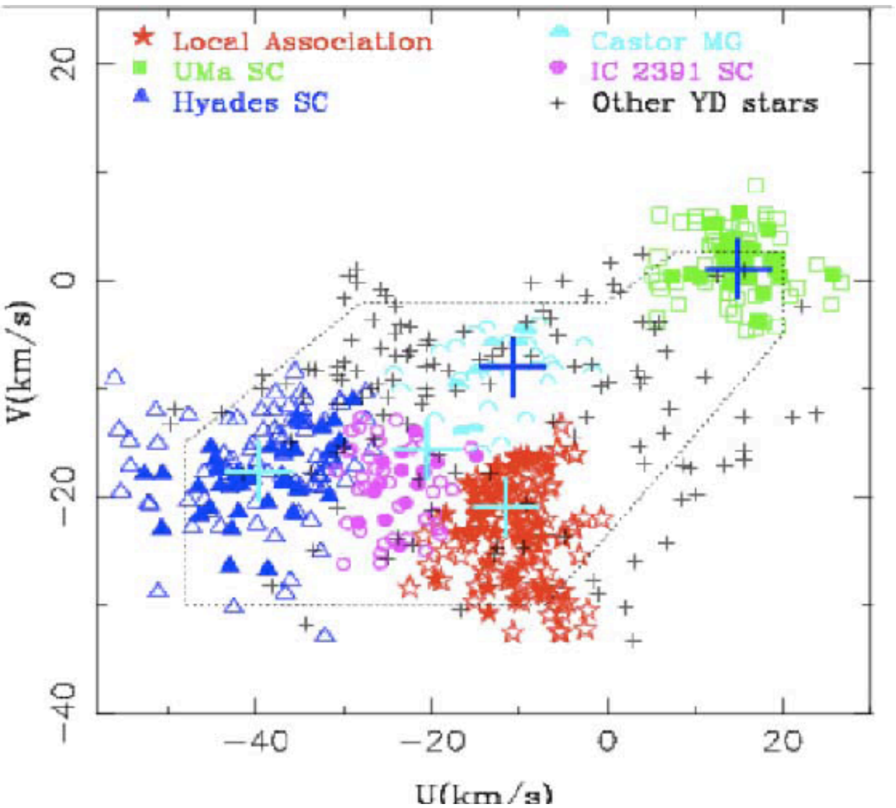
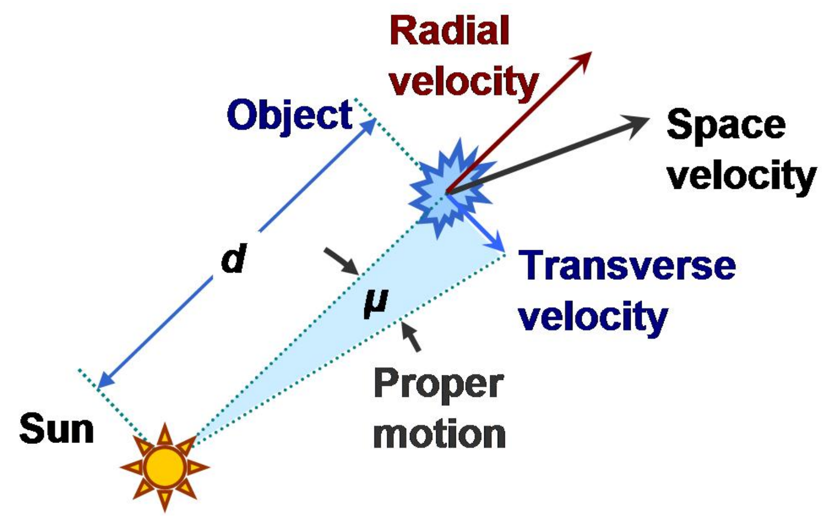
Astr 5465 Feb. 14, 2020
Kinematics of Nearby Stars

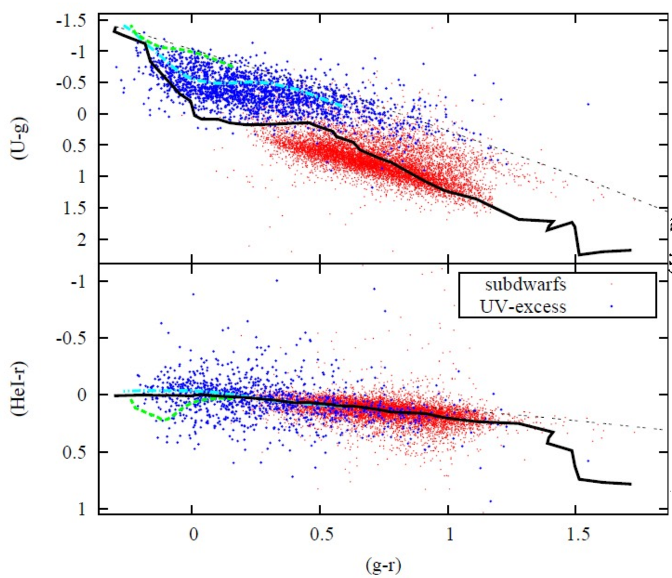
- **Properties of Nearby Stars**
  - Most in orbit with the Sun around Galactic Center
- **Stellar Kinematics Reveal Groups of Stars with Common Space Motion (Moving groups)**
  - Eggan 1971, PASP, 83, 251, etc.
  - Dehen 1998, AJ, 115, 2384
  - Montes et al. 2001, MNRAS, 328, 45
  - Metallicities Roughly Solar
  - Probably Associations

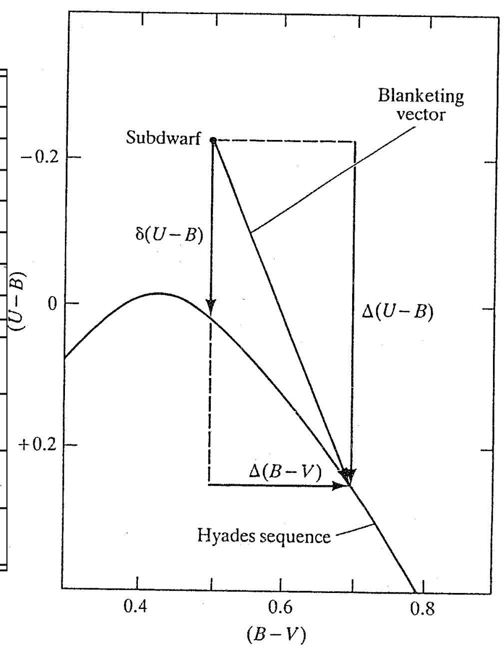


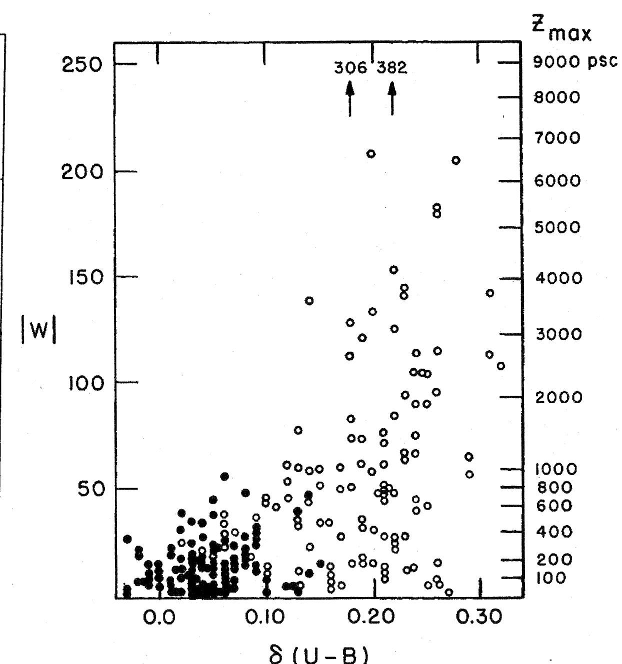
Kinematics of Nearby Stars

- **High Velocity Stars**
  - Subset of Nearby Stars with Large Space Velocities
    - Radial and Tangential
    - 3-d Space motions not in direction of Galacitic Rotation (Halo Stars)
  - UV Excess and Metallicity
  - http://www.astro.ru.nl/uvex/Uvexcesscatalog.html
  - Verbeck et al. 2012, MNRAS, 420, 1115









Correlations Between Metallicity & Kinematics

- **Correlation Between Metallicity & Kinematics**
  - **High Velocity Stars have Low Metallicity**
  - **Space Motion Associated with Halo**
  - **Disk Stars in Orbit with Sun Around the Galacitc Center**
  - **Eggen, et al. ApJ, 136, 748**
  - **Model: Continuous Collapse and Enrichment of Galaxy**
- **Age-Metallicity Relation**
  - **Eggen (1970) Found Metallicity Correlates with Age**
  - **Much of Trend is Selection Effect**
  - **Feltzing et al. (2001, A&A 377, 911)**
  - **Old metal-rich stars exist**
    - **Hotter (younger) Stars Show Trend (exclusion of cool dwarfs results in selection effect)**

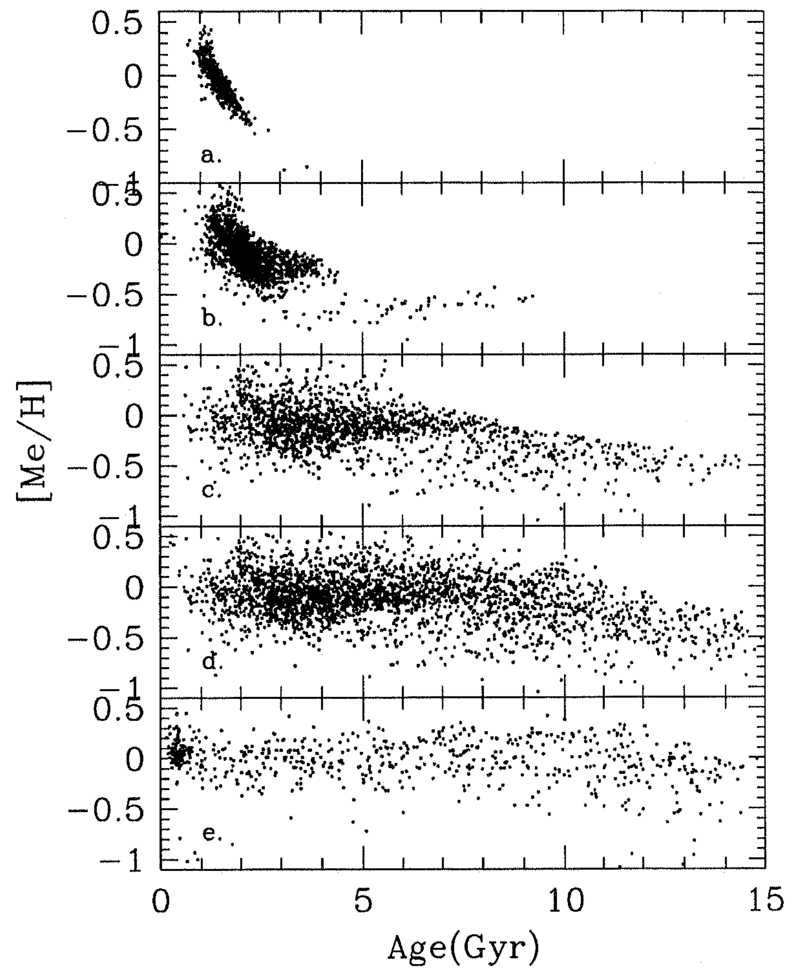


Fig. 13. Age-metallicity plots of different sub-samples from Fig. 10 and Fig. 12. **a)** Stars with $\log T_{\rm eff} > 3.83$, **b)** stars with $3.83 \geq \log T_{\rm eff} > 3.8$, **c)** stars with $3.8 \geq \log T_{\rm eff} > 3.77$, **d)** stars with $3.8 \geq \log T_{\rm eff} > 3.75$, **e)** stars with $3.75 \geq \log T_{\rm eff}$. For clarity we only show $[\mathrm{Me/H}] > -1$. All stars have, as before, $M_V < 4.4$ and $\sigma_\tau/\tau_{\rm mean} \leq 0.5$ and $n \geq 2$.

Distribution of Stellar Metallicities

- **Metallicity Distribution Function**
  - **Beers & Sommers-Larsen, 1995, ApJS, 96, 175**

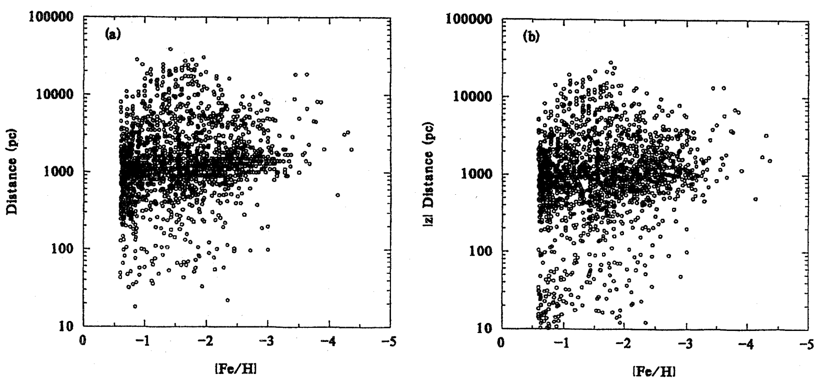
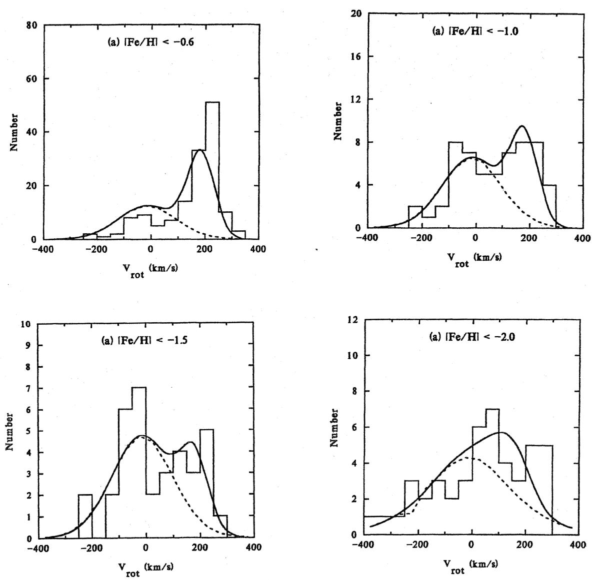
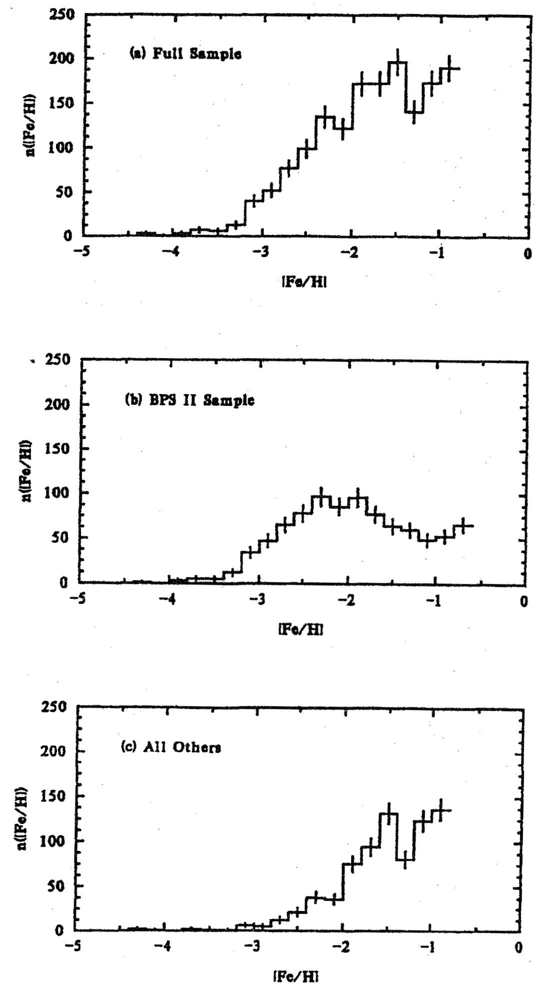


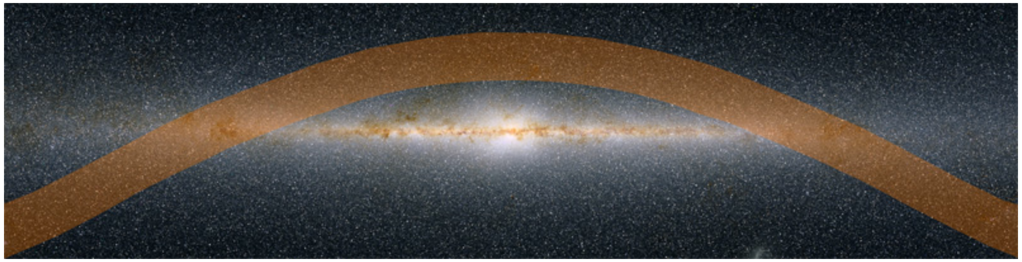
FIG. 4.—(*a*) Estimated distances from the Sun for stars in the present sample as a function of [Fe/H]. (*b*) Estimated distances above or below the Galactic plane for stars in the present sample as a function of [Fe/H].

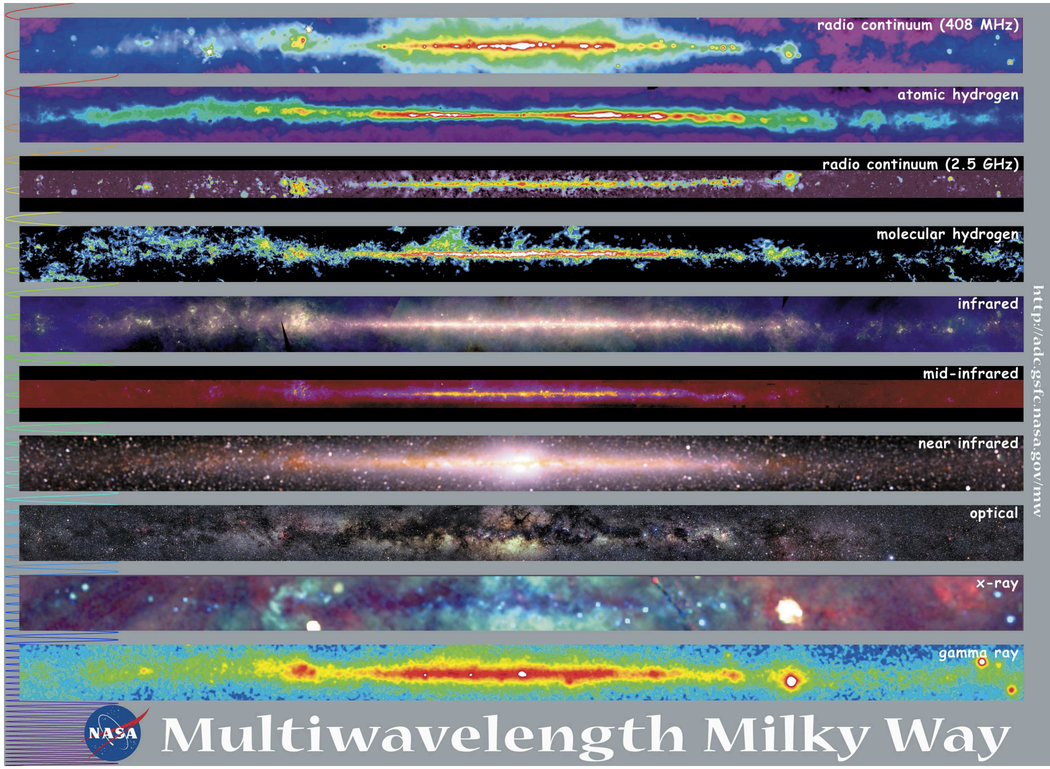




Properties of the Thin Disk

- Nearby Stars
  - Gould's Belt (Nearest stars tilted wrt Disk)
  - Early spectral Types Found Closest to Plane
  - Local Strucuture in MW?
- Multi-wavelength Surveys
  - 21 cm Radio: Warm Gas
  - Radio Continuum: Free-Free & Synchrotron from Ionized Gas
  - Microwave: Cold Molecular gas
  - Far Infrared: Cool Dust
  - Mid Infrared: Warm Gas
  - Near Infrared: Stars
  - Optical: Stars and Dust
  - X-rays: Hot Gas
  - Gamma Rays: Highest Energy Particles
- Maps of the ISM at Different Temperatures
  - Cold Molecular Gas
  - Warm Neutral Gas
  - Hot Ionized Gas
- Multi-phase Gas in Pressure Equilibrium





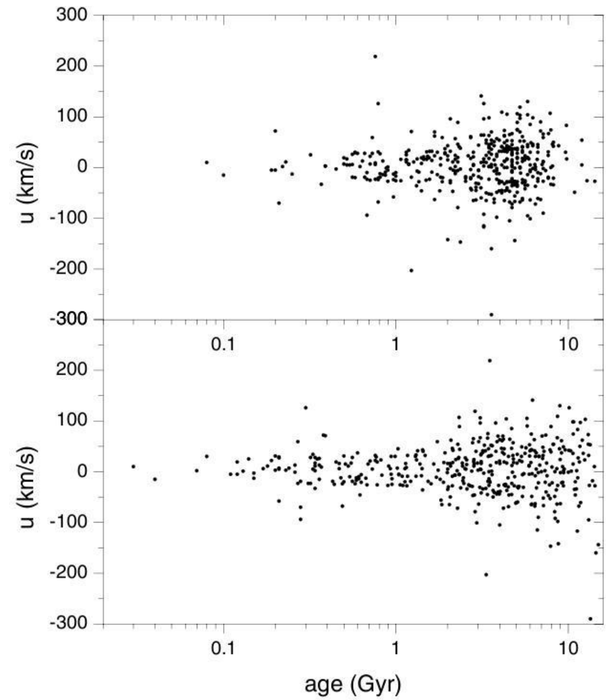
Properties of the Stellar Disk

- **Star Counts: Density Falls Exponentially with Height (z-direction)**
  - **Early-type Stars (young) Have Smallest Scale Height (90pc)**
  - **Later-type Stars (mixed) Have Larger Scale Height (350pc)**

  (Rocha-Pinto et al. 2004, AA 423, 517)
- **Excessive Counts at Large |z|**

  Gilmore & Reid
  - **Thin Disk Dominates at Small |Z|**
  - **Thick Disk Dominates at Large |Z|**
- **Model Including the Bulge**
  - **$R^{1/4}$ Bulge ($R_e \sim 2.7$ kpc, $\mu_0 \sim 15.1$/arcsec^2 (B), $L_B \sim 3 \times 10^9\ L_{sun}$ + Exp. Disk (right)**

  (Bahcall & Soniera 1984, ApJS 55, 67)
- **Summary (de Vaucouleurs & Pence 1978, AJ 83, 1163 & van der Kruit 1986, A&A 157, 230)**

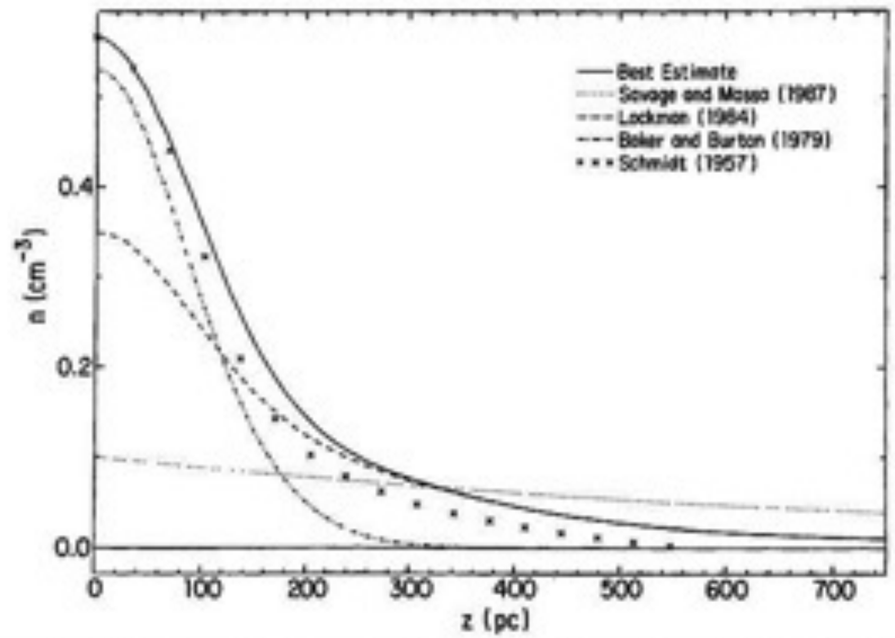


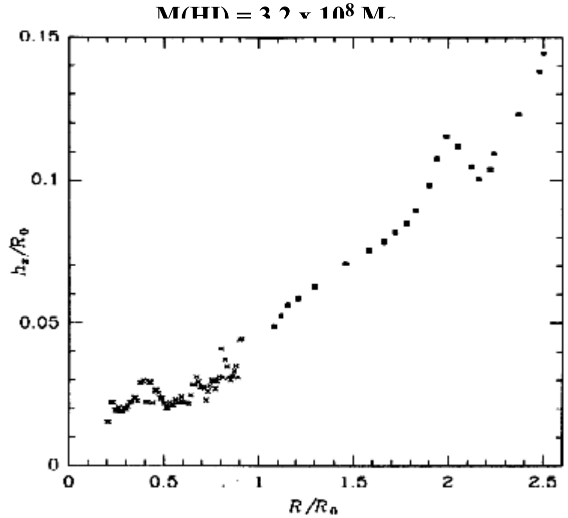
Increase of the *u* peculiar velocity with age, for uncorrected and corrected chromospheric ages.

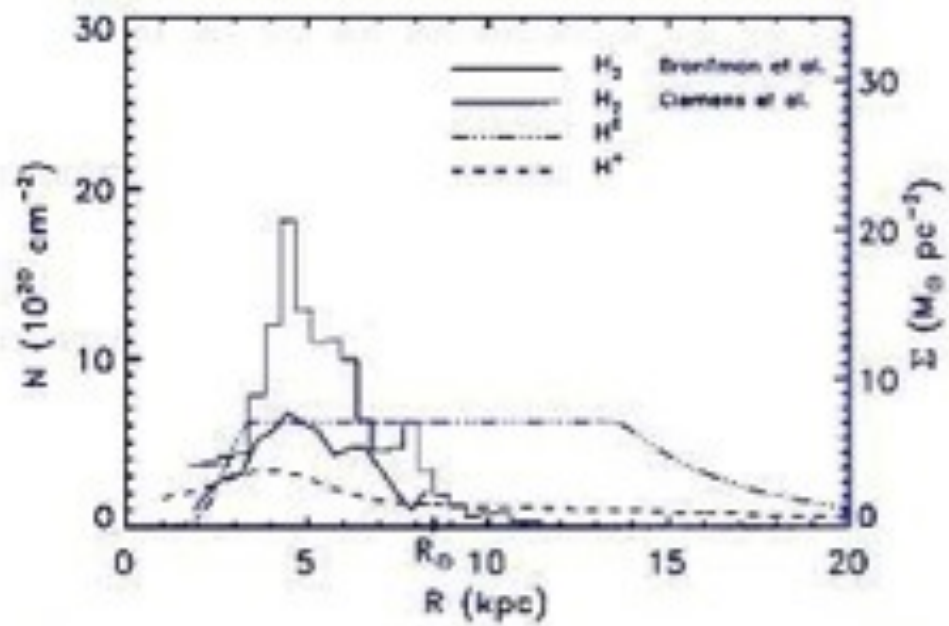
h_z 350 +- 50 pc
h_R = 5.0 +- 0.5 kpc
$\mu(R_{sun})$ = 22.1 +- 0.3 (B)
L_T (B) ~ 1.8 x 10^{10} L_{sun}

Properties of the HI Disk

- **HI Disk**
  - **Hyperfine Structure Line (21 cm)**
  - **Vertical Distribution Requires Two Components (Dicky & Lockman 1990)**
    - **Thin Disk Scale Height: 1000-200 pc**
    - **Thick Disk Scale Height: 1.6 kpc**
    - **Disk Flares Beyond Solar Circle**
  - **Radial Distribution**
    - **~ Constant surface density (R< 15 kpc)**
    - **Scale Length: 3.75 kpc**
    - **Outer Disk has Warp**
  - **Total HI Mass**
    - **$M(HI) = 3.2 \times 10^8 M_{\odot}$**



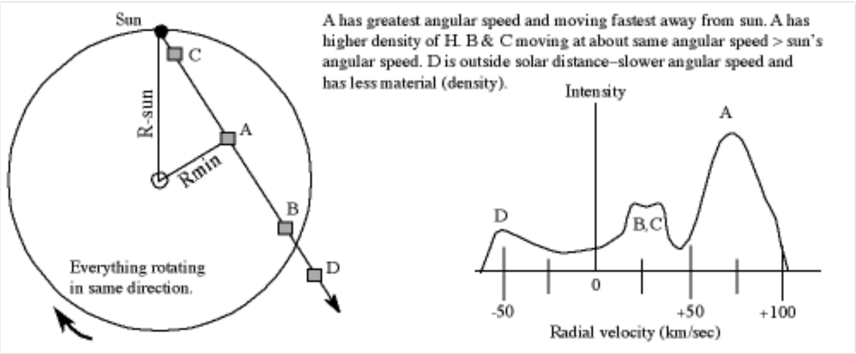




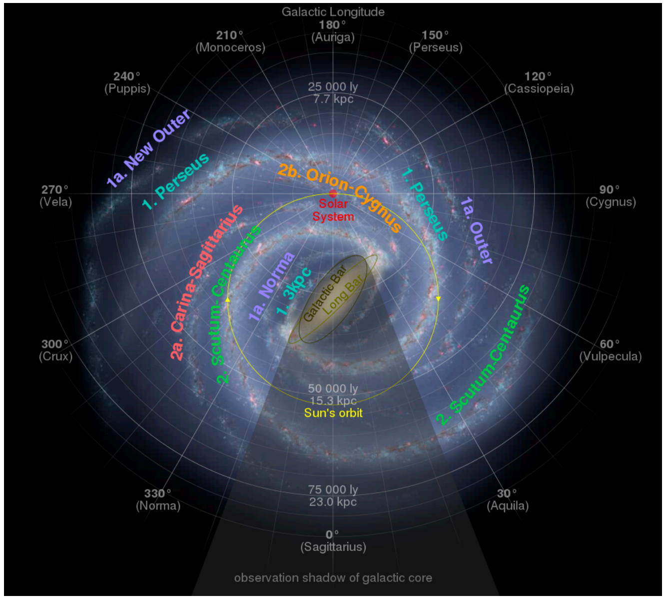
Properties of the HI Disk - II

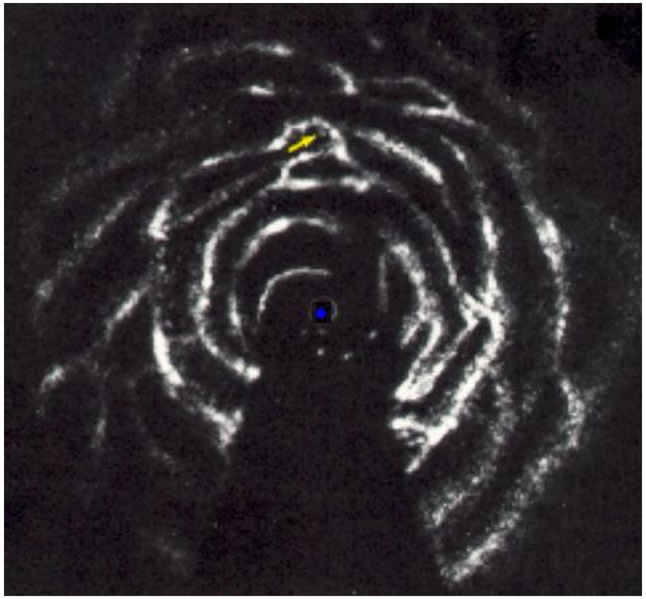
- **HI Disk**
  - Highly Flattened Disk
  - Location of Individual Clouds Found via the Tangent Point

  (see Oort et al. 1958, MNRAS 118, 379)
- **Suggestive of Spiral Structure**
- **Combining All Available Data in HI, HII, CO, OB Associations, etc. Reveals Distinct Spiral Arms (named by constellations towards which they are found)**



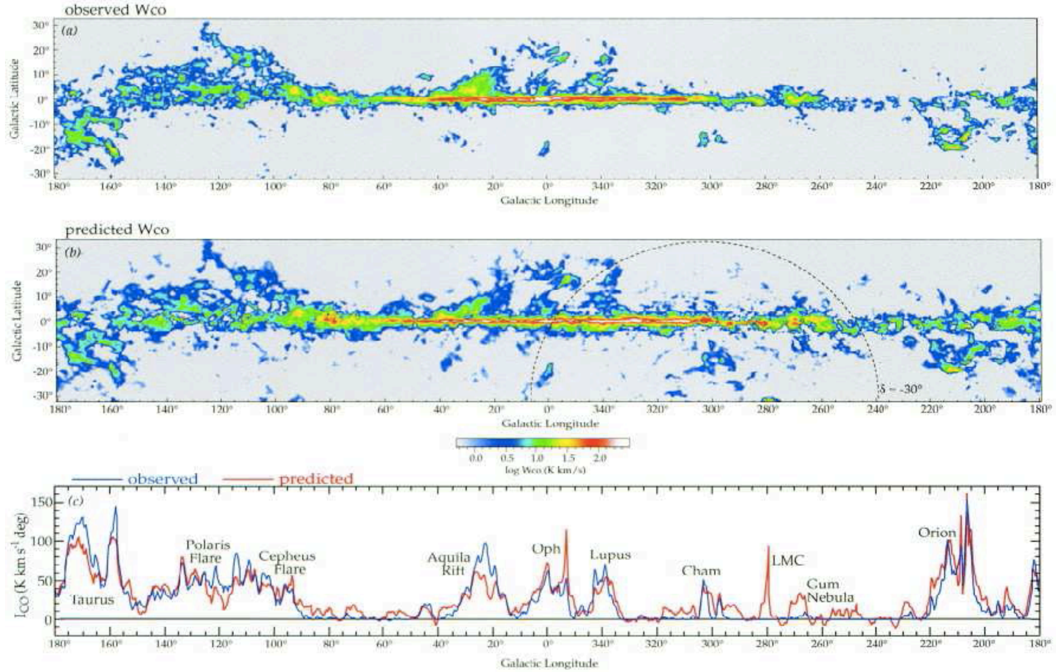
Four clouds all in the same direction. Use doppler shifts to distinguish one cloud from the other. Use the rotation curve to convert the doppler shifts of each cloud to distances from the center of the Galaxy. Do this for other directions to build up a map of the Galaxy strip by strip.

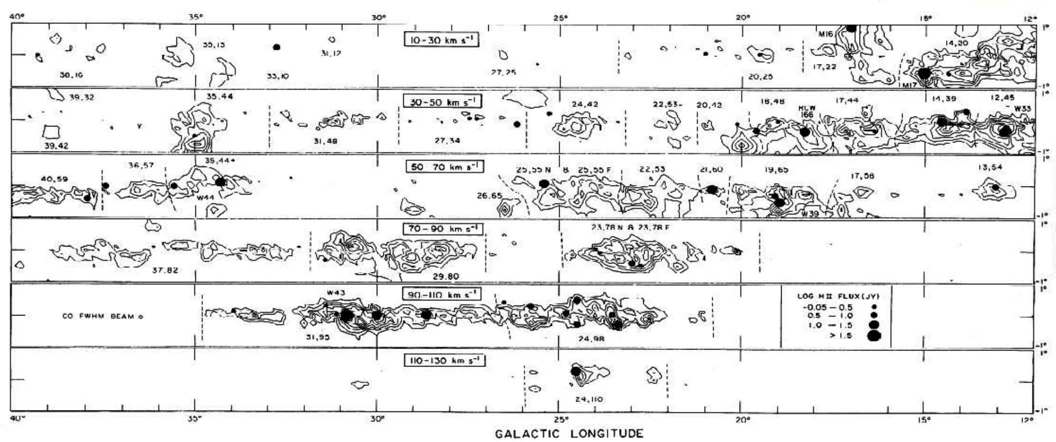


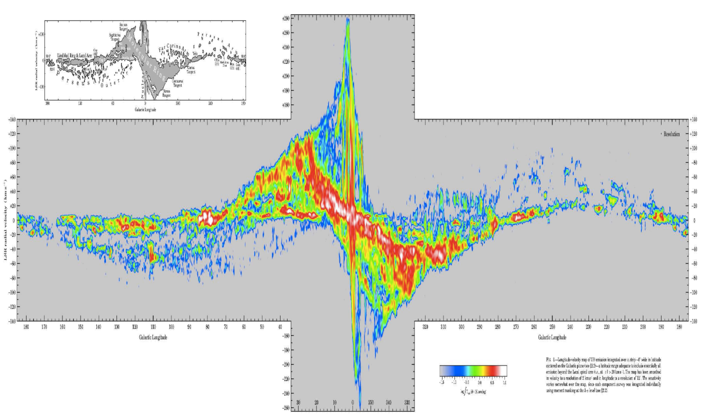


Properties of the Molecular (CO) Disk

- **Molecular Disk**
  - **Rotational Transitions from H2 Molecule Strongly Forbidden**
  - **Molecular Component Traced via CO**
    - **λ = 2.6 mm**
    - **Recent All-sky Survey (Dame et al. 2001)**
  - **Vertical Structure**
    - **Molecular Scale Height: 80 pc**
  - **Radial Distribution**
    - **Molecular Ring (R~ 3 kpc)**
    - **Strongly Clumped into Clouds (Meyers et al. 1986)**
    - **Outer Disk has Warp**
  - **Total Molecular Mass**
    $M(H_2) = 10^9\ M_{Sun}$





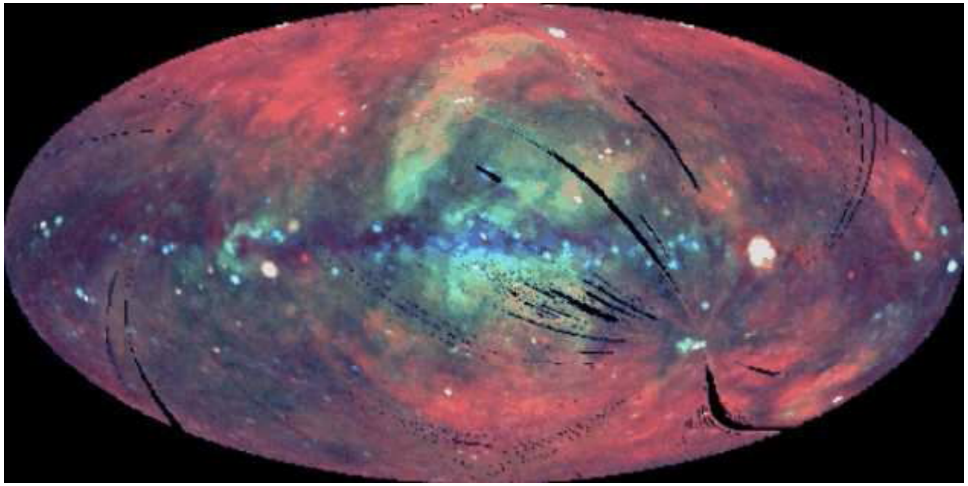


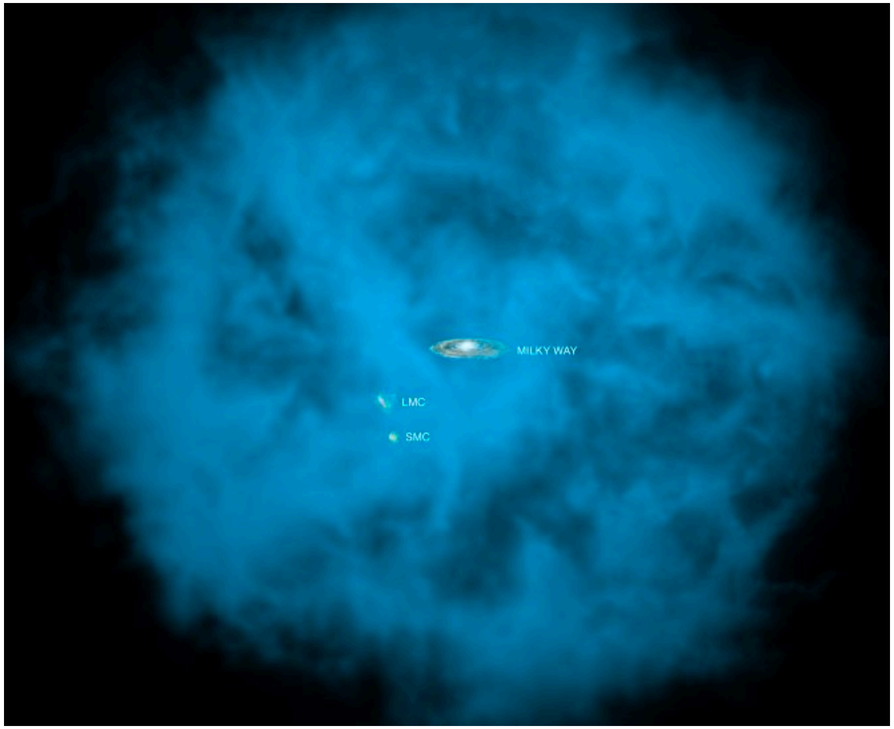
Properties of the Hot Disk

- **Hot Gaseous Disk**
  - OVI Lines Easily Detected in UV
  - N(OVI) = 2 x 10^8 cm^{-3}
  - Vertical Structure
    - Ionized Gas Scale Height: 5.5 kpc
  - Radial Distribution
    - Extends Over Disk
    - Diffuse, High-latitude Filaments
  - Hotter X-Ray Emitting Gas
    - Soft (0.1 – 0.8 keV) Emission at High Latitudes
    - Hard (1.8 – 2.4 keV) Penetrates HI Disk
  - Gamma Rays Concentrated to Plane
    - Mostly Discrete Sources
  - Supernova Remnants
    - Green Catalog

    www.mrao.cam.ac.uk/surveys/snrs/
- **Hot Gaseous Halo**
  - 10^6 K and Massive ~ 10^{11} M_{sun}

(Fang, Bullock & Boylan-Kolchin 2012, ApJ 762, 1)



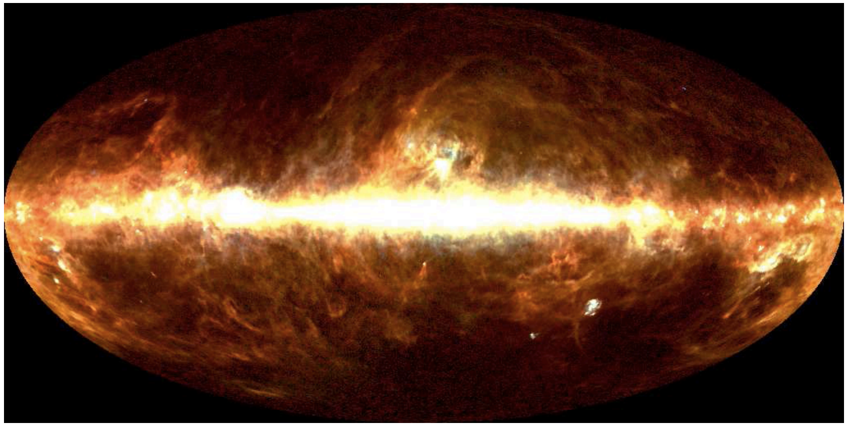


Dust, Bubbles & Chimneys within the Disk

- Dusty Disk
  - COBE IR Emission Maps
  - Concentrated to Disk
  - High Latitude Filaments
- Sun within Neutral Gas Cavity
- Chimneys Blown from Supernovae
  - Diameter: 80 – 140 pc
  - Must Be Filled with Hot Gass
  - Density: 4 x 10^{-3} cm^{-3}
  - Temperature: 10^6 K

  (Miller & Cox 1993)

  (Lallement et al. 2003)
- Star Formation & Feedback
- Origin of Gould's Belt?



314 D. Breitschwerdt et al.: Origin of H I clouds in the Local Bubble. I

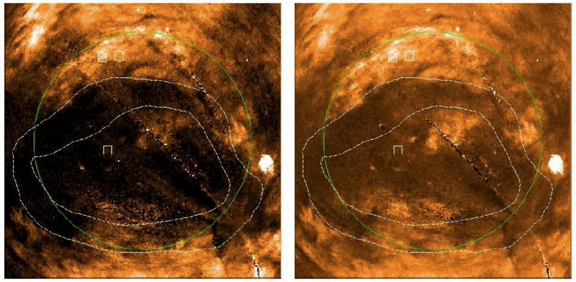


Fig. 5. ROSAT PSPC maps of the Loop I region in the R1 (left) and R2 (right) band centered on the centre of the radio continuum (RC) Loop I, $(l, b, r) = (330°, +17.5°, 58°)$. Dashed white lines mark the contours of the H I ring formed by the interaction of Loop I with the LB as described in Egger & Aschenbach (1995). For details see text.

452 R. Lallement et al.: Mapping the Local Bubble

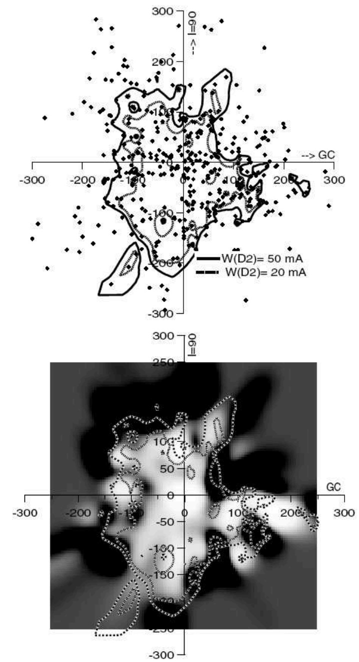


Fig. 4. Dense gas along the galactic plane: iso equivalent width contours for $W = 20$ mÅ and 50 mÅ resp. (top), calculated from 426 selected stars, and cut in the 3D volumic density obtained from the global inversion of the column-densities (bottom).

R. Lallement et al.: Mapping the Local Bubble

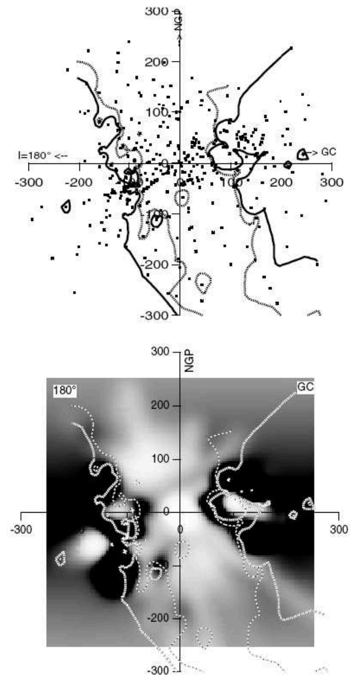


Fig. 4. in the meridian plane. The iso-contours are derived from 387 stars.

Star Formation within the Disk

- Early Infrared Surveys
  - First All-sky Surveys Find Sources
  - Orion Star Forming Region
  - Taurus-Auriga
- 2MASS Survey
  - First Modern All-sky Near-IR Survey
- VISTA VVV Survey
- Spitzer GLIMPSE
- WISE
  - Catalog of Galactic HII Regions

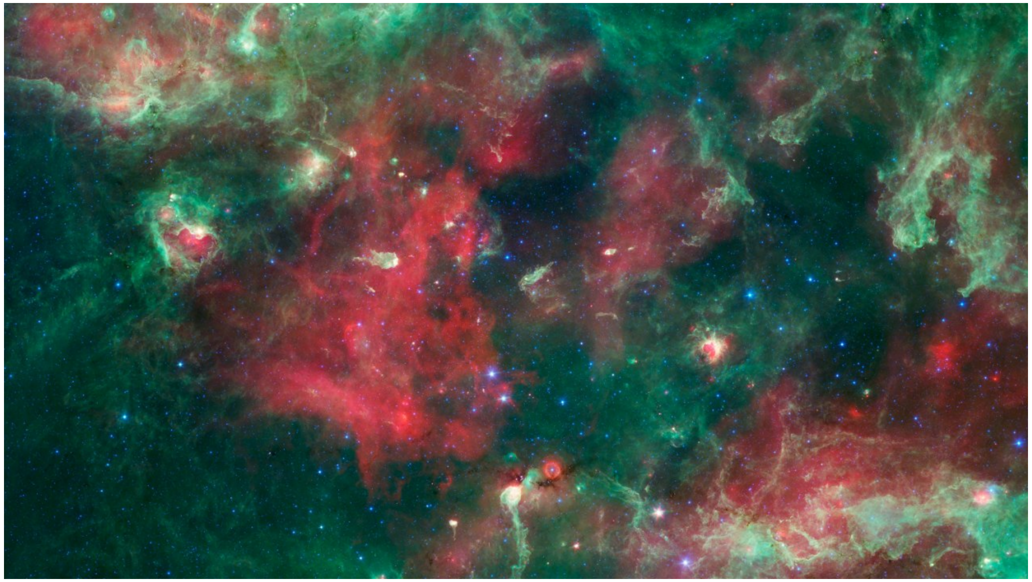
(Anderson et al. 2012, ApJS 212, 18; http://astro.phys.wvu.edu/wise)

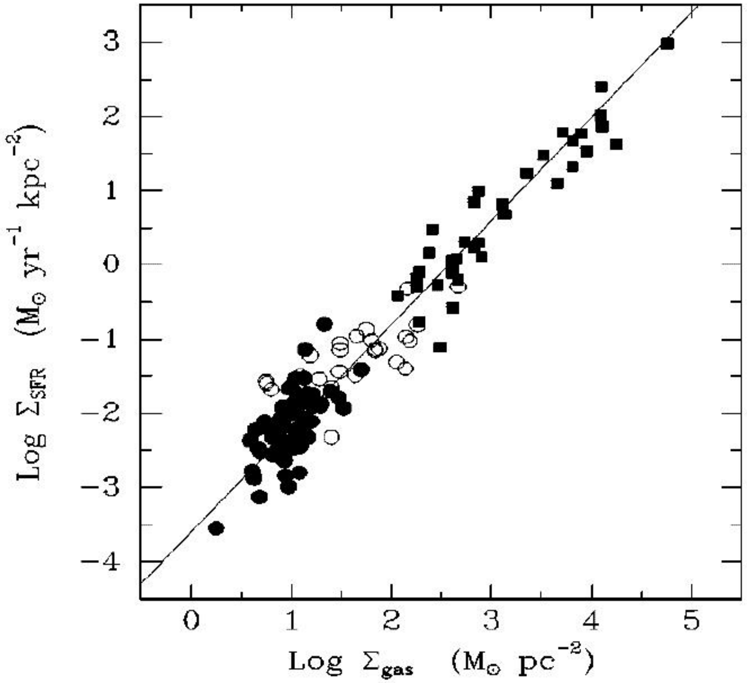
- Schmidt Law: Star Formation Correlates with Gas Density

(Schmidt 1959, ApJ 129, 243; Kennicutt 1998, ARAA, 36, 189)

- Hot Halo Fed From SNII Winds

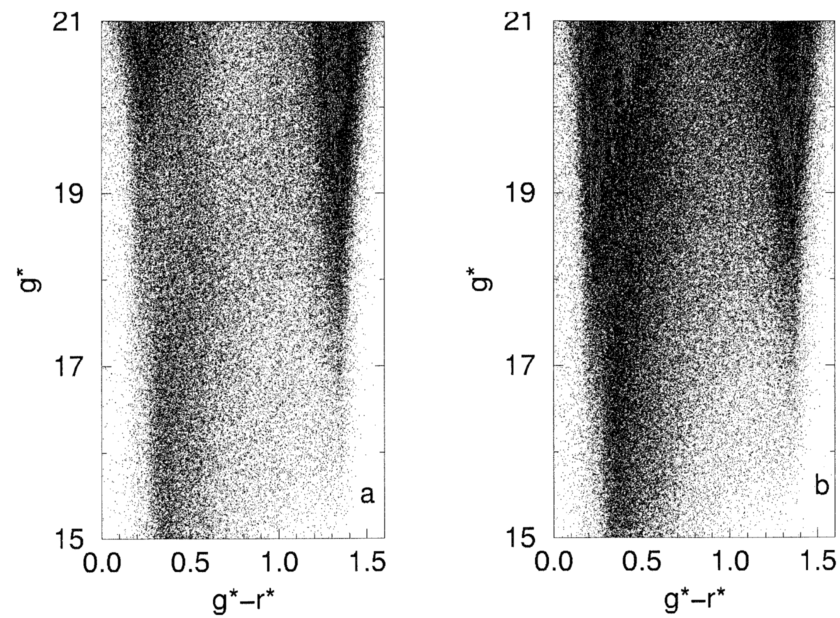
(Nakashima et al. 2018, ApJ 862, 34)

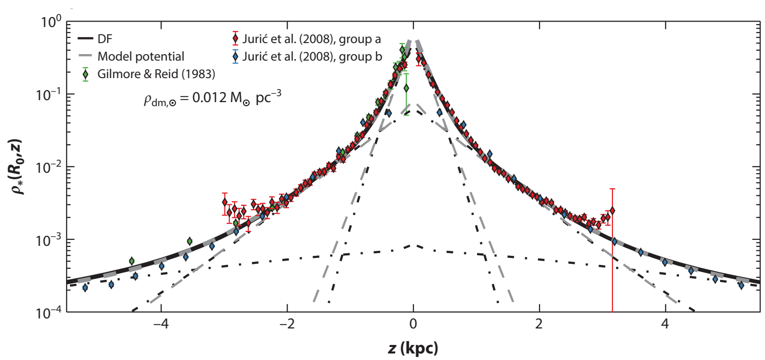


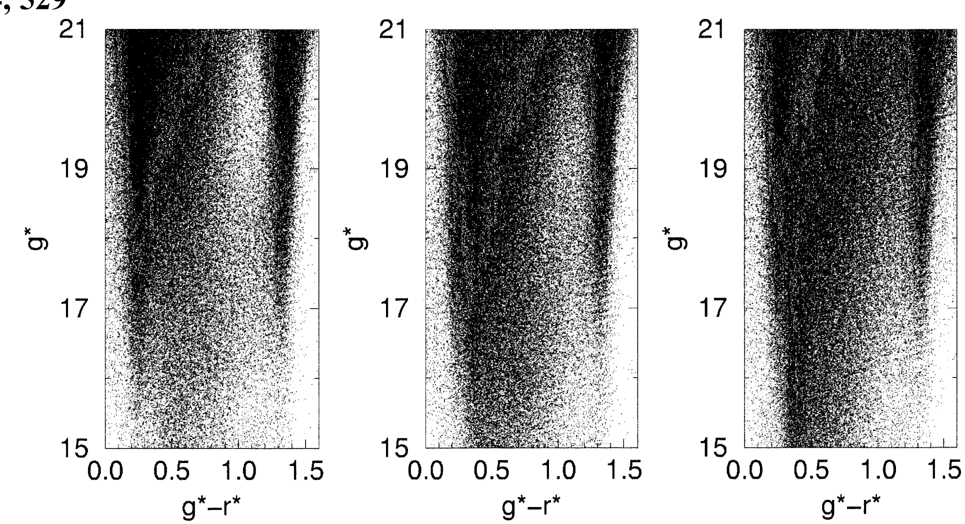


Properties of the Thick Stellar Disk

- **Star counts at High Latitudes**
  - Star Counts by Gilmore & Reid (1983 MNRAS 202, 1025) suggest a second, thicker exponential disk (bottom)
  - SDDS Counts (Chen et al. 2001, right)
  - Northern & Southern Strips
  - Thick Disk Properties
    - Scale Height ~ 0.6 – 1 kpc
    - Old Stars (Gilmore & Wyse 1995)
    - -1 < [Fe/H] < -0.2
    - 5% mass of thin disk
  - Early Heating of Thin Disk?
    - Likely Results from Heating of Thin Disk + Satellite Debris
    - Bland-Hawthorn & Gehard 2006, ARAA 54, 529

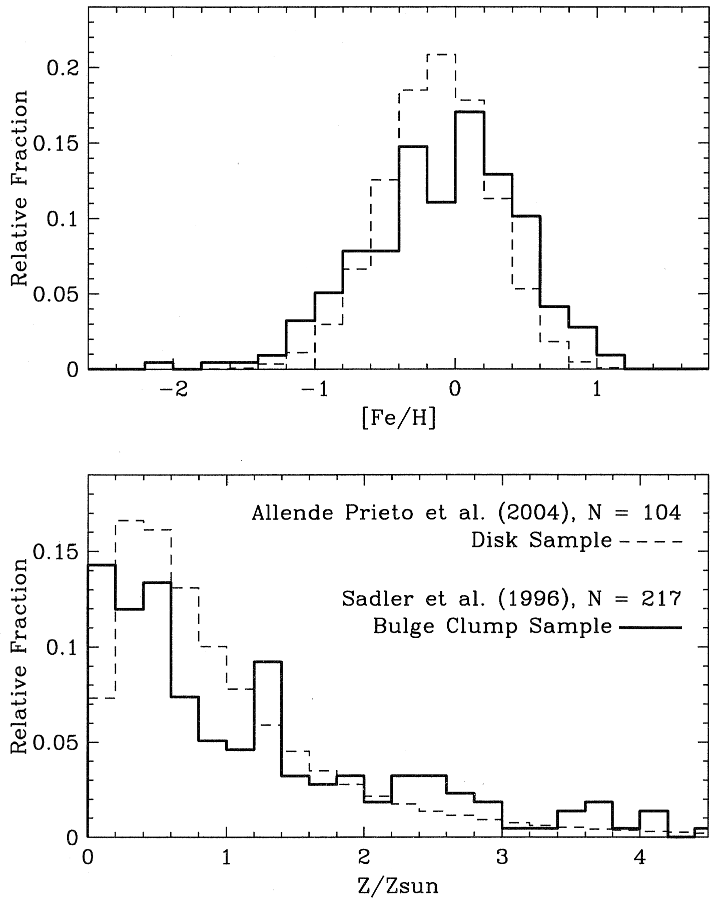






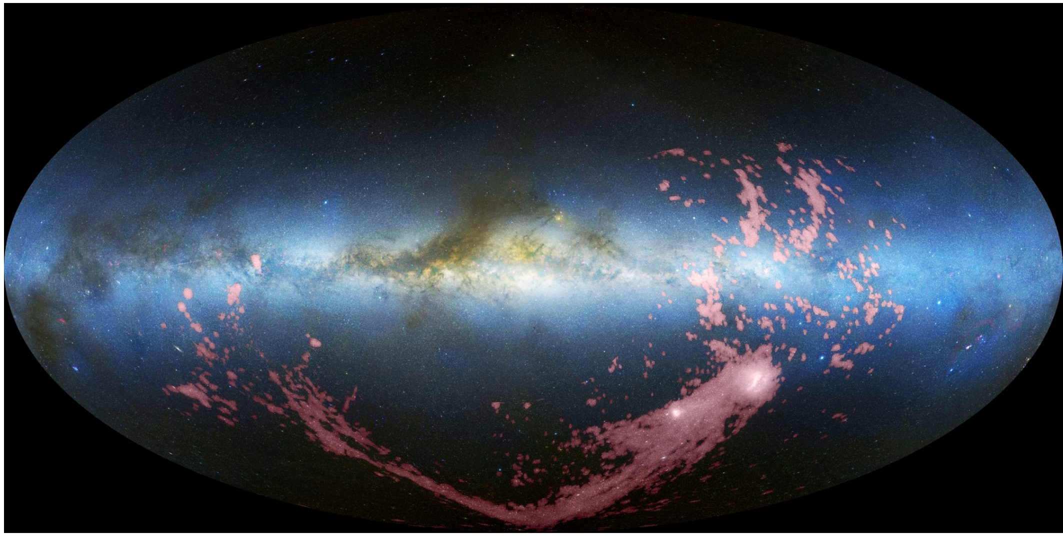
Properties of the Milky Way's Bulge

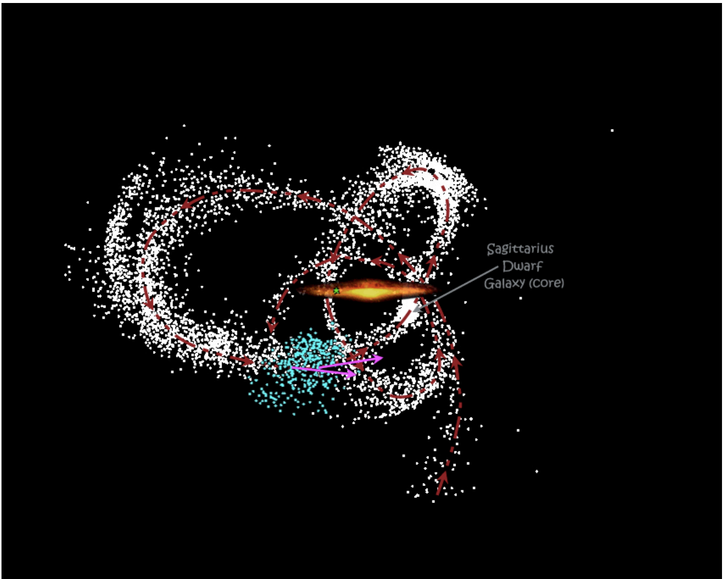
- **Baade's Window**
  - **Star Counts Reveal High Stellar Density**
  - **Optical Images Suggest Relatively Little Extinction in Baade's Window**
  - **Spectroscopy Indicates High Metallicity**
  - **No Simple Age-Metallicity Relation**
  - **SED can only be Fit with Asymptotic Giant Branch Stars**

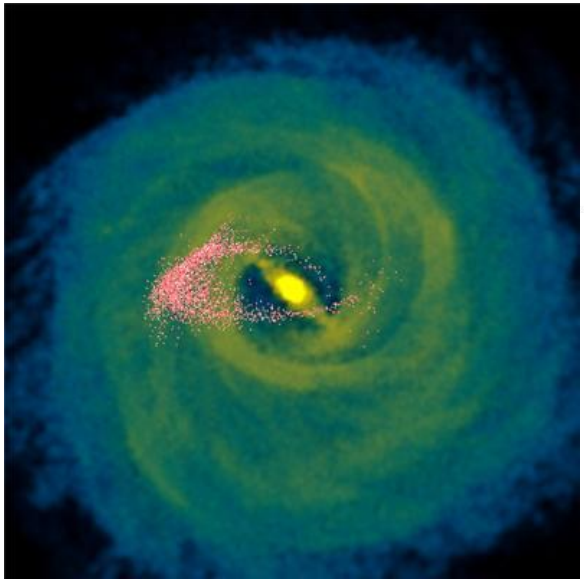


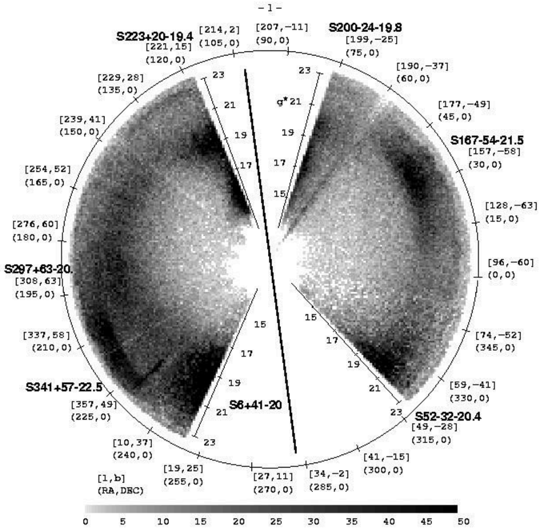
Stellar Streams and the Magellanic Stream

- **Magellanic Stream**
  - Stream of HI gas associated with Large & Small Magellanic Clouds
  - Must be tidal debris
  - Some RR Lyraes found along stream
- **Stellar Streams**
  - SDSS Revealed Streams of Stars
  - Sagitarius
  - Aquarius
  - Virgo
  - Monocerotis
- **Stellar Streams in the Bulge of M31**
  - Chapman et al. 2008



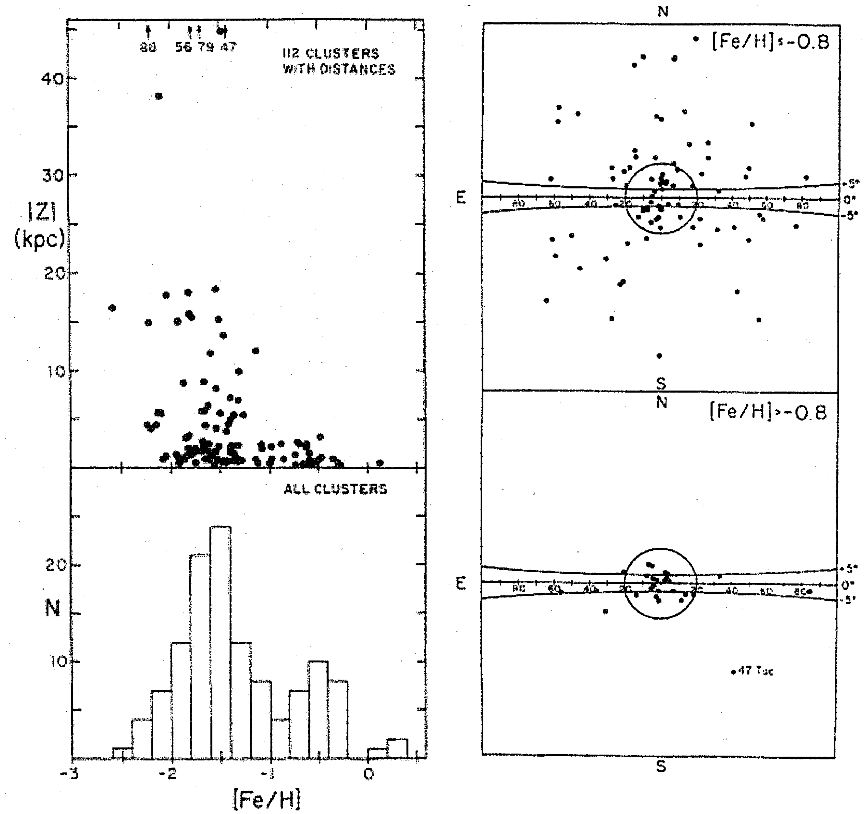


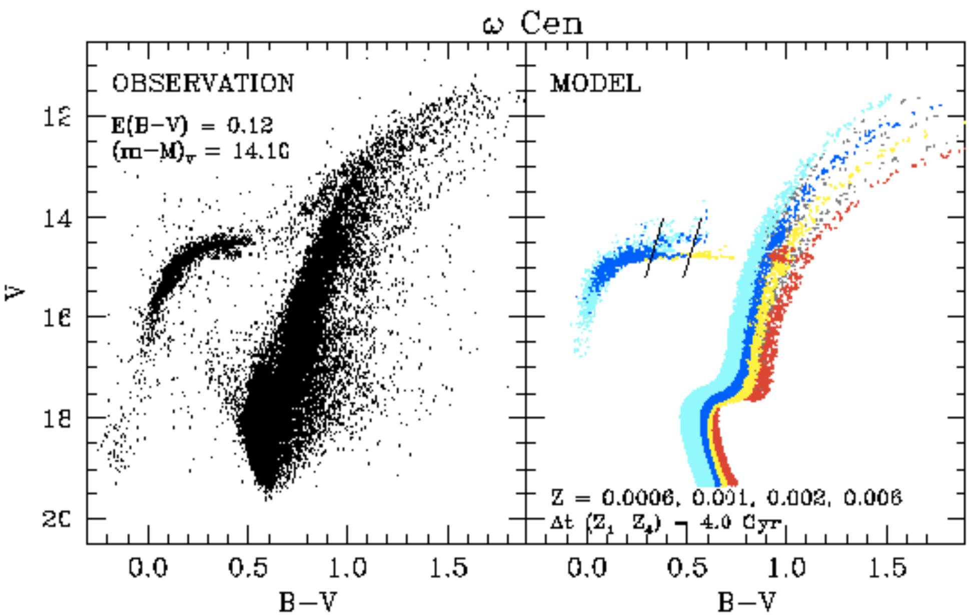




Globular Clusters & the Milky Way's Halo

- **Metallicity Distribution of Globular Clusters**
  - Metal-Rich Clusters Confined to Disk
  - Metal Poor Clusters Form Halo
  - Zinn
- **Evidence of Distinct Ages in Globulars**
  - CMDs Imply Different Ages and/or [Fe/H]
- **Globular Clusters and the Cores of Dwarf Galaxies**
  - Stellar Streams and Associated Globular Clusters (Pal 5) Imply Globulars are Cores of Accreted Galaxies
  - Halo Streams Reveal Tidal Debris





Rotation and Mass of the Milky Way

- **As Described Above the Maximum Velocity Found at Tangent Point Along Line of Sight**
- **HI Rotation Curve Beyond Solar Circle**
- **CO Velocities Within Solar Circle**
- **Mass of the Milky Way:**

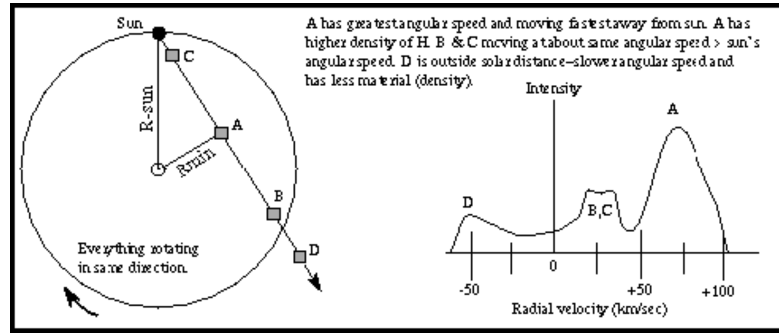
For Circular Motion:

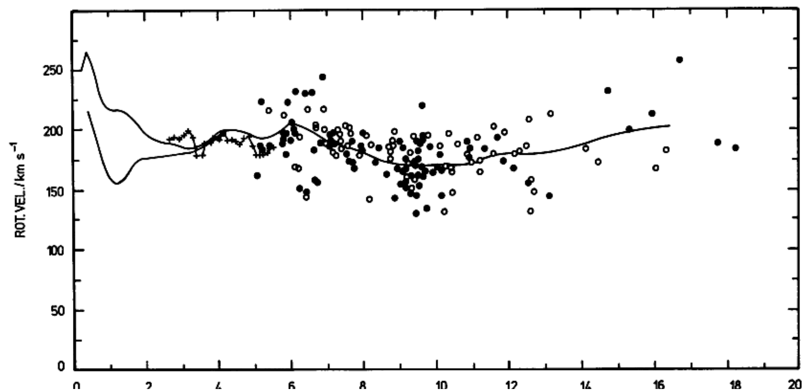
$$M(R) = V^2R/G$$

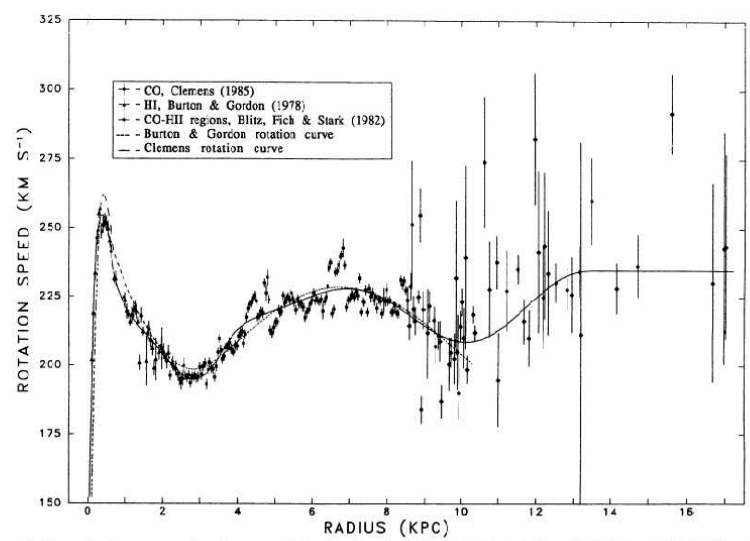
$M\ (R_{sun}) = 9.6 \times 10^{10}\ M_{sun}$

$M(R_{max}) \sim 10^{12}\ M_{sun}$

- **Evidence for Dark Matter**
  - **Since $L \sim 3 \times 10^9\ L_{sun}$ the Mass to Light Ratio Within Sun's Orbit is: $M/L \sim 30$ and is Approximately 300 if We Include Mass Within Maximum Extent of the Rotation Curve.**







Summary of the Milky Way

- Thin Disk at Low |Z| with Thicker Disk at High |Z|
- Youngest stars at smallest |Z| but |Z| Increases for Older stars
- Young Stars and HI Gas Shows Spiral Arms
  - Can Identify Major Arms
- Stellar Bar pointed Almost Towards the Sun
  - Star Counts (e.g., Hammersley et al. 2000, MNRAS 317, L45)
- Molecular Ring at R ~ 3kpc
- Star Formation Throughout Thin Disk
- Evidence for Accretion of Dwarf Galaxies
  - Magellanic and Stellar Streams Direct Evidence for Accretion of Dwarf Galaxies
  - Globular Clusters May be Surviving Cores of Dwarf Ellipticals