Assessing the predictive power of galaxy formation models

(a comparison of predicted & observed rest-frame optical LFs at 2<z<3.3)


HDF-South IJK composite (20'x10')

Danilo Marchesini & Pieter van Dokkum,

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★cosmic structures grow through gravitational instability (dissipationless) $\Rightarrow$ the evolution of the DM can be "easily" simulated

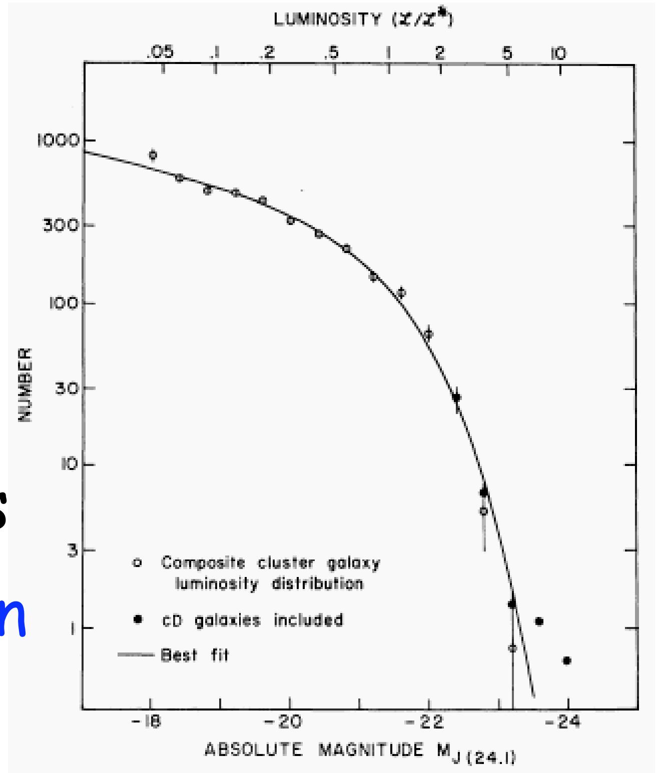
★the assembly of the stellar content of galaxies is governed by more complicated physics, dissipative and non-linear, poorly understood $\Rightarrow$ prescriptions are employed in the galaxy formation models

A powerful tool: the luminosity function

★ one of most fundamental of all cosmological observables

★ one of most basic descriptors of a galaxy population

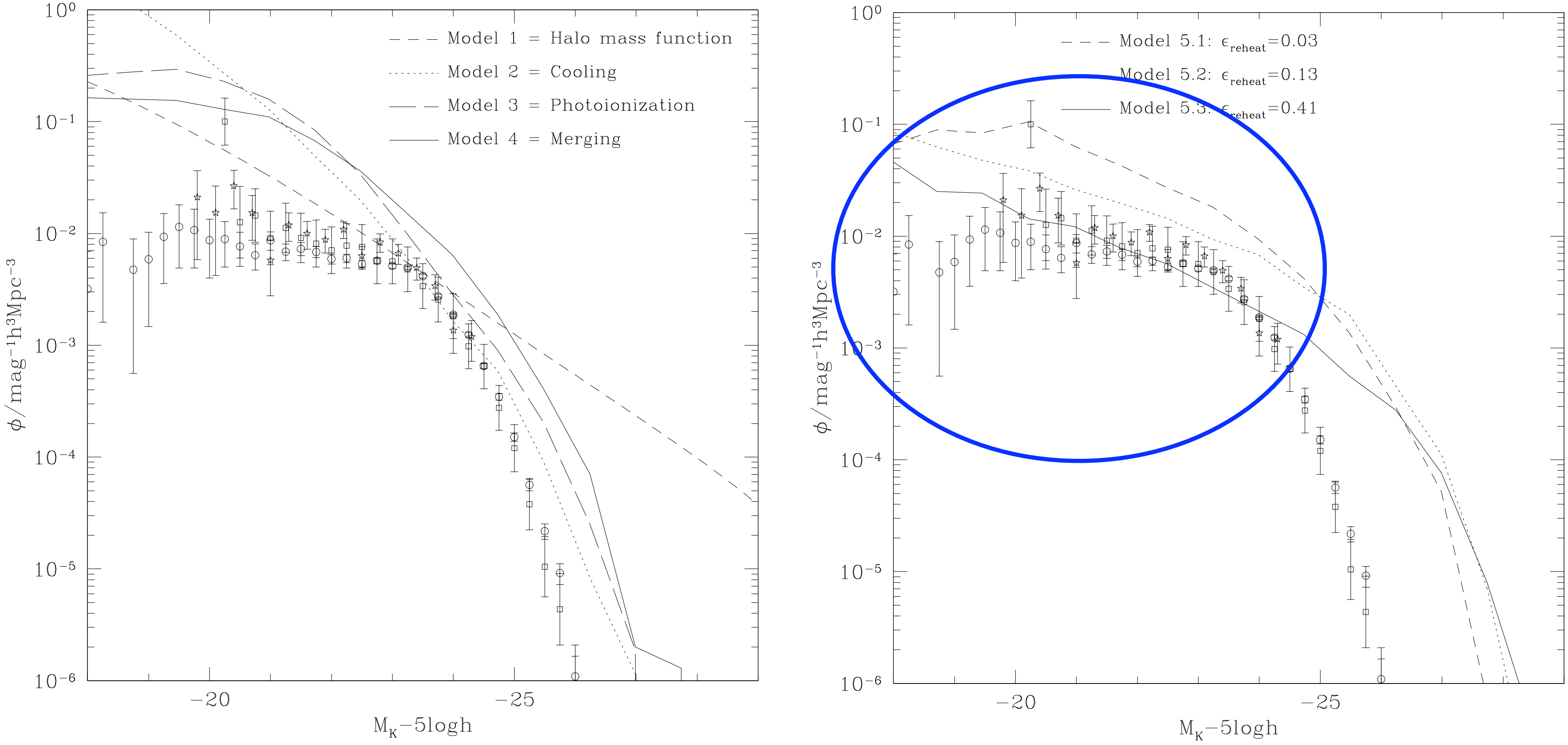
★ the shape of the luminosity function retains the imprint of galaxy formation and evolution processes



(Schechter 1976)

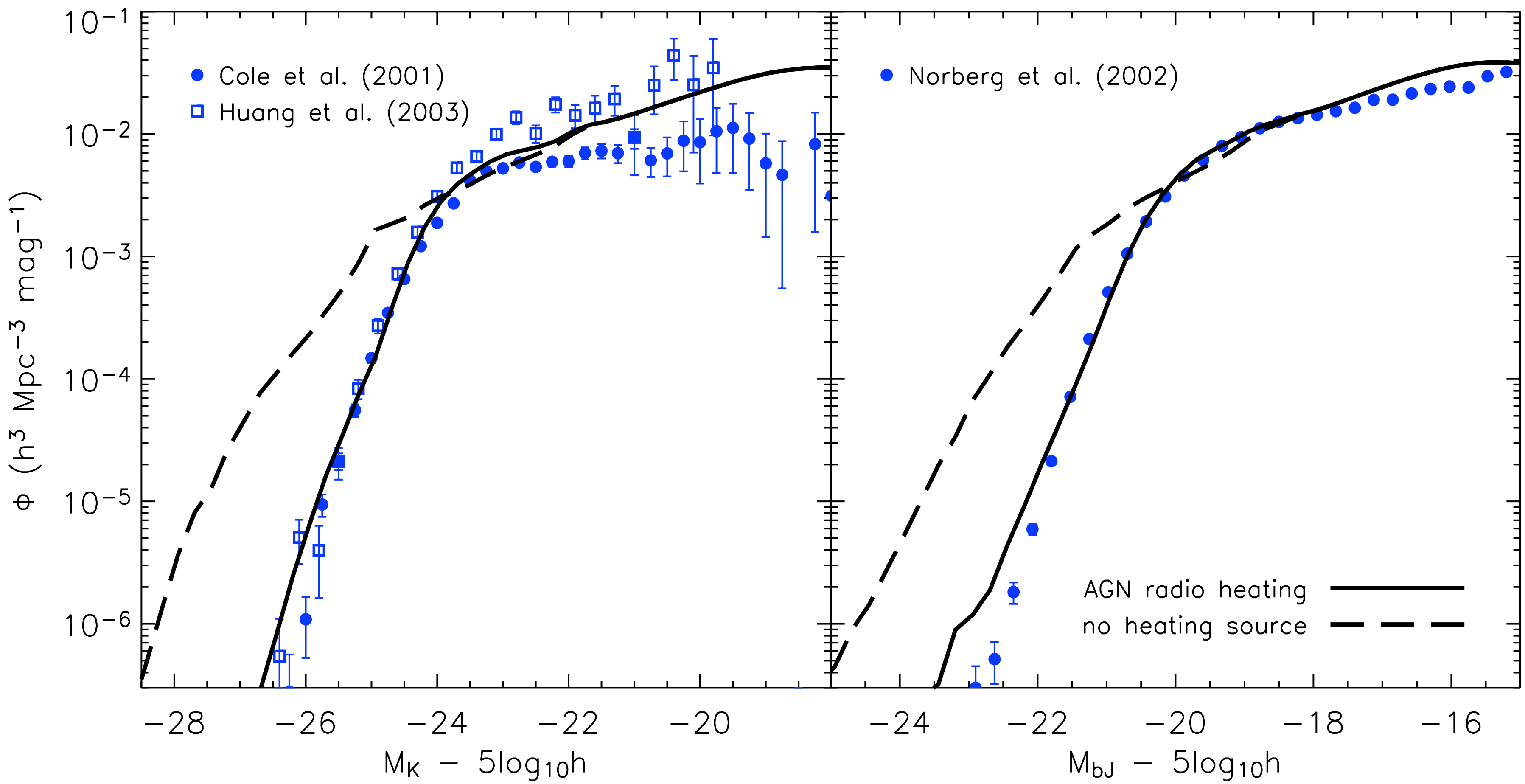
the LF is one of most powerful tools for constraining the physical processes encoded in the theoretical models

Matching the observed local LFs...



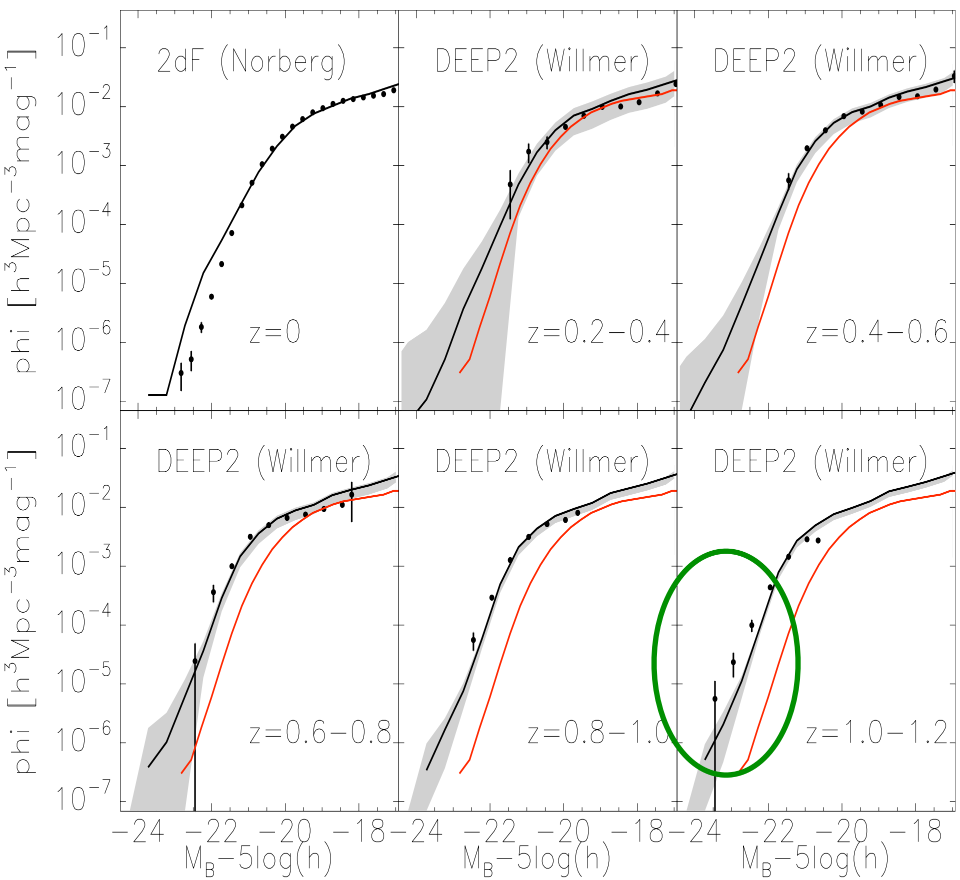
(Benson et al. 2003)

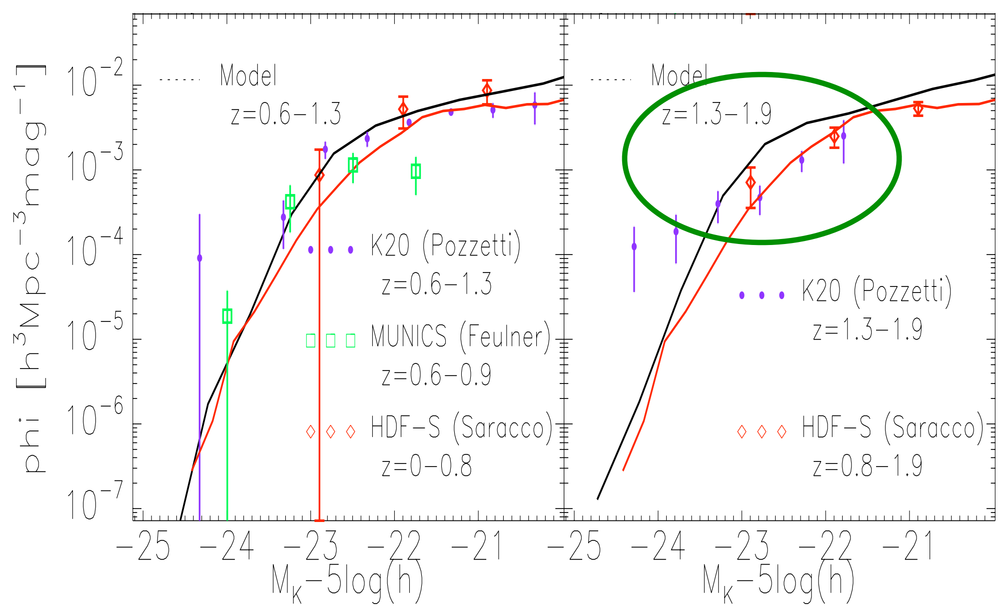
Comparison at z=0



(Croton et al. 2006;
see also Bower et al. 2006)

Comparison at z<2





(Kitzbichler & White 2007;
see also Bower et al. 2006)

The observed luminosity functions (LFs)

The observed rest-frame optical (B-, V-, and R-band) LFs at $z \geqslant 2$ were taken from Marchesini et al. (2007):

★K-selected sample constructed from the DEEP NIR MUSYC (Quadri, DM et al. 2007), FIRES (Franx et al. 2003), and GOODS-CDFS (Giavalisco et al. 2004) surveys

★the composite sample (~990 galaxies with $K_{\rm s}^{\rm tot}(AB) < 25$ at $2 \leq z \leq 3.5$) is unique for its combination of surveyed area (~$380\ arcmin^2$) and large range of luminosities

★limit the comparison between observed and predicted LFs to the rest-frame V-band at $2.7 \leqslant z \leqslant 3.3$ and $2 \leqslant z \leqslant 2.5$ (results qualitatively similar for other rest-frame bands)

The model-predicted LFs (1)

Semi-analytic model (SAM) of Bower et al. (2006) implemented on the Millennium dark matter simulation (Springel et al. 2005):

★ gas cooling

★ star formation

★ chemical and hydrodynamic feedback from SNs and stellar winds

★ stellar population synthesis modeling of photometric evolution

★ dust

★ growth of SMBHs by accretion and merging

★ suppression of infall onto dwarf galaxies as consequence of reionization heating

★ AGN feedback from galaxies at the centers of halos with quasi-hydrostatic cooling (Bower et al. 2006; Benson et al. 2003; Cole et al. 2000)

The model-predicted LFs (2)

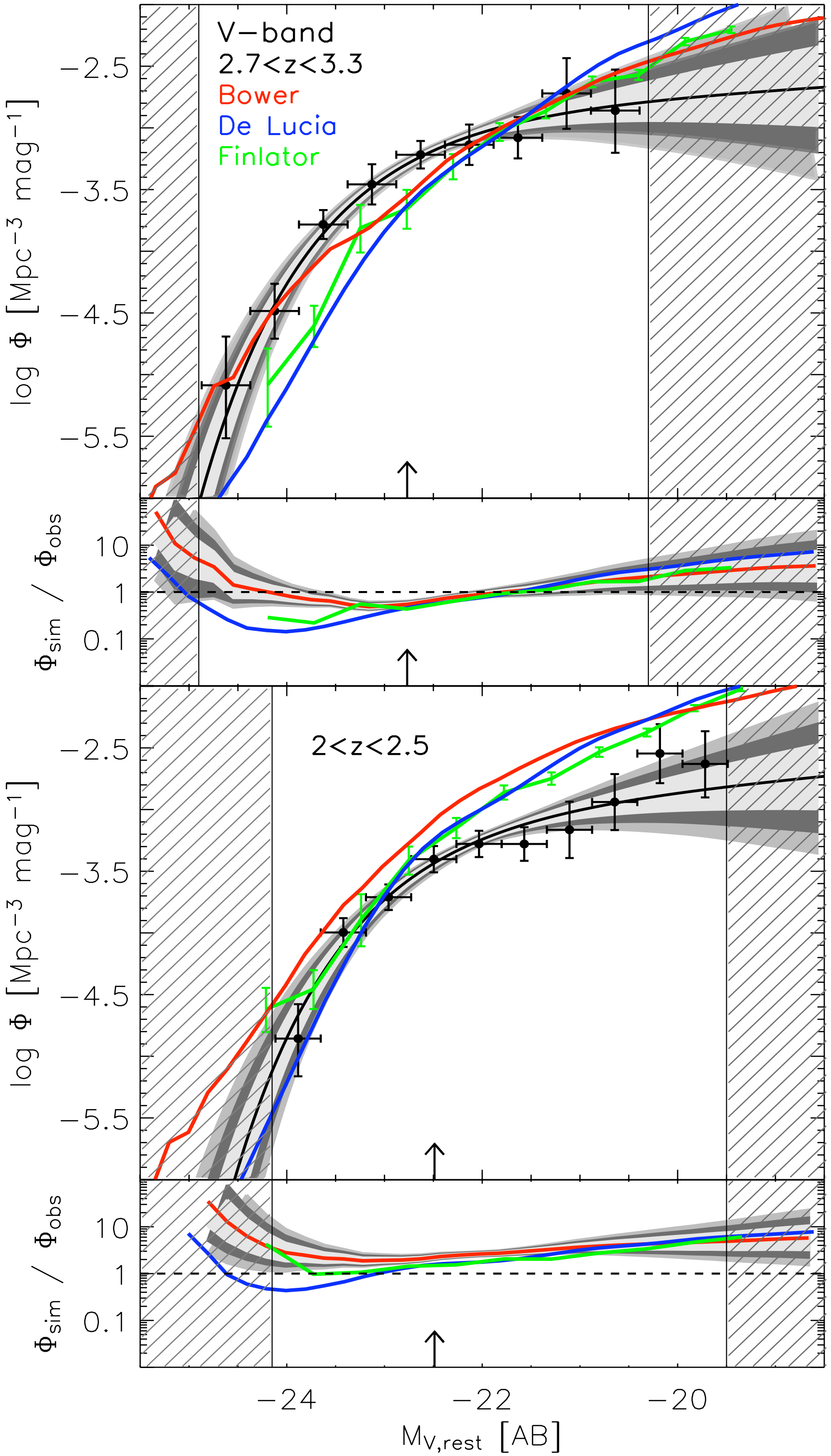
Semi-analytic model (SAM) of Croton et al. (2006) as updated by De Lucia & Blaizot (2007). This model differs from the SAM of Bower et al. (2006) in many ways:

- ★ scheme for building the merger trees is different
- ★ different prescriptions to model the baryonic physics (those associated with growth of and the feedback from SMBHs in galaxy nuclei and the cooling model)

The model-predicted LFs (3)

Cosmological Smoothed Particles Hydrodynamic (SPH) simulations of Oppenheimer & Dave' (2006):

- ★N-body+hydrodynamic code GADGET-2, modeling star formation, condensation and evaporation, feedback energy from Type II SNs, photoionization heating, radiative cooling and metal enrichment
- ★Key ingredient: superwind feedback (to avoid the overprediction of the observed global star formation rate) --> "momentum-driven wind" model
- ★32/h Mpc box simulation combined with a 64/h Mpc box to better sample the bright end of the LF.

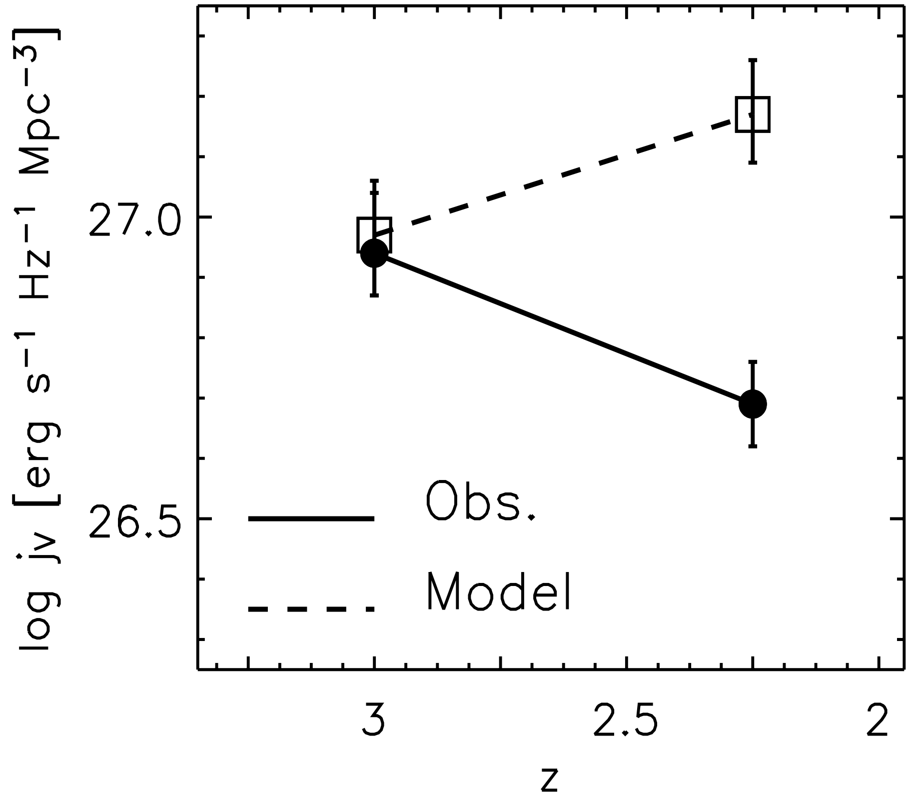


Results (1): LF comparison

- ★ At $2.7 \leqslant z \leqslant 3$ the global LF predicted by the SAM of Bower et al. (2006) agrees well with the observed LF; at $2 \leqslant z \leqslant 2.5$, the predicted characteristic density is $\Phi^{\star}$~2.5 times larger than the observed value
- ★ The SAM of De Lucia & Blaizot (2007) has difficulties with both the normalization and the slope of the LF
- ★ The SPH simulations predict LFs that are qualitatively similar to those predicted by the two SAMs

(DM & van Dokkum 2007)

Results (2): Luminosity density comparison



★ the Bower SAM matches the observed luminosity density at z~3

★ the Bower SAM does not match the evolution of the luminosity density with cosmic time

★ similar results for the De Lucia SAM, but strong dependency on the adopted faint-end integration limit

(DM & van Dokkum 2007)

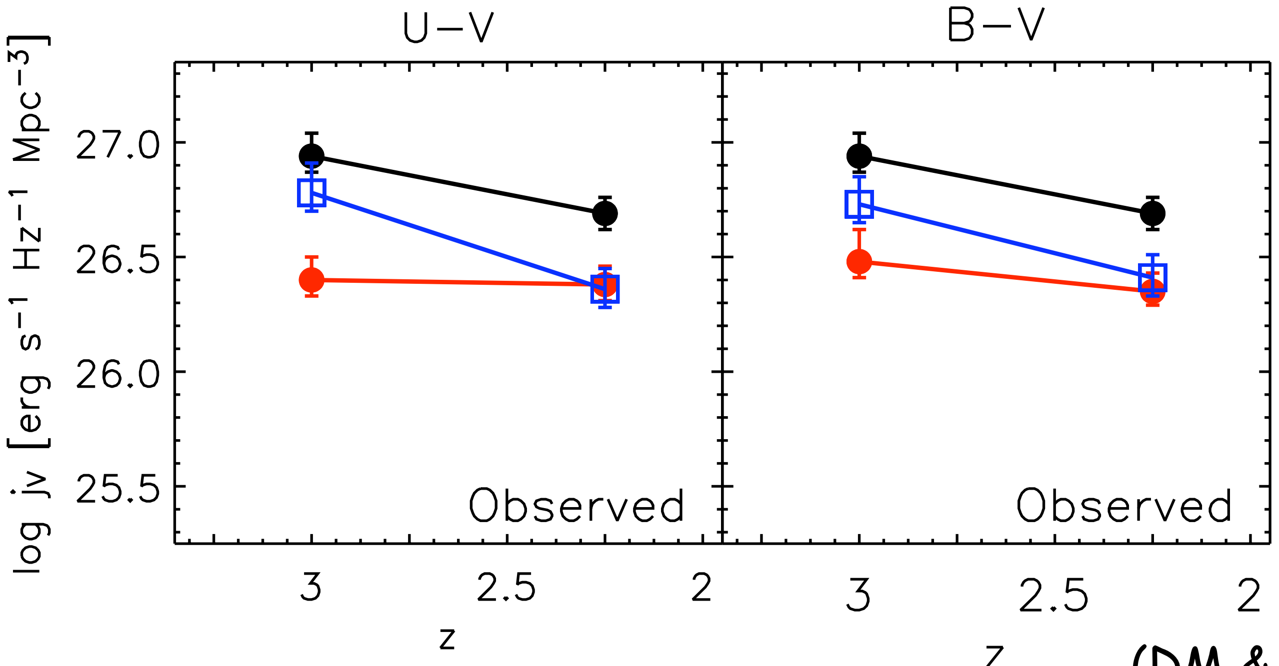
Splitting the sample into RED and BLUE galaxies

1. Split the sample based on rest-frame U-V color:

$$U - V \geq 0.25 \quad \text{red galaxies}$$
$$U - V < 0.25 \quad \text{blue galaxies}$$

2. Split the sample based on rest-frame B-V color:

$$B - V \geq 0.5 \quad \text{red galaxies}$$
$$B - V < 0.5 \quad \text{blue galaxies}$$



(DM & van Dokkum 2007)

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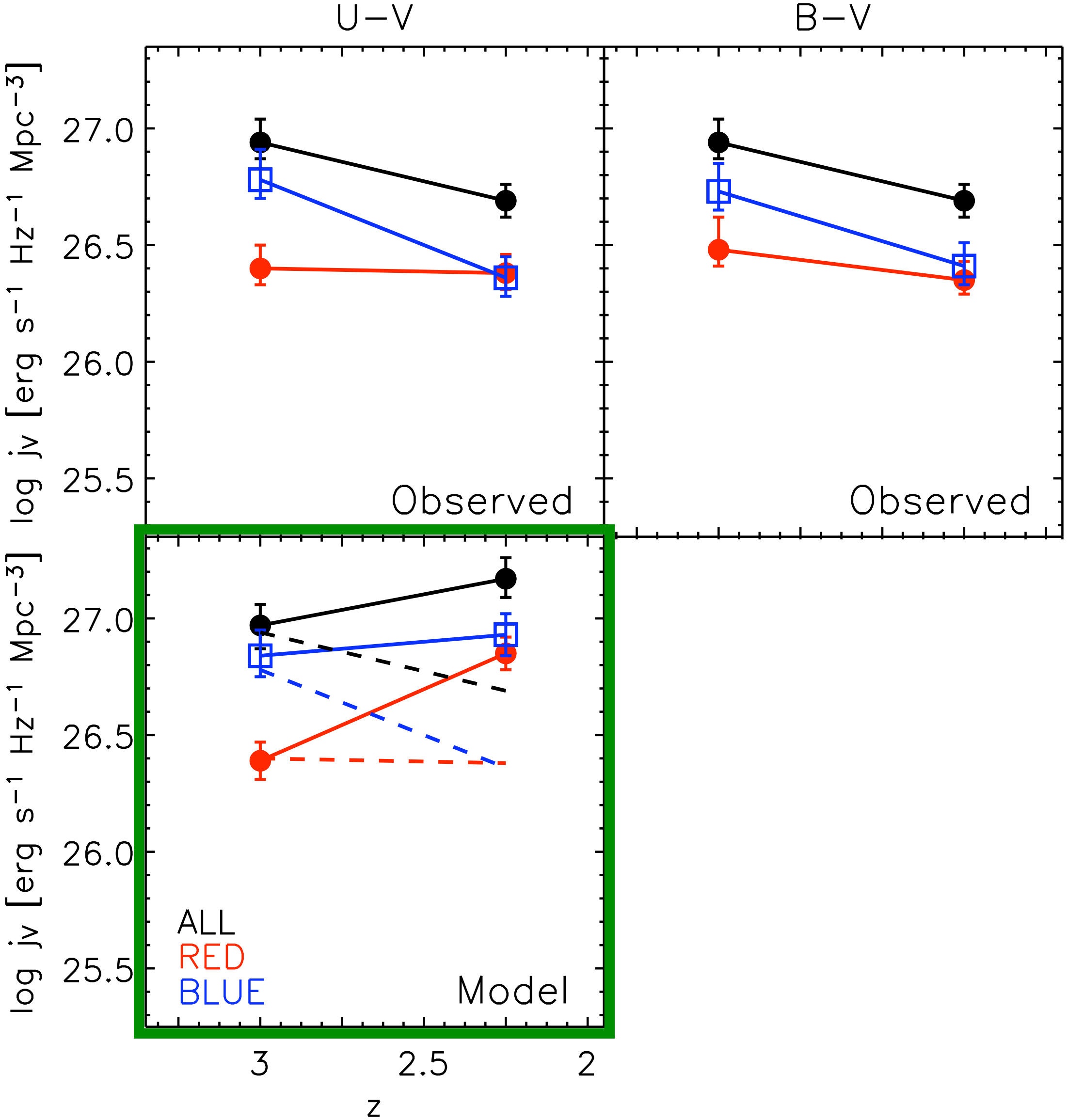

★ The Bower SAM reproduces the densities of red and blue galaxies at z~3 extremely well, but it overpredicts them at z~2.2

(DM & van Dokkum 2007)

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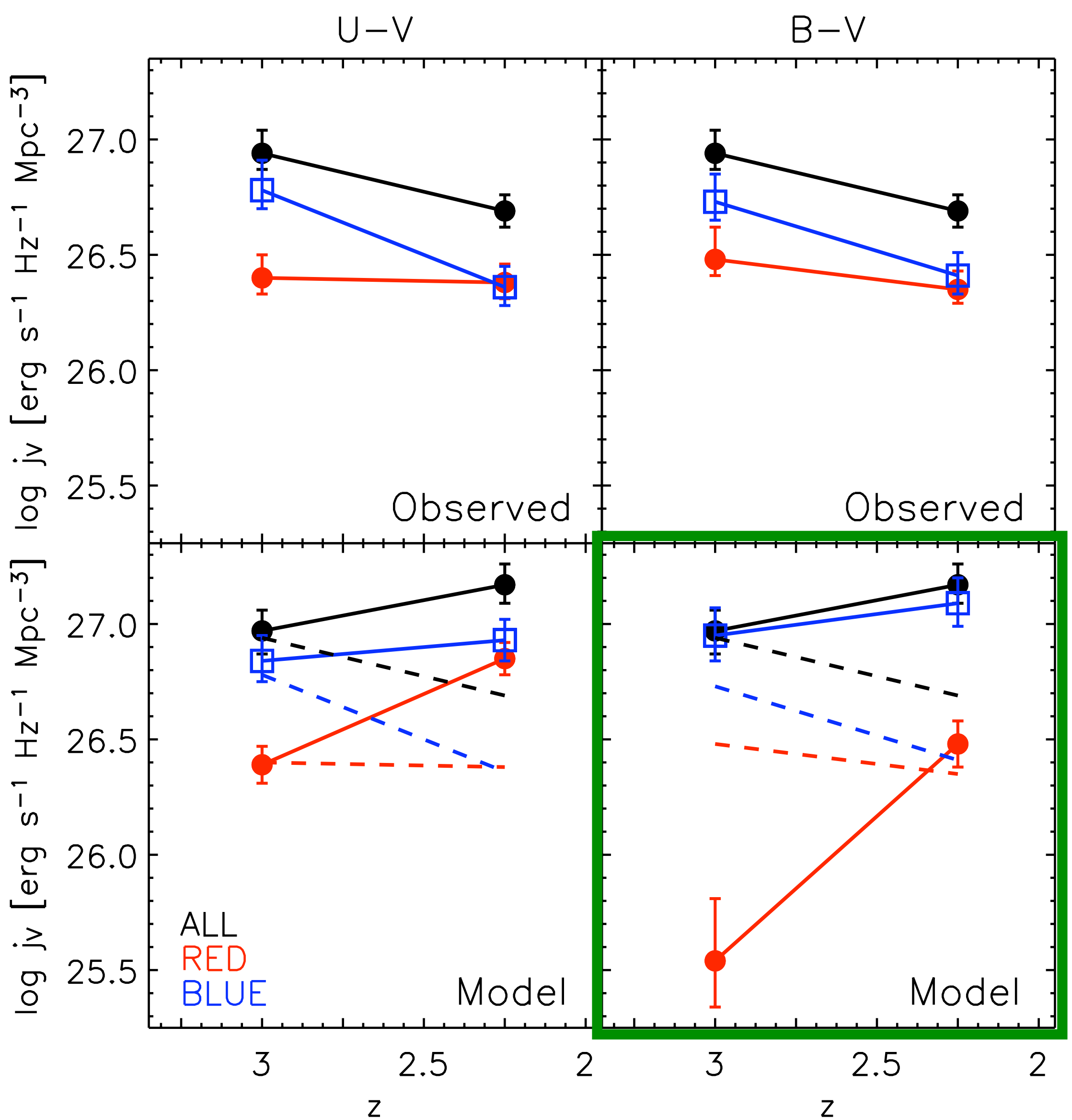

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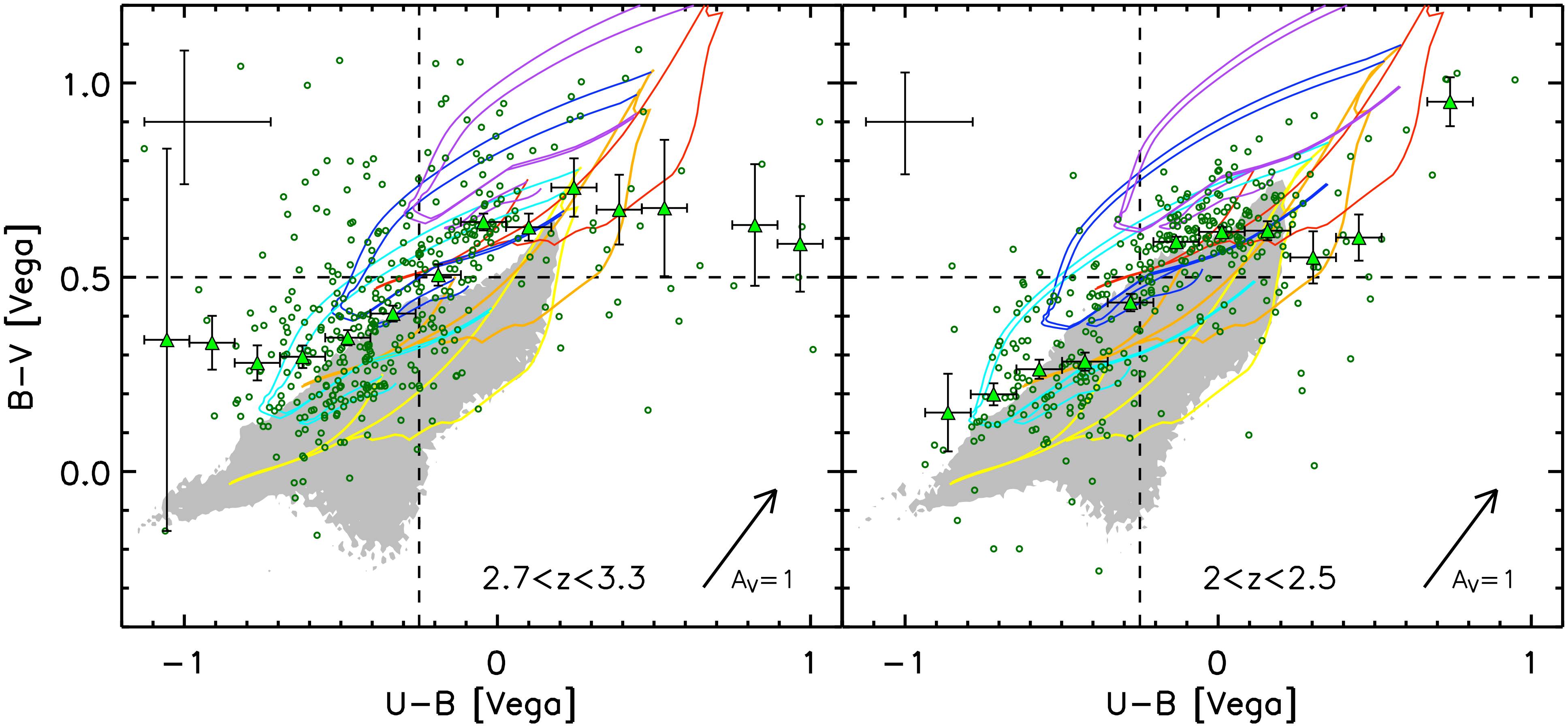
★ When B-V is used, the predicted densities are in severe disagreement with the observations, particularly at z~3

THE PREDICTED EVOLUTION OF THE RED AND BLUE LUMINOSITY DENSITIES IS IN QUALITATIVE DISAGREEMENT WITH THE OBSERVED EVOLUTION



Differences between observed and predicted colors could be due to larger amount of dust and/or more complex star formation histories in the observed galaxies

(DM & van Dokkum 2007)

Summary

1. The models succeed for some luminosity and redshift ranges, but fail for others. The SAM of Bower et al. (2006) reproduces the observed LF at z~3 well
2. all models predict an increase with time of the rest-frame V-band luminosity density, whereas the observations show a decrease
3. the models predict strong evolution in the red galaxy population, while in the observations most of the evolution is in the blue population
4. the models greatly underpredict the abundance of galaxies with B-V$\geqslant$0.5 at z~3
5. models have difficulties matching the observed rest-frame colors of galaxies
6. Ad hoc modifications of the dust treatment might help to alleviate some of the found disagreement, but not sufficient to accommodate the problem with global colors at z~3