The Cosmic Infrared Background (CIB)

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Outline:

- Introduction to CIB
- Some forecasts for AliCPT

SFR: star formation rate

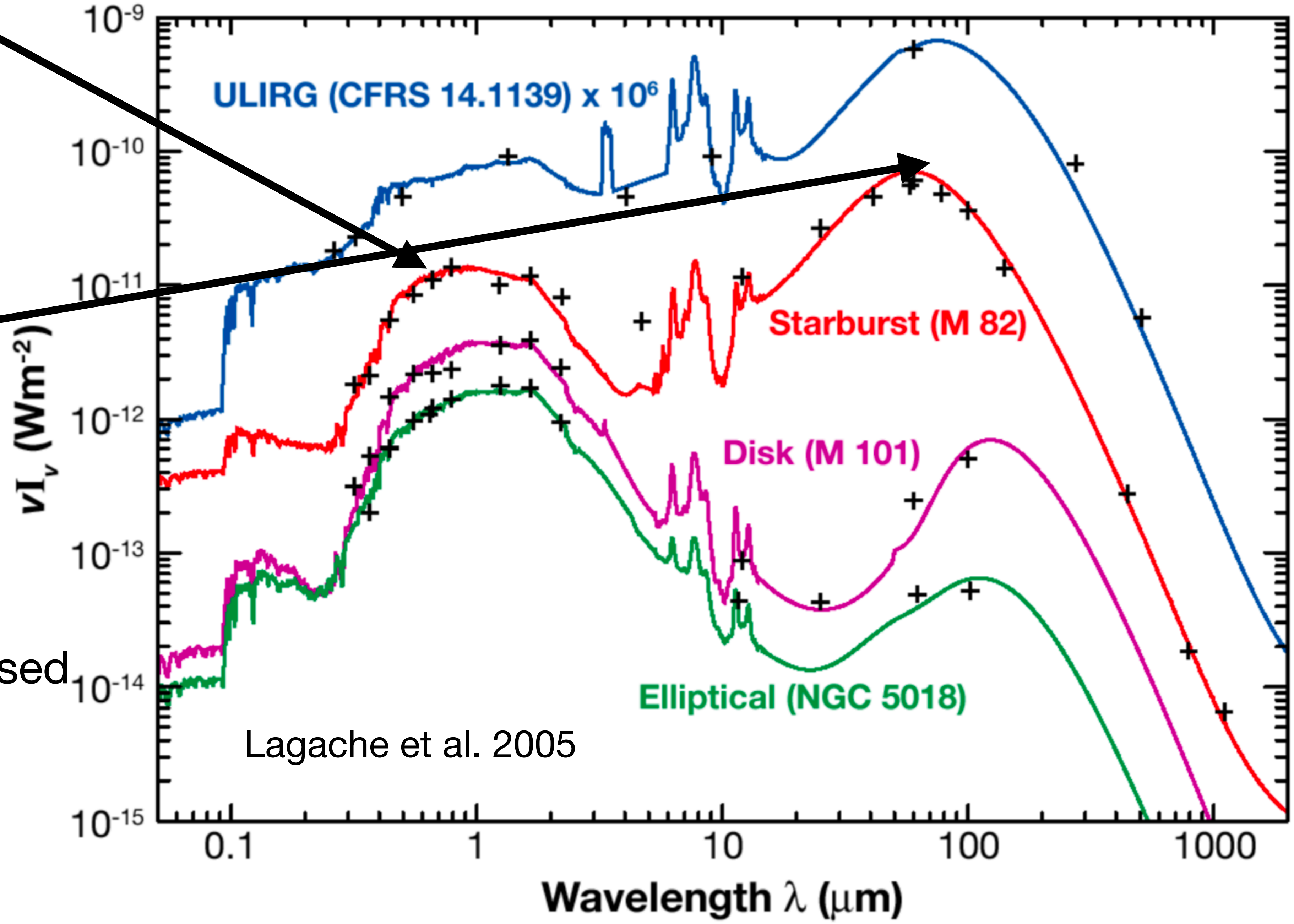
stellar emission

dust emission

$$L_{\mathrm{UV}} = \frac{1}{\mathcal{K}_{\mathrm{UV}}}\mathrm{SFR}$$

$$L_{\mathrm{IR}} = \frac{1}{\mathcal{K}_{\mathrm{IR}}}\mathrm{SFR}$$

IR is the re-processed UV photons



$$\begin{aligned}\mathrm{SFR} &= \mathcal{K}_{\mathrm{UV}} L_{\mathrm{UV}}^{\mathrm{intrinsic}} \\ &= \mathcal{K}_{\mathrm{UV}} L_{\mathrm{UV}}^{\mathrm{unobscured}} + \mathcal{K}_{\mathrm{UV}} L_{\mathrm{UV}}^{\mathrm{obscured}} \\ &= \mathcal{K}_{\mathrm{UV}} L_{\mathrm{UV}}^{\mathrm{unobscured}} + \mathcal{K}_{\mathrm{IR}} L_{\mathrm{IR}} \\ &= \mathrm{SFR}_{\mathrm{UV}} + \mathrm{SFR}_{\mathrm{IR}}\end{aligned}$$

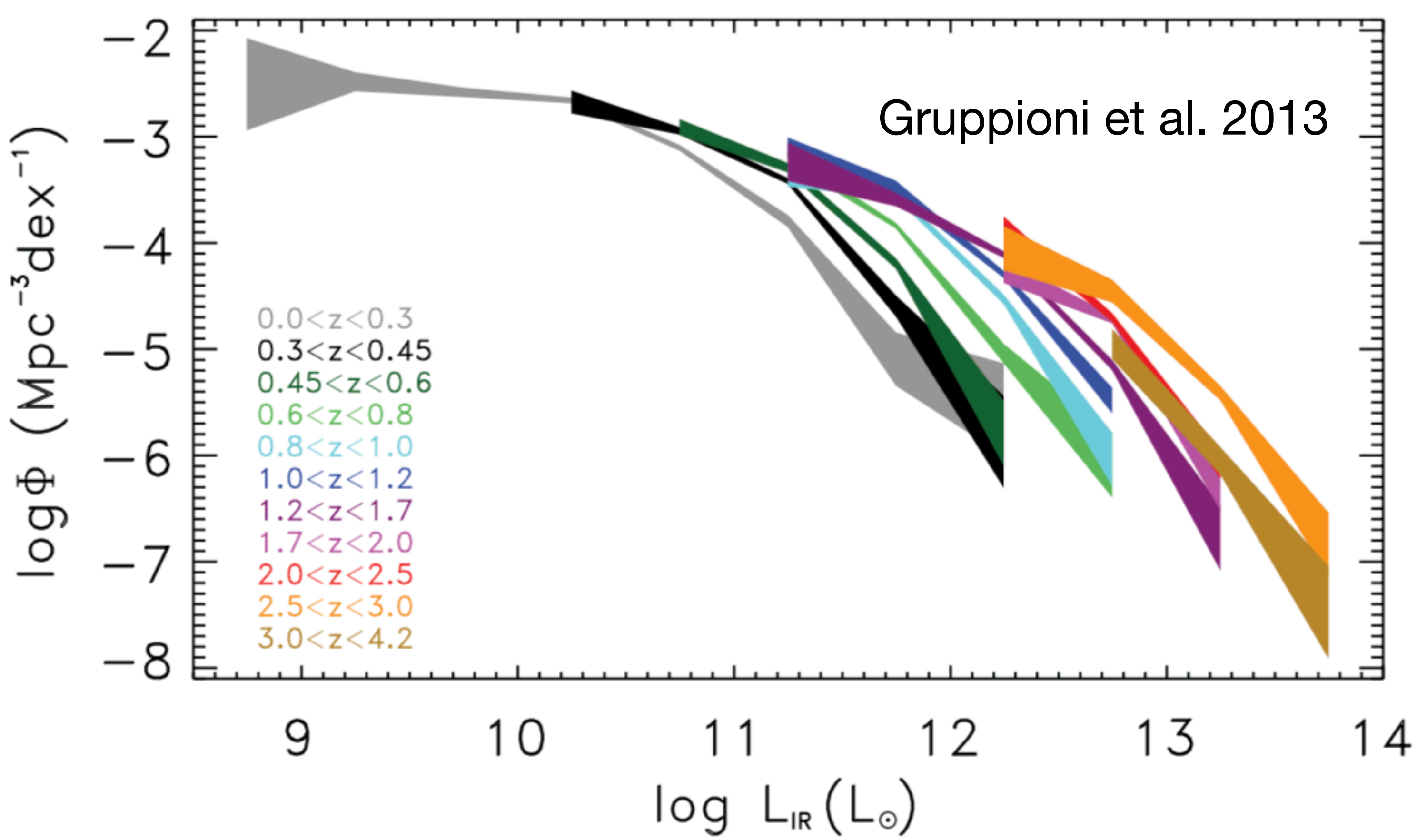
The IR luminosity function (LF) & star formation rate density (SFRD)

Redshift range	α	σ	$\log_{10}(L^*/L_\odot)$	$\log_{10}(\Phi^*/\mathrm{Mpc}^{-3}\,\mathrm{dex}^{-1})$
$0.0 < z < 0.3$	1.15 ± 0.07	0.52 ± 0.05	10.12 ± 0.16	-2.29 ± 0.06
$0.3 < z < 0.45$	1.2[a]	0.5[a]	10.41 ± 0.03	-2.31 ± 0.03
$0.45 < z < 0.6$	1.2[a]	0.5[a]	10.55 ± 0.03	-2.35 ± 0.05
$0.6 < z < 0.8$	1.2[a]	0.5[a]	10.71 ± 0.03	-2.35 ± 0.06
$0.8 < z < 1.0$	1.2[a]	0.5[a]	10.97 ± 0.04	-2.40 ± 0.05
$1.0 < z < 1.2$	1.2[a]	0.5[a]	11.13 ± 0.04	-2.43 ± 0.04
$1.2 < z < 1.7$	1.2[a]	0.5[a]	11.37 ± 0.03	-2.70 ± 0.04
$1.7 < z < 2.0$	1.2[a]	0.5[a]	11.50 ± 0.03	-3.00 ± 0.03
$2.0 < z < 2.5$	1.2[a]	0.5[a]	11.60 ± 0.03	-3.01 ± 0.11
$2.5 < z < 3.0$	1.2[a]	0.5[a]	11.92 ± 0.08	-3.27 ± 0.18
$3.0 < z < 4.2$	1.2[a]	0.5[a]	11.90 ± 0.16	-3.74 ± 0.30

[a] Fixed value.

$$\Phi_{\mathrm{IR}}(\log L_{\mathrm{IR}}, z) = \Phi_*(z)\left(\frac{L_{\mathrm{IR}}}{L_*(z)}\right)^{1-\alpha} \exp\left[-\frac{1}{2\sigma^2}\log^2\left(1+\frac{L_{\mathrm{IR}}}{L_*(z)}\right)\right]$$

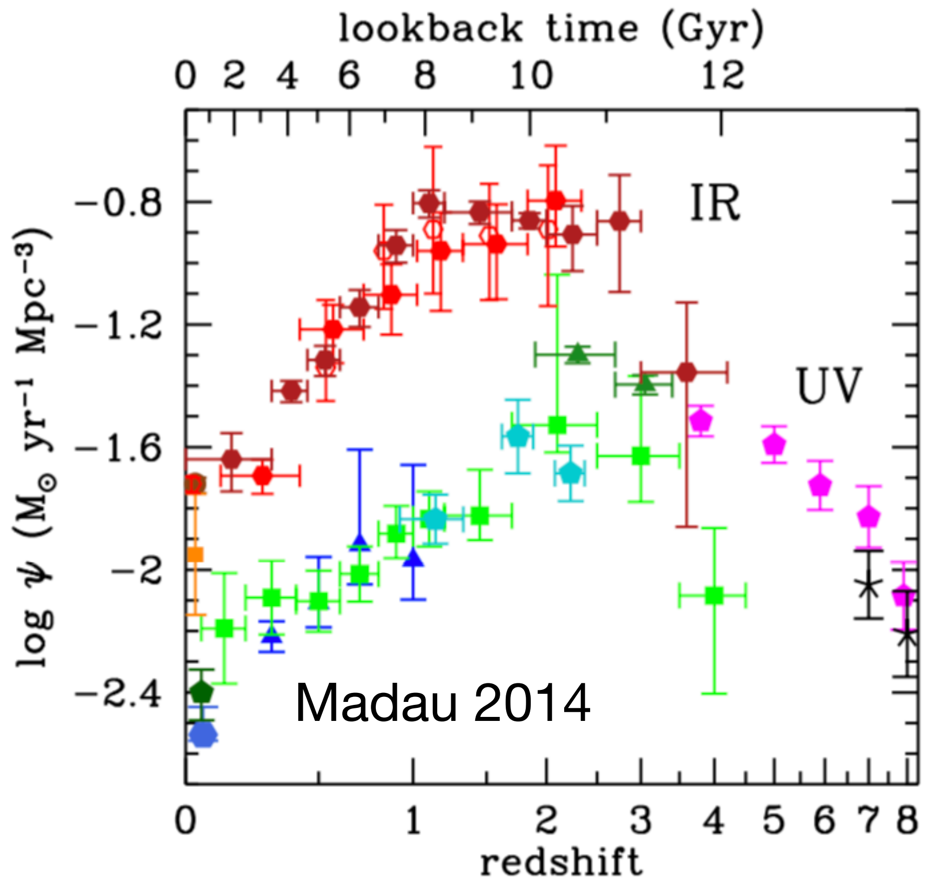
$$\mathrm{SFRD}(z) = \mathcal{K}_{\mathrm{IR}} \int L_{\mathrm{IR}} \Phi_{\mathrm{IR}}(\log L_{\mathrm{IR}}, z)\, d\log L_{\mathrm{IR}}$$



- At high-z, only brightest galaxies are detected in IR
- LF Slope is poorly constrained, however it is rather important for deriving the total IR luminosity density.

The cosmic star formation history:

$$\psi : \mathrm{SFRD} = \mathrm{SFRD_{UV}} + \mathrm{SFRD_{IR}}$$
$$= \mathcal{K}_{\mathrm{UV}}\rho_{\mathrm{UV}} + \mathcal{K}_{\mathrm{IR}}\rho_{\mathrm{IR}}$$
$$= \mathcal{K}_{\mathrm{UV}} \int L_{\mathrm{UV}} \frac{dn}{dL_{\mathrm{UV}}} dL_{\mathrm{UV}} + \mathcal{K}_{\mathrm{IR}} \int L_{\mathrm{IR}} \frac{dn}{dL_{\mathrm{IR}}} dL_{\mathrm{IR}}$$



- At z~<2-3, most SFR only seen in IR
- At z>~3, many galaxies only detected at UV

Questions:

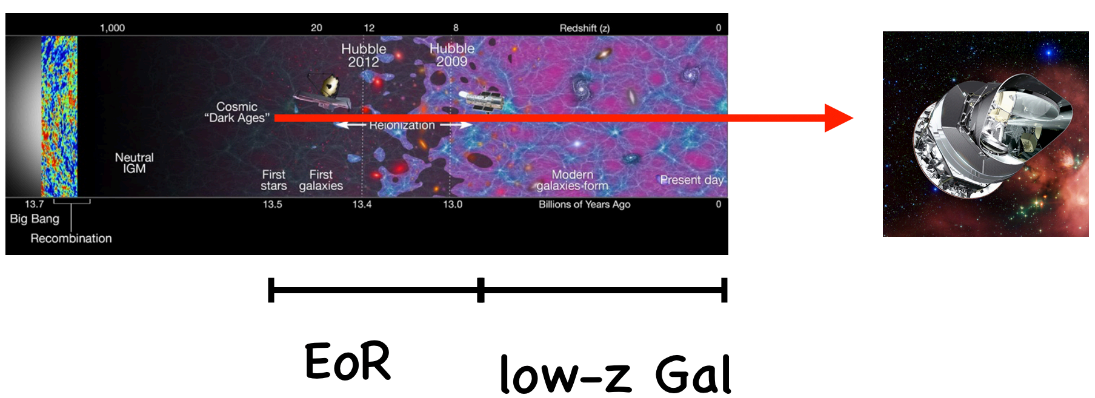
- Do we see the full star formation history?
- Do we miss some (or even most) SFR at high-z?

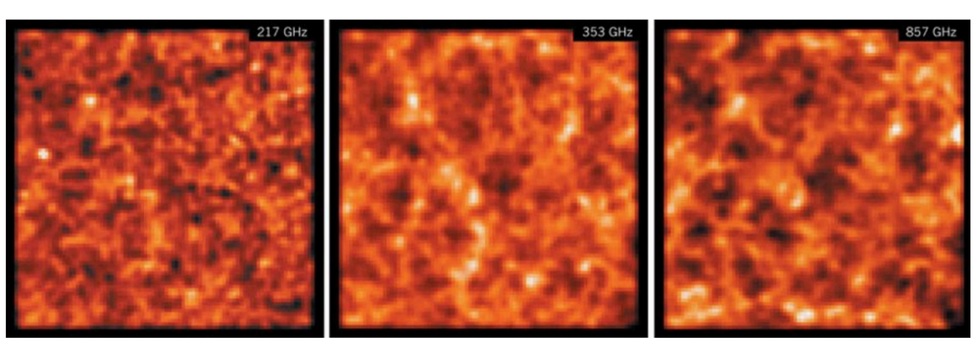
Motivation: background is the integrated flux from all galaxies at all redshifts

$$F(\nu_0) = \frac{1}{4\pi}\int \frac{c dz}{H(z)(1+z)} l(\nu)\mathrm{SFRD}(z)dz$$

$$\delta F(\nu_0) = \frac{1}{4\pi}\int \frac{c dz}{H(z)(1+z)} l(\nu)\delta\mathrm{SFRD}(z)dz$$

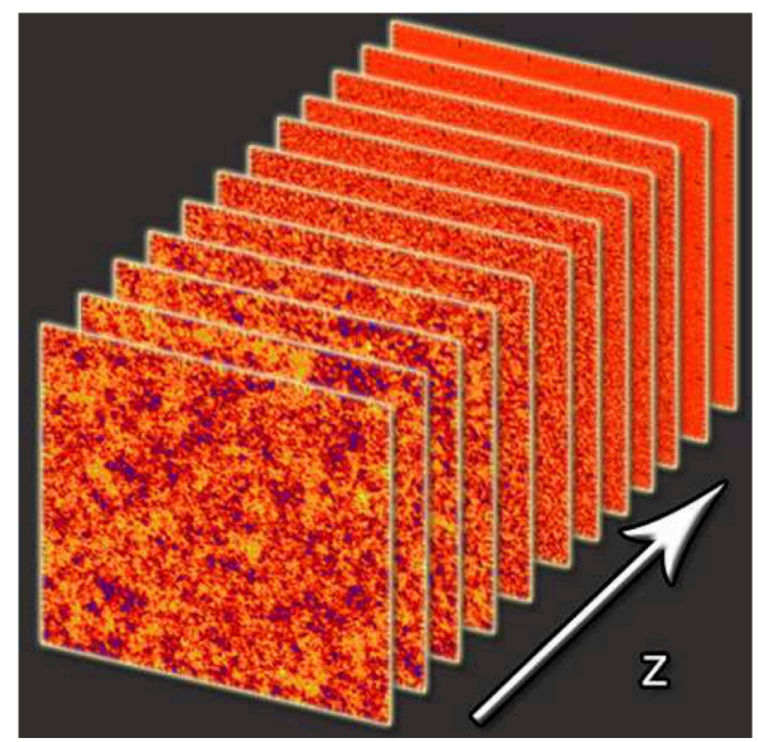
1) continuum background, projected multi-color 2D map; e.g., CIB, cosmic radio background, cosmic X-ray background …





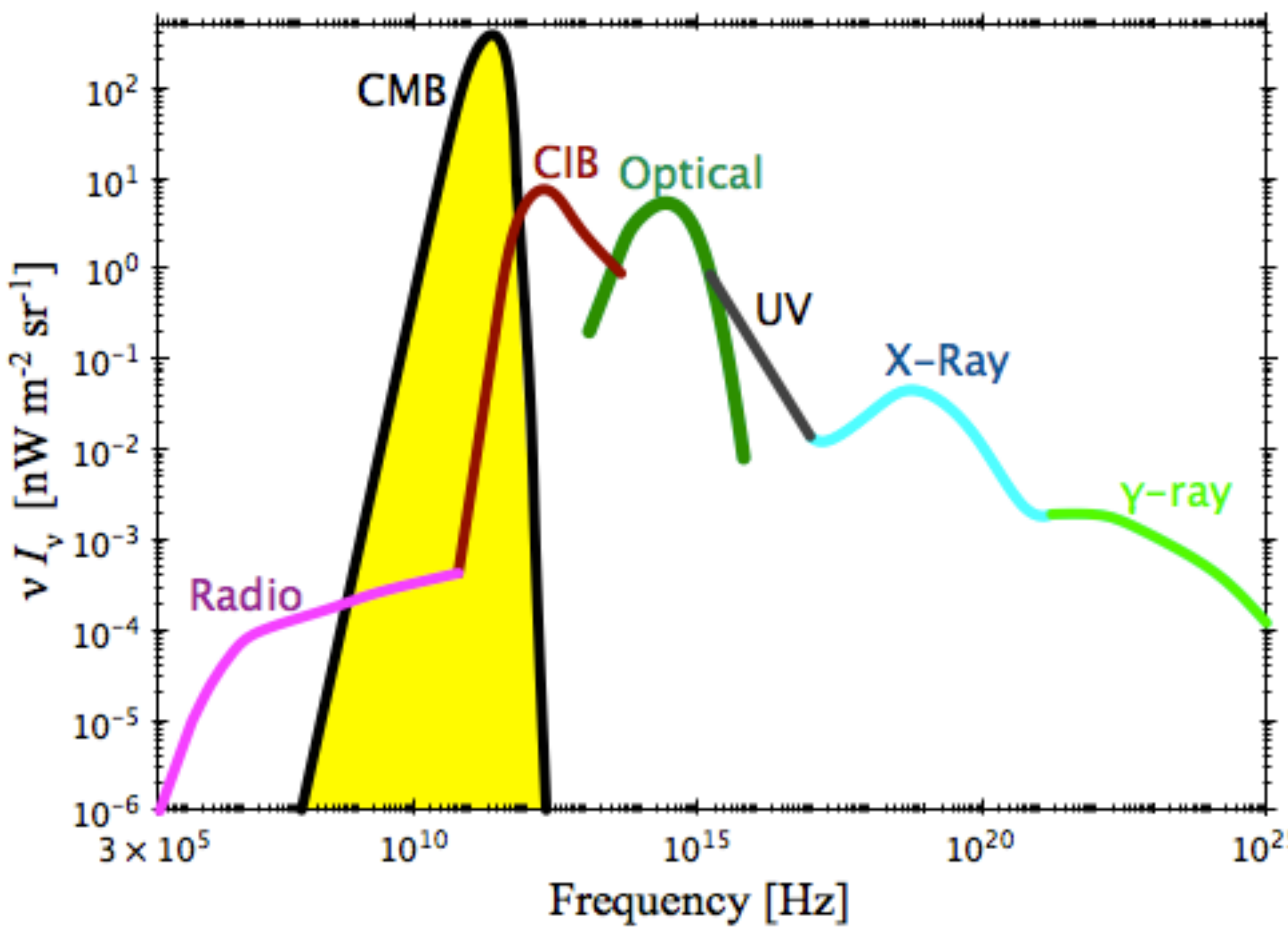
Credit: Planck

2) emission line background, intensity mapping (IM), 3D slices; e.g., 21cm



Credit: Romeo et al. 2017

The background from radio to gamma-ray

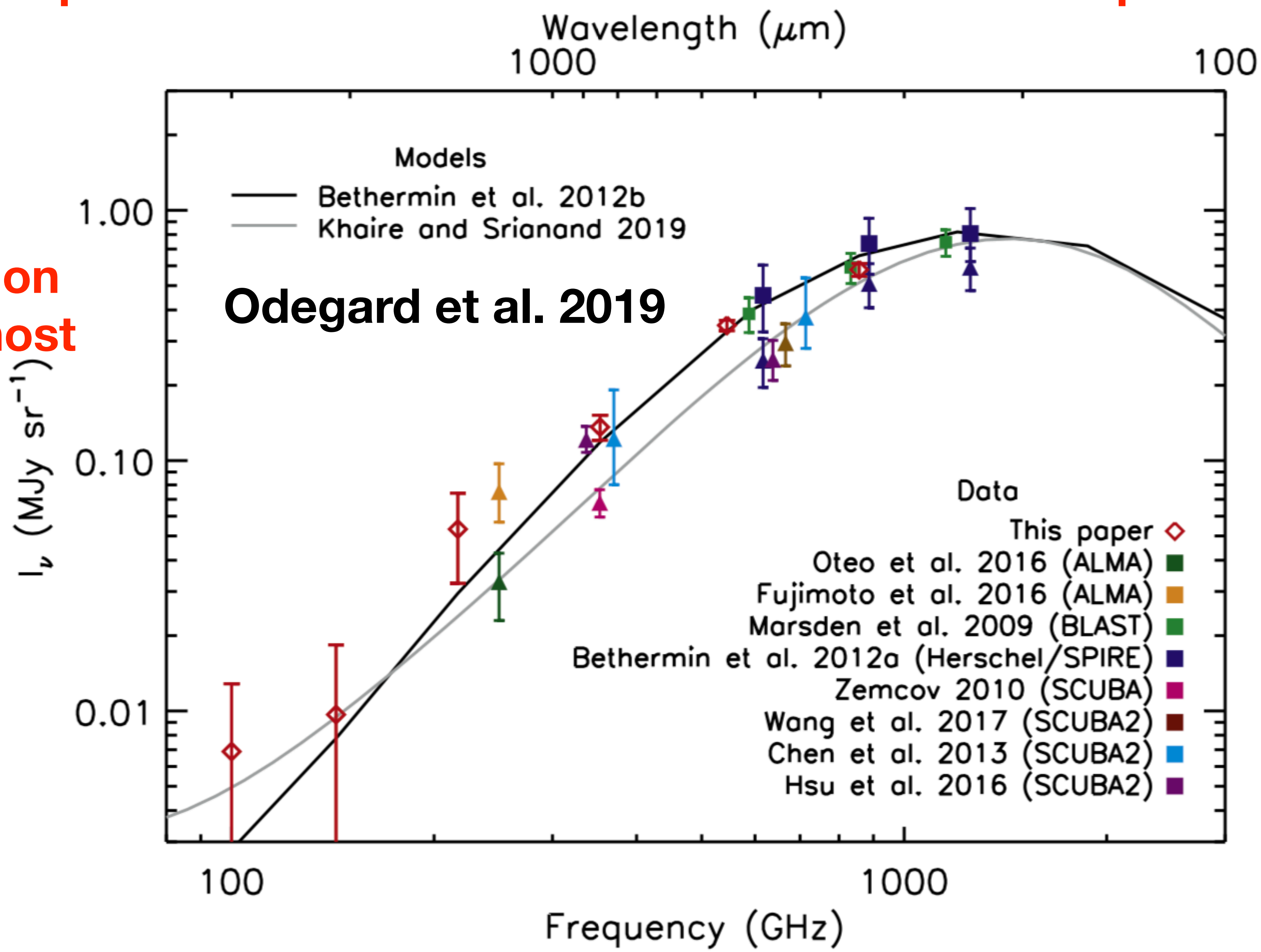


The CIB absolute flux:

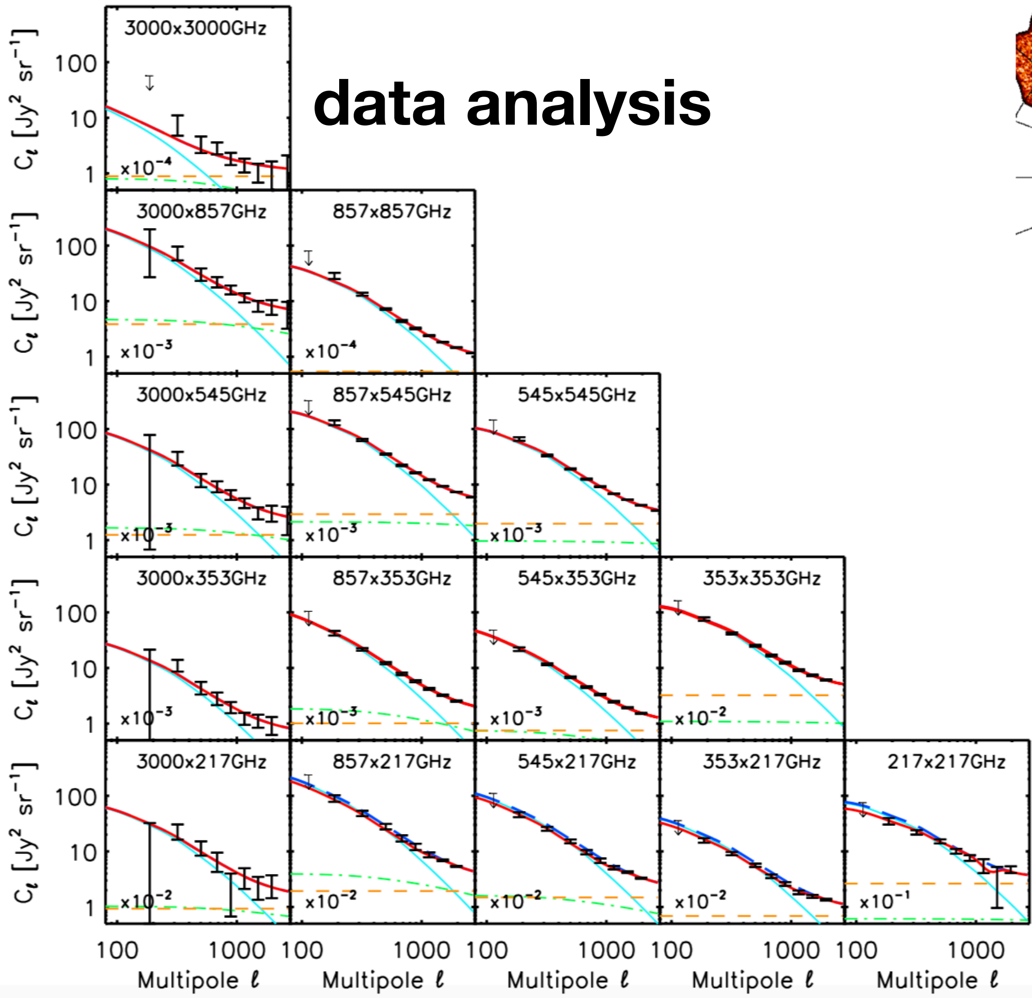
$$F(\nu_0) = \int d\chi W_\nu(z)$$
$$= \frac{1}{4\pi}\int \frac{cdz}{H(z)(1+z)} l_\nu(z)\mathrm{SFRD}(z)dz$$

mean galaxy SED: depends on interstellar radiation field & dust temperature

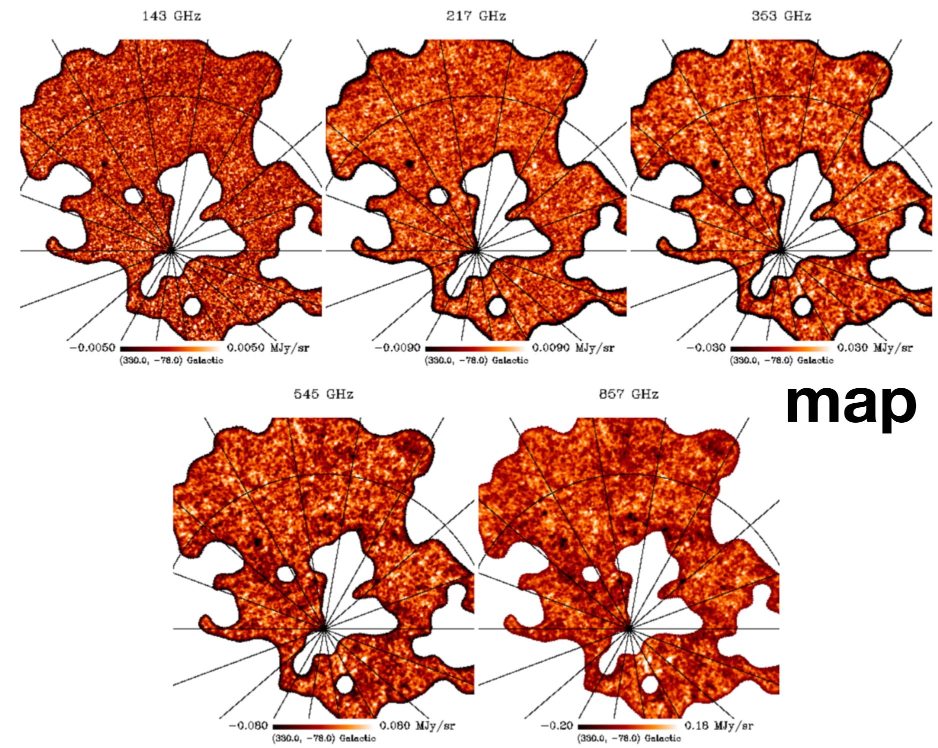
Absolute flux:
lack of the information between radiation-host halo relation



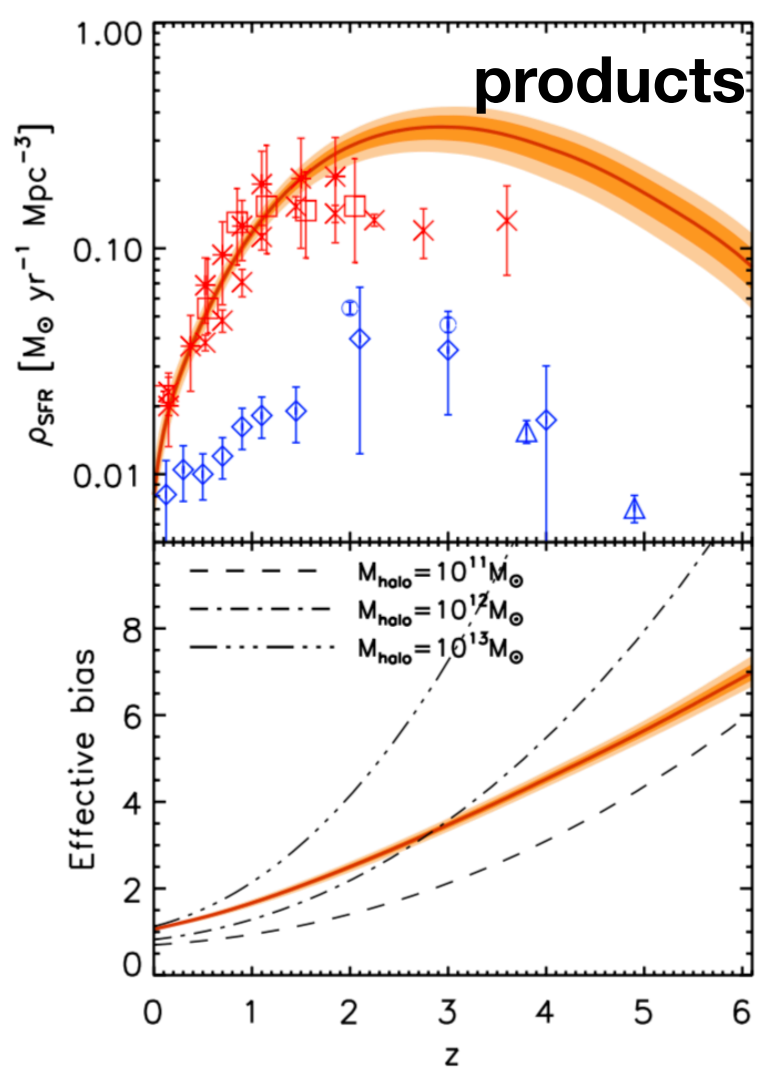
The CIB fluctuations has the information of host halos: HOD+IR luminosity density



data analysis



map



products

theory

$$C_l^{\nu,\nu} = \int d\chi \left(\frac{1}{\chi}\right)^2 W_\nu^2(z) P_{\rm gg}(k=l/\chi, z)$$

$$W_\nu(z) = a j_\nu(z) = a\frac{1}{4\pi} l_\nu(z)\rho_{\rm SFR}(z)$$

$$P_{\rm gg}(k,z) = P_{\rm 1h}(k,z) + P_{\rm 2h}(k,z)$$

$$P_{\rm 1h}(k,z) = \int dM \frac{dn}{dM} \frac{2N_{\rm sat}N_{\rm cen}u(k|M,z) + N_{\rm cen}^2 u^2(k|M,z)}{n_{\rm gal}^2}$$

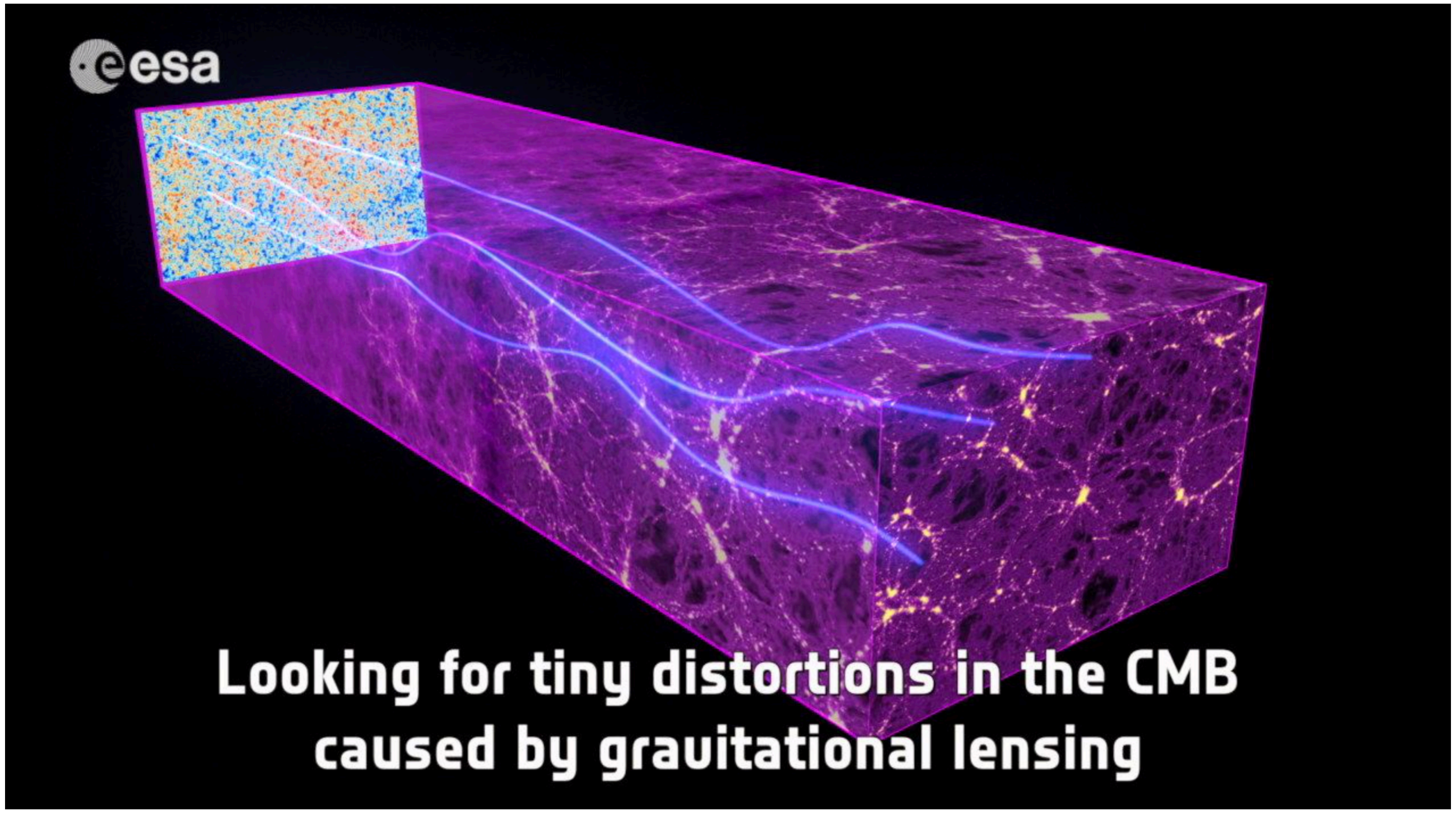
$$P_{\rm 2h}(k,z) = \left[\int dM \frac{dn}{dM} b(M,z) \frac{N_{\rm cen}+N_{\rm sat}}{n_{\rm gas}} u(k|M,z)\right]^2 \times P(k,z)$$

$$N_{\rm cen}(M) = \frac{1}{2}\left[1 + {\rm erf}\left(\frac{\log M - \log M_{\rm min}^{\rm HOD}}{\sigma_{\log M}}\right)\right]$$

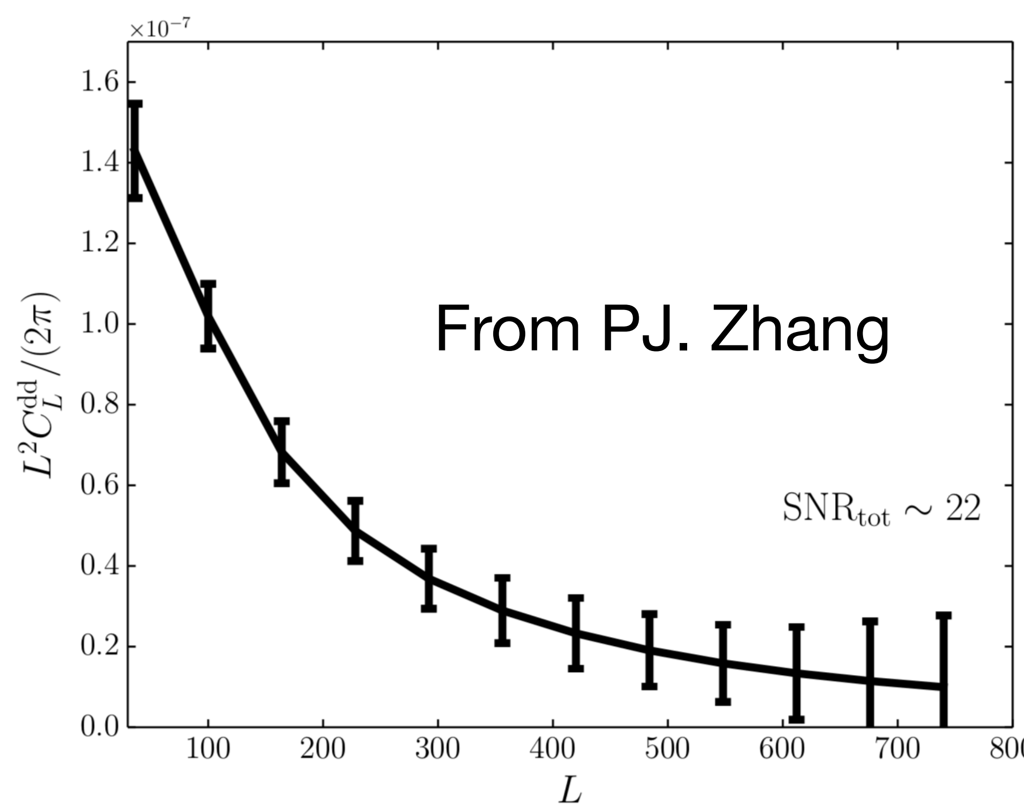
$$N_{\rm sat}(M) = \frac{1}{2}\left[1 + {\rm erf}\left(\frac{\log M - \log 2M_{\rm min}^{\rm HOD}}{\sigma_{\log M}}\right)\right]\left(\frac{M}{M_{\rm sat}^{\rm HOD}}\right)^\alpha$$

Planck 2013 XXX

more direct radiation-matter connection: the lensing-CIB correlation



See Ji's talk



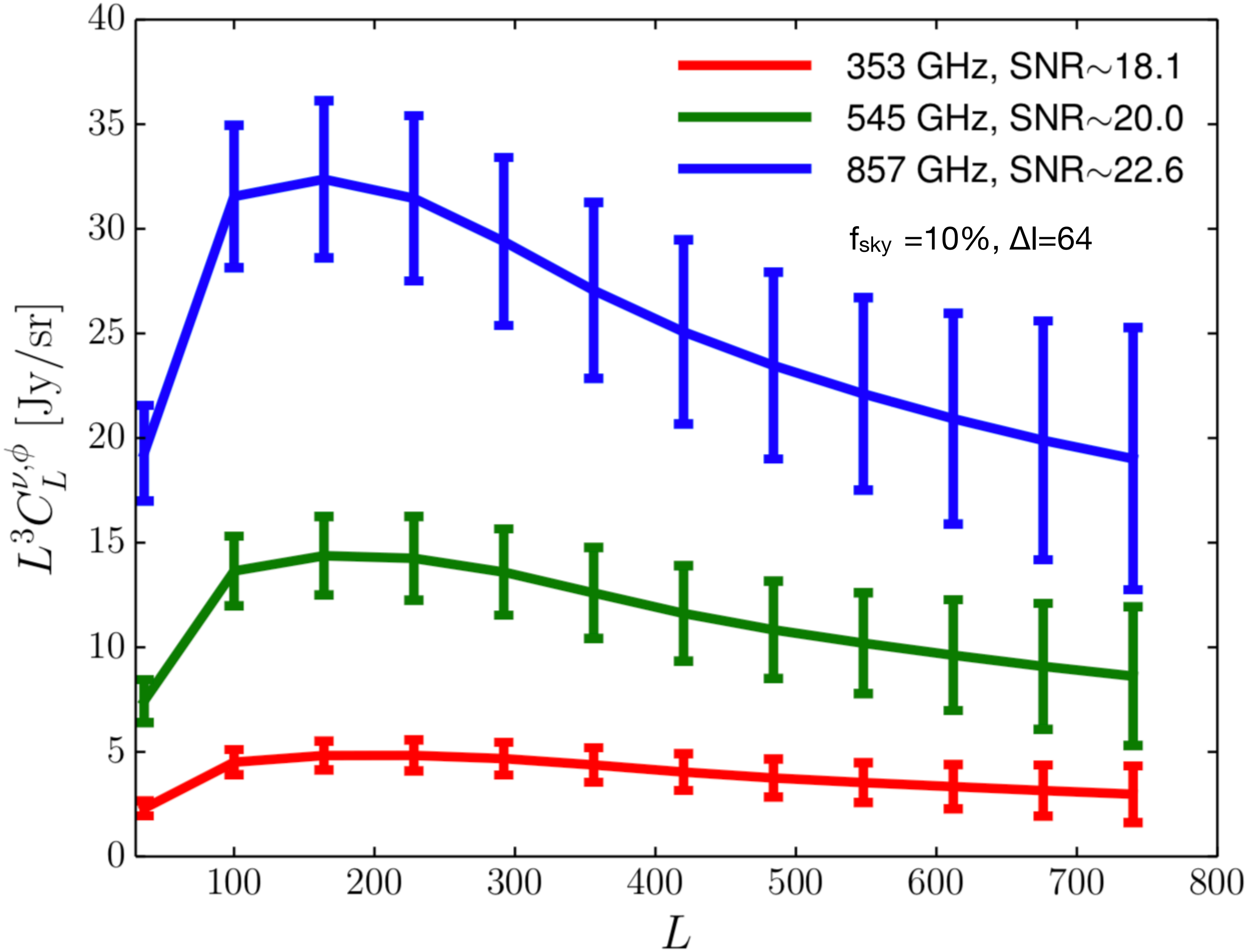
The cross-correlation between the gravitational lensing and the CIB provides the direct connection between IR radiation and matter

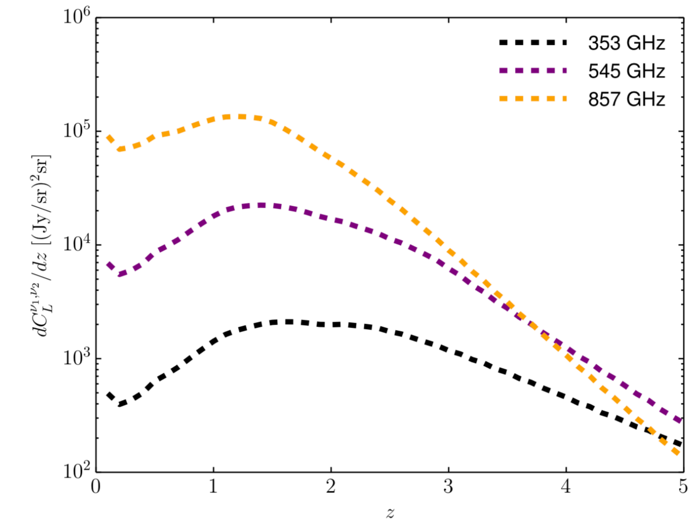
$$C_l^{\nu,\phi} = \int d\chi \left(\frac{1}{\chi}\right)^2 W_\nu W_\phi P_{\rm gm}(k = l/\chi, z)$$

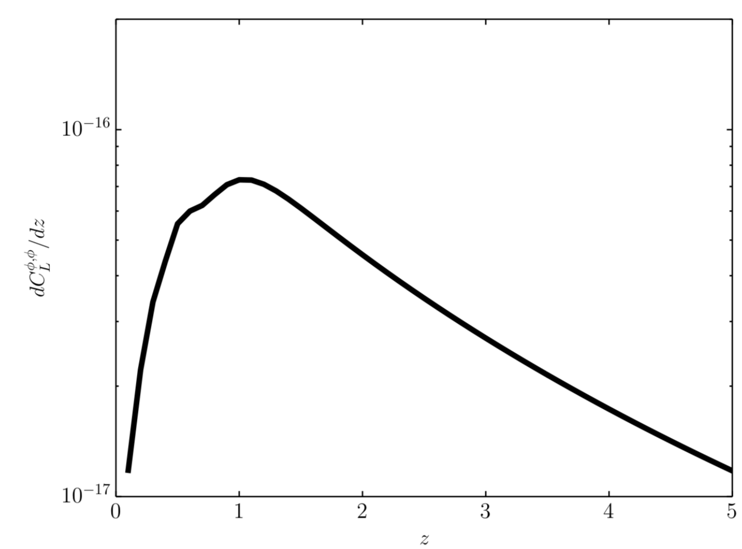
$$(\Delta C_l^{\nu,\phi})^2 = \frac{(C_l^{\nu,\phi})^2 + (C_l^{\nu,\nu} + N_l^{\nu,\nu})(C_l^{\phi,\phi} + N_l^{\phi,\phi})}{(2l+1) f_{\rm sky} \Delta l}$$

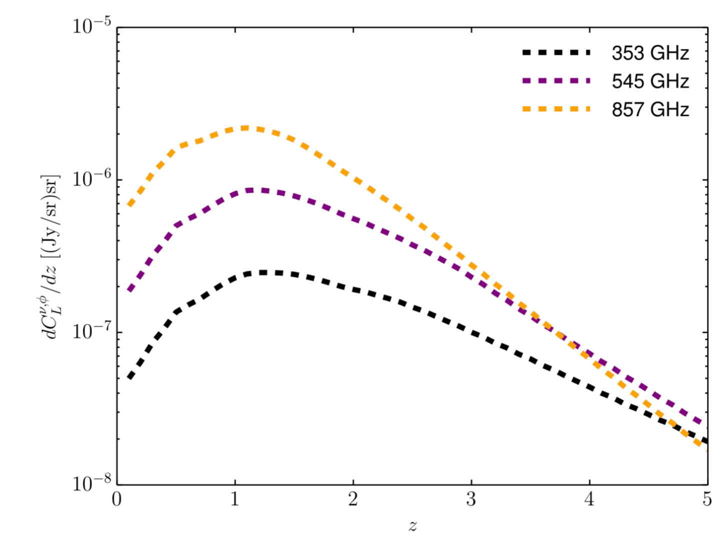
PJ. Zhang

Lenz et al. 2019

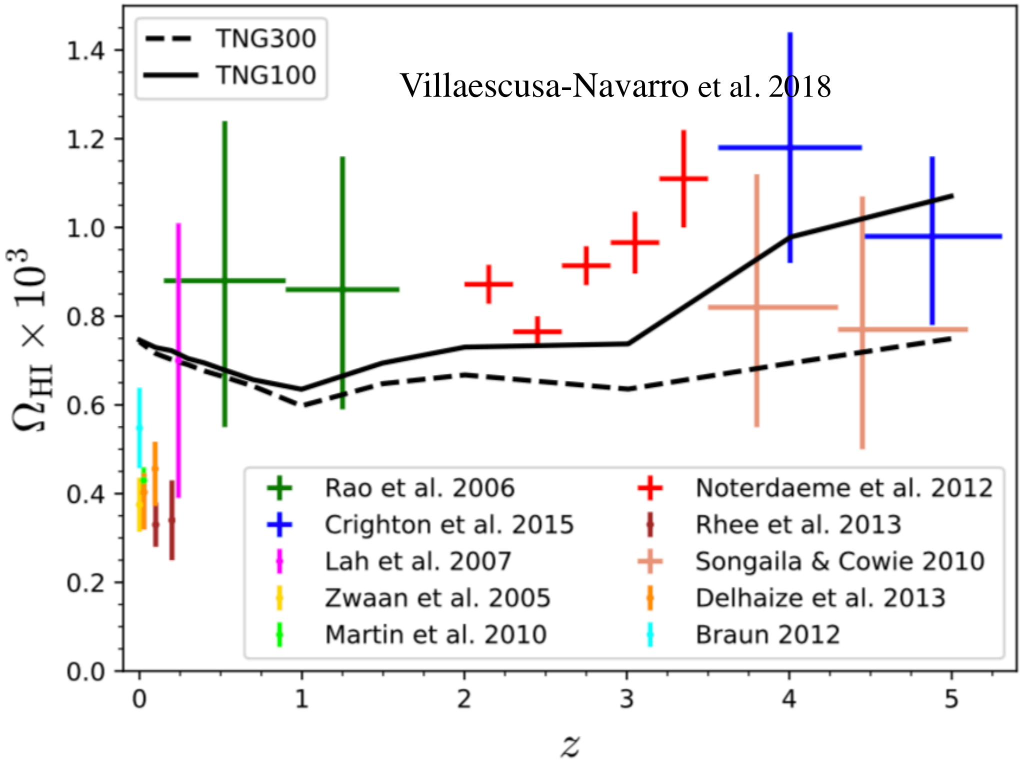


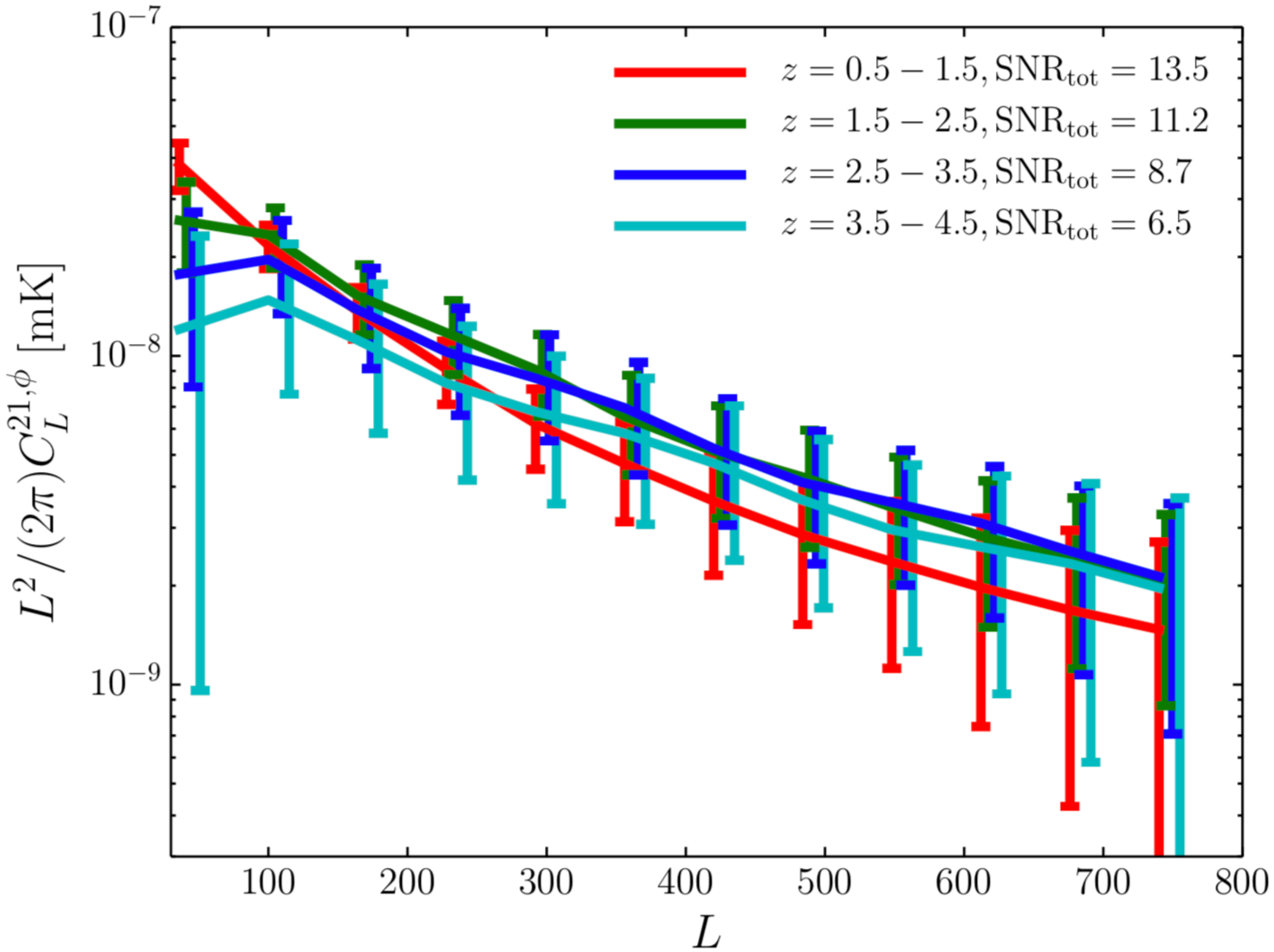


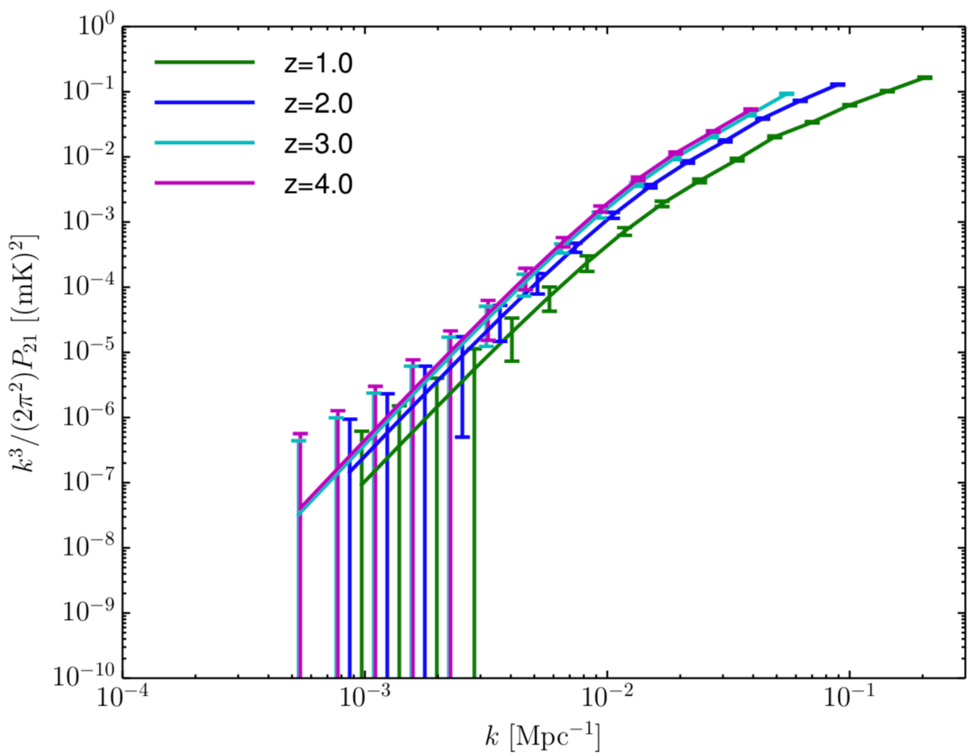




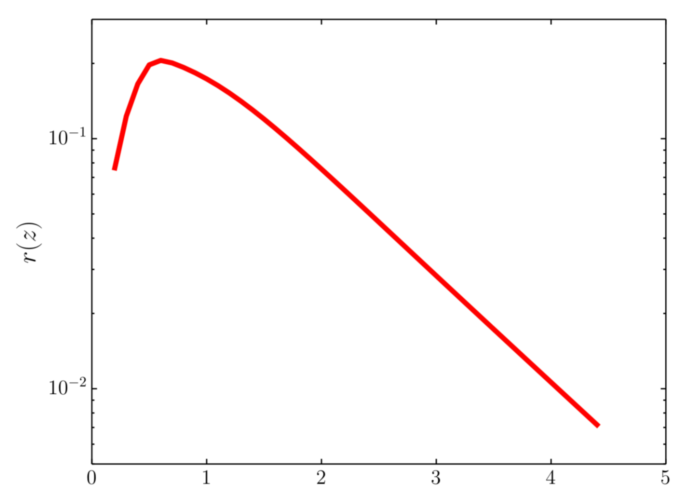
The cross-correlation between gravitational lensing and 21cm intensity mapping







$$\frac{dC_L^{\phi,\phi}}{C_L^{\phi,\phi} dz} \sim r(z) = \frac{(C_L^{21,\phi}(z))^2}{C_L^{\phi,\phi} \times C_L^{21,21}(z) \Delta z}$$



$T_{\rm sys}$	D	$f_{\rm fill}$	$t_{\rm obs}$	$f_{\rm sky}$	$N_{\rm feed}$	W_0	$\delta\nu_0$
50 K	100 m	0.1	5000 hr	0.1	100	100 MHz	1 MHz

ISM line candidates:

$$\alpha_J L_{\mathrm{CO}} + \beta_J = L_{\mathrm{IR}}$$

Greve et al. 2014

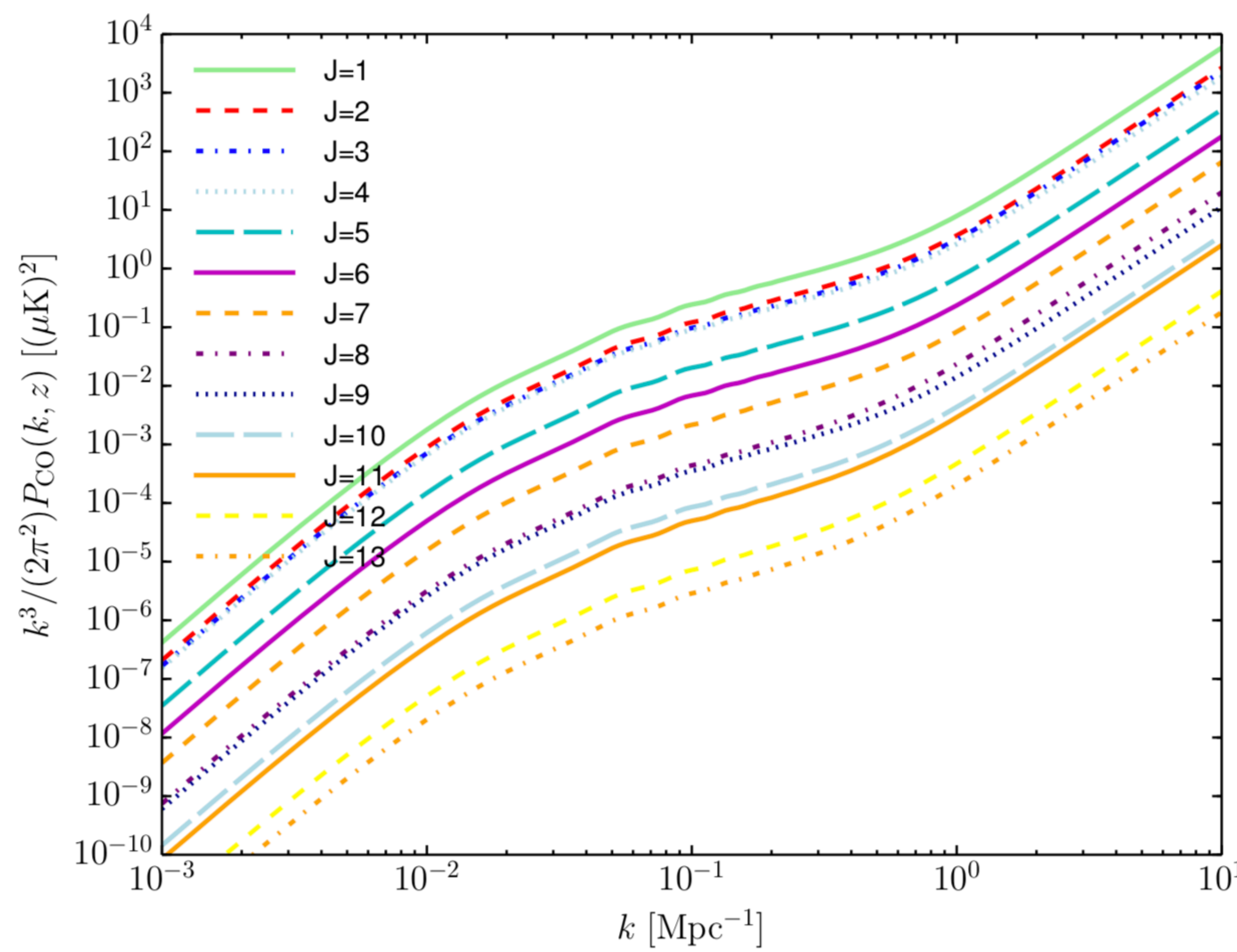
Observed IR LF
Gruppioni et al. 2013

Species	Emission Wavelength[μm]	R[$L_\odot/(M_\odot/\mathrm{yr})$]
CII	158	6.0×10^6
OI	145	3.3×10^5
NII	122	7.9×10^5
OIII	88	2.3×10^6
OI	63	3.8×10^6
NIII	57	2.4×10^6
OIII	52	3.0×10^6
^{12}CO(1-0)	2610	3.7×10^3
^{12}CO(2-1)	1300	2.8×10^4
^{12}CO(3-2)	866	7.0×10^4
^{12}CO(4-3)	651	9.7×10^4
^{12}CO(5-4)	521	9.6×10^4
^{12}CO(6-5)	434	9.5×10^4
^{12}CO(7-6)	372	8.9×10^4
^{12}CO(8-7)	325	7.7×10^4
^{12}CO(9-8)	289	6.9×10^4
^{12}CO(10-9)	260	5.3×10^4
^{12}CO(11-10)	237	3.8×10^4
^{12}CO(12-11)	217	2.6×10^4
^{12}CO(13-12)	200	1.4×10^4
CI	610	1.4×10^4
CI	371	4.8×10^4
NII	205	2.5×10^5
^{13}CO(5-4)	544	3900
^{13}CO(7-6)	389	3200
^{13}CO(8-7)	340	2700
HCN(6-5)	564	2100

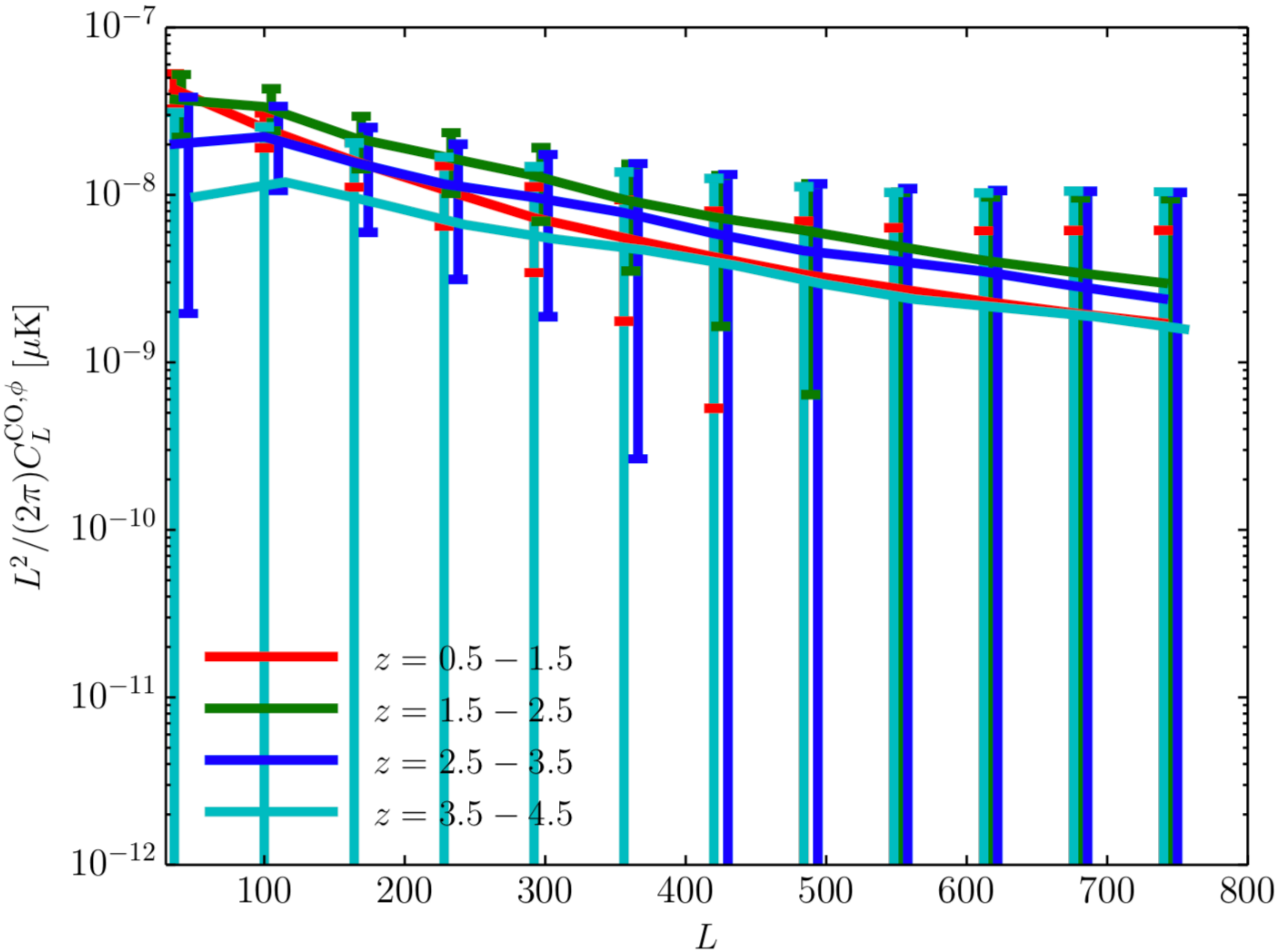
$$\nu_{\mathrm{CO}}(J) = 115J\ \mathrm{GHz}$$

Visbal et al. 2011

Power spectrum of z~2 CO IM with different J ladders



Lensing & CO IM cross-correlation



T_{sys}	D	t_{obs}	f_{sky}	$N_{\mathrm{bolometers}}$	Δz	$\delta\nu_0$
35 K	5 m	5000 hr	0.1	4000	1.0	1 GHz

Summary:

- The CIB is a powerful tool for recovering the full cosmic star formation history
- Cross-correlation between CIB & gravitational lensing provides the direct connection betwee radiation and matter
- IM & gravitational lensing cross-correlation is helpful for identifying the z-dependent contribution of lensing

Thanks!