

# Formation and Evolution of Galaxies

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# The "Big Picture"

- Galaxies form hierarchically, like the large-scale structure of the Universe
  - as opposed to monolithically --- form entire galaxy in one single episode
- Is this true?

- Many observations and models point towards the reality of the hierarchical formation scenario
  - WMAP: we seem to live in a  $\Lambda$ CDM universe
  - Dark matter likely to be significant contributor to galaxy masses
  - Luminosity function of galaxies
  - Morphology-density relation
  - On-going mergers of galaxies today
  - Recent star formation in "dead" galaxies
  - ... etc. ...

Is this the whole  
story?

• maybe not...

# The “big questions”

- Here are some of the big questions still outstanding...

# Dark matter

- need better inclusion of baryonic physics in N-body simulations (and not just recipes)
  - what is the distribution of dark matter in galaxy halos?
    - can we model rotation curves of galaxies correctly?
    - is this a function of galaxy mass?
  - what or where is the DM “substructure” seen in the simulations?
    - how does it evolve?
    - how does it connect to dwarf galaxies?

# Details of hierarchical paradigm still missing

- Link between small-scale (pc) physics and galaxy-/cosmological-scale (kpc/Mpc/Gpc) physics missing
  - feedback: the energy/momentum transfer between galaxies and the large-scale structure
    - still highly uncertain
  - chemical evolution: the lifecycle of nuclei
  - where do galaxies get their gas?

## • Galaxy mergers and merger rates

- Are dwarf galaxies really the building blocks of massive galaxies?
  - chemistry appears to be wrong!
- Can early-type (E and S0) galaxies actually be built from disk galaxies?
- does  $\Lambda$ CDM predict the correct evolution of the merger rate?

- When and how do big galaxies form?
  - When do big disk galaxies form?
    - How early can they form?
  - When do early-type galaxies form?
    - Have they stopped forming?
  - What causes the red-blue galaxy dichotomy?
    - When does it set in?
- Does formation and evolution depend on environment?

- What are the damped Ly- $\alpha$  systems?
- What are the sub-mm galaxies?
  - what do they evolve into?
  - is there significant "hidden" star formation at high redshifts?

- What is the environmental dependence of galaxy properties and evolution?
- What are the origins and evolution of galaxy scaling relations?
  - e.g., Tully–Fisher, Fundamental Plane, color–magnitude relation
    - what are the biases involved in interpreting these relations and their evolution?

# How does galaxy formation begin?

- When and how do the first stars form?
  - What (if anything) is the observational impact of these stars?
    - Pop III? Chemical signatures?

# The first black holes

- When and how do supermassive black holes form and grow?
  - connection to first stars?
  - do quasars form in pre-existing hosts?
  - what impact do SMBHs have on their hosts?
    - feedback
  - when does the black hole mass-velocity dispersion relation arise?

# Reionization

- What causes reionization?
  - stars? black holes? something more exotic?
- When does it happen?