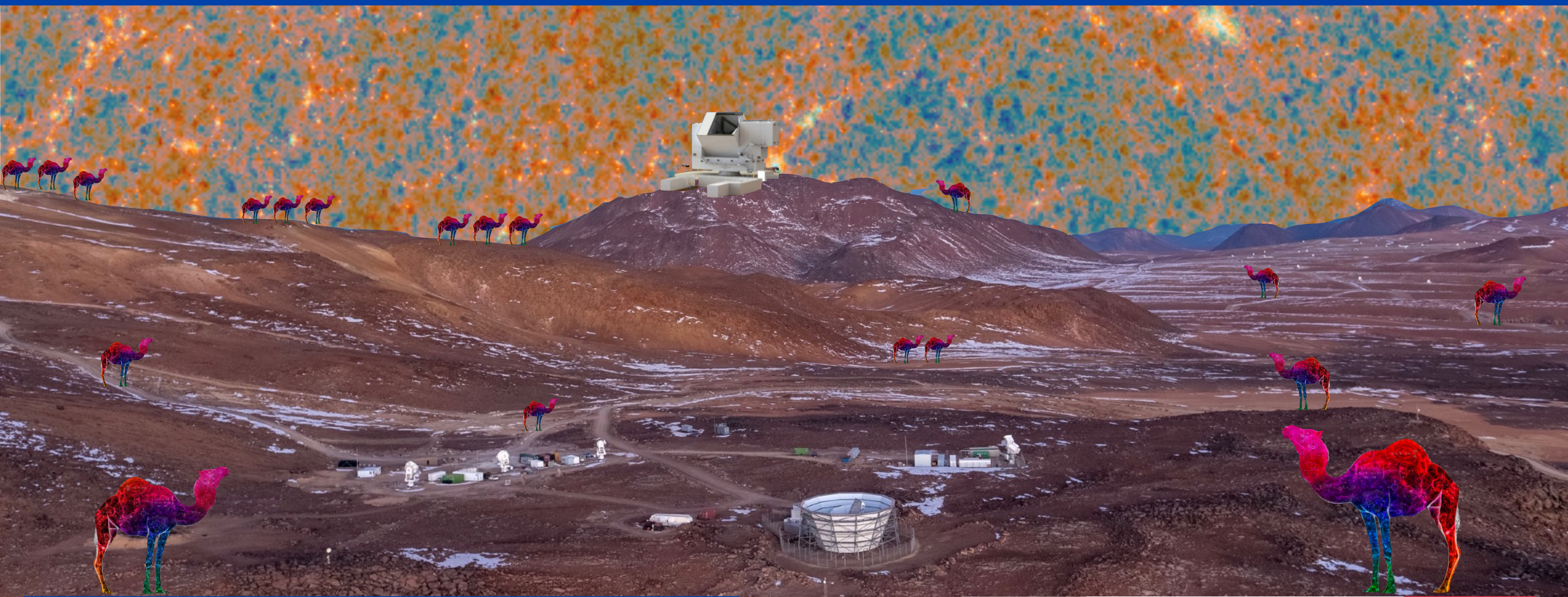
Modeling the Cosmic Infrared Background for mm-band observations with CAMELS

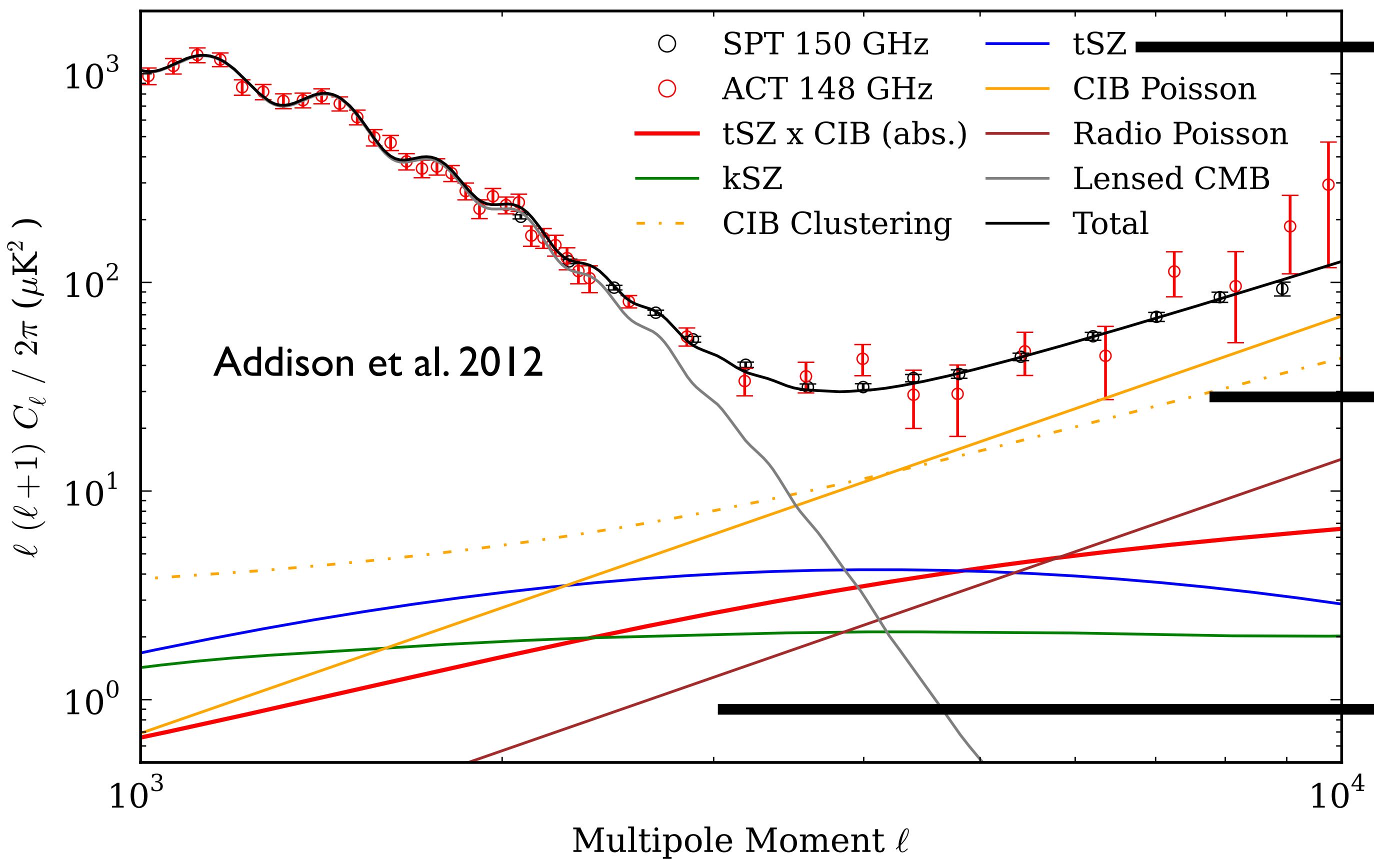


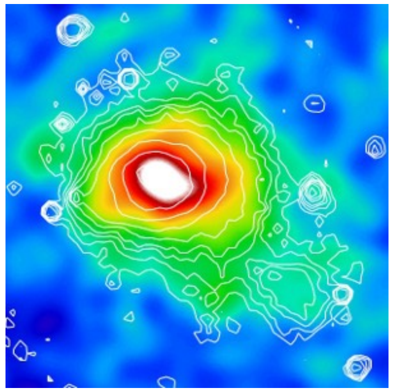
Giulio Fabbian
Marie Skłodowska Curie Global

MARIE CURIE ACTIONS
FLATIRON INSTITUTE
Division of Simons Foundation
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

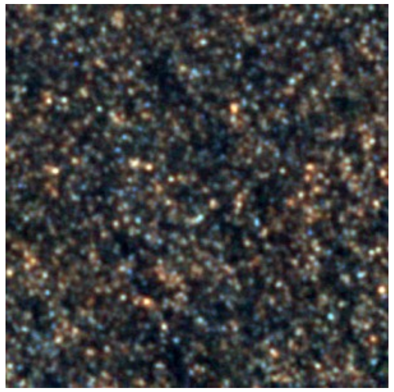
Is CMB "the" CMB?

- CMB is a snapshot of the universe at z ~1100.... plus lots of other things!
  - Galactic foreground emissions (dust, synchrotron, free-free, AME)
  - Imprint of astrophysical objects / late time physics

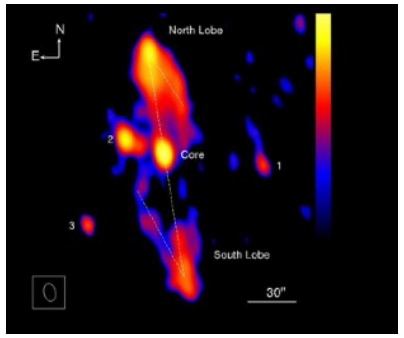




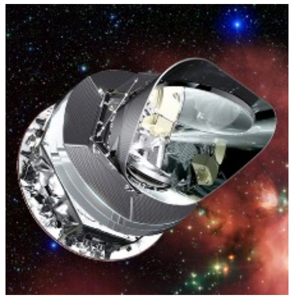
- ICM (g)astrophysics, cosmology (SZ)

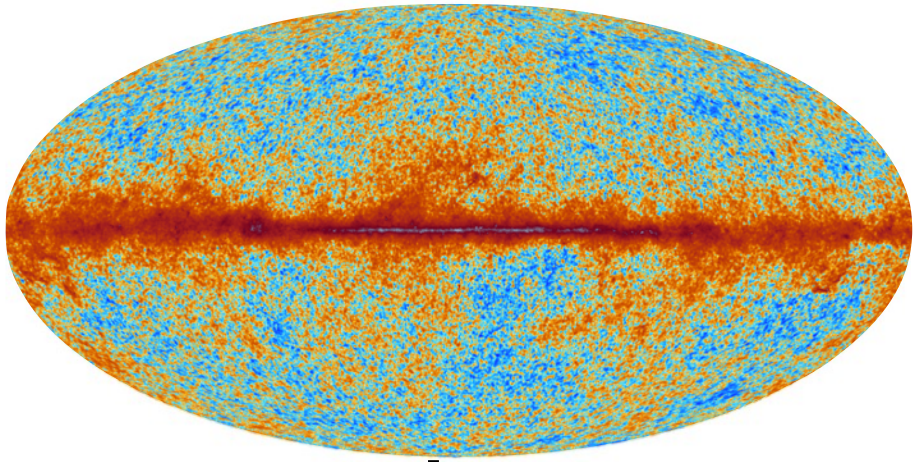


- Star formation, cosmology (CIB)



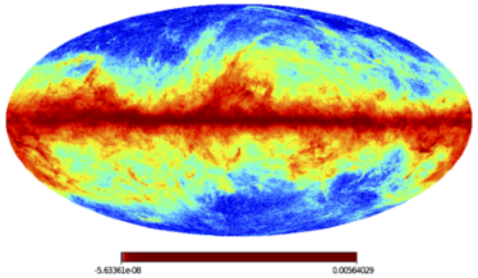
- Extragalactic astronomy, Galaxy evolution



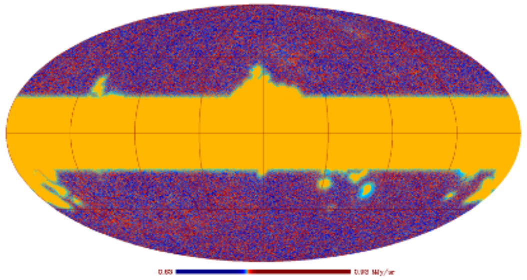


From multi-frequency data

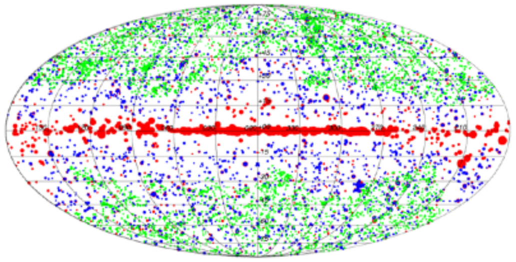
Knowing SED of components



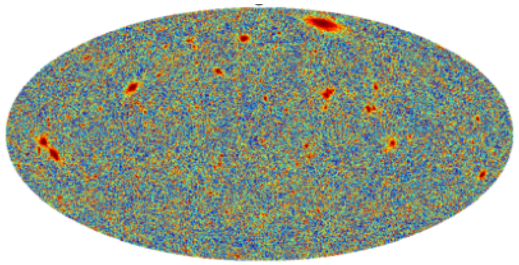
Dust



CIB (+dust)

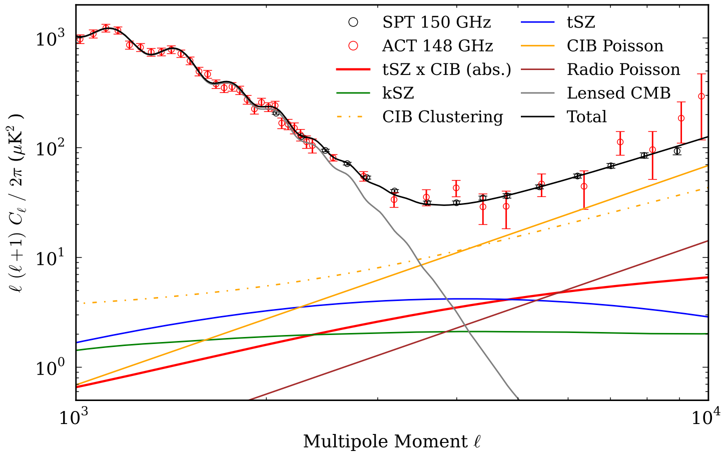


Point sources



tSZ

Fit power spectrum and foreground residuals

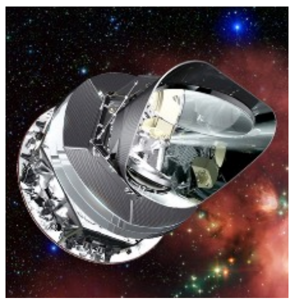


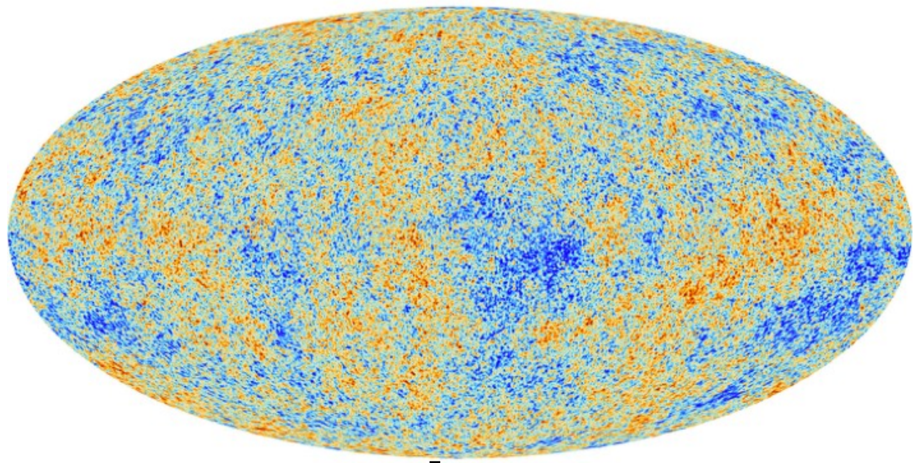
Get 22k citations!

Do other cool science!

$$\Omega_b, \Omega_{cdm}, \Omega_\Lambda, \Omega_k, n_s, \sigma_8, \tau, \sum m_\nu, w, h, N_{eff} \ldots$$

CMB analysis primer





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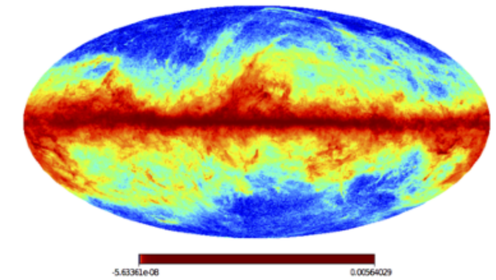

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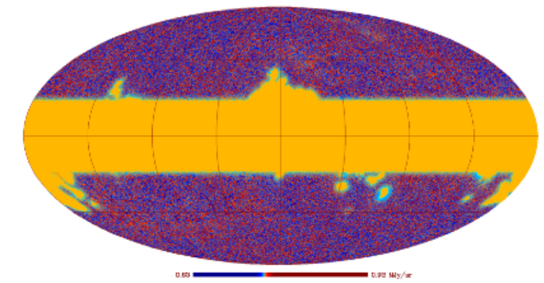
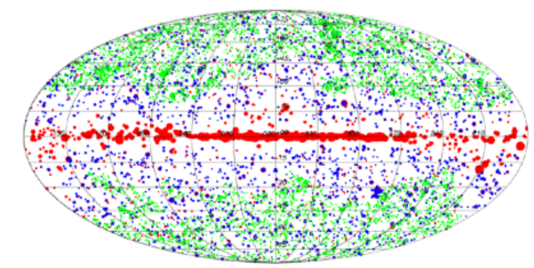


CIB (+dust)



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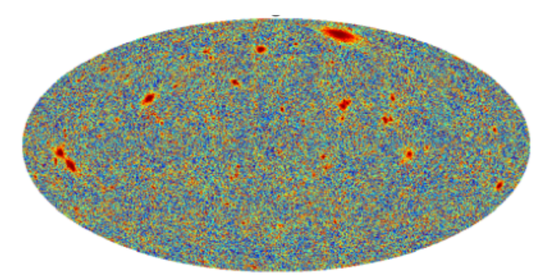

tSZ

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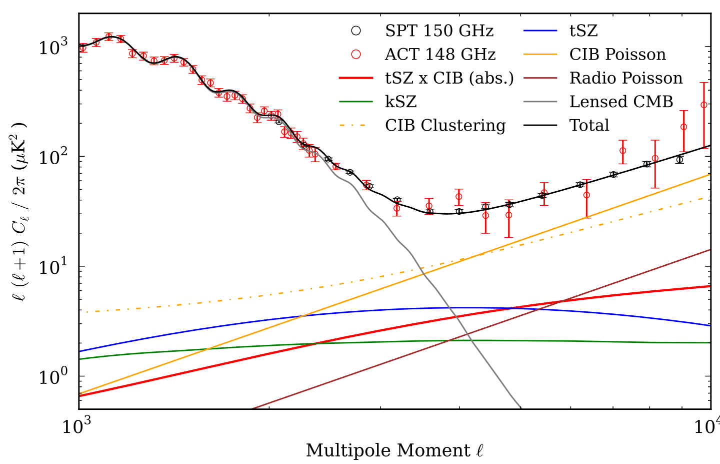

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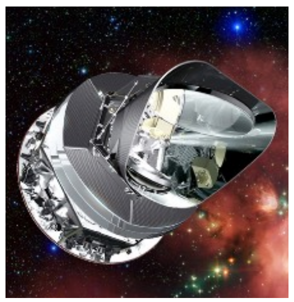

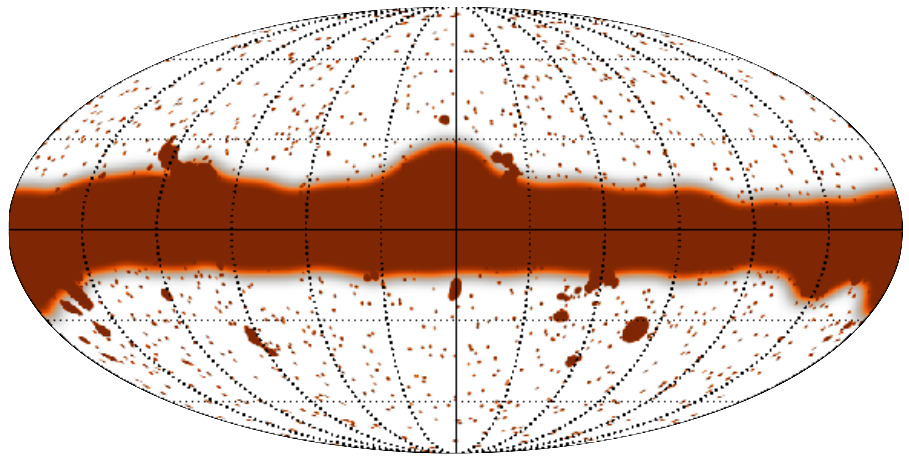

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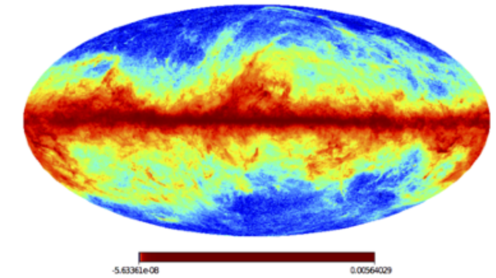

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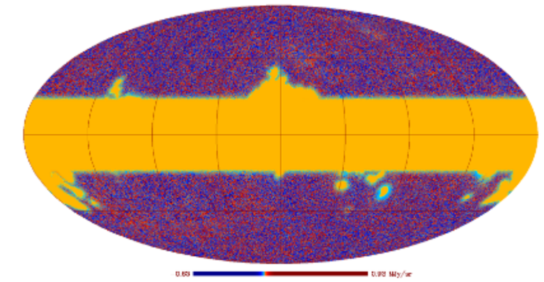

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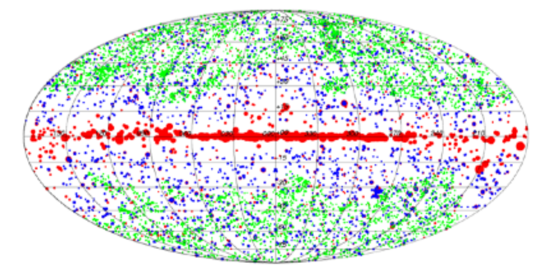

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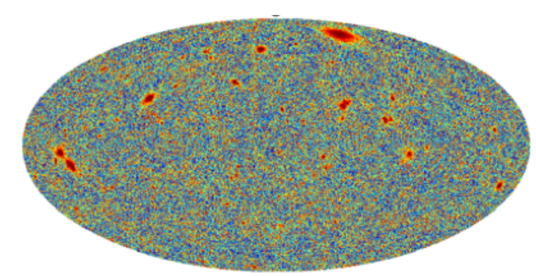

tSZ

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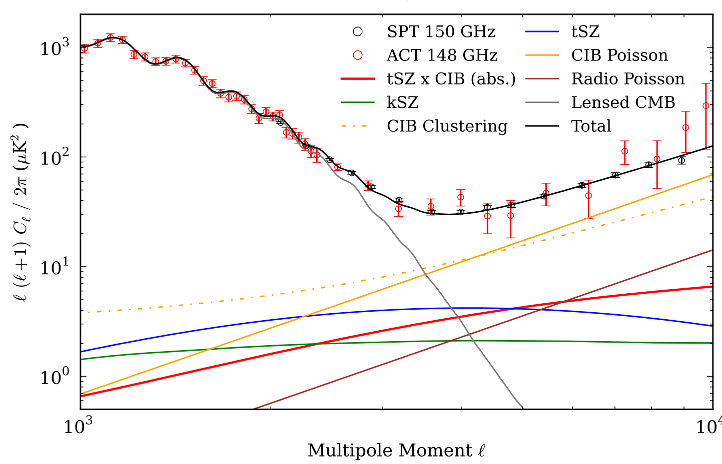

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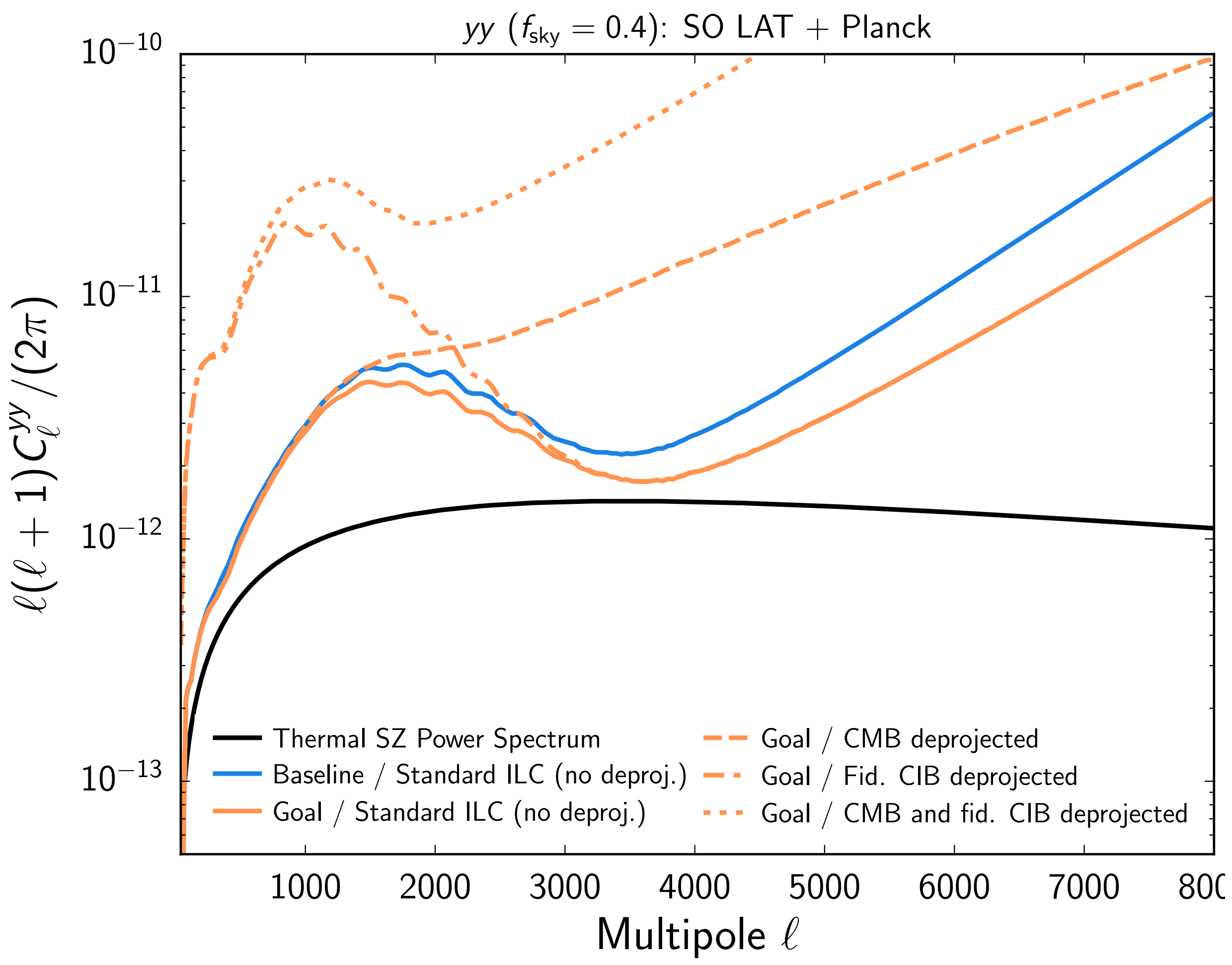
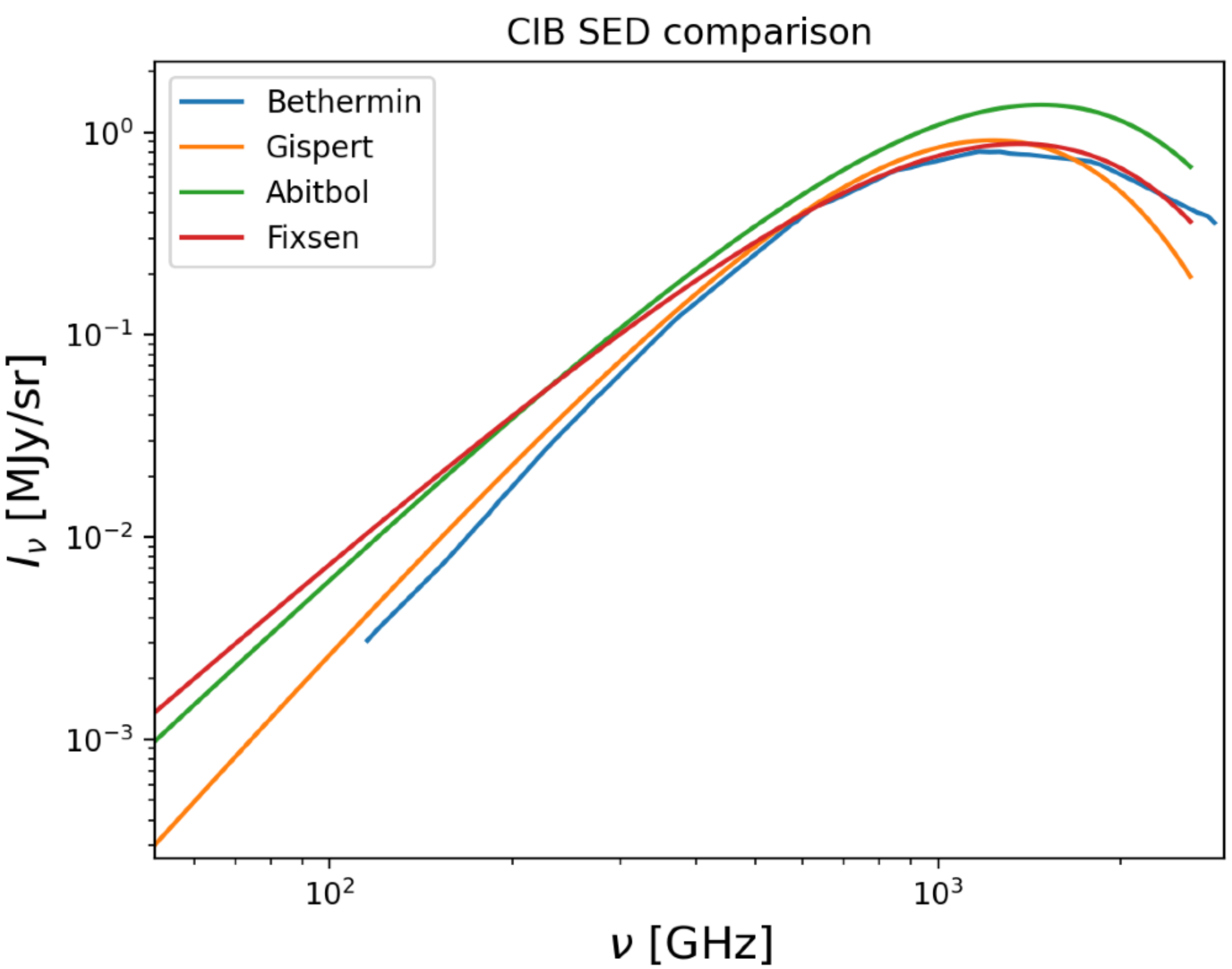
tSZ and CIB importance

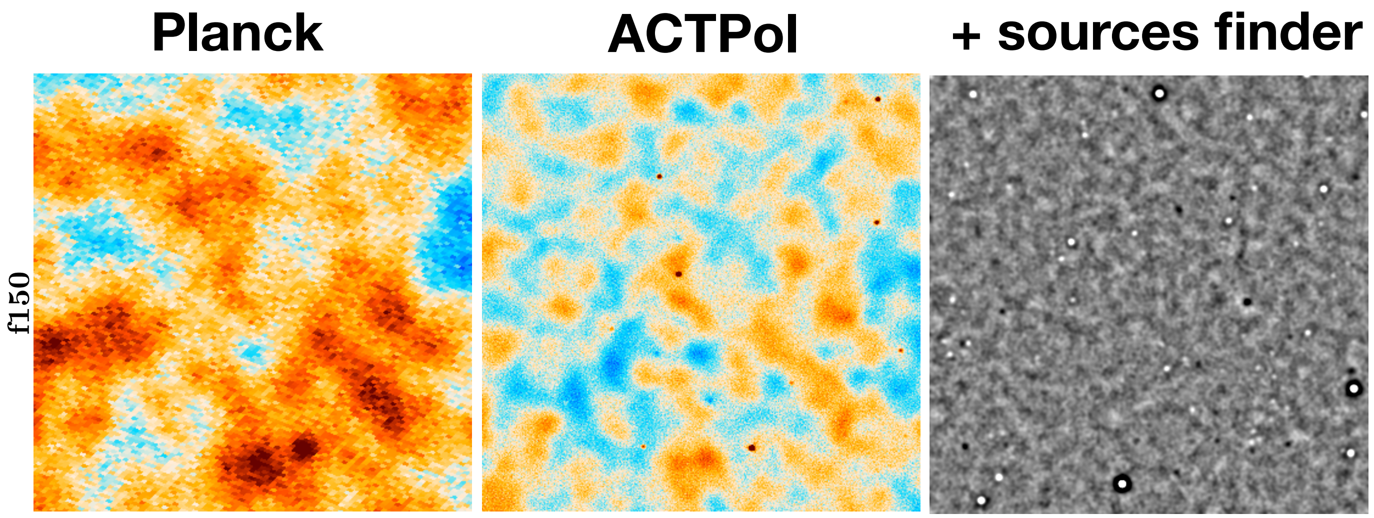
- tSZ cosmological constraining power depends on accuracy of knowledge of SED
  - CIB is the dominant residual in SZ maps, ~20% correlated due to dusty galaxies in clusters
- CIB and tSZxCIB sensitive to properties of different tracers of matter (e.g. mass range and physics)





Infrared sources

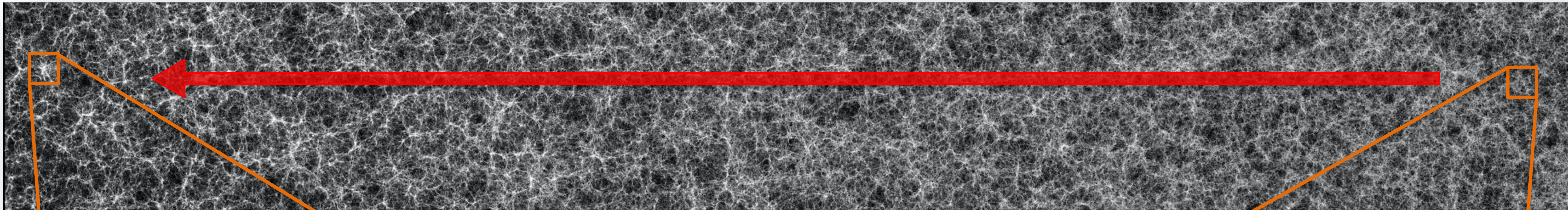
- High sensitivity, large sky area: large number of compact sources (~30k radio)
- AT 225 and 280GHz we will measure ~10.000 IR sources (both local and 2<z<4)
  - ~10/20 mJy at 220/280GHz, fainter sources achievable with match filters, can probe 1e9 Msun halos.



Few more words on protoclusters

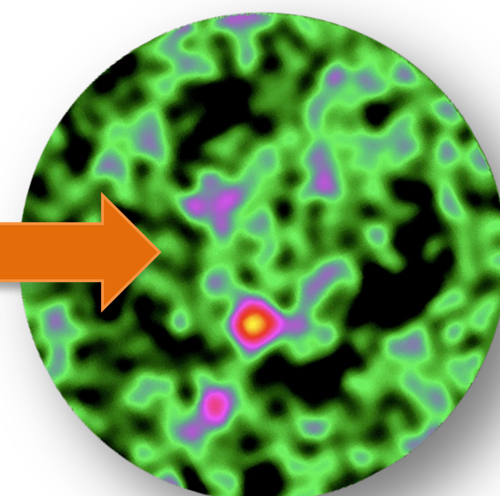
Present time
(z=0)

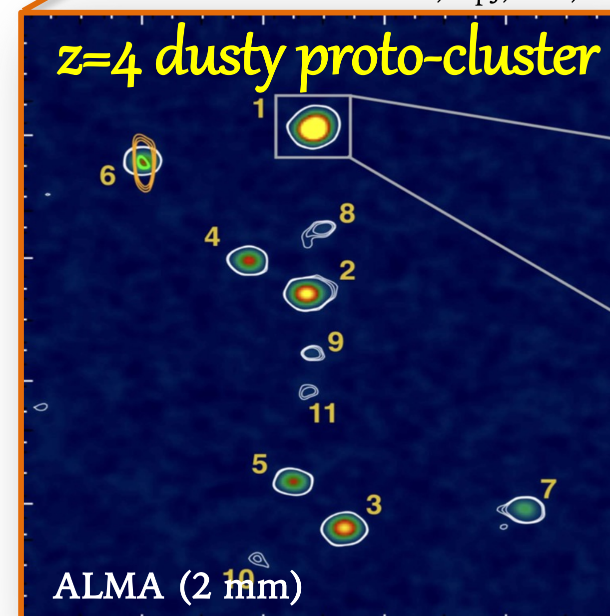
12 billion years ago
(z=4)



850μm SCUBA map of the HDF
[Hughes et al. 1998, *Nature*, 394, 241]

Oteo et al. 2018, ApJ, 856, 72]





The clusters core is dominated by **massive ellipticals**

Dusty SF galaxies (DSFGs) are the progenitors of **massive ellipticals**

High-z *clumps* of DSFGs are the **progenitors of** (the core of) **z=0 galaxy clusters**

Courtesy M. Negrello

Protoclusters forecasts

- Non virialized objects with size comparable to point-sources in CMB maps
  - Will select targets for follow-up observations e.g. w/ ALMA)
  - Few objects detected/confirmed so far and large modeling uncertainties Negrello+2017)

A model for the microwave sky

- ~8Gpc/h box, 6144^3 DM particles with peak-patch method. Gives halos M>10^12.

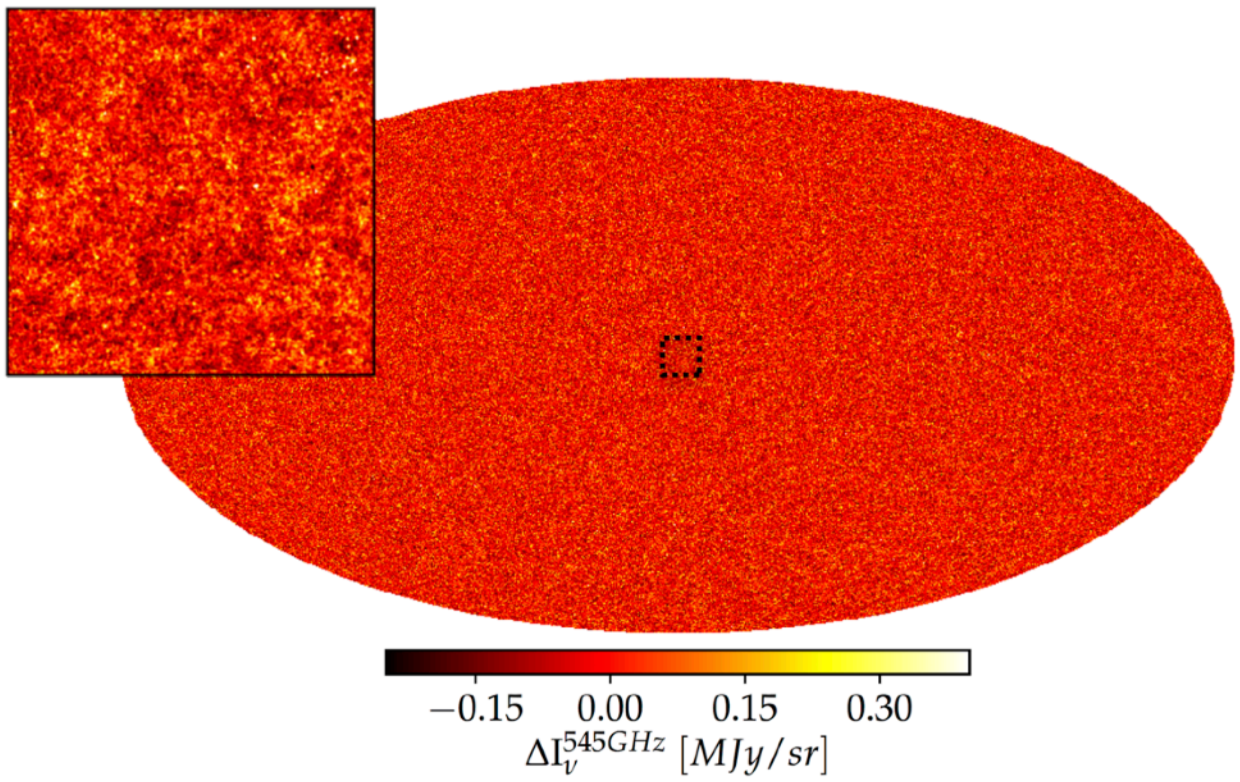
Sheng+2011

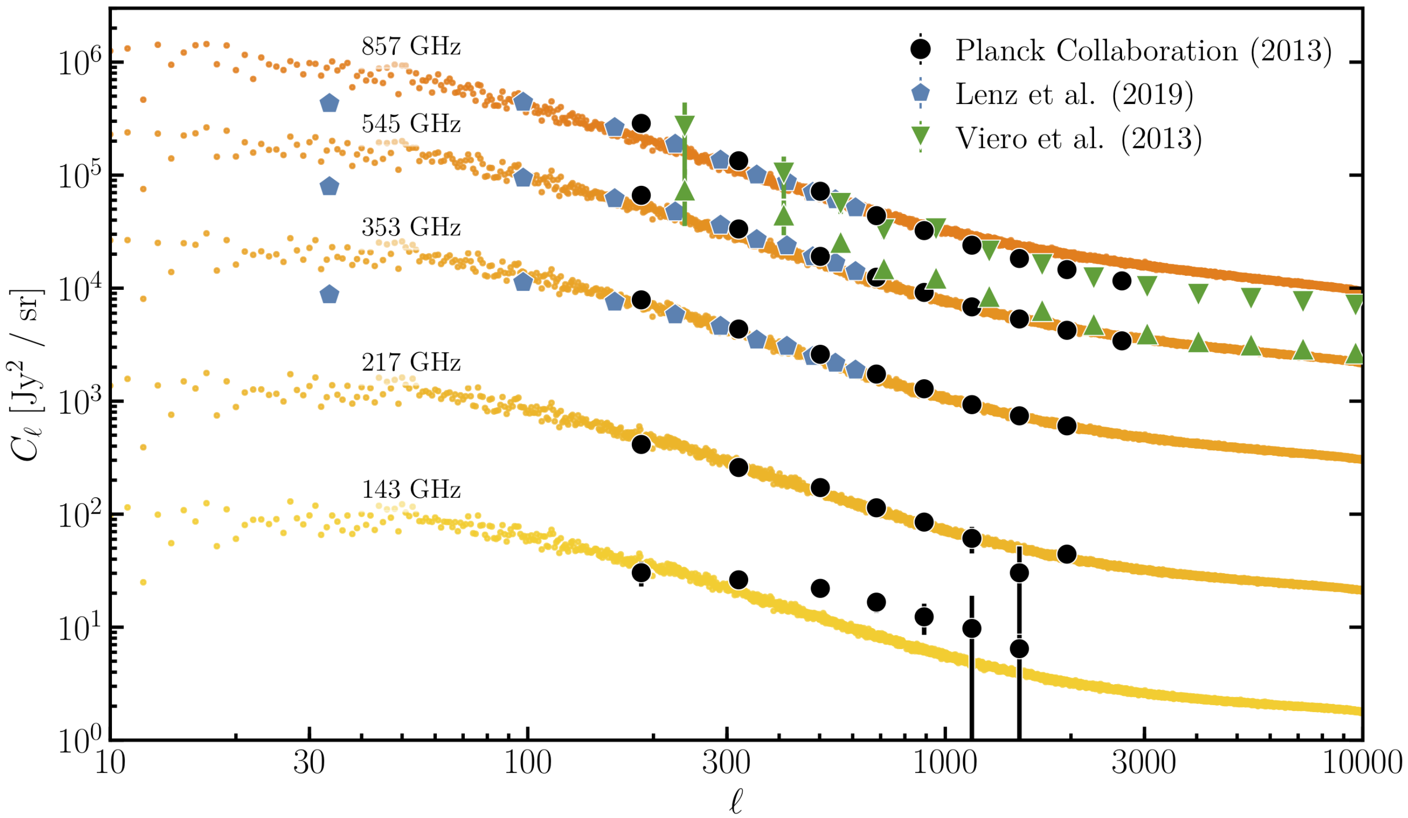
$$L_{(1+z)\nu}(M,z) = L_0 \Phi(z) \Sigma(M,z) \Theta[(1+z)\nu, T_d(z)]$$

- L_0: Global normalization from Planck
- $\Phi(z)$: Redshift normalization
- $\Sigma(M,z)$: Lognormal, suppressed ad low/high mass ends.
- Θ: Greybody SED with fixed dust T

- Power spectrum slope inconsistent with CMB constraints, no S > ~10 mJy at z>0.5.

  - Can we do better? Incorporate more physics to match counts and Cls





Beyond the Websky model

- Alternative halo model Maniyar+2021: more SED templates, SFR-M dependency

$$\mathrm{SFR}(M_h, z) = \eta(M_h, z) \times \mathrm{BAR}(M_h, z)\,.$$

$\eta(M_h, z)$ → Lognormal, suppressed ad low/high mass ends.

$\mathrm{BAR}(M_h, z)$ → "Theoretical"

$$\frac{d j_{\nu,c}}{d\log M_h}(M_h, z) = \frac{d^2 N}{d\log M_h dV} \times \chi^2(1+z) \times \frac{\mathrm{SFR}_c}{K} \times S_\nu^{\mathrm{eff}}(z)$$

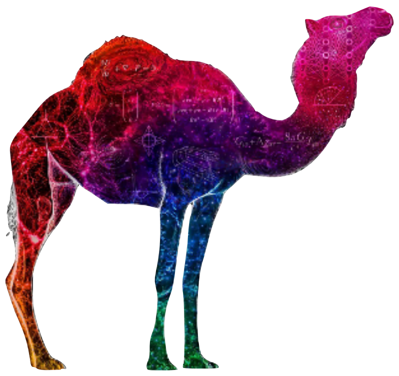
$\frac{d j_{\nu,c}}{d\log M_h}$ → Fitted to Herschel/ Planck power spectra

$S_\nu^{\mathrm{eff}}(z)$ → Template from Herschel

- Cochrane+2022: radiative transfer on FIRE ~10^12 Sun halos, fit scaling from SED fitting.

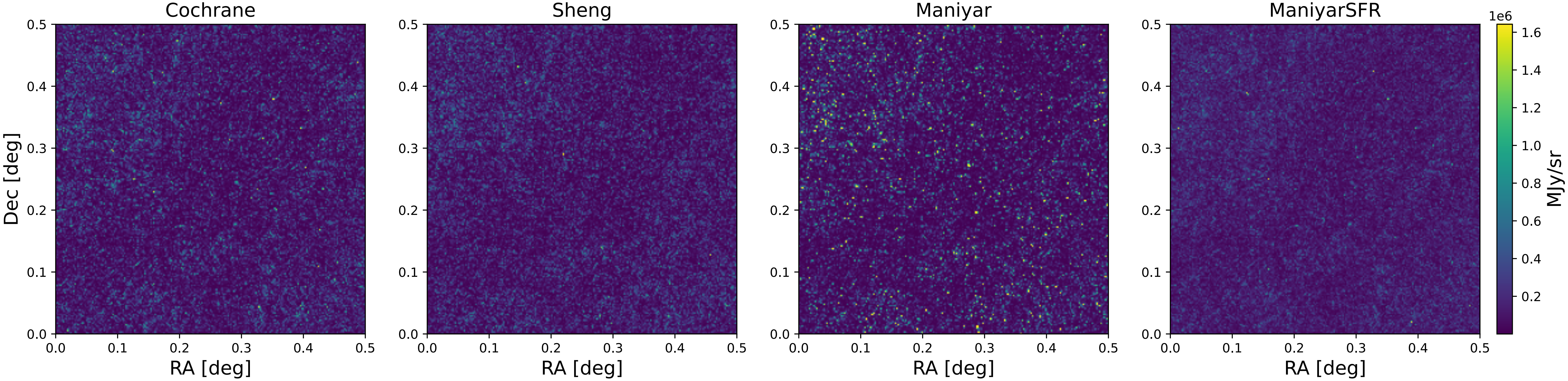
$$S_\nu/\mathrm{mJy} = \alpha \left(\frac{\mathrm{SFR}_{10}}{100\,\mathrm{M}_\odot \mathrm{yr}^{-1}} \right)^{\beta} \left(\frac{M_\star}{10^{10}\,\mathrm{M}_\odot} \right)^{\gamma} \left(\frac{M_{\mathrm{dust}}}{10^{8}\,\mathrm{M}_\odot} \right)^{\delta} (1+z)^{\eta}$$

  - Reproduce ALMA and EAGLE results, <0.2dex error.
  - Cheaper, can be applied to large volumes e.g. CAMELS-SAM
    - w / F. McCarthy, C. Lovell, R. Cochrane, C. Hayward, R. Somerville, D. Spergel, A. Young, F. Villaescusa-Navarro



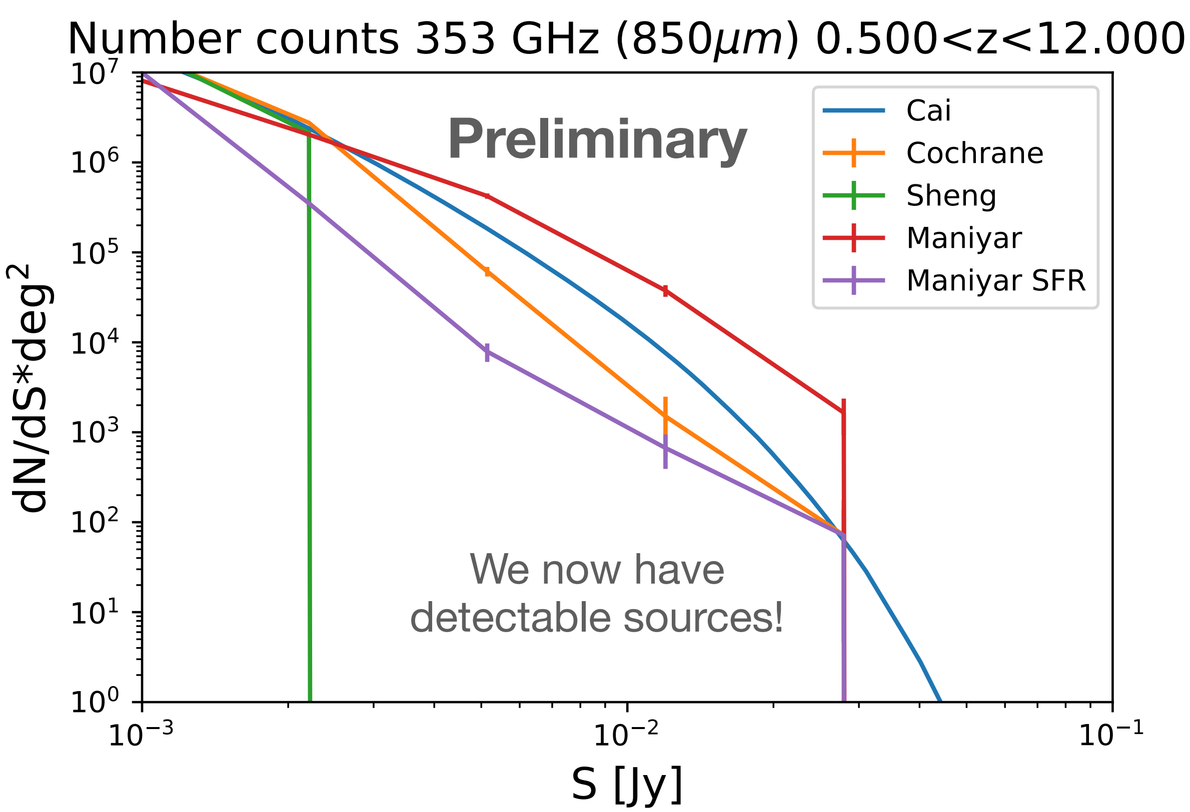
Light-cones

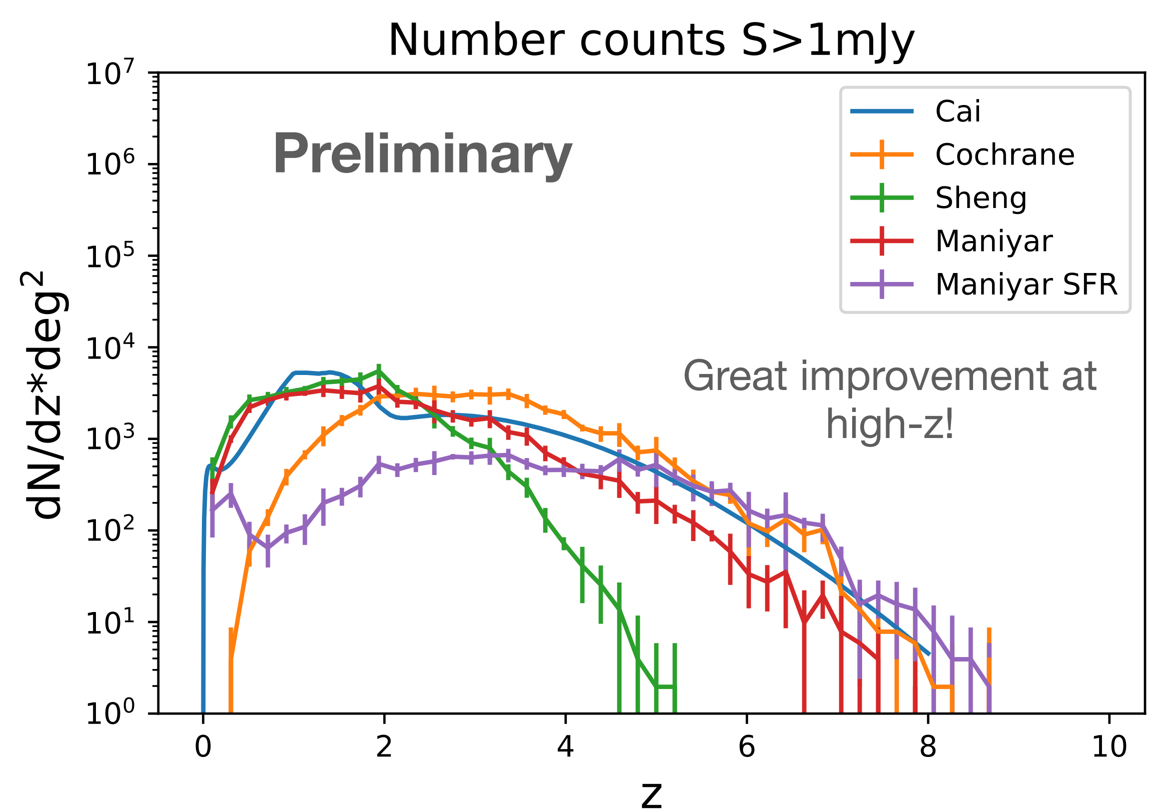
- Limited sky area ~0.5deg2, with all possible recipes starting from same DM subhalos



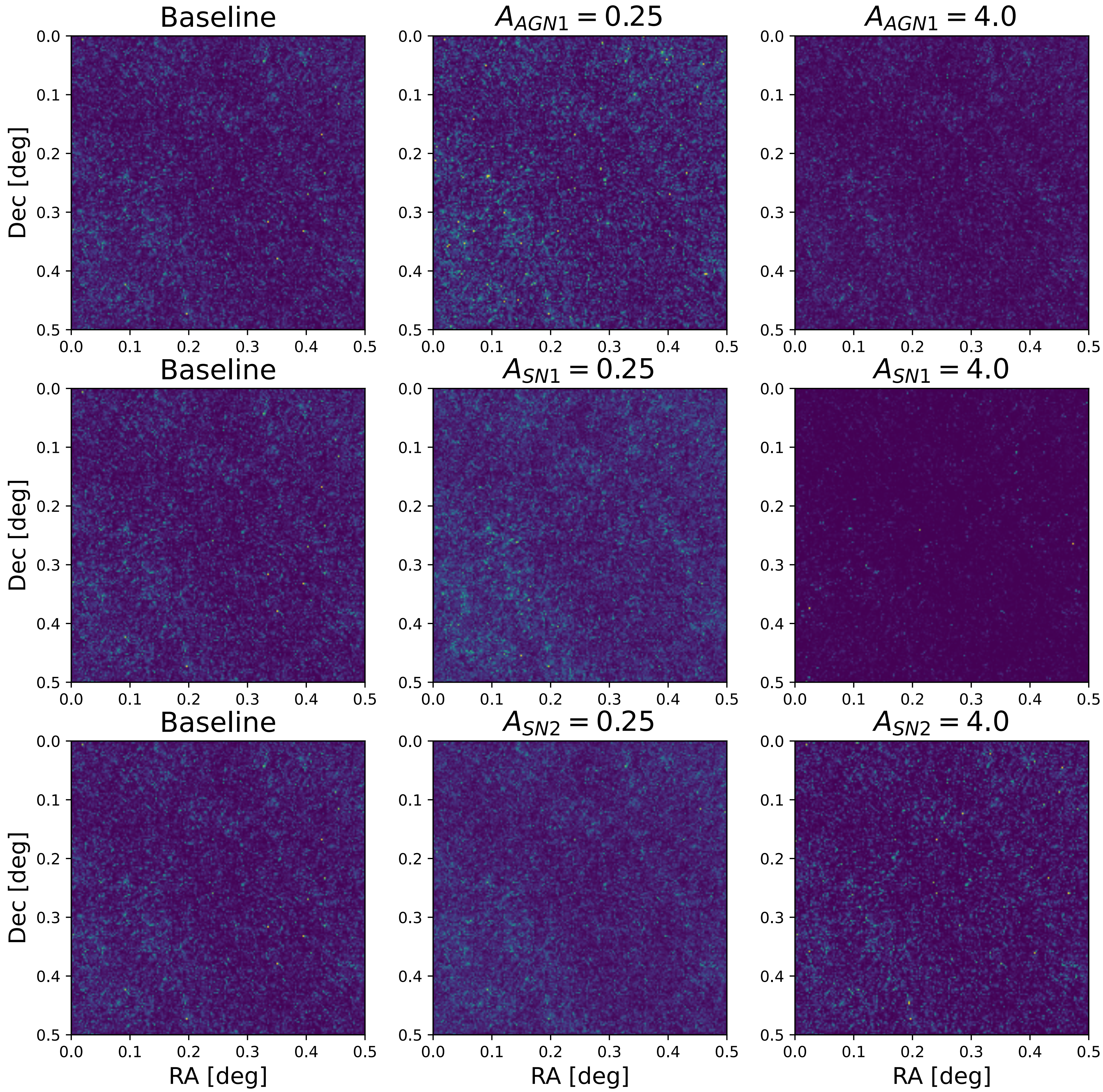
Normalized to FIRAS monopole!

Breaks SFR-M recipe

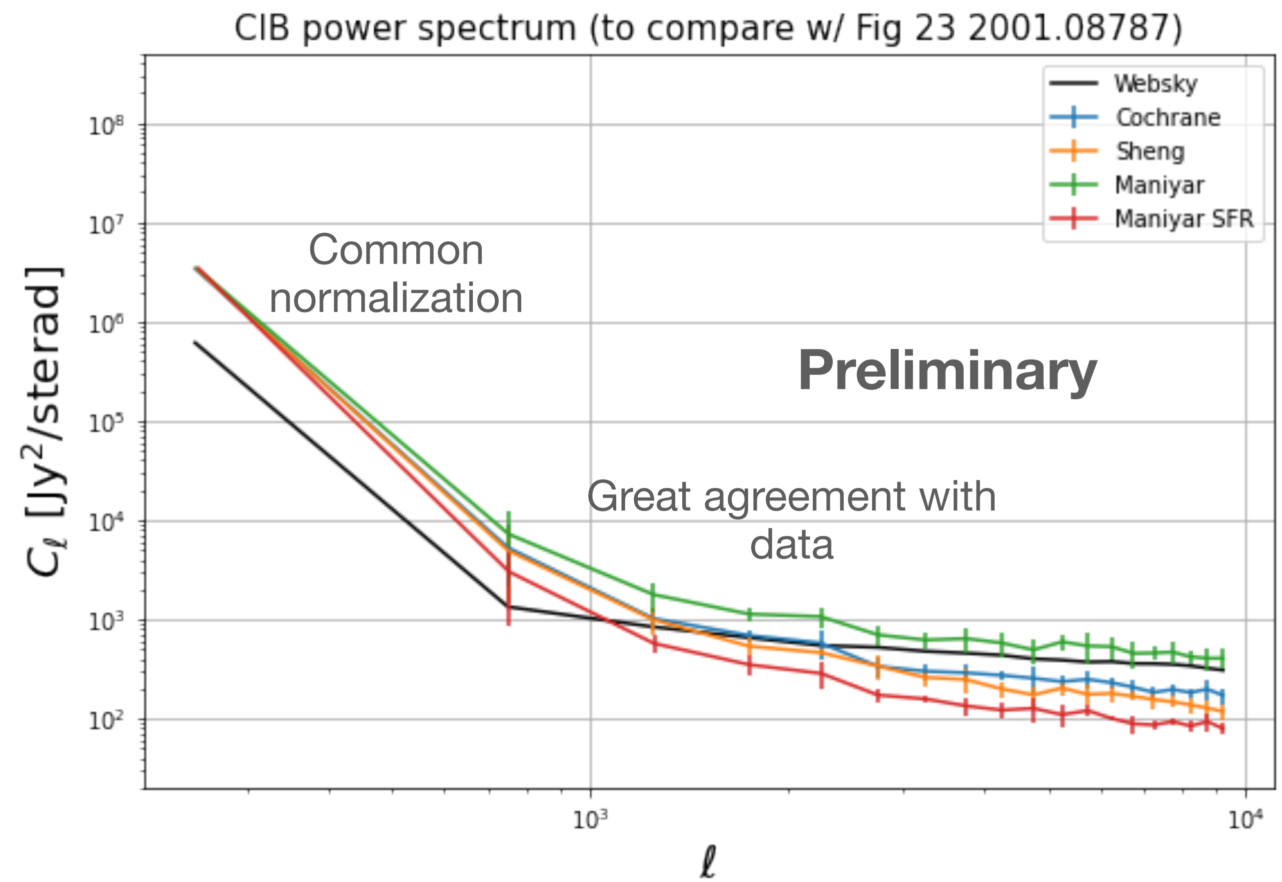




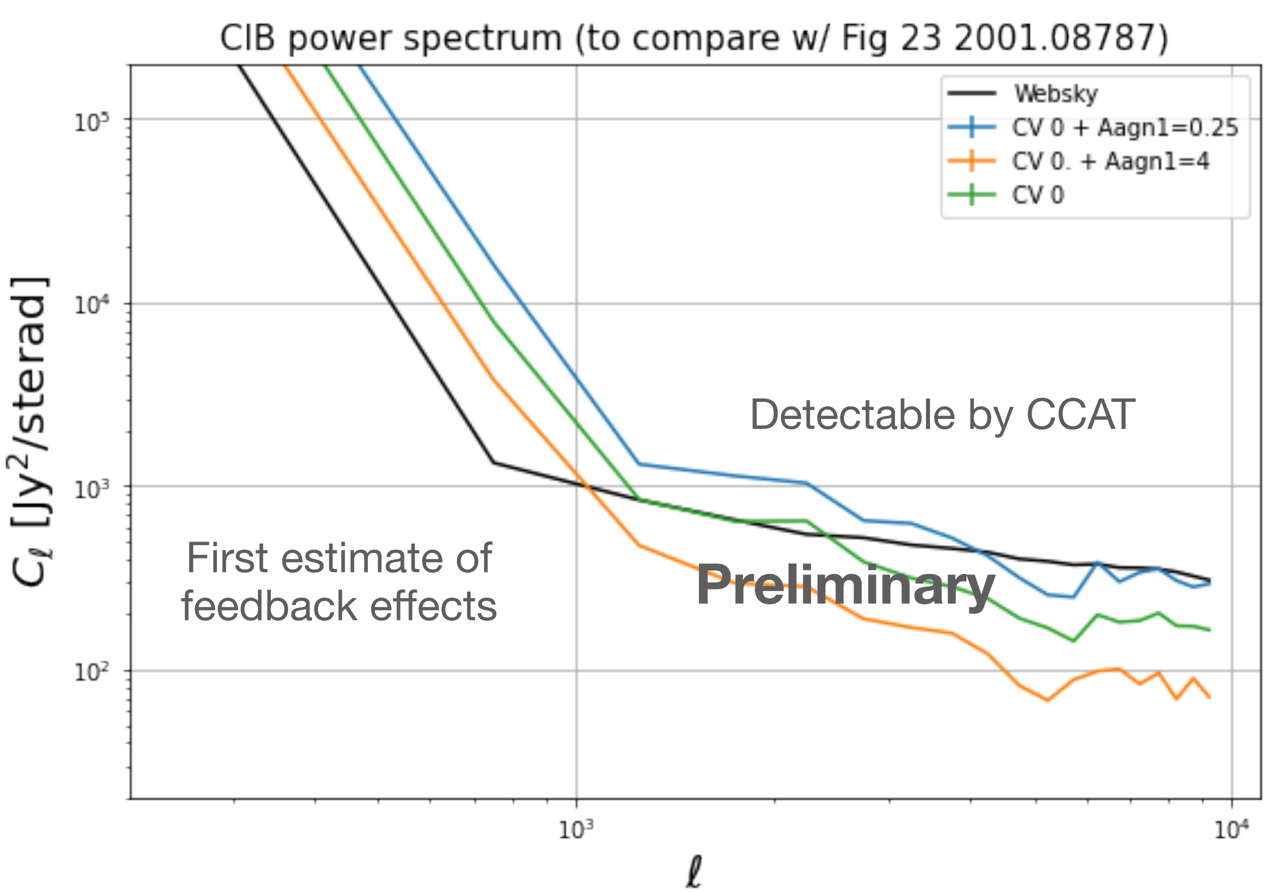
Lightcones and feedback parameters

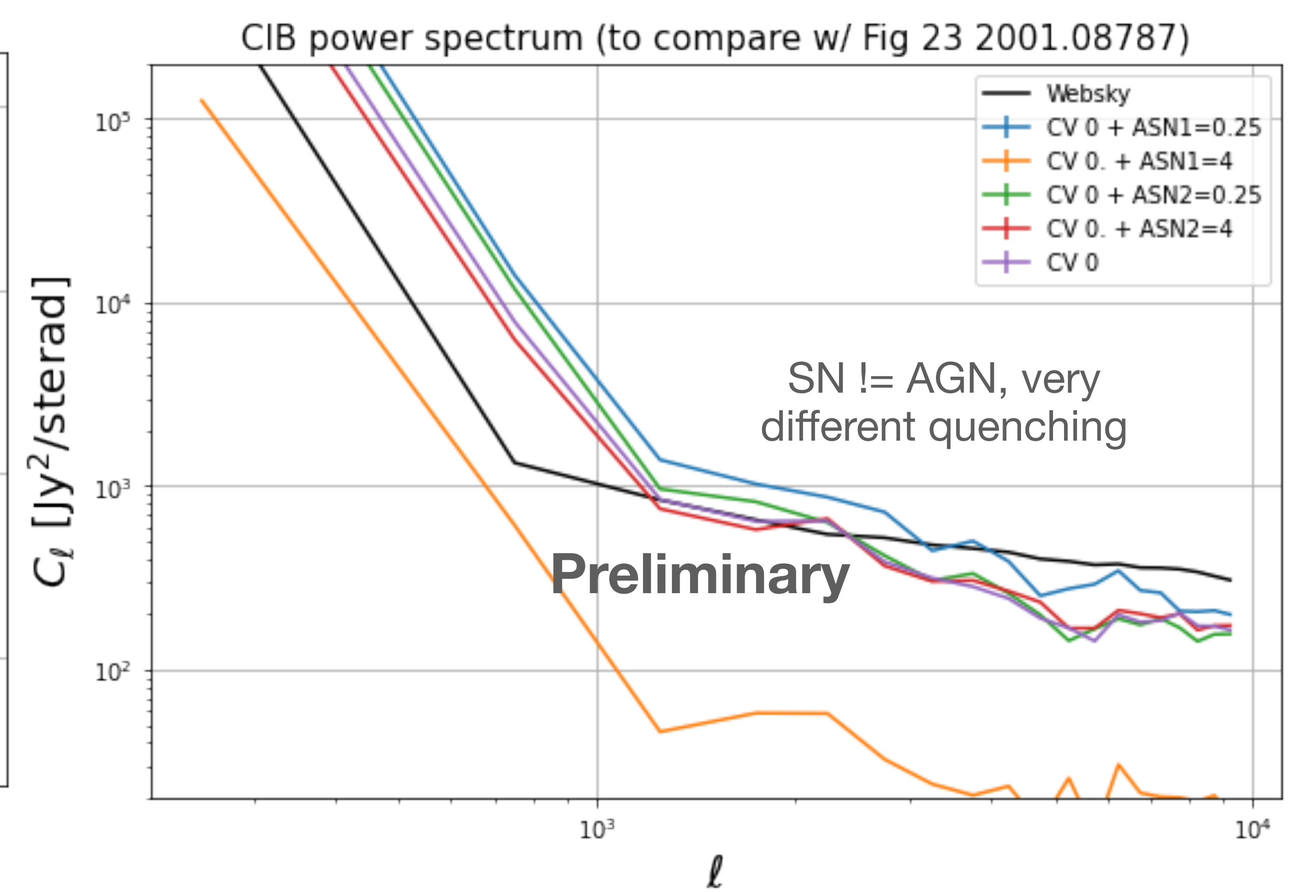


CIB power spectrum



Very different shape at small scale

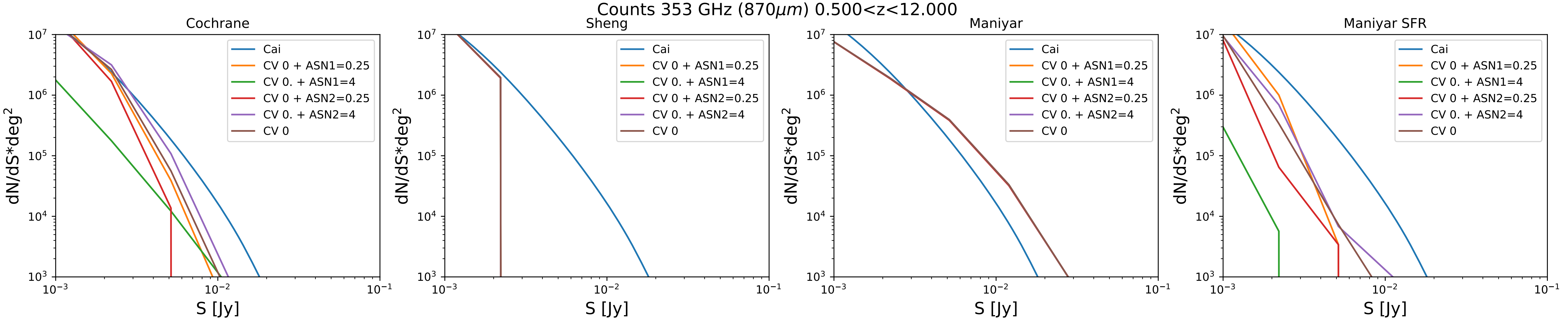


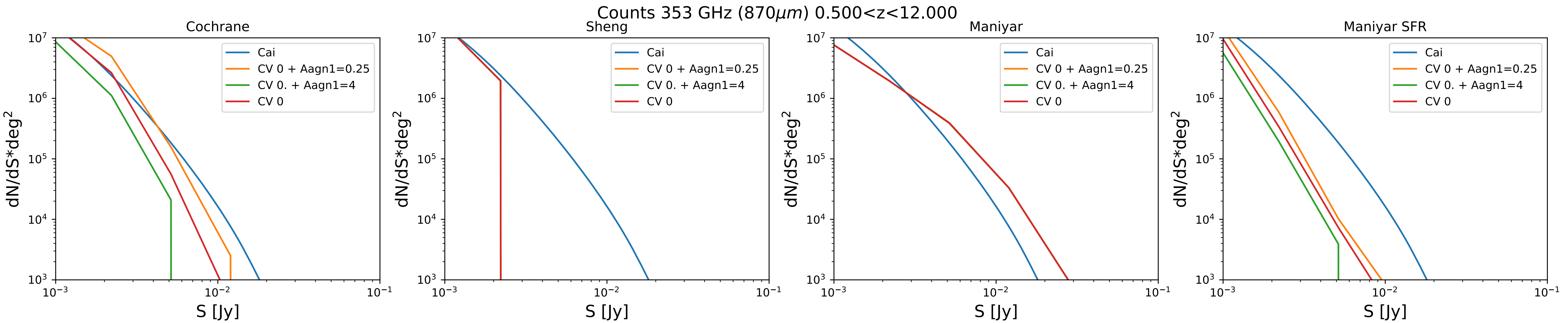


What's next?

- Strong dependency on cosmology and feedback, need to include this complexity ?

  - Emulators / SBI for future data





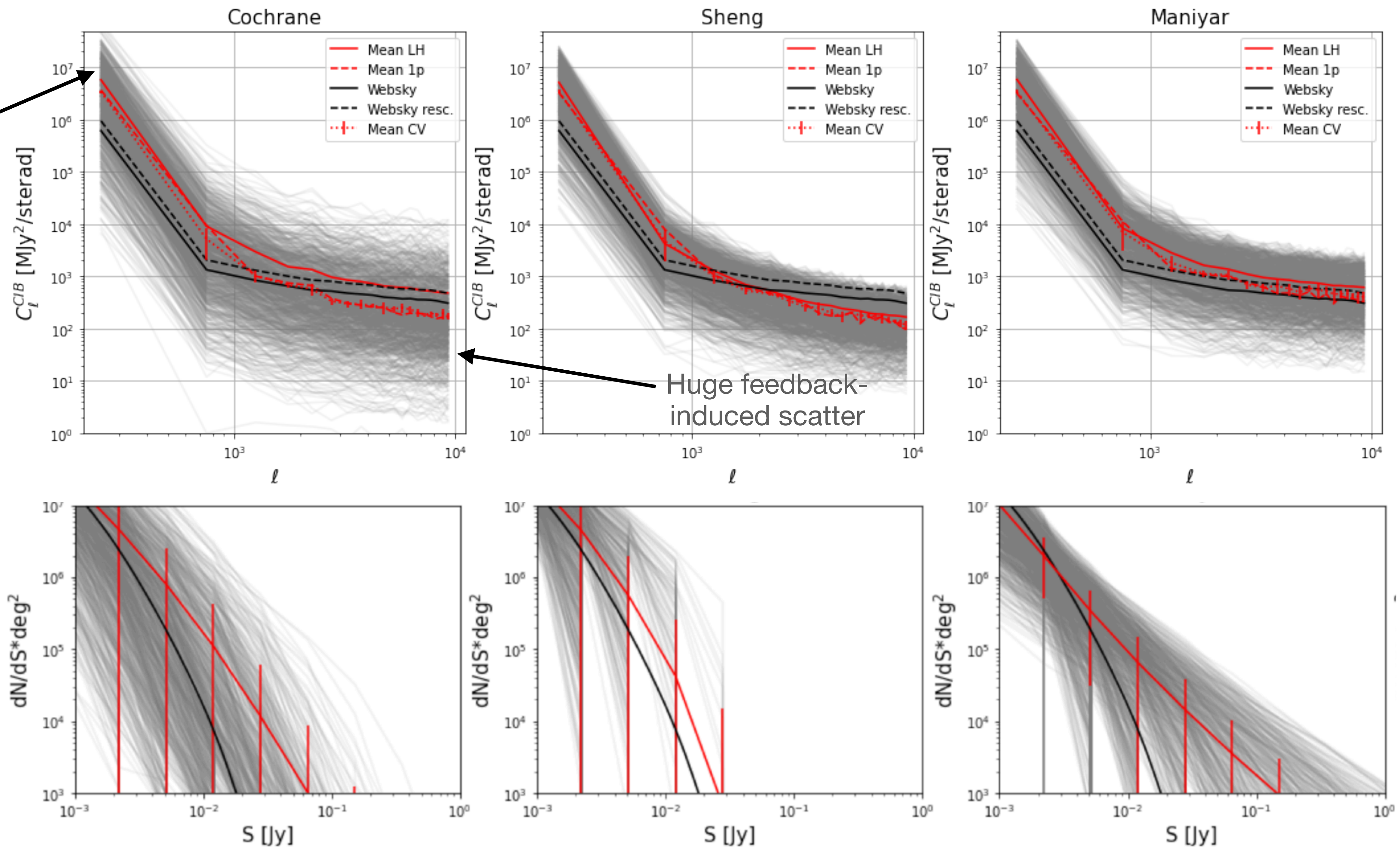
What's next?

- Strong dependency on cosmology and feedback, need to include this complexity ?
  - Emulators / SBI for future data sets (SO, S4, CCAT…)

Common FIRAS normalization, shows difference in monopole

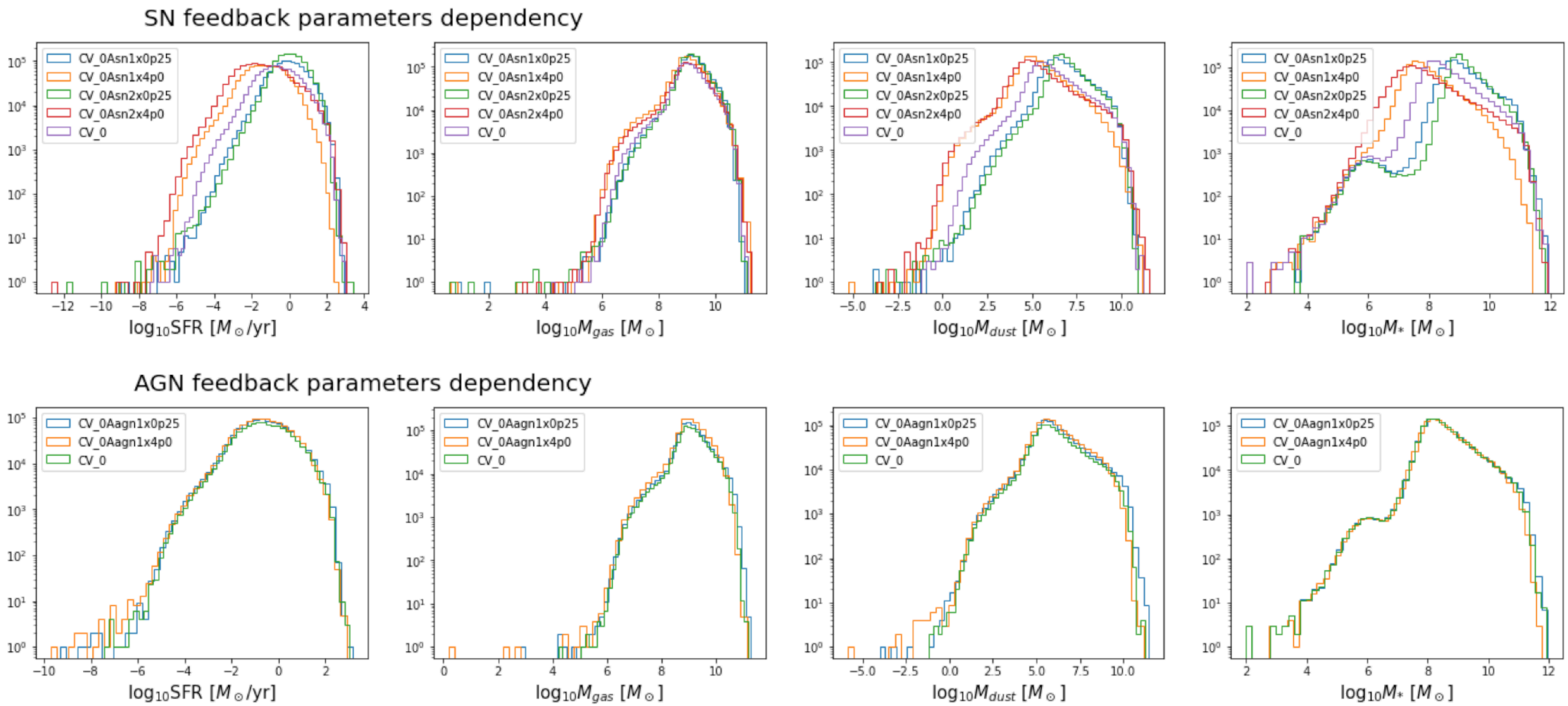
Preliminary

Source counts as probe of cosmology and astrophysics?



Ongoing

- Multi-dimensional problem, need to tie variation of observables to the physics of the sources
  - SN feedback has the strongest effect on a wide range of regimes.



Conclusions

- Cosmic Infrared background is a blessing and a curse for sub-mm observations
    - Hard-to-deal-with foreground for CMB and tSZ. Hard-to-model in simulations
    - Rich science for astrophysics and cosmology (and cross-correlation with lensing, delensing)
- Exciting progress enabled by the right CAMELS data set,
    - Comparison with 2deg2 CANDELS lightcones, adding SZ mocks for cross-correlations
    - Explore similar approach / synergies with hydro simulations (to avoid SAM limitations)
    - Building more informed models for observables and explore SBI or field-level inference
    - Improve simulation recipes with the goal of applying them to large DM simulations (with SAM or ML-inspired methods)
- **Get in touch if you're interested!**