esa

planck

cnes

agenzia spaziale italiana

NASA

CNRS

DTU Space
National Space Institute

Science & Technology Facilities Council

CSIC
Consejo Superior de Investigaciones Científicas

INAF ISTITUTO NAZIONALE DI ASTROFISICA

National Research Council of Italy

GOBIERNO DE ESPAÑA — MINISTERIO DE CIENCIA E INNOVACIÓN

CSA ASC

DLR — Deutsches Zentrum für Luft- und Raumfahrt e.V.

UK SPACE AGENCY

MAX-PLANCK-GESELLSCHAFT

HFI PLANCK
a look back to the birth of Universe

PLANCK LFI

IAS orsay

IAP

INAF - IASF BO
ISTITUTO NAZIONALE DI ASTROFISICA
ISTITUTO DI ASTROFISICA SPAZIALE E FISICA COSMICA DI BOLOGNA

Aalto University · APC · California Institute of Technology · ioa · Kavli Institute for Cosmology Cambridge (KICC) · Cavendish Astrophysics · University of Cambridge · Cardiff University / Prifysgol Caerdydd · irfu cea saclay · CEFCA · CESR · CITA–ICAT · IASF · CNRS INSU Observer & comprendre · CNRS IN2P3 Les deux infinis

ipac · Helsinki Institute of Physics · Instituto de Astrofísica de Canarias · IFCA Instituto de Física de Cantabria · Imperial College London · Università degli Studi di Milano · Néel institut · IPAG · ISDC Data Centre for Astrophysics · JPL · LAL Laboratoire de l'Accélérateur Linéaire · l'Observatoire de Paris · LERMA · LPSC Grenoble

The University of Manchester · MilliLab · Max-Planck-Institut für Astrophysik · NUI Maynooth · INAF Osservatorio Astronomico di Padova · University of Oxford · Sapienza Università di Roma · Science & Technology Facilities Council Rutherford Appleton Laboratory · Tor Vergata · Osservatorio Astronomico Trieste · UBC · UC Universidad de Cantabria · UCSB · SISSA · Stanford University

ALMA · ESO · US University of Sussex · Haverford · esa · University of Helsinki · Université de Genève · University of Toronto · Université de Paris-Sud XI · ISTI · asdc ASI Science Data Center

Bond since 1993, Canada since 2001, 1st CSA pre-launch contract 2002-09, post-launch 2010-11, 2011-15

A Cosmic Microwave Bonanza: Planck & ACT, SPT, WMAP9

Dick Bond

CITA ICAT

CBI pol to Apr'05 @Chile CBI2

Boom03@LDB

WMAP @L2 to 2010

DASI @SP

CAPMAP

QUaD @SP

Bicep @SP

Quiet1 @Chile

Planck09.4

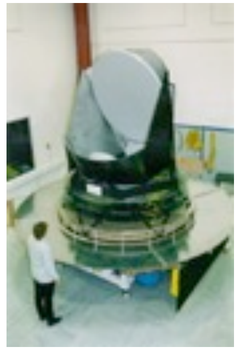
52 bolometers + HEMTs @L2

9 frequencies

Herschel

BLAST

Bicep2



Quiet2 1000 HEMTs

Keck@SP

ABS@ Chile

EBEX @LDB

Spider 2312 bolos @LDB

2013

Pixie/ COrE/ LiteBird @space

2004 2005 2006 2007 2008 2009 LHC 2011

Acbar to Jan'06, 08f @SP

SZA @Cal

AMI

GBT

APEX ~400 bolos @Chile

SPT 1000 bolos @SPole

ACT 3000 bolos 3 freqs @Chile

SCUBA2 12000 bolos JCMT @Hawaii

BLASTpol

Piper

Polarbear @Chile

SPTpol

ACTpol

ALMA

CCAT@Chile

LMT@Mexico

the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Mar 21, 2013 release *ESTEC apr2-5, 2013*

esa planck

Planck EXT

In Quest of Early U

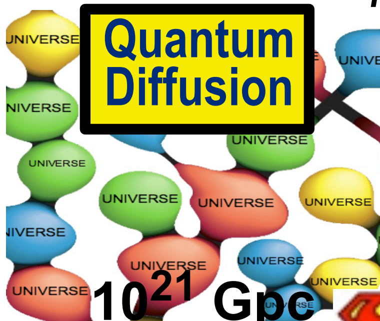
$n_s(k)$, isoc, $\varepsilon(Ha)$, *GW* $r(k)$

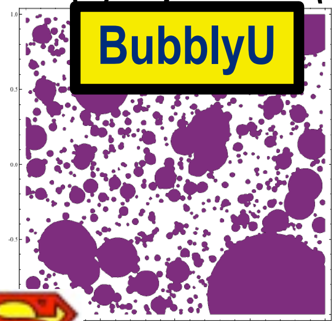
nonG f_{NL}++, strings, *the rare*

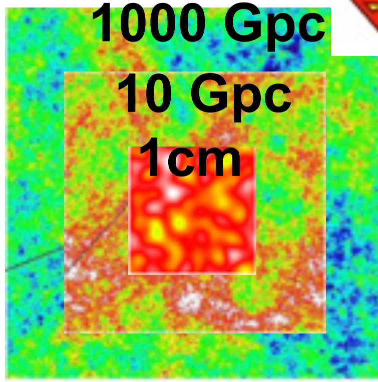
Late U

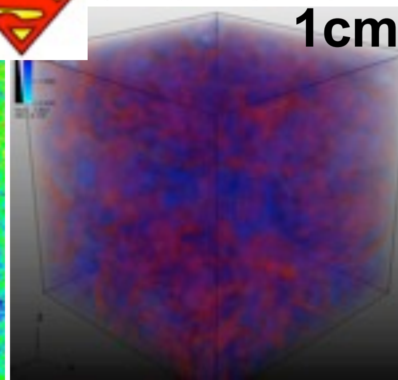
$\rho_{de}(t)$,+

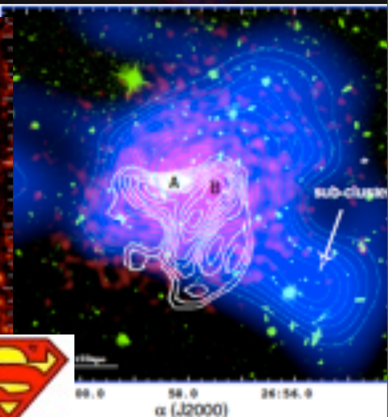
In Quest of Cosmic Information: the coherent & the entropic, from the ultra-early-U to Now to the ultra-late-U - broad prior(T) to posterior(T|D)





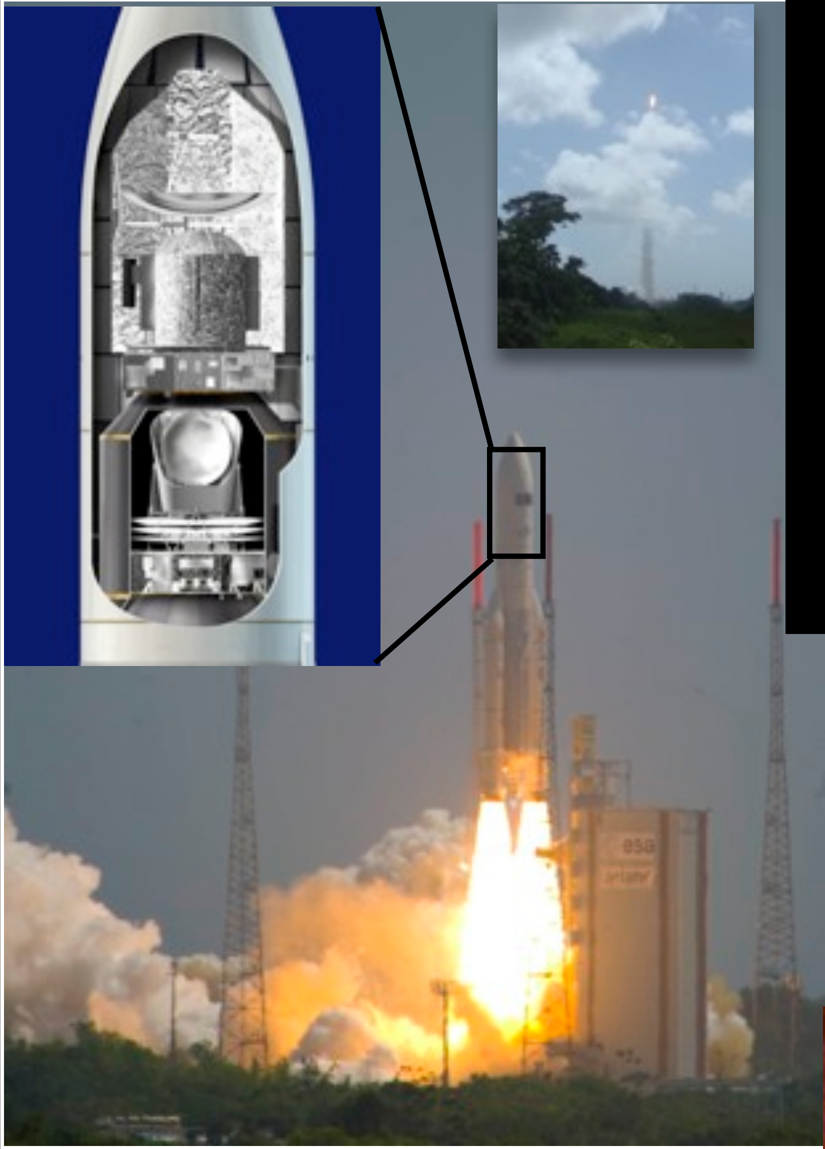






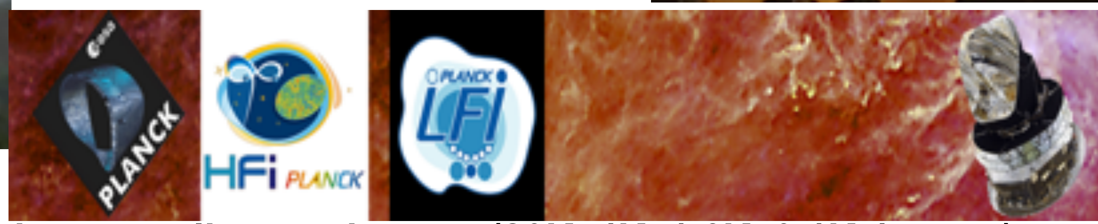
CMB@CITA: Boomerang, Acbar, CBI1,2, WMAP, Planck, ACT, Spider, Blast, & ACTpol, ABS, QUIET2; GBT-Mustang2, CARMA/SZA, SCUBA2, ALMA, CCAT. CMB@CIFAR: these + APEX , SPT, SPTpol, EBEX

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

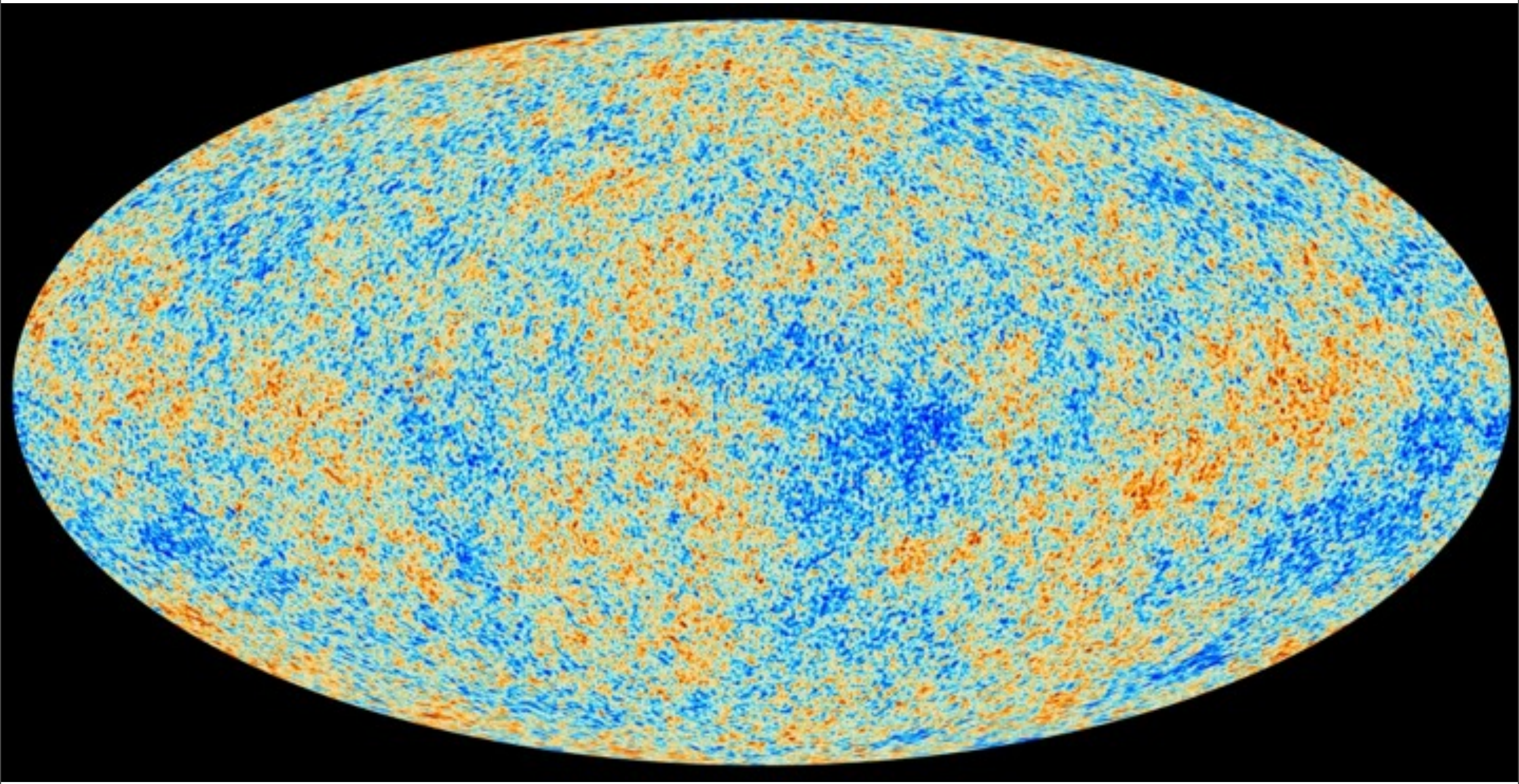


Left earth at ~10 km/s, 1.5 million km in 45 days, cooling on the way (20K, 4K, 1.6K, 0.1K 4 stage).
@L2 on July 2 09 -almost no trajectory correction @operational temp; Survey started on Aug 13 09
spin@1 rpm, 40-50 minutes on the same circle, covers all-sky in ~6 month, ~5 HFI surveys, ~8 LFI

Cosmic Information from the Microwave Background Radiation

Beyond the standard model: tilted ΛCDM + x

*Prob (**cosmic parameters & trajectories** | CMB+LSS data, theory-framework)*



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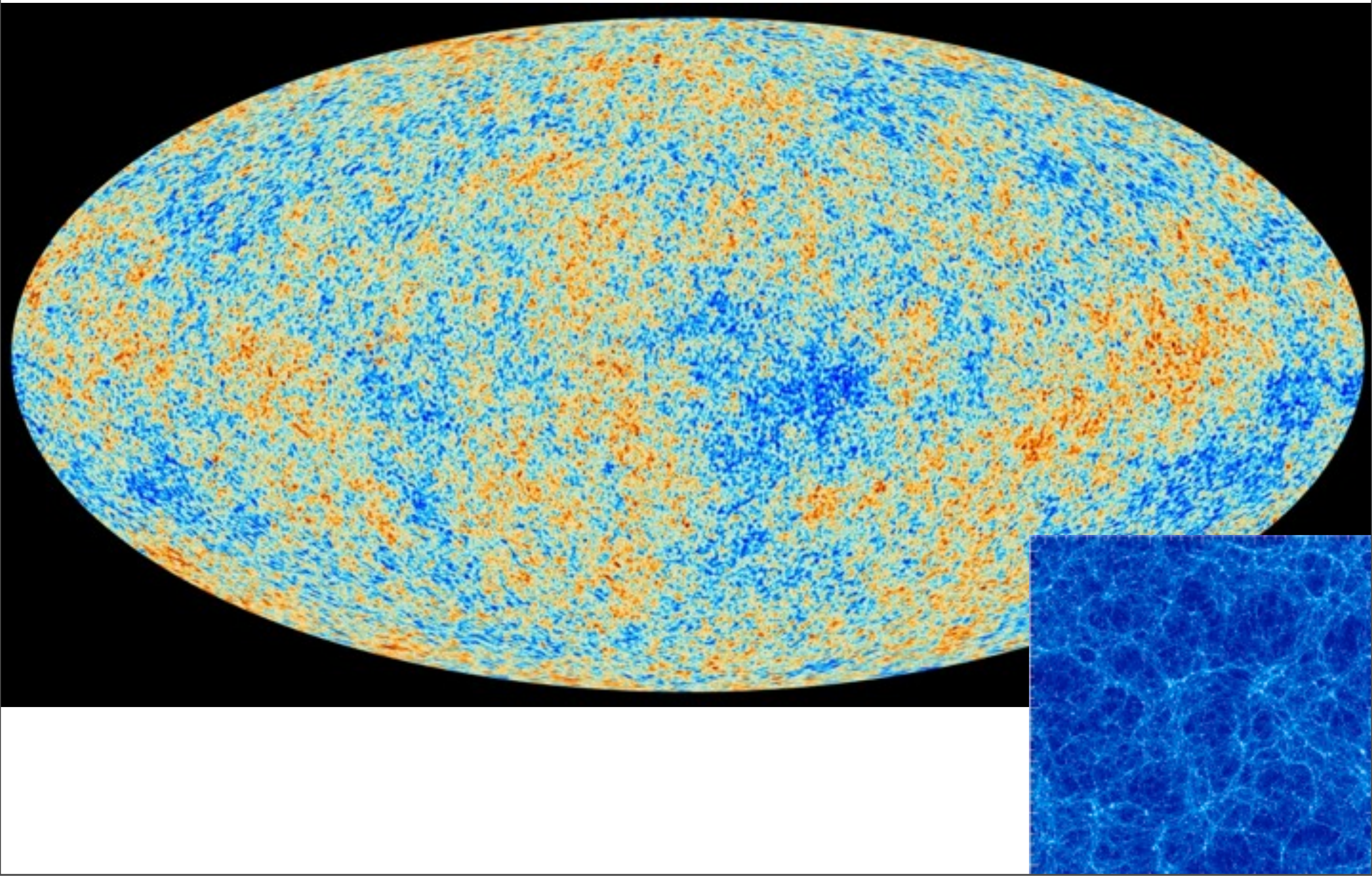

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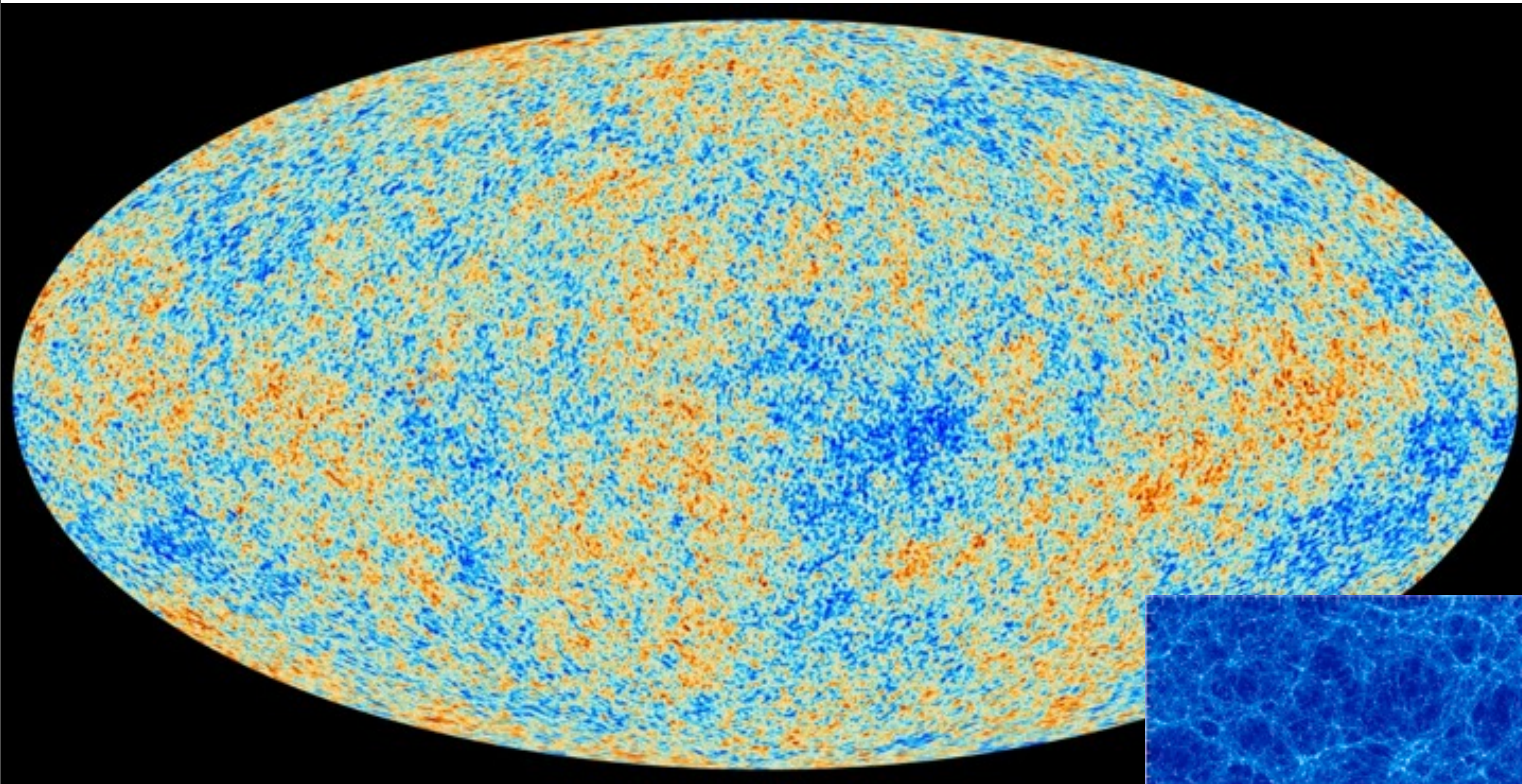

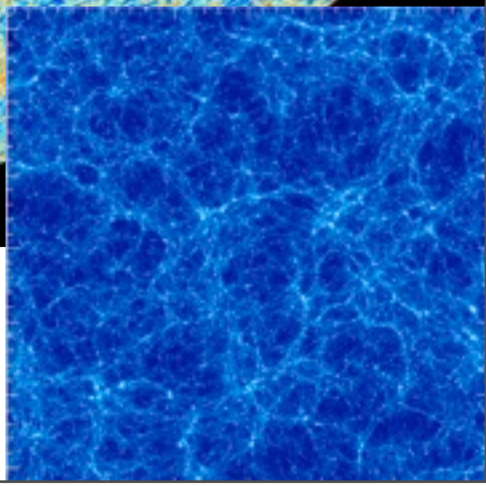

morphs *into the nonlinear* ***Cosmic Web: clusters, filaments, voids; galaxies (SZ)*** ***gastrophysical simulations with feedback from AGN / starbursts / SN .. confront CMB+LSS data***

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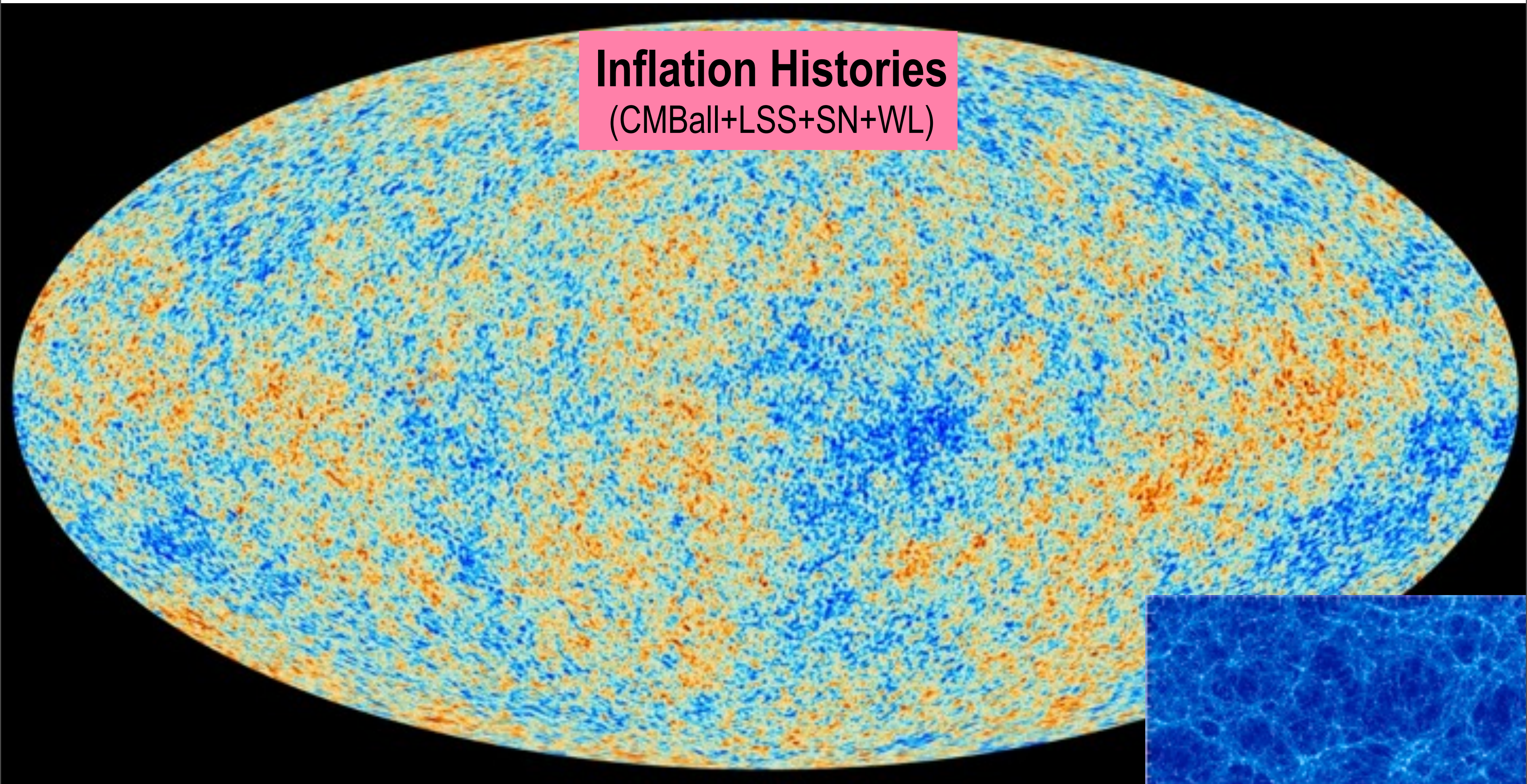

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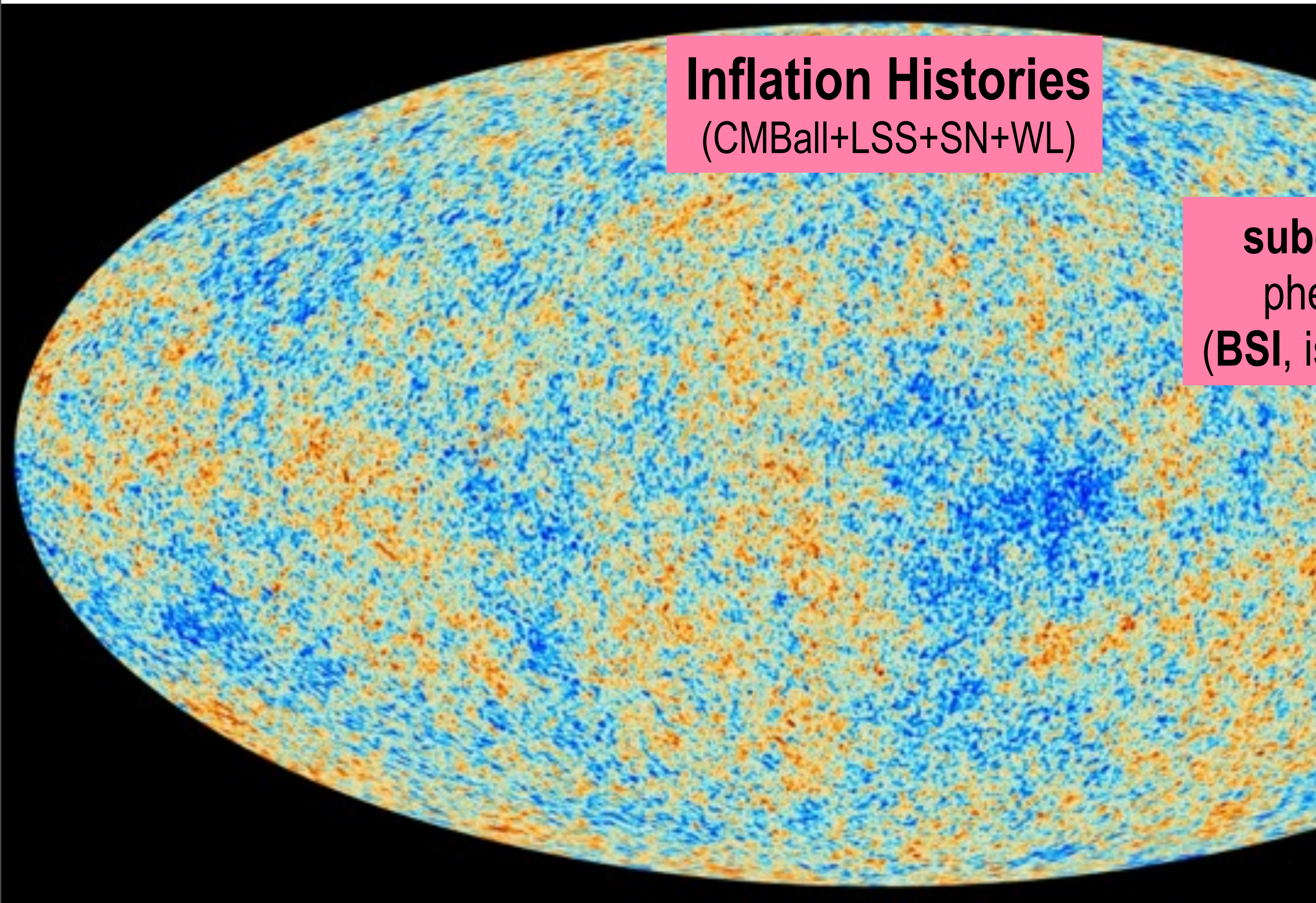

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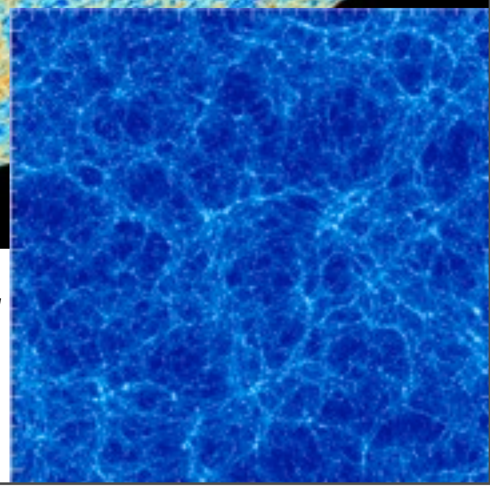

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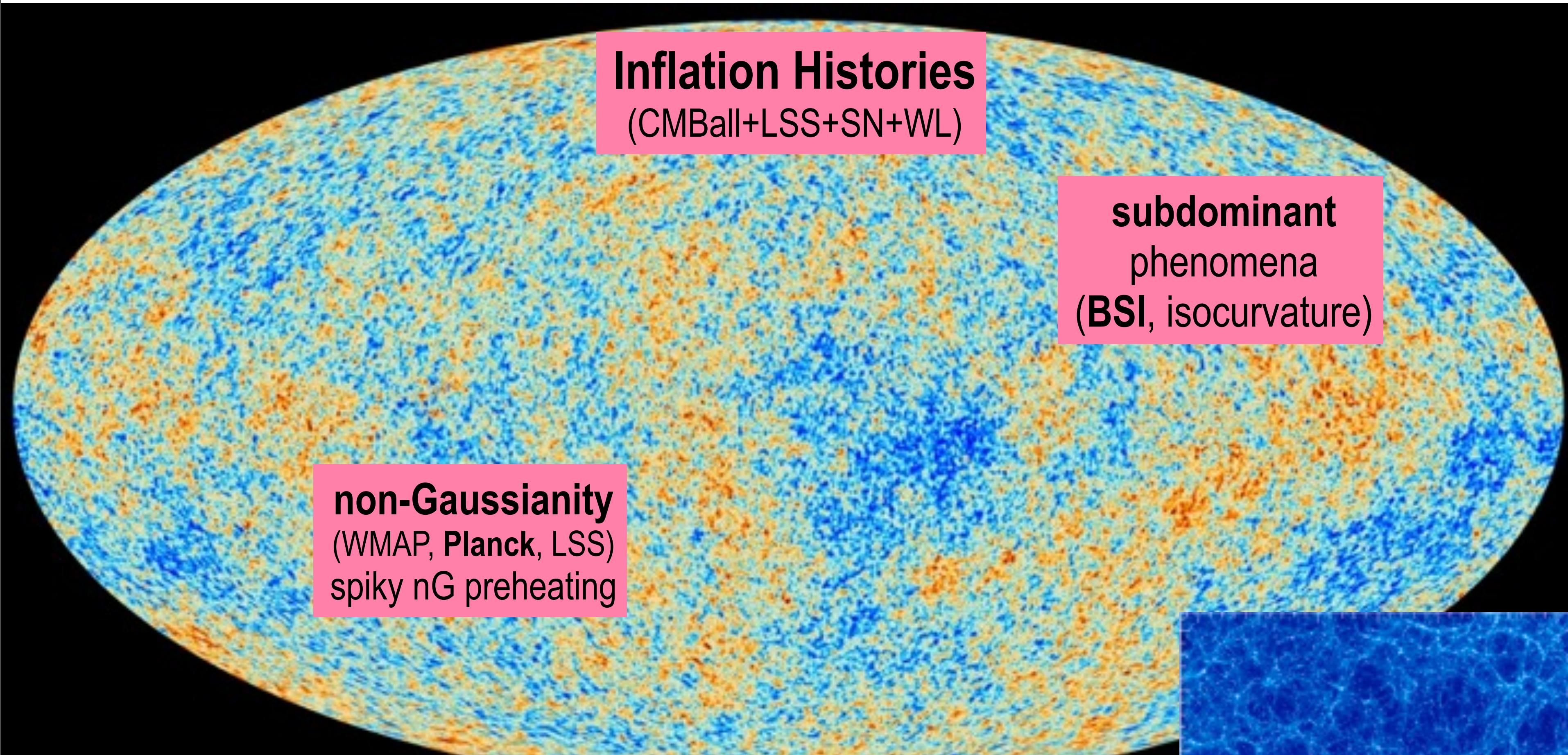

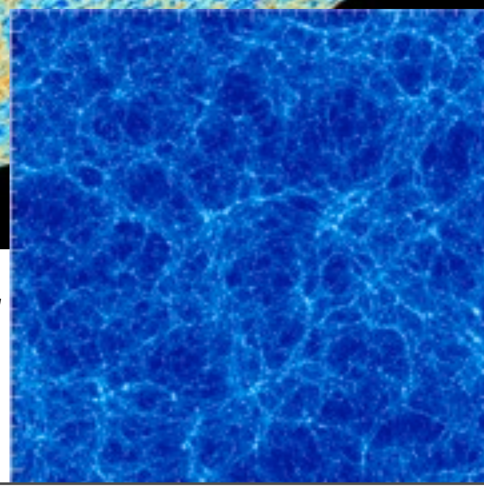

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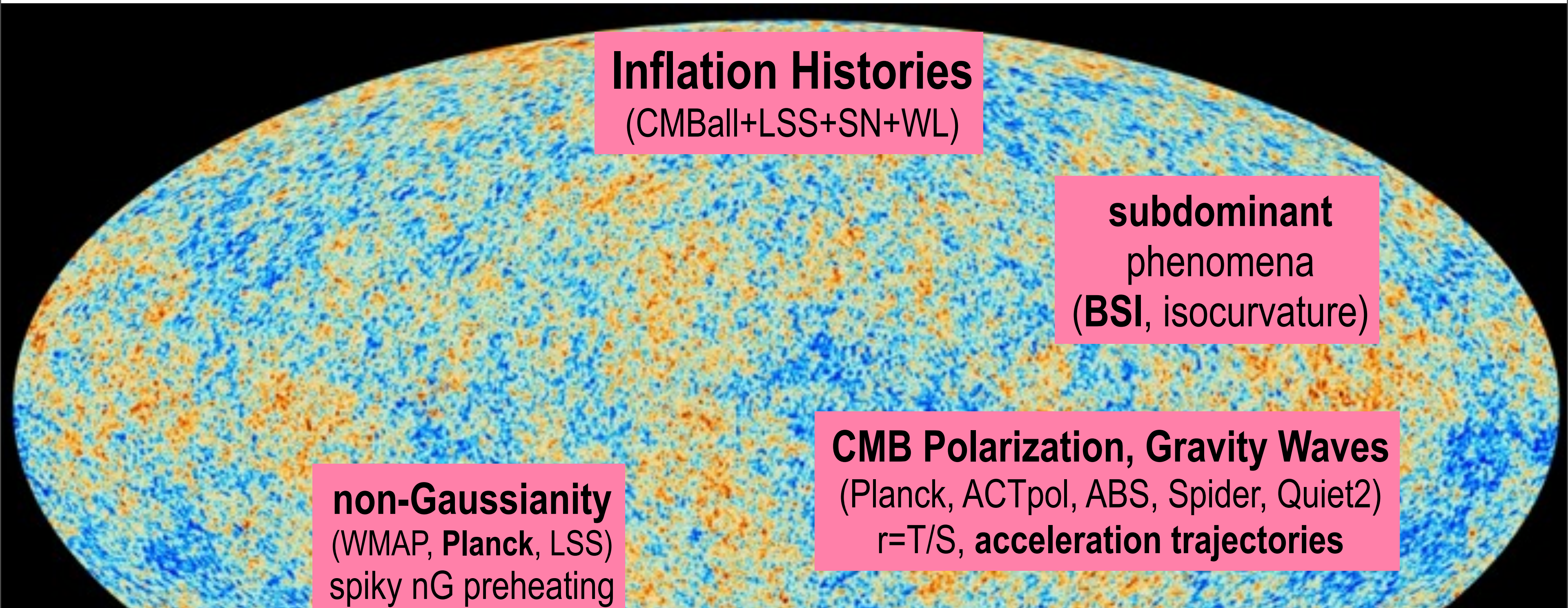

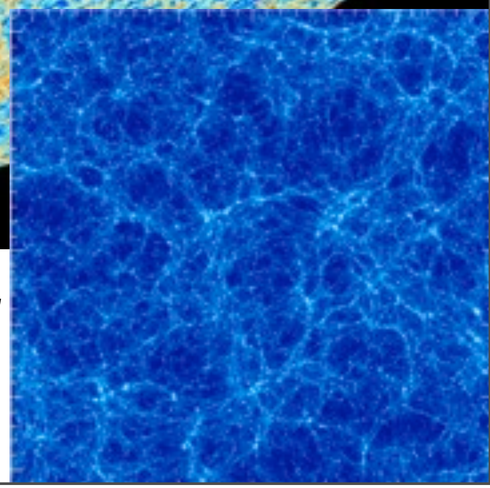

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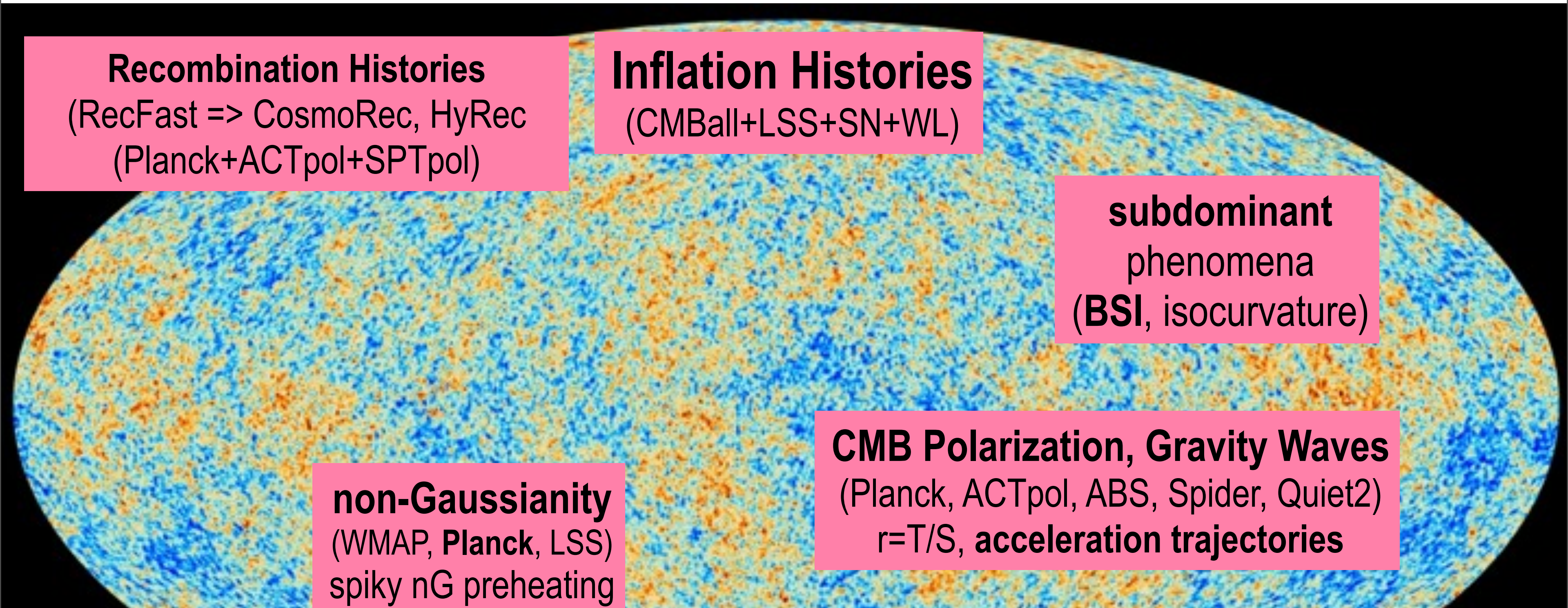

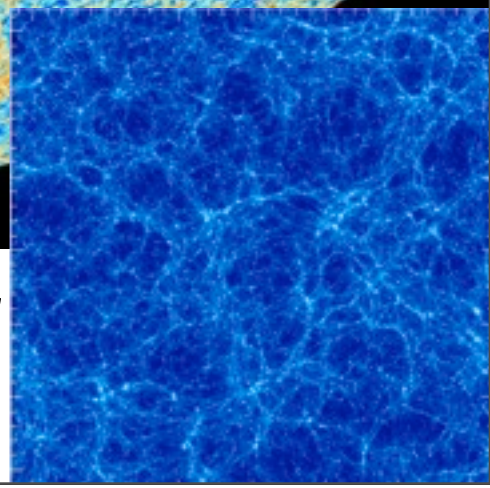

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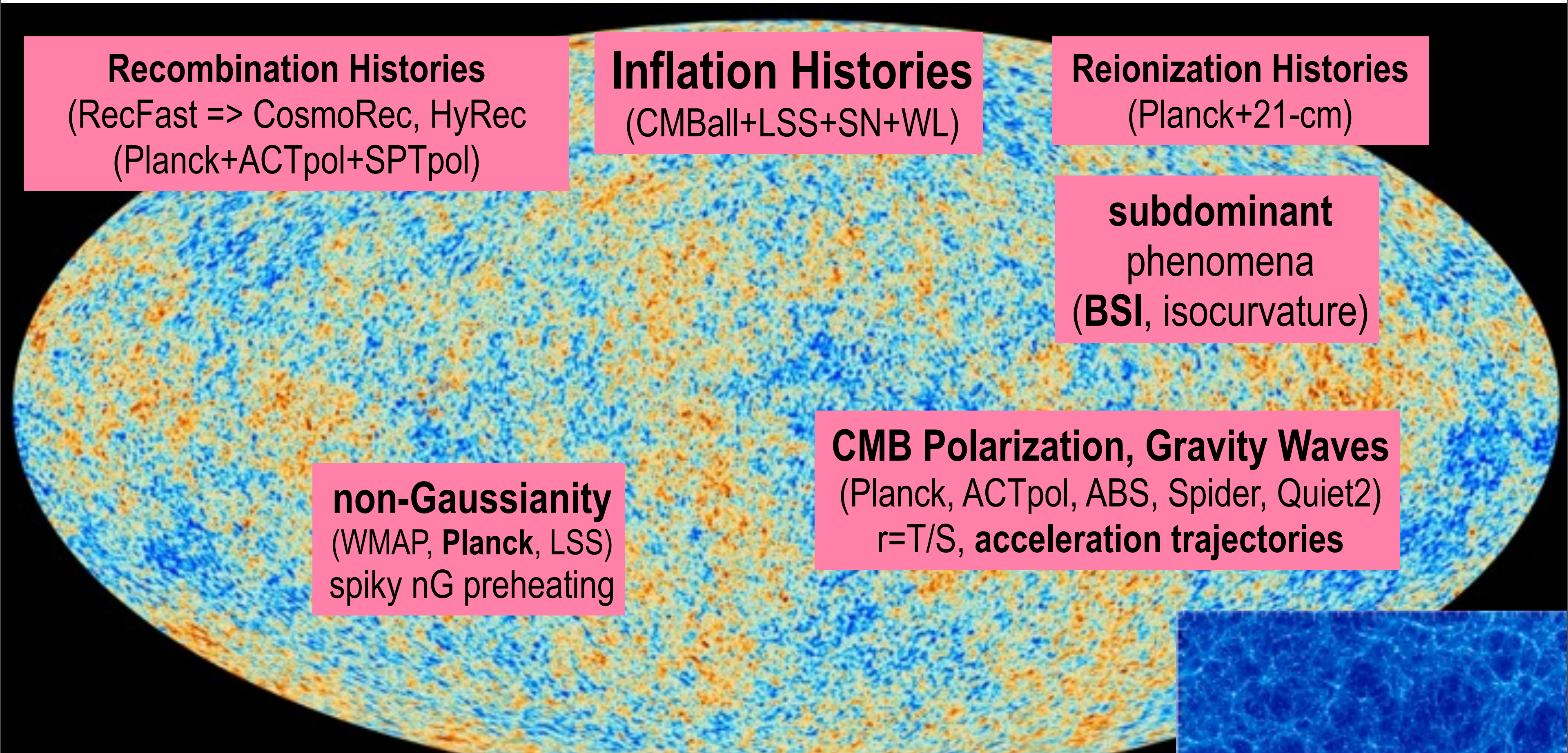


Recombination Histories
(RecFast => CosmoRec, HyRec
(Planck+ACTpol+SPTpol)

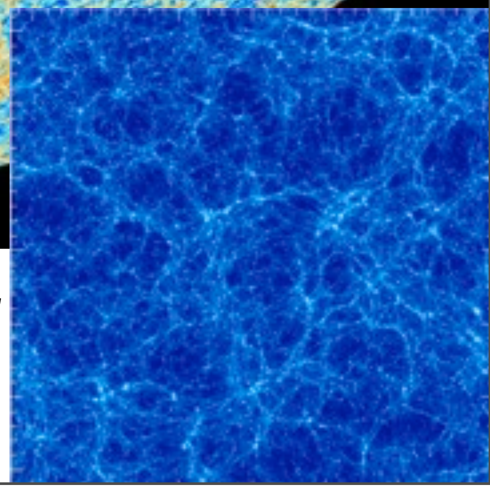
Inflation Histories
(CMBall+LSS+SN+WL)

Reionization Histories
(Planck+21-cm)

subdominant
phenomena
(**BSI**, isocurvature)

CMB Polarization, Gravity Waves
(Planck, ACTpol, ABS, Spider, Quiet2)
r=T/S, **acceleration trajectories**

non-Gaussianity
(WMAP, **Planck**, LSS)
spiky nG preheating



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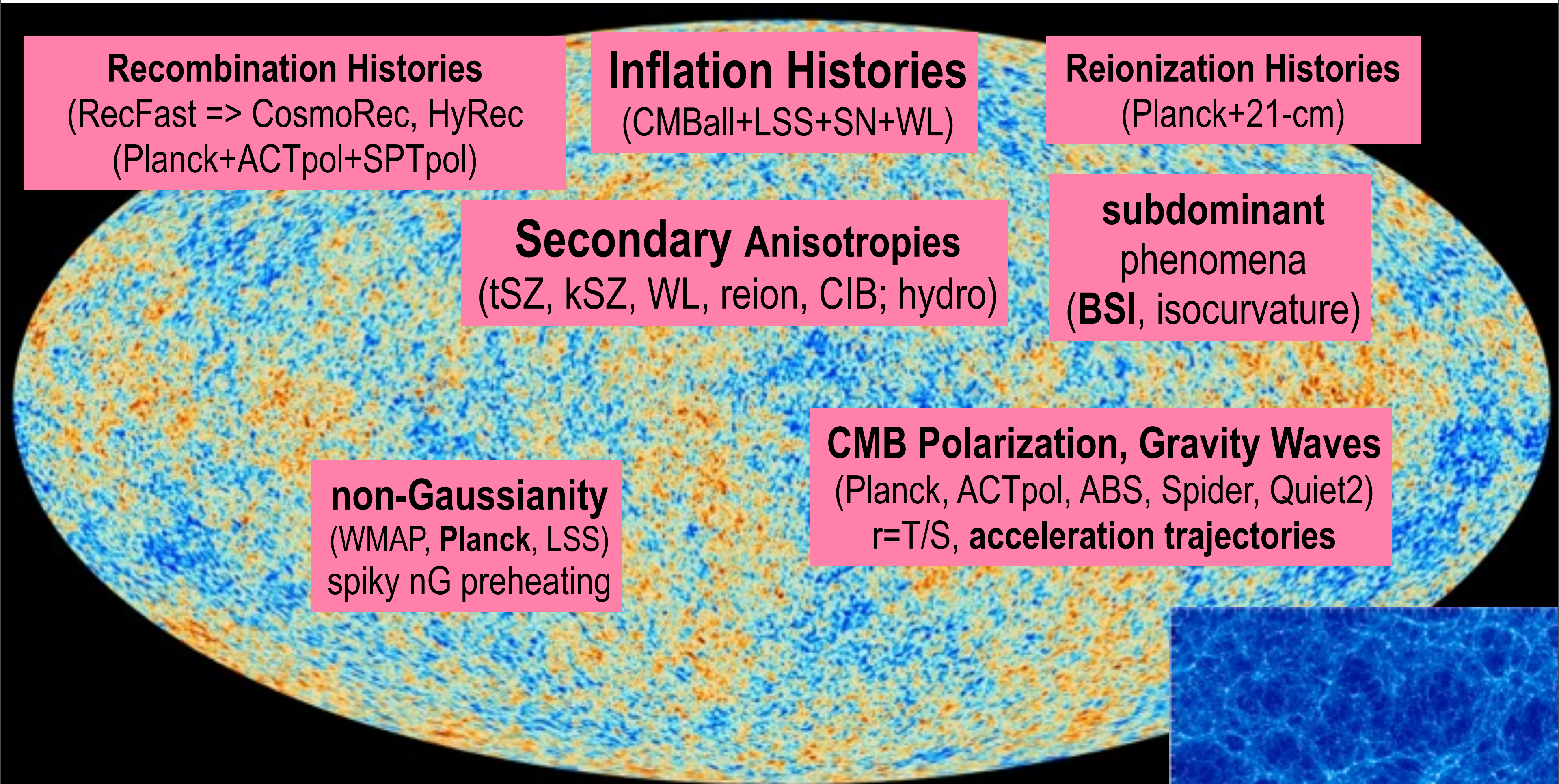

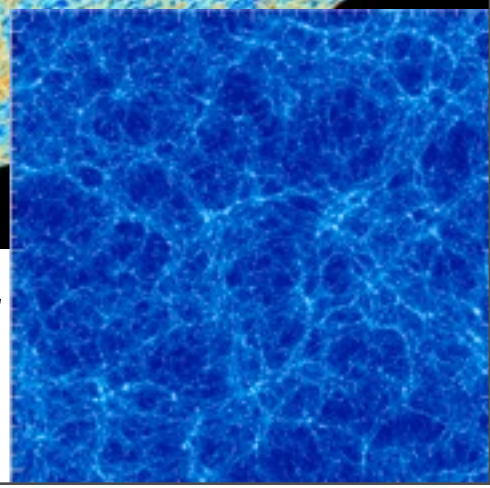

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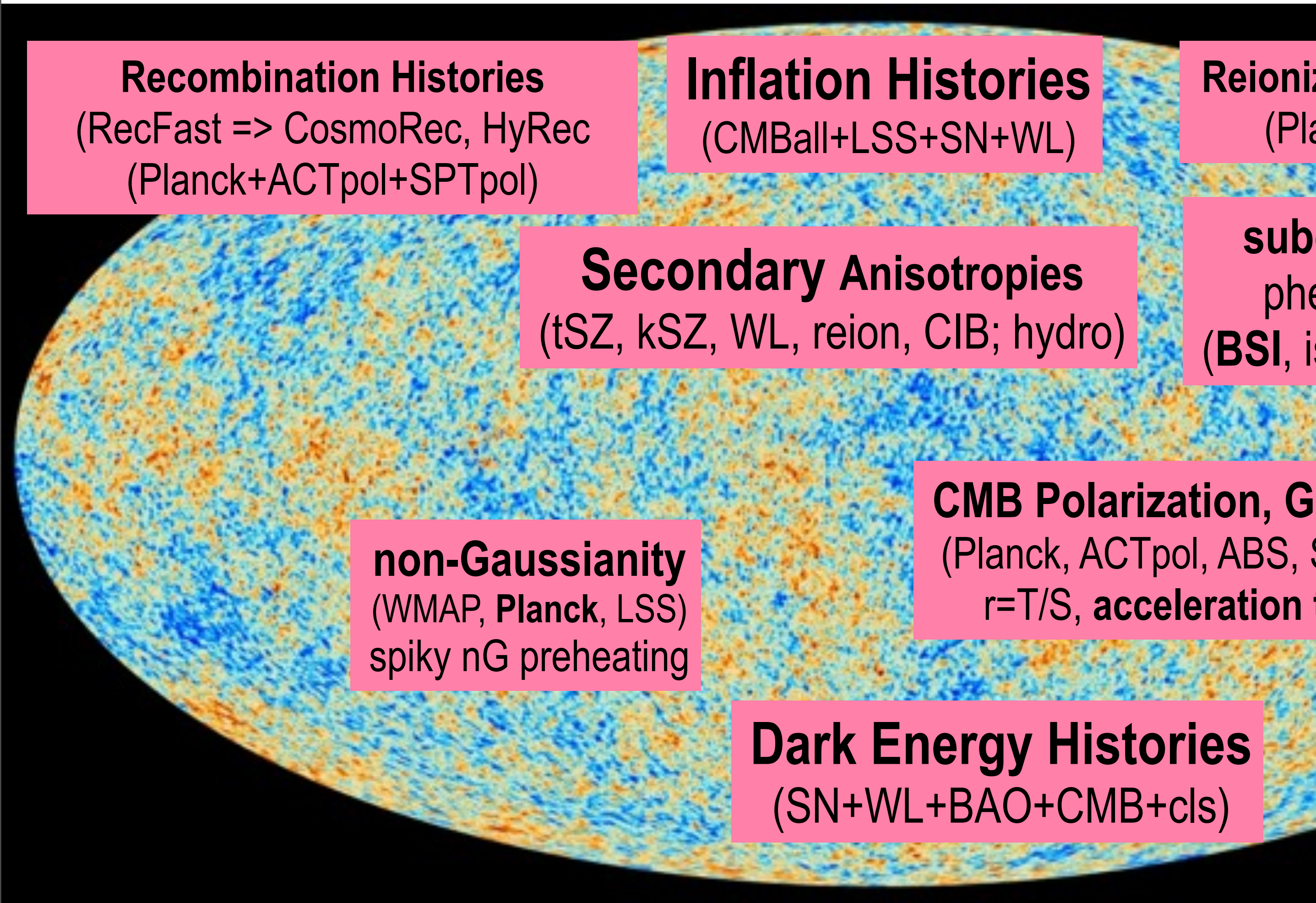


Recombination Histories
(RecFast => CosmoRec, HyRec
(Planck+ACTpol+SPTpol)

Inflation Histories
(CMBall+LSS+SN+WL)

Reionization Histories
(Planck+21-cm)

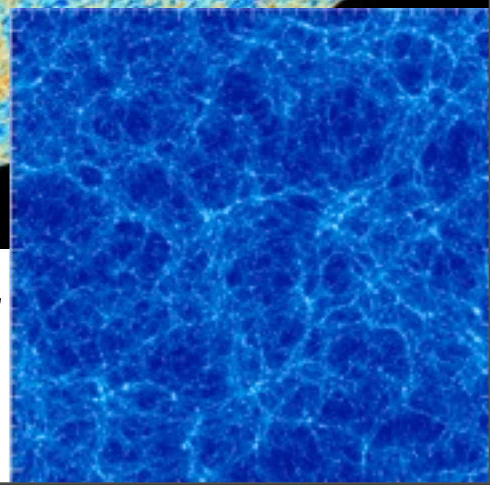
Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

subdominant
phenomena
(**BSI**, isocurvature)

CMB Polarization, Gravity Waves
(Planck, ACTpol, ABS, Spider, Quiet2)
r=T/S, **acceleration trajectories**

non-Gaussianity
(WMAP, **Planck**, LSS)
spiky nG preheating

Dark Energy Histories
(SN+WL+BAO+CMB+cls)



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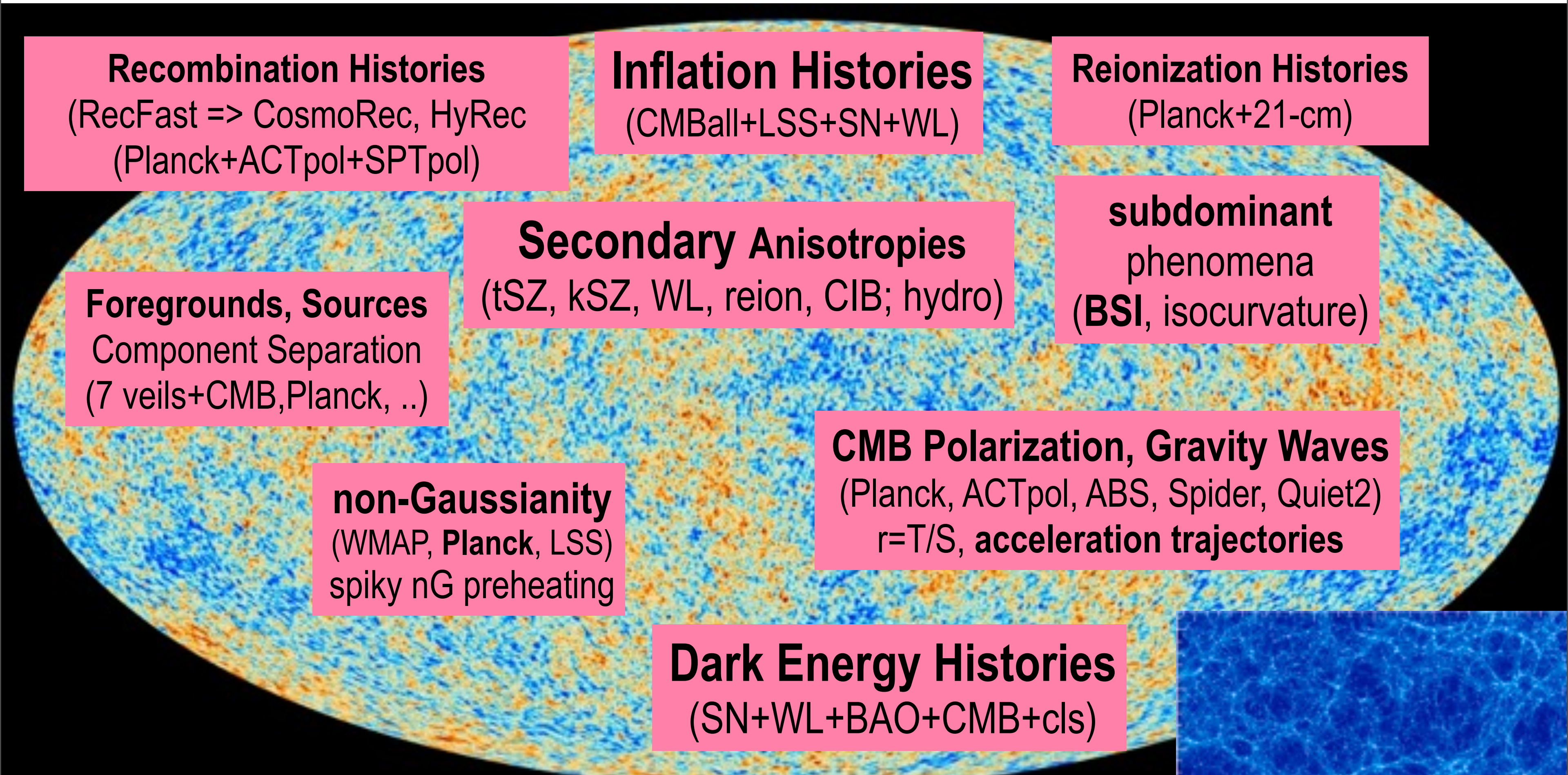

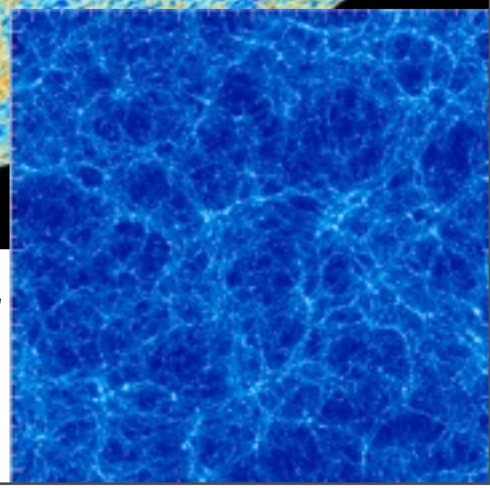

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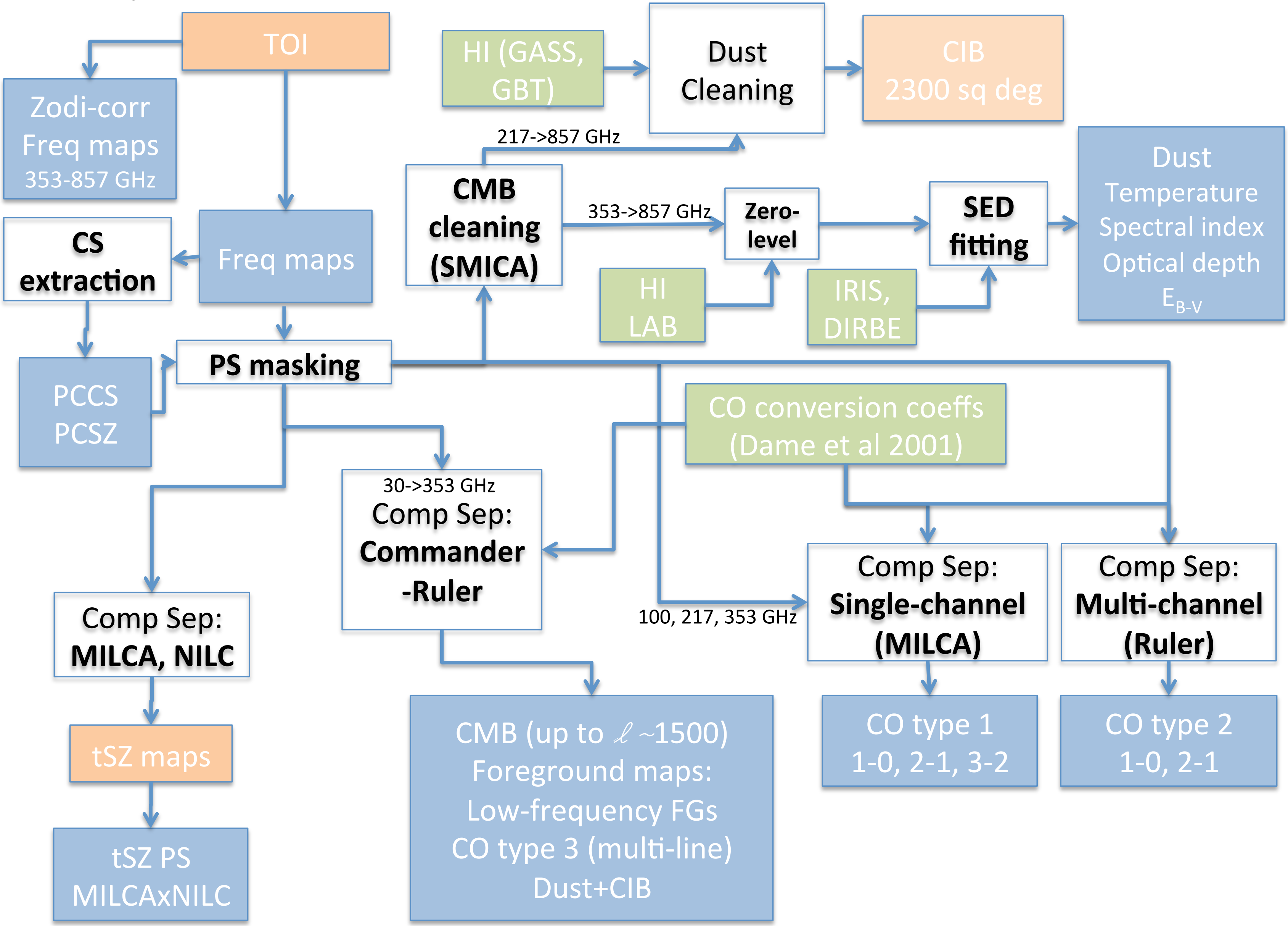
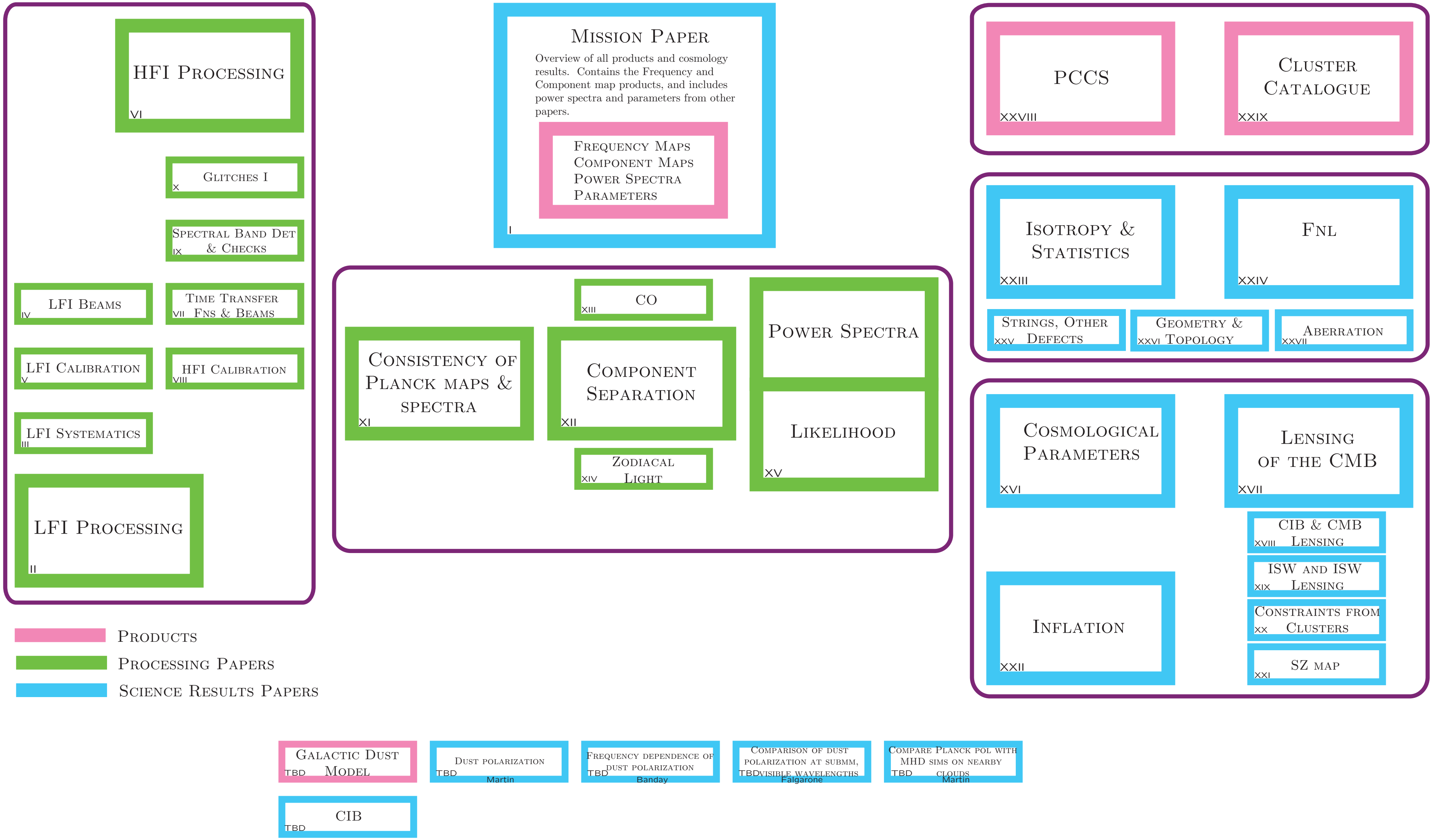
Planck1.3yr data products

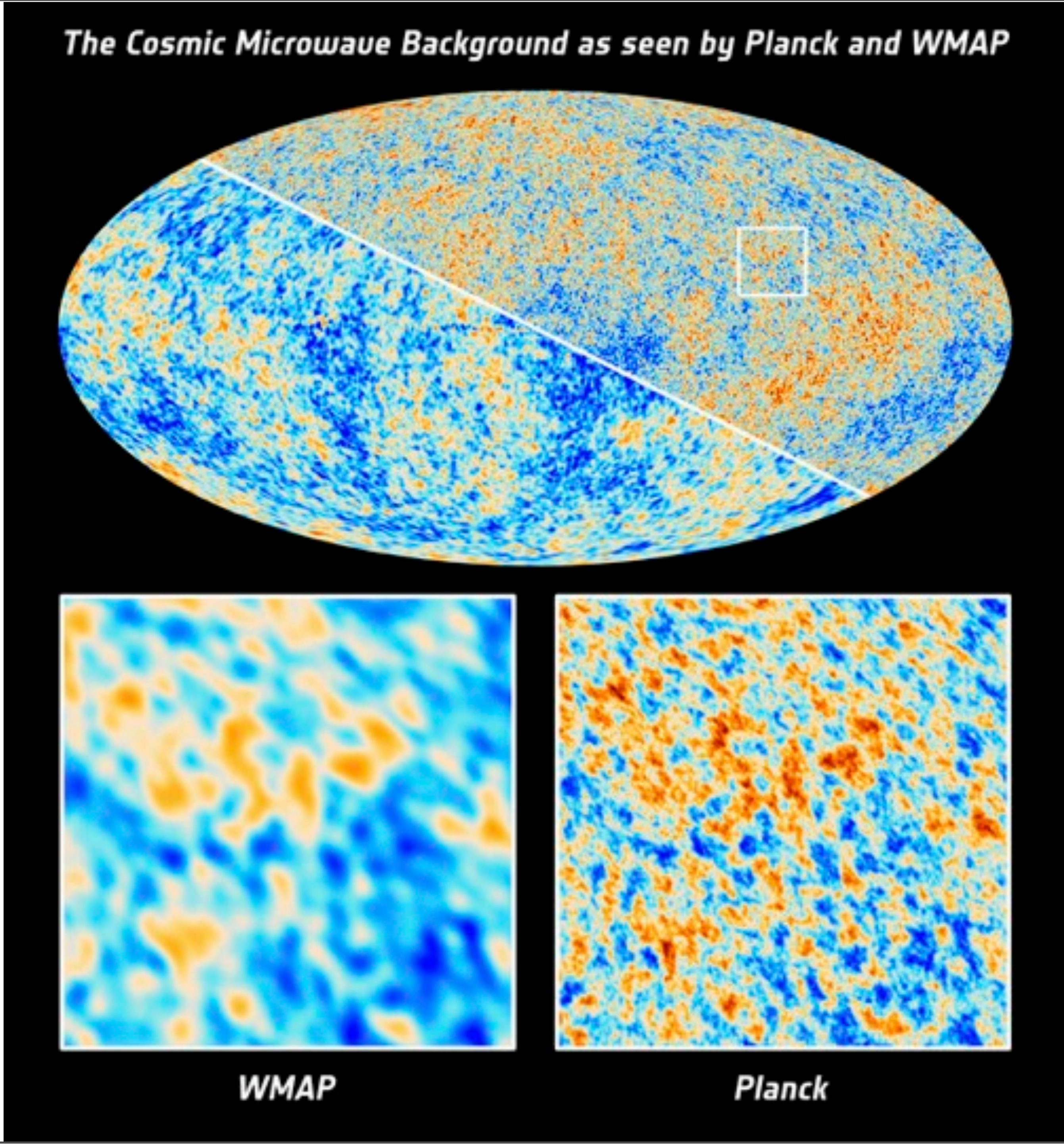


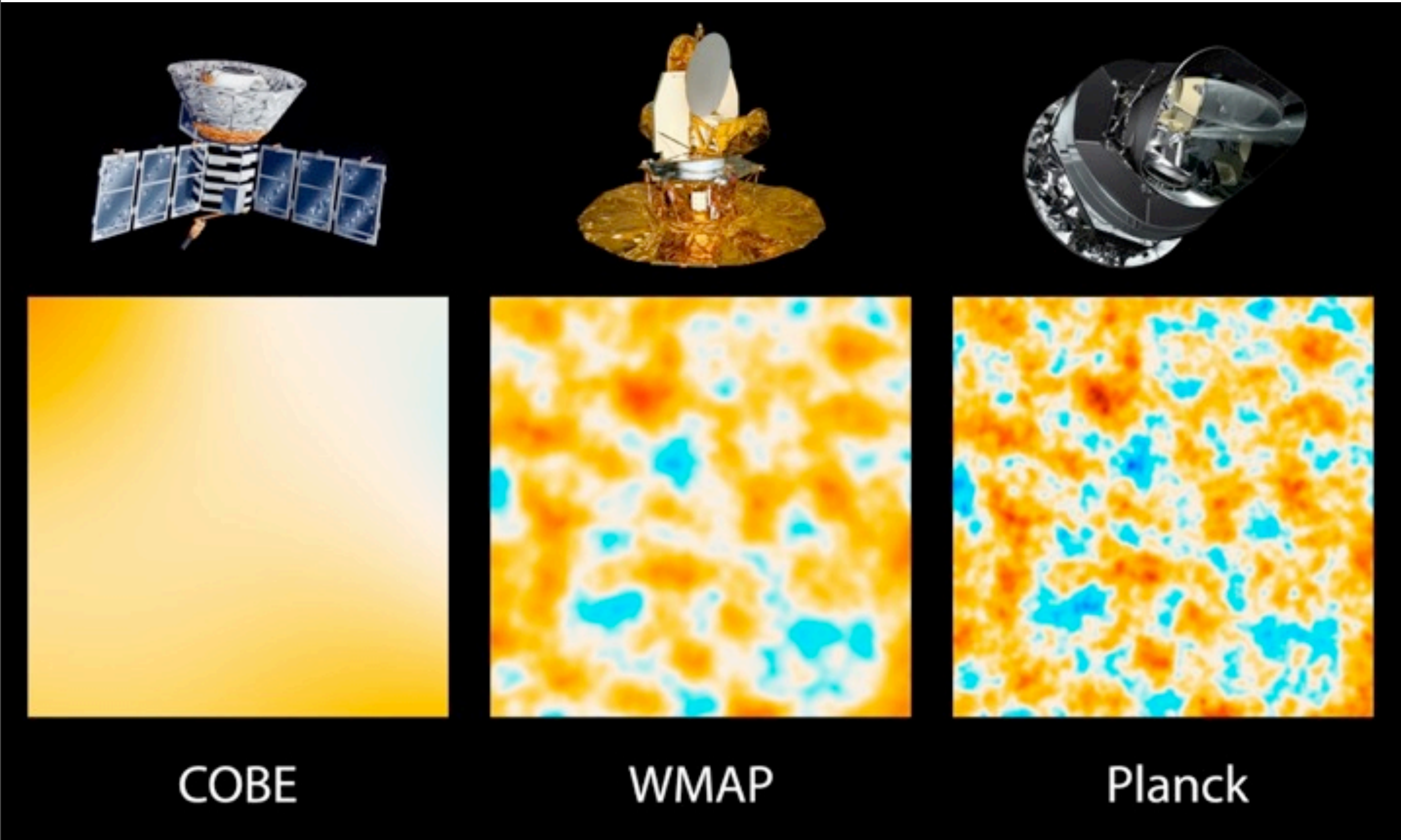
+ Likelihood code & T spectra

Planck1.3yr papers March 21, 2013



+ a PIP on kSZ


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



goal: high enough resolution to plumb all cosmic parameter information. but high L foregrounds, extragalactic sources => higher L expts ACT, SPT = PlanckEXT to nail the "nuisance"

media response was huge & wonderful for cosmology

e.g., CMB map tops Mar 22 NYTimes

& in Canada

CSA

media emphasis

age is 80Myr older than before Mar 21

a perfect U - NOT

Published: March 21, 2013

FACEBOOK TWITTER GOOGLE+ E-MAIL SHARE

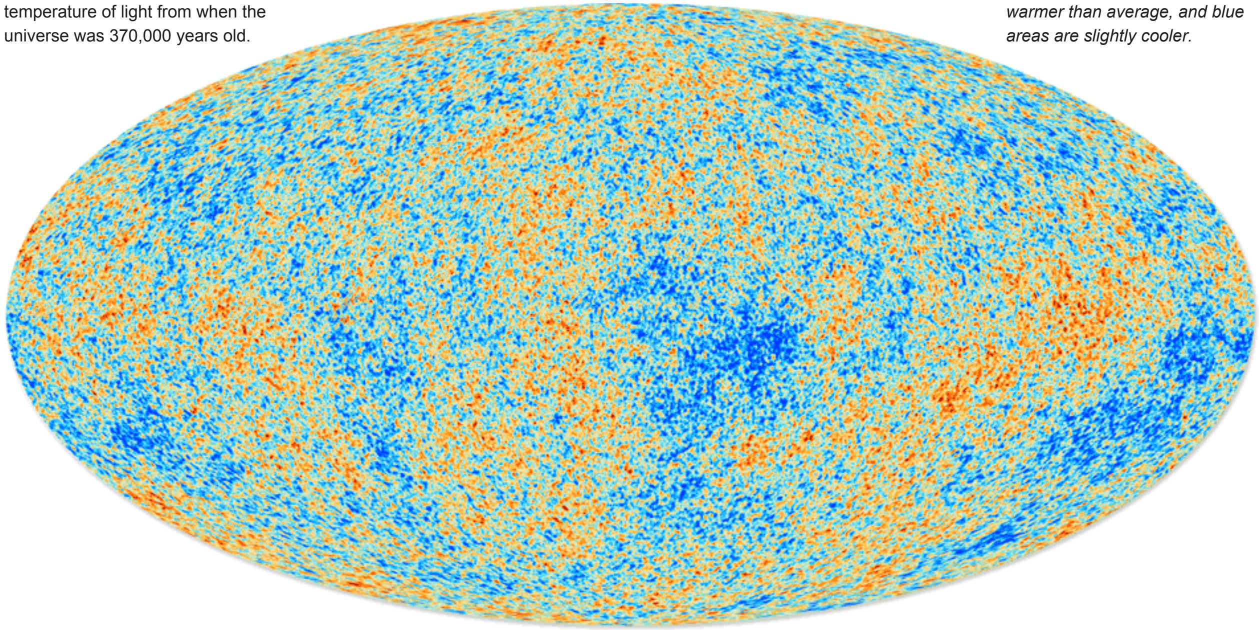
Mapping the Early Universe

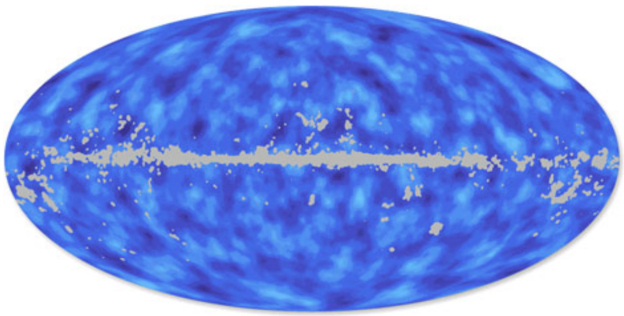
The Planck satellite has taken the most detailed images yet of the early universe. (Related Article)

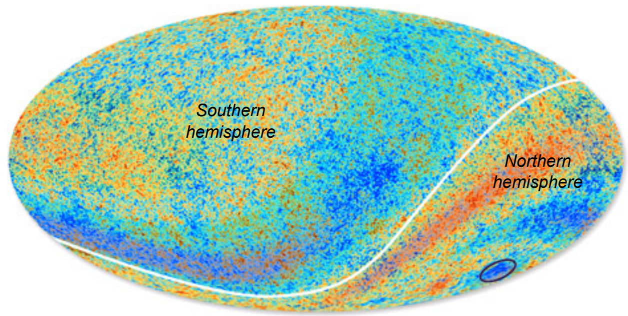
EARLY LIGHT

Planck studies minute fluctuations in the temperature of light from when the universe was 370,000 years old.

Orange areas are slightly warmer than average, and blue areas are slightly cooler.







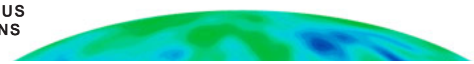
Mass and gravity

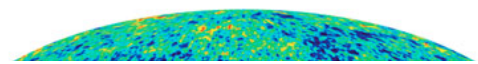
As ancient light travels toward Earth, it is warped and distorted by gravity. Planck measured this distortion to create a map of mass in the universe. Areas with more mass appear darker, while areas of the universe with less mass appear lighter. Gray areas are obscured by the disk of the Milky Way.

Temperature anomalies

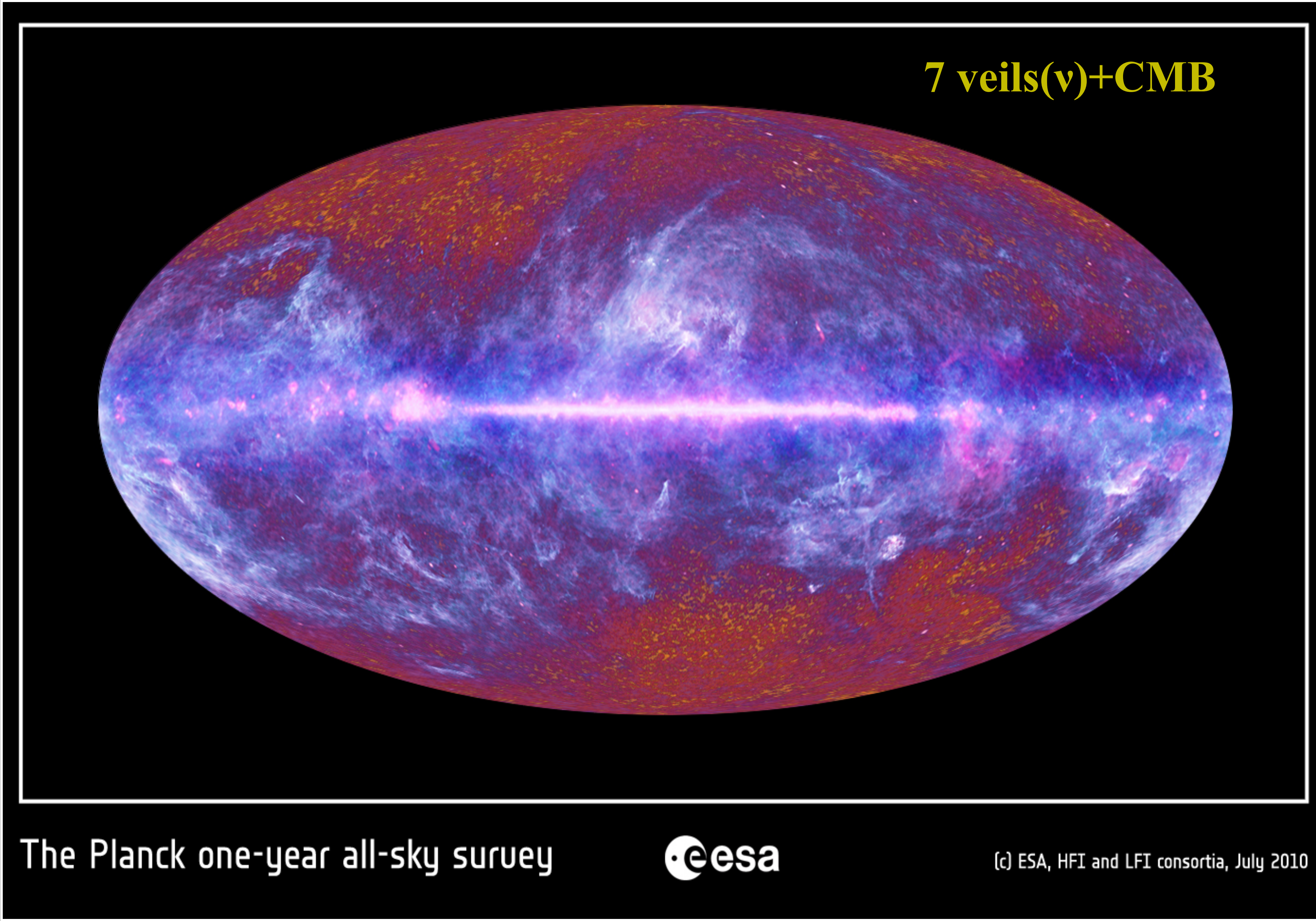
The new map confirms that temperature patterns in the early universe were slightly asymmetrical. The northern hemisphere of the universe (above the Sun) appears slightly cooler than the southern hemisphere (below the Sun), as shown in this enhanced image. An unexpectedly large cold spot is circled in black.

PREVIOUS MISSIONS



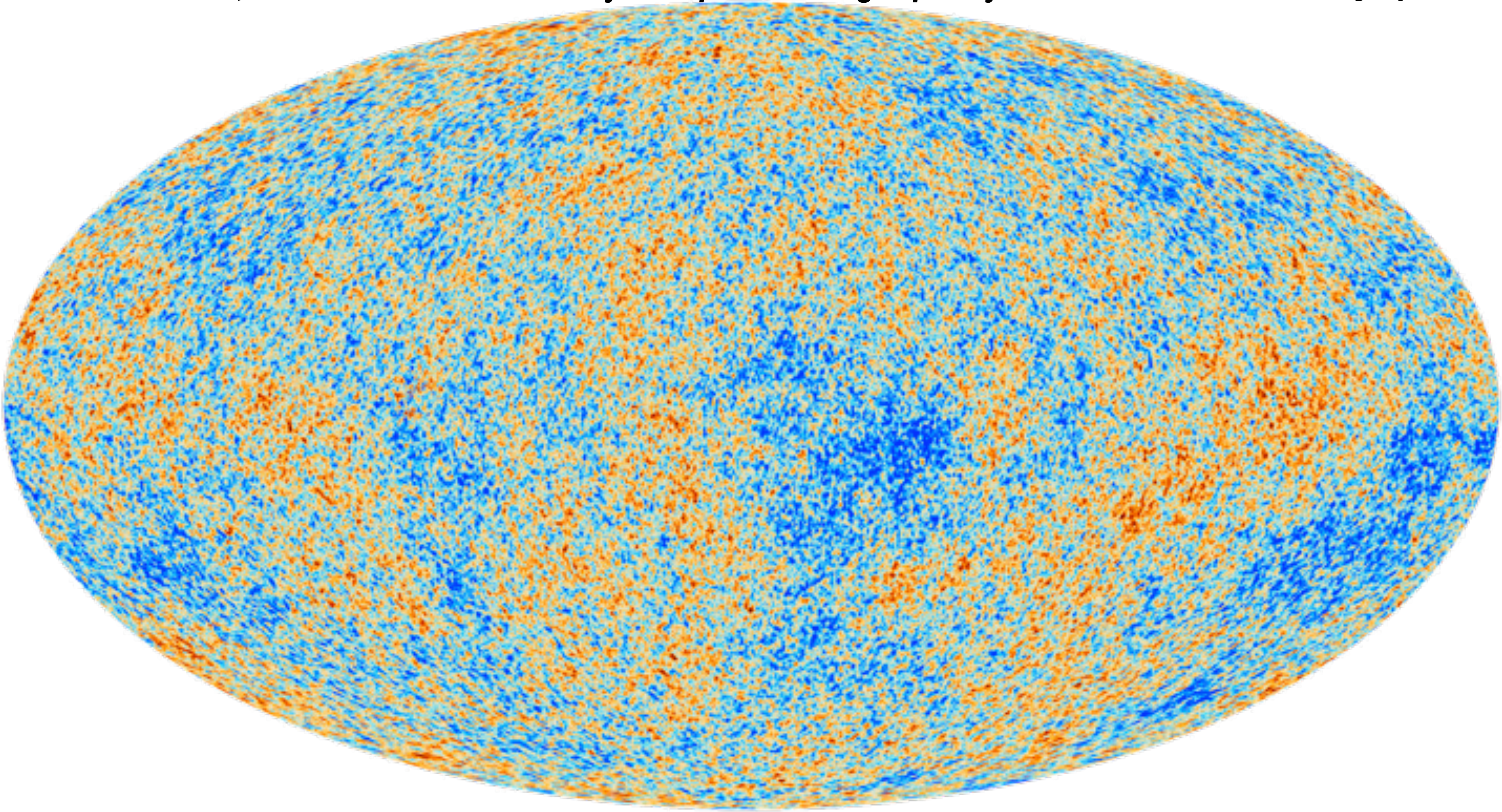


Planck2011: 26 early papers + ERCSC; 2012-12 ~20 intermediate papers



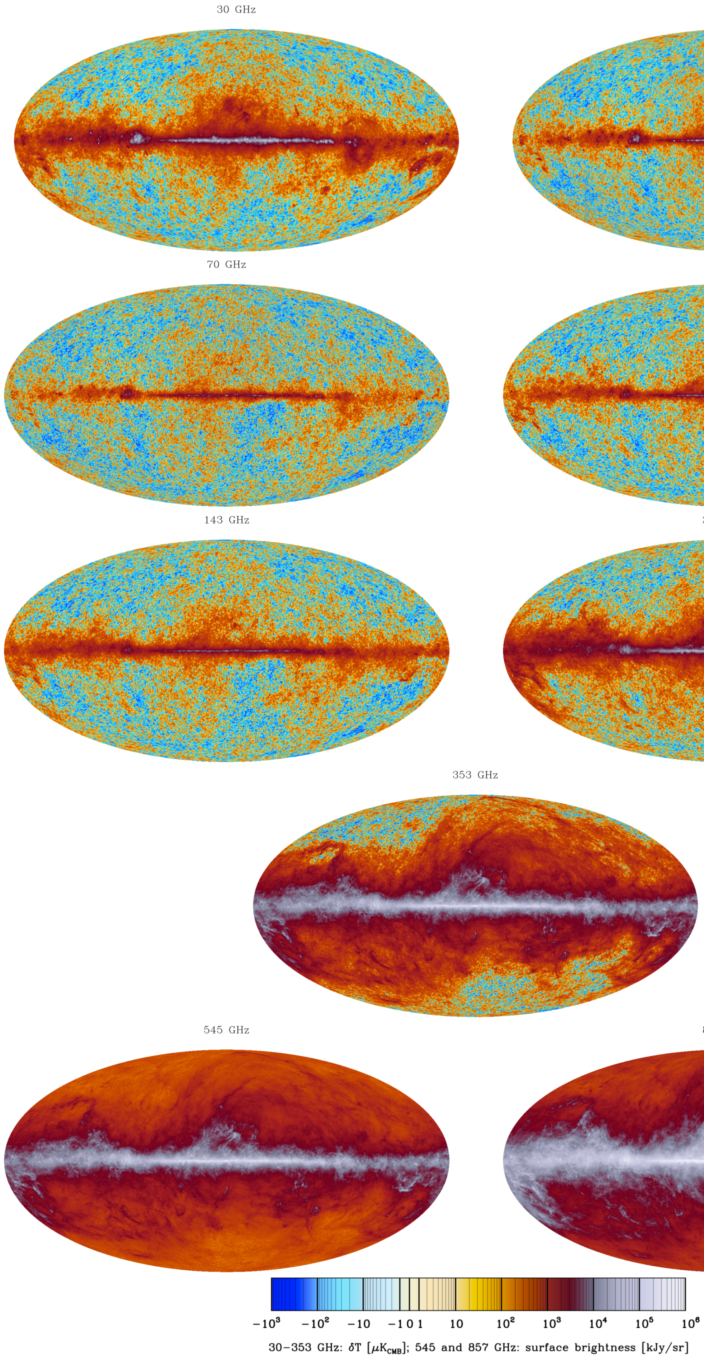
we compress the Petabit++ observed cosmic info into a precious few bits encoding 6+ parameters of the Minimal Cosmic Standard model (tilted ΛCDM)

raw digitized information: WMAP: 1.15 Tbits in 9yrs, cf. MyLifeBits, Gordon Bell, 1.28 Tbits in 9yrs, Planck 36 Tbits, ACT 304 Tbits. Radically Compress to high quality Bits. *Terabit=10^{12}bits=125 GigaBytes.*



a new figure of merit for experiments, <ln$VOLUME_{ps}$> ~ posterior Shannon entropy, of a Bayesian flow from time-streams => maps (pixel amplitudes = parameters) => isotropic power spectra C_L => cosmic parameters + experimental and Galactic/extragalactic "nuisance" parameters

Planck Frequency Maps

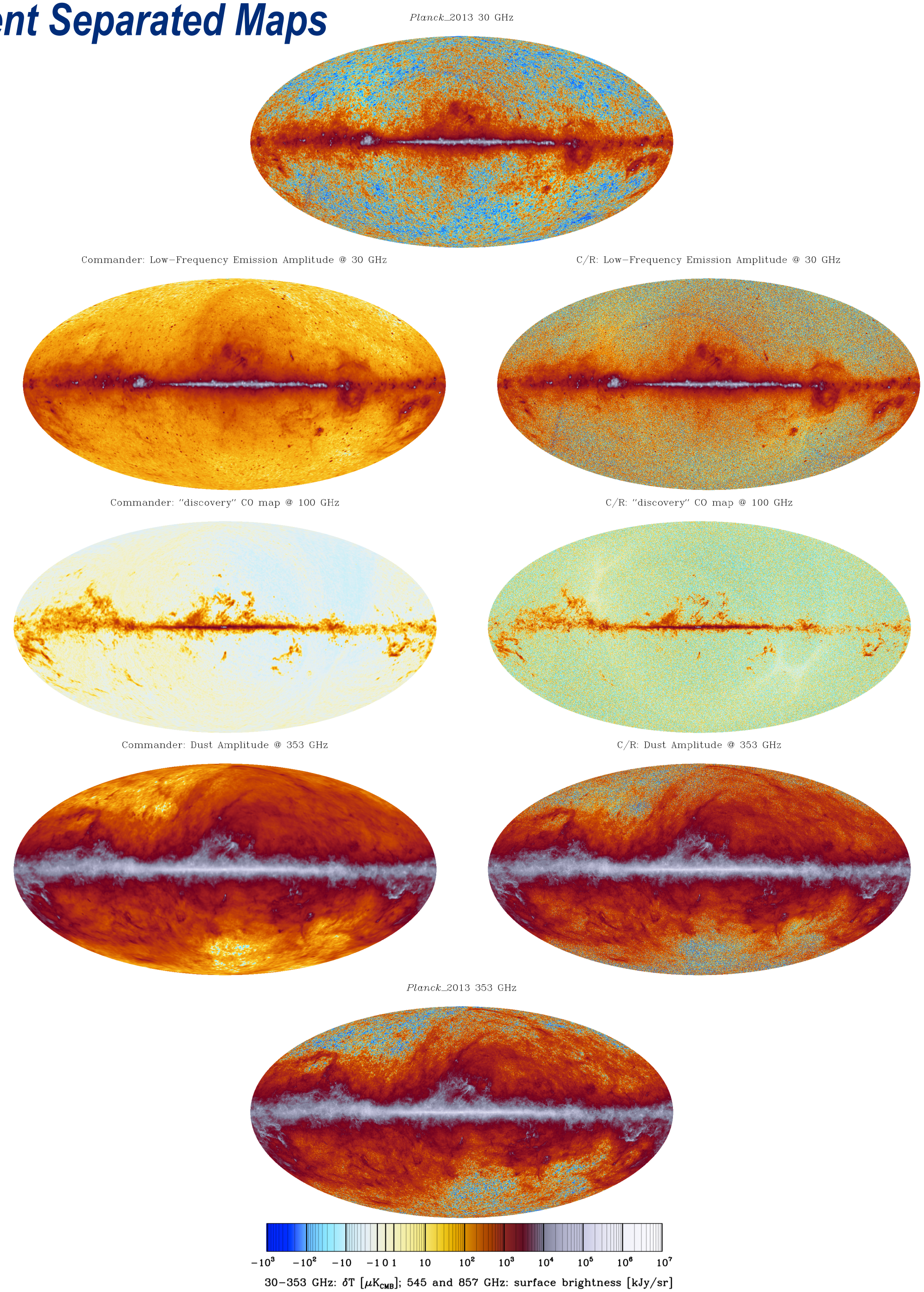


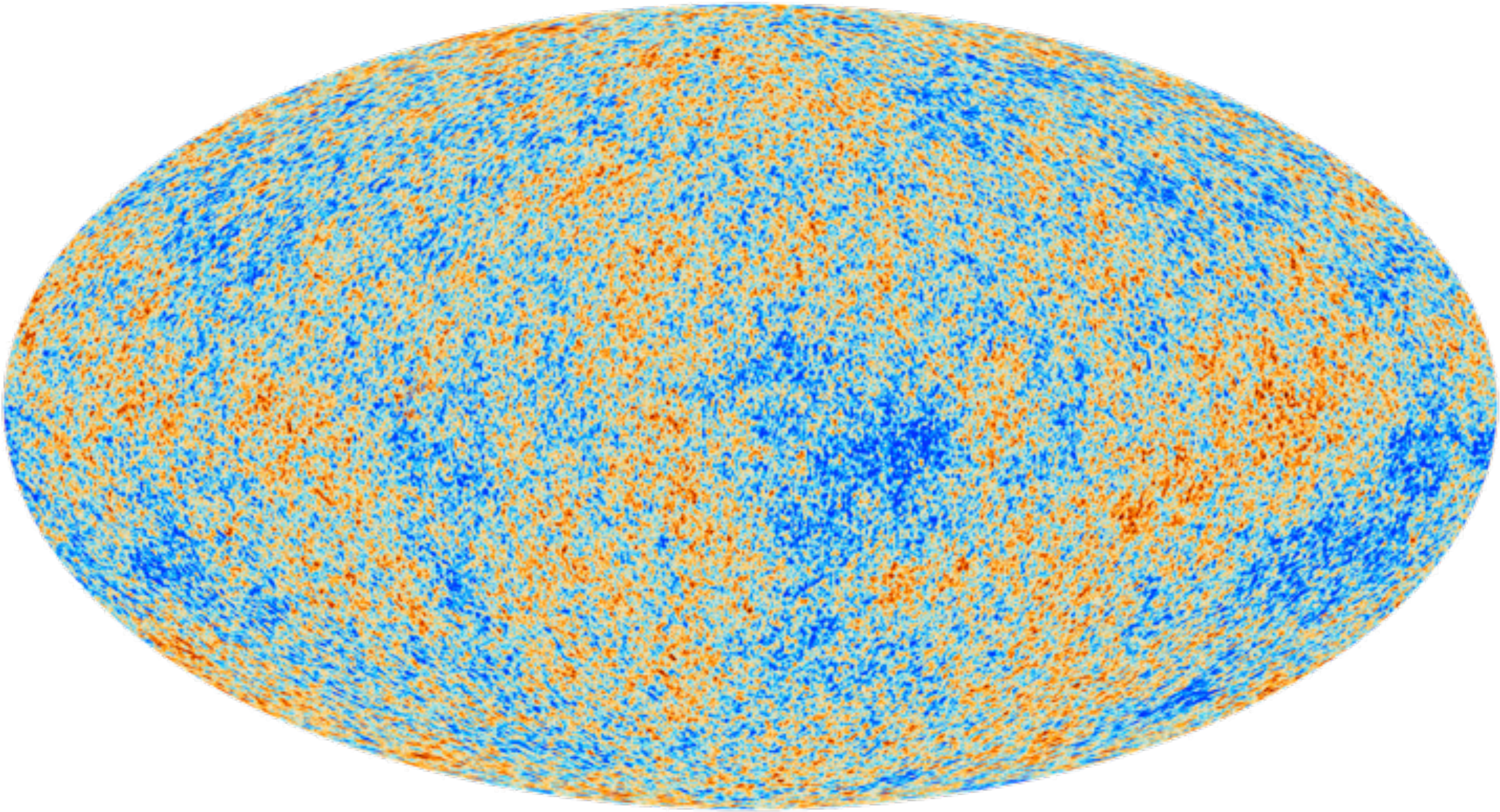
Some Planck Component Separated Maps

LF Synchrotron + bremsstrahlung

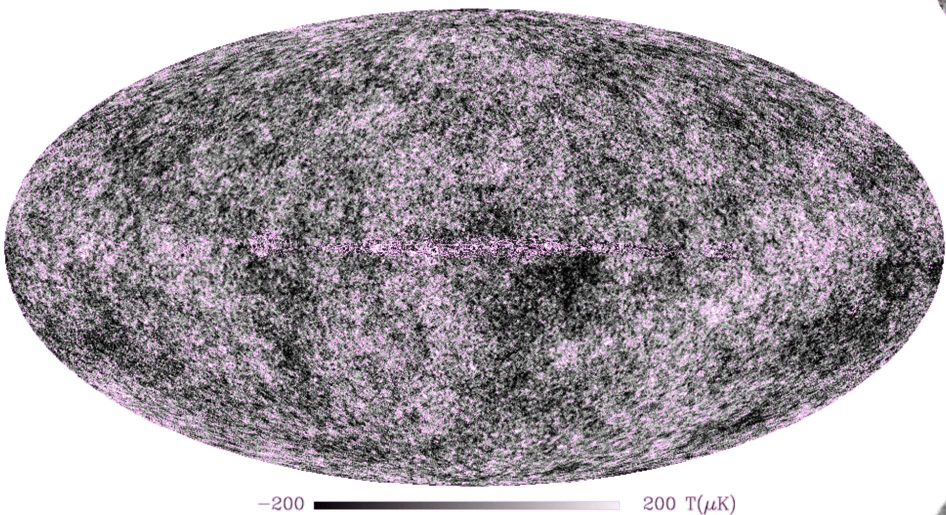
Galactic Carbon Monoxide

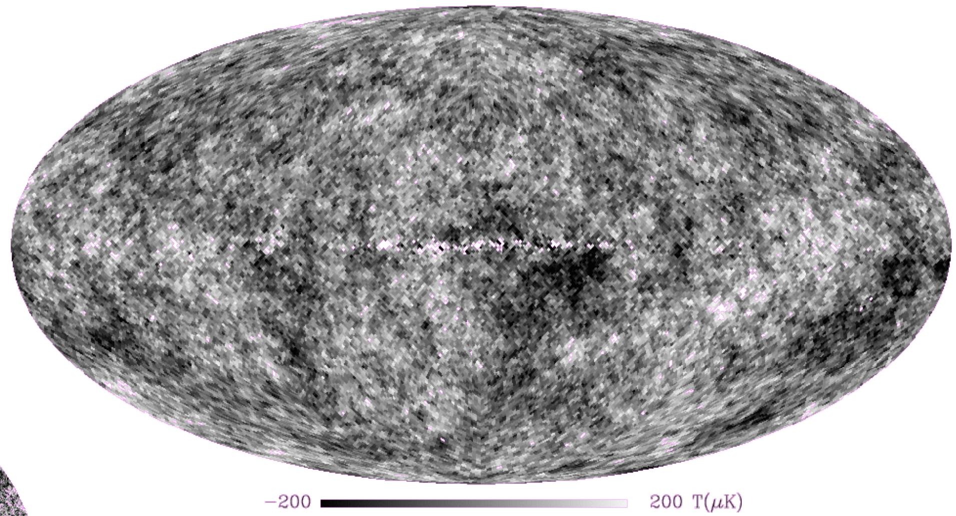
HF Thermal Dust Emission



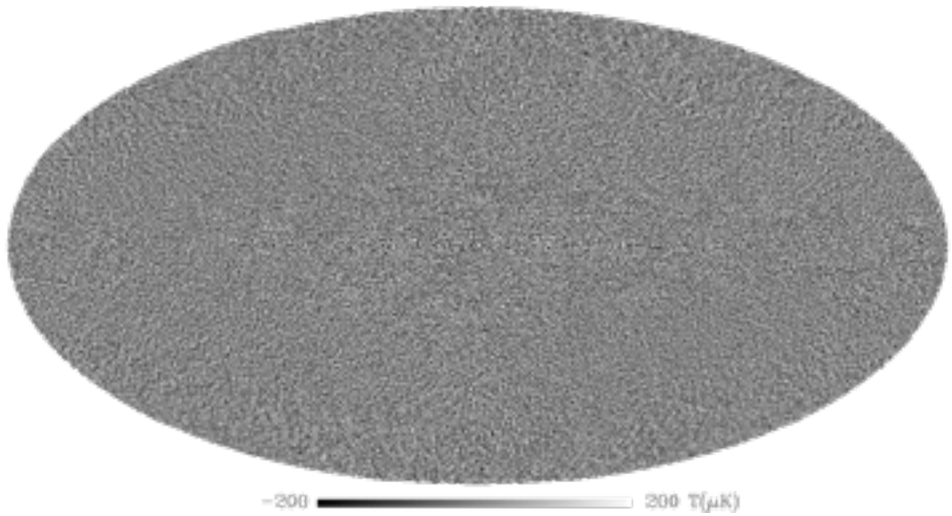


full Planck resolution

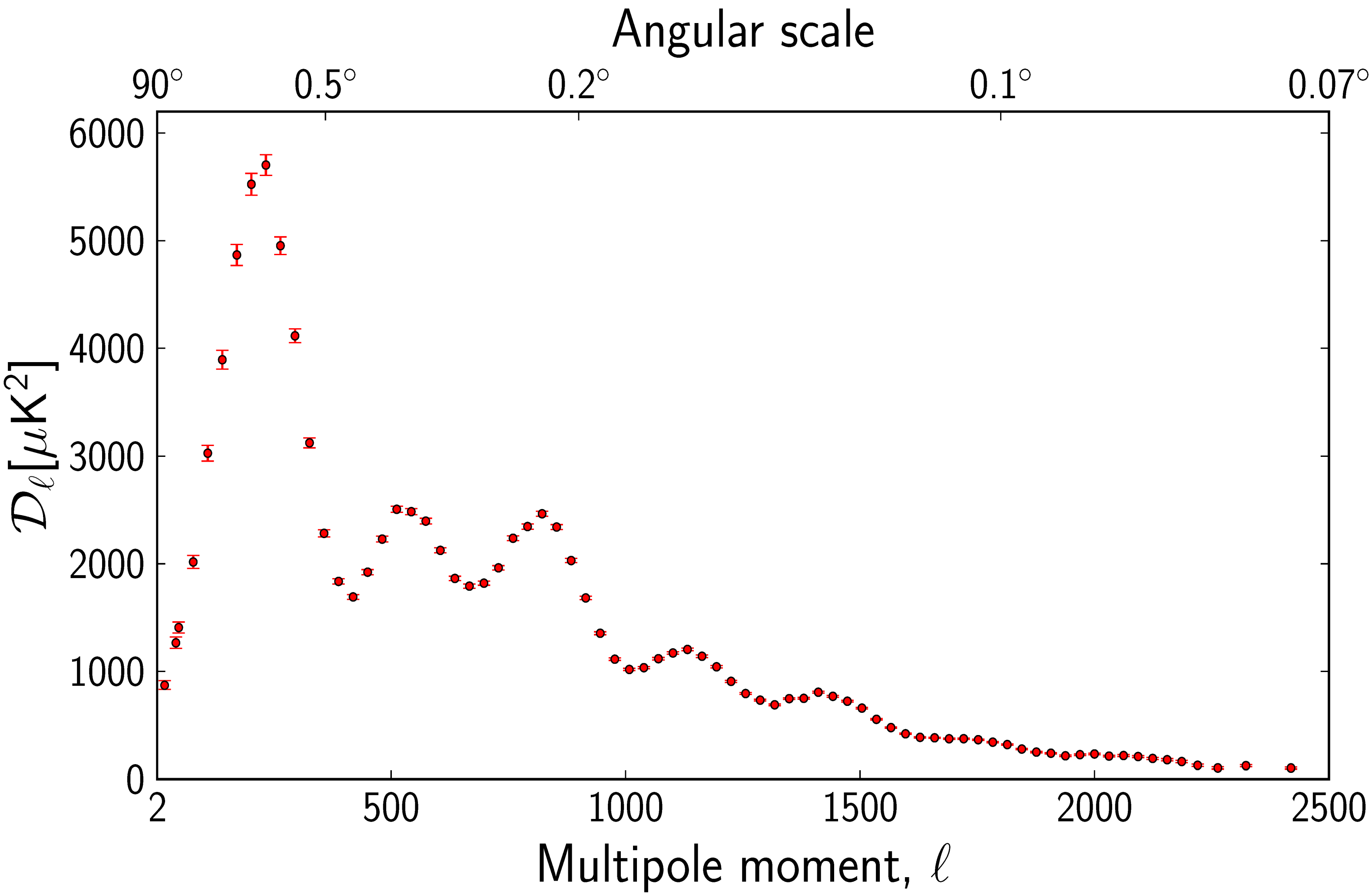




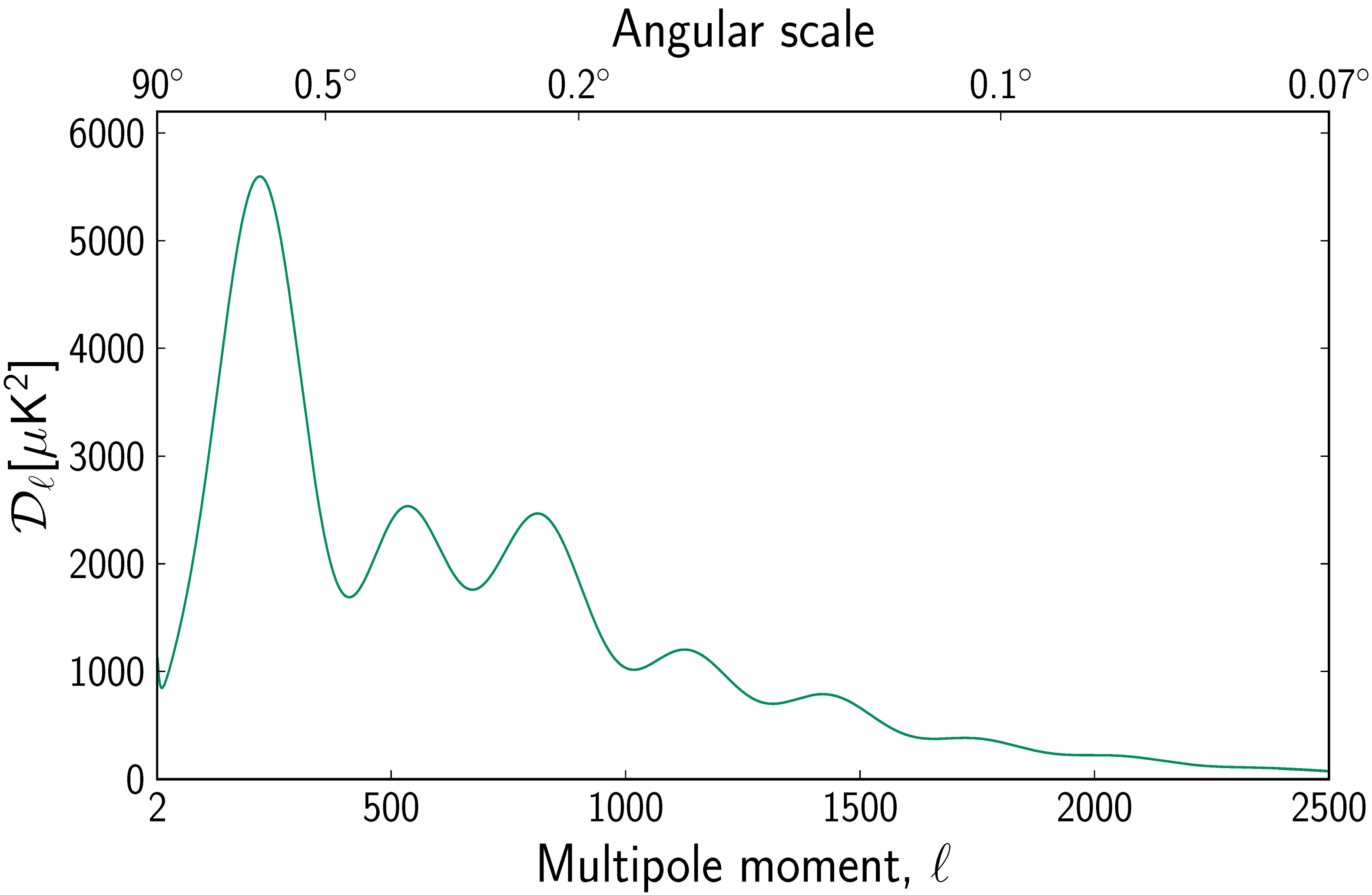
Planck smoothed to 1deg fwhm



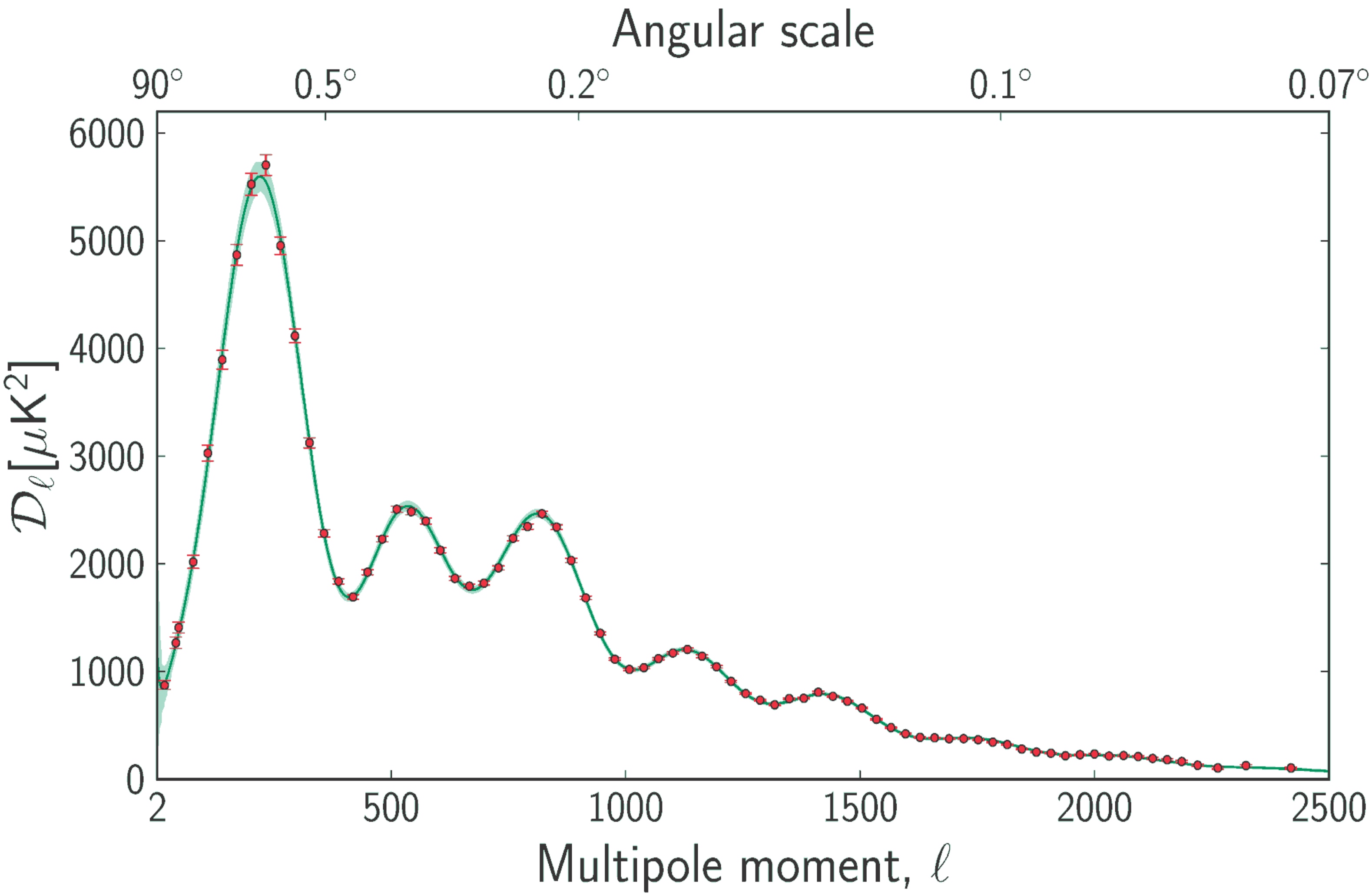
small scale leftover = where most of Planck’s information resides> 100X

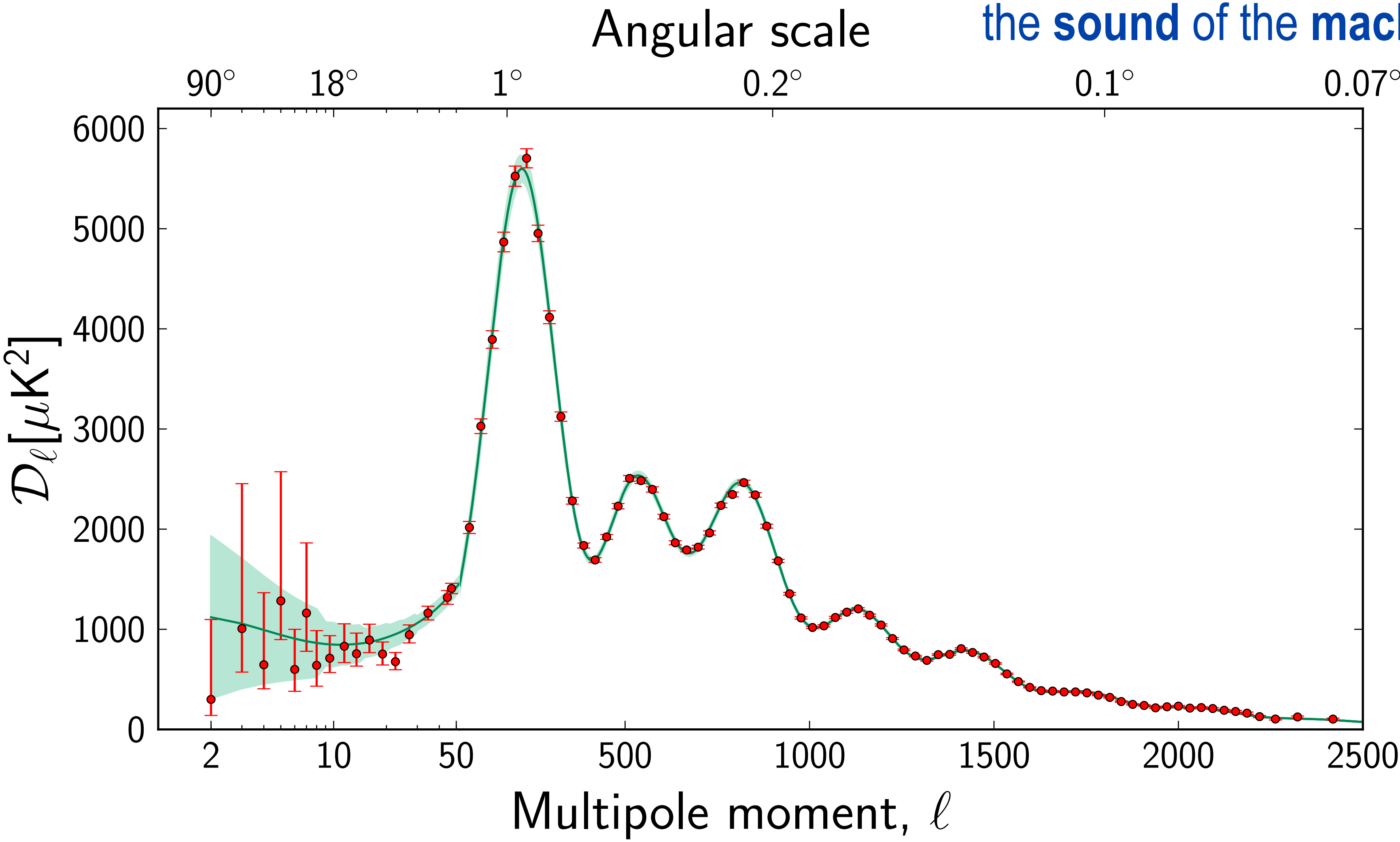

Angular scale
90°
0.5°
0.2°
0.1°
0.07°
6000
5000
4000
3000
2000
1000
0
$\mathcal{D}_\ell [\mu K^2]$
2
500
1000
1500
2000
2500
Multipole moment, ℓ

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

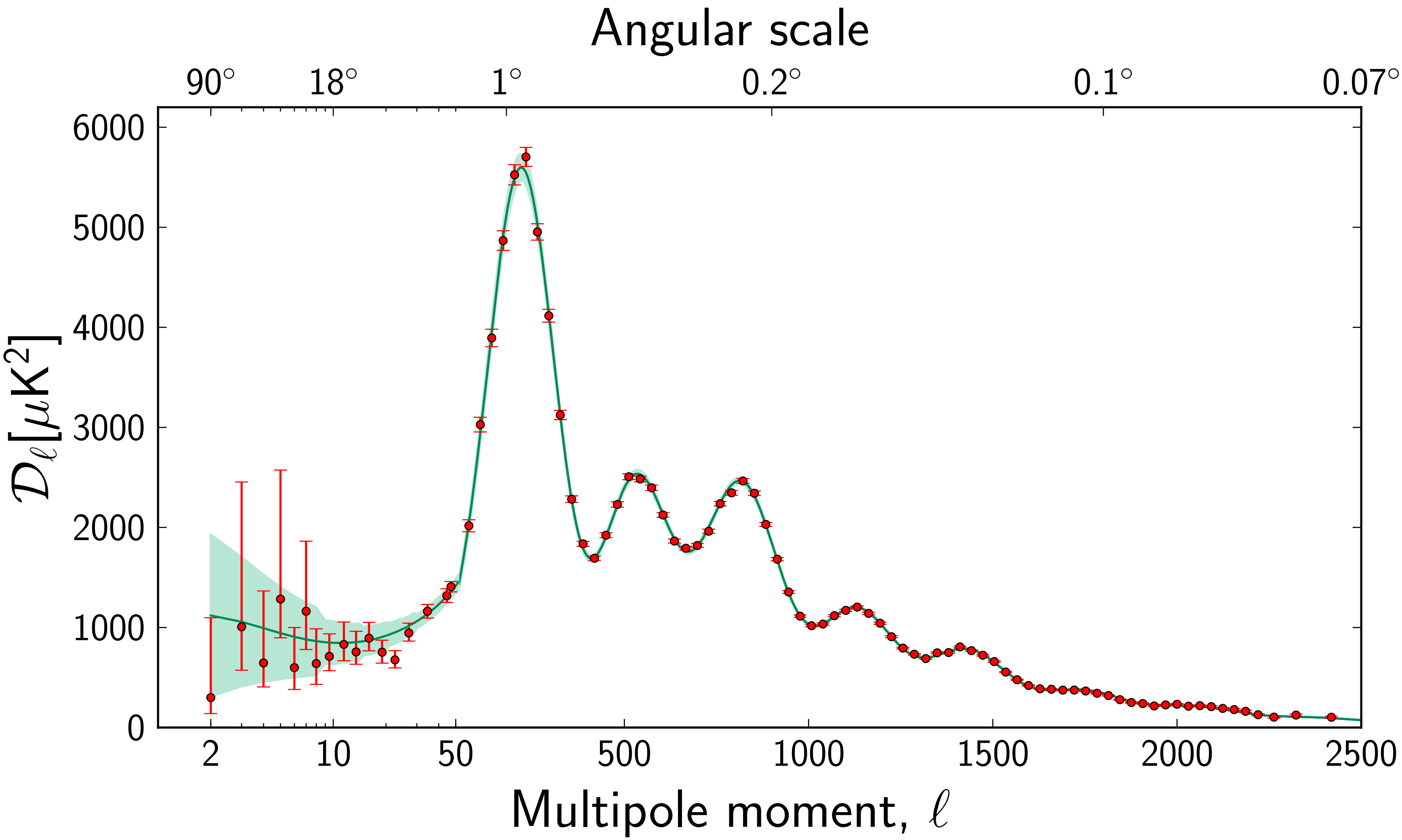


CMB Power Spectrum Propaganda: best fit basic 6 cosmic parameter model. Superb fit





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}



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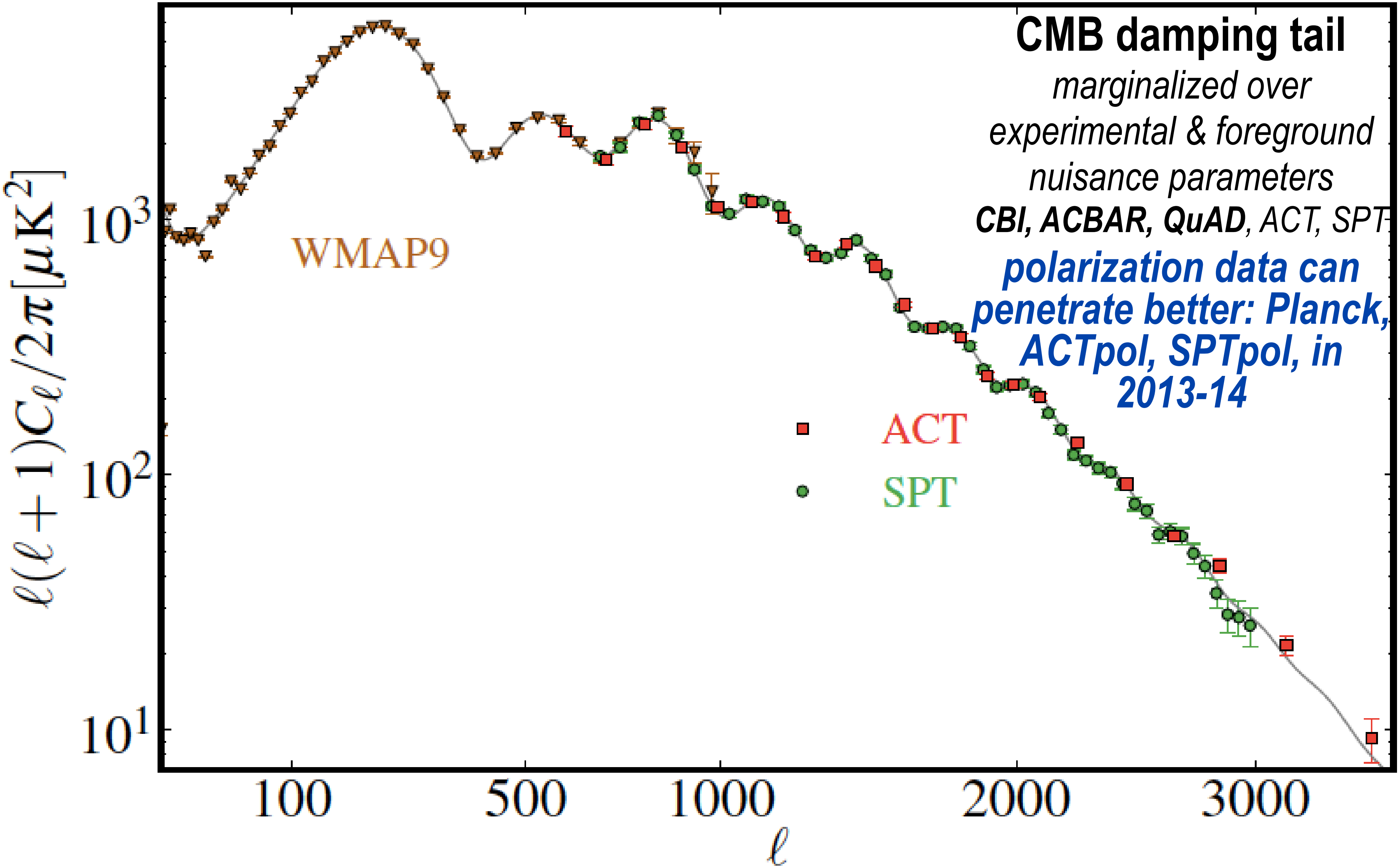
No substantial evidence for beyond basic single field slow roll, Bunch-Davis vacuum, standard kinetic term inflation. f_{NL}

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



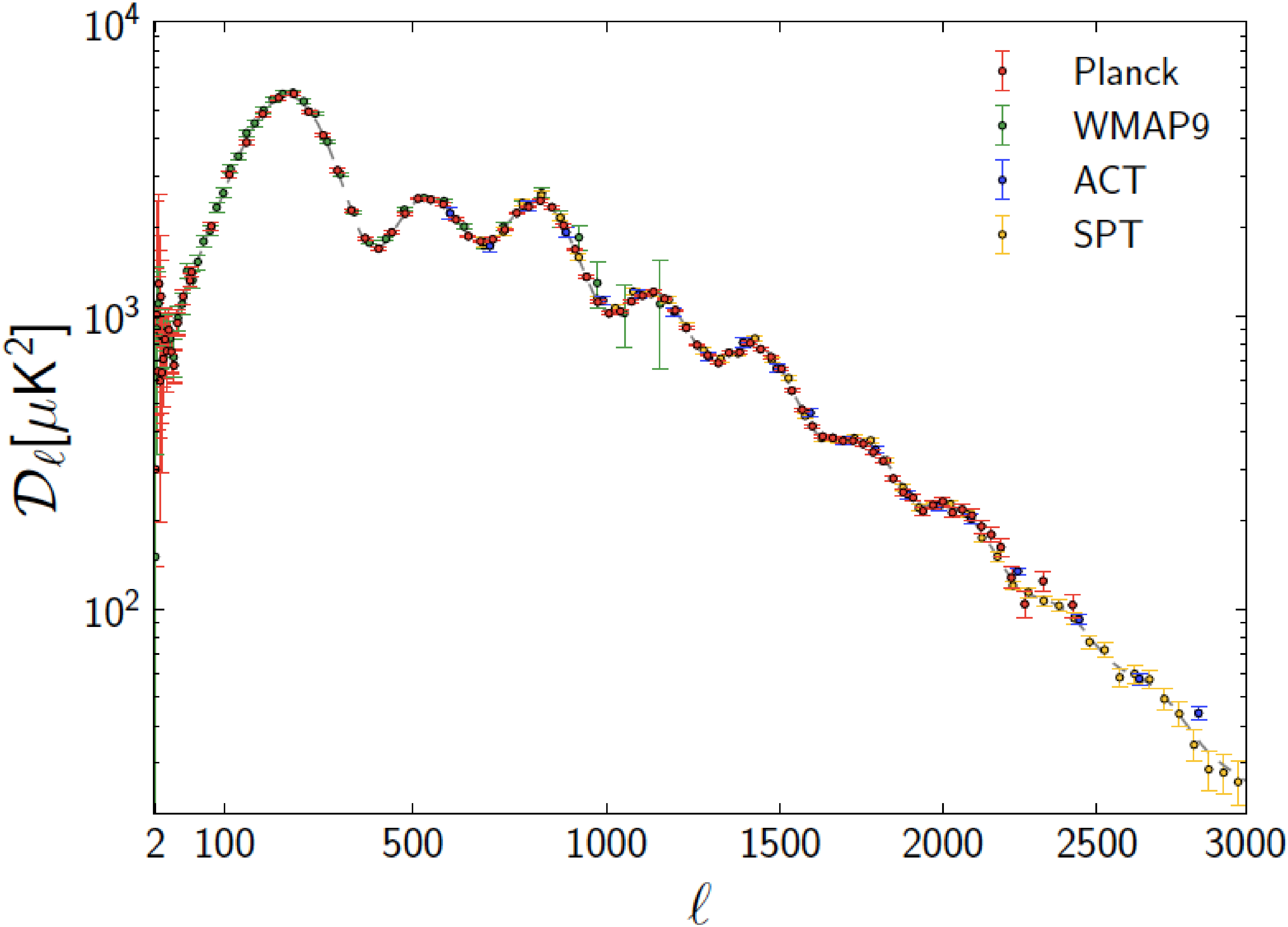
CMB damping tail

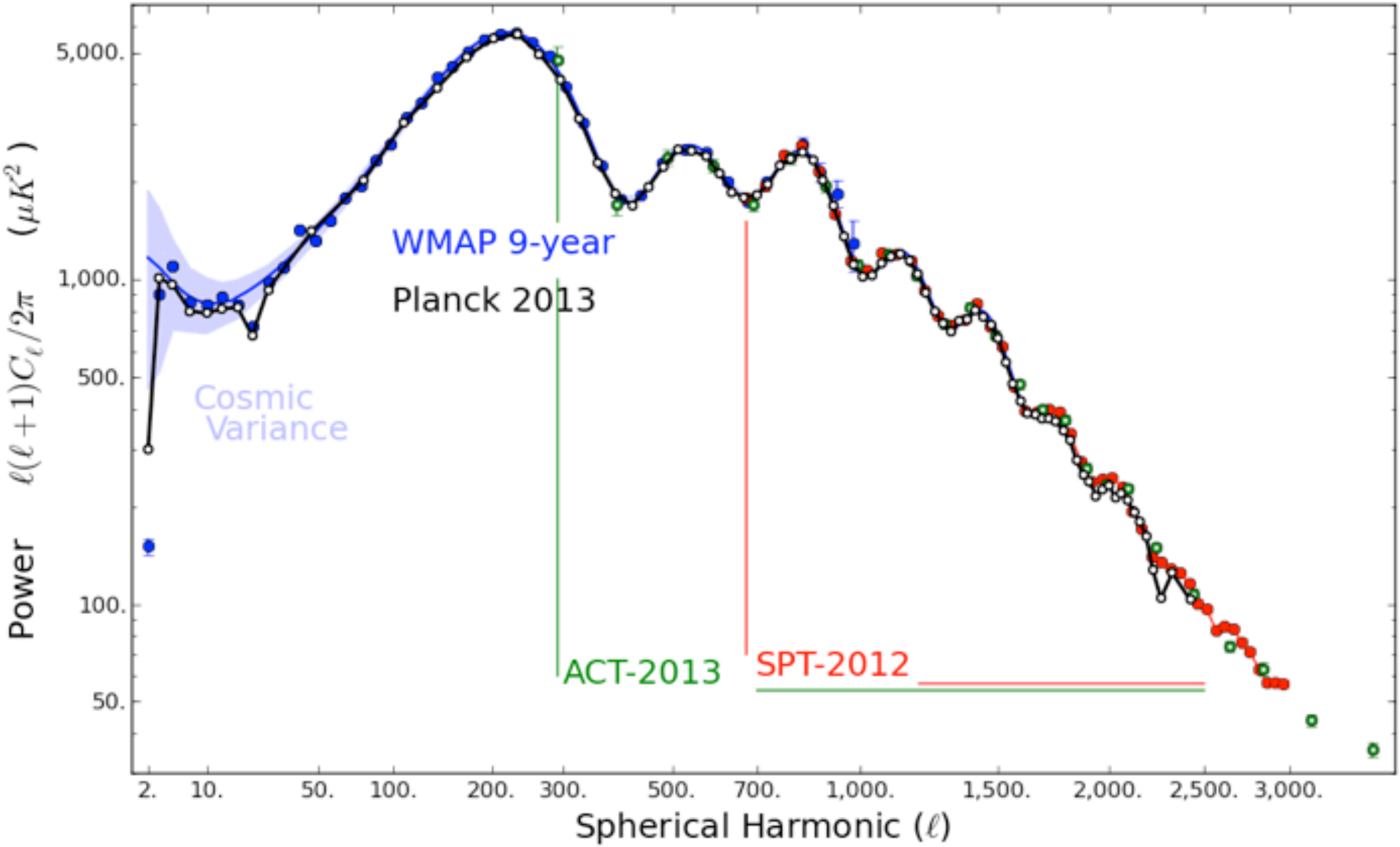
marginalized over experimental & foreground nuisance parameters

CBI, ACBAR, QuAD*, ACT, SPT*

polarization data can penetrate better: Planck, ACTpol, SPTpol, in 2013-14

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



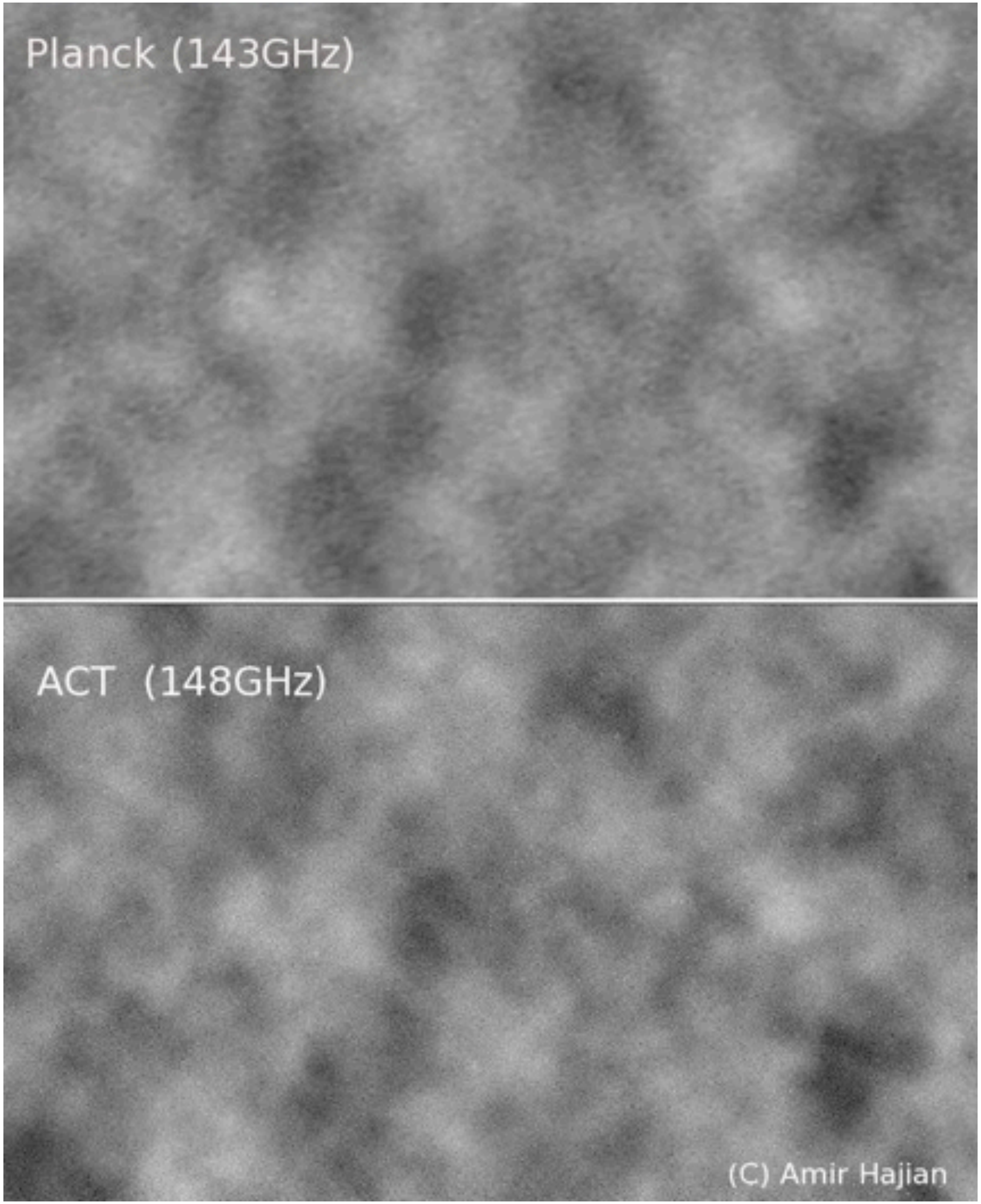


Halpern13 gif: WMAP9 cf. Planck2013 aka Planck1.3yr

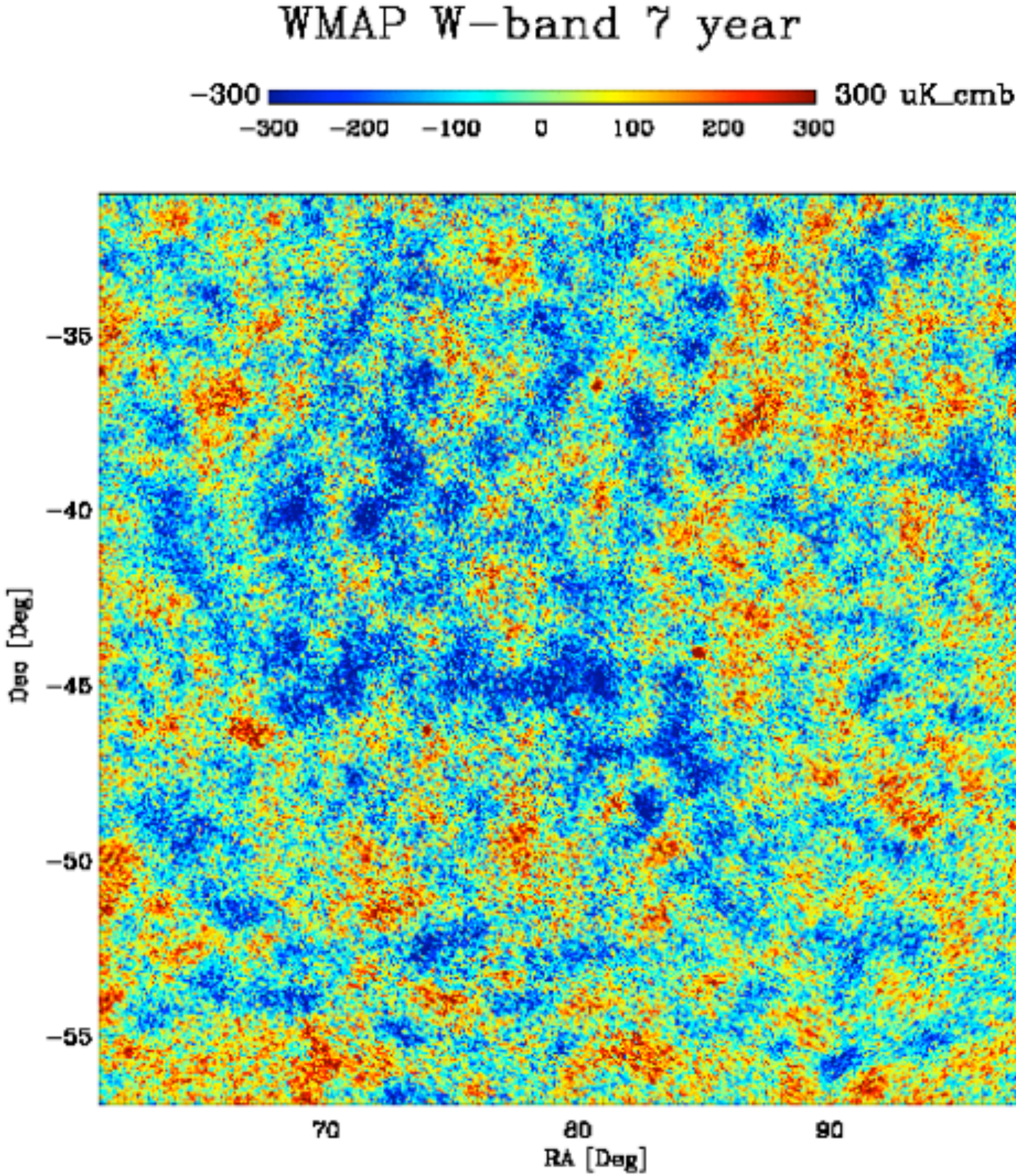
ACT12 vs Planck1.3 in limited sky region ***Hajian13@CITA***

excellent agreement

cross correlation also looks great

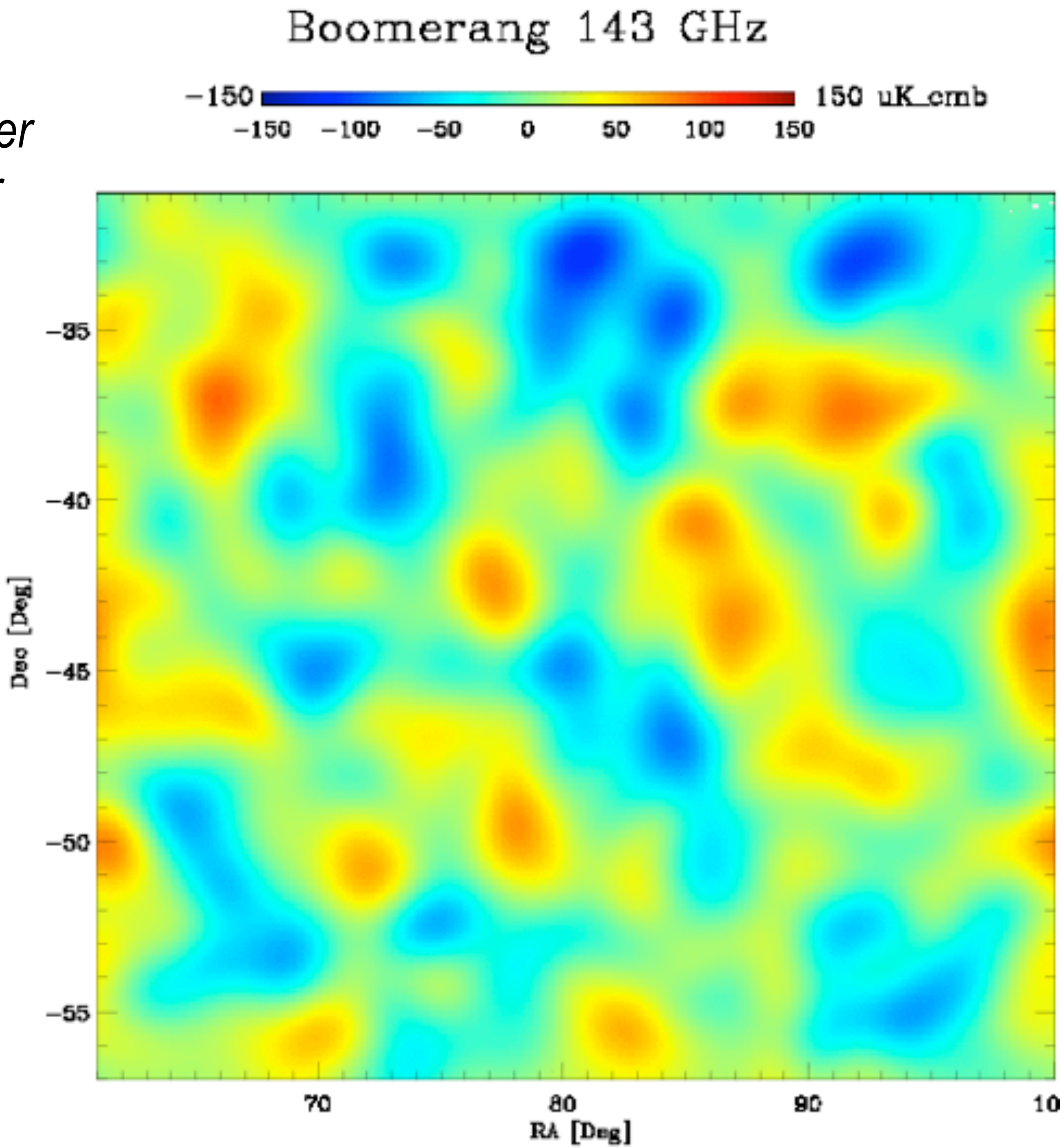


WMAP vs Boomerang03 vs HFI Planck1.3



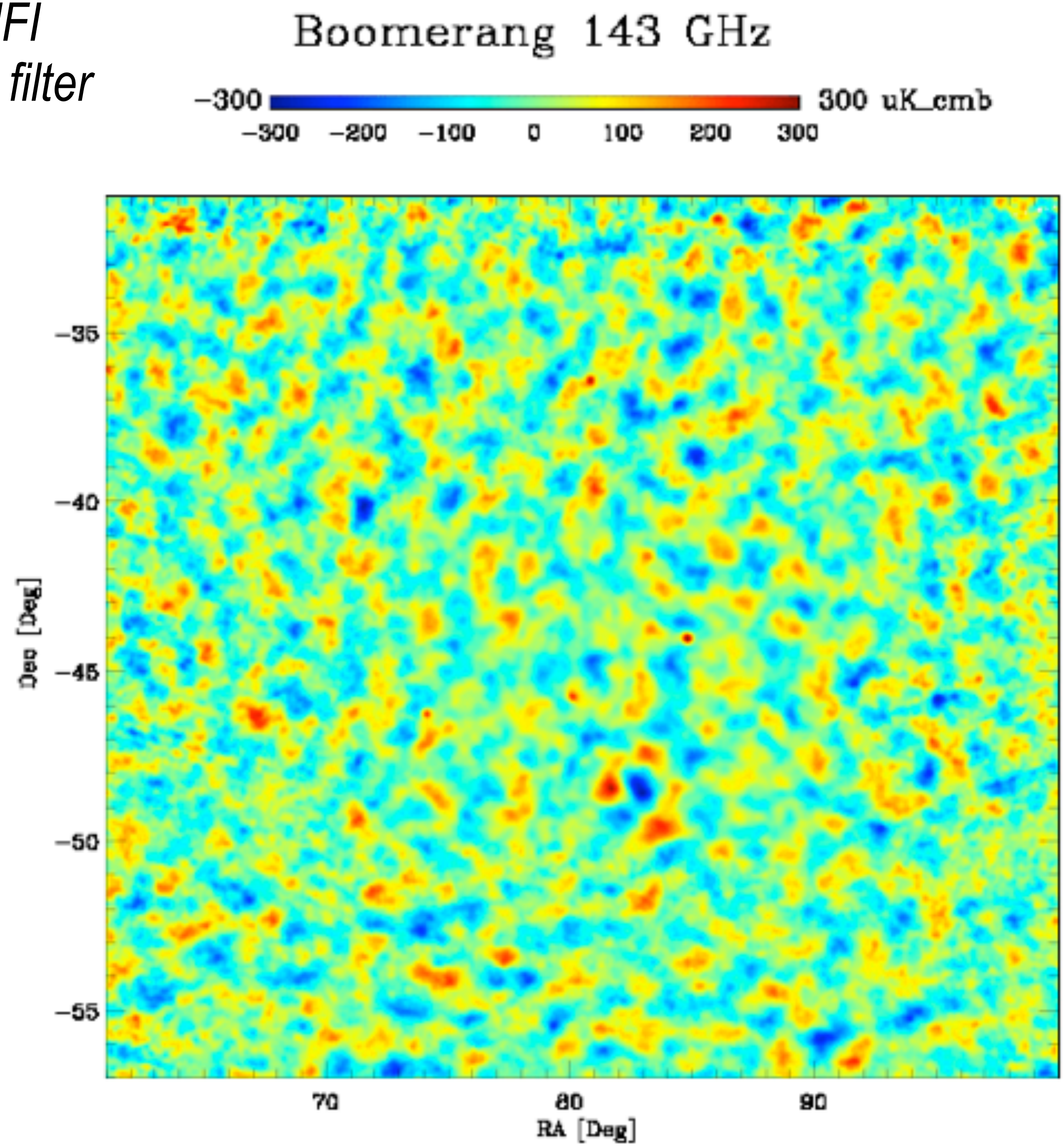
Jones13

Boom vs HFI
SachsWolfe filter
low pass filter



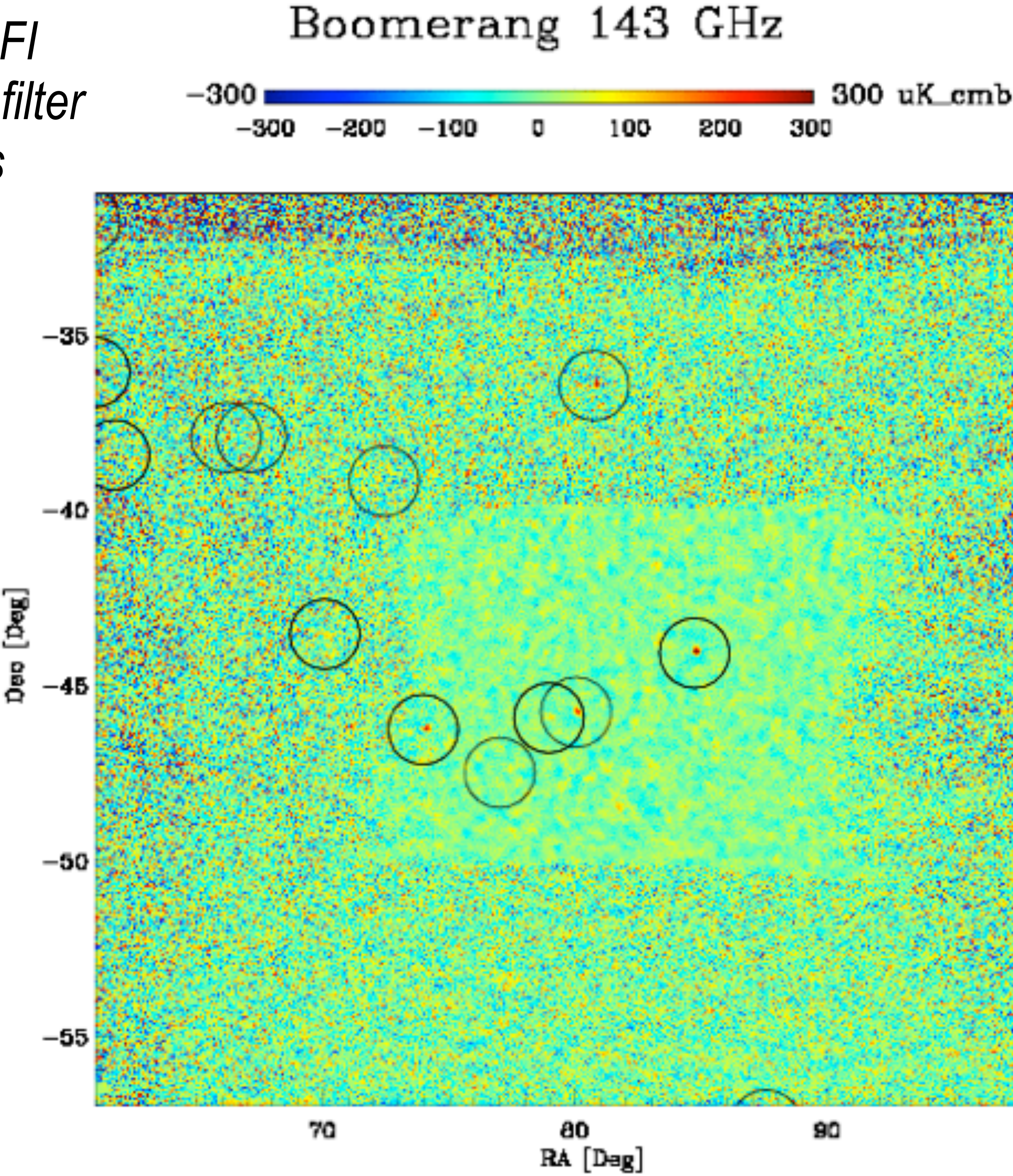
Jones13

Boom vs HFI
medium pass filter



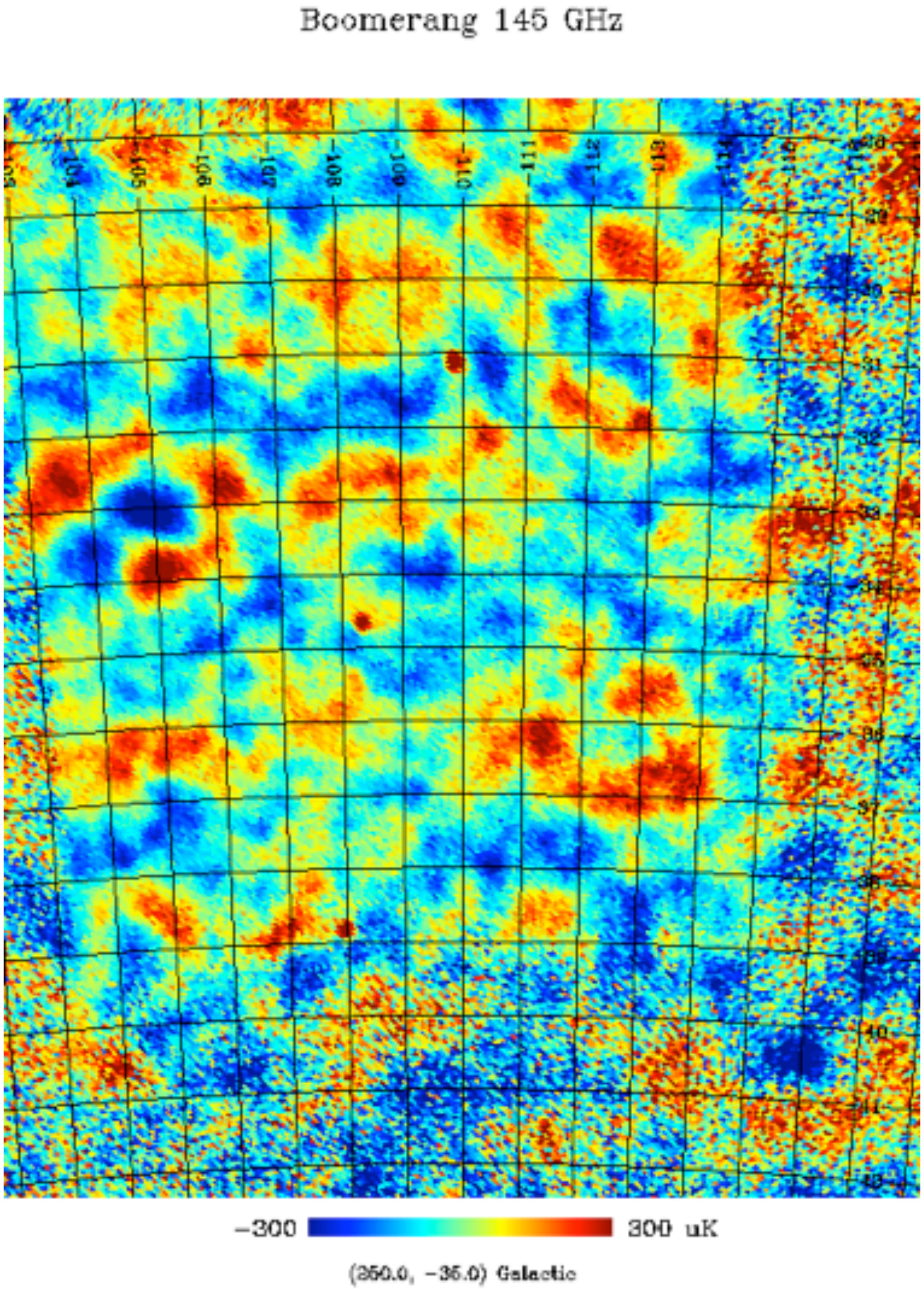
Jones13

Boom vs HFI
Silk damping filter
high pass

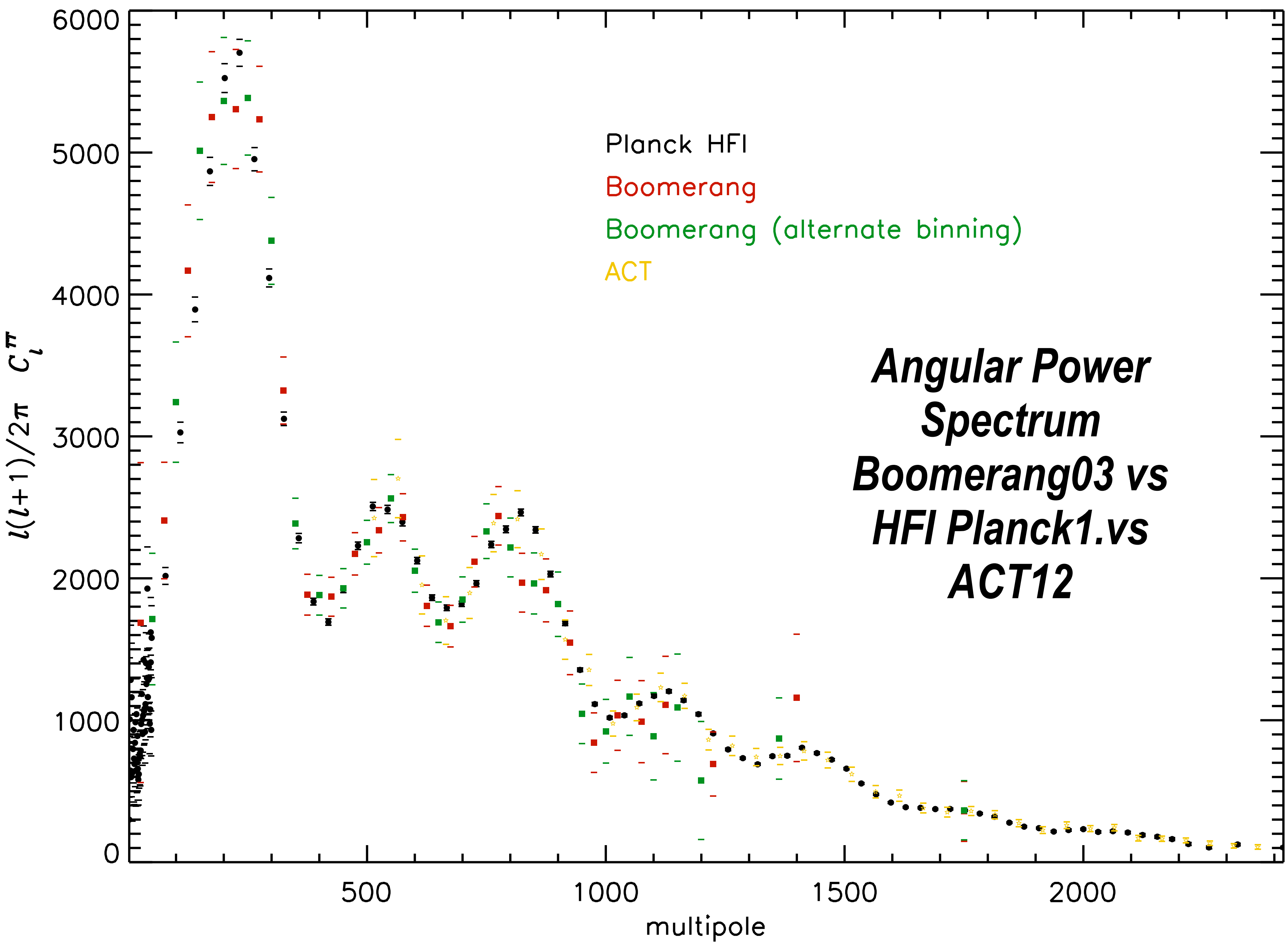


Jones13

WMAP vs Boomerang03 vs HFI Planck1.3

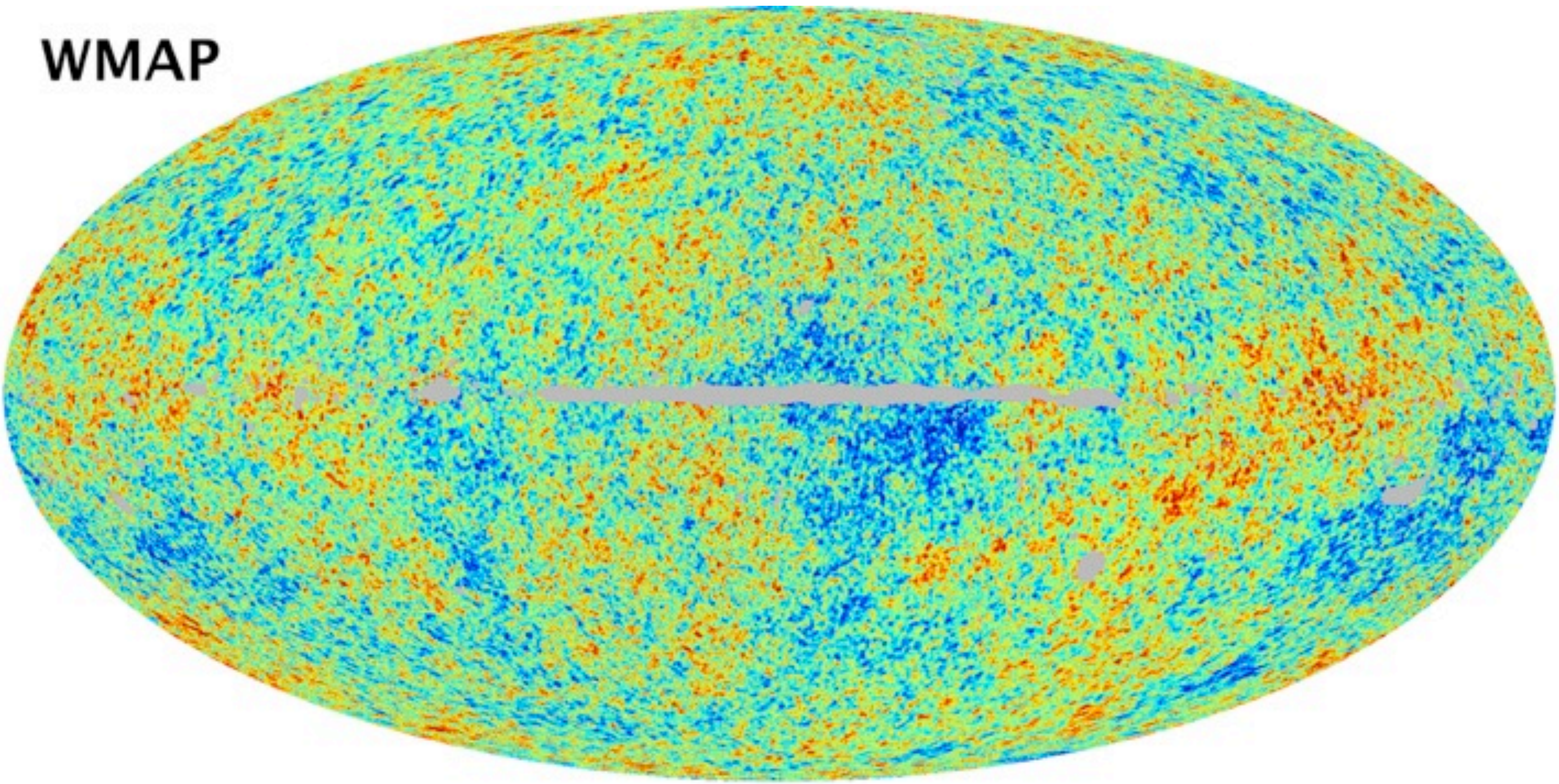


Piacentini13



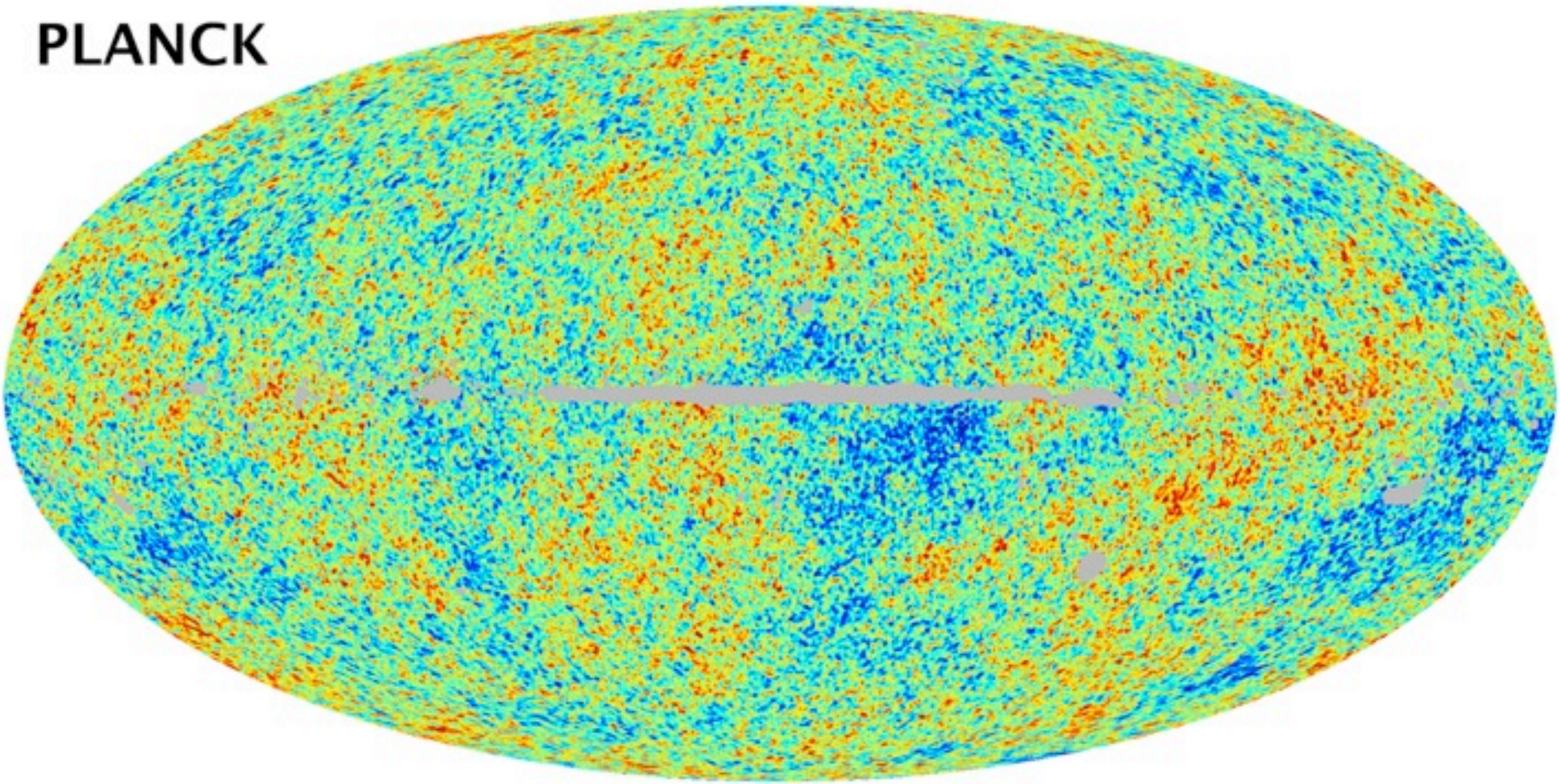
Planck HFI
Boomerang
Boomerang (alternate binning)
ACT
Angular Power Spectrum Boomerang03 vs HFI Planck1.vs ACT12
6000
5000
4000
3000
2000
1000
0
500
1000
1500
2000
multipole
$l(l+1)/2\pi \quad C_l^{\pi}$

WMAP W-band, Template Cleaned



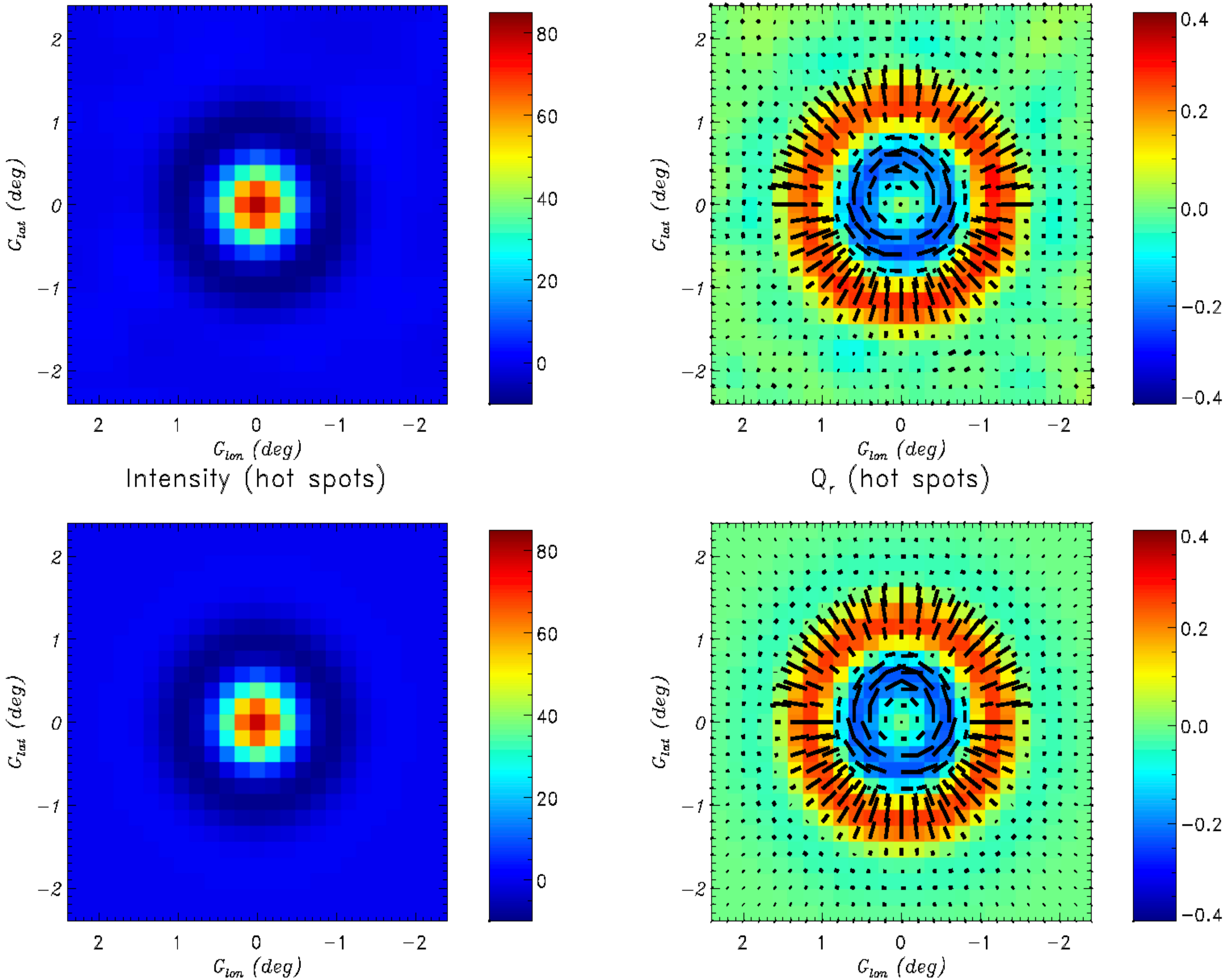
Cleaned with Planck 353 GHz dust map and low-frequency templates. 12′ resolution.

Planck SMICA Map



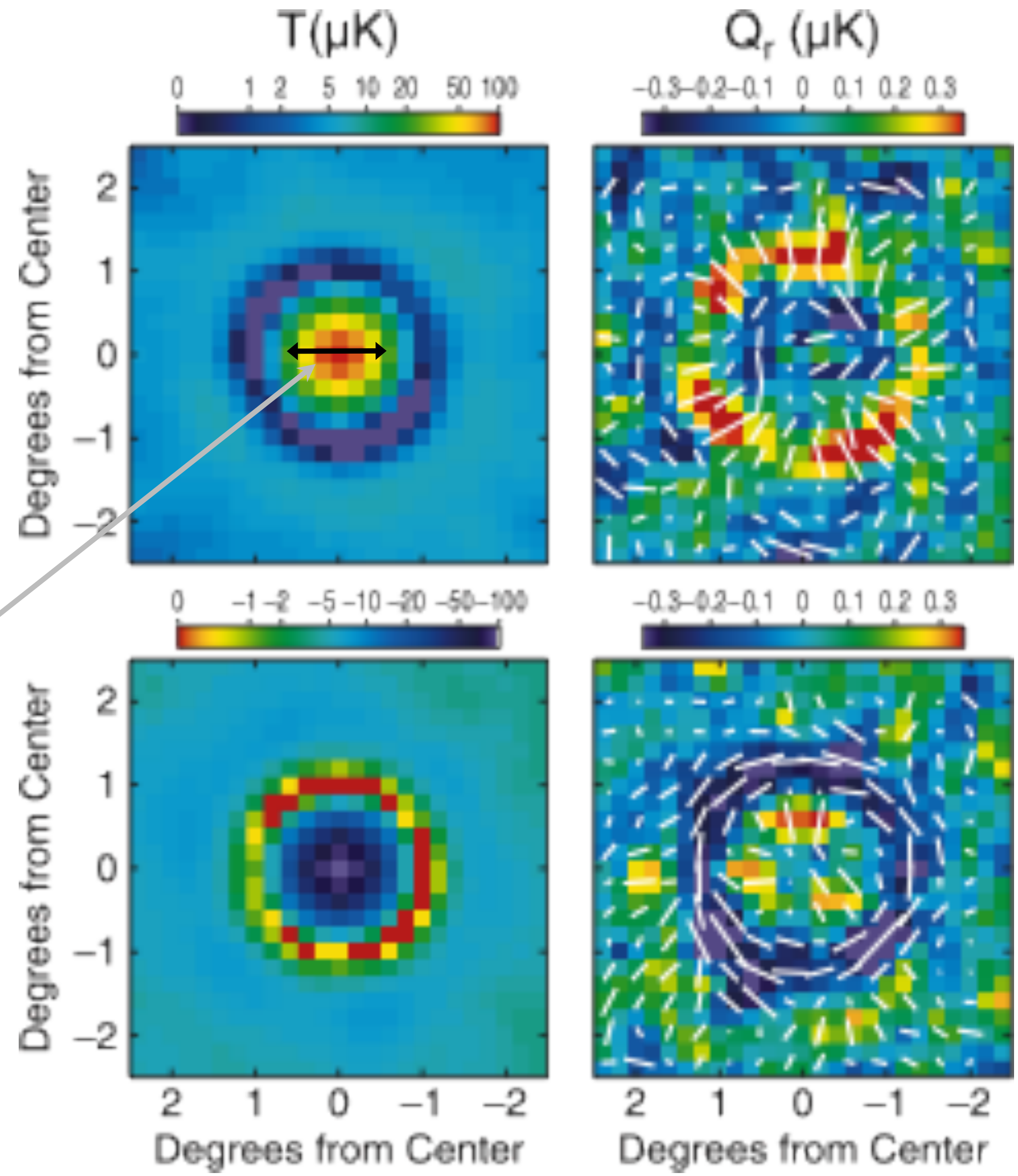
Planck/SMICA map, 5′ resolution.

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

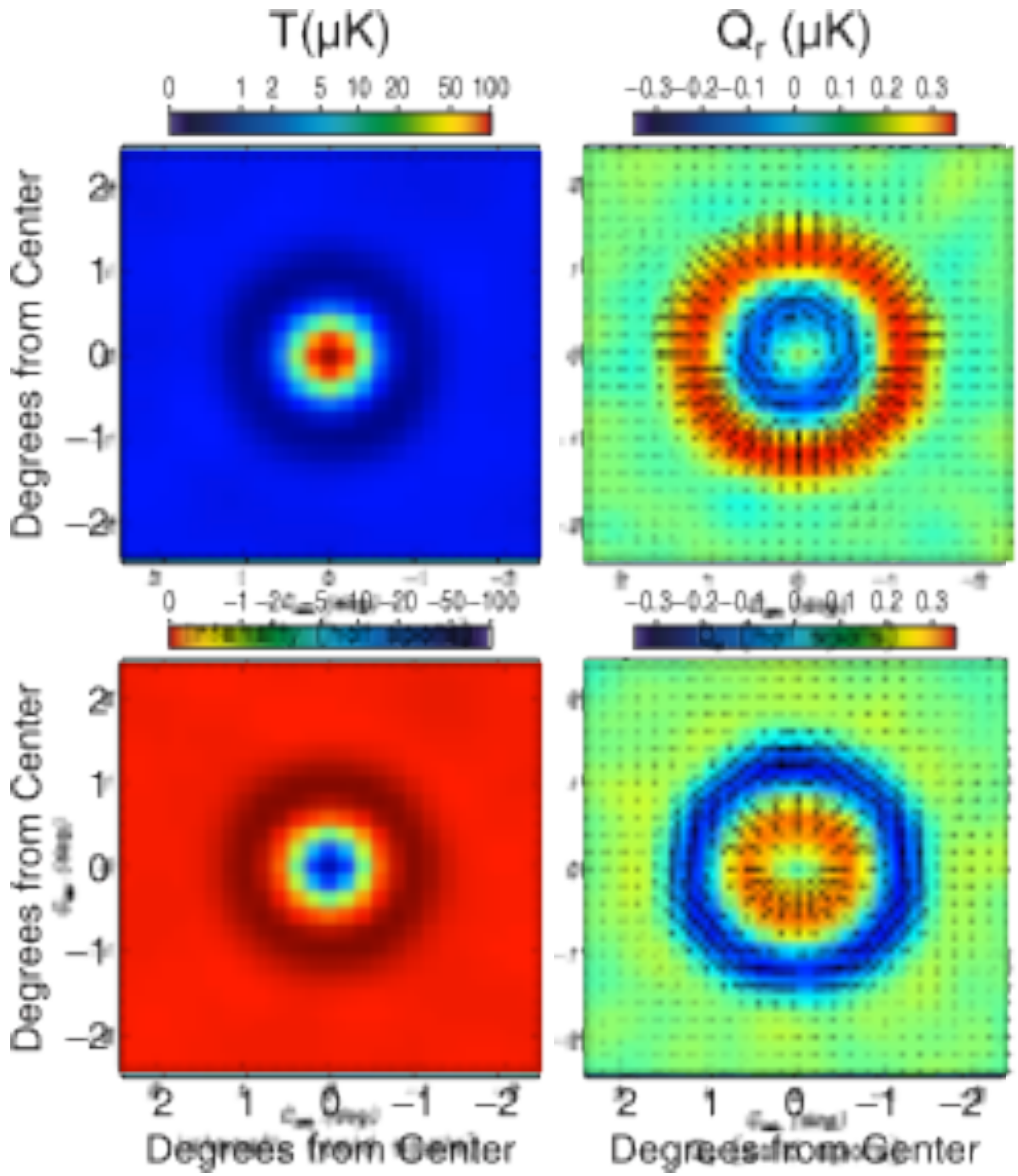


BAO in the CMB – WMAP

BAO scale:
145.8 ± 1.2 Mpc

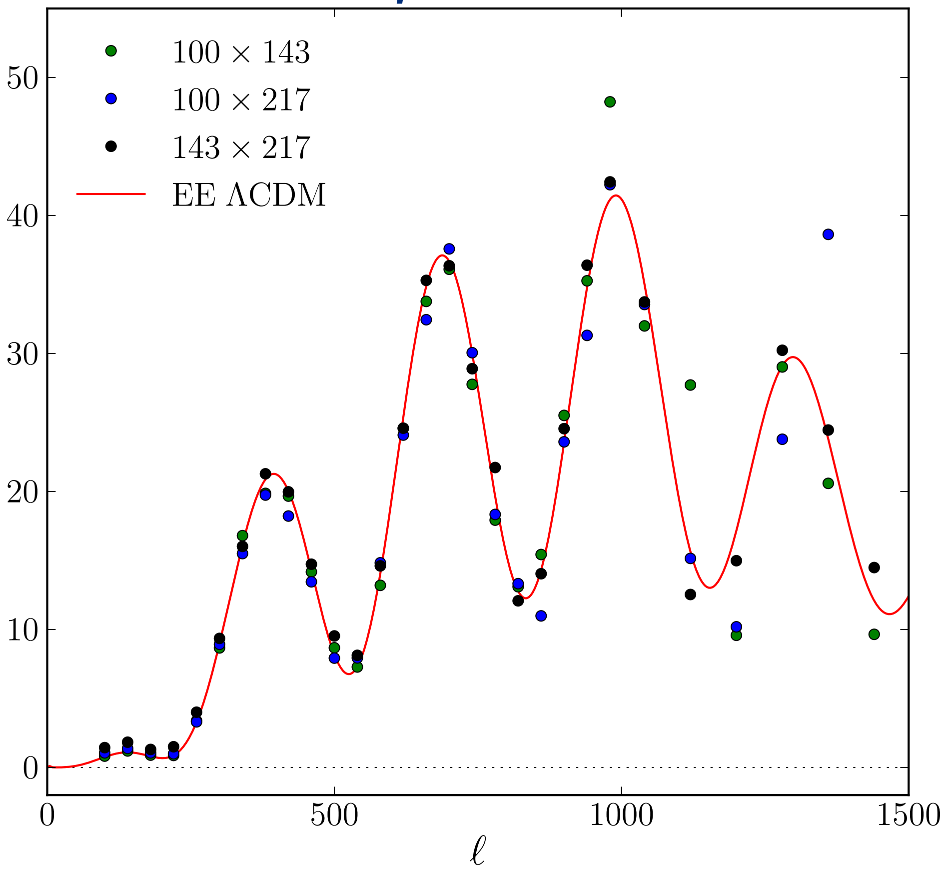


BAO in the CMB - Planck

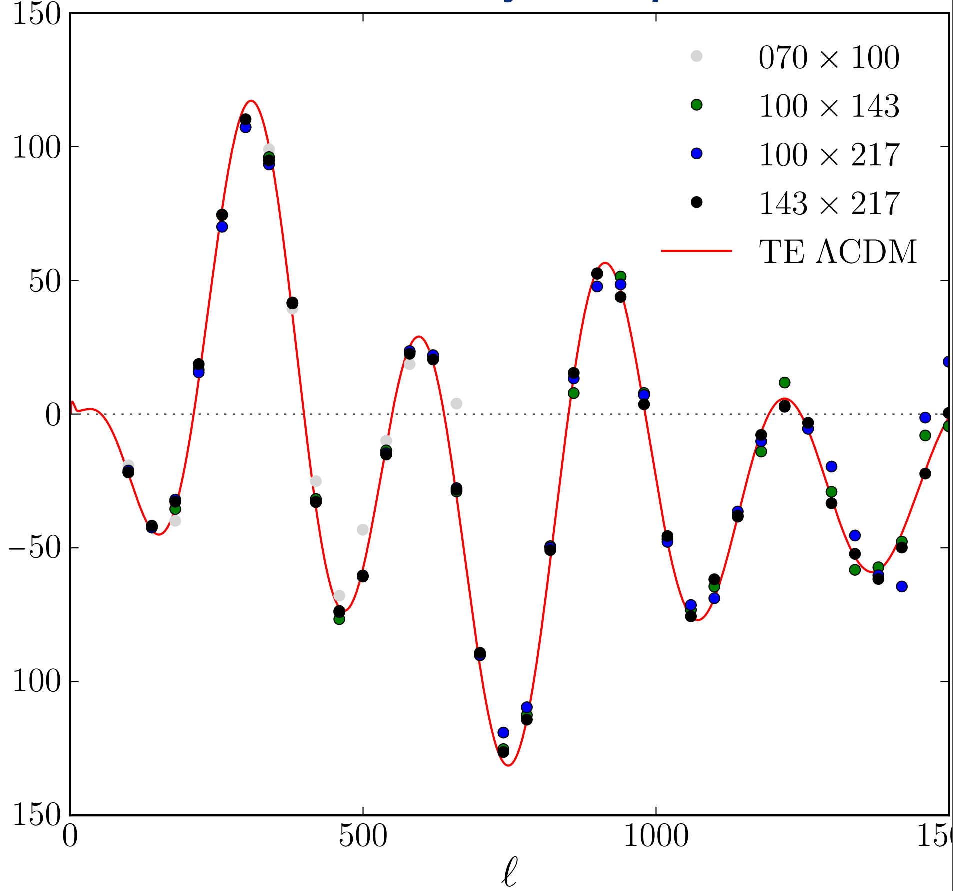


best-fit P1.3yr TT model predicts the polarization. works perfectly at all frequency cross correlations strengthens the case for the Galactic/extragalactic nuisance parameter model being accurate - error bars on EE and TE are not shown. for 2014

EE polarization



TE intensity cross polarization



Standard Parameters of Cosmic Structure Formation

$\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ Ω_k τ_c $\ln A_s$ n_s $r = A_t / A_s$ $dn_s / d\ln k$ n_t

$\Omega_{er} h^2$ $\Omega_{m\nu} h^2$ X_{He}

$1+w_0, w_a$ $\theta \sim \ell_s^{-1}$ $n_e(a)$ $\sim \ln \sigma_8^2$

new parameters: **trajectory probabilities for early-inflatons & late-inflatons (partially) blind cf. informed "theory" priors**

standard inflation space: n_s $dn_s/d\ln k$ r =T/S @k-pivots

Inflation Histories
(CMBall+LSS+SN+WL)

Standard Parameters of Cosmic Structure Formation

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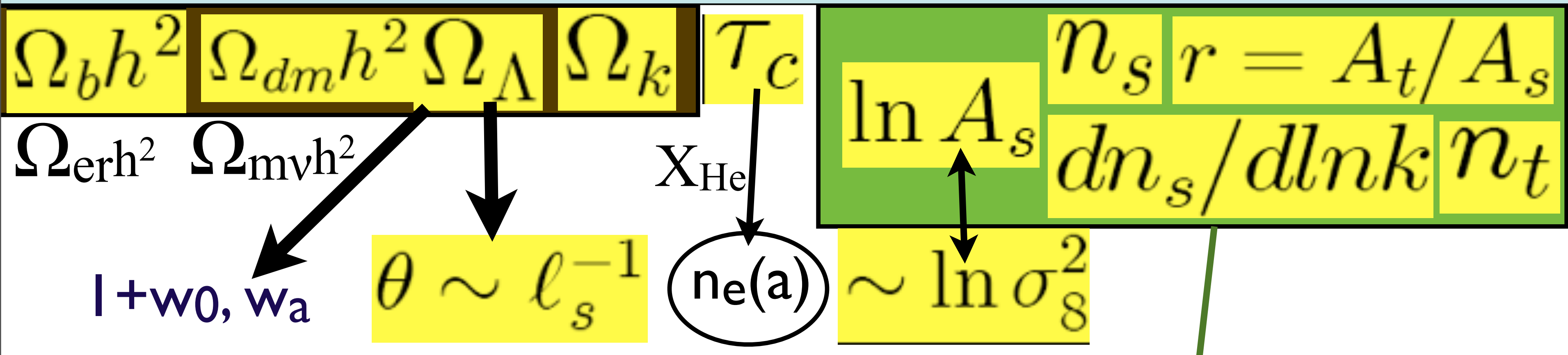
Recombination Histories
(RecFast => CosmoRec, HyRec (Planck +ACTpol+SPTpol)

Inflation Histories
(CMBall+LSS+SN+WL)

Standard Parameters of Cosmic Structure Formation



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standard inflation space: n_s $dn_s/d\ln k$ $r = T/S$ @k-pivots

Dark Energy Histories
(SN+WL+BAO+CMB+cls)

Recombination Histories
(RecFast => CosmoRec, HyRec (Planck +ACTpol+SPTpol)

Inflation Histories
(CMBall+LSS+SN+WL)

Standard Parameters of Cosmic Structure Formation

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Inflation Histories
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Reionization Histories
(Planck+21-cm)

Standard Parameters of Cosmic Structure Formation

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$\Omega_{er}h^2$ $\Omega_{m\nu}h^2$ X_{He}

$1+w_0, w_a$ $\theta \sim \ell_s^{-1}$ $n_e(a)$ $\sim \ln \sigma_8^2$

new parameters: **trajectory probabilities for early-inflatons & late-inflatons (partially) blind cf. informed "theory" priors**

standard inflation space: n_s $dn_s/d\ln k$ r =T/S **@k-pivots**

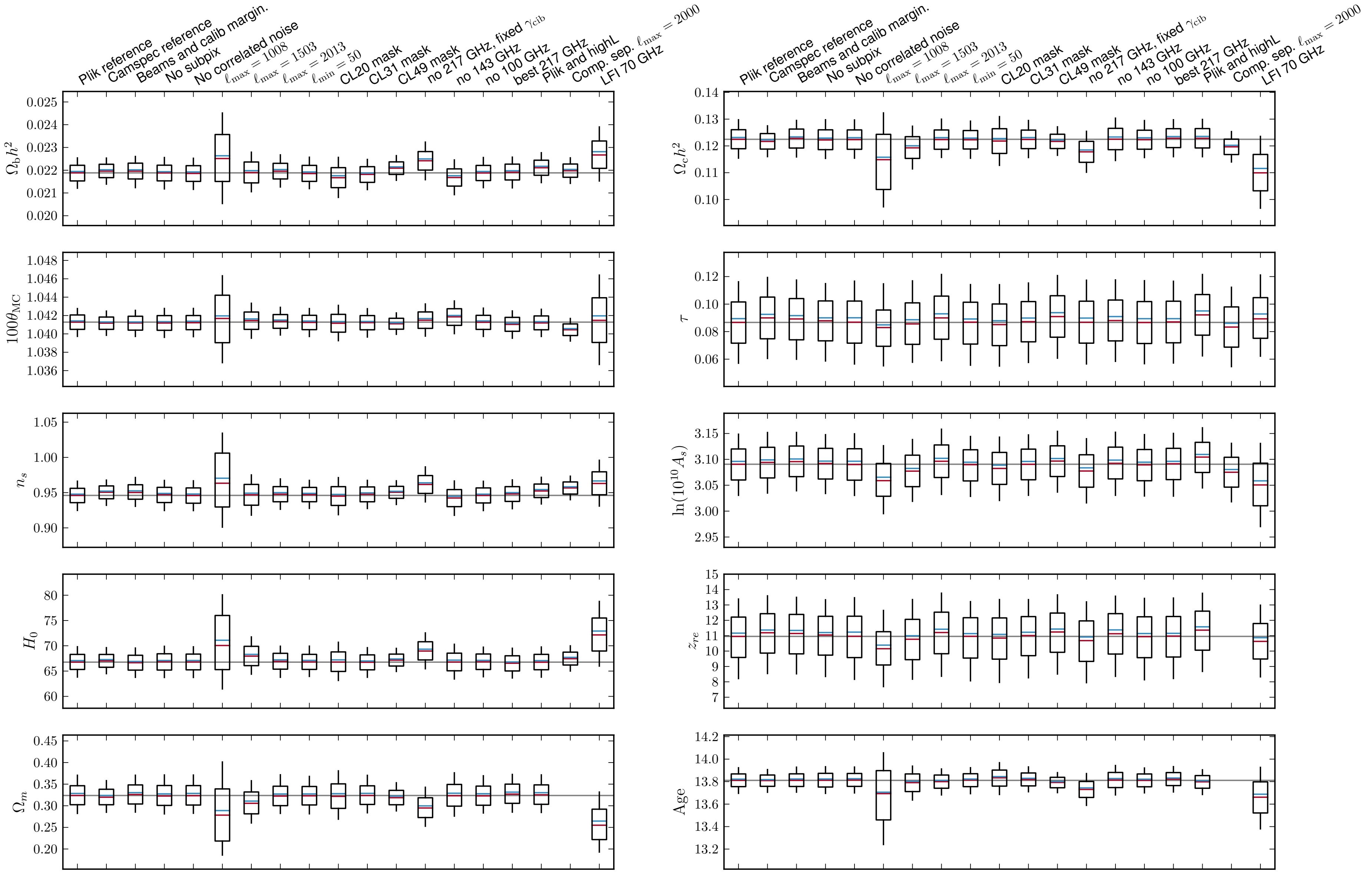
Dark Energy Histories
(SN+WL+BAO+CMB+cls)

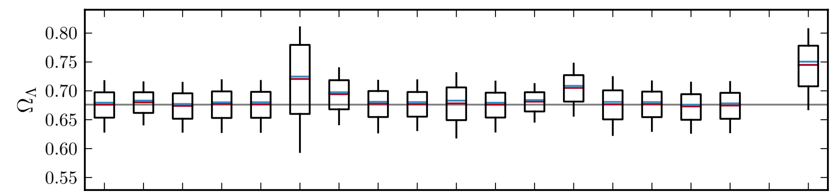
Recombination Histories
(RecFast => CosmoRec, HyRec (Planck +ACTpol+SPTpol)

Reionization Histories
(Planck+21-cm)

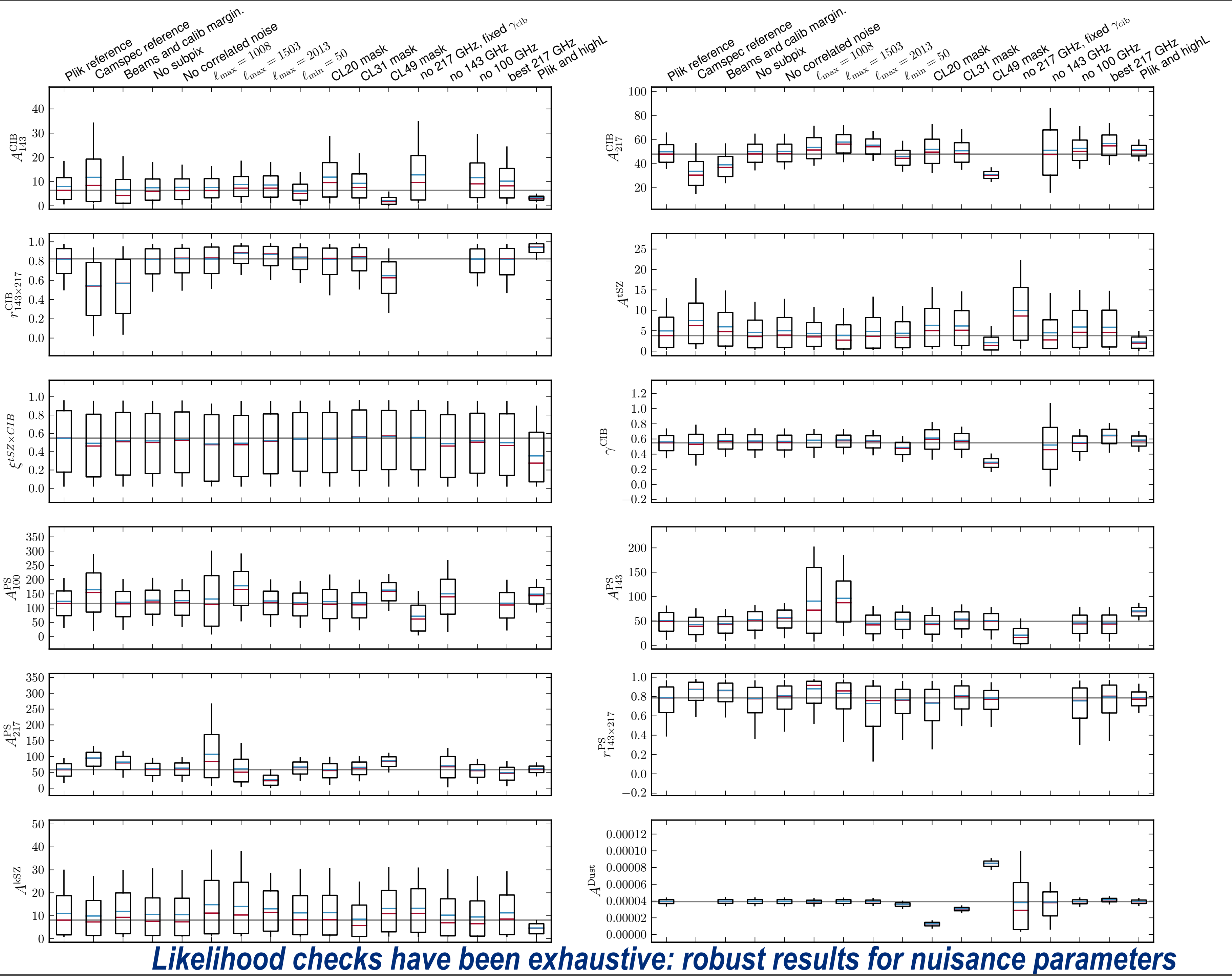
Inflation Histories
(CMBall+LSS+SN+WL)

CMB Polarization, Gravity Waves
(Planck, ACTpol, ABS, Spider, Quiet2)
r=T/S, **acceleration trajectories**





Likelihood checks have been exhaustive: robust results for cosmic parameters. conservative mask choices cf. component separated maps but params agree


Plik reference
Camspec reference
Beams and calib margin.
No subpix
No correlated noise
$\ell_{\max} = 1008$
$\ell_{\max} = 1503$
$\ell_{\max} = 2013$
$\ell_{\min} = 50$
CL20 mask
CL31 mask
CL49 mask
no 217 GHz, fixed $\gamma_{\rm cib}$
no 143 GHz
no 100 GHz
best 217 GHz
Plik and highL
$A^{\rm CIB}_{143}$
$r^{\rm CIB}_{143\times217}$
$\xi^{tSZ\times CIB}$
$A^{\rm PS}_{100}$
$A^{\rm PS}_{217}$
$A^{\rm kSZ}$
$A^{\rm CIB}_{217}$
$A^{\rm tSZ}$
$\gamma^{\rm CIB}$
$A^{\rm PS}_{143}$
$r^{\rm PS}_{143\times217}$
$A^{\rm Dust}$
Likelihood checks have been exhaustive: robust results for nuisance parameters

our Planck1.3 tilted LCDM Basic 6 + nuisance parameters

Parameter	*Planck* (CMB+lensing) Best fit	*Planck* (CMB+lensing) 68 % limits	*Planck*+WP+highL+BAO Best fit	*Planck*+WP+highL+BAO 68 % limits
$\Omega_b h^2$	0.022242	0.02217 ± 0.00033	0.022161	0.02214 ± 0.00024
$\Omega_c h^2$	0.11805	0.1186 ± 0.0031	0.11889	0.1187 ± 0.0017
$100\theta_{MC}$	1.04150	1.04141 ± 0.00067	1.04148	1.04147 ± 0.00056
τ	0.0949	0.089 ± 0.032	0.0952	0.092 ± 0.013
n_s	0.9675	0.9635 ± 0.0094	0.9611	0.9608 ± 0.0054
$\ln(10^{10} A_s)$	3.098	3.085 ± 0.057	3.0973	3.091 ± 0.025

cf. Calabrese+12 ***our ACT12,SPT12,WMAP9 CMB-only 6 + nuisance***

Parameter	WMAP9 +ACT	WMAP9 +SPT	WMAP9 +ACT+SPT
$100\Omega_b h^2$	2.260 ± 0.041	2.231 ± 0.034	2.245 ± 0.032
$100\Omega_c h^2$	11.46 ± 0.43	11.16 ± 0.36	11.23 ± 0.36
$100\theta_A$	1.0396 ± 0.0019	1.0422 ± 0.0010	1.0420 ± 0.0010
τ	0.090 ± 0.014	0.082 ± 0.013	0.085 ± 0.013
n_s	0.973 ± 0.011	0.9650 ± 0.0093	0.9678 ± 0.0088
$10^9 \Delta^2_{\mathcal{R}}$	2.22 ± 0.10	2.15 ± 0.10	2.17 ± 0.10

WMAP9

0.02264 ± 0.00050
0.1138 ± 0.0045
0.721 ± 0.025
2.41 ± 0.10
0.972 ± 0.013
0.089 ± 0.014

Parameter	*Planck* (CMB+lensing) Best fit	68 % limits	*Planck*+WP+highL+BAO Best fit	68 % limits
$\Omega_b h^2$	0.022242	0.02217 ± 0.00033	0.022161	0.02214 ± 0.00024
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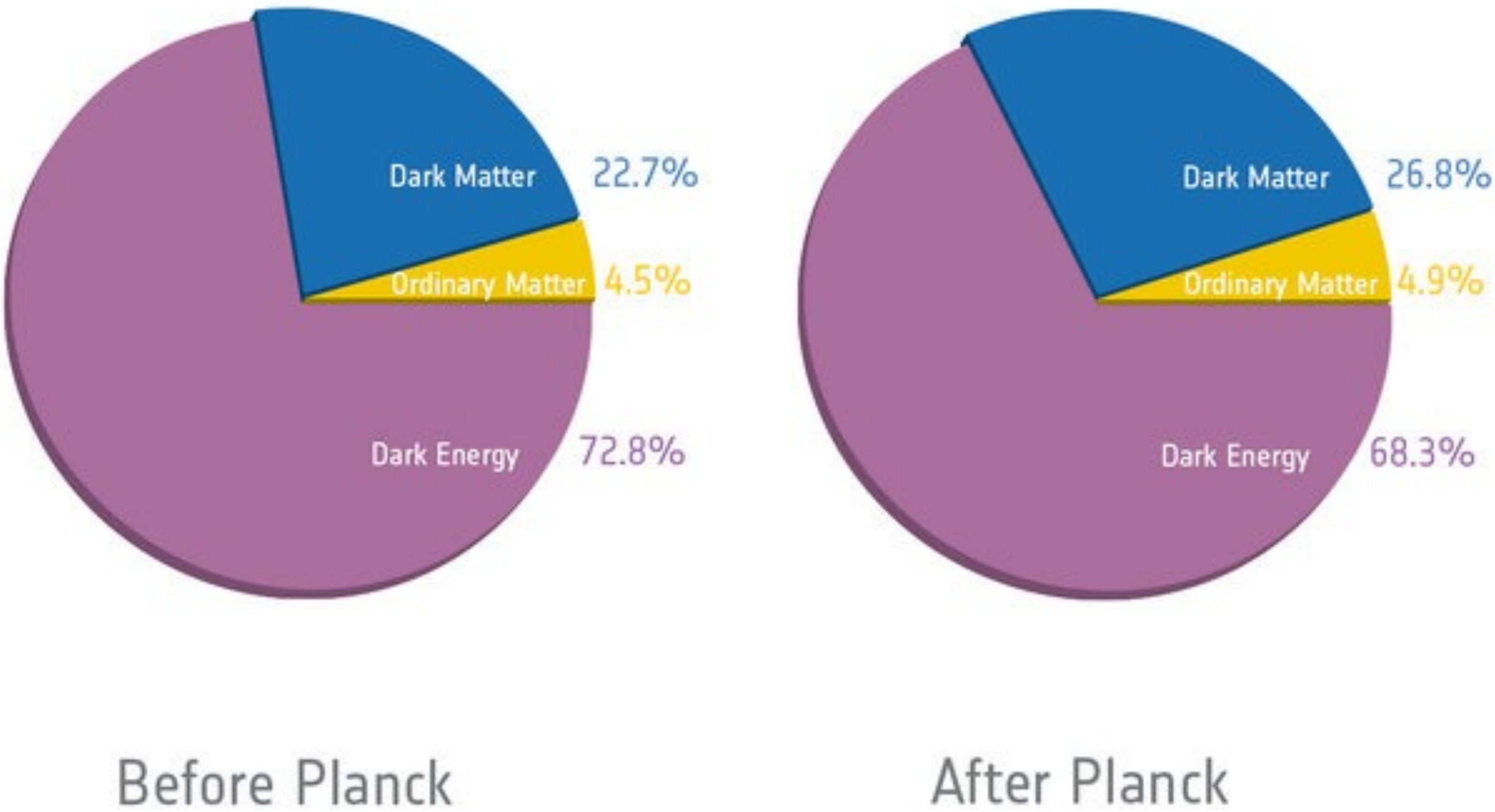
$\ln(10^{10} A_s)$	3.098	3.085 ± 0.057	3.0973	3.091 ± 0.025
Ω_Λ	0.6964	0.693 ± 0.019	0.6914	0.692 ± 0.010
Ω_m	0.3036	0.307 ± 0.019		
σ_8	0.8285	0.823 ± 0.018	0.8288	0.826 ± 0.012
z_{re}	11.45	$10.8^{+3.1}_{-2.5}$	11.52	11.3 ± 1.1
H_0	68.14	67.9 ± 1.5	67.77	67.80 ± 0.77
$10^9 A_s$	2.215	$2.19^{+0.12}_{-0.14}$		
$\Omega_m h^2$	0.14094	0.1414 ± 0.0029		
$\Omega_m h^3$	0.09603	0.09593 ± 0.00058		
Y_P	0.247785	0.24775 ± 0.00014		
Age/Gyr	13.784	13.796 ± 0.058	13.7965	13.798 ± 0.037
z_*	1090.01	1090.16 ± 0.65		
r_*	144.58	144.96 ± 0.66		
$100\theta_*$	1.04164	1.04156 ± 0.00066	1.04163	1.04162 ± 0.00056
z_{drag}	1059.59	1059.43 ± 0.64		
r_{drag}	147.74	147.70 ± 0.63	147.611	147.68 ± 0.45
k_D	0.13998	0.13996 ± 0.00062		
$100\theta_D$	0.161196	0.16129 ± 0.00036		
z_{eq}	3352	3362 ± 69		
$100\theta_{eq}$	0.8224	0.821 ± 0.013		
$r_{drag}/D_V(0.57)$	0.07207	0.0719 ± 0.0011		

tilted LCDM basic 6 cosmic parameters
+nuisance parameters
&
derived parameters

small shift in the pie chart make-up of the Universe



BaryonAcousticOscillation Optical Surveys agree with Planck1.3 forecast for tilted LCDM

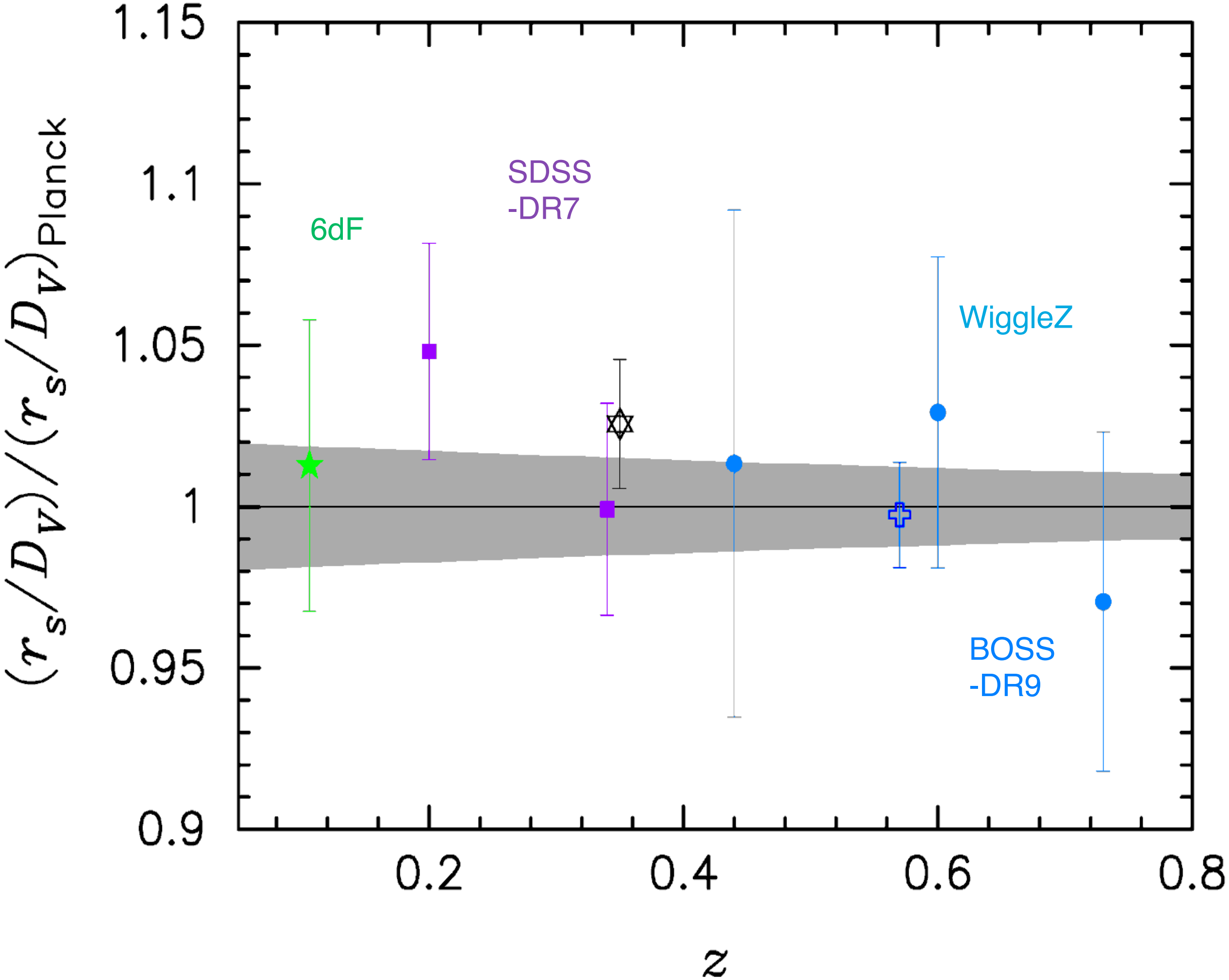
shows DarkEnergy Equation of State is consistent with 1+w = 0 =2 KE_{de} / (KE_{de}+PE_{de})

dark energy

Ω_Λ: 0.692± 0.010

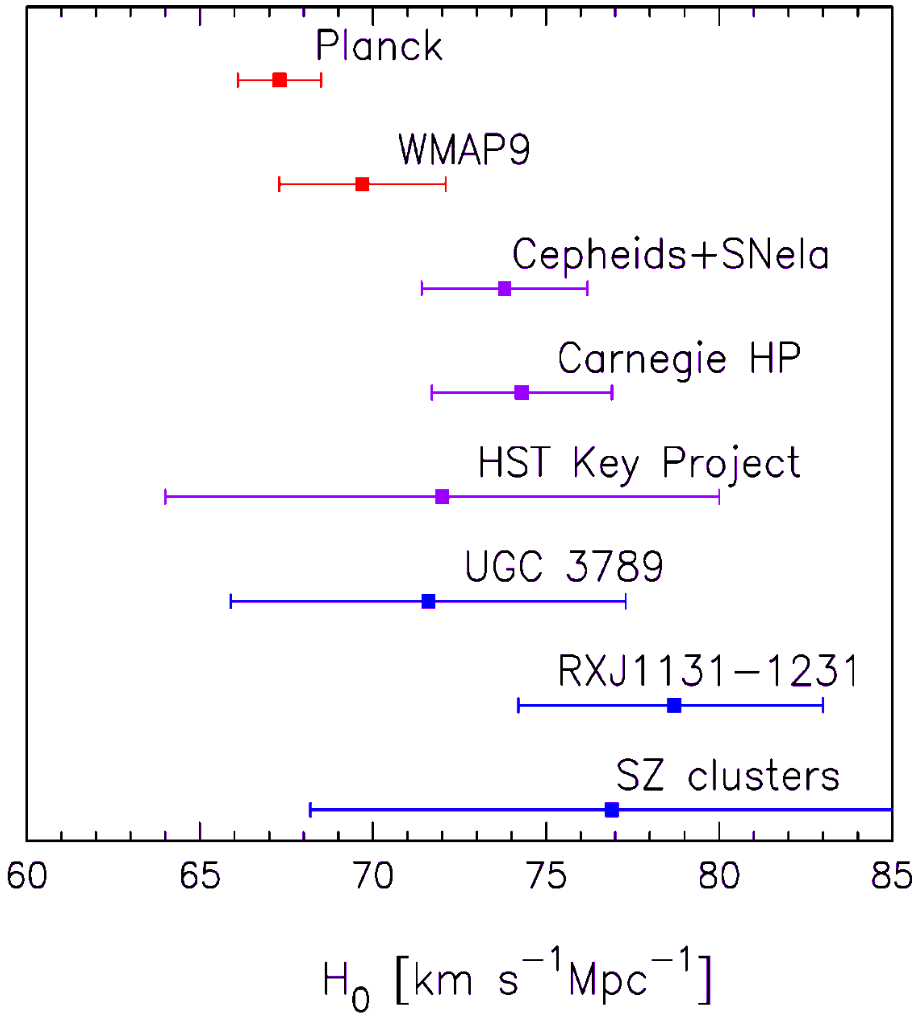
$1+w_0$: -0.13± 0.12 if w_a

Ω_κ: -.0005 ± 0.0066



H0 tensions

H0 from Planck
67.95 ± 1.5 (km/s/Mpc)
=> 67.80 ± 0.77 +BAO



H0
69.7 ± 2.0 act12+wmap9
71.5 ± 1.7 spt12+wmap9
71.2 ±1.6 act12+spt12+wmap9

age from Planck
13.796 ± 0.058 Gy
=> 13.798 ± 0.037 +BAO

age
13.752 ± 0.096 act12+wmap9
13.686 ± 0.065 spt12+wmap9
13.682 ± 0.063 act12+spt12+wmap9

beyond the standard model?
***tilted* LCDM+x, x=?**

Curved space, Ω_k
Dynamical dark energy, w
Non standard abundance of primordial Helium fraction, Y_P
Neutrino properties, i.e. how many (N_{eff}) and how massive (Σm_ν)
Curvature of the power spectrum of primordial fluctuations (running $dn_s/d\ln k$)
primordial gravitational waves, $r_{0.002}$
anomalies exist: large scale statistical anisotropy & non-Gaussianity

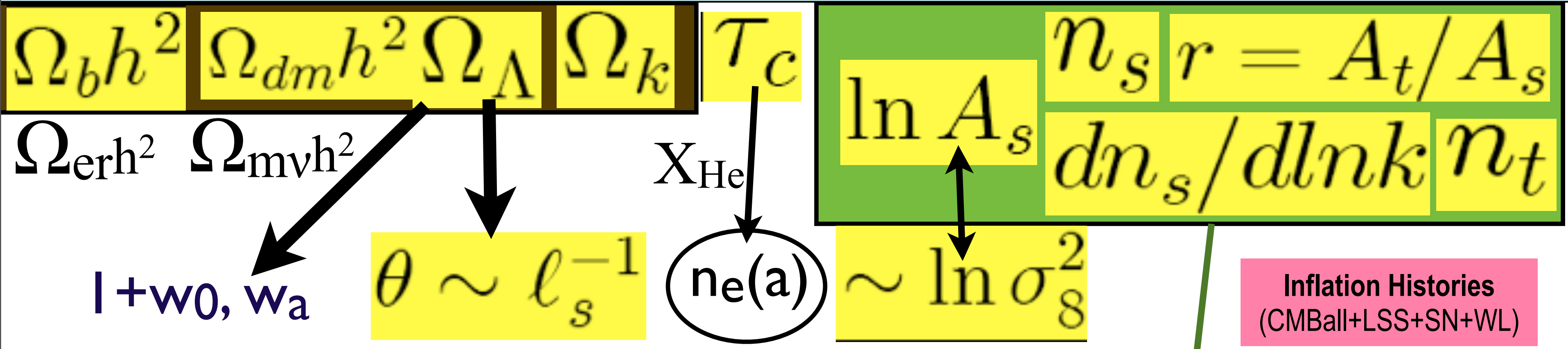
no compelling evidence for
an "isocurvature" part in the primordial fluctuations or broken scale invariance
cosmic strings ($G\mu/c^2<1.3\ 10^{-7}$)
nonG signatures of inflation at medium to high res ($f^{local}=2.7\pm5.8$, $f^{equil}=-42\pm75$, $f^{ortho}=-25\pm39$ 68%CL)
evolution of the fine structure constant, dark matter annihilation, primordial magnetic fields…

	Planck+WP		*Planck*+WP+BAO		*Planck*+WP+highL		*Planck*+WP+highL+BAO	
Parameter	Best fit	95% limits	Best fit	95% limits	Best fit	95% limits	Best fit	95% limits
Ω_K	−0.0105	$-0.037^{+0.043}_{-0.049}$	0.0000	$0.0000^{+0.0066}_{-0.0067}$	−0.0111	$-0.042^{+0.043}_{-0.048}$	0.0009	$-0.0005^{+0.0065}_{-0.0066}$
Σm_ν [eV]	0.022	< 0.933	0.002	< 0.247	0.023	< 0.663	0.000	< 0.230
$N_{\rm eff}$	3.08	$3.51^{+0.80}_{-0.74}$	3.08	$3.40^{+0.59}_{-0.57}$	3.23	$3.36^{+0.68}_{-0.64}$	3.22	$3.30^{+0.54}_{-0.51}$
Y_P	0.2583	$0.283^{+0.045}_{-0.048}$	0.2736	$0.283^{+0.043}_{-0.045}$	0.2612	$0.266^{+0.040}_{-0.042}$	0.2615	$0.267^{+0.038}_{-0.040}$
$dn_s/d\ln k$	−0.0090	$-0.013^{+0.018}_{-0.018}$	−0.0102	$-0.013^{+0.018}_{-0.018}$	−0.0106	$-0.015^{+0.017}_{-0.017}$	−0.0103	$-0.014^{+0.016}_{-0.017}$
$r_{0.002}$	0.000	< 0.120	0.000	< 0.122	0.000	< 0.108	0.000	< 0.111
w	−1.20	$-1.49^{+0.65}_{-0.57}$	−1.076	$-1.13^{+0.24}_{-0.25}$	−1.20	$-1.51^{+0.62}_{-0.53}$	−1.109	$-1.13^{+0.23}_{-0.25}$

parameters sensitive to the damping tail $N_{\nu,eff}$ =*3.30±0.27*, X_{He} =*0.267±0.020*

Σm_ν <0.230 ev primary *cf.* cl-PSZ

Standard Parameters of Cosmic Structure Formation



new parameters: **trajectory probabilities for early-inflatons & late-inflatons (partially) blind cf. informed "theory" priors**

Das+,Sievers+ 2013 ACT+WMAP7
Story+, Hou+ 2012 SPT+WMAP7
Bennet, Hinshaw+12 WMAP9+eCMB

standard inflation space: n_s $dn_s/d\ln k$ r =T/S **@k-pivots**

*ln***Power**$_s$~*ln***24.5x10^{-10}** ± 0.03 **ACT**12+ *ln***22x10^{-10}** ± 0.028 **SPT12+**

n_s = 0.971 ± 0.009 (ACT12+WMAP+BAO+H0) 0.952 ± 0.0082 SPT12+

$dn_s/d\ln k$=-0.003±0.013 (ACT12+WMAP+BAO+H0) -0.028 ± 0.010 SPT12+

r < 0.16, 0.11, 0.13 (95% CL, ACT12+WMAP+BAO+H0, SPT12, WMAP9)

Hlozek+11 **Primordial power spectra(k);** Bond, Contaldi, Huang, Kofman, Vaudrevange 2011 ***w/o & with T-S consistency***

ACT*12 final spectra & params, 1500 sq deg, ~600 for params,* ***SPT****12 2540 sq deg*

Standard Parameters of Cosmic Structure Formation

$\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ Ω_k τ_c $\ln A_s$ n_s $r = A_t/A_s$ $dn_s/d\ln k$ n_t

$\Omega_{er}h^2$ $\Omega_{m\nu}h^2$ X_{He}

$1+w_0, w_a$ $\theta \sim \ell_s^{-1}$ $n_e(a)$ $\sim \ln \sigma_8^2$

Inflation Histories
(CMBall+LSS+SN+WL)

new parameters: **trajectory probabilities for early-inflatons & late-inflatons (partially) blind cf. informed "theory" priors**

standard inflation space: n_s $dn_s/d\ln k$ r =T/S @k-pivots

Calabrese+12 ACT12+SPT12+WMAP9

*ln*Power$_s$~*ln*22.0x10^{-10} ±0.025 P1.3+ *ln*22x10^{-10} ±0.028 A12+S12+w9

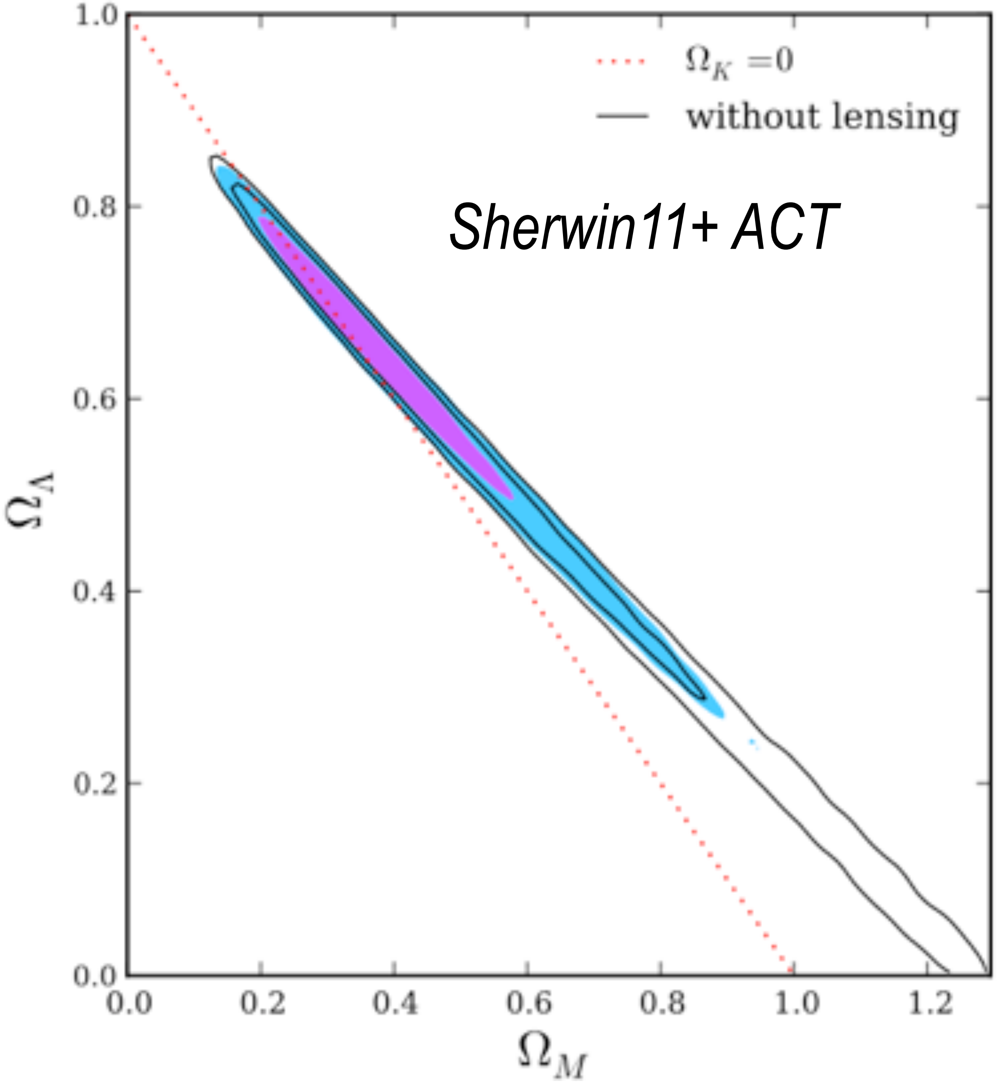
n_s =0.9608±0.0054 (P1.3+WP+hiL+BAO) 0.9678±0.0088 A12+S12+w9

$dn_s/d\ln k$=-0.014±0.009 (P1.3+WP, P1.3+WP+hiL+BAO) -0.028 ± 0.010 SPT12+

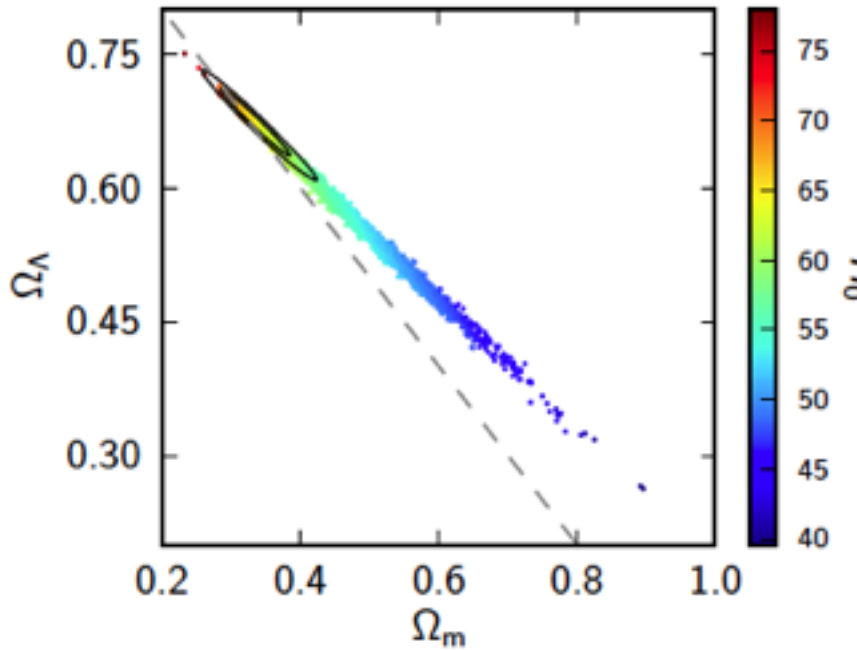
r <0.12, 0.11,0.16,0.11,0.13 (95% CL: P1.3+WP, P1.3+WP+hiL+BAO, A12,S12, W9)

Primordial power spectra(k)

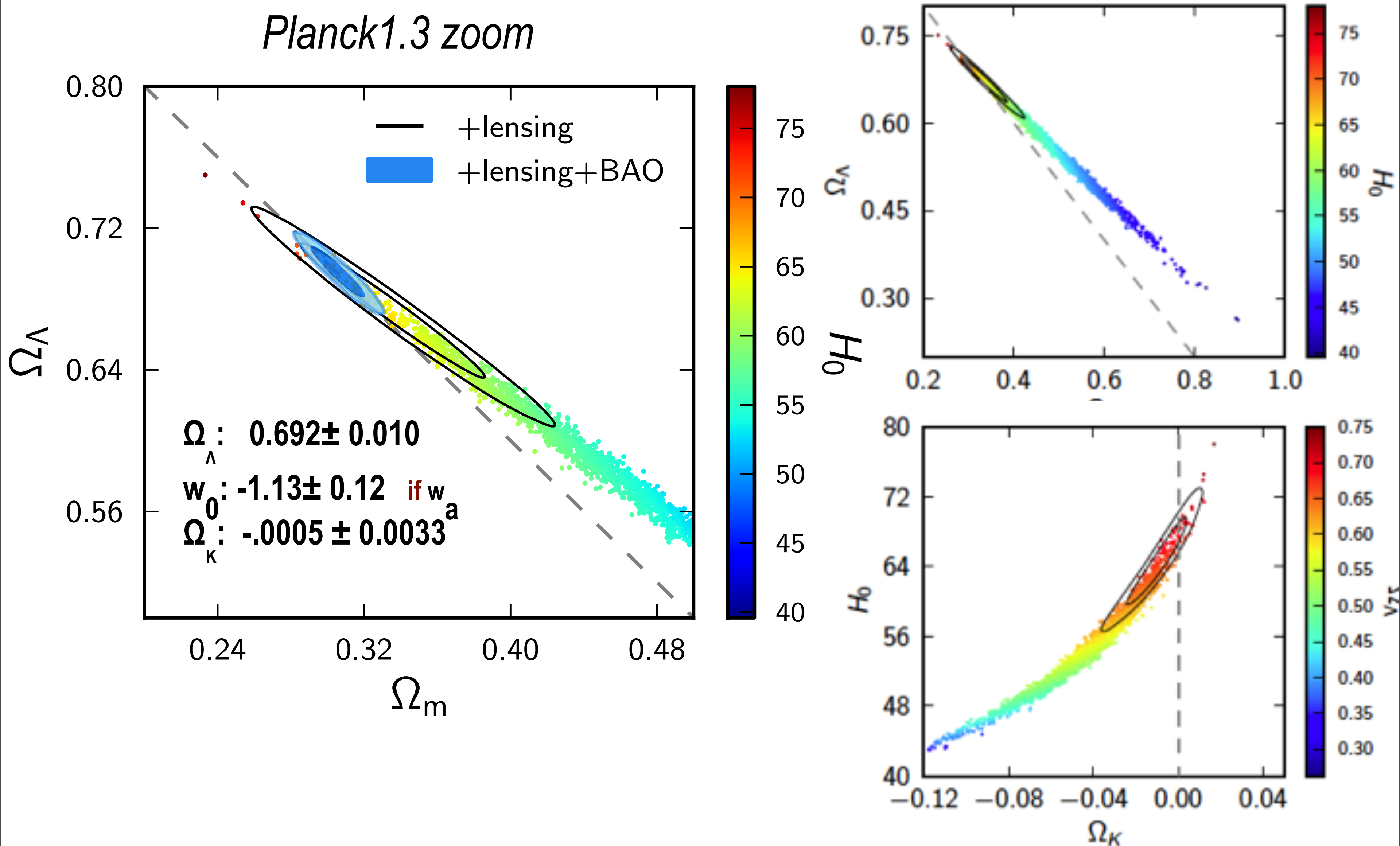
***P1.3** like, **ACT**12 final spectra & params, 1500 sq deg, ~600 for params, **SPT**12 2540 sq deg* *lensing breaks geometrical degeneracy: WMAP+ACT+ACTlens alone cf. Planck alone cf. Planck+BAO*



Planck1.3



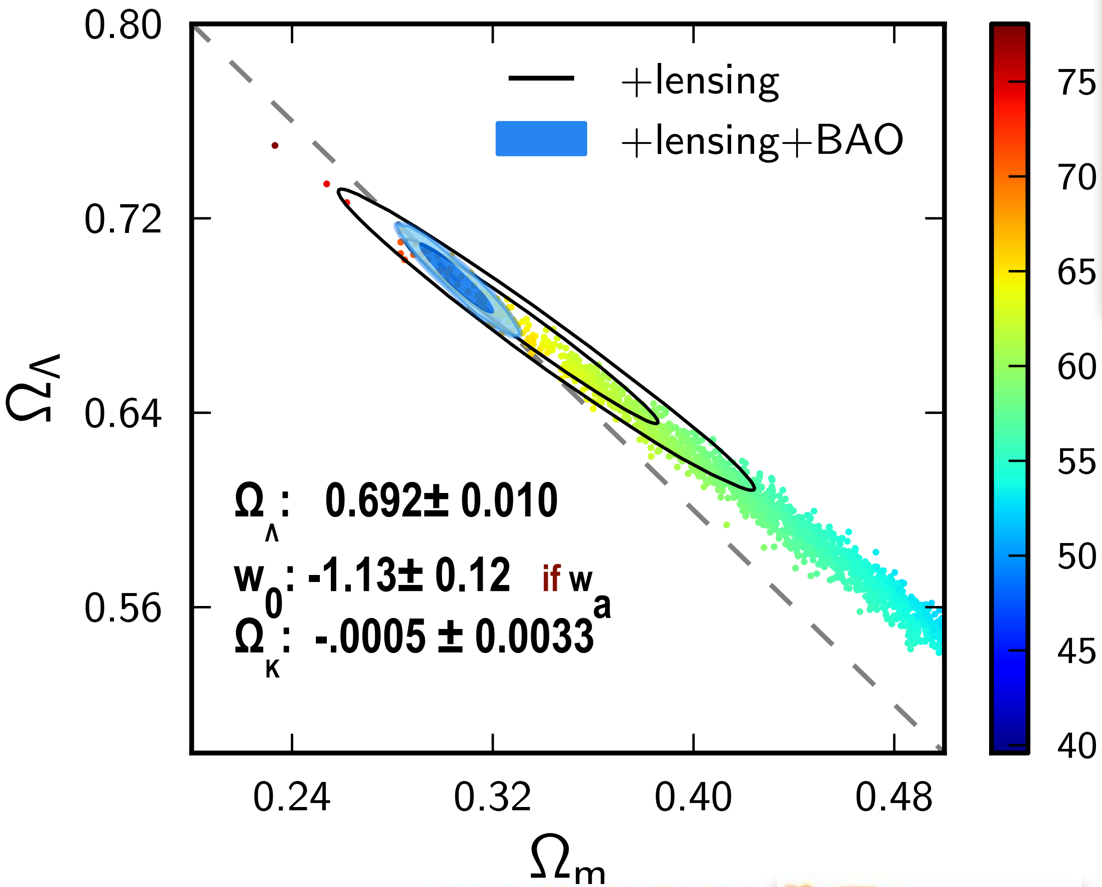
lensing breaks geometrical degeneracy: Planck alone cf. Planck+BAO

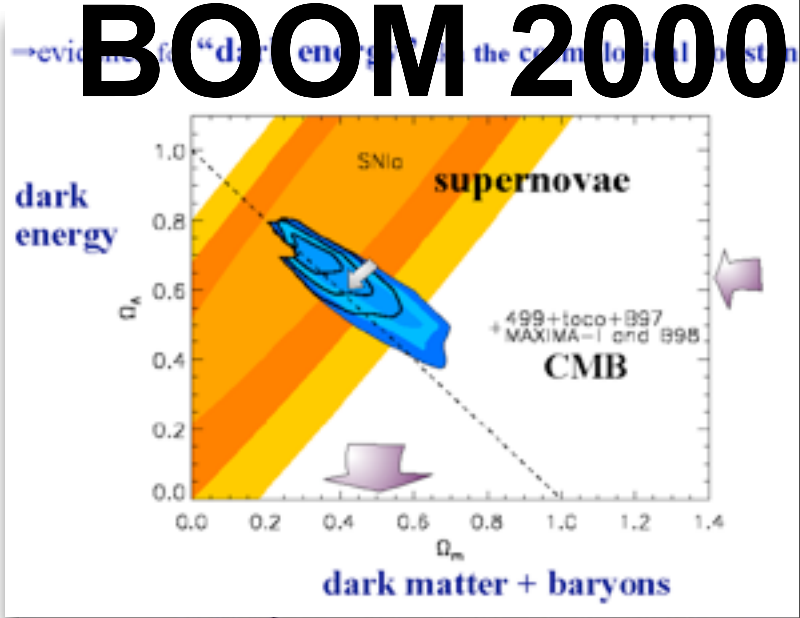


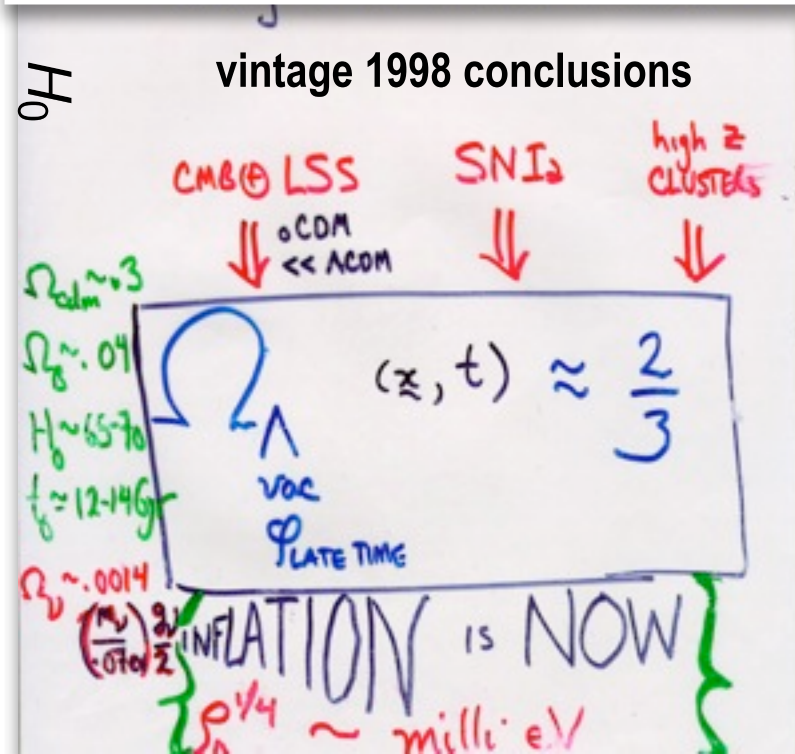
lensing breaks geometrical degeneracy:
Planck alone cf. Planck+BAO

BOOM 2000

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







B+Jaffe'96,'98

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

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

CITA = Cosmic Information Theory & Analysis: *IT from BIT, from BITs in IT,*

Studying the Cosmic Tango** en-TANGO-ment* **Universe=System+Res=Data+Theory =Signal(s)+noise=EFT+*Hidden variables

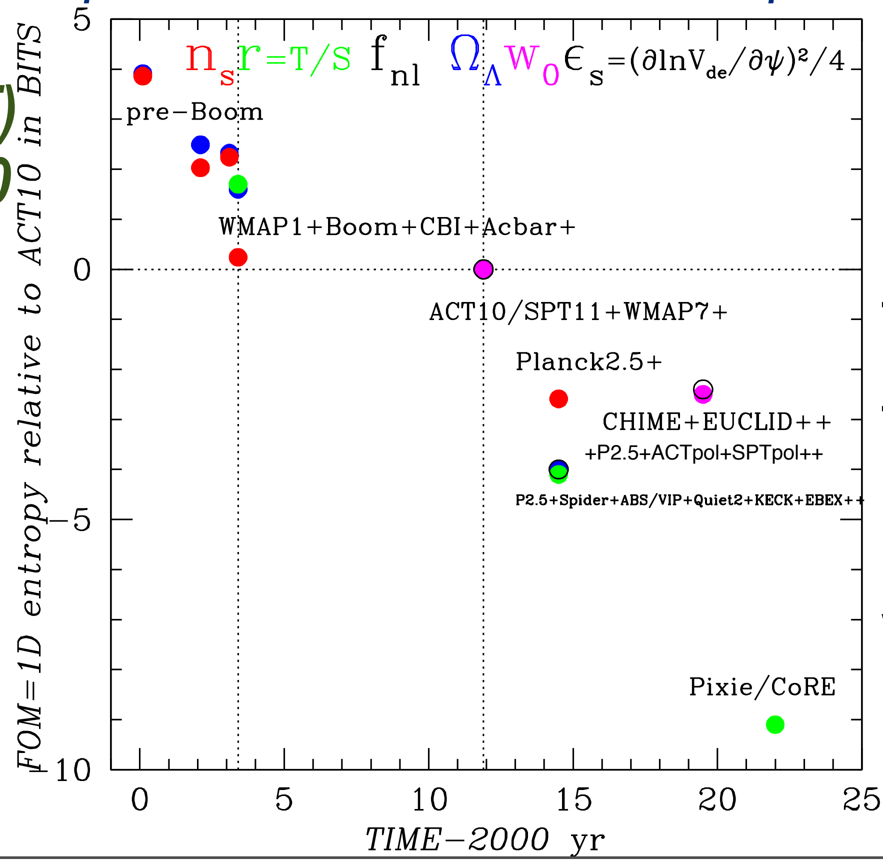
we compress the Petabit++ observed cosmic info into a precious few bits encoding 6+ parameters of the Minimal Cosmic Standard model (tilted ΛCDM)

WMAP: 1.15 Tbits in 9yrs, cf. MyLifeBits, Gordon Bell, 1.28 Tbits in 9yrs, Planck 36 Tbits, ACT 304 Tbits. Radically Compress to high quality Bits. Terabit=10^{12}bits=125 GigaBytes.

Shannon entropy difference $\Delta S_{fi}(q,DT)=\int dq\, P_f \ln P_f^{-1} - \int dq\, P_i \ln P_i^{-1}$

a new figure of merit for experiments, <ln$VOLUME_{ps}$> = posterior Shannon entropy: how the (radically compressed) one-dimensional entropy of cosmic parameters, the high quality bits we quest, did/will change as the experiments became/become more & more precise:

$\Delta S(q,DT)$ i=ACT10



inflation P1.3 cf. P2.5+extensions forecasts

n_s: 0.9608± 0.0054 => ± 0.002 (Pext)

$dn_s/d\ln k$: -0.014± 0.016

r: < 0.111 => < 0.007-0.013 (Pext)

f_{nl}: 2.7 ± 5.8 local => ± 5 (Pext)

f_{nl}: -42.3 ± 75.2 equil -25.3 ± 39.2 ortho

dark energy

Ω_Λ: 0.692± 0.010

w_0: -1.13± 0.12 if w_a

Ω_K: -.0005 ± 0.0033

2D ΔS_{2f} for DarkE can improve by ~5 bits

Standard Parameters of Cosmic Structure Formation

$\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ Ω_k τ_c $\ln A_s$ n_s $r = A_t/A_s$ $dn_s/d\ln k$ n_t

$\Omega_{er}h^2$ $\Omega_{m\nu}h^2$ X_{He}

$1+w_0, w_a$ $\theta \sim \ell_s^{-1}$ $n_e(a)$ $\sim \ln \sigma_8^2$

new parameters: **trajectory probabilities for early-inflatons & late-inflatons (partially) blind cf. informed "theory" priors**

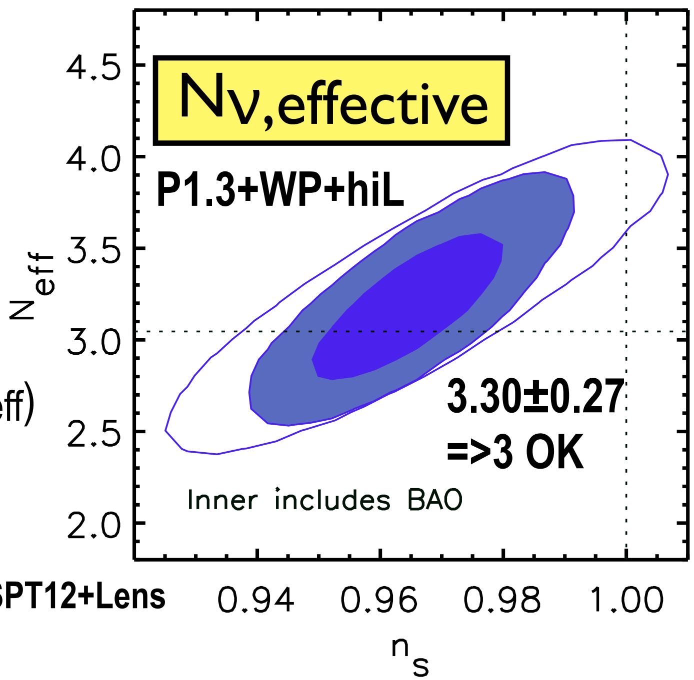
Relativistic Species

$\Omega_{er}h^2$

= $\Omega_{cmb}h^2$ * ($1+0.227N_{\nu,eff}$)

3.24±0.39

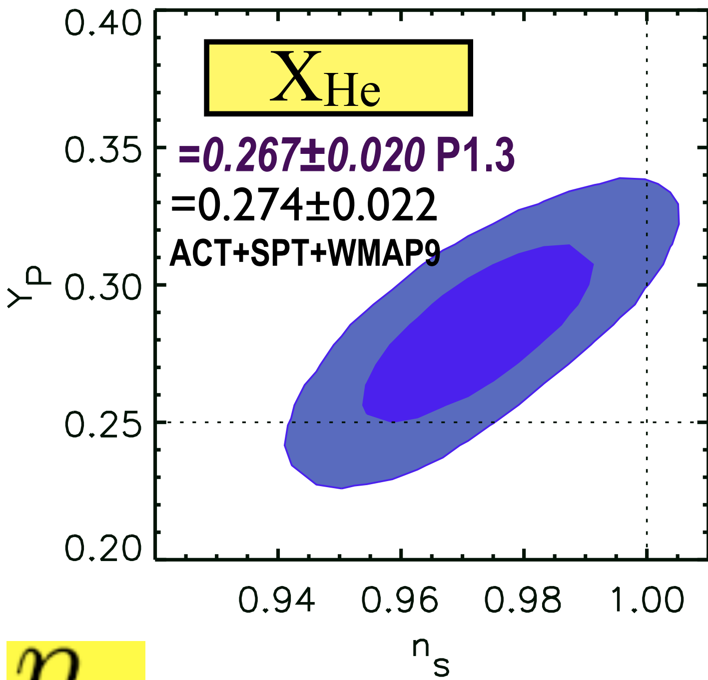
WMAP9+ACT12+SPT12+Lens



to ±0.11 Planck+ACTpol

n_s

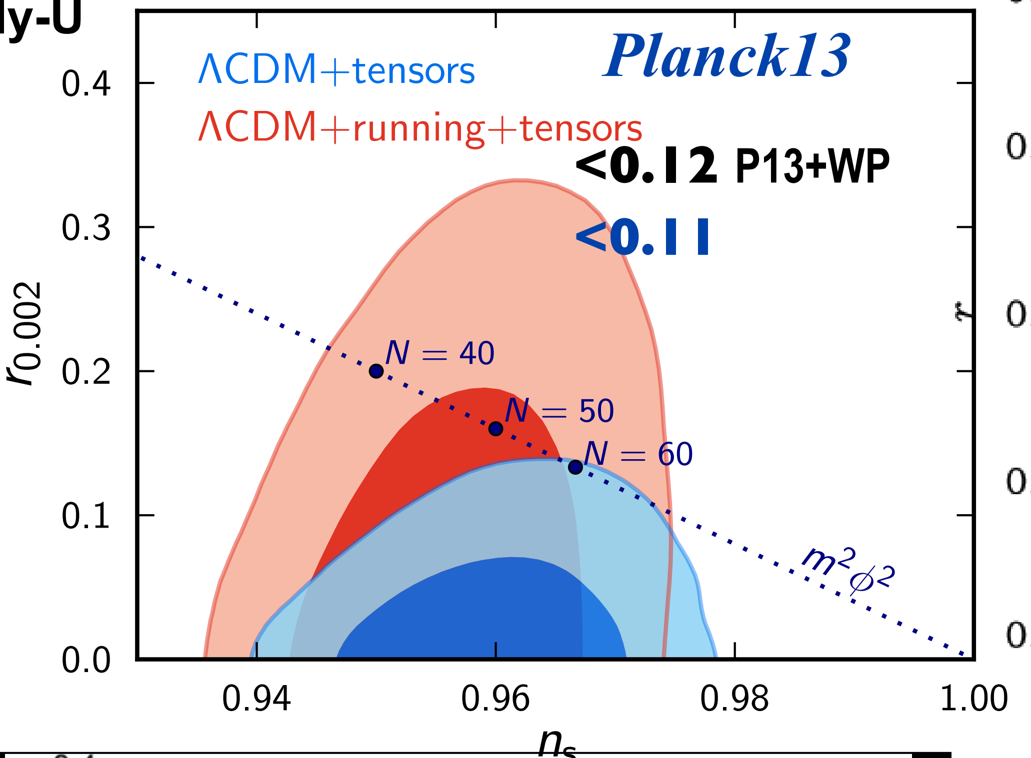
Primordial Helium

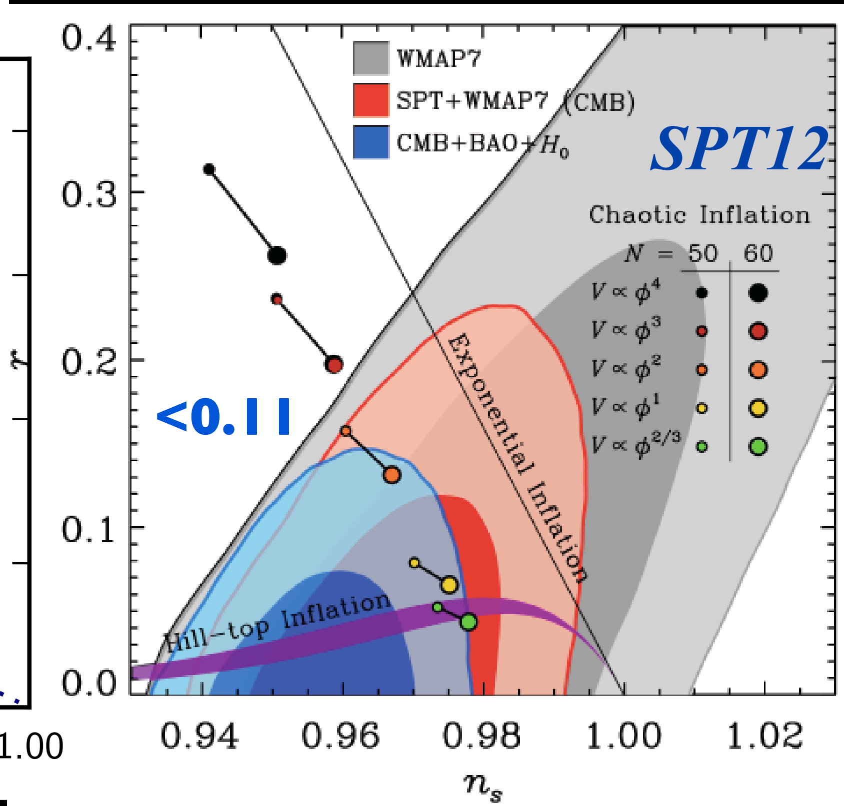


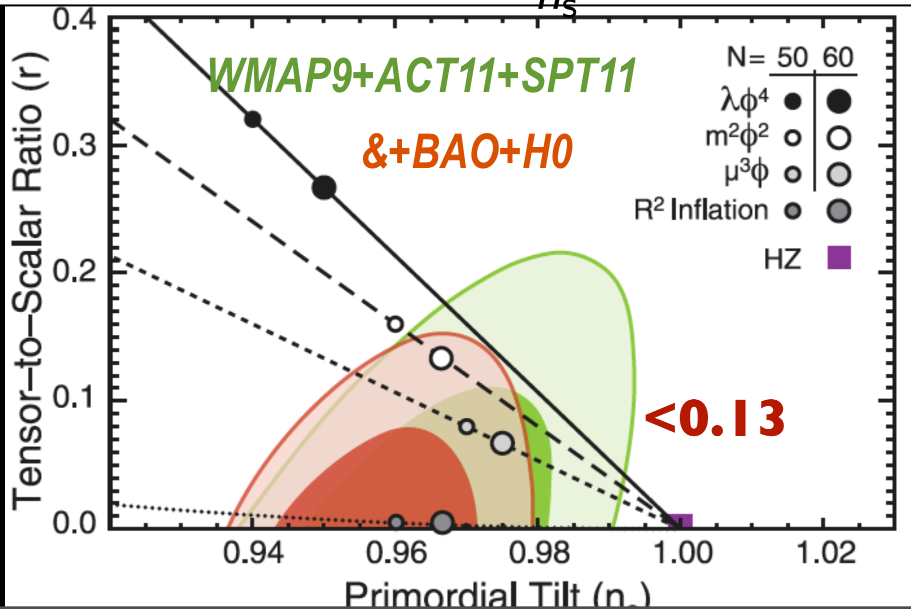
n_s

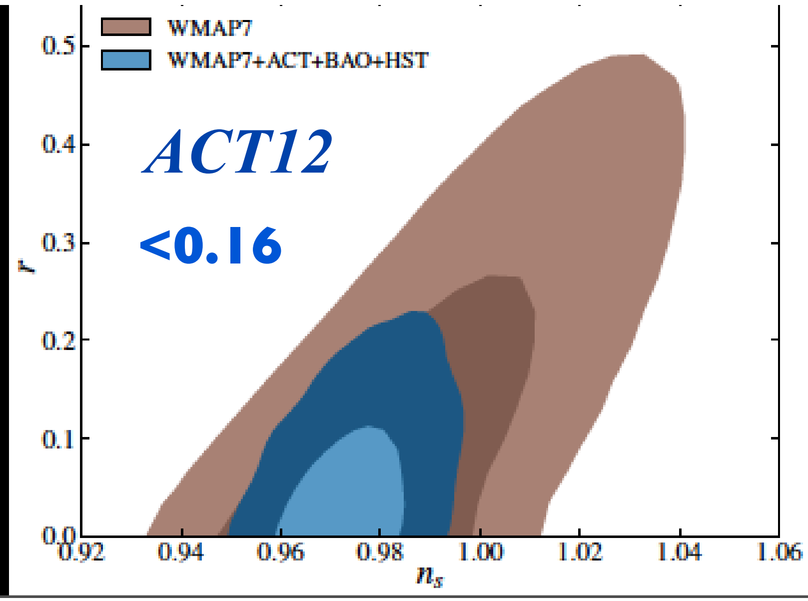
cf. BBN 0.24775 ± 0.00014 **P1.3**

early-U


Planck13
ΛCDM+tensors
ΛCDM+running+tensors
<0.12 P13+WP
<0.11
N = 40
N = 50
N = 60
$m^2\phi^2$
$r_{0.002}$
n_s
0.0
0.1
0.2
0.3
0.4
0.94
0.96
0.98
1.00


SPT12
WMAP7
SPT+WMAP7 (CMB)
CMB+BAO+H_0
Chaotic Inflation
N = 50 60
$V \propto \phi^4$
$V \propto \phi^3$
$V \propto \phi^2$
$V \propto \phi^1$
$V \propto \phi^{2/3}$
<0.11
Exponential Inflation
Hill-top Inflation
r
n_s
0.0
0.1
0.2
0.3
0.4
0.94
0.96
0.98
1.00
1.02


WMAP9+ACT11+SPT11
&+BAO+H0
N= 50 60
$\lambda\phi^4$
$m^2\phi^2$
$\mu^3\phi$
R^2 Inflation
HZ
<0.13
Tensor-to-Scalar Ratio (r)
Primordial Tilt (n_s)
0.0
0.1
0.2
0.3
0.4
0.94
0.96
0.98
1.00
1.02

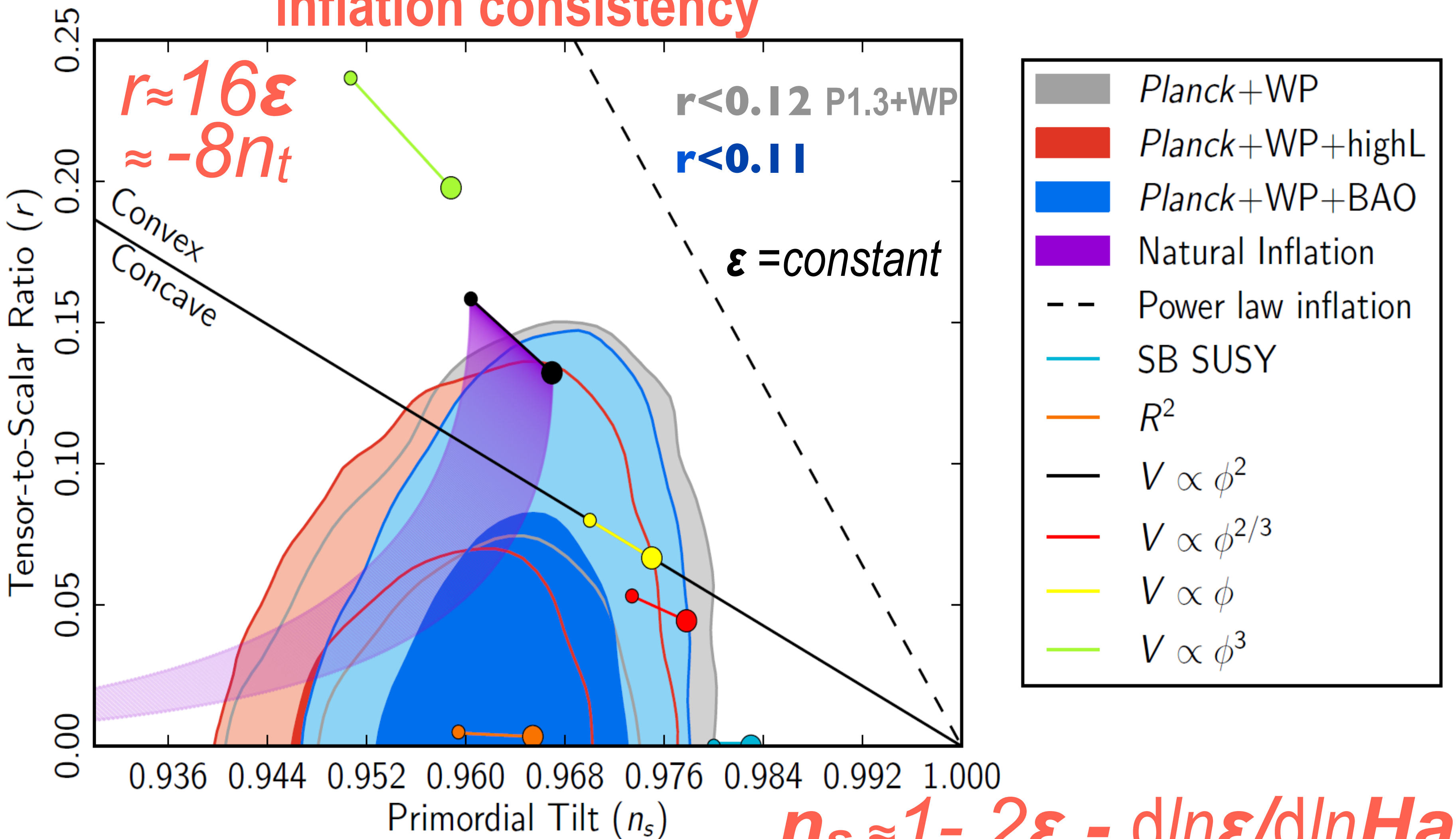

WMAP7
WMAP7+ACT+BAO+HST
ACT12
<0.16
r
n_s
0.0
0.1
0.2
0.3
0.4
0.5
0.92
0.94
0.96
0.98
1.00
1.02
1.04
1.06

Consistent with single field slow roll, standard kinetic term & vacuum (with f_{NL} upper limits)

uniform acceleration *line* $\varepsilon \equiv 3KE/(KE+PE)$ *= constant is* ***strongly ruled out***

=> early universe acceleration must change over observable scales (as well as to end inflation)

inflation consistency



$n_s \approx 1 - 2\varepsilon - d\ln\varepsilon/d\ln Ha$

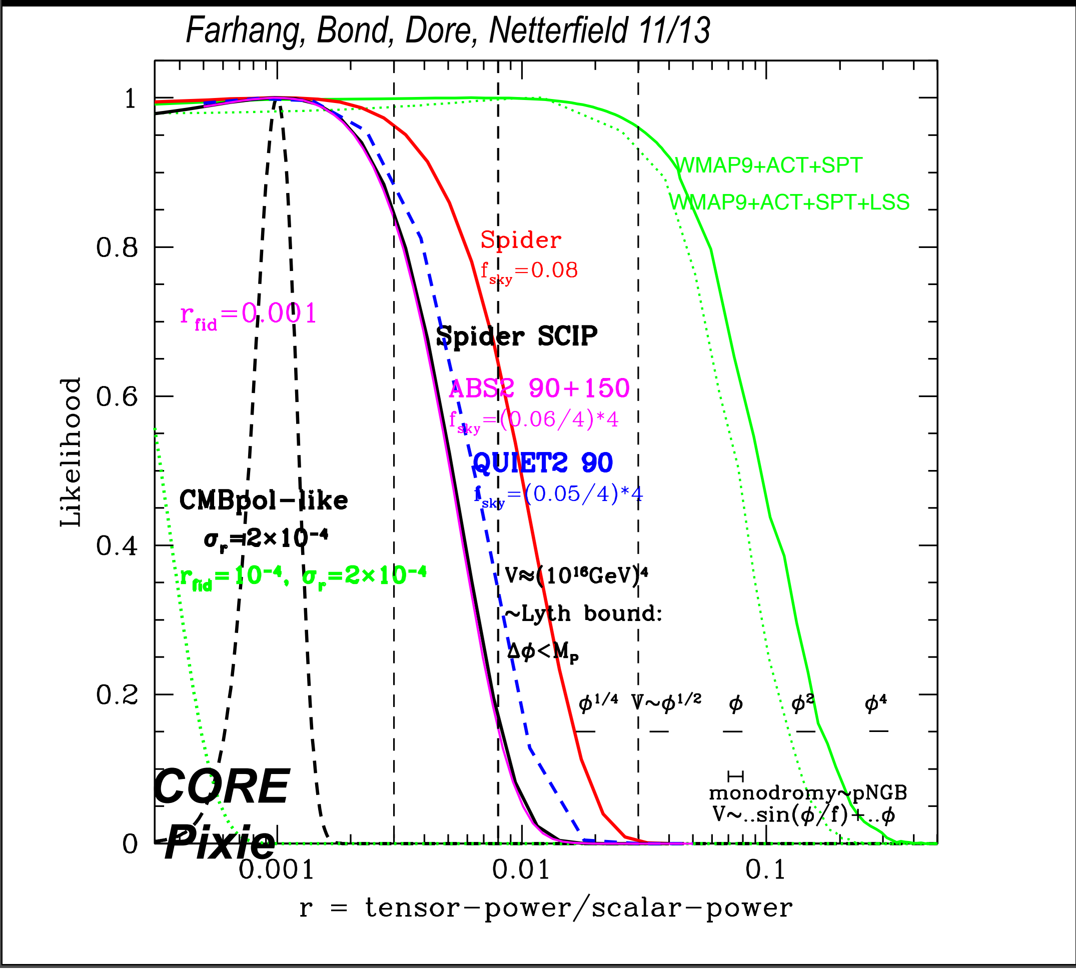
exponential potential models(power-law inf), the simplest hybrid inflationary models (Spontaneously Broken susy), and monomial potential models of degree n >2 do not provide a good fit to the data. No running. no CDM isocurvature of axion <3.9% (95% CL) & curvaton (< 0.25%) types.

Natural = pNGB-Inflation, monodromy = driven pNGB-Inflation, Roulette Inflation (shrinking holes in extra-dim), brane inflation survive.

matrix-QU-forecast for Spider24days+Planck2.5yr:

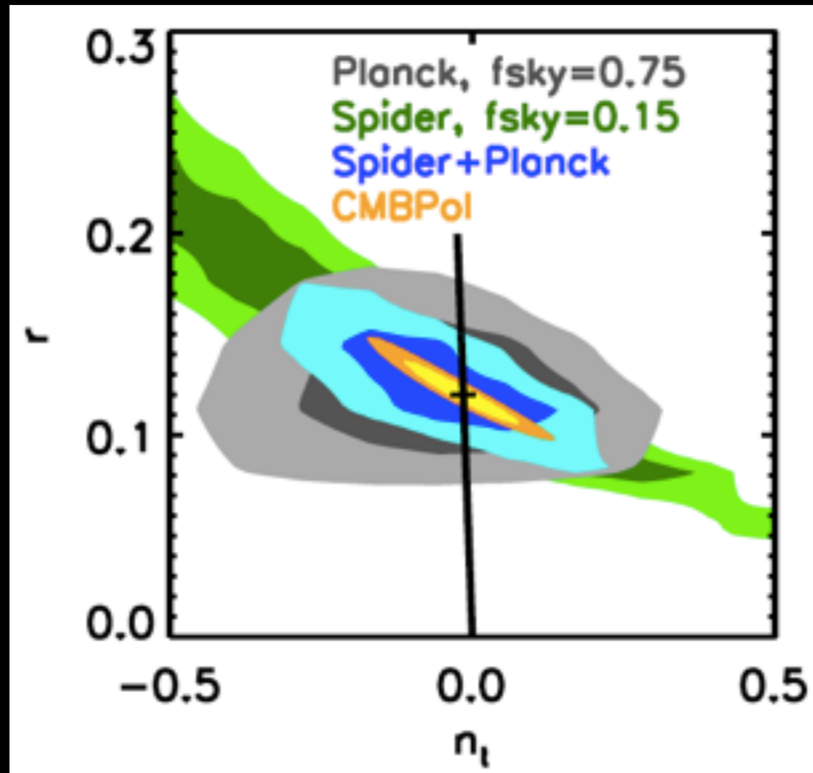
for r=0.12 input for $m^2\varphi^2$
($2\sigma_r$ ~0.02 including fgnds)

similar r-forecasts for ***ABS+/VIP, Quiet***



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

$-n_t \approx r/8$ consistency



inflation consistency

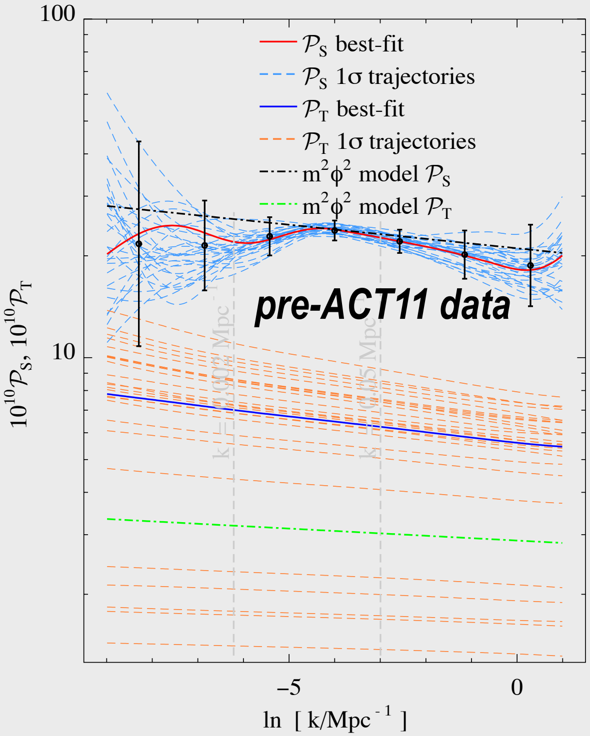
$-n_t \approx r/8 \approx 2\varepsilon(k)$

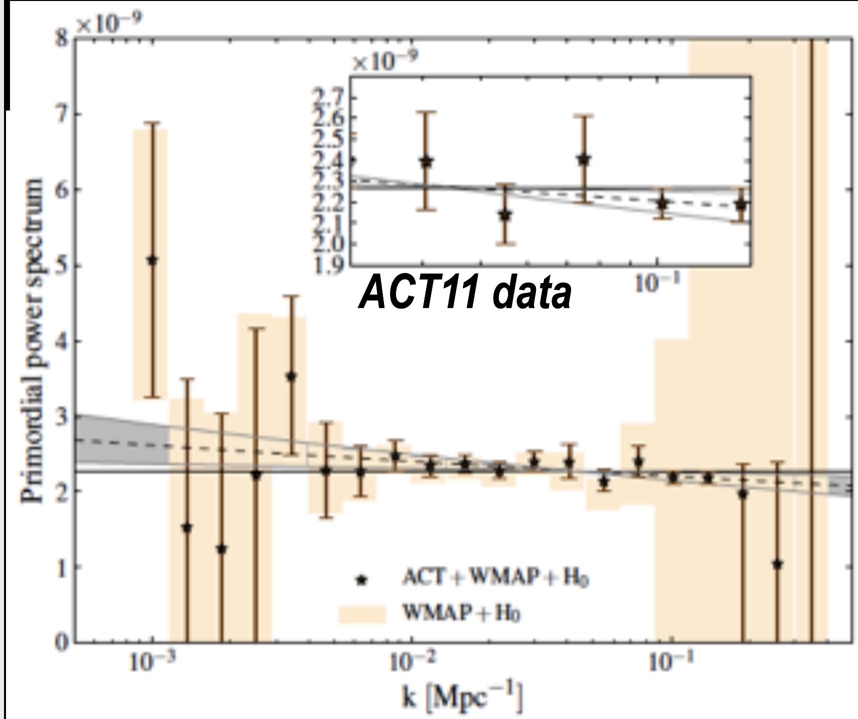
$1-n_s \approx 2\varepsilon + d\ln\varepsilon/d\ln Ha$

early-U, NOW

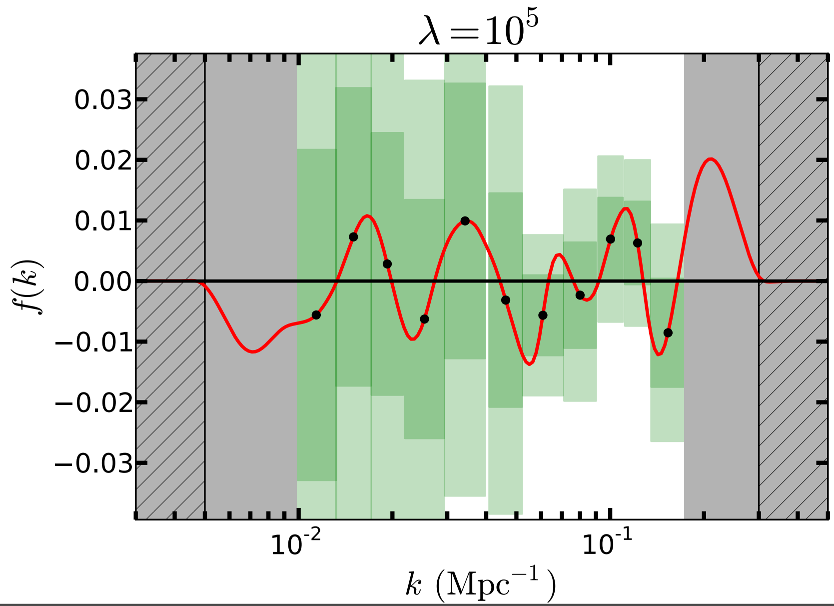
semi-blind & informed reconstruction of acceleration histories & S/T power spectra

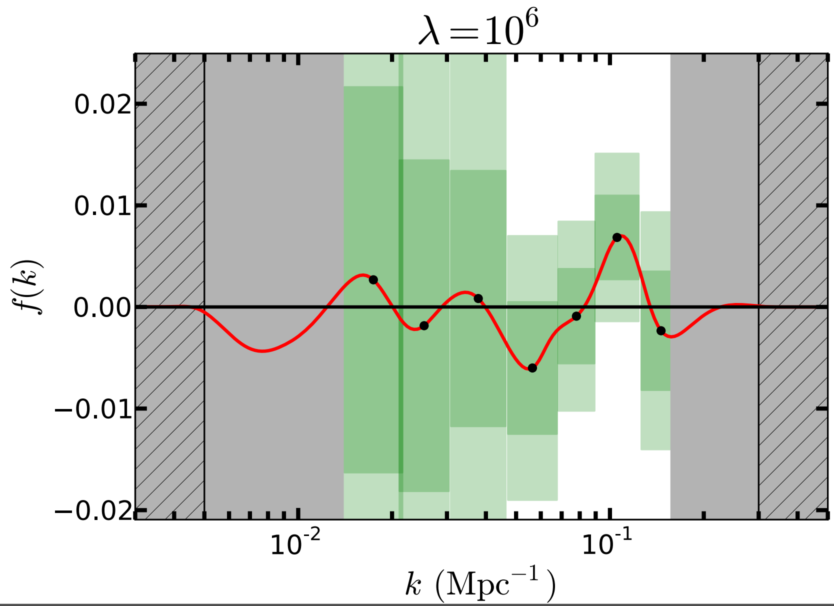
informed example: oscillation patterns of driven pNGB aka monodromy





Planck1.3

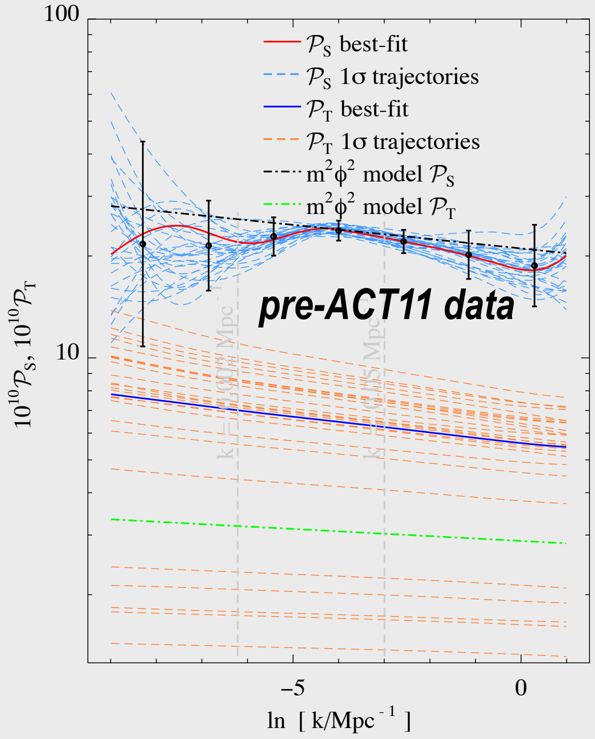


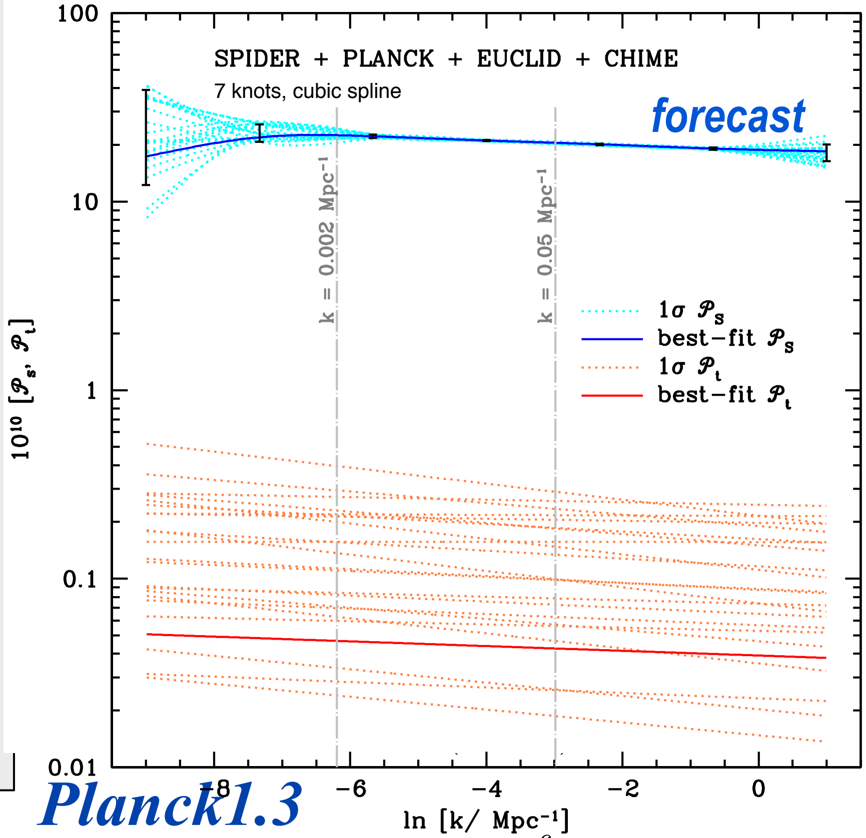


early-U, NOW

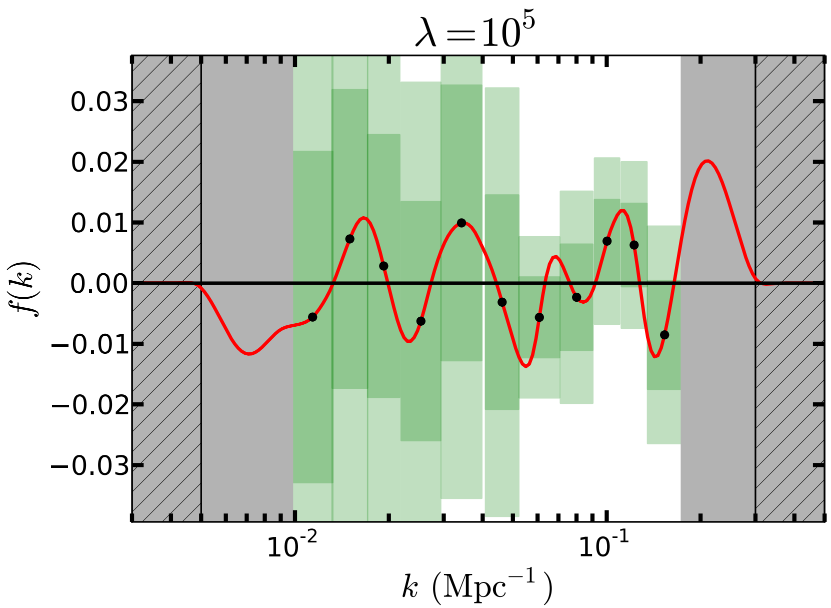
semi-blind & informed reconstruction of acceleration histories & S/T power spectra

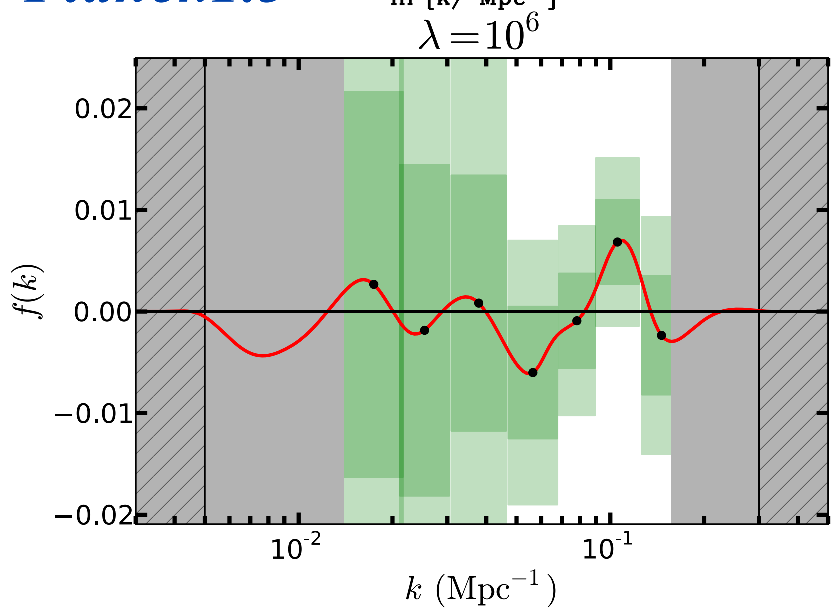
informed example: oscillation patterns of driven pNGB** aka **monodromy





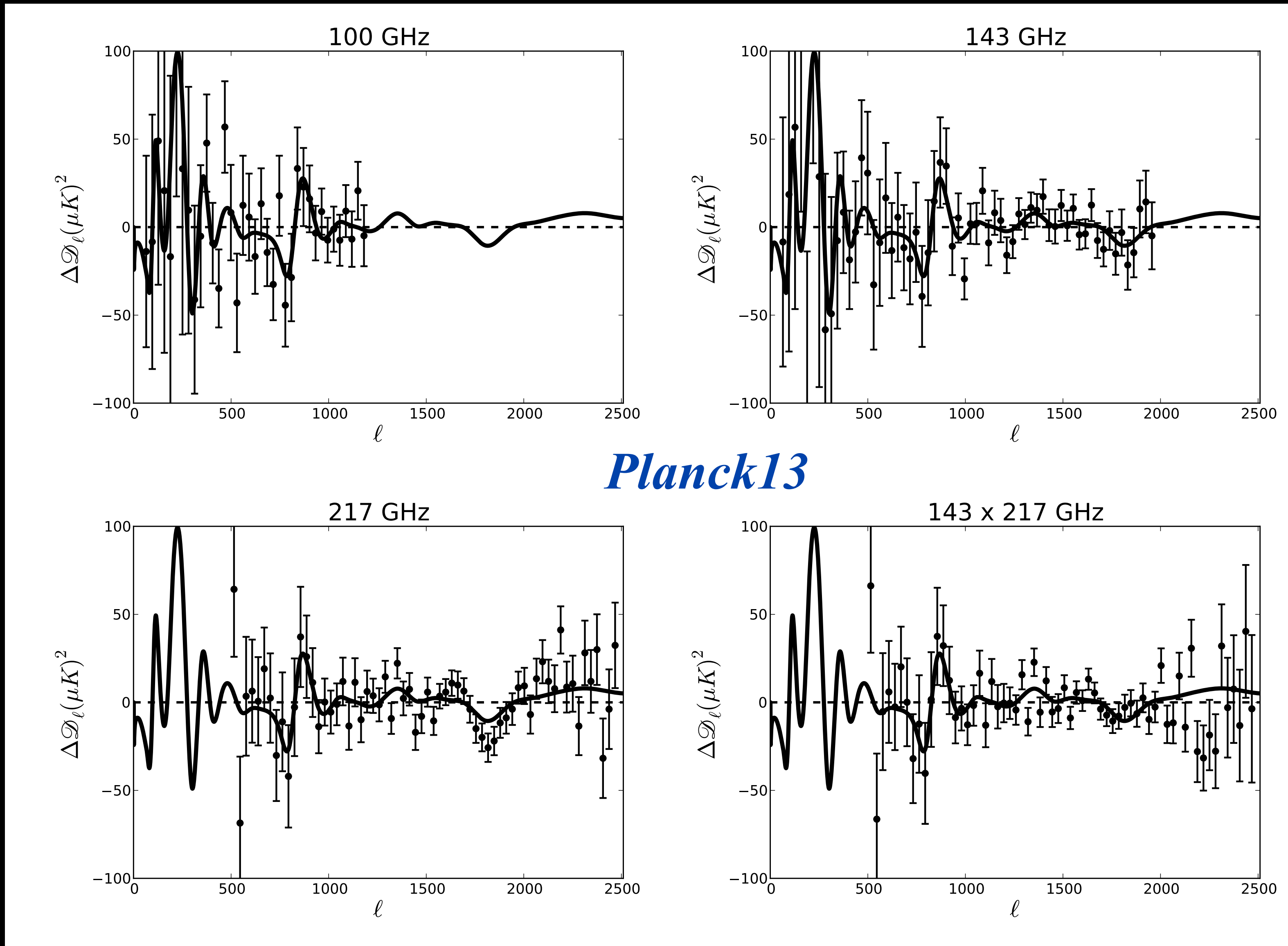
Planck1.3





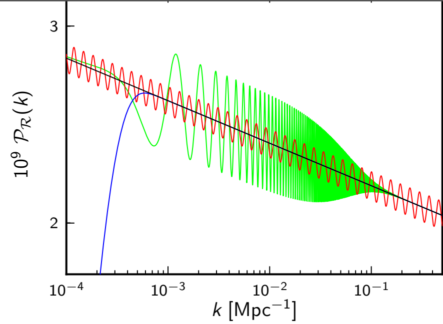
semi-blind & informed reconstruction of acceleration histories & S/T power spectra

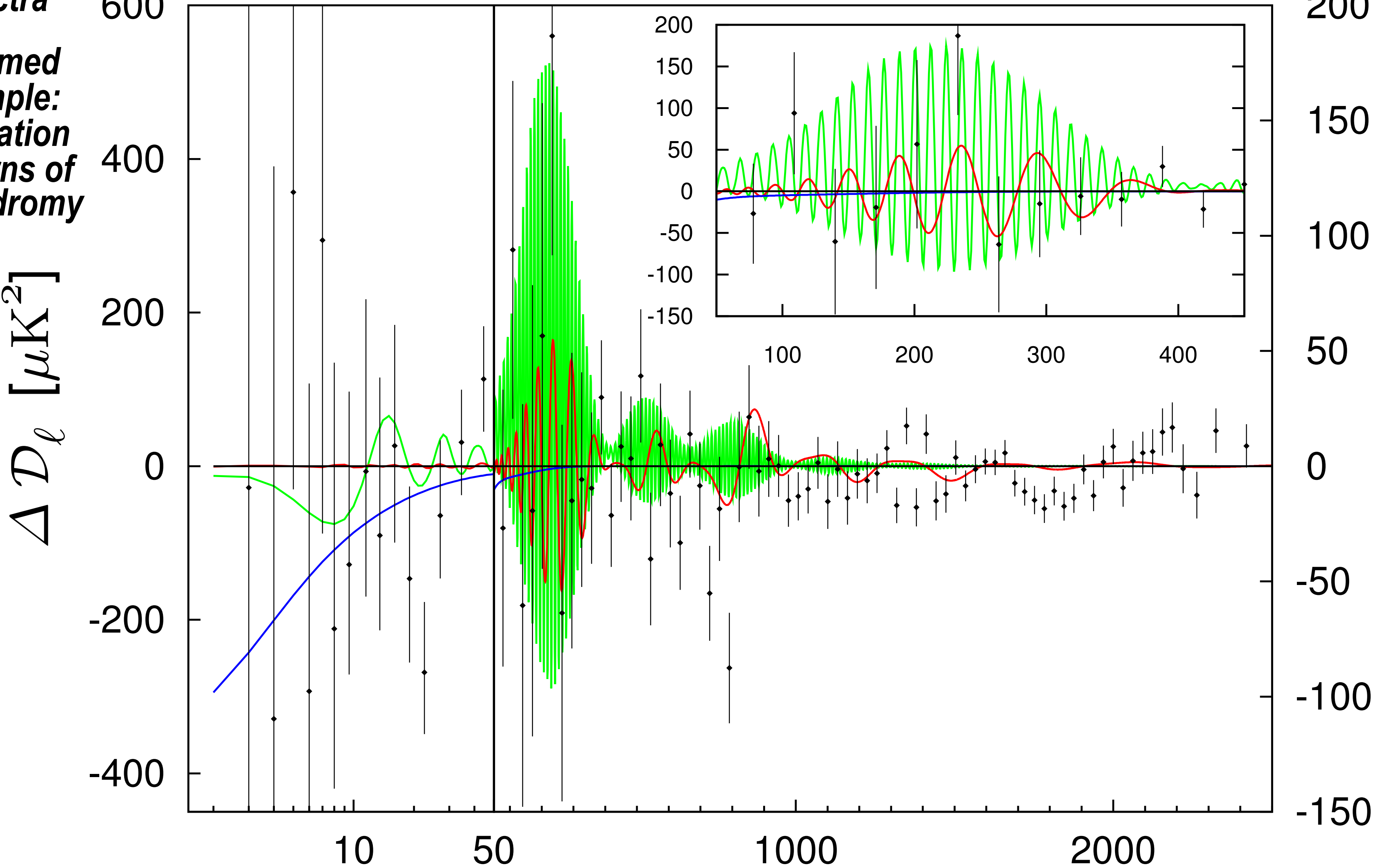
informed example: oscillation patterns of monodromy



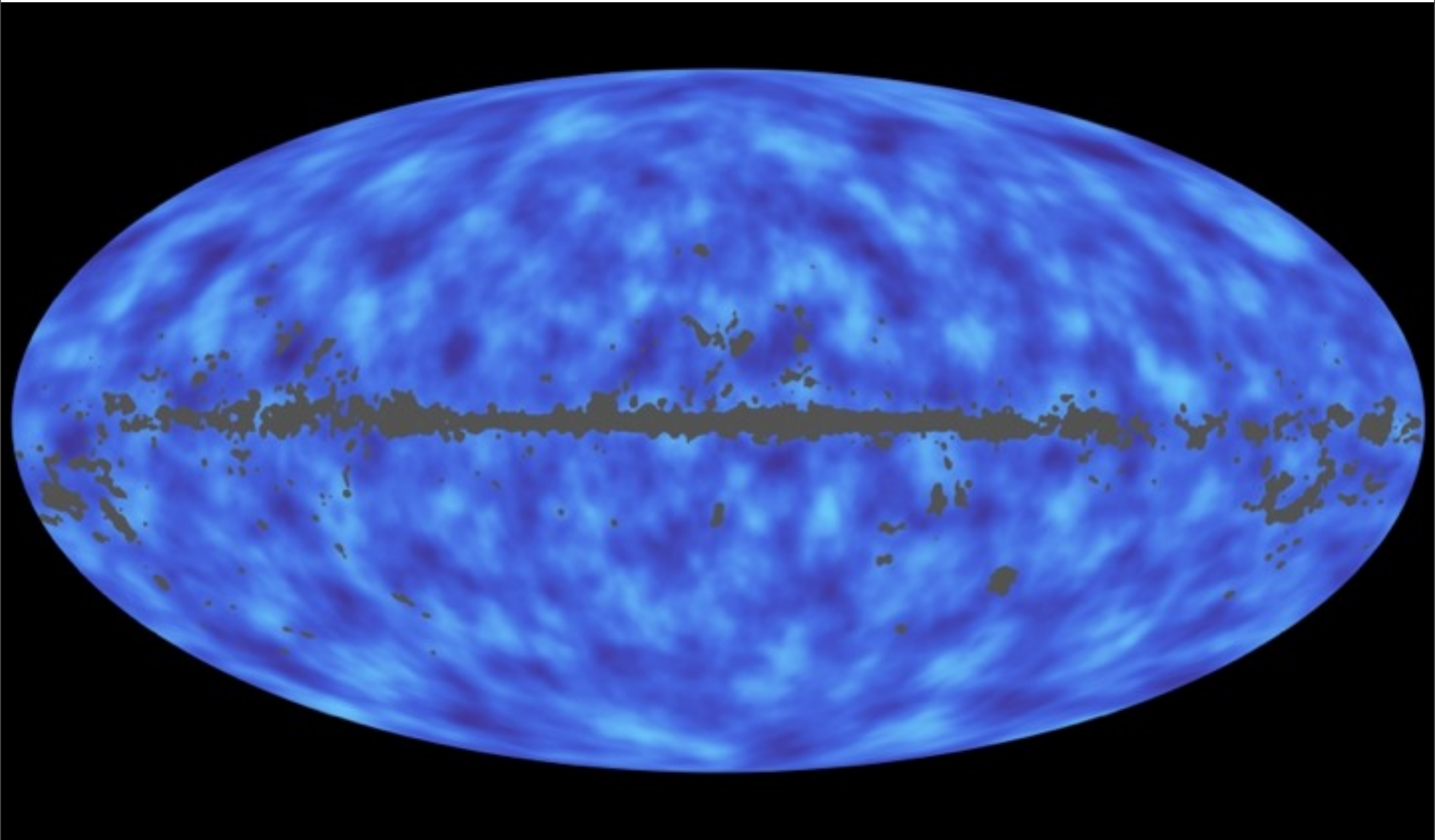
semi-blind & informed reconstruction of acceleration histories & S/T power spectra

informed example: oscillation patterns of monodromy

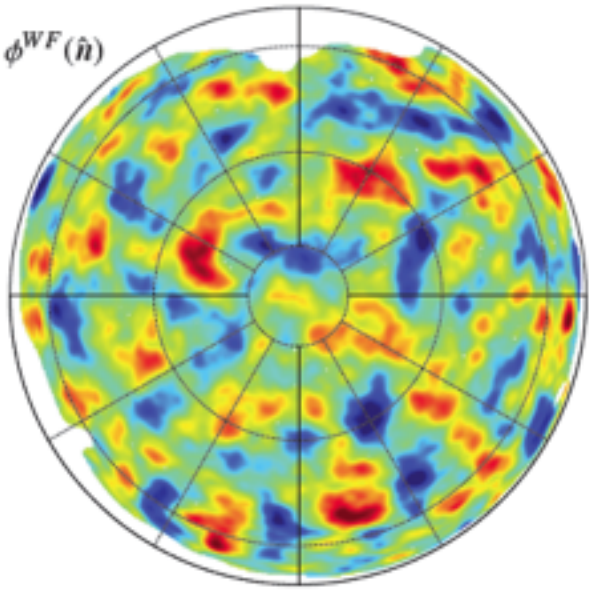




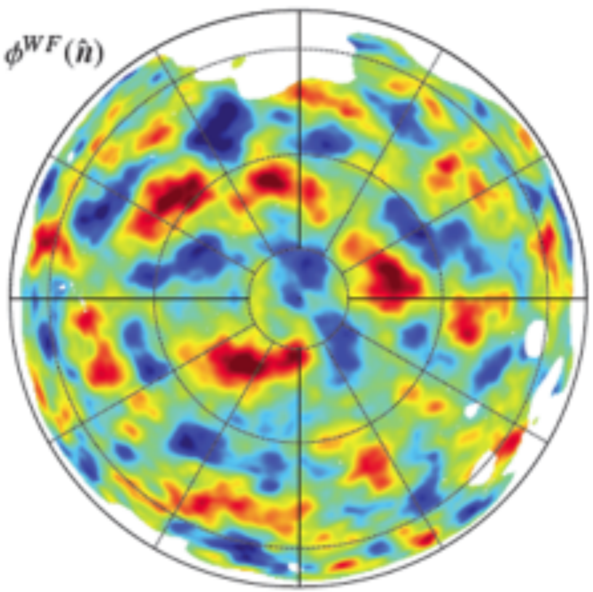
Planck1.3 CMB Lensing: reconstructed projected gravitational potential map (!) ~ *dark+baryonic matter map*, ***Wiener filter (beware: fluctuations about Wiener = mean-field)***



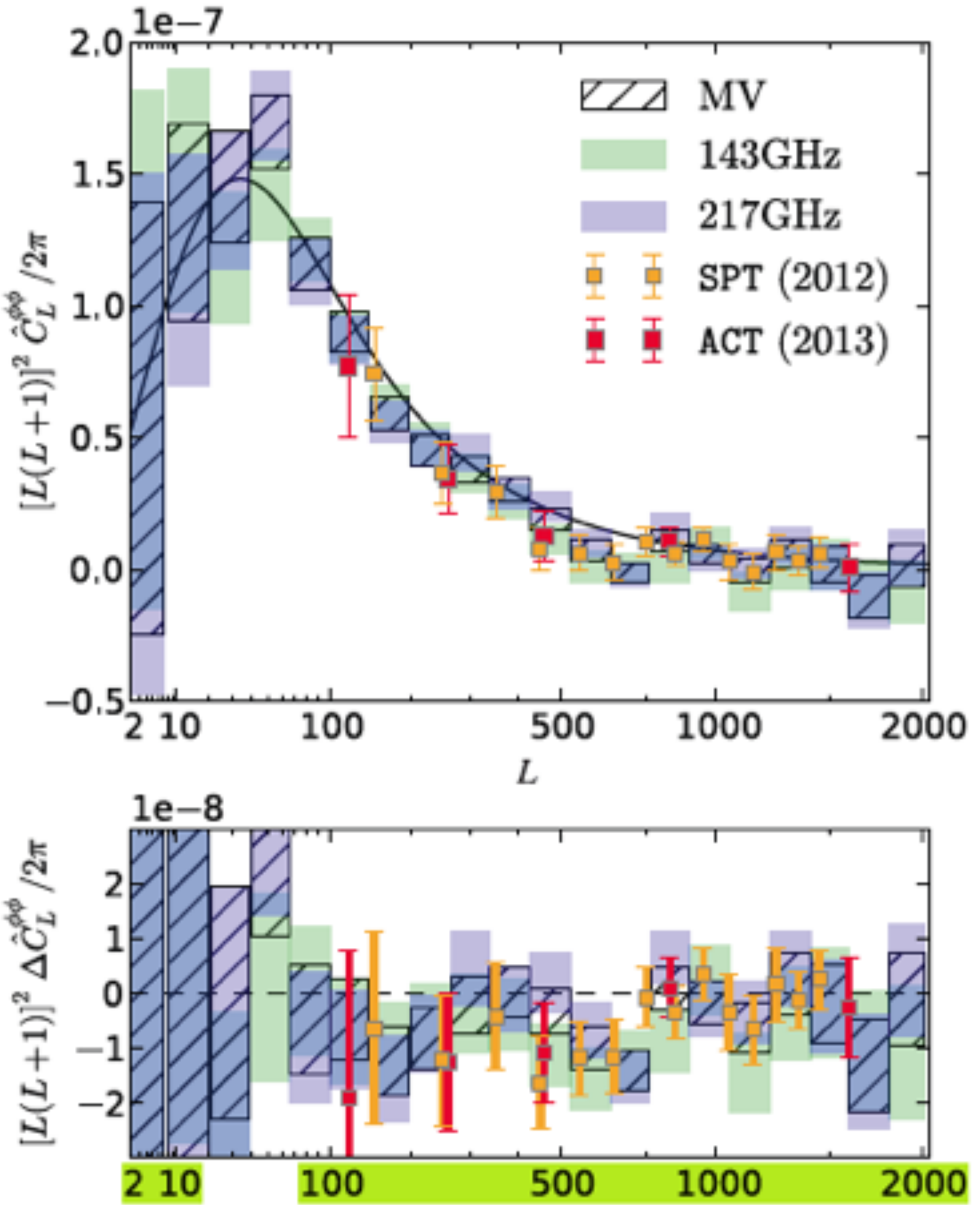
CMB Lensing: Planck13 cf. ACT12 and SPT12, good agreement



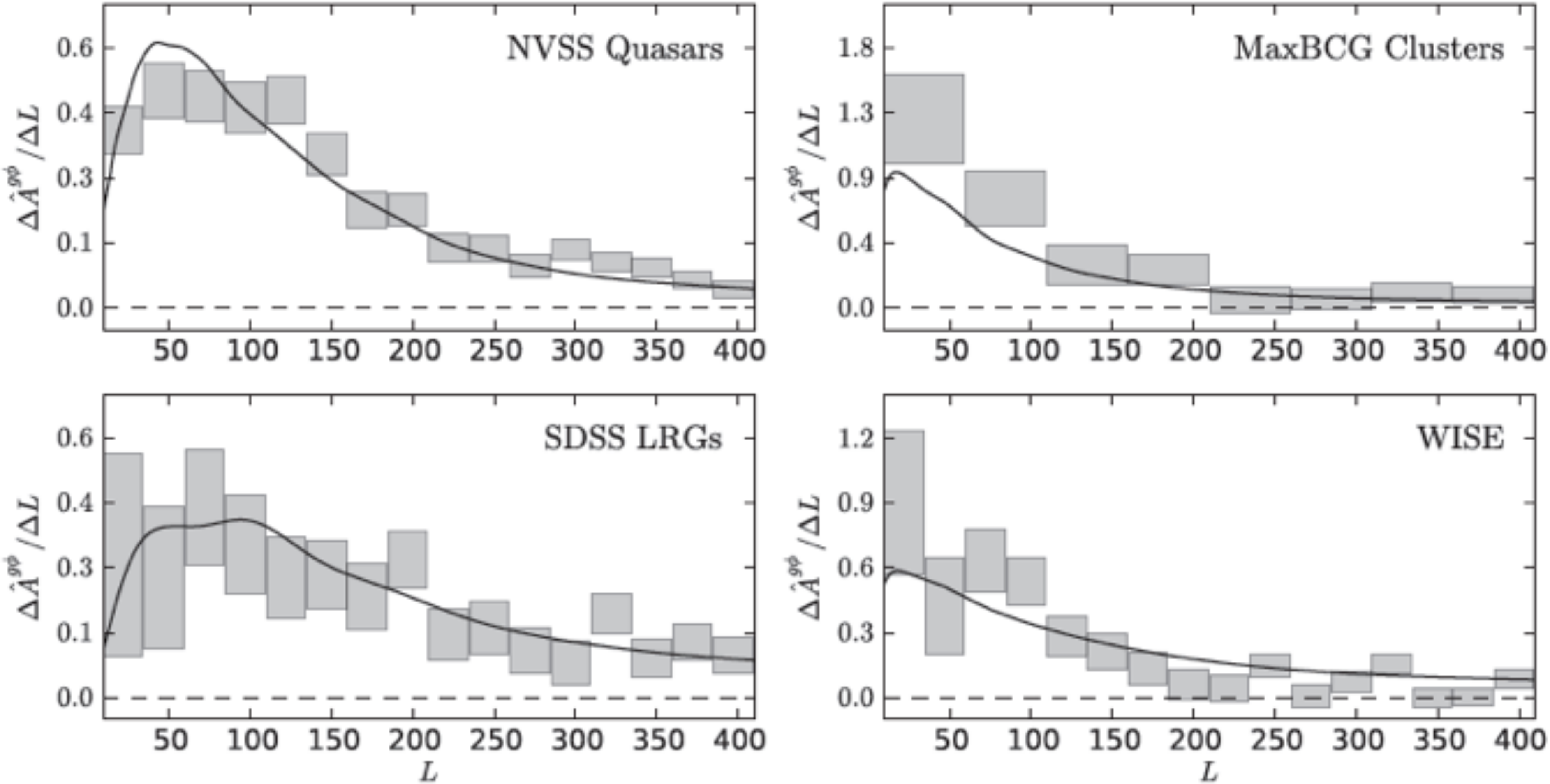
Galactic North



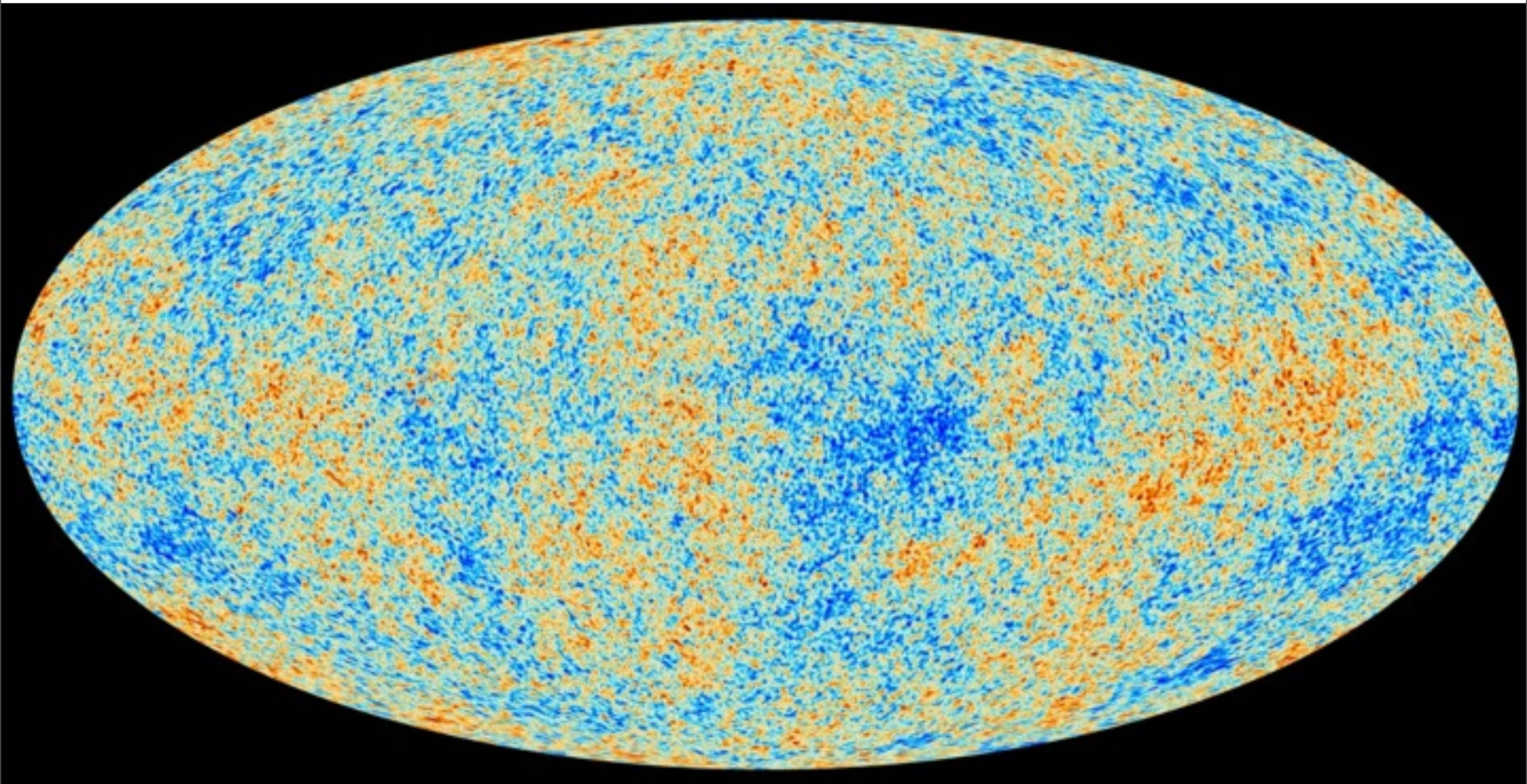
Galactic South



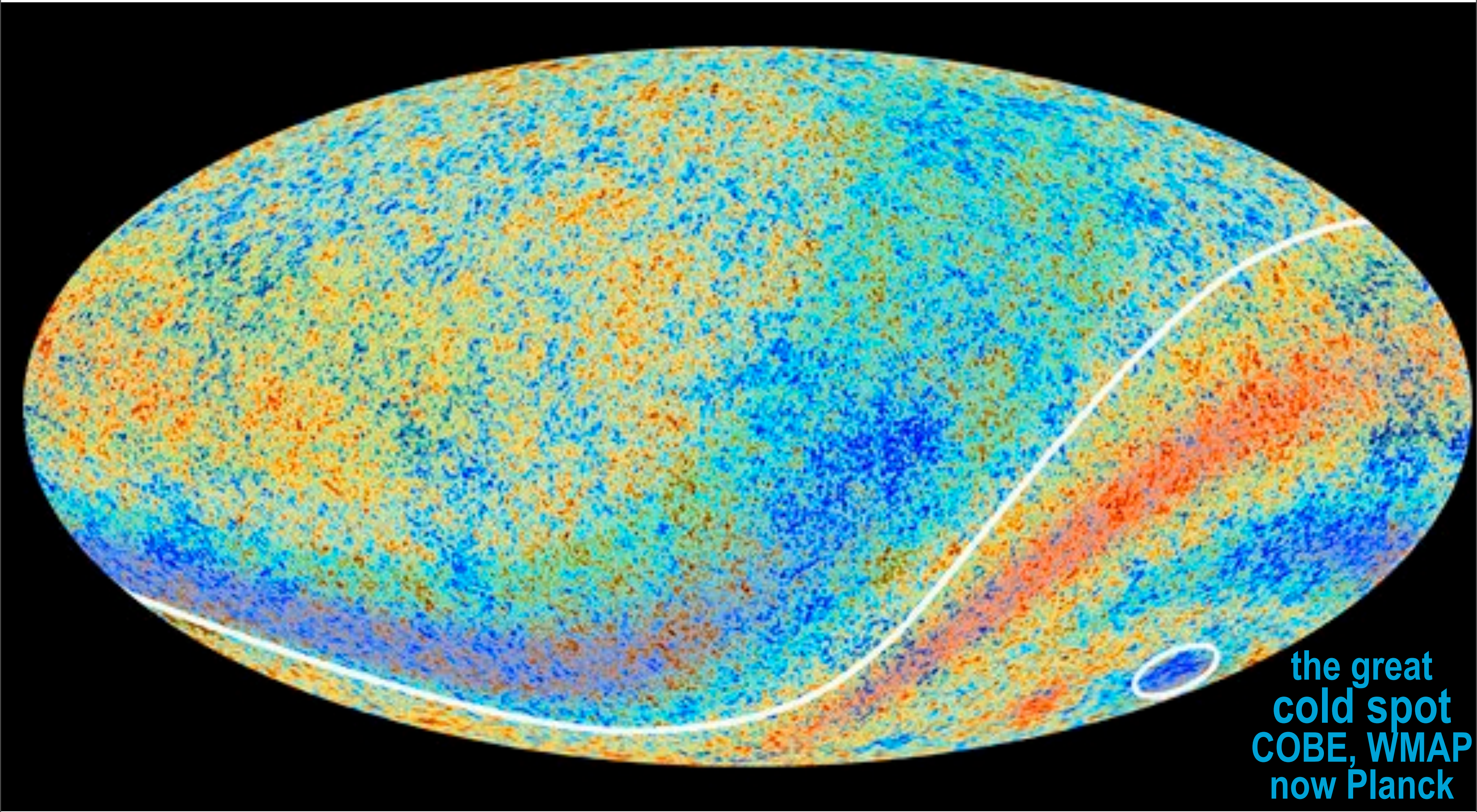
CMB Lensing: Planck13 X non-CMB surveys

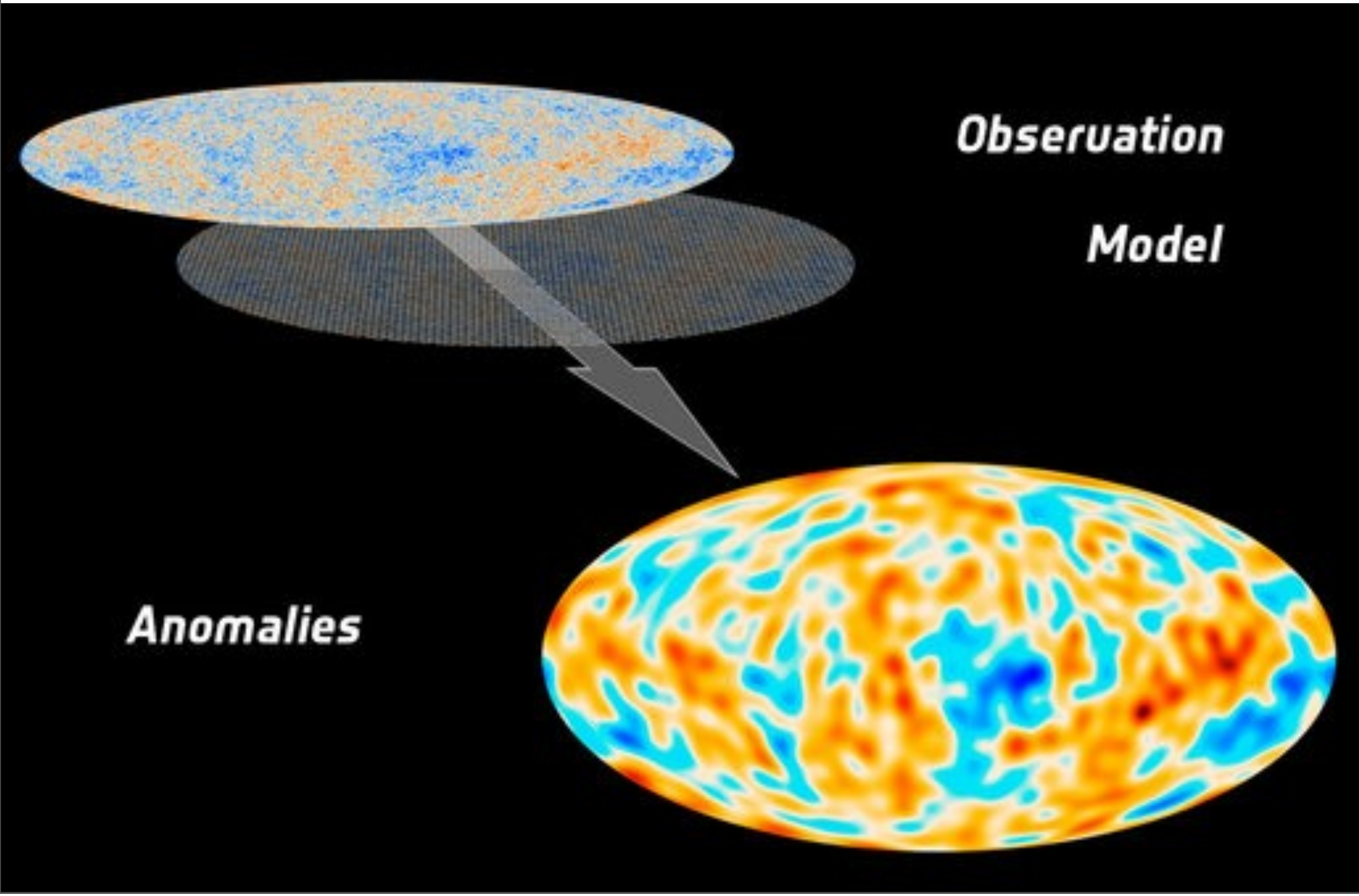


Large Scale Anomalies

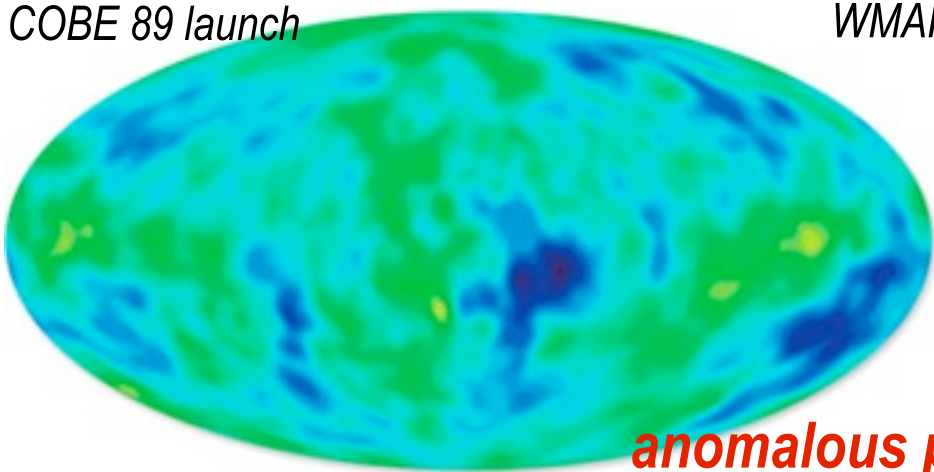


a Bianchi VII template pattern soaks up a number of large scale anomalies *(the template parameters are not viable for a physical Bianchi VII model with UltraLargeScale rotation & related shear)*

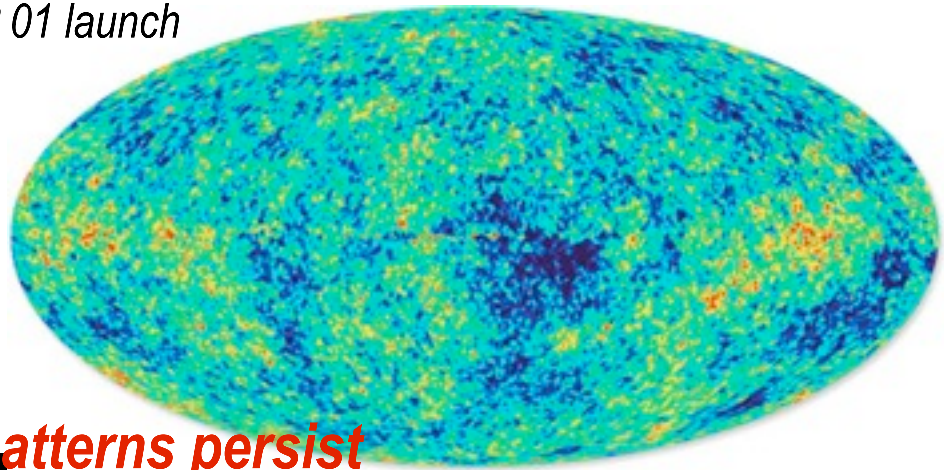



Observation
Model
Anomalies

COBE 89 launch

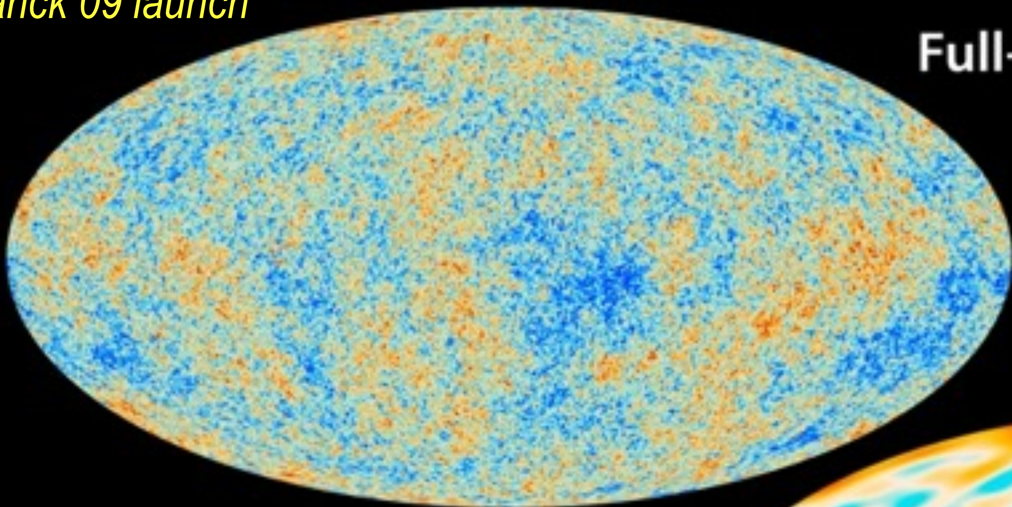


WMAP 01 launch



anomalous patterns persist

Planck 09 launch



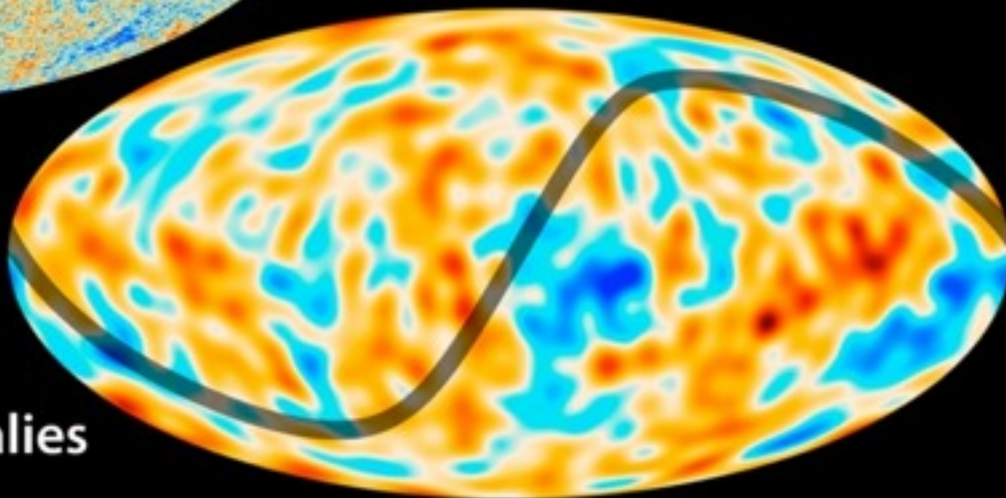
Full-Sky Map

NonGaussian 3-point-pattern measure

f_{nl}: 2.7 ± 5.8 local => ± 5 (Pext)

-f_{nl}: 42.3 ± 75.2 equil

-25.3 ± 39.2 ortho & f_{NL}^{eff}



Anomalies

primordial non-Gaussianity

$$\zeta(x)= \zeta_G(x)+ f_{NL} (\zeta_G^2(x)-\langle\zeta_G^2\rangle)$$

local smooth. use optimal pattern estimator

cf. DBI inflation: non-quadratic kinetic energy

cosmic/fundamental strings/defects

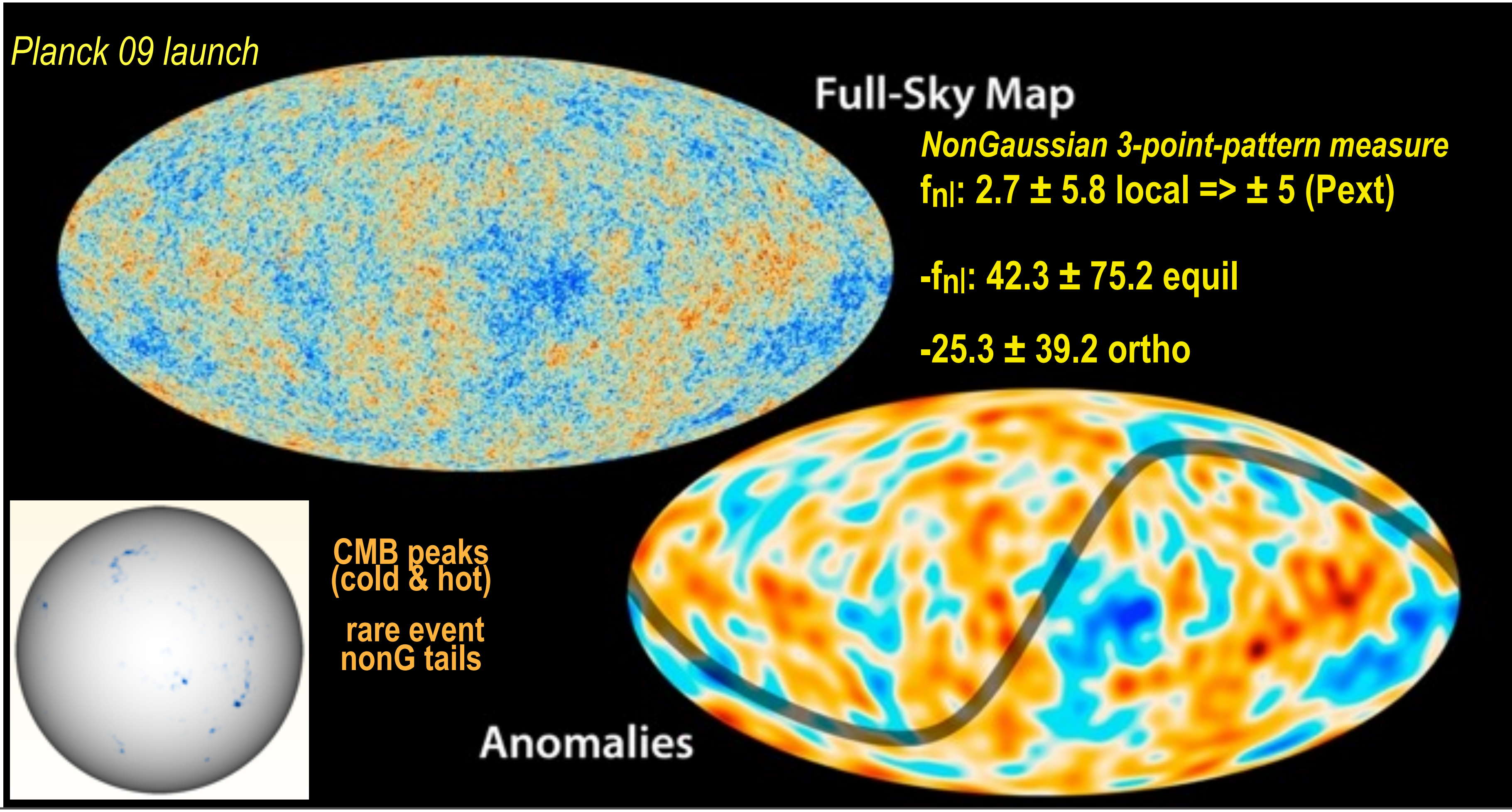
from end-of-inflation & preheating

$$\zeta(x)= \zeta_G(x)+F_{NL} (\chi_b(x))$$

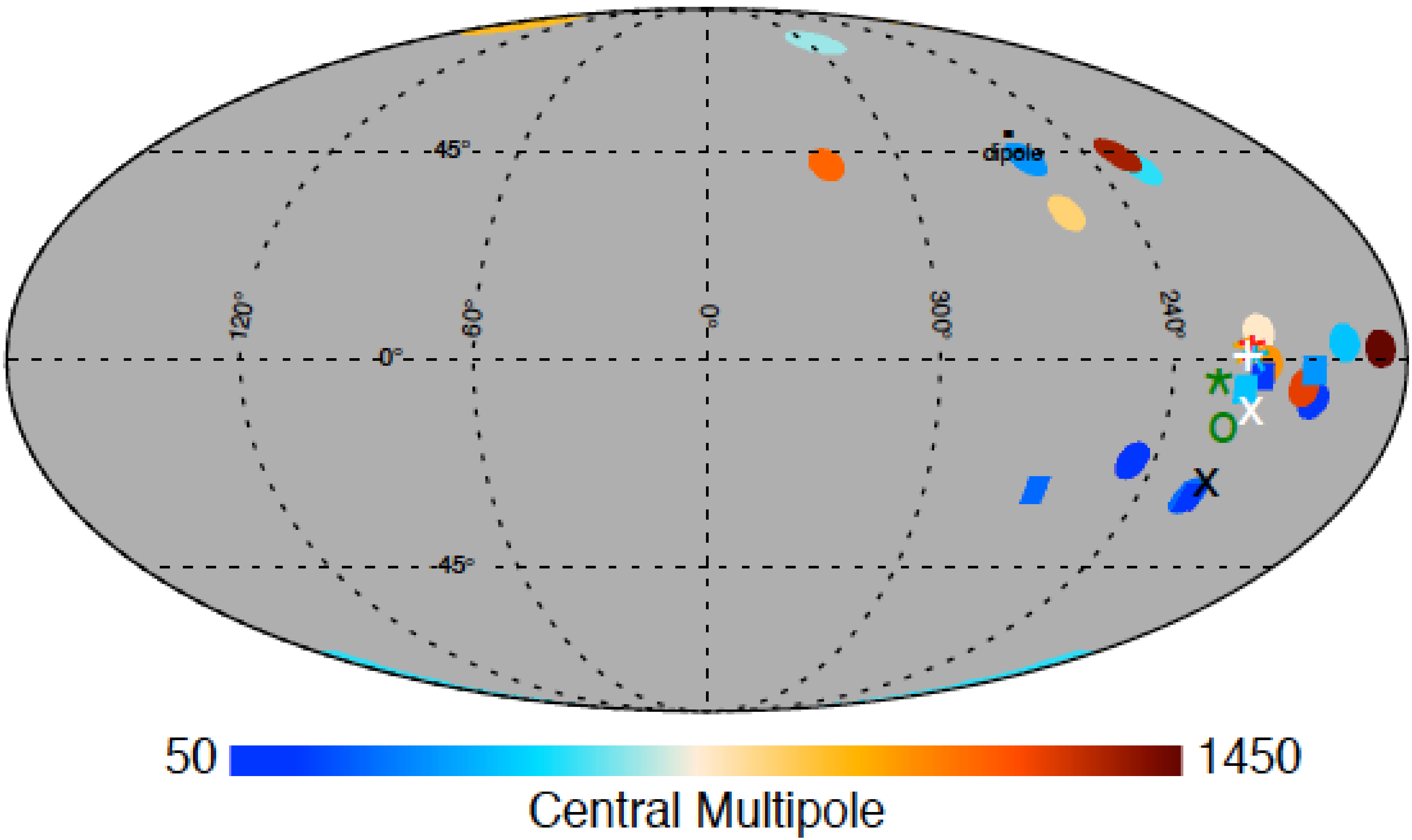
modulating preheating

f_{NLeff} + cold spots

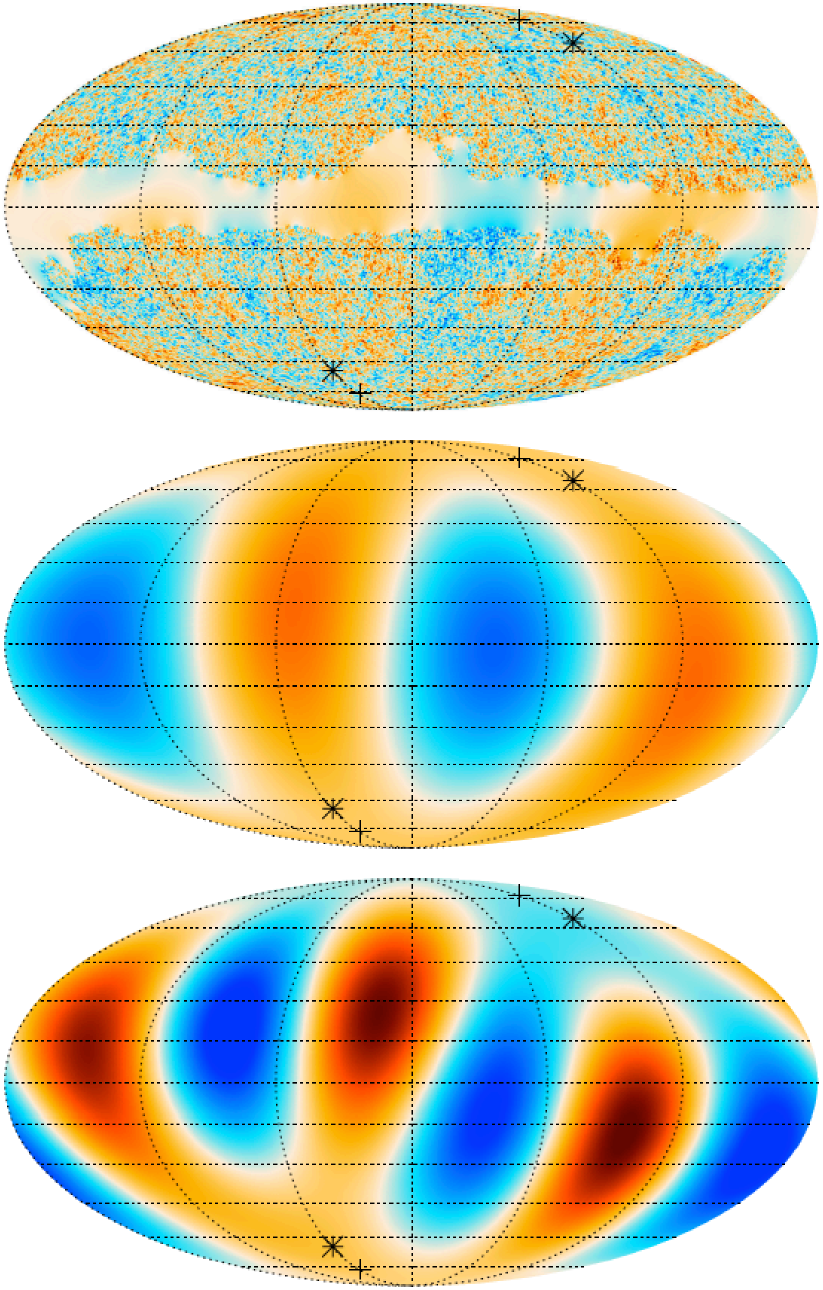
$$\zeta(x)= \zeta_G(x)+F_{NL} (g_b(x))$$



***power spectrum asymmetry**: dipole near Galactic Equator points towards LSS anomaly*



octupole quadrupole_alignment within ~10 deg



Are LargeScale anomalies statistically significant? no said WMAP7 ***Bennett+***

Seem to be says Planck1.3, so theorists should look again

Is there a "Grand Unified Model" tying the LS anomalies to one cause?

Nothing compelling so far. Bianchi VII template soaks up some but is not tied to a viable physical model

Topology constraints from Planck1.3 say ***Size of the Universe > 2*distance to recombination*** *for a variety of flat, plus and minus curved models, as did COBE and WMAP.*

Inflation models prefer a super-big universe, with nothing special just beyond our Hubble volume leaking in - maybe

Thus, can anomalies relate to inflation, given the strong non-G pattern-constraints from the 3-point function coded in f_{NL}

e.g., ***from LS-intermittency due to an ultraLS modulating field remembering post-inflation entropy generation (preheating) BFHK09, BBFH13***

Old view: Theory prior = delta function of THE correct one and only theory

New: Theory prior = probability distribution of late-flows on an energy LANDSCAPE

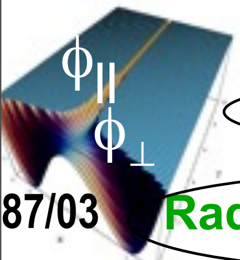
6/7 tiny extra dimensions

1980

R^2-inflation

Old Inflation

Chaotic inflation



New Inflation

Power-law inflation

Double Inflation

SUGRA inflation

87/03

Radical BSI inflation

running (nee variable M_P) inflation

Higgs inflation

Extended inflation

1990

Natural pNGB inflation

Hybrid inflation

KLS94 preheating

SUSY F-term inflation

Assisted inflation

SUSY D-term inflation

Brane inflation

2000

SUSY P-term inflation

Super-natural Inflation

K-flation

2003 KKLT

N-flation

ekpyrotic/ cyclic

D3,D7 brane inflation

DBI inflation

moving brane separations

Racetrack inflation

Tachyon inflation

Warped Brane inflation

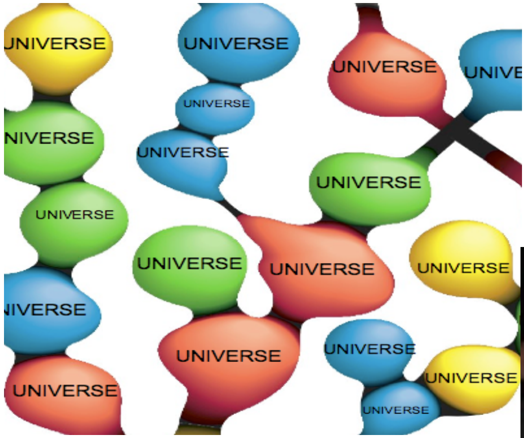
moduli fields

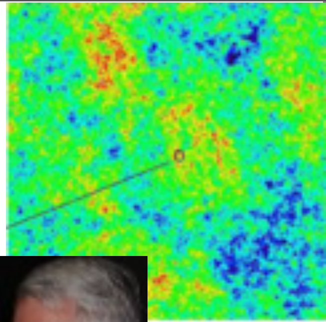
monodromy

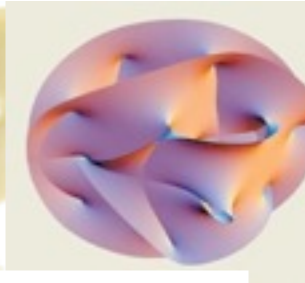
Higgs inflation

Roulette inflation Kahler moduli/axion

fibre inflation





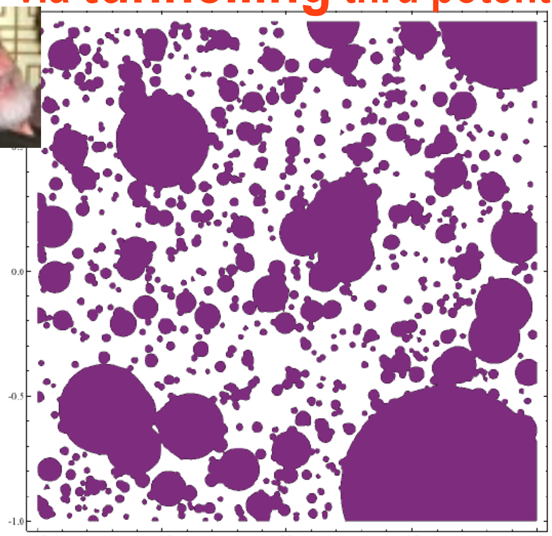


$S_{U,uuUULSS}$ $=\langle \ln P[U|Time]^{-1}\rangle$ *measure problem*

when quantum kicks *beat* classical drifts

we are in the semi-ETERNAL INFLATION regime

or via tunnelling thru potential wells



=> the hubble bubble U

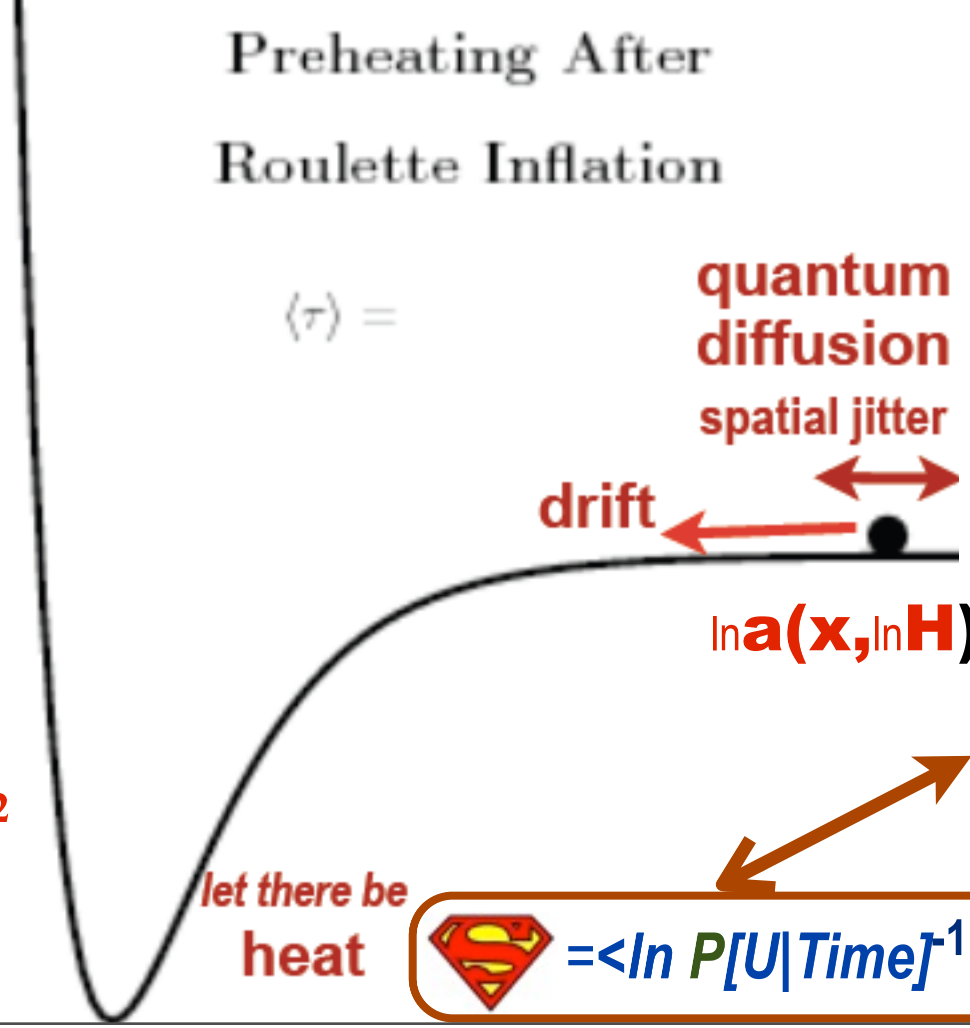
$S_{G,GH}$

$\propto m_P^2/H_V^2$

$\propto m_P^4/\rho_V$

statistical mini-landscapes e.g.,

Roulette Inflation in a holey U *cf.* braney Us



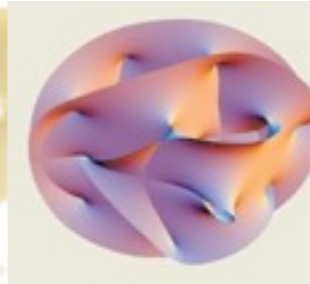
semi ETERNAL INFLATION

$=\langle \ln P[U|Time]^{-1}\rangle$

***entropy generation in preheating** from the **coherent inflaton** (**origin of all matter & radiation**)*

nonG from post-inflation but pre-entropy generation** (B²FH13) **drift trajectories can lead to pre-shock-in-time caustics and other phase space convergences in the deformations

$\partial \ln a / \partial \chi_i(x)$, $\partial \ln a / \partial g(x)$ =>



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

$P[\ln a(x),\ t_{shock} \mid \chi_i(x),\ g(x), t_{end\text{-}of\text{-}inflation}]$

***NL,nonG curvature distribution**($\chi_i(x)$, g(x),..)*

Barnaby,Bond,Huang,Kofman09

semi ETERNAL INFLATION

quantum diffusion

spatial jitter

drift

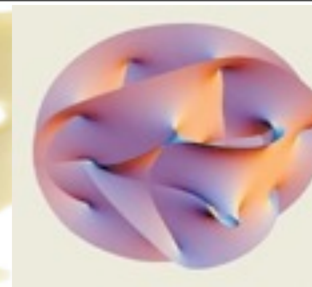
roulette oscillations
highly damped
=> no-non-G
if redirect by χ_i, **g**
=> non-G

let there be
heat

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

***entropy generation in preheating** from the*
coherent inflaton (origin of all matter & radiation)
nonG from post-inflation but pre-entropy generation (B²FH13) drift trajectories can lead to pre-shock-in-time caustics and other phase space convergences in the deformations

$\partial \ln a / \partial \chi_i(x)$, $\partial \ln a / \partial g(x)$ =>



$a =$ 1

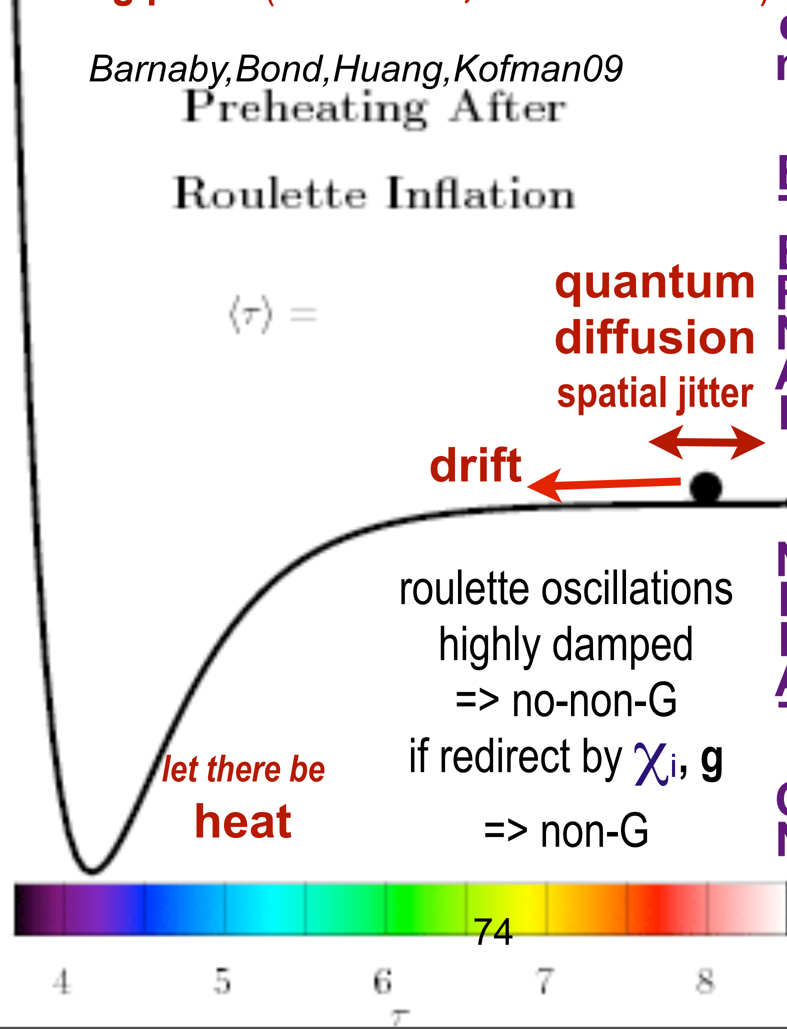
$P[\ln a(x),\ t_{shock} \mid \chi_i(x), g(x), t_{end\text{-}of\text{-}inflation}]$

NL,nonG curvature distribution(χ_i(x), g(x),..)

A visualized 2D slice

in lattice simulation

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

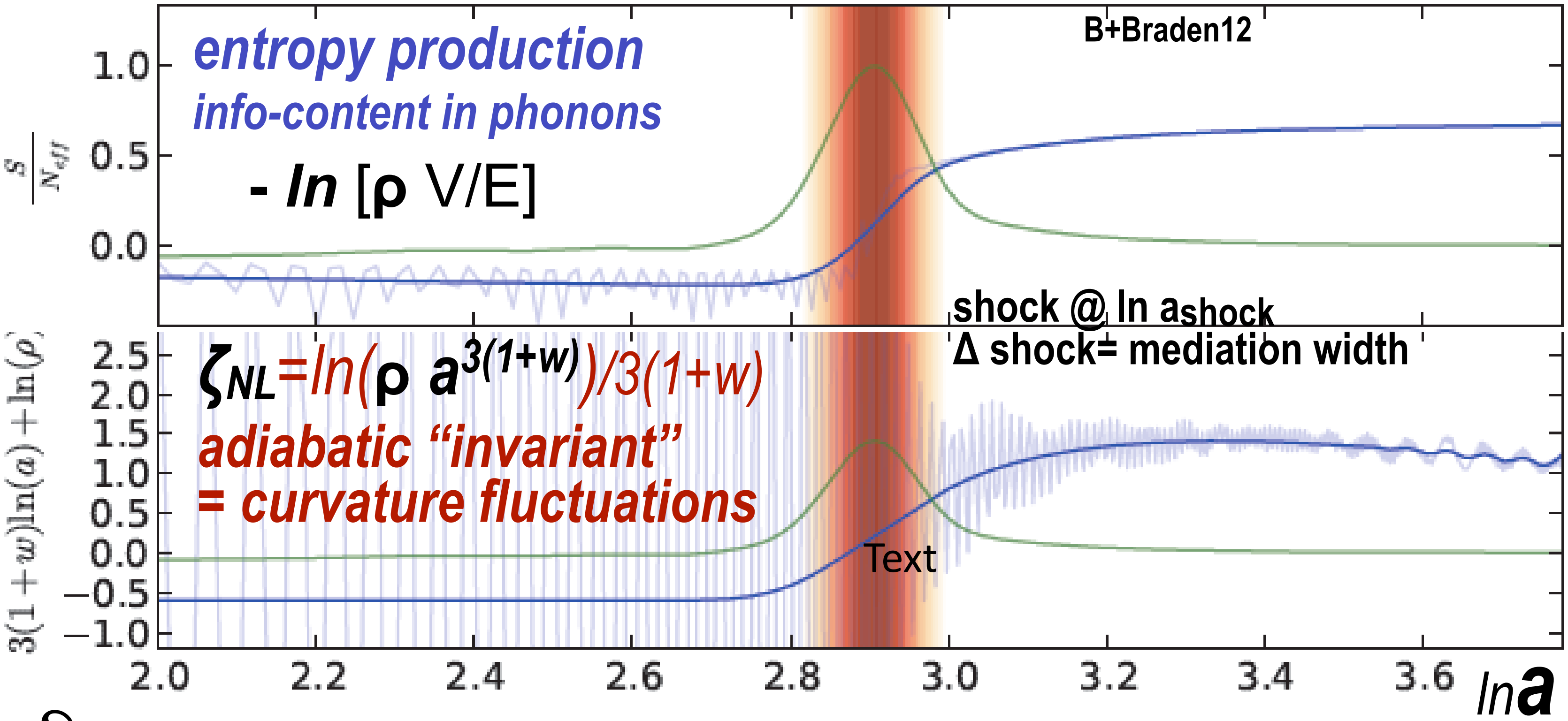


semi ETERNAL INFLATION

74

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

nonG from large-scale modulations of the shock-in-times of preheating



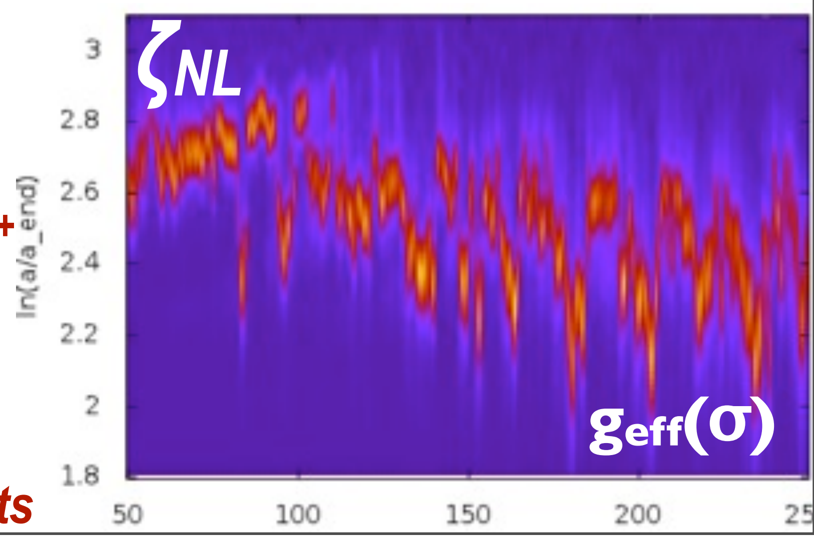
true thermal equilibrium far off ➤ & on to coupling to standard model degrees of freedom

$\delta\zeta_{NL shock}$ $(\mathbf{g}(\sigma(\mathbf{x}))$ => modulated non-G

$V(\phi,\chi) = 1/2\, m^2 \phi^2 + 1/2\, g_{eff}(\sigma)^2 \phi^2 \chi^2$

$\delta\zeta_{NL shock}(\chi_i(\mathbf{x})\ |g^2/\lambda))$ => *NonG cold spots ++*

$V(\phi,\chi) = 1/4\, \lambda\phi^4 + 1/2\, g^2 \phi^2 \chi^2$



V_{eff} is dynamical *Bond,Braden,Frolov,Huang13*

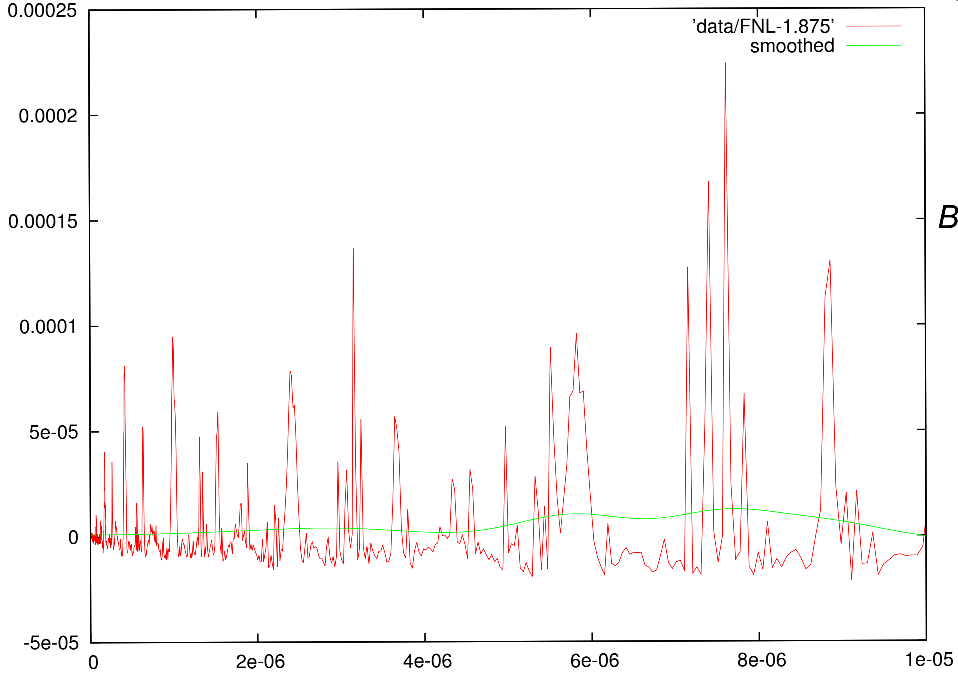
unconventional local non-G: no scale built into V;

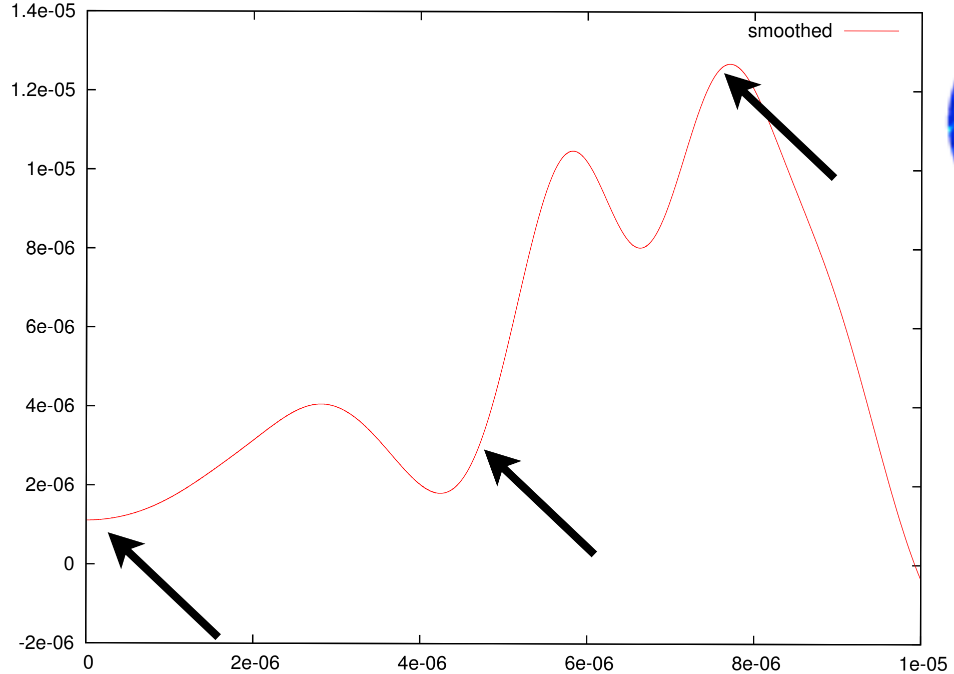
perturbative isocon-based f_{NL}; rare event cold spots

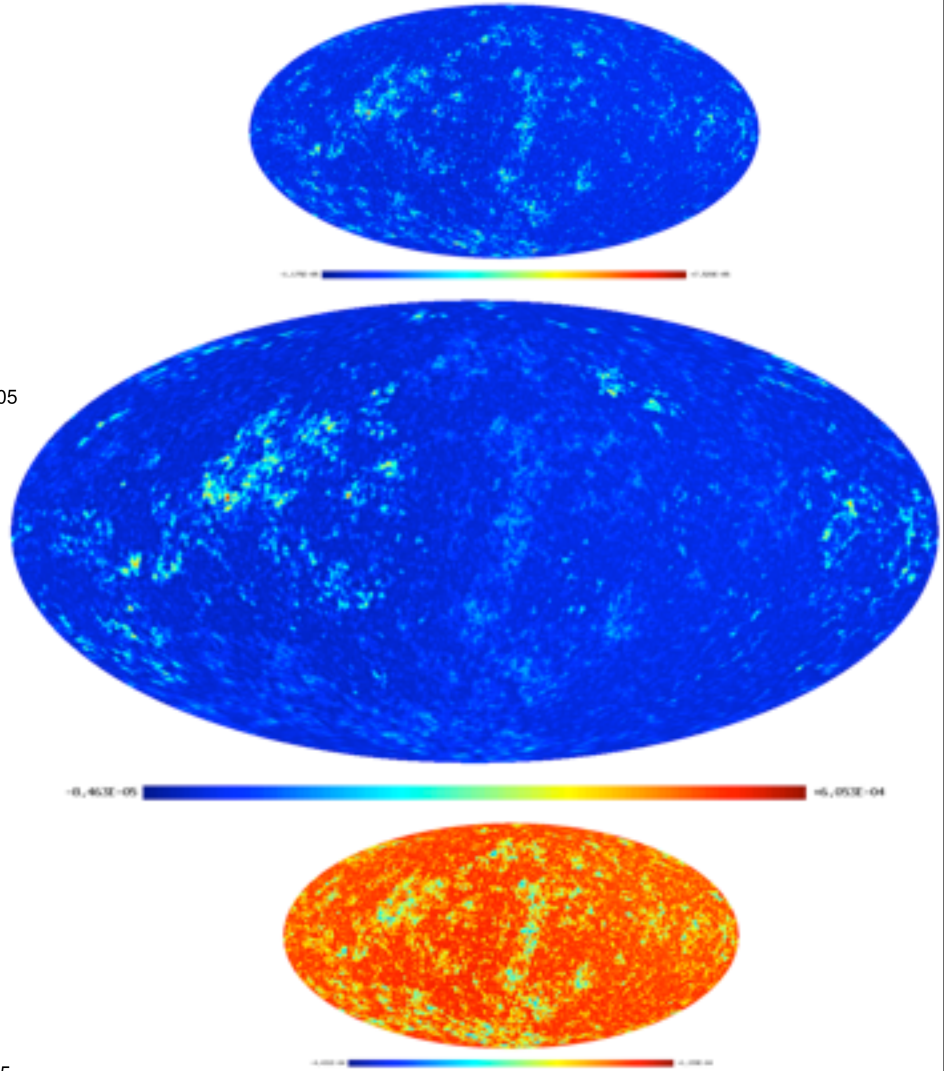
Samples of subdominant modulated preheating CMB*$\zeta_{NLshock}(\chi_i(x)\ |g^2/\lambda))$

intermittent NL isocon χ map to be superposed upon nearly Gaussian inflaton-generated curvature fluctuation map

Bond,Frolov,Huang, Kofman09 => Bond,Braden,Frolov,Huang13







CBI pol to Apr'05 @Chile **CBI2**

53+35 cls **(>=40)**

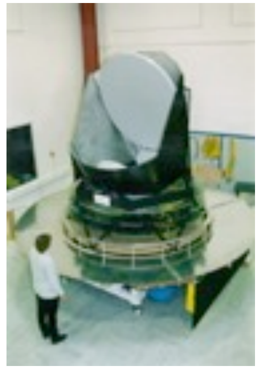
thermal SZ clusters

QUaD @SP

230 cls => 1227

Planck09.4

52+ bolometers
+ HEMTs @L2
9 frequencies



WMAP @L2 **to 2010**

2004 2006 2008 **LHC** 2011 **Bpol** @L2

2005 2007 2009

224 (>=750)

>96

OVRO /BIMA array

38 cls

80s-90s
Ryle
OVRO

Acbar@SP
~1 blind

SZA@Cal

3 cls (z>1), x?

AMI

7+1 cls >=50+25

AMIBA

6 cls

APEX
~400 bolos@Chile

~25 cls

GBT Mustang

4 cls (~25 CLASH)

SPT
1000 bolos
@SPole

ACT **23+68~91 cls**

3000 bolos
3 freqs @Chile

SCUBA2
12000 bolos
JCMT @Hawaii

SPTpol
ACTpol
ALMA

CCAT@Chile

LMT@Mexico

CBI pol to Apr'05 @Chile **CBI2**

53+35 cls **(>=40)**

thermal SZ clusters

QUaD @SP

230 cls => 1227

Planck09.4

Planck PSZ, cnts, ymap

861 confirmed, 178 by Planck + 683 known, **most z<.4,**

many ~ $10^{15}M_{sun}$ *0.<z<0.8*

52+ bolometers
+ HEMTs @L2
9 frequencies

WMAP @L2 **to 2010**

2004 2006 2008

2005 2007

Menanteau+12, Hasselfield+12

ACT Celestial Equator cls, 68 (49+19 in SDSS, half z>.5, 1 z~1.1 $10^{15}M_{sun}$
502 sq deg =>*91 in* *952 deg², 0.1<z<1.3*

100% purity for S/N>5. 60% > 4.5

No significant evidence of SZ/BCG offset
M_{SZ}-N_{200} weak correlation, large scatter

224 (>=750)

SPT
1000 bolos
@SPole

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3000 bolos
3 freqs @Chile

Acbar@SP
~1 blind

>96
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12000 bolos
JCMT @Hawaii

SPTpol
ACTpol
ALMA
CCAT@Chile
LMT@Mexico

CBI pol to Apr'05 @Chile **CBI2**

C_L^{SZ}

tSZ power spectrum

QUaD @SP

C_L^{SZ}

Planck1.3 matched filter all-sky

y-map => C_L^{tSZ}

observed clusters seen, cosmological parameters agree with those from counts!

low L tail from extended nearby cls

Planck09.4

52+ bolometers
+ HEMTs @L2
9 frequencies

WMAP @L2 **to 2010**

2004 2005 2006 2007 2008 2009 2011

LHC

Bpol @L2

>96

OVRO /BIMA array C_L^{SZ}

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ALMA

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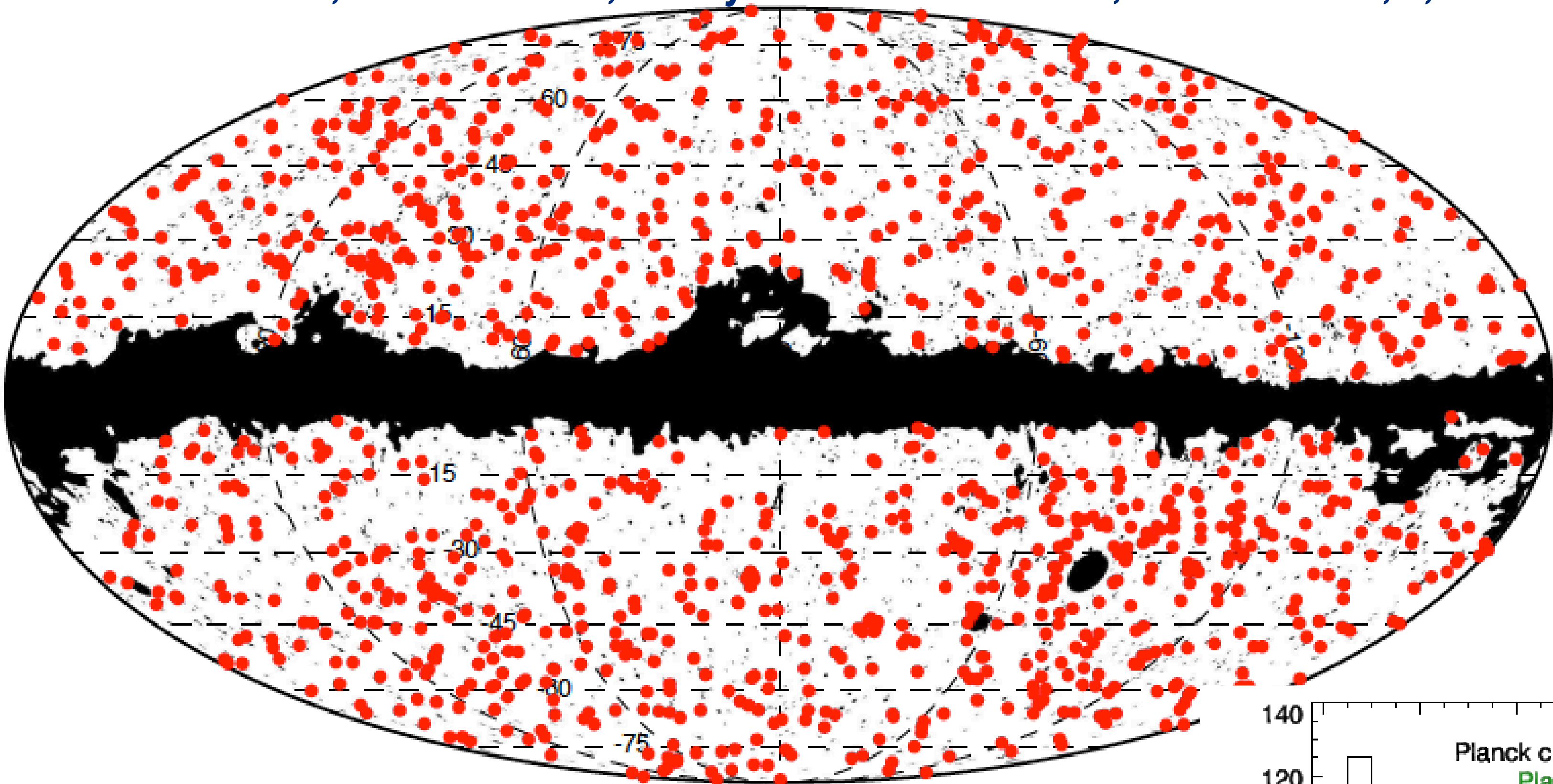
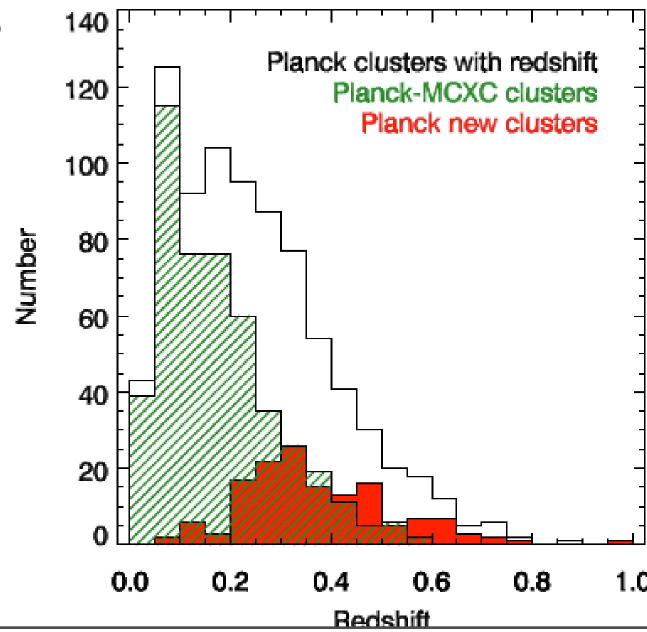
LMT@Mexico

80s-90s
Ryle
OVRO

thermal SZ clusters

PSZ: 1227 clusters, 861 confirmed, 178 by Planck + 683 known, rest in class 1, 2, 3

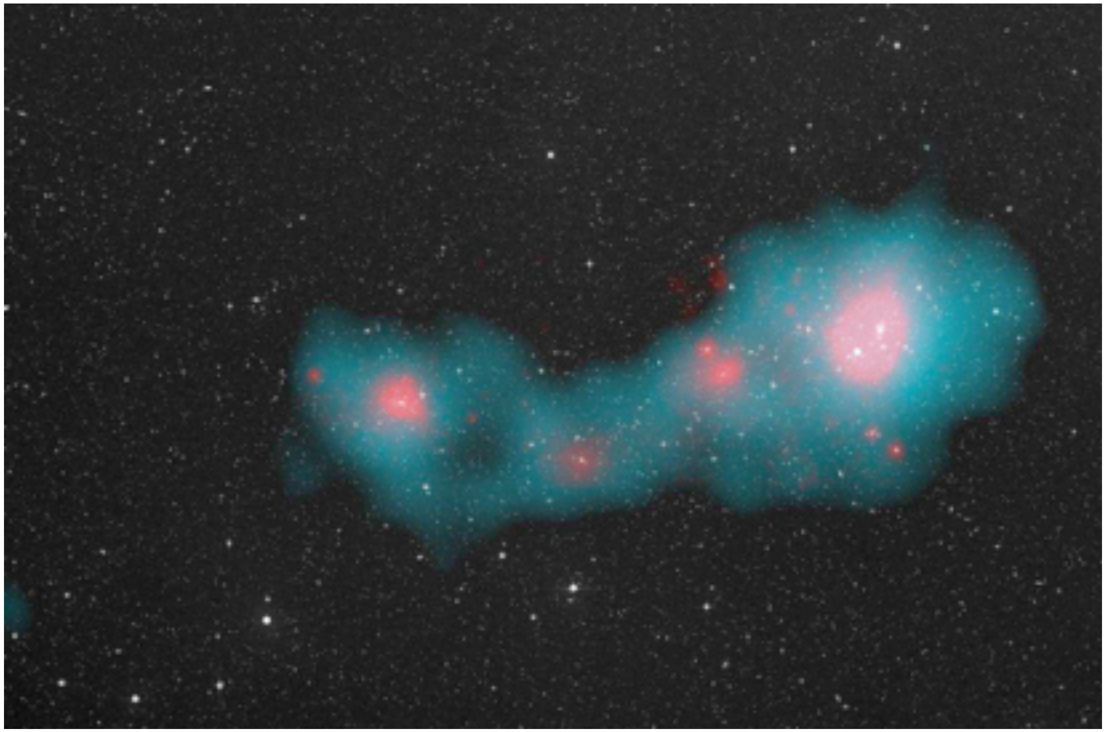


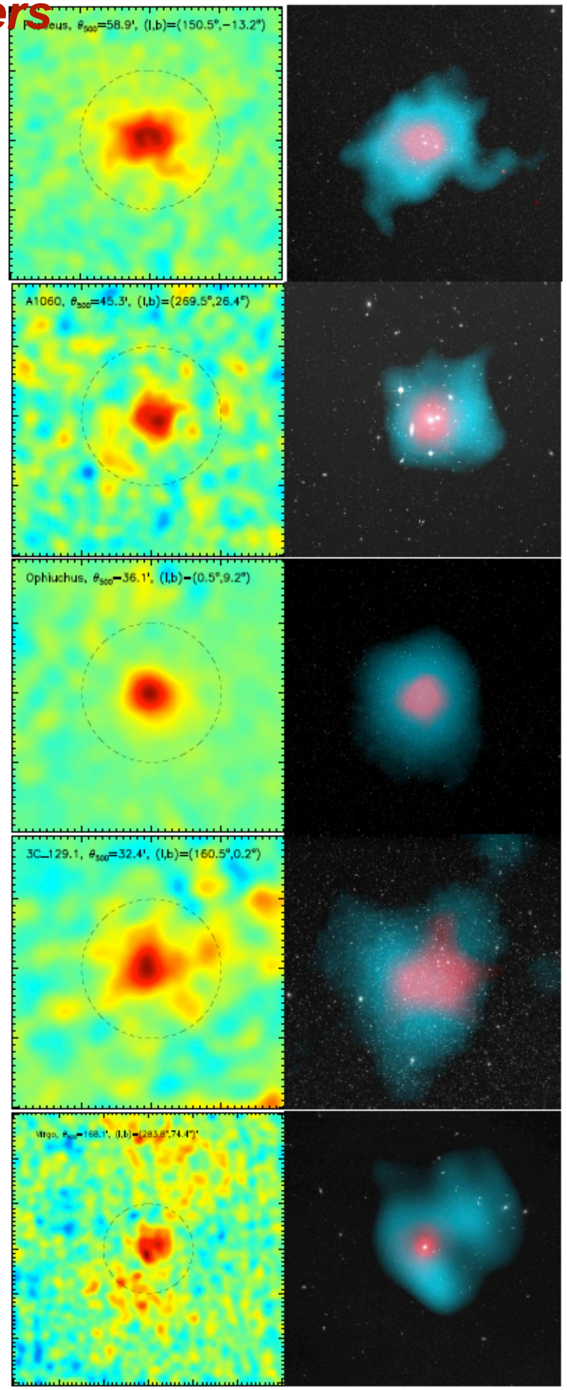


thermal SZ clusters

some nearby well-known clusters
from
Perseus to VIrgo

Shapley Supercluster

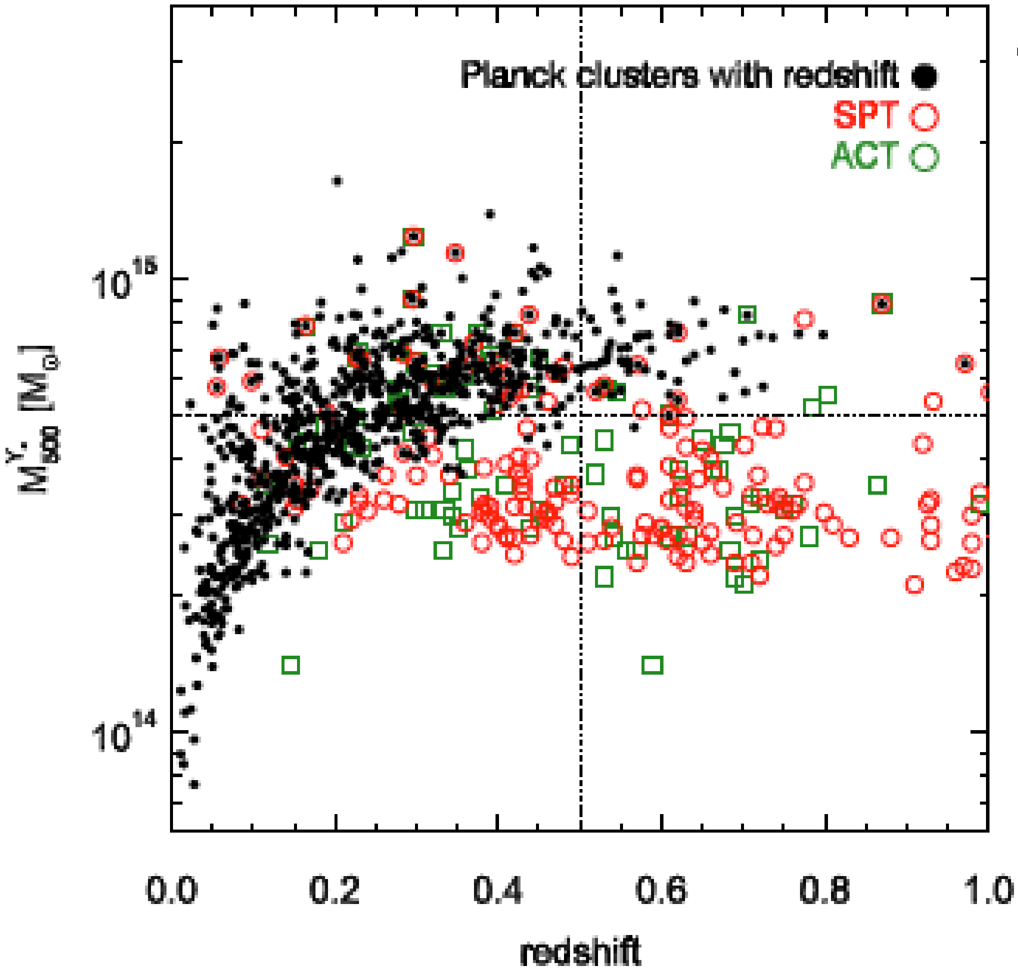


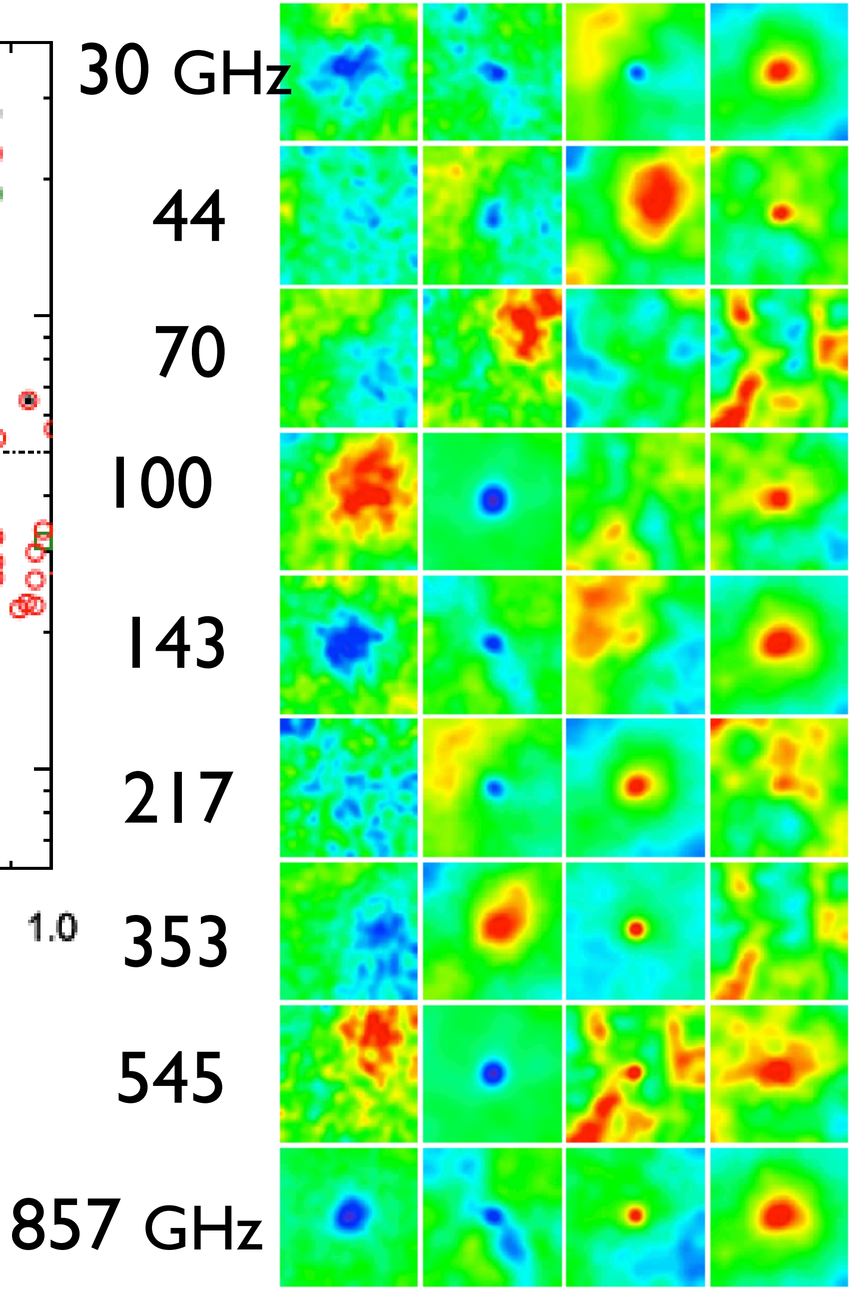


Planck picks massive cls

thermal SZ clusters

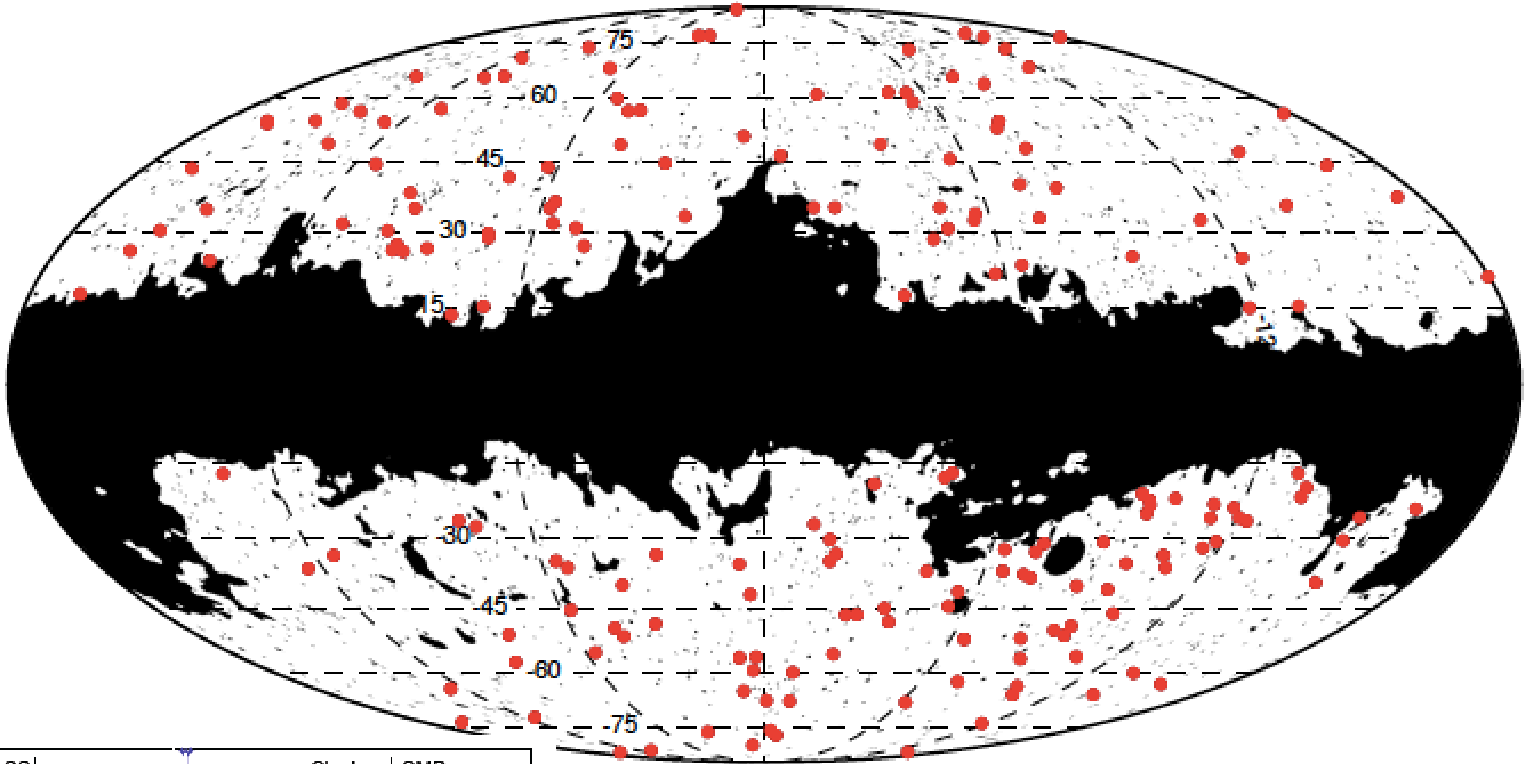
stacked: known-cls C1 C2 C3

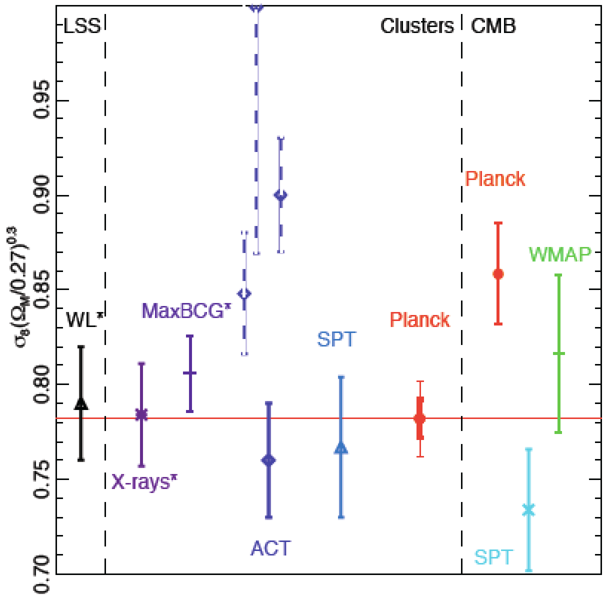




thermal SZ clusters

PSZ: 189 cls for cosmology constraints. sig8 = .77 +-.03, OmM=.29+-.02 cf. primary sig8=.826+-.012





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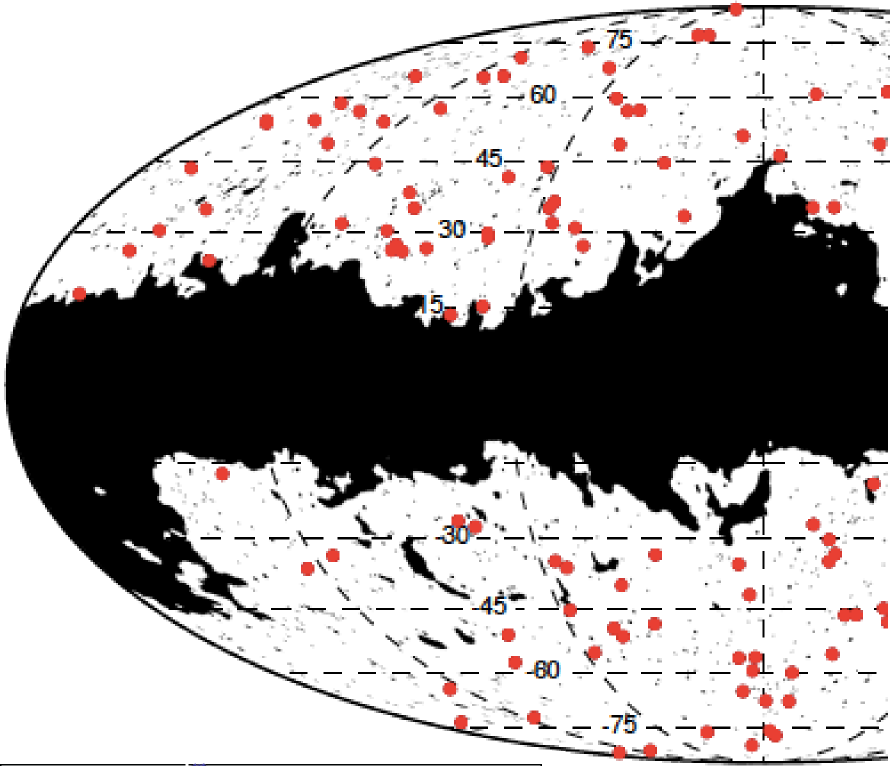
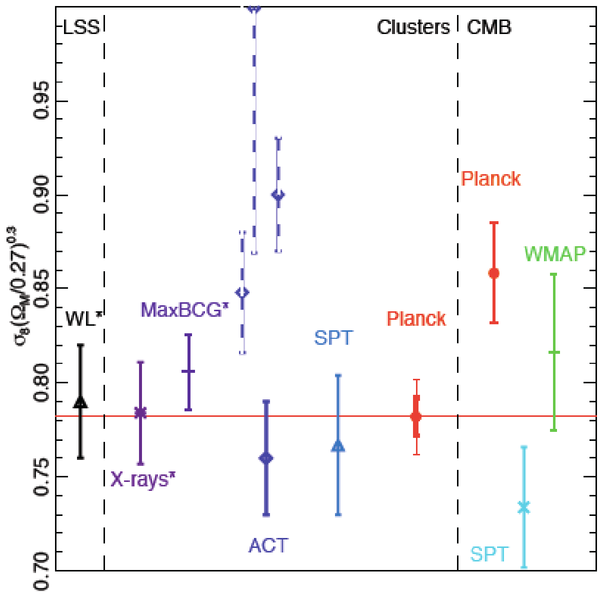




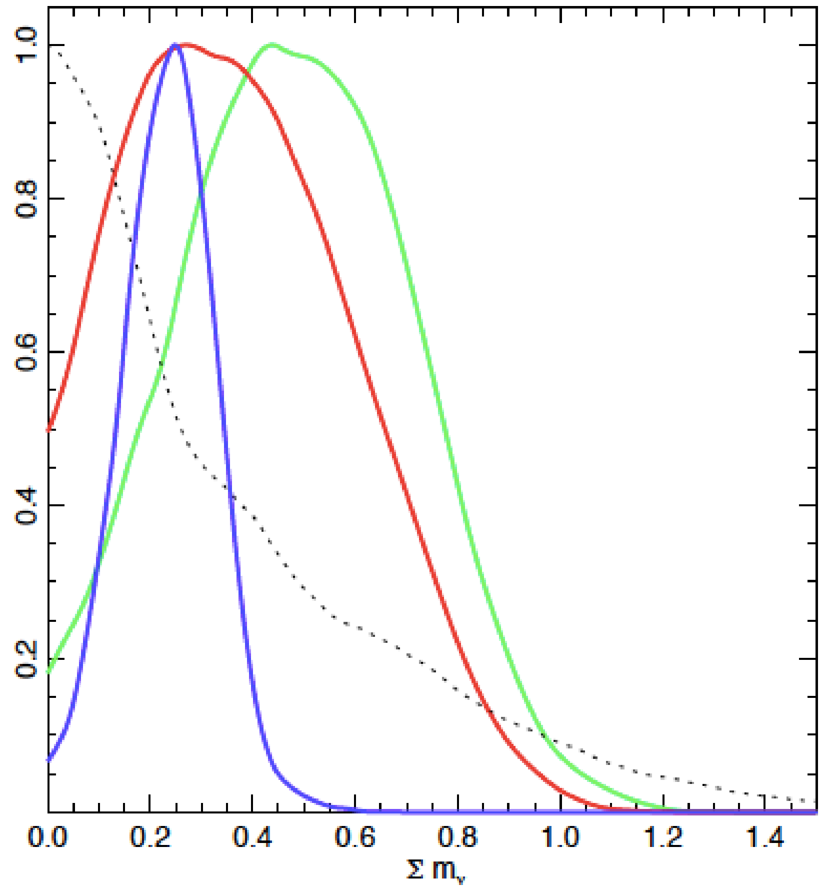
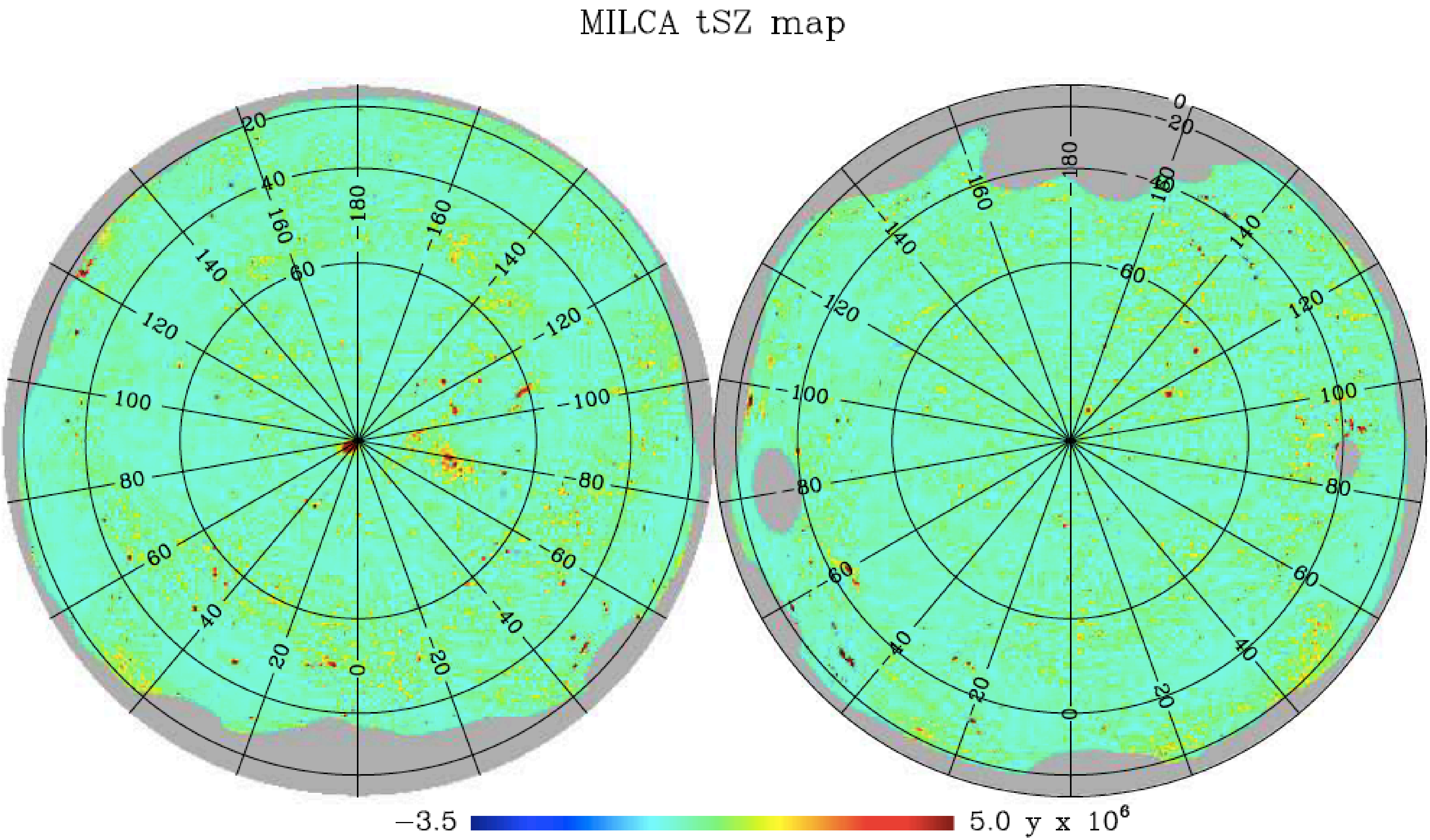


Fig. 12. Cosmological constraints when including neutrino masses $\sum m_\nu$ from: *Planck* CMB data alone (black dotted line); *Planck* CMB + SZ with $1-b$ in [0.7, 1] (red); *Planck* CMB + SZ + BAO with $1-b$ in [0.7, 1] (blue); and *Planck* CMB + SZ with $1-b = 0.8$ (green).

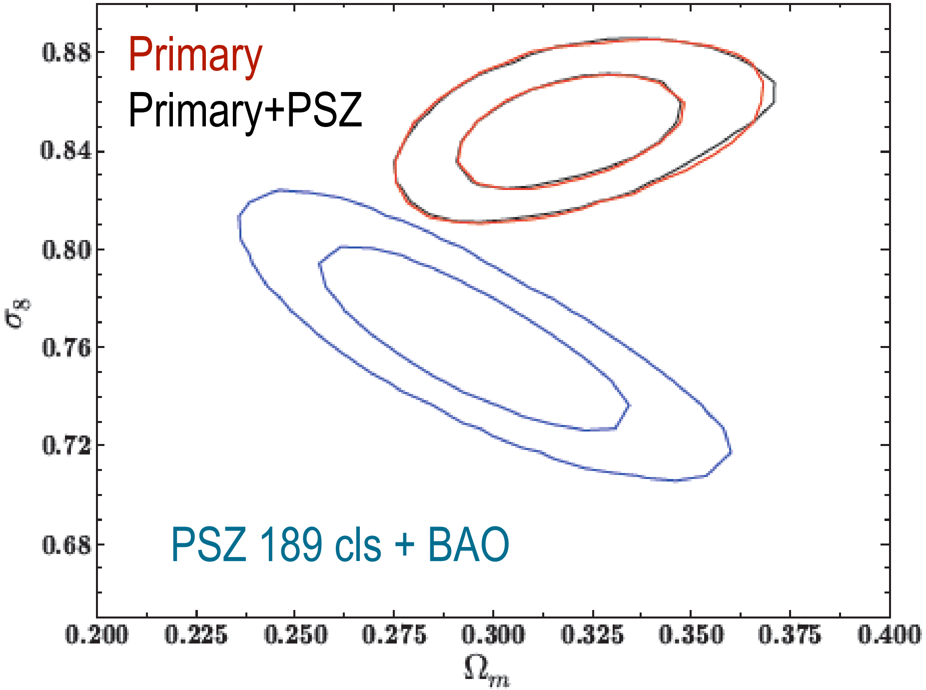
SZ power spectrum from ymaps

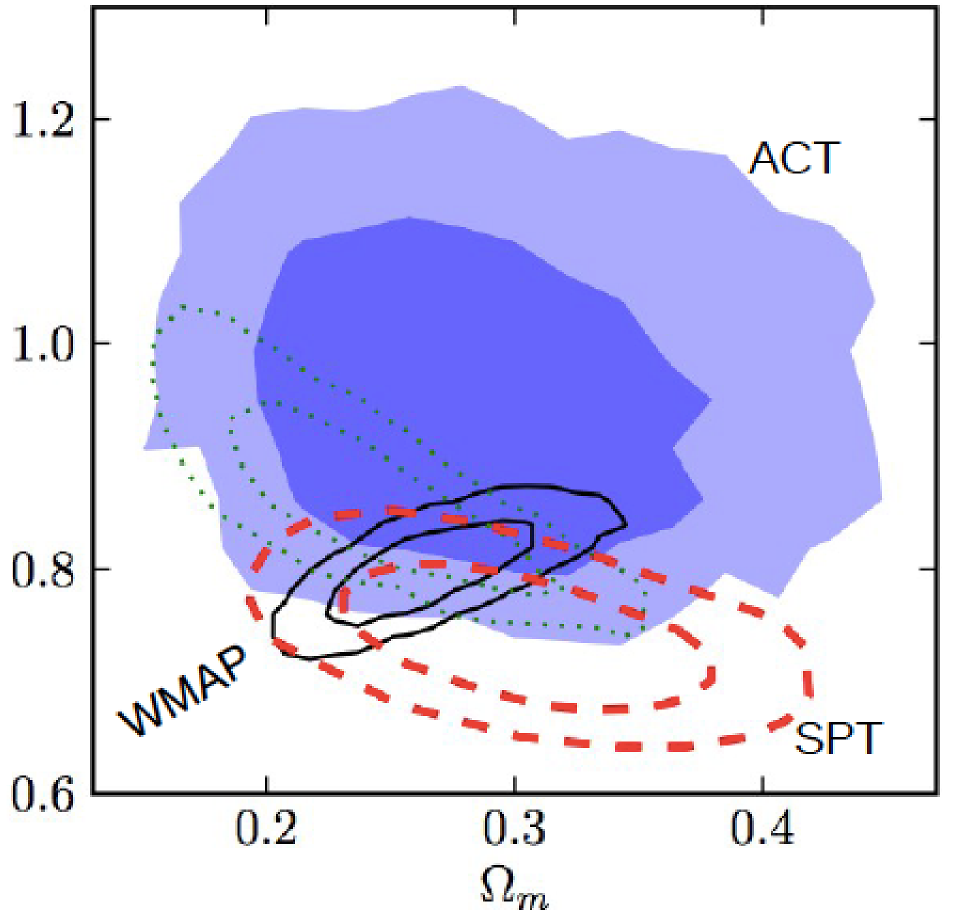
thermal SZ clusters



thermal SZ clusters

SPT Reichardt+12 different approach cf. ACT Hasselfield+12
X-ray mass proxy cf. dynamical mass proxy (lower bound for σ8, Ωm)
multi-scale S/N likelihood cf. Profile Based Amplitude Analysis single filter 5.9' not matched θ_{500} corrected
ACT and SPT at most mild tension (ACT SZ scaling priors - very broad, would that we knew them better)

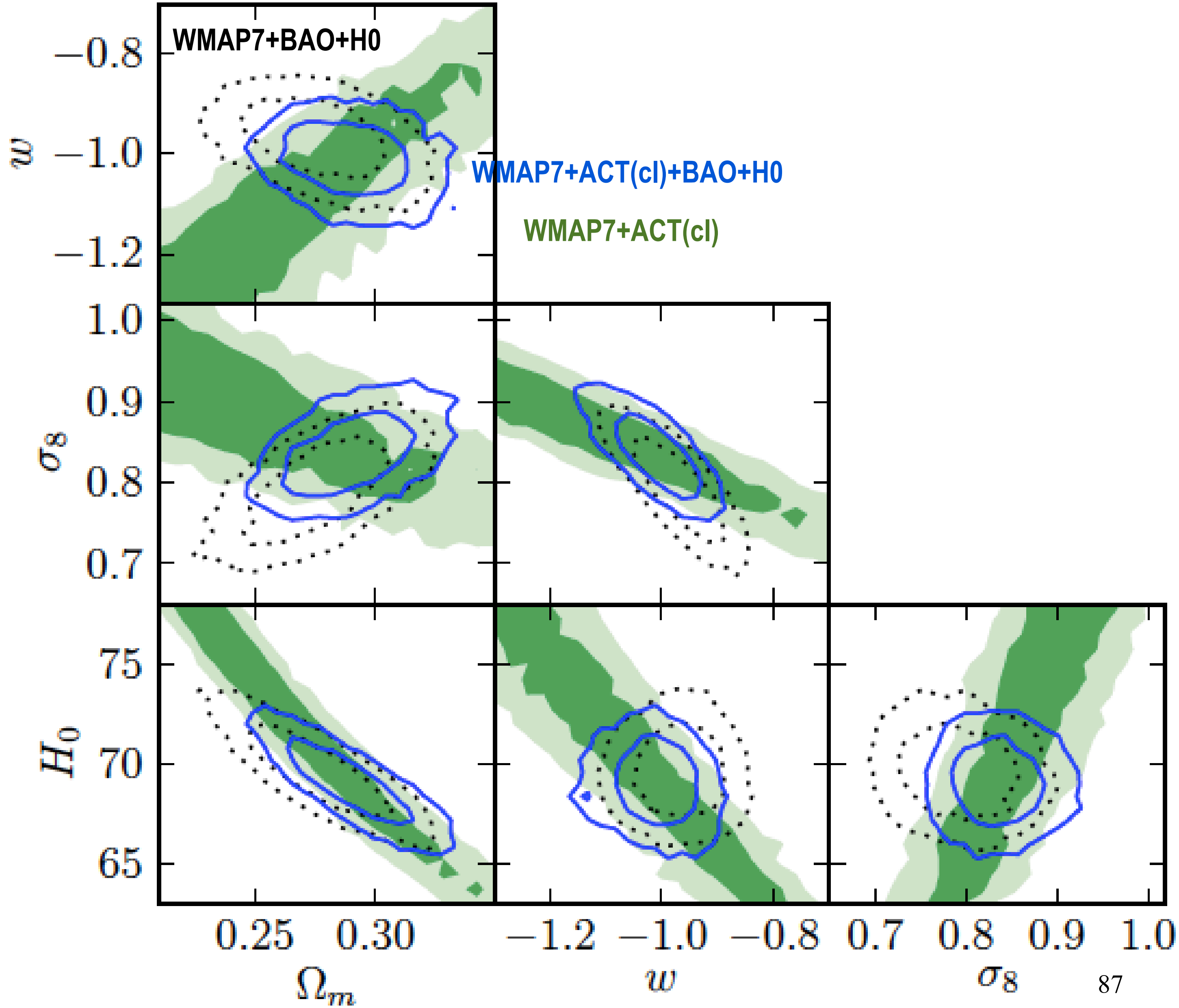




86

ACT Hasselfield+12

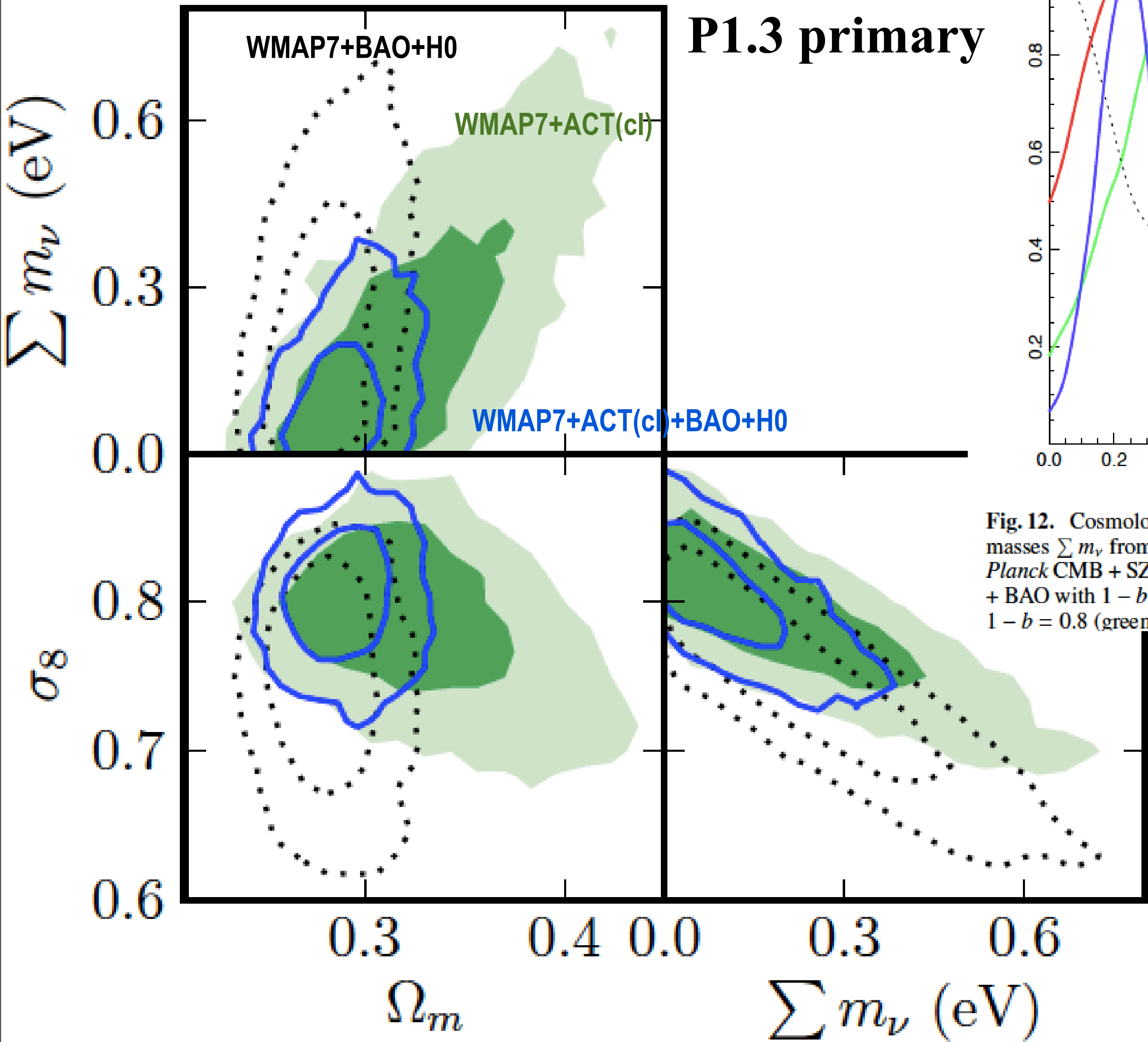
thermal SZ clusters

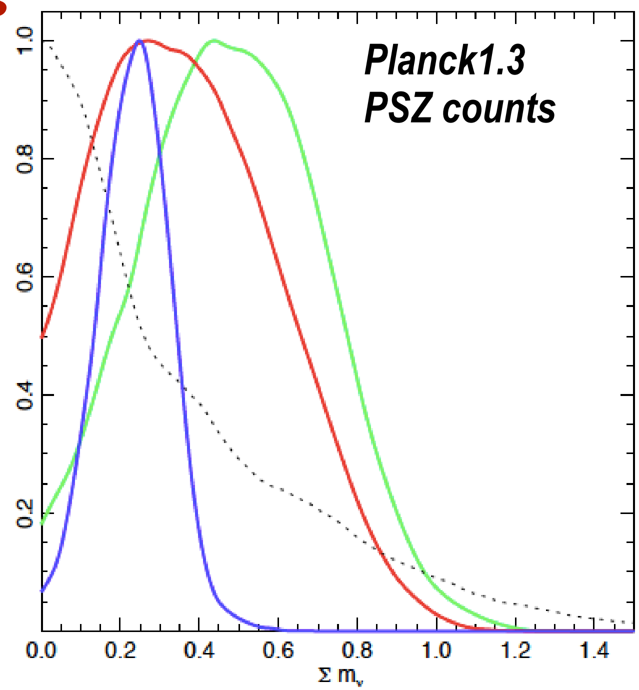


ACT Hasselfield+12

thermal SZ clusters

$\Sigma m_\nu < 0.230$ ev
P1.3 primary





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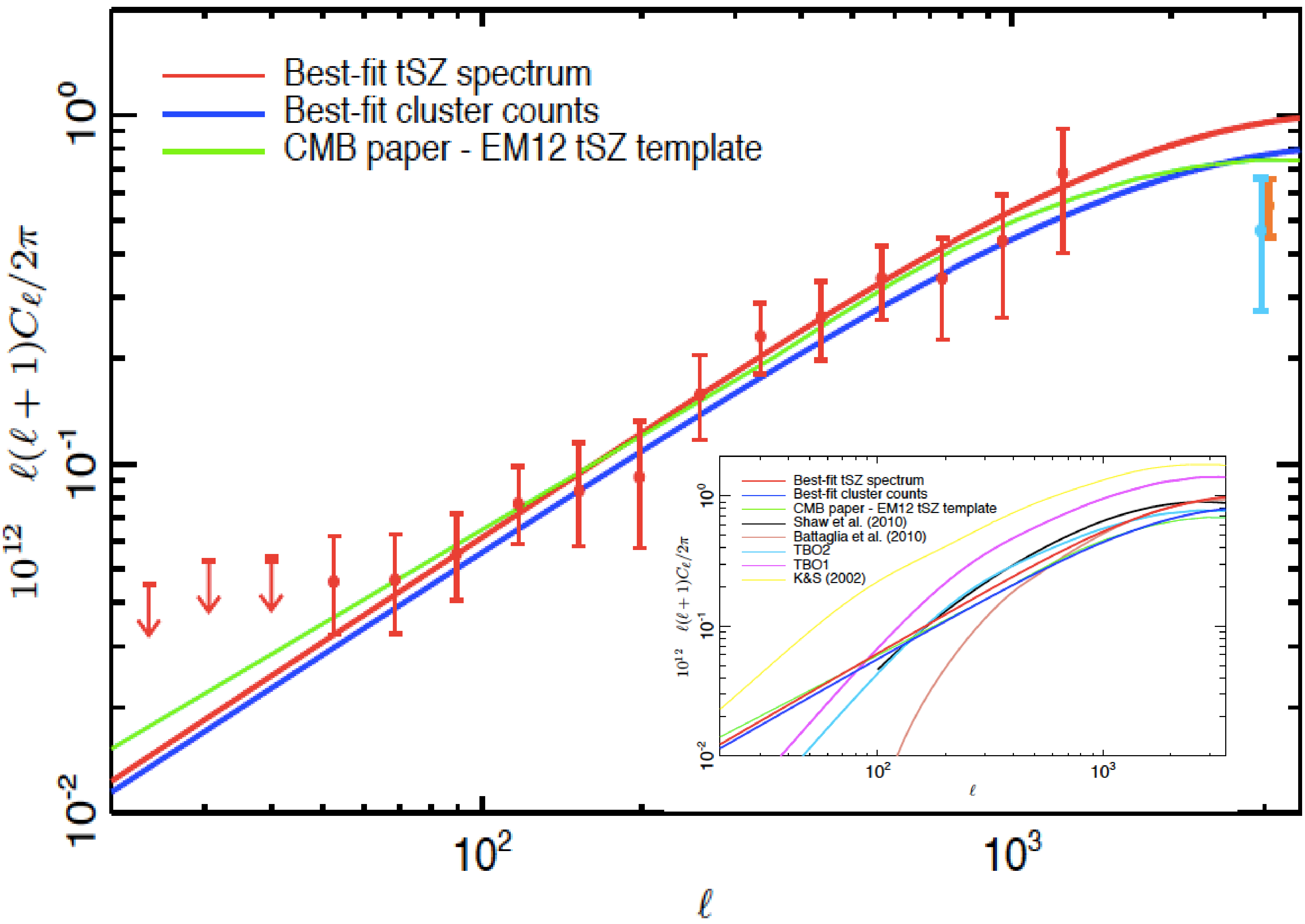
ACT Hasselfield+12

SZ power spectrum from ymaps

thermal SZ clusters



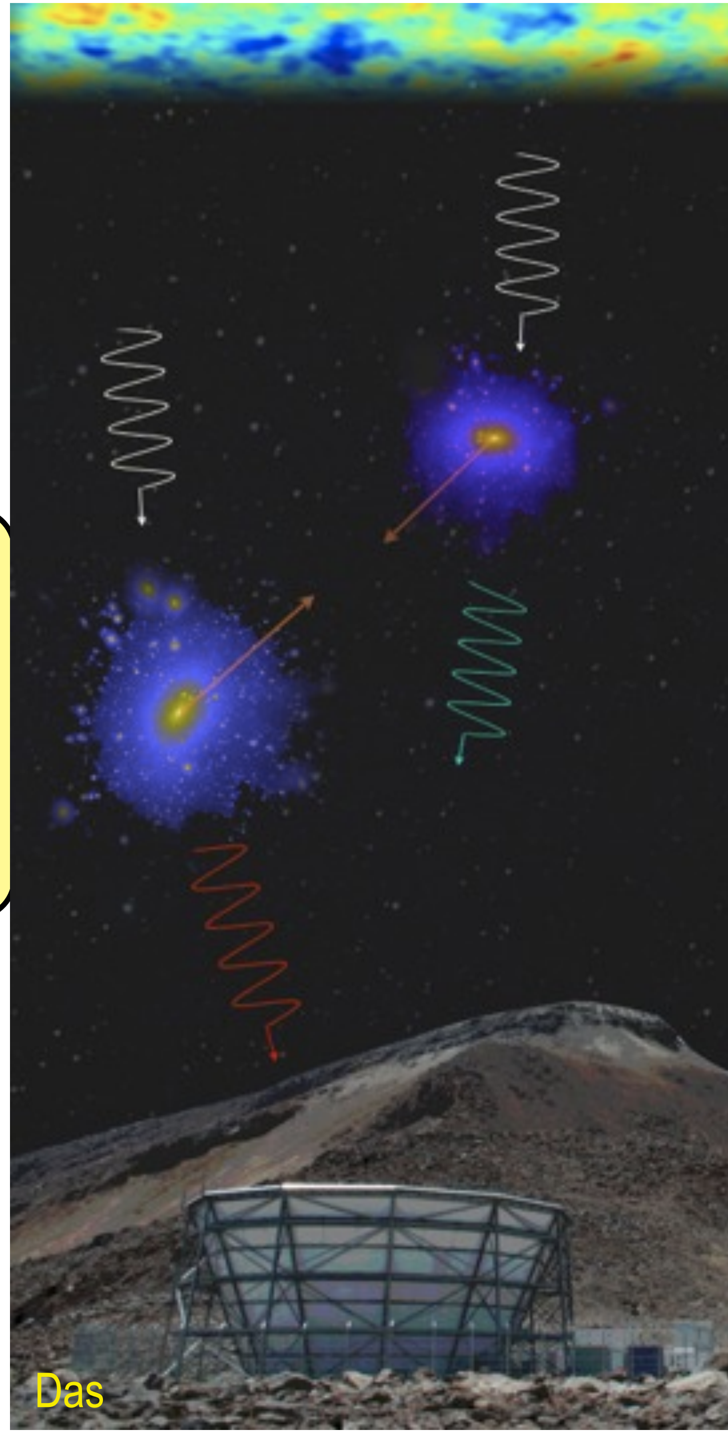
kinetic SZ:

$$\Delta T/T = \int n_e \, \mathbf{v}_{e||} / c \, \sigma_T \, d\mathit{los}$$

$$\sim \int J_e \, . \, dr$$

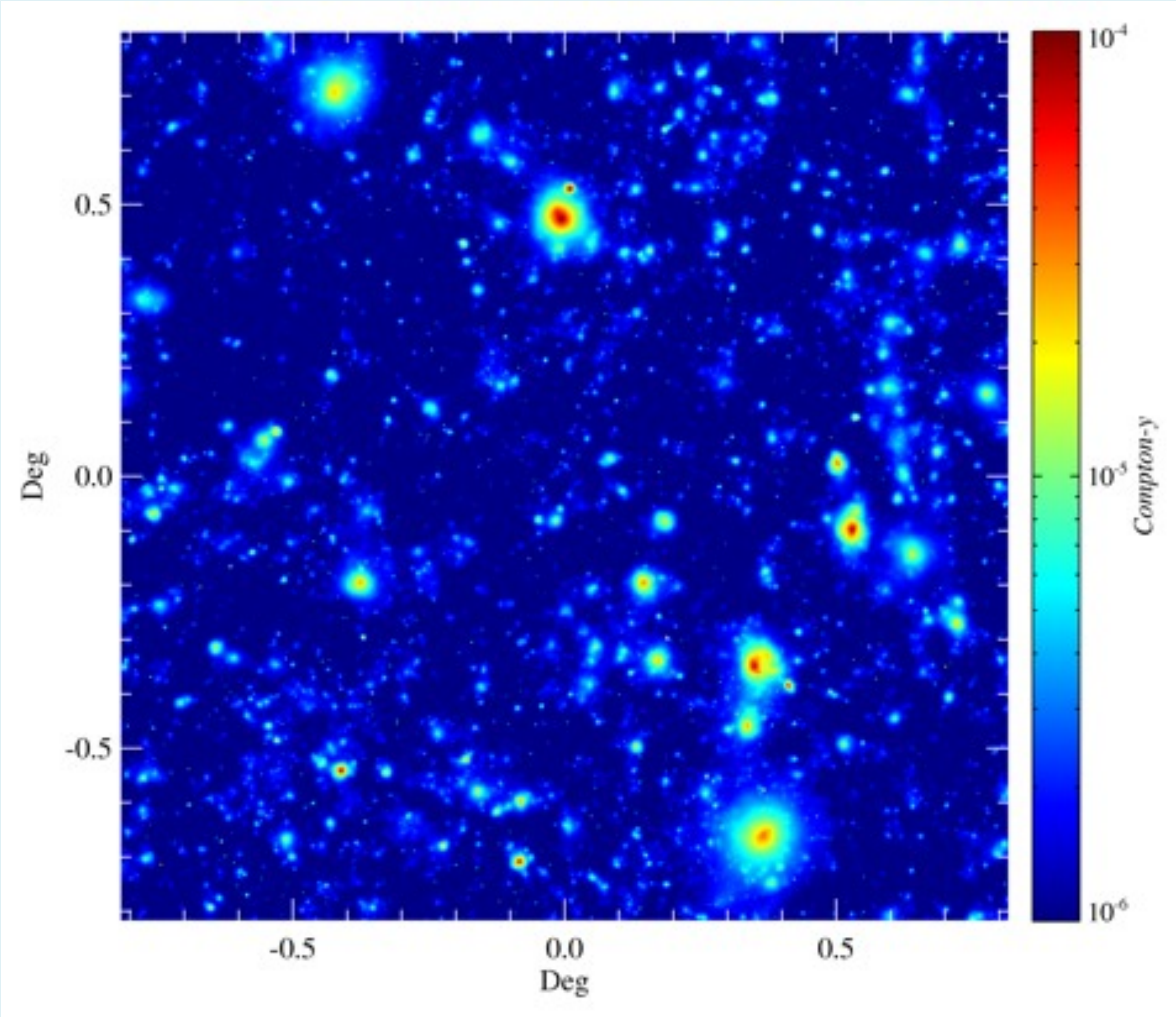
spectrally degenerate with primary anisotropies

$$\int \mathbf{kSZ}(\theta,\varphi)\mathbf{d\Omega} \sim \mathbf{M_{gas} V_{bulk}} / D_A{}^2$$



Compton-y map: Feedback

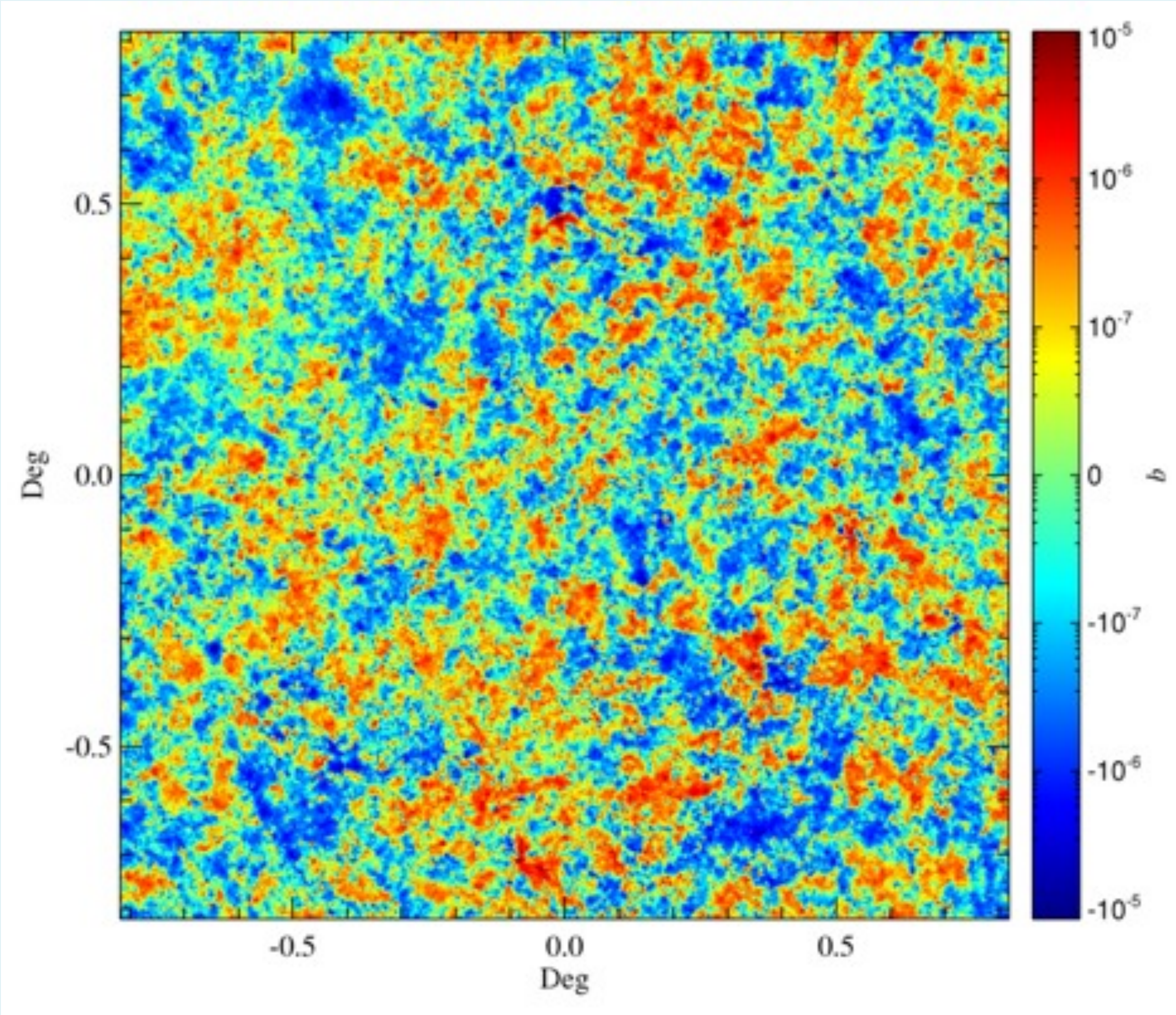
= AGN or Starburst E-feedback + radiative cool + SN energy + wind + (CR)



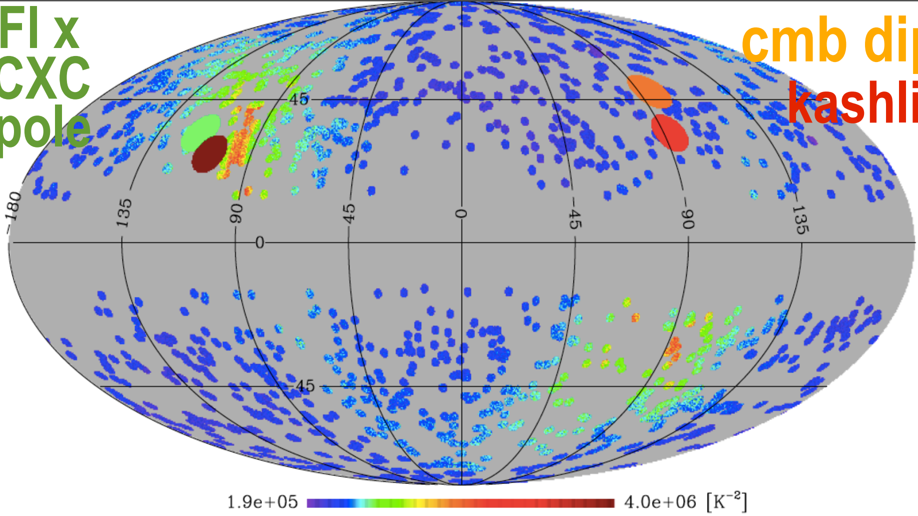
BBPS1,2,3,4,5

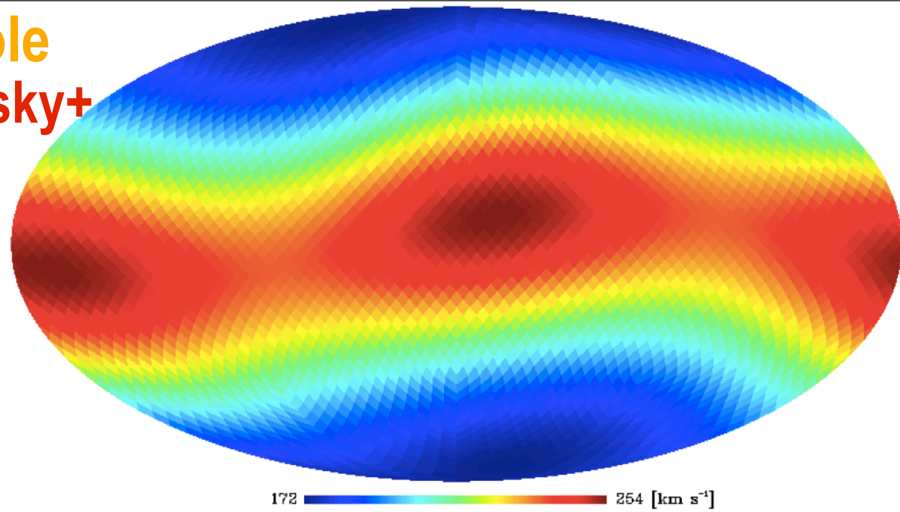
kinetic SZ map *(log)*: Feedback

= AGN or Starburst E-feedback + radiative cool + SN energy + wind + (CR)



BBPS1,2,3,4,5





kinetic SZ:

$$\Delta T/T = \int n_e \, \mathbf{v}_{e||} /c \, \sigma_T \, dlos$$

$$\sim \int J_{e,||} \, dr$$

spectrally degenerate with primary anisotropies

$$\int kSZ(\theta,\varphi) d\Omega \sim M_{gas} V_{bulk} / D_A^2$$

ACT x BOSS direct detection of the kSZ effect:

Hand+ 2012 arXiv/1203.4219 **<ΔT ng >** using 7,500 brightest of 27291 luminous BOSS galaxies 220 sq deg overlap with ACT equatorial strip 3x110 sq deg 2008-10 data. <z>~0.5.

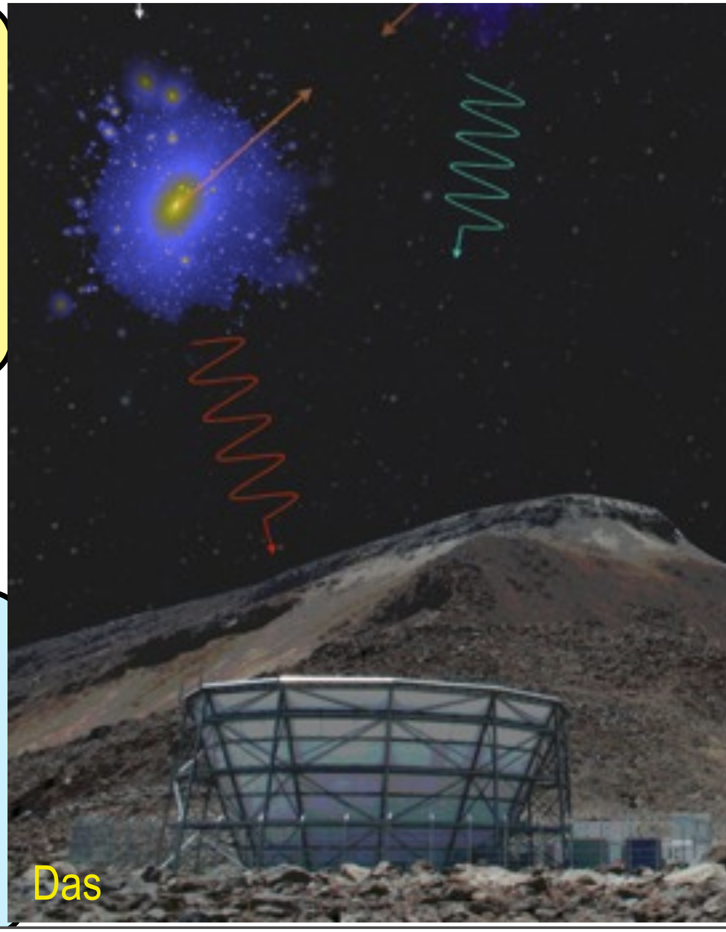
Planck13 X MCXC 1750 X-rays cls

Meta Catalogue of X-ray detected Clusters made for Planck

<z>~0.18, <v_radial> = 72 +- 60 km/s monopole

blind search < 254 km/s 95% CL

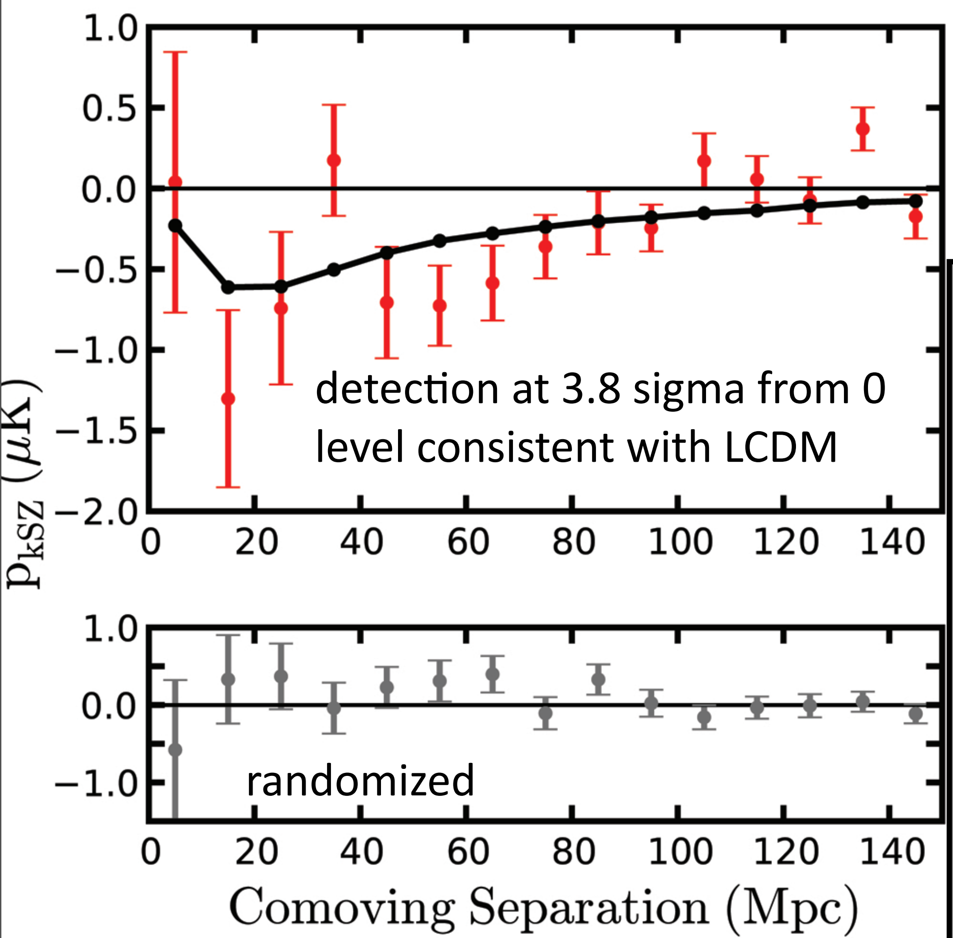
no super-bulk flow *aka the* ***Dark Flow*** *~1000 km/s*



kinetic SZ map *(log)*: Feedback

= AGN or Starburst E-feedback + radiative cool + SN energy + wind + (CR)

pair-wise velocities (momenta) statistic from **ACT x Opt-Cls/Gps** ~BOSS bright galaxies



$$\tilde{p}_{\rm pair}(r) = \frac{\sum_{i<j}(\mathbf{p}_i \cdot \hat{\mathbf{r}}_i - \mathbf{p}_j \cdot \hat{\mathbf{r}}_j)c_{ij}}{\sum_{i<j} c_{ij}^2}$$

$$c_{ij} \equiv \hat{\mathbf{r}}_{ij} \cdot \frac{\hat{\mathbf{r}}_i + \hat{\mathbf{r}}_j}{2} = \frac{(r_i - r_j)(1+\cos\theta)}{2\sqrt{r_i^2 + r_j^2 - 2r_i r_j \cos\theta}},$$

bulk velocity from **WMAP7 x Xray-Cls**

Kashlinsky, Atrio-Barandela, Kocevski & Ebeling08 reported a *3σ detection of v ~600 km/s to z=0.3* towards along *(l,b)*= (267°, 34°). *the Dark Flow*

Kashlinsky, Atrio-Barandela & Ebeling12 PhysRep

Keisler 09, Osborne+ 10, Zhang & Stebbins 11, & Mody & Hajian 12 (using Planck & Rosat cls) - *no significant detection of kSZ signal*

Planck1.3 x Clusters: ~ order of mag sensitivity gain, no detection

PUPPY and our hydro sims agree: *slower falloff than Arnaud+ X-ray UPP; although there are mass and redshift bin variations, universality is pretty good; variance in pressure profiles is wide*

pressure clumping is not small, *important for SZ- a consequence of merging history*

Universal Entropy Profile? *not as good as PUPPY. obs cf. theory needs work*

rare clusters are still consistent with std LCDM*; some highly non-eq, bullet el Gordo ++*

σ_8^{SZ} vs σ_8 mild tension from P1.3, ACT&SPT CL, P1.3 SPT ncl; ACT ncl ok **broad scaling priors**

Σm_ν ~0.3 ev a possibility

Use physical observables rather than funneling through halo Mass

i.e., not $\mathbf{n_{cluster}}(M_{halo}|z)$ but

$\mathbf{n_{cluster}}(Y_{SZ}, M_{lens}, Y_X, L_X, T_X, L_{cl,opt}, Rich, \ldots |z,$ gold-sample, thresholds$)$

$+ \mathbf{C_L^{SZ}}(cuts) + \xi_{cc}(r|n_{cl}) + f_{gas}$

these all deliver valuable cosmic gastrophysics.

Can they deliver fundamental physics: dark energy EOS?? σ_8 even? primordial non-Gaussianity???

theory/obs dispersion/systematics assessment is critical => mock sims for robust measures

beyond the standard model?
***tilted* LCDM+x, x=?**

Curved space, Ω_k
Dynamical dark energy, w
Non standard abundance of primordial Helium fraction, Y_P
Neutrino properties, i.e. how many (N_{eff}) and how massive (Σm_ν)
Curvature of the power spectrum of primordial fluctuations (running $dn_s/d\ln k$)
primordial gravitational waves, $r_{0.002}$
anomalies exist: large scale statistical anisotropy & non-Gaussianity

no compelling evidence either for
an "isocurvature" part in the primordial fluctuations or broken scale invariance
cosmic strings ($G\mu/c^2<1.3\ 10^{-7}$)
nonG signatures of inflation at medium to high res ($f^{local}=2.7\pm5.8$, $f^{equil}=-42\pm75$, $f^{ortho}=-25\pm39$ 68%CL)
Evolution of the fine structure constant, dark matter annihilation, primordial magnetic fields…

	Planck+WP		*Planck*+WP+BAO		*Planck*+WP+highL		*Planck*+WP+highL+BAO	
Parameter	Best fit	95% limits	Best fit	95% limits	Best fit	95% limits	Best fit	95% limits
Ω_K	−0.0105	$-0.037^{+0.043}_{-0.049}$	0.0000	$0.0000^{+0.0066}_{-0.0067}$	−0.0111	$-0.042^{+0.043}_{-0.048}$	0.0009	$-0.0005^{+0.0065}_{-0.0066}$
Σm_ν [eV]	0.022	< 0.933	0.002	< 0.247	0.023	< 0.663	0.000	< 0.230
$N_{\rm eff}$	3.08	$3.51^{+0.80}_{-0.74}$	3.08	$3.40^{+0.59}_{-0.57}$	3.23	$3.36^{+0.68}_{-0.64}$	3.22	$3.30^{+0.54}_{-0.51}$
Y_P	0.2583	$0.283^{+0.045}_{-0.048}$	0.2736	$0.283^{+0.043}_{-0.045}$	0.2612	$0.266^{+0.040}_{-0.042}$	0.2615	$0.267^{+0.038}_{-0.040}$
$dn_s/d\ln k$	−0.0090	$-0.013^{+0.018}_{-0.018}$	−0.0102	$-0.013^{+0.018}_{-0.018}$	−0.0106	$-0.015^{+0.017}_{-0.017}$	−0.0103	$-0.014^{+0.016}_{-0.017}$
$r_{0.002}$	0.000	< 0.120	0.000	< 0.122	0.000	< 0.108	0.000	< 0.111
w	−1.20	$-1.49^{+0.65}_{-0.57}$	−1.076	$-1.13^{+0.24}_{-0.25}$	−1.20	$-1.51^{+0.62}_{-0.53}$	−1.109	$-1.13^{+0.23}_{-0.25}$

parameters sensitive to the damping tail $N_{\nu,eff}$ =*3.30±0.27*, X_{He} =*0.267±0.020*

Σm_ν <0.230 ev primary cf. cl-PSZ

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.

Bond since 1993, Canada since 2001, 1st CSA pre-launch contract 2002-09, post-launch 2010-11, 2011-15