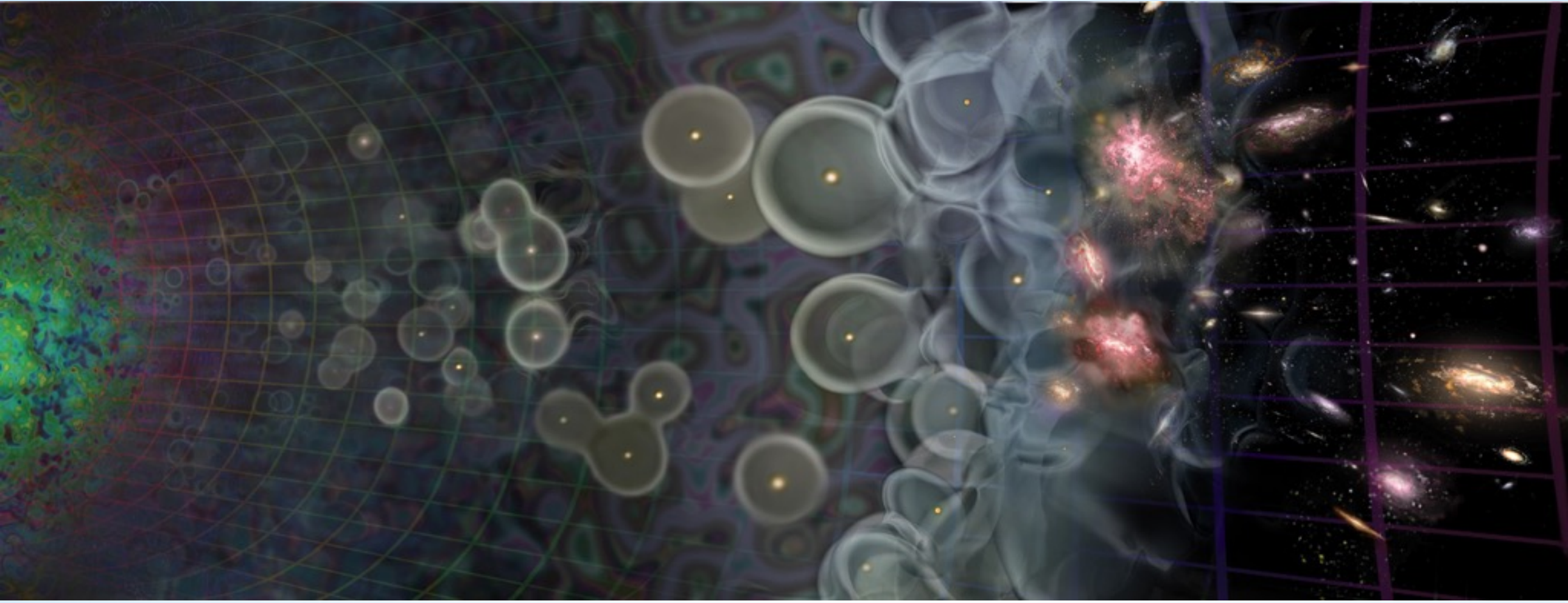
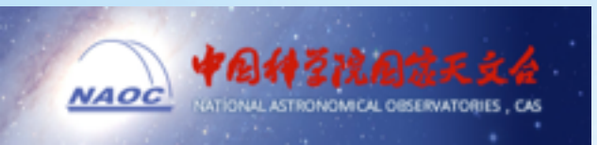


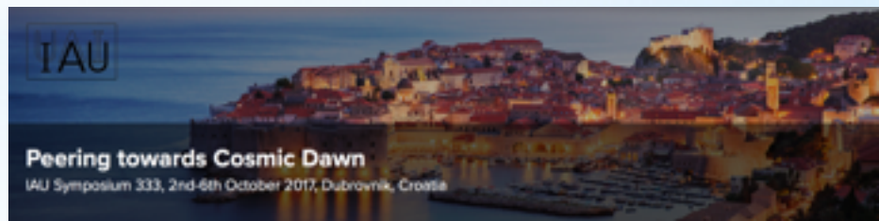
Detecting the Reionization Sources through Gravitational Lensing

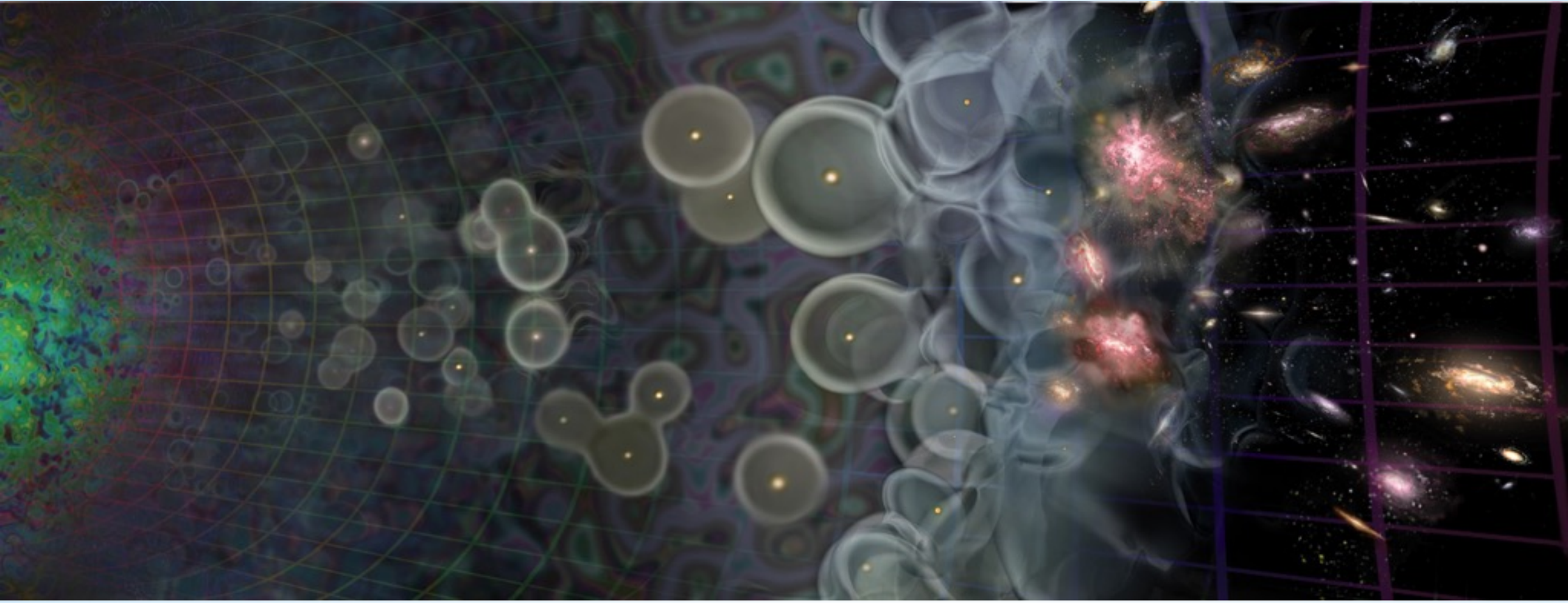
Bin Yue (岳斌)

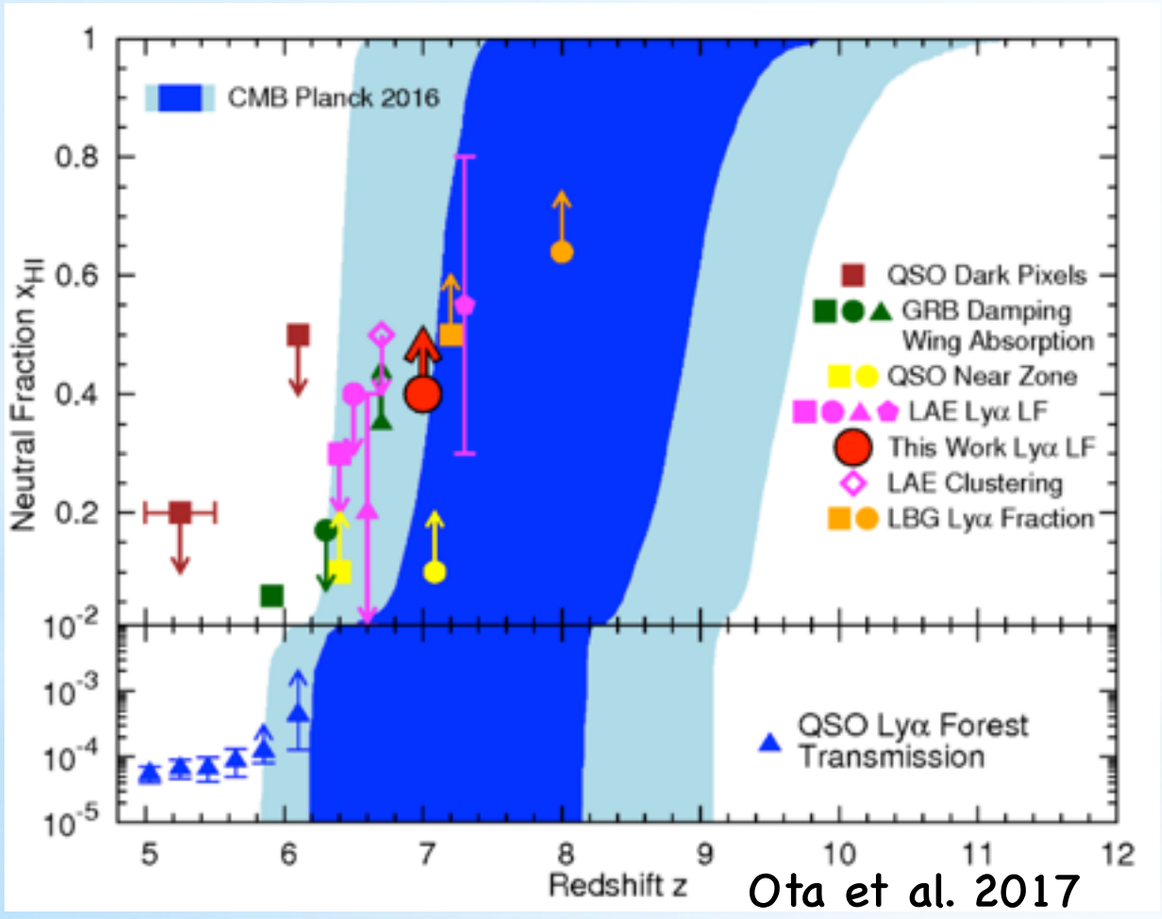
National Astronomical Observatories, Chinese Academy of Sciences

Collaborators: ASTRODEEP team + A. Ferrara, R. Salvaterra, E. Vanzella, Y. Xu

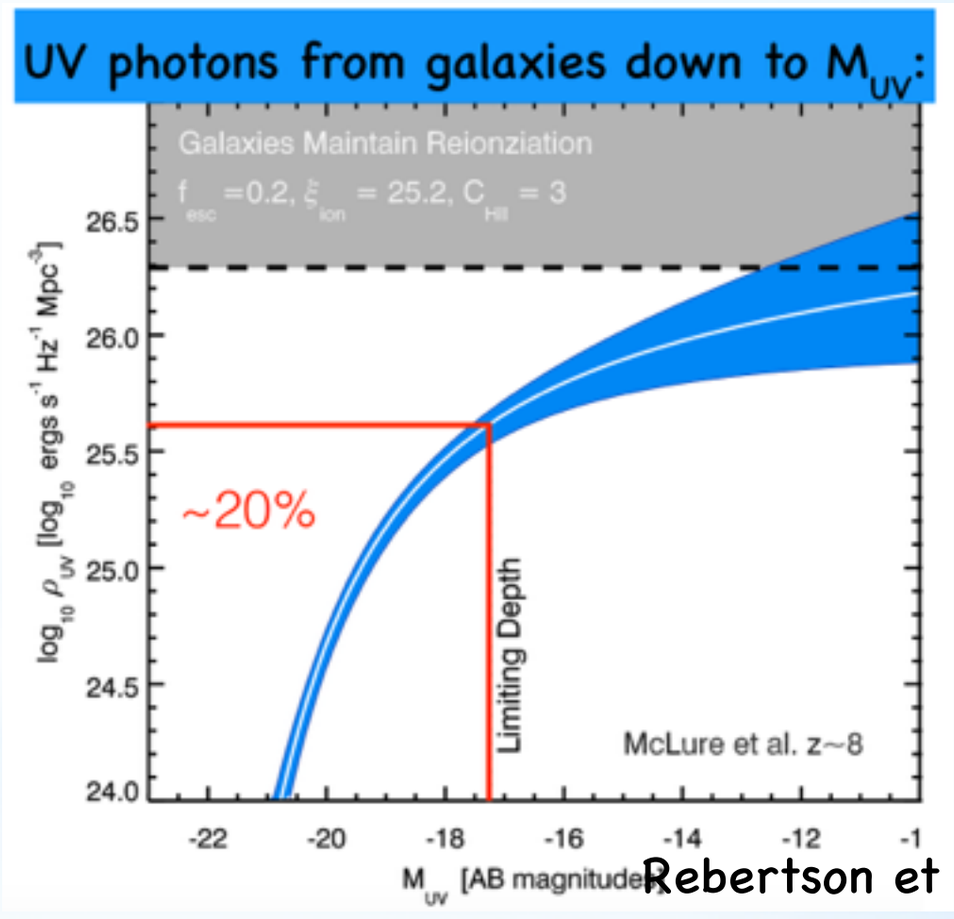








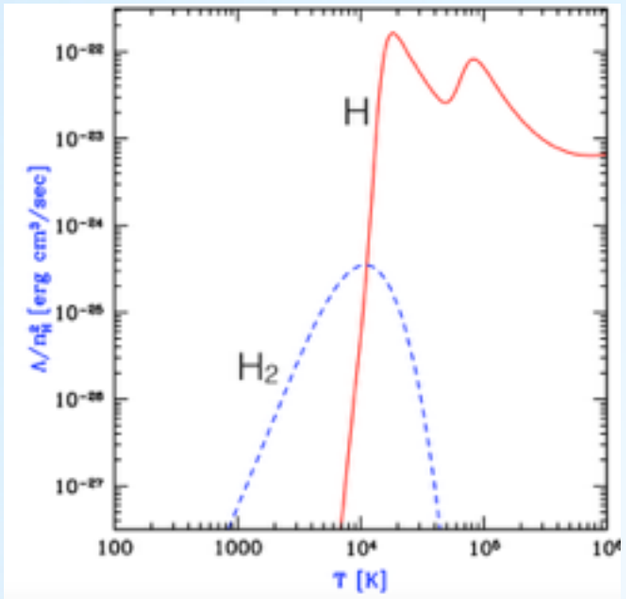
Ota et al. 2017



Rebertson et al. 2013

Star formation in smallest halos, feedback effects

1. Molecular hydrogen is fragile, atomic cooling threshold, $T_{vir} \gtrsim 10^4$ K, sets the minimum halos that can hold galaxies



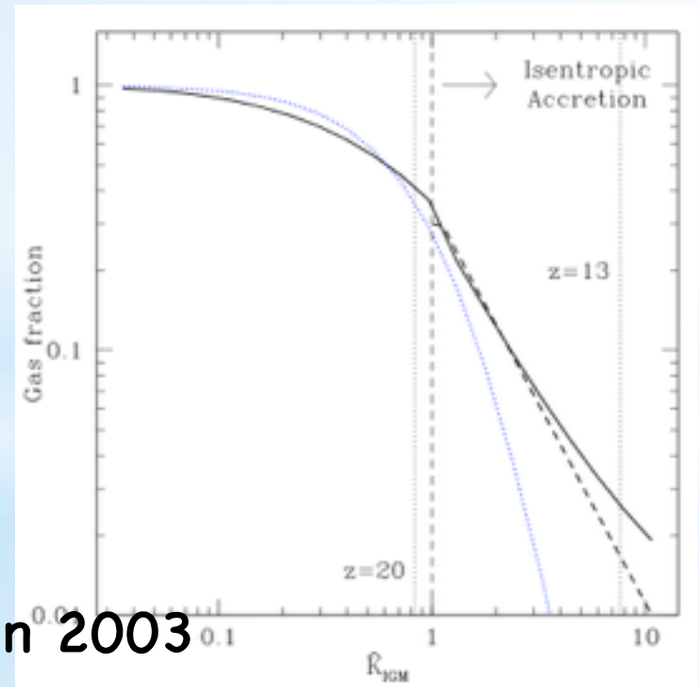
Barkana & Loeb 2001

2. SN explosion

$$m_\star \eta_{\rm SN} E_{\rm SN} < \frac{1}{2} M_{\rm h} f_{\rm g} v_{\rm esc}^2 = M_{\rm h} f_{\rm g} v_c^2,$$

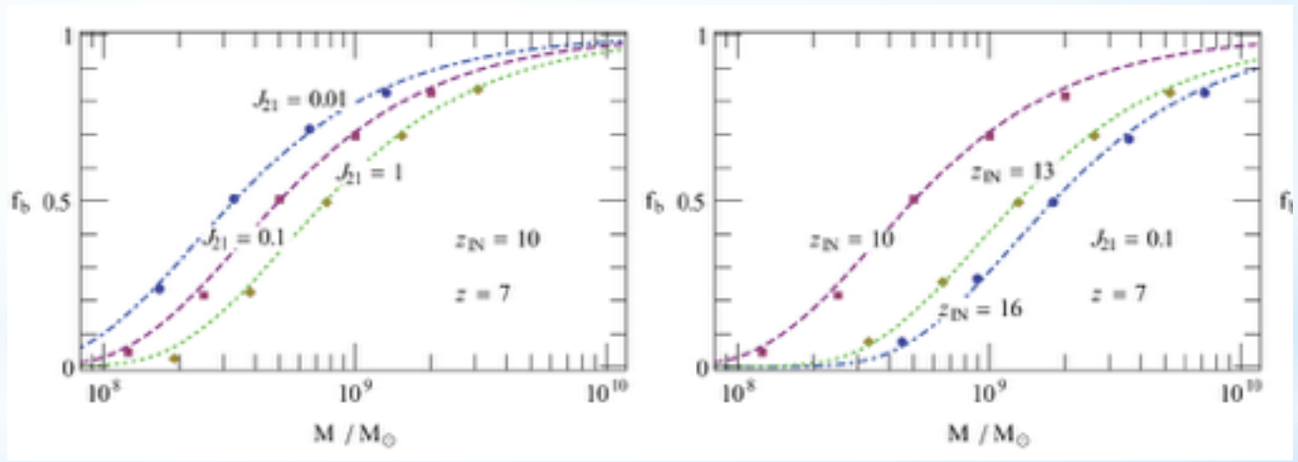
intermittent vs. continuous?

3. global entropy floor



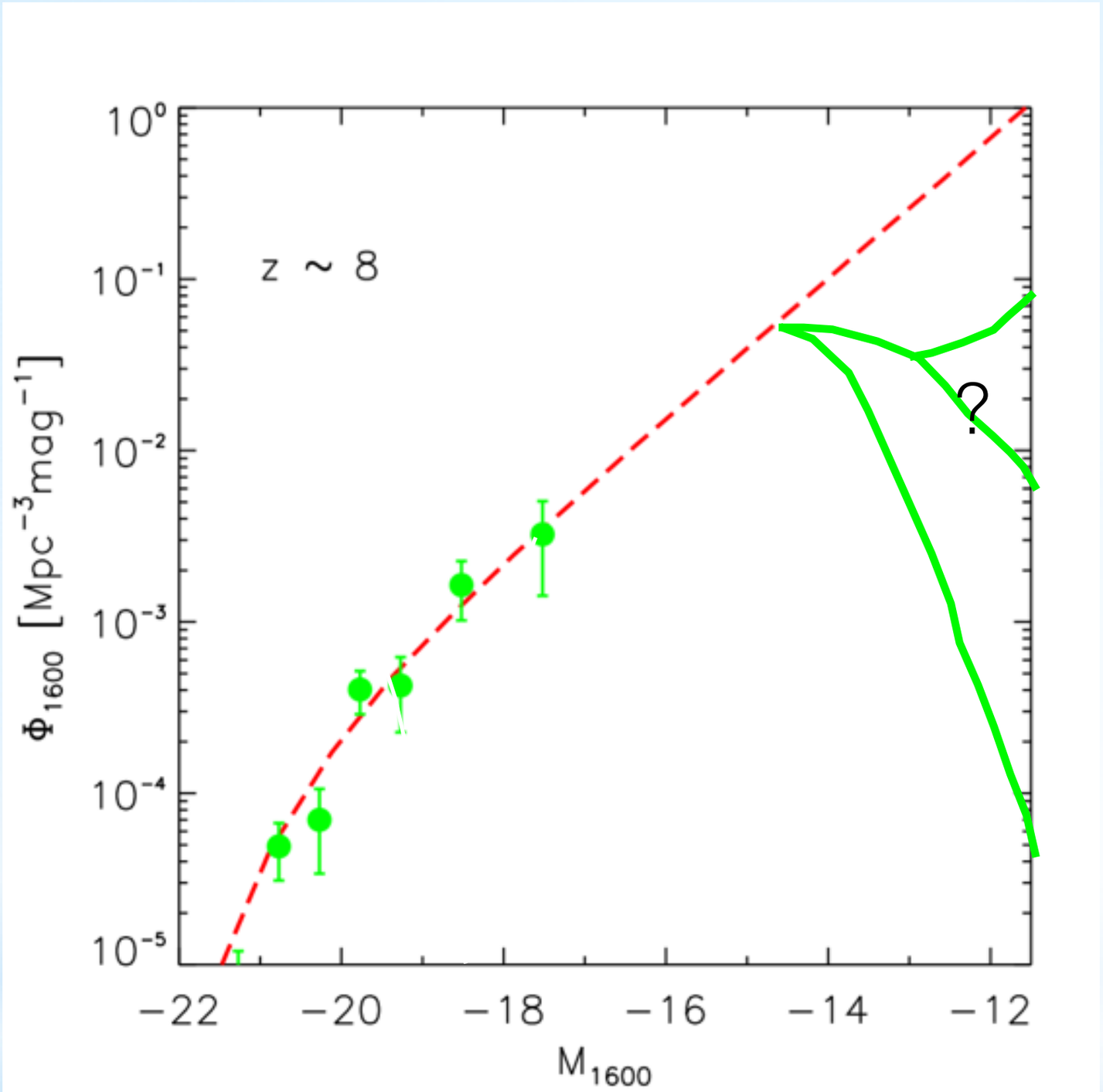
Oh & Haiman 2003

4. photoevaporation



Sobacchi & Mesinger 2013

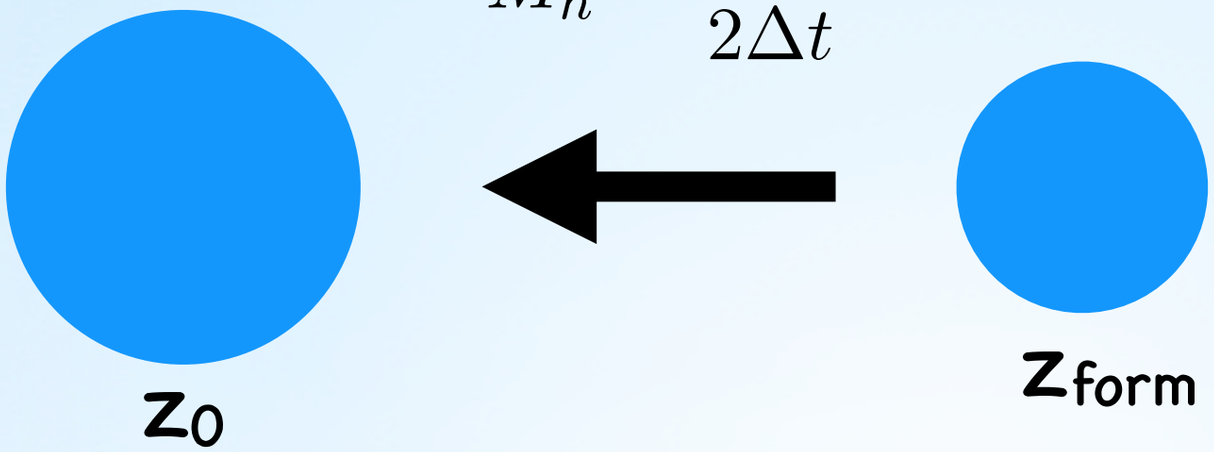
The behavior of the LF at faintest-end tells the story …

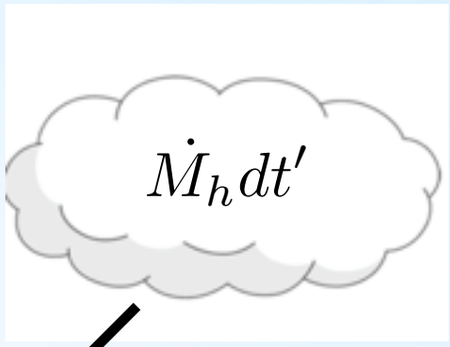


data points credit: Bouwens+15

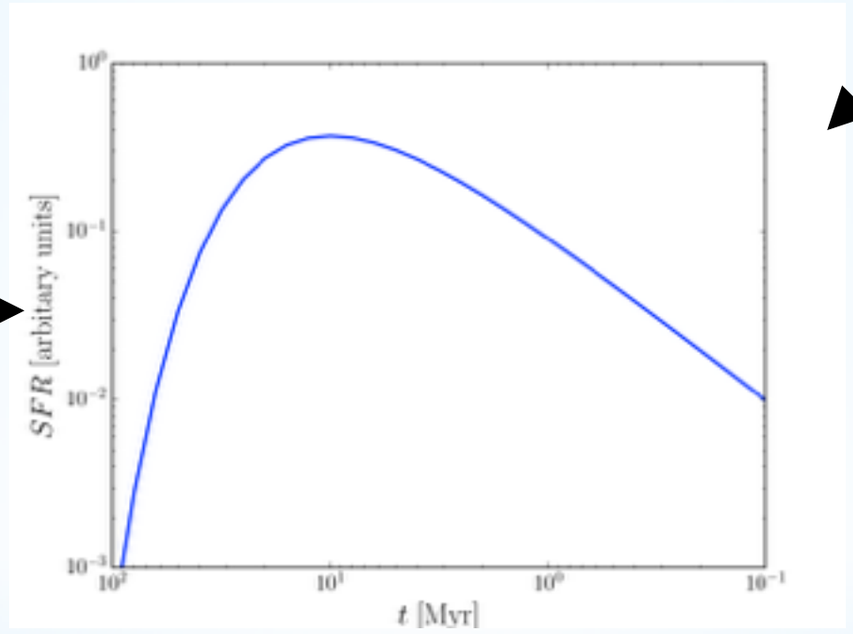
A luminosity function model:

$$\dot{M}_h = \frac{M_h}{2\Delta t}$$



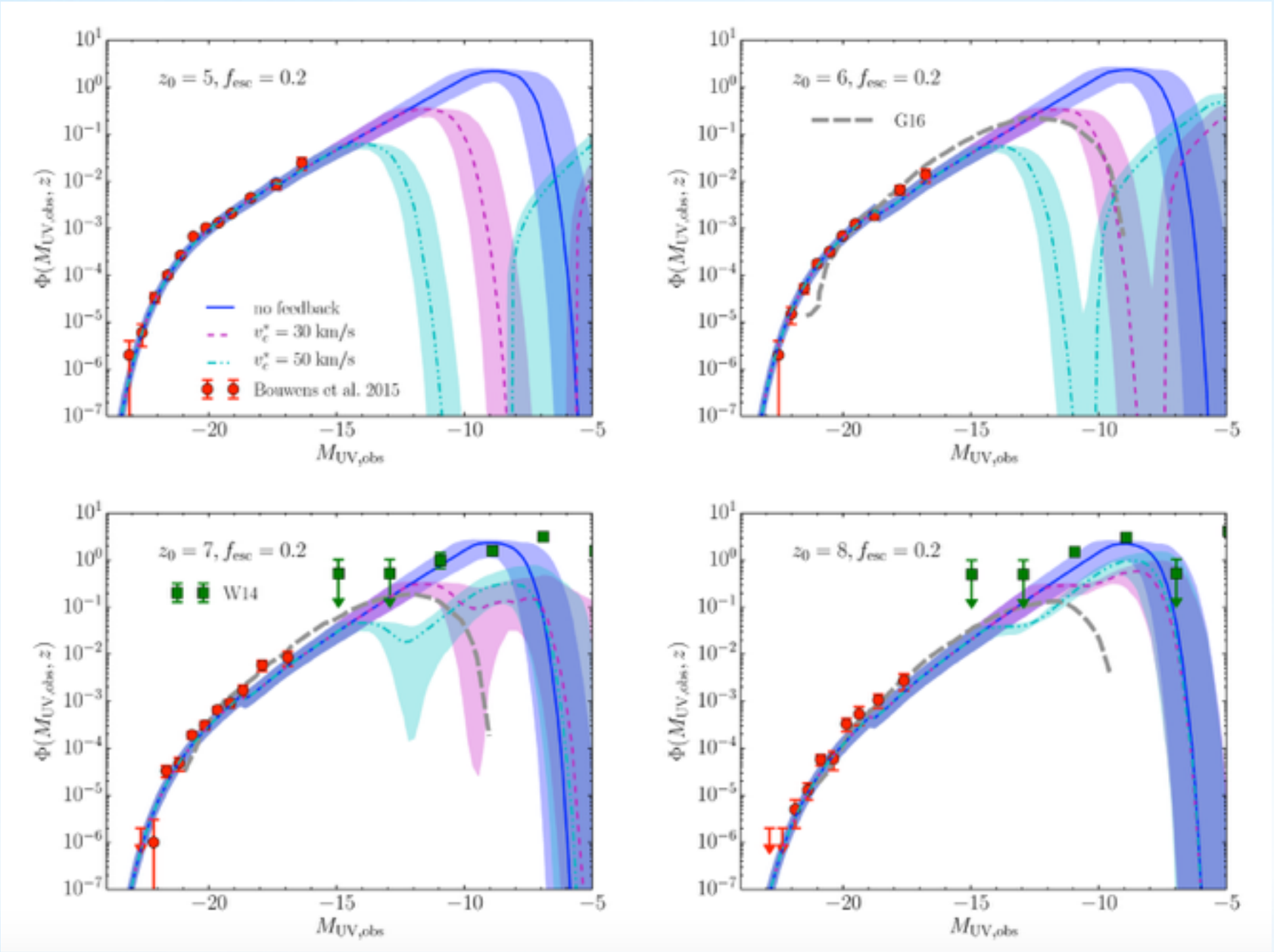


Calibrating the normalization from observed LF (see Mason et al. 2015, Trenti et al. 2010, Tacchella et al. 2013);



Extrapolating it to faint end, quenching the star formation in halos < v^*_c & in ionized regions;

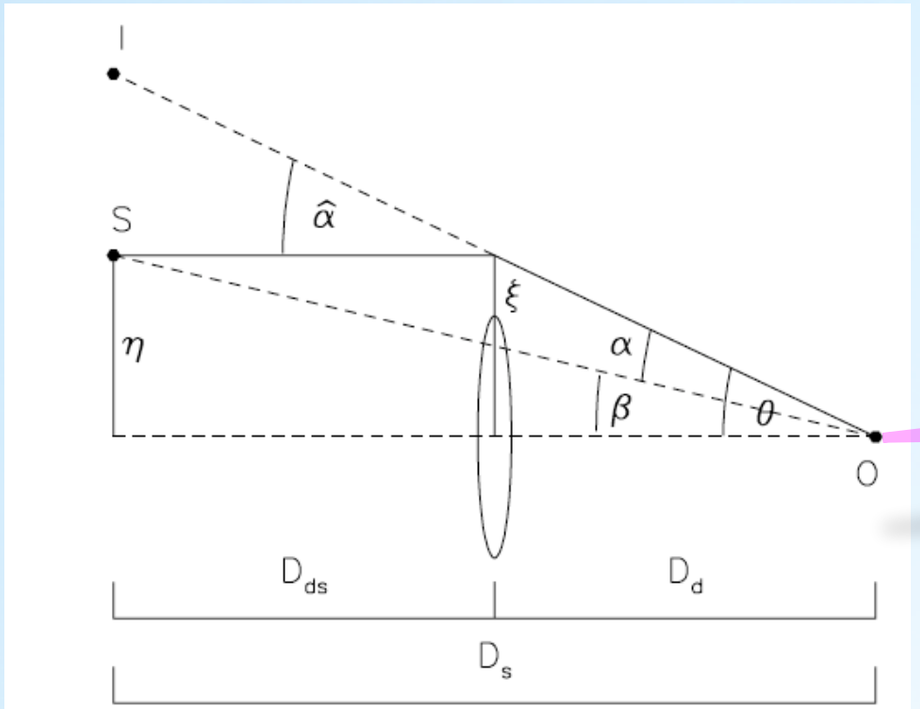
LFs during & after the EoR

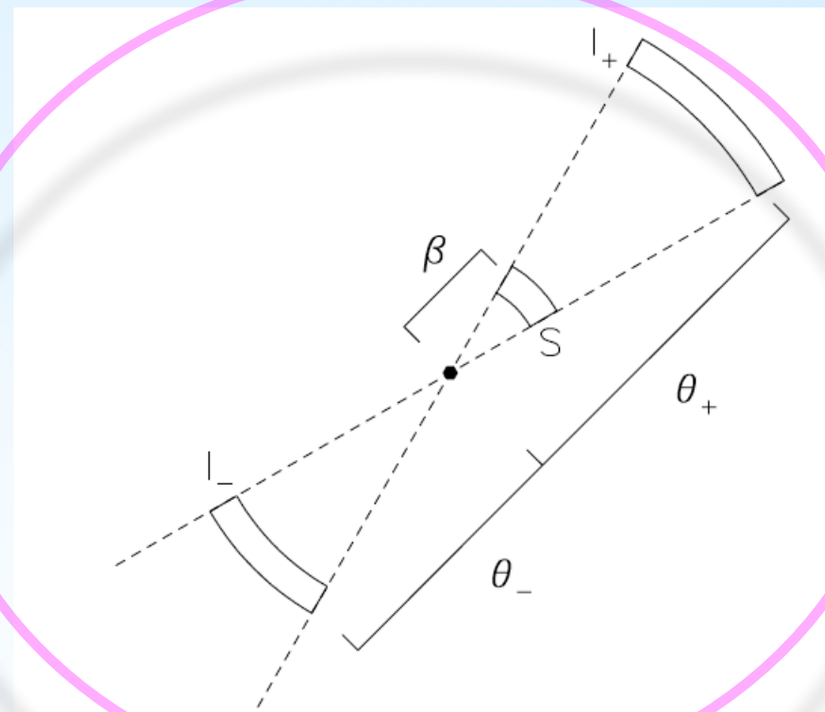


- During the EoR, the LFs are not suppressed heavily;
- At the faint-end there exist numerous relic galaxies;
- Looking for constraints on f_{esc} & v^*_c from gravitational lensing

Yue et al. 2016

Gravitational lensing





Narayan & Bartelmann: Lectures on Gravitational Lensing

$$\text{magnification} = \frac{\text{image area}}{\text{source area}} = \frac{\text{image brightness}}{\text{source brightness}}$$

high-z LF is steep

$$N_{\rm g}(>m) = \int_{z_1}^{z_2} dz' r^2 \frac{dr}{dz'} \iint_{\Omega} \frac{d\theta_y d\theta_x}{\mu(\theta_x, \theta_y, z')} \int_{L(m_{\rm lim})}^{L(m)} \Phi(L', z') dL',$$

number density dilution

brightness boost → $m_{\rm lim} = H_{\rm lim} + 2.5 \log \mu(\theta_x, \theta_y, z'),$

HST Frontier Fields (FFs):

Photometric surveys, six clusters & parallel blank areas;

Six Frontier Fields

Cluster Name	z	Cluster		Parallel Field	
		RA	Dec	RA	Dec
Year 1:					
Abell 2744	0.308	00:14:21.2	-30:23:50.1	00:13:53.6	-30:22:54.3
MACSJ0416.1-2403	0.396	04:16:08.9	-24:04:28.7	04:16:33.1	-24:06:48.7
Year 2:					
MACSJ0717.5+3745	0.545	07:17:34.0	+37:44:49.0	07:17:17.0	+37:49:47.3
MACSJ1149.5+2223	0.543	11:49:36.3	+22:23:58.1	11:49:40.5	+22:18:02.3
Year 3:					
Abell S1063 (RXCJ2248.7-4431)	0.348	22:48:44.4	-44:31:48.5	22:49:17.7	-44:32:43.8
Abell 370	0.375	02:39:52.9	-01:34:36.5	02:40:13.4	-01:37:32.8

http://www.stsci.edu/hst/campaigns/frontier-fields/

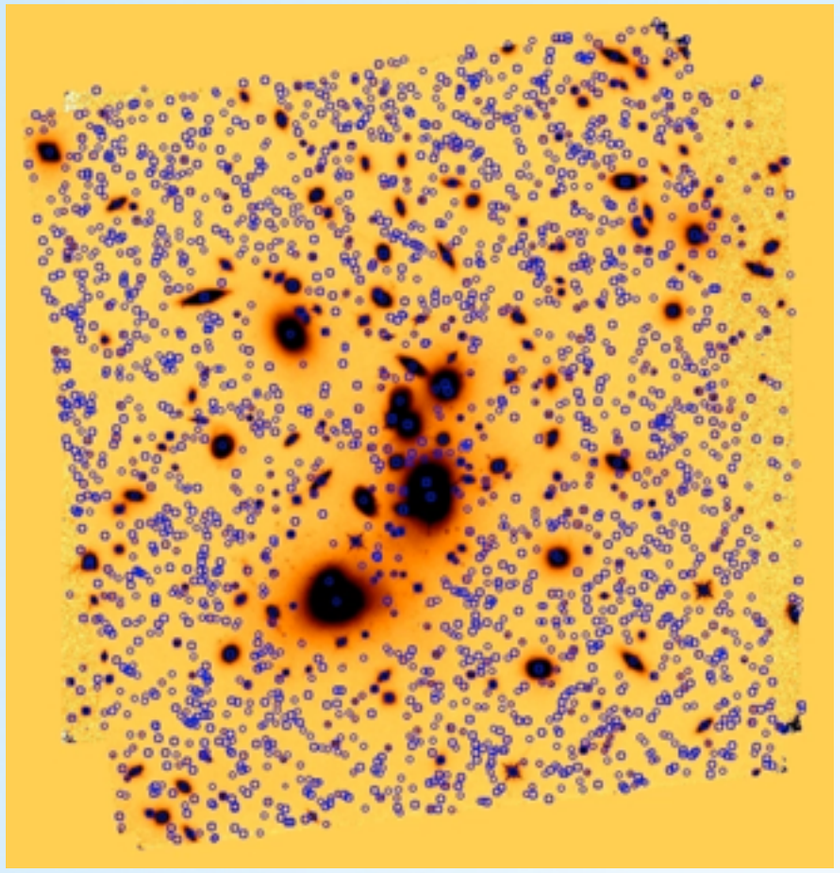
detection limits:

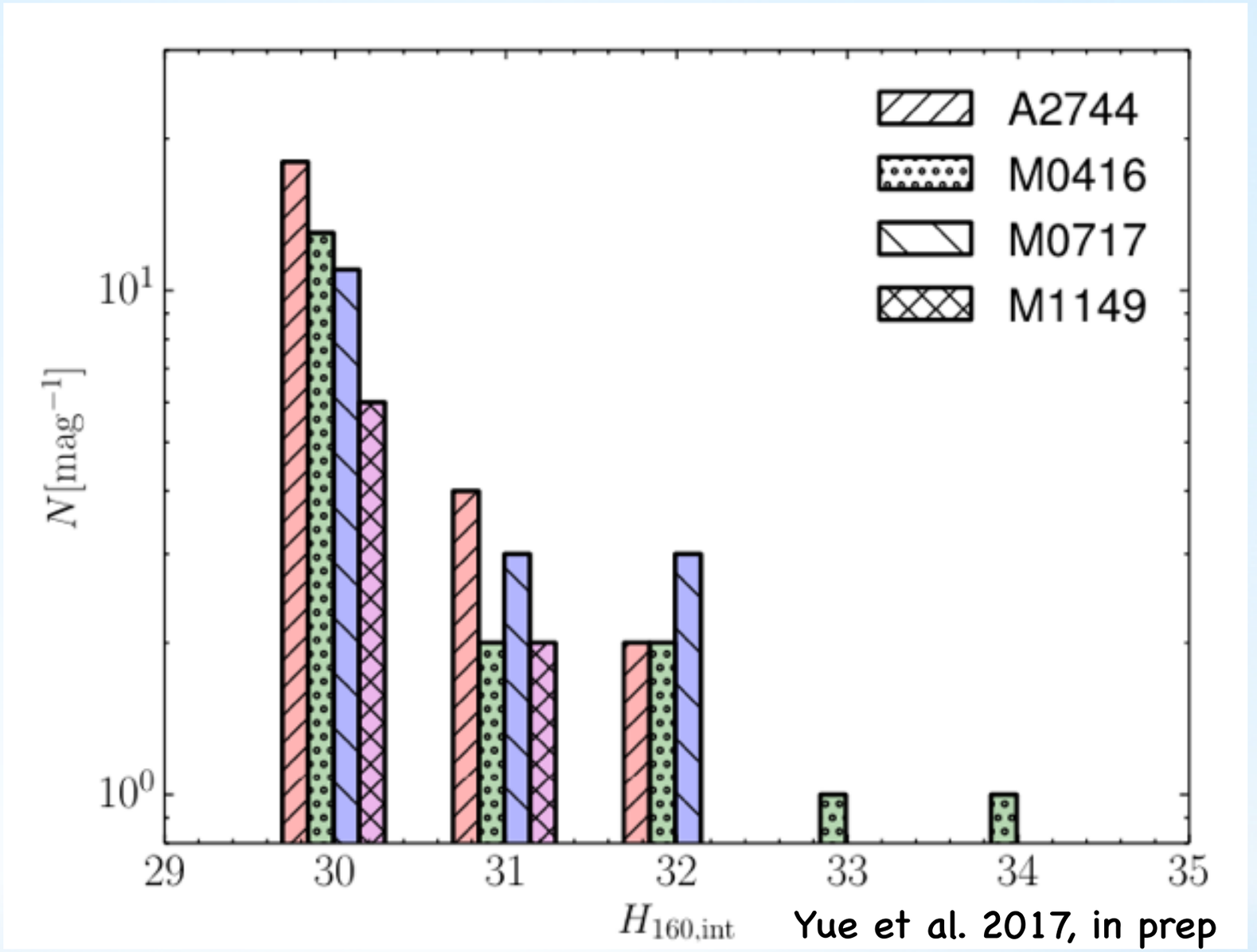
WFC3/IR: (70 orbits per position)		
Filter	Orbits	AB_mag
F105W	24	28.9
F125W	12	28.6
F140W	10	28.6
F160W	24	28.7

$$m_{\rm lim} = H_{\rm lim} + 2.5 \log \mu(\theta_x, \theta_y, z')$$

Gravitational lensing as a probe to see a few faint galaxies much below H_{lim}

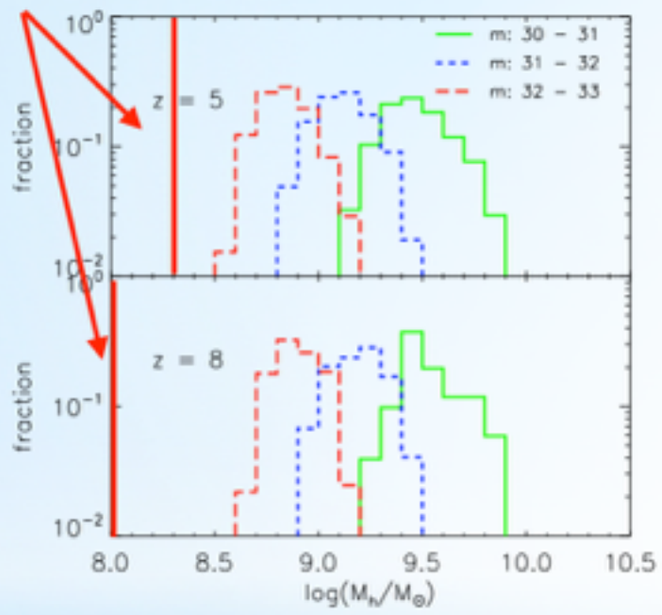
ASTRODEEP number counts:





Yue et al. 2017, in prep

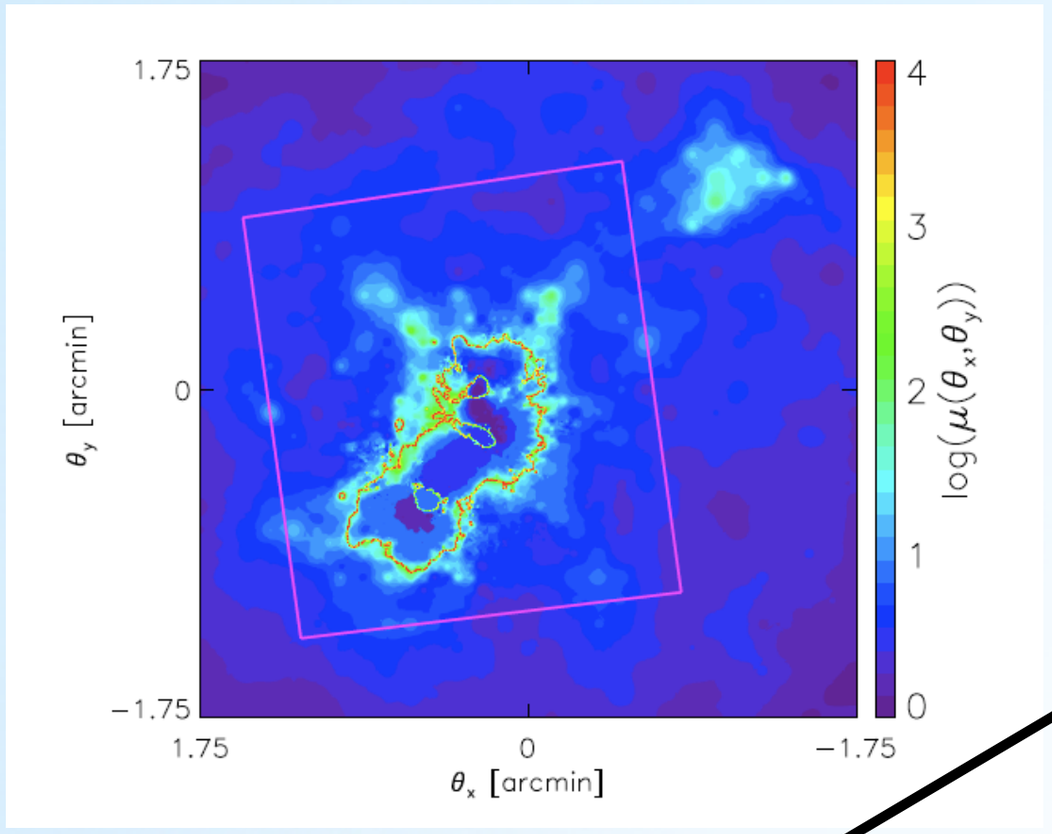
atomic cooling mass:

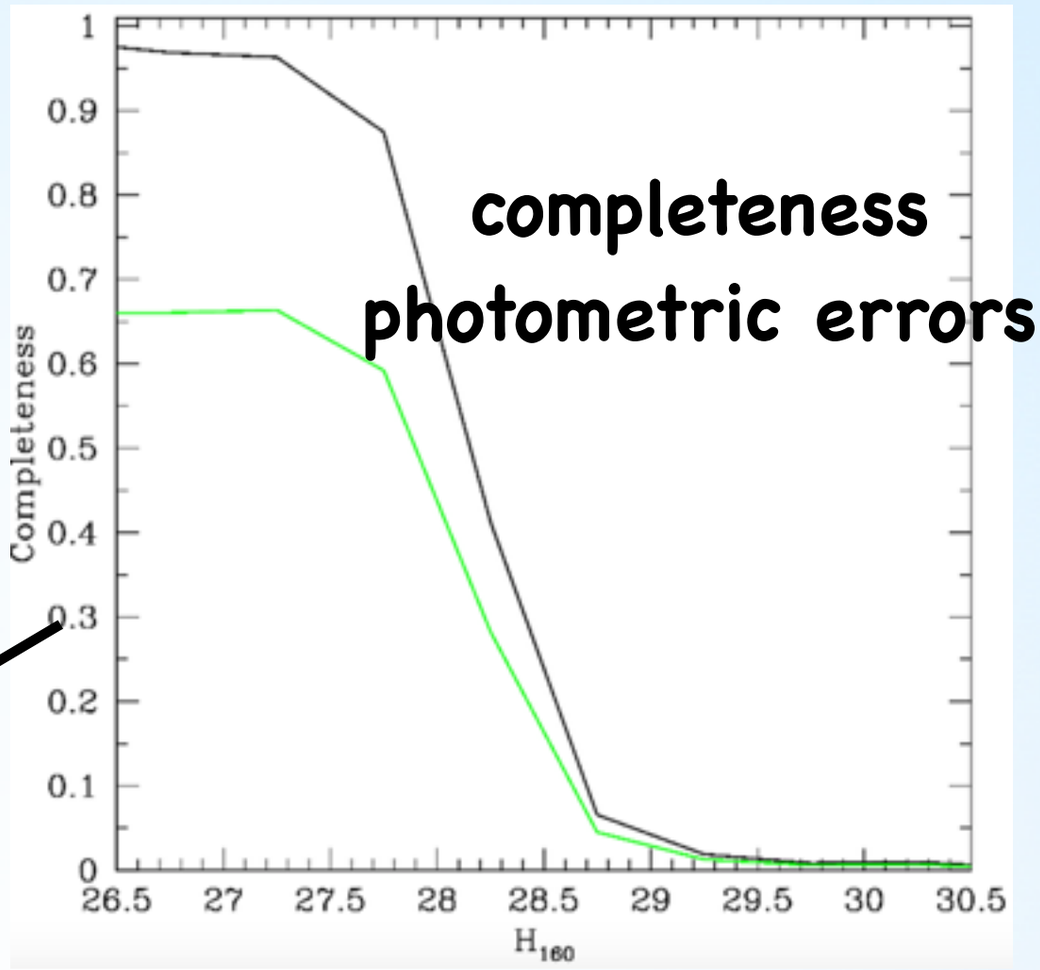


For each cluster there are handful lensing models, we take the median number count!

Luminosity Function

+





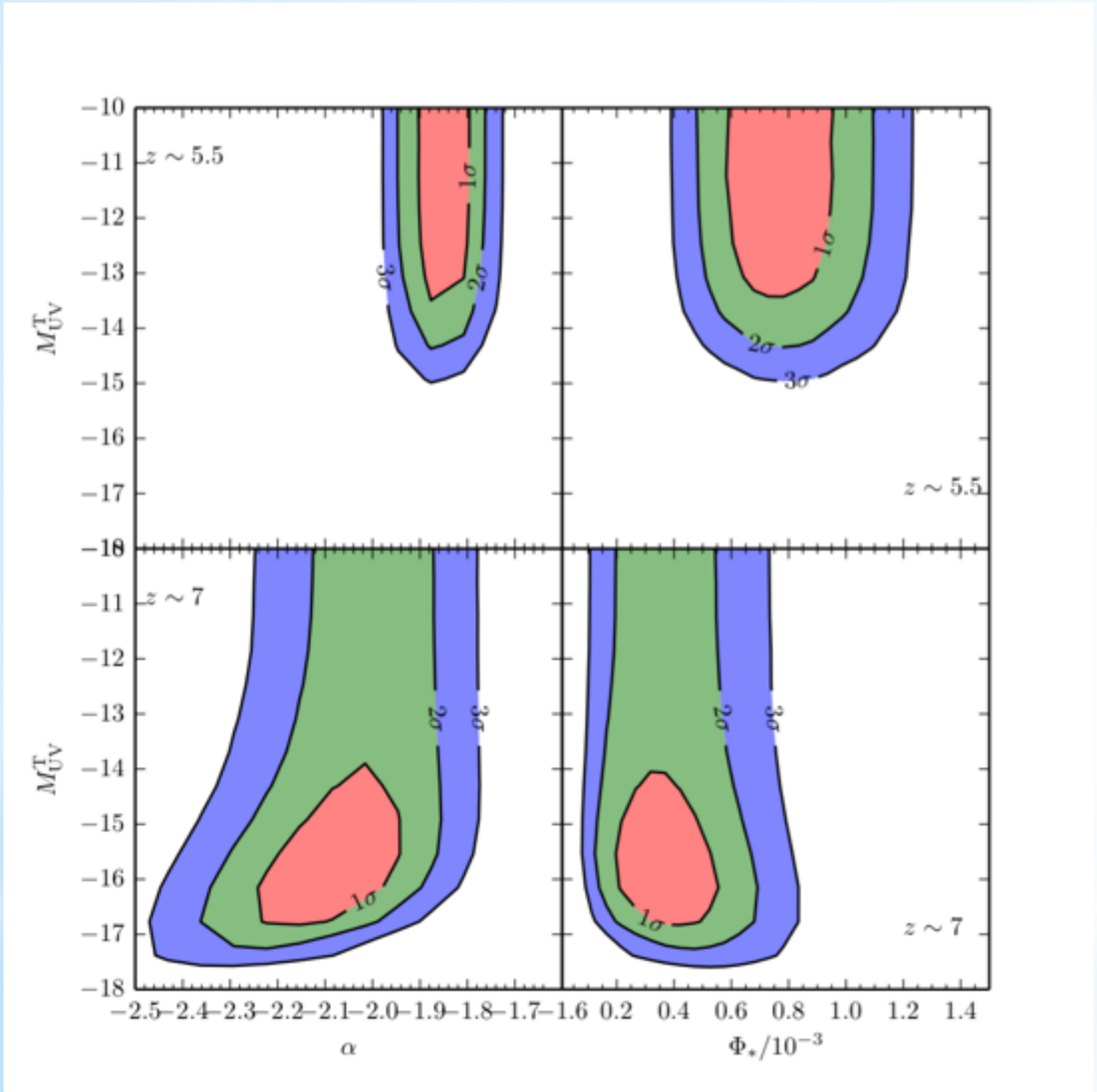
few faintest objects + CMB τ

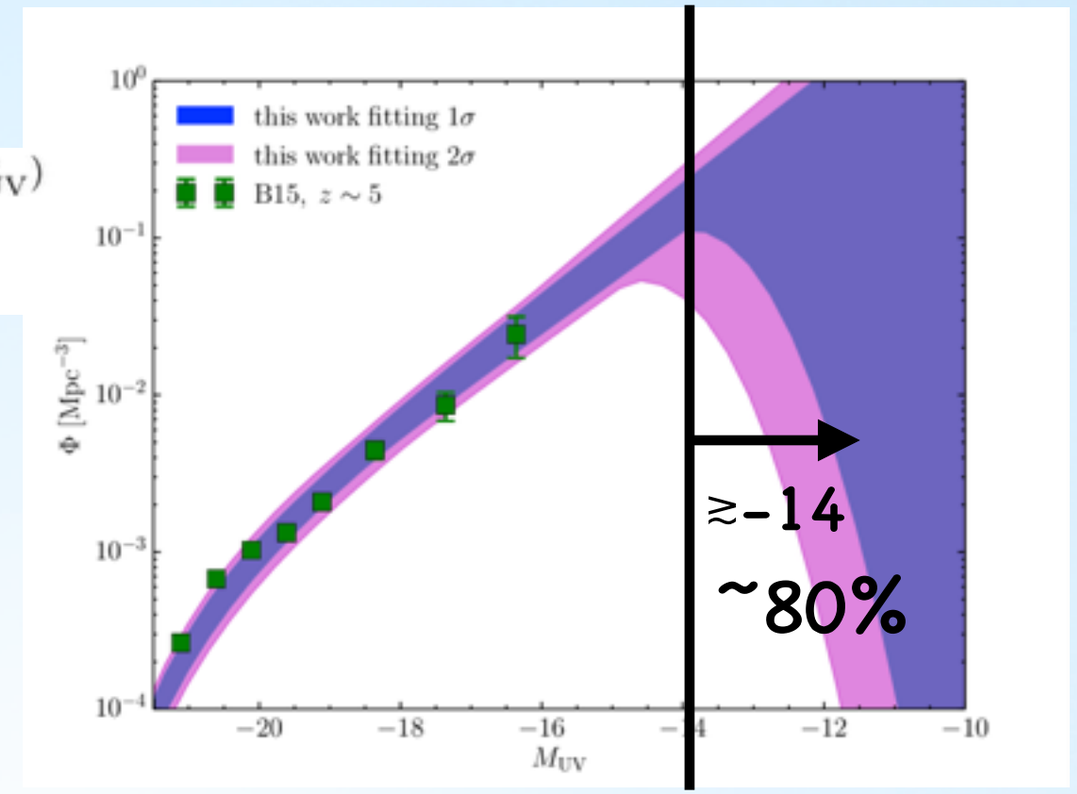
$$L \propto \left[\prod_i^{n_b} p_1(N_{\rm obs}^i|\mathbf{a})\right] \times p_2(\mathbf{a}),$$

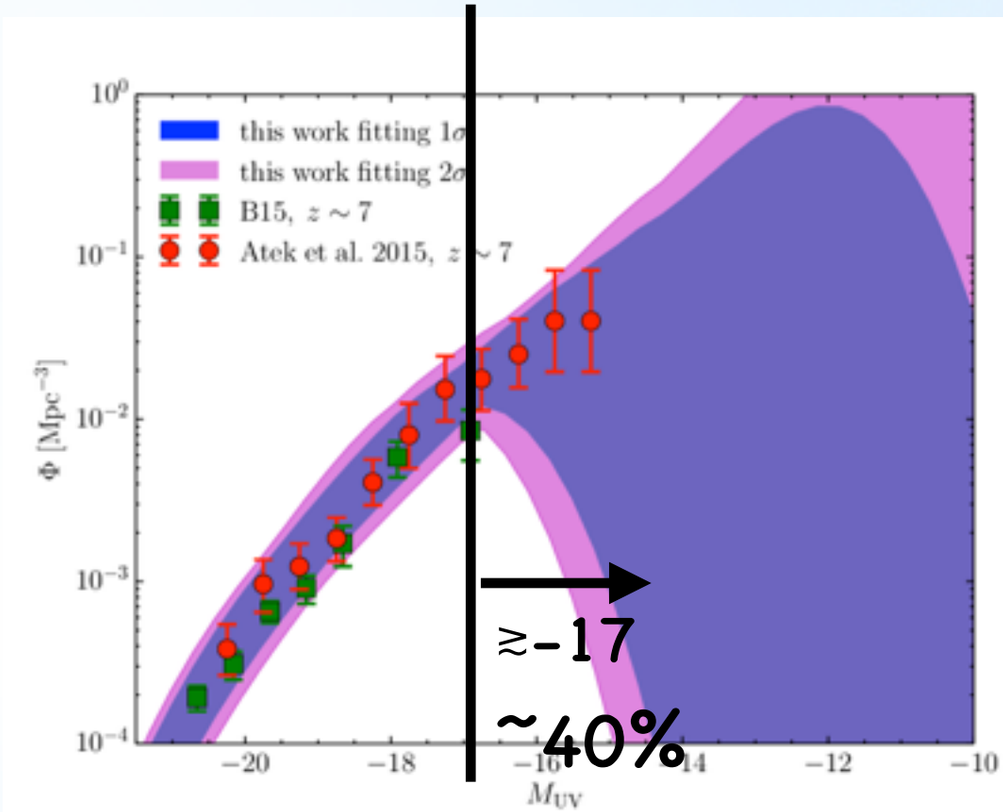
An empirical model:

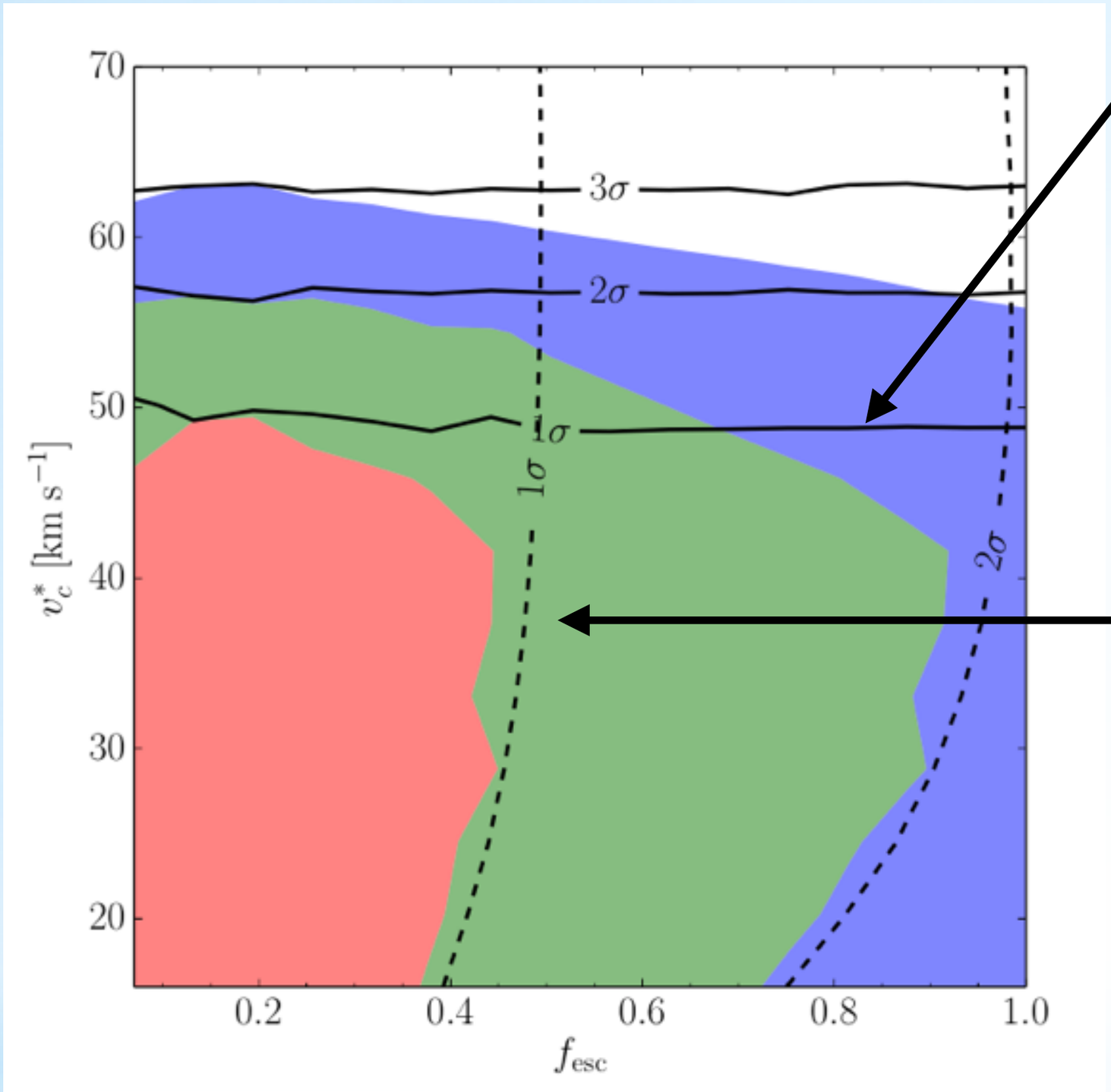
$$\Phi(M_{\rm UV}, z) = 0.4\ln(10)\Phi^* \exp[10^{-0.4(M_{\rm UV}-M^*_{\rm UV})}] 10^{-0.4(1+\alpha)(M_{\rm UV}-M^*_{\rm UV})} \times 0.5[(1-{\rm erf}(M_{\rm UV}-M^{\rm T}_{\rm UV})],$$

Caveat: Bouwens et al. 2015 as priors of the standard Schechter parameters









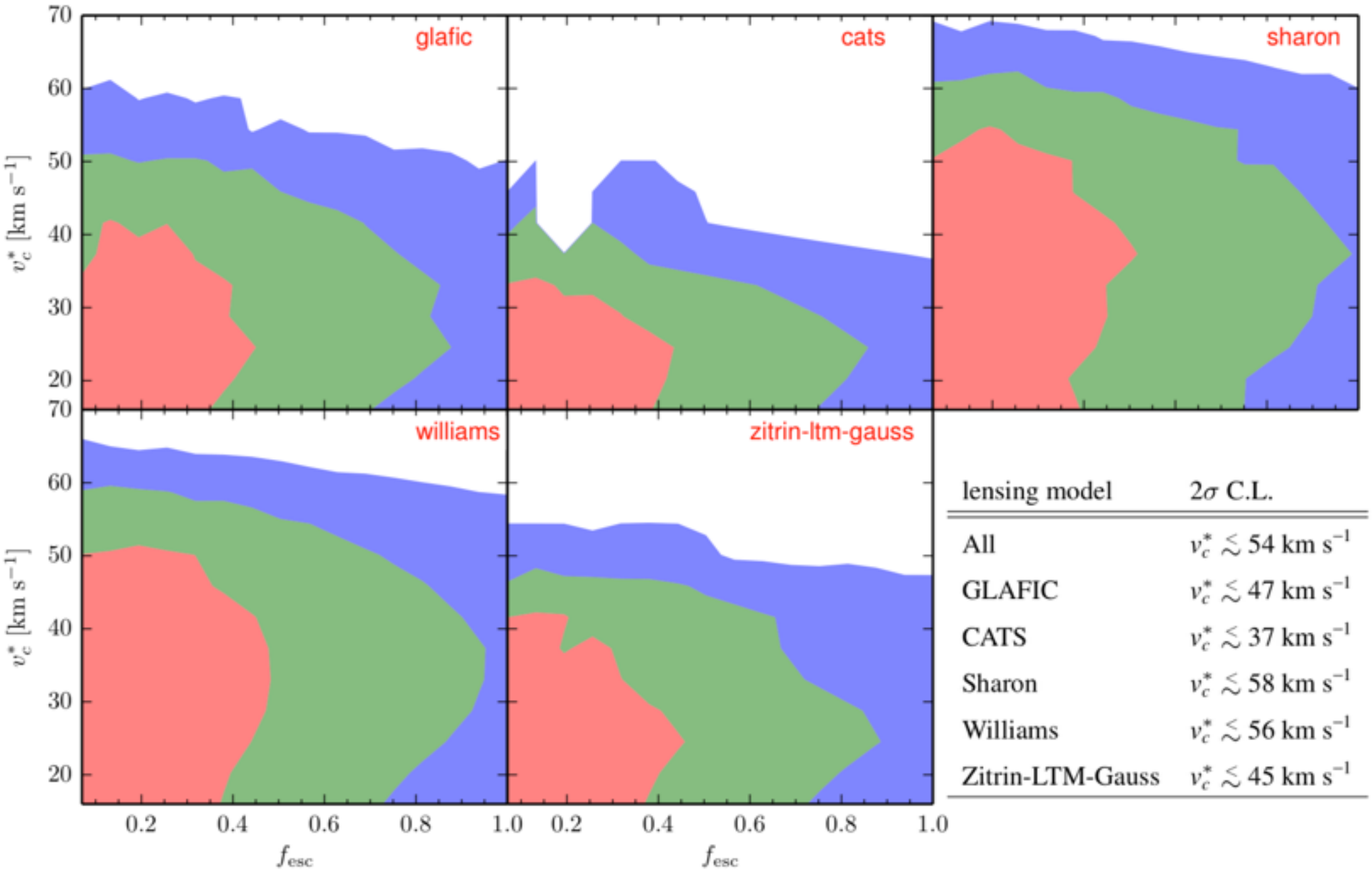
circular velocity threshold is mainly constrained by number count

escape fraction is mainly constrained by number count

circular velocity threshold $\lesssim$ 54 km/s, $M_{UV} \sim -15$, $M_h \sim (3\text{-}7)\times 10^9\ M_{SUN}$

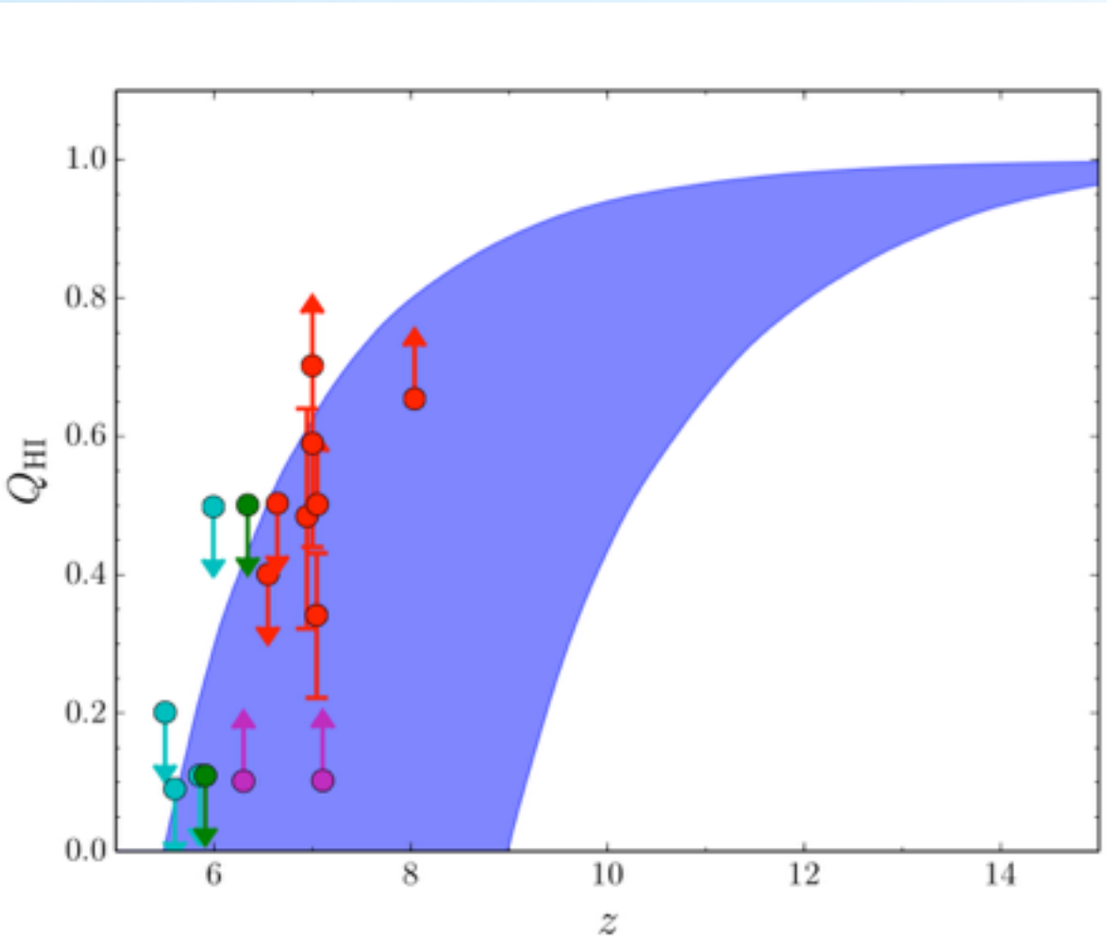
Variance among lensing models

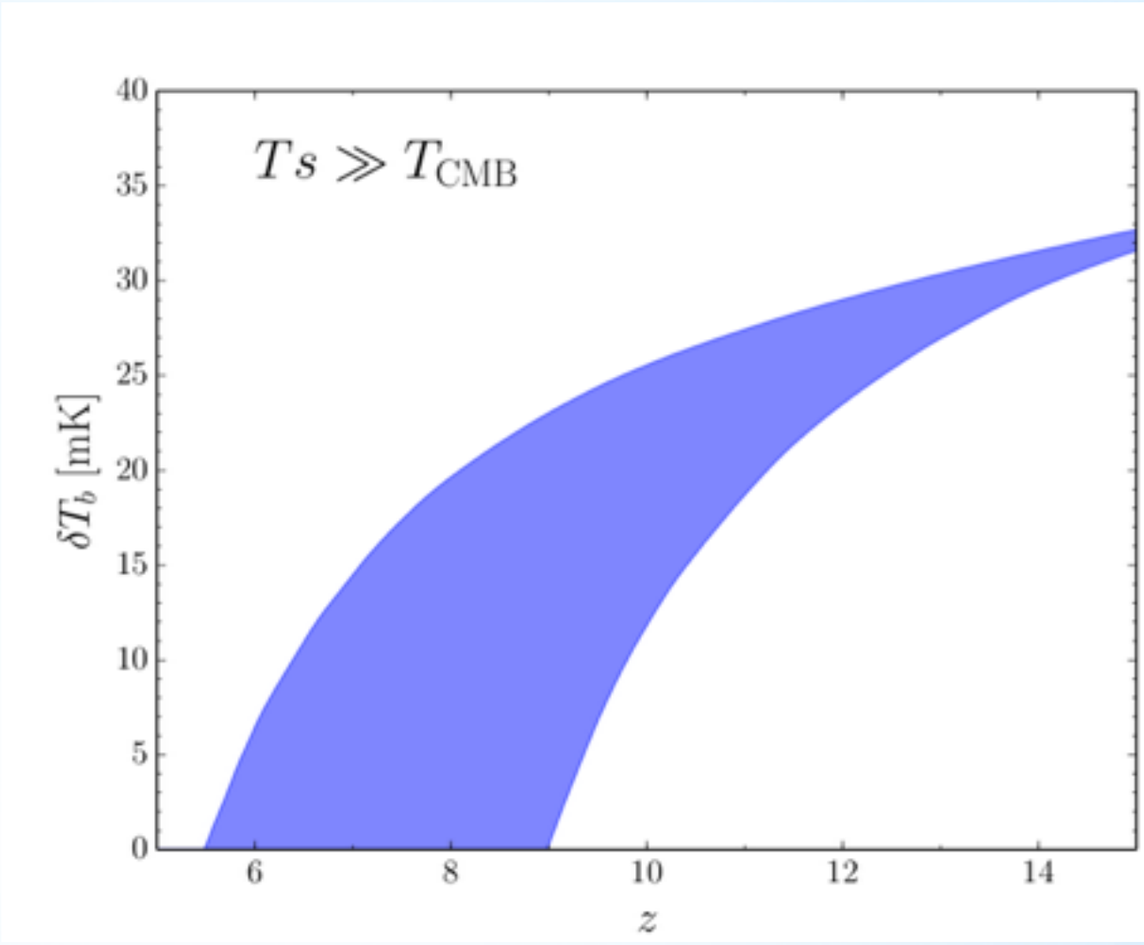
Cluster	Lensing model
Abell 2744 (A2744)	GLAFIC v3; Sharon v3; Williams v3; Zitrin-LTM-Gauss v3, Zitrin-NFW v3; CATS v3.1
MACSJ0416.1-2403 (M0416)	GLAFIC v3; Sharon v3; Williams v3.1; Zitrin-LTM-Gauss v3; Zitrin-LTM v3; CATS v3.1; Bradač v3; Diego v3
MACSJ0717.5+3745 (M0717)	GLAFIC v3; Sharon v2; Williams v1; Zitrin-LTM-Gauss v1; Zitrin-LTM v1; CATS v1; Bradač v1; Merten v1
MACSJ1149.5+2223 (M1149)	GLAFIC v3; Sharon v2.1; Williams v1; Zitrin-LTM-Gauss v1; Zitrin-LTM v1; CATS v1; Bradač v1; Merten v1



lensing model	2σ C.L.
All	$v_c^* \lesssim 54$ km s^{-1}
GLAFIC	$v_c^* \lesssim 47$ km s^{-1}
CATS	$v_c^* \lesssim 37$ km s^{-1}
Sharon	$v_c^* \lesssim 58$ km s^{-1}
Williams	$v_c^* \lesssim 56$ km s^{-1}
Zitrin-LTM-Gauss	$v_c^* \lesssim 45$ km s^{-1}

The reionization history & 21cm under the GL constraints (2σ)





Summaries

- Have seen galaxies as faint as $\sim$33 - 34 in FFs;
- Do not yet confirm the "turn-over" on the LF;
- Put constraints on reionization history and 21cm signal by FFs + Planck2016;
- The discrepancies among lensing models are currently the main uncertainties.

Thank you!