Planck Overview

• 2013 Results
• Since and next

François R. Bouchet
Institut d’Astrophysique de Paris
On behalf of the Planck collaboration
AFTER 16 YEARS OF HOPES & WORK

François R. Bouchet, "Planck Overview"
Planck Milestones

- 1993: CNES & ESA proposals, followed by a 3 years phase A study with ESA
- 1996 Selection by ESA (for a 2003 launch)
- …. (industry in, consortia in, design & tests...)

- 2009 August 13th: beginning of survey: Instruments very stable; Essentially no hiccups since, till the end of HFI: Details in 16 monthly reports to MOC, 13 bi-monthly to PSO (150 p. each), 138 « operation » teleconf. minutes, 169 weekly reports to MOC, 91 « cryo » teleconf., 8 coordination meetings, 978 daily quality reports & 127 HFI weekly health reports (97 800 plots), 1278 pages wiki écrites ou co-écrites ...

- 2010 June: first complete coverage of the sky by all detectors obtained with the first nearly 10 months of survey data. ERCSC release & 25 “Planck early results” papers submitted Jan 2011;
- 2010 November 27th: Nominal mission completed, having collected about 15.5 months of survey data insuring that all the sky at been seen at least twice by each detector:
  - 22 “Planck Intermediate results” papers on CMB foregrounds results submitted in 2012-14
  - public T data delivery on March 21st 2013, together with 28 “Planck 2013 results” papers (→ 32)
- 2012 Jan 14th: all HFI survey data acquired! 885 days of acquisition, 900 billion samples, 5 surveys, full mission = twice the nominal duration. With some additional LFI data, will be the basis of our next data delivery (DD2), including polarization & TOI. Target date of end of October (<dec 1st) 2014, together with ~ 35 papers.
- 2013 Oct 23rd: last command (off!) to the spacecraft from Darmstadt control room...
- Planning a “legacy release” at the end of 2015.
143 GHz & 217 GHz maps

Planck Collaboration: HFI data processing

Intensity maps

Planck Collaboration: HFI data processing

Difference between Half-ring maps

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Cleaning the background with a blind $l$-dependent linear combination

One of 5 methods which we developed as respective cross-checks

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The cosmic microwave background
Temperature anisotropies

6 million pixels of 5'

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European Space Agency
The Planck power spectrum of Temperature anisotropies
The gravitational effects of intervening matter bend the path of CMB light on its way from the early universe to the Planck telescope. This “gravitational lensing” distorts our image of the CMB (smoothing on the power spectrum, and correlations between scales).

\[ \hat{T}(\vec{\theta}) = T(\vec{\theta} + \vec{\nabla}\phi) \approx T(\vec{\theta}) + \vec{\nabla}\phi \cdot \vec{\nabla}T(\vec{\theta}) + \ldots \]

\[ \phi = \Delta^{-1} \vec{\nabla} \cdot \left[ C^{-1} T \ \vec{\nabla}(C^{-1} T) \right] \]

FFP14, Marseille, 2014 July 16th

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The (grey) masked area is where foregrounds are too strong to allow an accurate reconstruction.
The lensing potential spectrum

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Agrees well with the prediction from T alone

(26 detection)
Base $\Lambda$CDM model 6 parameters

Planck alone

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Planck (CMB+lensing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega_b h^2$</td>
<td>0.022242</td>
</tr>
<tr>
<td>$\Omega_c h^2$</td>
<td>0.11805</td>
</tr>
<tr>
<td>$100\theta_{MC}$</td>
<td>1.04150</td>
</tr>
<tr>
<td>$\tau$</td>
<td>0.0949</td>
</tr>
<tr>
<td>$n_s$</td>
<td>0.9675</td>
</tr>
<tr>
<td>$\ln(10^{10} A_s)$</td>
<td>3.098</td>
</tr>
</tbody>
</table>

The sound horizon, $\theta_s$, determined by the positions of the peaks (7), is now determined with 0.07% precision (links together $\Omega_b h^2$, $\Omega_c h^2$, $H_0$ - here as $\Omega_m h^3$)

Exact scale invariance of the primordial fluctuations is ruled out, at $\sim 4\sigma$

(as predicted by base inflation models)

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HL posterior correlations

Impact of foregrounds on cosmology:
Main correlations: $n_s / A_{PS, 217}$ & kSZ
The 2013 CMB temperature landscape

Angular scale

$D_\ell \, [\mu K^2]$

Multipole moment, $\ell$

Data from:
- Planck
- WMAP9
- ACT
- SPT
Base tilted $\Lambda$CDM model - 6 parameters

For the base model, results from High-l CMB experiments make little difference

High-l CMB experiments = ACT + SPT (600 & 2540 deg$^2$, 2 & 3 freq.)
Echos of the primordial drum...

BAO (Baryon Acoustic Oscillations) at $z=0$

Watch baryon/Photon at $z \sim 1100$ decoupling

BAO (Baryon Acoustic Oscillations) at $z=1100$

Changing equality rad/mat:
- $\rho_h^2 = 0.12$ (green),
- 0.13 (red),
- 0.14 (blue), and
- 0.105 in pure CDM
BAO acoustic-scale distance ratio

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Planck Prediction
(±1σ shaded area)

Planck & BAO are all in quite tight agreement

DE equation of state is consistent with $1+w = 0$
### Base ΛCDM model 6 parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Planck (CMB+lensing)</th>
<th>Planck+WP+highL+BAO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Best fit</td>
<td>68% limits</td>
</tr>
<tr>
<td>( \Omega_b h^2 )</td>
<td>0.022242</td>
<td>0.02217 ± 0.00033</td>
</tr>
<tr>
<td>( \Omega_c h^2 )</td>
<td>0.11805</td>
<td>0.1186 ± 0.0031</td>
</tr>
<tr>
<td>( 100\theta_{MC} )</td>
<td>1.04150</td>
<td>1.04141 ± 0.00067</td>
</tr>
<tr>
<td>( \tau )</td>
<td>0.0949</td>
<td>0.089 ± 0.032</td>
</tr>
<tr>
<td>( n_s )</td>
<td>0.9675</td>
<td>0.9635 ± 0.0094</td>
</tr>
<tr>
<td>( \ln(10^{10}A_s) )</td>
<td>3.098</td>
<td>3.085 ± 0.057</td>
</tr>
</tbody>
</table>

The sound horizon, \( \theta_s \), determined by the positions of the peaks (7), is now determined with 0.05% precision (links together \( \Omega_b h^2, \Omega_c h^2, H_0 \) – here as \( \Omega_m h^3 \)).

Exact scale invariance of the primordial fluctuations is ruled out, at more than 7σ (as predicted by base inflation models).

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The basic content of the Universe

Before Planck

After Planck

...has changed!

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The rate of expansion

Direct determinations of the distance ladder:

Riess et al. (2011)

Freedman et al. (2012),

Freedman et al. (2001)

Humphreys et al. (2013) revision of NGC4258 distance to \((7.60\pm0.23)\) Mpc leads to a lowering of the Hubble value from Riess, \(H_0=(74.8\pm3.1)\) to \(H_0=(72.0\pm3.0)\) km s\(^{-1}\) Mpc\(^{-1}\)

Planck H\(_0\) is \(67.95 \pm 1.5\) km/s/Mpc

Pap IV replacement on water maser UGC 3759: it is now at ~50 Mpc: \(H_0=68.9\pm7.1\) km/s/Mpc

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Summary on base tilted LCDM

- Base LCDM is a very good fit to Planck T spectrum, with parameters \((n_s, \Omega_b, \Omega_c, \theta/H_0)\) accurately determined by Planck alone, with the exception of the \((A_s, \tau)\) degeneracy which can be broken by adding WP.

- The model is fully consistent with two other Planck observables, Lensing and Polarization spectra.

- This model is also fully consistent with BAO, and show some tension with direct \(H_0\) determination. The situation regarding \(\Omega_m\) from SN unclear at time of writing (but see JLA below).

- CMB+LSS now exclude scale invariance \((n_s=1)\) at \(~7\sigma\)
Beyond the standard model

We tested many extension to the simplest, base, 6 parameters, LCDM model:

- **Curved space, \( \Omega_k \) \( (0\ ?) \)**
- **Dynamical dark energy, \( w \) \( (-1\ ?) \)**
- **Non-standard abundance of primordial Helium fraction, \( Y_p \) \( (0.2477\ ?) \)**
- **Neutrino properties, i.e. how many and how massive (\( N_{\text{eff}}, \Sigma m_\nu 3.046, 0.06\ ?) \)**
- **Curvature of the power spectrum of primordial fluctuations (running \( d n_s/d\ln k \) 0?)**
- **Existence of primordial gravitational waves, \( r_{0.002} \) \( (0\ ?) \)**

⇒ no compelling evidence for any of them↓

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Planck+WP</th>
<th>Planck+WP+BAO</th>
<th>Planck+WP+highL</th>
<th>Planck+WP+highL+BAO</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Omega_k )</td>
<td>-0.0105 ( -0.037^{+0.043}_{-0.049} )</td>
<td>0.0000 ( 0.0000^{+0.0006}_{-0.0007} )</td>
<td>-0.0111 ( -0.042^{+0.043}_{-0.048} )</td>
<td>0.0009 ( -0.0005^{+0.0006}_{-0.0066} )</td>
</tr>
<tr>
<td>( \Sigma m_\nu ) [eV]</td>
<td>0.022 (&lt; 0.933 )</td>
<td>0.002 (&lt; 0.247 )</td>
<td>0.023 (&lt; 0.663 )</td>
<td>0.000 (&lt; 0.230 )</td>
</tr>
<tr>
<td>( N_{\text{eff}} )</td>
<td>3.08 ( 3.51^{+0.80}_{-0.79} )</td>
<td>3.08 ( 3.40^{+0.59}_{-0.57} )</td>
<td>3.23 ( 3.36^{+0.68}_{-0.64} )</td>
<td>3.22 ( 3.30^{+0.54}_{-0.51} )</td>
</tr>
<tr>
<td>( Y_p )</td>
<td>0.2583 ( 0.283^{+0.045}_{-0.048} )</td>
<td>0.2736 ( 0.283^{+0.043}_{-0.045} )</td>
<td>0.2612 ( 0.266^{+0.040}_{-0.042} )</td>
<td>0.2615 ( 0.267^{+0.038}_{-0.040} )</td>
</tr>
<tr>
<td>( dn_s/d\ln k )</td>
<td>-0.0090 ( -0.013^{+0.018}_{-0.018} )</td>
<td>-0.0102 ( -0.013^{+0.018}_{-0.018} )</td>
<td>-0.0106 ( -0.015^{+0.017}_{-0.017} )</td>
<td>-0.0103 ( -0.014^{+0.016}_{-0.017} )</td>
</tr>
<tr>
<td>( r_{0.002} )</td>
<td>0.000 (&lt; 0.120 )</td>
<td>0.000 (&lt; 0.122 )</td>
<td>0.000 (&lt; 0.108 )</td>
<td>0.000 (&lt; 0.111 )</td>
</tr>
<tr>
<td>( w )</td>
<td>-1.20 ( -1.49^{+0.05}_{-0.57} )</td>
<td>-1.076 ( -1.13^{+0.24}_{-0.25} )</td>
<td>-1.20 ( -1.51^{+0.62}_{-0.53} )</td>
<td>-1.109 ( -1.13^{+0.23}_{-0.25} )</td>
</tr>
</tbody>
</table>

NB: no compelling evidence either for:
- Existence of an “isocurvature” part in the primordial fluctuations
- Existence of cosmic strings (\( G\mu/c^2<1.3\ 10^{-7} \))
- Non-Gaussian signatures of non-minimal inflation (\( f_{\text{local}}=2.7^{+5.8}_{-5.8} \), \( f_{\text{equil}}=-42^{+75}_{-75} \), \( f_{\text{ortho}}=-25^{+39}_{-25} 68\%\text{CL})
- Evolution of the fine structure constant, dark matter annihilation, primordial magnetic fields...

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Neutrinos masses

Planck constrains neutrino masses mostly through their effect via lensing: removing that constraint (marginalising over $A_L$) weakens considerably the limit: $\Sigma m_\nu < 0.66\text{eV (95CL PT+WP+HL)}$ becomes $\Sigma m_\nu < 1.08\text{eV (95CL PT+WP+HL)}$

NB: the (4-pt based) lensing likelihood would prefer higher values for $\Sigma m_\nu$ (i.e. it weakens the constraints): *time will tell*

With BAO:
$\Sigma m_\nu < 0.23\text{eV (95CL PT+WP+HL)}$

by $l=1000$ the lensing potential is suppressed by $\sim 10\%$ in power for $\Sigma m_\nu=0.66\text{eV}$.

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SZ / CMB tension

$\sigma_8$ measures the amplitude of fluctuations on the 8 h$^{-1}$ Mpc scale today; $\sigma_8 = F(A_s)$

CMB with $m_\nu > 0.06\text{eV}$

CMB – No $m_\nu$

Planck SZ +BAO+ BBN

68% CL
Neutrinos number (relativistic dof at decoupling)

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→ No evidence for additional neutrino-like relativistic particles beyond the three families of neutrinos in the standard model

\[ N_{\text{eff}} = 3.3 \pm 0.27; \Sigma m_\nu < 0.23 \text{ eV} \]

Bennett et al. 2013, v2

Wmap9+ excluded 3 neutrinos at more ~2.5σ (Bennett et al. 2013, v2)
Primordial nucleosynthesis

\[ Y_p = 0.2477 \quad 0.0001 \]

(as a derived quantity)

\[ N_{\text{eff}} = 3.046 \]

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Constraint on representative Inflation models

$$V_\star = (1.9 \times 10^{16} \text{ GeV})^4 \frac{r}{0.12} \text{ and } r < 0.11 \text{ @ 95% CL}$$

Exponential potential models (power-law inf.), simplest hybrid inflationary models (SB SUSY), monomial potential models of degree \( n > 2 \) do not provide a good fit to the data.
2013 Status of direct B-modes searches

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Bicep1 - 3 years

\[ r < 0.70 \text{ at 95\% confidence level.} \]
Encyclopædia Inflationaris

Bayesian Evidences $\ln(\mathcal{E}/\mathcal{E}_{\rm HI})$ and $\ln(L_{\rm max}/\mathcal{E}_{\rm HI})$

Schwarz-Terrero-Escalante Classification:

<table>
<thead>
<tr>
<th>Model</th>
<th>$A_{\text{TT}}$</th>
<th>$A_{\text{TE}}$</th>
<th>$A_{\text{EE}}$</th>
<th>$A_{\text{BB}}$</th>
<th>$A_{\text{TB}}$</th>
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<tr>
<td>CNNM</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
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<tr>
<td>CNNMS</td>
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<tr>
<td>GGMN</td>
<td>&lt; 0.01</td>
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</tr>
</tbody>
</table>

J. Martin, C. Ringeval, R. Trotta, V. Vennin
ASPIC project

Displayed Evidences: 193
A theorist dream, or nightmare?

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Zooming on the very largest scales, $\ell < 50$...

The first 30 modes are a bit smaller than expected from $\Lambda$CDM.
Inflaton potential reconstruction

Best fitting potentials, when \( V(\phi) \) is Taylor expanded at the \( n \)-th order around the pivot scale; Planck-T+WP;
Flat priors on \( \varepsilon, \eta, \xi^2 \);
\( \Phi_* \) in natural units / \((8\pi)^{1/2}M_p=1\).

This tail / -0.4 (for \( n=4 \)) generates a significant running at the largest scale, with a better fit at \( l < 30 \), while indistinguishable from LCDM at smaller scales.
Assuming a single isocurvature mode

\[ \frac{C_{\ell}^{TTio}}{C_{\ell}^{TTad}} \]

\[ D_i [\mu K^2] \]

... helps (somewhat) at low-l (again!)
Planck did confirm the COBE/WMAP anomalies (even if with somewhat different significance), relieving possible concerns about measurement technology and foreground contamination.

**NB:** Planck did the first direct detection of relativistic Doppler boosting in the CMB fluctuations through:

- **Aberration:** Spots are smaller in the direction of Earth’s motion.
- **Dipole modulation:** Features are enhanced in the direction of Earth’s motion.

\[ v = 384\pm78 \text{ (stat)}\pm115 \text{ (syst) km s}^{-1} \] (to compare to \( v_{\text{dipole}} = 368 \pm 2 \text{ km s}^{-1} \))
Since then...

(march 2013)
Fig. 18. Magnitude residuals relative to the base $\Lambda$CDM model that best fits the SNLS combined sample (left) and the Union2.1 sample (right). The error bars show the $1\sigma$ (diagonal) errors on $m_B$. The filled grey regions show the residuals between the expected magnitudes and the best-fit to the SNe sample as $\Omega_m$ varies across the $\pm2\sigma$ range allowed by Planck+WP+highL in the base $\Lambda$CDM cosmology. The colour coding of the SNLS samples are as follows: low redshift (blue points); SDSS (green points); SNLS three-year sample (orange points); and HST high redshift (red points).
Planck versus JLA (SNLS + SDSS)

François R. Bouchet, “Planck Overview”

<table>
<thead>
<tr>
<th></th>
<th>$\Omega_m$</th>
<th>$w$</th>
<th>$H_0$</th>
<th>$\Omega_b h^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planck+WP+BAO</td>
<td>0.303 ± 0.012</td>
<td>-1.027 ± 0.055</td>
<td>68.50 ± 1.27</td>
<td>0.0221 ± 0.0003</td>
</tr>
<tr>
<td>Planck+WP+BAO</td>
<td>0.295 ± 0.020</td>
<td>-1.075 ± 0.109</td>
<td>69.57 ± 2.54</td>
<td>0.0220 ± 0.0003</td>
</tr>
<tr>
<td>Planck+WP+SDSS</td>
<td>0.341 ± 0.039</td>
<td>-0.906 ± 0.123</td>
<td>64.68 ± 3.56</td>
<td>0.0221 ± 0.0003</td>
</tr>
<tr>
<td>Planck+WP+SDSS+SNLS</td>
<td>0.314 ± 0.020</td>
<td>-0.994 ± 0.069</td>
<td>67.32 ± 1.98</td>
<td>0.0221 ± 0.0003</td>
</tr>
<tr>
<td>Planck+WP+JLA</td>
<td>0.307 ± 0.017</td>
<td>-1.018 ± 0.057</td>
<td>68.07 ± 1.63</td>
<td>0.0221 ± 0.0003</td>
</tr>
<tr>
<td>WMAP9+JLA+BAO</td>
<td>0.296 ± 0.012</td>
<td>-0.979 ± 0.063</td>
<td>68.19 ± 1.33</td>
<td>0.0224 ± 0.0005</td>
</tr>
<tr>
<td>Planck+WP+C11</td>
<td>0.288 ± 0.021</td>
<td>-1.093 ± 0.078</td>
<td>70.33 ± 2.34</td>
<td>0.0221 ± 0.0003</td>
</tr>
</tbody>
</table>

Astroph1401.4064 Betoule et al. (JLA)
sound horizon

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Samples are for Planck only.

Tighter contours along the degeneracy direction are from Planck +lensing+ WP

\( r_s \) is constrained transversally

\( r_s \) constrains \( \Omega_m h^3 \) very tightly in LCDM; High \( \Omega_m \) corresponds to low \( n_s \) and \( H_0 \)
BICEP2, on March 17\textsuperscript{th}

NB: using 100 X 150 GHz, Dust spectral index disfavoured at 2.2 sigma level
Adding Bicep2 as stated in their paper
The 2013 main unidentified systematics have now been identified:

- Very long time constants (VLTC between 1 and 10 seconds) with very low amplitudes.
- These VLTC do shift the dipoles (by a few arcmin) and create a leakage of the solar dipole into the orbital dipole (& TF variation).
- The current accounting of this allows to calibrate HFI on the orbital dipole with a \(~0.1\%\) accuracy! (both intra and inter-bands). This matches LFI. Discrepancy / WMAP understood (inc. 0.6\% wrt WMAP dipole).
- The low-ell EE systematics has been reduced by a factor larger than a 100.
- We have also improved the leakage correction and the removal of glitch tails (lower 1/f noise).

The paper on the "dust polarisation angular power spectrum at high latitude from HFI" is going to be published (ASAP 😊) with the version of the data to be released by the end of the year (2014).
Dependence of the spectra on the sky fraction retained

Power law (in \( \ell \)) index = -2.4
At 353GHz, the amplitudes of the dust power spectra scale as $l_{353}^{1.9}$.

- SED is found to be fitted by the one from the May 2014 paper ($\text{Beta}_{\text{dust}} = 1.63$ and $T_{\text{dust}} = 18.7K$).
- The ratio of E to B modes is consistent with a constant value of 0.53.
Dust PS at high lat. and B modes detection

- Planck 353 GHz data give the average dust power spectrum amplitude as a function of $I_{353}$
  - from large areas: 30 to 50 and 70% of the sky
  - from sampling many 400 square degree fields at high latitude

- It shows an intrinsic dispersion which is larger than the expected sample variance for a stationary Gaussian field except for the lowest brightness fields.

- The most probable value predicted by these empirical relations for the BICEP2 field is close to the measured BICEP2 signal.

- The measured one in the broader BICEP2 field does not show evidence for a very discrepant value, although admittedly the uncertainties are large.

- *Properly removing the dust contribution in this field can only be done by combining the two data sets.*
Consequences

- There appears to be no field to measure the primordial B modes at the degree scale (in the recombination bump) which would be large enough and clean enough for the dust contribution to be neglected.

- The best 30% of the sky have a dust PS TT amplitude only 1.5 larger than the BICEP2 field.

- There are fields with lower $I_{353}$ than 0.038 MJy/sr (compared to 0.06) thus better by about a factor of 2 for the more probable value.

- The dispersion is large enough to remove the possibility to choose fields with only $I_{353}$

- The Planck collaboration aims at providing a sky map of the most promising fields for degree scale work.
Coming soon (October 2014?)

- Delivery through the Planck Legacy archive of the
  
  Full mission data (HFI 29months, LFI 48): $O(10^4)$ maps
  - $T, Q, U$ maps at 6 frequencies, 30-354GHz+ $T@545-857GHz$
  - “Half-Ring”, yearly, survey, detset maps
  - Ancillary maps (CO, dust, BP leakage, Zodi correction...)
  - IMO (beams, spectral bandpasses...)
  - CMB & FG maps & Compact sources catalogues (SZ)
  - PS & likelihood (& many model parameters)
  - TOIs of all detectors, clean & calibrated
  - 10 000 simulation of maps (CMB, FG, Noise...) – $O(10^5)$
  - Explanatory supplement

- Through astroph: ~ 35 papers
To do what?

- **Refined temperature analyses, and further checks of tantalizing hints/anomalies**

- **Polarisation frontier!**

- **Expected results:**
  
  - Better Temperature science (higher sensitivity, more redundancy & checks, improved analyses, eg on FG modelling, bispectrum osc.)
  
  - E polarisation: tau, independent parameters determination (with similar constraining power to T), fnl tigher, anomalies (large l)... 
  
  - T+E: joint constraints (independent check, improved constraints of e..g Isocurvature modes)
  
  - B modes polarisation from dust, from reionisation (l<15) and recombination bump, and in lensing dominated regime
  
  - Upper limits from EB, TB (TBC)
Conclusions

- Excellent agreement between the Planck 2013 temperature spectrum at high $l$ and the predictions of the tilted $\Lambda$CDM model using the simplest slow-roll inflationary models;
- But with tantalizing hints both at low-$l$ ($<30$) and high-$l$... (is there a model tying all Large Scale anomalies?)

- $n_s=0.963 \pm 0.006$ from PT+WP+BAO; $\Rightarrow$ HZ robustly excluded
- $\Omega_K=-0.006\pm0.018$ at 95%CL from Planck-T+L $\Rightarrow$ flat spatial geometry
- $f_{NL}^{LEO}$ (and others) consistent with zero; $\Rightarrow$ most stringent test of Gaussianity to date.
- No evidence for cosmic defects. Nambu-Goto strings have $G\mu/c^2 < 1.3 \times 10^{-7}$ ($\eta < 4.7 \times 10^{15}$ GeV).
- $r_{0.002} < 0.12$ (PT+WP alone) $\Rightarrow$ inflation energy scale $< 1.9 \times 10^{16}$ GeV at 95%CL.
- Concave potentials preferred.
- Strong constraints on parameters values of specific inflationary scenario
- Potential reconstructed in observable window shows that allowing a fourth order leads to deviation to slow-roll, and allows a better fit to the low-$l$ data (improvement of $\Delta\chi^2_{\text{eff}} \sim 4$). Idem when allowing for CDI isocurvature.
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.

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Exciting times

Still Lie ahead

François R. Bouchet, "Planck Overview"