The **S**imulated **I**nfrared **D**usty **E**xtragalactic **S**ky (SIDES): application to intensity mapping experiments and galaxy surveys

Athanasia Gkogkou

athanasia.gkogkou@lam.fr

M. Béthermin, **G. Lagache**, E. Jullo, M. Van Cuyck, S. de la Torre, and the **CONCERTO** collaboration

Laboratoire d'Astrophysique de Marseille (LAM)

"From galaxies to cosmology with deep spectroscopic surveys" @ Marseille

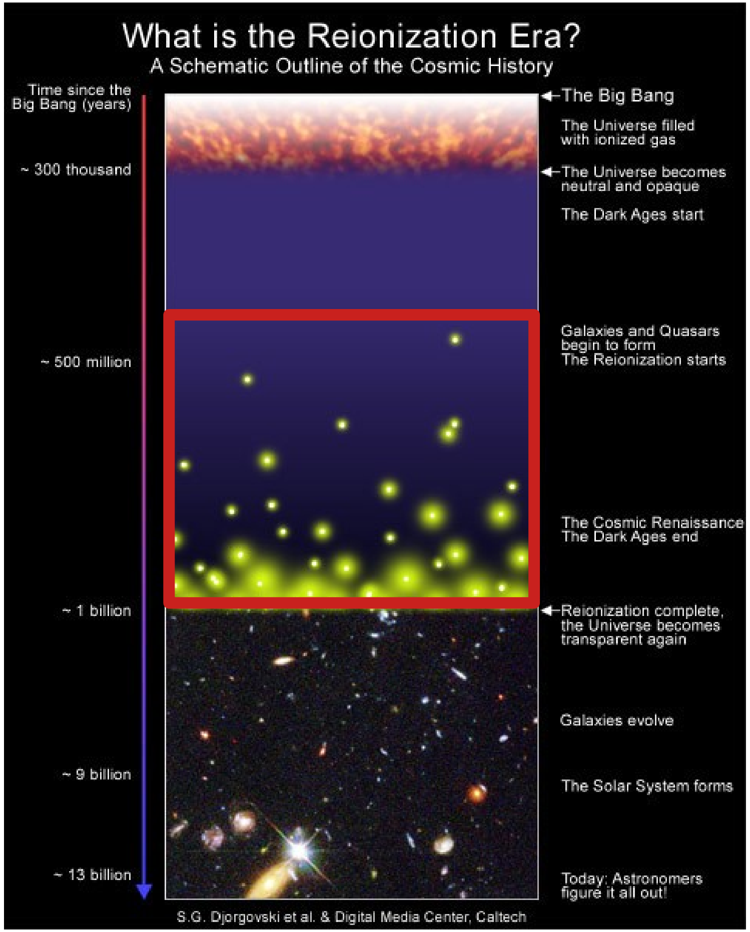
Why Line Intensity Mapping ?

- EoR: previously neutral intergalactic medium ionized by the emergence of the first luminous sources

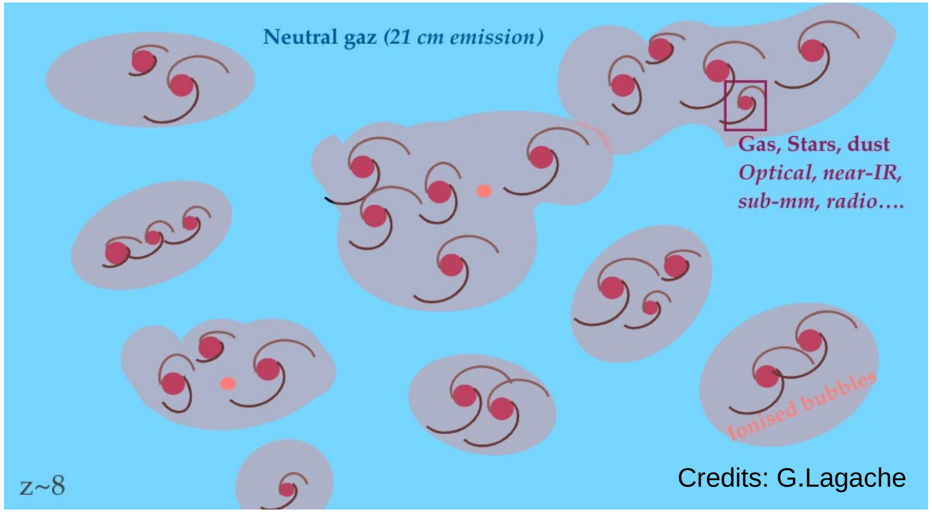
- Indications it happened around **$6 < z < 10$**

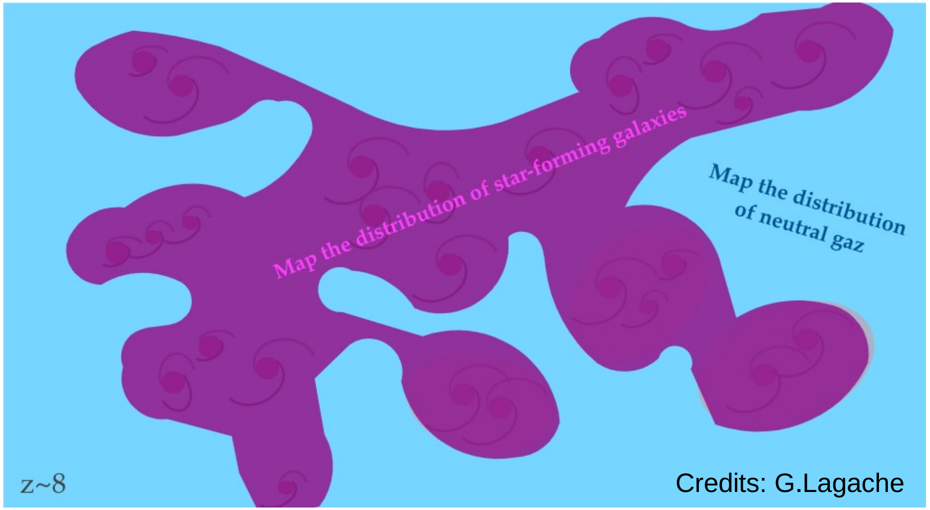
- Understand the role of early galaxies in reionization
  More accurate census of galaxies as far back in time as possible

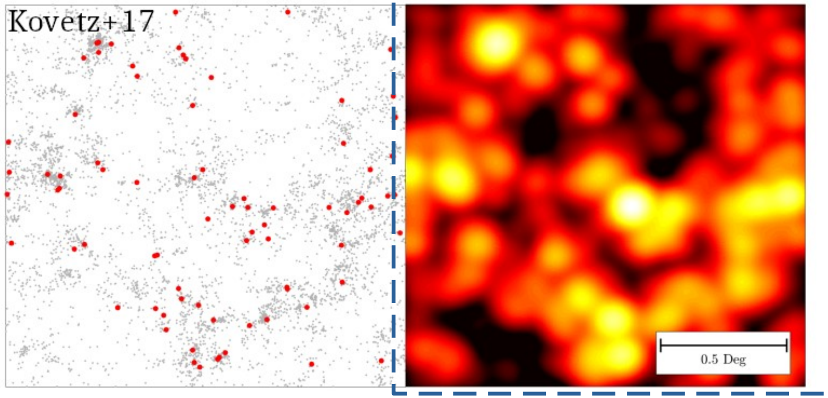
- Current/future surveys (e.g., HST, JWST, Euclid) detect the bright galaxy populations



Line Intensity Mapping (LIM)



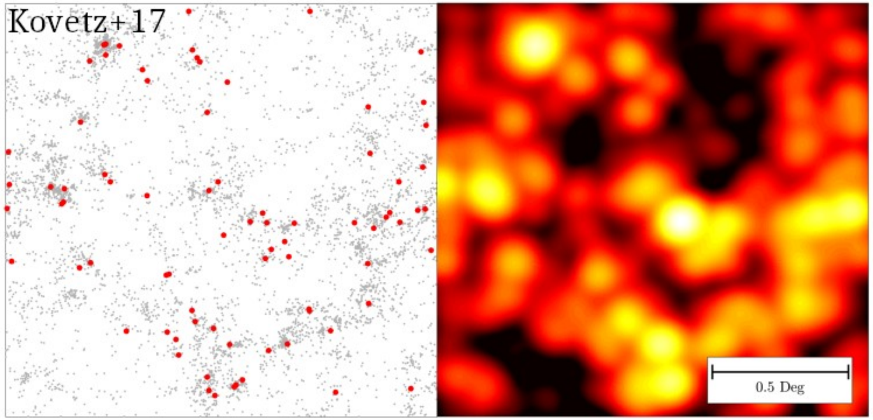


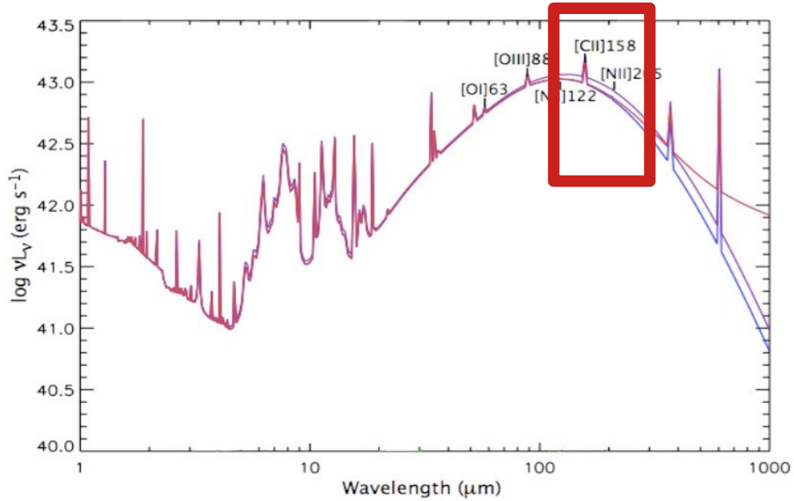


Line intensity mapping

Line Intensity Mapping (LIM)

- [CII] line intensity mapping
  - One of the brightest emission lines
  - Redshifted to sub-mm/mm atmospheric windows (for 4.5<z<9)
  - Extinction-free star formation tracer
  - Valuable dusty star formation tracer at high-z
- **CONCERTO**
  - In the 12m APEX telescope in Chile
  - measures the 3-D fluctuations of [CII] line at redshifts z > 5.2





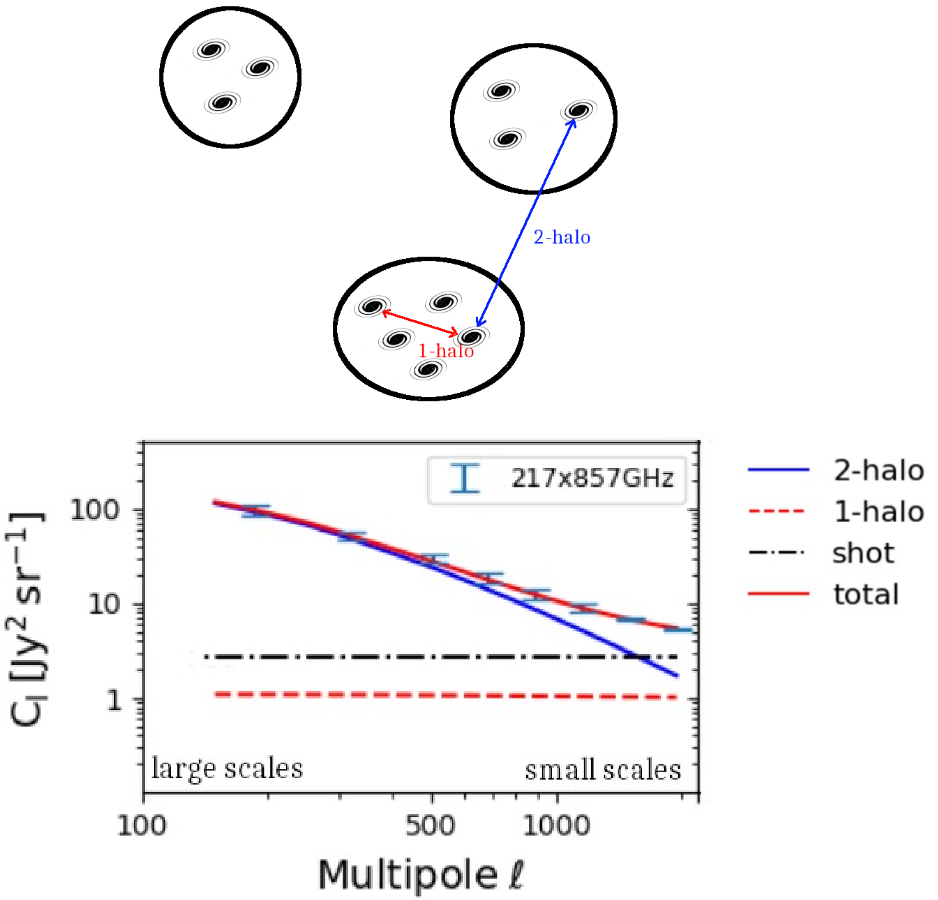
Line Intensity Mapping (LIM) product: Power spectrum

Power spectrum: measuring how much the anisotropies at different scales (different multipoles) contribute to the total line emission fluctuations

One halo term: correlated anisotropies inside the same main halo

Two halo term: correlated anisotropies in different halos

Poisson (shot noise) term: non correlated all scales anisotropies



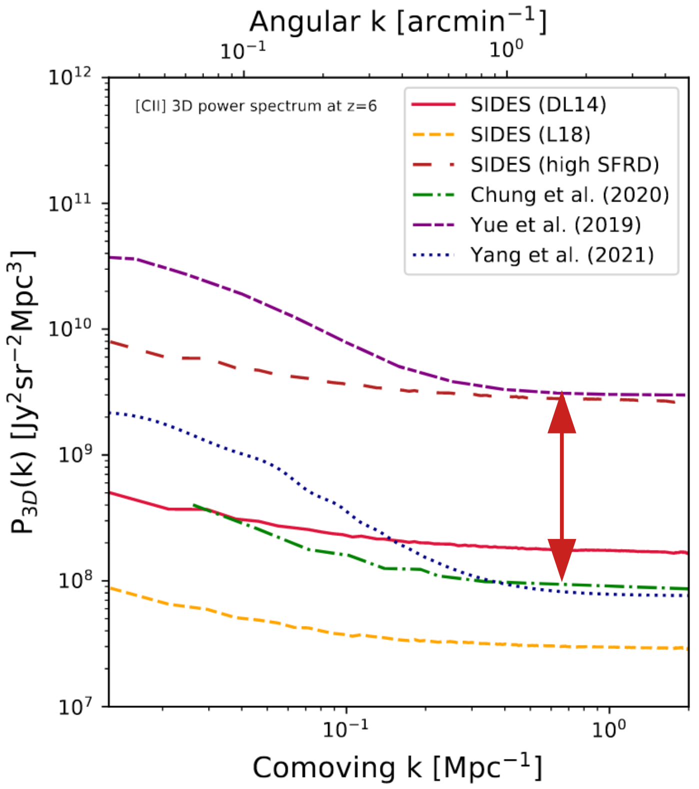
LIM simulation: SIDES

The existing models vary a lot (factor of **>10**)

Need for new realistic (LIM) simulation

Simulated **I**nfrared **D**usty **E**xtragalactic **S**ky (**SIDES**)
a simulation of the extragalactic sky in the FIR and mm including clustering, based on dark-matter simulations and empirical prescriptions

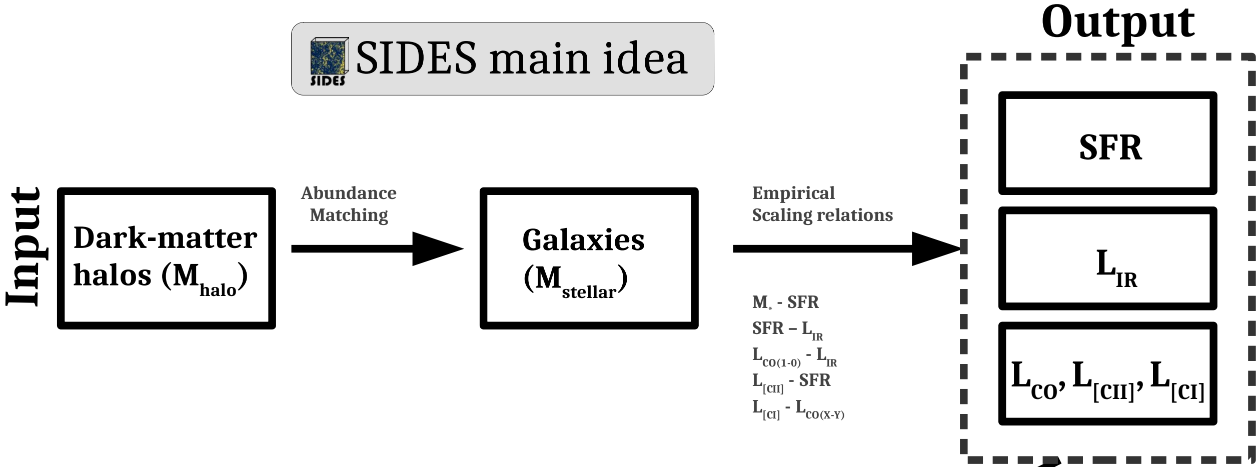
Béthermin+17, Béthermin, Gkogkou+, submitted



Béthermin, Gkogkou+, submitted

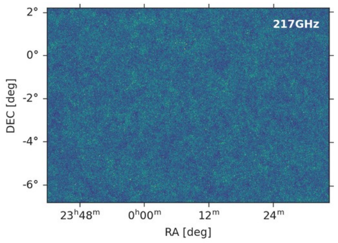
LIM simulation: SIDES

SIDES main idea



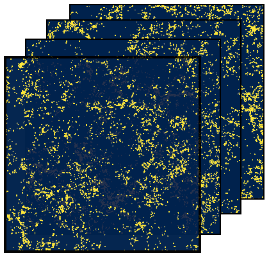
#	redshift	ra	dec	Mhalo	Mstar	SFR	LIR	LCII_Lagache
0	0.0125433	-3.59673	-5.91746	16350999552.0	32436525.4989	0.01149	114908696.272	49378.09724051
1	0.0168886	-3.63059	-6.73737	24526000128.0	187761568.735	0.01724	172433598.012	92158.67855716
2	0.0168895	-4.00797	-6.18176	105300000768.0	770238704.830	0.0	0.0	0.0
3	0.0168990	-3.69993	-6.76695	249839992832.0	16438527717.6	1.64845	16484542655.1	9400682.957055
4	0.0169214	-4.38760	-6.47405	6867400192.0	19094648.2121	0.00102	10272211.8753	536.5241647538
...	...	...	...	...	...	...	...	...
54,821,709	7.0387912	-4.44864	3.68041	8175499776.0	2650958.32680	0.02752	275297436.917	113543.3676063
54,821,710	7.0387940	-4.00128	3.27867	10138000384.0	2972850.04422	0.01671	167181378.974	49548.54983316
54,821,711	7.0387940	-4.17367	3.33224	37606998016.0	20245450.9266	0.04213	421384253.864	301306.6359685
54,821,712	7.0387940	-4.15751	4.09144	16677999616.0	8632126.09224	0.17103	1710330612.12	994789.2369777
54,821,713	7.0388024	-4.45143	3.67178	17659000832.0	5984521.24977	0.06946	694656711.860	190262.3586077

map maker + filter



Continuum emission
Planck 217GHz

cube maker

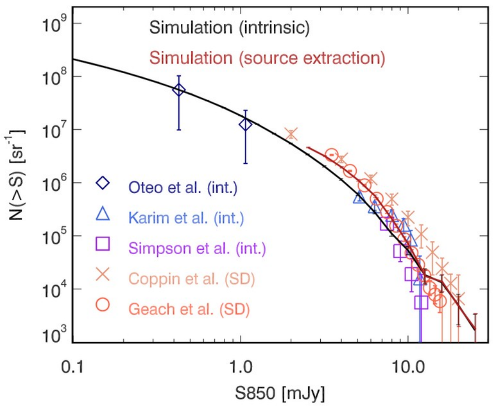


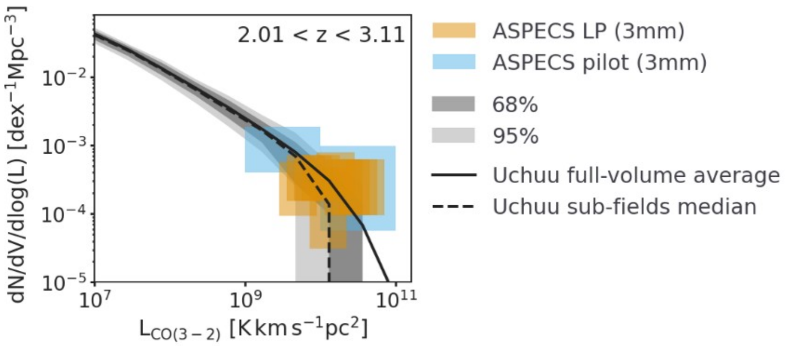
[CII] emission

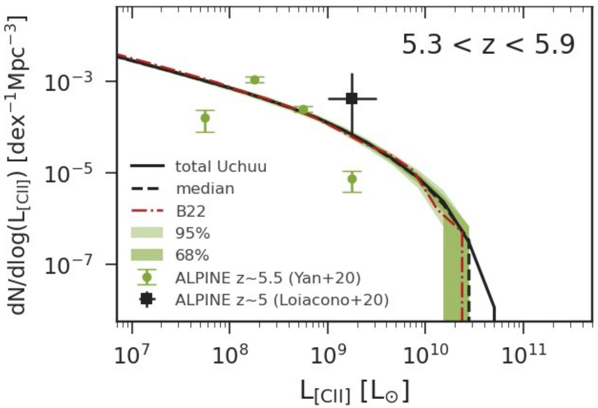
Béthermin+17
Béthermin, Gkogkou, + submitted

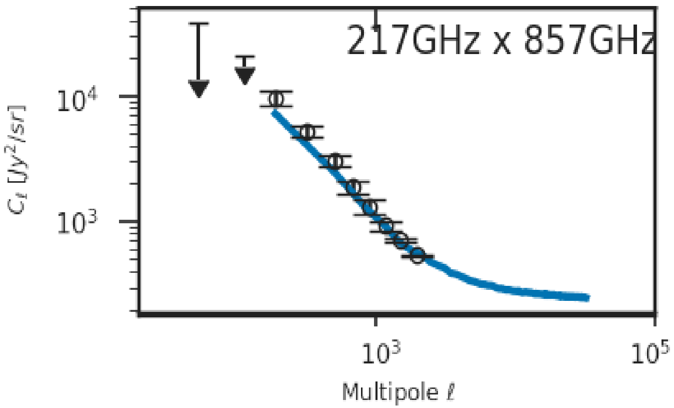
LIM simulation: SIDES

SIDES validation: number counts – luminosity functions - CIB fluctuations







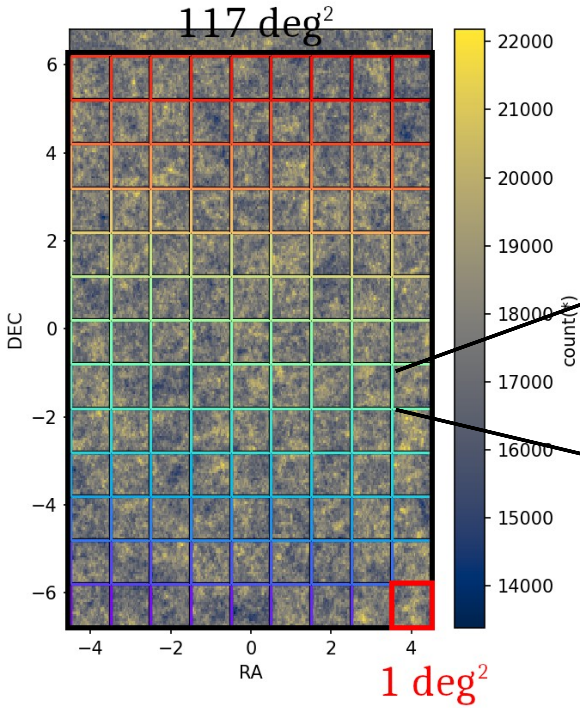


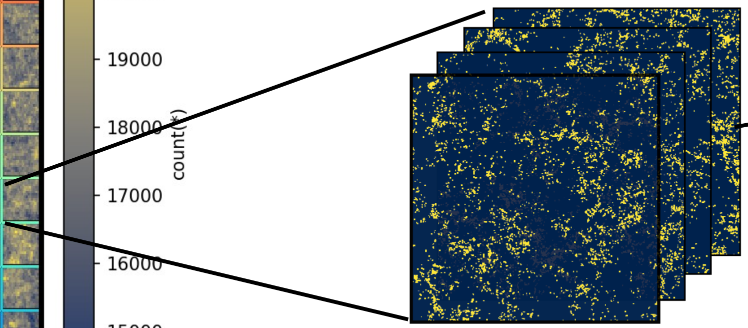
Béthermin+17

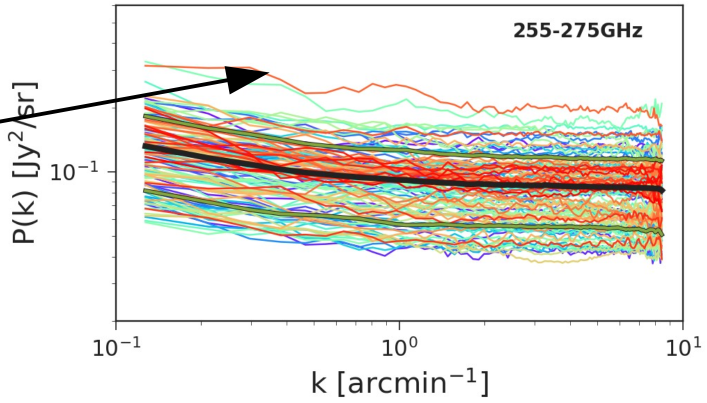
Gkogkou+, to be sub.

Application to Line Intensity Mapping

Uchuu: big cosmological simulation → **SIDES**: Generate simulated cube each slice → different frequency → 2D power spectrum computation for each cube slice





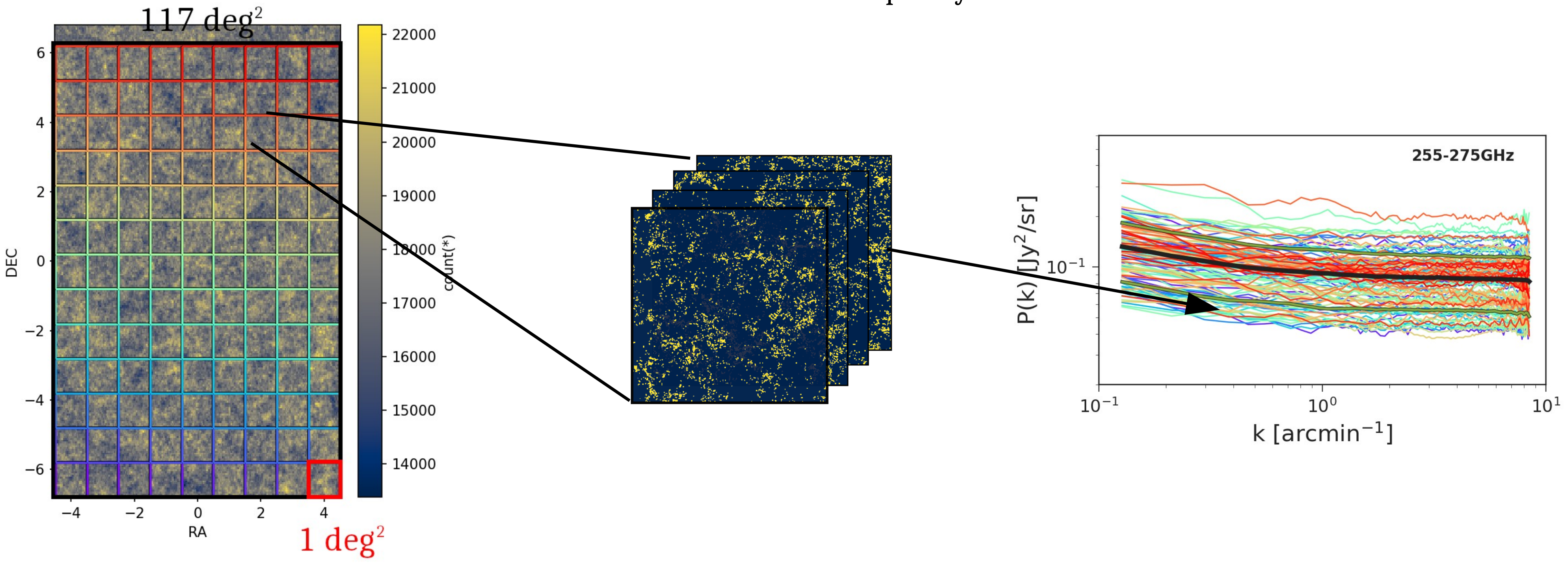


Ishiyama+20

Béthermin+17
Béthermin, Gkogkou, + submitted

Application to Line Intensity Mapping

Uchuu: big cosmological simulation → **SIDES**: Generate simulated cube each slice → different frequency → 2D power spectrum computation for each cube slice



Ishiyama+20

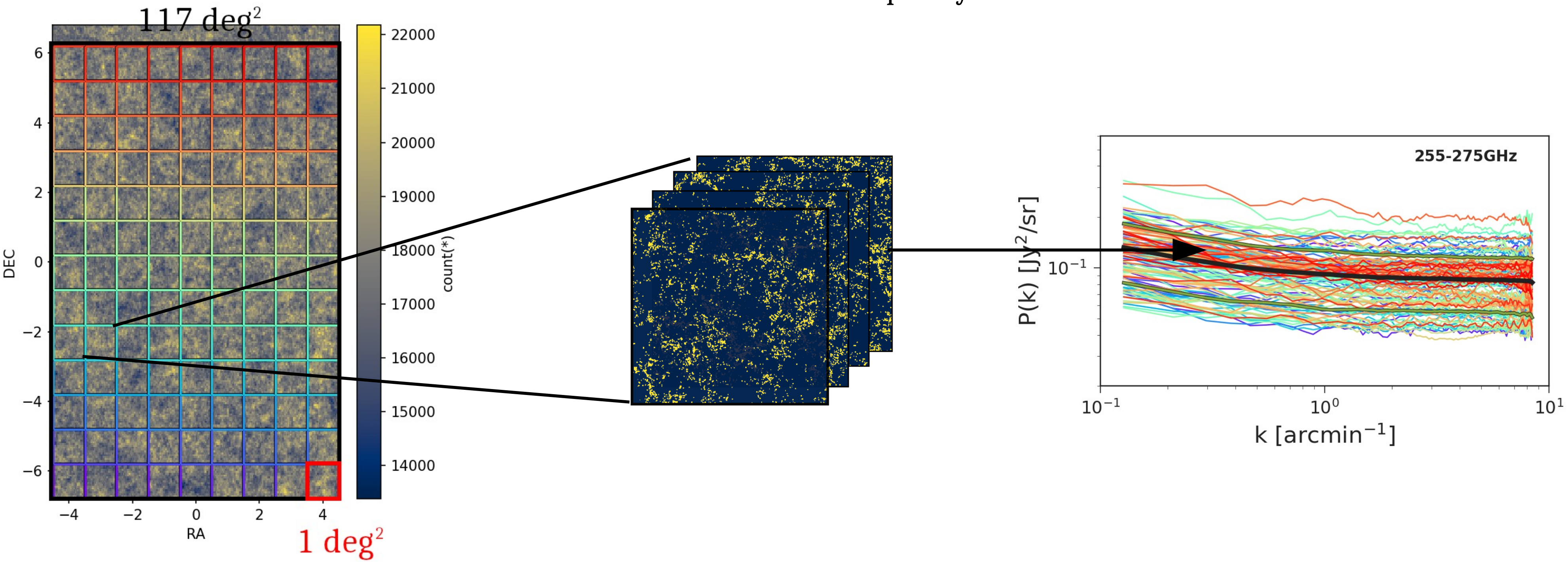
Béthermin+17
Béthermin, Gkogkou, + submitted

Application to Line Intensity Mapping

Uchuu: big cosmological simulation →

SIDES: Generate simulated cube each slice → different frequency →

2D power spectrum computation for each cube slice

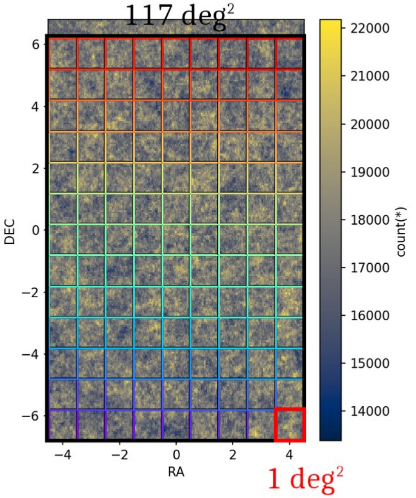


Ishiyama+20

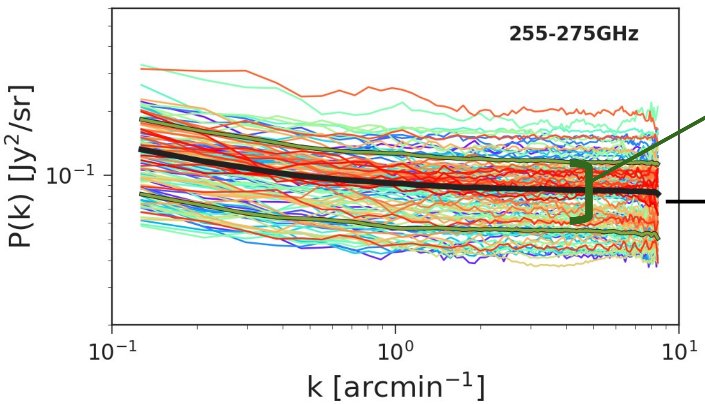
Béthermin+17
Béthermin, Gkogkou, + submitted

Line Intensity Mapping caveats

Uchuu: big simulation area



Field-to-field (ftf) variance



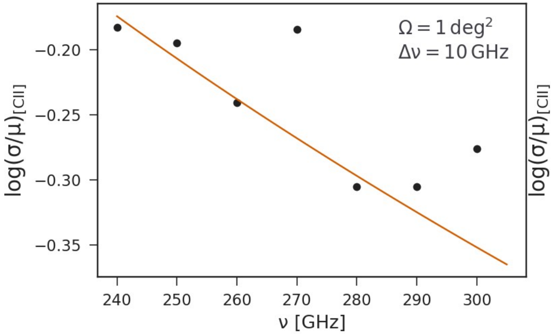
σ: standard deviation of P(k)

μ: mean P(k)

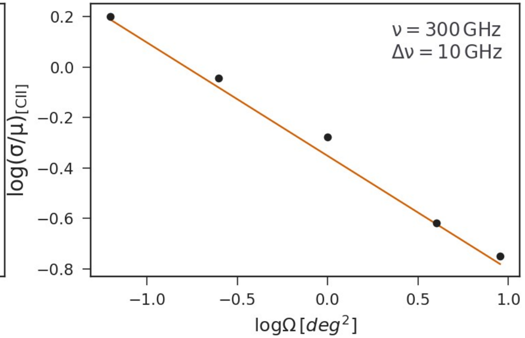
$$\frac{\sigma}{\mu} = c\left(\frac{\nu}{\nu_o}\right)^{\alpha}\left(\frac{\Delta\nu}{\Delta\nu_o}\right)^{\beta}\left(\frac{\Omega}{\Omega_o}\right)^{\gamma}$$

where $\nu_o = 200GHz$, $\Delta\nu_o = 5GHz$, and $\Omega_o = 1deg^2$

Dependence on frequency (ν)

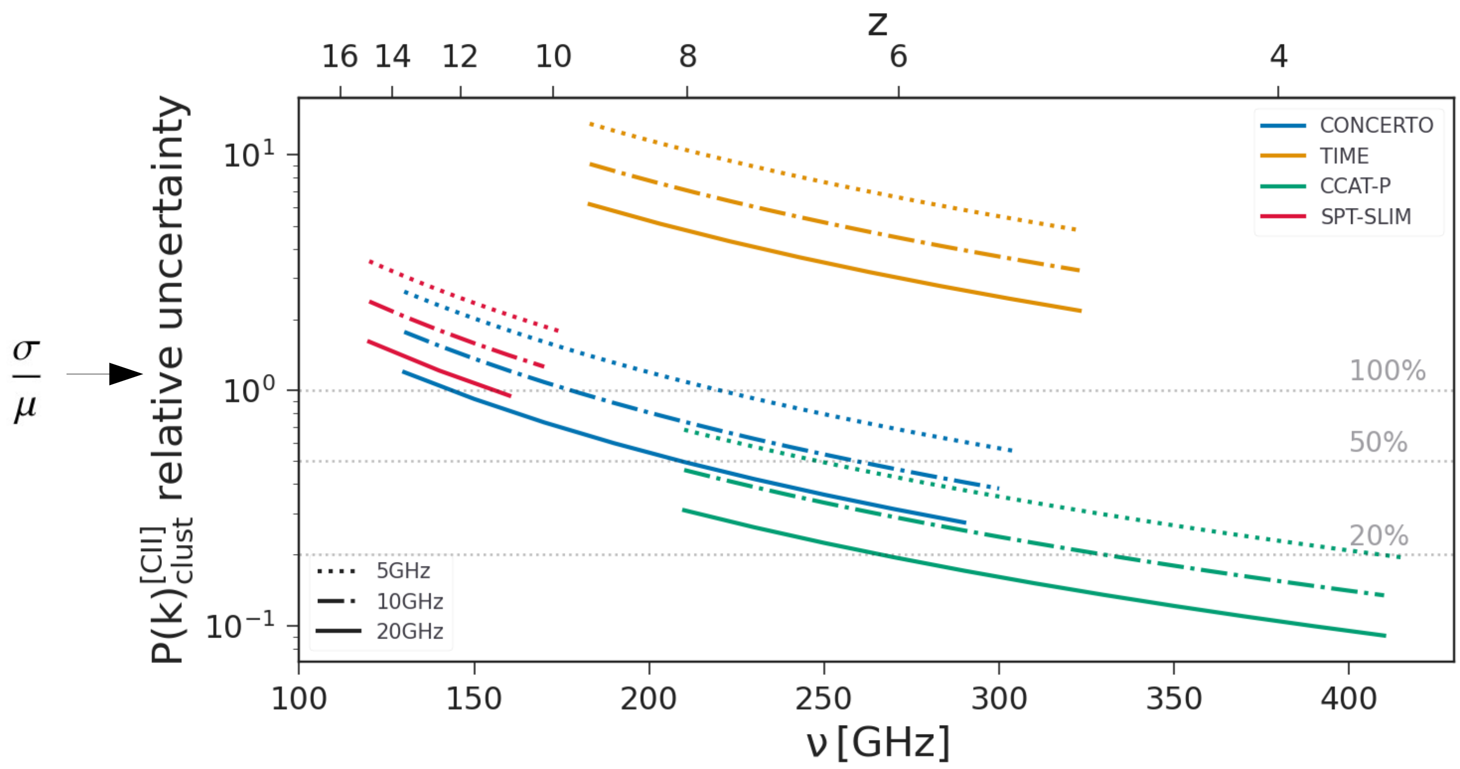


Dependence on survey size (Ω)



Gkogkou+, to be sub.

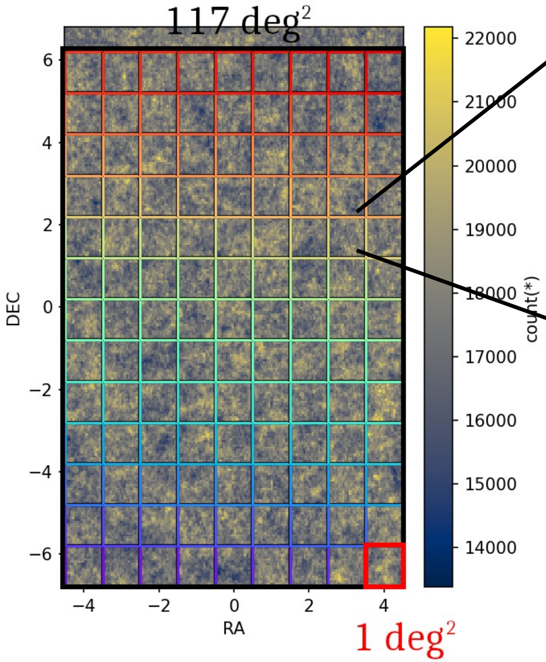
LIM experiments: expected ftf variance



Gkogkou+, to be sub.

SIDES: application to galaxy surveys

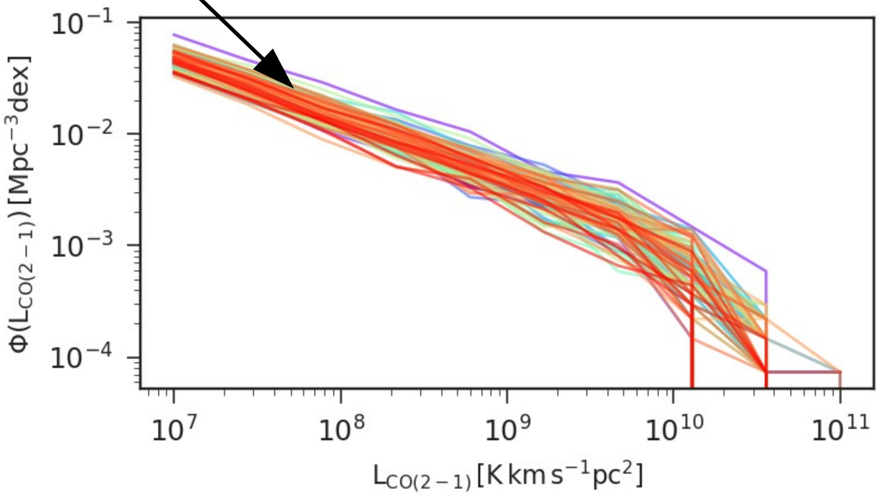
Uchuu: big cosmological simulation



#	redshift	ra	dec	Mhalo	Mstar	SFR	LIR	LCII_Lagache
0	0.0125433	-3.59673	-5.91746	16350999552.0	32436525.4989	0.01149	114908696.272	49378.09724051
1	0.0168886	-3.63059	-6.73737	24526000128.0	187761568.735	0.01724	172433598.012	92158.67855716
2	0.0168895	-4.00797	-6.18176	105300000768.0	770238704.830	0.0	0.0	0.0
3	0.0168990	-3.69993	-6.76695	249839992832.0	16438527717.6	1.64845	16484542655.1	9400682.957055
4	0.0169214	-4.38760	-6.47405	6867400192.0	19094648.2121	0.00102	10272211.8753	536.5241647538
...	...	...	...	...	...	...	...	...
54,821,709	7.0387912	-4.44864	3.68041	8175499776.0	2650958.32680	0.02752	275297436.917	113543.3676063
54,821,710	7.0387940	-4.00128	3.27867	10138000384.0	2972850.04422	0.01671	167181378.974	49548.54983316
54,821,711	7.0387940	-4.17367	3.33224	37606998016.0	20245450.9266	0.04213	421384253.864	301306.6359685
54,821,712	7.0387940	-4.15751	4.09144	16677999616.0	8632126.09224	0.17103	1710330612.12	994789.2369777
54,821,713	7.0388024	-4.45143	3.67178	17659000832.0	5984521.24977	0.06946	694656711.860	190262.3586077

SIDES: Generate simulated catalog
each row → galaxy and its properties

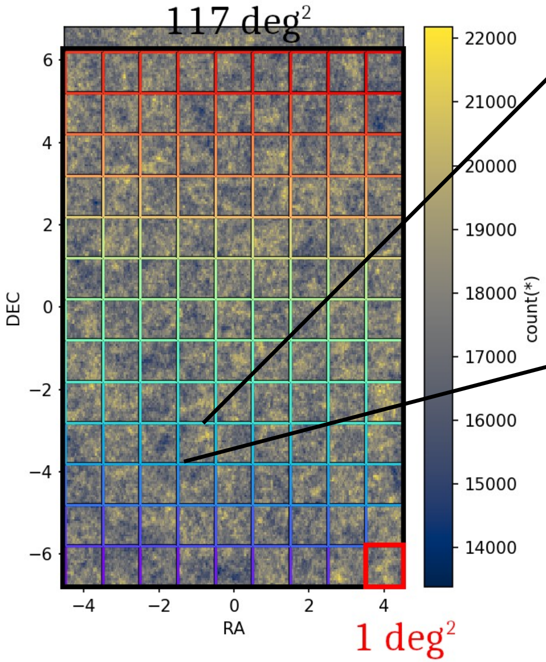
Luminosity function construction
Redshift slice, selected line (e.g., CO(2-1))



Gkogkou+, to be sub.

SIDES: application to galaxy surveys

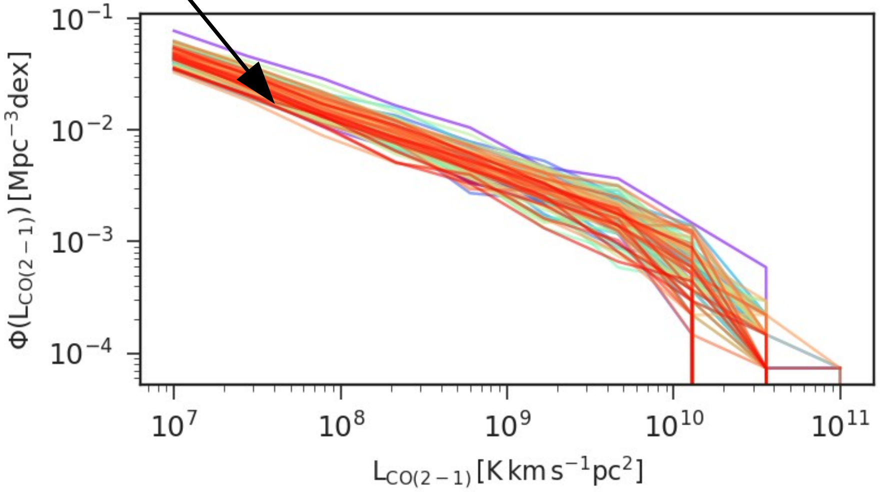
Uchuu: big cosmological simulation



#	redshift	ra	dec	Mhalo	Mstar	SFR	LIR	LCII_Lagache
0	0.0125433	-3.59673	-5.91746	16350999552.0	32436525.4989	0.01149	114908696.272	49378.09724051
1	0.0168886	-3.63059	-6.73737	24526000128.0	187761568.735	0.01724	172433598.012	92158.67855716
2	0.0168895	-4.00797	-6.18176	105300000768.0	770238704.830	0.0	0.0	0.0
3	0.0168990	-3.69993	-6.76695	249839992832.0	16438527717.6	1.64845	16484542655.1	9400682.957055
4	0.0169214	-4.38760	-6.47405	6867400192.0	19094648.2121	0.00102	10272211.8753	536.5241647538
...	...	...	...	...	...	...	...	...
54,821,709	7.0387912	-4.44864	3.68041	8175499776.0	2650958.32680	0.02752	275297436.917	113543.3676063
54,821,710	7.0387940	-4.00128	3.27867	10138000384.0	2972850.04422	0.01671	167181378.974	49548.54983316
54,821,711	7.0387940	-4.17367	3.33224	37606998016.0	20245450.9266	0.04213	421384253.864	301306.6359685
54,821,712	7.0387940	-4.15751	4.09144	16677999616.0	8632126.09224	0.17103	1710330612.12	994789.2369777
54,821,713	7.0388024	-4.45143	3.67178	17659000832.0	5984521.24977	0.06946	694656711.860	190262.3586077

SIDES: Generate simulated catalog
each row → galaxy and its properties

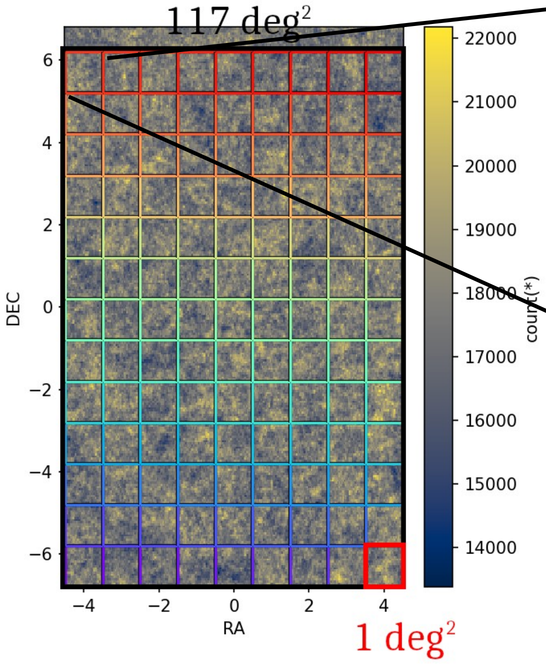
Luminosity function construction
Redshift slice, selected line (e.g., CO(2-1))



Gkogkou+, to be sub.

SIDES: application to galaxy surveys

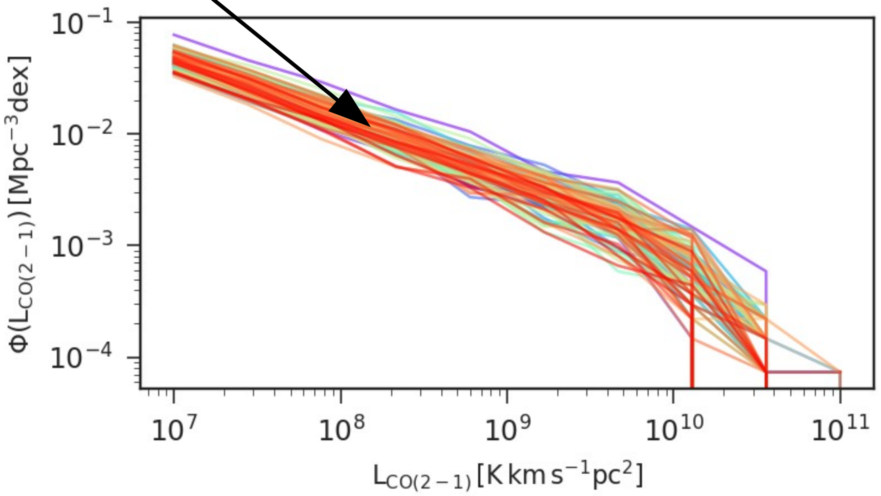
Uchuu: big cosmological simulation



#	redshift	ra	dec	Mhalo	Mstar	SFR	LIR	LCII_Lagache
0	0.0125433	-3.59673	-5.91746	16350999552.0	32436525.4989	0.01149	114908696.272	49378.09724051
1	0.0168886	-3.63059	-6.73737	24526000128.0	187761568.735	0.01724	172433598.012	92158.67855716
2	0.0168895	-4.00797	-6.18176	105300000768.0	770238704.830	0.0	0.0	0.0
3	0.0168990	-3.69993	-6.76695	249839992832.0	16438527717.6	1.64845	16484542655.1	9400682.957055
4	0.0169214	-4.38760	-6.47405	6867400192.0	19094648.2121	0.00102	10272211.8753	536.5241647538
...	...	...	...	...	...	...	...	...
54,821,709	7.0387912	-4.44864	3.68041	8175499776.0	2650958.32680	0.02752	275297436.917	113543.3676063
54,821,710	7.0387940	-4.00128	3.27867	10138000384.0	2972850.04422	0.01671	167181378.974	49548.54983316
54,821,711	7.0387940	-4.17367	3.33224	37606998016.0	20245450.9266	0.04213	421384253.864	301306.6359685
54,821,712	7.0387940	-4.15751	4.09144	16677999616.0	8632126.09224	0.17103	1710330612.12	994789.2369777
54,821,713	7.0388024	-4.45143	3.67178	17659000832.0	5984521.24977	0.06946	694656711.860	190262.3586077

SIDES: Generate simulated catalog
each row → galaxy and its properties

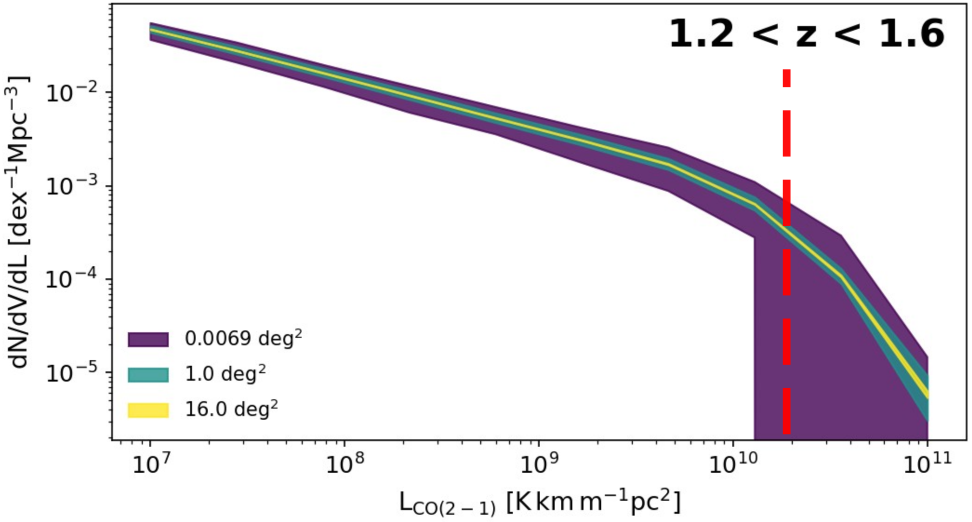
Luminosity function construction
Redshift slice, selected line (e.g., CO(2-1))



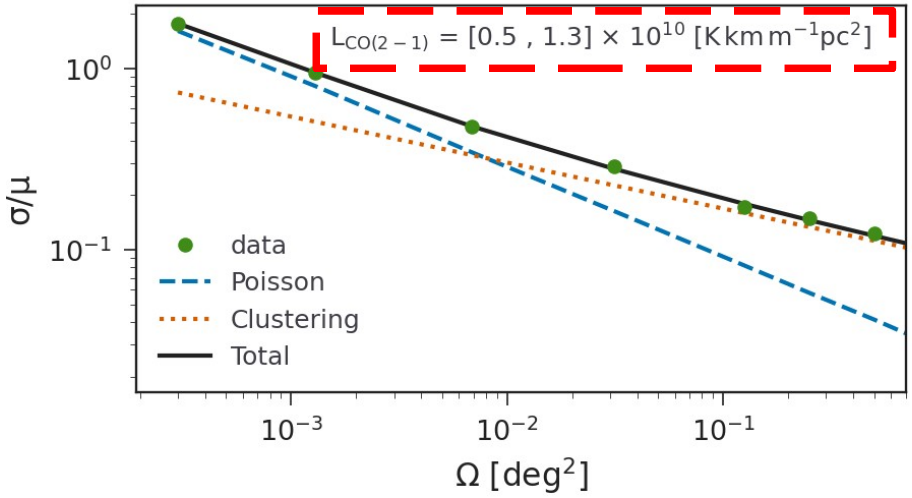
Gkogkou+, to be sub.

Ftf variance: Luminosity Functions (LFs)

Variance dependence on **field size**:
the smaller the survey size
the bigger the variance



Total variance = Poisson + clustering



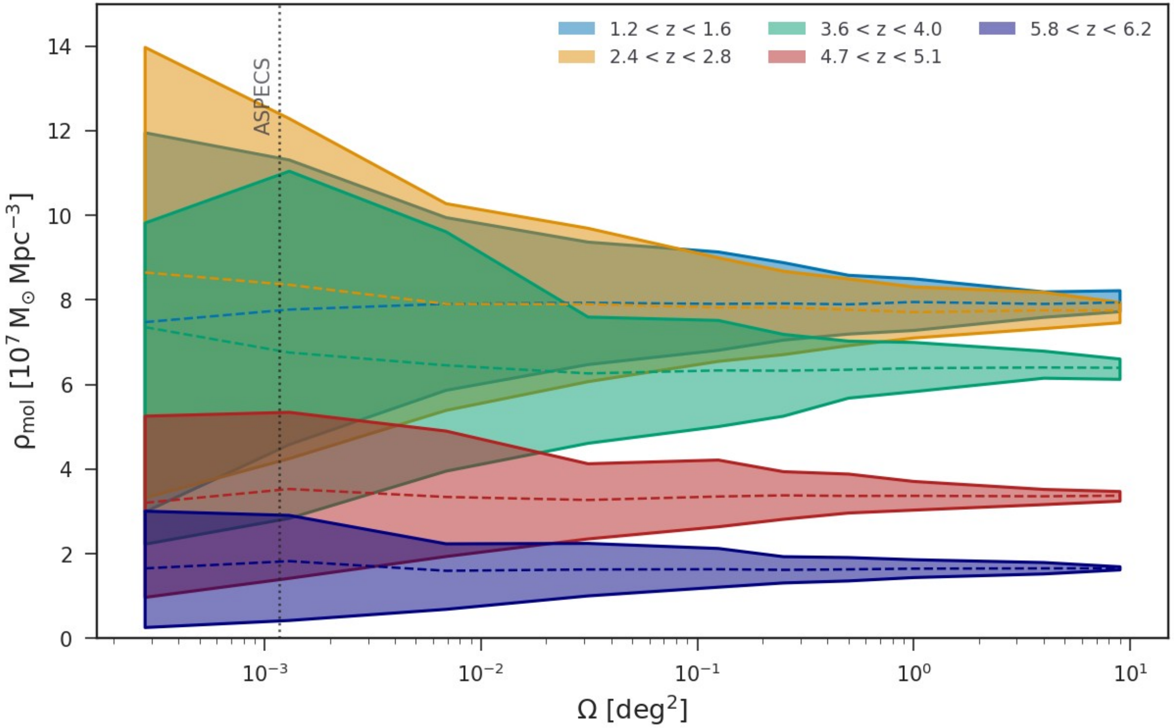
$$\frac{\sigma_{tot}}{\mu} = \frac{\sqrt{\sigma^2_{Pois} + \sigma^2_{clust}}}{\mu} = \sqrt{y + \left(\frac{1}{\sqrt{N}}\right)^2}$$

where $y = \frac{\int_{\rm field}\int_{\rm field} w(\theta)\,{\rm d}\Omega_1\,{\rm d}\Omega_2}{\Omega^2}$

Gkogkou+, to be sub.

Ftf variance: $\rho_{molecular}$

$$\rho_{\rm mol} = \alpha_{\rm CO} \times \int_0^\infty {\rm L}'_{\rm CO} \Phi({\rm L}'_{\rm CO})\, {\rm dlog}({\rm L}'_{\rm CO})$$



Gkogkou+, to be sub.

Summary

- LIM is a promising technique for high-z studies
- CONCERTO one of the first LIM instruments
- Field-to-field variance significant caveat
- Bigger survey sizes will provide better results

- SIDES: realistic simulation for LIM experiments but also galaxy surveys
- Public code and catalogs (2 deg^2) - https://cesamsi.lam.fr/instance/sides/home
- Very soon public catalogs of 120 deg^2 simulation