Astronomy 114

Lecture 28: Galaxies

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UMass/Astronomy Department
Announcements

Quiz #2: returned after class . . .
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- Analysis of scores
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  - Redux: due next Friday 27 Apr
  - PS#7: due next Monday 30 Apr
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Galaxies!
- Our Galaxy, Chap. 25
- Galaxies, Chap. 26
Radio emission from neutral hydrogen

HI emission is rare (per atom) but hydrogen is plentiful in the Galaxy
Rotation of the Disk

Measure using the Doppler Effect

Rotating Disk

- Approaching Side: Blueshift
- Receding Side: Redshift
Rotation of the Disk

- Measure using the Doppler Effect
  - Stars: Doppler shifts of stellar absorption lines
  - Ionized Gas: emission lines from HII regions
  - Atomic Hydrogen (HI) Gas:
    - Cold H clouds emit a radio emission line at a wavelength of 21-cm
    - Can trace nearly the entire disk beyond where the stars have begun to thin out
Using HI to measure the rotation of the disk

- From external galaxies, disks of galaxies are axisymmetric
- Have approx. circular orbits, like solar system
- Density increases toward center
- Use Doppler shift
Using HI to measure the rotation of the disk

- From external galaxies, disks of galaxies are axisymmetric
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- Peak velocity and peak emission will come from smallest radius
- Also use absorption lines in stellar spectra
Using HI to measure the rotation of the disk

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Mapping the Milky Way (1/3)

You are here

Center of Galaxy
Mapping the Milky Way (2/3)

NGC 1232 (similar to the Milky Way, face on...)

A114: Lecture 28—20 Apr 2007  Read: Ch. 25,26  Astronomy 114—7/18
NGC 4565 (similar to the Milky Way, edge on...)

Mapping the Milky Way (3/3)
Artist’s view of the Milky Way from above

Milky Way: four-armed barred spiral
Rotation curves (1/3)

Why do we care about these velocities?

- A galaxy is bound together by the mutual gravitational attraction of all of its parts
- Total mass can be determined from the velocity using Newton’s Laws
Rotation curves (1/3)

Why do we care about these velocities?

- A galaxy is bound together by the mutual gravitational attraction of all of its parts
- Total mass can be determined from the velocity using Newton’s Laws
- Recall:
  \[ P^2 = \frac{4\pi^2}{GM(r)}r^3 \]
  
  \( r \) is the radius of a star
  \( M(r) \) is the mass of the Galaxy inside this radius
- For a circular orbit:
  \[ P = \frac{2\pi r}{v} \]
Rotation curves (2/3)

Substitute and solve:

\[ M(r) = \frac{rv^2}{G} \]
Rotation curves (2/3)

Substitute and solve:

\[ M(r) = \frac{rv^2}{G} \]

Example: mass inside the solar circle

\[
M(r) = \frac{8 \text{kpc} \ (200 \text{km/s})^2}{6.67 \times 10^{-11} \text{m}^3/\text{s}^2 \ \text{kg}} \\
= \frac{8 \times 10^3 \text{pc} \times 3.09 \times 10^{16} \text{m/pc} \ (2 \times 10^5 \text{m/s})^2}{6.67 \times 10^{-11} \text{m}^3/\text{s}^2 \ \text{kg}} \\
= 1.5 \times 10^{41} \text{kg} \times \frac{1 \text{M}_\odot}{1.989 \times 10^{30} \text{kg}} = 7.4 \times 10^{10} \text{M}_\odot
Rotation curves (3/3)

\[ v(r) \text{ tells us } M(r) = \frac{rv^2}{G} \]

- Solid-body, like merry-go-round or CD, \( M(r) \propto r^3 \)
Rotation curves (3/3)

\( v(r) \) tells us \( M(r) = \frac{rv^2}{G} \)

- Solid-body, like merry-go-round or CD, \( M(r) \propto r^3 \)
- Keplerian, like solar system, \( M(r) \propto \text{constant} \)
Rotation curves (3/3)

\[ v(r) \text{ tells us } M(r) = \frac{r v^2}{G} \]

- Solid-body, like merry-go-round or CD, \[ M(r) \propto r^3 \]
- Keplerian, like solar system, \[ M(r) \propto \text{constant} \]
- Flat, galactic disk, \[ M(r) \propto r \]
Rotation curves (3/3)

a. Actual rotation of our Galaxy

b. If our Galaxy rotated like a solid disk

c. If the Sun and the stars obeyed Kepler’s third law
Astronomers (since mid 20th century) divide 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

<table>
<thead>
<tr>
<th>Location:</th>
<th>Disk and Open Clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age:</td>
<td>Mix of young and old stars</td>
</tr>
<tr>
<td>Composition:</td>
<td>Metal rich (roughly solar composition)</td>
</tr>
<tr>
<td>Environment:</td>
<td>Often gas rich, especially for the young stars</td>
</tr>
</tbody>
</table>

- 70% Hydrogen
- 28% Helium
- 2% "metals"
### Population II

<table>
<thead>
<tr>
<th>Location:</th>
<th>Spheroid and Globular Clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ages:</td>
<td>Oldest stars, &gt;10 Gyr</td>
</tr>
<tr>
<td>Composition:</td>
<td>Metal Poor (0.1-1% solar)</td>
</tr>
<tr>
<td>Environment:</td>
<td>gas poor, no star formation</td>
</tr>
</tbody>
</table>

- 75% Hydrogen
- 24.99% Helium
- 0.01% metals
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.
Stellar Kinematics

Galactic plane
Population I

Galactic plane
Population II