Galaxy Formation and the Milky Way

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What is Galaxy Formation?



Credit: NASA/WMAP Science Team

Why is it important to understand how galaxies form?

- Constrain fundamental physics parameters
- Understand the history of our galaxy
- Understand the past and future of our universe

What physics is involved in galaxy formation?

- Essentially, **all** of it
 - Gravity
 - Chemistry
 - Radiative transfer (aka light)
 - Stellar physics
 - Cosmology



- Ingredients:
 - Fluctuations in the early universe
 - Gravity
 - Cosmology

Credit: NASA / WMAP Science Team WMAP Credit: Hans Wolff



5%

69%

26%

Dark Energy

Dark Matter

Baryons



- Distances:
 - Light year ~ 6 trillion miles
 - pc (parsec) 3.26 light years
 - kpc (kiloparsec) 1000 pc
 - Mpc (megaparsec) 1000 kpc
 - Gpc (gigaparsec) 1000 Mpc







- Key Ideas Needed for Today
 - Smaller galaxies form earlier, can then fall onto larger galaxies
 - Large scale structure collapses into sheets, then filaments, then points
 - The whole process is quite messy

- Smaller galaxies form earlier (Hierarchical Structure Formation)
 - Arises due to small fluctuations in the early universe which collapse before larger fluctuations
 - These small galaxies can then merge to form larger galaxies



Collapse assuming spherical symmetry



Collapse assuming non-spherical symmetry







• Quiz: which box is the biggest/smallest?



Crash Course in Galaxy Formation Milky Way - M31 Analogue



Crash Course in Galaxy Formation Milky Way - M31 Analogue



Nice model but many open questions:

- What is the mass distribution in the Milky Way?
- Is the substructure in simulations real?

















Credit: V. Belokurov and the Sloan Digital Sky Survey.



D. Martinez-Delgado, R. Jay Gabani, et al. 2008

- Tidal streams are almost orbits
 - Orbital velocity and radius tell you mass inside
 - Twisting of the stream also gives information



• Constrain Milky Way mass by fitting orbits to streams





Radius in kpc

with S. Koposov and V. Belokurov



with S. Koposov, V. Belokurov

- Streams will be disrupted by substructure
 - Look for gaps in streams





Ngan, Carlberg 2014

- And many other things:
 - Testing dark force models
 - Merger history of the Milky Way
 - Mass distribution of other galaxies

Galaxy Formation

- Small galaxies collapse first
- The cosmic web
- Tidal streams are almost like orbits and are sensitive to their environment