NGC1300
(Eridanus)

GALAXIES:
Island Universes in the Cosmos

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Star Party
26 August 2011
Storyline

- Some history
- Simulations and Collisions!
- Modeling galaxies

Not today...

- Black holes (lots of galaxies have them!)
- Active galaxies (quasars, Seyferts, AGN)
- Cosmic structure, galaxies and dark matter
Galactic skies...

- One of the most prominent features of the night sky is the **Milky Way** (especially at ISP!)

- To the naked eye, it simply looks like a cloud

- With a telescope, it resolves into billions of stars

- Telescopes also reveal that there are **many more galaxies** than our own!
Simple Facts

- The largest, easily observed structures in the Universe

- Estimates suggest there are more than **100 billion galaxies**

- There are about **100,000 per square degree** on the sky

- Comprised primarily of stars and unincorporated gas, and **dark matter**
Over 10 days in 1995, the Hubble Space Telescope looked at the same spot in Ursa Major (an “empty spot”)

Result: the **Hubble Deep Field (North)** — a single image, covering an area about the size of the eye of FDR when you hold a dime at arms length.

~3000 **galaxies** in this single image!
The nearest galaxy to the Milky Way is the **Small Magellanic Cloud** 180,000 lightyears away (or the Canis Major Dwarf at 25,000 lightyears).

Farthest known galaxy: **Abell 1835 IR1916**, 13.23 billion lightyears distant.
Closest and Farthest

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Galaxies are everywhere!
Galaxies are everywhere!
Galaxies are everywhere!

M81

M82
The natural question is: **what are the galaxies?**

In 1755, *Immanuel Kant* speculated (on philosophical grounds) that there should exist distant “**island universes**” of stars (much like the Milky Way).
The Milky Way is a diffuse band of light stretching across the sky that was not understood until the invention of the telescope.

In 1785, William Herschel decides to map the Milky Way by counting all the stars he can see in every direction.

He finds we are near the center of a flattened distribution of stars (a disk).
The Milky Way

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In the Olden Days

- We used to think that galaxies were **nebulae**

- **Through a scope**, you might see how this could be
The Spiral Nebulae

- In 1845, William Parsons was observing with his 72-inch Leviathan of Parsonstown.
- He detected **spiral structure** in nebulae, and promptly adopted the name “**island universes**”.
- Parsons was observing **M51** (the Whirlpool Galaxy). Today, an average amateur instrument (10”) will show the spiral structure.
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Shapley-Curtis Debate (The Great Debate)

- **26 April 1920**: Smithsonian Museum of Natural History
- **Central question**: Were the spiral nebulae in the Milky Way, or were they Island Universes very far away?
- Ultimately it did little to change anyone’s minds, because we **needed better observations**!
Shapley’s Arguments...

- Shapley believed the **Milky Way was the entire Universe**, and the spiral nebulae were simply nearby gas clouds.
- If the Andromeda Nebula were the size of the Milky Way, it would be **enormously far away**.
- Observations had claimed to measure the Andromeda Nebula’s rotation (would **violate the speed of light limit** if it were far away).
Curtis argued that the **spiral nebulae were galaxies** much like our own and far away.

- Count the **number of novae** toward the Andromeda Nebula; the density is much higher than elsewhere on the sky.
- **Massive Doppler Shifts** detected in other galaxies.
Cepheid Variables

- Resolving the galaxy debate would depend on **getting distances** to the spiral nebulae.
- **Henrietta Swan Leavitt** discovered **Cepheid variables** in 1912 at Harvard College Observatory.
- Cepheid variables can be used to determine distance! (Period-luminosity relation)
- Her work was rapidly adopted to measure distances in the Milky Way.
The Andromeda Nebula
On **30 Dec 1924**, Hubble announced observations of Cepheid variables in **other galaxies**, firmly establishing that the spiral nebulae were distant star systems.
The most distant object visible to the naked eye is a Spiral galaxy similar to the Milky Way, 2.5 million light-years away.
**O.I.Y: M31**

- The most distant object visible to the naked eye
- Spiral galaxy similar to Milky Way
- 2.5 million lyr away
Galaxy Groups

- Galaxies often live together in **large groups (galaxy clusters)**
- The Local Group, the Virgo Cluster, the Coma Cluster, ...
- With galaxies in such close proximity, one asks "**do they ever collide?**"
A Direct Hit...

Cartwheel Galaxy
M31-Milky Way Collision

- Milky Way and M31 are approaching one another at ~125 km/s, and will collide in 3-4 billion years.
- Simulations suggest the most likely result will be a single elliptical galaxy (forms about 1 billion years after collision starts).
M31-Milky Way Collision (view from Sun)

www.galaxydynamics.org
Galaxy Mysteries...

- We see galaxies all the time, but there is still a **tremendous amount we don’t know**
- What is the dark matter in galaxies?
- How do different kinds of galaxies form?
- Which came first, the star or the galaxy?
- What is in the galactic halo?
- What happens in the cores of galaxies?
- **What is the shape and density of the galaxy?**
WHAT DO I DO?

Matt Benacquista
UT - Brownsville

Shane Larson
Utah State

Krzysztof Belczynski
Los Alamos

Ashley Ruiter
Max Planck

Brett Taylor
Radford University
- **5 million kilometer** laser interferometer in space
- LISA will see 10 million binary stars in the Milky Way galaxy
Population Synthesis of Galaxies...

- Note **simple rules to describe the population** of stars in the galaxy, then base a computer simulation on those rules.

- Consider a large population from a sample of those at this lecture: **80 people, identified by age**

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Count</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>Old Coots</td>
<td>10</td>
<td>12.5%</td>
</tr>
<tr>
<td>Boomers</td>
<td>20</td>
<td>25.0%</td>
</tr>
<tr>
<td>Yuppies</td>
<td>25</td>
<td>31.25%</td>
</tr>
<tr>
<td>College</td>
<td>15</td>
<td>18.75%</td>
</tr>
<tr>
<td>Kids</td>
<td>10</td>
<td>12.5%</td>
</tr>
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</table>
Population Synthesis of People...

- Build a 3000 person population randomly, but consistent with what I see in the group here. Run it 3 times.

<table>
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<th>College</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>368 (12.3%)</td>
<td>737 (24.6%)</td>
<td>941 (31.4%)</td>
<td>577 (19.2%)</td>
<td>377 (12.6%)</td>
</tr>
<tr>
<td></td>
<td>354 (11.8%)</td>
<td>752 (25.1%)</td>
<td>969 (32.3%)</td>
<td>581 (19.4%)</td>
<td>344 (11.5%)</td>
</tr>
<tr>
<td></td>
<td>375 (12.5%)</td>
<td>713 (23.8%)</td>
<td>960 (32.0%)</td>
<td>546 (18.2%)</td>
<td>406 (13.5%)</td>
</tr>
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- Population synthesis tells me what the galaxy might be like!
Rules for making galaxies...

- Synthesis rules for galaxies are simple questions:
  - How massive is the star?
  - Is the star in a binary?
  - Where was it born? How does it live and die?
Simulated Galaxies...

- The result are galaxies with different shapes, and a unique combination of **young stars**, **old stars**, and **stellar remnants** (black holes, neutron stars, white dwarfs)
Mystery Galaxy

- The Splinter Galaxy
- Edge on spiral galaxy
- 50 million lyr away
- Mystery: low metalliclicity, few giant stars, lots of dwarf stars
Galaxies on your own...

- **GALAXY MORPHOLOGY**: [www.galaxyzoo.org](http://www.galaxyzoo.org)

- **ASTROPHYSICS WITH A PC** (Paul Hellings)
  - Star formation in the galaxy
  - Stellar orbits in the galaxy

- Sky & Telescope’s Astronomical Computing columns

- Codes: [www.skyandtelescope.com/resources/software/3304911.html](http://www.skyandtelescope.com/resources/software/3304911.html)
  - Modeling Spiral Galaxies: December 1990 (spiral.bas)

- Come to USU to study — *I’ll put you to work!*
Sculptor Galaxy

- **THANKS for coming!**
- Bright, can be seen in binoculars from dark sites (like ISP!)
- Nearly edge on spiral galaxy
- 8 million lyr away