PICO Legacy Catalogs

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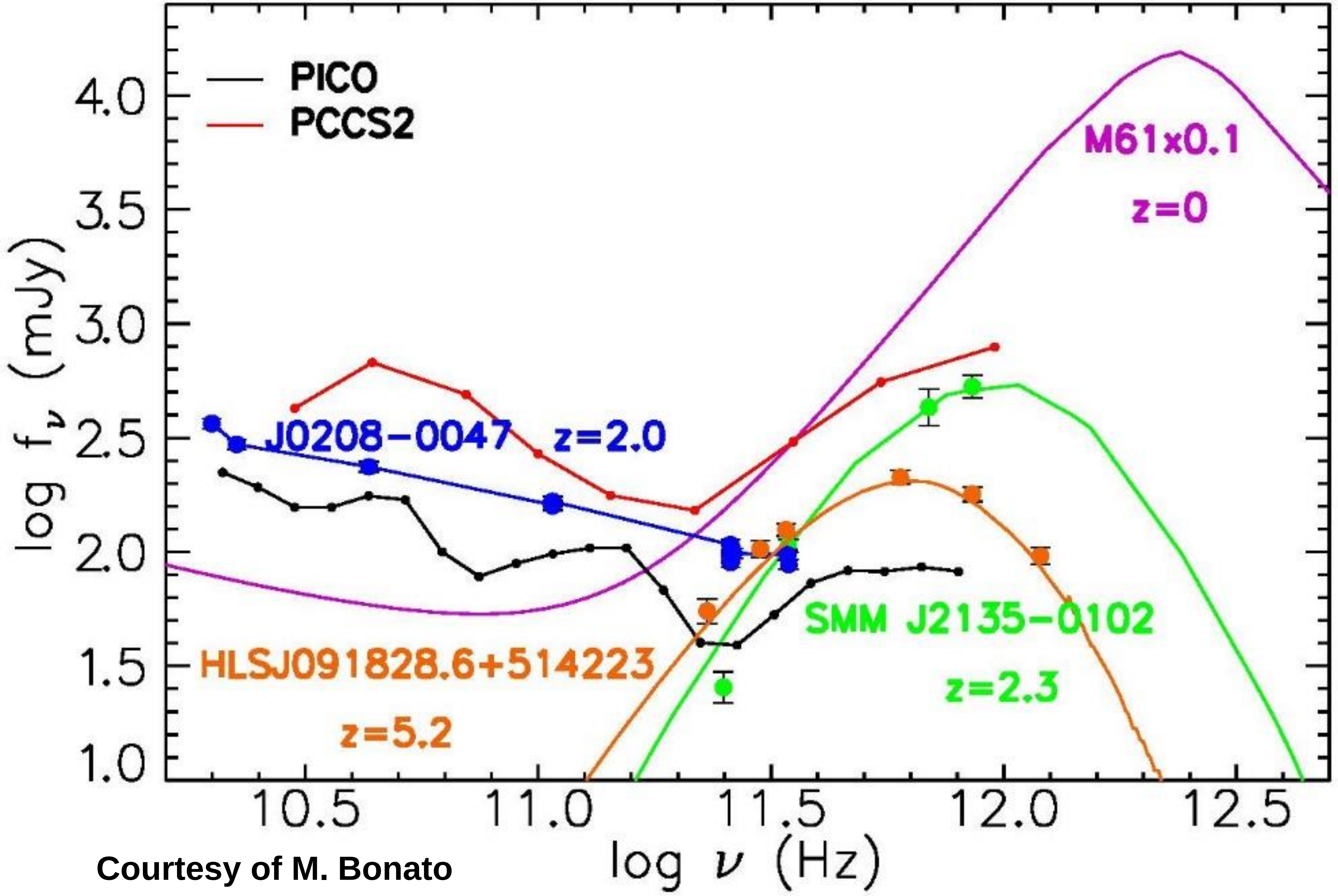
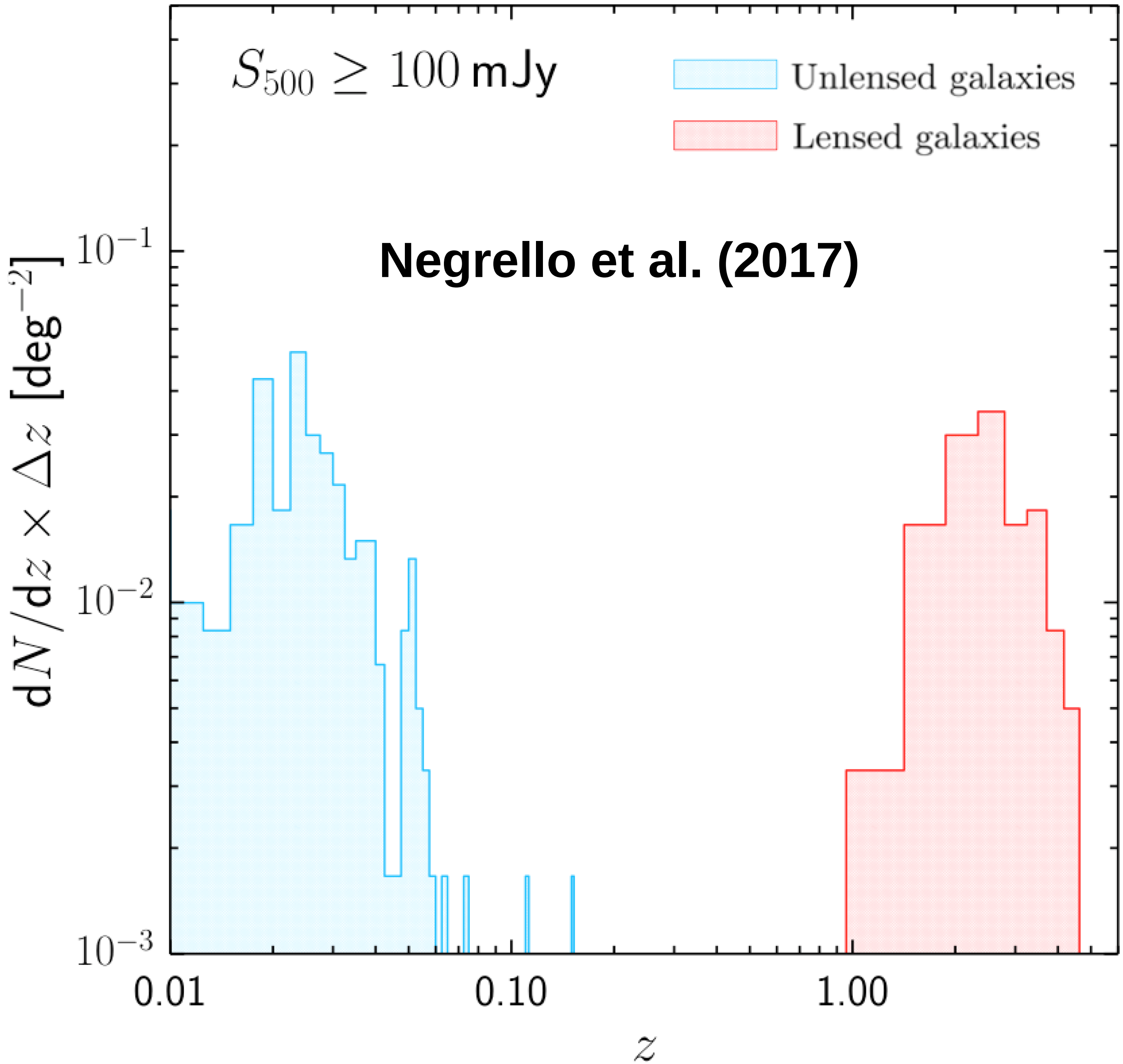
Thanks to Matteo Bonato, Mattia Negrello, Zhen-Yi Cai, Marcos Lopez-Caniego, Diego Herranz, Mathieu Remazeilles

Extragalactic source populations in PICO range

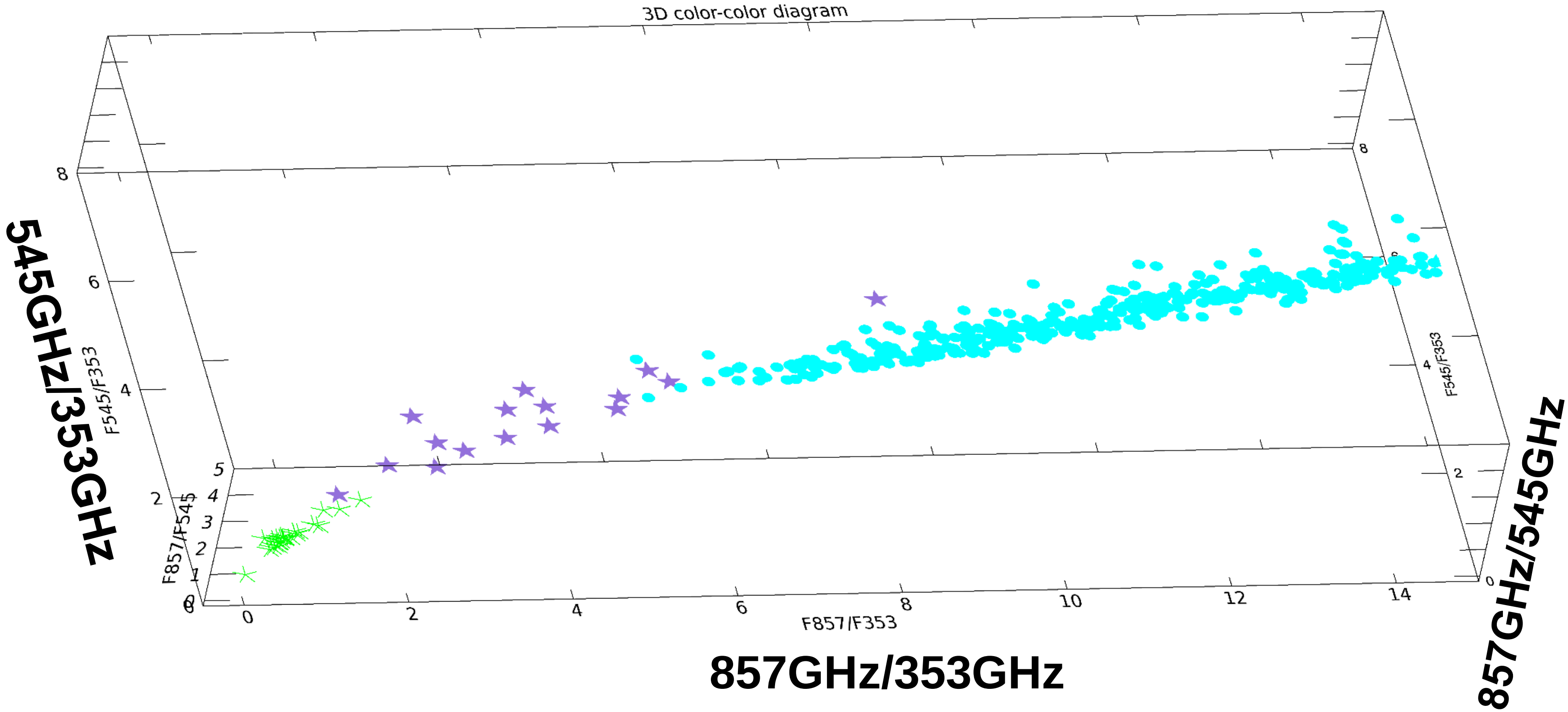


Courtesy of M. Bonato



Redshift distribution of H-ATLAS galaxies with 500μm flux densities > 100 mJy ≈ PICO detection limit. Lensed and unlensed galaxies are separated in redshift, hence have clearly different sub-mm colors.

Courtesy of T. Trombetti



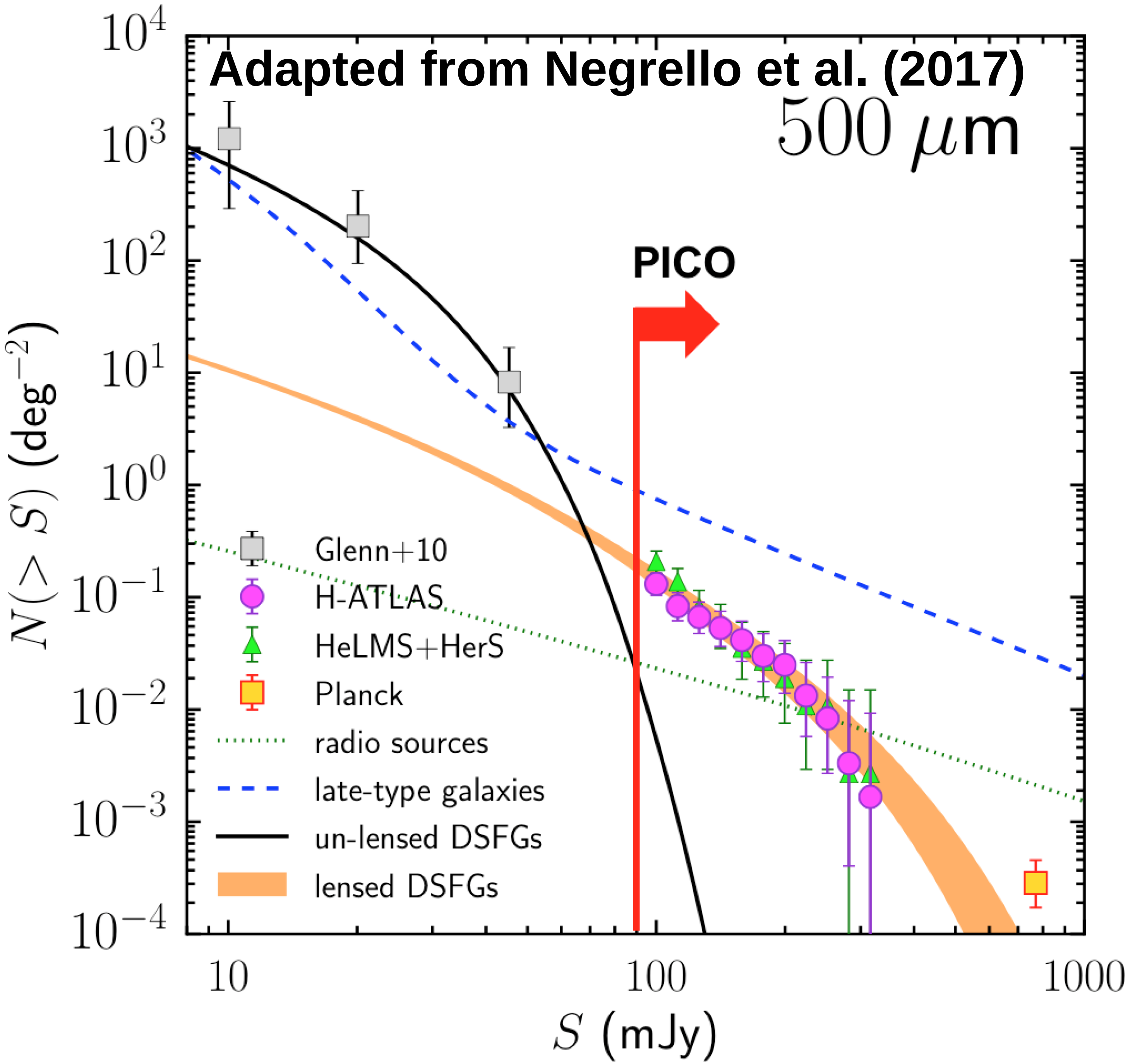
3D sub-mm color-color plot of *Planck* sources, showing that the different populations of extragalactic sources detected line up along a well defined sequence with blazars (green) having the reddest colors and low-z galaxies (cyan) the bluest. Colours of high-z strongly lensed galaxies are in between. Ambiguities due to dust temperature/redshift degeneracy easily resolved using radio or optical all-sky surveys.

Sub-mm searches of strongly lensed galaxies vs searches in other wavebands - 1

- Sub-mm strongly lensed galaxies are relatively numerous (comparable numbers of lensed and unlensed galaxies at the PICO detection limit) while they are a tiny minority ($\sim$1/1000) in the other wavebands;
- are very easy to single out because of their different colors, while in the optical lensed and unlensed galaxies look very much the same;
- the background lensed galaxy and the foreground lens show up in different wavebands: we don't have the problem of removing the mutual contamination in the lens modelling;

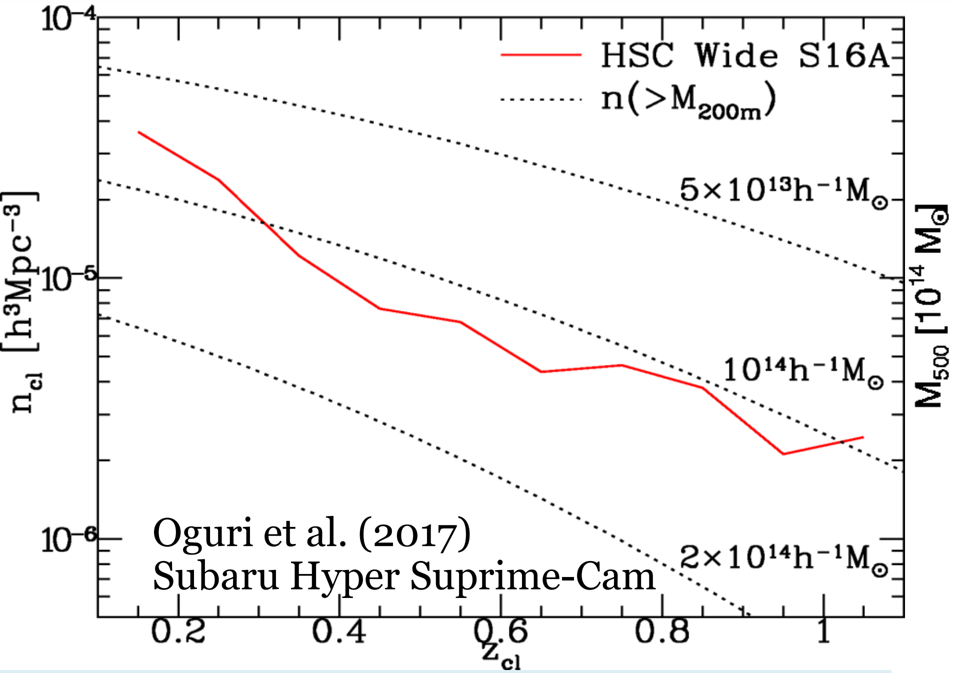
Sub-mm searches of strongly lensed galaxies vs searches in other wavebands - 2

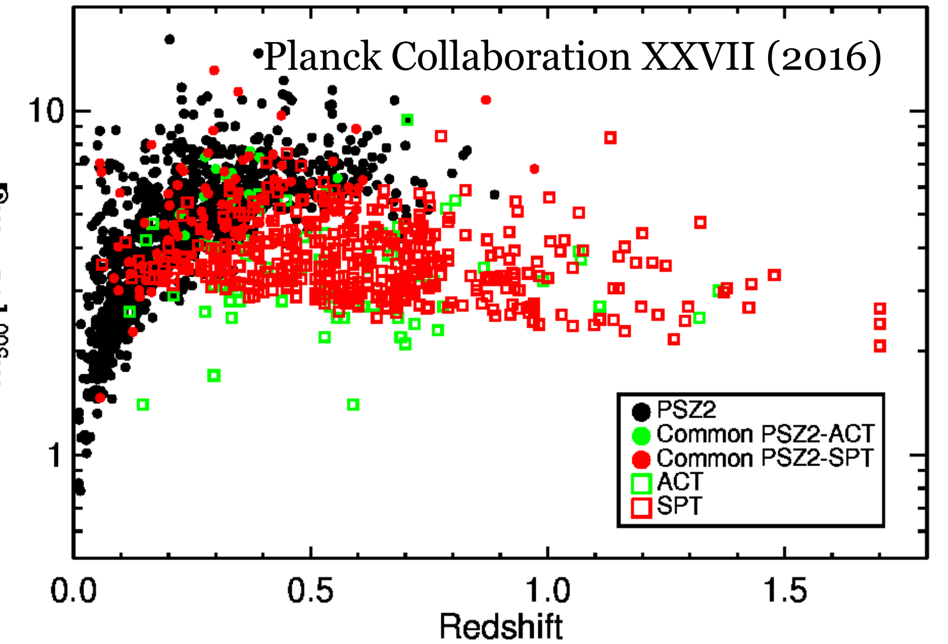
- sub-mm lensing probes the most active star-formation phases, hardly visible in the optical; thanks to the combination of magnification and image stretching, with the ALMA resolution it is possible to study the structure of these objects down to scales of 50 pc, smaller than those of Galactic giant molecular clouds;
- the higher redshifts of magnified galaxies correspond to higher redshifts of foreground lenses; this will allow us to investigate the total (visible and dark) mass of the lensing galaxies, their density profiles, dark matter sub-structures in a higher redshift range.

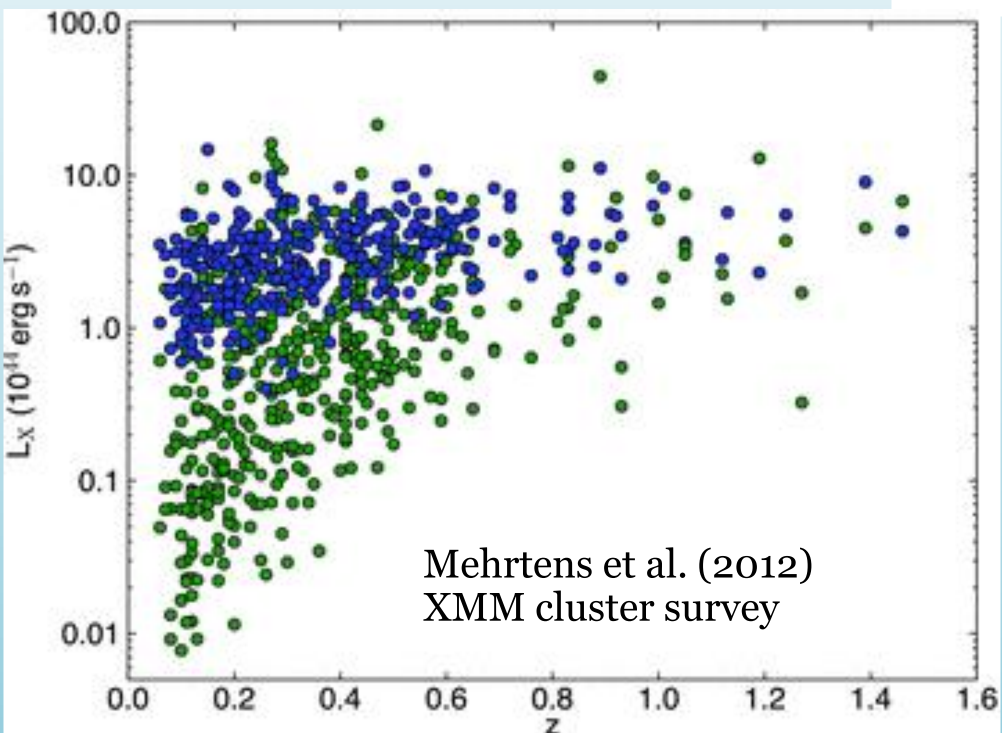


Herschel large-area surveys have covered ~1000 deg^2, discovering ~160 strongly lensed galaxy candidates with S_{600GHz} > 100 mJy. PICO will reach approximately the same flux density limit, increase the number of detections by a factor of ~30.

Proto-clusters of galaxies





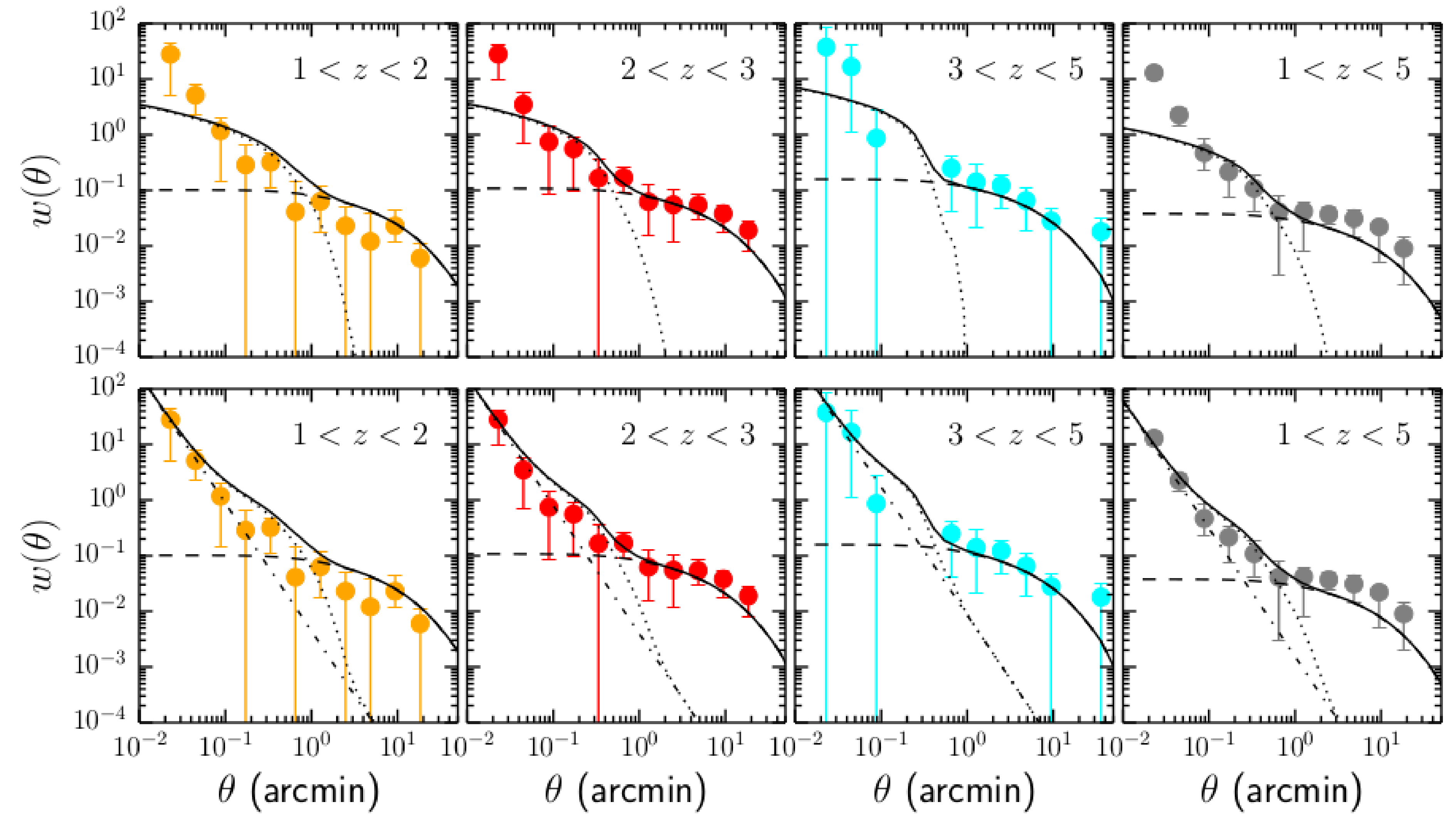


Classical techniques for detecting galaxy clusters (optical/near-IR "red sequence", X-ray emission, SZ effect) preferentially or exclusively select evolved objects, with mature galaxy populations and a hot intra-cluster medium. As a result, most known clusters are at redshifts <1.5, i.e. below that of the peak of global star-formation activity.

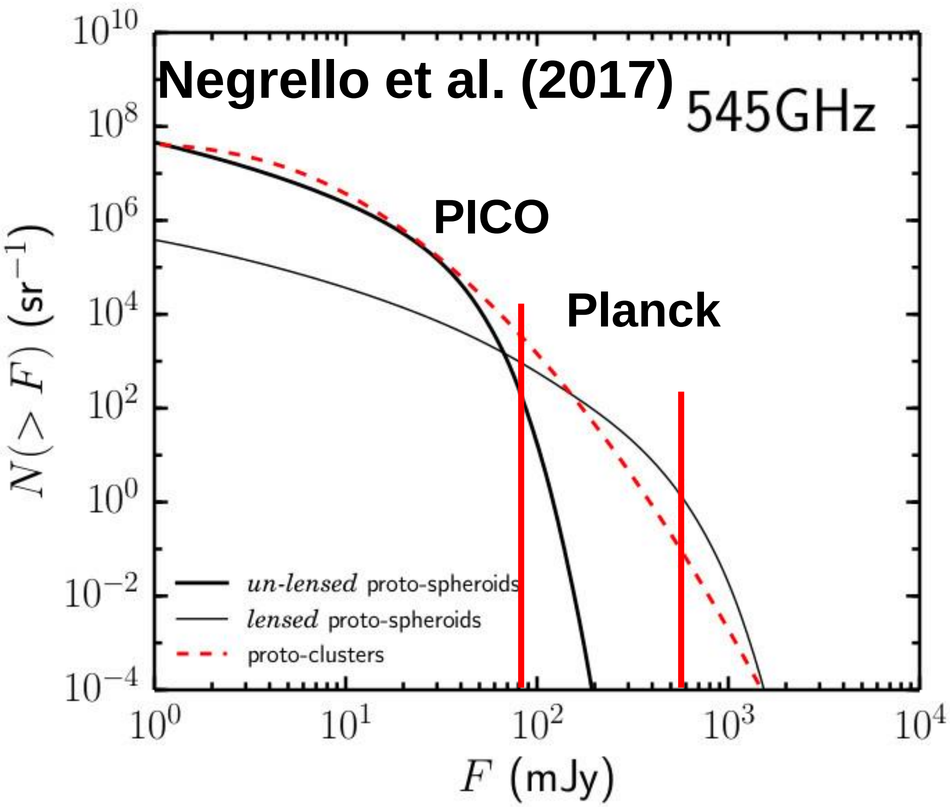
Proto-clusters in the sub-mm

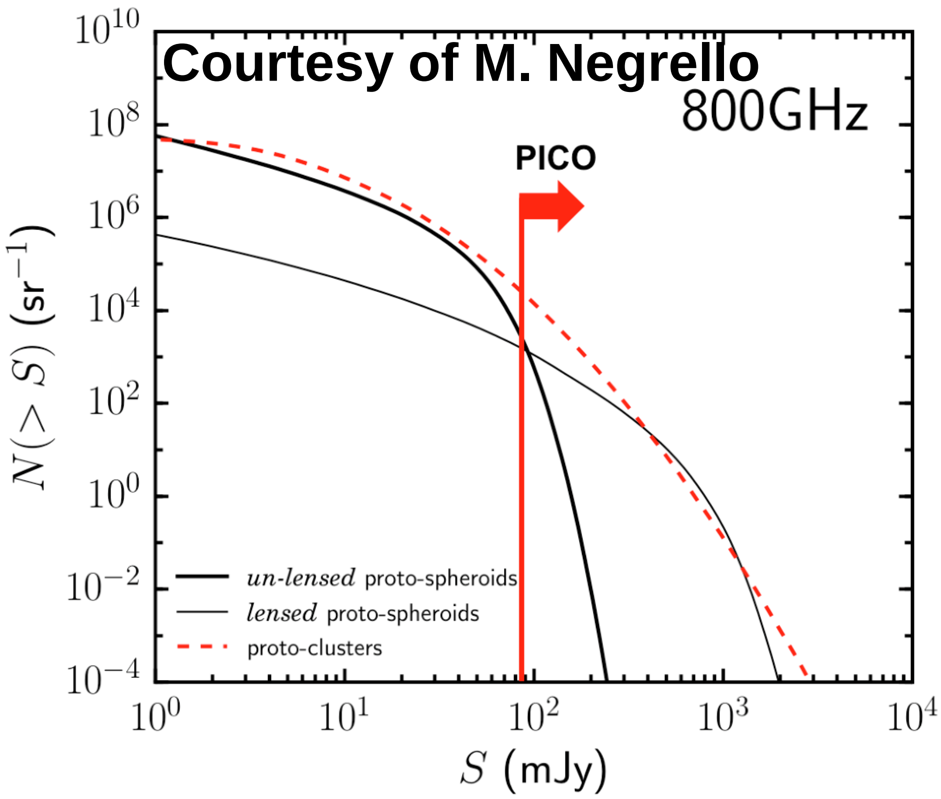
- Measurements of the integrated SFR per unit halo mass in clusters have found that this quantity is evolving much faster than in the field (Alberts et al. 2014, 2016). Hence, clusters become increasingly faint in the optical and increasingly bright in the far-IR/sub-mm.

- During the early phases of cluster evolution the hot IGM is not in place yet, preventing the cluster detection via X-ray emission or the SZ effect. As a result, most known clusters are at redshifts <1.5, i.e. below that of the peak of global star-formation activity. .

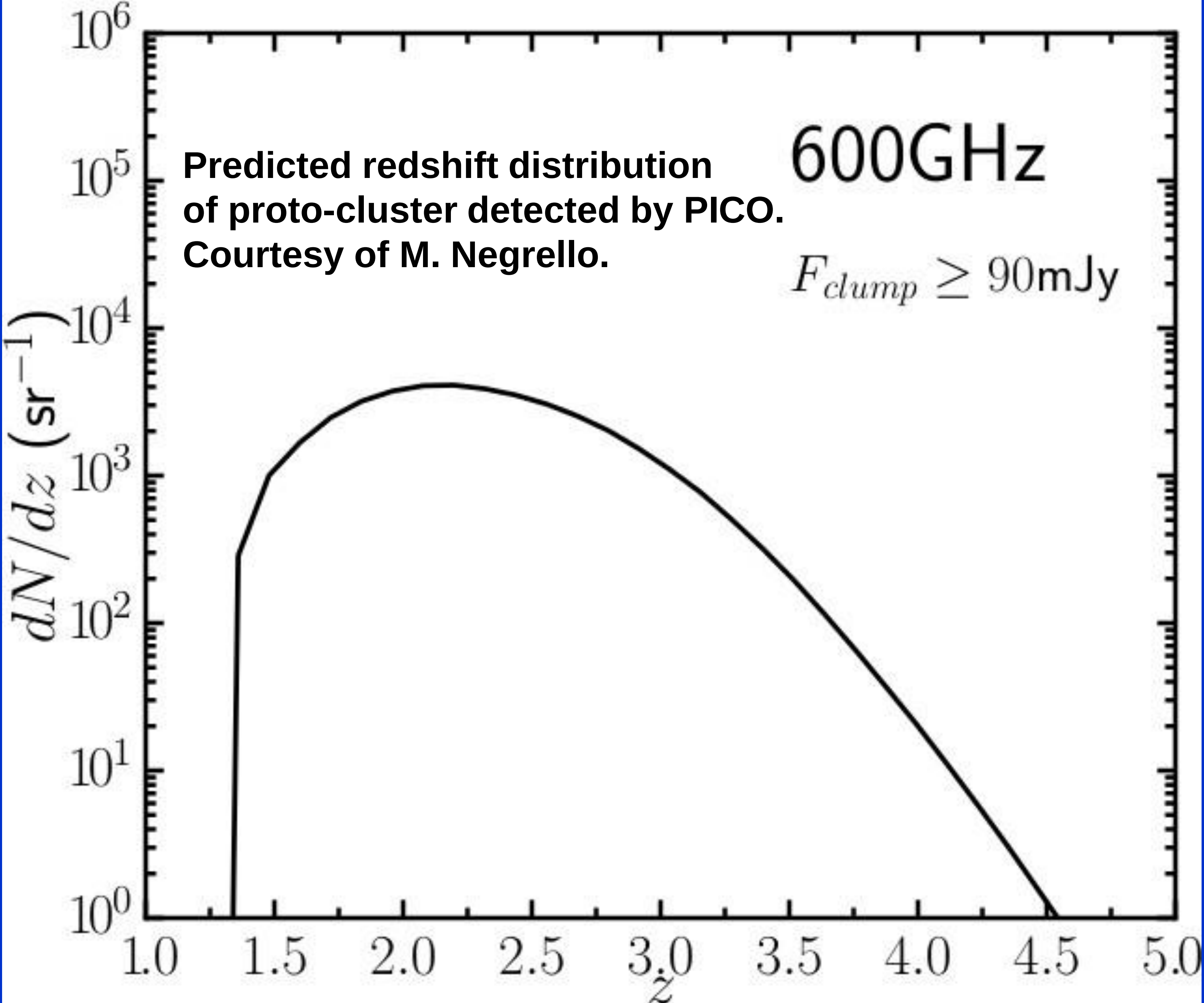


Clustering data of high-z star-forming galaxies show that the typical scale of non-linear overdensities is ~1′, close to the PICO high-frequency resolution (Negrello et al. 2017; data from Chen et al. 2016).





The predicted counts of proto-clusters by Negrello et al. (2017; dashed red line), successfully tested against the (admittedly poor) data currently available, are very steep. Thus the number of detections decreases by orders of magnitude as the resolution worsens. PICO is expected to detect tens of thousands proto-clusters, independently of whether they have developed a hot IGM.

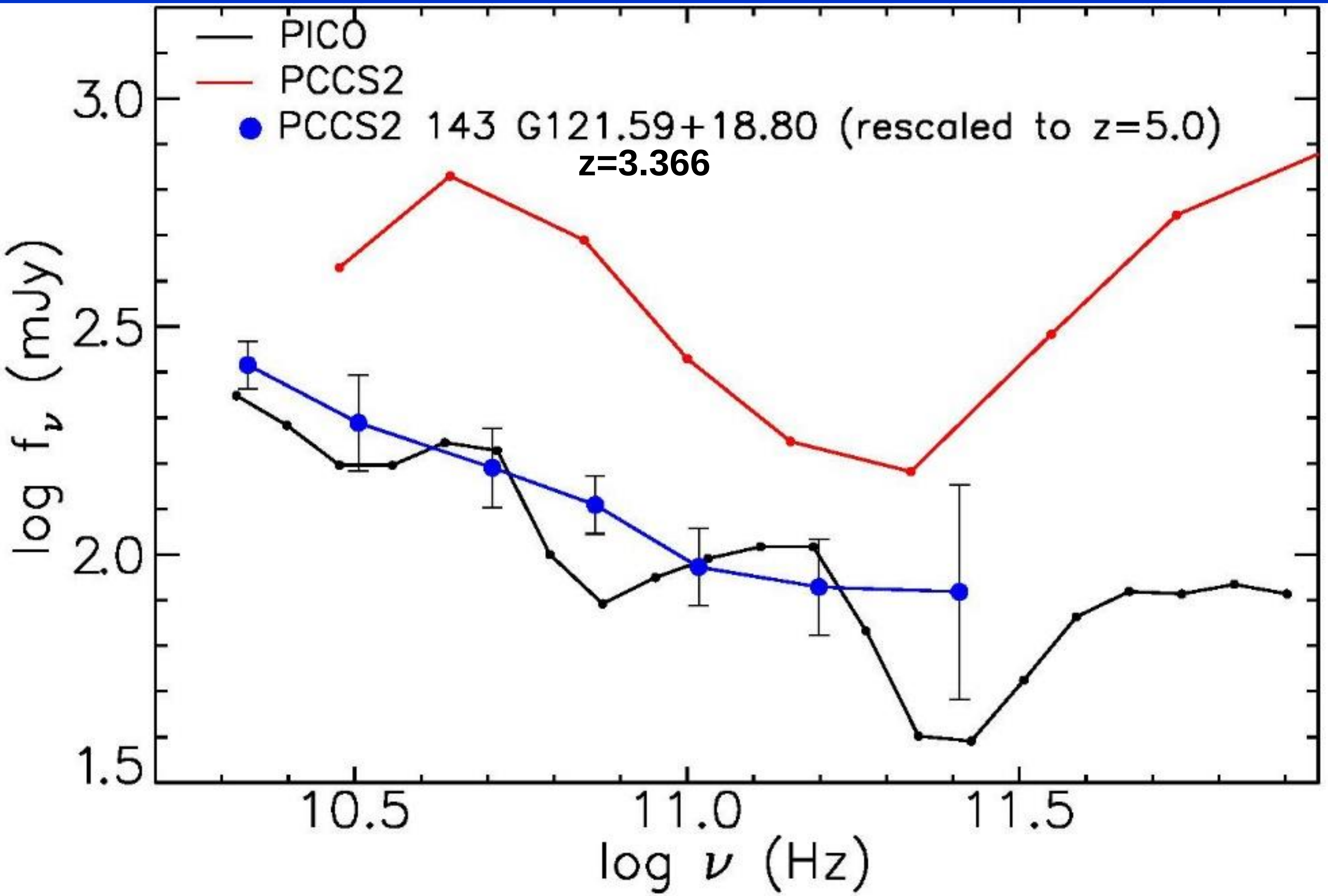

Predicted redshift distribution
of proto-cluster detected by PICO.
Courtesy of M. Negrello.
600GHz
$F_{clump} \geq 90$mJy
dN/dz (sr^{-1})
10^0
10^1
10^2
10^3
10^4
10^5
10^6
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
z

Flat-Spectrum Radio Quasars (FSRQs) - 1

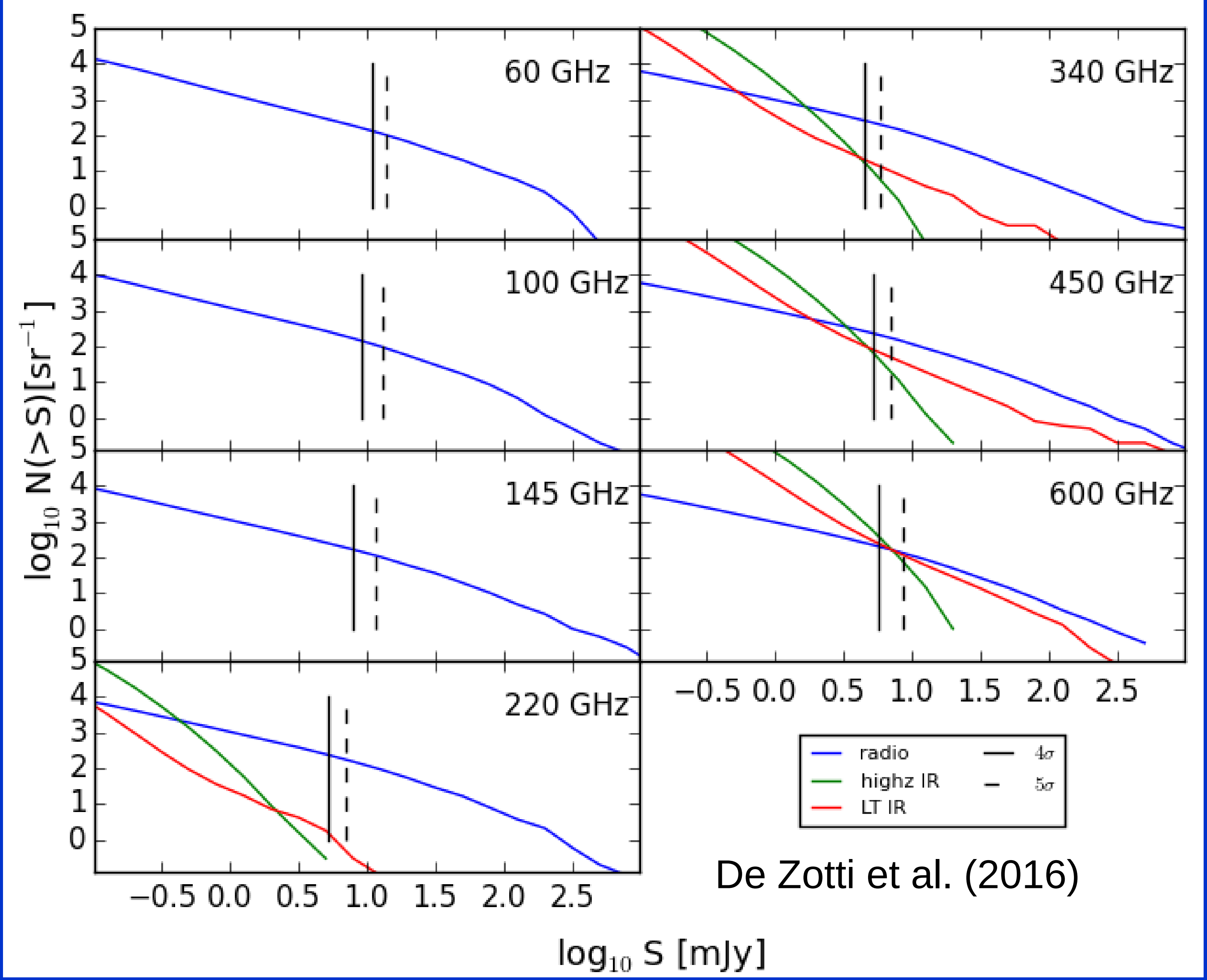
- The most luminous high-z FSRQs were found black holes with the largest masses, up to $\sim 4\times 10^{10}$ M_{sun} (S5 0014+813, at z = 3.366; Ghisellini et al. 2013).
- Such objects have particularly hard mm-wave spectra. Thus PICO surveys are well suited to detect them.
- Blazar searches are an effective way to detect the most massive black holes at high z because of the Doppler boosting of their flux densities, making them very bright.
- Since the flux boosting occurs for jets closely aligned with the line of sight ($\theta < 1/\Gamma$, $\Gamma \sim$ 15 being the bulk Lorentz factor), for each FSRQ there are other $2\Gamma^2$ (i.e. hundreds) sources of similar intrinsic properties but pointing elsewhere.
- .

FSRQs - 2

- Very large black hole masses at high-z are puzzling because it is challenging to grow a seed BH from stellar mass to > 10^9 M_{sun} in the limited age of the universe.
- It is even more challenging in the case of jetted quasars because it is commonly believed that the jets are associated with rapidly spinning black holes. But then the radiative efficiency is large and the mass growth is slower.
- Yet at least 4 FSRQs has been discovered at z>5 (up to z=5.48; Romani et al. 2004). One (SDSS J013127.34–032100.1 at z = 5.18) has estimated BH mass of $\sim 1 \times 10^{10}$ M_{sun} (Ghisellini et al. 2015)
- PICO can detect FSRQs up to z>5.


PICO
PCCS2
PCCS2 143 G121.59+18.80 (rescaled to z=5.0)
z=3.366
log f_ν (mJy)
3.0
2.5
2.0
1.5
10.5
11.0
11.5
log ν (Hz)

Polarization



Predicted counts in polarization for CORE with 1m (dashed) and 1.5 m telescope (solid).

Conclusions - 1

As amply demonstrated by Planck, space-borne CMB experiments, like PICO, thanks to their all-sky coverage and broad frequency range hardly or not accessible from the ground, provide unique information of great astrophysical interest on extragalactic sources.

Examples are:

- **Population properties and SEDs of blazars and of star-forming galaxies**
- **Discovery of extreme strongly lensed galaxies at high-z**
- **Discovery of candidate proto-clusters of galaxies, caught in the pre-virialization phase, when their member galaxies were forming most of their stars**

Conclusions - 2

The substantially better angular resolution and sensitivity of planned next generation experiment like CORE and PICO, even with the same telescope size as Planck, will boost by large factors the number of detections. Great progress in the field also expected from the ground-based CMB-S3/S4 project

But next-generation experiments will also make possible entirely new science such as:

- **The direct detection of large proto-cluster samples up to $z \approx 4$**
- **The study of the evolution of the star-formation in virialized groups and cluster of galaxies**
- **The study of the polarization properties of large samples of radio sources and of dusty galaxies at mm and sub-mm wavelengths**