Astronomy 5465
Galaxies

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  - **Office Hours**
    - **By Appointment**

Astro 5465 Tuesday. Jan. 18, 2022
Today's Topics

- **Class Overview**
  - **Overview of Material**
  - **Syllabus**
  - **Schedule**
- **Introductions**
  - **Who are you?**
  - **Who am I?**
- **Course Prologue**
  - **Summary of Galactic and Extragalactic Astronomy**
  - **Historical Overview**

Highlights of the Syllabus

- **Text:**
  - Galaxies in the Universe – Sparke & Galagher
- **Additional References:**
  - Galactic Astronomy – Binney and Merrifield
  - Galactic Dynamics – Binney & Tremaine
- **Popular Texts:**
  - Coming of Age in the Milky Way – Ferris
  - Lonely Hearts of the Cosmos - Overbye
  - Minding the Heavens: Story of Our Discovery of the Milky Way - Belkora
- **Additional Readings:**
  - Articles & Papers from the Literature, especially Annual Reviews
- **Lectures: Reading done in advance, notes on the web**
  - **One chapter covered each week!**
- **Homework: Typically Assigned/Due on Wednesdays**
- **Exams: Midterm Exam + Final Presentation**
- **Grading: Exams – 50%, Homework - 50%**

Syllabus Continued

- This Course will Feature Three Themes:
- Galaxies as stellar population factories
- Galaxies as fossil remnants of early formation processes
  - Secular evolution, evolution of stellar populations, etc.
- Sites of unique astrophysics (dark matter)
- Lecture:
  - I plan to lecture 3 hours per week but let each of you lead a discussion of the assigned readings (~ 15 min. on Friday).
- Homework (25%):
  - Homework will be assigned periodically: analytic & computational
- Exams (50%):
  - Midterm (25%) and Final Presentation (25%)

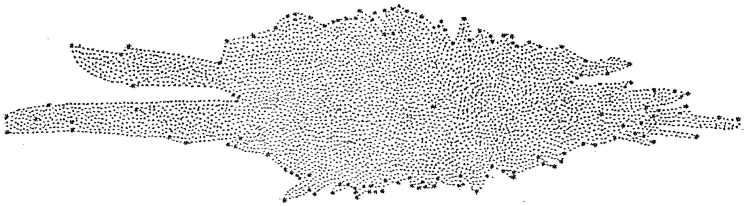
Who am I?

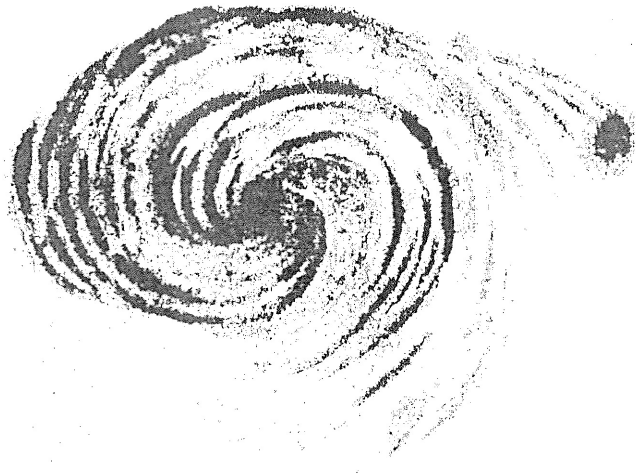
- **Background**
  - **Ph.D University of Hawaii**
    - **Measured Expansion of the Universe**
    - **Inferred Existence of Dark Energy**
  - **Plaskett Fellow, Herzberg Institute for Astrophysics (Victoria, BC)**
  - **Research Fellow, Kitt Peak National Obs. (Tucson, AZ)**
  - **Assistant Professor, Indiana University**
  - **Associate Professor, University of Wyoming**
- **Research Interests**
  - **Evolution of Galaxies**
  - **Gravitational Lensing & Cosmology**
  - **Astronomical Instrumentation**

What Do You Think of When You Think of Galaxies?

Brief History of Galaxies

- **Galileo - Uniform distribution of Bright Stars but Faint Stars form Flattened Plane - Milky Way**
- **Kant – Galaxies as Island Universes**
  - **Solar System analogy: flattened structure dominated by gravitational force**
  - **The Nebulae could be similar but very distant systems**
- **Messier's Catalog of the brightest nebulae (star clusters & galaxies)**
- **Herschel's catalogs of nebulae (circa 1780) followed by Dreyer's NGC (New General Catalog)**
- **Herschel's star counts (#stars vs. mag.) reveal flattened disk of stars**
- **Ross (circa 1845) observes spiral structure in some nebulae**



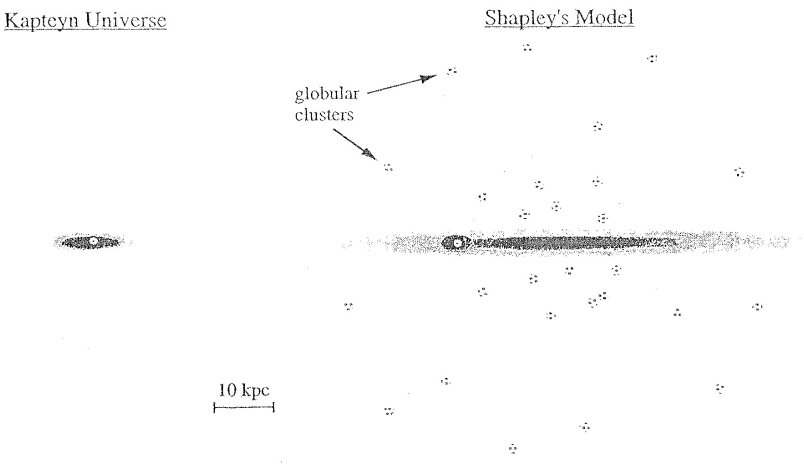


Brief History of Galaxies Cont.

- **Kapteyn Selected Areas around the sky (~ 200 designated by IAU)**
  - **World-wide effort to count stars vs. mag. (pg mags: calibration wrt North Polar Sequence)**
  - **Spectral Types and velocities of brightest stars**
  - **Results (collected by Kapteyn [1909, Ap.J. 29, 46, 30, 284, 398]):**
    - **MW is a flattened distribution of stars (5:1 axial ratio)**
    - **Sun at center with density decrease in all directions (50% at 800 pc, 10% at 2800 pc)**
    - **Sun about 650 pc from center**
    - **Kapteyn considered extinction but since reddening was modest concluded it was negligible (assumed scattering dominated, not extinction)**
- **Trumpler (1930) discovers significant extinction using Galactic clusters**
  - **stars in clusters dim faster than distance (angular size) would produce**
  - **star counts in "dark nebulae" are offset wrt unobscurred regions**

Brief History of Galaxies Cont.

- **Shapley (1918, 1919) discovers the true size of the Milky Way**
  - **distribution of Globular Clusters not centered on Sun**
    - **centered about 15 kpc from Sun (RR Lyrae variables)**
    - **concentrated in direction of Sagittarius**
    - **Milky Way is 100 kpc across**
    - **Recognized "zone of avoidance" but didn't connect it with extinction**
- **Shapley-Curtis Debate (1920) on**
  - **Size of the Milky Way and Location of the Sun**
  - **Distance and Nature of Spiral Nebulae**
- **Shapley – Galaxy is very big and contains spiral nebulae**
- **Curtis – Galaxy is small and spiral nebula are distant galaxies**
- **Oort Suggested Extinction**



Brief History of Galaxies Cont.

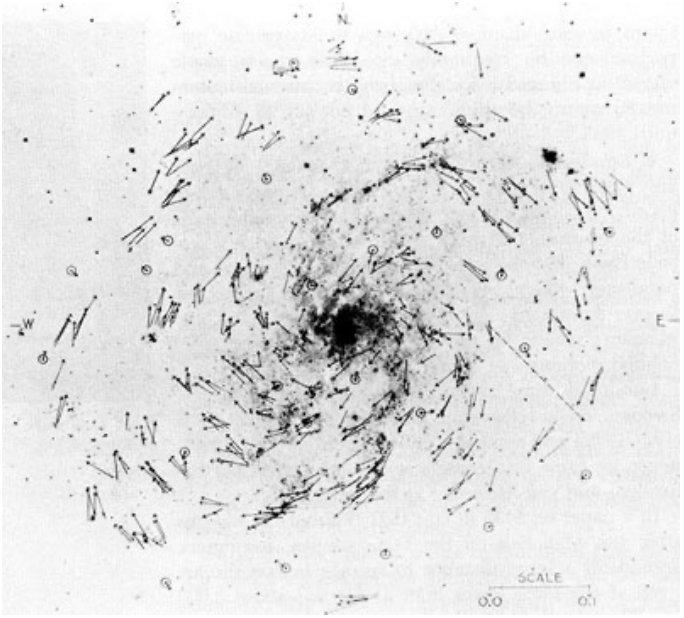
- **Summary of the Great Debate on the Nature of Spiral Nebulae**
- **Both were right and both were wrong! Details:**

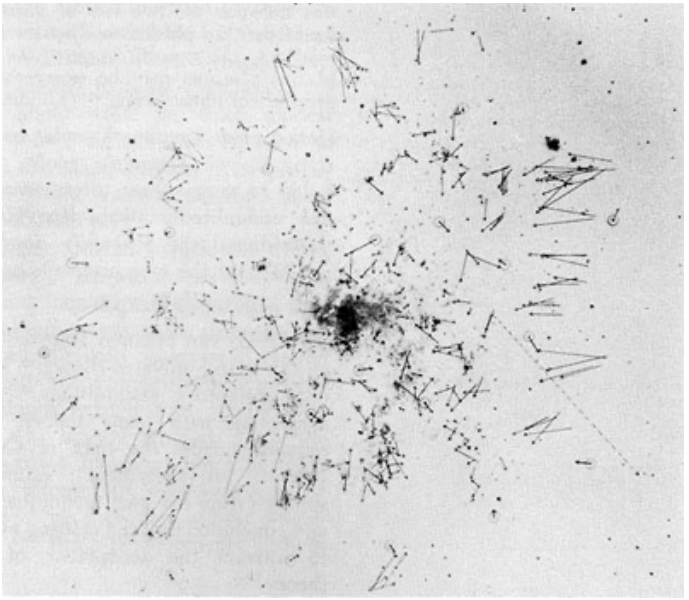
	Curtis:	**Shapley:**
•	**Kapteyn: right (MW ~ 10 kpc)**	**wrong (MW ~ 100 kpc)**
•	**SN1885: Nova – M31 at 150 kpc**	**Nova – M31 at 150 kpc**
•	**(external galaxy)**	**(M31 inside MW!)**
•	**van Maanen's rotation of M33: ??**	**if V ~ 200 km/s, D < 50 kpc**
•	**high v stars: unbound to MW, why?**	**OK since MW is massive**
•	**MW appearance: like edge-on nebulae**	**??**
•	**Zone of Avoidance: neglected extinction**	**destruction of globulars**

- **Hubble's Measurements of Extragalactic Cepheids**
  Hubble resolves M31 disk into stars (1920)
  Cepheid Period-Luminosity Relation (Leavitt 1920)
  - **Finds Cepheids in NGC 6822 and M31 (1922) and shows they are ~ 300 kpc away**

Van Maanen vs. Lunmark

- **Van Maanen claimed to have measured proper motion of rotation within M33**
  - **Most talented and respected astrometrist of his day**
  - **Work was unquestioned since it demonstrated what most expected.**
- **Lundmark checked this after Hubble's measurement of extragalactic Cepheids**
  - **Unable to confirm van Maanen's results**
  - **No evidence for rotation.**
  - **Huge embarrassment for Van Mannen**
- **This is an excellent example of the scientific method.**
  - **Best theoretical expectation of the day**
  - **Initially confirmed**
  - **New data led to inconsistency**
  - **Ultimately overturned.**





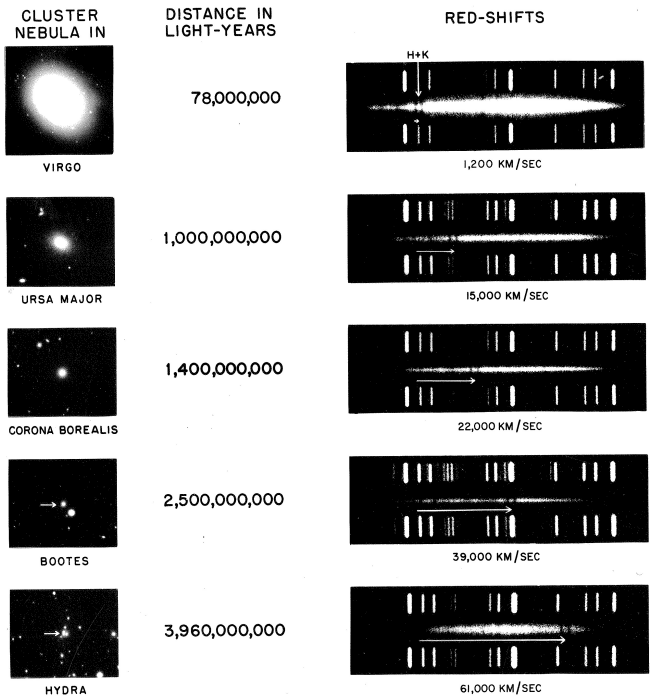
Early Ideas Regarding Stellar Populations

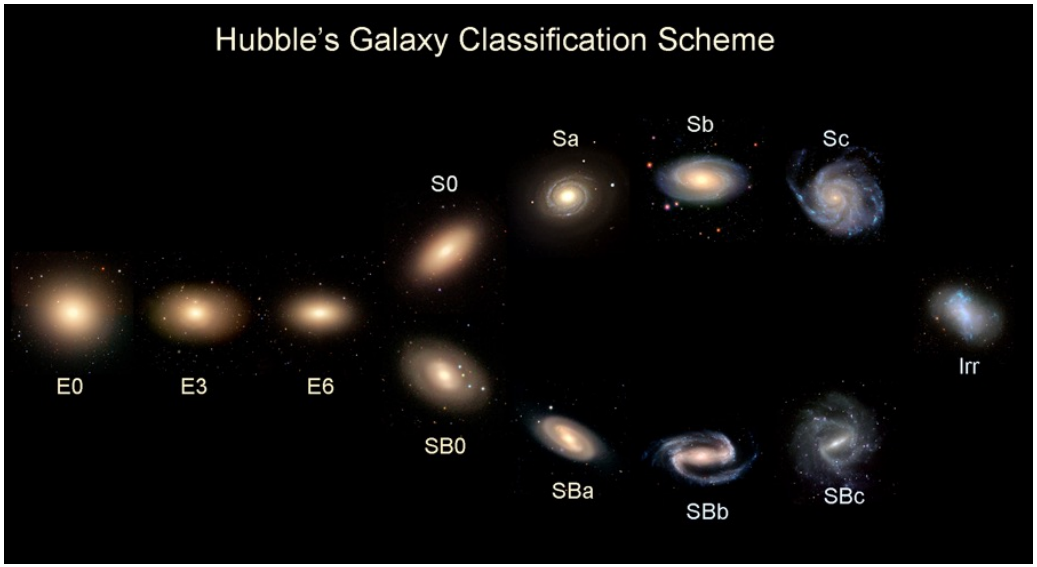
- **Lindblad (1927) – stars move under mutual attraction of gravity**
  - **MW is an axisymmetric disk with 2 components:**
  - **One component with rotational motion**
  - **One component with random motion (explained high velocity stars)**
- **Oort (1927,28) – high velocity stars form a distinct kinematic component, but most in circular orbits traveling with the Sun**
- **Baade (1944, Ap.J. 100, 137, 147) – develops concept of two distinct stellar populations**
  - **Resolves bulge of M31 into stars (i.e., Tip of Red Giant Branch)**
  - **Spiral Galaxies Also Composed of Two Populations (just like MW)**
- **Pop. I – Blue and Red Supergiants**
  - **Disk-like structure with rotational motion**
  - **Young and metal rich (Solar comp.) but some older stars (Sun-like) too**
- **Pop. II – Red Giants and dwarfs**
  - **Spherical-like structure with random motions**
  - **old, metal poor (no young metal-poor stars or old metal-rich stars)**
  - **MW bulge? No! not associated with the local metal-poor stars (the halo)**
- **Pop. III (extremely low metallicity but what about bulges)?**

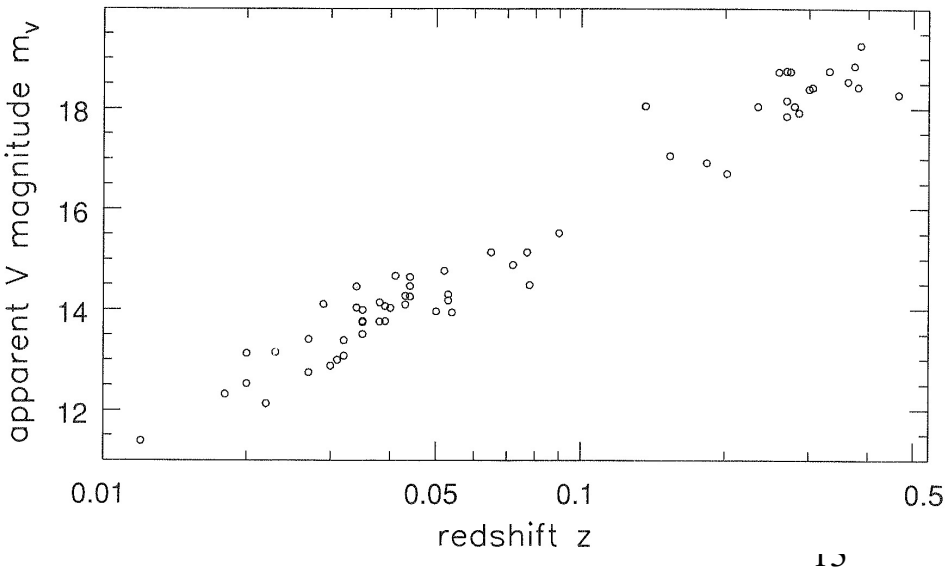
Optical Classification of Other Galaxies

- **Hubble Morphological Sequence**
  - **Nebulae are Galaxies but so different**

  E's -> S0s -> Sa -> Sb -> Sc with parallel barred sequence
- **Structural and Color Trends**
  - **Yes, red and blue sequences**
  - **Populations I & II? (No!)**
- **Kinematical Difference**
  - **Rotation vs. Velocity Dispersion**
- **Velocity-Distance Relation**
  - **Universe expanding (more later)**

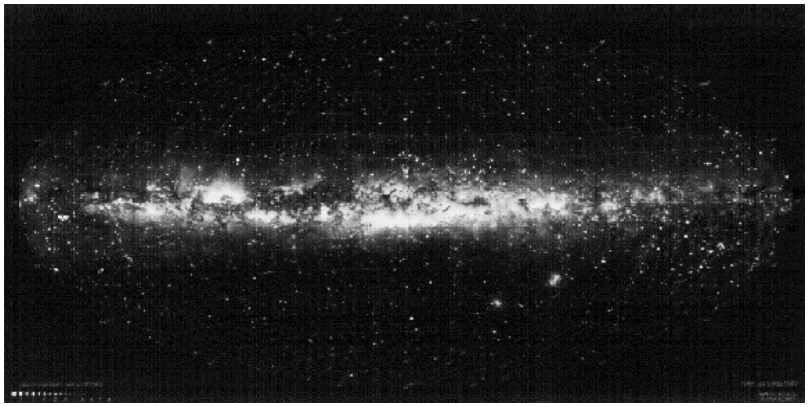


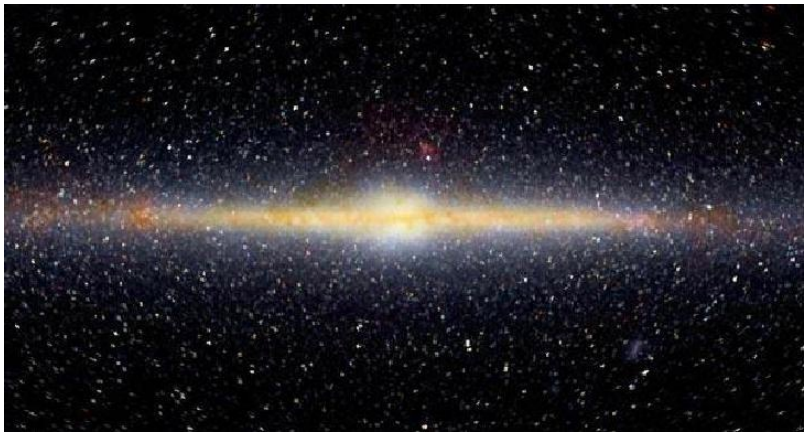




Milky Way is a Disk Galaxy

- **Optical Morphology Reveals Disk of Stars and Dust**
  - **HII Regions, Star Clusters, etc.**
  - **Bulge Seen Through "Baade's Window"**
- **Near Infrared Reveals Near Dust Free Distribution of Stars**
  - **Fall-off in Stellar Density with Radius**
  - **Full Bulge and it's "Boxy" Morphology**
- **Far Infrared Reveals Cool Dust**

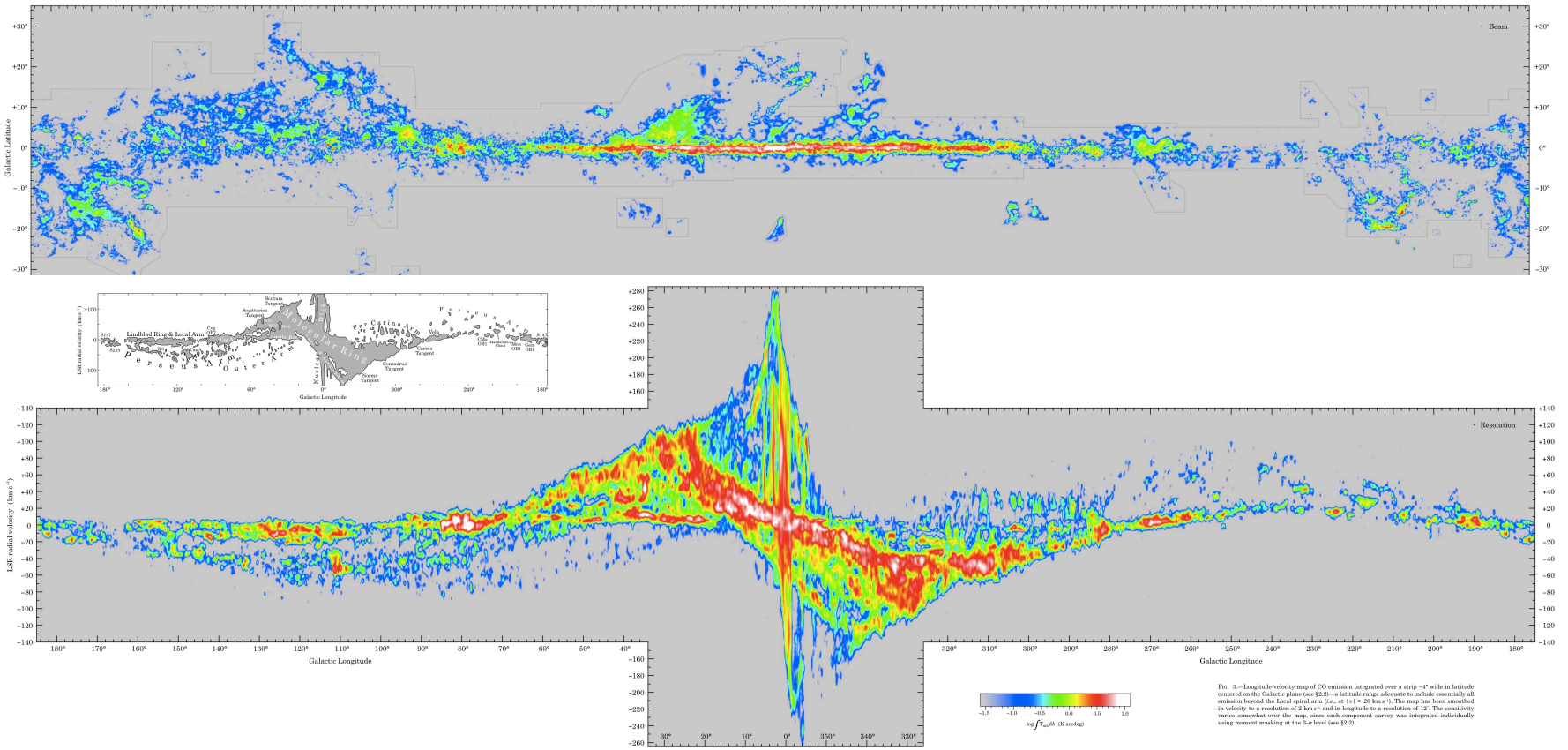




http://astrog80.astro.cf.ac.uk/Chromoscope-tiles/

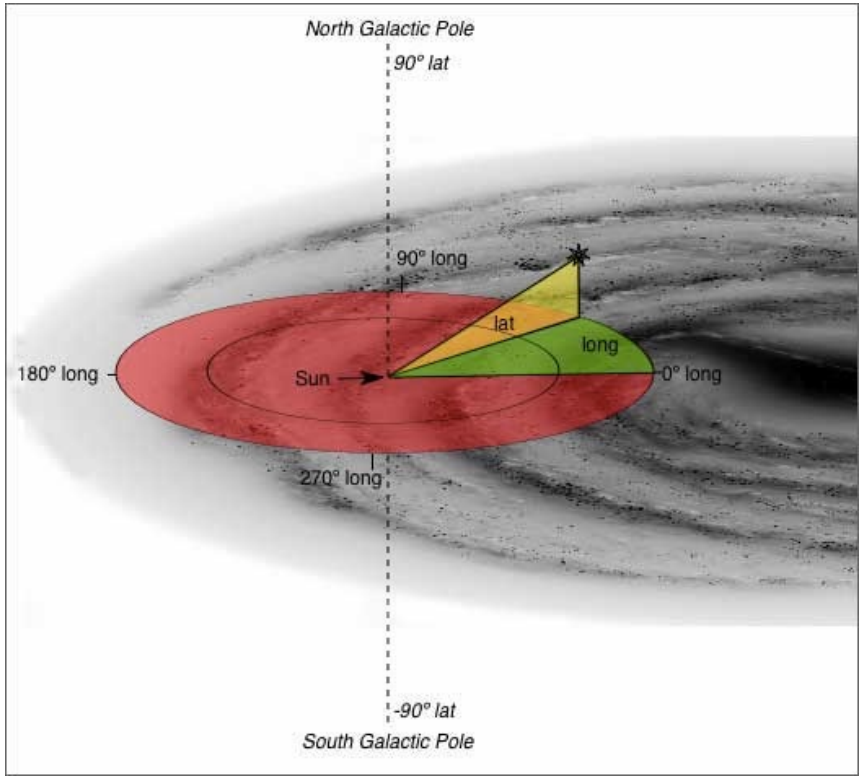
Interstellar Medium of the Milky Way

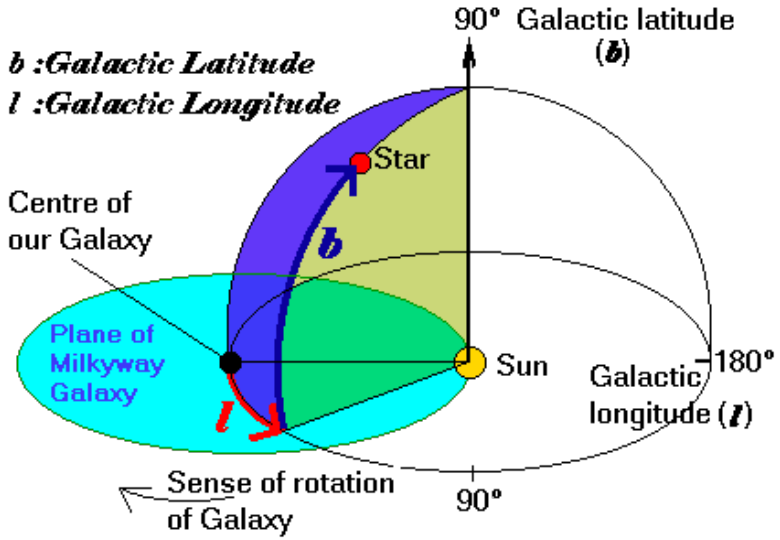
- **Jansky (1932) discovers radio continuum of the Milky Way**
- **Van de Hulst (1944) uses quantum mechanics to predict the 21-cm line (hyperfine) line of neutral Hydrogen**
- **Oort et al. (1958) map the MW at 21-cm (maximum velocity = tangent point, more later)**
- **Recent Maps of MW in CO (Dane et al. 2001)**



Galactic Coordinate System

- **Galactic Coordinates are Defined wrt The Center of the Galaxy**
  - **Transformations given below are in 1950 coords. So you need to precess coords. First (astropy.coordinates)**



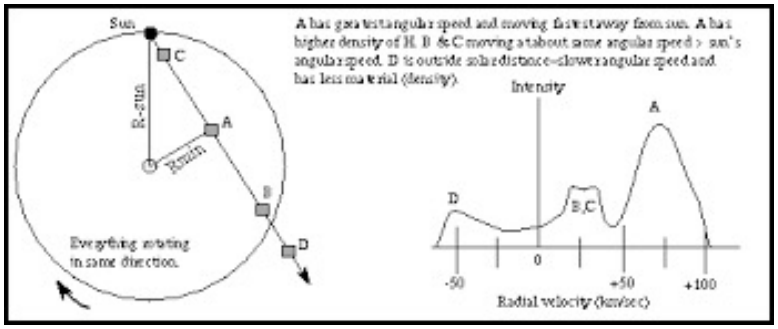


$$l = 303^\circ - \arctan\left(\frac{\sin(192^\circ.25 - \alpha)}{\cos(192^\circ.25 - \alpha)\sin 27^\circ.4 - \tan\delta\cos 27^\circ.4}\right)$$

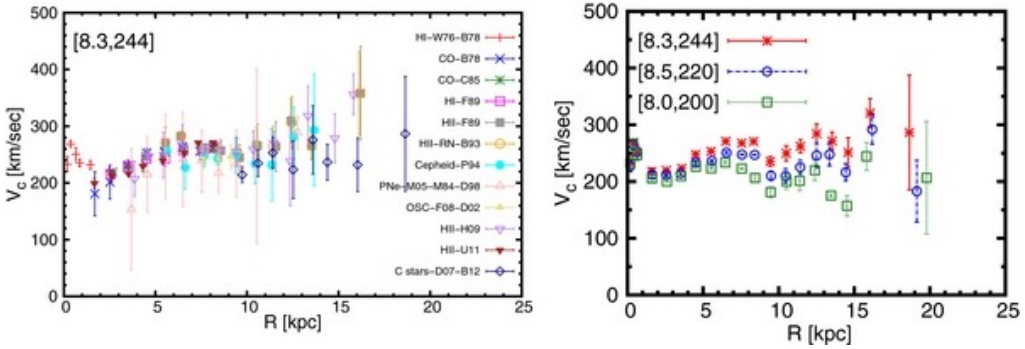
$$\sin b = \sin\delta\sin 27^\circ.4 + \cos\delta\cos 27^\circ.4\cos(192^\circ.25 - \alpha)$$

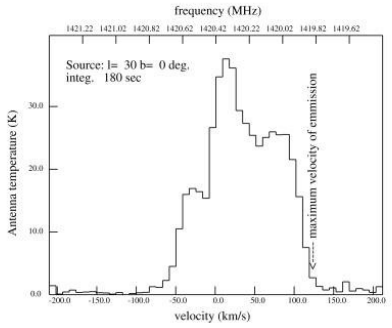
Milky Way HI Rotation Curve

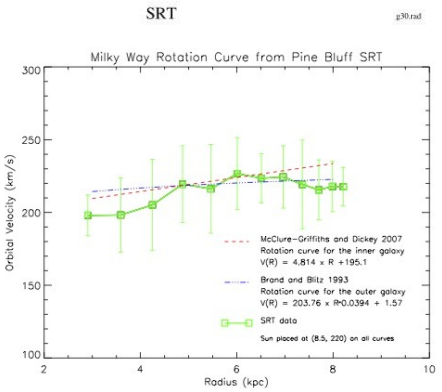
- **MW HI Easily Detected as 21-cm Emission**
- **Along Any Line-of-Sight HI Has Range of Velocity**
  - **Clouds, Complex Structure**
  - **Maximum Velocity Found Near Tangent Point Due to Orbital Projection**
  - **Nice Data from Student Led Projects (see Figure Spectrum from Haystack Obs.)**
  - **Review: Bhattacharjee 2014 (ApJ 785, 63)**



Cool Student Data from Pine Bluff, WI (Alt et al. 2015)







Reading this Week

By Thursday:

Start Reading Chapter 1 in text:

(review of stellar properties)

HW #1 (due Tues. Jan 25):

a) Use the data summarized by Bhattacharjee (2014) to plot the rotation curve in Python. Use your own judgement on how to plot it.

b) Compute an appropriate average by fitting a spline to each data set for interpolation and combining them.

c) Assume a spherical mass model for the Galaxy and compute both M(R) and ρ(R). Make a plot of your results and fit a polynomial model. Comment on your results and provide a summary of your results.