Intensity Mapping of High Redshift Galaxies

Andrea Ferrara

Scuola Normale Superiore, Pisa, Italy

INTER STELLAR

erc

CORTÉS

@ferrara_sns

- ✓ Allows access to high-z galaxies below detection limit
- ✓ Collects radiation from galaxies in a selected redshift range
- ✓ Spurious flux due to contaminating radiation and noise can be in principle removed or suppressed.
- ✓ If the galaxy luminosity function has a sufficiently steep faint end, the observed radiation is dominated by unresolved sources
- ✓ [C II] 157.7μm fine-structure line from $^2P_{3/2} \rightarrow ^2P_{1/2}$ transition is the **brightest** metal line emitted by the ISM of star-forming galaxies.
- ✓ Complementary to Lyα line and other lines (e.g. 21 cm, HeII1640,..)

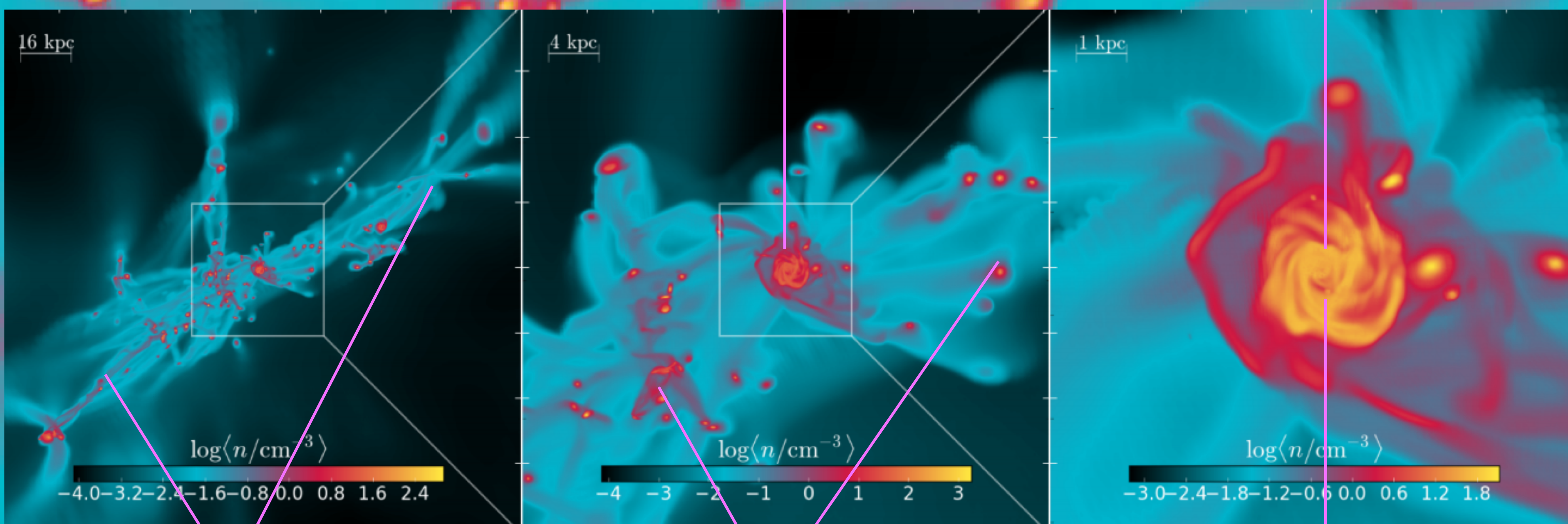
Pallottini+17

"DAHLIA", A LBG @ $z = 6$

AMR simulation (RAMSES)
Spatial res = 20 pc
H_2- based SFR prescription
Updated SN feedback model
Radiation pressure

$M_h = 1.8 \times 10^{11}\ M_\odot$
$M_\star = 1.6 \times 10^{10}\ M_\odot$
$\Sigma_\star = 15\ M_\odot yr^{-1}\ kpc^{-2}$

$M_{H2} = 3 \times 10^9\ M_\odot$
$r_e = 0.6$ kpc



over-dense accreting filaments

merging clumps/satellites

Molecular/stellar disk
$< Z > = 0.5\ Z_\odot$

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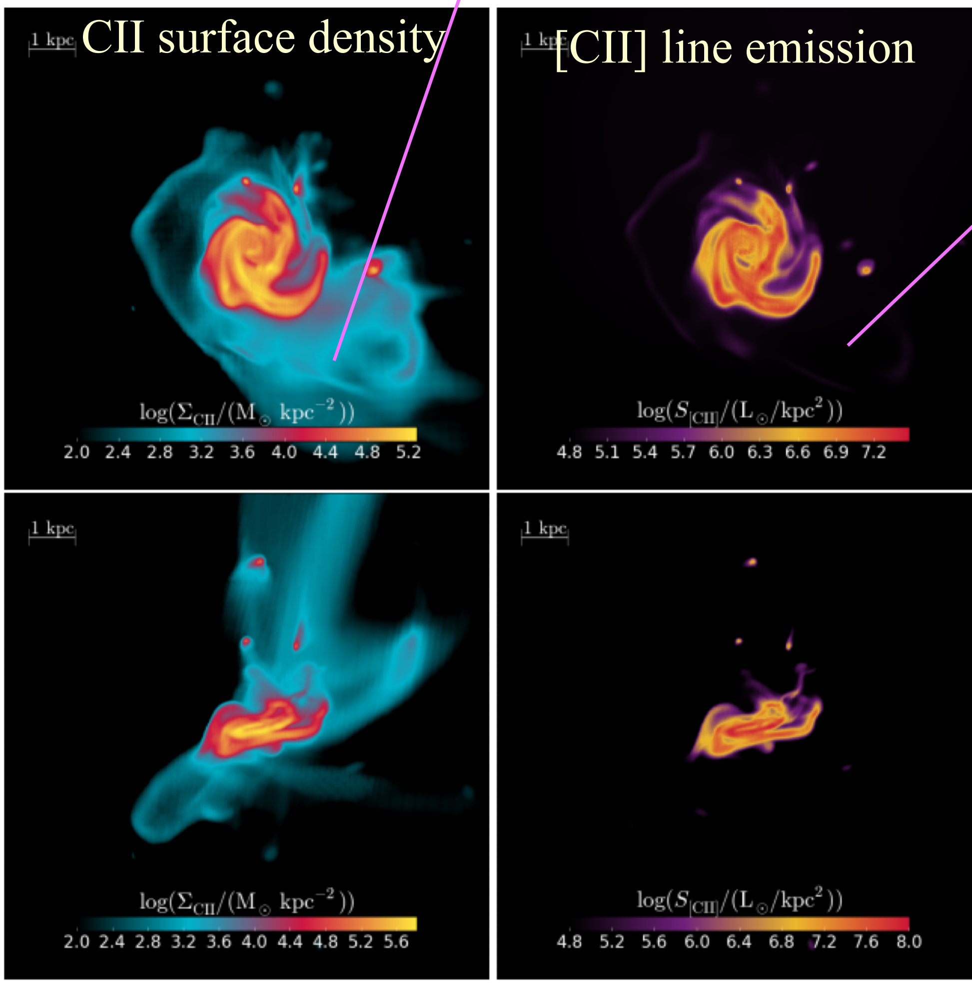
DAHLIA: ISM SEEN IN [CII]

⅓ of CII mass in diffuse, low-Z, weakly emitting gas (invisible due to CMB)

Face on

Edge-on



Total [CII] Luminosity
$L_{CII} = 3.5\times10^{7}\ L_{\odot}$

❖

95% of emission co-located with H_2 disk

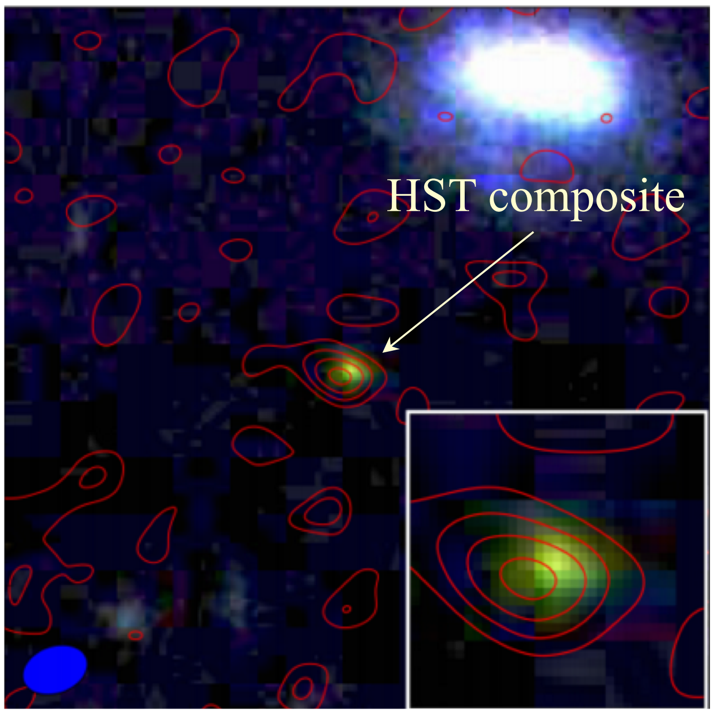
Maiolino+15, Capak+15, Knudsen+16, Pentericci+16

[CII]-SFR RELATION

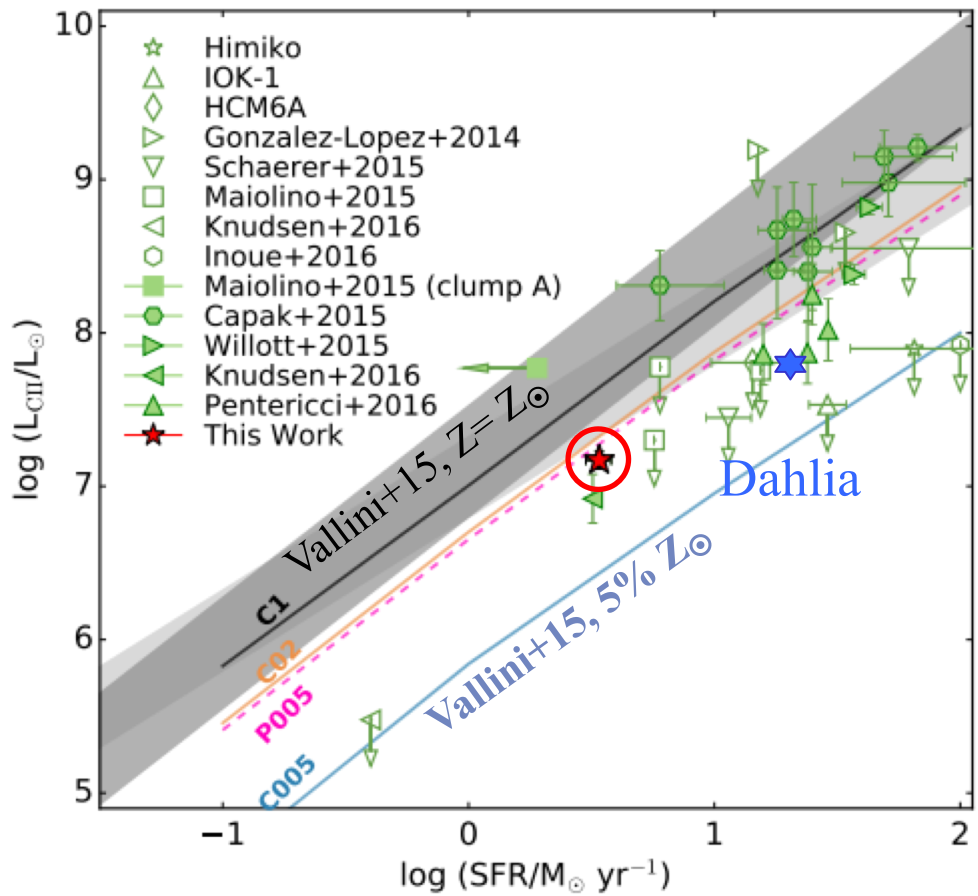
Best fit relation (*Yue+15*)

ALMA [CII] detection
5× Lensed LAE @ z=6.765
$L_{CII} = 1.4 \times 10^7 L_\odot$
Low [CII]-Lyα shift = 20 km/s

$$\text{Log } L_{CII} = 7.0 + 1.2 \log(SFR) + 0.021 \log Z + 0.012 \log(SFR) \log Z - 0.74 \log^2 Z$$



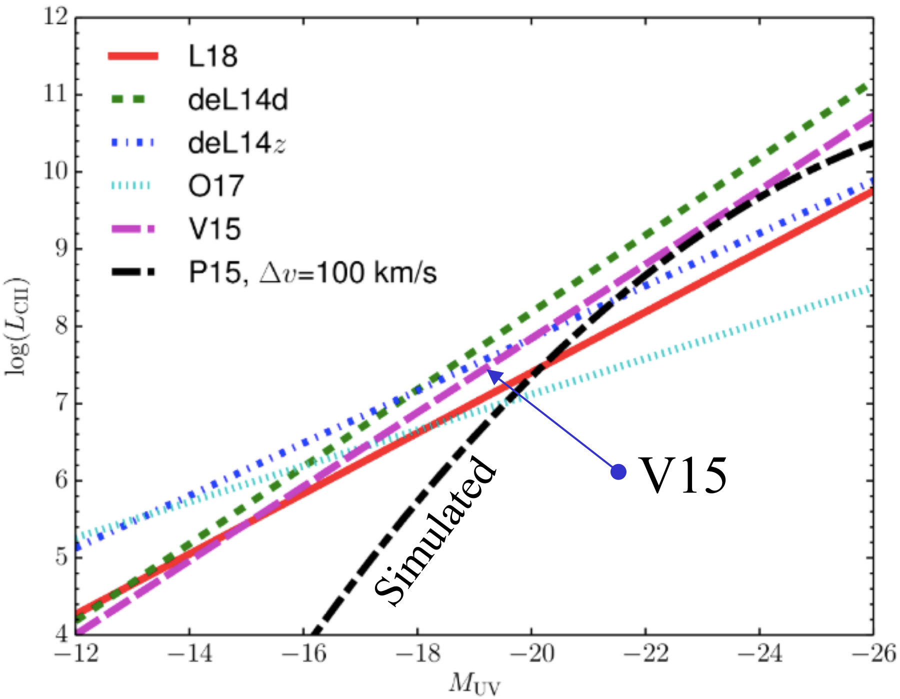
Bradac+17



Yue & AF 19, submitted

$L_{[CII]}$ - M_{UV} RELATION

[CII] Luminosity Function $= \dfrac{dn}{d\log L_{CII}} = \dfrac{dn}{dM_{UV}} \dfrac{dM_{UV}}{d\log L_{CII}}$

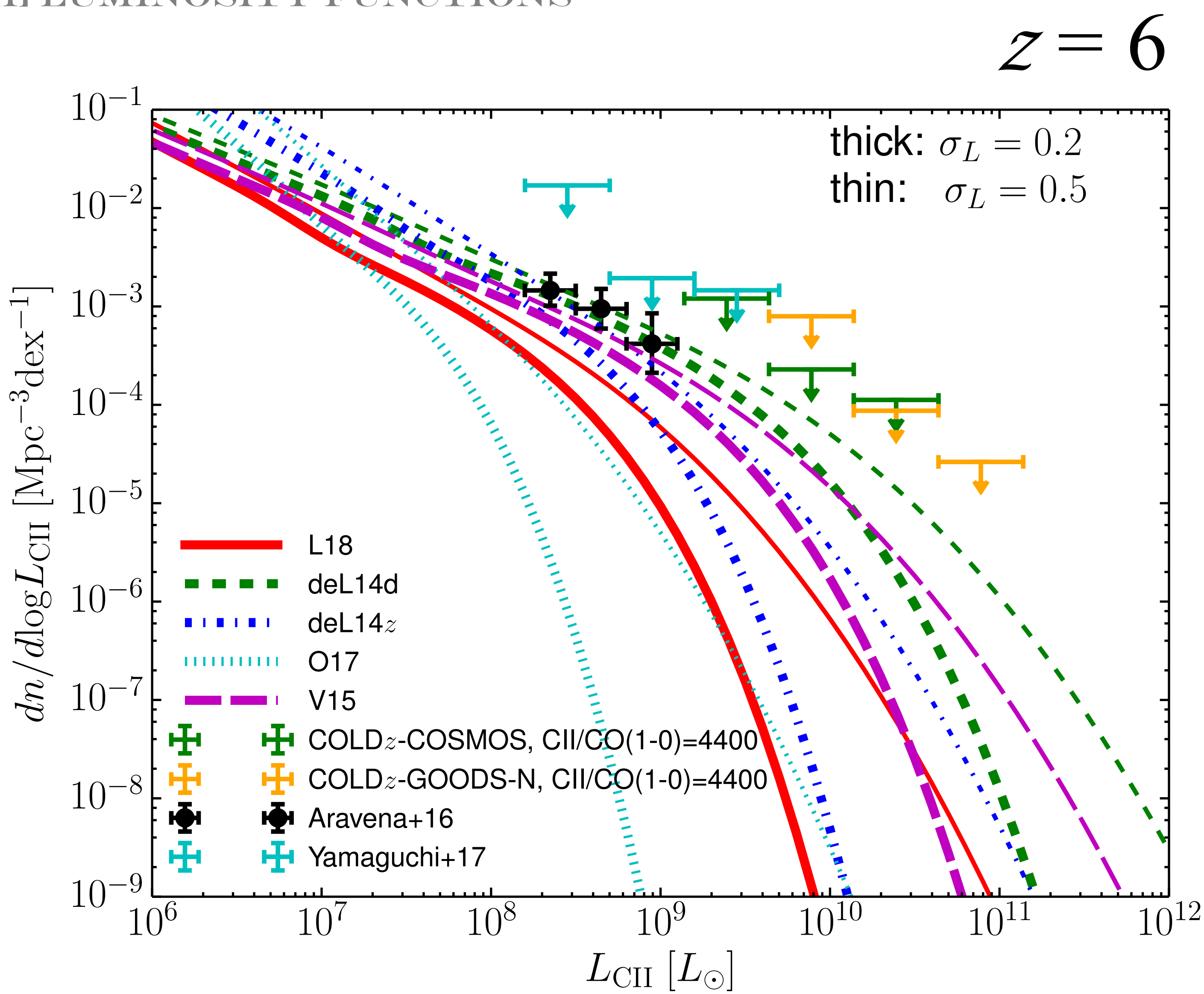


$$L_{[CII]} = A \times SFR^{\gamma}$$

		log A	*γ*
L18	Lagache+18	6.68	0.98
deL14d	deLooze+14	7.26	1.25
deL14z	deLooze+14	7.22	0.85
O17	Olsen+17	6.69	0.58
V15	Vallini+15	6.96	1.20

[CII] LUMINOSITY FUNCTIONS

Yue & AF 19, submitted



BASIC FORMULAE

$$P_{\rm CII}(<L_{\rm CII},k,z) = P^{\rm CL}_{\rm CII}(<L_{\rm CII},k,z) + P^{\rm SN}_{\rm CII}(<L_{\rm CII},z)$$

Total — Clustering — Shot-noise

Clustering

$$P^{\rm CL}_{\rm CII}(<L_{\rm CII},k,z) = \left(\frac{c}{4\pi\nu_{\rm CII}H(z)}\right)^2 \left(\int dM_h \frac{dn}{dM_h} L_{\rm CII}(M_h) b_{\rm SMT}\right)^2 P(k,z),$$

Shot-noise

$$P^{\rm SN}_{\rm CII}(<L_{\rm CII},z) = \left(\frac{c}{4\pi\nu_{\rm CII}H(z)}\right)^2 \int_0^{\log L_{\rm CII}} d\log L_{\rm CII} \frac{dn}{d\log L_{\rm CII}} L^2_{\rm CII};$$

Variance

$$\sigma^2_{\rm CII}(<L_{\rm CII},k,z) = \frac{1}{N_m(k)}\left(P_{\rm CII}(<L_{\rm CII},k) + P_{\rm N}\right)^2,$$

$$N_m(k) \approx 2\pi k^3 d\ln k \frac{V_{\rm survey}}{(2\pi)^3}$$

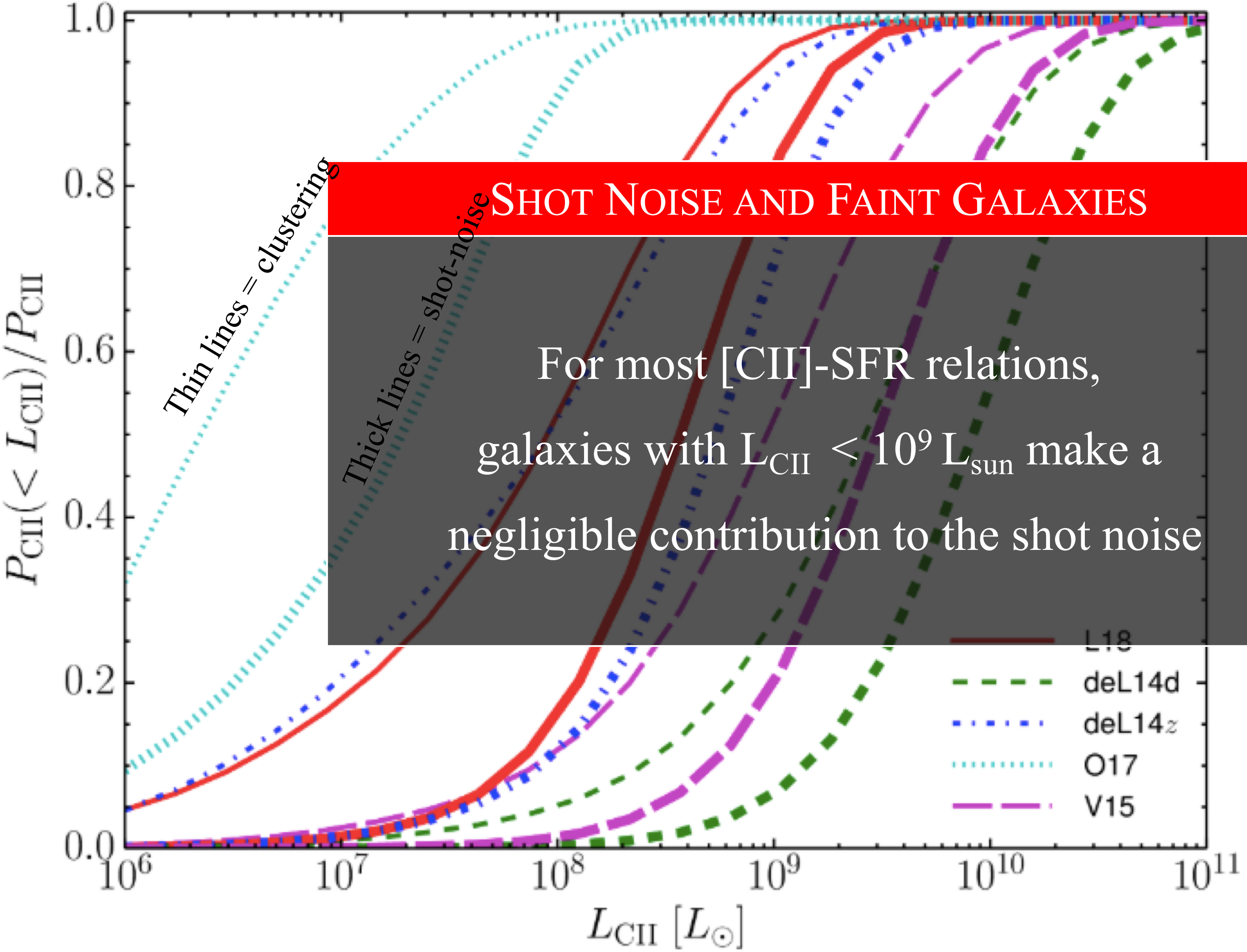
Number of sampled k-modes

$$P_{\rm N} = \left[\frac{2k_B T_{\rm sys}}{D^2\sqrt{\delta\nu_0 t_{\rm vox}}}\frac{1}{\Omega_{\rm beam}}\right]^2 V_{\rm vox};$$

Instrumental noise power-spectrum

Yue & AF 19, submitted

FRACTIONAL CONTRIBUTION



Shot Noise and Faint Galaxies

For most [CII]-SFR relations, galaxies with $L_{CII} < 10^9 L_{sun}$ make a negligible contribution to the shot noise

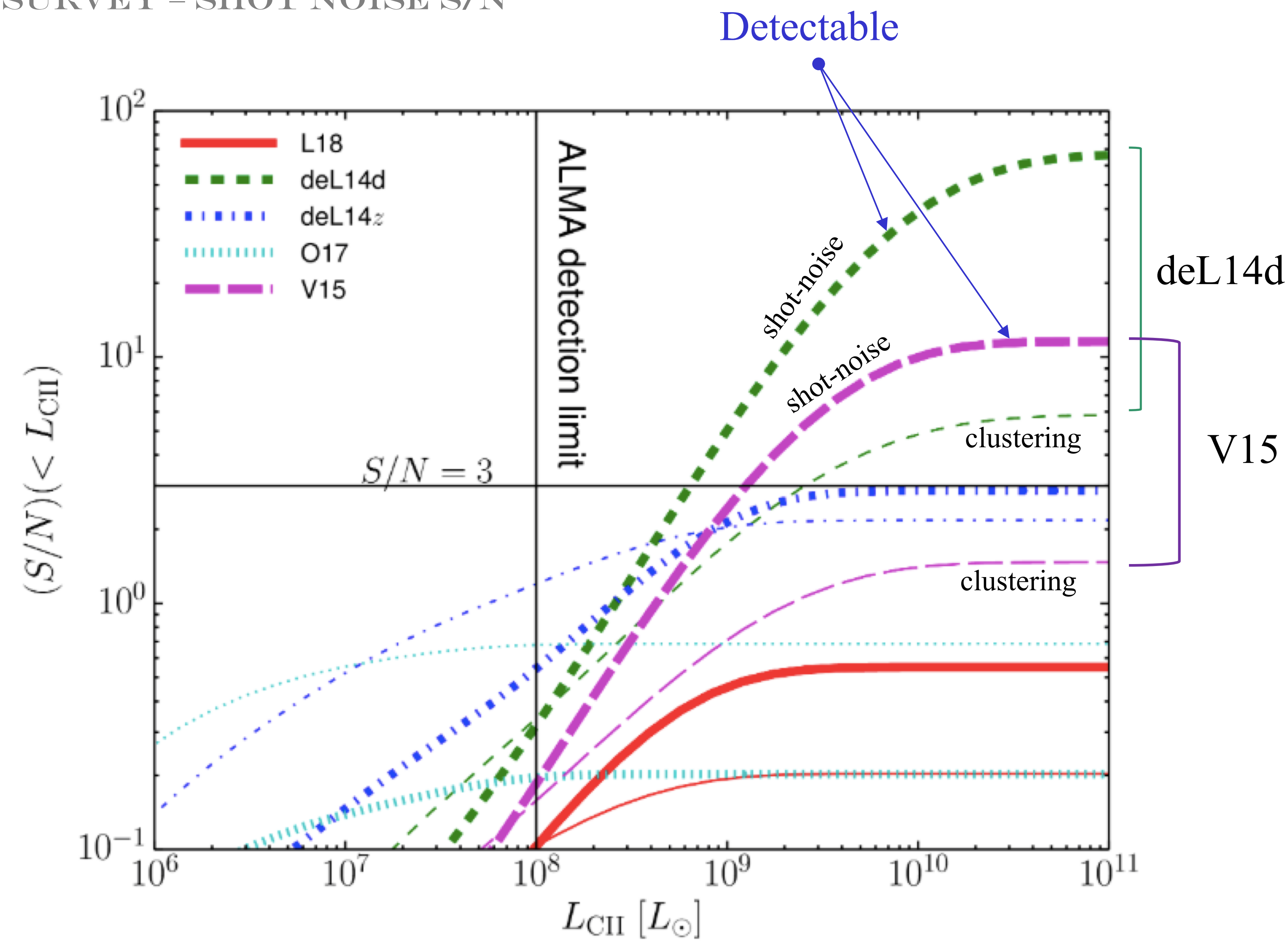
SURVEY STUDY

		CCAT-like S1 FIDUCIAL	S2 WIDE	S3 BIG DISH	S4 MINI
Name		S1*	S2	S3	S4
D	[m]	6	6	25	6
$N_{\rm det}$	#	4000	4000	4000	400
$\delta\nu_0$	[GHz]	1.0	1.0	1.0	0.1
$T_{\rm sys}$	[K]	50	50	50	150
NEFD	Jy sr^{-1} s$^{1/2}$	2.4×10^6	2.4×10^6	2.4×10^6	2.3×10^7
Band	[GHz]	237.6 – 271.5	237.6 – 271.5	237.6 – 271.5	267.7 – 271.5
Bandwidth	[GHz]	33.9	33.9	33.9	3.8
Redshift		6.0 – 7.0	6.0 – 7.0	6.0 – 7.0	6.0 – 6.1
Survey area	[deg^2]	4.0	100.0	4.0	0.04
Beam†	[arcsec]	46.3	46.3	11.1	46.3
Survey volume	[Mpc^3]	3.2×10^7	8.1×10^8	3.2×10^7	3.7×10^4
$V_{\rm vox}$	[Mpc^3]	39.6	39.6	2.3	4.0
$t_{\rm obs}$	[hour]	10 – 2000	10 – 2000	10 – 2000	10 – 2000
Instrumental noise+	[Jy sr^{-1}]	1.8×10^4	9.1×10^4	7.6×10^4	5.8×10^4
–	[mJy beam^{-1}]	0.92	4.6	0.2	2.9
$k_{\rm max}$	[Mpc^{-1}]	1.7	1.7	6.9	3.3

* S1 (for $t_{\rm obs} = 1000$ hour) is our fiducial survey.
† At 271.5 GHz.
+ For $t_{\rm obs} = 1000$ hour.

Yue & AF 19, submitted

S1 SURVEY – SHOT NOISE S/N



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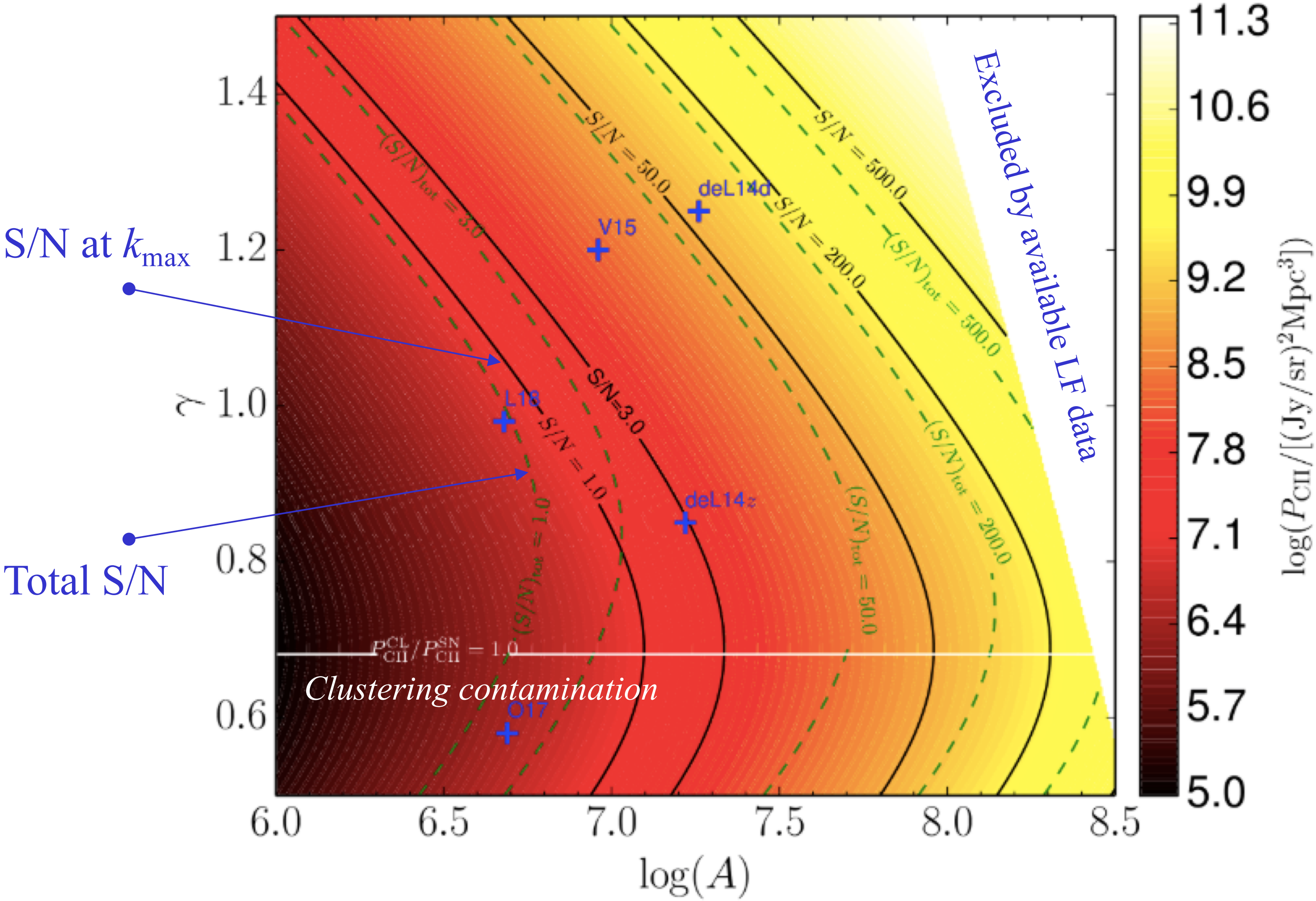
SURVEY S1 - SHOT NOISE SIGNAL



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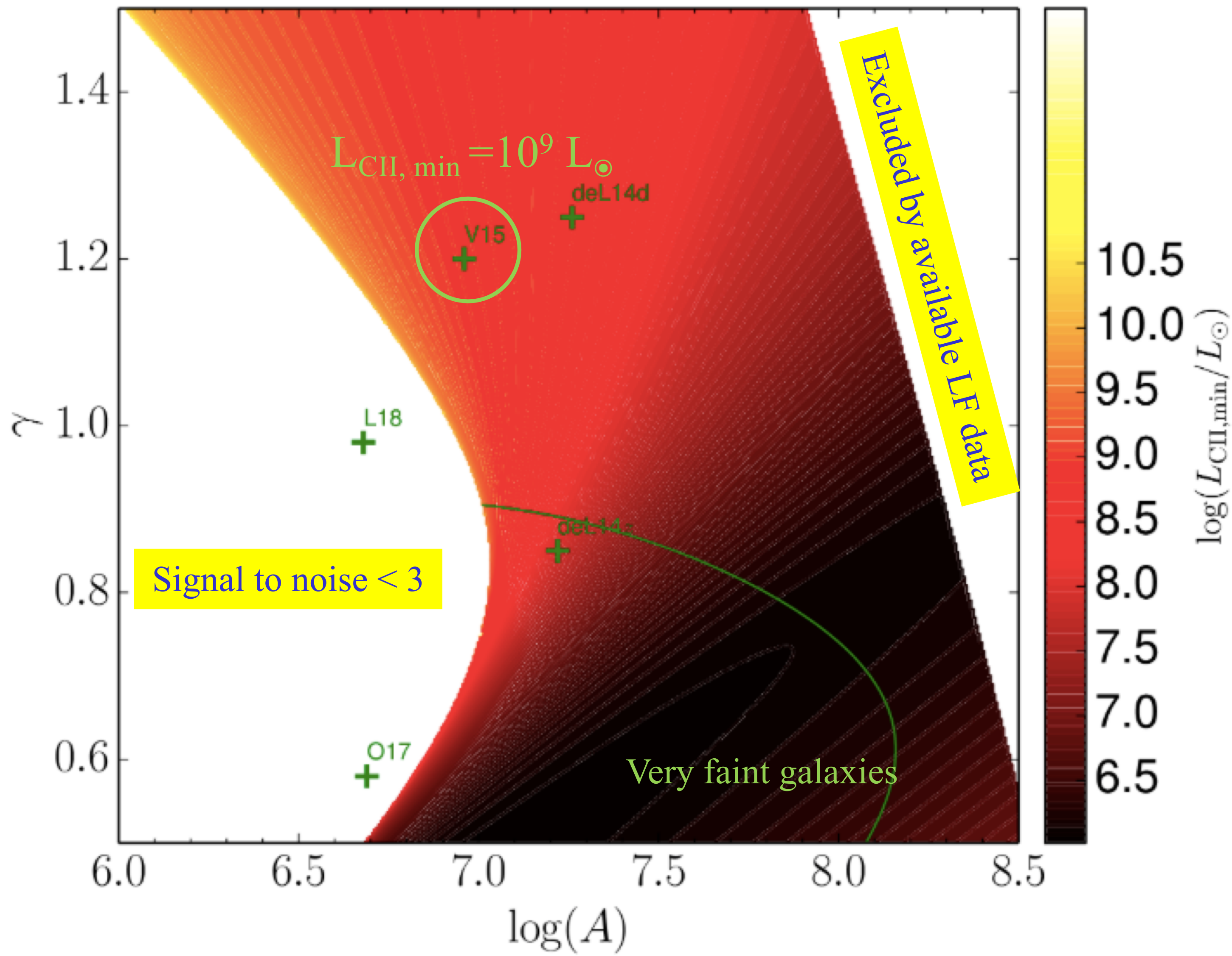
THE FAINTEST DETECTABLE L_{CII}



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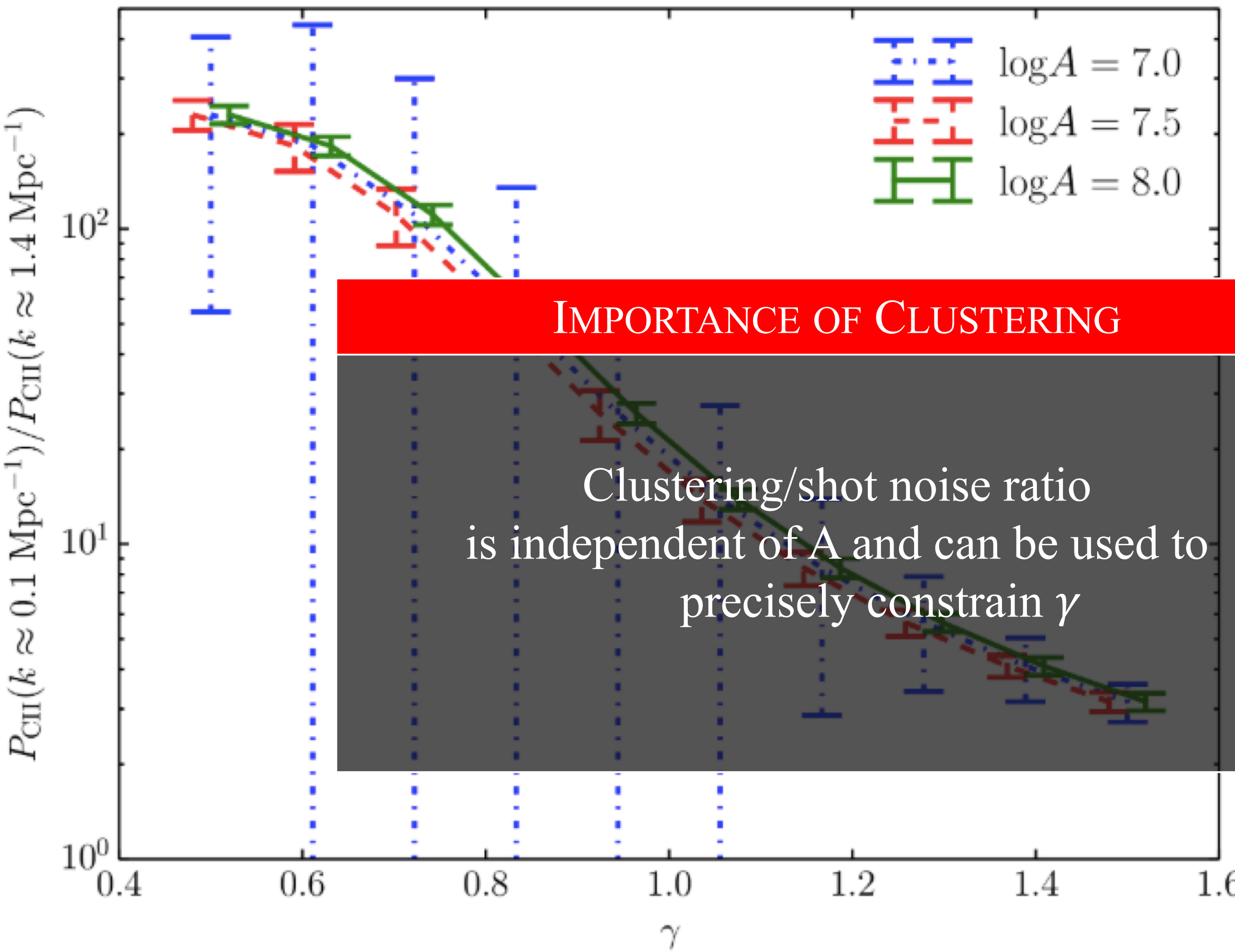
BREAKING THE LOG A-γ DEGENERACY

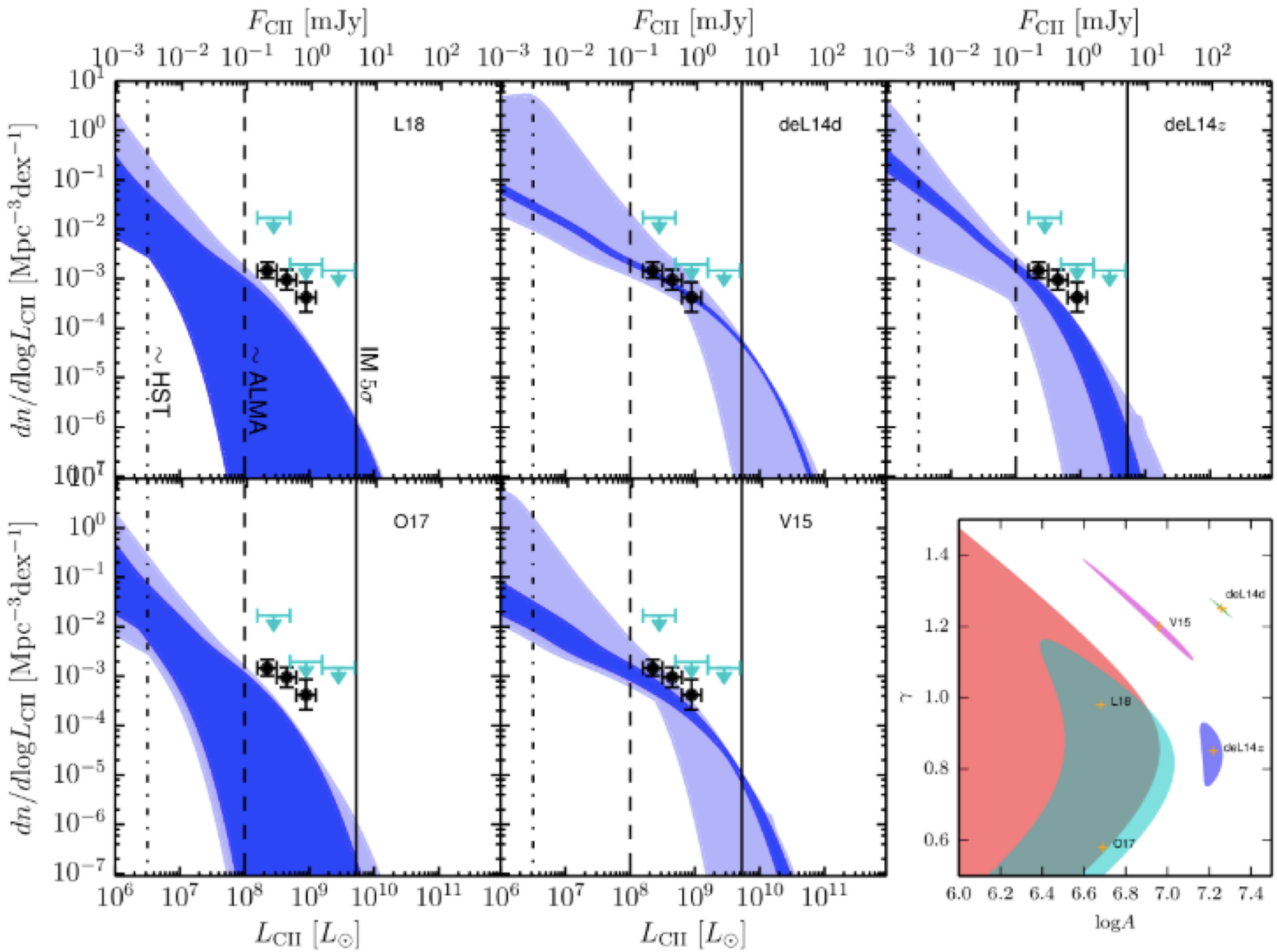
Clustering/Shot Noise Ratio



IMPORTANCE OF CLUSTERING

Clustering/shot noise ratio is independent of A and can be used to precisely constrain γ

RECOVERING LUMINOSITY FUNCTIONS



Fiducial (S1)

Wide (S2)

1σ constraints on LF parameters

SUMMARY

- [CII] Intensity Mapping provides new windows on the ISM of galaxies in the EoR.
- In fiducial survey S1 (inspired by CCAT-p/1000 hr) at z=6 the shot-noise (clustering) signal is detectable for 2 (1) of the 5 proposed L_{CII} – SFR relations.
- The shot noise is dominated by galaxies with $L_{CII} > 10^9\ L_{\odot}$, already well at reach of ALMA. However, crucial information on the bright-end of the LF can be obtained.
- If $L_{CII}=A\times SFR^{\gamma}$ relation varies in a wider (log A–γ) range, the signal produced by galaxies as faint as $L_{CII} \backsimeq 10^6\ L_{\odot}$ can be detected (shallow relation/steep faint-end)
- Clustering measurements crucial to break the degeneracies between LF parameters. Larger area surveys decrease uncertainties.
- The detection of the CII power spectrum signal will allow to reconstruct the [CII] LF, including uncertainties induced by instrumental noise and L_{CII} – SFR variance.