Unique extragalactic science with CMB Probe

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1 Preliminary remarks

Given the sensitivity levels of CMB probe, its surveys of extragalactic sources will be confusion limited. For the relevant angular scales, the confusion limit scales roughly as the effective solid angle, i.e. with the square of the FWHM (cf. fig. 3 of De Zotti et al., 2015). For diffraction-limited observations, high spatial resolution means high frequencies which have the additional advantage that dusty galaxies are brighter.

The main strengths/uniqueness of all-sky surveys with moderate sensitivity and angular resolution are:

1. the capability of detecting rare objects with extreme luminosity
2. the capability of integrating over substantial solid angles, picking up the contributions of even the faintest sources in overdensities, missed by higher resolution surveys.

Both points have been substantiated by *Planck*, but with very small samples (point 1) or in a fuzzy way (point 2).

2 Extreme luminosity galaxies

The detection of high-z galaxies is greatly favoured by strong gravitational lensing. *Planck* has detected 11 extreme cases of such sources, with $z = 2.2$–3.6 (Cañameras et al., 2015). CMB Probe will detect about 3,000 strongly lensed galaxies brigher than its detection limit of 90 mJy at 600 GHz (fig. 1). Identifying such objects will be straightforward, as demonstrated by *Herschel* (Negrello et al., 2010). The availability of thousands of strongly lensed galaxies opens exiting prospects both on the astrophysical and on the cosmological side (cf., e. g., Treu, 2010).

The CMB Probe surveys will have critical advantages over other facilities that will generate large gravitational lens catalogues (e.g., *Euclid*, Gaia, SKA):

- the selection of these objects will be far more efficient;
- their photometry will be only very weakly contaminated by the foreground lens, even in the case of close alignment along the line-of-sight, allowing

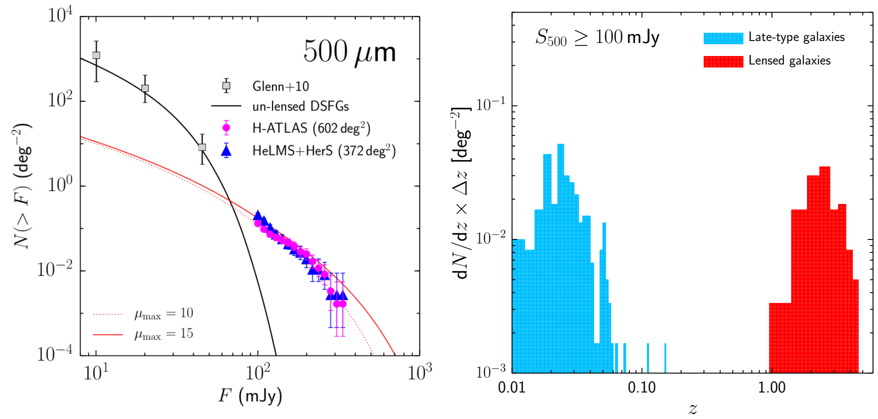

Figure 1: **Left panel.** Integral counts of strongly lensed galaxies from *Herschel* surveys at 500 μm (600 GHz; blue and magenta data points). The counts of un-lensed proto-spheroidal galaxies are also shown for comparison (black squares and solid line). From Negrello et al. (2017a). **Right panel.** Redshift distribution of galaxies brighter than 100 mJy at 500 μm, derived from the full H-ATLAS catalogue. There is a clear bimodality. On one side we have nearby late-type galaxies, almost all at $z \leq 0.06$, and hence easily recognizable in optical/near-infrared catalogues. On the other side we have dust enshrouded, hence optically very faint, gravitationally lensed galaxies at $z \geq 1$ and up to $z > 4$. From De Zotti et al. (2016).

the detection of the most extreme magnifications; this has been demonstrated by *Planck*: the magnification factors of "*Planck*'s dusty GEMS" are estimated to be of up to 50 Cañameras et al. (2015);

- the all-sky coverage maximizes the detections of the rare brightest sources, best suited for follow-up;
- the mm/sub-mm selection, with its strongly negative K-correction, allows us to extend the detection of sources and lenses to much higher redshifts.

CMB Probe will also explore essentially the entire Hubble volume for the most intense hyperluminous starbursts, testing whether there are physical limits to the star-formation rates of galaxies.

3 Early phases of cluster evolution

CMB Probe will open a new window for the investigation of early phases of cluster formation, when their member galaxies were actively star forming and before the hot intergalactic medium was in place. In this phase traditional approaches to cluster detection (X-ray and SZ surveys, searches for galaxy red sequences) do not work. Proto-clusters stand out more clearly in moderate resolution surveys like those by CMB Probe than in high resolution surveys because a large fraction of the proto-cluster luminosity is contributed by faint sources, below the detection limits of existing or planned high resolution surveys.

A few examples of such proto-clusters have been already reported (left-hand panel of fig. 2). CMB Probe will detect thousands of these objects up to $z \gtrsim 4$ (right-hand panel of fig. 2). *Planck* has already demonstrated the power of low-resolution surveys for the study of large-scale structure (Planck Collaboration Int. XXXIX, 2016) but its resolution was too poor to detect individual proto-clusters (Negrello et al., 2017b).

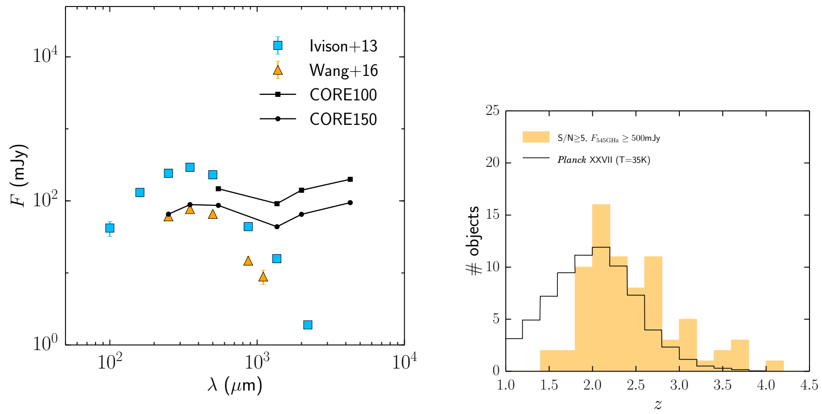

Figure 2: **Left panel.** Spectral energy distributions (SEDs) of the cores of two proto-clusters of starbursting galaxies discovered by Ivison et al. (2013) at $z = 2.41$ and by Wang et al. (2016) at $z = 2.506$ (Wang et al., 2016). The solid black lines show the CORE detection limits for the 1-m and 1.5-m telescope (from top to bottom). CMB Probe will be at the level of CORE150. From De Zotti et al. (2016). **Right panel** Predicted redshift distribution of proto-clusters $F_{545\mathrm{GHz}} \geq 500\,\mathrm{mJy}$ (yellow histogram). For comparison we show the photometric redshift distribution of the *Planck* candidate proto-clusters is also shown. From Negrello et al. (2017b).

CMB Probe will also provide unique information on the evolution of star formation in cluster members.

4 Source polarization

Accurate simulations (Remazeilles et al., 2017) showed that, for a tensor-to-scalar ratio $r \simeq 10^{-3}$ (i.e. at levels predicted by models currently of special interest, such as Starobinsky's R^2 and Higgs inflation), the overall uncertainty on r is dominated by foreground residuals and that unresolved polarized point sources can be the dominant foreground contamination over a broad range of angular scales ($\ell \gtrsim 50$). An accurate understanding of the polarization properties of extragalactic sources is therefore crucial.

While the distribution of polarization degrees of radio sources adopted in these simulations is based on observations, albeit at lower frequencies, essentially nothing is known on the polarization properties of dusty galaxies. The mean polarization fraction of 1% adopted by Remazeilles et al. (2017) is just a reasonable guess. Bonavera et al. (2017), applying stacking techniques to dusty galaxies detected by *Planck* in total intensity, found an average fractional polarization of $\simeq 3\%$, that would imply a factor of 9 increase of the amplitude of the power spectrum.

Moreover, while the power spectrum of unresolved radio sources is easy to model, being white noise to a very good approximation, the power spectrum of unresolved dusty galaxies is more complex and less well known, being dominated

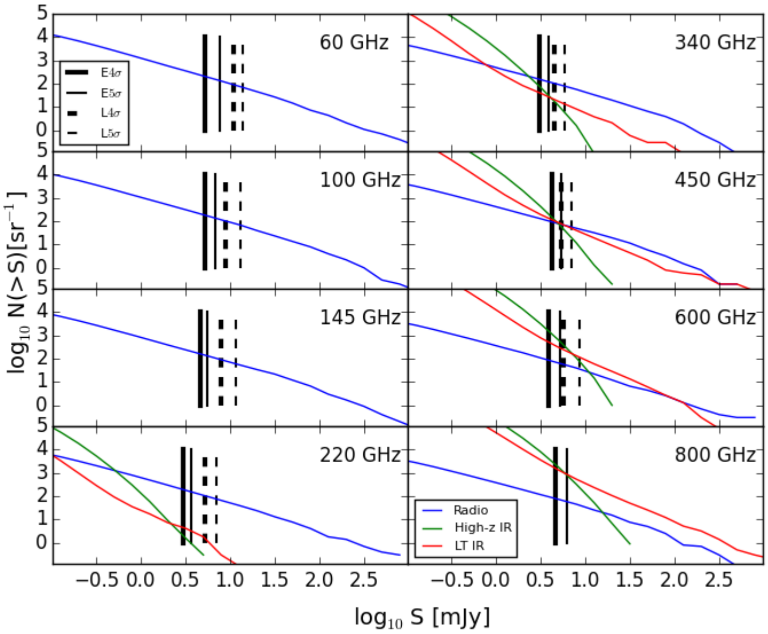

Figure 3: Comparison of the estimated source number counts in polarization for a selection of CORE channels and different source populations: radio sources (solid blue line); and two populations of dusty galaxies (proto-spheroids and late-type, spiral and starburst, galaxies). Proto-spheroids, labelled "High-z IR" (solid green line) dominate at faint flux densities while late-types (LT IR, solid red lines) dominate at the brighter flux densities. The vertical lines show the 4σ and 5σ detection limits obtained from the simulations for the 1-m (dashed) and 1.5-m (solid) telescope. From De Zotti et al. (2016).

by clustering. Fortunately, CMB Probe will be capable of providing, for the first time, direct counts in polarization both for radio sources and for dusty galaxies (see fig. 3, where the counts refer to the case of a mean dusty galaxies polarization of 1%). This spectacular improvement over *Planck* is due to the fact that, at variance with total intensity, in the case of polarization the detection limit is dictated by sensitivity, not by confusion noise.

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