Milky Way

View of the Milky Way

- band of stars stretching across the sky in a great circle.
- the band is brighter and thicker in one direction (Sagittarius) and dimmer and thinner in a direction 180° away (Taurus)

Implies

- Most of the stars in a plane or disk
- The sun is close to the plane of the MW.
- The sun is not at the center nor at the edge.

Early Studies of the Milky Way

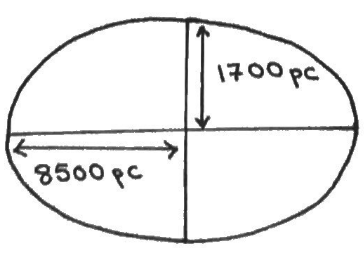
William Herschel started making star counts around 1782. From the star counts he built a model of the Milky Way. He found the Milky Way to be ellipsoidal with the sun near the center.

Around 1918, Kapteyn tried to refine Herschel's work

- Studied 200 selected areas in the sky
- Obtained star counts, brightness estimates, spectroscopic classifications, proper motions and radial velocities
- From proper motion data he obtained average distances for stars at various apparent luminosity levels
- From star counts he obtained the distribution of stars
- Kapteyn Universe

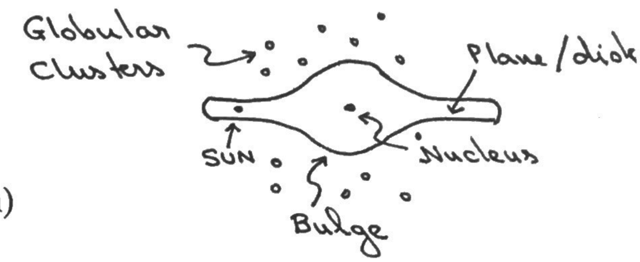
His universe was ellipsoidal. The sun was 650 pc from the center and 38 pc above the plane. The density of stars decreased uiformly from the center. The diameter of the Milky Way was 17 Kpc [the distance at which the density of stars was 1% of the central density]

- The Kapteyn Universe was completely wrong. Since Kapteyn had neglected to take into account the effects of dust.



Around 1915 Harlow Shapley studied the distribution of globular clusters.

- Measured distances to 93 globular clusters using RR Lyrae stars.
- Globular clusters were not uniformly distributed but concentrated in the direction of the constellation Sagittarius.
- Shapley argued that the center of the Milky Way was in the direction of Sagittarius
- Estimated the sun's distance from the center to be 15,000pc or 15 Kpc
- The size of the Milky Way (according to Shapley)~100 Kpc in diameter



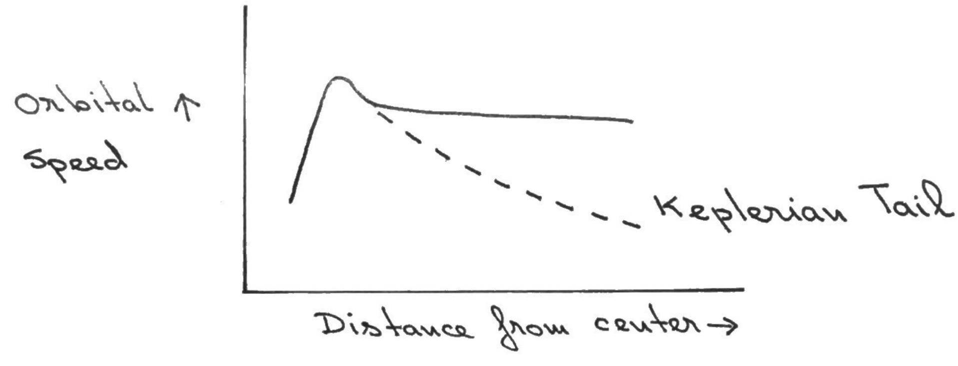
Properties of the Milky Way

Mass : 1.4×10^{11} $M_\odot$ (interior to $\odot$'s position)
Diameter of disk : 30 Kpc
Diameter of central bulge : 10 Kpc
Sun's distance from center : 10 Kpc (possibly less ~8.5 Kpc)
Thicknes of disk : 1 Kpc (at $\odot$'s position)
Number of stars : 4×10^{11}
Typical density of stars : 20 stars / pc^3 (solar neighborhood)
Average density of ISM : 10^{-24} gm / cm^3 [~1 H atom / cm^3]
Luminosity : $2 \times 10^{10} L_\odot$
Absolute magnitude : -20.5

Galactic Rotation

- Rigid rotation near the center
- Differential rotation in the outer parts [Linear and angular speeds different at different distances from the center]
- Sun's orbital speed around the center of MW ≈ 250 km/s and the orbital period ≈ 250 million years.
- Sun's peculiar velocity w.r.t. neighboring stars ≈ 20 km/s

- Rotation curve



<u>Solar Motion</u>

- The sun and the stars in its neighborhood (out to about 50pc from the sun) are moving around the galactic center.
- Local Standard of Rest (LSR) = imaginary point moving in circular orbit around the galactic center with the average velocity of stars in the solar neighborhood.
- Solar Apex = the direction in which the sun is moving with respect to nearby stars about 10° from the star Vega.
- Peculiar velocity = velocity w.r.t. LSR

<u>Mass of the Galaxy</u>

Use Kepler's 3rd law : $(M_G + M_\odot) P^2 = (4\pi^2/G) a^3$

$P = \odot$'s orbital period

$a = \odot$'s distance from galáctic center

$M_G = 1.4x10^{11} M_\odot$ (mass within sun's orbit)

To measure mass beyond the sun's orbit use the velocity of HI gas from the rotation curve $M_G \geq 6x10^{11} M_\odot$

Ultraviolet observations indicate hot rarefied gas extending several thousands parsecs above and below the plane of the MW

Indicates massive halo of dark matter
- black dwarfs (burnt out stars), brown dwarfs (<0.08 $M_\odot$)
- neutron stars, black holes
- massive elementary particles

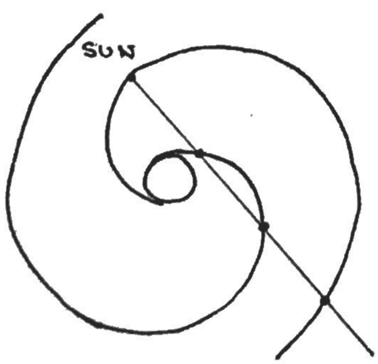
Mapping the Galactic Structure

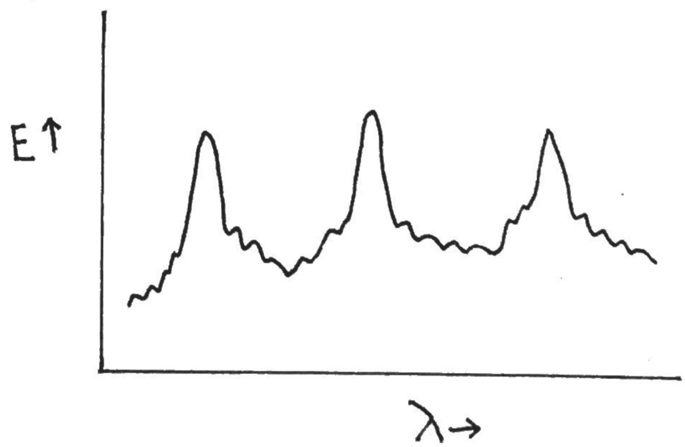
Trace the distribution of O and B associations. Can be applied to a limited distance due to extinction due to dust in the plane of the Galaxy. MW has at least four arms

- Perseus arm (+1)
- Orion arm (0) [sun on the inner edge of arm]
- Sagiitarius arm (-1)
- Centaurus arm (-2)

Map the 21-cm emission line of neutral hydrogen

- Different radial velocities due to differential rotation and angle to the line of sight
- Use a set of equations to convert from radial velocity to distance from the galactic center
- Can also obtain spiral structure by mapping the molecular clouds. Trace the CO emission by radio telescopes.





Stellar Populations

	PopI	PopII
	Young	Old
	Metal rich	Metal poor
	Found in the disk & spiral arms	Found in the halo and central bulge
e.g.	O, B associations	Globular clusters
	Type I Cepheids	Type II Cepheids, RR Lyrae stars

PopI stars close to the sun move in roughly circular orbits in the galactic plane. Relative velocity w.r.t. the sun is small
PopII stars have randomly oriented elliptical orbits. Relative velocity w.r.t. the sun is high, hence called high velocity stars.

Galactic Center

Central bulge : R = 5 Kpc, mostly old, reddish stars, little gas & dust
3 Kpc arm - discovered from radio observations > 107 M,. Circular velocity 210 km/s. One side approaching us at -53 km/s the other side receding from us at +135 km/s - indicates explosive acitivity ~30 million years ago.
Central star cluster - within inner 3 pc. 107x density of starsin the solar neighborhood 106 stars brighter than Sirius. Starlit night 200x full moon night.
Ring of gas 2 pc outwards - asymmetrical. Infrared observation of NeII show turbulent gas motion around center. Broad emission ines. Doppler shifts upto 200 km/s. If gas is in circular motion central mass $10^6 M_\odot$
High resolution radio observation of galactic center

SgrA : 150 x 300 pc on the east side emits synchrotron emission - 2 to 5 x ISM magnetic field - possibly supernova remnant?
SgrA West : 10 pc - 60 million stars, HII regions + dust. Stars ~1600 AU apart and temp of gas cloud ~35,000°k.
Inner 20 AU - spiral arm like features - actualy independent streamers of ionized gas falling inward - increasing velocity as it nears the center.

There are 2 theories to explain the violent activity in the galactic center :
1) "Starburst" theory : Galactic center is a region of active star formation - of supermassive stars 500 to 1000 $M_\odot$ - which are unstable, have short lifetimes and become supernovae.
2) Central black hole : 10^6 $M_\odot$ black hole with accretion disk.

Stochastic, self-propagating star formation model

- Can explain flocculent spirals - ones with broad, fuzzy, chaotic, poorly defined spiral arms.
- Star formation (in a region without spiral arms) produces some hot massive stars. Their radiation compresses the nearby ISM and trigger more star formation. Some become supernovae producing shock waves inducing still more star formation. Galaxy's differential rotation draws the star forming region into a spiral arm. Spiral arms are produced in bits and pieces in random places in the galaxy. They disappear when the massive stars die.

Density Wave Theory

Tries to explain grand-design spirals - ones with thin, delicate, graceful, well-defined spiral arms.
How are the spiral arms maintained?
- Density wave - a longitudinal wave that creates alternate dense and relatively empty regions.

- Density wave affects the ISM more than stars hence the waves are regions of high concentration of gas and dust.
- Simple model has two arms. The wave is a fixed pattern and rotates at a constant rate. Wave motion is distinct from stellar motion and is slower than stellar motion.
- Star formation occurs in the inner edge where stars and gas clouds catch up with the density wave.
- Very massive (luminous) stars die before they can leave the arms. Less massive stars can move out of the spiral arm and orbit the galaxy several times.
- How did the initial pattern originate?

  Gravitational interaction with neighboring galaxies

  Asymmetric mass distribution in the central region (non-circular central bulges).

Evolution of the Galaxy (Milky Way)

- Spherical gas cloud - first objects to form globular clusters having randomly oriented orbits
- Owing to rotation the cloud collapsed - stars formed during the collapse had highly elongated orbits - PopII stars.
- Gas cloud collapsed to a disk. Stars in the halo unaffected by the collapse.
- The disk had rotation and the ISM was enriched with heavier elements from supermassive stars that became supernovae.
- Stars that formed in the disk (PopI) had higher metal content and were in circular orbits in the plane of the Galaxy