THE BLUETIDES SIMULATION

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MOTIVATION AND REQUIREMENTS

The aim of BlueTides is to understand the physics of early galaxy formation and evolution by simulating the population of galaxies (including SMBHs) at high-redshift (EoR) observationally accessible to HST, VISTA, ALMA, JCMT, JWST, WFIRST, ELTs, and Herschel.

The aim is to simulate statistically useful samples of galaxies over a stellar-mass range of $10^{7.5}$ - $10^{10.5}$ $M_{\odot}$ at z~6-8.

BLUETIDES
SIMULATION

BlueTides is a **very large** cosmological hydrodynamical simulation of the high-redshift Universe run using the NCSA BlueWaters facility.

- It simulates down to z=8 (phase I, completed) and z=6 (phase II, ongoing)
- Simulates a volume ~577^3 Mpc^3
- Roughly 200 times larger than EAGLE and Illustris. 10,000 times that of a single NIRSpec pointing at z=8-9.
- 2×7040^3 ~ 0.7 trillion particles
- Mass/Spatial resolution is slightly worse than EAGLE and Illustris

See: Feng et al. 2015, 2016; Wilkins et al. 2016bcde; Waters et al. 2016ab; di Matteo et al. 2016; and others in the future

BLUETIDES

GALAXY STELLAR MASS FUNCTION

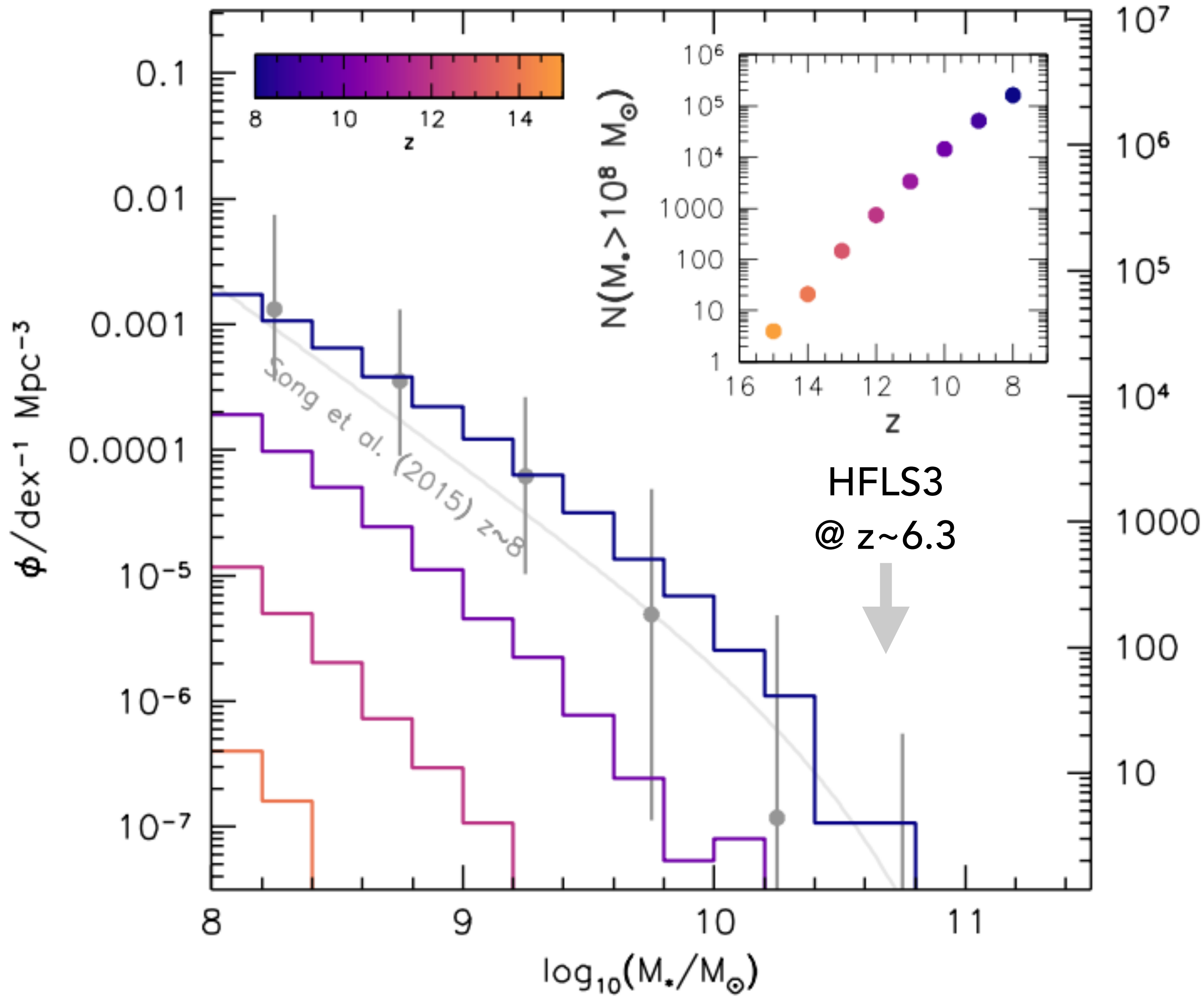
BlueTides reproduces observational constraints on the GSMF at z~8.

It simulates sufficient volume to include the most massive galaxies identified at high-redshift.

Observations from Song et al. (2015). Note: observational estimates of the GSMF at high-redshift are highly uncertain, with significant variation between different studies.

number of galaxies in each mass bin in BLUETIDES.

Wilkins et al., 2016d, submitted.



Wilkins et al., 2016d, submitted.

B L U E T I D E S

G A L A X Y S T E L L A R M A S S F U N C T I O N

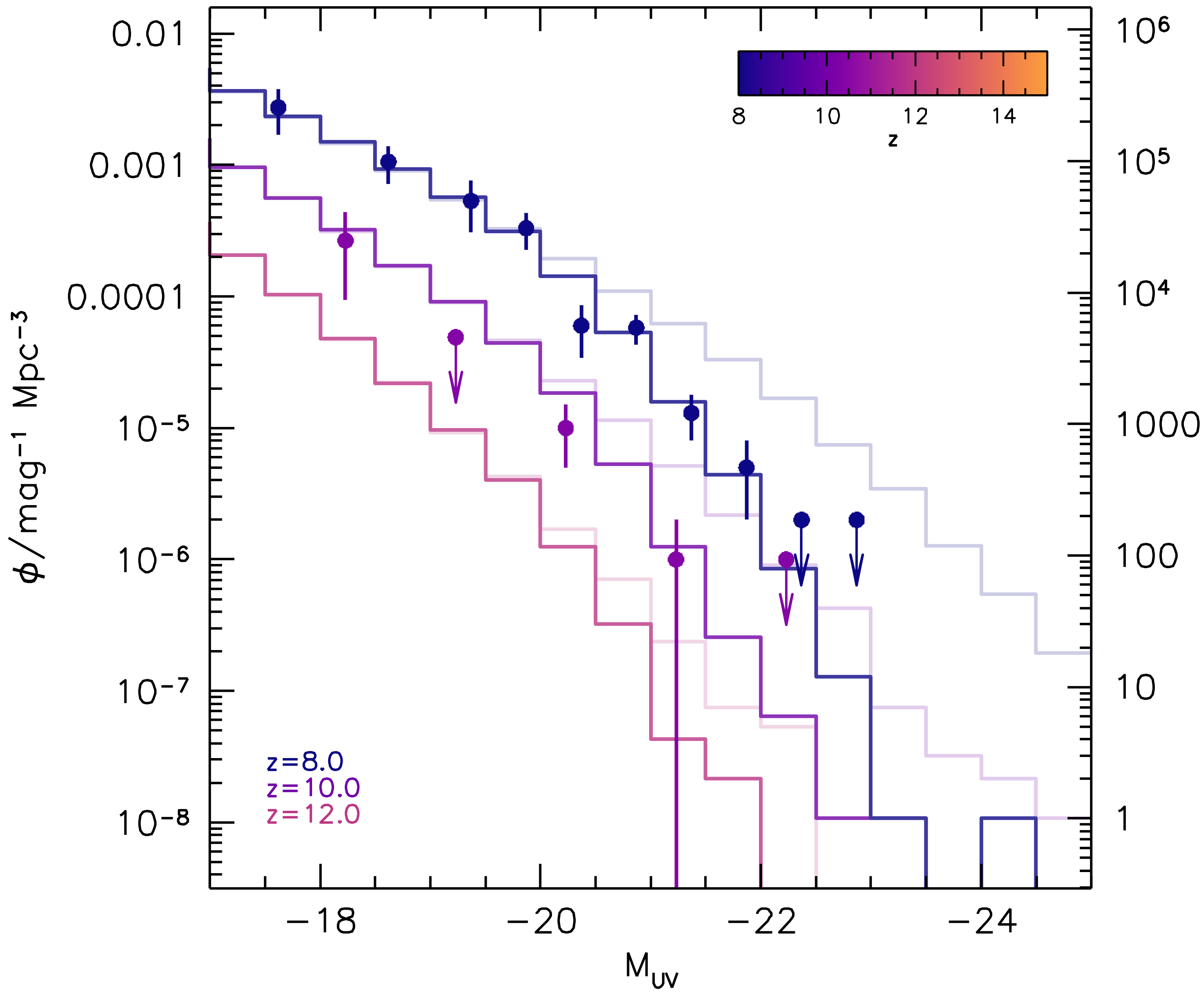
BlueTides reproduces observational constraints on the UVLF at z~8 and 10.

(More on dust in a second)

Observations from ***Bouwens et al. (2015)****. Note: faint-lines show the intrinsic luminosity function.*

number of galaxies in each mass bin in BLUETIDES.

Wilkins et al., 2016d, submitted.



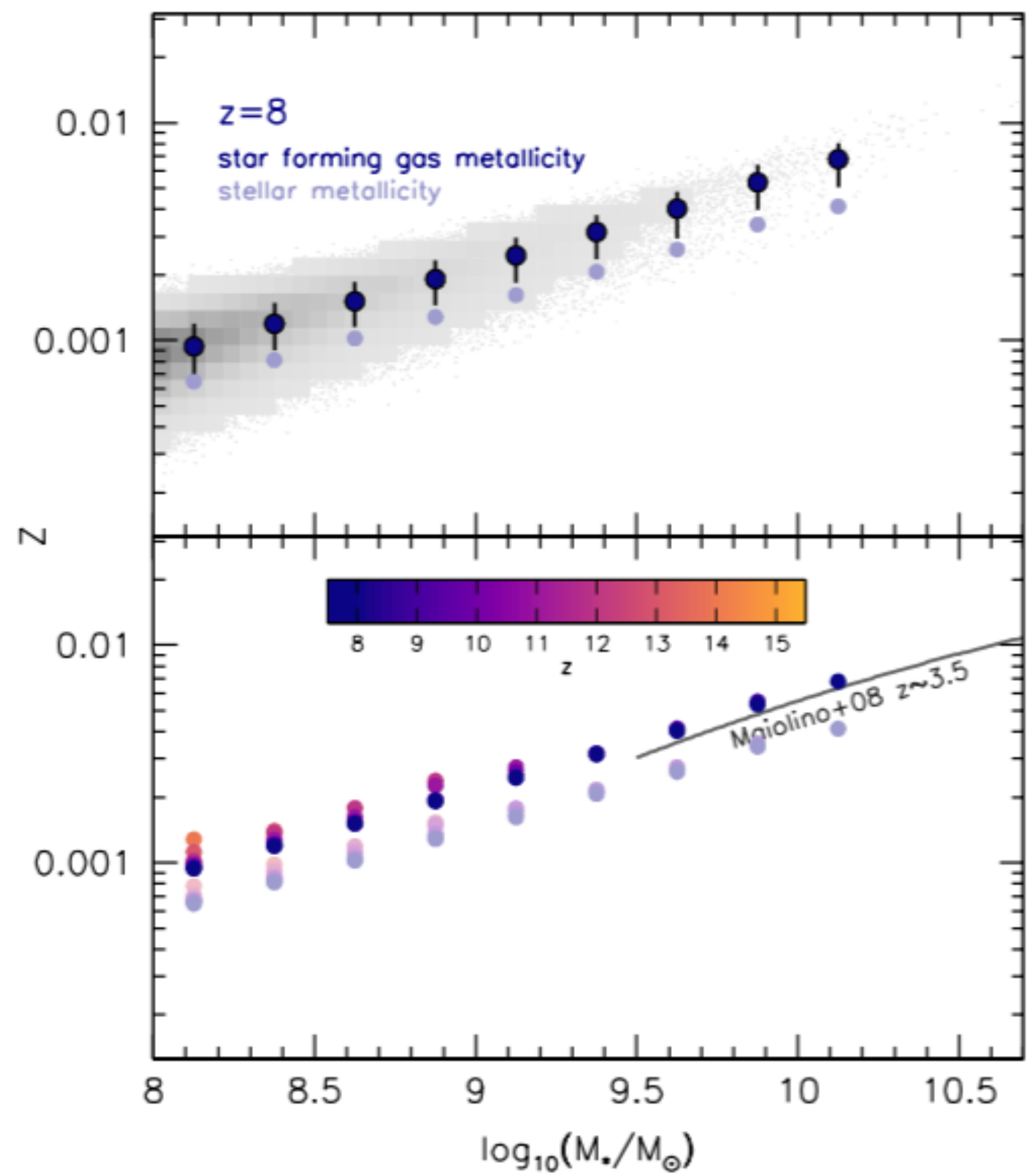
Wilkins et al., 2016d, submitted.

BLUETIDES
PHYSICAL PROPERTIES

There is a strong mass-metallicity relations in place.

Approaching ~50% solar at 10^{10} $M_{\odot}$. Overlaps observational constraints at z~3.5.

Wilkins et al., 2016d, submitted.



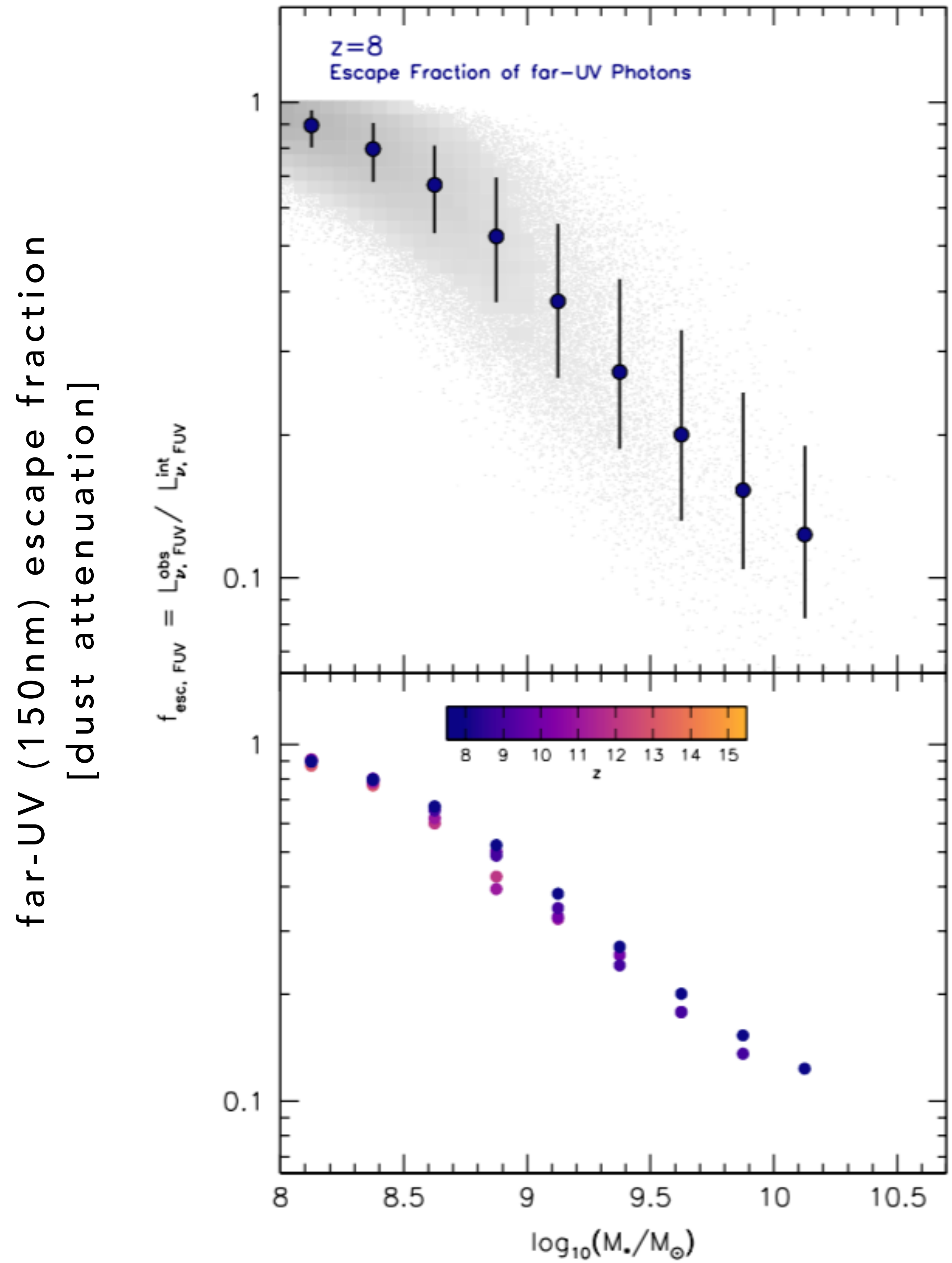
BLUETIDES
PHYSICAL PROPERTIES

Explored several different dust models.

This model simply links the integrated line-of-sight surface density of metals to the dust optical depth for each star particle.

The result is a **strong correlation between stellar-mass ($M^{*}>10^{8}$ M⊙) and the attenuation.** Galaxies at $M^{*}\sim10^{10}$ M⊙ have a UV attenuation of A~2.5.

Wilkins et al., 2016d, submitted.
Wilkins et al. in-prep



B L U E T I D E S

P H Y S I C A L P R O P E R T I E S

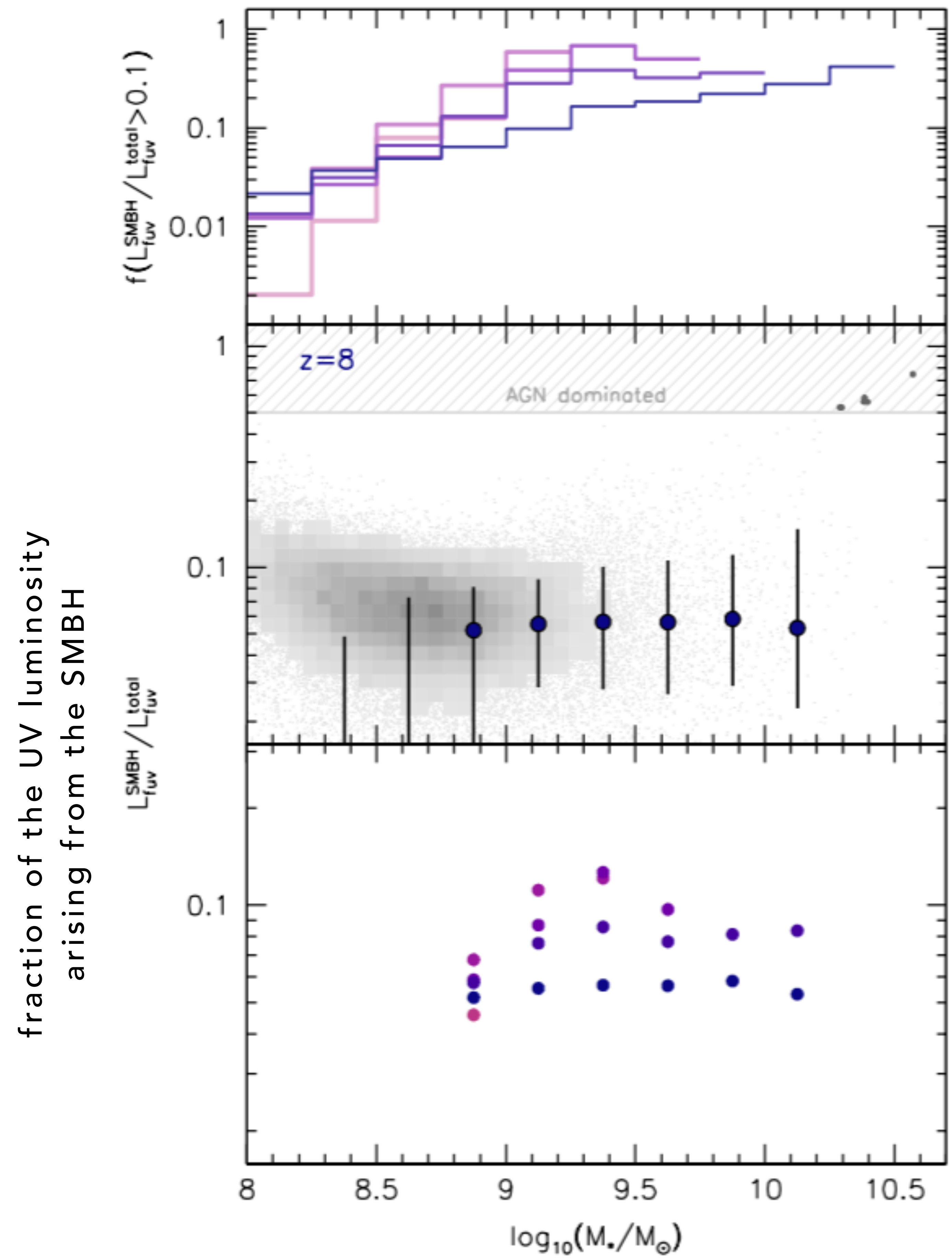
Includes the growth of SMBHs

SMBHs at z~8 contribute ~5% of the average far-UV luminosity.

In the very most massive galaxies the SMBH dominates the far-UV luminosity.

For more information see ***Di Matteo et al., submitted****; Feng et al. 2015; Wilkins et al. 2016d, submitted*

Wilkins et al., 2016d, submitted.
di Matteo et al., 2016, submitted



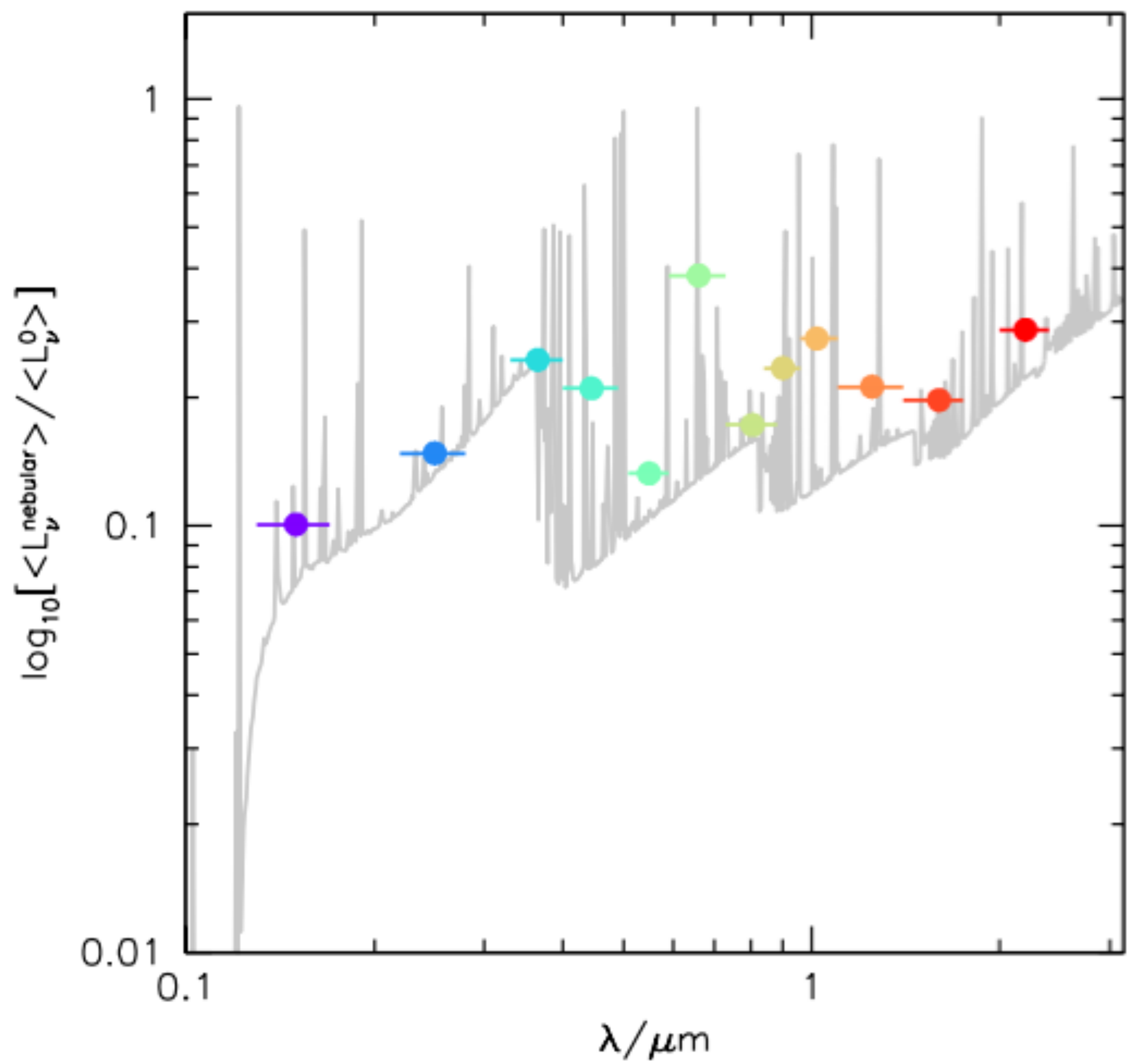
S E D   M O D E L L I N G

N E B U L A R   E M I S S I O N

Assuming the PEGASE.2 SPS model for the galaxy population at z=8 nebular emission **accounts for between 10-40%** of the total emission in the various broad-bands <u>if the escape fraction is zero</u>.

Wilkins et al., 2016c, accepted (1605.05044).

Fraction of the emission arising from nebular emission.



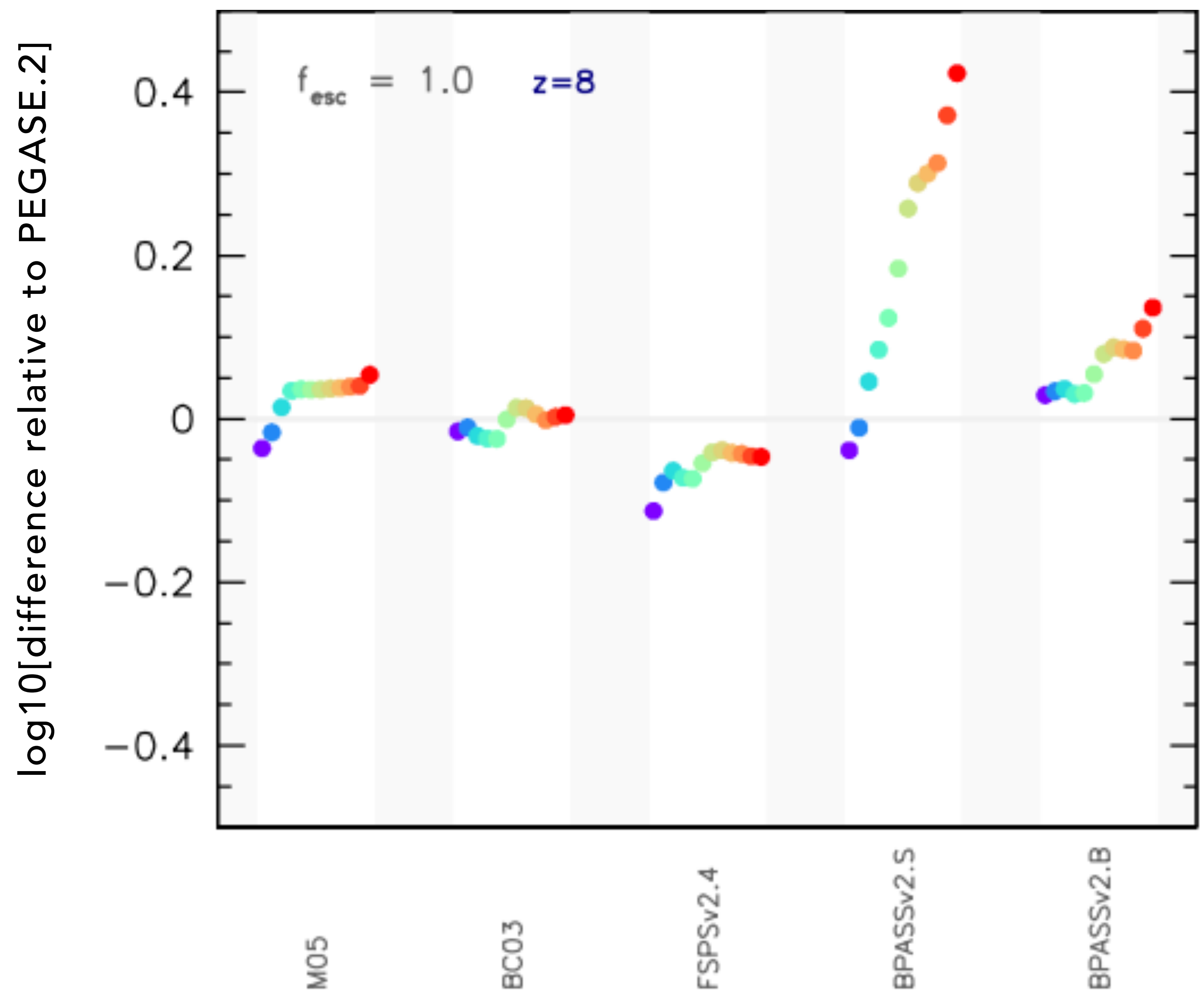
The fractional contribution of nebular (continuum and line) emission to the SED (medium resolution spectroscopy and selected broad-bands shown).

SED MODELLING
SPS MODEL

The choice of SPS model can also have a **significant impact** upon predicted SEDs.

The difference between the SEDs predicted using various SPS models (x-axis) and the PEGASE.2 model.

Wilkins et al., 2016c, accepted (1605.05044).



SED MODELLING

SPS MODEL AND IONISING PHOTON PRODUCTION EFFICIENCY.

The **ionising production efficiency** links the observed UV luminosity to the number of ionising photons produced by a galaxy. This is a critical component in assessing whether star forming galaxies are capable of re-ionising the Universe.

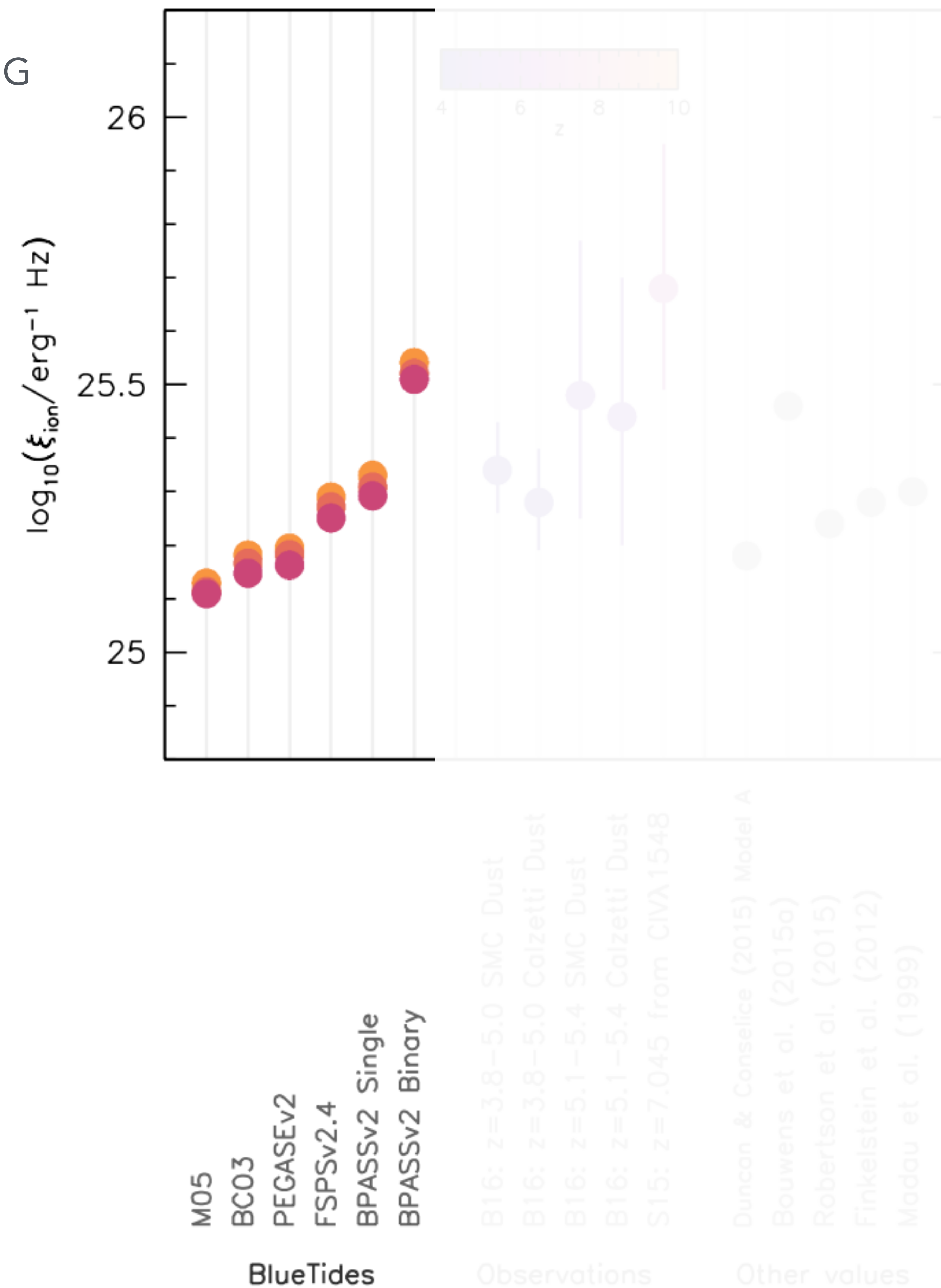
$$\dot{n}_{\rm ion} = f_{\rm esc,LyC}\, \xi_{\rm ion}\, \frac{\rho_{\rm uv}}{f_{\rm esc,uv}}$$

We can predict this from simulations, however, because both the ionising photon production rate and the UV luminosity are affected by the choice **SPS model** it will be too.

SED MODELLING

SPS MODEL AND IONISING PHOTON PRODUCTION EFFICIENCY.

- The production efficiency varies by a **factor of ~2.5** between different SPS models.
- The production efficiency evolves with redshift, although slowly.

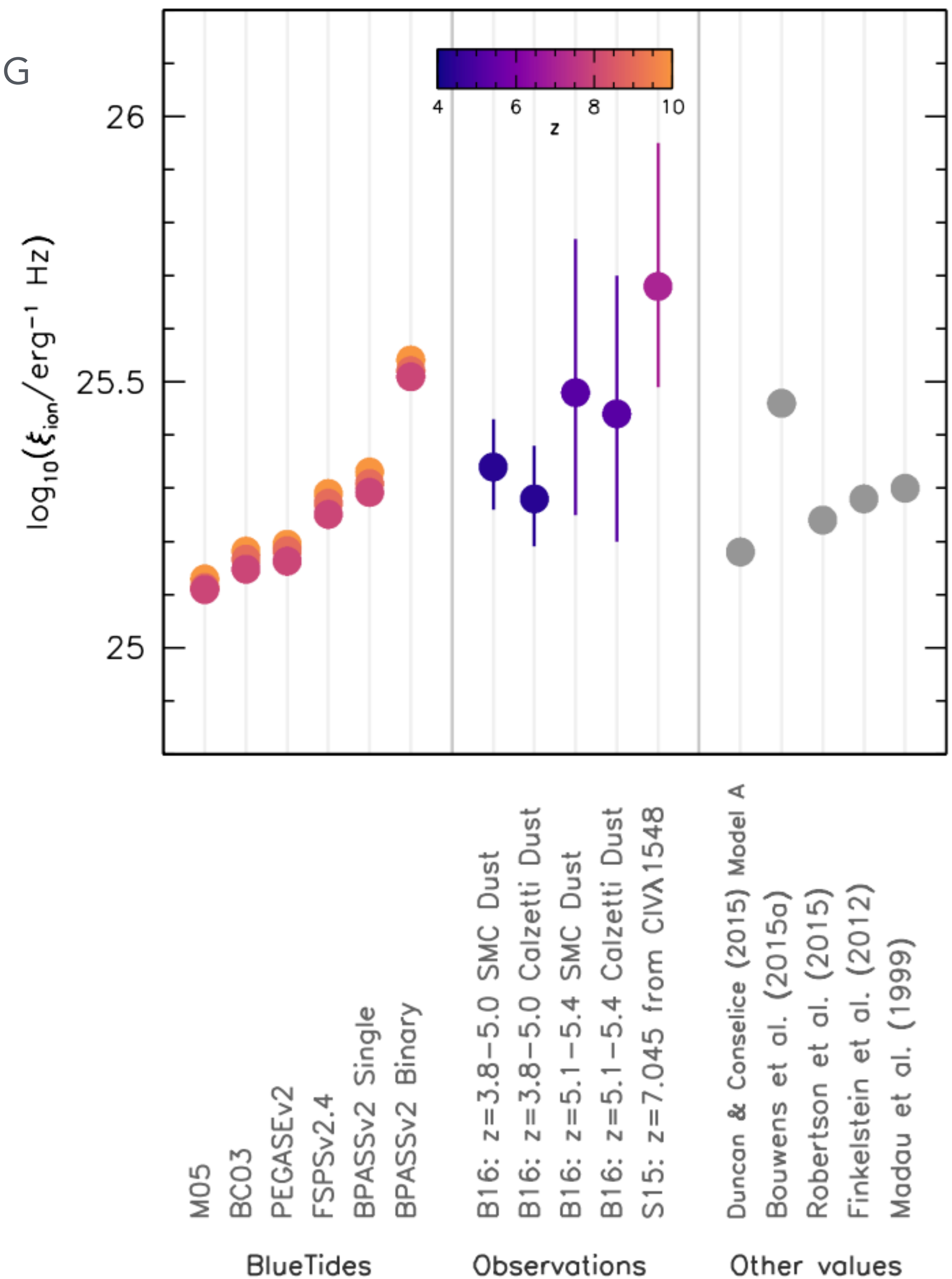


Wilkins et al., 2016b, published (1512.03214).

SED MODELLING

SPS MODEL AND IONISING PHOTON PRODUCTION EFFICIENCY.

- The ionising photon production efficiency can be observationally constrained from emission line measurements.
- Current observational constraints appear to favour higher values than predicted by BlueTides+ most SPS models. Seemingly a model predicting a larger number of ionising photons (like the BPASS model, see Stanway et al. 2016) is preferred.



Wilkins et al., 2016b, published (1512.03214).

SED MODELLING

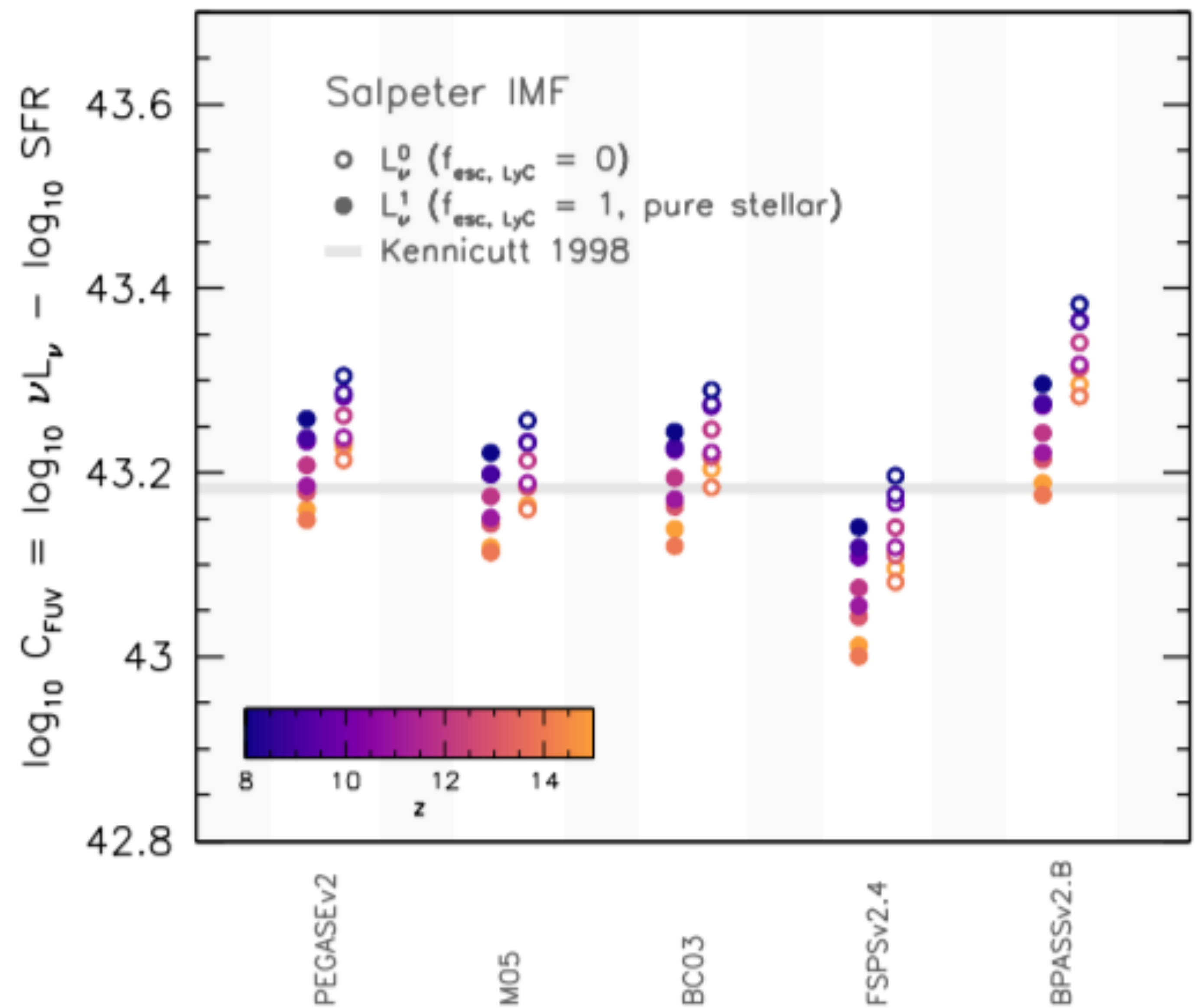
STAR FORMATION INDICATORS

Wilkins et al., 2016c, accepted (1605.05044).

We can also predict the value of the UV - SFR calibration.

The choice of SPS model, escape fraction, and IMF also affect the calibration between the SFR and the intrinsic UV luminosity.

$$\log_{10}(\mathrm{SFR/M_{\odot}\,yr^{-1}}) = \log_{10}(\nu L_{\nu,\,\mathrm{fuv}}/\mathrm{erg\,s^{-1}}) - \log_{10} C_{\mathrm{fuv}}$$



SED MODELLING

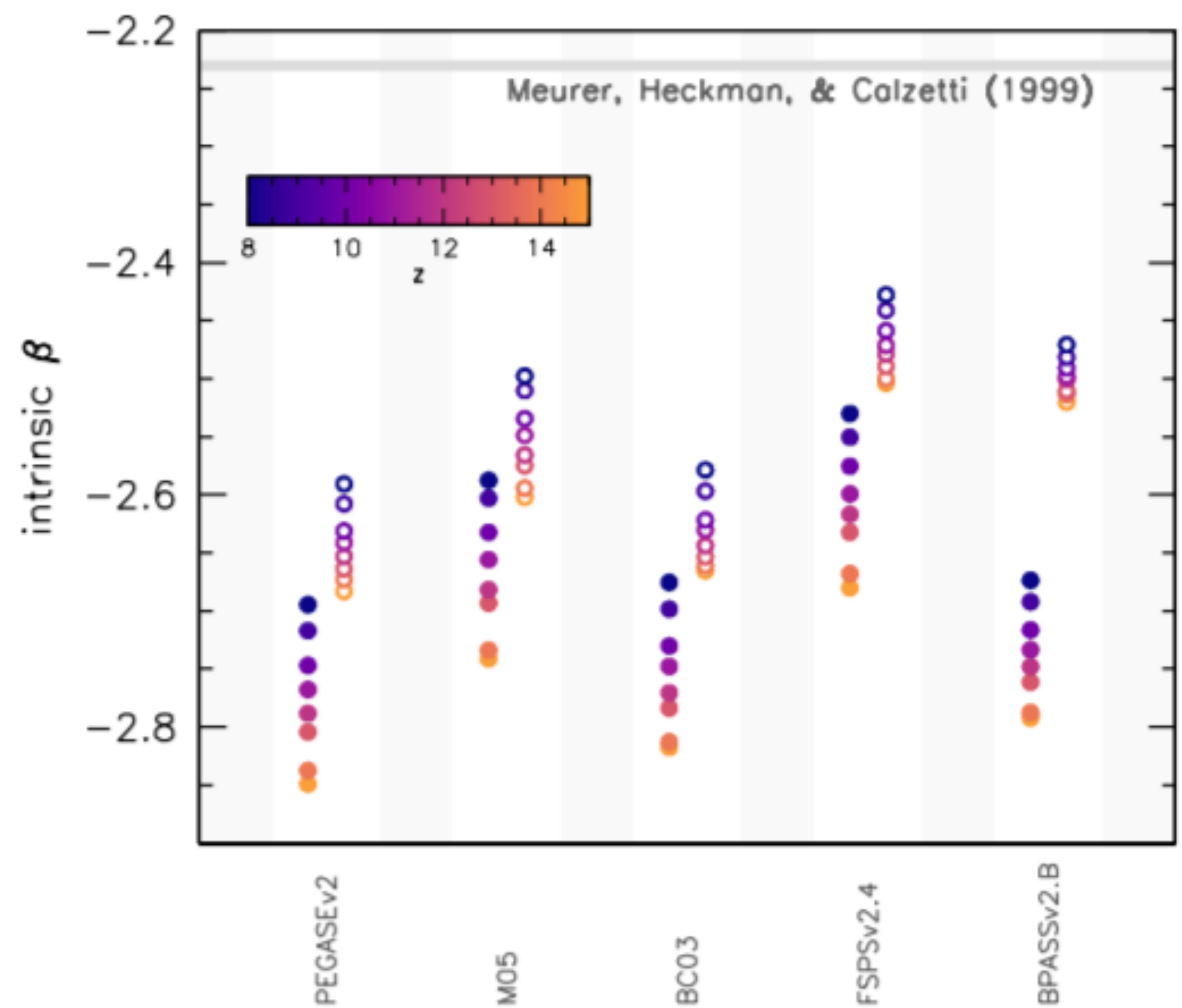
UV CONTINUUM SLOPE

Wilkins et al., 2016c, accepted (1605.05044).

Also, the intrinsic UV continuum slope.

This is important as the UV continuum slope is one of few diagnostics available for constraining dust attenuation at high-redshift.

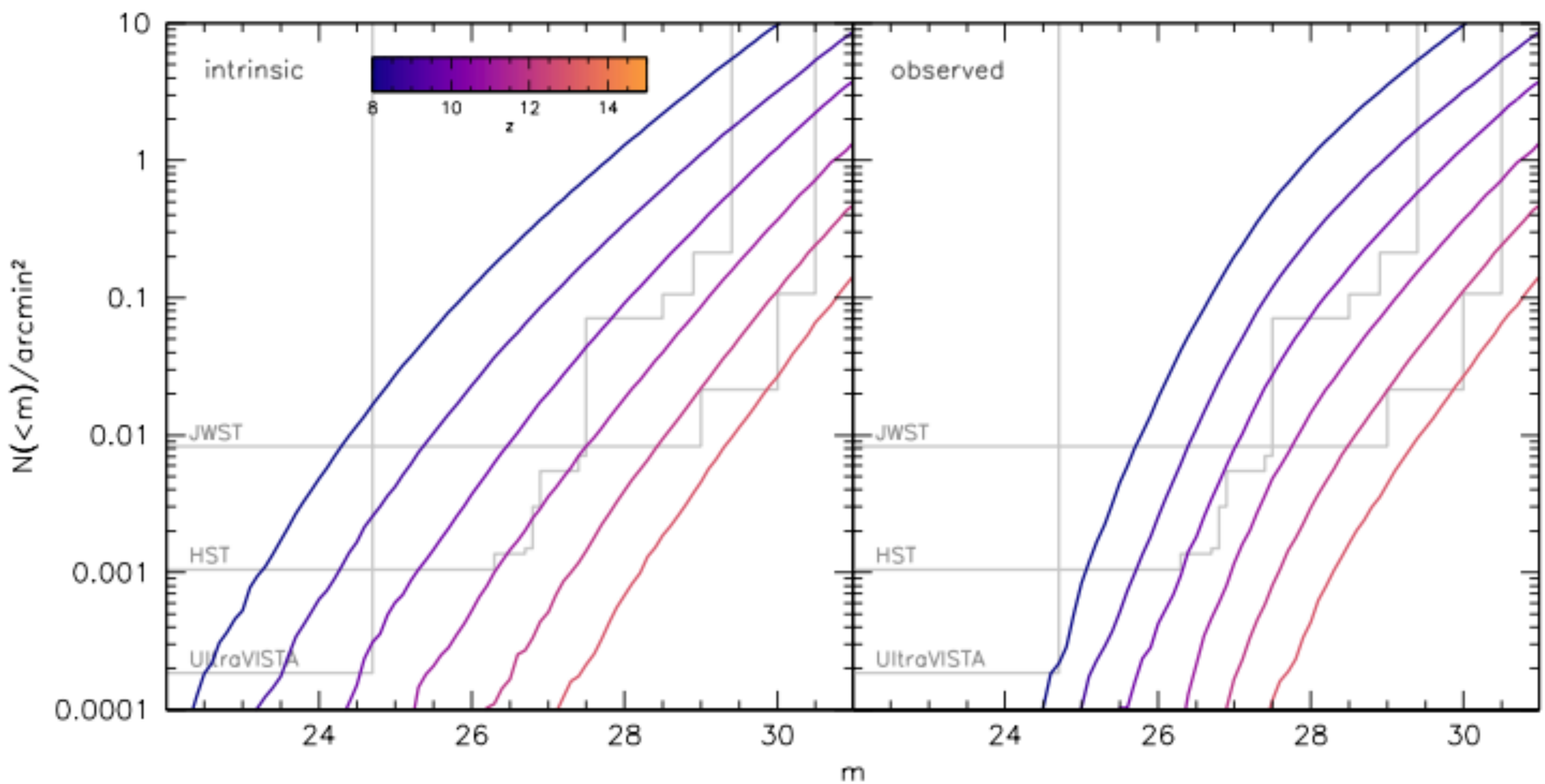
$$A_\lambda = \frac{\mathrm{d}\beta}{\mathrm{d}A_\lambda}(\beta_{\rm obs} - \beta_{\rm int})$$



PREDICTIONS FOR JWST
SURFACE DENSITIES

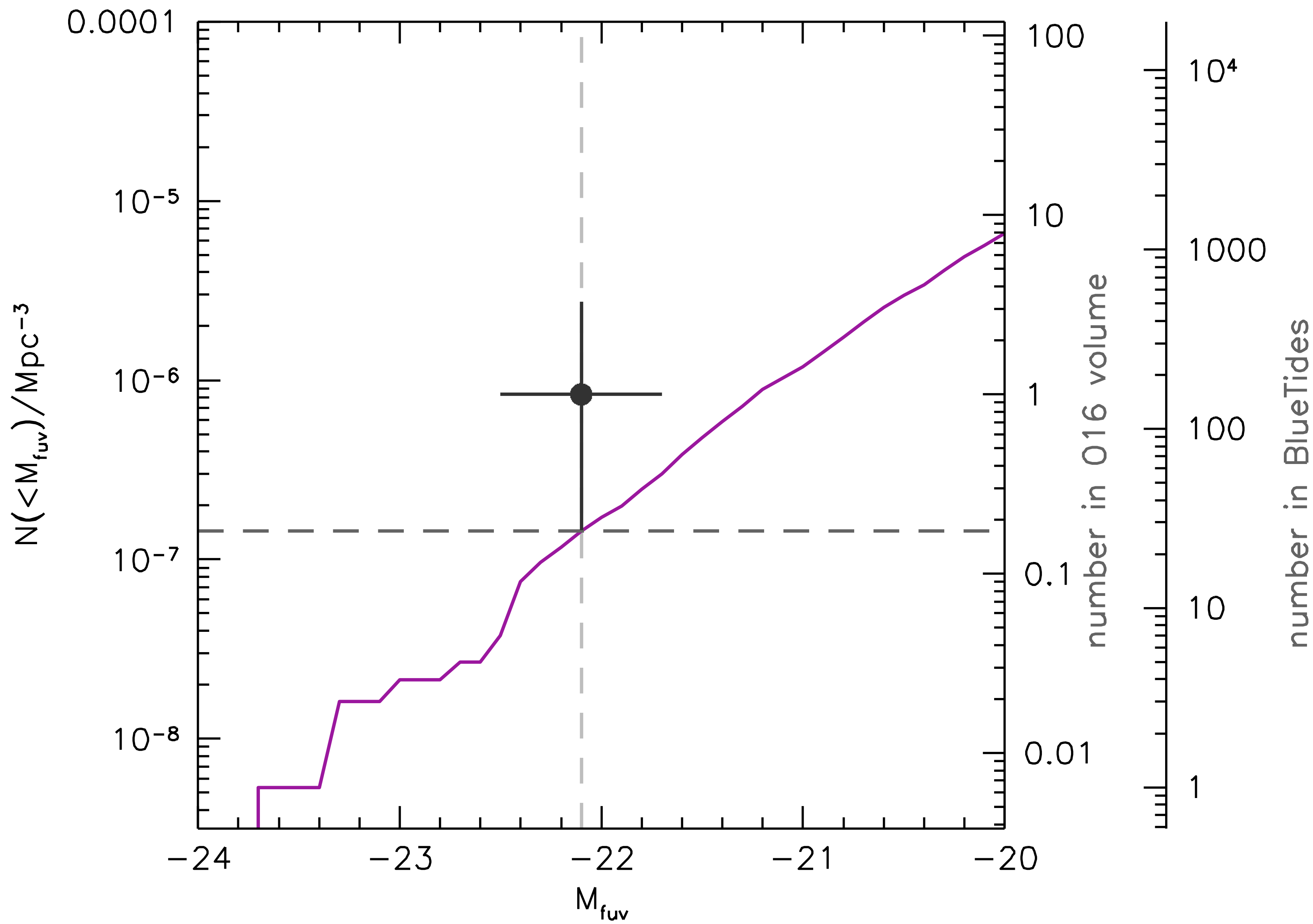
Wilkins et al., 2016e, submitted.

We can predict the surface density of sources across a wide redshift and luminosity range.



The predicted surface density of sources is consistent with the discovery of a bright galaxy at z~11 by Oesch et al. (2016).

Waters et al. 2016a, accepted

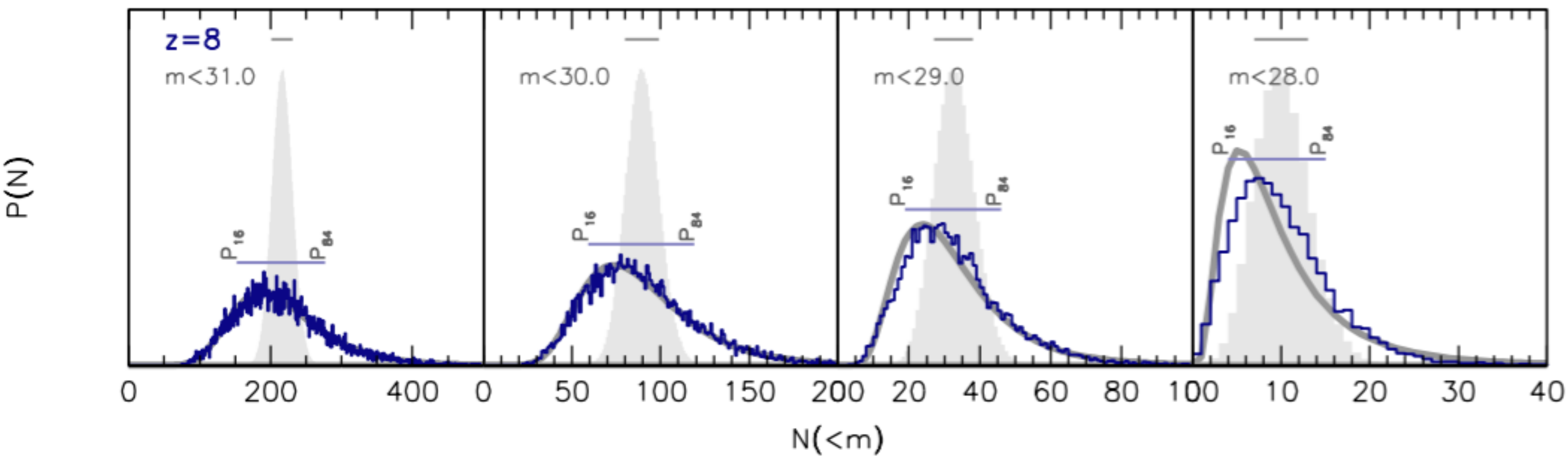


PREDICTIONS FOR JWST

COSMIC VARIANCE

Wilkins et al., 2016e, submitted.

BlueTides simulates sufficient volume to calculate the effect of field-to-field variance (cosmic variance) for reasonably sized surveys with JWST.



The distribution of number counts in a single JWST/NIRCam pointing at z=7.5-8.5. The grey histograms show the result if galaxies were spread randomly.

PREDICTIONS FOR JWST

SURFACE DENSITIES

Wilkins et al., 2016e, submitted.

Expected surface densities for a **single** JWST/NIRcam pointing.

Dust attenuated far-UV photometry												
z	$m < 28$			$m < 29$			$m < 30$			$m < 31$		
	P_{16}	P_{50}	P_{84}	P_{16}	P_{50}	P_{84}	P_{16}	P_{50}	P_{84}	P_{16}	P_{50}	P_{84}
8	4	**9**	15	19	**30**	46	59	**85**	119	152	**208**	277
9	0	**2**	4	4	**8**	15	16	**26**	40	50	**74**	107
10	0	**0**	1	1	**2**	5	5	**10**	17	19	**31**	48
11	0	**0**	0	0	**0**	2	1	**3**	6	6	**11**	19
12	0	**0**	0	0	**0**	0	0	**1**	2	1	**4**	7

CONCLUSIONS

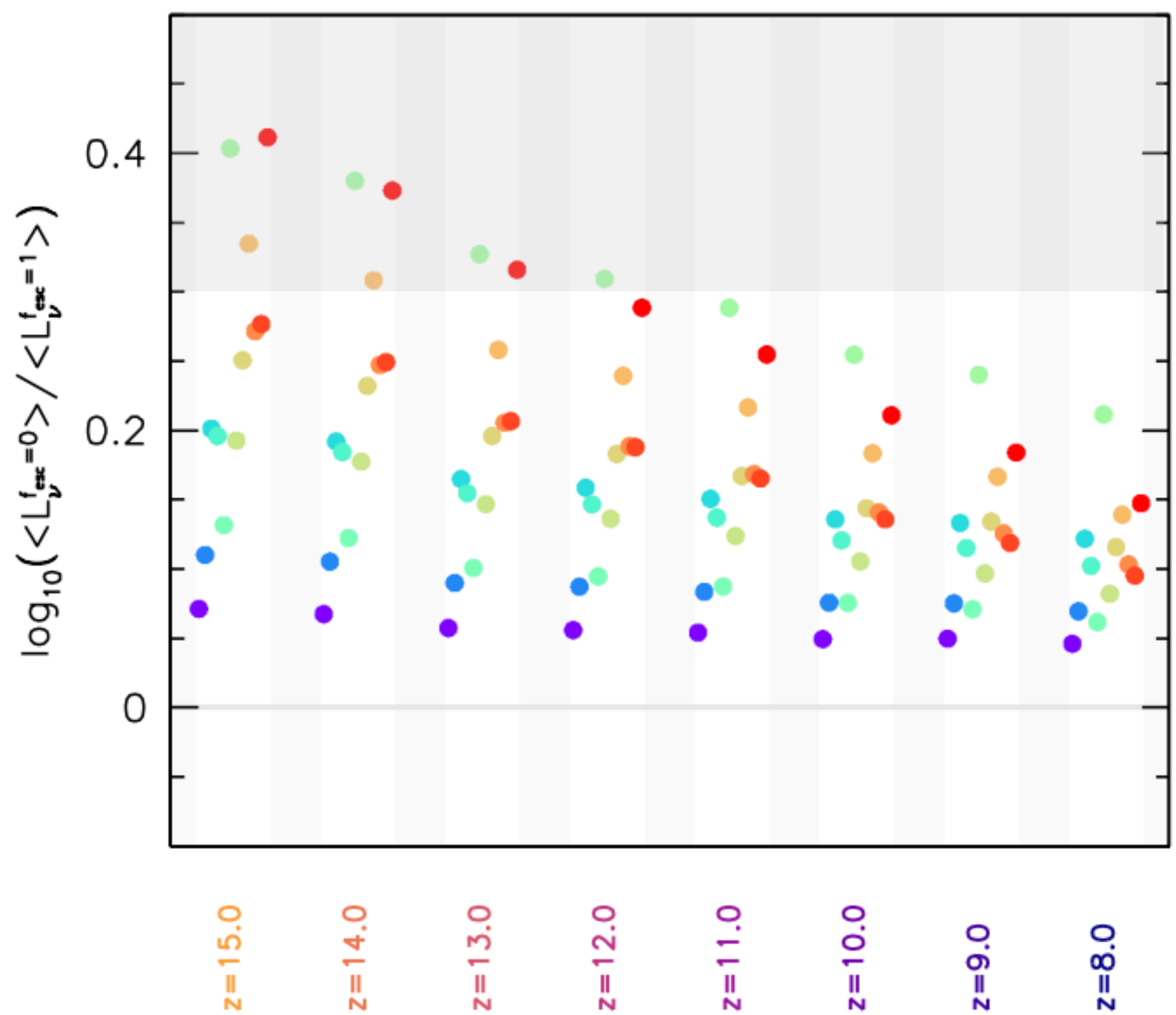
BlueTides is a very large cosmological hydrodynamical simulation that has a resolution and volume well matched to current and future observational constraints.

- BlueTides reproduces the Galaxy Stellar Mass Function and UV luminosity function at z~8 and above.
- We can predict the SEDs of galaxies, these are sensitive to our choice of assumptions (IMF, nebular emission, dust emission, SPS model etc.)
- We can predict the ionising photon production efficiency. This is very sensitive to the choice of SPS model.
- JWST will likely discover many galaxies at z~8-10 though relatively few at z~12 and above.

SED MODELLING

NEBULAR EMISSION

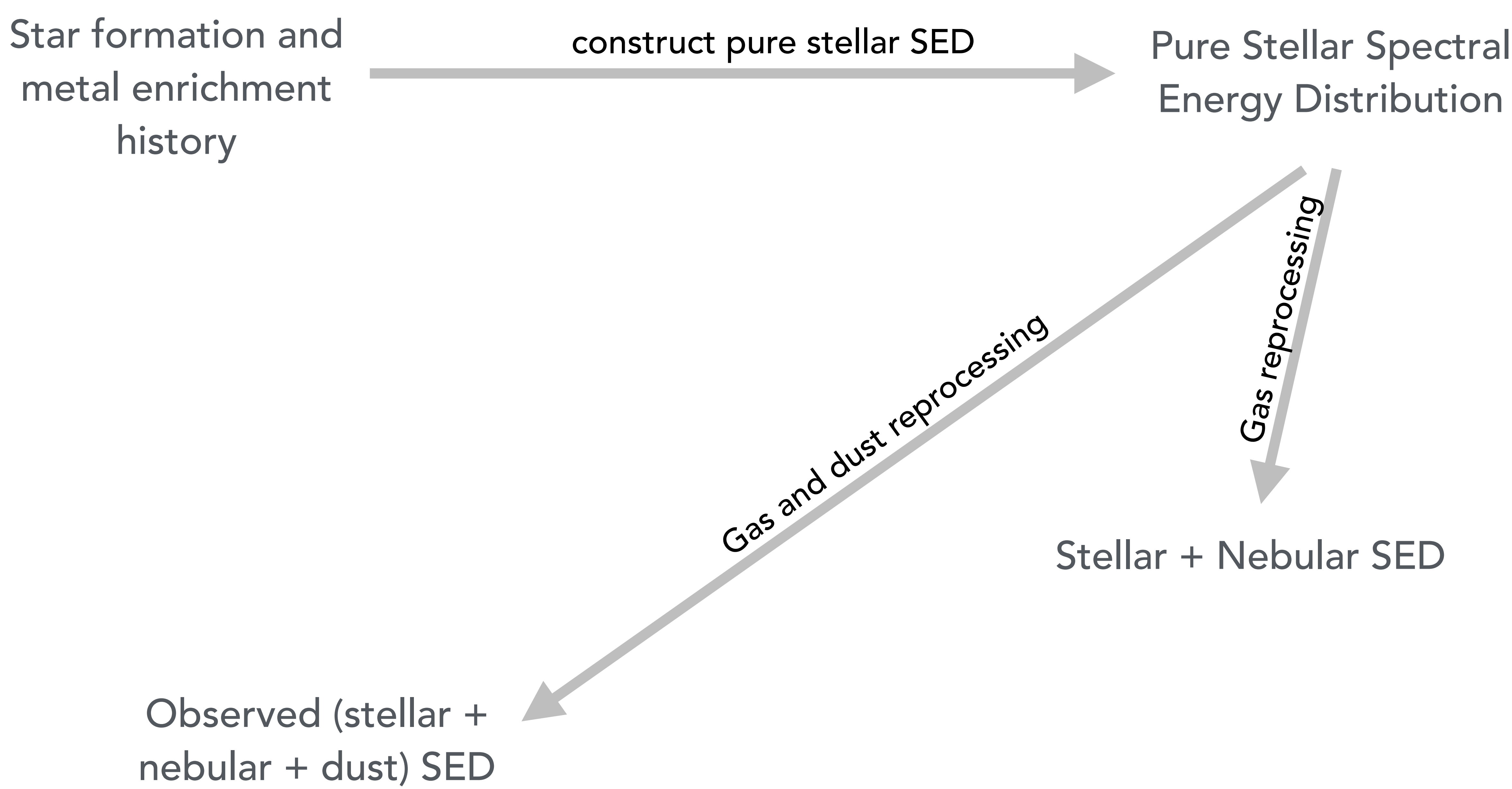
The contribution of nebular emission **increases** to higher-redshift.



The fractional contribution of nebular (continuum and line) emission to broad-band SEDs from z=15-8.

Wilkins et al., 2016c, accepted (1605.05044).

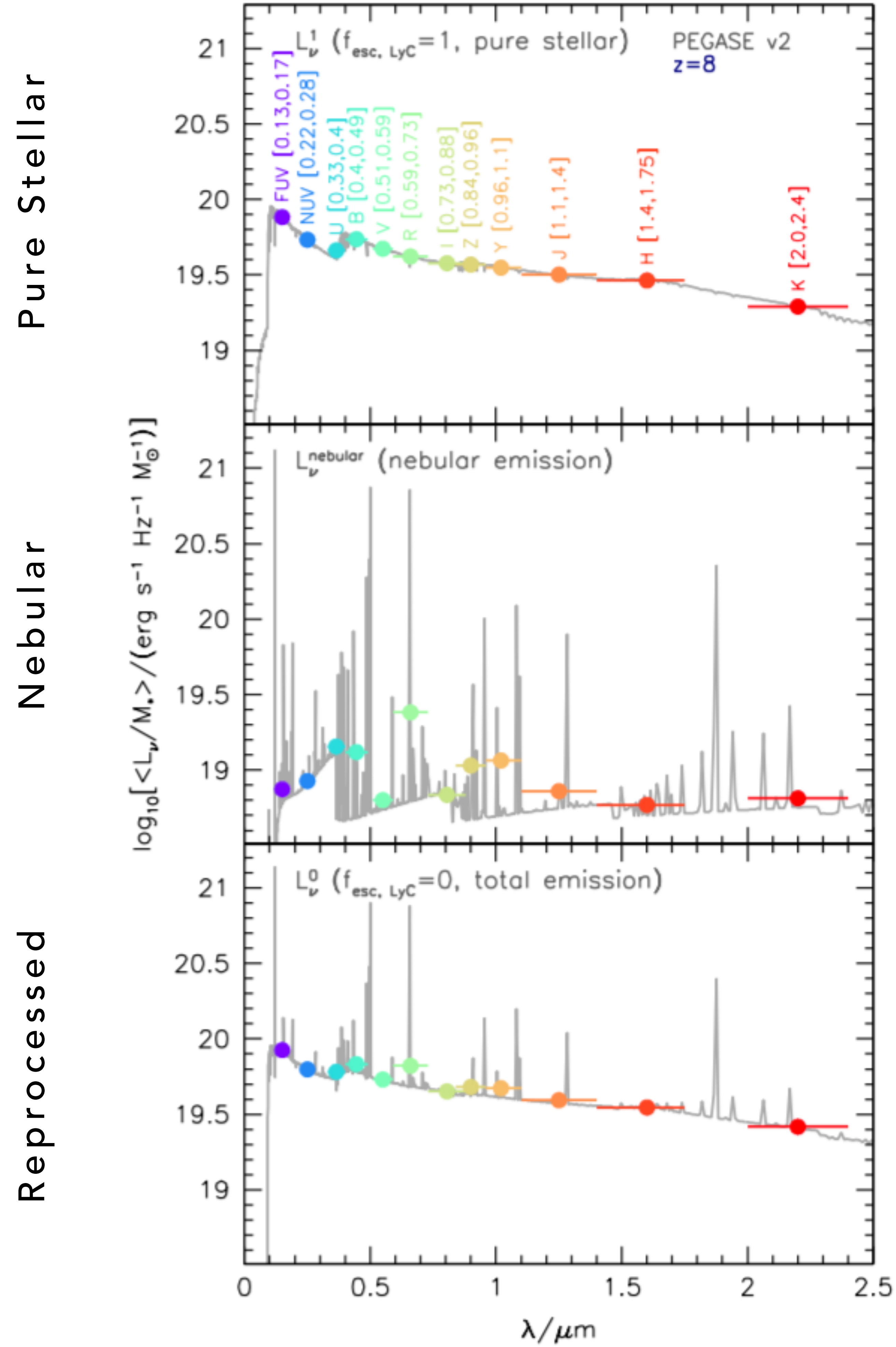
S E D   M O D E L L I N G



SED MODELLING
NEBULAR EMISSION

The simplest scenario is to utilise a photoionisation code (like CLOUDY) and assume a simple spherically symmetric density and gas-phase metallicity equal to calculate the nebular emission from each star particle.

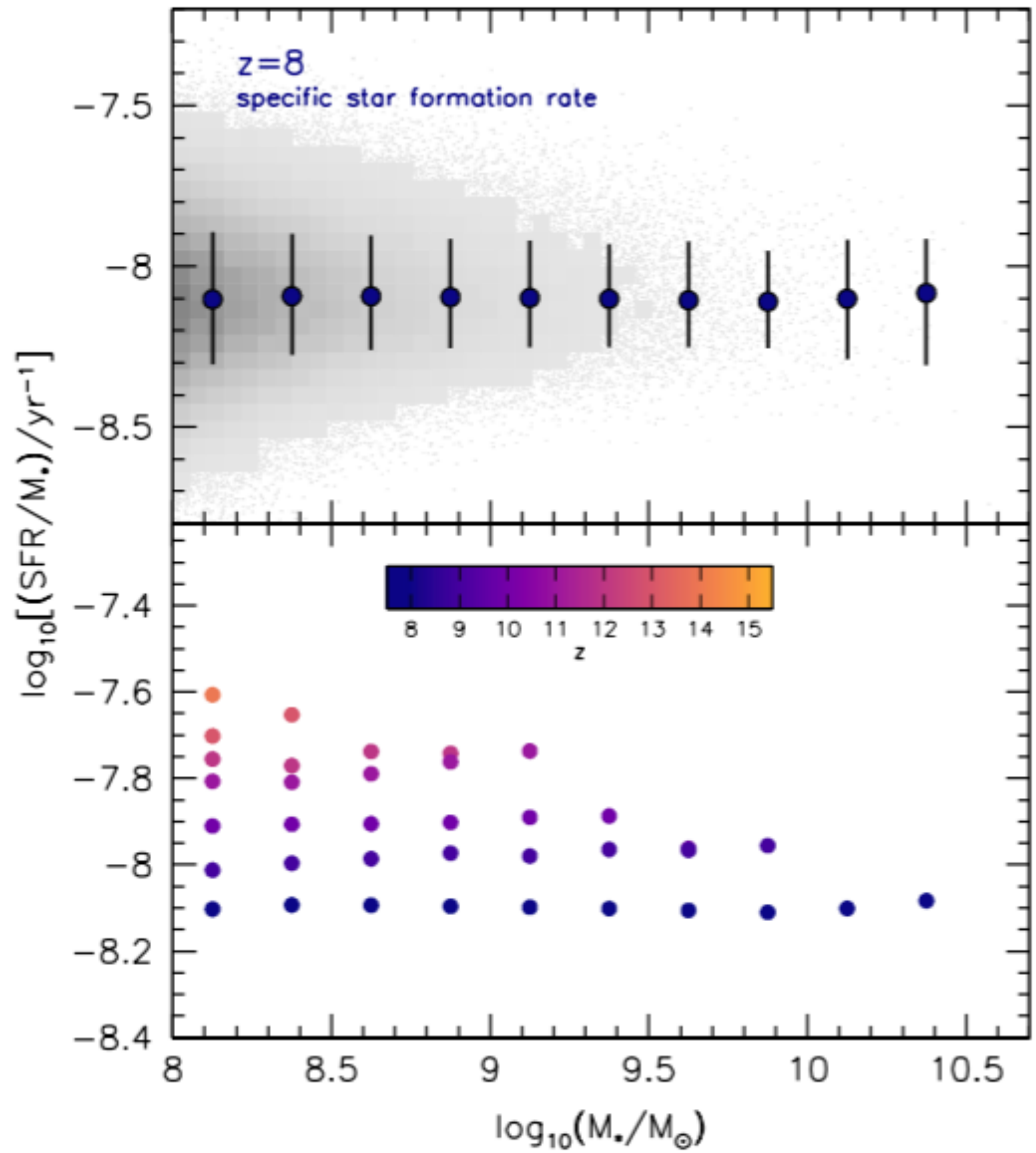
Wilkins et al., 2016c, accepted (1605.05044).



BLUETIDES

PHYSICAL PROPERTIES

Wilkins et al., 2016d, submitted.



The average shape of the SFH (and therefore average age and specific SFR) shows virtually **no variation with mass** though does **evolve strongly with redshift.**

TALK OUTLINE

Motivation for **BlueTides**

Basic details of **BlueTides**

Basic physical properties of galaxies

SED modelling and photometric properties.

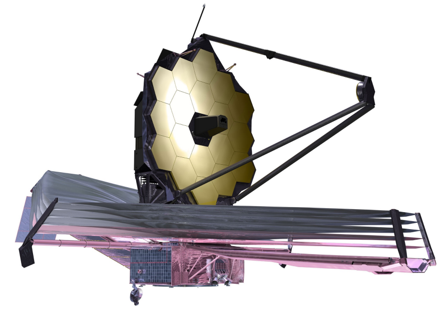
- Rest-frame UV - near-IR SED
- Ionising production efficiency
- UV - SFR calibration
- UV continuum slope

Including the effect of the assumed SPS model.

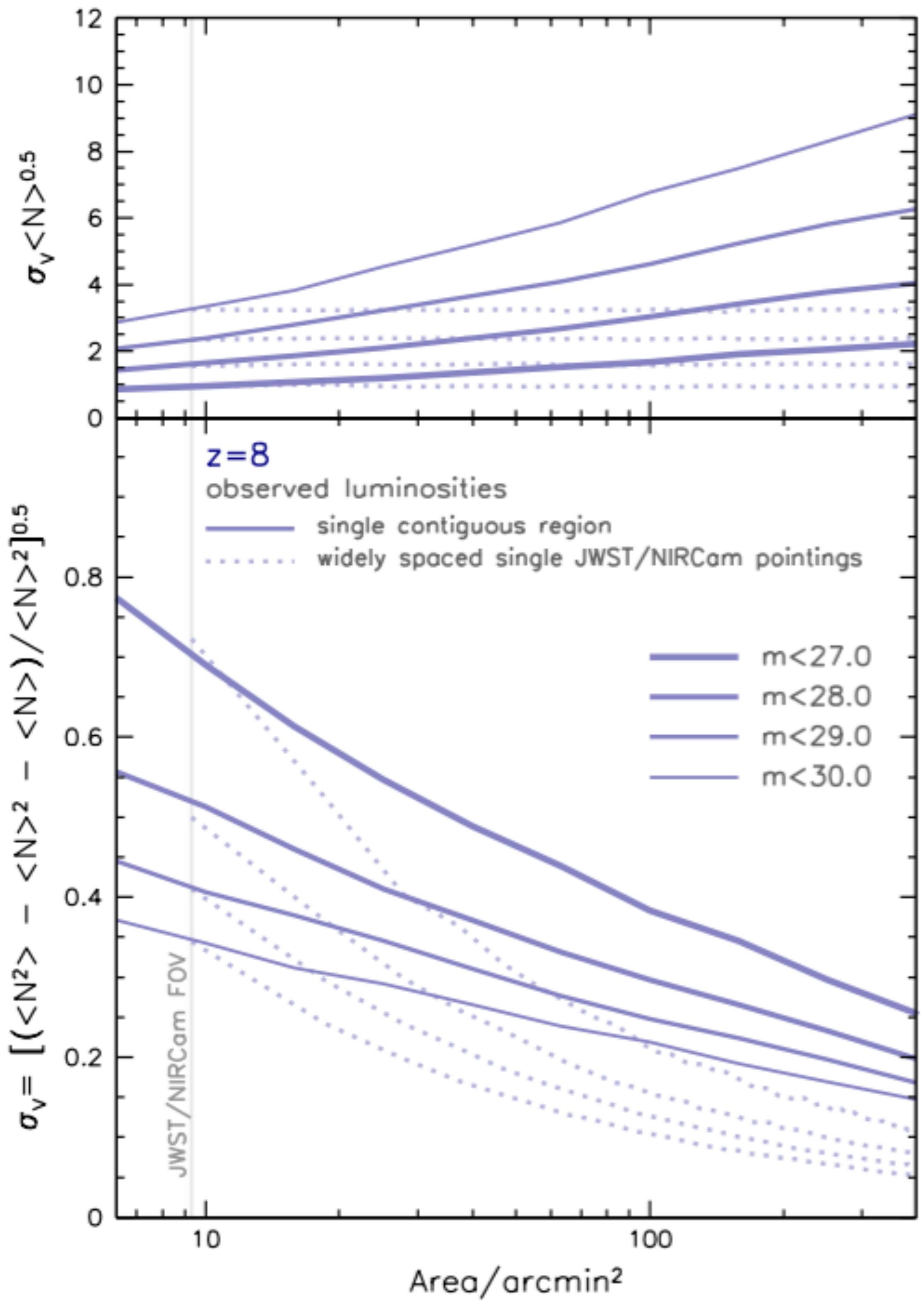
Predictions for JWST

PREDICTIONS FOR JWST

SURFACE DENSITIES



Wilkins et al., 2016e, submitted.

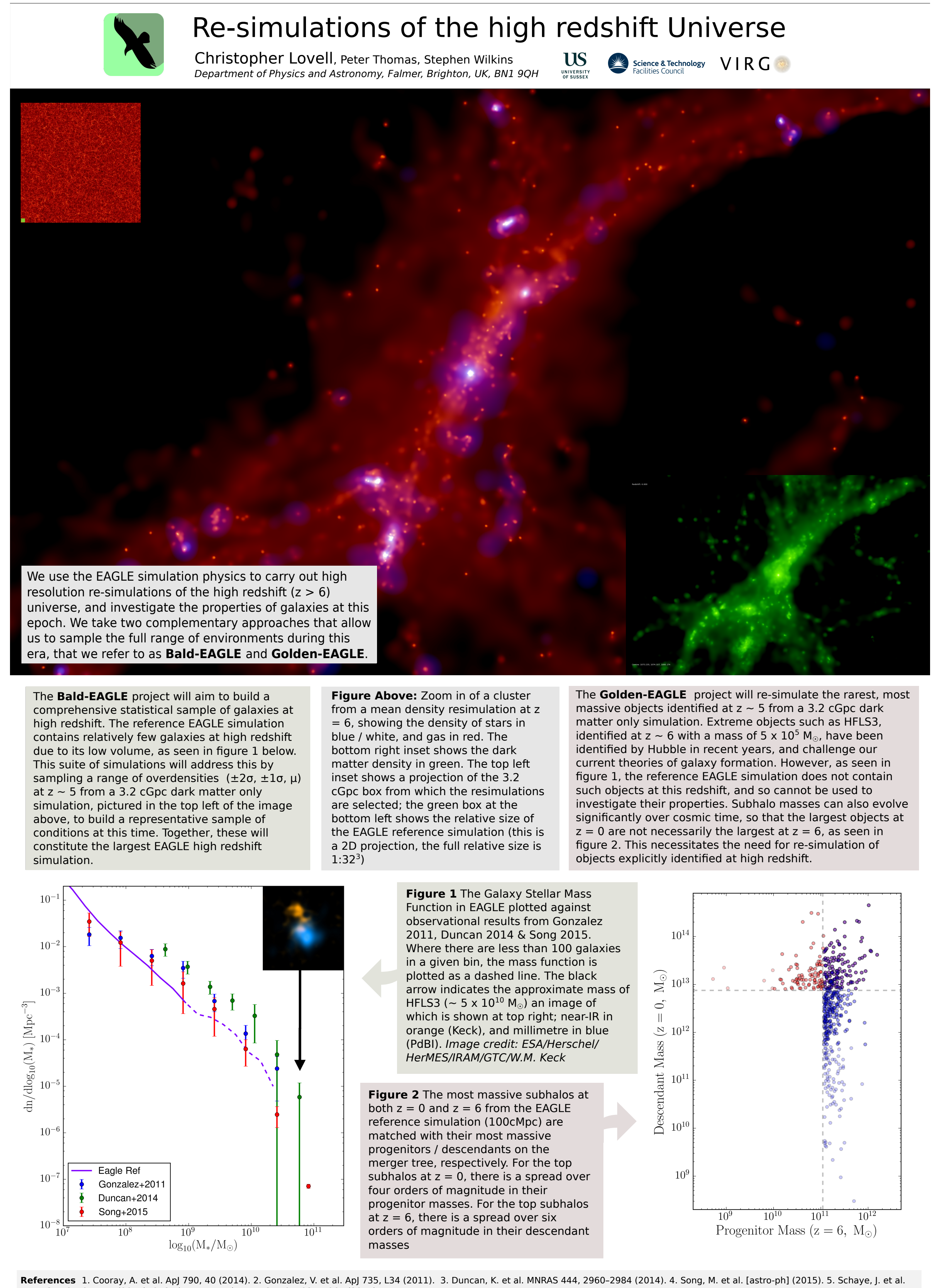


Bottom: How cosmic variance is affected by the area covered (both for a contiguous region and widely spaced random pointings) and magnitude limit. Top: The ratio of cosmic variance to sample (Poisson) variance.

To complement BlueTides at the highest masses and push to lower redshift we are re-simulating massive galaxies.

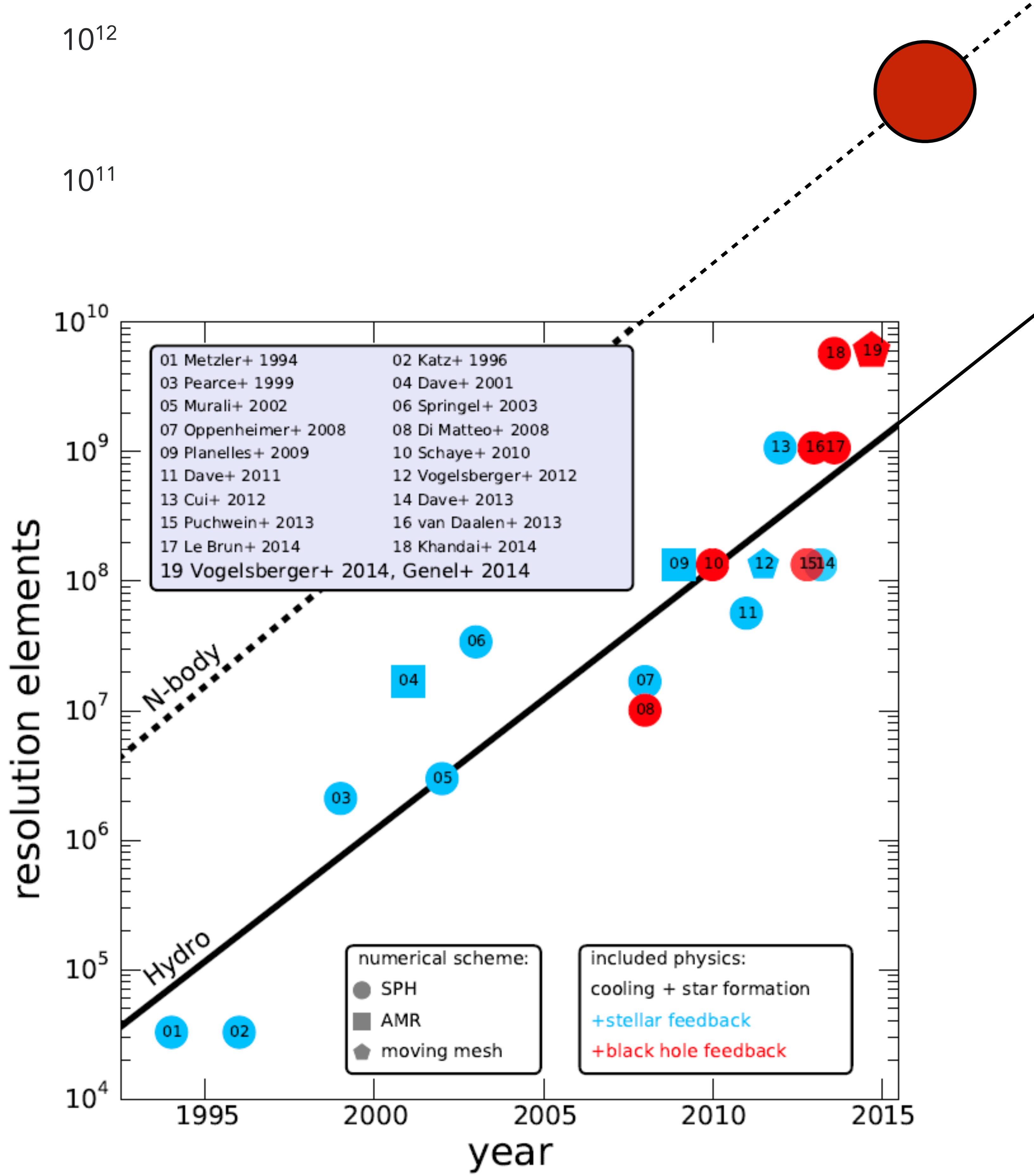
We will also look closely at the physics implementation (initially using the EAGLE physics) and how that affects the results.

See poster by Chris Lovell.



BLUETIDES
SIMULATION

Of course this is **very misleading** as BlueTides only runs to z=8 (z=6 in the future).



S E D M O D E L L I N G

Star formation and metal enrichment history

construct pure stellar SED →

Pure Stellar Spectral Energy Distribution

SED MODELLING

Star formation and metal enrichment history

construct pure stellar SED

Choice of SPS model and IMF

Pure Stellar Spectral Energy Distribution

S E D M O D E L L I N G