Observatoire **astronomique** de Strasbourg | ObAS

SIDES

S04 Modeling galaxies at different scales, journées SF2A, Grenoble, 22 juin 2026

SIDES: a Semi-Empirical Simulation for Long-Wavelength Extragalactic Surveys

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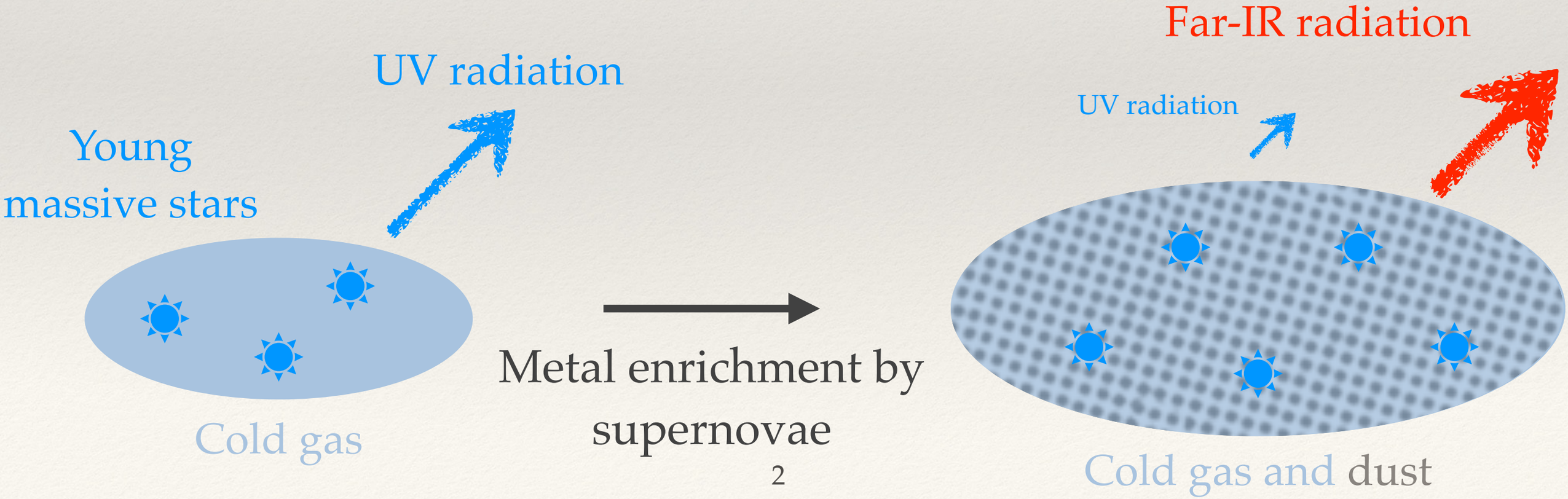
Long wavelengths to study massive galaxies

- Rapid production of dust in massive high-z systems

  (e.g., Fudamoto+20)

  => UV emission from young stars absorbed and re-emitted in the far IR

- Tracers of cold/neutral gas: submillimeter lines (CO, [CII], [CI], HCN…) and radio (HI at 21 cm)



Long wavelengths to study massive galaxies

- Rapid production of dust in massive high-z systems

  (e.g., Fudamoto+20)

Long wavelength are thus essential to measure:

- the gas content of the first massive galaxies,

- dust-obscured star formation

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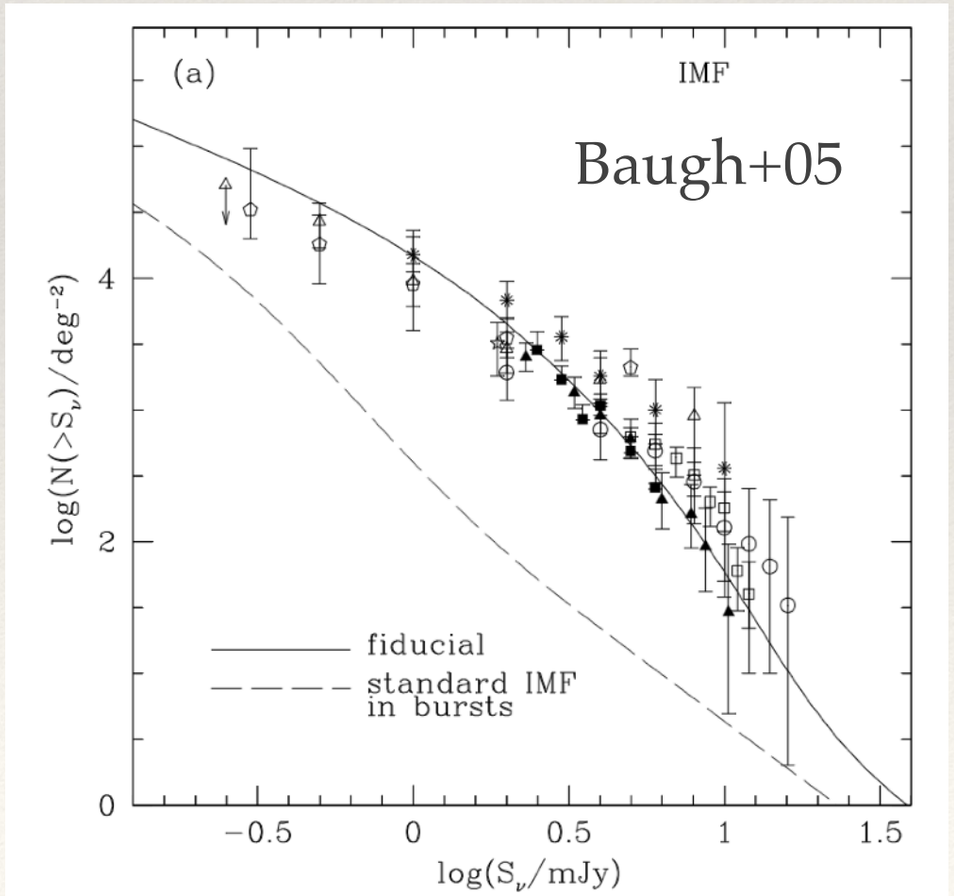
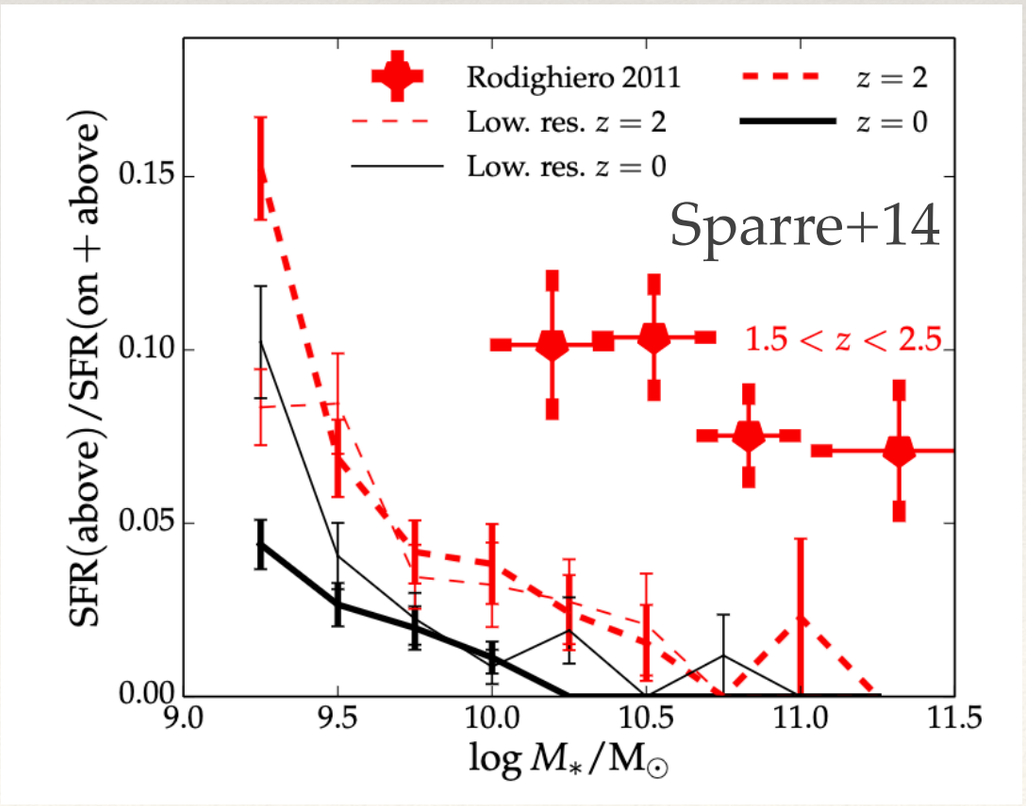
Limitations of physical models at long wavelengths

- Semi-analytical models and hydrodynamical simulations tend to under predicts the number density of high-z high-SFR dusty galaxies.
- Improvements usually take years if not decades. We need complementary tools to react quickly to new datasets.

Old SAMs needed top-heavy IMF to reproduce the statistics of submillimeter galaxies



Too low fraction of starbursts in Illustris



(Semi)-empirical modeling

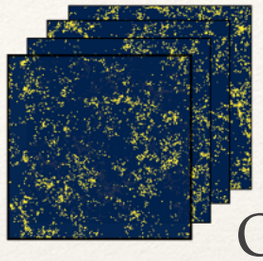
- Observers need flexible models reproducing current constraints to:
  - optimize surveys using reliable forecast calibrated on the latest observations
  - test data analysis pipelines with end-to-end simulations
  - quick but simple interpretation of new results
  - identification and correction of observational biases
- This motivated the development of empirical models dedicated to >8 micron observations: e.g., Chary&Elbaz+01, Franceschini+01, Lagache+03, Le Borgne+09, Béthermin+11, Gruppioni+11, Schreiber+17, Bisigello+21
- Advantage: can almost run on a laptop / easy to modify
- Price to pay: limited amount of physics learnt from this exercise

The SIDES simulation

Two light cones are available:
- SIDES-Bolshoi (2 deg², Béthermin+22)
- SIDES-Uchuu (118 deg², Gkogkou+22)

Abundance matching

Dark matter halo catalog → Galaxy catalog (Stellar masses) → Galaxy properties (passive/normal/ starburst, SFR)



[CII] emission

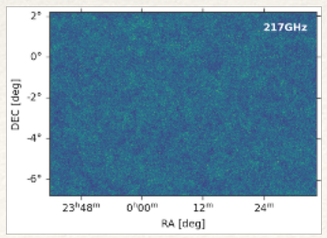
Observed SFR-luminosity relation

CO SLED templates

Line fluxes

Observed scaling relations:
- fraction of passive galaxies
- main-sequence and scatter

SED templates



Continuum emission
Planck 217GHz

Continuum fluxes

Tested against a large set of observables

Galaxy number counts from mid-IR to radio

=> Test galaxy evolution and SEDs

Cosmic infrared background anisotropies

=> test the distribution of star-forming galaxies into LSS

Redshift distributions of flux-selected samples

=> Test galaxy evolution and SEDs

CO and [CII] line luminosity functions

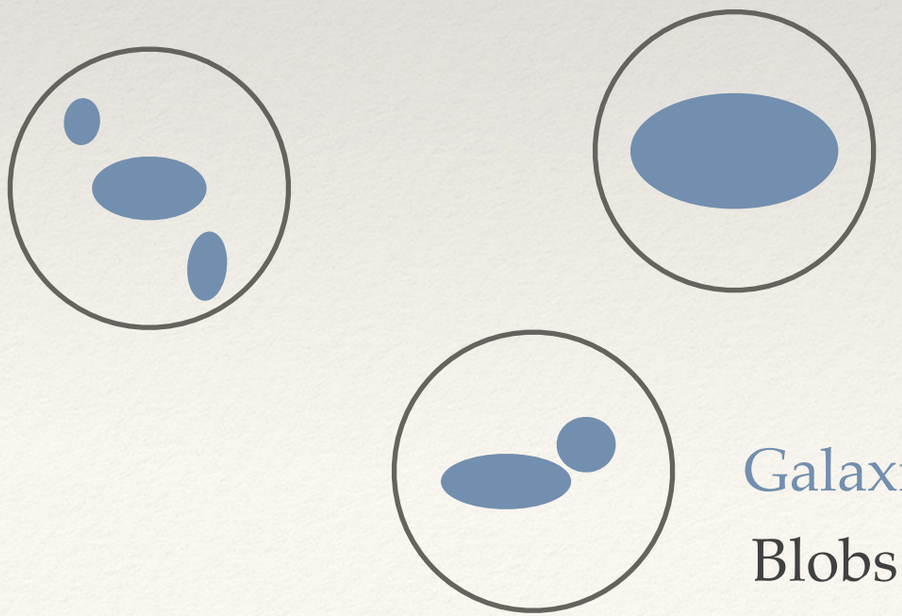
=> test the modeling of sub-mm lines

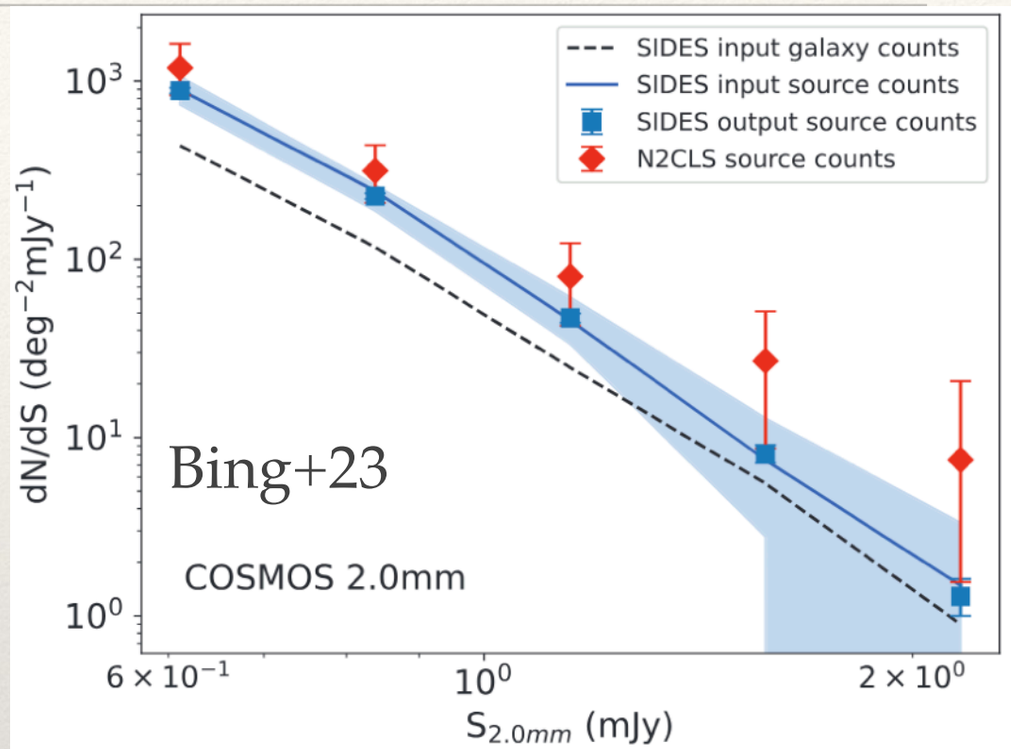
Deep fields: understanding resolution effects

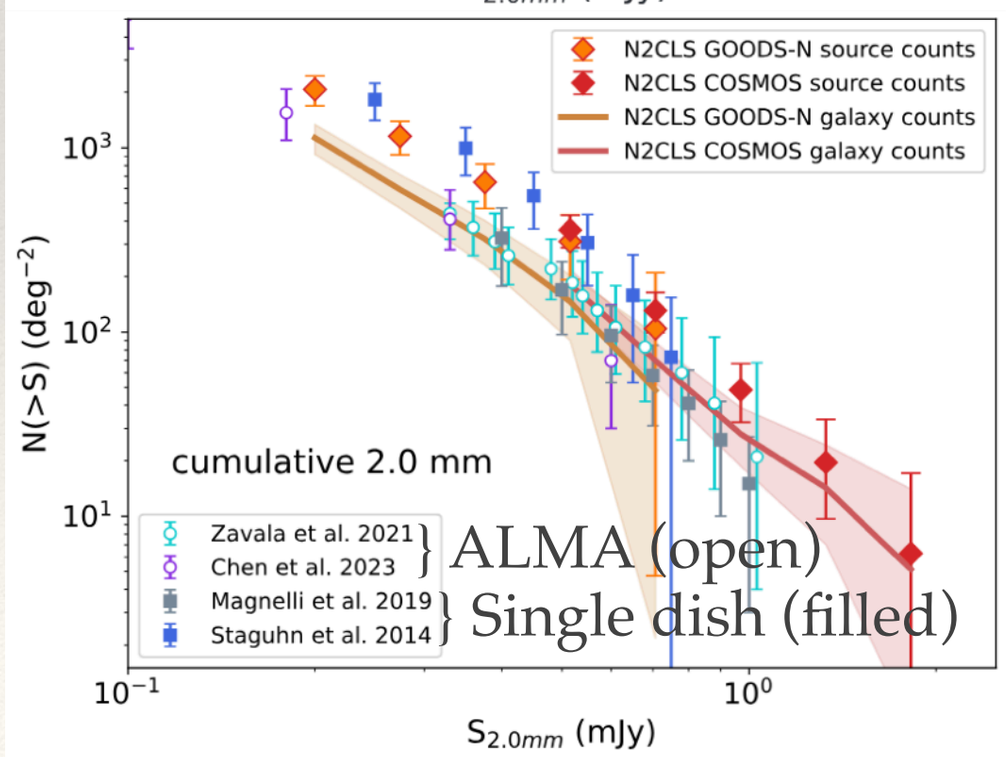
- Disagreement between number densities from single-dish telescope (low resolution) and interferometers (high resolution)
- After taking into resolution effects, SIDES agree with both, solving this tension (Béthermin+17, Bing+23).

Galaxy counts: flux distribution of individual galaxies; measured by interferometers

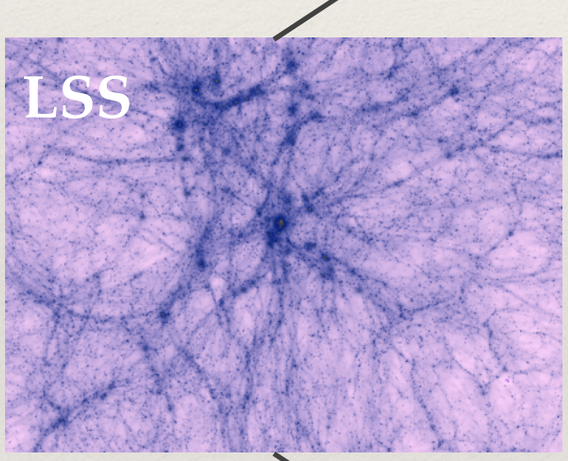
Source counts: flux detected in a large single-dish beam; can come from several sources

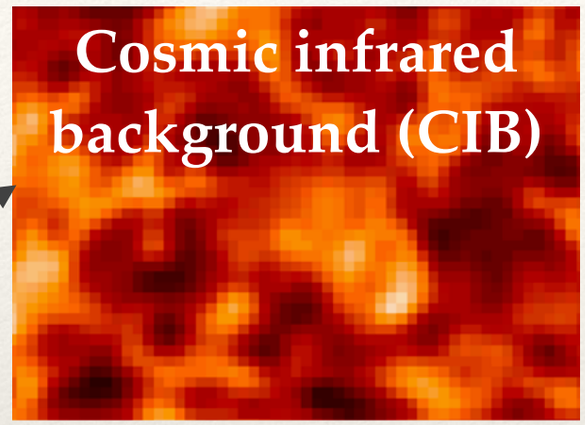






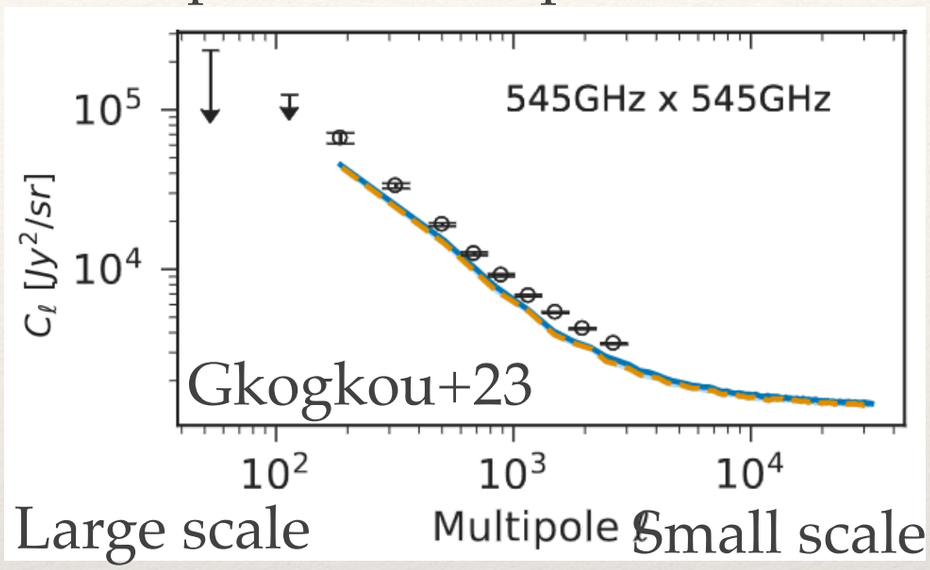
CIB and sub-mm intensity mapping



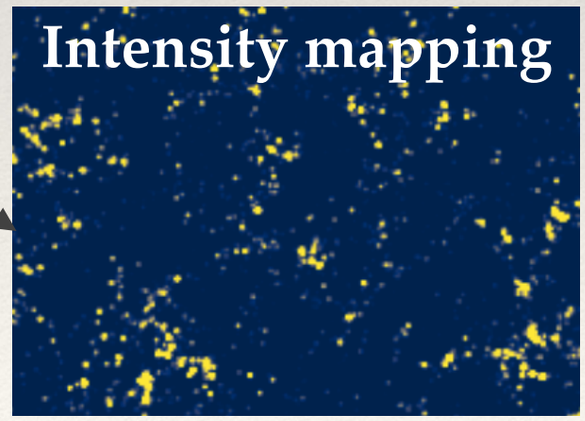


Integrated emission of dust

Power spectrum compared to Planck



New result: SIDES allowed us to find problems with halo models used to fit the CIB and correct them (Gkogkou+25, Jego+ in prep.)

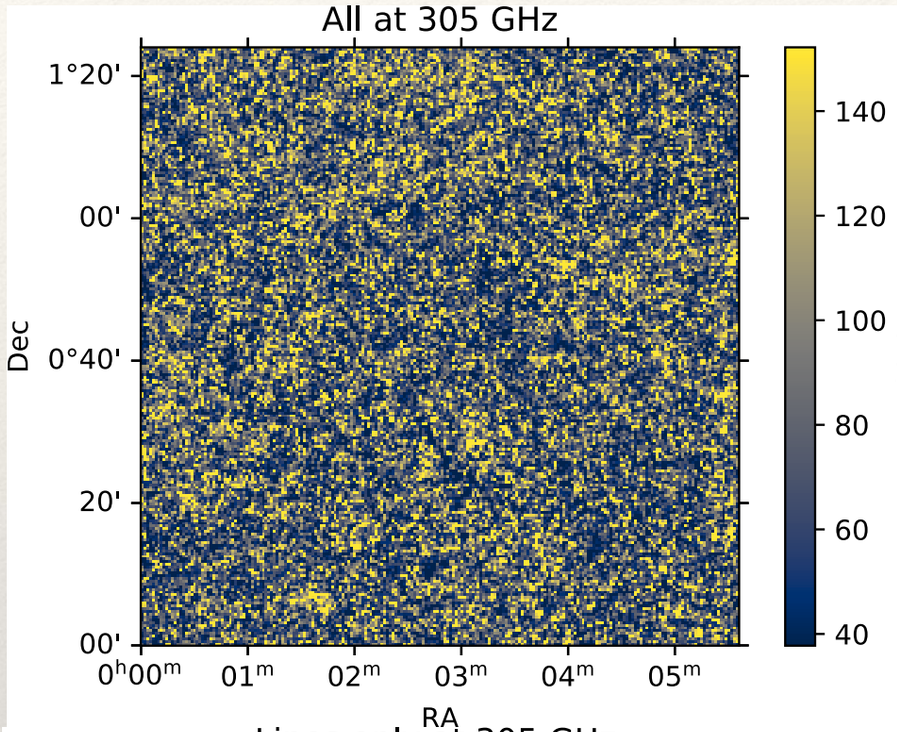


[CII] @ z=5

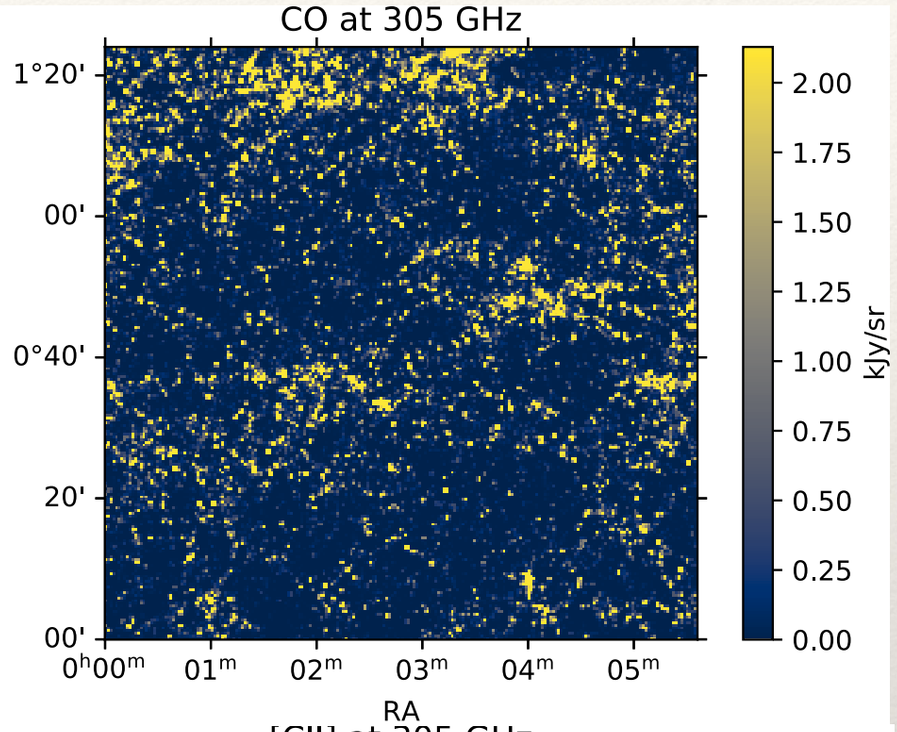
New field: SIDES used to for the CONCERTO experiment.

Simulated intensity mapping cube slices

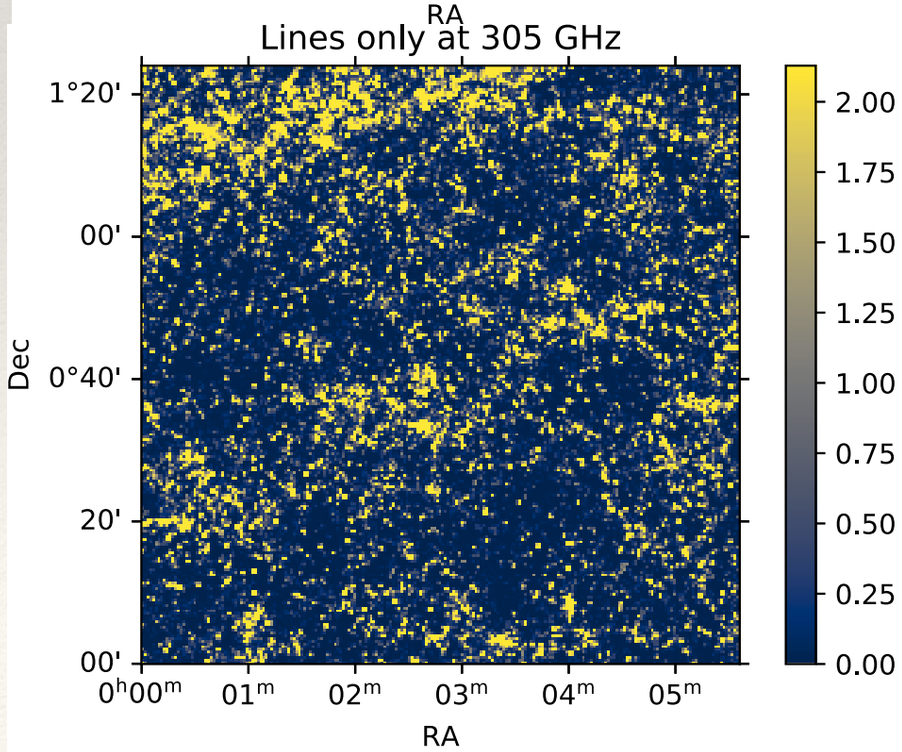
All (simulated CONCERTO cube slice of 1GHZ)



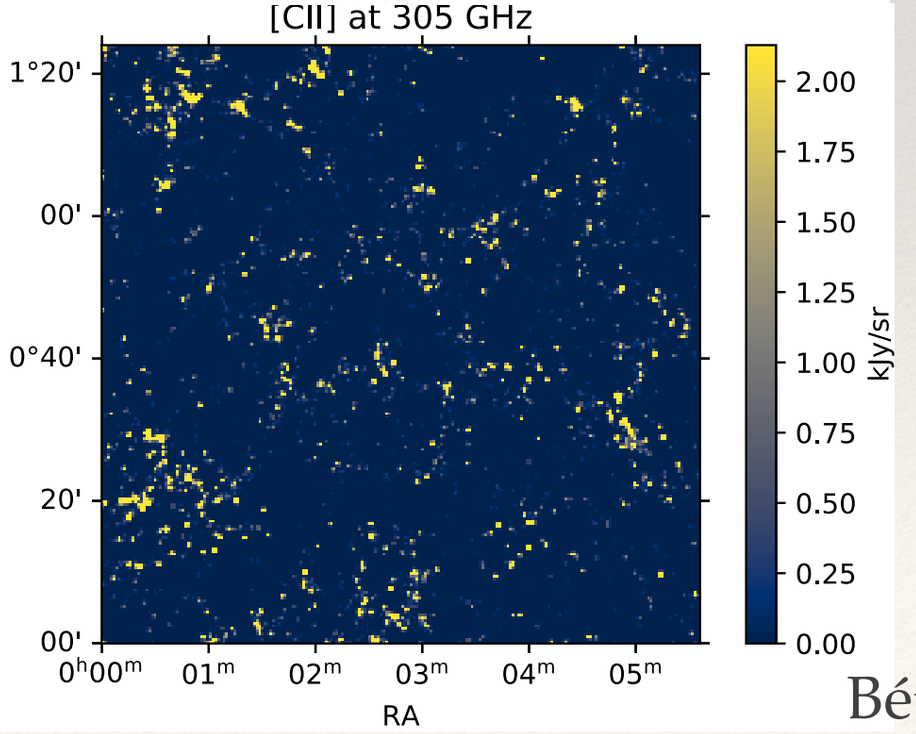
CO



Lines only



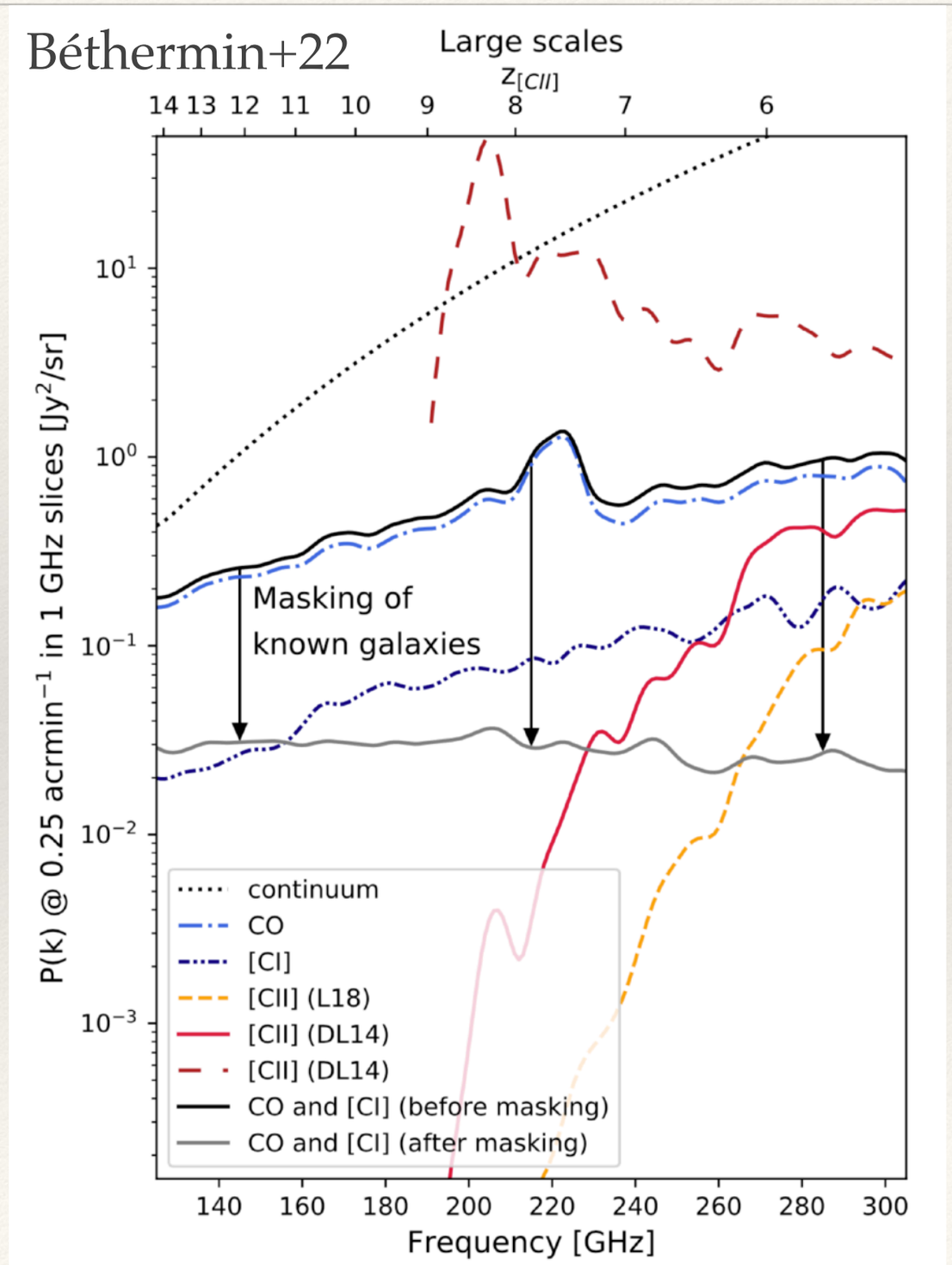
[CII]



Béthermin+22

What contributes to sub-mm intensity mapping signal?

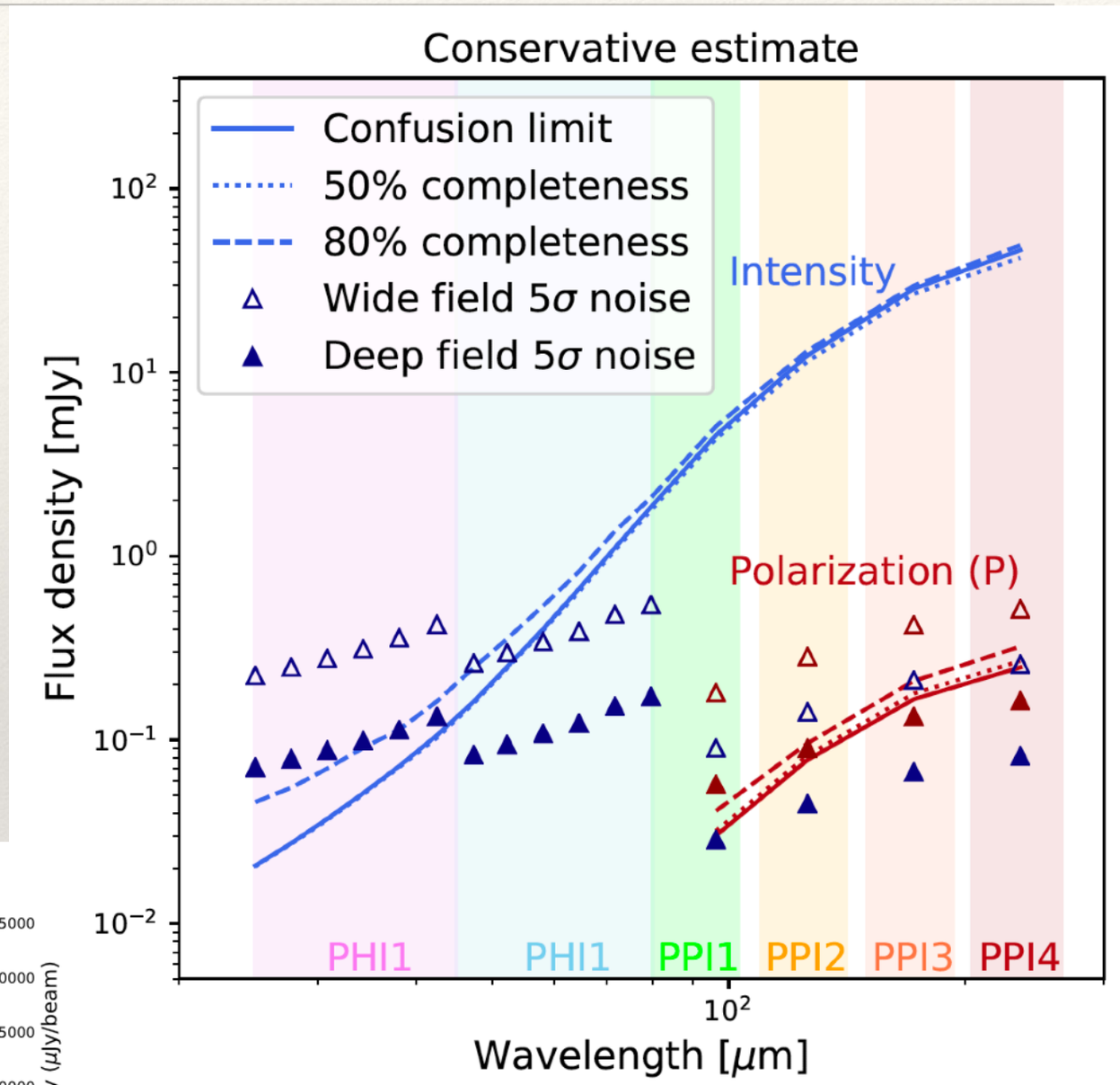
- The contribution of the various components (continuum, CO, [CI], [CII]) varies with frequency
- [CII] will be easier to detect at higher frequency
- Even at 300 GHz, CO is brighter than [CII]
- Masking technique can be used to remove the continuum and the low-z lines (Van Cuyck+23)

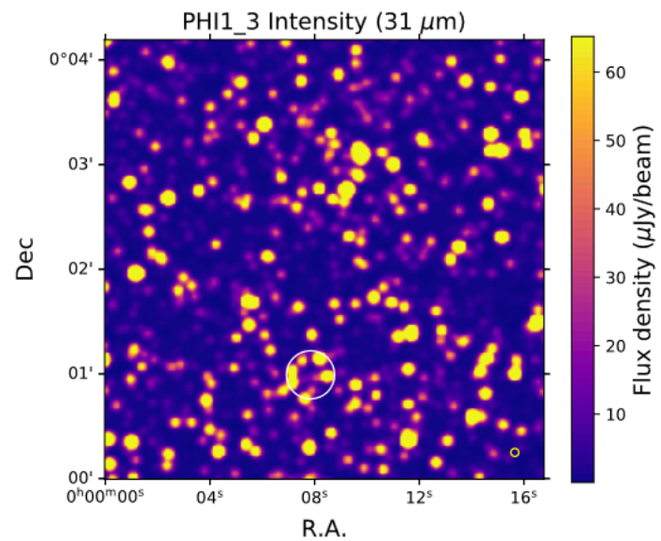


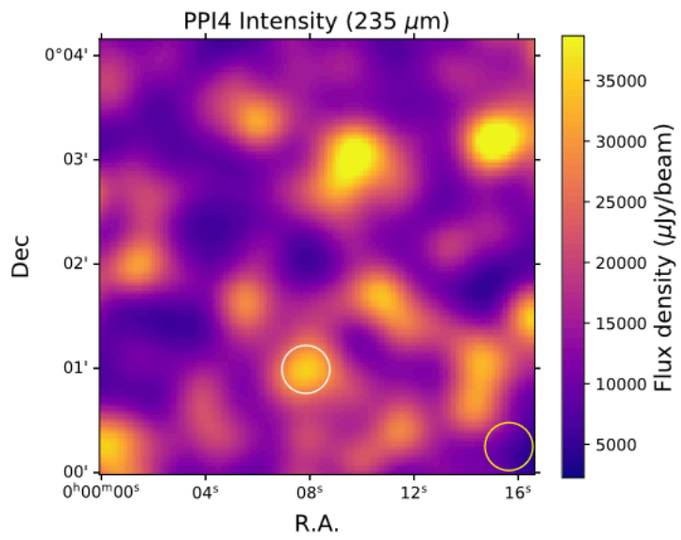
Impact of confusion on the future PRIMA mission

- PRIMA is a NASA project of cool far-infrared telescope.
- Its small mirror (1.8 m) will limit resolution.
- SIDES forecasted the confusion limit both in intensity and polarization.

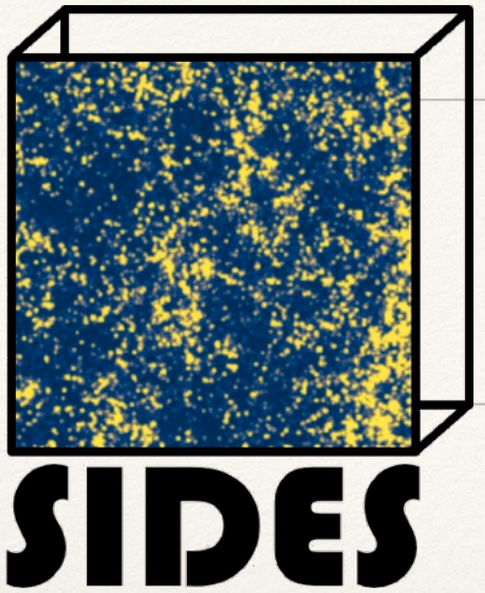
Increasing wavelength/Decreasing resolution →







Béthermin+24



Conclusion

- SIDES is semi-empirical code focused extragalactic statistical observables at long wavelength.
- Despite its relative simplicity, SIDES can address a large variety of questions: resolution effets between instruments, validity of CIB models, preparation of sub-mm line intensity mapping, confusion for PRIMA
- Products: https://data.lam.fr/sides/home
  Code: https://gitlab.lam.fr/mbethermin/sides-public-release