Galaxies: Structure, formation and evolution

Lecture 13

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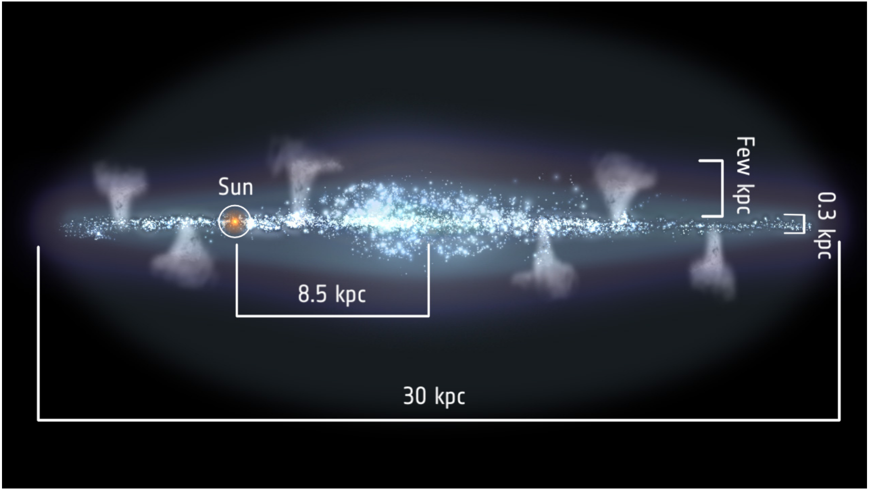
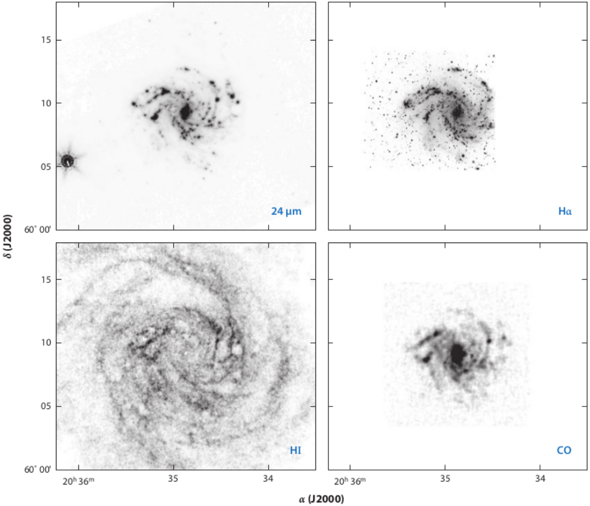
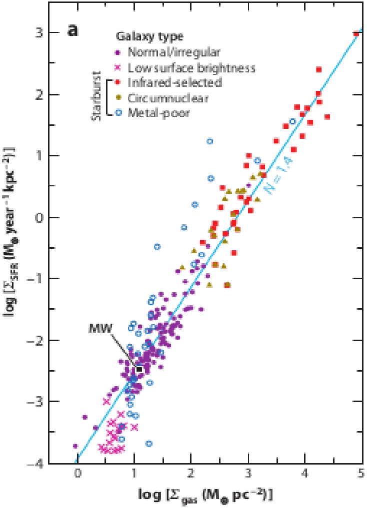
Galactic fountain model makes hot halo

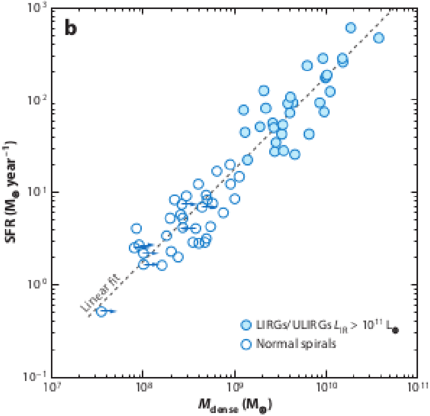


Star-formation tracers NGC 6946



Kennicutt relation - SFR with total mol. + atomic mass, Molecular mass





Kennicutt & Evans (2014)

Kennicutt relation on sub-galactic scales

Will the relation hold on sub-galactic scales?

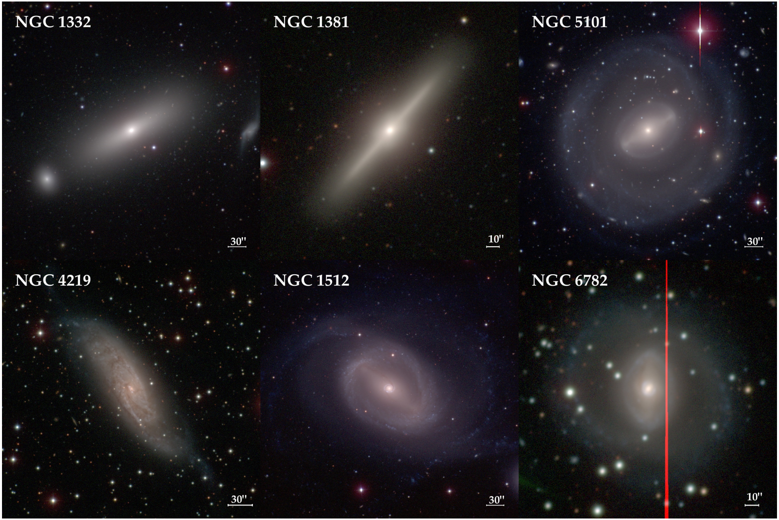
Relevant questions in star-formation studies

- How should we interpret observations of the main molecular diagnostic lines (e.g., CO, HCN) and millimeter-wave dust emission? How does this interpretation change as a function of metallicity, surface density, location within a galaxy, and star-formation environment?
- How does the structure of the ISM, the structure of star-forming clouds, and the star formation change as a function of metallicity, surface density, location within a galaxy, and star-formation environment?
- How do the mass spectra of molecular clouds and dense clumps in clouds vary between galaxies and within a galaxy?
- How constant is the IMF, and how are SFR measurements affected by possible changes in the IMF or by incomplete sampling of the IMF?

Relevant questions in star formation studies

- What are the limits of applicability of current SFR tracers? How are current measurements biased by dust attenuation or the absence of dust, and how accurately can the effects of dust be removed? How do different tracers depend on metallicity, and what stellar-mass ranges and timescales do they probe?
- How long do molecular clouds live, and how can we best measure lifetimes? Do these lifetimes change systematically as functions of cloud mass, location in a galaxy, or some other parameter?
- Do local observations provide any evidence for bimodality in modes of star formation, such as, for example, distributed versus clustered and low-mass versus high-mass star formation?
- On the scale of molecular clouds, what are the star-formation efficiencies, and SFRs per unit mass, and do these efficiencies vary systematically as functions of cloud mass or other parameters?

Classical and Pseudo bulges



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in high mass galaxies	in low mass galaxies

How does pseudo/classical occurence depend on environment? Are their stellar ages correlated with the disc? Why are classical bulges more common in S0s?

Mishra et al. 2017a, 2017b, 2018

Formation mechanisms for ellipticals and spirals

- Eggen, Lynden-Bell & Sandage (1962) considered a model in which galaxies form from the collapse of gas clouds, and suggested that the difference between ellipticals and spirals reflects the rapidity of star formation during the collapse.
- If most of the gas turns into stars as it falls in, the collapse is effectively dissipationless and infall motions are converted into the random motion of stars, resulting in an elliptical.
- If the cloud remains gaseous during collapse, the gravitational energy can be effectively dissipated via shocks and radiative cooling. In this case, the cloud will shrink until it is supported by angular momentum, leading to the formation of a rotationally supported disk.

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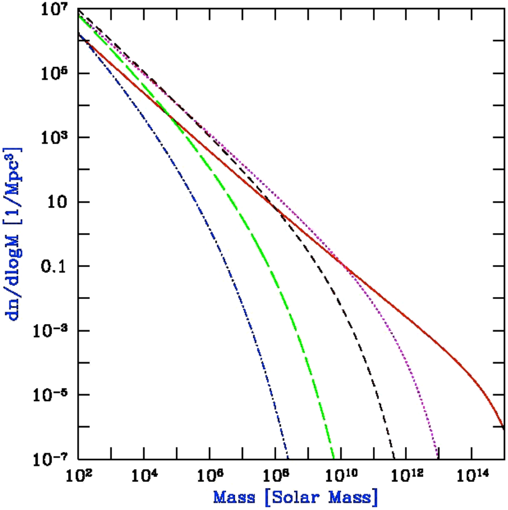
- The JWST frontier is at $z \sim 7 - 20$, the so-called Reionization Era

Galaxy formation timeline from the star formation perspective

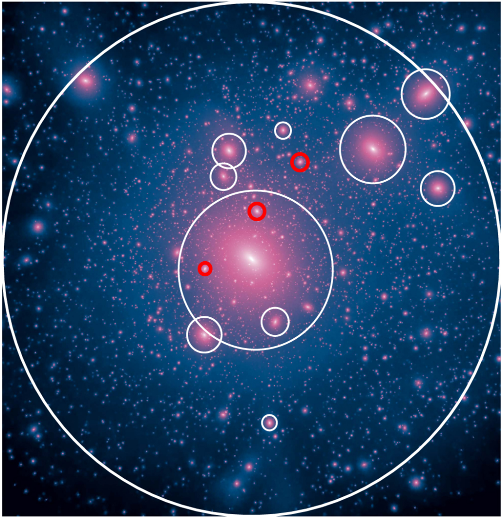
- The smallest scale density fluctuations keep collapsing, with baryons falling into the potential wells dominated by the dark matter, achieving high densities through cooling
- This process starts right after the recombination at $z \sim 1100$
- Once the gas densities are high enough, star formation ignites probably around $z \sim 20 - 30$
- By $z \sim 6$, UV radiation from young galaxies reionizes the universe
- These protogalactic fragments (of stars and gas) keep merging, forming larger objects in a hierarchical fashion. During this,
- Star formation enriches the gas, and some of it is expelled in the intergalactic medium, while more gas keeps falling in
- If a central massive black hole forms, the energy release from accretion can also create considerable feedback

Dark matter mass function evolves too



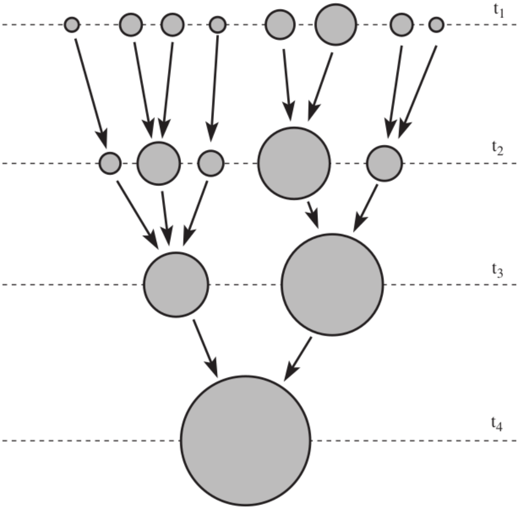
Barkana and Loeb (2001)

Haloes, subhaloes, centrals and (missing) satelites

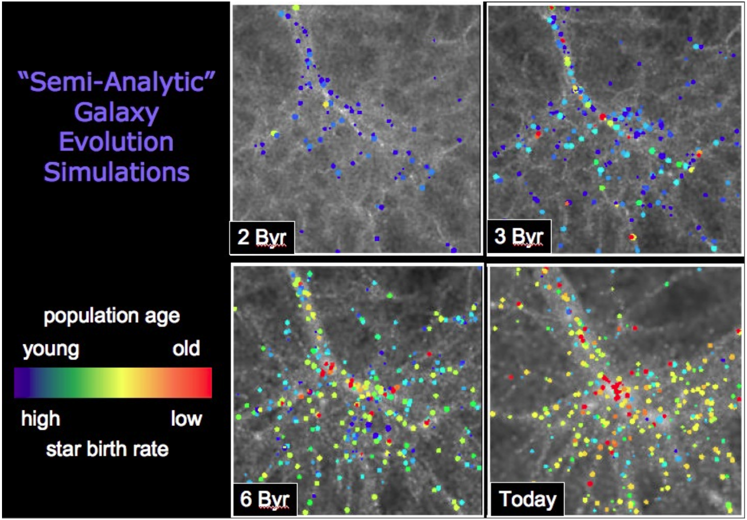


Can baryonic properties be determined by the properties of the dark matter halo? See: Paranjape et al. (2018)

Halo merger trees- hierachical “bottom up” growth



Galaxy formation simulations match reality

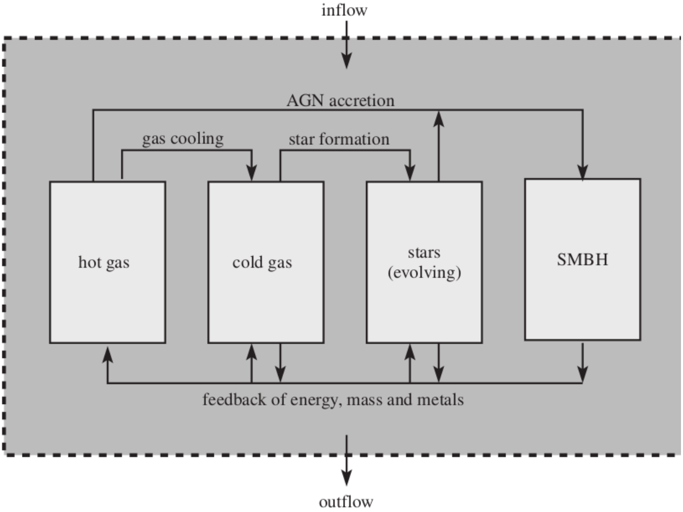


Why is galaxy formation difficult?

Galaxy formation is actually a much messier problem than structure formation. In addition to gravity and build-up of host dark halos (fairly well understood) we need to add relatively poorly understood baryonic processes:

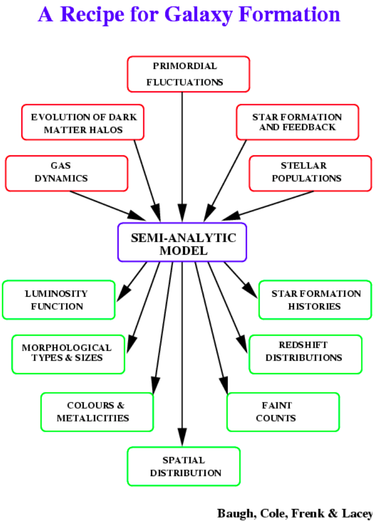
- Shock heating of gas
- Cooling of gas into dark halos
- Formation of stars (also not a well understood process!) from the cold gas
- The evolution of the resulting stellar population
- Feedback processes generated by the ejection of mass and energy from evolving stars
- Production and mixing of heavy elements (chemical evolution)
- Effects of dust obscuration
- Formation of black holes at galaxy centers and effects of AGN emission, jets, etc.

Evolution of an individual galaxy

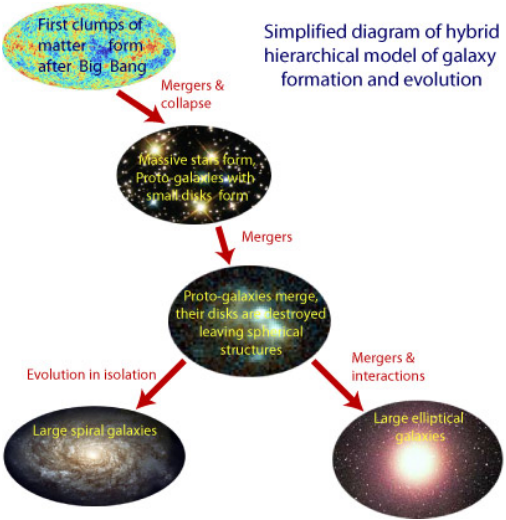


Mo et al. (2010)

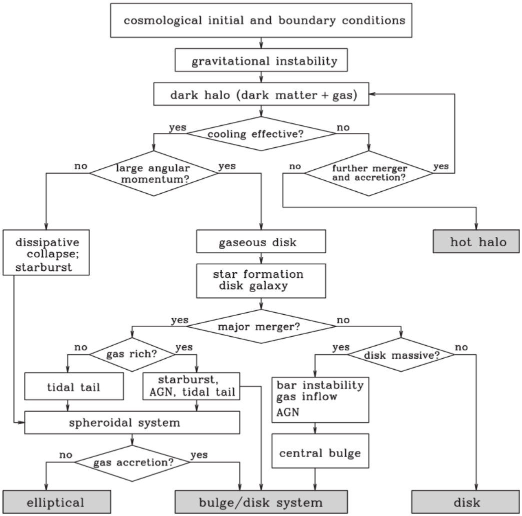
Galaxy formation recipe



Galaxy formation schematic



Galaxy formation flowchart - simplified reality



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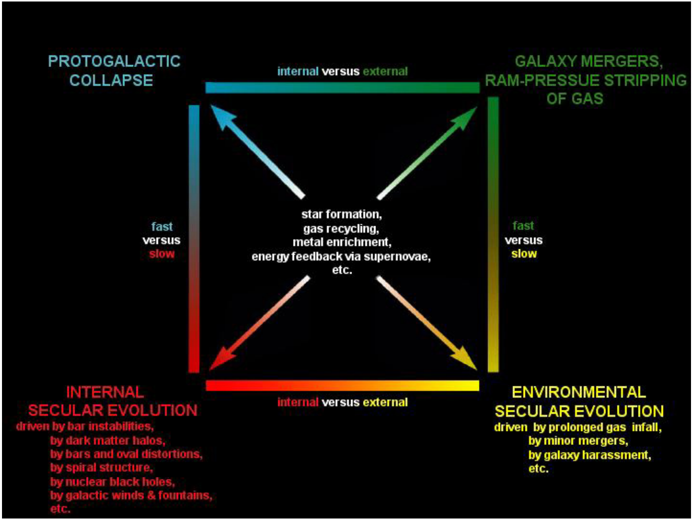
Galaxy formation and evolution in one diagram



see review by Kormendy & Kennicutt (2004)