B-mode forecasts from extra-galactic point sources

Giuseppe Puglisi
with V. Galluzzi, L. Bonavera, J. Gonzalez-Nuevo, A. Lapi , M. Massardi, F. Perrotta, C. Baccigalupi, A. Celotti and L. Danese

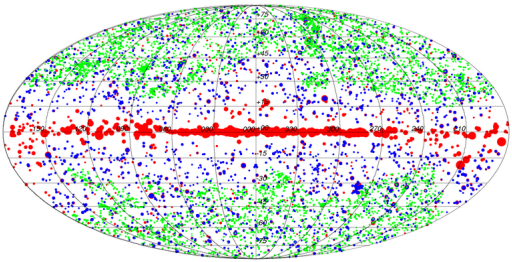
ApJ doi:10.3847/1538-4357/aab3c7

CMB foregrounds for B-mode studies
Tenerife

October 17, 2018

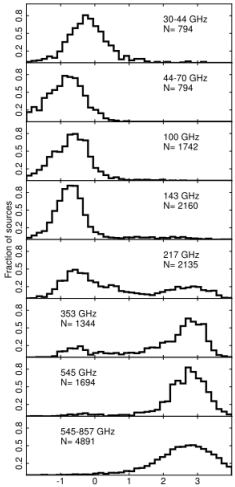
Stanford
University

Extragalactic Sources in CMB surveys



from Planck Catalogue PCCS2 Planck Collaboration (2015)
30 GHz 150 GHz 857 GHz

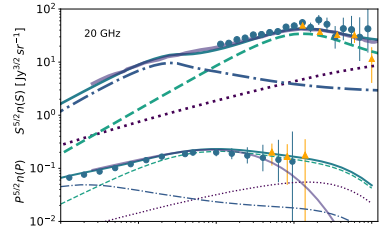
Radio Sources (RS)



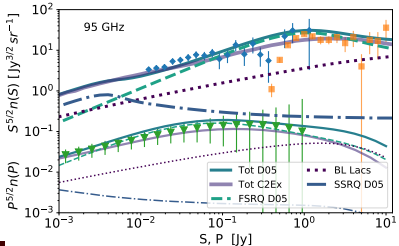
Dust Galaxies (DSFGs)

RS and DSFG Euclidean number counts

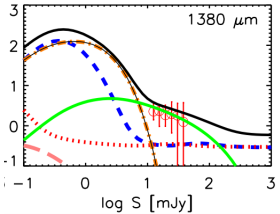
RS predictions from de Zotti et al. (2005) and Tucci et al. (2011)

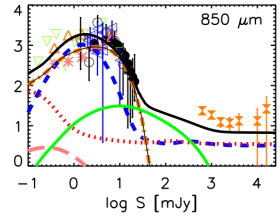


(Puglisi et al., 2018)



DSFG predictions from Cai et al. (2013); Béthermin et al. (2012)





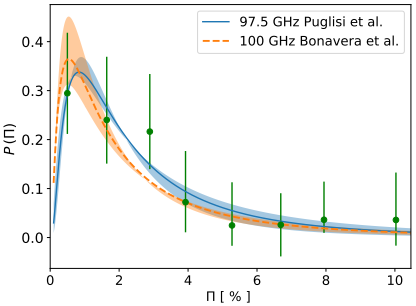
(Cai et al., 2013)

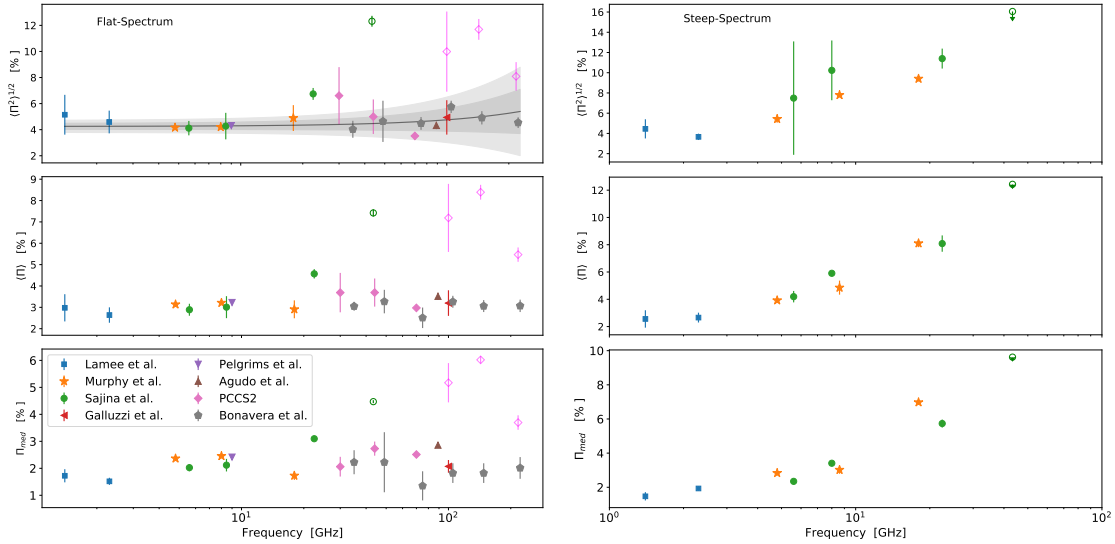
Stellar and AGN component of Proto-Spheroids, Strongly lensed Proto-Spheroids, *cold* and *warm* late-type galaxies

Applied methodology Puglisi et al. (2018)

	Frequency [GHz]	Sky Region	FWHM	Detect. flux	90% Compl.	# Sources
NVSS	1.4	$\delta > -40°$	$45''$	0.29 mJy/beam	2.3 mJy	1.8×10^6
S-PASS	2.3	$\delta < -1°$	$8.9'$	1 mJy/beam	420 mJy	533
JVAS	8.4	$\delta \geq 0°, \lvert b\rvert \geq 2.5°$	$0.2''$	50 mJy	200 mJy	2720
CLASS	8.4	$0 \geq \delta \geq 70°$	$0.2''$	20 mJy	30 mJy	16503
AT20G	4.8, 8.6, 20	$\delta < 0°, \lvert b\rvert < 1.5°$	$10'', 6'', 11''$	40 mJy	100 mJy/beam	5890
VLA	4.8, 8.5, 22.5, 43.5	$\delta > -15°$	$12'', 6'', 4'', 2''$	0.7, 0.3, 0.9, 1.2 mJy/beam	40 mJy	159
PACO	20	Ecl. lat.$< -65°$	$11''$	40 mJy	200 mJy	104
XPOL-IRAM	86	$\delta > 30°$	$28''$	0.5 Jy	1 Jy	145
PCCS2	30, 44, 70, 100, 143, 217	Full sky	$32.4', 27.1', 13.3', 9.7', 7.3', 5.0'$	117,229, 225, 106, 75,81 mJy	427,692, 501,269, 177,152 mJy	1560,934, 1296,1742, 2160,2135

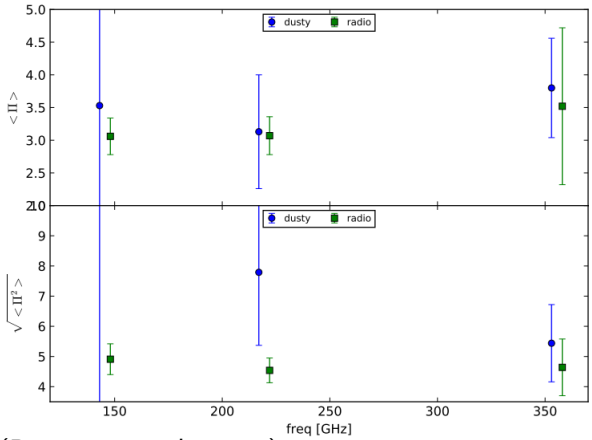
- 32 polarized sources detected at 97.5 GHz by ALMA (Galluzzi et al. 2018 (submitted))
- compute the fractional polarization distributions from all catalogues
- Lognormal best-fit $\Rightarrow$ estimate average fractional polarization




Flat-Spectrum
Steep-Spectrum
$(\Pi^2)^{1/2}$ [%]
$\langle\Pi\rangle$ [%]
Π_{med} [%]
Lamee et al.
Murphy et al.
Sajina et al.
Galluzzi et al.
Pelgrims et al.
Agudo et al.
PCCS2
Bonavera et al.
Frequency [GHz]

Accounting for DSFGs

- Forecasts for frequency > 160 GHz
- so far, contribution from clustering included for TT spectra only , $\mathcal{D}_\ell \propto \ell^{0.8}$, (George et al., 2015)
- Average value of $\langle \Pi^2_{dusty} \rangle$ from measurements at 143, 217, 353 GHz with stacking technique, from Bonavera et al. (2017), $\Pi \sim 3 \div 3.5\%$ (Trombetti et al. (2017) found upper limits on Π_{dusty})



(Bonavera et al., 2017)

Point-Source ForeCast (PS4C)

PS4C is a python package publicly available[1], tutorial and documentation are also provided

The input to PS4C are the specifics of a given experiment:

- frequency channels
- sensitivities
- beam resolutions
- survey area

```
sensitivities = [20.8,14.3,3.3, 4.1 ]
fsky=.2
S0=Experiment( ID='Simons Observatory',sensitivity= sensitivities, frequency=freqs ,nchannels=len(freqs), fwhm=fwhms
                    units_sensitivity='uKsqrts',units_beam='arcmin', timeobserv=5*u.yr)

fcS0=Forecaster(S0, ps4c_dir=dir_ps)
fcS0.forecast_pi2scaling(verbose=False, include_steep=False )

fcS0()
```

[1] https://gitlab.com/giuse.puglisi/PS4C

- Estimate contribution of undetected sources given a sensitivity intensity flux cut $S < S_{cut} = 5\sigma_{det}$

$$C_\ell^{TT,\nu} \propto \int_0^{S_{cut}} dS S^2 \frac{dN_\nu}{dS}$$

with dN/dS, differential number counts from total intensity measurements

- polarization power spectra: $C_\ell^{BB} \propto C_\ell^{TT,\nu_b} \langle \Pi^2_{\nu_b} \rangle$ see Puglisi et al. (2018)

PS4C on SO LAT, (The Simons Observatory Collaboration et al., 2018)

ν[GHz]	Sensitivity $[\mu\mathrm{K\,arcmin}]$	FWHM	f_{sky}
27	52	$7.4'$	0.4
39	27	$5.1'$	0.4
93	5.8	$2.2'$	0.4
145	6.3	$1.4'$	0.4
225	15	$1'$	0.4
280	37	$0.9'$	0.4

PS4C on SO LAT, (The Simons Observatory Collaboration et al., 2018)

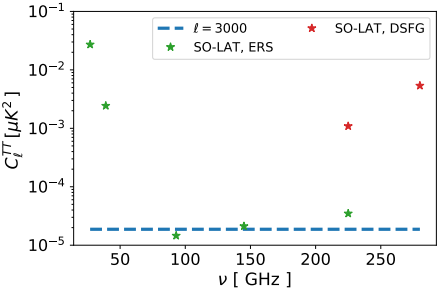
ν[GHz]	Sensitivity $[\mu\mathrm{K\,arcmin}]$	FWHM	f_{sky}
27	52	$7.4'$	0.4
39	27	$5.1'$	0.4
93	5.8	$2.2'$	0.4
145	6.3	$1.4'$	0.4
225	15	$1'$	0.4
280	37	$0.9'$	0.4

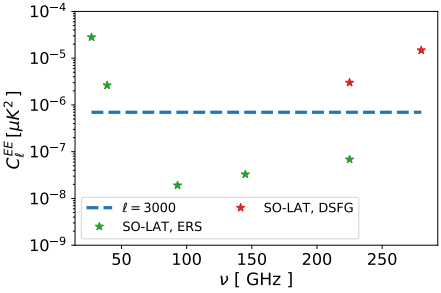
RS
DSFG

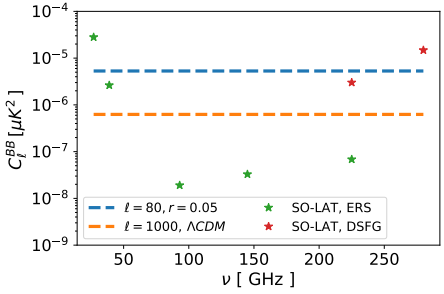
PS4C on SO LAT

ν[GHz]	Sensitivity $[\mu\mathrm{K\,arcmin}]$	FWHM	f_{sky}	$5\sigma_{det}$ [mJy]	$N_{ERS,pol}$	$N_{DSFG\,pol}$
27	52	$7.4'$	0.4	20	80	...
39	27	$5.1'$	0.4	10	150	...
93	5.8	$2.2'$	0.4	7	270	...
145	6.3	$1.4'$	0.4	10	70	...
225	15	$1'$	0.4	36	40	8
280	37	$0.9'$	0.4	238	...	1

see The Simons Observatory Collaboration et al. (2018, Sect.8)


10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$C_\ell^{TT}\,[\mu K^2]$
50
100
150
200
250
ν [GHz]
$\ell = 3000$
SO-LAT, ERS
SO-LAT, DSFG


10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
$C_\ell^{EE}\,[\mu K^2]$
50
100
150
200
250
ν [GHz]
$\ell = 3000$
SO-LAT, ERS
SO-LAT, DSFG


10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
$C_\ell^{BB}\,[\mu K^2]$
50
100
150
200
250
ν [GHz]
$\ell = 80, r = 0.05$
$\ell = 1000, \Lambda CDM$
SO-LAT, ERS
SO-LAT, DSFG

QUIJOTE MFI (10-20 GHz) forecasts

ν[GHz]	Sensitivity $[\mu\mathrm{K\,deg}]$	FWHM	f_{sky}
11	30	1°	0.5
13	30	1°	0.5
17	30	1°	0.5
19	30	1°	0.5

QUIJOTE MFI (10-20 GHz) forecasts

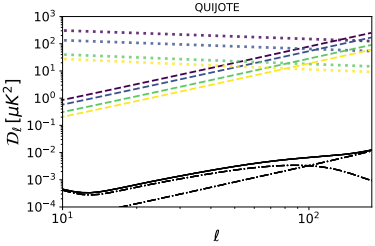
ν[GHz]	Sensitivity $[\mu\mathrm{K\,deg}]$	FWHM	f_{sky}	S_{lim} [Jy]	N_{src}	$N_{src,pol}$
11	30	1°	0.5	0.5	508	4
13	30	1°	0.5	0.7	318	2
17	30	1°	0.5	1.2	138	...
19	30	1°	0.5	1.5	85	...

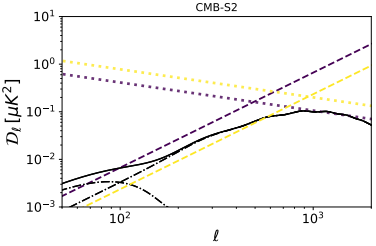
Summary

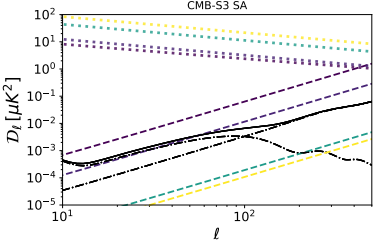
- We combined state-of-the-art observations of polarized extra-galactic radio sources from 1.4 to 353 GHz
- We developed a **forecast package** PS4C that can be easily applied for future and forthcoming CMB experiments from ground and space
- **Undetected** polarized point sources can contaminate CMB small angular scales in EE and BB power spectrum
- Future CMB experiments will detect an increasing number of polarized radio sources (up to ~ 200) at high-radio frequencies (from 20 to 220 GHz)
- Dusty sources heve been *recently* included in this analysis (they are expected to dominate above 150 GHz)

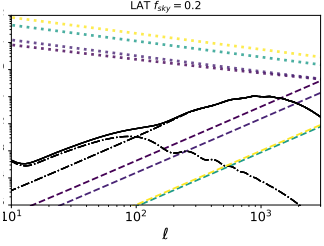
Thank you!

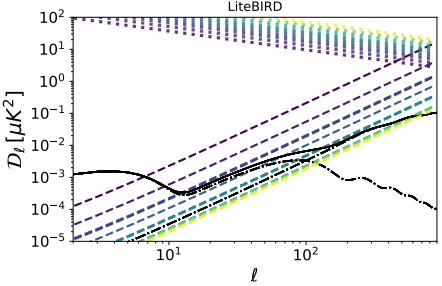
Backup

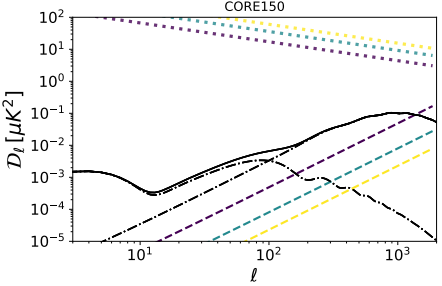

QUIJOTE
$\mathcal{D}_\ell\,[\mu K^2]$
ℓ

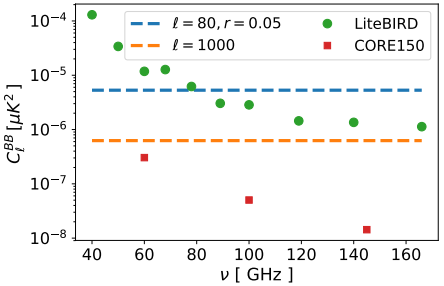

CMB-S2
$\mathcal{D}_\ell\,[\mu K^2]$
ℓ

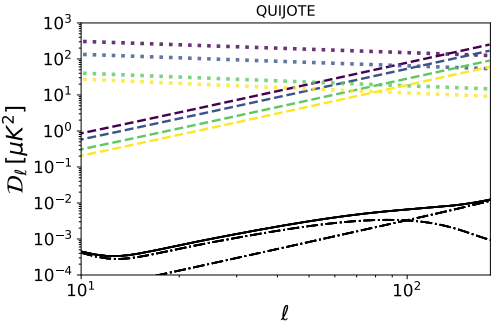

CMB-S3 SA
$\mathcal{D}_\ell\,[\mu K^2]$
ℓ


LAT $f_{sky} = 0.2$
ℓ


LiteBIRD
$\mathcal{D}_\ell\ [\mu K^2]$
ℓ


CORE150
$\mathcal{D}_\ell\ [\mu K^2]$
ℓ


$\ell = 80, r = 0.05$
$\ell = 1000$
LiteBIRD
CORE150
$C_\ell^{BB}\ [\mu K^2]$
ν [GHz]


QUIJOTE
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$\mathcal{D}_\ell\,[\mu K^2]$
10^1
10^2
ℓ

QUIJOTE MFI (10-20 GHz) forecasts

ν[GHz]	Sensitivity $[\mu\mathrm{K\,deg}]$	FWHM	f_{sky}
11	30	1°	0.5
13	30	1°	0.5
17	30	1°	0.5
19	30	1°	0.5

QUIJOTE MFI (10-20 GHz) forecasts

ν[GHz]	Sensitivity $[\mu\mathrm{K\,deg}]$	FWHM	f_{sky}	$5\sigma_{det}$ [Jy]	N_{src}	$N_{src,pol}$
11	30	1°	0.5	0.5	508	2
13	30	1°	0.5	0.7	318	1
17	30	1°	0.5	1.2	138	...
19	30	1°	0.5	1.5	85	...

Bibliography

Matthieu Béthermin, Emanuele Daddi, Georgios Magdis, Mark T. Sargent, Yashar Hezaveh, David Elbaz, Damien Le Borgne, James Mullaney, Maurilio Pannella, Véronique Buat, Vassilis Charmandaris, Guilaine Lagache, and Douglas Scott. A UNIFIED EMPIRICAL MODEL FOR INFRARED GALAXY COUNTS BASED ON THE OBSERVED PHYSICAL EVOLUTION OF DISTANT GALAXIES. *The Astrophysical Journal*, 757(2):L23, oct 2012. ISSN 2041-8205. doi: 10.1088/2041-8205/757/2/L23. URL http://stacks.iop.org/2041-8205/757/i=2/a=L23?key=crossref.cfa25c64671c0d8d227b36811aa49f40.

L. Bonavera, J. González-Nuevo, B. De Marco, F. Argüeso, and L. Toffolatti. Statistics of the fractional polarization of extragalactic dusty sources in Planck HFI maps. *Monthly Notices of the Royal Astronomical Society*, 472(1):628–635, nov 2017. ISSN 0035-8711. doi: 10.1093/mnras/stx2102. URL http://academic.oup.com/mnras/article/472/1/628/4082846/Statistics-of-the-fractional-polarization-of.

Zhen-Yi Cai, Andrea Lapi, Jun-Qing Xia, Gianfranco De Zotti, Mattia Negrello, Carlotta Gruppioni, Emma Rigby, Guillaume Castex, Jacques Delabrouille, and Luigi Danese. A HYBRID MODEL FOR THE EVOLUTION OF GALAXIES AND ACTIVE GALACTIC NUCLEI IN THE INFRARED. *The Astrophysical Journal*, 768(1):21, apr 2013. ISSN 0004-637X. doi: 10.1088/0004-637X/768/1/21. URL http://stacks.iop.org/0004-637X/768/i=1/a=21?key=crossref.f8cb924cf7d65a1a11d58f7d316d03d6.

G. de Zotti, R. Ricci, D. Mesa, L. Silva, P. Mazzotta, L. Toffolatti, and J. González-Nuevo. Predictions for high-frequency radio surveys of extragalactic sources. *Astronomy and Astrophysics*, 431:893–903, March 2005. doi: 10.1051/0004-6361:20042108.

E. M. George, C. L. Reichardt, K. A. Aird, B. A. Benson, L. E. Bleem, J. E. Carlstrom, C. L. Chang, H-M. Cho, T. M. Crawford, A. T. Crites, T. de Haan, M. A. Dobbs, J. Dudley, N. W. Halverson, N. L. Harrington, G. P. Holder, W. L. Holzapfel, Z. Hou, J. D. Hrubes, R. Keisler, L. Knox, A. T. Lee, E. M. Leitch, M. Lueker, D. Luong-Van, J. J. McMahon, J. Mehl, S. S. Meyer, M. Millea, L. M. Mocanu, J. J. Mohr, T. E. Montroy, S. Padin, T. Plagge, C. Pryke, J. E. Ruhl, K. K. Schaffer, L. Shaw, E. Shirokoff, H. G. Spieler, Z. Staniszewski, A. A. Stark, K. T. Story, A. van Engelen, K. Vanderlinde, J. D. Vieira, R. Williamson, and O. Zahn. A MEASUREMENT OF SECONDARY COSMIC MICROWAVE BACKGROUND ANISOTROPIES FROM THE 2500 SQUARE-DEGREE SPT-SZ SURVEY. *The Astrophysical Journal*, 799(2): 177, jan 2015. ISSN 1538-4357. doi: 10.1088/0004-637X/799/2/177. URL http://stacks.iop.org/0004-637X/799/i=2/a=177?key=crossref.b702b691740638e9154d82fae3152a44.

Planck Collaboration. Planck 2015 results. XXVI. The Second Planck Catalogue of Compact Sources. *Astronomy & Astrophysics*, 594:A26, oct 2015. ISSN 0004-6361. doi: 10.1051/0004-6361/201526914. URL http://www.aanda.org/10.1051/0004-6361/201526914.

G. Puglisi, V. Galluzzi, L. Bonavera, J. Gonzalez-Nuevo, A. Lapi, M. Massardi, F. Perrotta, C. Baccigalupi, A. Celotti, and L. Danese. Forecasting the Contribution of Polarized Extragalactic Radio Sources in CMB Observations. *The Astrophysical Journal*, 858(2):85, may 2018. ISSN 1538-4357. doi: 10.3847/1538-4357/aab3c7. URL http://stacks.iop.org/0004-637X/858/i=2/a=85?key=crossref.8fabfadab2badba8bccaabda16342429.

The Simons Observatory Collaboration, P. Ade, J. Aguirre, Z. Ahmed, S. Aiola, A. Ali, D. Alonso, M. A. Alvarez, K. Arnold, P. Ashton, and et al. The Simons Observatory: Science goals and forecasts. *ArXiv e-prints*, August 2018.