Bond's science @ CIFAR16 review

Submitted blurb based on NOI for NSERC 2017-22 Discovery Grant - all aspects are of relevance for GEU 17-22

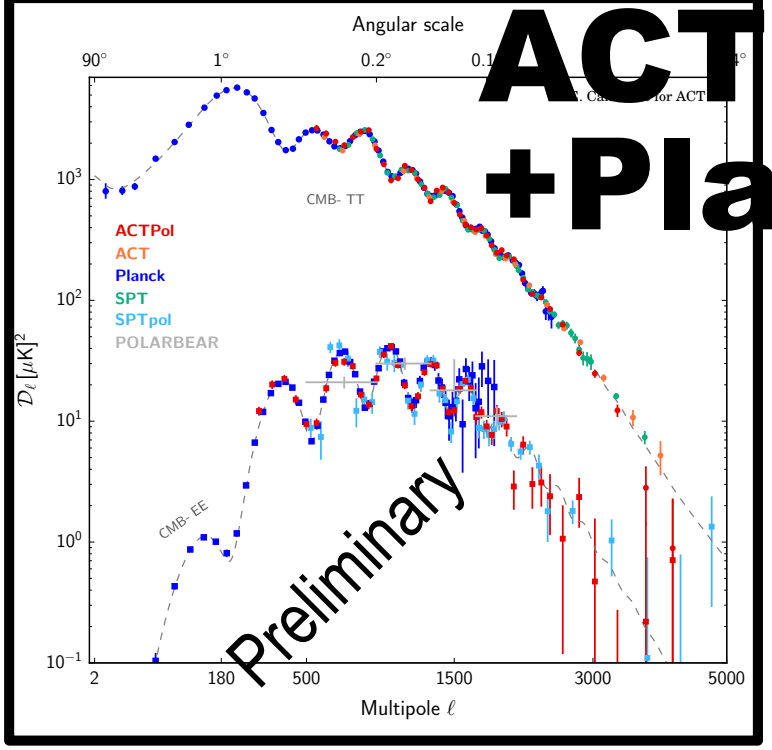
Planck 11-16 ~18000 citations ~133 papers post launch; 2013 5 of ten most cited in physics & astro; 2015/16 4 of ten most cited in phys and astro, a 5th was number 11

snapshot of Bond's travel illustrates where JRB's current & future action is re C&G=>GEU

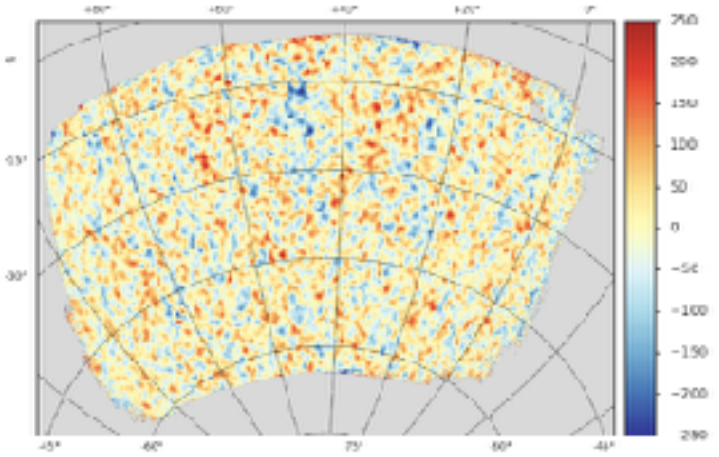
Feb 2016 ACTpol/AdvACTpol consortium mtg Princeton
Mar 2016 CMB Stage 4 meeting Berkeley
Mar 2016 Planck Core team meeting Paris (CMB+dust)
Apr 2016 CIFAR Annual Meeting - Mocking Heaven tSZ, kSZ, CIB, optical, HI, CO
Simons Observatory = AdvACT + Polarbear team Page, Spergel, Dobbs, Halpern
May 2016 Planck Core Team meeting Paris Efstathiou, White
May 2016 CASCA Winnipeg; Low L Planck polarization and tau (redshift gal formation)
June 2016 Great Lakes, McMaster Low L Planck polarization and tau (redshift gal formation)
July 2016 Large Scale Structure and Bias workshop Leiden: mass-peak patches & mocking heaven
July 2016 Spider consortium workshop Cleveland Netterfield
Sept 2016 Planck Core Team meeting Paris (CMB+dust, 2016 => 2017 papers => 2018 research)
Sept 2016 CMB Stage 4 Chicago (S4 will heavily use "mocking heaven" sims for low L, high L)
Sept 2016 Korea/ China Sun Yat Sen Univ g\CMB public lecture
Oct 2016 Simons Observatory face to face mtg Princeton
Nov 2016 Euclid simulations meeting Barcelona ("mocking heaven")
Nov 2016 Planck 2017 Papers Meeting Madrid
Nov 2016 Cdn Space Agency mtg on science futures Montreal - Litebird, Pixie, Core, WFIRST
Nov 2016 CITA workshop on gastrophysical & neutrino influence on galaxy bias

+ various collaborator visitor flux into CITA to work on projects

ACTpol +Planck



SPIDER

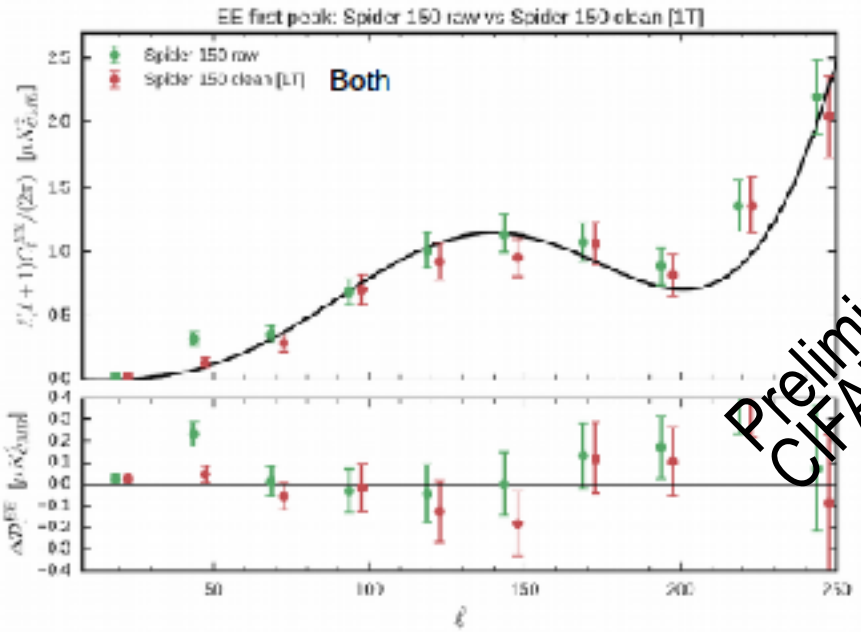


r target: 0.03 (3-sigma, ignoring foregrounds)

Release timescale: months

S4 target w/ fgnds 0.001

Toronto analysis team:
Netterfield, Bond, Nolte, Padilla, Hartley, Galloway, Lipton



Preliminary
CIFAR review only

Next 5 Years:

Spider:
- Spider 1 Analysis (- 2017)
- Spider 2 rebuild/flight (2017/2018)
- Spider 2 analysis (2019 - 2022)

Next-Gen Balloon Polarimeter
- Proposal (2018)
- Construction (2019 – 2022)
- Flights/analysis (2022 2027)

CIFAR CANADIAN INSTITUTE FOR ADVANCED RESEARCH

CITA ICAT

Dick Bond

CITA = Cosmic Information Theory & Analysis

from ***SuperWeb simplicity*** *to* ***complex Intermittency*** *in the Cosmic Web*

IT from BIT, from BITs in IT, ***Studying the Cosmic Tango***

Universe=System+Res, =Data+Theory ***en-TANGO-ment***

CIFAR Cosmology & Gravity Program: >1985, Bond Director 2002-17 20 Sr Fellows & Fellows (5@UofT), 21 associates + 6 Advisory Board members; CITA: 6+ faculty, >20 PDFs & Sr RAs + ~15 grad students; Bond: projects 3 grad students, 2 SrRAs, 2 (++) PDFs

Cosmic standard model SMc = xCDM, x=dark energy+tilt: **what is U made of? Planck15** *dark energy, dark matter, baryons, CMB, CIB, CnuB, GW:* $\rho_{dm}/\rho_b = 5.43$ $\rho_{de}/\rho_{dm} = 2.53$ $\Omega_m = 0.32 \pm .009$, $\Omega_\Lambda = 0.68 \pm .009$ =>

BSMc Beyond the SMc *eg* $\Omega_\Lambda(t,x)$, neutrino properties, inflation anomalies

How Structure in the Universe Arose?: ***fluctuation generation in curvature from an early inflaton: POWER(lna,isoc,GW(k): isocurvature, Gravity Wave;***
(coherence + quantum noise => incoherence via entropy/information generation) via nonlinear lattice simulations of multiple scalar fields at the end of inflation & "ballistics"

=> CMB/LSS Anomalies and intermittent non-Gaussianity cf. perturbative non-Gaussianity, correlated & uncorrelated. probe with CMB + LSS large surveys

CMB*ology* **precision cosmic parameters *Planck* 2013-15-17 intensity + polarization** ***+ ACTpol + BKP +SPT*** **+LSS =>** ***Spider, Advanced ACTpol => Simons Obs => CMB Stage 4, ..***

LSS*ology* ***CHIME, COMAP, Euclid … cross correlations: CMBxLSS***

morphs *into the nonlinear* ***Cosmic Web:*** ***clusters*** **SZ**, ***filaments, voids; galaxies Mass-peak-patches, N-body, gas to "Mock Heaven" tSZ, kSZ, CIB,CO, HI, optical (HOD),*** ***CIB,CO,HI***

What is the fate of the U: (coupled?) dark energy driving late inflation

CIFAR
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from SuperWeb si[illegible] Complex Intermittency in the Cosmic Web

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SAMPLE C&G=>GEU PROJECTS

C&G=>GEU: structure formation
3D bubble simulations
Planck/AdvACT/SO/S4

C&G=>GEU: nu mass, nu number BSMc
cosmic neutrino decoupling & BBN

C&G=>GEU: structure formation - anomalies
preheating, caustics, shocks-in-time
& intermittent non-Gaussianity
Planck/AdvACT/Spider/LSS/Euclid

C&G=>GEU: structure; GWaves
ln a(x,t) early U maps
potential reconstructions
acceleration histories
Planck/AdvACT/Spider/LSS

C&G=>GEU: Mocking Heaven aka "all" CMB+LSS surveys
hydro sims, mass-peak-patches & potential pits, flows beyond 2LPT, 3D non-Gaussian
Planck/ACT/SO/S4/CHIME(HI)/HIRAX/EUCLID/LSST/COMAP/CCAT-p(CII)

C&G=>GEU: CMB analysis T,E,B => r ; Dusty pol
Netterfield, Halpern, Page, Spergel, Efstathiou, White..
Dobbs, Holder (SO/S4)
Planck/Spider/AdvACTpol/Spider/SO/S4

C&G=>GEU: dark energy inflaton
modified gravity / coupled DE
Planck/AdvACT/SO/S4/CHIME/
EUCLID/LSST +

Cosmic[illegible]el SMc = xCDM energy+t[illegible] **t is U made of**

[illegible], dark m[illegible], CMB, CIB, [illegible]

2.5[illegible] -0.32 ± 0[illegible] =>

[illegible] SMc [illegible]x), neutrin[illegible] anomali[illegible]

H[illegible]cture in t[illegible] Arose [illegible]neration i[illegible] from

an early infl[illegible]c,GW[illegible]ature, Gr[illegible]

(coheren[illegible] here[illegible]ntropy/in[illegible]

nonline[illegible]ultiple sc[illegible] fields a[illegible]s"

=> CMB[illegible]s and intermittent[illegible]

Gaussia[illegible]related & uncorrelat[illegible]

CMB*ology* precision cosm[illegible] + polari[illegible]n

+ ACTpol + BKP +SPT +L[illegible]

LSS*olog[illegible]* => CMB [illegible]

[illegible]ions: C[illegible]

morphs *into t[illegible]mic Web[illegible]aments, v[illegible]*

peak-patches, N[illegible]s to "Mock Heaven[illegible]SZ, CIB,CO[illegible]IB,CO,HI

What is the fate of the U: (coupled?) dark energy d[illegible] inflation

the ζ-**scape** & the **CMB**

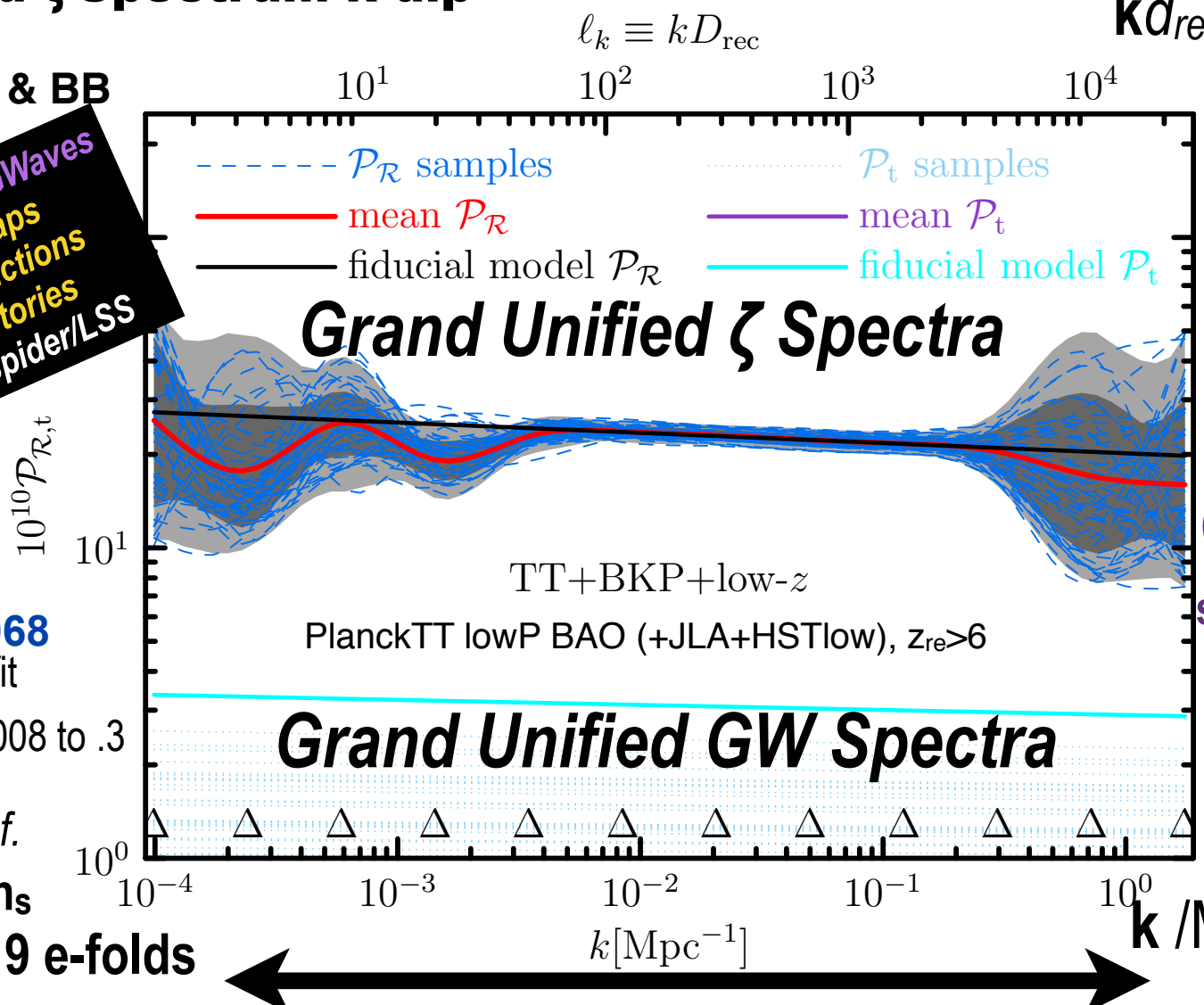
aka mapping early U sound/phonons

CMB TT power L~ 20-30 dip =>
Grand Unified ζ-Spectrum k-dip

quadratic map,
includes lensing & BB

kd$_{rec}$ ≳L

C&G=>GEU: structure; GWaves
In a(x,t) early U maps
potential reconstructions
acceleration histories
Planck/AdvACT/Spider/LSS



EE (L>30) looks similar

=> V(ϕ)

uniform **n$_s$=0.968**
P15+LSS best fit

superb 12-knot fit k~ .008 to .3

r<.11 95%CL *cf.*
r<0.09 uniform n$_s$

9 e-folds

k /Mpc

Will any

Anomalies in the CMB

turn into Subdominant Physics?

sigh, Mother Nature puts her Anomalies @ low L where sample variance => tantalizing ~ 2σ's? if a GUTA then maybe >>2σ?

Planck 2013, 2015 cf. WMAP7,9 basic verification. polarization aspects coming in P17; P15: only polarized stackings of various sorts

more exploration of relations - instructive mapping, - spatial and L-bands, but nothing really compelling

BSMc = SMc + primordial anomalies

sigh, Mother Nature puts her Anomalies @ low L where sample variance => tantalizing ~ 2σ's?

early Universe maps of curvature fluctuations from CMB data

$<\zeta|T,E>+\delta\zeta,\ \zeta = \ln a(x,t)|_H$ Planck 2015 XVII nonGaussianity paper

C&G=>GEU: structure; GWaves ln a(x,t) early U maps
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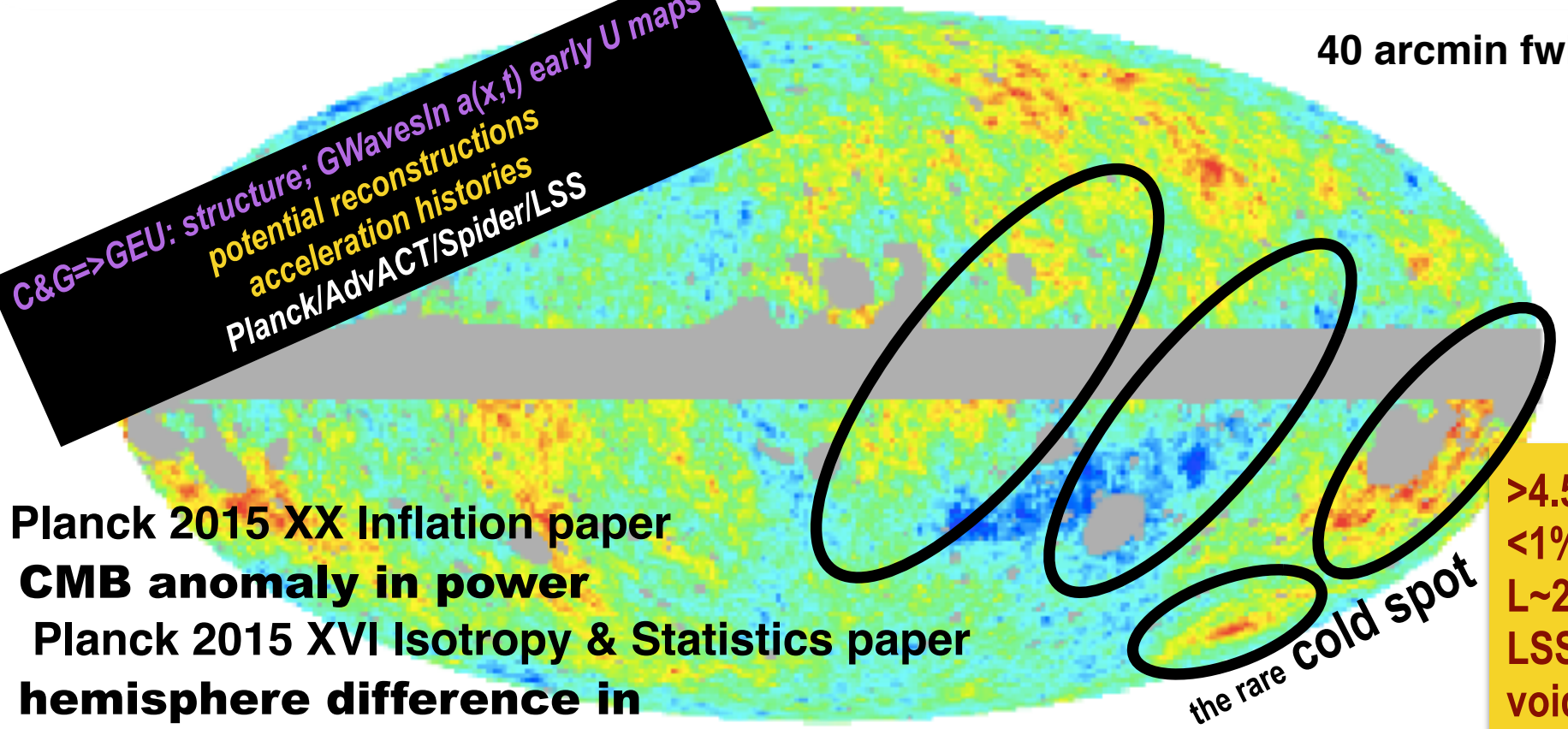


Planck 2015 XX Inflation paper
CMB anomaly in power
Planck 2015 XVI Isotropy & Statistics paper
hemisphere difference in power ~7% at low resolution

>4.5σ
<1%
L~20
LSS void?

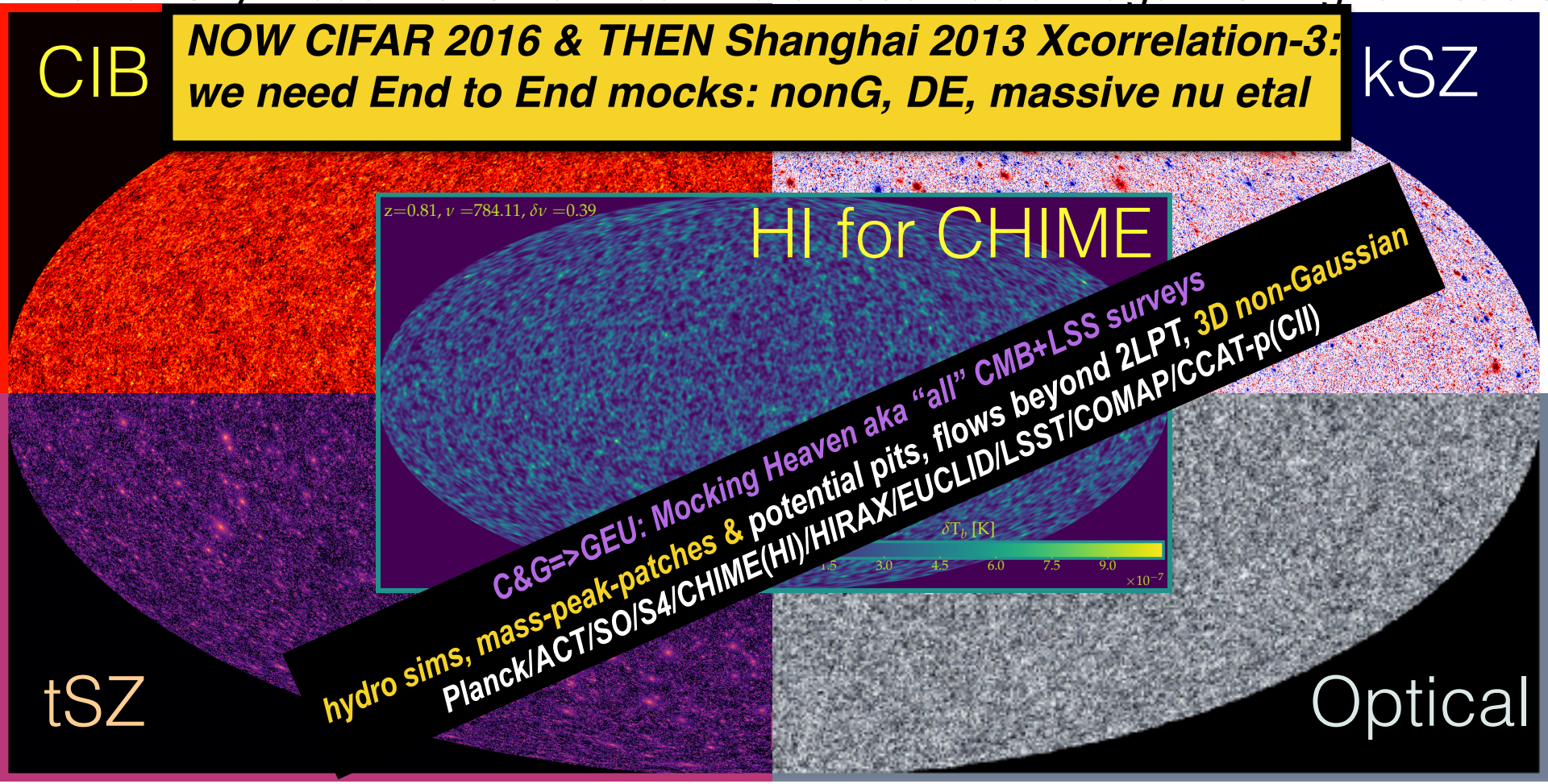
intermittent?

Mocking Heaven @ CIFAR16 Dick Bond

Peak Patch Full Sky Models: @CIFAR1991 tSZ,CIB

Peak Patch tSZ,kSZ in Planck 90s Bouchet-Gispert the cosmic sandwich

Planck Sky Model 2015 not-Peak-Patch 00s-10s extragal+ISM fgnd models

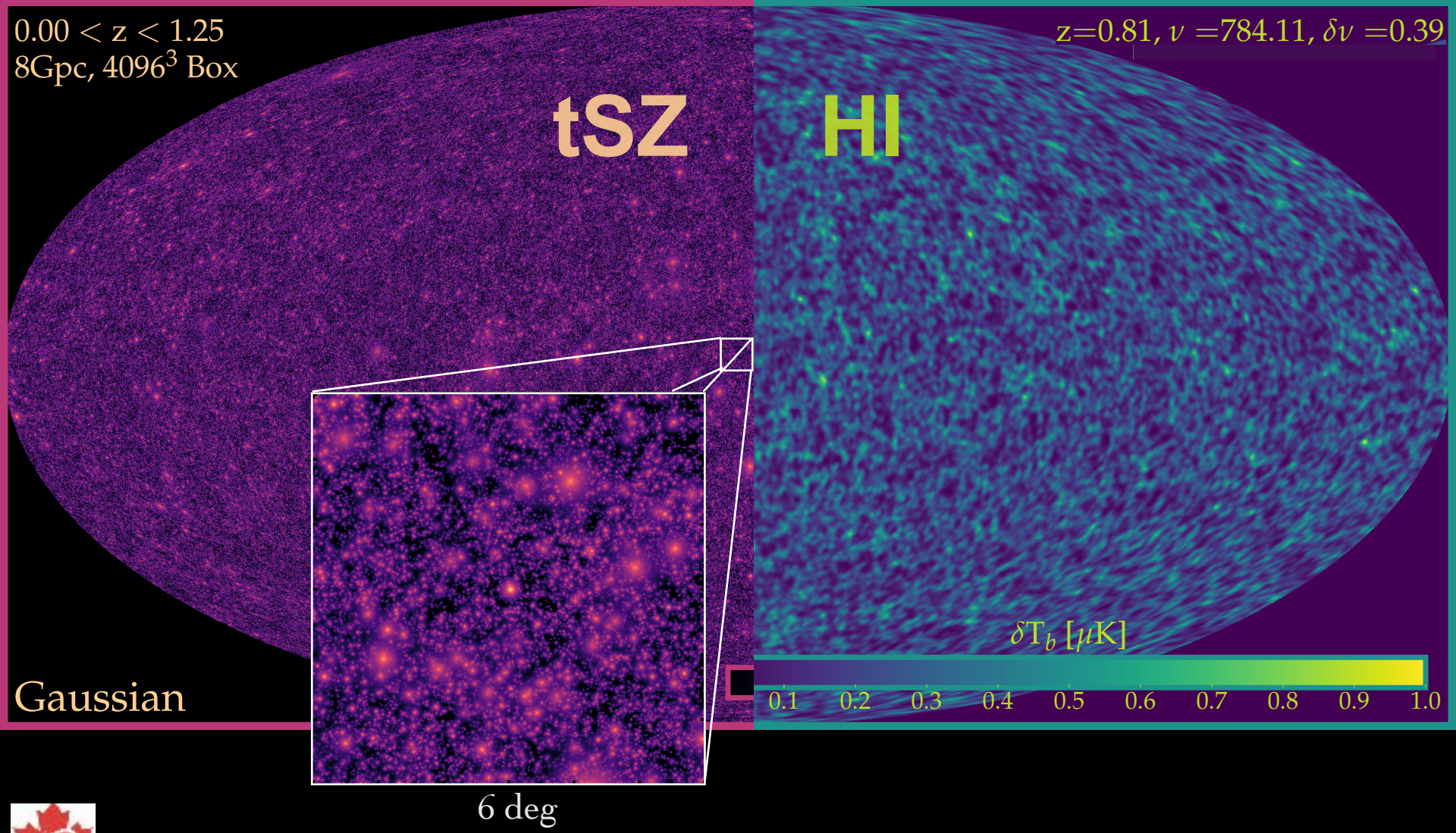


*Planck 2015 XII: Full Focal Plane Sims (Nov): FFP8 ensemble of10K **End**to**End** mission realizations in 1M maps. instrument noise + CMB + PSM + .. (25M NERSC CPU hrs)*

Compton Scattering (Sunyaev-Zeldovich) Simulations for ACT, Planck, Simons Obs &CMB Stage 4 Cluster Observations

Using high res Gas Hydro Sims

HI Intensity Mapping simulations of CHIME / HIRAX .. z=0.8-2.5, ~(8 Gpc)^3



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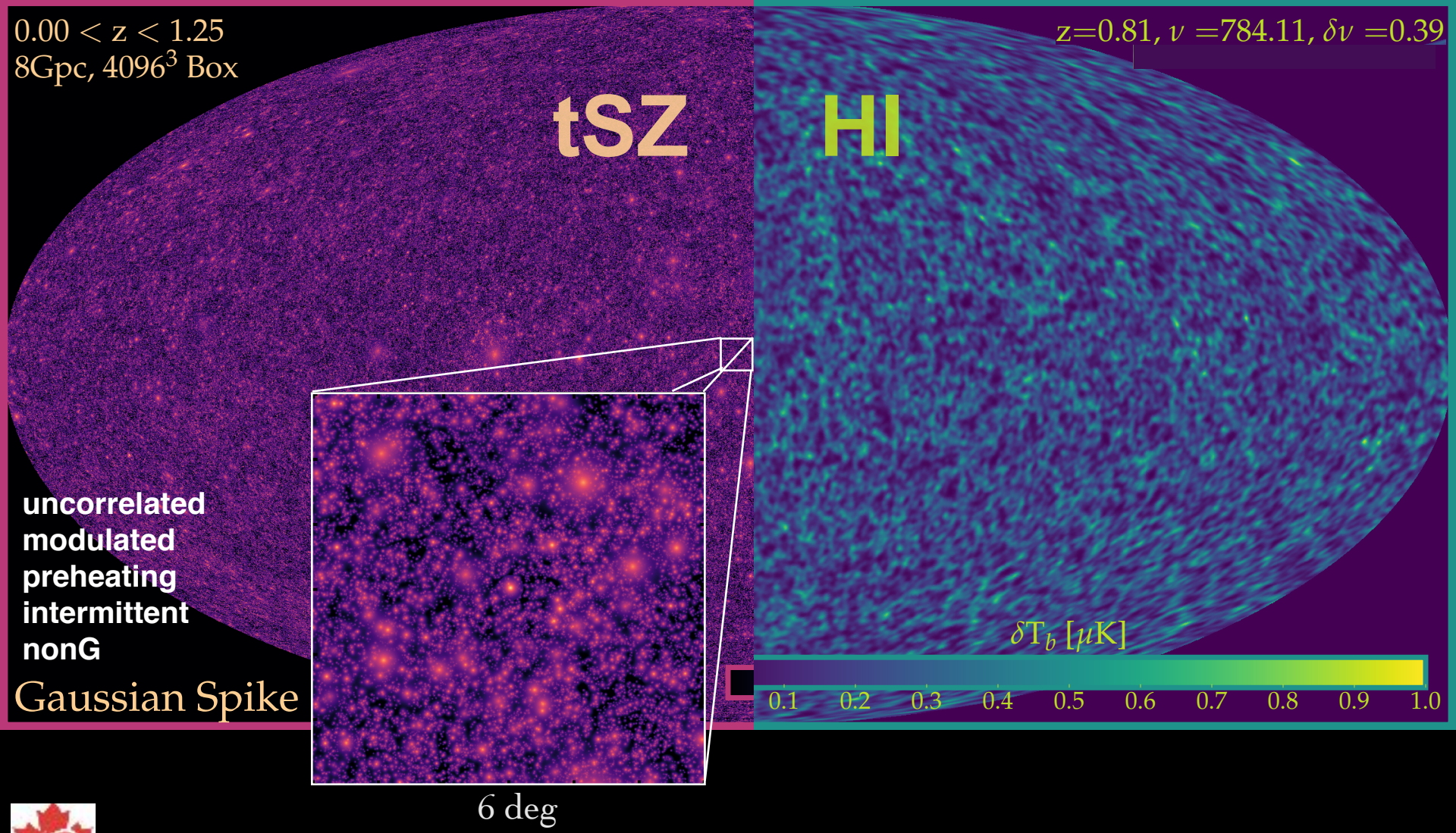
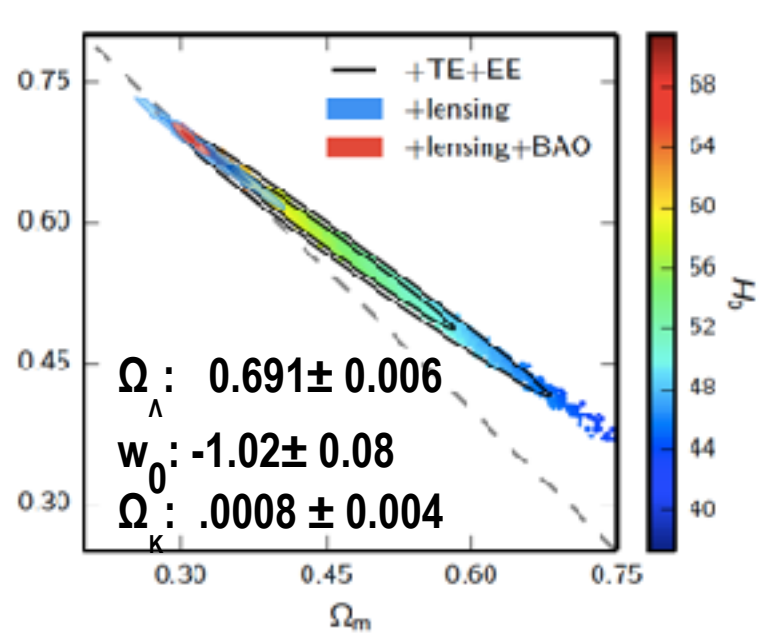


DE



Planck 2015 late inflaton
=> CMB/LSS S4+Euclid+ future in GEU

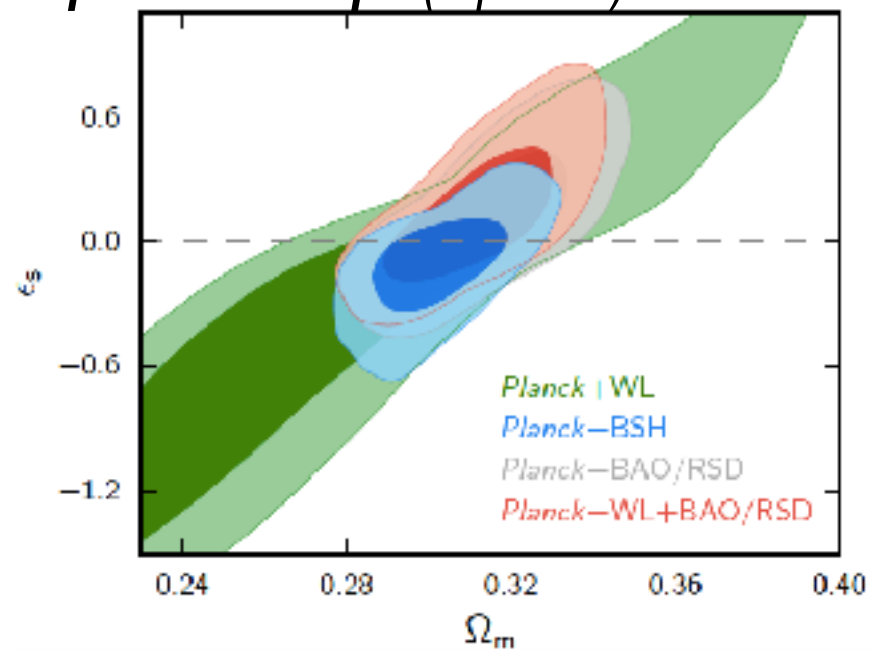
$N_{veff} = 3.15 \pm 0.23$ relativistic dof

$\sum m_\nu > 60$ meV

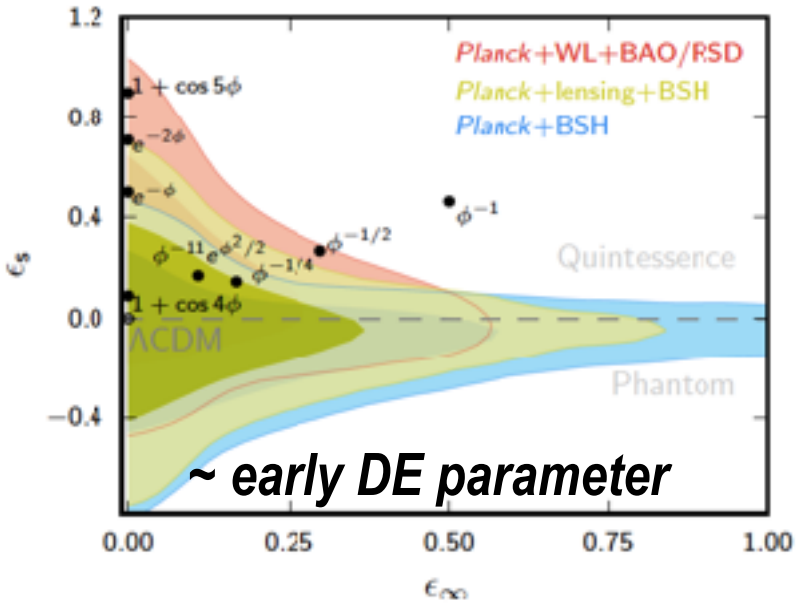
$\sum m_\nu < 220$ meV 95% P15+Planck(cls)+BAO

$\sum m_\nu < 170$ meV 95% P15+BAO

~ potential slope *(squared)*



~ potential slope *(squared)*



~ early DE parameter

SIMPLICITY

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

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

stacked linear map aka mean-field map

Planck2015 early U structure map

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

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

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

2⁺ numbers

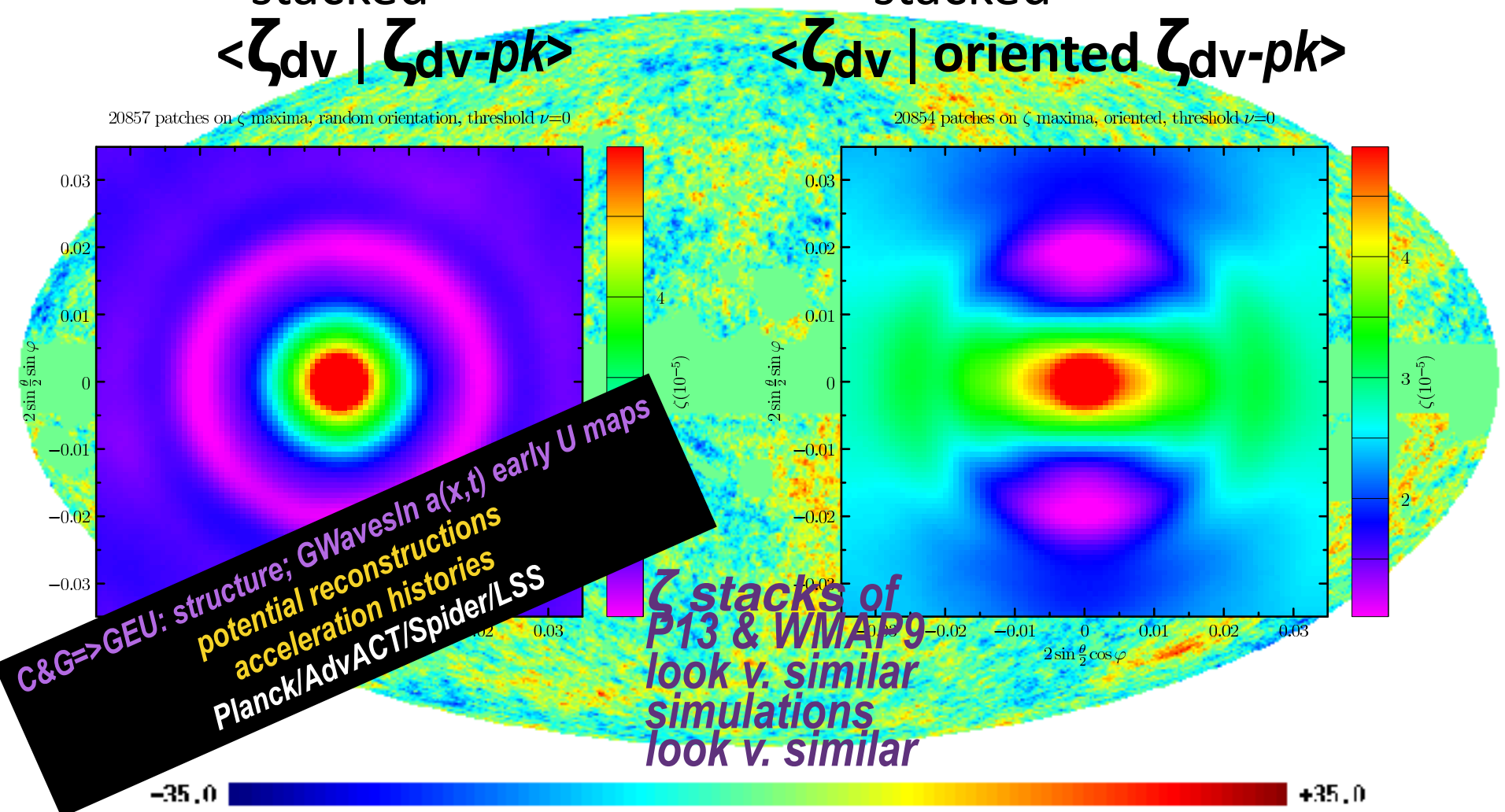
10^5 zeta

stacked

$\langle \zeta_{dv} \mid \zeta_{dv\text{-}pk} \rangle$

stacked

$\langle \zeta_{dv} \mid$ oriented $\zeta_{dv\text{-}pk} \rangle$



C&G=>GEU: structure; GWavesIn a(x,t) early U maps

potential reconstructions

acceleration histories

Planck/AdvACT/Spider/LSS

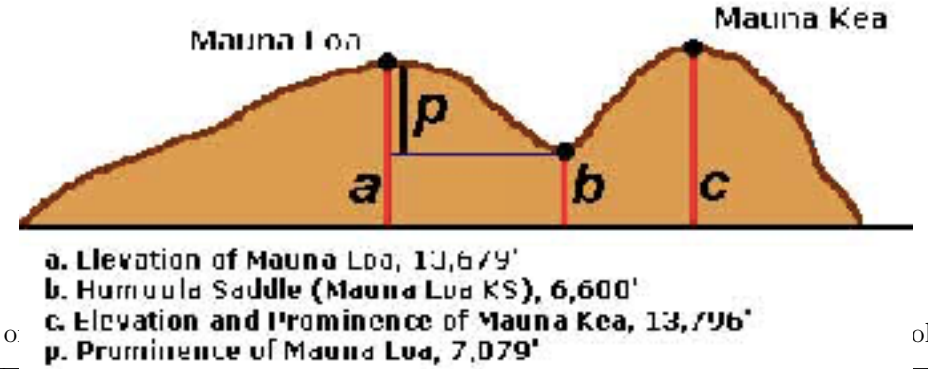
ζ stacks of P13 & WMAP9 look v. similar simulations look v. similar

Topography of the CMB Web & Interstellar Web

statistics of CMB / dust / synch intensity & polarization of maps
oriented stacking on field points, peaks & saddle points (cols, passes)
to aid in component separation, e.g., of the B-mode of polarization

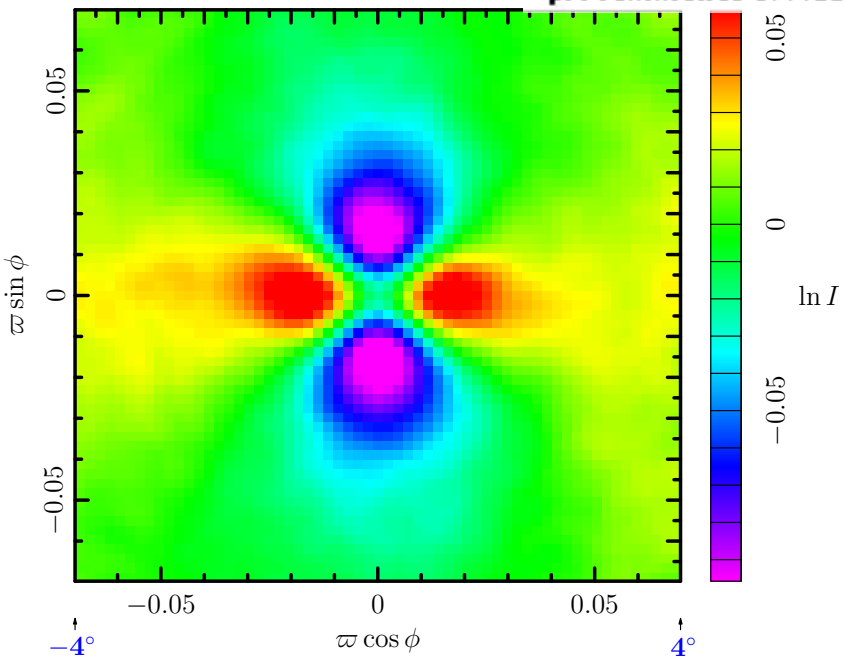
e.g., Planck2015 353 GHz dust = anisotropic non-Gaussian random field
quest for prominences & filament ubiquity, size, shape.

stacked + Hessian
<ln I \| I-saddle>



stacked + Hessian
+ direction info
<ln I \| I-saddle
broken symm>

stacked on 7779 cols, Hessian o



ols, Hessian oriented