Cosmology
Lecture 17

Baryons and Photons II: Galaxies and Stars

Lectures

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<u>17: Baryons & Photons II</u>

Learning objectives

How the structure created by the gravitational collapse of dark matter helps to entrain baryonic matter.

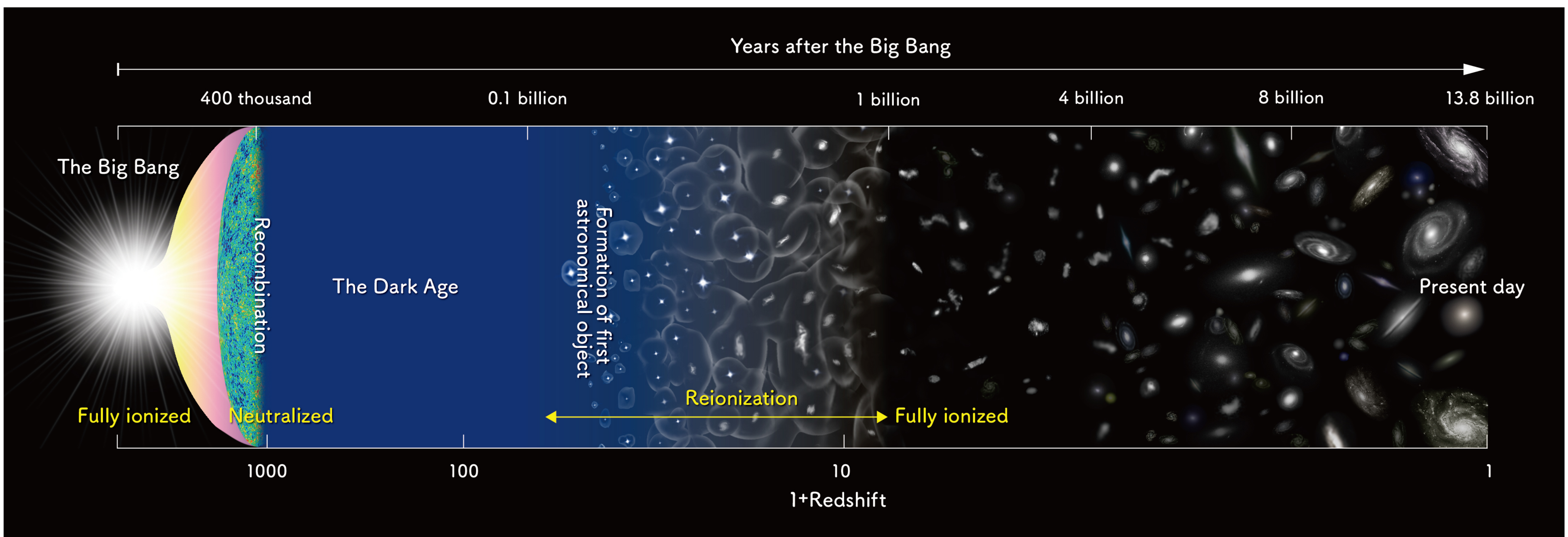
The mass distribution of dark matter halos and galaxies, and why there is a galaxy “mass limit”.

How Giant Molecular Clouds cheat the Jean’s mass and collapse to form stars.

If we have time, we’ll finish with a recap of the module.

The epoch of ionisation

- In the previous lecture, we considered the fact that, despite recombination, the Universe is now largely (re)-ionised.
- We looked at when re-ionisation likely occurred (given the observed opacity of the CMB).
- And we also considered two possible causes of reionisation: the first stars and accreting supermassive black holes, finding that stars were the most likely culprits.

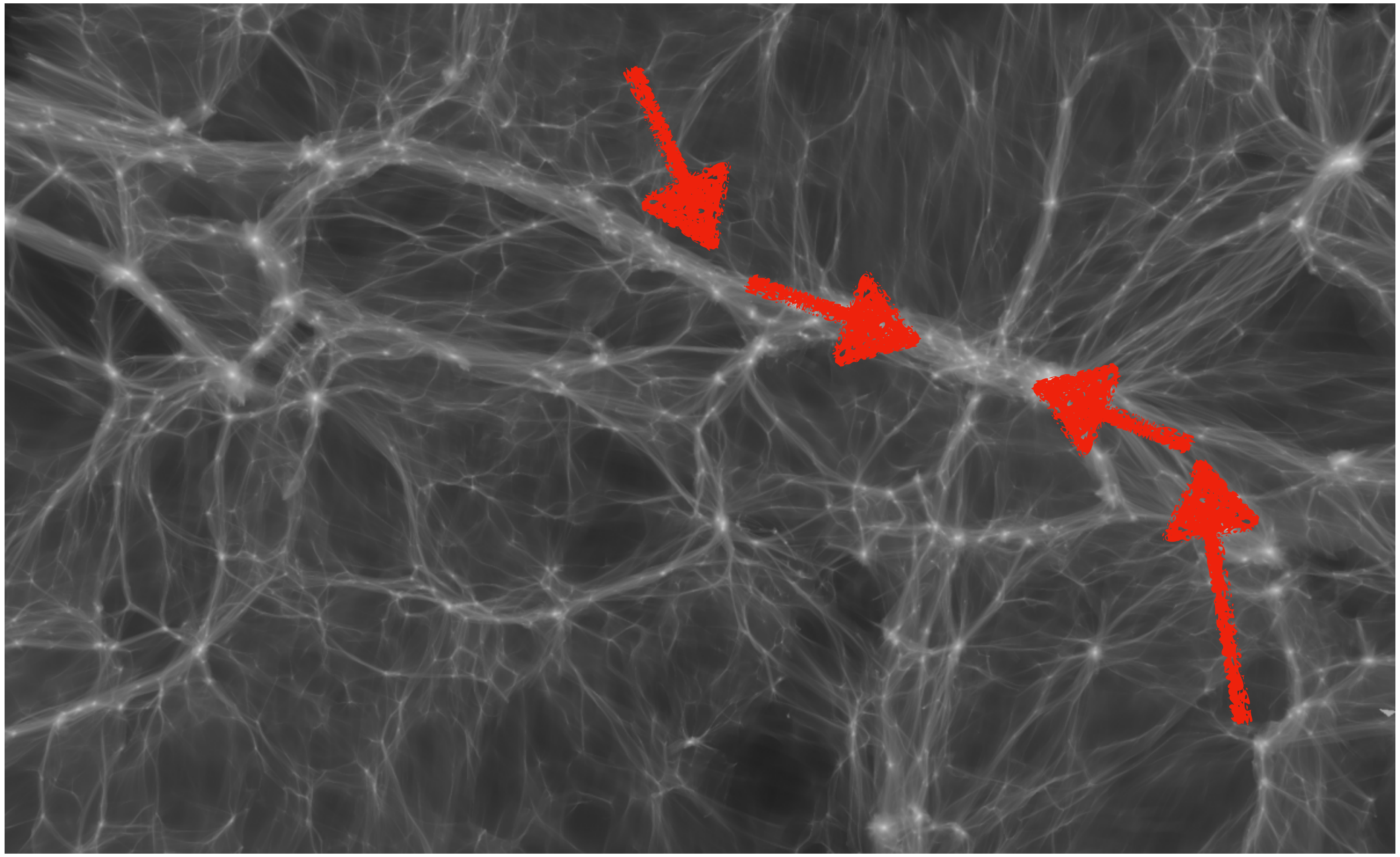


The first galaxies

While the first stars likely formed between 50-200 Myr after the Big Bang, the first galaxies formed somewhat later.

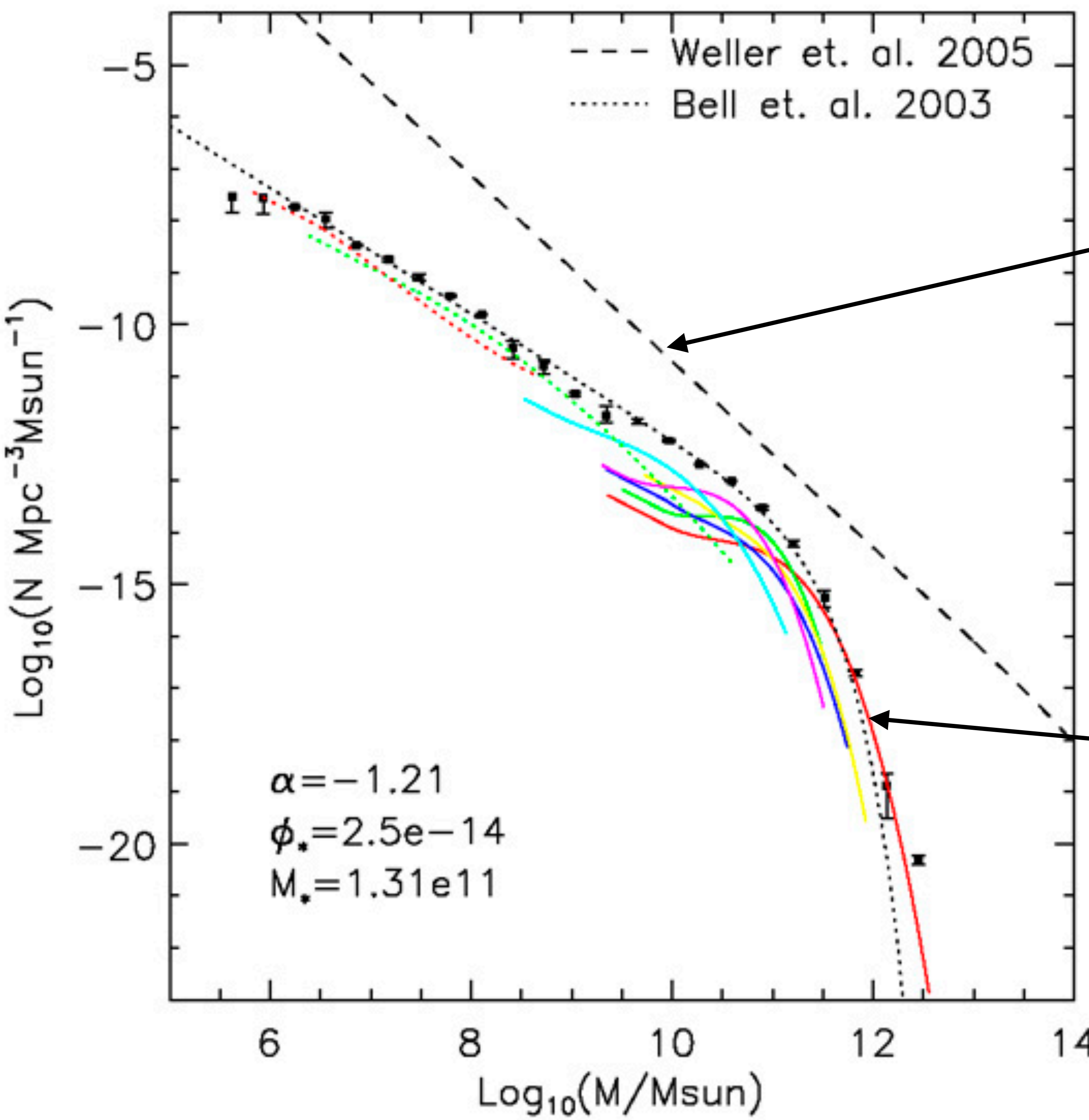
Building a galaxy requires *lots* of Baryonic material to be concentrated in a relatively small volume.

To achieve this, the Universe uses gravity from Dark Matter to attract Baryonic matter.



The dark matter and galaxy mass functions

In astronomy, a mass function is basically a histogram which tells us the relative numbers of “things” (e.g., stars, galaxies, dark matter halos) within a given mass range…

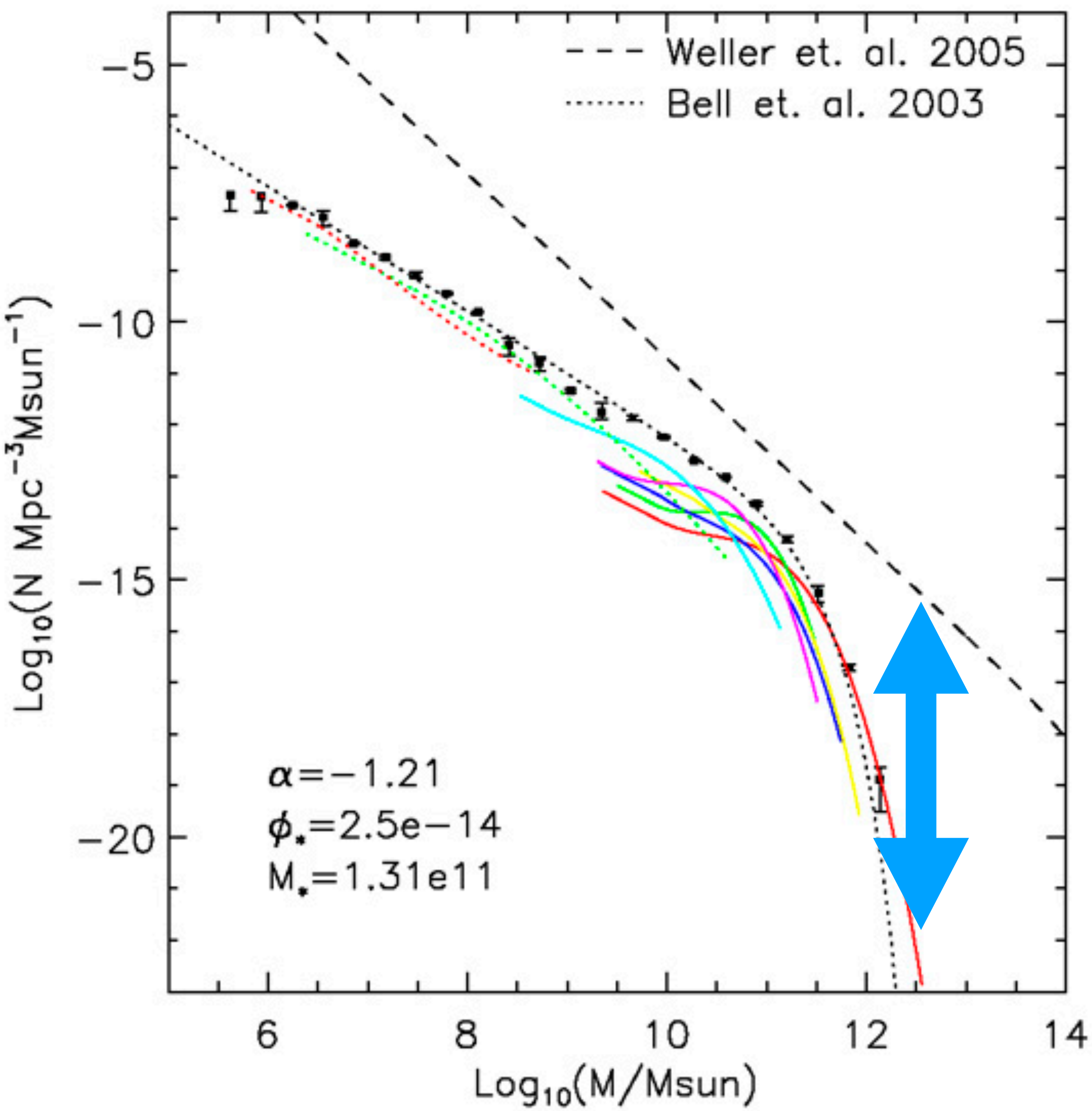


Dark matter halo mass function from simulations.

Galaxy mass function(s) from observations.

The “missing” high mass galaxies

It’s clear that the Universe has no problems creating very high mass dark matter halos, but it struggles to form comparatively massive galaxies.

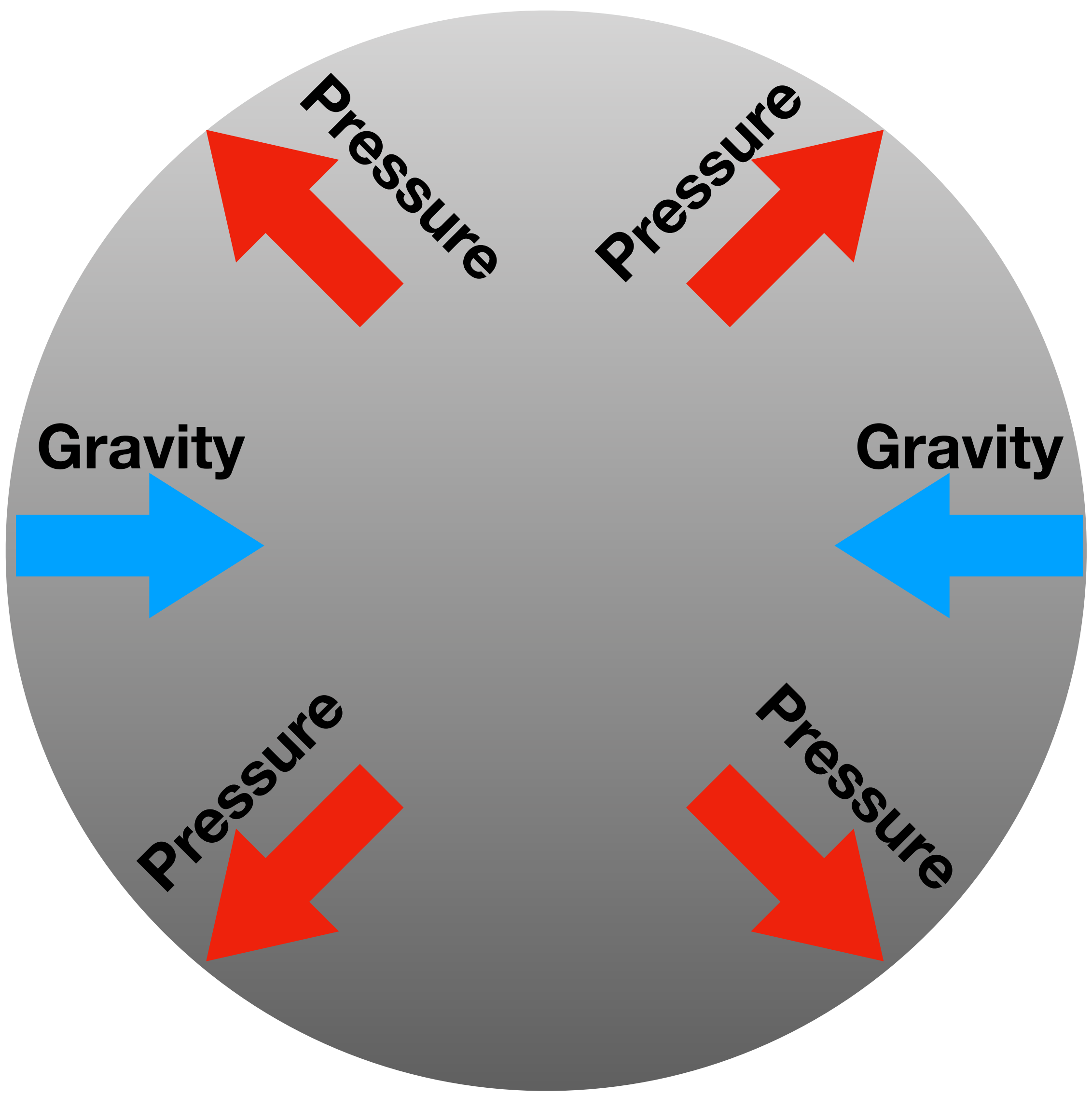


Why is this?

Consider a large sphere of gas…

Gravity will cause the sphere to collapse, which will cause the density and pressure and temperature of the gas to increase.

Eventually, the sphere will reach hydrostatic equilibrium, in which the pressure balances gravity. This happens when…



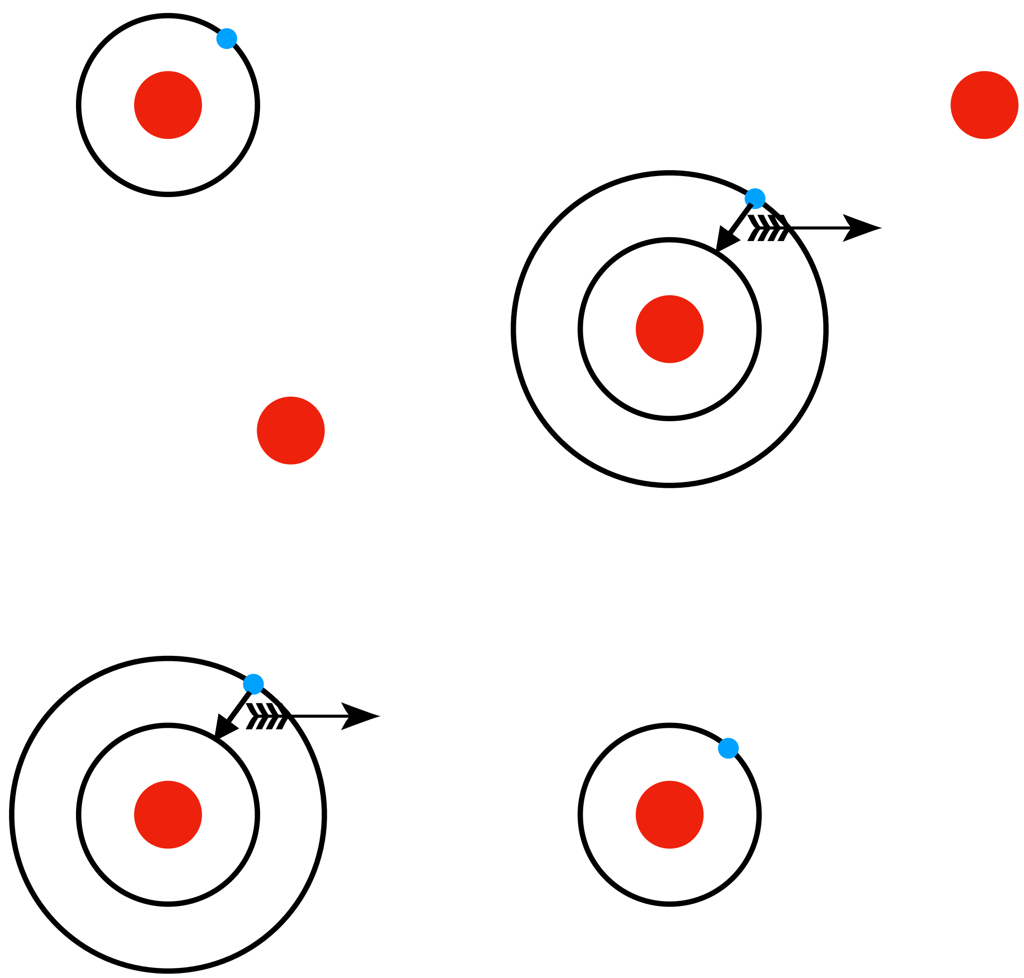
$$kT_{\rm gas} = \frac{GM_{\rm tot}\mu}{\beta R_{\rm halo}}$$

for a halo whose density falls as: $\rho \propto r^{-\beta}$
with a mean atomic mass of μ

The hotter the gas…

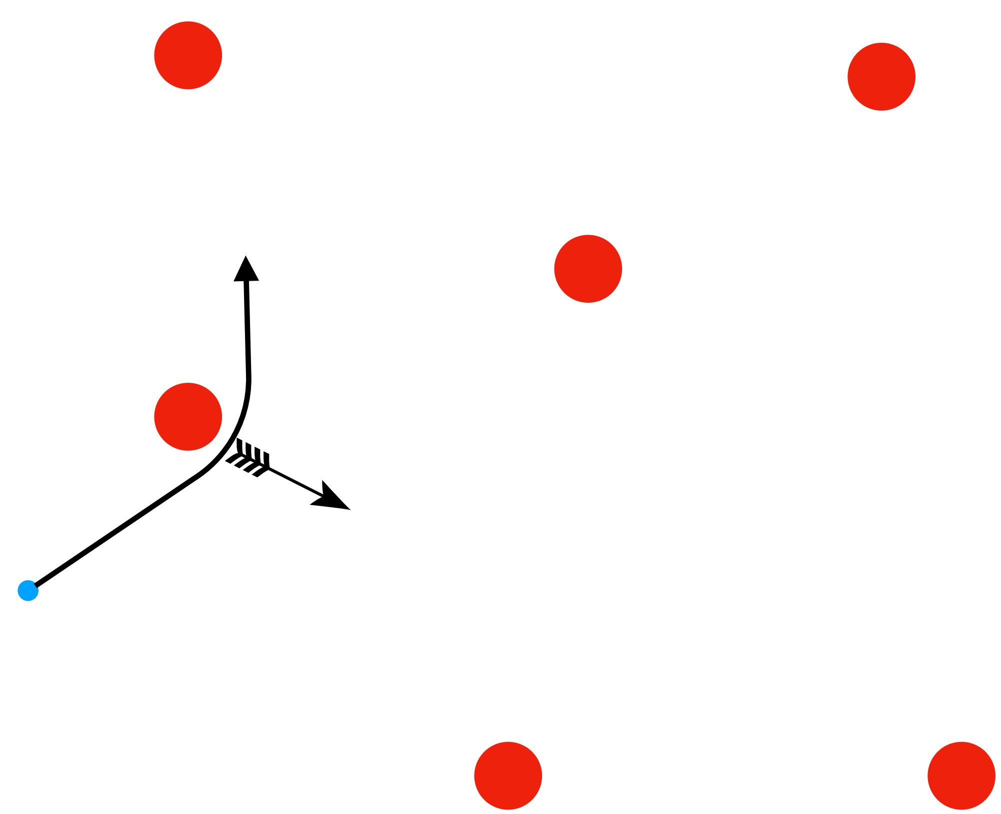
…the harder it is to cool.

At $T<10^6$K



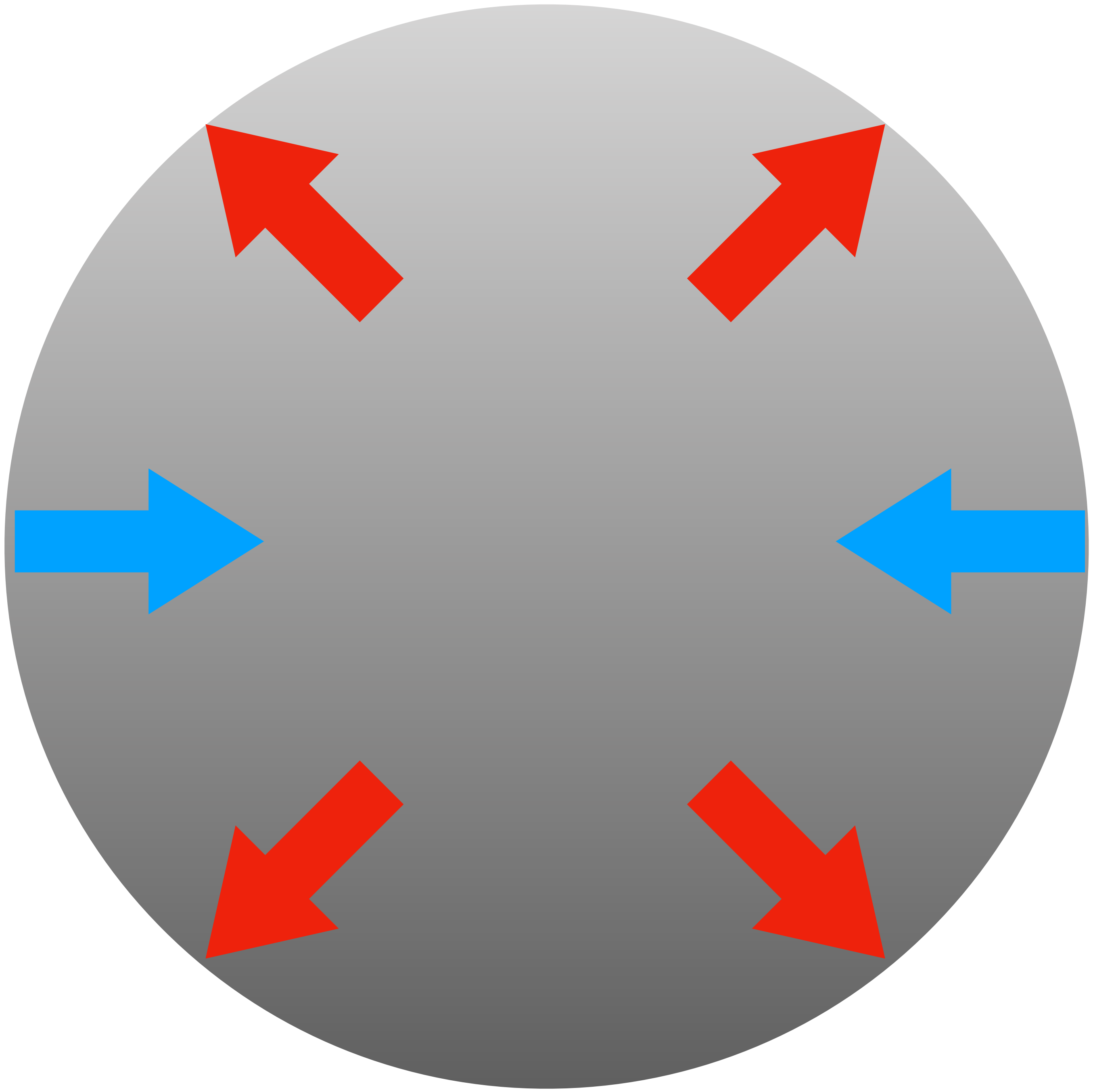
Some atoms still exist, meaning the gas can lose energy by electrons falling from a higher orbital to a lower one.

At $T>10^6$K

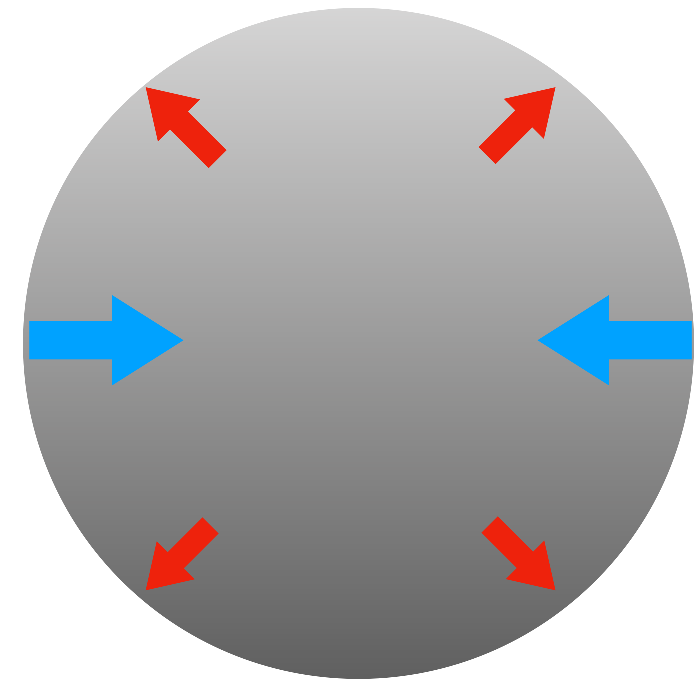


All atoms are ionised, so the only way to release energy is via bremsstrahlung radiation, which is much less efficient.

More massive clouds find it harder to collapse



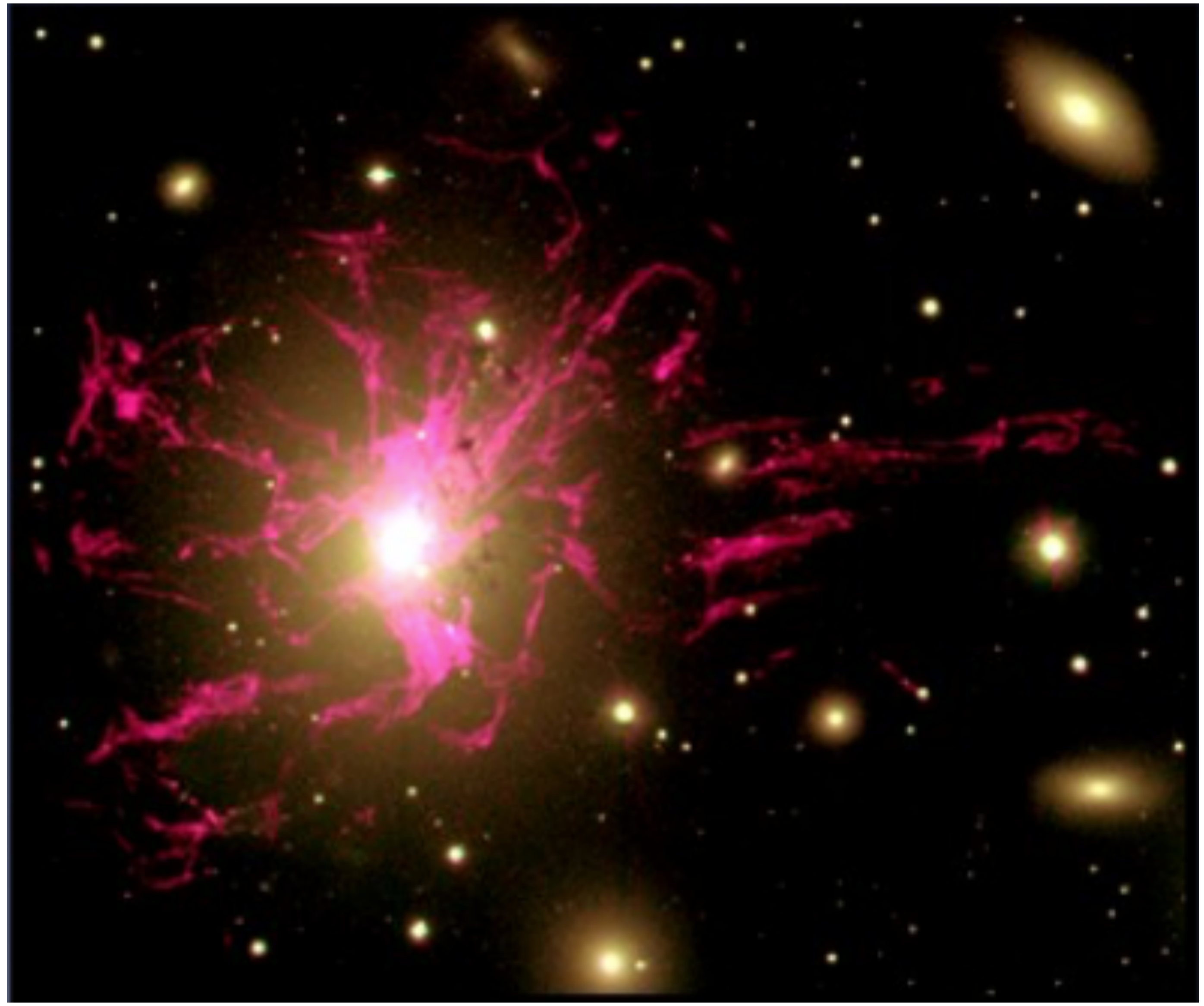
$10^{14}\ M_{Sun}$



$10^{12}\ M_{Sun}$

Because higher mass clouds have higher hydrostatic temperatures, they cool less efficiently and thus struggle to collapse. For example, a $10^{14}\ M_{Sun}$ cloud will take 42 Gyr to collapse, which is ~3 times longer than the age of the Universe.

The clumpy intergalactic medium



Perseus A galaxy, with “cooling flows” shown

While considering a “uniform sphere” of gas is good enough to get an overall picture, we know that the real Universe is not uniform on the scales of galaxies and clusters.

Instead, it clumps into regions of high density, which can cool more effectively to form stars…

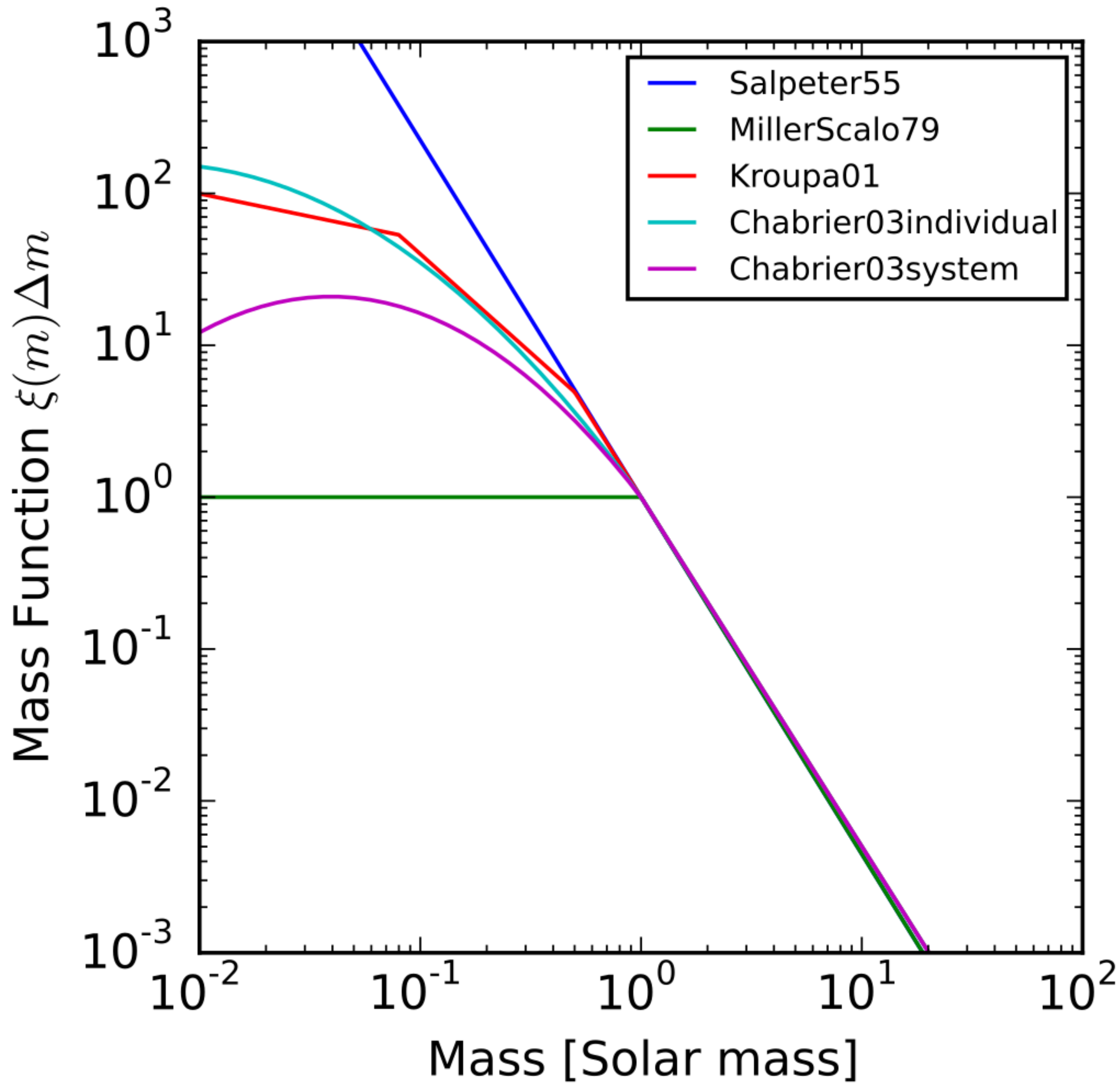
Giant molecular clouds

Eventually, gas falling onto/into galaxies cools to form giant molecular clouds.

Because these contain lots of atoms and molecules, they are very effective at releasing energy and cooling.

The Initial Mass Function

Cooling Giant Molecular Clouds eventually fragment to form a population of stars with masses given by the Initial Mass Function…



Creating today's stellar populations

A recap of the module…

- The Universe is homogeneous and isotropic, which leads directly to $D_{x,y}(t) = a(t)r_{x,y}$ and $H = \dot{a}/a$
- That spacetime, and thus the Universe, can be curved, but that it can only be positively or negatively curved, or flat.
- How distances are measured in (curved) spacetime, and that *cosmological* redshift tells us how much the Universe has expanded or contracted since the light was emitted.
- Proper distances in the Universe, and how to calculate them from the time-evolving scale factor.
- And that the Friedmann Equation relates the scale factor to the contents and curvature of the Universe.
- How the energy density contents of the Universe change with scale factor.
- And how we can use these and the FE to calculate how different types of Universe evolve over time.

A recap of the module…

- We looked at how cosmologists solve the FE for our own Universe, and how they “work backwards” to determine cosmological parameters from observations (SNe).
- There was a bit of an aside to “look” at the Dark Universe.
- We considered how the CMB was produced during recombination, and how it provides a wealth of information on the properties of the Universe.
- We considered how the first nuclei were produced in the first few minutes of the Universe…
- …and the need for inflation in the very early Universe.
- Next, we considered how we went from the Big Bang to the formations of structures, and how it is affected by the temperature of Dark Matter.
- And that we can use BAOs as an “echo” of the CMB to gain further constraints on cosmological parameters.
- Finally, we briefly looked at reionisation, and how clouds of baryons collapsed to form todays galaxies and stars.