


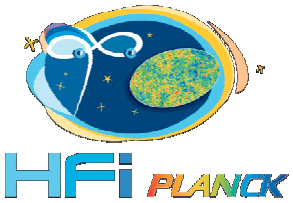


The *Planck* Catalogue of Compact Sources

Planck Collaboration

presented
by
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Outline

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

Introduction

- The Planck satellite was launched in May 2009 and since then it has been observing the microwave sky between 30 and 857 GHz.
- It is an ESA satellite with contributions from the US and Canada, and over 100 institutes participate in the project.
- There are two instruments on board Planck, the LFI and HFI, two consortia responsible of them and two DPCs in charge of the construction, operation and delivery of the scientific products to ESA.
- LFI: 30, 44 and 70 GHz and HFI: 100, 143, 217, 353, 545 and 857 GHz.
- The initial “Nominal Mission” covered the first 15.5 months of data.
- During this period of time, the satellite has surveyed the whole sky 2.5 times.
- The performance of Planck is allowing for and additional 4 and 5 surveys with both instruments and three more surveys with the LFI only.

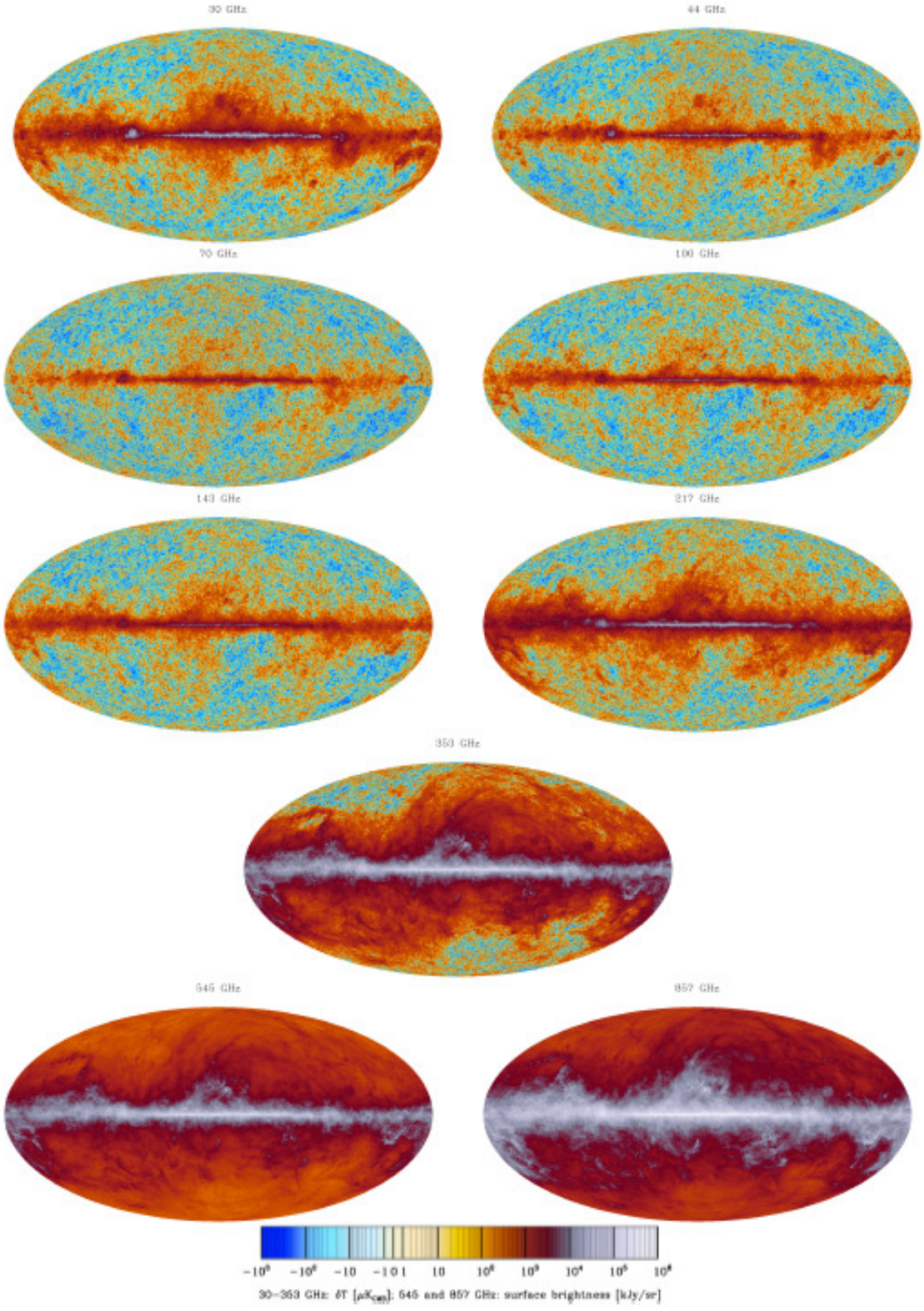
Introduction

- In March 2013 we have delivered the first set of "Nominal" products: CMB maps, Diffuse Foreground maps, Catalogues of SZ and Compact Sources (PCCS) and 28 papers describing the mission, performances, cosmology and astrophysics.
- 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 180-190 mJy in the best channels it will allow important astrophysical studies of both Galactic and extragalactic sources

PCCS: Detection pipeline

Data:

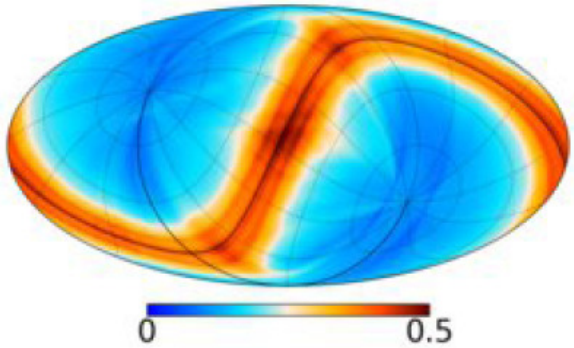
- "Nominal mission": between 12-08-2009 and 27-11-2010
- Input maps: the nine *Planck* frequency channel maps


30 GHz
44 GHz
70 GHz
100 GHz
143 GHz
217 GHz
353 GHz
545 GHz
857 GHz
-10^5 -10^4 -10 -1 0 1 10 10^2 10^3 10^4 10^5 10^6
30–353 GHz: δT [μK$_{CMB}$]; 545 and 857 GHz: surface brightness [kJy/sr]

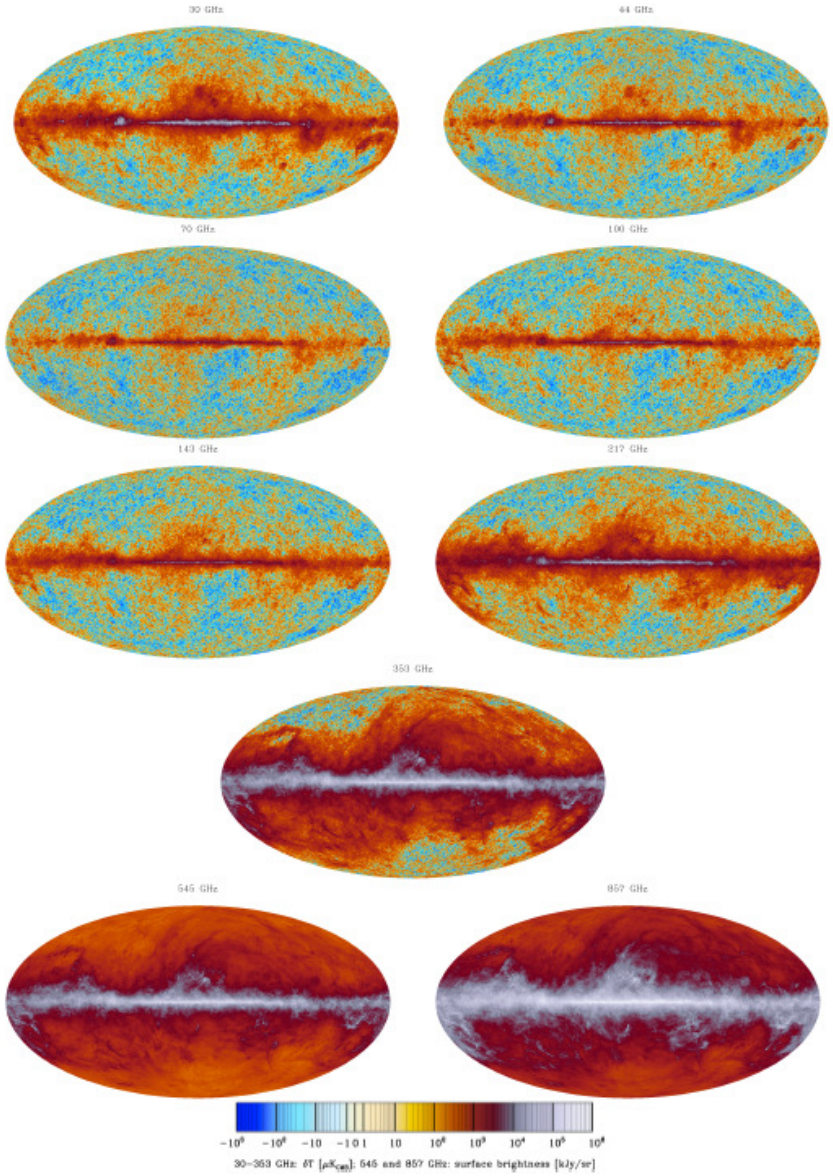
PCCS: Detection pipeline

Data:

- "Nominal mission": between 12-08-2009 and 27-11-2010
- Input maps: the nine *Planck* frequency channel maps
  - No CMB or FGDs removal
  - A Zodiacal Light emission model was subtracted at 353, 545 & 857 GHz (Planck Collaboration XIV, 2013)



Planck ZL model @857GHz

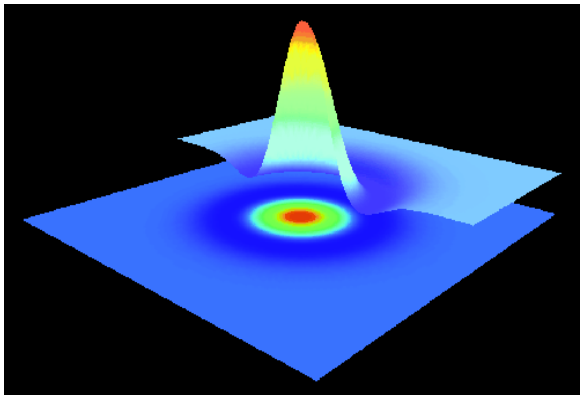


Planck frequency maps

PCCS: Detection pipeline

Algorithm:

- The MHW2 has been selected as the baseline method for the production of the PCCS.
- How to obtain it: 2nd derivative of the MHW and 4th derivative of the 2D Gaussian (González-Nuevo et al., 2006, L-C et al., 2006)

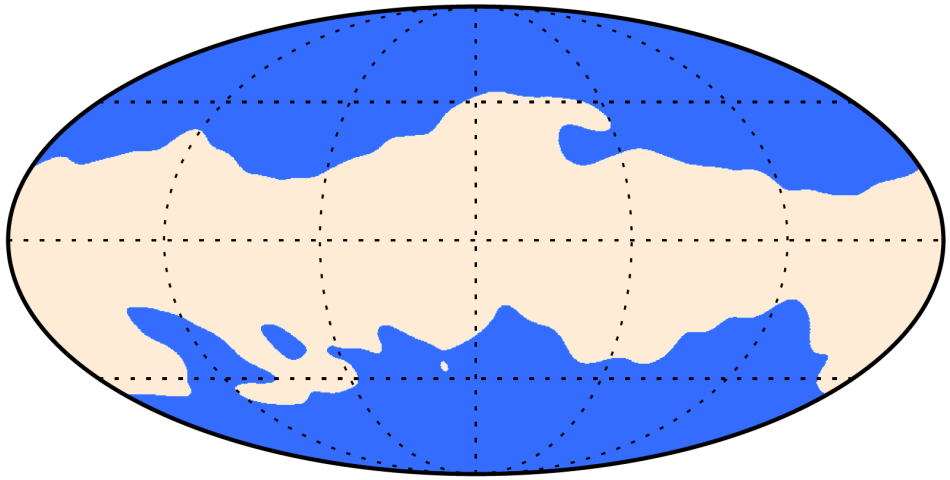


- We have tested several algorithms and the MHW2 is very robust and performs very well at all the *Planck* channels and Galactic latitudes.
- Two different implementations of the same algorithms for each DPC.

PCCS: Detection pipeline

Selection criteria

- Reliability goal of R~80%
  - Reduce thresholds in S/N
  - Increase the completeness and allow new fainter sources to be included.
- 30-70 GHz:
  - S/N=4 imposed to minimize upward bias on fainter flux densities.
  - R>80%
- 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



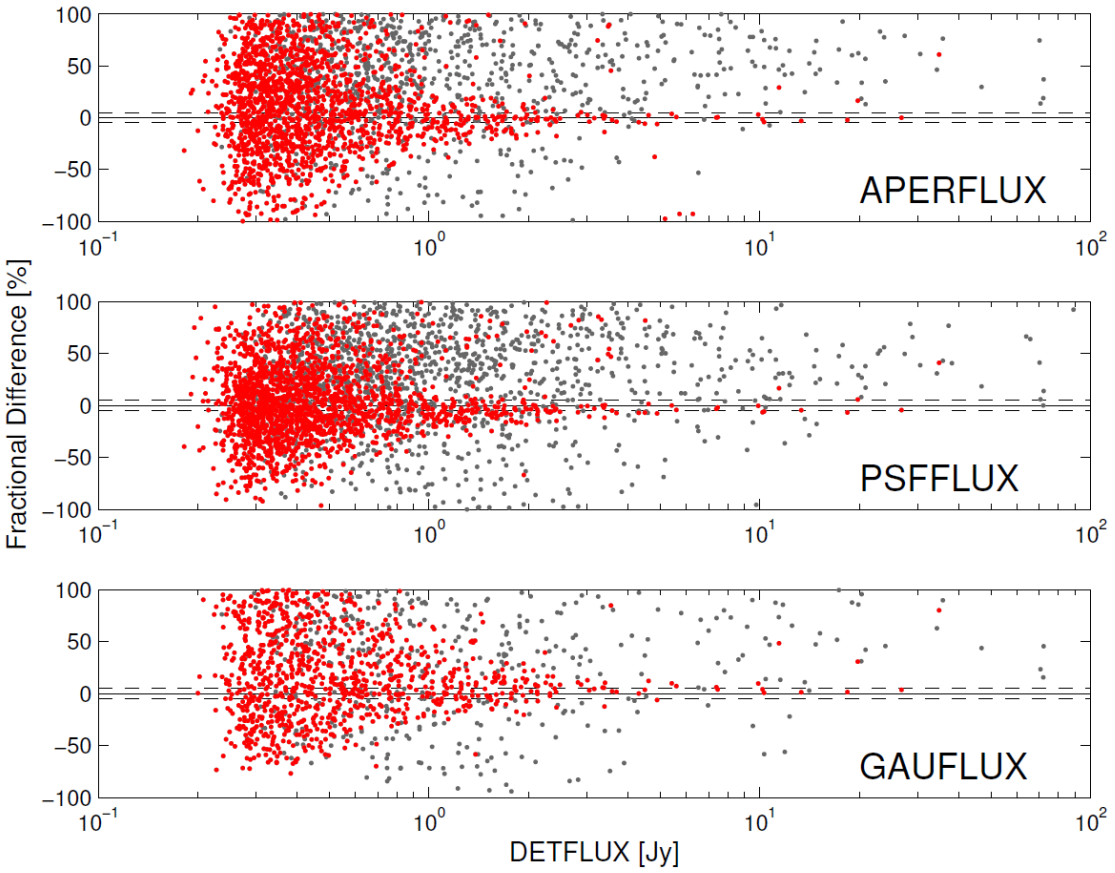
The Galactic (52%) and extragalactic (48%) zones used to define the S/N threshold to meet the reliability target. (Mollweide projection)

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 and baseline as a free parameters.
- GAUFLUX (Gaussian fit photometry)
  - Fit to a elliptical 2D 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

- Both LFI and HFI carrid out internal validation tests using similations.
- The catalogues for the HFI channels have been mainly validated through an internal Monte-Carlo quality assessment (QA) process of source injection on both real and simulated maps.
- Completeness, photometry and astrometry uncertainties are assessed by source injection on real maps.
- Reliability:
  - "*Simulation reliability*": requires very accurate realistic simulations (only available up to 217 GHz to precisely know the origin of each detection.
  - "*Injection reliability*": can also be estimated by building a catalogue with the detected sources and comparing the source number counts obtained from this catalogue with the number counts of the injected catalogue.

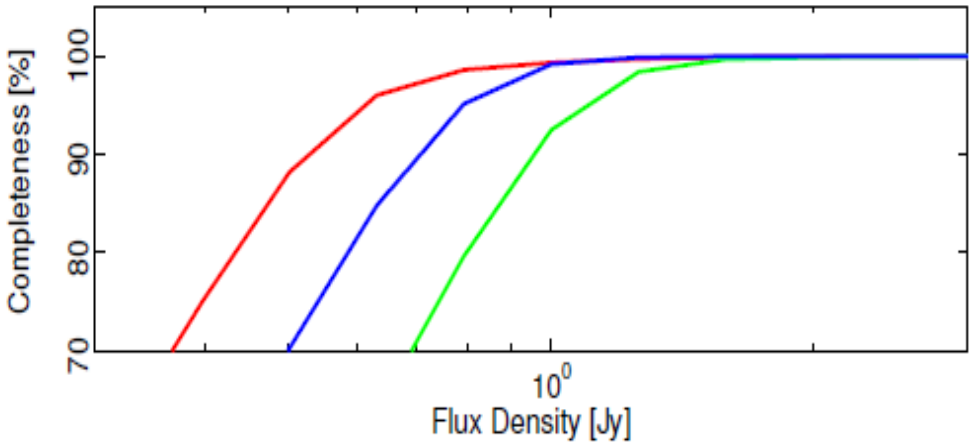
PCCS: External validation

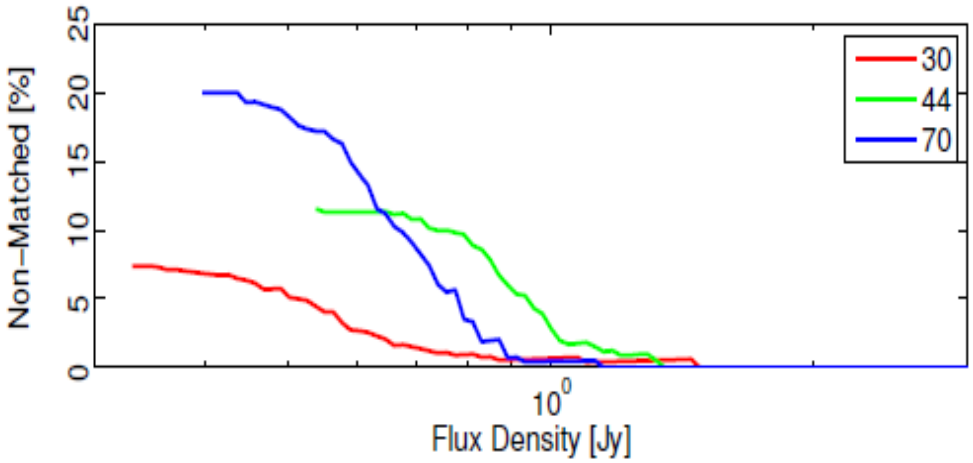
- Reliability, completeness, positional and flux density accuracy can also be validated using external data sets when possible.
- List of external data sets used:
  - Low frequencies (30-70 GHz): NEWPS (WMAP; LC06, Massardi et al. 2009); AT20G (Murphy et al. 2010); CRATES (Healey et al. 2007); PACO (Massardi et al. 2011); Metsahovi (Planck Collaboration XV, 2011); VLA (R. 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)

PCCS: External validation (examples)

External validation of the LFI channels at 30-70 GHz:

- **Completeness**:
  - If estimated using ancillary data at different frequencies then it is just providing lower limits.
  - Can estimated from the counts and noise in the filtered patches (ERF approx.)
- **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





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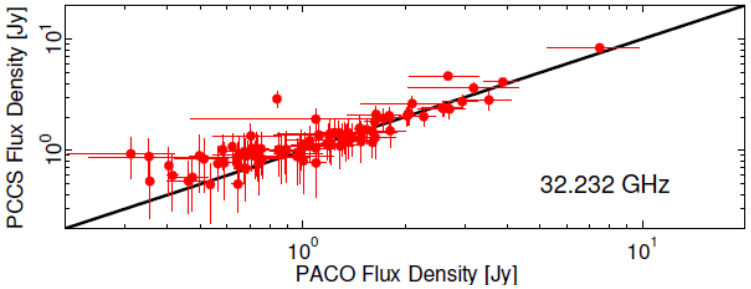
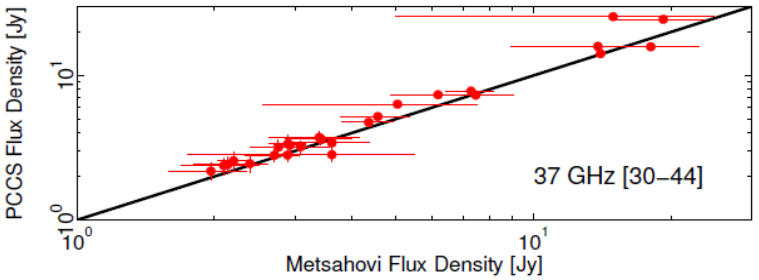
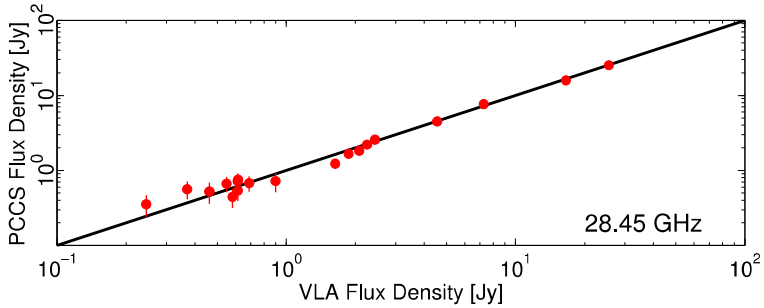
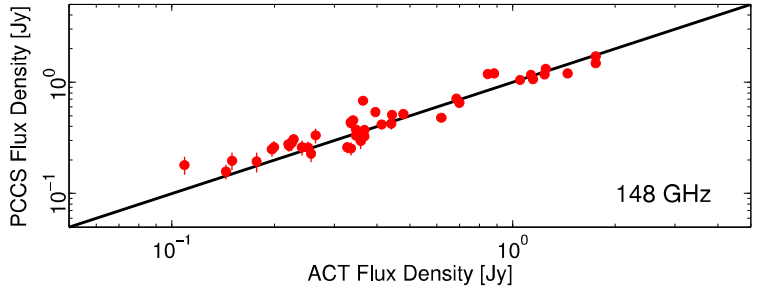
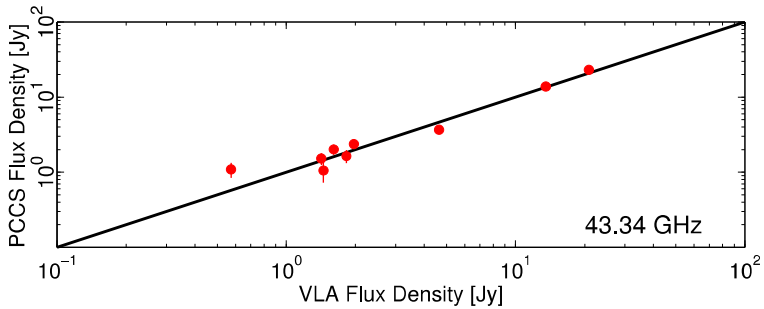
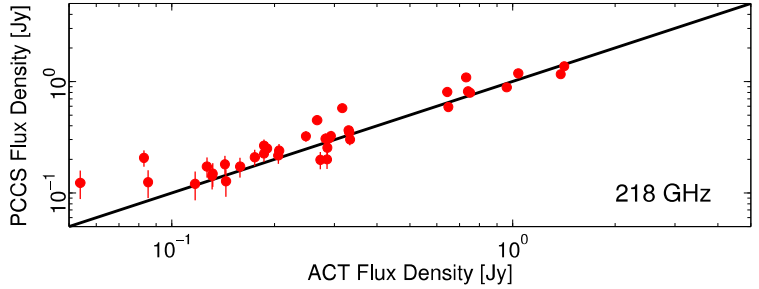








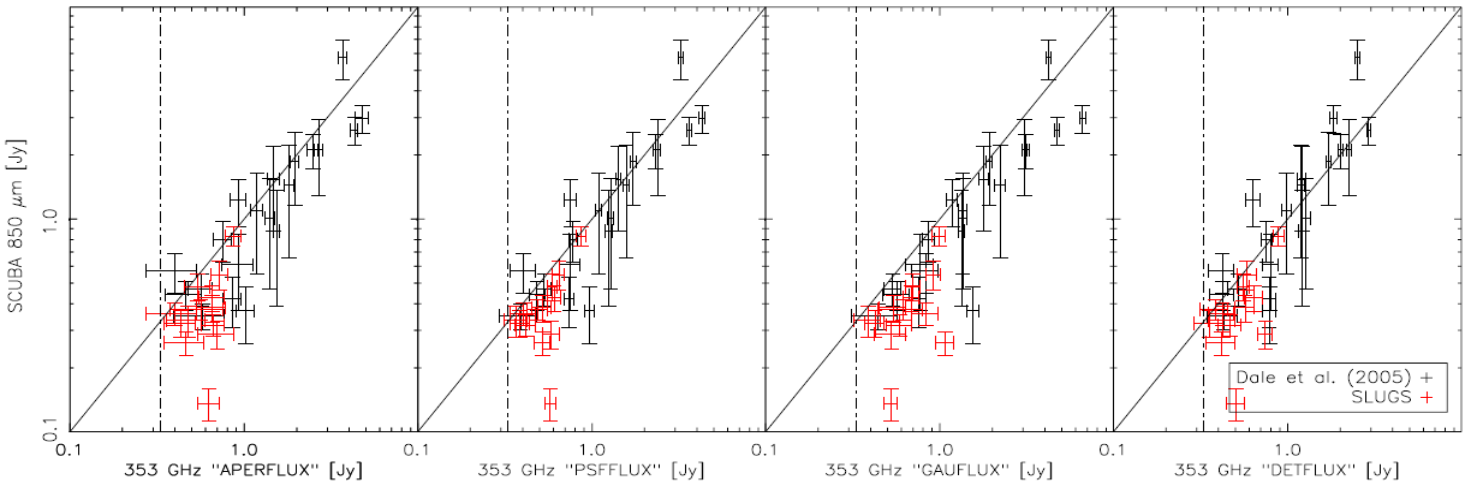




PCCS flux density = DETFLUX

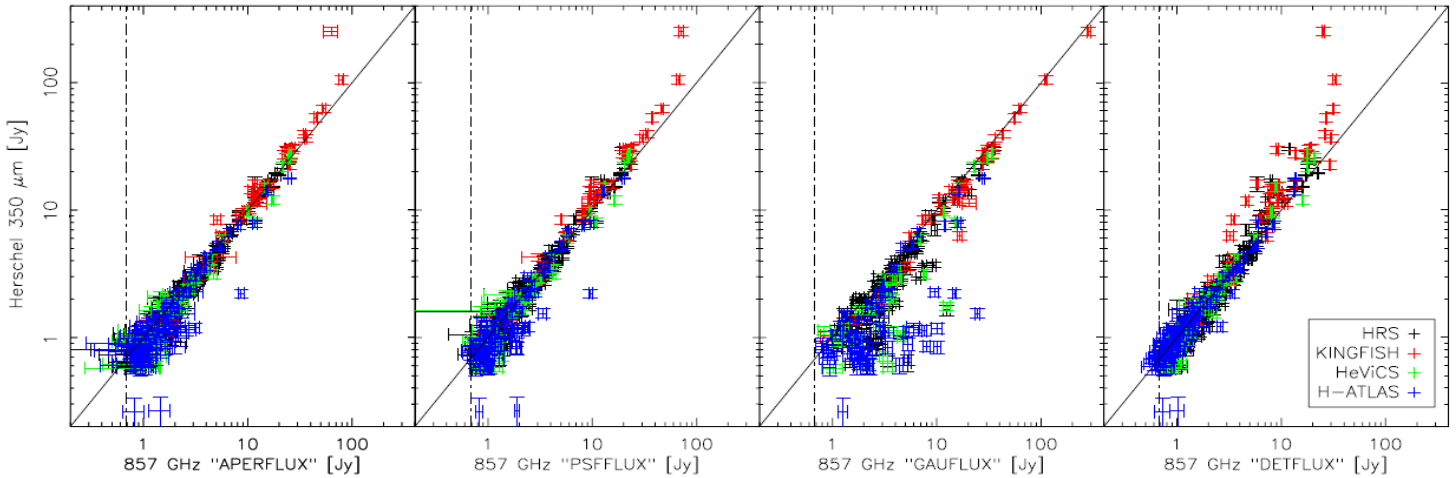
PCCS: External validation (examples)

SCUBA



Large uncertainties prevent us from drawing firm conclusions

Herschel



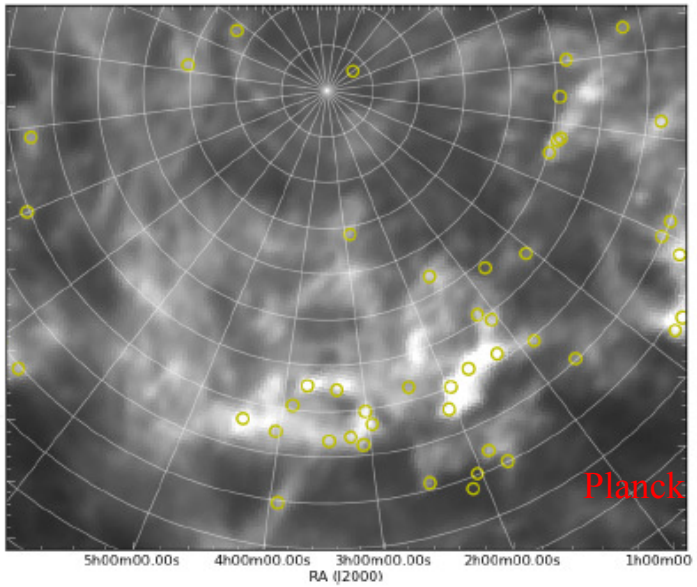
Some photometries work better than others: DETFLUX is good for point-sources and GAUFLUX for nearby galaxies reolved by Planck

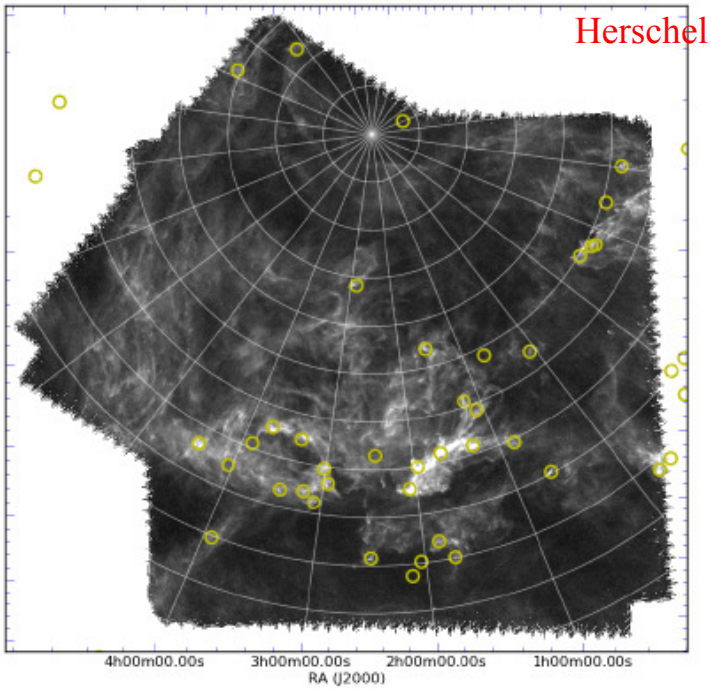
Photometry: Very good overall agreement, 0.8 ± 4.6 % (i.e., beam solid angles well understood)

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 frequency 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*.
- These objects contaminate the catalogue and it is important to find a way to remove them or at least to flag them. See Herranz et al (2013).
- Since Herschel and Planck have two bands in common, we have used the Herschel fields available to 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.





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.

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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

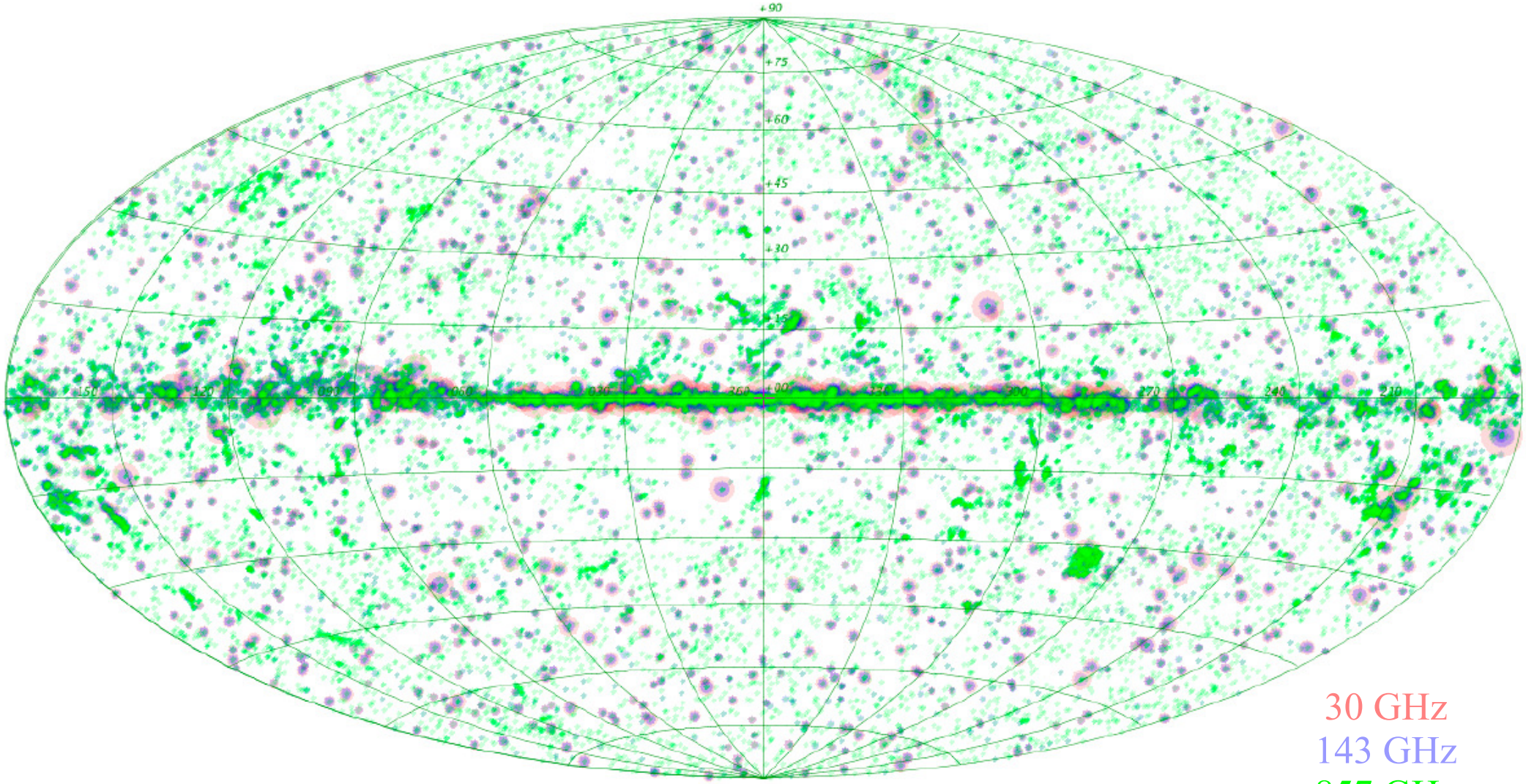
[a] FEBeCoP band-averaged effective beam. This table shows the exact values that were adopted for the PCCS. For HFI channels, these are the FWHM of the mean best-fit Gaussian. For the LFI channels, we use $FWHM_{\rm eff} = \sqrt{\frac{\Omega_{\rm eff}}{2\pi} 8 \log 2}$, where $\Omega_{\rm eff}$ is the 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).

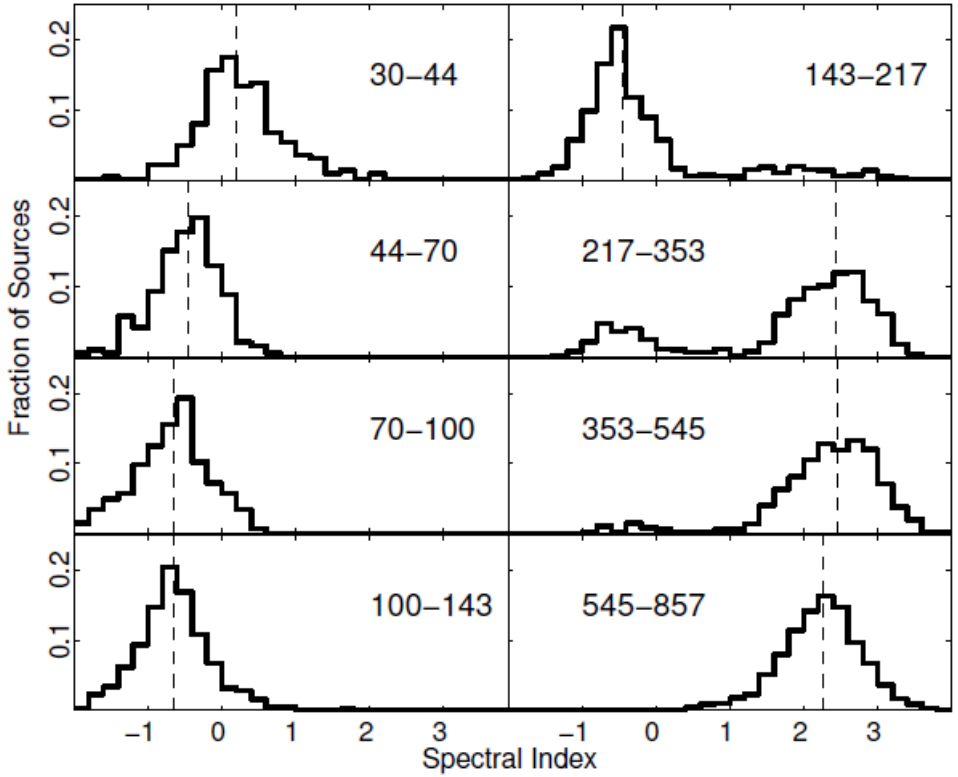
PCCS: Characteristics

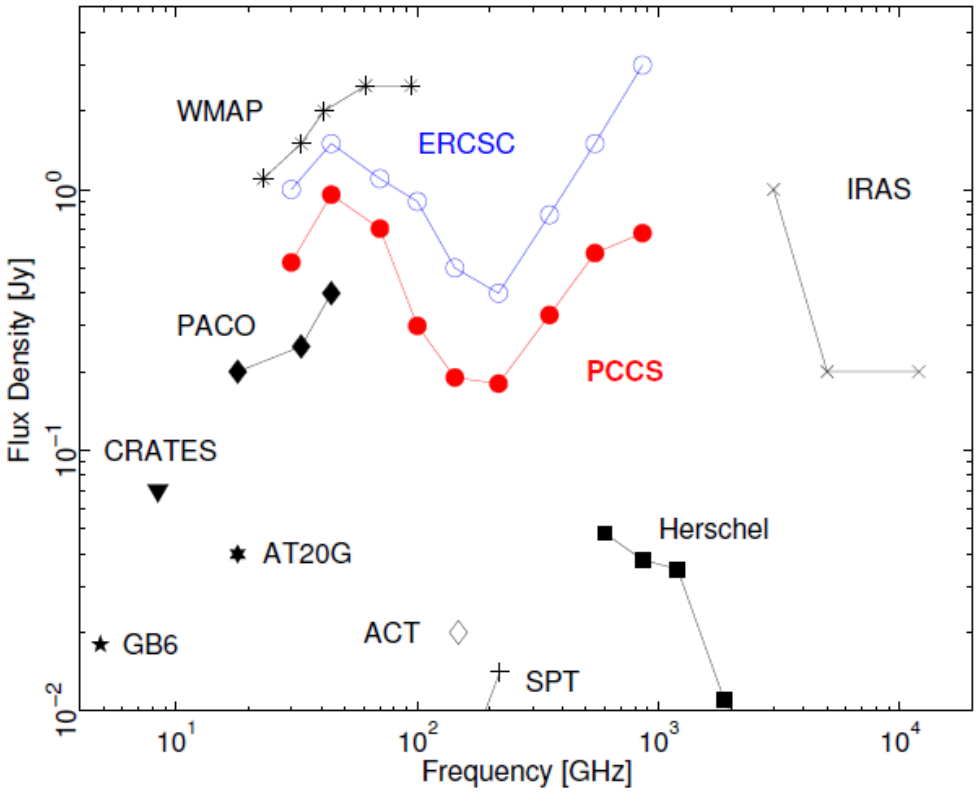


PCCS: Statistical properties and Sensitivity

Some of the previous results (Planck Collaboration XIII, 2011; Planck Collaboration Int. VII, 2013) have been confirmed

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





Note the transition from flat to steep and from synchrotron to dust

Access and description

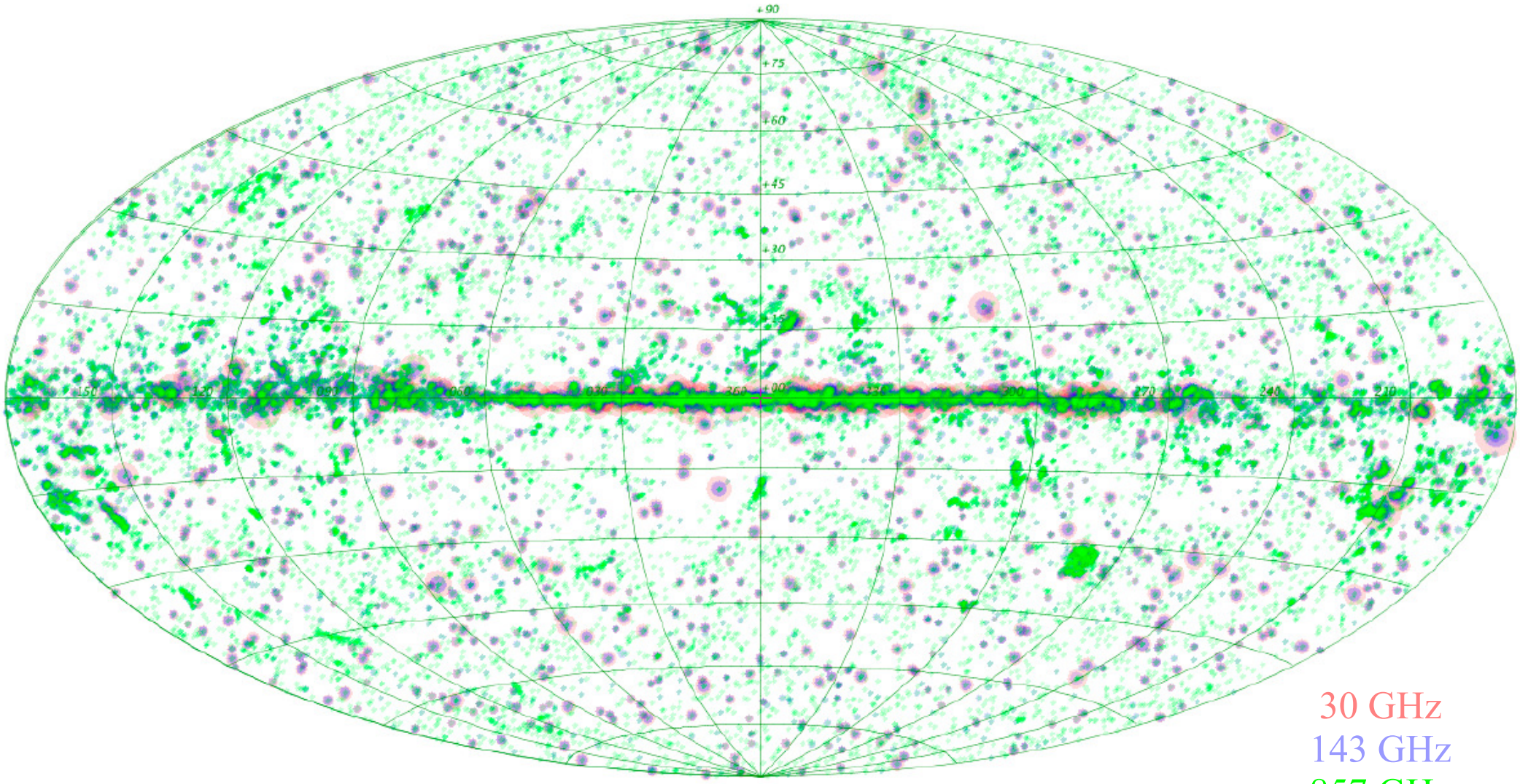
- The PCCS can be downloaded from the Planck Legacy Archive (PLA): pla.esac.esa.int/pla/pla.jnlp
- It can also be retrieved from mirrors in the US:
  - lambda.gsfc.nasa.gov
  - irsa.ipac.caltech.edu
  - common astronomical tools as Aladin or TopCat.
- The PCCS is described in the Planck Collaboration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

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 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.


+90
+75
+60
+45
+30
+15
30 GHz
143 GHz
857 GHz

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 and better completeness.
    - Explore possibly interesting new sources at fainter flux density levels (unidentified blazars, high-z sources, lensed galaxies, …).