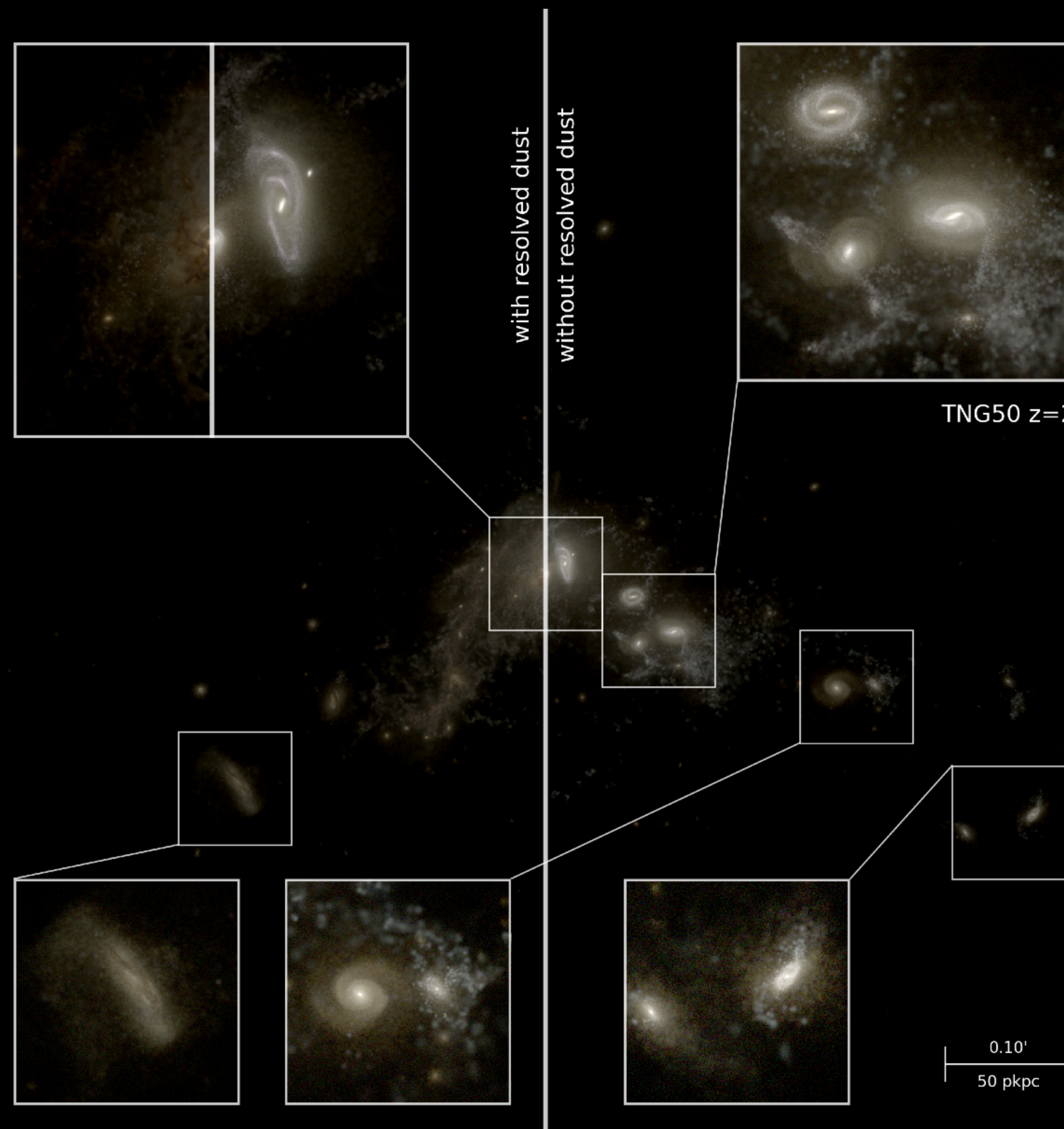
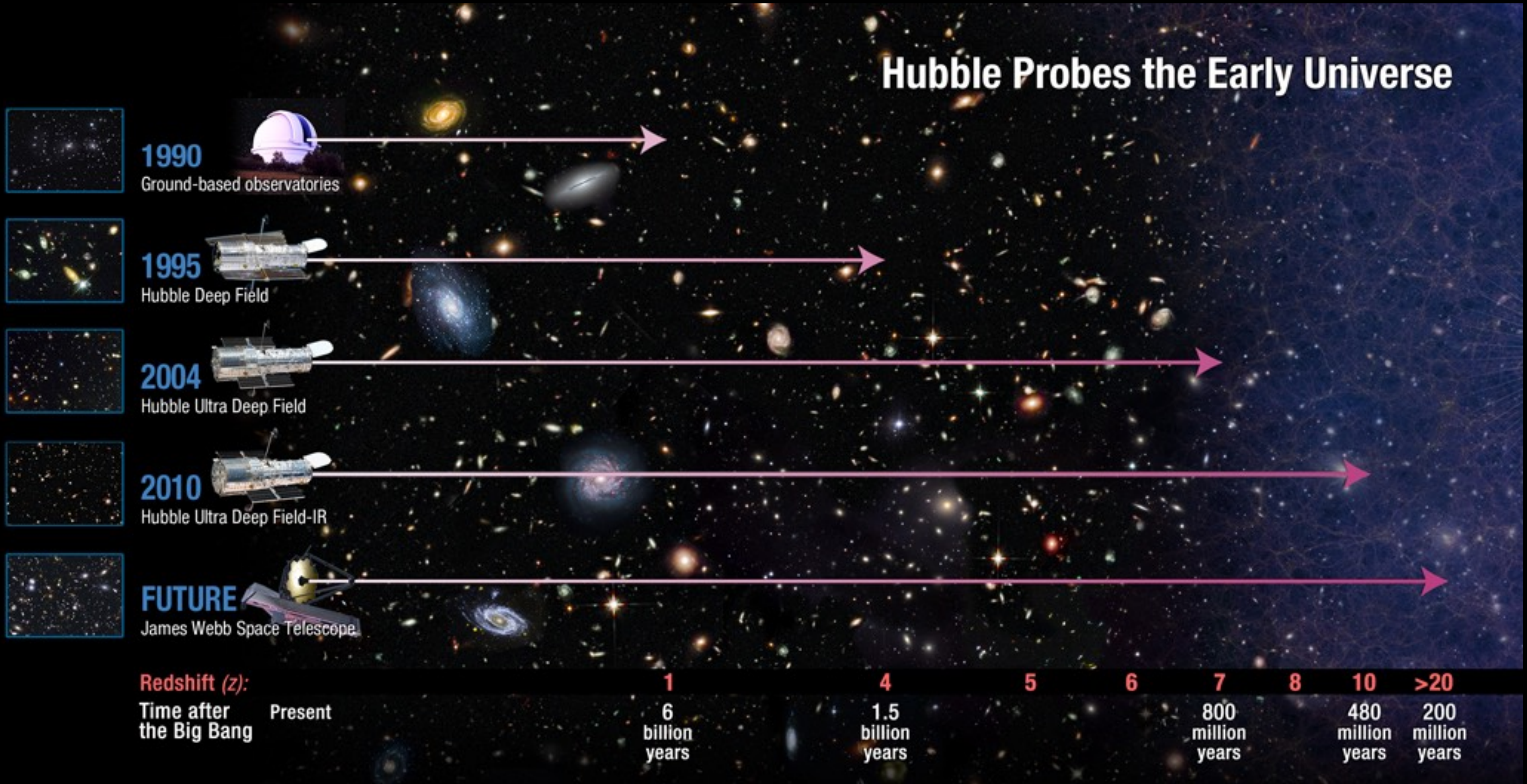
Predictions on High Redshift Galaxies from IllustrisTNG

Xuejian Shen



In collaboration with:
Mark Vogelsberger @MIT
Dylan Nelson @MPIA
Annalisa Pillepich @MPIA
Sandro Tacchella @Harvard

Observations



Wikipedia

- Galaxy rest-frame UV LF up to z ~ 10
- Photometric SEDs of several thousands galaxies up to z=8
- High-res spectroscopic observations up to z=3
- Limited wavelength coverage of the HST
- Sensitivity of current IR instruments

Theoretical Predictions

Empirical models

(e.g., Tacchella et al. 2013, 2018; Mason et al. 2015)

Semi-analytical models

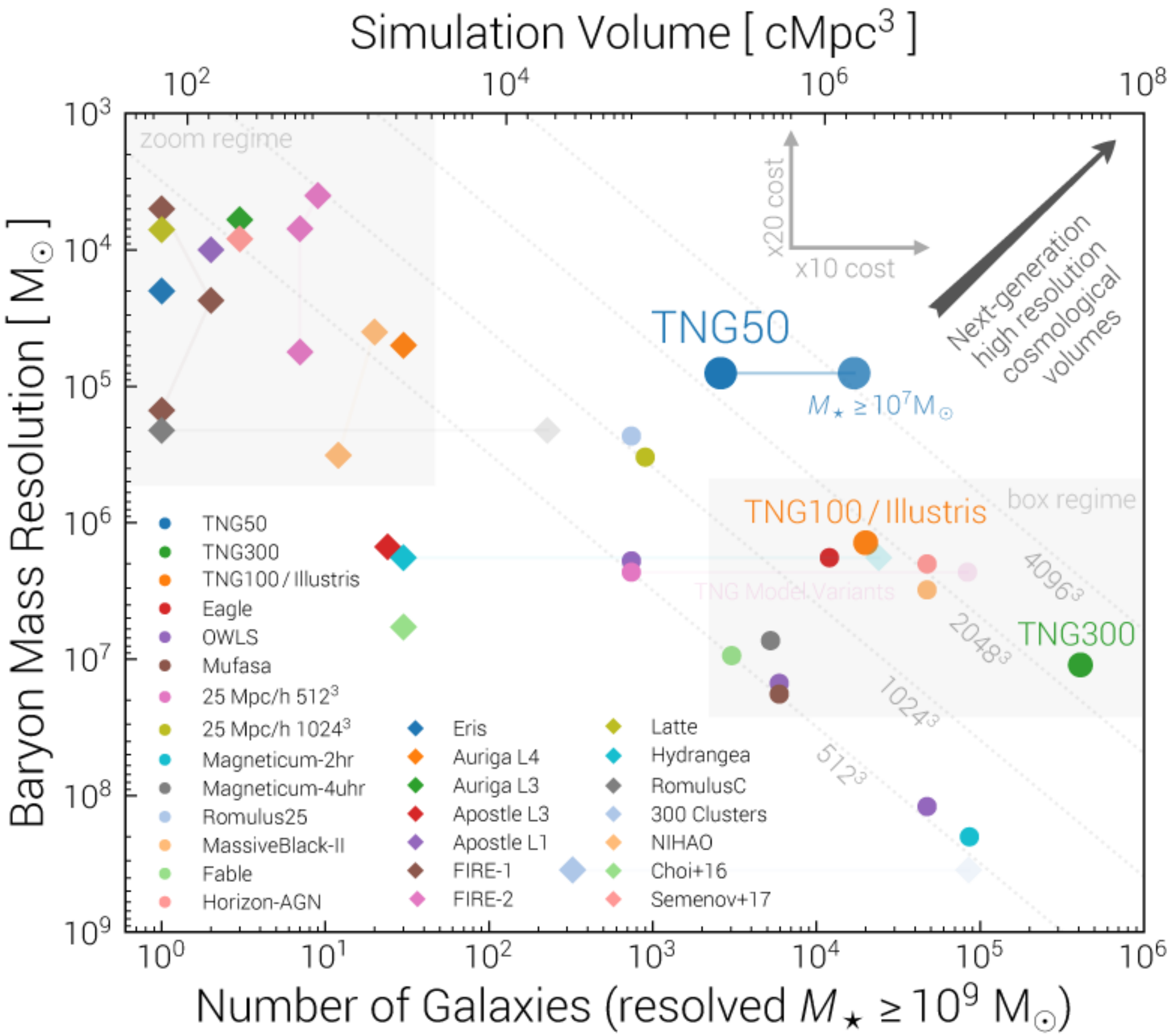
(e.g., Cowley et al. 2018; Yung et al. 2018)

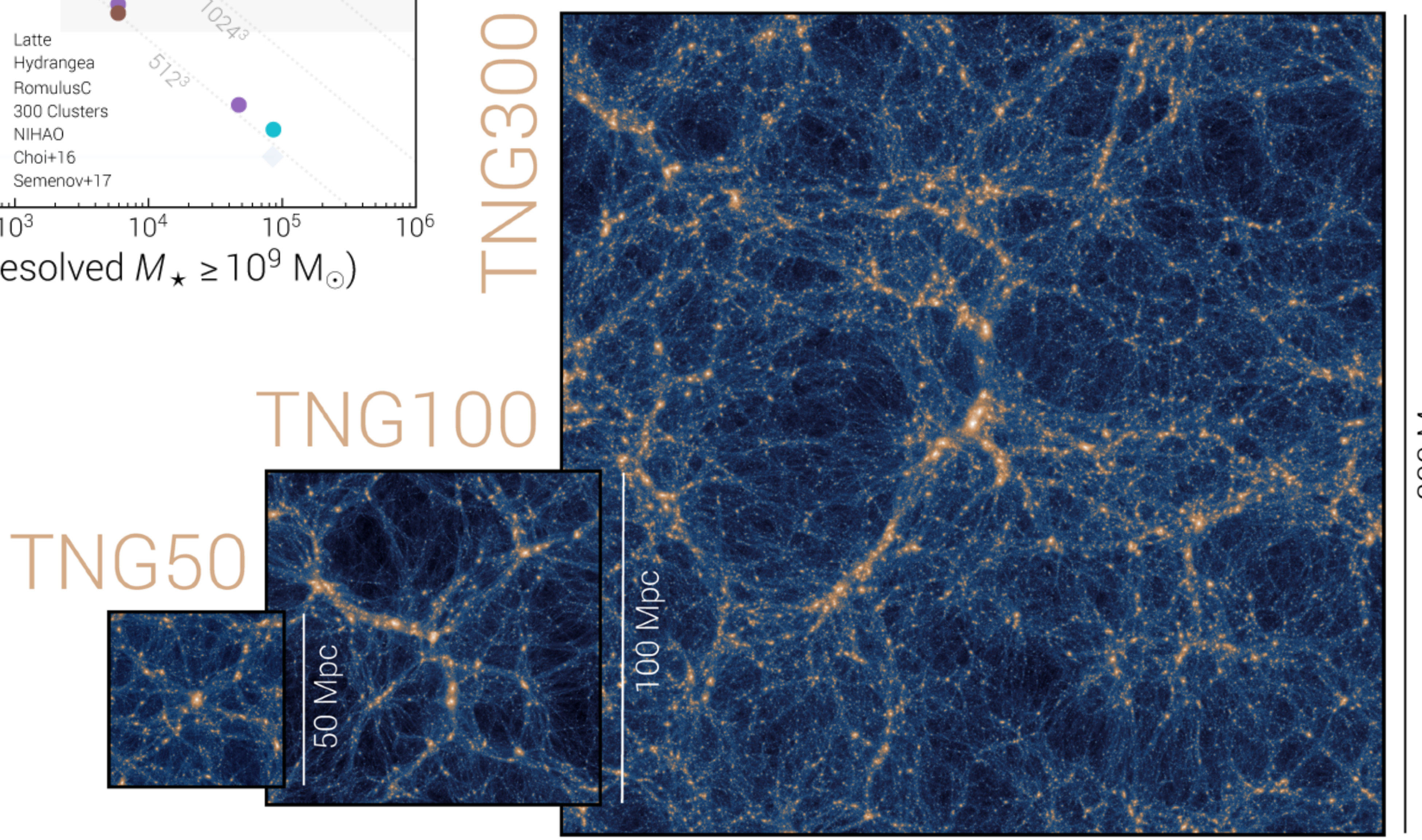
Hydrodynamical Simulations

First Billion Years suites (e.g., Paardekooper et al. 2013)
BlueTides (e.g., Wilkins et al. 2016, 2017)
Renaissance (e.g., Xu et al. 2016; Barrow et al. 2017)
FIRE-2 (e.g., Ma et al. 2018a)
Sphinx (e.g., Rosdahl et al. 2018)

but only evolved down to relatively high z, ~4-5
- not yet tested over numerous local observational constraints

IllustrisTNG
- The Next Generation of large box cosmological hydrodynamical simulations





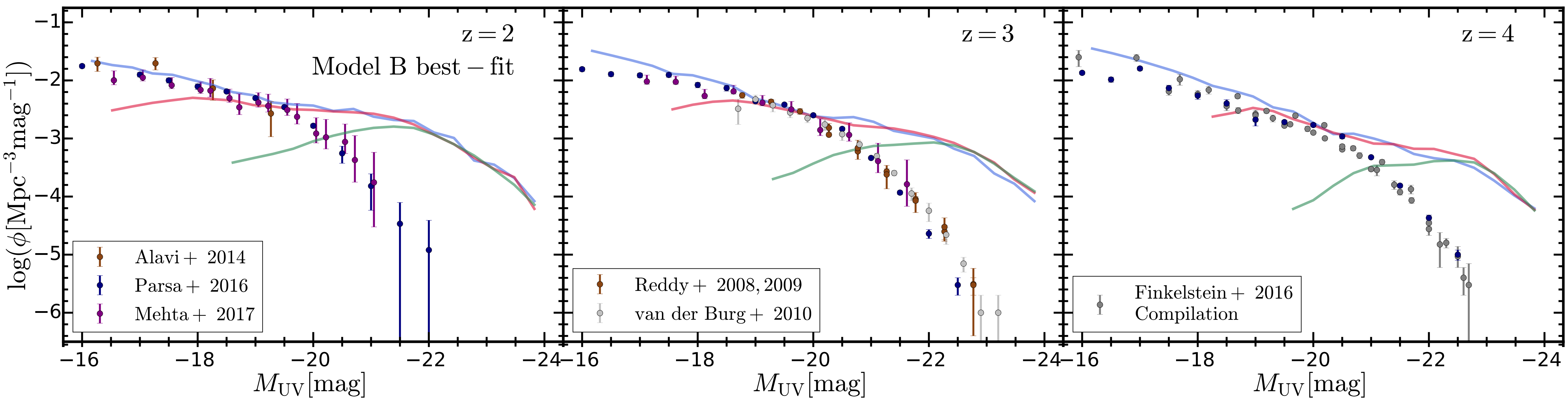
credit to the TNG collaboration

Observables? → Stellar Population Synthesis

(e.g., FSPS, Conroy et al. 2009; Conroy & Gunn 2010; Groves et al. 2008)

TNG100,300 not converged → Resolution correction based on halo mass

UV luminosity function (number density versus UV luminosity):



Predictions from different simulations nicely patched together; but the predicted galaxies are way brighter than the observed ones

What is missing?

Dust

Dust absorbs the UV photons from stars and reprocesses them to infrared

- A. Empirical corrections based on observed relations

$$A_{\rm UV} = C_0 + C_1\beta.$$

$$\langle\beta\rangle(M_{\rm UV}^{\rm dust}) = \frac{{\rm d}\beta}{{\rm d}M_{\rm UV}^{\rm dust}}(z)\,[M_{\rm UV}^{\rm dust} - M_0] + \beta_{M_0}(z),$$

- B. “Assign” attenuation on particles based on optical depth

Column density of resolved gas for each stellar particle

Dust column density /Optical depth

Assumptions on the geometry

Attenuation

$$\tau_{\rm V}^{\rm res} = \tau_{\rm dust}(z)\left(\frac{Z_{\rm g}}{Z_\odot}\right)^{\gamma}\left(\frac{N_{\rm H}}{N_{\rm H,0}}\right),$$

$$A_{\rm V}^{\rm res} = -2.5\log\left(\frac{L_{\rm V}^{\rm dust}}{L_{\rm V}^{\rm dust-free}}\right) = -2.5\log\left(\frac{1-e^{-\tau_{\rm V}^{\rm res}}}{\tau_{\rm V}^{\rm res}}\right).$$

$$A^{\rm res}(\lambda) = A_{\rm V}^{\rm res}\left(\frac{k'(\lambda)}{4.05}\right),$$

- C. Radiative transfer

(Baes et al. 2011; Camps et al. 2013; Camps & Baes 2015; Saftly et al. 2014).

SPS

Stellar particles

Source distribution

Release photon packages

Collect photons with mock detectors

emulate the scattering, absorption and emission by dust in a Monte Carlo fashion

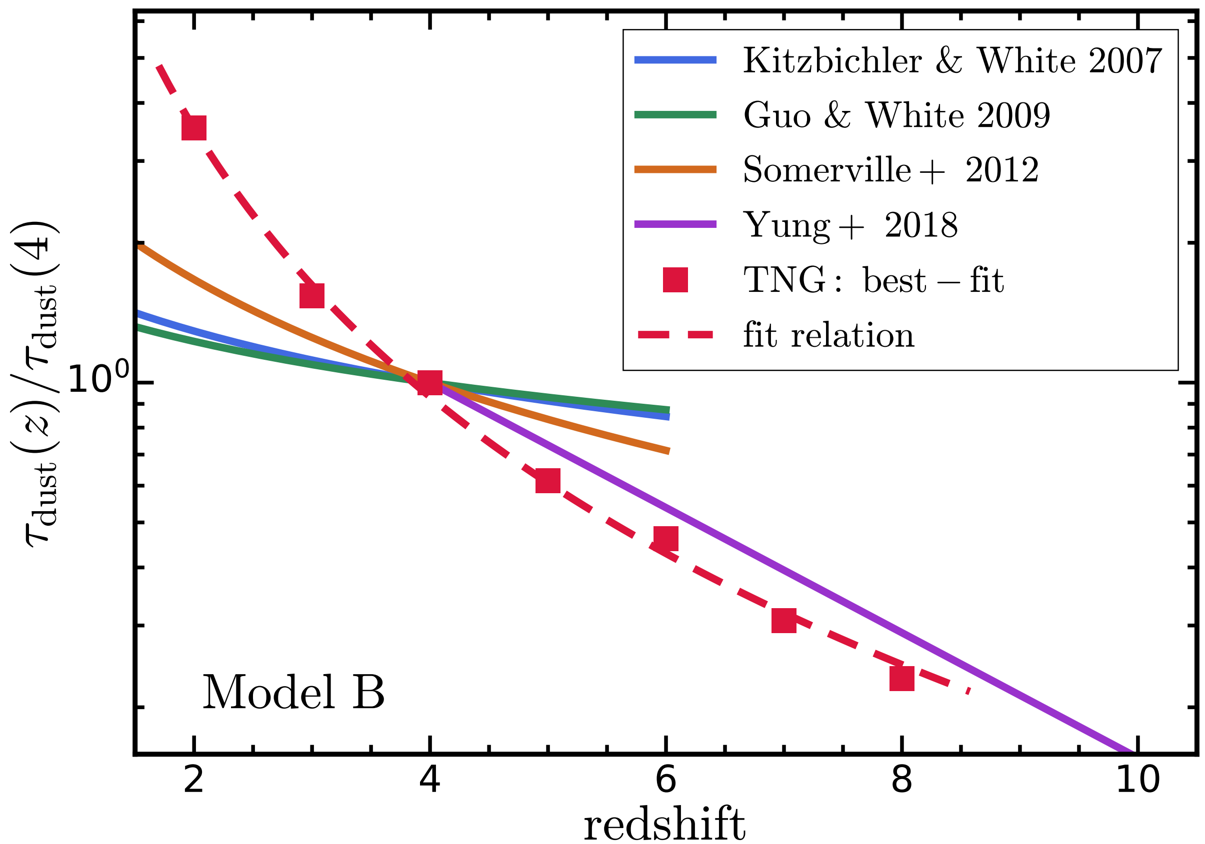
Cold star-forming Gas cells

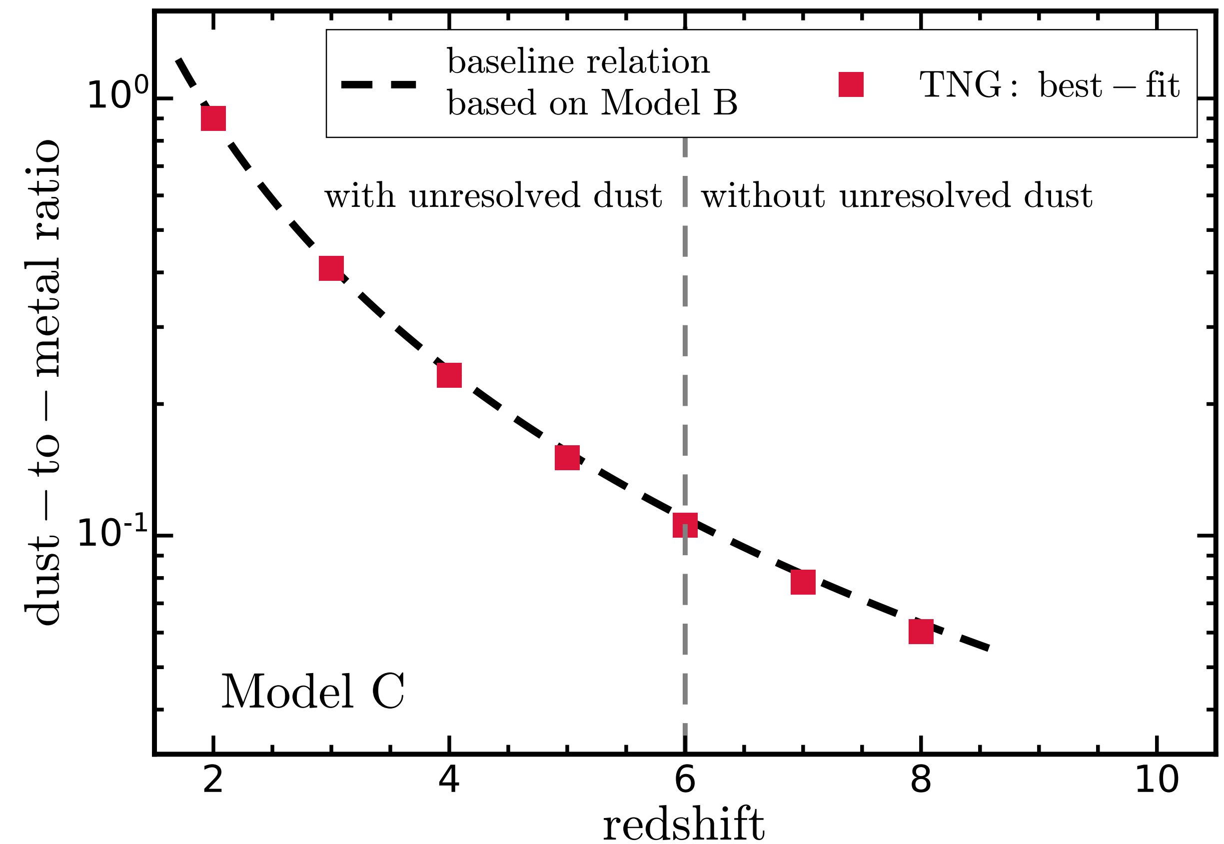
Metal distribution

Dust-to-metal ratio

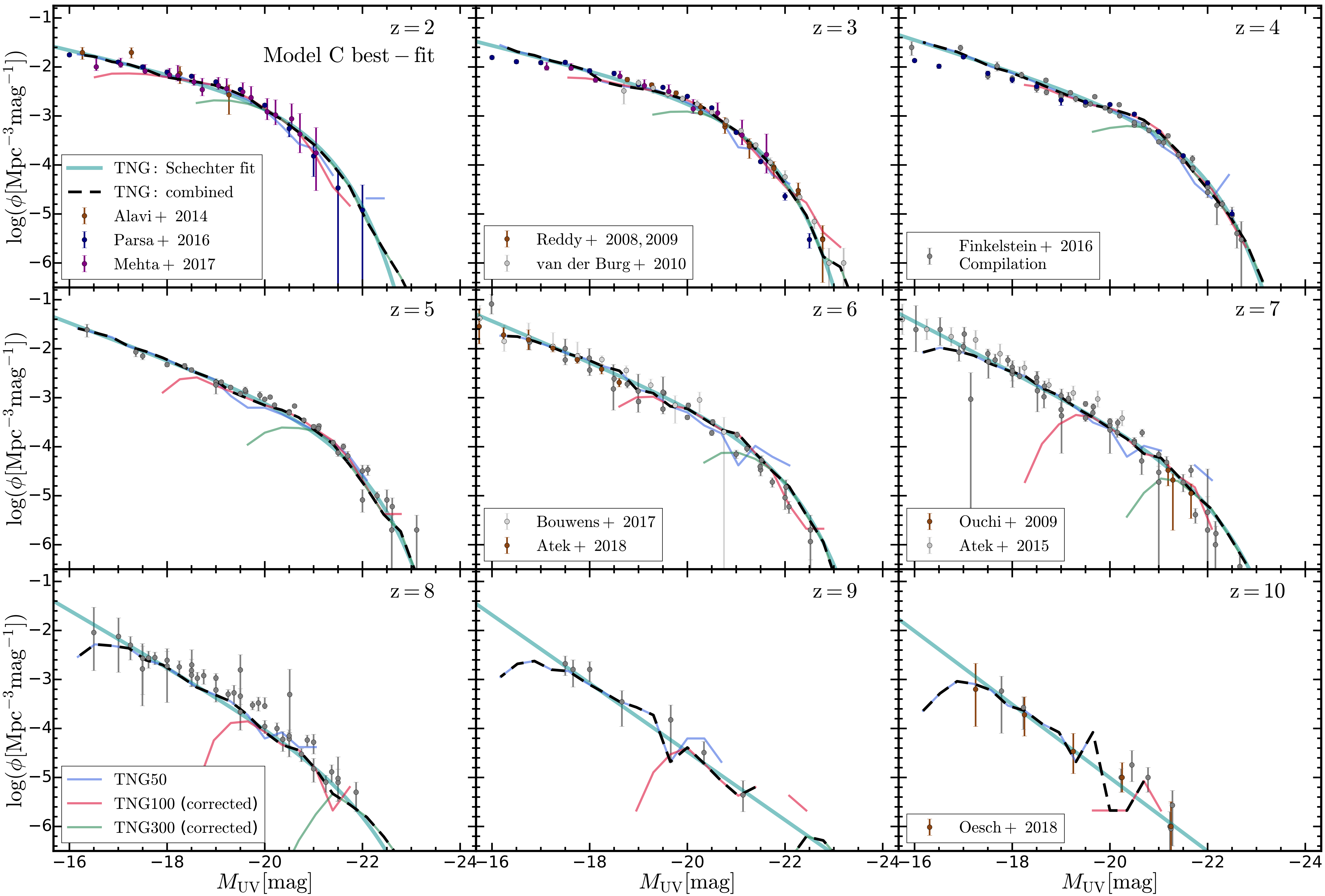
Dust distribution

Calibrations





Calibrate Model B first and use it as a guide in the calibration of Model C

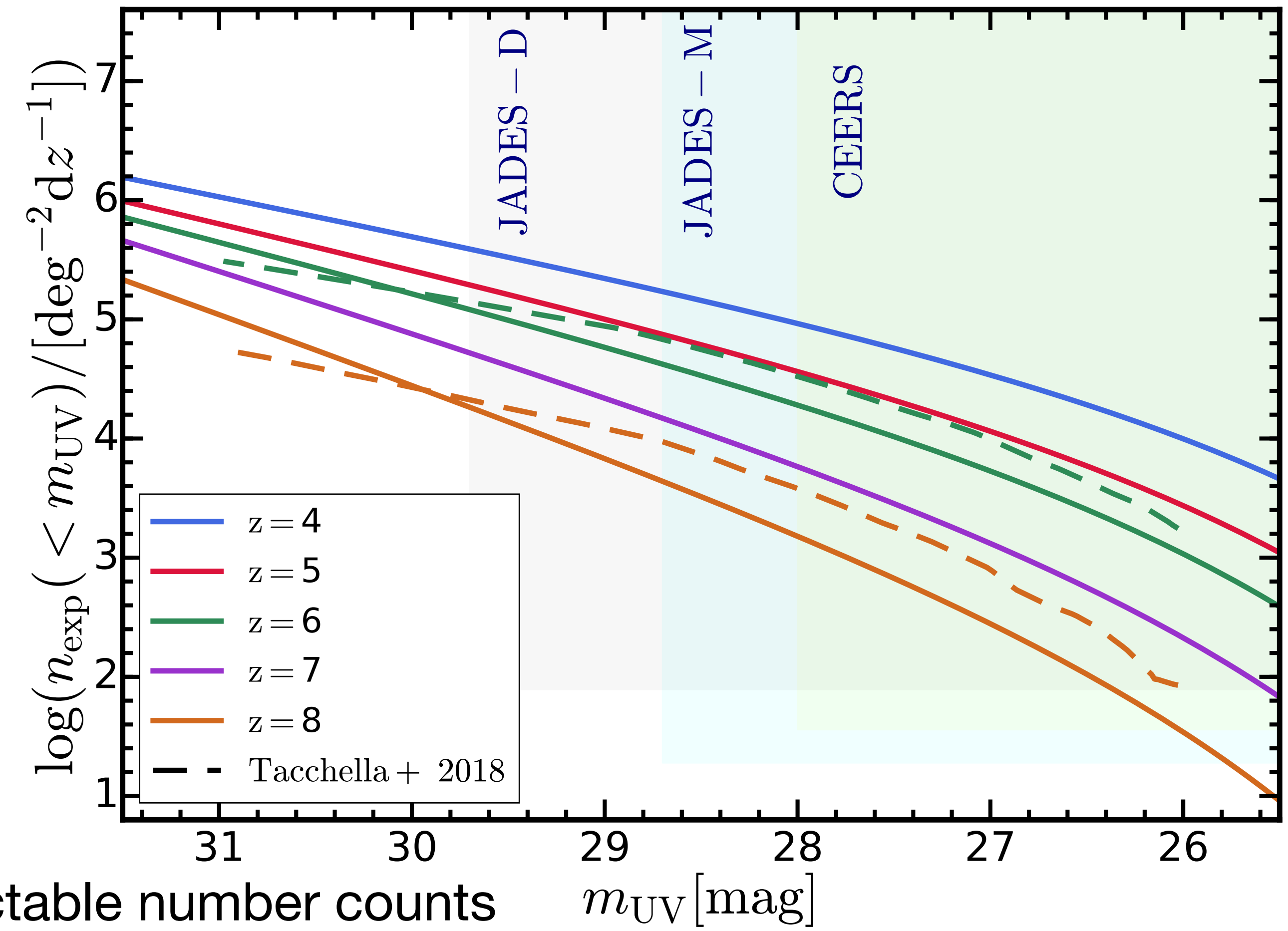


z = 2
Model C best − fit
TNG : Schechter fit
TNG : combined
Alavi + 2014
Parsa + 2016
Mehta + 2017
z = 3
Reddy + 2008, 2009
van der Burg + 2010
z = 4
Finkelstein + 2016
Compilation
z = 5
z = 6
Bouwens + 2017
Atek + 2018
z = 7
Ouchi + 2009
Atek + 2015
z = 8
TNG50
TNG100 (corrected)
TNG300 (corrected)
z = 9
z = 10
Oesch + 2018
$\log(\phi[\mathrm{Mpc}^{-3}\mathrm{mag}^{-1}])$
$M_{\mathrm{UV}}[\mathrm{mag}]$

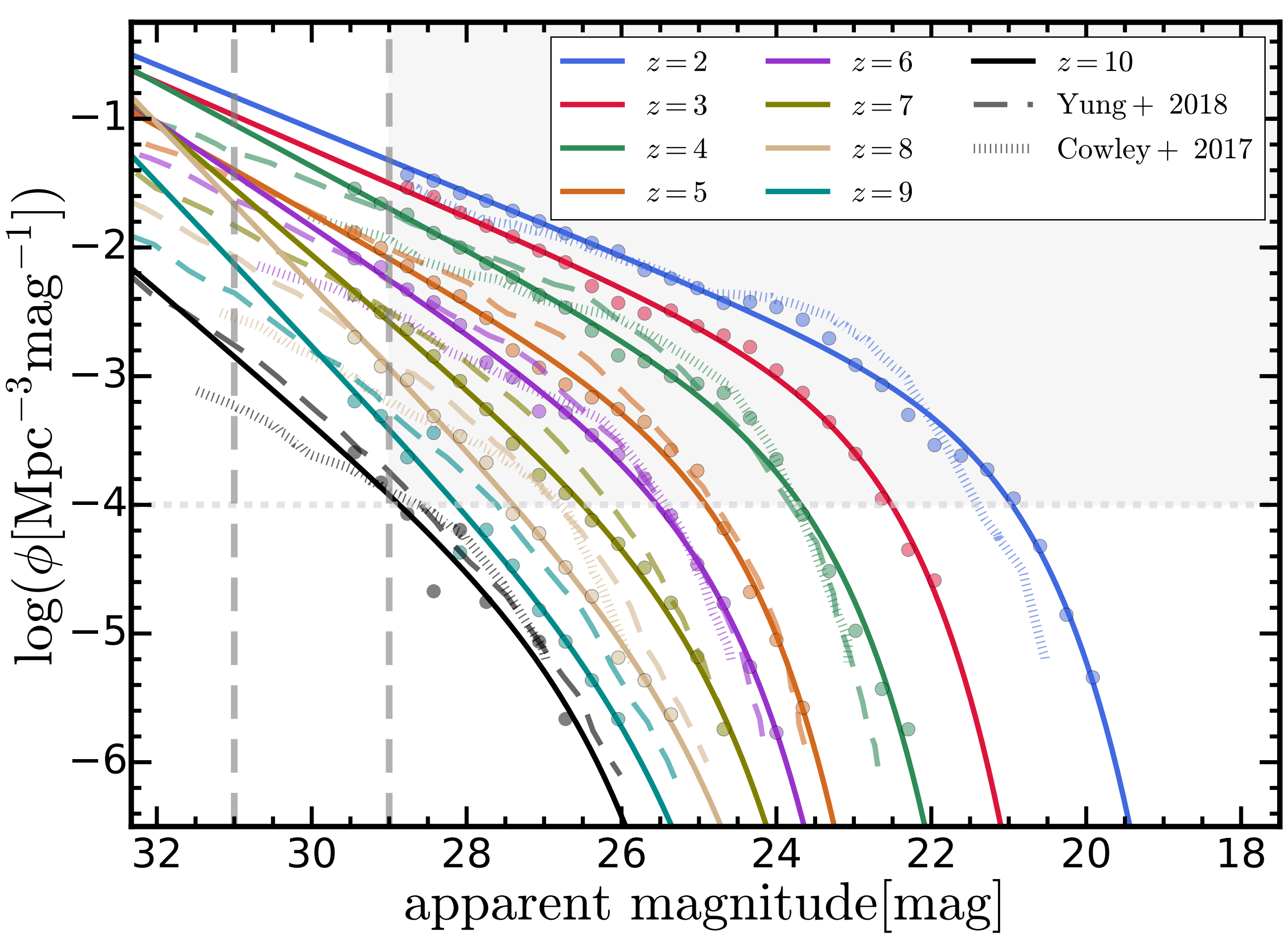
A catalog of high-z galaxies with …

Broadband Photometry

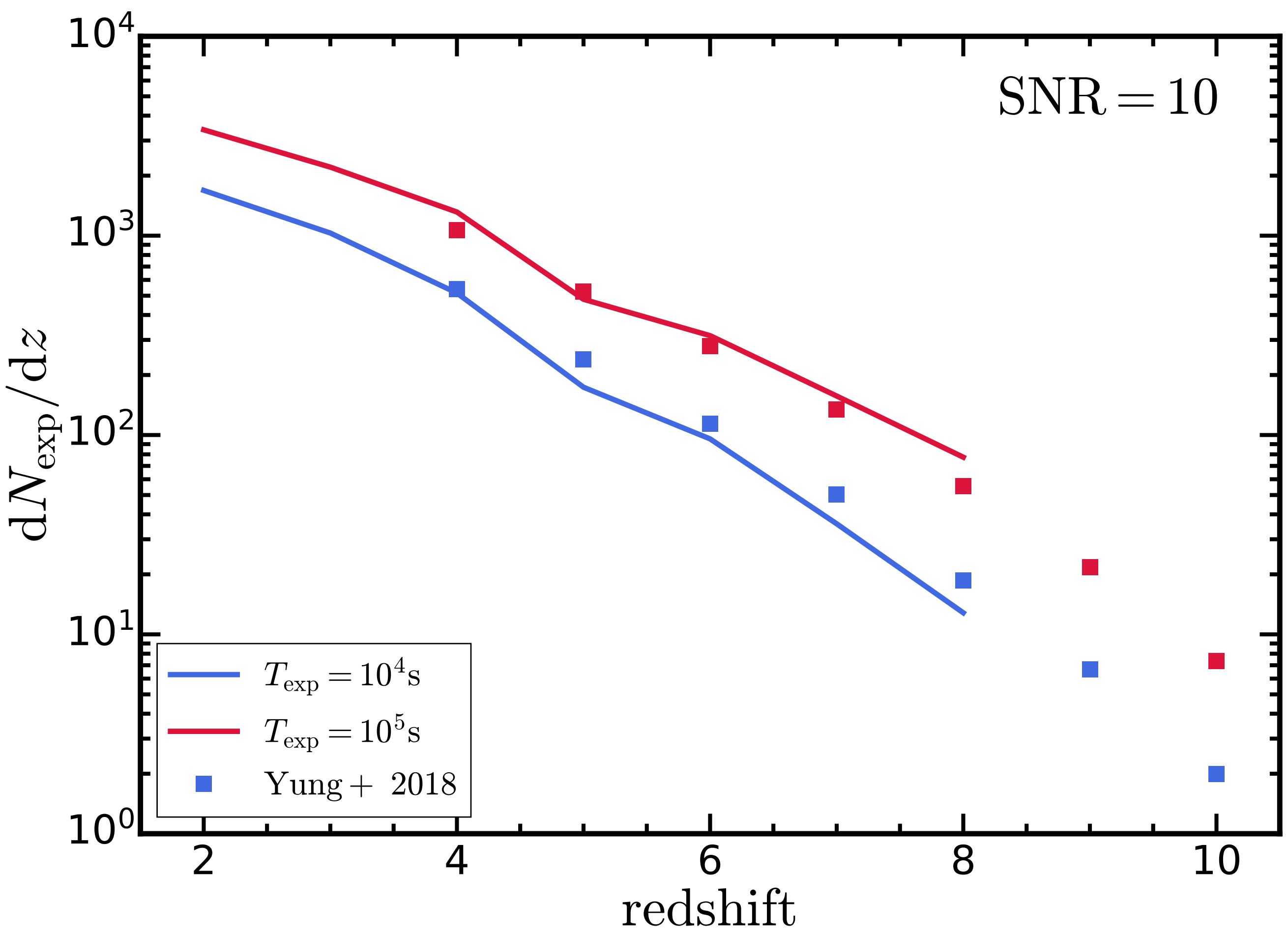
Predictions for wide-field surveys



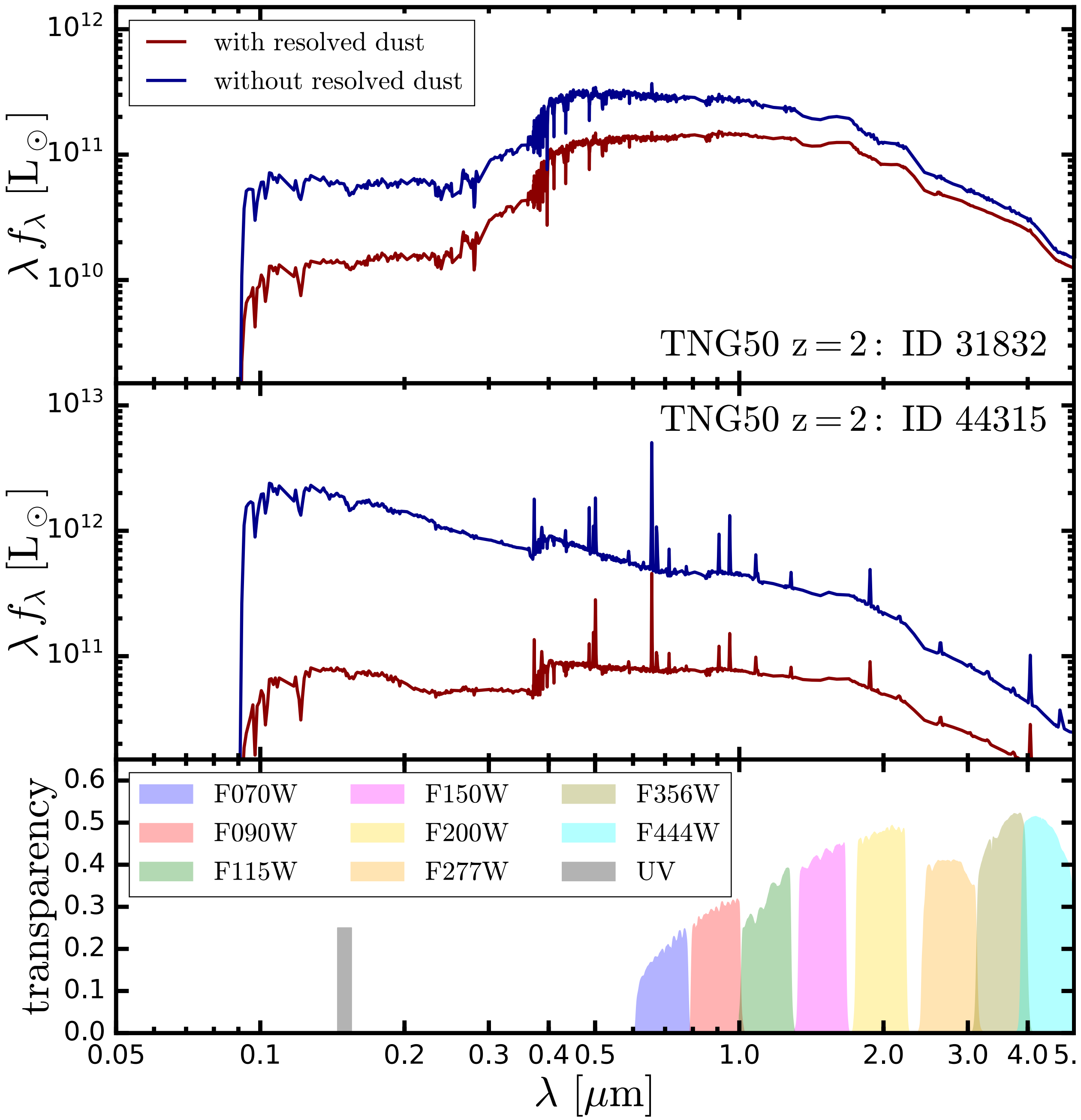
JWST F200W apparent LF



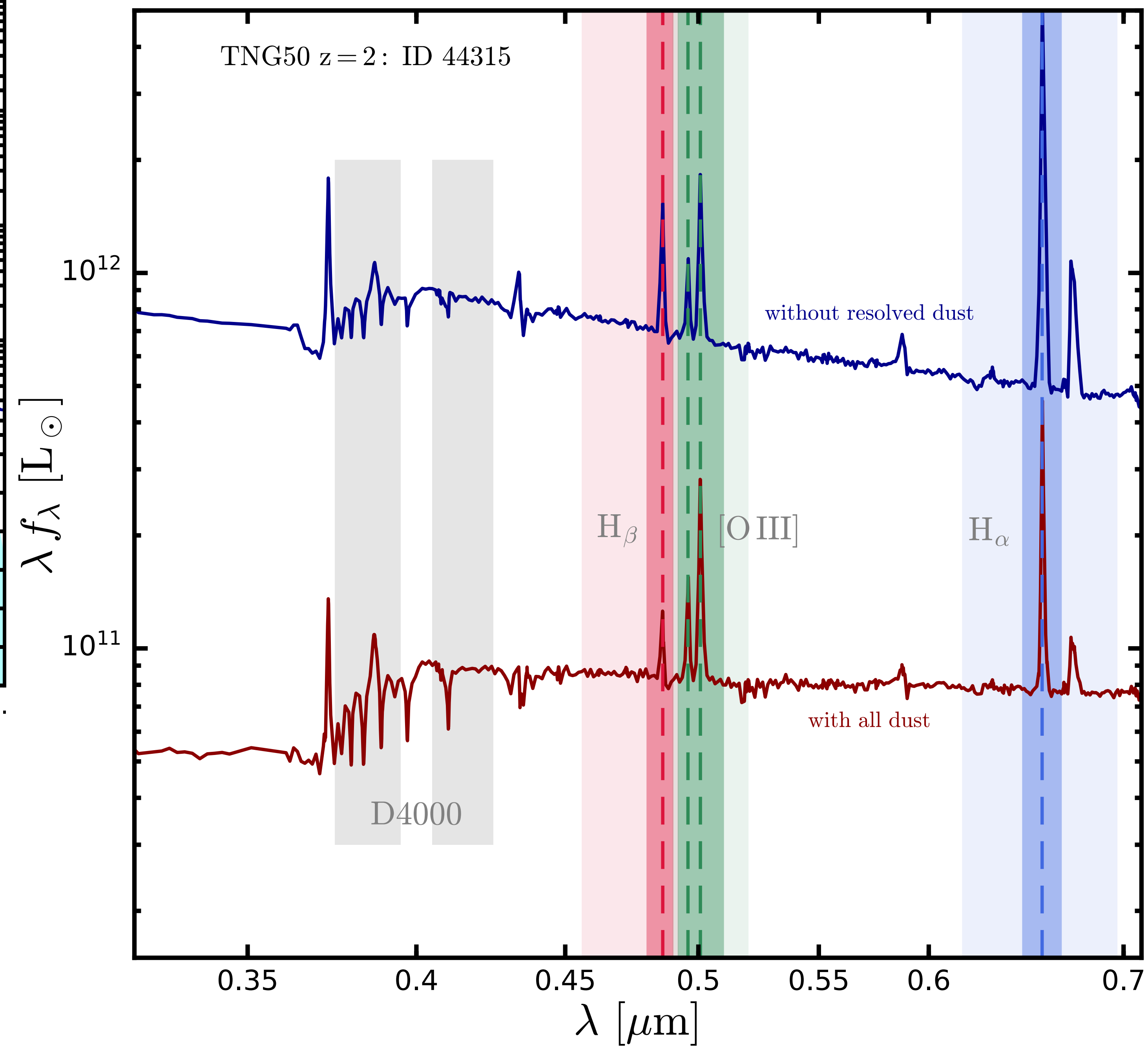
Detectable number counts



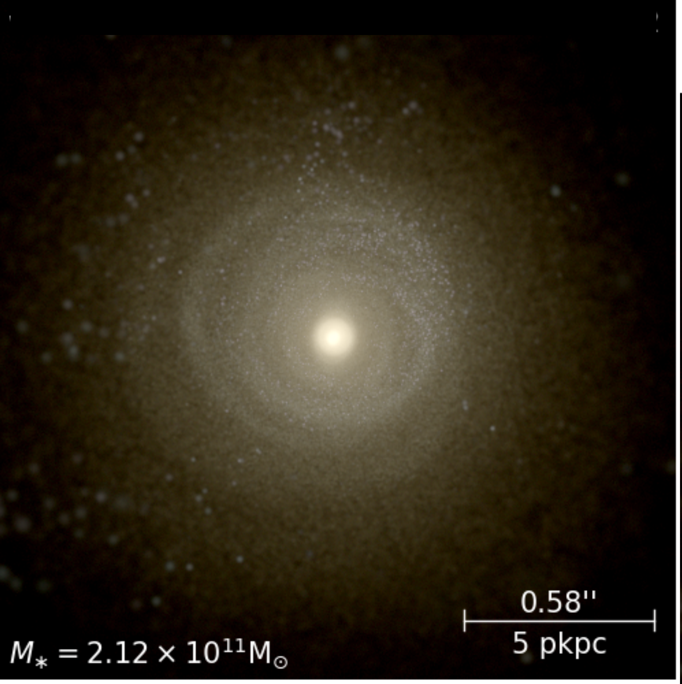
UV to NIR SEDs

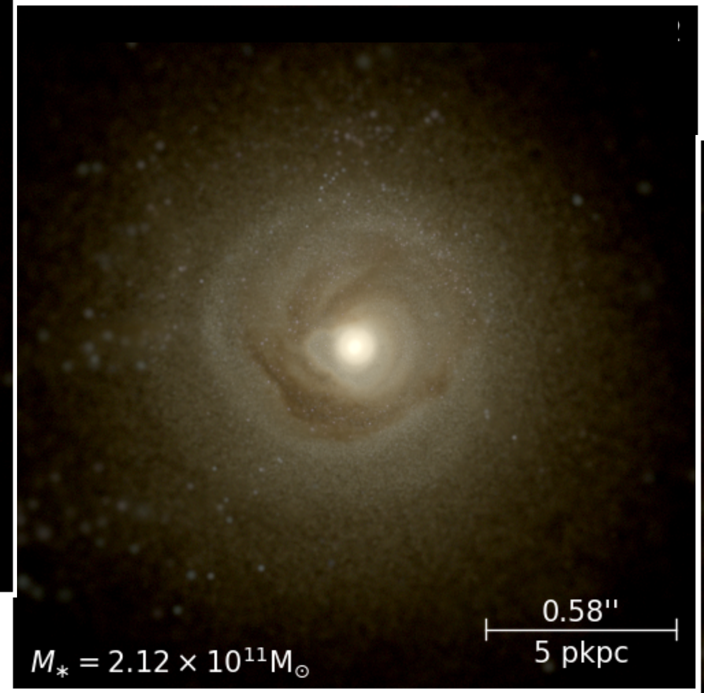


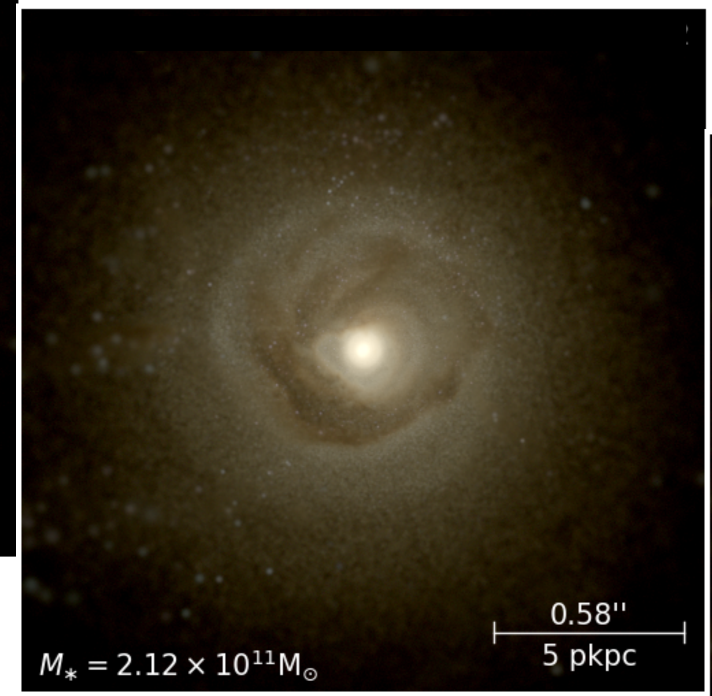
Well-resolved spectral features:
e.g., emission lines, the Balmer break

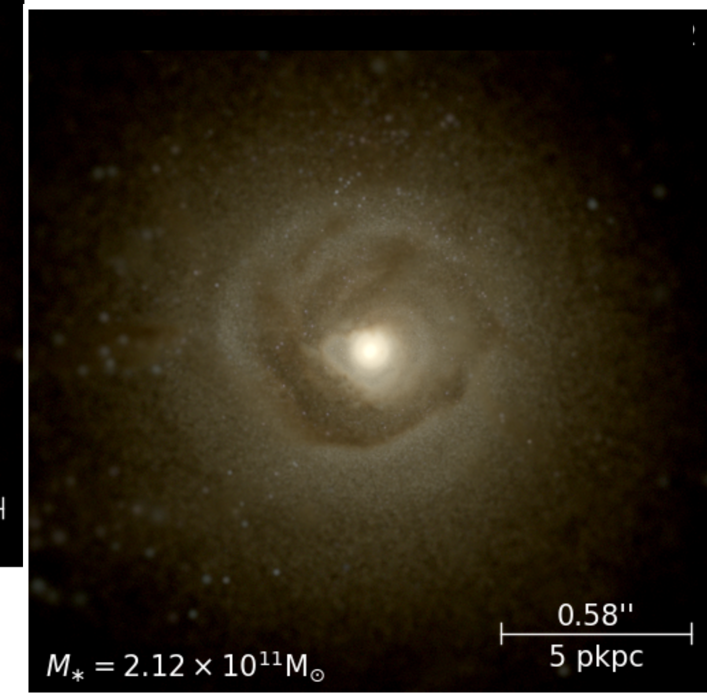


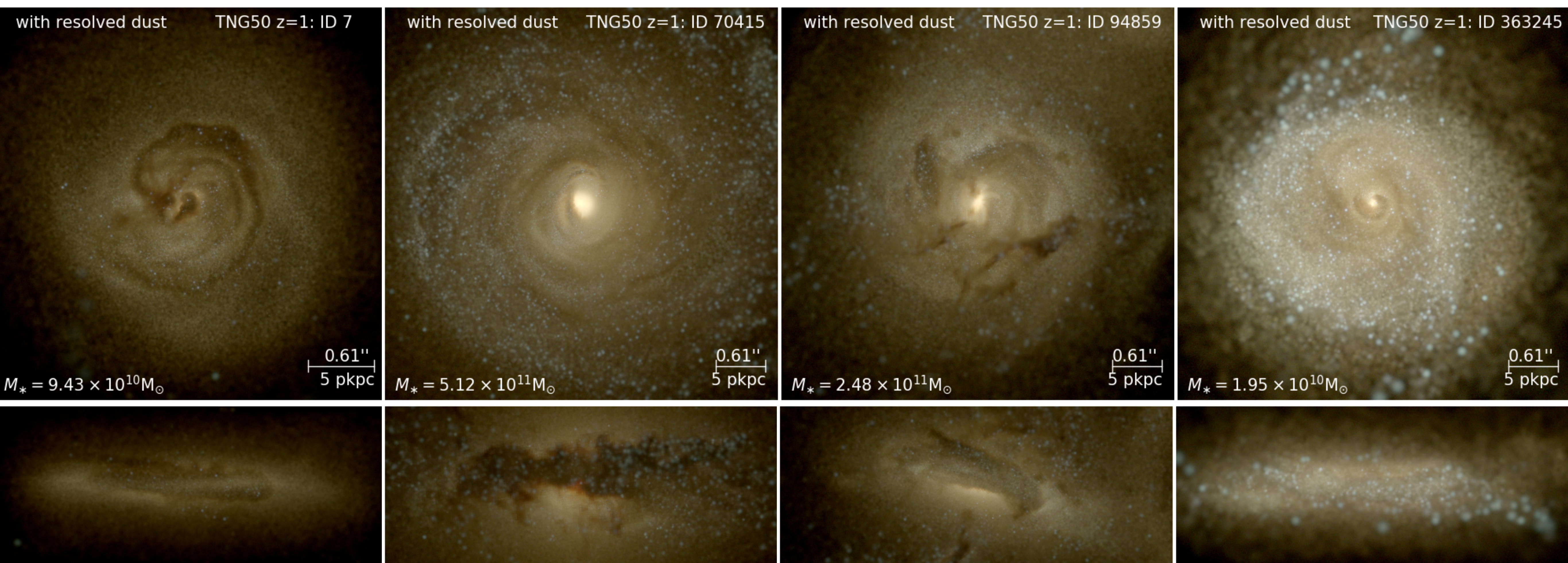
JWST Mock images





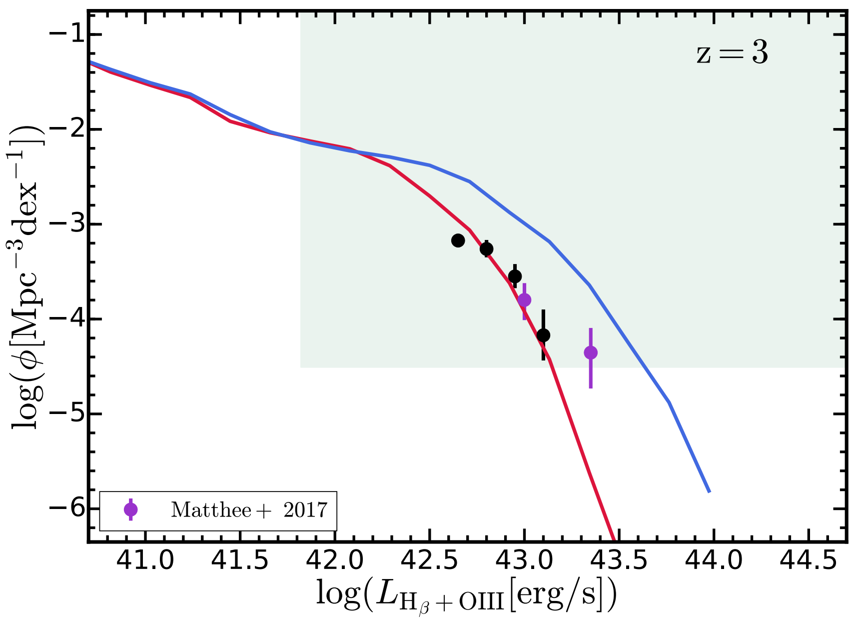






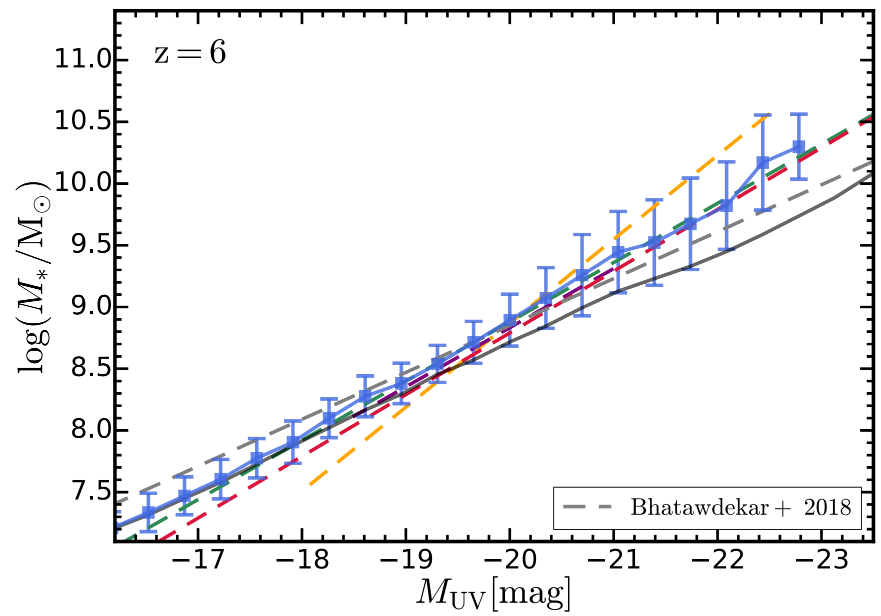
Emission line LFs

e.g., H_β + [O III] LF

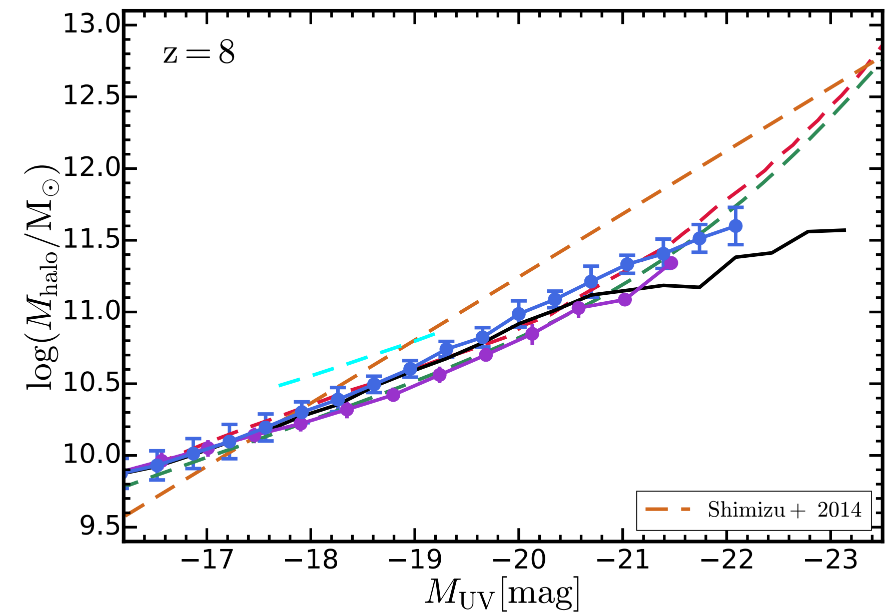


Scaling relations

$M_* - M_{\mathrm{UV}}$

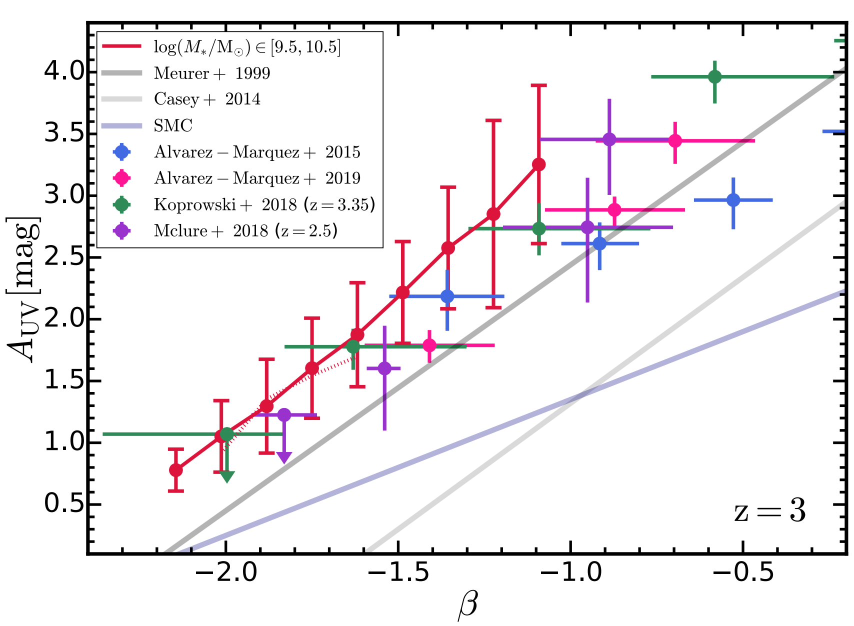


$M_{\mathrm{halo}} - M_{\mathrm{UV}}$



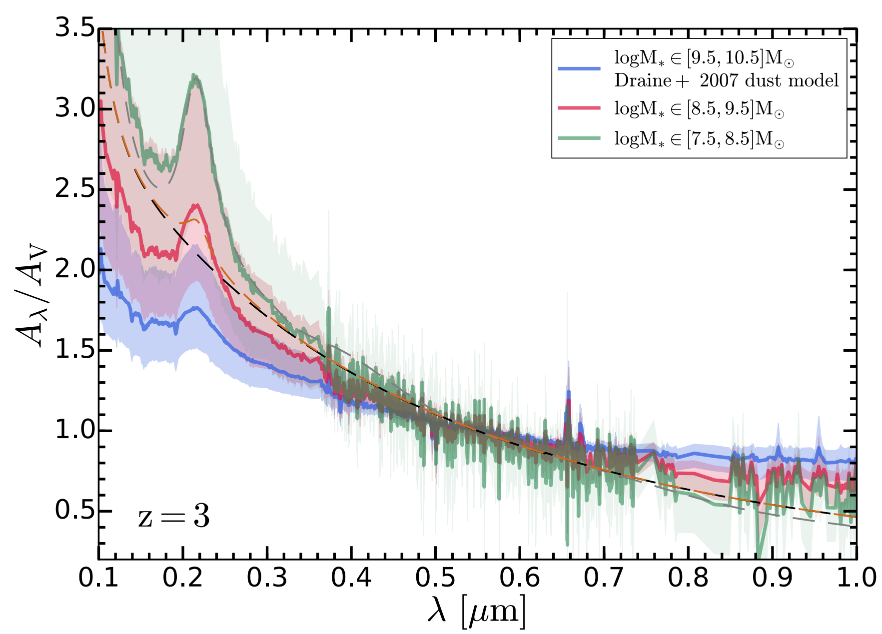
Dust indicators

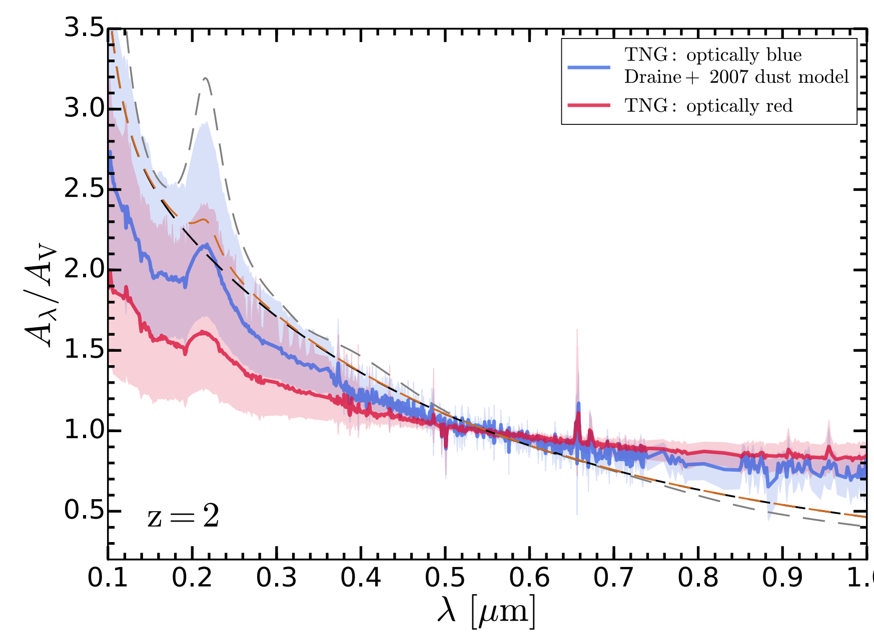
e.g., UV continuum slope



Attenuation curves (only geometrical influence)

e.g., variation, dependence on stellar mass, color etc.





Thanks!