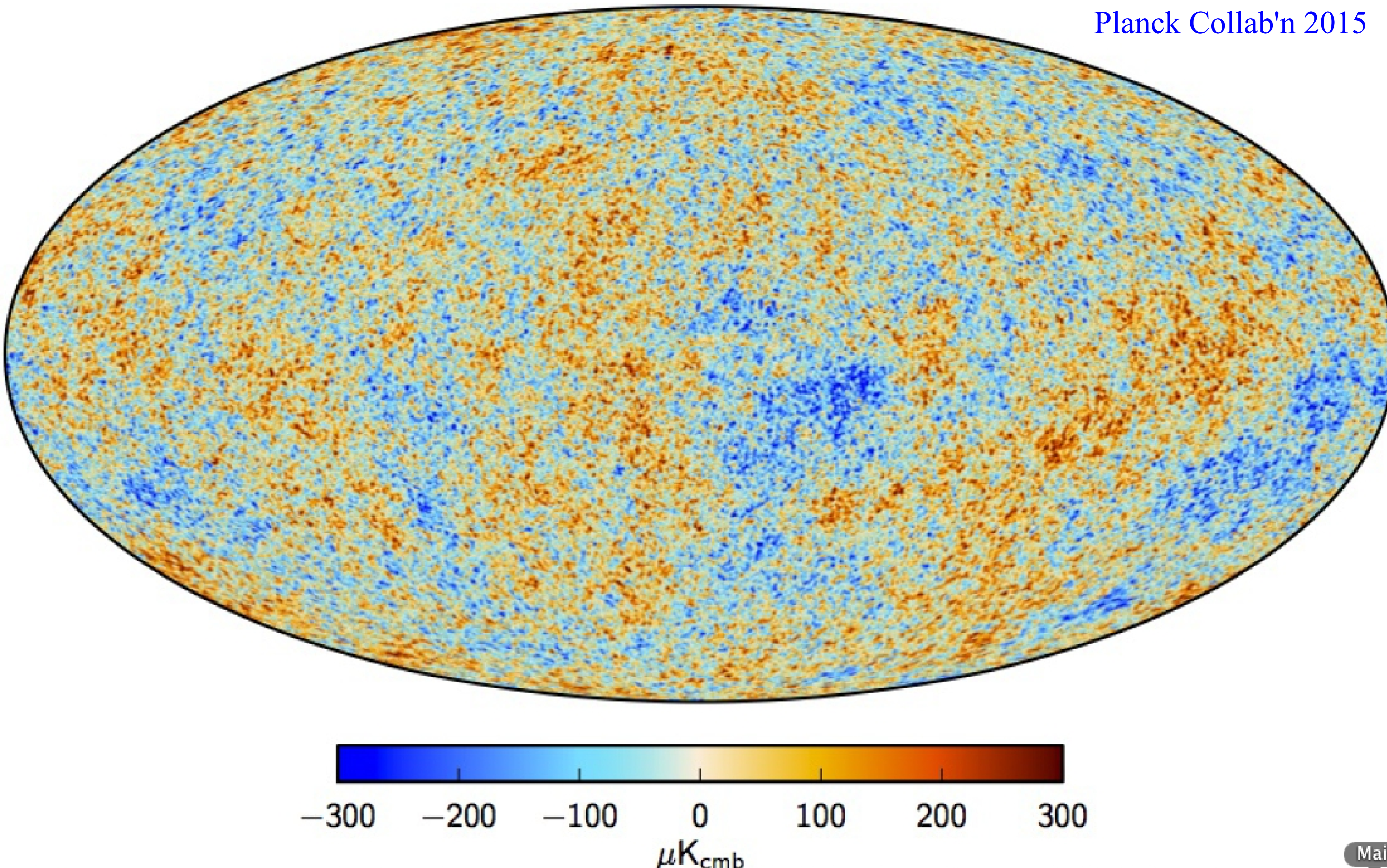
Introduction

Simon White
Max Planck Institute for Astrophysics

CMB map from the full *Planck* mission

Planck Collab'n 2015



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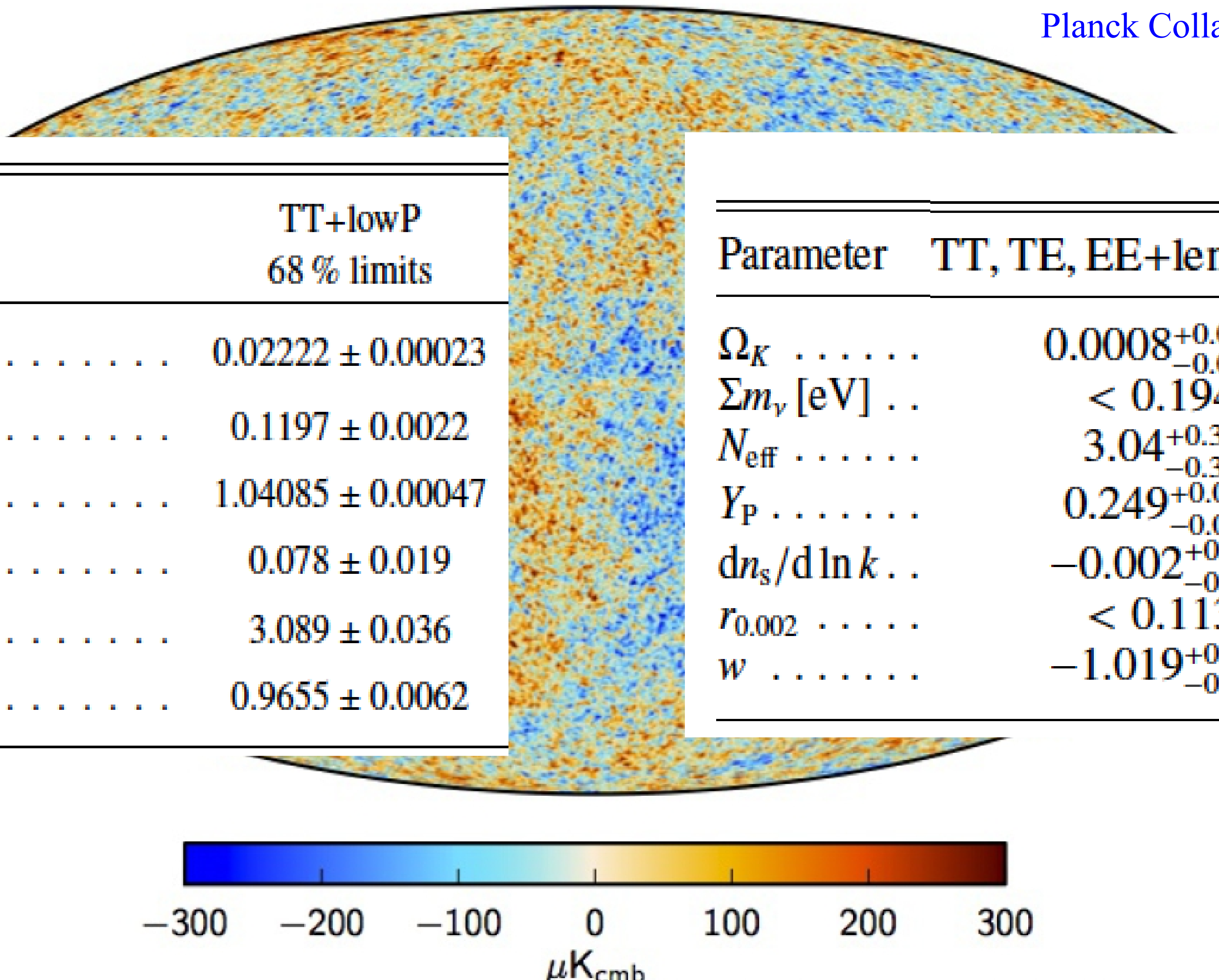
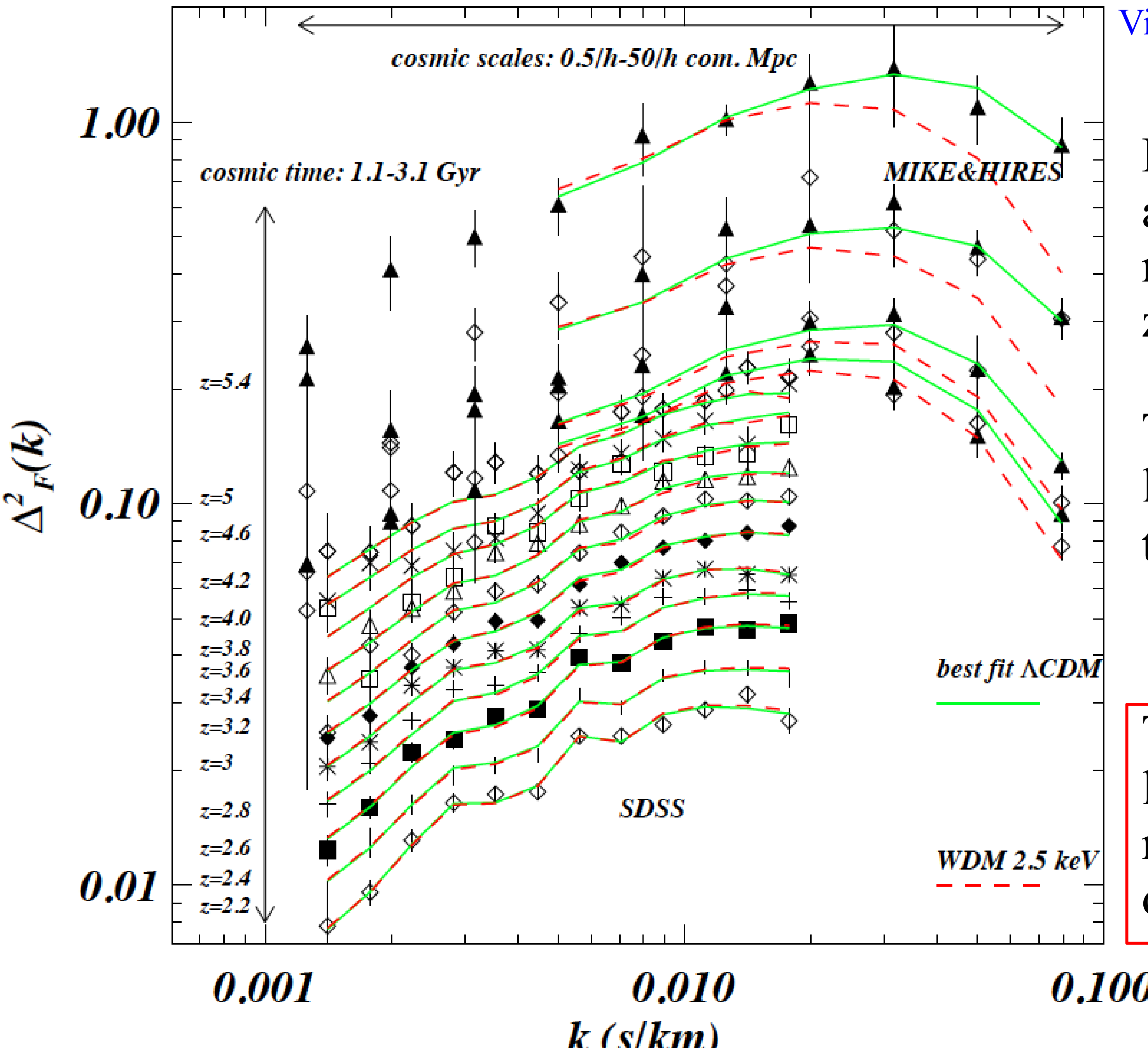


Parameter	TT+lowP 68 % limits
$\Omega_b h^2$	0.02222 ± 0.00023
$\Omega_c h^2$	0.1197 ± 0.0022
$100\theta_{MC}$	1.04085 ± 0.00047
τ	0.078 ± 0.019
$\ln(10^{10} A_s)$	3.089 ± 0.036
n_s	0.9655 ± 0.0062

Parameter	TT, TE, EE+lensing+ext
Ω_K	$0.0008^{+0.0040}_{-0.0039}$
Σm_ν [eV] . .	< 0.194
N_{eff}	$3.04^{+0.33}_{-0.33}$
Y_P	$0.249^{+0.025}_{-0.026}$
$dn_s/d\ln k$ . .	$-0.002^{+0.013}_{-0.013}$
$r_{0.002}$	< 0.113
w	$-1.019^{+0.075}_{-0.080}$

Lyman α forest spectra for WDM relative to CDM



Viel, Becker, Bolton & Haehnelt 2013

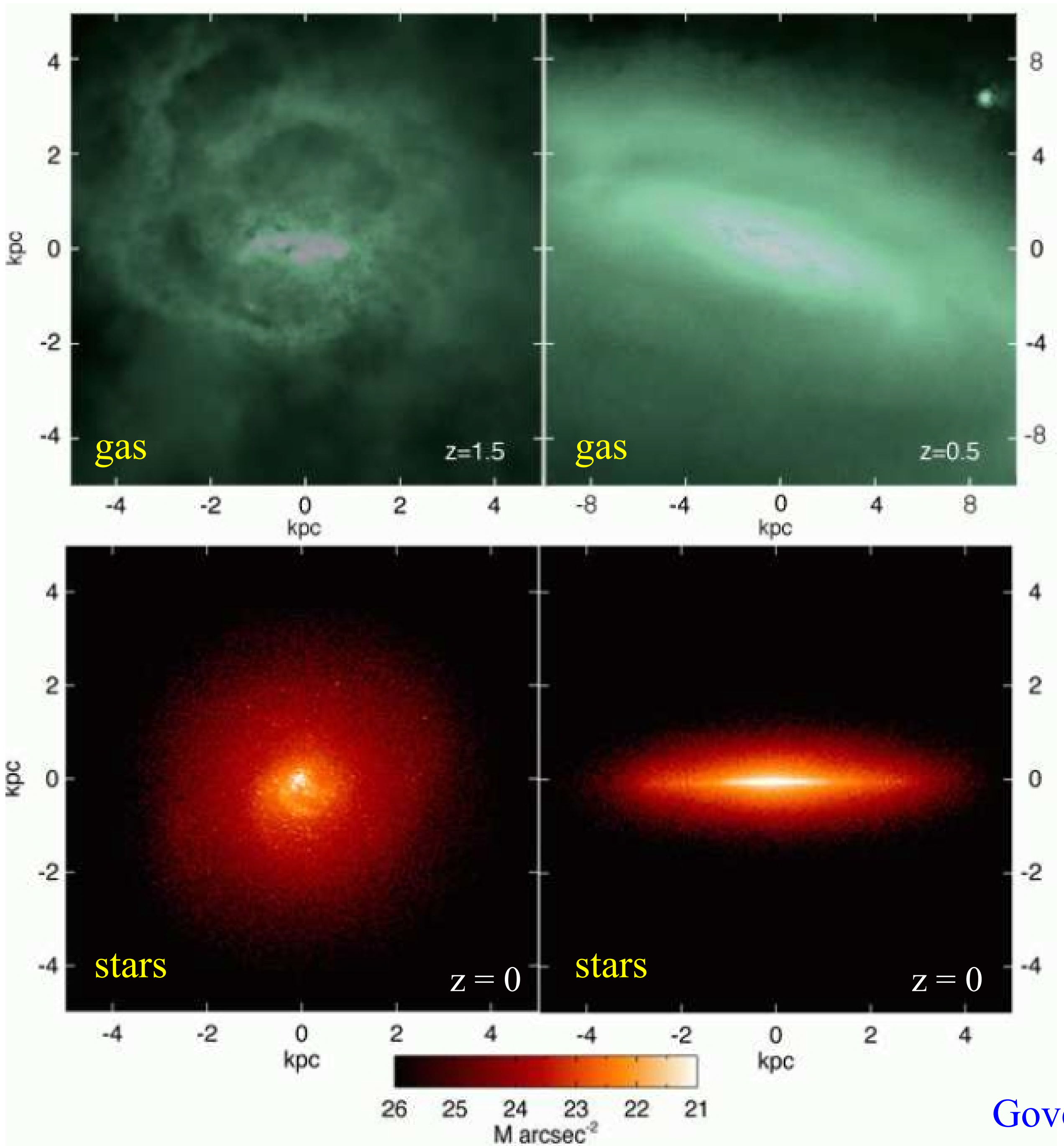
High-resolution Keck and Magellan spectra match ΛCDM up to z = 5.4

This places a 2σ lower limit on the mass of a thermal relic

$m_{WDM} > 3.3$ keV

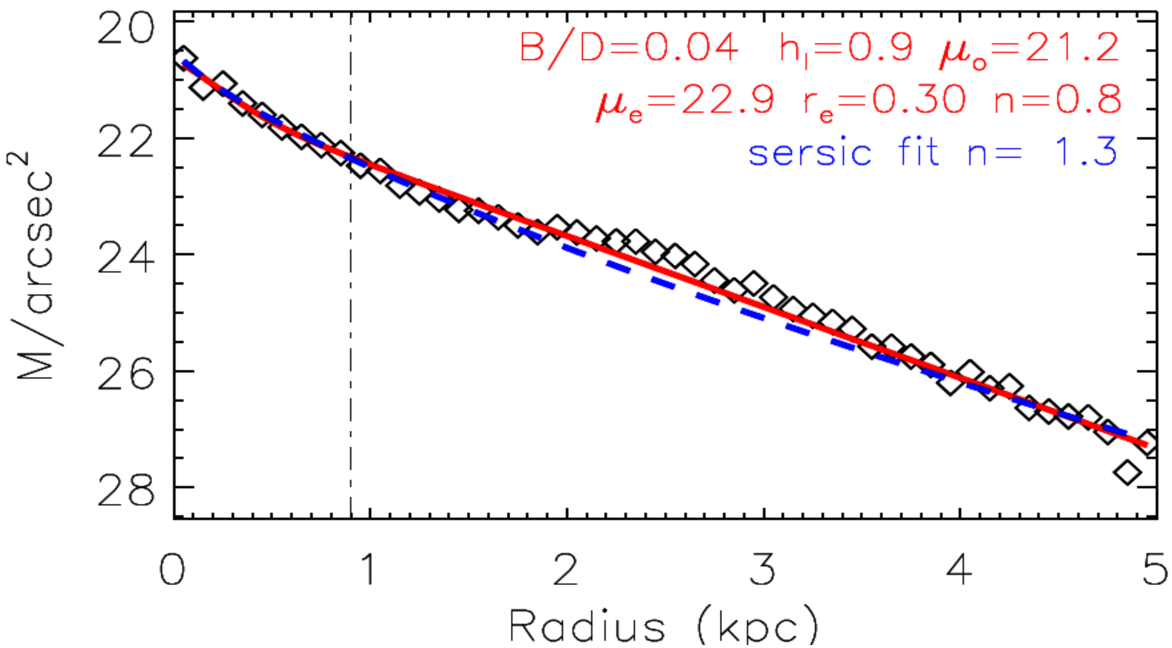
This lower limit is too large for WDM to have much effect except on dwarf galaxy cores

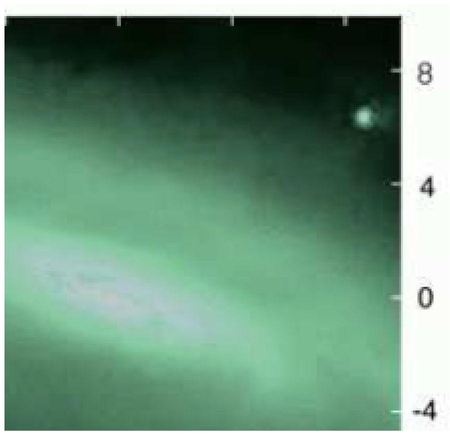
DG1 – a bulgeless dwarf



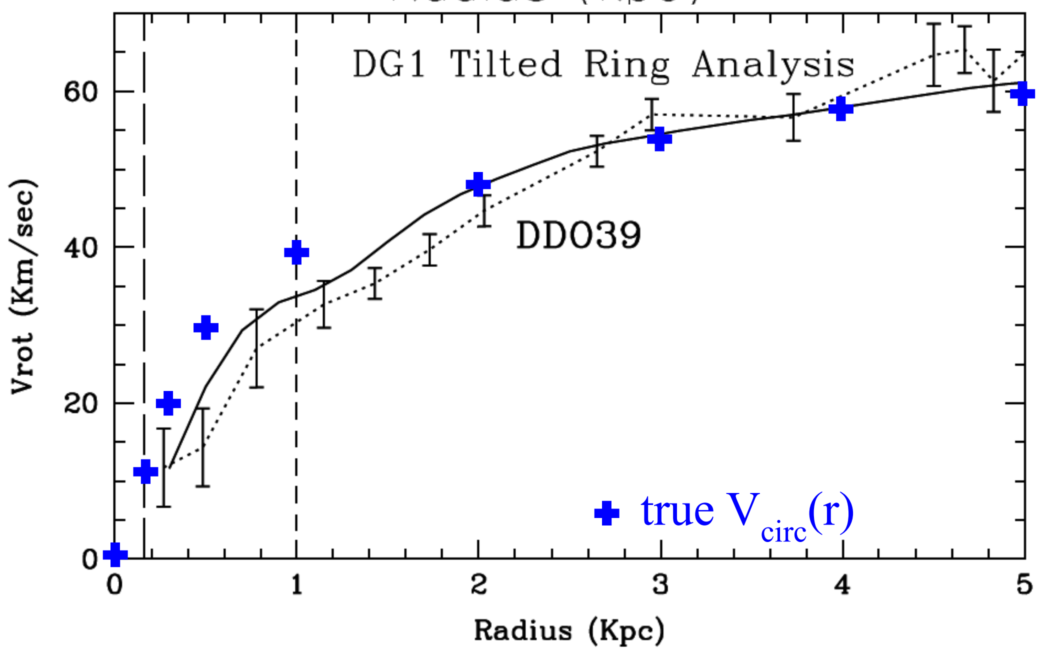
Governato et al 2010

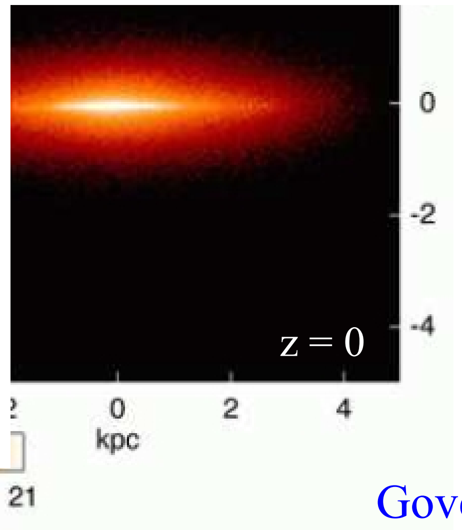
DG1 – a bulgeless dwarf





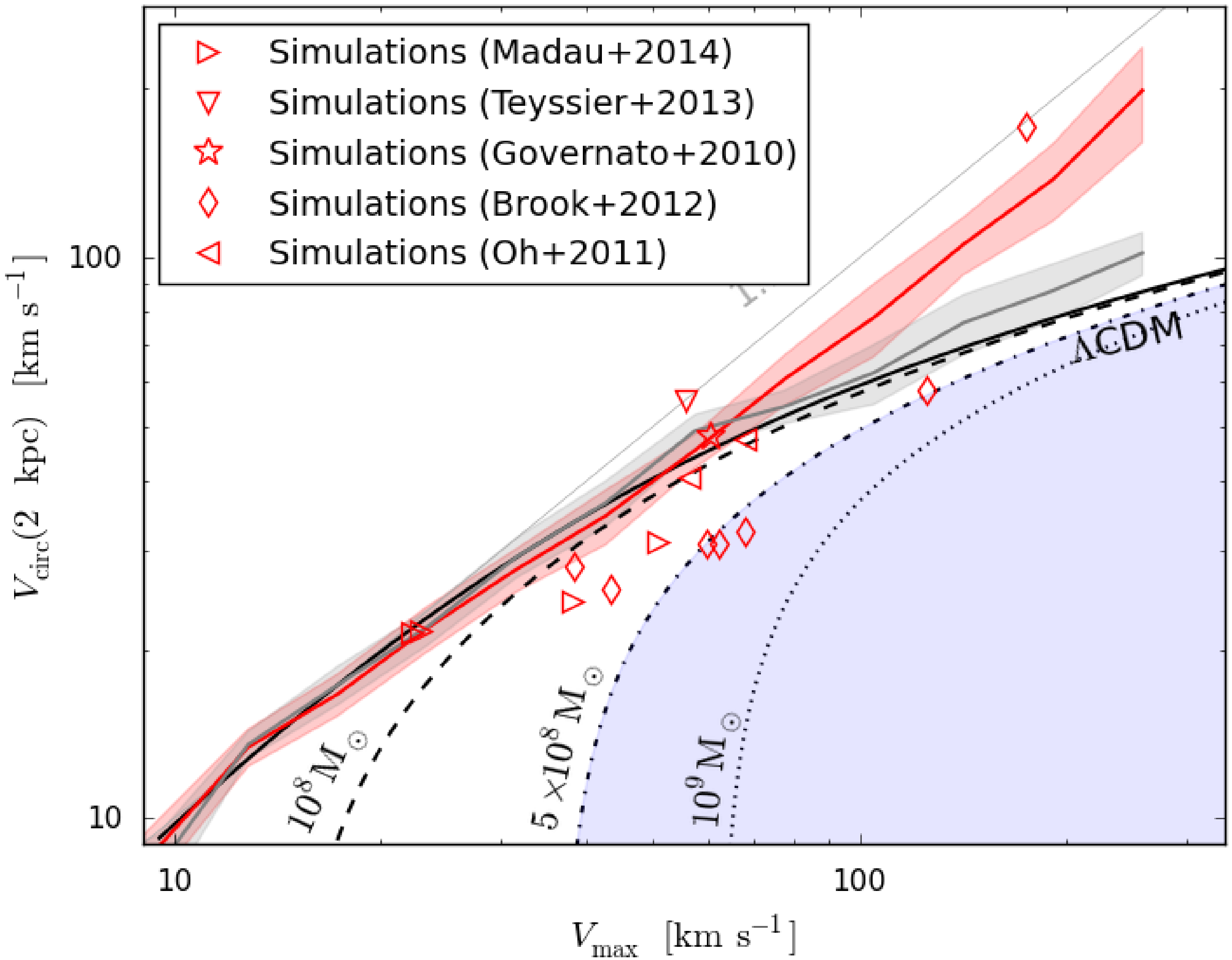
- Success due to bursty, high threshold star formation?
- "Cored" rotation curve is due to "observational" analysis





Governato et al 2010

V_{circ}(2 kpc) versus V_{max} for ΛCDM galaxies

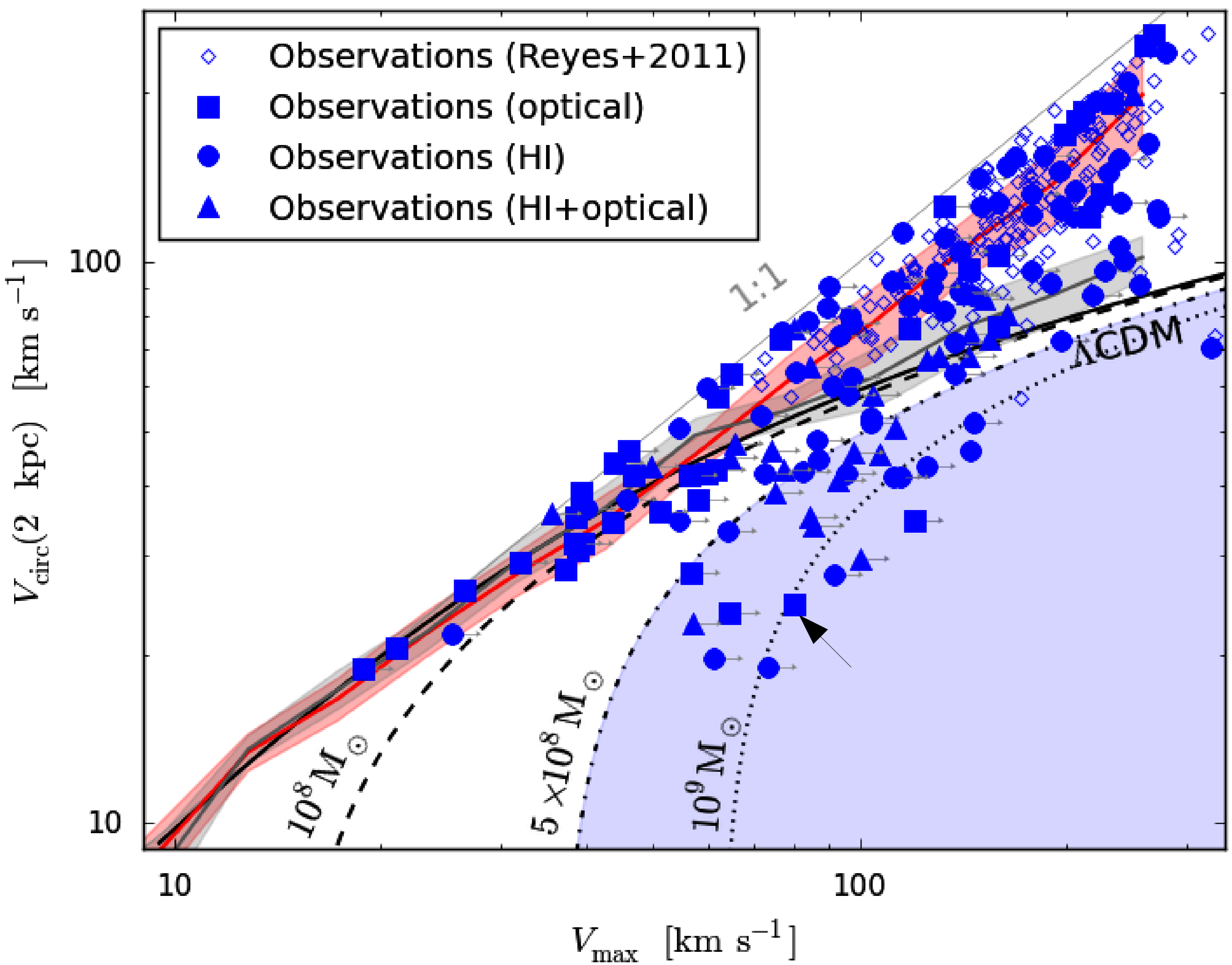


Simulations with high SF thresholds and strong feedback

→ cusps expand into cores

Oman et al 2015

V_{circ}(2 kpc) versus V_{max} for observed dwarfs



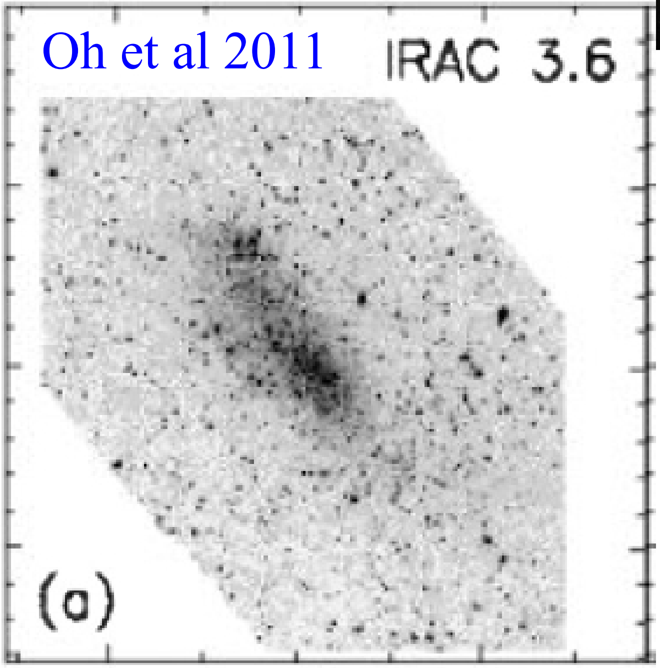
Enormous apparent <u>diversity:</u>

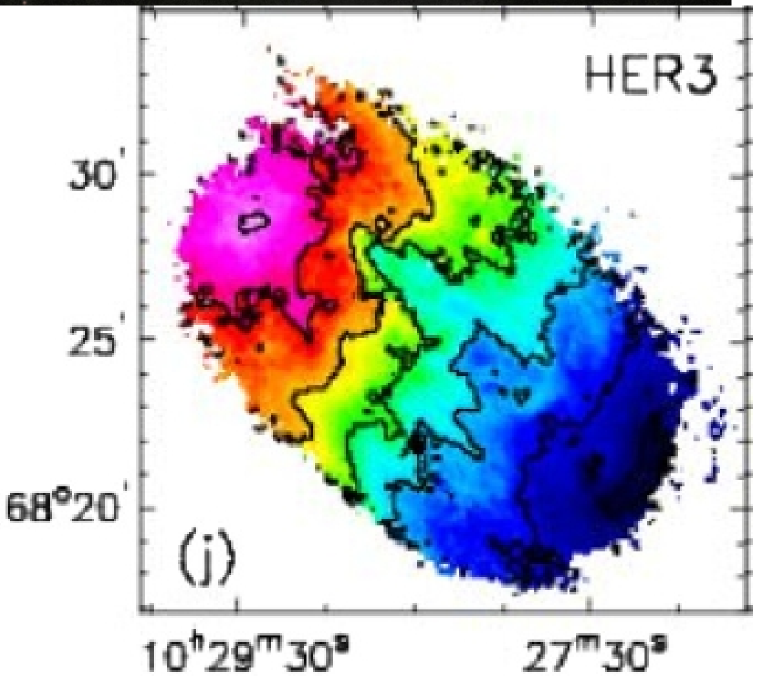
Too large for baryon effects proposed so far?

Too large to reflect DM properties alone?

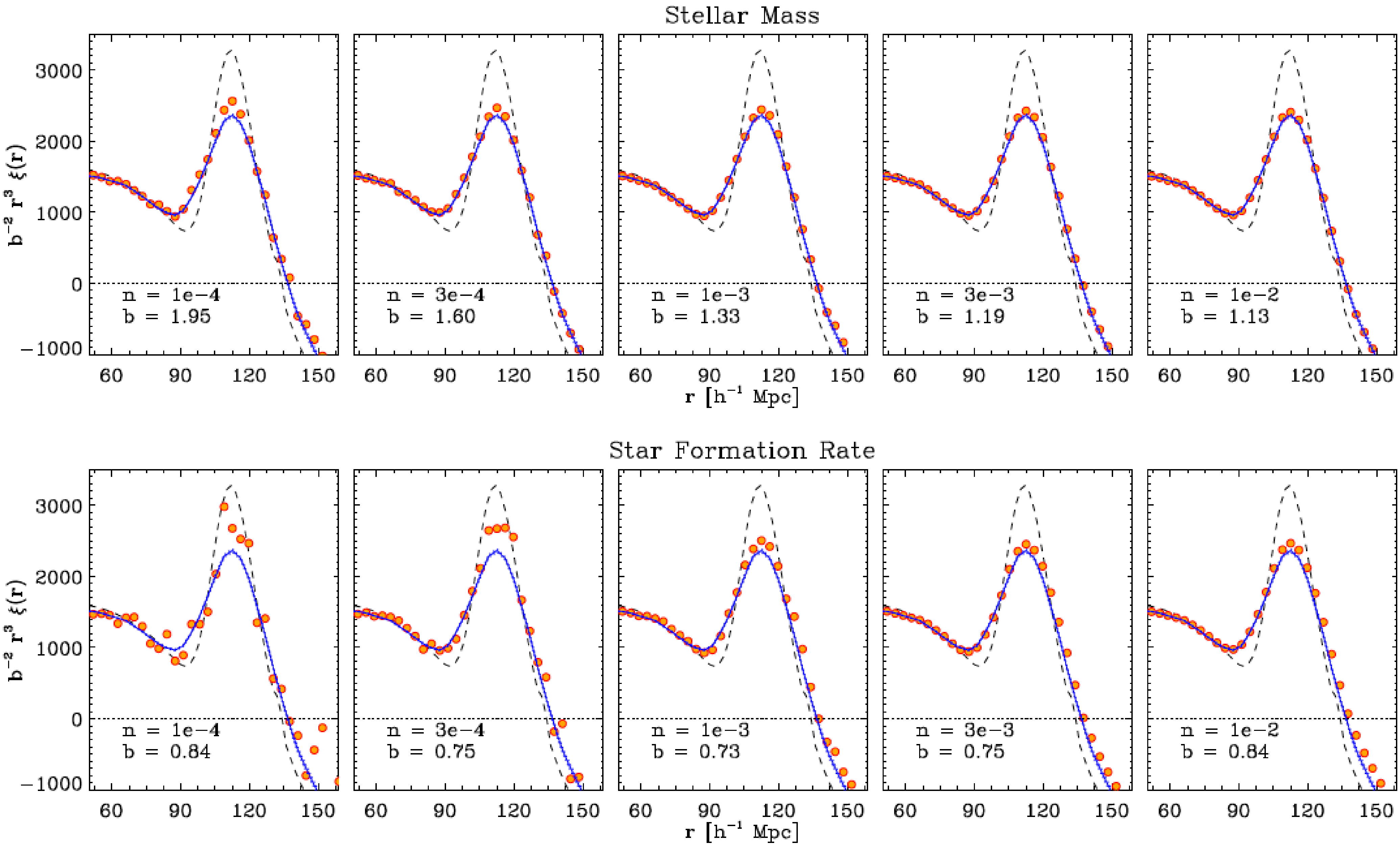
Oman et al 2015


IC 2574


Oh et al 2011
IRAC 3.6
(a)


HER3
30'
25'
68°20'
(j)
10h29m30s
27m30s

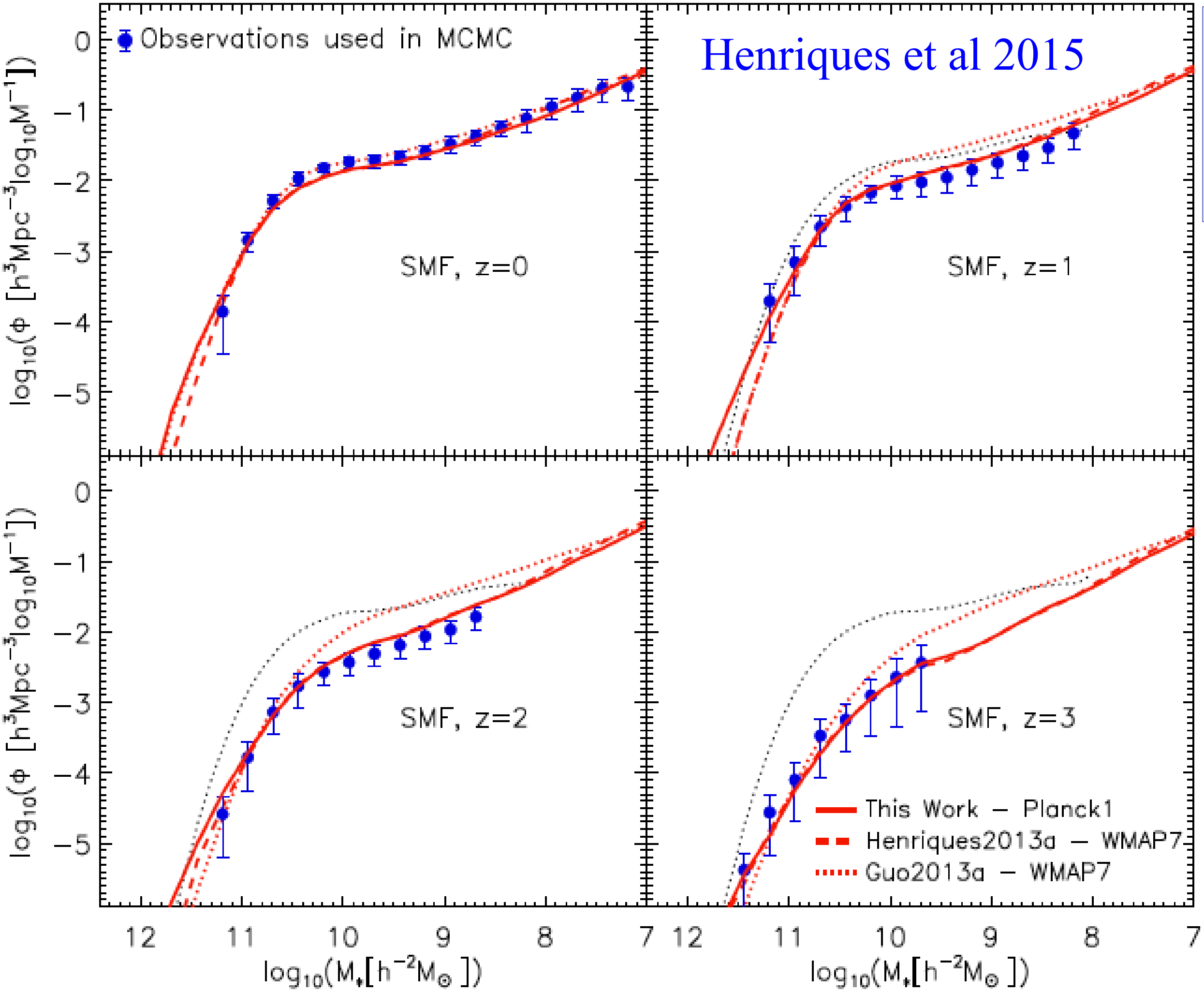
Distortions of BAO feature in the galaxy population



Angulo et al 2013

Small but measurable shifts for different selection methods

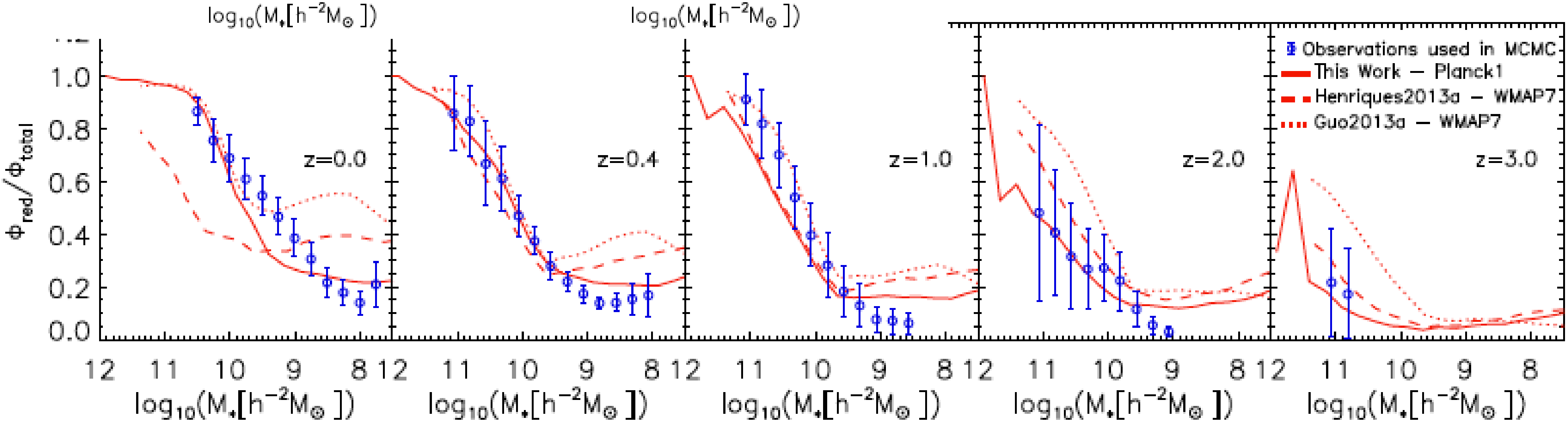
Large volume galaxy population simulations



Simulation volume >300 times Illustris or Eagle

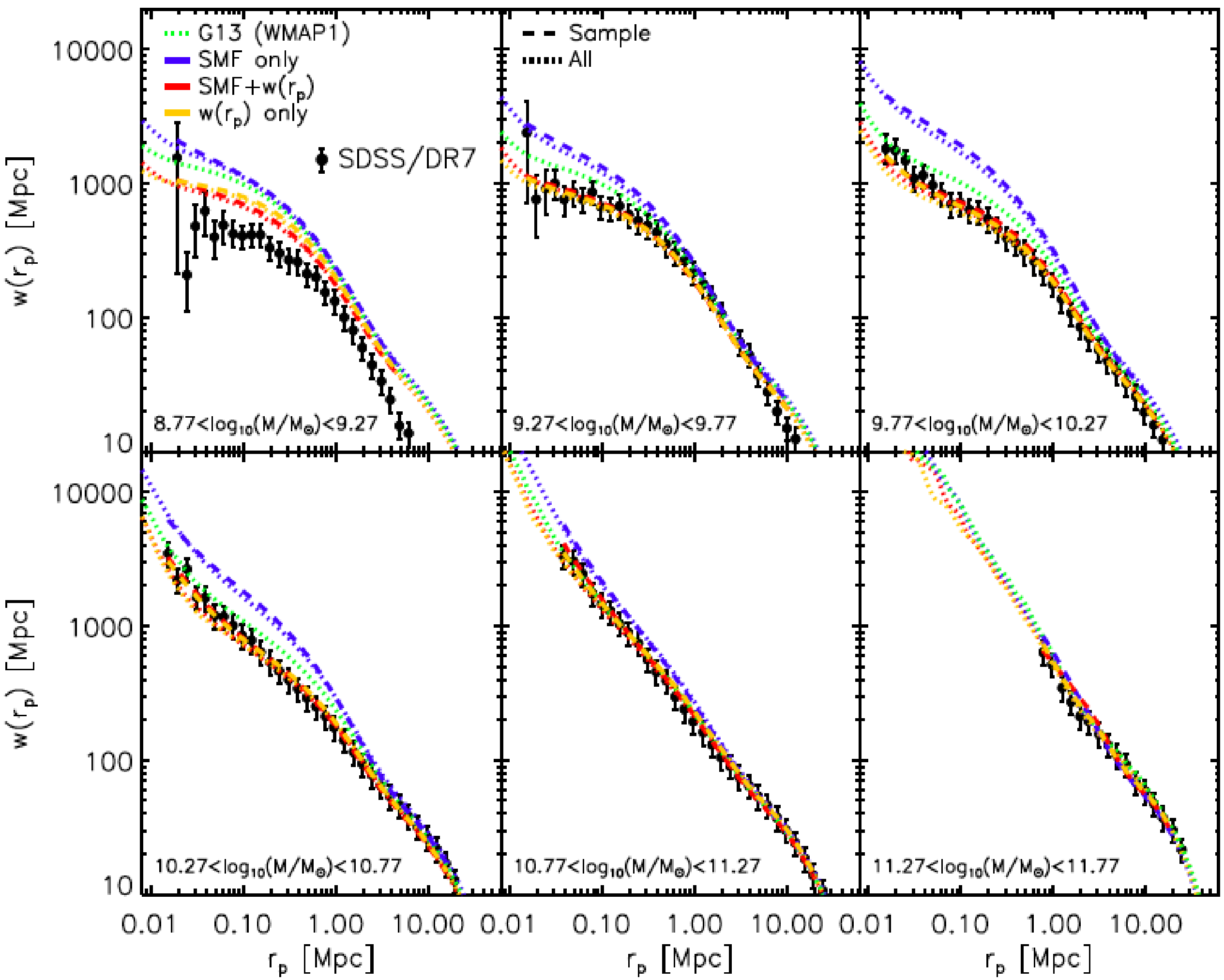
MCMC exploration of full 17-D galaxy formation parameter space by MCMC

→ close fit to calibrating data



Large volume galaxy population simulations

Van Daalen et al 2016

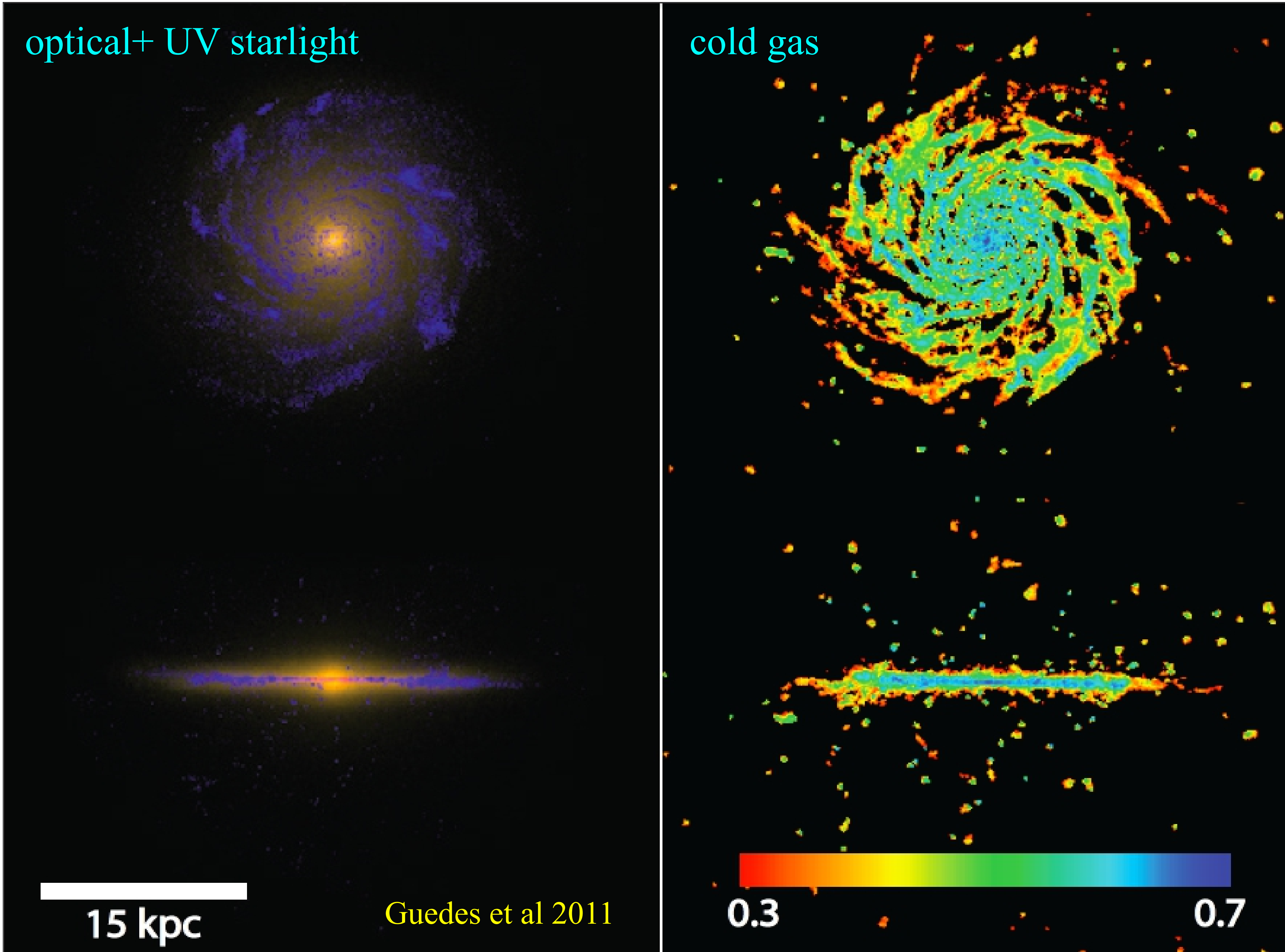


Simulation volume >300 times Illustris or Eagle

MCMC exploration of full 17-D galaxy formation parameter space by MCMC
→ close fit to calibrating data

Can calibrate on clustering as well as on abundances
→ can model data usually fit by HODs over a wide z-range in a physically consistent way

Eris – a particularly successful example ?



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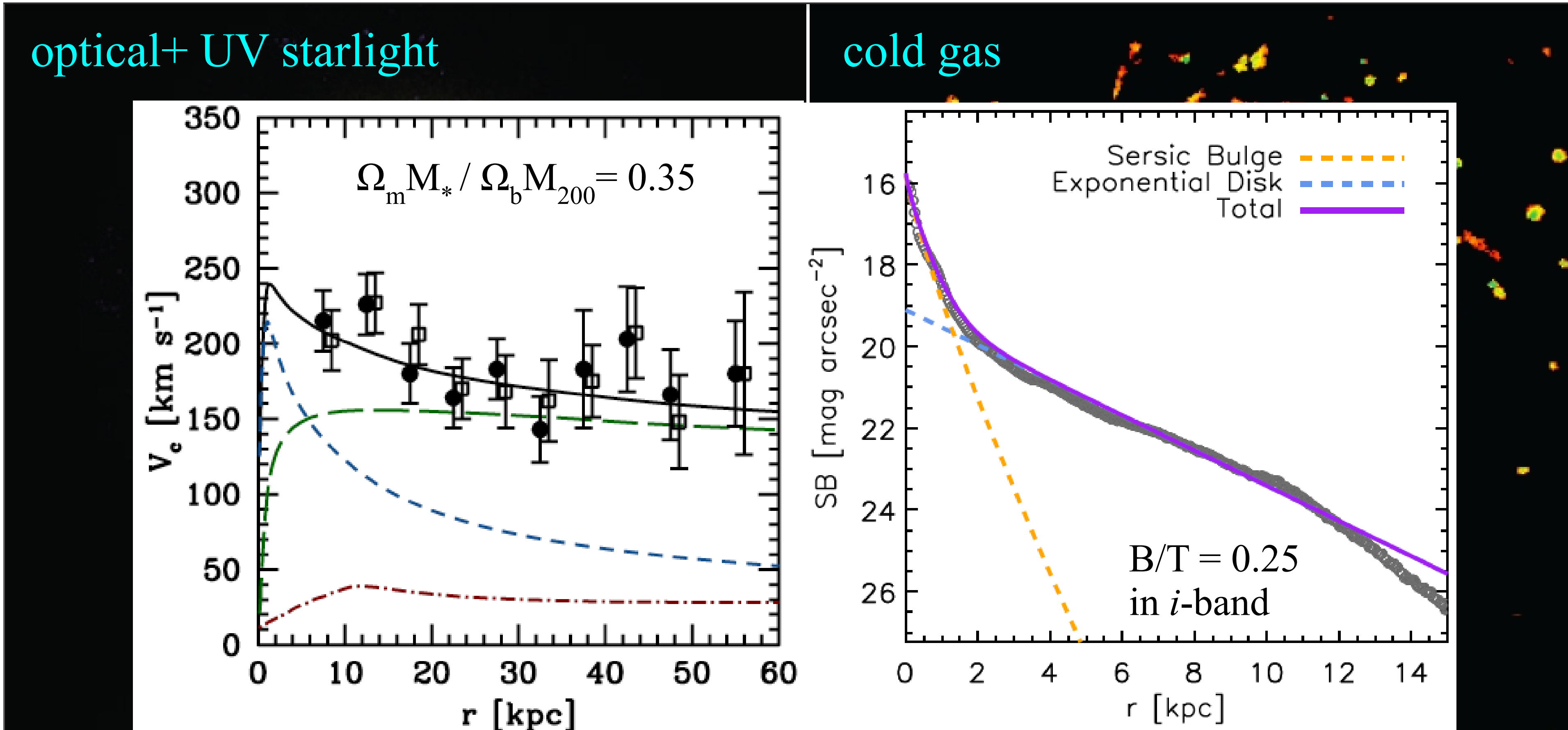
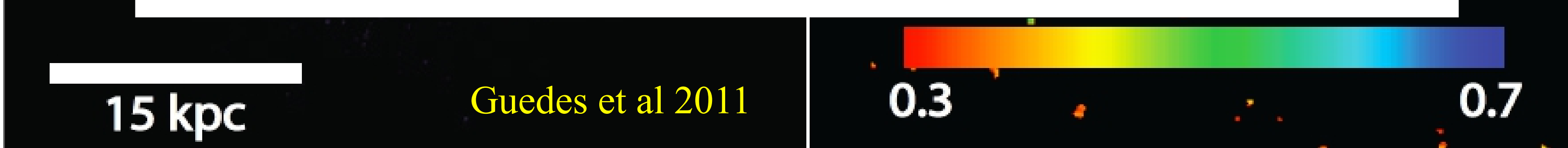
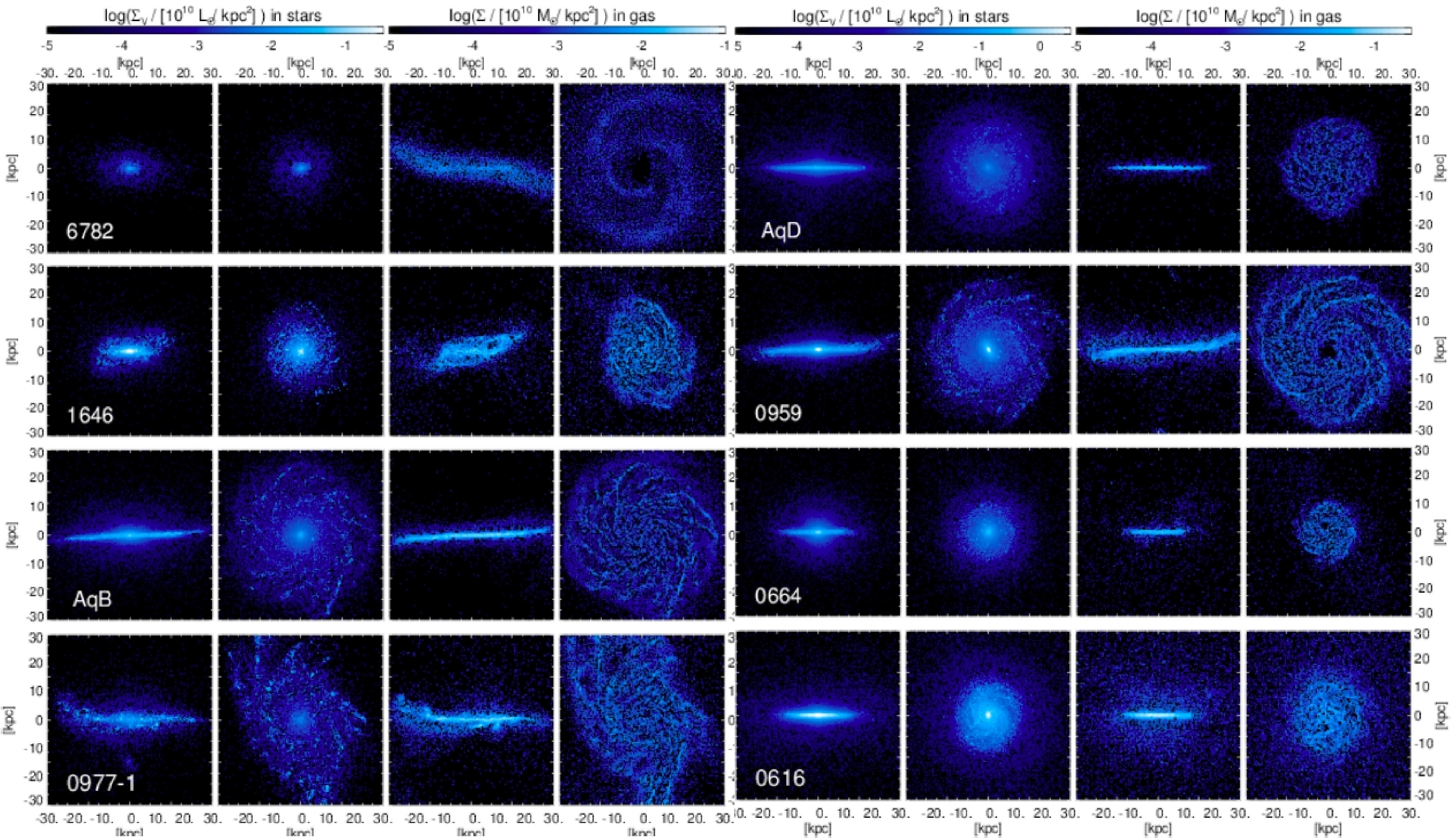


"Success" due to: high spatial and mass resolution
high density threshold for star formation
→ an efficient wind ("good" M*/Mhalo)
...but high-T metal cooling not included?



An abundance of disks, invariant to assumptions?

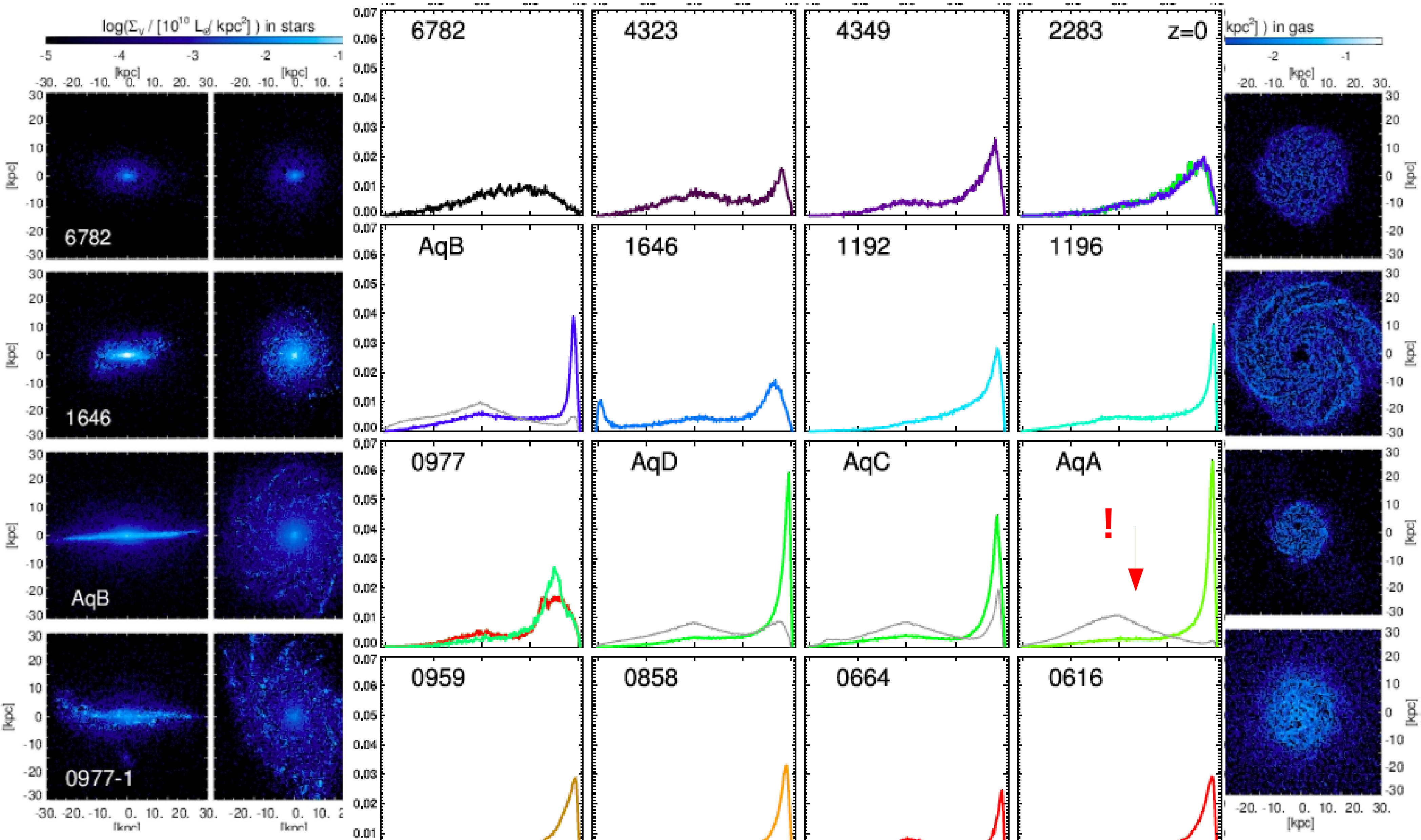


Aumer et al 2013

Low star formation threshold

Explicitly multiphase gas → promotes winds

An abundance of disks, invariant to assumptions?



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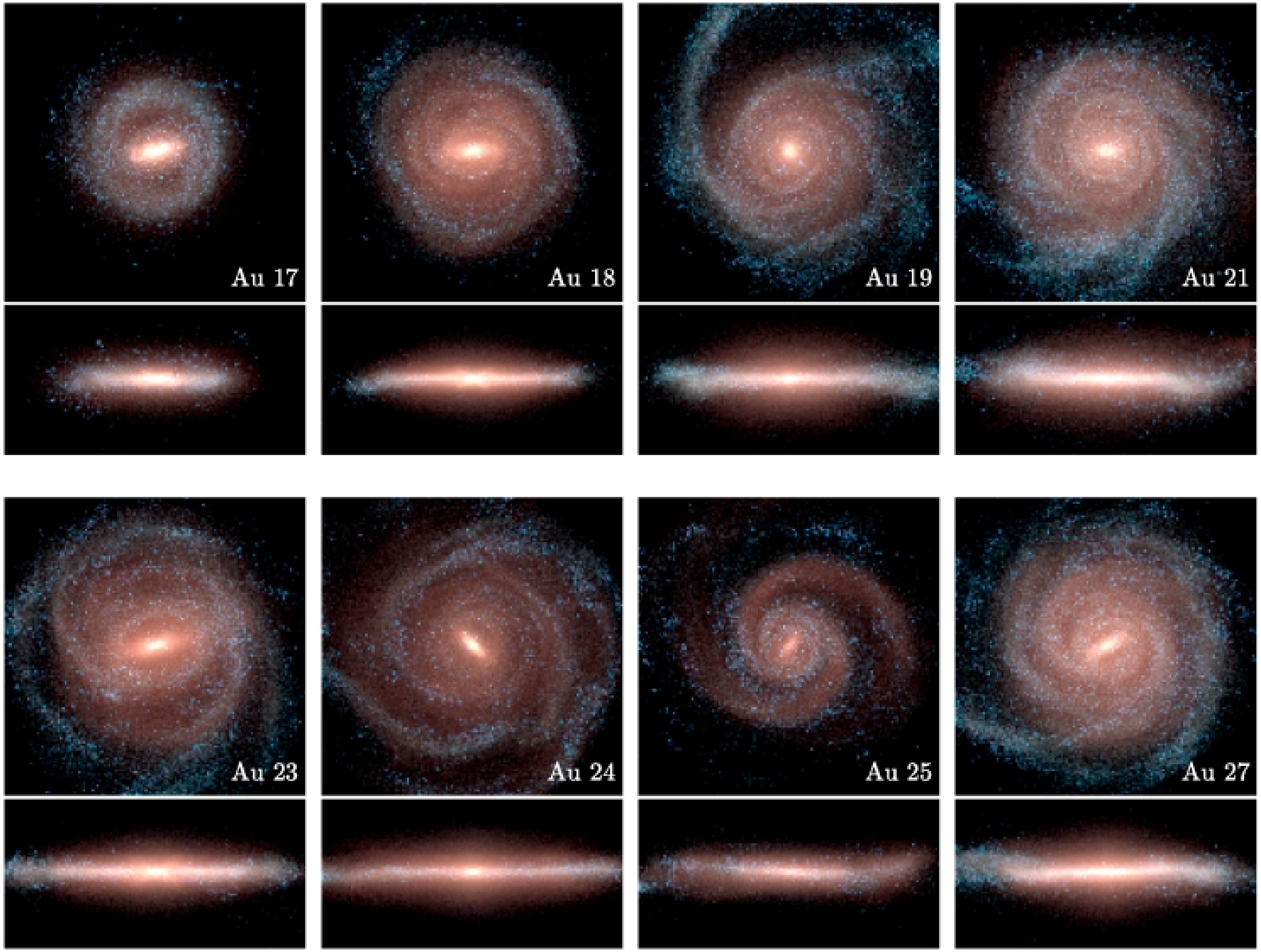

Grand et al 2016

AREPO used for the hydrodynamics
Springel&Herquist ISM model + *ad hoc* wind generation

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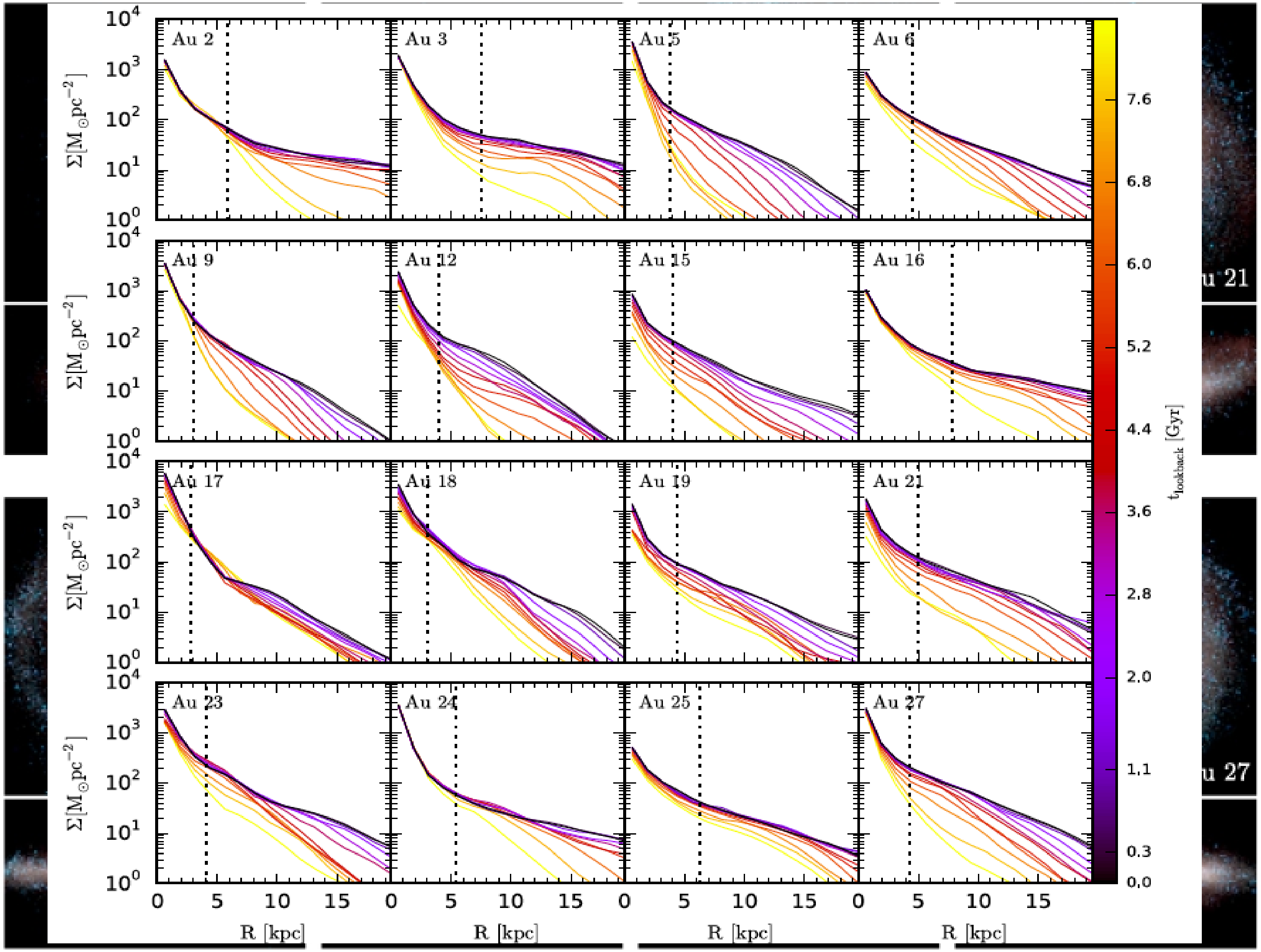

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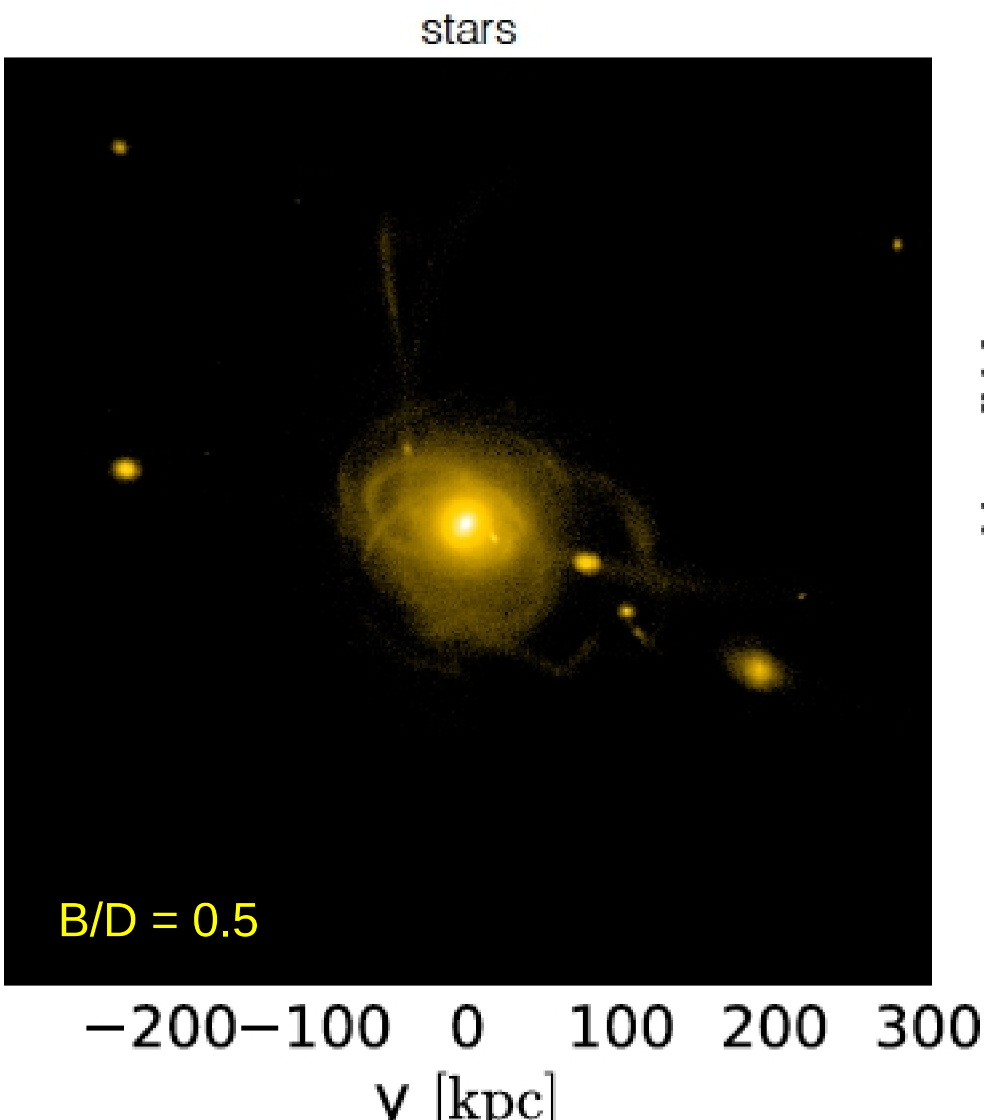
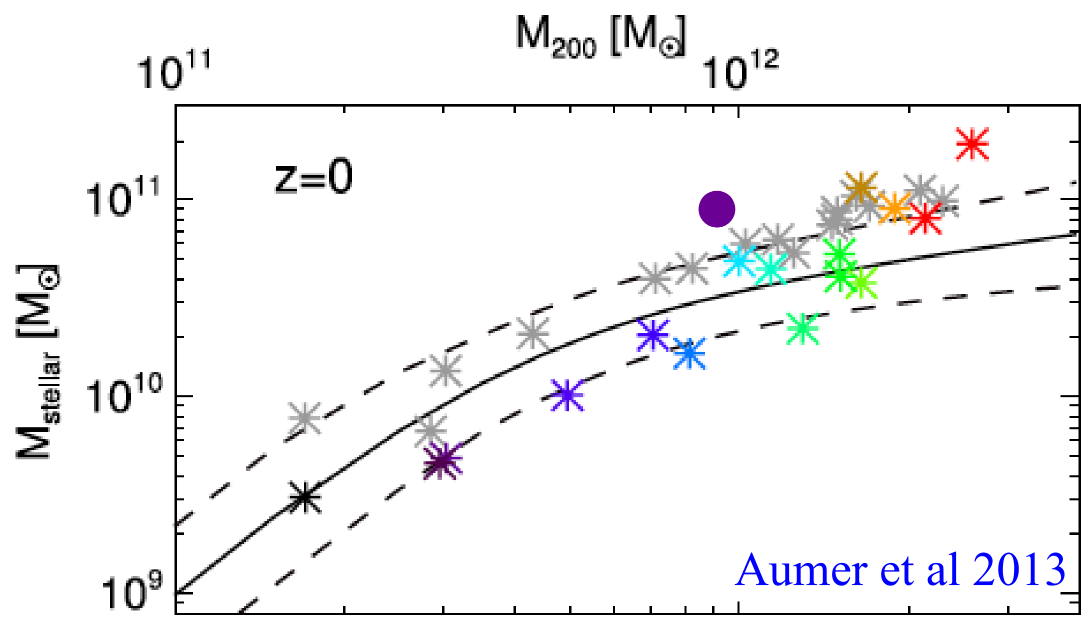


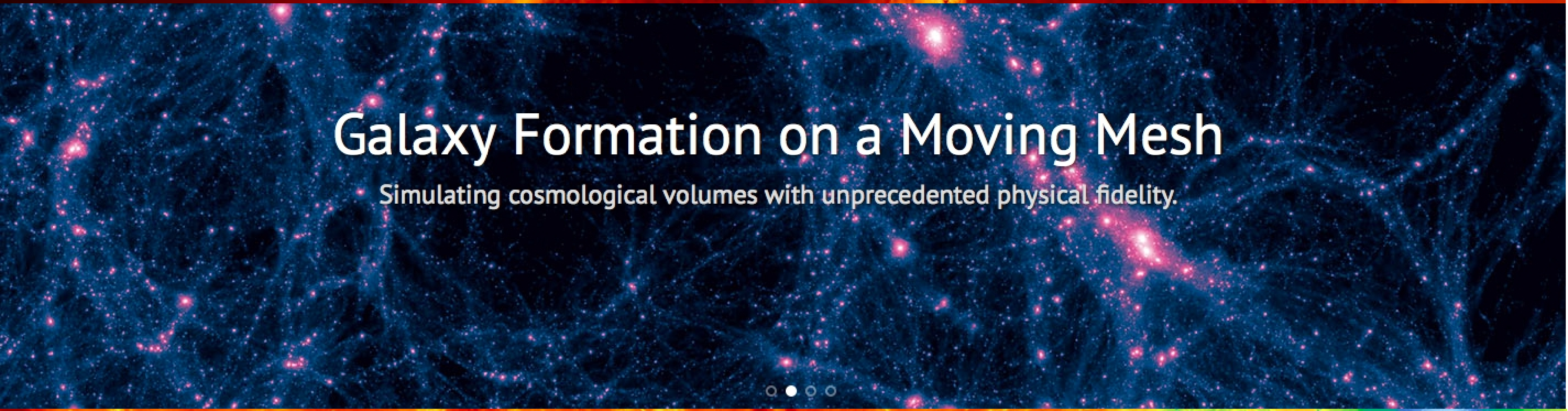


Wetzel et al 2016

GIZMO-MFM hydrodynamics

FIRE model for astrophysics ("*no tuning of parameters*" but a new update of the *ad hoc* wind model)


The Illustris Simulation
Towards a predictive theory of galaxy formation.
www.illustris-project.org

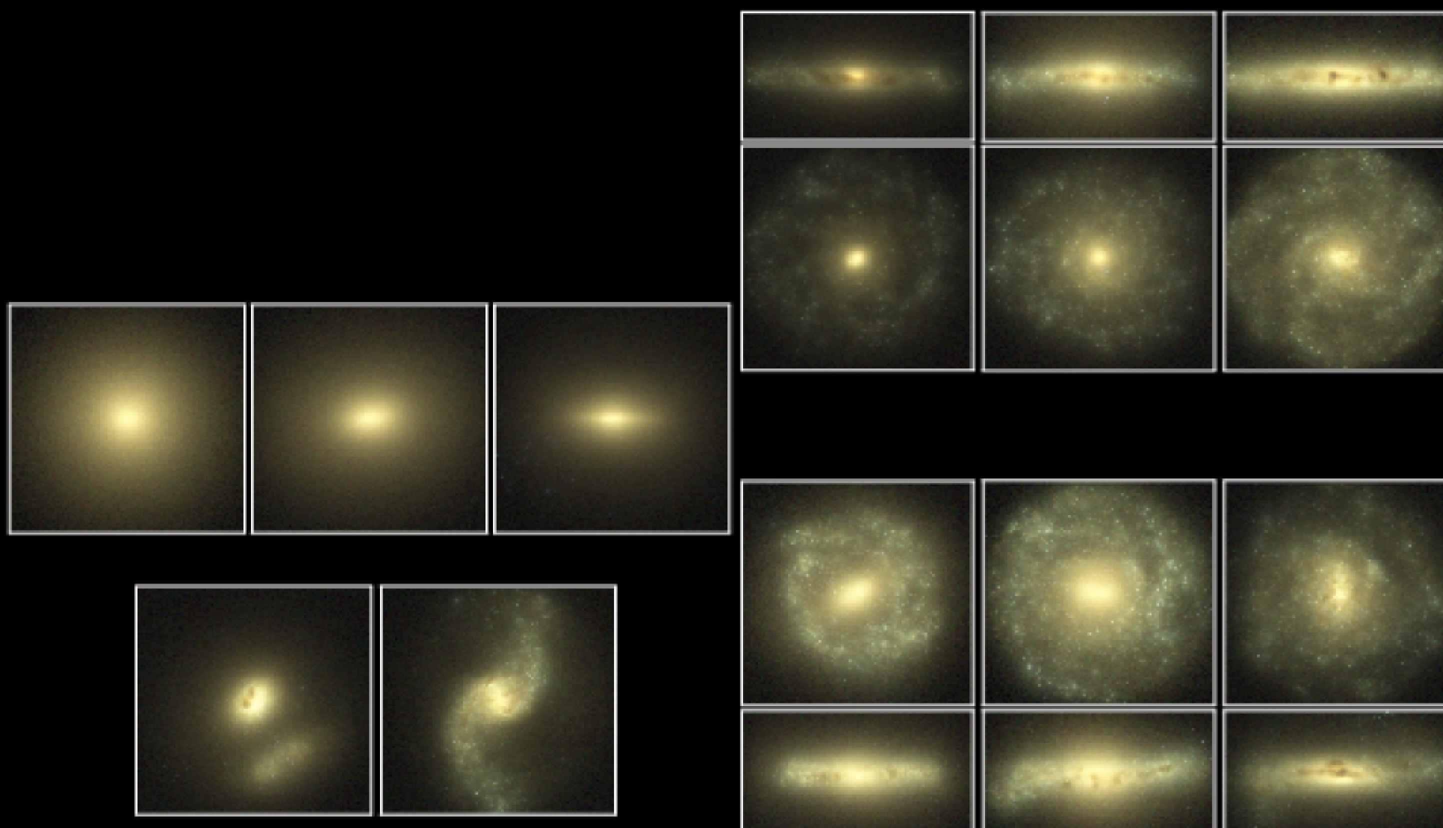

Galaxy Formation on a Moving Mesh
Simulating cosmological volumes with unprecedented physical fidelity.


Populating the Hubble Sequence
Recovering the diversity of galaxy morphologies.

The EAGLE Simulations

Search

Evolution and Assembly of GaLaxies and their Environments



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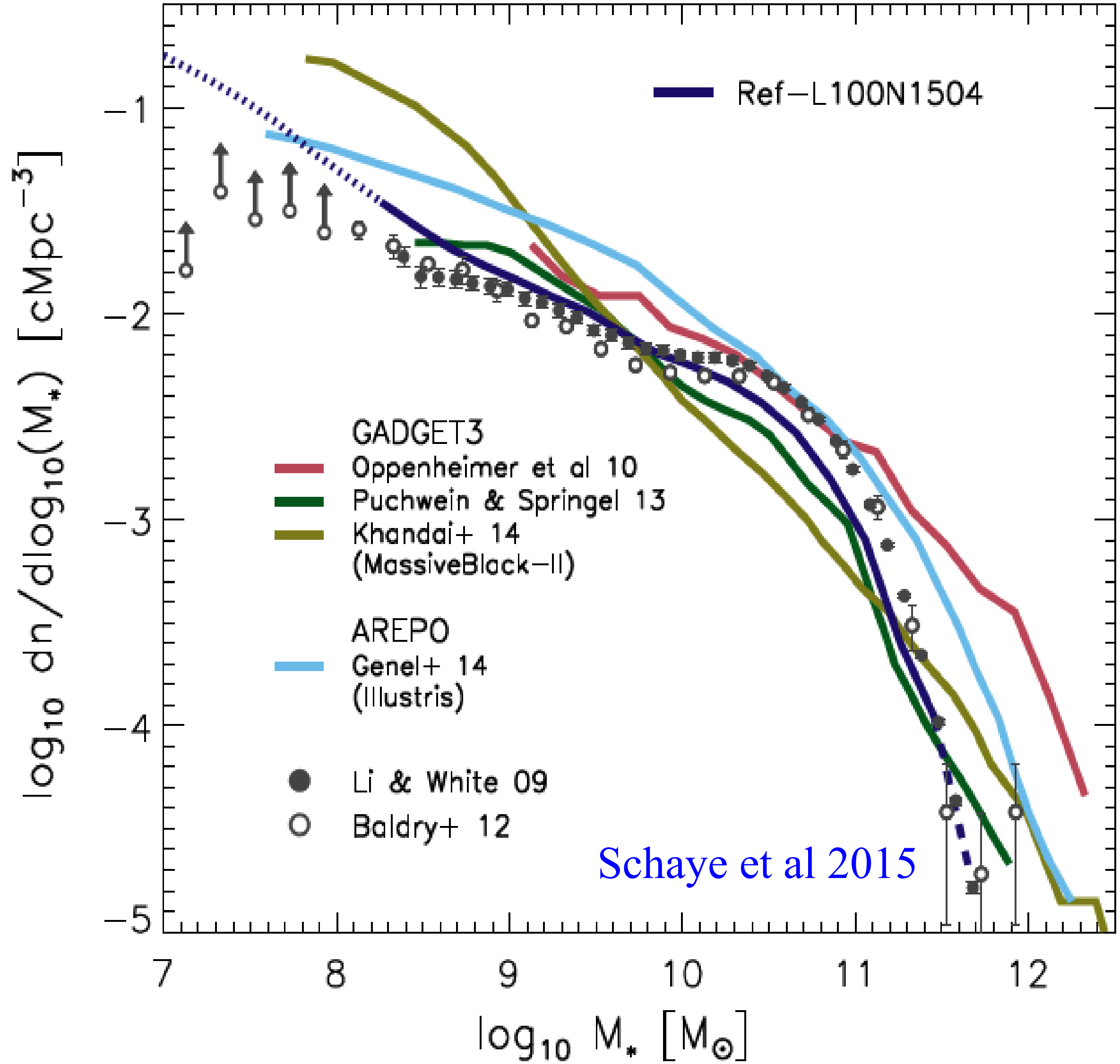
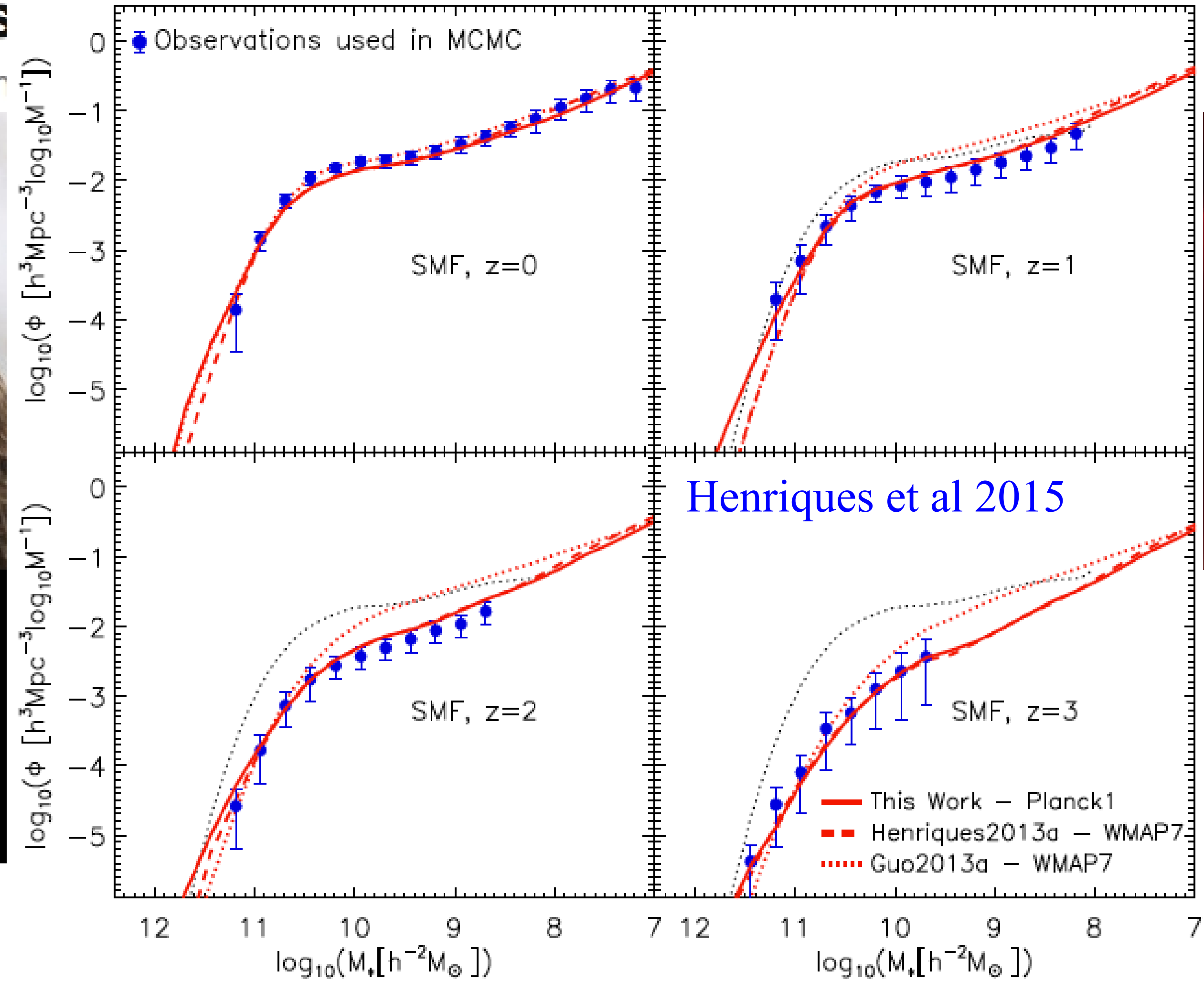


SN and BH feedback in both EAGLE and Illustris were *tuned* to reproduce the SMF at z = 0

Some other properties agree well with observation, some do not.



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Some other properties agree well with observation, some do not

Systematic calibration to a range of data is much easier in semi-analytic simulations

...but critical physics is likely missing or misrepresented in all approaches

Is there ANY consensus on galaxy formation?

Assembly? cold flow/halo cooling/wind recycling → star-forming ISM?

Star formation? need for H2? metallicity-dependence? role of dust? RT?

Stellar feedback? Algorithm? YSO winds? Z-dependence? CR+B field?

Violent disk instabilities? Are they important? Building bulges/cores?

AGN feedback? Radiative/mechanical/CR? QSO/RG? intermittent? role in quenching?

Winds? Mass-loading? Z-loading? reach? CR-driven? mixing with ambient hot gas and infall? relation to observed CGM?

Bulge formation? Secular/classical; **Environment?** satellite quenching

Hydro scheme? Numerical convergence? Softening?

How do we develop <u>consensus</u> about what is well established?

Re-emphasise traditional ethics and standards of scholarship

De-emphasise marketing – the goal is not to sell our model to observers, funding agencies or employers, but to understand galaxy formation

Be up-front, even-handed and <u>explicit</u> about limitations, assumptions and failures, in addition to exhibiting successes

Read and discuss related published work <u>in detail</u> – establish, as far as possible, the reasons **<u>why</u>** it agrees or disagrees with our results

Be sufficiently detailed and explicit about what was done in each paper that it is possible for others to understand if they agree or not

Do not stop after exhibiting agreement with (some) observations – does this reflects calibration/tuning or an underlying physical regularity?