The Milky Way

Astronomy 101
The Milky Way

• Diffuse band of light crossing the night sky.

• All human cultures have names for it:
  – Celestial River
  – Celestial Road or Path

• “Milky Way” from Latin by way of Greek:
  – Greeks: Galaxias kuklos = “Milky Band”
  – Romans: Via Lactea = “Road of Milk”
Panoramic view of the Milky Way
“The Starry Messenger”

- **1610**: Galileo observed the Milky Way with his new telescope.
- Published his findings in his pamphlet, *Siderius Nuncius* (The Starry Messenger):
  - “For the Galaxy is nothing else than a congeries of innumerable stars distributed in clusters.”
A Section of the Milky Way
Philosophical Interlude

• **Thomas Wright (1750):**
  Picture motivated by theological considerations
  Wright made no new observations.

• **Model:**
  – Milky Way is a thin spherical shell of stars with Sun about midway inside the shell.
  – Look along the tangent: broad band of stars
  – Look along thin part: few stars
Wright’s Milky Way (1750)

Few Stars

Many stars
Theory of the Heavens

• **Immanuel Kant (1755):**
  Misread a newspaper account of Wright’s model.
  Also made no observations.

• **Model:**
  – Lens-shaped disk of stars rotating about its center.
  – Other “nebulae” are distant, rotating milky ways like ours.
The Herschels’ Star Gauges

• **William & Caroline Herschel (1785):**
  Counted stars along 683 lines of sight using their 48-inch telescope.
  Assumed all stars are the same luminosity, and that they could see to the edges of the system.

• **Model:**
  – Flattened Milky Way ("grindstone")
  – Sun very near the center.
The Herschels’ Milky Way Map
The Kapteyn Universe

• Jacobus Kapteyn (1901 thru 1922):
  Used photographic star counts
  Estimated distances *statistically* based on parallaxes & proper motions of nearby stars.
  Neglected interstellar absorption of starlight.

• Model:
  – Flattened disk 15 kpc across & 3 kpc thick with the Sun slightly off center.
Kapteyn Model (1922)

~15 kpc

~3 kpc

kpc = kiloparsec = 1000 pc
Harlow Shapley (1915 thru 1921)

- Harvard Astronomer
- Noticed two facts about Globular Clusters:
  - Uniformly above & below the Milky Way.
  - Concentrated on the sky toward Sagittarius.
- Observations:
  - Globular Cluster distances from RR Lyrae stars
  - Mapped the cluster distribution in space.
Shapley’s Globular Cluster Distribution
The Greater Milky Way

• Shapley’s Results (1921):
  – Globular clusters form a subsystem centered on the Milky Way.
  – The Sun is 16 kpc from the MW center.
  – MW is a flattened disk ~100 kpc across

• Right basic result, but too big:
  – Shapley ignored interstellar absorption
  – Caused him to overestimate the distances.
The Problem of Absorption

• Absorption of Starlight by Interstellar Dust:
  – Interstellar space is filled with gas and dust
  – Dust absorbs/scatters light, making distant objects look *fainter*.
  – *Overestimate* Luminosity distances.

• Plagues all maps of the Milky Way:
  – Shapley & Kapteyn thought it was small.
  – Trumpler (1930) showed it was significant.
Present Picture

• Largely Shapley’s model, corrected for the effects of interstellar absorption.
  – A flattened disk of stars with a central bulge.
  – ~25 kpc in diameter and ~1 kpc thick
  – Sun is ~8 kpc from the center in direction of Sagittarius
  – Galactic Center and much of the disk is obscured by dust in the plane of the Galaxy
Infrared Panoramic of the Galaxy
More generally, what are “Galaxies”? 

- Large assemblies of stars, gas and dust, held together by gravity.
- Sizes:
  - Largest: ~1 Trillion stars (or more)
  - Smallest: ~10 Million stars
  - Milky Way & Andromeda: ~200 Billion stars
- [For comparison, Nabisco has baked ~350 Billion Oreos™ since 1913, or ~1 for each star…]
Andromeda (M31)

• Nearest bright galaxy to the Milky Way:
  – Distance ~700 kpc

• Many similarities to the Milky Way
  – Both large spiral galaxies
  – Similar stellar and gas content

• Andromeda gives us an approximate outside view of our own Galaxy.
Disk & Spheroid

• Spiral galaxies have a disk/spheroid structure:
  • Disk:
    – Extended, thin disk of stars, gas, & dust
    – Crossed by *spiral arms* of blue stars & dust.
  • Spheroid:
    – Thick, centrally concentrated spheroid of stars
    – Little or no gas or dust
Sombrero Galaxy (M104)
Walter Baade (c. 1944)

• Took deep red & blue photos of Andromeda:
  – Disk looked blue
  – Spheroid looked red
  – Could detect many individual stars in both

• Made H-R diagrams of disk & spheroid stars:
  – Disk stars had H-R diagrams like open clusters
  – Spheroid stars had H-R diagrams like globular clusters.
Stellar Ages (Revisited)

- Massive Stars live short lives:
  - Massive main-sequence stars must be young.
  - Low-mass M-S stars can be young or old.
- Star Cluster H-R Diagrams:
  - Young Clusters: blue main-sequence stars
  - Old Clusters: no blue main-sequence stars
- “Old” = ~10 Gyr or more.
Stellar Populations

• Baade divided stars into two “Populations”:
  • **Population I**:  
    – Disk and Open Cluster stars
  • **Population II**:  
    – Spheroid and Globular Cluster stars
• Distinguished by:  
  – Location, Age, and Chemical Composition
Population I

- **Location**: Disk and in Open Clusters
- **Age**: Mix of young and old stars
- **Composition**: Metal rich (roughly solar)
  - 70% Hydrogen
  - 28% Helium
  - ~2% “metals”
- **Environment**: Often gas rich, especially for the young stars.
Population II

- **Location**: Spheroid and in Globular Clusters
- **Ages**: Oldest stars, 10–15 Gyr
- **Composition**: Metal Poor (0.1–1% solar)
  - 75% Hydrogen
  - 24.99% Helium
  - ~0.01% metals
- **Environment**: gas poor, no star formation
Stellar Orbits

• A galaxy is bound together by the mutual gravitational attraction of all of its parts.
• Stars orbit about the center of mass of the galaxy.
  – Milky Way: measure the proper motions and radial velocities of individual stars
  – Andromeda: measure the combined Doppler motions of large numbers of stars.
Stellar Kinematics

• **Disk Stars:**
  – Ordered, roughly circular orbits in a plane.
  – All orbit in the same general direction.
  – Orbit speeds similar at a given radius.

• **Spheroid Stars:**
  – Disordered, elliptical orbits at all inclinations.
  – Mix of prograde and retrograde orbits
  – Wide ranges of orbital speeds.
# Contrast & Compare

<table>
<thead>
<tr>
<th><strong>Population I</strong></th>
<th><strong>Population II</strong></th>
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<tr>
<td>Disk &amp; Open Clusters</td>
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<td>Young &amp; Old Stars</td>
<td>Oldest Stars</td>
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<td>Metal-rich</td>
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<td>Blue M-S stars</td>
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<td>Random elliptical orbits</td>
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<td>Gas-rich environment</td>
<td>Gas-poor environment</td>
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Chemical Evolution

• Metals form by fusion inside of massive stars
  – Supernova explosions enrich the interstellar medium with metals.
  – The next generation of stars form out of the metal-enriched interstellar gas.
  – Successive generations get more metal rich.

• Higher Metal Content in Later Generations.
Clues to Galaxy Formation?

• Chemical Evolution only affects *populations*.  
  – Fusion occurs in the deep interiors of stars.  
  – Except for CNO elements, surface composition remains effectively unchanged over a star’s life.  
  – Once a star forms, its chemical composition is mostly fixed for life.

• Metal content gives us a clue to the formation history of *populations* of stars.
Phase I: Spheroid Formation

- Start with slowly rotating, metal-poor gas clouds
  - First generation of stars are metal-poor spheroid & globular cluster stars (Pop II)
  - Massive Pop II stars go supernova and enrich the gas with metals.
  - Low-mass Pop II stars are still around today.
  - Star formation stops early-on in the spheroid.
Phase II: Disk Formation

• Metal-enriched gas settles into a *rotating disk*.
  – Next generation (old Pop I) stars have more metals, and ordered disk rotation
  – Massive old Pop I stars go supernova, enriching the disk gas further
  – Following generations (young Pop I) have even more metals (e.g., the Sun).
  – Star formation is still going on in the disk
Summary:

• The *Milky Way* is our Galaxy
  – Diffuse band of light crossing the sky
  – Galileo: Milky Way consists of many faint stars

• The Nature of the Milky Way
  – Philosophical Speculations: Wright & Kant
  – Star Counts: Herschels & Kapteyn
  – Globular Cluster Distribution: Shapley
Summary:

• Disk & Spheroid Structure of the Galaxy
• Pop I Stars:
  – Young, metal-rich, disk stars
  – Ordered, nearly circular orbits in the disk
• Pop II Stars:
  – Old, metal-poor, spheroid stars
  – Disordered, elliptical orbits in all directions
• Gives clues to the formation of the Galaxy.