An introduction to

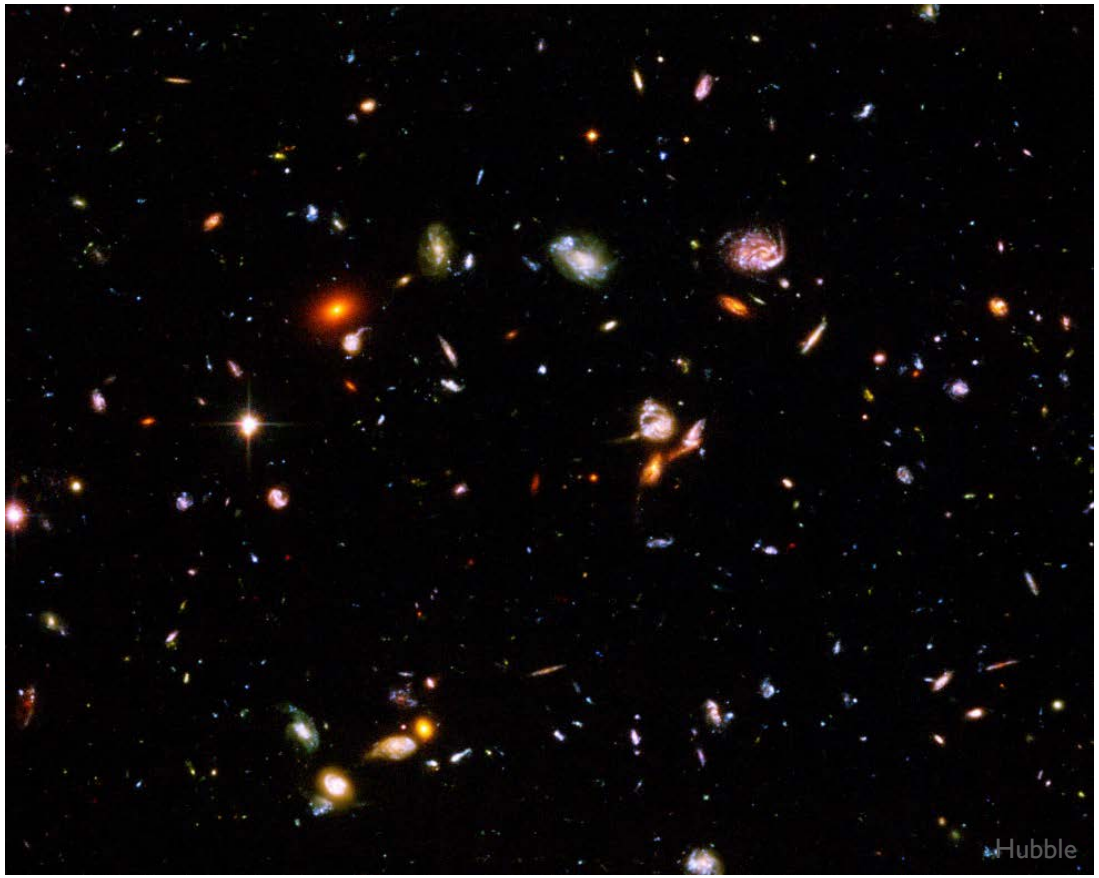
Galaxy Evolution

Zach Meisel

Ohio University - ASTR1000

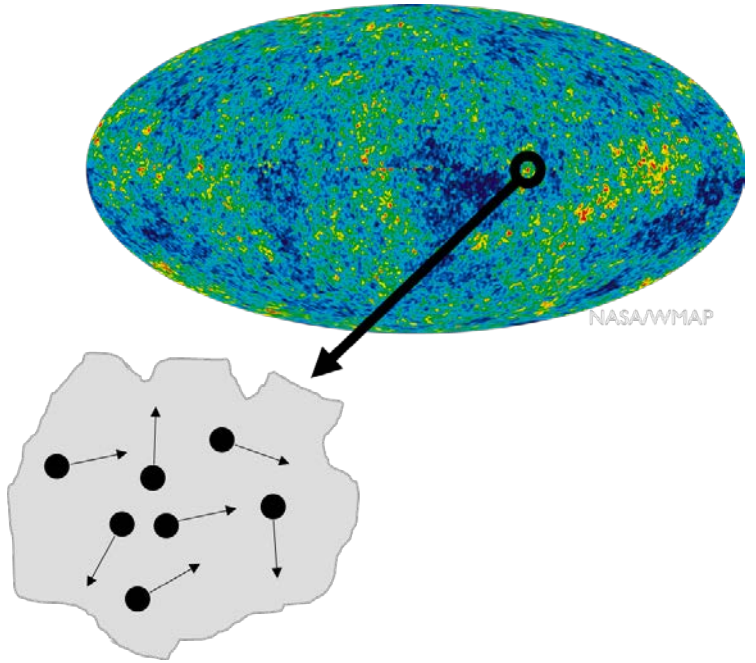
First, how do we know how a galaxy evolves over time?

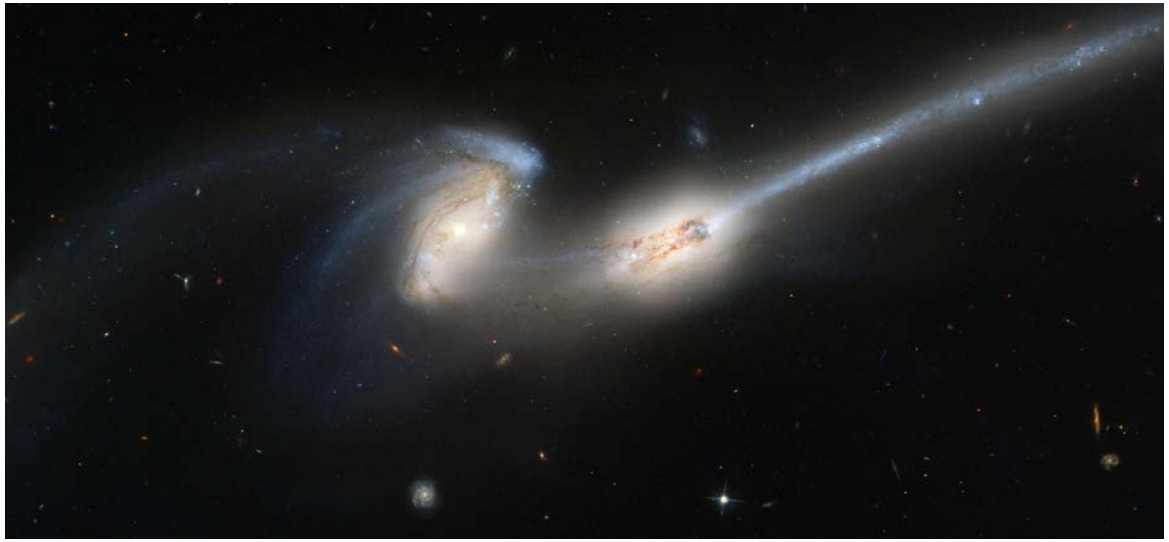
- Galaxy evolution is way too slow for sitting & watching to be useful *(even with the time travel face bag)*
- Instead, we take advantage of light travel time and look further away to look further back in time
  - …sort of like archaeology
- The challenge is to get enough examples over time to piece together the likely steps
  (and cross check with simulations)
- The further back you look, the more rough of a guide you have.
  For furthest galaxies, just shape & color
- The census of galaxies at various distances/times gives clues too
- Individual stars can be used for galactic ages
- Have to account for bias!
  Brighter galaxies are easier to detect.



Ellipticals: top-down *and* bottom-up formation

- **Observation:** The early universe hosts quasars, supermassive black holes feeding on galactic gas to make jets that outshine the rest of the galaxy
  Inference: Large galaxies were formed early in the universe, top-down.
  - *Why no disk?* Because little net angular momentum
- **Observation:** Giant elliptical galaxies are not seen earlier than ~6Gyr into the universe's lifetime
  Inference: Large elliptical galaxies were formed bottom-up by mergers
  - *Why no disk?* Because there isn't the gas from the original cloud to cause collisions that ultimately flatten a rotating orb into a disk. So stars orbit in lots of orientations.
- Both appear to be true



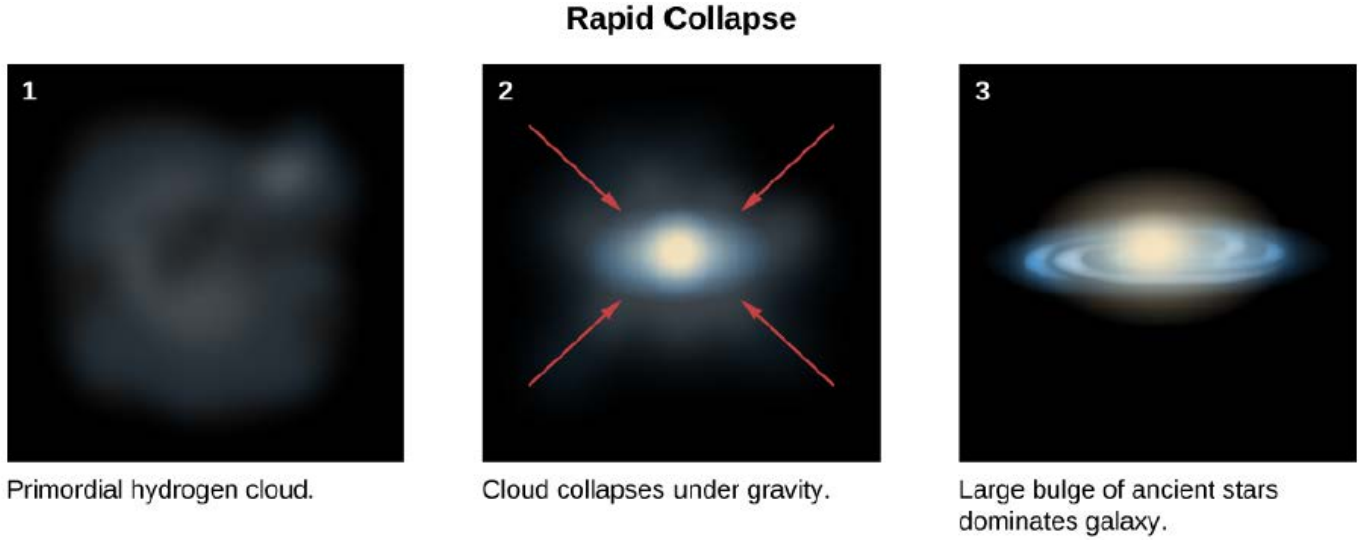


NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M.Clampin (STScI), G. Hartig (STScI), the ACS Science Team, and ESA

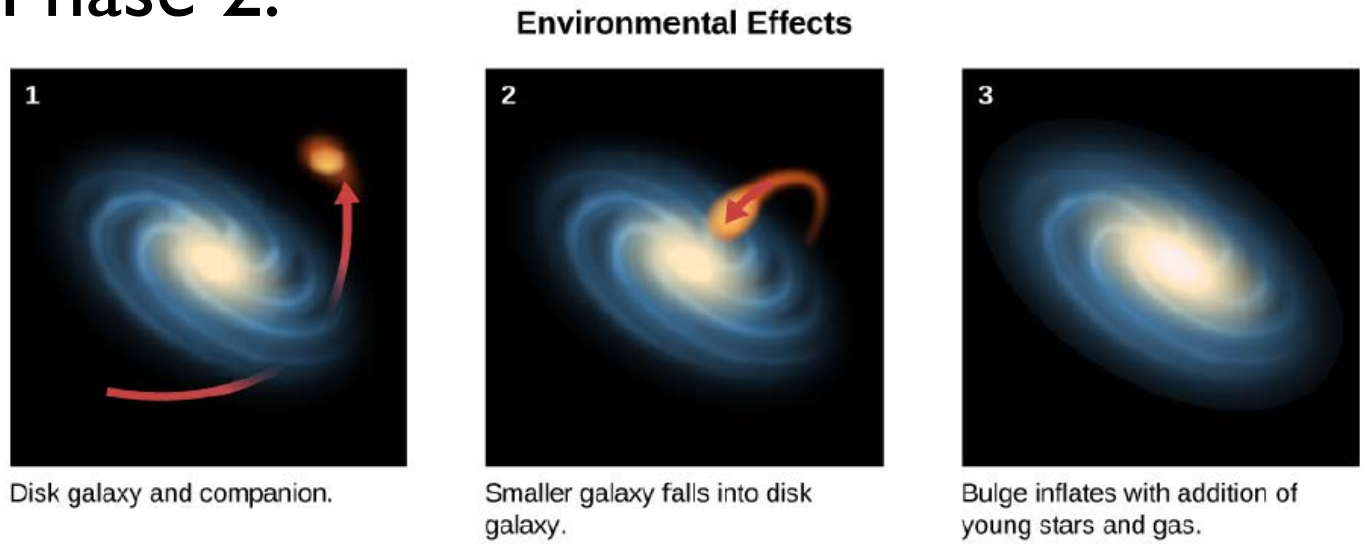
Spirals: mostly bottom-up formation

- **Observation:** Spirals host old stars in the bulge and younger stars in the disk
  Inference: The bulge initially formed top-down, then most of the disk formed later
- **Observation:** Chemically distinct stars are found in streams of the Milky Way.
  Inference: Spiral galaxies grow by mergers with smaller galaxies

Phase 1:



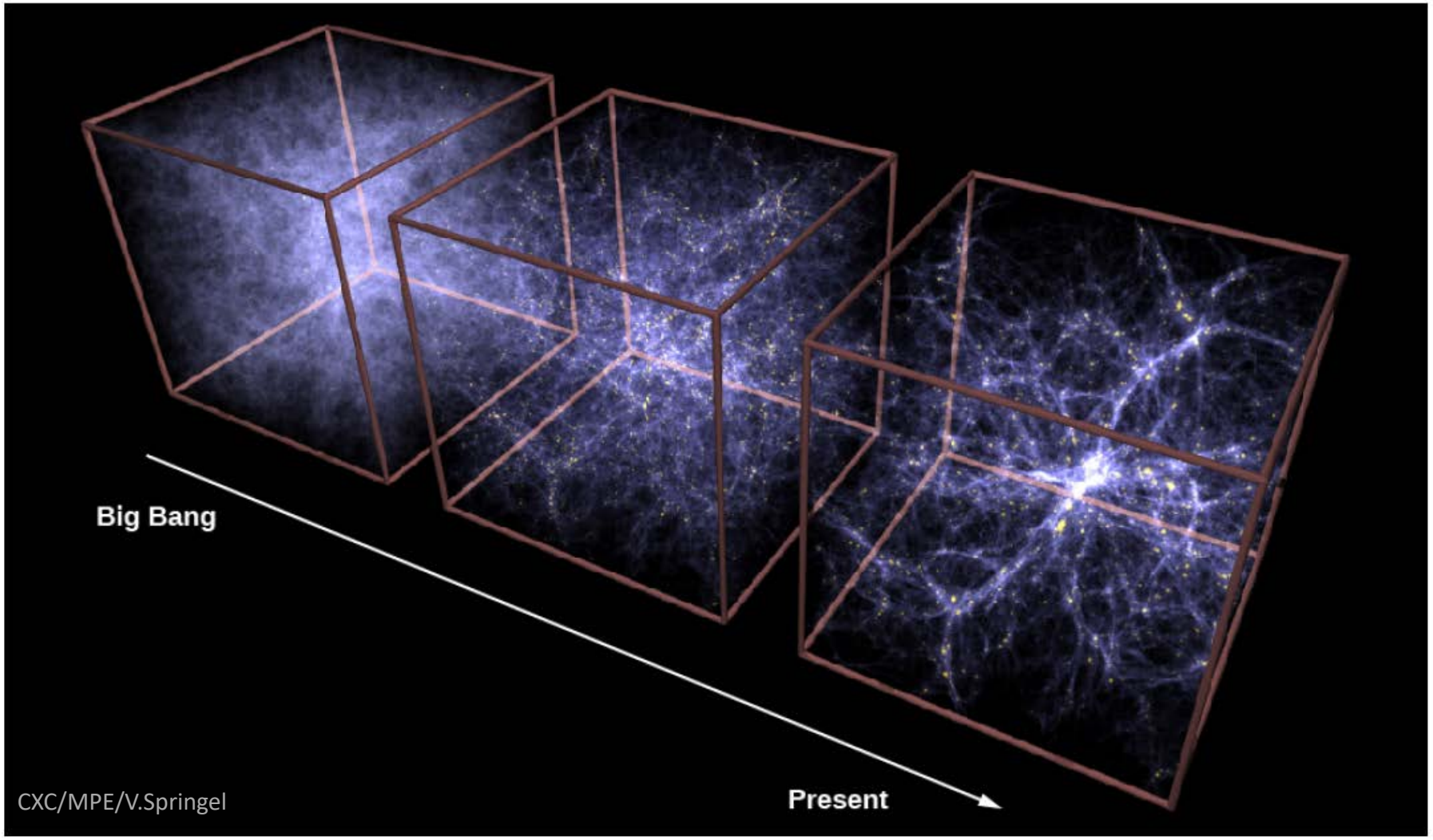
Phase 2:

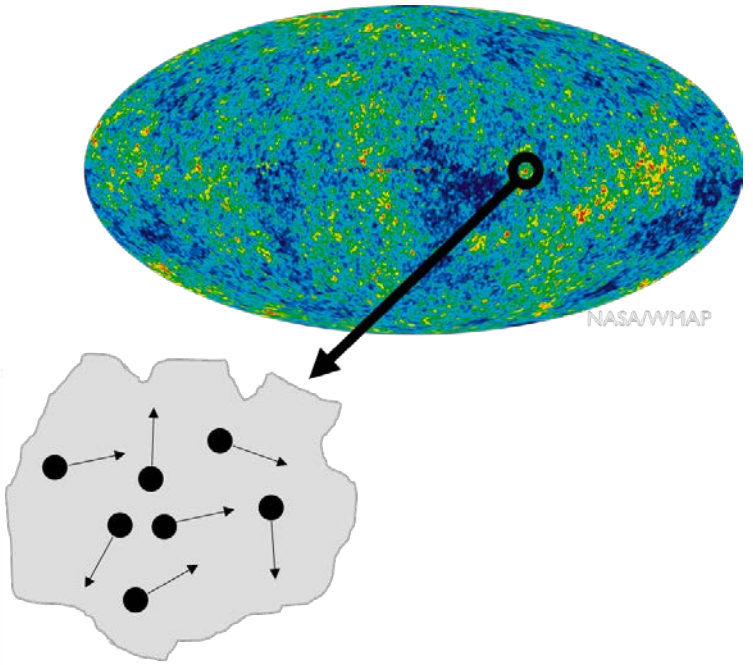


openstax

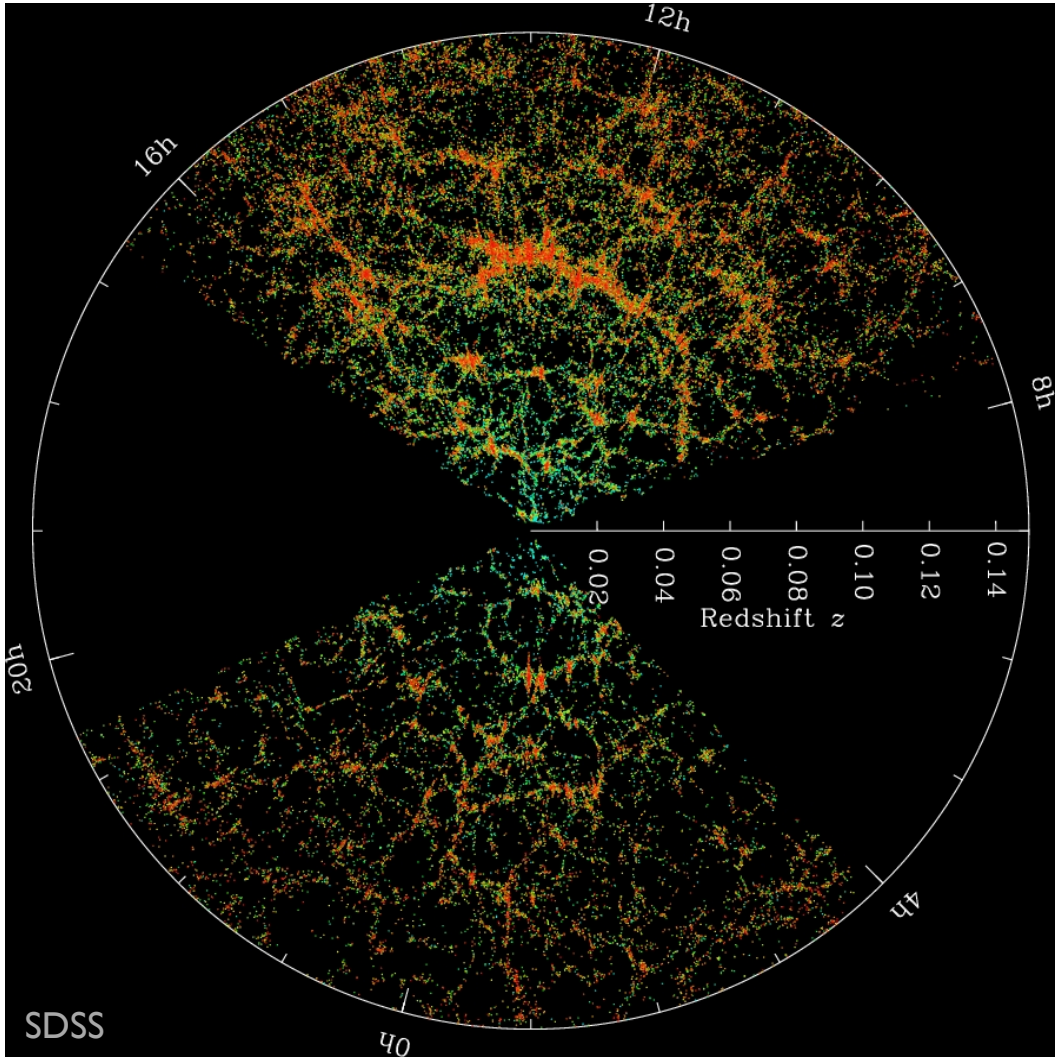
Galaxy cluster formation

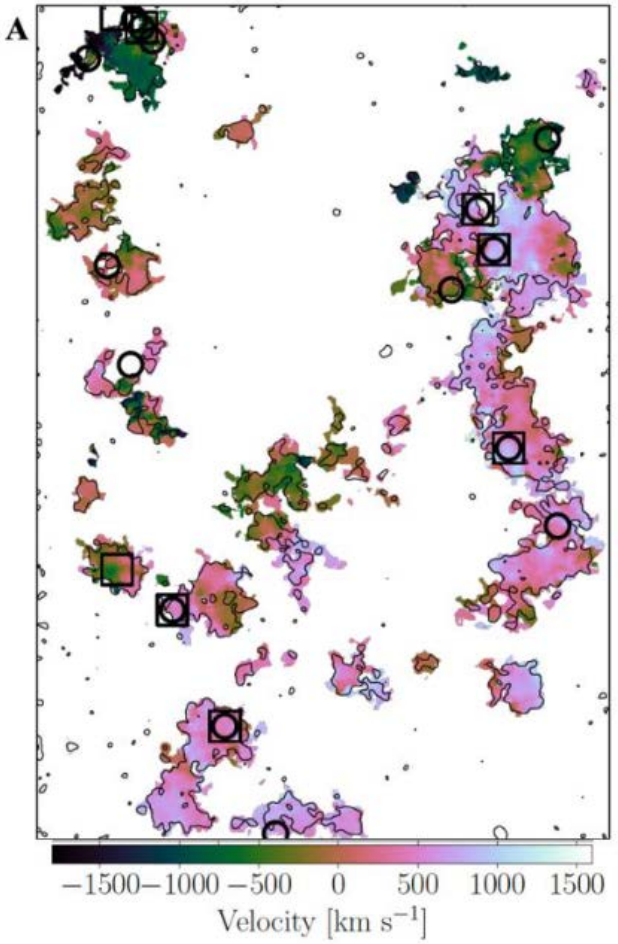
Similar to galaxy formation, local perturbations in density cause overdense regions to collapse.
Lots of these result in a filament structure.

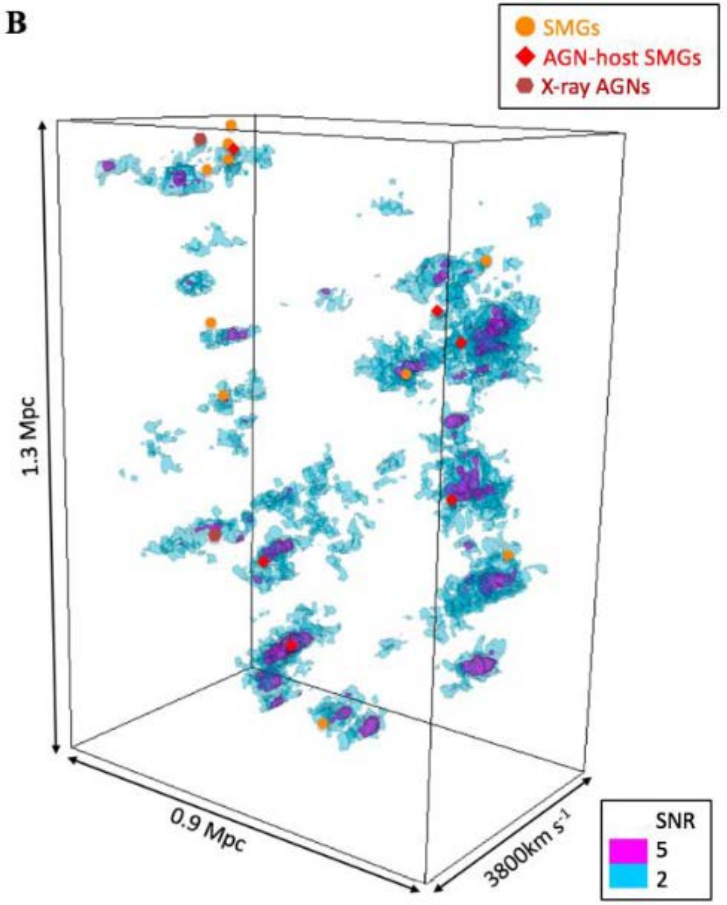




The cosmic web, observed:







Umehata et al. Science 2019

You'll never guess how galaxy clusters form…

It's the same story as for essentially everything else:

local density differences

\+ gravity

\+ time