INTENSITY MAPPING BEYOND HI: EXPLORING NEW WAYS OF PROBING LSS

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in collaboration with Marta Silva and Mário G. Santos.

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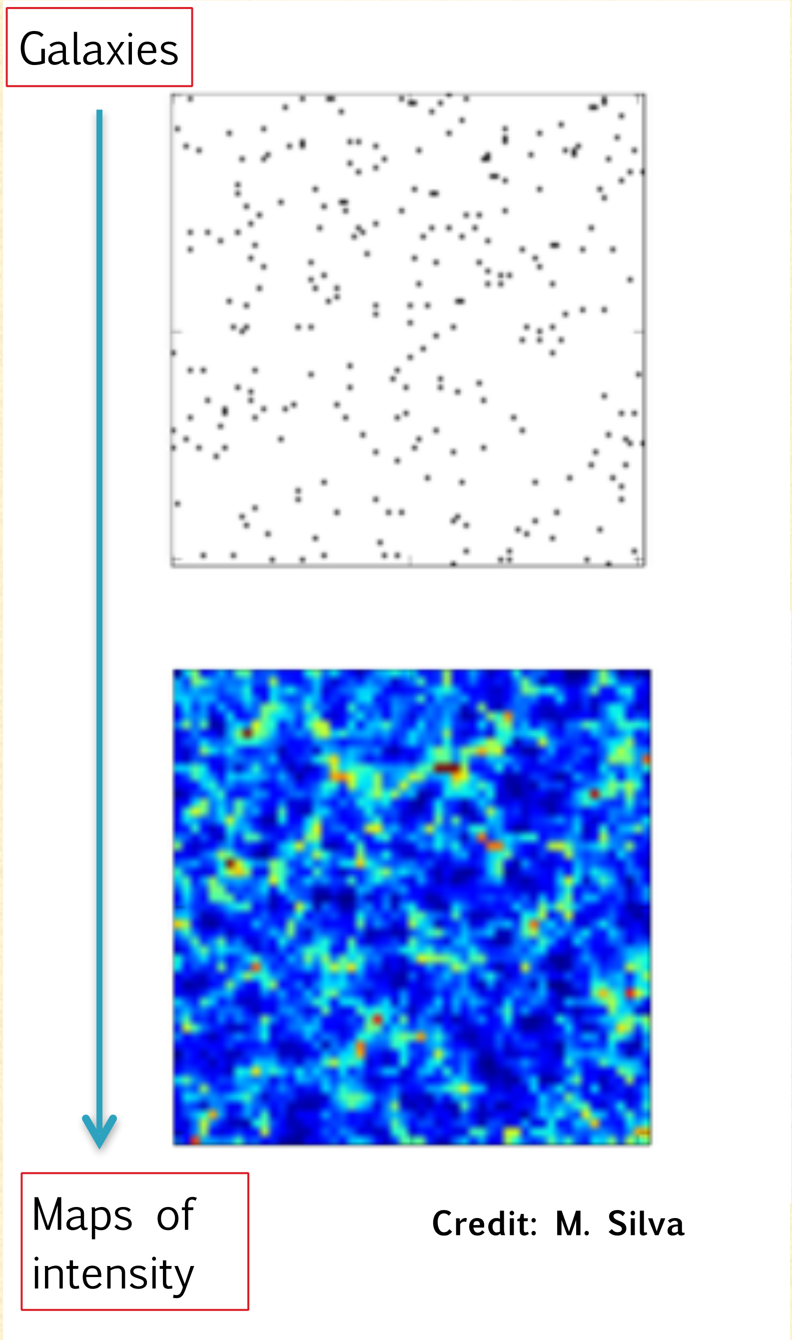
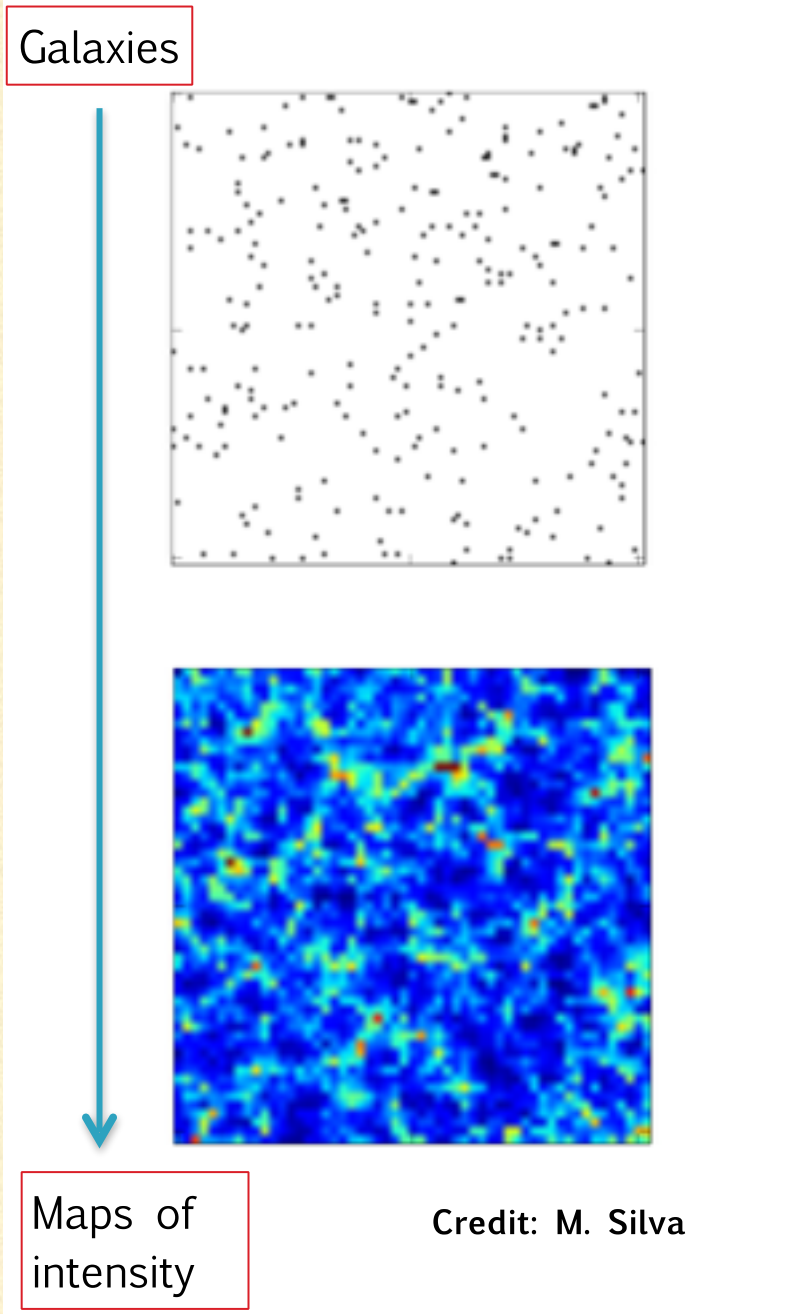
INTENSITY MAPPING

- Powerful technique to measure the large scale structure of the universe;
- We don't need to resolve individual galaxies;
- All emitters contribute to the signal;
- Intensity traces the density field;
- Wavelength/frequency bins are equivalent to redshift bins.



INTENSITY MAPPING

- Most studies are for HI emission (as you know by now);
- EoR: Lyα (Silva et al. 2013), CII (Gong et al. 2012), CO (Gong et al. 2011) or others (Visbal & Loeb 2010);
- Low z: Lyα - Pullen et al. (2014), CII - Uzgil et al. 2014, CO(1-0) - Breysse et al. 2014. All used different means of estimating the average signal;
- Aim: have a systematic study of all the lines (besides HI) that can in principle be used for intensity mapping in the late universe with a reasonable experimental setup and compare to access which are the optimal lines to target for intensity mapping.



Credit: M. Silva

ESTIMATING LINE INTENSITY

Line Luminosity as a function of halo mass M

$$\bar{I}_\nu(z) = \int_{M_{min}}^{M_{max}} \mathrm{dM} \, \frac{dn}{dM} \, \frac{L(M,z)}{4\pi D_L^2} \, \tilde{y} D_A^2$$

Halo Mass function (Sheth&Tormen 99)

$$M \in [10^8, 10^{15}]$$

Volume factor

$$\tilde{y} \equiv \frac{d\chi}{d\nu} = \frac{\lambda_e (1+z)^2}{H(z)}$$

Caveat: one has to assume a sharp emission line profile.

How to relate L with M?

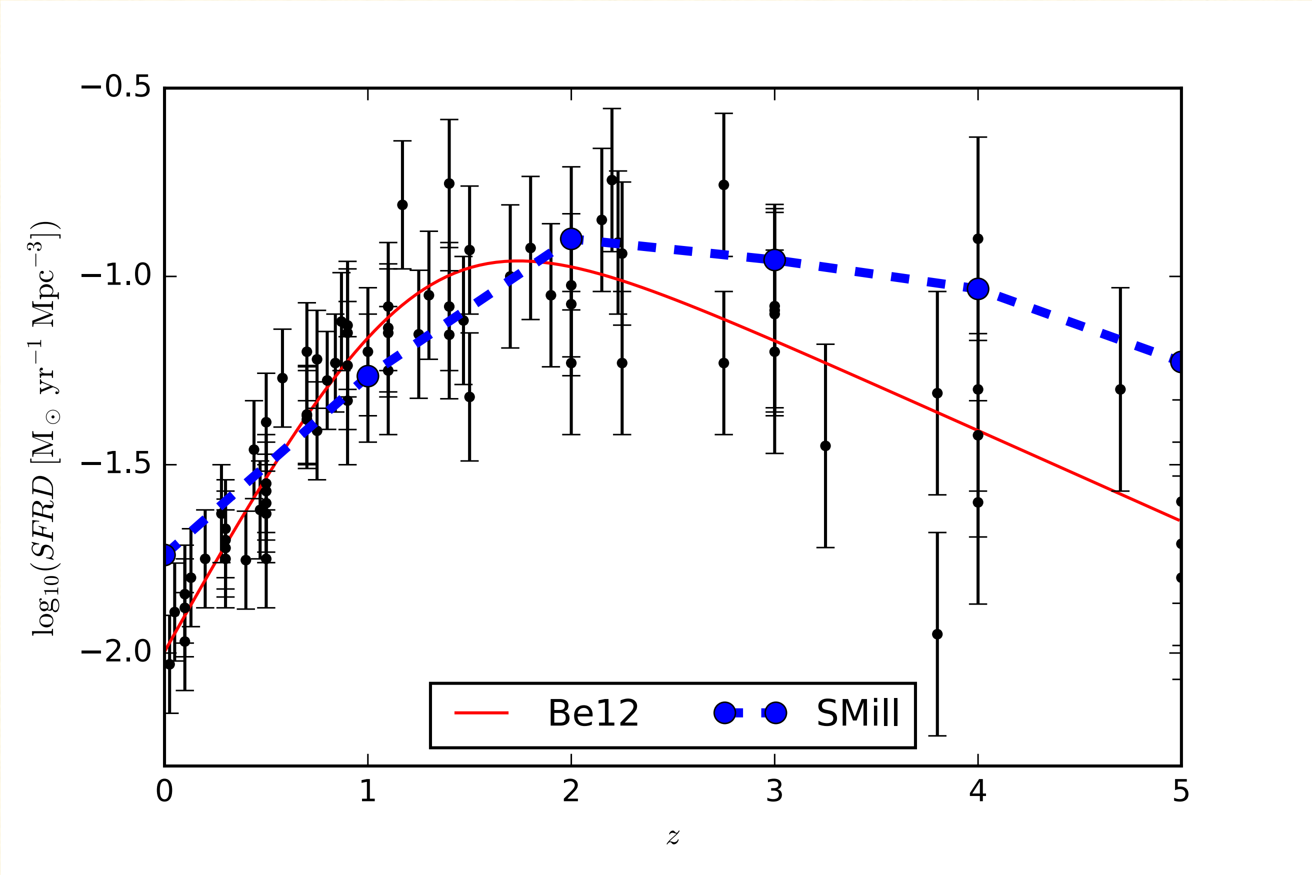
ESTIMATING LINE INTENSITY

How to relate L with M? We use the star formation rate (SFR).

$$L = K(z) \times \left(\frac{SFR(M,z)}{\mathrm{M}_\odot/\mathrm{yr}} \right)^\gamma$$

We use 2 models of SFR to account for uncertainties for z>2:

- Behroozi et al. (2013) - fit to a recollection of several observational constraints - Be12;
- Fit to galaxy catalogs obtained by De Lucia & Blaizot (2007) and Guo et al. (2011) who post processed the Millennium I and II simulations - SMill;



LYMAN ALPHA EMISSION

UV line, 121.6 nm and linear in the SFR.

$$K^{\mathrm{Ly}\alpha}(z) = (f^{\mathrm{UV}}_{dust} - f^{\mathrm{UV}}_{esc}) \times f^{\mathrm{Ly}\alpha}_{esc}(z) \times R^{\mathrm{Ly}\alpha}$$

photons that are not absorbed by dust: ~1 mag extinction +/- 0.2

$$f^{\mathrm{UV}}_{\mathrm{dust}} = 10^{-E_{\mathrm{UV}}/2.5}$$

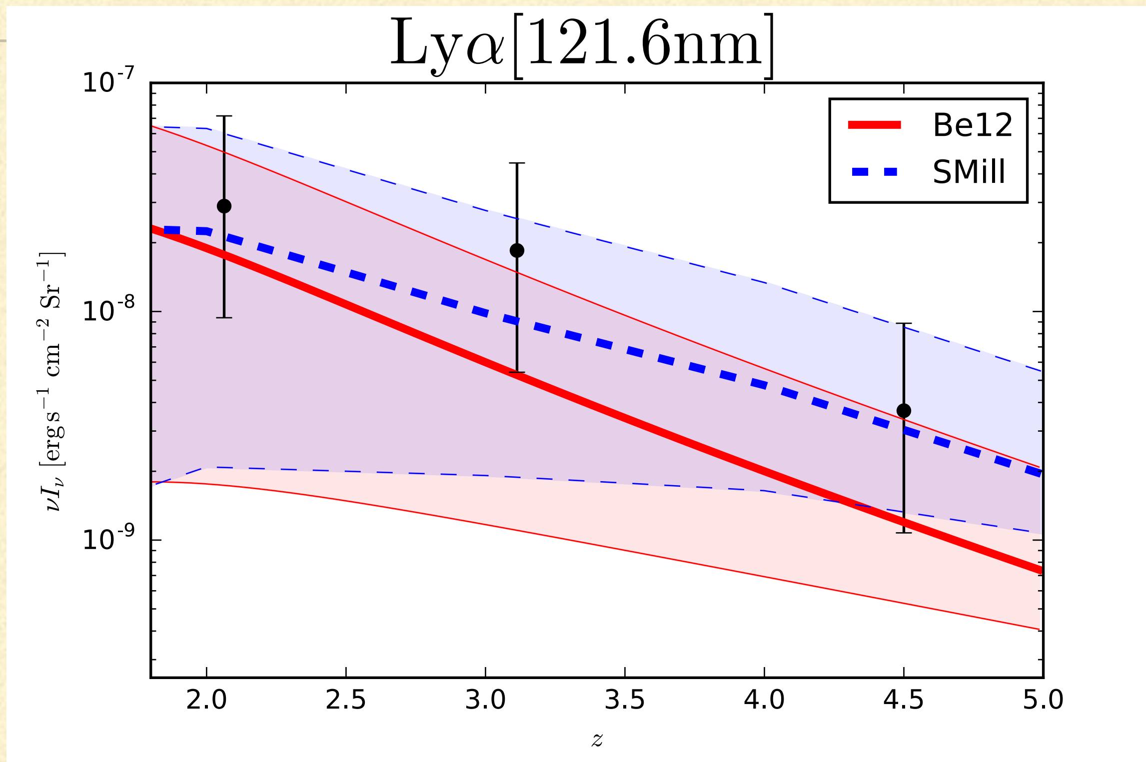
UV photons that escape the galaxy: ~ 0.2 (Yajima et al. 2014)

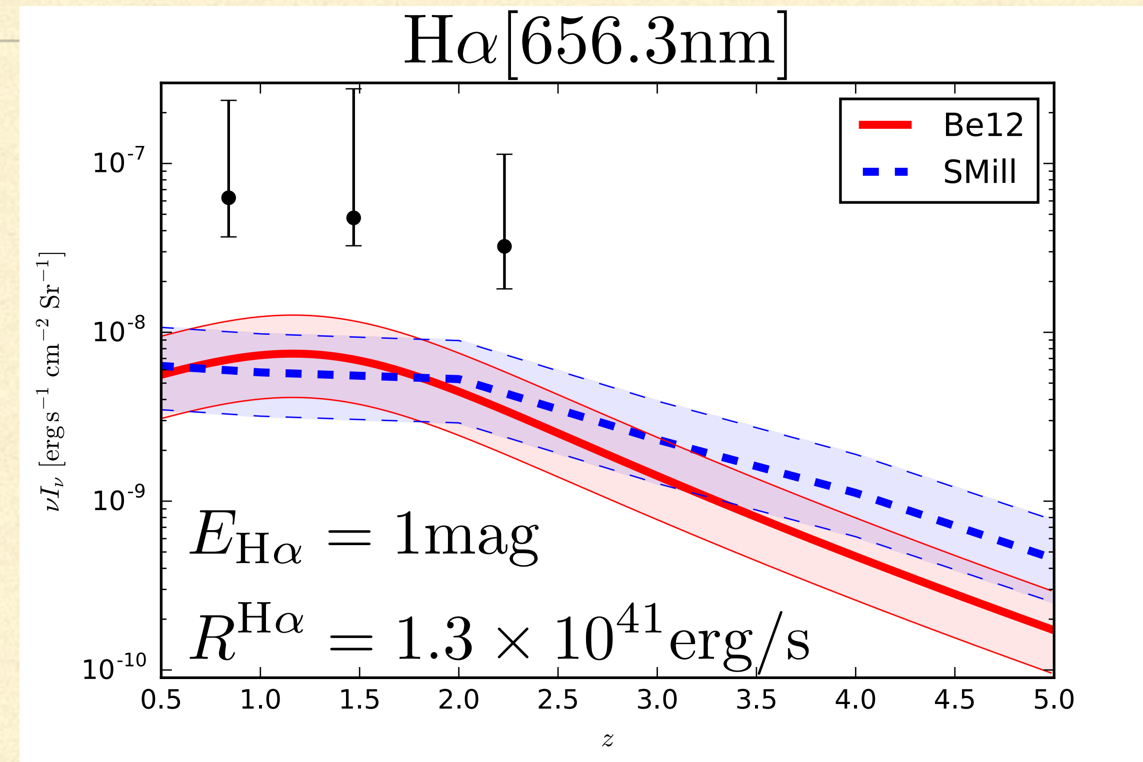
Lyα photons that escape the galaxy: 0.1-0.4

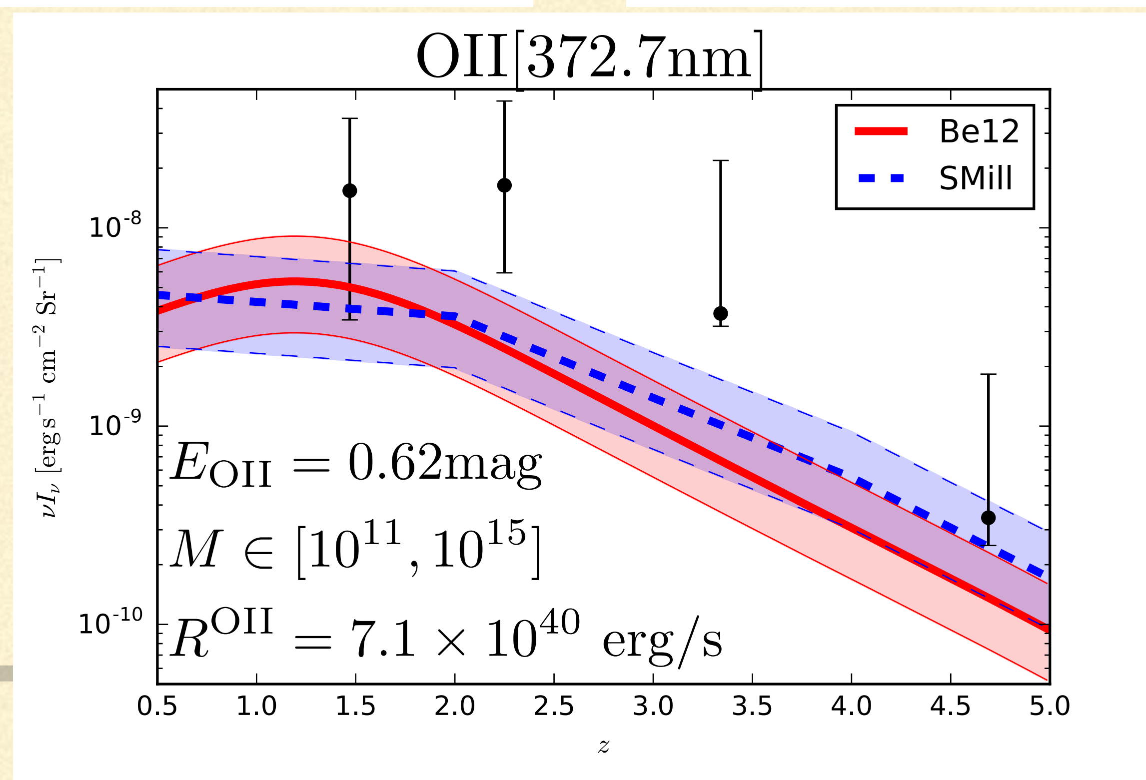
Kennicutt 1998: Optically thick interstellar medium, Case B recombination, and a Salpeter (1955) universal initial mass function

$$R^{\mathrm{Ly}\alpha}_{rec} = 1.1 \times 10^{42}\ \mathrm{erg/s}$$

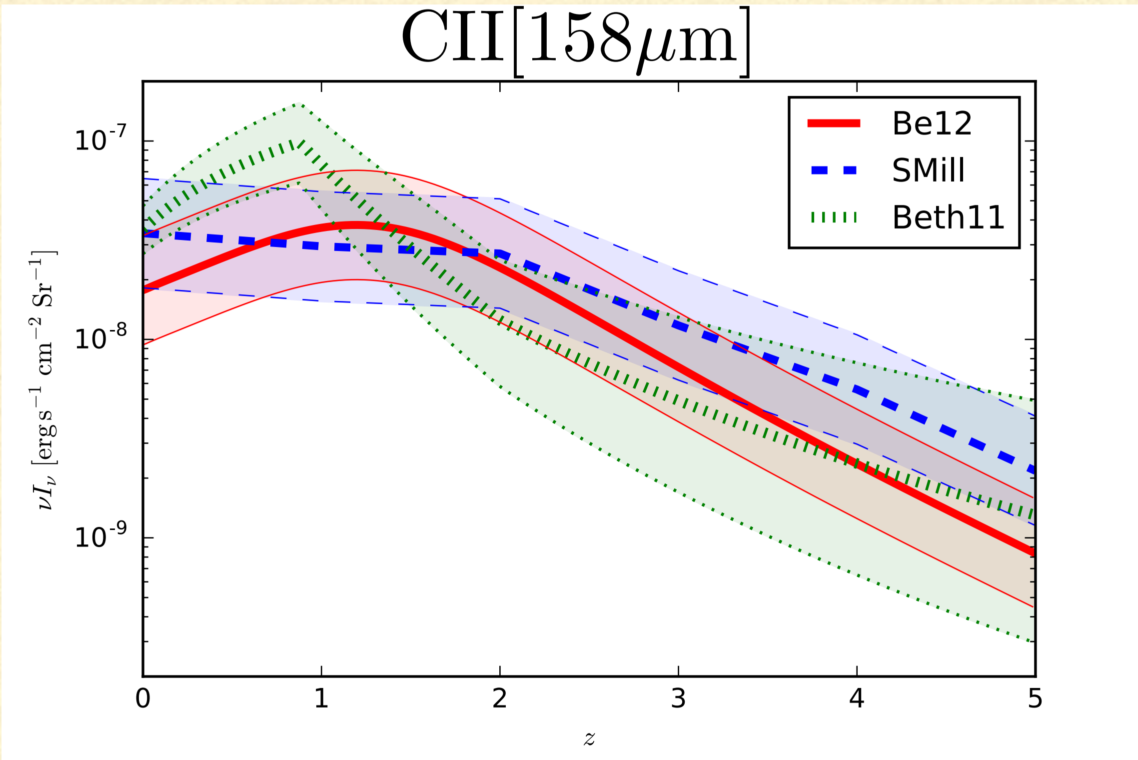
UV AND OPTICAL LINES

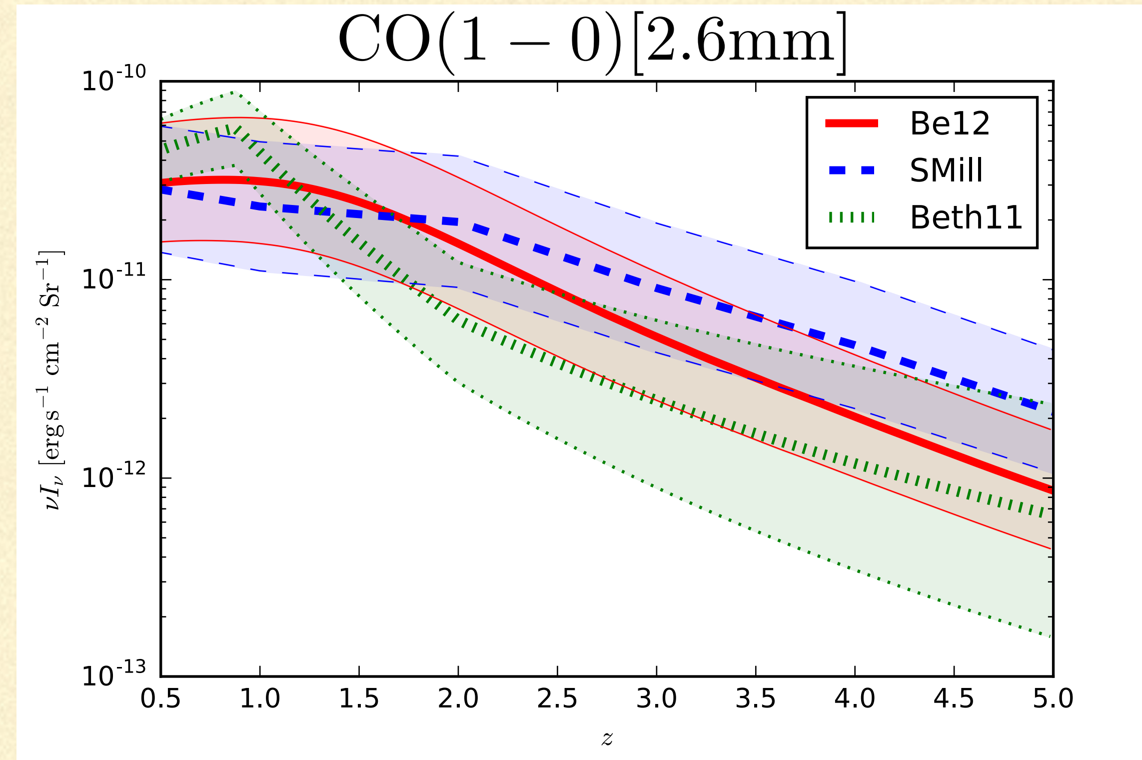






INFRA-RED LINES





$$L_{\rm CII} = 5.06 \times 10^{40} \left(\frac{SFR}{\rm M_\odot \ yr^{-1}} \right)^{1.02} \quad \rm erg/s$$

$M \in [10^{10}, 10^{15}]$

De Looze et al. 2011

$$\log_{10}(L'_{CO})[\rm K\,km/s\,pc^2]) = \alpha \log_{10}(L_{FIR}[\rm L_\odot]) + \beta$$

$$\alpha_{CO(1-0)} = 0.81 \pm 0.03\,, \ \beta_{CO(1-0)} = 0.54 \pm 0.02$$

$$L_{CO} = 1.88 \times 10^{29} \left(\frac{\nu_{\rm CO,rest}}{\rm 115.27 GHz} \right)^3 \frac{L'_{CO}}{\rm K\,km/s\,pc^2} \, \rm erg/s$$

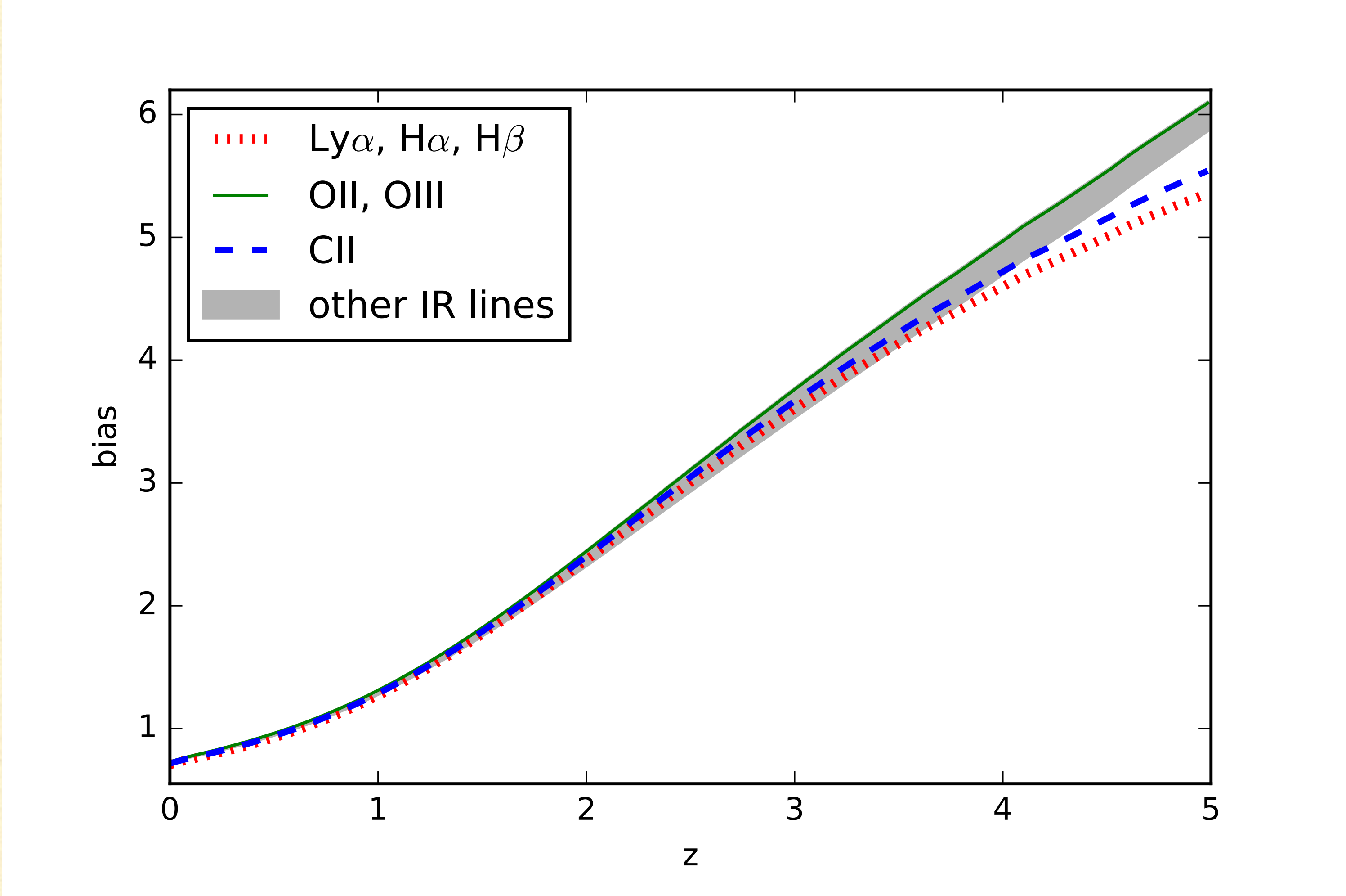
Sargent et al. 2014

Luminosity function from Bethermin et al. 2011

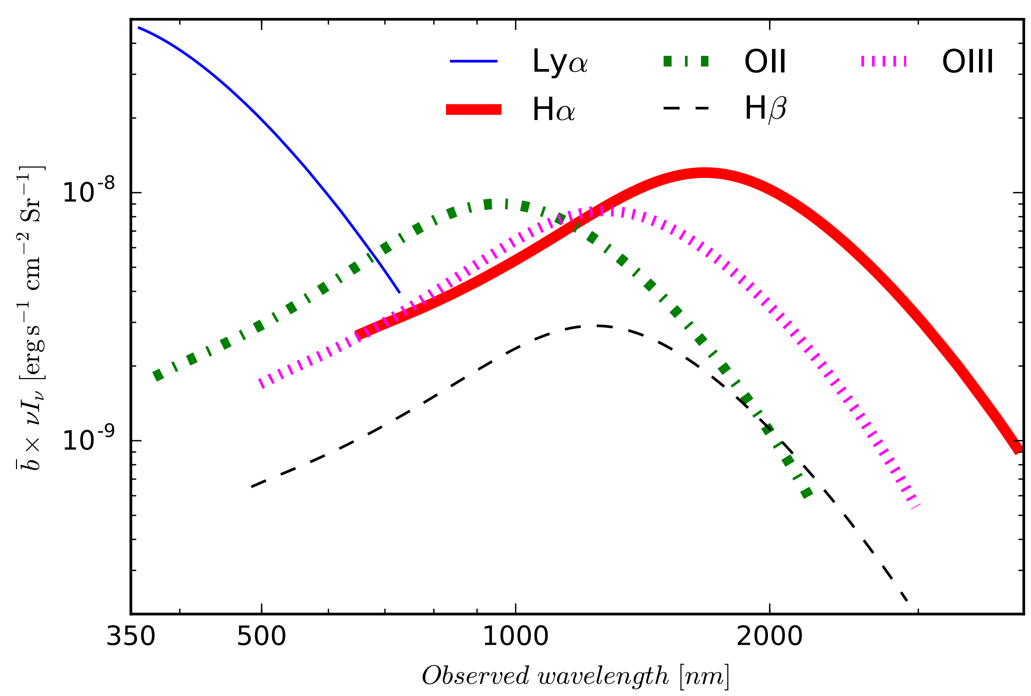
COMPARISON BETWEEN LINES

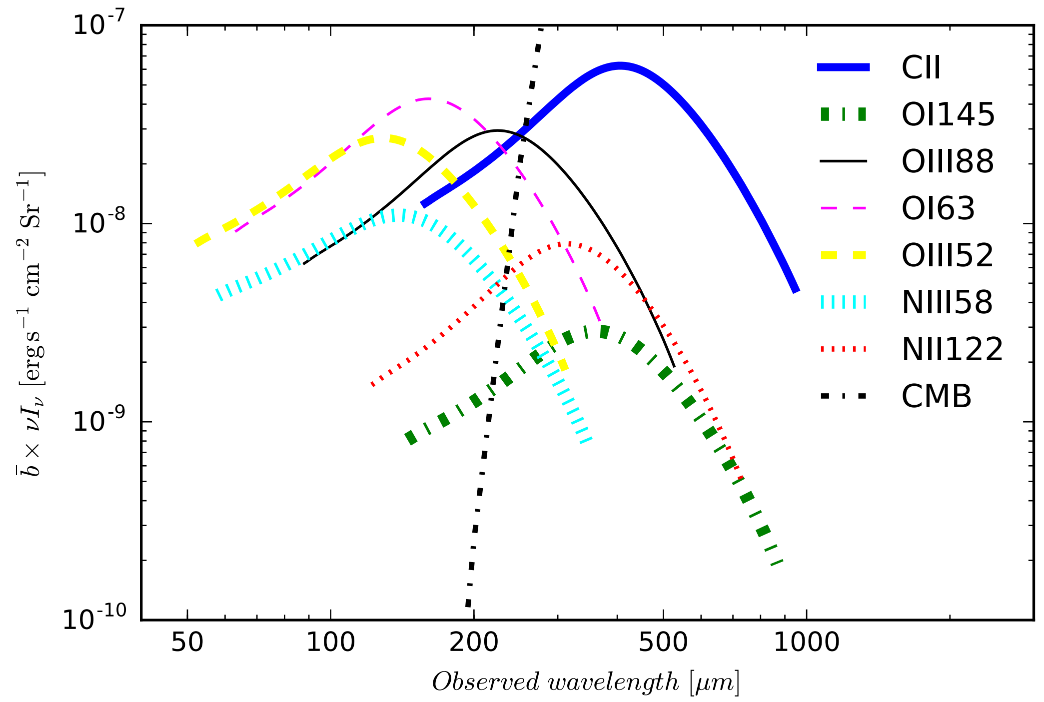
Bias

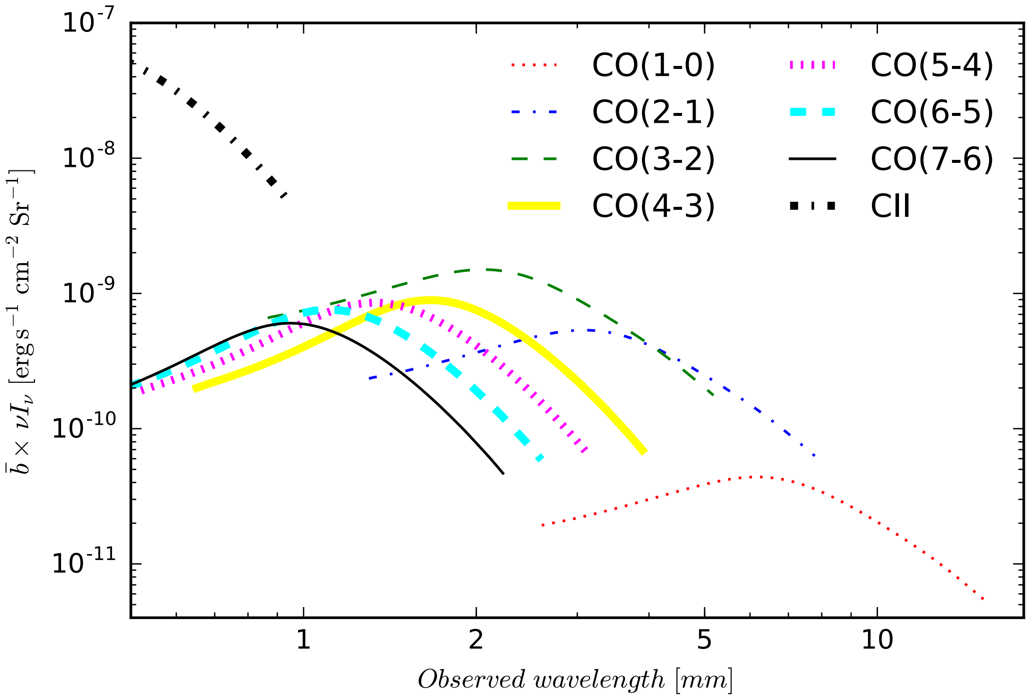
$$\bar{b}(z) \equiv \frac{\int_{M_{min}}^{M_{max}} \mathrm{dM}\ b(M,z)L(M,z)\ \frac{dn}{dM}}{\int_{M_{min}}^{M_{max}} \mathrm{dM}\ L(M,z)\ \frac{dn}{dM}}$$



COMPARISON BETWEEN LINES



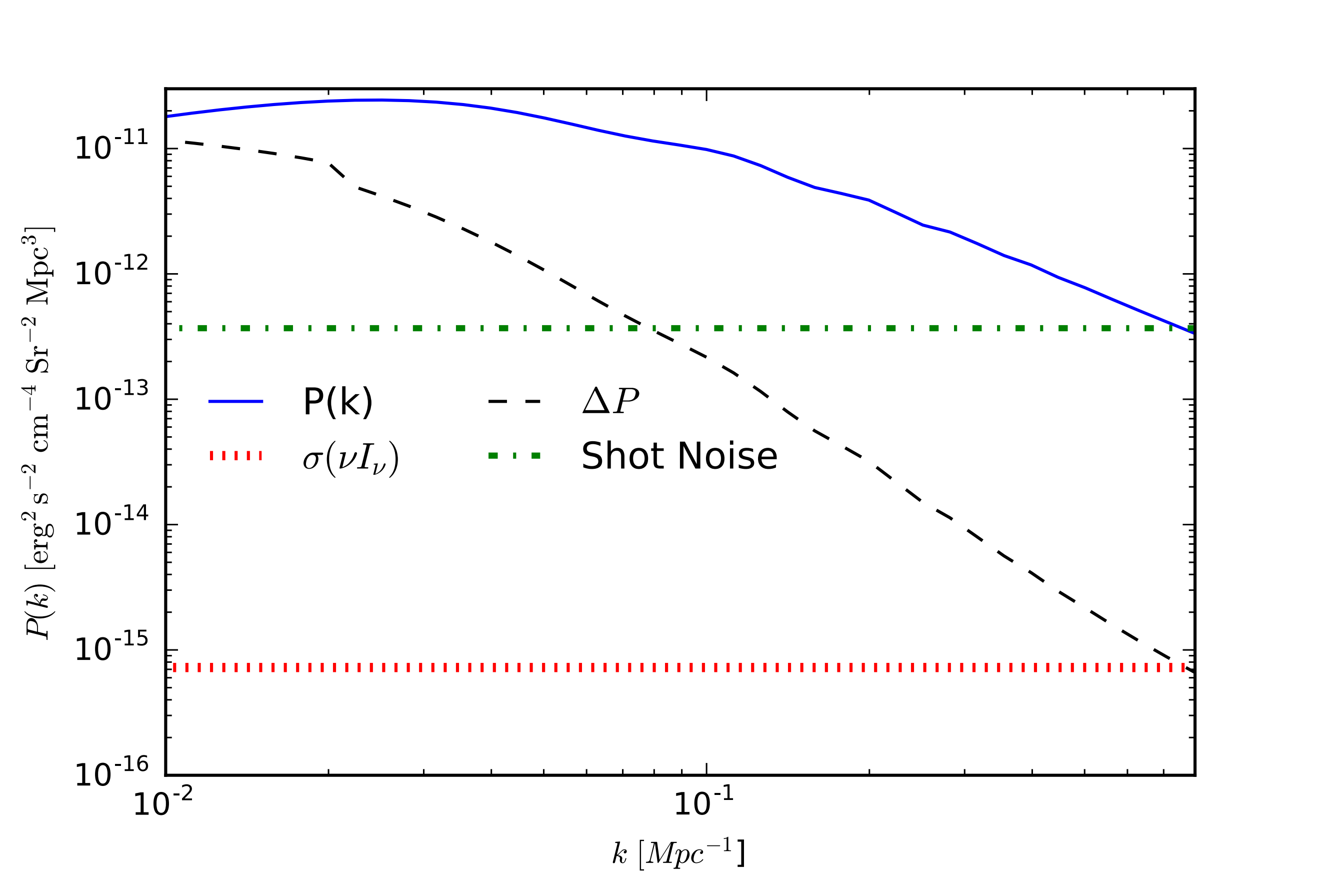


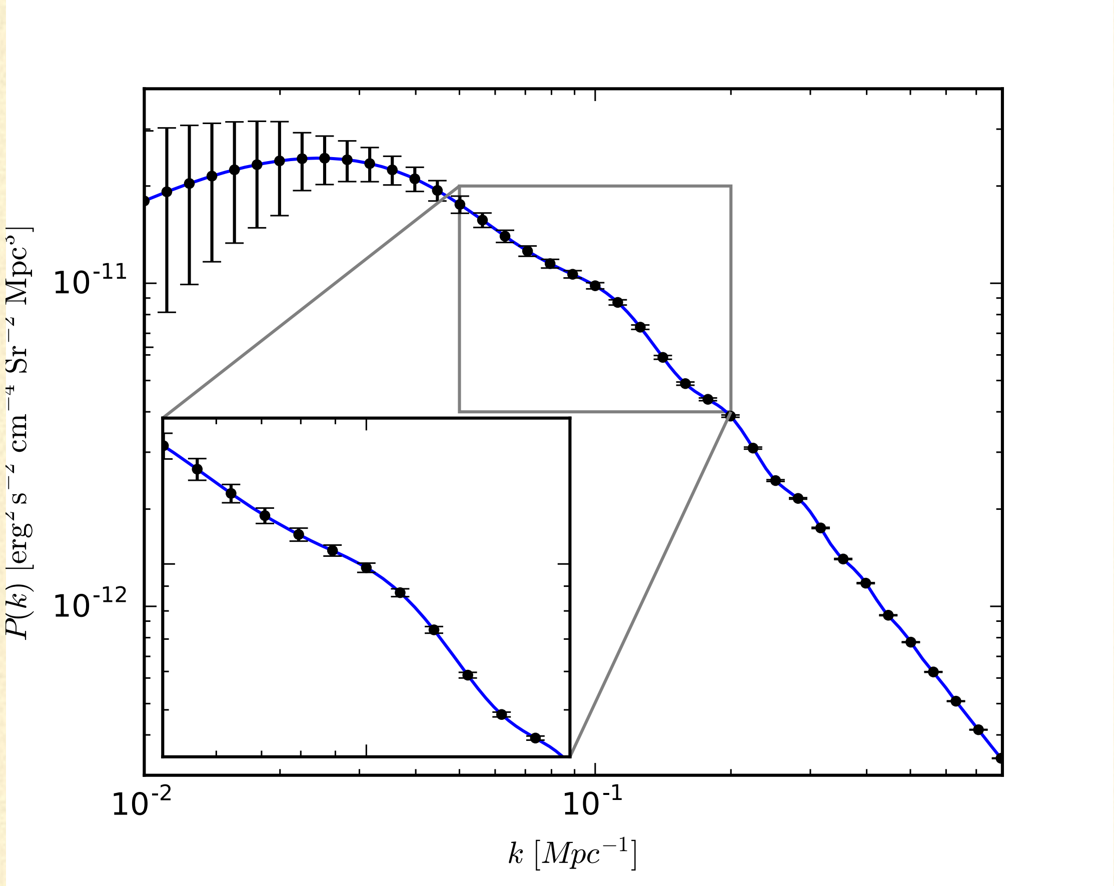


Emission line	Wavelength range	Redshift range	Spectral class
Lyα	122-679 nm	0.0-4.58	UV/Optical
OII	679-1131 nm	0.82-2.03	Optical/NIF
Hα	1.25-3.94 μm	0.9-5	NIF
CII	249-948 μm	0.57-5	FIR
CO(3-2)	1.24-4.06 mm	0.43-3.69	Radio(Millimetre)
CO(2-1)	4.06-7.8 mm	2.12-5	Radio(Millimetre)
CO(1-0)	8.48-15.6 mm	2.60-5	Radio(Millimetre)

LYMAN ALPHA IM WITH HETDEX

z=2.5, 300 deg^2

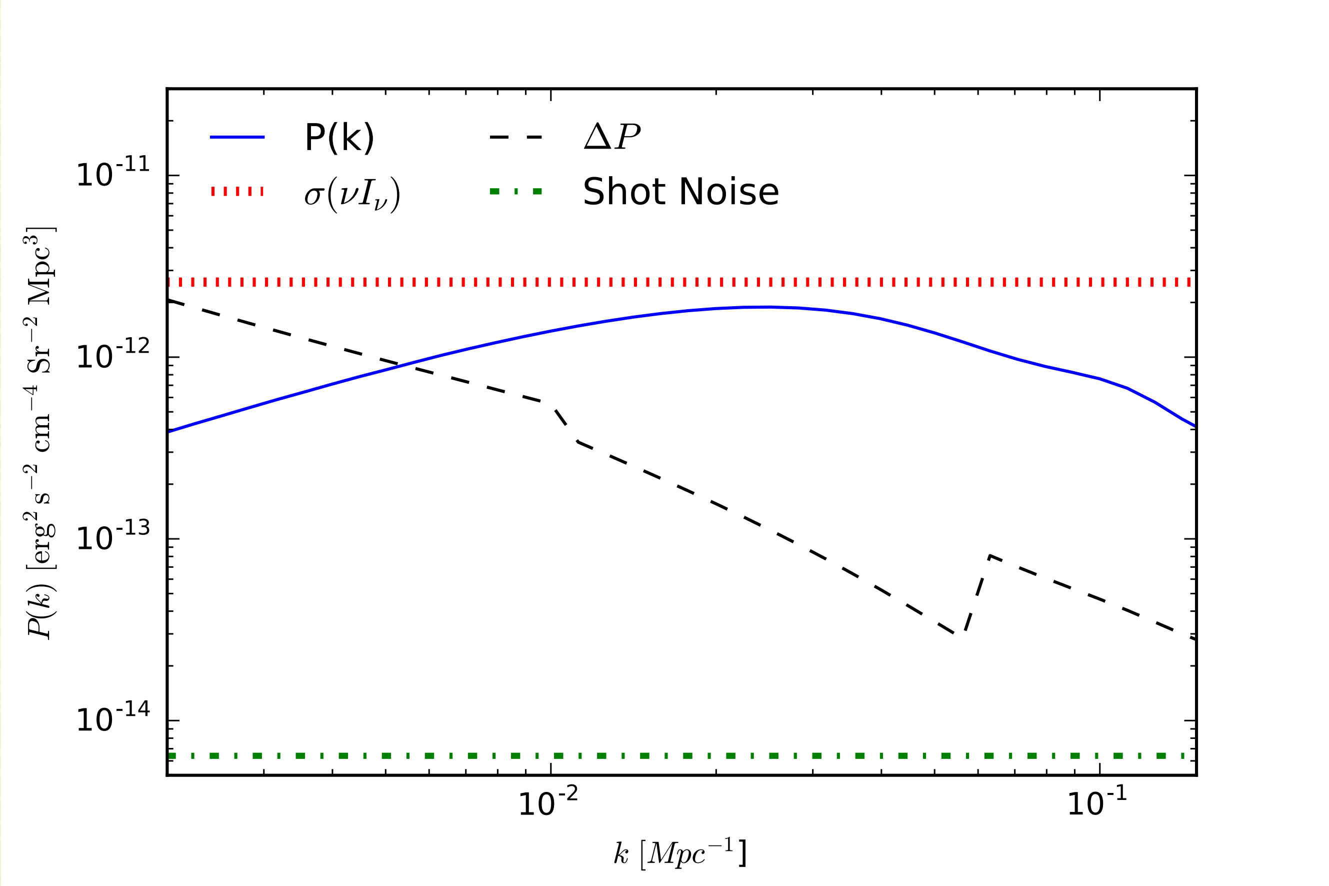


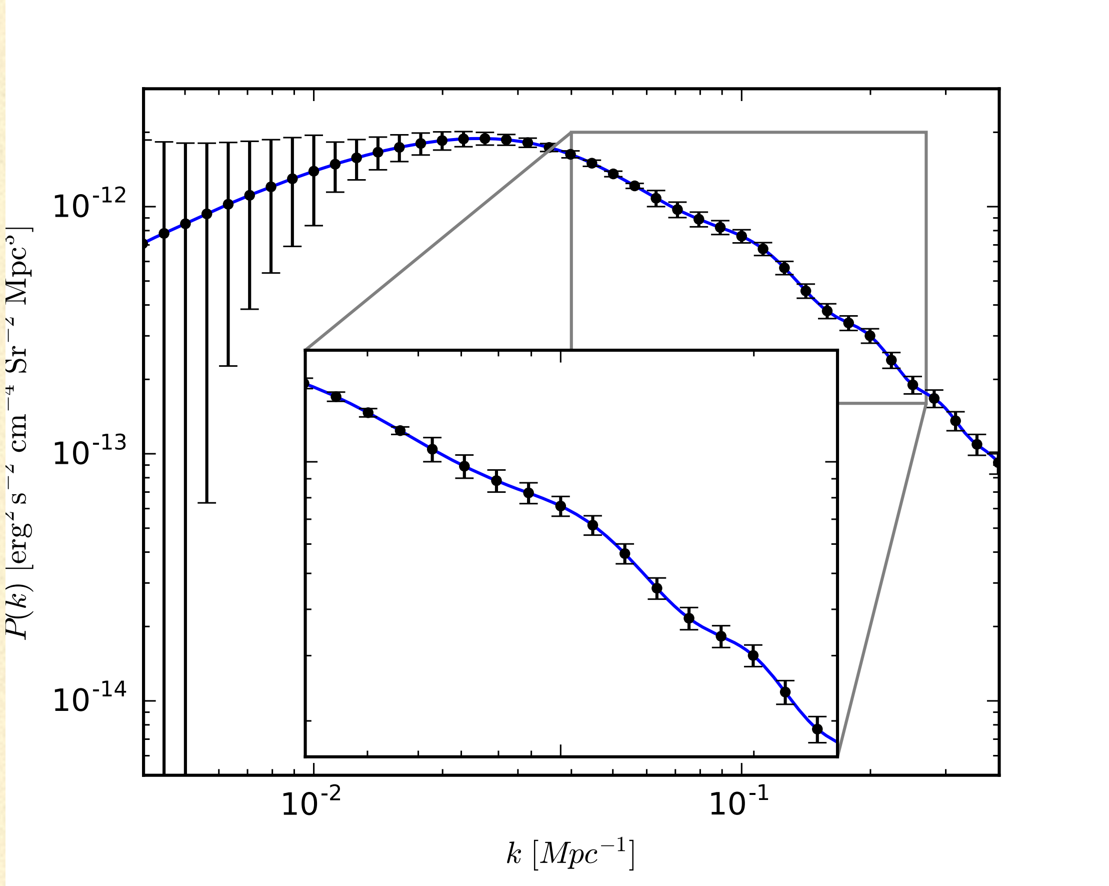


HETDEX - www.hetdex.org

H-ALPHA IM WITH SPHEREX

z=1.9, 7000 deg^2

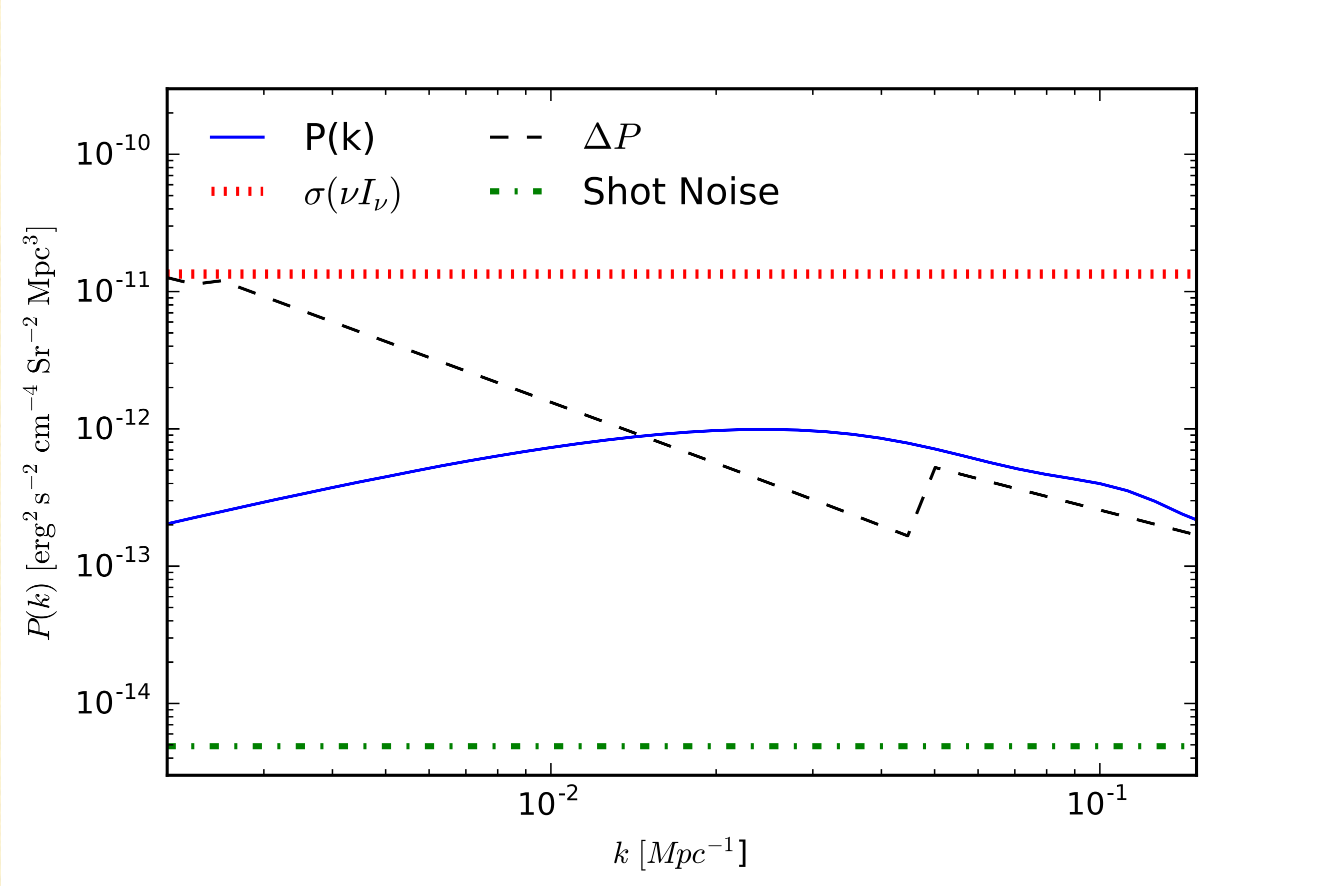


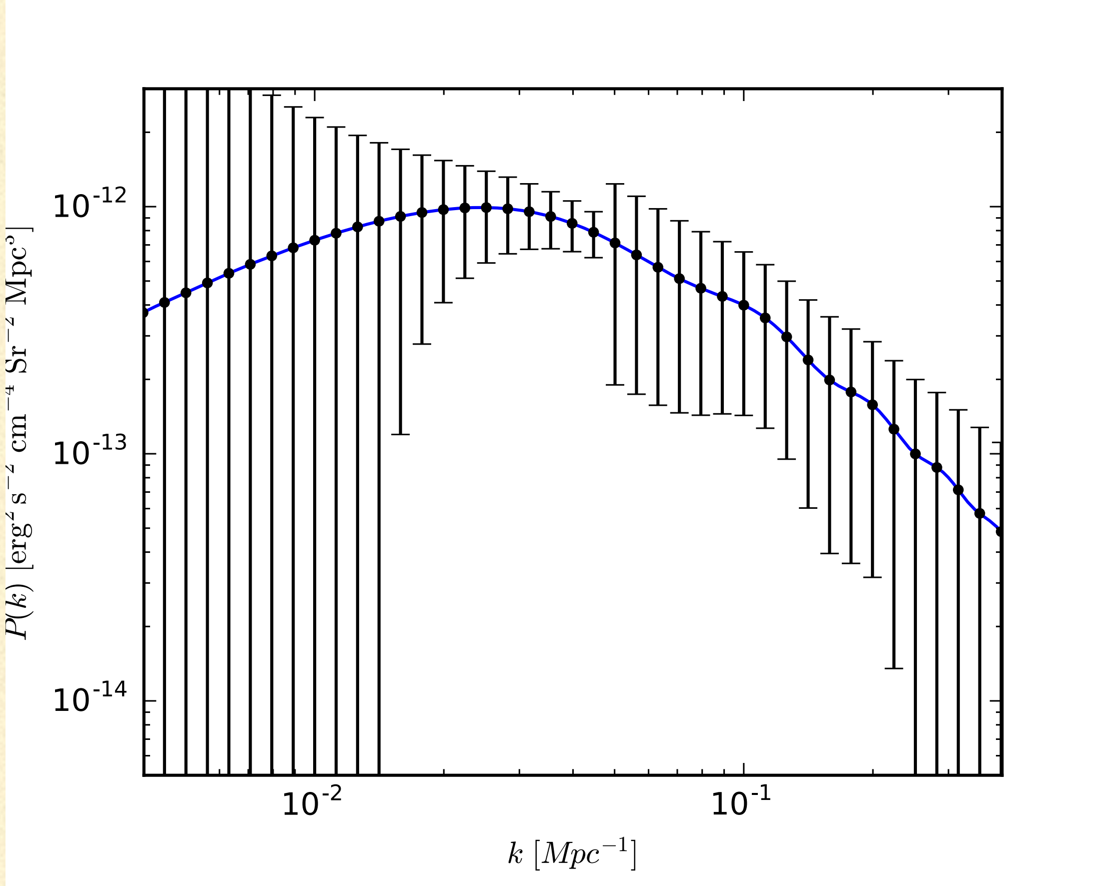


SPHEREx (Doré et al. 2014) - http://spherex.caltech.edu

OII IM WITH SPHEREX

z=1.2, 7000 deg^2

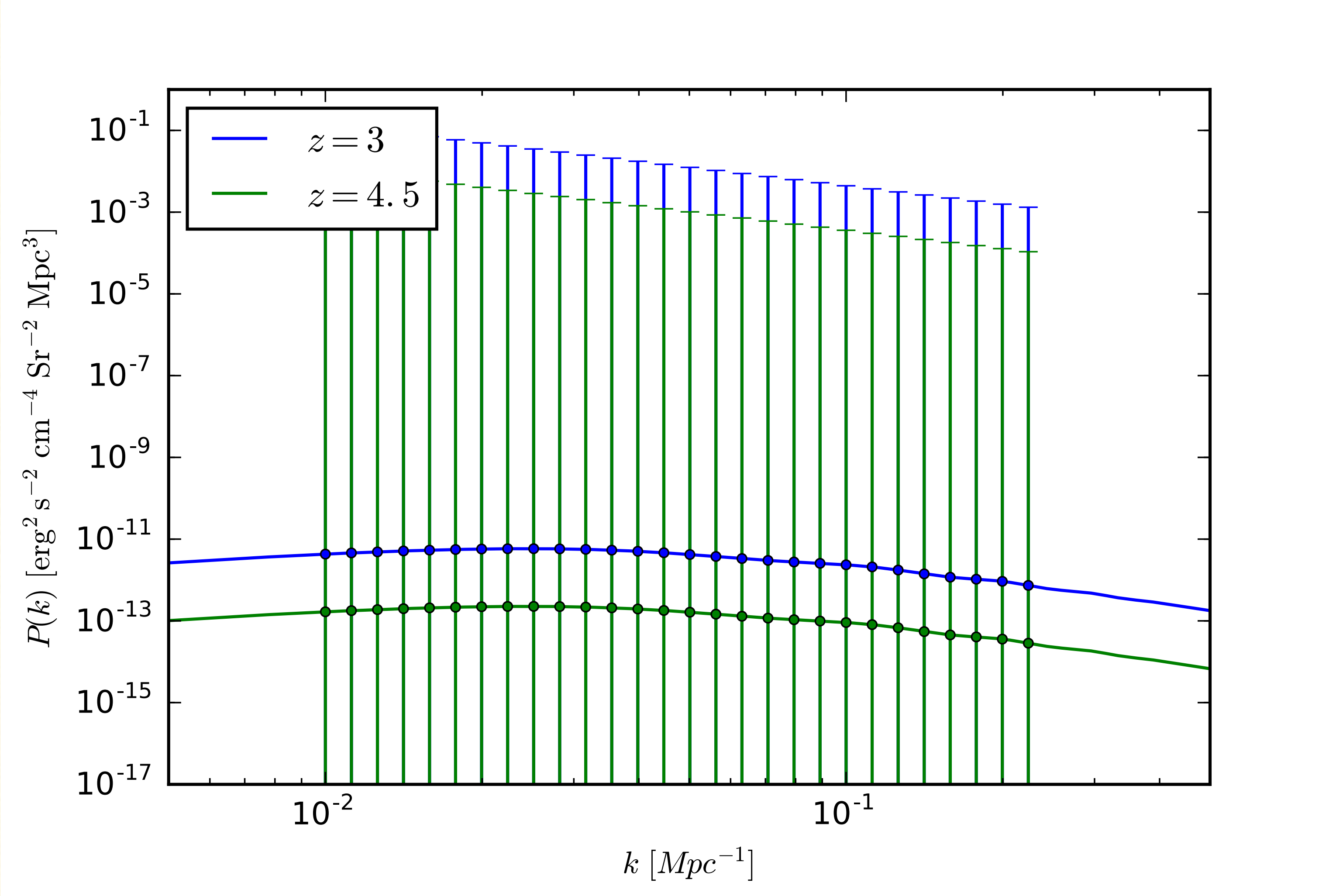




SPHEREx (Doré et al. 2014) - http://spherex.caltech.edu

CII WITH ALMA IN SINGLE DISH

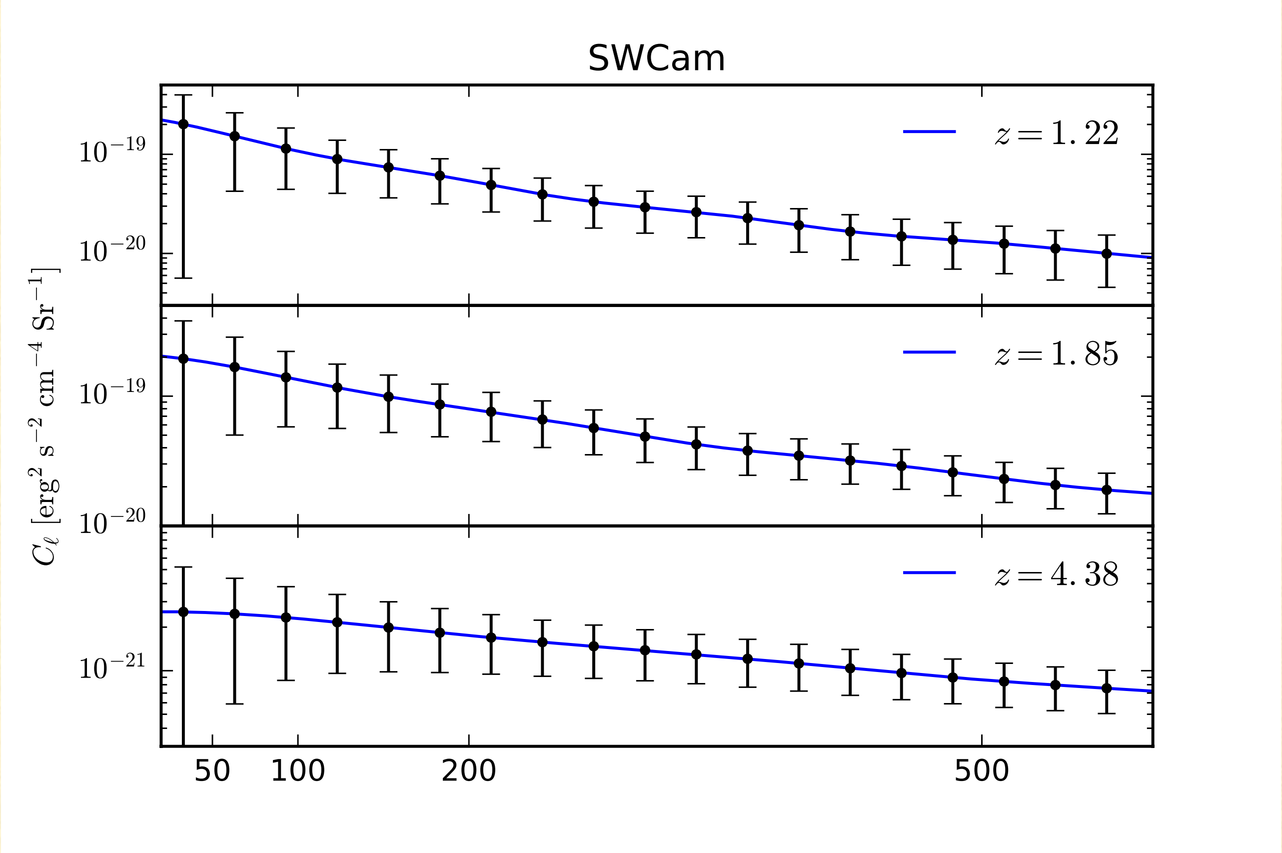
4 antennas
500 deg^2

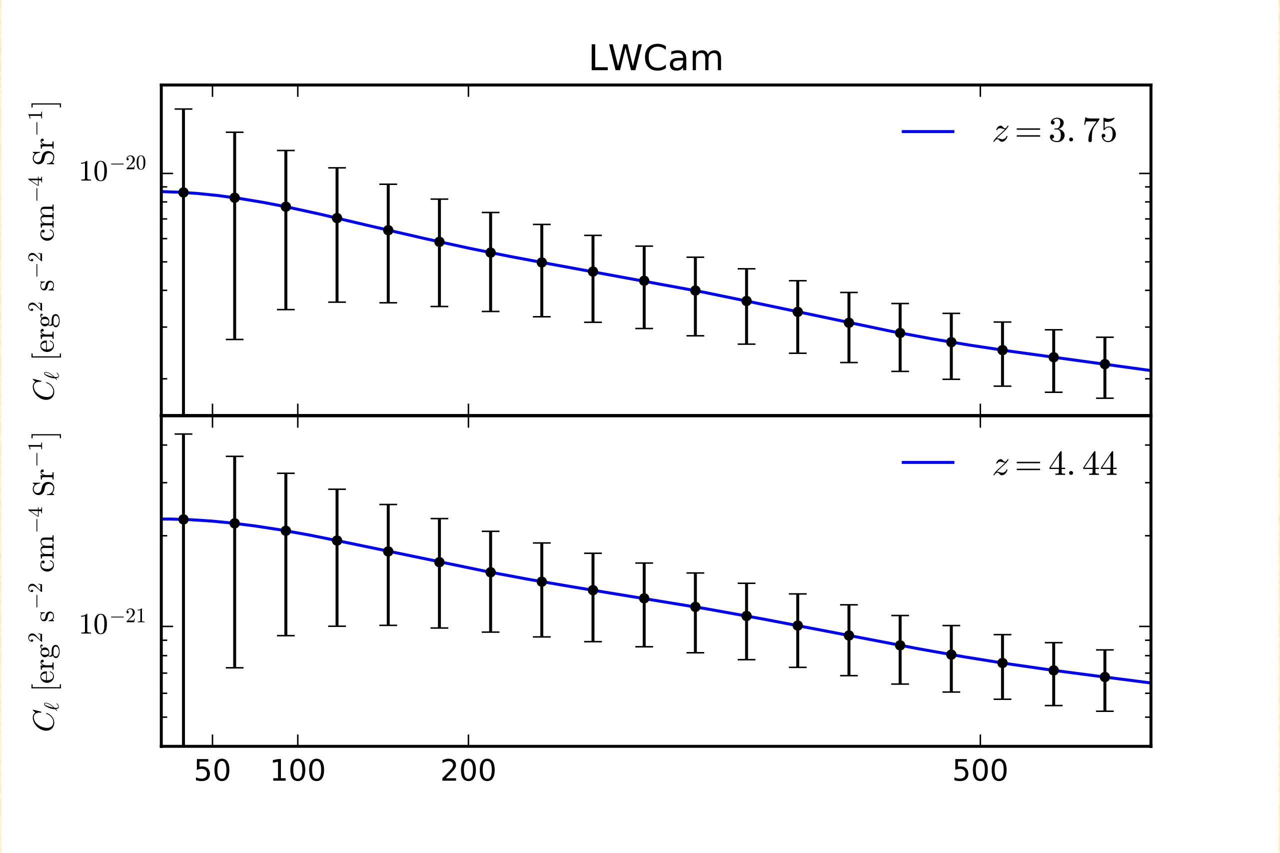


Similar for CO…

CII WITH CCAT

1500 deg^2

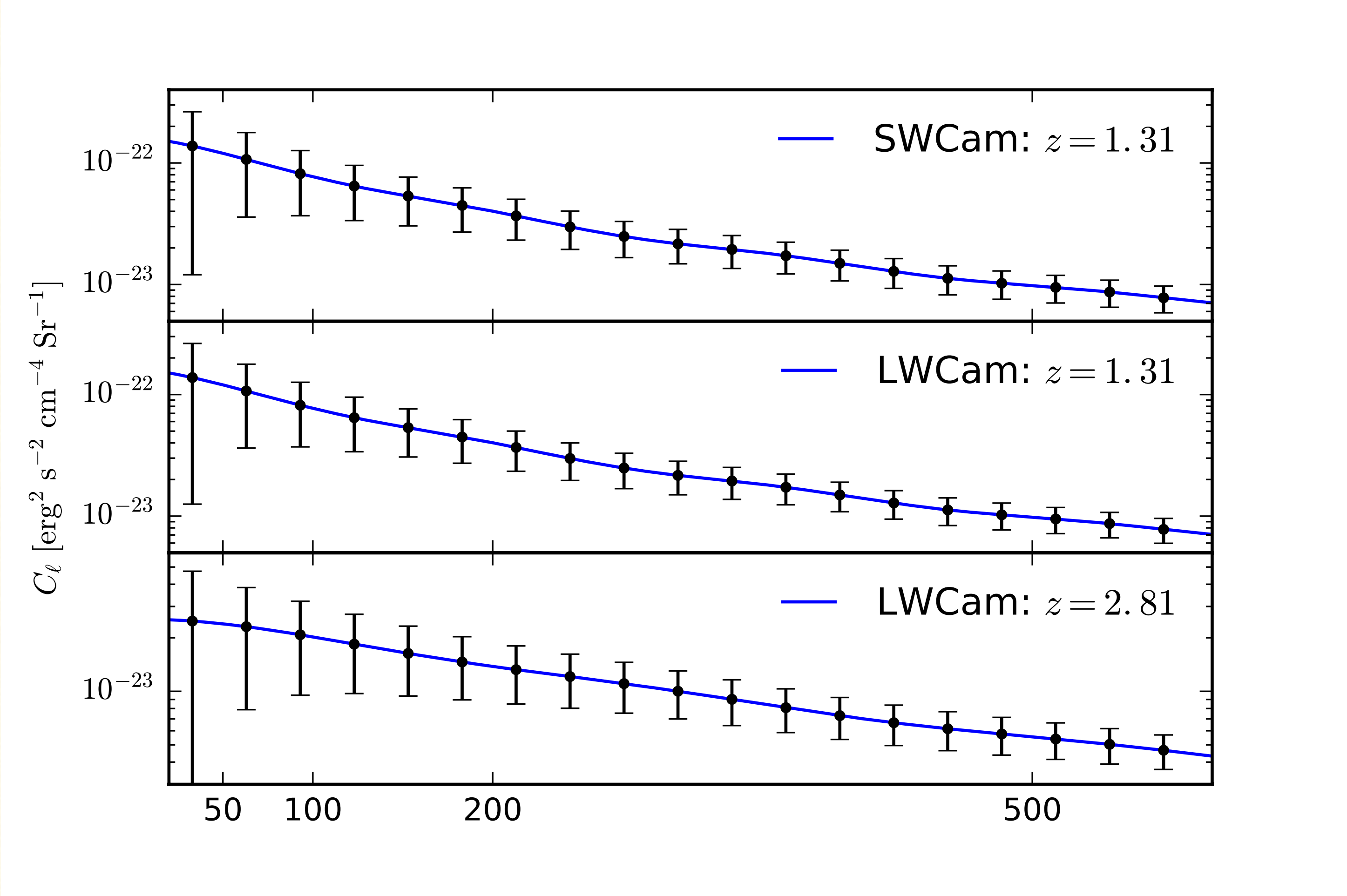




CCAT - https://www.ccatobservatory.org

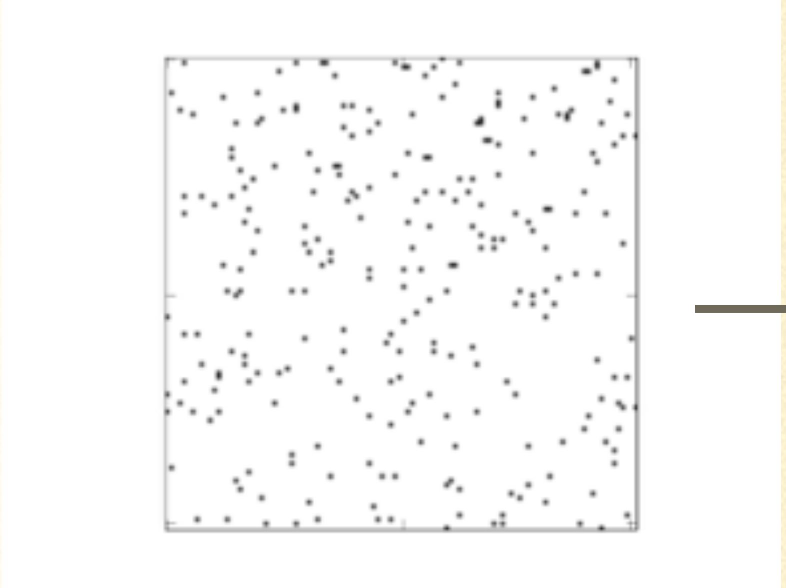
CO(3-2) WITH CCAT

1500 deg^2



CCAT - https://www.ccatobservatory.org

DISCUSSION



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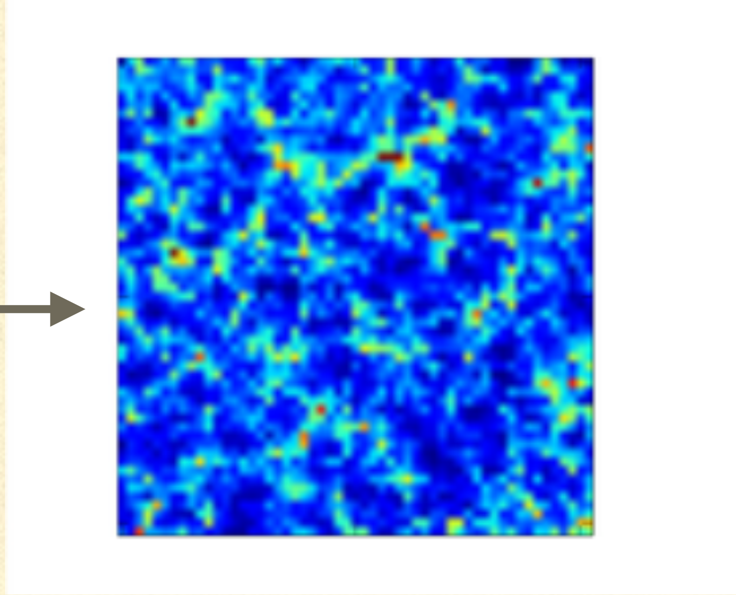

- The models depend on the astrophysics but Line IM can also be used to constrain gastrophysics and properties of galaxies;
- foregrounds/backgrounds contaminants and systematics can be dealt using cross-correlation (akin to Multi-tracer techniques);
- IM of lines other than HI 21cm is possible but new experimental designs are needed.