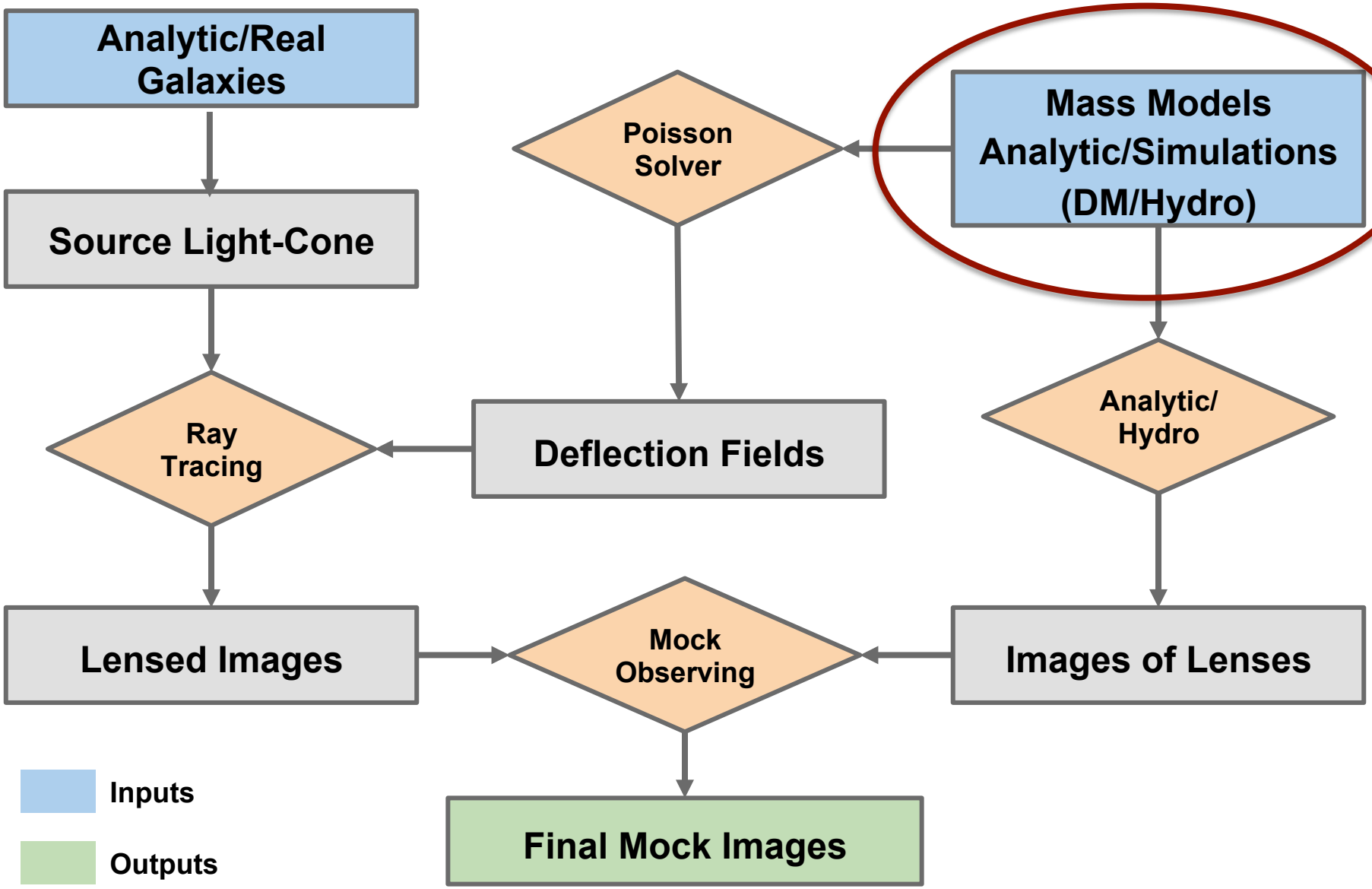
The cold dark matter model

Carlos S. Frenk
Institute for Computational Cosmology,
Durham University

The new Ogden Centre at Durham

Mock making

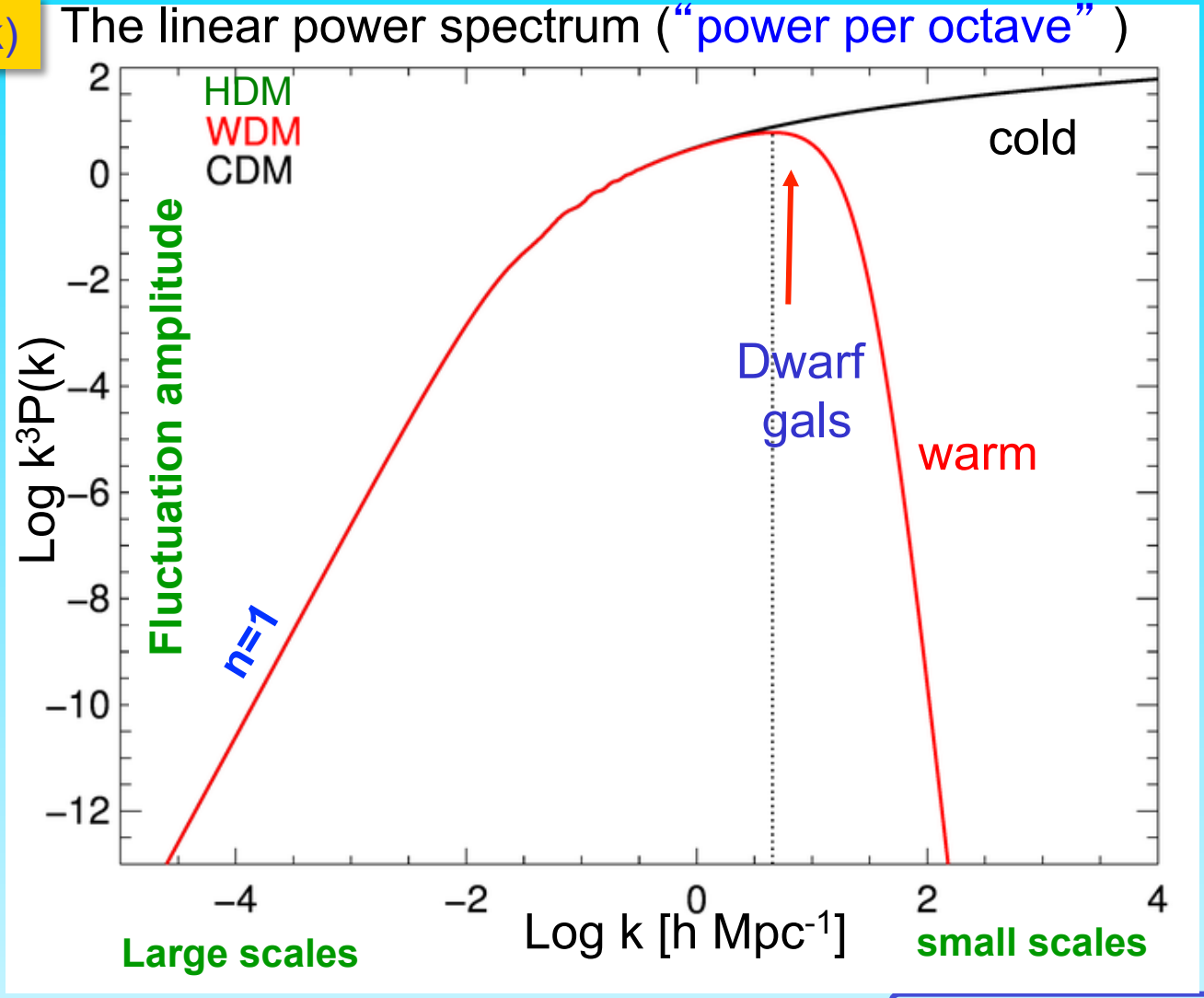


From Nan Li

University of Durham

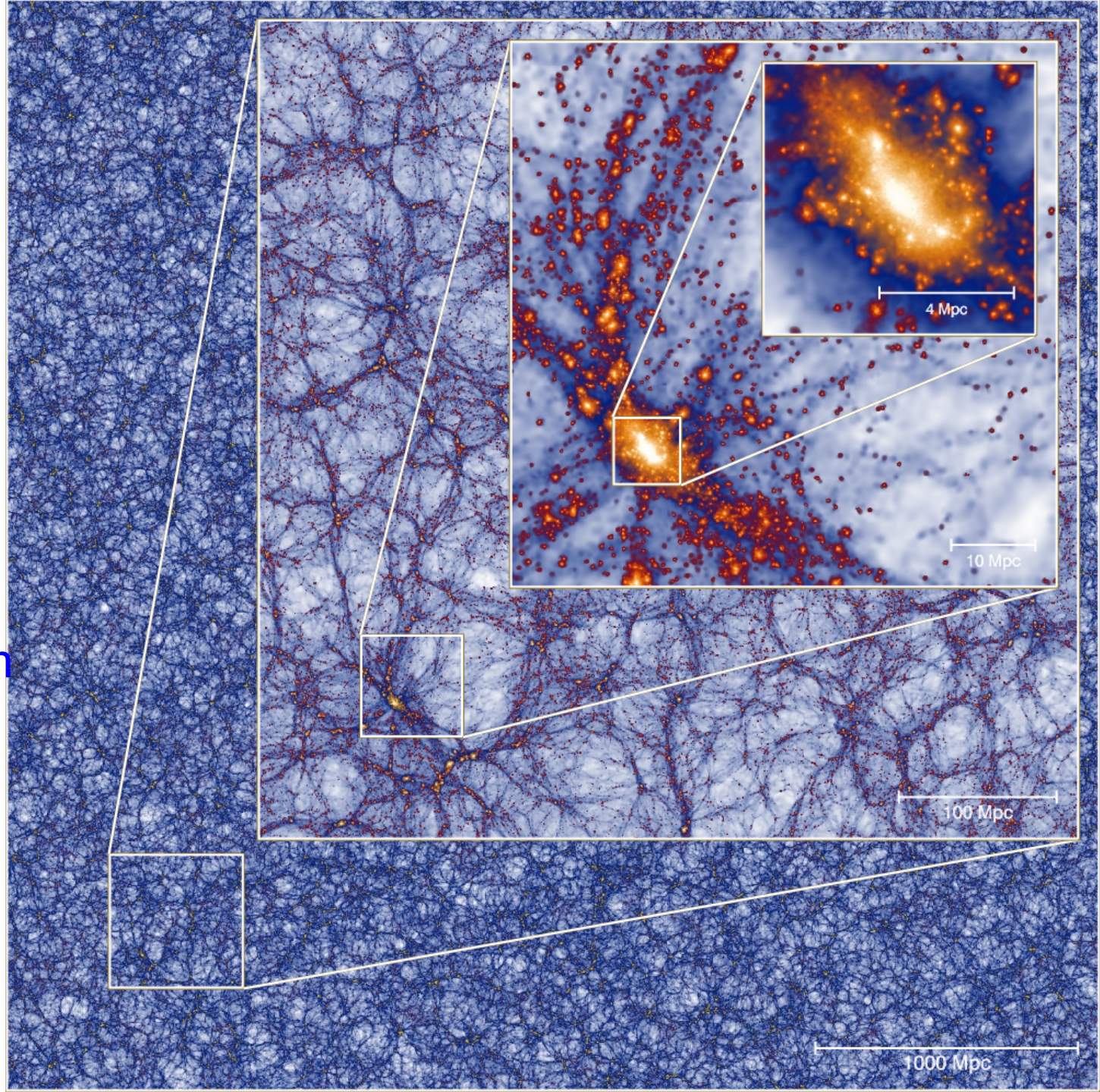
The dark matter power spectrum

$k^3 P(k)$ The linear power spectrum ("power per octave")



N-body simulations

The formation, evolution, abundance, clustering & structure of dark matter halos from CDM initial conditions is a solved problem

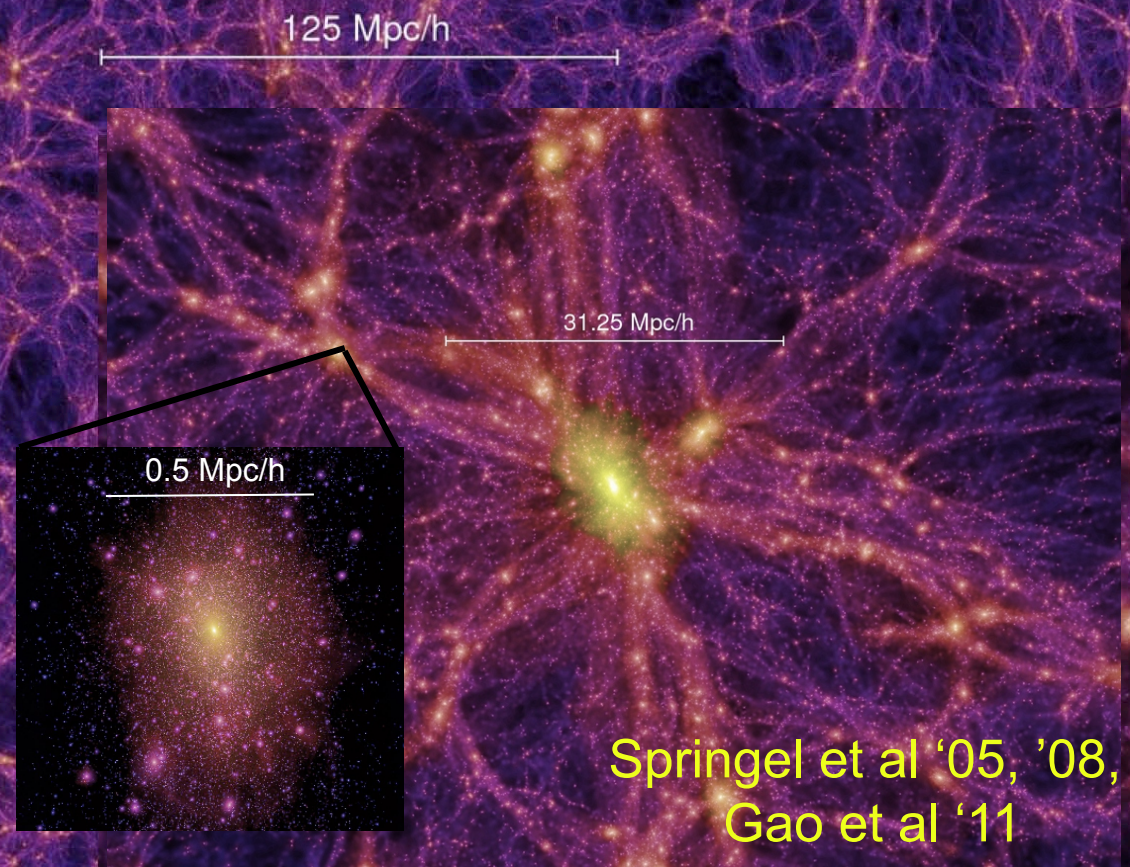


The Millennium/Aquarius/Phoenix simulation series

Simulations give a full characterization of the (hierarchical) clustering of cold dark matter on large and small scales.

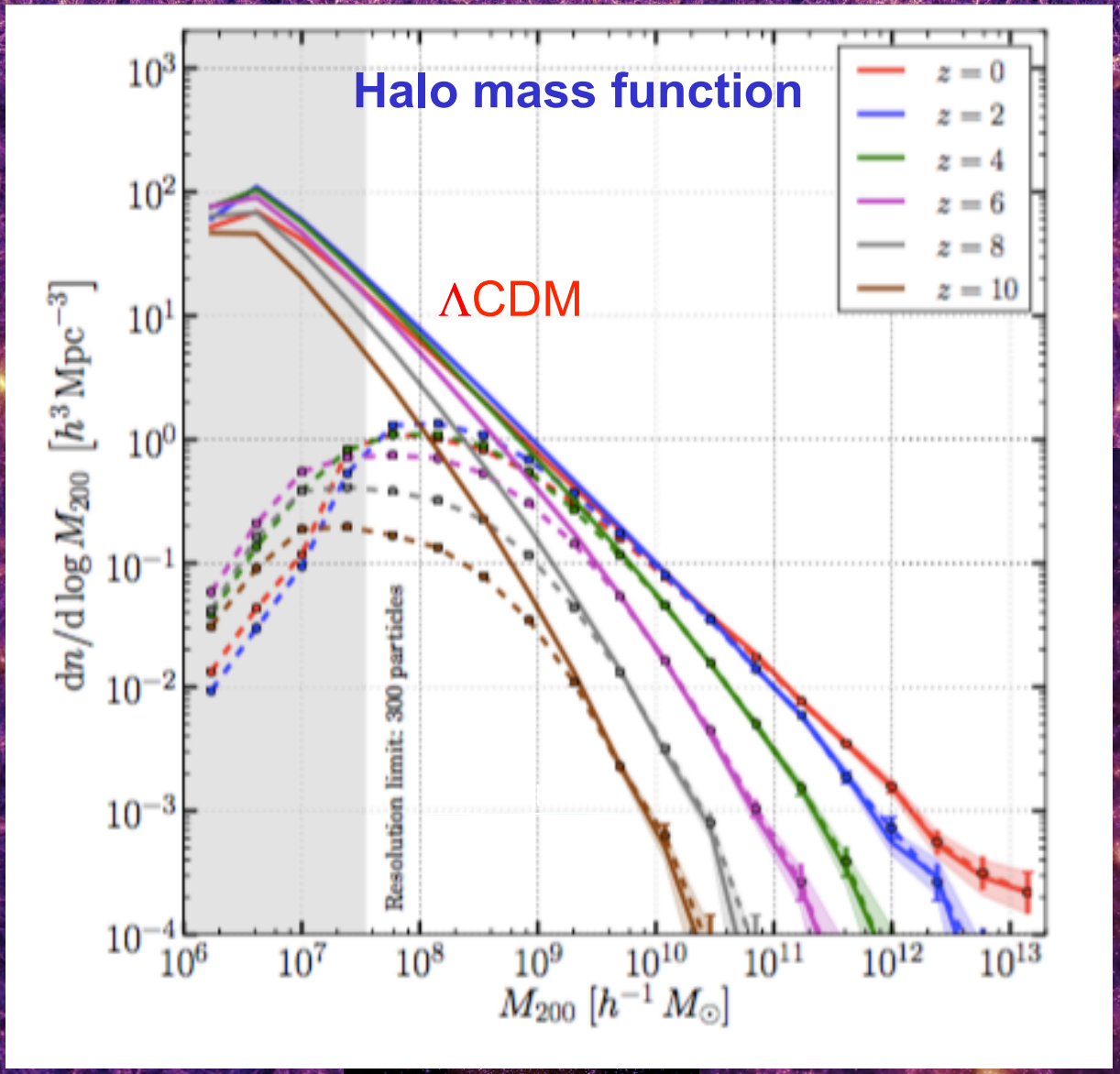
From L=3 Gpc
$m_{particle} = 5 \times 10^9 M_0$

to L= 1 Mpc -
$m_{particle} = 10^3 M_0$



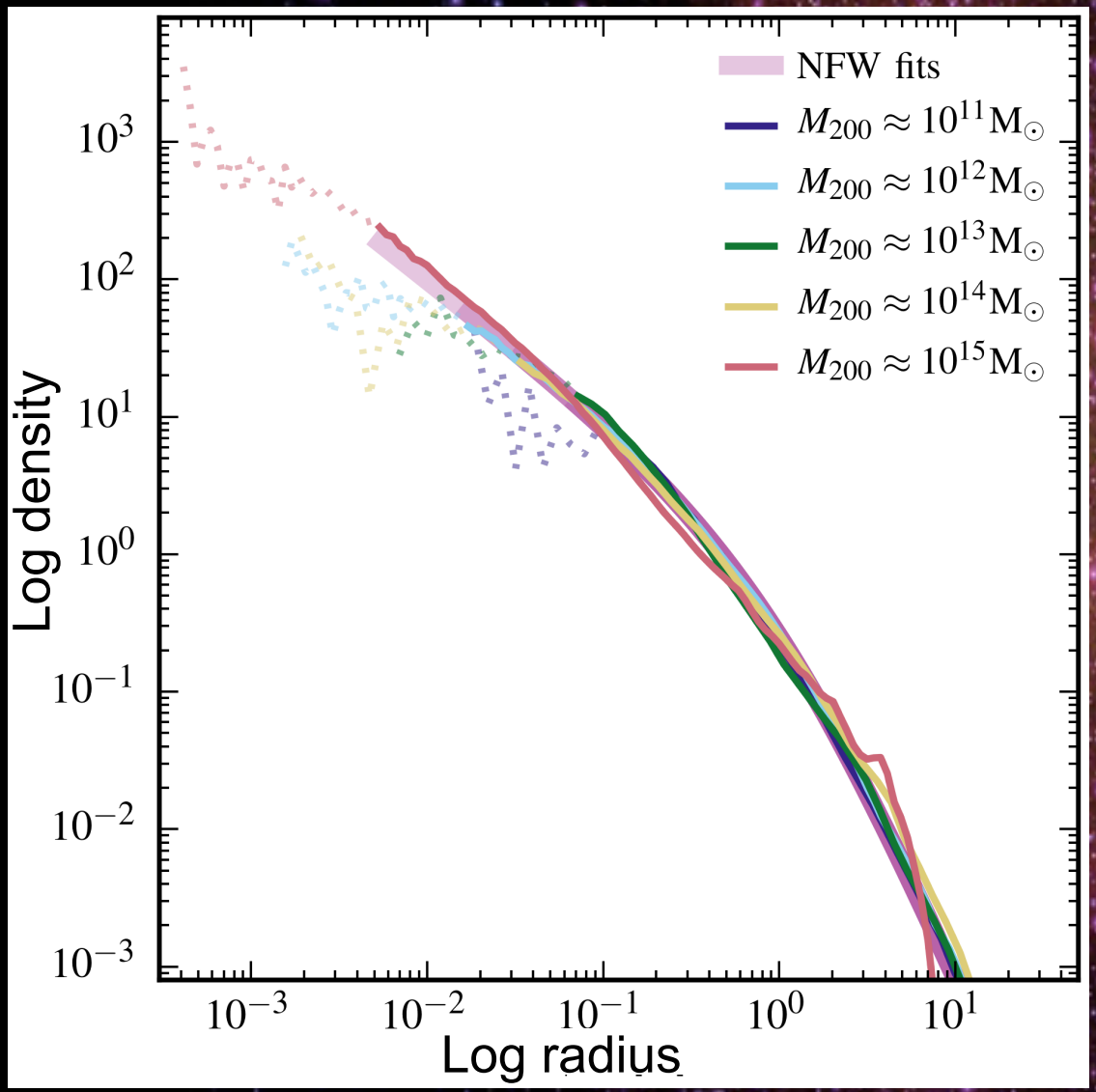
Springel et al '05, '08,
Gao et al '11

The Millennium/Aquarius/Phoenix simulation series



Bose et al '15

The Density Profile of Cold Dark Matter Halos



Shape of halo profiles ~independent of halo mass & cosmological parameters

Density profiles are “cuspy” - no `core’ near the centre

Fitted by simple formula:

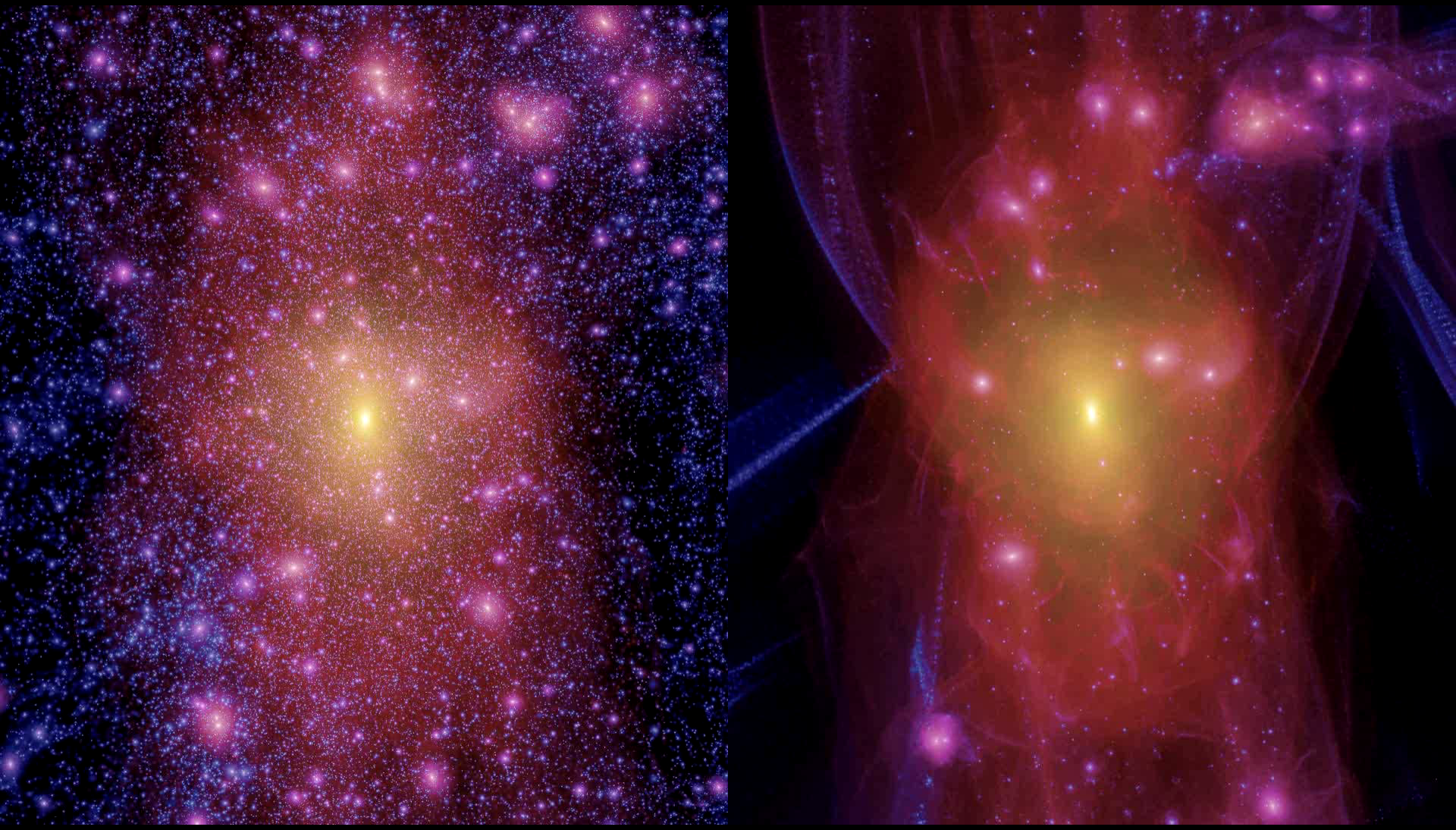
$$\frac{\rho(r)}{\rho_{crit}} = \frac{\delta_c}{(r/r_s)(1+r/r_s)^2}$$

(Navarro, Frenk & White ’97)

More massive halos and halos that form earlier have higher densities (bigger δ)

cold dark matter

warm dark matter



Lovell, Eke, Frenk, Gao, Jenkins, Wang, White, Theuns, Boyarski & Ruchayskiy ‘12

VIRGO

EAGLE full hydro simulations

Local Group

Sawala et al ‘14

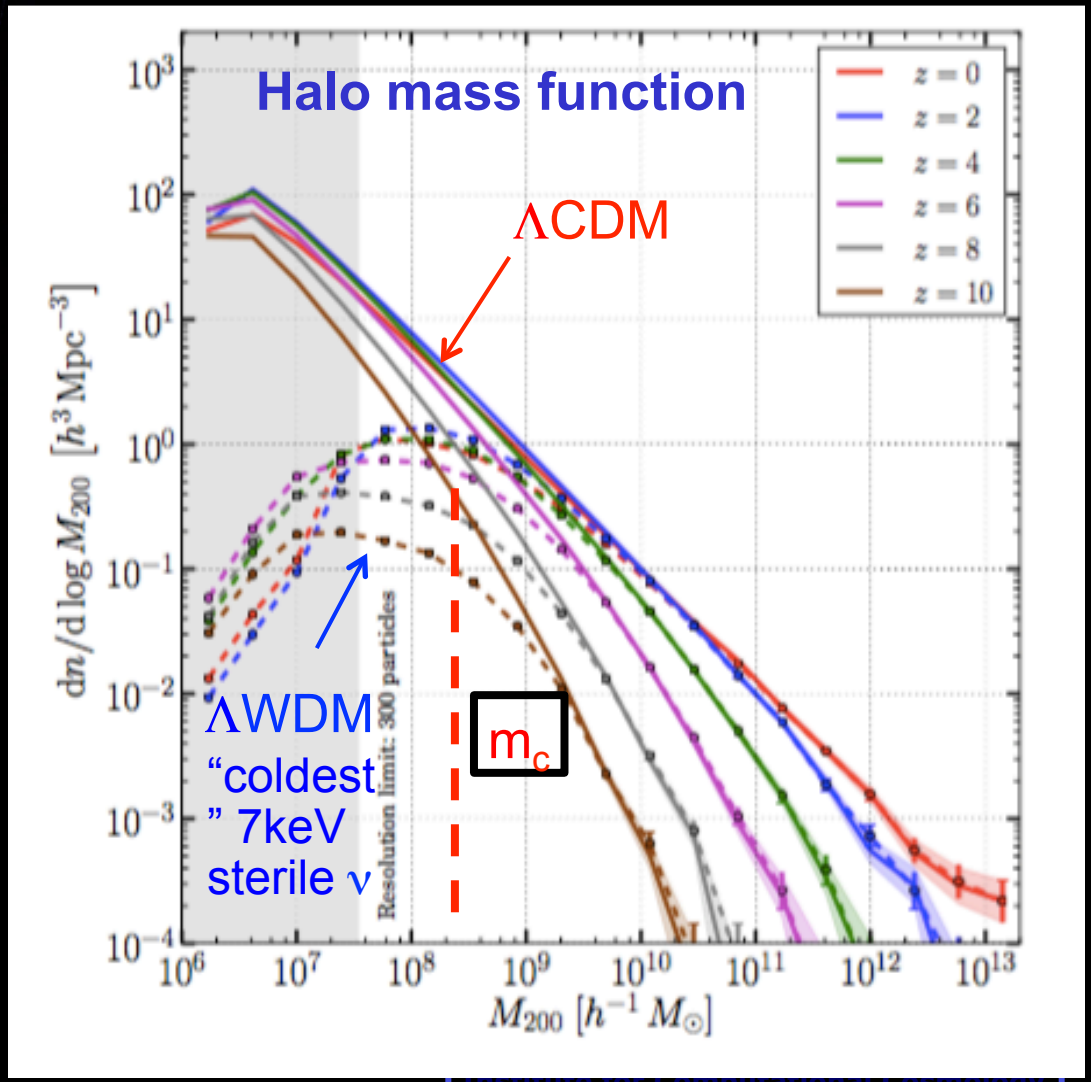
The subhalo mass function

CDM WDM

3 x fewer WDM subhalos at $3 \times 10^9\ M_o$

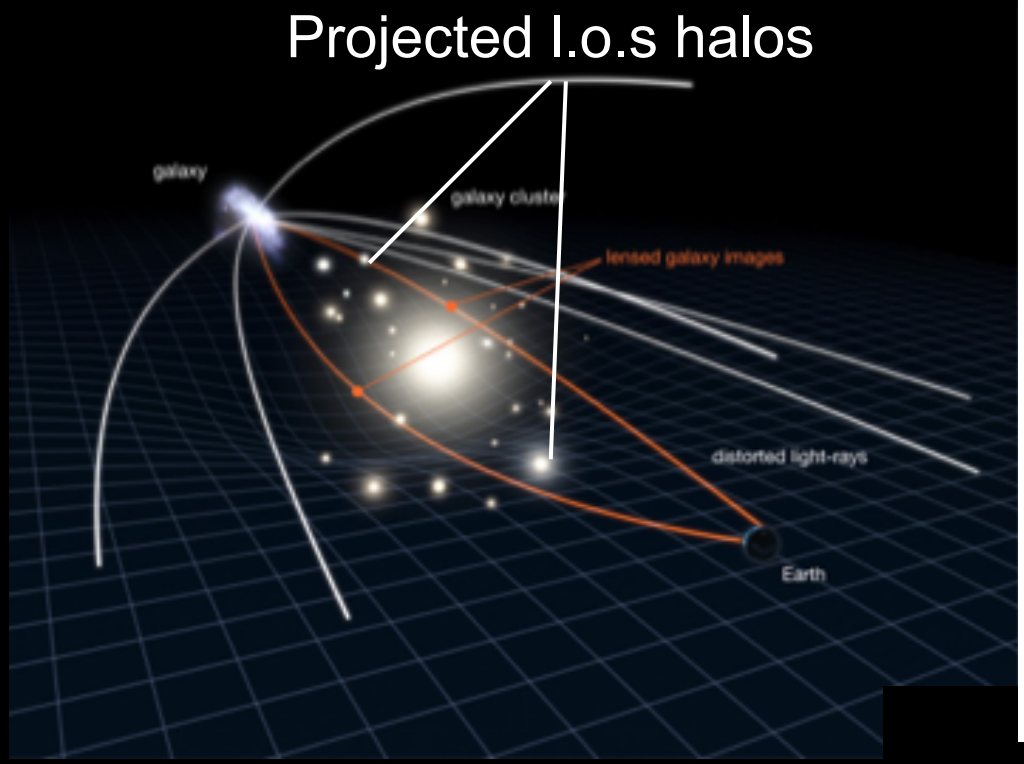
10 x fewer at $10^8\ M_o$

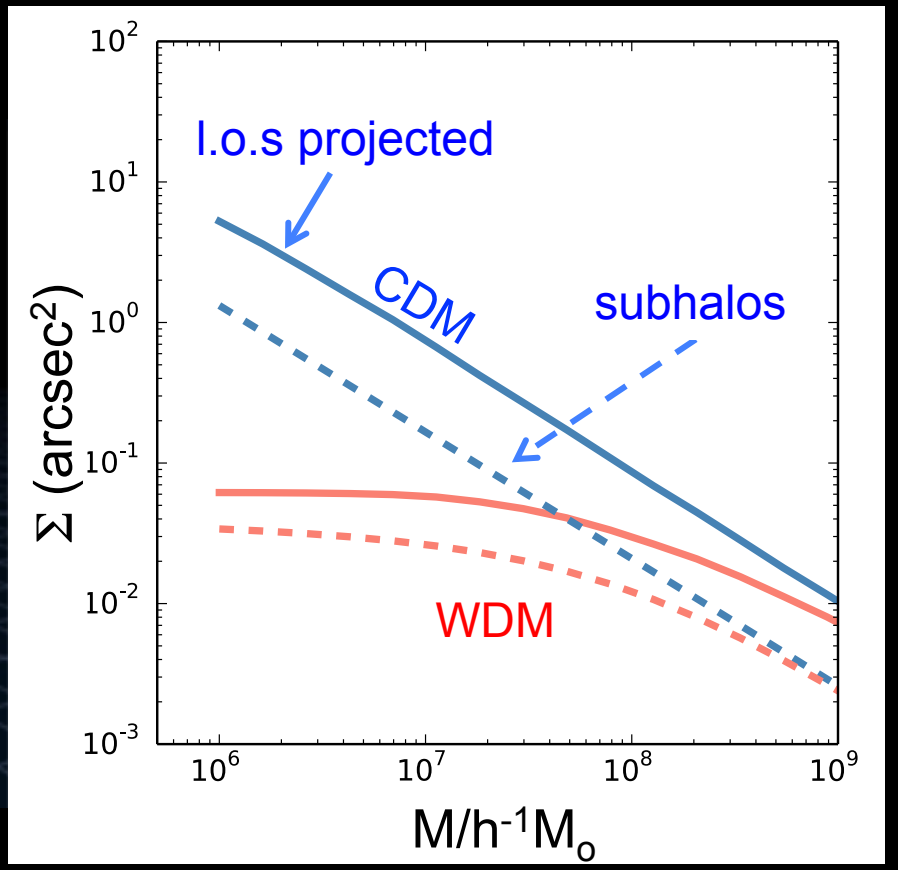
Bose, CSF et al '16



Substructures vs interlopers

Subhalos & halos projected along the l.o.s both lens: who wins?





The number of line-of-sight haloes is larger than that of subhaloes

Li, CSF et al. ’16; see also Despali et al. ‘18

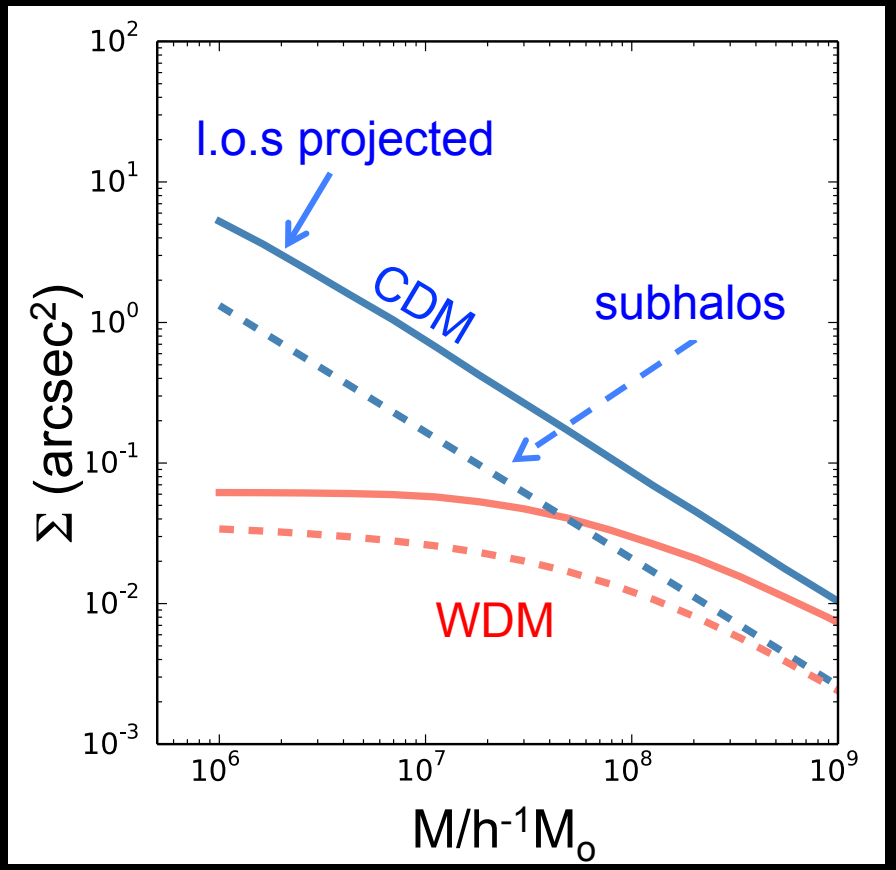
Substructures vs interlopers

Subhalos & halos projected along the l.o.s both lens: who wins?

Subhalos in the lens and field halos of $M>5x10^8M_o$ are affected by baryon effects (e.g. enhance tidal disruption)

→ include baryon effects

Realistic baryon simulations also needed to model lens



The number of line-of-sight haloes is larger than that of subhaloes

Li, CSF et al. ’16; see also Despali et al. ‘18

VIRGO

icc.dur.ac.uk/Eagle

"Evolution and assembly of galaxies and their environment"

THE EAGLE PROJECT

Virgo Consortium

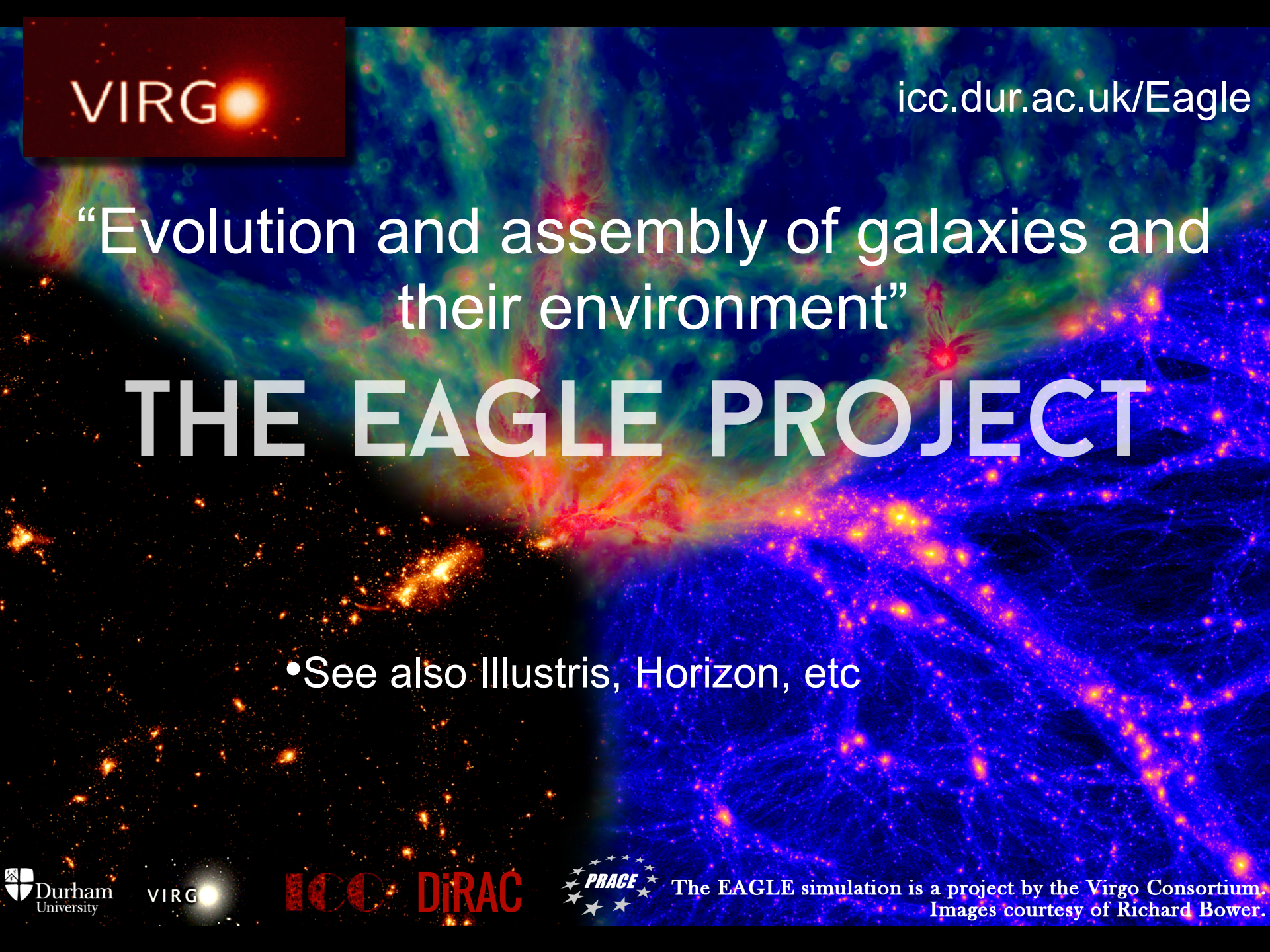
Durham: Richard Bower, Michelle Furlong, Carlos Frenk, Matthieu Schaller, James Trayford, Yelti Rosas-Guevara, Tom Theuns, Yan Qu, John Helly, Adrian Jenkins.

Leiden: Rob Crain, Joop Schaye.

Other: Claudio Dalla Vecchia, Ian McCarthy, Craig Booth...

Durham University VIRGO ICC DiRAC PRACE

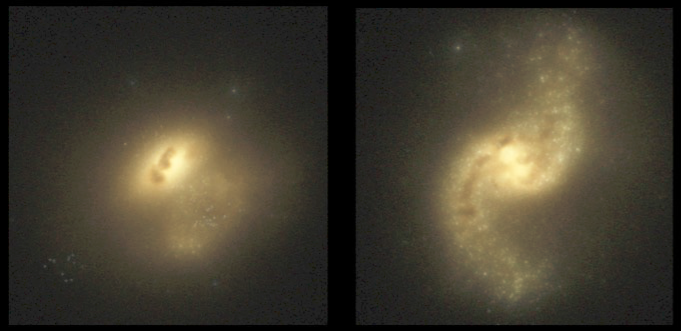
The EAGLE simulation is a project by the Virgo Consortium.
Images courtesy of Richard Bower.

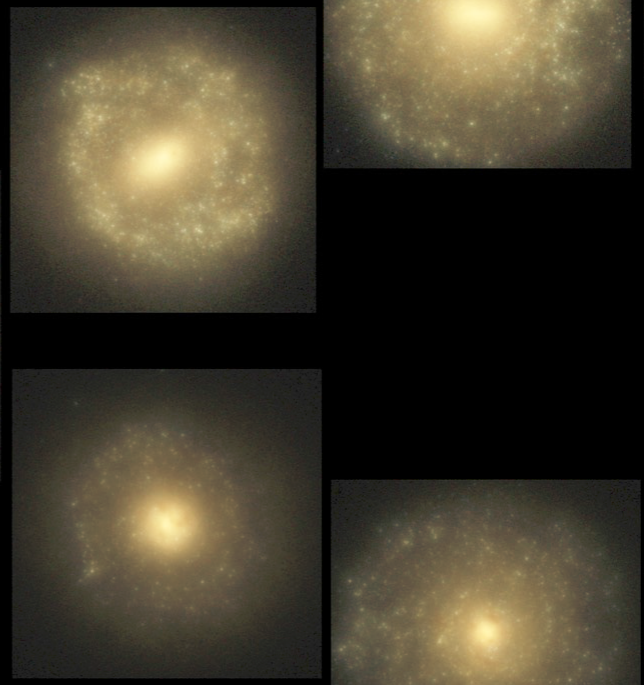

VIRGO
icc.dur.ac.uk/Eagle
"Evolution and assembly of galaxies and their environment"
THE EAGLE PROJECT
•See also Illustris, Horizon, etc
Durham University
VIRGO
ICC
DiRAC
PRACE
The EAGLE simulation is a project by the Virgo Consortium.
Images courtesy of Richard Bower.

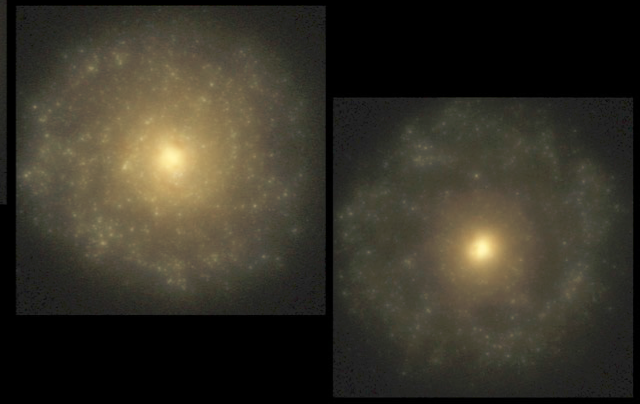
The Eagle Simulations

EVOLUTION AND ASSEMBLY OF GALAXIES AND THEIR ENVIRONMENTS

The Hubble Sequence realised in cosmological simulations





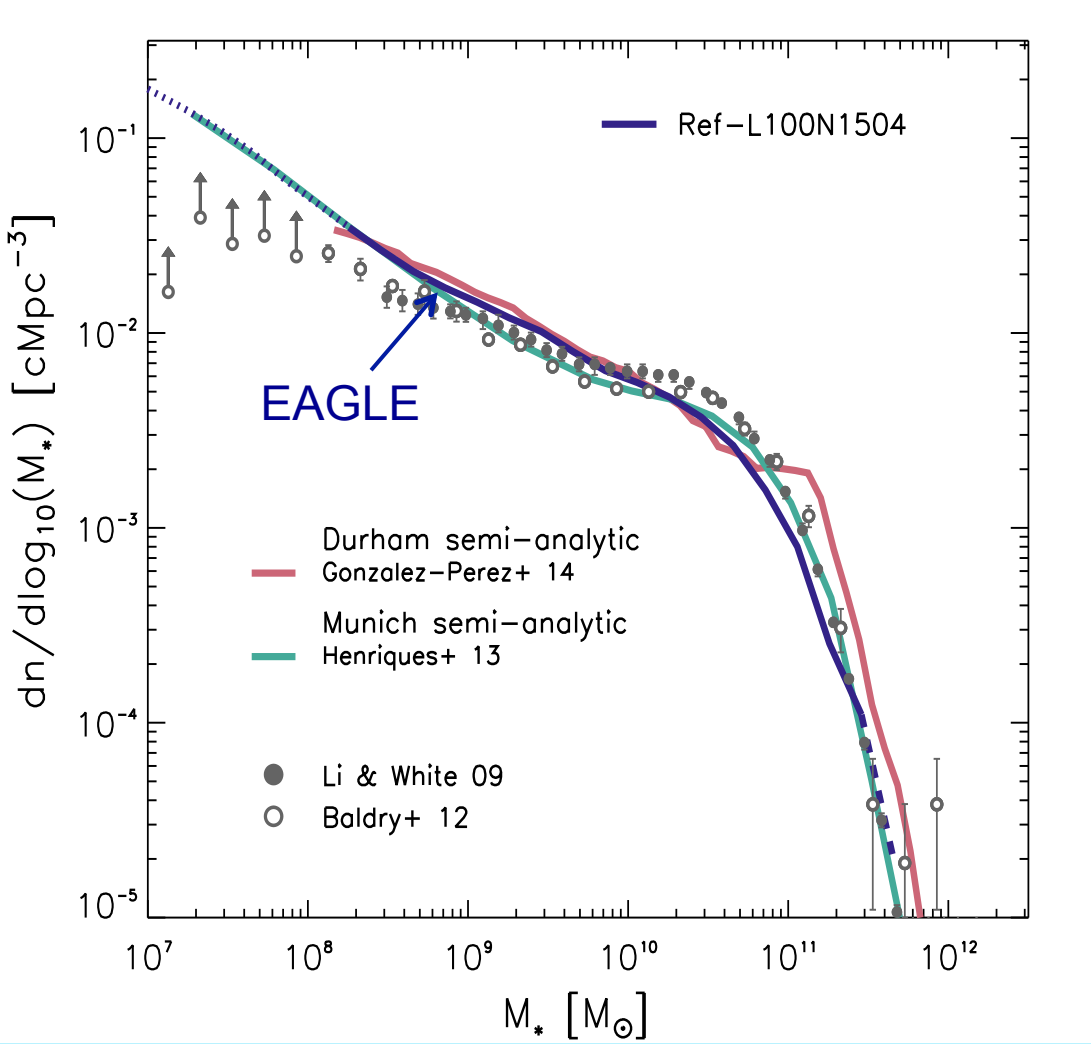


Trayford et al ‘15

University of Durham

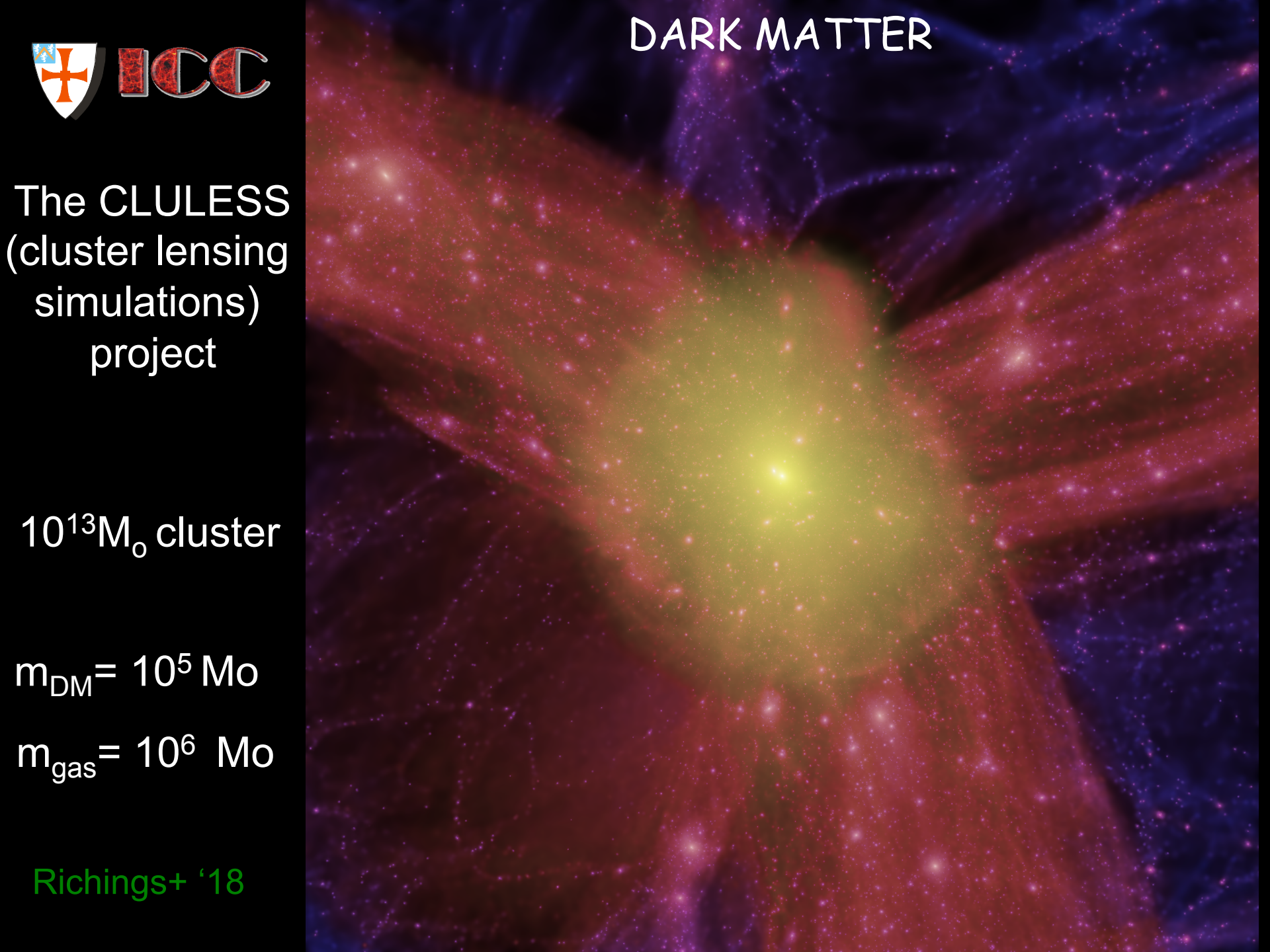
Galaxy stellar mass function

Eagle has large volume (L=100 Mpc) and reproduces many observables as a function of redshift, but resolution ($m_{parlticle}=10^7\ M_o$) is insufficient for lensing



Schaye et al '15

Institute for Computational Cosmology



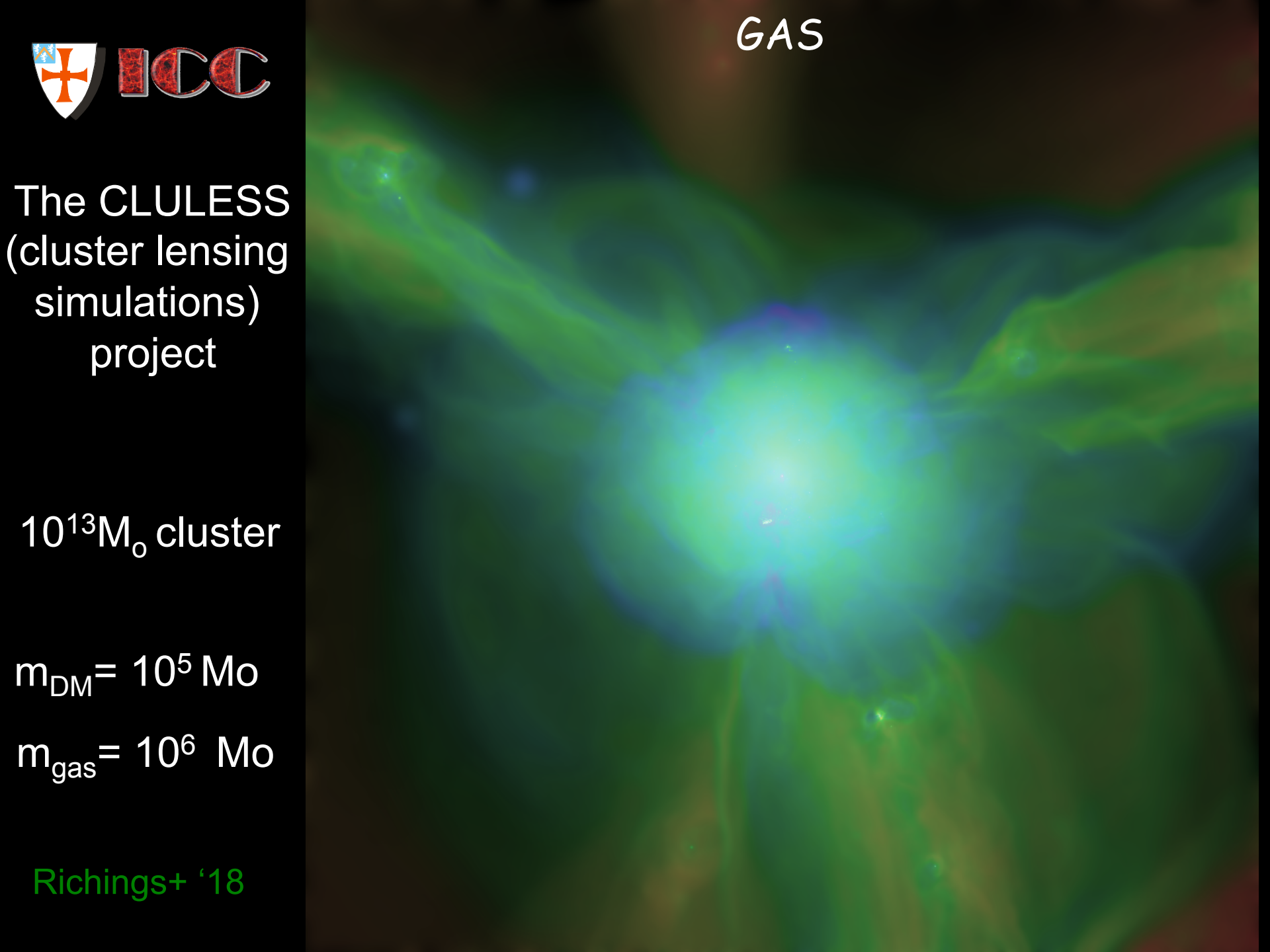
The CLULESS (cluster lensing simulations) project

$10^{13} M_o$ cluster

$m_{DM} = 10^5$ Mo

$m_{gas} = 10^6$ Mo

Richings+ ‘18


ICC
The CLULESS (cluster lensing simulations) project
$10^{13} M_o$ cluster
$m_{DM} = 10^5$ Mo
$m_{gas} = 10^6$ Mo
Richings+ '18
GAS

Conclusions

- The abundance, clustering and structure of dark matter halos in ΛCDM and ΛWDM is well understood from N-body simulations
- A range of N-body simulations suitable for lensing mocks exist
- Image distortions dominated by field halos (rather than subhalos)
- Baryon simulations still needed to (i) model the lens; (ii) include halos of of $M>5x10^8M_o$ (which are luminous); (iii) calculate baryon effects in dark subhalos (e.g. tidal disruption)
- Mocks from the CLULESS project ideal to assess baryon effects