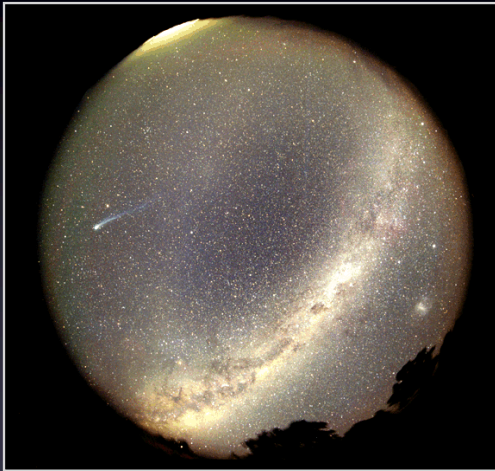
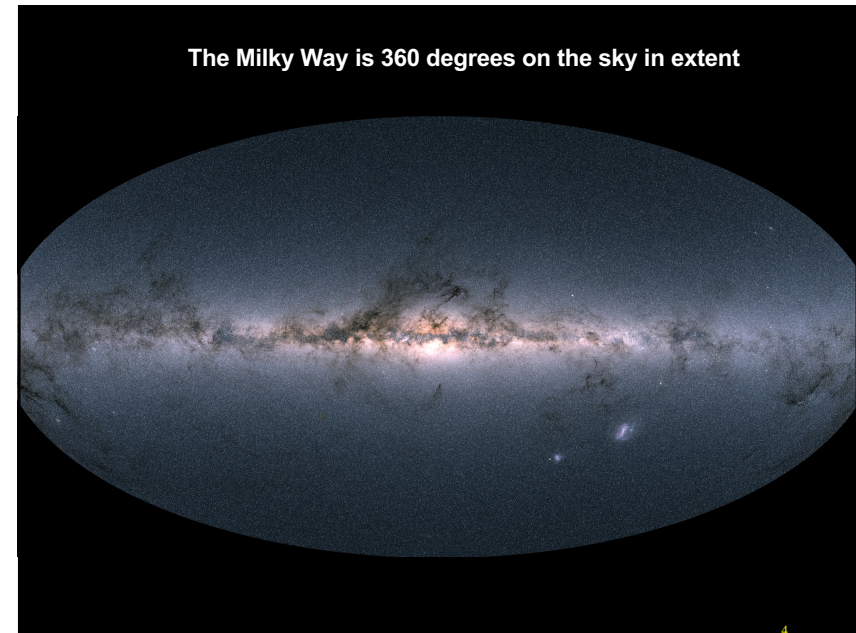
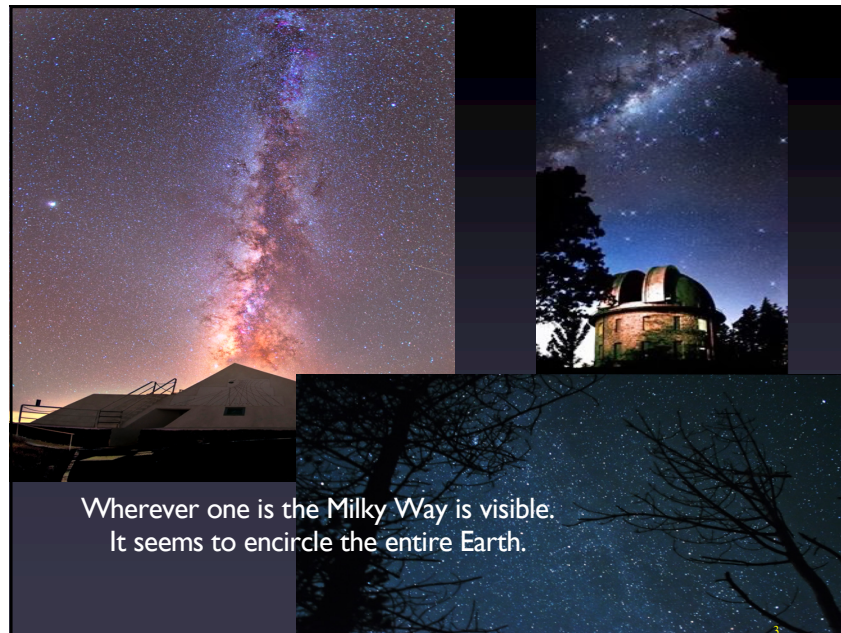


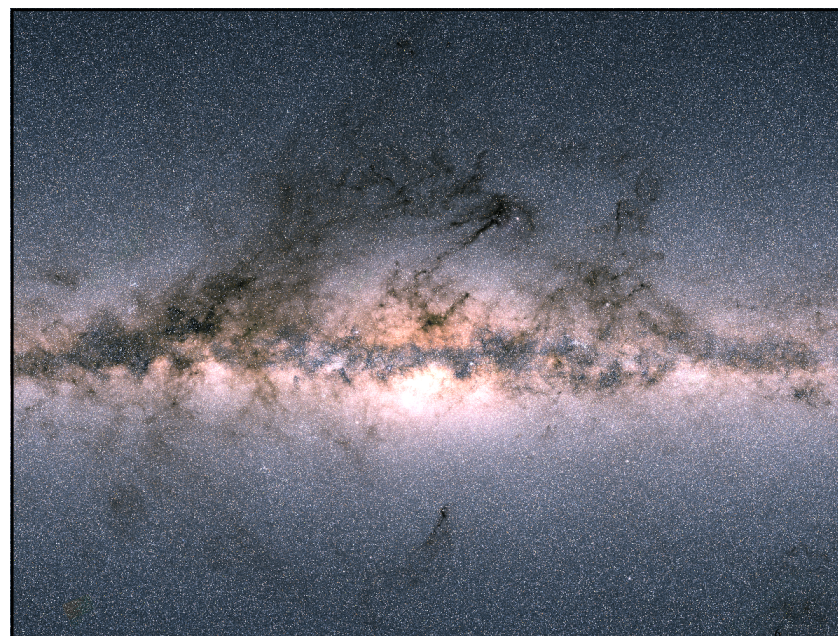
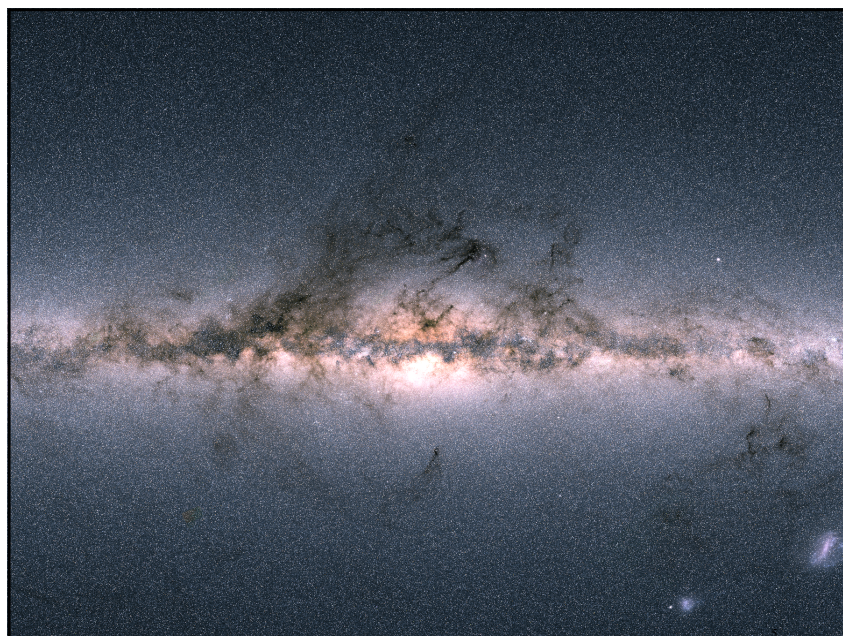
The Milky Way



Koupelis : chapter 16
OpenStax : chapter 25

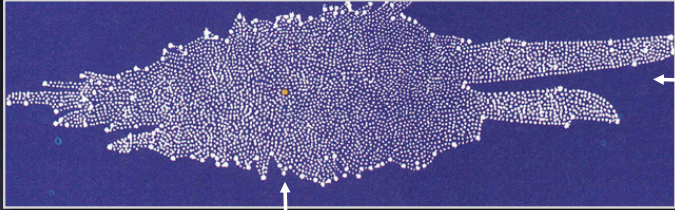






The Milky Way according to Herschel (± 1780)

based on star counts with a telescope from the northern hemisphere



effect of dust

Position of the Sun (suspicious!)


The Milky Way seemed to be flattened with the Sun near the center.

Kapteyn (early 20th century) : measuring distances to the stars
 \Rightarrow density of stars decreases outwards.

However, the existence of interstellar dust was unknown!

A 'band' on the sky implies a flattened distribution of stars:

If Milky Way were spherical, numerous stars would lie in all directions.

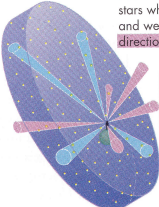


Earth

We would see stars scattered uniformly.

uniform spatial distribution

Because the Milky Way is a disk, we see lots of stars when we look in directions lying in the disk, and we see very few stars when we look in directions that lie out of the disk.



We see stars in a concentrated band.

flattened spatial distribution

Star clusters

Open clusters

- hundreds of young stars
- located mainly in the Milky Way plane



Owl cluster (NGC 457)

Globular clusters

- hundreds of thousands old stars
- mainly outside Milky Way plane



Messier 80

9

open star clusters

Messier 7



distance = 1.000 light years

Messier 6



distance = 1.600 light years

Distances based on MS-fitting

10

globular star clusters

NGC 6541



distance = 22.800 light years

47 Tucanae



distance = 16.000 light years

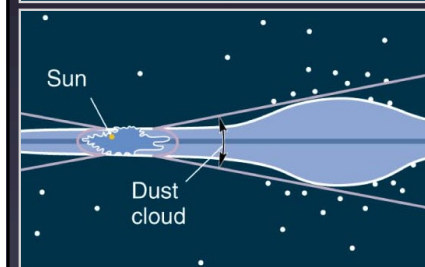
Distances based on RR Lyrae variable stars

11

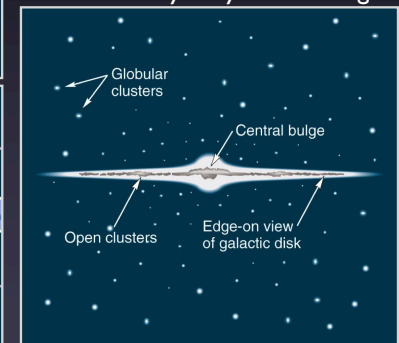
The Milky Way according to Shapley (± 1917)



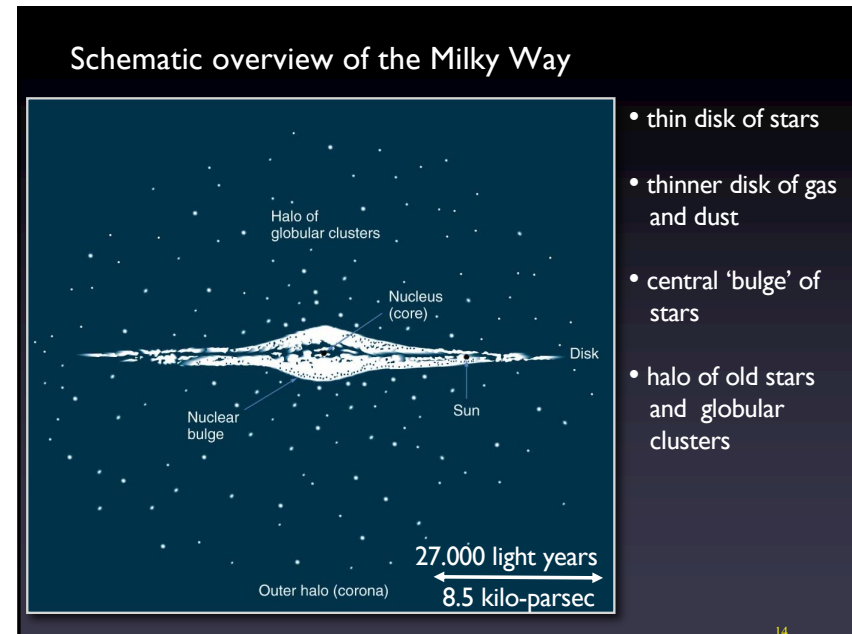
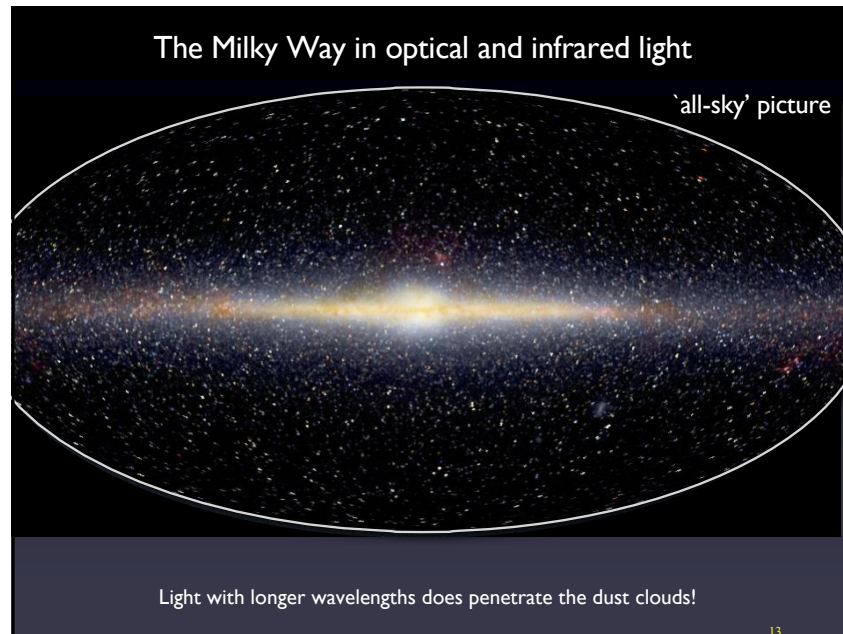
Globular clusters seem to be distributed around a different location.



The Milky Way is much larger!



12

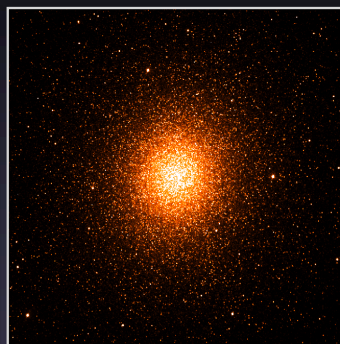


Population I stars:

- young
- metal rich
- located in the disk

Population II stars:

- old
- metal poor
- located in the halo



'Metal' according to astronomers : anything more massive than Hydrogen, Helium and Lithium.

15

the orbits of pop-I and pop-II stars

move in circular orbits in the disk

move randomly through the halo

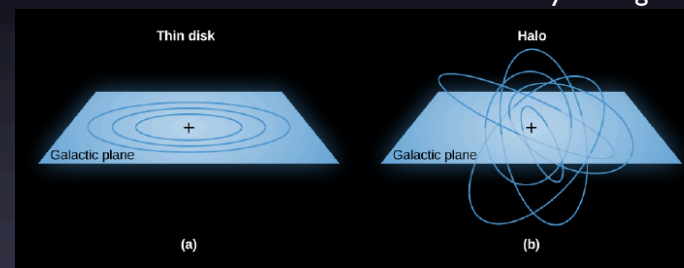
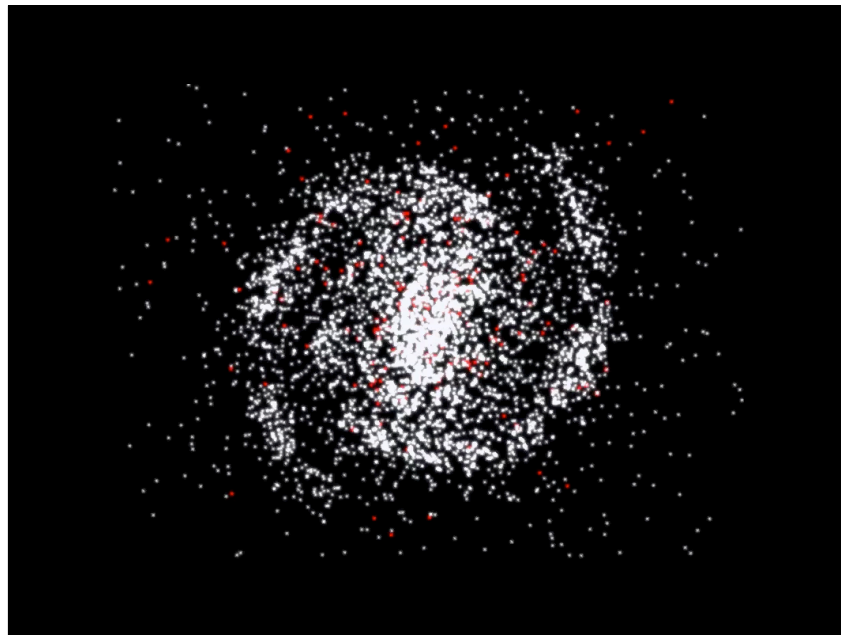


Figure 25.19 How Objects Orbit the Galaxy. (a) In this image, you see stars in the thin disk of our Galaxy in nearly circular orbits. (b) In this image, you see the motion of stars in the Galaxy's halo in randomly oriented and elliptical orbits.

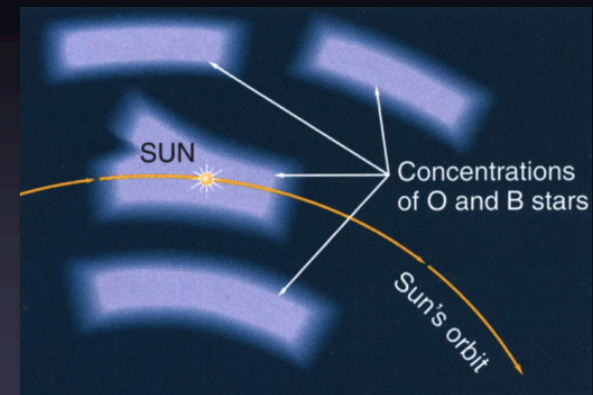
Rotation around the Galactic centre
is in the same sense

Rotate around the Galactic centre
in random directions

16

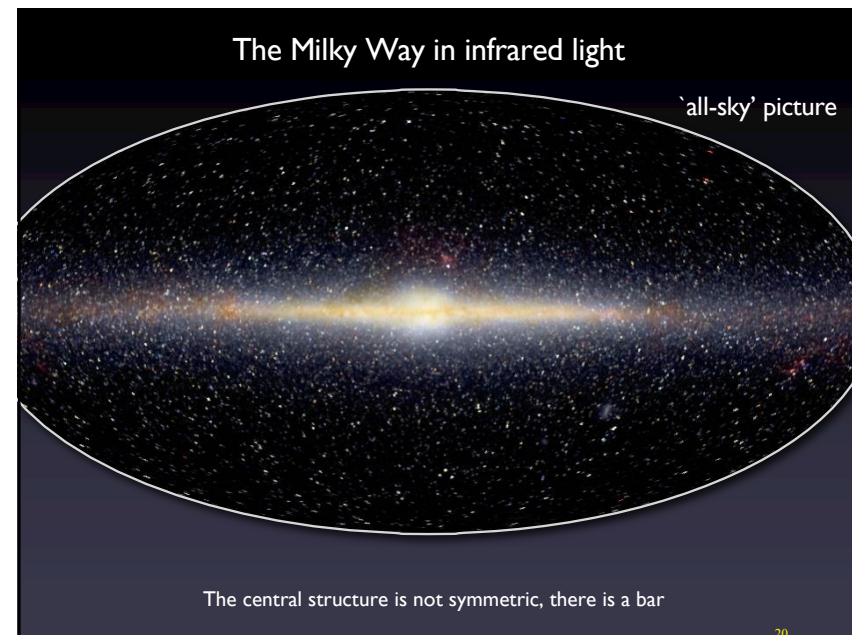
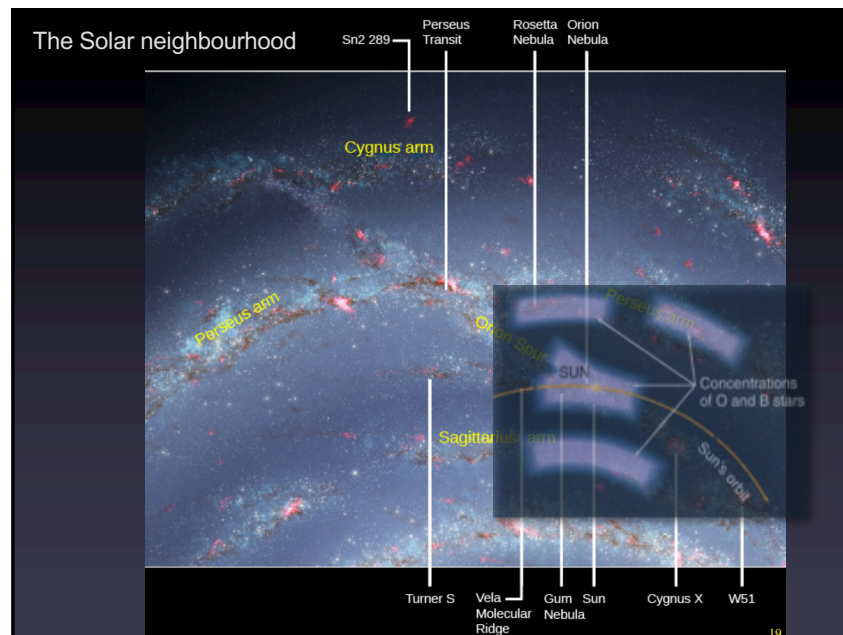


Distribution of young O- and B-type stars near the Sun

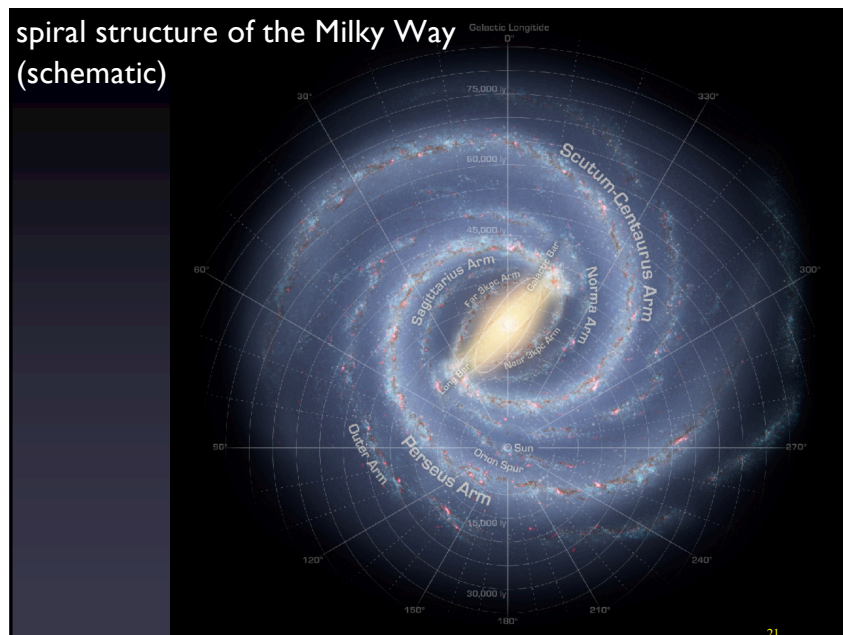


a first hint at spiral structure in the Milky Way disk

18



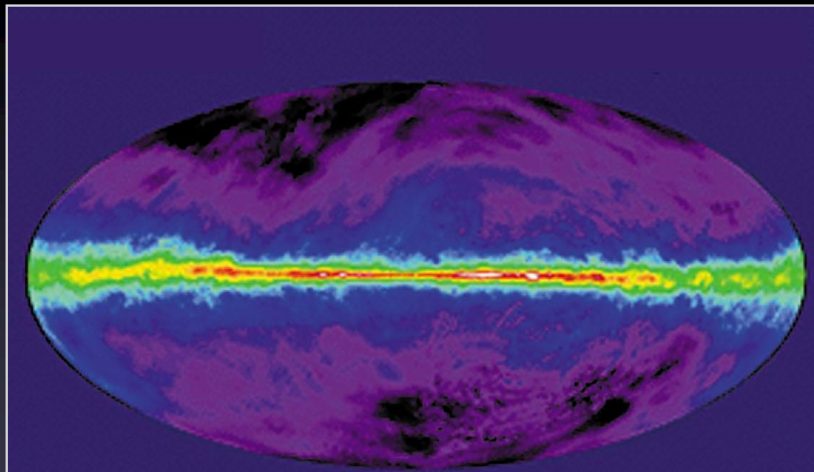
spiral structure of the Milky Way
(schematic)



NGC 1232



distribution of Hydrogen gas in the Milky Way

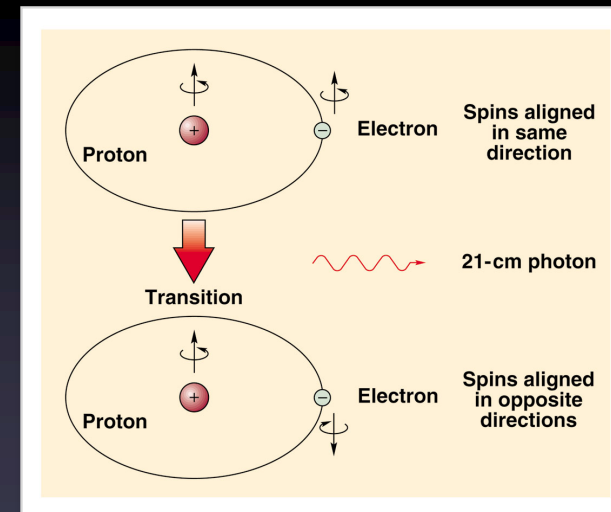


red : high intensity
blue: low intensity

Most Hydrogen gas is located in a very thin disk.

23

The electron flip in a Hydrogen atom

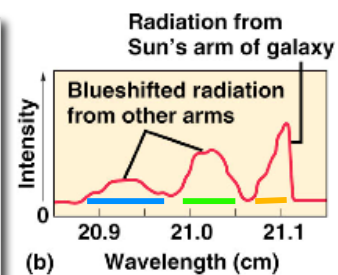
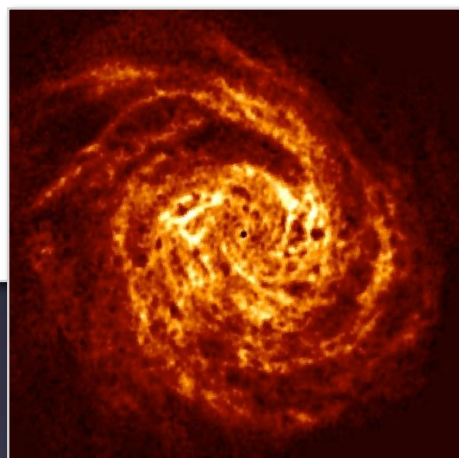


produces a radio-emission line with a wavelength of 21 cm

24

hints for the existence of spiral arms

the Doppler-effect helps us again!



'21 cm map' of the distribution of Hydrogen gas in another Milky Way like galaxy.

(Westerbork radio telescope)

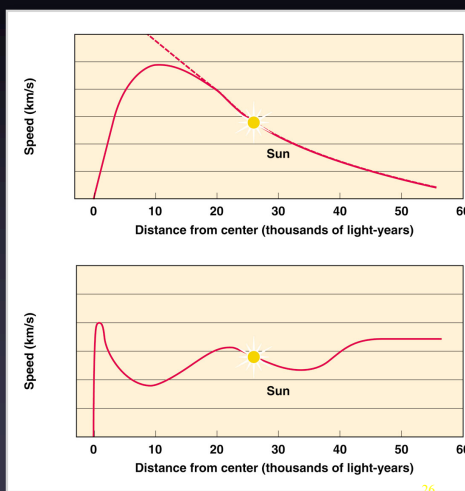
25

The rotation curve of the Milky Way

The speed with which a star or gas orbits the center of the Milky Way depends on the amount of matter (gravity) inside their orbit

The orbital speed of the Sun: approximately 230 km/s.

The rotation curve of the Milky Way is almost flat:
⇒ lots of Dark Matter



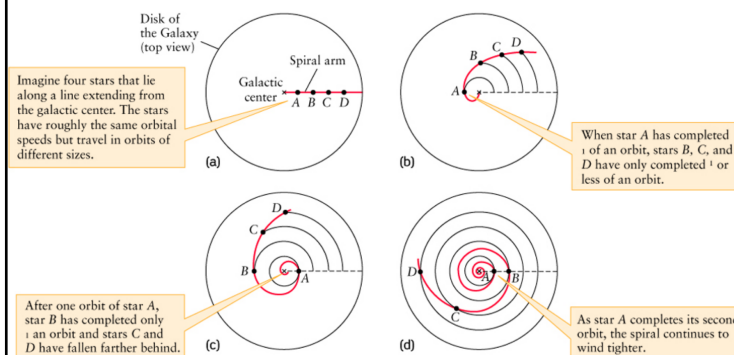
26

NGC 1232



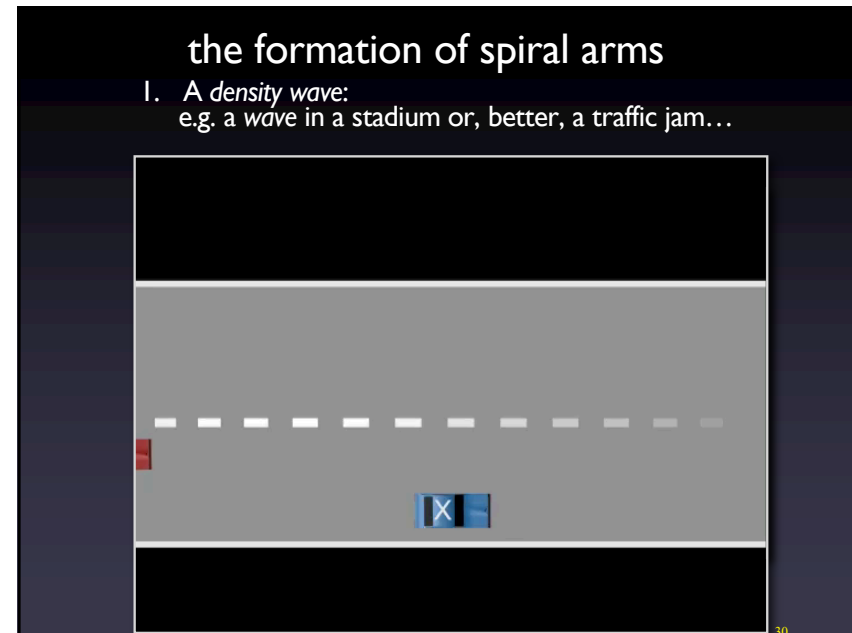
What is the origin of spiral arms in spiral galaxies ?

- First of all:
- Spiral arms **cannot be made from the same material throughout the galaxy history.**
- Reason -- **winding problem**



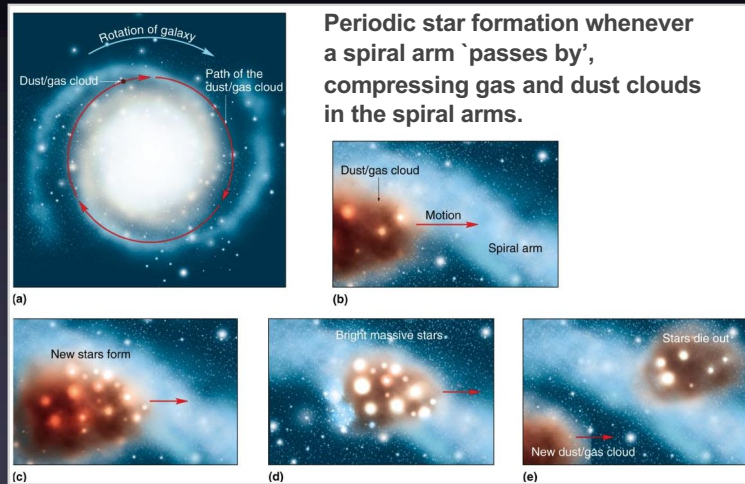
- Galaxy like Milky Way made ~200 revolutions through its lifetime. **Material spirals arms would be very tightly wound**

https://sites.ualberta.ca/~nogosyan/teaching/ASTRO_122/lect24/lecture24.html



the formation of spiral arms

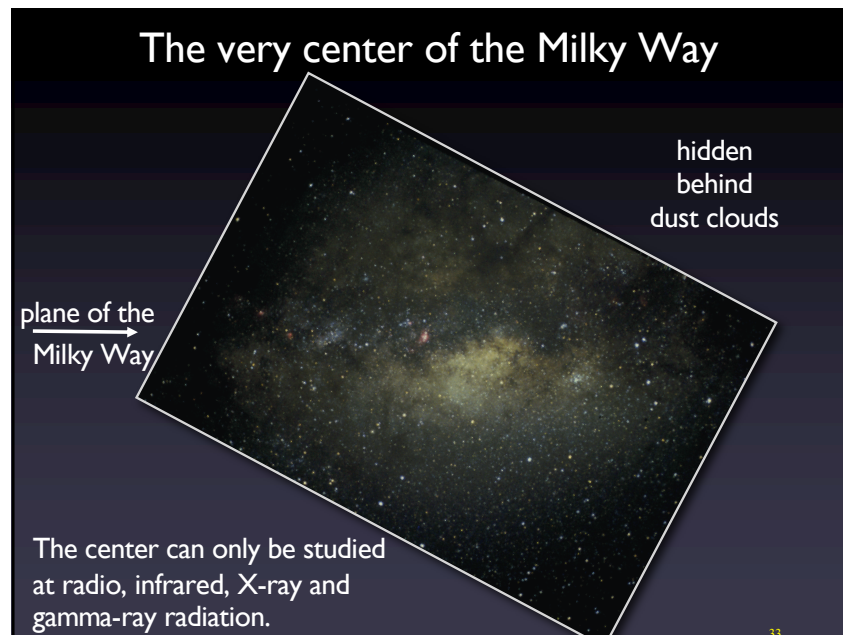
2. A star formation 'relay'



spiral arms: not everything can be explained with density waves



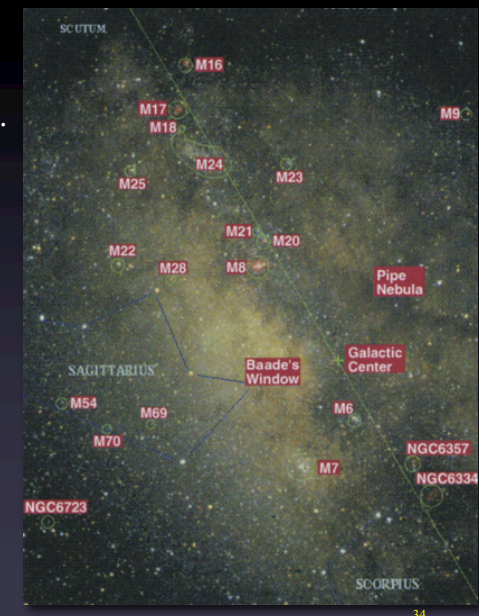
- thin filaments between the spiral arms
- spiral structure all the way to the center



The center of the Milky Way is located in the constellation of Sagittarius.

Many star clusters, gas nebulae and dark dust clouds.

The center is hidden behind thick dust clouds.



enormous star clusters near the center of the Milky Way



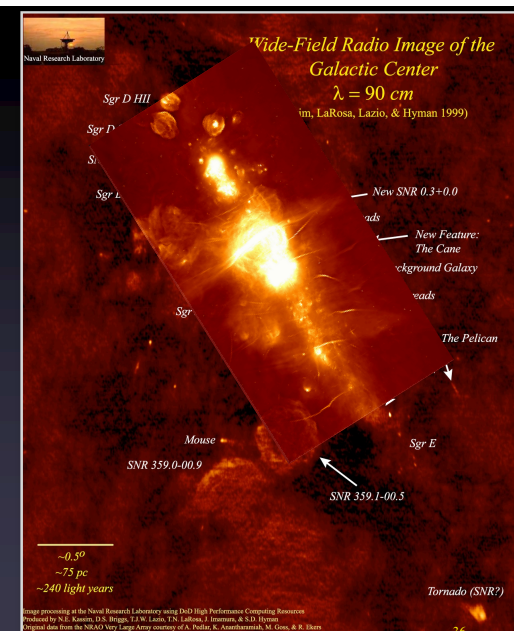
imaged with an infrared camera on the Hubble Space Telescope

the density of stars strongly increases towards the center

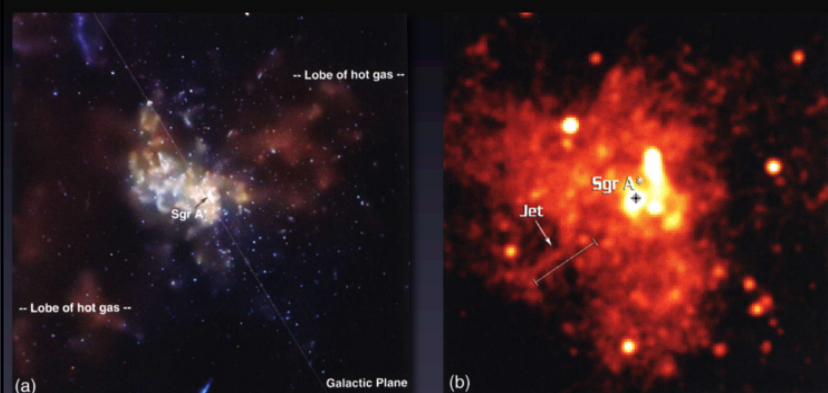
35

The center of the Milky Way

as seen with a radio telescope



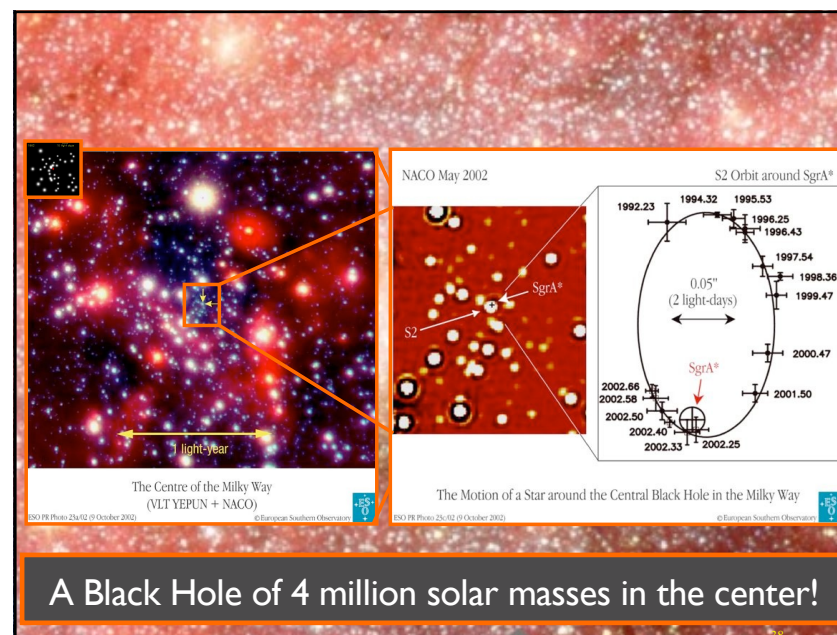
The center of the Milky Way seen in X-rays



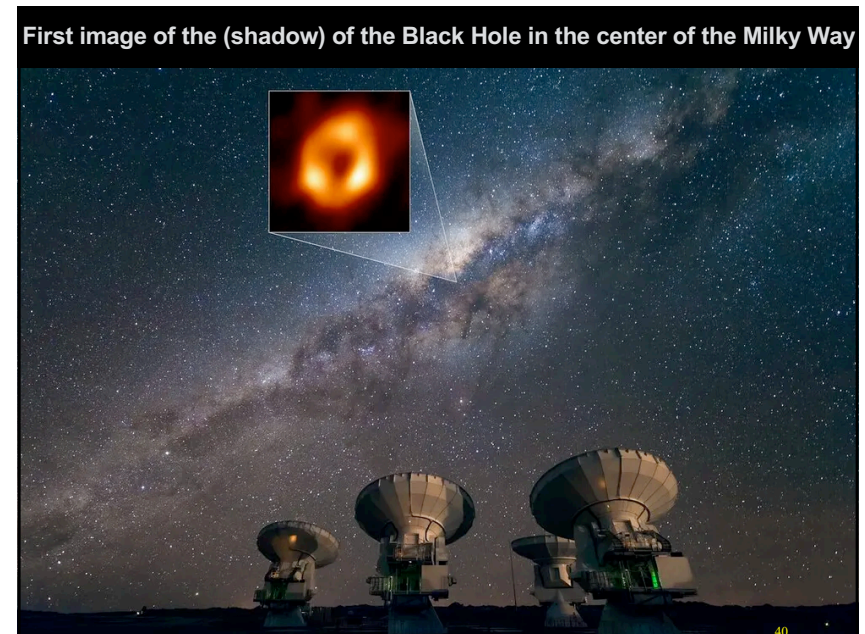
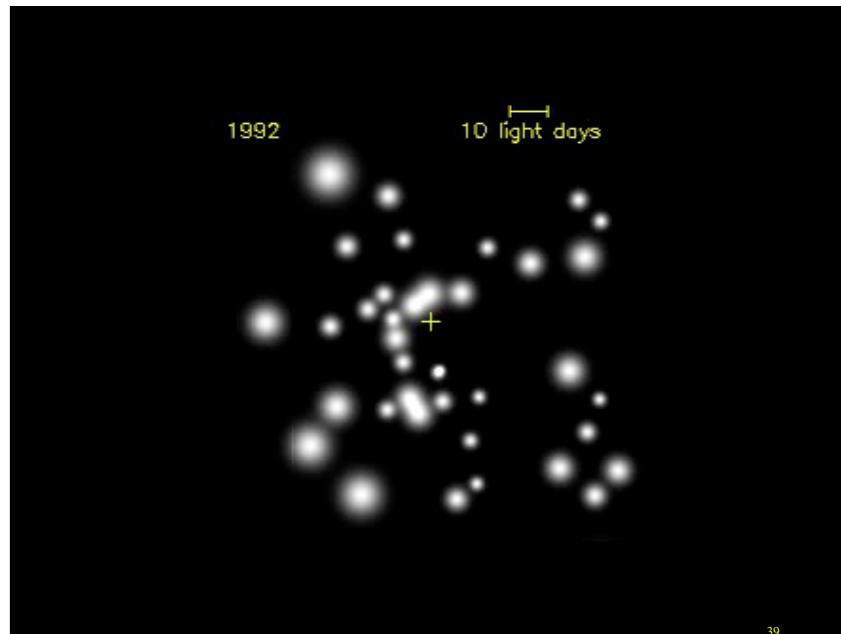
imaged by the Chandra X-Ray Observatory

indicates the presence of highly energetic processes

37



A Black Hole of 4 million solar masses in the center!



Properties of the Milky Way

Basic components:

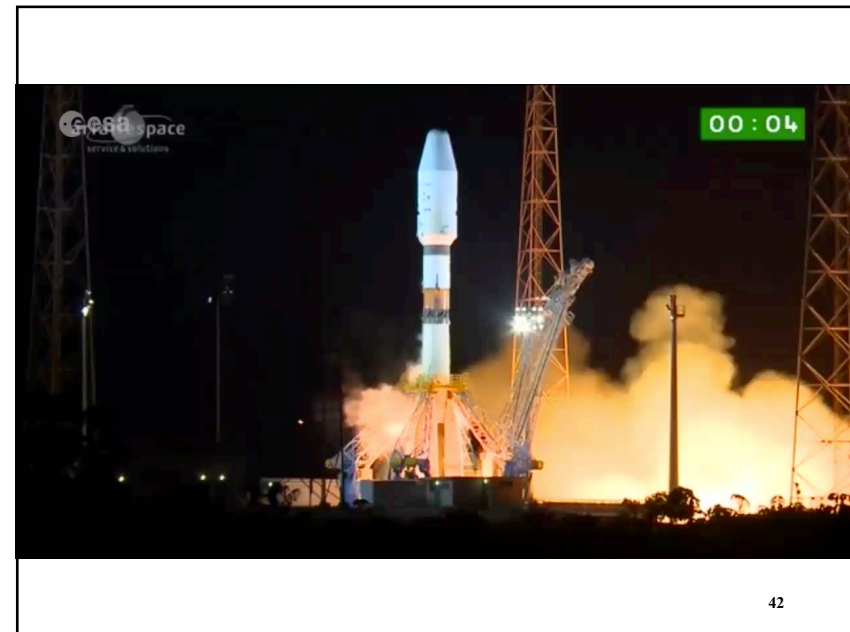
- a thin rotating disk of stars, gas and dust with spiral arms
- a central (slowly rotating) bar/bulge with more random motions
- an extended halo of old stars, globular clusters and Dark Matter
- a super-massive Black Hole in the very center

diameter of the disk	:	160.000	light years
thickness of the disk	:	3.000	light years
diameter of the central bulge	:	6.000	light years
diameter of the halo	:	400.000	light years

distance of Sun from Galactic center :	27.000	light years
orbital speed of the Sun :	230	km/s
orbital period of the Sun :	250.000.000	years

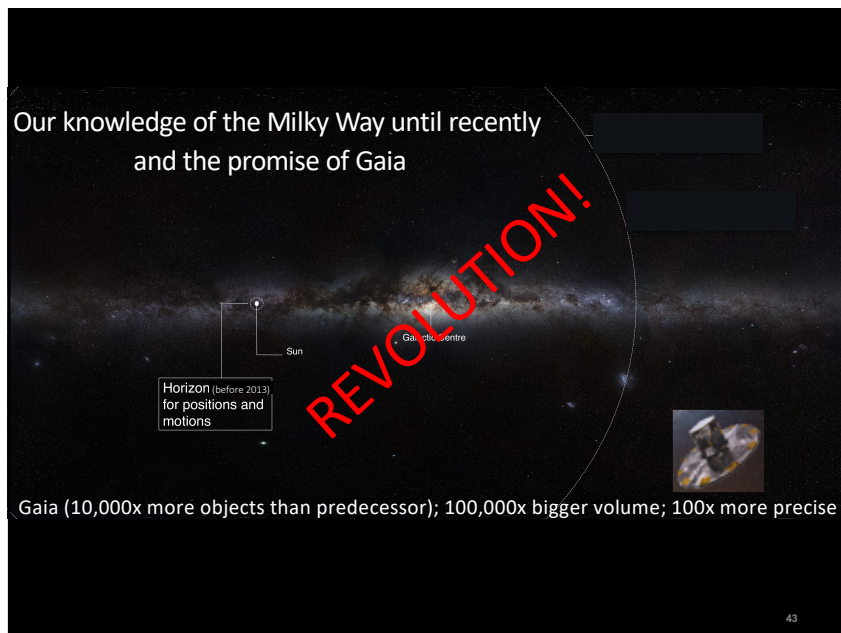
number of stars in the Milky Way :	200 - 400	billion
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41



42

Our knowledge of the Milky Way until recently
and the promise of Gaia



Horizon (before 2013)
for positions and
motions

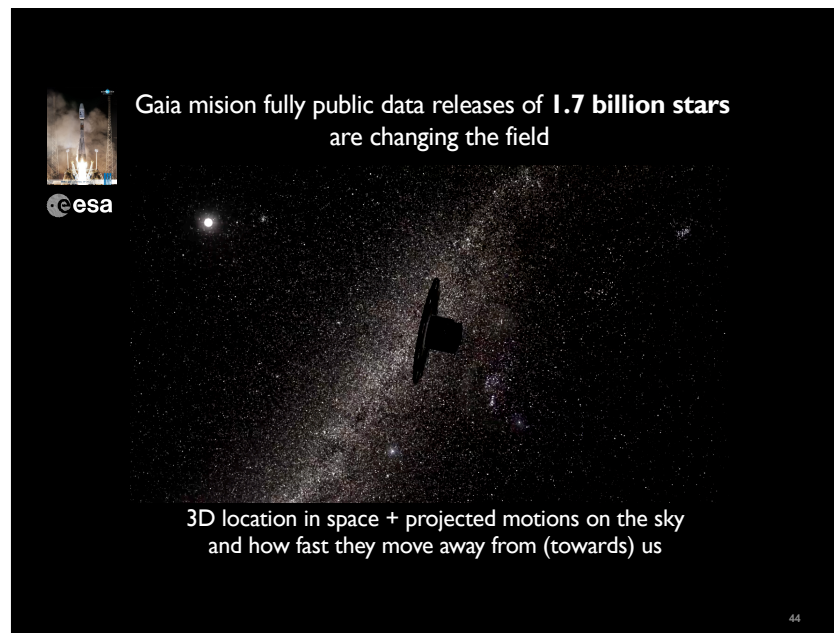
Sun

Gaia centre

Gaia (10,000x more objects than predecessor); 100,000x bigger volume; 100x more precise

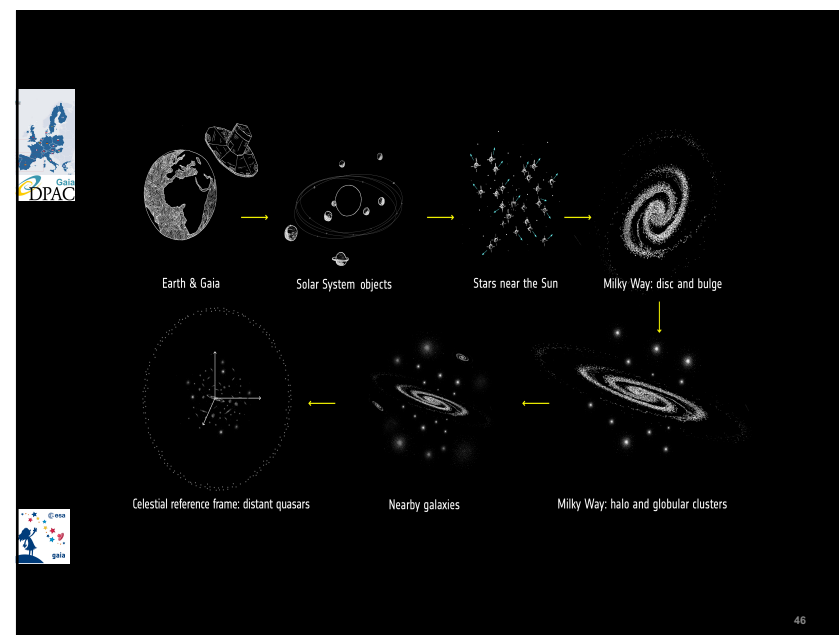
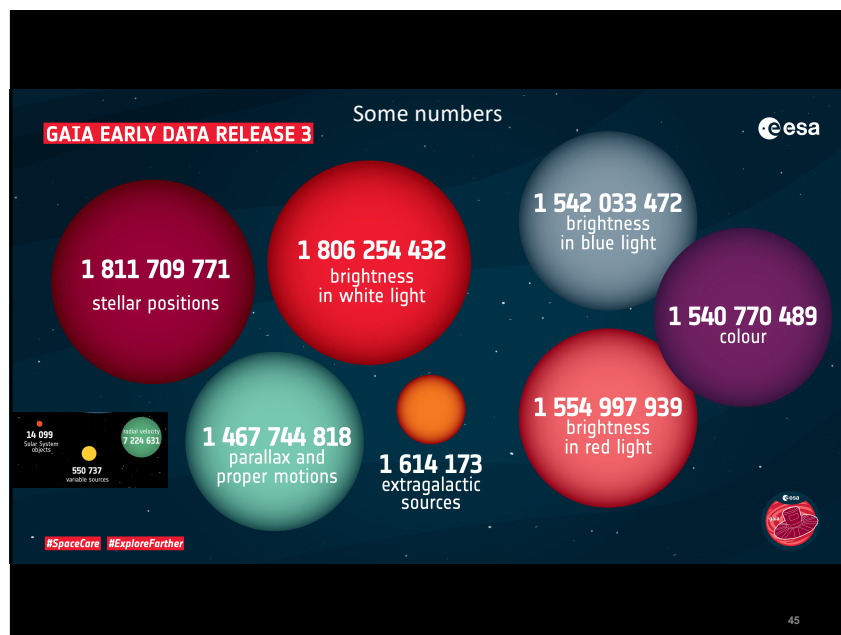
43

Gaia mission fully public data releases of **1.7 billion stars**
are changing the field

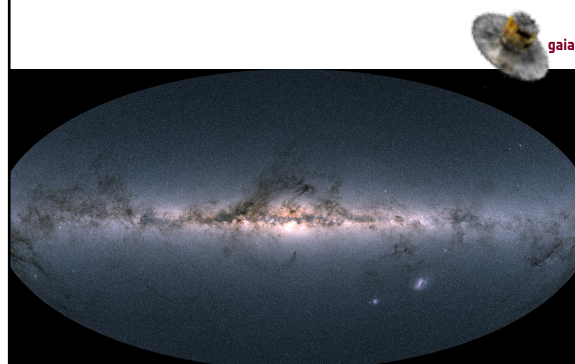


3D location in space + projected motions on the sky
and how fast they move away from (towards) us

44



How did the Milky Way come to be like this?



47

F₄GGIE
 Figuring Out Galaxies & Galaxies In Time
 Peebles et al

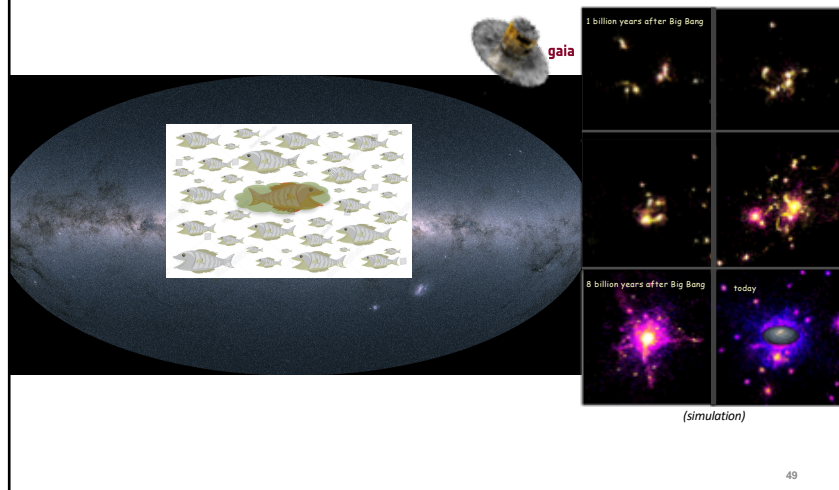
Stellar halo:
 a treasure trove

Mergers: characteristic of cosmological model

$t = 1.1 \text{ Gyr}$
 $z = 5.28$

Stars' motions, chemistry and
 ages trace origin

How did the Milky Way come to be like this?



A milestone in Galactic history:
the last big merger, 10 billion years ago



