Blind Search for Variability in Planck Data

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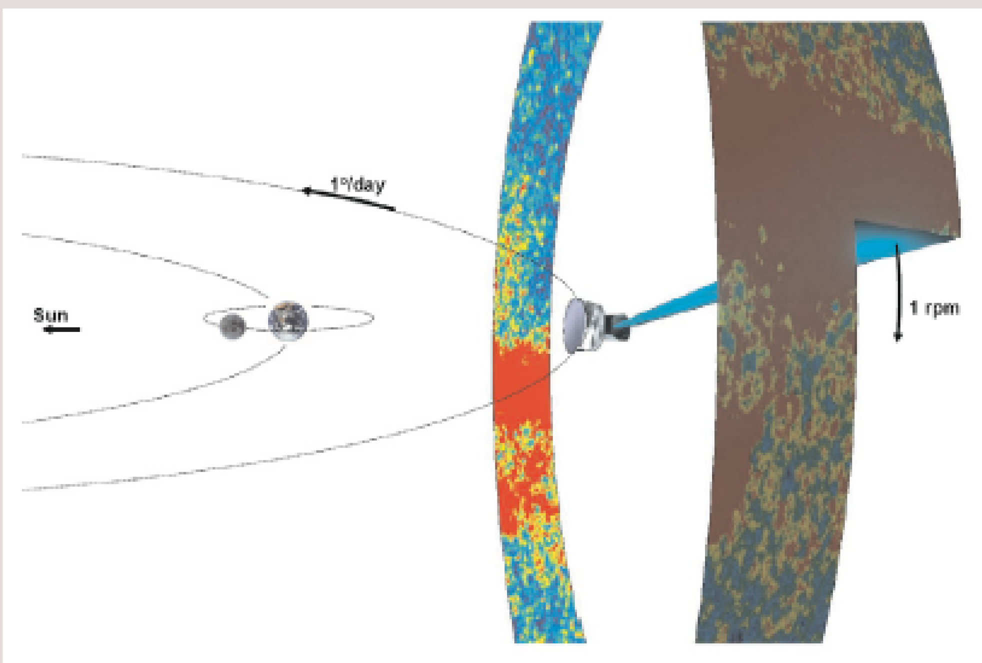
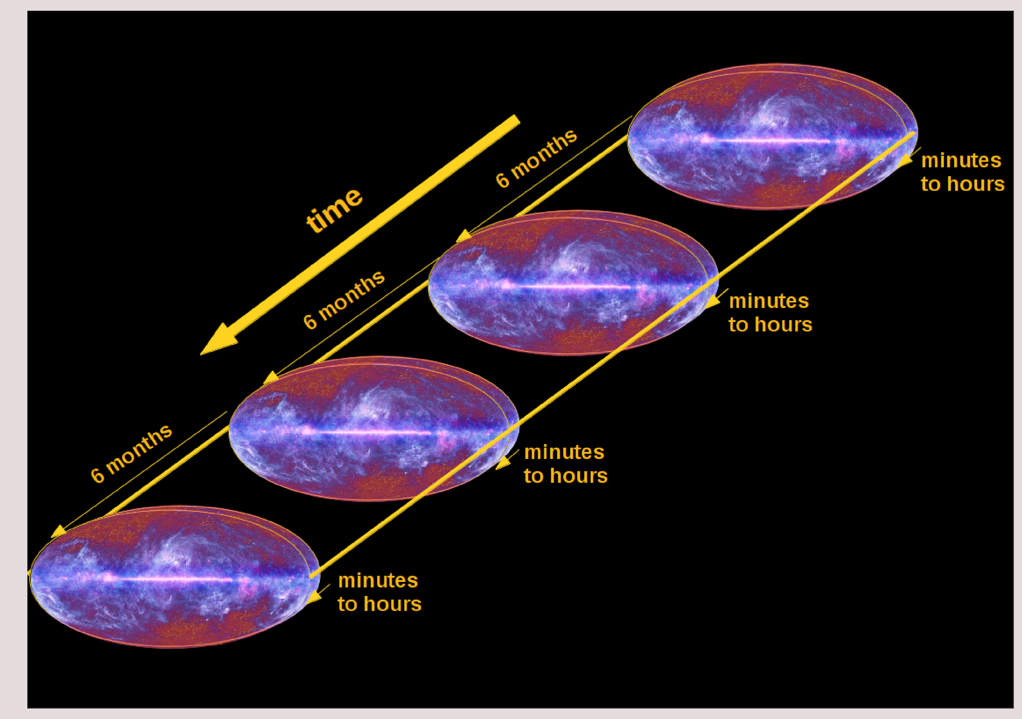


Planck Scanning

Planck provides 8 full sky surveys (Aug 2009 – Aug 2013) at the frequencies of its LFI instrument (30, 44, and 70 GHz), and 4–5 full surveys (– Jan 2012) 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 to 30 PIDs (depending on frequency) for each survey; for sources near the ecliptic poles the coverage can be much larger. A technical description of *Planck* is given by Tauber et al. (2010), Planck Collaboration I (2011), and references therein.



ArtDeco: Beam Deconvolution

Time-ordered data from *Planck* receivers are modulated by beam asymmetry effects. The signal t_j received by a detector at a given time τ_j is written as

$$t_j = \sum_{slmk} a_{slm} b^*_{slk} D^{l*}_{mk}(\theta_j, \phi_j, \psi_j) + n_j \, .$$

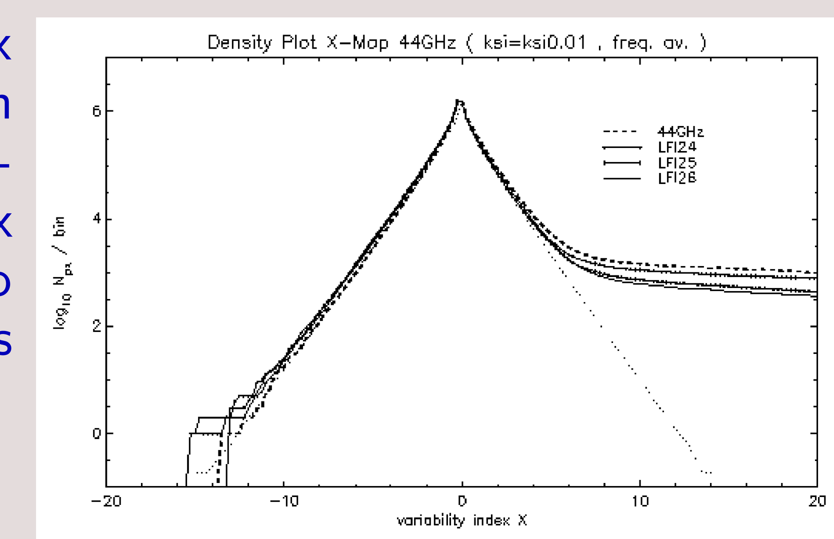
The a_{slm} ($s = 0, \pm 2$) are harmonic coefficients that represent temperature and polarisation of the sky signal, b_{slk} are corresponding beam coefficients, and n_j represents noise. The Euler angles θ_j, ϕ_j, ψ_j define the position and orientation of the beam. D^l_{mk} is a Wigner function that defines a rotation of the beam from a fiducial orientation at the north pole to its actual position.

ArtDeco is a beam deconvolution code, designed for absolute CMB experiments (Keihänen & Reinecke, 2012). The code takes as input the time-ordered data and pointing information, and the known beam shapes, and performs a linear least-squares fit of a_{slm} to the data up to some multipole $l_{\max}$. With the beam asymmetry parameter, $k_{\max}$, this yields a linear system of equations, which is solved through conjugate-gradient iteration. From the obtained harmonic coefficients of the sky one can construct the I, Q and U polarization maps free from beam asymmetry effects.

MATTI: Mapping of Time 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 pointing periods. From this, ArtDeco constructs an average sky signal S_k. A variability map is then a 2-dim Healipx map of a quantity

$$X_k = \frac{1}{2}\,\mathrm{sgn}(\hat{\chi}^2_k - 1)\, \mathrm{N}_k \left[\hat{\chi}^2_k - 1 - \ln \hat{\chi}^2_k\right]$$



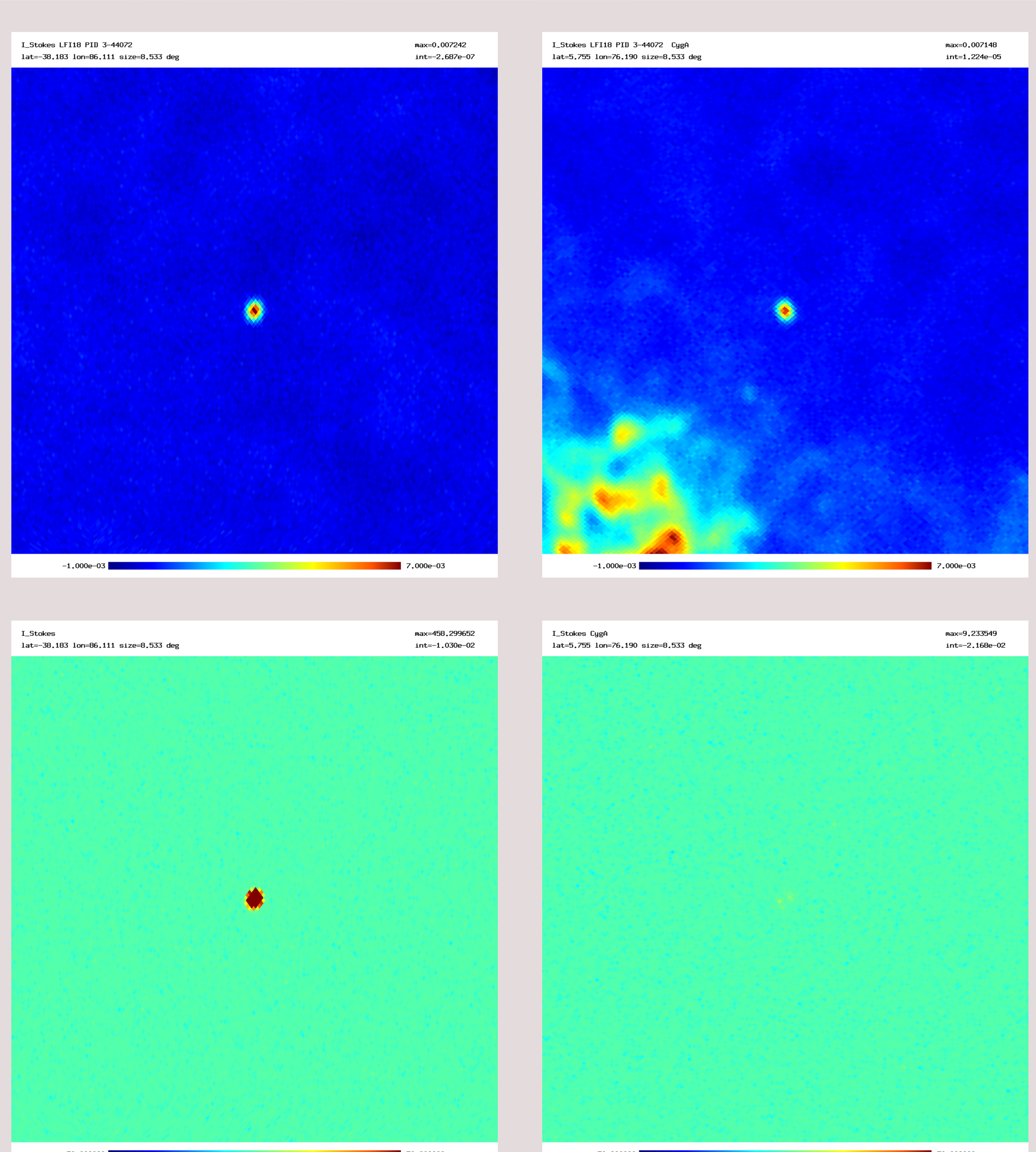
where

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

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 $P(\chi^2)$, with $X \le -\ln(1 - P(\chi^2))$ for $\hat{\chi}^2 \ge 1$, and $X > \ln P(\chi^2)$ for $\hat{\chi}^2 < 1$. The figure shows a 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.

Test: Known Variable and Non-Variable Sources

If noise and instrumental effects are well estimated, X-maps should show the significance of true sky variability in a pixel k regardless of the total intensity in that pixel. The two examples shown left show intensity maps and X-minimaps of the blazar 3C 454.3, a source which was extremely variable during the Planck mission (see, e.g., Fuhrmann et al. 2014), and the similarly bright FR-II radio galaxy Cygnus A, where we also see bright extended emission from the Galaxy. While 3C454.3 reveals its variability by an extremely large value $X_{\max} = 458.3$, the emission of Cyg A and its surroundings does not cause significant X-values - the visible bipolar signal at $X \approx 10$ is likely due to beam inaccuracies. All maps are evaluated for the LFI18 70 GHz horn over the full LFI mission (8 surveys) and assuming $\xi = 0.03$.



Time Resolved Planck Fluxes

As the analysis of time variations in the sky is essentially background-free, our method provides an easy 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, either by blind detection or from a catalog of known sources, 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. For details of this method and a science application, see poster FM5p.43 in this session.

Current Status and Future Prospects

ArtDeco and MATTI 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 initial 4D-mapping are in place at both the LFI and HFI DMC. In particular for HFI, we are still in the process of understanding and properly characterizing intrumental effects, but first useful results on known variable sources have been obtained (see also poster FM5p.43). We expect that all Planck frequencies will be analysed for variability, and science results prepared for publication well before the Planck Legacy release.

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