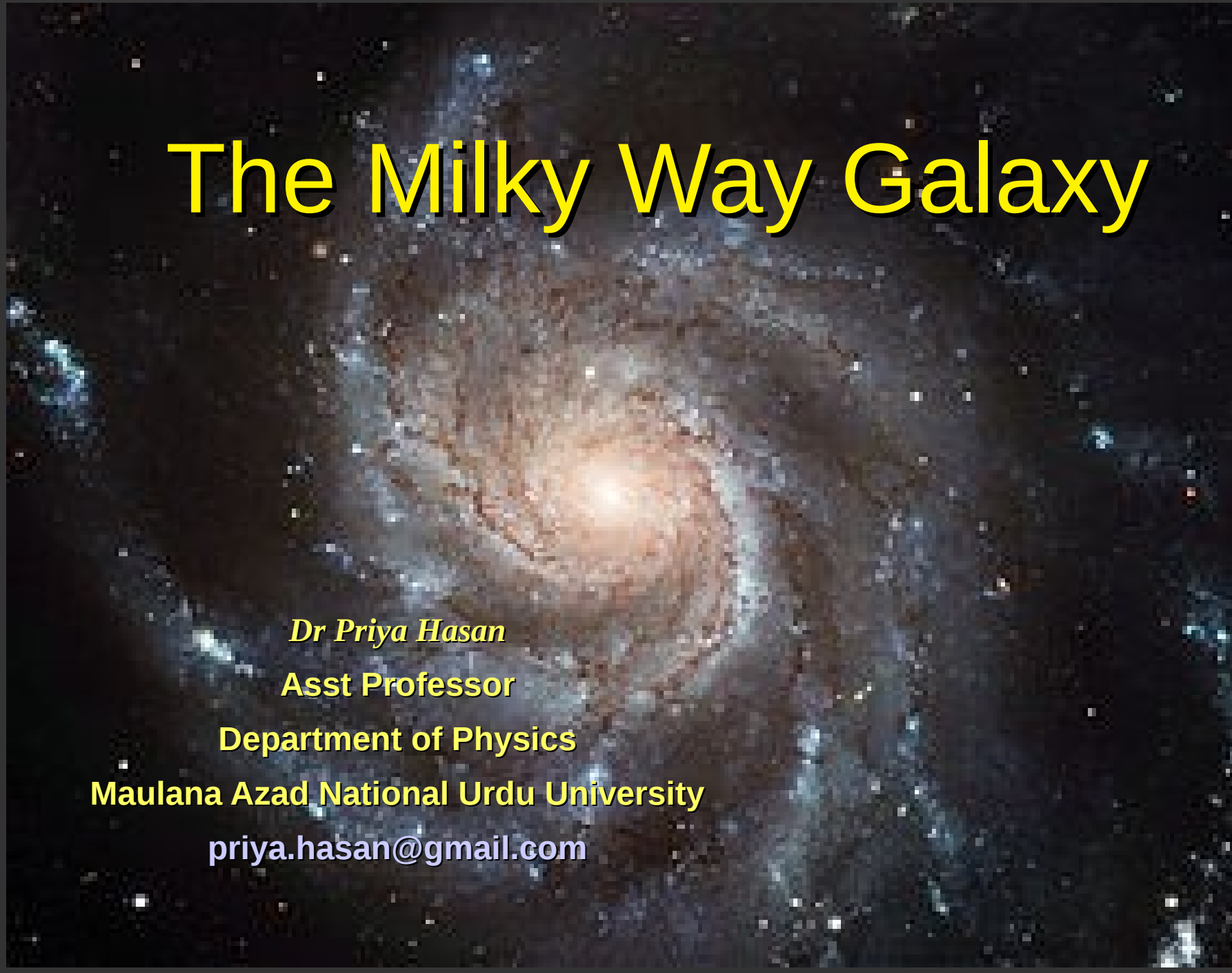

The Milky Way Galaxy

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We see the Milky Way as a band across the sky because we're looking at a vast disk of stars from inside.

Historical Perspective

- Heliocentric (Copernicus, 1543)

  accepted in ~ mid 17th century
- Galileo (17th century) turned his telescope to the Milky Way.
- late 18th century
- Single Galaxy (1900-1920)

  Shapley-Curtis debate
- (1920-1930)

  Hubble resolves stars in the Andromeda Galaxy,

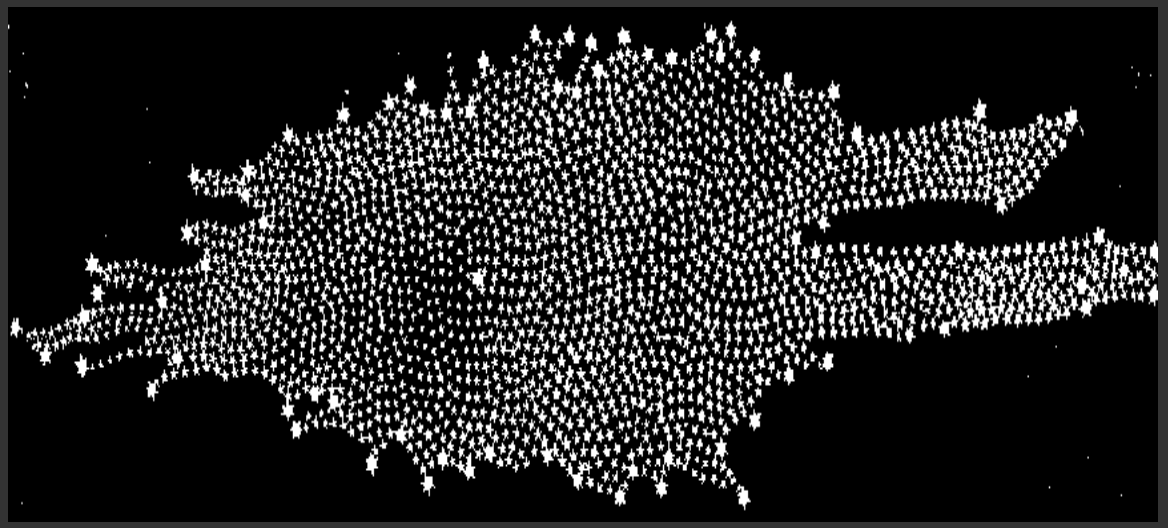
  Spectroscopic measurements of

  Slipher & works of Humason & Hubble

Galaxies: Large collection of Stars, Dust and Gas

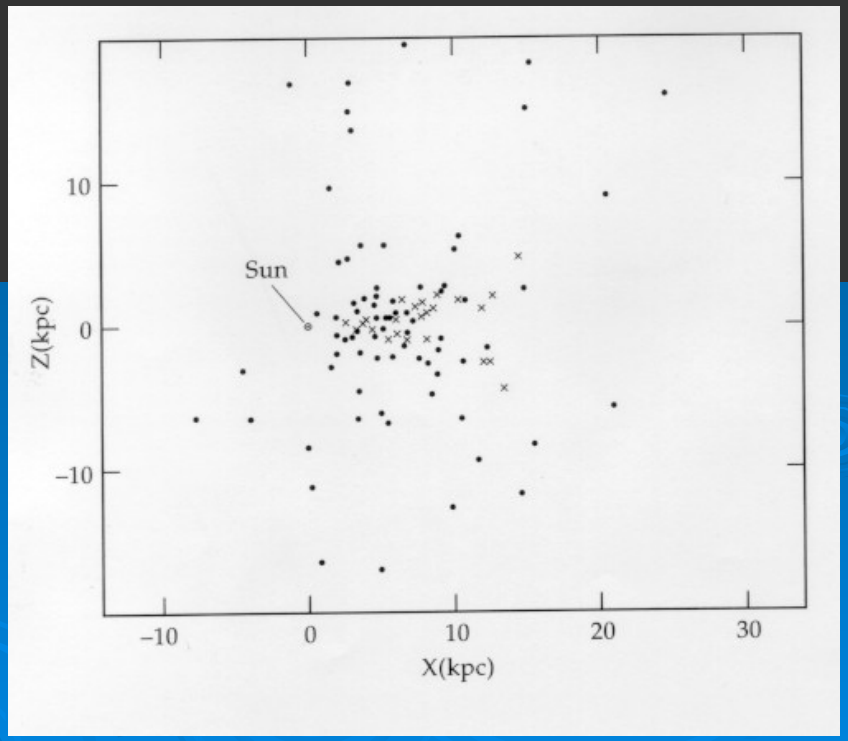
- Typical Mass:
  10^9 - 10^{12} M_{sun}
  M_{sun}~ 10^{30} kg
- Typical Size
  30 kpc
  1 kpc = 1000 pc.
  1 pc ~ 3.26 lt. yrs.
  1 lt. yr = distance traveled by light in 1 year.

1781: William Herschel Reveals the Shape of our Galaxy



Measured the approximate distance to as many stars as possible. He used the rough approximation that all stars are equally bright. Although today we know that assumption to be wrong, it allowed him to estimate the distance to several hundred stars.

1920: Shapley Finds Our Place in the Milky Way



Using the 60-inch reflecting telescope at Mount Wilson Observatory, Shapley was able to identify Cephied variable stars in 93 globular clusters to map out their distances using the luminosity-period relationship of Cepheids discovered by Henrietta Leavitt

Ext

- 1. Reduced *ma*
- 2. Reddened
  scattered

Extinction – interste ar

Evident dark ts in t lax
suspec
interstella light
from sta

Diffuse interstellar dust in the plane of our Galaxy is estimated to cause extinction (and reddening) at the rate of 1 magnitude per kpc

If we ignore the effects of extinction is to misjudge distances by great amounts!

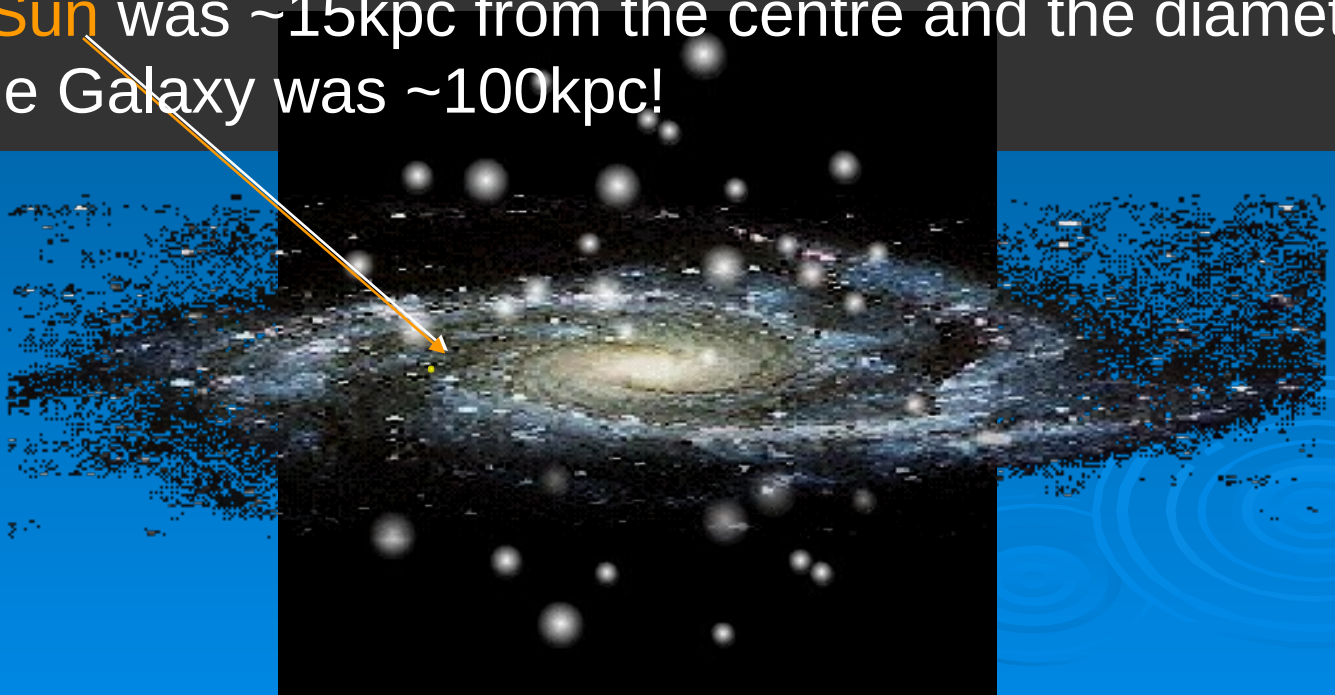
Extinction errors

Modern

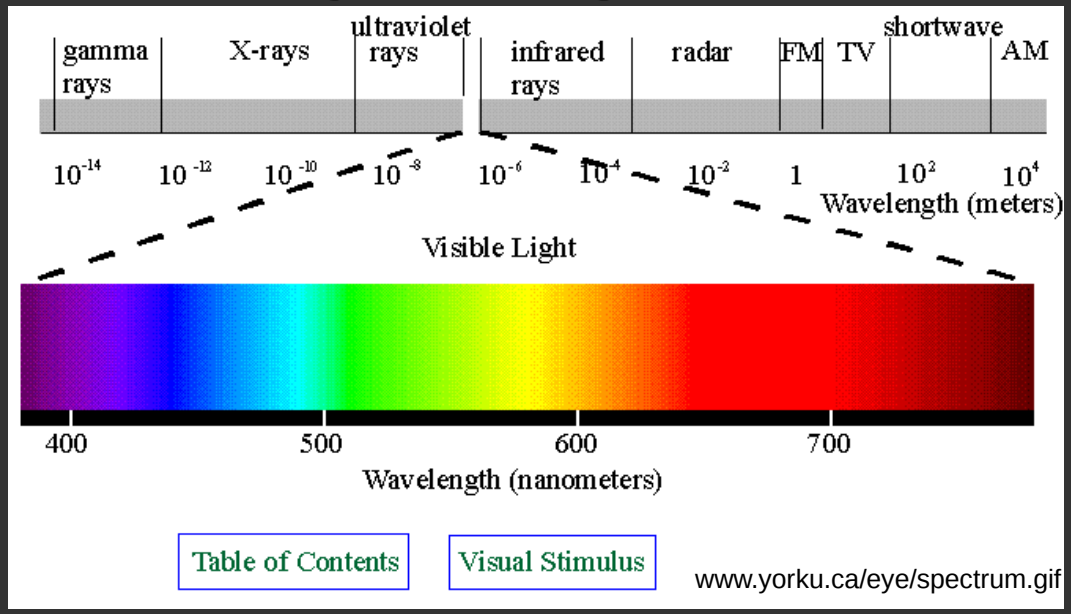
- Early size estimates of our Galaxy differed wildly.

Kapteyn:
(20th century)

Shapley's (2nd decade of 20th cent.) use of globular clusters* to locate the centre of the Galaxy suggested the Sun was ~15kpc from the centre and the diameter of the Galaxy was ~100kpc!



Not everything is visible…

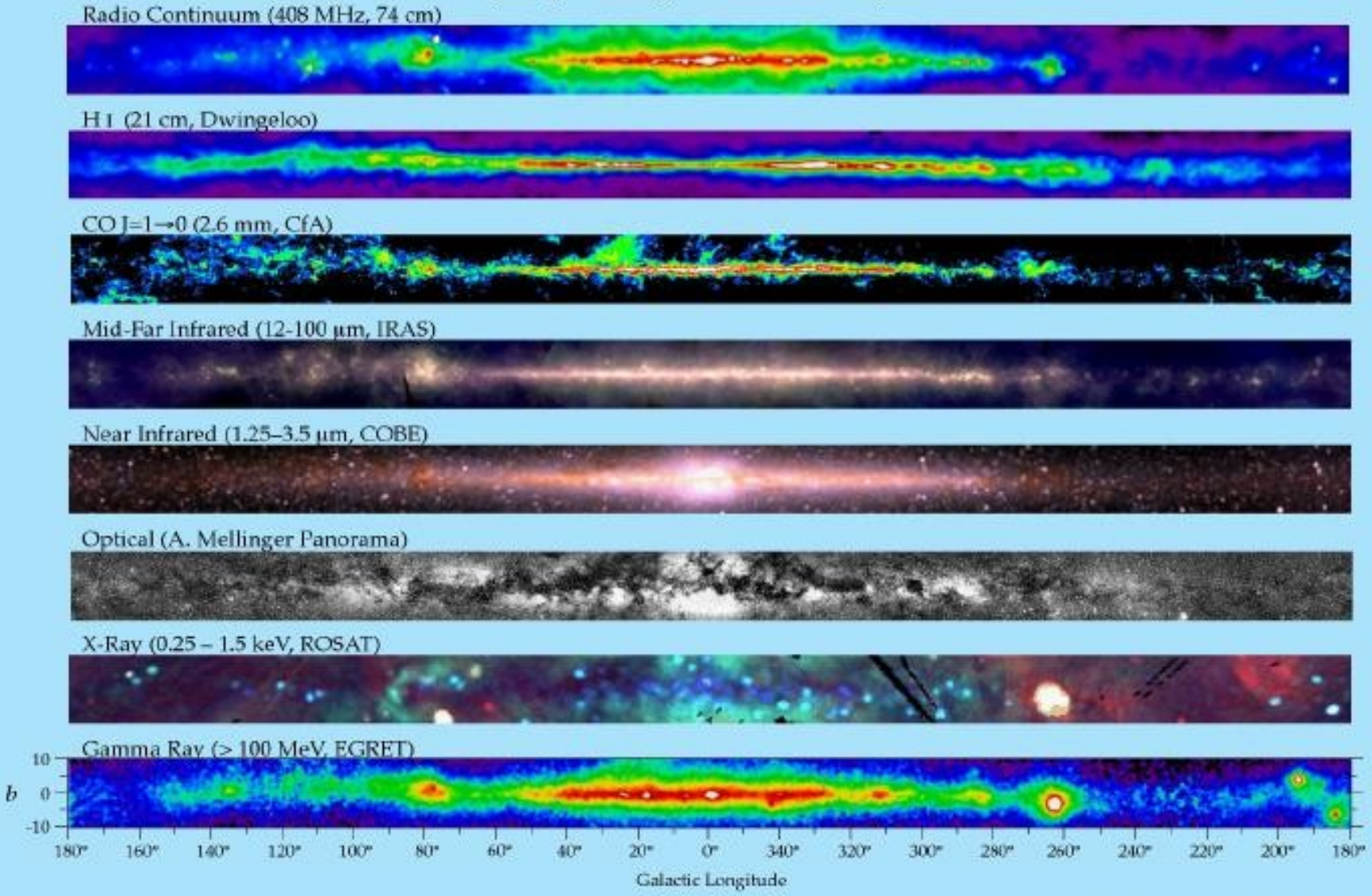


- Visible light is only a small fraction of the electromagnetic spectrum
- Different physical processes to study objects
- Radio , x-ray, gamma-ray telescopes explore the electromagnetic spectrum.


Radio
Microwave
Infrared
UV
X-Ray
Gamma Ray
Radio
Infrared
Optical
Ultraviolet
X-ray
Multiwavelength Whirlpool Galaxy
COLD GAS: Radio waves reveal regions of gas cool enough for CO_2 molecules to exist.
COOL STARS: Infrared shows smaller cool red stars that make up most of the galaxy.
SOLAR STARS: Optical light comes from stars around the size of the Sun.
HOT STARS: Ultraviolet shows the larger hot blue stars that are less frequent in galaxies.
HOT GAS: X-rays are emitted from the hottest regions of gas where atoms are ionized.
COOL LOW ENERGY RADIATION
VISIBLE LIGHT
HOT HIGH ENERGY RADIATION

Multiwavelength Milky Way

(images mainly from GSFC/ADC)

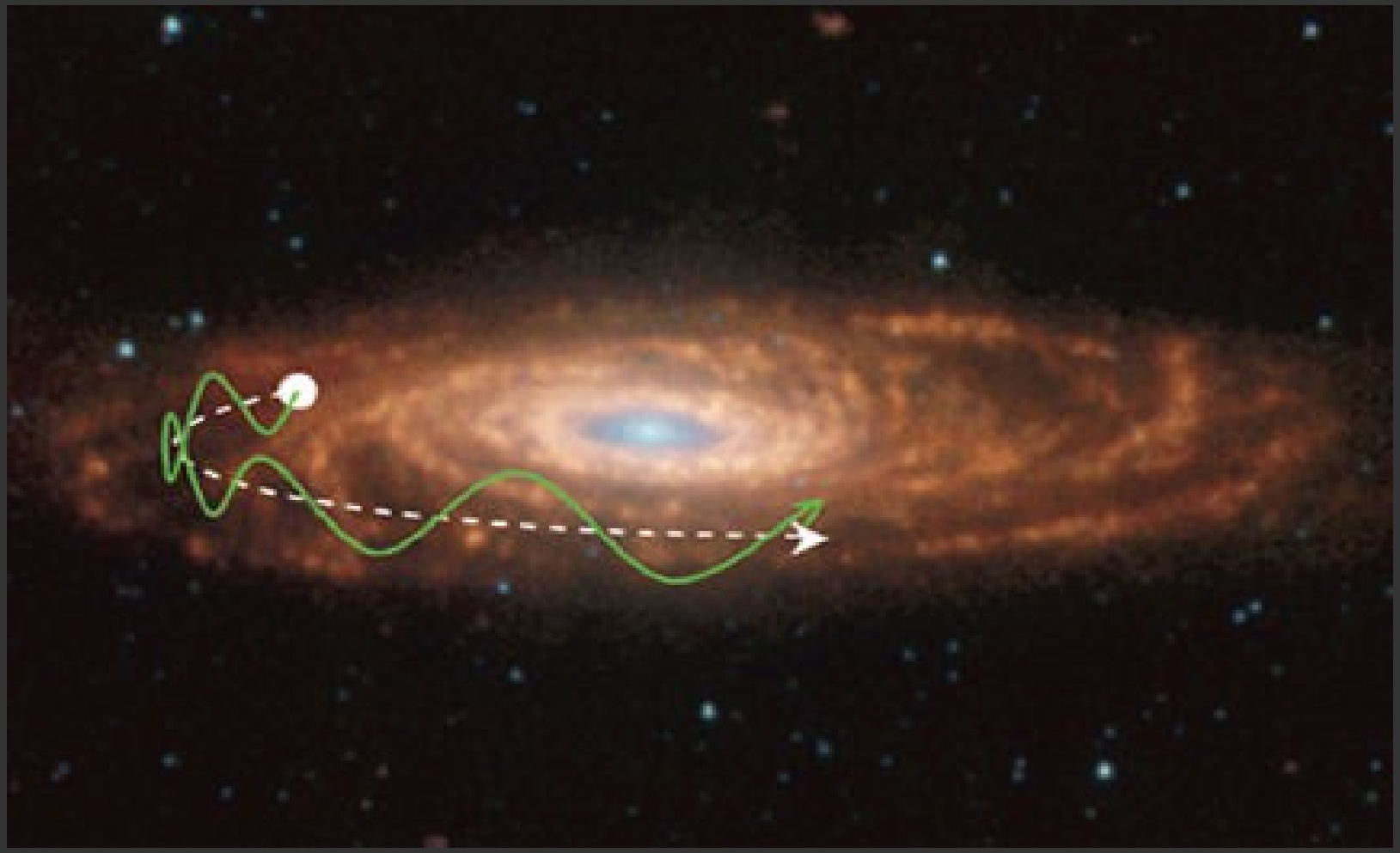


slide courtesy of T. Dame

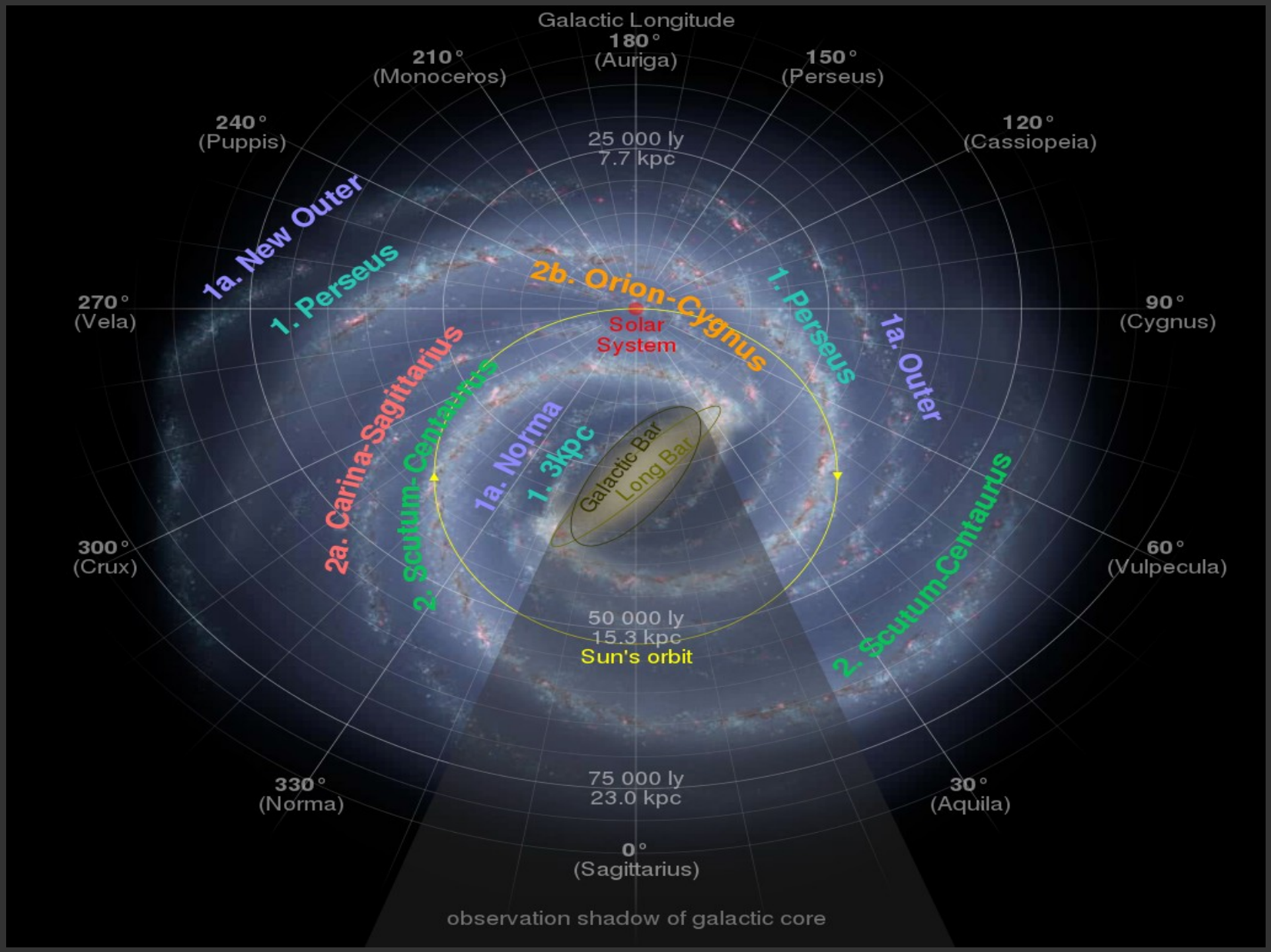
What is the Galaxy made of?

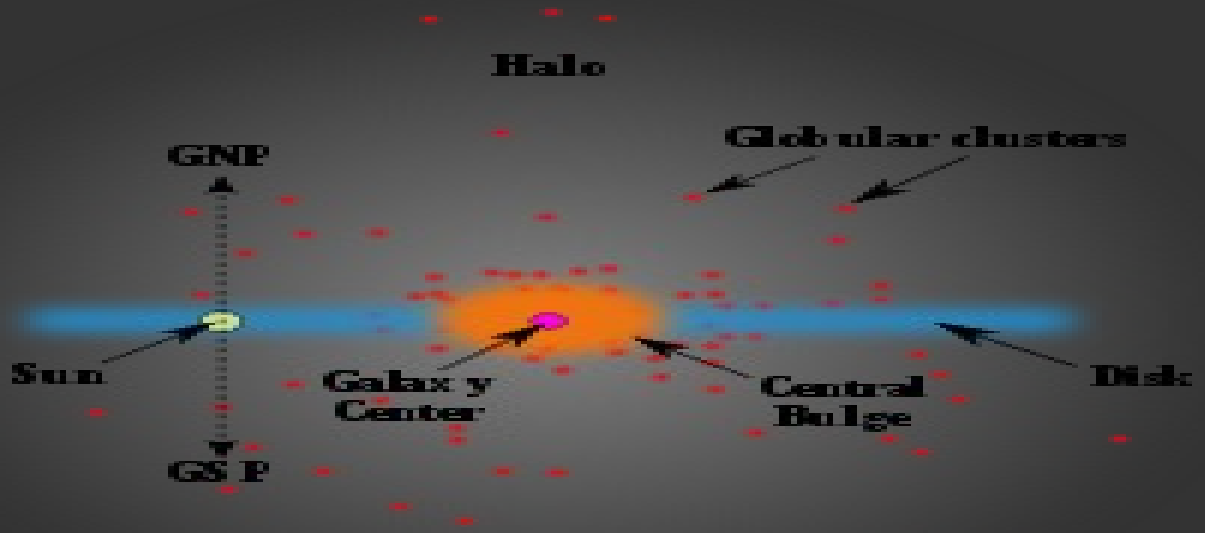
- Stars
- Stellar remnants
- Clouds of gas & dust
  - 70 % hydrogen
  - 28 % helium
  - 2 % ‘other elements’
    - Heavy elements

Sun - in fact, our whole solar system - orbits around the center of theMilky Way Galaxy at an average velocity of 828,000 km/hr. It takes us about 230 million years to make one complete orbit around the Milky Way!



The Sun executes oscillations around its mean orbit in the Galaxy, periodically crossing the Galactic plane.The Sun is currently above the plane and moving upwards, and each cycle takes about 70 million years with an amplitude of 100pc (Matese et al. 1995), it will be roughly 30 million years before we cross the plane again.


Galactic Longitude
180°
(Auriga)
210°
(Monoceros)
150°
(Perseus)
240°
(Puppis)
120°
(Cassiopeia)
25 000 ly
7.7 kpc
270°
(Vela)
90°
(Cygnus)
300°
(Crux)
60°
(Vulpecula)
50 000 ly
15.3 kpc
Sun's orbit
330°
(Norma)
30°
(Aquila)
75 000 ly
23.0 kpc
0°
(Sagittarius)
observation shadow of galactic core
1a. New Outer
1. Perseus
2b. Orion-Cygnus
Solar System
1. Perseus
1a. Outer
2a. Carina-Sagittarius
2. Scutum-Centaurus
1a. Norma
1. 3kpc
Galactic Bar
Long Bar
2. Scutum-Centaurus



The MW has three main parts: bulge, disk, & halo

The disk

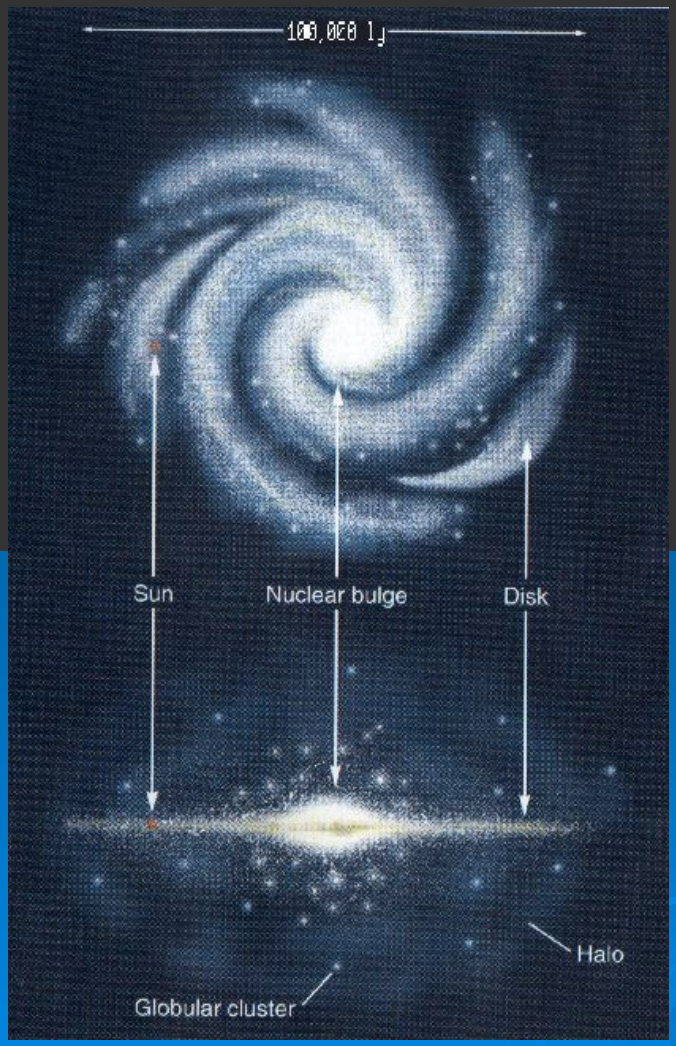
- ~ 1 kpc thick
- Contains:
  - All types/ages of stars, nebulae, etc.
  - OB stars, HII regions, Cepheid variables, open clusters …….
  - Red variables, late type giants ….

    z ~ 500-600 pc
- Spiral arms
  - *Not* “where the stars are”
  - Rather, where the *most luminous* stars are
    - *Luminous* stars are *massive* stars
    - *Massive* stars are *young* (they don’t live long)
    - *Spiral arms show recent star formation*

The halo

- Stars in the halo are mostly old (Pop II)
  - Therefore mostly low mass
- Many are found in globular clusters

Distribution of clusters in the Galaxy



- Halo
- Disk
- Bulge
- Pop I :Spiral arms, young, metal rich stars
- Pop II: Halo, old, metal poor stars

Star Formation

70 – 90% of stars form in embedded clusters, some of which remain bound and evolve to open clusters, and the remainder disperse and contribute to the Galactic field.

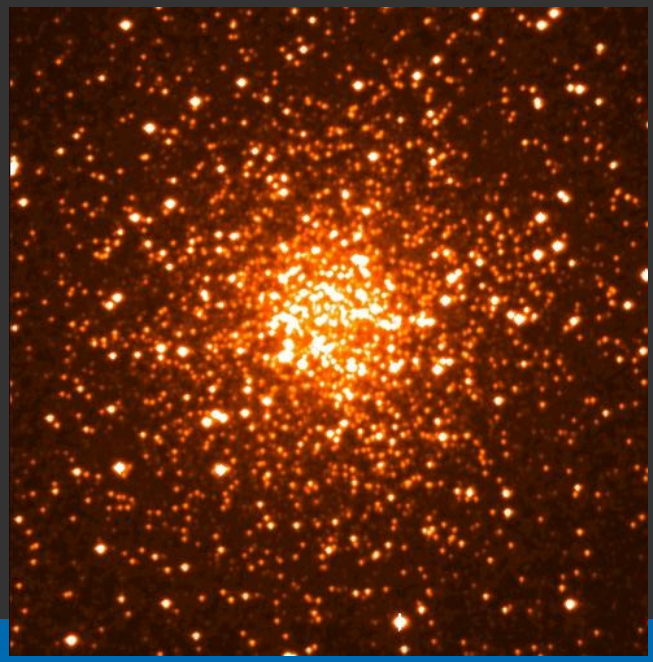
About half the stars in the sky have stellar companions, bound together by gravity and in orbit around each other.

Multiplicity is the norm.....

*A star cluster is a sample of stars formed from the same molecular cloud, where all the stars have the same age, chemicall composition and are at the same distance, differ only in **mass**!!*

Types of Clusters

- Open Clusters
- Globular clusters
- Associations



Stars formed at the same time,distance, chemical composition…..differ only in mass.

Globular Clusters

appearance compact

number of stars 50,000 – 1,000,000

Mass 10^5 M_{sun}

colors mostly red

age very old, ~10^{10} yrs

distribution more broadly distributed, are gravitationally bound, are spherical in shape

population Pop II

orbits highly eccentric, elliptical

Open Clusters

appearance Loose

number of stars 20 – 1000

Mass 10^5 M_{sun}

colors mostly blue

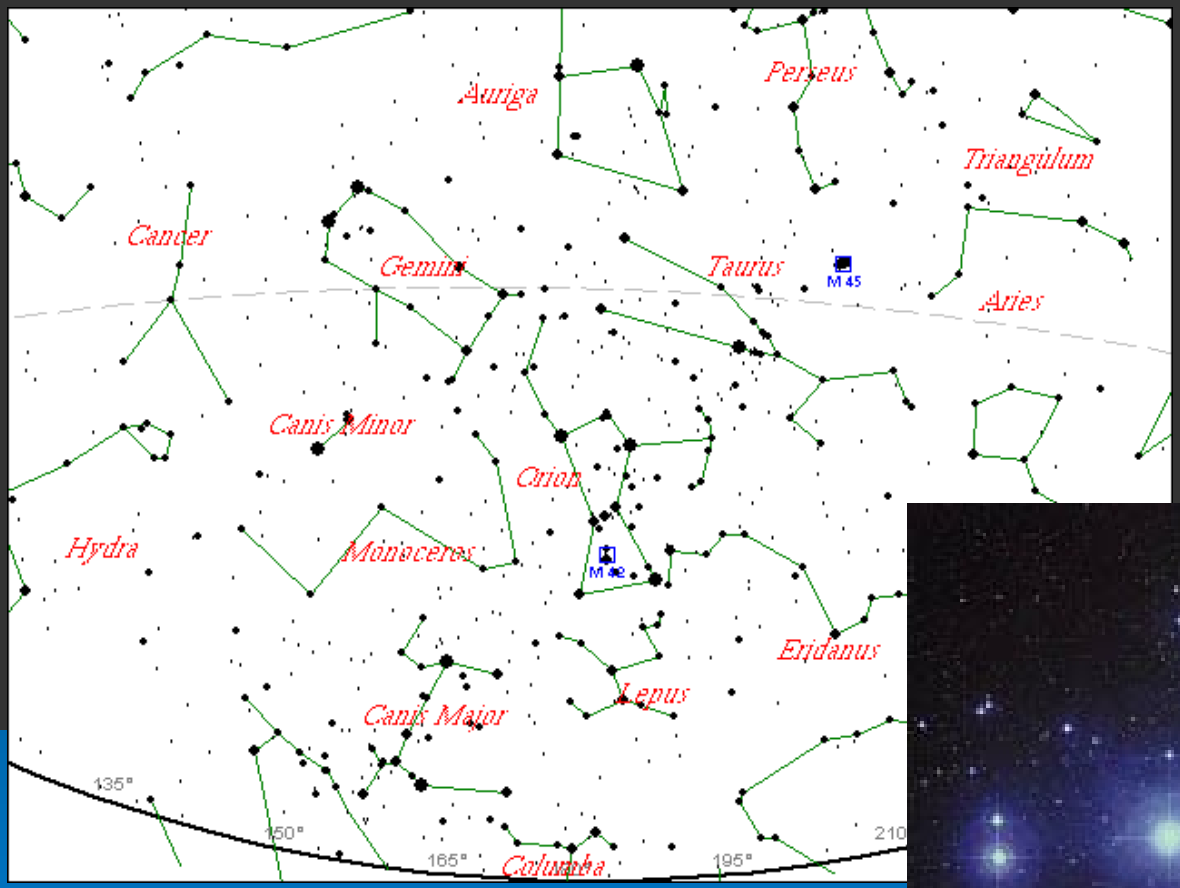
age young ~10^6-10^8 yrs

distribution close to the plane of the Milky Way, may not be bound by their own gravity, spiral arm tracers

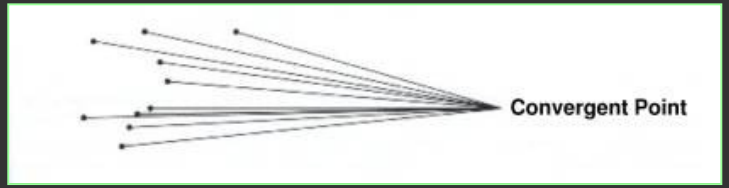
population Pop I

orbits Regular, planar

The Pleiades



Associations

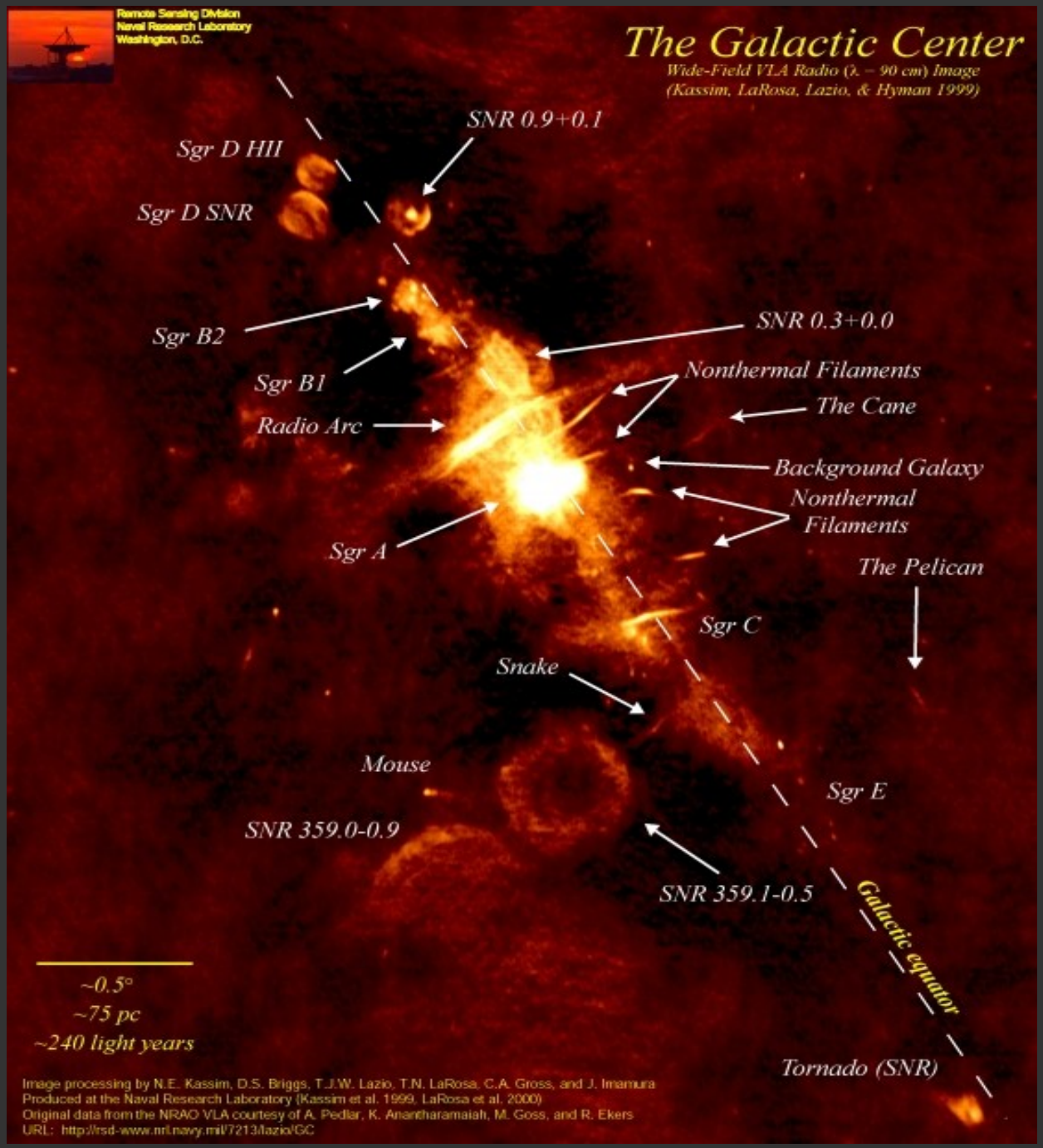


- O, B Associations
- T Associations
- Recently formed stars, not bound gravitationally but are expanding away from some common center, which presumably marks their birthplace.
- Plane of the galaxy
- 10^2 pc, 10^6-10^7 yrs
- Prodigious sources of energy
- Stellar winds, ionize ISM

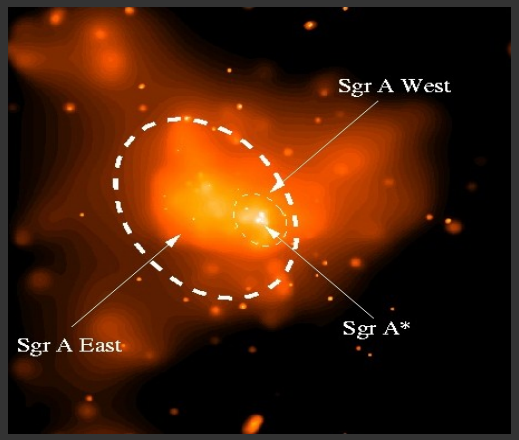
The Galactic center

The Galactic center

- In the direction of Sagittarius
- Observation:
  - Lots of gas, moving at *very* high speeds, within a very small region
- This requires lots of gravity in a very small space
- Likely explanation:
  - A massive black hole at the center of the galaxy
  - M ~ 3 million solar masses

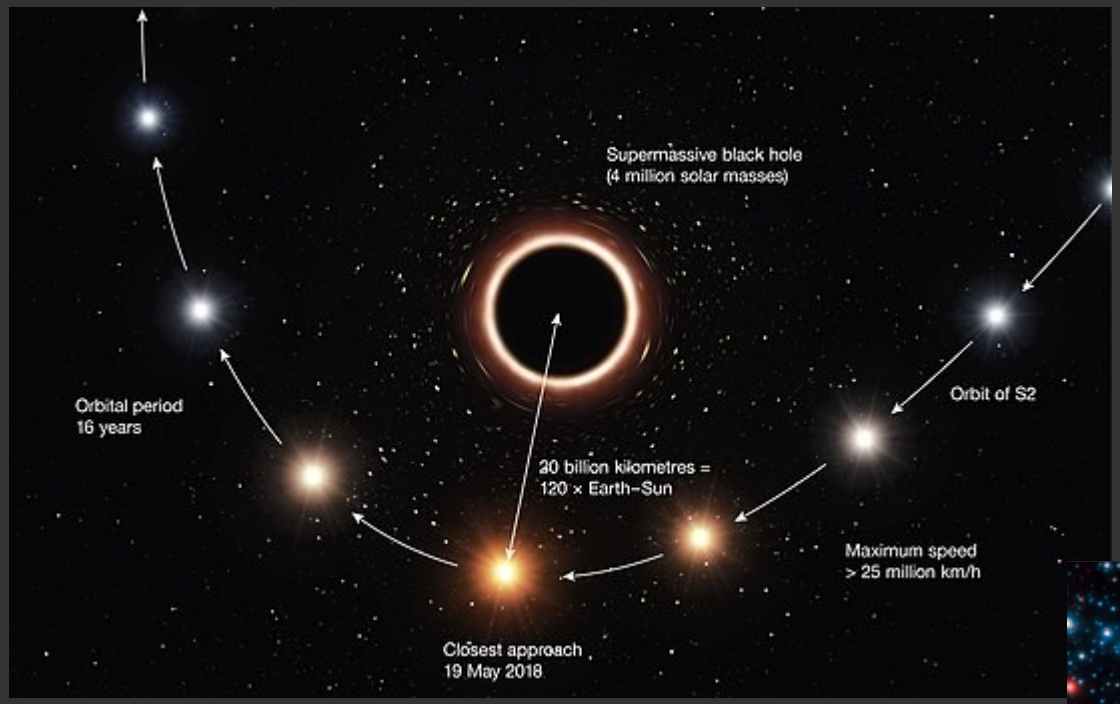


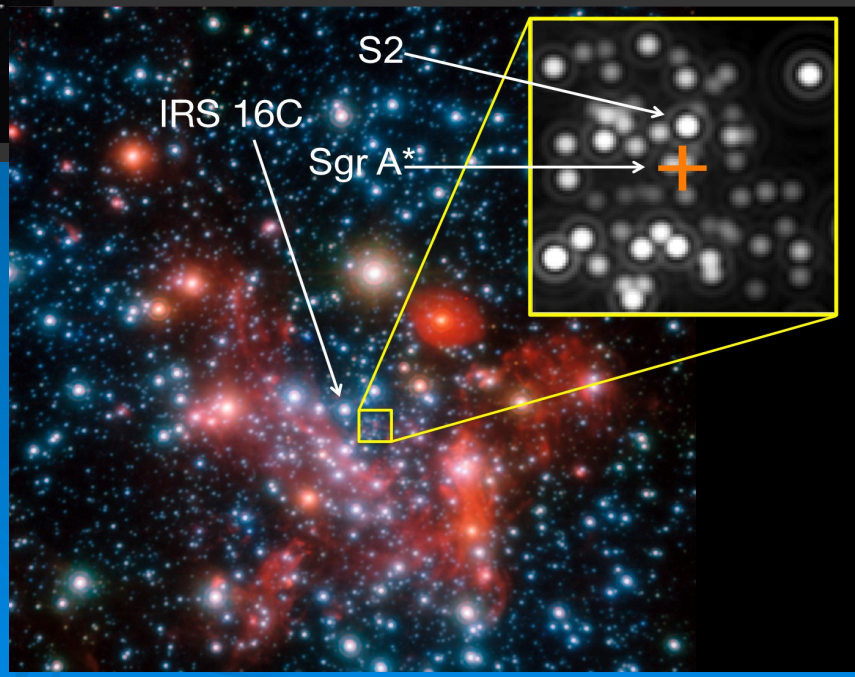
National Radio Astronomy Observatory's Very Large Array



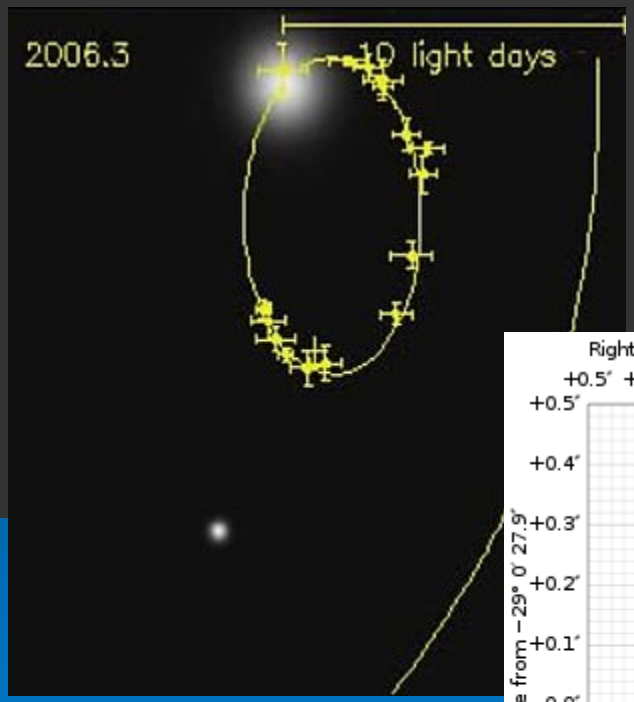
Xrays Chandra Image of Sgr A,I, including a small point source called Sagittarius A*.

Most galaxies have a (super)massive black hole at their centers

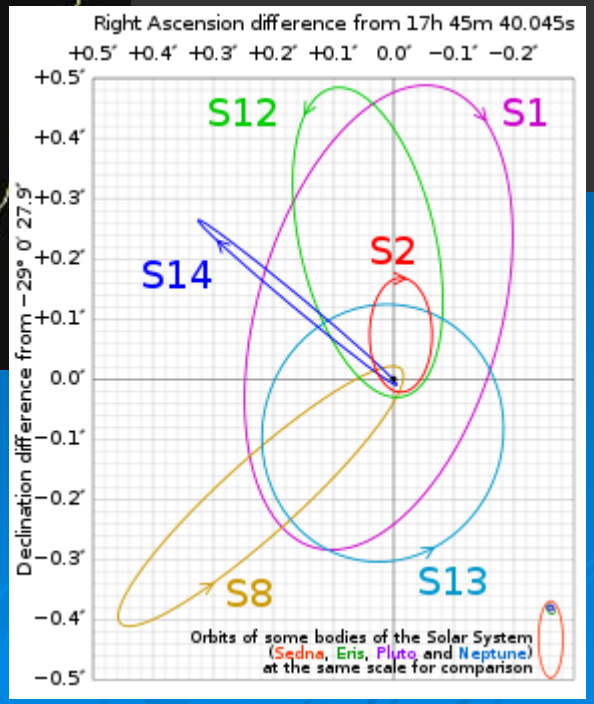




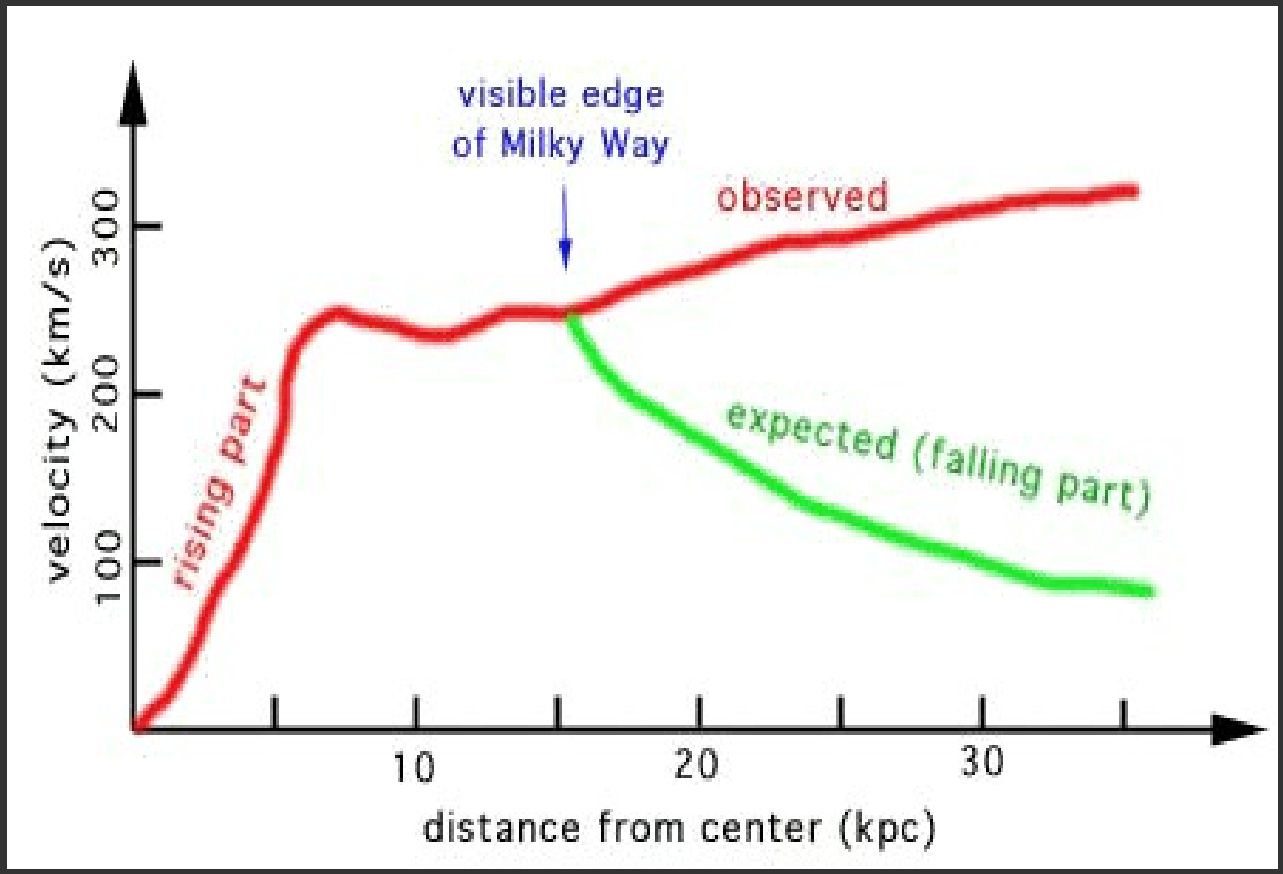
S2, also known as S0–2, is a star that is located close to the radio source , orbiting it with a period of 16.0518 years, a of about 970 , and a distance of 17

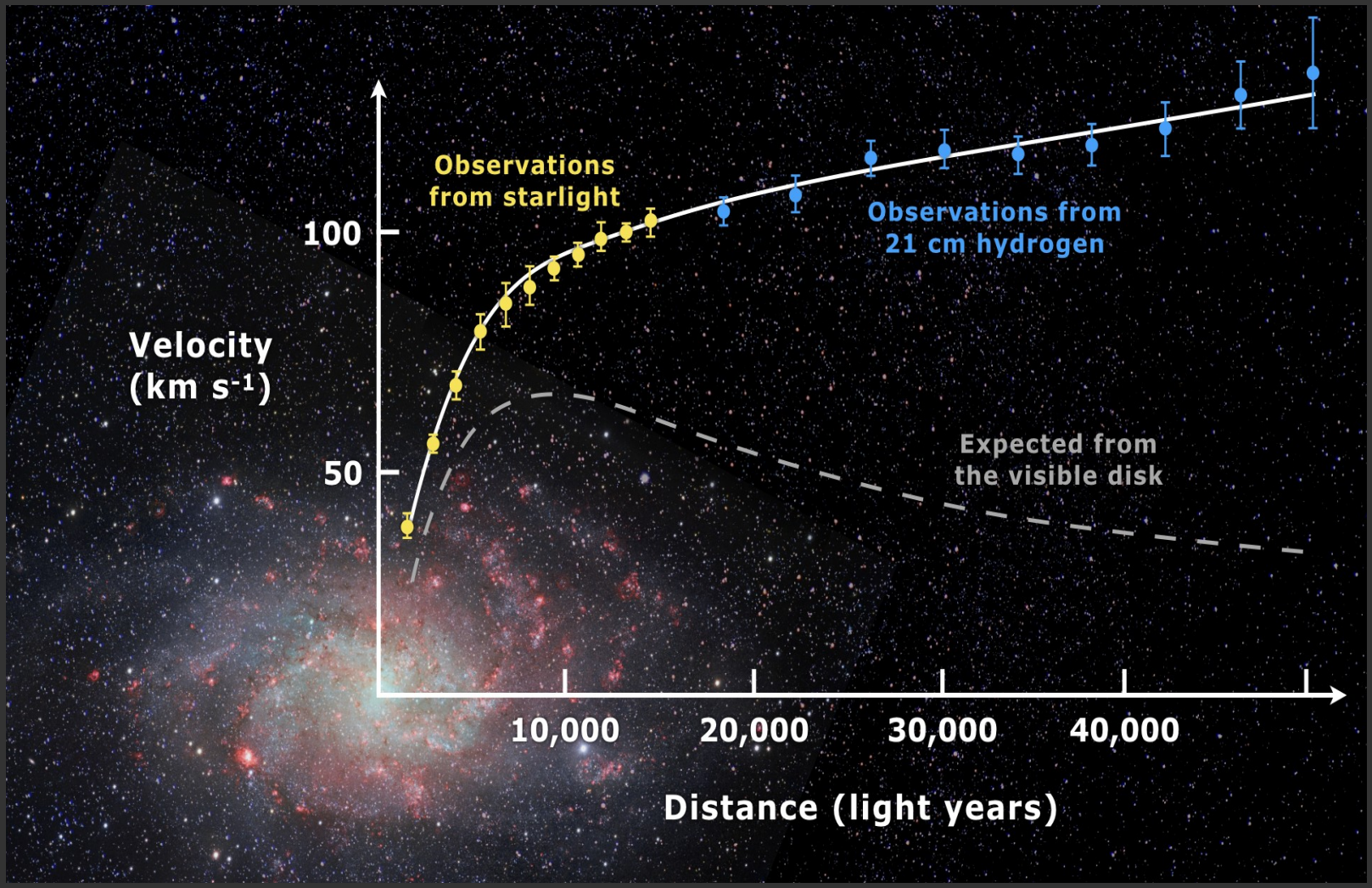


Galactic BH: 4.31 million for the mass of the black hole and S2's close approach, this makes S2 the fastest known ballistic orbit, reaching speeds exceeding 5,000 km/s!



Rotation Curves

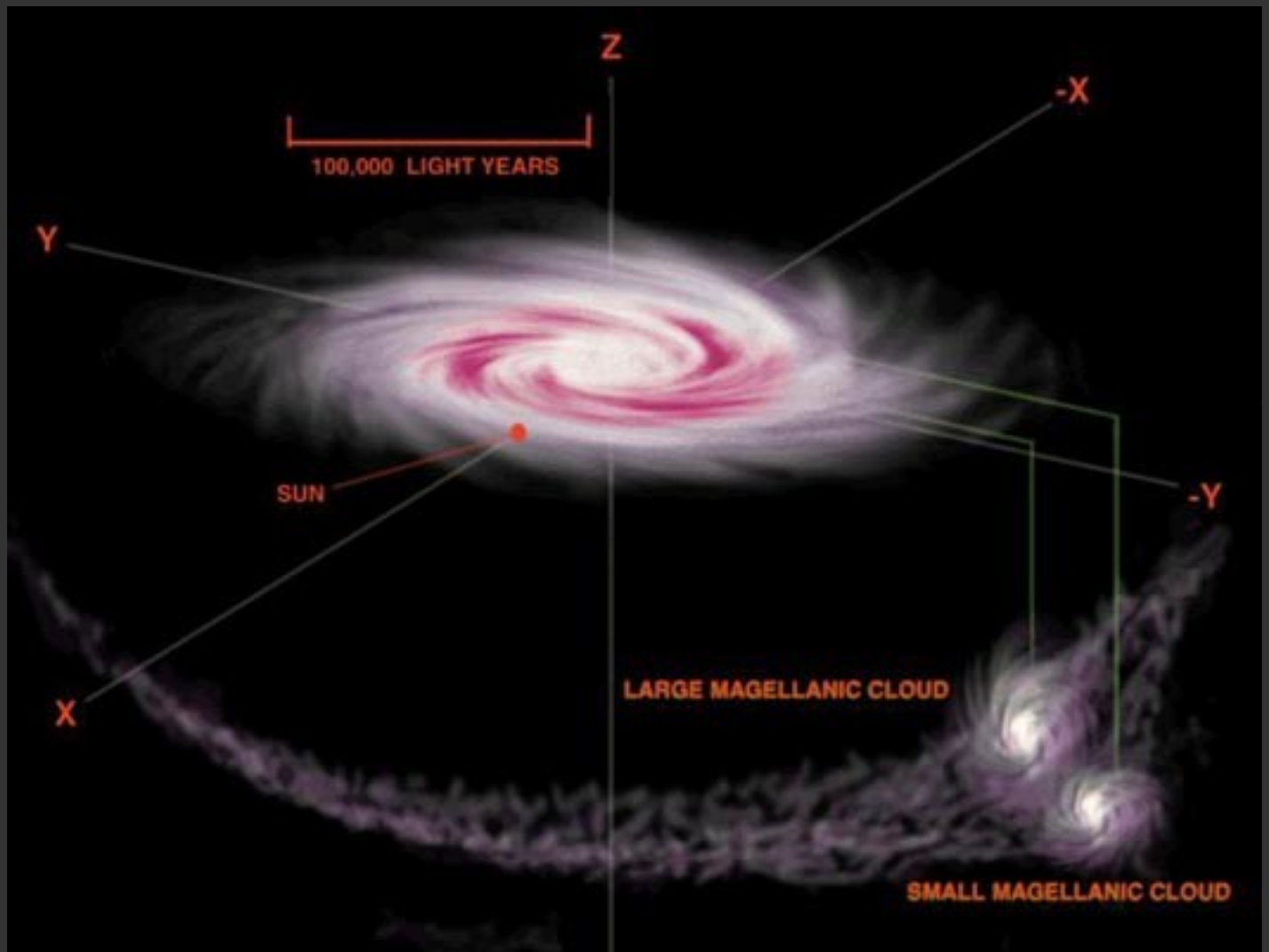


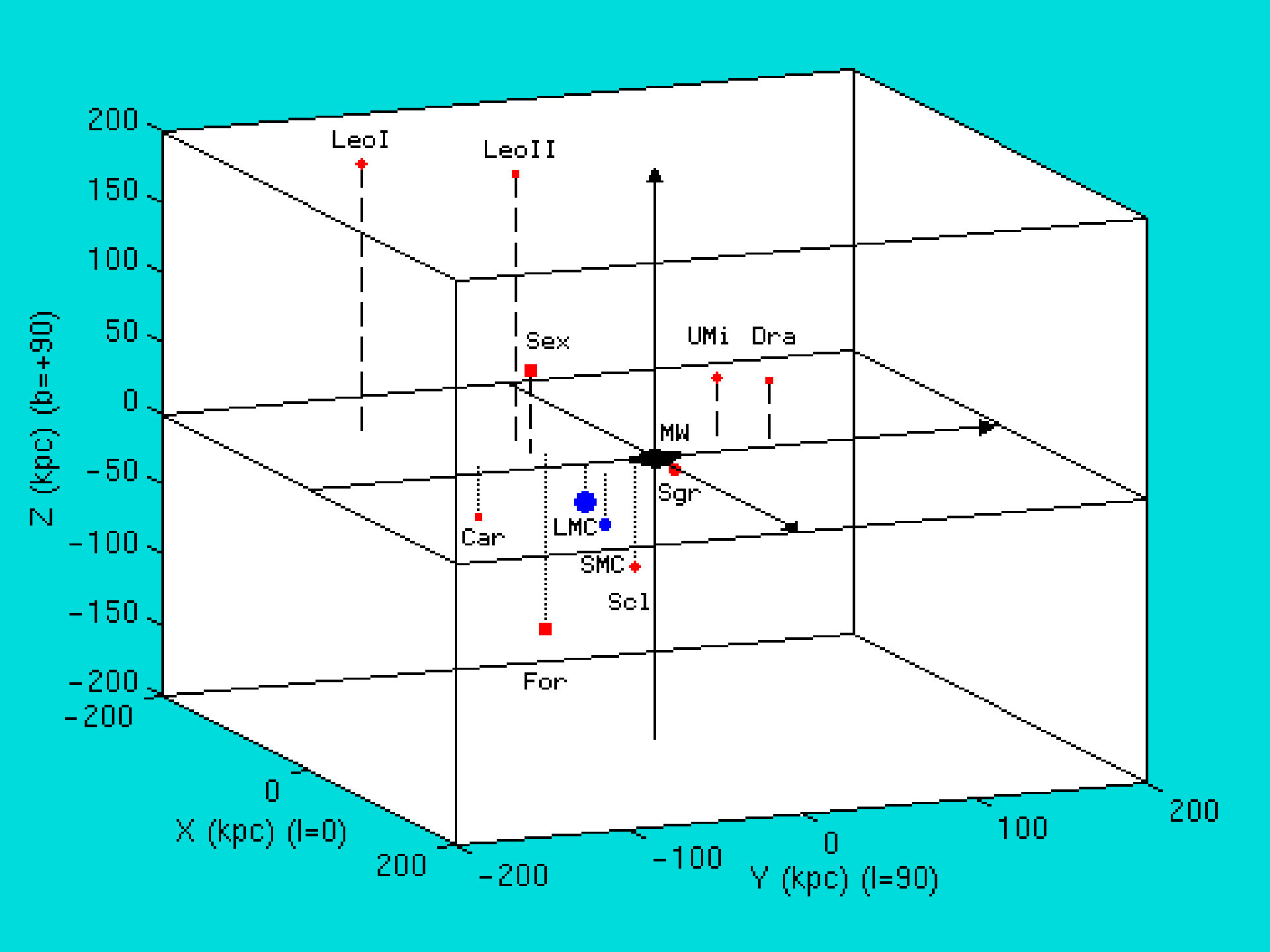

Observations
from starlight
Observations from
21 cm hydrogen
Expected from
the visible disk
100
50
Velocity
(km s-1)
10,000
20,000
30,000
40,000
Distance (light years)

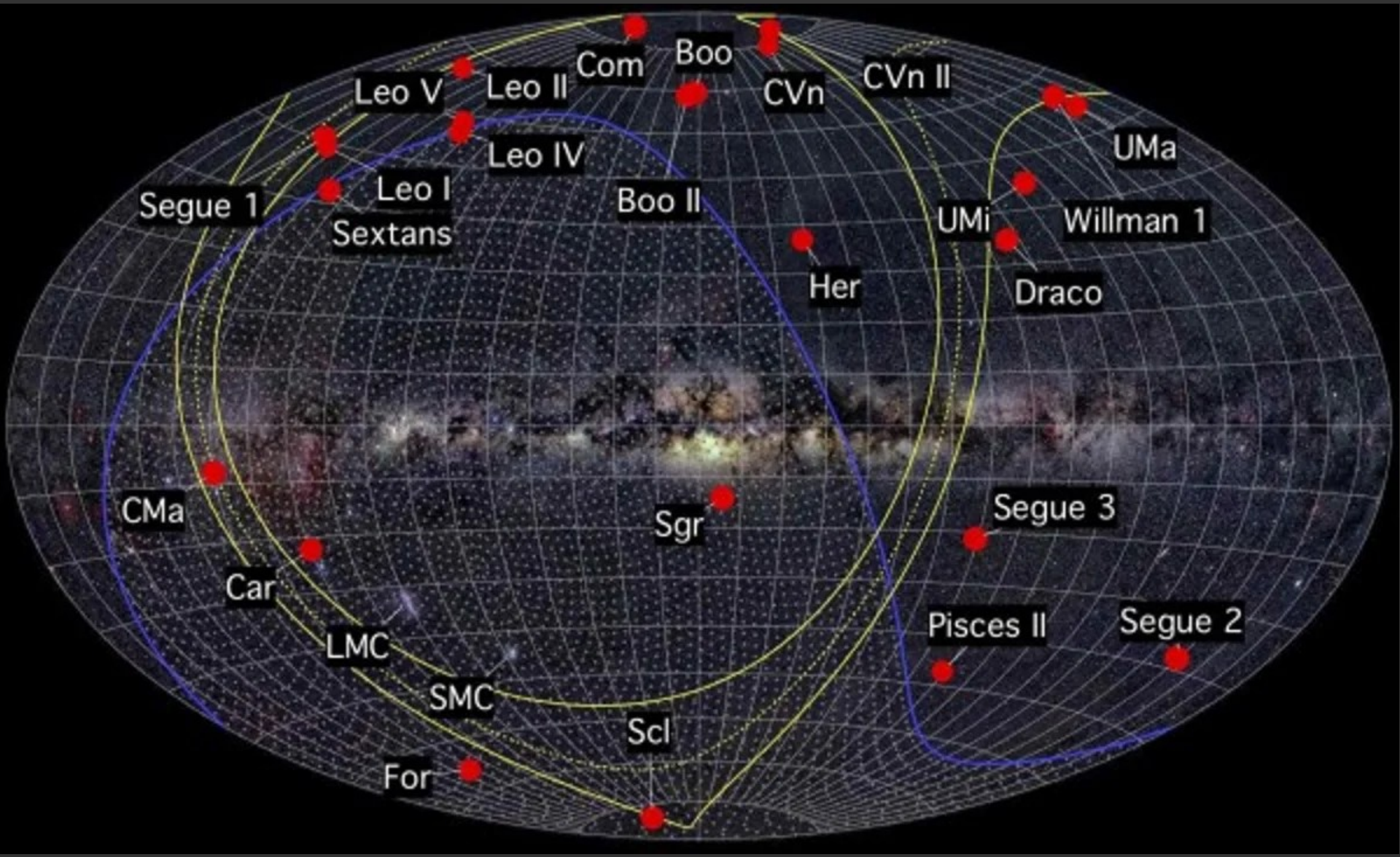
Dark Matter!

- *Most of the mass of our galaxy is not visible to us!*
- This invisible mass is called dark matter
- No one knows what it is at this time
- Makes up as much as *90 % of the Milky Way's mass!*
- One of the most important questions in modern astronomy

Our local neighbourhood



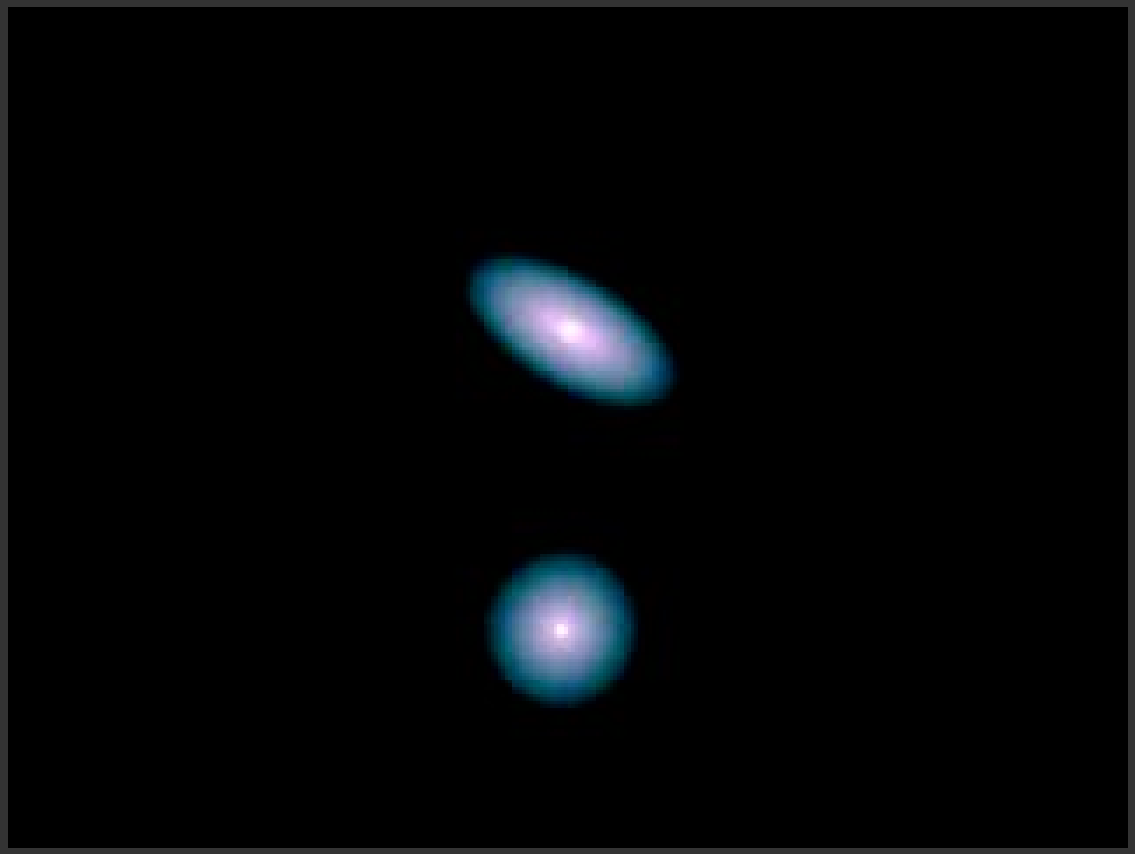

LeoI
LeoII
Sex
UMi
Dra
MW
Sgr
Car
LMC
SMC
Scl
For
200
150
100
50
0
-50
-100
-150
-200
Z (kpc) (b=+90)
-200
0
200
X (kpc) (l=0)
-200
-100
0
100
200
Y (kpc) (l=90)


Com
Boo
Leo V
Leo II
CVn
CVn II
UMa
Leo IV
Leo I
Segue 1
Sextans
Boo II
UMi
Willman 1
Her
Draco
CMa
Sgr
Segue 3
Car
LMC
Pisces II
Segue 2
SMC
Scl
For

The fate of our Milky Way

Andromeda Galaxy is approaching the Milky Way at about 110 kilometres per second as indicated by blueshift.

- Collision after ~4.5 billion years
- merge to form an elliptical galaxy after 1 billion years



https://www.youtube.com/watch?v=4disyKG7XtU

Milkomeda or Milkdromeda

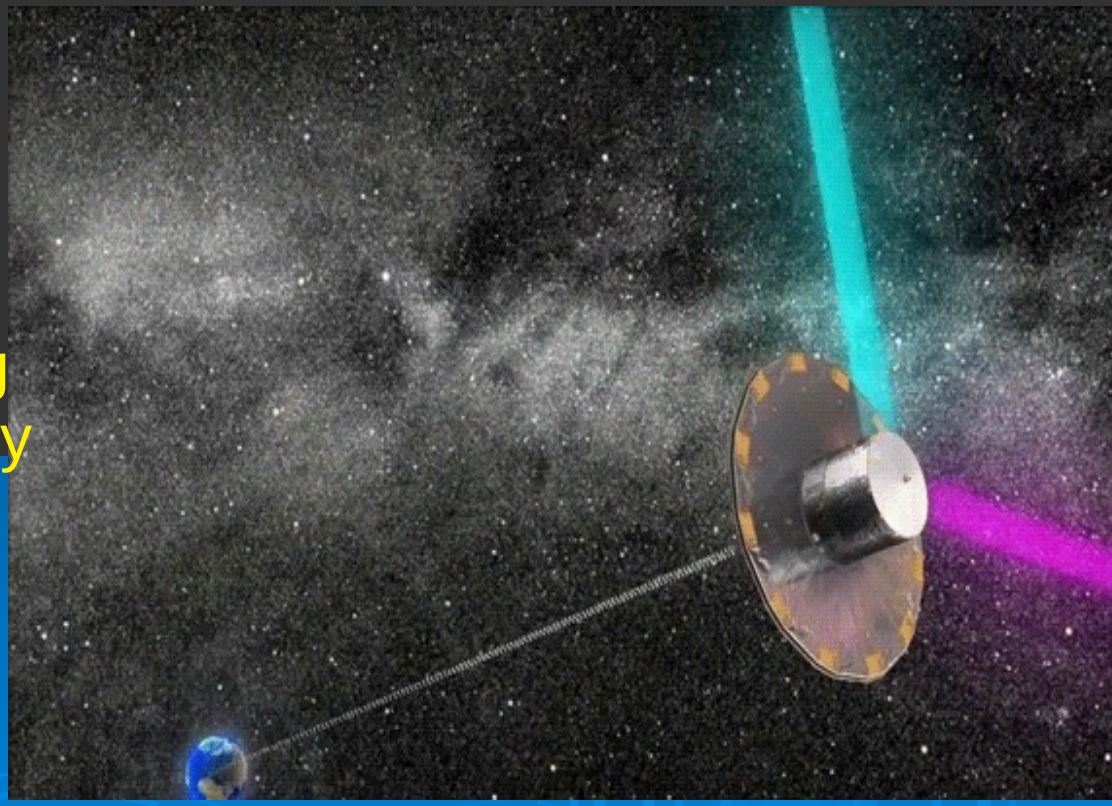
The resulting object will be a large lenticular galaxy depending on the amount of remaining gas in the Milky Way and Andromeda.

Roughly 150 billion years from now, the remaining galaxies of the Local Group will coalesce into this object, that being the next evolutionary stage of the local group of galaxies

GAIA: 6D revolution

RA, Dec, parallax, RV, pmra, pmdec

Two identical, three-mirror anastigmatic (TMA) telescopes, with apertures of
1.45 m × 0.50 m pointing in directions separated by the basic angle
(Γ = 106 ◦ .5)
Accuracy of 24 microarcsec= 42 kpc,
0.06arcsec pixels



The Milky Way
Gaia

Thanks..

Natures produces a variety of Black Holes....

Black hole classifications

Class	Mass	Size
Supermassive black hole	~10^5–10^{10} M_{Sun}	~0.001–400 AU
Intermediate-mass black hole	~10^3 M_{Sun}	~10^3 km ≈ R_{Earth}
Stellar black hole	~10 M_{Sun}	~30 km
Micro black hole	up to ~M_{Moon}	up to ~0.1 mm