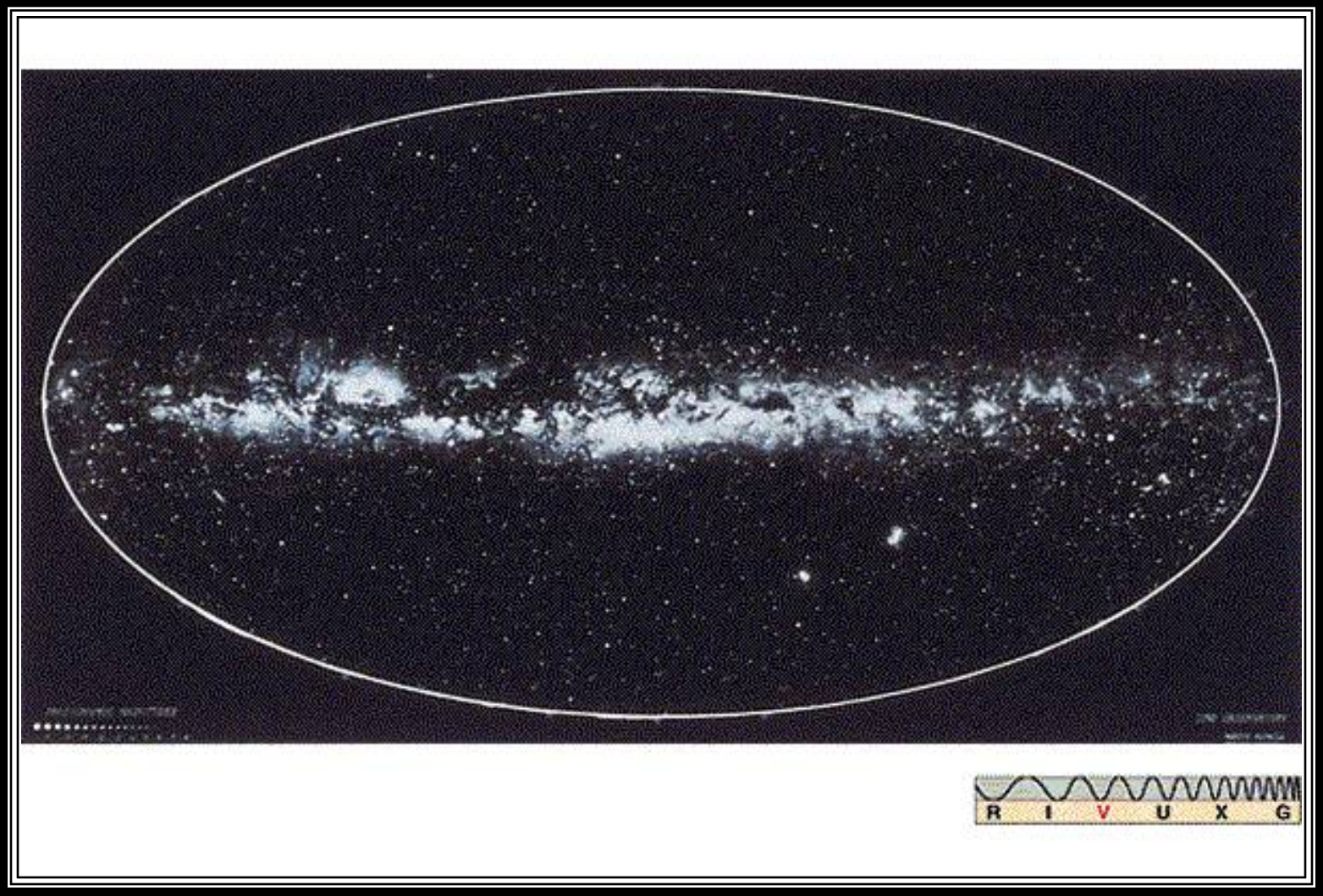
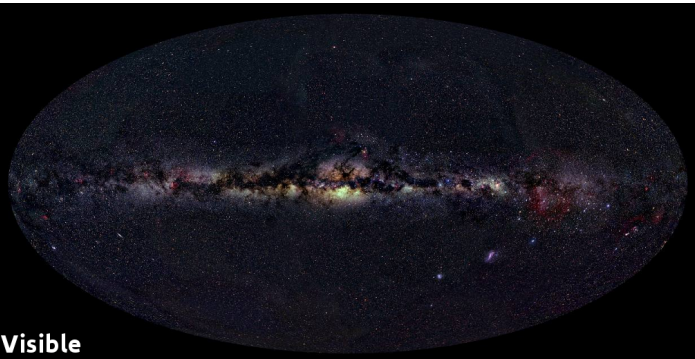
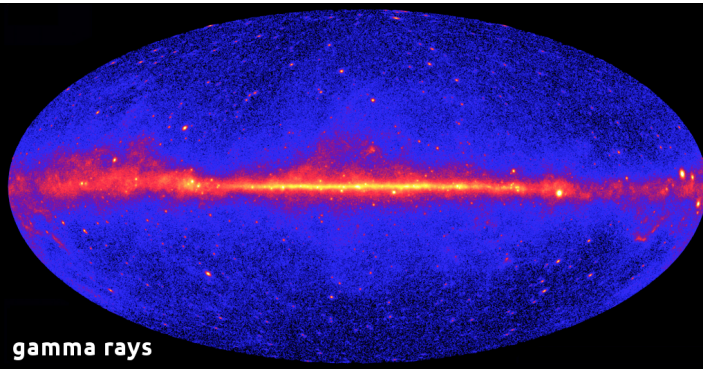
The Milky Way Galaxy



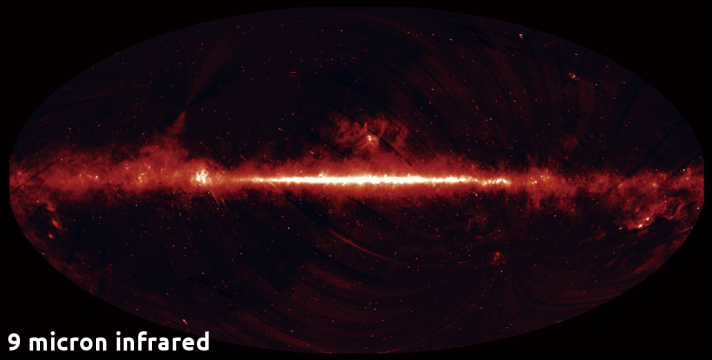
Sky Maps in Different Bands



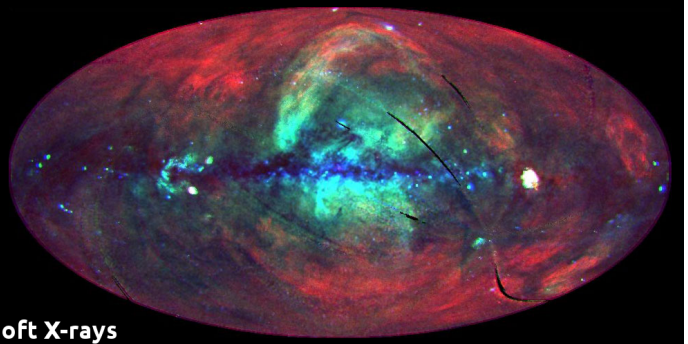
Visible



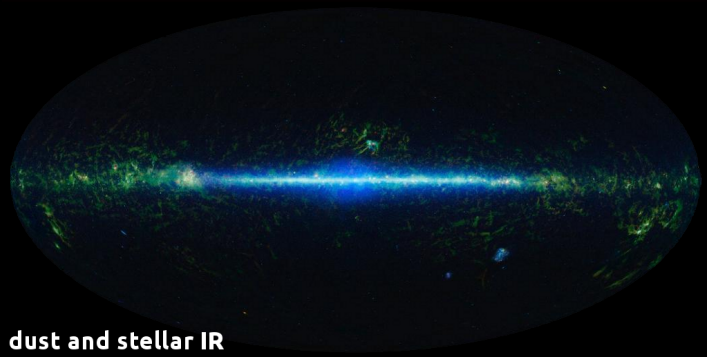
gamma rays



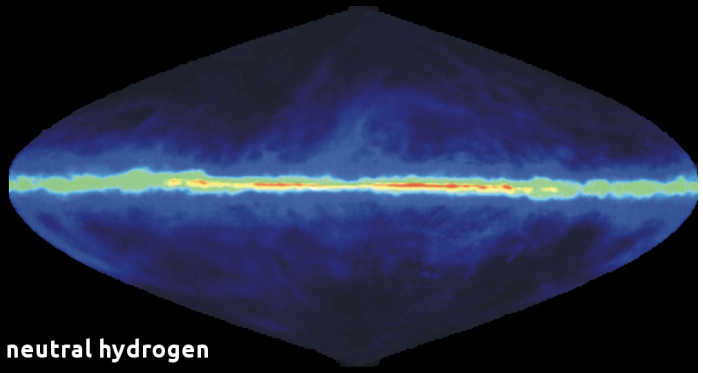
9 micron infrared



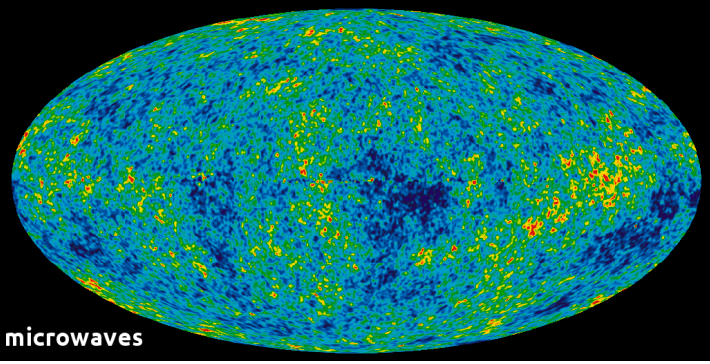
soft X-rays



dust and stellar IR



neutral hydrogen



microwaves

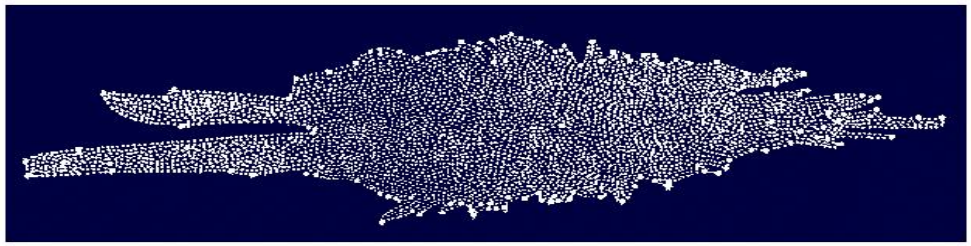
The Milky Way: Historical Prelude

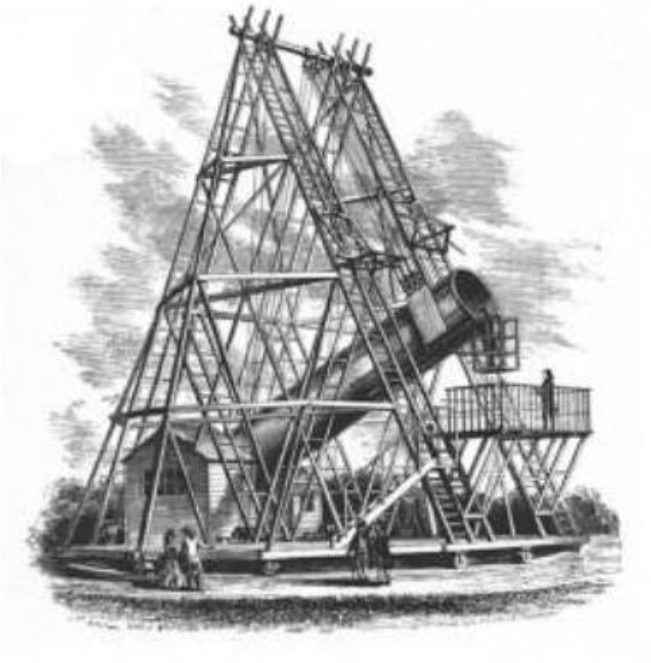
- William Herschel (1785) – shape of MW from counting stars; region of more stars implies greater extent
- Jacobus Kapteyn (~1900) – similar result as Herschel

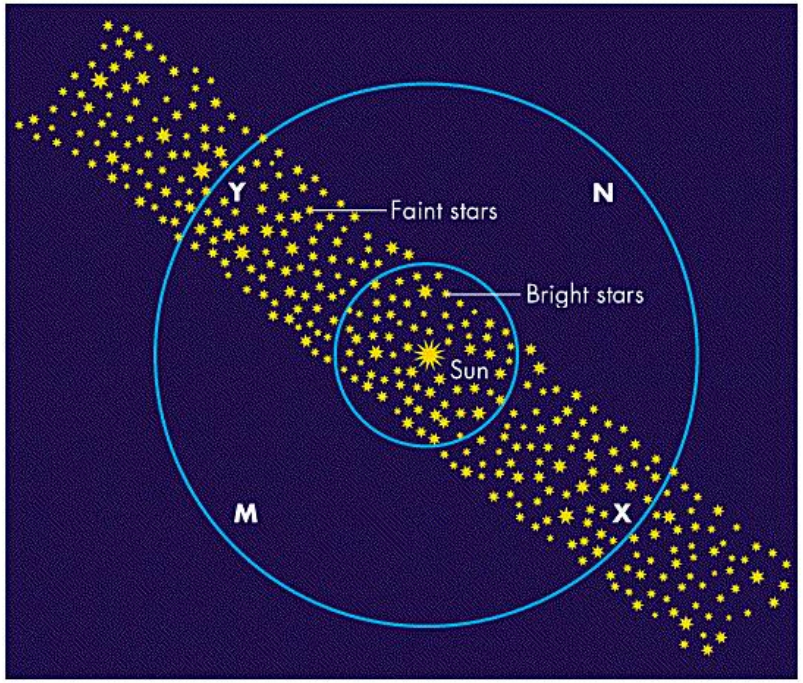
Both Herschel and Kapteyn inferred MW to be a flat disk, but incorrectly placed Sun near center.

They did not know about extinction!

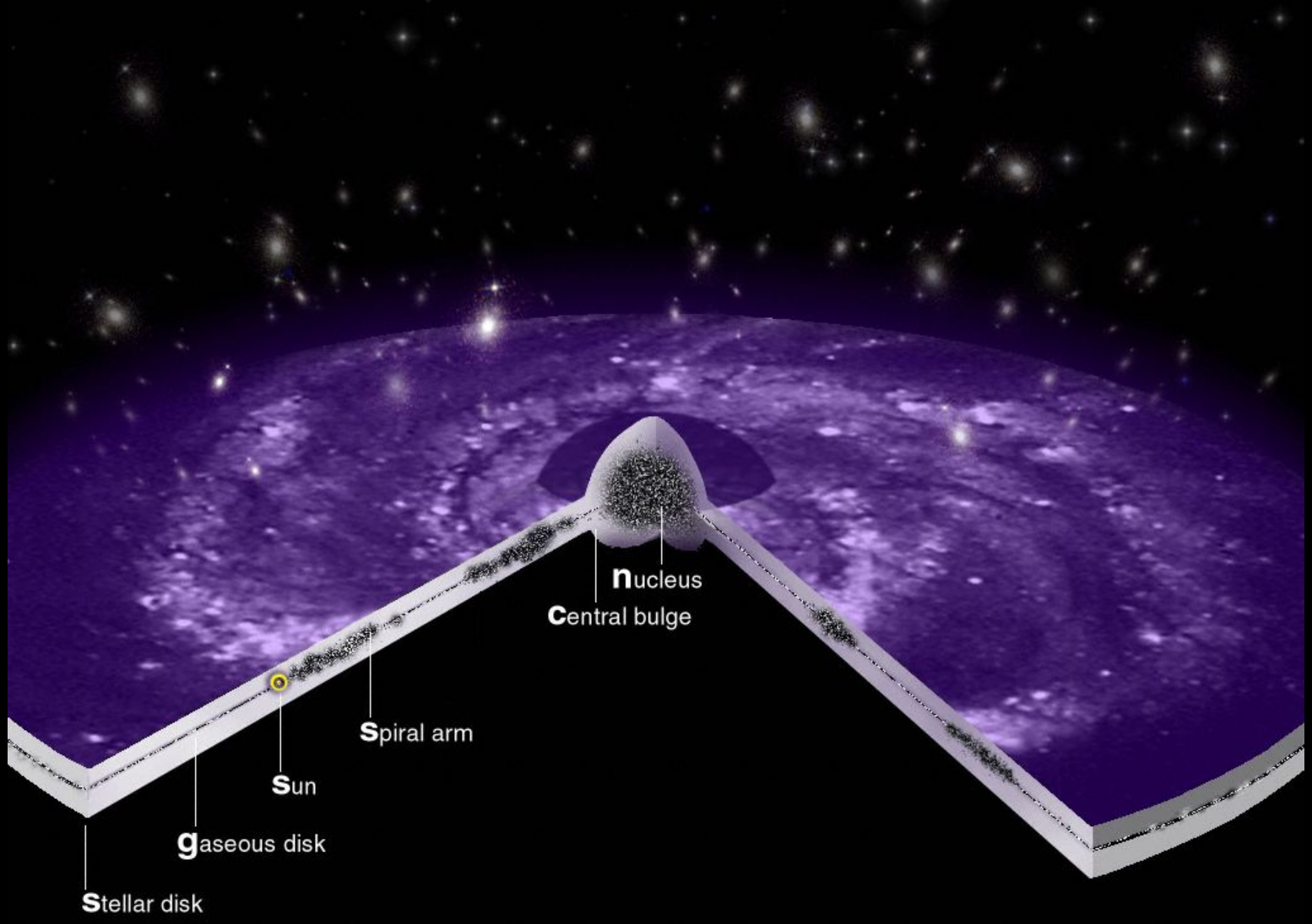
Hershel's Map







Living on the Inside



Locating the Galactic Center

Harlow Shapley (1915) – Identified RR Lyraes in globular clusters, so he measured their distances

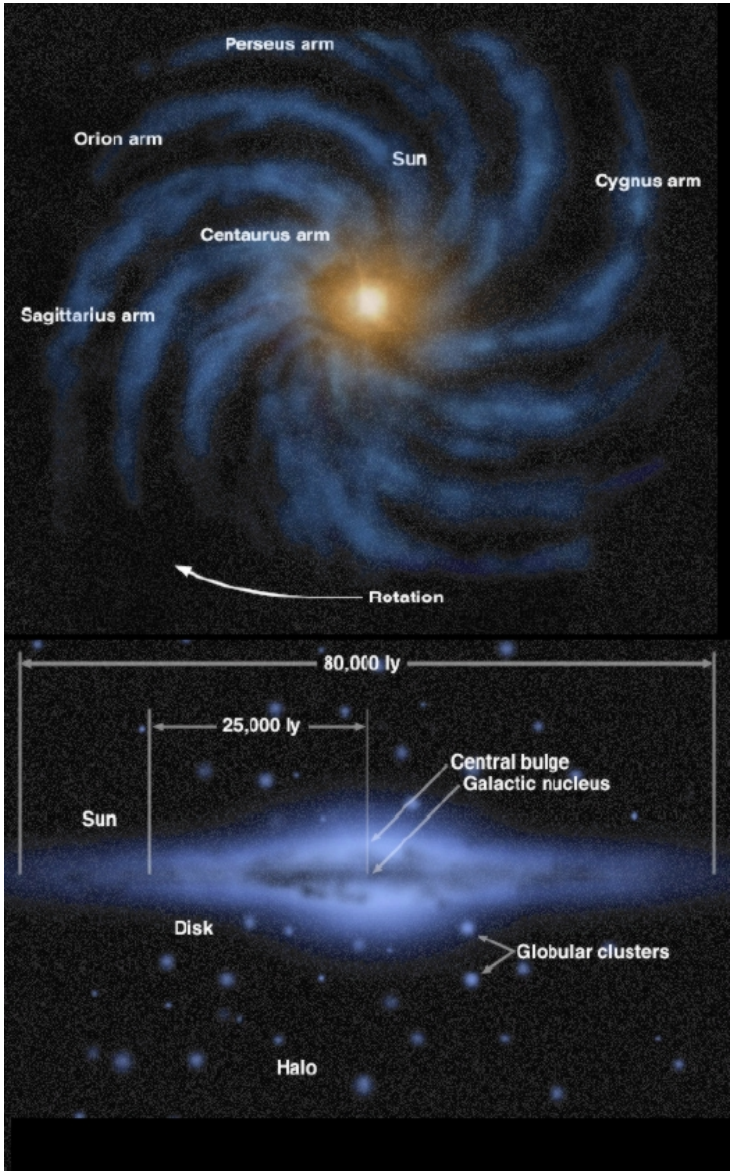
He further noted that globulars tended to be in one part of the sky

He thus located the MW center in a “mobile” deprojection style approach.

Milky Way Components

- Disk – contains most of gas and stars
- Nuecleus – central region of MW, likely with a 10^6 M_o black hole at center
- Bulge – sorta spherical region of stars around nucleus
- Halo – extended spherical region with globular clusters, old stars, and “dark matter”

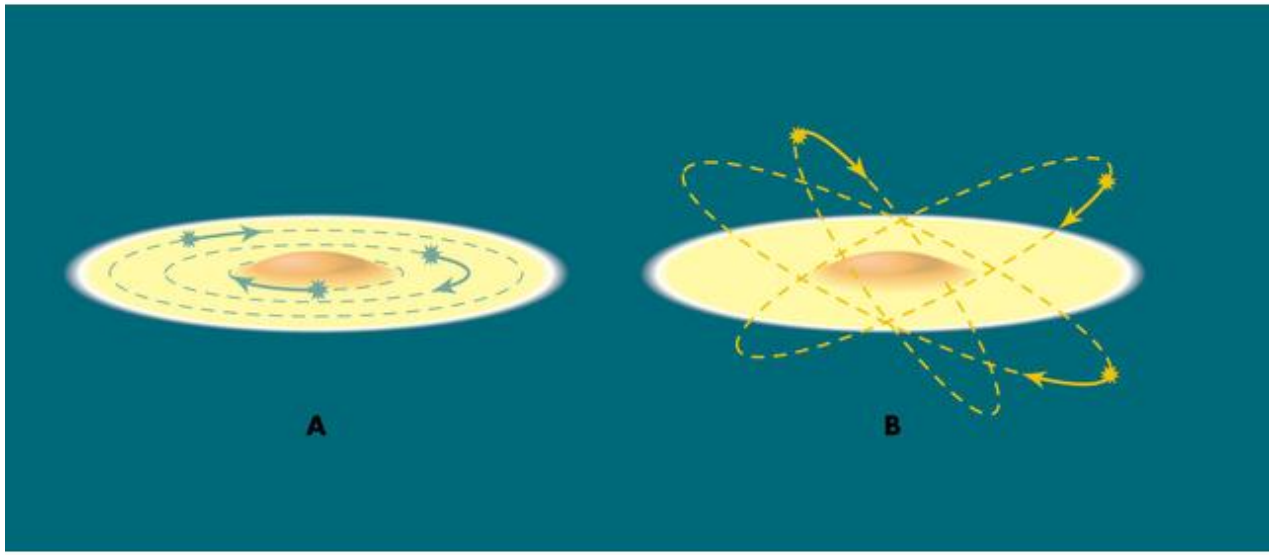
Anatomy of the Milky Way



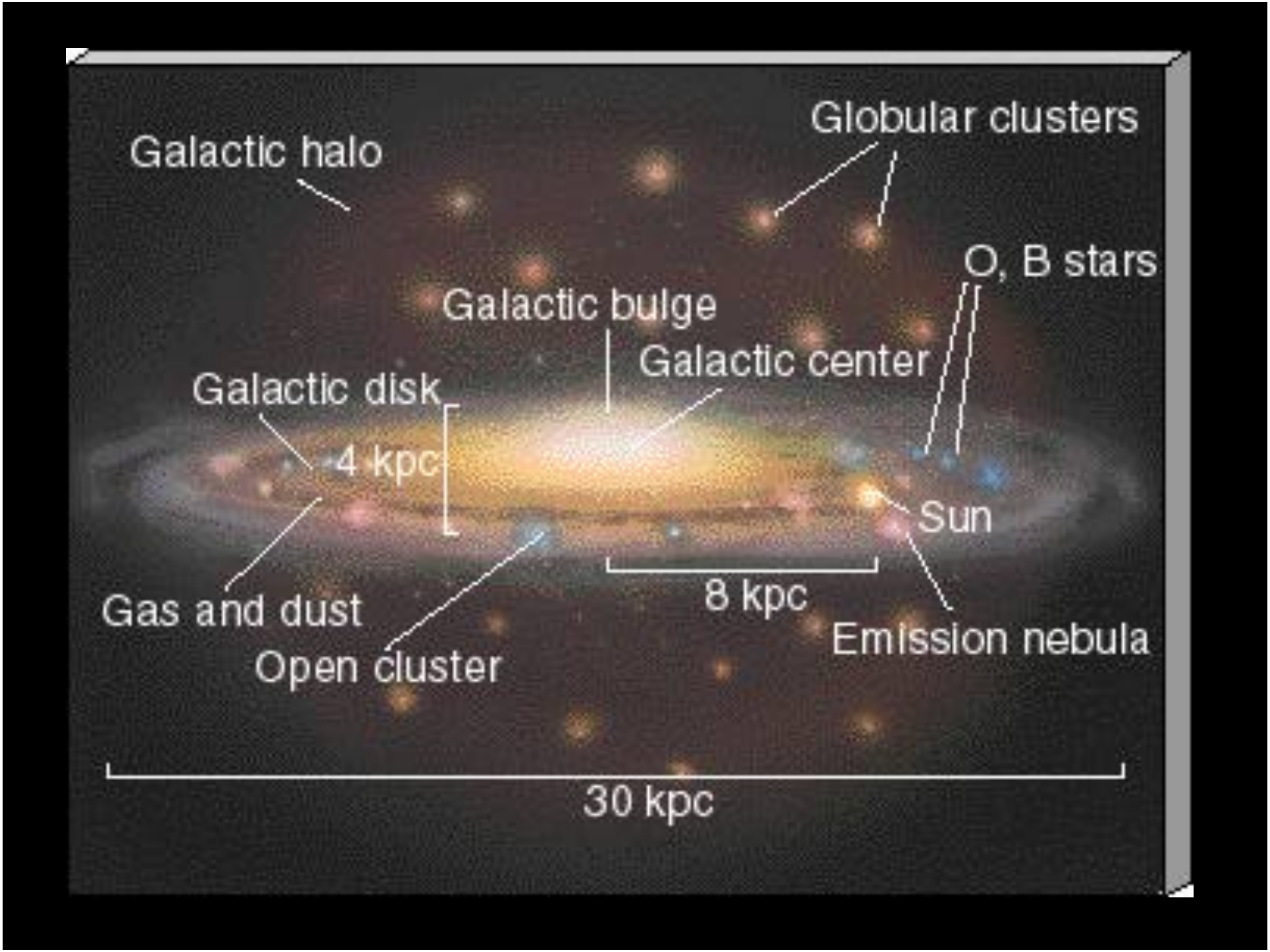
Milky Way Properties

- Diameter of Disk: ~ 40 kpc
- Diameter of Halo: ~ 70 kpc (?)
- Diameter of Bulge: ~ 6 kpc
- Location of Sun: ~ 8.5 kpc from center of disk
- Mass of MW:
  - Total ~ 10^{12} M_o
  - Gas ~ 10^{10} M_o
  - Stars ~ 10^{11} M_o
  - Dark Matter ~ 10^{12} M_o

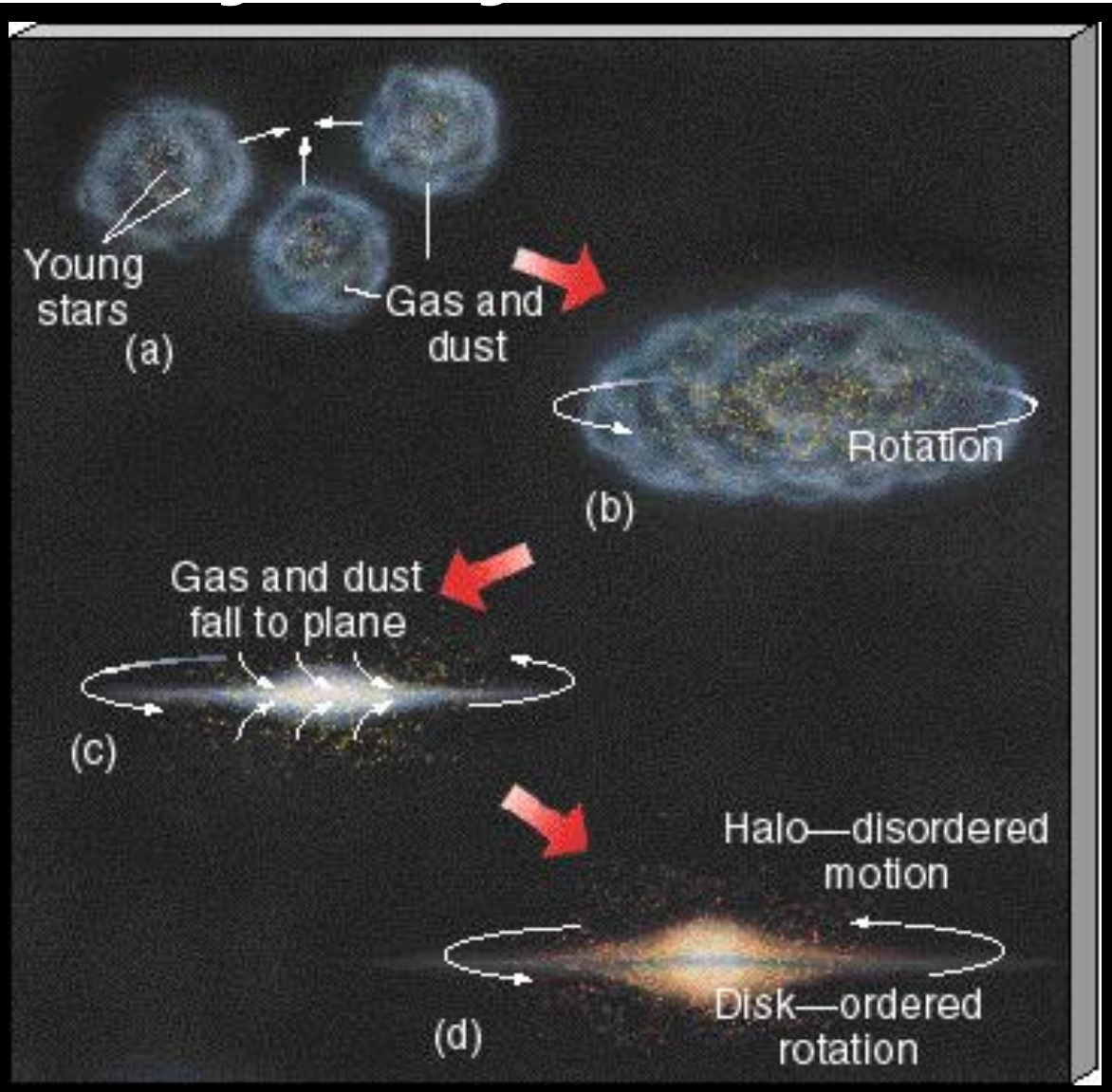
Stellar Populations in the MW



- Pop. I
  - Stars in disk
  - Orbits lie in disk
  - Stars have trace metals
- Pop. II
  - Stars in halo
  - Orbits are “random” about G.C.
  - Extremely trace metals

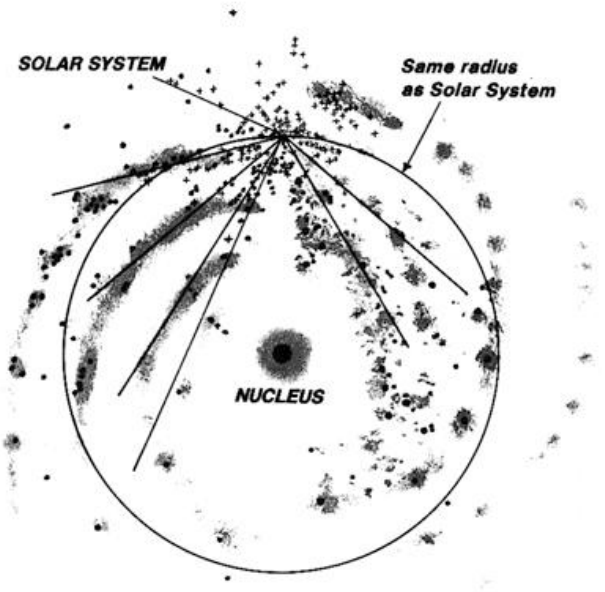

Globular clusters
Galactic halo
O, B stars
Galactic bulge
Galactic center
Galactic disk
4 kpc
Sun
8 kpc
Gas and dust
Open cluster
Emission nebula
30 kpc

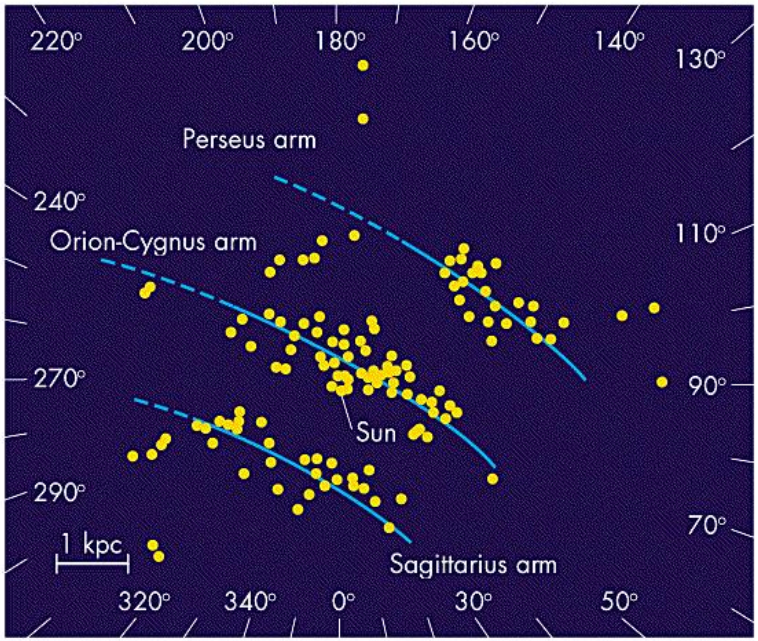
Milky Way Formation



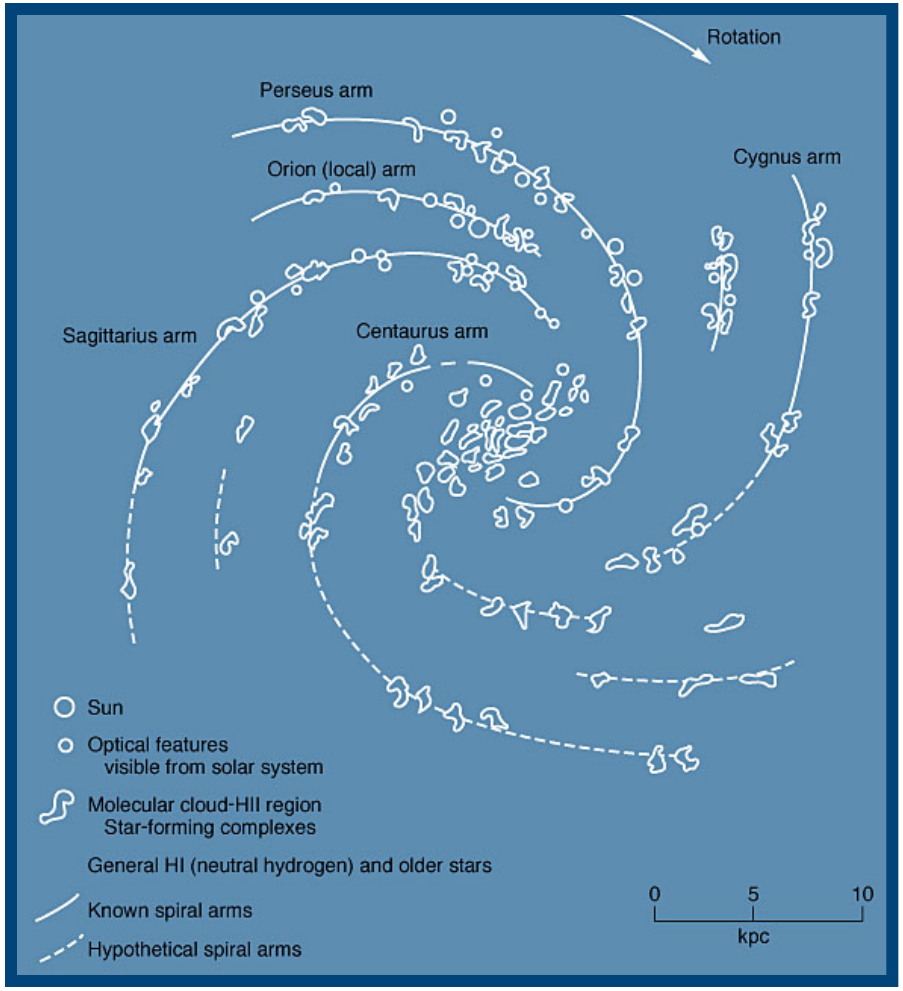
Spiral Arms

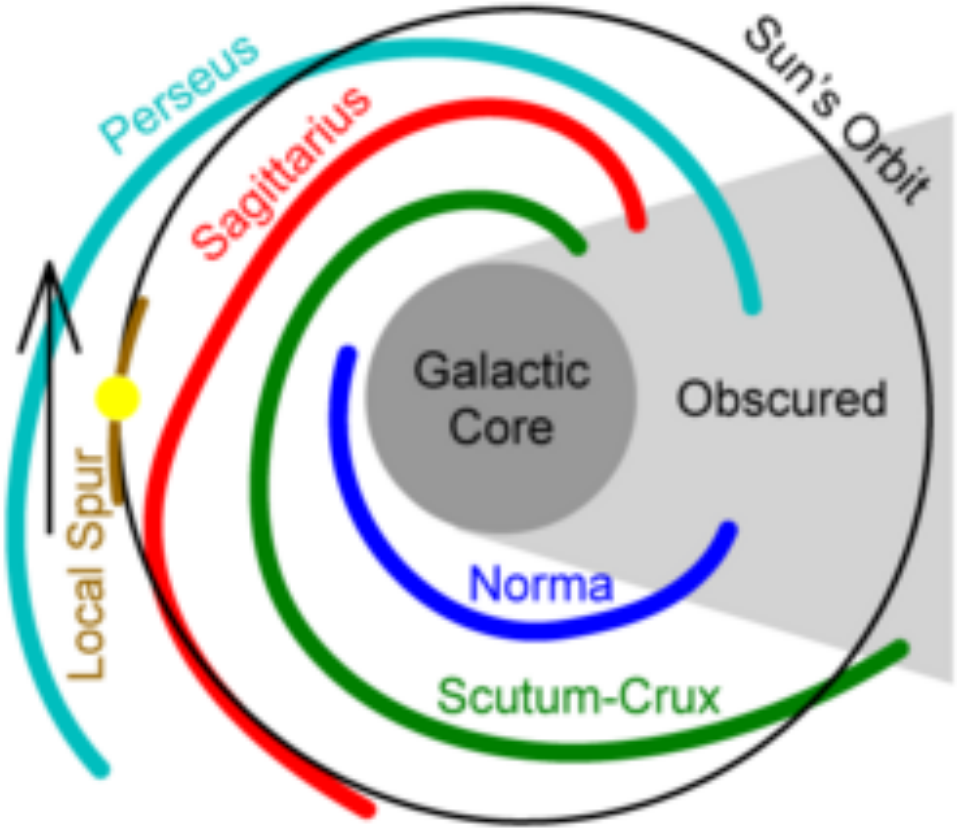
- O & B stars form where there is gas and live short lives.
- Distances reveal that these stars group along “segments”, suggesting spiral arms
- Radio measurements have mapped out the spiral structure in H-gas
- The arms are a “pattern”, where MW matter moves slow inside arms and fast inbetween



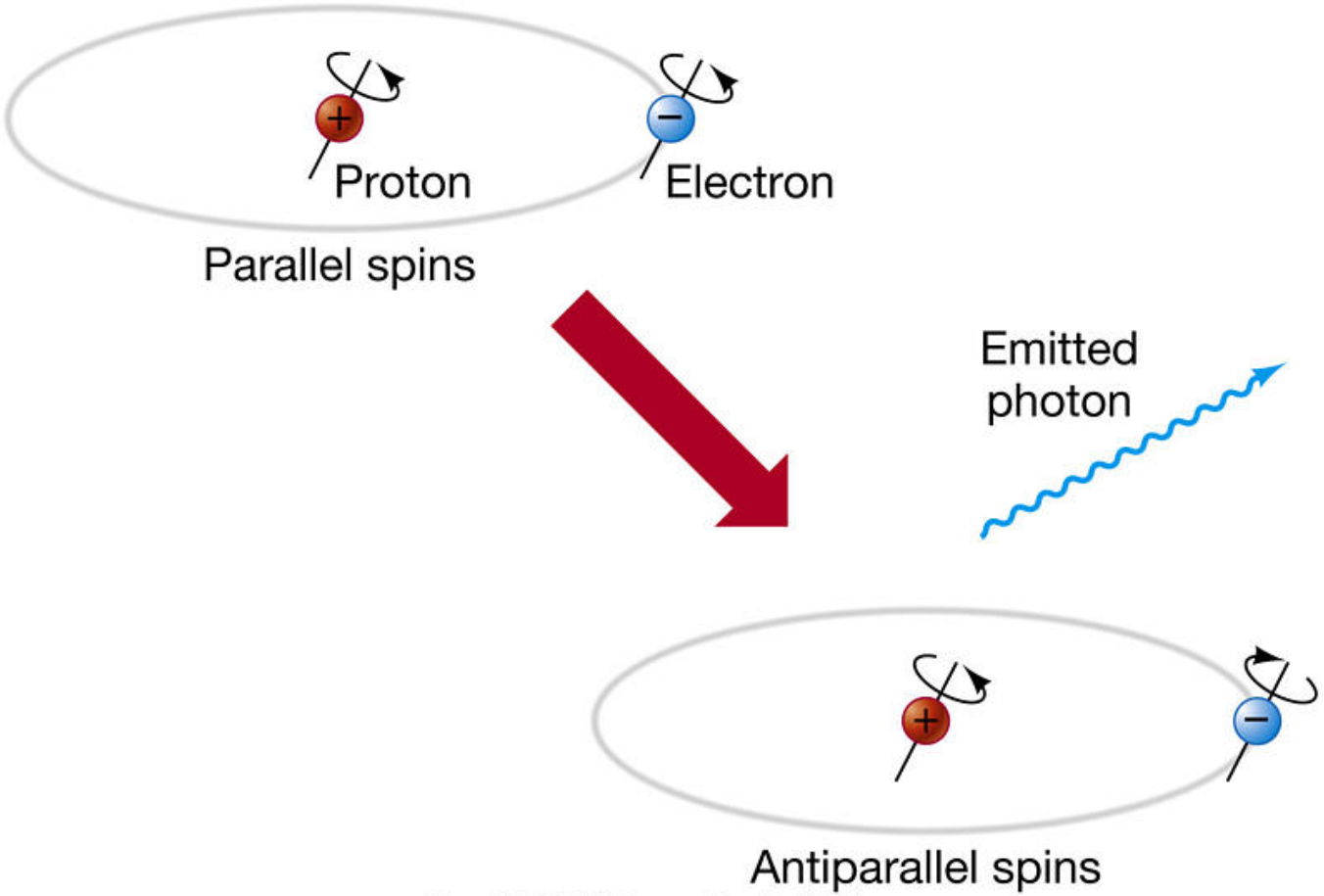


The Arms

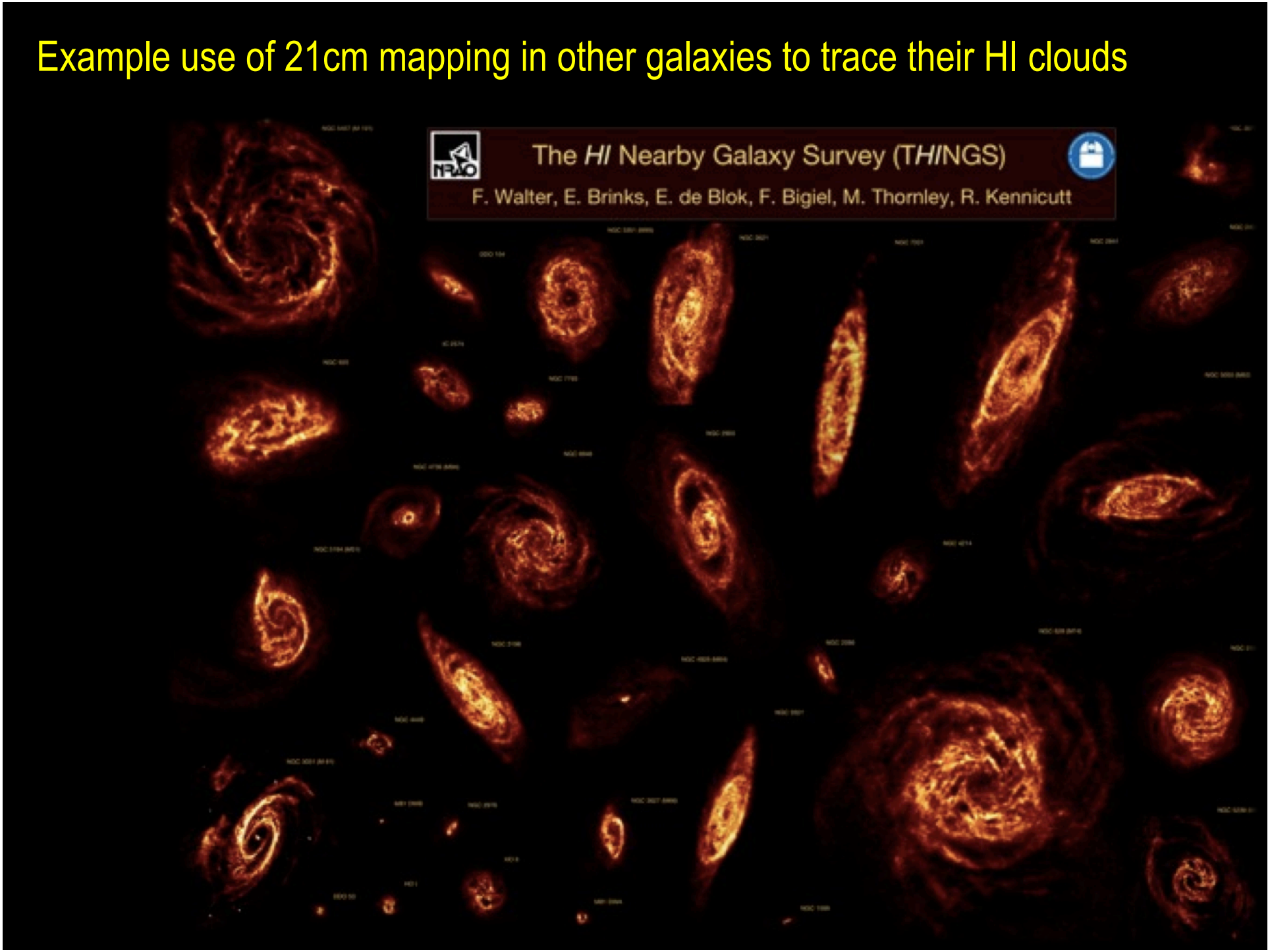

Rotation
Perseus arm
Orion (local) arm
Cygnus arm
Sagittarius arm
Centaurus arm
Sun
Optical features visible from solar system
Molecular cloud-HII region Star-forming complexes
General HI (neutral hydrogen) and older stars
Known spiral arms
Hypothetical spiral arms
0
5
10
kpc


Perseus
Sagittarius
Sun's Orbit
Galactic Core
Obscured
Local Spur
Norma
Scutum-Crux

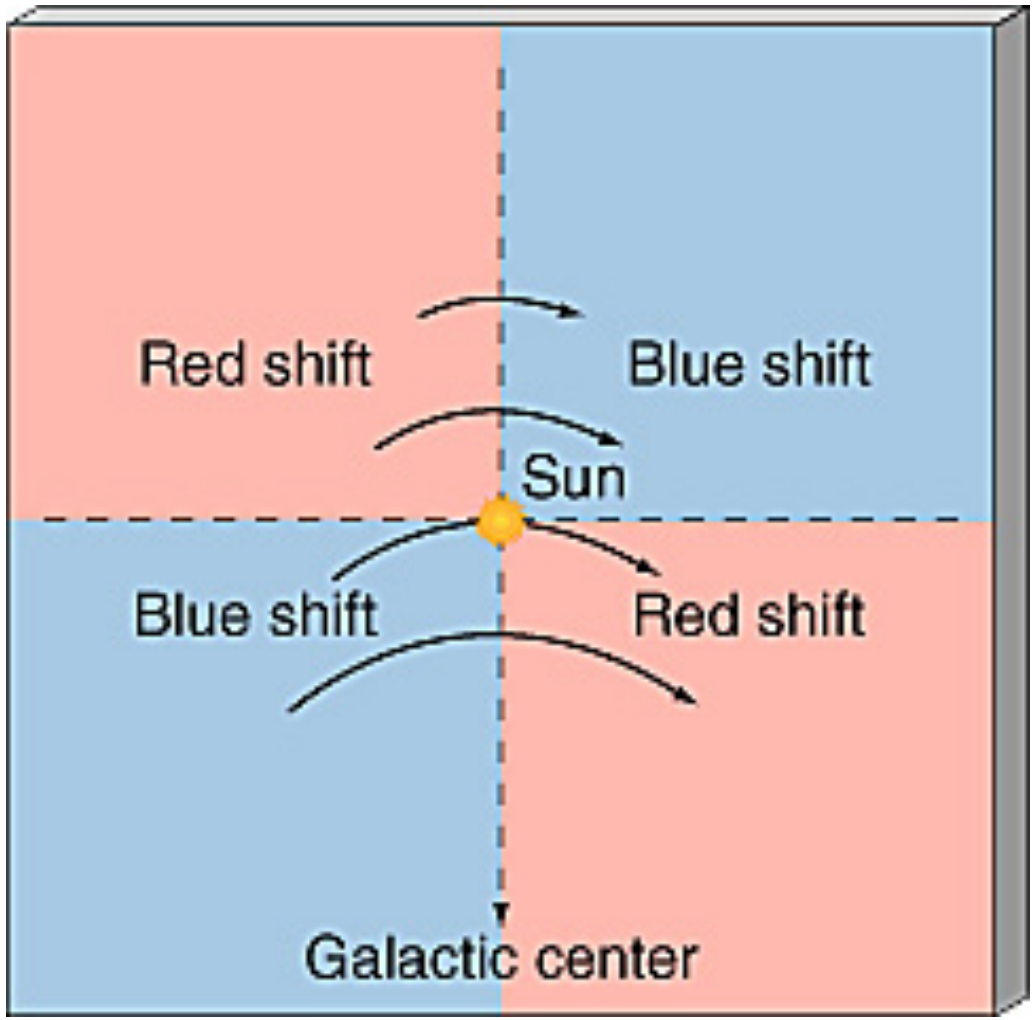
The Process of Radio 21 cm Radiation

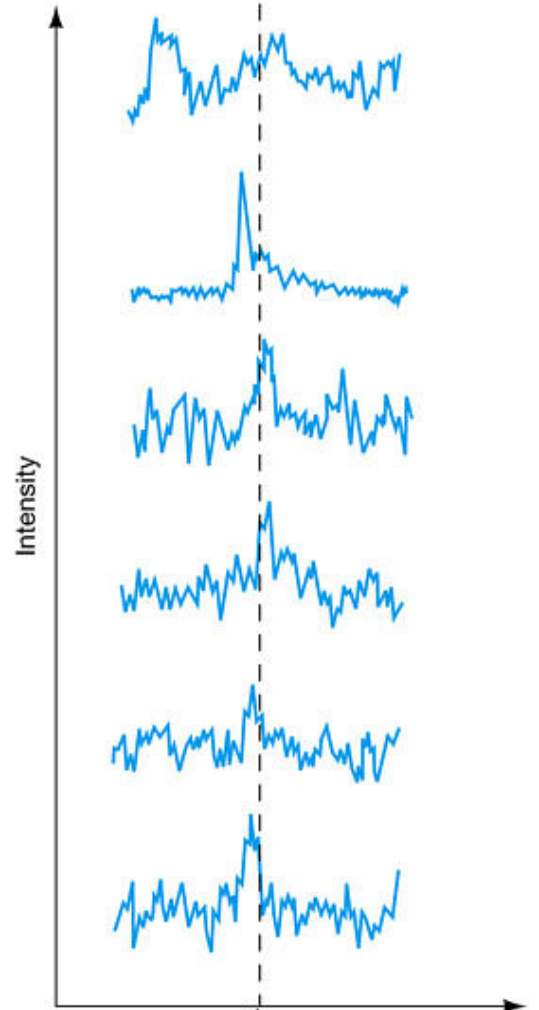


Example use of 21cm mapping in other galaxies to trace their HI clouds

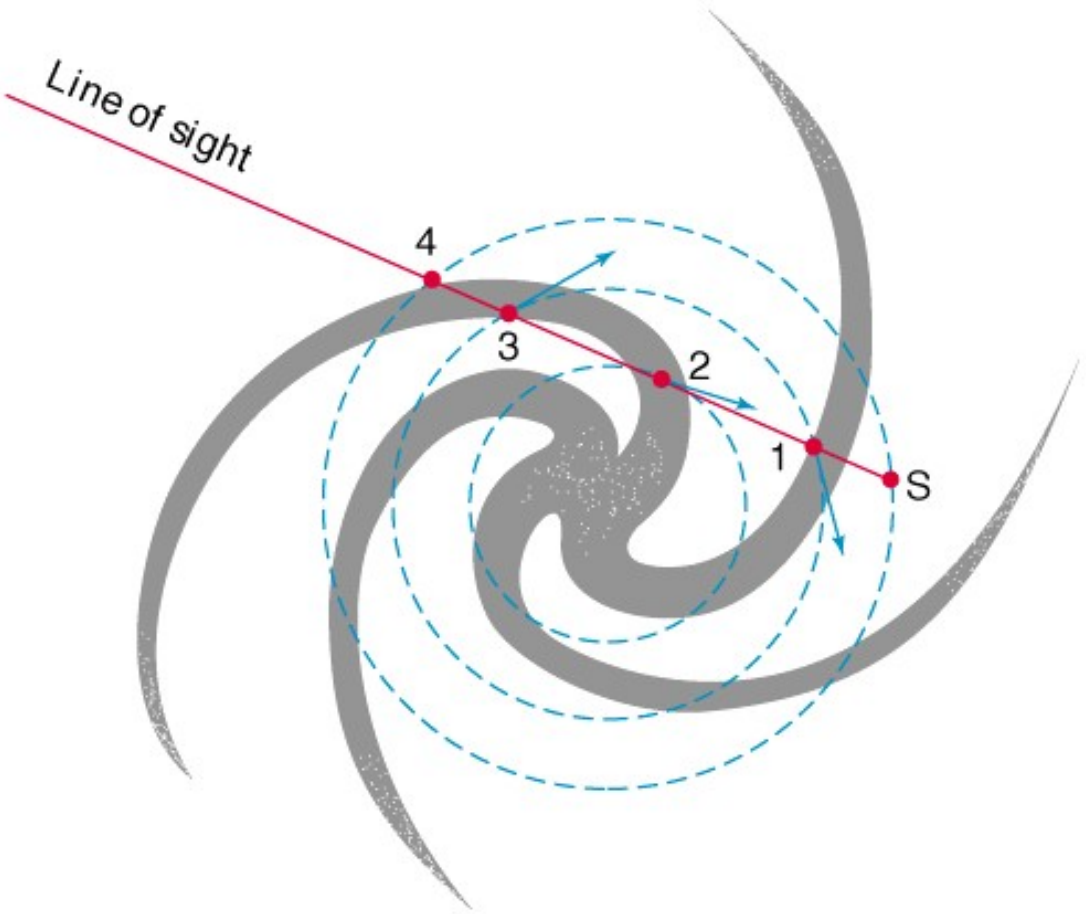


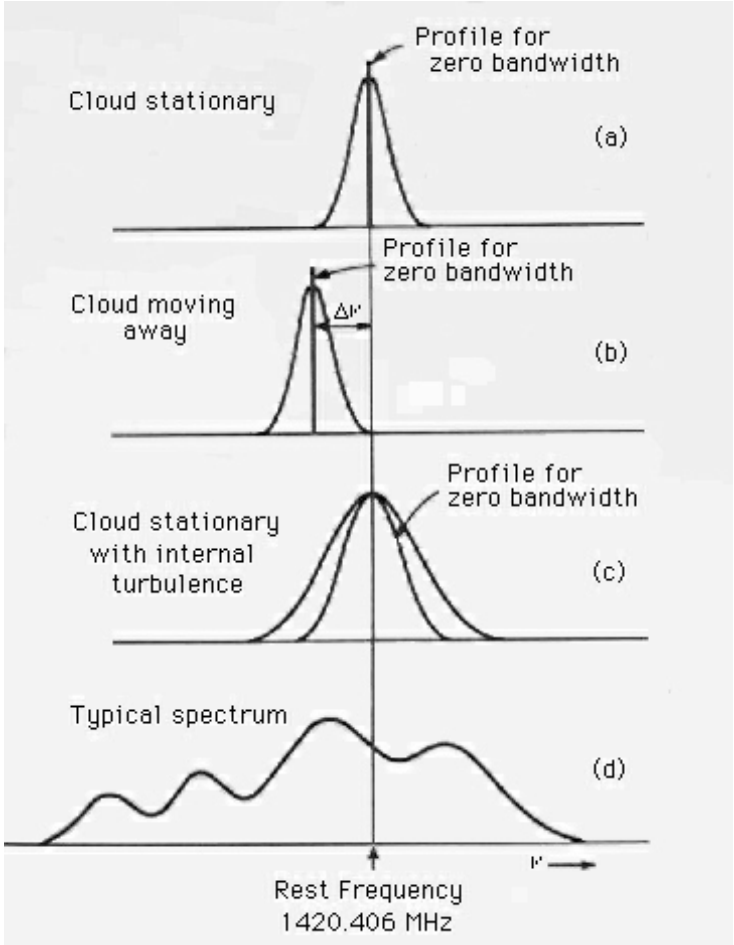
Radio Mapping the MW Arms



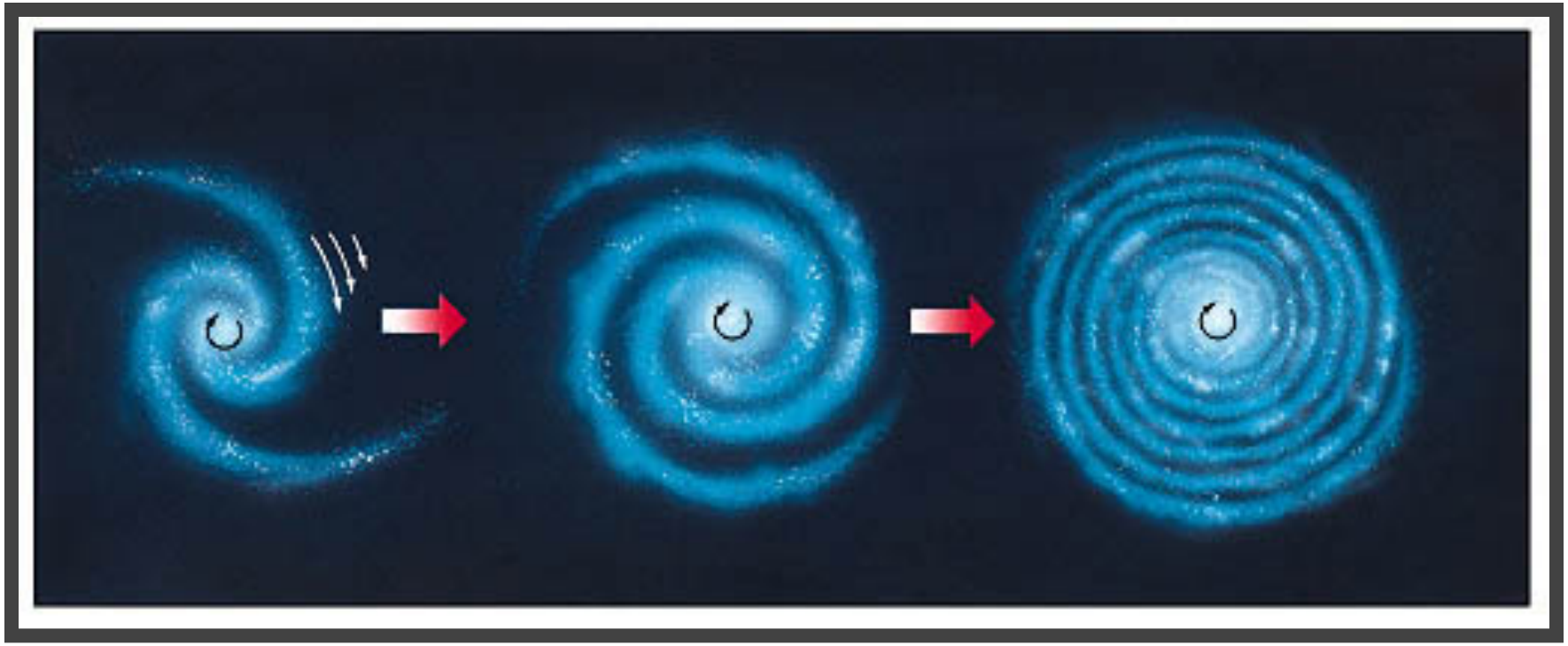


Mapping Example

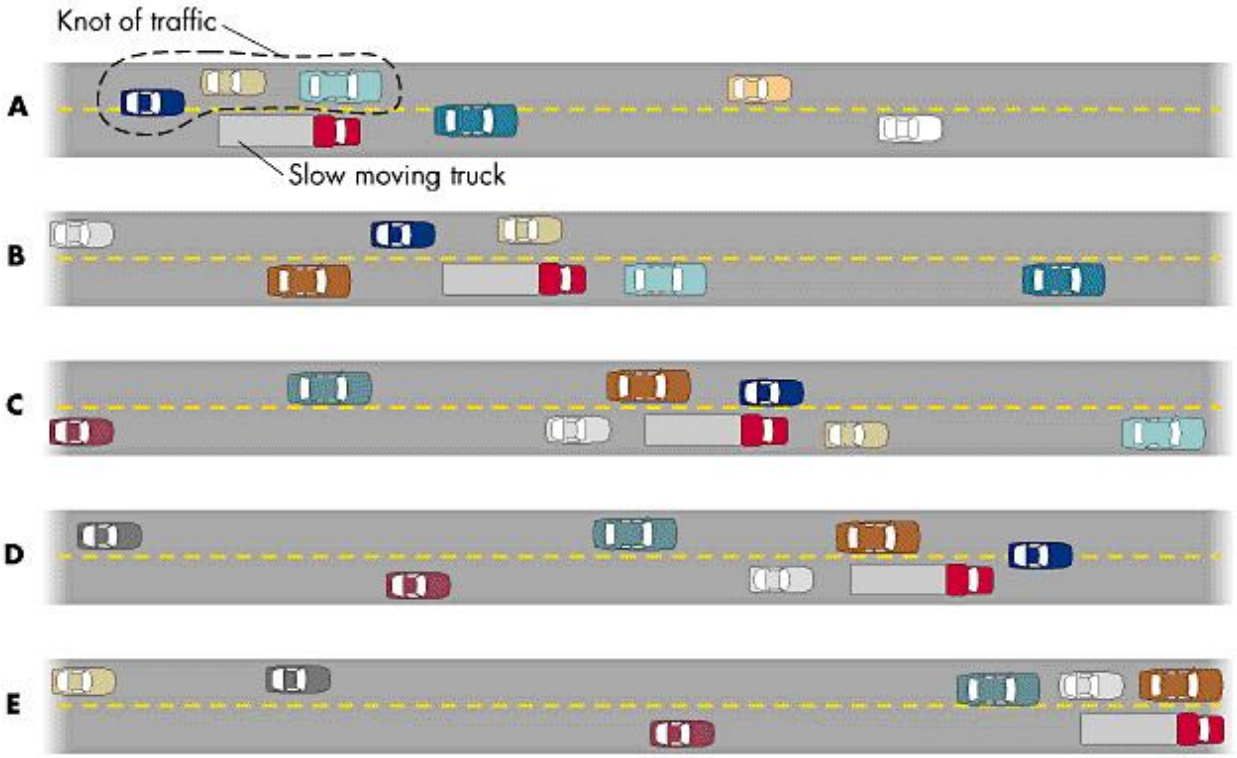




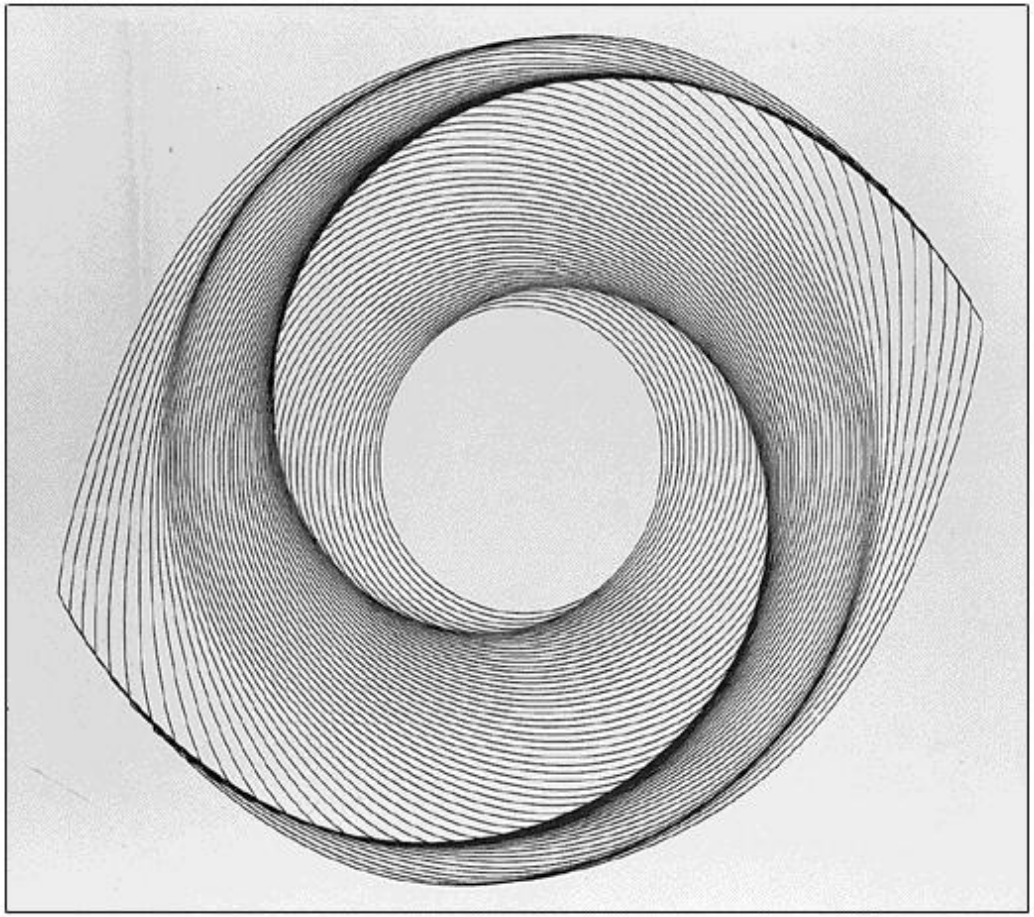
The Arms: The Winding-Up Problem



Spiral Arms as a Pattern



Spiral Pattern Models



The Galactic Rotation Curve

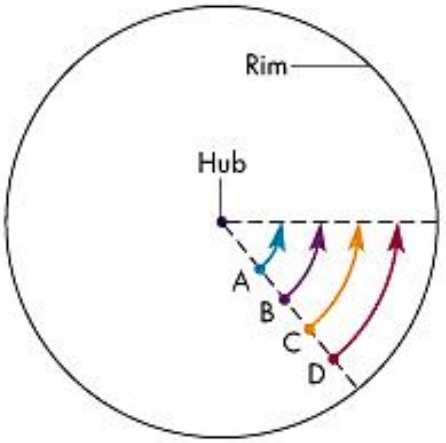
- Sun, stars, and gas orbit around MW center in a disk, obeying Kepler's 3rd Law,

$$M(r) = \frac{r v^2}{G}$$

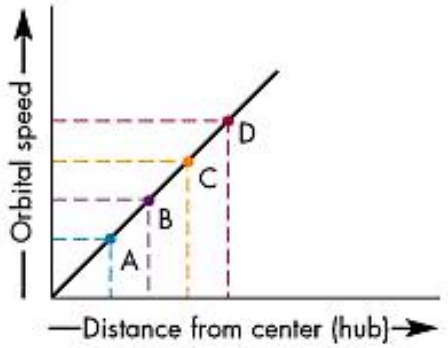
- Know r(Sun) = 8.5 kpc, v_{rot}(Sun) = 220 km/s, so that mass interior to the Sun's orbit is ~ 10^{11} M_o

  [Note, v_{rot} ~ 46 AU/yr or 1 circuit every ~10^8 yrs]

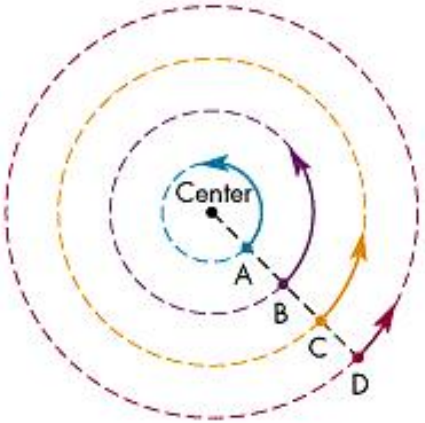
Example Rotation Curves



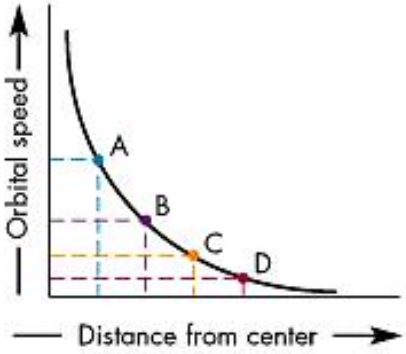
A Wheel-like rotation



Rotation curve for wheel-like rotation

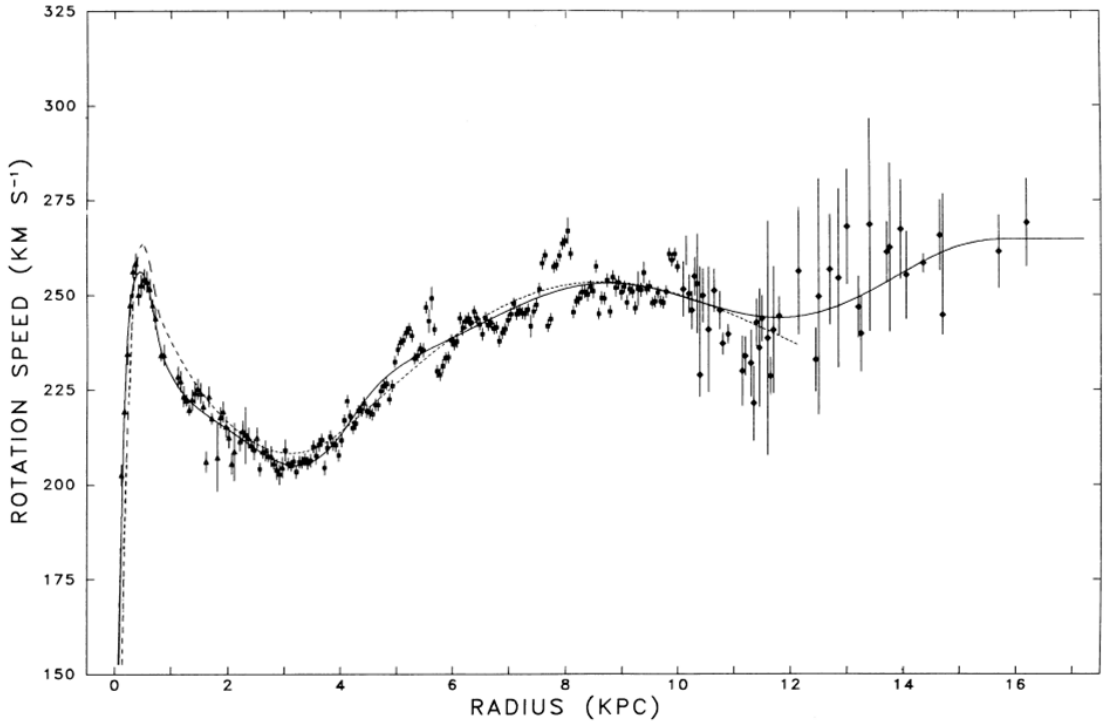


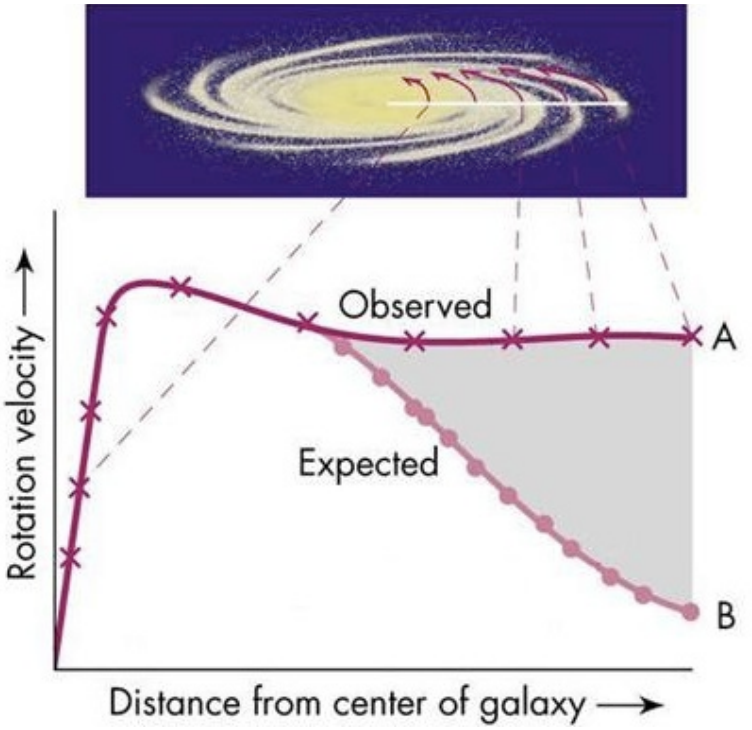
B Planet-like rotation



Rotation curve for planet-like rotation

Milky Way Rotation Curve





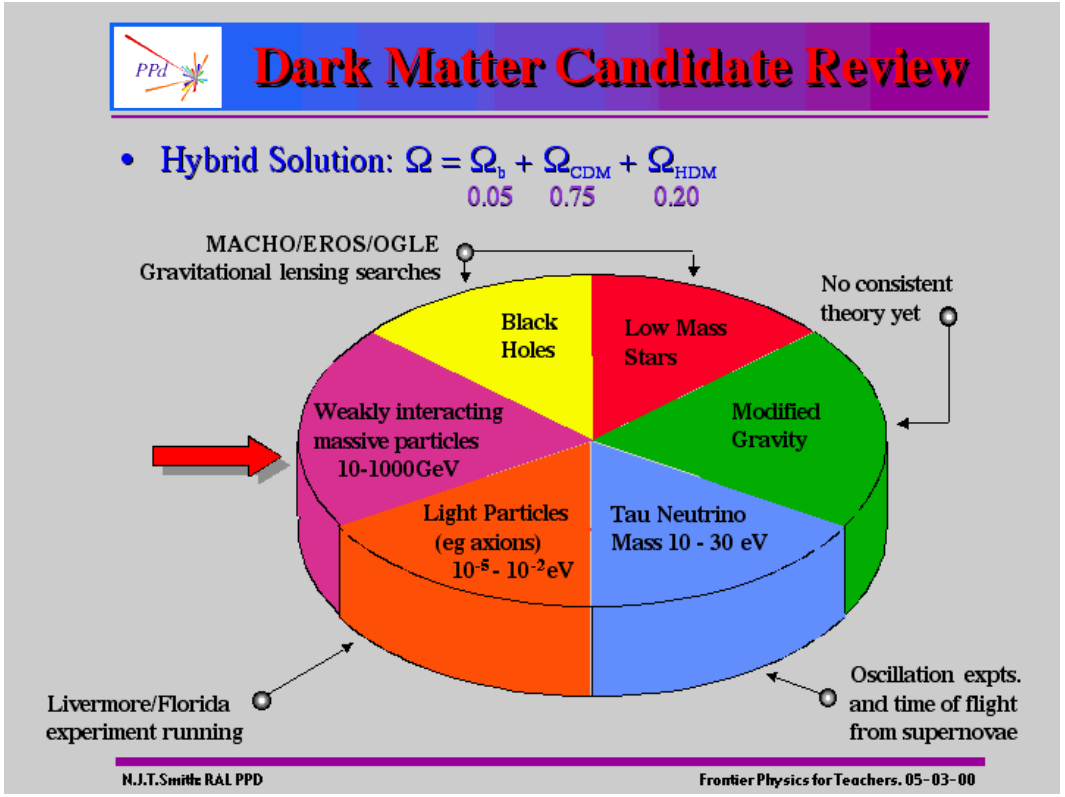
The Dark Matter

- Can construct a rotation curve by using other "markers" – stars and clouds
- Observe a "flat" rotation curve with v_{rot}=constant
- But this implies that M ~ r ! Where does it end?
- At MW edge, expect to see $v = \sqrt{GM/r}$
- Estimates set $M_{MW} \sim 10^{12} M_o$, 10x more than observed luminous matter, hence 90% of our Galaxy remains "unseen" and mysterious

Dark Matter Candidates

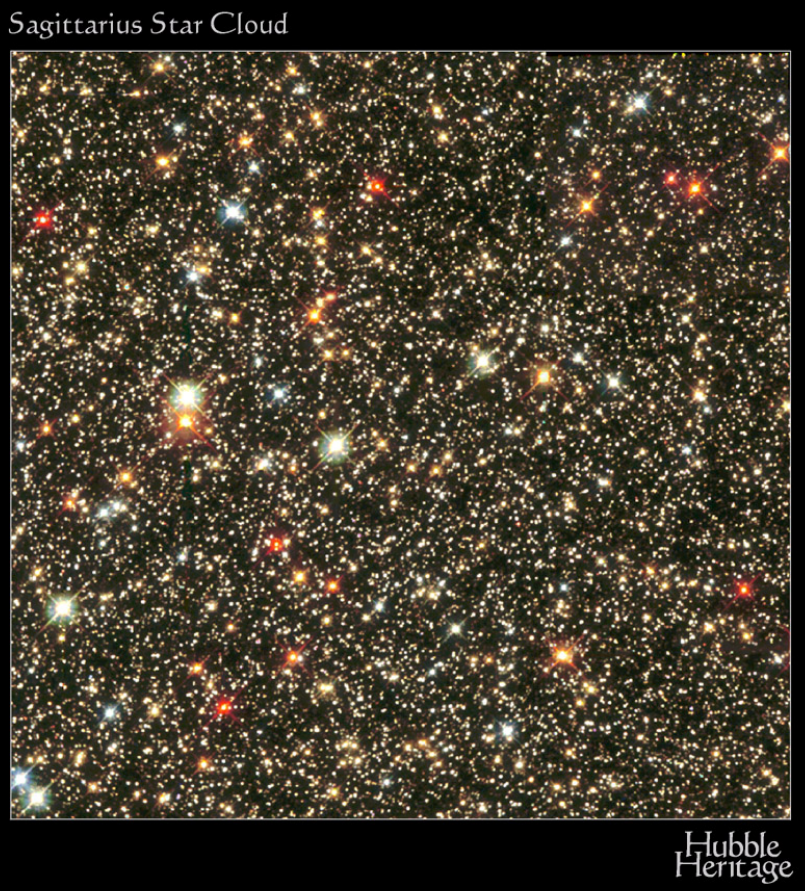
Remains unclear

1. Old WDs
2. Brown Dwarfs
3. Planets
4. BHs
5. Neutrinos
6. H_2 gas clouds
7. Modified gravity

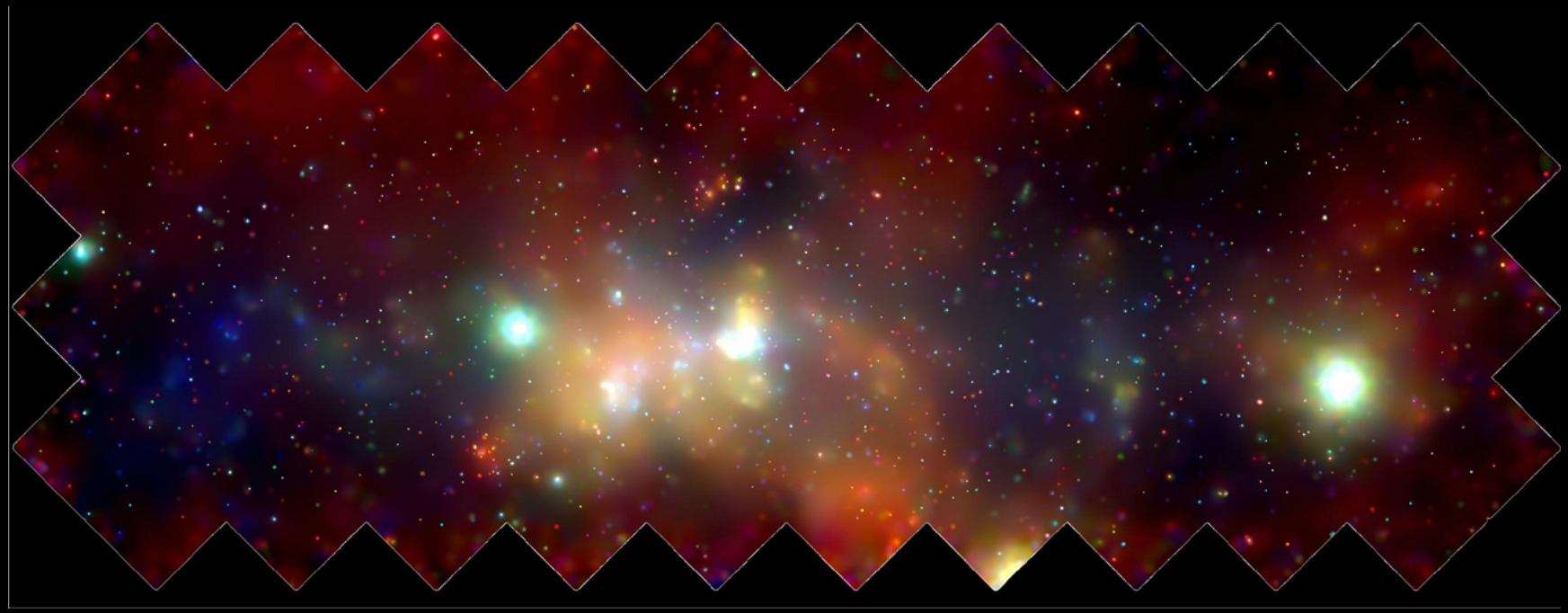


The Galactic Center

- Cannot "see" in visible light, so must study in other bands (X-ray, IR, radio)
- Crowded with stars
- At very center is a large rotating ring of gas, with about 10^4 M_o, stretching from r=2 pc to r=8pc, rotating at 110 km/s, implying 10^7 M_o of matter interior to 2 pcs
- Difficult to cram so much matter in so little space!



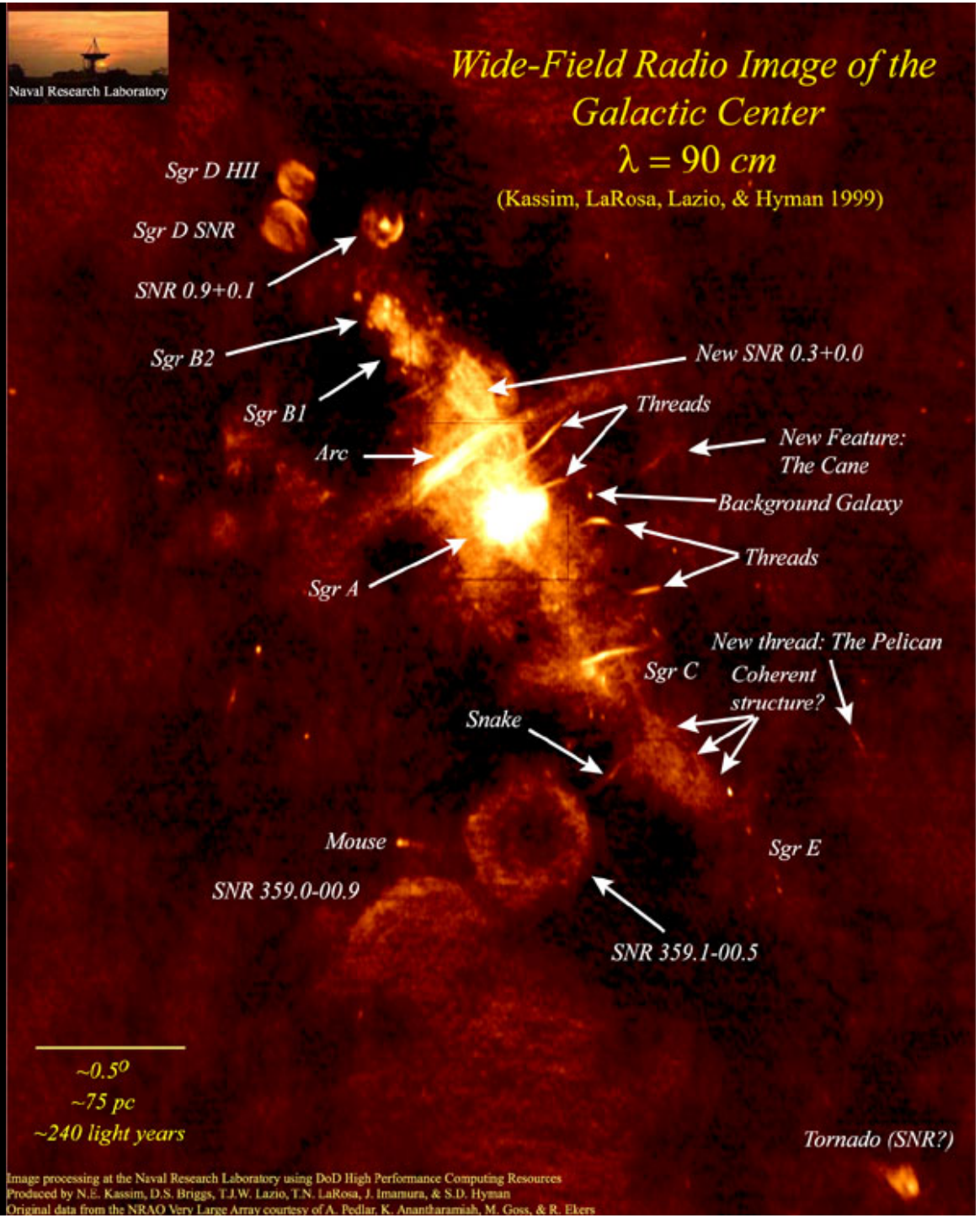
Galactic Center from Chandra



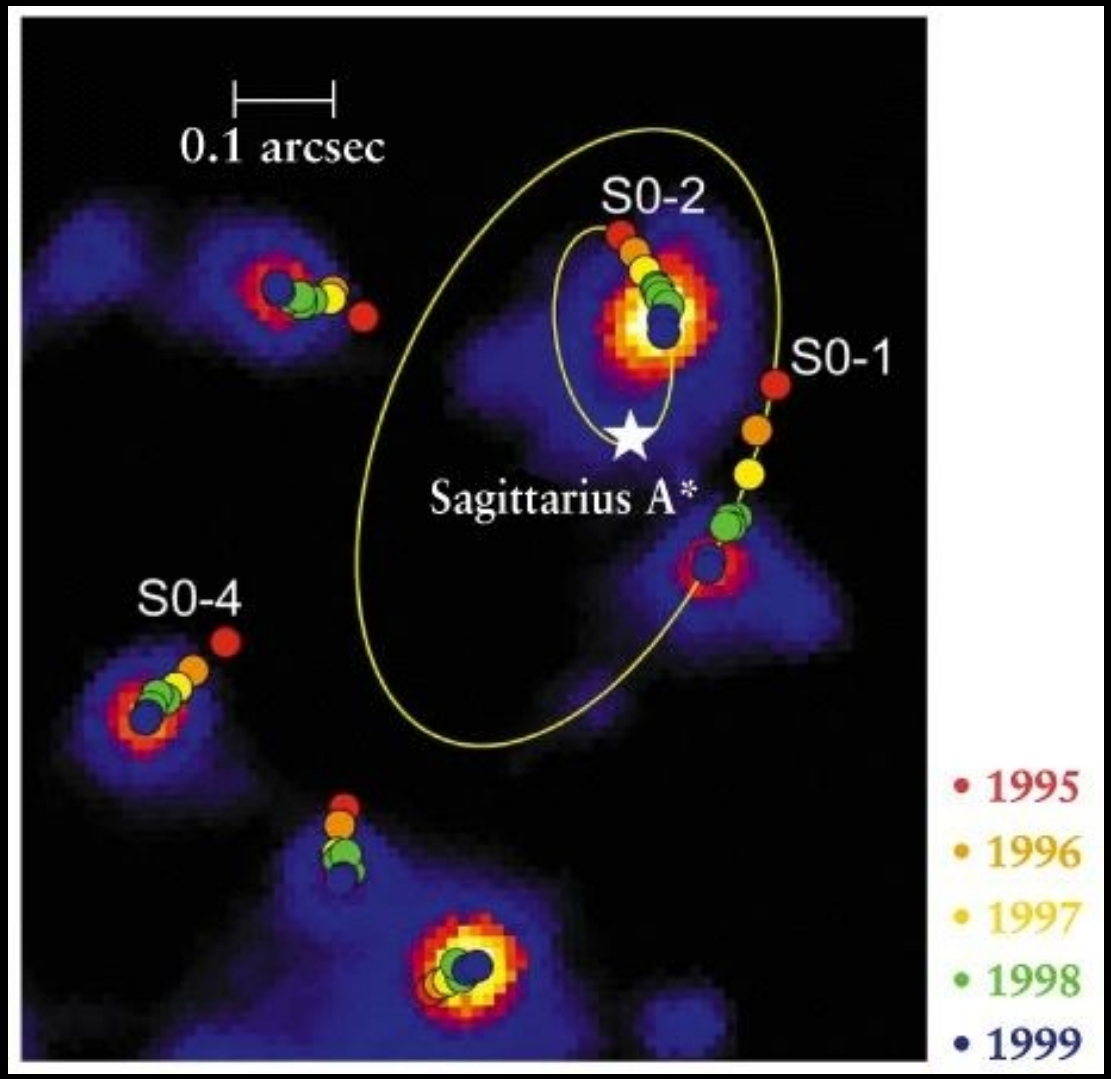
Different colors for different energies of the X-ray photons

Radio Maps of the Galactic Center:

The bright spot in the center is Sgr*, the center of our Galaxy



Orbits of Stars at MW Center:
(More evidence for a massive BH)



The Central Black Hole

- Strong suggestion of a super-massive BH (SBH) of $M \sim 10^7 M_o$, with $R_S \sim 0.2$ AU
- Main evidence from a compact (13 AU in size) and bright radio source at Sgr A*
- Possibly an accretion disk of gas that feeds the SBH