Title: Self-consistent CMB secondaries in the FLAMINGO simulations

Speakers: Ian McCarthy

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Subject: Cosmology

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Abstract:

Secondary anisotropies in the cosmic microwave background (CMB) contain a wealth of cosmological and astrophysical information. However, cleanly separating the individual contributions of the various kinds of anisotropies from each other can be a very challenging task, owing to uncertainties in their spatial, temporal, and spectral dependencies. Realistic mock simulations of the CMB sky are invaluable for testing our methods of separating out the various signals and for making like-with-like comparisons between theory and observations. Previous mocks have relied mostly on dark matter-only simulations with various prescriptions for "painting on" astrophysical signals. Here we present a new set of mocks based on the FLAMINGO suite of cosmological hydrodynamical simulations, where the various anisotropies (tSZ, kSZ, screening, CIB, lensing, radio sources) are derived directly from the properties of the matter, gas and accreting black holes in the simulations. We show that the simulations can reproduce various observational constraints with high accuracy. We also show how these signals depend on cosmology and feedback modelling, and we predict interesting cross-correlations between some of the signals that differs significantly from that predicted by previous mocks.

Self-consistent CMB secondaries in the FLAMINGO simulations

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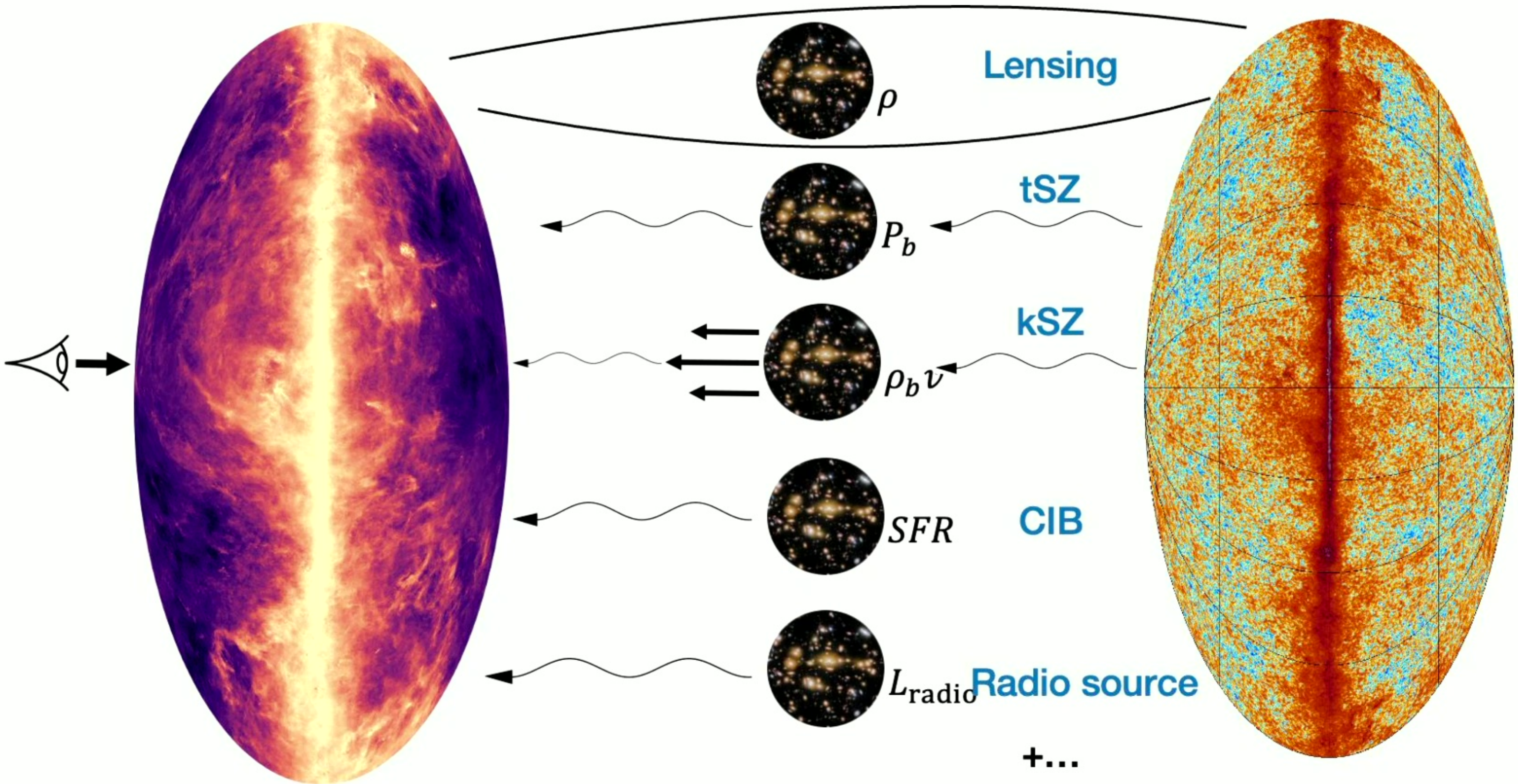
FLAMINGO builders: Joop Schaye, Roi Kugel, John Helly, Matthieu Schaller

+ Boris Bolliet, Jens Chluba, Will Coulton, Fiona McCarthy

Motivation: primary + secondary effects



Project aim

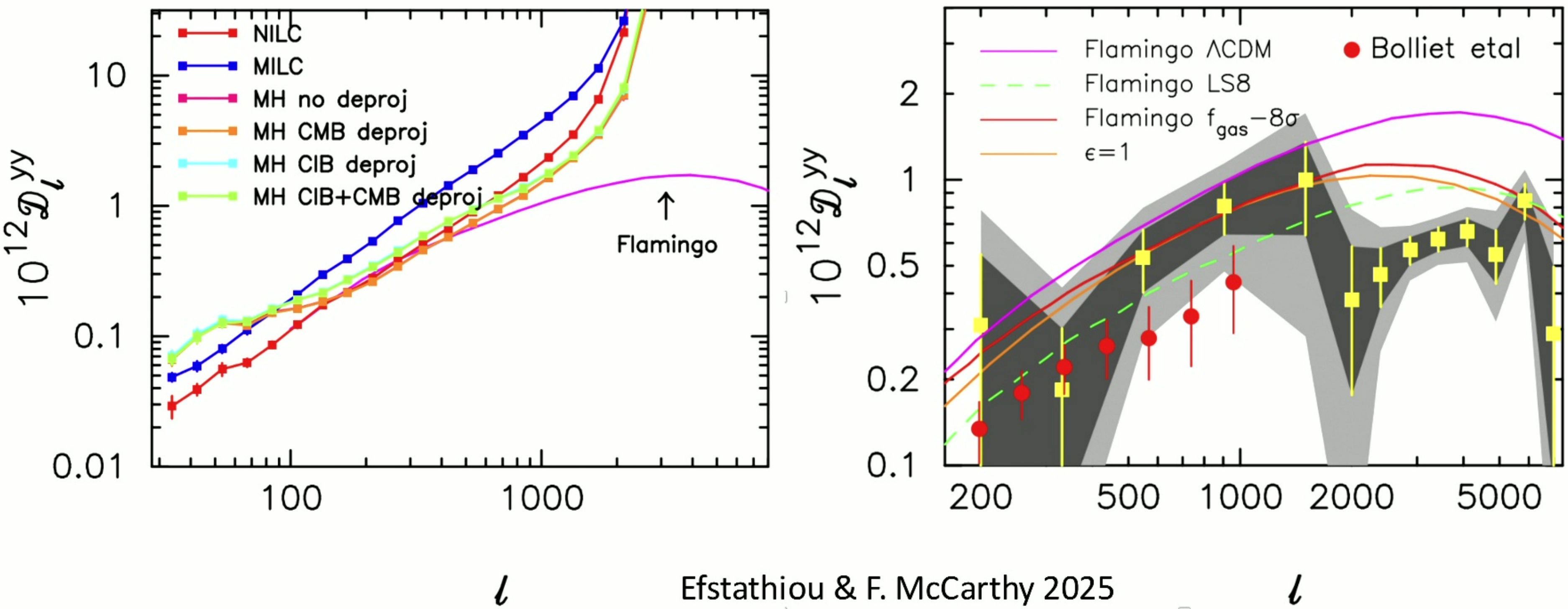
CMB secondaries contain a wealth of information about cosmology and astrophysics

Extracting it can be complicated because of uncertain dependencies of components on spatial scale, frequency, redshift, feedback, etc. ——multi-component CMB simulations are needed.

Goal: create full-sky maps of CMB secondary anisotropies self-consistently, using large-volume hydrodynamical simulations.

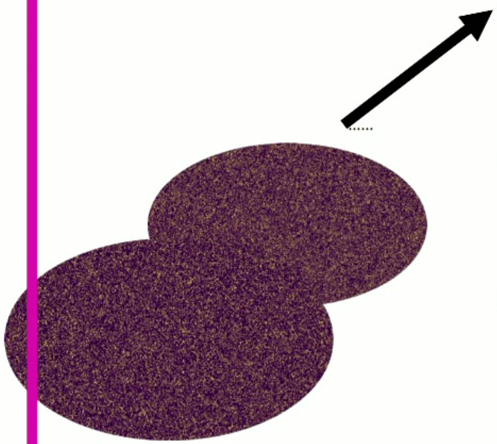
Previous studies (e.g., Sehgal+2010, Websky [Stein+2020], AGORA [Omori 2024]) rely on halo model-based calculations and/or N-body simulations.

Case in point: tSZ power spectrum



Efstathiou & F. McCarthy 2025

CIB modelling



1. Start from the SFR full-sky map: $\frac{L_{\rm bol}}{1\times10^{N_s}L_\odot} = \frac{SFR}{1M_\odot yr^{-1}}$

2. Convert $L_{\rm IR,bol}$ to $L_{\rm IR,\nu}$ using the SED: $L_{IR,\nu} = L_{\rm IR,bol}(SFR)\frac{\int d\nu\Phi(\nu)\tau(\nu)}{\int d\nu\Phi(\nu)}$,

 with SED $\Phi(\nu)$ modelled as a greybody radiation:

$$\Phi(\nu, z, T_0, \beta_d, \alpha_d) = [exp(\frac{h\nu}{kT_{\rm dust}}) - 1]^{-1}\nu^{\beta_d+3},$$

 with $T_{\rm dust} = T_0(1+z)^{\alpha_d}$

3. Compute flux density $S_{\rm IR,\nu}$ per lightcone map: $S_{\rm IR,\nu} = \frac{L_{\rm IR,\nu(1+z)}}{4\pi\chi^2(1+z)}$

4. Compute $S_{\rm IR,\nu}$ power spectrum per lightcone:

$$C_\ell^{\rm iperlc} = C_\ell^{S_{\nu,i},S_{\nu,i}} + 2\Sigma_{i>j}C_\ell^{S_{\nu,i},S_{\nu,j}},$$

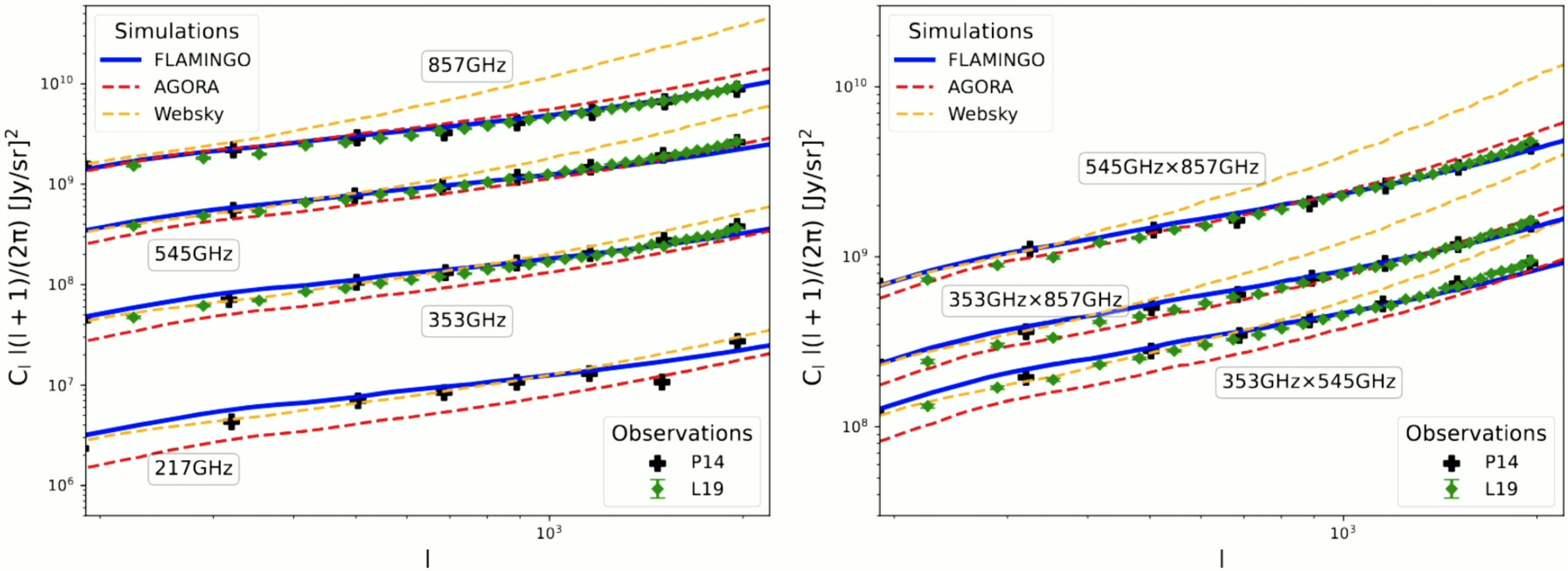
 where $C_\ell^{S_{\nu,i},S_{\nu,j}}$ accounts for the cross-shell correlation term

5. Stack the ps curves up to z = 4.5, fitted with CIB auto-PS data at 353, 545, 857 GHz from Lenz et al. (2019).

Yang, McCarthy+2025, in prep

CIB auto- and cross-ps

SED best fit: $T_0 = 35.11 \pm 0.20, \beta_d = 1.66 \pm 0.05$



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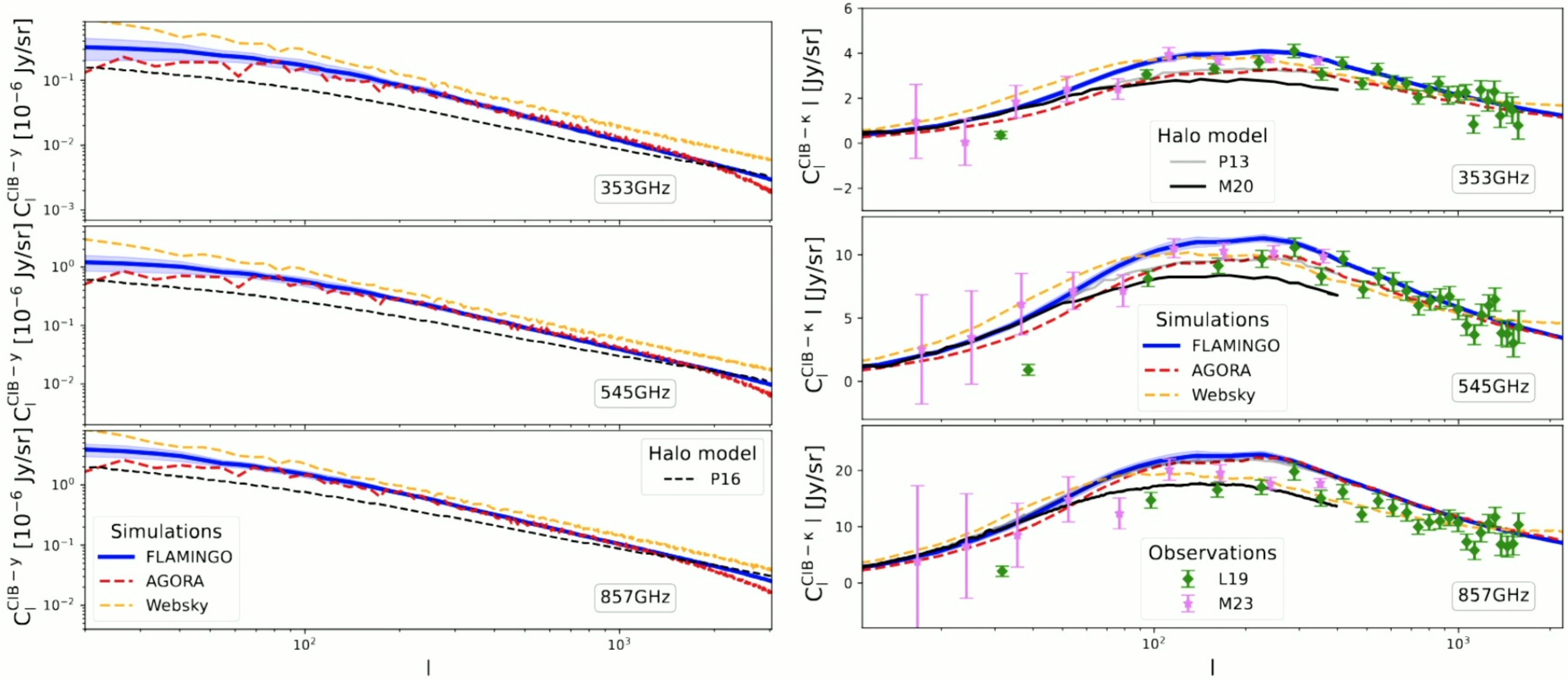
CIB-xxx cross-ps with other CMB secondaries



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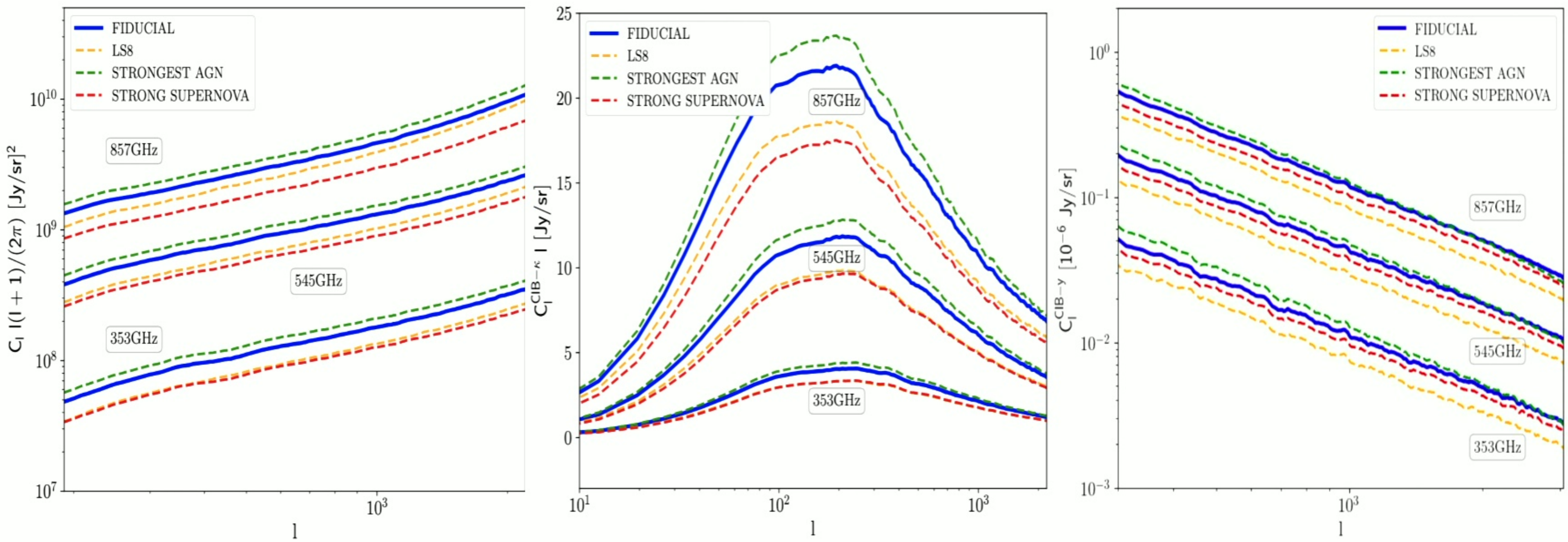
How does feedback affect the CIB and its various crosses?

- Fix the best-fit SED parameters fitted from the FIDUCIAL model, then apply them to SFR maps from other model variations.



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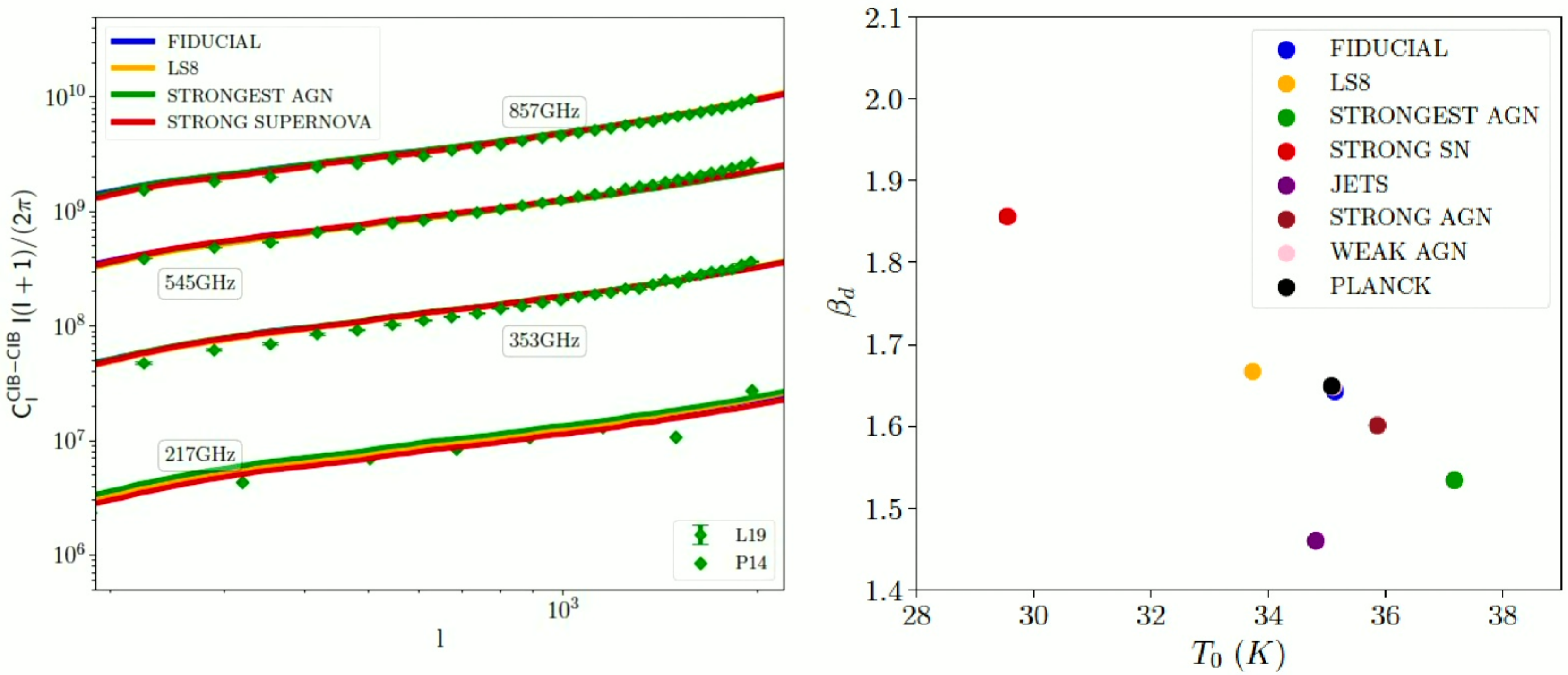
How does feedback affect the CIB and its various crosses?

- Refit SED parameters for each simulation variant (bad news)



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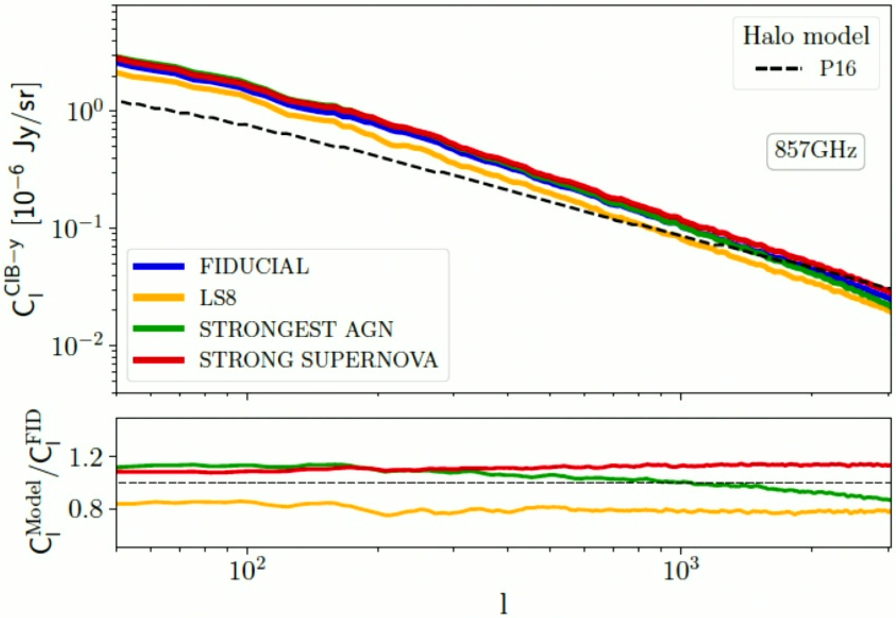
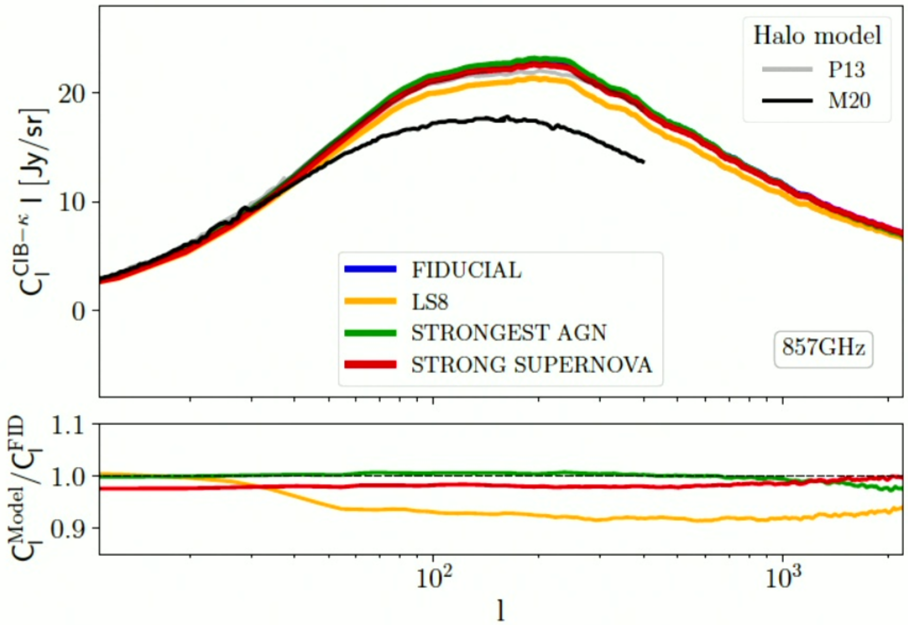




Dependence on feedback and cosmology is retained in the cross-power spectra (good news)

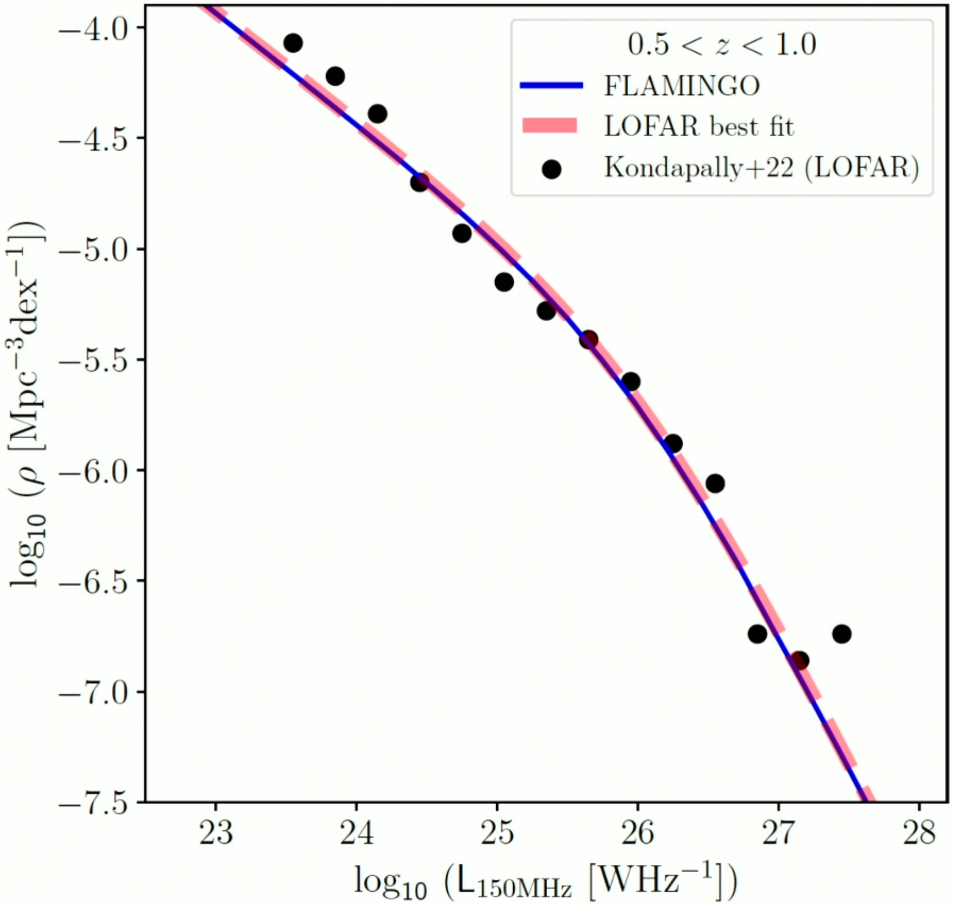
Alternatively: fit CIB params to cross-spectra and predict auto

Radio point

- For each BH ... from $L_{\text{bol,radio}}$ by abundance-r... measured at 150 MHz from th... $M_{\text{BH}}c^2$

- Extrapolate ...encies using $S_\nu =$ $S_{150\text{MHz}}(\nu/150$ ... source count curves from

- Group samp... es ($\lambda_{\text{edd}} =$ $L_{\text{bol,radio}}/L_{\text{edd}}$ ... other LSS tracers separately.



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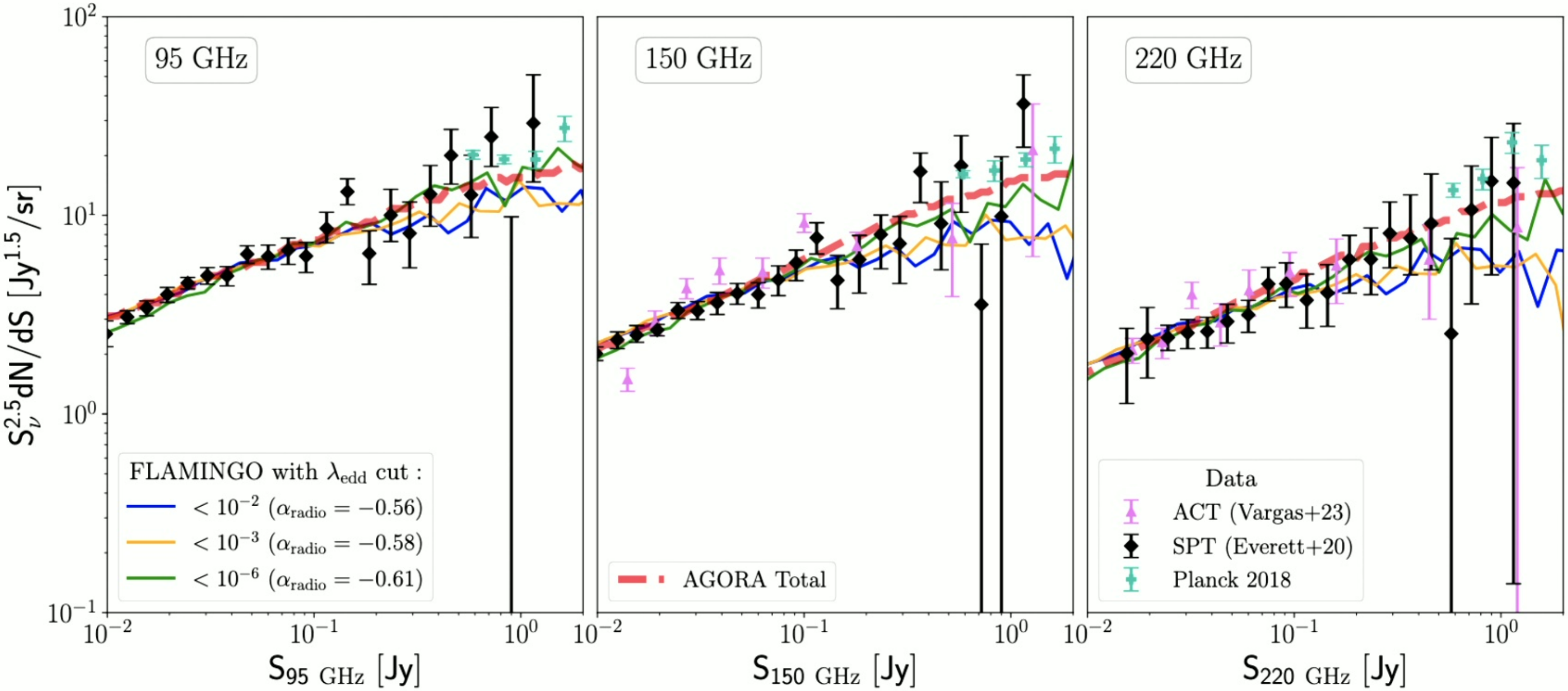
Radio point sources

Source number count:



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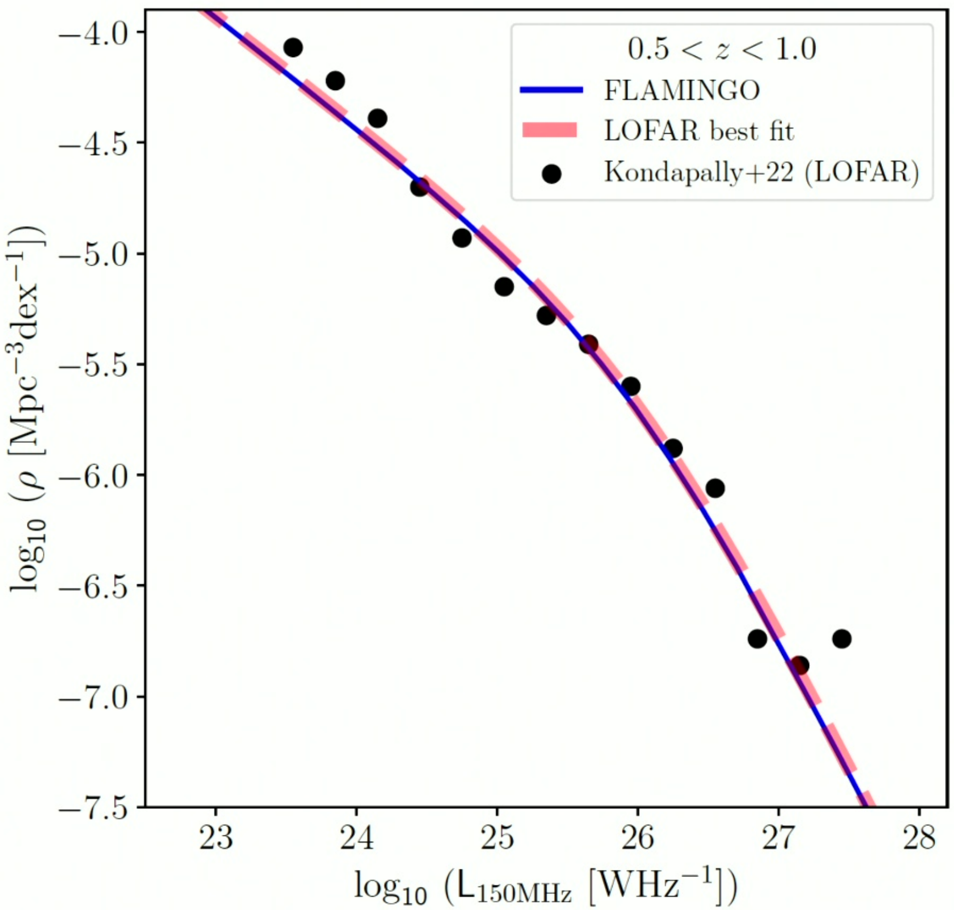

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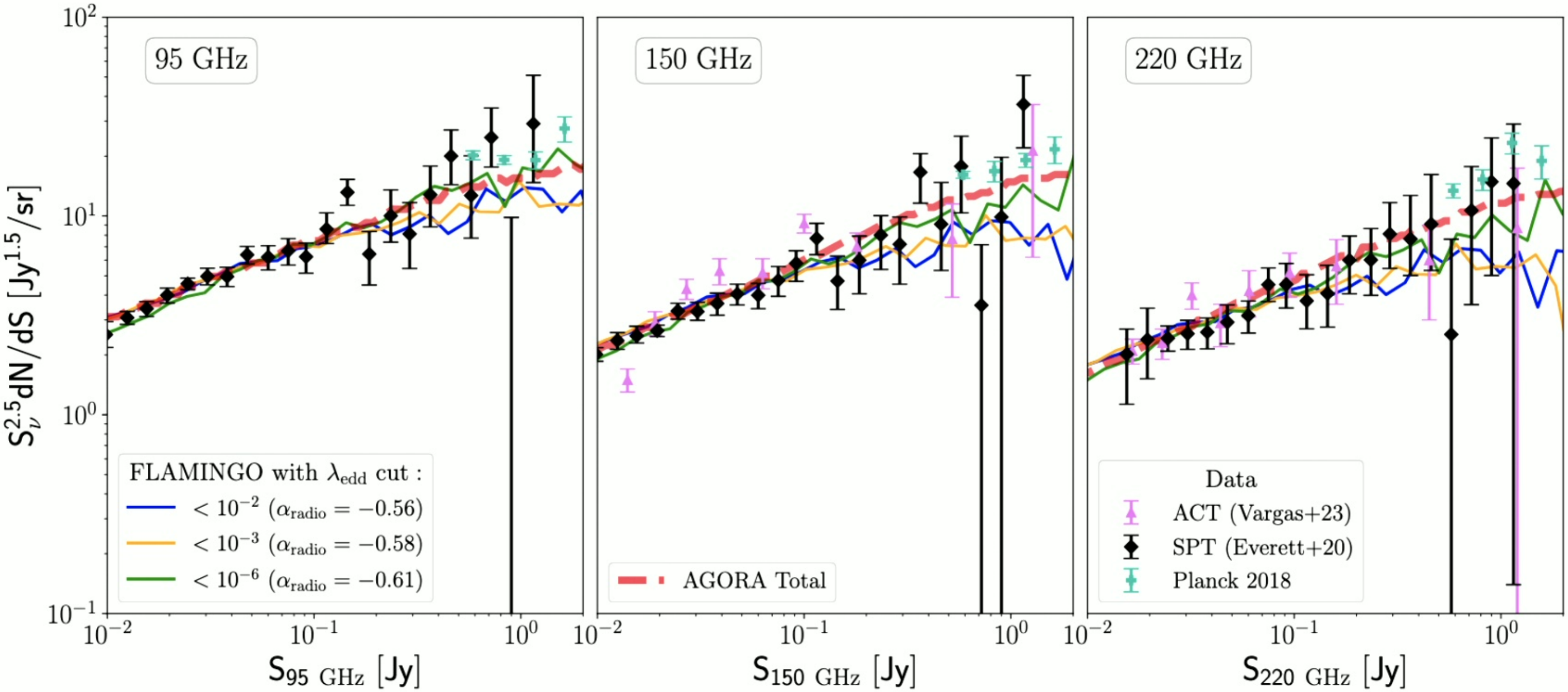
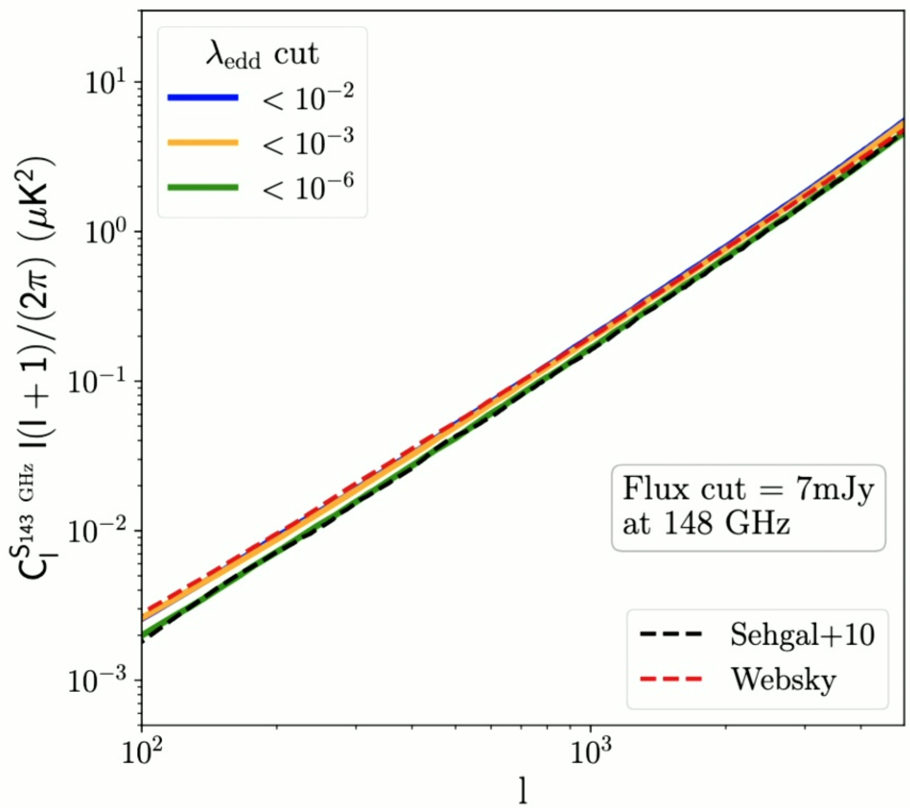
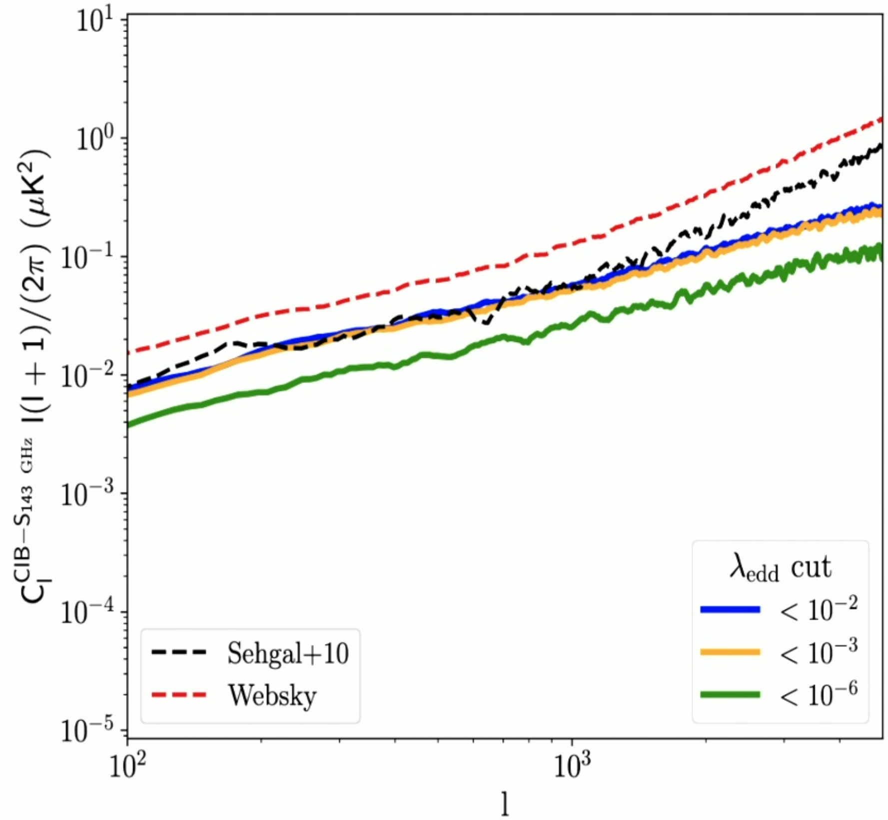


Radio point source

Auto-/cross-power spectrum:

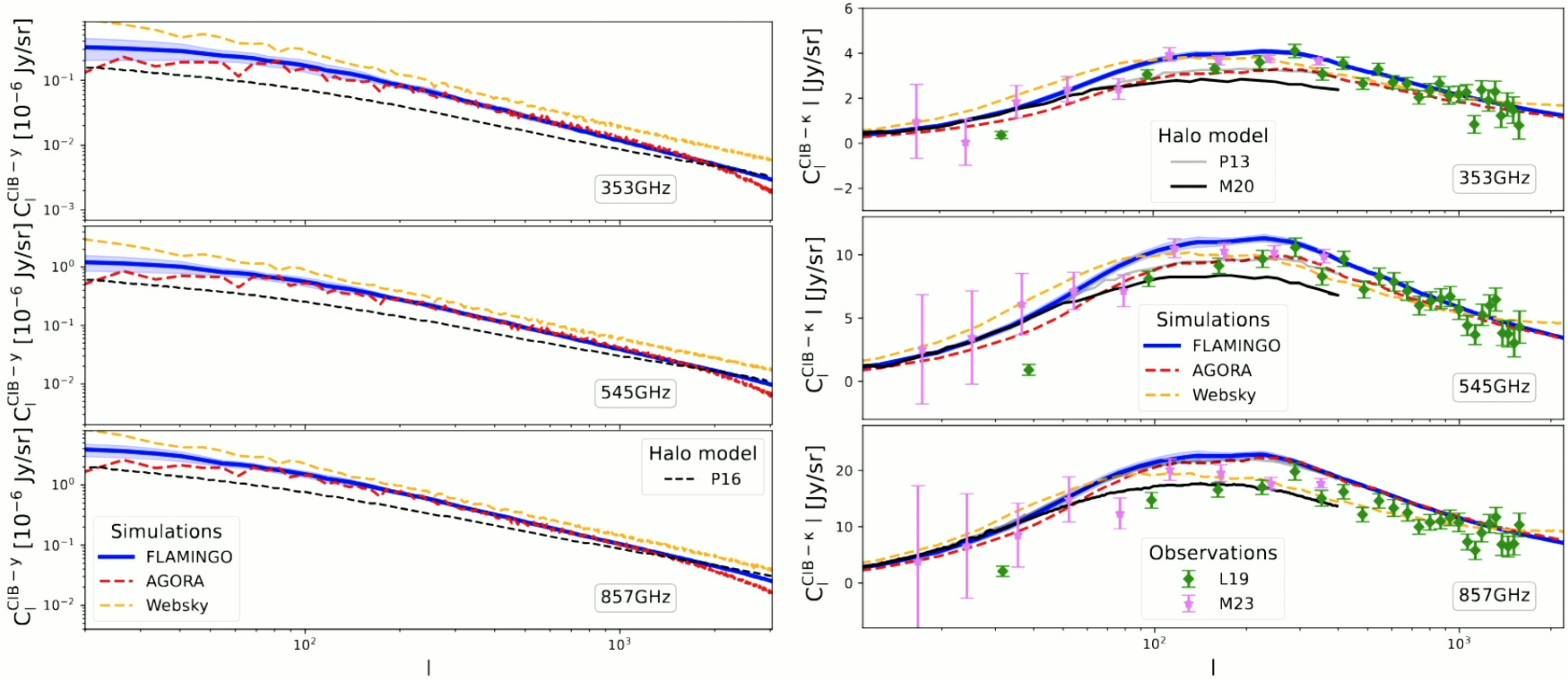




Discussion and Future steps

- We have created a set of CMB secondary anisotropies full-sky maps using the FLAMINGO simulation and its model variants.
- By using the spatial clustering of star-forming gas, we have reconstructed relevant CIB statistics. Feedback effects are noticeable in CIB and CIB-LSS power spectrum.
- We have constructed reasonable SZ statistics that are comparable to other CMB simulations.
- We have recovered the observed source number count from our simple radio model, and there are non-negligible radio-LSS correlations at low frequencies.
    - A more thorough observational comparison (e.g. compared with new ACT data, mask construction, with systematics added and apply with real pipelines—— planned next step)
    - FRBs and line intensity mapping
    - Relativistic tSZ effect

CIB-xxx cross-ps with other CMB secondaries



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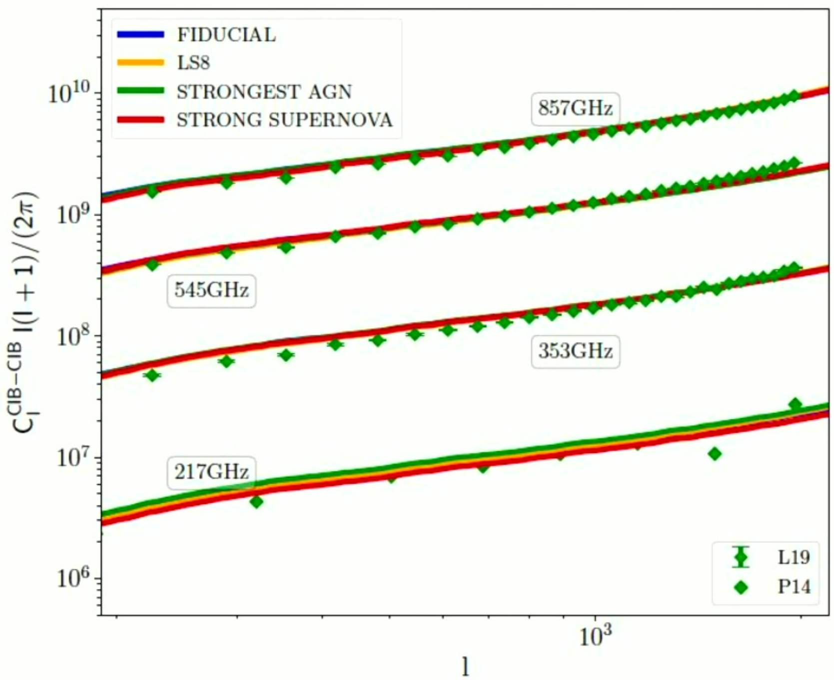

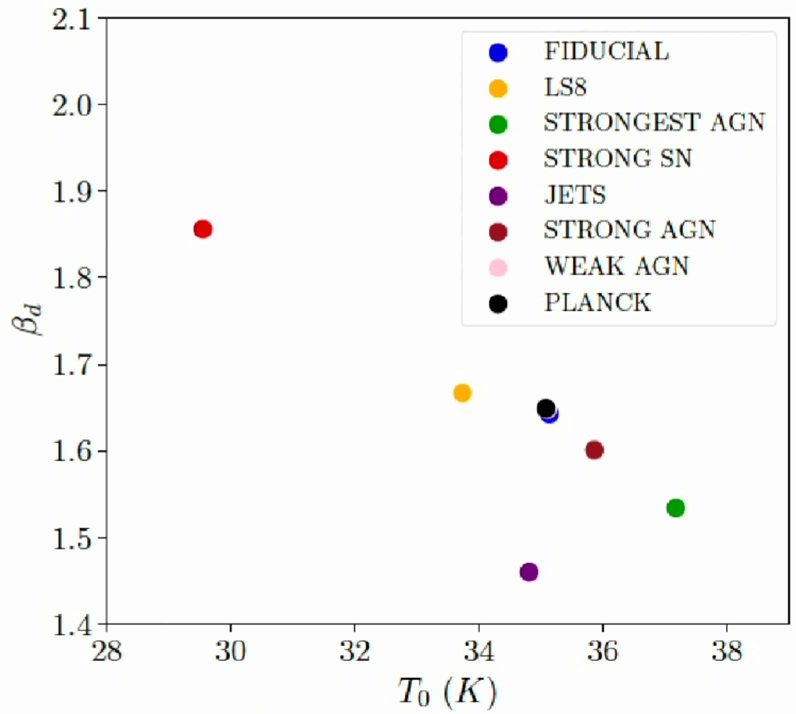

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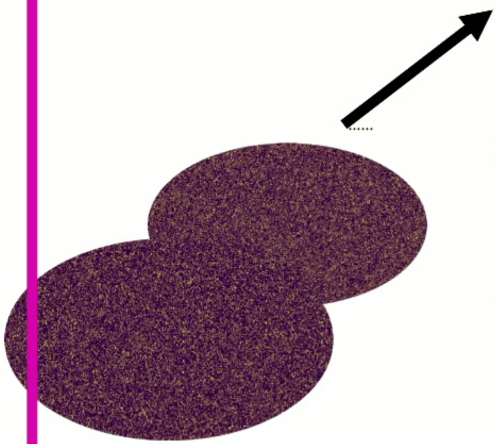
CIB modelling

To sum up:

- Using star formation rate*** lightcones output (up to z = 4.5) from the FLAMINGO
  - $C_\ell^{\mathrm{iperlc}} = C_\ell^{S_{\nu,i},S_{\nu,i}} + 2\Sigma_{i>j} C_\ell^{S_{\nu,i},S_{\nu,j}}$
    - with $C_\ell^{i,i}$ as the auto-PS per shell, and $C_\ell^{i,j}$ as the cross-shell term
- Jointly fitting with CIB auto-PS data at 353, 545, 857 GHz from Lenz et al. (2019).
- Covariance matrix is given by an analytical Gaussian approximation.
- Lensing effect: lensed shell by shell, using the integrated κ-map up to the each shell

*** We have also explored CIB maps using SFR + dust proxy maps

CIB modelling



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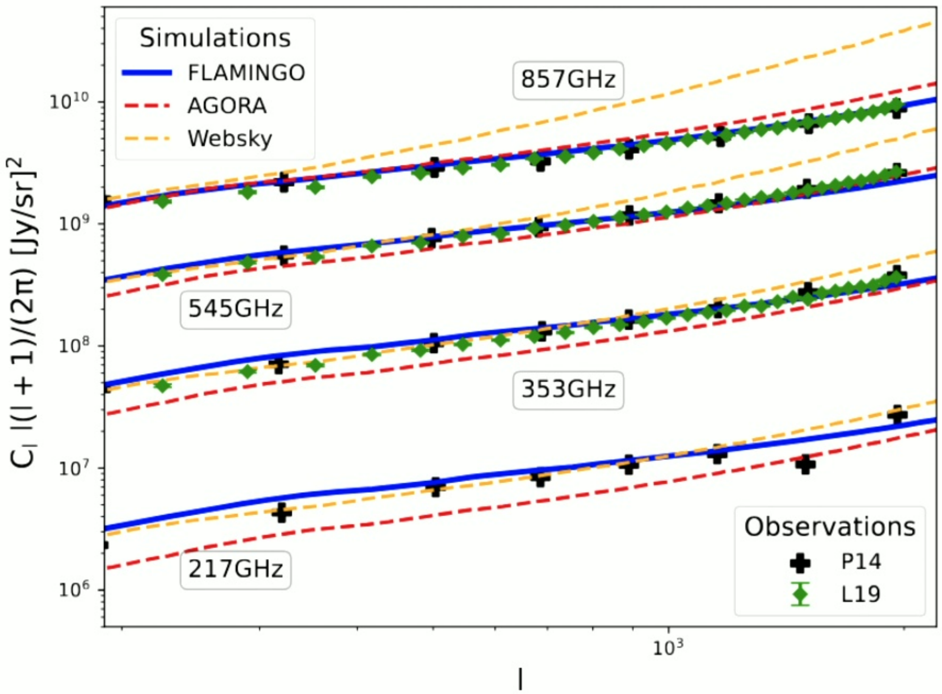

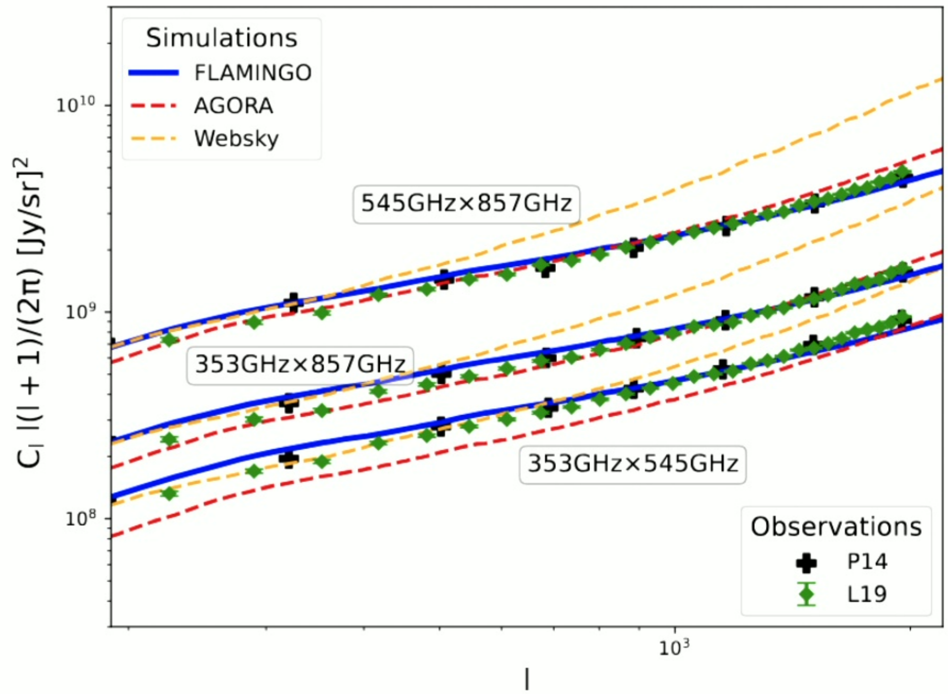

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