Exploring The Dusty Star-Forming Galaxy Population: A Mock Redshift Survey For Deep mm-Wavelength Observations

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We present a cosmologically motivated mock redshift survey of the Dusty Star-Forming Galaxy (DSFG) population. Some DSFGs exhibit SFR > 100 $M_\odot$/yr, contributing significantly to the cosmic star formation rate at $z < 4$, their contribution at higher redshifts remains uncertain due to the lack of large galaxy samples. Our mock redshift survey, based on a dark matter simulation, covers 5.3 deg^2 from z = 0 to 7, with a minimum stellar mass resolution of $10^{8.75}$ $M_\odot$, and includes gravitational lensing effects. It closely reproduces DSFG observations, allowing us to characterize the future extragalactic ultra-deep legacy survey (UDS) that will be conducted with the TolTEC camera on the Large Millimeter Telescope. We also investigate the impact of galaxy clustering on flux density measurements due to the blending of weak, undetectable sources with those that are potentially detectable.

Methodology

We use Bolshoi-Plank dark matter halo simulation (Klypin et al. 2016, Rodríguez-Puebla et al. 2016) to generate a lightcone covering an area of 5.3 deg^2 from z = 0 to 7.

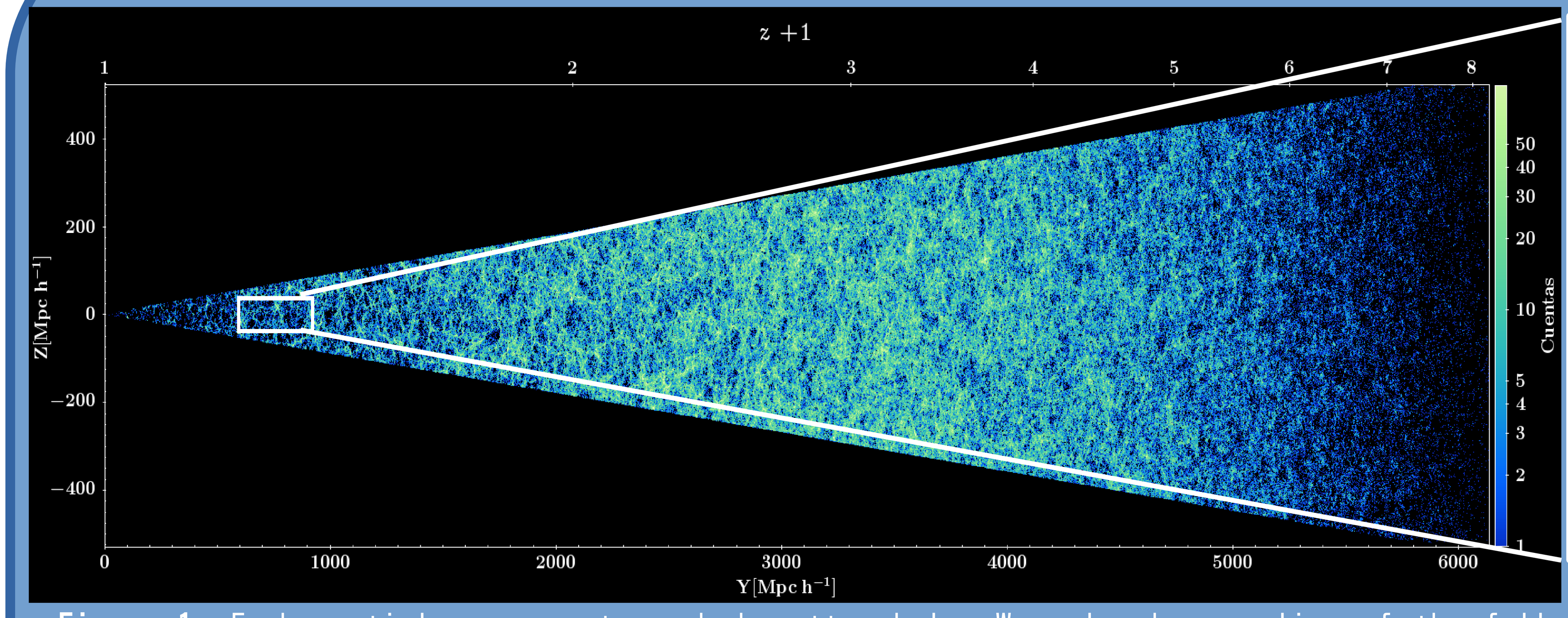

Figure 1. Each particle represents a dark matter halo. We only show a slice of the full cone. The figure shows the filaments, clusters and voids of the large scale structure.

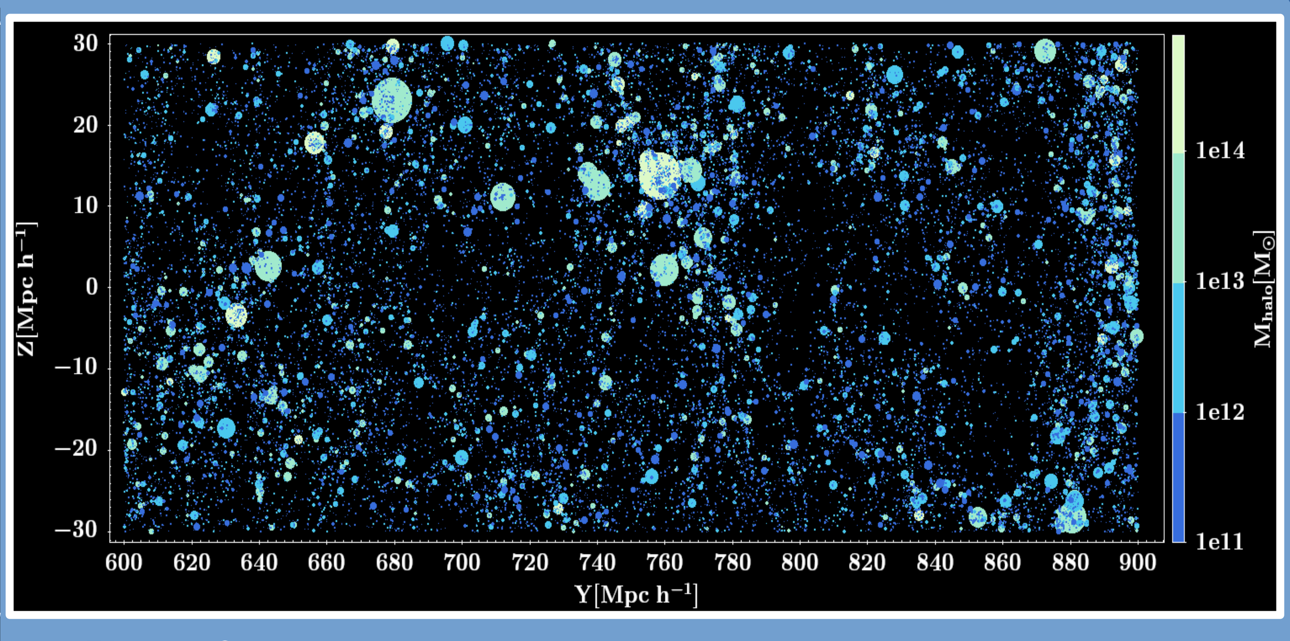

Figure 2. Amplified view of a small projected volume from the lightcone.

We used an update version to the semi-empirical galaxy-halo connection model developed by Rodríguez-Puebla et al. (2017) to populate the dark matter halos with galaxies. It allows us to establish the stellar masses ($M_\star$ > $10^{8.75}$ $M_\odot$) and SFR to each galaxy in the lightcone.

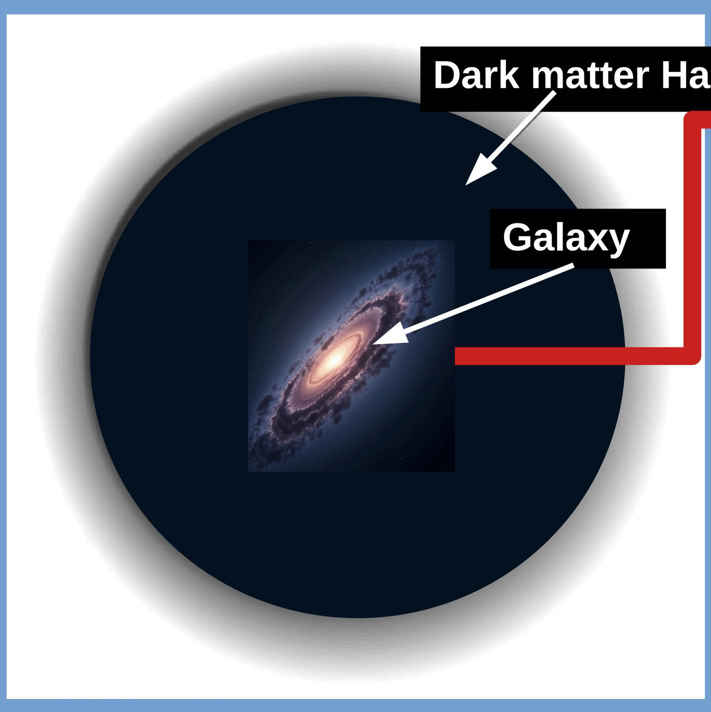

Figure 3. Representation of a dark matter halo and its host galaxy.

★ **Obscured SFR and Infrared luminosity:**

$$\mathrm{SFR_{IR}} = f_{\mathrm{obs}} \times \mathrm{SFR}$$

Kennicutt (1998)

$$\frac{\mathrm{SFR_{IR}}}{1\mathrm{M_\odot yr^{-1}}} = \frac{L_{\mathrm{IR}}}{1.09 \times 10^{10}\mathrm{L_\odot}}$$

★ **Dust Temperature, T_d, Casey et al. (2018):**

$$\langle \lambda_{\mathrm{peak}}(L_{\mathrm{IR}}) \rangle = \lambda_0 \left(\frac{L_{\mathrm{IR}}}{L_t}\right)^{\eta}$$

$$\lambda_{\mathrm{peak}} \approx \frac{2.898 \times 10^3\ \mu\mathrm{m\ K}}{T^{0.9}}$$

★ **Observed flux density at different wavelengths, S_ν:**

z, L_{IR}, T_d, $f_\nu(T_d, \beta)$

$$S_\nu = \frac{1+z}{4\pi D_L^2} L \frac{f_{\nu(1+z)}}{\int f_{\nu'}\, d\nu'}$$

★ **Gravitational lensing:**

- Point mass model to reproduce the gravitational lensing effect.
- Lens effect by halo-galaxy interaction.

Results

Number Counts

Our mock catalogue (5.3deg^2) reproduces the observations at different wavelengths (1.1, 1.4 and 2.0 mm, black line). At the bright end our mock survey begins to reflect the impact of gravitational lensing. However, the area is small to fully capture the effect at 1.4 and 2.0 mm.

We predict the number counts for the UDS/TolTEC areas (205 arcmin^2 and 0.5 deg^2, red and blue lines). The new observations will allow us constrain the number counts at low flux densities ($S_{1.1}$<5mJy, $S_{1.4}$<2mJy, $S_{2.0}$<0.7 mJy). At higher flux densities, the observations will be significant dominated by cosmic variance, especially in the smallest area.

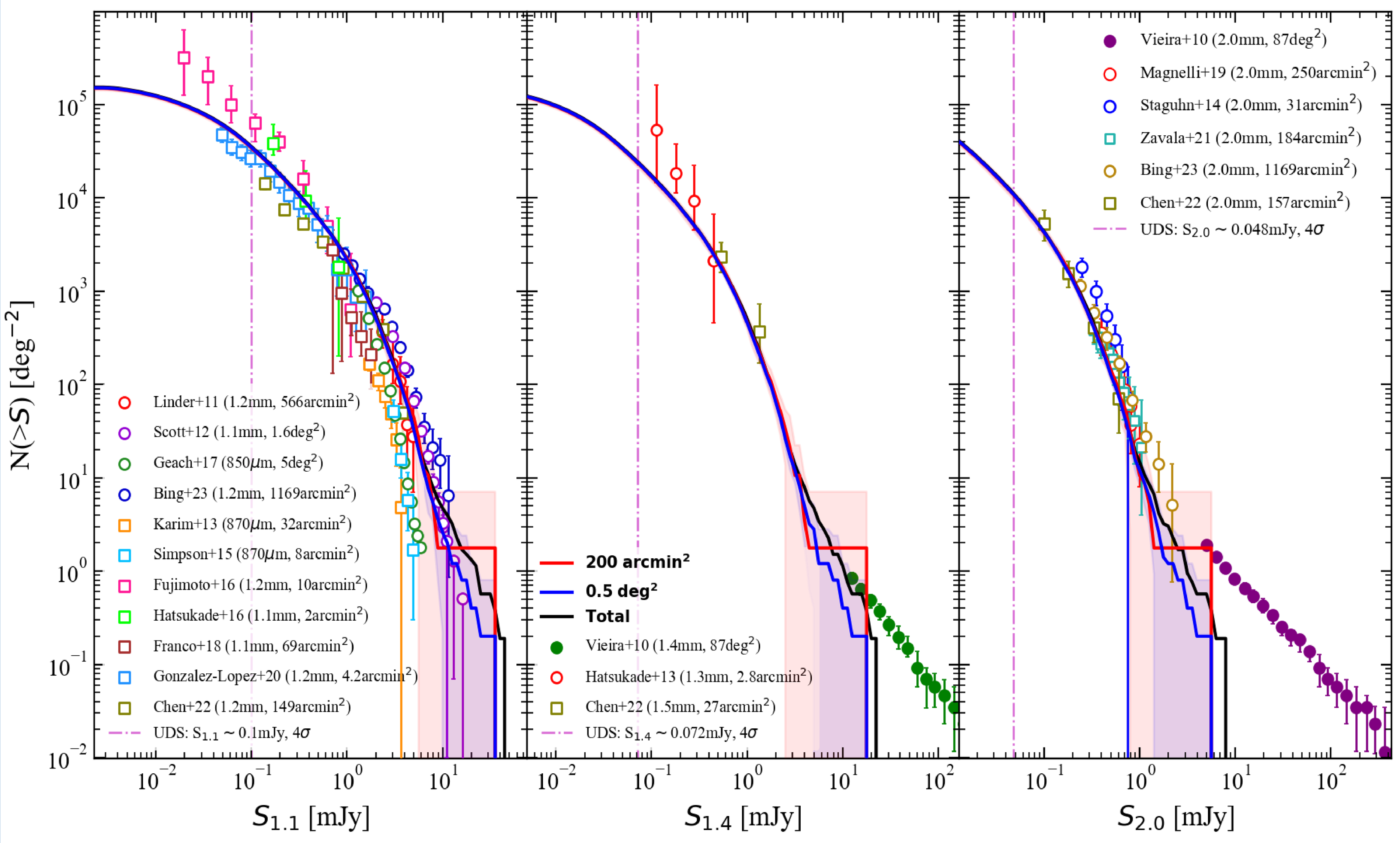

Figure 4. Predictions in the Number Counts measured for our mock redshift survey and the UDS/TolTEC areas. The observational counts at high flux densities are derived from surveys of ~100 sq. deg., which are sensitive to rare bright gravitational lensed sources.

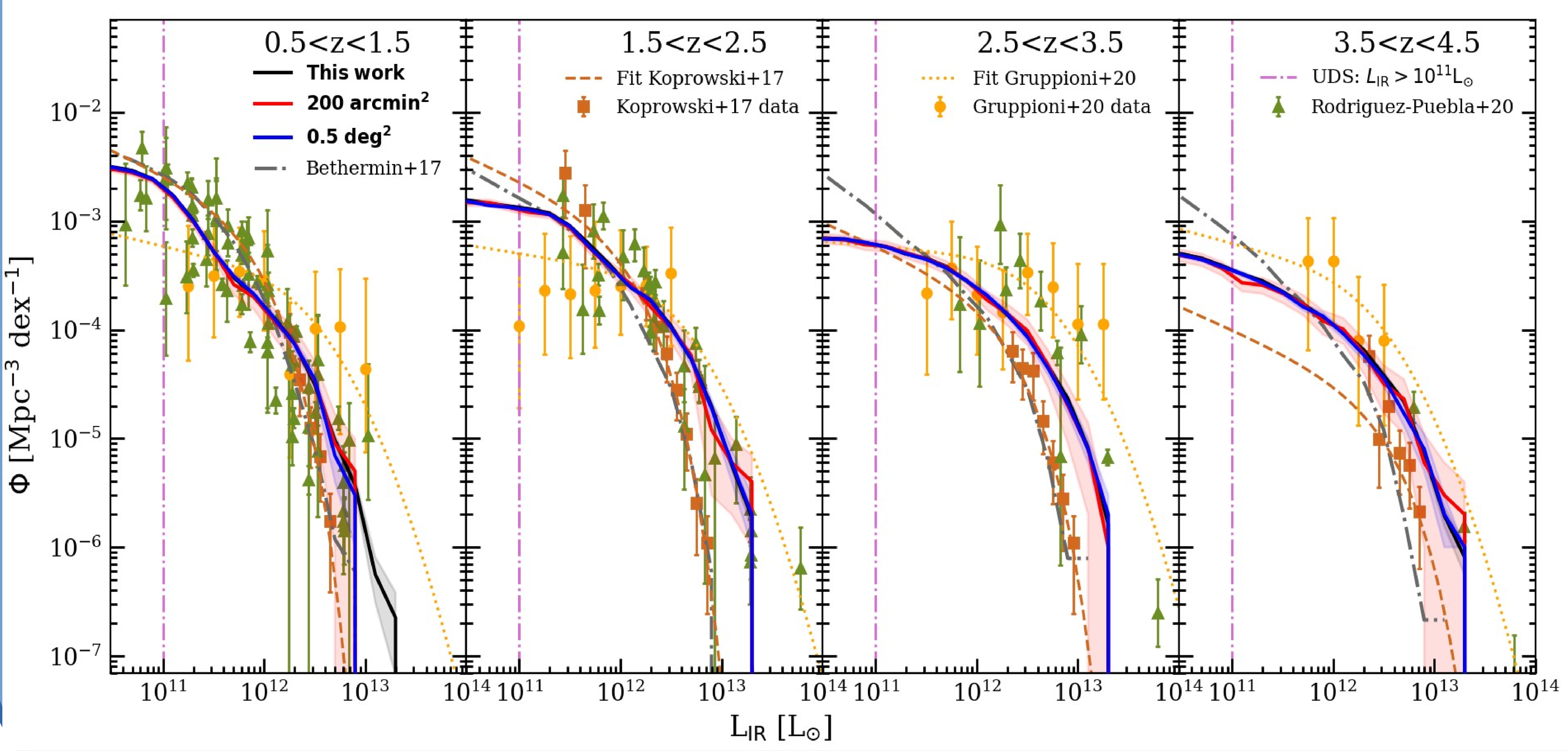

Figure 4. Luminosity Function of our mock redshift survey and predictions for the UDS/TolTEC areas.

Luminosity Function (LF)

The measured LF exhibit significant uncertainties. Figure 4 shows the LF measured in our mock survey (5.3 deg^2, black line) compared to measurements in the literature. Our findings indicate that the density of infrared galaxies at low luminosities decrease as z increases. Our predictions for the UDS/TolTEC areas (205 arcmin^2 and 0.5 deg^2, red and blue lines with 1σ shaded regions) show how this future survey will improve the constraints of the LF. The 0.5 deg^2 area will provide more reliable estimates of the LF in the bright end and up to $L_{\mathrm{IR}} \sim 10^{13}$ $L_\odot$.

Application

The boosting effect in the UDS/TolTEC areas

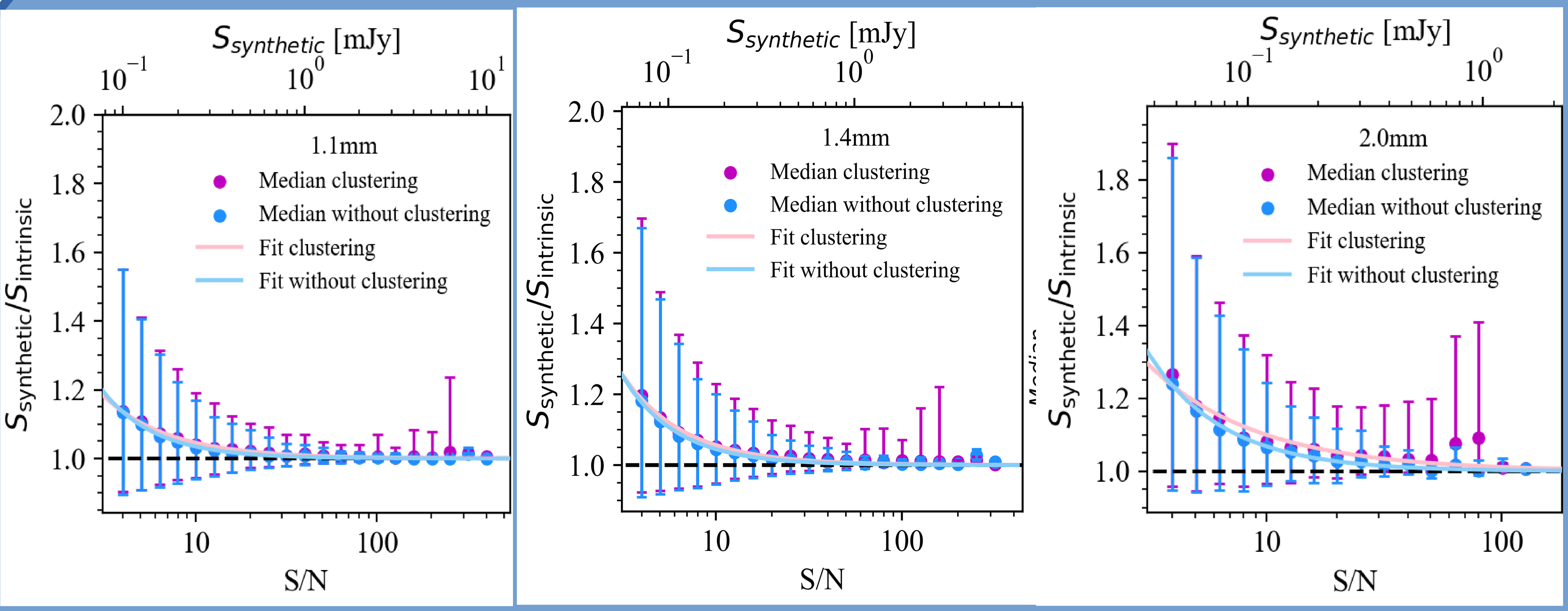

Figure 5. Median boosting factor versus S/N for an area of 1 deg^2 at 1.1, 1.4, and 2.0 mm. The magenta dots represent the median boosting factor measured in a map with galaxy clustering, the blue dots correspond to the median boosting factor measured in a map with sources in random positions. The solid curves are fits to the points. The vertical bars represent the 1σ error in the medians.

The measured flux densities of sources in a real observation can sometimes be overestimated due to several factors, including the contribution from faint unresolved sources and the influence of neighbouring sources that may be blended together within the telescope beam. This effect is commonly referred to as flux boosting.

Our results show that, on average, clustering increases the boosting factor by 0.5±0.1, 0.8±0.1 y 1.6±0.2 percent at 1.1, 1.4 and 2.0 mm, respectively. The boosting factor will increase as the angular resolution of the observations decreases.

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