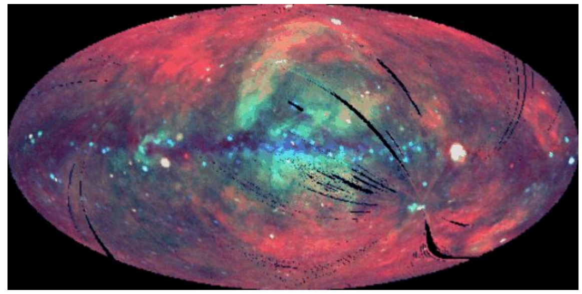
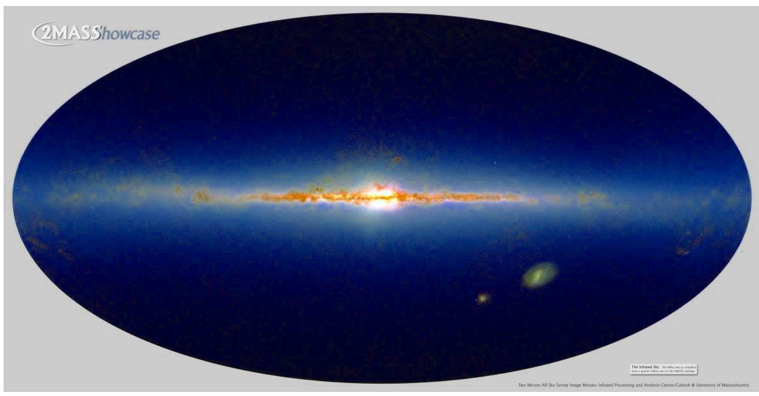
Milky Way S&G Ch 2

- **Why study the MW?**
  - its "easy" to study: big, bright, close
  - Allows detailed studies of stellar kinematics, stellar evolution. star formation, direct detection of dark matter??
- Problems
  - We are in it
  - Distances *were* hard to determine
  - Dust is a serious issue



Milky Way in X-rays- Image of the Hot ISM



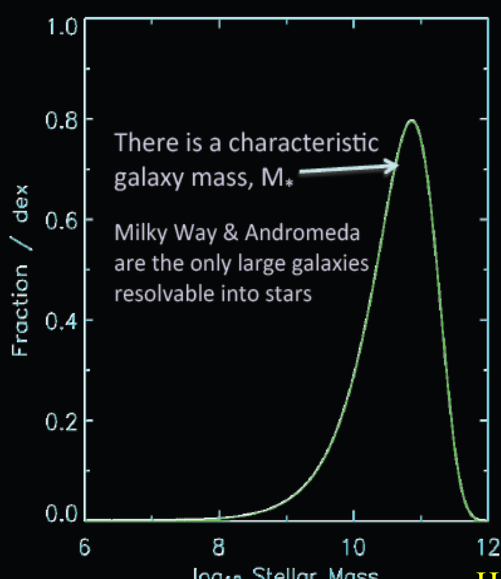
Enormous recent progress with GAIA and dedicated surveys

the exact positions, motions, brightnesses, and colors of 1.3 billion stars in the Milky Way,

Milky Way in near IR

www.milkywaproject.org

Why might the Milky Way be a good test-bed for galaxy formation?



- The Milky Way is an unusually typical galaxy
  - $6\times10^{10} M_{Sun}$ in stars, ¾ in a disk

[redacted]

- It's what we got (best)
  - star-by-star in 6+N dimensions

$p(\boldsymbol{r},\boldsymbol{v}, M_*, L_*, \log g, T_{eff}, t_{age}, [X/H]\ldots)$

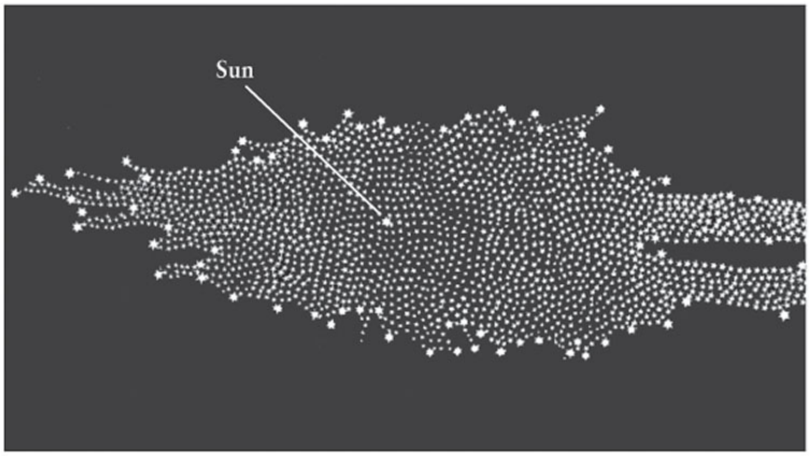
H-W Rix- http://online.kitp.ucsb.edu/online/galarcheo-c15/rix/

What aspects of (disk) galaxy formation can be uniquely tested/inferred in the Milky Way?

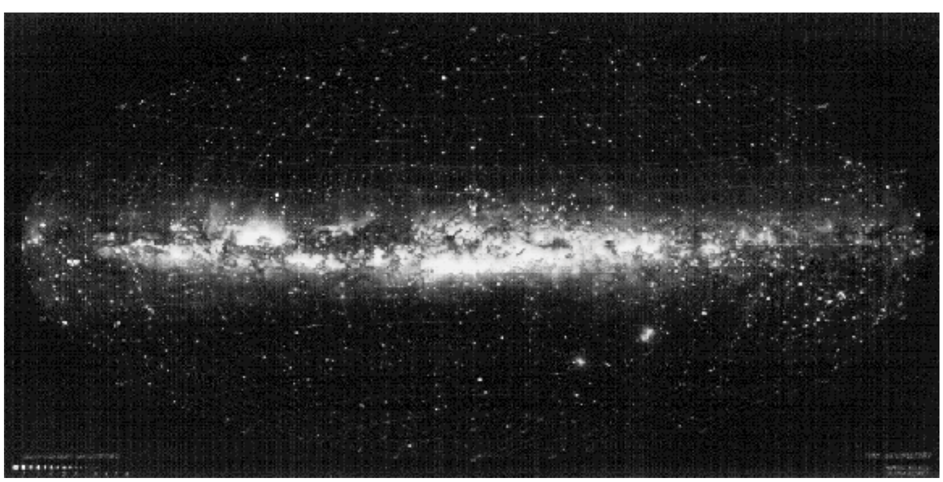
- 3D distribution of the (dark) matter
- What processes create a stellar halo?
  - What processes shape the population of satellite galaxies?
- What (init) conditions & processes set stellar disk structure?
- What processes shape the "innards" (bulge, bar, etc..)?
- How does chemical enrichment "work"?
  - How does gas inflow/accretion & feedback work?
  - Is primeval IMF dramatically different?

Our place in the Galaxy

- We live in a large disk galaxy of average mass
  - The sun is in the disk, towards the edge (~8kpc from center)
  - Projected onto the sky, this disk of stars looks like a band of light that rings the sky… the Milky Way
- This realization came somewhat slowly…
  - Disk-like nature of galaxy realized by Thomas Wright (1780); refined by Kant
  - First attempt to map out galaxy made by William Herschel (1785); refined by Kapteyn in 1920
  - Herschel came to the conclusion that we sit at the center of the Galactic disk. In fact, **he was wrong**… had not accounted for absorption by dust! *(something that he did not know about)*



Herschel's map of the Galaxy

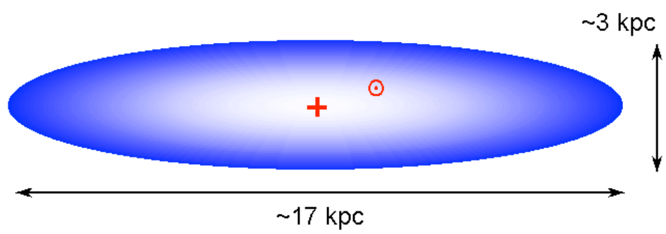


MilkyWay in optical light

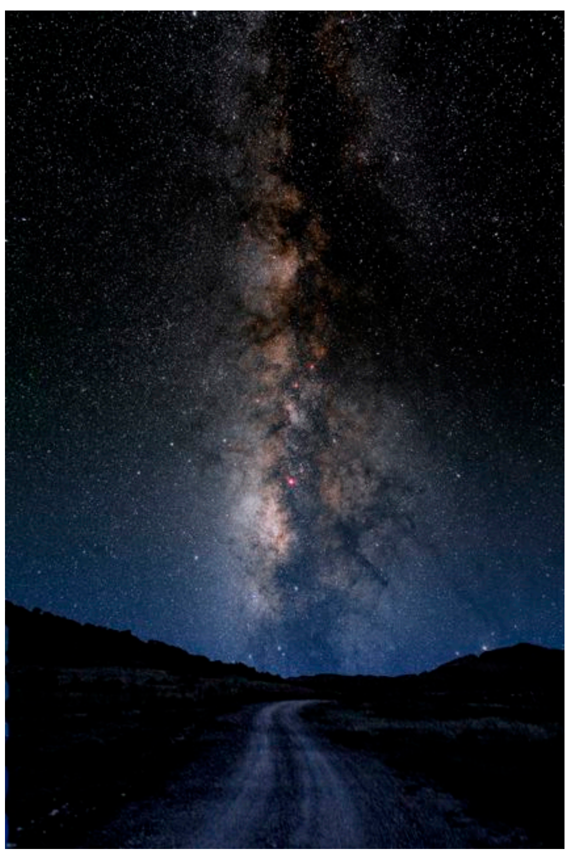
Kapteyn (1920's)- photographic star counts and estimated distances using parallaxes and examining the proper motion of nearby stars. Found MW ~ 33,000 light years x 6,500 light years and that the Sun was around 2,000 light years from the center of the galaxy. (present values- 80,000 light years x 2,000 light years in size and that the Sun is 25,000 light years from the center of the galaxy)

Kapteyn Model (1922)

Kapteyn deduced that we were very nearly at MW center

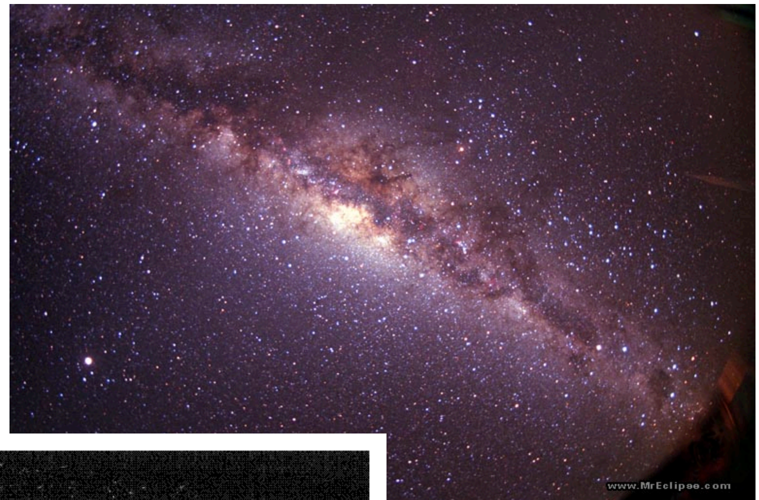


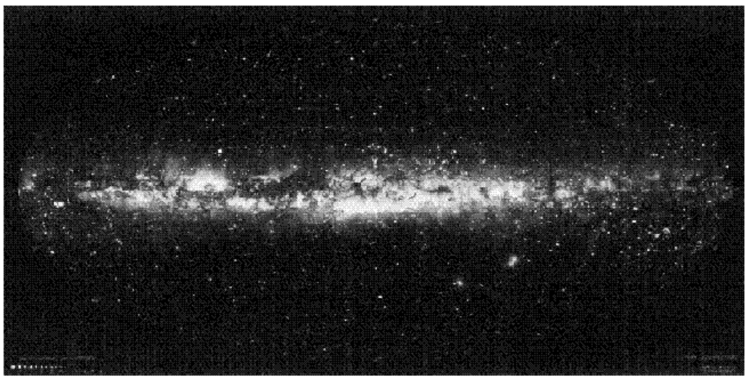
kpc = kiloparsec = 1000 pc



MW in Optical

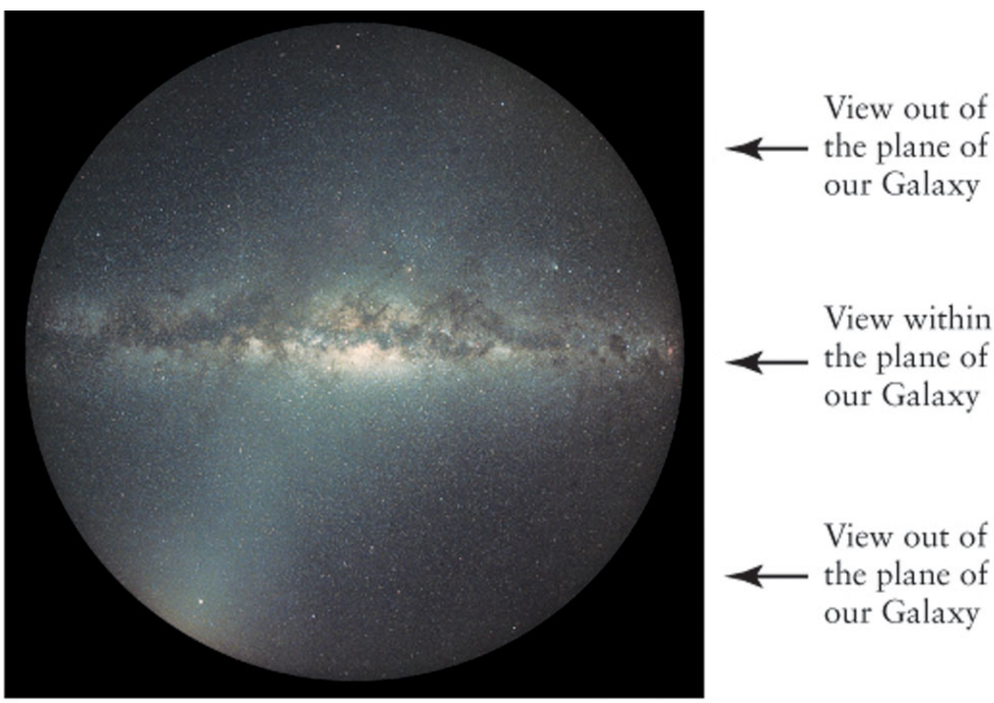
- Notice the strong effect of dust.





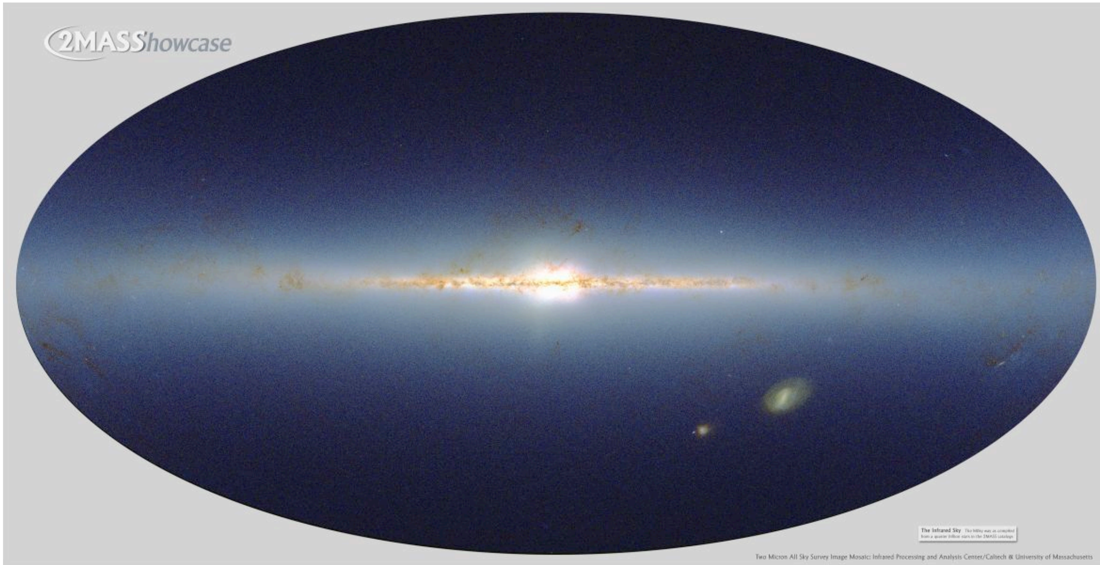
this is a drawing of the MW all sky- state of the art 1950's

Milky Way, Sbc-galaxy (all-sky projection in optical)

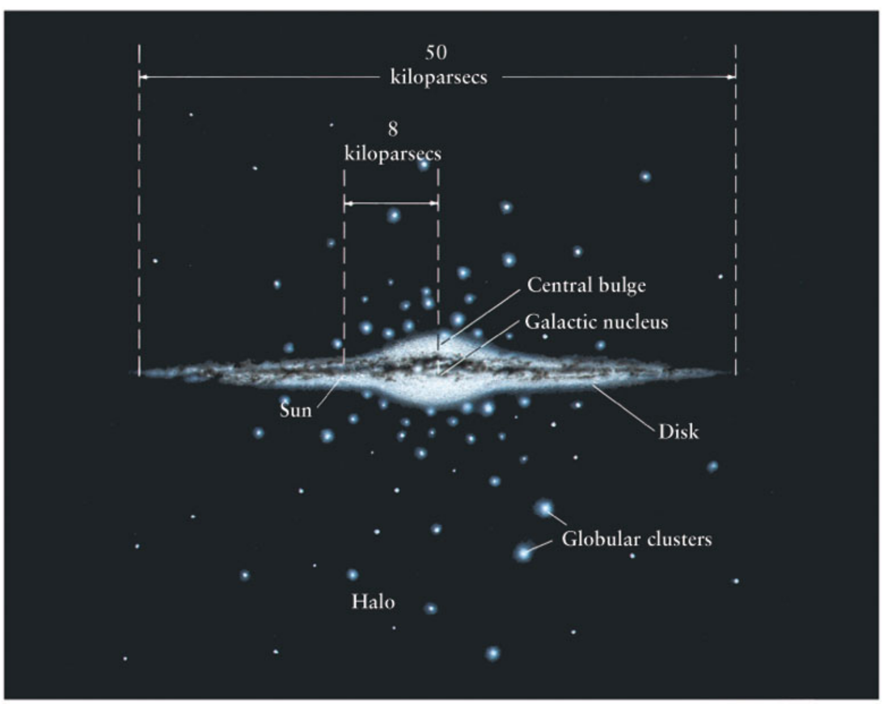


(b)

Galactic coordinates (l,b), Galactic center at (0,0) S&G 1.2.2

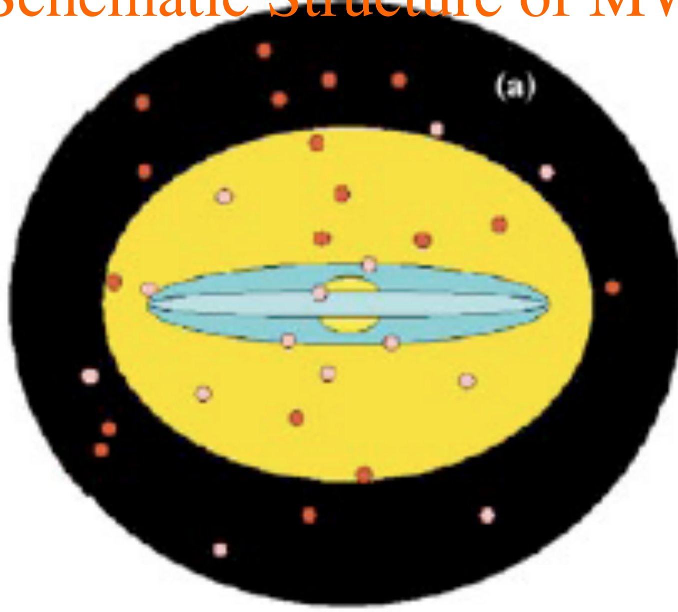


The MW galaxy as seen by an infrared telescope- IR light is much less sensitive to 'extinction' by dust than optical light



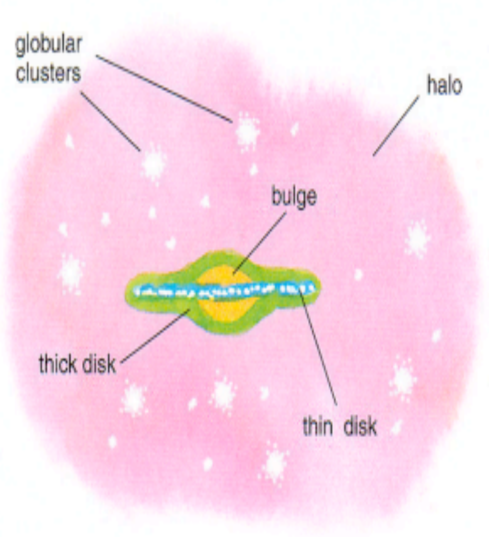
1 kiloparsec=3.26x10^3 lightyears=3.08x10^{19}m

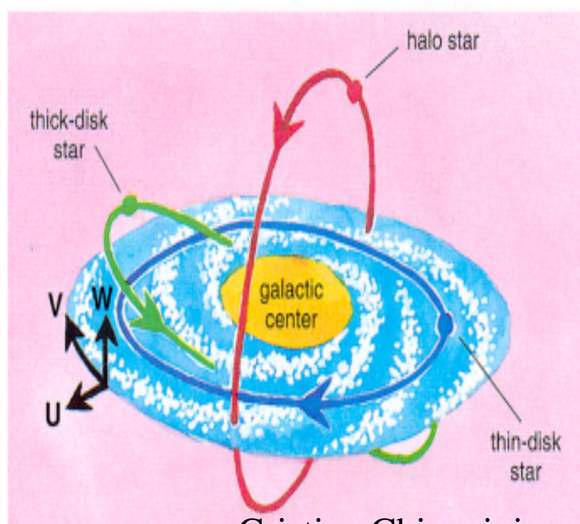
Schematic Structure of MW



stellar disk (*light blue*), thick disk (*dark blue*), stellar bulge (*yellow*), stellar halo (*mustard yellow*), dark halo (*black*) and globular cluster system (*filled circles*). (Freeman and Bland-Hawthorn 2002)

Schematic Image and Dynamics of MW



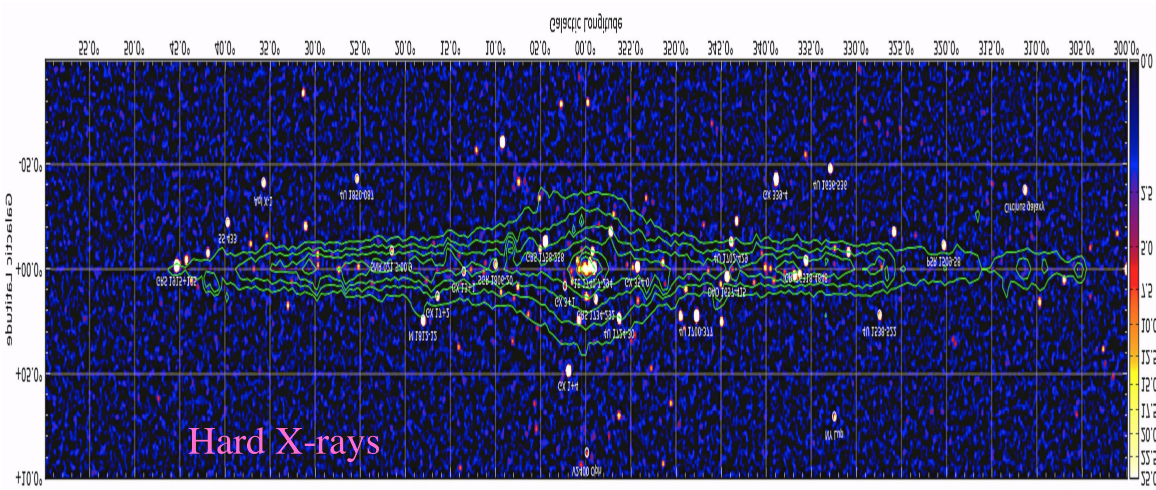


Cristina Chiappini

Other Wavelengths

In 'hard' (2-10 kev) x-rays one sees
accreting x-ray binaries neutron stars and black holes
- 2 Populations, companions

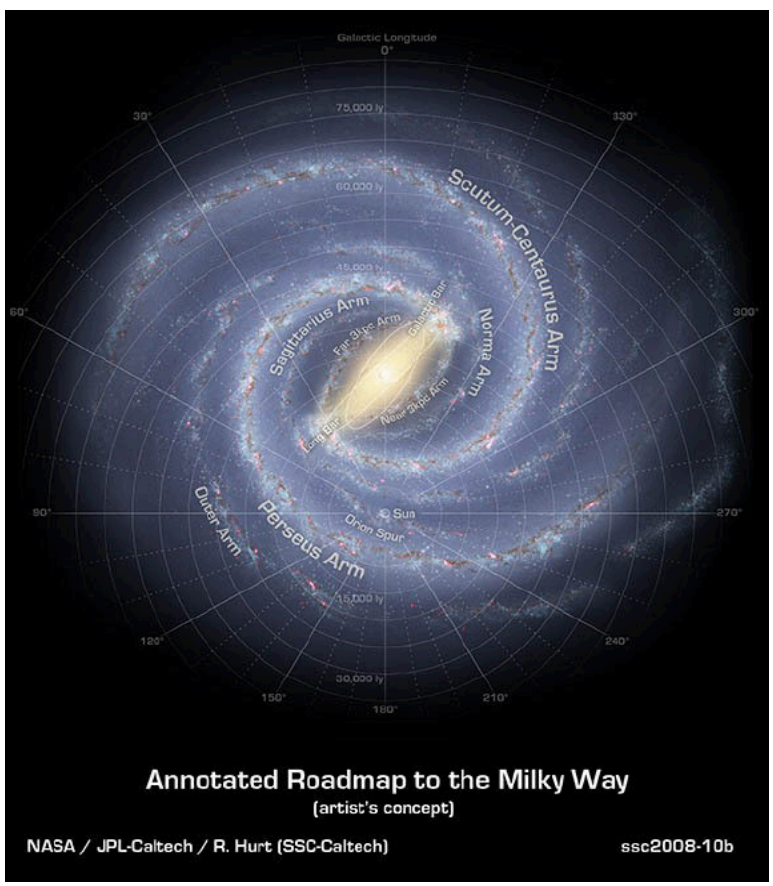
1) are massive and young (high mass x-ray binaries) POP I
2) old (Low mass x-ray binaries) POP II

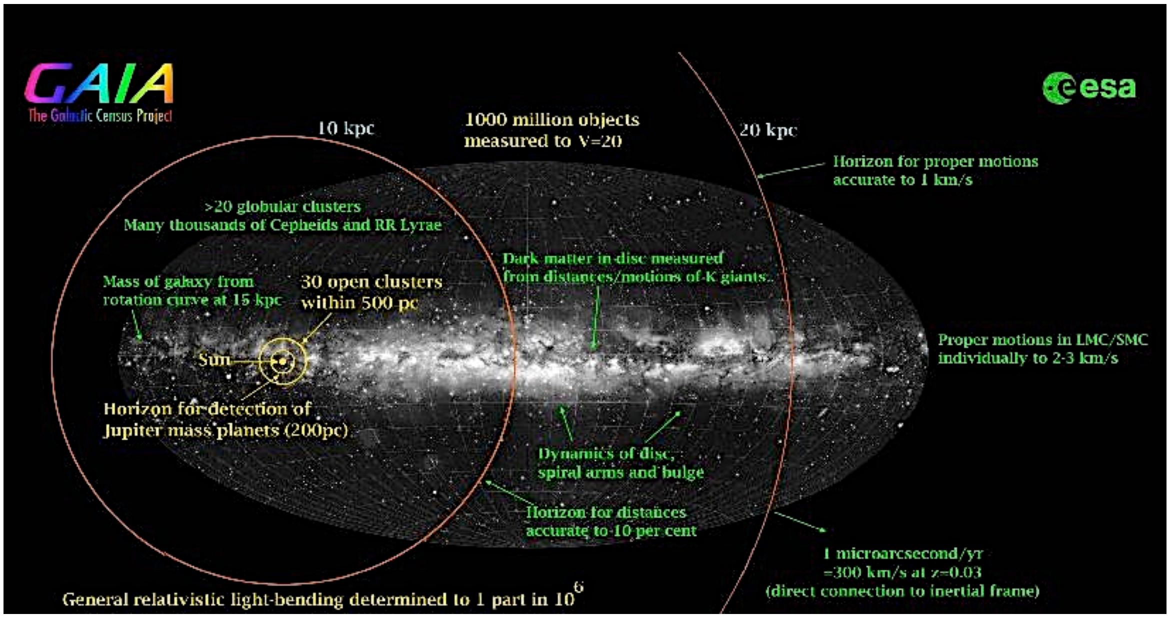


- Its only in the MW and a few other nearby galaxies that fossil signatures of galaxy formation

  + evolution (ages dynamics and abundances for individual stars) is possible.

These signatures allow a probe back to early epochs and constraints on theories of galaxy formation





Components of MW Disk

- The positions, velocities, chemical abundances, and ages of MW stars are very strongly and systematically correlated
  - For example in the disk:
    - younger and/or more metal-rich stars tend to be on more nearly circular orbits with lower velocity dispersions.
- Subcomponents of the Disk can be defined on the basis of the spatial distribution, kinematics, or chemical abundances.
- Disk components
  - dominant thin disk
  - a thick disk

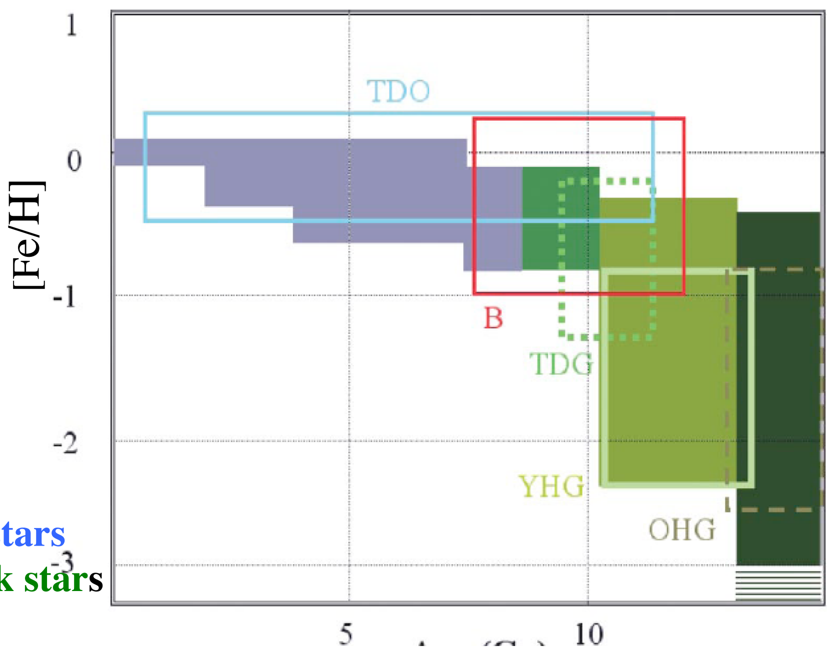
can be defined spatially, kinematically, or chemically

Components of MW Disk

- The age-metallicity relation of the Galaxy for the different components
- It is common to describe the Disk in terms of a dominant thin disk and a thick disk, with thin–thick disk samples of stars defined spatially, kinematically, or chemically

blue= thin disk stars
green =thick disk stars
B= bulge stars
black= halo stars

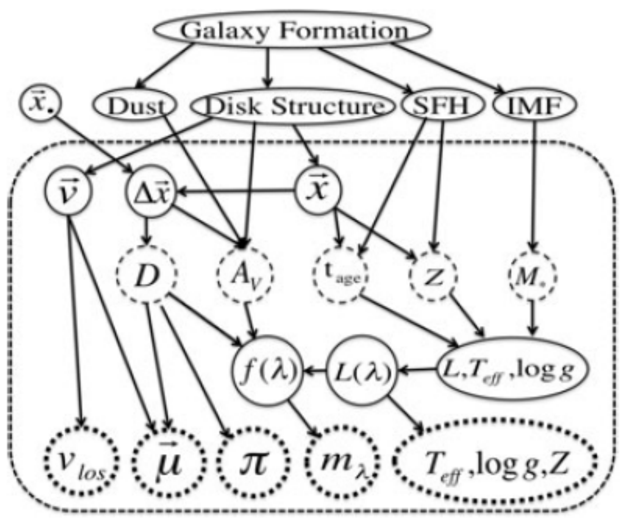
Freeman and Bland-Hawthorn



AGE (Gyrs)

Observables and What we Want to Learn

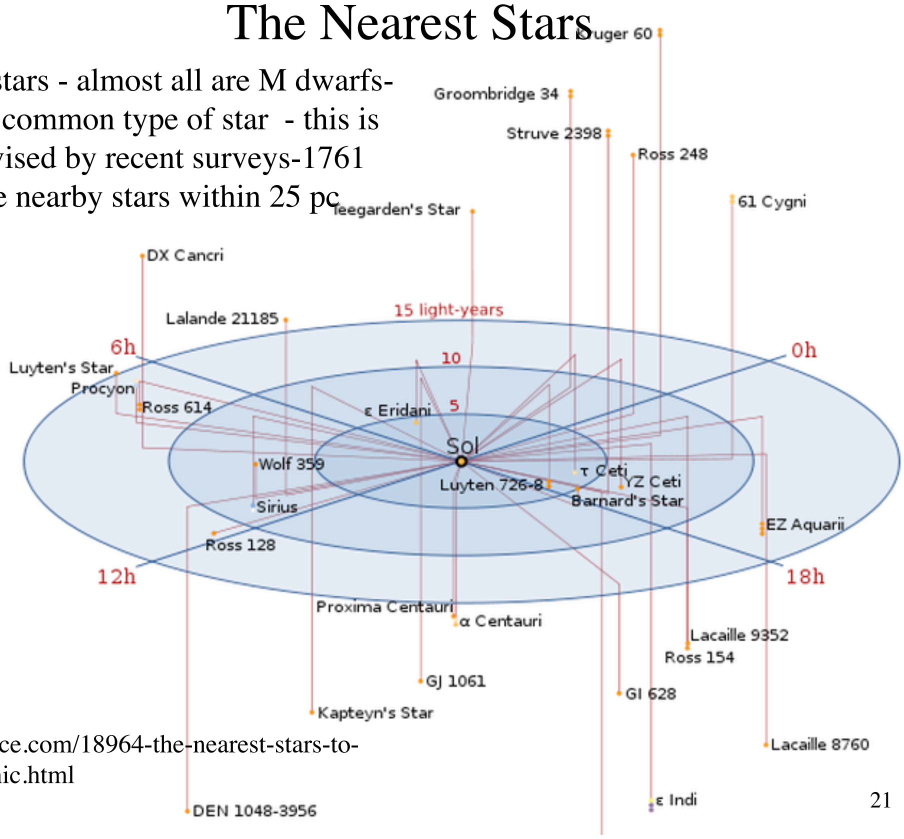
- Observables and desired information (solid ellipses)
- Observables:
  line-of-sight-velocity, v_{los}, proper motions, $\boldsymbol{\mu}$, parallax π, multi-band photometry m_λ, and stellar parameters derived from spectra (T_{eff}, log g, abundances, Z); most of them depend on the Sun's position x , $\Delta \boldsymbol{x}$.
- Desired information is
  stellar masses M, age t_{age} and abundances Z, distance D from the Sun and the (dust) extinction along the line of sight, A_V .



Rix and Bovy 2013

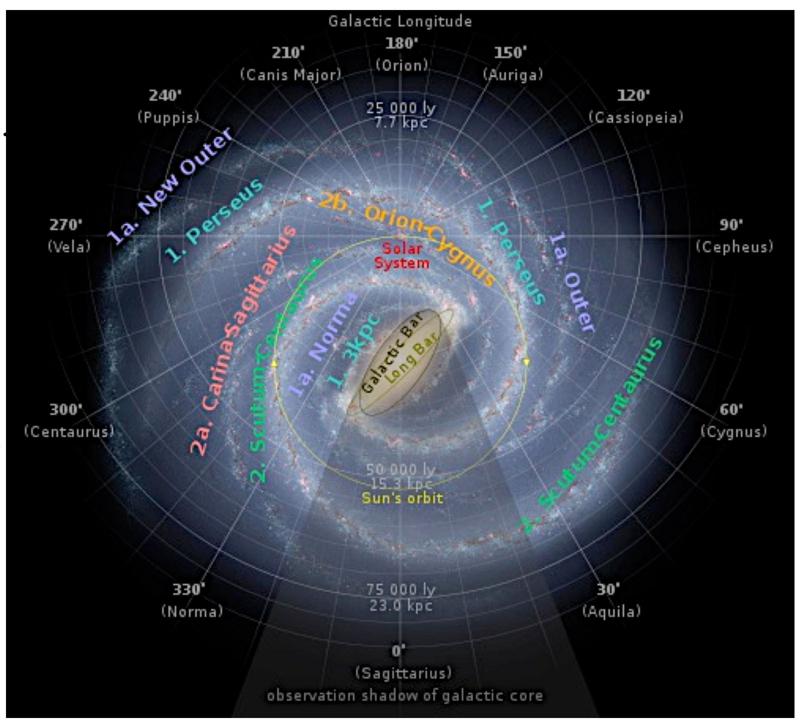
The Nearest Stars

- Nearest stars - almost all are M dwarfs- the most common type of star - this is being revised by recent surveys-1761 candidate nearby stars within 25 pc



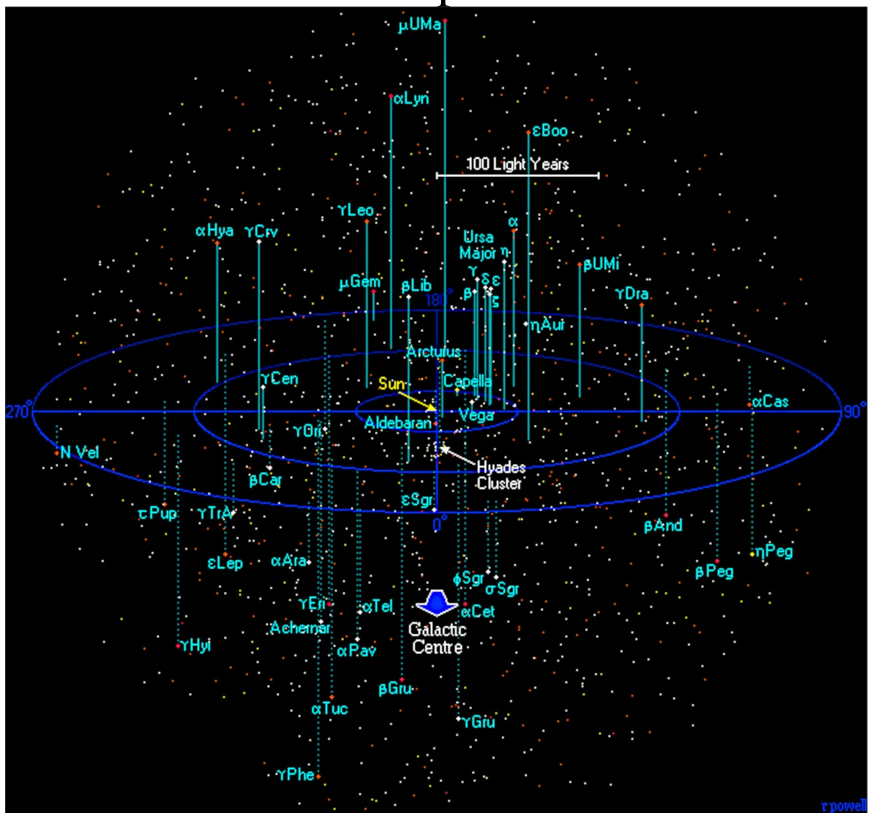
http://www.space.com/18964-the-nearest-stars-to-earth-infographic.html

- http://www.atlasoftheuniverse.com/12lys.html
- **SEGUE: Mapping the Outer Milky Way http://www.sdss.org/surveys/segue/**
- SEGUE-2 and APOGEE: Revealing the History of the Milky Way
- **https://www.zooniverse.org/projects/povich/milky-way-project**

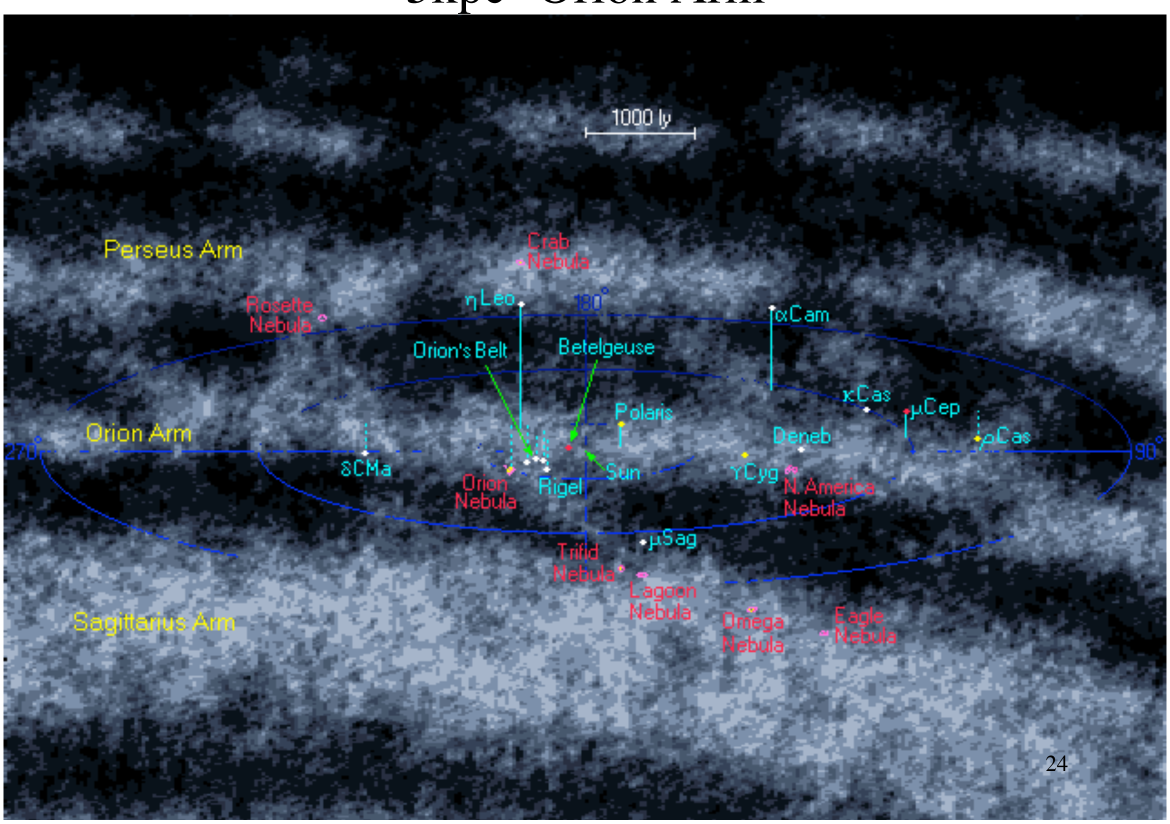


Stars Within 250pc

- This is a small subset of the stars
- Volume limited sample dominated by low mass red dwarfs

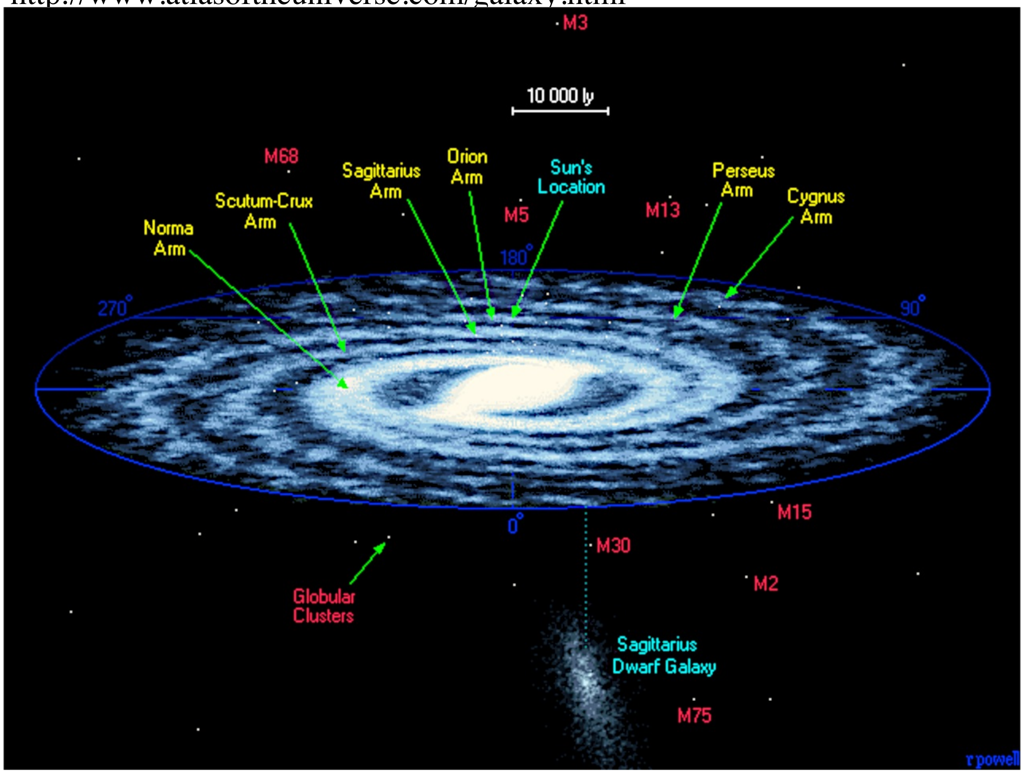


5kpc- Orion Arm



The MW

- http://www.atlasoftheuniverse.com/galaxy.html

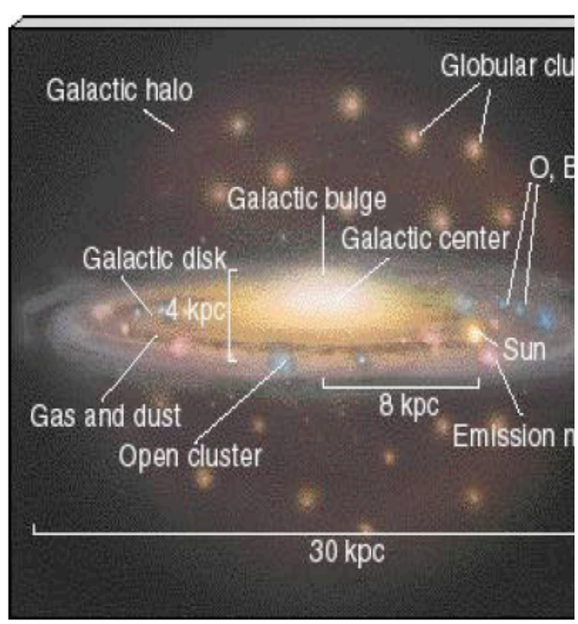


Basic Structure of Milky Way

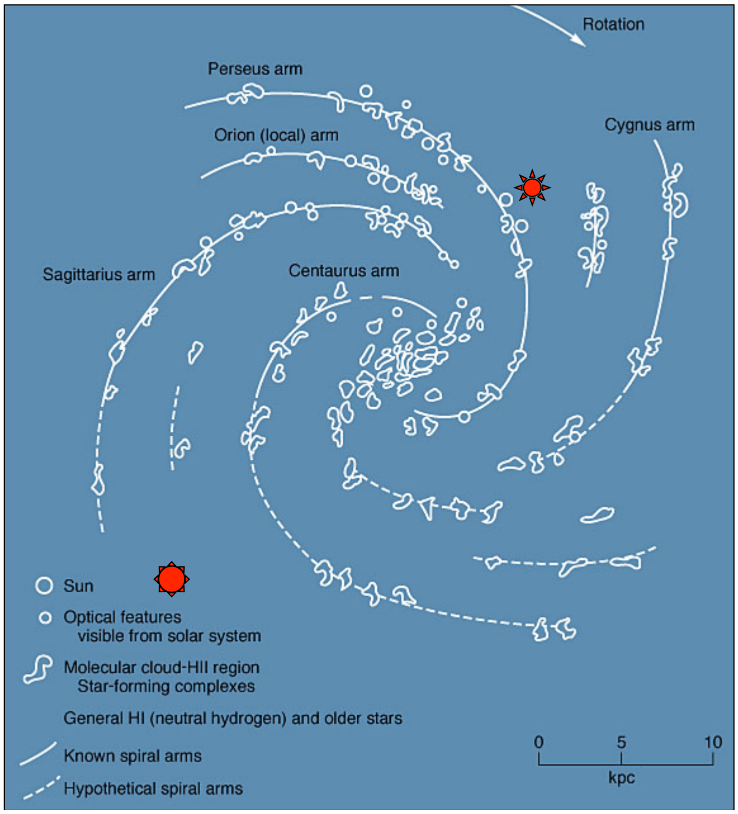
Bulge is quite spherical and is dominated by old stars

Disk- location of almost all the cold gas and most of the HI- site of star formation and thus young stars- wide range in metallicity

Halo- globular clusters, most of MW dark matter, only 1% of stars



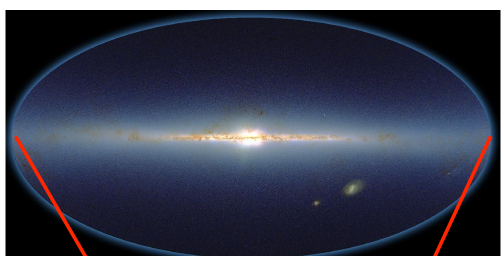
Map of the Milky Way Galaxy

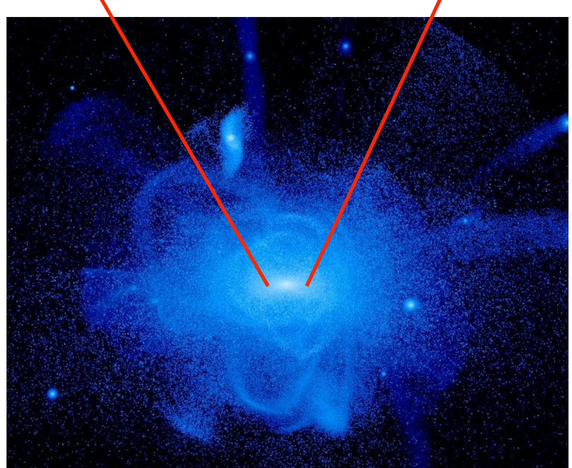


map made from HI velocity data
sec 2.3.1 in S+G

Theorists View of Dynamics of Stars in MW

- In cold dark matter theories of structure formation many mergers have occurred - it takes a VERY long time for the orbits to 'relax' and thus there should be dynamical signatures of the mergers
- Only in MW and LMC/SMC can we determine the 3-D distribution of velocities and positions to constrain such models in DETAIL (galactic archeology)-http://science.sciencemag.org/content/338/6105/333.full
- Look for signs of assembly of MW galaxy in our stellar halo (and thin/thick disk)
  - Stellar halo is conceivably all accreted material
  - Stellar streams in the solar neighborhood

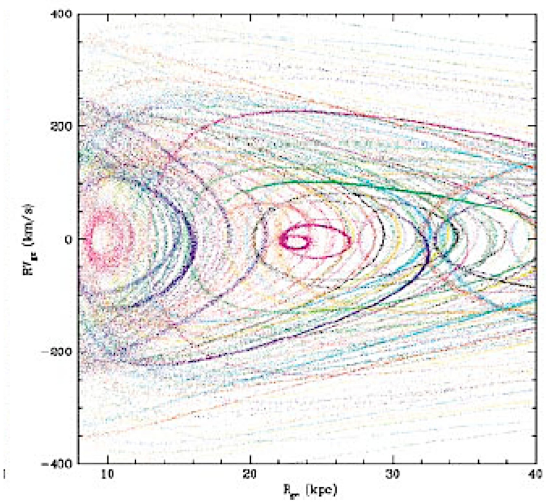




H. Rix

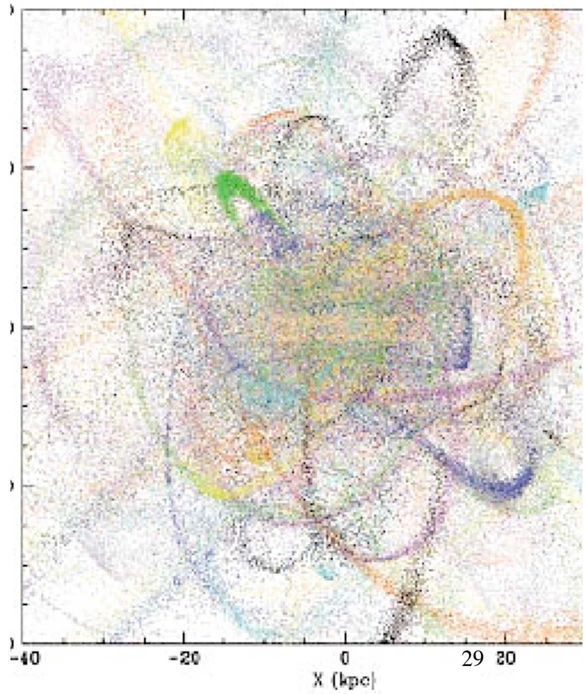
Theorists View- Continued

- Each merged galaxy is a separate color (Freeman and Bland-Hawthorn)



radial velocity vs orbital radius

position of stars in x,z plane



Simplified View of Streams

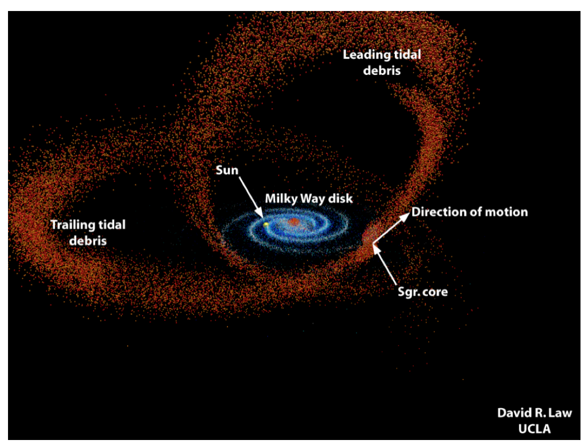
- galactic haloes are threaded with the remains of dwarf satellites and globular clusters that have been destroyed by the tides of their host's gravitational potential.

These tidally disrupted stars may make a significant fraction of the halo

- these dynamical tracers can provide constraints on the mass distribution of the baryonic and dark matter components of the Milky Way

- Tidal disruption radius (S&G 4.1.4)

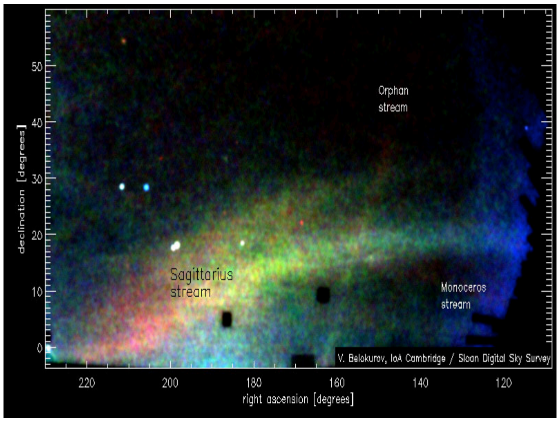
dwarf has mass m and radius r, MW mass M and separation between the 2 is R - consider the dwarfs gravitational binding force Gm^2/r^2



Disrupting force due to MW is $(GMm/2)[(1/(R-r)^2 - 1/(R+r)^2)]$; when r<<R this is $\sim GMmR/r^3$

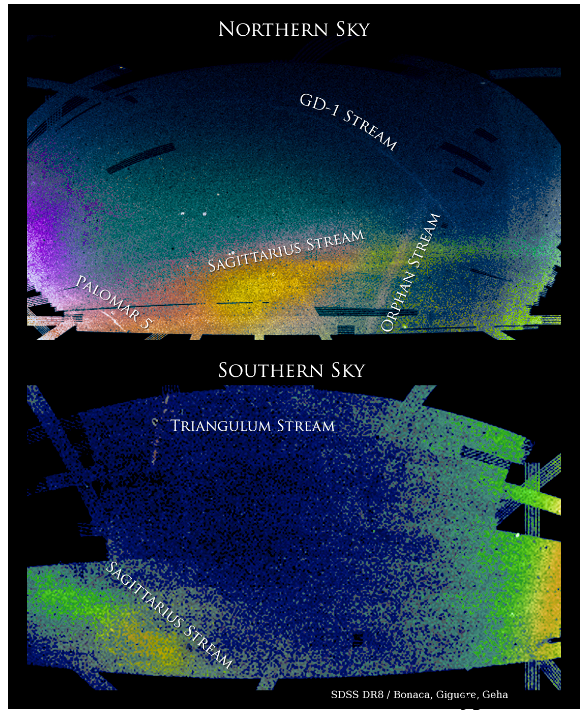
2 are equal when **$r \sim R(m/kM)^{1/3}$**
k depends on structure of object
See B&T sec 8.3 or Roche limit

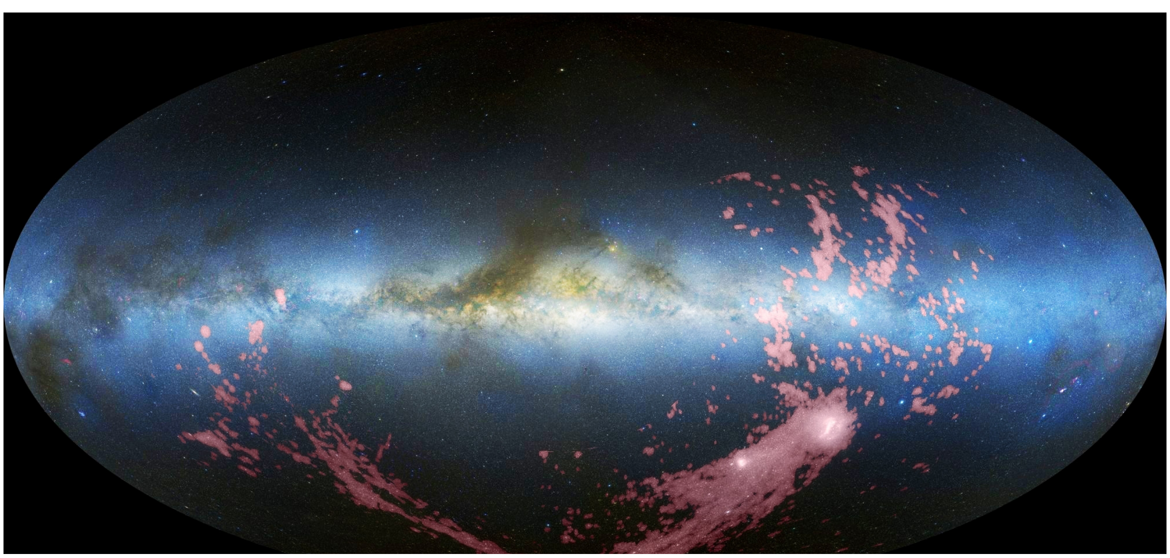
Streams in the MW



- map of stars in the outer regions of the Milky Way (1/4 of sky). The trails and streams that cross the image are stars torn from disrupted Milky Way satellites. The color corresponds to distance, with red being the most distant and **blue being the closest**. The large, forked feature is the Sagittarius stream, further away from us (lower left) and closer to us (middle right). Other features marked are the Monoceros ring

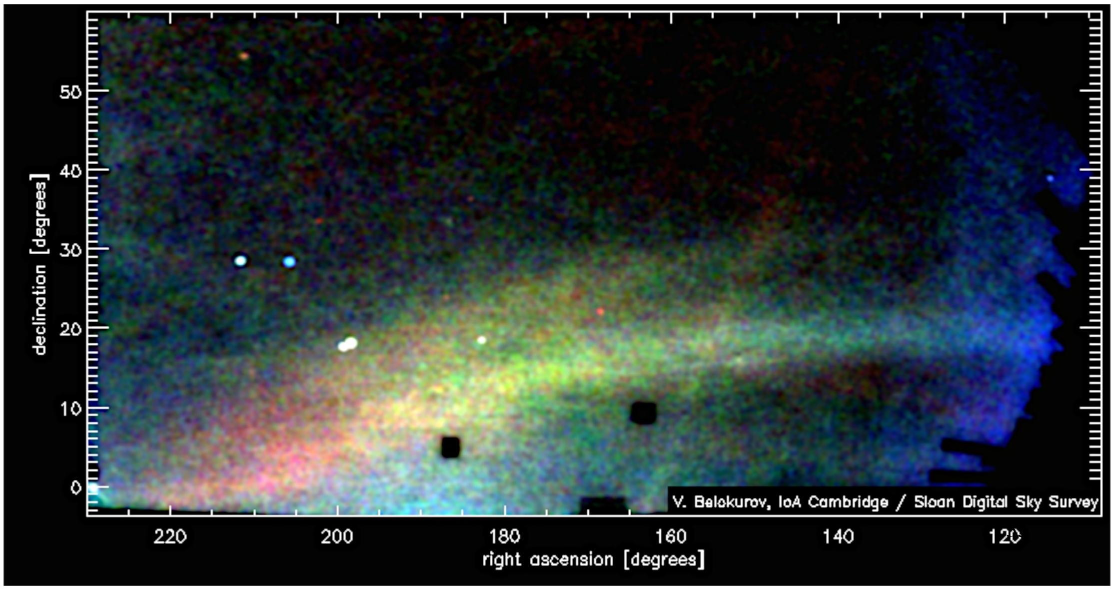
V Belokurov, SDSS-II Collaboration)



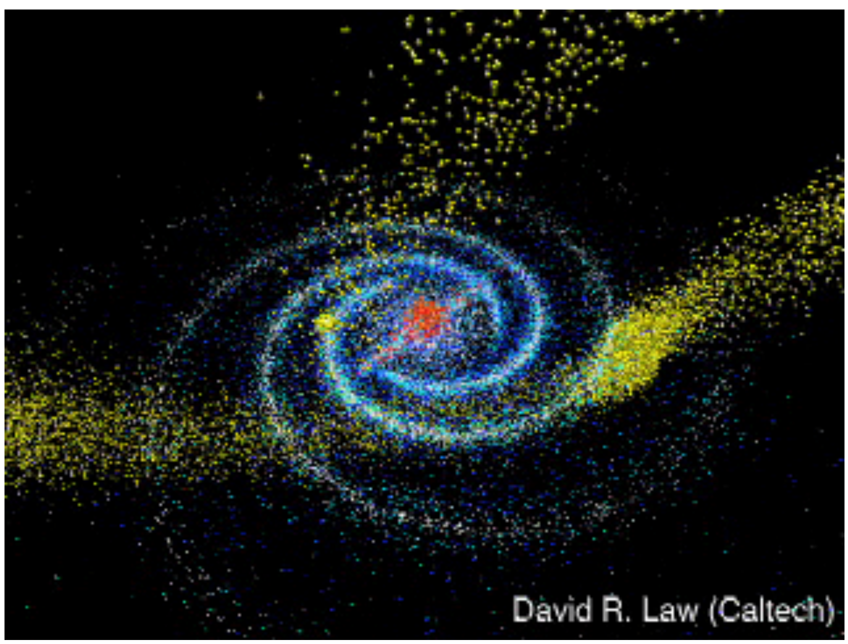


Stellar halo : fossil record of assembly?

- Dwarf galaxies are disrupting and contributing to the stellar halo
  - 1% of stellar mass of our galaxy
  - takes ~5Gyr for MW to 'digest' a merging dwarf
  - See such effects in nearby galaxies (see later lecture on mergers)



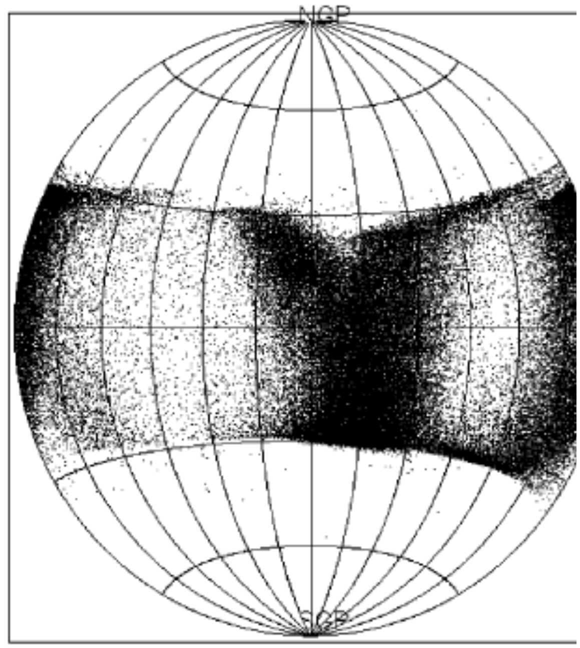
- Milky Way Galaxy (blue/white points and orange bulge) with the Sun (yellow sphere), inner and outer Sgr stream models (yellow/red points respectively), Monoceros tidal stream model(violet points), and observed Triangulum-Andromeda structure (green points).



http://www.astro.caltech.edu/~drlaw/MWstreams.html

What Happens to Disrupted Satellite

- One realization of how the stars from a disrupted satellite would appear 8Gyrs after the merger.



e 9 A satellite in orbit about the Milky Way as it would appear
stars from the disrupted satellite appear to be dispersed over a very
, it will be possible to deduce the parameters of the original event us
ques (see text). (We acknowledge A. Helmi and S. White for this im