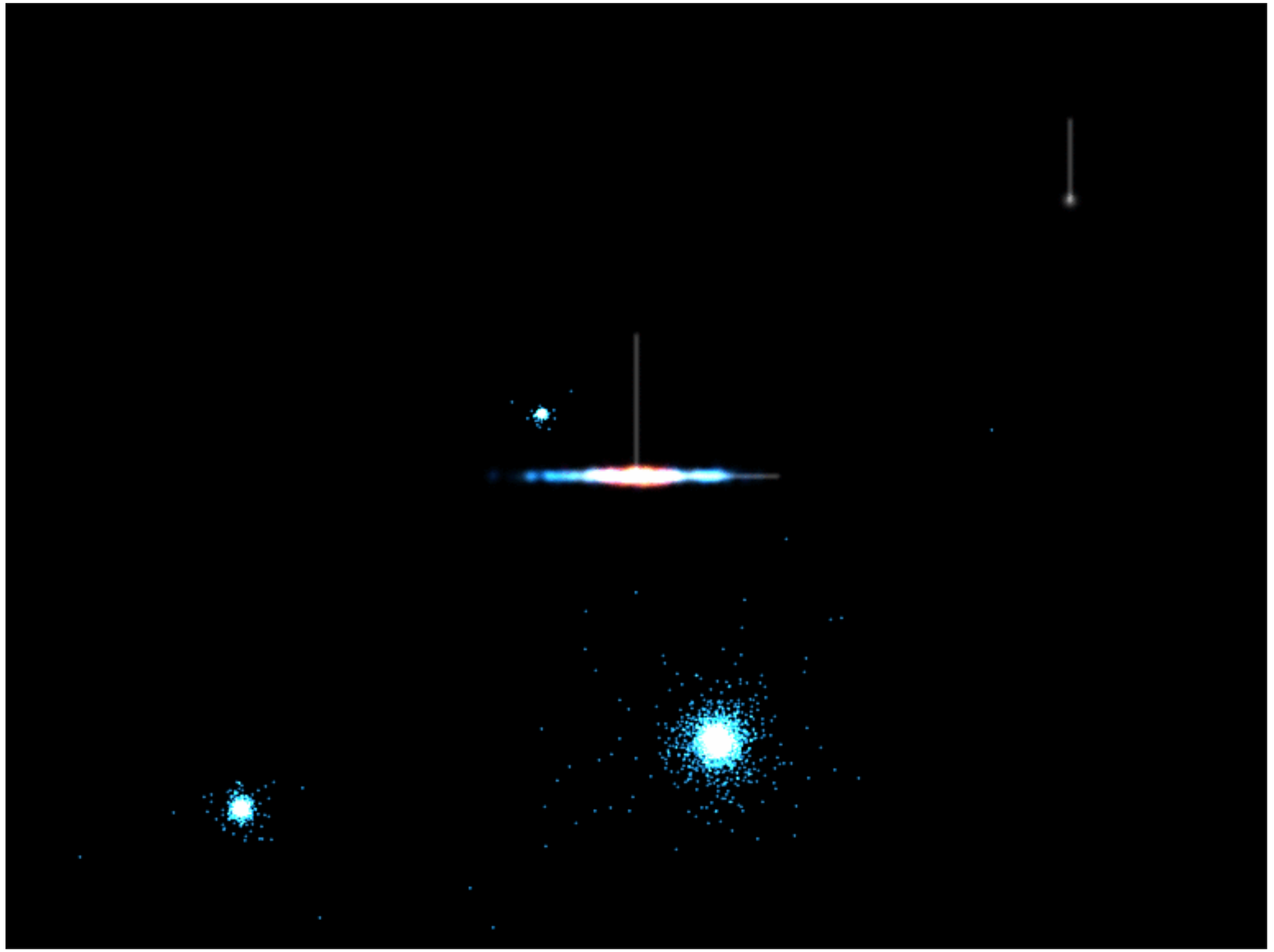
Halo


~125,000 parsecs
~30,000 parsecs
Globular clusters
M15
Bulge
Nucleus
Disk
M110
dwarf galaxy
8 light minutes
Sun
Earth
Mercury
Venus
Magellanic Clouds
(not to size scale)

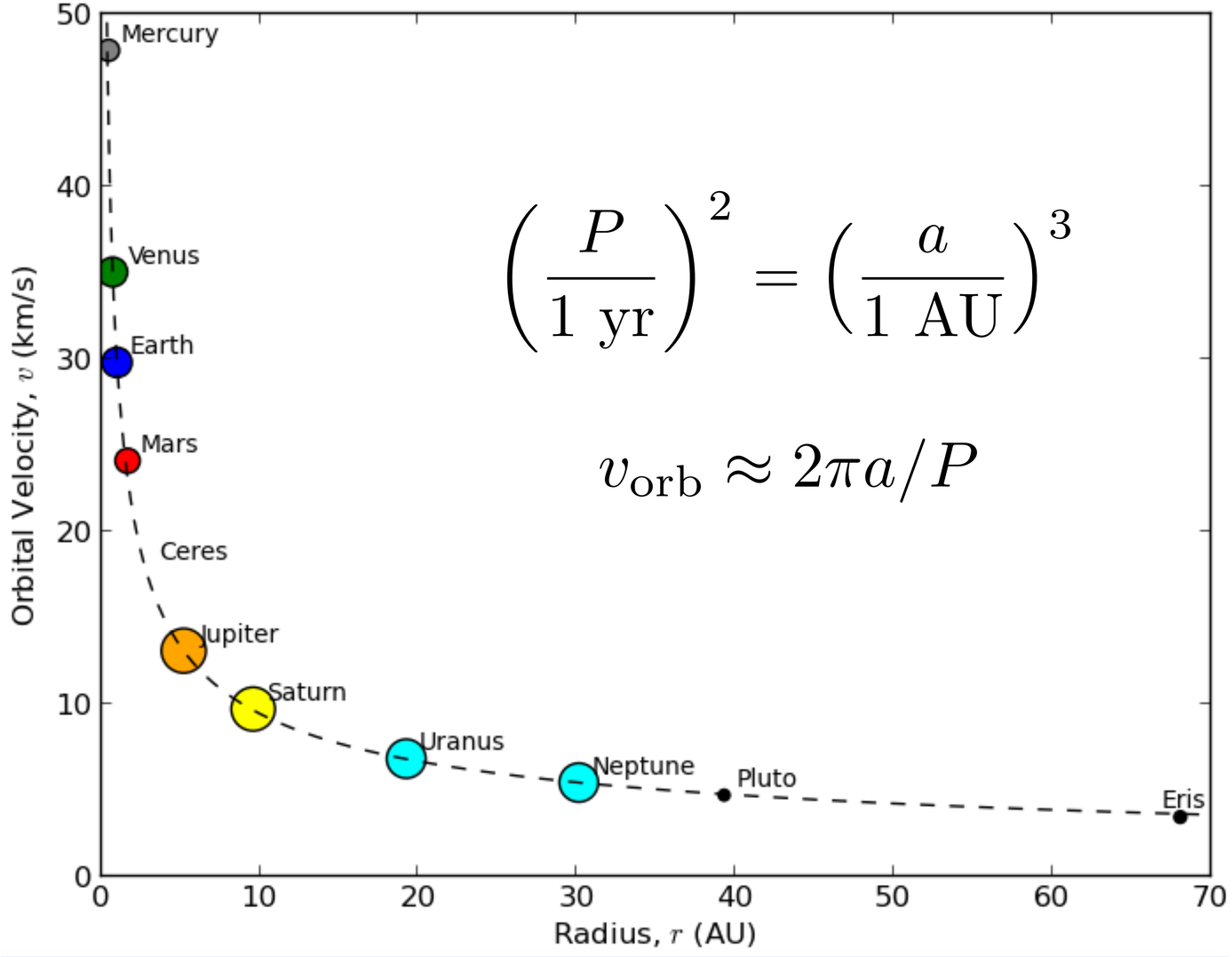
Halo


SDSS Field of Streams
Orphan stream
NGC 2419
Canes Venatici dwarf
Sagittarius stream B
NGC 5466
NGC 5272
NGC 5024
NGC 5053
NGC 4147
Sagittarius stream A
Bootes dwarf
Monoceros stream
V. Belokurov, IoA Cambridge / Sloan Digital Sky Survey
declination [degrees]
right ascension [degrees]
Halo
Bulge
Nucleus
8 light minutes
Sun
Earth
Mercury
Venus
NGC 5907

Small galaxies get shredded into the halo



How do stars move in the Galaxy?



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

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

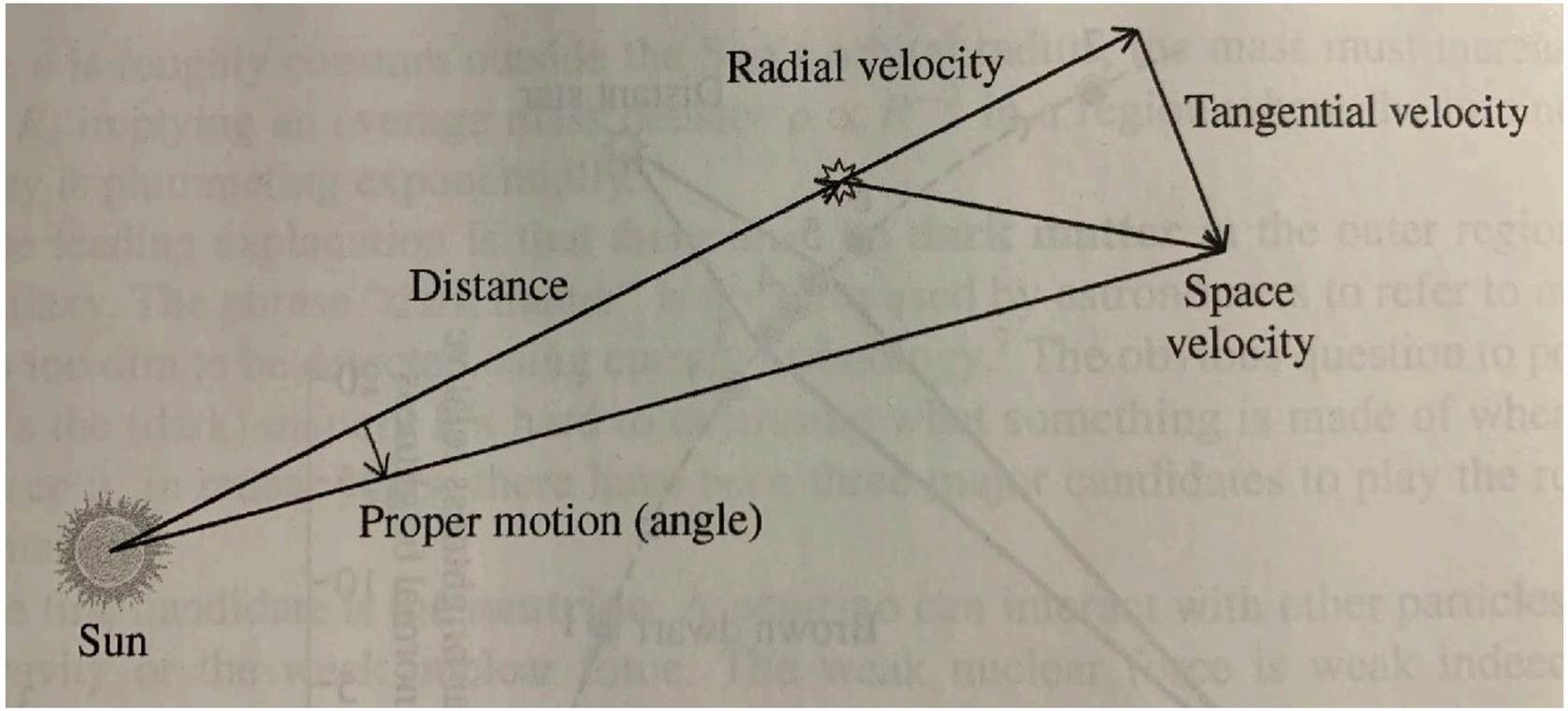
Kepler's 3rd Law in the Galaxy

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

Mass inside Sun's orbit

How do we get 3D star velocities?

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

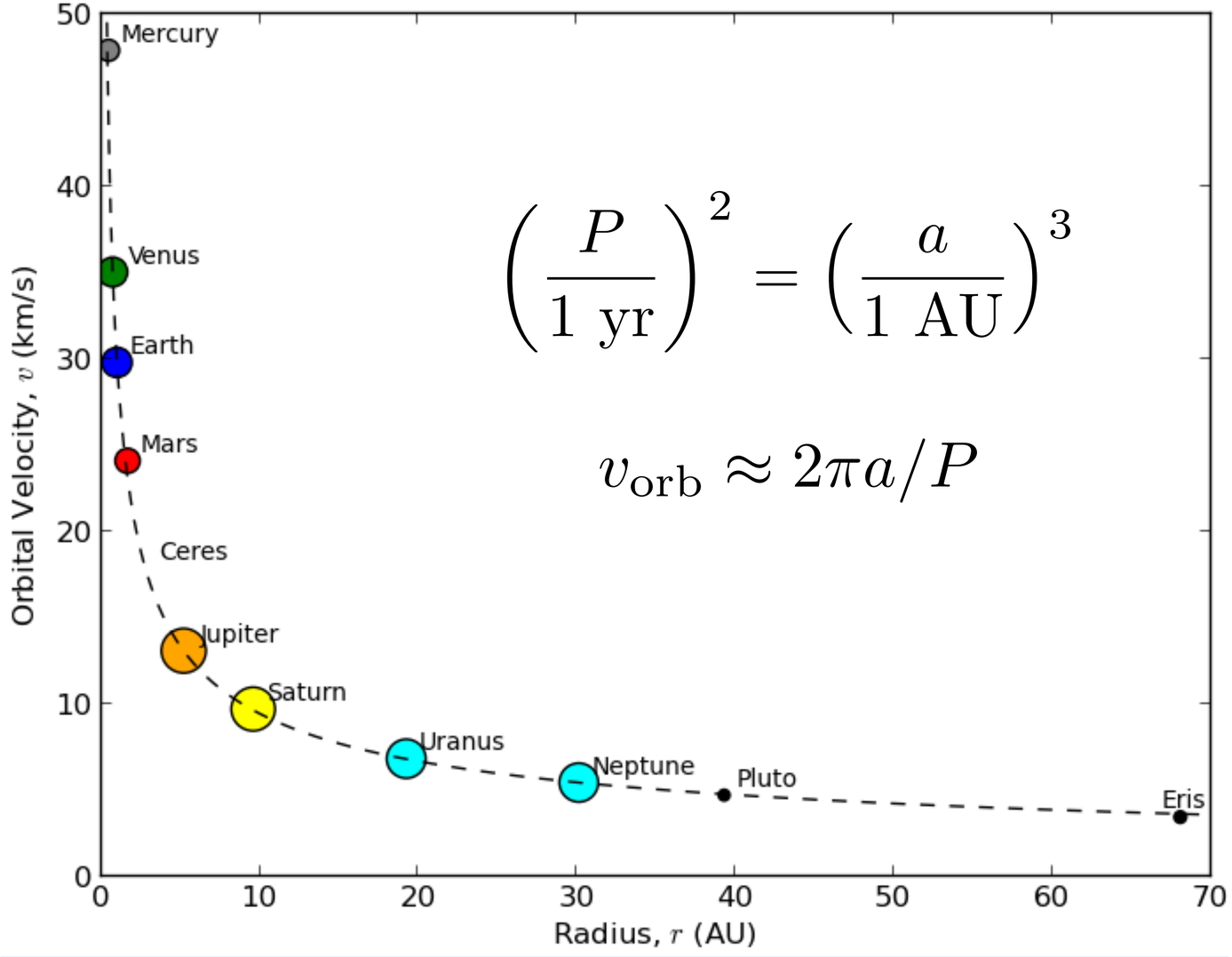


Proper Motion:

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

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

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

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

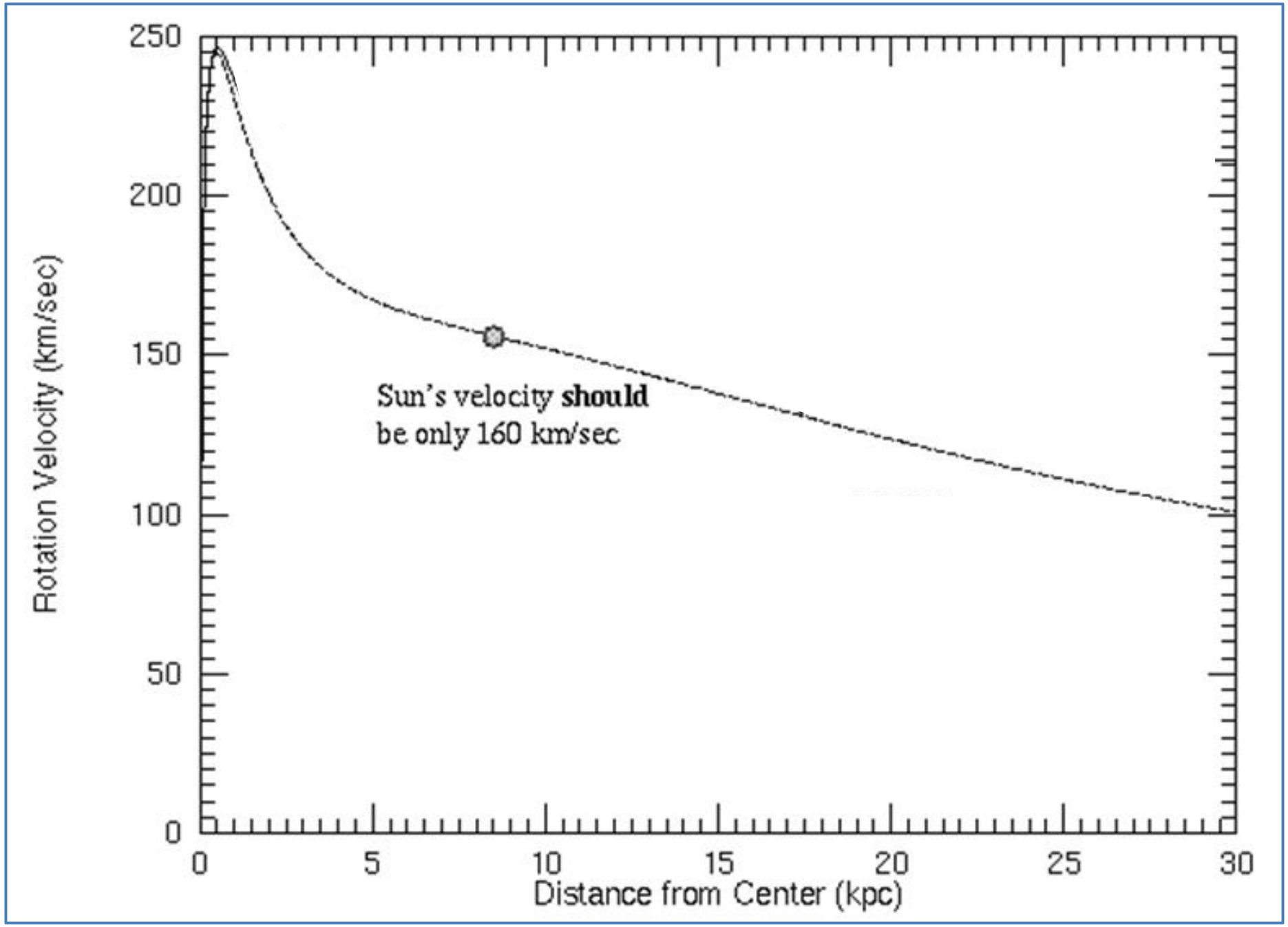
Mass inside Sun's orbit

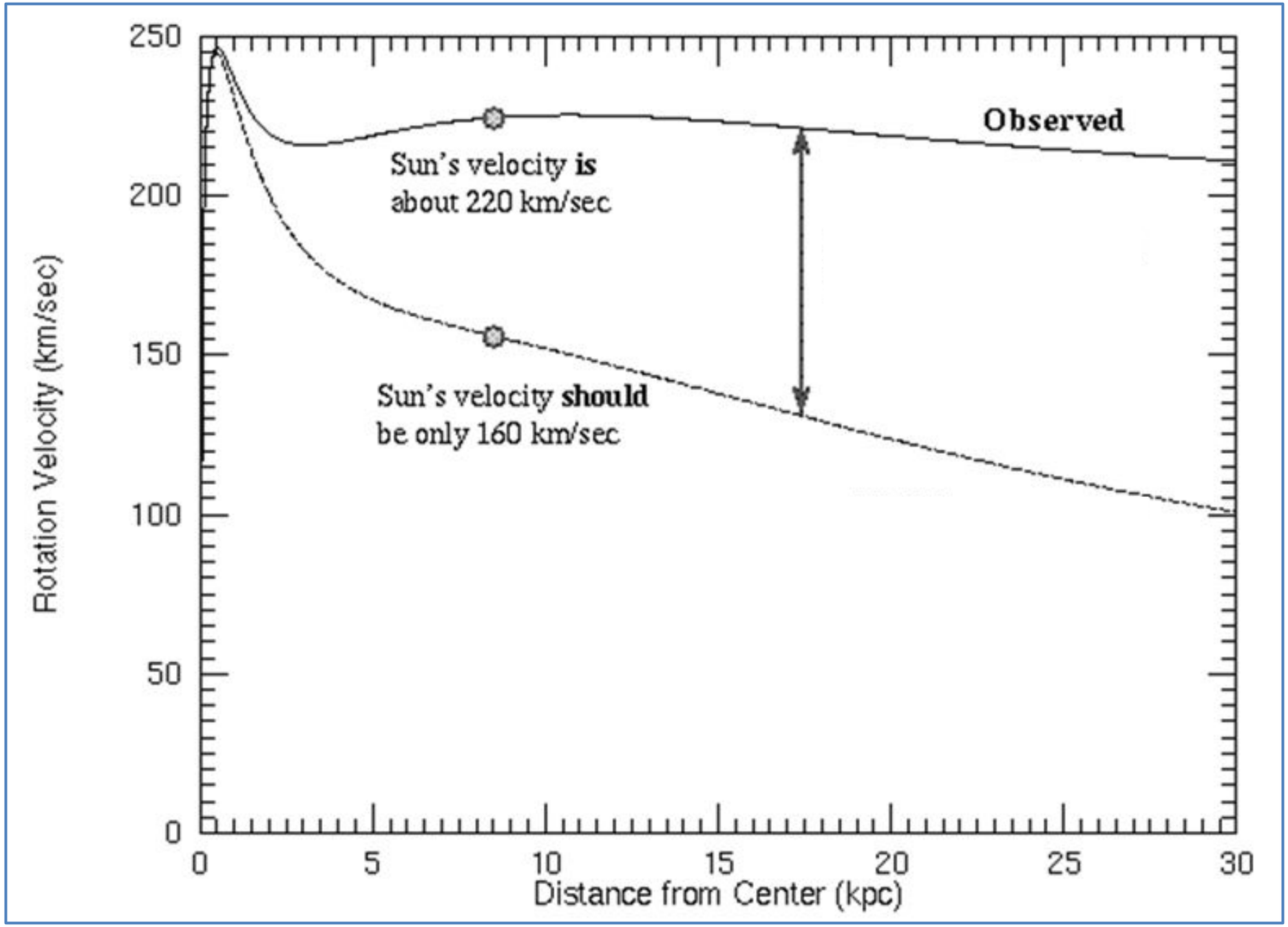
$$a \approx 8\ \mathrm{kpc}$$
$$P \approx 220\ \mathrm{Myr}$$

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

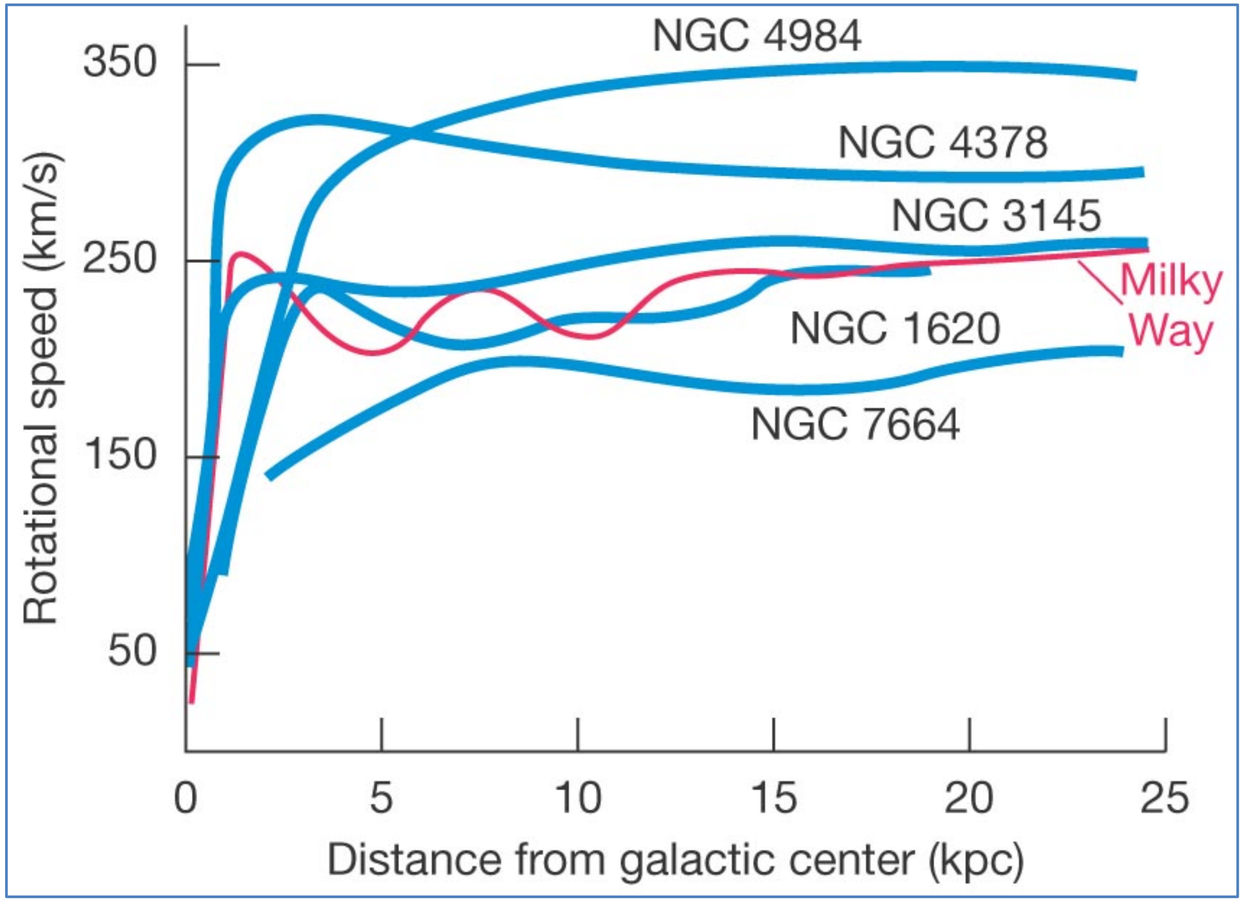
$$\frac{v(R)^2}{R} = \frac{GM_G(<R)}{R^2}$$

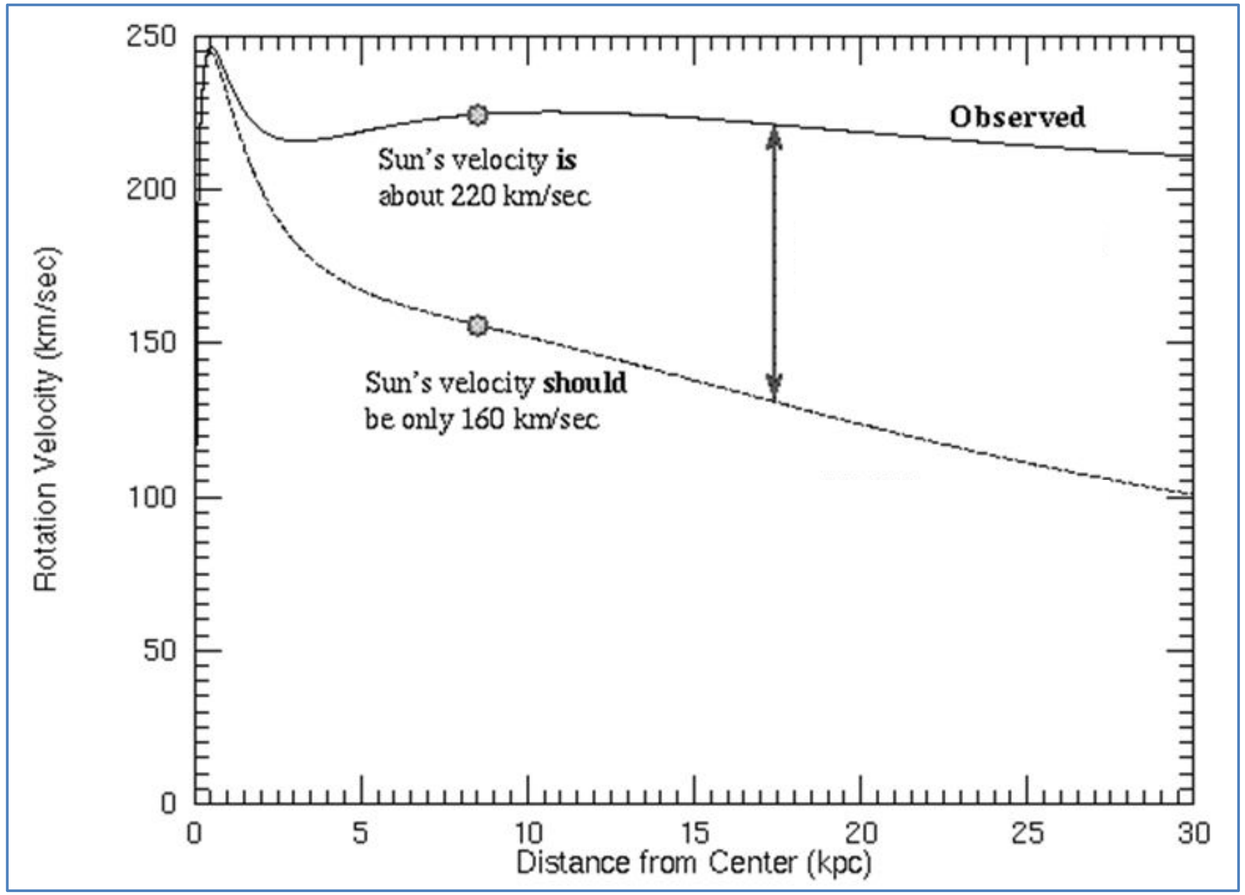
$$v(r) \propto \left(\frac{M_G(<R)}{R}\right)^{1/2} \propto R^{-1/2}$$


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)

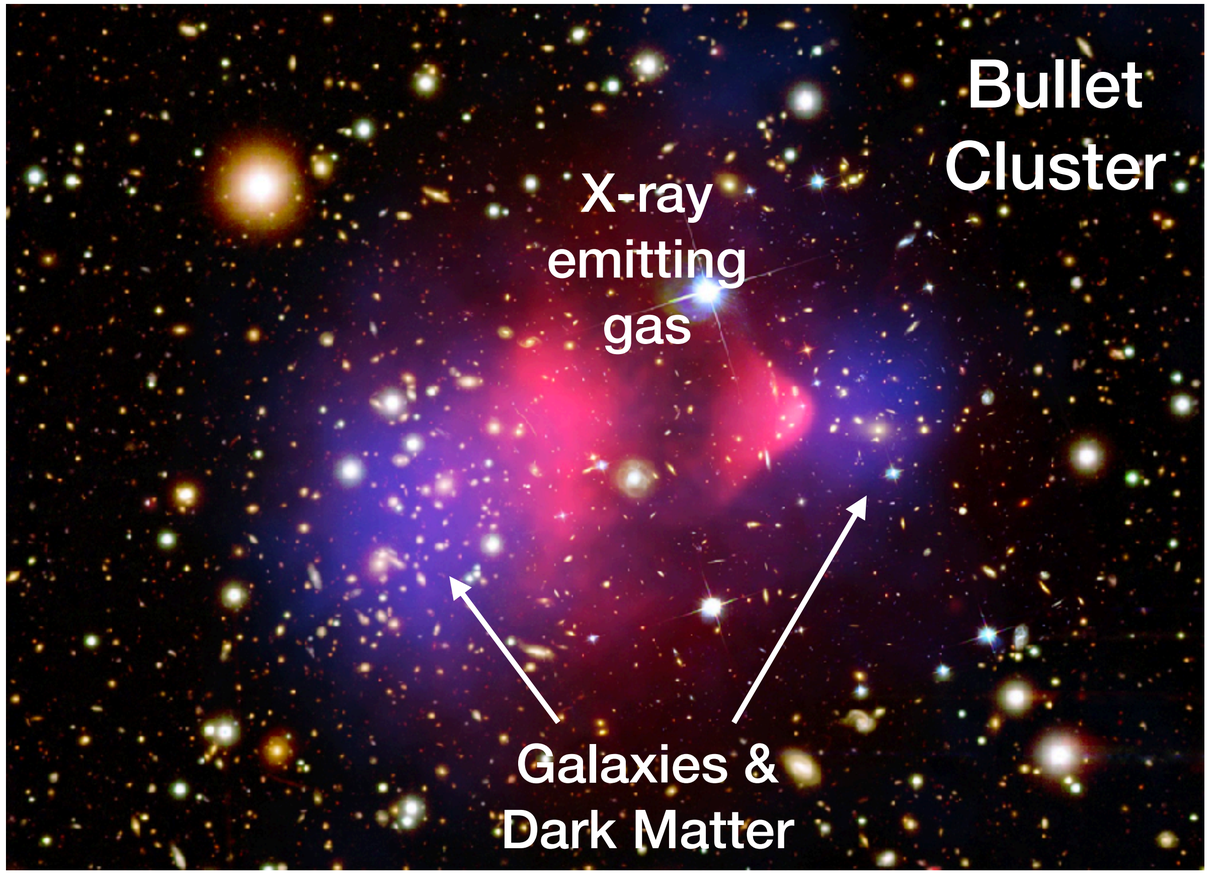

Observed
Sun's velocity is
about 220 km/sec
Sun's velocity should
be only 160 km/sec
Rotation Velocity (km/sec)
250
200
150
100
50
0
0
5
10
15
20
25
30
Distance from Center (kpc)

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





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…)