esa

planck

cnes

asi agenzia spaziale italiana

NASA

CNRS

DTU Space
National Space Institute

INAF Istituto Nazionale di Astrofisica

Science & Technology Facilities Council

CSIC
Consejo Superior de Investigaciones Científicas

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

CIFAR CANADIAN INSTITUTE FOR ADVANCED RESEARCH

CITA ICAT

Dick Bond @ POTUS14

Mapping the Early Universe with **Planck**

Planck collaboration results 2013, TBD 2014 1,…,~30, 2015, 1, … N

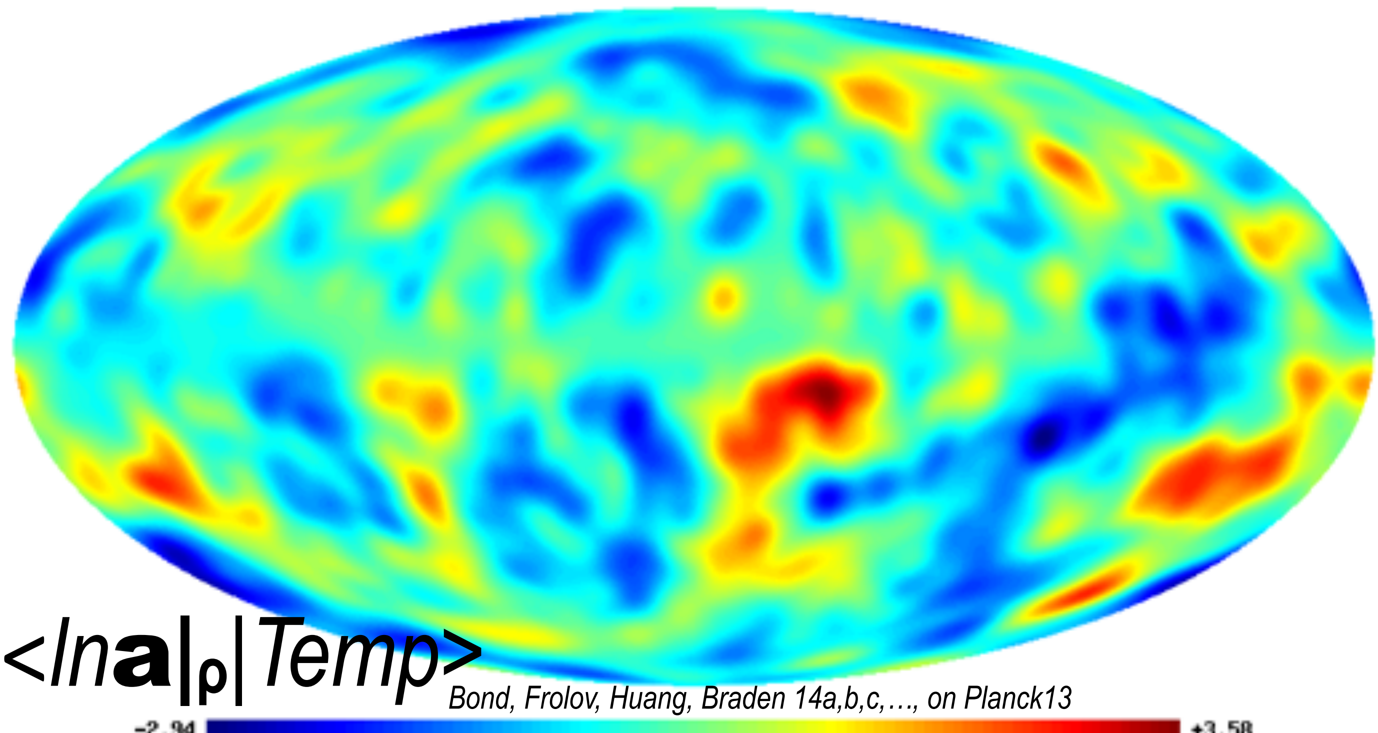
*a **Map** is an **ensemble = mean-map + fluctuation-maps**, e.g.,*

***linear:** $\langle T\rangle$(pixel)+C^{TT}(pix, pix')$^{1/2}$ GRD$_{pix'}$, **quadratic:** $\langle C^{TT}_L\rangle + \langle \Delta C^{TT}_L \Delta C^{TT}_{L'}\rangle^{1/2}$ GRD$_{L'}$;*

Planck 2013 delivered 9 frequency T maps, component separated CMB T maps using SMICA, n FFP6 simulations (*ensemble*), data split maps, Likelihood, 30 papers+30PIPs

Maps = *(radical)* **compressions** *of the* ***time ordered information ToI***,

pixel (maxL +), bandpowers (asymmetric, correlated errors), Likelihood -> parameters (marginalized)



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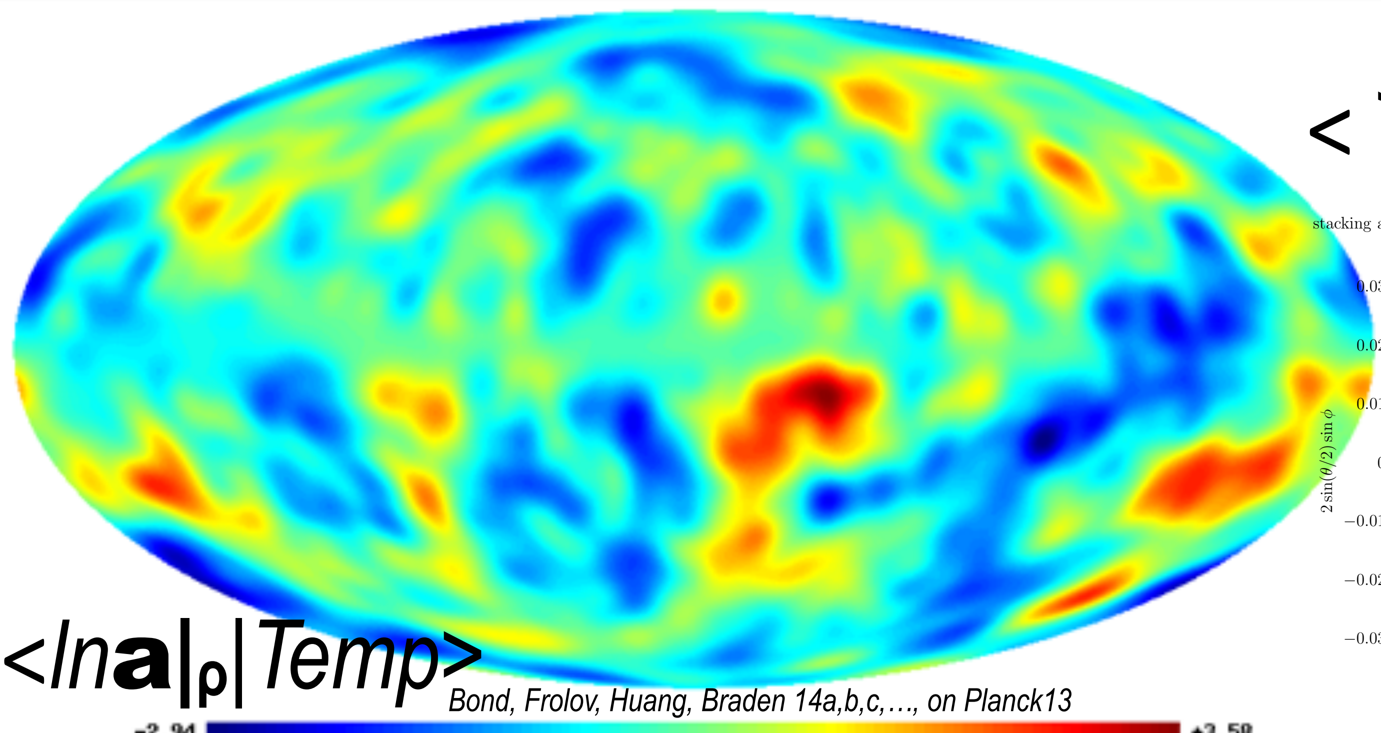

stacked
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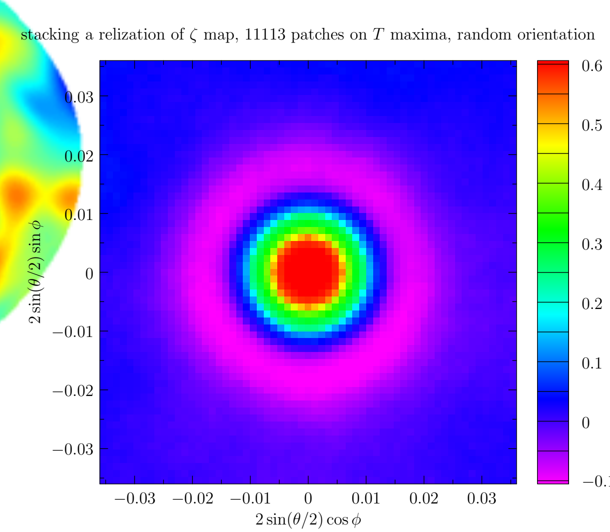

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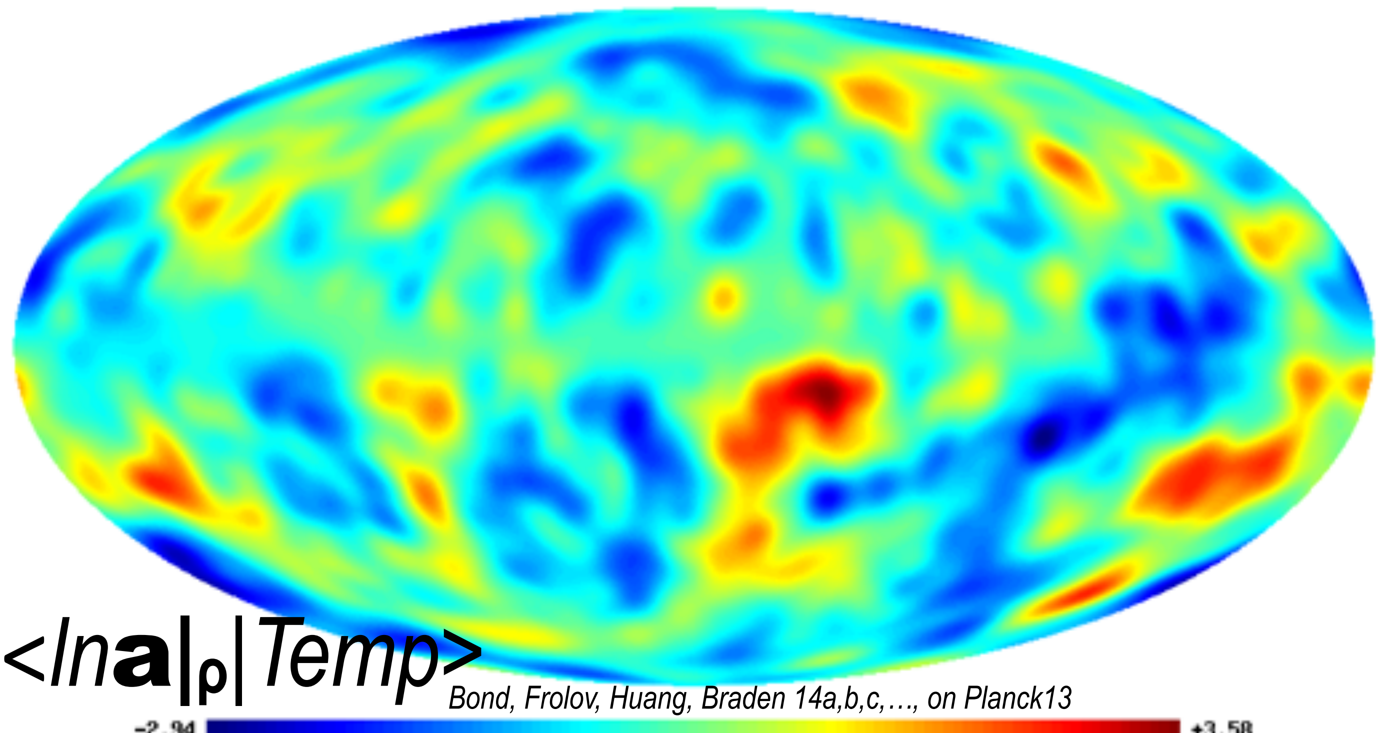

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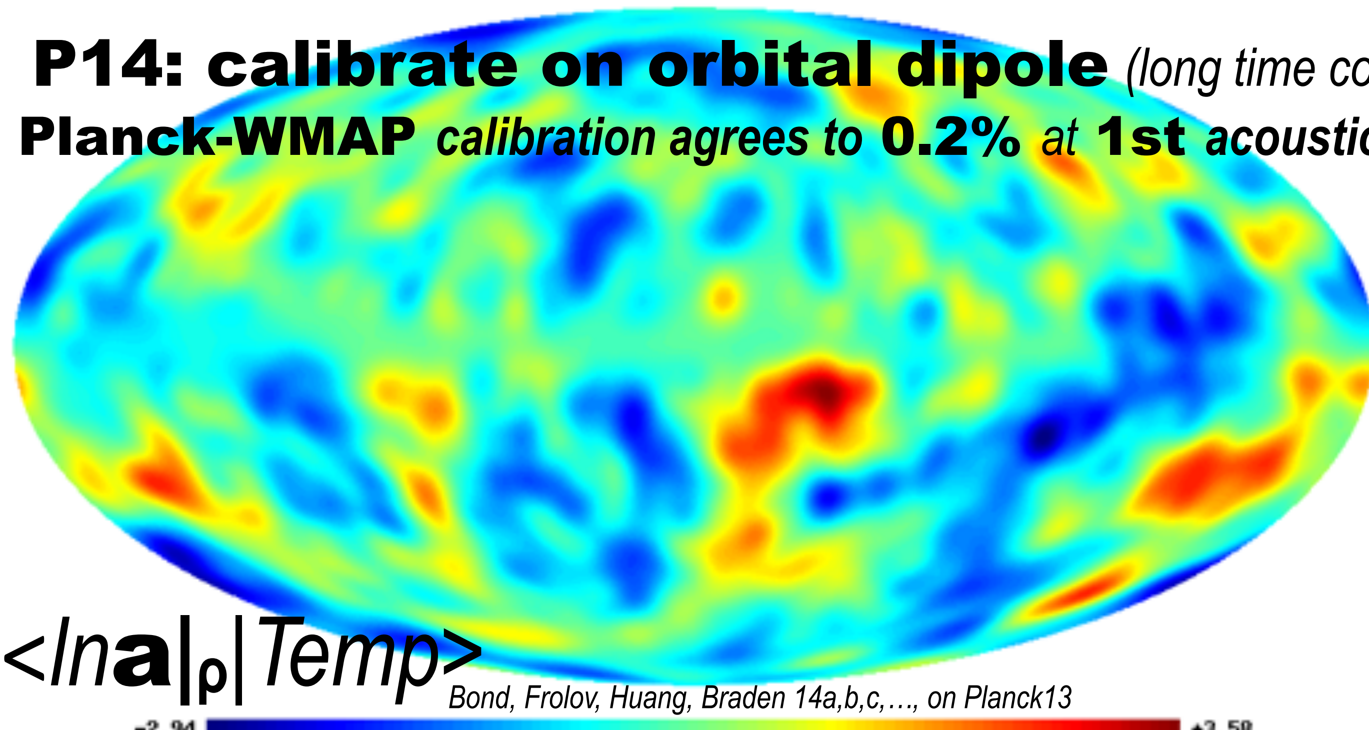
P14: calibrate on orbital dipole *(long time constants, ADC nonlinearity)*

Planck-WMAP *calibration agrees to* **0.2%** *at* **1st** *acoustic* **peak** *cf.* **2.4% P13**



$\langle ln\mathbf{a}|_{\rho}|Temp\rangle$

Bond, Frolov, Huang, Braden 14a,b,c,…, on Planck13

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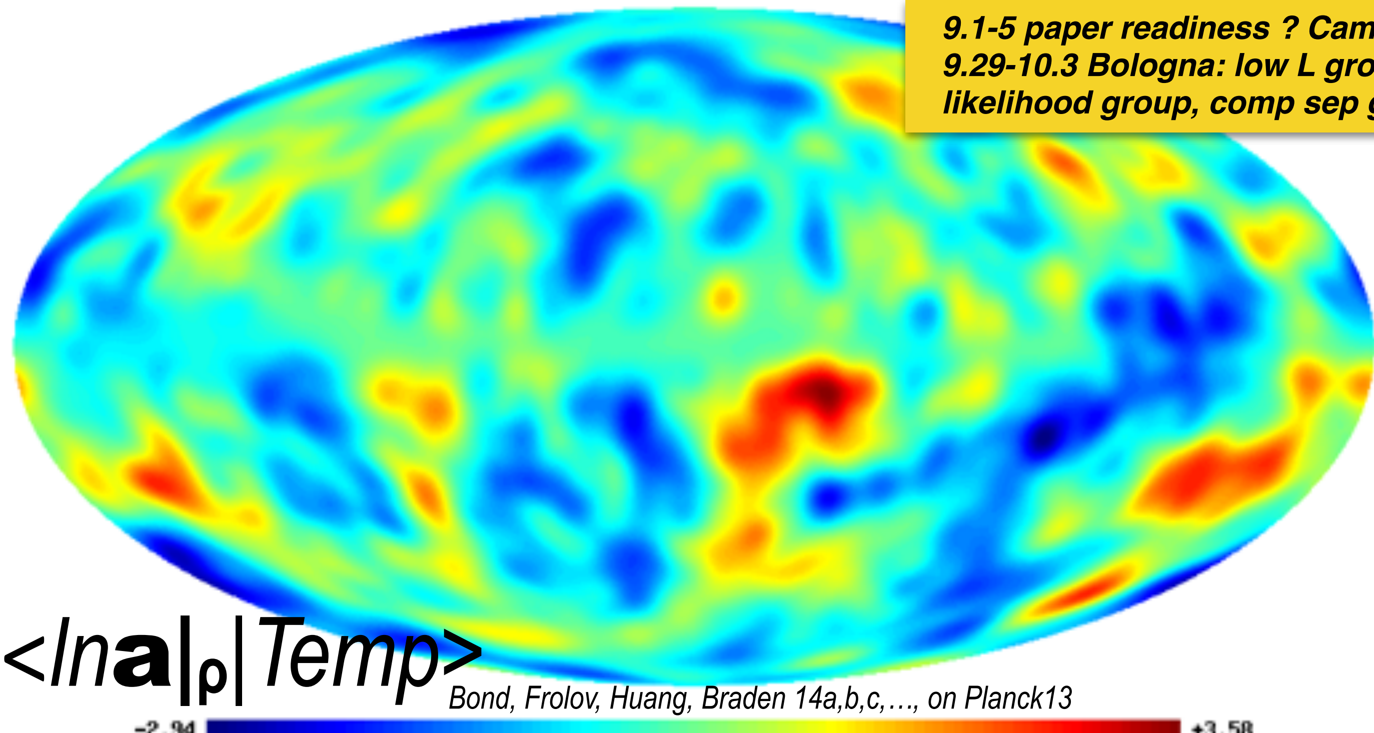
9.29-10.3 Bologna: low L group, inflation group (4 papers)
likelihood group, comp sep group, FFP8 sims group blasting



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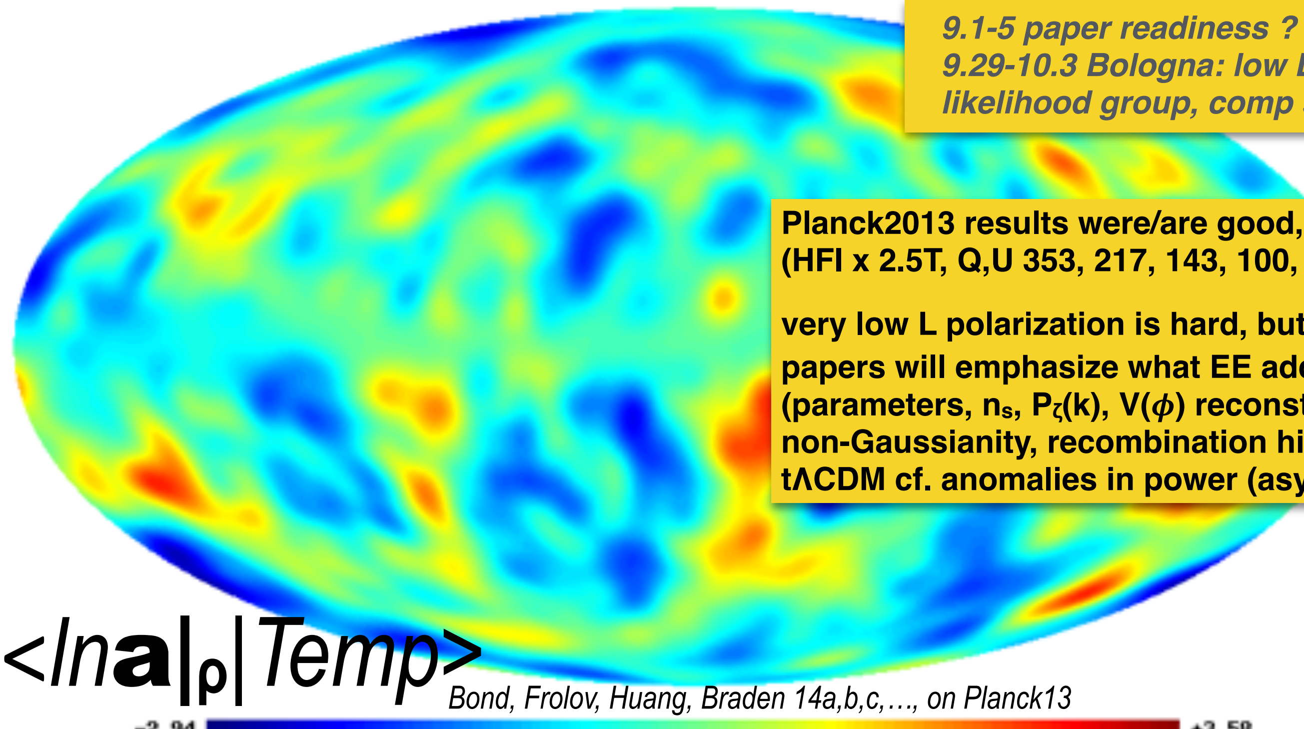
Planck2013 results were/are good, now more data
(HFI x 2.5T, Q,U 353, 217, 143, 100, LFI x4 T, all Q, U)

very low L polarization is hard, but expect Planck2014 τ_C z_{reion}
papers will emphasize what EE adds to the stories
(parameters, n_s, $P_\zeta(k)$, $V(\phi)$ reconstructions, r, isocurvature constraints, non-Gaussianity, recombination history, .. robustness TT TE EE results, …)
tΛCDM cf. anomalies in power (asymmetry), in entities (cold spot, …)



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PIP97: Planck intermediate results XXX arXiv submission 14.09.19, 5th in Galactic dust polarization series

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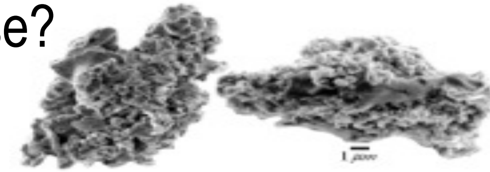
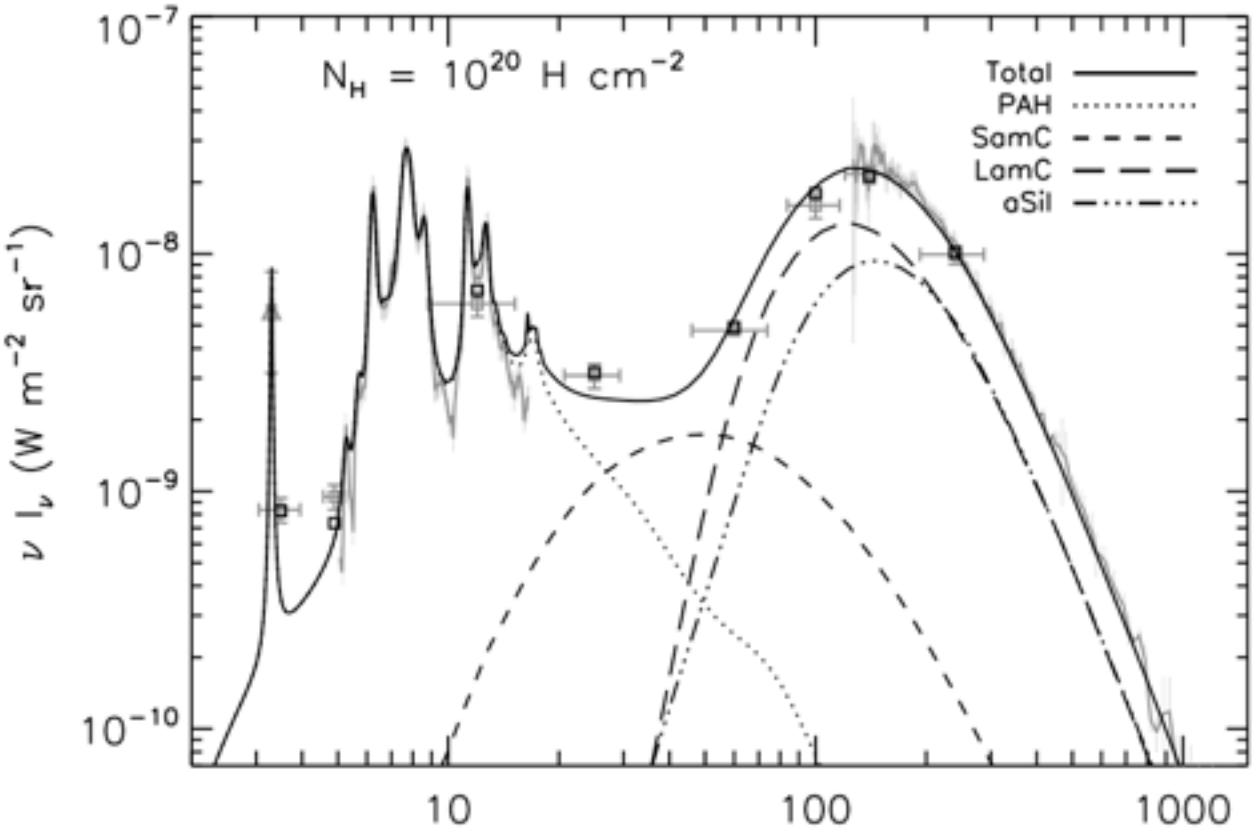
gastrophysics gastrointestinal disorder? or gourmand's paradise?

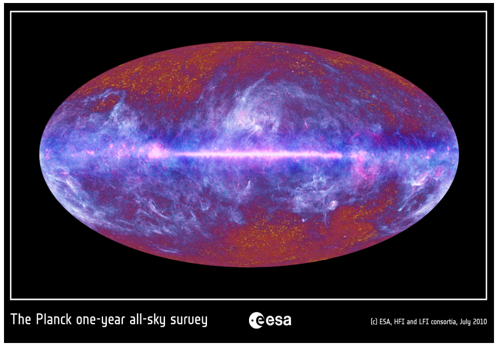
entropy of the U: CMB ~ CνB > CIB (nuclear waste heat) **> shocks**



interplanetary dust



Campiegne+10, DustEM code



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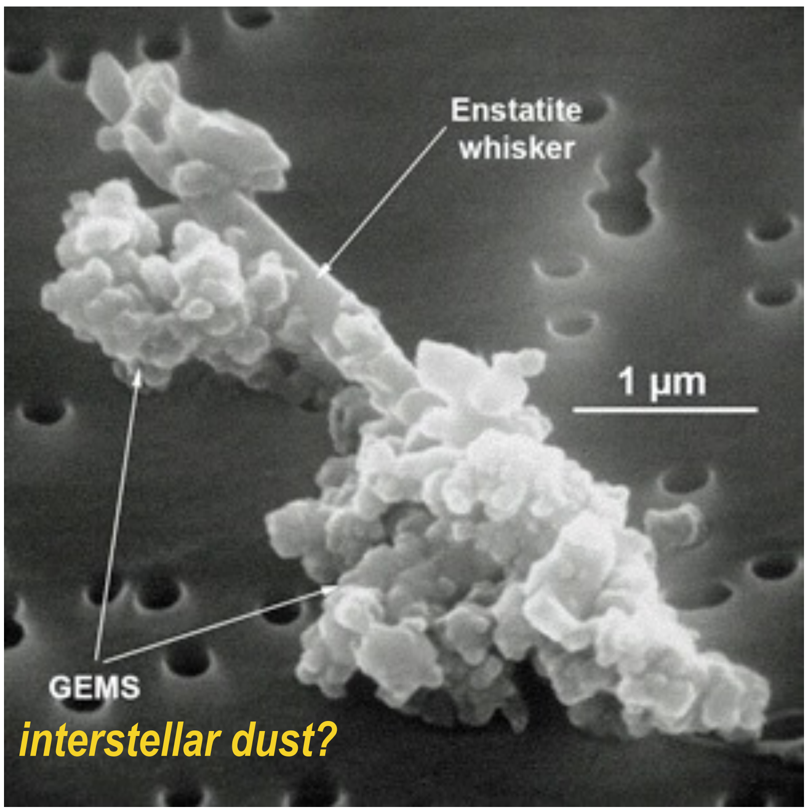
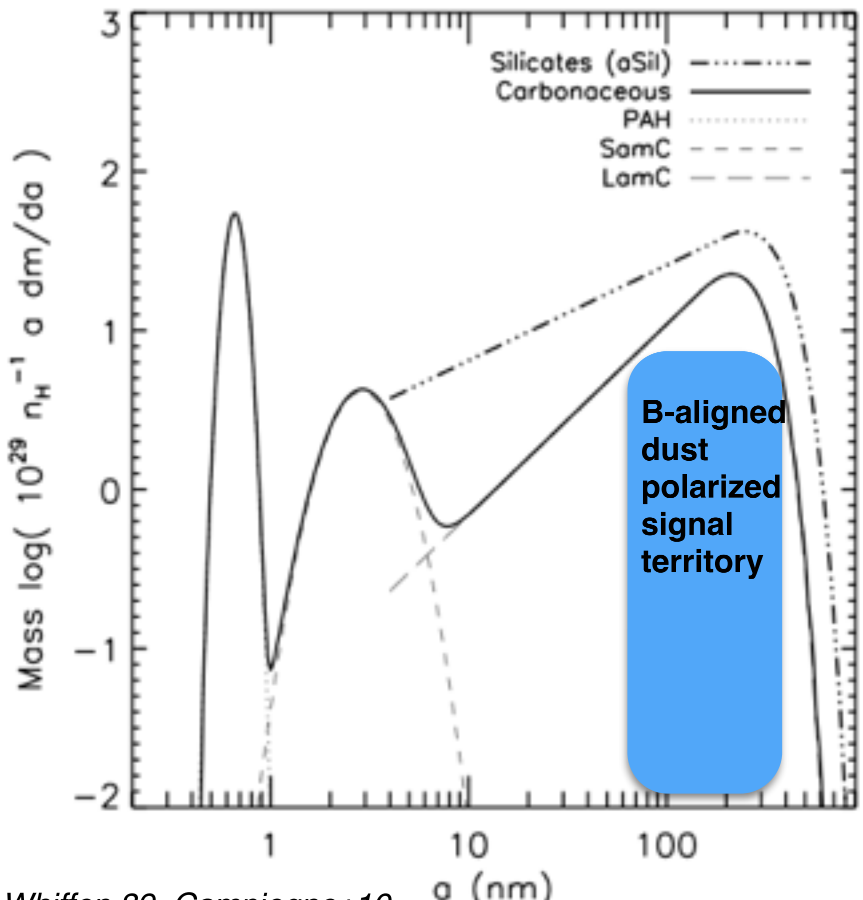


interstellar dust



Draine+Lee 84, Mathis+Whiffen 89, Campiegne+10

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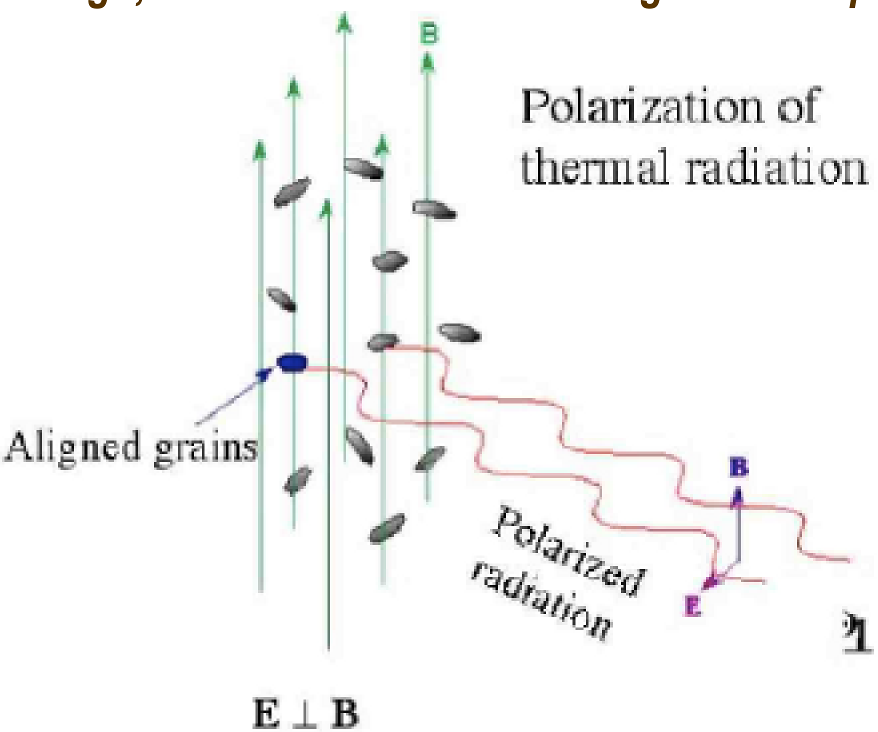
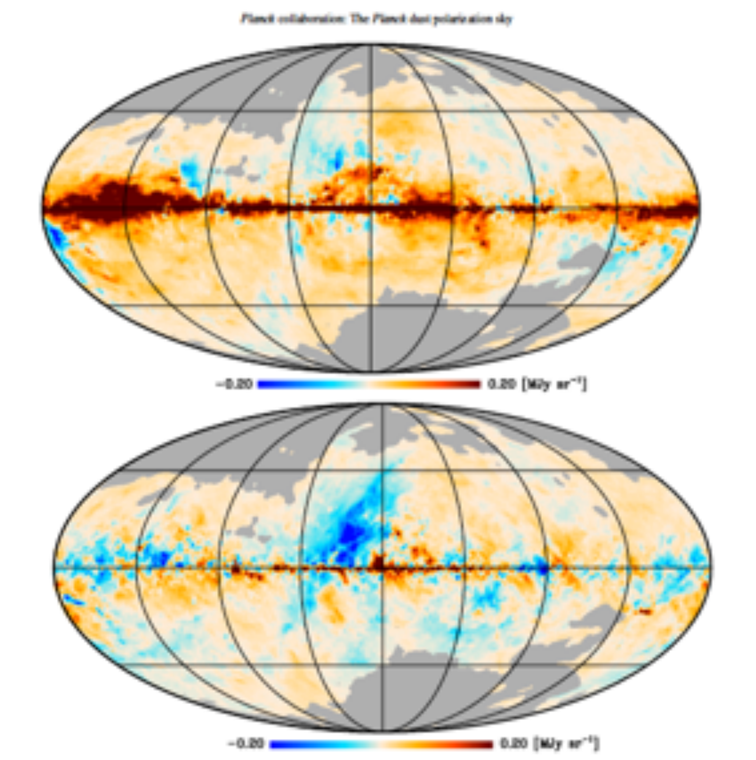


Lazarian+07 pic, benton 14 Blastpol/Spider thesis



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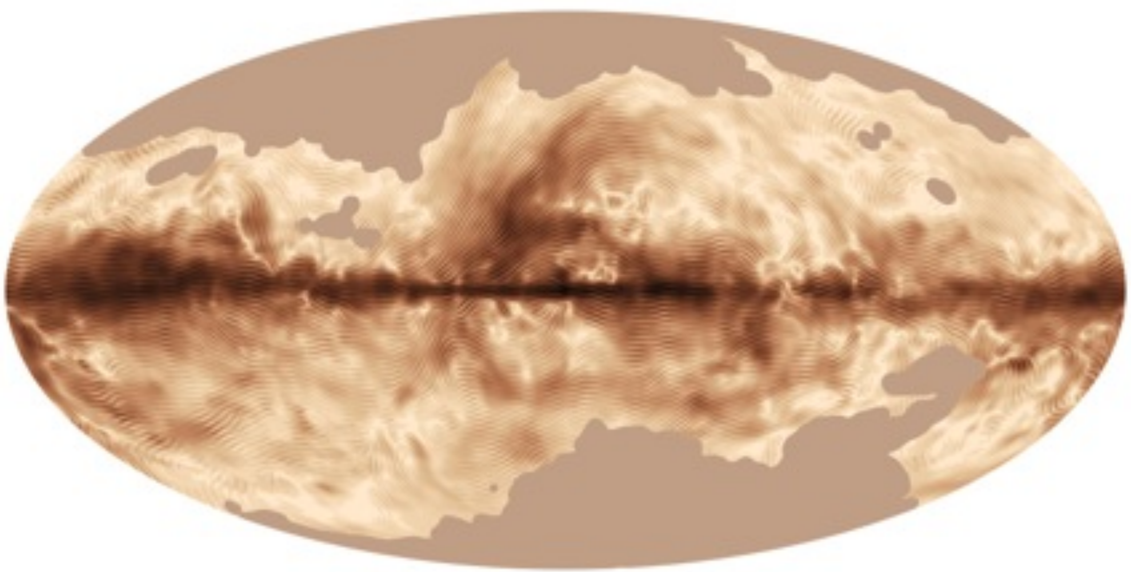
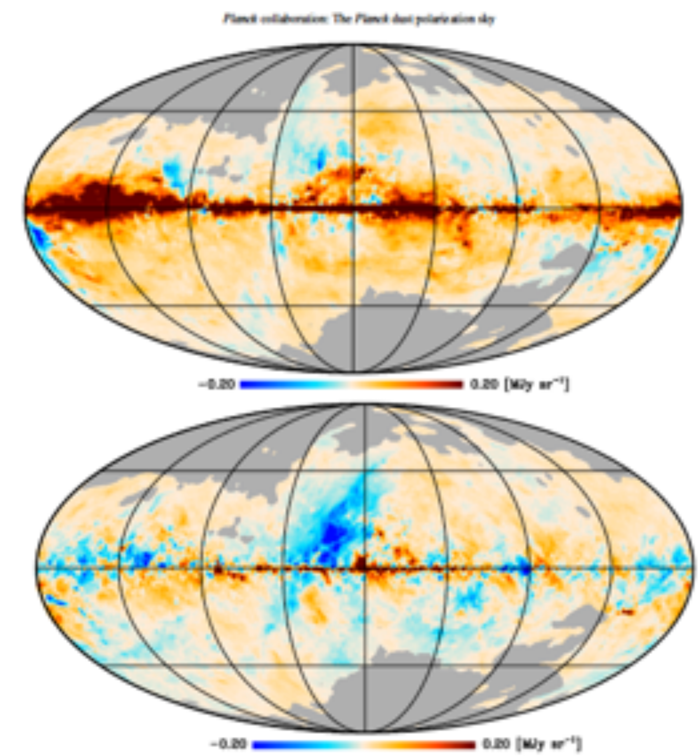


=> magnetic fingerprint map Planck May14, rotated pol by 90 degrees



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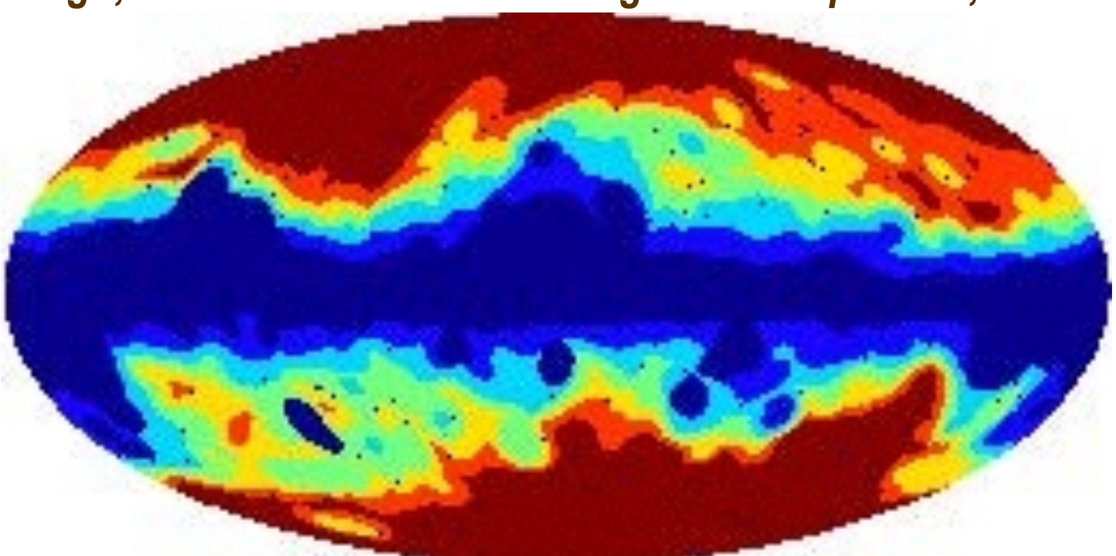

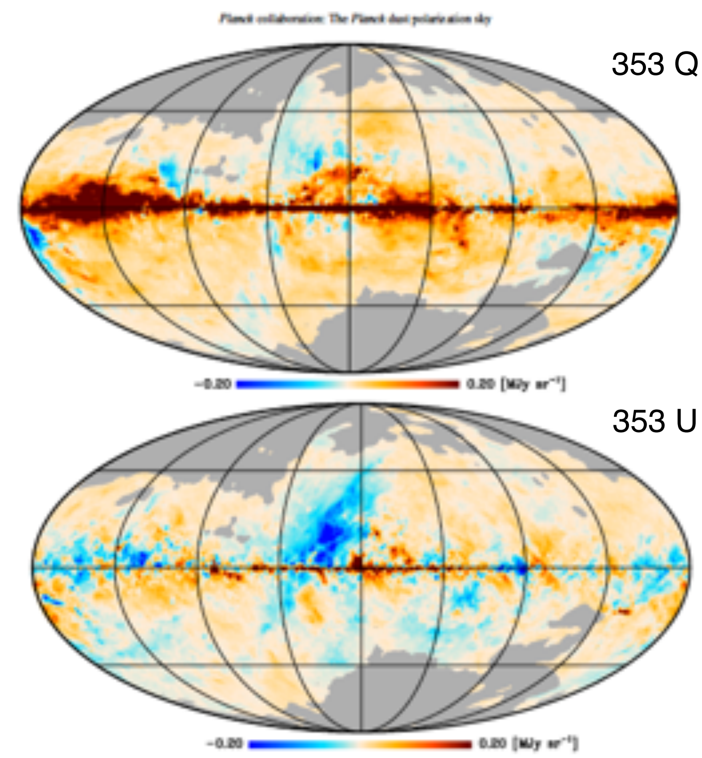

explore f_{sky} from 0.8 (I_{353} high) to 0.3 (I_{353} low), L=40-600

$\mathcal{D}_{EE,L}, \mathcal{D}_{BB,L} \sim I_{353}^{1.9} L^{-0.4}$ $\mathcal{D}_{BB} \sim 0.5\, \mathcal{D}_{EE}$

explore 352 f_{sky} ~0.0097 disks (400 sq deg) to mimic ground r-expts

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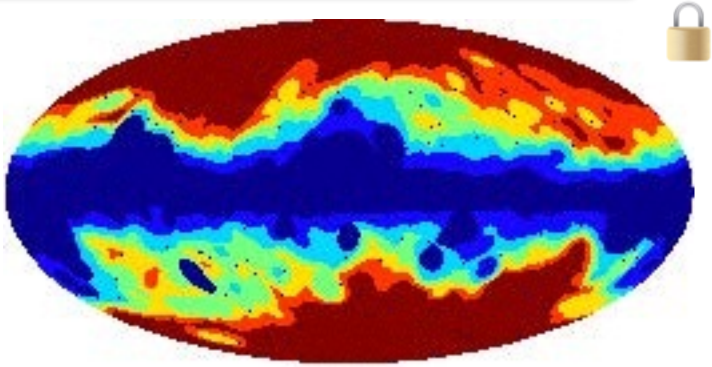
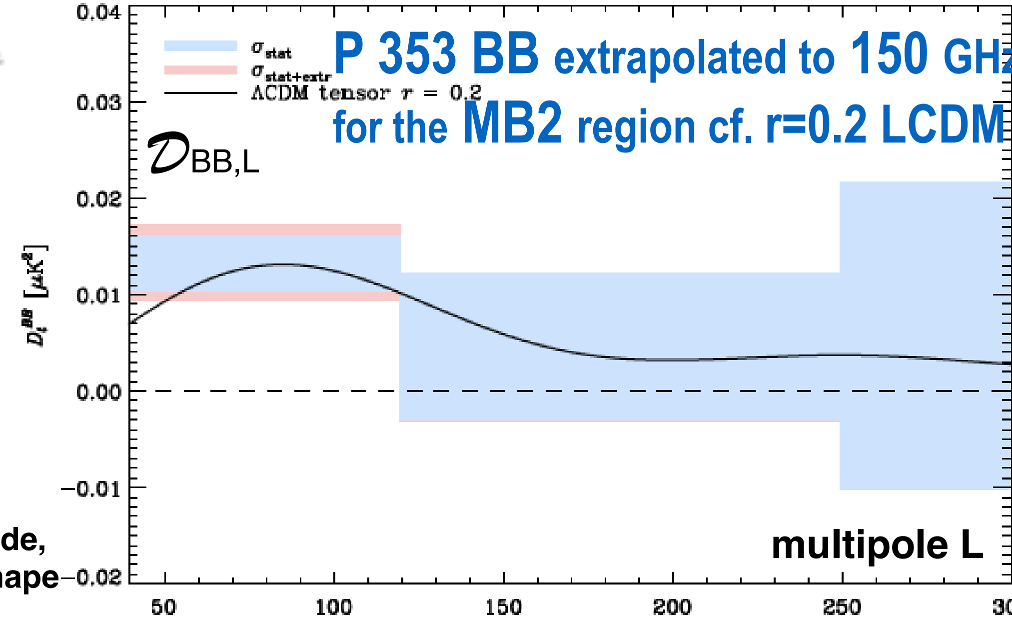
The angular power spectrum of polarized dust emission at intermediate and high Galactic latitudes

unlocked Sunday night





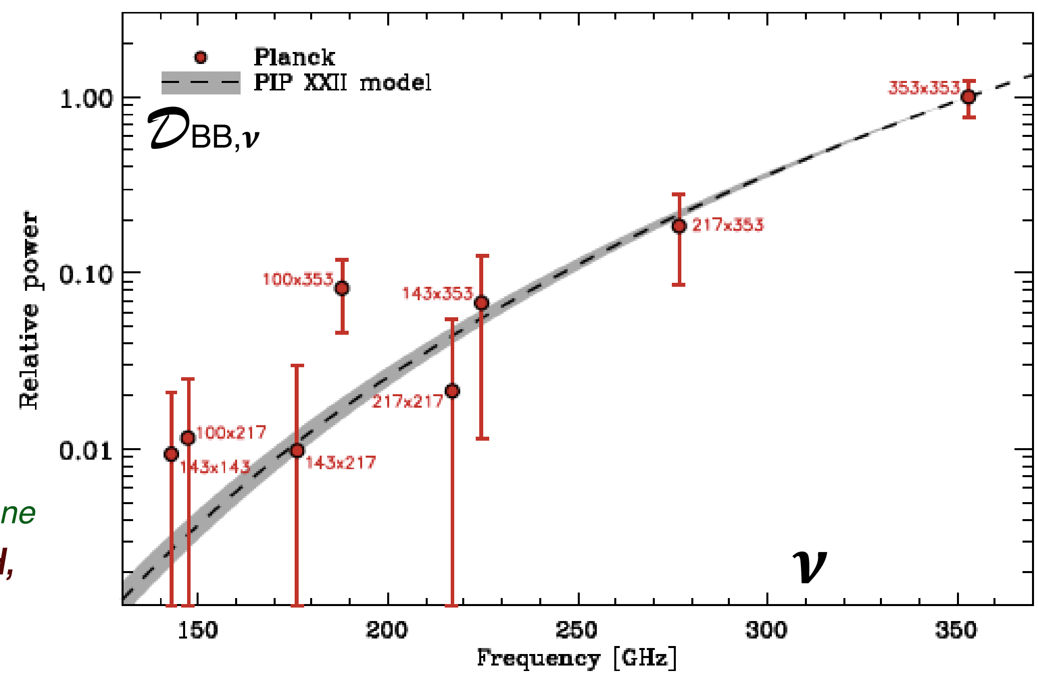
dust pol power is complex even at high Galactic latitude,
yet with simplifying trends for emissivity(ν), amp & shape

PIP97 also mimics the Bicep2 region, MB2,
690 cf. 373 sq deg B2 deep.
extrapolation from 353 indicates
the 150 BB signal may be just dust pol, BUT

Cautions: Planck alone cannot apodize and filter
exactly as Bicep2 did without PxB2 joint work.
power spectrum analysis is good,
but pattern analysis (P 353 cf. B2 150) is better

Hence: **BICEPxPlanck MOU + paper is in the works**
a goal is a joint likelihood for r for parameter
estimation *=> intense joint work among the two groups,*
a nice example of how this complex science should be done

future r-expts must plan for component separation, DUH,
and the quest for r is an ISM+cosmology problem
i.e., broad frequency coverage



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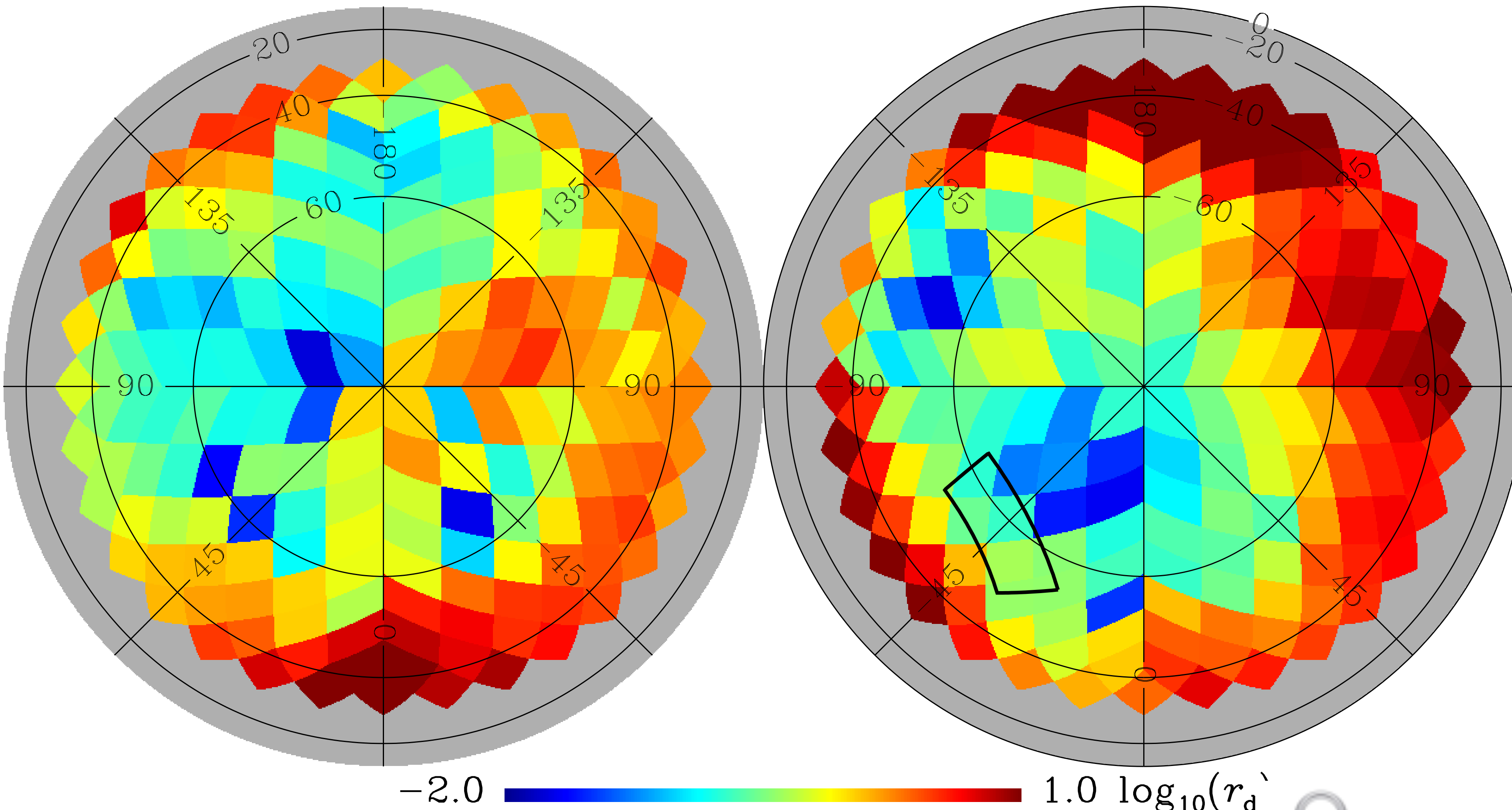
Blue = 400 sq deg regions of lowest extrapolated dust B-mode emission

=> *regions to target with small-sky B-mode expts (Bicep2 is low, but others are ~2X lower)*

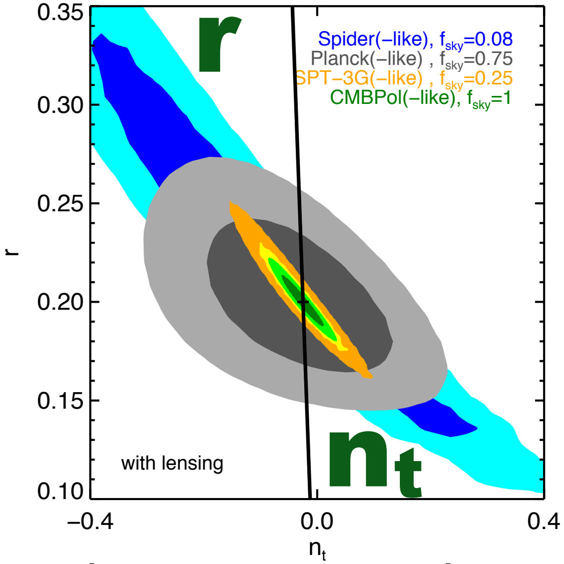


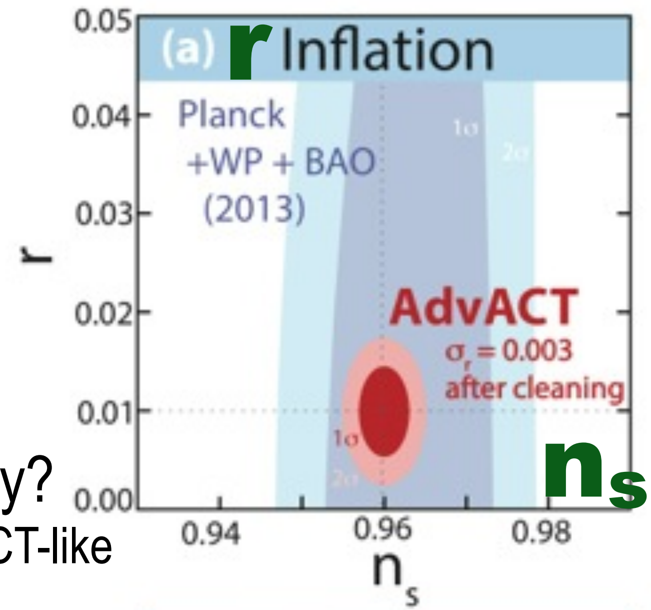
unlocked Sunday night

future

AdvACTpol (f_{sky}~50%): *Cosmological Forecasts*

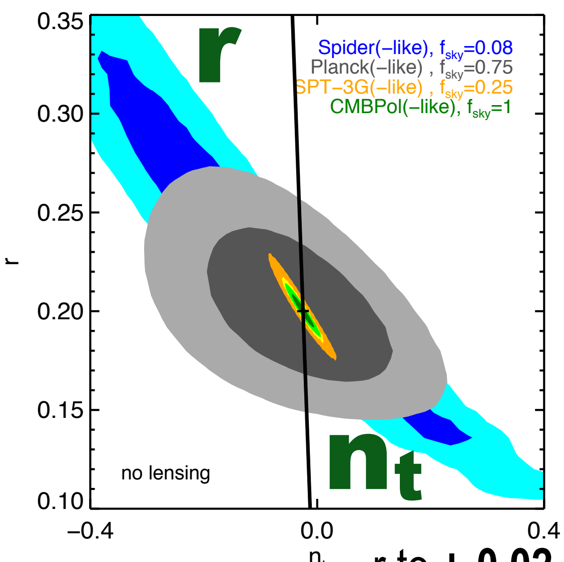
Planck_f, Spider, SPT3g, .. CMBpol (CoRE,Pixie,..)





testing tensor consistency?

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

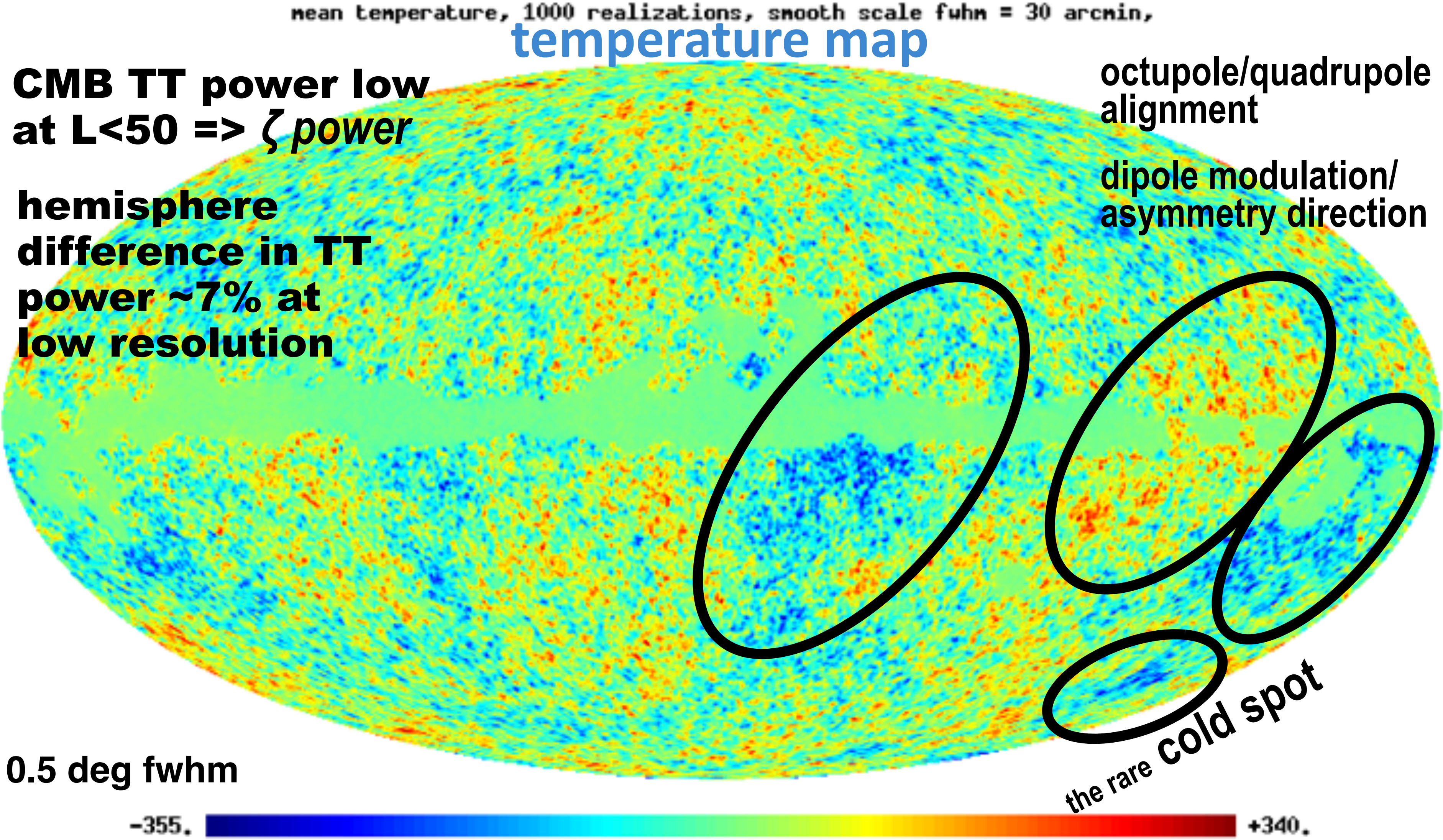


r to **+-0.02 Spider** forecast

r to **+-0.003 AdvACTpol** forecast w/ fgnds

CMB ζ maps = Gaussian to high precision for high L *but* anomalies at low multipoles, non-Gaussian, anisotropic

anomalies => inflation COMPLEXITY at t~10^{-36} seconds?



Grand Unified Theory of Anomalies? TBD

intermittent *strain-power bursts (in curvature)?*

$\ln a|_\rho$

$\zeta_{NL} = \ln(\rho\, a^{3(1+w)})/3\langle 1+w \rangle$ => ultra-early Universe **sound** spectrum

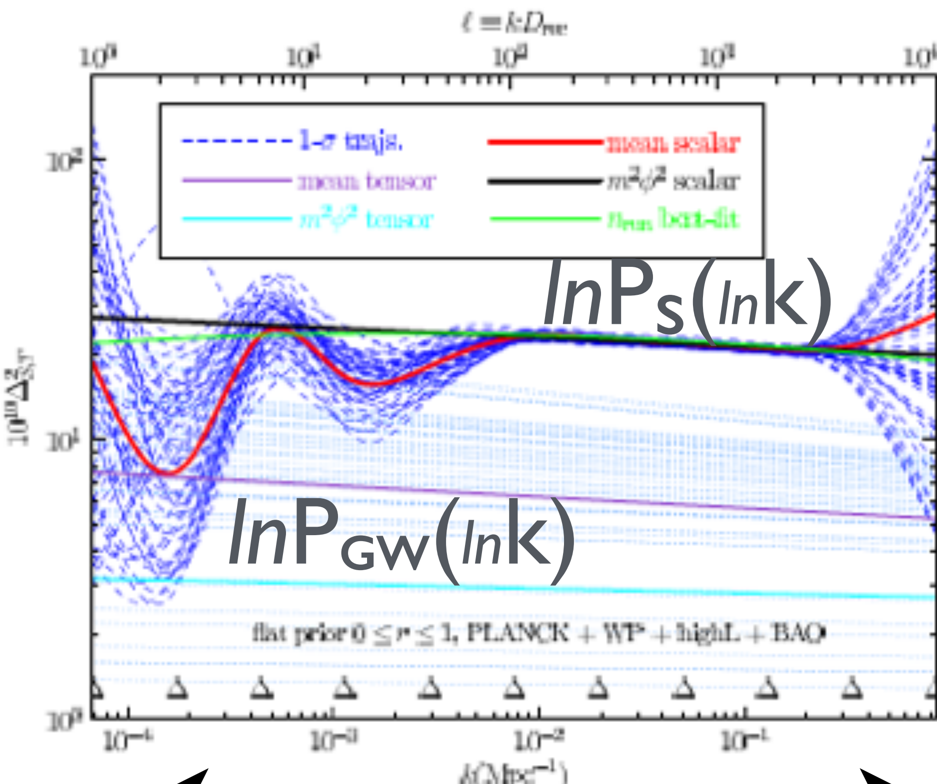
Quadratic expansions in mode functions => Quadratic *Wiener-filtered maps!*

here MCMC <power> trajectory, 1 sigma mean+fluctuation trajectories

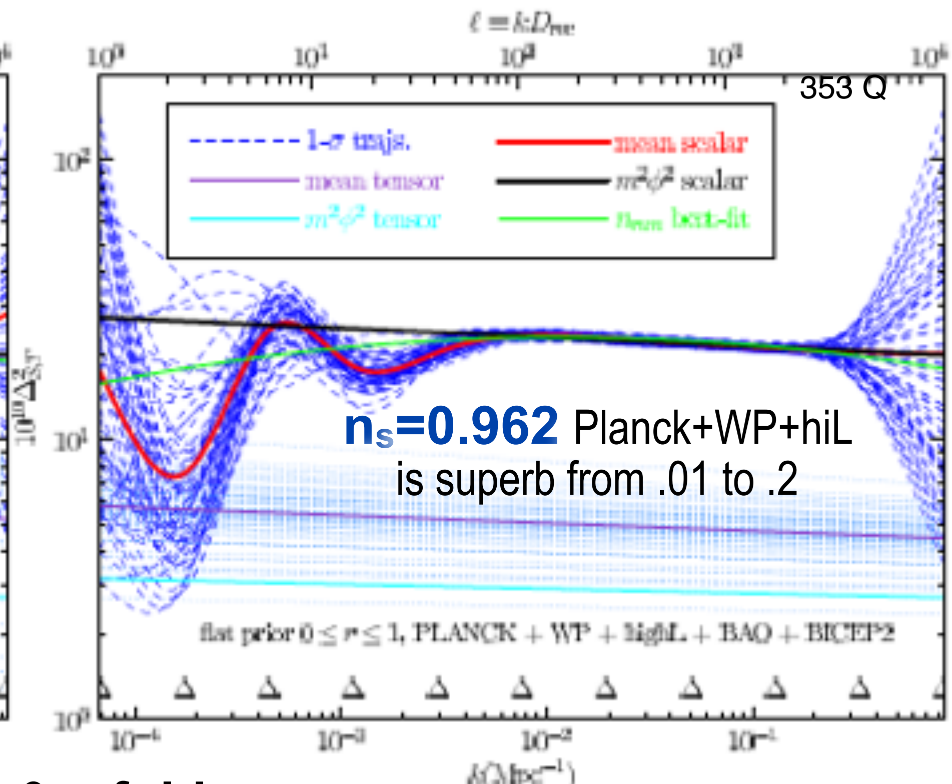
no strong evidence for oscillation patterns, cutoffs, local features; but a change on large L<100 scales

there will be ~ 3-4 reconstruction approaches in the Planck2014 inflation paper, this is one method

Planck13



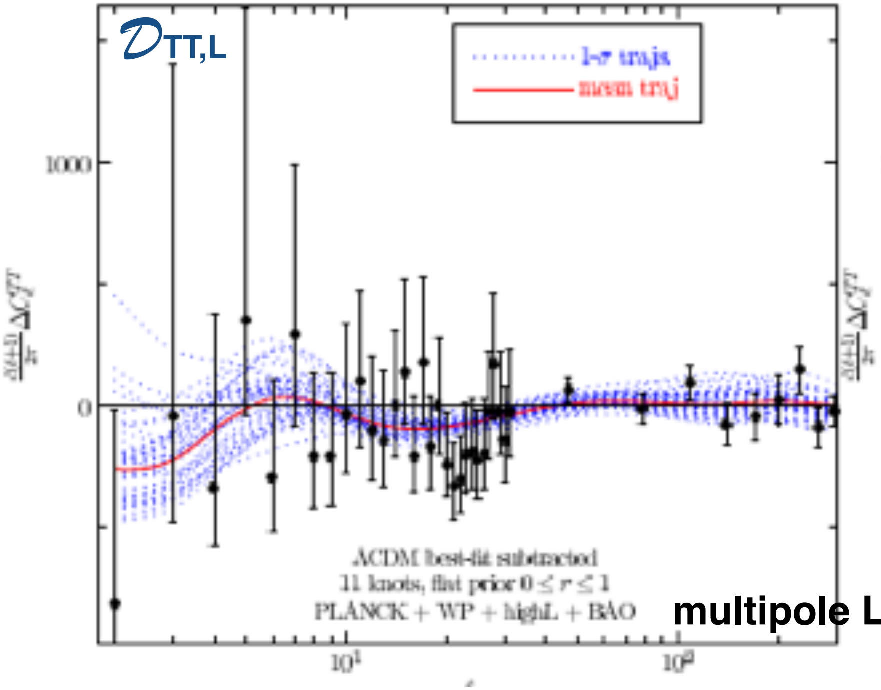
Planck13+BICEP2

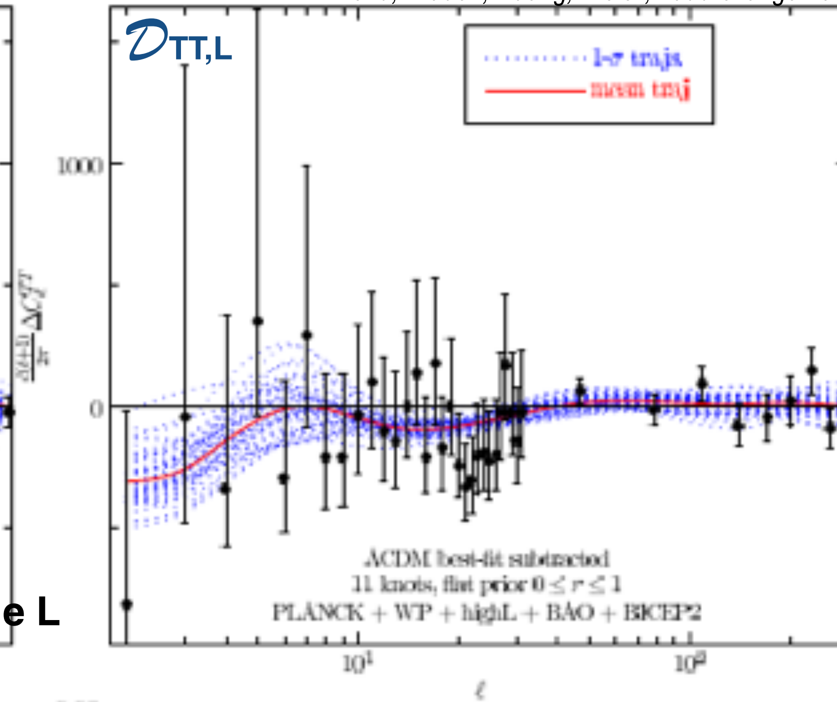


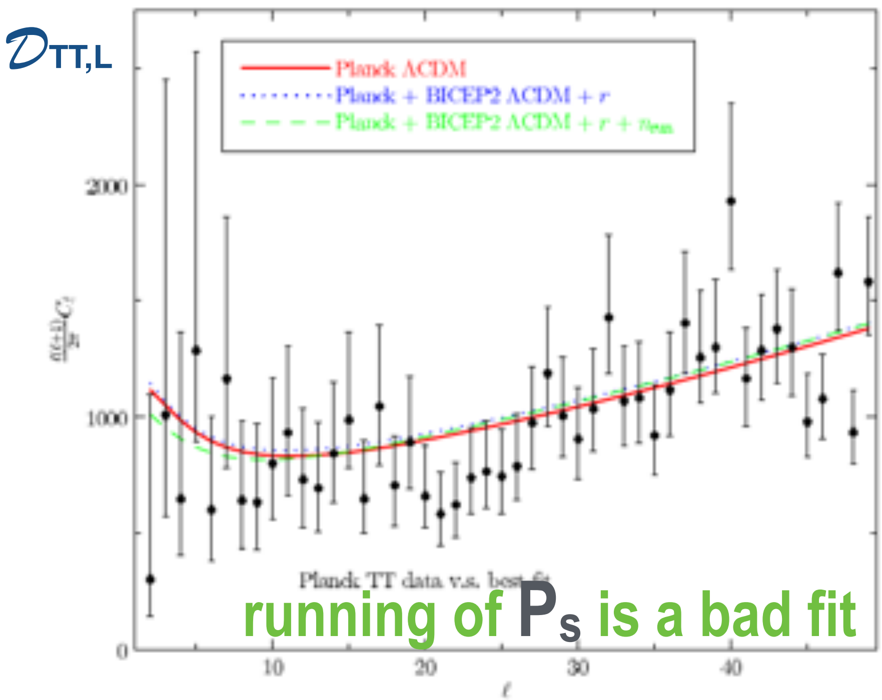
9 e-folds

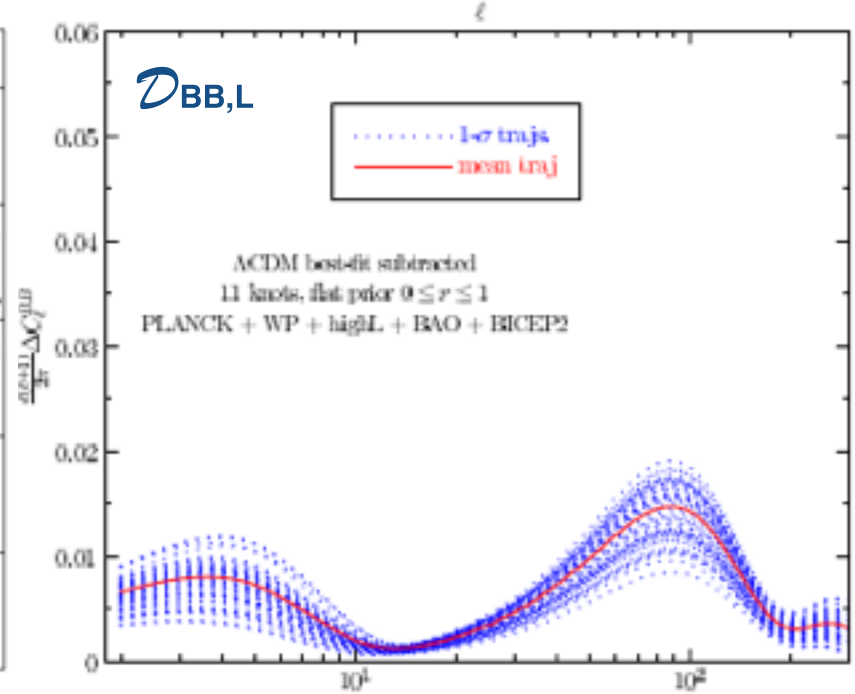
Bond, Braden, Huang, Frolov 2014

Bond, Braden, Huang, Frolov, Vaudrevange 2014







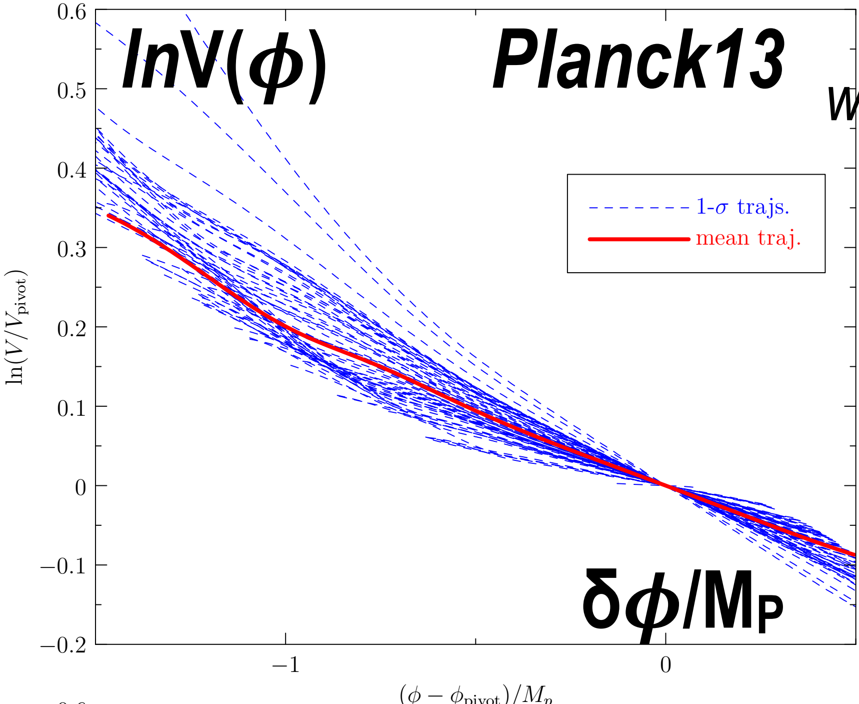


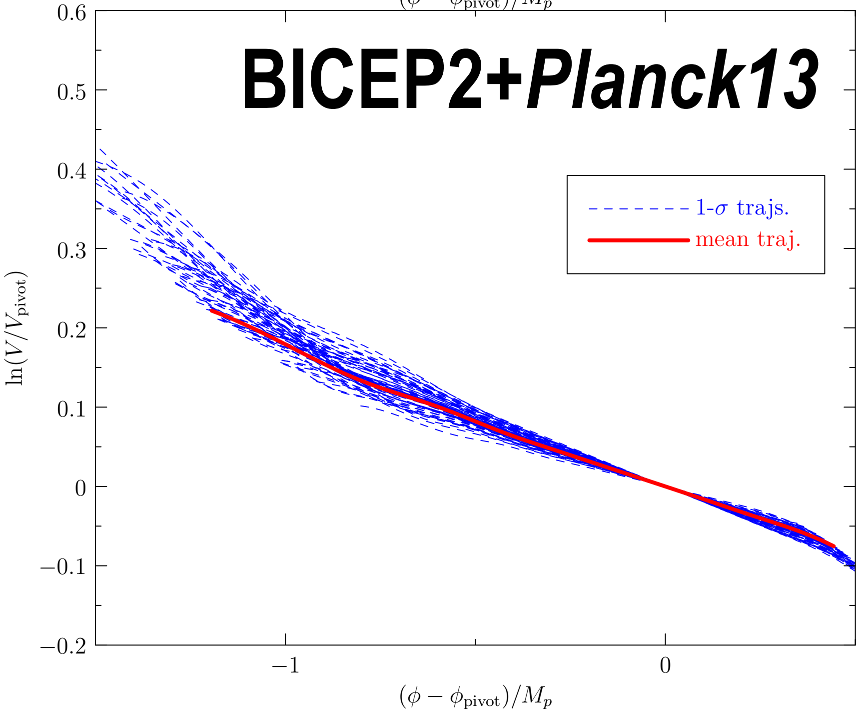
Bond, Braden, Huang, Frolov 2014

maps of the inflaton's $V(\phi)$

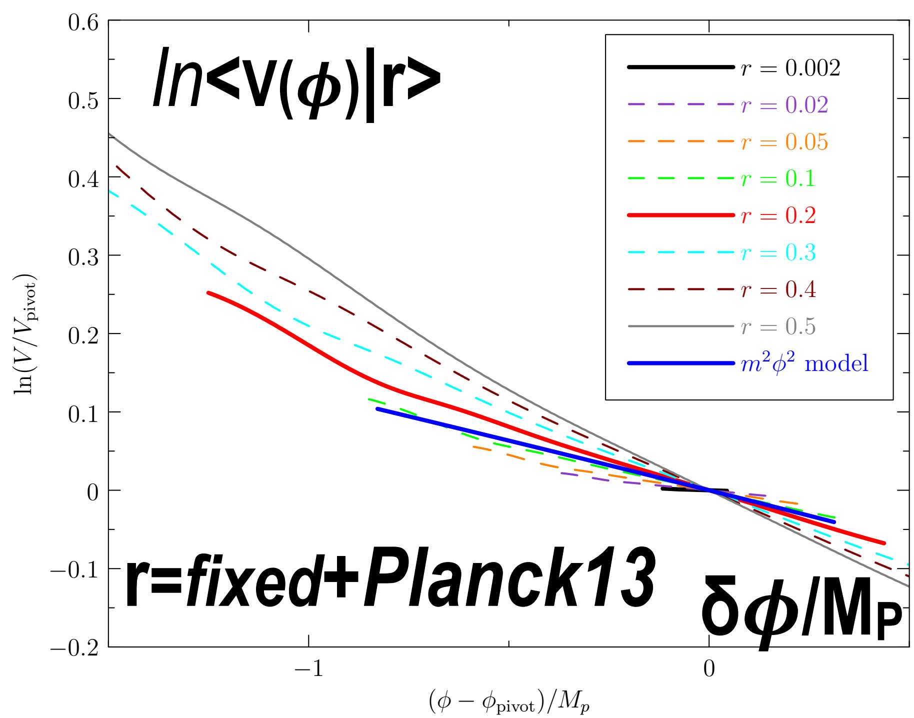
we **reconstruct** *the* ***scalar curvature power*** *(isotropic strain) & the early universe* **acceleration histories** *as well*

detecting r ~ 0.2 =>
$V(\phi)$ shape cannot be too flat over the observable range



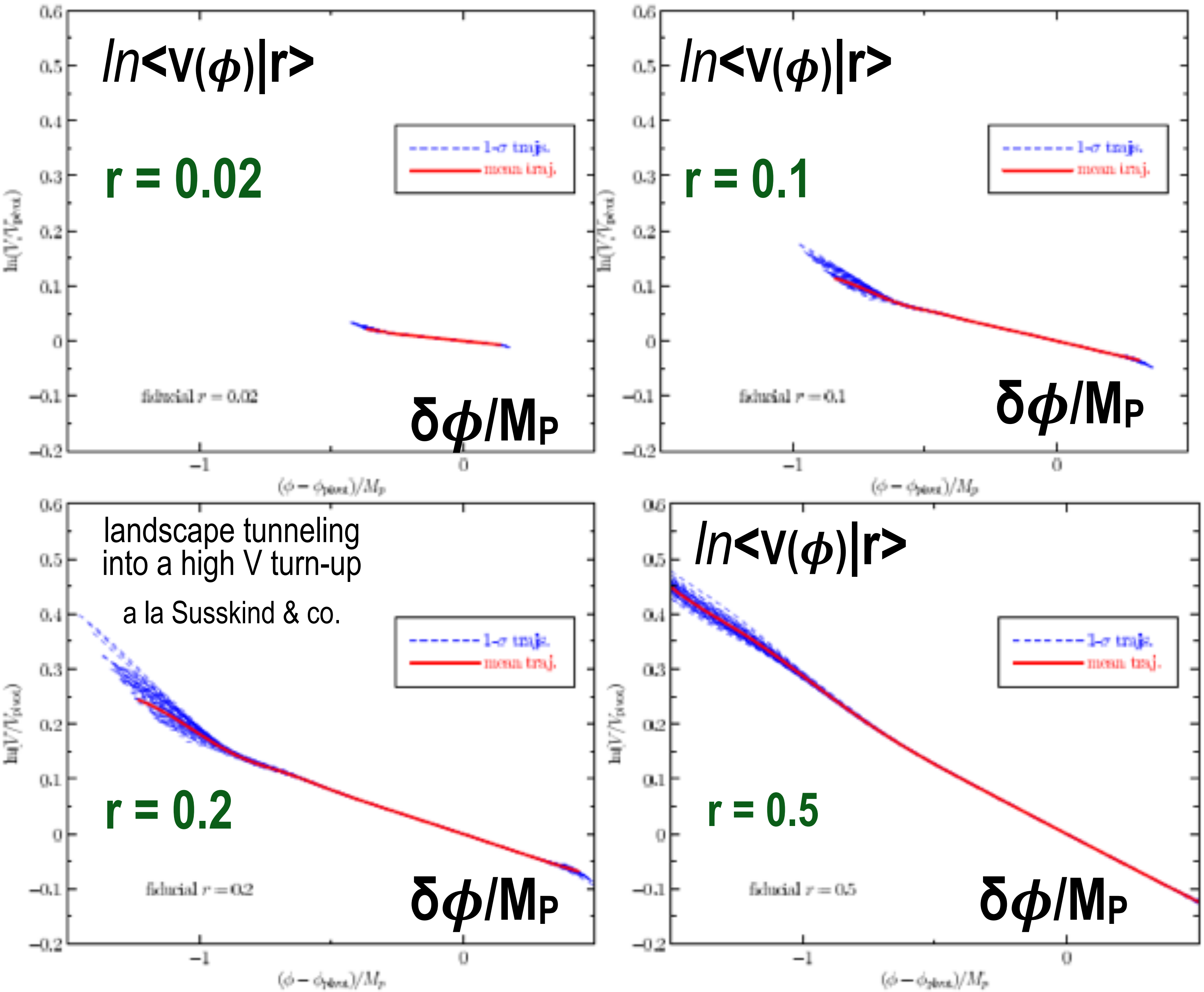


Reconstructed mean potential (without BICEP constraint)



simplest is $V(\phi) \sim m^2\phi^2$

Bond, Braden, Huang, Frolov 2014



r to **+-0.02 Spider** forecast

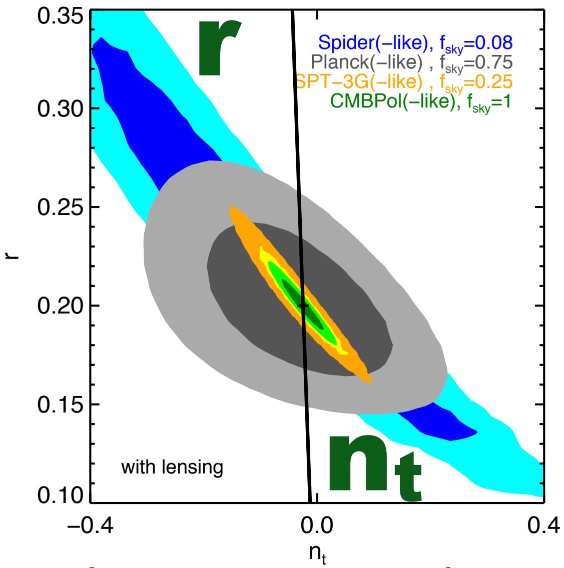
r to **+-0.003 AdvACTpol** forecast w/ fgnds

Bond, Braden, Huang, Frolov 2014

future

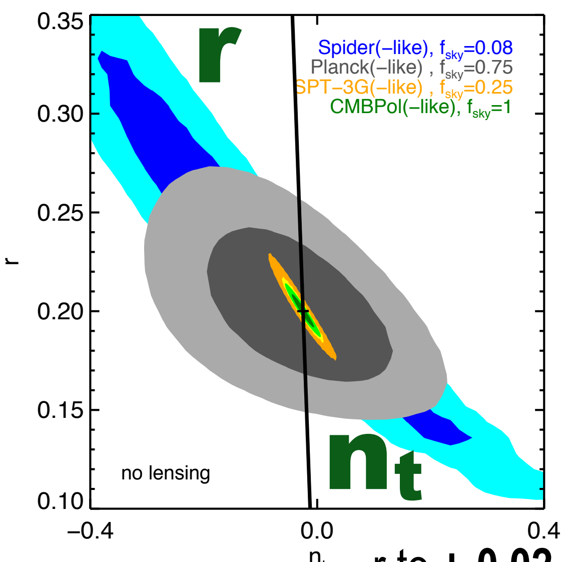
AdvACTpol (f_{sky}~50%): ***Cosmological Forecasts***

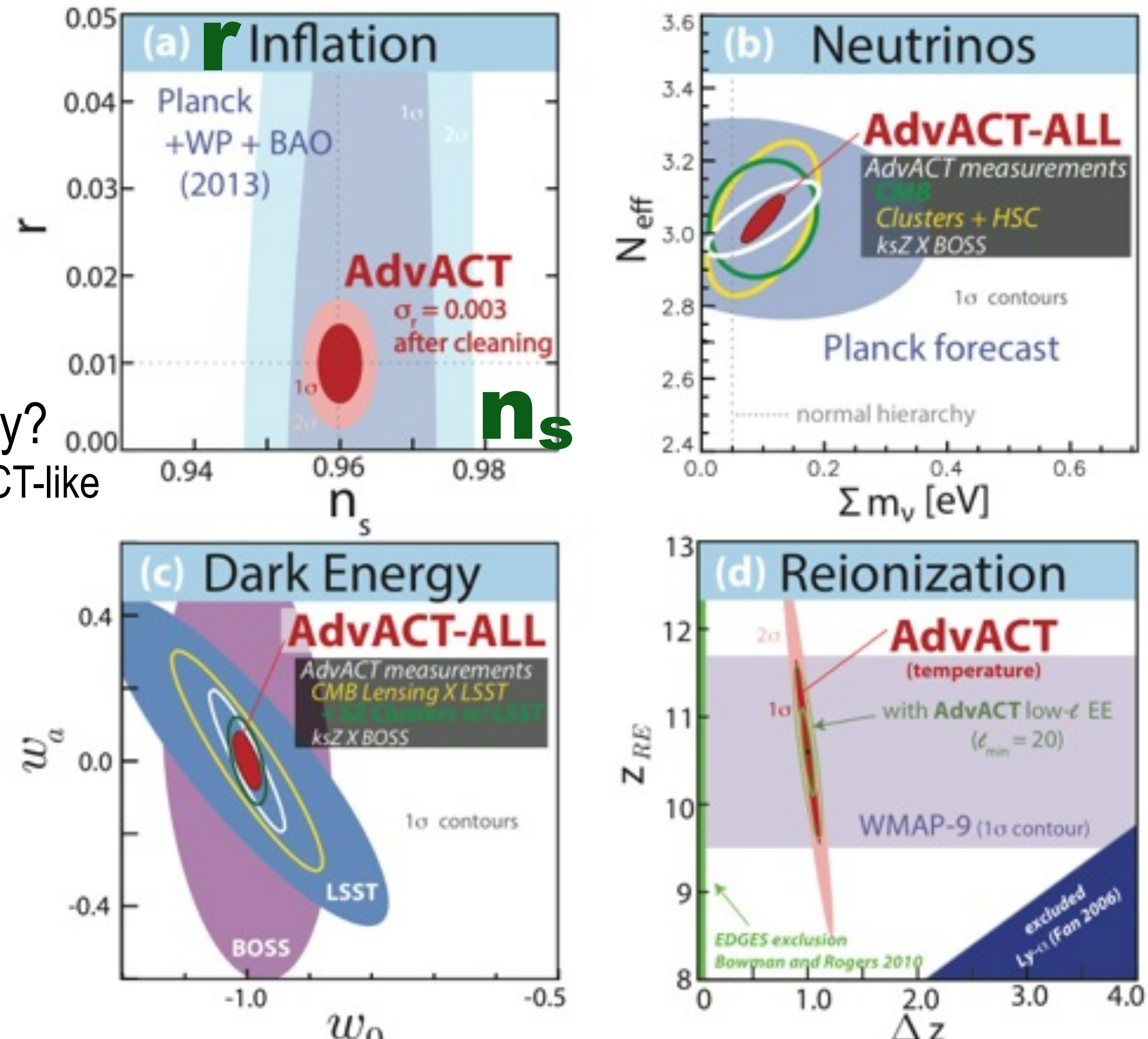
Planck_f, Spider, **SPT3g**, .. CMBpol (CoRE,Pixie,..)



testing tensor consistency?

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





r to **+-0.02 Spider** forecast

r to **+-0.003 AdvACTpol** forecast w/ fgnds esa

planck

cnes

agenzia spaziale italiana

NASA

CNRS

DTU Space
National Space Institute

INAF Istituto Nazionale di Astrofisica

Science & Technology Facilities Council

CSIC
Consejo Superior de Investigaciones Científicas

National Research Council of Italy

Gobierno de España – Ministerio de Ciencia e Innovación

CSA ASC

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

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HFI PLANCK
a look back to the birth of Universe

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