The *Planck* Catalogue of Compact Sources

Planck Collaboration presented by
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Introduction

- The *Planck* Catalogue of Compact Sources (PCCS) is a set of nine single-frequency lists of sources extracted from the *Planck* nominal mission data.
- As its predecessor the Early Release Compact Source Catalogue (ERCSC), the PCCS has the widest frequency coverage of any catalogue produced by a single telescope scanning the whole sky (30-857 GHz;10000-350 μm).
- With an angular resolution from ~33' down to ~5' and a sensitivity of 180 mJy in the best channel it will allow important astrophysical studies of both Galactic and extragalactic sources.
- No polarization information is provided for the sources at this time.

Access and description

- The PCCS can be downloaded from the Planck Legacy Archive (PLA): http://pla.esac.esa.int/pla/pla.jnlp
- It could be also retrieved using common astronomical tools as Aladin or TopCat.
- The PCCS is described in the Planck Collaboration XXVIII (2013) paper: arXiv:1303.5088
- Additional information about the format and usage can be found in the *Planck* Explanatory Supplement (at PLA)

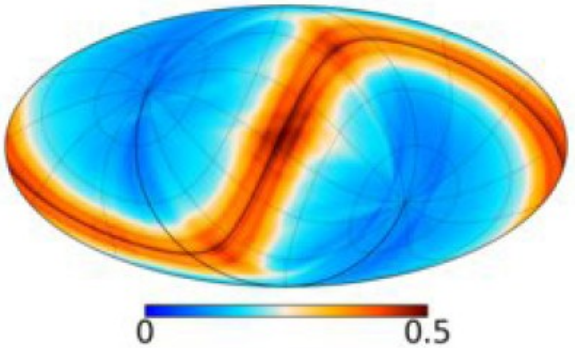
Outline

- Detection pipeline
- Validation process
  - Internal validation (by simulations)
  - External validation (by comparison with other observations)
- Characteristics
  - Statistical properties
  - Sensitivity
  - Comparison with ERCSC
- Conclusions

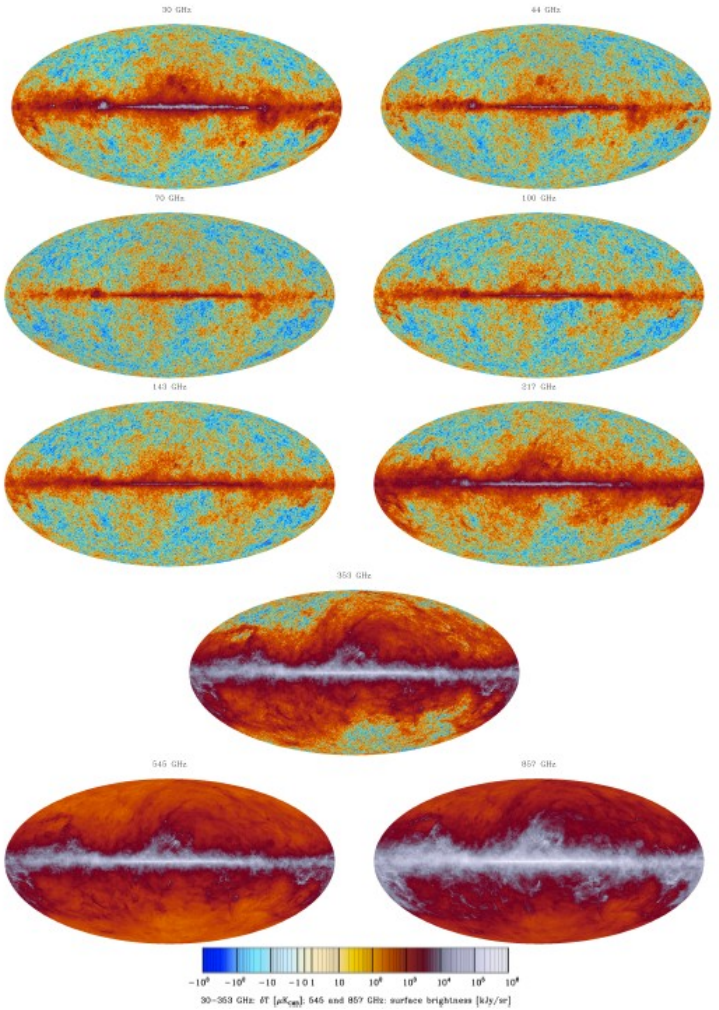
PCCS: Detection pipeline

Data:

- "Nominal mission": between 12-08-2009 and 27-11-2010
- Input maps: the nine *Planck* frequency channel maps
  - A Zodiacal Light emission model was subtracted at 353, 545 & 857 GHz (Planck Collaboration XIV, 2013)



Planck ZL model @857GHz

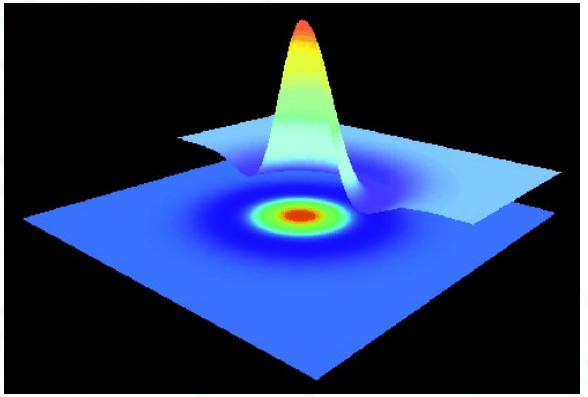


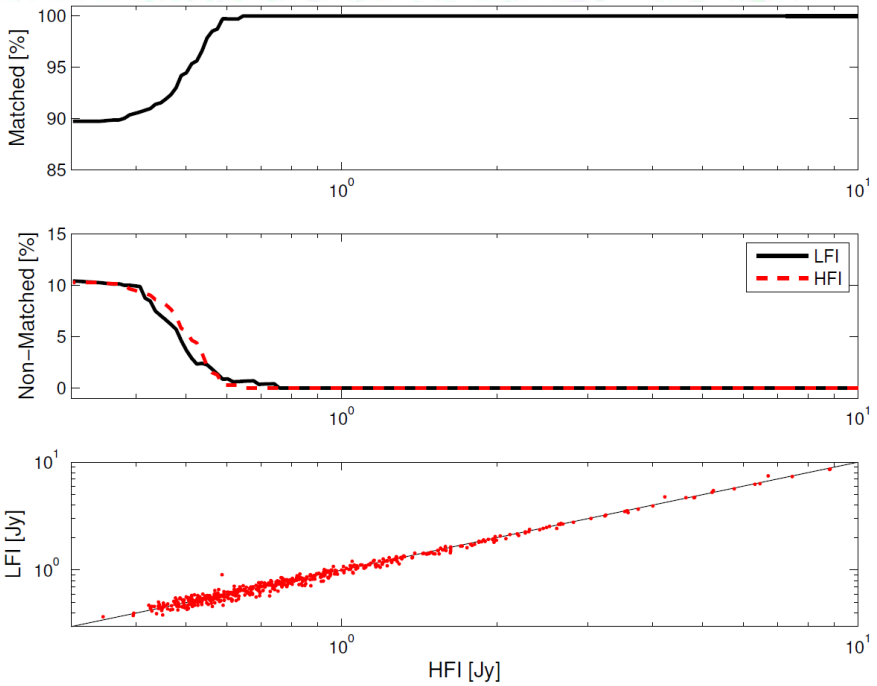
Planck frequency maps

PCCS: Detection pipeline

Algorithm:

- The MHW2 (second member of the Mexican Hat Wavelet Family; Gonzalez-Nuevo et al., 2006, Lopez-Caniego et al., 2006) has been selected as the baseline method for the production of the PCCS.
- This algorithm was demonstrated to be robust and to give good performance at all the *Planck* channels and Galactic latitudes.
- Two different implementations of the same algorithms for each DPC.



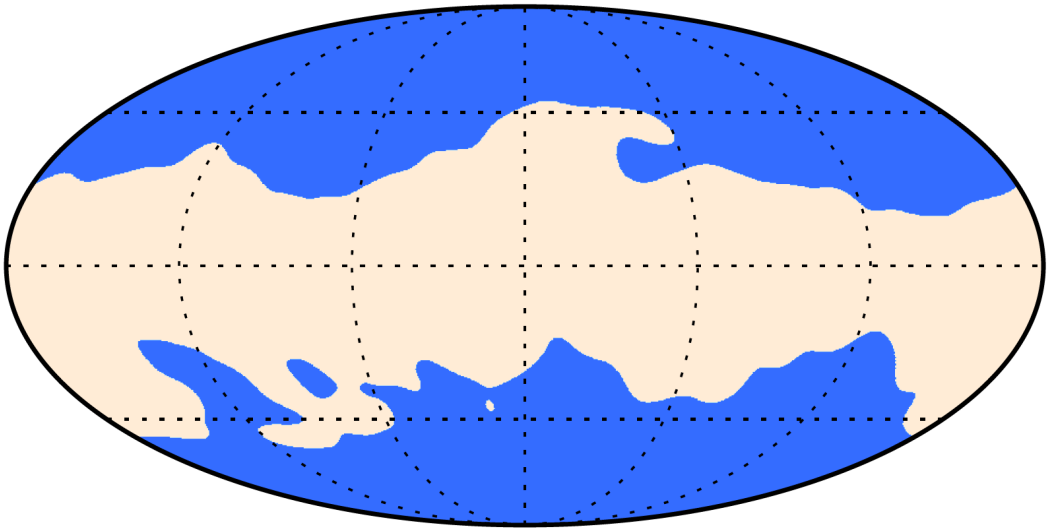


Comparison of LFI/HFI MHW2 implementations @30 GHz

PCCS: Detection pipeline

Selection criteria

- Reliability goal of R~80%
  - Increase in the completeness and possibly interesting new fainter sources.
- 30-70 GHz:
  - R>80% but S/N=4 imposed to minimize upward bias on fainter flux densities.
- 100-217 GHz:
  - S/N threshold estimated in the extragalactic zone but applied all-sky
- 353-857 GHz:
  - Different S/N thresholds in both zones

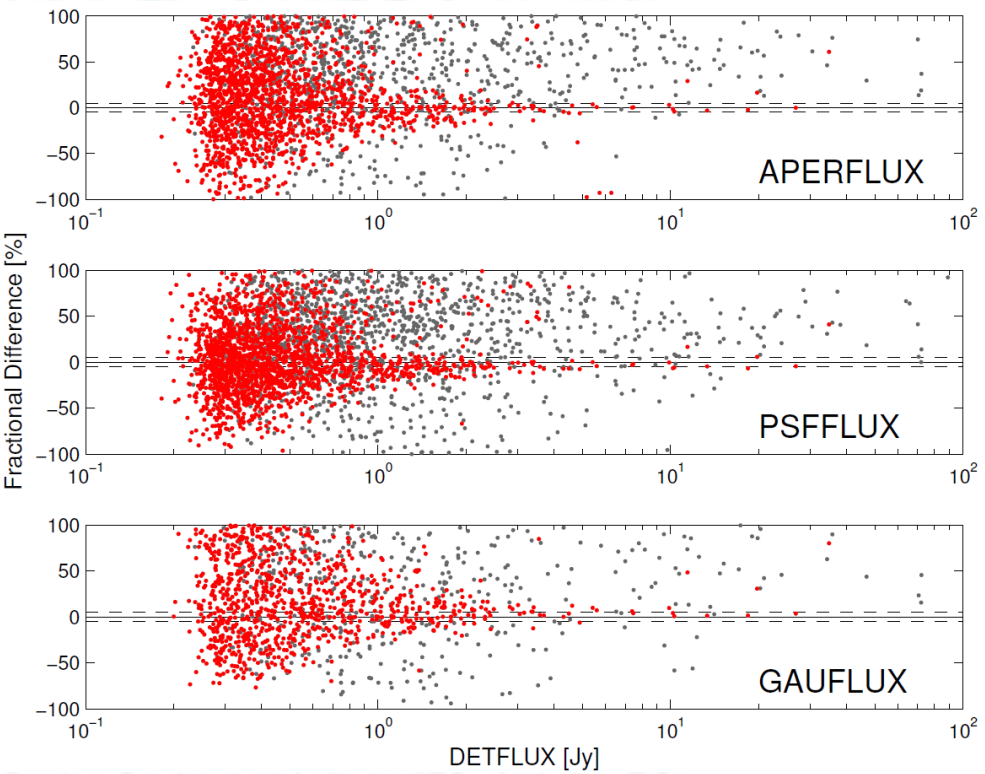


The Galactic (52%) and extragalactic (48%) zones used to define the S/N threshold to meet the reliability target. (Mollweide projection)

PCCS: Detection pipeline

Photometry

- DETFLUX (detection pipeline photometry)
  - Estimated from the source peak using the beam solid angle.
  - Obtained directly from the filtered maps and used during selection process
- APERFLUX (aperture photometry)
  - Integration inside a circular aperture. Background evaluated inside an annulus around the aperture
- PSFFLUX (PSF fit photometry)
  - Fit to a model of the effective beam at the source position, with the amplitude as a free parameter.
- GAUFLUX (Gaussian fit photometry)
  - Fit to a Gaussian model with amplitude, size and shape allowed to vary.

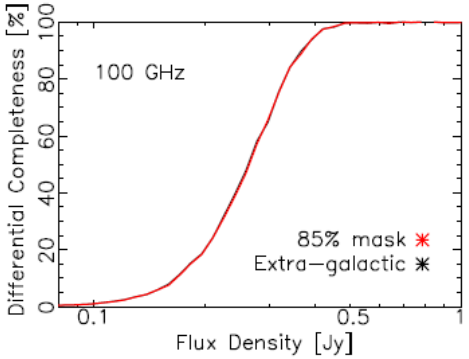


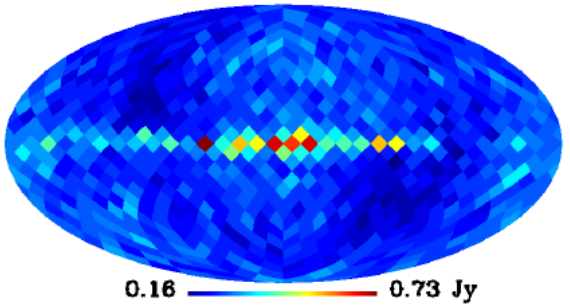
Photometry comparison @100 GHz,
$(S-S_{det})/S_{det}*100$
Gray points: Sources at |b|<5º
Red points: Sources at |b|> 5º

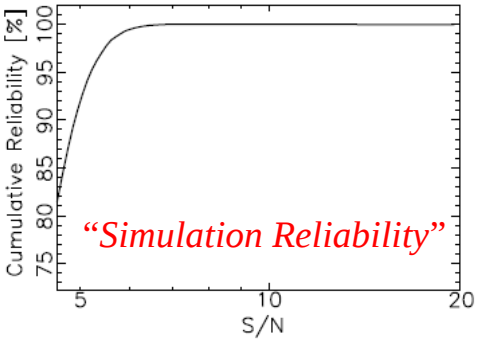
PCCS: Internal validation

- The catalogues for the HFI channels have primarily been validated through an internal Monte-Carlo quality assessment (QA) process of source injection on both real and simulated maps.
- Completeness, photometry and astrometry uncertainty are assessed by source injection on real maps.
  - Reliability can also be estimated by comparing the recovered (matched) source number counts with the real catalogue total counts ("*Injection reliability*").
- Reliability ("*Simulation reliability*") requires very accurate realistic simulations (only available for 100-217 GHz).

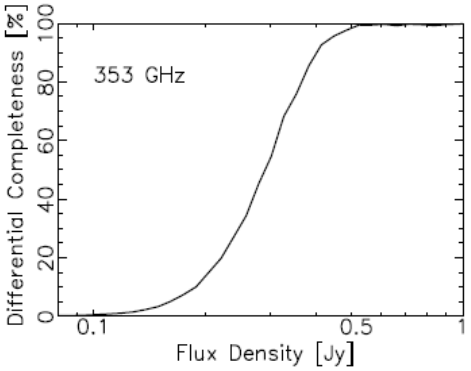
PCCS: Internal validation (examples)

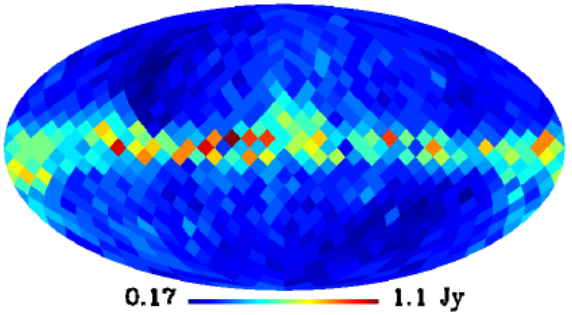


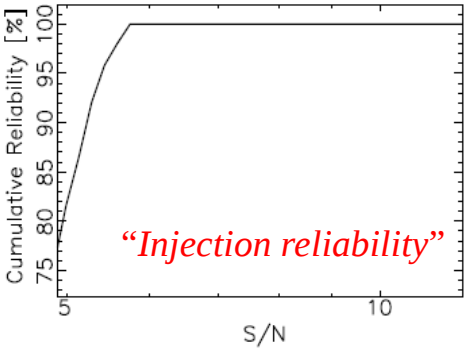




"Simulation Reliability"

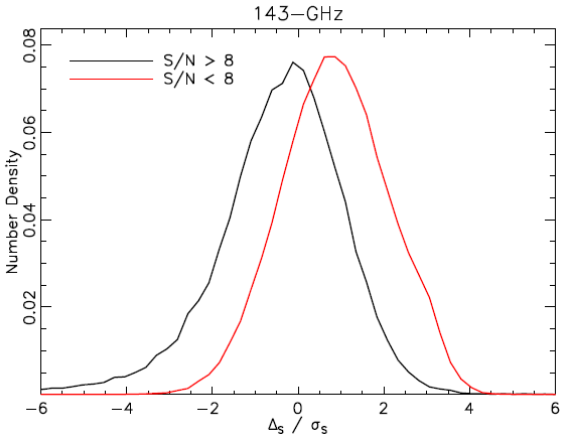




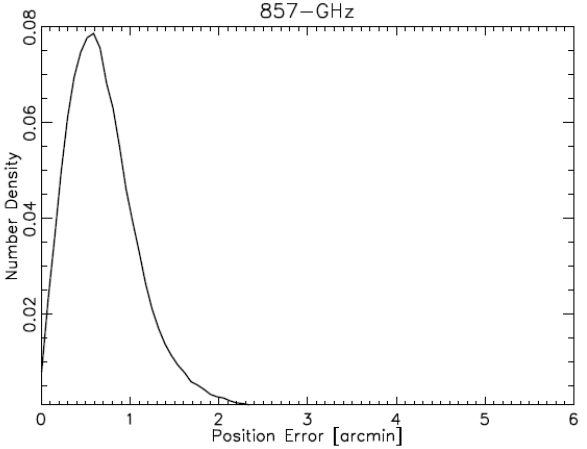


"Injection reliability"

Sensitivity (@ 50% completeness)



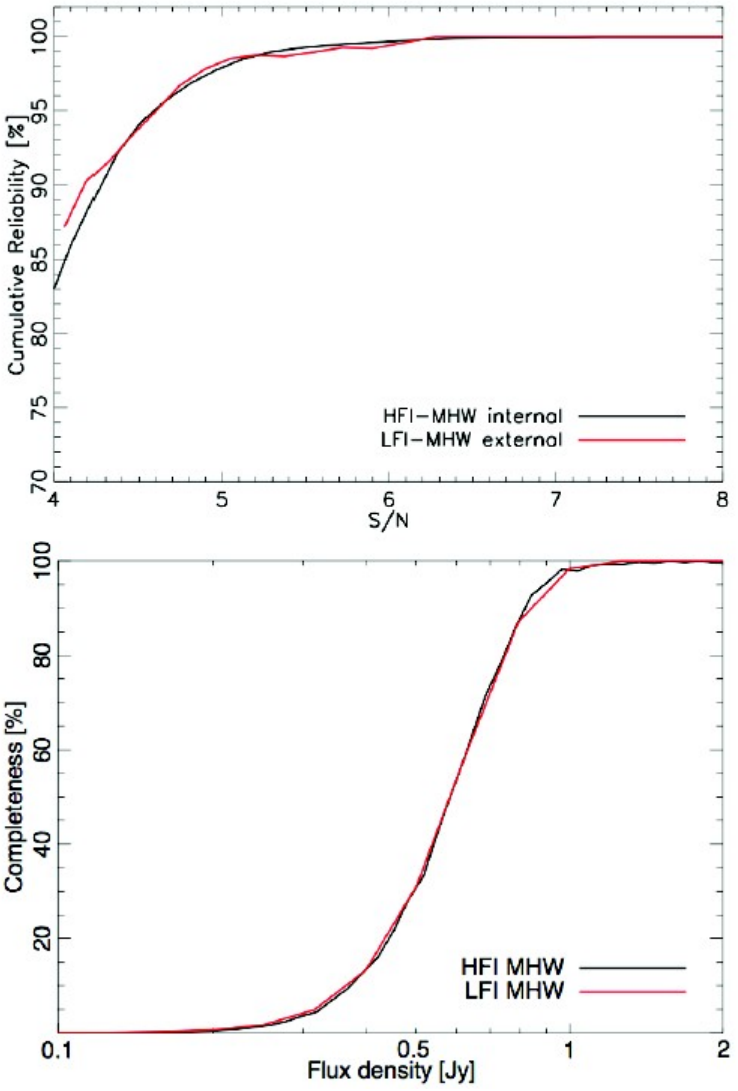
Photometric recovery



Positional error

PCCS: External validation

- Reliability, completeness, positional and flux density accuracy can also be validated using external data sets when possible.
- List of external data sets used:
  - Low frequencies (30-70 GHz): NEWPS (WMAP; Massardi et al. 2009); AT20G (Murphy et al. 2010); CRATES (Healey et al. 2007); PACO (Massardi et al. 2011); Metsahovi (Planck Collaboration XV, 2011); VLA (Rick Perley private communication)
  - Intermediate frequencies (143-217 GHz): ACT (Gralla and members of the ACT team in prep)
  - High frequencies (353-857 GHz): SCUBA (Dale et al. 2005; Dunne et al. 2000); Herschel catalogues (HRS, Kingfish, HeViCS, H-ATLAS)
- Similar results from both the internal/external validation methods

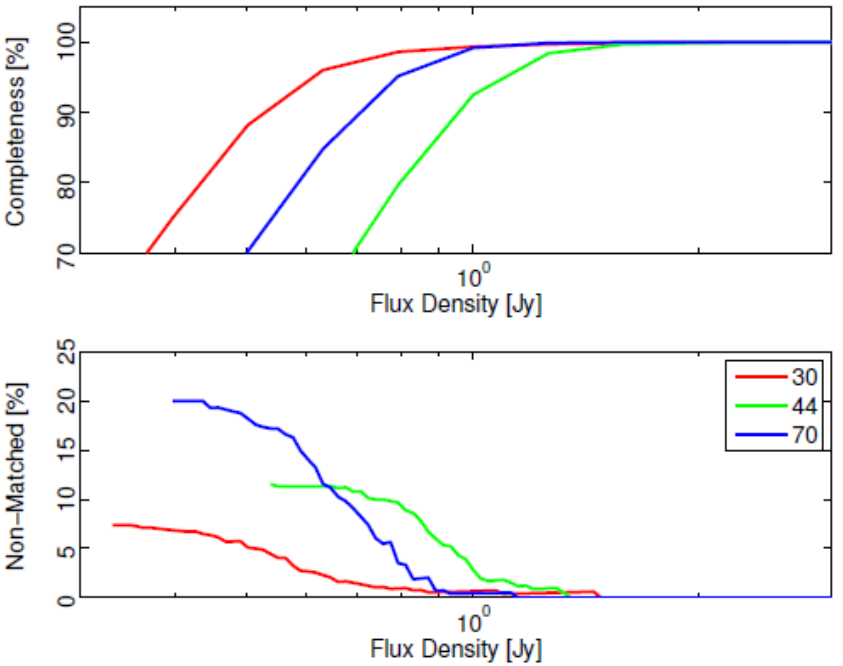


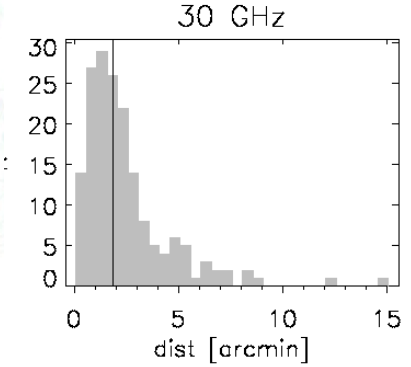
Comparison @70 GHz

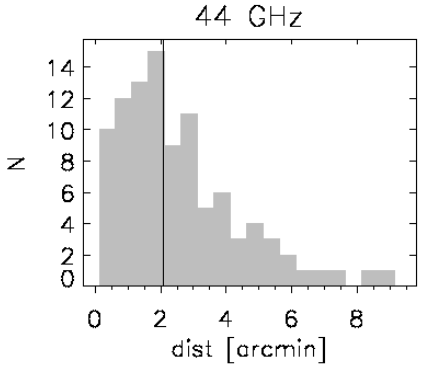
PCCS: External validation (examples)

External validation of the LFI channels (30-70 GHz):

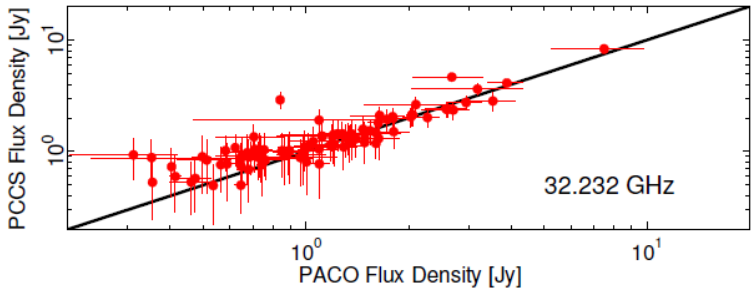
- Completeness:
  - If estimated from ancillary data at different frequencies then just a lower limit due to spectral effects.
  - Therefore, estimated from the noise in the filtered patches (ERF approximation)
- Reliability:
  - Using only large-area surveys at “similar” frequencies (NEWPS, AT20G & CRATES) + ERCSC (>95% of its sources for <100 GHz were already validated).
- Positional accuracy:
  - Comparison with PACO positions until 353 GHz.
  - Comparison with Herschel positions at 545 and 857 GHz

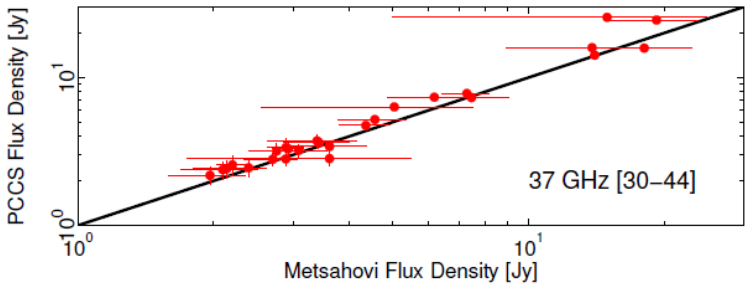


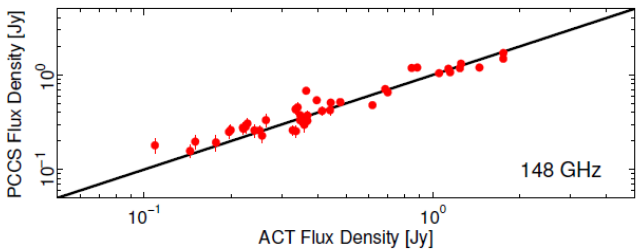


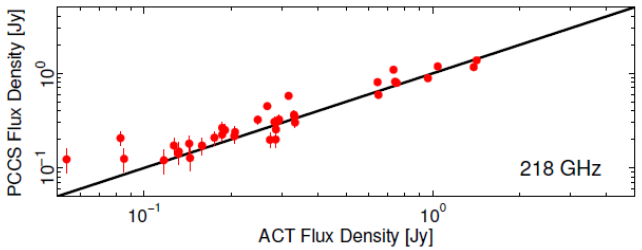


PCCS: External validation (examples)



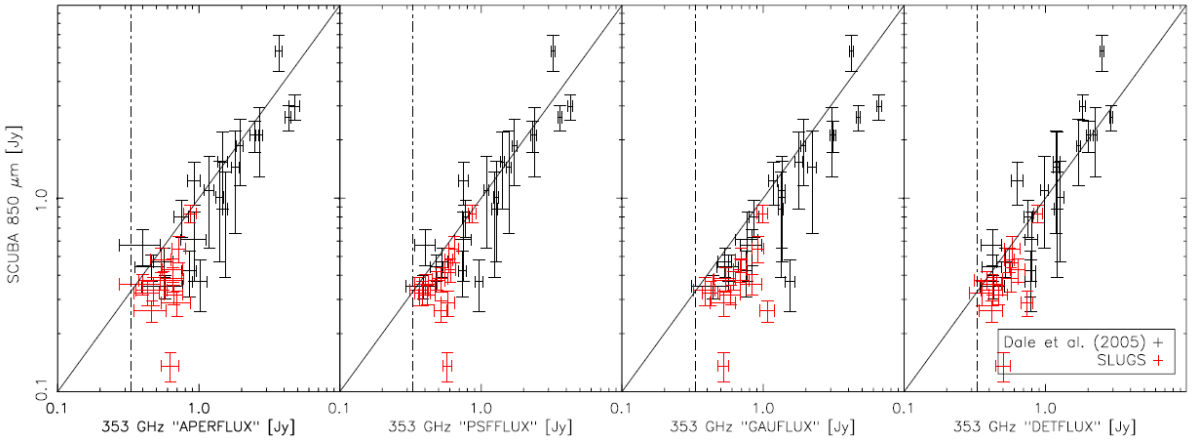




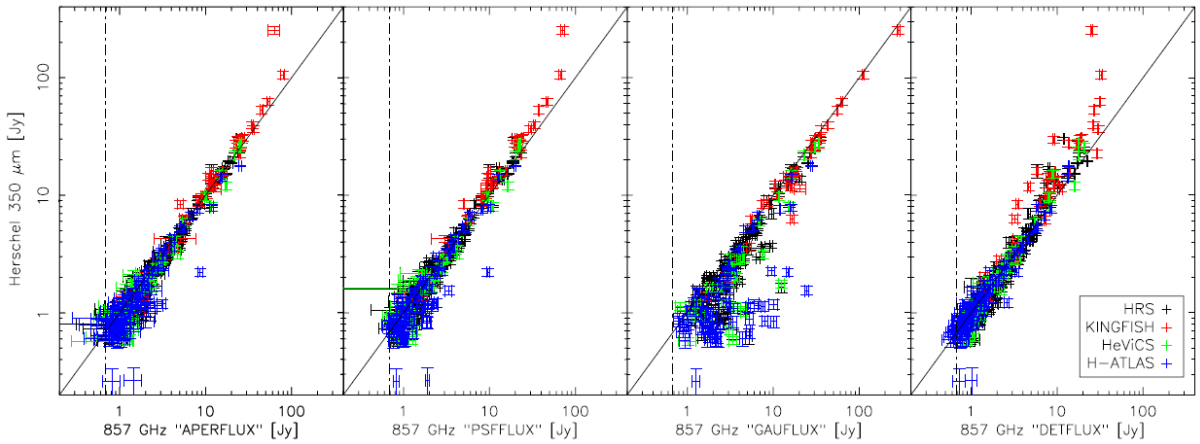


PCCS flux density = DETFLUX

SCUBA



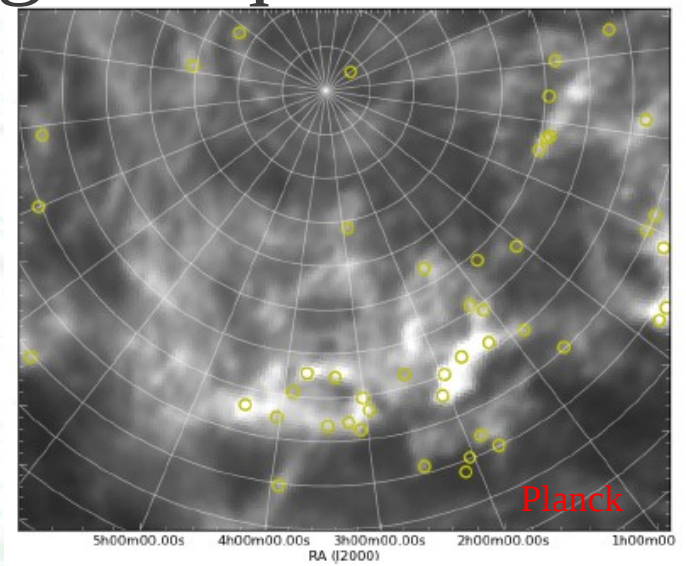
Herschel

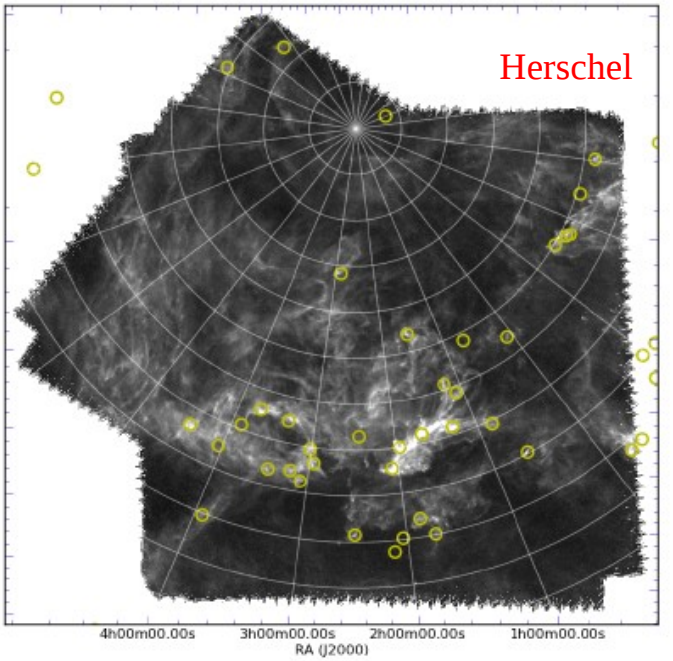


Photometry: Very good overall agreement, 0.8 ± 4.6 % (i.e., beam solid angles well understood)
The four photometries allow an improvement on the flux density measurements at different intensities/sizes of the sources.

PCCS: Galactic Cirrus at high frequencies

- The intensity fluctuations in the *Planck* high frequencies maps are dominated by faint star-forming galaxies and Galactic cirrus.
- The filamentary structure of Galactic cirrus at small scales (as seen by *Herschel*) is often seen as knots by *Planck*.
- We consider real sources to be dense structures not part of the interstellar quasi-stationary turbulent cascade.
- Using the few Herschel fields available we performed a statistical evaluation of how the "cirrus" source behave.
  - To control the inclusion of such sources we apply a higher S/N in the Galactic zone above 353 GHz.
  - A rough intensity threshold of 3-5 MJy/sr in the 857GHz map minimizes "cirrus" sources.





Polaris field observed @857 GHz

PCCS: Characteristics

Table 1. PCCS characteristics

Channel	30	44	70	100	143	217	353	545	857
Freq [GHz]	28.4	44.1	70.4	100.0	143.0	217.0	353.0	545.0	857.0
λ [μm]	10561	6807	4260	3000	2098	1382	850	550	350
Beam FWHM[a] [arcmin]	32.38	27.10	13.30	9.65	7.25	4.99	4.82	4.68	4.33
S/N thresholds									
Full sky	4.0	4.0	4.0	4.6	4.7	4.8	...	...	...
Extragactic zone[b]	...	...	...	...	...	...	4.9	4.7	4.9
Galactic zone[b]	...	...	...	...	...	...	6.0	7.0	7.0
Number of sources									
Full sky	1256	731	939	3850	5675	16070	13613	16933	24381
$\|b\| > 30°$	572	258	332	845	1051	1901	1862	3738	7536
Flux densities									
Minimum[c] [mJy]	461	825	566	266	169	149	289	457	658
90 % completeness [mJy]	575	1047	776	300	190	180	330	570	680
Uncertainty [mJy]	109	198	149	61	38	35	69	118	166
Position uncertainty[d] [arcmin]	1.8	2.1	1.4	1.0	0.7	0.7	0.8	0.5	0.4

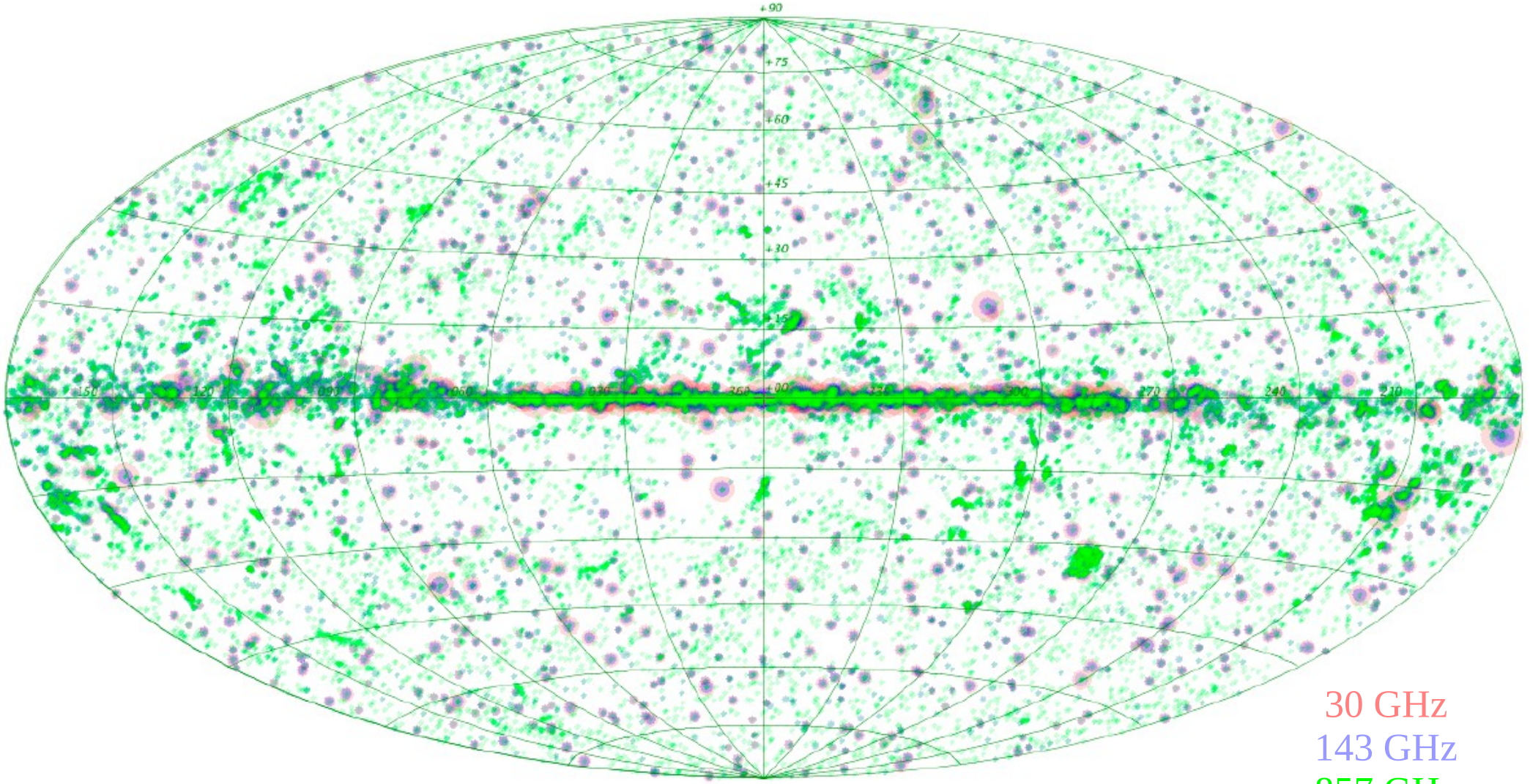
[a] FEBeCoP band-averaged effective beam. This table shows the exact values that were adopted for the PCCS. For HFI channels, these are the FWHM of the mean best-fit Gaussian. For the LFI channels, we use $FWHM_{\rm eff} = \sqrt{\frac{\Omega_{\rm eff}}{2\pi} 8 \log 2}$, where $\Omega_{\rm eff}$ is the FEBeCoP band-averaged effective solid angle (see Planck Collaboration IV 2013 and Planck Collaboration VII 2013 for a full description of the *Planck* beams). When we constructed the PCCS for the LFI channels we used a value of the effective FWHM slightly different (by $\ll 1\%$) of the final values specified in the Planck Collaboration IV (2013) paper. This small correction will be made in later versions of the catalogue.

[b] The Galactic and extragalactic zones are defined in Sect. 2.3.

[c] Minimum flux density of the catalogue at $|b| > 30°$ after excluding the faintest 10 % of sources.

[d] Positional uncertainty derived by comparison with PACO sample (Massardi et al. 2011; Bonavera et al. 2011; Bonaldi et al. 2013) up to 353 GHz and with *Herschel* samples in the other channels (see Sect. 3.2.3 for more details).

PCCS: Characteristics



PCCS: Statistical properties

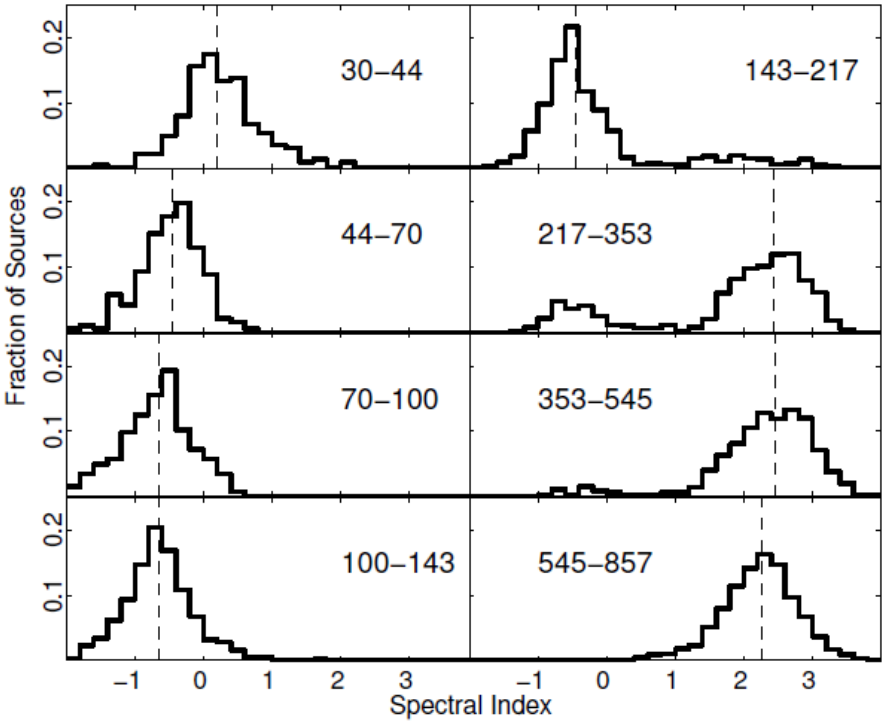
- Special effort to use simple selection procedures.
- With a common detection method and three additional photometries, spectral analysis can also be done safely.

Table 3. Summary of sources matched between neighbouring channels.

Channel	No. sources	No. matched		Frac. matched
		Above and below	Above or below	
30[a]	1256	...	629	50.1%
44.....	731	530	664	90.8%
70.....	939	552	815	86.8%
100....	3850	772	2758	71.6%
143....	5675	2454	4645	81.9%
217....	16070	3351	10624	66.1%
353....	13613	8029	12079	88.7%
545....	16933	9382	14535	85.8%
857[b] ..	24381	6904	18061	74.9 %

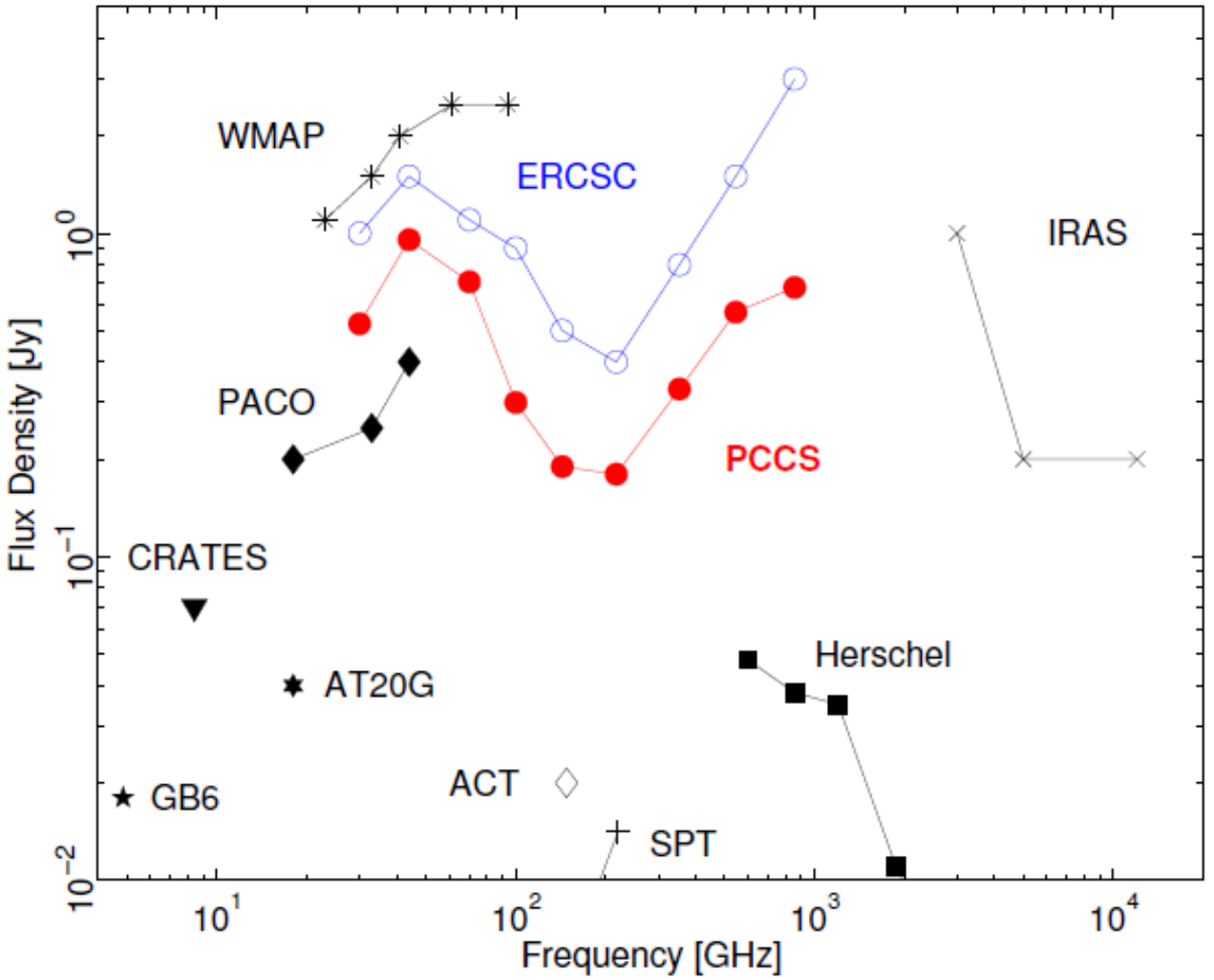
[a] The 30 GHz channel is only matched with the 44 GHz channel above.
[b] The 857 GHz channel is matched above with a catalogue extracted from the IRIS maps using the HFI–MHW. Both catalogues were cut with the IRIS mask prior to matching.

- High level of matching sources between neighbouring channels
- Some of the previous results (Planck Collaboration XIII, 2011; Planck Collaboration Int. VII, 2013) are easily confirmed



PCCS: Sensitivity

- PCCS is the most complete all-sky catalogue in the microwave band.



PCCS: Comparison with ERCSC

- One of the primary goals of the ERCSC was to provide an early catalogue of sources for follow-up observations with existing facilities, in particular *Herschel*, while they were still in their cryogenic operational phase.
- The PCCS differs from the ERCSC both in the data and the philosophy.
  - Data: 2.6 surveys vs 1.6 surveys, i.e., better sensitivity.
  - Better knowledge of the instruments, i.e., improved calibration and quality of the maps.
  - Better characterization of the beams (~2-8% variation with respect to the ERCSC beam solid angles)
  - Simplification of the selection procedure, i.e., easier statistical analysis
  - Relaxation of the Reliability constraint to ~80%
    - Higher number of detections per channel (a factor ~2-4 more sources) and better completeness.
    - Explore possibly interesting new sources at fainter flux density levels (unidentify blazars, high-z sources, lensed galaxies, …).

Conclusions

- The PCCS lists sources extracted from the Planck nominal mission data in each of its nine frequency bands
- By construction its reliability is > 80 % and a special effort was made to use simple selection procedures in order to facilitate statistical analyses.
- With a common detection method for all the channels and the additional three photometries, spectral analysis can also be performed safely.
- The deeper completeness levels and, as a consequence, the higher number of sources compared with its predecessor the ERCSC, will allow the extension of previous studies to more sources and to fainter flux densities.
- The PCCS is the natural evolution of the ERCSC, but both lack polarization and multi-frequency information.
- Future releases will take advantage of the full mission data and they will contain information on properties of sources not available in this release, including polarization and variability, and association of sources detected in different channels.

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

planck

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.