# What can we learn from CMB polarisation ?

That we can't learn from anisotropies alone...

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# Anisotropies : the success !!

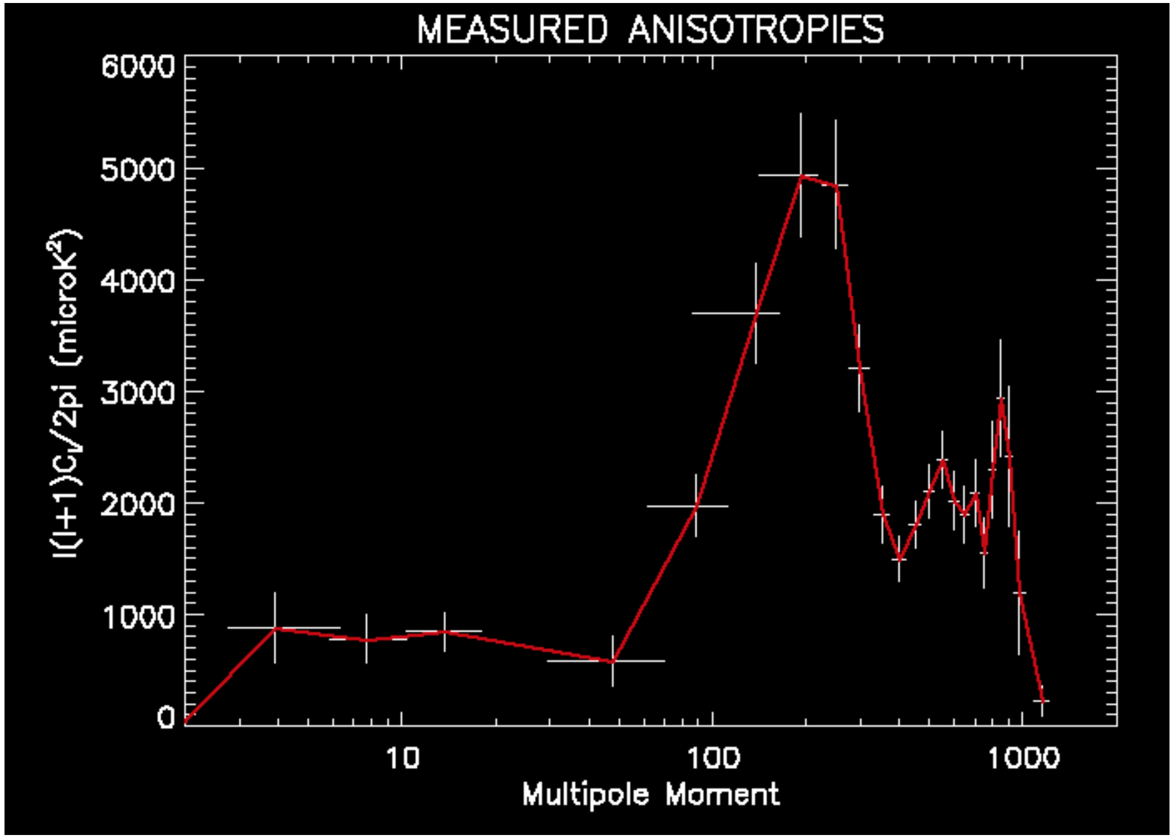
Constrains on
Cosmological
Parameters
(previous talks)
$\Omega_b$, $\Lambda$, $n_s$, ...

$\Omega \sim 1$

Peaks observed

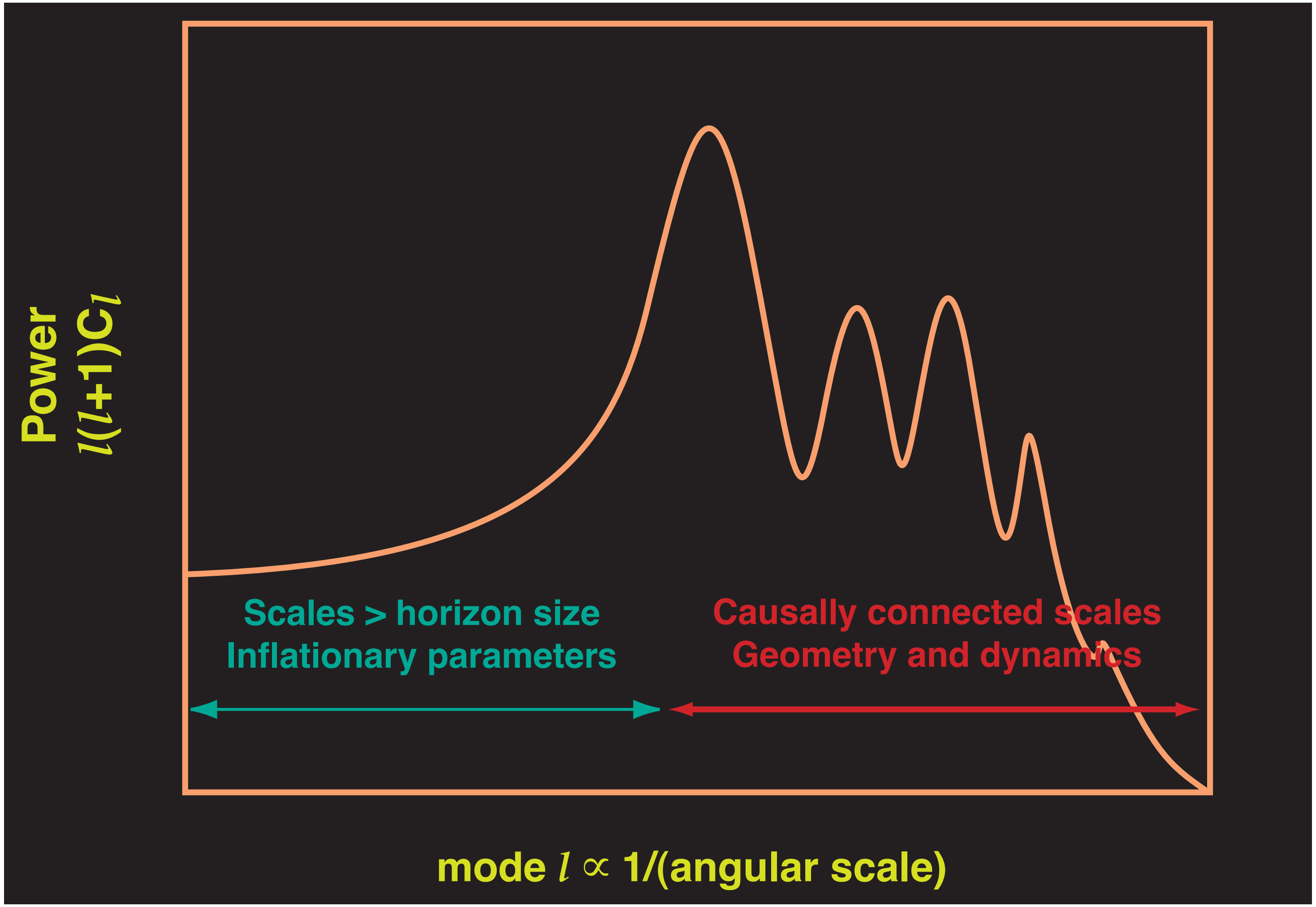
gaussianity

Inflation really happened !




Data binning from Wang et al., astro-ph/0105091

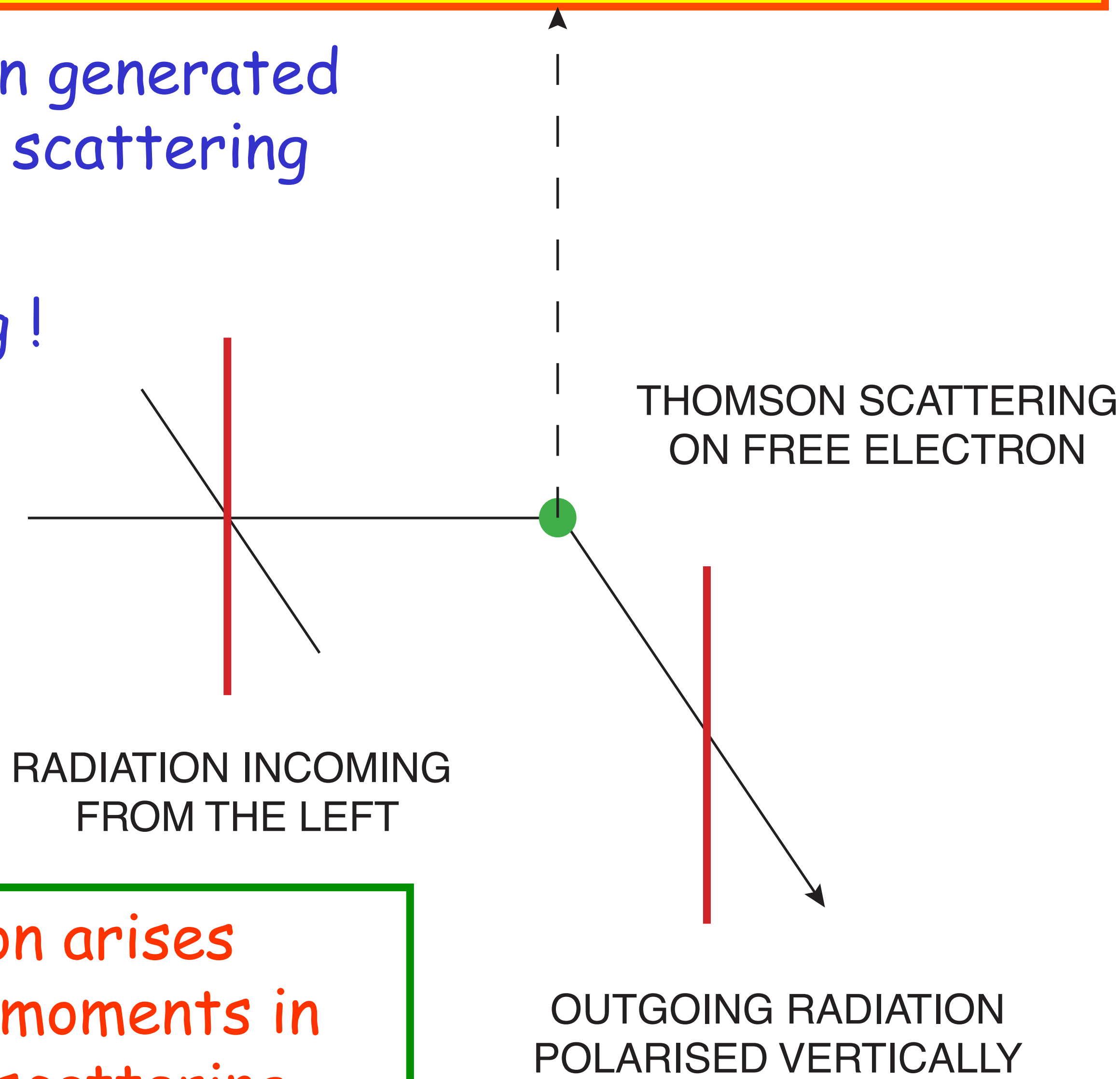
# What information from CMB anisotropies



# Generation of CMB polarization

- Linear polarization generated through Thomson scattering

- At last scattering !

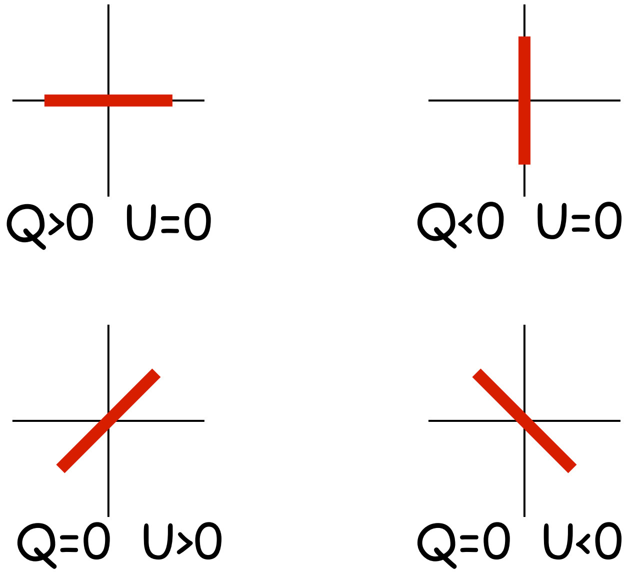



- Linear polarization arises from quadrupole moments in radiation at last scattering

# Description of polarization

- Linear polarization fully described by Q and U Stokes parameters

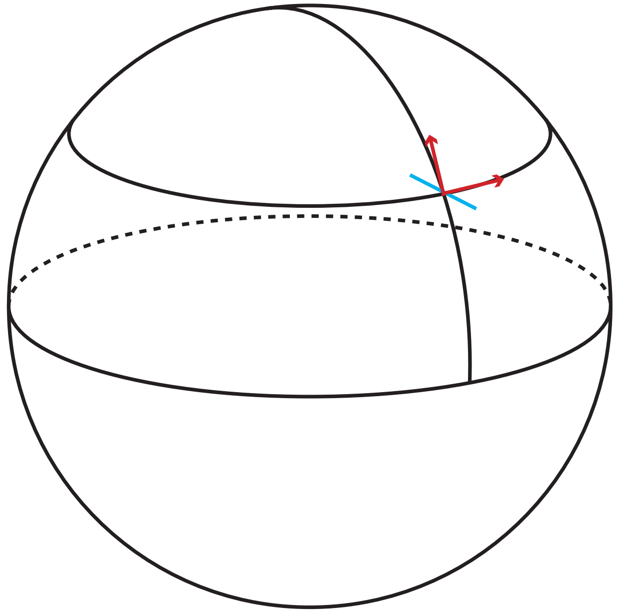
  - $Q = I_0 - I_{90} = |E_x|^2 - |E_y|^2$
  - $U = I_{45} - I_{135} = E_x^* E_y$




  - Q and U are not invariant under a rotation of the coordinates by an angle $\alpha$

# Description of polarization (cont 'd)

- Particularly problematic on the sphere !!



- $Q+iU \longrightarrow e^{-2i\alpha}(Q+iU)$ and $Q-iU \longrightarrow e^{+2i\alpha}(Q-iU)$
- spin ±2 quantities can be expanded in terms of ${}_sY_{lm}(\theta,\varphi)$

# Polarization spectra

- Start from Q and U in spherical coordinate system $(e_\theta, e_\varphi)$

notations from Seljak and Zaldarriaga

- It is useful to expand
  - $(Q+iU)(n) = \Sigma\, a_{2,lm}\; {}_2Y_{lm}(n)$
  - $(Q-iU)(n) = \Sigma\, a_{-2,lm}\; {}_{-2}Y_{lm}(n)$

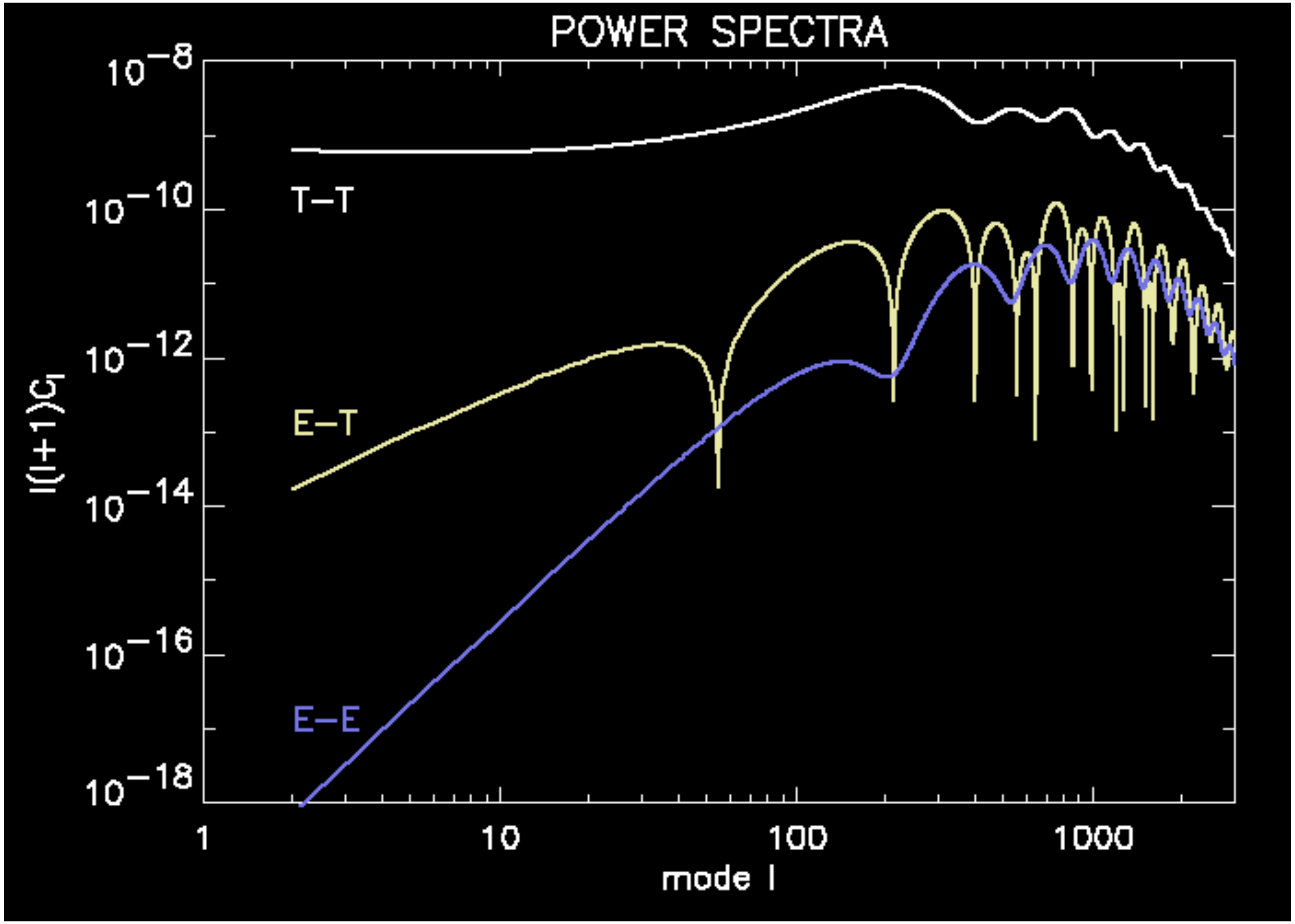
- Define
  - $a_{E,lm} = -(a_{2,lm} + a_{-2,lm})/2$
  - $a_{B,lm} = i\,(a_{2,lm} - a_{-2,lm})/2$

- and
  - $E = \Sigma\, a_{E,lm}\, Y_{lm}(n)$ even parity
  - $B = \Sigma\, a_{B,lm}\, Y_{lm}(n)$ odd parity

# Polarization spectra : exemple

$H_0 = 65$
$\Omega_B = .05$
$\Omega_{tot} = 1$
$\Omega_\Lambda = .65$
$n_s = 1$

scalar modes only

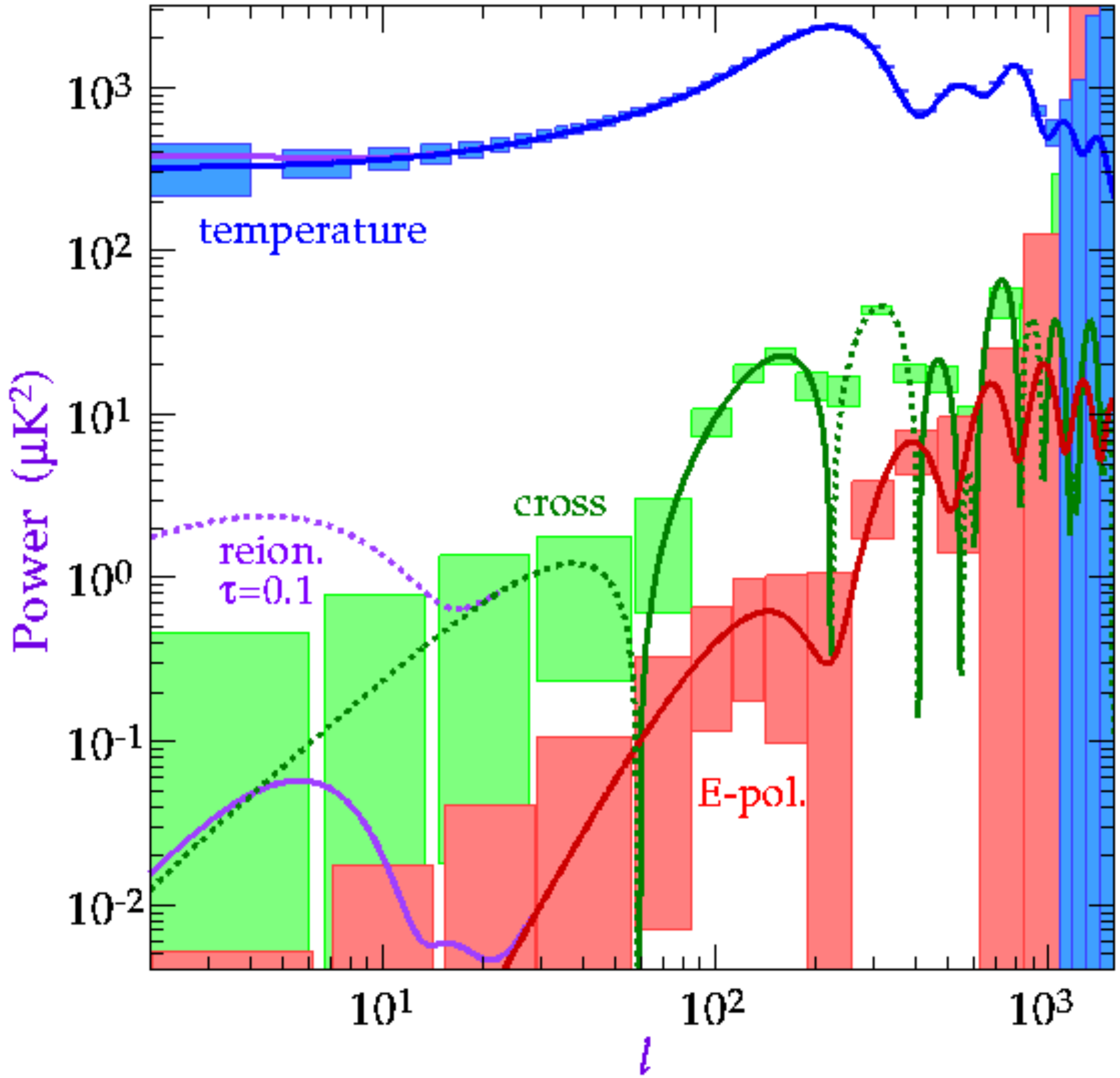


# Comments

- The amplitude of polarisation signals is small
- Very low power especially on large scales
- Neat peak structure observable in E-E, in quadrature with T-T

- Cross-check for the basic acoustic oscillation picture

# Predictions for MAP




From Hu & White

Constraining reionization with polarization

Cross-check for the basic acoustic oscillation picture …

Constraining reionization …

# Constraining Inflation

# Generation of CMB anisotropies

- Initial perturbations are generated at the epoch of INFLATION

- Scalar perturbations (density fluctuations)

  - $P(k) \sim k^{ns}$ primordial spectrum, with $n_s \sim 1$
  - Evolution through gravitational instability resisted by radiation pressure
  - Give rise to temperatures, densities and velocities at last scattering
  - structures at causally connected scales

# Generation of CMB anisotropies (cont'd)

- Tensor perturbations (gravity waves)
  - $P(k) \sim k^{n_t}$ primordial spectrum (with $n_t \sim 0$ ?)
  - Decay as they enter the horizon because of the damping term (expansion)
  - Negligible power on small scales ($l > 70$ or so)

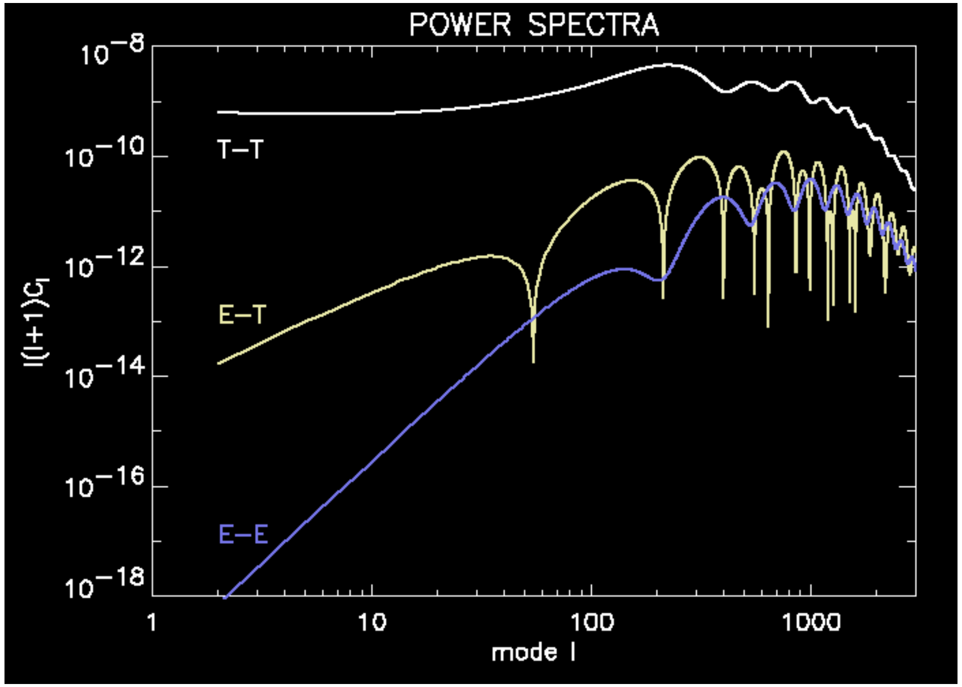
# Inflation

- Several models, described by a potential $V(\phi)$
- In slow-roll approximation 3 main parameters :
  $\varepsilon$, $\eta$ and r

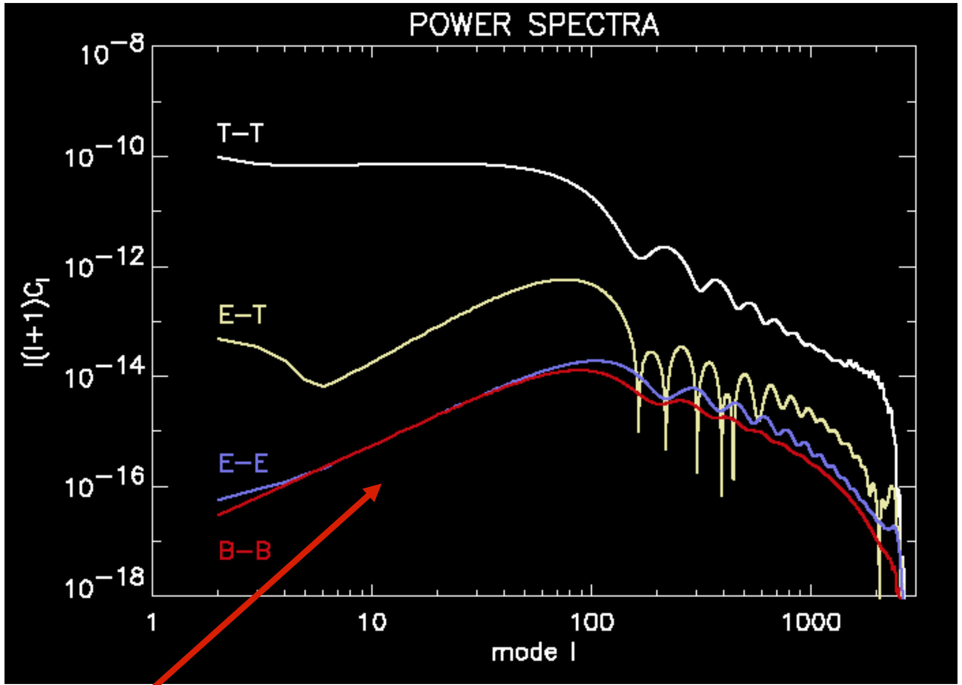
  - $\varepsilon = (m_{pl}^2/16\pi) . (V'/V)^2 \quad \sim 0.01 \quad \ll \quad 1$
  - $\eta = (m_{pl}^2/16\pi) . [2V''/V - (V'/V)^2] \quad \ll \quad 1$
  - $r = T/S$ ratio of tensor to scalar quadrupole
  - $n_s = 1-4\varepsilon+2\eta \qquad n_t = -2\varepsilon$

# Typical predictions

$H_0 = 65,\ \Omega_B = .05,\ \Omega_{tot} = 1,\ \Omega_\Lambda = .65,\ n_s = 1,\ n_t=0,\ T/S = 0.15$




Scalar modes

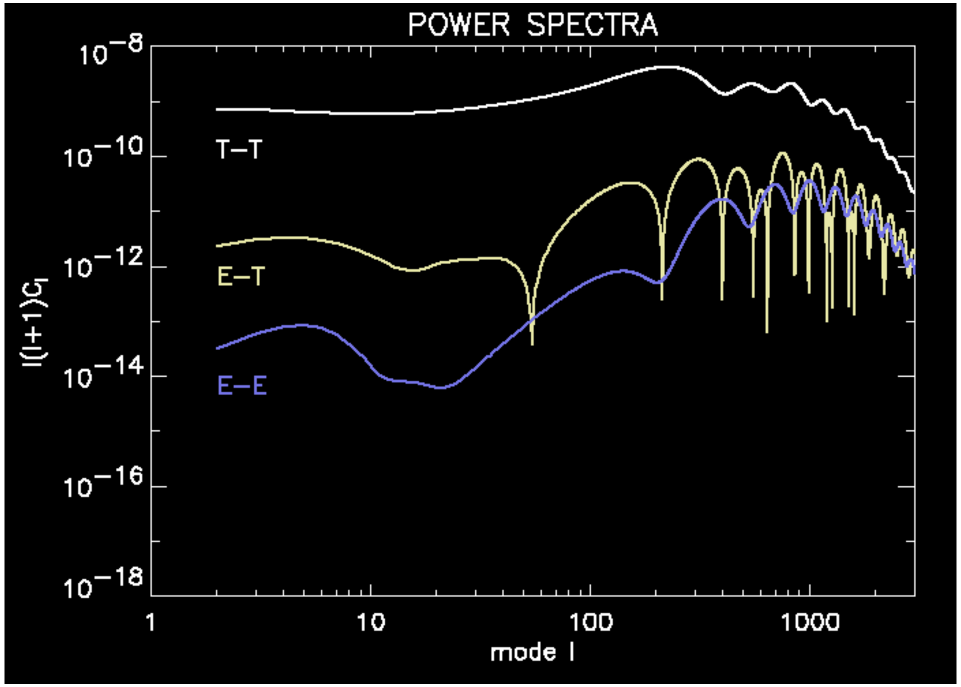



Tensor modes

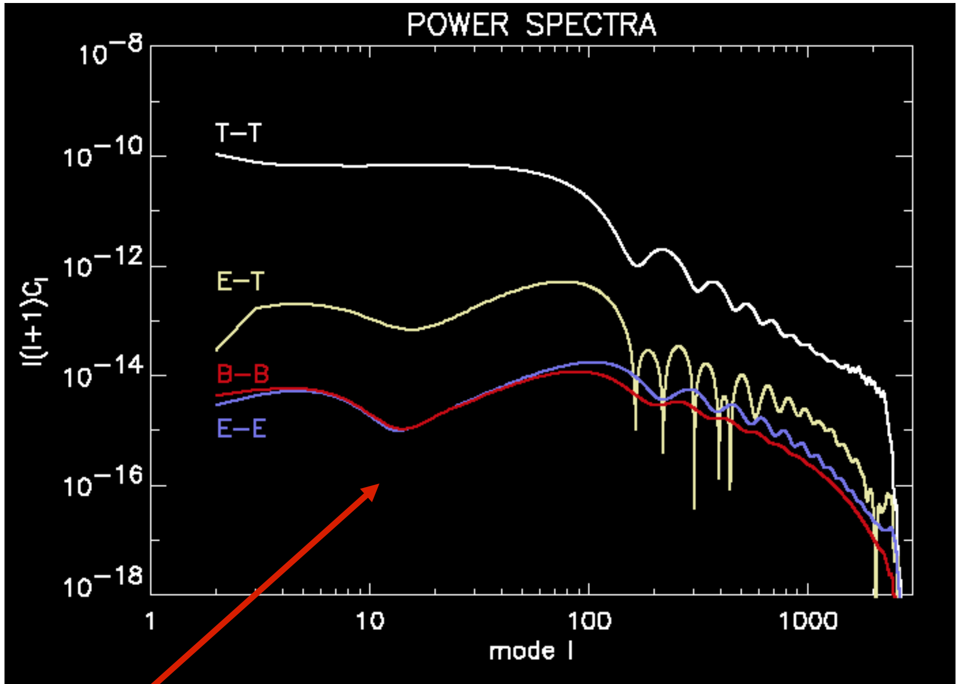
Non-vanishing B contribution
only from tensor modes

# With reionization

$H_0 = 65$, $\Omega_B = .05$, $\Omega_{tot} = 1$, $\Omega_\Lambda = .65$, $n_s = 1$, $n_t=0$, $T/S = 0.15$, $\tau=0.1$




Scalar modes




Tensor modes

Non-vanishing B contribution
only from tensor modes

# Inflation : observables

| | from anisotropies | from polarization |
|---|---|---|
| - $n_s = 1-4\varepsilon+2\eta$ | small error<br>limited by noise | small error<br>limited by noise |
| - $n_t = -2\varepsilon$ | not measurable<br>limited by cosmic variance | limited by noise<br>and cosmic variance |
| - $r = T/S$ | error >~ r<br>limited by cosmic variance | small error<br>limited by noise<br>and cosmic variance |

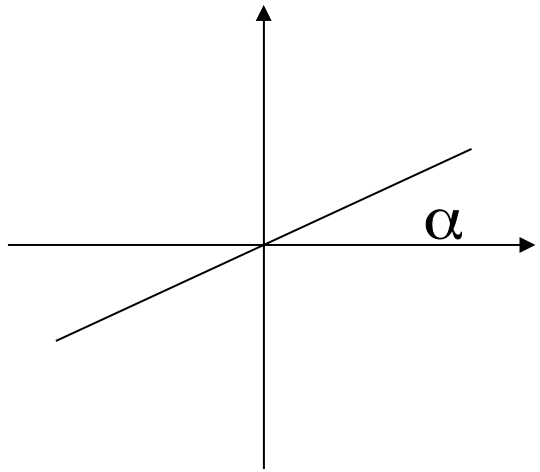
# Measuring CMB polarization

# Problems for measuring polarization

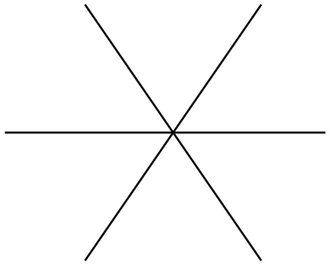
- Sensitivity levels
  - At least an order of magnitude smaller than anisotropies !
- Foregrounds
  - Foregrounds contribute E and B modes
- Incomplete sky coverage (at least galaxy cutoff)
  - Separation of E and B not so easy for arbitrary coverage
- Several measurements needed in same pixel
  - I, Q and U

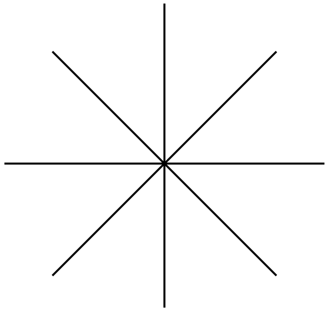
# Detector measurement

- With one detector sensitive to one linear polarization :
  $I_\alpha \sim I + Q\cos 2\alpha + U\sin 2\alpha + \text{noise}$




- Need combining at least 3 measurements at same point to get I, Q, and U



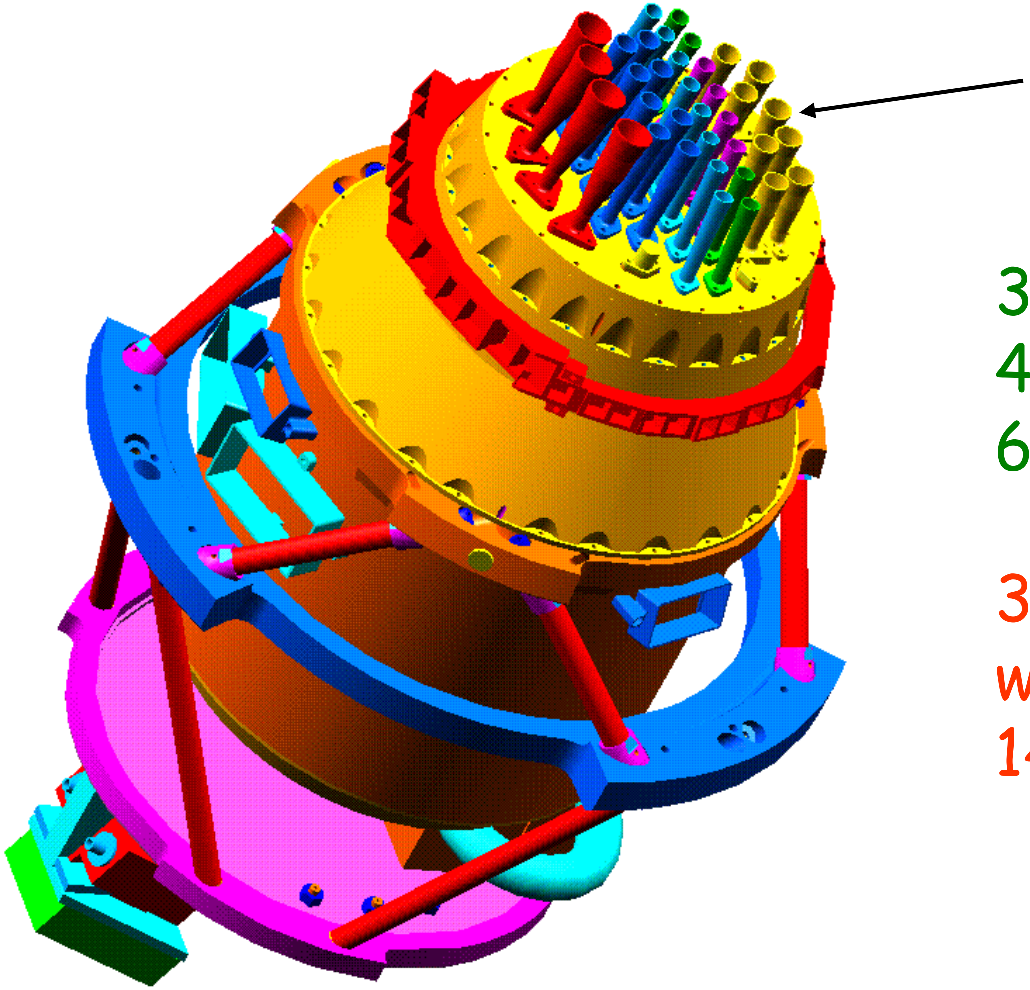


Optimized Configurations

Couchot et al.

# The Planck HFI polarisation measurement concept

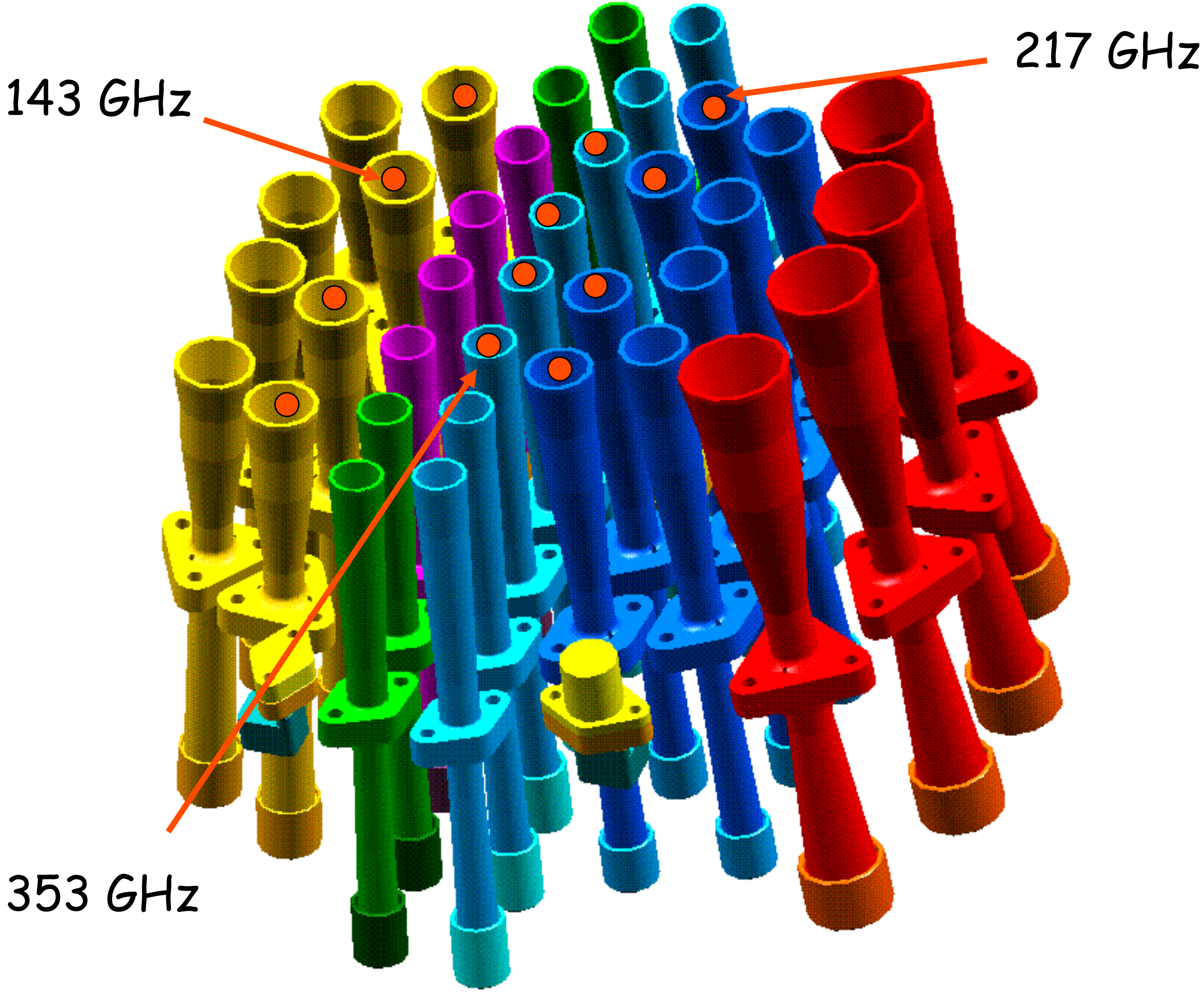
# The Planck HFI



Focal plane

36 feed horns
48 detectors
6 frequency channels

3 polarised channels
with 4 PSB pairs at
143, 217 and 353 GHz

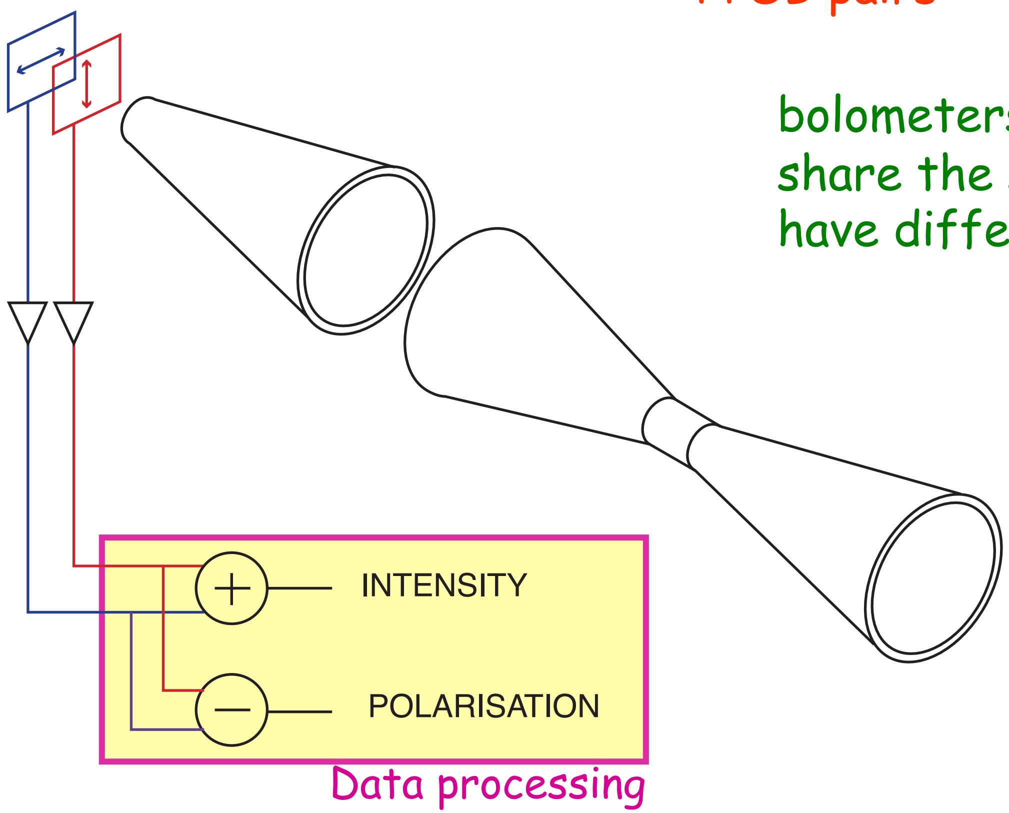

143 GHz
217 GHz
353 GHz

# Polarisation Measurement with the Planck HFI

- Polarisation sensitive bolometers (PSB)
  - 143 GHz, 217 GHz, 353 GHz

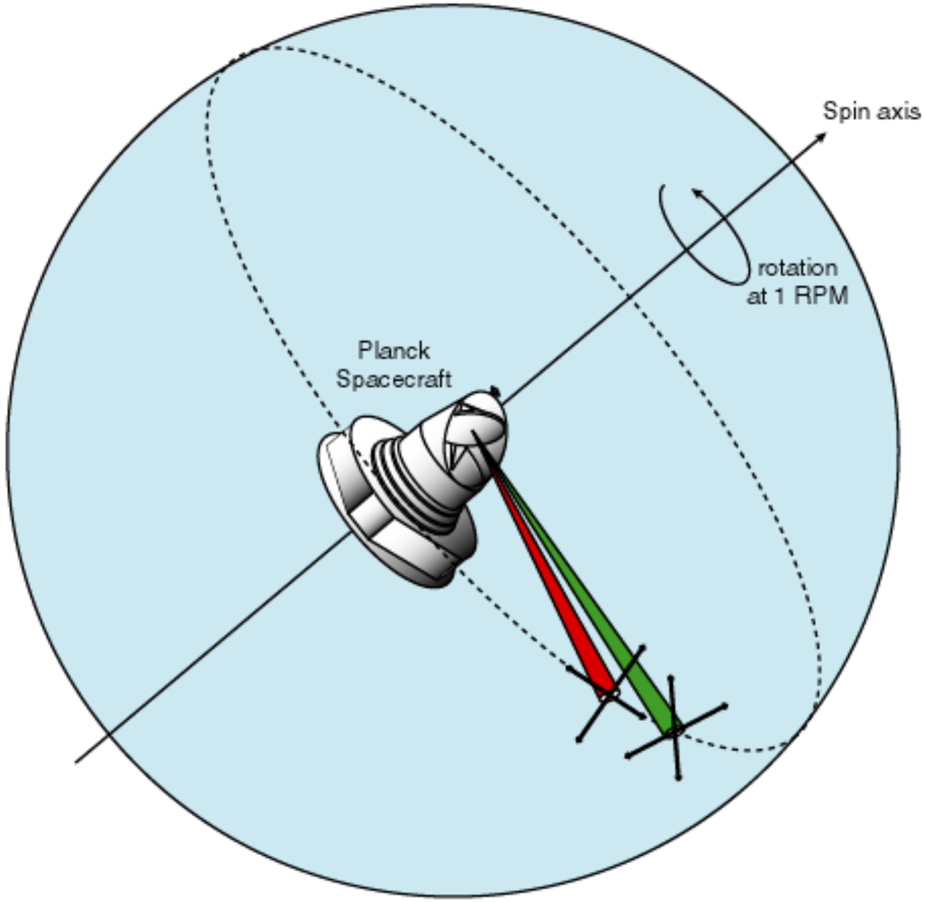
4 unpolarised bolometers

4 PSB pairs




bolometers from a PSB pair share the same optics but have different readouts.

# The Planck observing strategy and polarisation timelines




A given PSB pair is used to produce directly a polarisation signal after relative calibration :

$$U_{fp} = s_1 - s_2$$

or

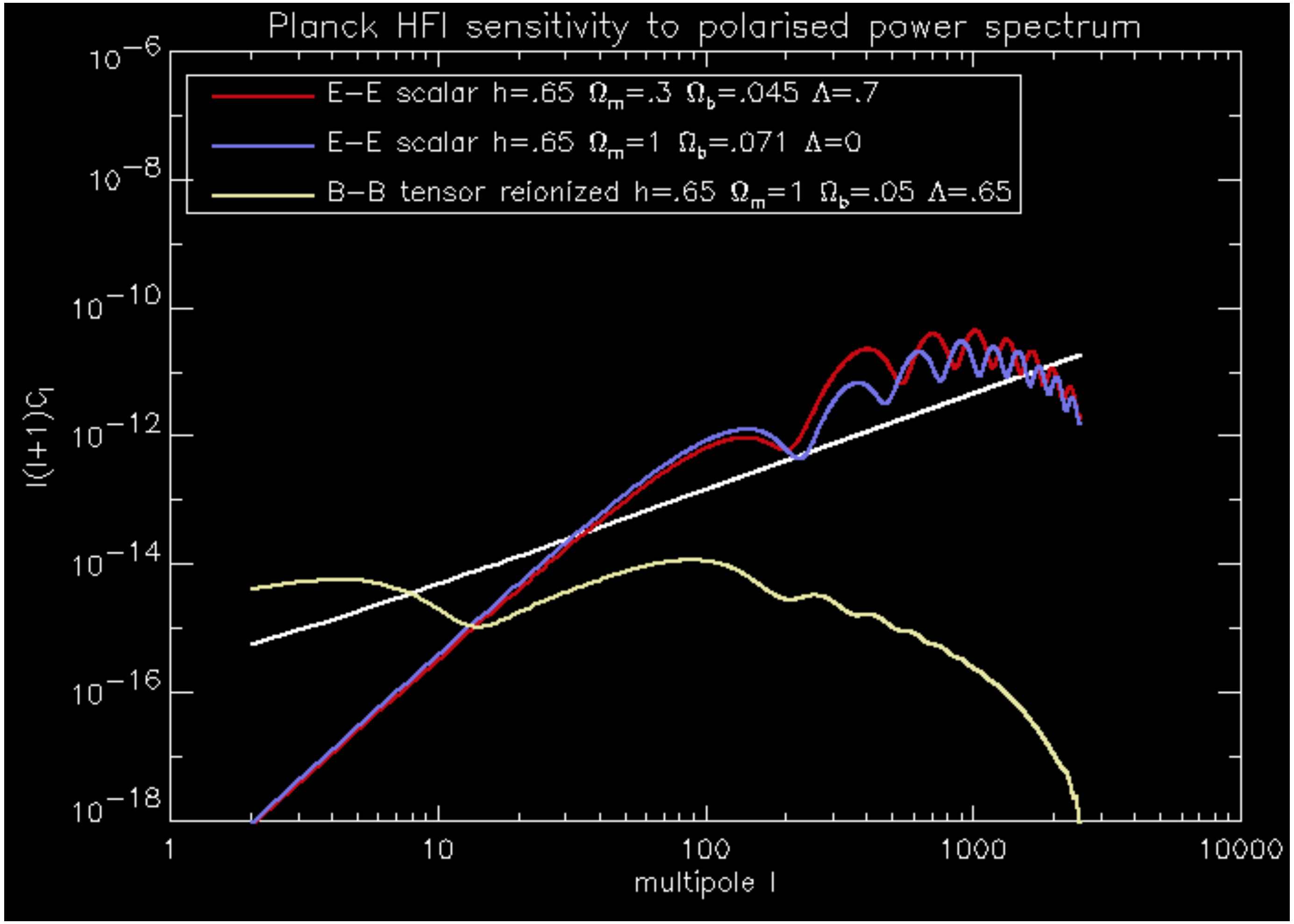
$$Q_{fp} = s_1 - s_2$$

# Final Planck HFI expected sensitivity

# HFI polarisation sensitivity (current best guess)

| Channel | 143 GHz | 217 GHz | 343 GHz |
|---|---|---|---|
| Beam size | 7' | 5' | 5' |
| ΔI (per beam size pixel) | 6,1 μK | 13 μK | 39 μK |
| ΔQ, ΔU (per beam size pixel) | 12 μK | 25 μK | 78 μK |

# HFI sensitivity to polarisation power spectra



# Conclusion

- It is worth measuring CMB polarization
  - Consistency check of basic acoustic oscillations picture
  - Constraining reionization
  - Constraining inflationnary models
- Planck HFI polarisation measurement capability
  - Simple concept with built-in redundancy
  - S/N ~ 1 per 15 ′ pixel on CMB polarisation
  - Good sensitivity to scalar modes
  - Marginal sensitivity to tensor modes