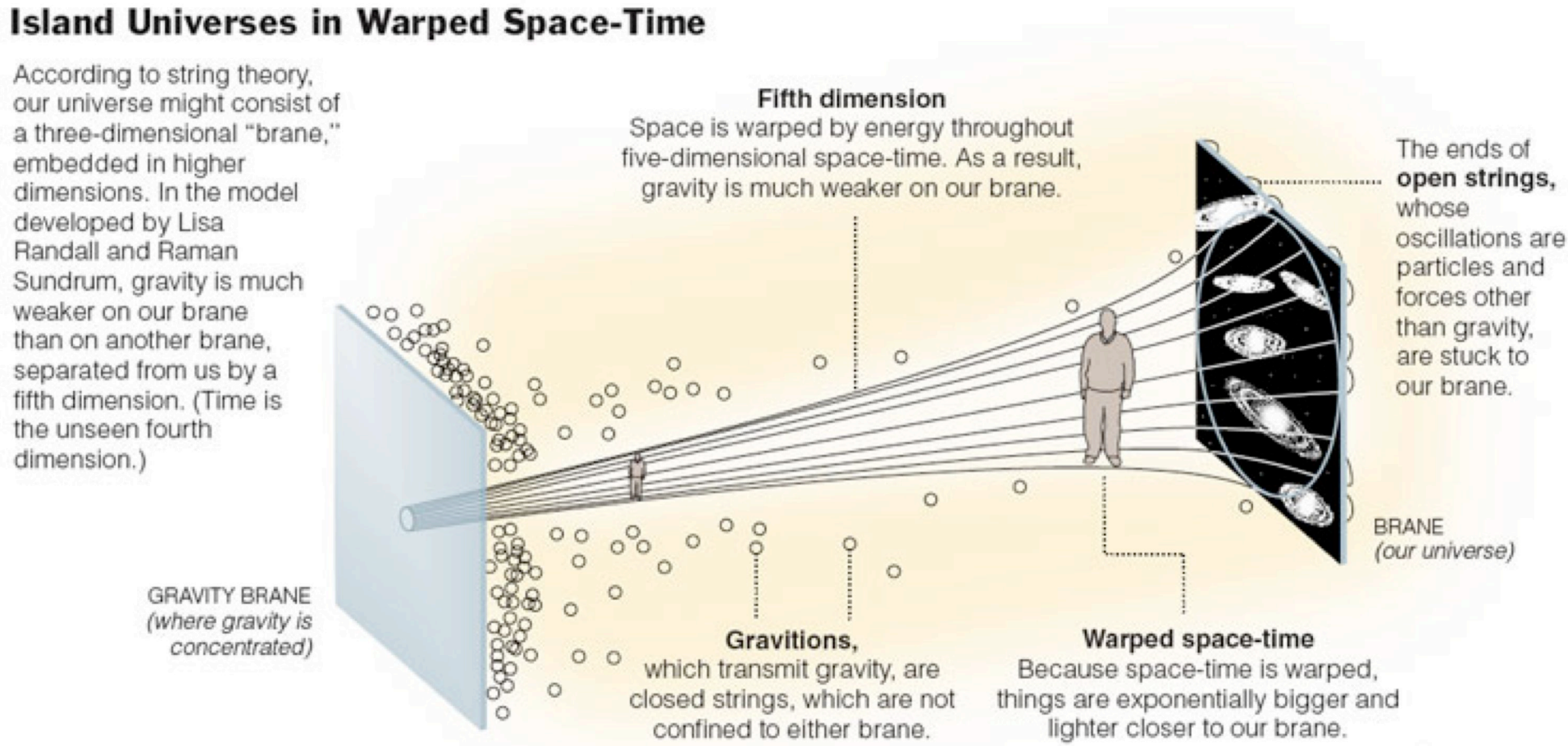
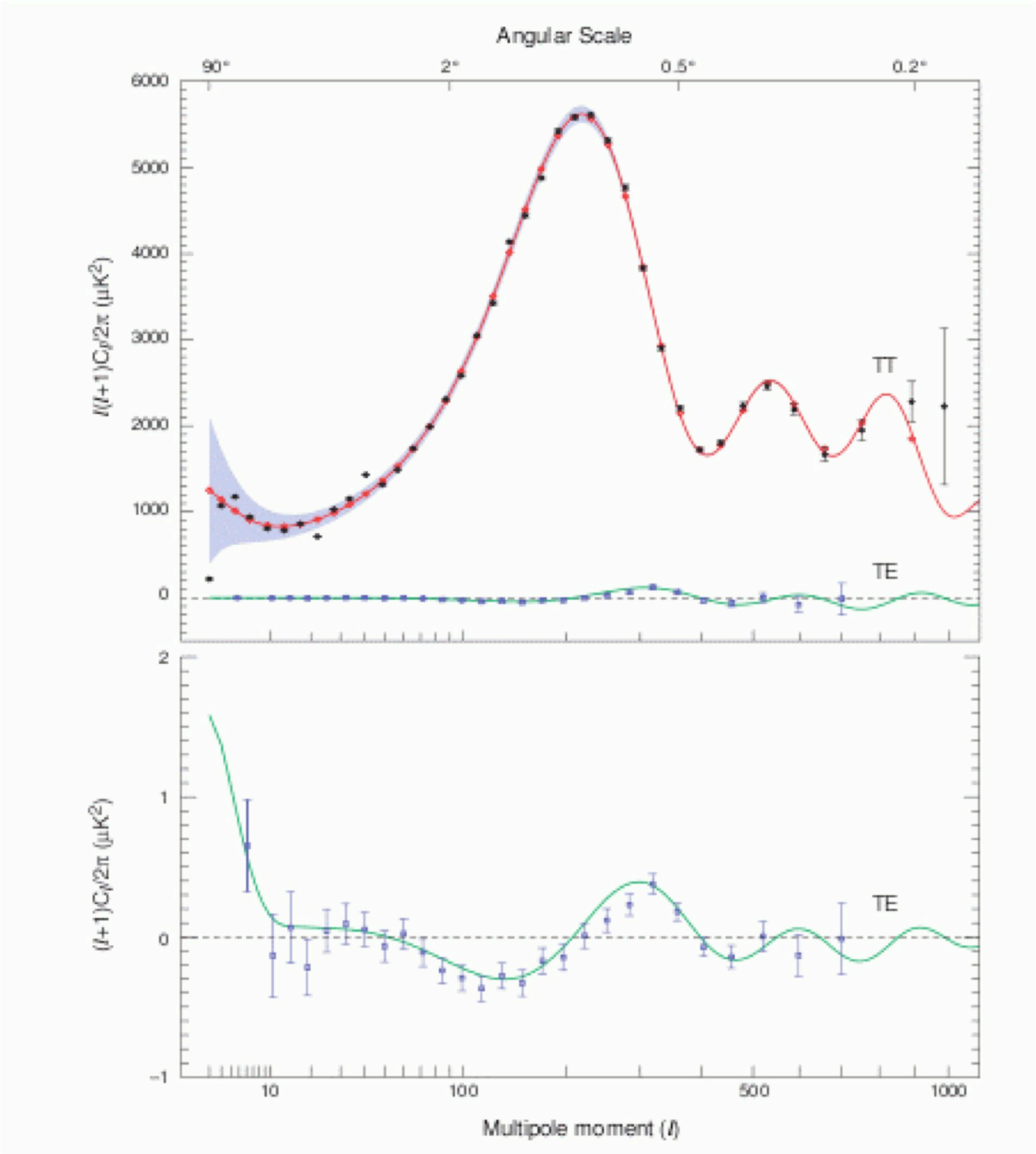
Where are we going in Cosmology?



- **Fundamental Physics and origins:**
  - Inflationary dynamics
  - Origin of fluctuations
  - Before the Big Bang
- **Fundamental Physics and the present Universe:**
  - Nature of dark matter and dark energy
- **Complexity in the Universe:**
  - Formation of non-linear structures, first stars, galaxies, black holes, ...


Angular Scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
l(l+1)Cl/2π (μK2)
TT
TE
2
1
0
−1
(l+1)Cl/2π (μK2)
TE
10
100
500
1000
Multipole moment (l)

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

@ Paul Shellard

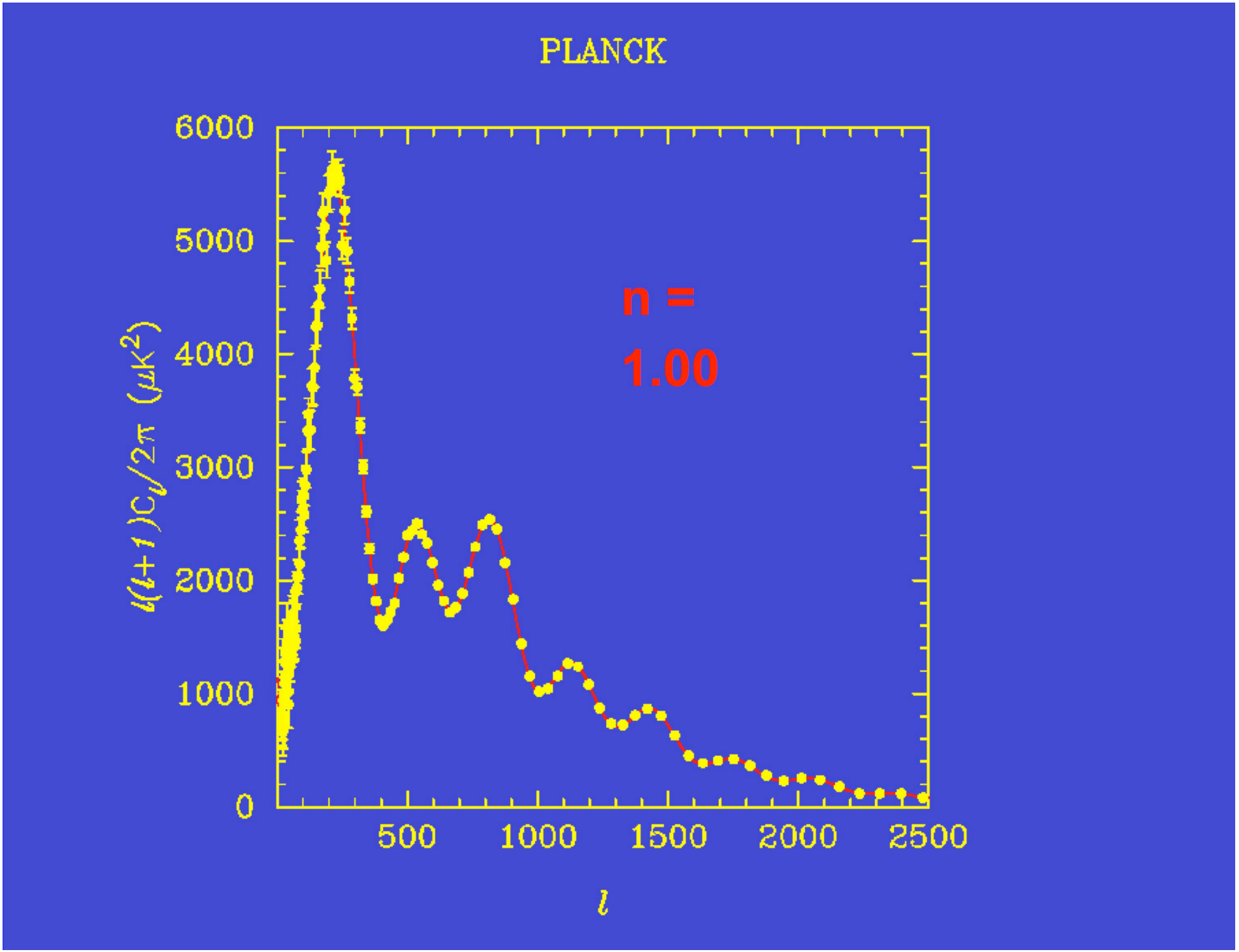
Spergel et al 2006 astro-ph/0603448:

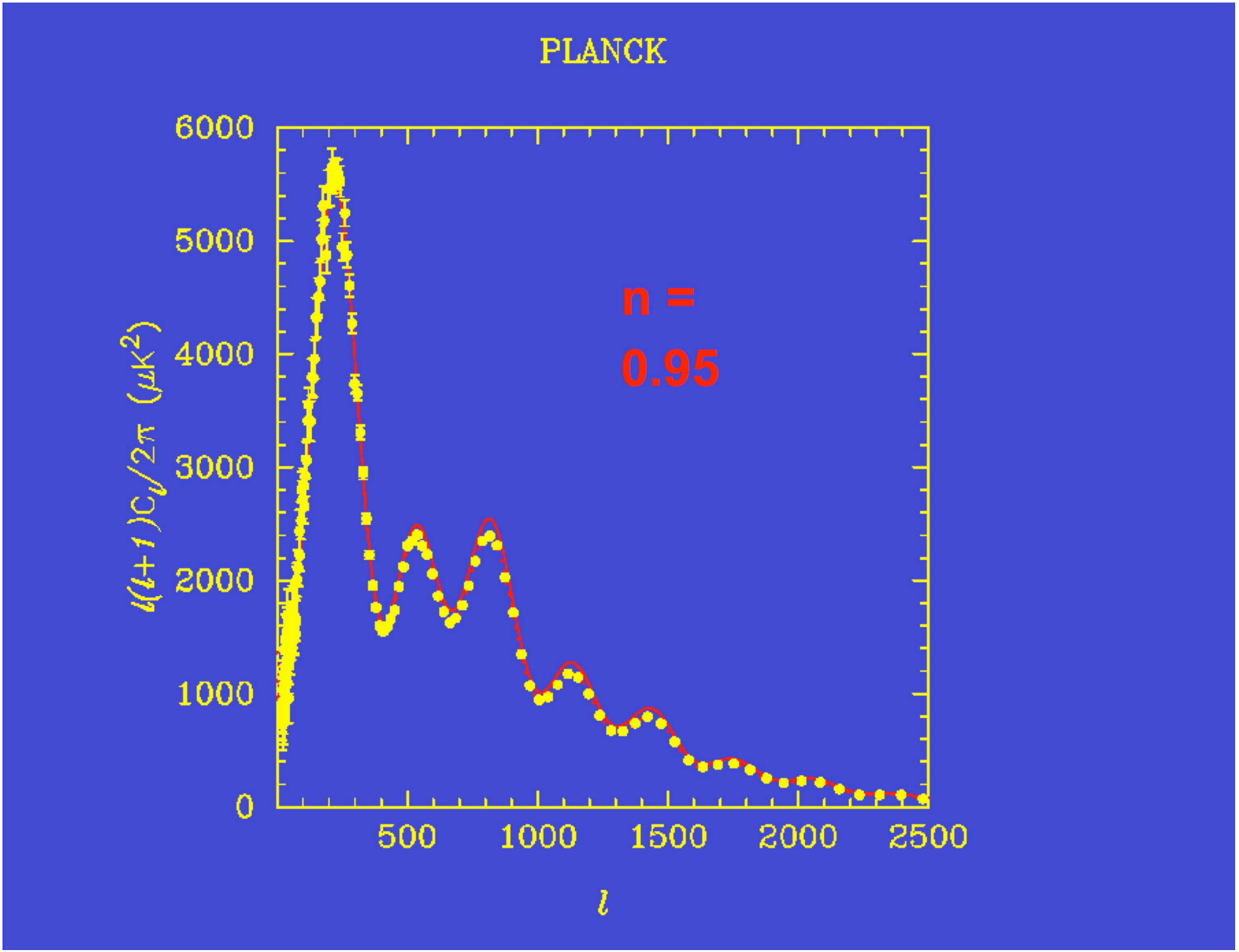
$$n_s = 0.958 \pm 0.016 \quad (2.6\,\sigma)$$

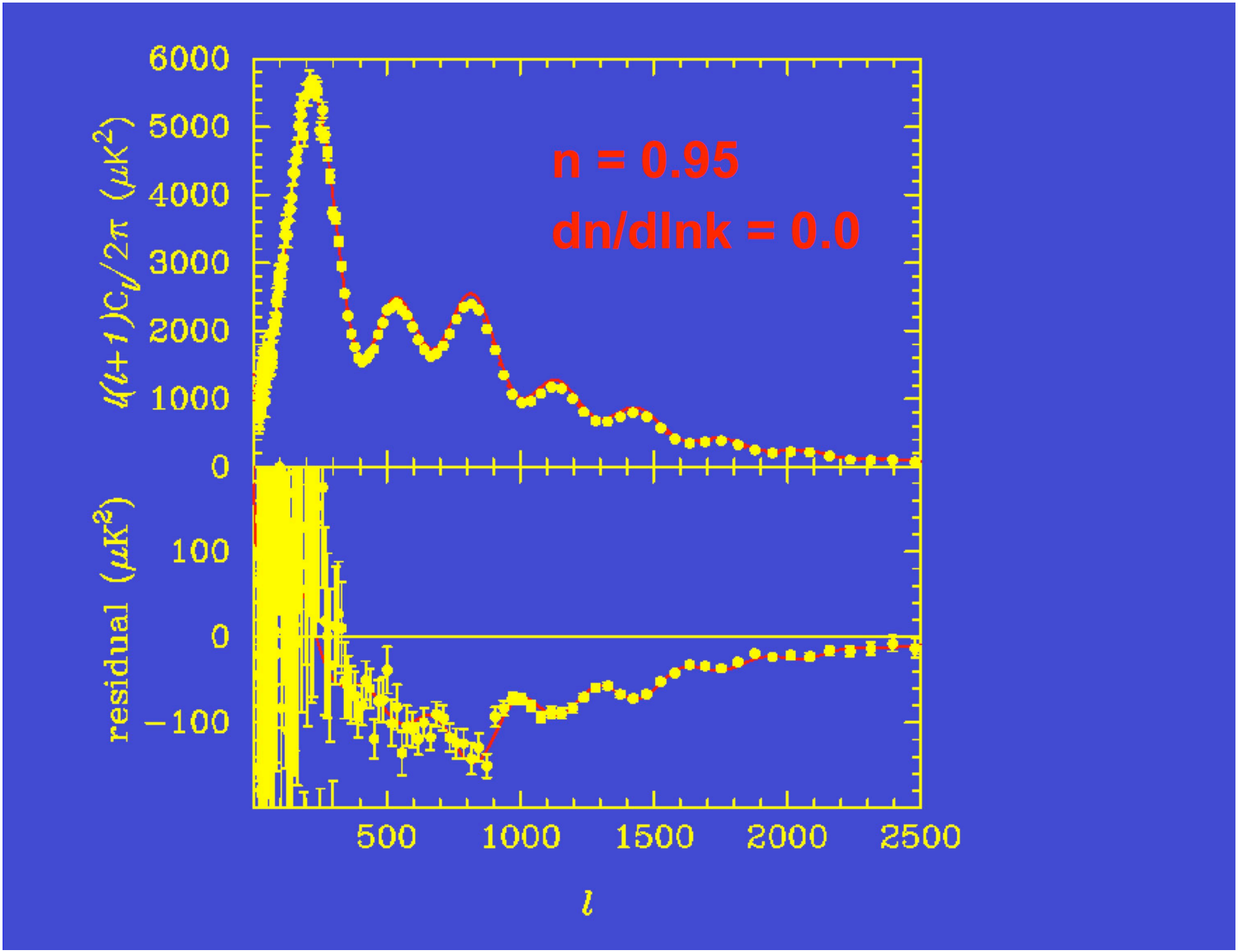
Huffenberger etal astro-ph/0606538

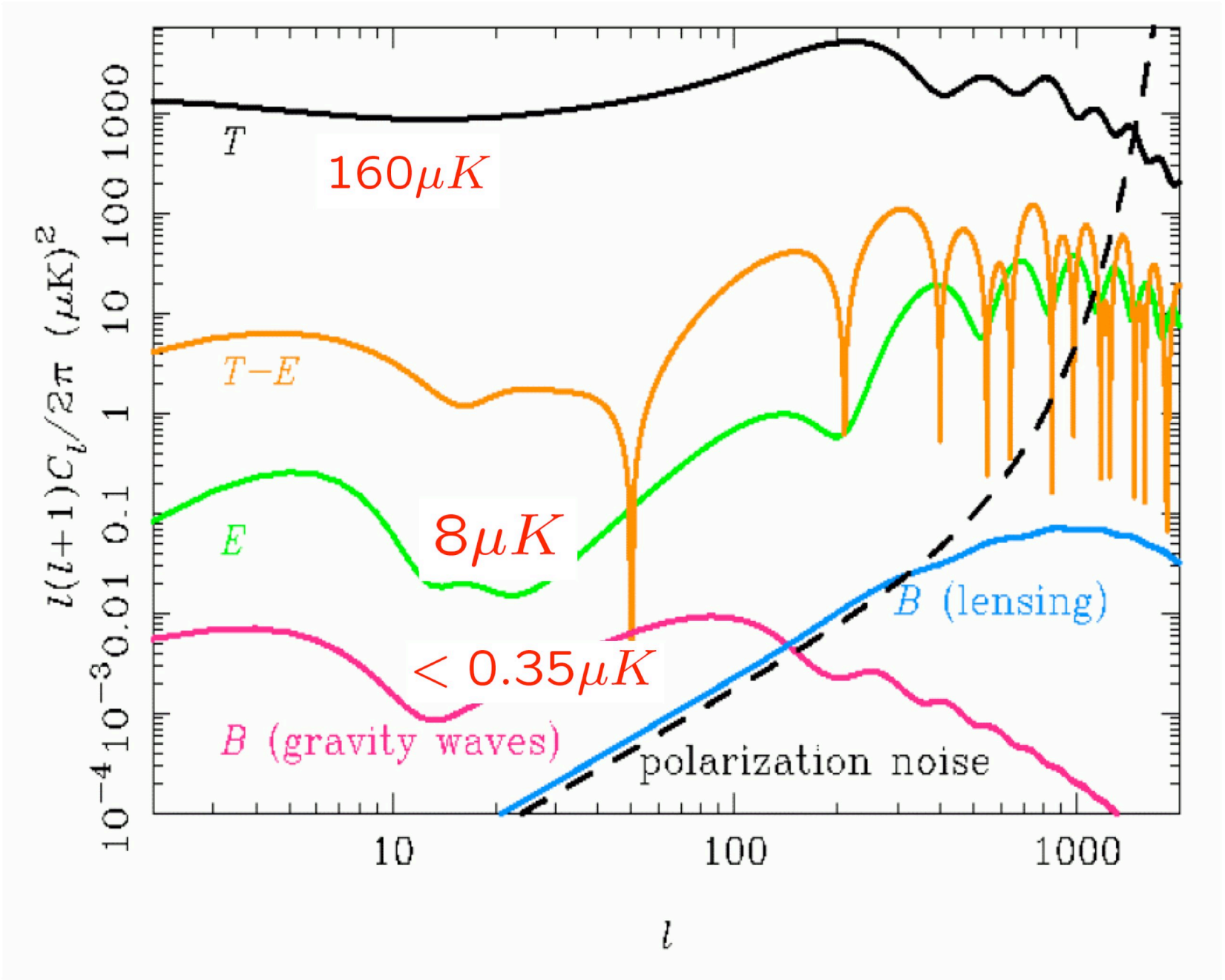
Eriksen etal astro-ph/0606088

$$n_s = 0.964 \pm 0.016 \quad (2.2\,\sigma)$$

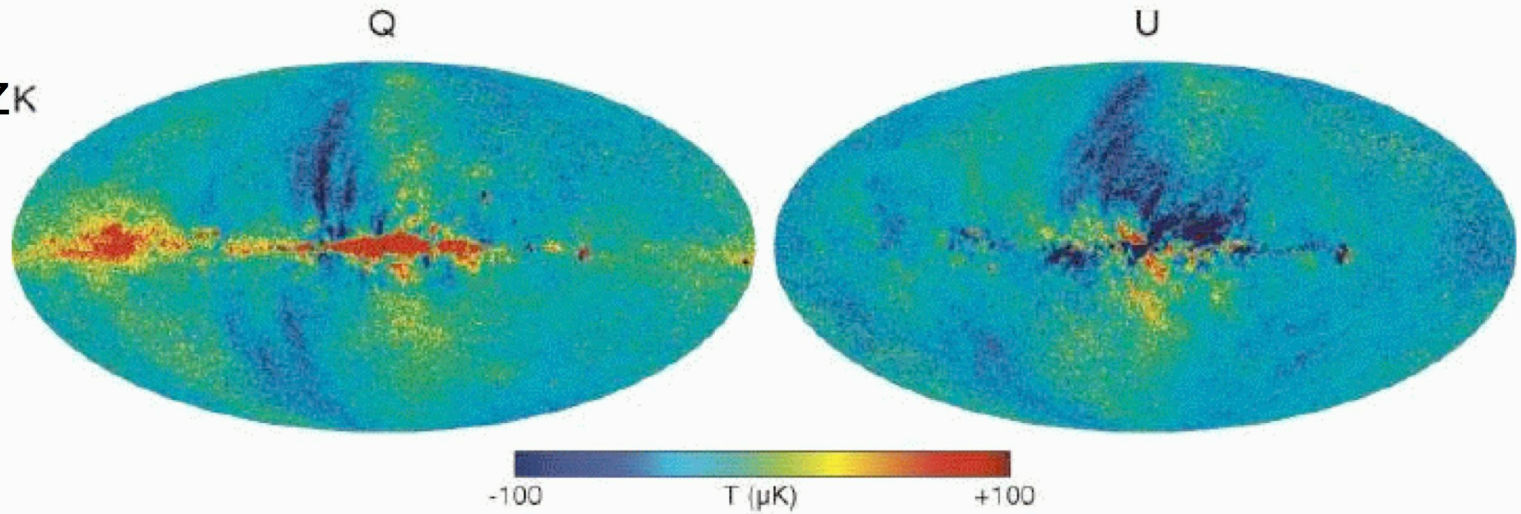

PLANCK
6000
5000
4000
3000
2000
1000
0
500
1000
1500
2000
2500
$l(l+1)C_l/2\pi\ (\mu K^2)$
l
n =
1.00


PLANCK
6000
5000
4000
3000
2000
1000
0
500
1000
1500
2000
2500
$l(l+1)C_l/2\pi\ (\mu K^2)$
l
n =
0.95


n = 0.95
dn/dlnk = 0.0
6000
5000
4000
3000
2000
1000
0
$l(l+1)C_l/2\pi\ (\mu K^2)$
100
0
−100
residual (μK^2)
500
1000
1500
2000
2500
l


$l(l+1)C_l/2\pi$ $(\mu K)^2$
10^{-4} 10^{-3} 0.01 0.1 1 10 100 1000
10
100
1000
l
T
$160\mu K$
$T-E$
E
$8\mu K$
$< 0.35\mu K$
B (gravity waves)
B (lensing)
polarization noise

22.5GHzK



32.8GHzKa

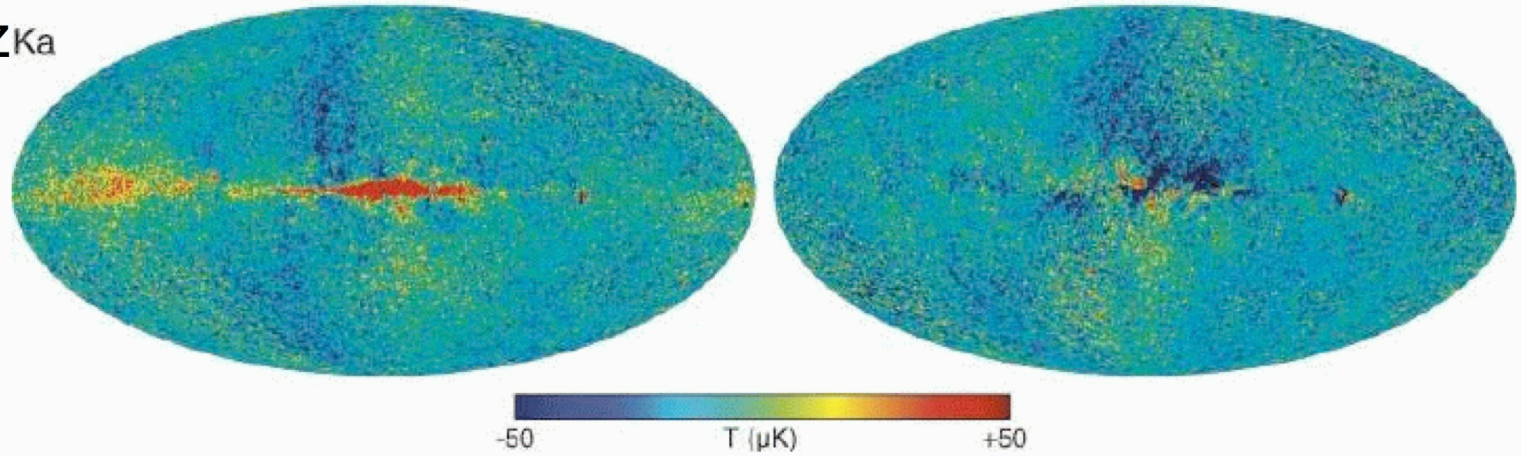
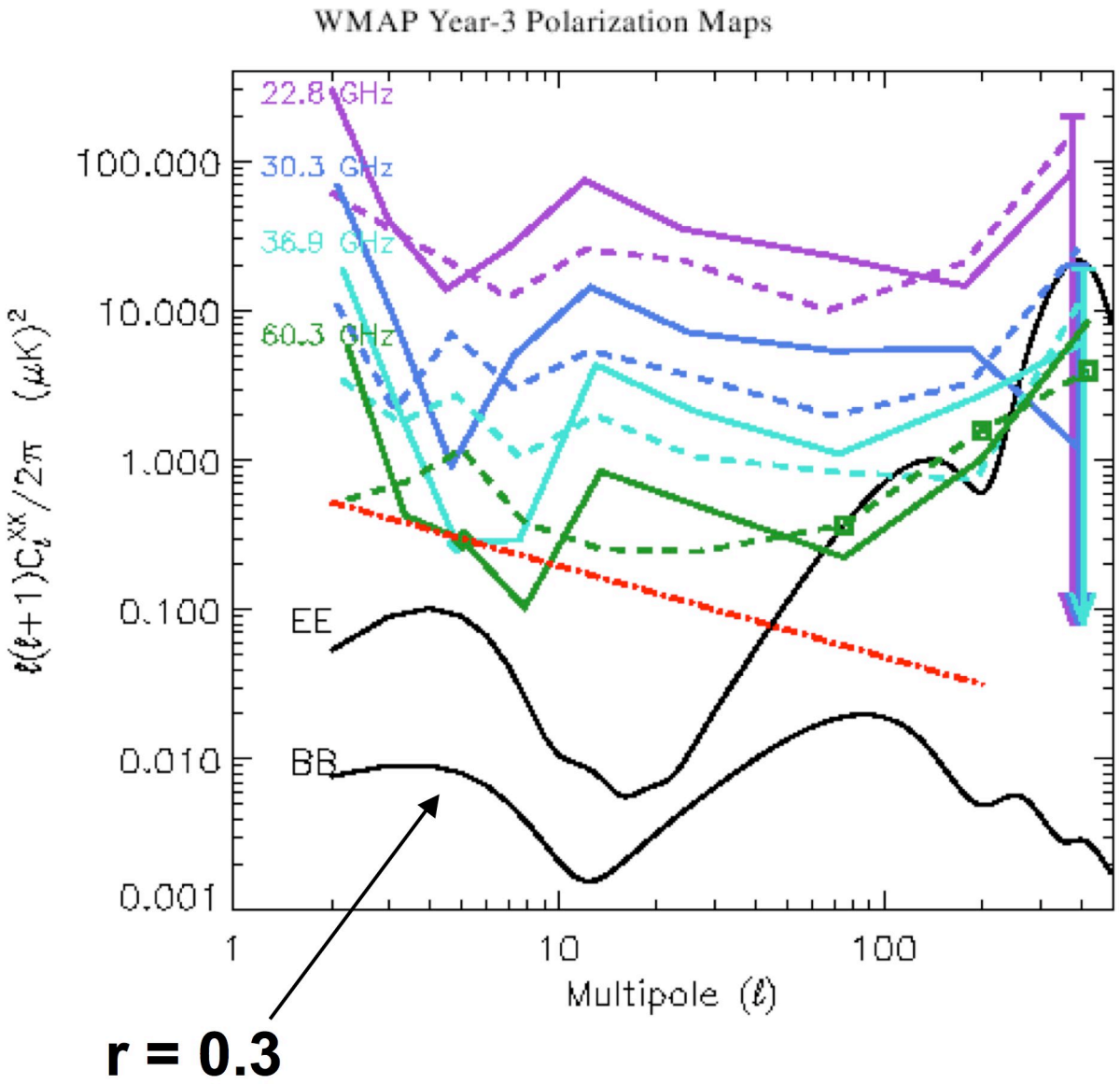
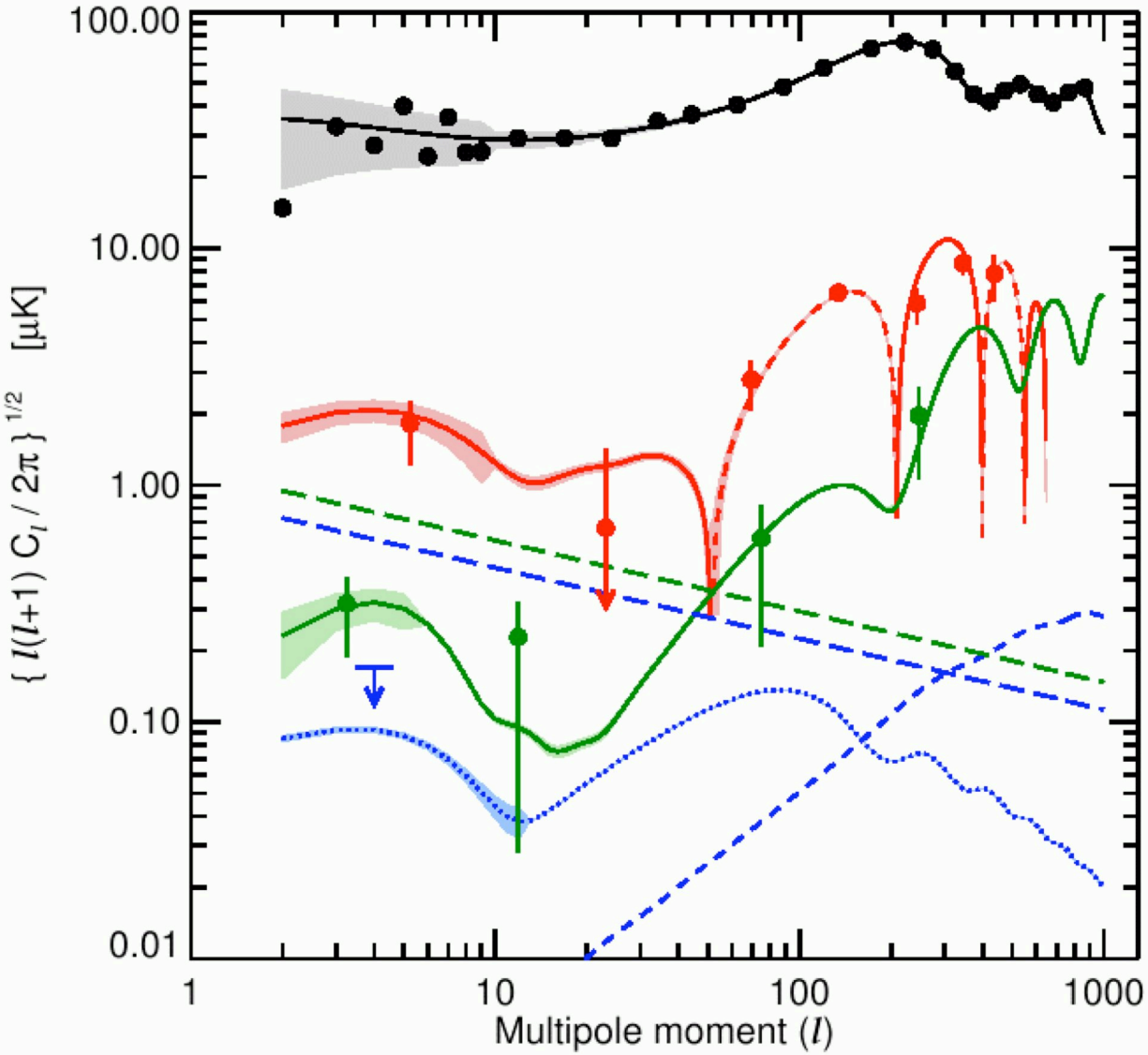
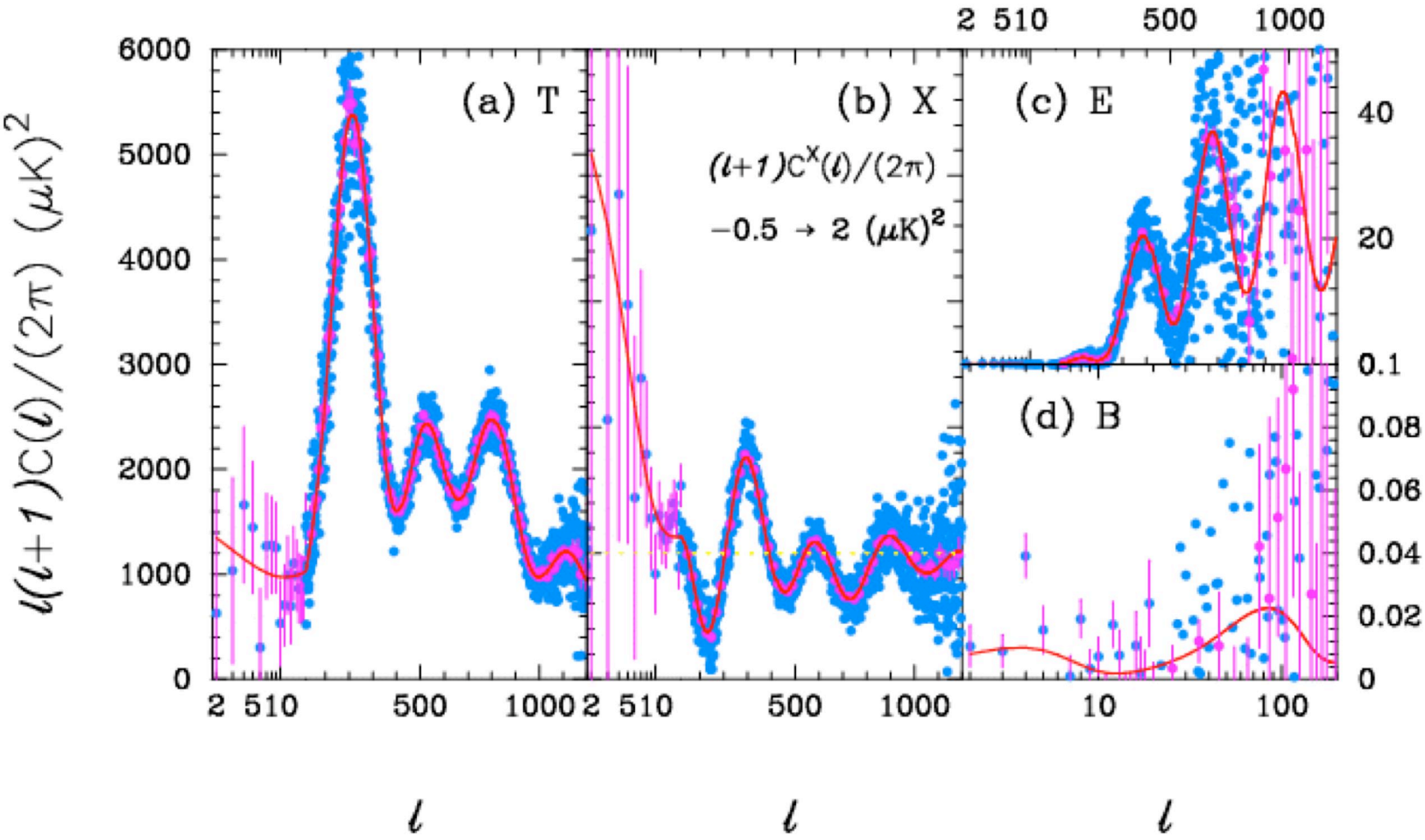


FIG. 6.— Stokes Q and U maps in K and Ka bands. The Galactic plane is dominated by positive Stokes Q because the foreground polarization direction is perpendicular to the plane. As discussed in §4, this is expected because the Galactic magnetic field is predominantly parallel to the plane. For comparison, the Stokes Q and U maps of a noiseless CMB simulation have peak-to-peak values of less than 6 μK. These maps have been smoothed to 1°.


WMAP Year-3 Polarization Maps
22.8 GHz
30.3 GHz
36.9 GHz
60.3 GHz
EE
BB
100.000
10.000
1.000
0.100
0.010
0.001
1
10
100
Multipole (ℓ)
ℓ(ℓ+1)C_ℓ^XX/2π (μK)^2
r = 0.3


100.00
10.00
1.00
0.10
0.01
1
10
100
1000
Multipole moment (l)
{ l(l+1) C_l / 2π }^1/2 [μK]


(a) T
(b) X
(c) E
(d) B
$(\ell+1)C^X(\ell)/(2\pi)$
$-0.5 \rightarrow 2\ (\mu K)^2$
$\ell(\ell+1)C(\ell)/(2\pi)\ (\mu K)^2$
ℓ
ℓ
ℓ
6000
5000
4000
3000
2000
1000
0
2 510 500 1000
2 510 500 1000
2 510 500 1000
10 100
40
20
0.1
0.08
0.06
0.04
0.02
0

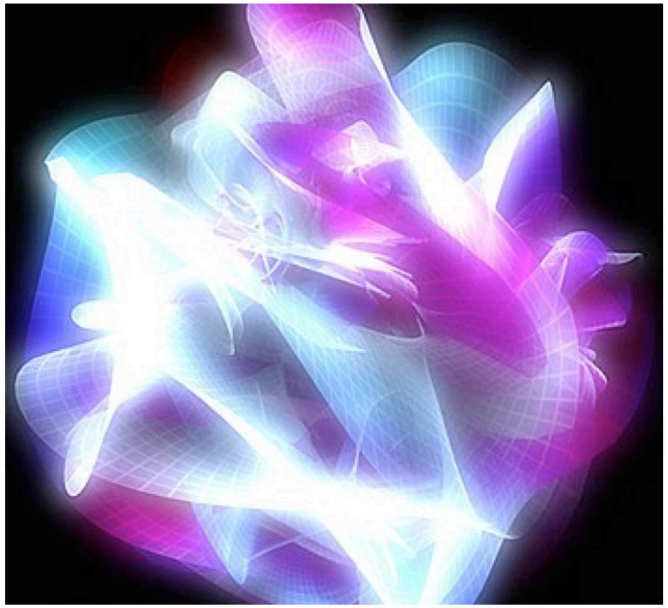
Theoretical predictions of r?

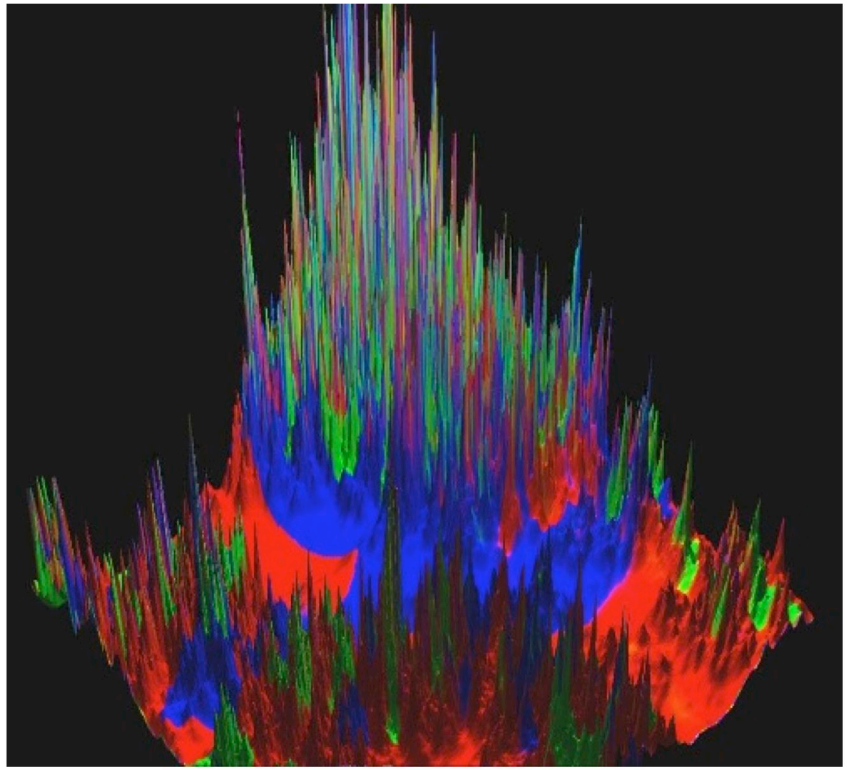
D'Oh!

$r < 10^{-11}$?

Experiment	tensor-scalar limit	$V^{1/4}$ (GeV)
Planck	$r \sim 0.1$	1.8×10^{16}
Clover/QUIET	$r \sim 0.01$	1.0×10^{16}
BBO/DECIGO	$r \sim 10^{-3}$	5.9×10^{15}
ultimate DECIGO	$r \sim 10^{-6}$	1.0×10^{15}

The Cosmic Landscape and The Measure Problem





We cannot predict ANYTHING until we solve this problem!

Nature of Dark Energy

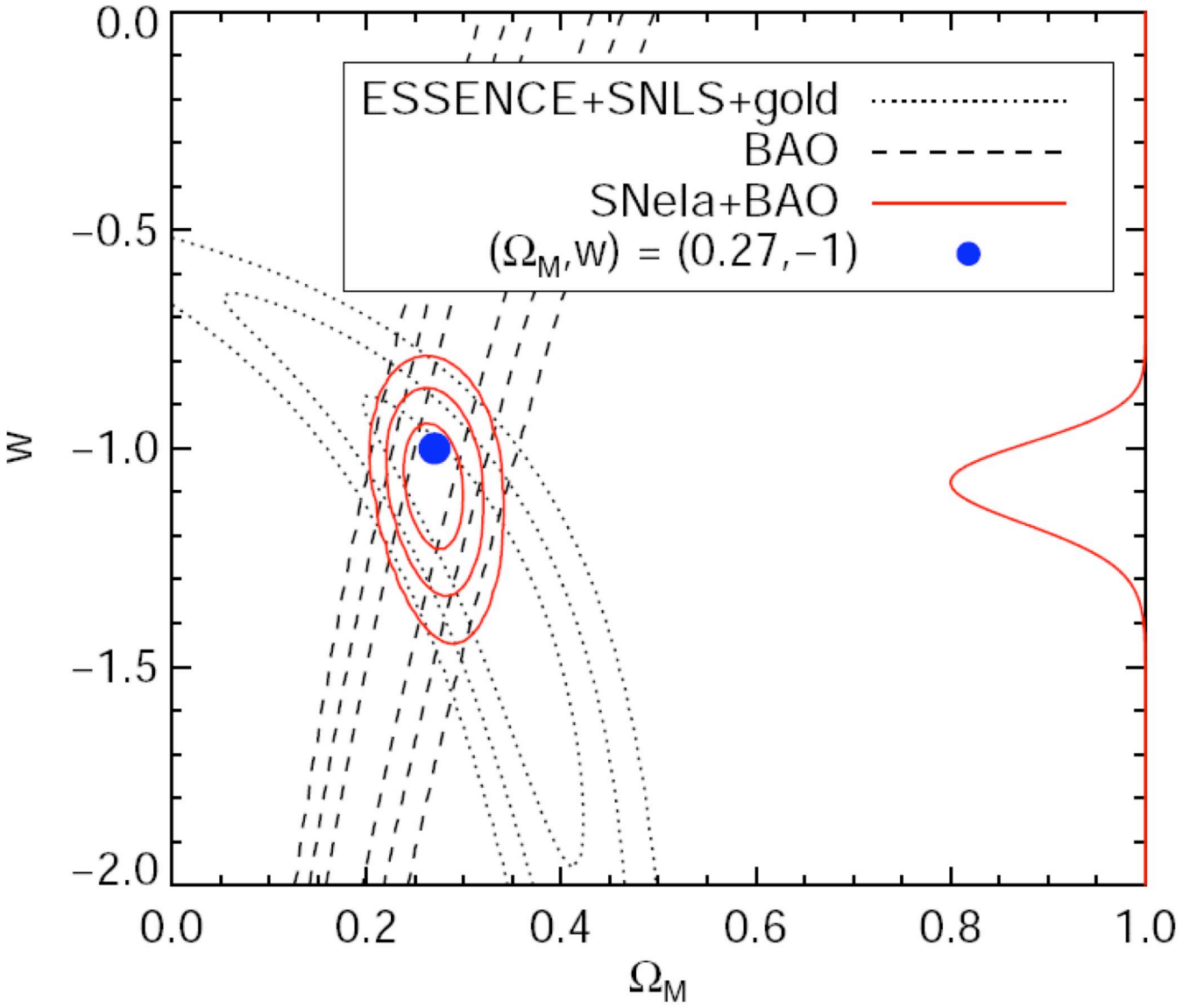
Cosmological constant problem:

$$\rho_\Lambda \sim H_0^2 m_{pl}^2 \sim (10^{-3}\mathrm{eV})^4$$

Quintessence?

$$m_\phi^2 \sim \frac{d^2V}{d\phi^2} \sim \frac{\rho_\phi}{\phi^2} < H_0^2 \sim (10^{-33}\mathrm{eV})^2$$

Wood-Vasey etal astro-ph/0701041

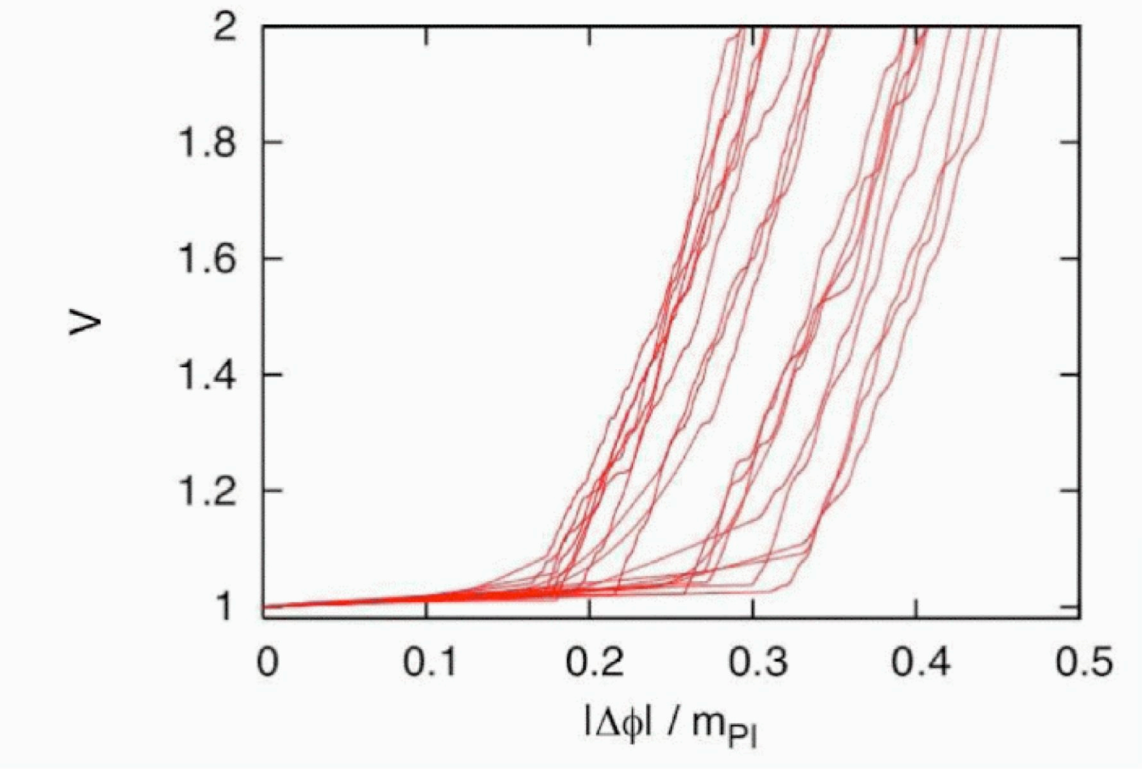


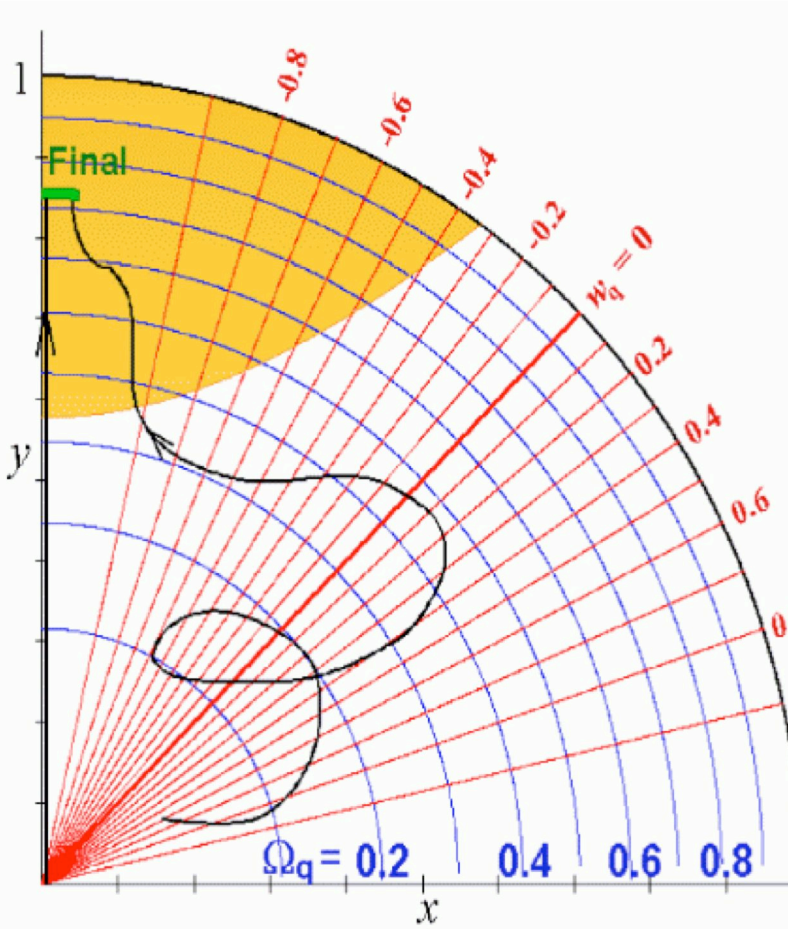
Chongchitnan and Efstathiou astro-ph/0705.1955

Energy variables

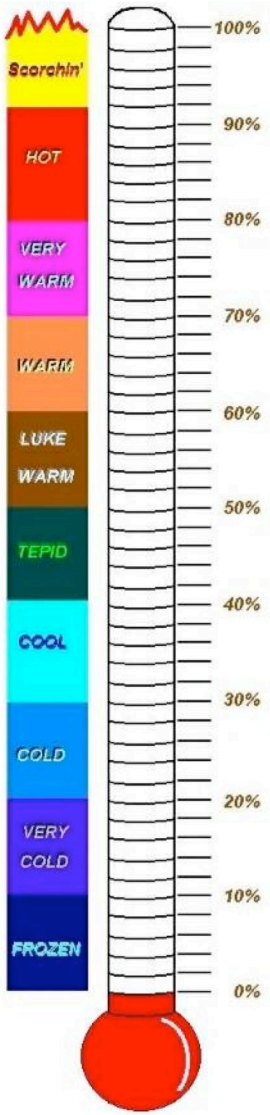
$$x = \frac{\dot{\phi}}{\sqrt{6}Hm_{\rm pl}}, \qquad y = \frac{\sqrt{V}}{\sqrt{3}Hm_{\rm pl}}$$

$$x^2 + y^2 = 1 - \Omega_m - \Omega_r$$





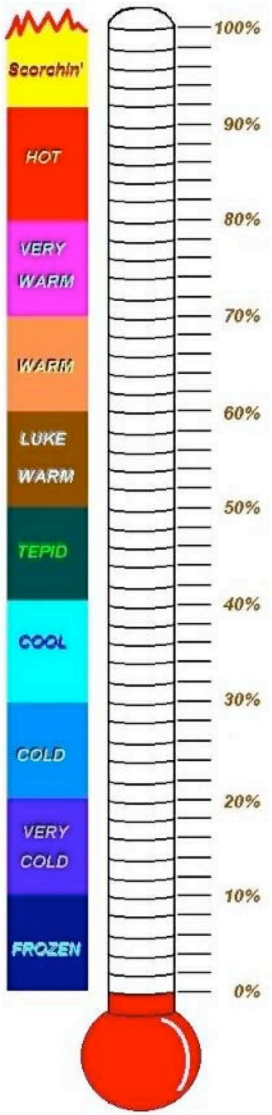
Fundamometer



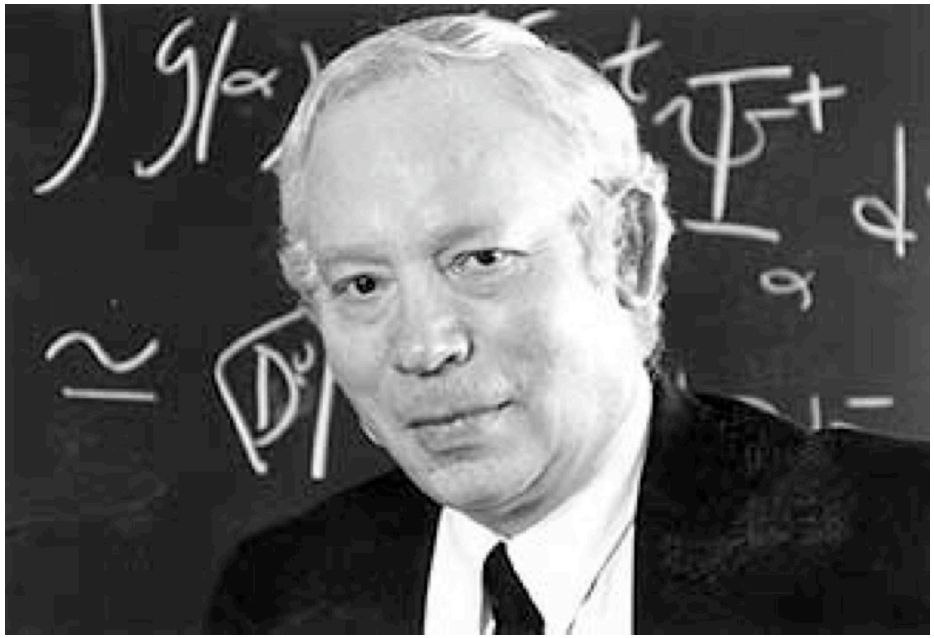
Strong test of fundamental physics

Weak test of fundamental physics

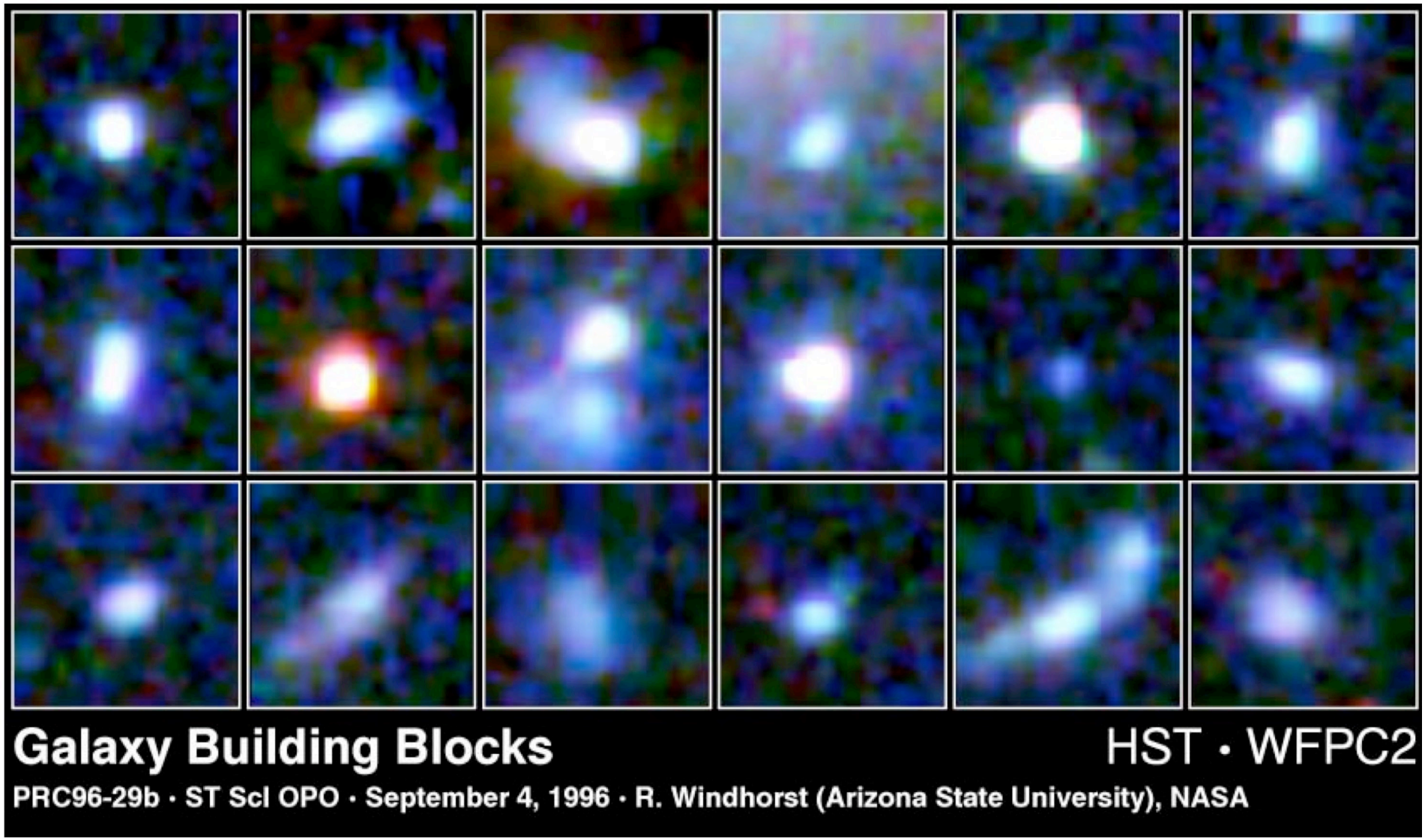
Fundamometer

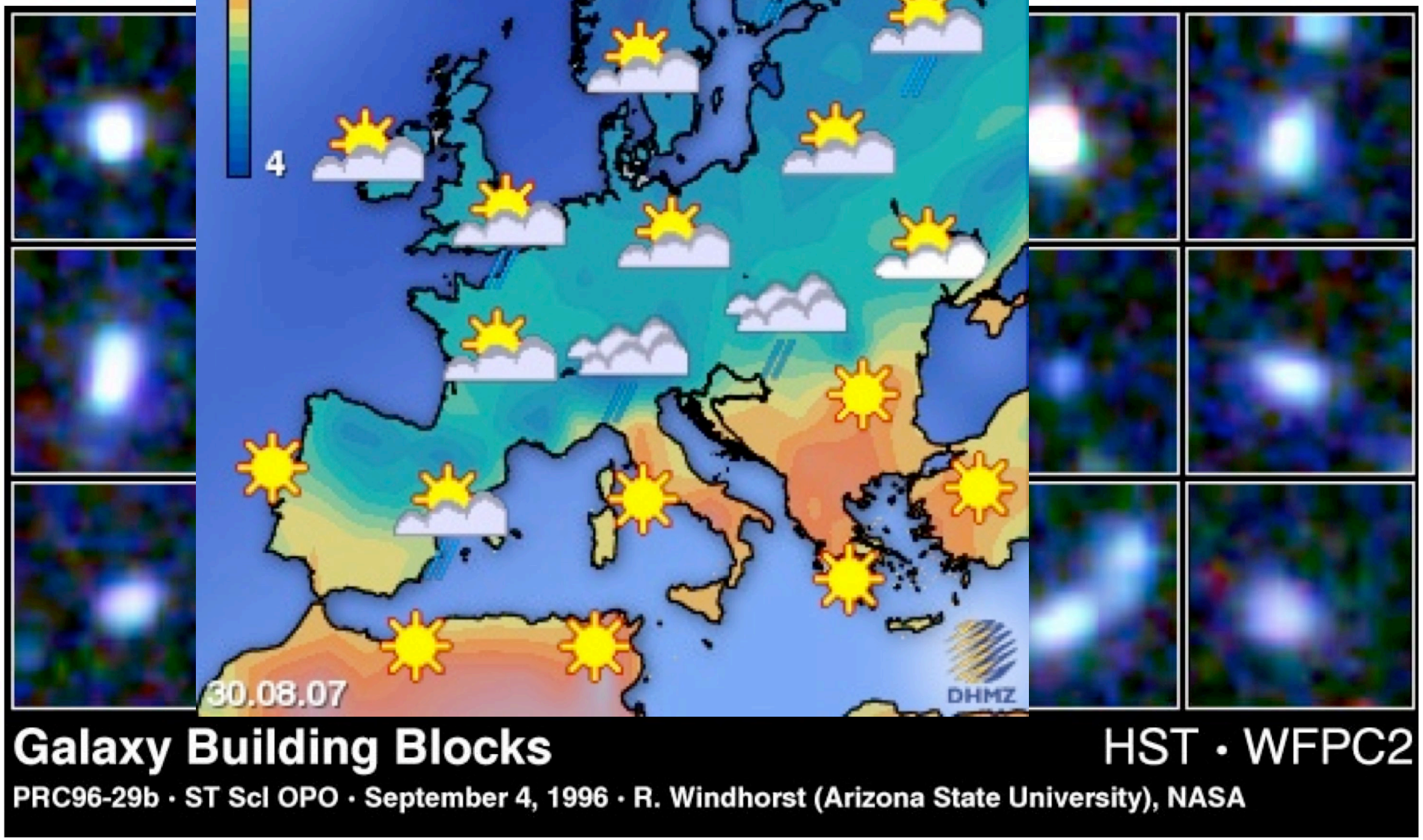


← Strong test of fundamental physics



← Weak test of fundamental physics


Galaxy Building Blocks
HST • WFPC2
PRC96-29b · ST ScI OPO · September 4, 1996 · R. Windhorst (Arizona State University), NASA



Galaxy Building Blocks

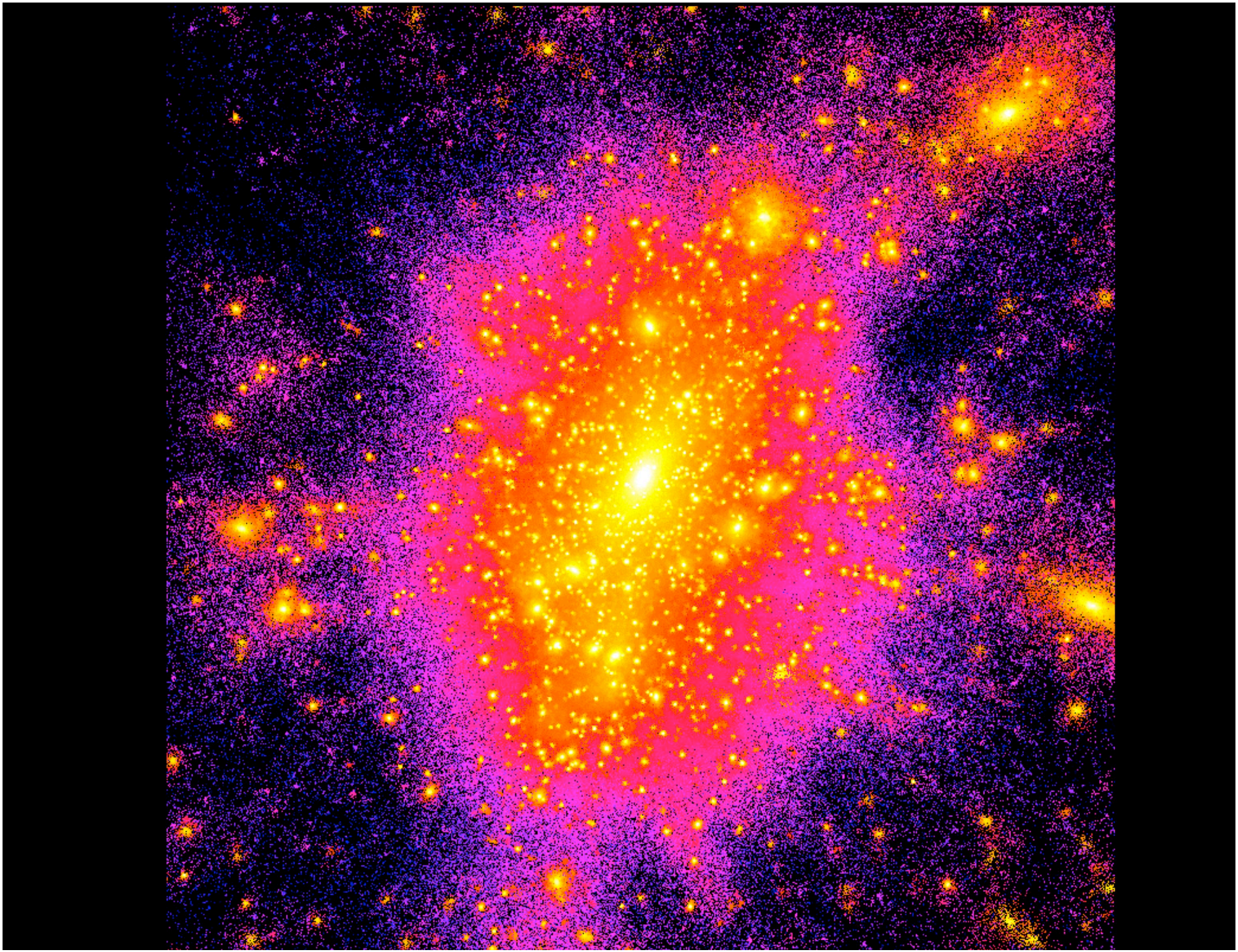
HST • WFPC2

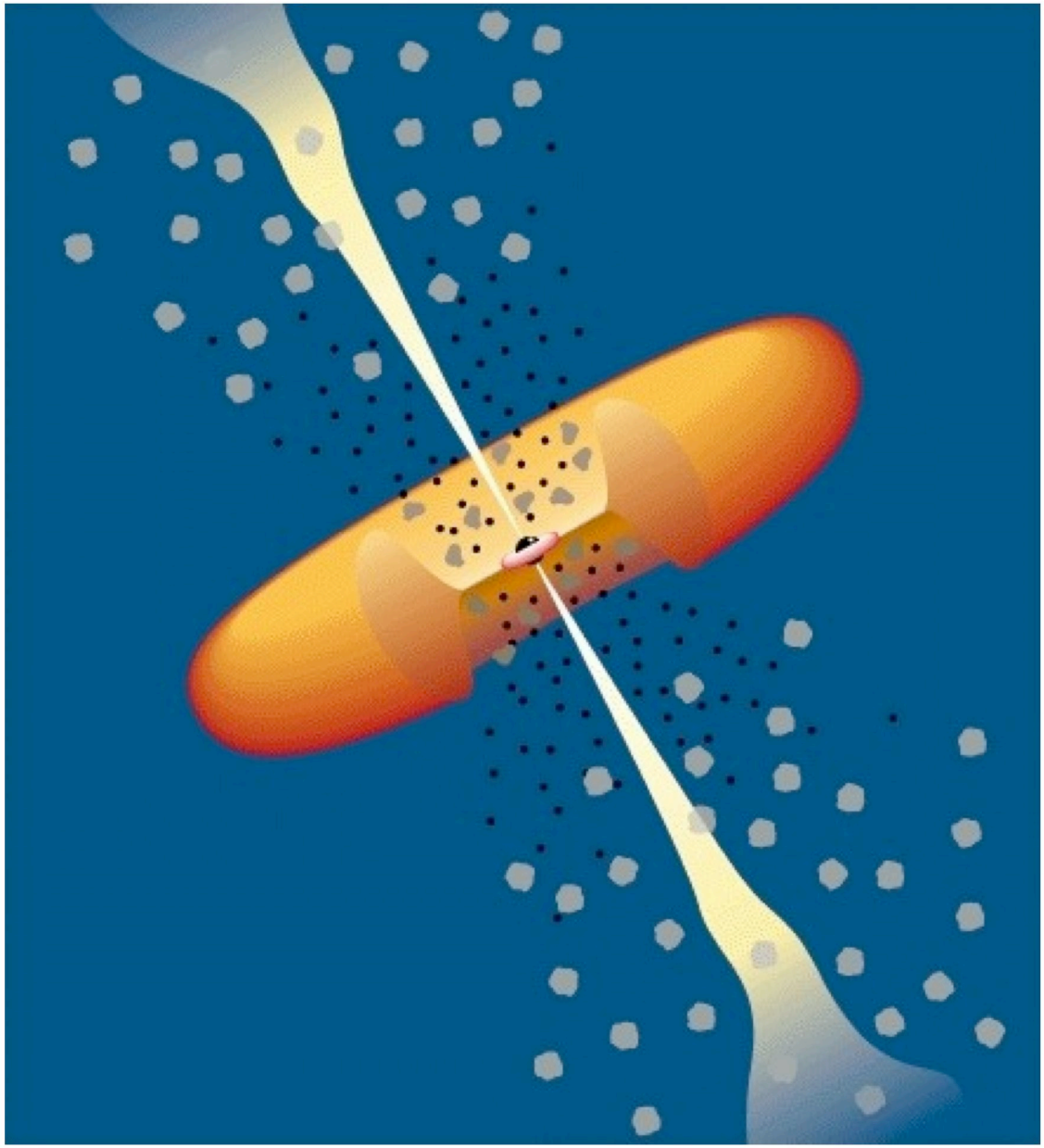
PRC96-29b · ST ScI OPO · September 4, 1996 · R. Windhorst (Arizona State University), NASA

- **Topological defects**
- **Nature of dark matter (detection, properties..)**
- **Dynamical dark energy**
- **Non-minimal coupling between dark matter and dark energy**
- **Non-Gaussianity**
- **Features (spikes....) in the fluctuation spectrum**
- **Modifications to GR (higher dimensions)**
- **Signatures of other Universes (pre-big bang, tunnelling events .....)**
- **.....**

But--- Rejoice in Complexity!!

- **Assembly of galaxies**
- **Formation of massive black holes**
- **Evolution of quasars – understanding AGN**
- **Gamma ray bursts**
- **Nature of the first stars**
- **Origin of magnetic fields**
- **Evolution of the IGM**
- **Clusters of galaxies**
- **.....**





What I would do:

- **Search for tensor modes *from the ground* to r~0.01. If no detection probably give up!**
- **Do surveys to test for dynamical dark energy, *but expect failure!***
- **Avoid hubris (we have been lucky) and pay close attention to systematic errors.**
- **Continue experiments for direct detection of dark matter.**
- **Exploit facilities to complete our understanding of non-linear structure (avoid weather forecasting).**
- **Wait ~ 5-10 years before simulating galaxy formation!**

Finally

Finally