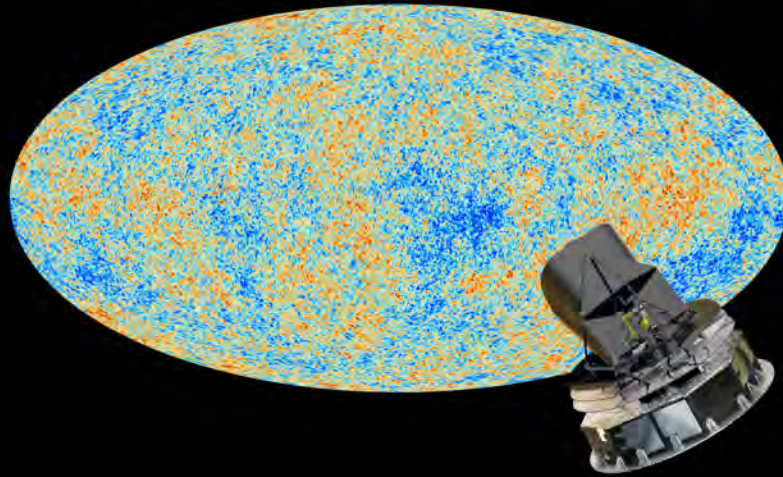
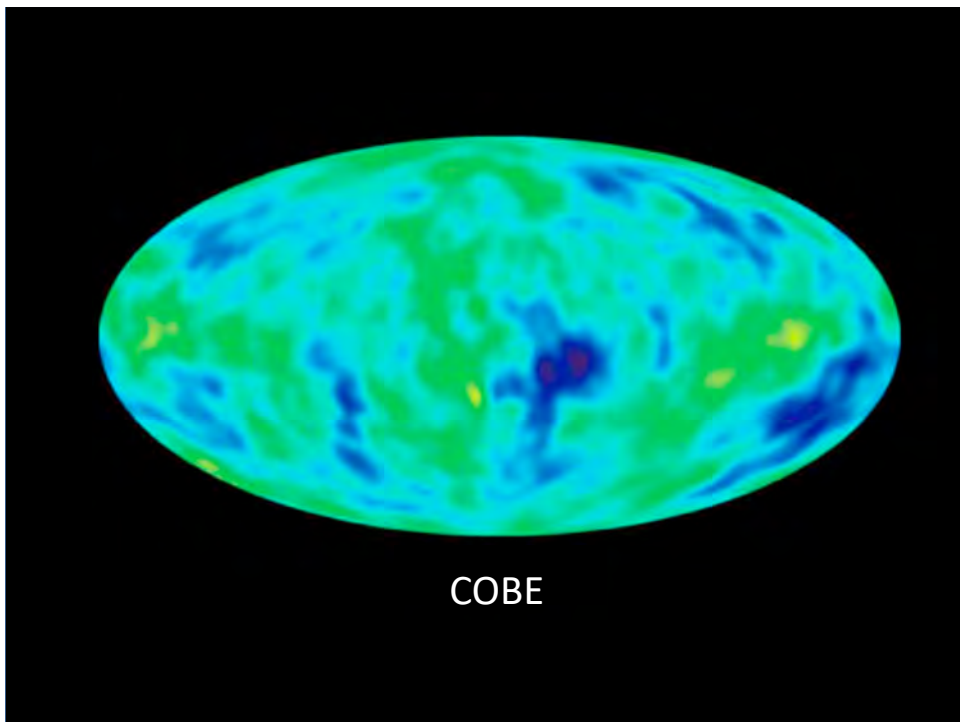
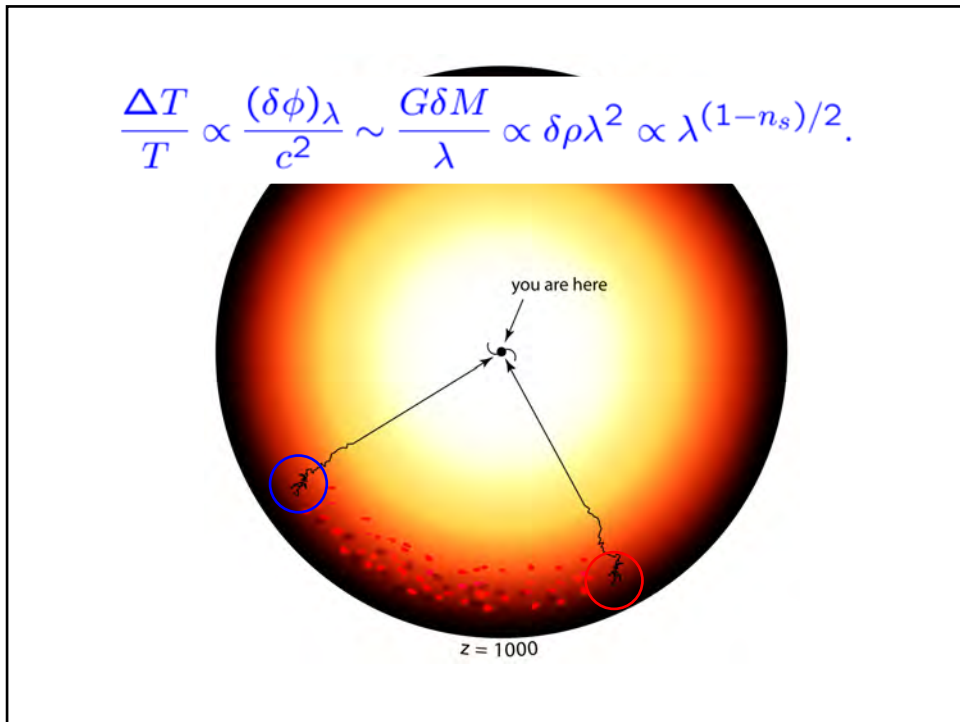


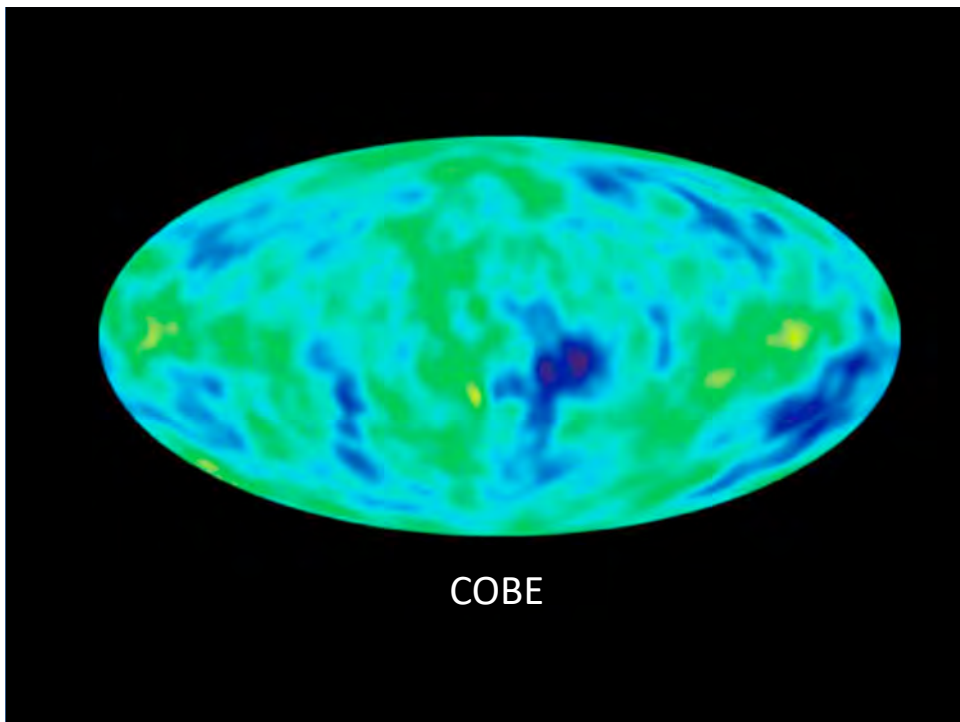
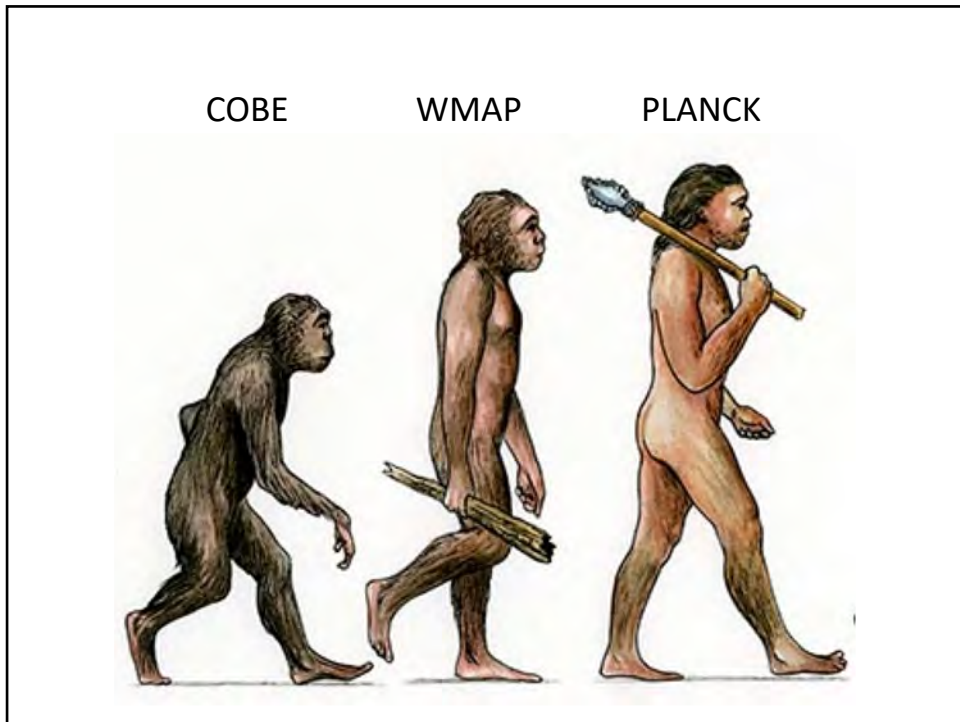
The Planck Legacy: Inflation and the Origin of Structure in the Universe

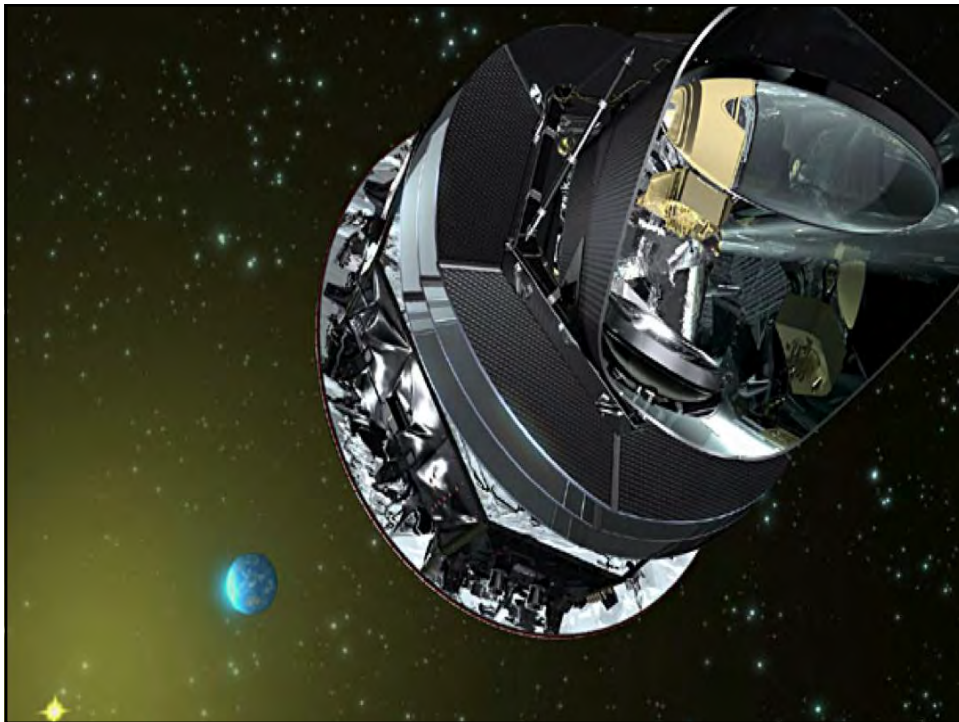
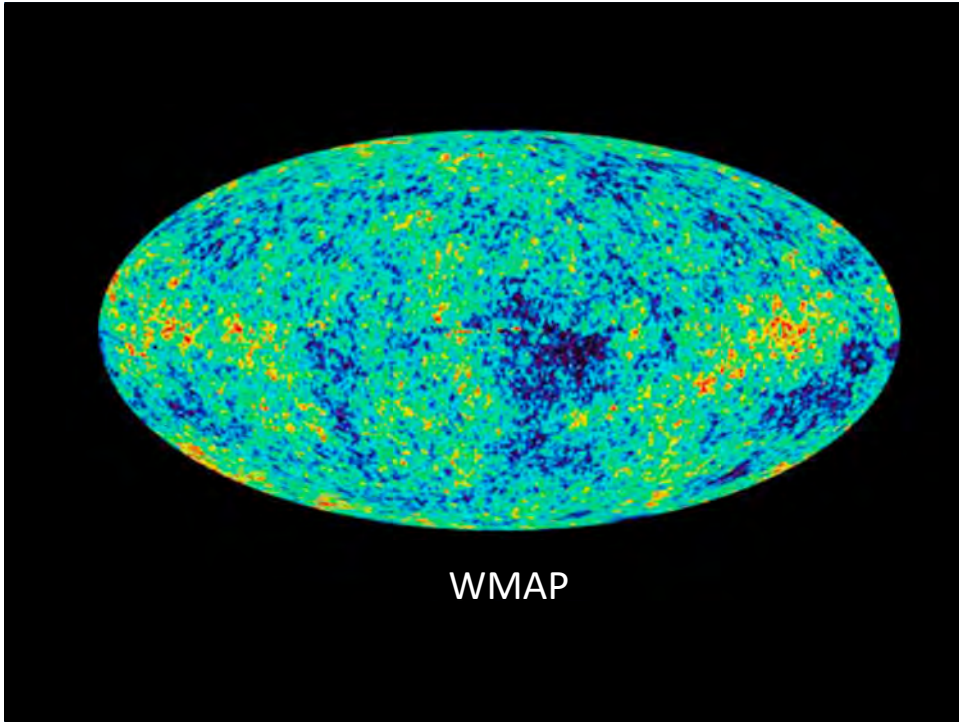
George Efstathiou KICC



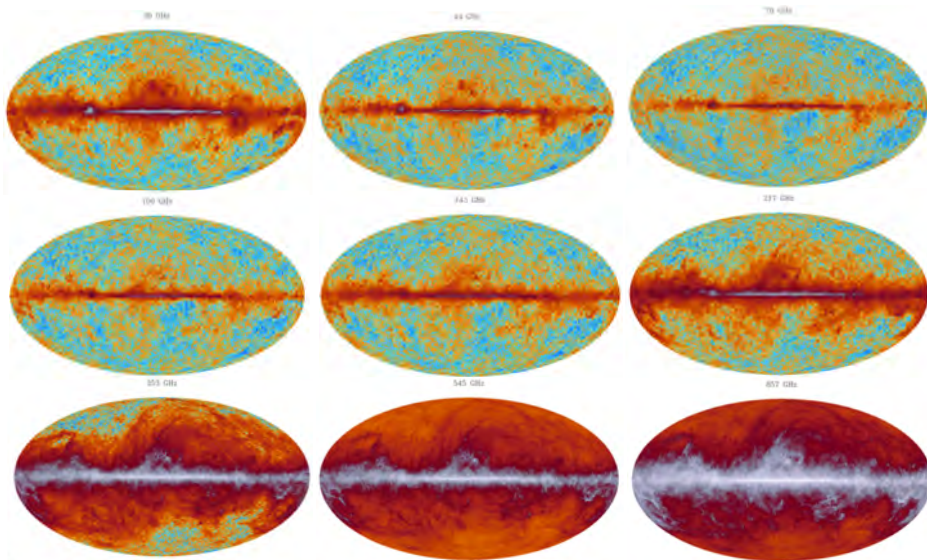




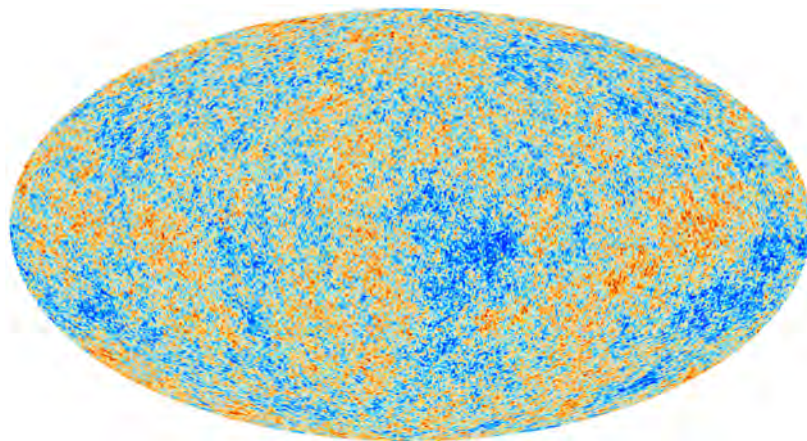




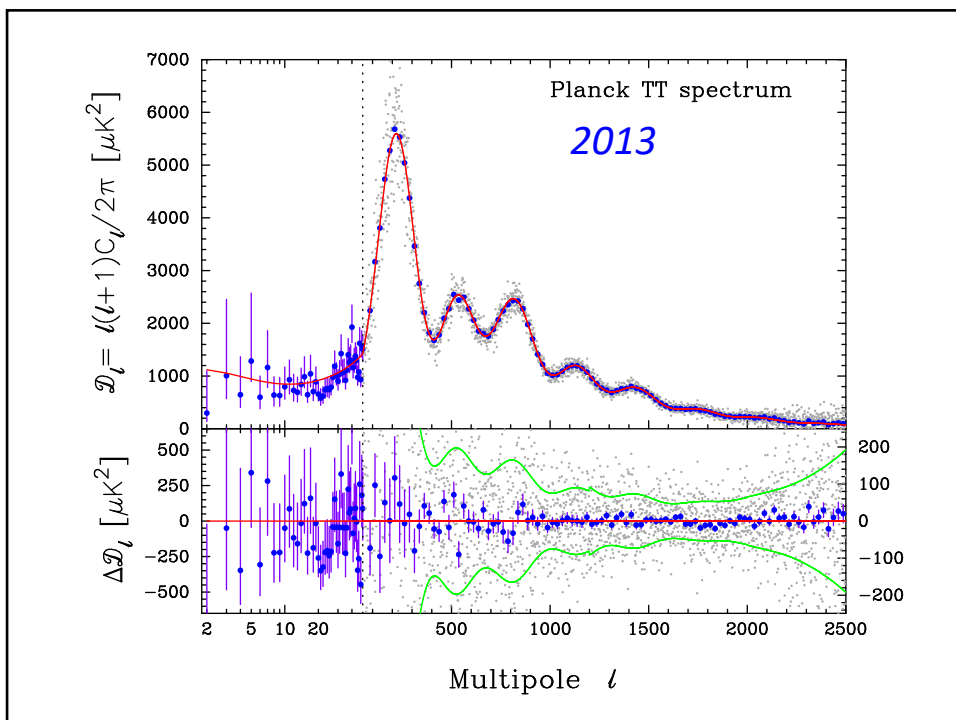
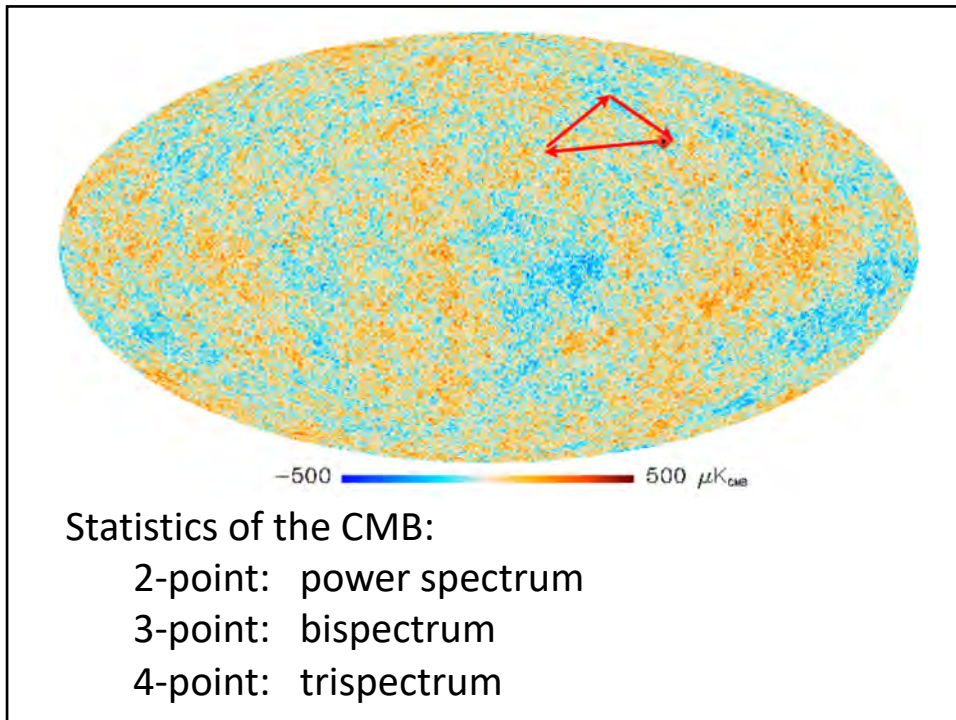
PLANCK FREQUENCYMAPS

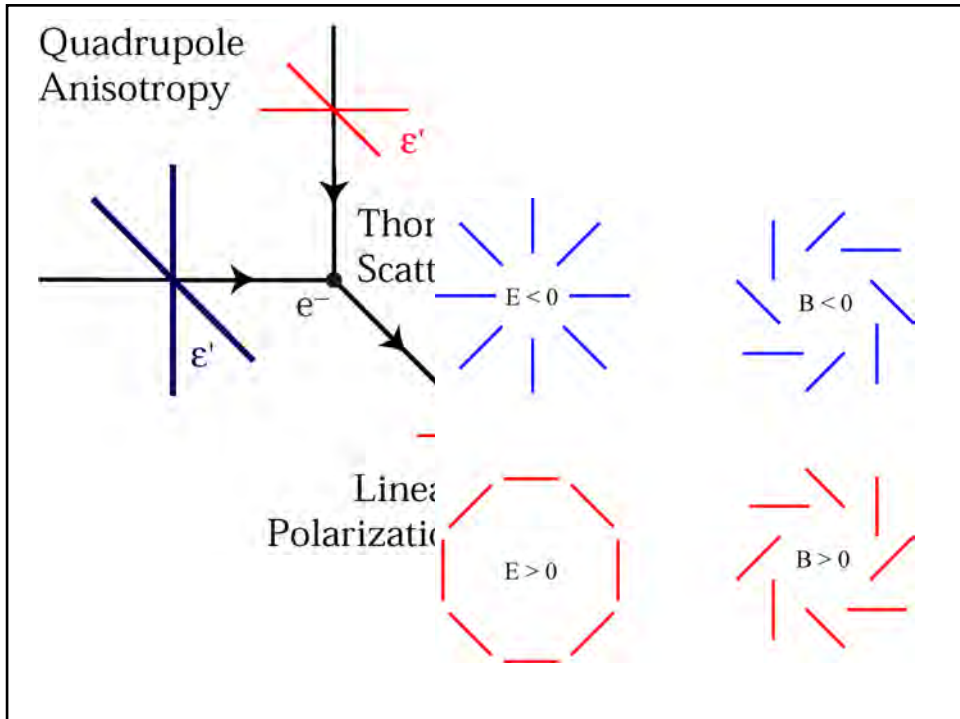
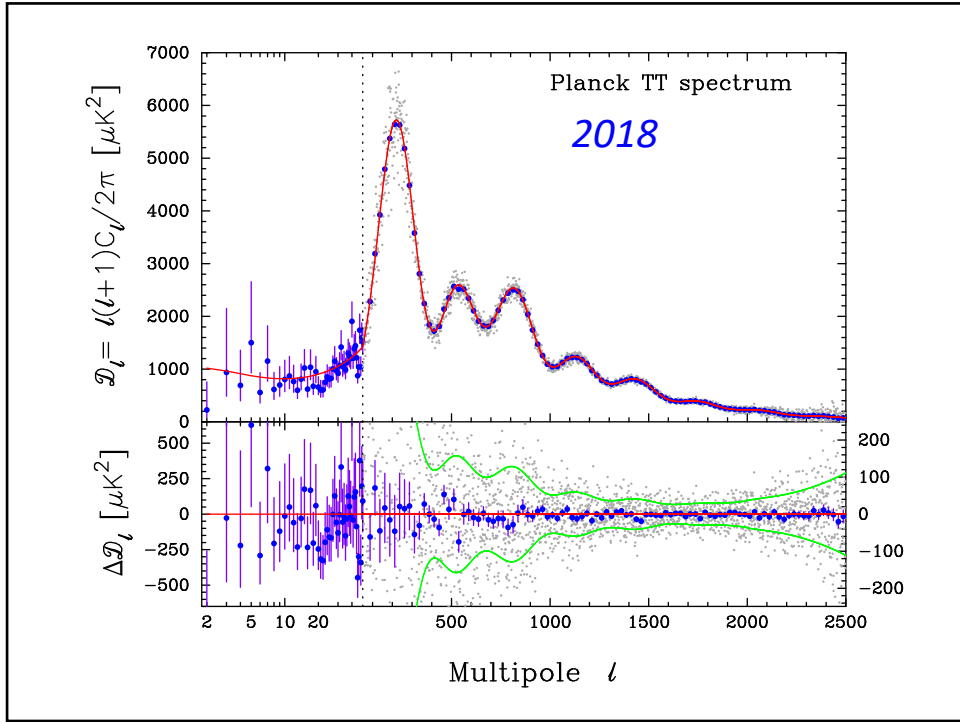


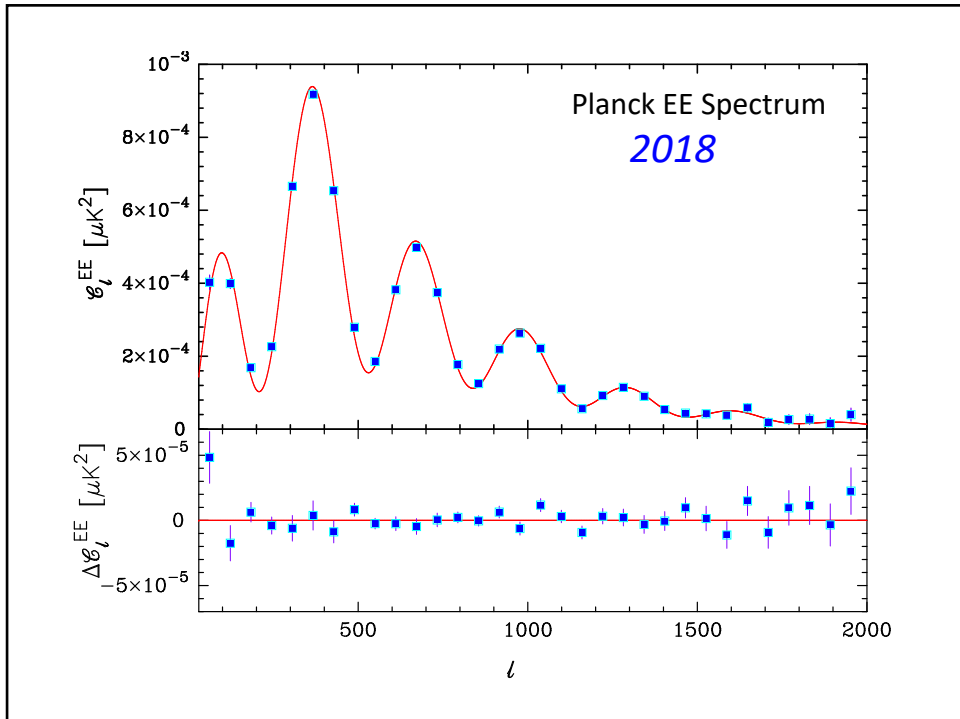
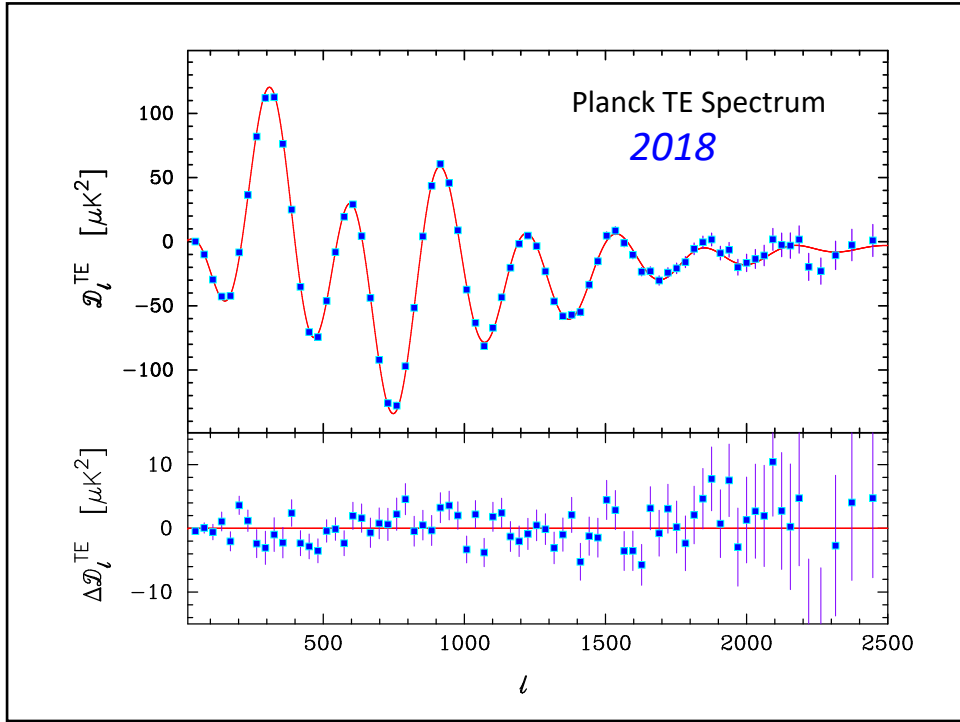
THE CMB AS SEEN BY PLANCK

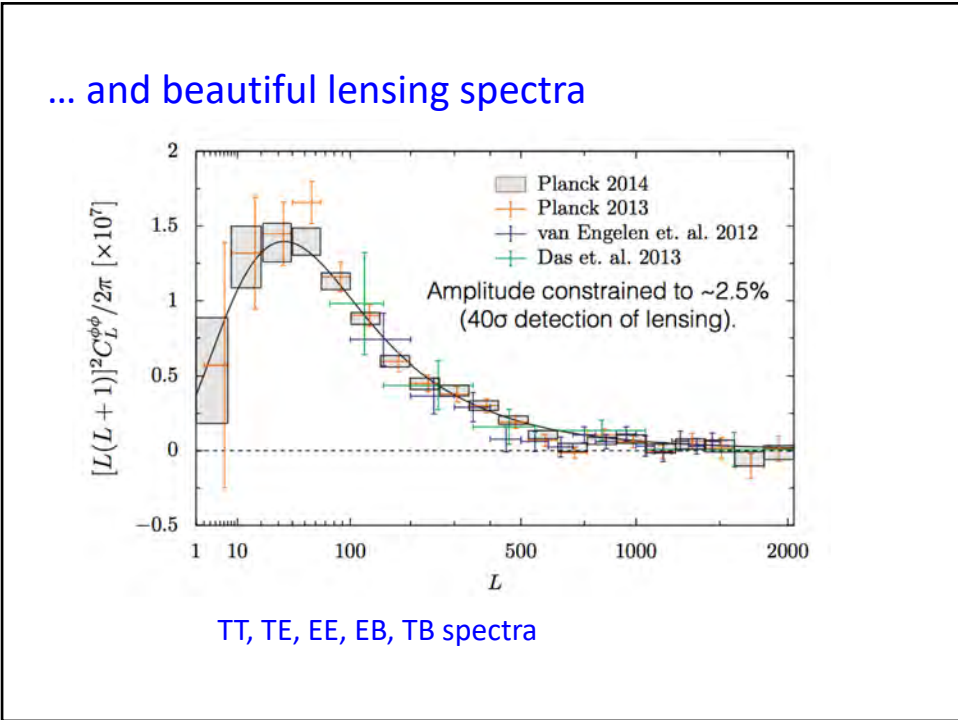
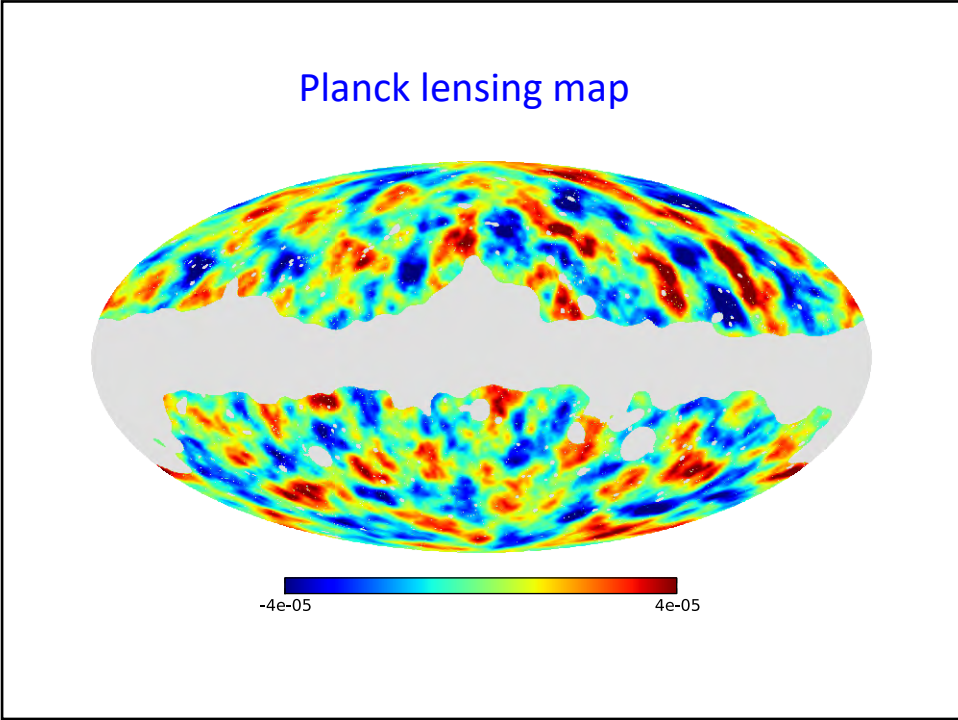












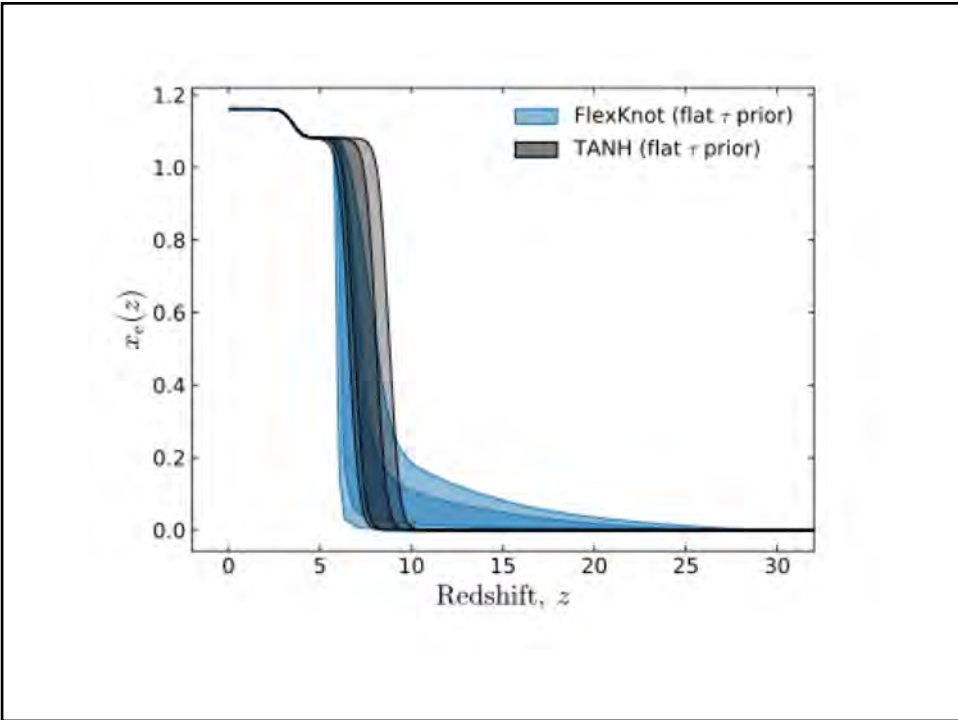
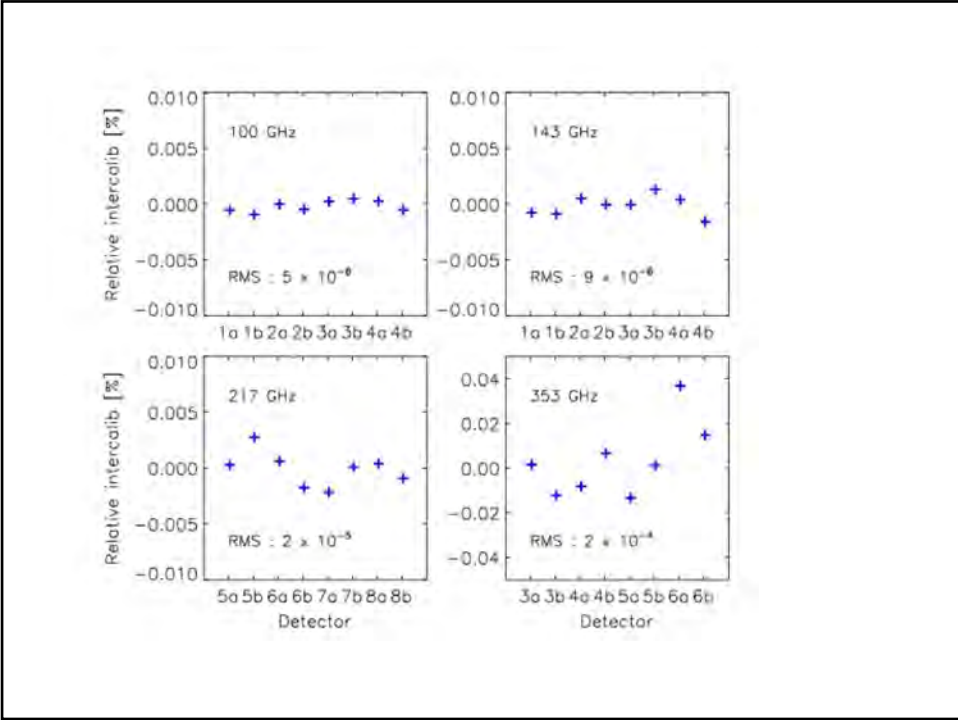
TT, TE, EE, EB, TB spectra

Other science

- Clusters of galaxies
- infrared luminous and radio galaxies
- cosmic infrared background
- synchrotron, free-free and 'anomalous' dust emission
- Galactic dust emission in temperature and polarization
- Maps of CO emission, evidence of 'dark' HI
- Magnetic field structure of the Galaxy
- Cold 'clumps' in our Galaxy
-



1. Baryon density ($\Omega_b h^2$)
2. Cold dark matter density ($\Omega_c h^2$)
3. Angular scale of acoustic peaks (θ)
4. Amplitude of fluctuations (A_s)
5. Spectral index of fluctuations (n_s)
6. Reionization optical depth (τ)



BASE Λ CDM MODEL

Parameter	TT	TT,TE,EE+lensing
$\Omega_b h^2$	0.02212 ± 0.00022	0.02237 ± 0.00015
$\Omega_c h^2$	0.1206 ± 0.0021	0.1200 ± 0.0012
$100\theta_*$	1.04077 ± 0.00047	1.04092 ± 0.00031
τ	0.0522 ± 0.008	0.0544 ± 0.0073
n_s	0.9626 ± 0.0057	0.9649 ± 0.0042
H_0	66.88 ± 0.92	67.36 ± 0.54
Ω_m	0.321 ± 0.013	0.3153 ± 0.00073
σ_8	0.8118 ± 0.0089	0.8111 ± 0.0060
z_{re}	7.50 ± 0.82	7.67 ± 0.73

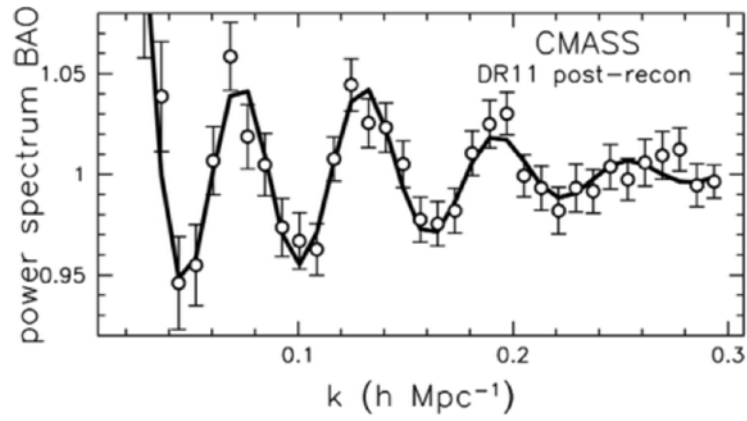
...and so cosmology is done!

Planck 2013:

- good agreement with Planck lensing
- consistent with BAO
- $\sim 2\sigma$ tension with Ia SNe
- $\sim 2.5\sigma$ tension with H_0 **XX 3.8 σ AGR etal**
- tension with measures of σ_8 including:
 - weak lensing ?
 - cluster counts ?
 - redshift space distortions

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

Baryon Acoustic Oscillations (BAO)



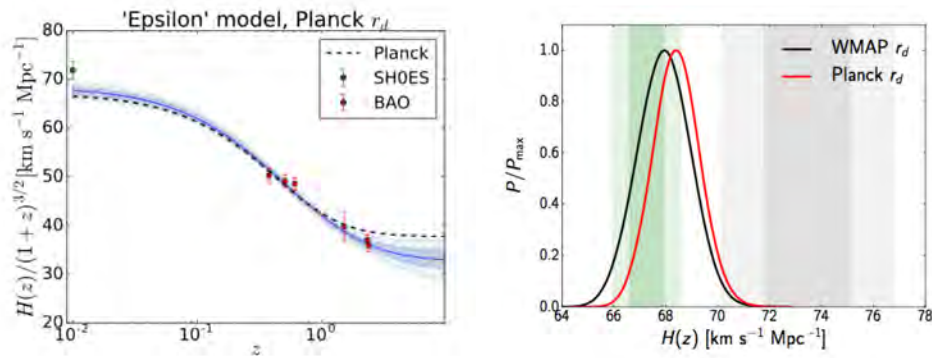
Forward distance ladder Riess et al

$$H_0 = 73.52 \pm 1.62 \text{ km s}^{-1} \text{ Mpc}^{-1}$$



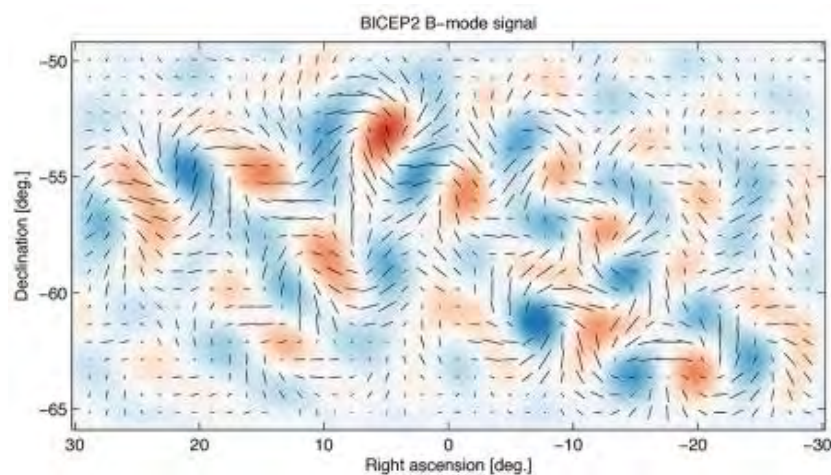
Inverse distance ladder

Lemos et al arXiv:1806.06781



$$H^2(z) = H_{\text{fid}}^2 [A(1+z)^3 + B + Cz + D(1+z)^\epsilon],$$

Planck and BICEP



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30 January 2015 Last updated at 20:54

Cosmic inflation: New study says BICEP claim was wrong

By Jonathan Amos
Science correspondent, BBC News



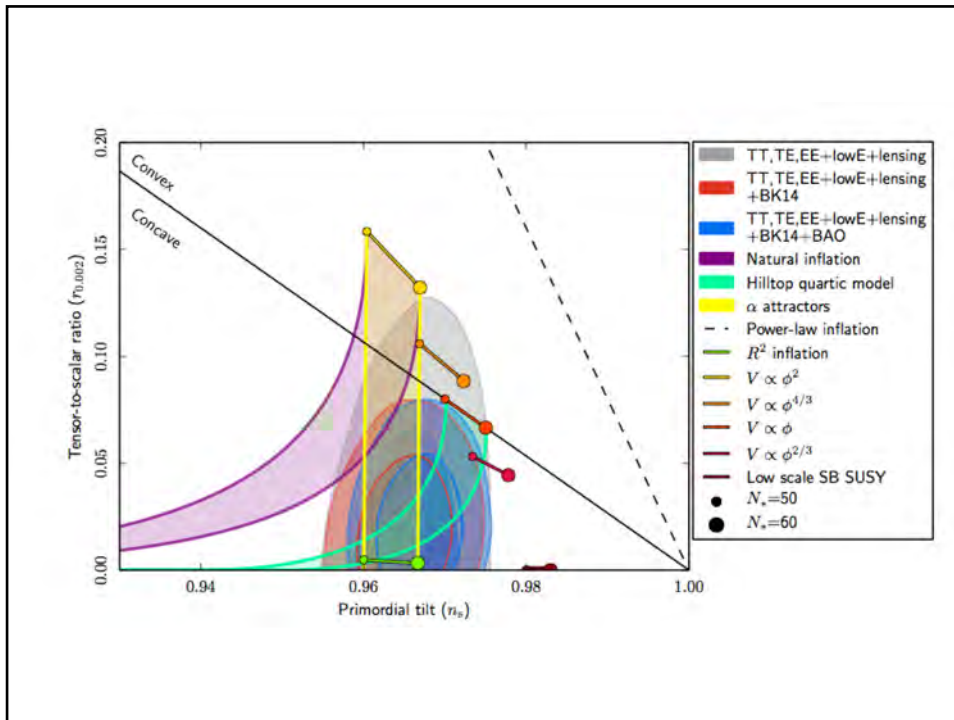
STEPHEN RICHTER, HARVARD UNIVERSITY

The measurements were taken using the BICEP2 instrument at the South Pole Telescope facility

Scientists who claimed last year to have found a pattern in the sky left by the super-rapid expansion of space just fractions of a second [Related Stories](#)

In fact there are many, many, models of inflation..... @ Paul Shellard

- | | |
|-----------------------------------------|---------------------------------------|
| S-dimensional assisted inflation | dual inflation |
| assisted brane inflation | dynamical inflation |
| anomoly-induced inflation | dynamical SUSY inflation |
| assisted inflation | eternal inflation |
| assisted chaotic inflation | extended inflation |
| boundary inflation | extended open inflation |
| brane inflation | extended warm inflation |
| brane-assisted inflation | extra dimensional inflation |
| brane gas inflation | F-term inflation |
| brane-antibrane inflation | F-term hybrid inflation |
| braneworld inflation | false-vacuum inflation |
| Brans-Dicke chaotic inflation | false-vacuum chaotic inflation |
| Brans-Dicke inflation | fast-roll inflation |
| bulky brane inflation | first-order inflation |
| chaotic inflation | gauged inflation |
| chaotic hybrid inflation | Hagedorn inflation |
| chaotic new inflation | higher-curvature inflation |
| D-brane inflation | hybrid inflation |
| D-term inflation | hyperextended inflation |
| dilaton-driven inflation | induced gravity inflation |
| dilaton-driven brane inflation | intermediate inflation |
| double inflation | inverted hybrid inflation |
| double D-term inflation | isocurvature inflation..... |



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Observations

A Cosmic Controversy

A *Scientific American* article about the theory of inflation prompted a reply from a group of 33 physicists, along with a response from the article's authors

What goes the universe

THE LATEST ASTROPHYSICAL MEASUREMENTS, COMBINED WITH THEORETICAL PROBLEMS, CAST DOUBT ON THE LONG-CHERISHED INFLATIONARY THEORY OF THE EARLY COSMOS AND SUGGEST WE NEED NEW IDEAS

By Anna Ijjas, Paul J. Steinhardt and Abraham Loeb

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Single field inflation:

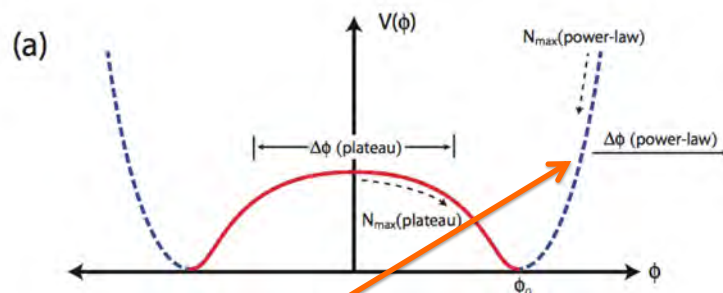
$$V(\phi) = \lambda\phi^\alpha$$

$$1-n_s = (\alpha + 2)/N, \quad r = 4\alpha/N$$

$$\text{For } n_s = 0.965, N \approx 60, \quad \alpha \approx 2.2, r \approx 0.15$$

$$\epsilon = (m_{\text{pl}}^2/16\pi) (V'/V)^2, \quad \eta = (m_{\text{pl}}^2/8\pi)(V''/V)$$

$$n_s = 1 - 6\epsilon + 2\eta, \quad r = 16\epsilon, \quad n_t = -2\epsilon/N$$

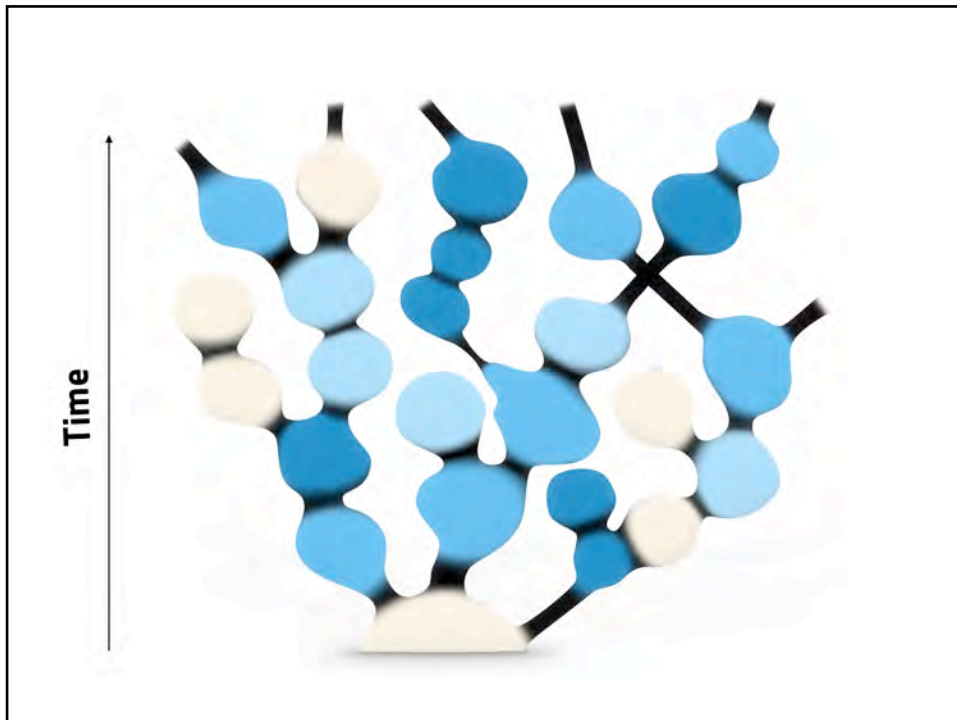


Generically would expect

$$1 - n_s \sim 1/N$$

$$r \sim 1/N$$

otherwise we need to 'fine-tune' the potential



Are Ijjas, Steinhardt and Loeb right?

- Yes! Inflation is an incomplete theory
Initial conditions,
Measure problem,
Infinities
.....
- No! This does not mean that inflation is 'in trouble'.
It just means that there are many, many open problems in cosmology,
and we should acknowledge this when we teach inflation.

- **Λ CDM is not Fake News!**
- **Are there alternatives to inflation?**
- **What sets the initial conditions for inflation?**
- **Multiverse and measures?**
- **Are there signatures from a ‘pre-big bang phase?’**

‘This is not the end. It is not even the beginning of the end. But perhaps, the end of the beginning.’ Winston Churchill

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.

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