Our galaxy: the Milky Way

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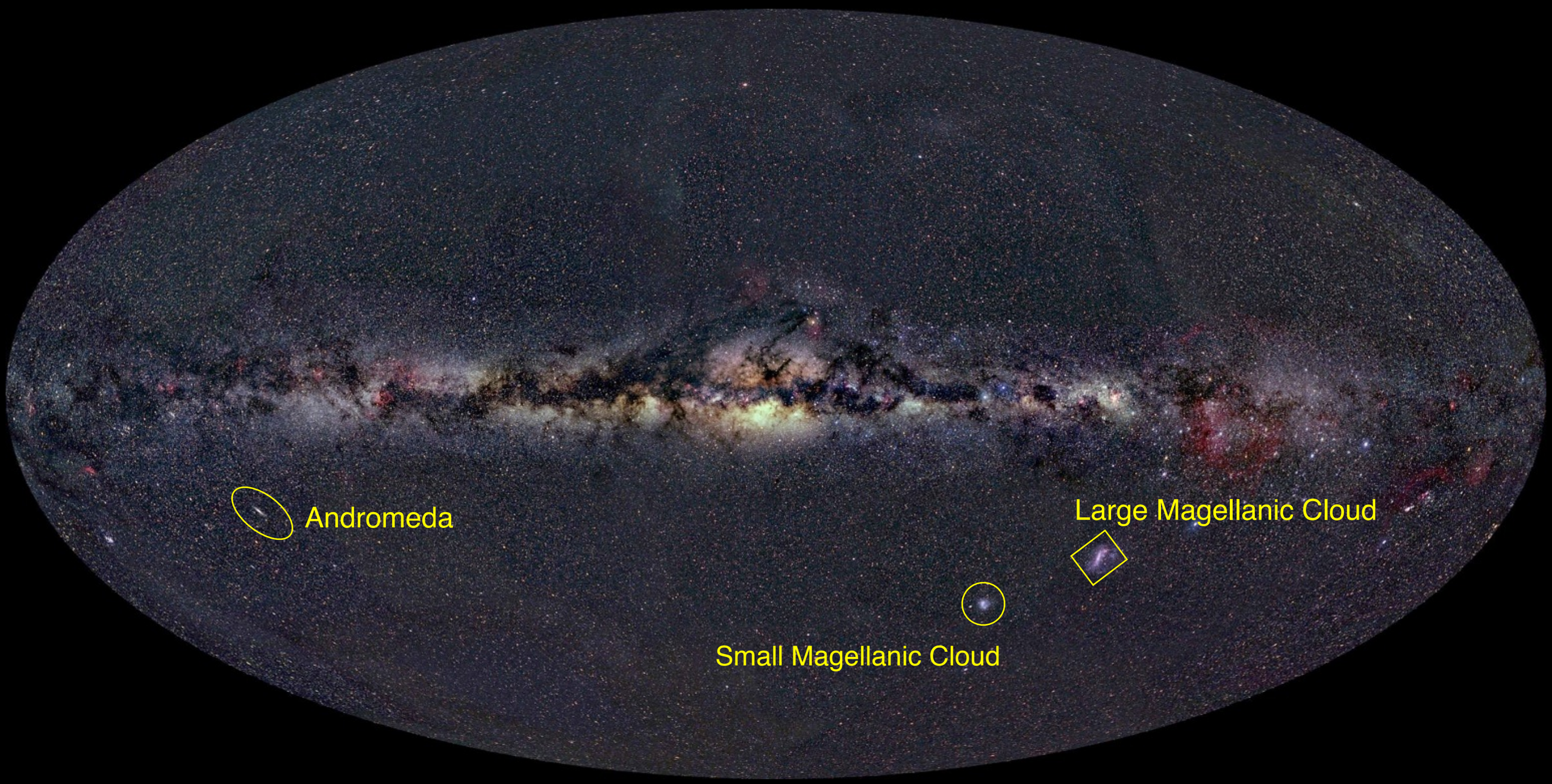


Optical image of the sky taken with *Hubble Space Telescope*
Apparent size: 3.5×3.5 arcmin^2

Is this object inside or outside the Milky Way?
Outside!

Is the Milky Way similar to this object?
Yes it is!

Edge-on spiral galaxy

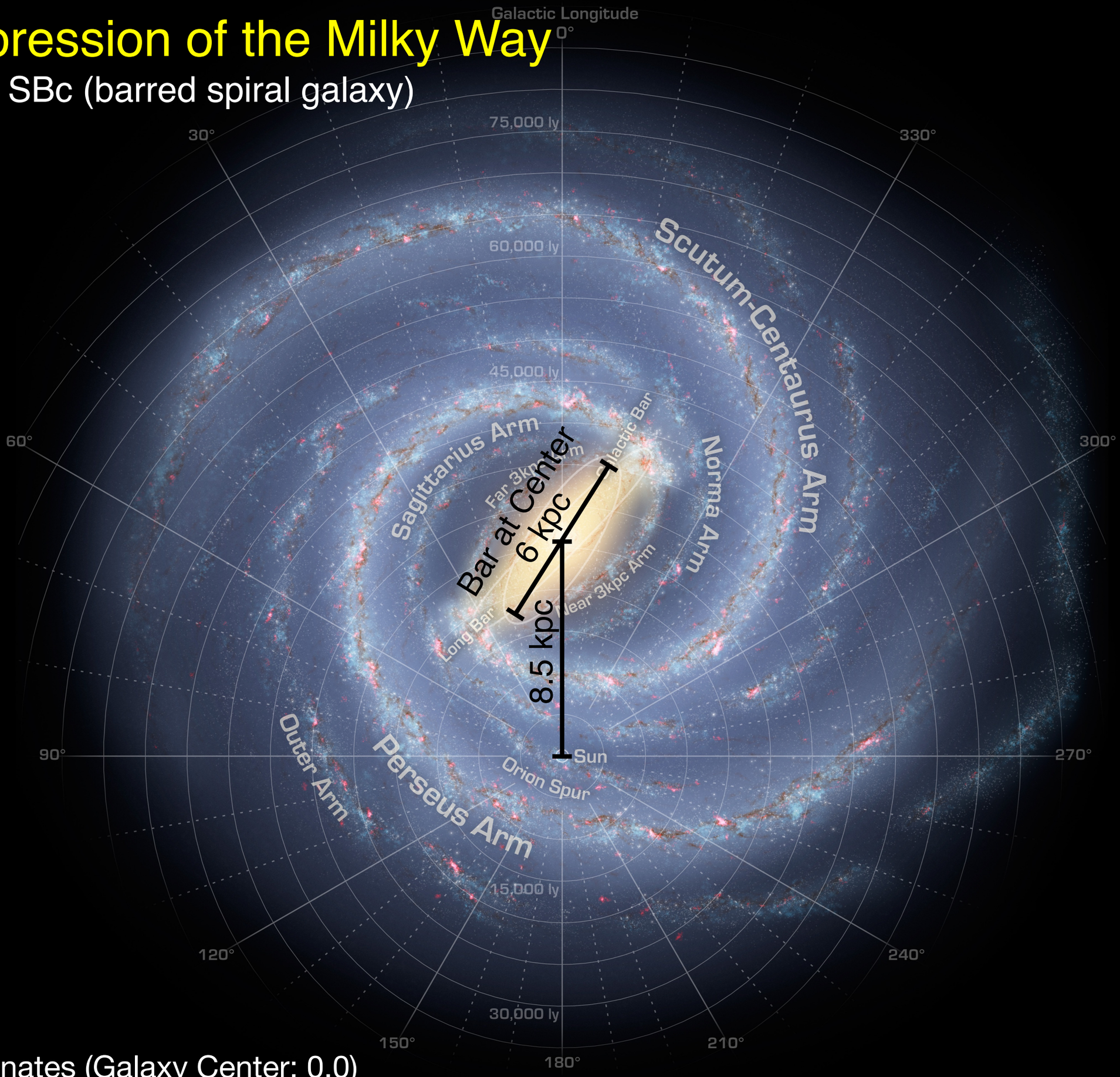
NGC 891

Face-on spiral galaxy

Messier 74

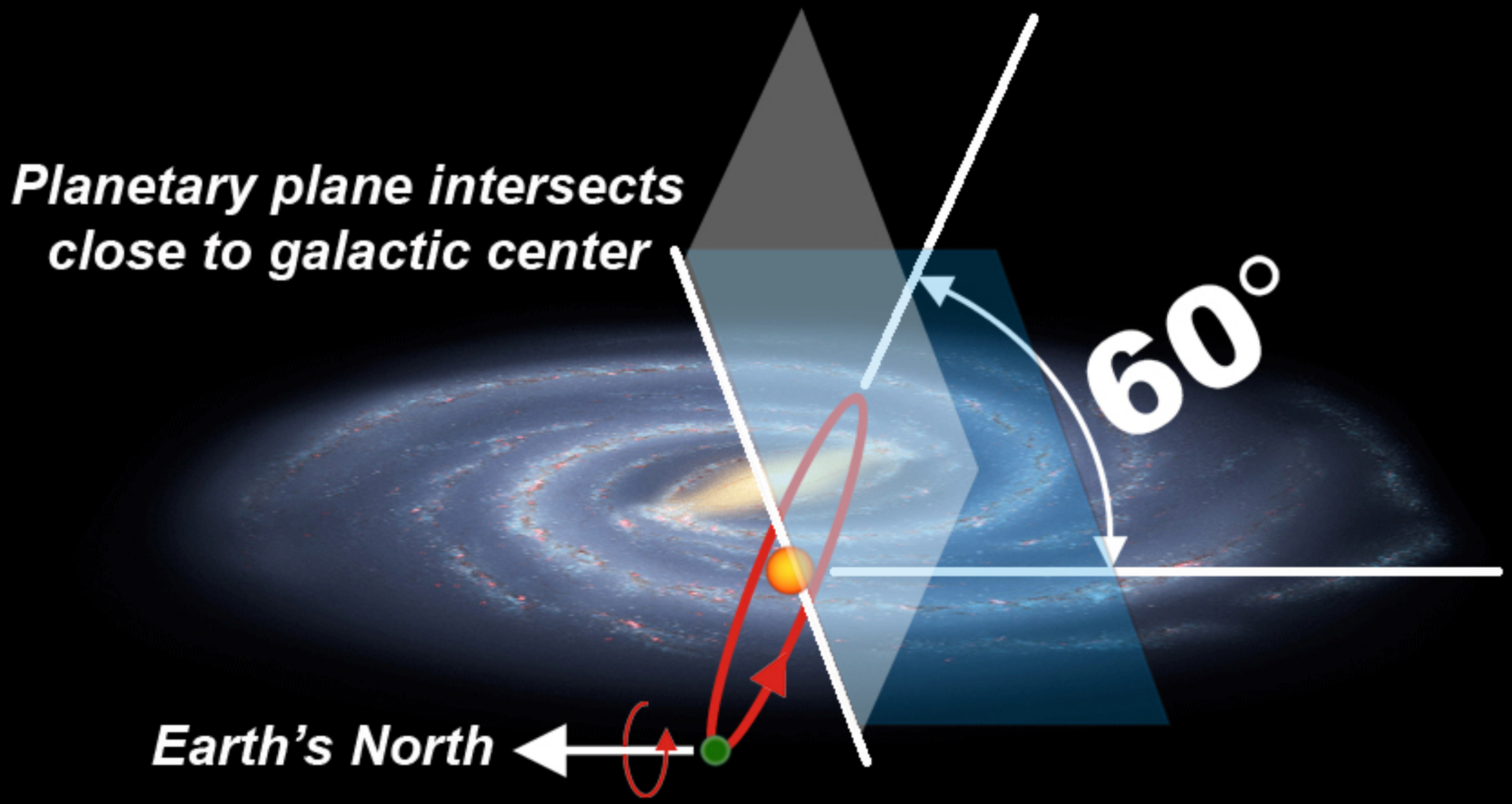
Artist impression of the Milky Way

Galaxy type: SBc (barred spiral galaxy)



Galactic coordinates (Galaxy Center: 0,0)

Location of the Sun in the Milky Way



The planetary plane in which earth orbits makes an angle of about 60 degrees with the galactic plane. Earth's tilt relative to its orbital plane is 23 degrees, which brings earth's axis close to parallel with the galactic plane. The planetary plane intersects close to the center of the galaxy

Galaxies are much larger than what is shown by stars

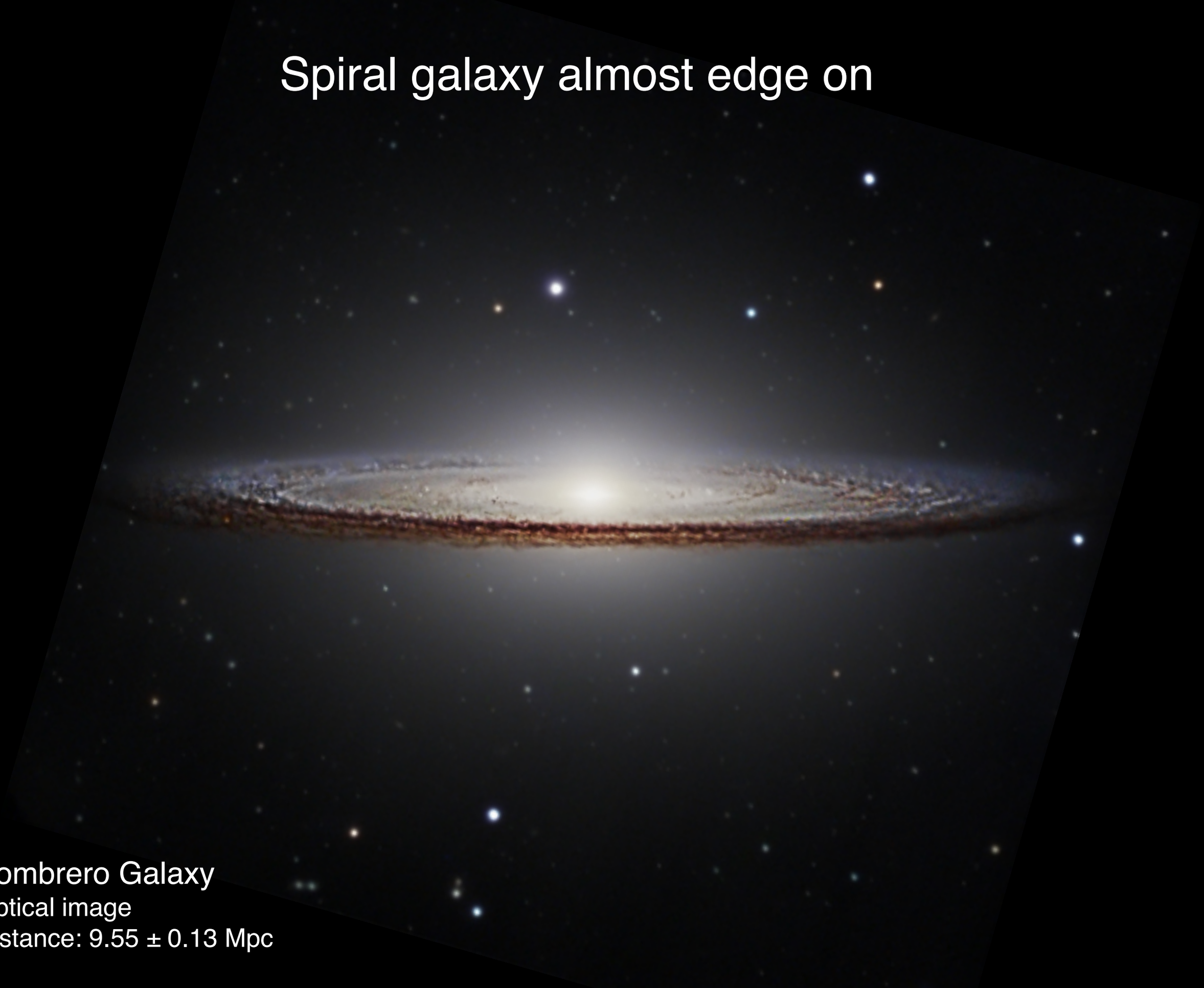
Pinwheel Galaxy (Messier 101)
Optical image
Distance: 6.4 ± 0.5 Mpc

Galaxies are much larger than what is shown by stars

Radio 21 cm emission (green image)
(ν = 1420 MHz)

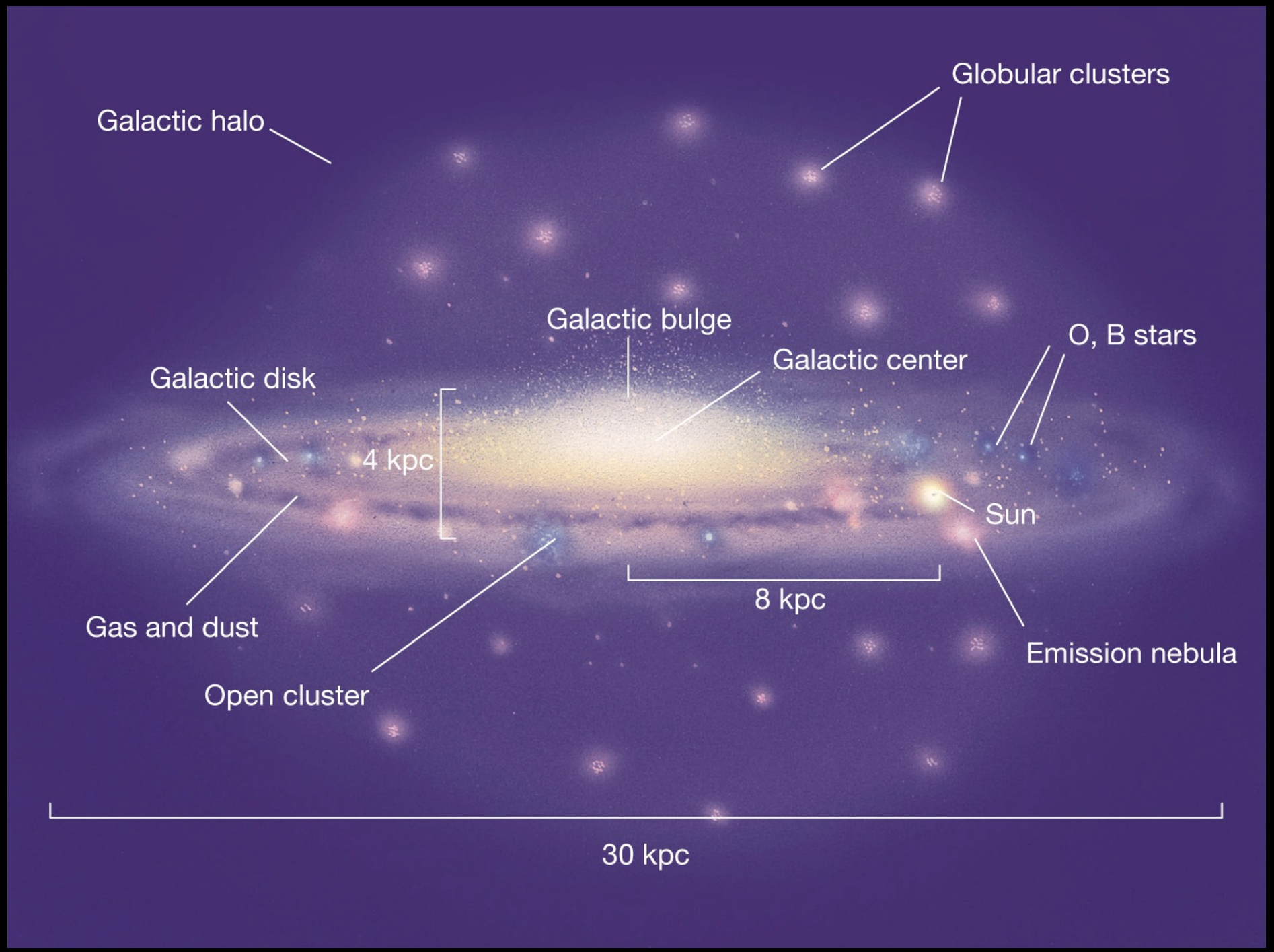
Pinwheel Galaxy (Messier 101)
Optical image
Distance: 6.4 ± 0.5 Mpc

Spiral galaxy almost edge on

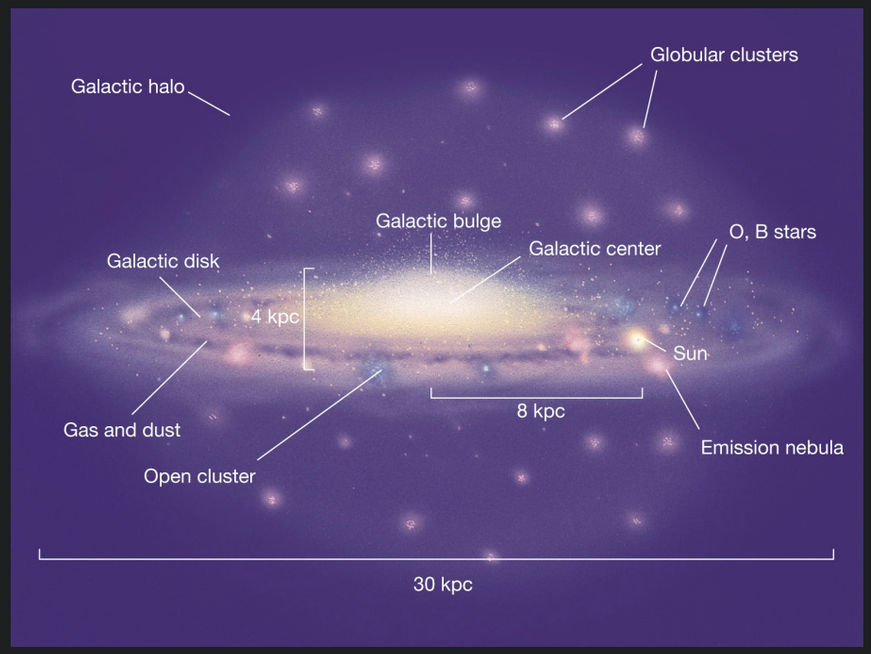


Sombrero Galaxy
Optical image
Distance: 9.55 ± 0.13 Mpc

The structure of the Milky Way

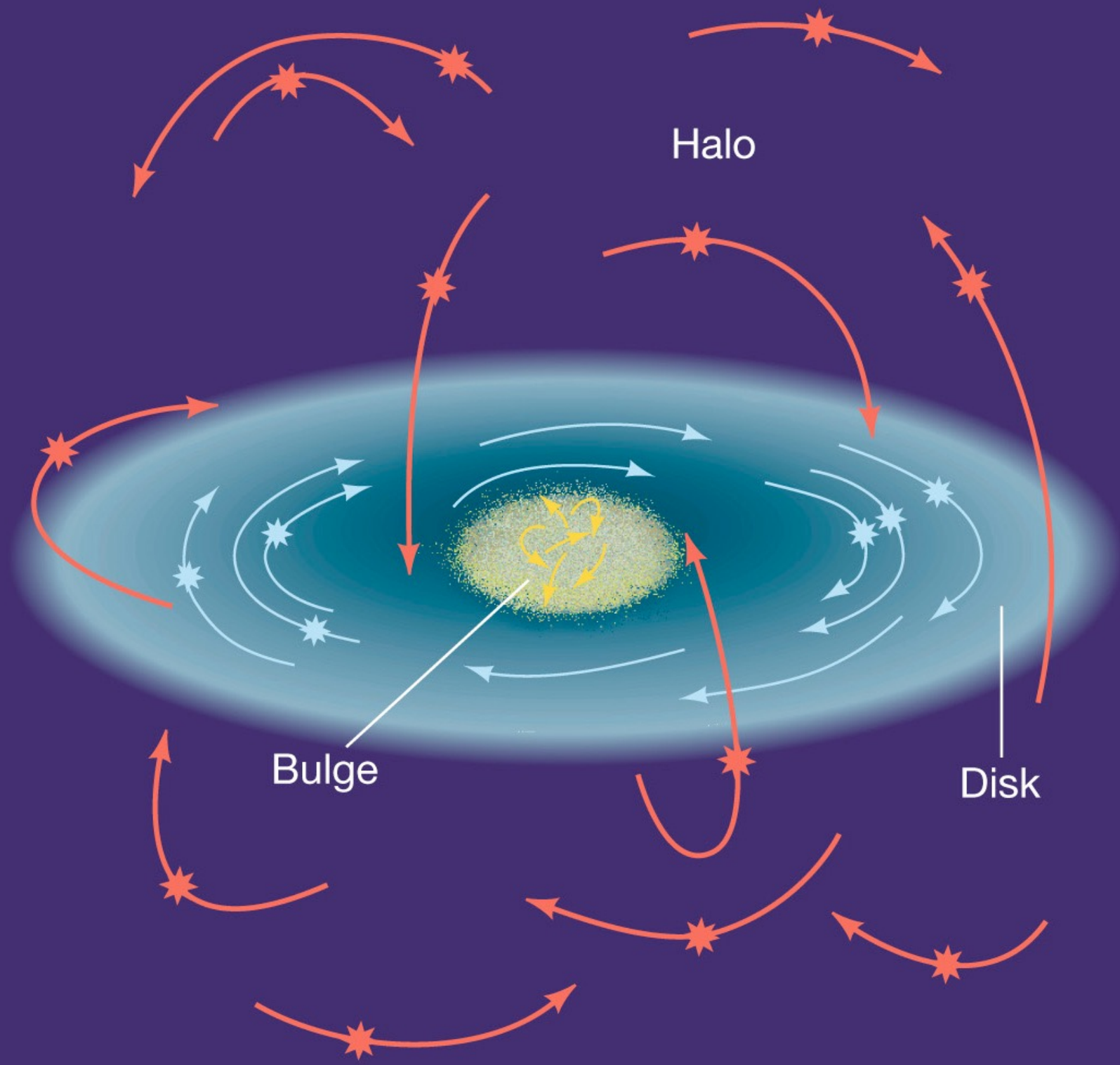


Halo (oblate spheroid) dominated by presence of *Dark Matter*



100 kpc

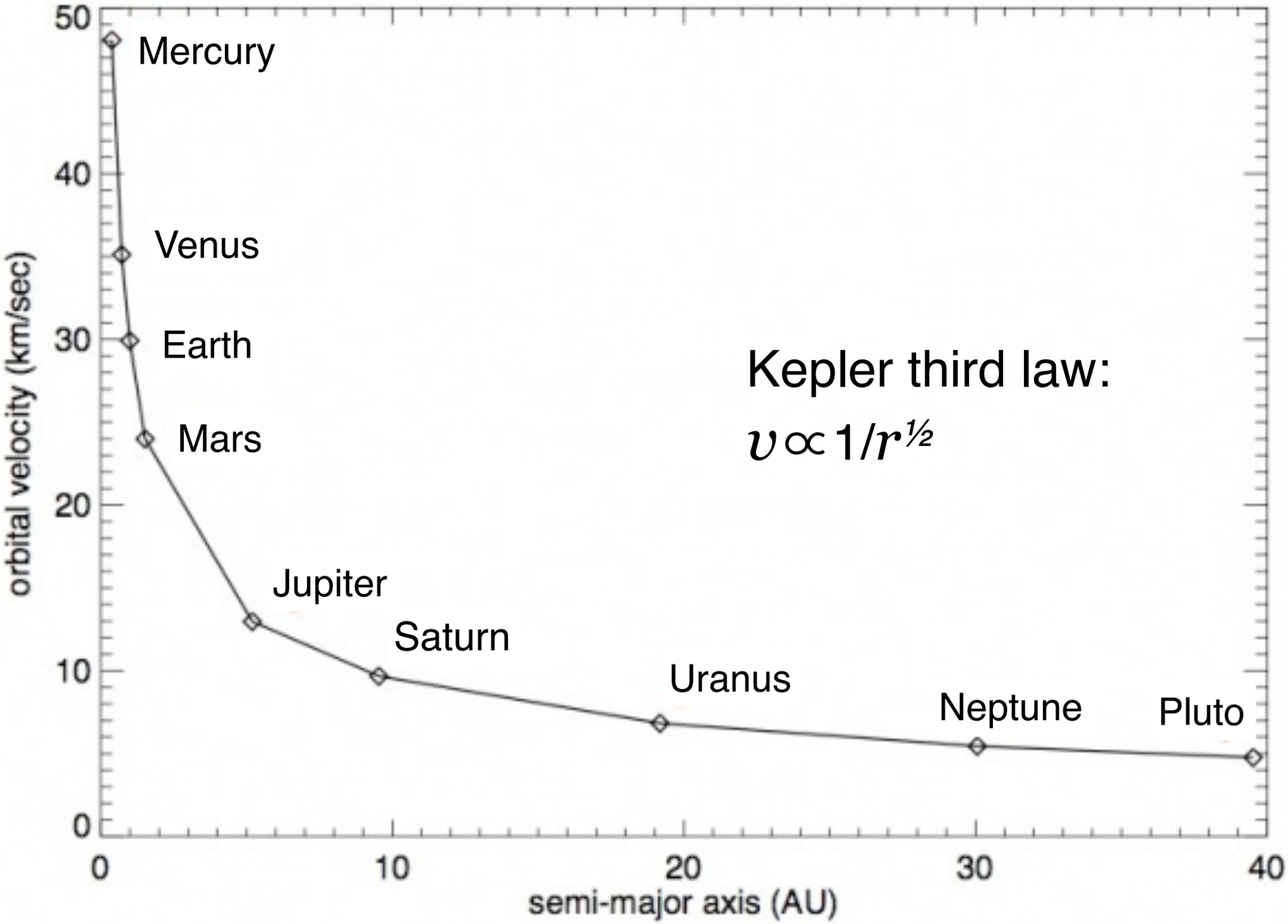
Stars in halo of Milky Way have random rotation around center



While stars in disk rotate in same direction around center

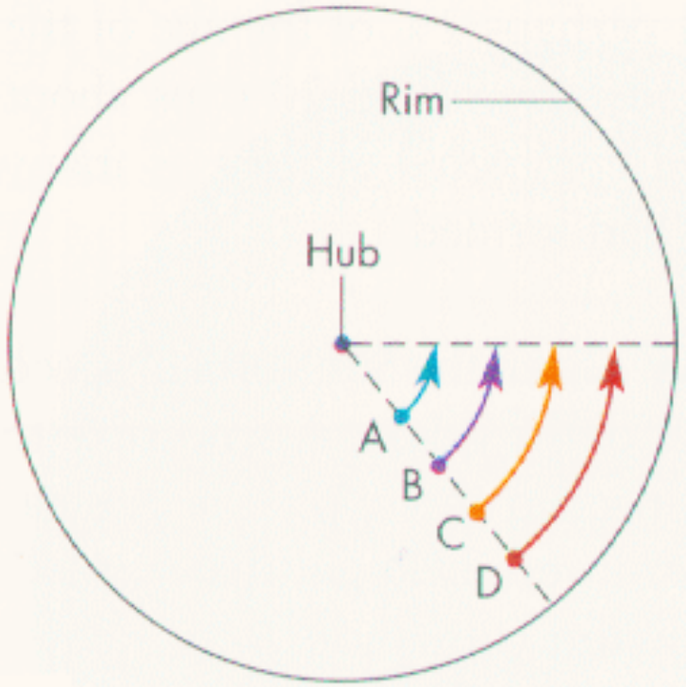
Mass of the Milky way

Orbital velocity of planets in solar system

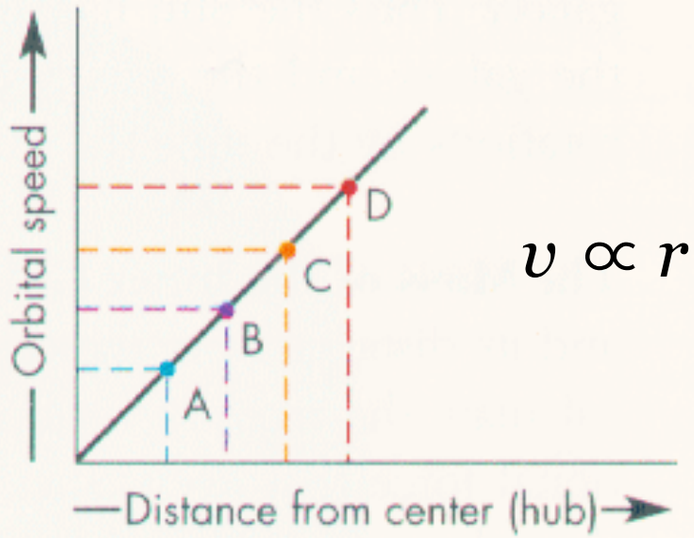


Possible orbital velocities

Solid body



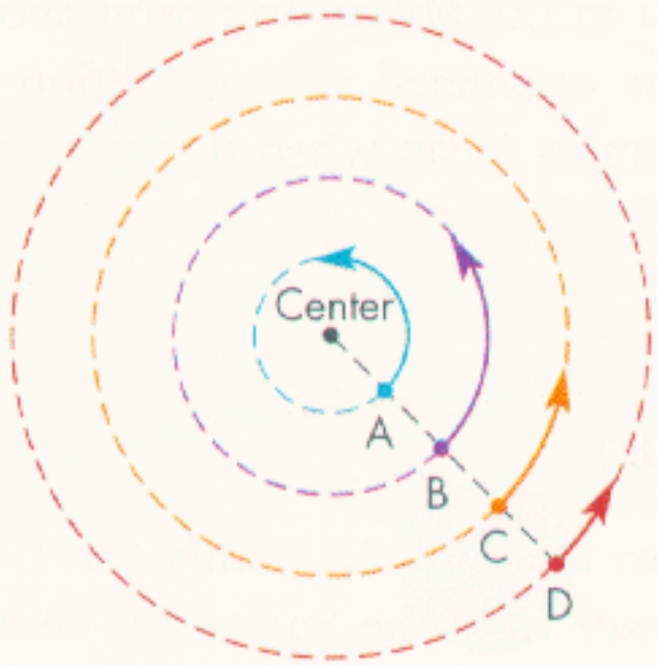
Wheel-like rotation



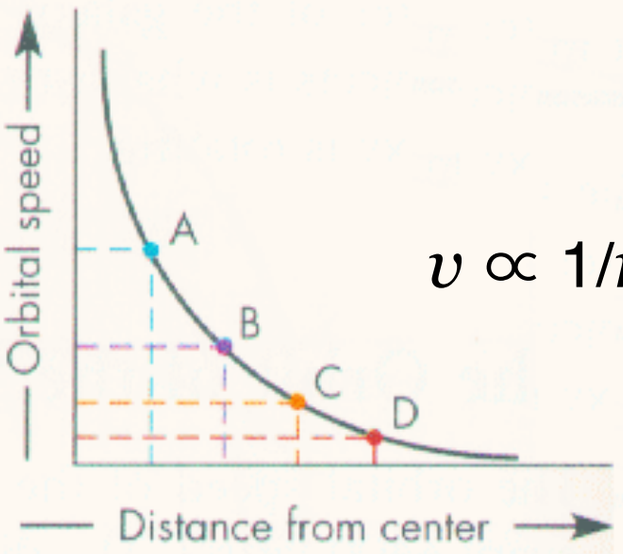
Rotation curve for wheel-like rotation

$v \propto r$

Planet system



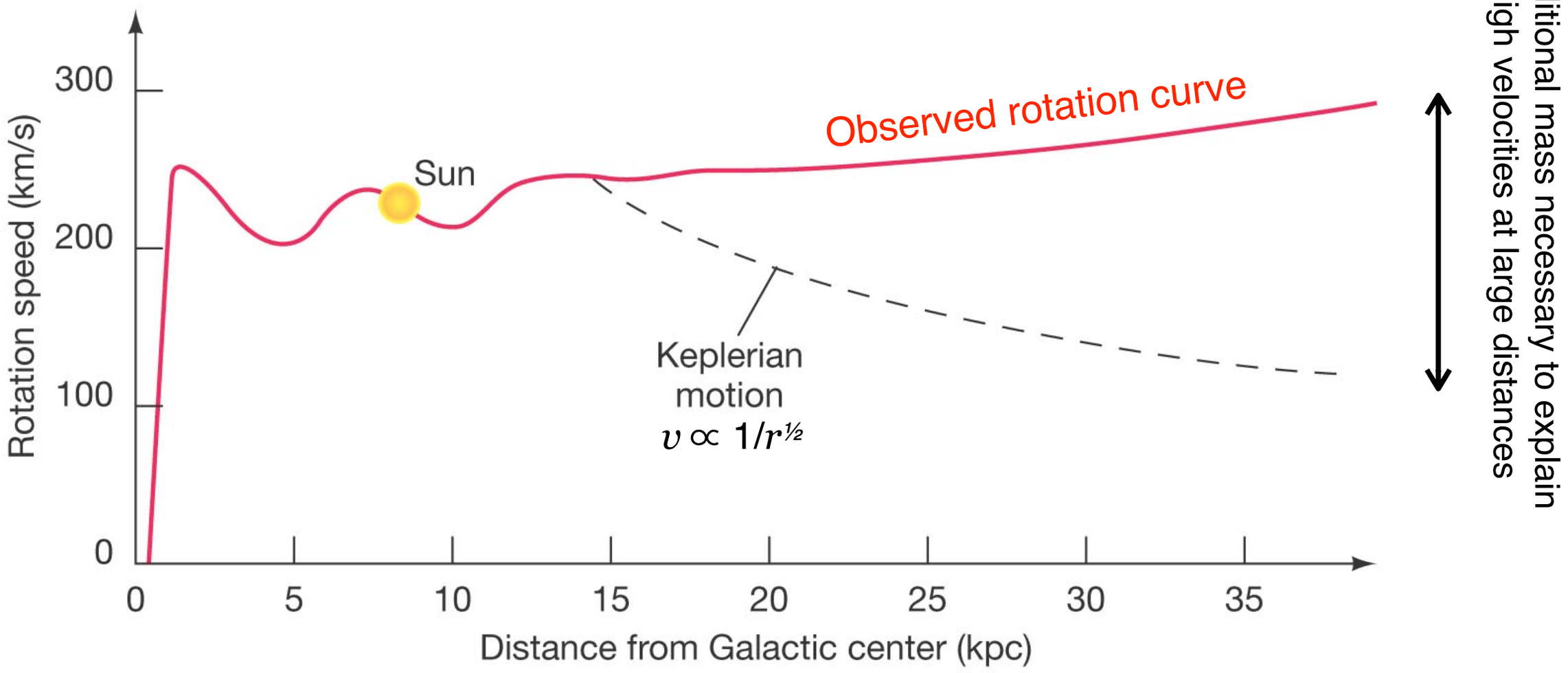
Planet-like rotation



Rotation curve for planet-like rotation

$v \propto 1/r^{1/2}$

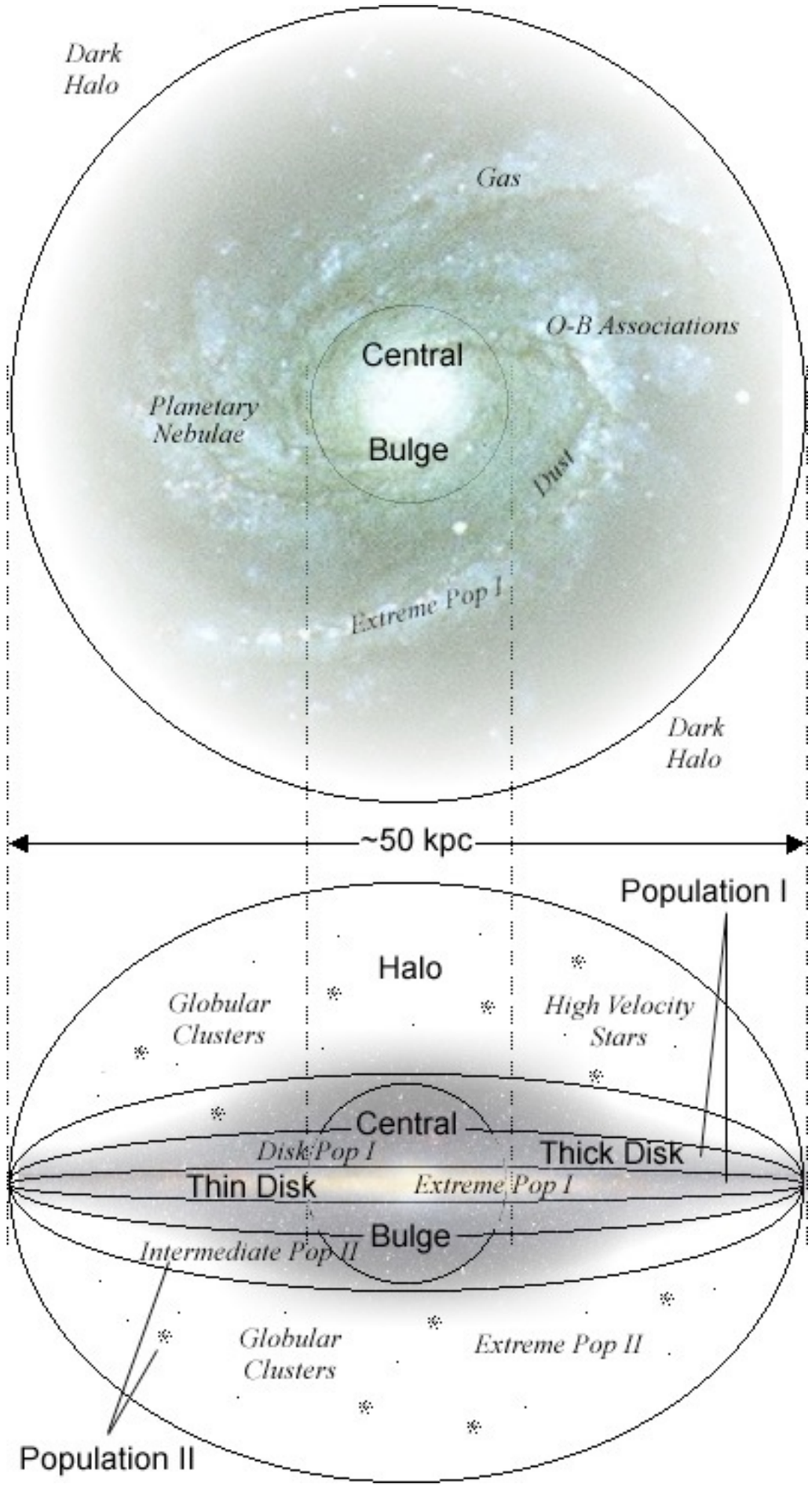
Rotation of objects around Galaxy Center (*rotation curve*) as evidence of presence of **dark matter**



Mass required to explain rotation curve is *not seen* (no emission of radiation of any kind): **dark matter!**

The structure of the Milky Way

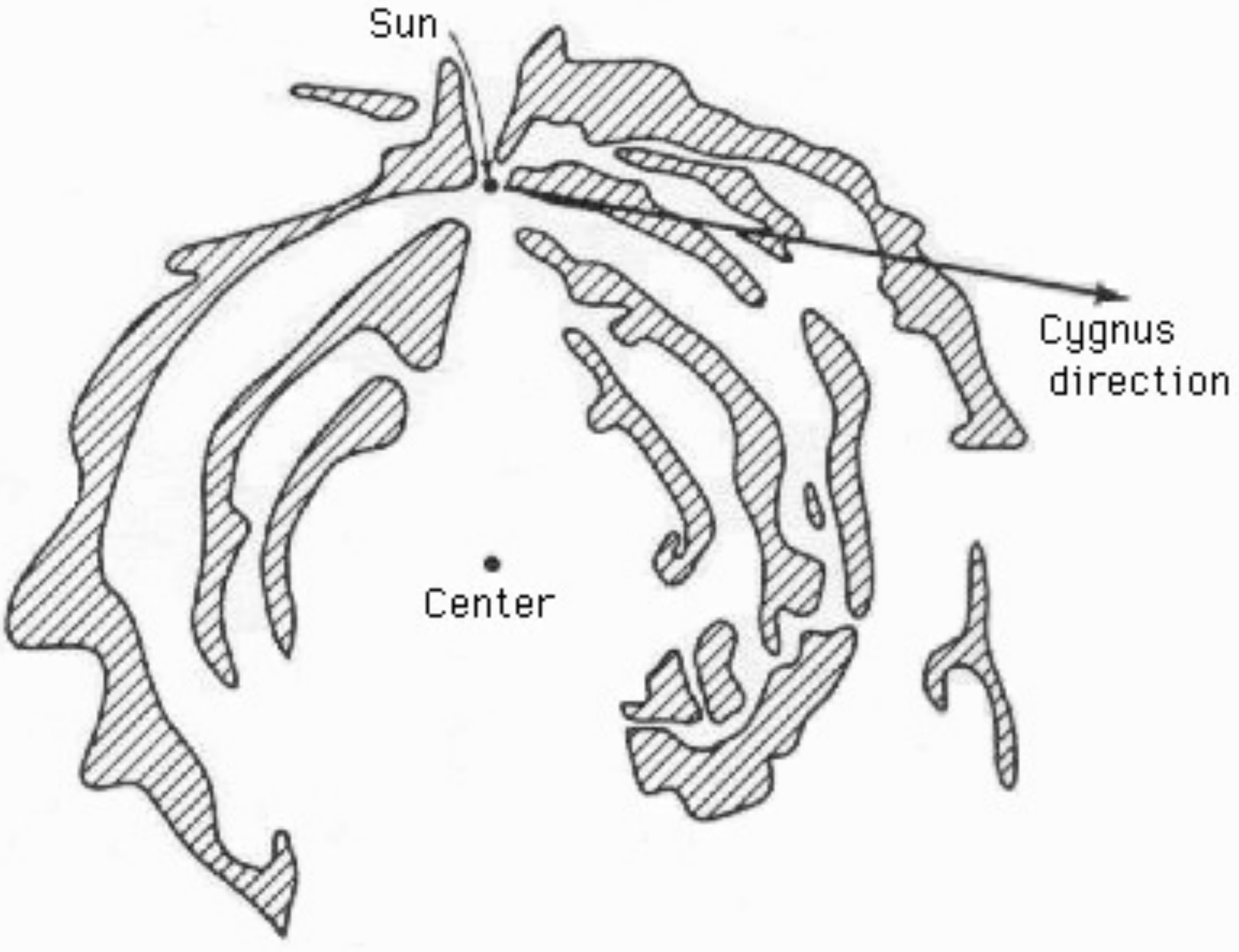
Spatial distribution of stars in our Galaxy



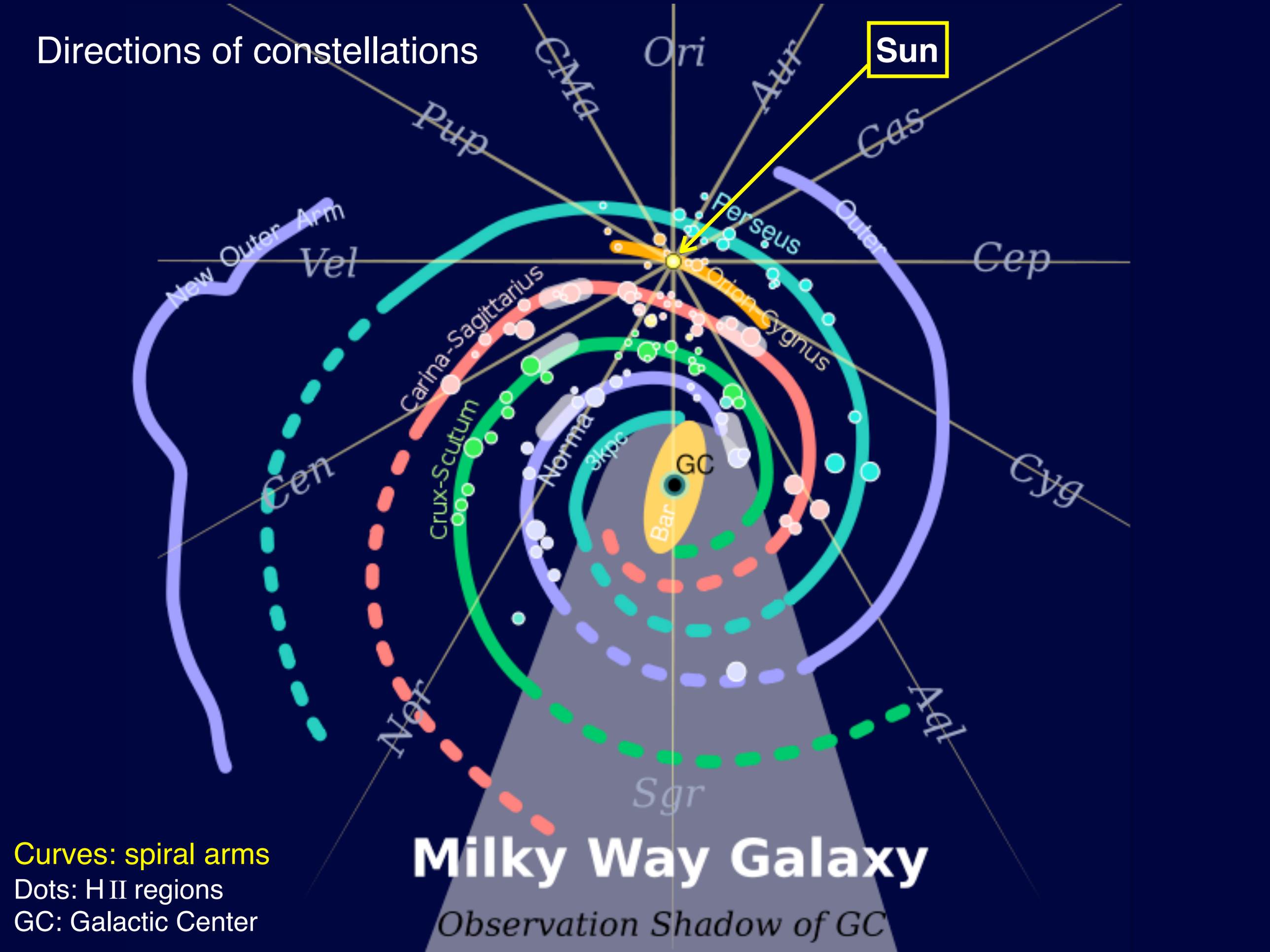
Different components in our Galaxy

Component	Shape	Size (kpc)	Stellar component	Gas component	Mass ($M_\odot$)
Dark-matter halo	Oblate spheroid?	> 100			$\sim 10^{12}$
Stellar halo	Oblate spheroid *c/a ~ 0.8*	> 40	Pop II	Little gas	$\sim 10^{9}$
Thick disk	Flat disk + spiral arms	30×2	Old-interm.	Little gas	$\sim 10^{10}$
Thin disk	Flat disk + spiral arms	30×1	Pop I	Dense/ diffuse...	$\sim 10^{11}$
Nuclear bulge	Triaxial spheroid (bar)	6	Black hole		$\sim 10^{10}$

Radio map of our Galaxy seen with hydrogen 21 cm emission



Directions of constellations



Curves: spiral arms
Dots: H II regions
GC: Galactic Center

Spiral arms are very common in galaxies
(long-lived structures)

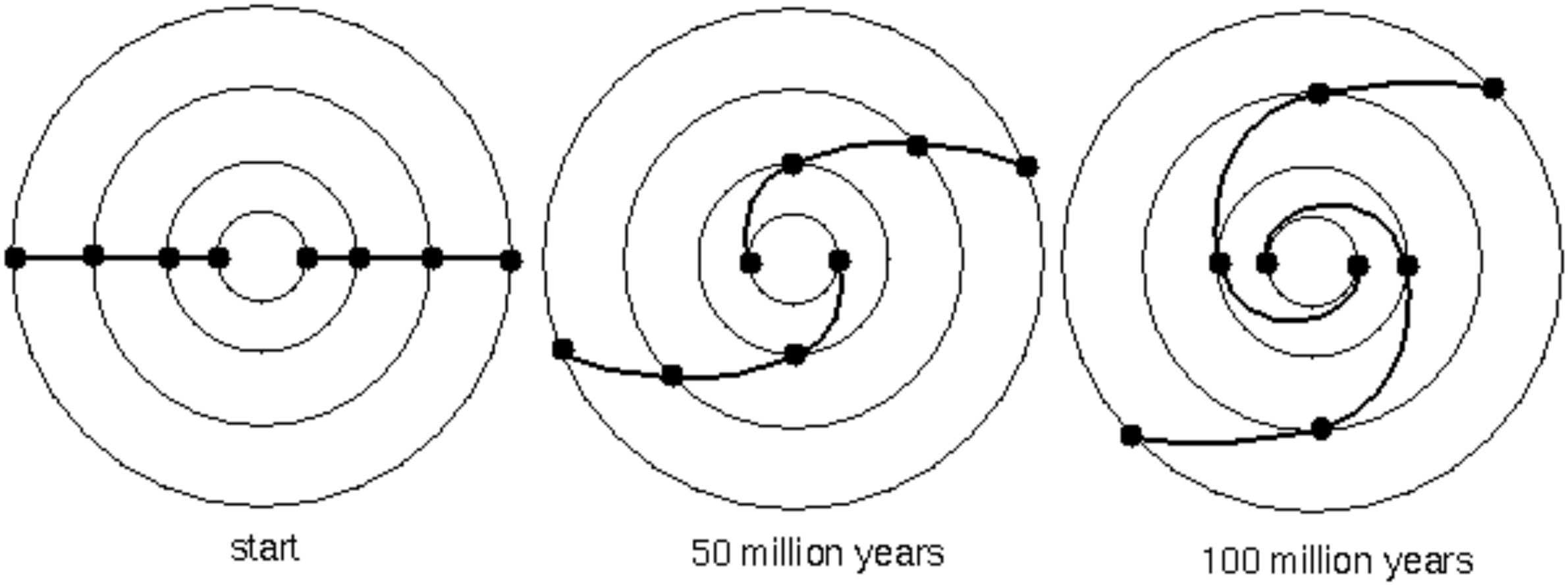
NGC 6744
Galaxy type: SBbc (barred spiral galaxy)
Distance: 9.5 ± 1.6 Mpc

Bar-shaped central region is stabilising structure

NGC 1300
Galaxy type: SB (barred spiral galaxy)
Distance: 18.8 Mpc

Differential rotation of stars in Milky Way

What if arms are traced by motion of stars?

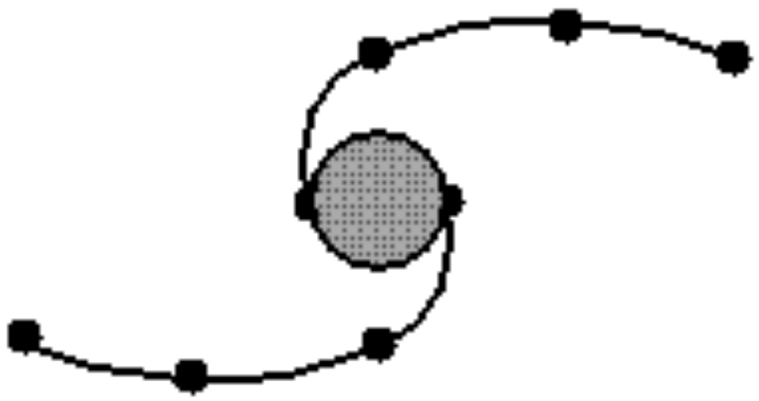


Stars closer to center
complete orbits in less time

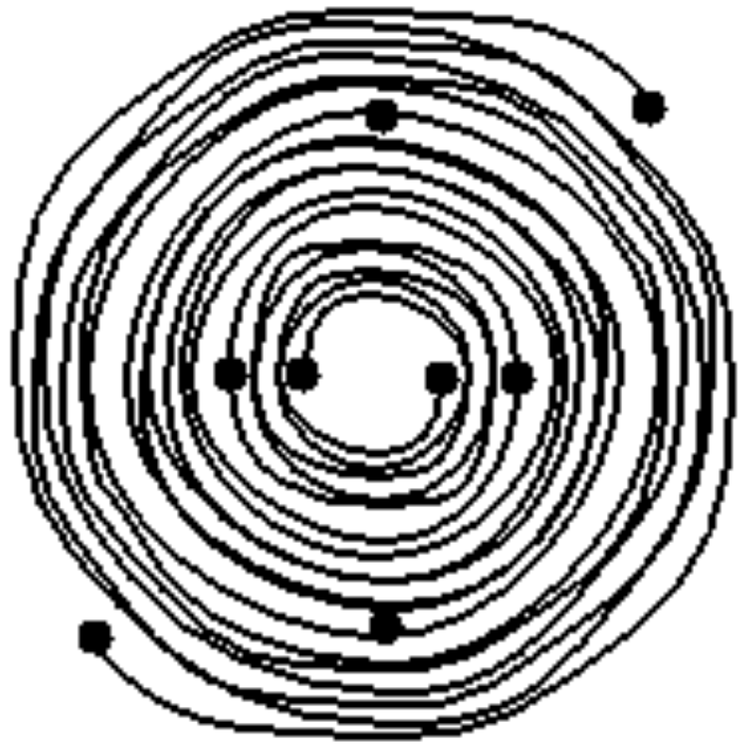
If arms are traced by stars,
they would not be permanent

Differential rotation of stars in Milky Way

What if arms are traced by motion of stars?



Observation: 15,000 million years



Prediction: 500 million years

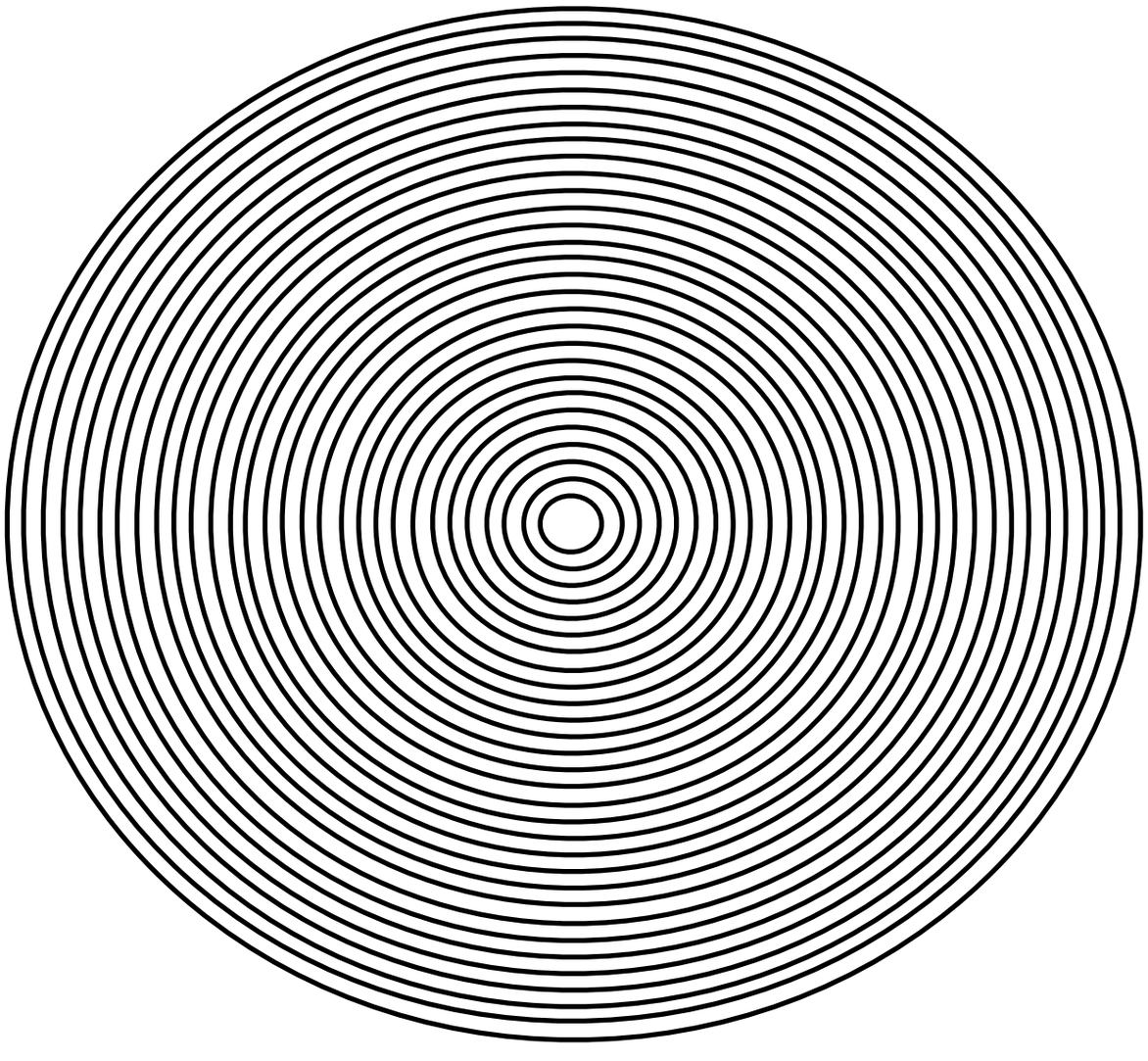
Similar structures never seen in spiral galaxies!

Consequence: ***apparent motion*** not involving stars

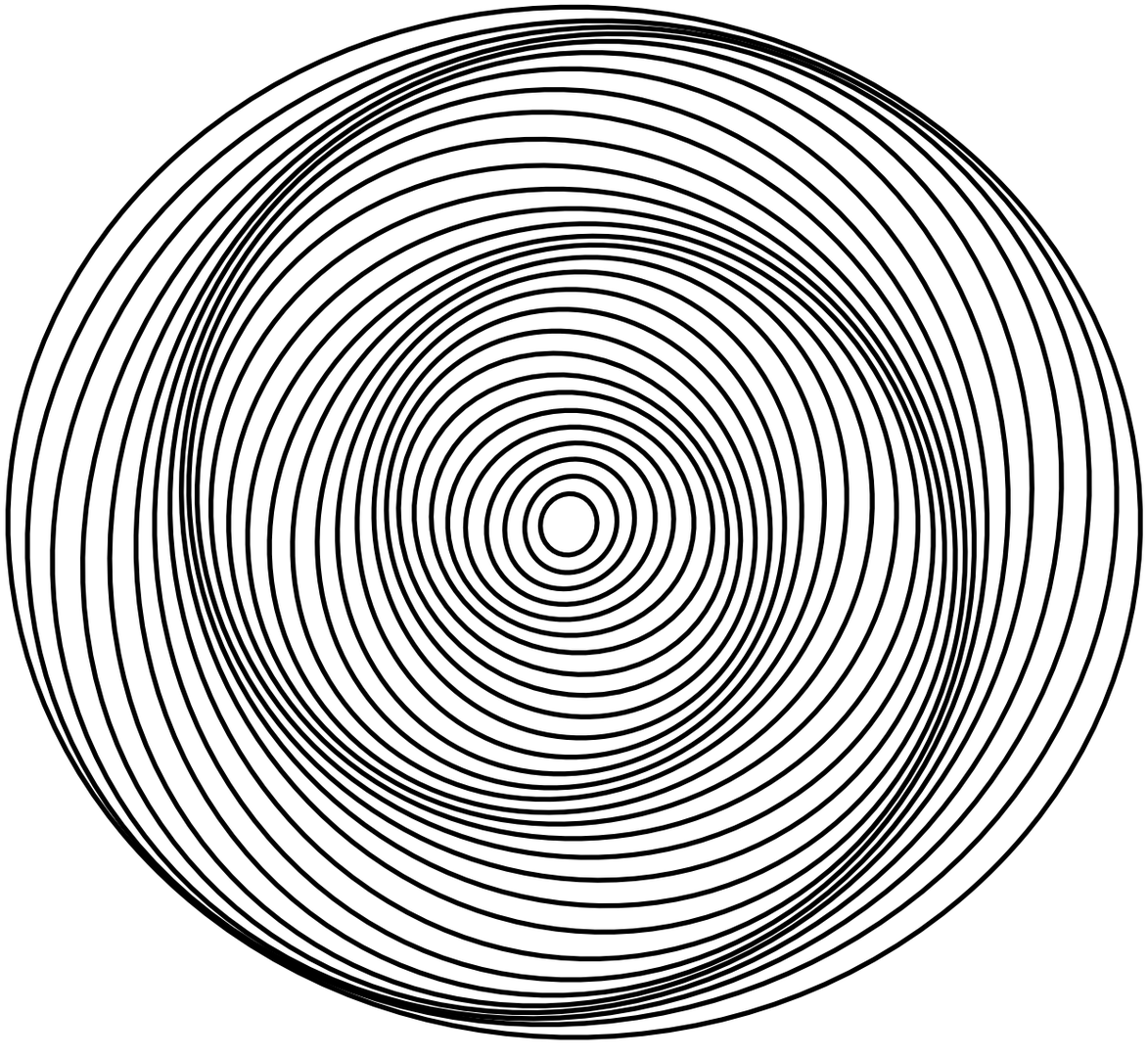
Spiral density wave in spiral galaxies

Stars & gas orbiting in ellipses

Orbits of stars & gas (ellipses)
with same orientation



If ellipses are slightly misaligned

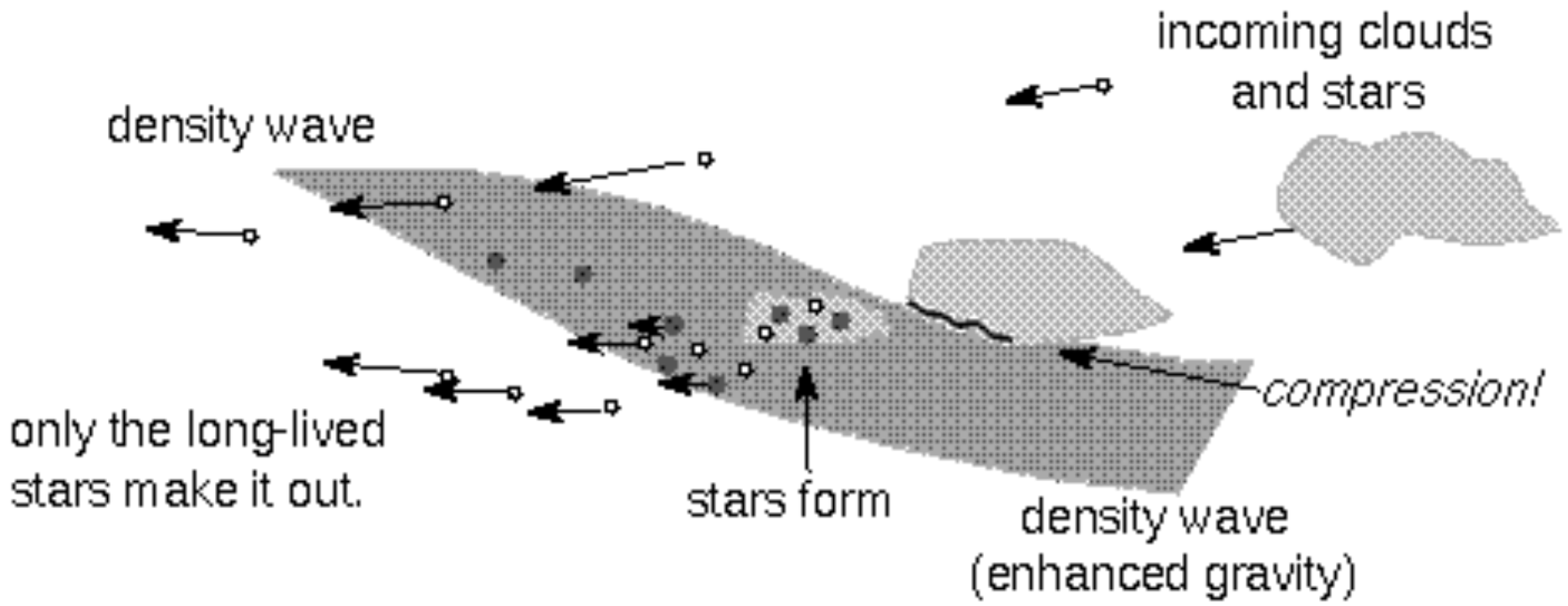


Spiral arms: permanent pattern
of **density enhancement**

Spiral density wave

(like cars and trucks in heavy traffic)

individual cars move through the traffic jam



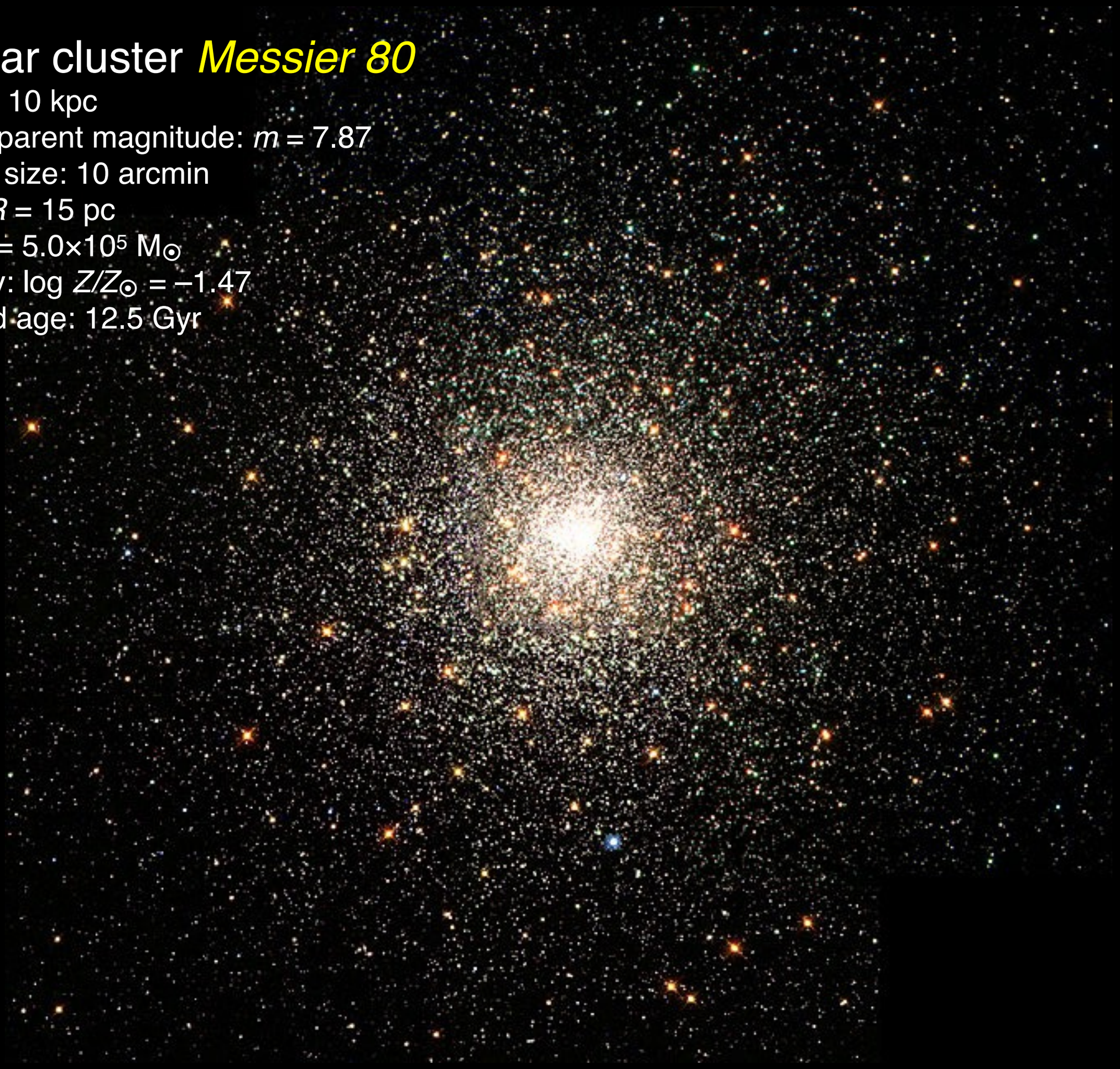
Star formation and young stars in spiral arms

Whirlpool Galaxy
Distance: 7.1 ± 1.2 Mpc
Redshift: v = 463 ± 3 km/s (z = 0.00154)
Apparent dimensions: 11.2′ × 6.9′
Apparent magnitude: m = 8.4

Spatial distribution of globular clusters

Globular cluster *Messier 80*

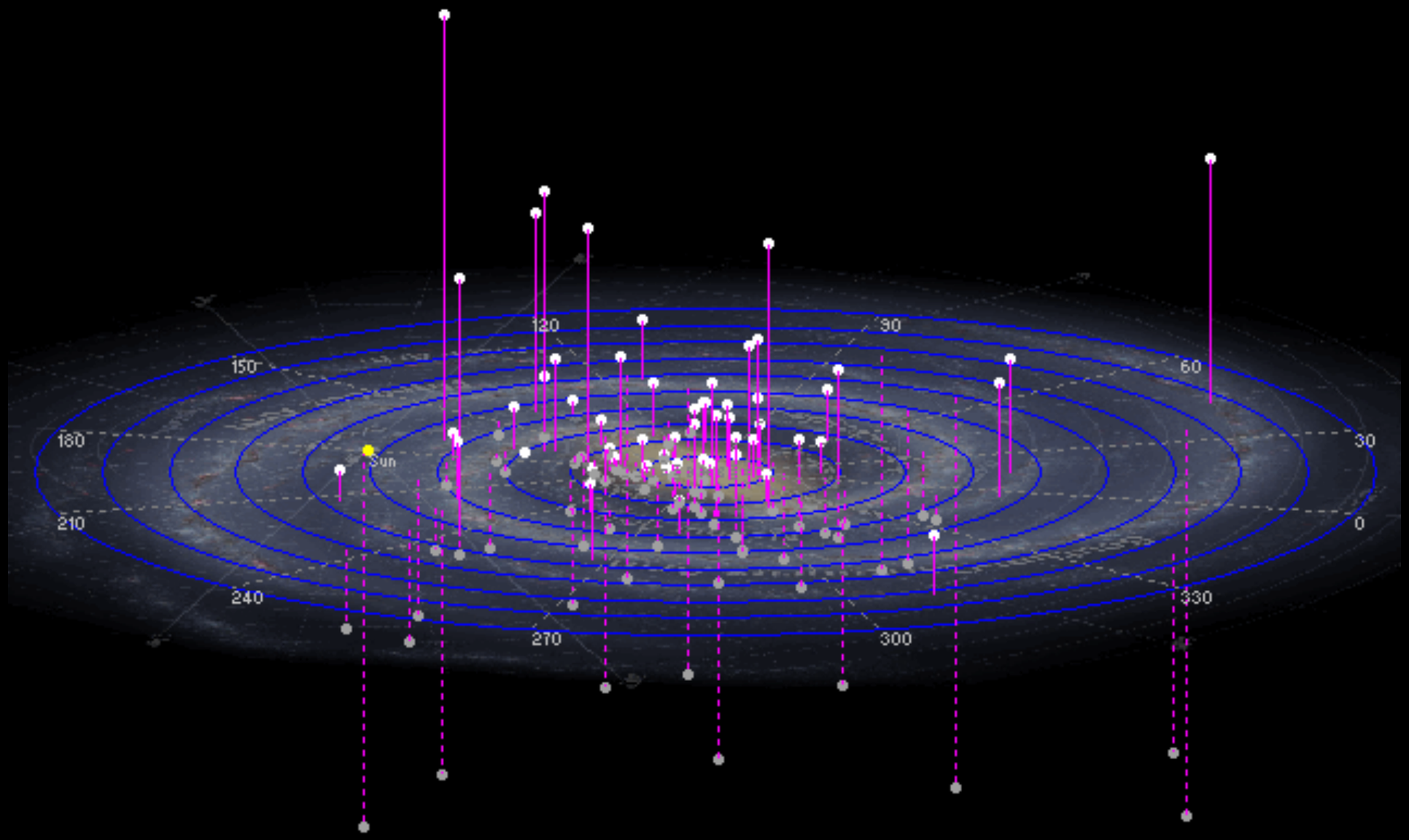
Distance: 10 kpc
Visual apparent magnitude: $m = 7.87$
Apparent size: 10 arcmin
Radius: $R = 15$ pc
Mass: $M = 5.0 \times 10^5\ M_\odot$
Metallicity: $\log Z/Z_\odot = -1.47$
Estimated age: 12.5 Gyr



The 119 globular clusters within 50,000 LY of the galactic centre

Galactic centric (galactic longitude and latitude)

5,000 LY

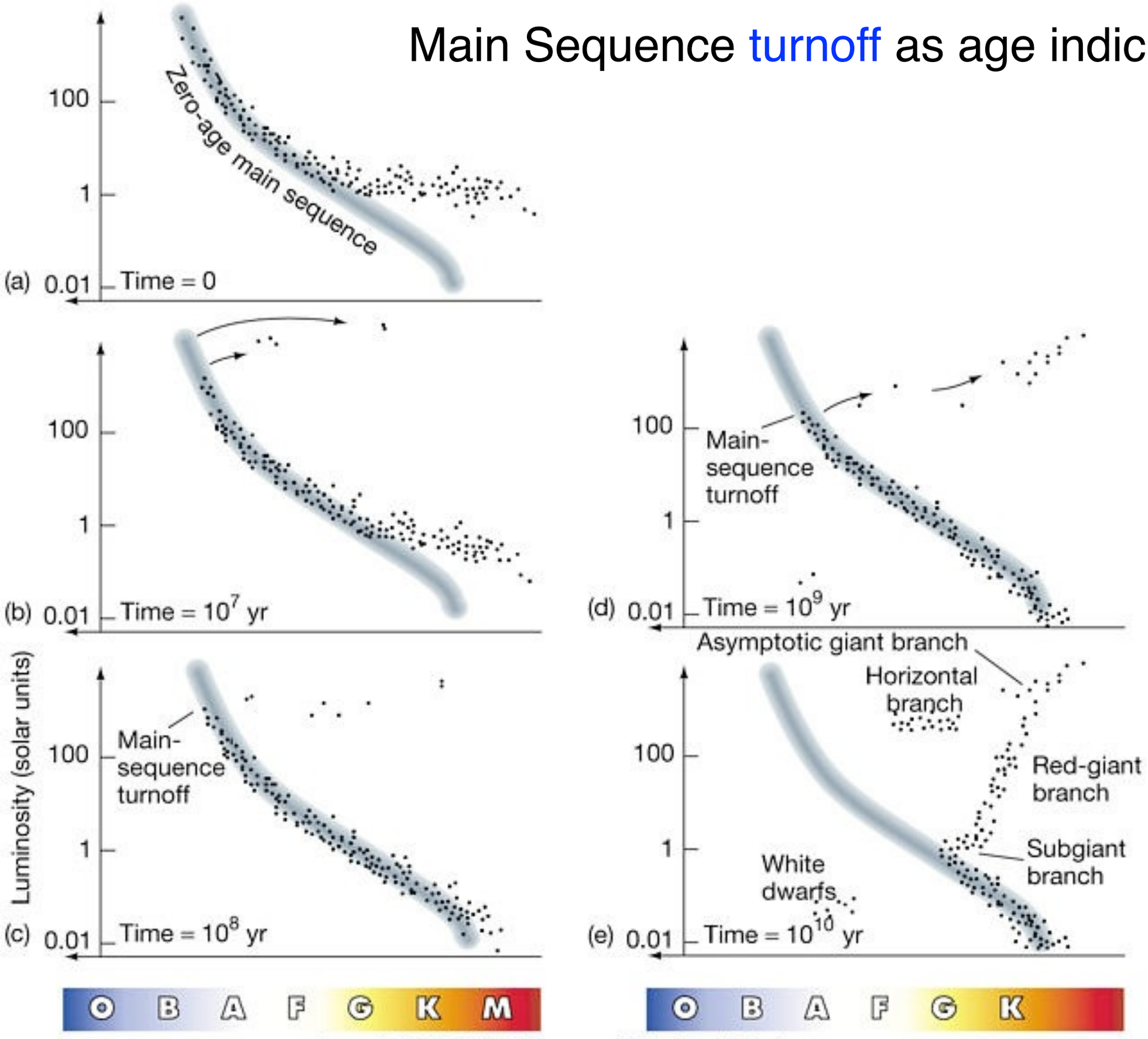


More than 157 Milky Way globular clusters known (as of May-June 2011)

Data from William E. Harris, McMaster University
http://www.physics.mcmaster.ca/Globular.html

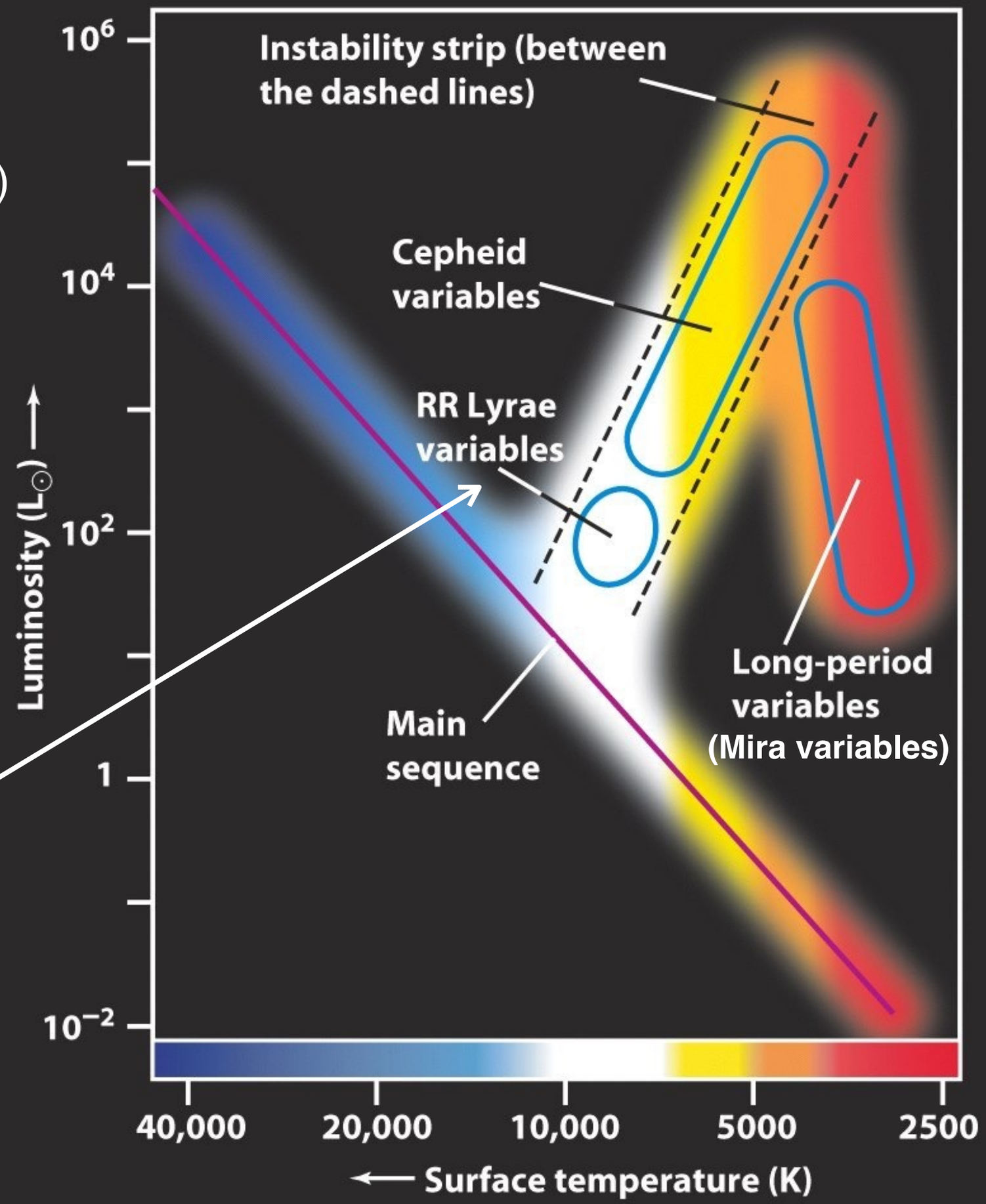
3D Diagram by Larry McNish

Main Sequence turnoff as age indicator



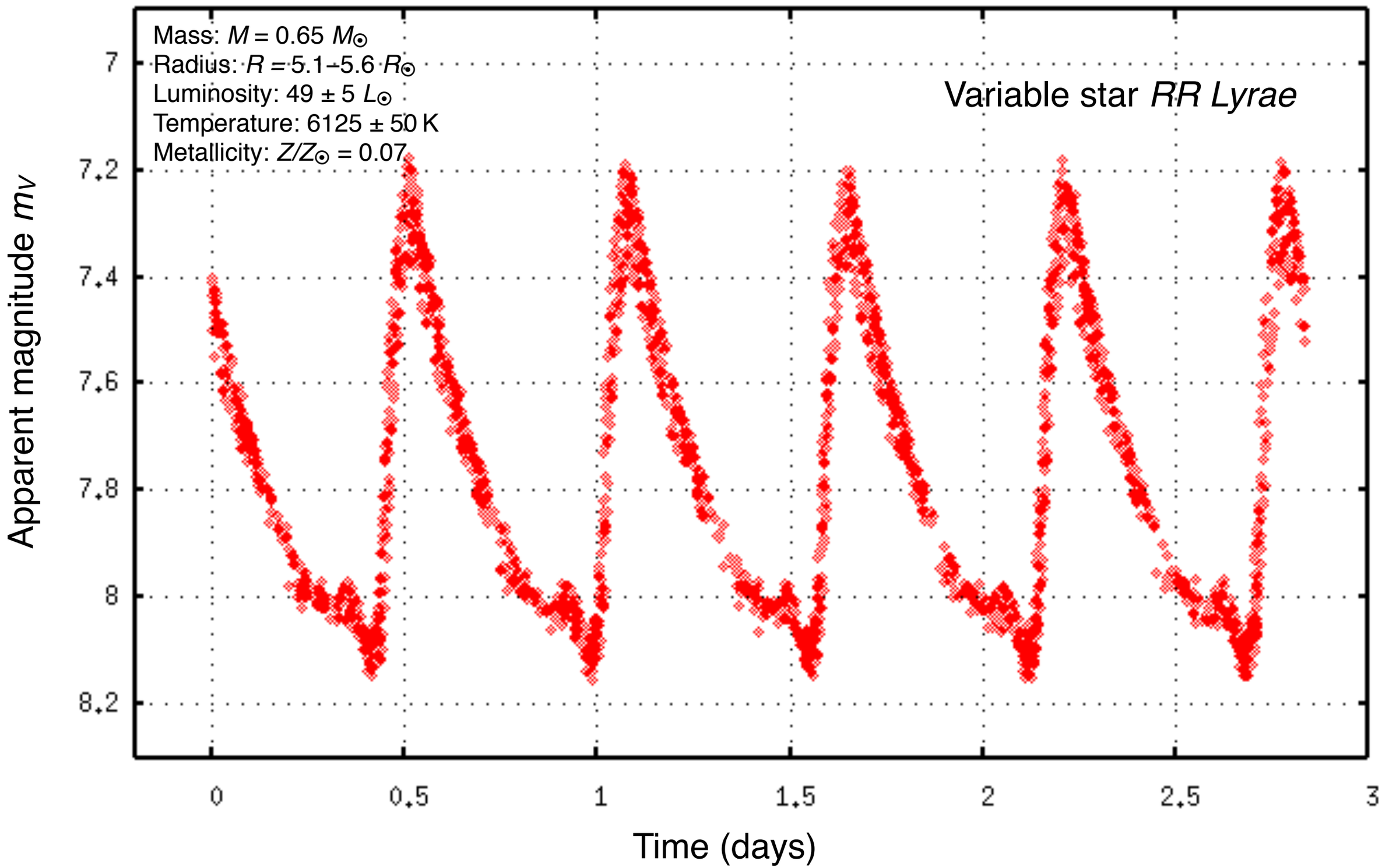
Size and shape of the Halo of the Milky Way

Pulsating stars are *Cepheids* and *RR Lyrae* (found with *Hertzsprung–Russell diagram*) used to measure size of the Milky Way

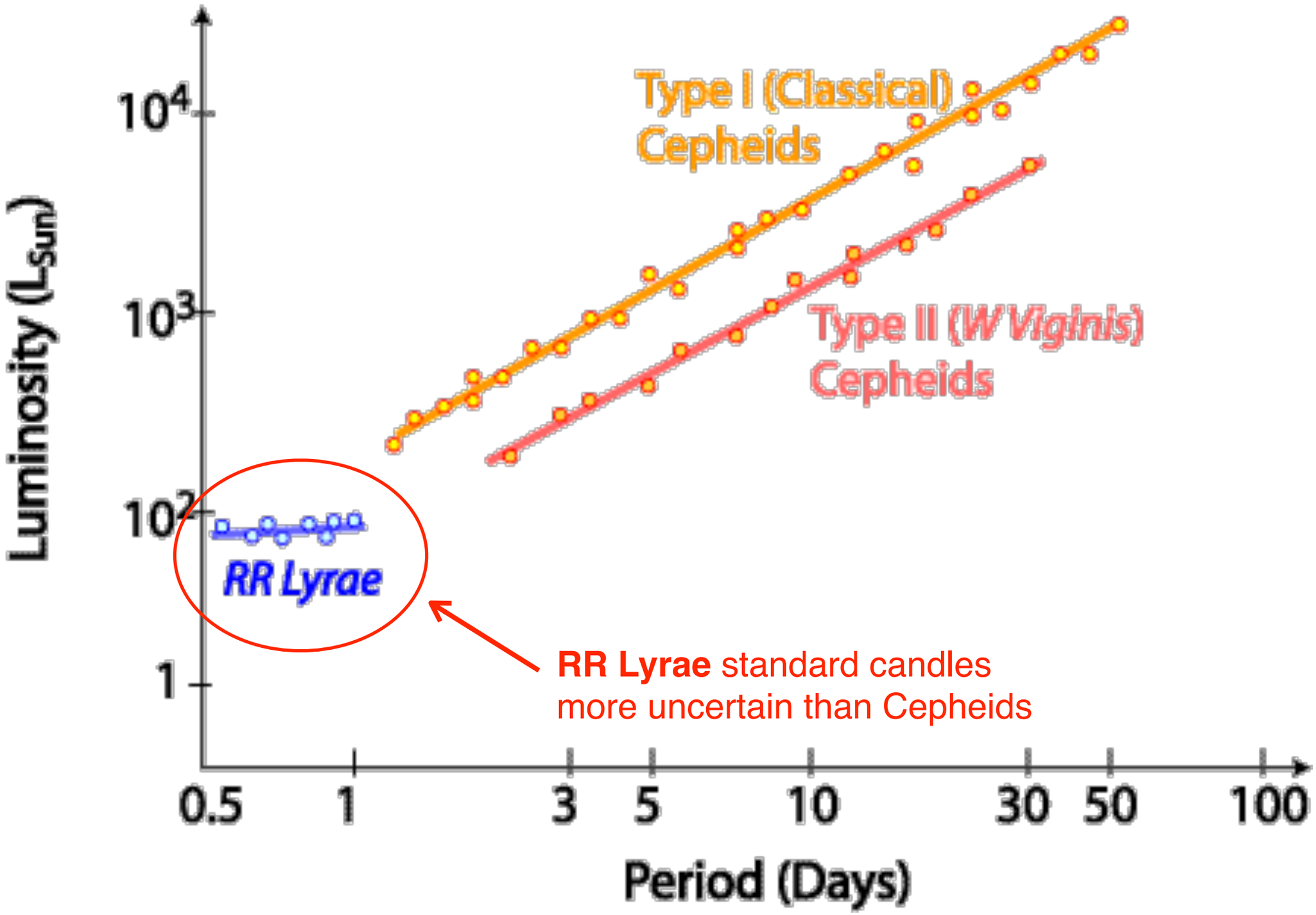


RR Lyrae are old, relatively low mass, metal-poor stars used to reach large distances (standard candles) because more common than *Cepheids*

Apparent *V*-band magnitude of variable star *RR Lyrae*

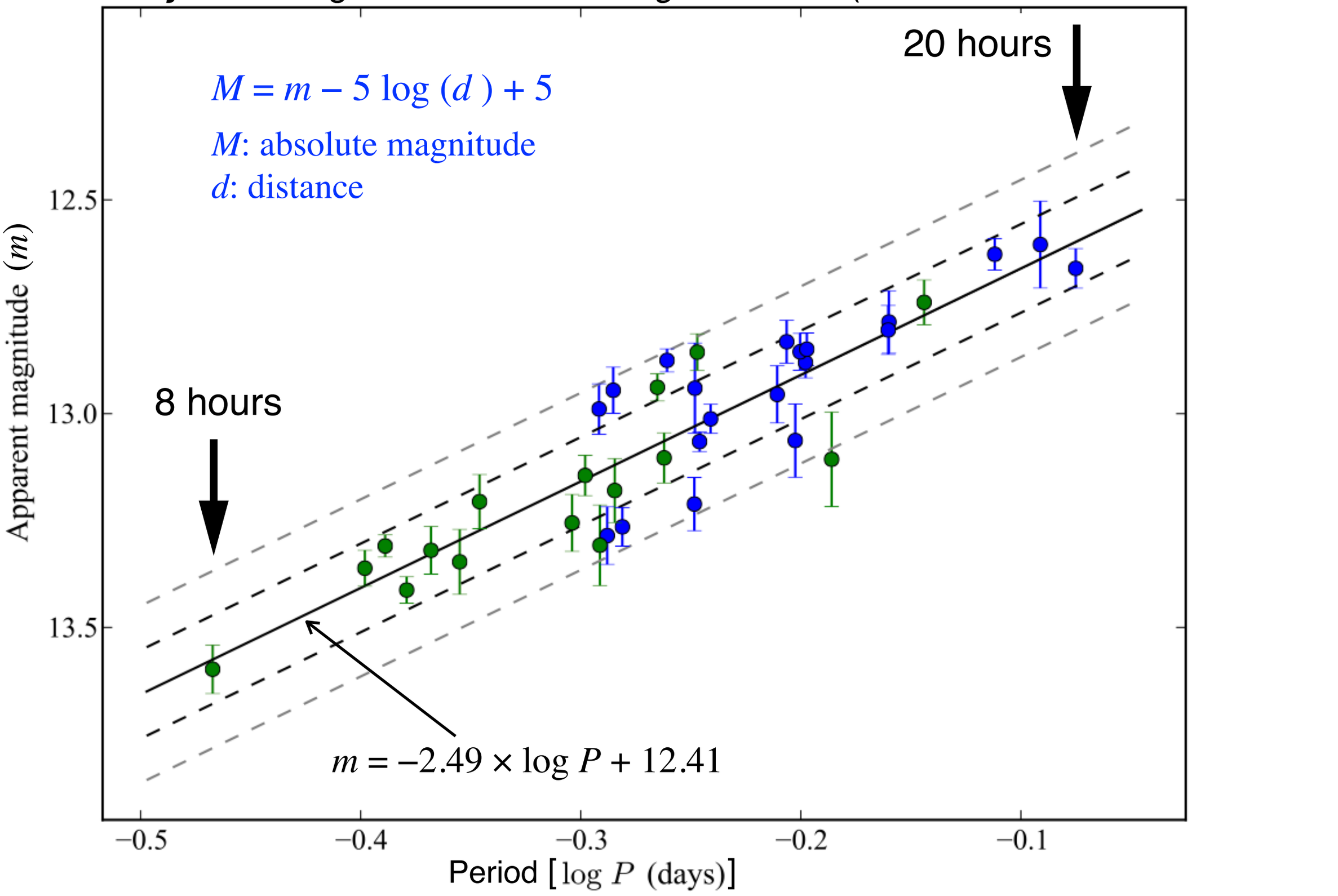


Period-Luminosity relation in variable stars *Cepheids* and *RR Lyrae*



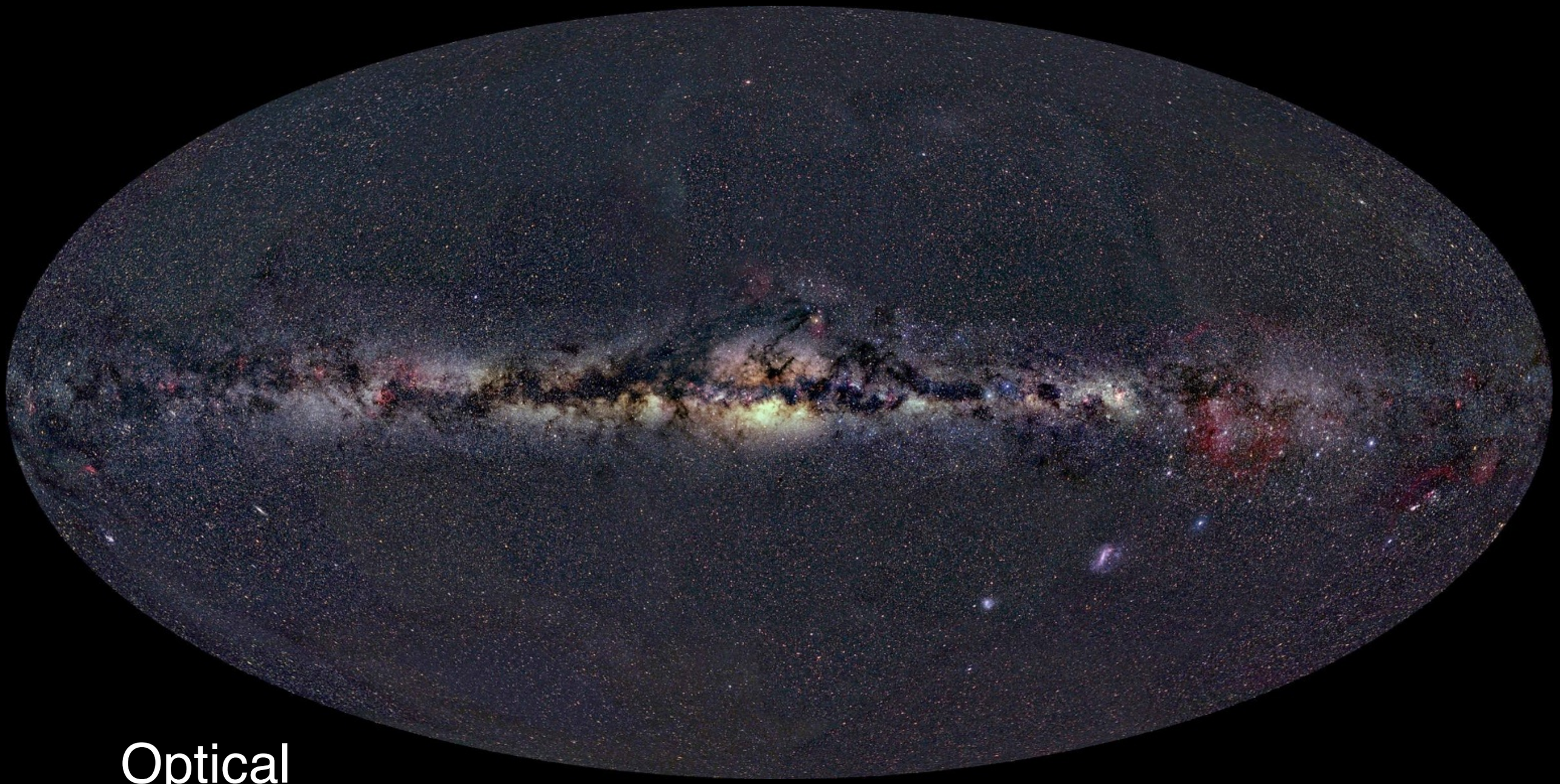
Period vs. apparent magnitude relation to derive distance

36 RR Lyrae from globular cluster *Omega Centauri* (all stars at same distance



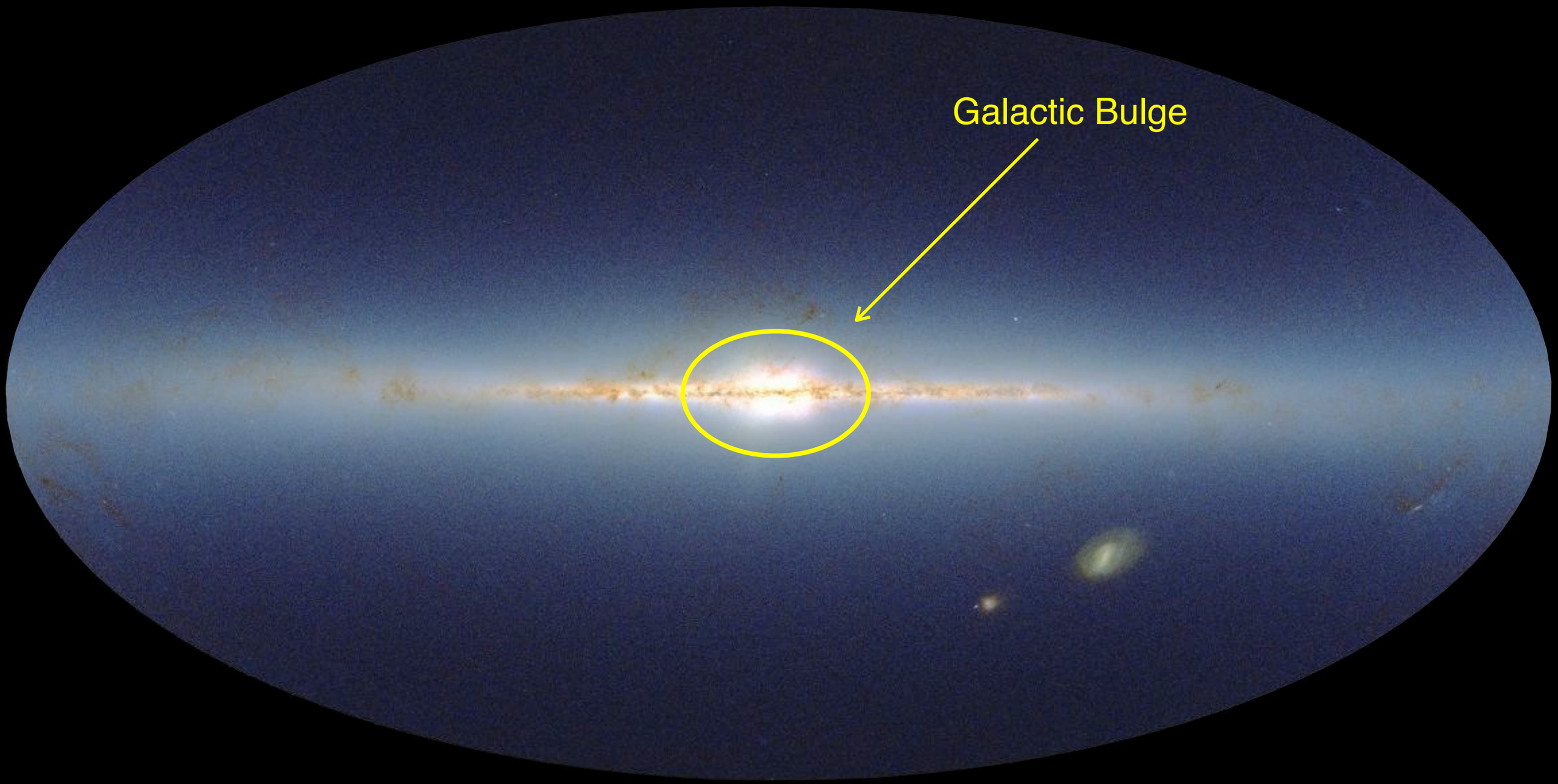
The center of our Galaxy

Milky Way



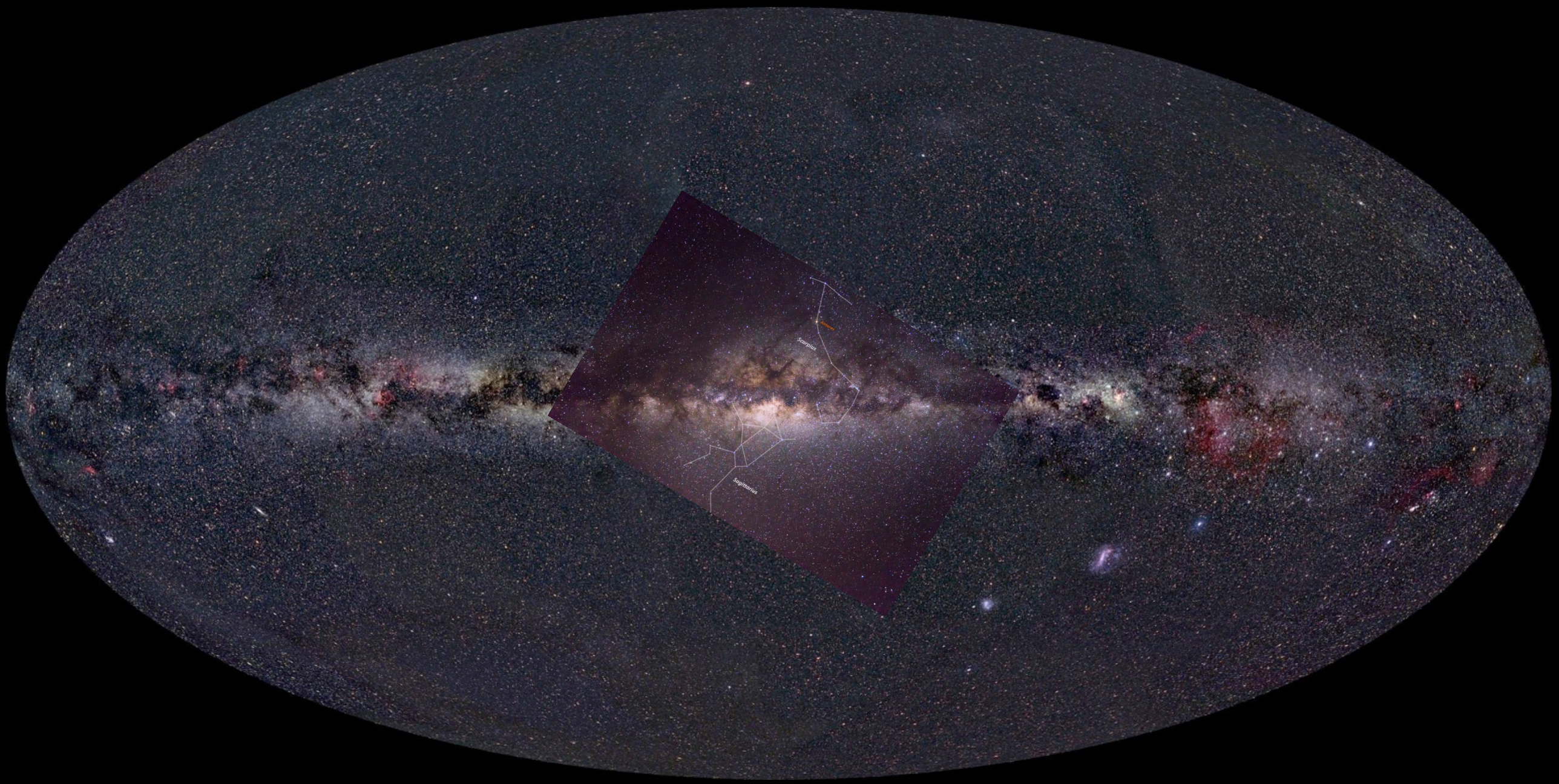
Optical

Milky Way

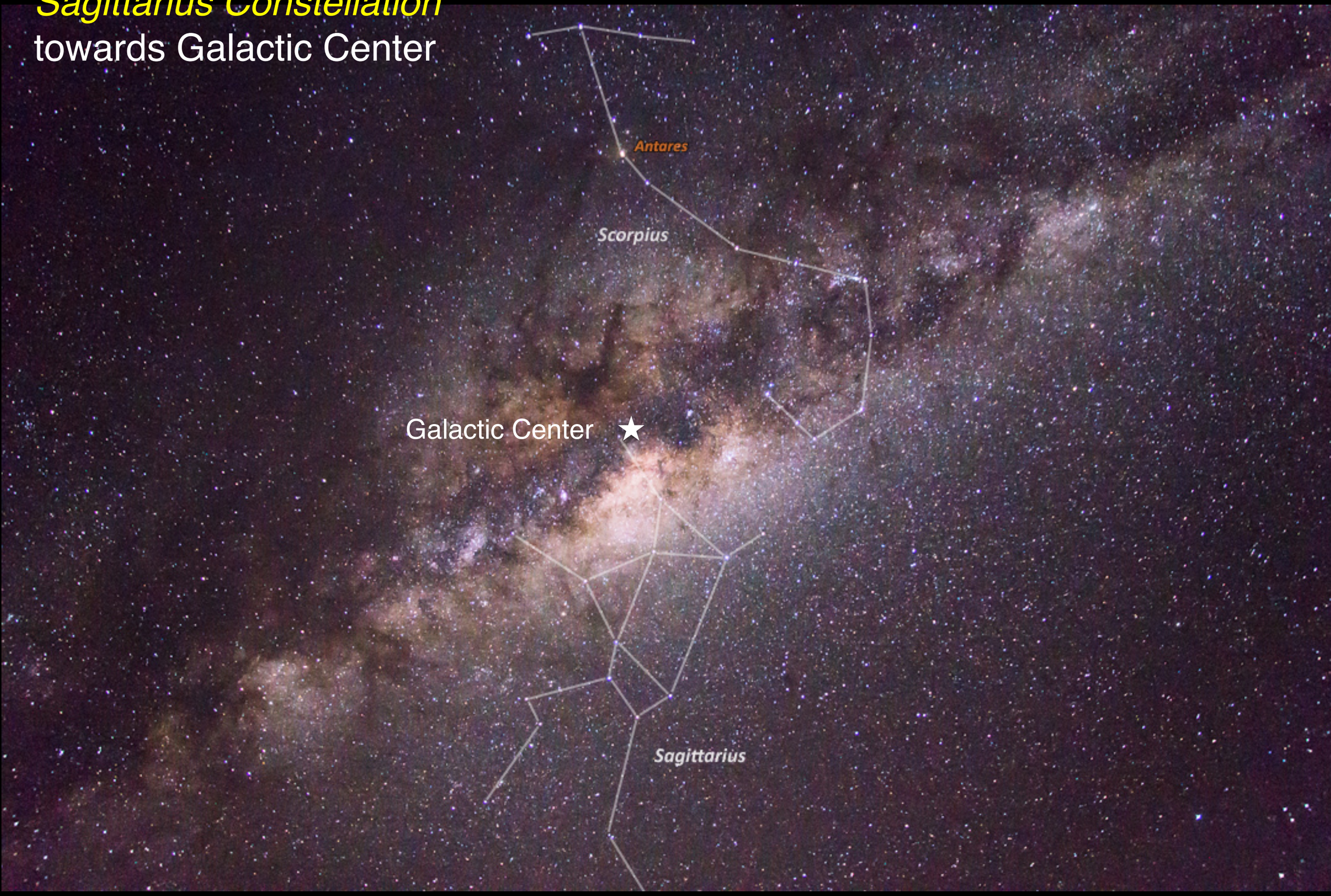


Near IR

Milky Way



Sagittarius Constellation
towards Galactic Center

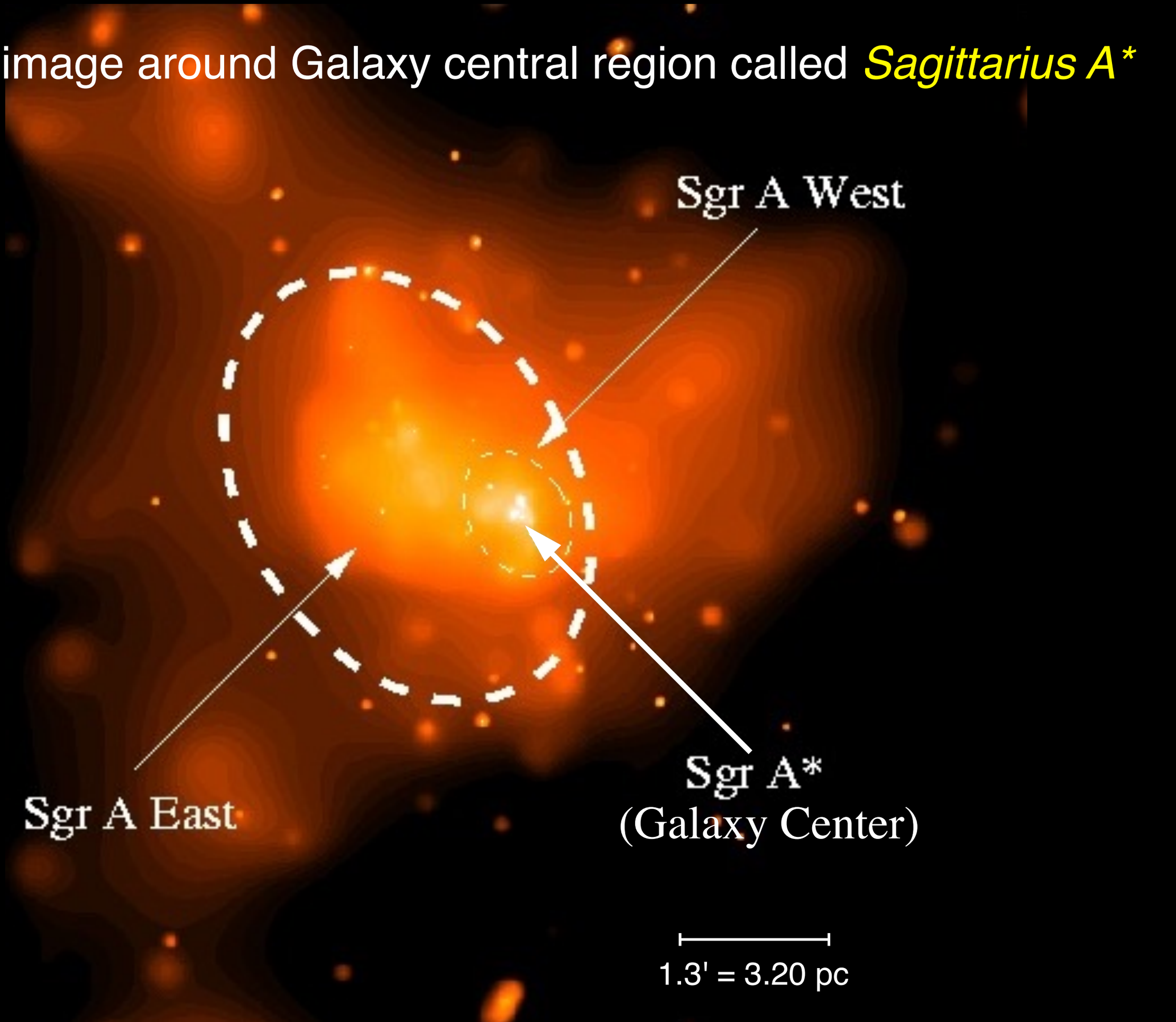


Zooming into the center of the Milky Way

Inside red circle gas cloud falling rapidly towards the central black hole

Video: https://www.youtube.com/watch?v=t7GgqHIGbKw

X-ray image around Galaxy central region called *Sagittarius A**



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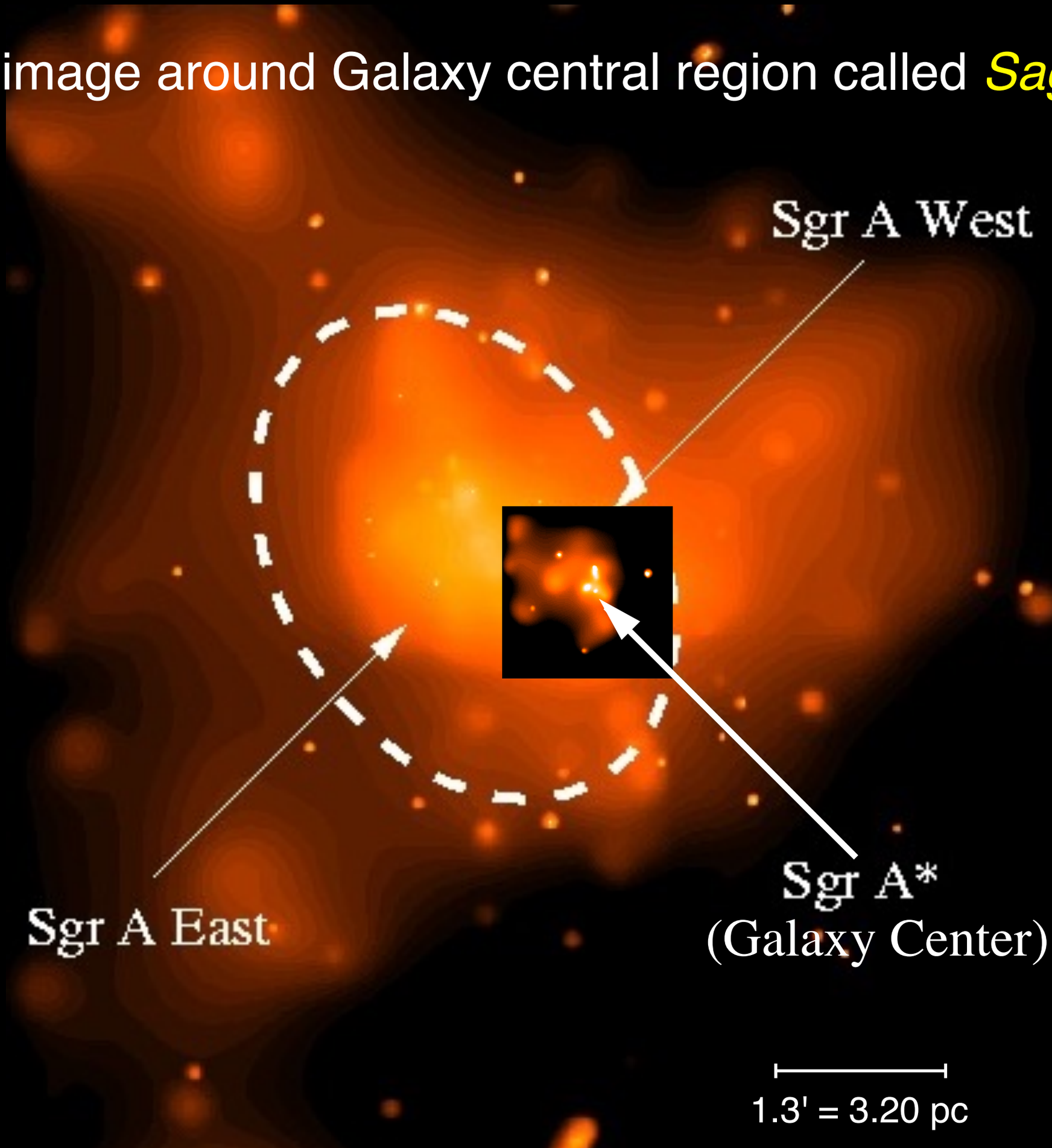
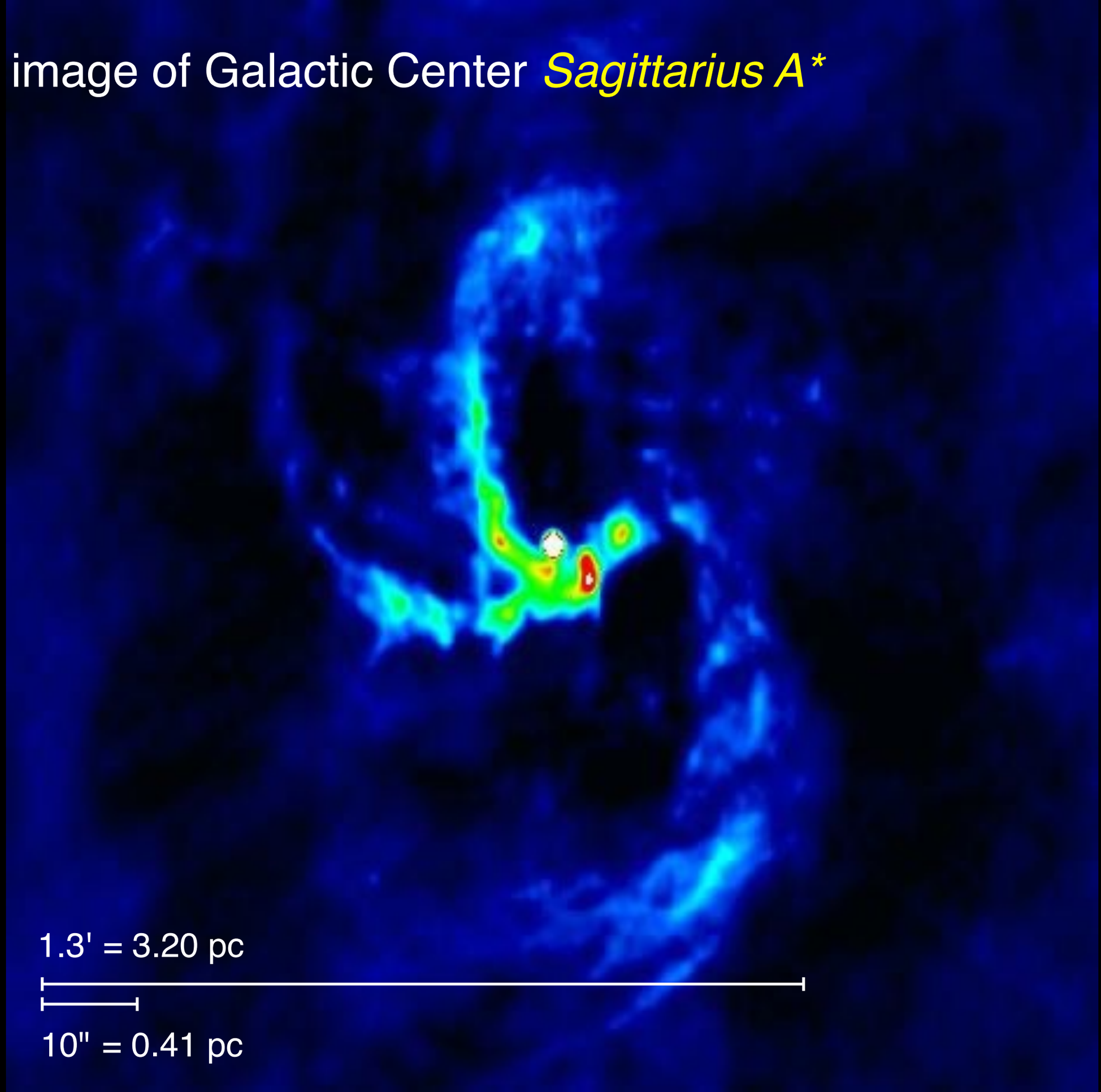
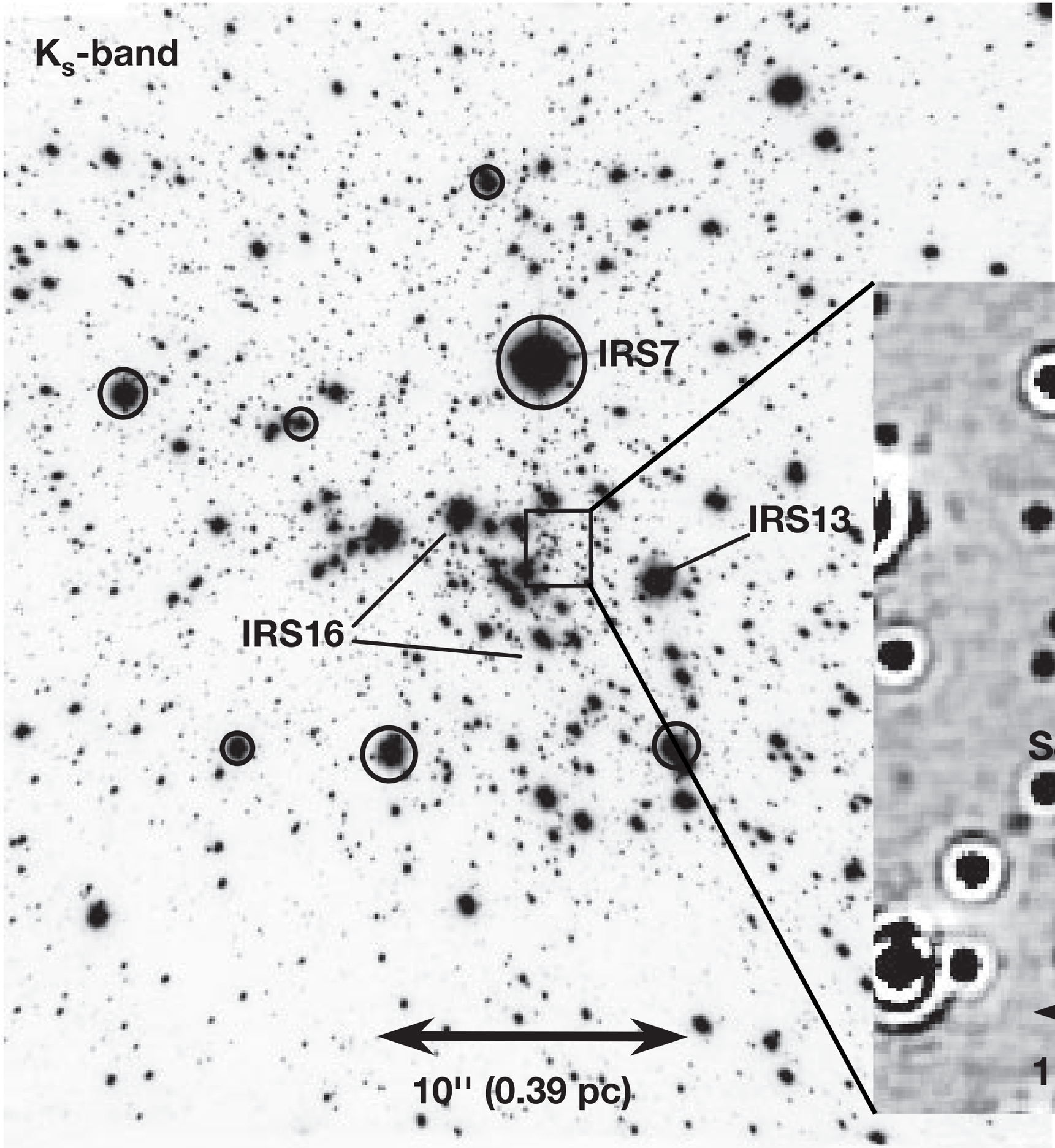
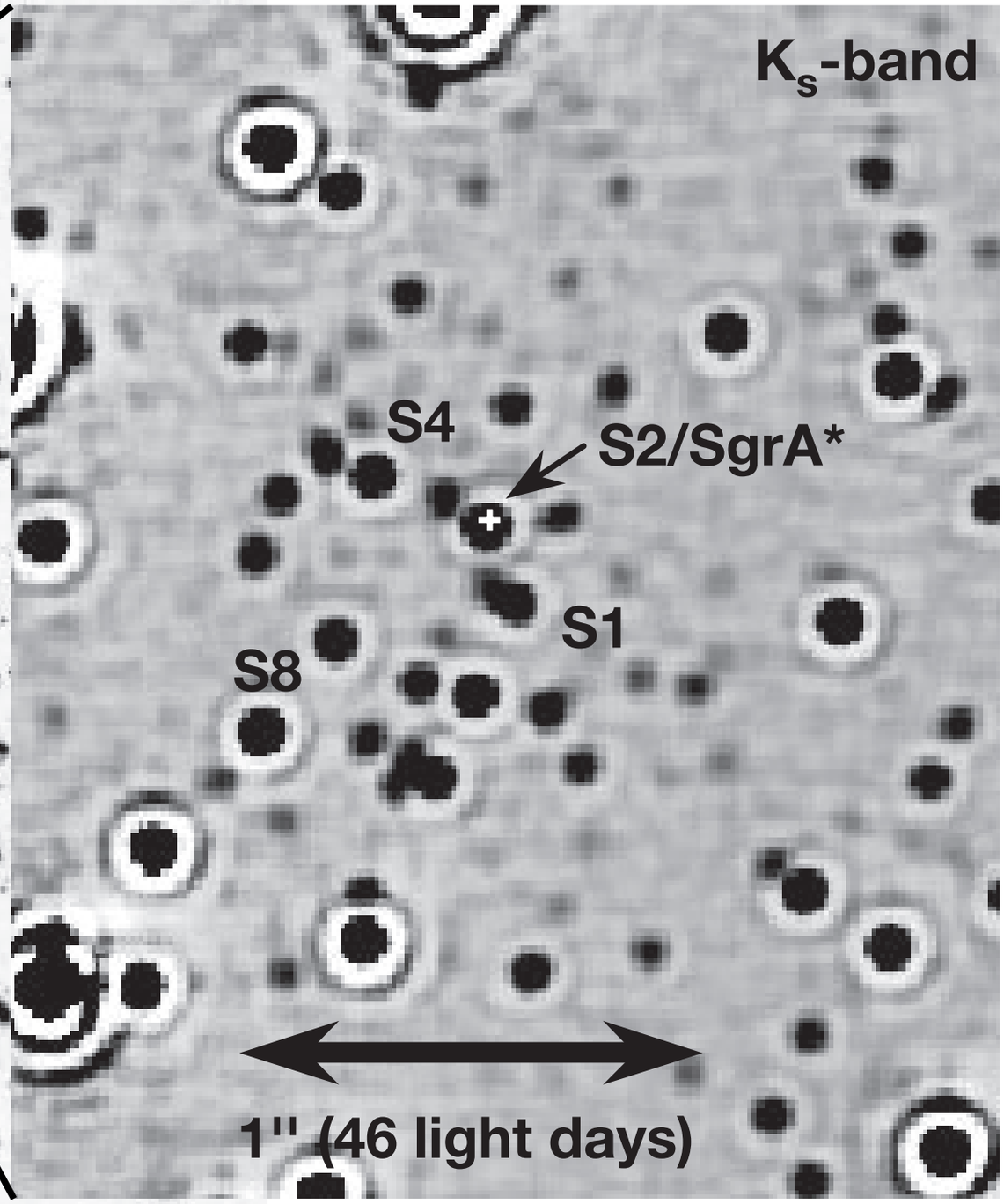


Radio image of Galactic Center *Sagittarius A**

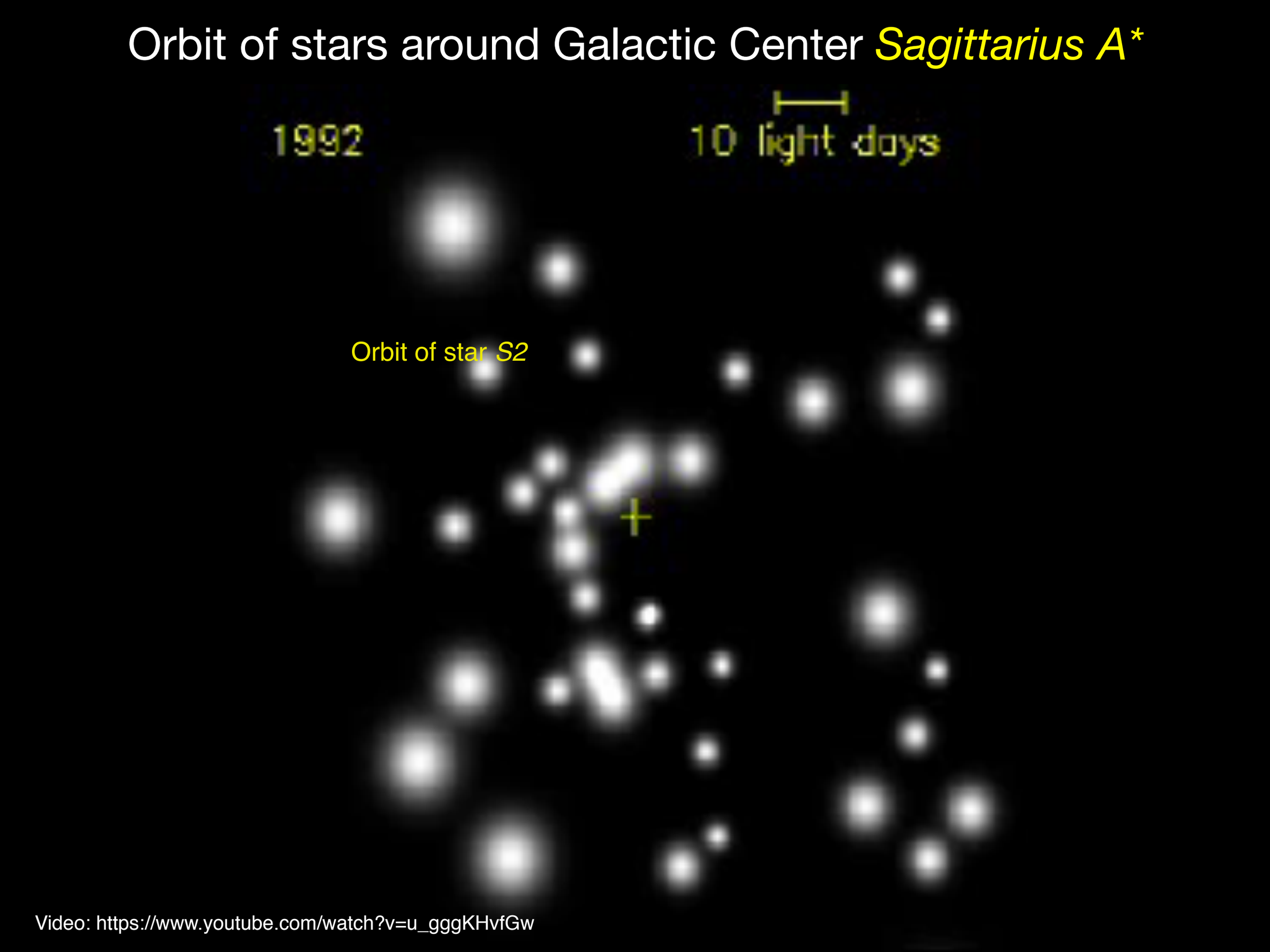


Near IR image of the Galactic Center



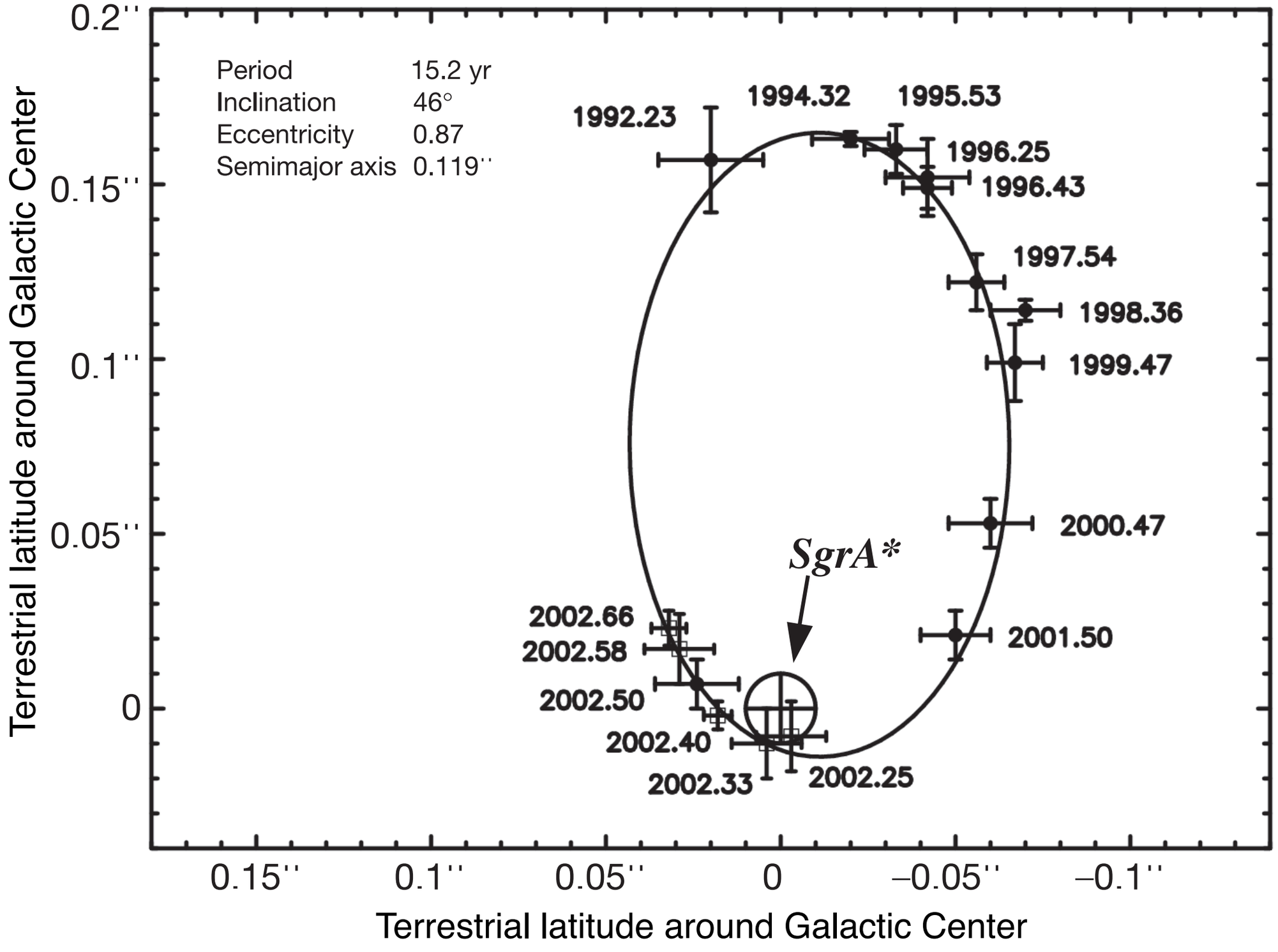


Orbit of stars around Galactic Center *Sagittarius A**

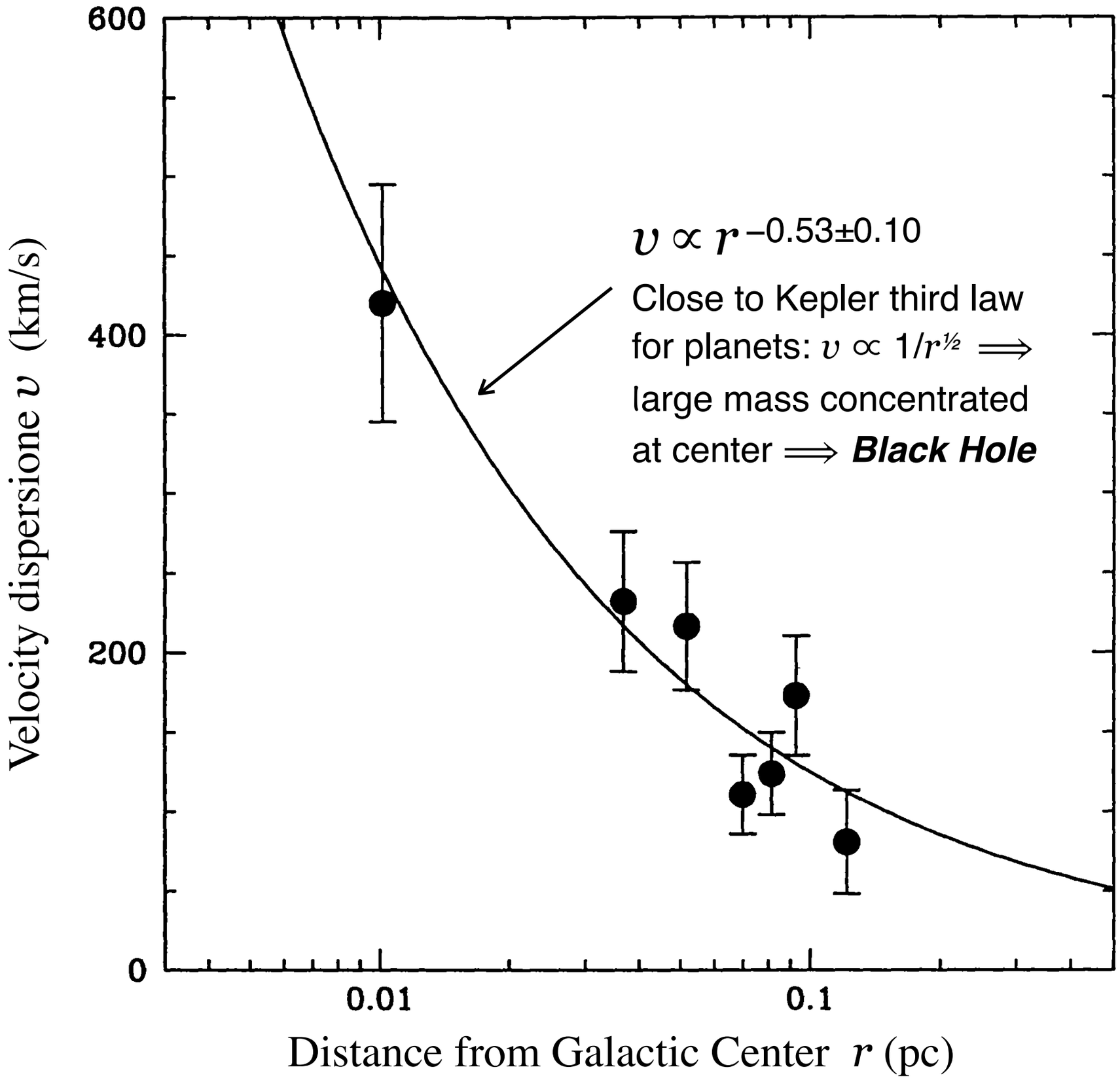


Video: https://www.youtube.com/watch?v=u_gggKHvfGw

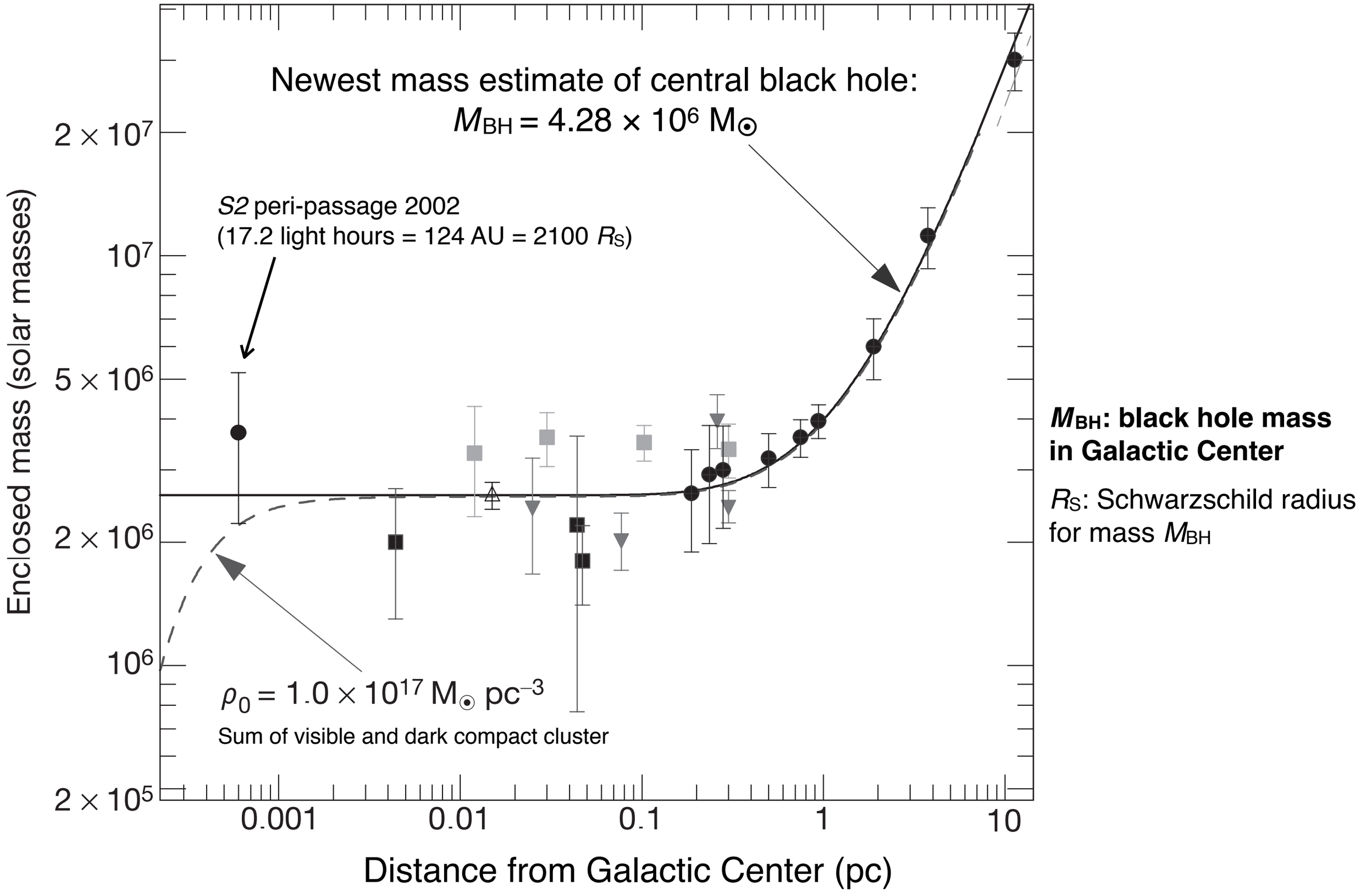
Orbit of star *S2* around *Sagittarius A** from 1992 to 2002



Velocities of stars as a function of distance from *Sagittarius A**



Mass distribution in the **Galactic Center**



M_{BH}: black hole mass in Galactic Center

R_S: Schwarzschild radius for mass M_{BH}