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Blind Search for Variability in Planck Data

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Abstract. The sky is full of variable and transient sources on all time scales, from milliseconds to decades. *Planck*'s regular scanning strategy makes it an ideal instrument to search for variable sky signals in the millimetre and submillimetre regime, on time scales from hours to several years. A precondition is that instrumental noise and systematic effects, caused in particular by non-symmetric beam shapes, are properly removed. We present a method to perform a full sky blind search for variable and transient objects at all Planck frequencies.

Keywords. space vehicles: instruments, methods: statistical, techniques: miscellaneous

1. Introduction

Planck (Tauber et al. 2010, Planck Collaboration I. 2011) provides 8 full sky surveys at the frequencies of its LFI instrument (30, 44, and 70 GHz), and 5 full surveys at the 6 HFI frequencies in the range 100–857 GHz. The satellite rotates with 1 rpm around an axis kept fixed for a pointing period (PID) of about 50 minutes, then shifts along the ecliptic by 2'. This keeps a point source near the ecliptic in the main beam (2 FWHM) for about 5−30 PIDs (depending on frequency) for each survey; for sources near the ecliptic poles the coverage can be much larger. Analysing the time information in Planck data for a particular sky direction thus allows to search for variability in the sky signal.

2. Mapping of time ordered information

Variability mapping is based on four-dimenional Healpix (Górski et al. 2005) constructs called 4D-maps, which record for every sky pixel k all contributions of a given detector at times t_j and beam orientation b_j, where the index j refers to Planck PIDs. To construct an average sky signal S_k free from beam orientation effects, we use the *ArtDeco* beam deconvolution code (Keihänen & Reinecke 2012). A variability map is then a two-dimensional Healpix map of a quantity

$$X_k = \frac{1}{2}\,\mathsf{sgn}(\hat{\chi}^2_{\mathsf{k}} - 1)\,\mathsf{N_k}\left[\hat{\chi}^2_{\mathsf{k}} - 1 - \ln\hat{\chi}^2_{\mathsf{k}}\right]$$

where

$$\hat{\chi}^2_k \equiv \frac{\chi^2_k}{N_k} = \frac{1}{N_k}\sum_j \frac{(I_{kj} - (S{*}b)_{kj})^2}{\sigma_k^2} \qquad \text{with} \qquad \sigma^2_{kj} = \sigma^2_{\mathsf{n}} + \xi^2\,(S{*}b)^2_{kj}\ .$$

N_k is the number of entries for pixel k in the 4D signal map I_{kj}, $(S{*}b)_{kj}$ is the beam-reconvolved average 4D-map based on the *ArtDeco* map S_k, σ_{n} is the detector white noise, and ξ combines all instrumental fluctuations which factor on the signal (e.g., calibration, inaccuracies of the beam model). The definition of X is motivated by the Chernoff bound on the CDF $P_N(\chi^2)$, with $X \leqslant -\ln(1 - P_N(\chi^2))$ for $\hat{\chi}^2 \geqslant 1$, and $X > \ln P_N(\chi^2)$ for

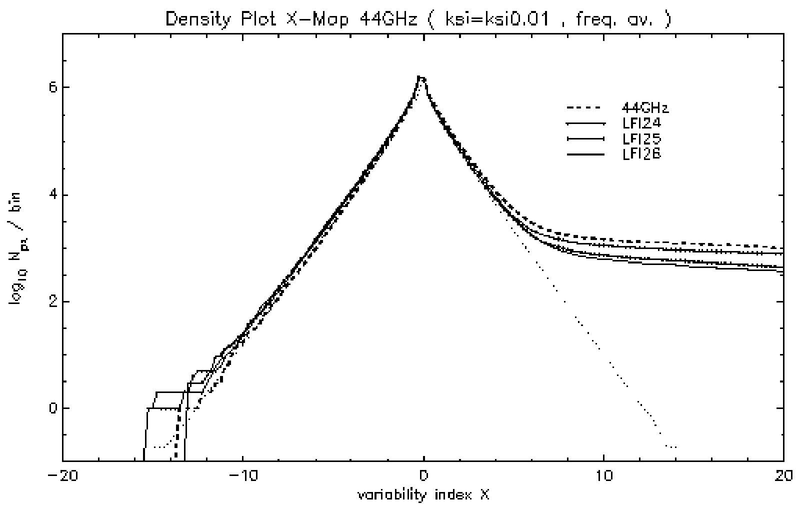

Figure 1. Histogram of an X-map for the LFI 44 GHz detectors for $\xi = 0.01$, and detector noise n_s as given in Planck Collaboration II. (2014), thin dotted lines show the distribution expected for pure Gaussian noise. The tail to large values of X indicates the presence of true sky variability. A tail to large negative values of X would indicate an overestimation of ξ, an offset of the peak from $X = 0$ an incorrect estimation of n_s.

$\hat{\chi}^2 < 1$. The distribution of X-values over a sky map is indicateive not only of variability, but also to incorrect estimations of noise and instrumental variations (see Fig. 1).

3. Time resolved Planck fluxes, status and outlook

As the analysis of time variations in the sky is essentially background-free, our method provides a way to extract time resolved Planck fluxes down to a time resolution of a few hours. If the position of a variable point source is known, the residual 4D-map, $R_{kj} = I_{kj} - (S{*}b)_{kj}$, can be beam-deconvolved to the source position by a simple division and thus provide an estimate of the flux variation, $\langle \Delta S(t_j) \rangle_k = R_{kj}/b_{kj}$, where b_{kj} is a *beamfactor map* expressing the measured flux of a unit emitter at the source position in a beam centered at pixel k and time t_j. This method is used, e.g., to extract time-resolved Planck fluxes for co-eval monitoring of blazars with the F-GAMMA program (Fuhrmann et al. 2007, Rachen et al. 2015).

Our analysis tools work on unified data structures, which ensures that all methods for variability analysis and flux extraction are applicable to LFI and HFI data in the same way. Interfaces for intitial 4D-mapping are in place at both the LFI and HFI DPC. We expect that all Planck frequencies will be analysed for variability, and science results prepared for publication well before the Planck Legacy release.

References

Fuhrmann, L., Zensus, J.A., Krichbaum,T.P., Angelakis, E., Readhead,A.C.S. 2007, *AIPC*, 921,249
Keihänen, E., Reinecke, M. 2012, *A&A* 548, A110
Górski, K. M., Hivon, E., Banday, A. J., et al. 2005, *ApJ*, 622, 759
Planck Collaboration I. 2011, *A&A* 536, A1
Planck Collaboration II. 2011, *A&A* 571, A2
Rachen, J.P., Fuhrmann, L., Krichbaum, T.P., et al. 2015, IAU GA FP5p.43, and 28$^{\text{th}}$ Texas Symposium on Relativistic Astrophysics, Geneve
Tauber, J.A., Mandolesi, N., Puget J.-L., et al. 2010, *A&A*, 520, A1