We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time

– T. S. Eliot

early-inflaton DE acceleration trajectories then

Bond, Huang 2013

$\varepsilon = -\, d\ln H / d\ln a$; $V(\psi) \approx 3M_P^2H^2(1-\varepsilon/3)$; $d\psi/d\ln a = \pm\sqrt{\varepsilon}$

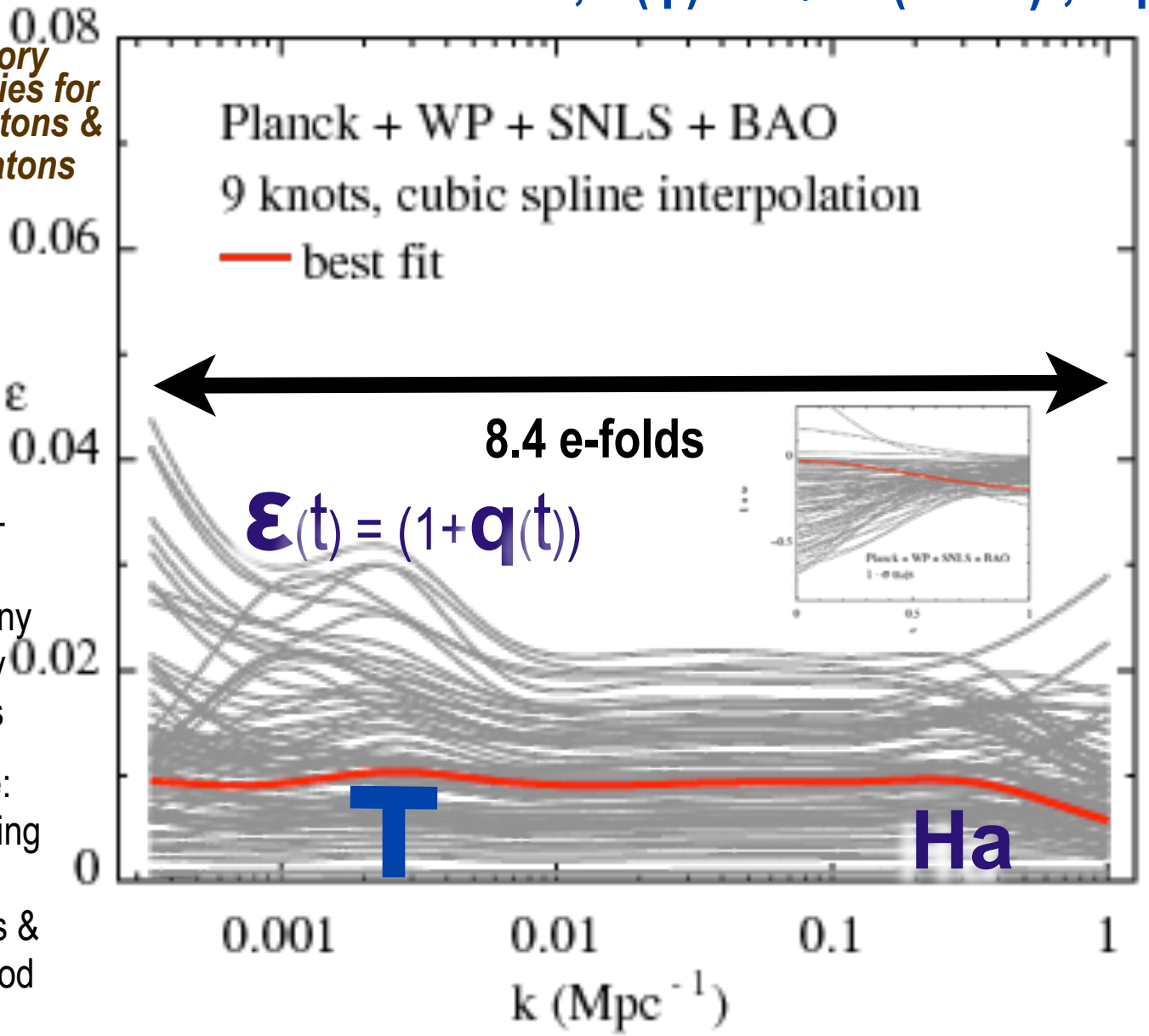
aka

$(1+w_{de})^{3/2}$

then

(hydro)

trajectory probabilities for early-inflatons & late-inflatons



***resolution ln**k* ~ *ln**Ha** dynamics*

$\varepsilon \approx r/16$

can post-process bands in any trajectory variables

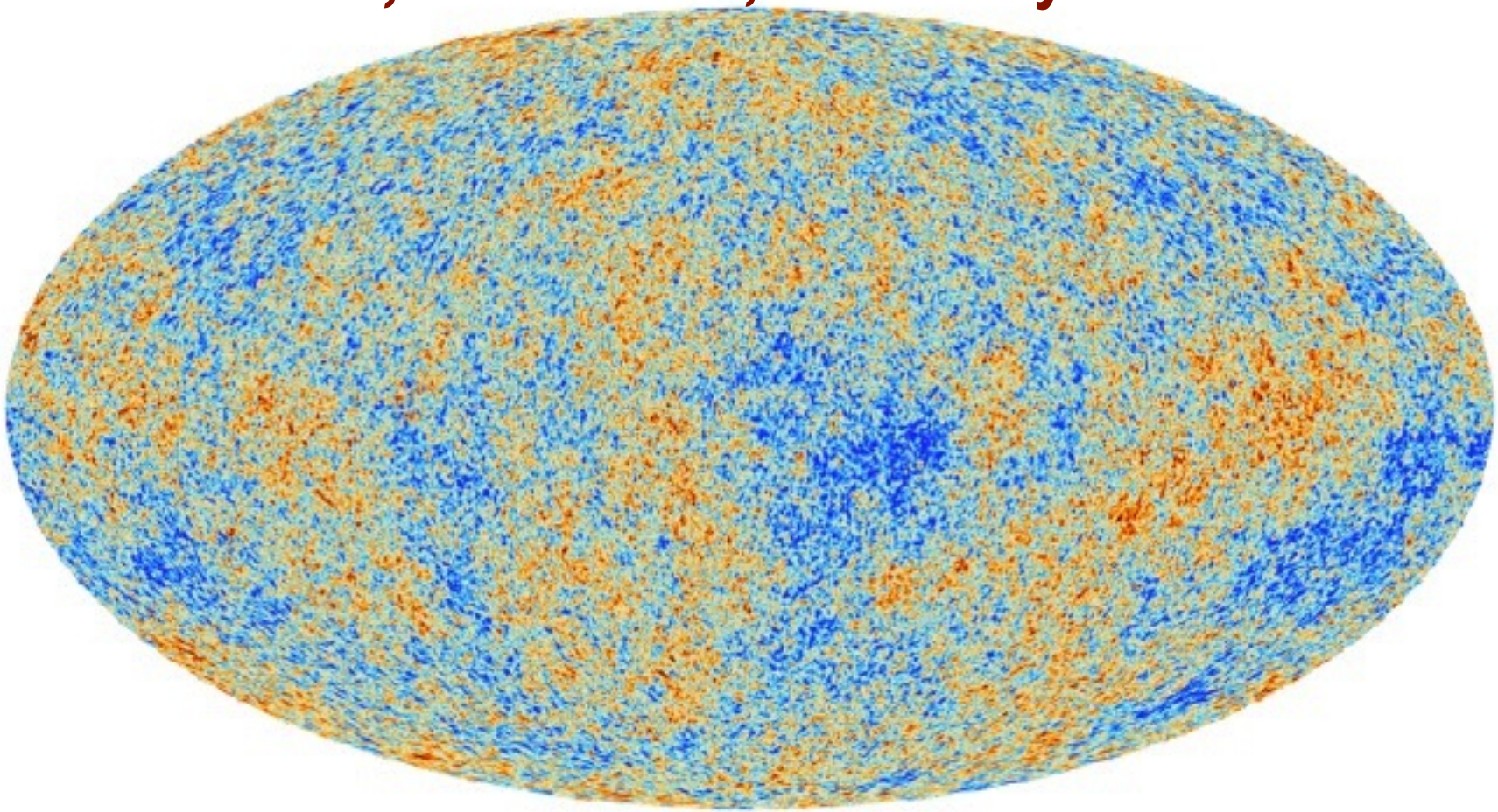
key issue: characterizing the correlations & the likelihood surface

$\varepsilon \approx V$ / $0.0005\ (10^{16}\text{Gev})^4$

reveals **primordial sound waves**

=> the inharmonious *'music of the spheres'*

7^{+} numbers, 3 densities, 2+1 early-Universe inflation



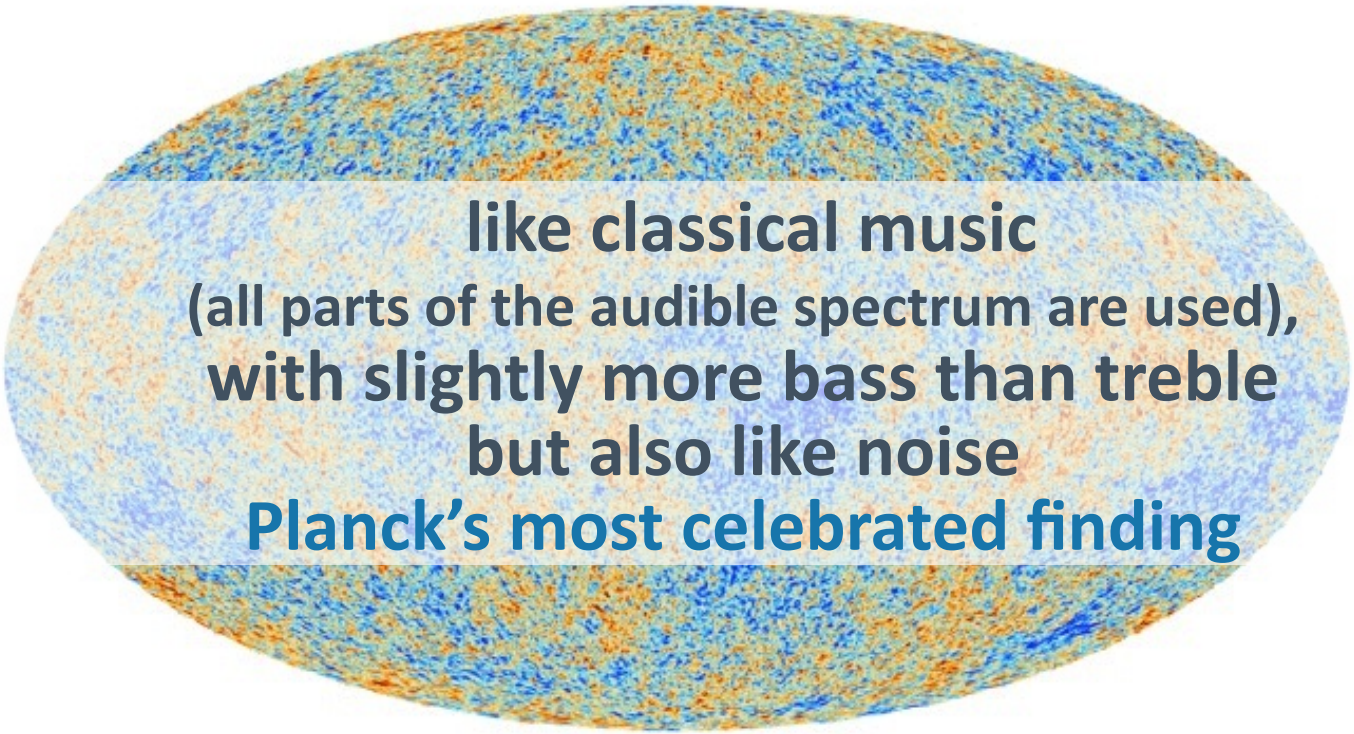
Temperature changes
in micro-degrees

reveals **primordial sound waves**

=> the inharmonious *'music of the spheres'* in 7^+ numbers

=> learn **matter & energy content & structure** at $a \sim e^{-7}$ 380000 yr

=> infer structure **far far earlier** $a \sim e^{-127} \sim 1/10^{55}$ **in 2 numbers**

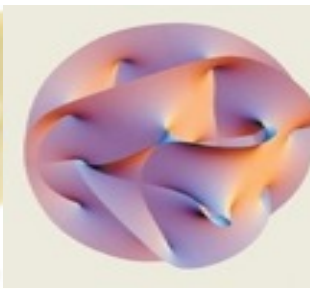


$n_s = 0.9608 \pm 0.0054$ ***5σ from 1***

Temperature changes in micro-degrees

how was *matter & entropy generated at the end of acceleration = inflation*?

Relate it to the Higgs & standard model?

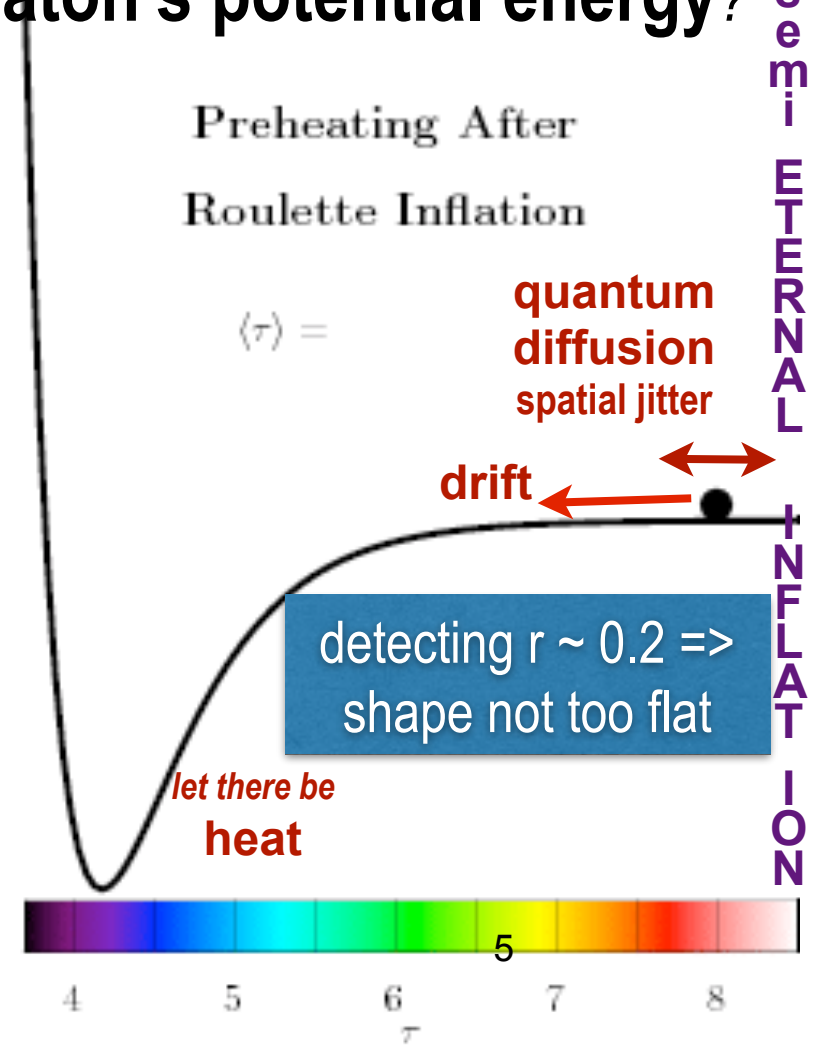


$a =$ [1] **what is the inflaton's potential energy**?

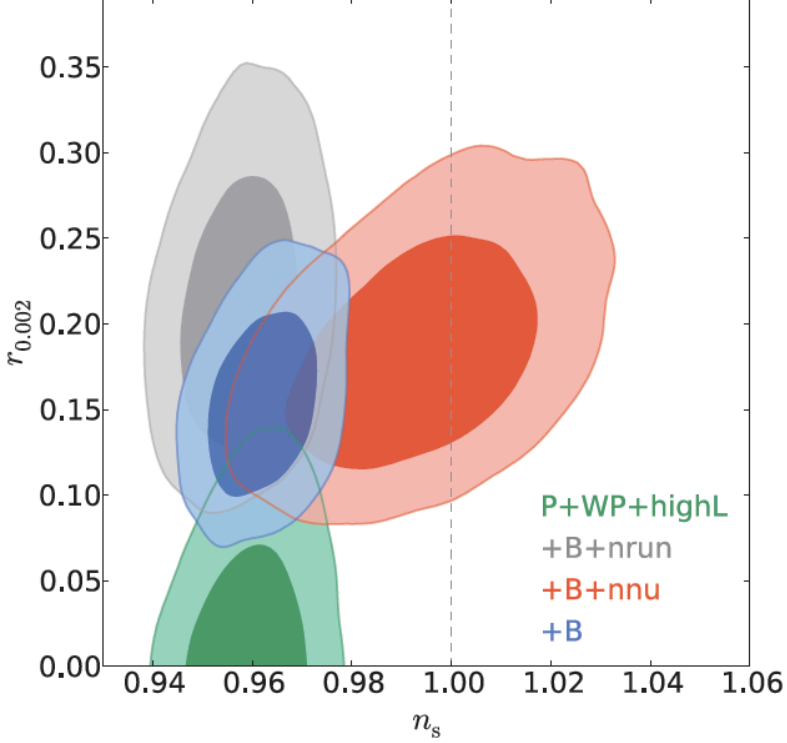
pre-heating patch (**<1cm**-now, **<10^{-30} cm**-then)

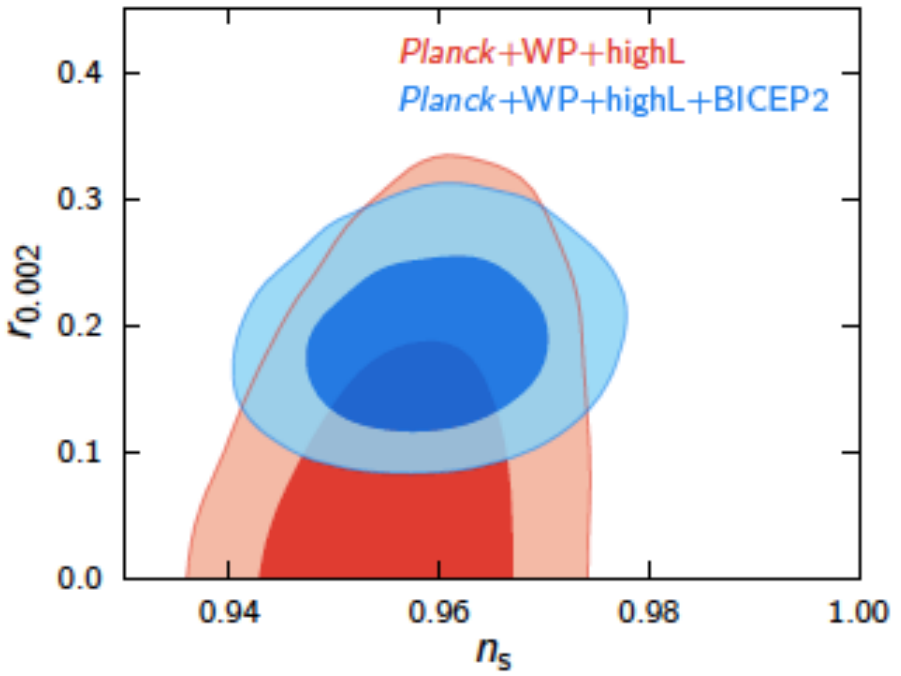
A visualized 2D slice

in lattice simulation

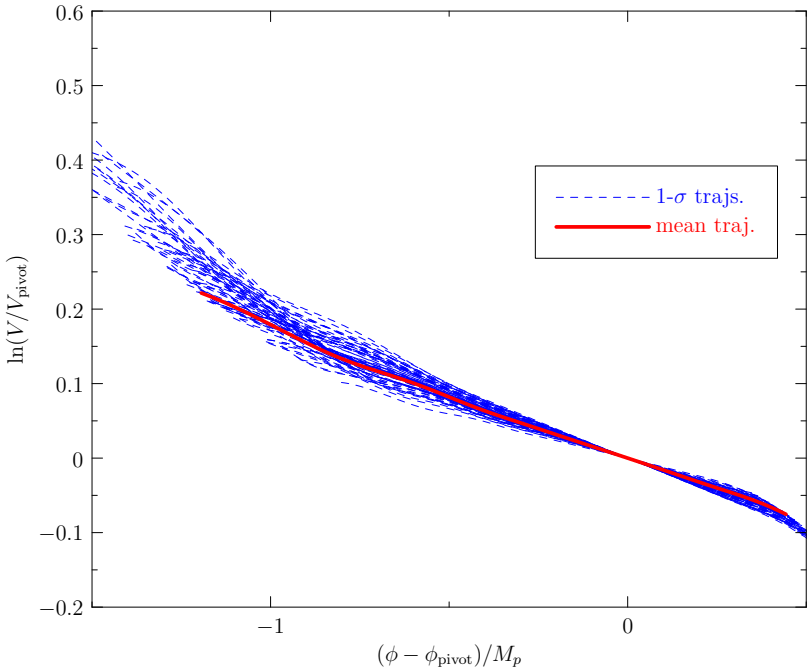


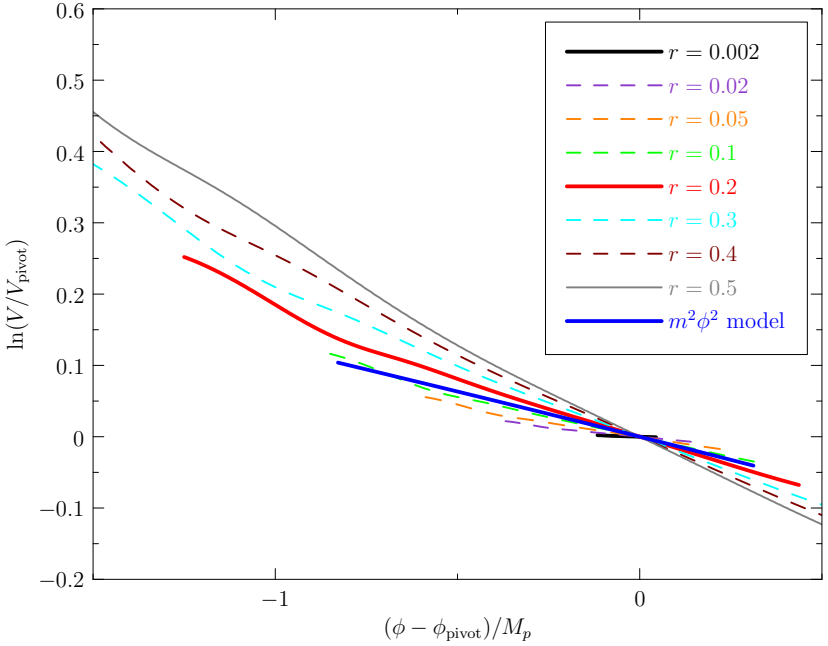
www.youtube.com/watch?v=FW__su-W-ck&NR=1





Reconstructed mean potential (without BICEP constraint)



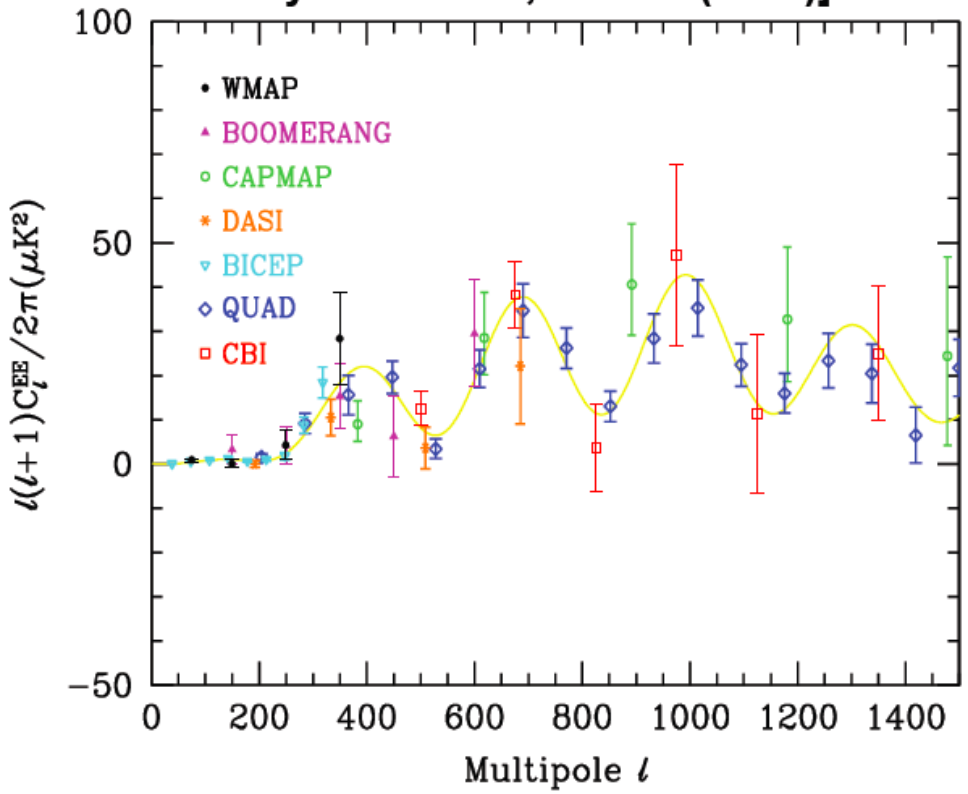


best-fit P1.3yr TT model predicts the polarization. works perfectly at all frequency cross correlations strengthens the case for the Galactic/extragalactic nuisance parameter model being accurate

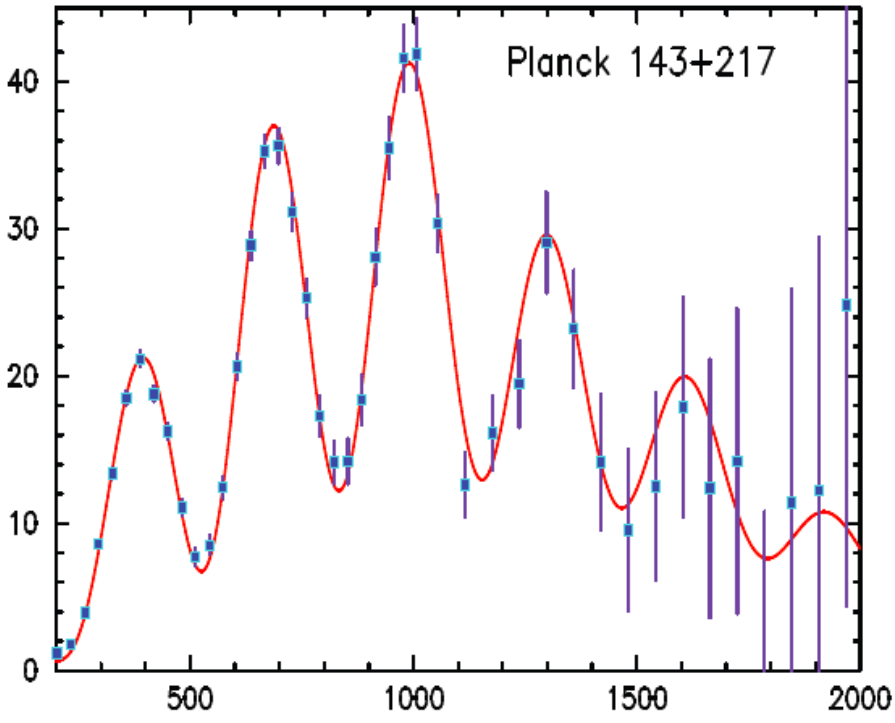
teaser for 2014

EE polarization

[J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012)]



[Planck 2013 results. XVI. Cosmological parameters]

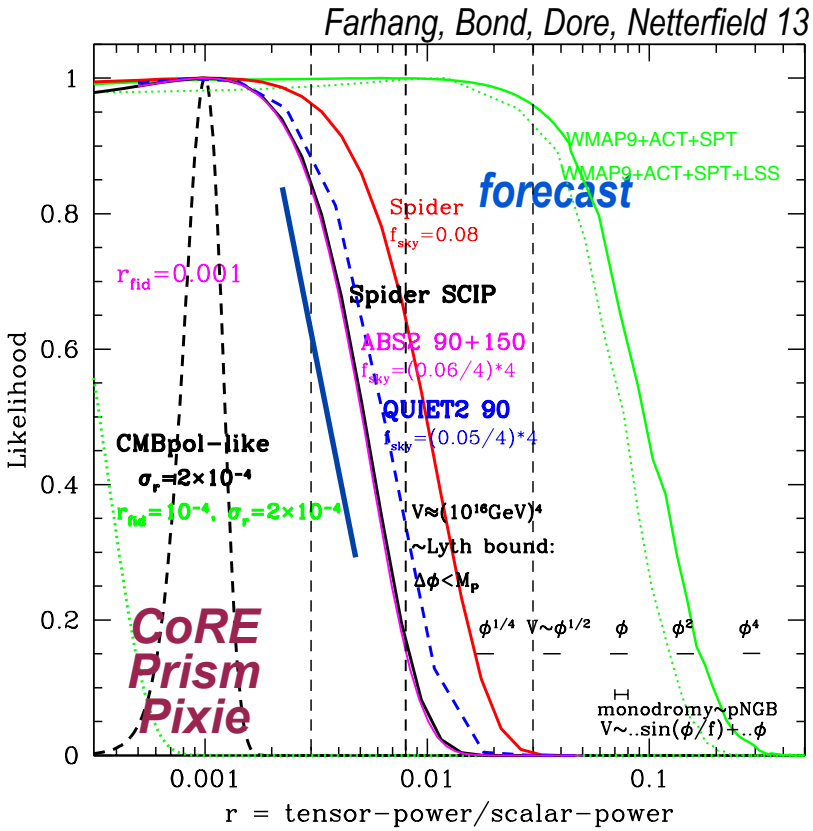


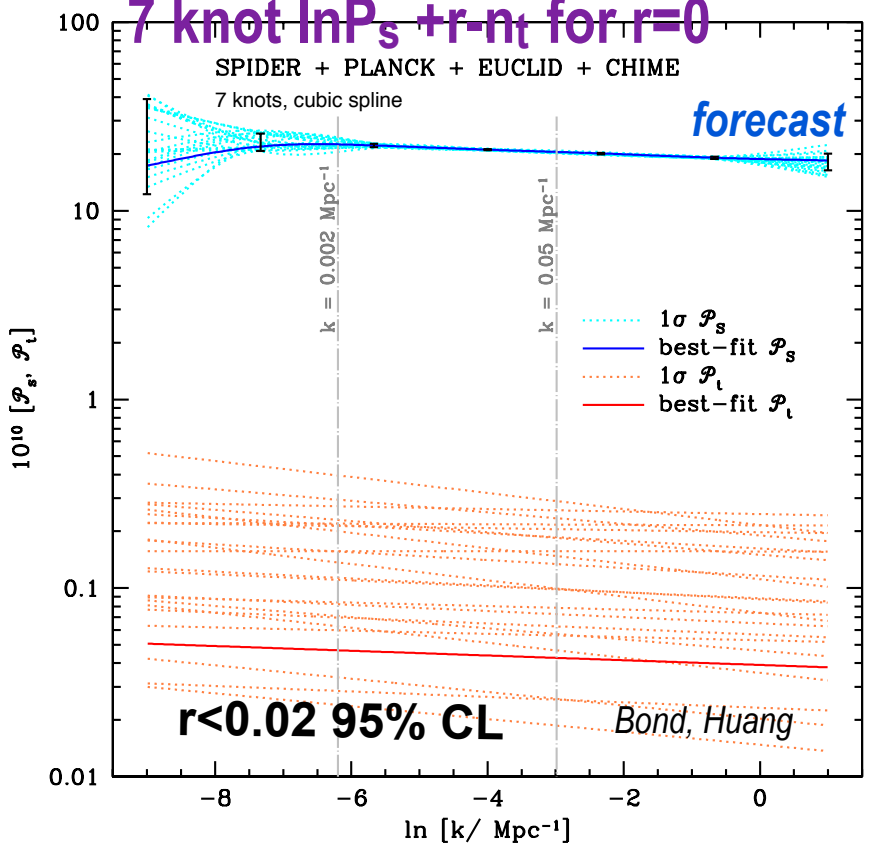
a long path to constrain the B-mode of polarization at the r =.02 to .05 level of P2.5 forecasts

CMB Lensing induces B-mode of polarization from E-mode: *Detection of **B**-mode Polarization in the Cosmic Microwave Background with Data from the South Pole Telescope* **Hanson+13 using Herschel sub-mm+SPT-E-mode x SPT B-mode to confirm detection at 7.7sigma**

Spider24days+Planck2.5yr: r-n_t *matrix*-forecast for r=0.12 input for $m^2\varphi^2$ ($2\sigma_r$ ~0.02 including fgnds)

*similar r-forecasts for **ABS+, Quiet2, Keck, ..***

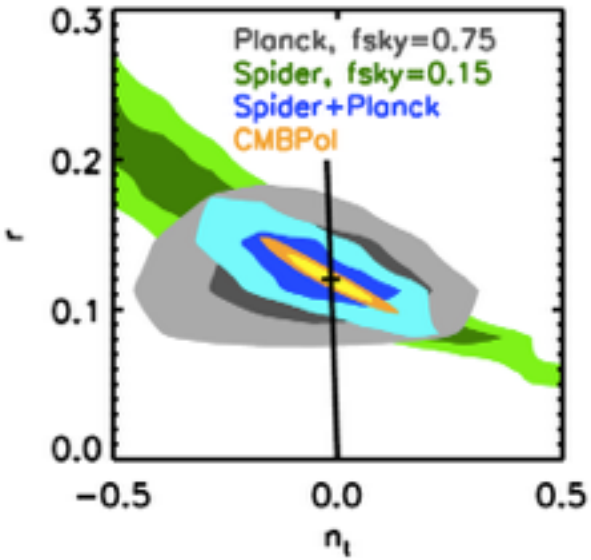




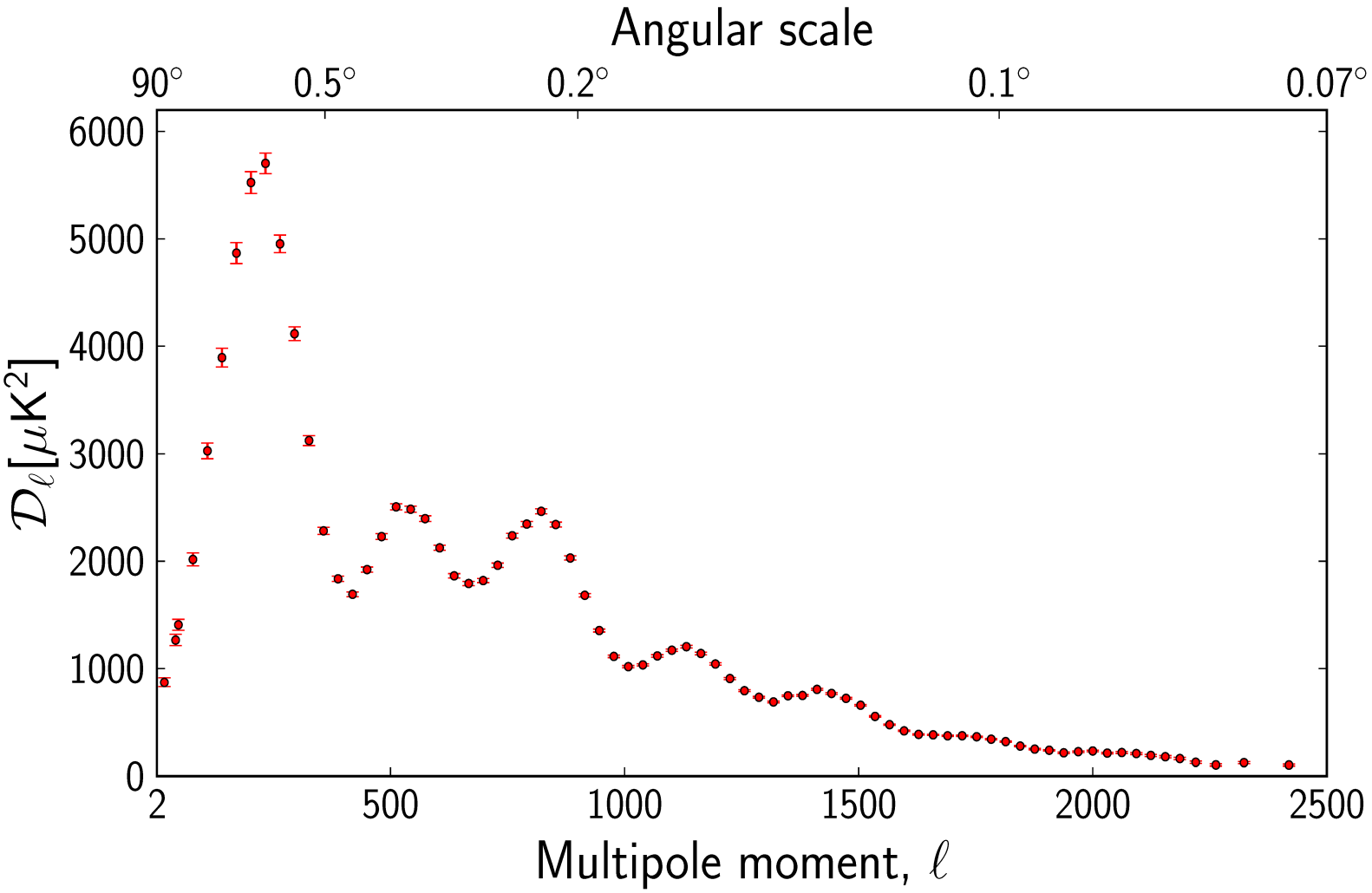
can get B-mode shapes but without the precision needed to check

$-n_t \approx r/8$ consistency

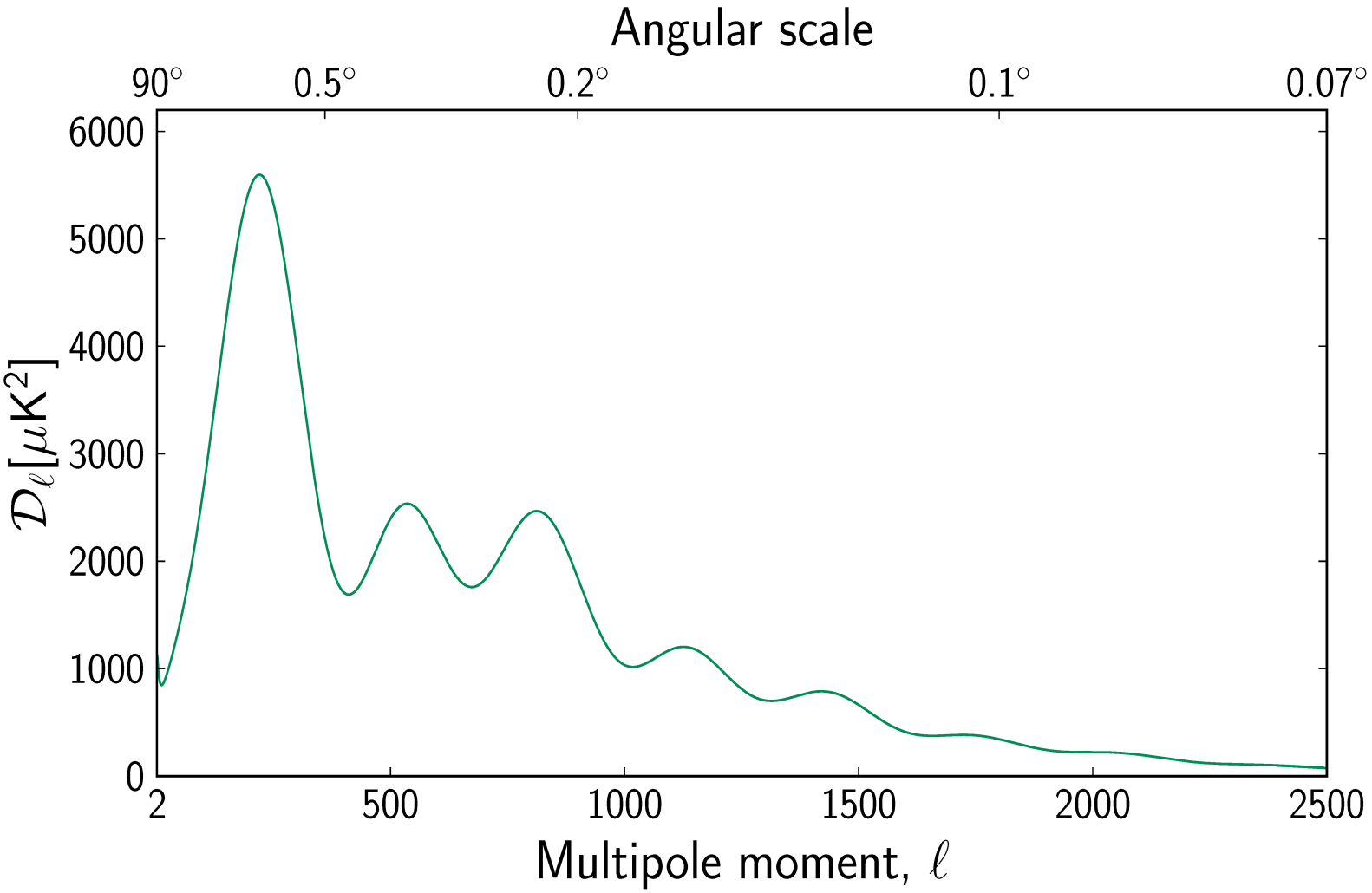
COBE-like errors on tilt



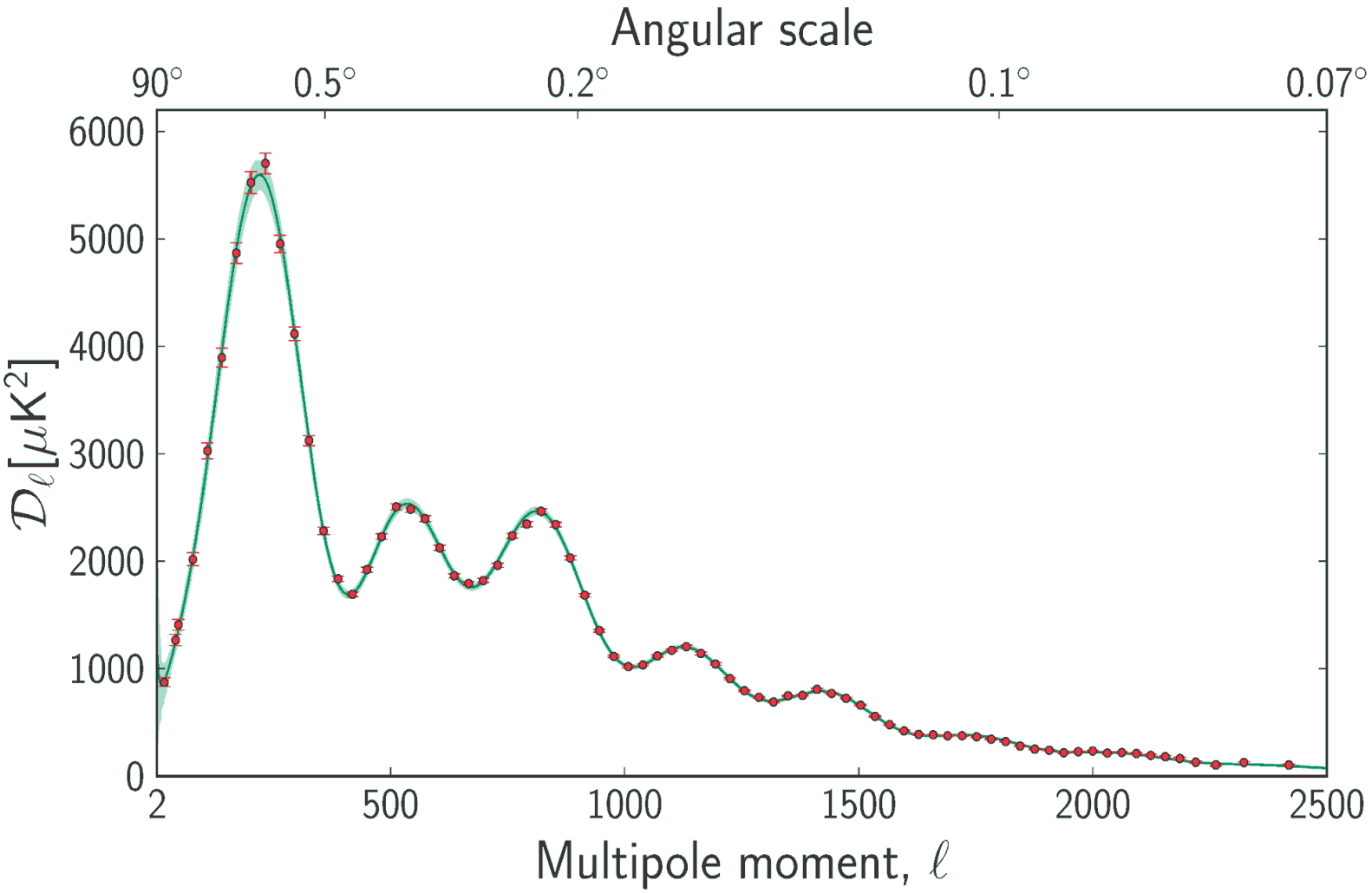
CMB Power Spectrum Propaganda

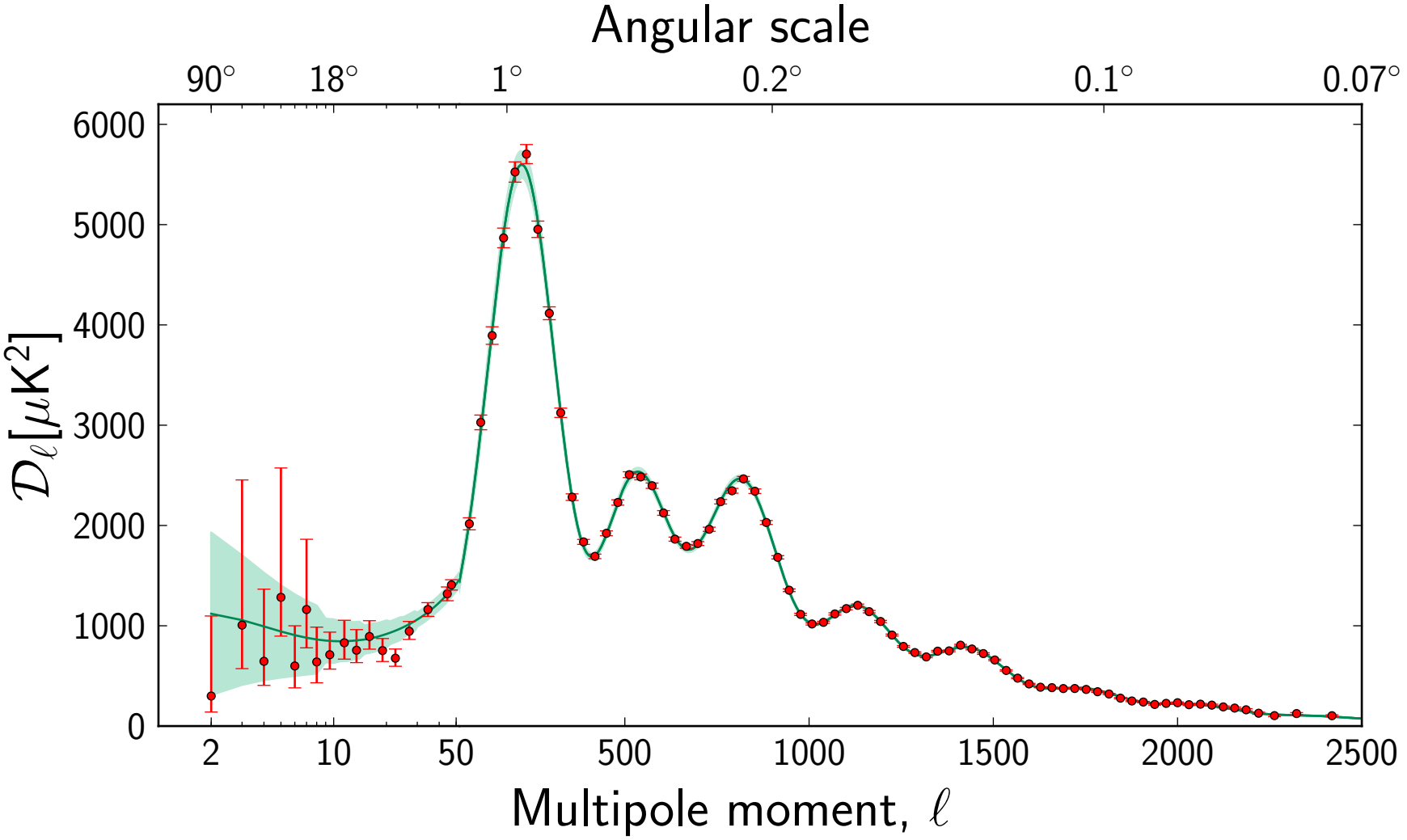


CMB Power Spectrum Propaganda: best fit basic 6 cosmic parameter model



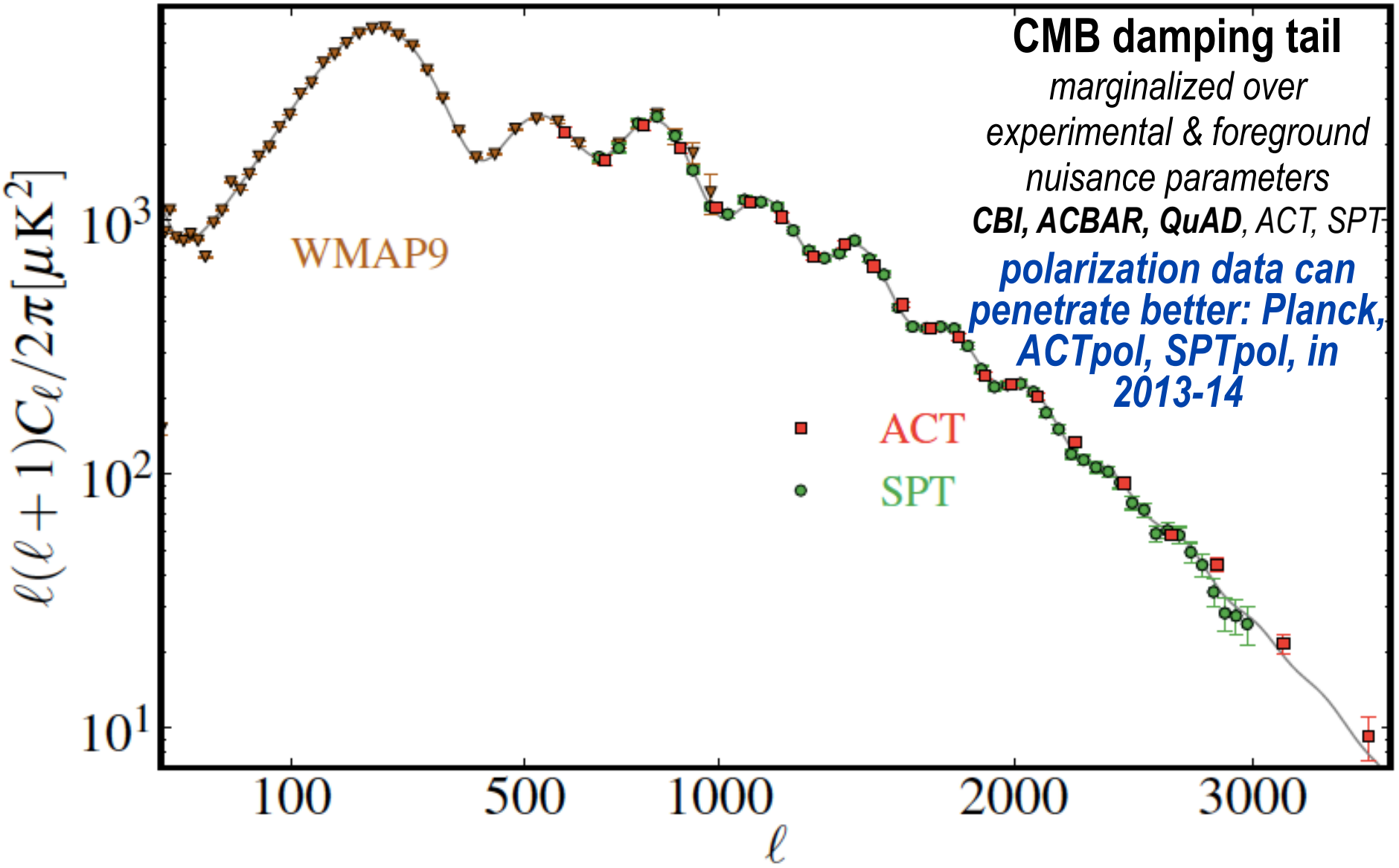
CMB Power Spectrum Propaganda: best fit basic 6 cosmic parameter model. Superb fit



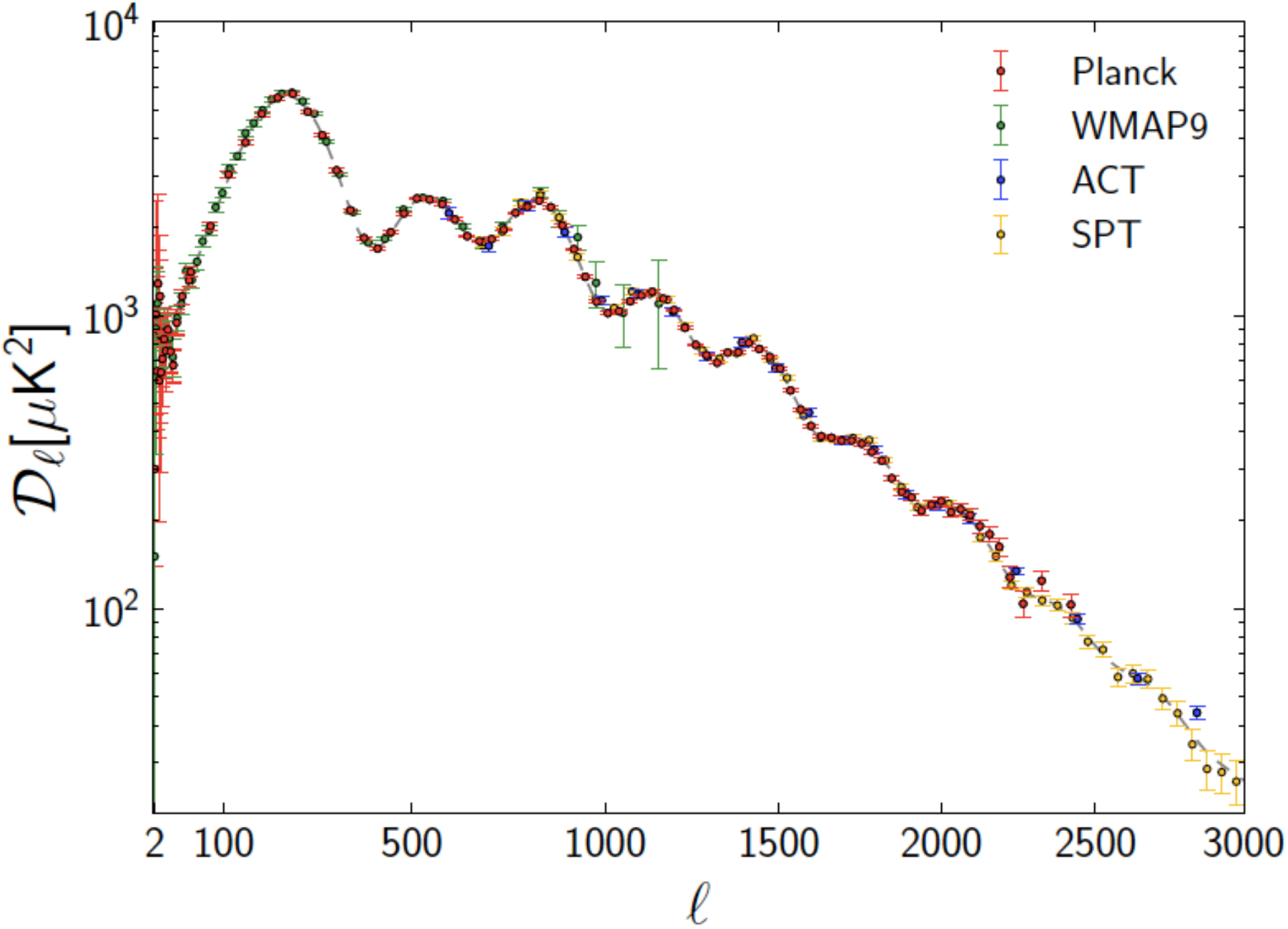


Excellent agreement between the Planck temperature spectrum at high l and the predictions of the tilted ΛCDM model.
Checks with polarization data provide full support to this conclusion.
extensive grid of cosmic models strongly constrain the x in tilted ΛCDM +x, x = subdominant deviations
Planck basic parameters (Ω_b, H_o ...), agree with BBN, BAO measure of acoustic scale. but H_o lower than HST, small age change
No evidence for additional neutrino-like relativistic particles beyond the three families of neutrinos in the standard model.
The first 30 multipoles are low for the standard ΛCDM, with no obvious explanation.
Exact scale invariance ruled out, $n_s < 1$, at >4σ Planck alone, >5.4σ Planck + WMAP polarization
No substantial evidence for beyond basic single field slow roll, Bunch-Davis vacuum, standard kinetic term inflation. f_{NL}

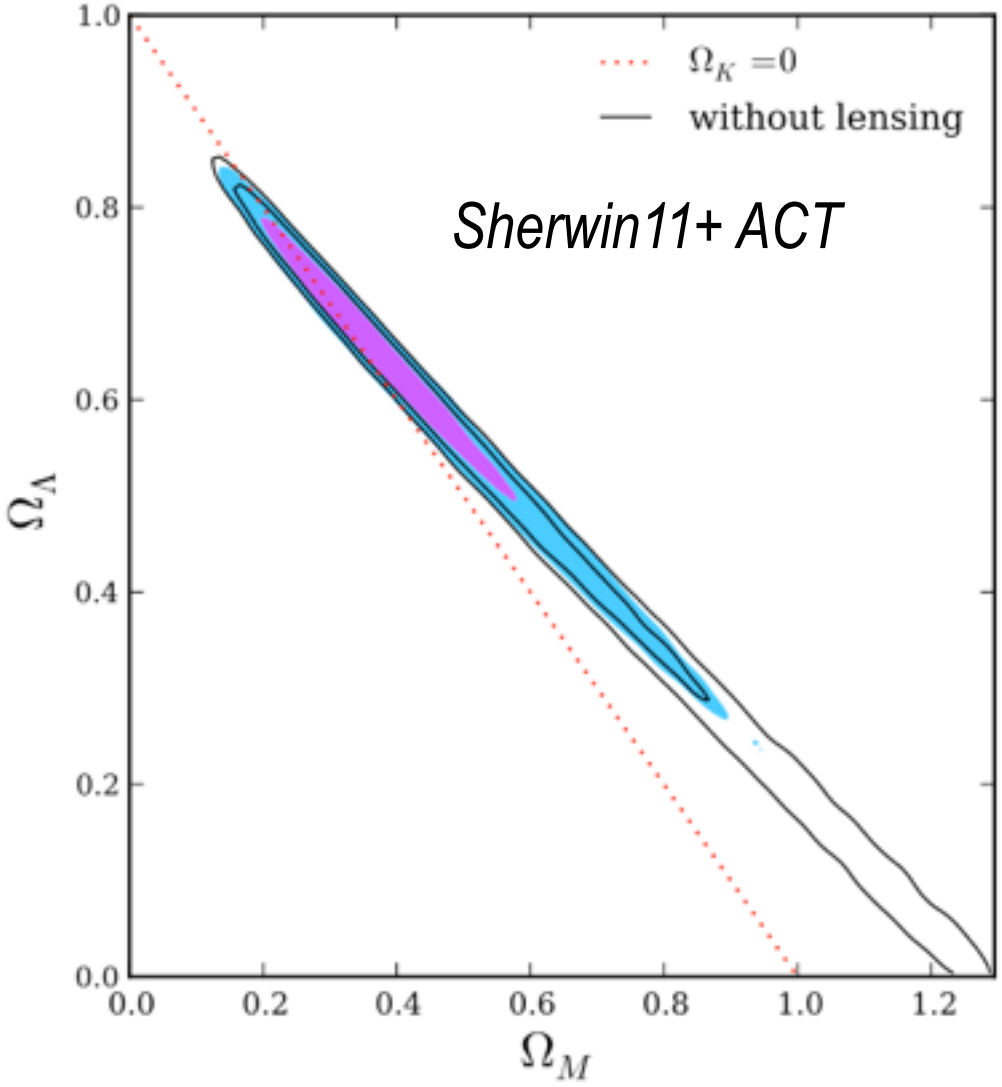
Calabrese+12 our ACT12,SPT12,WMAP9 *CMB grand unified spectra*



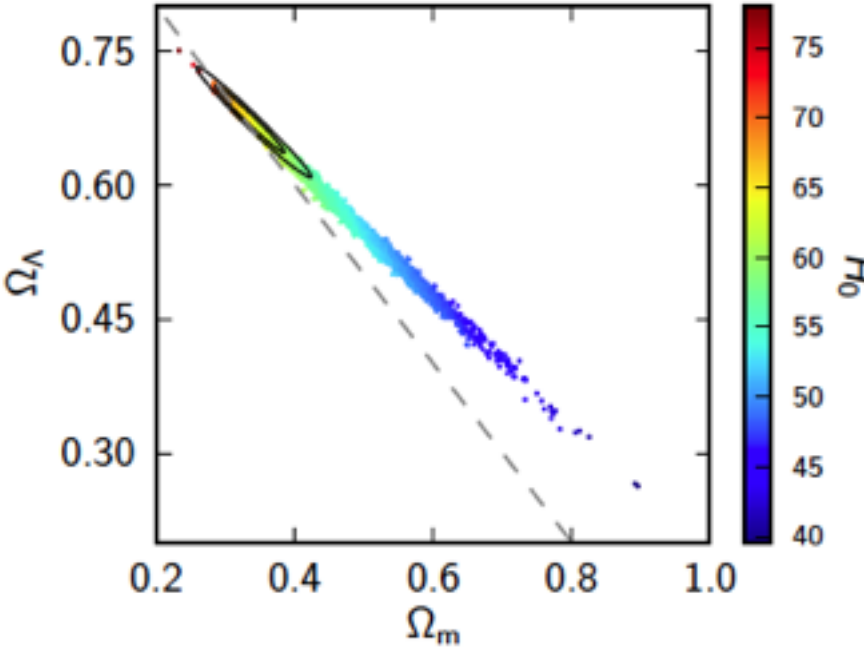
the **sound** of the **machine: replay**



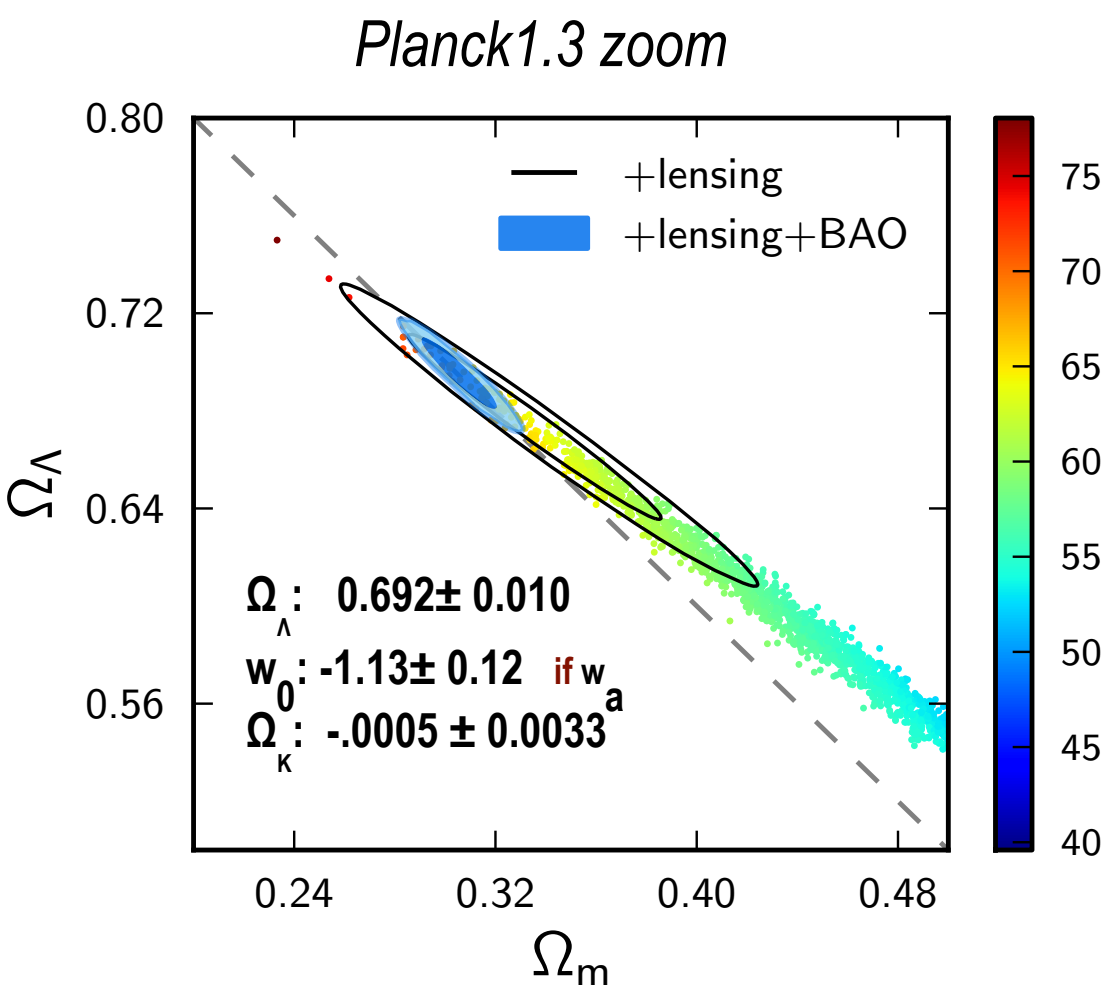
lensing breaks geometrical degeneracy: WMAP+ACT+ACTlens alone cf. Planck alone cf. Planck+BAO

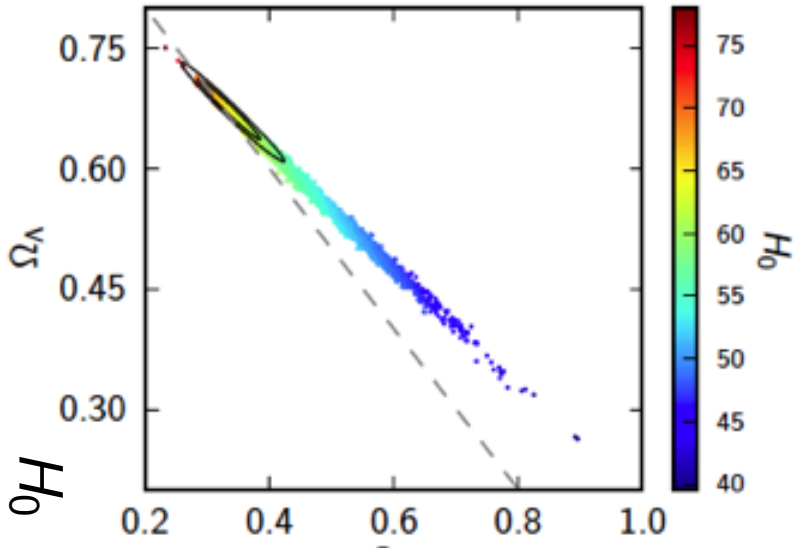


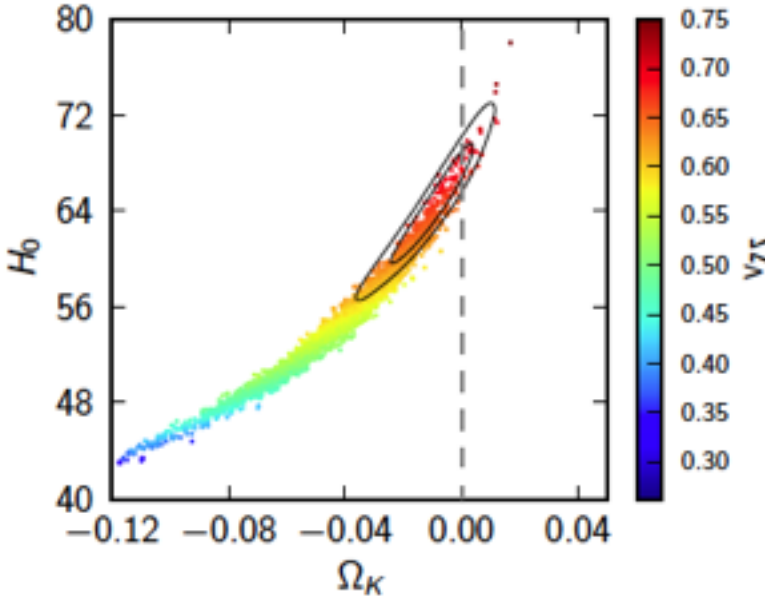
Planck1.3



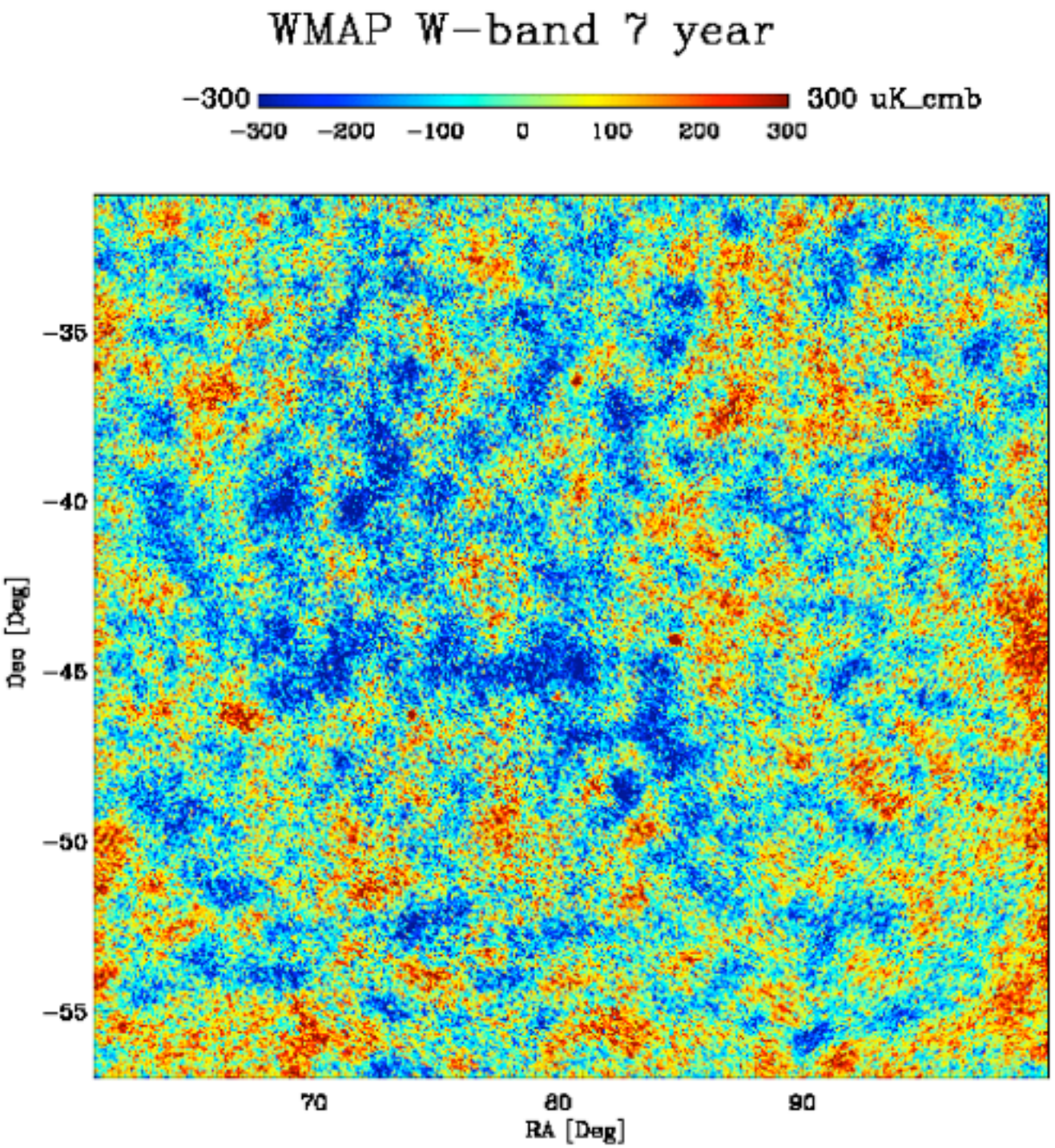
lensing breaks geometrical degeneracy: Planck alone cf. Planck+BAO





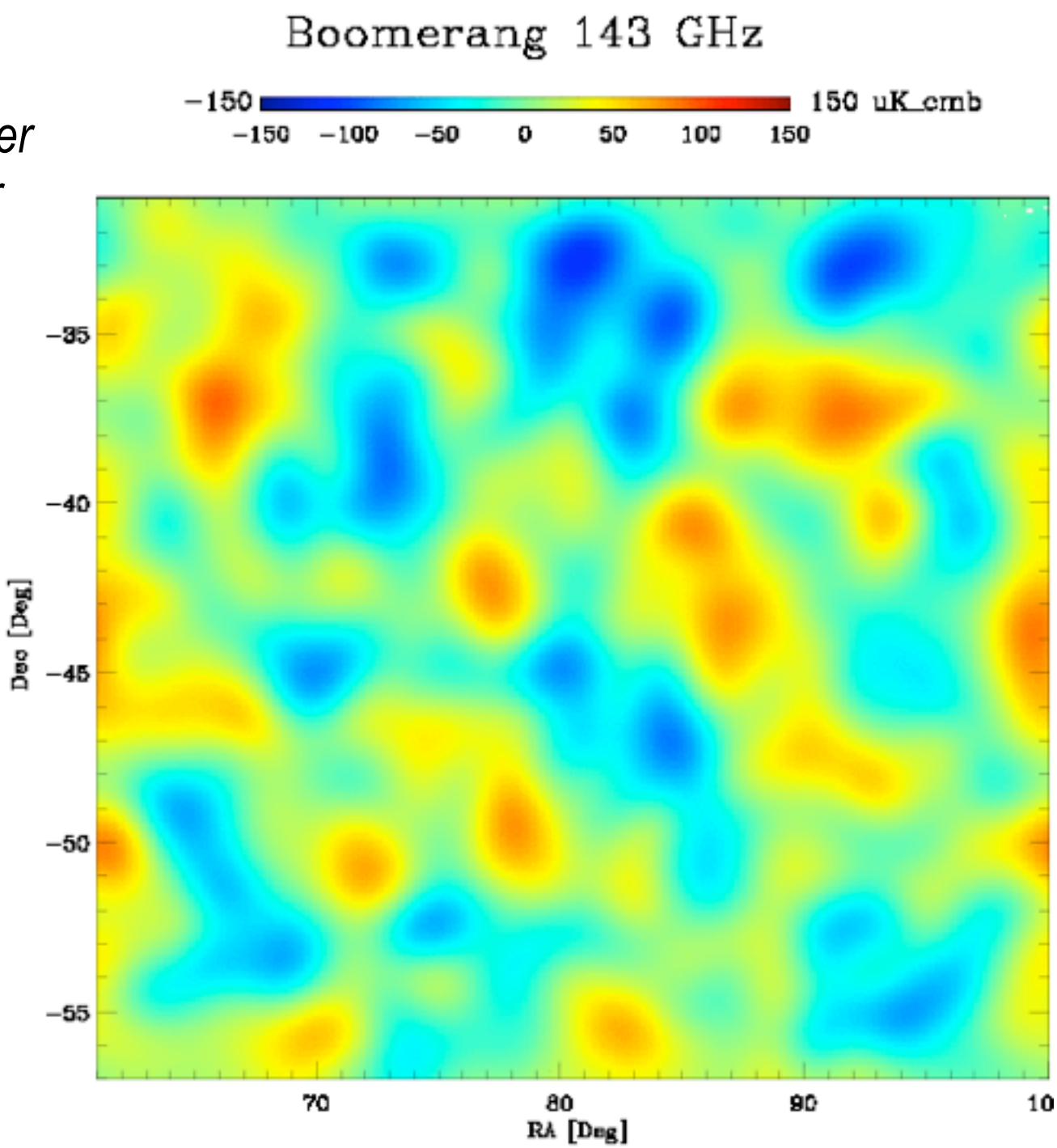


WMAP vs Boomerang03 vs HFI Planck1.3



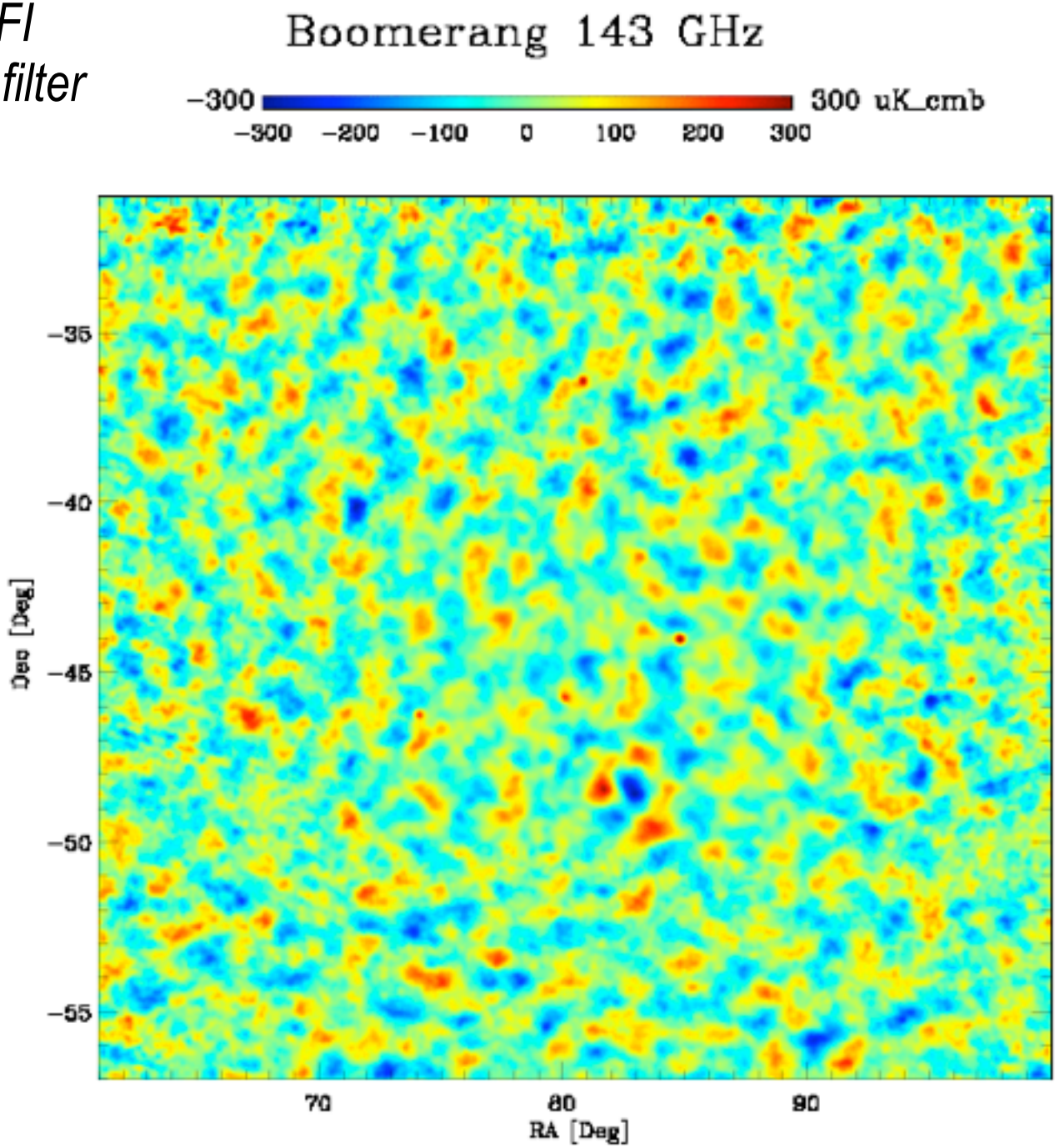
Jones13

Boom vs HFI
SachsWolfe filter
low pass filter



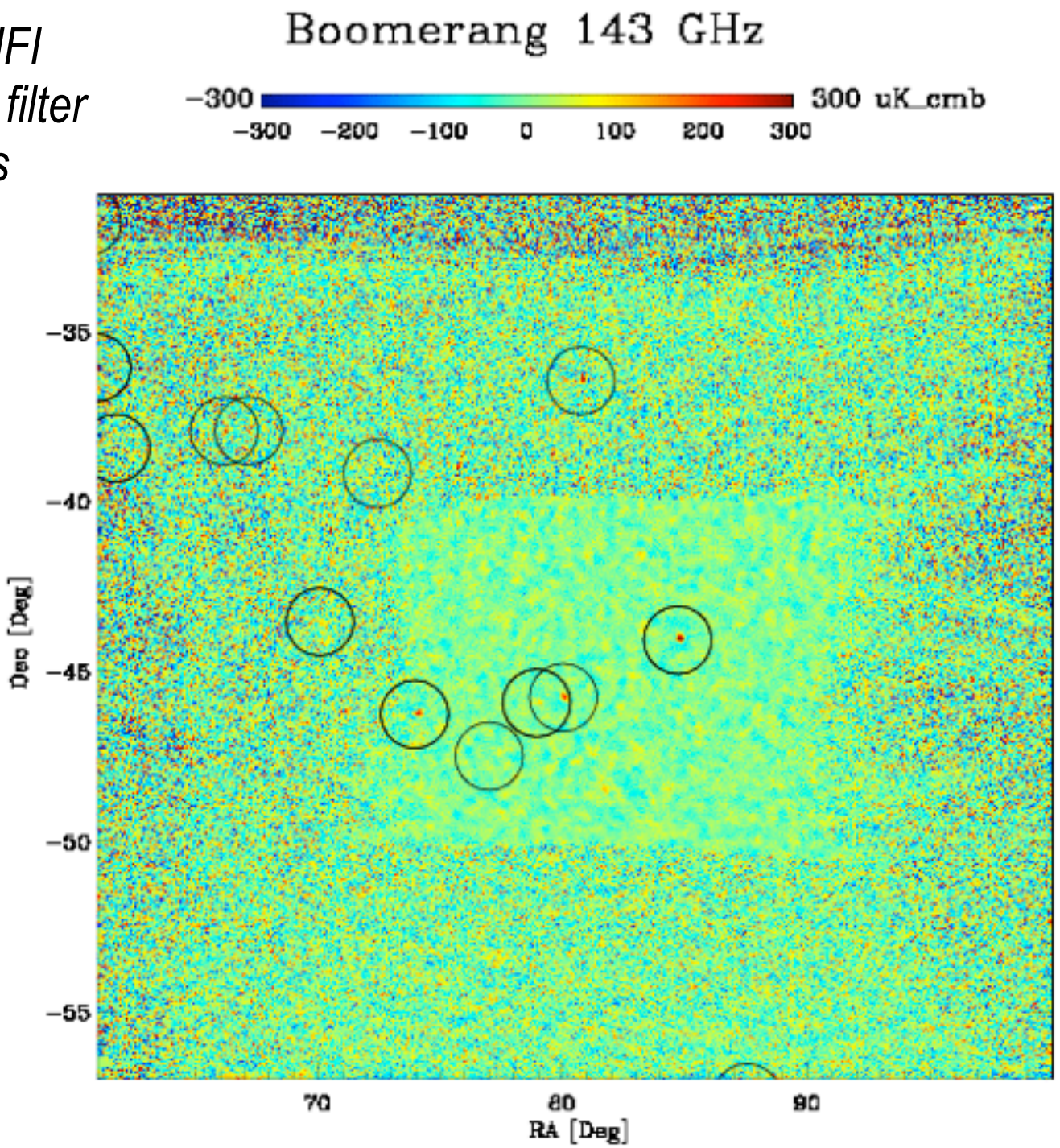
Jones13

Boom vs HFI
medium pass filter



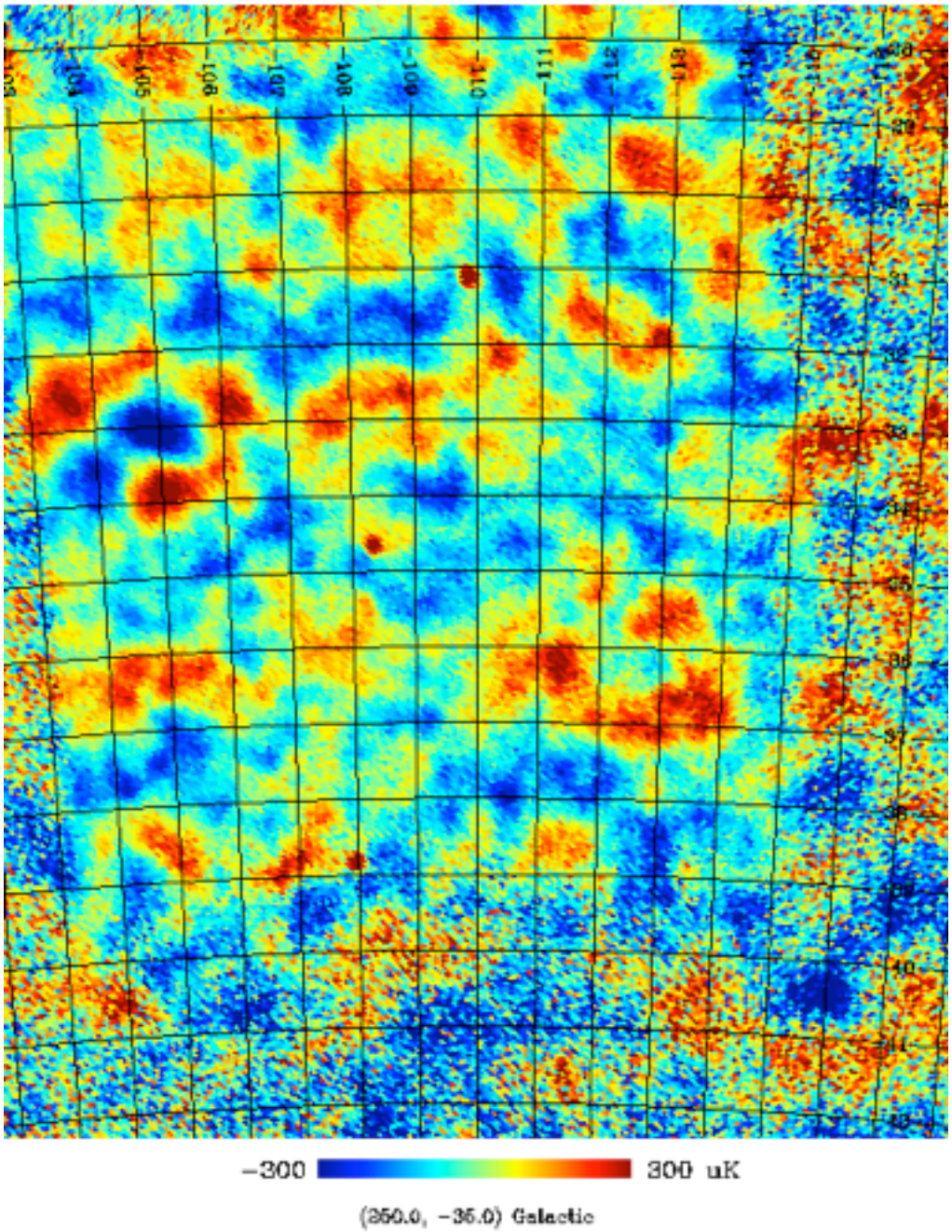
Jones13

Boom vs HFI
Silk damping filter
high pass

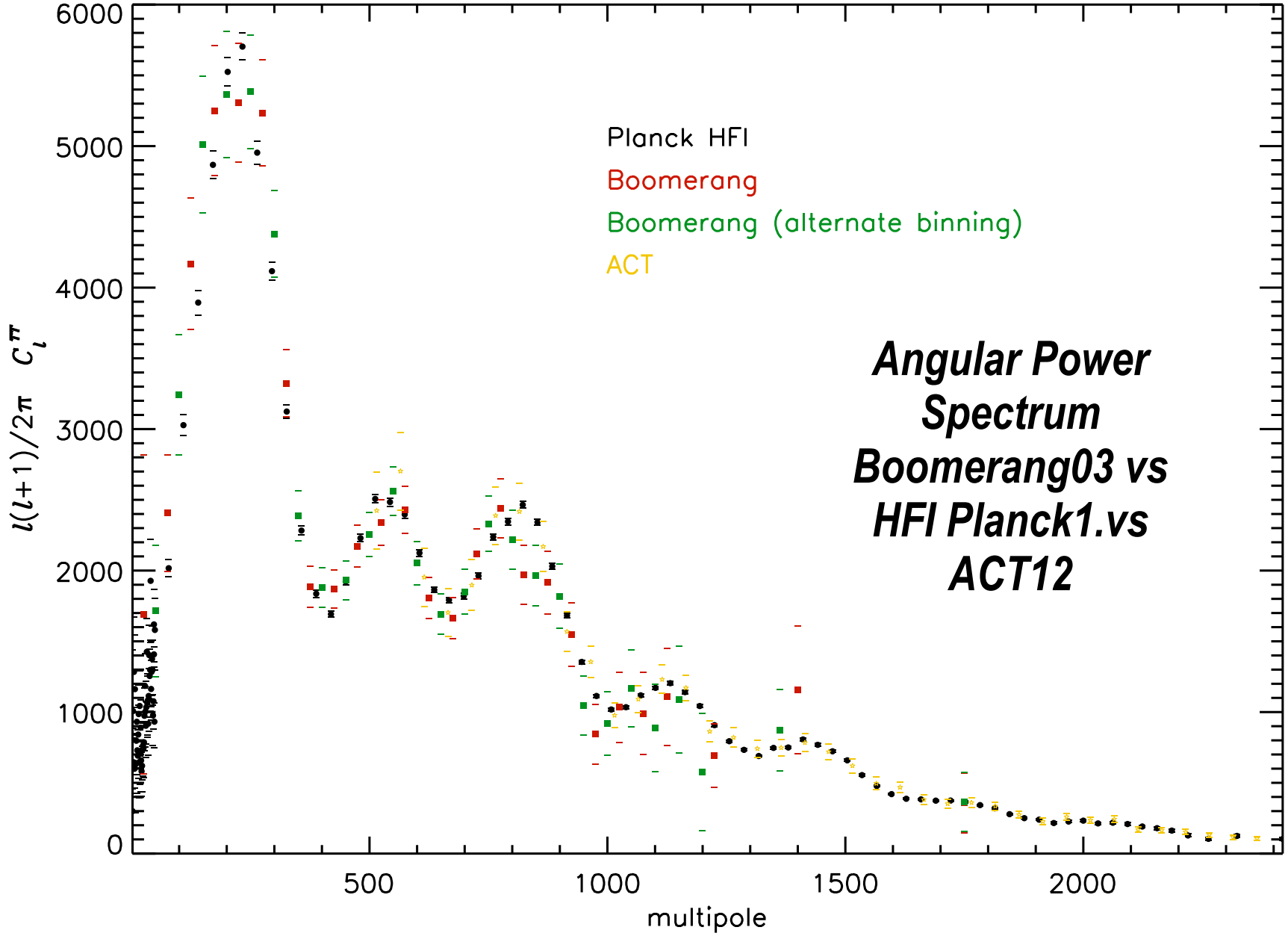


Jones13

WMAP vs Boomerang03 vs HFI Planck1.3



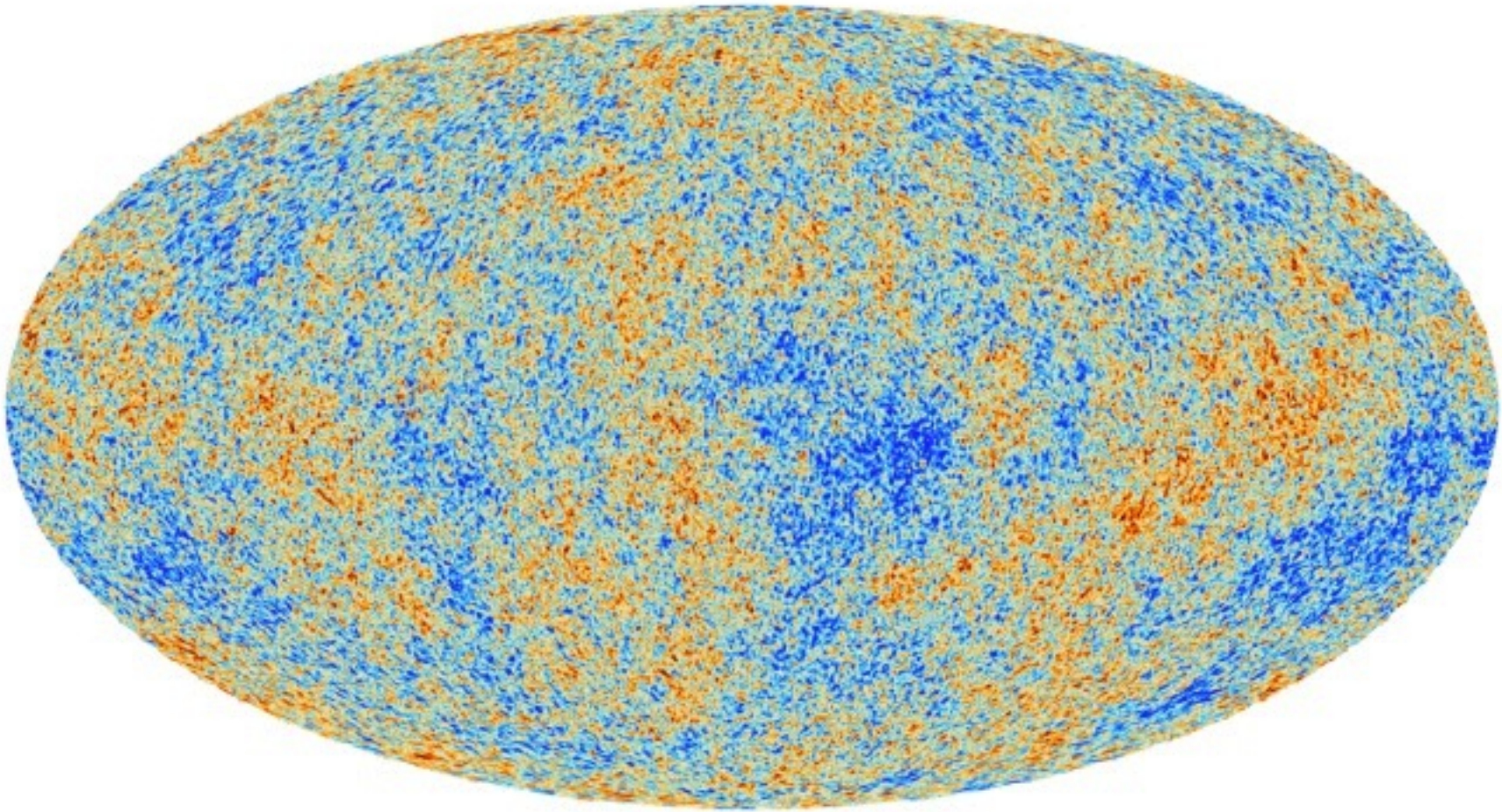
Piacentini13


Planck HFI
Boomerang
Boomerang (alternate binning)
ACT
Angular Power Spectrum Boomerang03 vs HFI Planck1.vs ACT12
$l(l+1)/2\pi \quad C_l^{TT}$
multipole
0
1000
2000
3000
4000
5000
6000
500
1000
1500
2000

reveals **primordial sound waves**

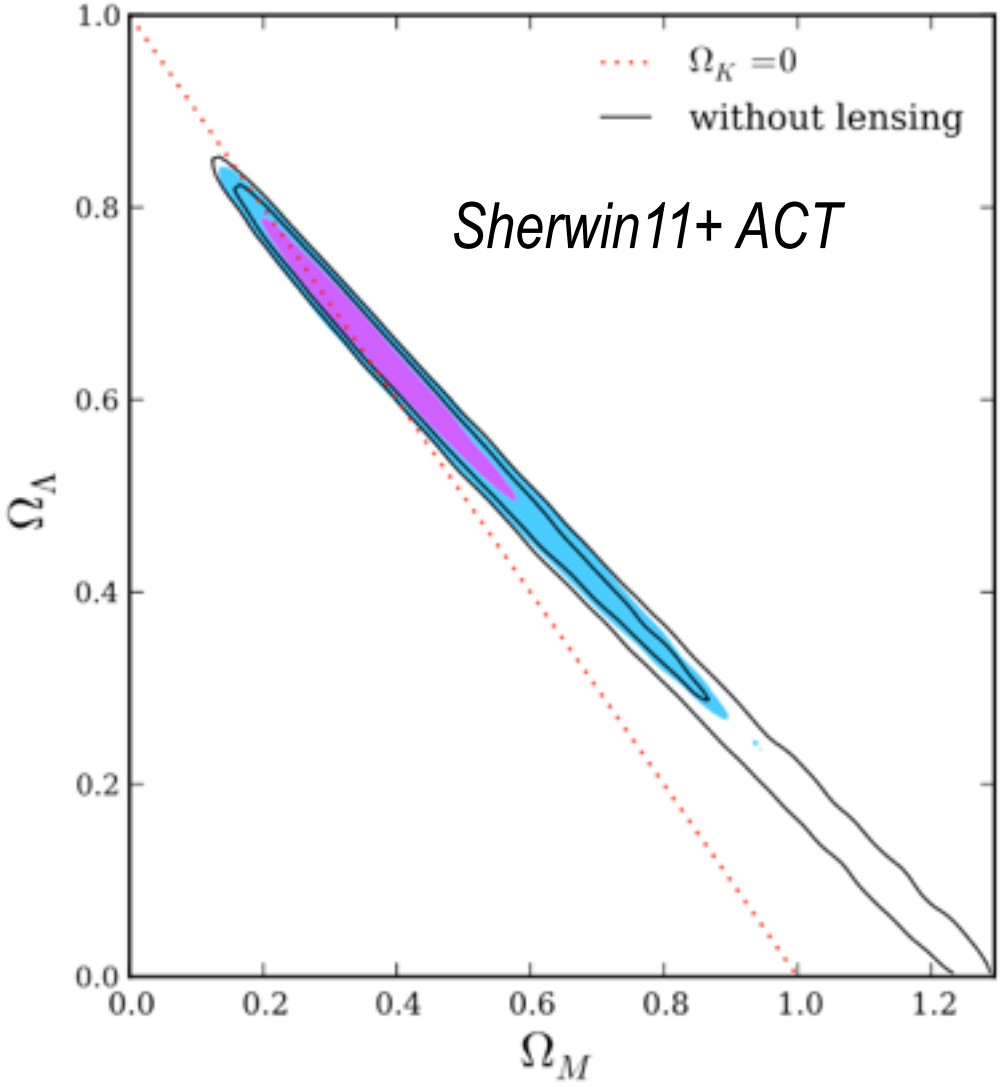
=> the inharmonious *'music of the spheres'*

in 7^{+} numbers

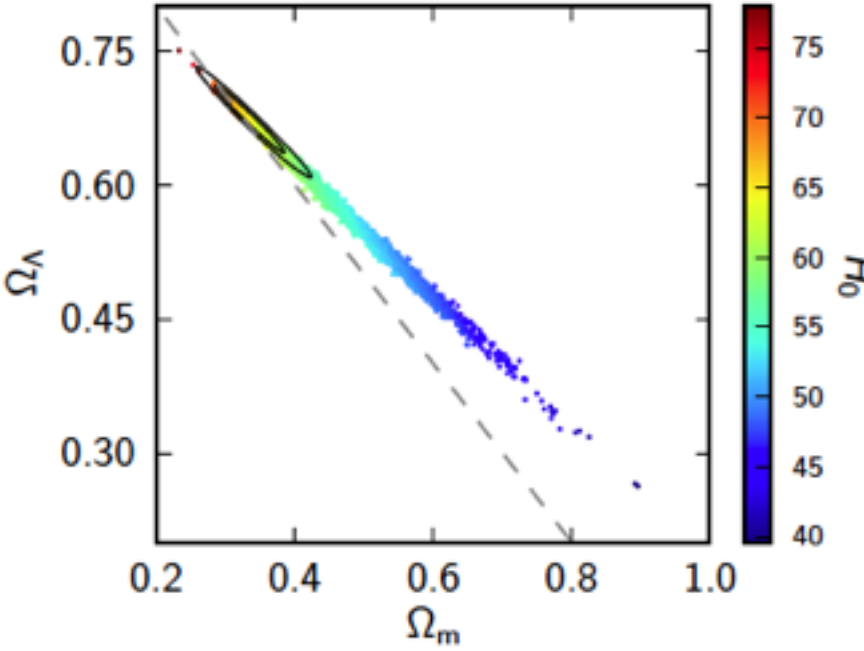


Temperature changes
in micro-degrees

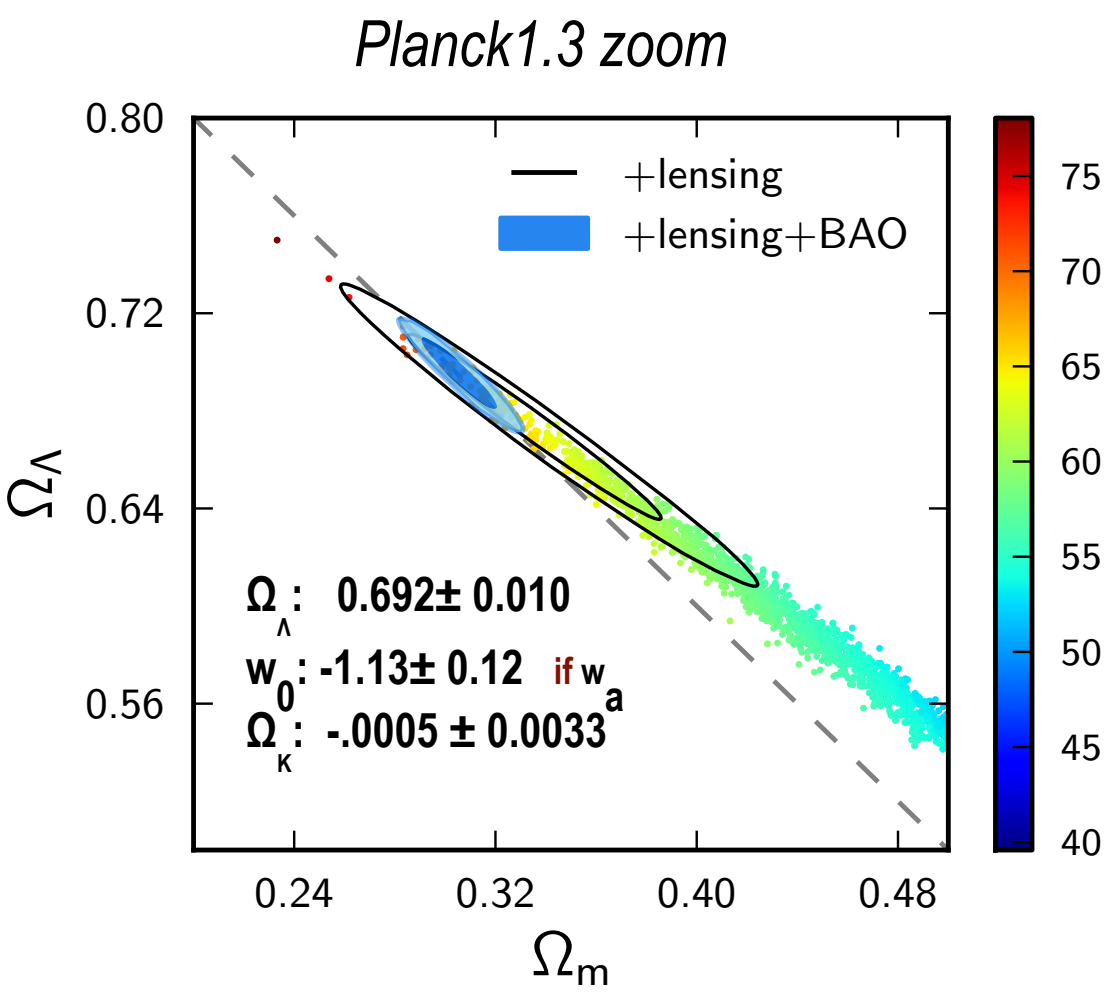
lensing breaks geometrical degeneracy: WMAP+ACT+ACTlens alone cf. Planck alone cf. Planck+BAO

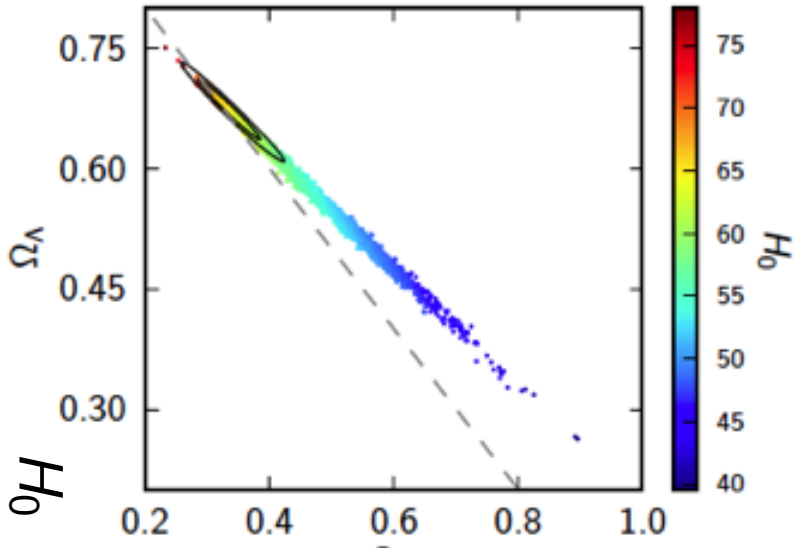


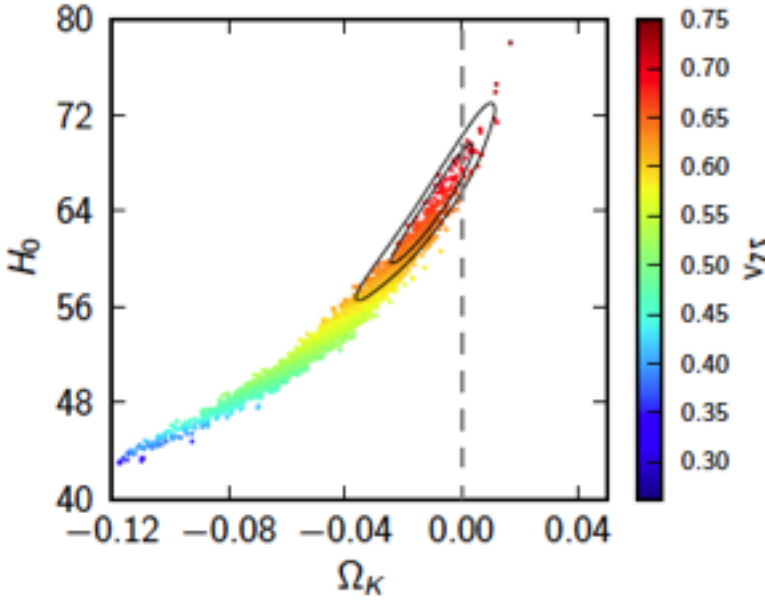
Planck1.3



lensing breaks geometrical degeneracy: Planck alone cf. Planck+BAO

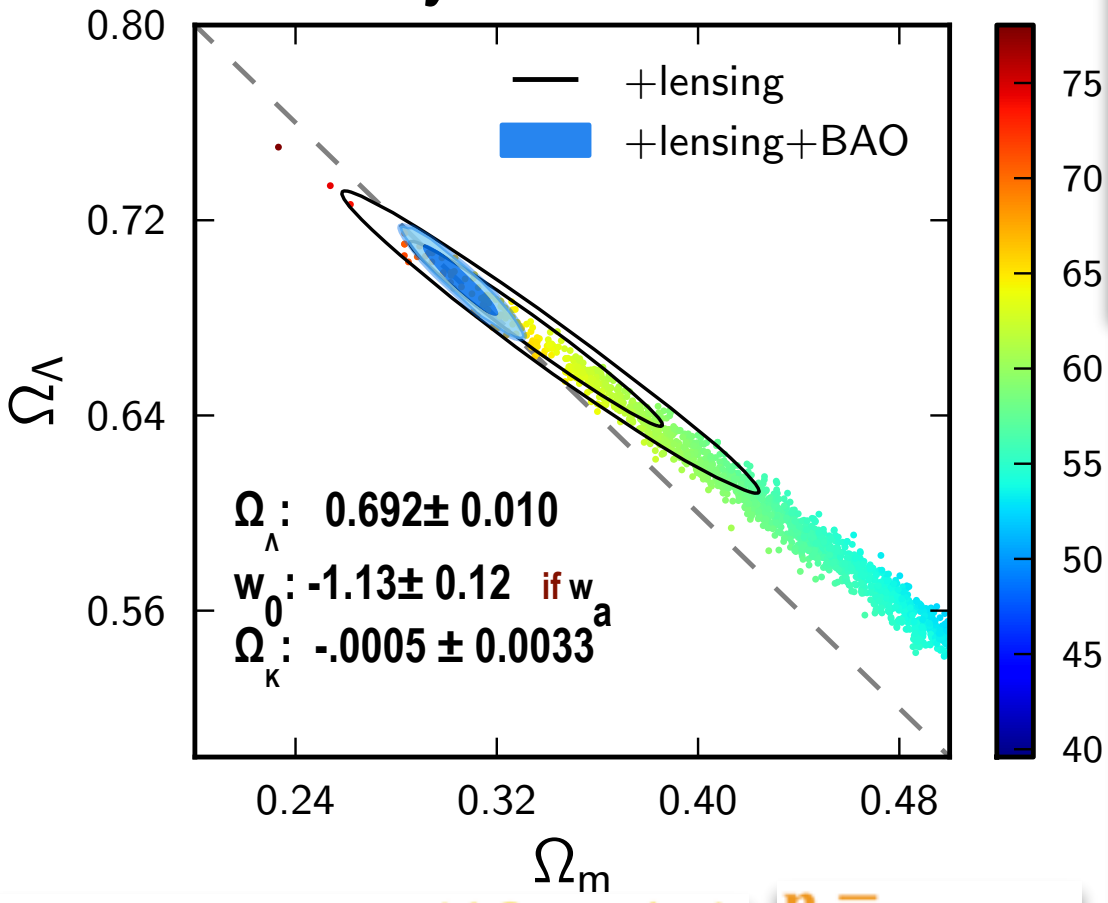




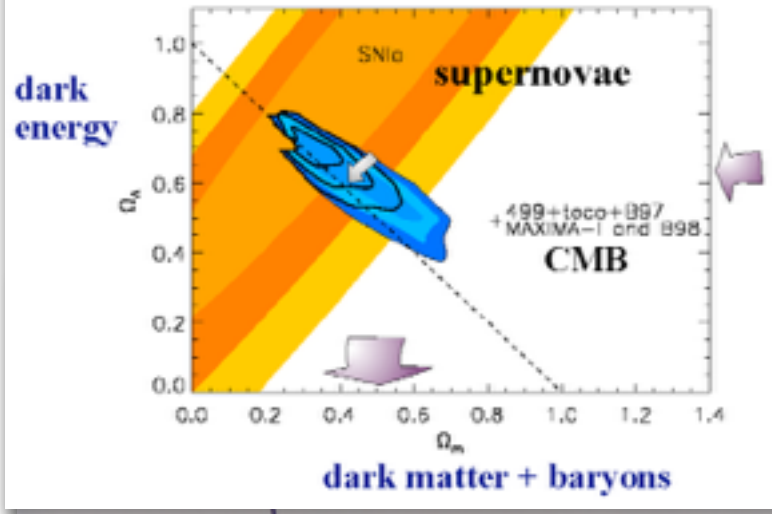


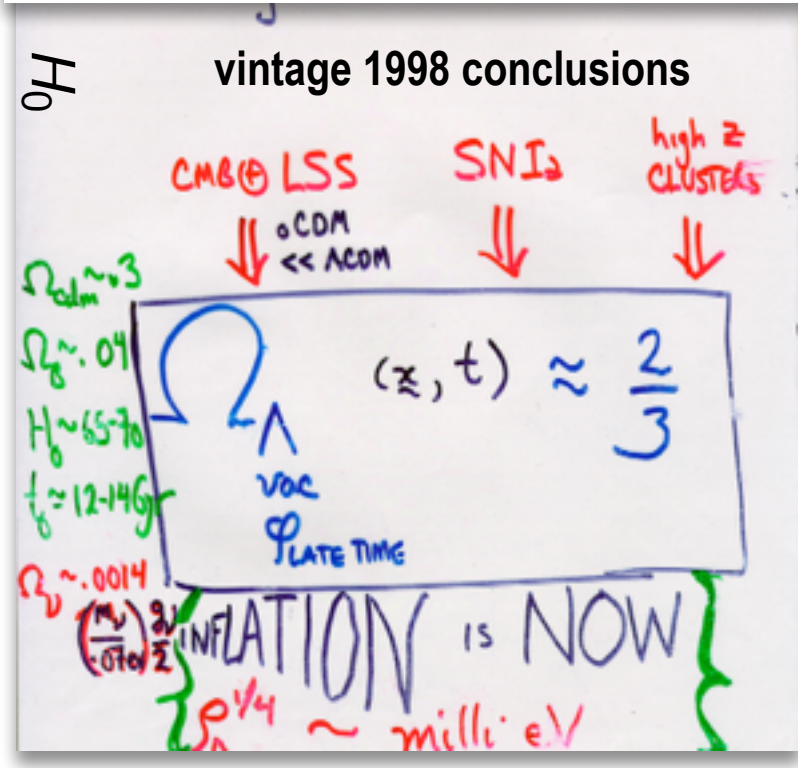
lensing breaks geometrical degeneracy:
Planck alone cf. Planck+BAO

Planck1.3 cf. CMB+LSS
history of $\Omega_\Lambda = PE_{de}/E_{crit}$



BOOM 2000



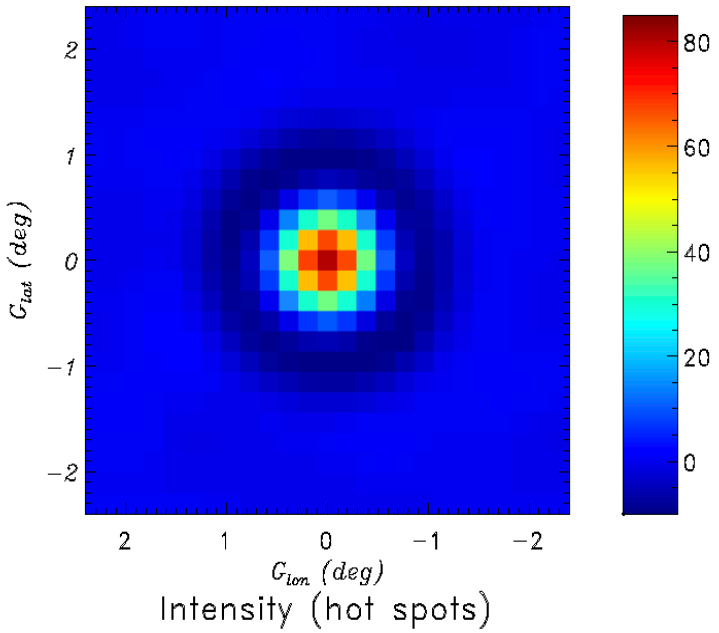


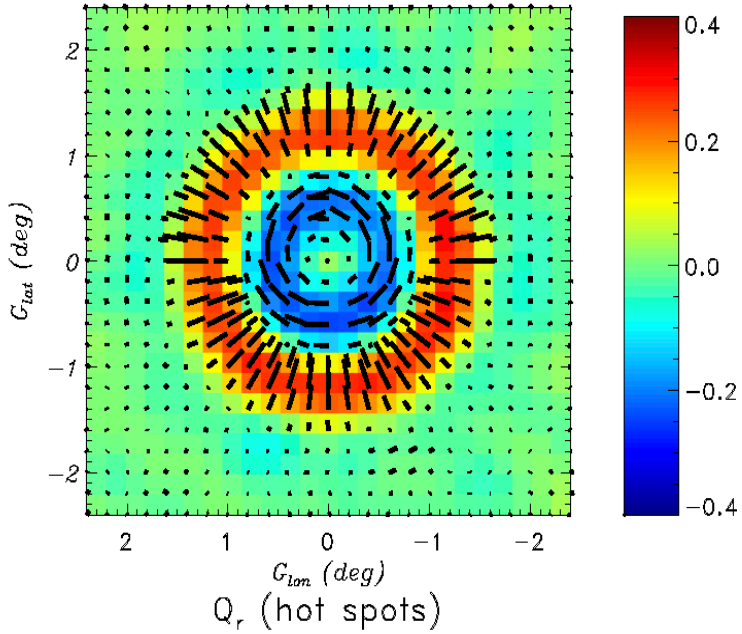
B+Jaffe'96,'98

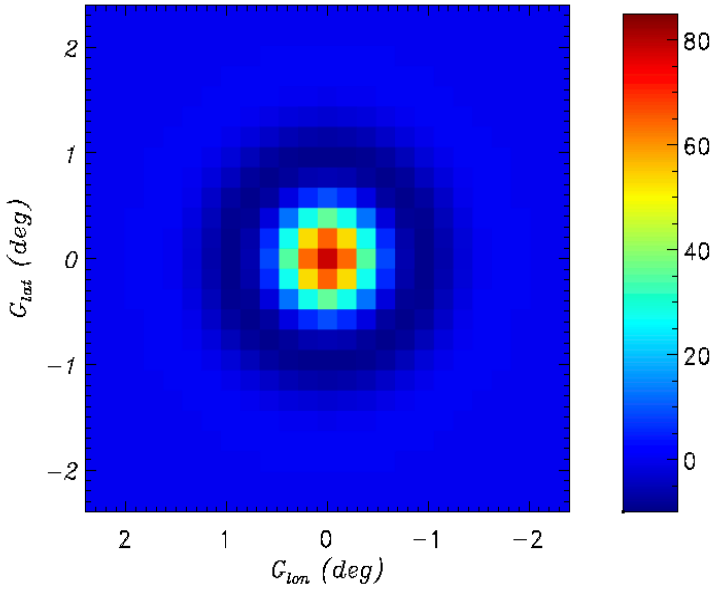
$\Omega_\Lambda \approx 2/3 \pm .07$ +LSS

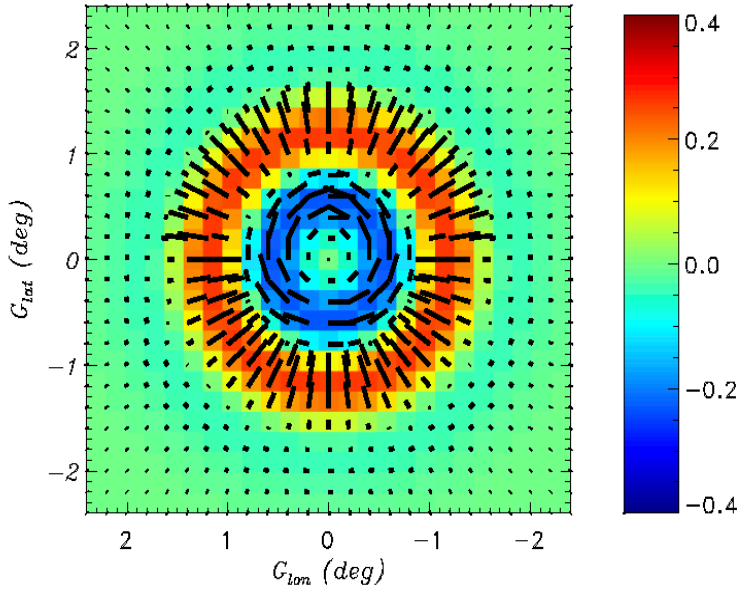
$n_s =$
$.98 \pm .07$
$.96 \pm .06$

P1.3: stacked intensity and polarization around hot & cold spots: data vs simulation



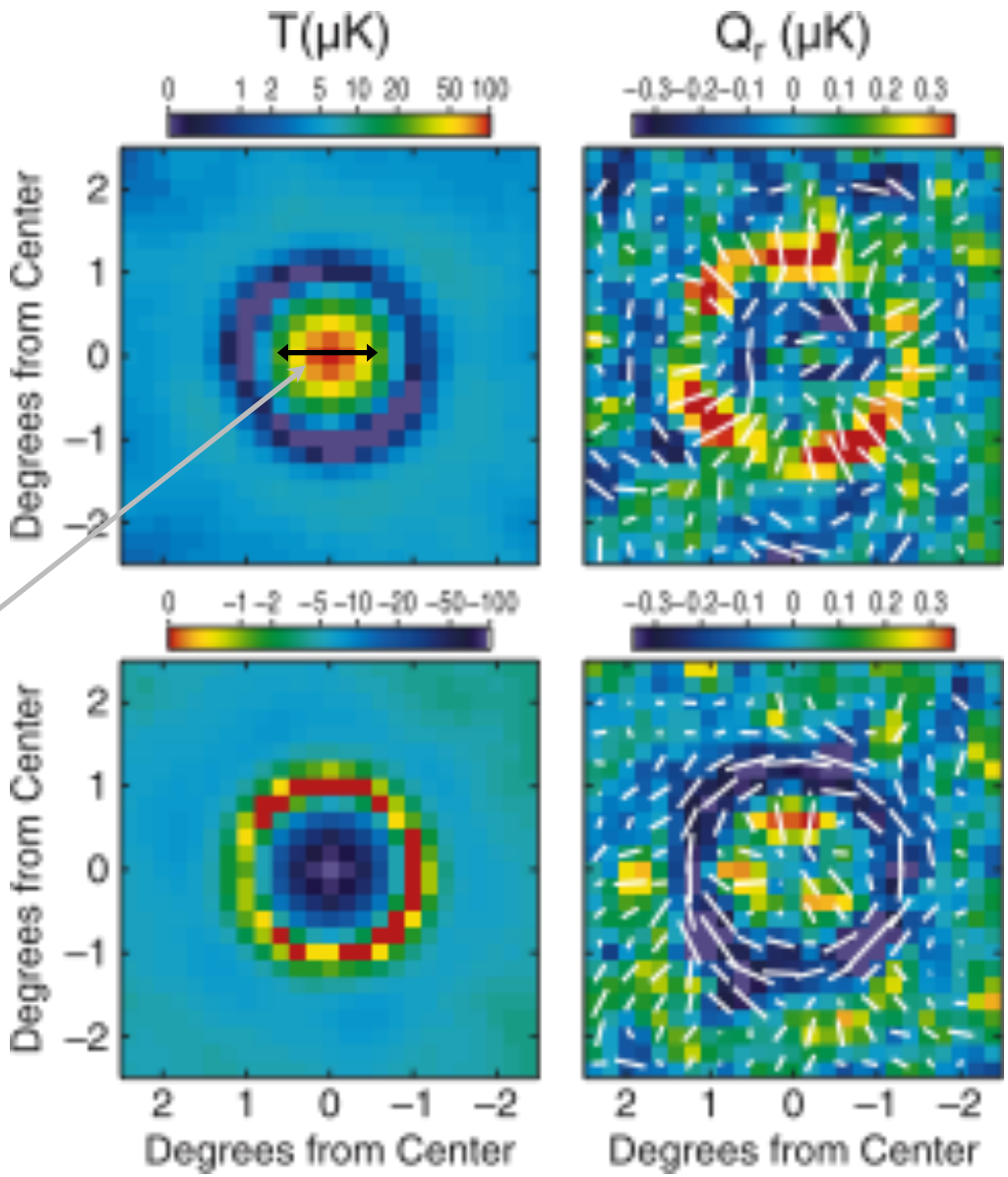




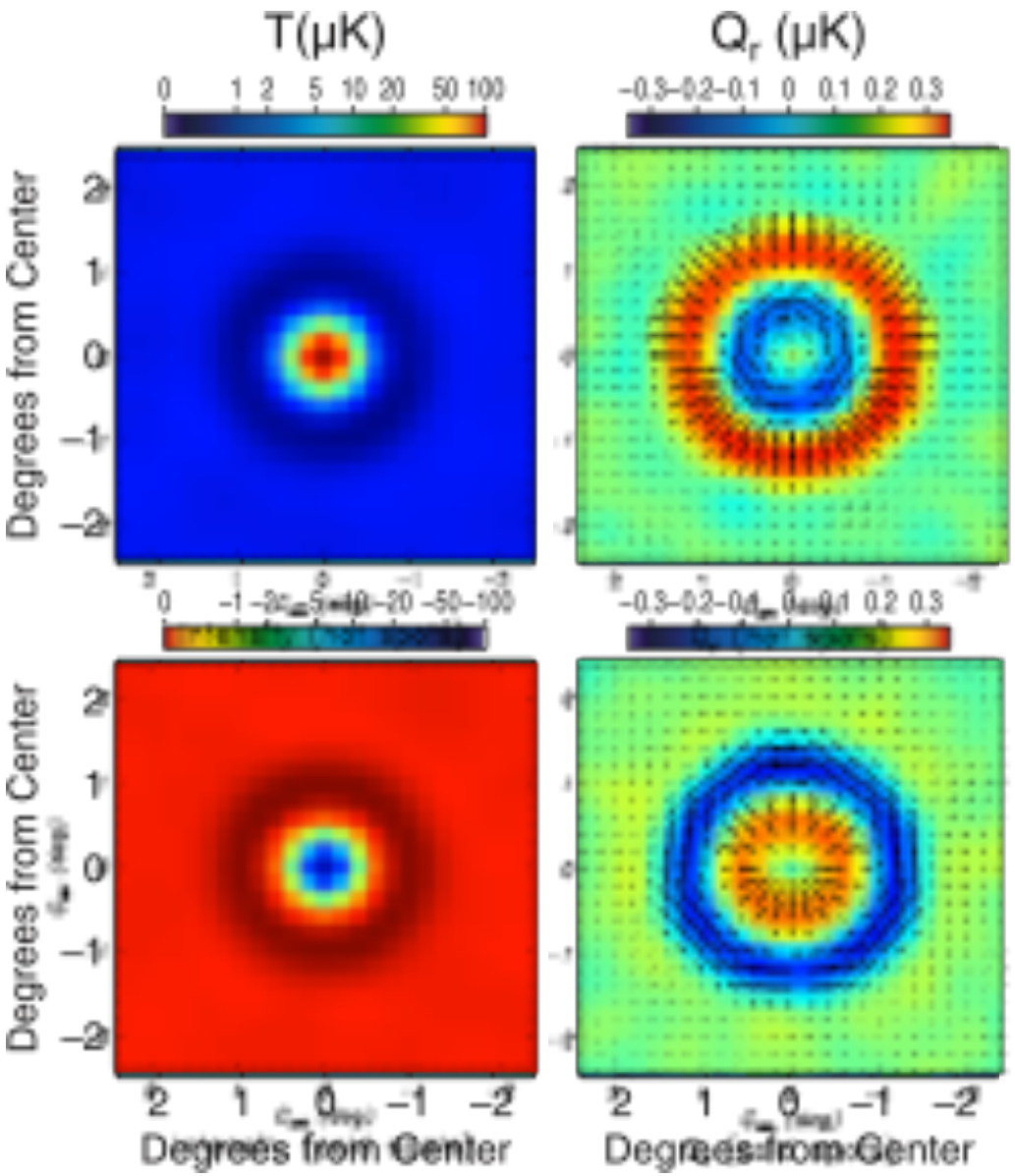


BAO in the CMB – WMAP

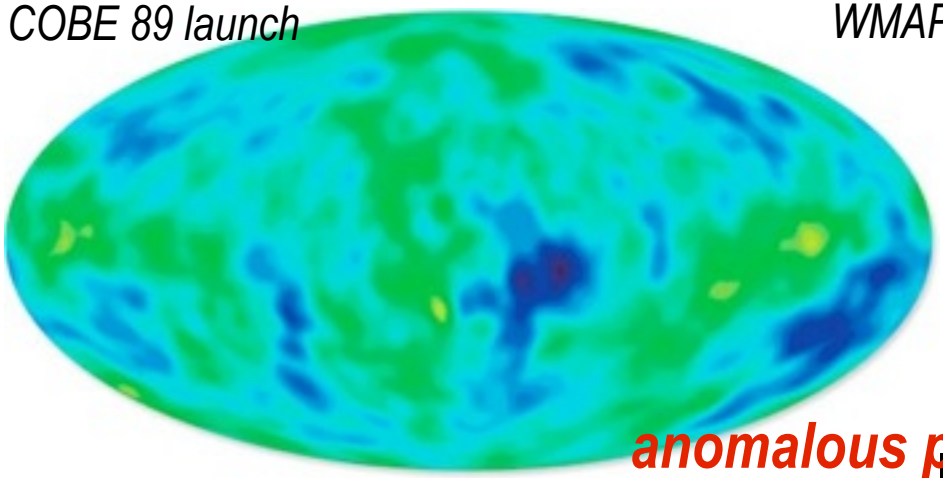
BAO scale:
145.8 ± 1.2 Mpc



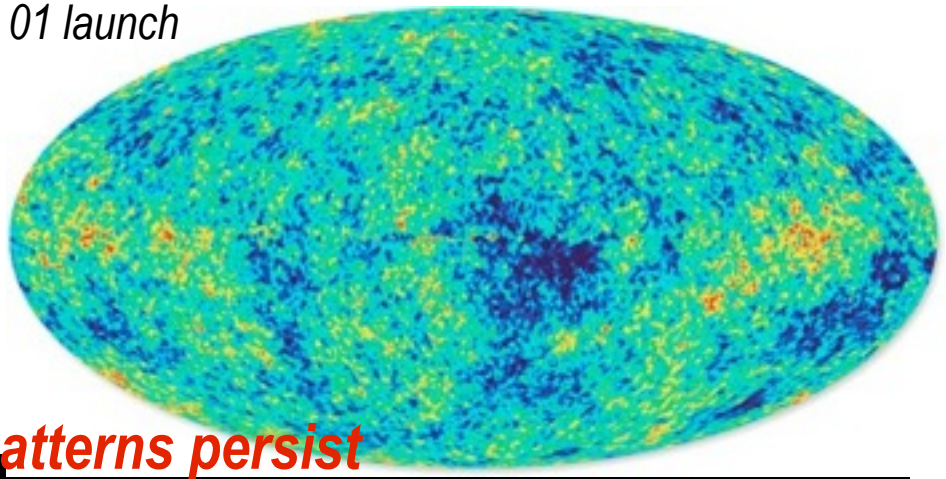
BAO in the CMB – Planck



COBE 89 launch

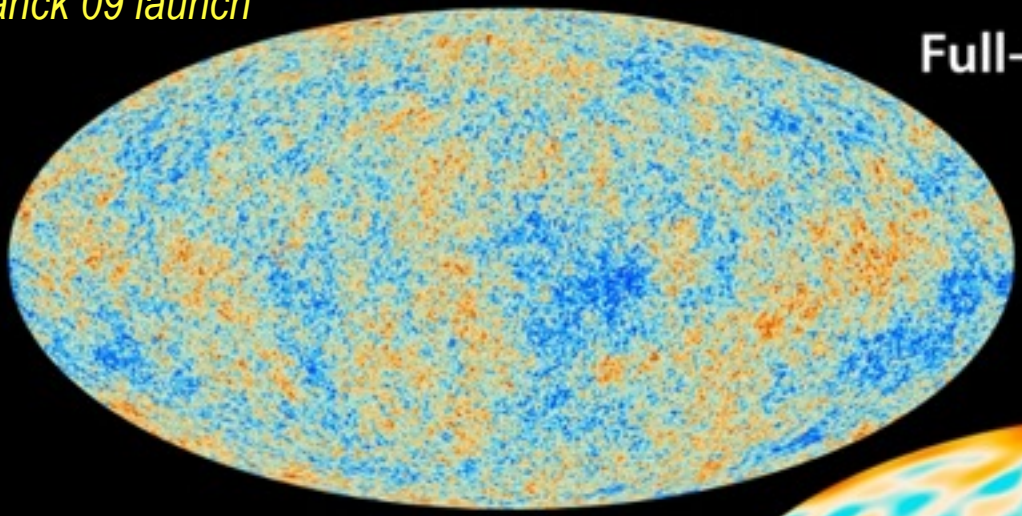


WMAP 01 launch

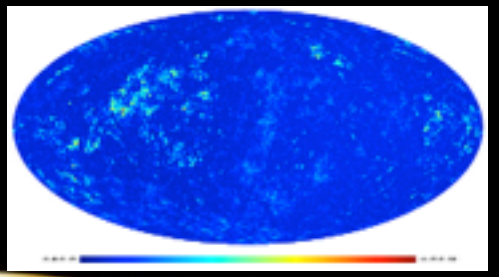


anomalous patterns persist

Planck 09 launch

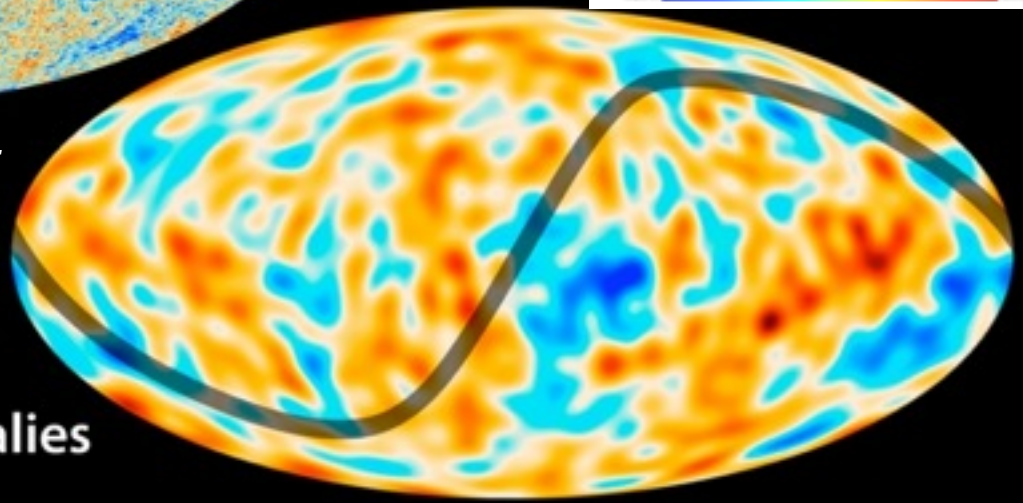


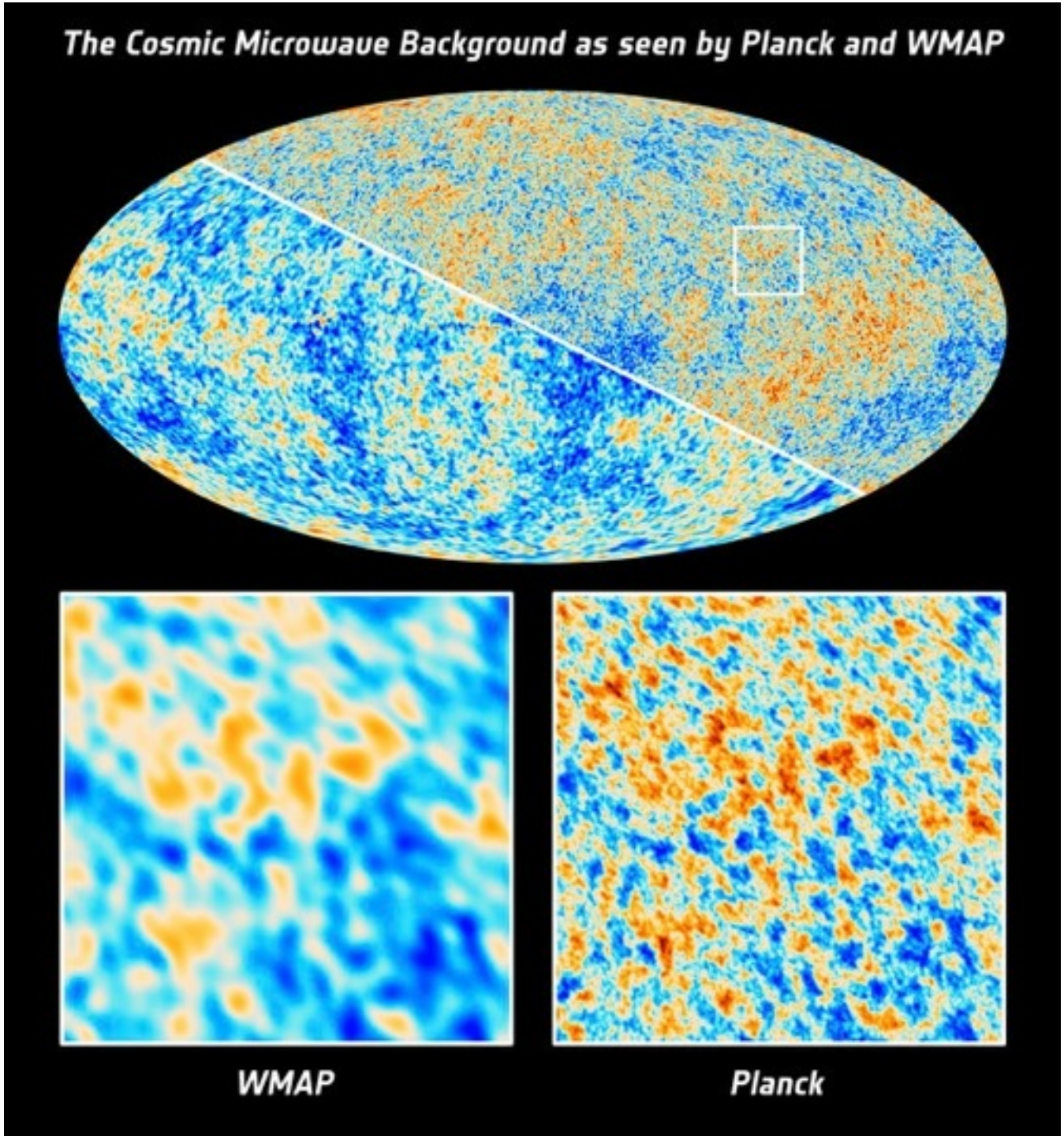
***maybe* a super-bias of ULSS & LSS fields modulating preheating: intermittency from rare event nonG tails**



a homogeneous, anisotropic Bianchi VII$_h$ model: ultralarge scale rotation/vorticity and shear, *fit parameters require high curvature -* ***crazy***

Grand Unified Theory of Anomalies still TBD




The Cosmic Microwave Background as seen by Planck and WMAP
WMAP
Planck

SIMPLICITY

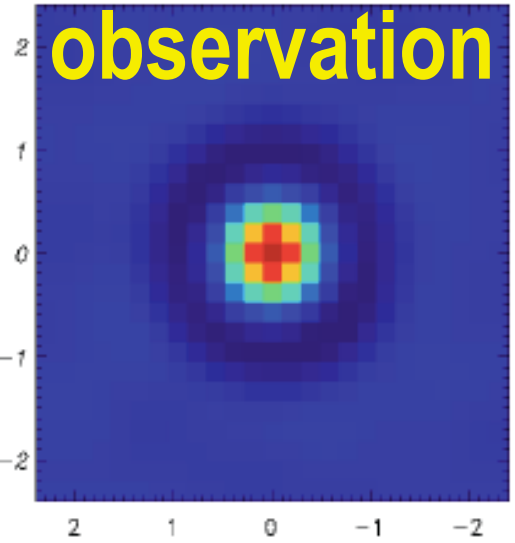
at $a \sim e^{-7} \sim 1/1100$ =>

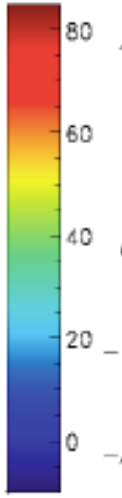
at $a \sim e^{-67+60} \sim 1/10^{30+25}$

reveals ***primordial sound waves*** *in matter*

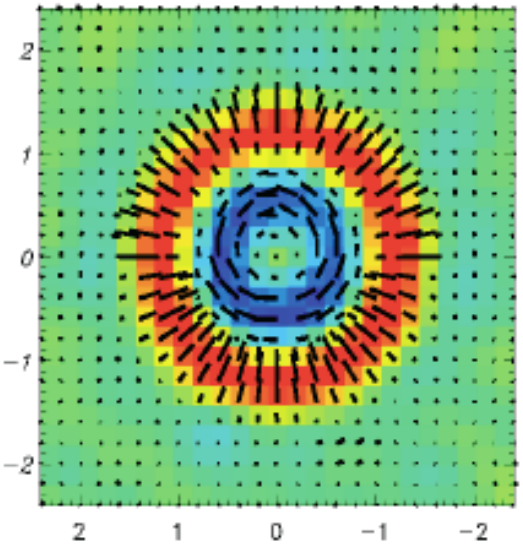
=> *learn* ***contents*** *&* ***structure*** *at 380000 yr,* $a \sim e^{-7}$

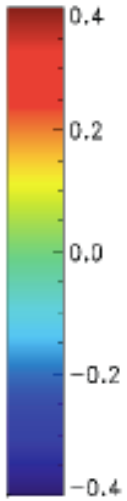
=> *infer the structure far far earlier* $a \sim e^{-67+60}$





$C_{T,pk}$





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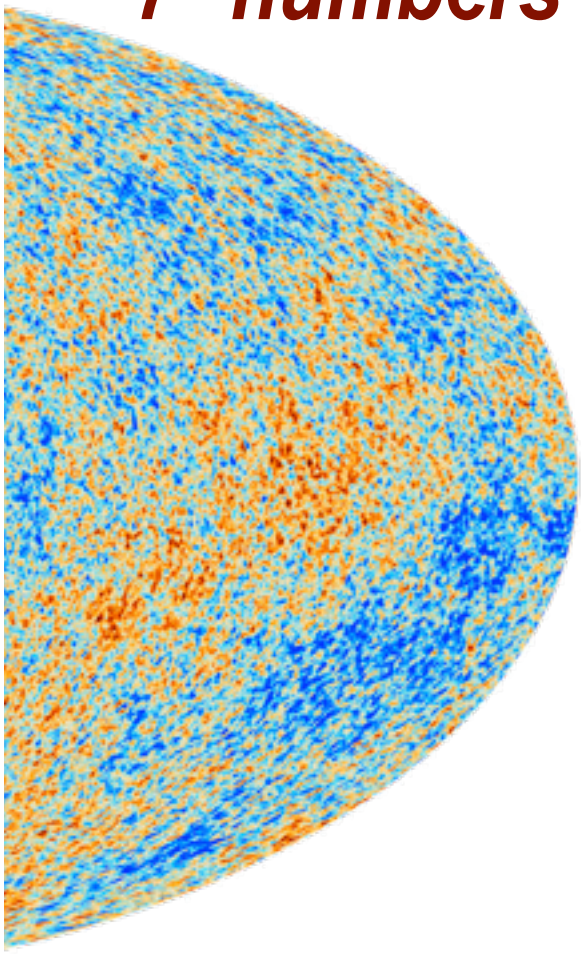
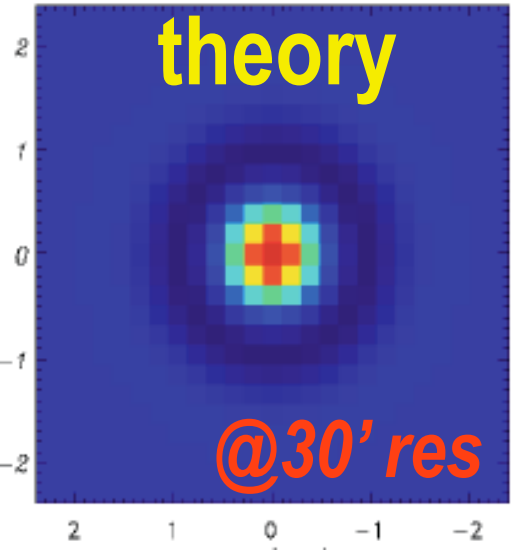
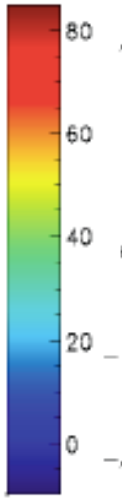
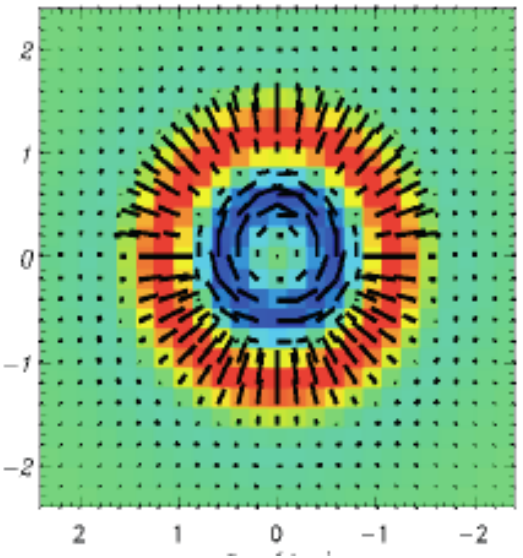
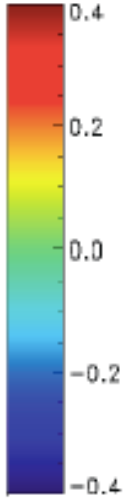








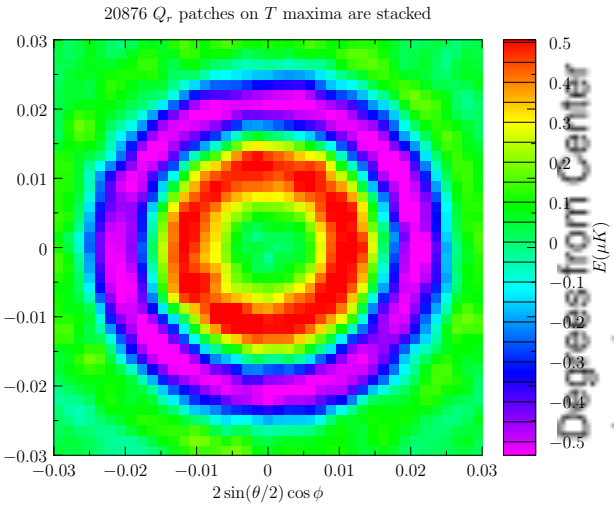


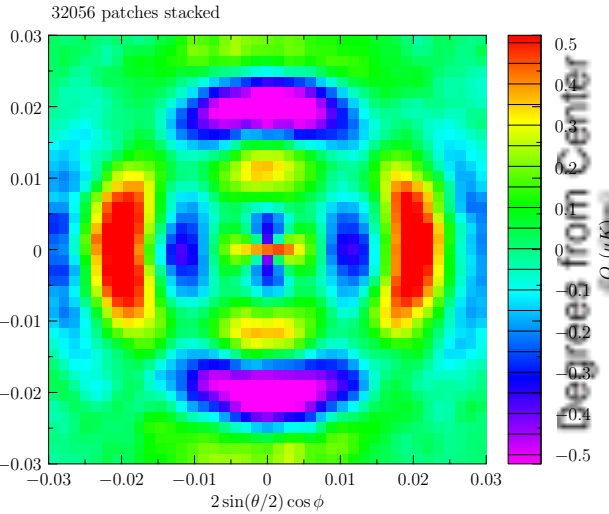
CMB Peak Statistics @CITA

CMB Polarization

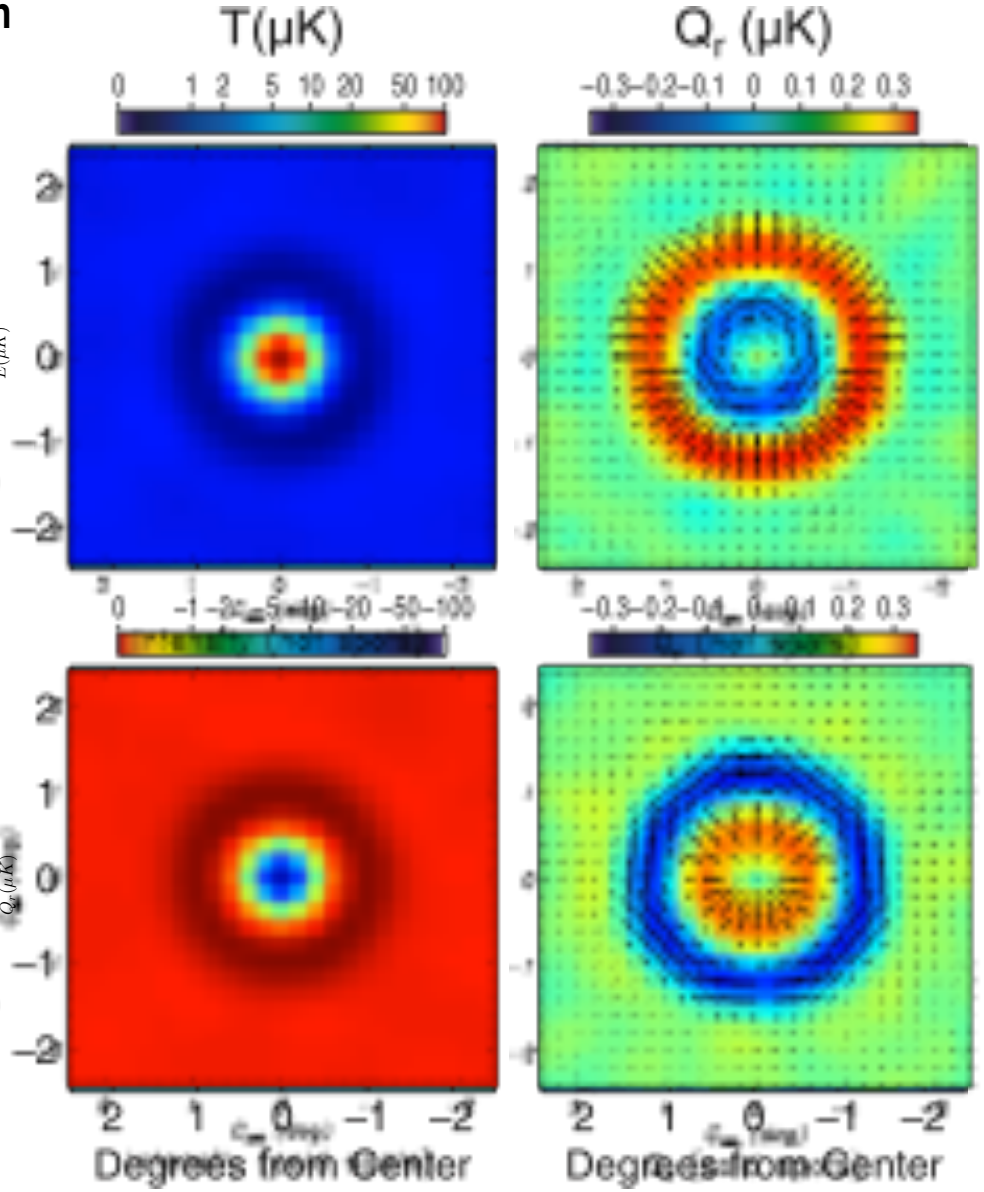
for ***Planck2014, 2015 ACTpol, ABS, Spider, AdvACT,*** *GLP, ..*

polarization rotated & stacked on temperature Peaks, L_S=300





polarization rotated & stacked on oriented anisotropic-strain-Peaks



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reveals primordial **sound waves** *in matter*

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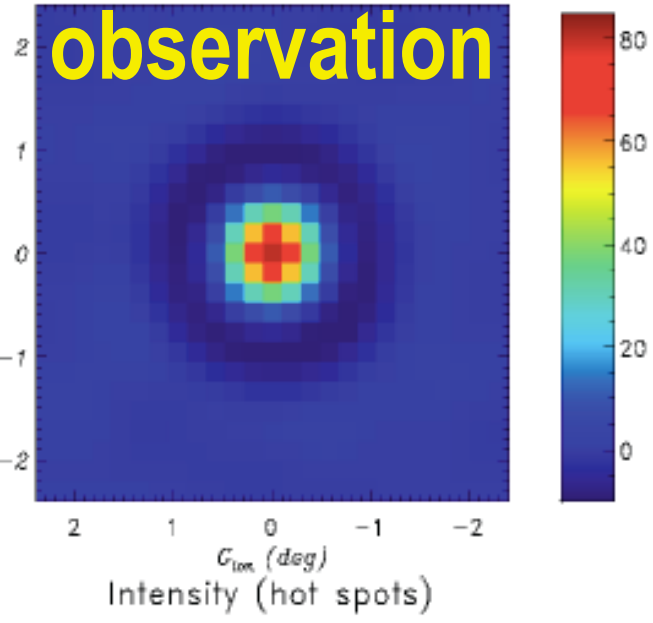
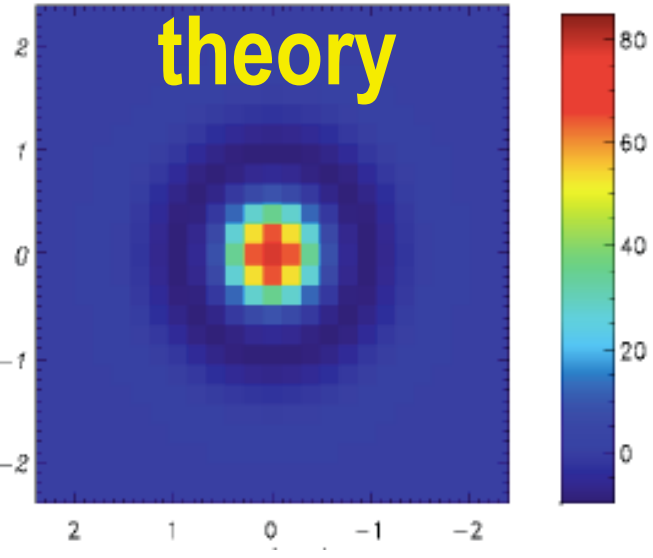
observation



theory



7^{+} *numbers*

CONTENTS

Dark Energy 69.2 ± 1.0%

Dark Matter 26.0 ± 1%

Ordinary Matter: 4.8%

free H & He 4.3%, in stars 0.5%, in heavy nuclei 0.025%

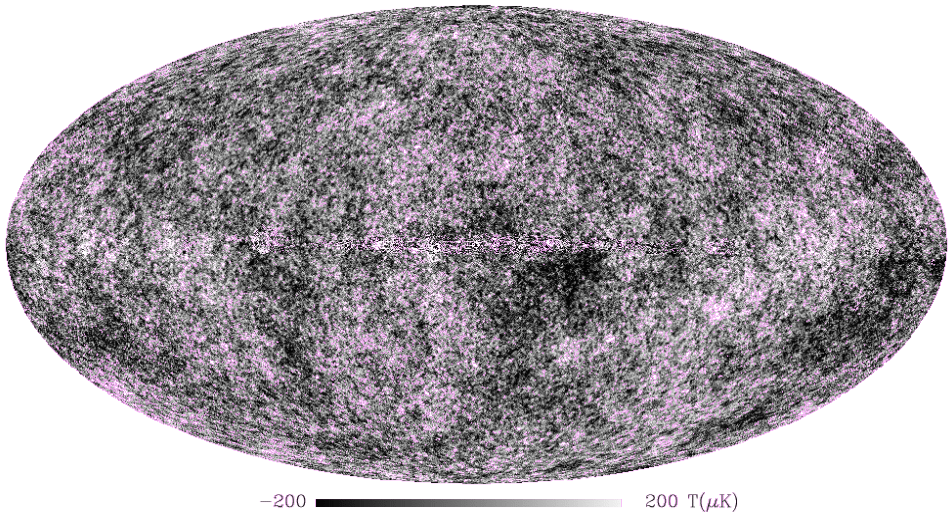
Radiation: 0.005%

Neutrinos > 0.47%

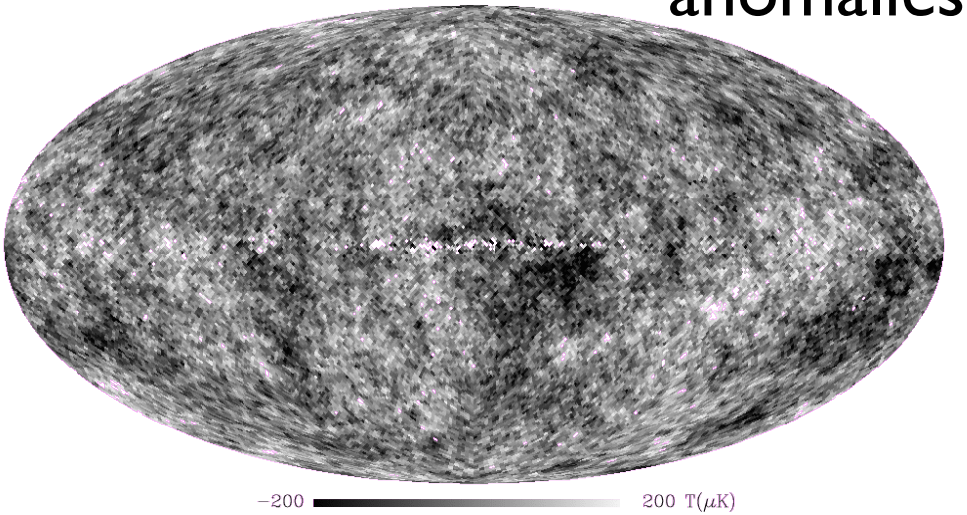
Black Holes 10^{-5} %

Gravity Waves ~10^{-12} -10^{-8} %

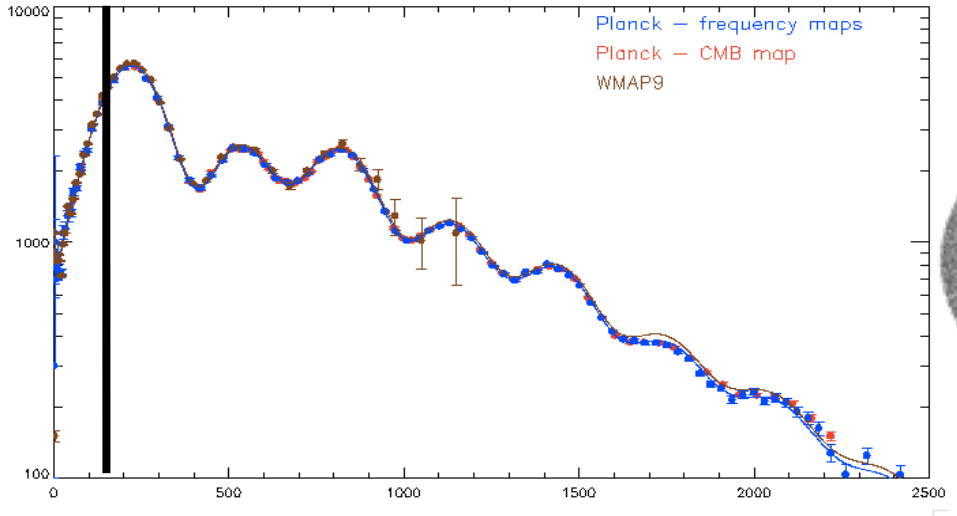
full Planck resolution



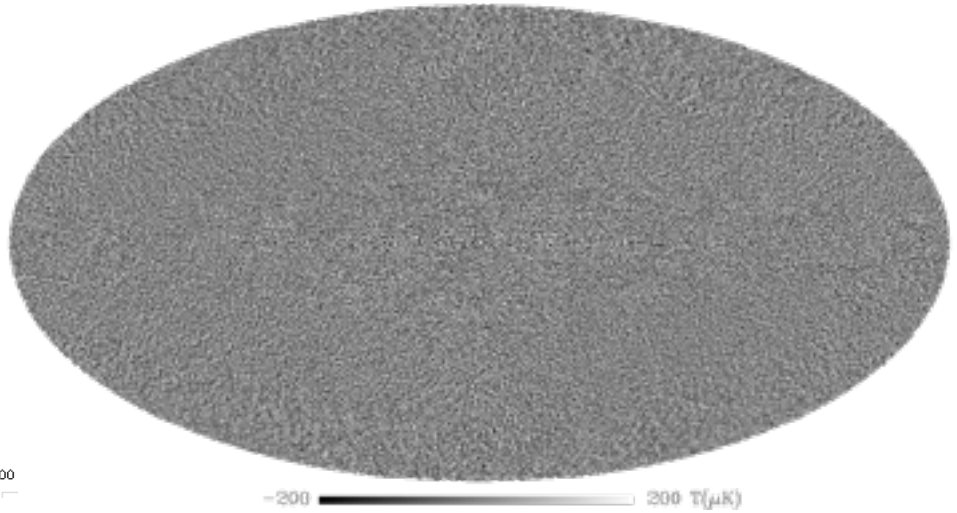
Planck smoothed to 1deg fwhm



L<134 anomalies



L>134 concordance



small scale leftover = where most of Planck's information resides> 120X, > 4X WMAP9

SIMPLICITY

at a~e^{-7}~1/1100 =>

at a~e^{-67+60}~1/10^{30+25}

reveals ***primordial sound waves*** *in matter*

=> *learn* ***contents & structure*** *at 380000 yr,* a~e^{-7}

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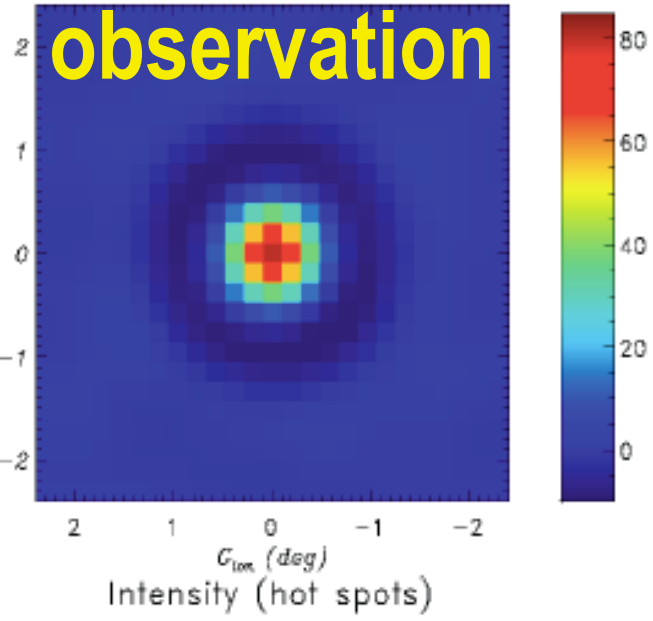
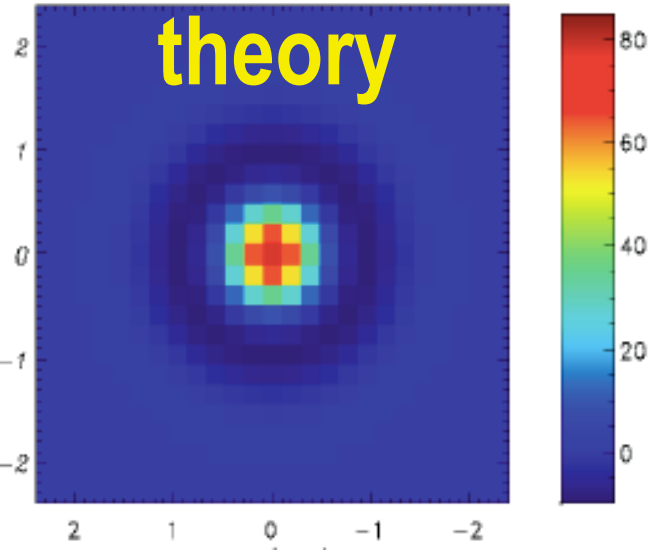
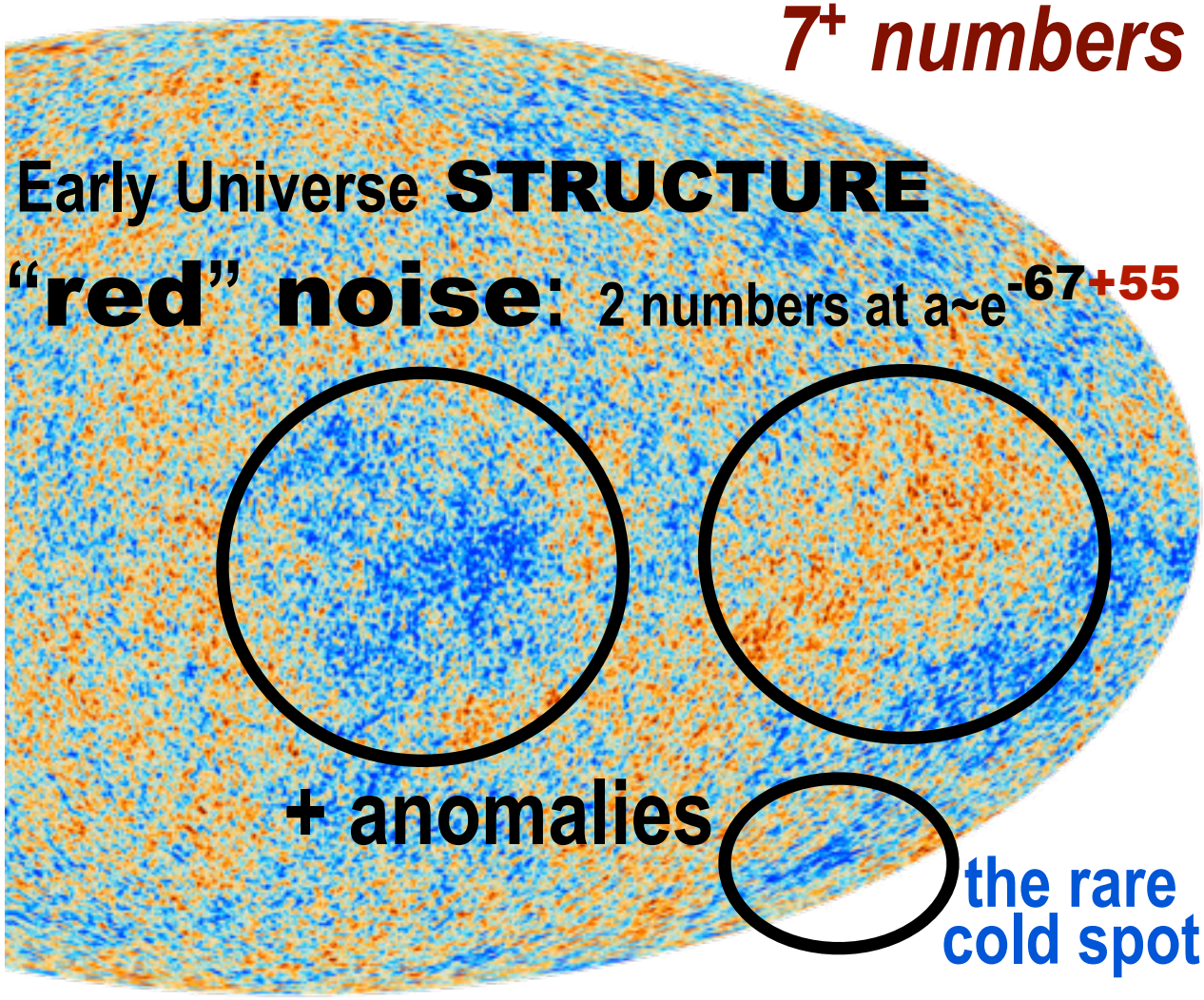
7^{+} numbers





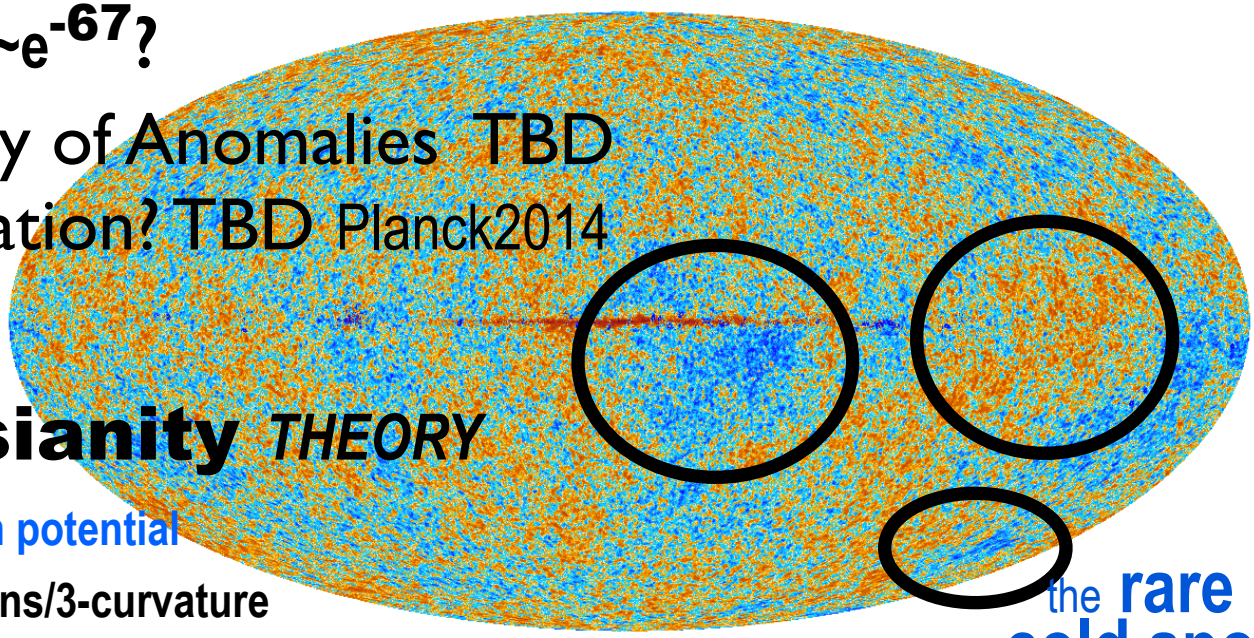


COMPLEXITY *at* a~e^{-67}?

COMPLEXITY *at* $a\sim e^{-67}$?

Grand Unified Theory of Anomalies TBD

Anomalies in Polarization? TBD Planck2014



primordial **nonGaussianity** *THEORY*

f_{nl}: 2.7 ± 5.8 **local** for Newton potential

=> f_{NL^*} =0.44 ± 3.5 for phonons/3-curvature

from end-of-inflation & preheating chaos

the **rare cold spot**

intermittent *CMB power bursts from super-bias of a*

$\chi_b(x),g(x)$ *modulating Gaussian field landscape scan*

$$\zeta_{NL}(x)= \zeta_G(x)+ F_{NL}(\chi_b(x),g(x))$$

bubble collisions *CMB Euclidean SO(4) => real SO(3,1) => SO(2,1) collisions, oscillon broken*

ANALYSIS

WHITEN => MASK => FILTER BANK => EXTRACT *hierarchical* **PeakPatches**

filter = extra dimension: **scale space** analysis

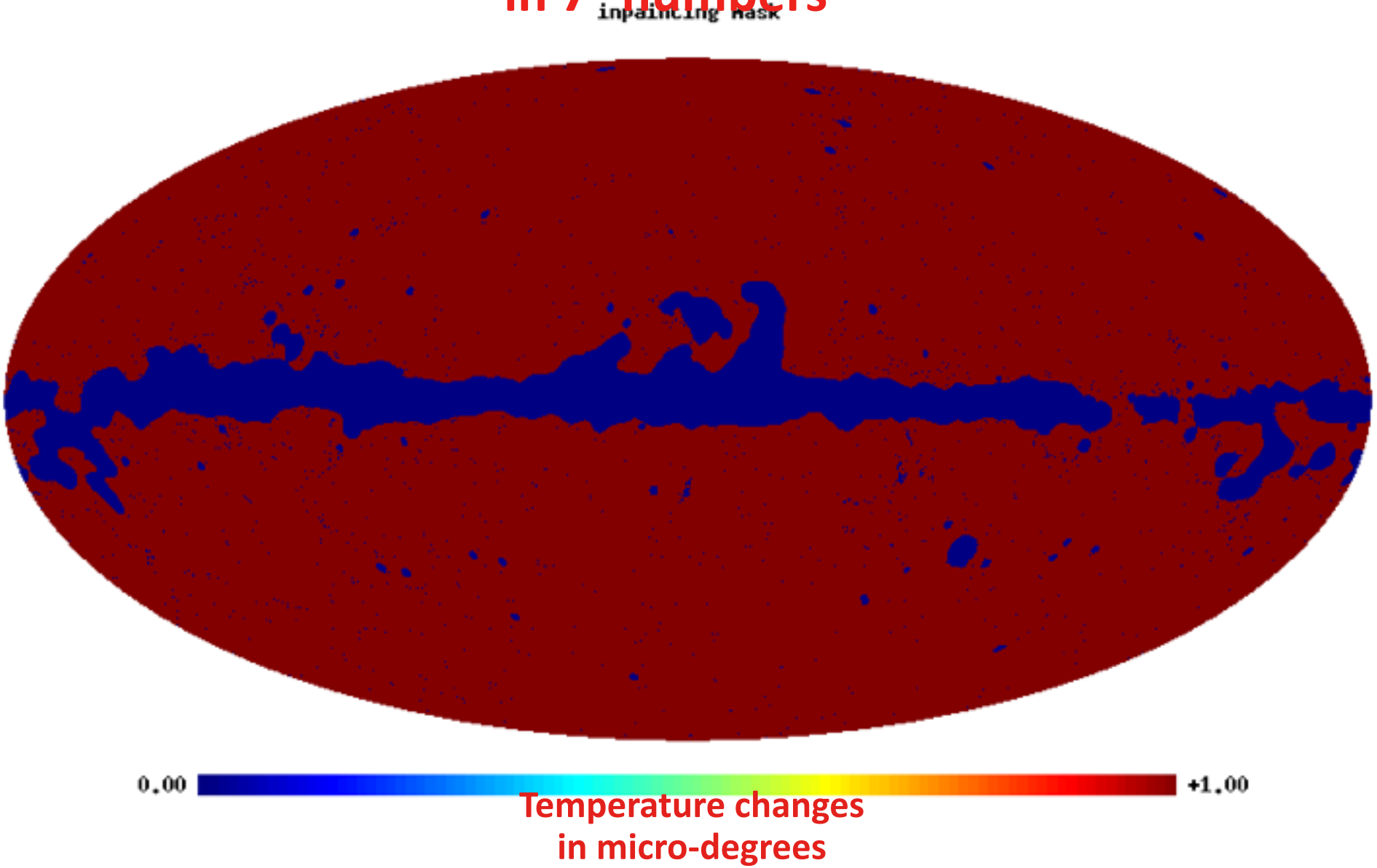
hot & cold peaks *agree with BE87* ***Gaussian stats*** $n_{pk}(<\nu)$

PLANCK2013: 826', 105 peaks, coldest -4.97σ 1:497

reveals **primordial sound waves**

=> the inharmonious *'music of the spheres'*

in 7^{+} numbers



reveals **primordial sound waves**

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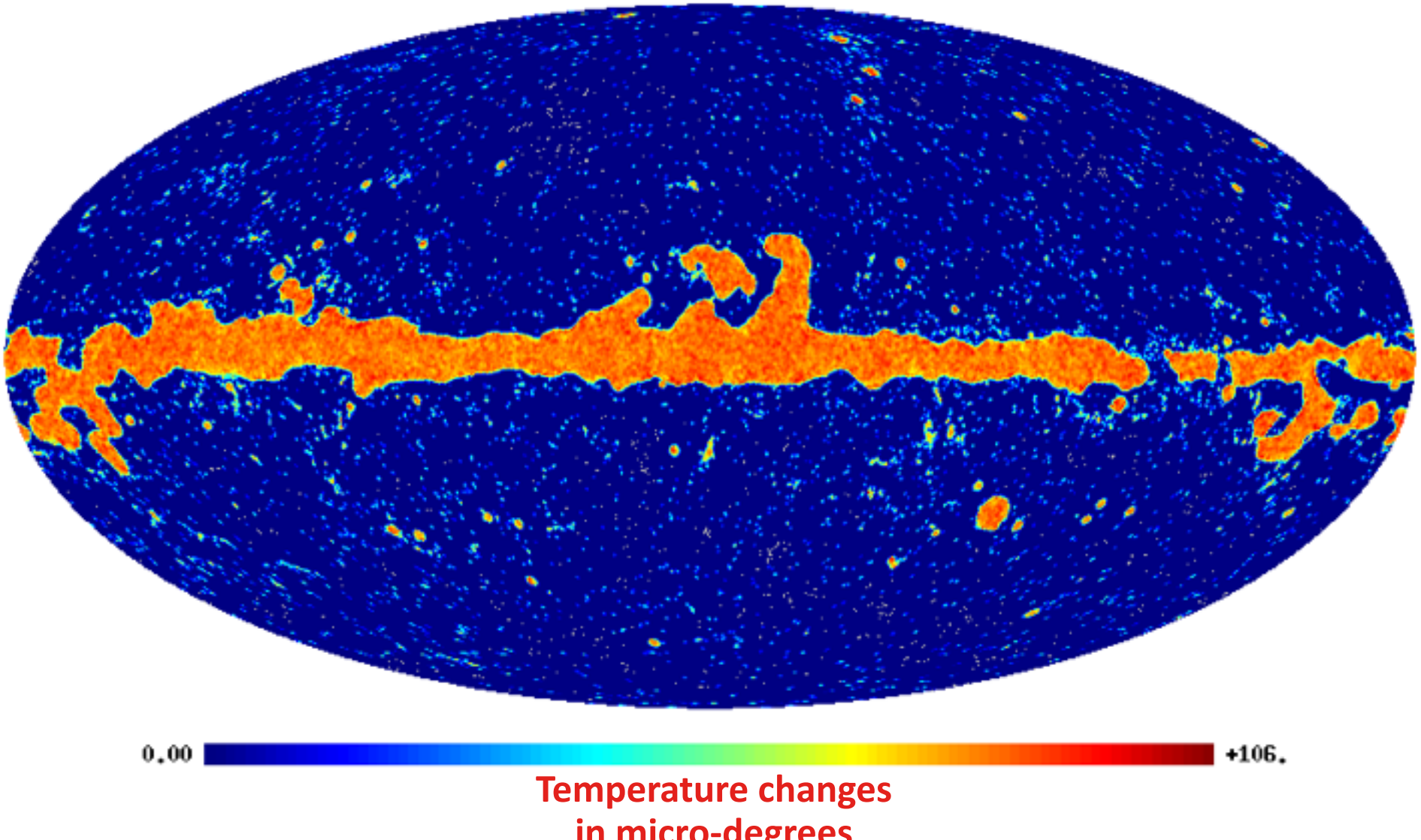
in 7^{+} numbers

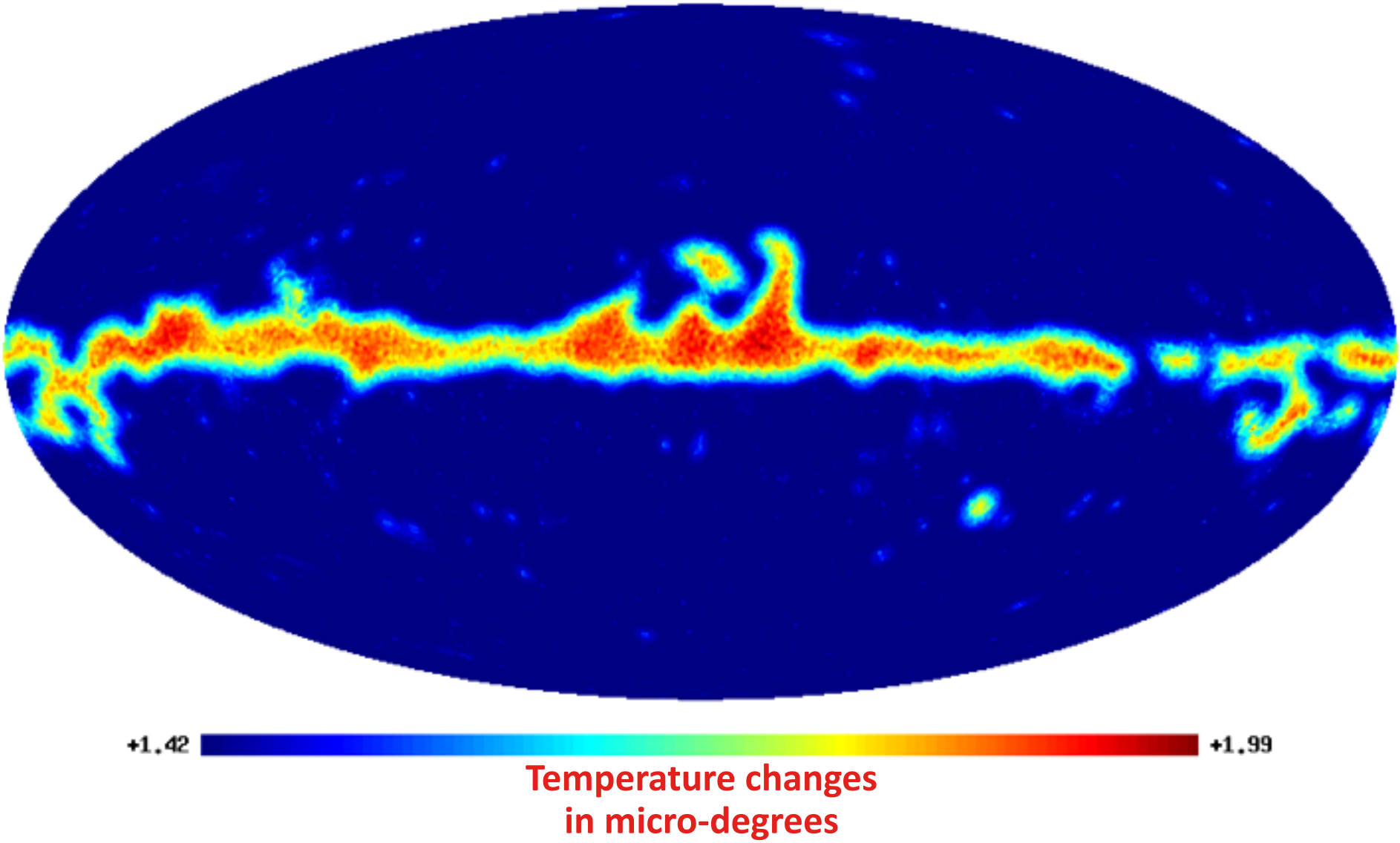


Temperature changes
in micro-degrees

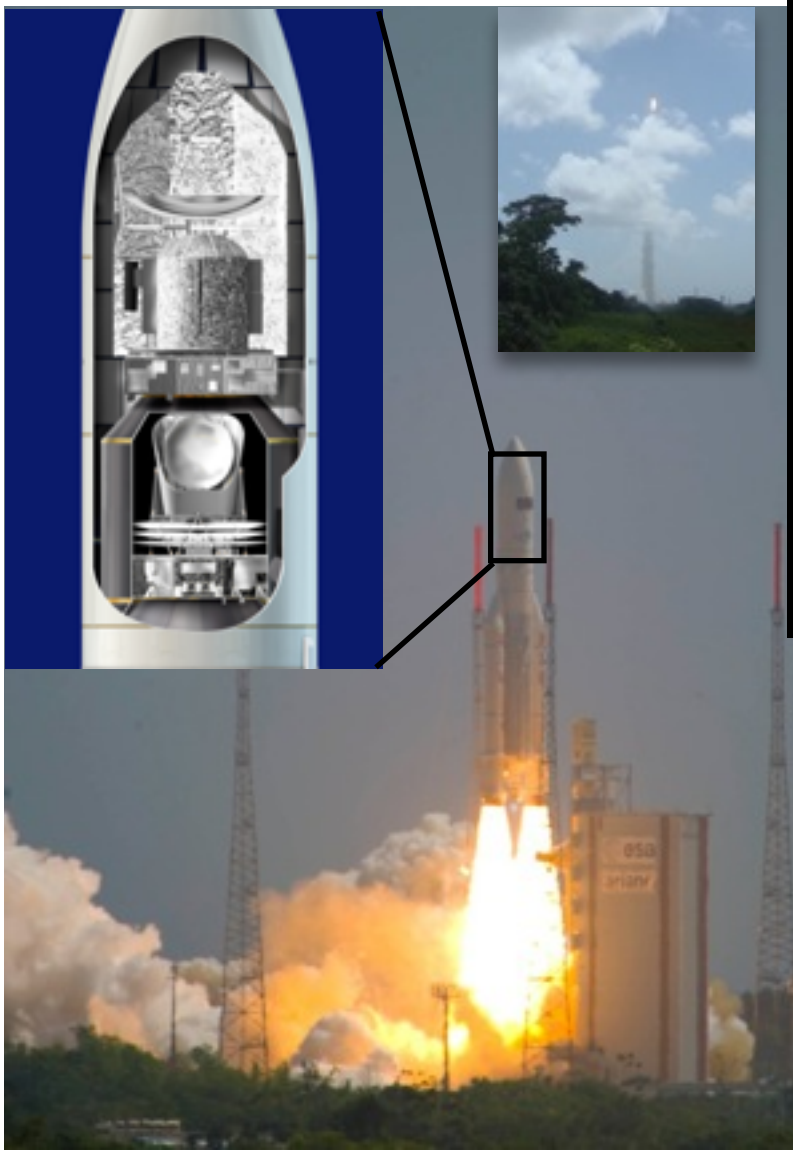
reveals **primordial sound waves**

=> the inharmonious *'music of the spheres'*

in 7^{+} numbers

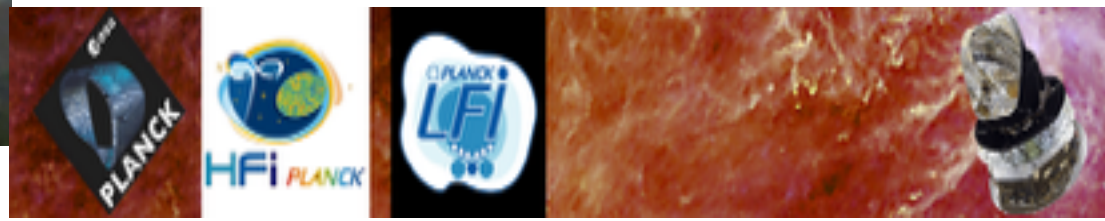


Planck+Herschel Launch May14 09 Fr. Guiana



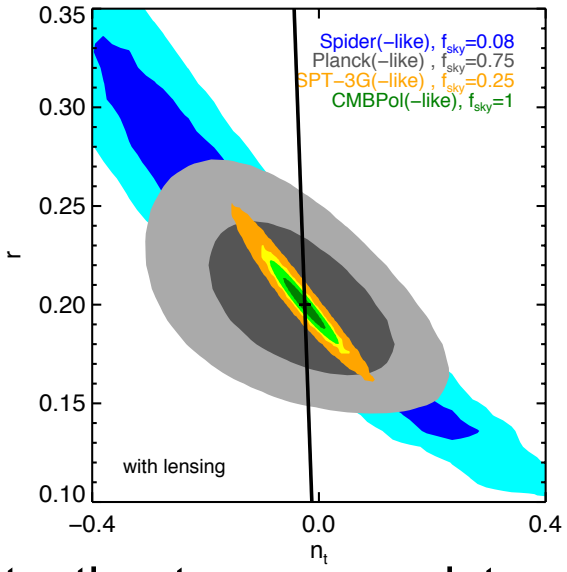
1.5m telescope, HFI bolometers @6freq <100mK, LFI HEMTs@3freq, some bolometers & all HEMTS are polarization sensitive

HFI+LFI performance to spec or better



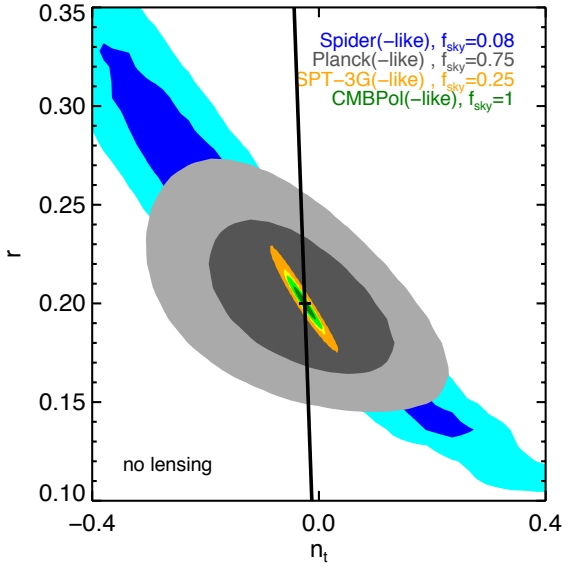
Left earth at ~10 km/s, 1.5 million km in 45 days, cooling on the way (20K, 4K, 1.6K, 0.1K 4 stage). @L2 on July 2 09 -almost no trajectory correction @operational temp; Survey started on Aug 13 09 spin@1 rpm, 40-50 minutes on the same circle, covers all-sky in ~6 month, ~5 HFI surveys, ~8 LFI

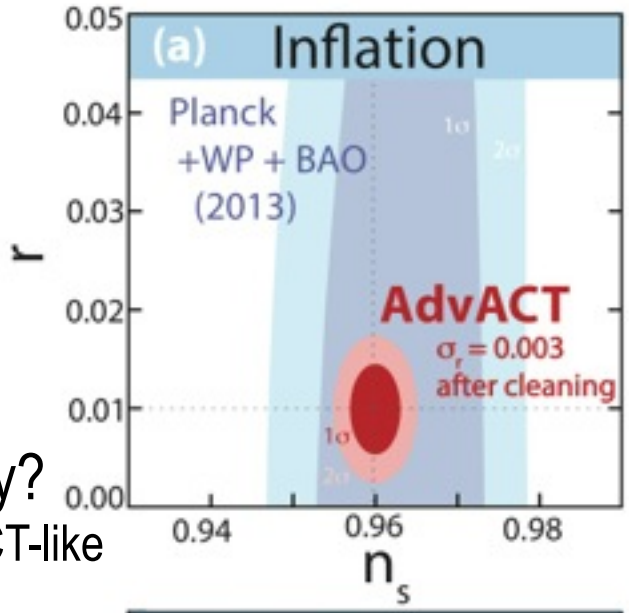
AdvACT: Cosmological Forecasts & Planck2.5, Spider, future SPT3g, CMBpol

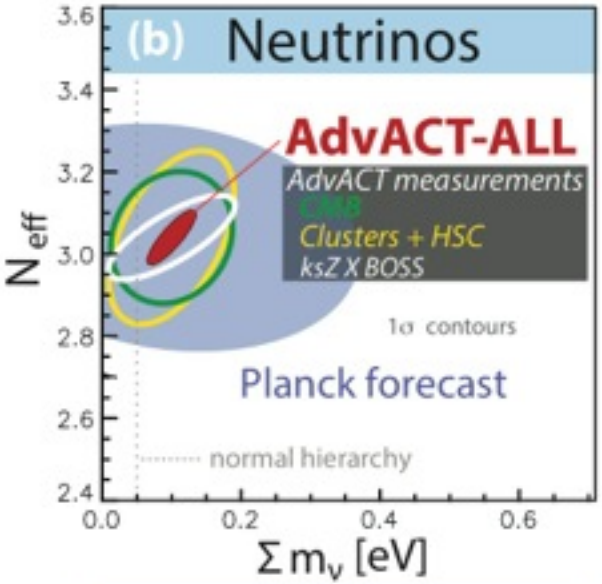


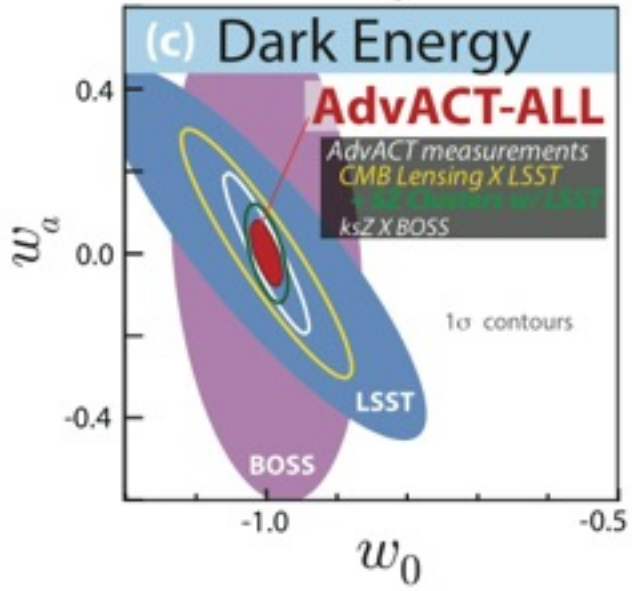
testing tensor consistency?

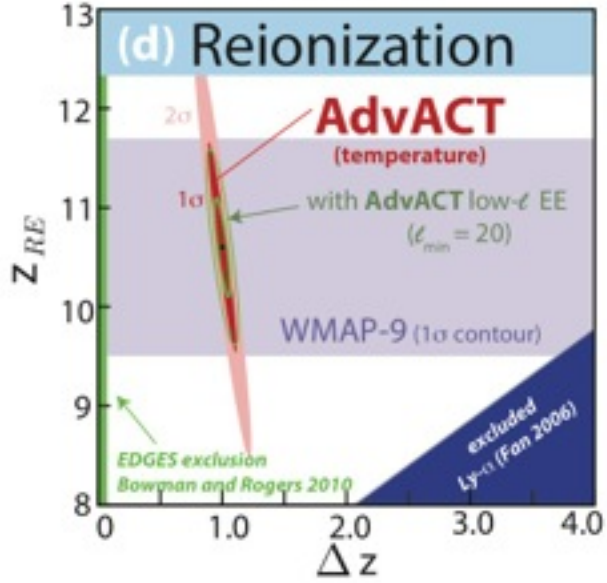
better f_{sky}=25% for spt3g/AdvACT-like than current 6% goal for spt3g





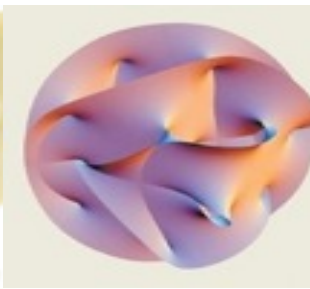






how was *matter & entropy generated at the end of acceleration = inflation*?

Relate it to the Higgs & standard model?

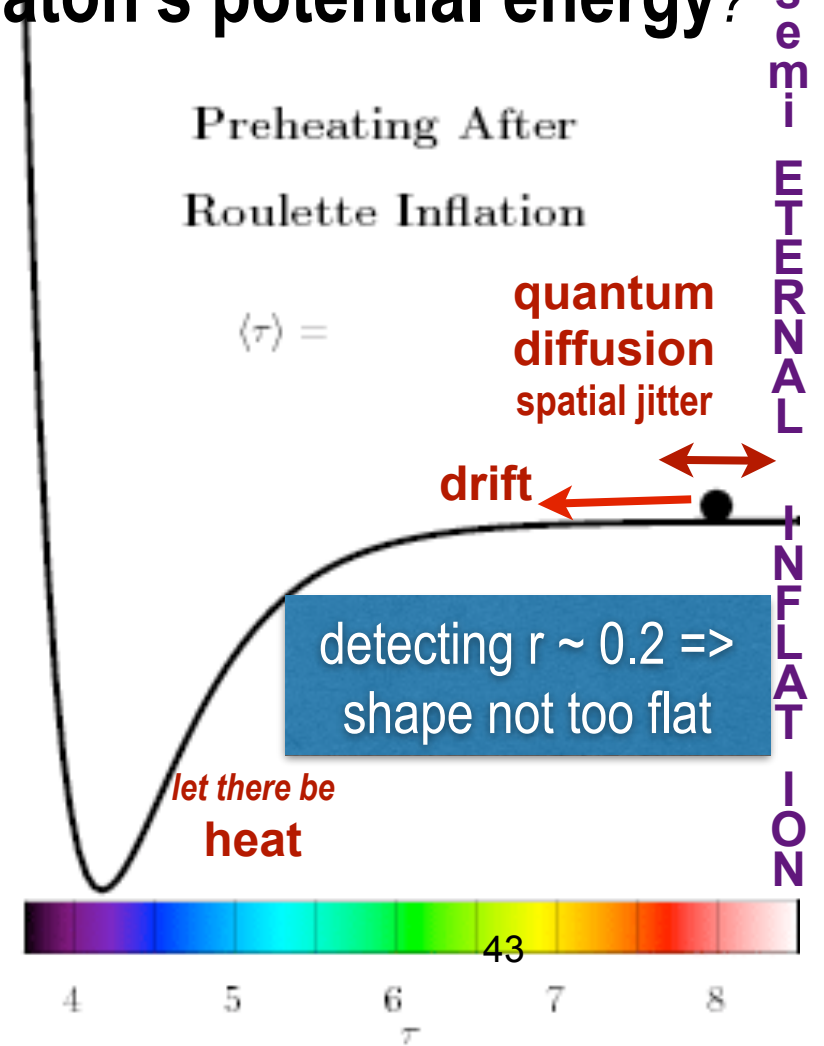


$a =$ [1] **what is the inflaton's potential energy**?

pre-heating patch (**<1cm**-now, **<10^{-30} cm**-then)

A visualized 2D slice

in lattice simulation



www.youtube.com/watch?v=FW__su-W-ck&NR=1