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

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Is CMB “the” CMB?

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

![Plot of CMB power spectra](image)

- ICM (g)astrophysics, cosmology (SZ)
- Star formation, cosmology (CIB)
- Extragalactic astronomy, Galaxy evolution

Addison et al. 2012
CMB analysis primer

Fit power spectrum and foreground residuals

From multi-frequency data

Knowing SED of components

Do other cool science!

Get 22k citations!

\[ \Omega_b, \Omega_{cdm}, \Omega_\Lambda, \Omega_k, n_s, \sigma_8, \tau, \sum m_\nu, w, h, N_{eff} \ldots \]
CMB analysis primer

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CMB analysis primer

1. Fit power spectrum and foreground residuals

2. Knowing SED of components

3. From multi-frequency data

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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

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.

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

- **z=0 galaxy cluster**
  - Courtesy M. Negrello

- **z=4 dusty proto-cluster**
  - Courtesy M. Negrello

- **ALMA (2 mm)**
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


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

Global normalization from Planck
Redshift normalization
Lognormal, suppressed ad low/high mass ends.
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 CIs
**Beyond the Websky model**

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

\[
SFR(M_h, z) = \eta(M_h, z) \times BAR(M_h, z).
\]

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

\[
S_{\nu}/\text{mJy} = \alpha \left( \frac{\text{SFR}_{10}}{100 \, M_\odot \, \text{yr}^{-1}} \right)^{B} \left( \frac{M_*}{10^{10} \, M_\odot} \right)^{\gamma} \left( \frac{M_{\text{dust}}}{10^{8} \, M_\odot} \right)^{\delta} (1 + z)^{\eta}
\]

- 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
- Limited sky area \( \sim 0.5\text{deg}^2 \), with all possible recipes starting from same DM subhalos

**Number counts 353 GHz (850\,\mu m) 0.500<z<12.000**

We now have detectable sources!

**Number counts S>1mJy**

Great improvement at high-z!
Lightcones and feedback parameters

Baseline

$A_{\text{AGN}} = 0.25$

$A_{\text{AGN}} = 4.0$

Baseline

$A_{\text{SN1}} = 0.25$

$A_{\text{SN1}} = 4.0$

Baseline

$A_{\text{SN2}} = 0.25$

$A_{\text{SN2}} = 4.0$

Giulio Fabbian

CAMELS workshop 2022
CIB power spectrum

- Common normalization
- Great agreement with data
- Very different shape at small scale

- Detectable by CCAT
- First estimate of feedback effects

- SN != AGN, very different quenching

Preliminary
What’s next?

- Strong dependency on cosmology and feedback, need to include this complexity?
- Emulators / SBI for future data
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- Strong dependency on cosmology and feedback, need to include this complexity?

- Emulators / SBI for future data sets (SO, S4, CCAT…)

Preliminary

Common FIRAS normalization, shows difference in monopole

Huge feedback-induced scatter

Source counts as probe of cosmology and astrophysics?
• 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!