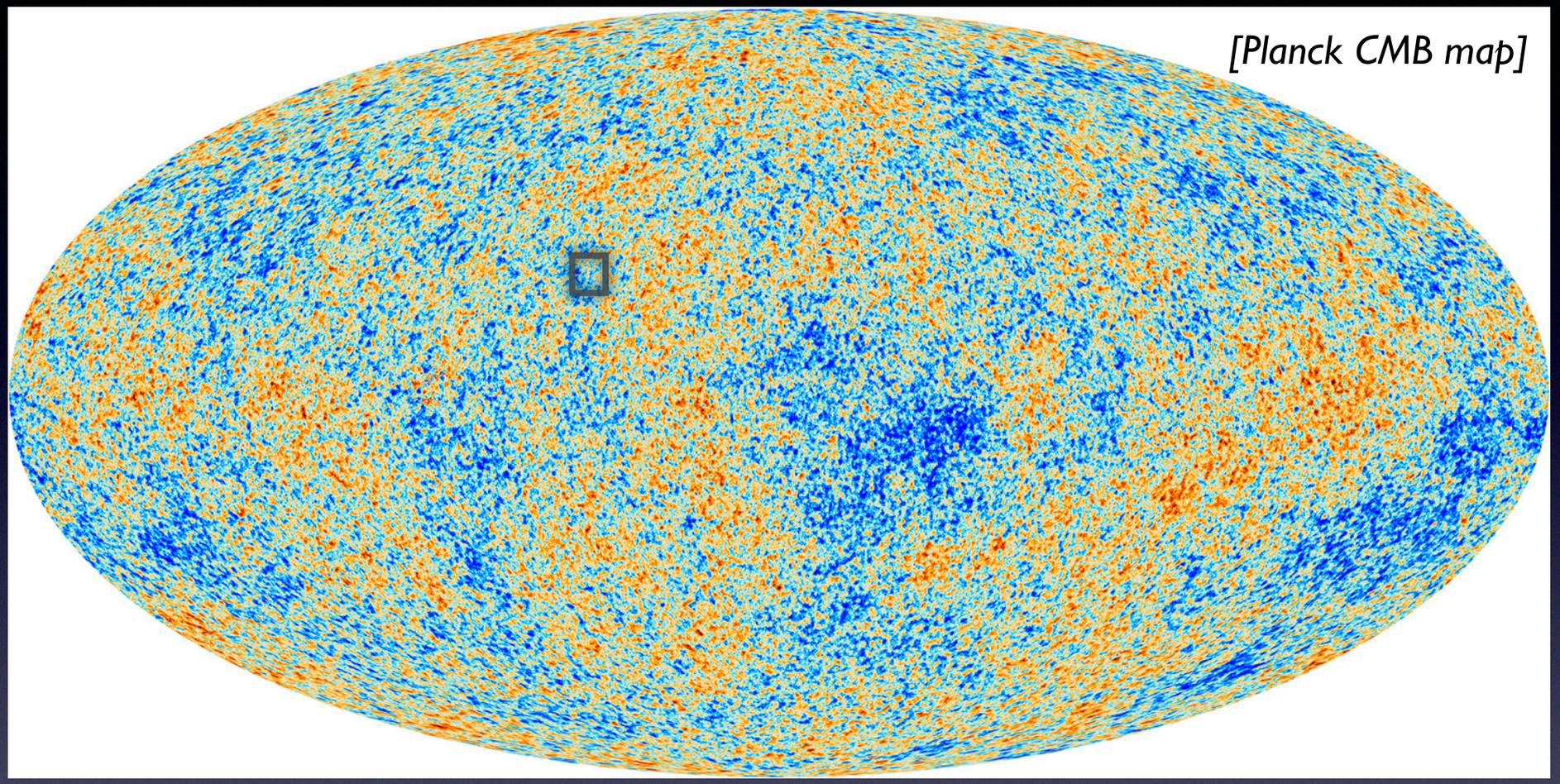
Multiphase gas around galaxies

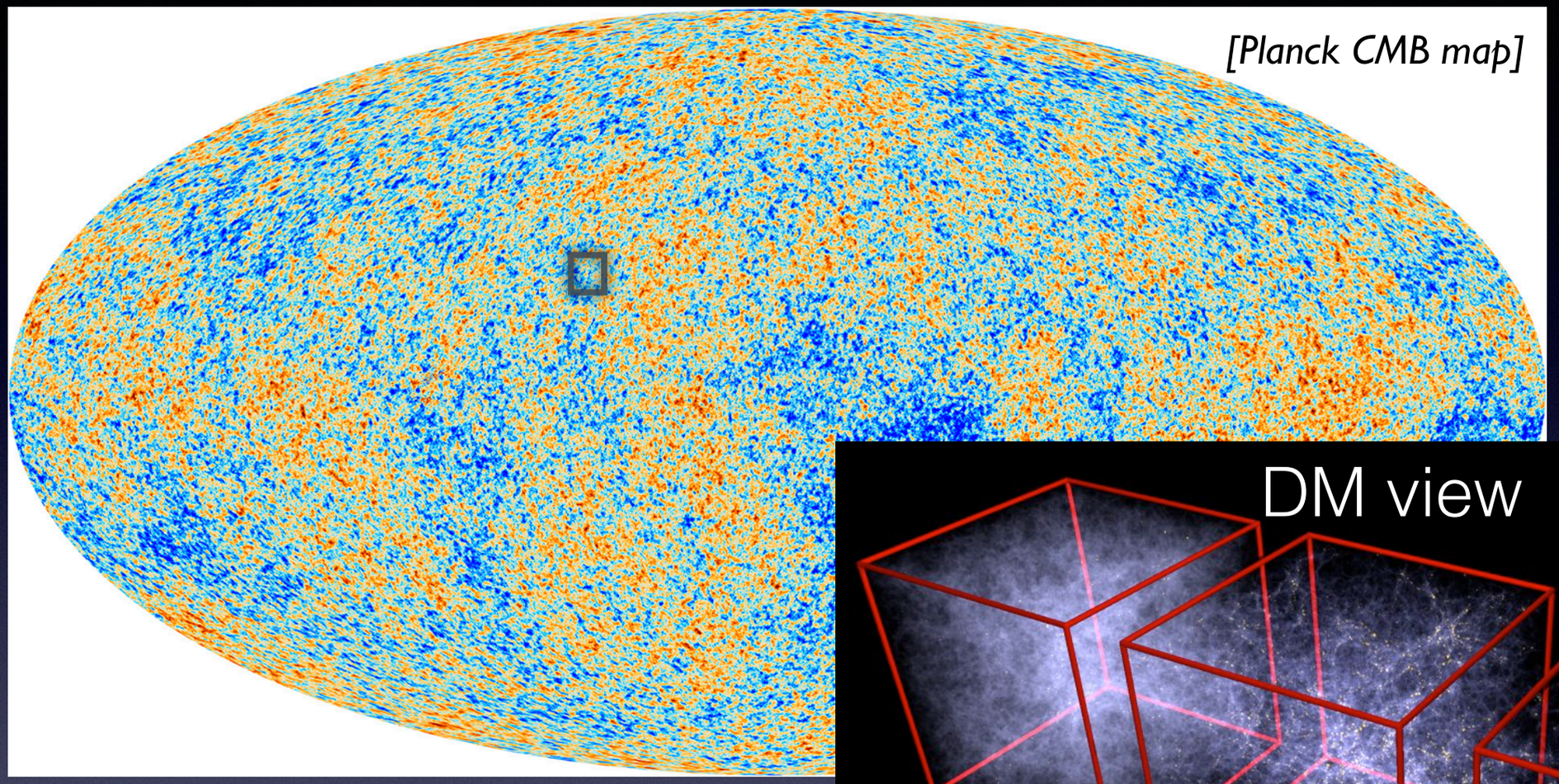
Prateek Sharma, IISc

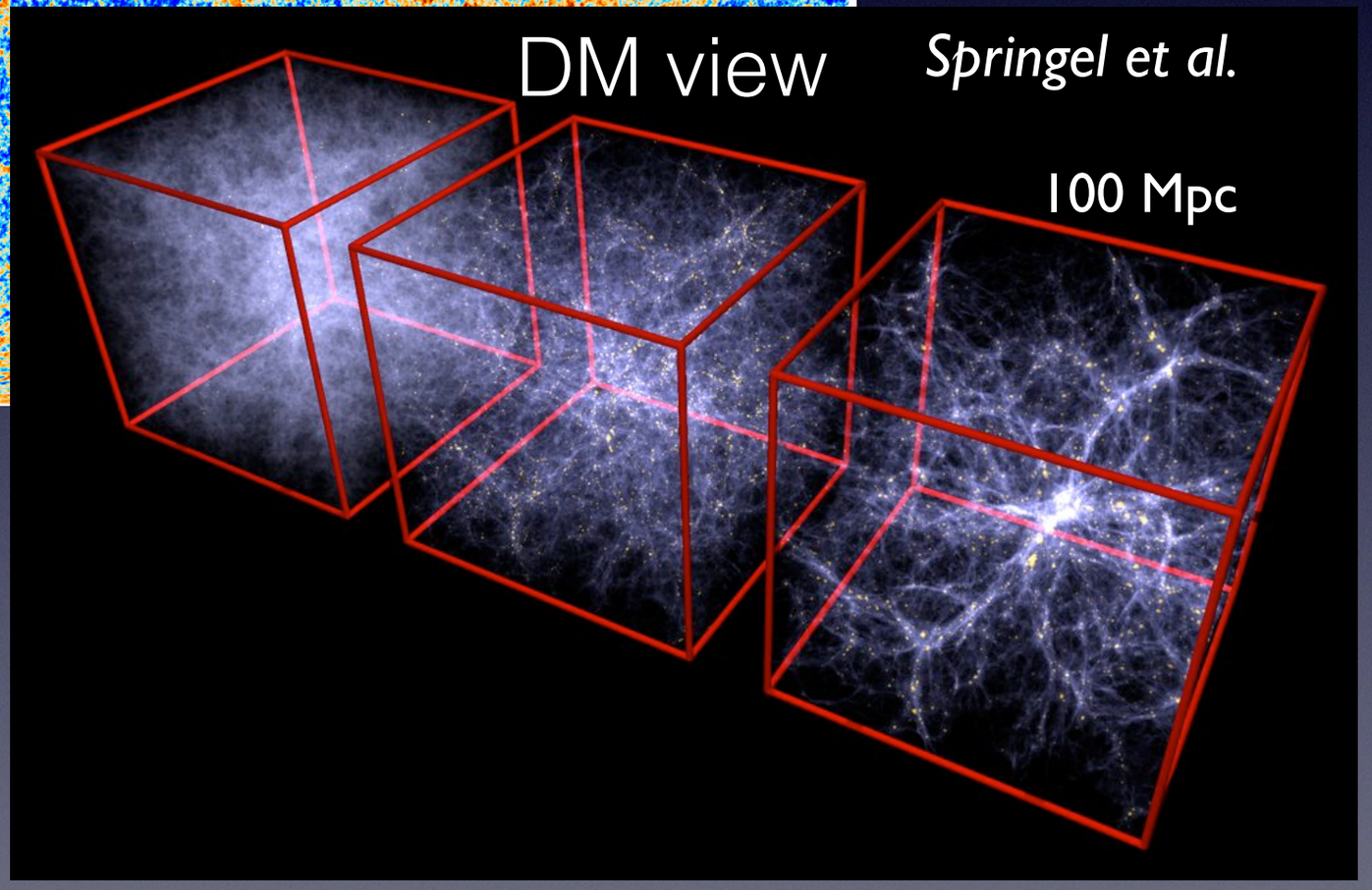
Fluids Day at ICTS, 2020

The BIG picture



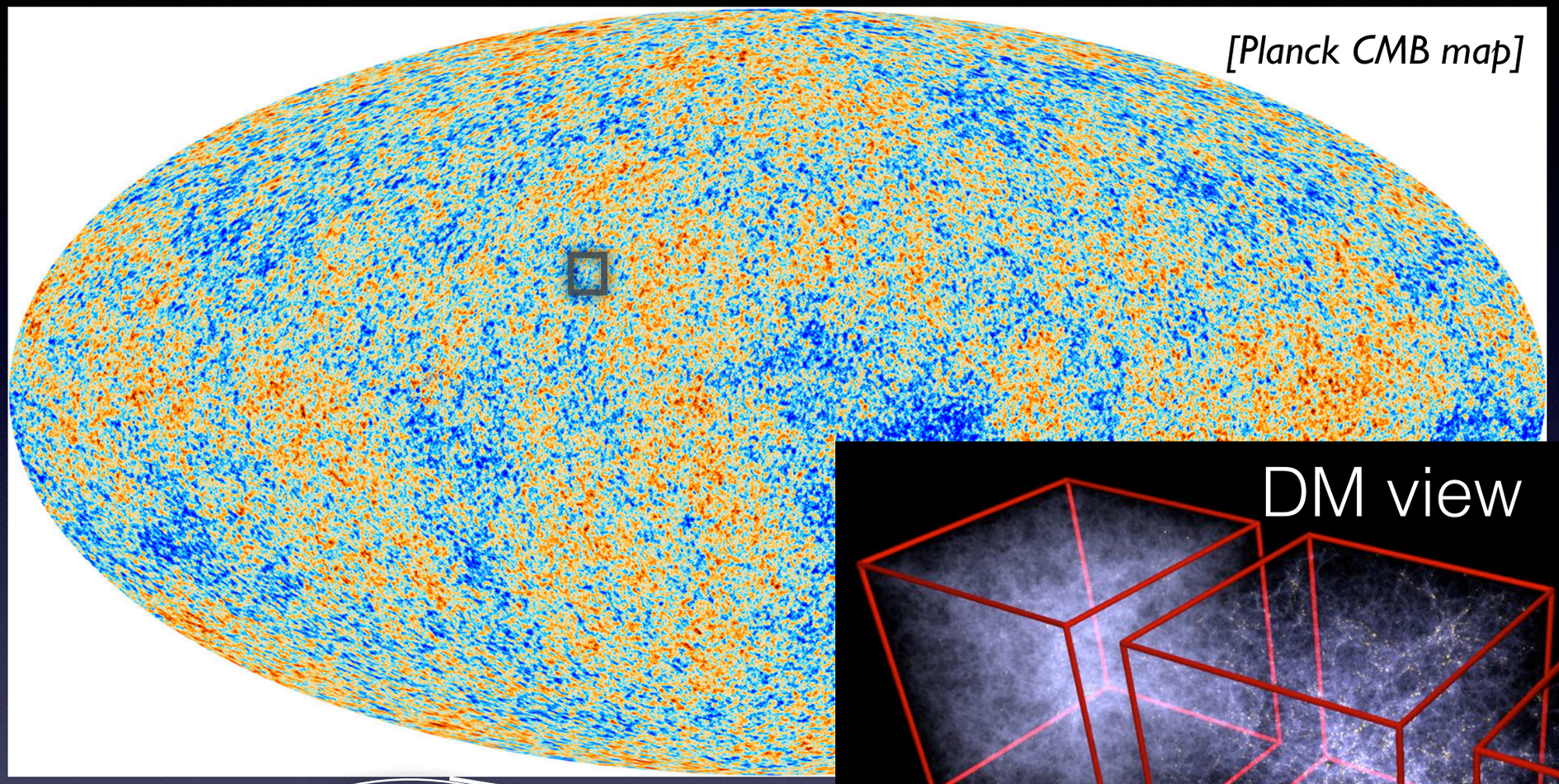
The BIG picture

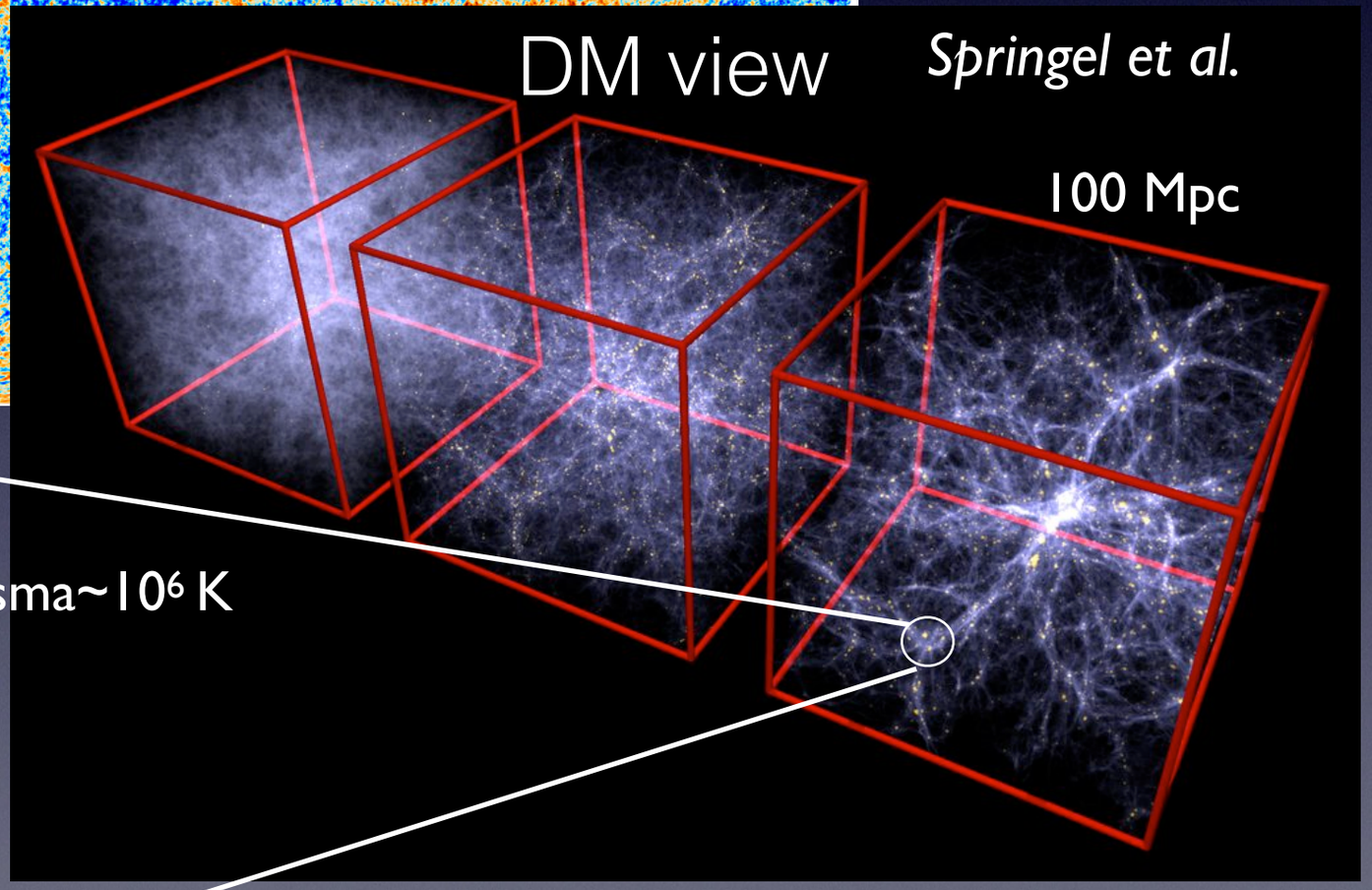


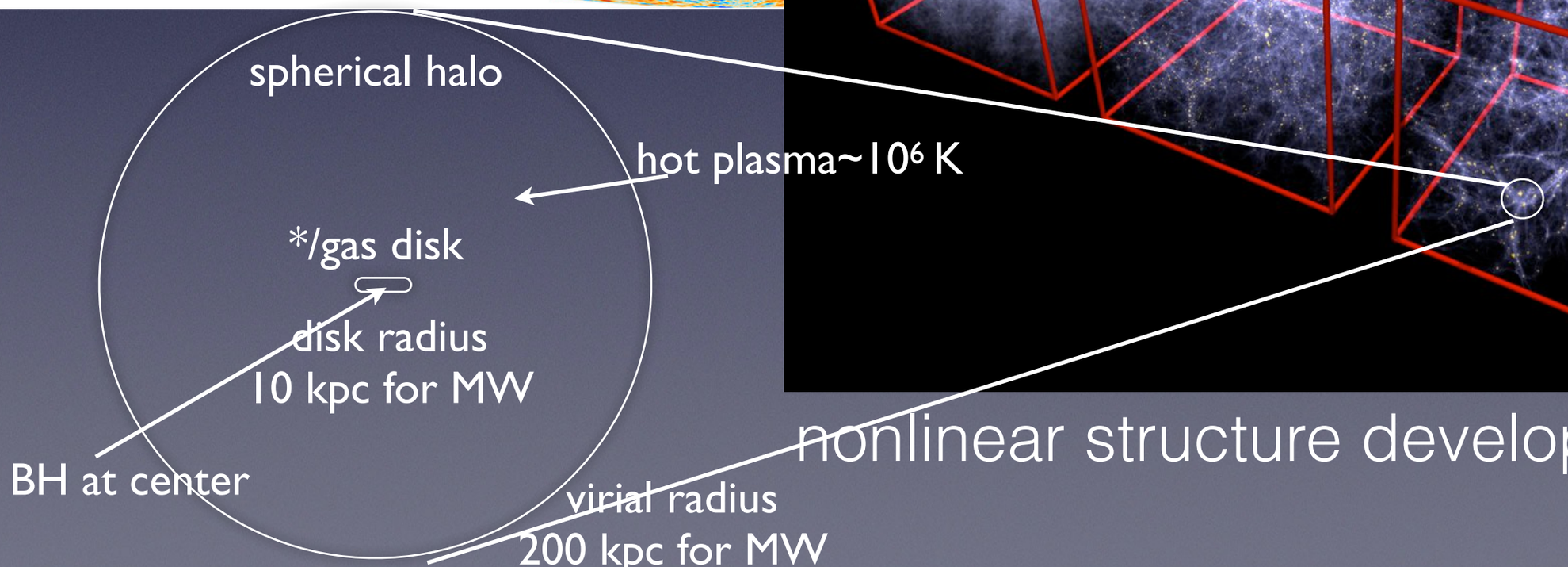


nonlinear structure develops in time

The BIG picture

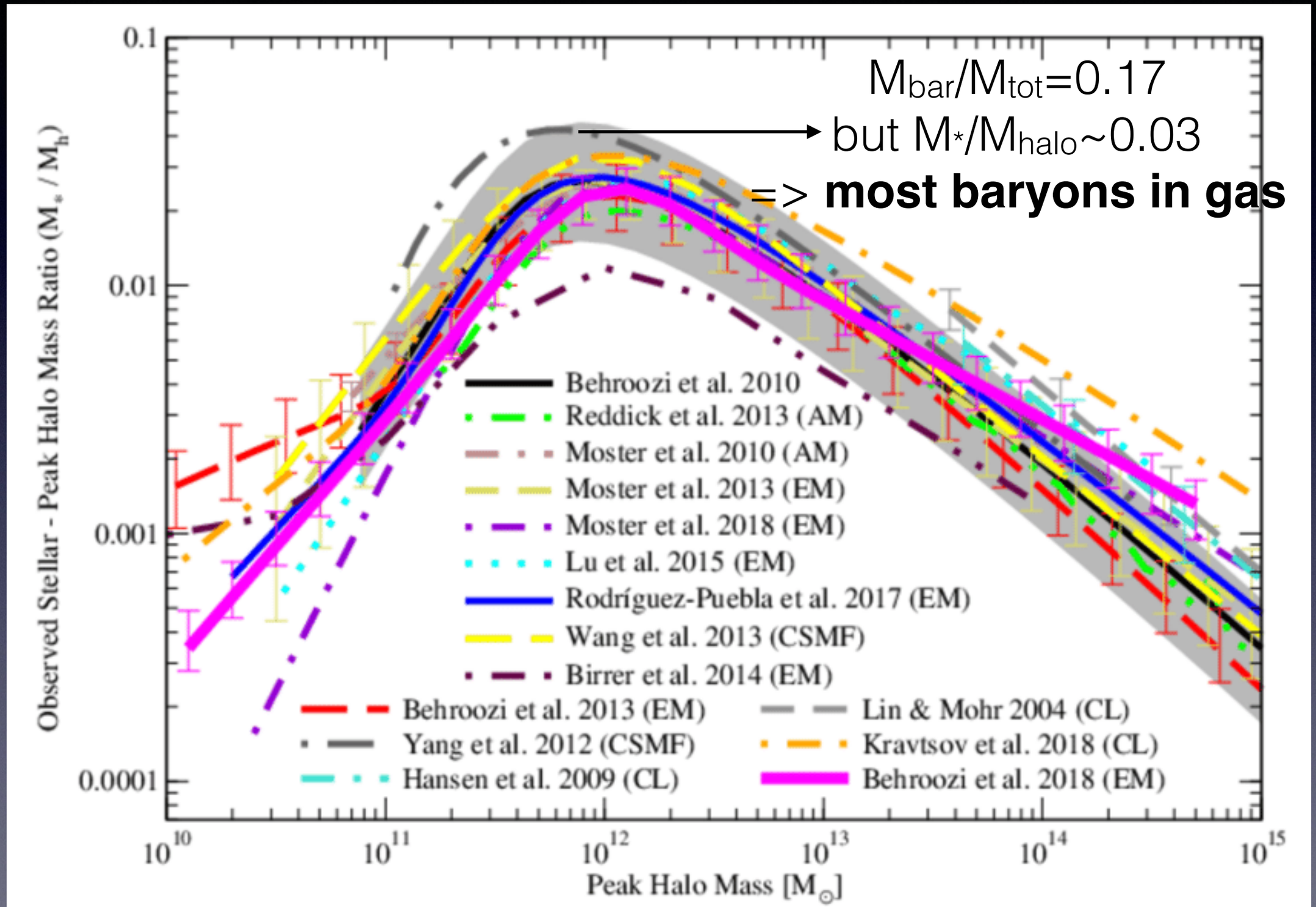




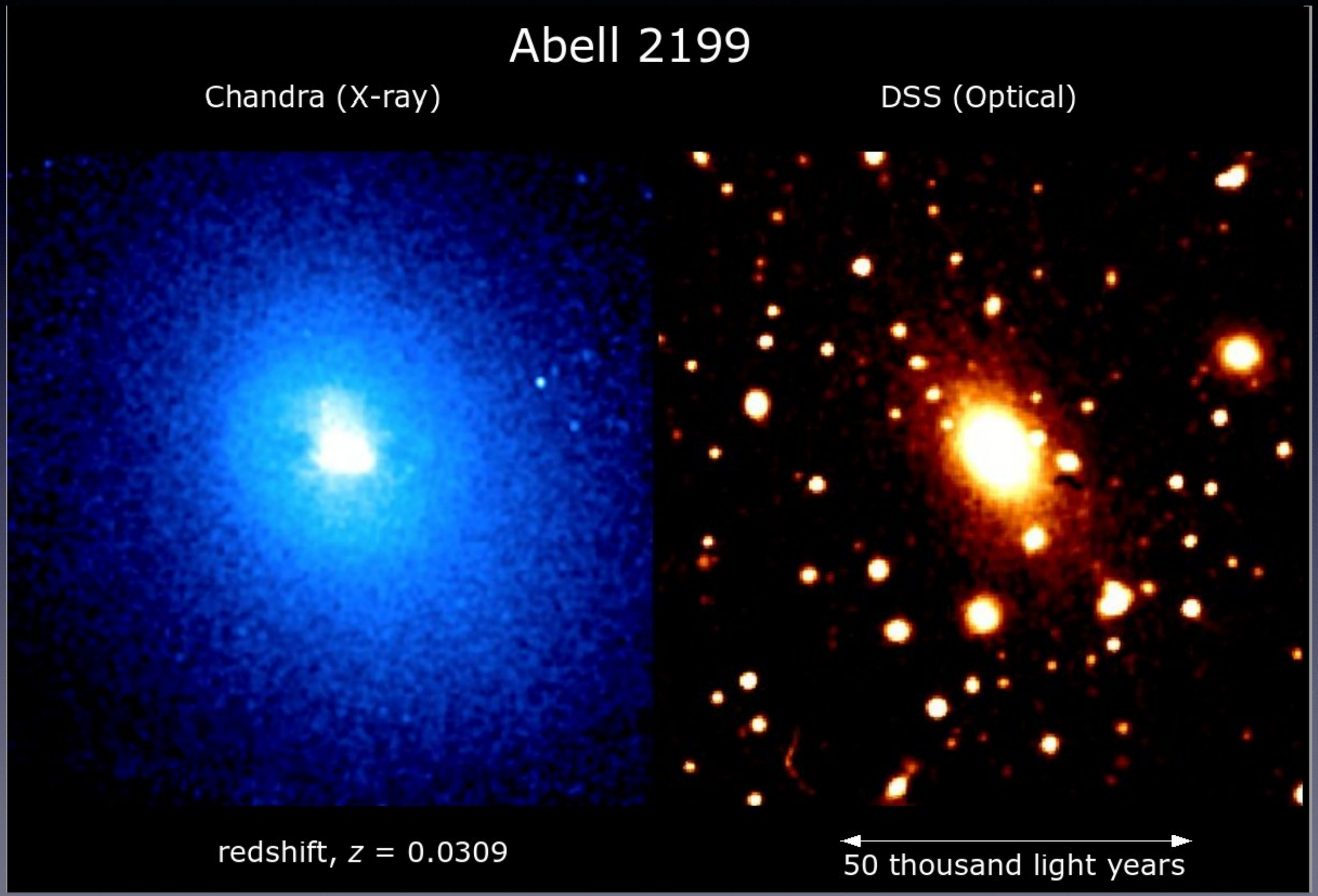


nonlinear structure develops in time

Most baryons not in stars!

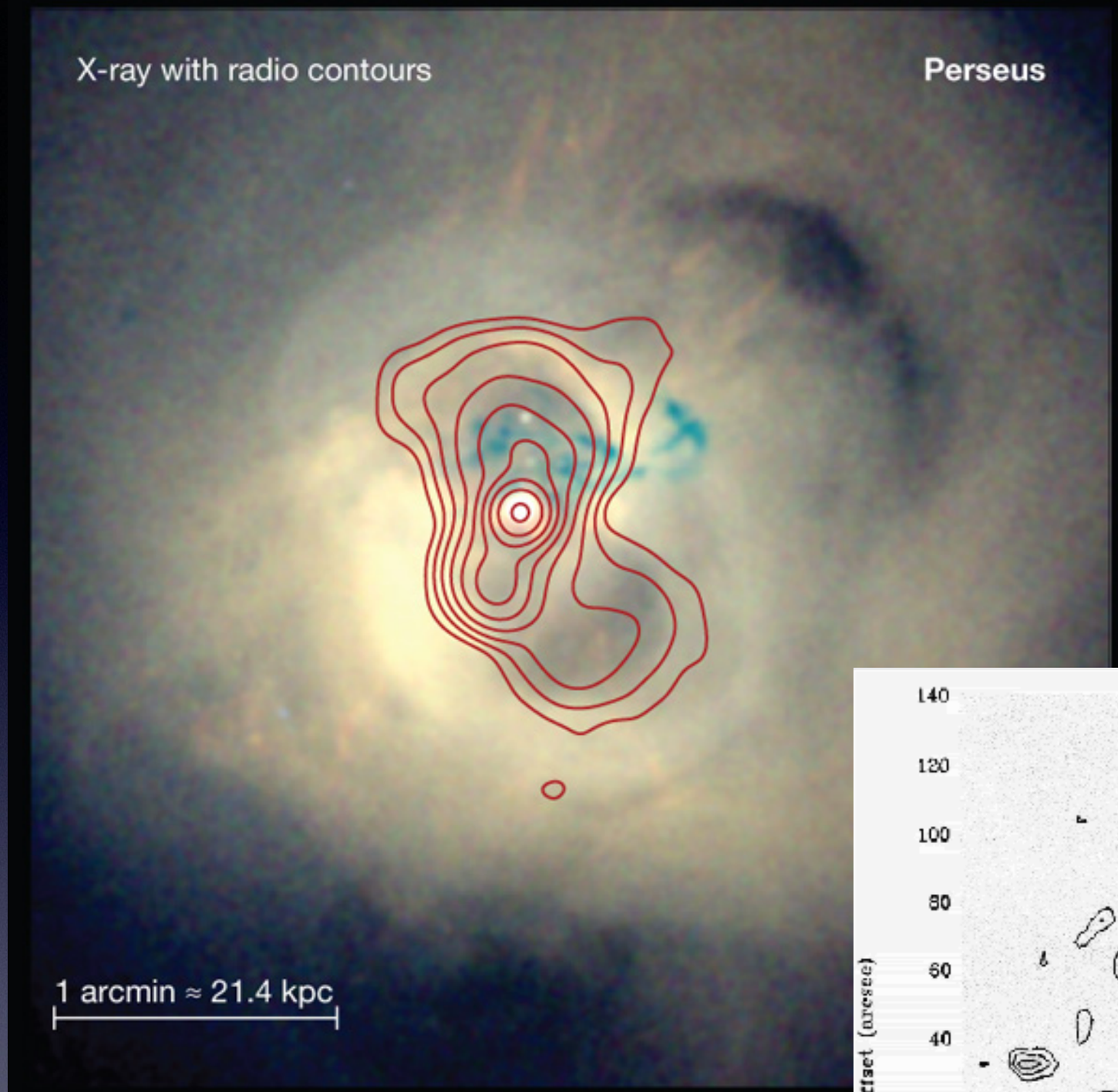


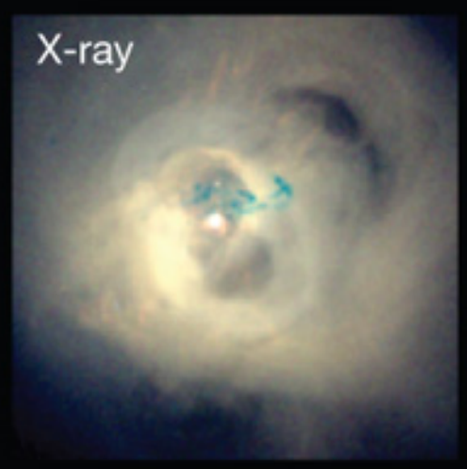
Galaxy clusters: $10^{14\text{-}15} M_{sun}$ halos

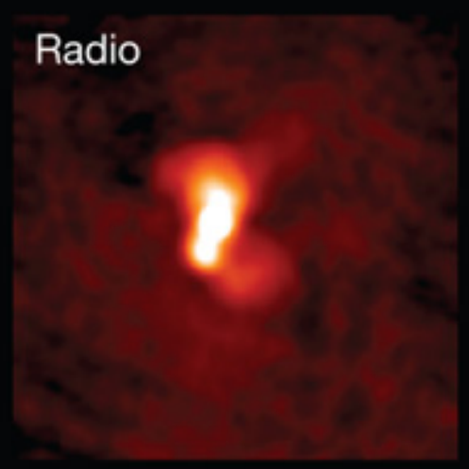


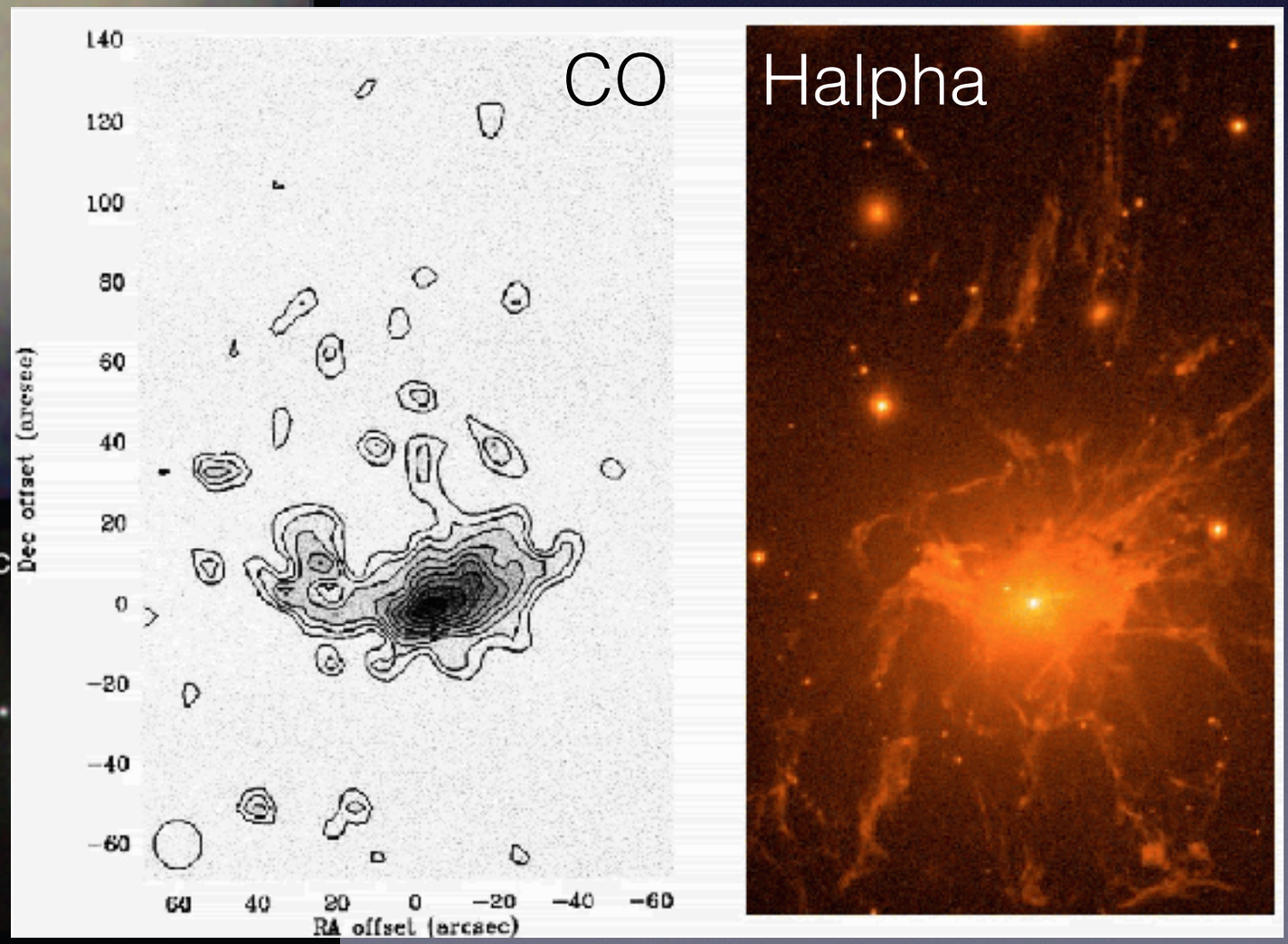
$14\text{-}15 M_{sun}$ halos

Not only emit in X-rays,
but in radio, CO and Halpha



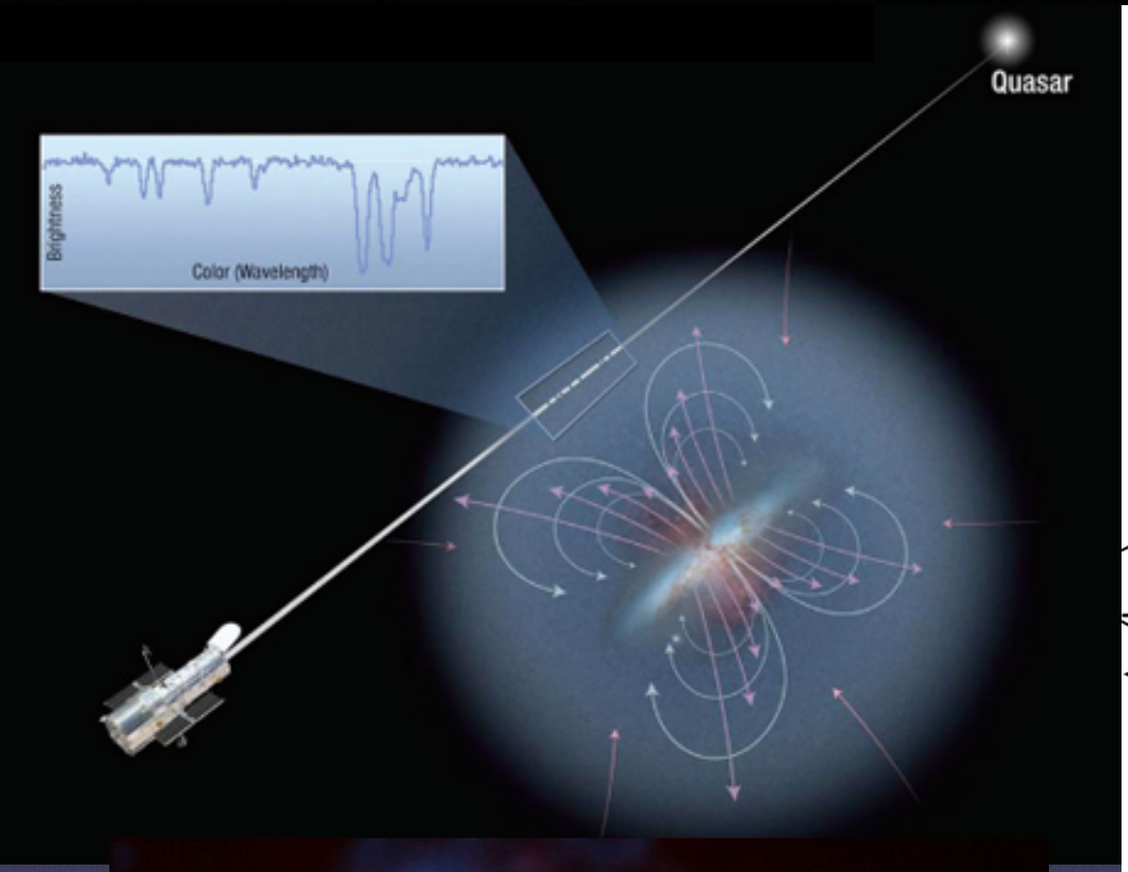


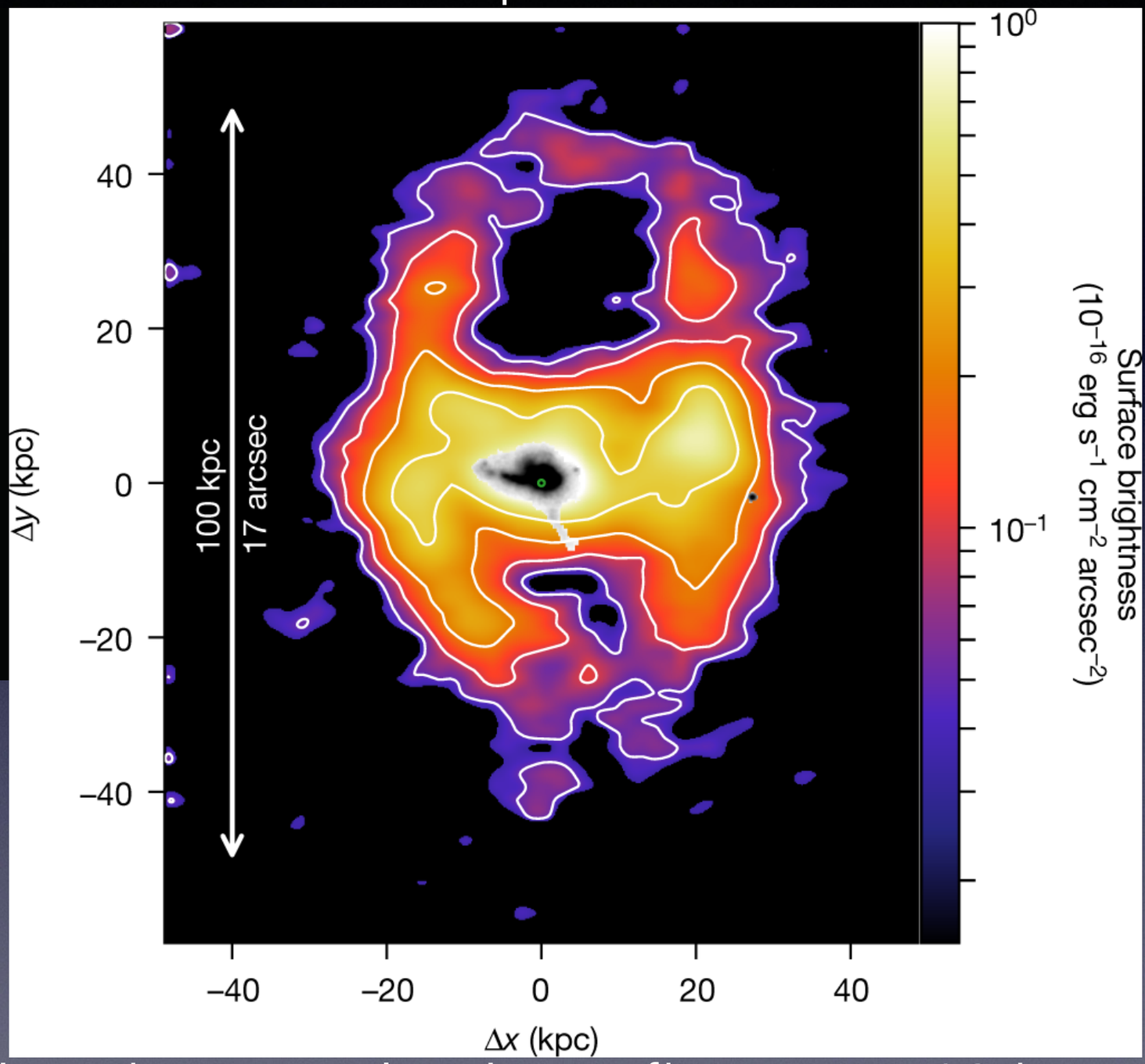


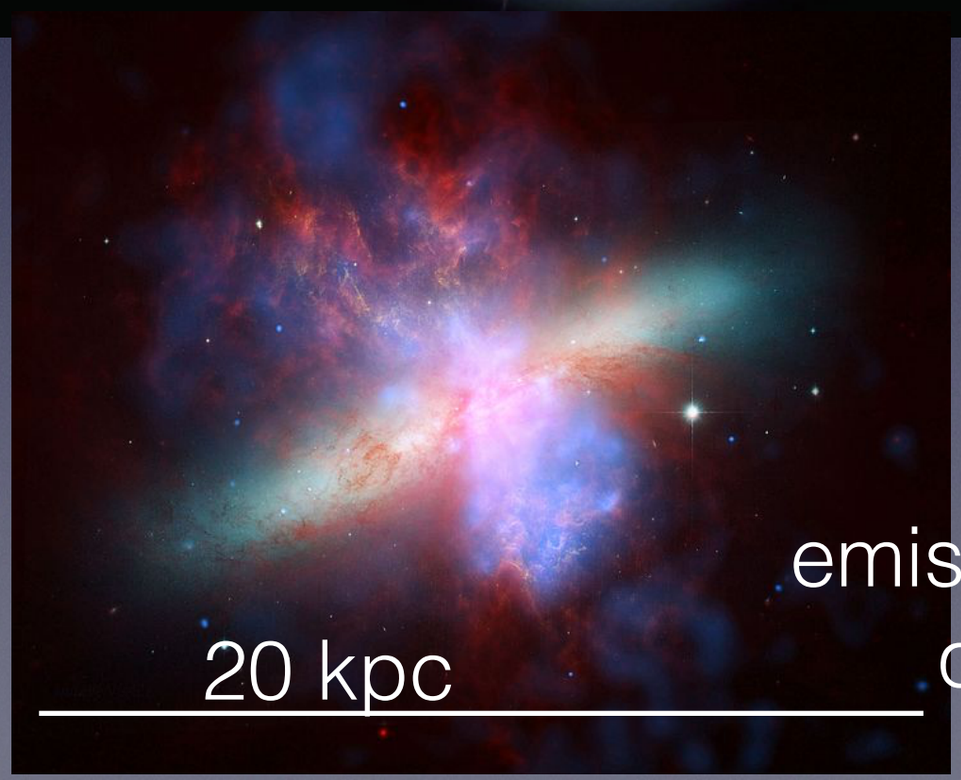


Milky Way (10^{12} M_{sun}) halos

harder to detect in emission: absorption studies







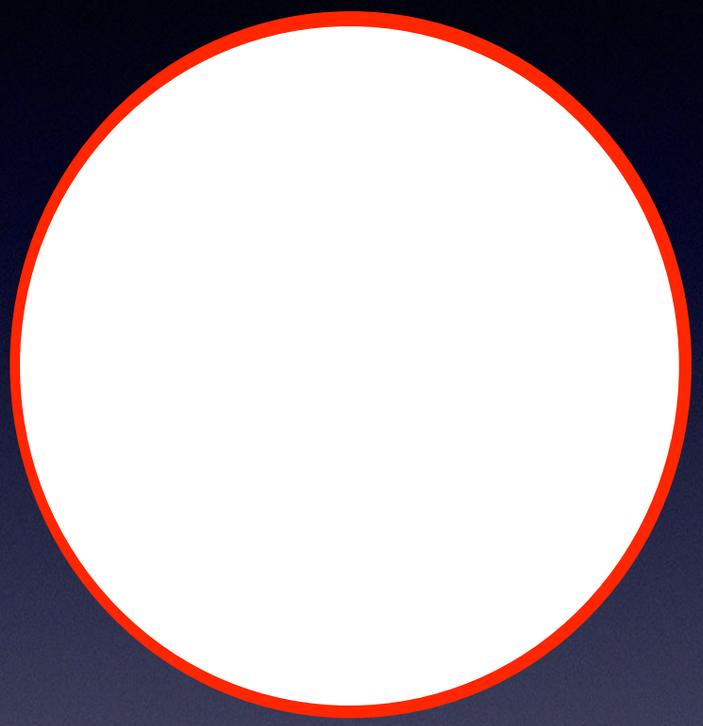
emission due to galactic outflows at ~10 kpc

quiescent CGM not seen in emission

BIG questions

- Why multiphase gas? t_{cool}/t_{ff}, entrainment
- Dynamics (turbulence) and thermodynamics crucial
- Non-eq. ionization/recombination cooling/heating
- Mass, volume, area fractions of cold gas
- Spatial structure: clouds, mist, filaments
- Velocity: phases comoving? terminal velocity

Condensation due to TI



hydrostatic equilibrium: $dp/dr = -\rho g$
gravity due to dark matter

heating~cooling at every radius
(to explain lack of cooling flows)
but local **thermal instability**!

Emergent principle: condensation happens only when $t_{cool}/t_{ff} \lesssim 10$

$$t_{\rm TI} \approx t_{\rm cool} = \frac{1.5 n k_B T}{n_e n_i \Lambda[T]}$$

$$t_{\rm ff} = \sqrt{\frac{2r}{g(r)}}$$

Our equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$ mass

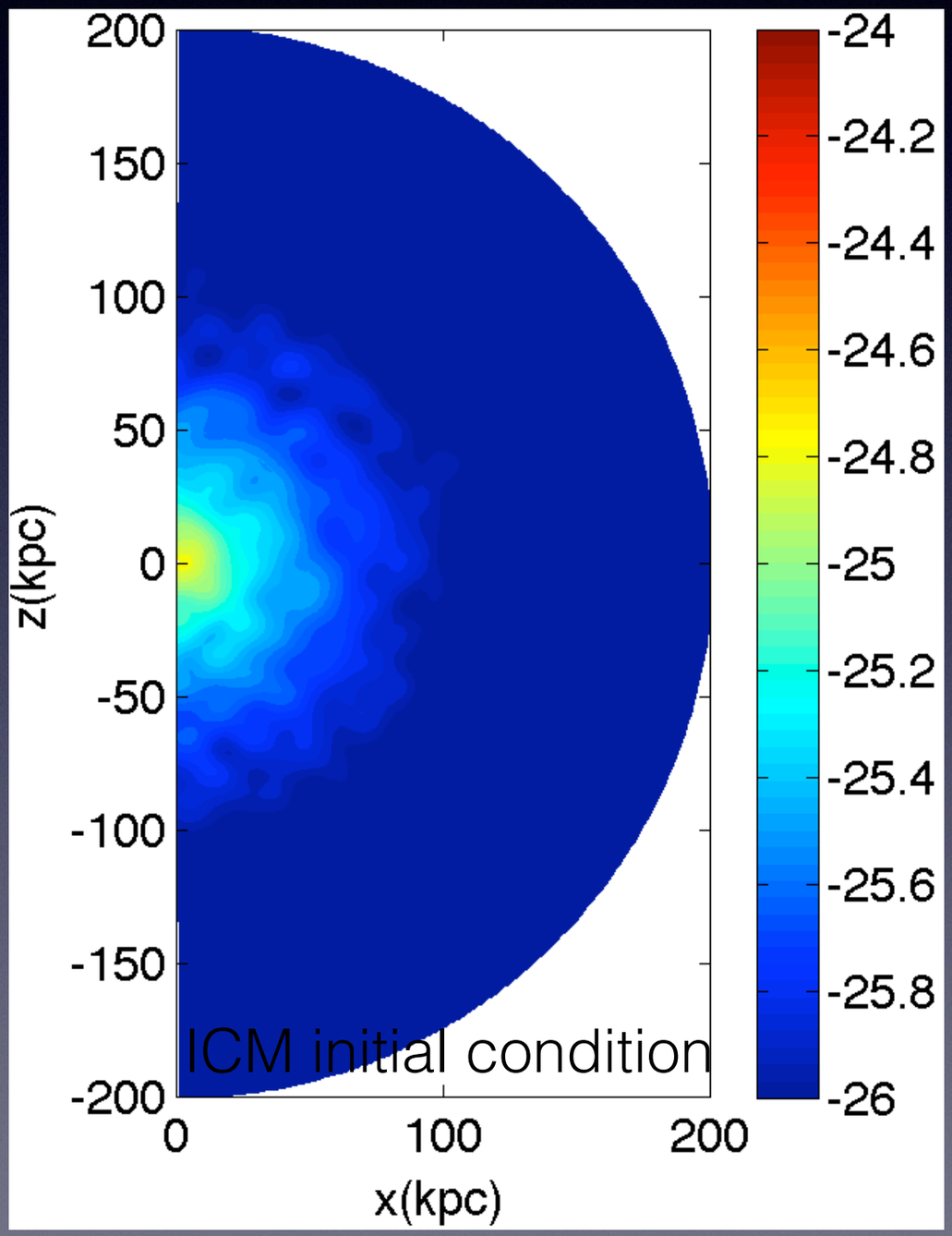
$$\frac{\partial}{\partial t}(\rho \mathbf{v}) + \nabla \cdot (\rho \mathbf{v}\mathbf{v} + p\mathbf{I}) = 0$$ momentum

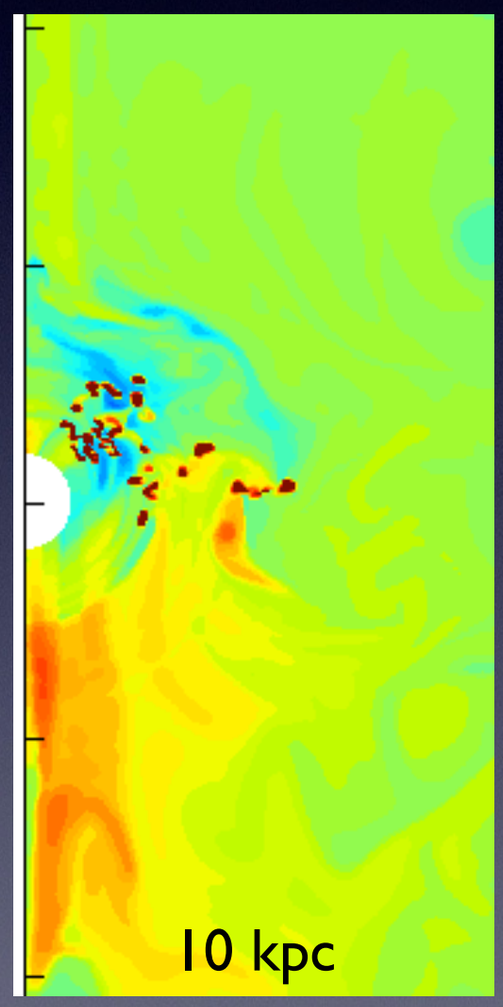
$$\frac{\partial}{\partial t}\left(\frac{\rho v^2}{2} + \frac{p}{(\gamma - 1)}\right) + \nabla \cdot \left[\left(\frac{\rho v^2}{2} + \frac{\gamma p}{(\gamma - 1)}\right)\mathbf{v}\right] = q^+(\mathbf{x}, t) - q^-(p, \rho)$$ energy

Our approach: variants of these eqs. for various Qs that we ask finite volume Astrophysical HD/MHD code **PLUTO**
No explicit dissipation Implicit Large Eddy Simulations (ILES)

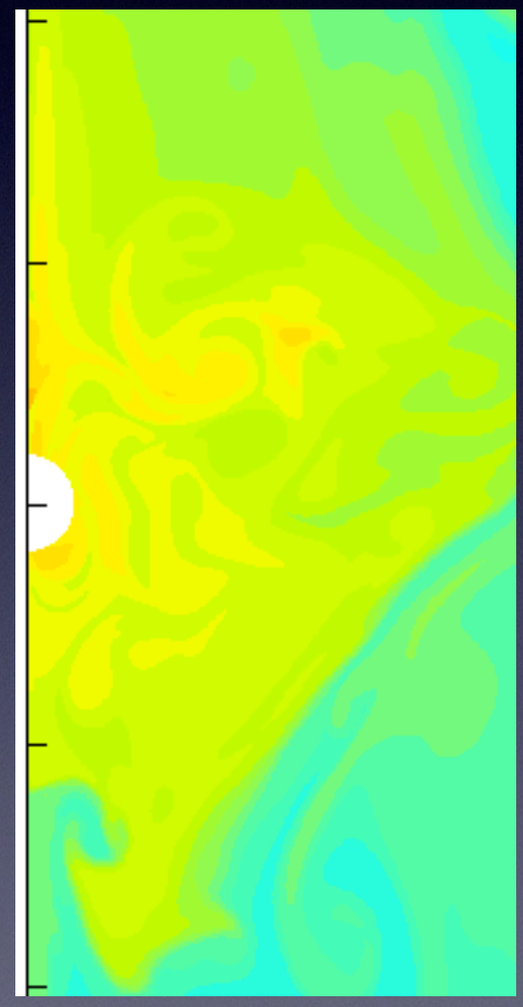
Idealised cluster sims.

[Sharma et al. 2012]



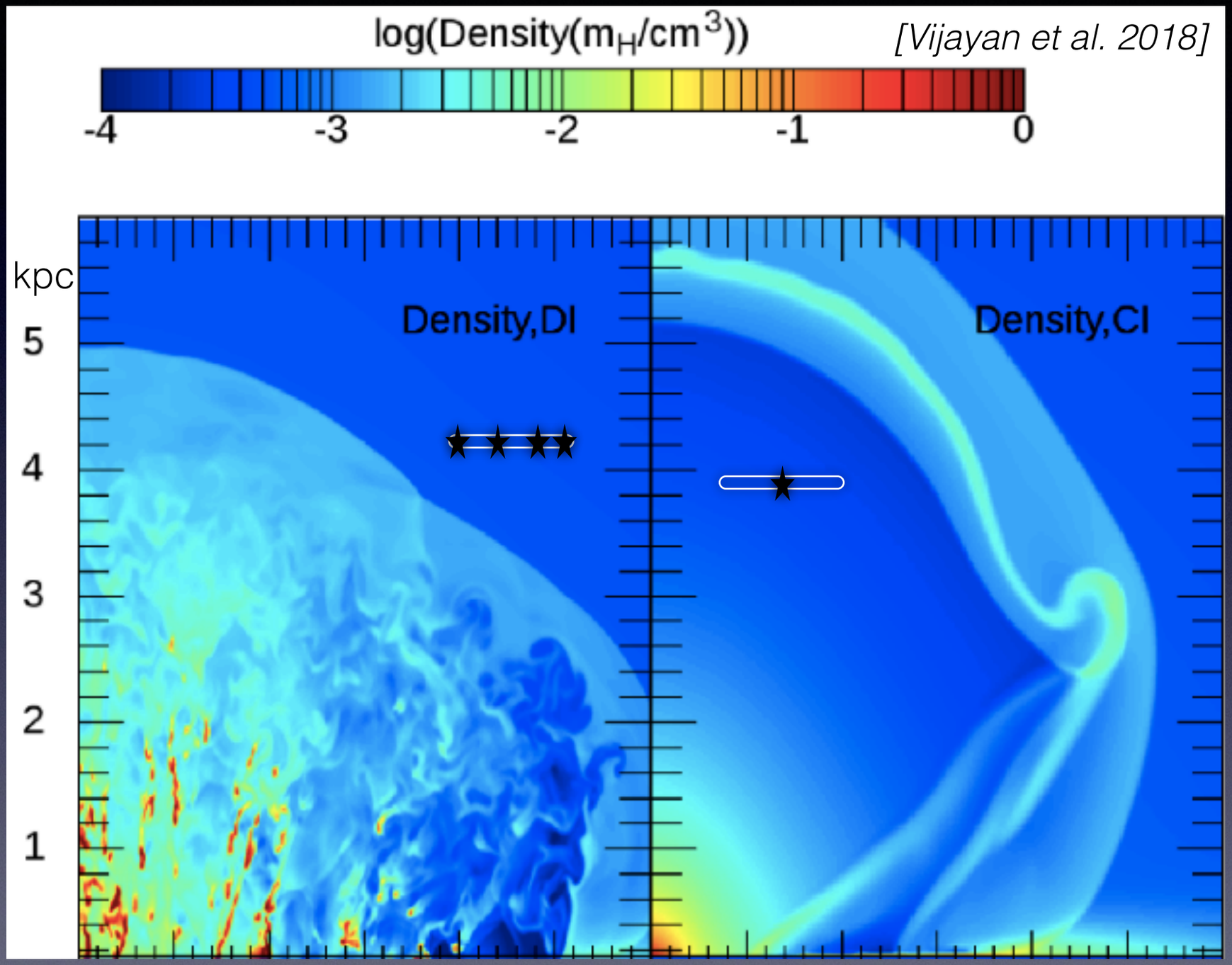


Log10 ρ



similar results for jet-ICM sims.
For more: Prakriti's talk later

MP gas in galactic outflows



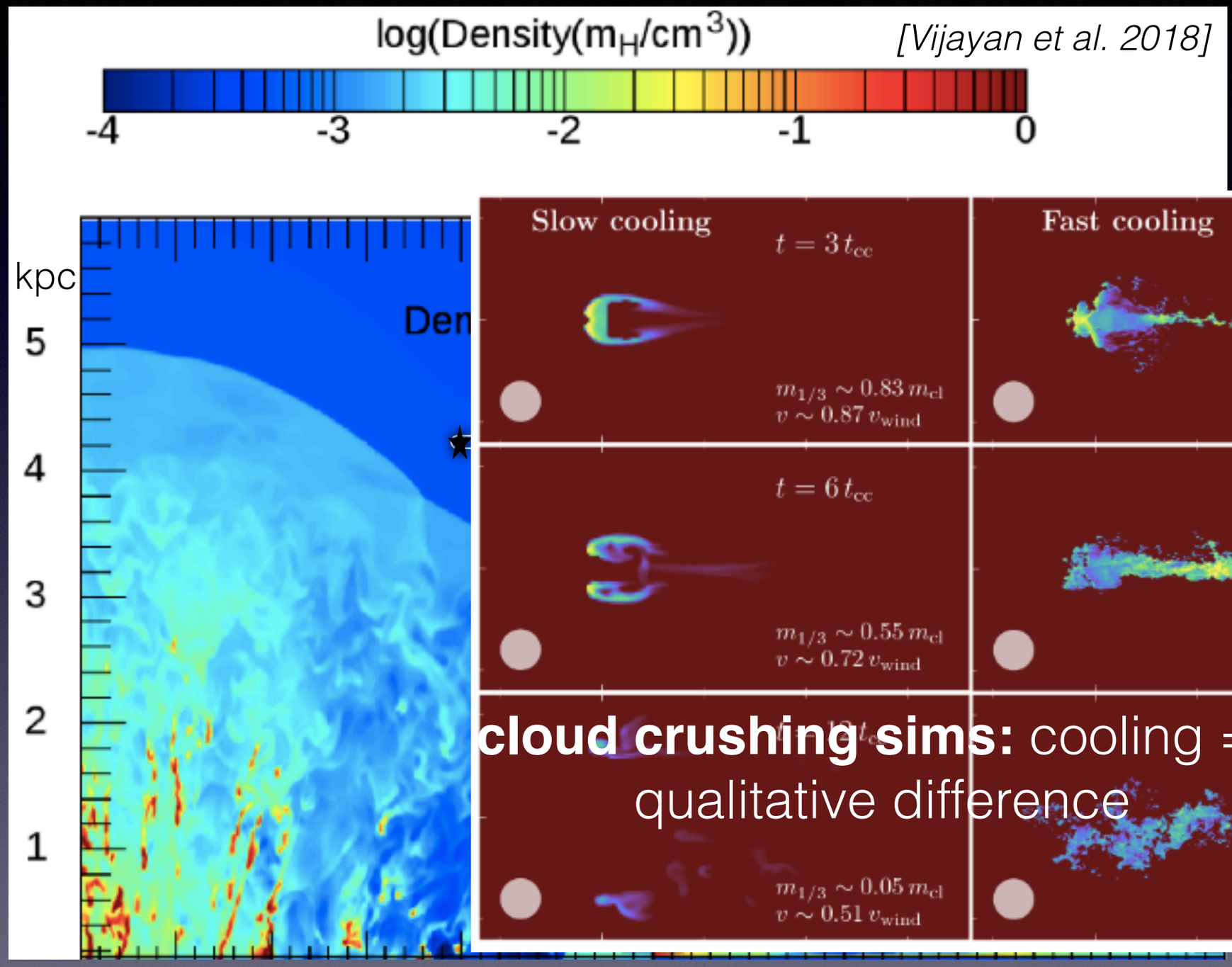
[Vijayan et al. 2018]

central injection doesn't give MP clouds

Where do cold clouds in galactic outflows come from in the first place?
seeds needed to grow cold gas

from multiple *SN spread throughout* disc throwing up cold clouds

MP gas in galactic outflows



[Vijayan et al. 2018]

cloud crushing sims: cooling => qualitative difference

Where do cold clouds in galactic outflows come from in the first place?
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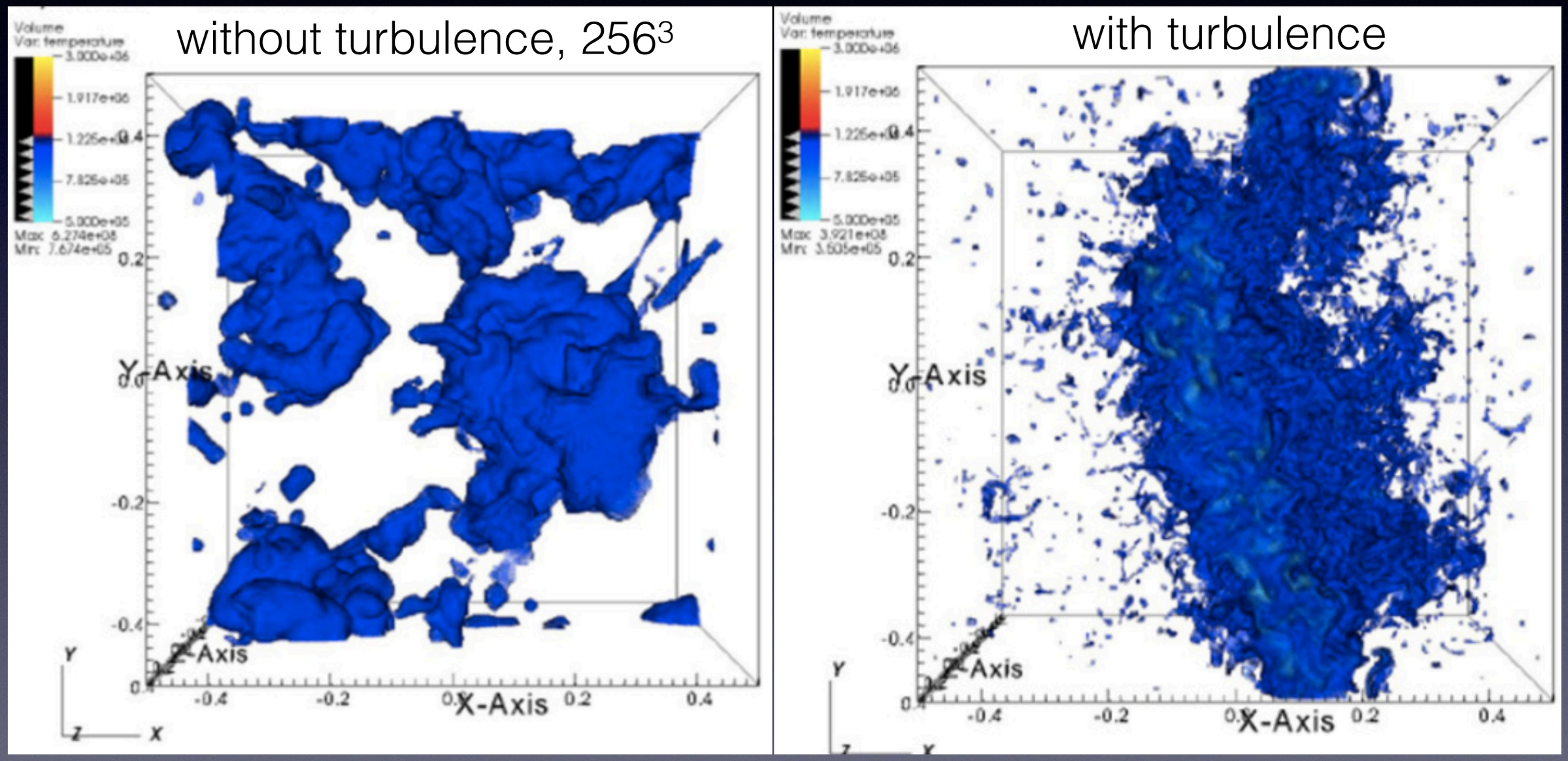
Turbulence & MP gas

Volume rendering of cold structures

[Mohapatra & Sharma 2019]

without turbulence, 256^3

with turbulence



evolution without turbulence shows nonlinear coalescence

turbulence determines structure of cold gas
MP gas is created & destroyed dynamically

Analogies?

- Terrestrial clouds, mist
- Combustion: chemistry, thermodynamics, turbulence; $$\mathrm{Da} = \frac{\text{flow timescale}}{\text{chemical timescale}}$$
- Multiphase flows: particle laden flows
- **Novelty is to come up with idealised setups**, BCs etc. are higher order Qs

Thank you!