Internship
Simulating the sky map at 272 GHz using analytical function and comparing it with SIDES distribution

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1 Analytical dN/dS and deriving the sample distribution from it

In this internship, we started by probing and then deciding on the optimum dN/dS analytical function to apply. We calculated the source flux densities using the analytical function for producing source maps.

The Schechter function used for our analysis is from the paper [1]. It is described as:

$$\frac{dN}{dS} = \frac{N_{knot}}{S_{knot}} \left(\frac{S}{S_{knot}} \right)^{\alpha} e^{-S/S_{knot}} \tag{1}$$

where N_{knot} is the normalization parameter, S_{knot} specifies where the power-law's knee (bend) is located, where the regime shift occurs between the power-law and exponential law, and α is the power-law's slope.

The values chosen for the parameters are:

N_{knot} = 2290 deg^{-2}

s_{knot} = 1.12 mJy

alpha = -1.97

Thus, after the analytical dN/dS, we did the numerical integration to find the cumulative frequency distribution (CDF) of our function. The CDF indicates the total number of sources that have a flux less than or equal to that value.

From CDF, we randomly distributed the values and for each random value, we found the corresponding flux using interpolation.

The Schechter function values are normalized so that they can be plotted next to the histogram. This division makes sure that the histogram's area and the area under the original Schechter function's curve match.

Total number of flux sources: 218361

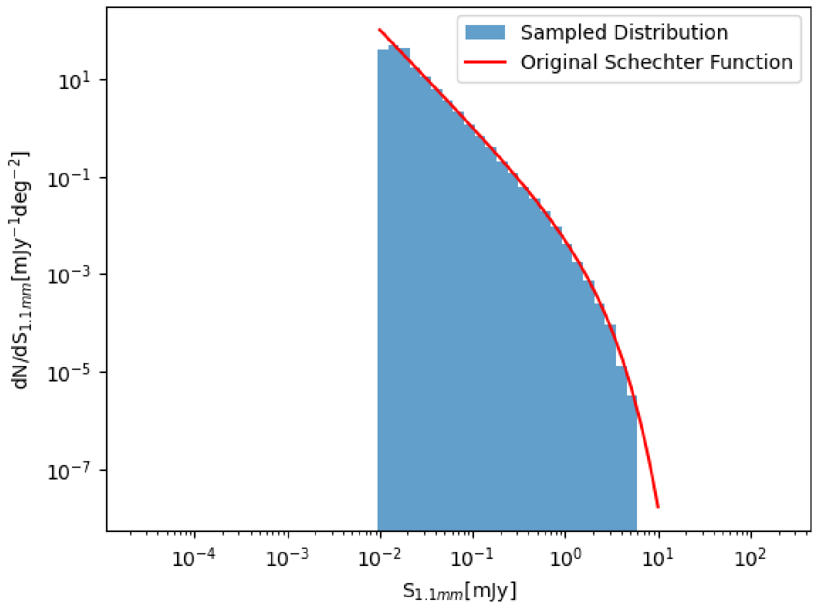

Figure 1: Analytical dN/dS function with the samples distribution histogram for 272 GHz.

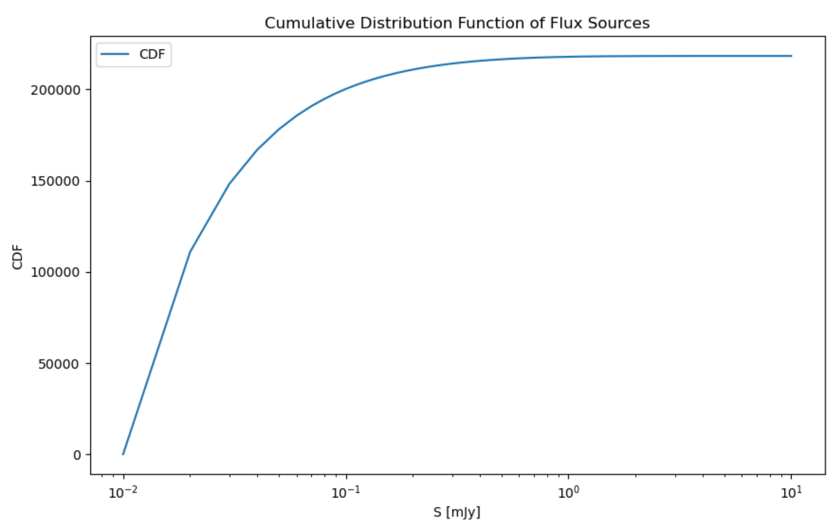

Figure 2: Cumulative Distribution Function

2 Generating a 2D sky map

We divided the sampled flux values across a 2D grid to represent a section of the sky. In accordance with the Nquist-Shannon Sampling principle, we assumed that the pixel size would be 1/4 of our 45" beam width [2], or 11.25" per pixel.

The amount of pixels required for the sky map (in one dimension) is computed using the pixel scale and the overall sky coverage. To position the RA and Dec values on the 2D grid, the data are transformed into pixel indices. By dividing the coordinates by the pixel scale and rounding to integer values, this conversion is performed. Multiple sources' fluxes are added together if they end up in the same pixel.

The histogram of the sky map already functions as a smoothed variant of the original dN/dS histogram due to the size of our pixel values.

After fitting a gaussian to it, we can calculate the shot noise of our sky map which is around 0.66 mJy or 1.03 mJy/beam where to get the rms value per beam, we define the beam area as:

beam area = π * (fwhm arcsec / (2 * sqrt(log(2)))^2)

stddev mJy per beam = stddev mJy * sqrt(pixel area / beam area)

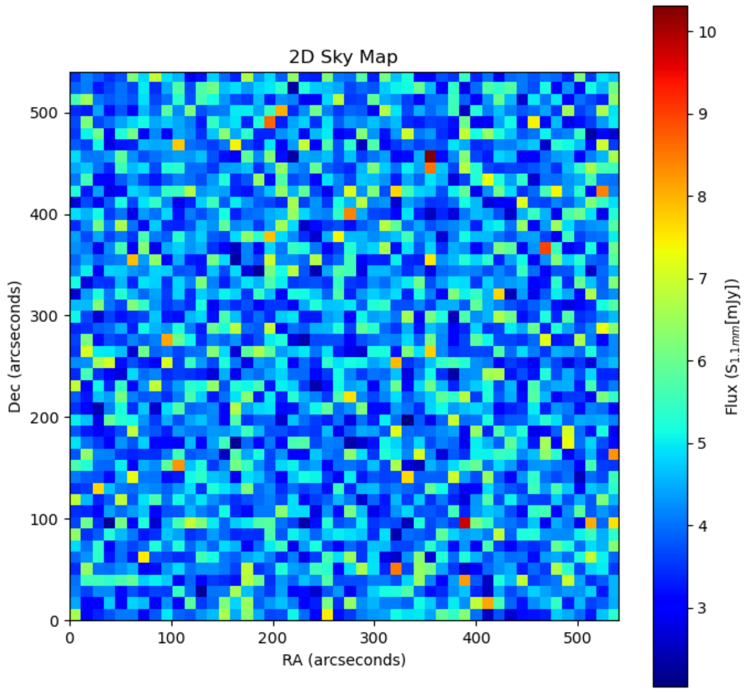

Figure 3: Sky map of the dN/dS distribution.

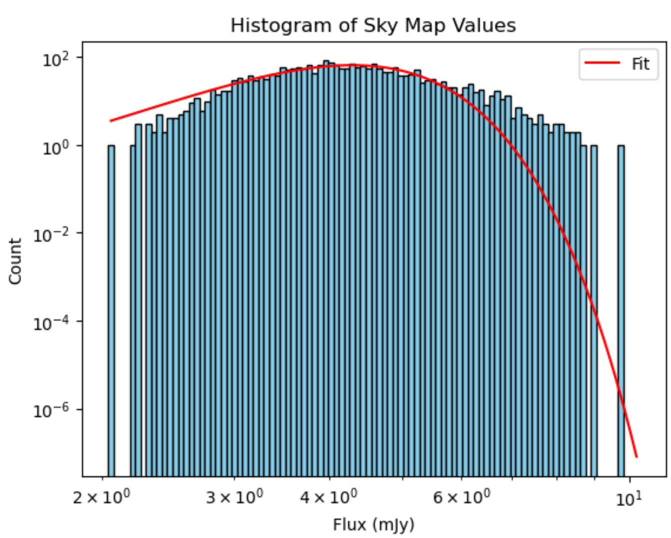

Figure 4: Histogram of the pixel flux values of the sky map.

3 Smoothing the sky maps

If we use the sky coverage of 1.4 degrees, then we see that the histogram of our sky map is the distorted version of the original dN/dS histogram. Thus, using the scipy gaussian kernel we can smooth the map to mimic the effect of the telescope's beam.

Smoothing intentionally averages out data to reduce random fluctuations and enhance clarity. it reduces the shot noise.

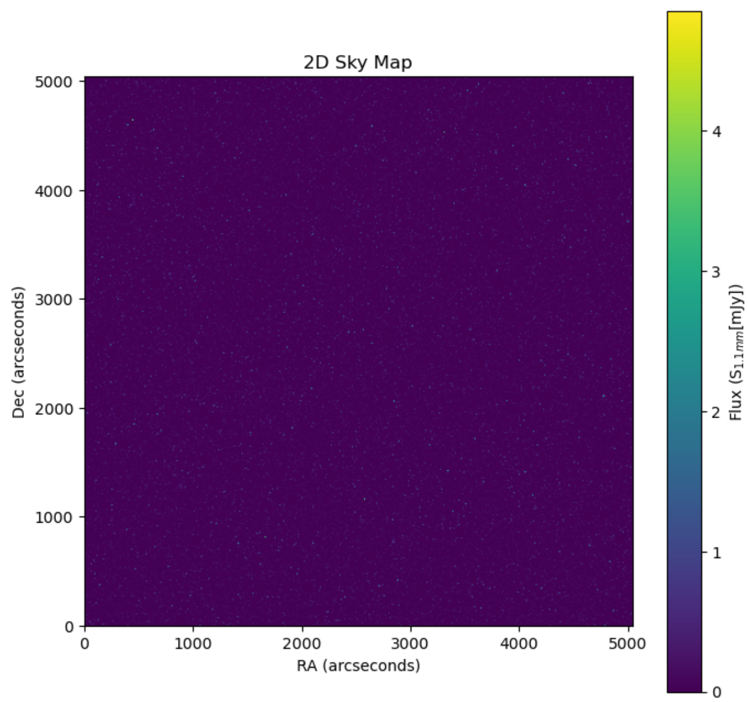

Figure 5: Sky map of the dN/dS distribution with a sky coverage of 1.4 degrees and at 272 GHz.

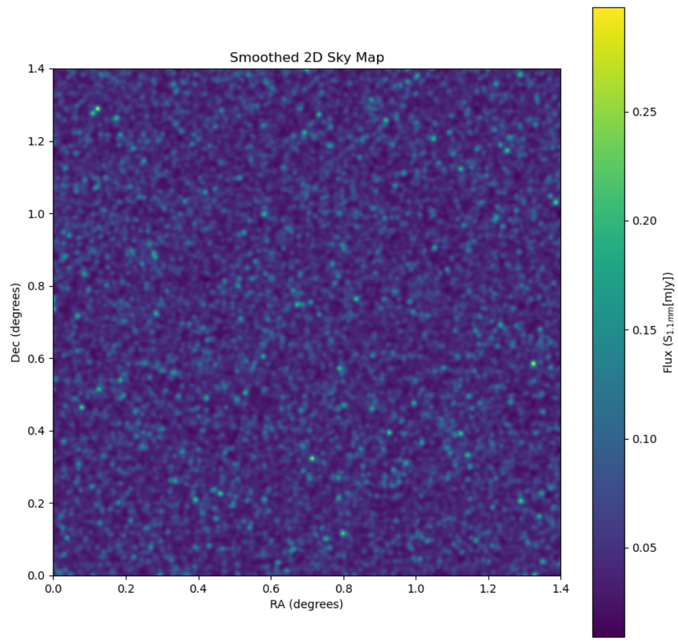

Figure 6: Sky map smoothed with a gaussian kernel at 272 GHz.

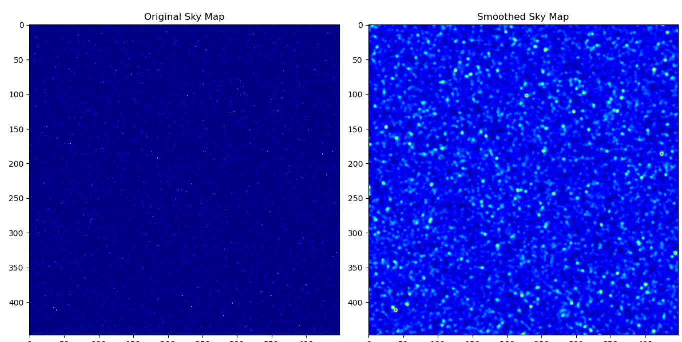

Figure 7: To check if the total flux of the image is same before or after smoothing as scipy gaussian filter should be normalized. We get Total intensity before smoothing: 10005.53 and total intensity after smoothing: 10005.53.

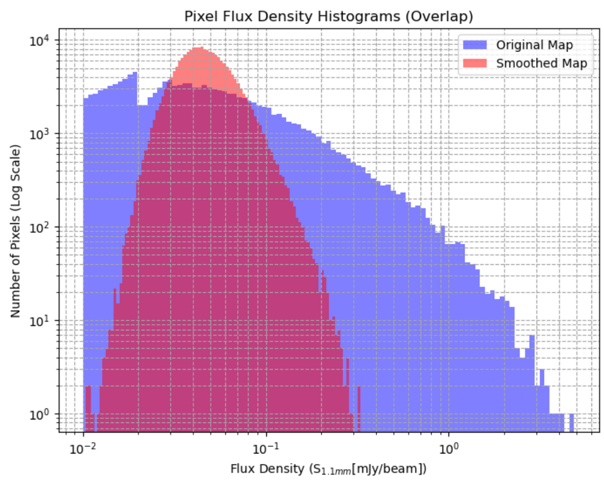

Figure 8: Unsmoothed and smoothed maps of point sources' pixel flux density histograms in logarithmic scale. Smoothing considerably alters the pixel flux density distribution's structure and redistributes it more uniformly, filling in pixels with low to zero flux density and reducing the amount of pixels with high flux density.

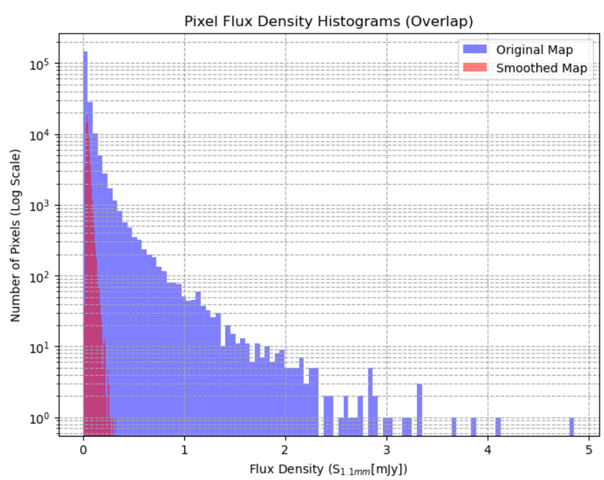

Figure 9: Unsmoothed and smoothed maps of point sources' pixel flux density histograms in logarithmic scaling of y axis. We can see the presence of very bright sources which needs to removed by source extractor tools such as pyBDSF.

4 RMS and Confusion Noise

The root-mean-square noise (RMS noise), denotes the standard deviation of the background signal in an astronomical radio spectrum. It gives a measurement of the data's fluctuations. The faintest sources that can be recognized in a given observation are fundamentally constrained by the RMS noise.

Thus, as the smoothing factor increases, it has a broader influence, averaging out random noise and reducing its impact on the data. This noise reduction leads to a decrease in the standard deviation.

In other words, increasing the smoothing factor (FWHM) will typically result in a stronger smoothing effect being applied to the image. An image becomes more blurred or smoothed as the FWHM increases because nearby pixel values are more strongly averaged. The standard deviation calculates the spread or dispersion of the image's pixel values. A higher standard deviation denotes more pixel value variability or fluctuations.

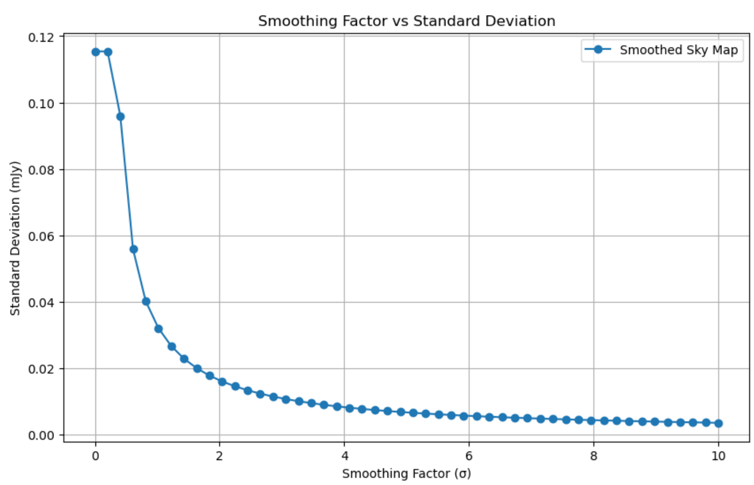

Figure 10: Smoothing factor vs standard deviation.

Confusion noise is not the rms of everything. It is the residual noise after sources have been removed. As a result, as the beam gets smaller, we may exclude more and more sources, which lowers the noise that remains. In essence, a smaller beam lowers the probability that many sources would be contained inside it, hence lowering the confusion noise. Therefore, the ability to recognize, model, and subtract individual sources improves as the beam gets smaller (or resolution improves), which in turn lowered the residual noise in the data. As a result of low resolution, confusion noise is the accidental blurring or mixing of various sources, making it more difficult to discriminate between different sources.

5 SIDES and its comparison with the analytic function

Simulated Infrared Dusty Extragalactic Sky or SIDES is a simulation of the extragalactic sky in the far-infrared and the mm domain, including clustering, based on dark-matter simulations and empirical prescriptions [3].

So far with the analytical function, we were neglecting the redshift distribution of sources and it was therefore not representative of actual observations. Therefore, we made a catalogue from the SIDES simulation. To make a catalogue, the relevant values we get from SIDES are source redshift, location and flux density. It consisted of around 1 million sources. These sources were obtained by applying a lower cut at 10^{-2} mJy to 10 mJy for 250 GHz flux density and leaving out the SIDES sources at z (redshift) < 0.2 which can be very bright.

We can clearly see the clustering in the sky map produced for sources with SIDES.

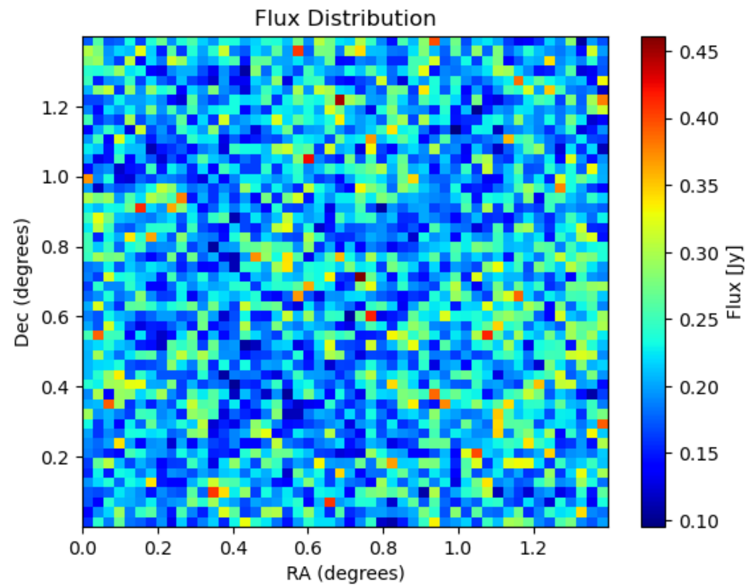

Figure 11: The 2D sky map using the SIDES simulation for 250 GHz.

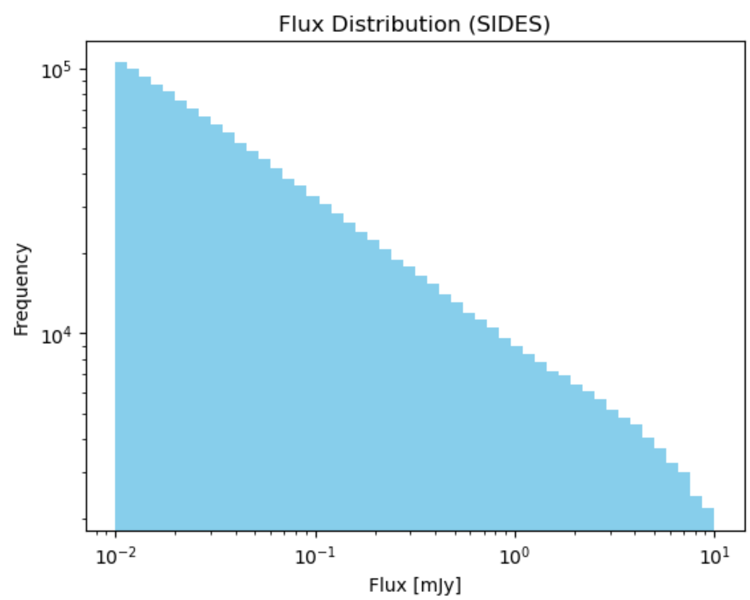

Figure 12: Histogram of the pixel flux densities for the sky map produced via SIDES simulation at 250 GHz.

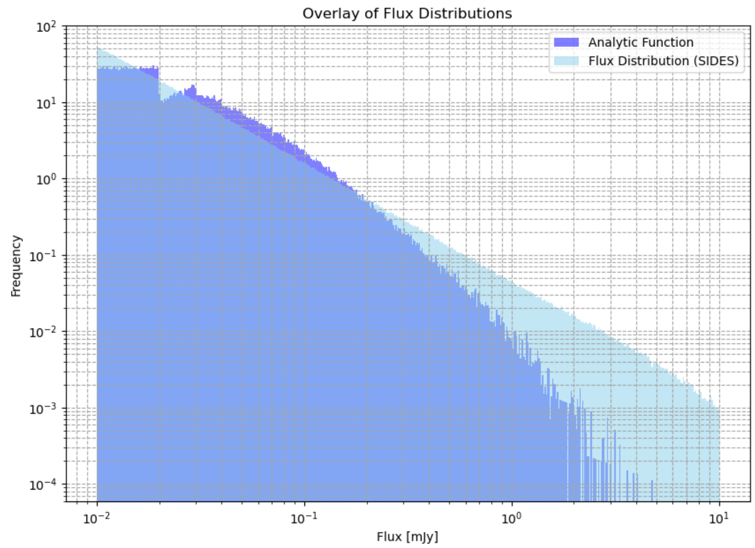

Figure 13: Histogram of the pixel flux densities for the sky map produced via SIDES simulation at 250 GHz overlayed with the histogram of the analytical dN/dS at 272 GHz.

The analytic function creates more mid-range fluxes than the SIDES catalogue, as seen by a comparison between the histograms from the two functions. Additionally, the fact that they are operating at close frequencies rather than the same one, i.e., the analytic one at 272 GHz and the SIDES at 250 GHz, may potentially contribute to the disparity that we observe. The parameters S_{star} and α could be adjusted so that it overlaps the SIDES histogram exactly. For this, we opted a curve fitting and found the best fit parameters for S_{star} and α which came out to be 0.05 and -1.47 respectively. The histograms still don't exactly overlap at the low flux values and further analysis is required for this.

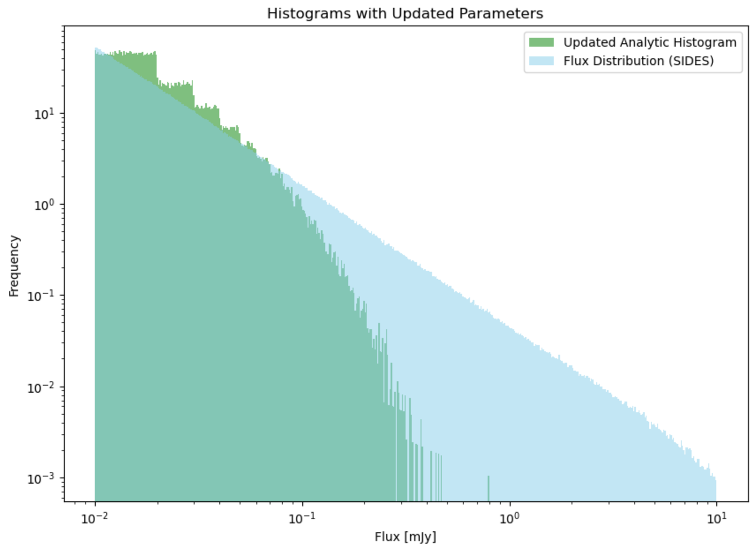

Figure 14: Histogram of the pixel flux densities for the sky map produced via SIDES simulation at 250 GHz overlayed with the histogram of the analytical dN/dS at 272 GHz for the best fit parameters.

References

[1] Gómez-Guijarro, C. et al. (2021). GOODS-ALMA 2.0: Source catalog, number counts, and prevailing compact sizes in 1.1mm galaxies. *Astronomy & Astrophysics*

[2] Choi, S. K., et al. (). Sensitivity of the Prime-Cam Instrument on the CCAT-prime Telescope. *Journal of Low Temperature Physics*

[3] Béthermin et al. (2022). CONCERTO: High-fidelity simulation of millimeter line emissions of galaxies and [CII] intensity mapping. *Astronomy & Astrophysics*, 667, A156. 10.1051/0004-6361/202243888