Ground based radio observations for Planck

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Observing extragalactic sources with Planck and from the ground

The role of SED, variability and confusion

Pre-emptive observations and follow-up

The observing projects

The CMB-dipole based calibration of ground based telescopes
The reasons to observe: spectral properties

The knowledge of the properties of extragalactic radio source populations at frequencies $>10$ GHz is poor because large-area high-frequency surveys are very time-consuming with high sensitivity ground-based diffraction-limited telescopes.

To date, the Australia Telescope 20 GHz (AT20G, Murphy et al. 2010) is the largest ground-based sample of the high radio frequency sky: it is 93% complete above 100 mJy at 20 GHz over the whole Southern sky with follow-up (within a few weeks time) at 4.8 and 8.6 GHz. No comparable samples exist for the Northern hemisphere.

It demonstrated that (MM et al. 2010):

- The bright samples are dominated by flat-spectrum sources
- Steep-spectra sources grew important at lower flux densities and higher frequencies
- The spectral behaviour cannot be easily described by a power law
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- Steep-spectra sources grew important at lower flux densities and higher frequencies
- The spectral behaviour cannot be easily described by a power law
- The spectral index distribution changes with flux density and frequency
- The median 1yr variability at 20GHz is 6.9% increasing with frequency (Sadler et al. 2006)
Fluctuations due to radio sources are the main contaminants of the CMB signal on scales smaller than 30 arcmin (De Zotti et al. 1999, Toffolatti et al. 2005).

They need therefore to be carefully subtracted to avoid biasing the estimates of cosmological parameters.

Extrapolation from low frequencies are highly unreliable and modelization of source population is extremely challenging.

Planck offers a unique opportunity to carry out an unbiased investigation of the spectral properties of radio sources in a poorly explored frequency range, partially unaccessible from the ground.
Simultaneous observations

Data as close in time as possible is useful to
@ **estimate the contribution** of sources to the CMB observations.
@ **improve the knowledge** of the SEDs
@ **assess quality** of detection techniques

Planck scanning strategy is known and it is possible to predict when each beam passes through a given (source) position. **The Planck On-the-Flight Forecaster** (POFF, MM & Burigana 2010) has been developed for this reason.

L2 orbit
Focal plan at 85° from spin axis.
**Spins around its axis once a min**
scanning close to the ecliptic poles.
Repoint the spin axis every hour
**6 months to cover the whole sky**

**Different beams cover the same position in slightly different time.**
Observing a source

Scan direction

Source at the Ecliptic Equator

1 week
Observing a source at the Ecliptic Pole

2.5 months!!!!
The **POFF** allows to know when Planck will be observing (or has observed) a given position (with 1 hr resolution), on the bases of the real shape of the focal plane and the predicted pointing lists. The code is available to everybody on request.

Fraction of right ascension region observable for each week of a Planck survey in 6 months for each hemisphere.
## Pre-emptive or follow-up observations?

<table>
<thead>
<tr>
<th>Pre-emptive</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Known objects</td>
<td>New / peculiar sources</td>
</tr>
<tr>
<td>Could be planned in advance</td>
<td>Cannot be planned close to Planck observations (except for very peculiar objects)</td>
</tr>
<tr>
<td>Selection of complete samples (but not at Planck frequencies)</td>
<td>Selection of peculiarities at Planck frequencies</td>
</tr>
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<td>Completeness is affected by variability</td>
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<tr>
<td>Telescopes used so far: APEX, ATCA, Effelsberg, IRAM, Medicina, Metsahovi, OVRO, RATAN, UMRAO, VLA</td>
<td>Proposal are being considered at VLA</td>
</tr>
<tr>
<td>Telescope</td>
<td>Frequency [GHz]</td>
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<tr>
<td>-------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>APEX, Chile</td>
<td>345</td>
</tr>
<tr>
<td>ATCA, Australia</td>
<td>5, 9, 18, 24, 33, 39</td>
</tr>
<tr>
<td>Effelsberg, Germany</td>
<td>3, 5, 8, 10, 15, 23, 32, 43</td>
</tr>
<tr>
<td>IRAM 30m, Spain</td>
<td>86, 142</td>
</tr>
<tr>
<td>Medicina, Italy</td>
<td>5, 8, 21</td>
</tr>
<tr>
<td>Metsahovi, Finland</td>
<td>37</td>
</tr>
<tr>
<td>RATAN-600, Russia</td>
<td>1, 2, 5, 8, 11, 22</td>
</tr>
<tr>
<td>VLA/EVLA, USA</td>
<td>5, 8, 22, 43</td>
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Nearly simultaneous (within 10 days from Planck observations) with ATCA multi-frequency observations (from 4.5 to 40 GHz) in total intensity and polarisation.
The selection was done in the AT20G catalogue + long term observations data

1) Complete sample of **inverted and upturning sources** between 5 and 20 GHz (69)

2) Complete sample of **flux density selected:**
   - 162 S(@20GHz)>200 mJy (Bonavera et al. In prep)
   - 189 S(@20GHz)>500 mJy (MM et al. 2011)

3) **Variable sources** (in ATCA observations)

4) 63 **known Blazars** observed with APEX

**Total number of sources: 483**
More than 450 h with ATCA in 65 epochs between Jul 2009-Aug 2010

Frequency channels (with CABB): 5.5 – 9 GHz
18 – 24 GHz
33 – 39 GHz

Data reduction pipeline

**Automatic flagging** of bad data on each single source

Calibration (Bandpass, Primary, Leakage), self-phase calibration

**Band splitted for spectral details**

**Triple product** technique to get the flux density (see AT20G)

**Methods to distinguish between extended and compact objects** (phase closure and flux ratio on shortest vs all spacings)

**Quality assessment and a-posteriori flagging based on polinomial SED fitting** to remove outliers: more than 85% of good data!

**Error estimation**

based on the rms fractional divergence between data and polinomial fit
**PACO: the bright sample analysis**

174 bright sample compact sources

**Fit with a double power law**

\[ S(\nu) = \frac{S_0}{(\nu/\nu_0)^{-a} + (\nu/\nu_0)^{-b}} \]

- estimation of spectral indices on the fit
- source classification
- estimation of peak frequency for the peaked

Distribution of peak frequency in obs and rest frame

Mean 17.3+-4.5 GHz

Radio colour-colour plot between 5-10 and 30-40 GHz:
-11% single power law – mostly flat
- few low freq rising probably self-absorbed
- 20% peaking
The variability index

\[ V_{\text{rms}} = \frac{100}{\langle S \rangle} \sqrt{\frac{\sum (S_i - \langle S \rangle)^2}{n} - \sum \sigma_i^2} \]

Has been estimated for the best couple of observations for each source.
We confirmed the trend towards an increase of variability with frequency and a marginal indication of a larger variability on longer time scales.

The median variability at 20GHz on 9 months is about 9%
PACO+Planck: the SEDs

SEDs between 4.5 and 857 GHz

PACO, asterisks (different colours = different epochs)

ERCSC, diamonds

AT20G, triangle

NEWPS, squares
Flux density comparison for almost simultaneous observations between PACO and Planck at 30 and 44 GHz (Toffolatti, Gonzalez-Nuevo Early paper 2011).

These plots have been used to validate the ERCSC results and estimate the Eddington and detection levels in Planck maps.
From the comparison with the AT20G source counts we could estimate the incompleteness in the measured 33 and 40 GHz source counts and correct them (Bonavera et al, in prep).

That can be used to estimate the level of signal due to sources below the Planck detection limits.
PACO faint sample: contamination to CMB

Sources < 800 mJy

33 GHz
40 GHz
Simultaneous Medicina Planck Experiment (SiMPlE)

These observations will provide information for the Northern hemisphere useful to

- **quantify the quality of the point source detection techniques** applied to the Planck maps
- **reconstruct the SED across the radio and FIR bands in several epochs** to investigate the properties of populations and improve the models of the sources
- providing a list of useful sources for SRT

**Medicina 32m single dish**

OTF scanning technique

Frequencies available **5, 8.3 and 22 GHz** (with a multibeam receiver at 22 GHz)
- The **NEWPS (MM et al. 2009) sample with declination >0° (252 objects)** positions from NVSS or GB6 where there is an available counterpart 5 GHz maps to identify/confirm/discard object without identification

- **104 known bright** blazars followed up on long time scales at Metsahovi at 7mm

- **11 variable Galactic objects** previously in the Noto project

- We got **up to 24 hours every 10 days allocated for 12 months from June 2010**

- IRA people are contributing to assess the system quality

- a **new pipeline for scheduling and data reduction** developed on purpose and now available to Medicina users

- all the sample observed at 5 GHz and 8 GHz (Procopio et al. In prep)

- 22 GHz observations are on-going
Absolute calibration of the Planck detectors (up to 353 GHz) is derived from the annual modulation of the CMB dipole by the Earth’s orbit around the Sun.

**Absolute dipole measurement is obtained by differentiating along a spin period.**

Calibration at mm freqs for ground based telescopes is generally done using planets. They are the most reliable mm primary flux calibrators, since point sources are variable and/or faint.
Calibration models are not easy to be estimated at high frequencies.
By exploiting the CMB dipole-based Planck calibration we can

- **Establish the relative flux scale** between Planck and ground-based telescopes at mm frequencies
- **Define an absolute calibration for all the telescope**
- The fluxes can be both transferred to the primary calibrators and used to **improve the models** for planets and calibrator sources

How to cross-calibrate the g-b telescopes:

- **Using strong sources in common to all the telescopes** avoiding objects known as “too highly variable”, observing them simultaneously with the g-b telescopes and Planck (we need to choose equatorial sources to do it on both hemispheres)

- **Calibrate calibrators** (point like object) of each telescope observing it simultaneously with Planck. Then it is better to choose few bright not variable objects near the ecliptic pole (frequent Planck observations).

**Exercises for cross-comparisons have been run at 3-6cm on some equatorial sources between ATCA and Medicina,**

at 7mm between ATCA and VLA + Planck,

at 3mm between ATCA and CARMA + Planck.
Ground based observing projects are being carried out to take advantage from Planck results for SED reconstructing without variability biases.

Pre-emptive and follow-up observations are on-going with many facilities around the world.

Multifrequency detailed SED knowledge helps to build models for AGN populations.

Simultaneous deep ground-based observations help Planck to reconstruct the contamination to CMB due to sources below the detection limits.

They help ground-based telescopes to define an absolute calibration.