# CMB-HD Foregrounds: Source Detection and Removal

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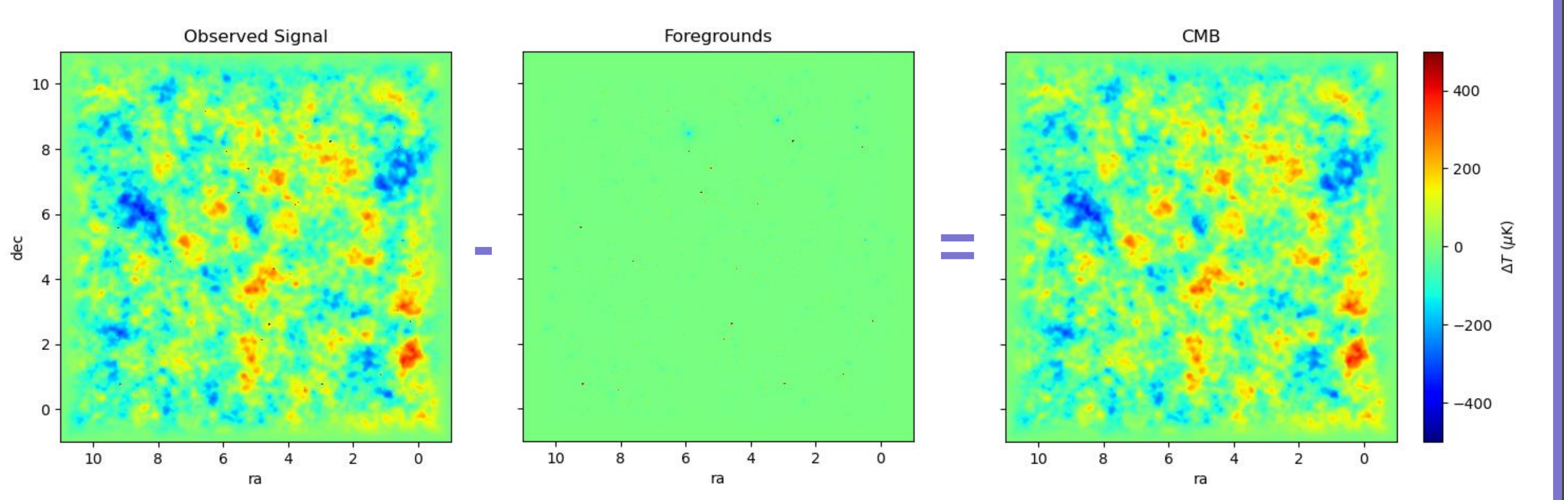
## CMB Foregrounds

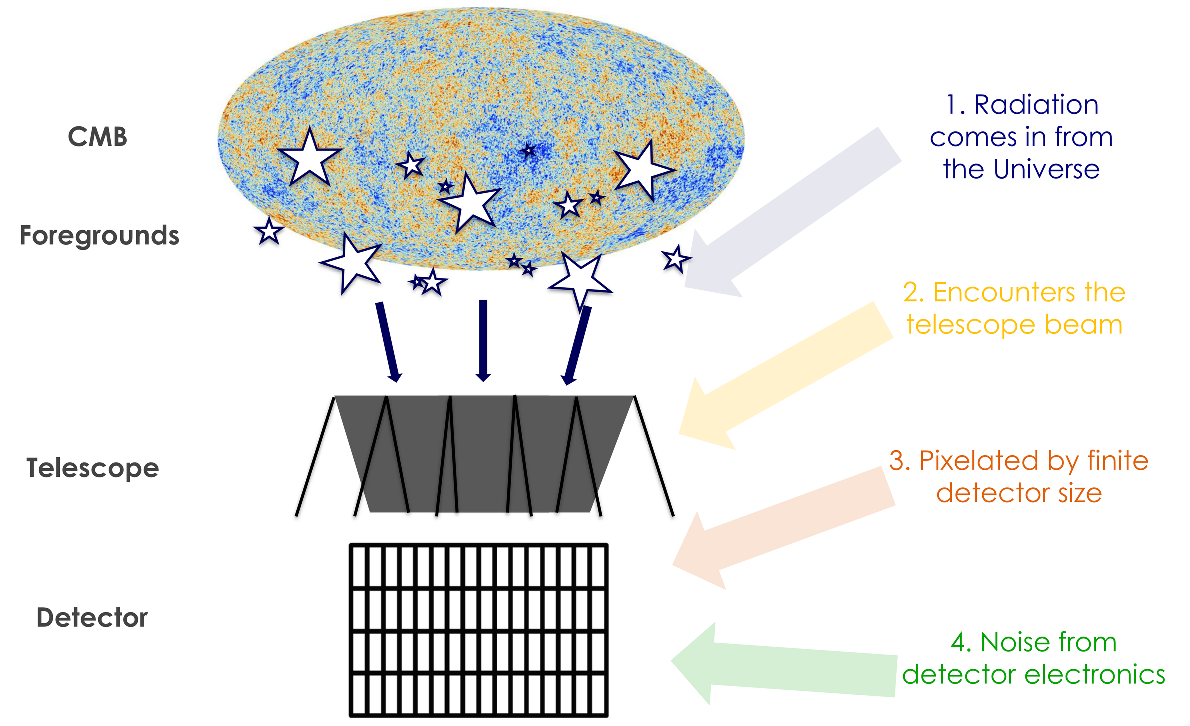
The Cosmic Microwave Background (CMB) is a faint pattern of light from 13.8 billion years ago that permeates the sky. It has been instrumental in shaping our modern understanding of the Universe and its evolution. The proposed CMB-HD experiment will be able to measure the CMB signal at higher levels of precision than ever before, granting us finer inferences of the contents and history of the Universe. Thus, it becomes vital that we can measure this light in a manner that isn't contaminated by the various foregrounds of the Universe.

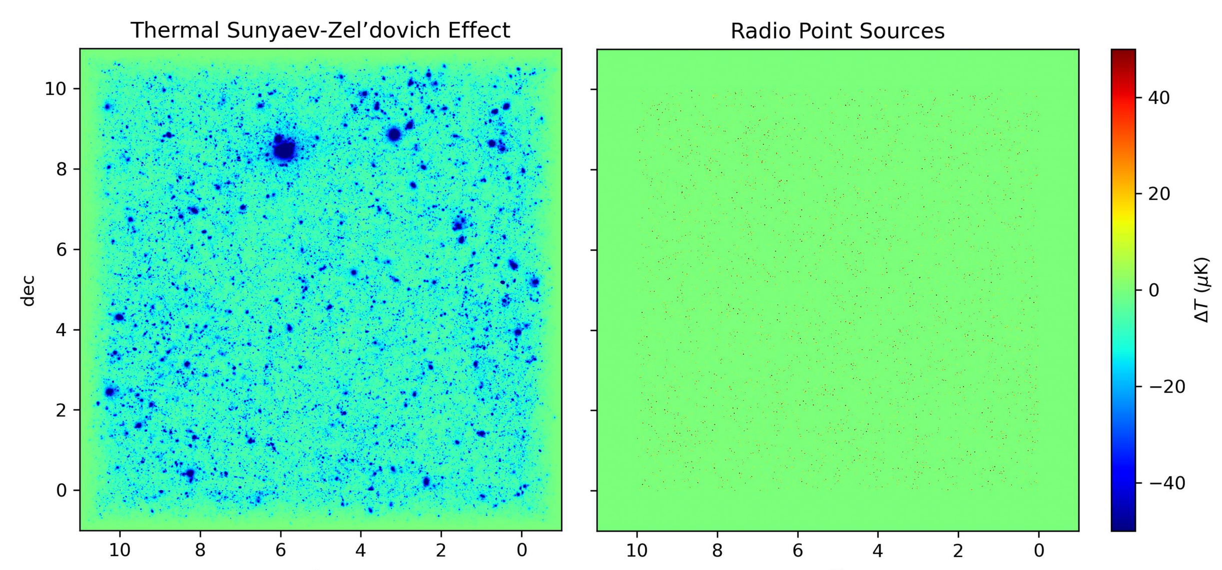
Between us and the CMB are various foregrounds that obstruct clean measurement of the CMB. This includes emission from the Milky Way and galaxy radio sources, radiation from early Universe galaxies (the Cosmic Infrared Background), and inverse-Compton scattering of CMB photons with high-energy ionized gas (the thermal and kinetic Sunyaev-Zel'dovich effects). We aim to show that, for the upcoming high-resolution CMB measurements from the CMB-HD observatory, one can remove extraneous sources and recover the underlying CMB signal. Here, we focus on the detection and removal of radio point sources.




## High-Resolution Foreground Maps

Previous work (Sehgal et al. 2010) developed realistic, full-sky simulations of the CMB lensed by dark matter structure and including intergalactic gas and the Sunyaev-Zel'dovich effect as matched to galaxy cluster and group populations. To mimic upcoming high-resolution measurements, we take patches from the full-sky simulation (for diffuse foregrounds) or create new patches from simulation galaxy catalogs (for point sources), then convolve with the telescope beam and pixel window.

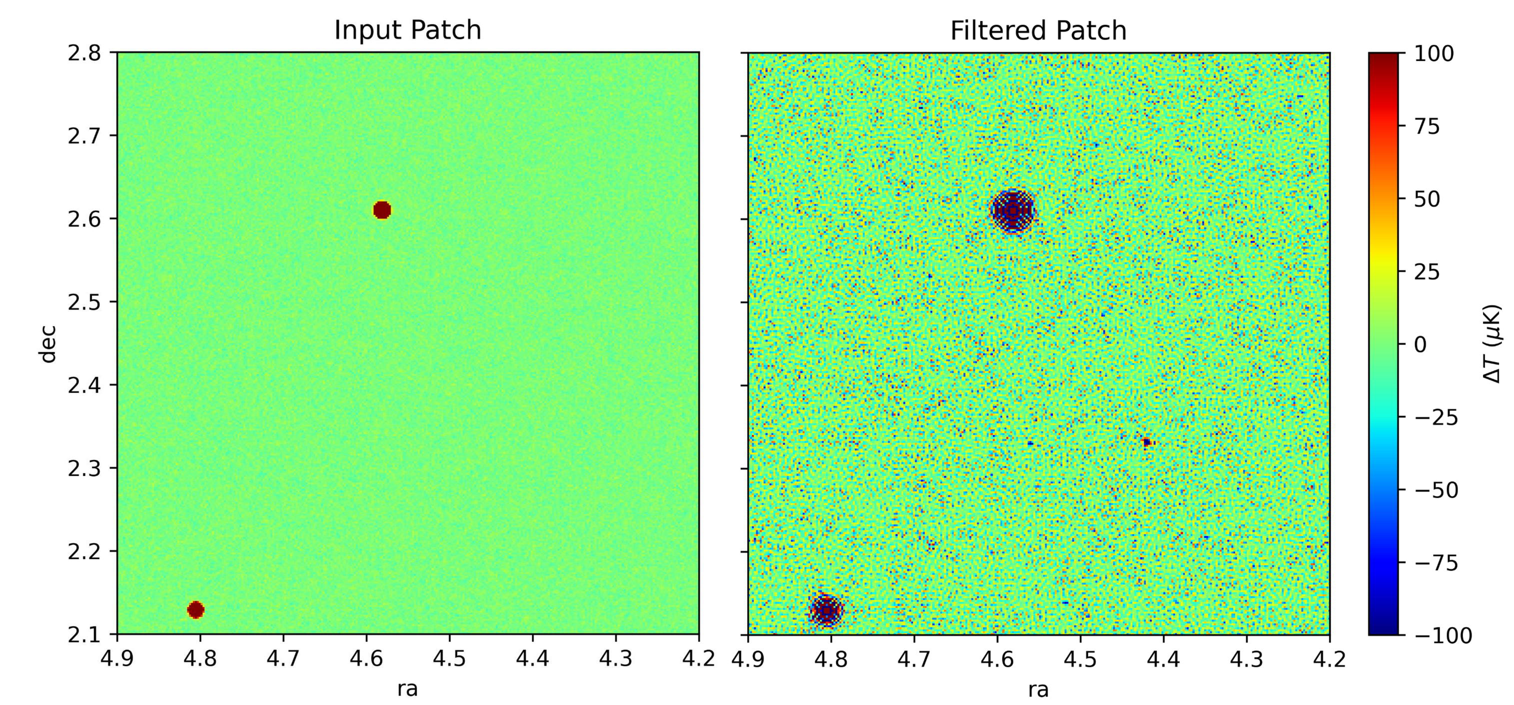



## Point Source Detection

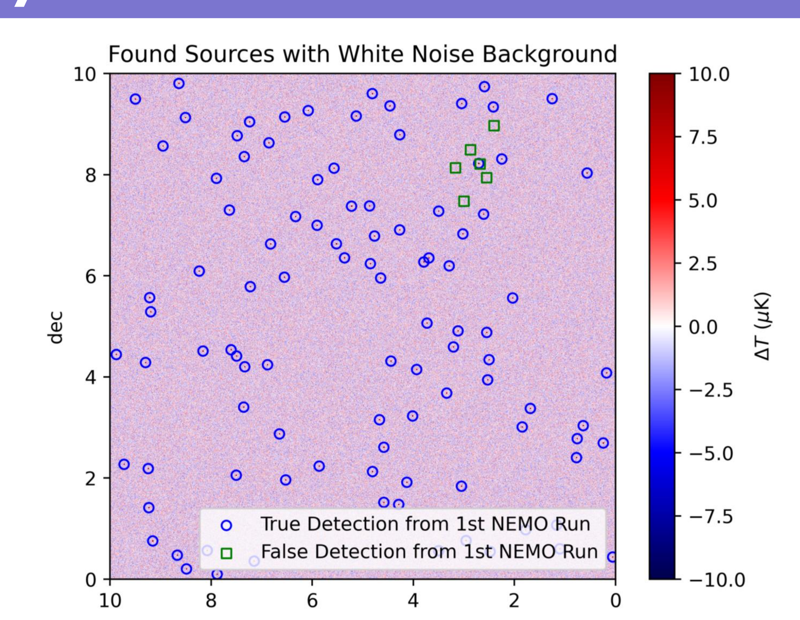
To search for point sources in our patch of sky, we apply a beam matched filter in Fourier space. This amplifies signals that resemble point sources convolved with the telescope beam and reduces extended, diffuse signals. We use the Nemo python implementation to search for sources with a signal-to-noise ratio greater than 5, and catalog those as "found sources."

We found that a multi-step, iterative procedure performs the best. First, we mask the brightest sources in the map (with a flux greater than 50 mJy) to reduce their large contamination. Then, we use several runs of Nemo, where the sources found in a previous iterations are masked for the next run; this improves the detection and flux measurement of the fainter sources.

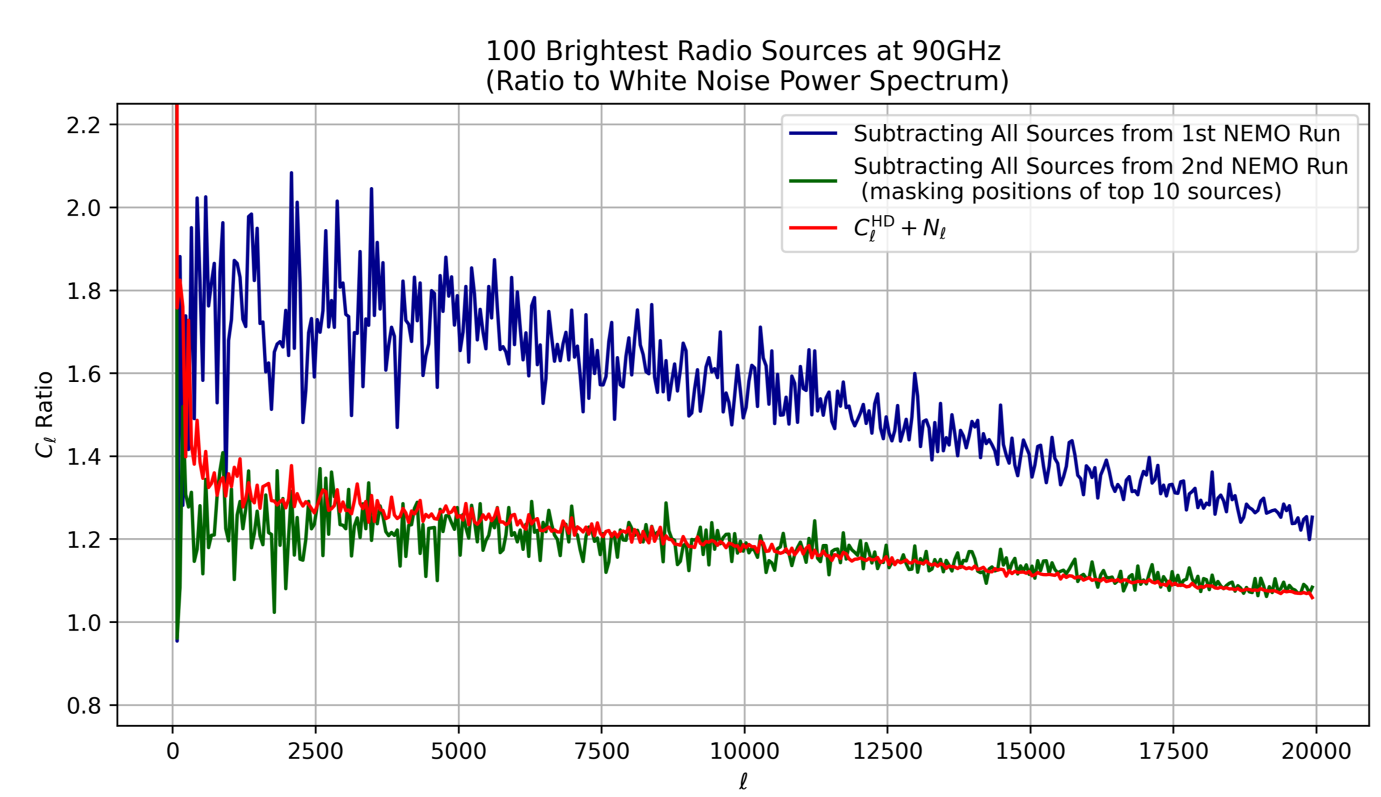



## Toy Scenario

We first consider a toy scenario: just the 100 brightest sources in our chosen patch of sky. Performing one run of Nemo leads to 6 false detections (see: right). By masking the 10 brightest sources and performing a second Nemo run, we can recover all the sources without false detections.



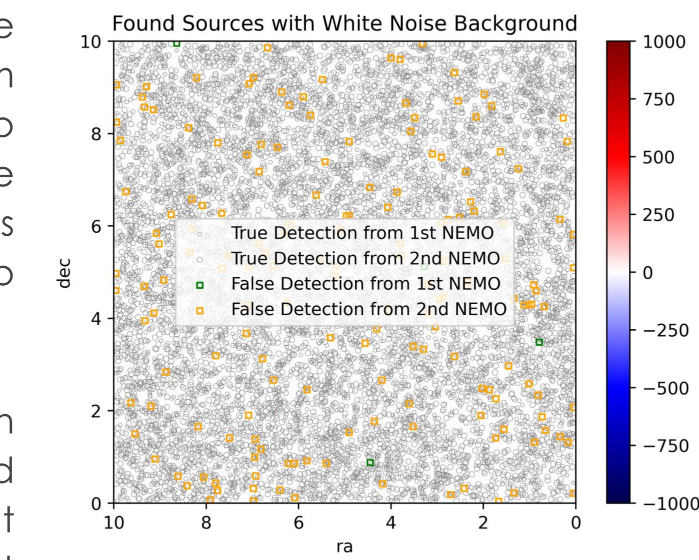

To characterize the effectiveness of source detection and subtraction, we use the output source catalog from Nemo to simulate a patch of sky and subtract that signal from the input patch. We then take the power spectrum of that source-subtracted map and take the ratio to the power spectrum of pure white noise (i.e. what would result from perfect subtraction).

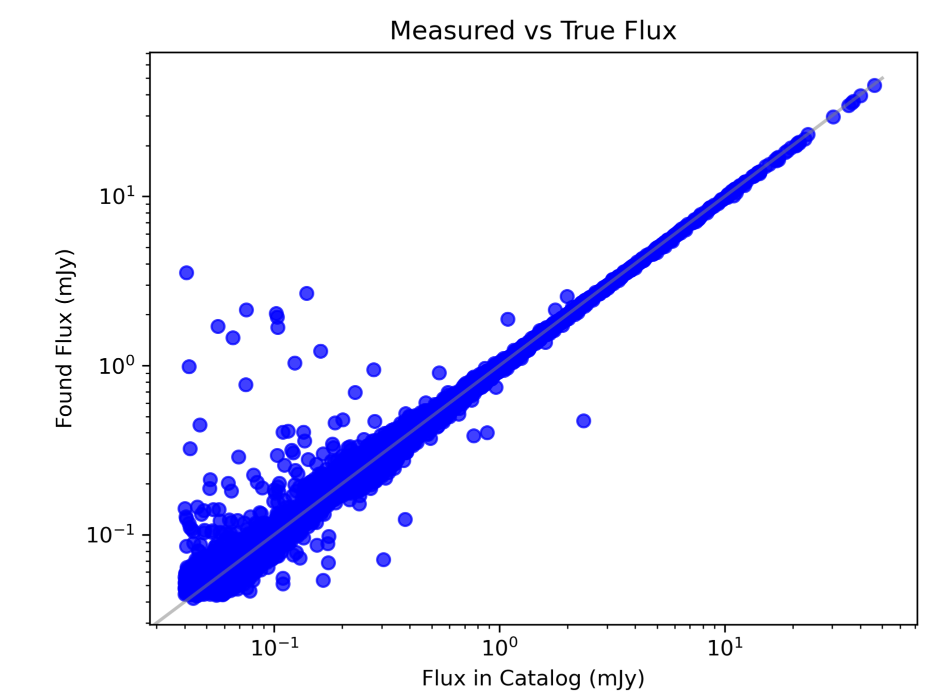


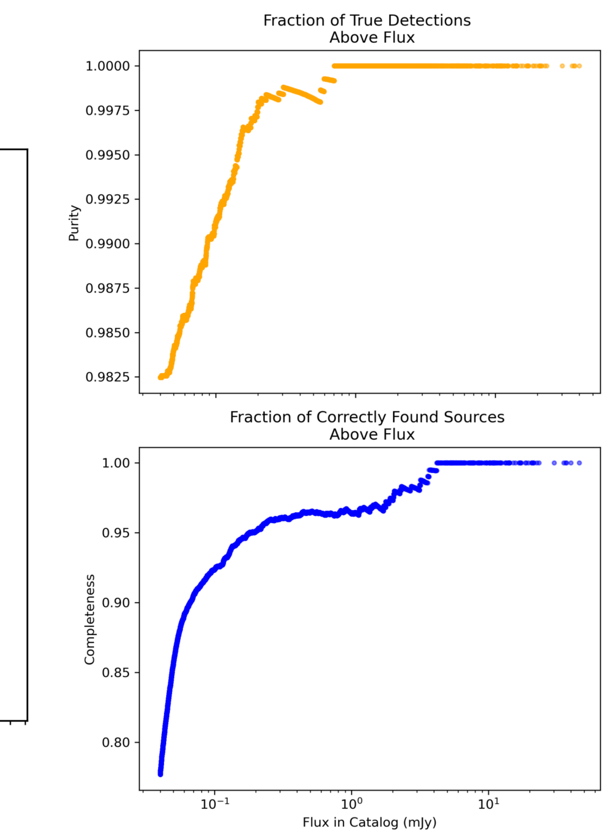

## All Radio Sources

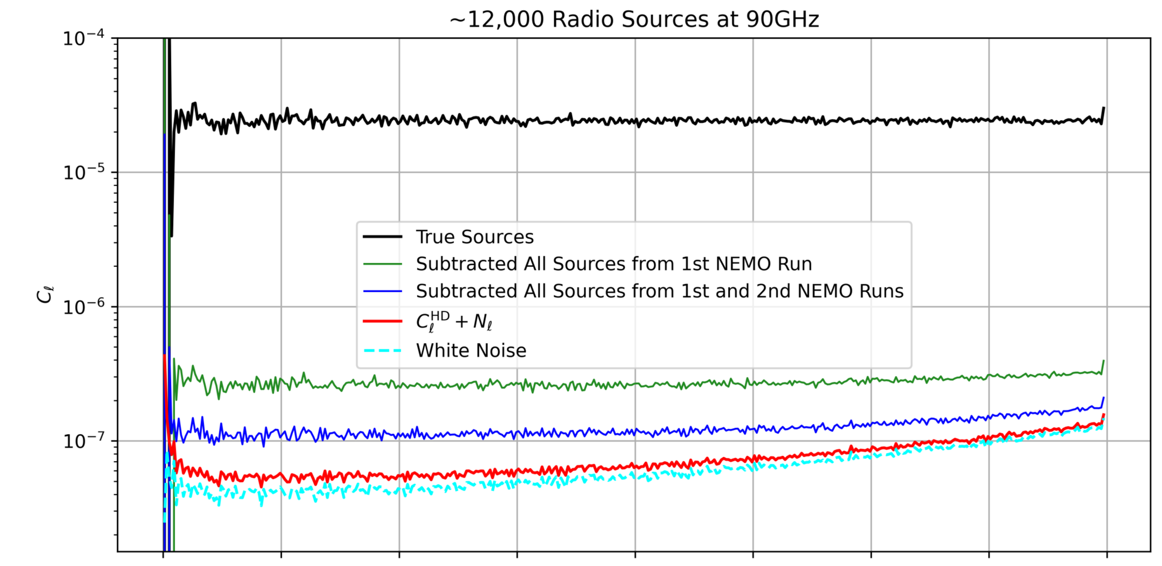
Moving away from the toy model, we attempt to measure all ~12,000 sources from 0.04 to 50 mJy. We use a two-step approach, where all found sources from the first run are masked for the second, thus allowing the fluxes of fainter point sources to be found more accurately.

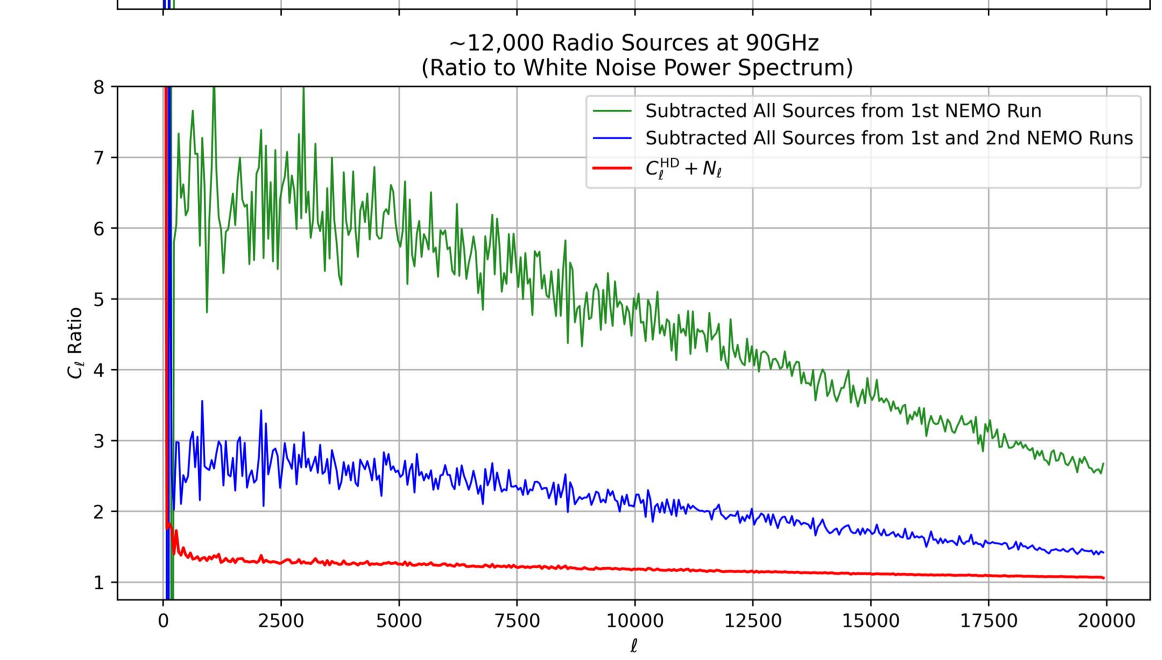
"Completeness" refers to the level to which we find all sources above a certain flux and "purity" refers to how confident we are that the sources above a certain flux are not false detections.



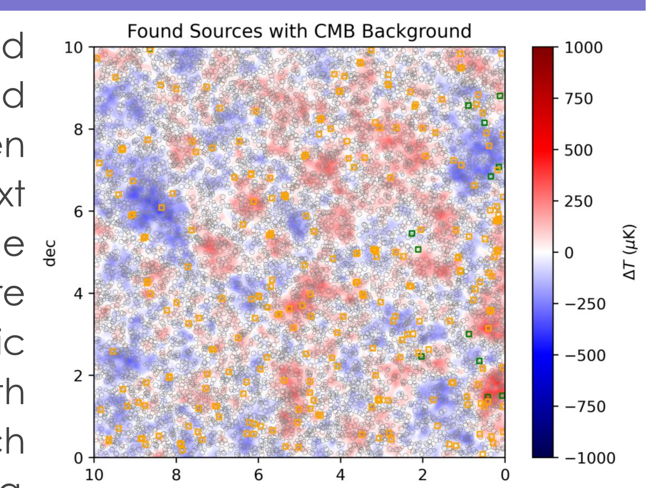




## Next Steps...

It is clear that we are able to correctly detect and remove many (but not all) point radio sources, and early tests show that this continues to be true when placing those sources on a CMB background. Next steps will involve more accurately identifying the fluxes of detected sources (perhaps through more Nemo iterations or techniques other than basic masking), combining our radio point sources with the other foregrounds (e.g. the Sunyaev Zel'dovich effect and Cosmic Infrared Background), and using multiple frequencies to mimic a realistic signal. Preliminary further investigations have already shown that we can lower the residual radio source foreground spectra to within 10% of our target, and further work is ongoing.

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