Preliminary 2014 results from Planck
George Efstathiou on behalf of the Planck collaboration
... and beautiful polarization spectra
... and beautiful lensing spectra

TT, TE, EE, EB, TB spectra (see talk by Antony Lewis)
Constraints on reionization optical depth $\tau$
Polarization spectra are generally highly consistent with TT spectra.
## BASE $\Lambda$CDM MODEL

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TT</th>
<th>TT,TE,EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega_b h^2$</td>
<td>$0.02222\pm0.00023$</td>
<td>$0.02224\pm0.00015$</td>
</tr>
<tr>
<td>$\Omega_c h^2$</td>
<td>$0.1199\pm0.0022$</td>
<td>$0.1199\pm0.0014$</td>
</tr>
<tr>
<td>$100\theta_*$</td>
<td>$1.04086\pm0.00048$</td>
<td>$1.04073\pm0.00032$</td>
</tr>
<tr>
<td>$\tau$</td>
<td>$0.078\pm0.019$</td>
<td>$0.079\pm0.017$</td>
</tr>
<tr>
<td>$n_s$</td>
<td>$0.9652\pm0.0062$</td>
<td>$0.9639\pm0.0047$</td>
</tr>
<tr>
<td>$H_0$</td>
<td>$67.3\pm1.0$</td>
<td>$67.6\pm0.6$ (+BAO)</td>
</tr>
<tr>
<td>$\Omega_m$</td>
<td>$0.316\pm0.014$</td>
<td>$0.316\pm0.009$</td>
</tr>
<tr>
<td>$\sigma_8$</td>
<td>$0.830\pm0.015$</td>
<td>$0.831\pm0.013$</td>
</tr>
<tr>
<td>$z_{re}$</td>
<td>$9.9\pm1.9$</td>
<td>$10.7\pm1.7$</td>
</tr>
</tbody>
</table>

...but beware there are still low level systematics in the polarization spectra

preliminary
Planck 2013:

- good agreement with Planck lensing ✔
- consistent with BAO ✔
- ~2σ tension with Ia SNe ✔
- ~2.5σ tension with $H_0$ ✔️ GPE ✗ AGR
- tension with measures of $\sigma_8$ including:
  - weak lensing ✗
  - cluster counts ✗
  - redshift space distortions ?

Some skeptics even doubted the fidelity of the Planck data! ✗

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2014 Planck lensing \( \chi^2 = 15.4 \) (8 bins)

\[ [\ell(\ell+1)]^2 \frac{C_{\ell}^{\phi\phi}}{2\pi} \times 10^7 \]

\[ [\ell(\ell+1)]^2 \frac{\Delta C_{\ell}^{\phi\phi}}{2\pi} \times 10^8 \]

Multipole \( \ell \)
Baryon Acoustic Oscillations (BAO)

\[
\frac{D_L(z)}{r_s} / \frac{D_L(z)}{r_s}^{\text{Planck}}
\]

\[
H(0.57)(r_s / r_s^{\text{fid}}) \; \text{[km s}^{-1}\text{Mpc}^{-1}]\]

\[
D_A(0.57)(r_s^{\text{fid}} / r_s) \; \text{[Mpc]}\]

preliminary
.... leading to remarkable constraints on spatial curvature $\Omega_k = 0.000 \pm 0.005$ (95%)
.... and to neutrino masses $\Sigma m_\nu < 0.21$ eV (95%)
Possible tensions: Weak gravitational lensing (CFHTlens)


..... and redshift space distortions......

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..... and one example of what these tensions can do......

\[ w(a) = w_0 + (1-a)w_a \]
..... and another ......

Modified gravity: $\mu$ modifies gravitational potential, $\eta$ is the ratio of the potentials $\Phi$ and $\Psi$.

(see talk by Valeria Pettorino)

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There is no doubt that in base $\Lambda$CDM Planck wants high $\sigma_8$: 

![Diagram showing $\sigma_8$ vs $\Omega_m$ with various Planck data sets and constraints.](image)
Primordial nucleosynthesis (deuterium abundance) and $N_{\text{eff}}$

- $b_0$
- $b_1$
- $b_2$
- $b_3$
- $b_4$
- $b_5$
- $b_6$
- $b_7$

$N_{\text{eff}}$

- Aver et al. (2013)
- Iocco et al. (2008)
- Cooke et al. (2014)

$\omega_b$

- Preliminary
The three faces of BICEP
\[ \Delta N_{\text{eff}} = 0.39 \ (\text{Planck TT+lowP+lensing}) \]

\[ \Lambda CDM \ (\text{Planck TT+lowP}) \]

\[ \Lambda CDM \ (\text{Planck TT+lowP+ext}) \]

Starobinsky \((R^2)\) inflation

\[ n_s \approx 1 - \frac{2}{N} \approx 0.967 \]

\[ r \approx \frac{12}{N^2} \approx 0.0033 \]

\[ \frac{dn_s}{d\ln k} \approx -\frac{2}{N^2} \approx -0.0006 \]

...... but, there is plenty of room at the top (and to the side!)

preliminary
Isocurvature modes
(simple case of fully correlated matter isocurvature modes)

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\[
\begin{array}{|c|c|c|}
\hline
0.945 & 0.960 & 0.975 & 0.990 \\
\hline
0.012 \\
0.006 \\
0.000 \\
\hline
\end{array}
\]

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Planck TT+lowP
Planck TT,TE,EE+lowP

preliminary
Power spectrum reconstruction (typical example)
Searches for features:

Feature in the potential:

$$V(\phi) = \frac{m^2}{2} \phi^2 \left[ 1 + c \tanh \left( \frac{\phi - \phi_c}{d} \right) \right]$$

Non vacuum initial conditions/instanton effects in axion monodromy

$$V(\phi) = \mu^3 \phi + \Lambda^4 \cos \left( \frac{\phi}{f} \right)$$

$$P_{R}^{\log}(k) = P_{R}^{0}(k) \left[ 1 + A_{\log} \cos \left( \omega_{\log} \ln \left( \frac{k}{k_*} \right) + \varphi_{\log} \right) \right].$$

Linear oscillations as from Boundary EFT

$$P_{R}^{\text{lin}}(k) = P_{R}^{0}(k) \left[ 1 + A_{\text{lin}} \left( \frac{k}{k_*} \right)^{n_{\text{lin}}} \cos \left( \omega_{\text{lin}} \frac{k}{k_*} + \varphi_{\text{lin}} \right) \right].$$

see talk by Fabio Finelli on Thursday for more details.
Large Angle Anomalies

Look elsewhere!
As in 2013 base ΛCDM continues to be a good fit to the Planck data, *including polarization*. 

No convincing evidence for any simple extensions.

Some tensions with astrophysical data that measure the amplitude of matter fluctuations.

Planck constraints on r as in 2013 
\[ r < 0.11 \quad (95\%) \]
(but this constraint is model dependent).

Scalar fluctuations consistent with pure adiabatic modes with a featureless tilted spectrum.

*preliminary*
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.