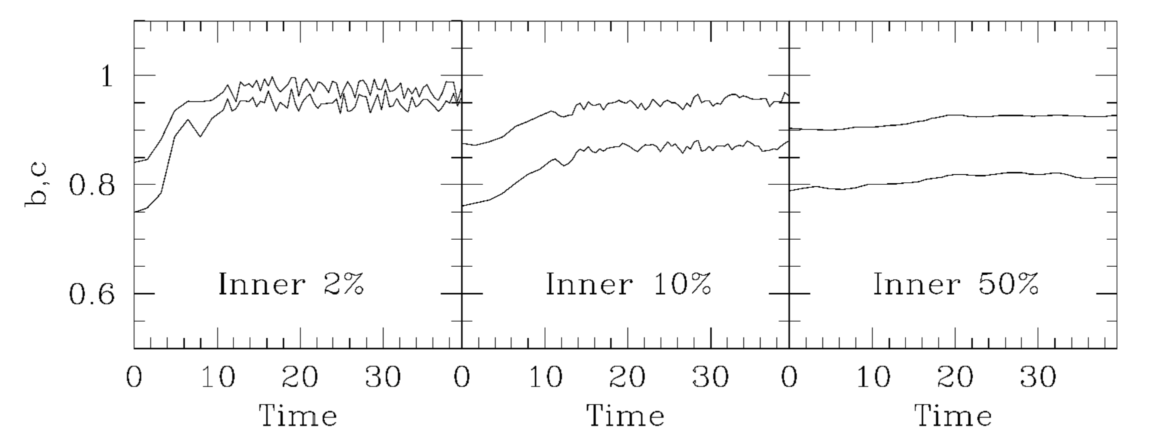
The effect of black holes

Black holes accrete matter and drive active galactic nuclei (AGN). They also inject energy into the interstellar medium via photoionization and shocks. But what do they do to the distribution of stars?

Holley-Bockelmann +02

Black holes scatter stars off box orbits: erode triaxiality.

Simulation 👉: Grow 1% mass black hole in nucleus of triaxial galaxy model (a=1, b=0.85, c=0.75). Box orbits become chaotic and isotropic. Inner regions get rounder. Important for nucleus, less so for bulk of galaxy.



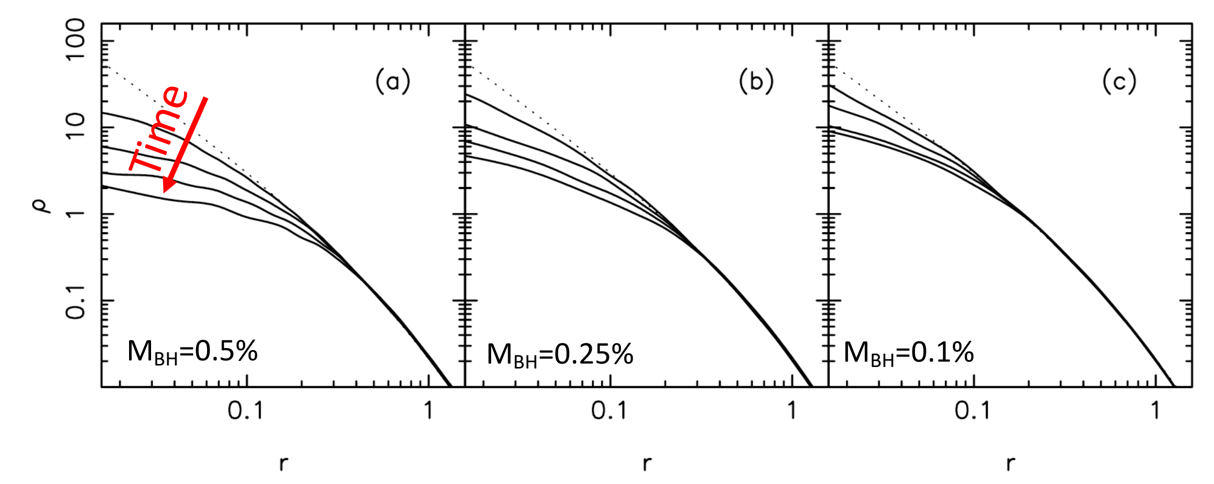
Binary black holes: "scour nucleus", reduce central density.

Merritt 06

Stars interact with binary black hole, gain energy, get ejected from nucleus. Black hole binary loses energy, binary gets closer ("hardens") eventually merges.

Question: Why would there be a binary black hole?

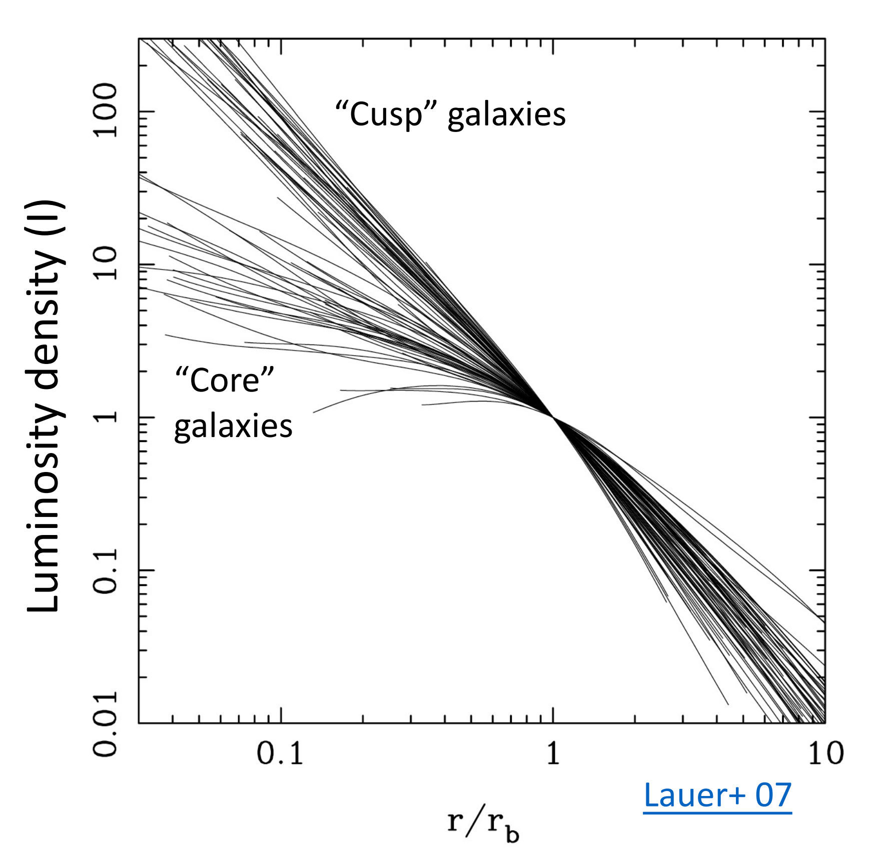
Simulation👉: Multiple BH binary events.

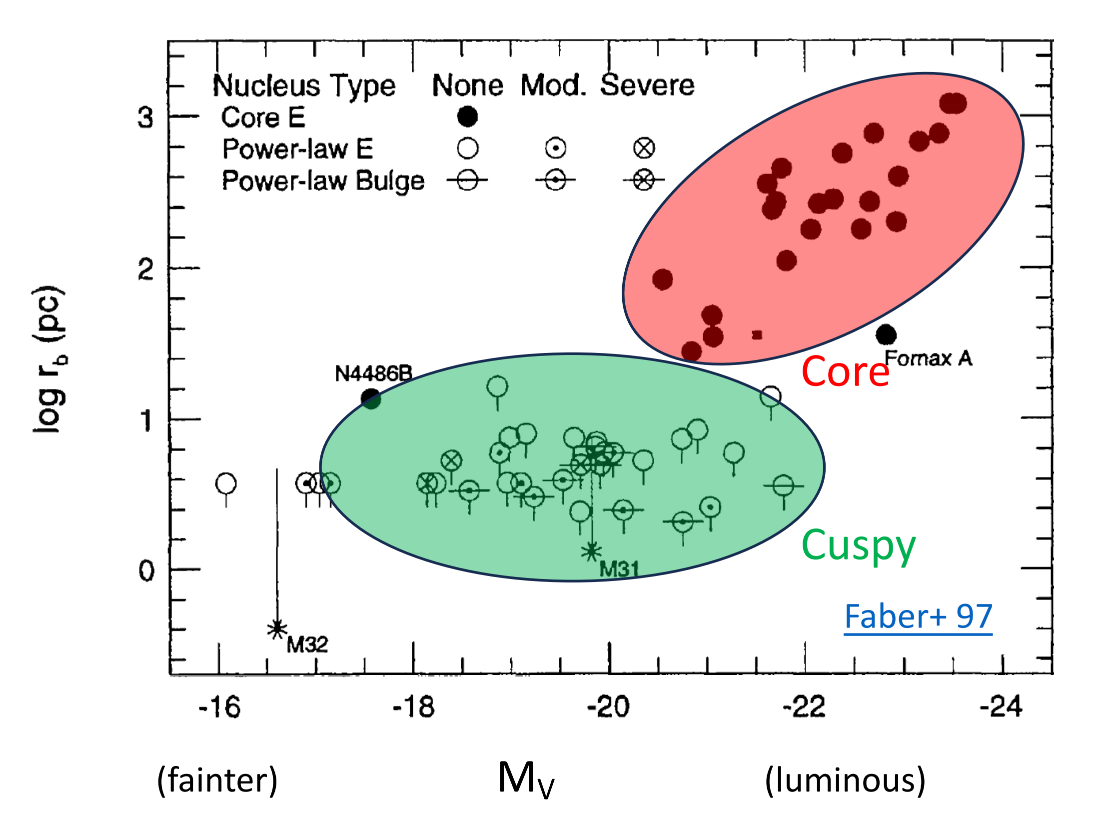


Nuclei of elliptical galaxies: cusp/core profiles

HST studies of the nuclear surface brightness profiles of ellipticals show evidence for "cusp/core" dichotomy.

At small radius, the profile often shows a break from the outer profile. Inside this break radius (r_b) characterize the logarithmic slope of the density profile as $\gamma = \frac{d \log I}{d \log r}$. Cusp: steep profile ($\gamma > 0.3$), Core: shallow profile ($\gamma < 0.3$).





Luminous ellipticals are typically core galaxies; cuspy galaxies are lower luminosity systems.

Significant overlap at intermediate luminosity.

Nuclei of elliptical galaxies: cusp/core profiles

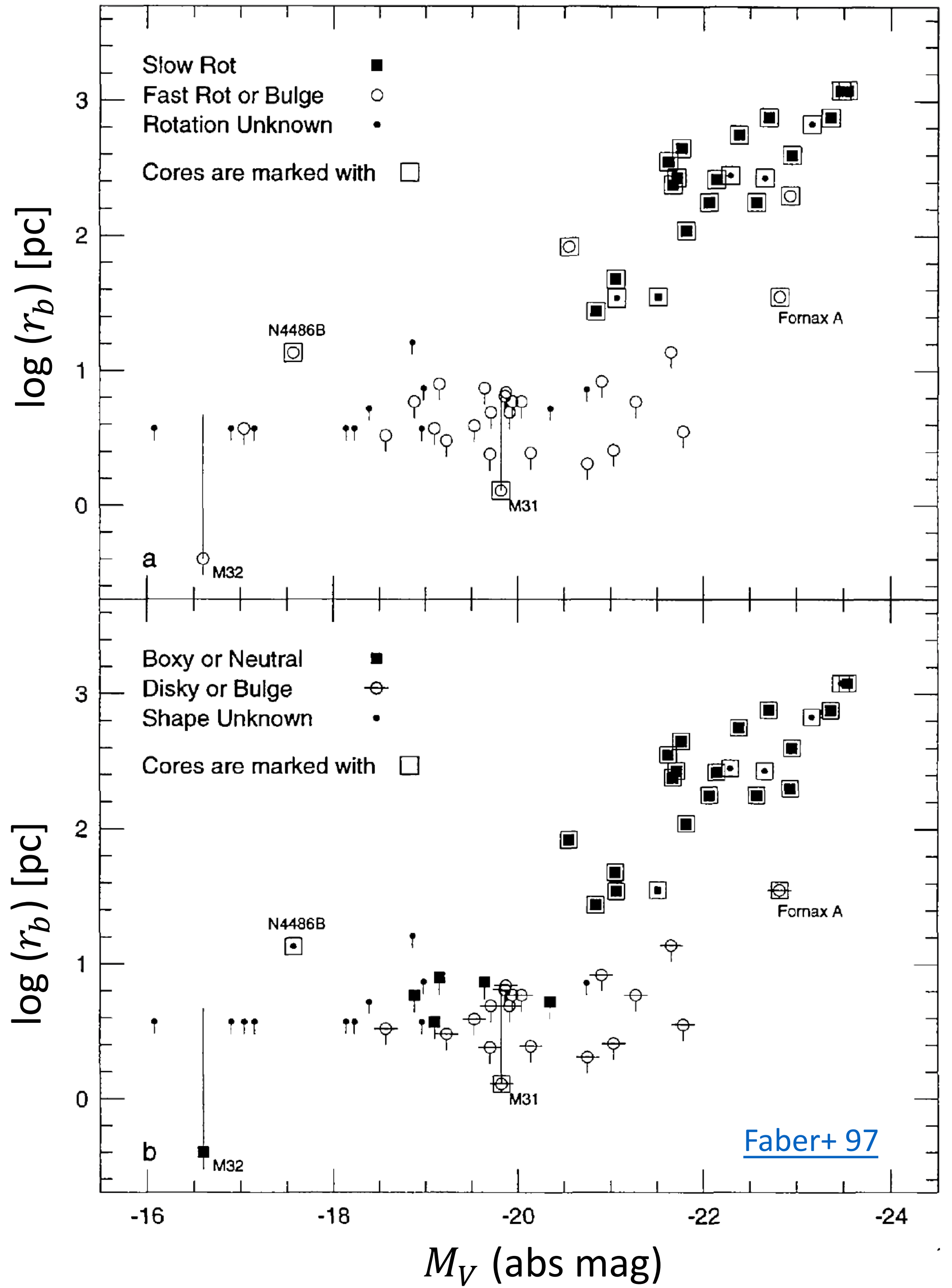
Cusp/core also correlates with other properties such as

- **Slow vs Fast Galaxy Rotation ⇒**

  ■ Slow rotators: big core radii, flat core profiles
  ○ Fast rotators: small or no core radii, cuspy profiles

- **Boxy vs Disky Galaxy Isophotes ⇒**

  ■ Boxy galaxies: big core radii, flat core profiles
  ⦶ Disky galaxies: small or no core radii, cuspy profiles



Faber+ 97

Elliptical galaxy dichotomy?

Most Massive Ellipticals	Moderate Mass Ellipticals
Very luminous ($M_V < -21.5$)	Lower luminosity ($M_V > -21.5$)
Cores	Cusps
Boxy	Disky
Slow Rotators	Fast(er) Rotators
High Sersic indices (n>4): large extended envelopes.	Lower Sersic indices (4-ish): very deVaucouleur-like.
Very old stellar pops	Slightly younger (but still old) stellar pops
Often in densest environments	Range of environments

Remember, these are all biggish ellipticals, not dwarf ellipticals, dwarf spheroidals etc.

Merger Trees

Way of showing accretion/assembly history of a galaxy:

- time runs vertically down
- size of trunk/branches show mass of object.
- branch/merge points: merger event.

A massive galaxy today ($t=t_0$) was in many smaller units at higher redshift.

Q: How does one define "formation time"?

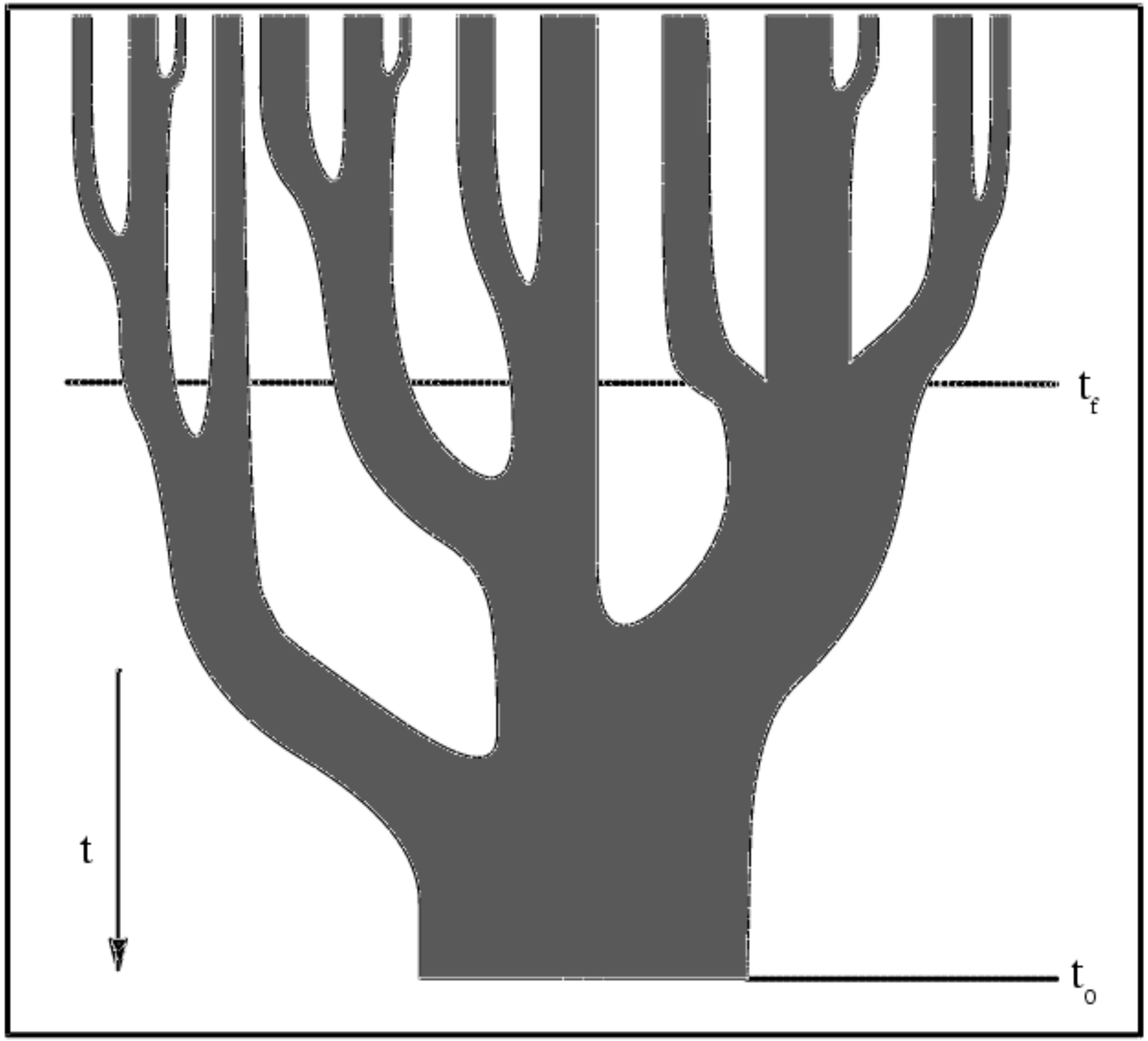
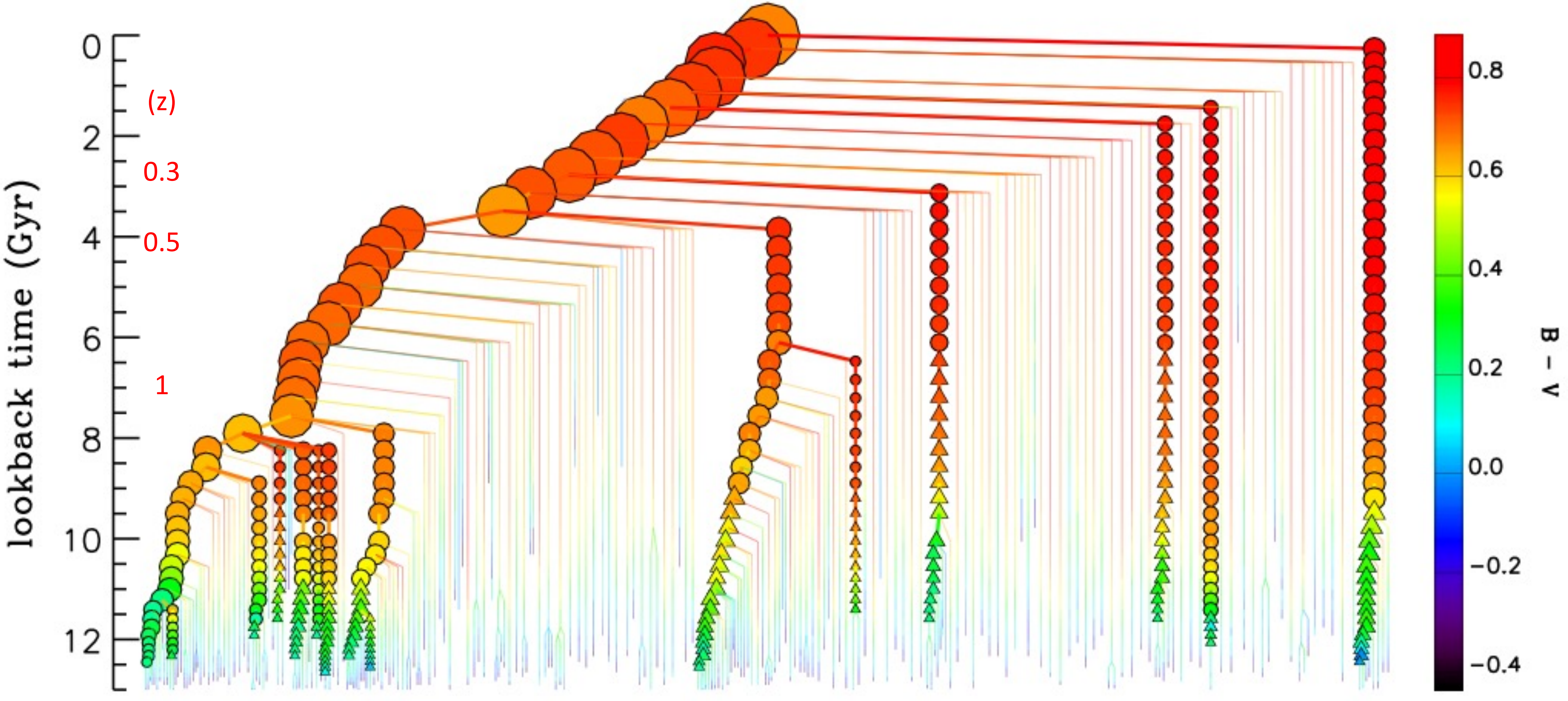


Figure 6. A schematic representation of a "merger tree" depicting the growth of a halo as the result of a series of mergers. Time increases from top to bottom in this figure and the widths of the branches of the tree represent the masses of the individual parent halos. Slicing through the tree horizontally gives the distribution of masses in the parent halos at a given time. The present time t_0 and the formation time t_f are marked by horizontal lines, where the formation time is defined as the time at which a parent halo containing in excess of half of the mass of the final halo was first created.

Merger tree for a massive cluster elliptical (cD)

Key:
Size of circle ⇒ stellar mass of objects
Color of circle ⇒ integrated color of stellar populations

de Lucia & Blazoit 07



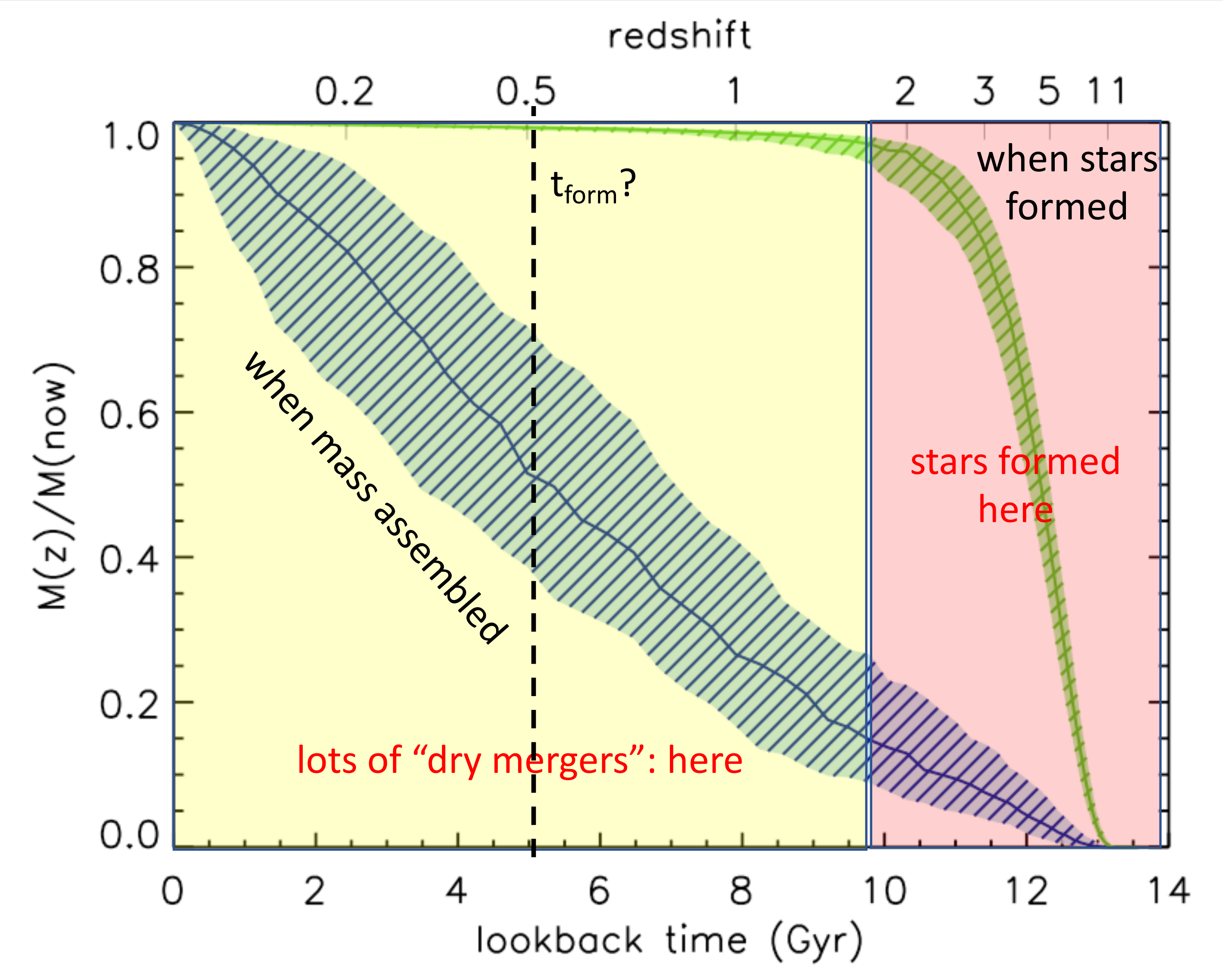
Star Formation History vs Assembly History

de Lucia & Blazoit 07

Look at the galaxy today. Two ways to think about the stellar mass:

1) star formation history: when did the stars actually form?

2) assembly history: what fraction of the stars were in a single object, as a function of time?



Characterizing Mergers

Wet vs dry:

- Wet merger: gas-rich galaxies, gas inflow, strong star formation, AGN
- Dry merger: gas-poor galaxies, only stars.

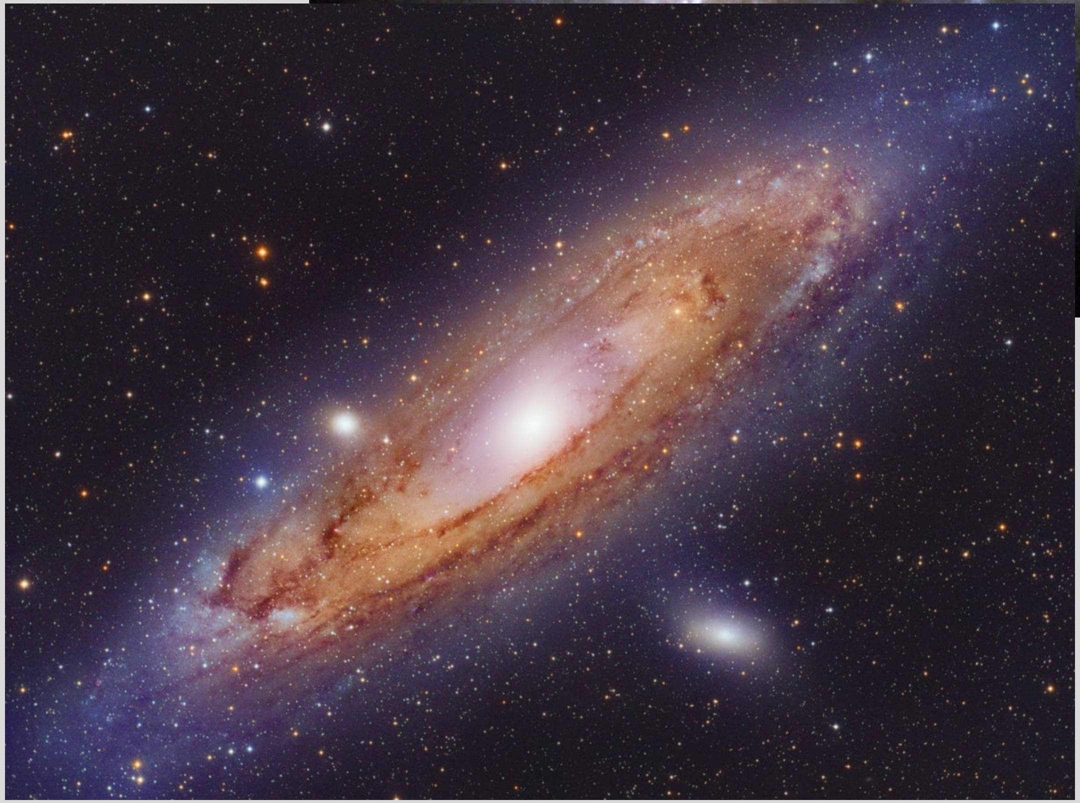
Characterizing Mergers

Wet vs dry:

- Wet merger: gas-rich galaxies, gas inflow, strong star formation, AGN
- Dry merger: gas-poor galaxies, only stars.

Mass ratio:

- Major merger: galaxies have comparable mass
- Minor merger: one galaxy is much smaller



Characterizing Mergers

Wet vs dry:

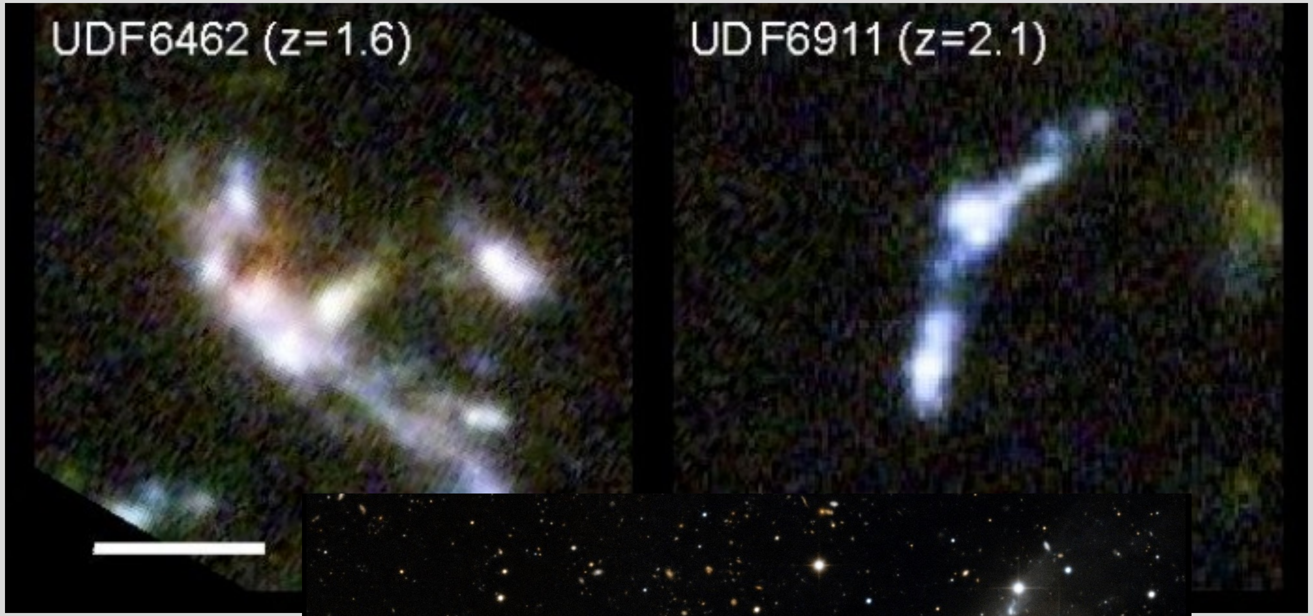
- Wet merger: gas-rich galaxies, gas inflow, strong star formation, AGN
- Dry merger: gas-poor galaxies, only stars.

Mass ratio:

- Major merger: galaxies have comparable mass
- Minor merger: one galaxy is much smaller

Timing of mergers:

- Early (high redshift)
- Late (low redshift)



Characterizing Mergers

Wet vs dry:
- Wet merger: gas-rich galaxies, gas inflow, strong star formation, AGN
- Dry merger: gas-poor galaxies, only stars.

Mass ratio:
- Major merger: galaxies have comparable mass
- Minor merger: one galaxy is much smaller

Timing of mergers:
- Early (high redshift)
- Late (low redshift)

Number of mergers
- One big one?
- Many smaller ones?

None of these are either/or possibilities, of course.....

Elliptical galaxy dichotomy?

Most Massive Ellipticals	Moderate Mass Ellipticals
Very luminous ($M_V < -21.5$)	Lower luminosity ($M_V > -21.5$)
Cores	Cusps
Boxy	Disky
Slow Rotators	Fast(er) Rotators
High Sersic indices (n>4): large extended envelopes.	Lower Sersic indices (4-ish): very deVaucouleur-like.
Very old stellar pops	Slightly younger (but still old) stellar pops
Often in densest environments	Range of environments

Remember, these are all biggish ellipticals, not dwarf ellipticals, dwarf spheroidals etc.

General picture: the most massive mergers likely formed through many dry mergers over time, typically in dense clusters. Lower mass systems more likely to come from wet mergers (in groups and field?), maybe marked by only one or a few big mergers.