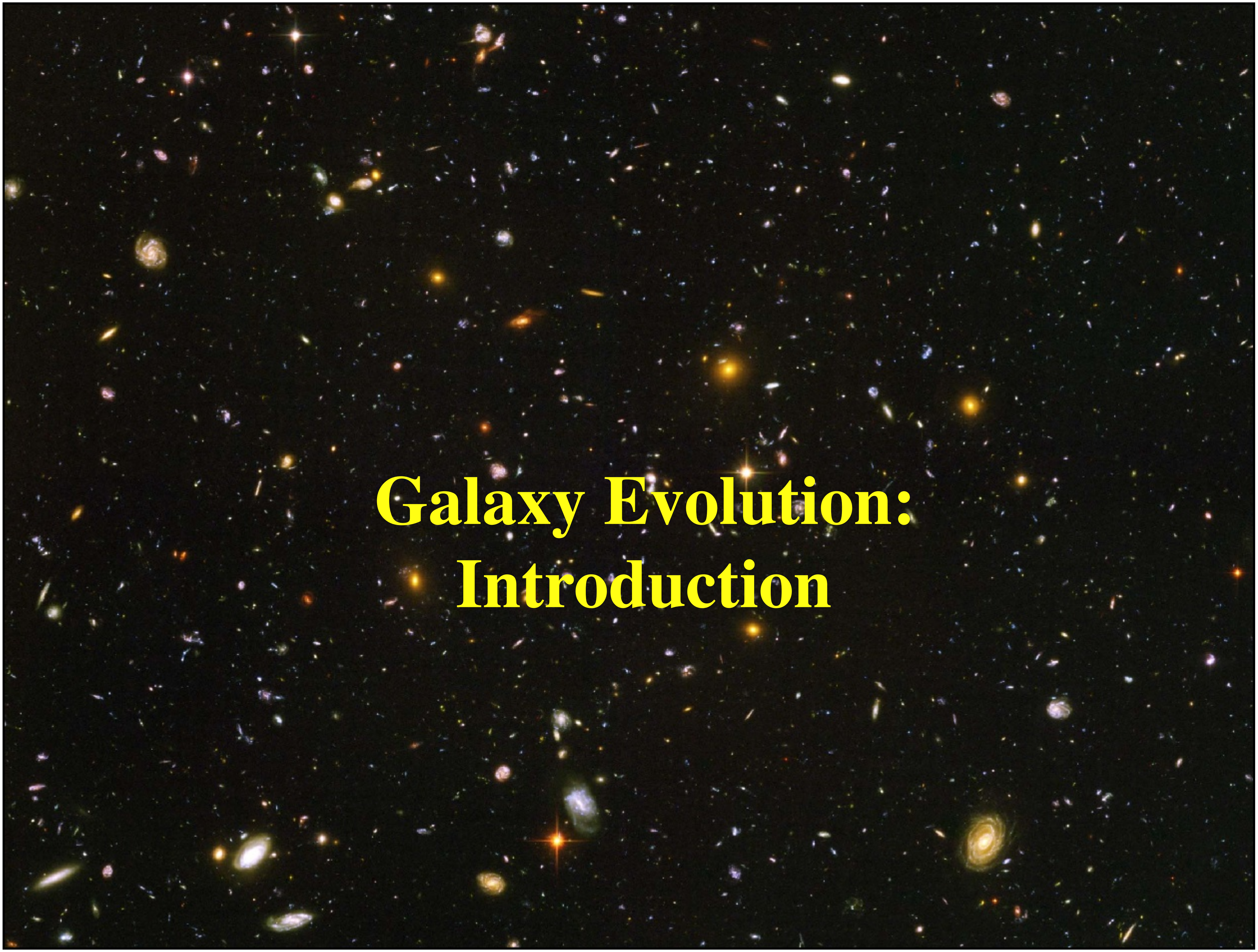
Galaxy Evolution: Introduction



Galaxies Must Evolve

- Stars evolve: they are born from ISM, evolve, shed envelopes or explode, enriching the ISM, more stars are born…
- Structure evolves: density fluctuations collapse and merge in a hierarchical fashion

Galaxy Evolution

Assembly of the mass → Conversion of gas into stars and v.v., feedback processes

DM dominated
Cannot be observed directly, but may be inferred
Easy to model, mainly dissipationless

This is what is observed, and where energy is generated
Dissipative, and very hard to model

Evolution Timescales and Evidence

Timescales for galactic evolution span wide range:

~ 100 Myr - galaxy free-fall and cooling time scales

10 -100 Myr - lifetimes of massive stars

10 -100 Myr - lifetime of the bright phase of a luminous Active Galactic Nucleus (?)

Few x 100 Myr - rotation period of spiral galaxy

~ Gyr - time required for two galaxies to merge

~ 10 Gyr - age of the Universe

Observational evidence for evolution is found in:

- Stellar populations in the Milky Way (e.g., metallicity as a function of stellar age, etc.)
- Systematics of nearby galaxy properties
- **Properties of distant galaxies seen at earlier epoch**

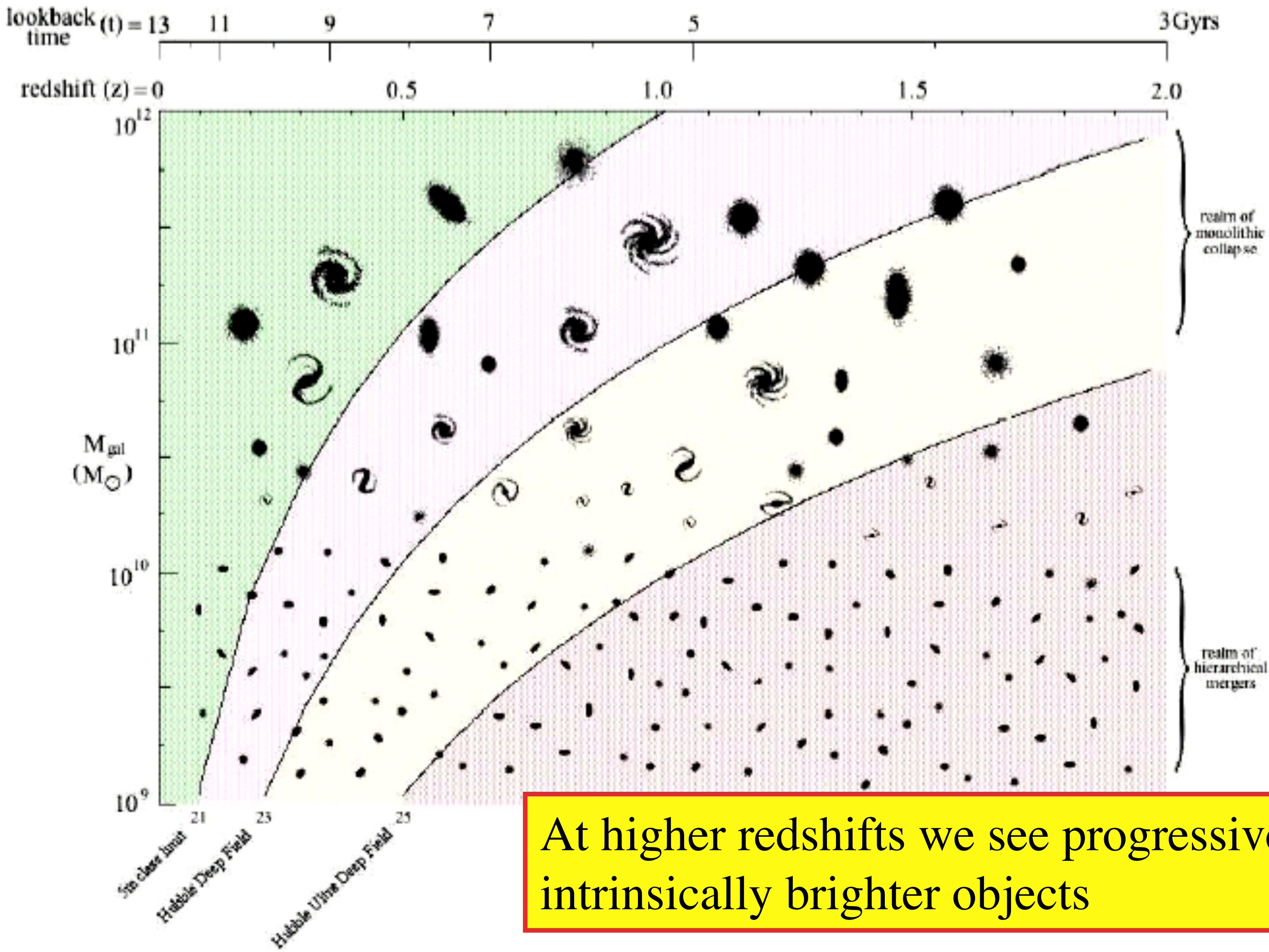
Theoretical Tools and Approaches

1. **Assembly of the mass:** numerical modeling of structure formation. Fairly well advanced, but it is hard to treat any dissipative processes very accurately. Well constrained from cosmology (LSS formation)
2. **Evolution of stellar populations:** based on stellar evolution models, and fairly well understood. Lots of parameters: the stellar initial mass function, star formation history, stellar evolutionary tracks and spectra as functions of metallicity. Poorly constrained a priori.
3. **Hybrid schemes,** e.g., "semi-analytical" models. Use both of the above to assemble comprehensive models, but not constrained very well

Observational Tools and Approaches

- **Deep imaging surveys** and source counts, at wavelengths from UV to FIR
  - Sources are always selected in emission, and any given band has its own selection effects and other peculiarities
  - With enough bandpasses, one can estimate "photometric redshifts", essentially very low resolution spectroscopy; may be unreliable
  - Measurements of clustering provide additional information
- **Deep spectroscopic redshift surveys**: redshifts are usually obtained in the visible, regardless of how the sources are selected
  - As a bonus, one can also estimate current star formation rates and rough chemical abundances from the spectra
- **Diffuse extragalactic backgrounds:** an integrated emission from all sources, regardless of the flux or surface brightness limits
  - Extremely hard to do
  - No redshift information

Beware of Selection Effects



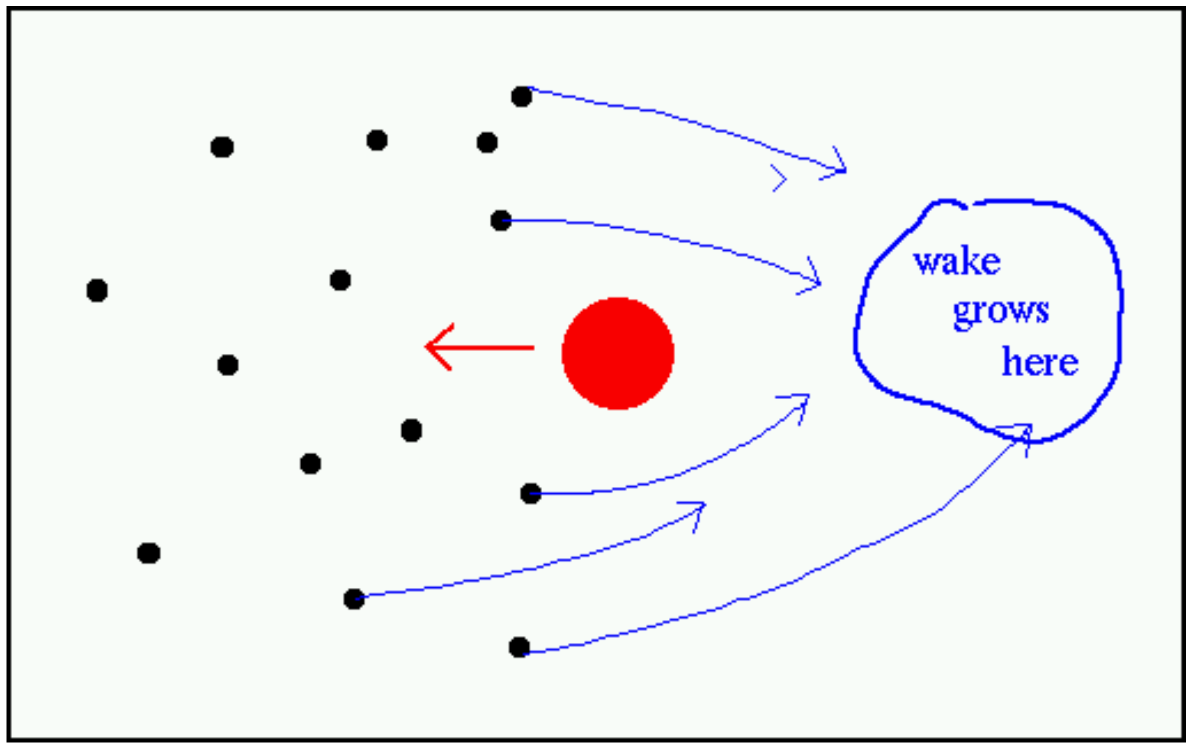
At higher redshifts we see progressively intrinsically brighter objects

Galaxy Merging / Dynamical Evolution

- Commonly observed today, and must have been more important in the past, a part of the overall hierarchical structure formation
- By definition it changes the numbers and mass distribution function of galaxies, and their internal structure/morphology
- Dissipative merging can lead to starbursts and feeding of AGN

Dynamical Friction

- As a massive galaxy moves through a "sea" of stars (and the dark halo), it causes a wake behind it increasing the mass density behind it; the same effect applies to galaxy pass-bys
- This increase in density causes the galaxy to slow and lose its orbital kinetic energy
- The galaxy will eventually fall in and merge with its companion
- Local example: the Magellanic Clouds



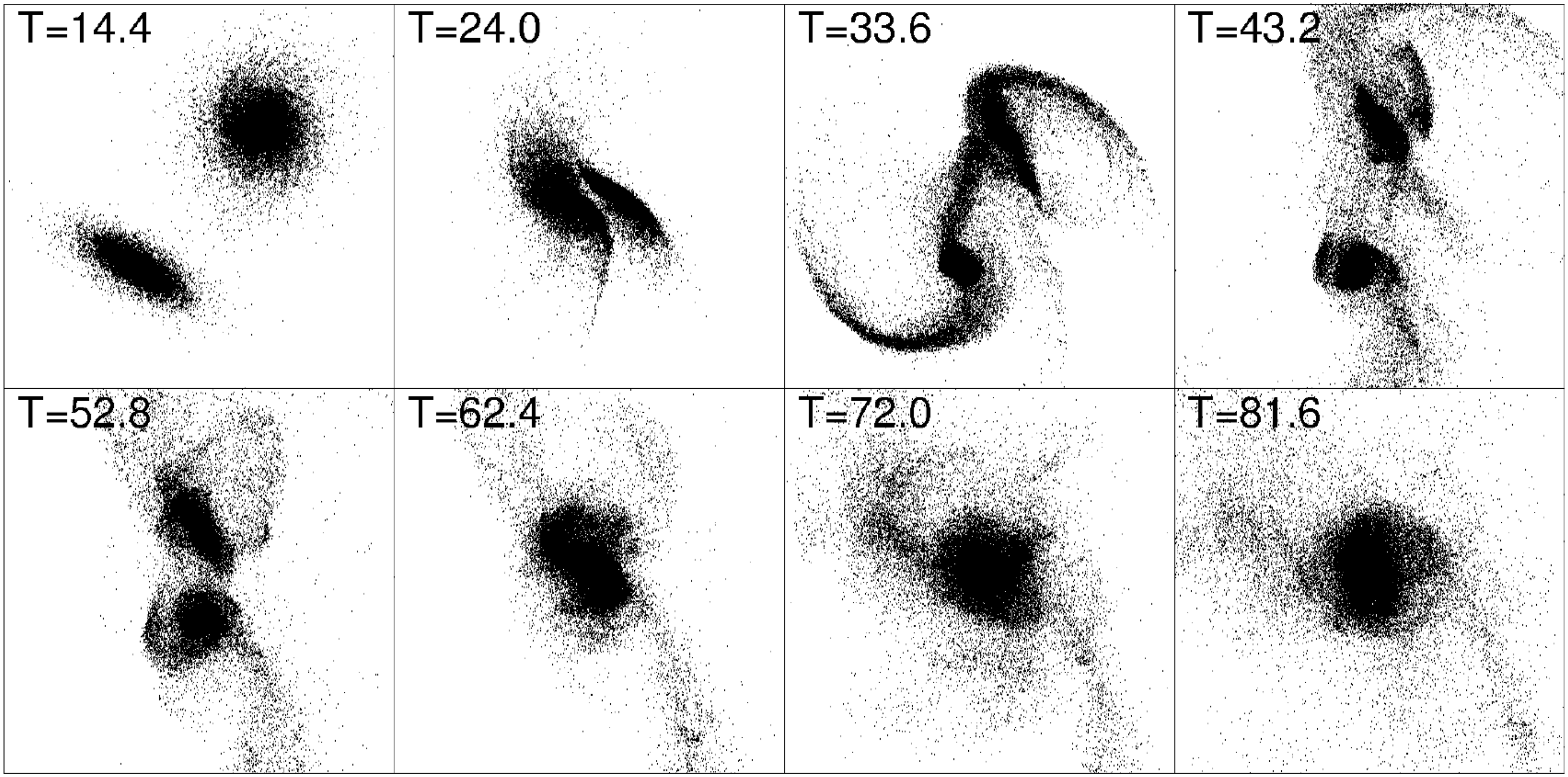
Dynamical Friction

- Time scale for dynamical friction (~ merging):

$$t_{friction} \approx \frac{V}{|dV/dt|} \approx \frac{V^3}{4\pi G^2 M \underbrace{nm}_{\text{Mass density}} \underbrace{\ln\Lambda}_{\text{Coulomb logarithm, } \sim 3}}$$

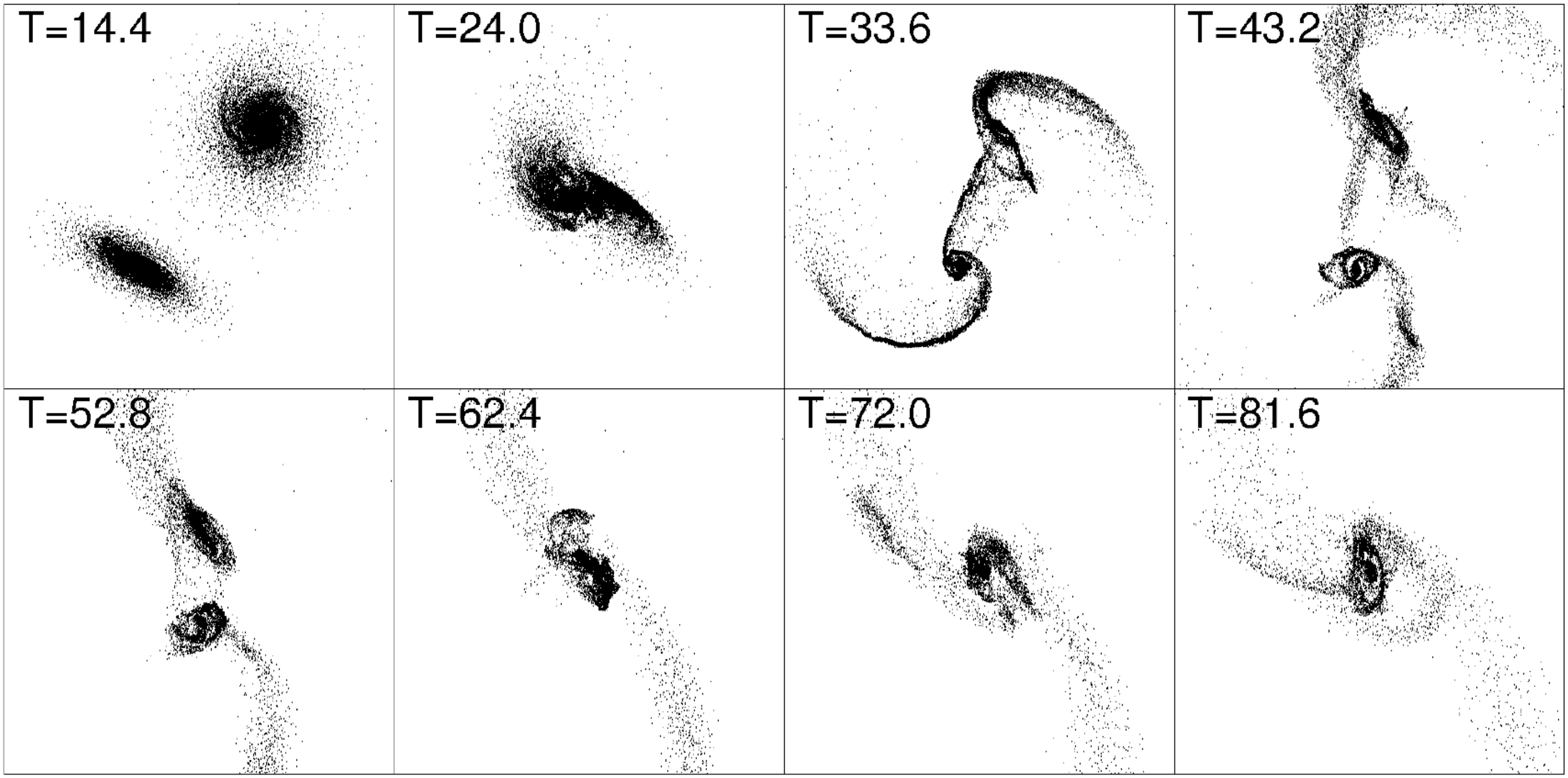
- For typical values, this comes to be around ~ 1 Gyr, or an orbital time scale for galaxy encounter
- Implications:
  - The slower the galaxy's speed, the stronger the dynamical force, the more intense the interaction
  - The more massive the object, the greater the effect

Galaxy Merger: Stars

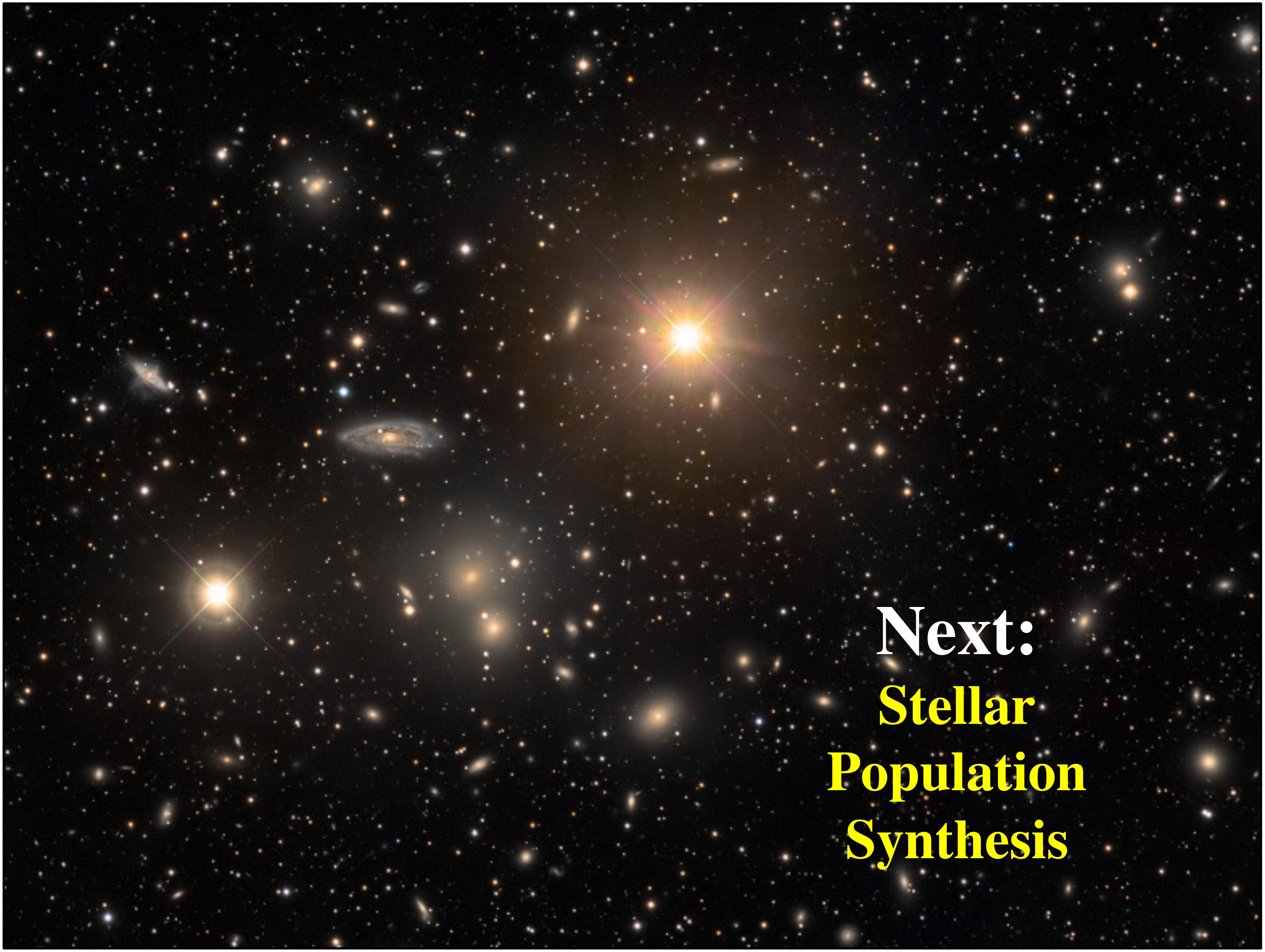


Merge 2 nearly equal mass disk galaxies; in a few dynamical times, the remnant looks just like an elliptical galaxy

Galaxy Merger: Gas



In the same merger, gas quickly looses energy (since it is dissipative), and sinks towards the center of the remnant, where it can fuel a starburst, or an AGN if a massive black hole is present


Next:
Stellar
Population
Synthesis