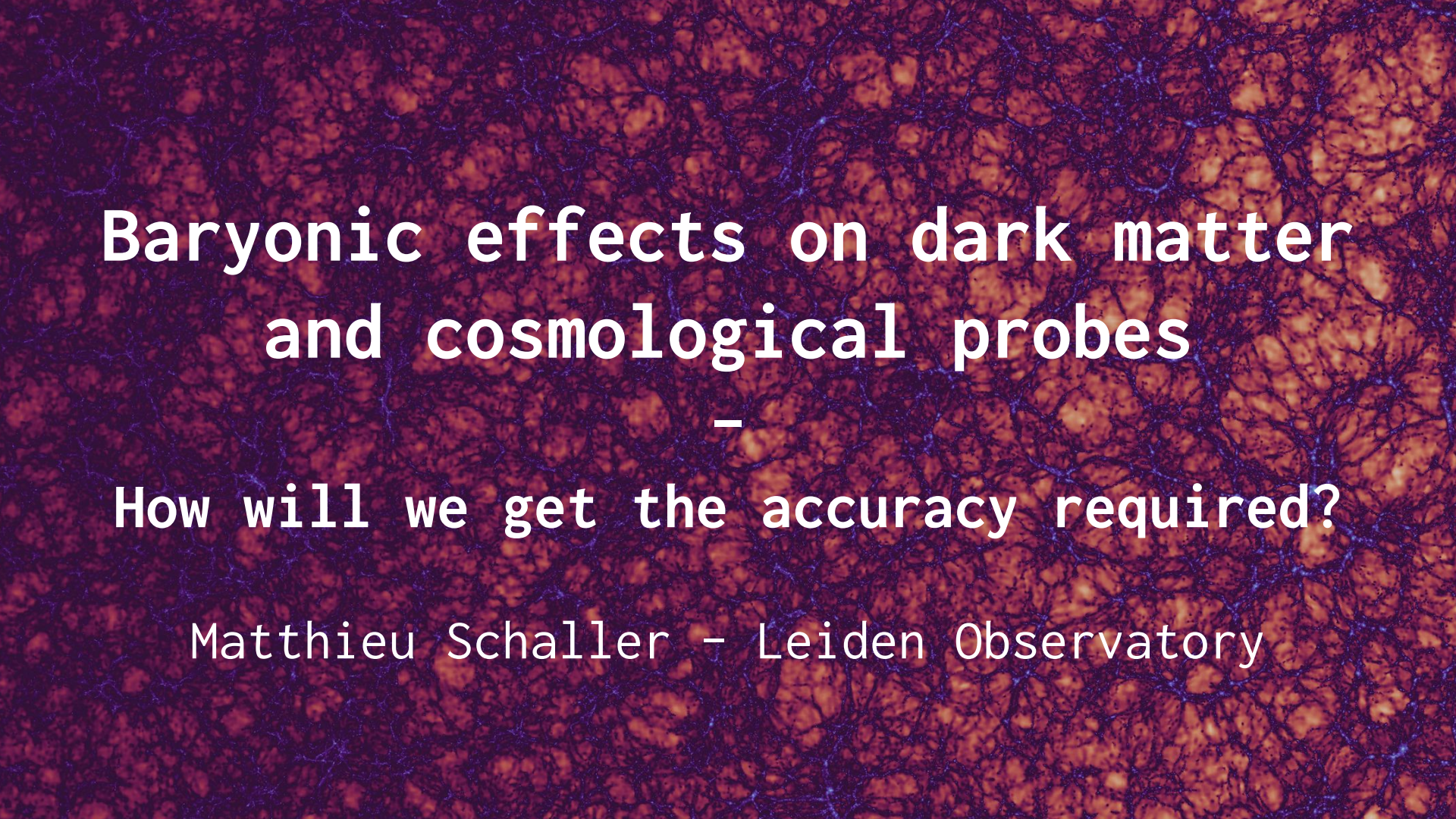
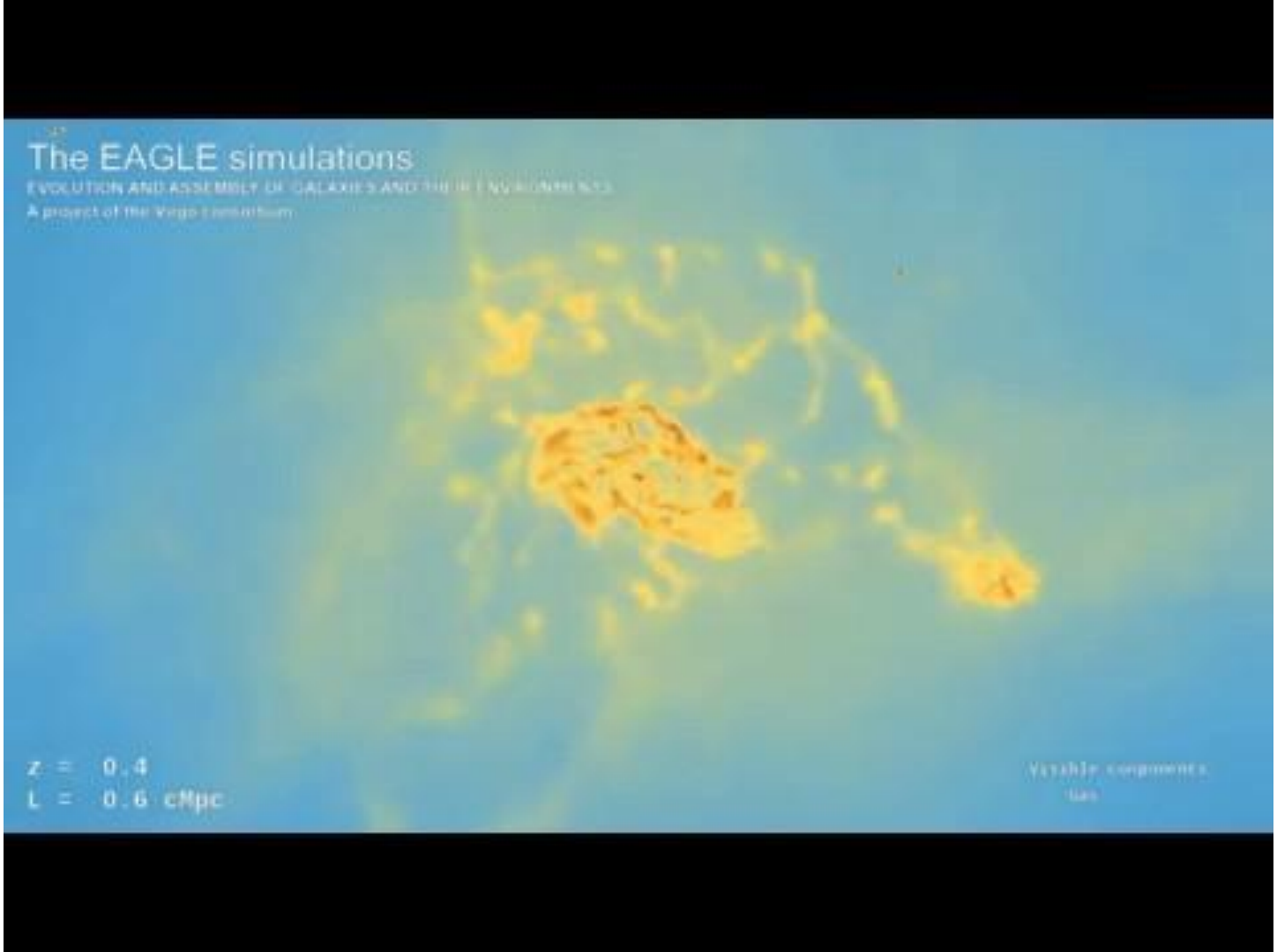


Baryonic effects on dark matter and cosmological probes
–
How will we get the accuracy required?

Matthieu Schaller - Leiden Observatory

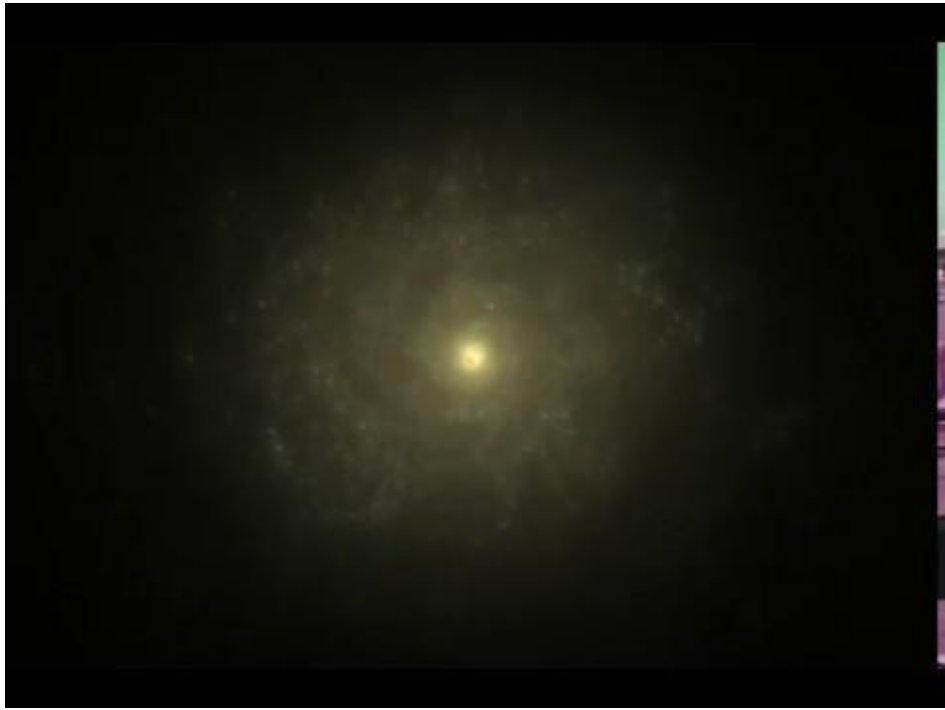


Movie by
R. Crain

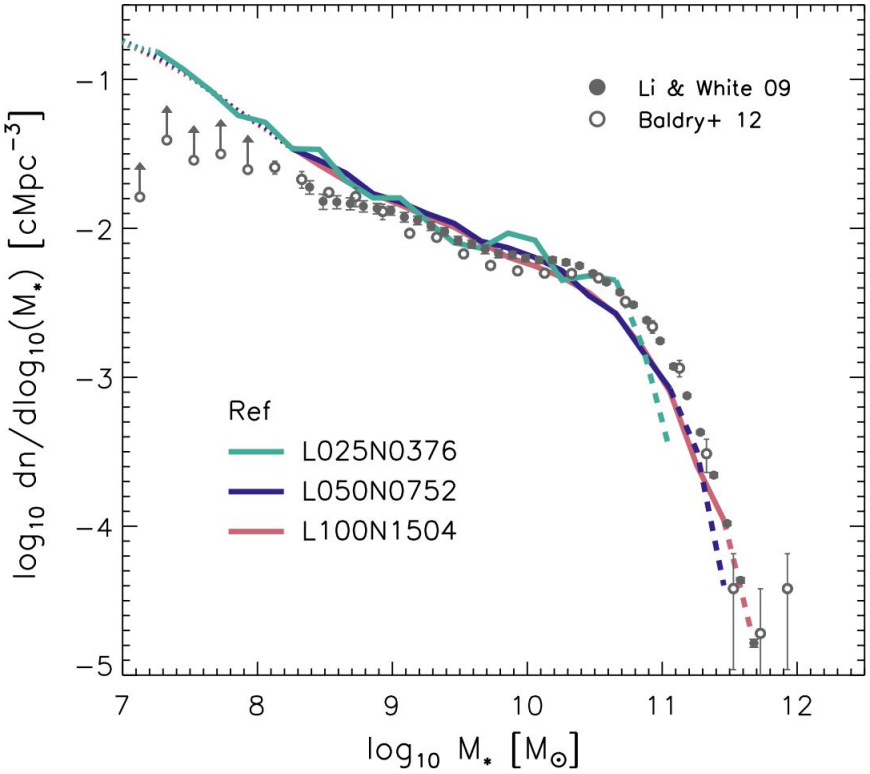
The EAGLE simulations

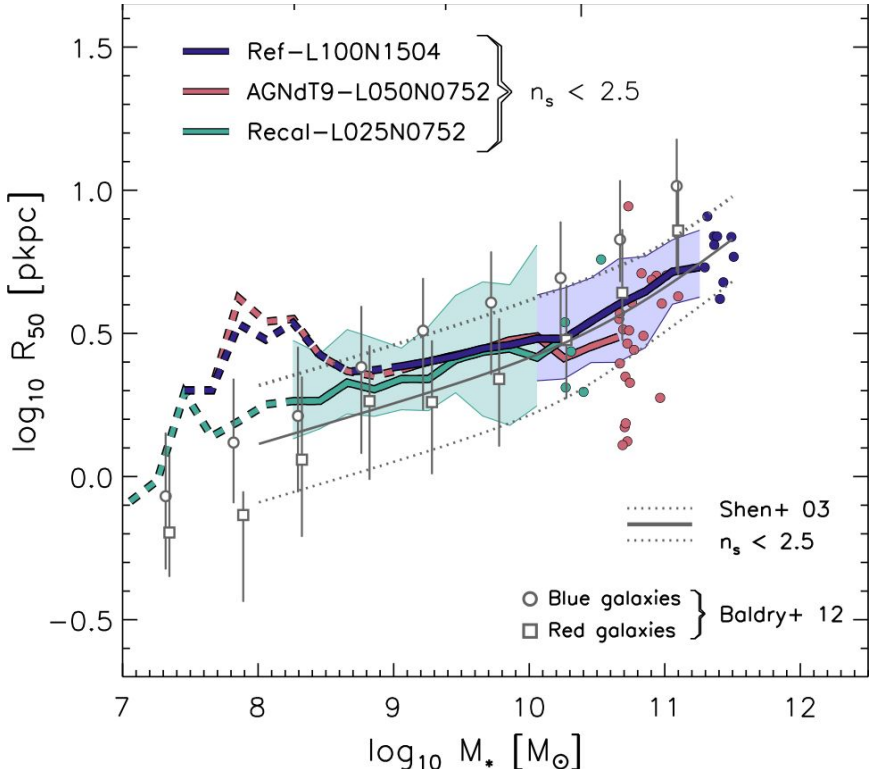
EAGLE quick introduction

- 100^3 Mpc^3 simulation with 2×10^6 $M_\odot$ gas mass resolution (SPH).
- Resolving the warm ISM phase with the hydrodynamics solver.
- Sub-grid model for galaxy formation calibrated to match:
  - The z=0 stellar mass function.
  - The z=0 galaxy mass-size relation.
  - The z=0 BH mass - stellar mass relation.



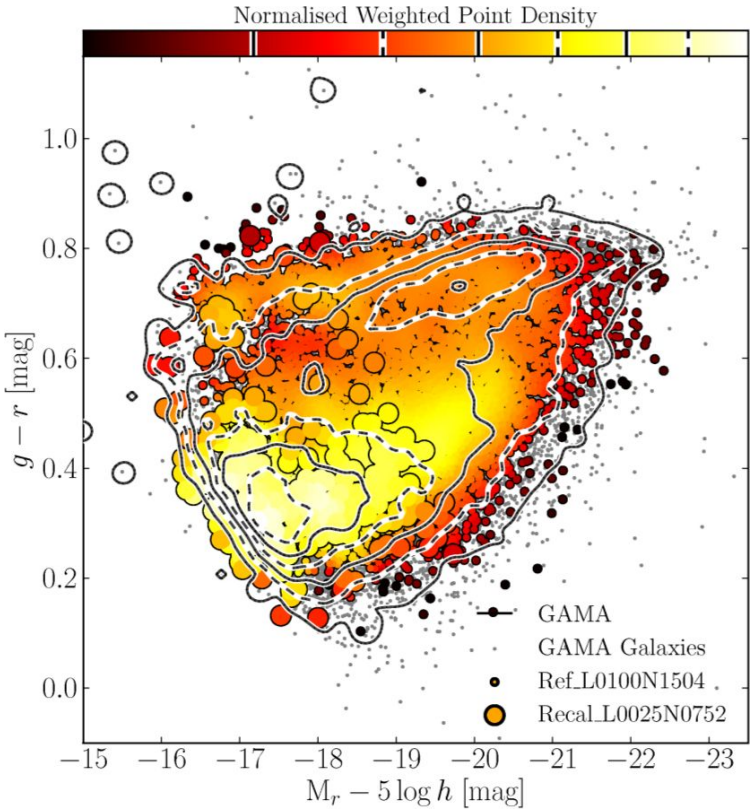
Many results





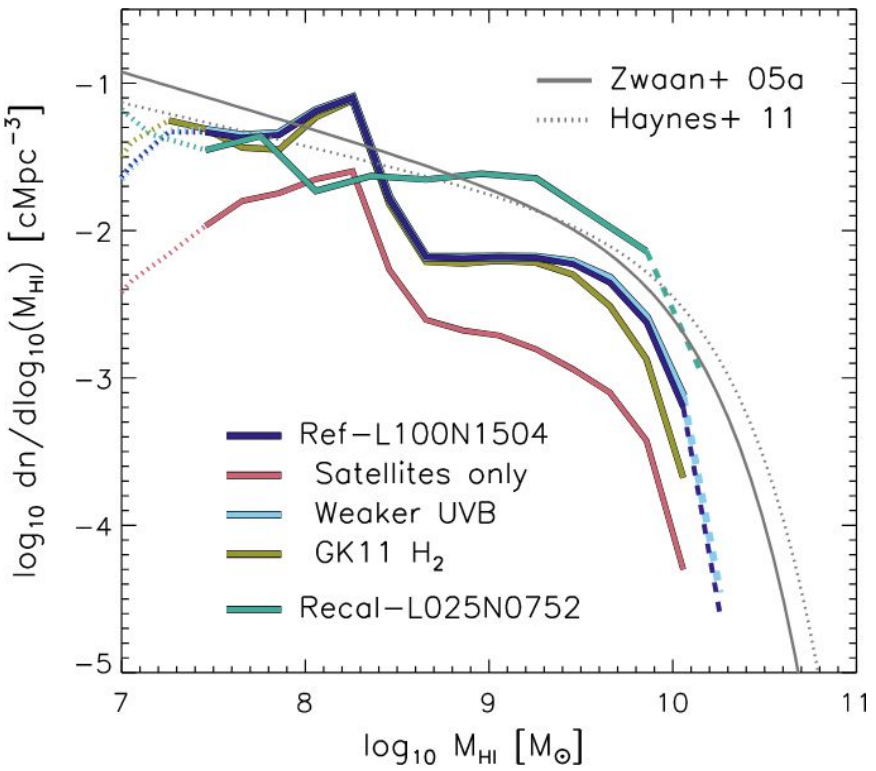
Schaye+15

A personal favourite

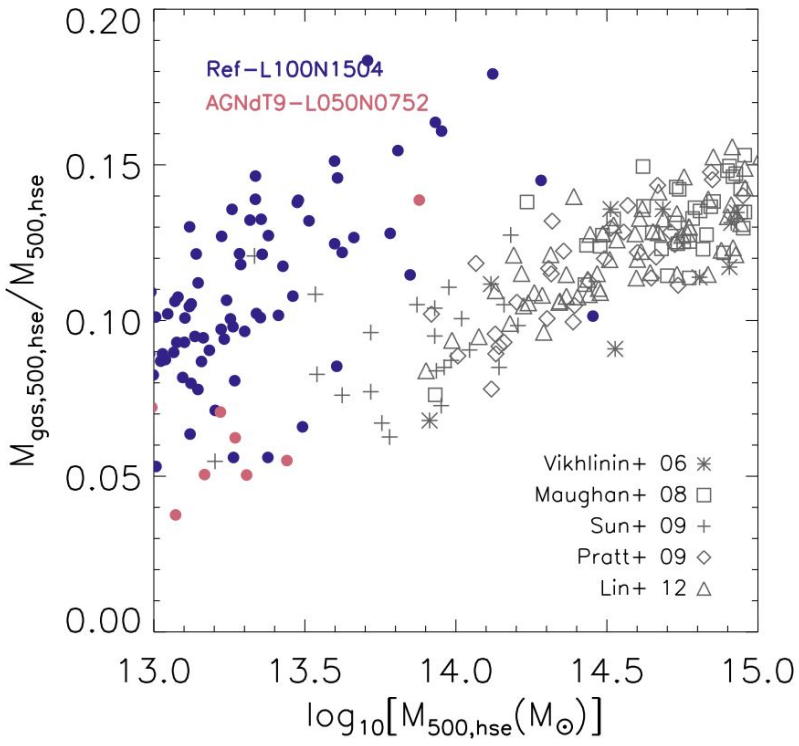


Trayford+16

Things to improve in the future

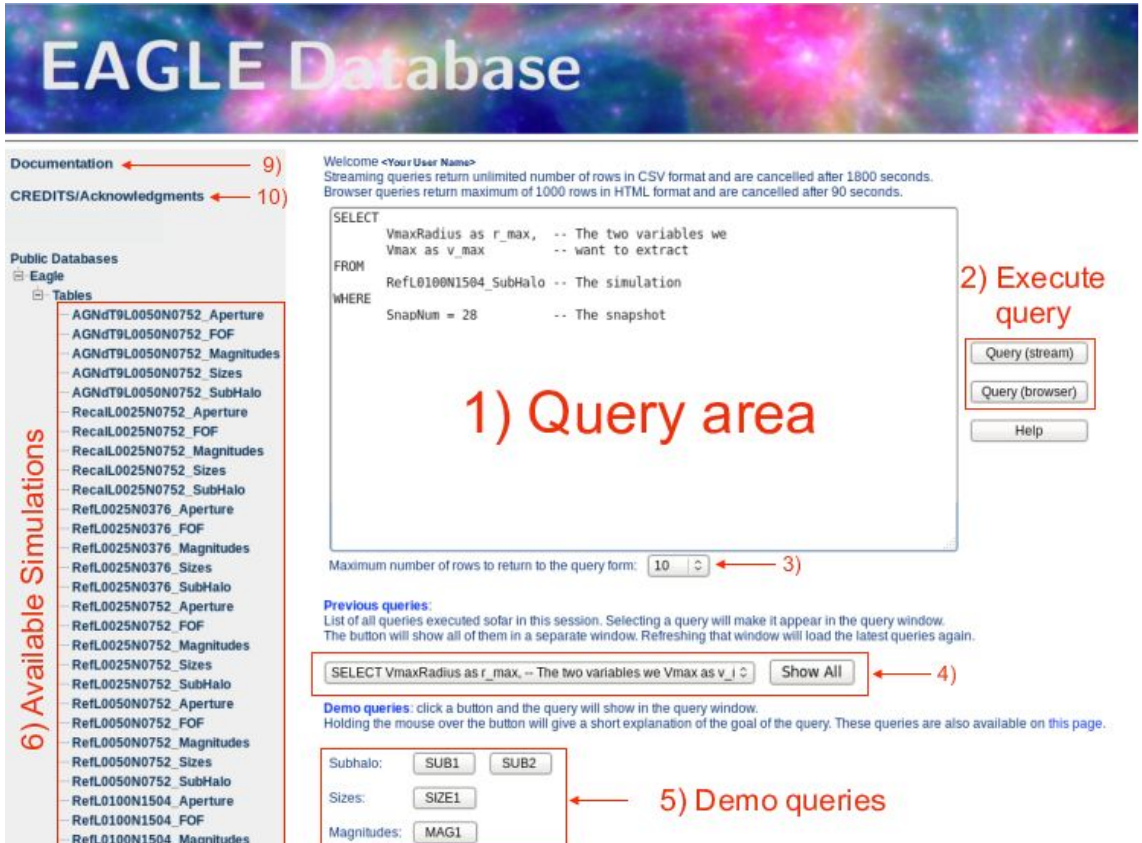


Crain+17



Schaye+15

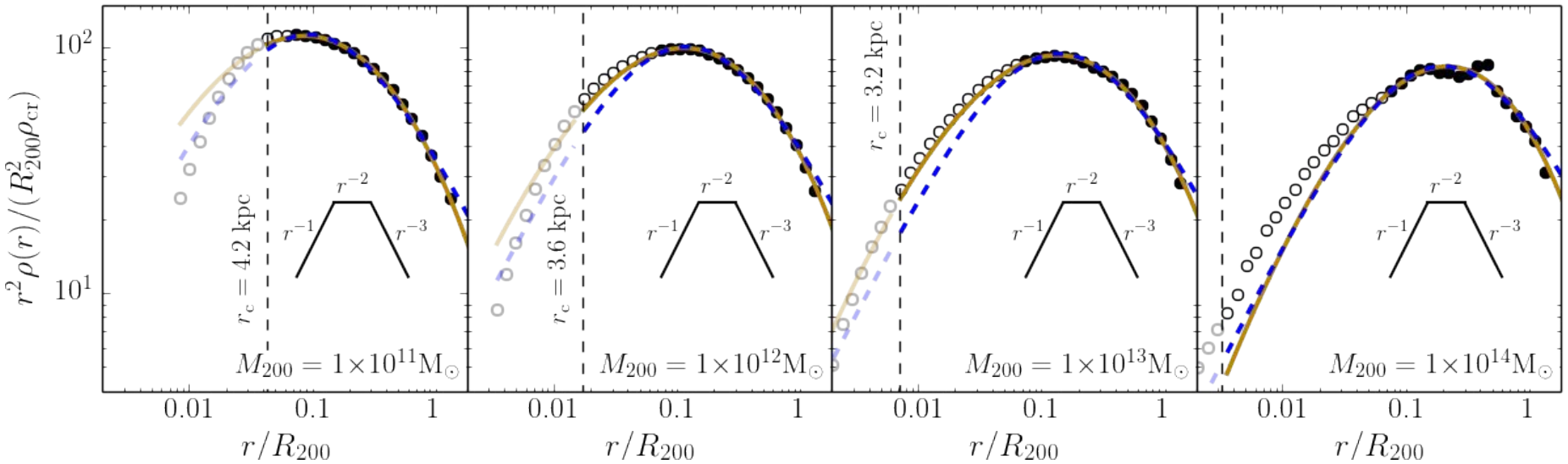
Get your own EAGLE @ home



McAlpine+16

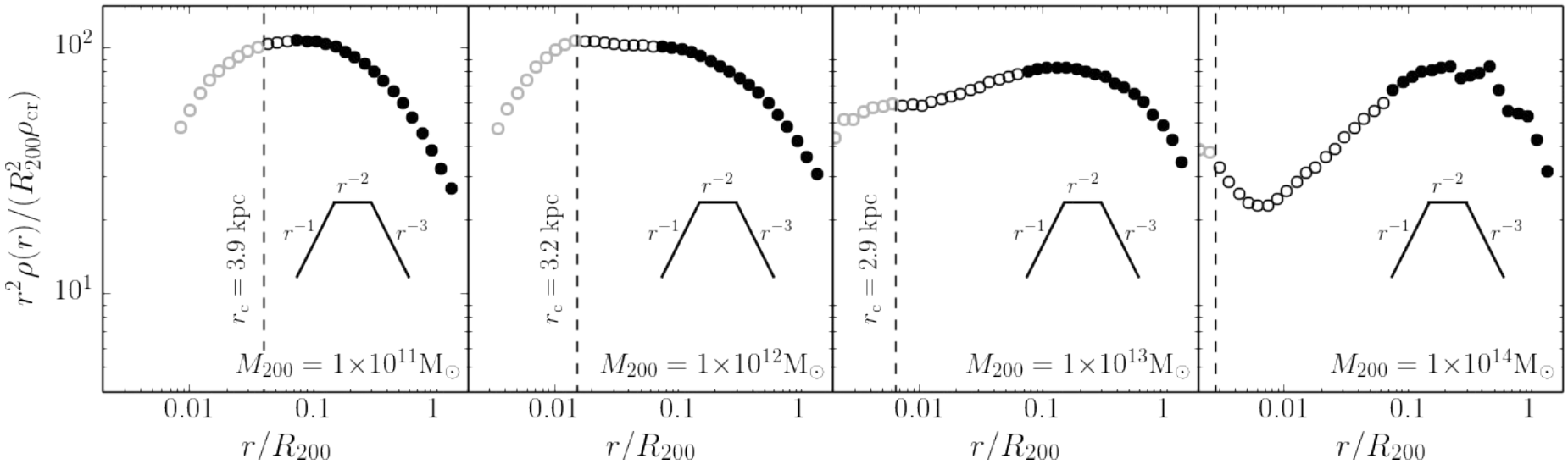
Effects of baryons on dark matter

Halo profiles



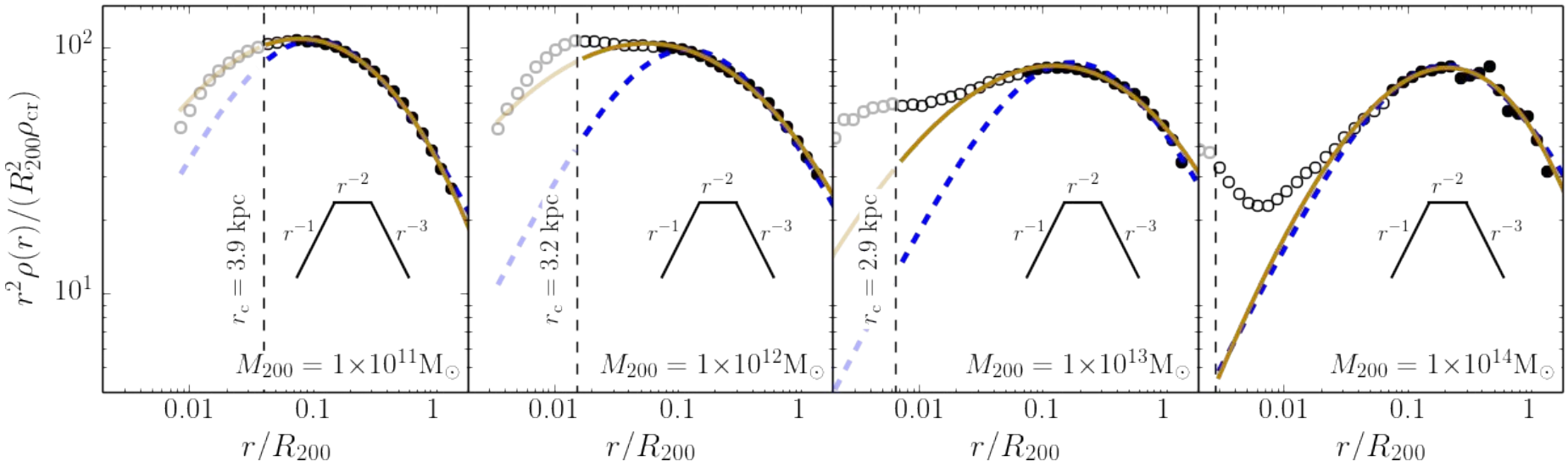
Schaller+15

Halo profiles



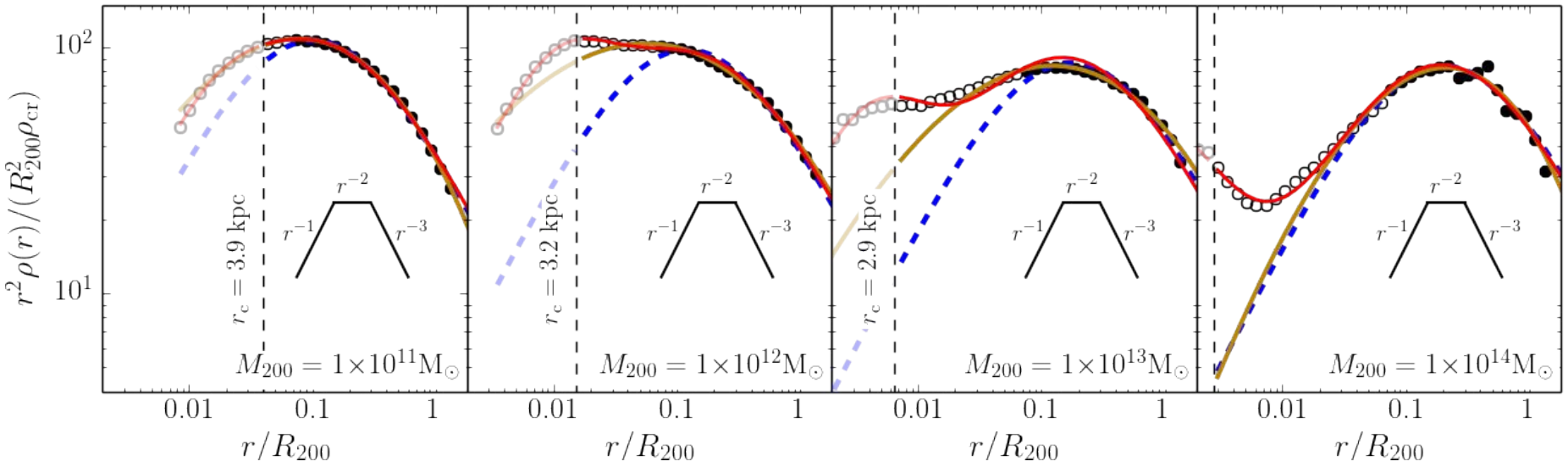
Schaller+15

Halo profiles



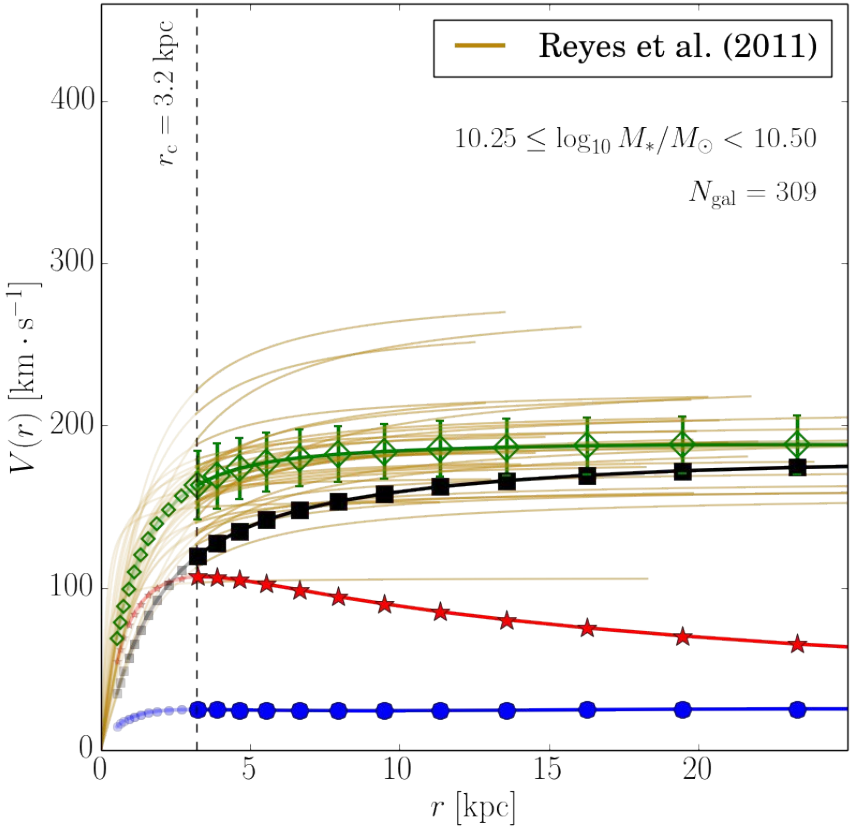
Schaller+15

Halo profiles

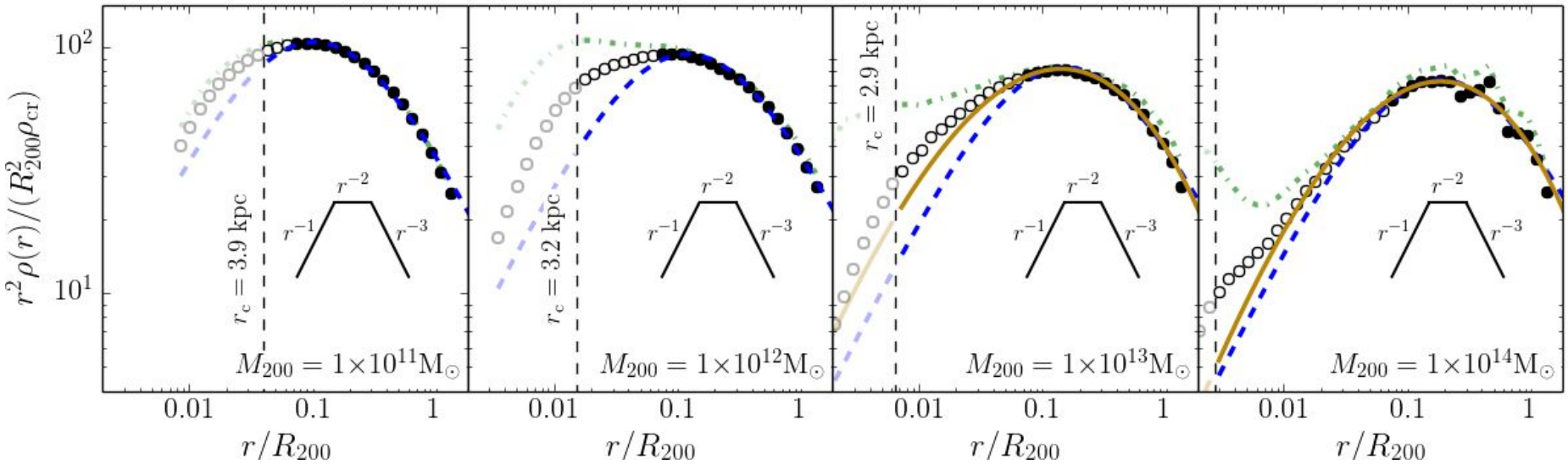


Schaller+15

Does it look realistic?

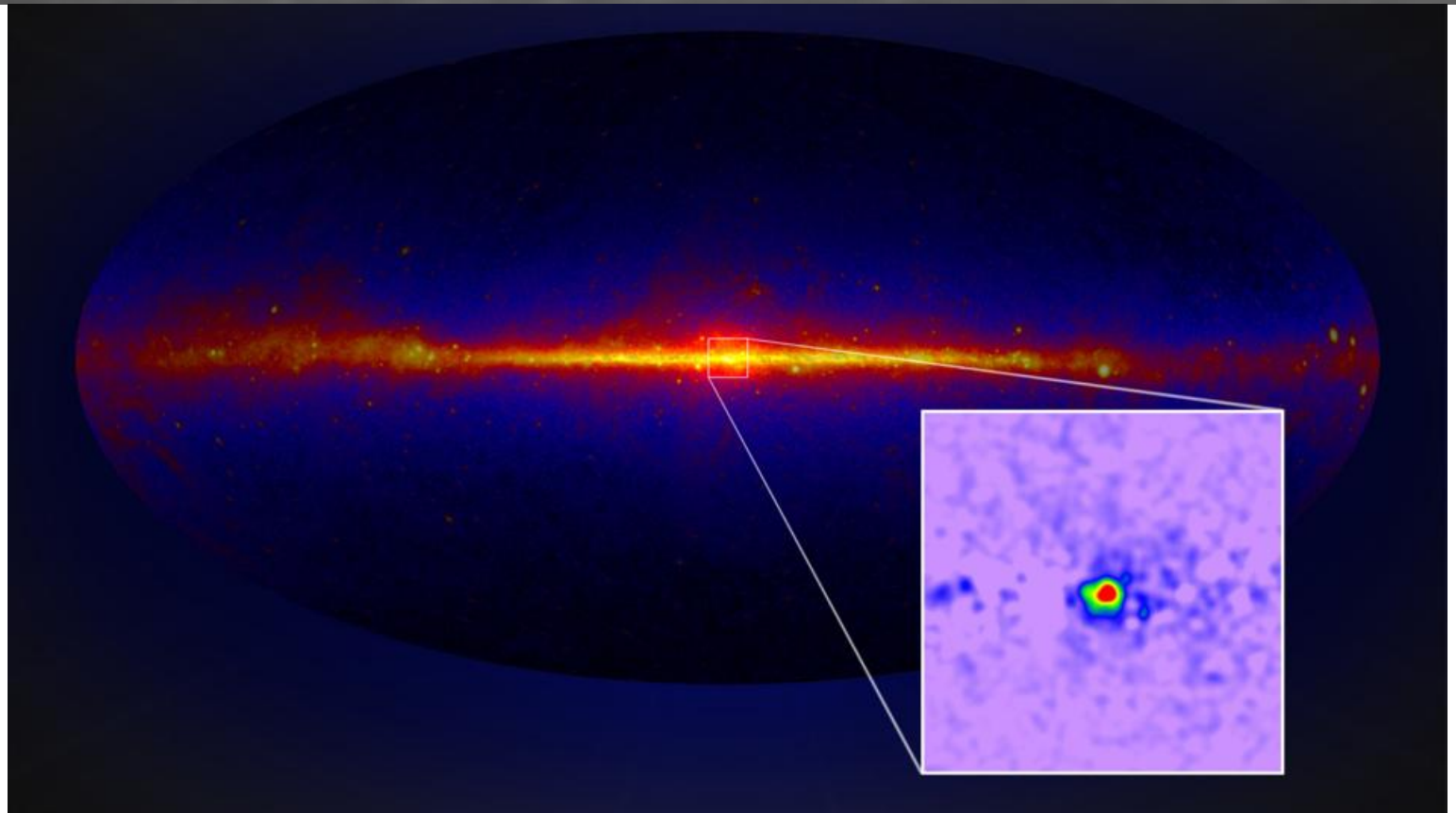


What about the dark matter itself?

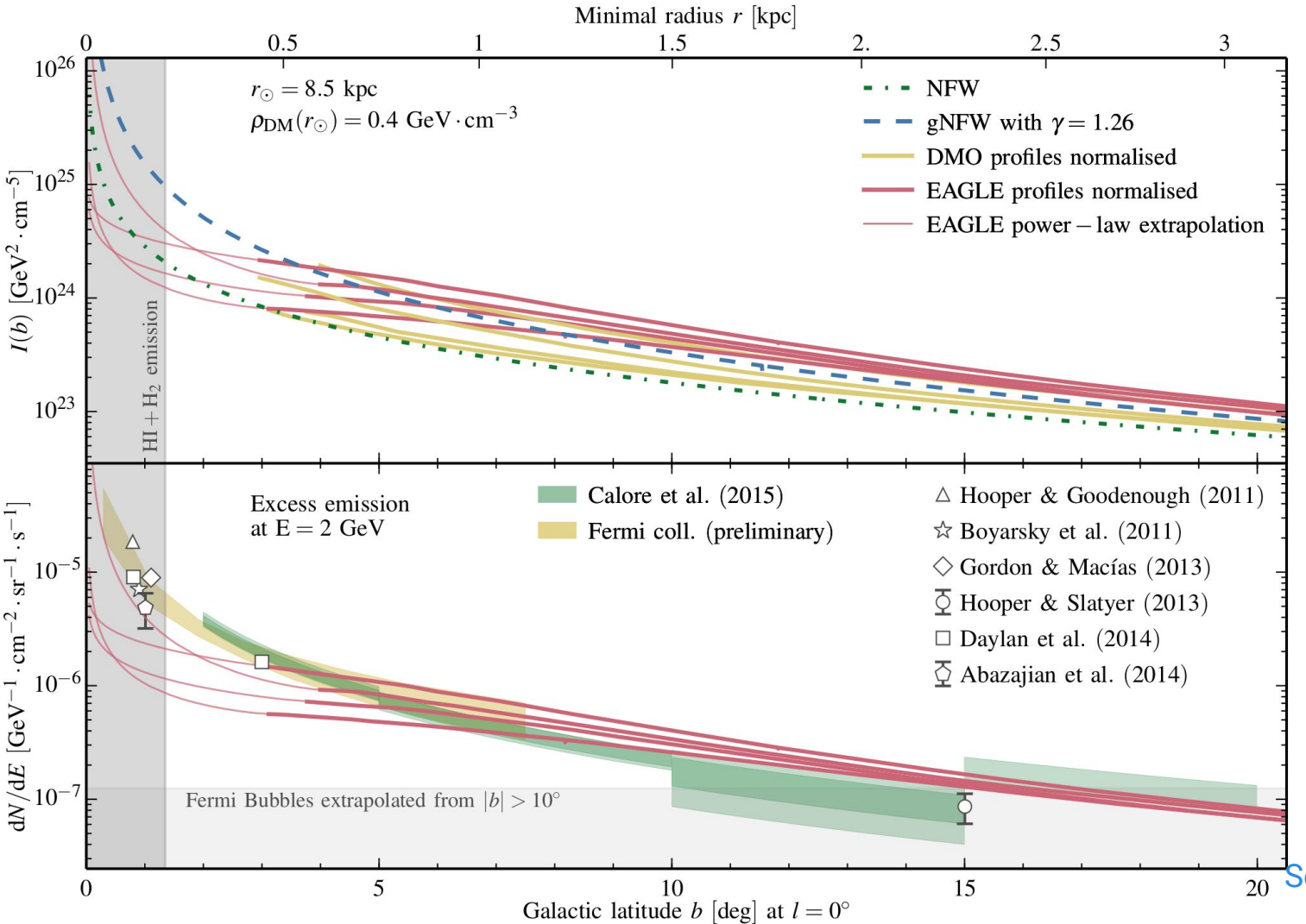


Schaller+15

Implication for DM searches

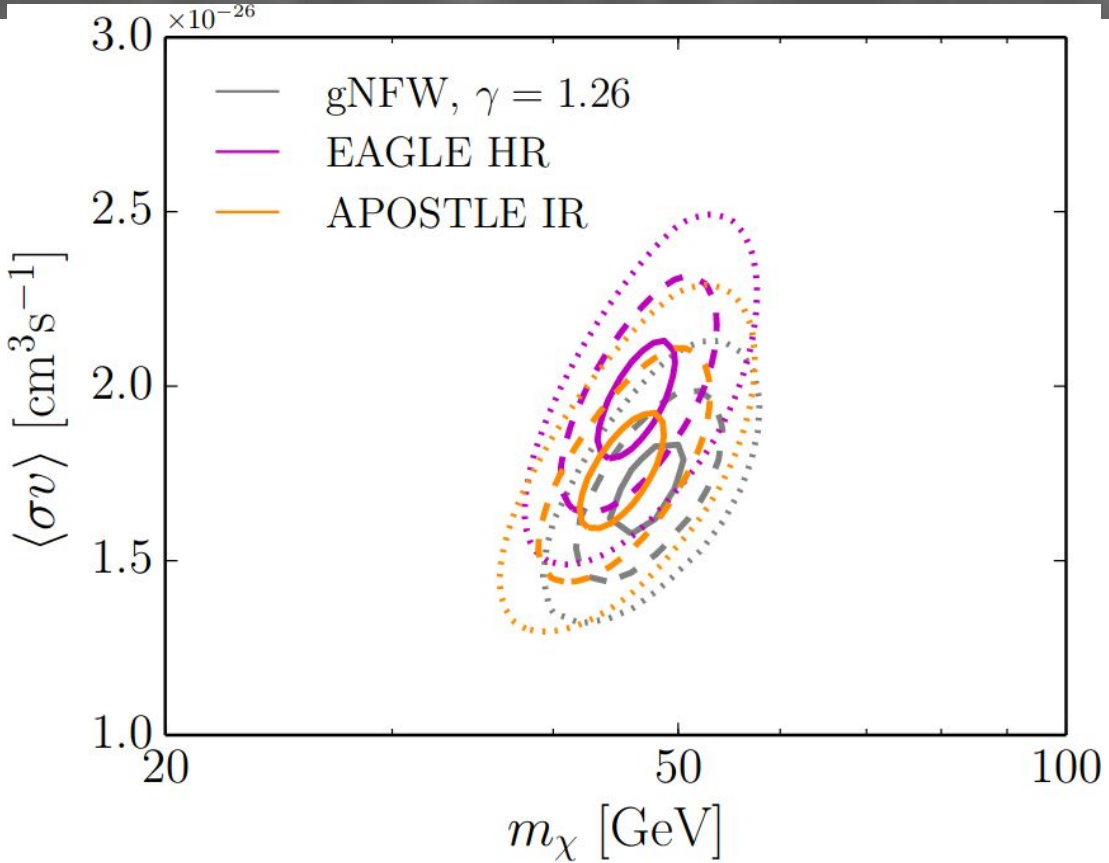


Credit: NASA, Fermi


Minimal radius r [kpc]
0
0.5
1
1.5
2.
2.5
3
$r_\odot = 8.5$ kpc
$\rho_{\rm DM}(r_\odot) = 0.4$ GeV$\cdot$cm^{-3}
NFW
gNFW with $\gamma = 1.26$
DMO profiles normalised
EAGLE profiles normalised
EAGLE power – law extrapolation
$I(b)$ [GeV$^2\cdot$cm^{-5}]
10^{26}
10^{25}
10^{24}
10^{23}
HI + H$_2$ emission
Excess emission
at E = 2 GeV
Calore et al. (2015)
Fermi coll. (preliminary)
Hooper & Goodenough (2011)
Boyarsky et al. (2011)
Gordon & Macías (2013)
Hooper & Slatyer (2013)
Daylan et al. (2014)
Abazajian et al. (2014)
dN/dE [GeV$^{-1}\cdot$cm$^{-2}\cdot$sr$^{-1}\cdot$s^{-1}]
10^{-5}
10^{-6}
10^{-7}
Fermi Bubbles extrapolated from $|b| > 10°$
0
5
10
15
20
Galactic latitude b [deg] at $l = 0°$

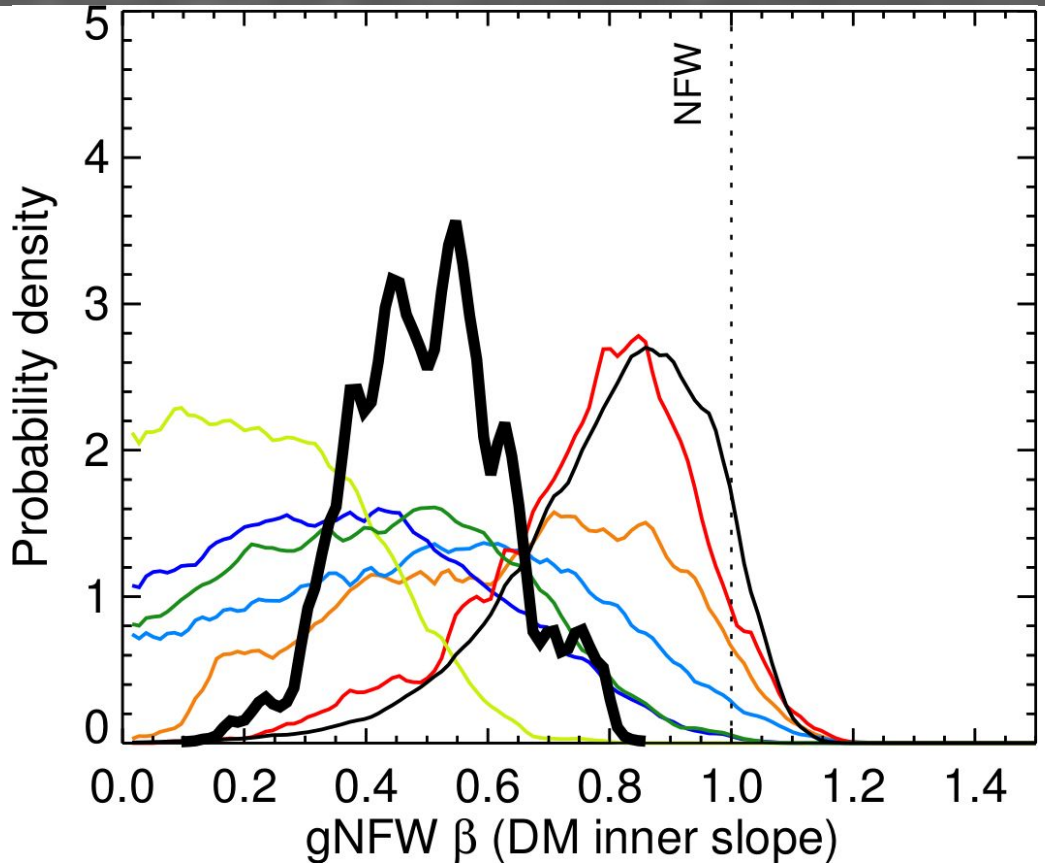
Schaller+16

Constraints assuming a decay channel



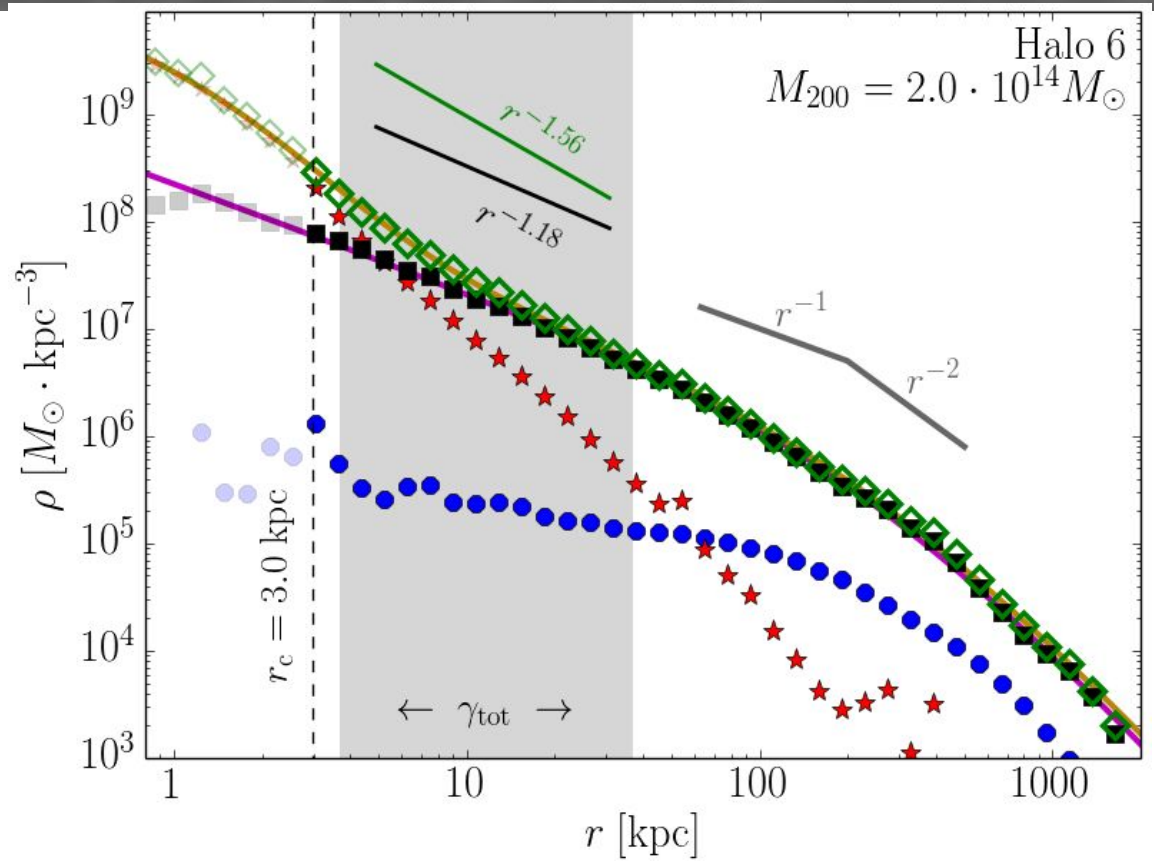
Calore+17

Obs. constraints on DM slope?



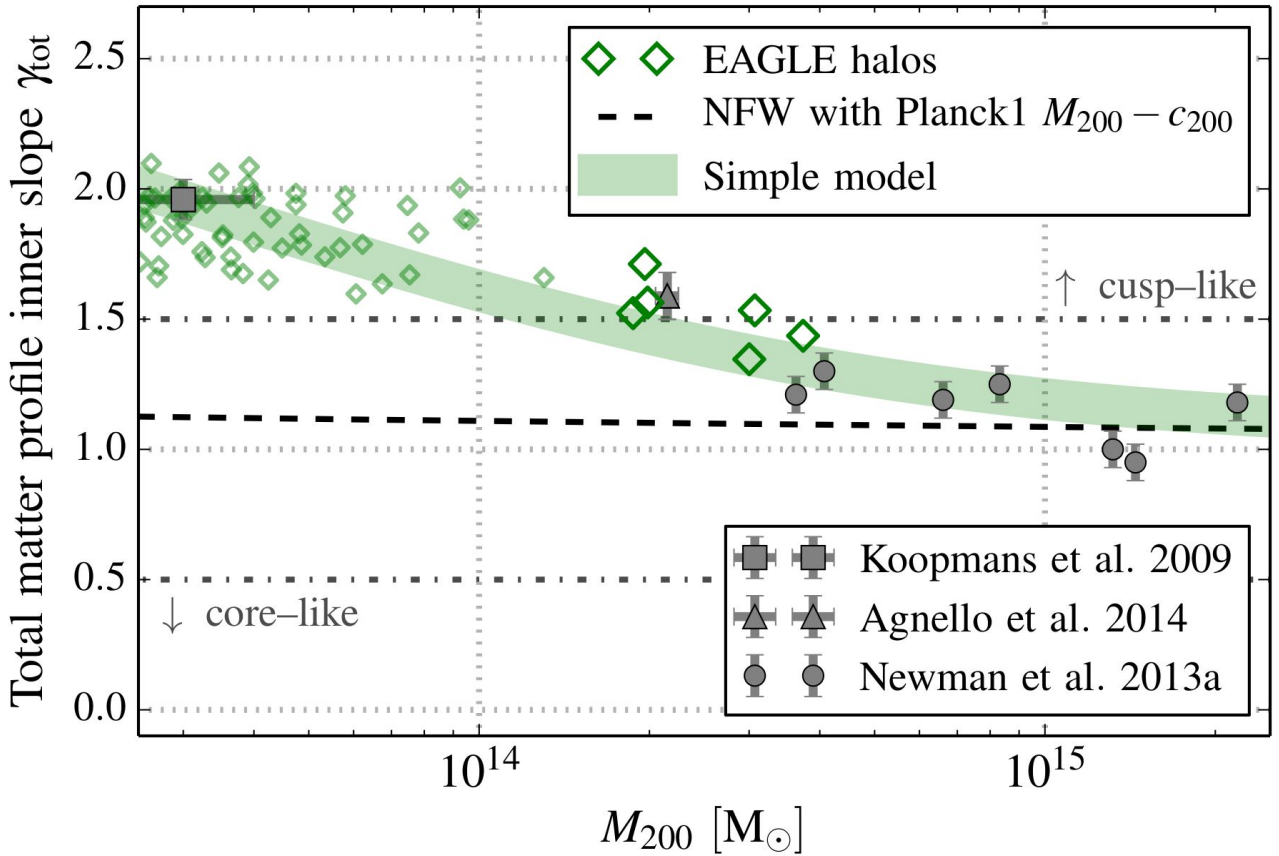
Newman+13

Cluster profiles

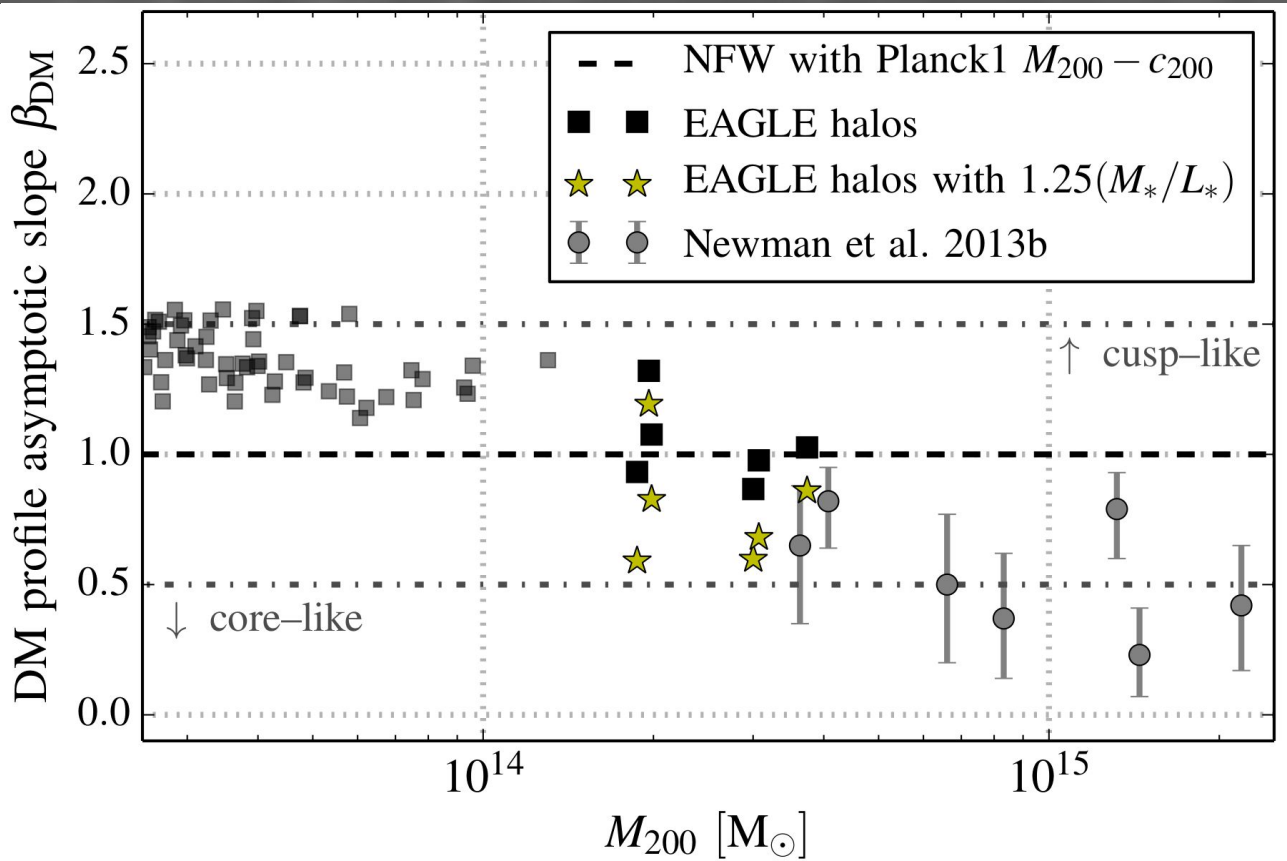


Schaller+16b

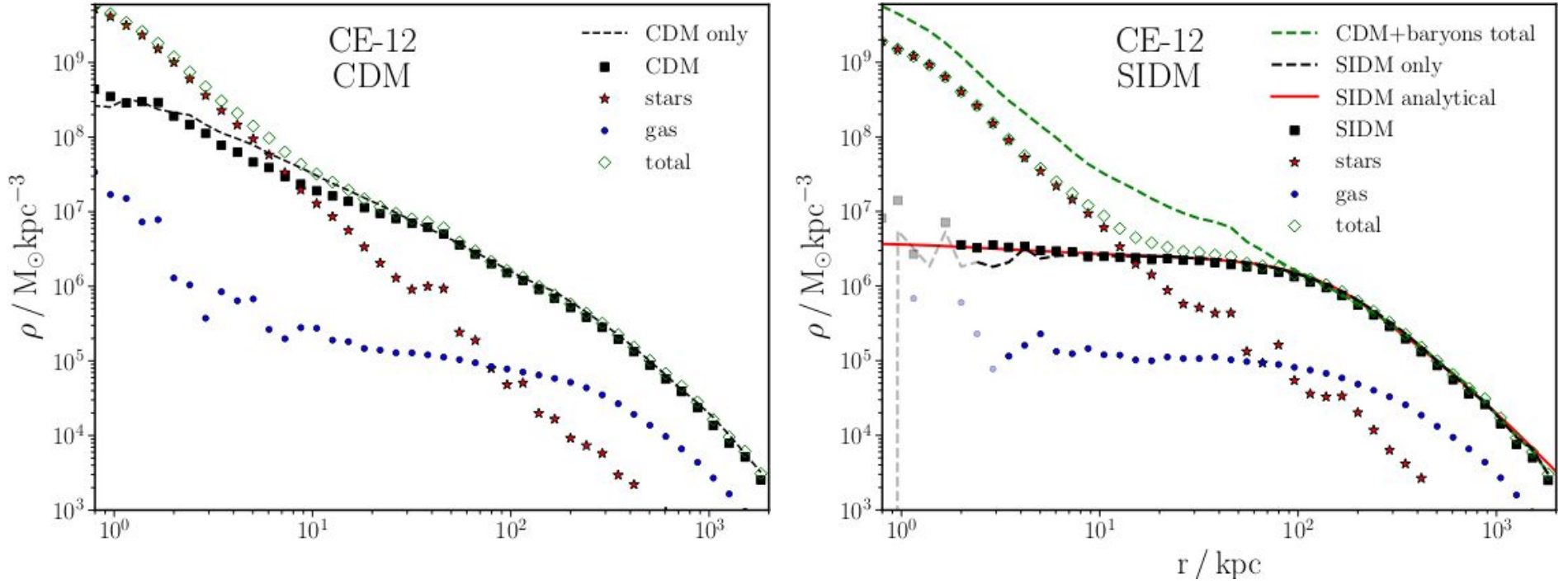
Total matter profile



Dark matter profiles

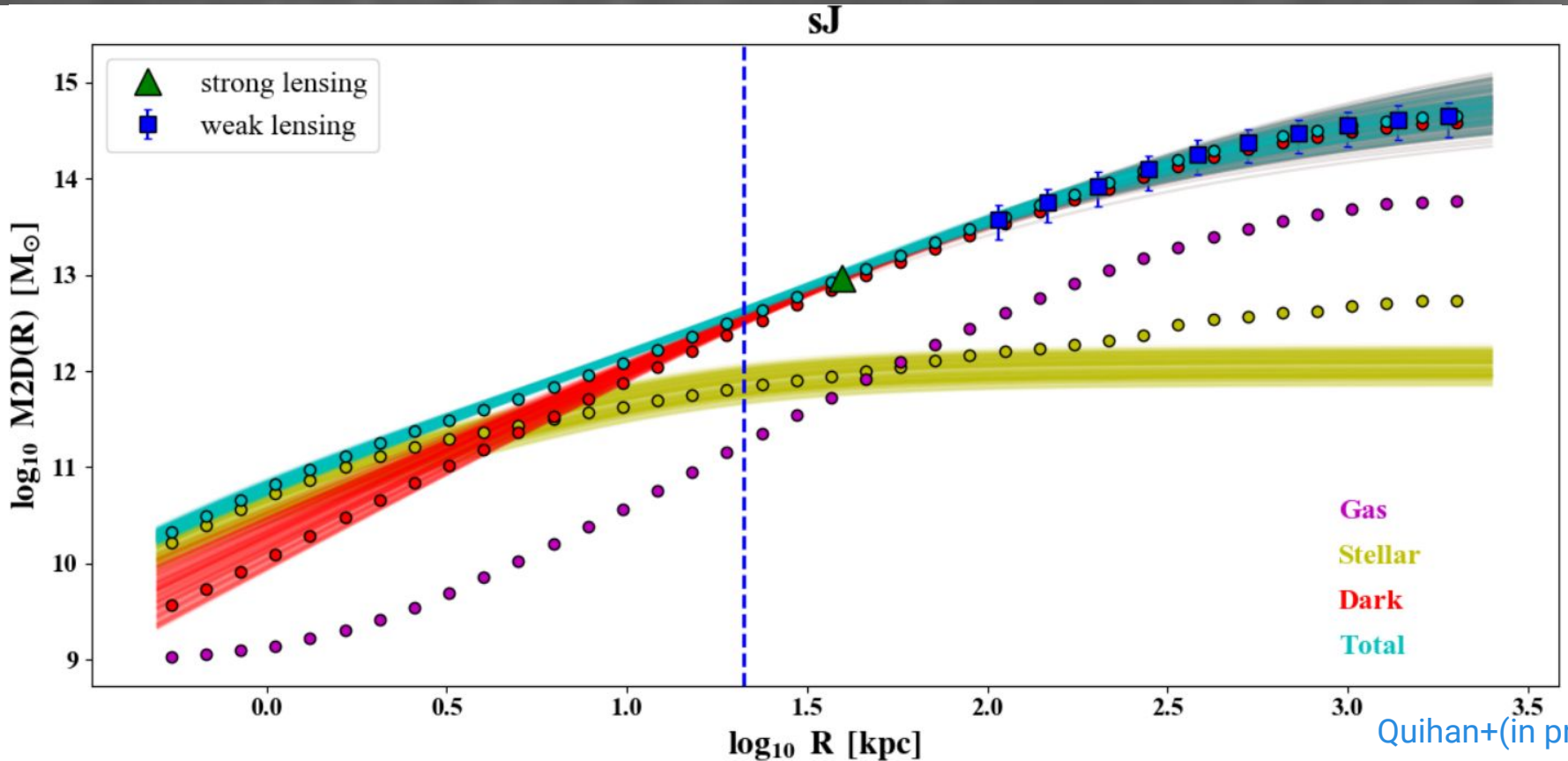


Self-interacting dark-matter?



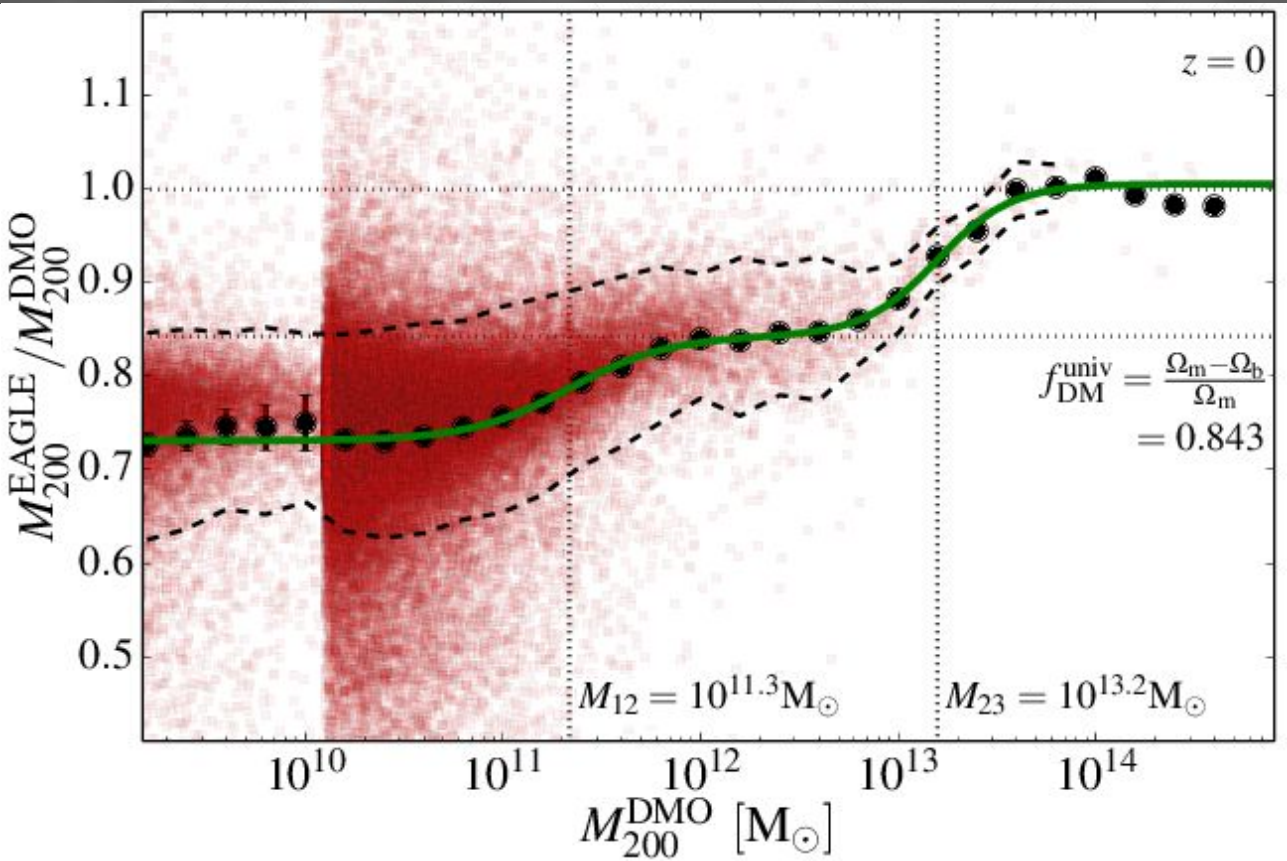
Robertson+18

Or could the analysis be “wrong” ?



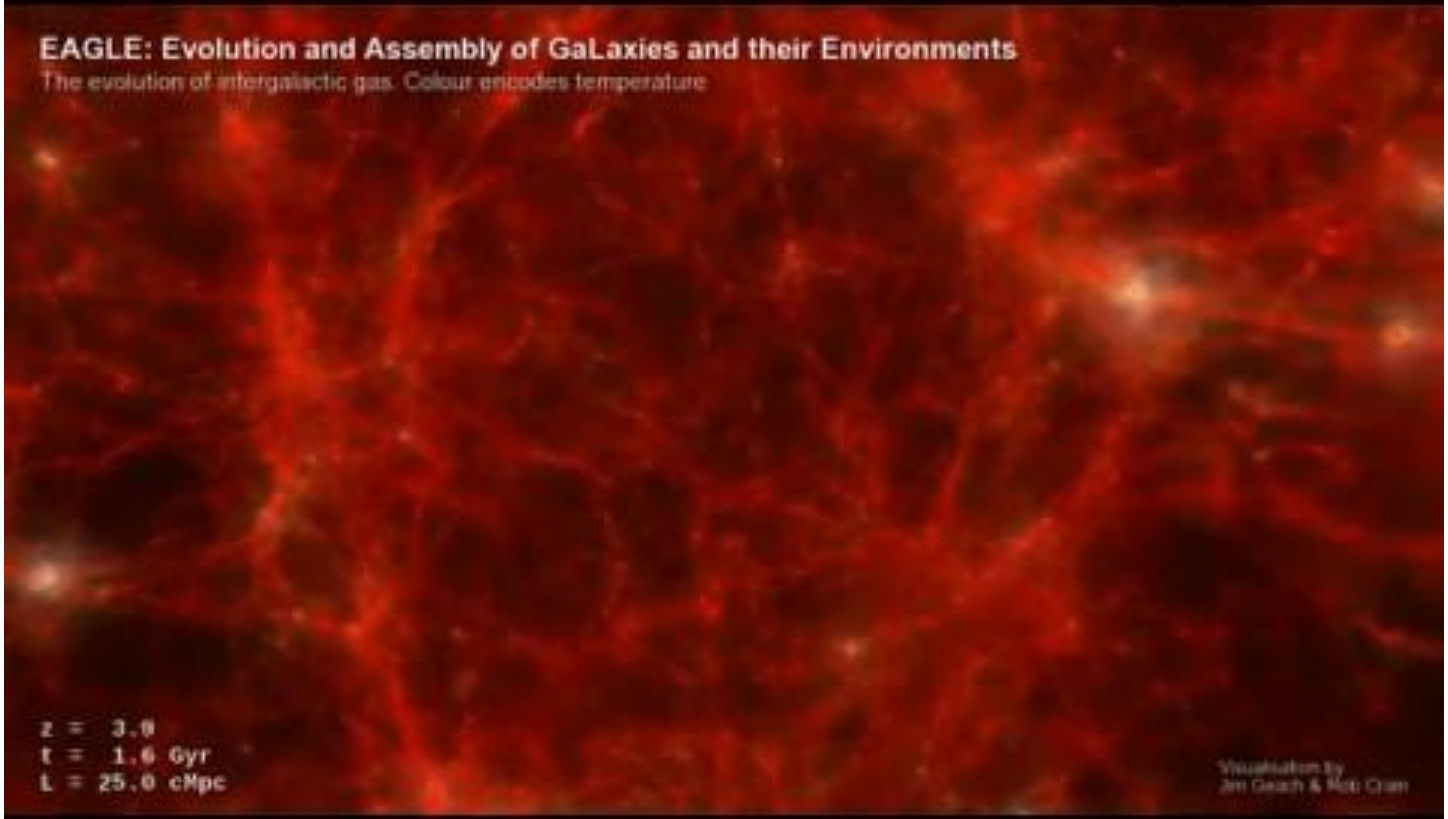
Quihan+(in prep)

Effects on the halo masses

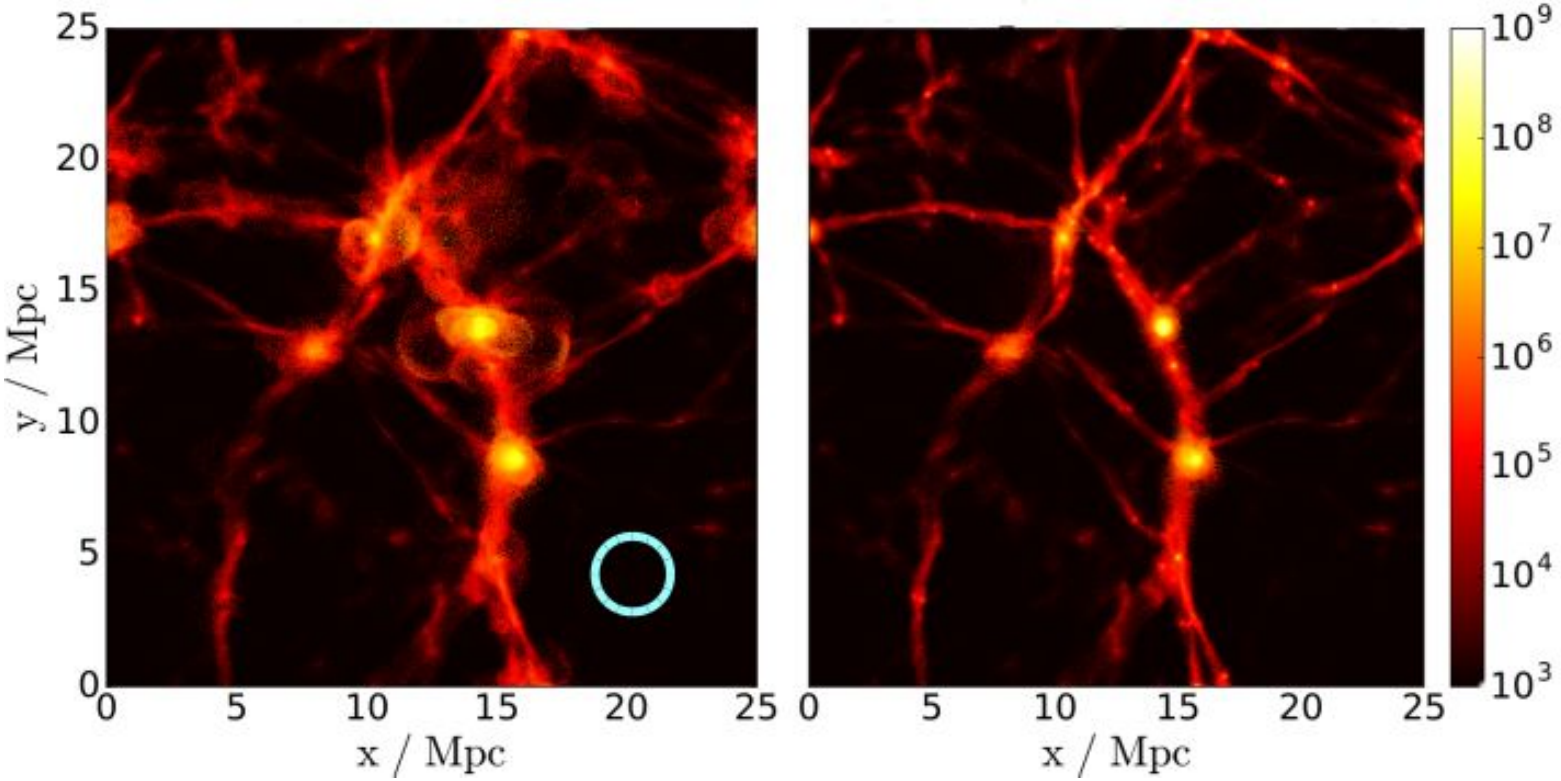


Schaller+15

Effects on cosmological probes

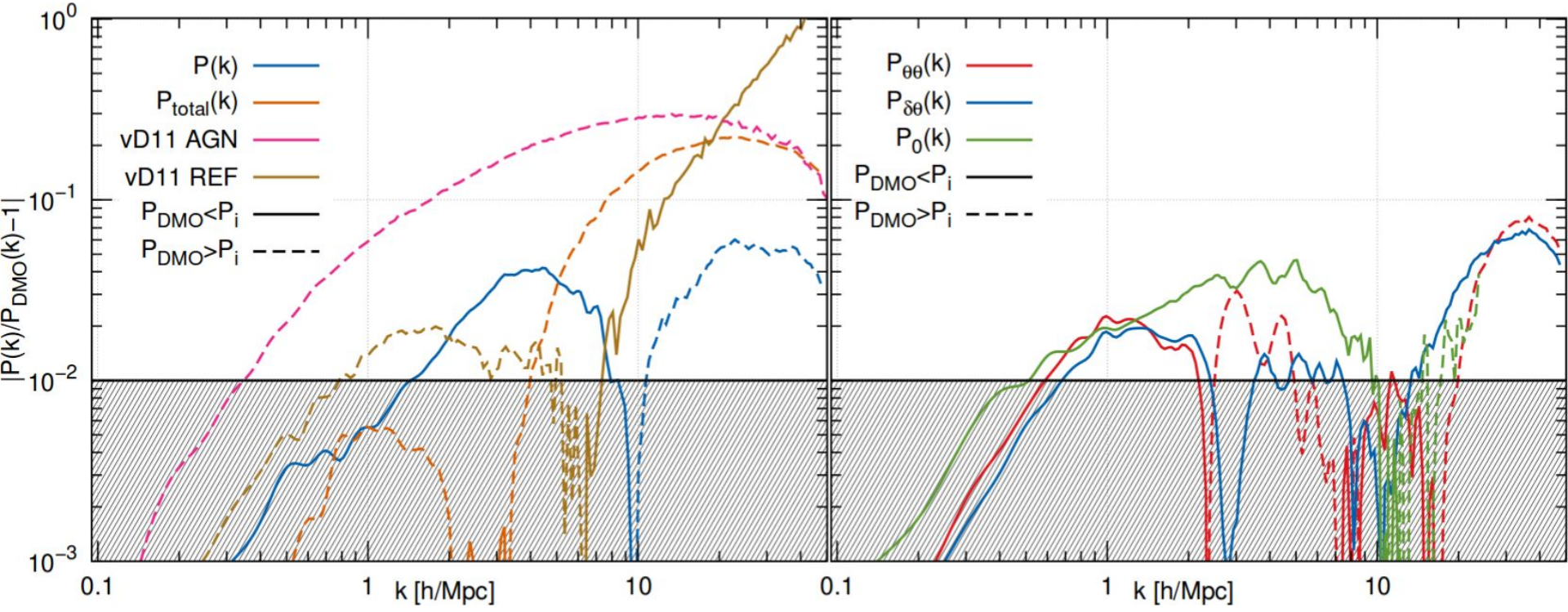

EAGLE: Evolution and Assembly of GaLaxies and their Environments
The evolution of intergalactic gas. Colour encodes temperature
z = 3.0
t = 1.6 Gyr
L = 25.0 cMpc
Visualisation by
Jim Geach & Rob Crain

Baryon effects



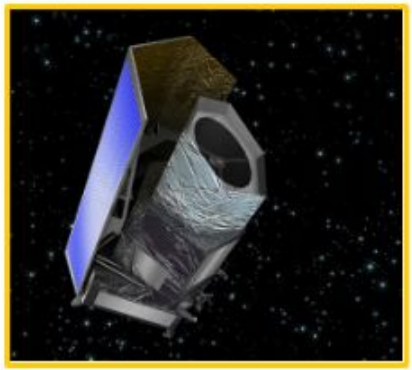
Paillas, MS+2019

In terms of power-spectrum

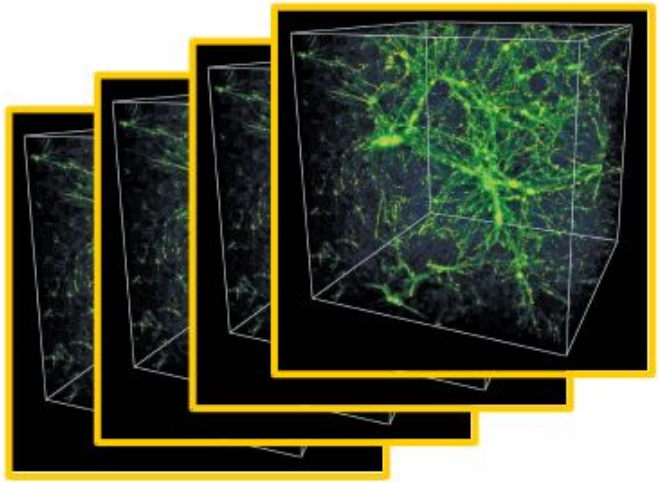


Hellwing, MS+2016

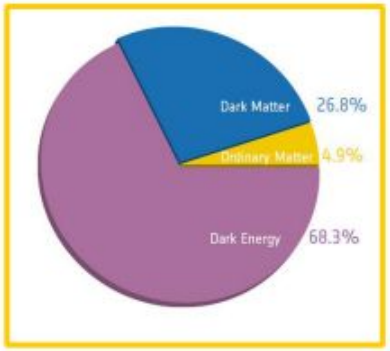
From raw data to cosmology



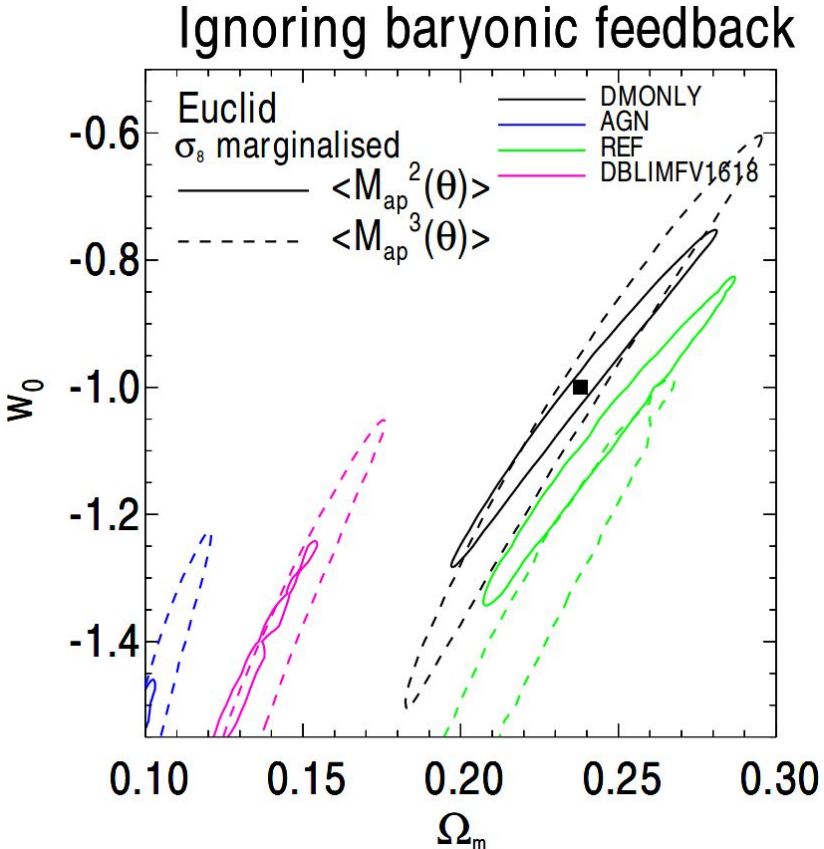
+



=



Weak-lensing forecast



Sembolini+2014

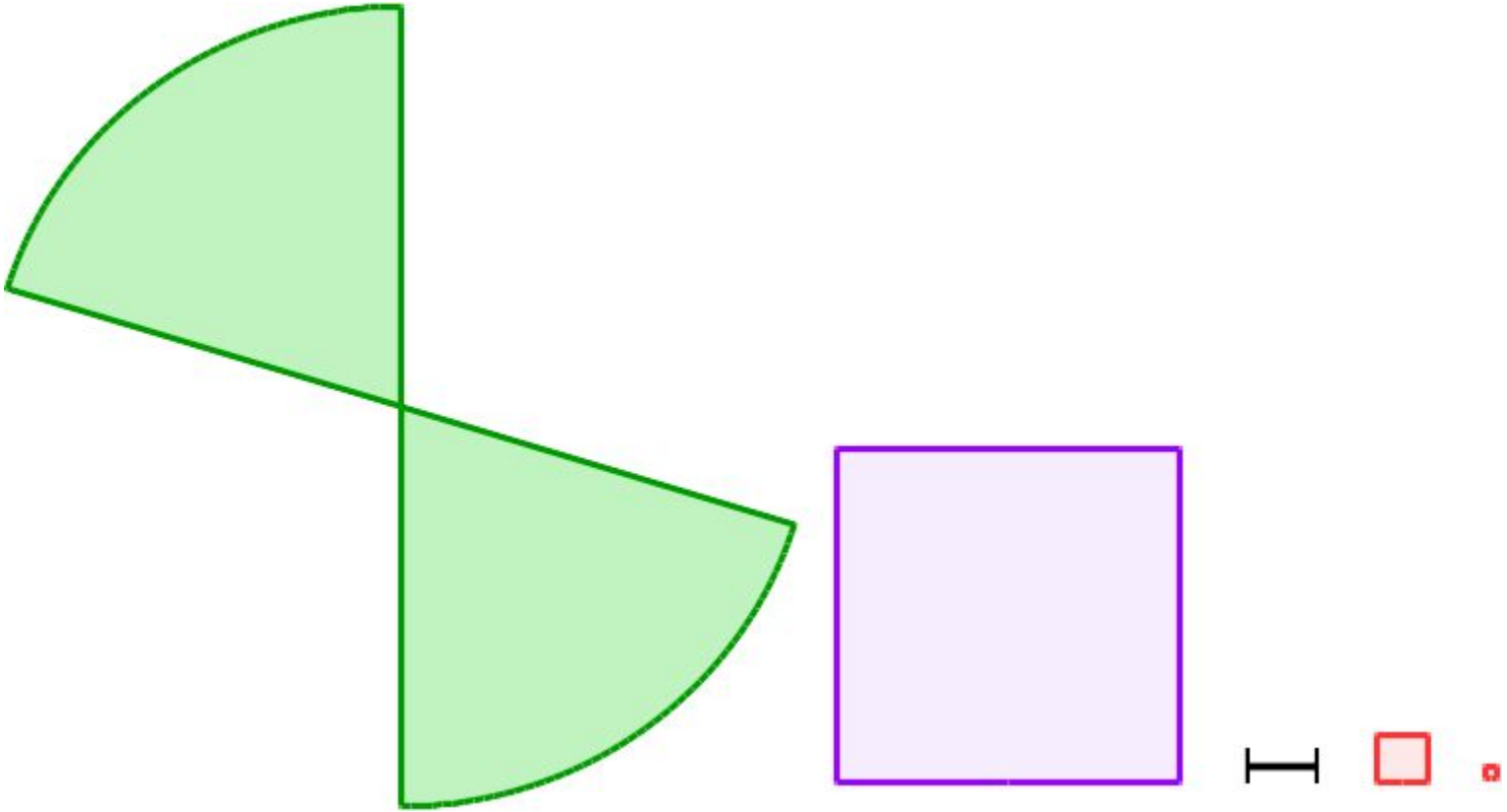
Do we need bigger runs?

Thinking of future weak-lensing surveys:

- Measure some cosmological information on scales down to ~ 1-30 Mpc. Clearly “baryon effects” seen on these scales.

- “Common wisdom” asks for volume in excess of 300 Mpc.

Cosmological scales in hydro runs?



Do we need bigger runs?

Thinking of future weak-lensing surveys:

- Measure some cosmological information on scales down to ~ 1-30 Mpc. Clearly “baryon effects” seen on these scales.
- “Common wisdom” asks for volume in excess of 300 Mpc.
- That asks for particles counts > 4500^3 ~ 100 billion (@ EAGLE res.).

  -> With EAGLE code that would be >300M CPU hours and 1.3PB of RAM

Future with the SWIFT code?

SWIFT principles

- Fully open-source cosmological simulation software for the community.
- Testable, designed to easily manage multiple schemes, subgrid models, physics problems.
- Scalable, fast and exploiting the latest hardware using modern algorithm.

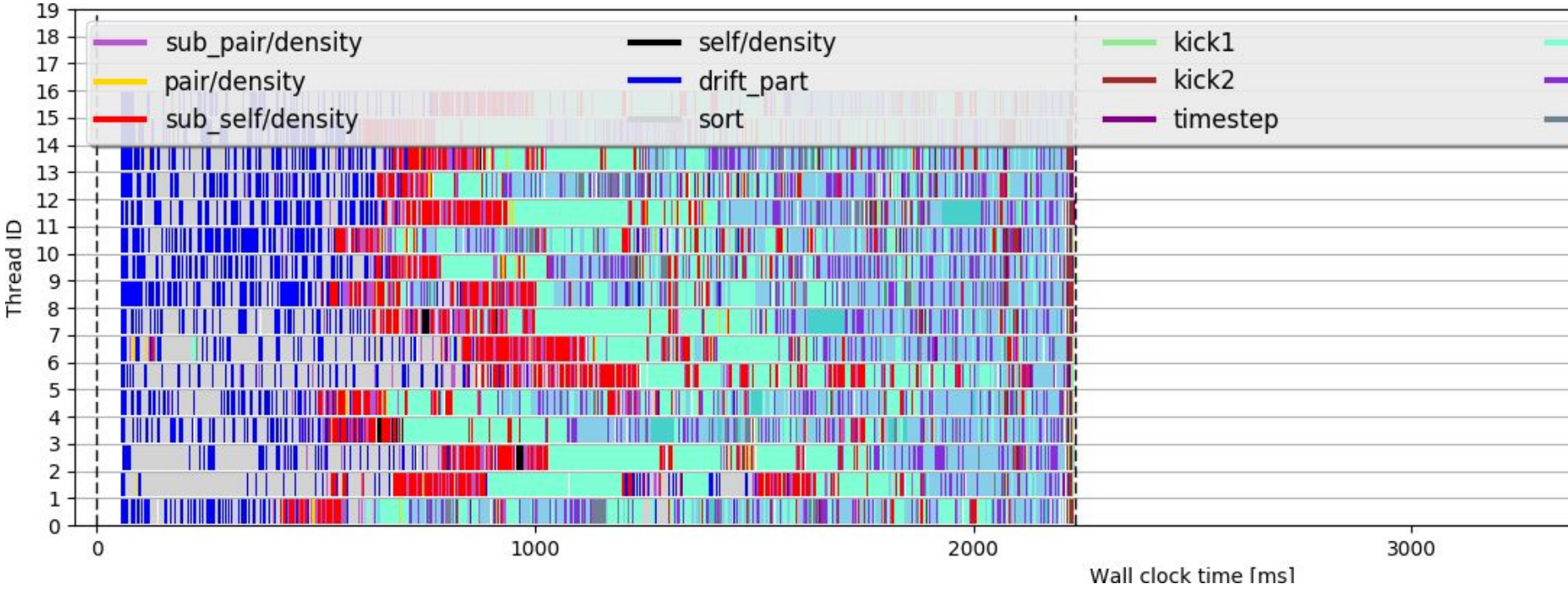
Under the hood

- Using task-based parallelism, modern algorithms, better parallelisation and domain decomposition we get an *order of magnitude speed-up* over Gadget on representative problems.

- Leaner memory footprint, faster i/o, more modular, multiple hydro schemes.

- Collaboration with computer scientists and industry.

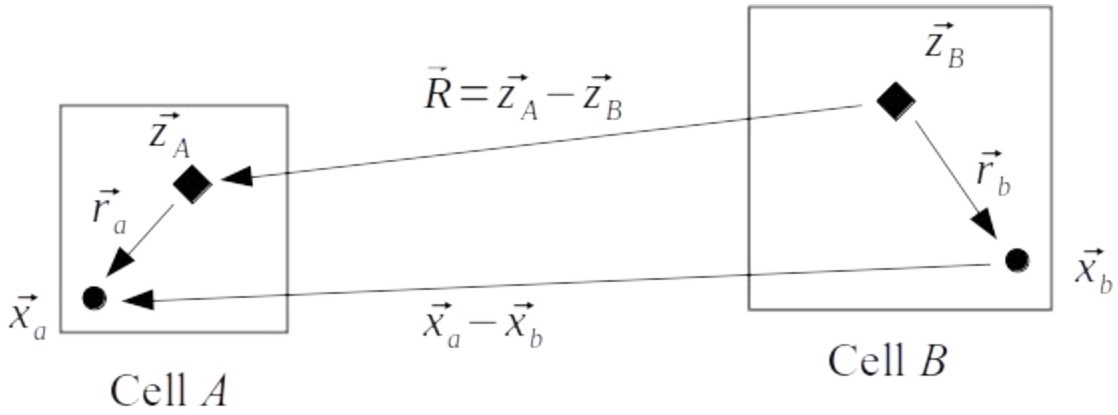
Task-based parallelism in action

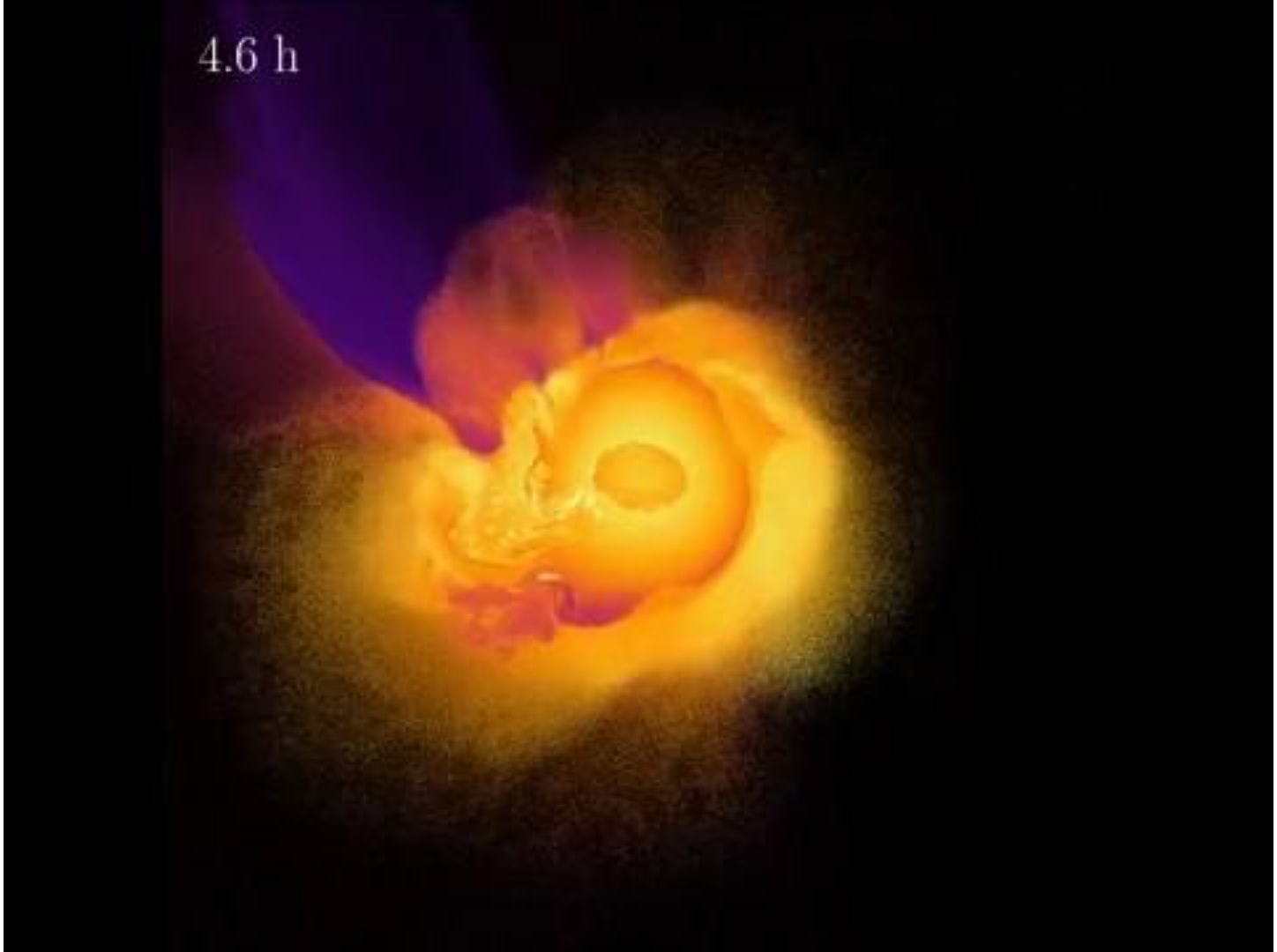


Some physics

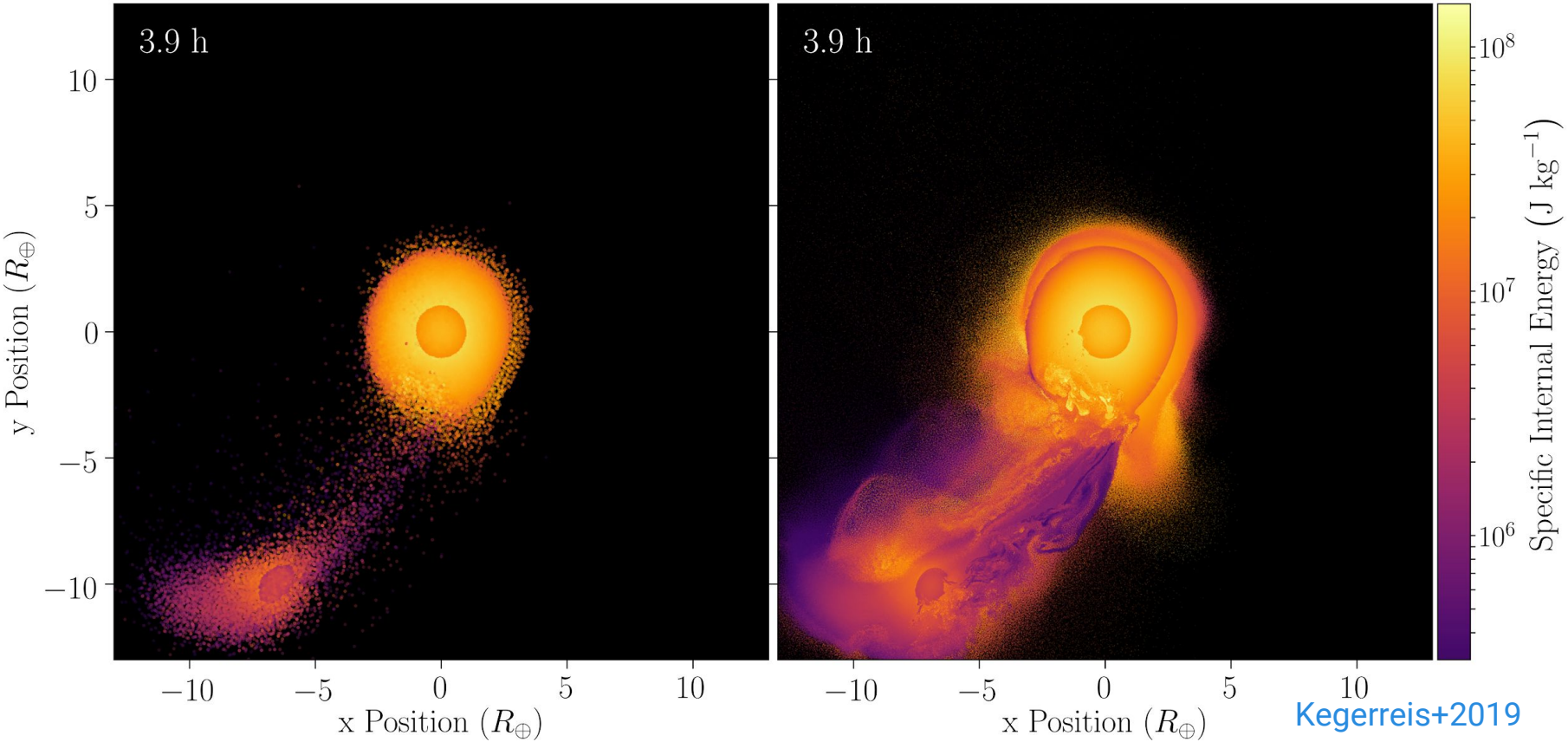
- Hydro neighbour finding based on regular AMR cell structure. Many flavours of SPH + “GIZMO”.
- 5^{th} order FMM for gravity with a multipole-mesh method for periodic gravity.
- Particles sorted to enhance the vectorization of the code.
- Activation of work only in the “active” parts of the tree.

FMM principles



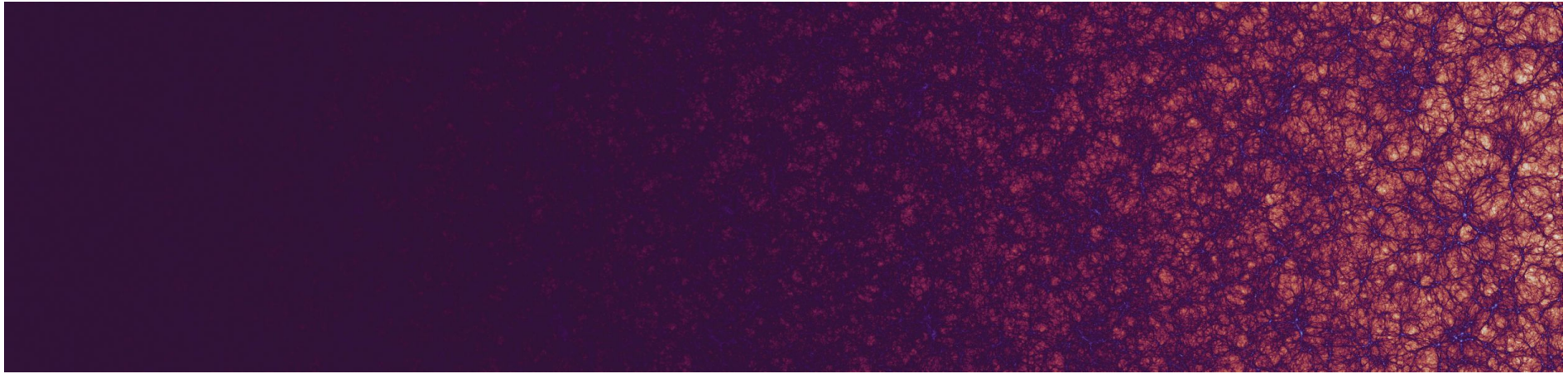

4.6 h

Planet formation - Tilt of Uranus

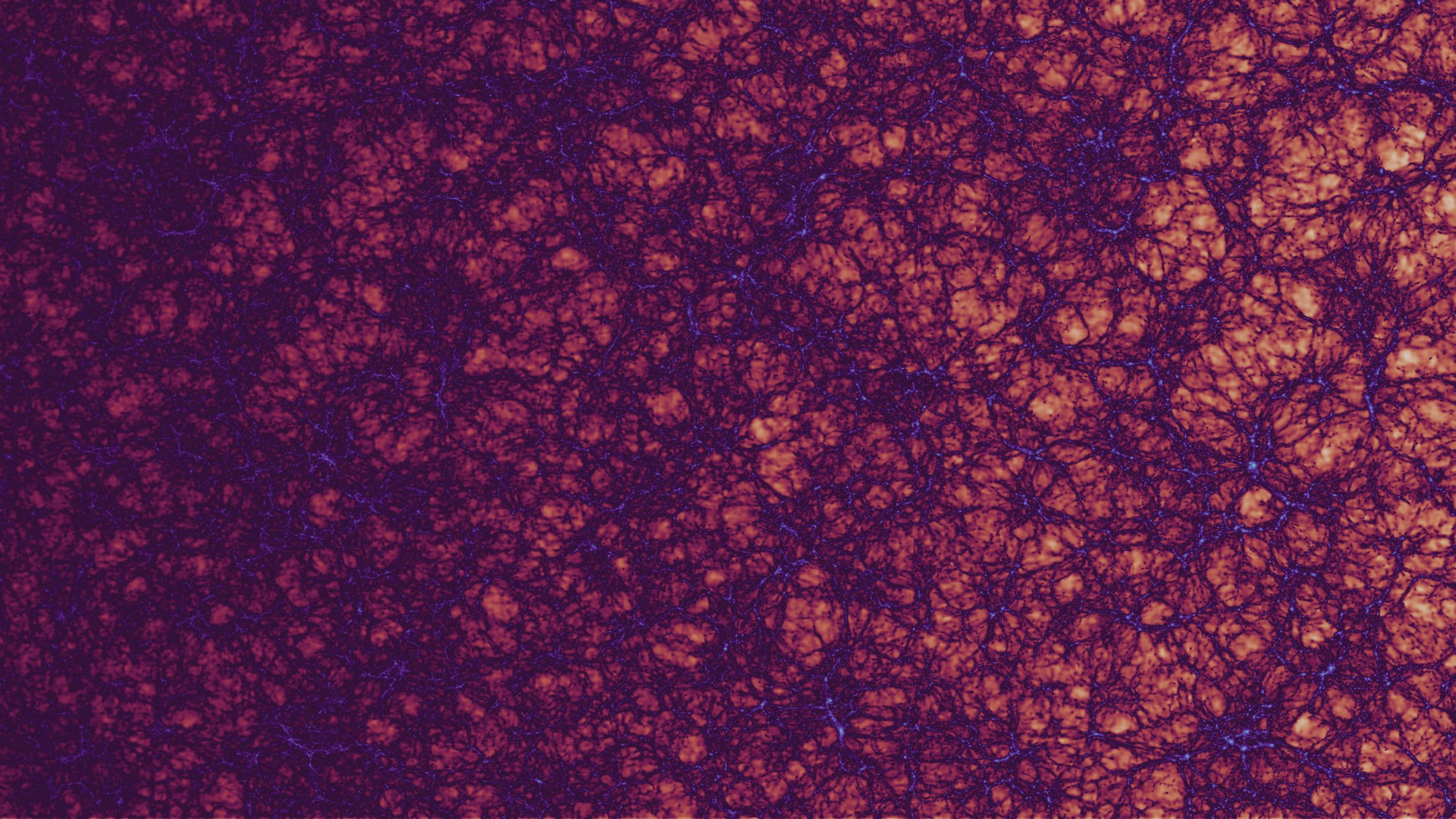


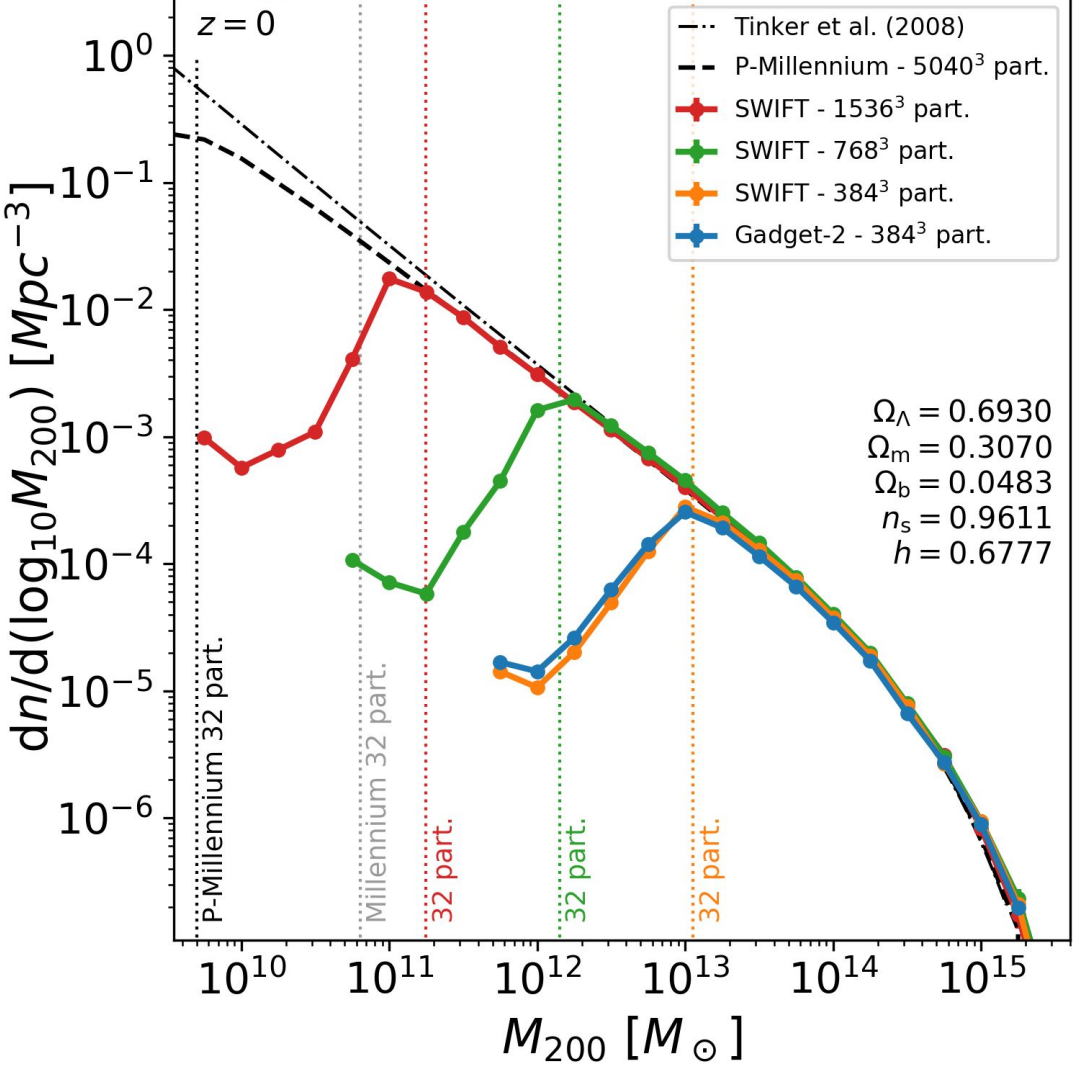
Kegerreis+2019

Cosmological simulations

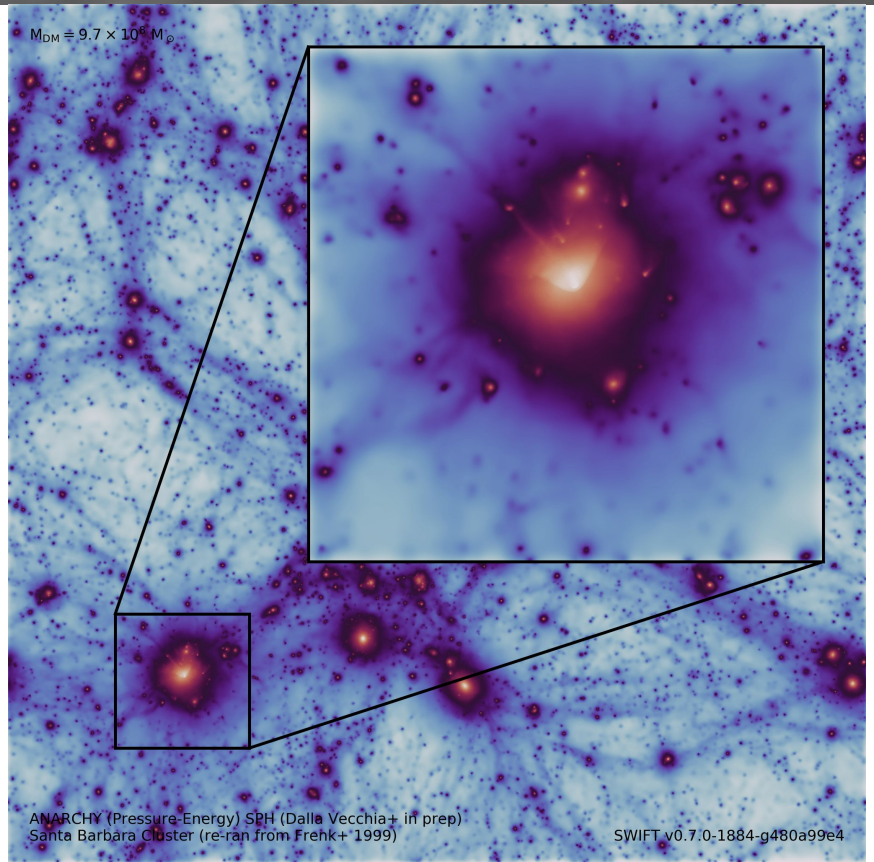


DM-only simulation. 800^3 Mpc^3 volume. 1536^3 particles. 4 computing nodes. 4 days of wall-clock time.




$z = 0$
Tinker et al. (2008)
P-Millennium - 5040^3 part.
SWIFT - 1536^3 part.
SWIFT - 768^3 part.
SWIFT - 384^3 part.
Gadget-2 - 384^3 part.
$\Omega_\Lambda = 0.6930$
$\Omega_m = 0.3070$
$\Omega_b = 0.0483$
$n_s = 0.9611$
$h = 0.6777$
P-Millennium 32 part.
Millennium 32 part.
32 part.
32 part.
32 part.
$\mathrm{d}n/\mathrm{d}(\log_{10}M_{200})\ [Mpc^{-3}]$
$M_{200}\ [M_\odot]$

Same with hydro-dynamics



Some conclusions

- Mock observations are crucial to shed light on the nature of dark matter.
- Constraining baryonic effects (feedback) is crucial to exploit next-generation cosmology probes.
- Larger simulation with wider parameter space are a key tool on this path.
- The SWIFT code enables such simulations.
  Come and play with it!

SPH **W**ith **I**nterleaved **F**ine-grained **T**asking

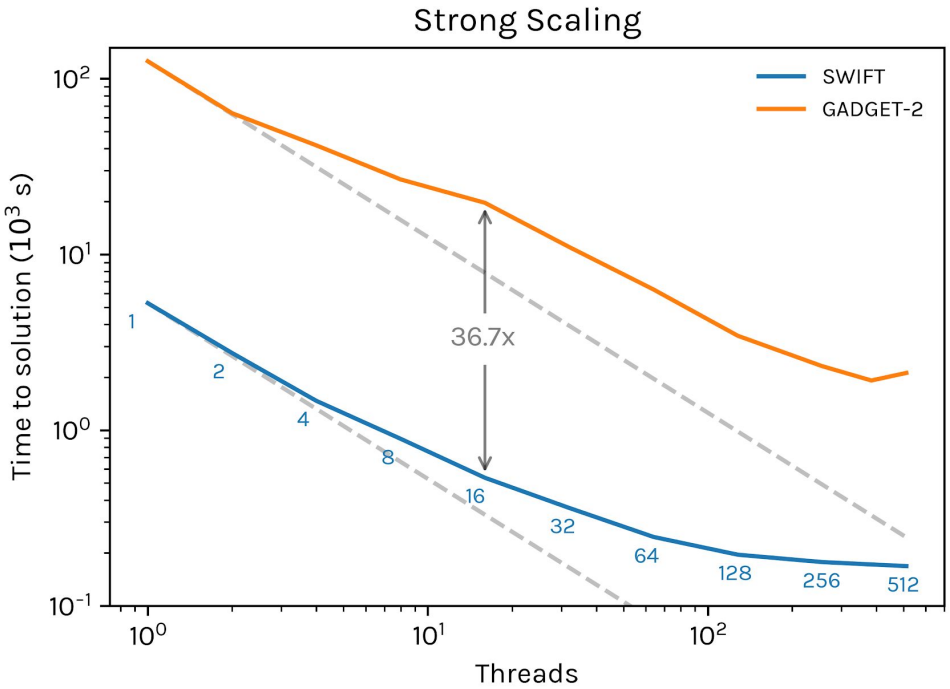
Full source code, examples, documentation & tutorials:

www.swiftsim.com

@SwiftSimulation

Example Plot

- Wow
- Such
- Results
- Colours:
  - Blue: #298BDF
  - Dark Blue: #145289
  - Orange: #DF4229
  - Dark Orange: #90382B



Use a text box with 14 pt. Roboto Bold for Captions.

SWIFT Template

When using this template, you may notice the ‘extra’ image around the edge of the slides. Leave this be -- it avoids things looking weird at the edges of your slides when presenting.

- Bullet Points
- Make Slides
- Great Again