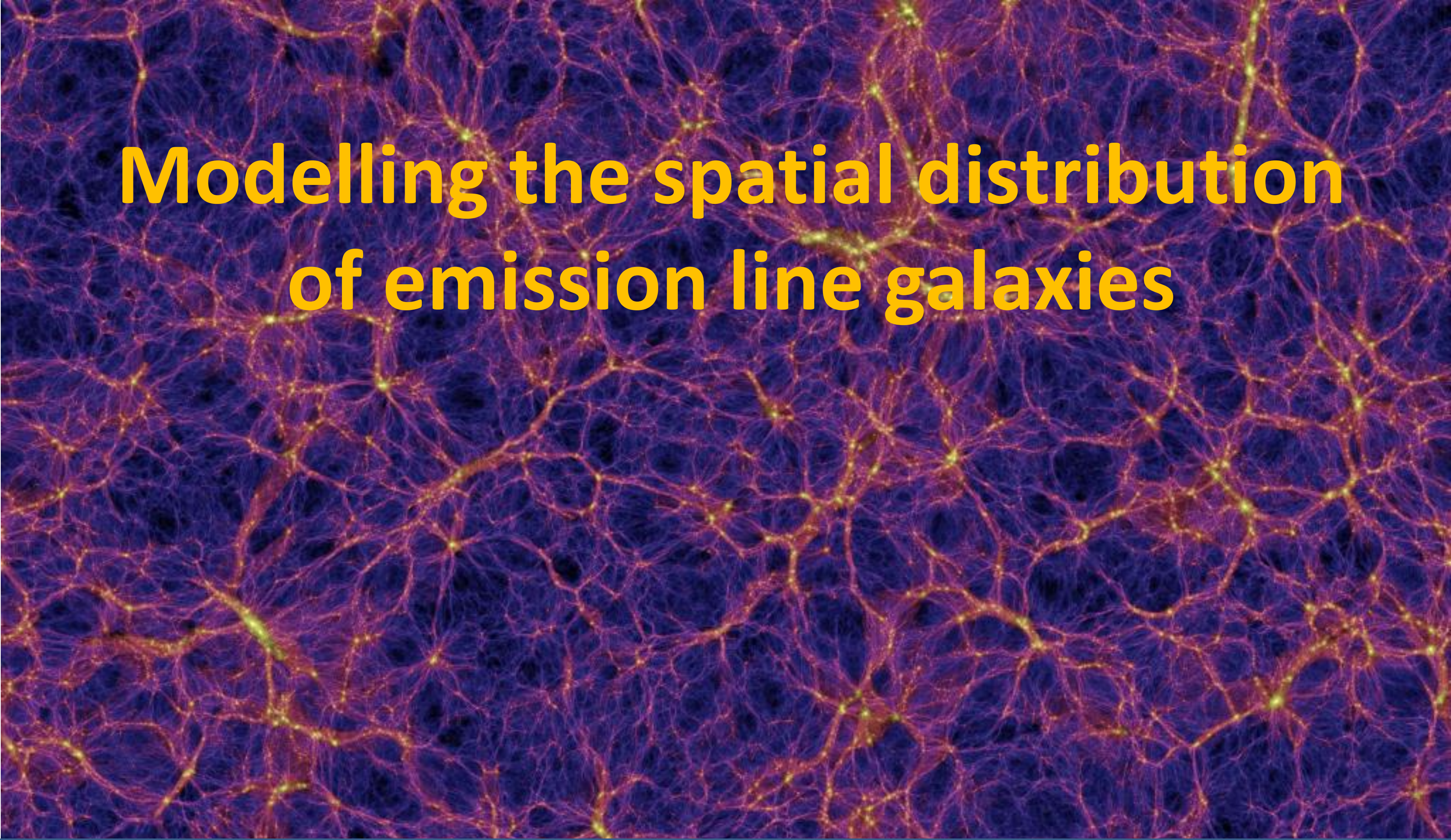


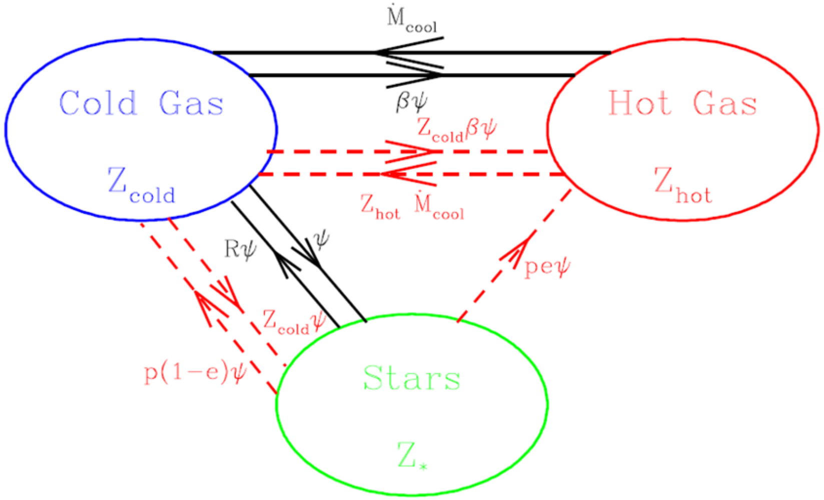
Modelling the spatial distribution of emission line galaxies

Durham University

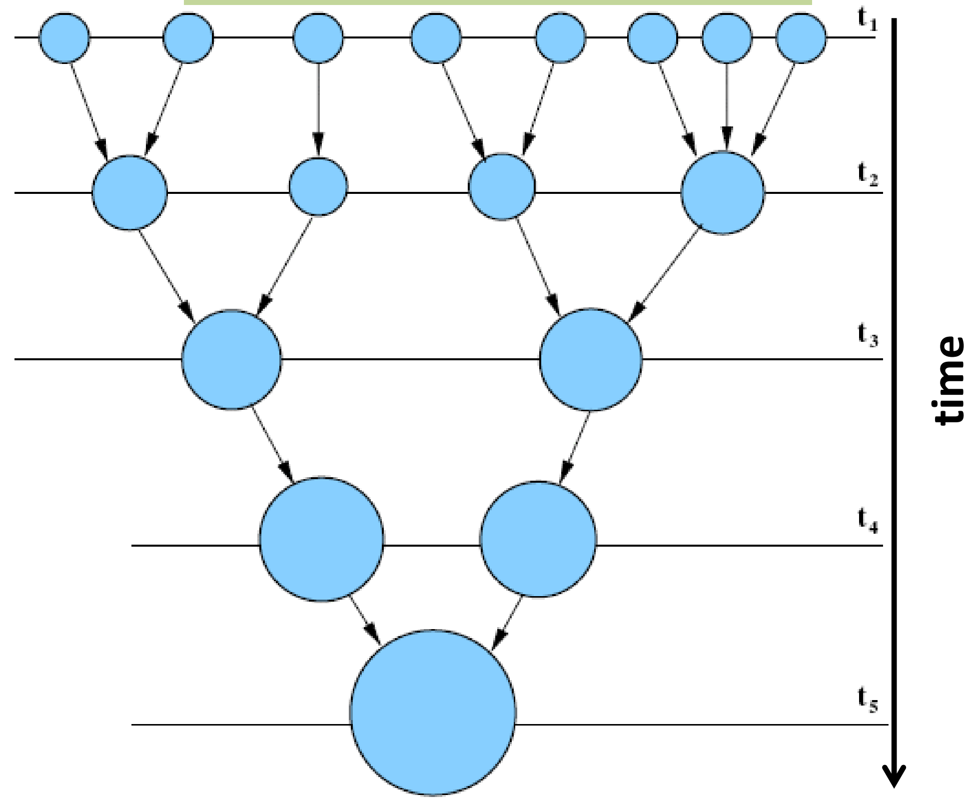
Carlton Baugh

Institute for Computational Cosmology

Semi-analytical galaxy formation



Dark matter halo merger tree



$$\dot{M}_* = (1 - R)\psi$$

$$\dot{M}_{hot} = -\dot{M}_{cool} + \beta\psi$$

$$\dot{M}_{cold} = \dot{M}_{cool} - (1 - R + \beta)\psi$$

$$\dot{M}_*^Z = (1 - R)Z_{cold}\psi$$

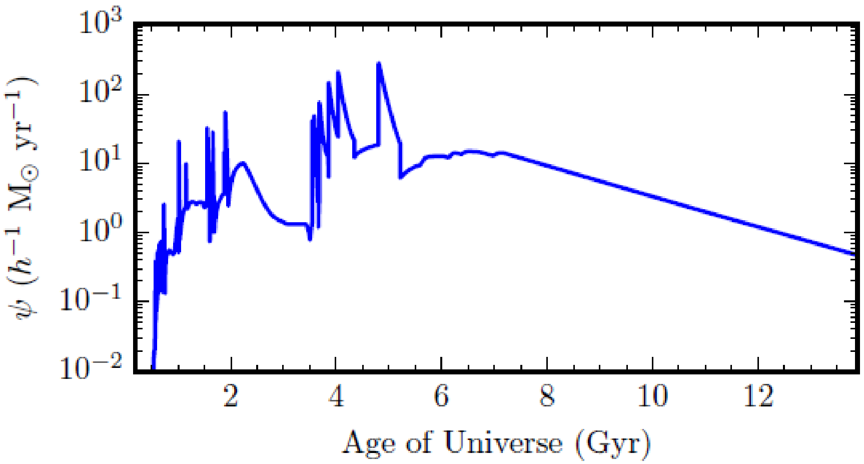
$$\dot{M}_{hot}^Z = -\dot{M}_{cool}Z_{hot} + (pe + \beta Z_{cold})\psi$$

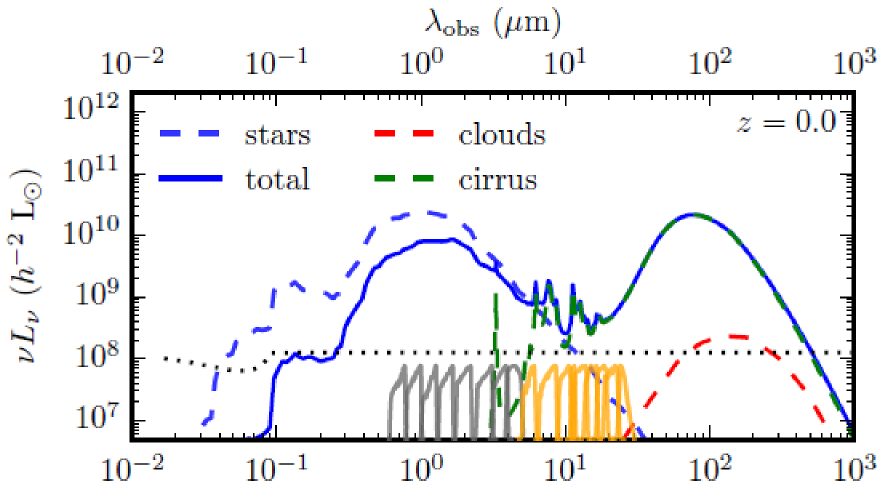
$$\dot{M}_{cold}^Z = \dot{M}_{cool}Z_{hot} + [p(1 - e) - (1 + \beta - R)Z_{cold}]\psi,$$

Solve set of coupled differential equations

Baugh 2006, Benson 2010

Predict star formation histories of galaxies





Star formation history

Spectral energy distribution

Cowley et al. 2018 arXiv:1702.02146

A unified multi-wavelength model of galaxy formation

Lacey et al. 2016 MNRAS, 42, 3854
arXiv:1509.08473
(see also models by Gonzalez-Perez et al 2014, 2018)

- How many model parameters?
- Example of parameter recalibration

Model parameters-I

Table 1. Table of parameters. F=fixed, P=primary, S=secondary. P_0 has units $k_B\mathrm{cm}^{-3}\mathrm{K}$.

parameter	value	range	type=F/P/S	description	Eqn/paper
Cosmology				Komatsu et al. (2011)	
Ω_{m}	0.272	-	F	matter density	
Ω_{b}	0.0455	-	F	baryon density	
h	0.704	-	F	Hubble parameter	
σ_8	0.81	-	F	Fluctuation amplitude	
n_s	0.967	-	F	Scalar spectral index	
Stellar population					Maraston (2005)
IMF : quiescent					
x	Kennicutt	-	F	IMF	Eq. 32
p	0.021	-	F	yield	Eq. 31
R	0.44	-	F	recyled fraction	Eq. 30
IMF : starburst					
x	1	0-1	P	IMF slope	Eq. 32
p	0.048	-	P	yield	Eq. 31
R	0.54	-	P	recyled fraction	Eq. 30
Star formation: quiescent					Lagos et al. (2011b)
ν_{SF}	$0.74\mathrm{Gyr}^{-1}$	$0.25-0.74\mathrm{Gyr}^{-1}$	P	efficiency factor for molecular gas	Eq. 7
P_0	1.7×10^4	-	F	normalisation of pressure relation	Eq. 6
α_P	0.8	-	F	slope of pressure relation	Eq. 6
Star formation: bursts					Baugh et al. (2005)
f_{dyn}	20	0 - 100	P	Multiplier for dynamical time	Eq. 9
$\tau_{*\mathrm{burst,min}}$	0.1 Gyr	0-1.0	P	minimum burst timescale	Eq. 9
Photoionization feedback					Benson et al. (2003)
z_{reion}	10	-	F	reionization redshift	
V_{crit}	$30\mathrm{km\,s}^{-1}$	-	F	threshold circular velocity	

Lacey et al. 2016

Model parameters -II

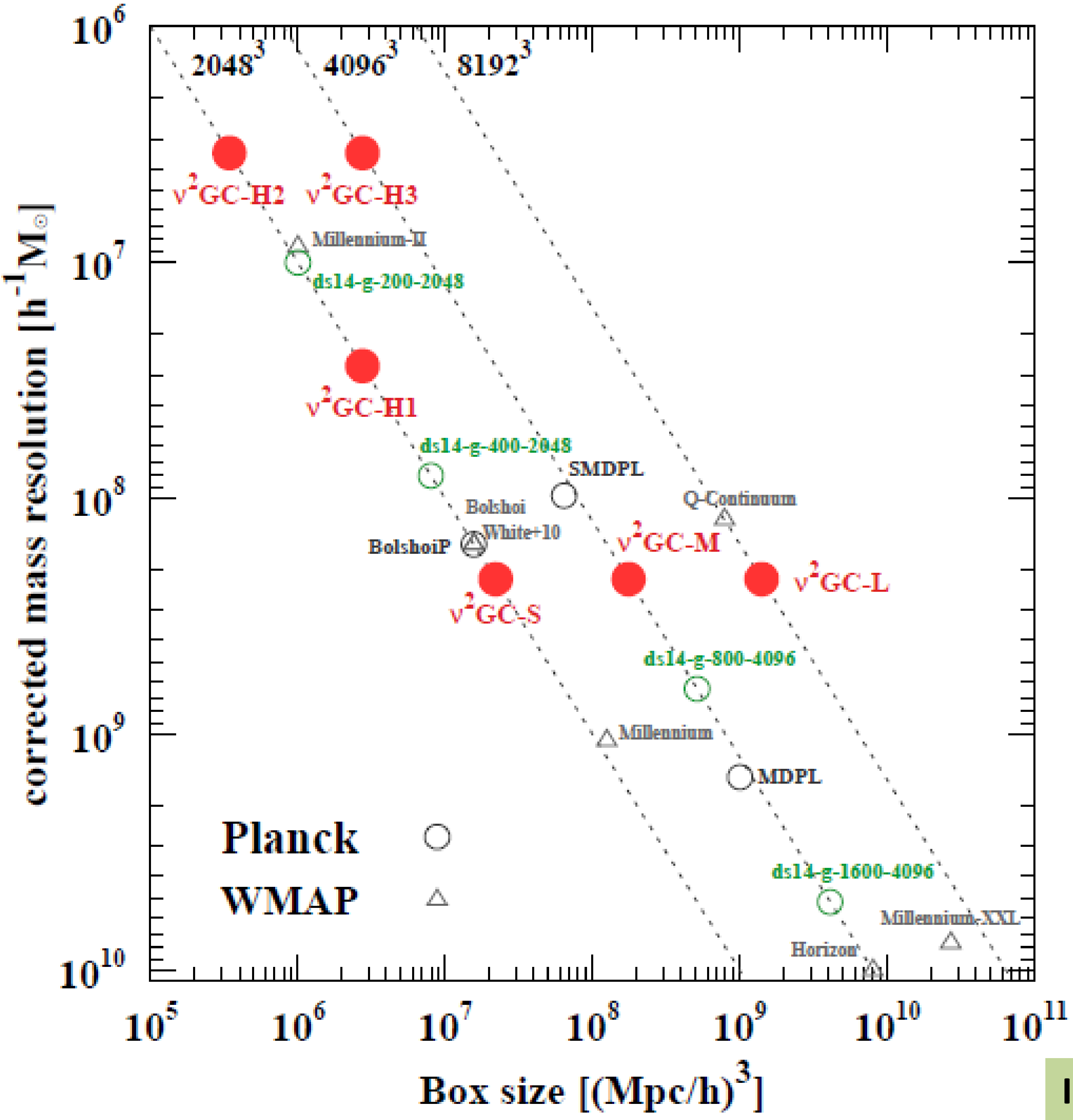
SNe feedback					Cole et al. (2000)
$V_{\rm SN}$	$320 \rm km\, s^{-1}$	anything	P	pivot velocity	Eq. 10
$\gamma_{\rm SN}$	3.2	0-5.5	P	slope on velocity scaling	Eq. 10
$\alpha_{\rm ret}$	0.64	0.3-3	P	reincorporation timescale multiplier	Eq. 11
AGN feedback & SMBH growth					Bower et al. (2006)
$f_{\rm BH}$	0.005	0.001-0.01	S	fraction of mass accreted onto BH in starburst	Malbon et al. (2007)
$\alpha_{\rm cool}$	0.8	0-2	P	ratio of cooling/free-fall time	Eq. 12
$f_{\rm Edd}$	0.01	-	S	controls maximum BH heating rate	Eq. 13
$\epsilon_{\rm heat}$	0.02	-	S	BH heating efficiency	
Disk stability					Cole et al. (2000)
F_{stab}	0.9	0.9-1.1	P	Threshold for instability	
Galaxy mergers					Jiang et al. (2008)
Size of merger remnants					Cole et al. (2000)
$f_{\rm orbit}$	0	0 - 1	S	orbital energy contribution	Eq. 19
$f_{\rm DM}$	2	-	S	dark matter fraction in galaxy mergers	
Starburst triggering in mergers					Baugh et al. (2005)
$f_{\rm ellip}$	0.3	0.2 - 0.5	P	Threshold on mass ratio for major merger	
$f_{\rm burst}$	0.05	0.05 - 0.3	P	Threshold on mass ratio for burst	
Dust model					Granato et al. (2000)
$f_{\rm cloud}$	0.5	0.2 - 0.8	P	fraction of dust in clouds	
$t_{\rm esc}$	1Myr	$1-10$Myr	P	escape time of stars from clouds	
β_b	1.5	1.5 - 2	S	sub-mm emissivity slope in starbursts	Eq. A17

Lacey et al. 2016

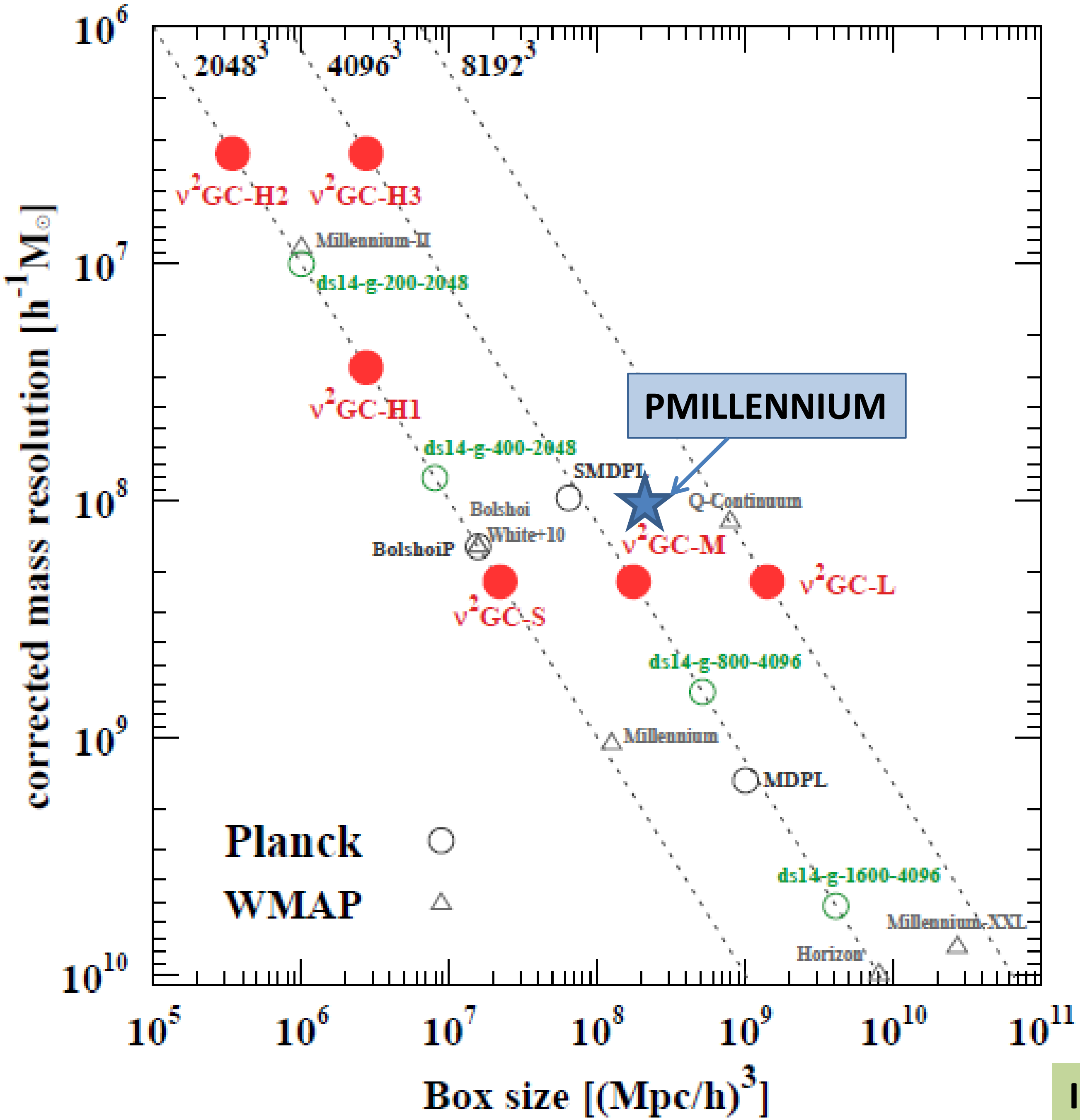
The Planck Millennium N-body

Ω_M	Ω_b	n_{spec}	h	σ_8	L_{box} (h^{-1} Mpc)	N_p	M_p (h^{-1} $M_\odot$)	M_h (h^{-1} $M_\odot$)	Label
0.25	0.0455	1.0	0.73	0.9	500	2160^3	8.56×10^8	1.71×10^{10}	MSI
0.25	0.0455	1.0	0.73	0.9	100	2160^3	6.86×10^6	1.37×10^8	MSII
0.272	0.0455	0.961	0.704	0.801	500	2160^3	9.31×10^8	1.86×10^{10}	WM7
0.307	0.0483	0.967	0.678	0.829	542.16	5040^3	1.06×10^8	2.12×10^9	PMILL

- Planck cosmology
- 800 Mpc box
- 512x EAGLE volume
- 271 outputs
- 128 billion particles
- 1.06e+08/h Msun particle mass
- 2.12e+09/h Msun halo mass
- Almost x10 better halo resolution than Millennium
- 7 million CPU hours (inc SUBFIND runtime)
- One snapshot 32Tb

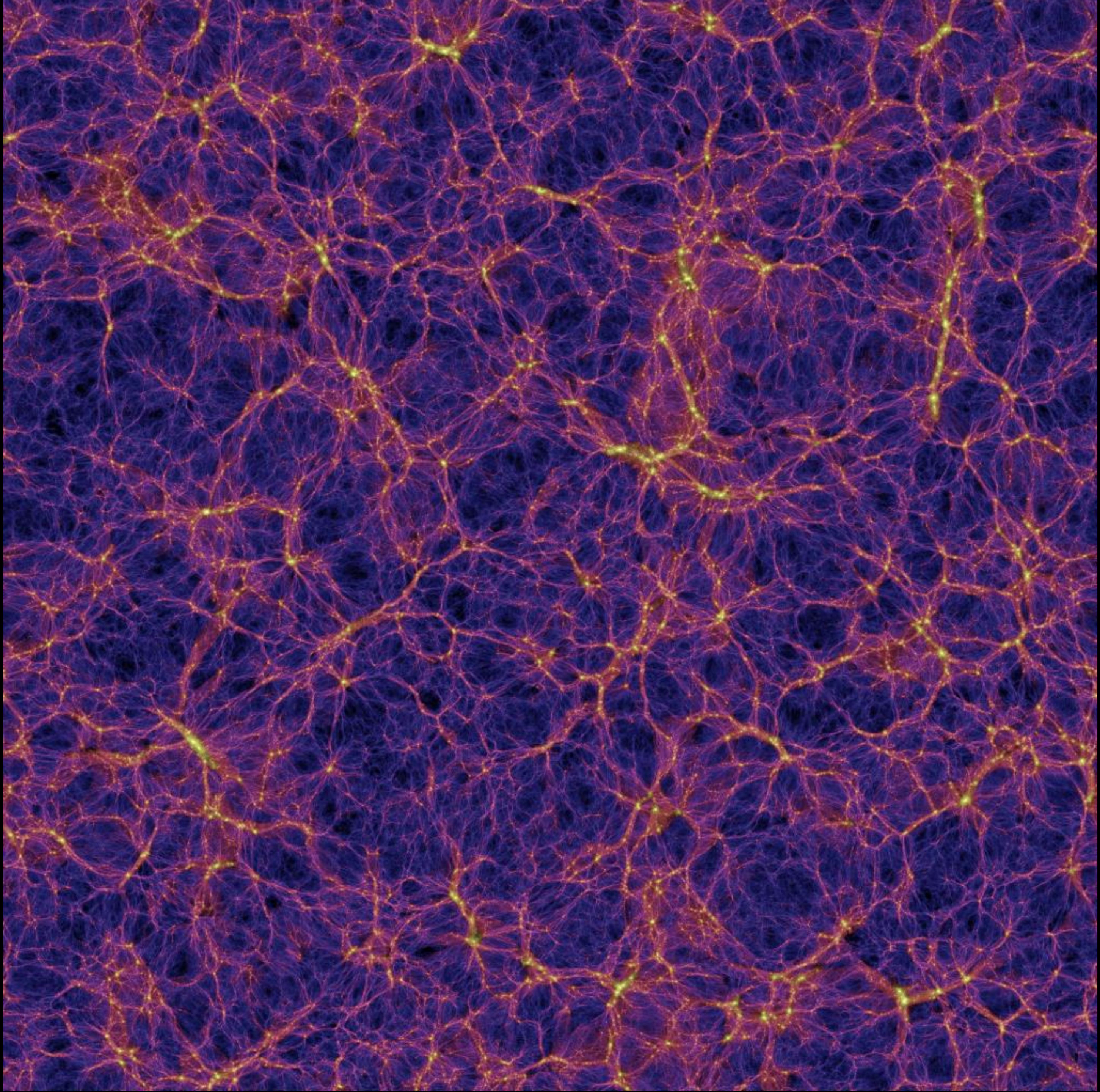


Ishiyama 2015 PASJ

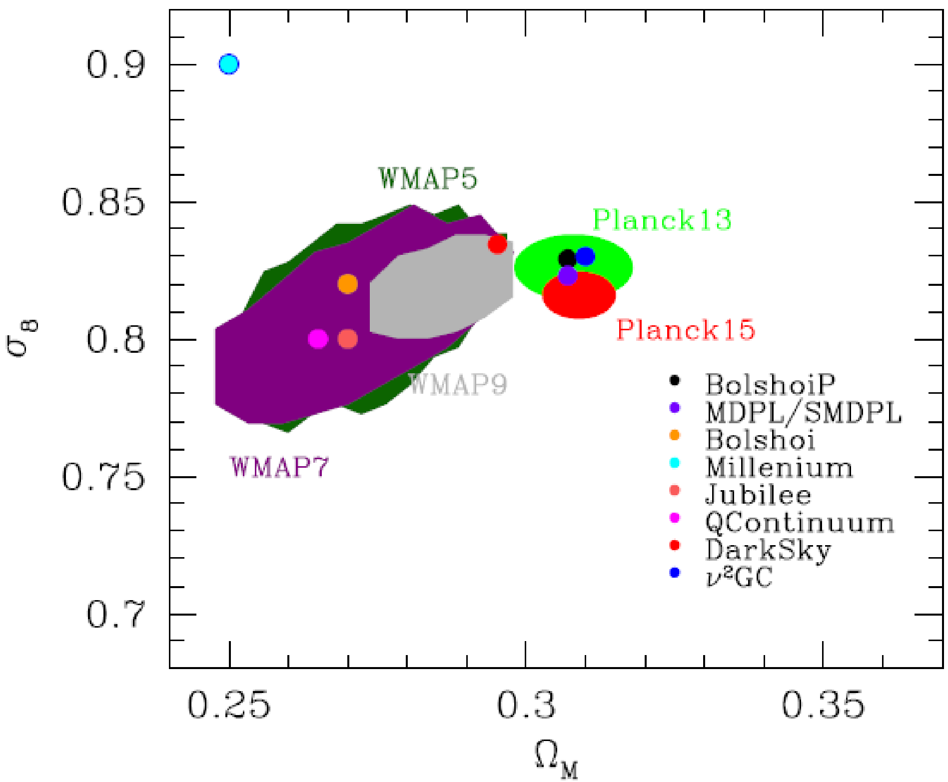


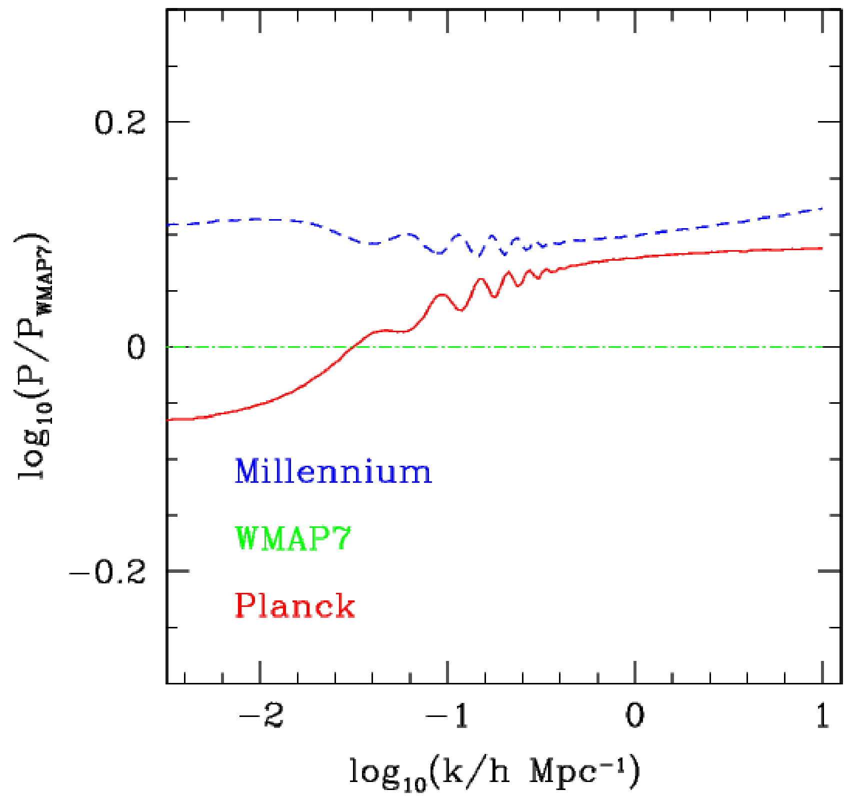
Ishiyama 2015 PASJ

PLANCK MILLENNIUM

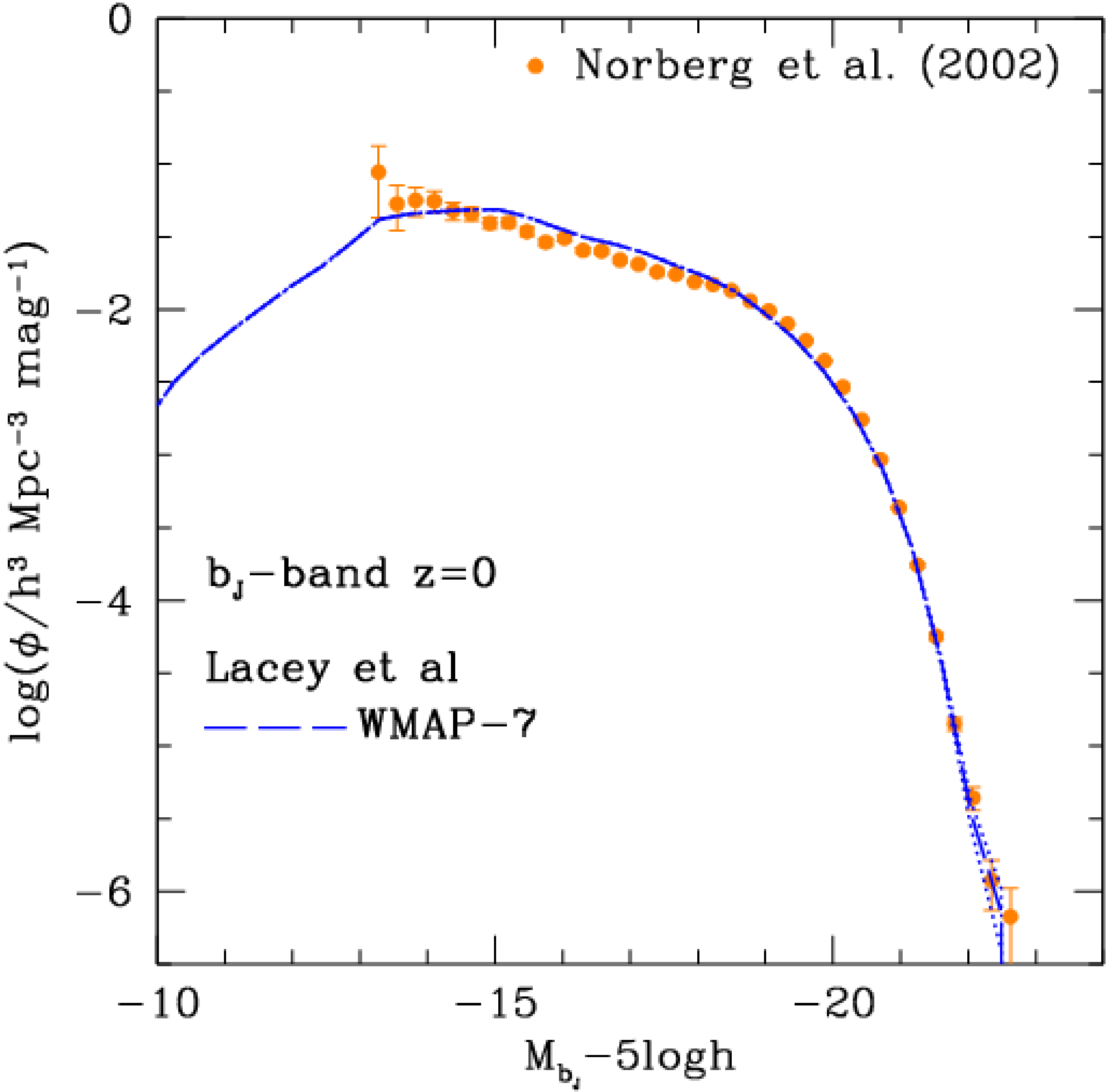


Planck versus Millennium cosmology

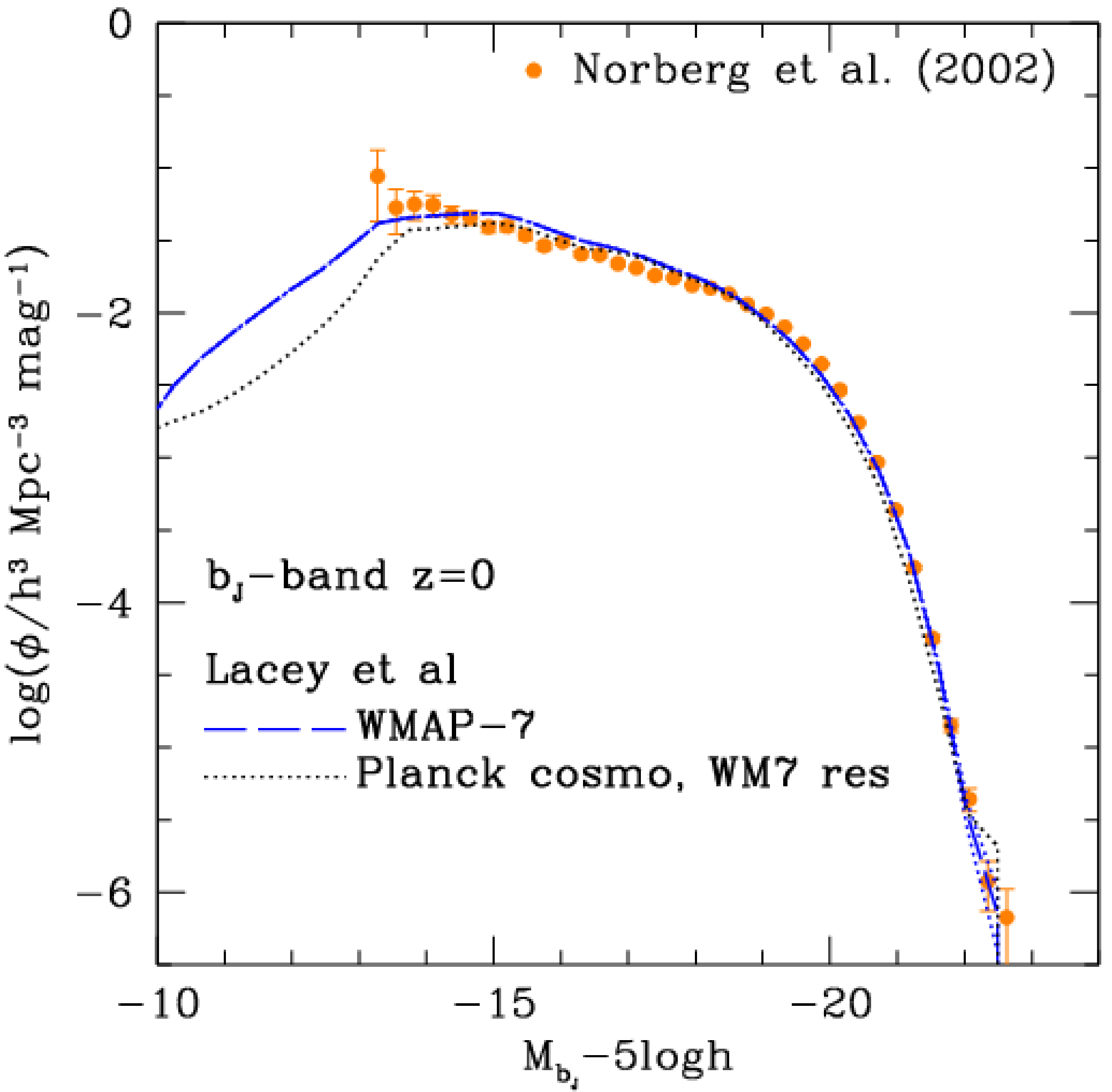




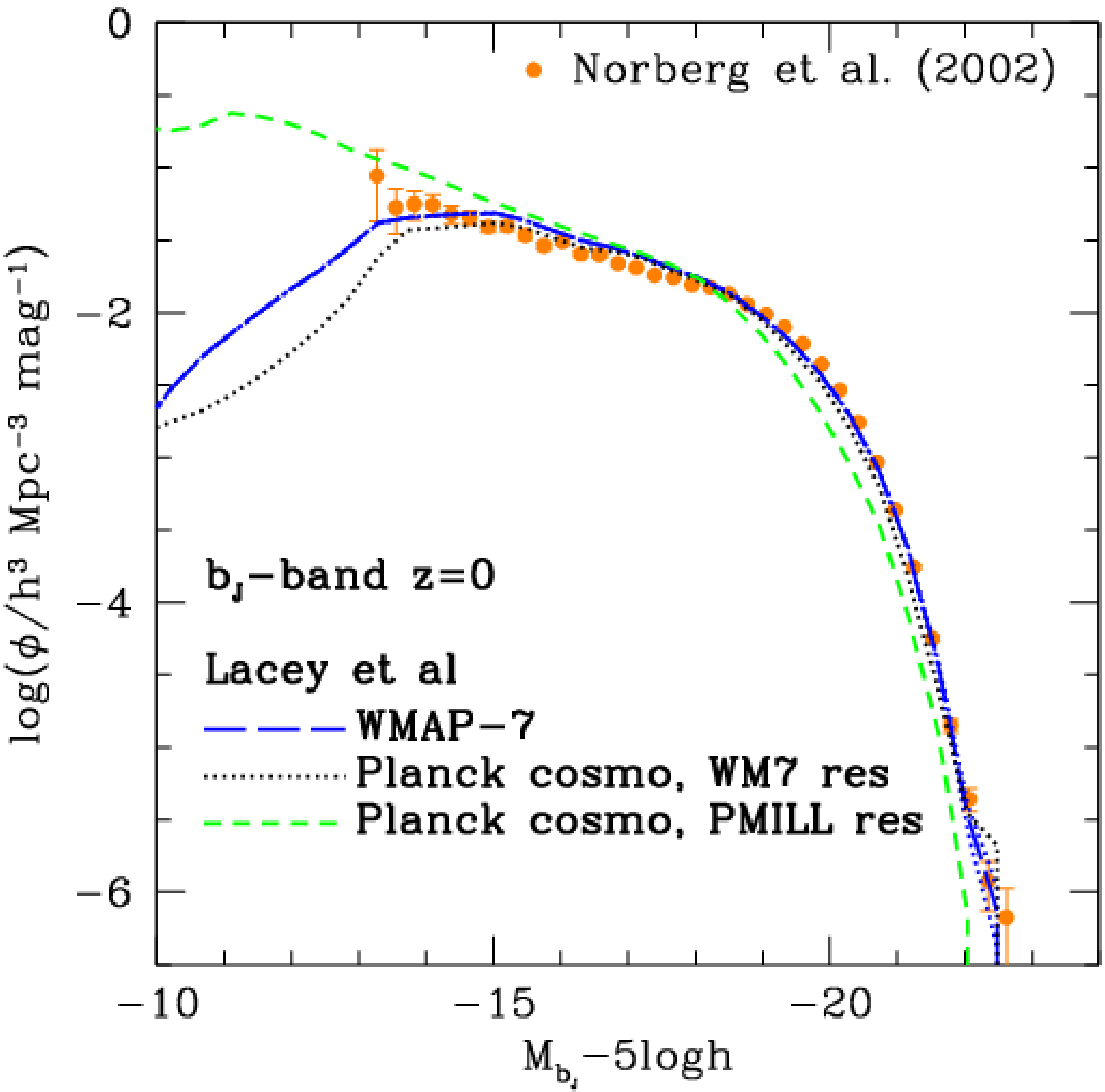
(image from Rodrıguez-Puebla et al. 2016)



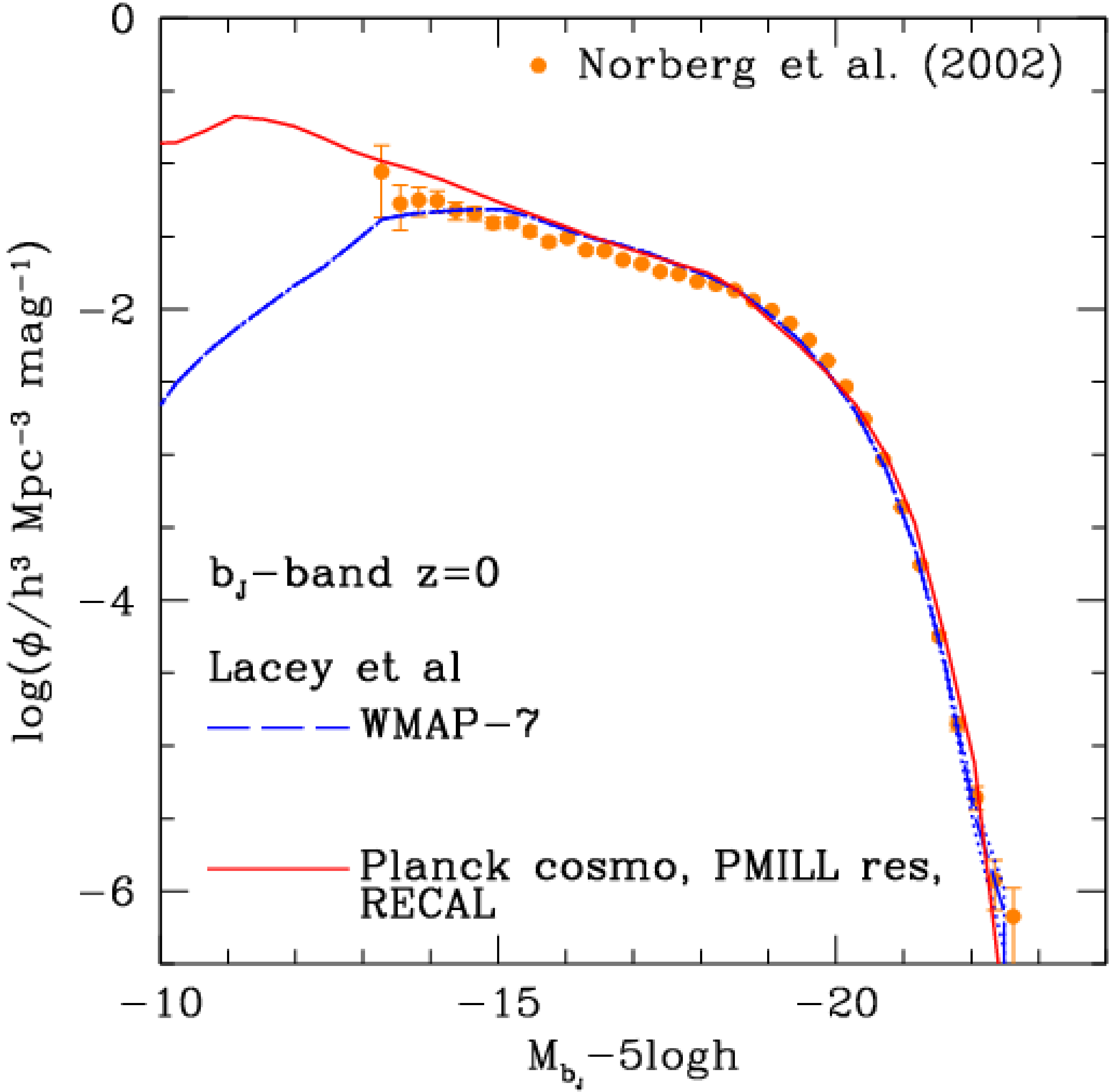
The local luminosity function



Change cosmology – but keep galaxy formation parameters the same



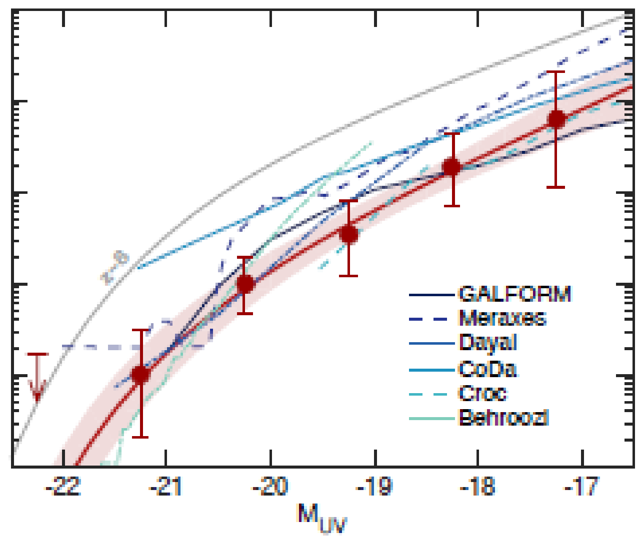
Change cosmology and use full resolution of P-Mill trees

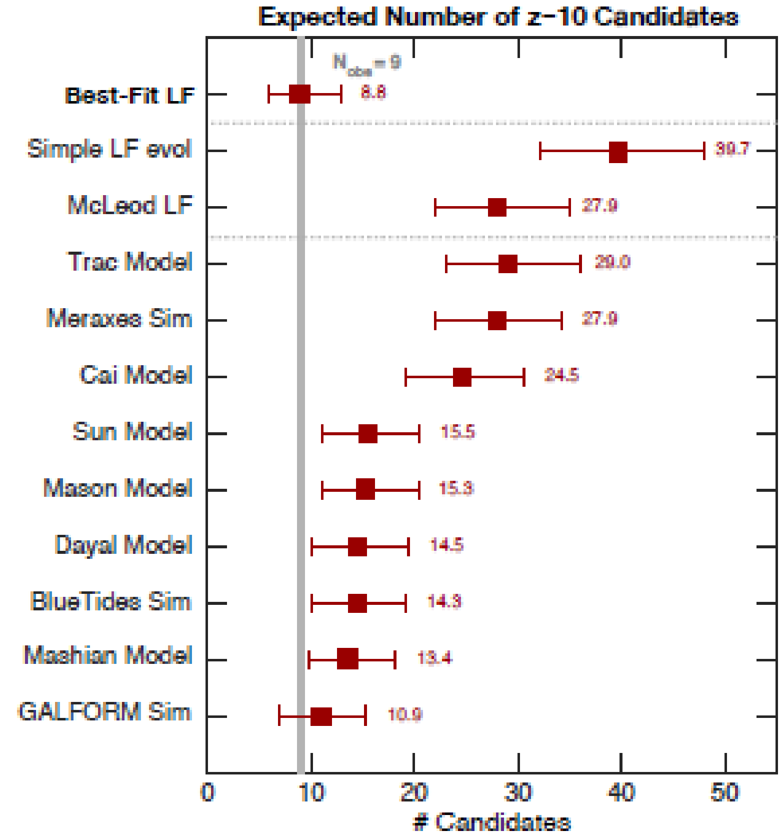


0
−2
−4
−6
log(ϕ/h³ Mpc⁻³ mag⁻¹)
−10
−15
−20
M_bJ −5logh
Norberg et. al. (2002)
bJ−band z=0
Lacey et al
WMAP−7
Planck cosmo, PMILL res,
RECAL

UV LF at z ~ 10

Oesch et al. 2017 (arXiv:1710.11131)



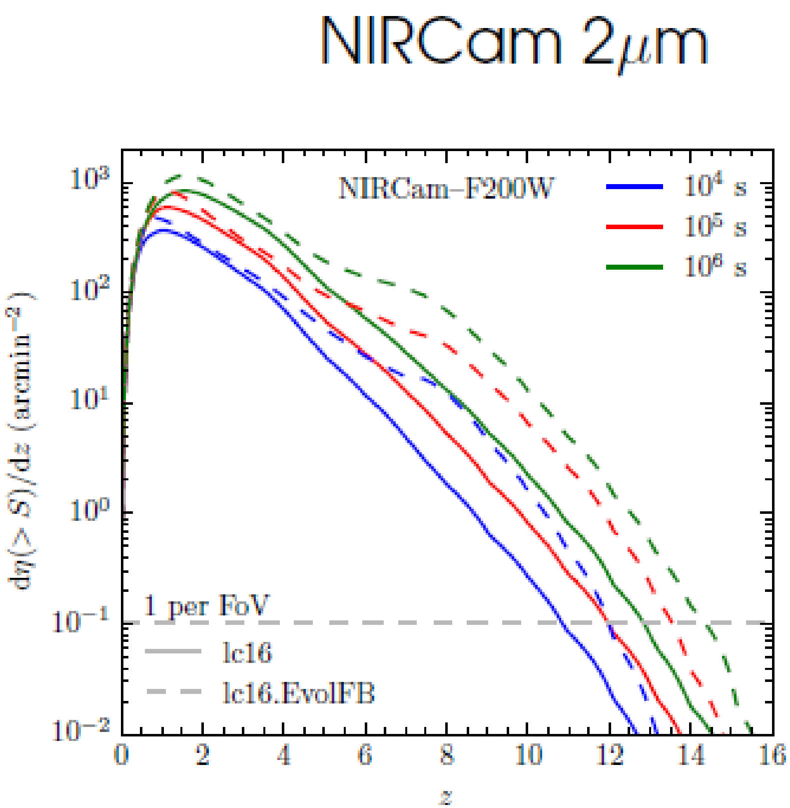


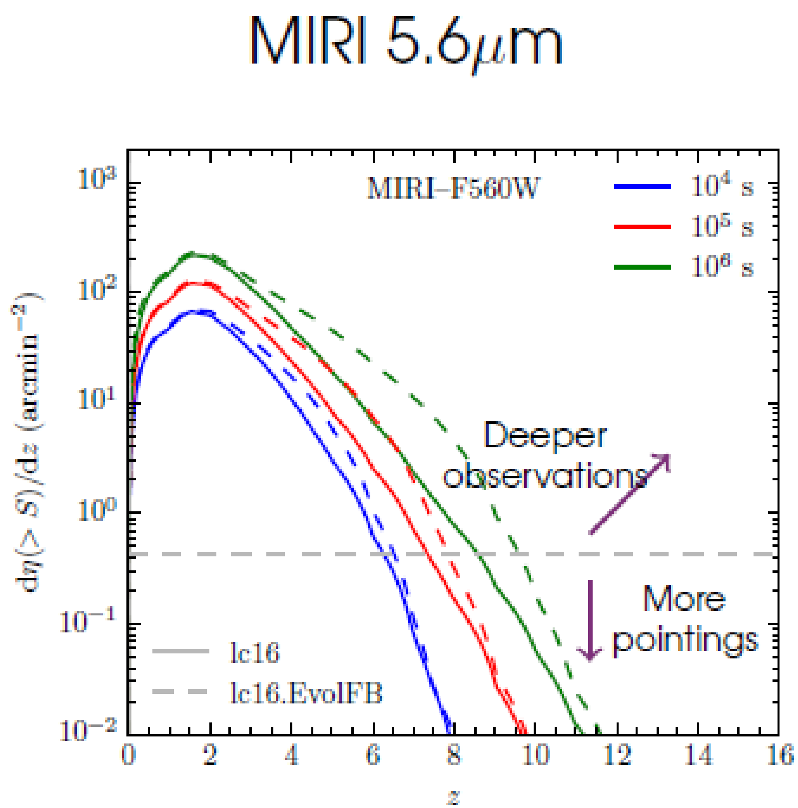
"The only model that is in close agreement with the observed number counts and also with the observed LF is the one based on GALFORM presented in Cowley et al. (2017)."

Predictions for deep galaxy surveys with JWST from ΛCDM
Cowley et al. 2018 MNRAS 474 2352 (arXiv:1702.02146)

Results

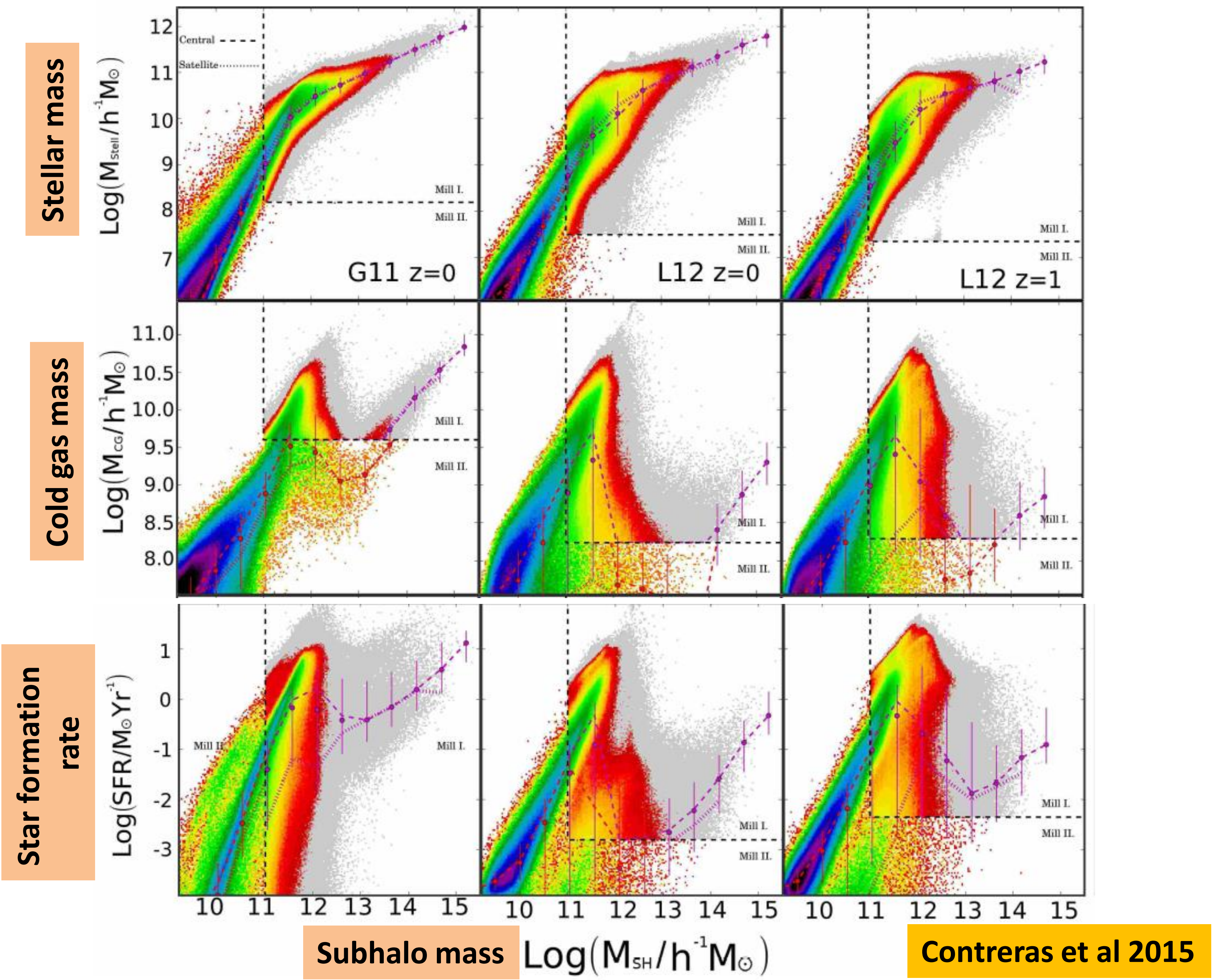
Changing exposure time & FoV



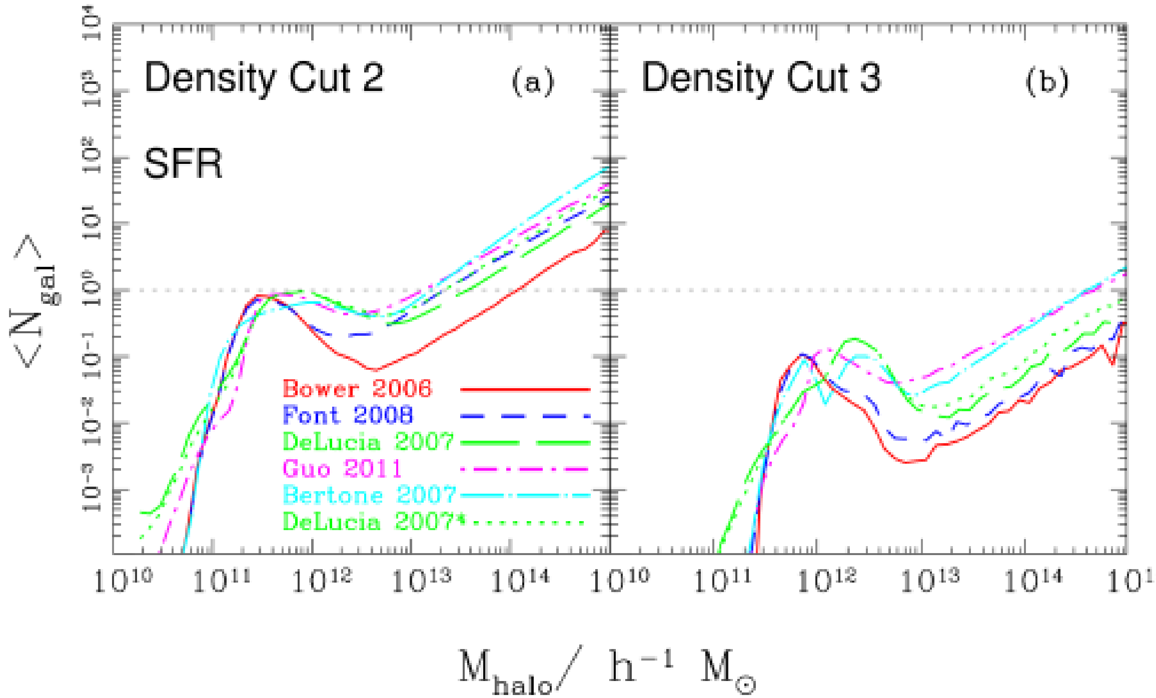


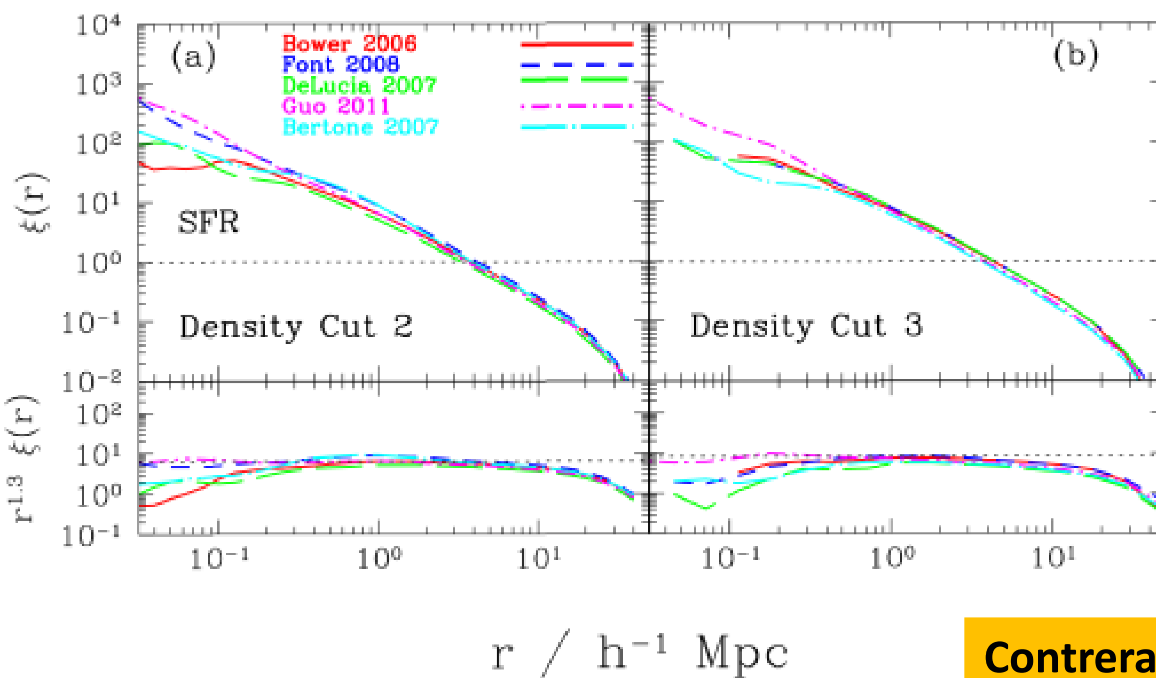
For given science goals model predictions can inform observing strategy

Predictions for deep galaxy surveys with JWST from ΛCDM
Cowley et al. 2018 MNRAS 474 2352 (arXiv:1702.02146)


Stellar mass
Cold gas mass
Star formation rate
Log(M_Stell/h^-1 M⊙)
Log(M_CG/h^-1 M⊙)
Log(SFR/M⊙ Yr^-1)
Central
Satellite
Mill I.
Mill II.
G11 z=0
L12 z=0
L12 z=1
Subhalo mass
Log(M_SH/h^-1 M⊙)
Contreras et al 2015

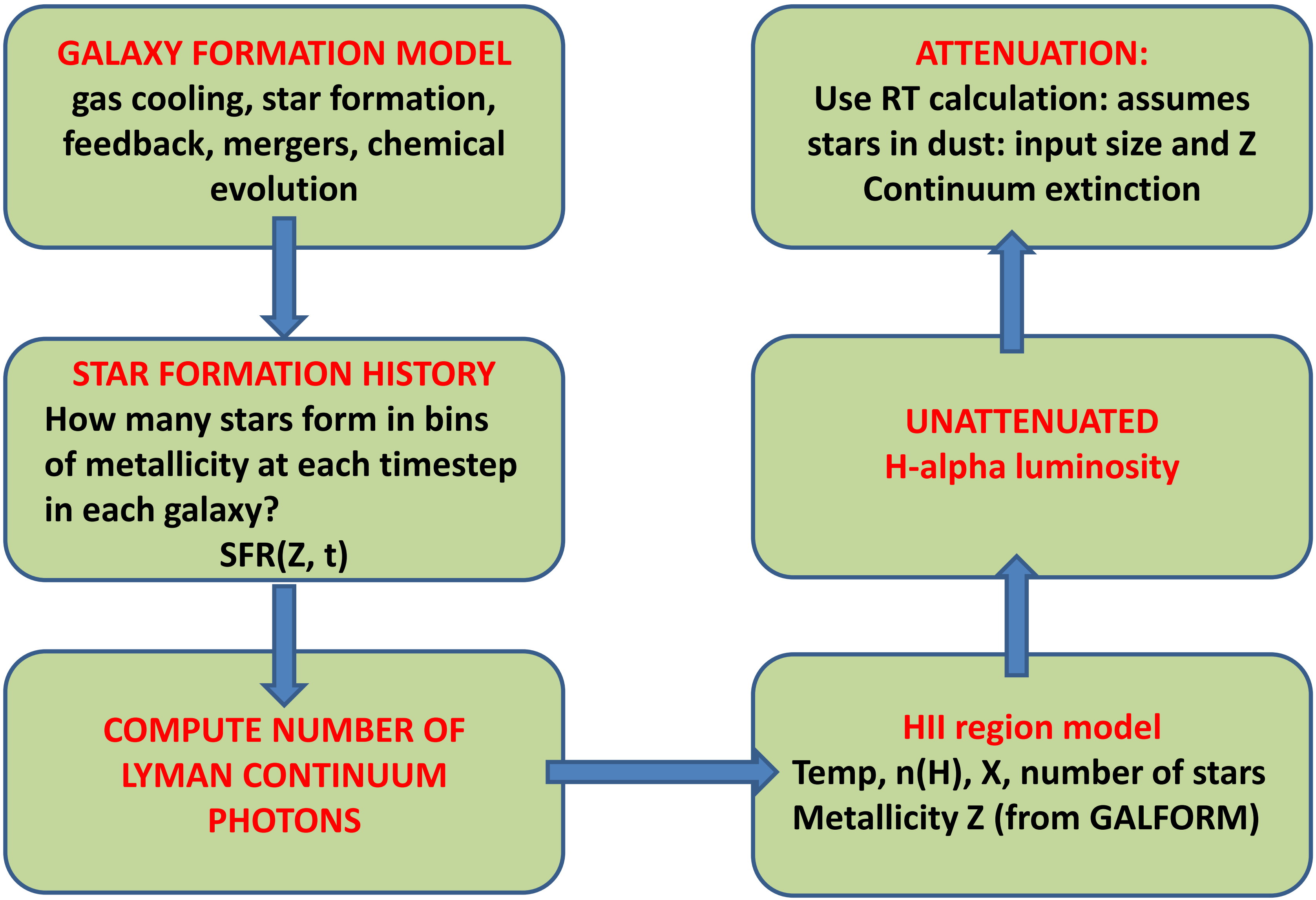
Star Formation Rate Samples





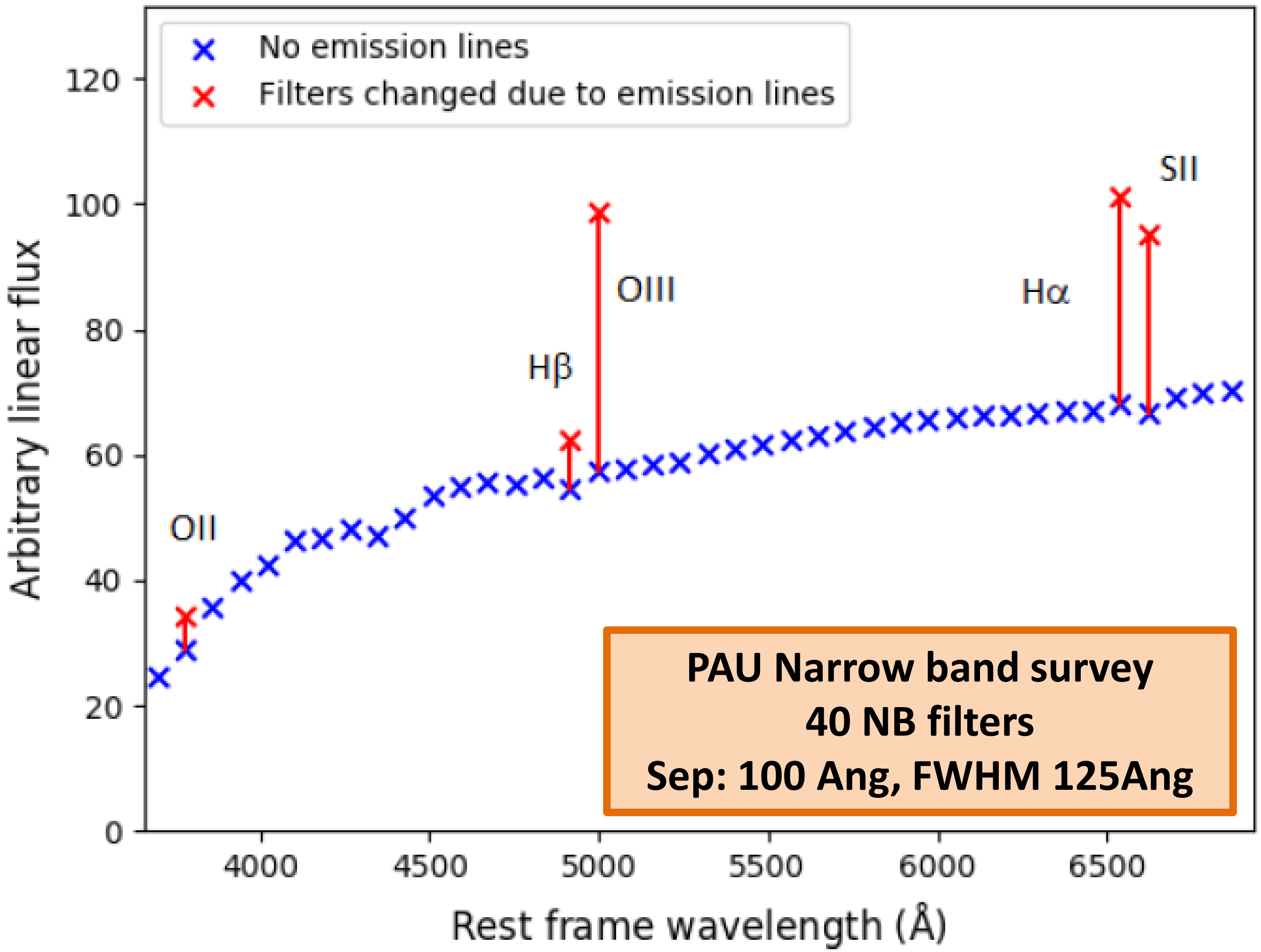
Contreras et al. 2013

CALCULATION OF EMISSION LINES IN GALFORM



(e.g. Gonzalez-Perez et al 2018)

Impact of emission lines on NB flux

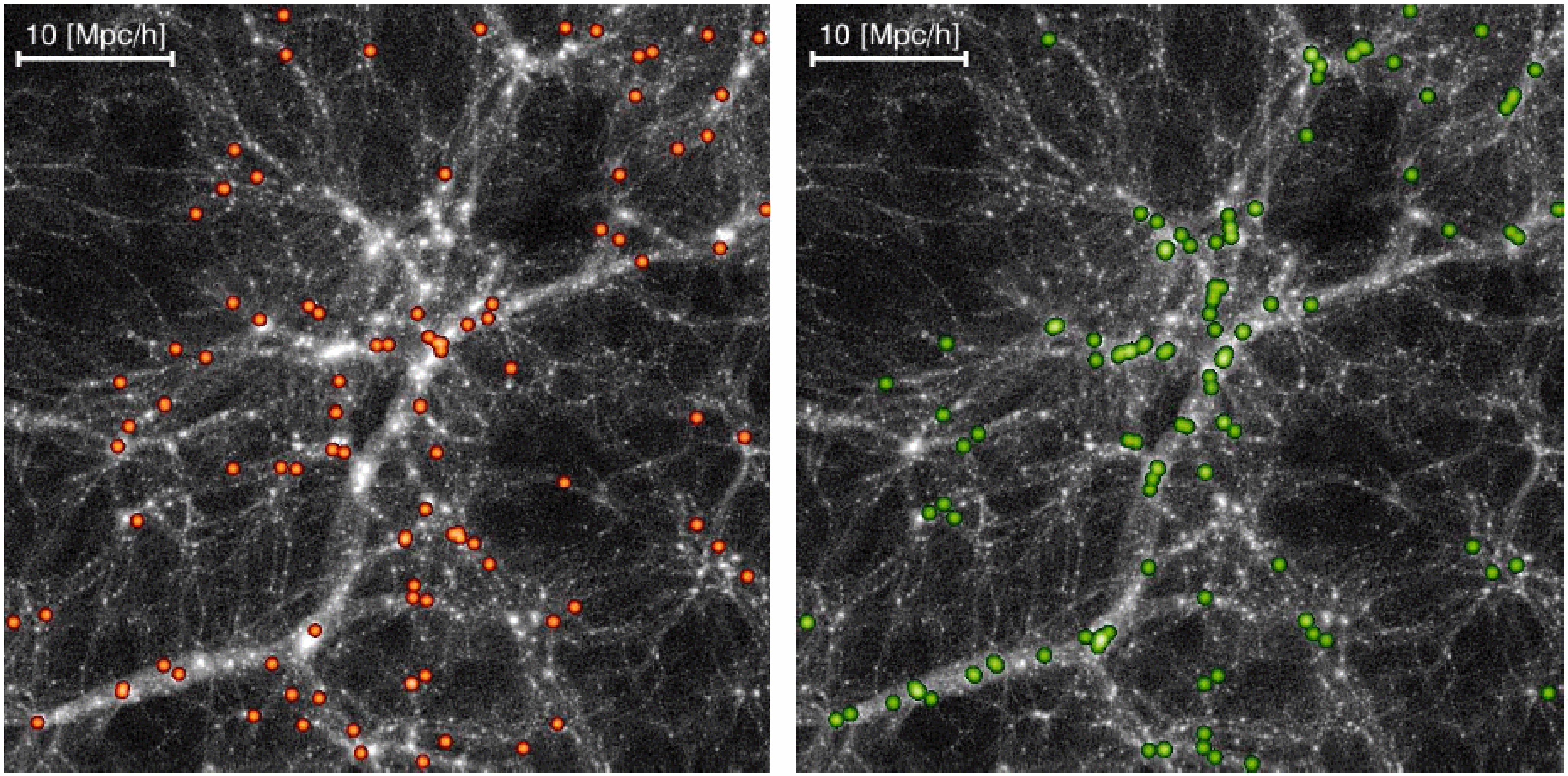


PAU Narrow band survey
40 NB filters
Sep: 100 Ang, FWHM 125Ang

GALFORM + WMAP7 Millennium run : PAU survey lightcone

Stothert et al. 2018

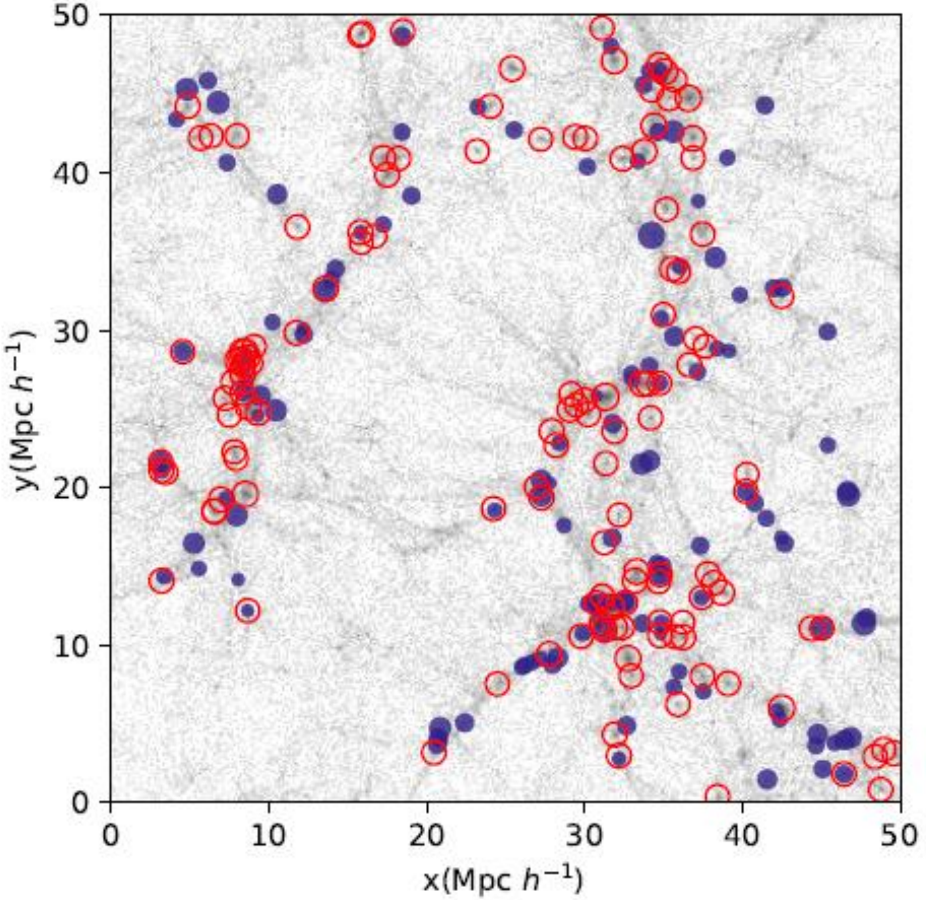
Connecting galaxies to mass

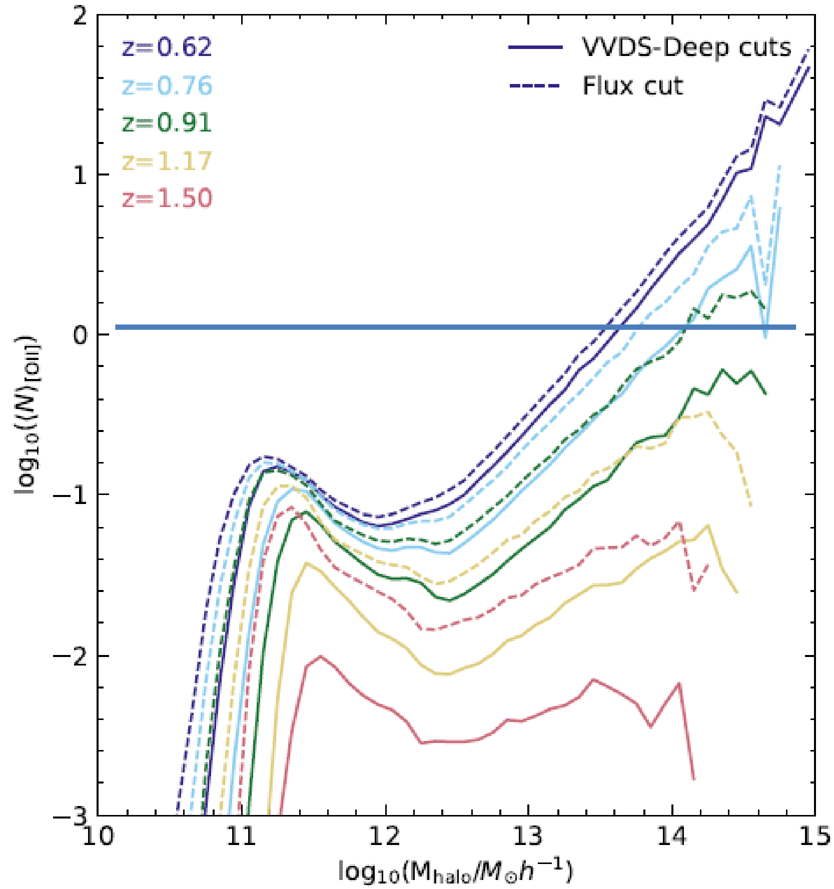


H-α **H-band**

Orsi et al. 2010

Spatial distribution of OII emitters



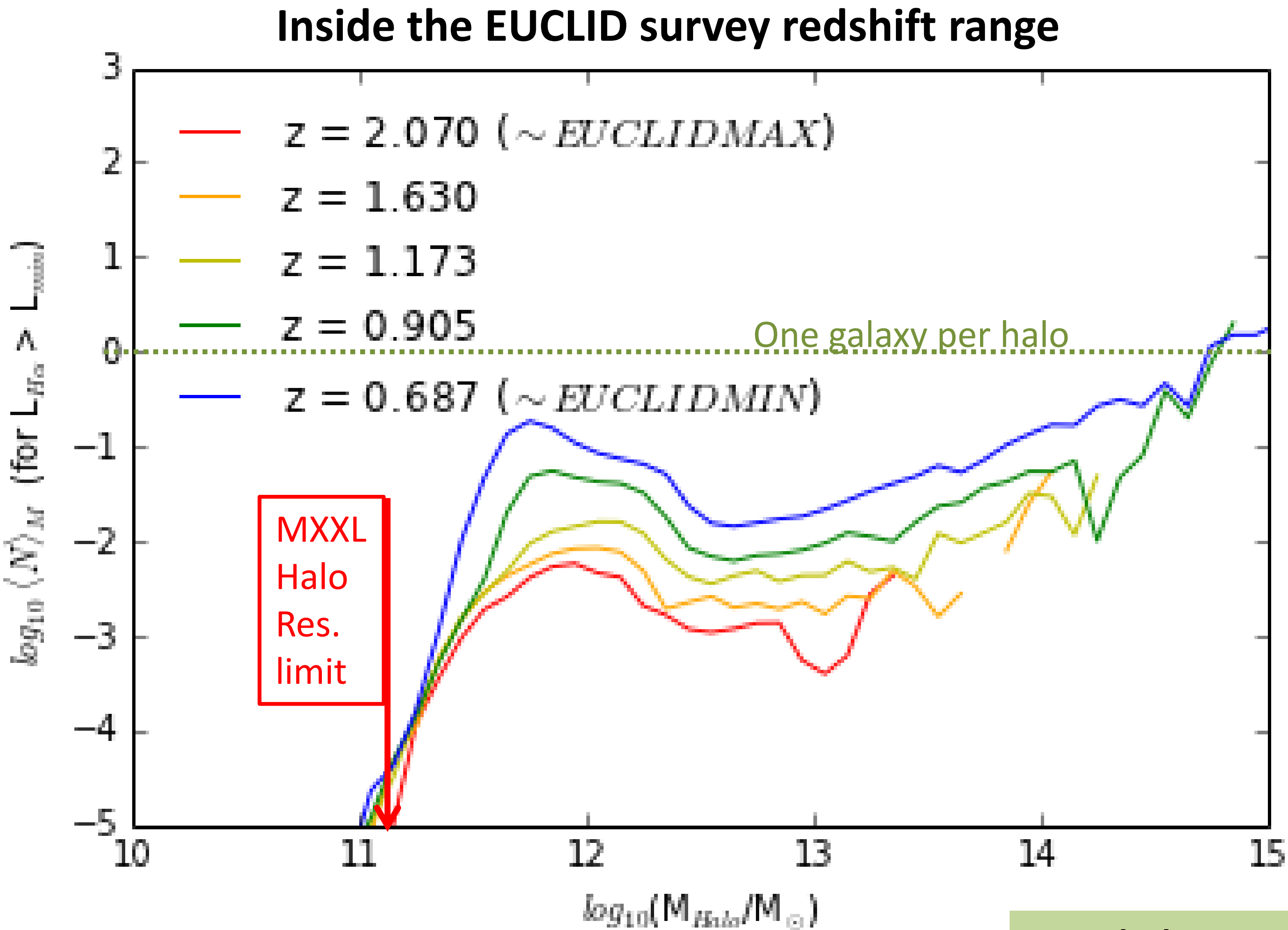


OII emitters

DM haloes: ranked by mass

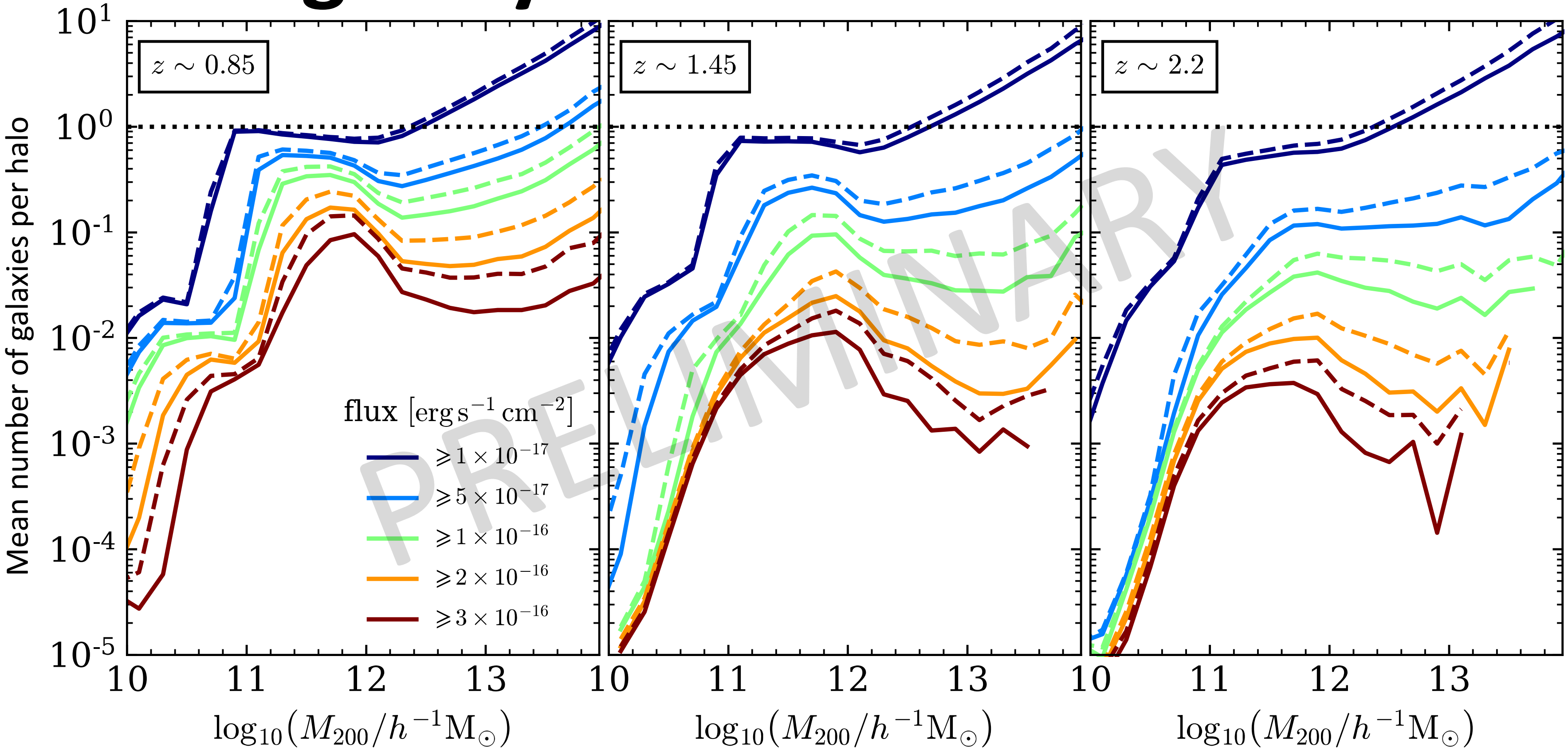
Gonzalez-Perez et al. 2018 arxiv:1708.07628

Hα HOD **output** by GALFORM



Ben Clarke L4 project

Ongoing work by Alex Merson+: Hα galaxy HODs from Galacticus



- At z~1.45 for f>2 × 10^{-16} erg/s/cm^{-2} expect one Hα-emitting galaxy per ~100 DM halos.
- Next step: use HODs and LFs to predict Hα galaxy bias as function of redshift and luminosity.

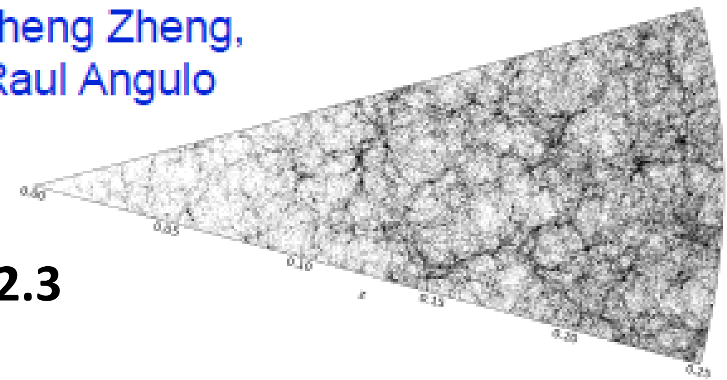
Merson et al. (in prep.)

A Lightcone Catalogue from MXXL

Alex Smith

arXiv:1701.06581

Shaun Cole, Carlton Baugh, Zheng Zheng,
Idit Zehavi, Peder Norberg, Raul Angulo

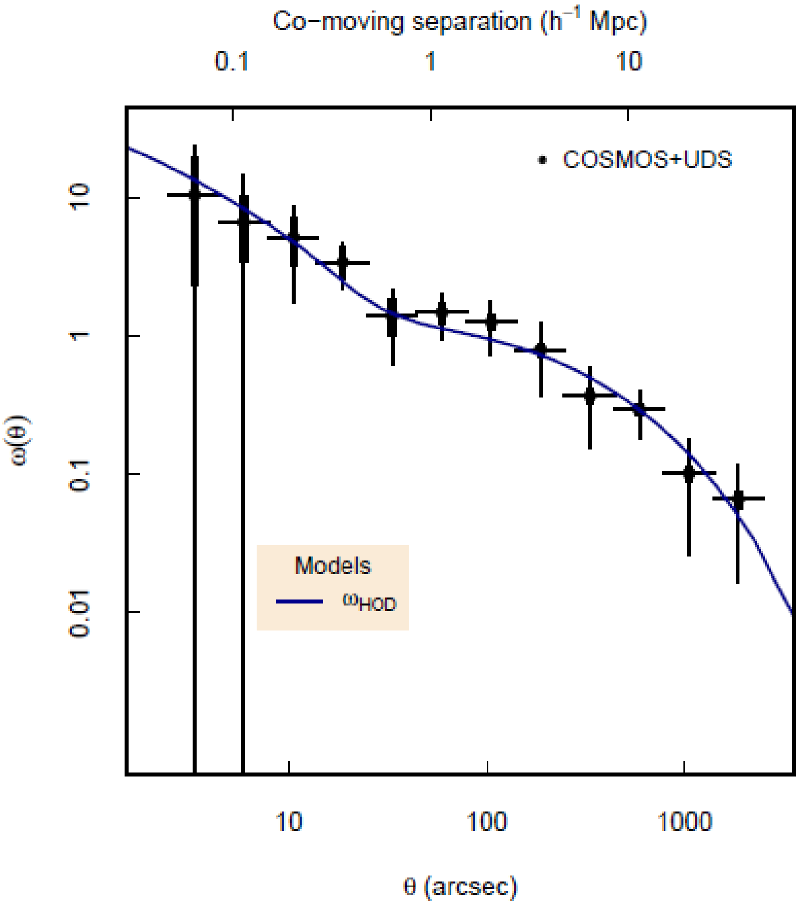


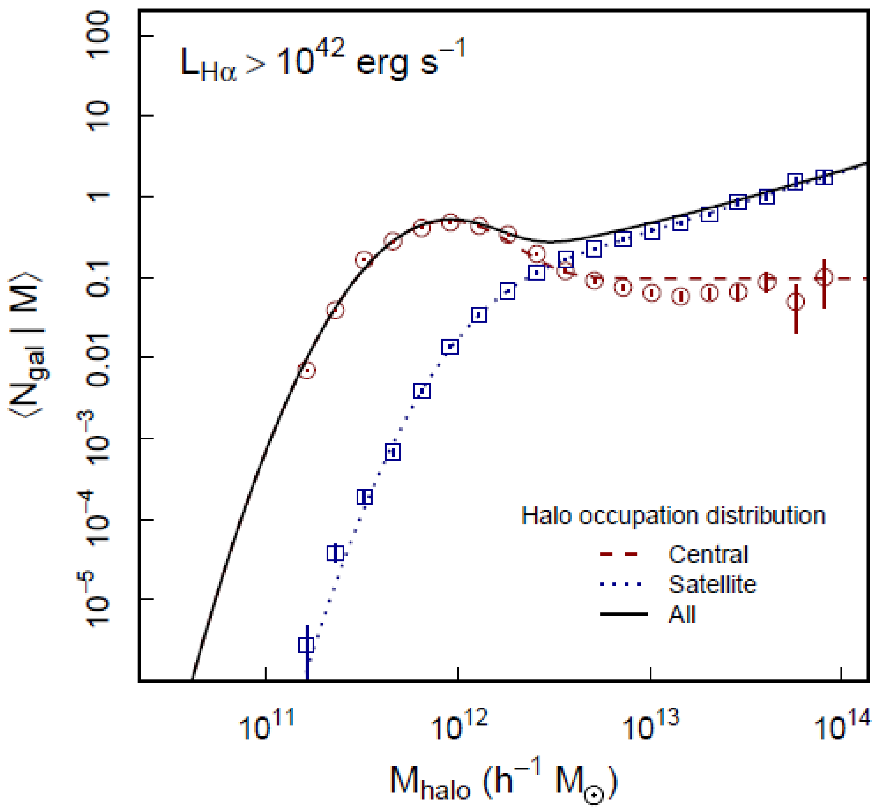
- **Produced an ALL SKY halo lightcone to z=2.3**
- **Can be used to produce mocks for Euclid**
- **Can use HOD predicted by GALFORM or another SAM to populate MXXL halos**
- **Essentially all H-alpha galaxies are in resolved halos**
- **Could add second property e.g. extinction, SED using Smith et al approach, in addition to H-alpha luminosity**

Summary

- Emission luminosity depends on Lyman continuum photons and HII region model
- Number of Lyman continuum photons depends on metallicity & SF history
- Also need to include dust extinction
- HOD for Euclid flux limits: <N> << 1
- Smith et al. : HOD method including L + property
- Applied to MXXL halo lightcone
- Will apply to H-alpha HODs from GALFORM an Galacticus (Alex Merson et al.) to populate MXXL

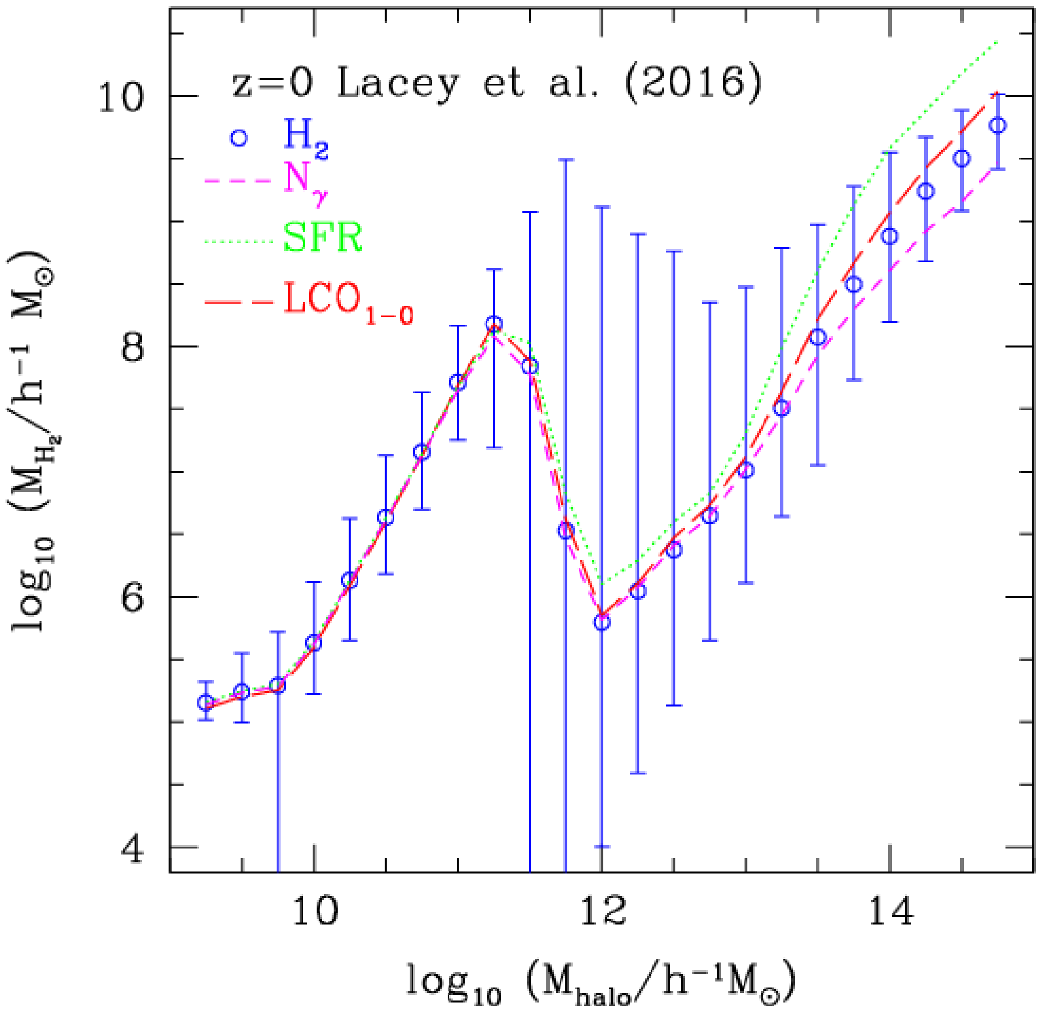
HOD of H-α emitters at z=2.23





370 emitters, ~2sq deg z=2.23 Geach et al. 2012 arXiv:1206.4052

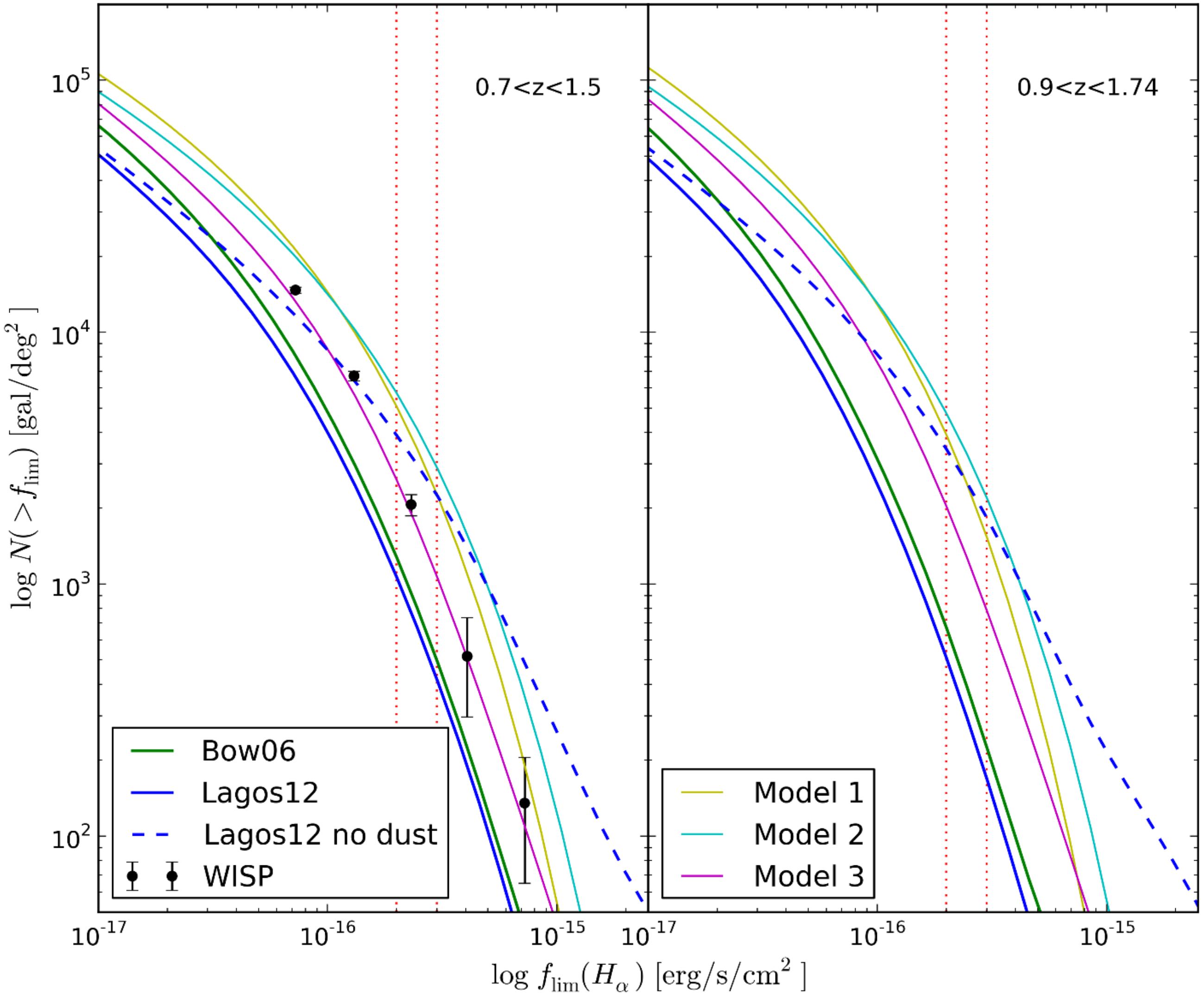
Dependence of SFR & Lyman continuum photons on host halo mass



In this example, adding up contribution from ALL galaxies in halo

Hα emitter number counts predictions of GALFORM models

GALFORM predictions match the observed number counts of Hα emitters better on turning off dust extinction



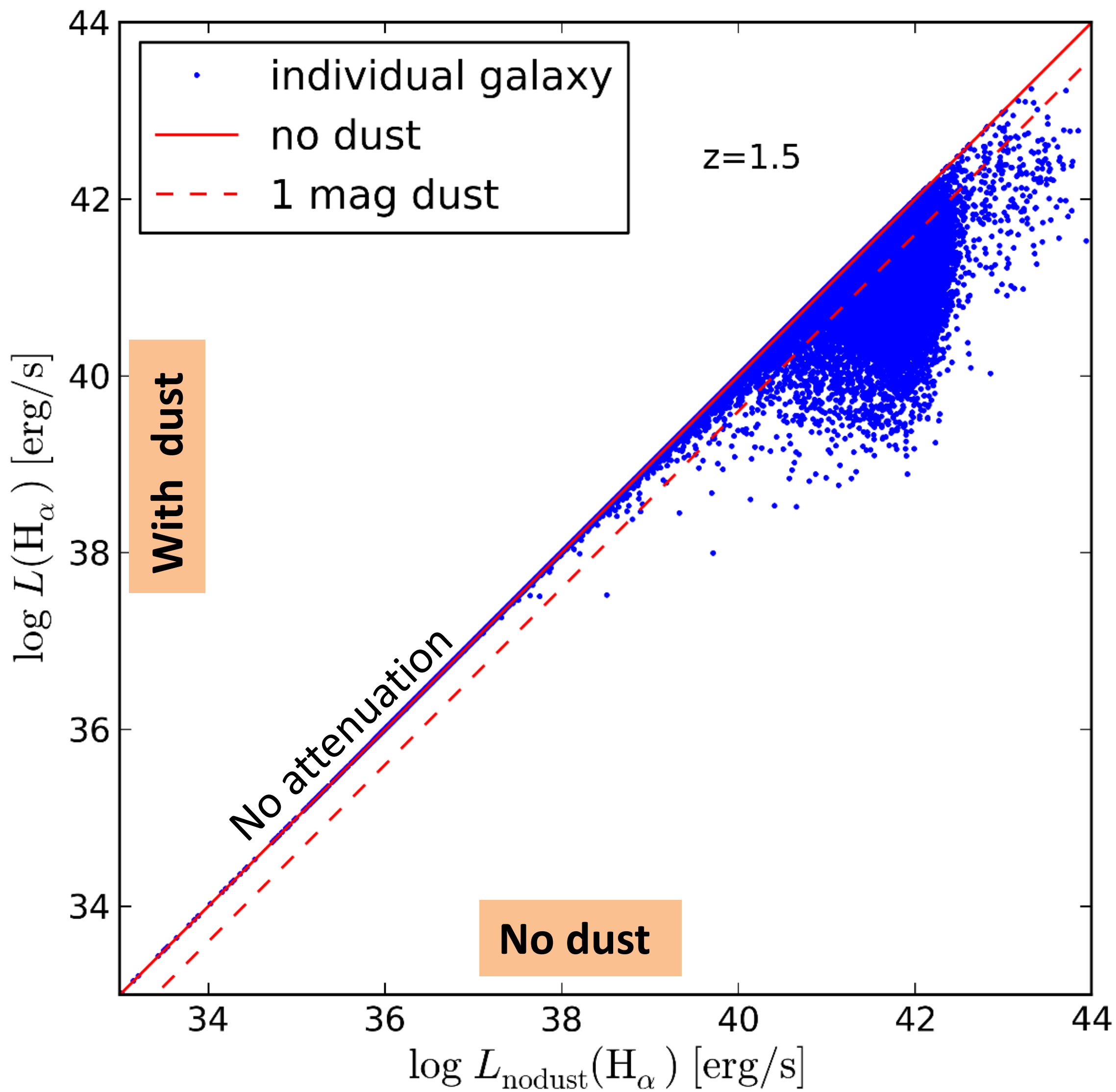
Pozzetti et al. 2016
Difu Shi PhD Thesis

Dust extinction in GALFORM

Observers typically assume fixed 1 magnitude dust extinction

GALFORM calculates the dust extinction of every galaxy using dust grain model and distribution of sizes.

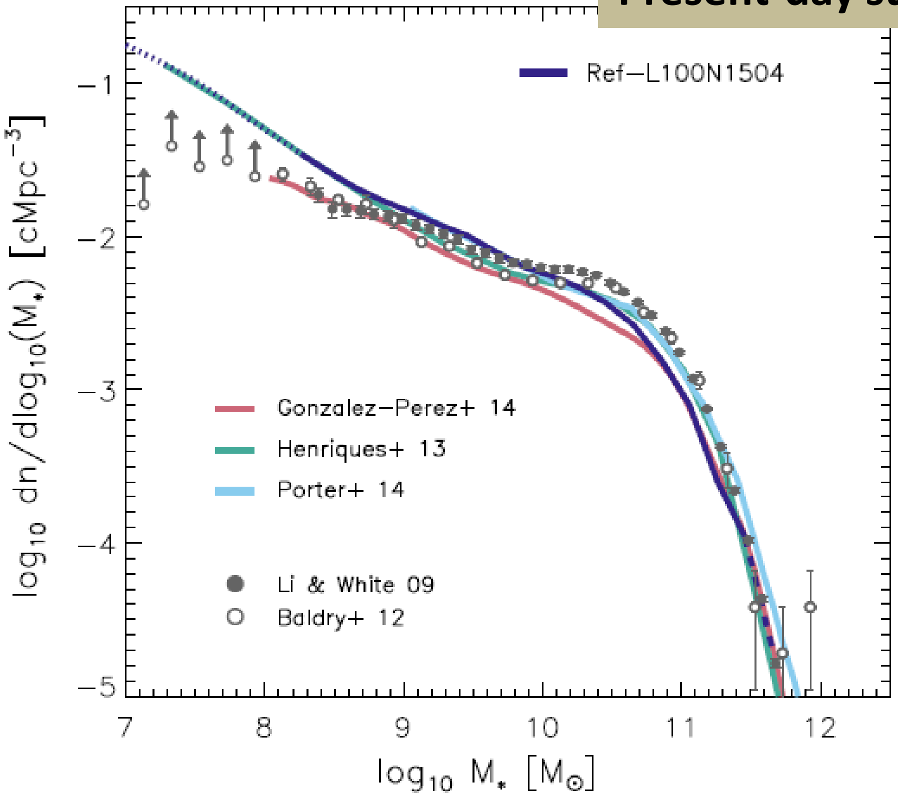
In one simulation sub volume, for galaxies brighter than 10^41 erg/s, 13.3% (3385 out of 25315) show more dust extinction than 1 magnitude (marked by the red dashed line).



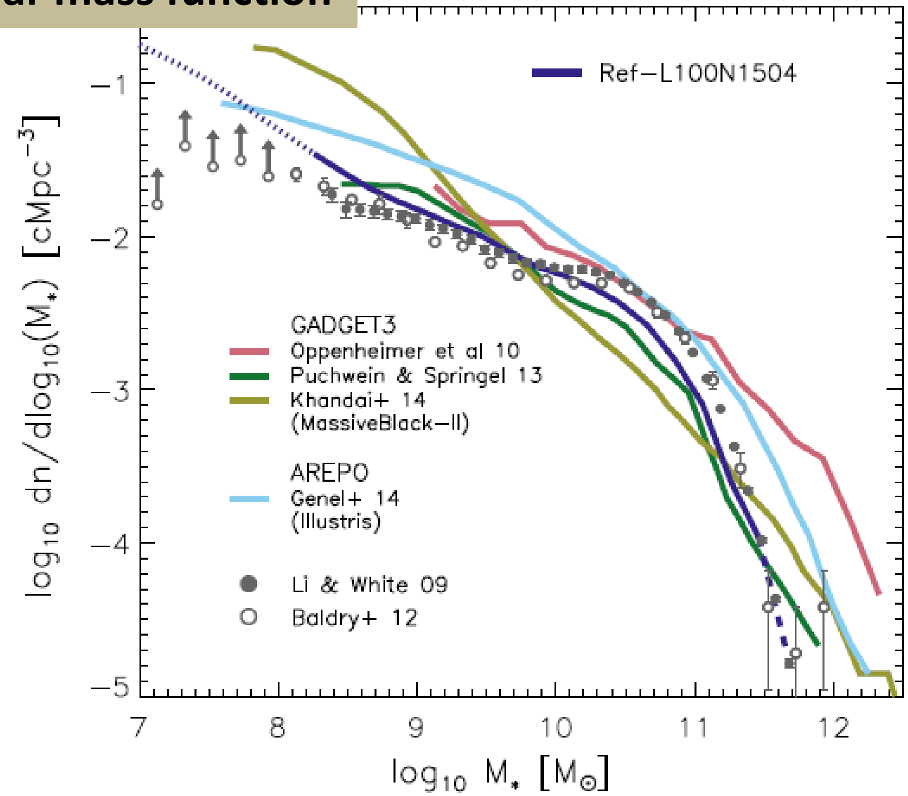
Difu Shi PhD Thesis

SAMs vs gas simulations

Present-day stellar mass function



SAMs vs EAGLE



GAS SIMs vs EAGLE

Schaye et al. 2015