CIFAR CANADIAN INSTITUTE FOR ADVANCED RESEARCH

CITA ICAT Canadian Institute for Theoretical Astrophysics / L'institut canadien d'astrophysique théorique

Dick Bond

= Cosmic Information Theory & Analysis

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

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

CIFAR Cosmology & Gravity Program: >1985, 20 Sr Fellows & Fellows (5@UofT), 17 associates + 6 Advisory Board members; CITA: 6+1 faculty, ~25 PDFs & Sr RAs + ~15 grad students; Bond: projects with 3-2 grad students, 4-1 SrRAs, 2 PDFs (++)

Cosmic history: what is U made of? Planck13$\Rightarrow \rho_{dm}/\rho_b = 5.4$

$\Rightarrow \rho_{de}/\rho_{dm} = 2.7$ & $\Omega_m = 0.31 \pm .01$, $\Omega_\Lambda = 0.69 \pm .01$

How Structure in the Universe Arose?: *fluctuation generation in curvature from an early inflaton: isocurvature, Gravity Wave, non-Gaussianity signatures*

(coherence + quantum noise => incoherence via entropy/information generation)

via ***nonlinear lattice simulations of multiple scalar fields*** *at the end of inflation*

=> Anomalies and intermittent non-Gaussianity

CMB*ology* & ***x*CDM, *x*=dark energy+*tilt***: the cosmic standard model

Planck *cosmology Mar13 precision on cosmic parameters* 2011-12; **14-15 pol *ACTpol, ABS, Spider,*** ***AdvACT,*** *GLP, .. ALMA, CARMA,* ***Mustang2*** *on GBT,* ***COMA, CCAT.. CHIME*** *21cm*

morphs *into the nonlinear* ***Cosmic Web:*** ***clusters*** *t/k* **SZ**, ***filaments, voids; galaxies*** **CIB,CO,HI**

*via hydro sims with feedback tSZ; PeakPatch mocks 1st *, dG,Gals, cls/gps, Xcorr, nonG++*

What is the fate of the U: dark energy properties driving late inflation

SIMPLICITY

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

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

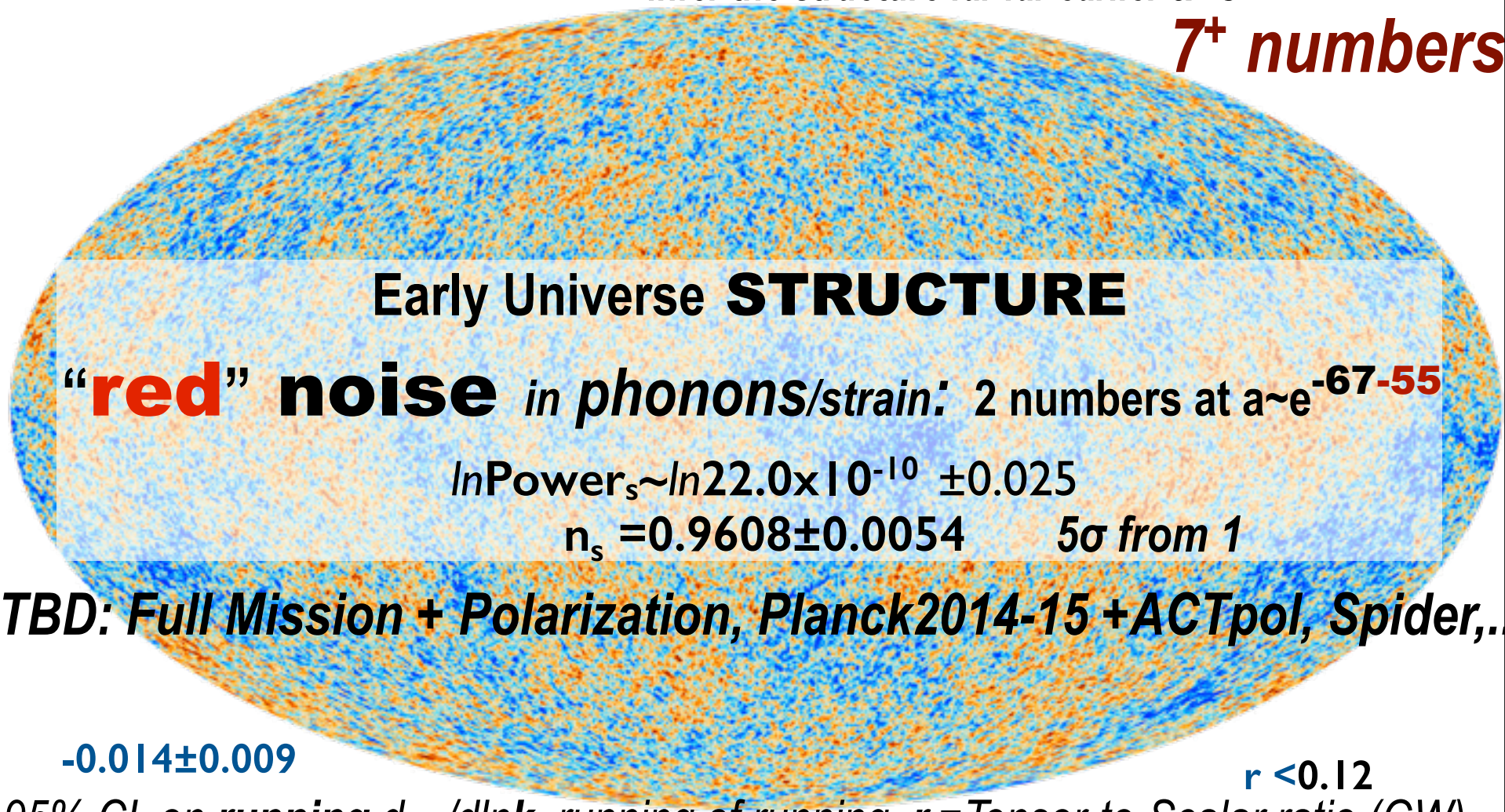
Planck2013 CMB map

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

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

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

7⁺ numbers



Early Universe **STRUCTURE**

"red" noise *in* ***phonons****/strain:* 2 numbers at $a\sim e^{-67-55}$

$ln\text{Power}_s \sim ln\,22.0\times10^{-10} \pm 0.025$

$n_s = 0.9608 \pm 0.0054$ *5σ from 1*

TBD: Full Mission + Polarization, Planck2014-15 +ACTpol, Spider,..

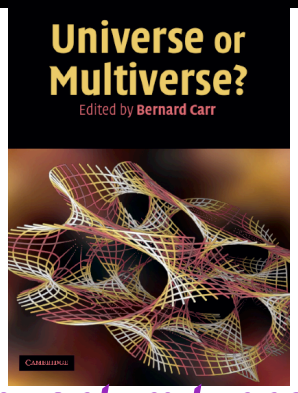
-0.014±0.009

r <0.12

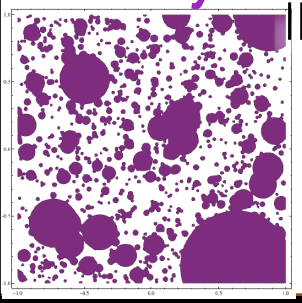
95% CL on ***running*** $dn_s/d\ln k$, *running of running,* ***r*** *= Tensor-to-Scalar ratio (GW),* ***isocurvature modes*** *for axions (<3.9%), baryons, neutrinos, curvatons (<0.25%)*

ultra-Ultra Large Scale Structure of the Universe

Horizons: the ultimate-speed constraint on light & information

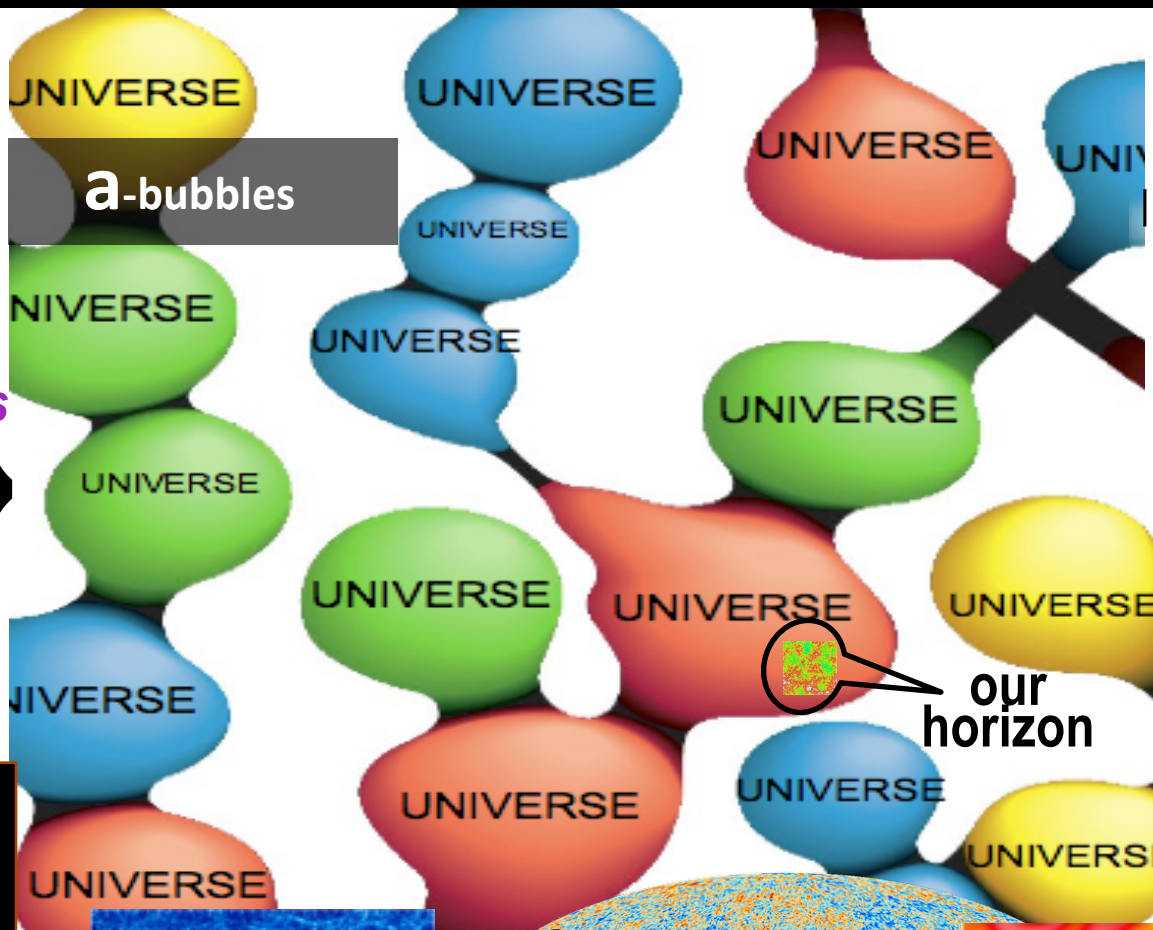


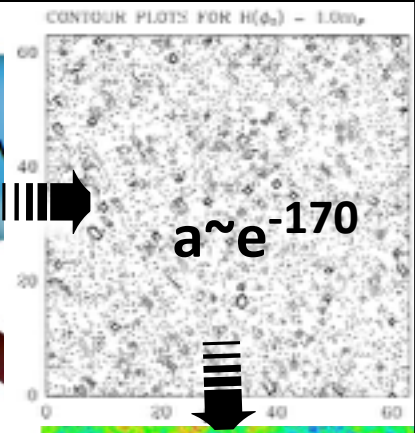
quantum tunnels = bubbly-U

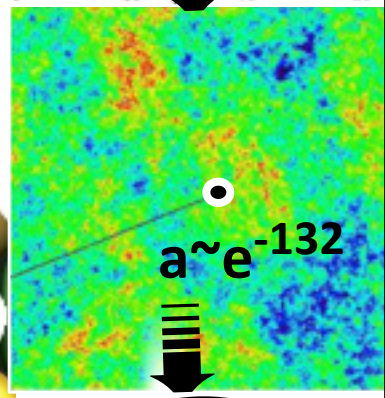


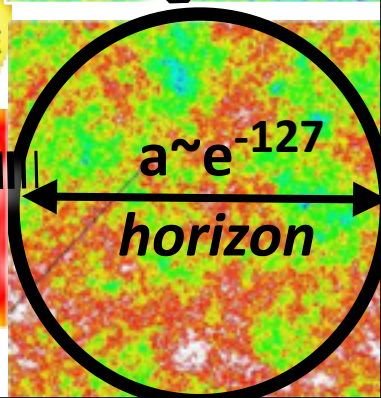
END
a future DE-Void

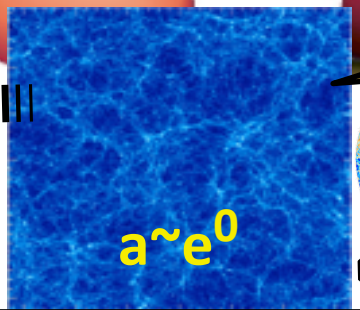
$a \sim e^{+++}$

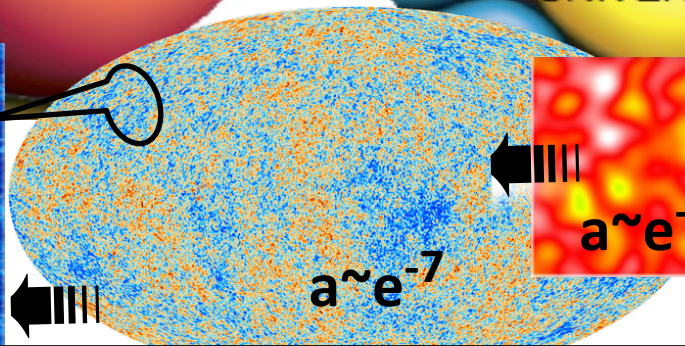












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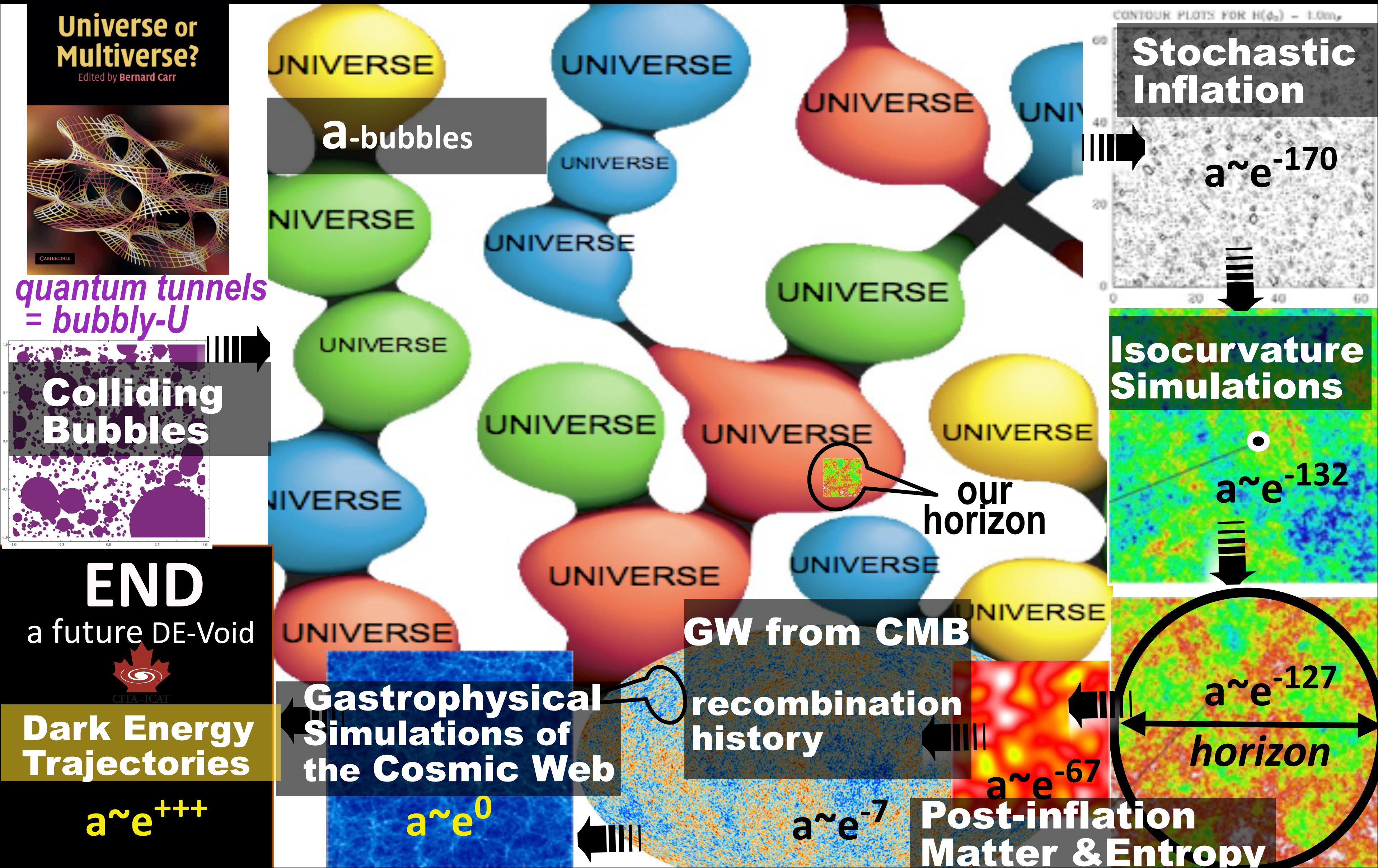
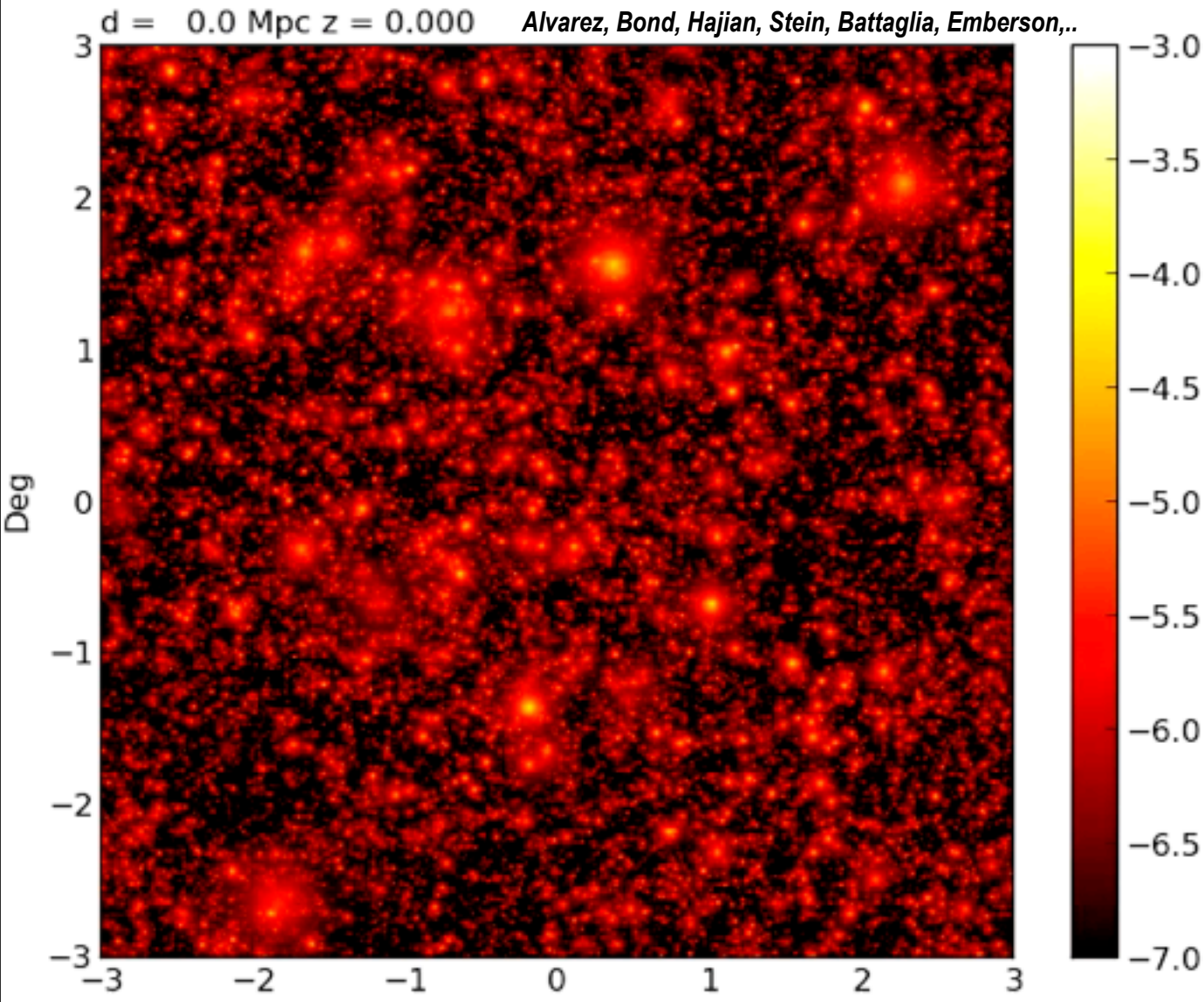


Mocking Heaven: long-wavelength-threaded multi-box-tiled Peak Patch lightcone simulation for Planck-ish tLCDM. mean X-corr tSZ field, 36 sq deg, to z=2

Planck all-sky tSZ mock takes < 1day on SciNet, 30000 core IBM GPC cluster!!



thermal Sunyaev-Zeldovich maps *aka* Peak Patch *thermal pressure* maps *show* ***random field intermittency***

uses our BBPS hydro sims

beyond-mean-Xcorr-field *for* higher *tSZ* map accuracy:

intracluster residual pressure fluctuations

& cluster orientation *via* *Lagrangian-strain to Eulerian* pressure-inertia-tensor

kSZ PkPatch maps use cluster/group dominance

TBD: mocking CIB, HI, CO at high z

Planck, ACTpol, AdvACT, *ALMA, CARMA,* ***Mustang2*** *on GBT,* ***eRosita****.. COMA, CCAT.. CHIME*

CMB Peak Statistics

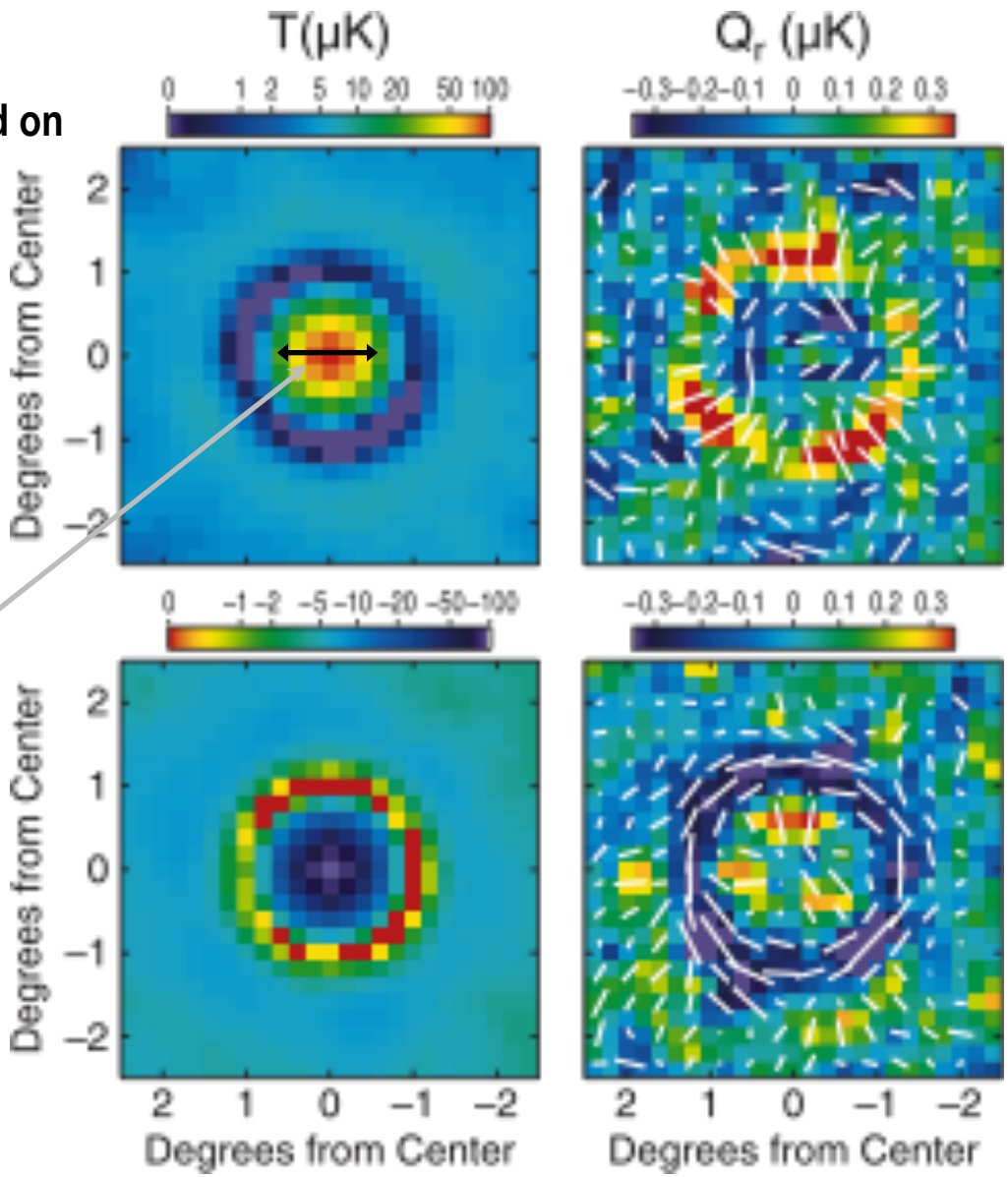
temperature stacked on temperature Peaks

polarization rotated & stacked on temperature Peaks

BAO scale:
145.8 ± 1.2 Mpc

⟷

BAO in the CMB – WMAP9

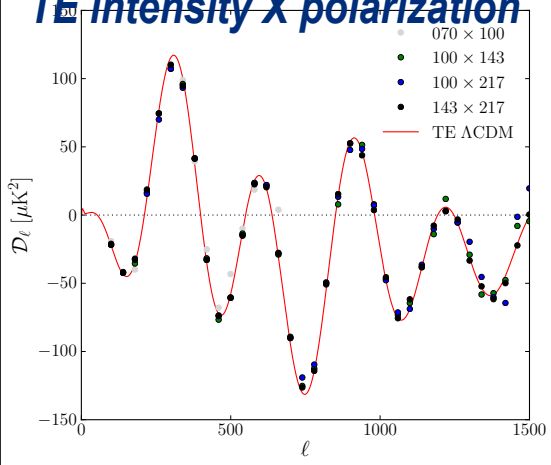


CMB Peak Statistics

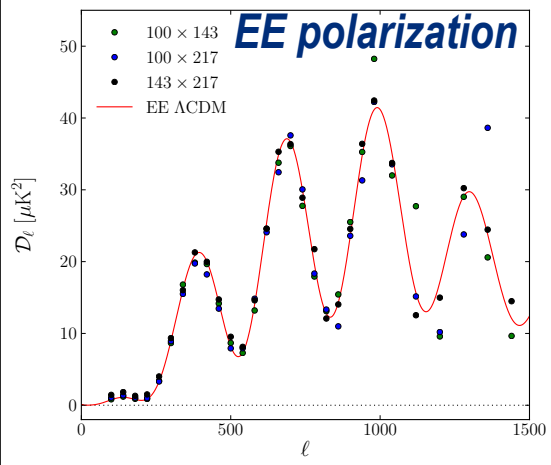
temperature stacked on temperature Peaks

polarization rotated & stacked on temperature Peaks

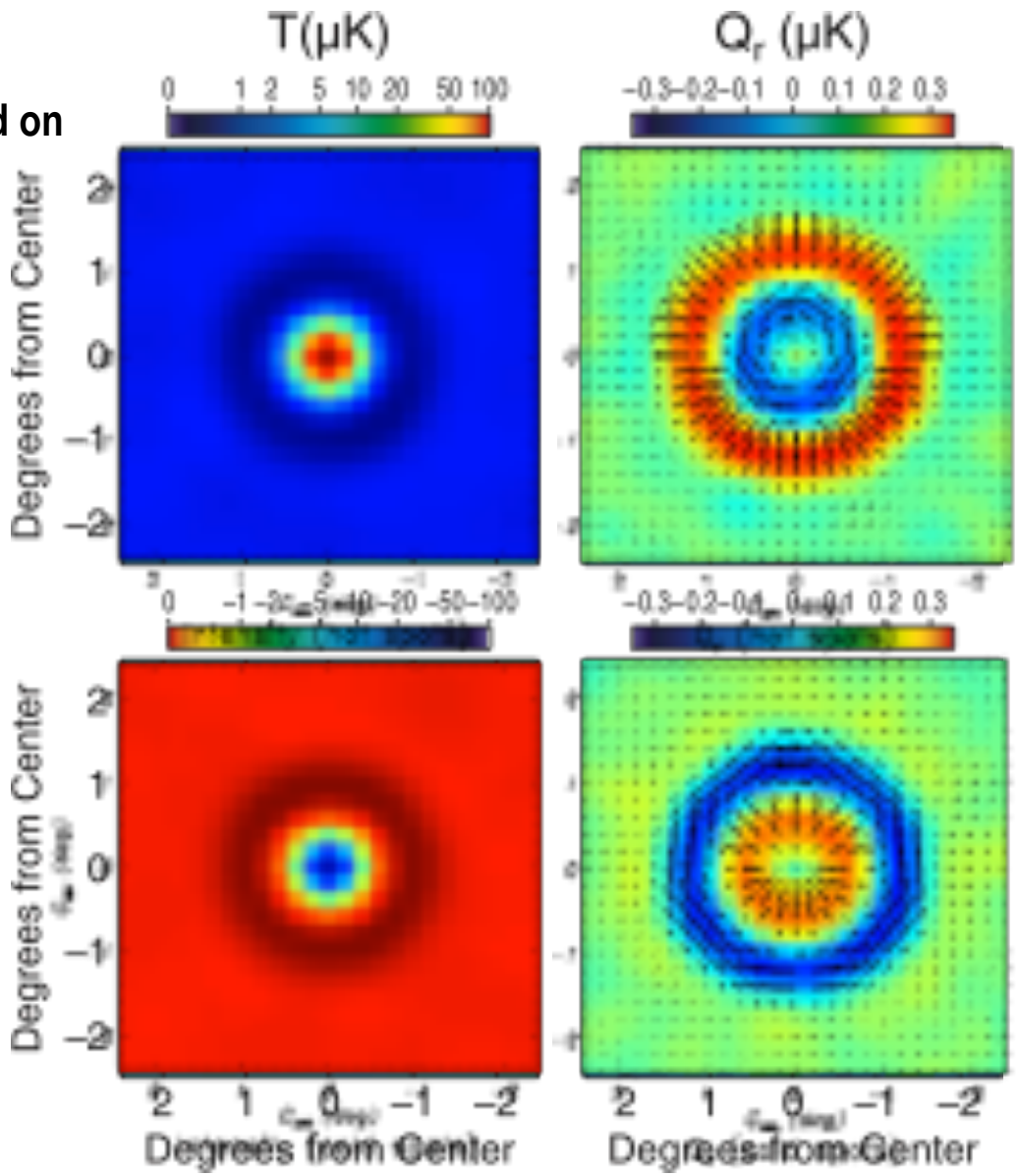
TE intensity X polarization



EE polarization



BAO in the CMB – Planck2013

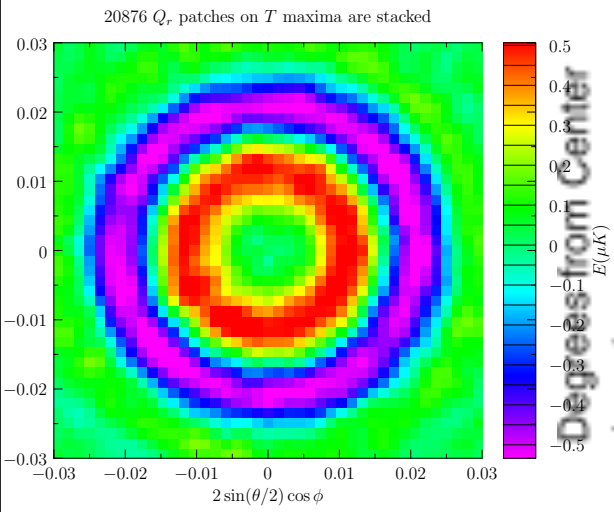


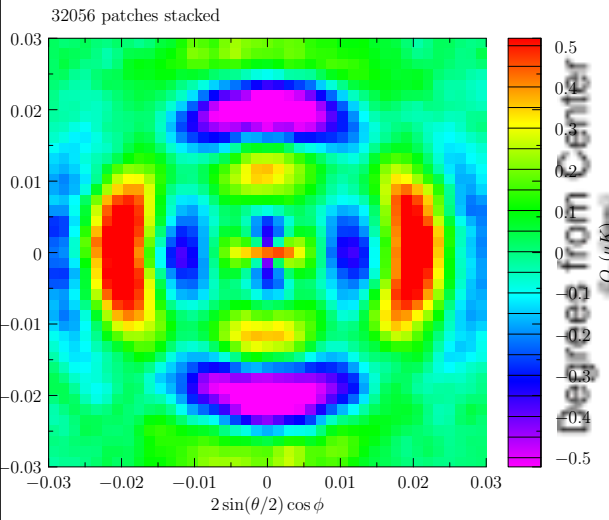
Planck2013 teaser for Planck2014 polarization release

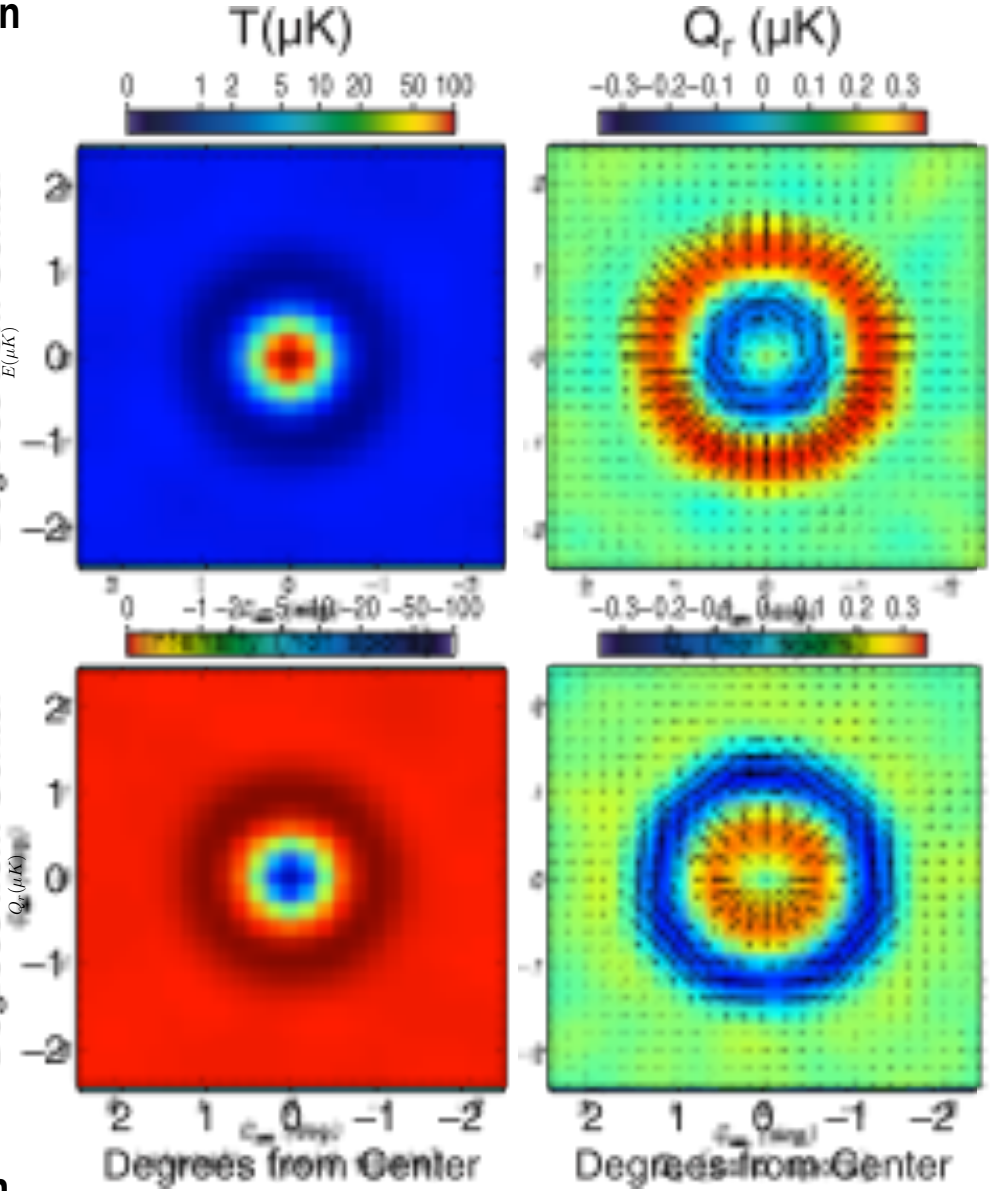
CMB Peak Statistics @CITA

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

polarization rotated & stacked on temperature Peaks, L_S=300





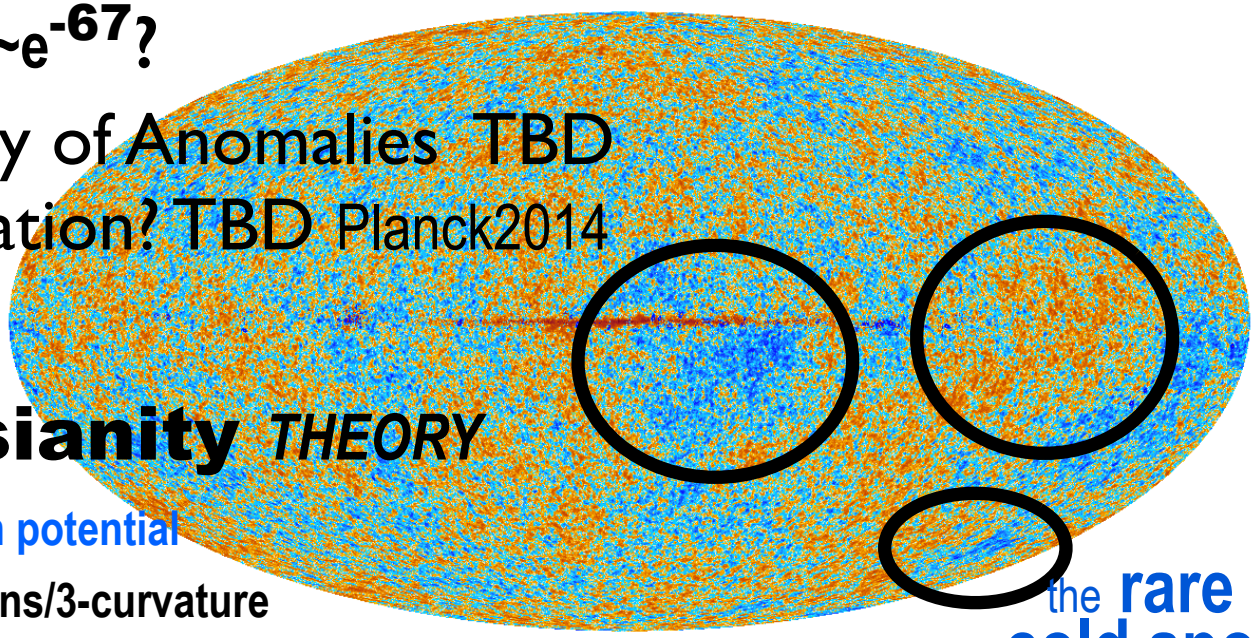


polarization rotated & stacked on oriented anisotropic-strain-Peaks

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

Grand Unified Theory of Anomalies TBD

Anomalies in Polarization? TBD Planck2014



primordial **nonGaussianity** *THEORY*

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

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

from end-of-inflation & preheating chaos

the **rare cold spot**

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

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

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

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

ANALYSIS

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

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

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

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

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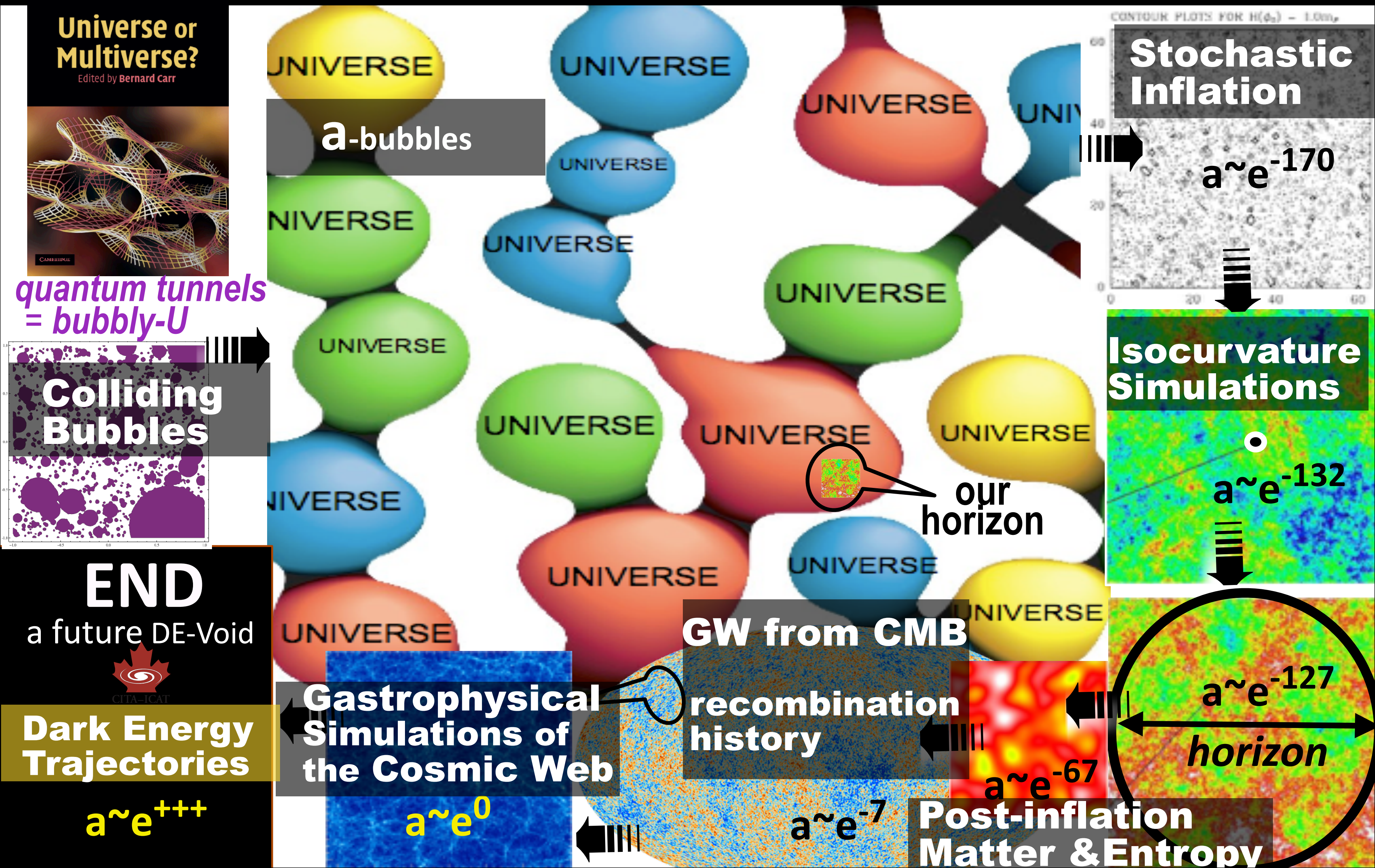
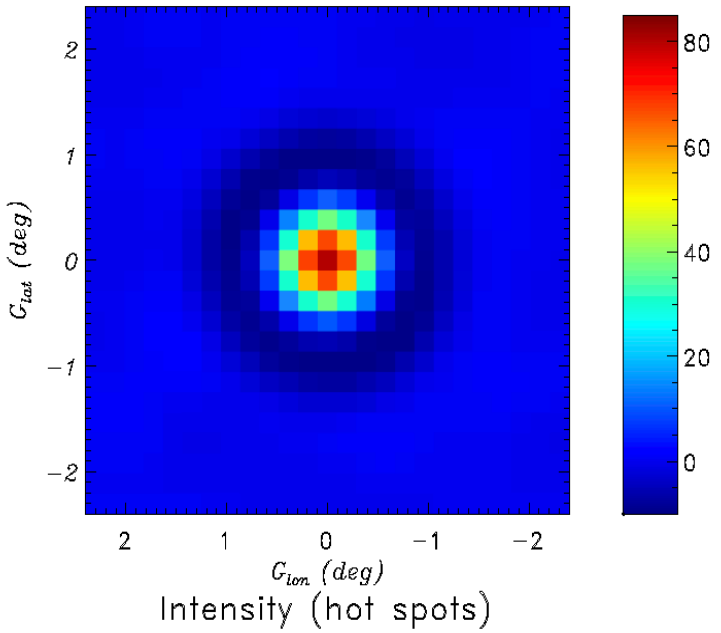
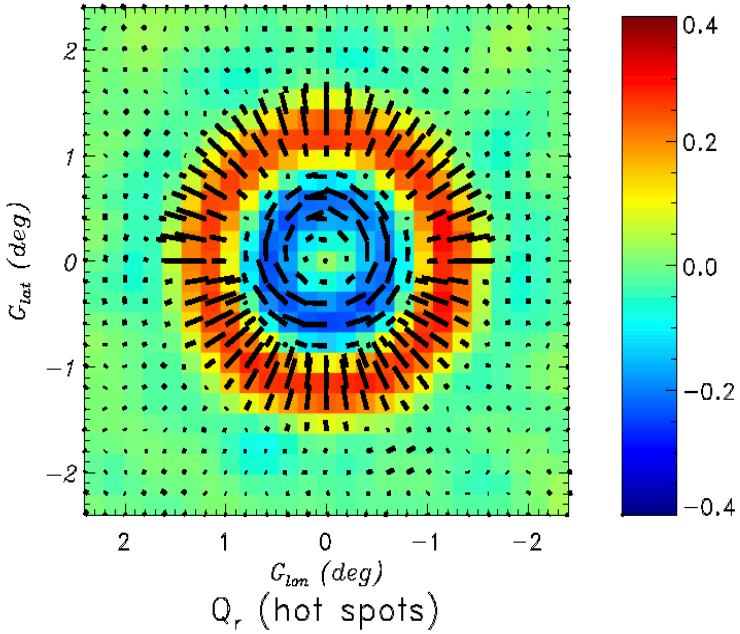


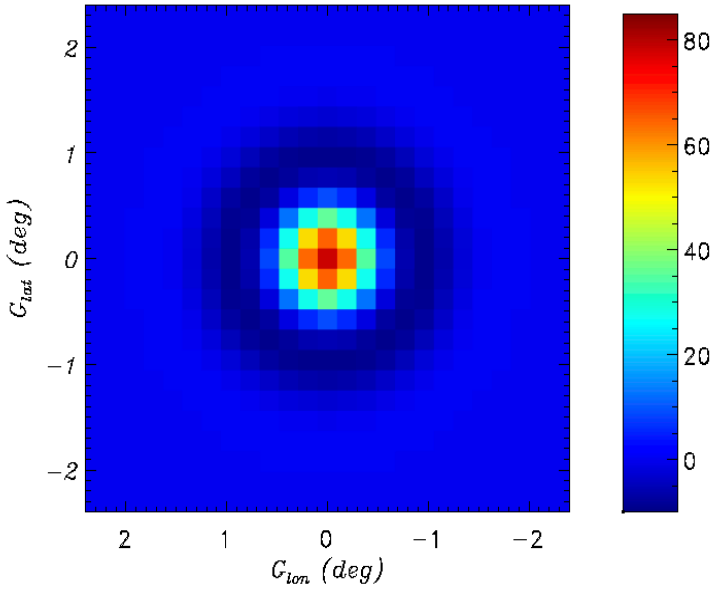
P1.3: stacked intensity and polarization around hot & cold spots: data vs simulation

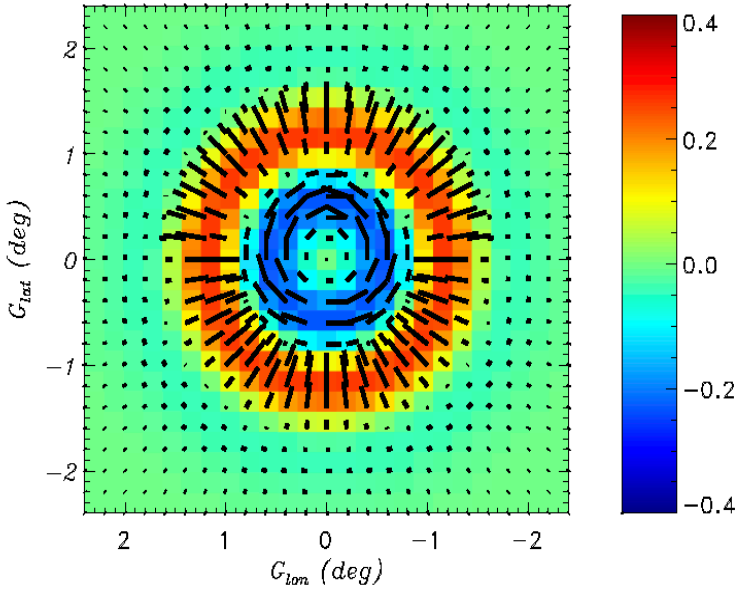


Intensity (hot spots)



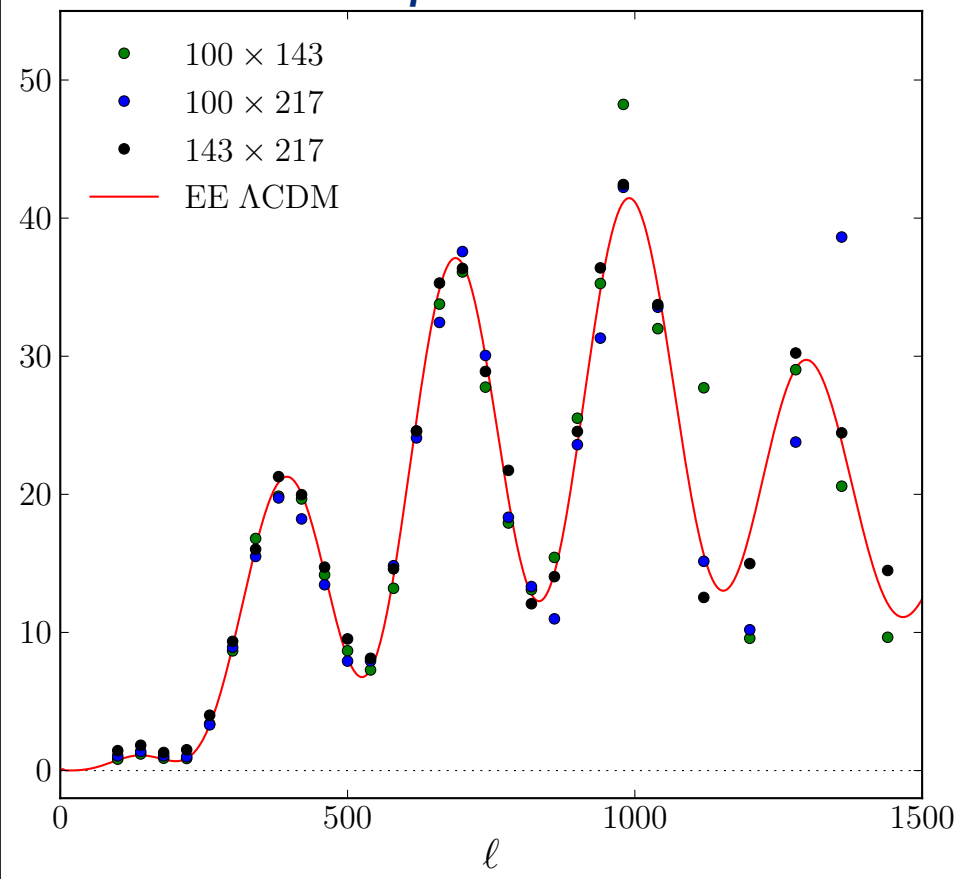
Q_r (hot spots)



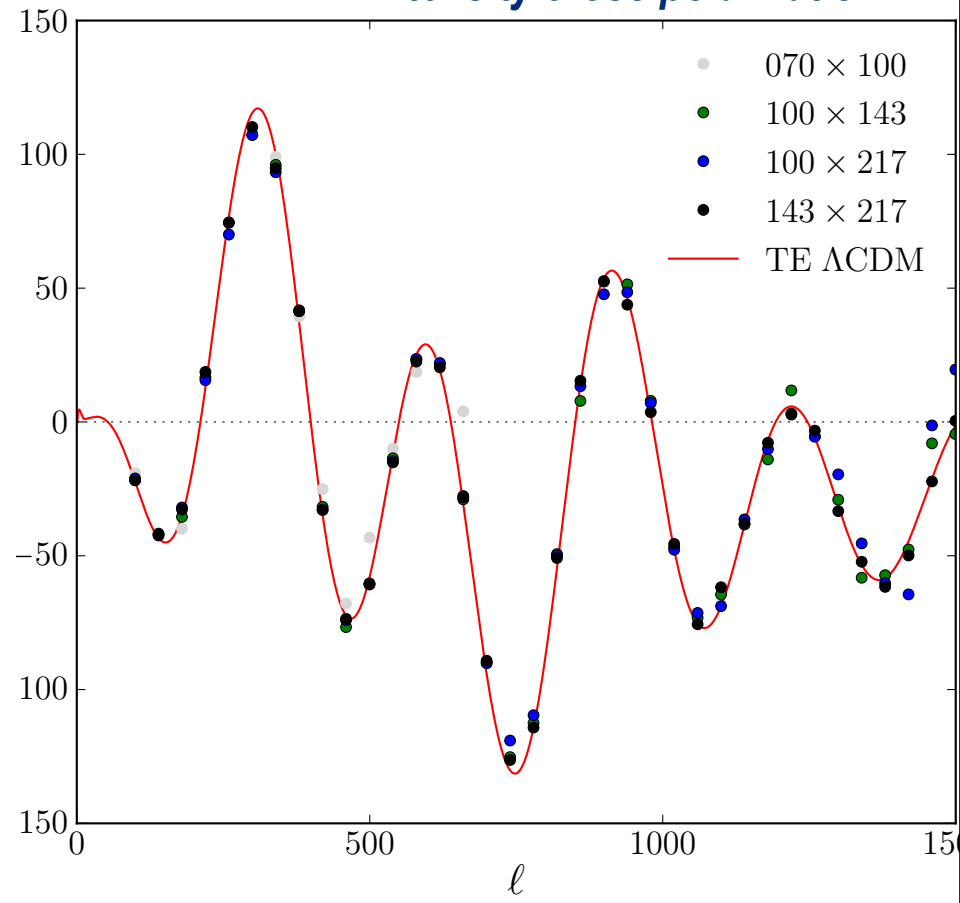


best-fit P1.3yr TT model predicts the polarization. works perfectly at all frequency cross correlations strengthens the case for the Galactic/extragalactic nuisance parameter model being accurate - error bars on EE and TE are not shown. for 2014

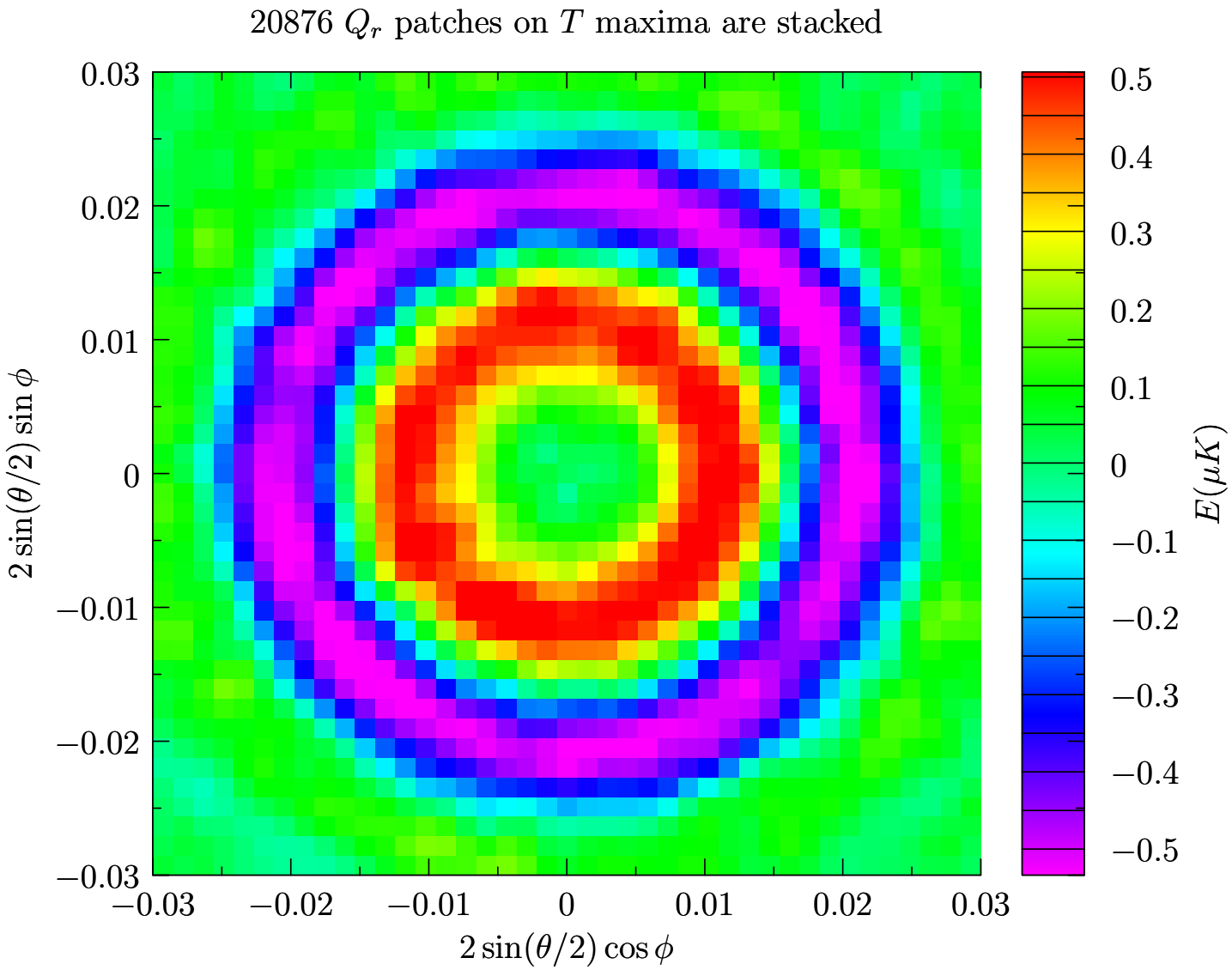
EE polarization



TE intensity cross polarization



polarization rotated & stacked on ~20K Peaks in the temperature field. LG=300



polarization rotated & stacked on ~32K oriented Peaks in the anisotropic-strain-eigenvalue field