The Eagle simulations

An attempt to reproduce the observed galaxy population (and more!) in a cosmological framework

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Large Magellanic Cloud

Herschel / Spitzer composite

Tarantula Nebula

Large Magellanic Cloud

Herschel / Spitzer composite

~3 kpc

Typical resolution scale of gravity calculation

Best resolution of hydro calculation

Tarantula Nebula

Calculating radiative losses in the ISM is beyond cosmo simulations.

↓

Feedback efficiencies cannot be estimated from first principles.

↓

Only recourse is to calibrate feedback against observables.

Which brings us on to convergence...

Clearly a prerequisite for predictive power.

Convention: construct subgrid models to be insensitive to numerical resolution.

⟶ I'll call this strong convergence.

Strong convergence demands big sacrifices

Artificially manipulate the hydro scheme:

- **Decouple outflows from hydro forces**
- **Disable cooling in outflows**

Feedback must scale with converged quantities:

- **Only real option DM e.g. halo mass or dispersion**
- **Moves us closer to *semi-analytics***

Clearly a prerequisite for predictive power.

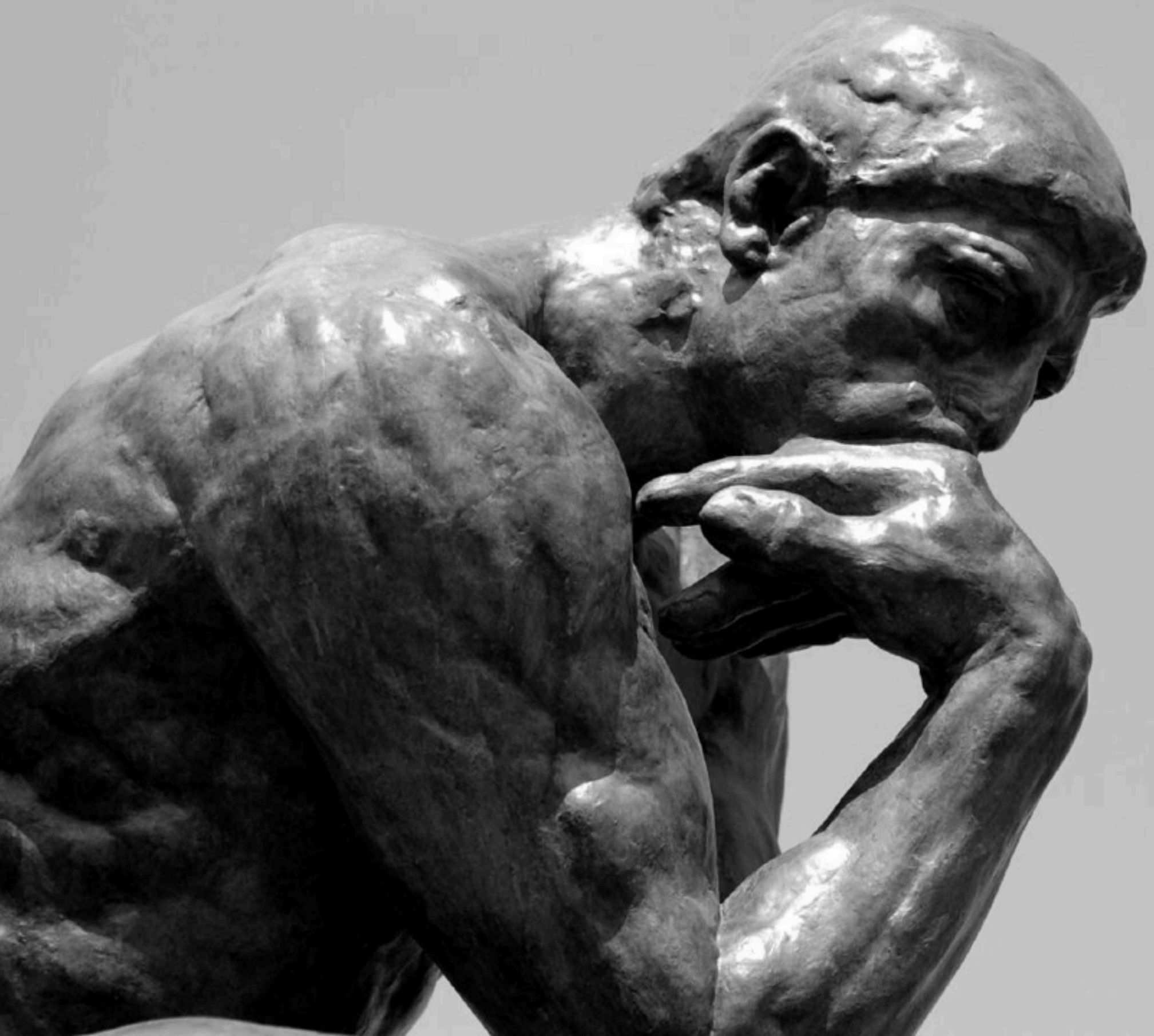
Convention: construct subgrid models to be insensitive to numerical resolution.

→ I'll call this strong convergence.

Without predictive power, is this necessary?

Can instead seek convergence at higher resolution after recalibrating subgrid models.

→ I'll call this weak convergence.



Working philosophy:

- appeal to weak convergence
- adopt simple, natural feedback:
  - ➡ no decouping, no cooling shut-off
  - ➡ scale with local, baryonic properties
  - ➡ one mode SF, one mode AGN
- calibrate f/b efficiencies to reproduce observed properties
  - ➡ reject clearly unphysical models

The Eagle simulations

Evolution and Assembly of GaLaxies and their Environments

Cosmo-hydro simulations of 25-100 Mpc periodic volumes.

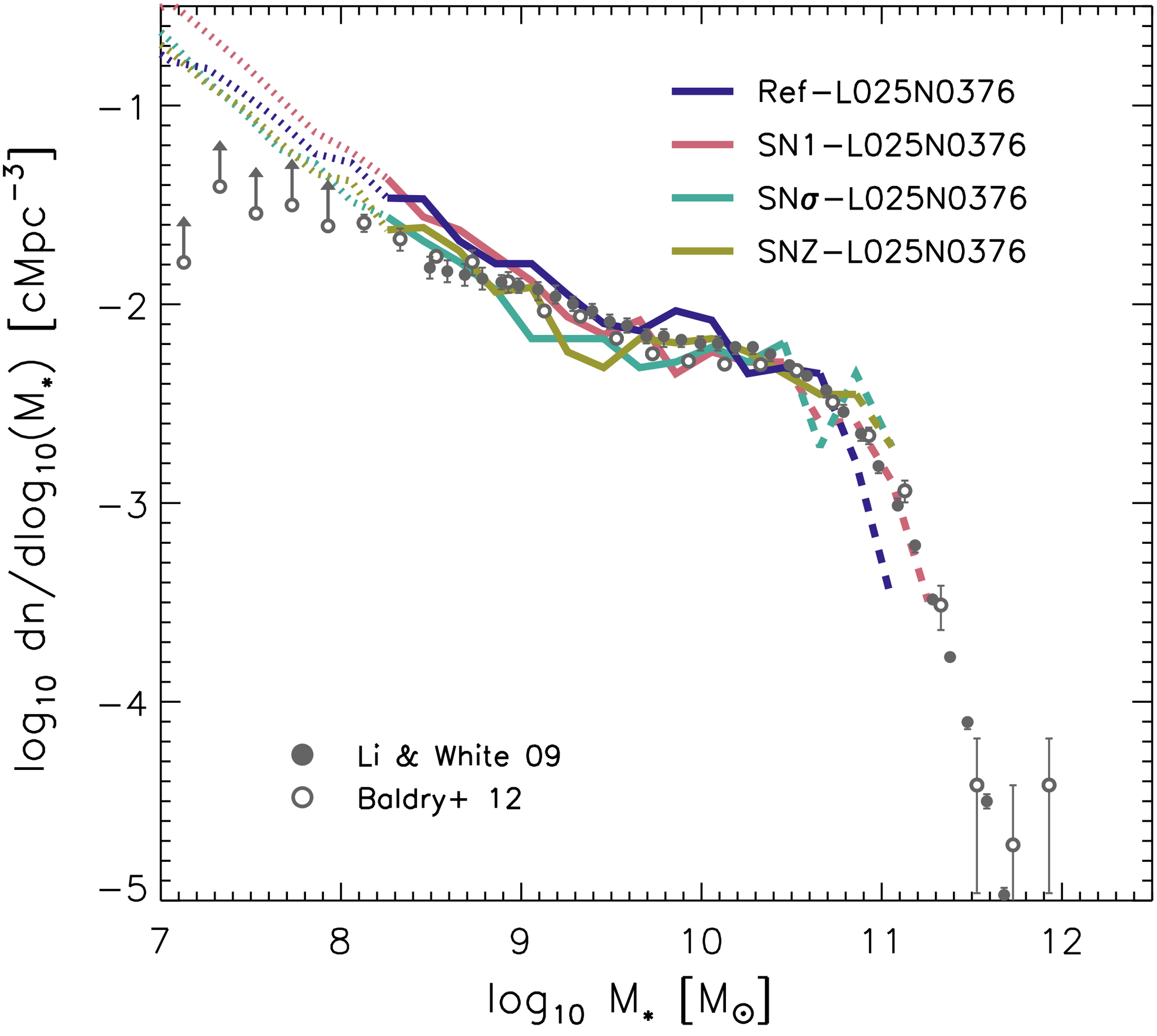
Standard res of $10^6 M_{sun}$ gas particles and smoothing length of 0.7 pkpc.

Major overhaul of OWLS code, including updated SPH and subgrid modules.

Eagle at a glance...

- 11 species radiative cooling (always on)
- Star formation with Z-dependent density threshold, implemented as a pressure law
- Mass loss from AGB, Type Ia+II SNe (single loading)
- BH growth by accretion and mergers
- Stochastic thermal f/b from stars+AGN (no decoupling)
  - ➡ One mode of stellar f/b, one mode of AGN f/b

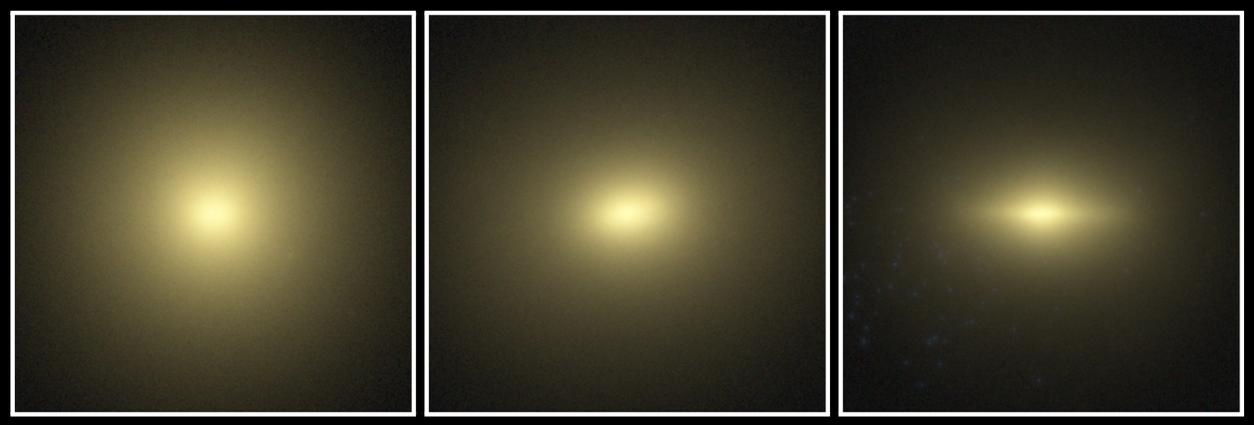
- Calibrate stellar feedback to reproduce z~0 GSMF and AGN efficiency to reproduce BH scaling relations.
- Stellar feedback varied with local ISM properties
  - ➡ metallicity + density scaling works well


Ref−L025N0376
SN1−L025N0376
SNσ−L025N0376
SNZ−L025N0376
Li & White 09
Baldry+ 12
log10 dn/dlog10(M*) [cMpc−3]
log10 M* [M⊙]
−1
−2
−3
−4
−5
7
8
9
10
11
12

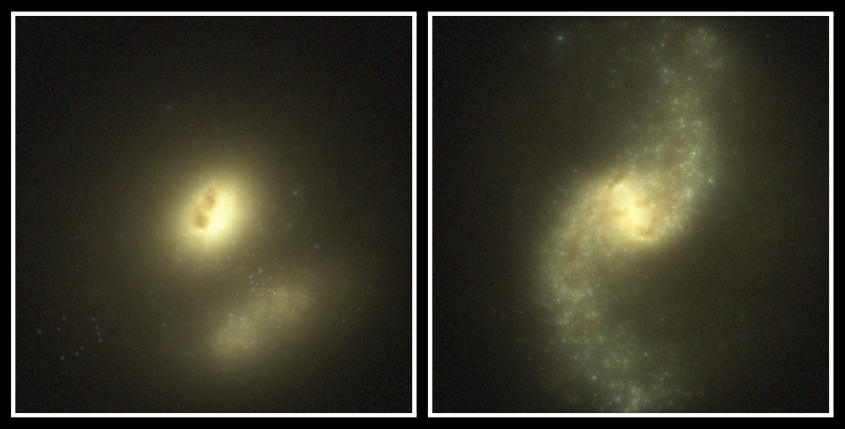
Ref−L025N376
SN1−L025N376
$n_s < 2.5$
Shen+ 03
$n_s < 2.5$
Blue galaxies
Red galaxies
Baldry+ 12
$\log_{10} R_{50}$ [pkpc]
$\log_{10} M_*$ [$M_\odot$]
1.5
1.0
0.5
0.0
−0.5
7
8
9
10
11
12

Images from 3-colour (u,g,r) filters + dust

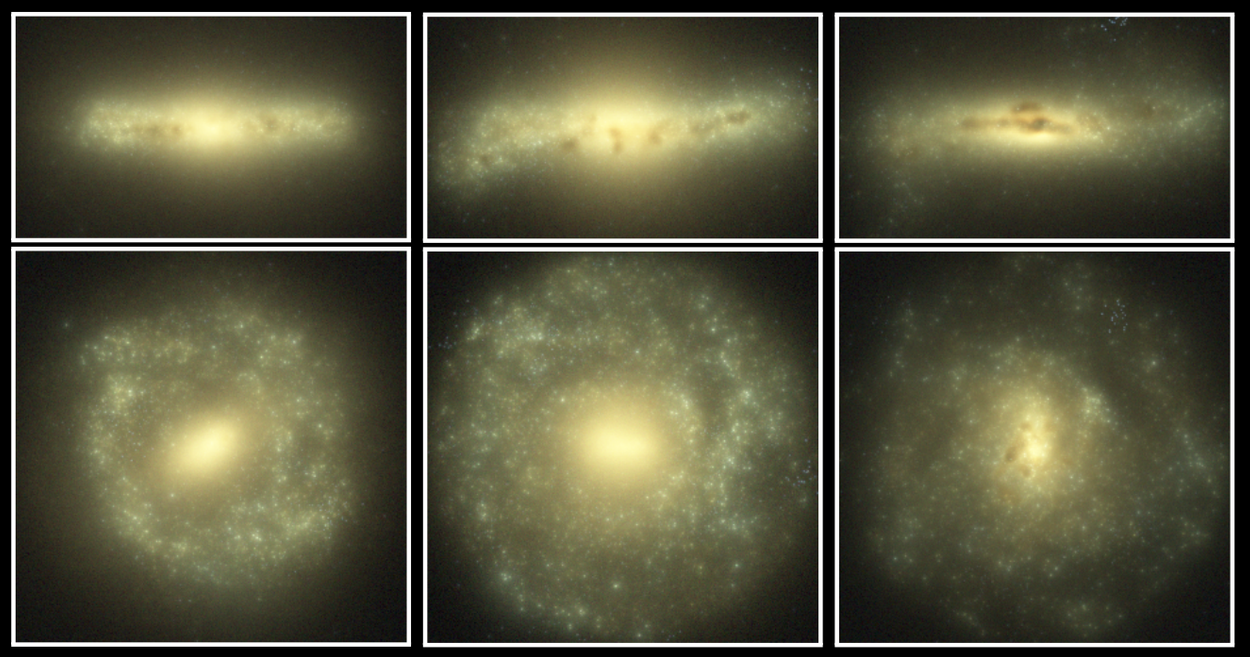
Ellipticals



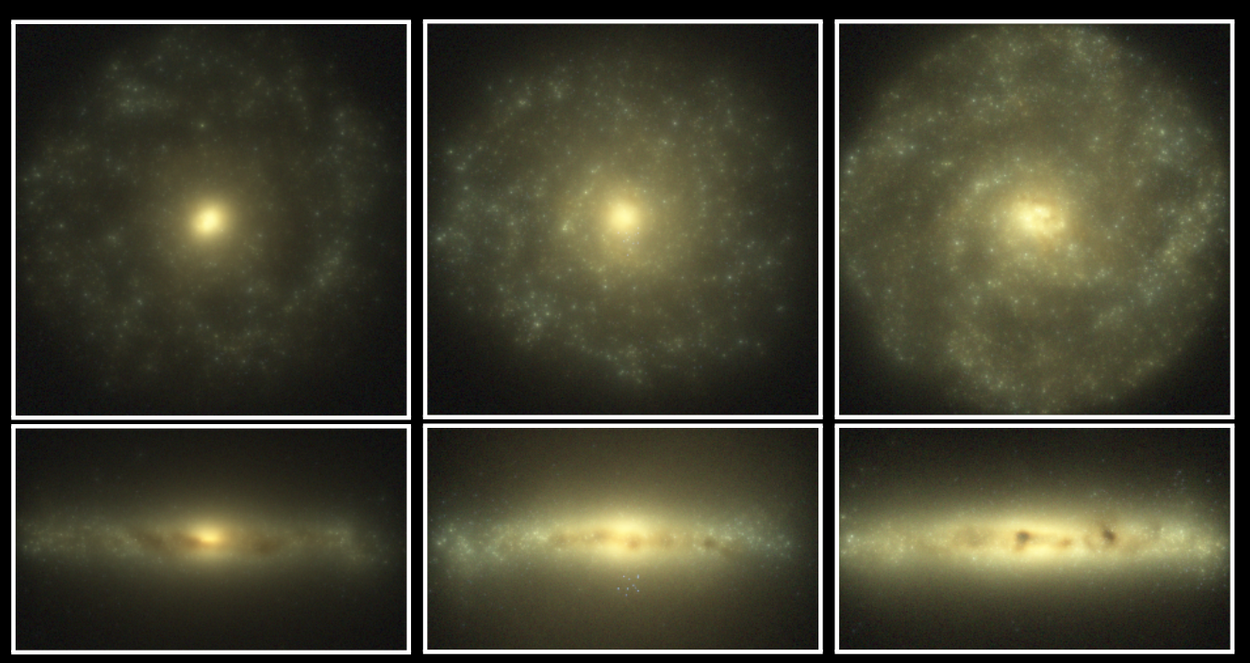
Irregulars

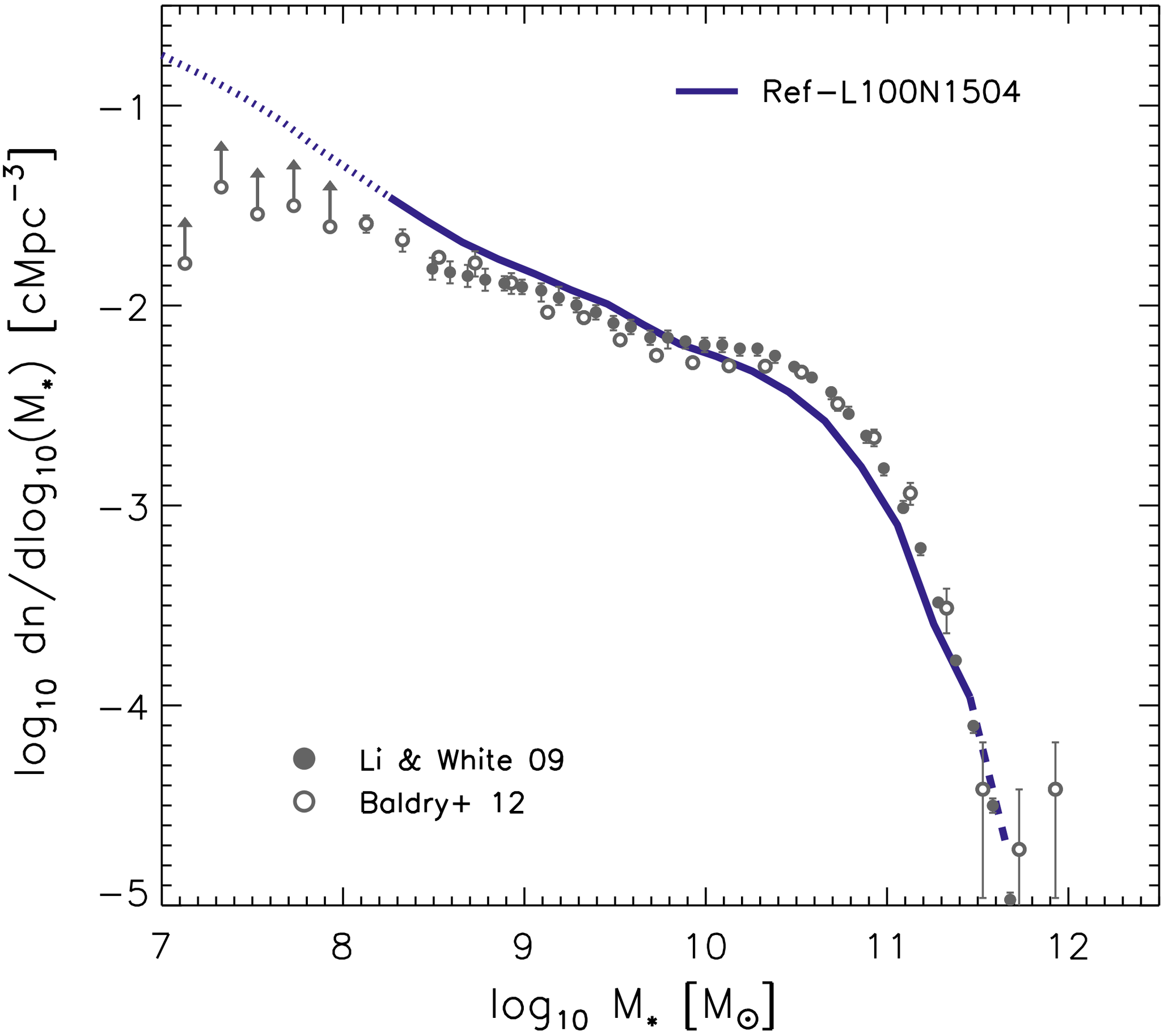


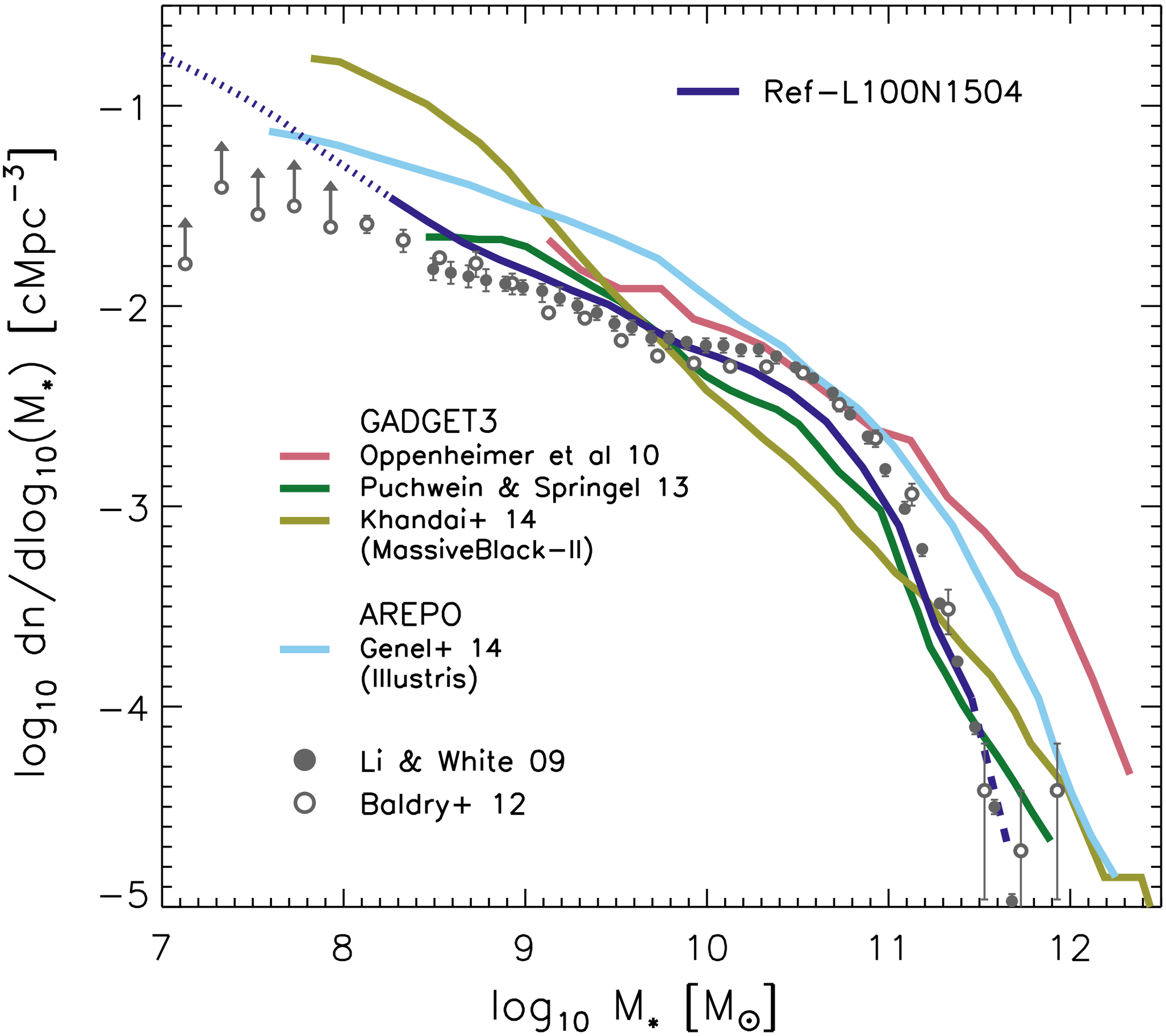
Barred discs

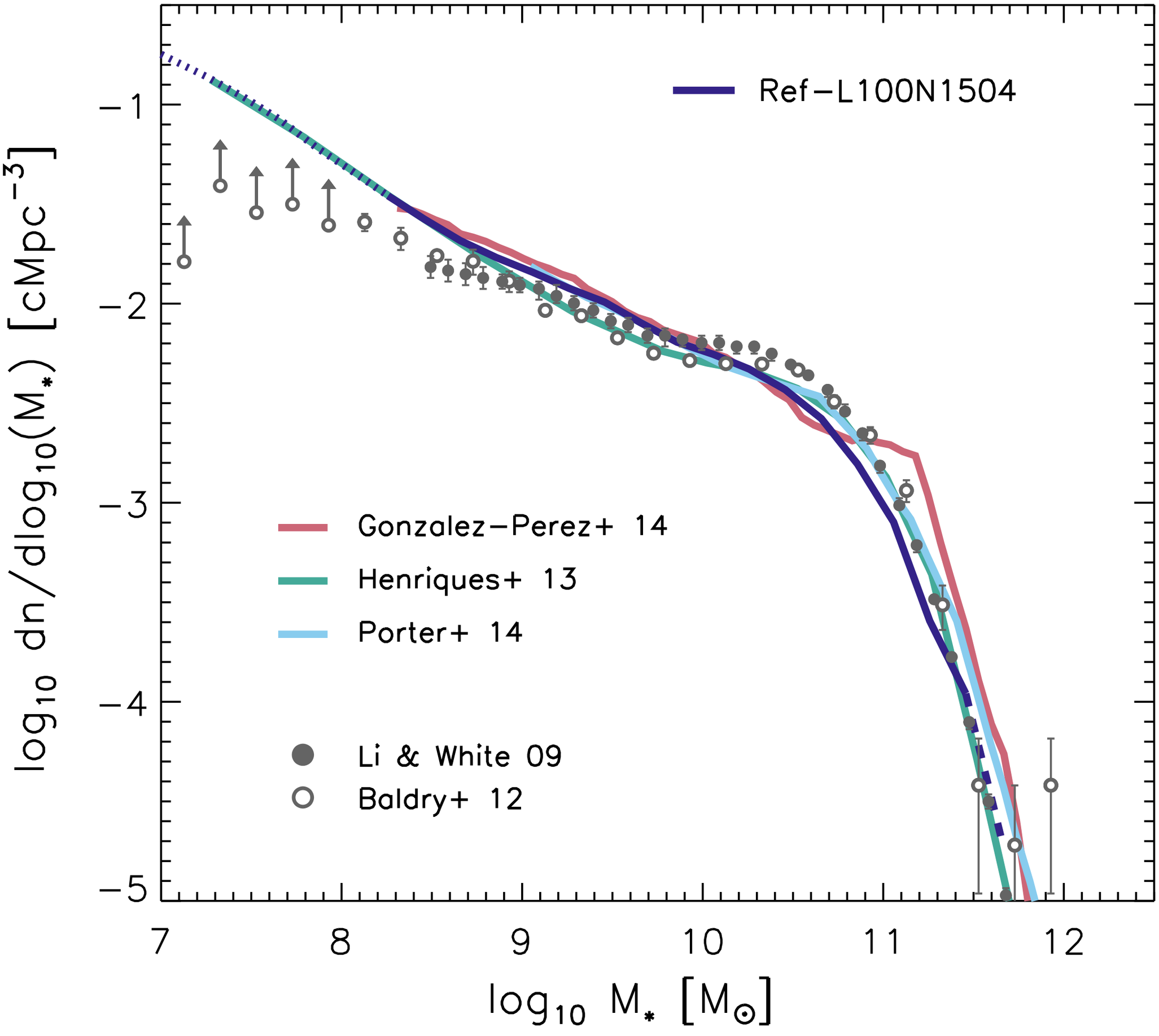


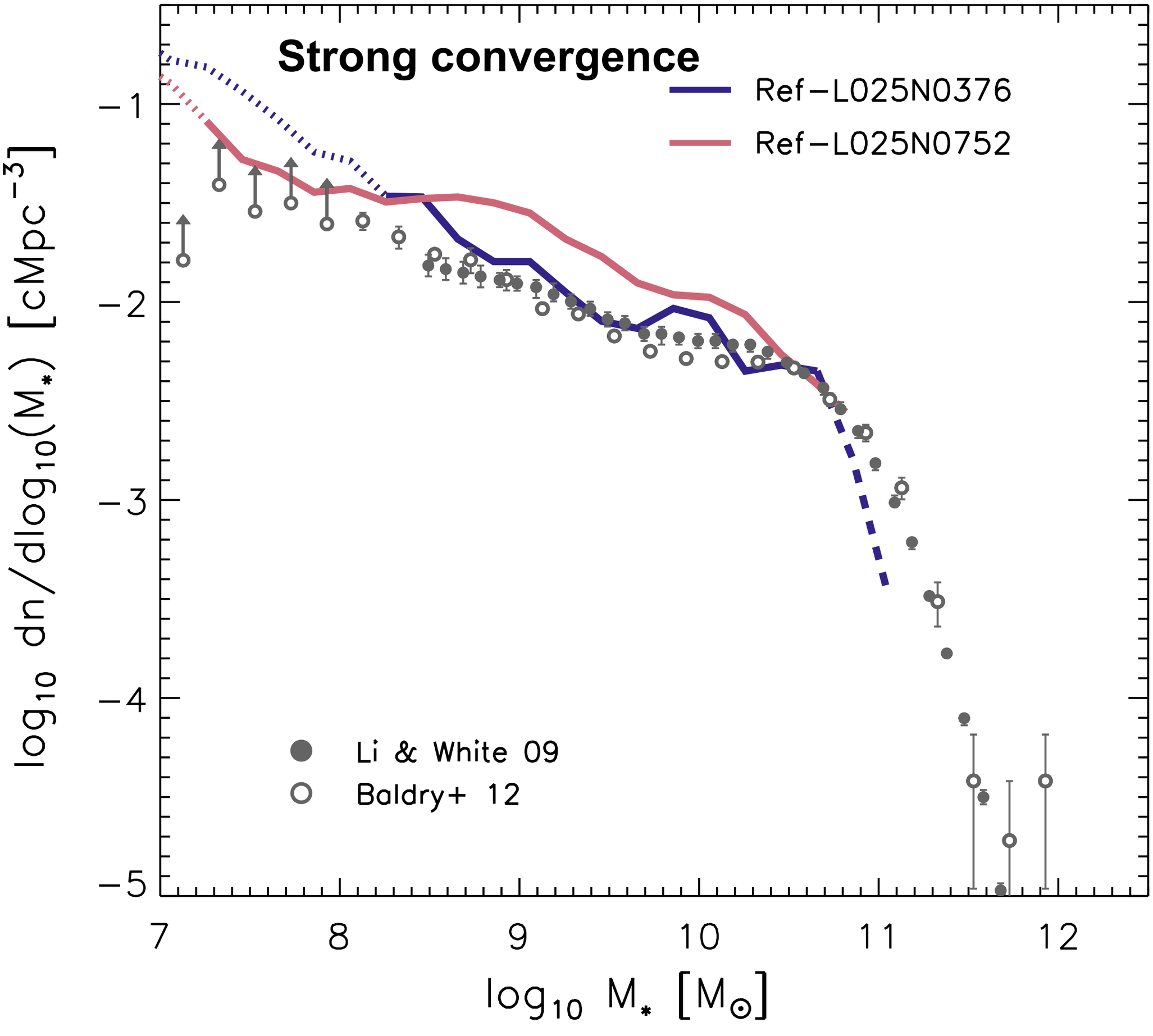
Discs

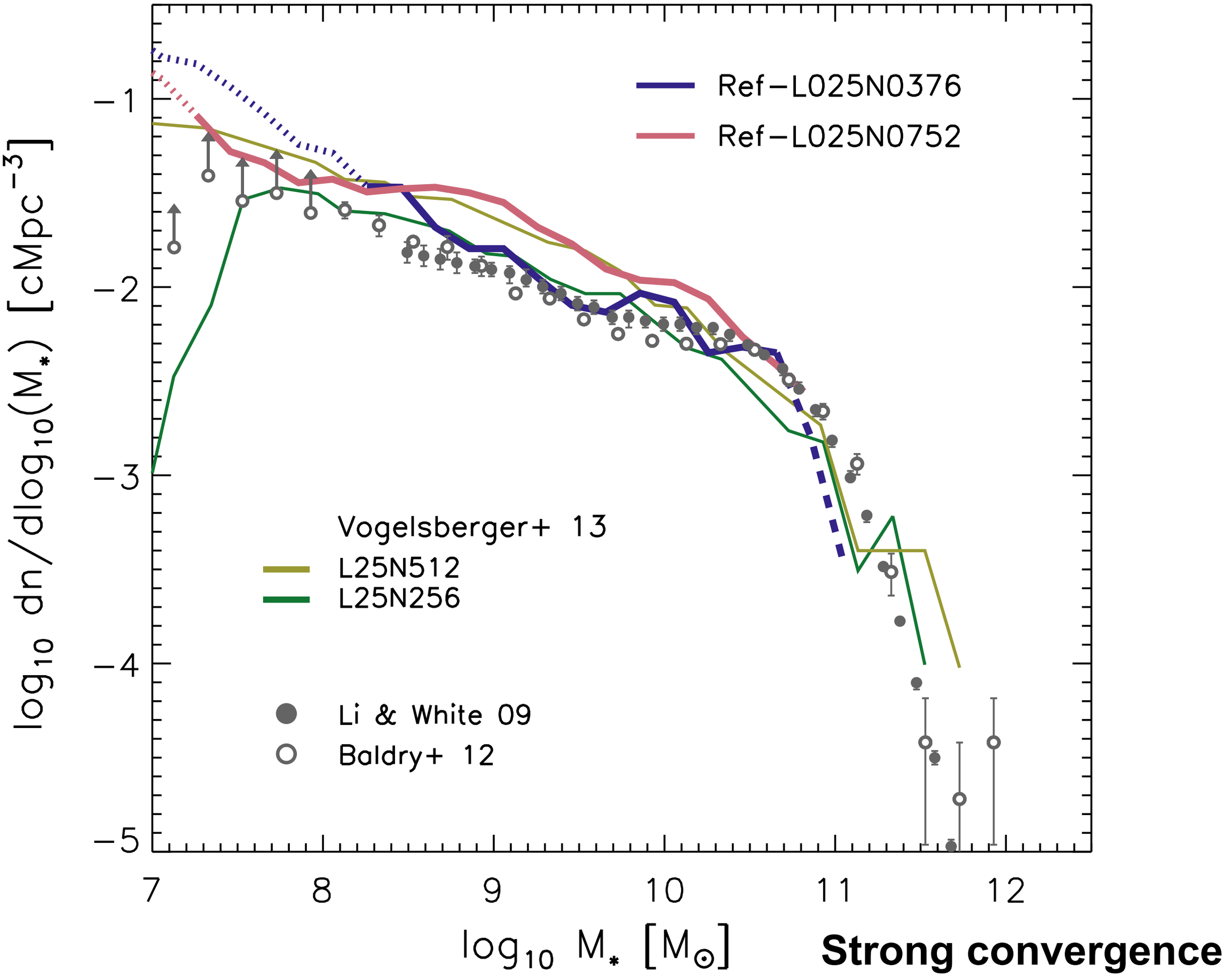



Ref−L100N1504
Li & White 09
Baldry+ 12
log10 dn/dlog10(M*) [cMpc−3]
log10 M* [M⊙]
−1
−2
−3
−4
−5
7
8
9
10
11
12

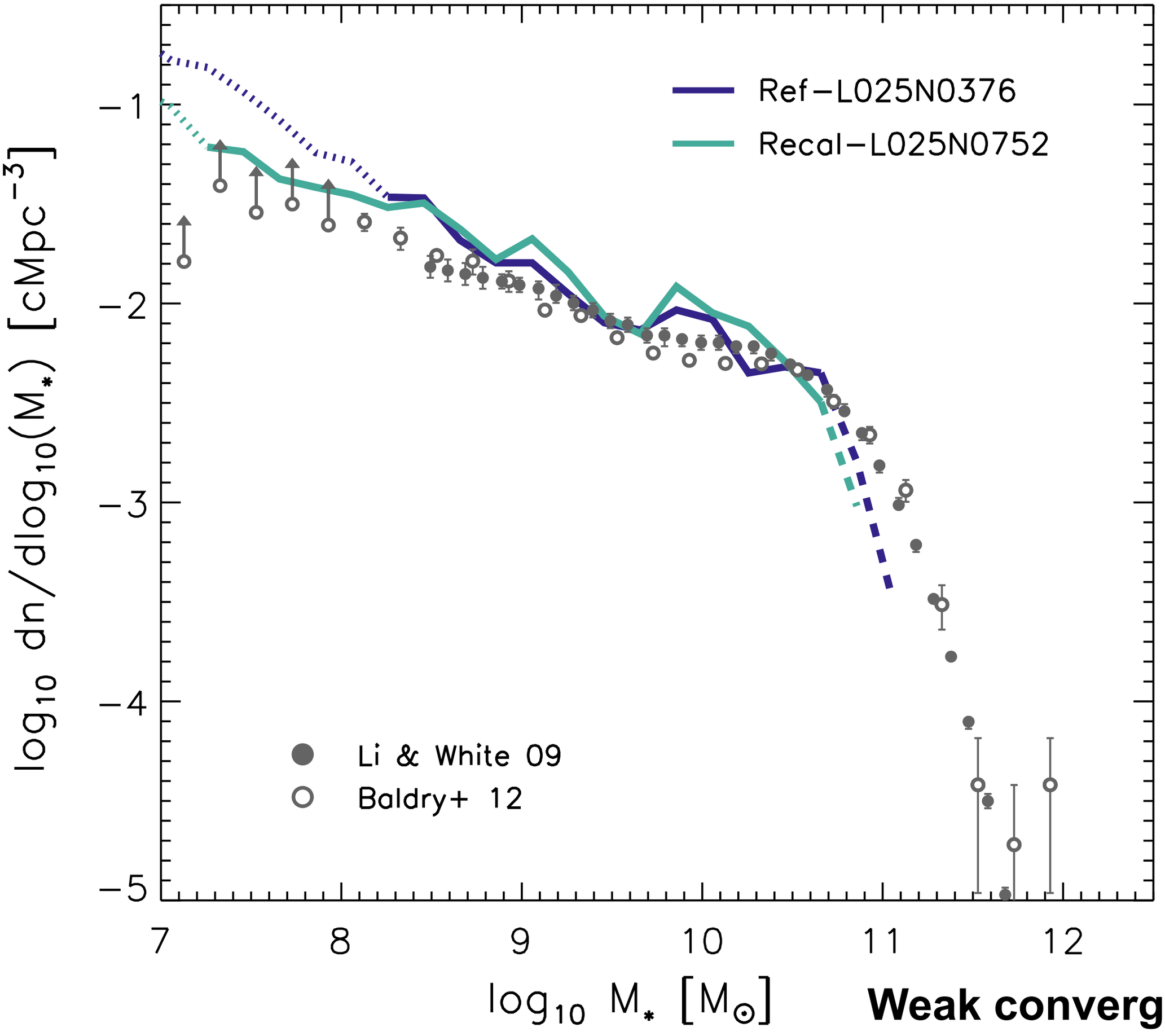

Ref−L100N1504
GADGET3
Oppenheimer et al 10
Puchwein & Springel 13
Khandai+ 14
(MassiveBlack−II)
AREPO
Genel+ 14
(Illustris)
Li & White 09
Baldry+ 12
log10 dn/dlog10(M*) [cMpc−3]
log10 M* [M⊙]
−1
−2
−3
−4
−5
7
8
9
10
11
12


Ref−L100N1504
Gonzalez−Perez+ 14
Henriques+ 13
Porter+ 14
Li & White 09
Baldry+ 12
−1
−2
−3
−4
−5
7
8
9
10
11
12
log10 dn/dlog10(M*) [cMpc−3]
log10 M* [M⊙]

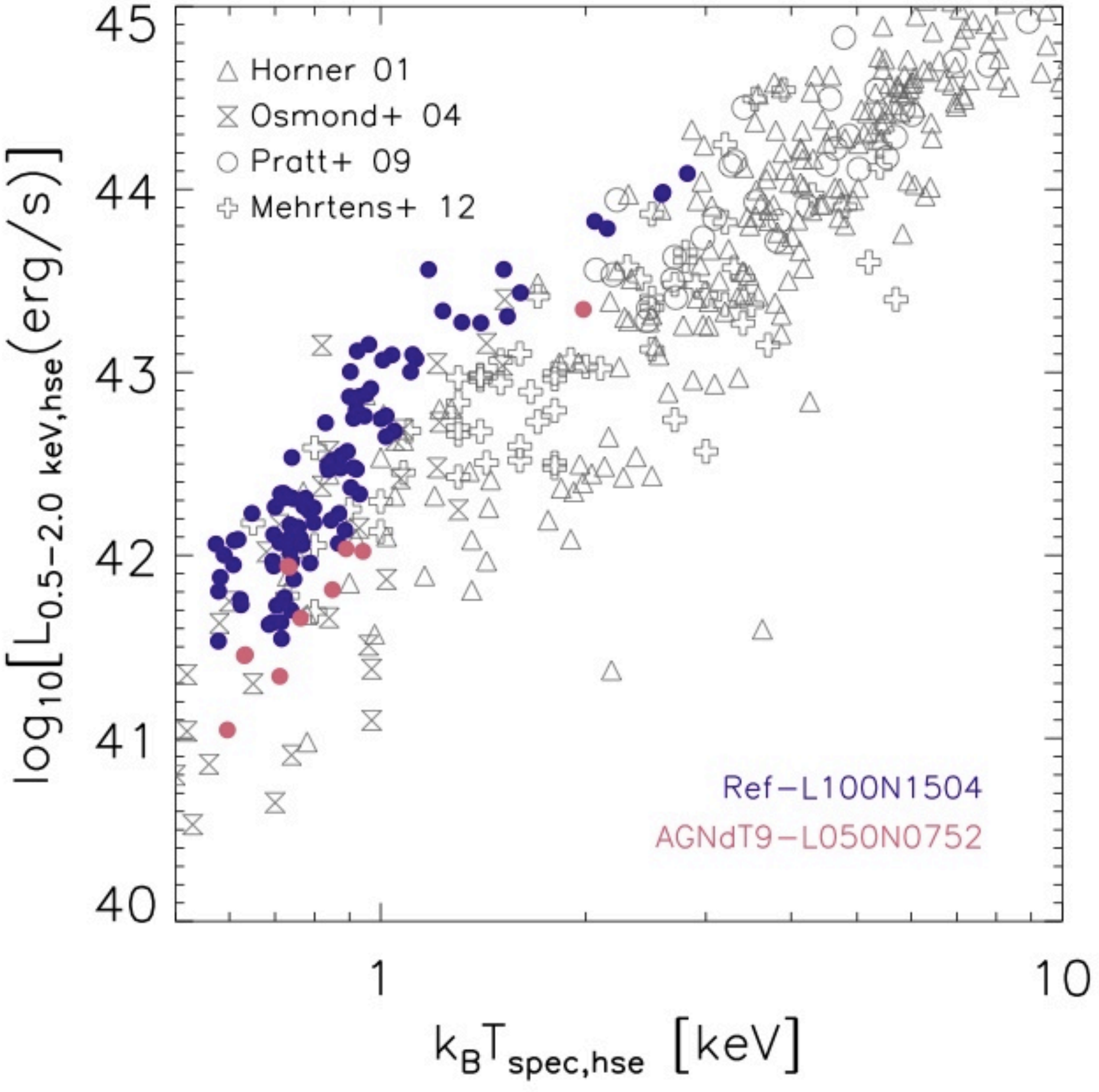

Strong convergence
Ref−L025N0376
Ref−L025N0752
Li & White 09
Baldry+ 12
log10 dn/dlog10(M*) [cMpc−3]
log10 M* [M⊙]
−1
−2
−3
−4
−5
7
8
9
10
11
12

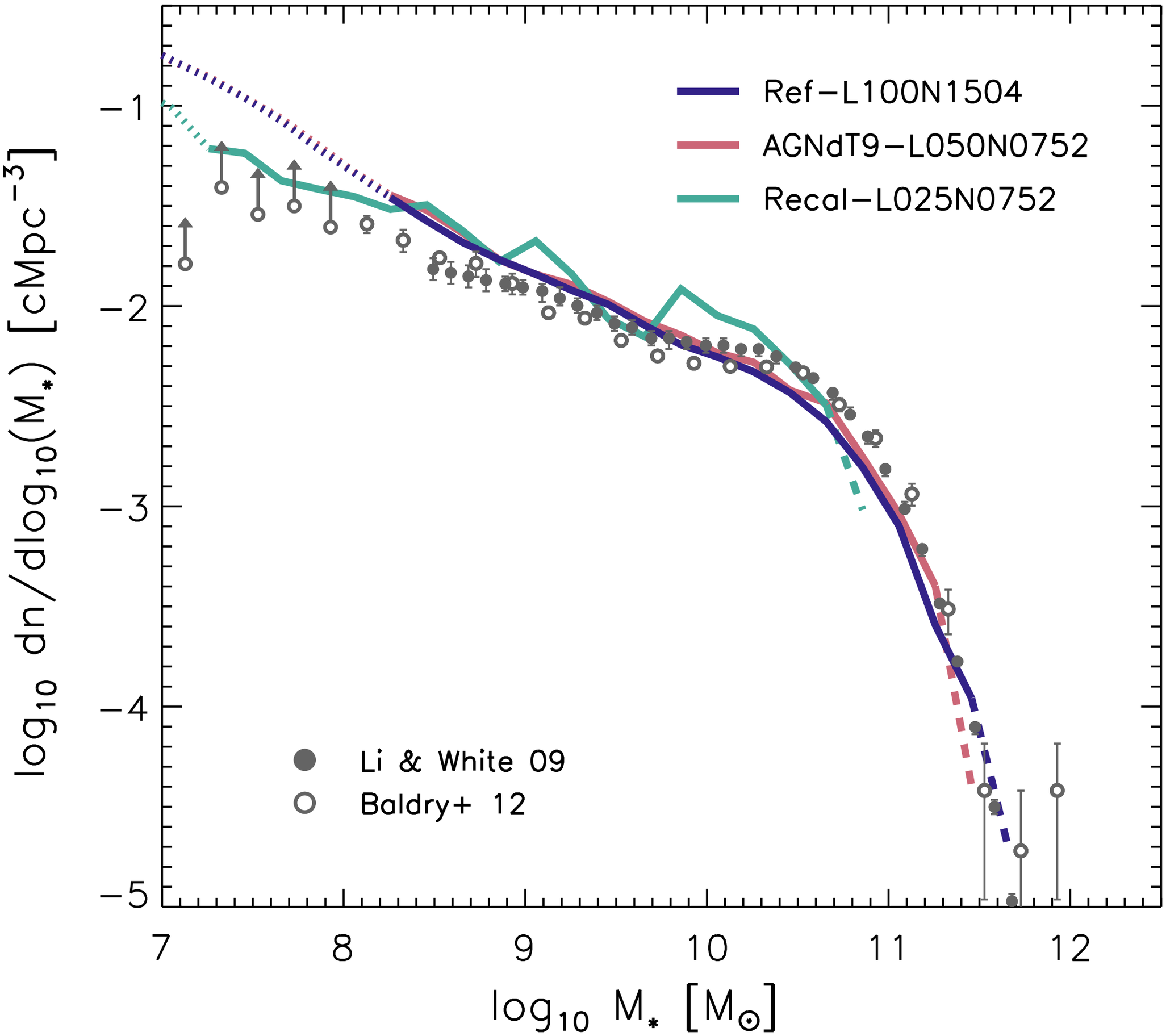


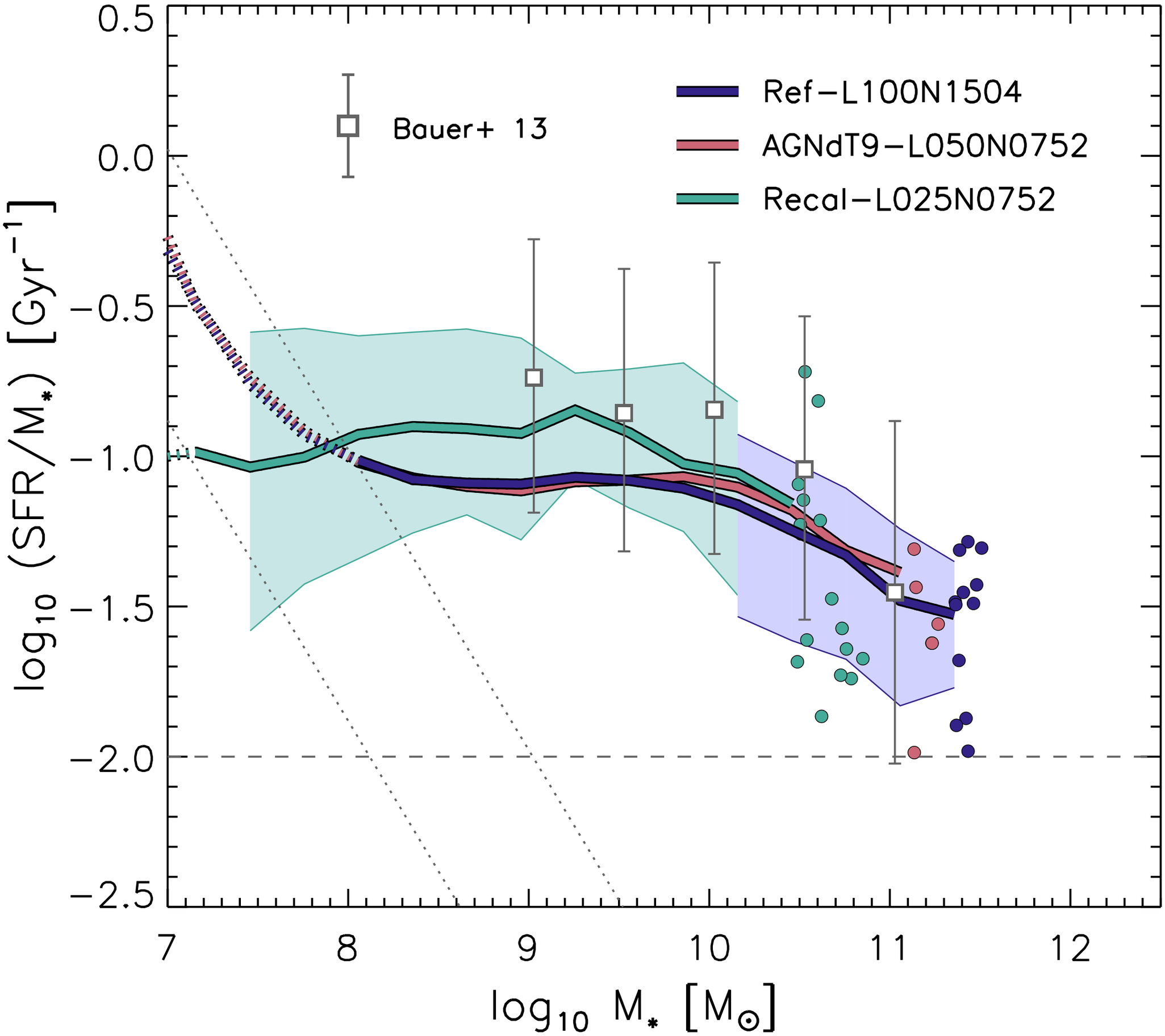
Strong convergence



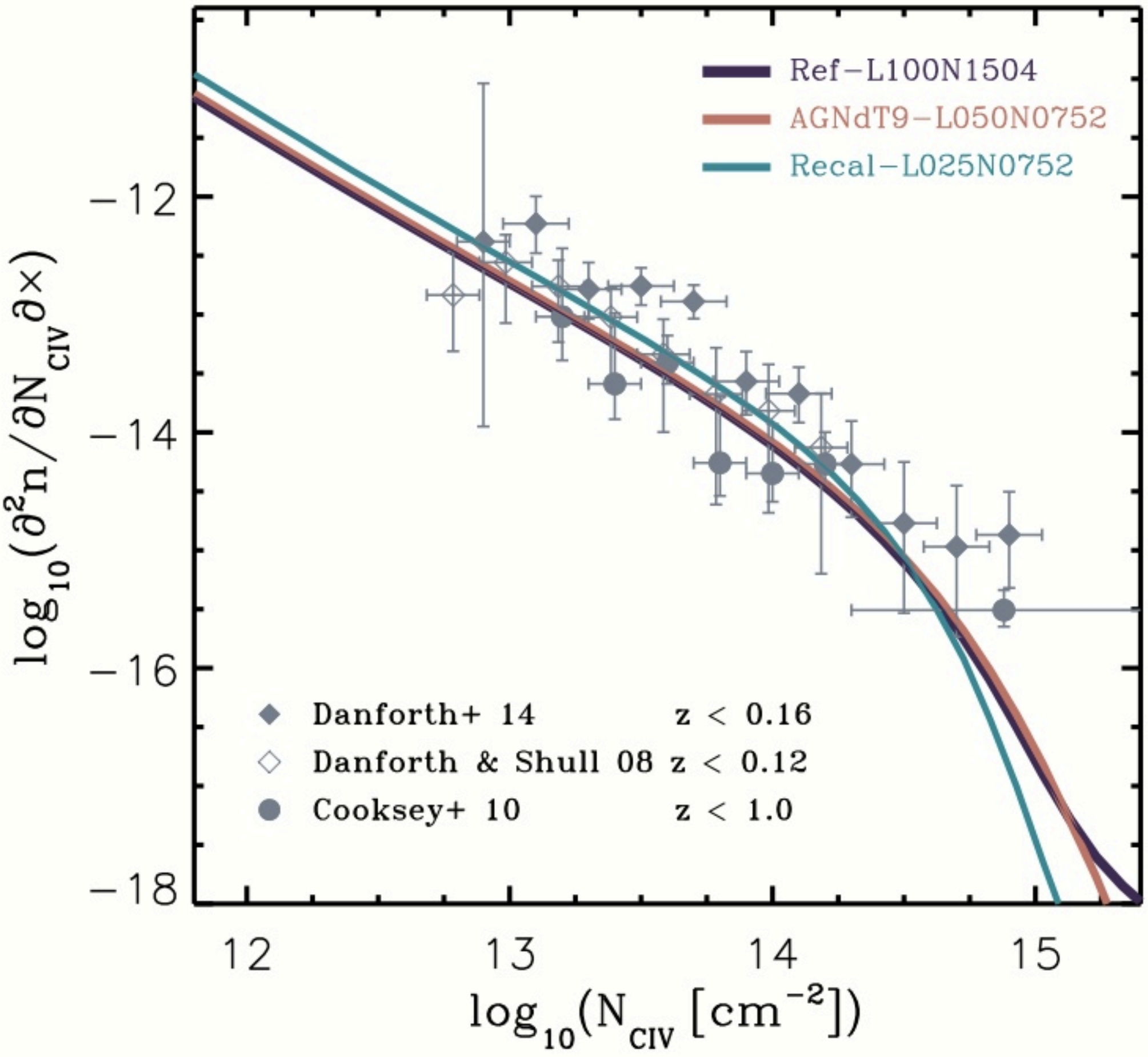
Weak convergence

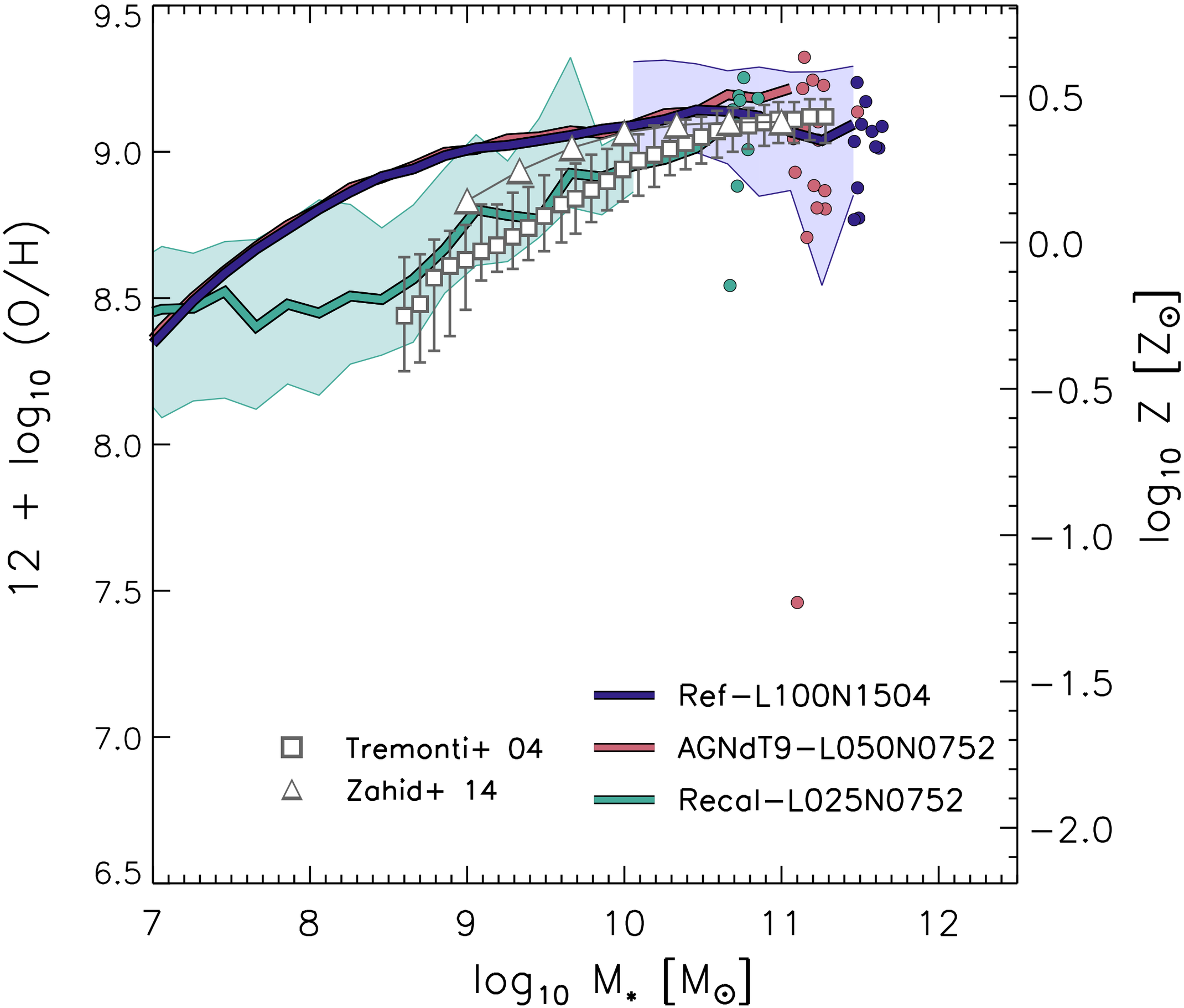

45
44
43
42
41
40
1
10
$\log_{10}[L_{0.5-2.0\ keV,hse}(erg/s)]$
$k_B T_{spec,hse}$ [keV]
Horner 01
Osmond+ 04
Pratt+ 09
Mehrtens+ 12
Ref−L100N1504
AGNdT9−L050N0752


Ref−L100N1504
AGNdT9−L050N0752
Recal−L025N0752
Li & White 09
Baldry+ 12
log10 dn/dlog10(M*) [cMpc−3]
log10 M* [M⊙]
−1
−2
−3
−4
−5
7
8
9
10
11
12


Bauer+ 13
Ref−L100N1504
AGNdT9−L050N0752
Recal−L025N0752
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
log10 (SFR/M*) [Gyr−1]
7
8
9
10
11
12
log10 M* [M⊙]

Ref−L100N1504
AGNdT9−L050N0752
Recal−L025N0752
Bauer+ 13
Moustakas+ 13
Passive fraction
$\log_{10} M_* [M_\odot]$
1.0
0.8
0.6
0.4
0.2
0.0
7
8
9
10
11
12


Ref−L100N1504
AGNdT9−L050N0752
Recal−L025N0752
Danforth+ 14 z < 0.16
Danforth & Shull 08 z < 0.12
Cooksey+ 10 z < 1.0
−12
−14
−16
−18
12
13
14
15
log10(∂²n/∂NCIV∂x)
log10(NCIV [cm⁻²])


9.5
9.0
8.5
8.0
7.5
7.0
6.5
12 + log10 (O/H)
0.5
0.0
−0.5
−1.0
−1.5
−2.0
log10 Z [Z⊙]
7
8
9
10
11
12
log10 M* [M⊙]
Tremonti+ 04
Zahid+ 14
Ref−L100N1504
AGNdT9−L050N0752
Recal−L025N0752


ADMIT
ONE

Summary

We cannot predict f/b efficiencies from first principles

- natural solution is to calibrate them
- relaxes convergence requirements
- enables simpler feedback implementation

Eagle simulations adopt this philosophy

- calibrate to z~0 GSMF and BH scaling relns
- match with same precision as SAMs
- convergence properties understood

Powerful resource for probing physical mechanisms

- many variation runs
- foundation for more detailed modelling