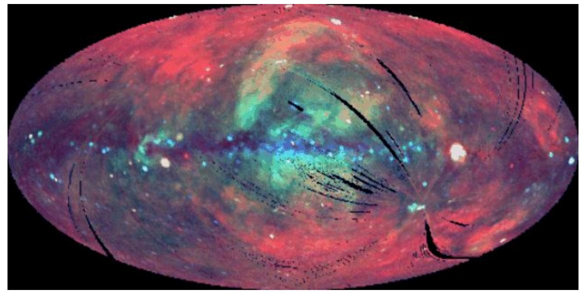
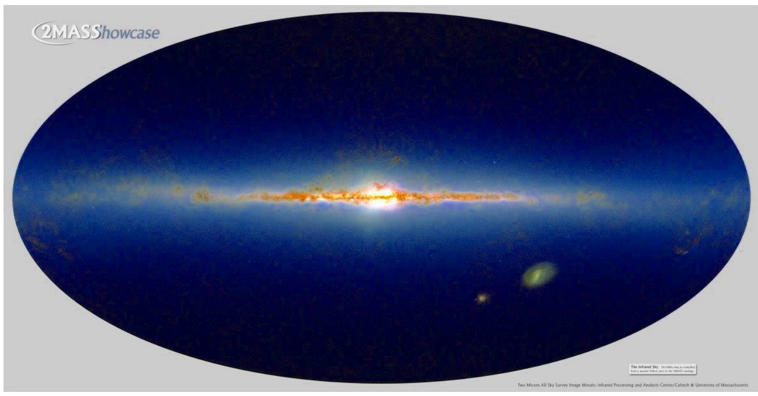
Milkyway

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



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



Milky Way in near IR
www.milkywaproject.org

Recent reviews

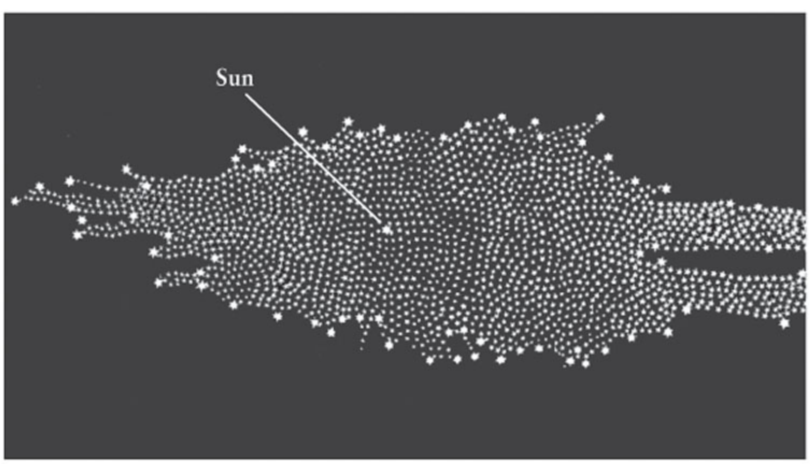
The Milky Way’s stellar disk-Mapping and modeling the Galactic disk Hans-Walter Rix · Jo Bovy Astron Astrophys Rev (2013) 21:61

Detailed study of the MW is a very active field

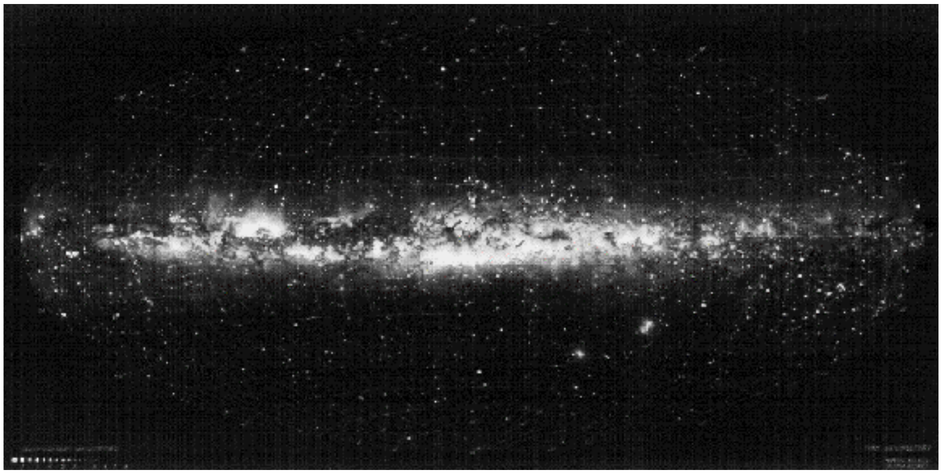
- The stellar halo of the Galaxy Amina Helmi The Astronomy and Astrophysics Review 2008, Volume 15, Issue 3, pp 145-188,
- Freeman KC, Bland-Hawthorn J (2002) ARA&A 40:487 The New Galaxy: Signatures of Its Formation

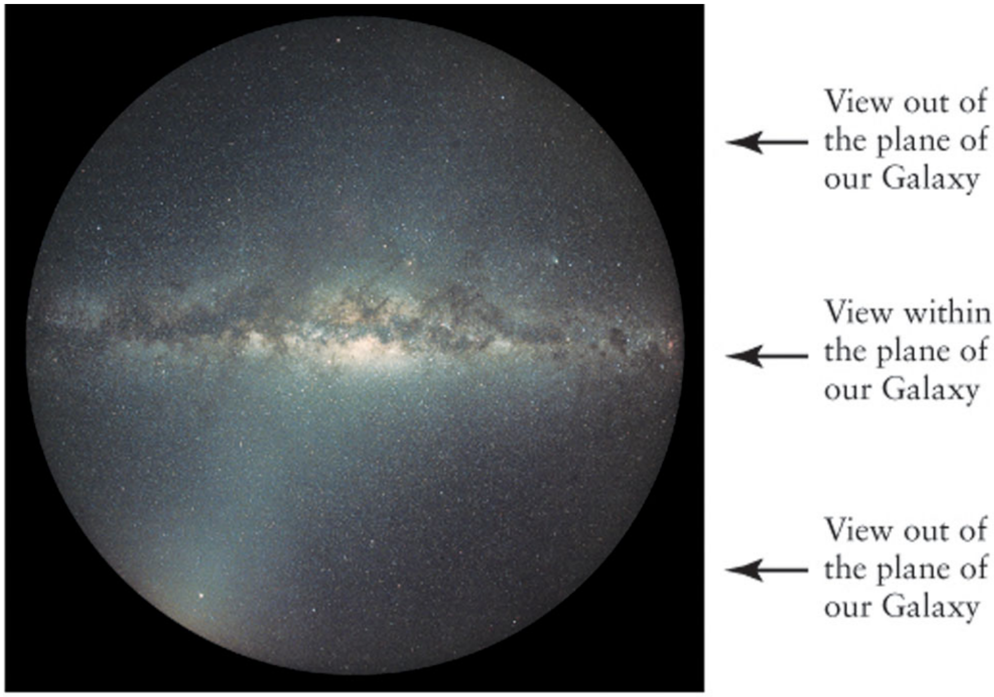
Our place in the Galaxy

- We live in a large disk galaxy of average mass
  - The sun is in the disk, towards the edge (8kp 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 absorption by dust! *(something that he did not know about)*



Herschel's map of the Galaxy





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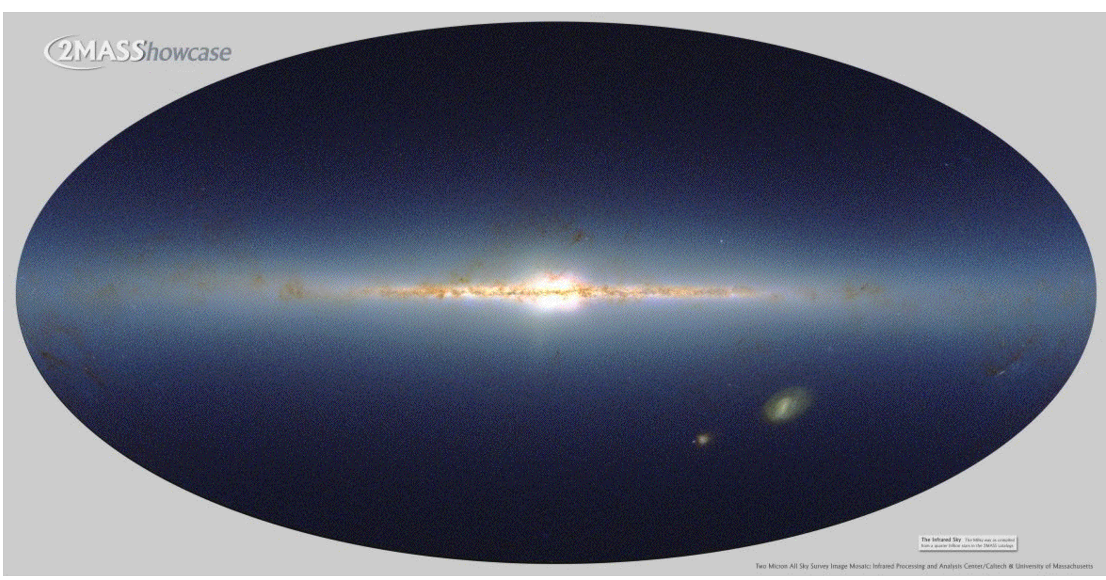
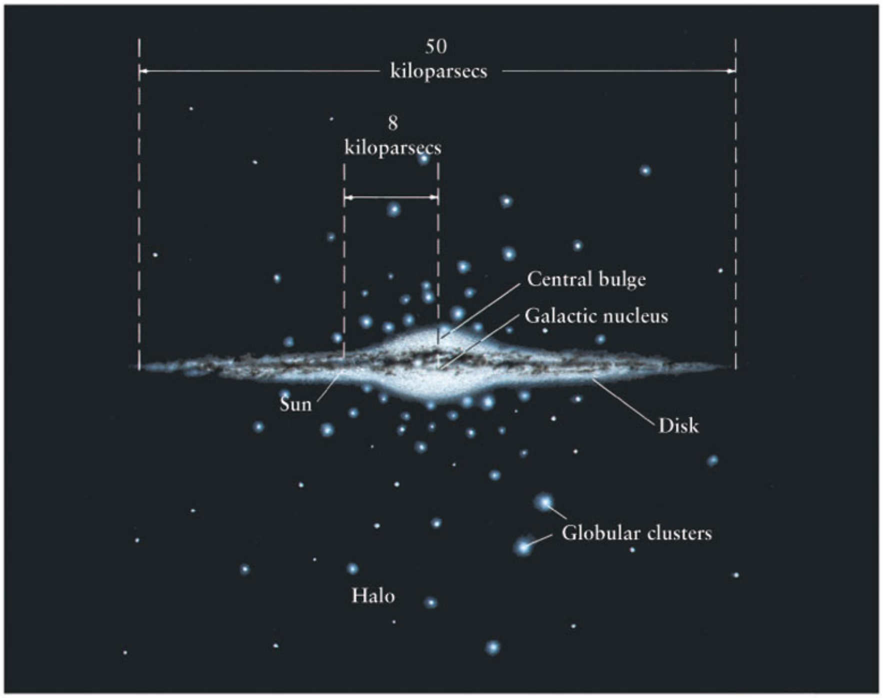
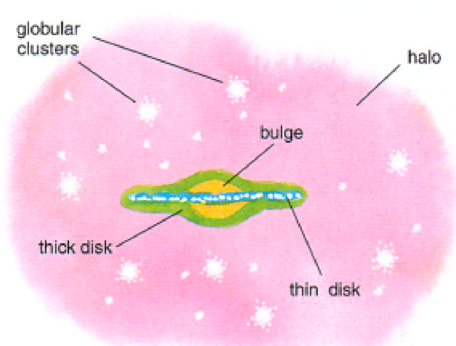


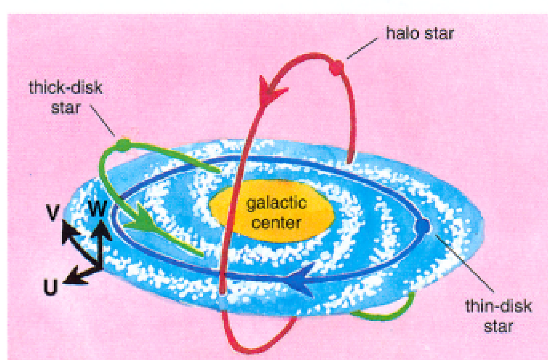
The MW galaxy as seen by an infrared telescope- IR light
is much less sensitive to 'extinction' by dust than optical light



1 kiloparsec=3.26×10^{3} lightyears=3.08×10^{19}m

Schematic Image and Dynamics of MW

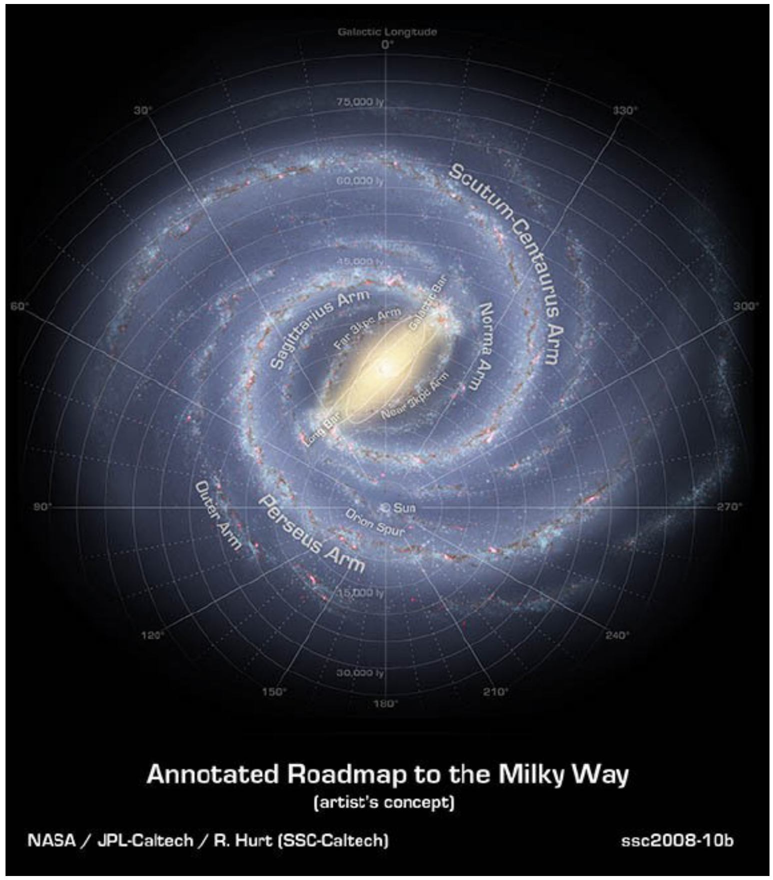




Cristina Chiappini

- 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



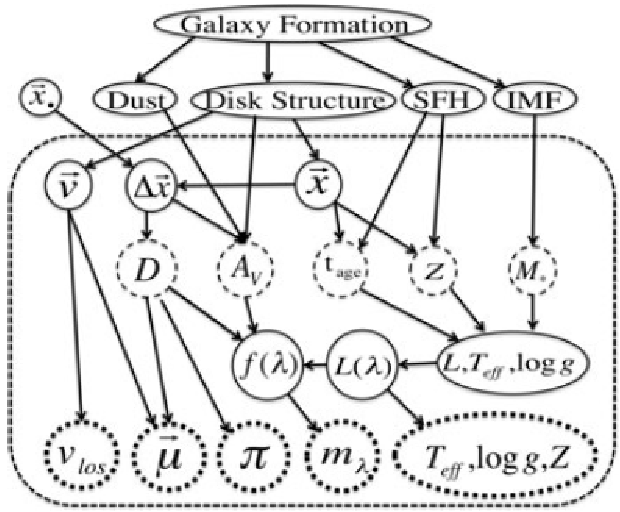
- The positions, velocities, chemical abundances, and ages of MW stars are very strongly and systematically correlated
- In the disk:
  - younger and/or more metal-rich stars tend to be on more nearly circular orbits with lower velocity dispersions.
- Subcomponents of the Disk can be defined on the basis of the spatial distribution, kinematics, or chemical abundances.
- Most common has been 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

Observables and What we Want to Learn

- Observables are in dotted and desired information in solid ellipses
- Observables

  line-of-sight-velocity, v_{los}, proper motions, μ, 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

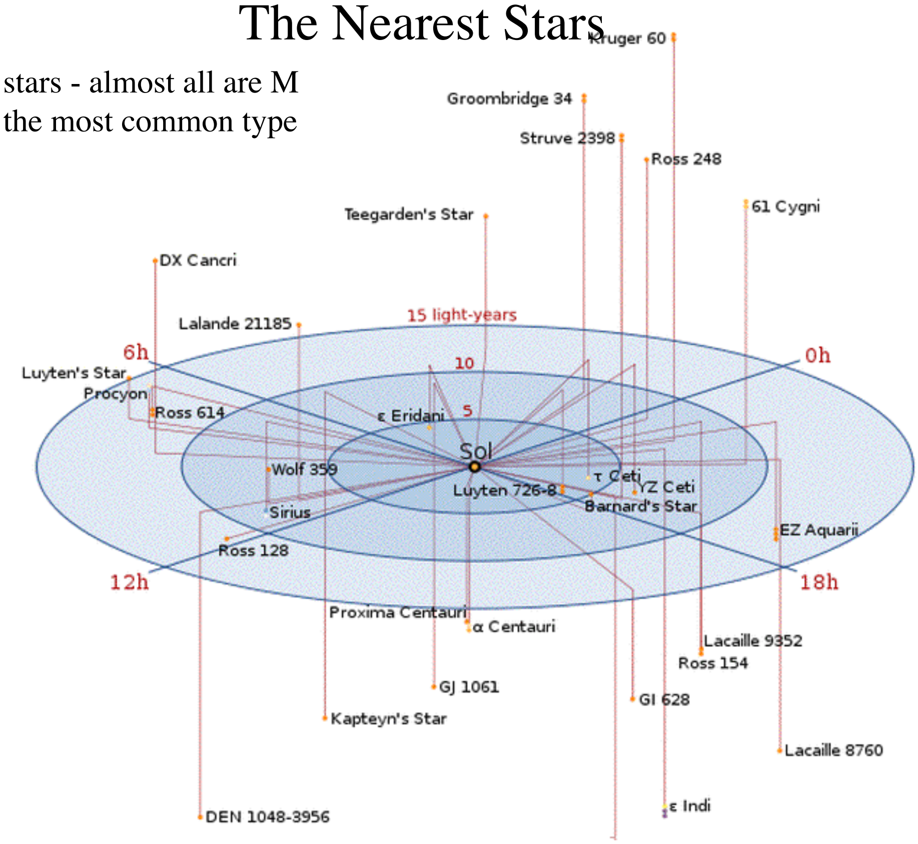
  stellar masses M, age t_{age} and abundances Z, distance D from the Sun and the (dust) extinction along the line of sight, A_V .



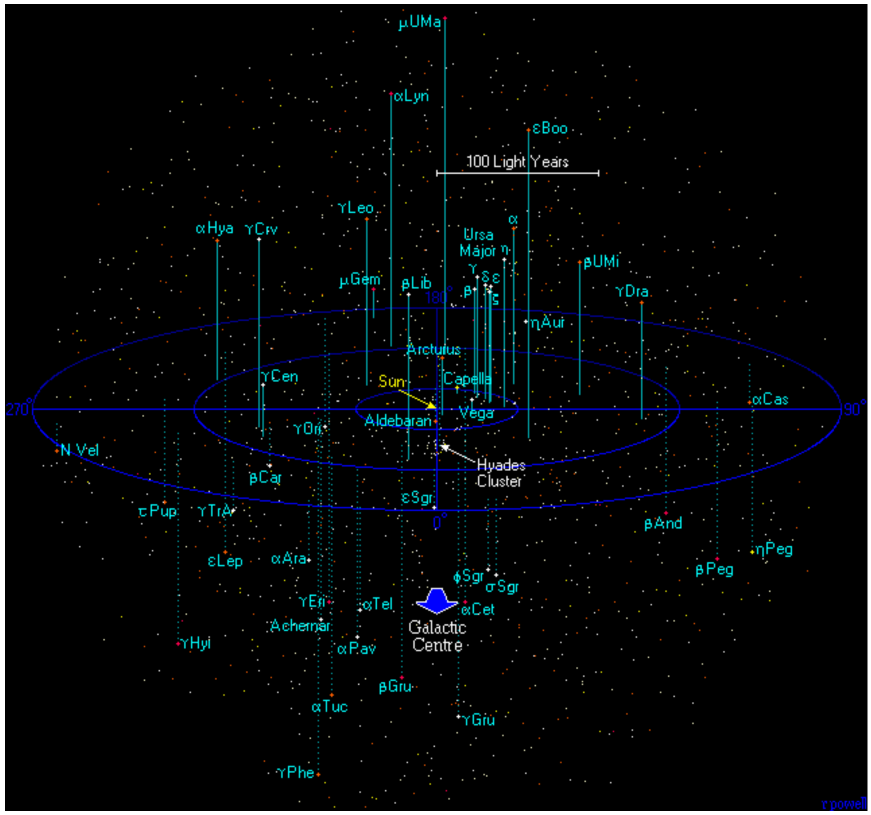
Rix and Bovy 2013

The Nearest Stars

- Nearest stars - almost all are M dwarfs- the most common type of star



Stars Within 250pc

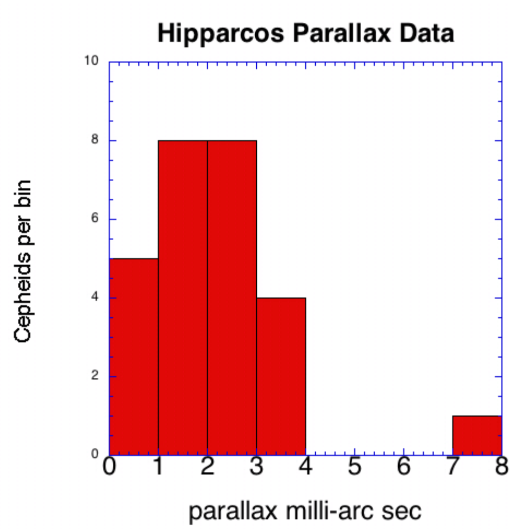


Relative vs Absolute Distances

- H. Levitt determined that Cepheids were very good relative distance determiners- how to connect with stellar parallax absolute distance measurements??
- This was done in 1913 by Hertzsprung using statistical parallax-Traditional annual parallax techniques are not capable of determining distances to even the closest Cepheids because the 2AU base line is not long enough.

It wasn't until 1997 that the parallax was directly to the nearest Cepheids using the Hipparcos satellite- the reason is that the closest Cepheids have parallaxes of **milliarc** secs- now HST has 13 - see

A 3% Solution: Determination of the Hubble Constant with the Hubble Space Telescope and Wide Field Camera 3 Reiss et al 2012



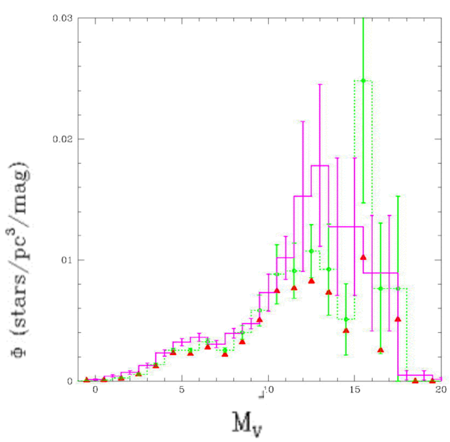
- Can measure 3D structure from star counts
- Can measure dynamics from individual stars
- Can only do in the MW: (a lot more later)
- Need to find a good tracer of potential

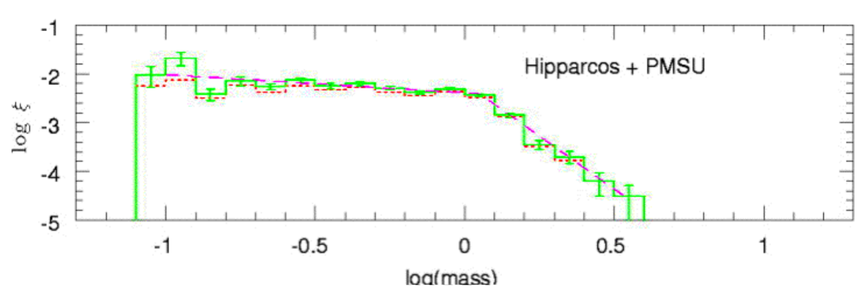
that probes the disk (z<~1kpc)

- numerous sufficiently old, well-mixed well-calibrated distances good radial velocity measurements
- Lower main sequence stars (G - K dwarfs)
- Parameterize possible potentials
- Known star populations + gas + dark disk + halo
- Bottom line No convincing evidence for 'cold' DM component in the disk .

Luminosity and Mass Function

- A fundamental property of stars is how they are distributed in mass and luminosity- the mass and luminosity functions
- One has to transform the observables (flux, color etc) into physical units (luminosity in some band, temperature) using theoretical stellar models and distances determined via a variety of means
- The best set of distances are from parallax and the largest data set is for the solar neighborhood (R~25pc) from the Hipparchos satellite set by its ability to measure small parallaxes





Star Counts

- We wish to determine the structure of the MW
- Define 2 functions
  - A(m,l,b): # of stars at an **apparent mag m**, at galactic coordinates l,b per sq degree per unit mag.
  - N(m,l,b): cumulative # of stars with mag **< m**, at galactic coordinates l,b per sq degree per unit mag.
- Then clearly dN(m,l,b)/dm=A(m,l,b)
  - or $N(m,l,b)=\int A(m',l,b)\, dm$

- Simplest galaxy model : uniform and infinite

if ρ_*= density of stars and Ω= solid angle of the field, the volume of a shell at distance r is $\Omega r^2 dr$ and the number of stars is $N(r)=\int_0^R \Omega r^2 \rho_* dr= 1/3\Omega R^3\rho_*$

  - Now if all the stars have the same luminosity (e.g. absolute magnitude)M and utilize (from the definition of absolute mag m-M=5logr-5
  - (e.g. $r=10^{(0.2(m-M)+1)}$ pc) then $dr=(0.2)(\ln 10)10^{(0.2(m-M)+1}dm$
  - and thus $N(m)=\int_{-\infty}^{m} \Omega\rho_*=(0.2)(\ln 10)(10^{(0.2(m-M)+1)})^3 dm$; oh the pain of magnitudes

Star Counts

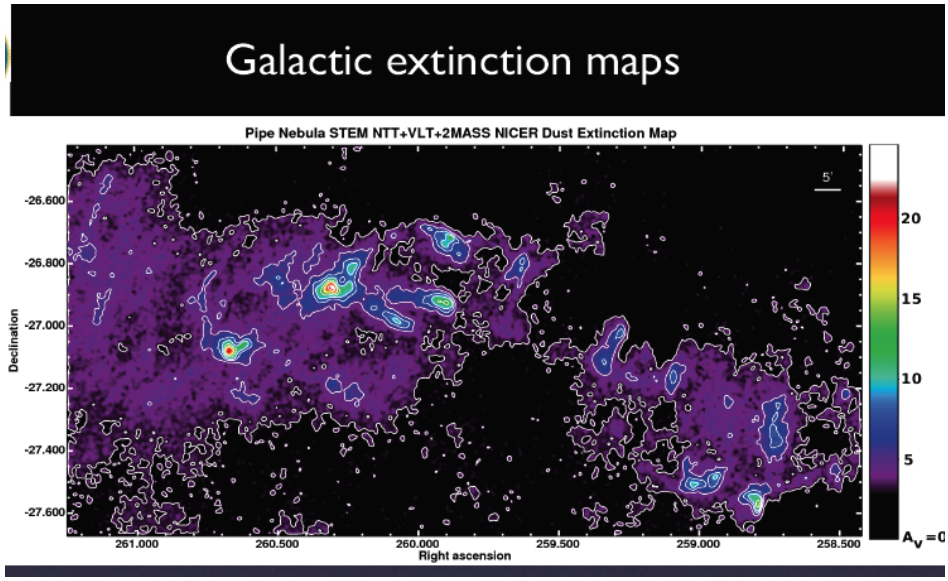
- $N(m)= \int_{-\infty}^{m} \Omega\rho_*=(0.2\text{x}10^3)(\ln 10)\int_{-\infty}^{m} (10^{(0.6(m-M))})dm'$
- or (finally)
- $N(m)= 333\Omega\rho_*\, 10^{(0.6(m-M))}$

- This is not what is observed
  - finite size of disk (not sphere)
  - effects of dust

- Olbers paradox: if galaxy (universe) was infinite the total light would diverge

- Goal is to find the true space density of stars as a function of distance, galactic coordinates, luminosity, spectral time, age, metallicity etc
- Luminosity function of stars f(m,etc)

Need to Measure Extinction Accurately



Luminosity Function

- Simplest form f(m)=# of stars per unit volume with luminosity (absolute mag) between M and M+dm

- Observationally it is a time dependent quantity (since stars evolve and are born and die and since stellar ages are function of mass)
  - thus the luminosity function, while an observable, has to be carefully defined.
- Observational issues
  - incompleteness due to flux limited samples in a given bandpass,
  - uncertainty in distances (need to transform from observed flux to true luminosity)
  - effects of dust
  - need a large volume (stars are very rare at high luminosities)
- Many of these problems were overcome by Hipparchos (large number of parallax distances) and near IR surveys (relatively free from effects of dust);
    - major advance expected with launch of GAIA in Oct 2013

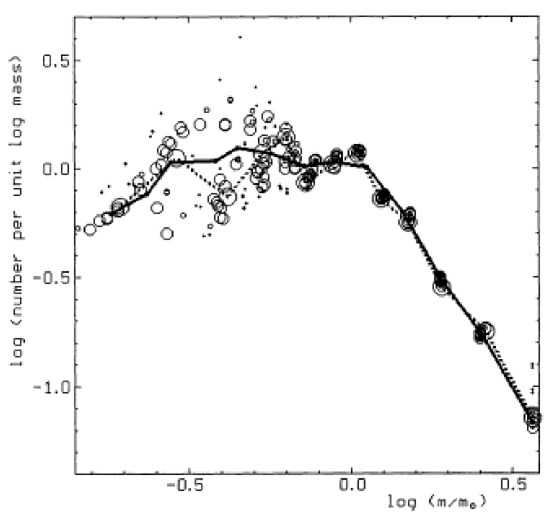
IMF of MW Stars

- Observing the IMF is tricky, 3 approaches
- Observe a young cluster and count the stars in it as a function of mass. (e.g. the Pleidaes) straightforward , but limited by the number of young clusters where we can directly measure individual stars down to low masses. get a clean measurement, but the statistics are poor.
- field stars in the solar neighborhood whose distances are known. statistics are much better, but only use this technique for low mass stars, few massive stars in local volume and numbers controlled by star formation hitory
- get limits on the IMF from the integrated light and colors of stellar populations
- despite these problems most results show that the IMF is very similar from place to place

Luminosity and Mass Function

- There are several 'nasty' problems
  - since stars evolve the 'initial' mass function can only be observed in very young systems
  - none of these are close enough for parallax measurements

842 H. Meusinger et al.: The mass function of the Pleiades down to 0.3 $M_\odot$



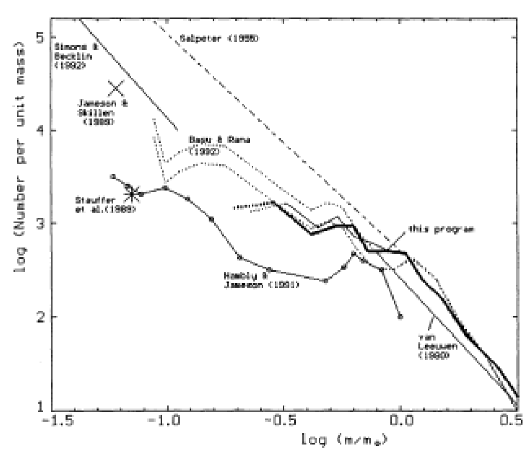
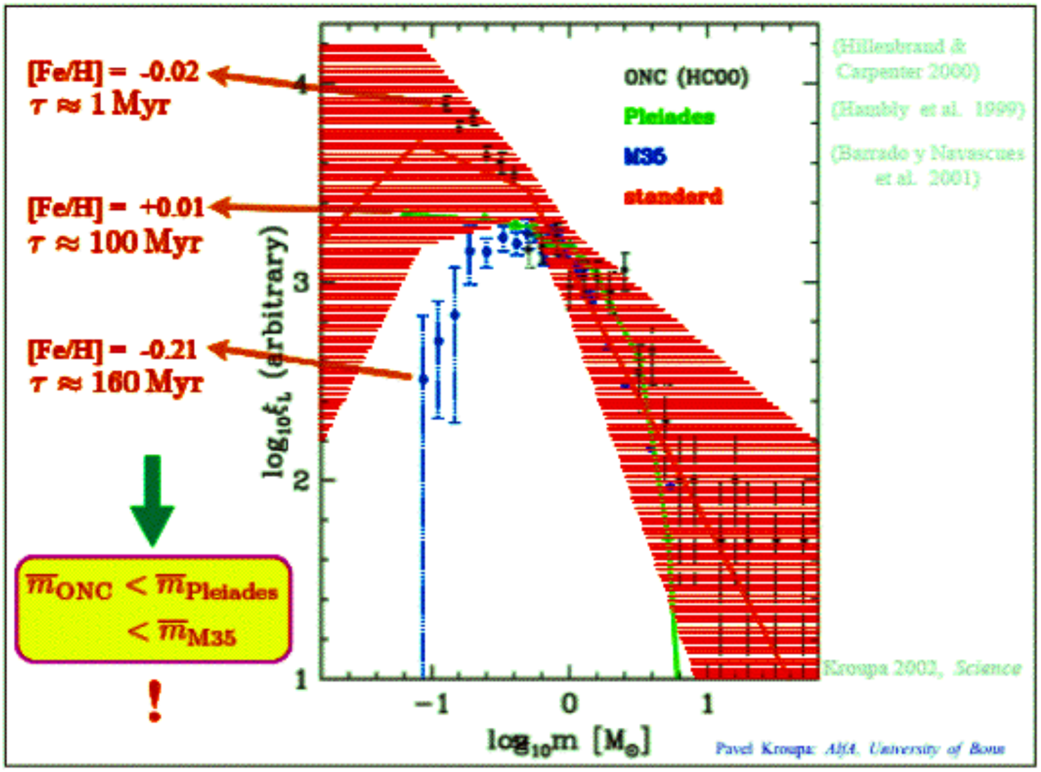


Fig. 11. A comparison of the Pleiades IMF from the present program (the weighted-averaged IMF from Fig. 10) with results from other stud-

IMF



Open Star Clusters- A SSP

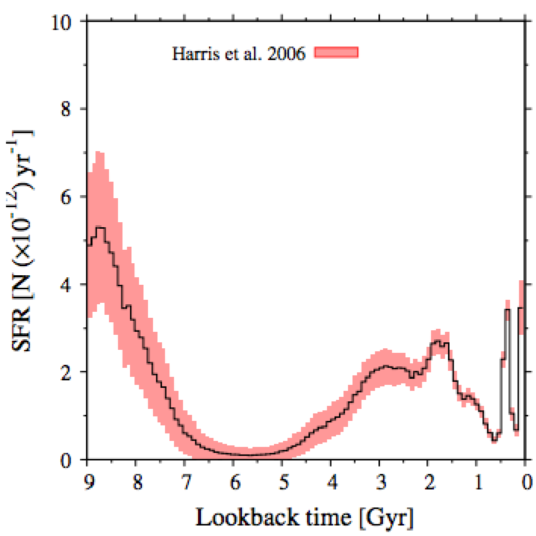
- the individual stars of the Galactic plane different not only in the masses and angular momenta, but also in their ages and in their chemical compositions at birth.
- This multiplicity of free-parameters complicates the study of stars. For instance, the initial mass, the initial chemical composition, and the age of a star determining the star's color and luminosity.
- Open star clusters are sets of stars that differ only in their masses at birth and in their angular momenta. They formed at the same time from the same molecular cloud with ~ the same chemical composition at birth and the same age.
- The stars of a single open cluster show how initial mass alone affects color and luminosity, and the comparison of stars from two different clusters shows how initial chemical composition affects color and luminosity and how stars evolve over time.
- The extent to which the massive stars deviate from the main sequence defines an age for the cluster. The Hyades cluster is estimated to be 625±50 million years old
- Over 1 billion years, encounters with molecular clouds cause an open cluster to totally dissipate.

Nearby Stars

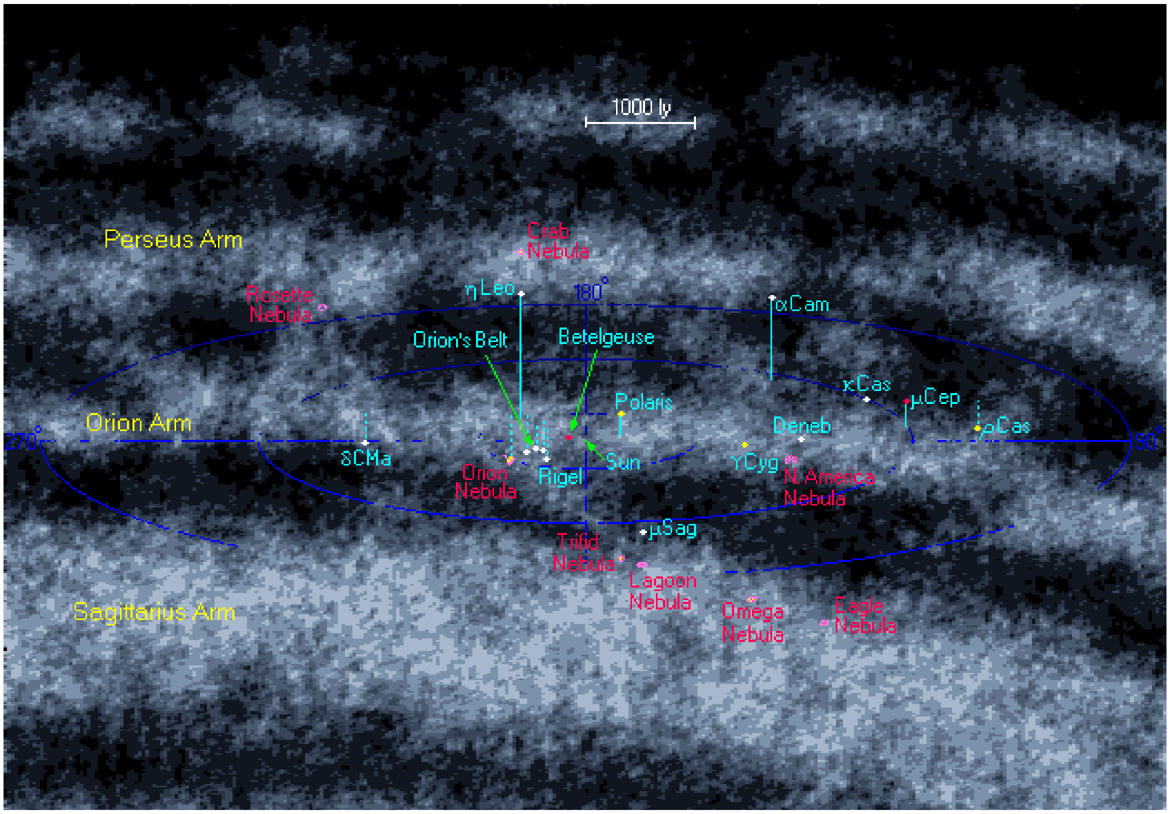
- Historically one dealt with flux (magnitude) limited samples of stars
- the Hipparchos satellite measured the absolute distances to many stars via parallax - now have a proper census of the stars at <100pc) (at this close distance effects of dust are small)- Major change coming up SOON with the launch of GAIA- in the mean time
  - Local Group and Star Cluster Dynamics from HSTPROMO (The Hubble Space Telescope Proper Motion Collaboration) R. P. van der Marel arxiv 1309.2014
    - Goal to determine fully three-dimensional velocities, need to determine Proper Motions. If get to DPM≈ 50mas/yr ,corresponds to a velocity accuracy dv ≈ (D/4) km/s at distance D kpc.
  - RAVE and SEGUE velocity surveys: SEGUE will observe ~ 240, 000 stars in the range $15 < V < 21$, while RAVE aims at 10^6 stars with $9 < I < 12$. The average velocity errors that these surveys can achieve are of the order of 10 and 1 km/s, respectively.

SFR In Solar Neighborhood

- By modeling the white dwarf age/density distribution one can estimate the SFR rate 'nearby' (Rowell 2012)
- We will later compare this to the overall rate of SF of the universe and find significant differences
  - is it because the local neighborhood is not representative of the whole MW?
  - or because the MW is not representative of the average of the universe??



5kpc- Orion Arm



The MW

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