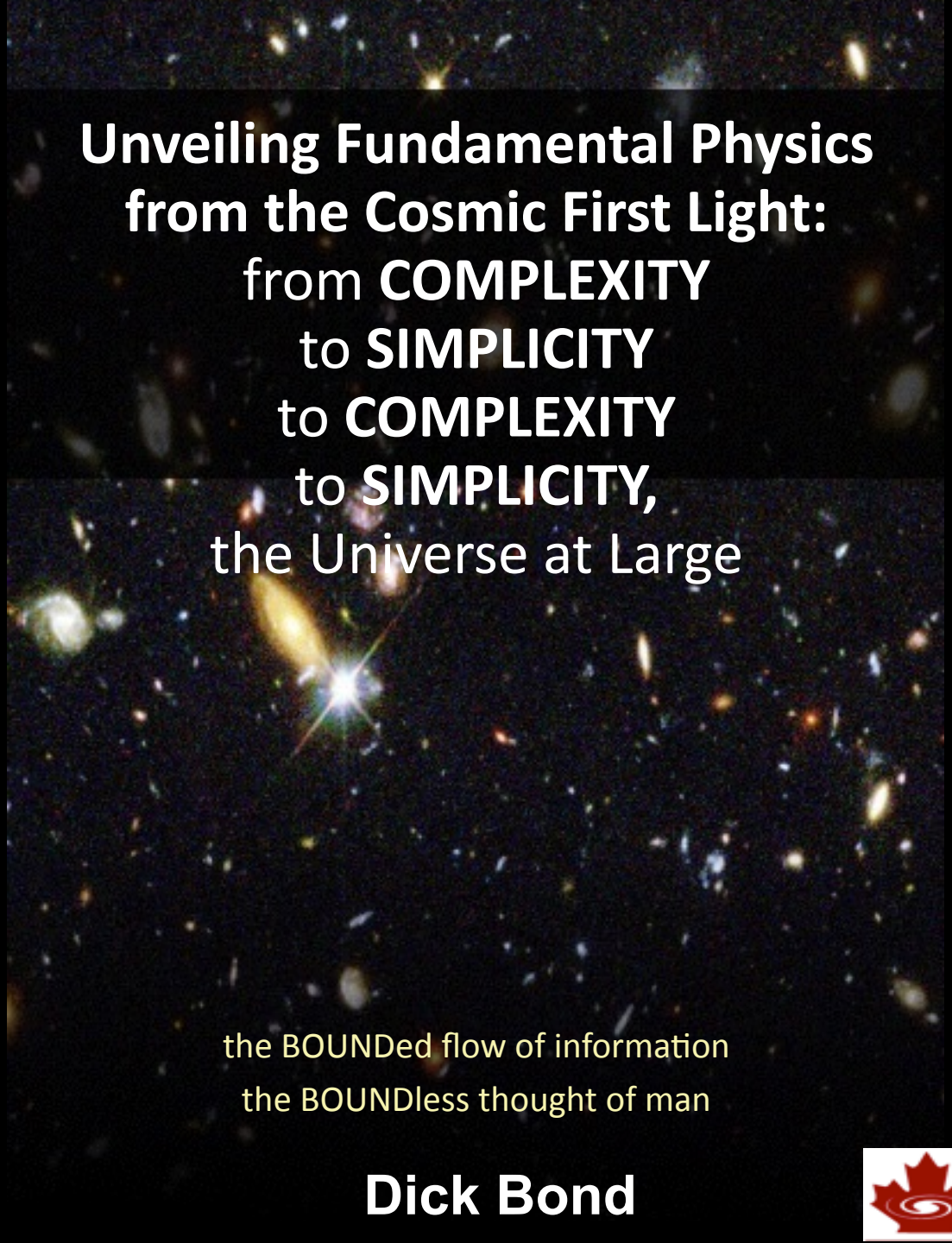


Unveiling Fundamental Physics from the Cosmic First Light:

from **COMPLEXITY**
to **SIMPLICITY**
to **COMPLEXITY**
to **SIMPLICITY,**
the Universe at Large

the BOUNDed flow of information
the BOUNDless thought of man

Dick Bond

CIFAR
CANADIAN INSTITUTE FOR ADVANCED RESEARCH

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

“To me every hour of the light and dark is a miracle. Every cubic inch of space is a miracle.”

– Walt Whitman

IN EVERY teaspoon of air ~*5* cubic cm

Ordinary Matter ~amu /nm^3 4.8% O_2 N ; H,He

THE DARK

Dark Matter

~amu /m^3 26.0 ± 1% compressed in MilkyWay ~0.1 amu /cm^3 ; for LHC@CERN-type relics ~ 1 every 10 cm

Dark Energy

~vacuum potential ~ 3 amu /m^3 69.2 ± 1.0%

THE LIGHT

cosmic radiation

the 1st light of the universe 412 /cm^3 0.005%

cosmic neutrinos ~cosmic photons > 0.47%

cosmic gravity waves << cosmic photons

THE VACUUM

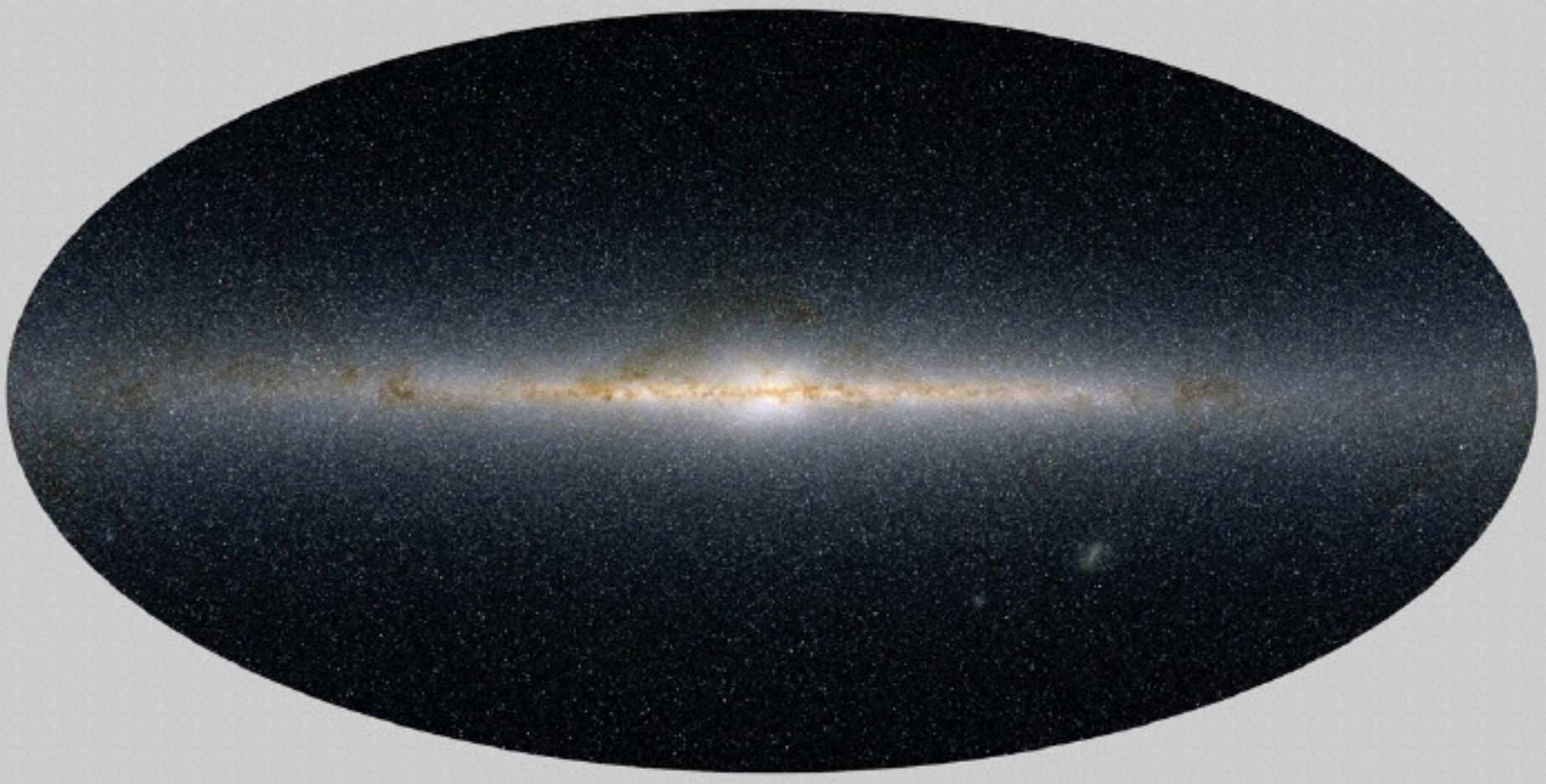
Higgs@CERN vacuum origin of mass

vacuum fluctuations origin of all the cosmic structure we see

\

Milky Way in infra-red:

half a billion stars, a disk galaxy



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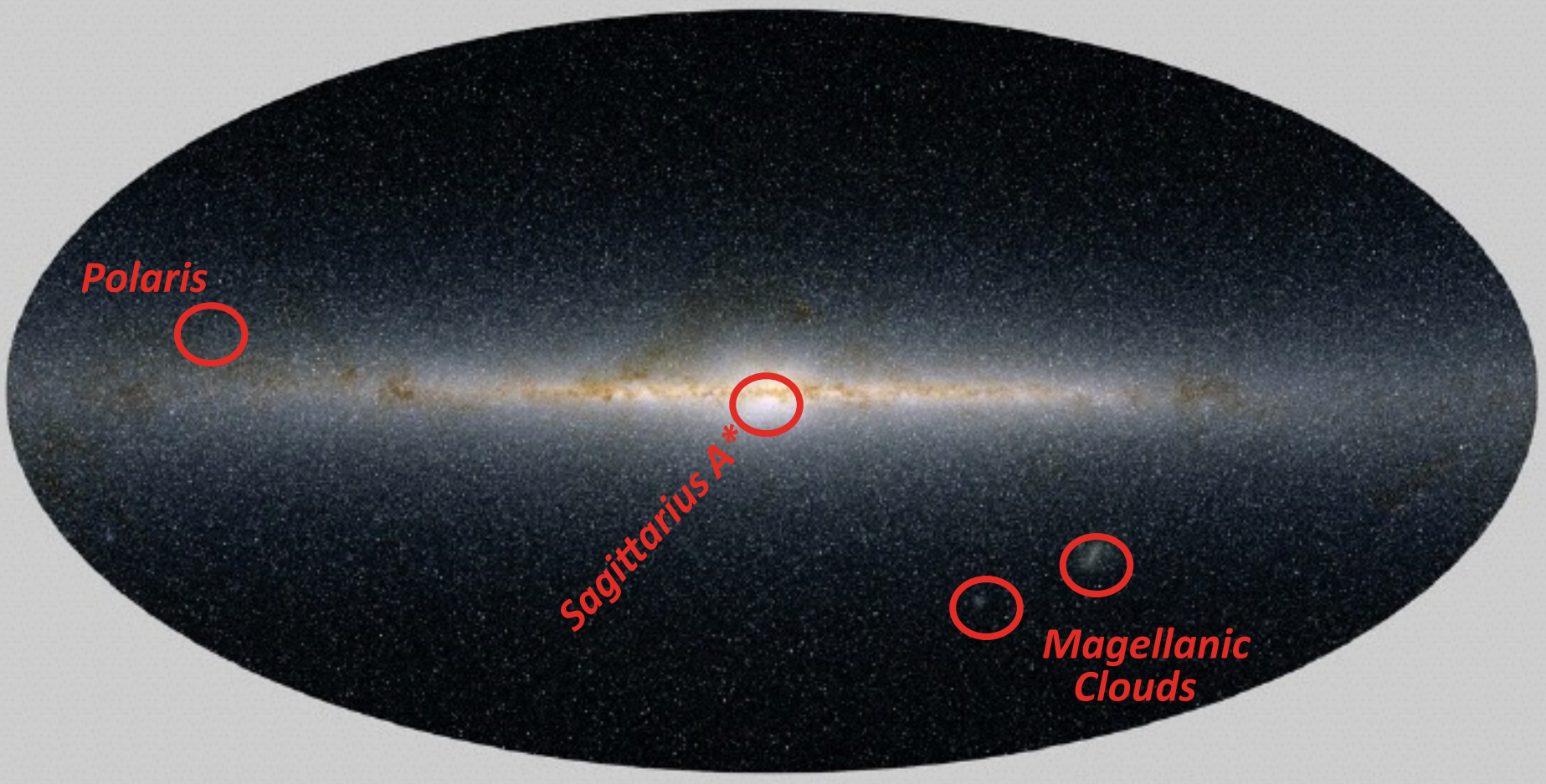
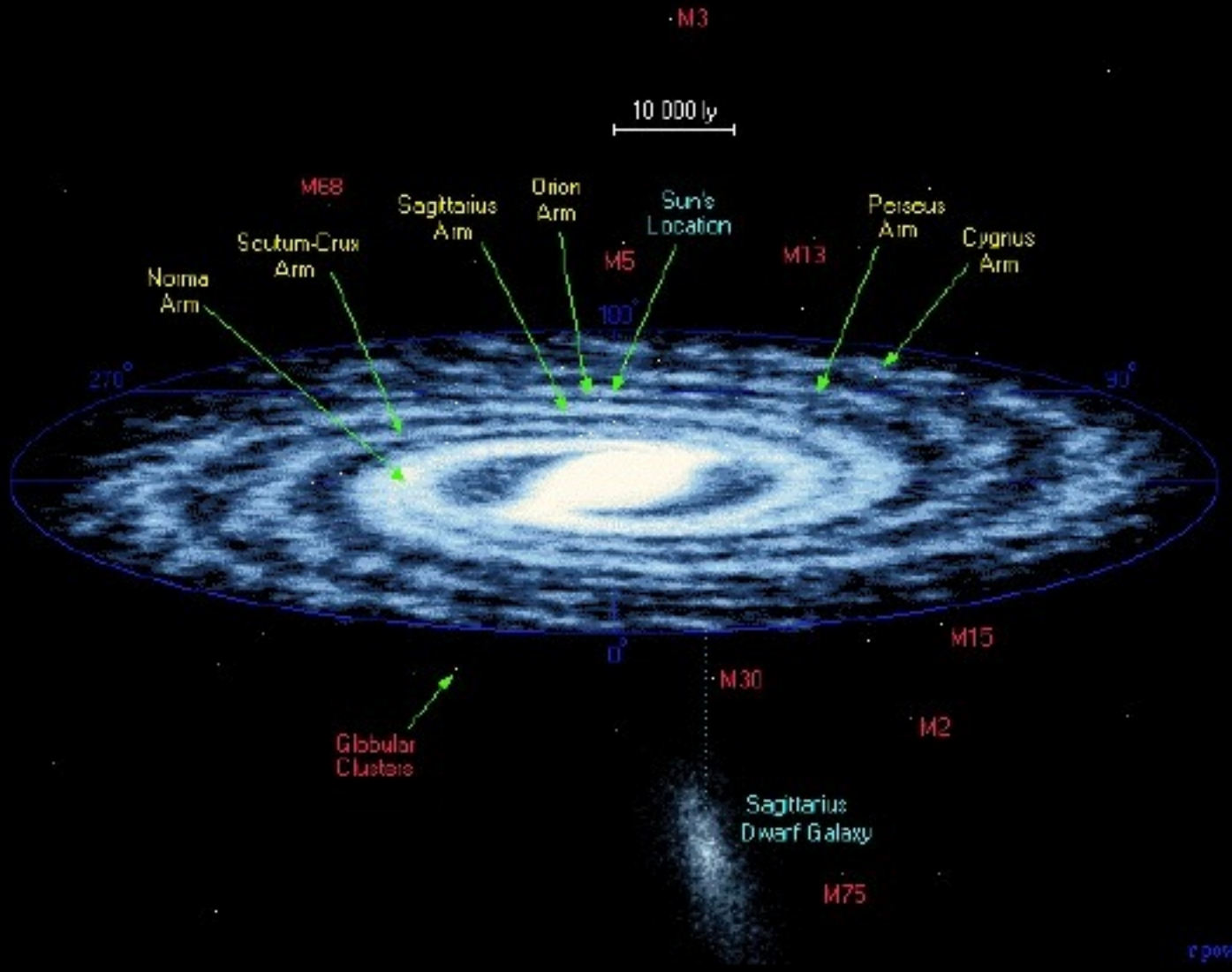


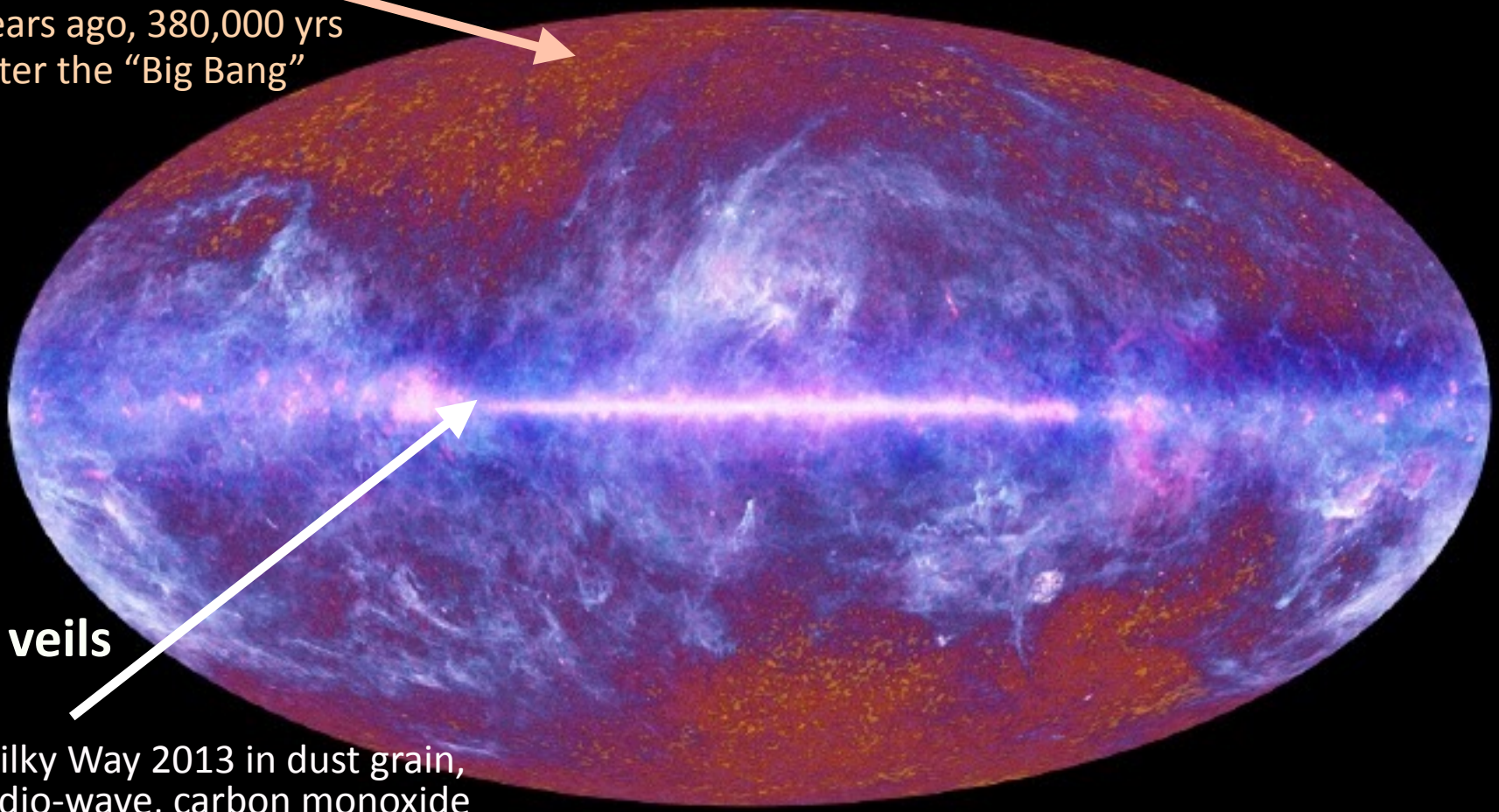
Milky Way in 3D:

a disk galaxy with a large dark matter halo



COMPLEXITY of here & now

the primordial light, released 13.8 billion years ago, 380,000 yrs after the "Big Bang"



7 veils

Milky Way 2013 in dust grain, radio-wave, carbon monoxide emissions; plus stellar, X-ray, gamma ray, cosmic ray emissions ...

COMPLEXITY of here & now

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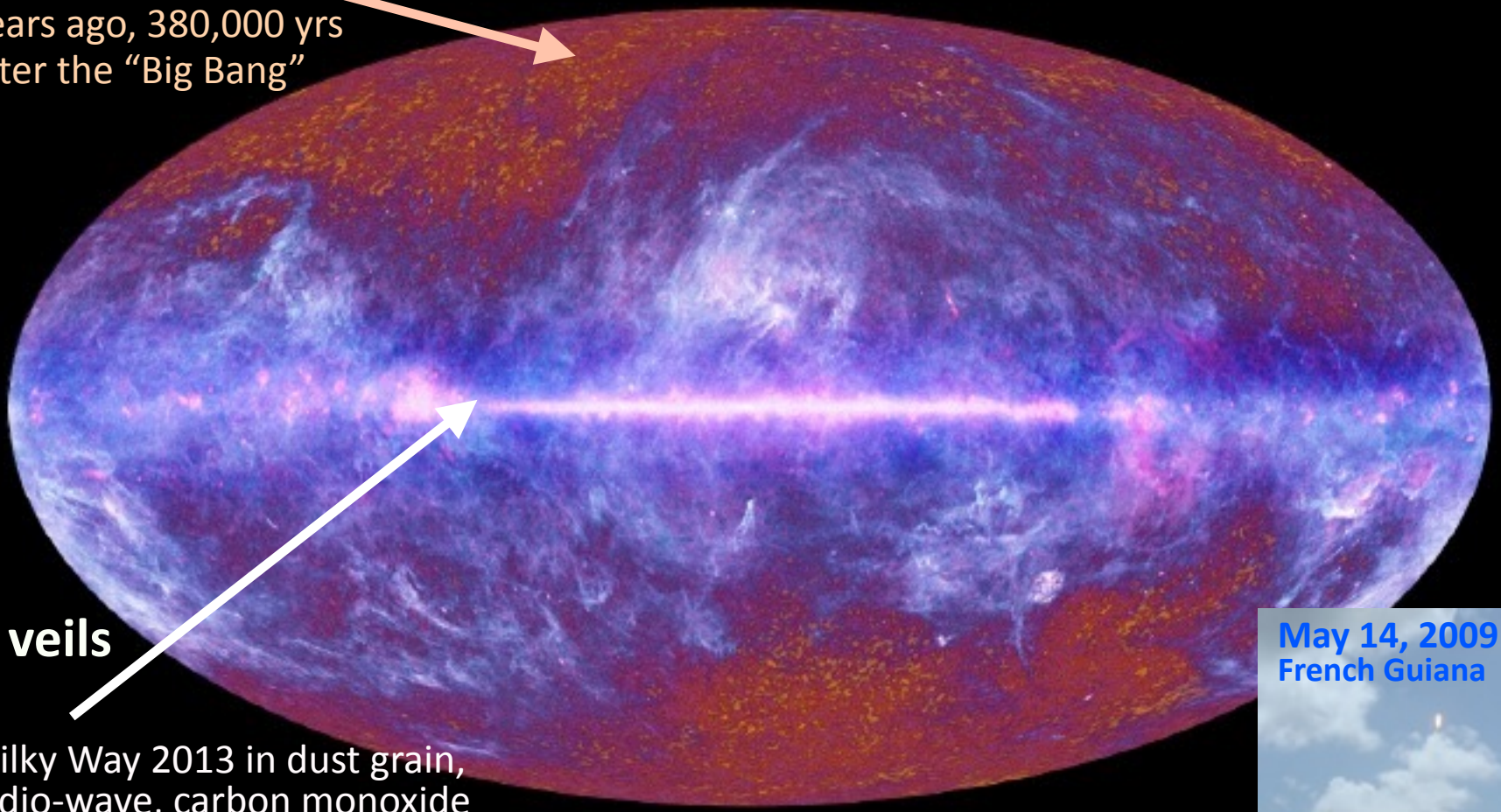

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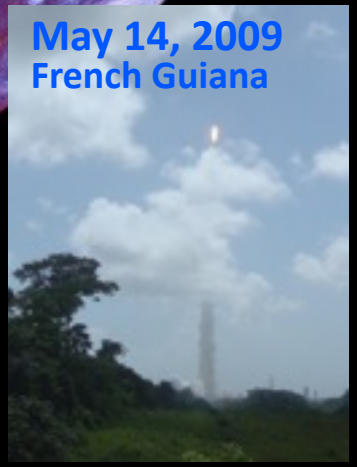


esa

planck

cnes

agenzia spaziale italiana

NASA

cnrs

DTU Space
National Space Institute

Science & Technology Facilities Council

INAF ISTITUTO NAZIONALE DI ASTROFISICA

CSIC
Consejo Superior de Investigaciones Científicas

National Research Council of Italy

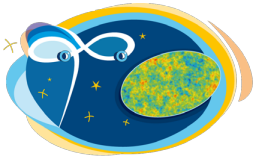
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN

CSA ASC

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

UK SPACE AGENCY

MAX-PLANCK-GESELLSCHAFT



PLANCK LFI

HFI PLANCK
a look back to the birth of Universe

IAS orsay

IAP

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

Aalto University

ioa

KICC

Cavendish Astrophysics

University of Cambridge

Cardiff University
Prifysgol Caerdydd

irfu
cea
saclay

CEFCA

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IASF

cnrs INSU
Observer & comprendre

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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
Institut de Planétologie et d'Astrophysique de Grenoble

ISDC
Data Centre for Astrophysics

JPL

Laboratoire de l'Accélérateur Linéaire

l'Observatoire de Paris — LERMA

LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie

MilliLab

Max-Planck-Institut für Astrophysik

NUI Maynooth

INAF Osservatorio Astronomico di Padova

University of Oxford

Dipartimento di Fisica Sapienza Università di Roma

Science & Technology Facilities Council
Rutherford Appleton Laboratory

Tor Vergata

Osservatorio Astronomico di Trieste

UBC

UC Universidad de Cantabria

UCSB

SISSA

ALMA

ESO

University of Sussex

Haverford

esa

University of Helsinki

Université de Genève

University of Toronto

Université de Paris-Sud XI

asdc
ASI Science Data Center

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

Planck+Herschel Launch May14 09 French Guiana

1.5m telescope,

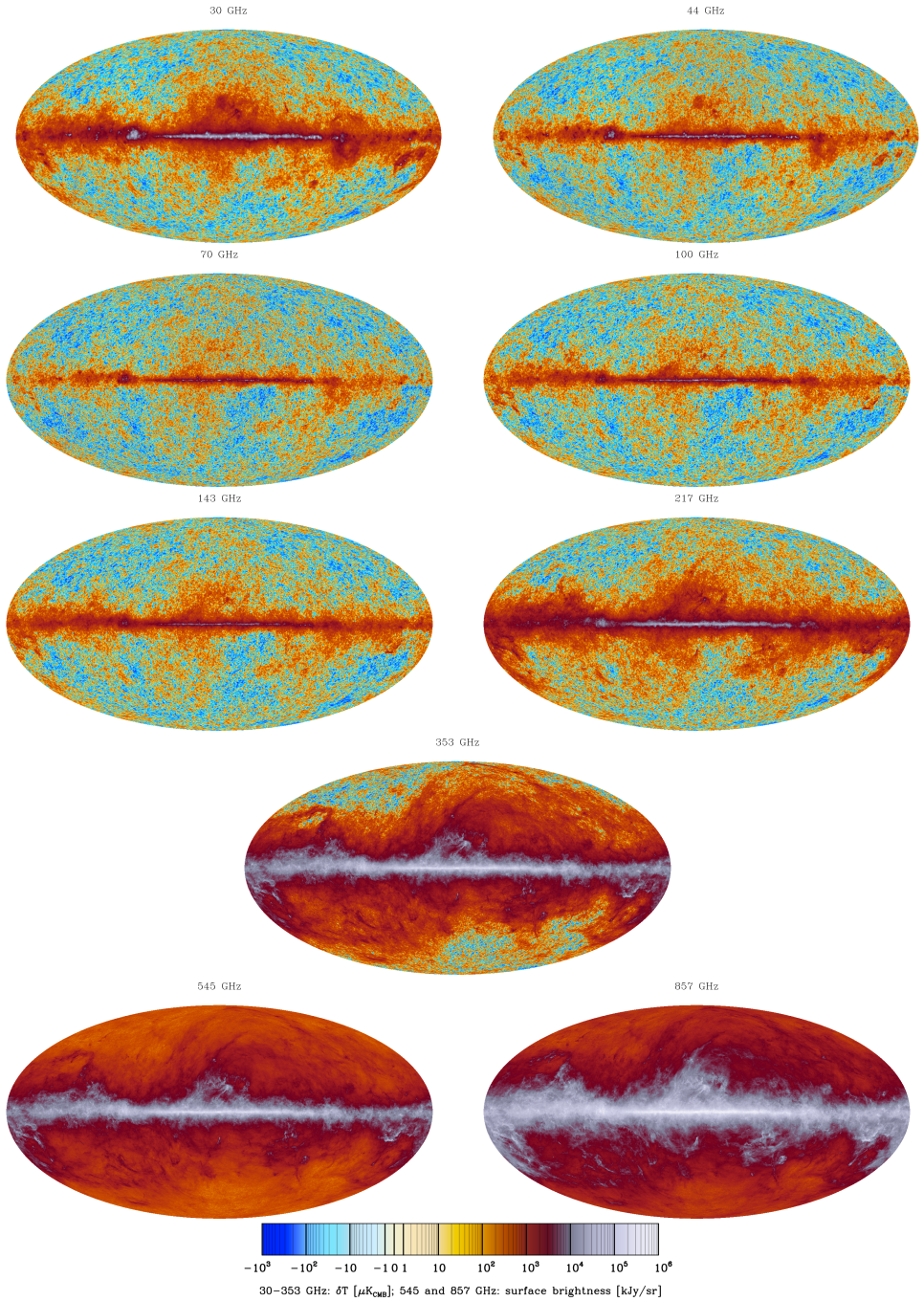
HFI bolometers @6freq <100mK,

LFI HEMTs@3freq,

some bolometers & all HEMTS are polarization sensitive

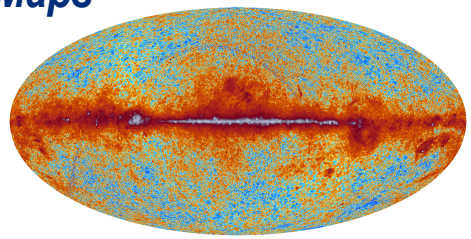
- Left earth at ~10 km/s, 1.5 million km in 45 days, cooling on the way (20K, 4K, 1.6K, 0.1K 4 stage). @L2 on July 2 09; Survey started on Aug 13 09
- spin@1 rpm, 40-50 minutes on the same circle, covers all-sky in ~6 month, ~5 HFI surveys, ~8 LFI surveys
- kicked out of L2 Oct 2013

Planck 1.3yr Frequency Maps



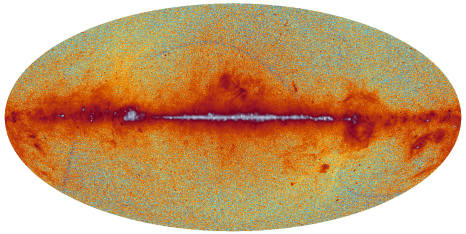
Some Planck Component Separated Maps

*Planck*_2013 30 GHz



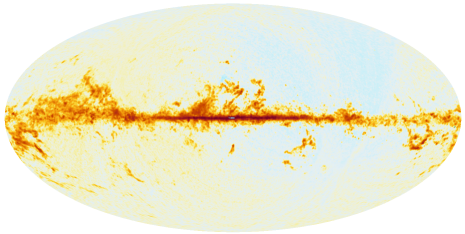
Commander: Low-Frequency Emission Amplitude @ 30 GHz

C/R: Low-Frequency Emission Amplitude @ 30 GHz

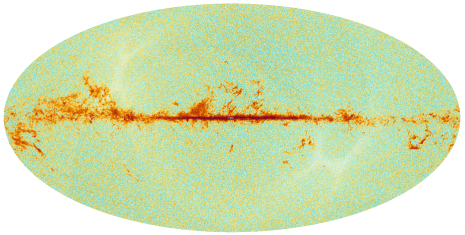


LF Synchrotron + bremsstrahlung

Commander: "discovery" CO map @ 100 GHz

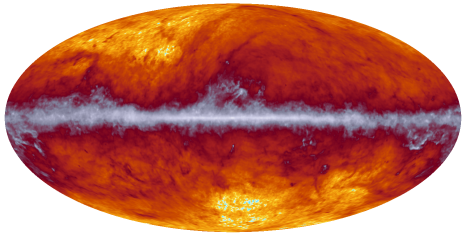


C/R: "discovery" CO map @ 100 GHz

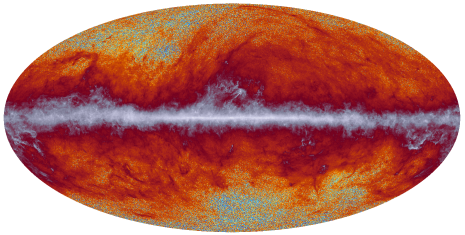


Galactic Carbon Monoxide

Commander: Dust Amplitude @ 353 GHz

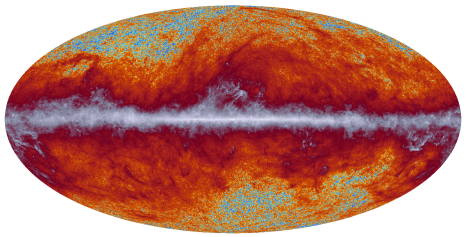


C/R: Dust Amplitude @ 353 GHz



HF Thermal Dust Emission

*Planck*_2013 353 GHz

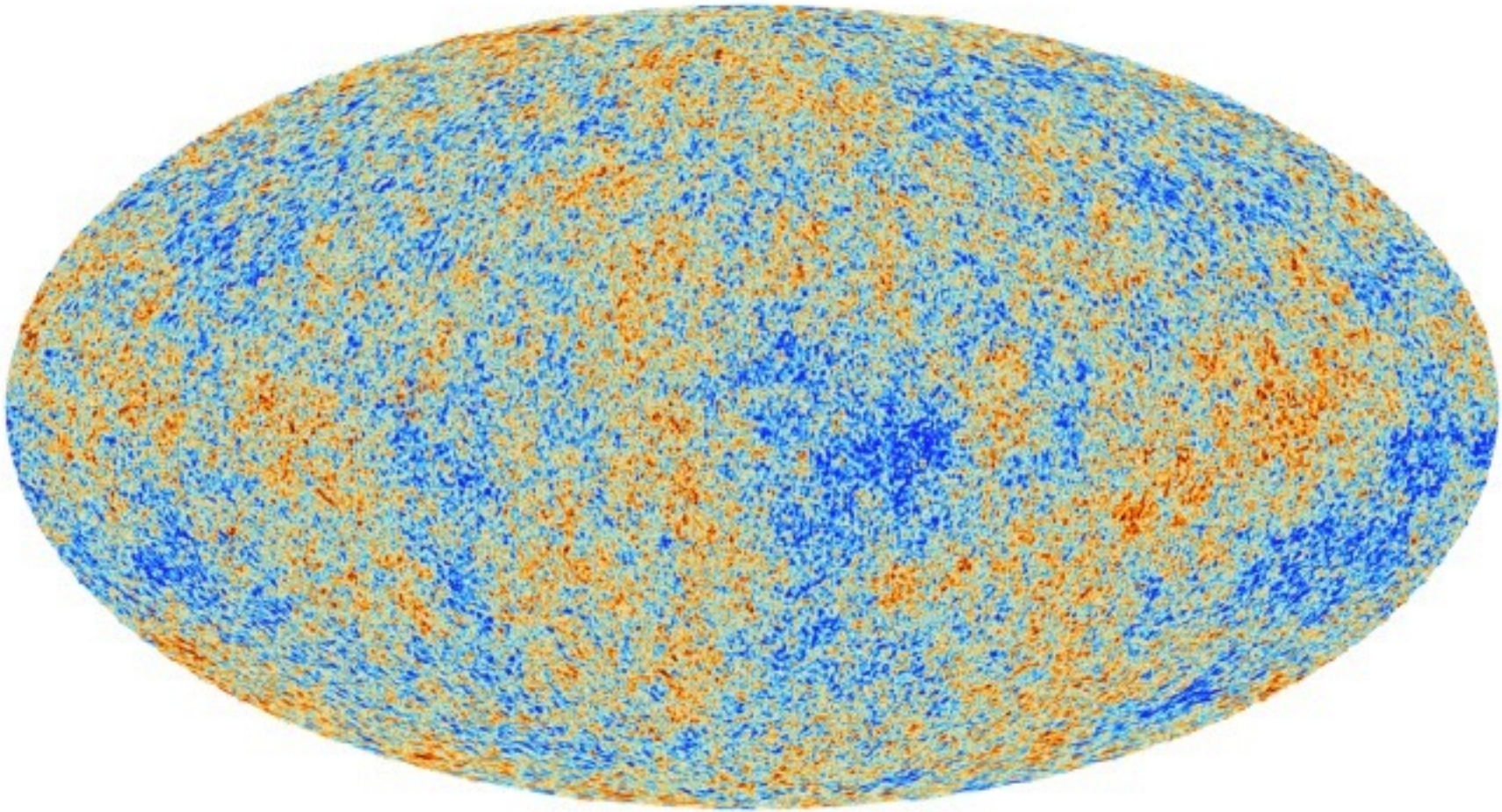


30–353 GHz: δT [μK_{CMB}]; 545 and 857 GHz: surface brightness [kJy/sr]

Planck's primordial light unveiled, March 21, 2013

reveals the SIMPLICITY of primordial cosmic structure

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



Temperature changes in micro-degrees

Google "Planck Satellite 2013 results" yields ~ 1 million links

Google "gravity waves from inflation 2014" yields ~ 0.3 million links"

THE GLOBE AND MAIL

SPACE

New glimpses of ancient light fuel cosmic debate

Government of Canada / Gouvernement du Canada

Canada

Canadian Space Agency

Home > Audiences > Media > News releases > 2013 > Canadian astronomers reveal surprising new portrait of the Early Universe

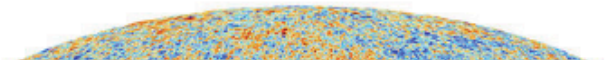
Canadian astronomers reveal surprising new portrait of the Early Universe

The New York Times

Space & Cosmos

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION | ENVIRONMENT | SPACE & COSMOS

Universe as an Infant: Fatter Than Expected and Kind of Lumpy



L'enfance de l'Univers dévoilée

LE MONDE | 21.03.2013 à 11h27 • Mis à jour le 21.03.2013 à 13h44

gravity waves from inflation

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CIFAR cosmologists contribute to new portrait of the Early Universe

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NEWS ARCHIVE

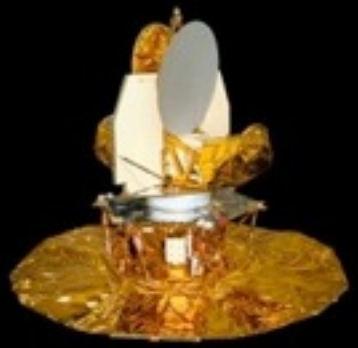
PLANCK

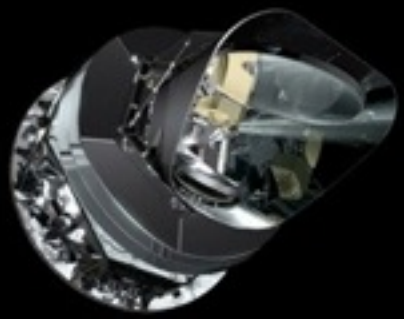
Light

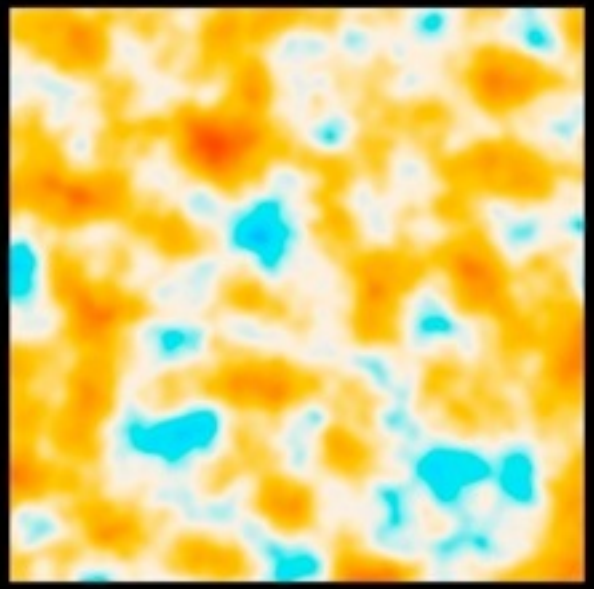
http://www.nytimes.com ***Space Ripples Reveal Big Bang's Smoking Gun*** *By DENNIS OVERBYE MARCH 17, 2014*

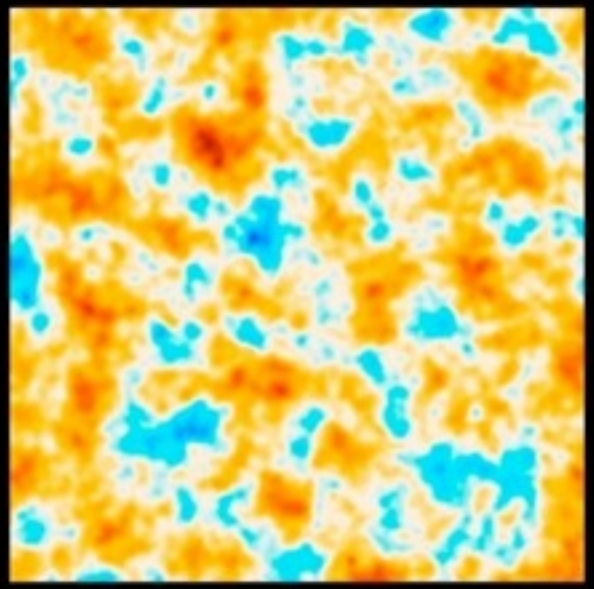
Comparison of CMB Space Experiments: Resolution, 420', 12.5', ~5-7'

COBE 89 launch *WMAP 01 launch* *Planck 09 launch*









COBE WMAP Planck

goal: high enough resolution to plumb all cosmic parameter information. but high L foregrounds, extragalactic sources => higher L expts ACT (1.4'), SPT (1') = PlanckEXT to nail the "nuisance"

SIMPLICITY

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

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

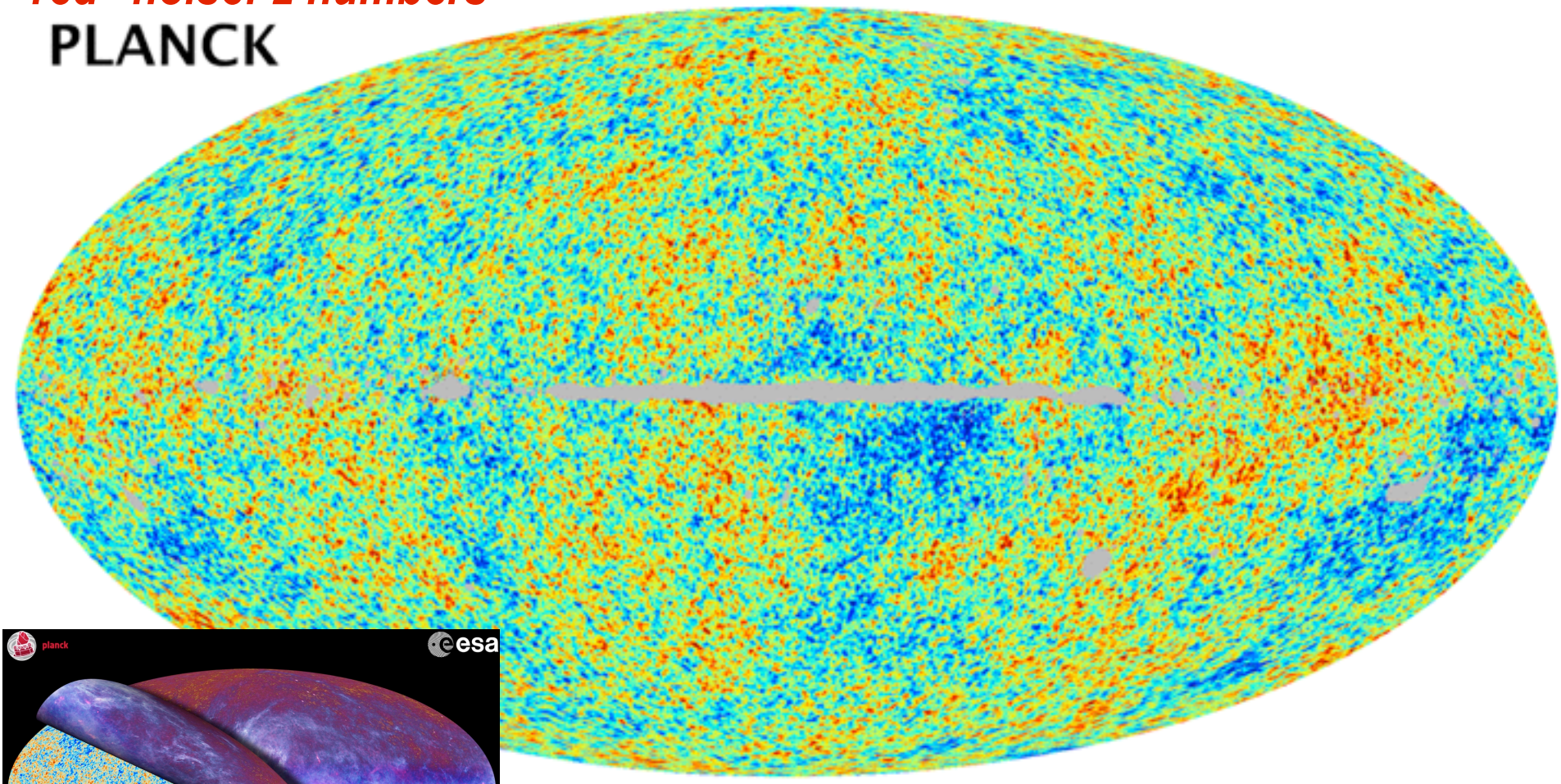
"red" noise: 2 numbers

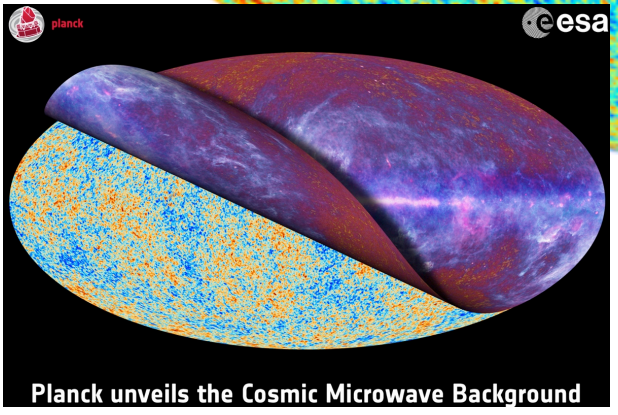
PLANCK

Planck 09 launch

Planck SMICA Map

CMB-data Concordance





Planck CMB/SMICA map, ~5' resolution
+ NILC, SEVEM, C-R 3 independent component separated CMB maps show the same features

SIMPLICITY

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

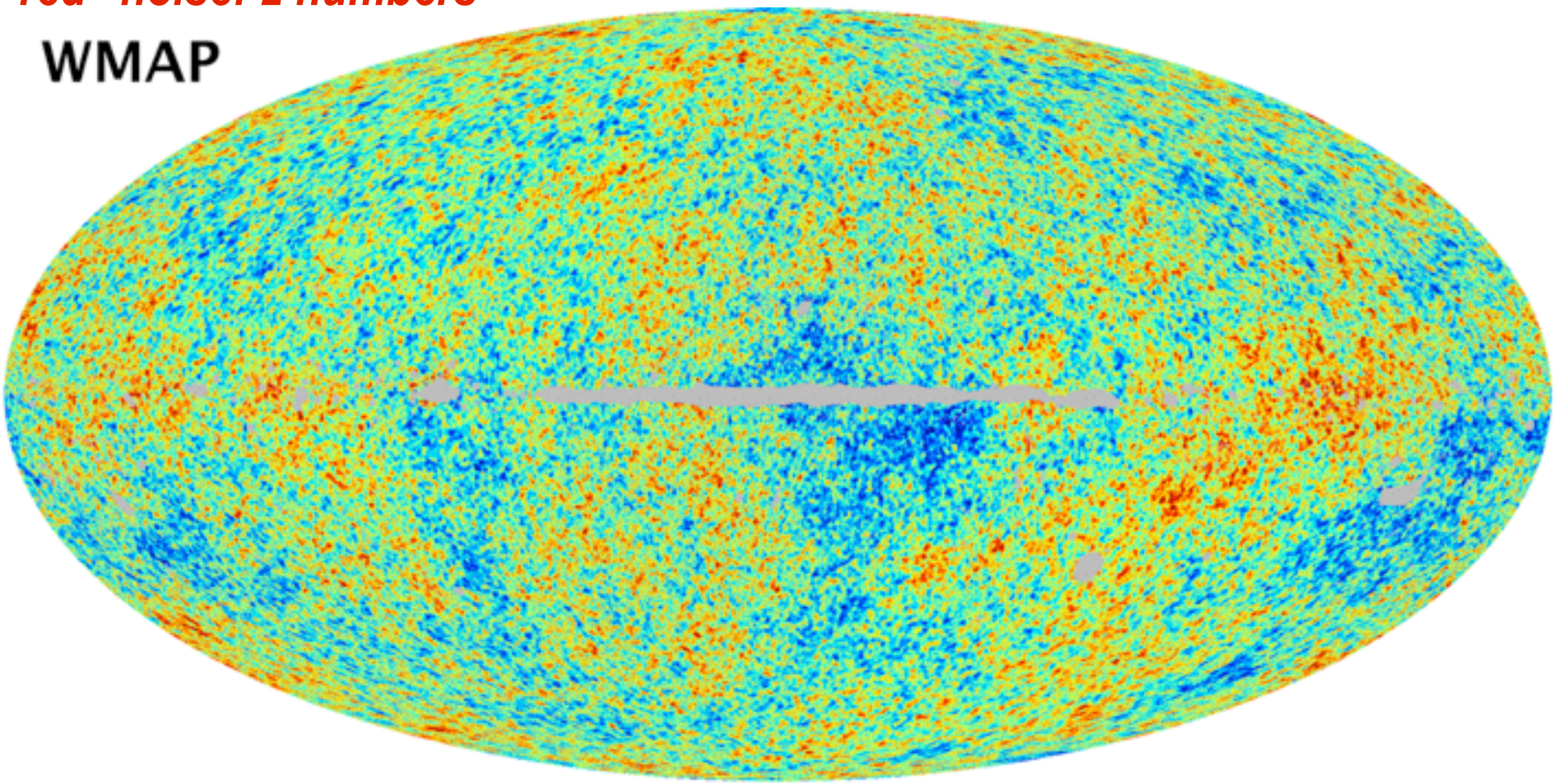
at $a \sim e^{-67+60} \sim 1/10^{30+25}$

"red" noise: 2 numbers

WMAP 01 launch

WMAP W-band, Template Cleaned

CMB-data Concordance



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

similar tremendous agreement with the much higher (5X) resolution ACT & SPT maps

total focus on the 1.2% difference in "calibration" between P13 (HFI &LFI) & WMAP9

Planck's information > 4X WMAP9 in multipoles

SIMPLICITY

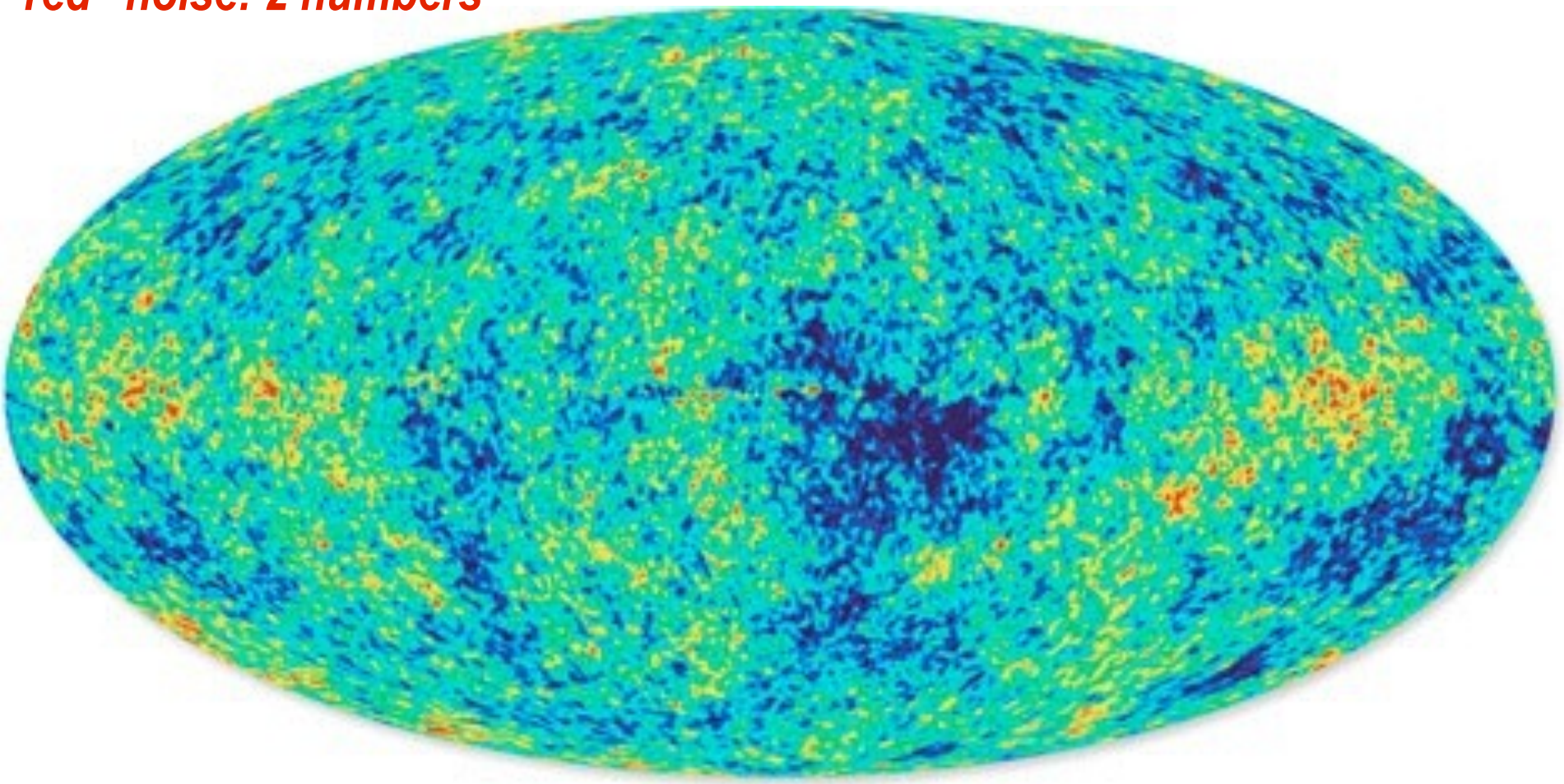
at $a \sim e^{-7} \sim 1/1100$ =>

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

"red" noise: 2 numbers

WMAP 01 launch

WMAP W-band, Template Cleaned CMB-data Concordance



Cleaned with low-frequency templates only.

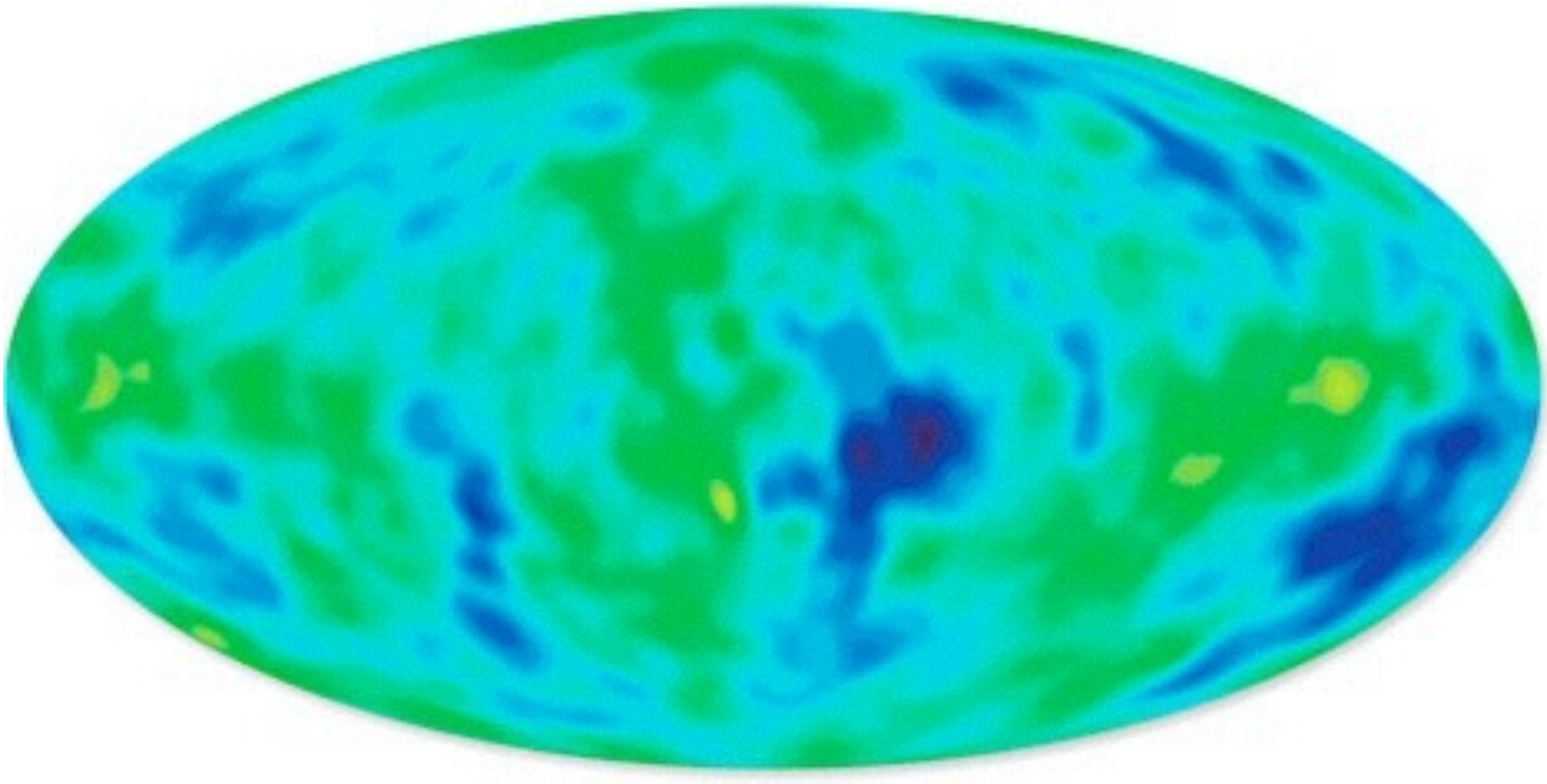
similar tremendous agreement with the much higher (5X) resolution ACT & SPT maps

total focus on the 1.2% difference in "calibration" between P13 (HFI &LFI) & WMAP9

COBE 89 launch

COBE

CMB-data Concordance



ACT (1.4 arcmin res) vs Planck1.3 (~5.5 arcmin res @217) in limited sky region => excellent agreement; cross correlations also look great

ACT collaboration: Louis+14

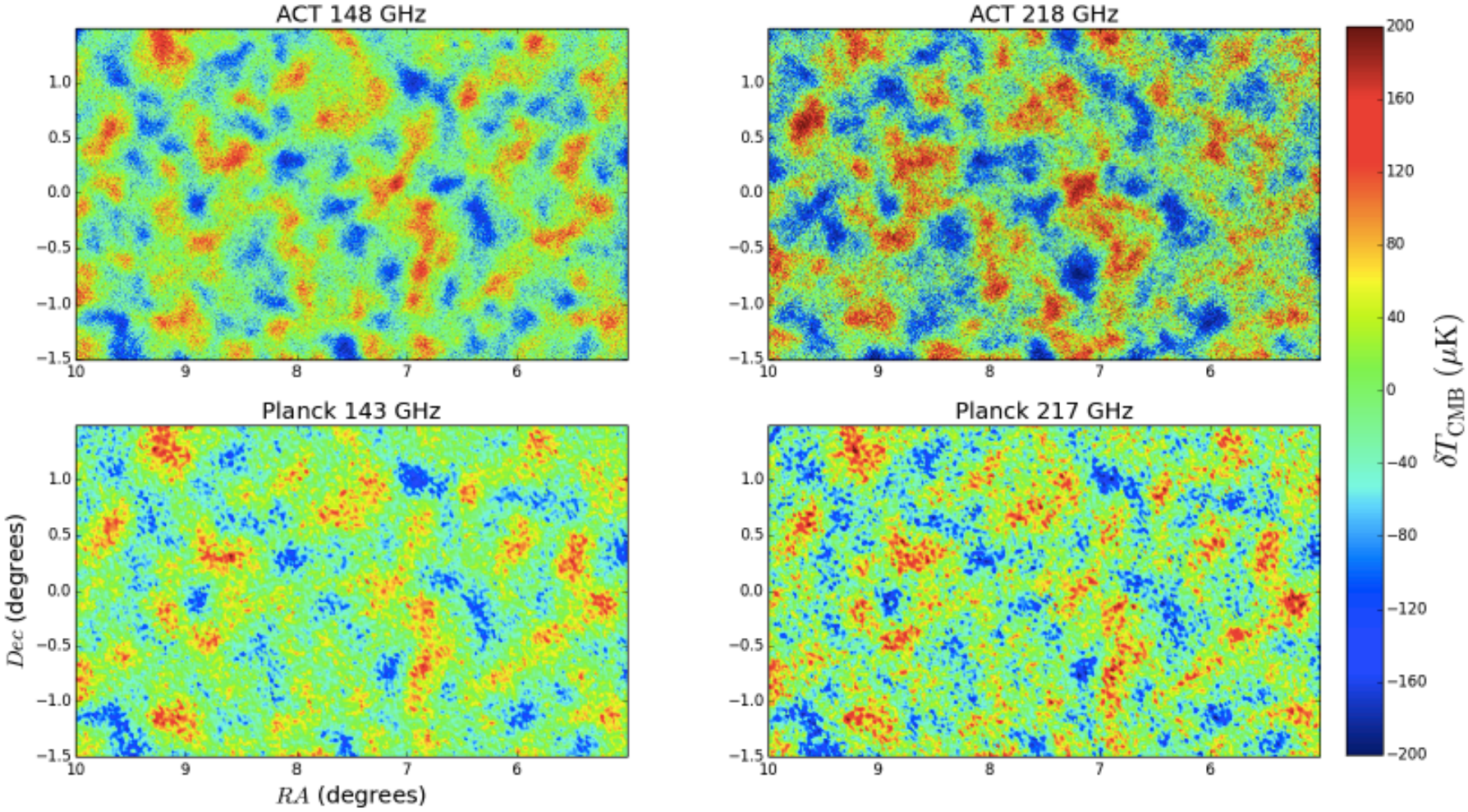
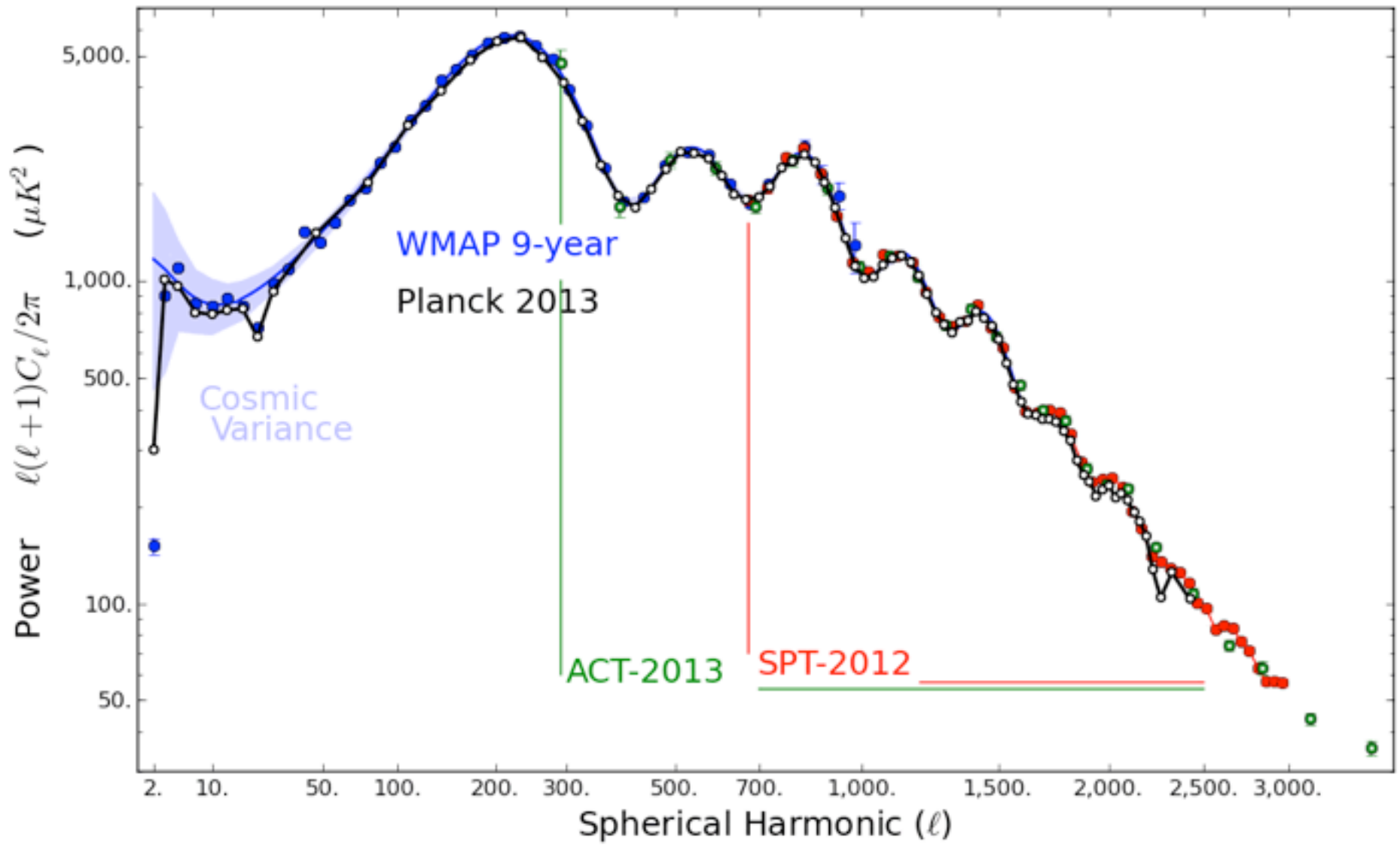


FIG. 1.— Comparison of ACT (*top*) and *Planck* (*bottom*) maps for a 15 deg^2 patch in the ACT Equatorial region. The maps are the inverse variance weighted combination of all ACT data at 148 GHz (*left*) and 218 GHz (*right*) and all *Planck* data at 143 GHz and 217 GHz. All maps have been filtered with a high pass filter (for modes on scales: $\ell < 500$). Artifacts of the HEALpix pixelization are seen in the *Planck* maps. The agreement is visually excellent.

Boomerang 2000, 2003 also agree, as does SPT in the overlap region

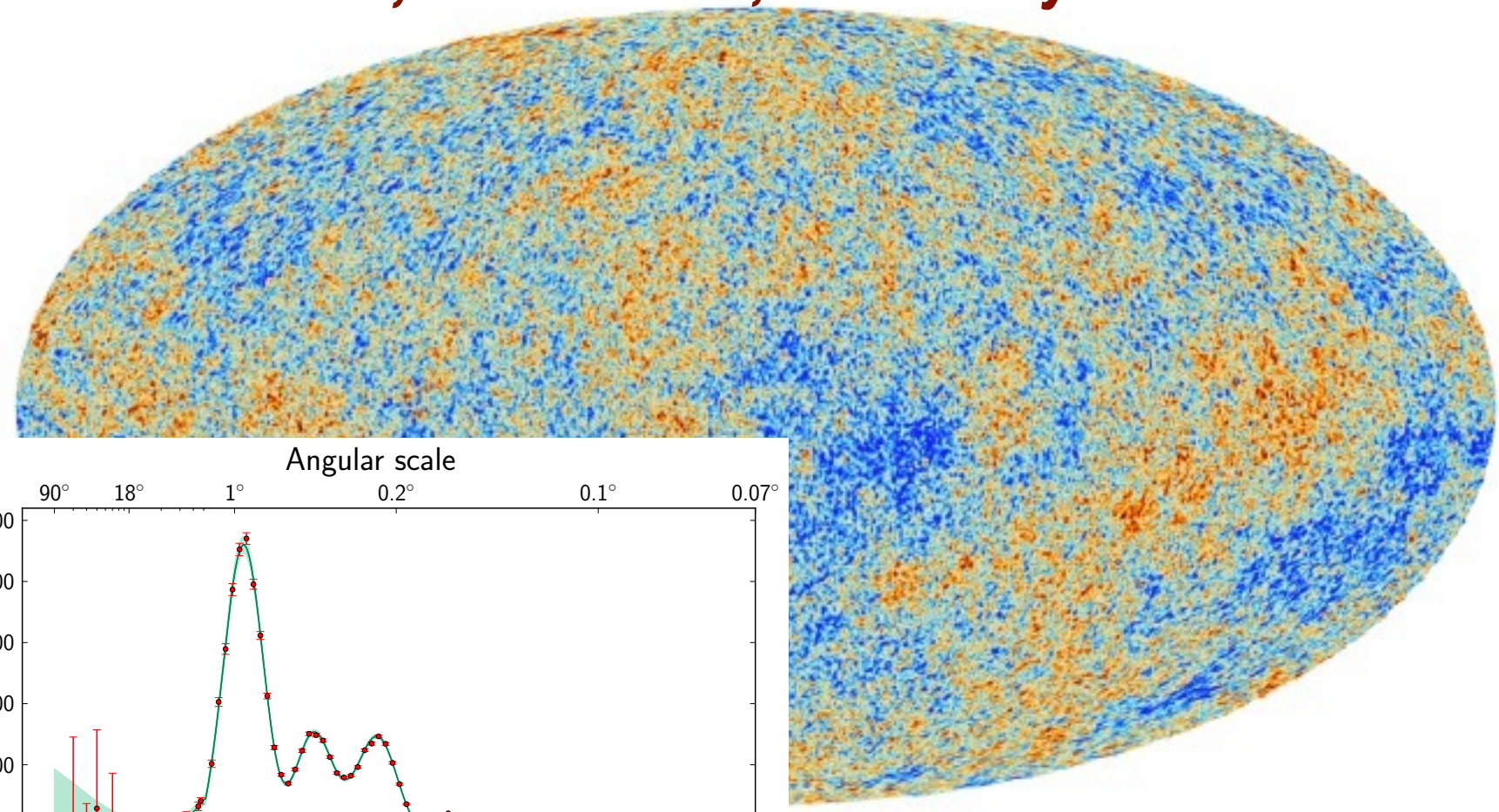


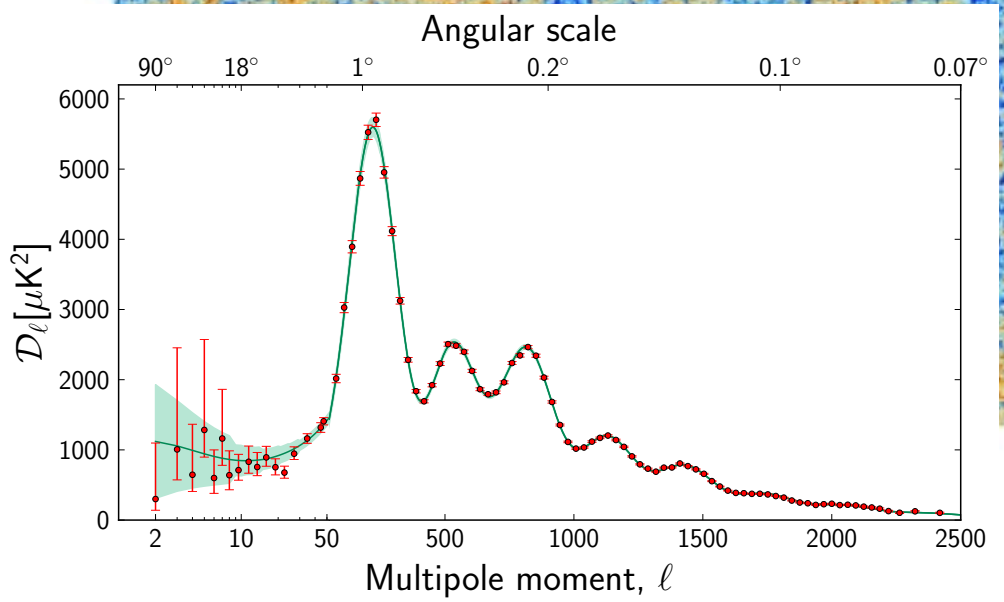
Halpern13 gif: WMAP9 cf. Planck2013 aka Planck1.3yr

reveals **primordial sound waves**

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

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





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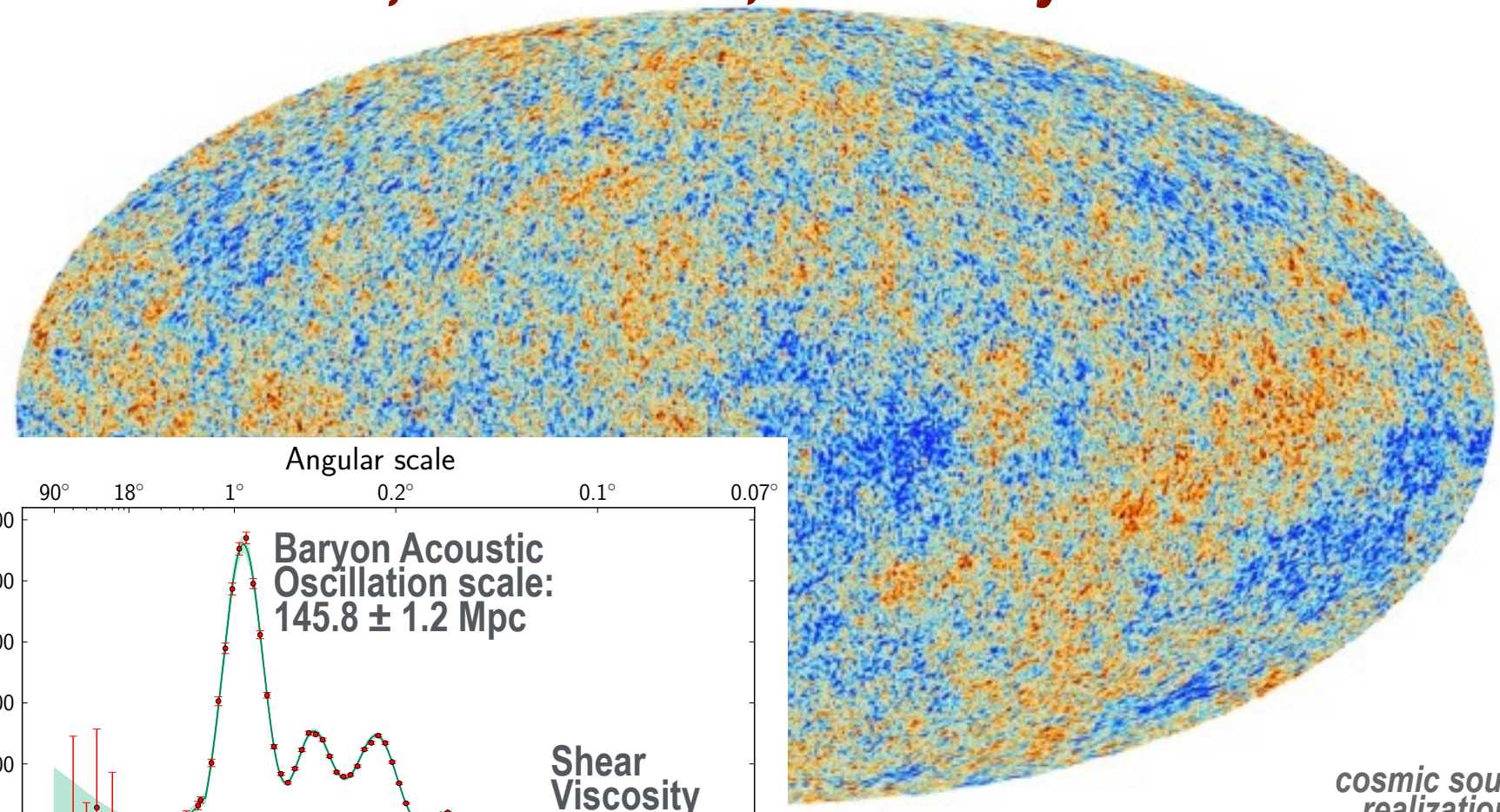
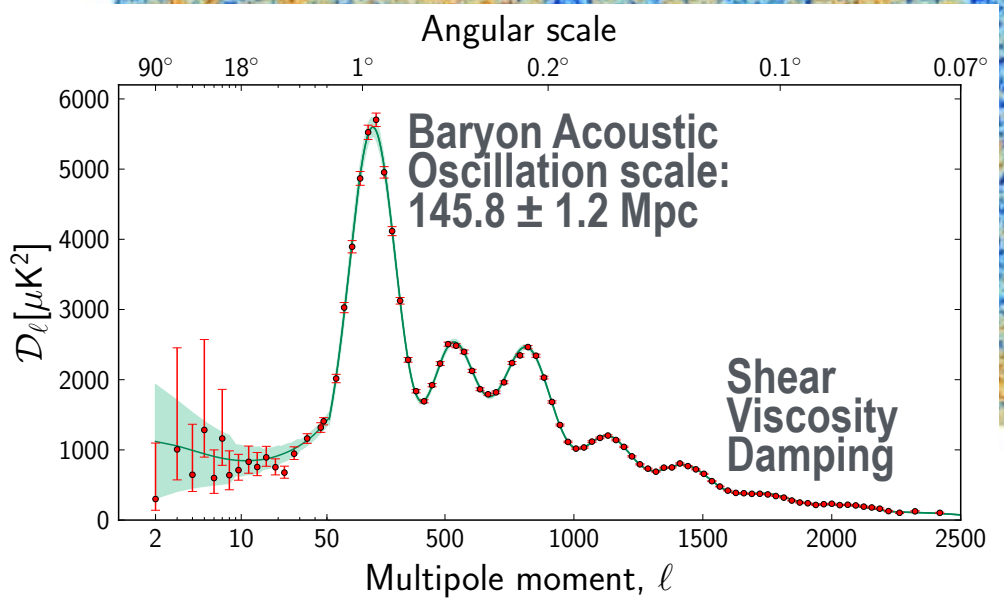




cosmic sound realization

SIMPLICITY

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

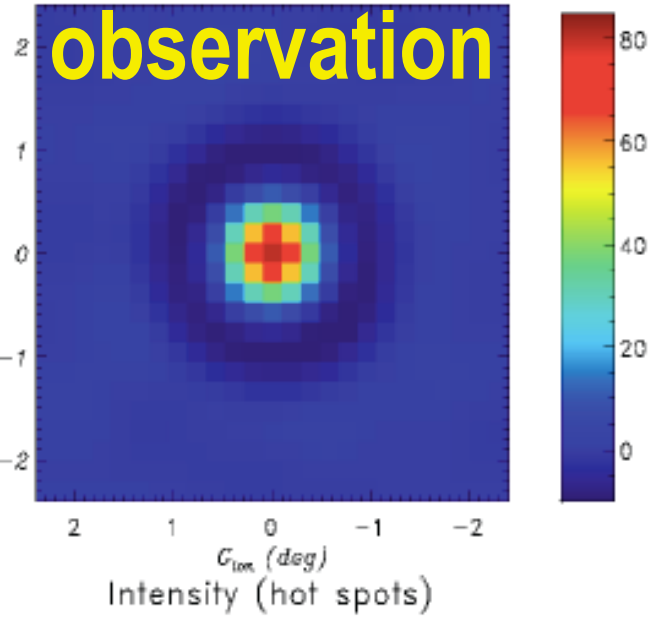
at $a \sim e^{-67+60} \sim 1/10^{30+25}$

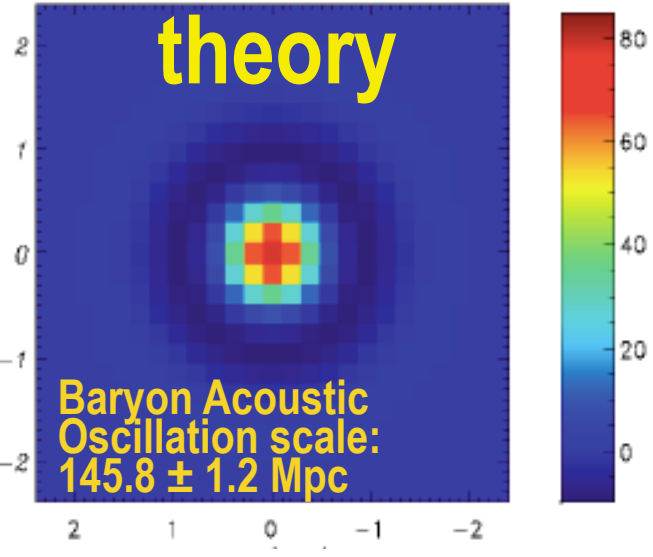
reveals ***primordial sound waves*** *in matter*

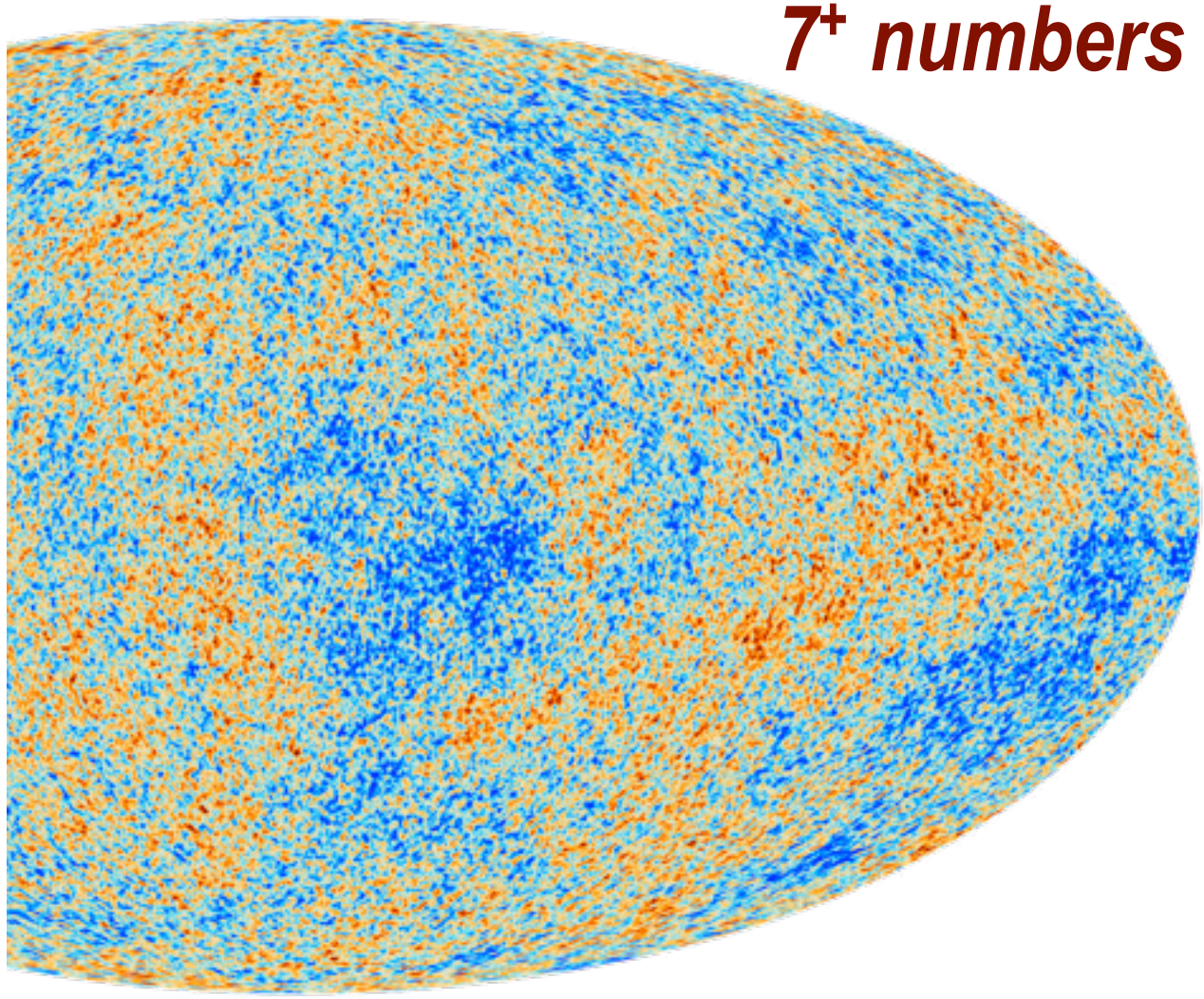
=> *learn* ***contents & structure*** *at 380000 yr,* $a \sim e^{-7}$

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

7+ numbers







photons redshift via strain

a scale of the Universe **=1/ (1+redshift)**

now = **1** when we **observe** the **1st light**

then = **1/1100** when the **1st light** was **released from matter**, billion X denser

galaxies forming ~ 1/4

there were **no galaxies** when a < 1/20

mean (isotropic) number of e-foldings of scale ≡ $\langle \ln a \rangle$

a scale of the Universe

$\langle \alpha \rangle$

0

now = **1** when we **observe** the **1st light**

then = **1/1100** when the **1st light** was **released from matter**, billion X denser **7**

galaxies forming ~ 1/4 **1 ⇓ 2**

there were **no galaxies** when a < 1/20 **3**

light nuclei

Dark Matter **21 ⇓ 35**

Heat: matter & **radiation** **67**

quantum **noise** **67 ⇓ 127**

$a_J^i(r,t)$ scale-tensor of the Universe

$$dX^i(r,t) = a_J^i(r,t)dr_{eq}^J$$

$$a_J^j \equiv exp(\alpha)_J^j$$

$$\alpha_J^j \equiv \langle ln\ a \rangle \delta_J^j + \varepsilon_J^j$$

ε=strain tensor

$$dV^i(r,t) = H_J^i(r,t)dX^i(r,t)$$

H_J^i=*Hubble aka* ***shear*** $=d\alpha_J^j/dt$

general relativity

Earth under Strain:
earthquakes, seismic waves

elastic deformation $dx^i = e_J{}^i dx_{eq}{}^J$
anisotropic strain, shear waves ε-Trace(ε)/3
isotropic strain, sound Trace(ε)

ε=strain tensor

Universe under Strain:
space-quakes, gravity waves

scale-deformation $a_J{}^i$
anisotropic strain, gravity waves
isotropic strain, sound

linear: strain ∝ tide

light and gravity are entangled: wavelength stretches under space-strain: ***redshift***

the vacuum is modified under space-strain: inflation theory

general relativity => **a=** *drei*bein, triad, Lagrangian-space metric **g=aa†**

4D *vier*bein strain of time cf. of space

Dick Bond

Cosmic Observables for Fundamental Physics, revealing Simplicity & Complexity

the nonlinear COSMIC WEB

recombination

dS_G/dt

INFLATION

primary anisotropies

- linear perturbations: scalar/density, tensor/gravity wave dS/dt>0
- tightly-coupled photon-baryon fluid: oscillations δγ vγ πγ
- viscously damped
- polarization πγ
- gravitational redshift Φ SW dΦ/dt

Decoupling LSS

Type to enter text

17 kpc (19 Mpc)

secondary anisotropies

- nonlinear evolution
- weak lensing
- thermal SZ +kinetic SZ
- dΦ /dt
- dusty/radio galaxies, dGs

Lsound/ksound

DarkM

DarkE

dS/dt>0

Type to enter text

z=0

Bayesian flow prior to posterior via likelihood

dS_astro <0

reionization

z ~ 1100

redshift z

z ~ 10

dS/dt>0

13.8-10^-50 Gyrs

13.8-10^-3.4 Gyrs

time t

10Gyrs

today

Dick Bond *Cosmic Observables for Fundamental Physics, revealing Simplicity & Complexity*

the **nonlinear COSMIC WEB**

recombination

dS_G/dt

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- viscously damped
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- gravitational redshift Φ SW dΦ/dt

DarkM

Decoupling LSS

17 kpc (19 Mpc)

7

secondary anisotropies

- nonlinear evolution
- weak lensing
- thermal SZ +kinetic SZ
- dΦ /dt
- dusty/radio galaxies, dGs

Lsound/ ksound

2

3

CMB LENS

SNa LENS

H0

BAO (z)

cls

ISW

DarkE

Type to enter text

0

z=0

2⇓1

Bayesian flow prior to posterior via likelihood

dS_astro <0

INFLATION 67

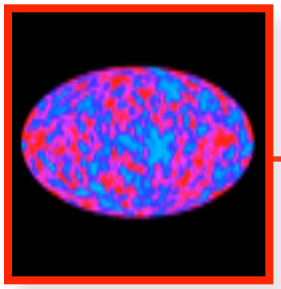
dS/dt>0

z ~ 1100

redshift z

z ~ 10

13.8-10^-50 Gyrs | *13.8-10^-3.4 Gyrs* | time t | *10Gyrs* | *today*

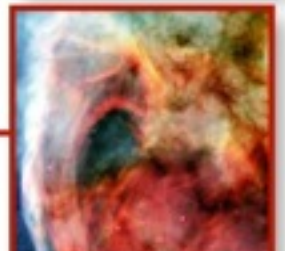


Radiation:
0.005%

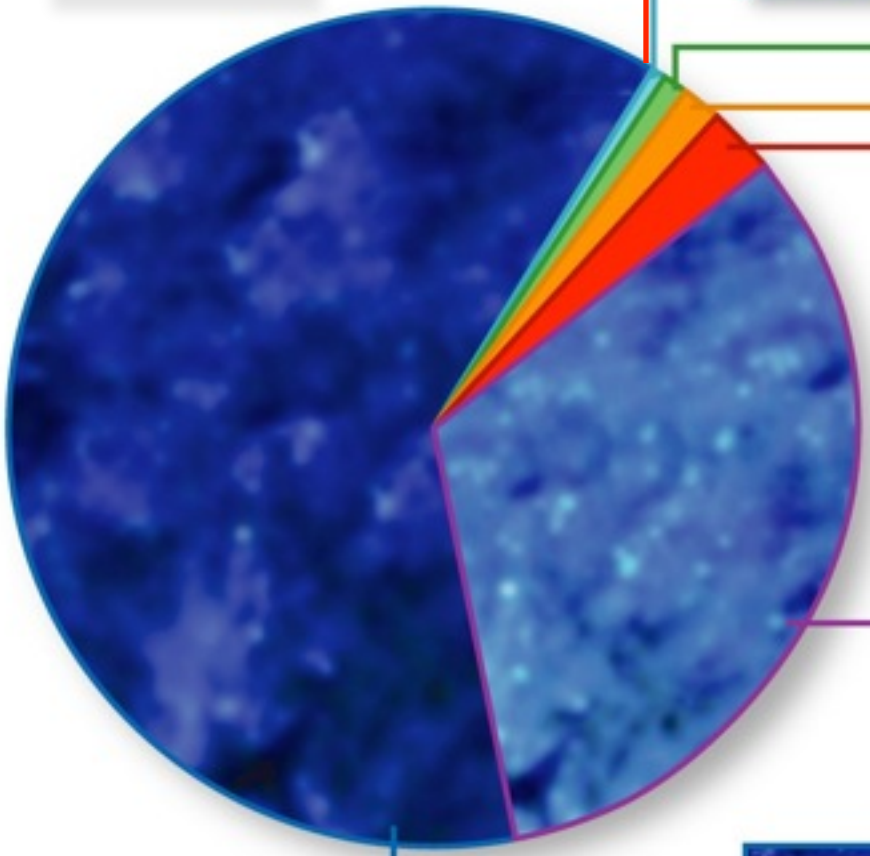
Chemical Elements:
(other than H & He) 0.025%

Neutrinos:
> 0.47%

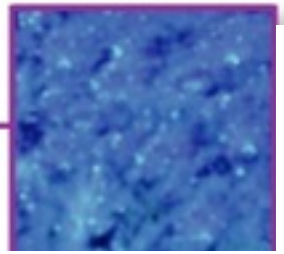
Stars:
0.5%



Free
H & He:
4.3%



$\Omega_{total} = 1$



Dark Matter:

$\Omega_{dm} = 26.0 \pm 1\%$

Gravity Waves

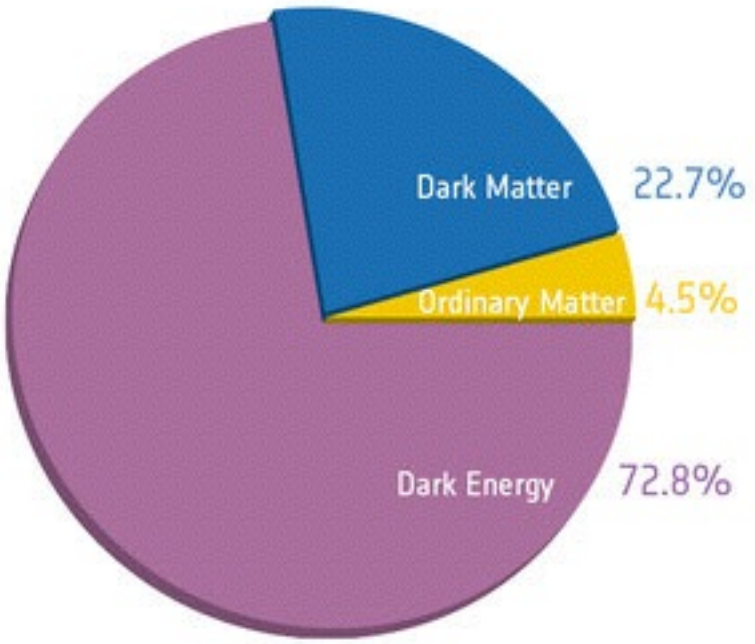
Ω_{GW} ~10^{-14} - 10^{-10} LIGO

$\Omega_{BlackHoles}$ ~10^{-7}

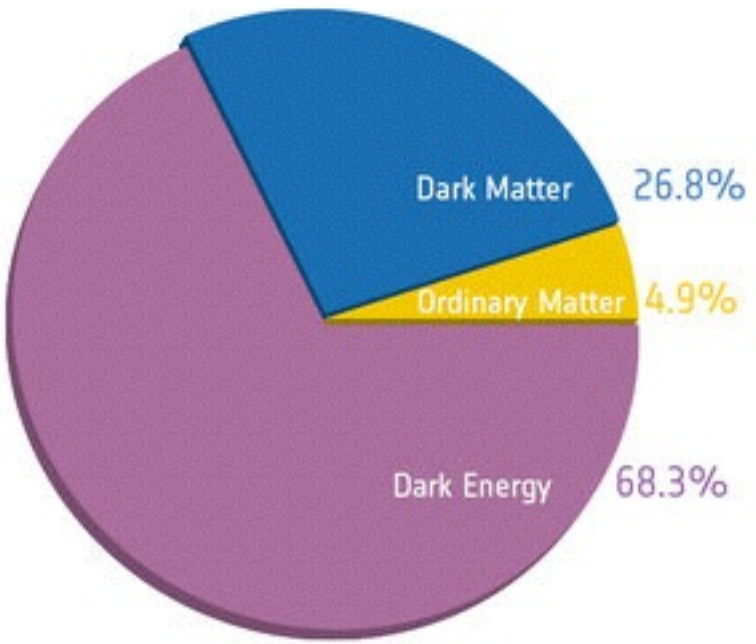
Dark Energy:

$\Omega_{de} = 69.2 \pm 1.0\%$

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



Before Planck



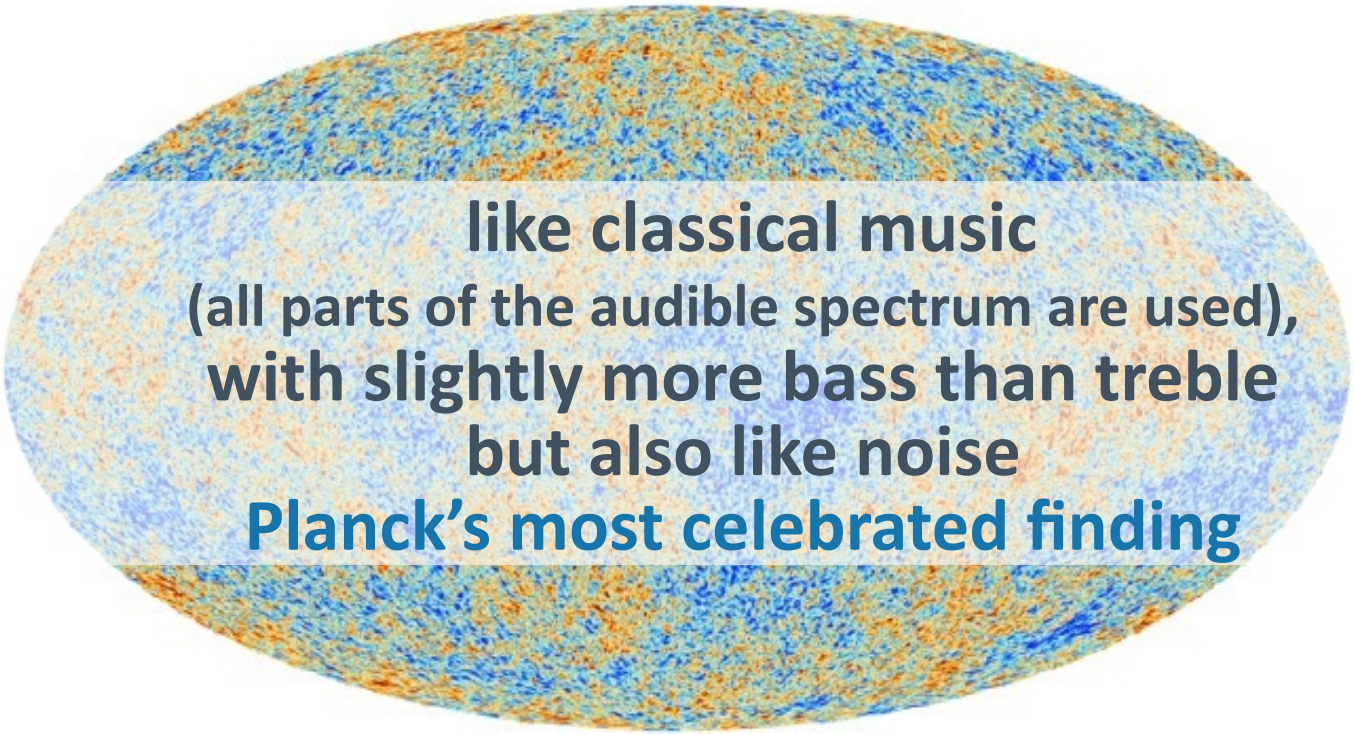
After Planck

reveals **primordial sound waves**

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

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

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



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

Temperature changes in micro-degrees

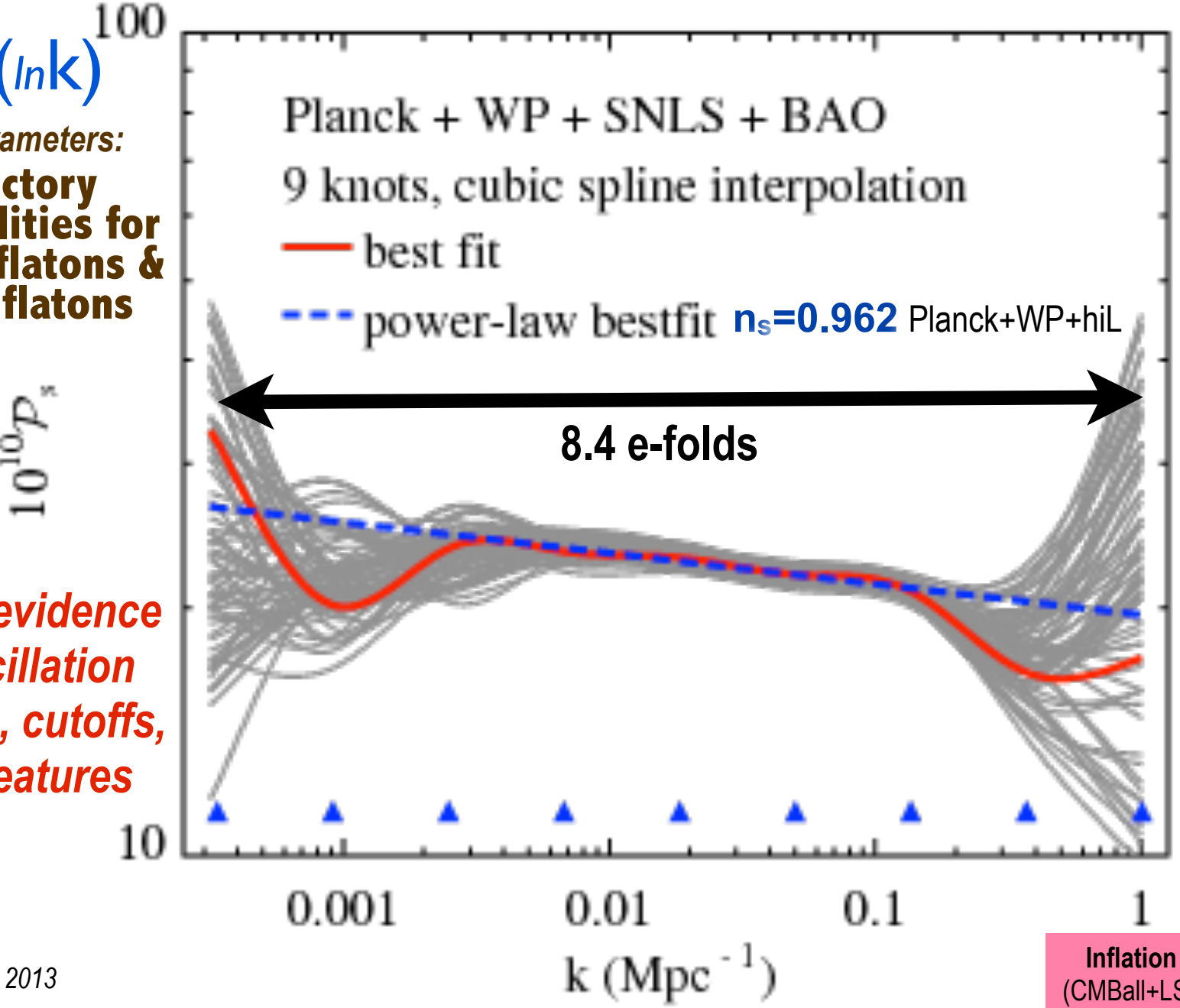
*scan ln***P**$_s$(*ln*k)/A$_s$, *ln***A**$_s$=*ln*P$_s$($k_{pivot,s}$), ***r***($k_{pivot,t}$); *consistency => reconstruct* **ε**(*ln***Ha**), **V(ψ)**

*ln*P$_s$(*ln*k)

new parameters:

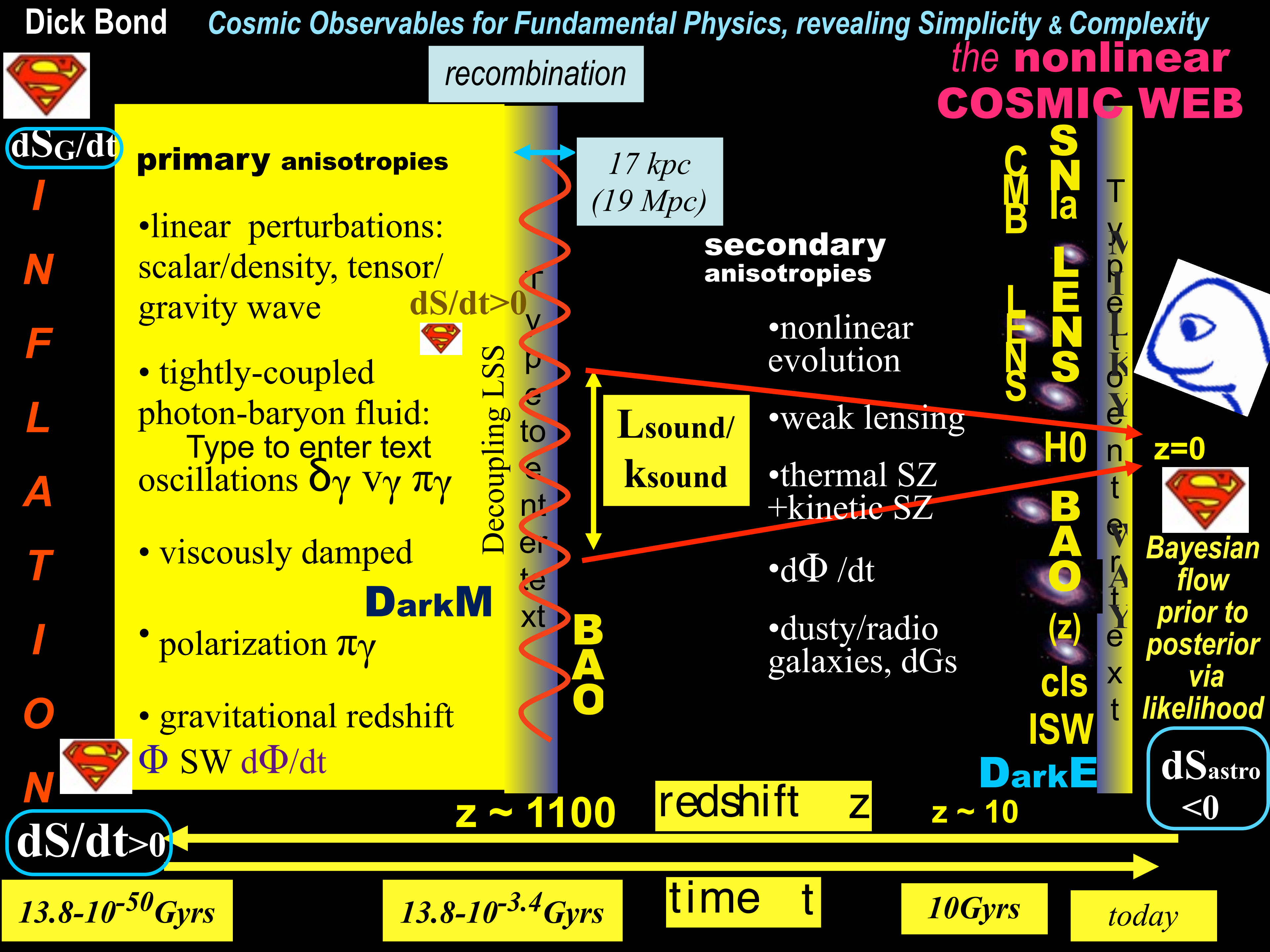
trajectory probabilities for early-inflatons & late-inflatons

no strong evidence for oscillation patterns, cutoffs, local features



Bond, Huang 2013

Inflation Histories
(CMBall+LSS+SN+WL)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13.8-10^-50 Gyrs
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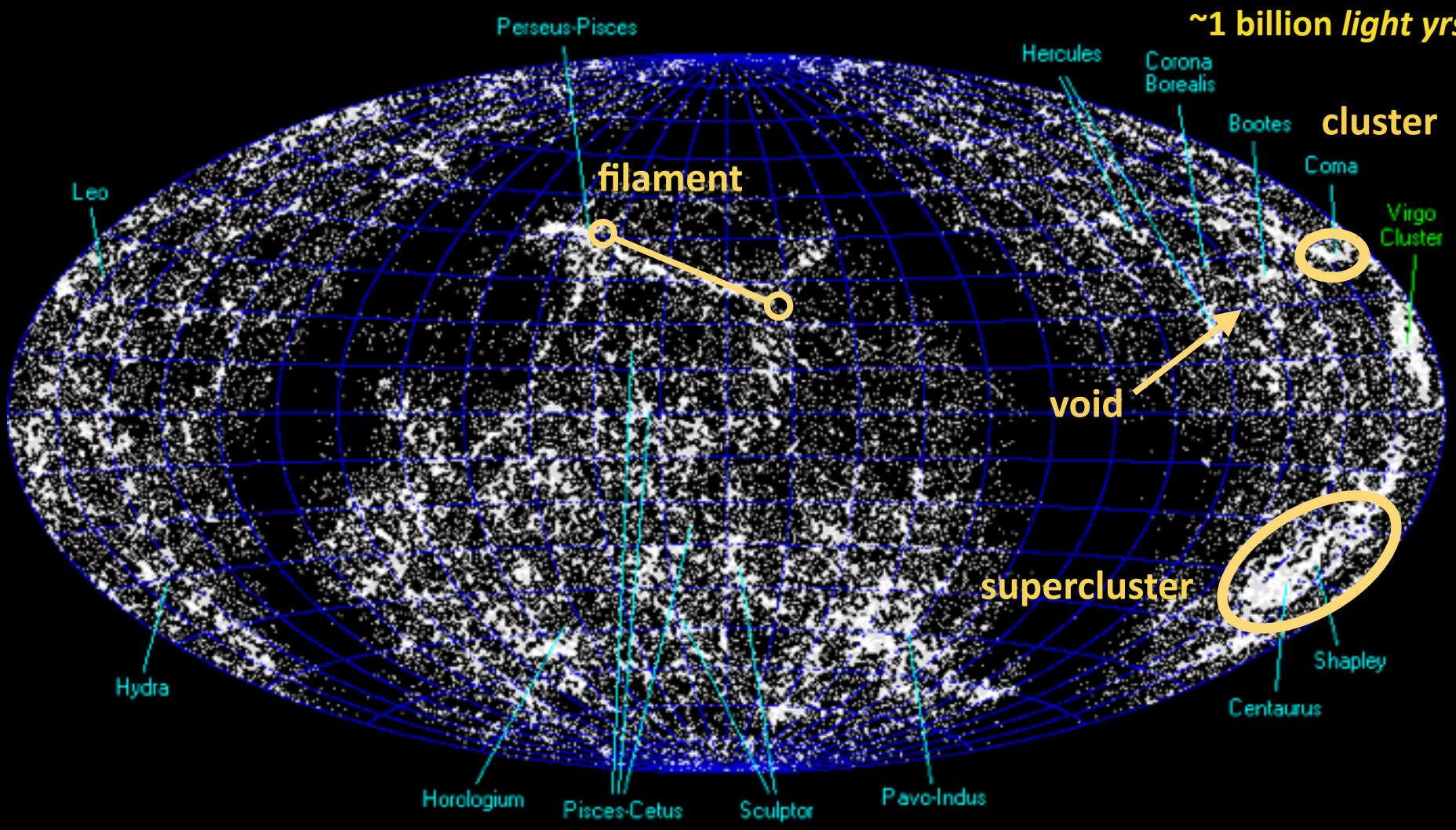
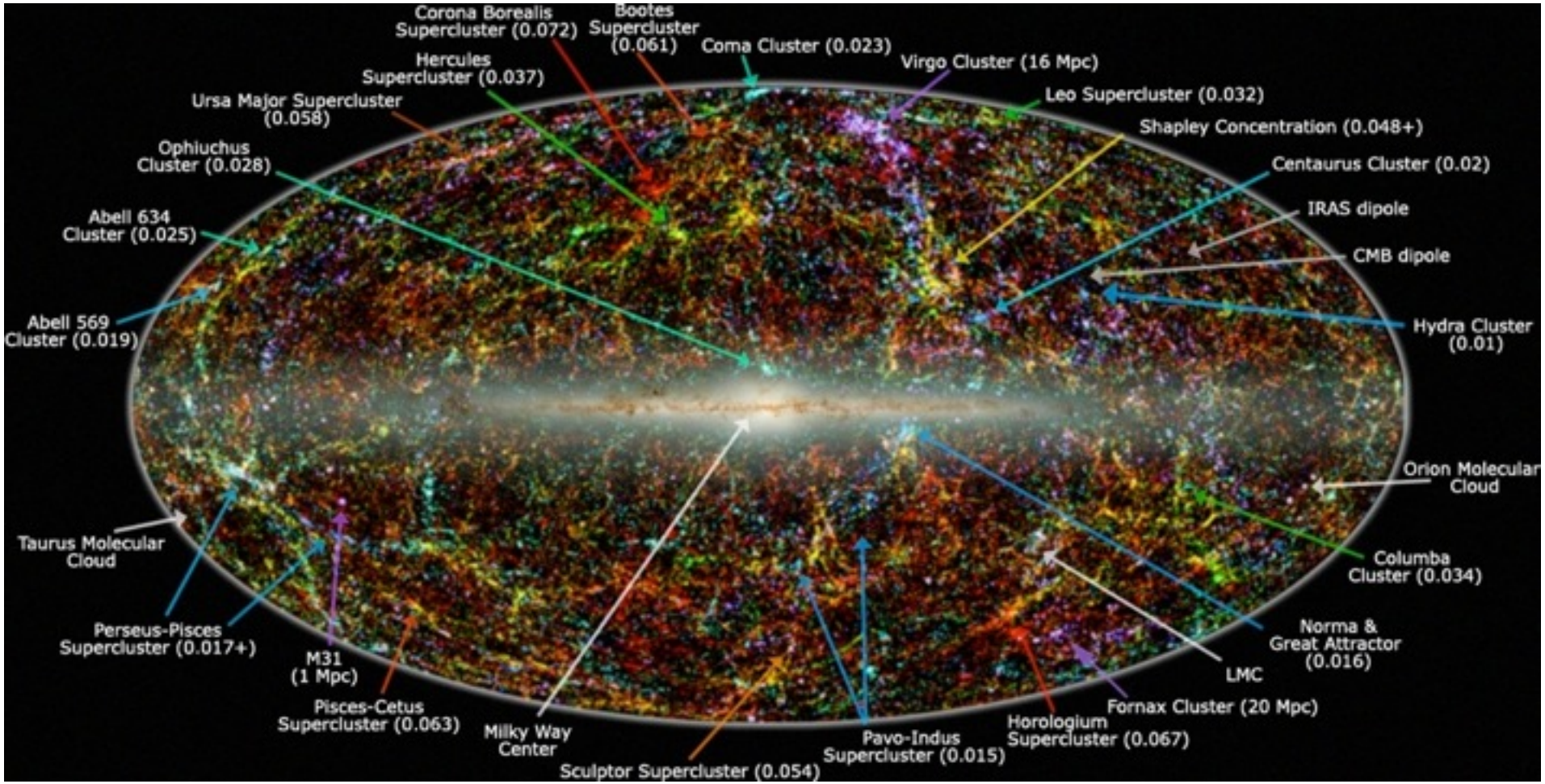
10Gyrs
today

Cosmic Web of 60,000 nearby galaxies: exhibits "local" **COMPLEXITY**



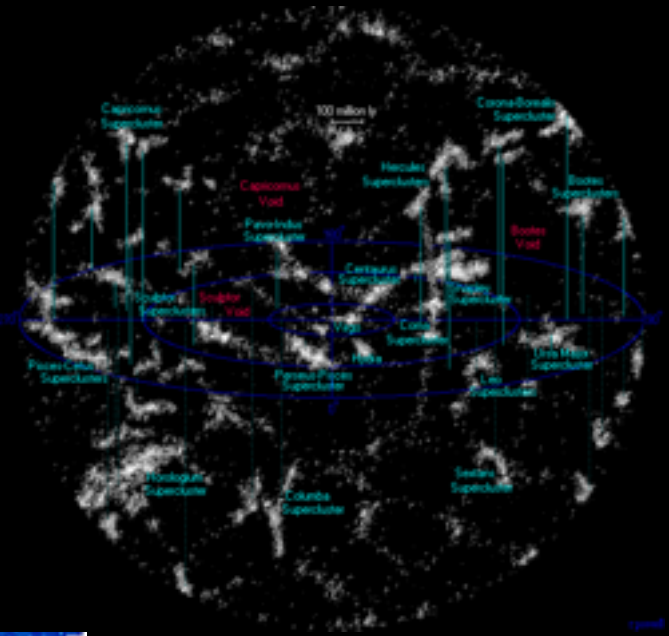
cosmic web of **nearby superclusters** from ***2mass+***



Simulation of the 7^+ numbers

begets the **Cosmic Web** of clusters

now a~1 & galaxies then a~1/4



SIMPLICITY to COMPLEXITY under Gravity

filament

void

cluster

supercluster

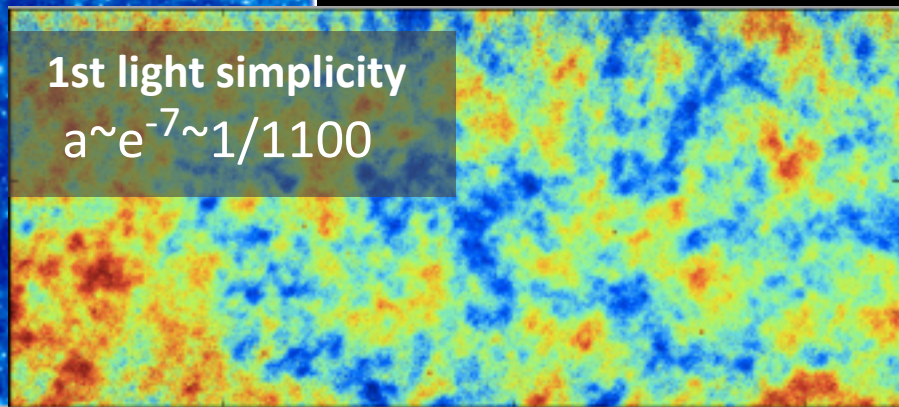
~ billion light years

state of the art simulations
a~1 to 1/1.1

ordinary matter
dark matter
dark energy

1st light simplicity

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



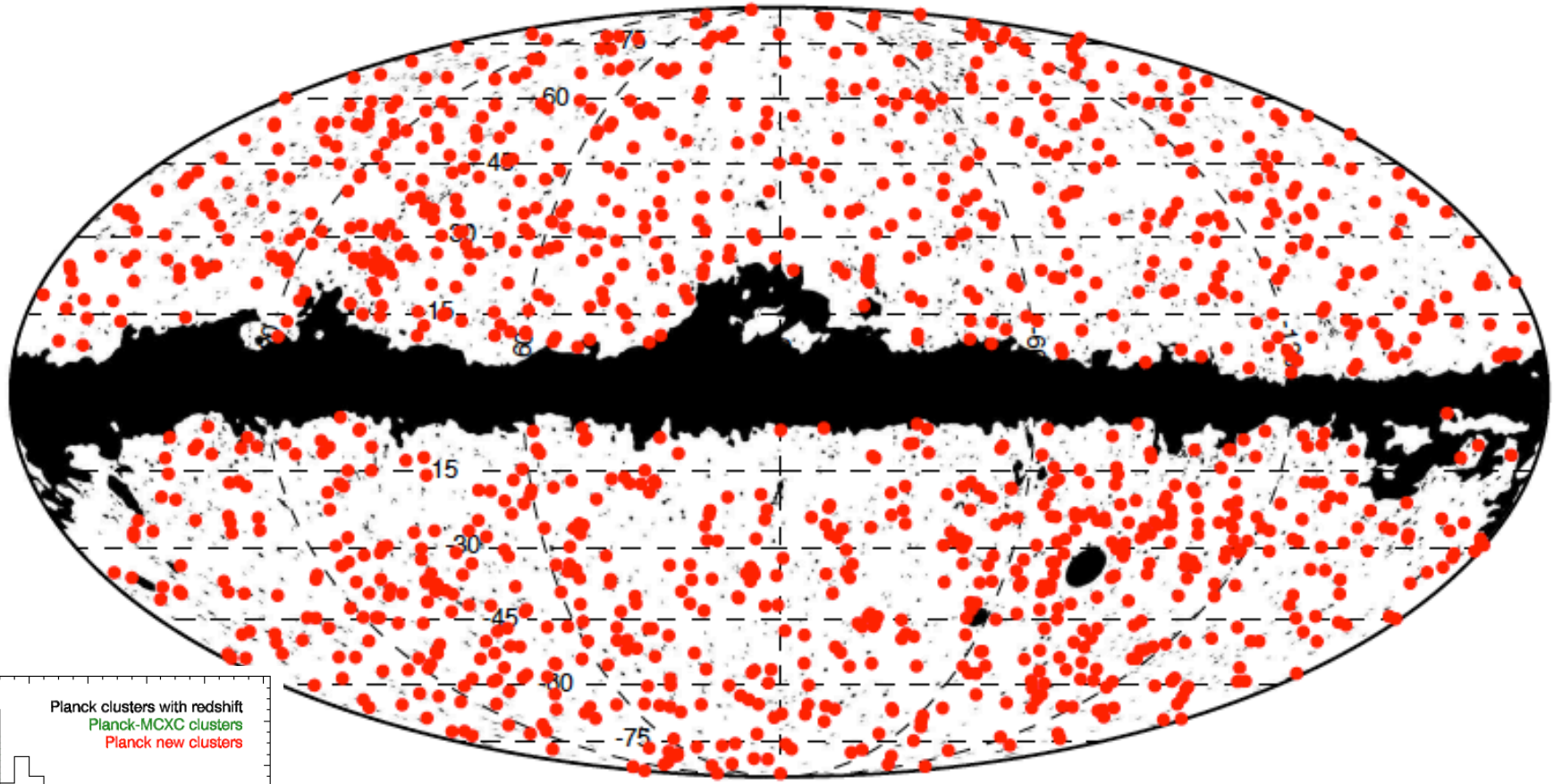
Compton cooling of high pressure / entropy electrons by the CMB

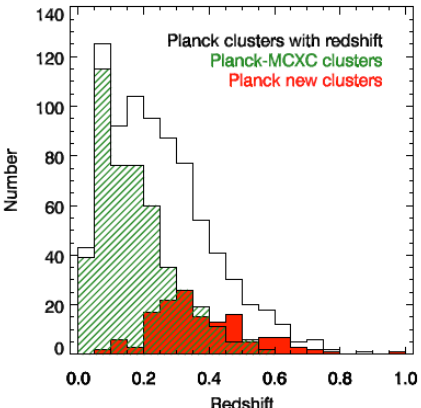
thermal SZ effect **Planck2013 1227 clusters, SPT 224 =>747cls, ACT 91 cls**

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

cf. X-ray sample from ROSAT+ All-sky distribution of MCXC clusters ~1600 *(Piffaretti et 10)*

REFLEX, BCS, SGP, NEP, MACS, CIZA, 400SD, 160SD, SHARC, WARPS, EMSS



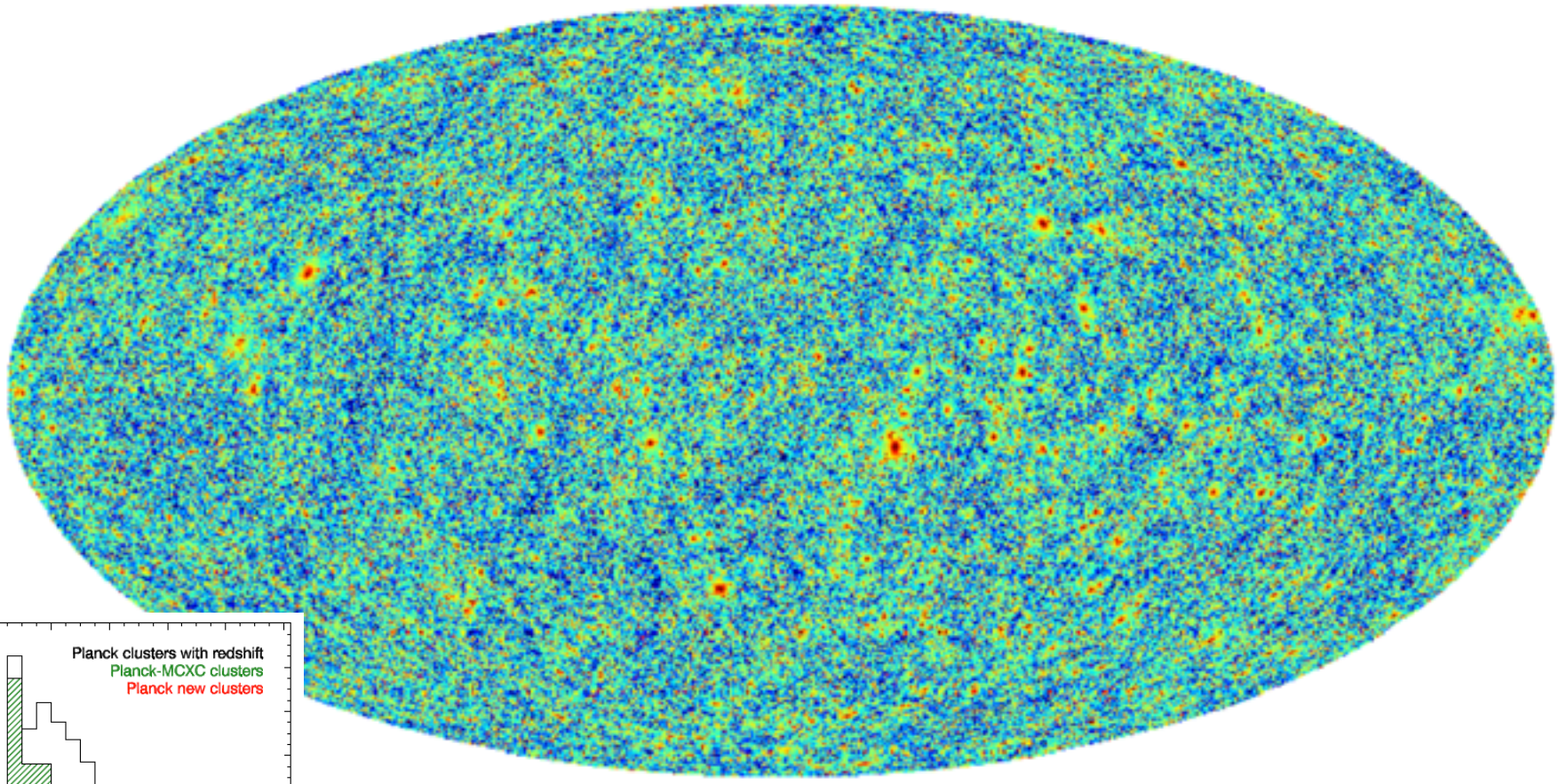


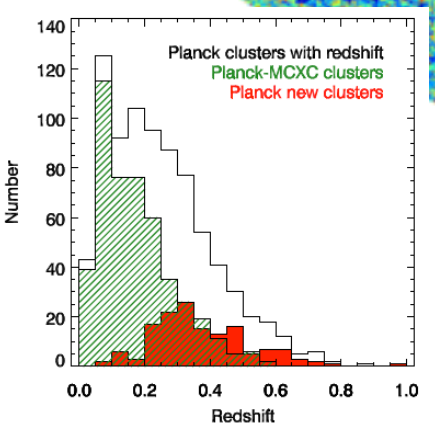
the Cosmic Web of Clusters, seen thru Compton cooling of high pressure electrons by the CMB

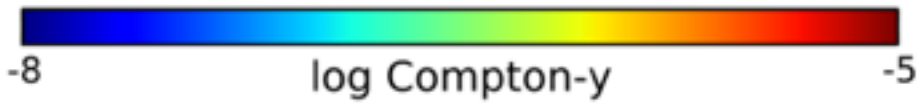
tSZ effect

Lightcone Simulation of 35000 Clusters > 2×10^{13} M_{sun} to z=0.5 in projected pressure

Alvarez, Bond, Hajian, Stein, Battaglia, Emberson,..2014

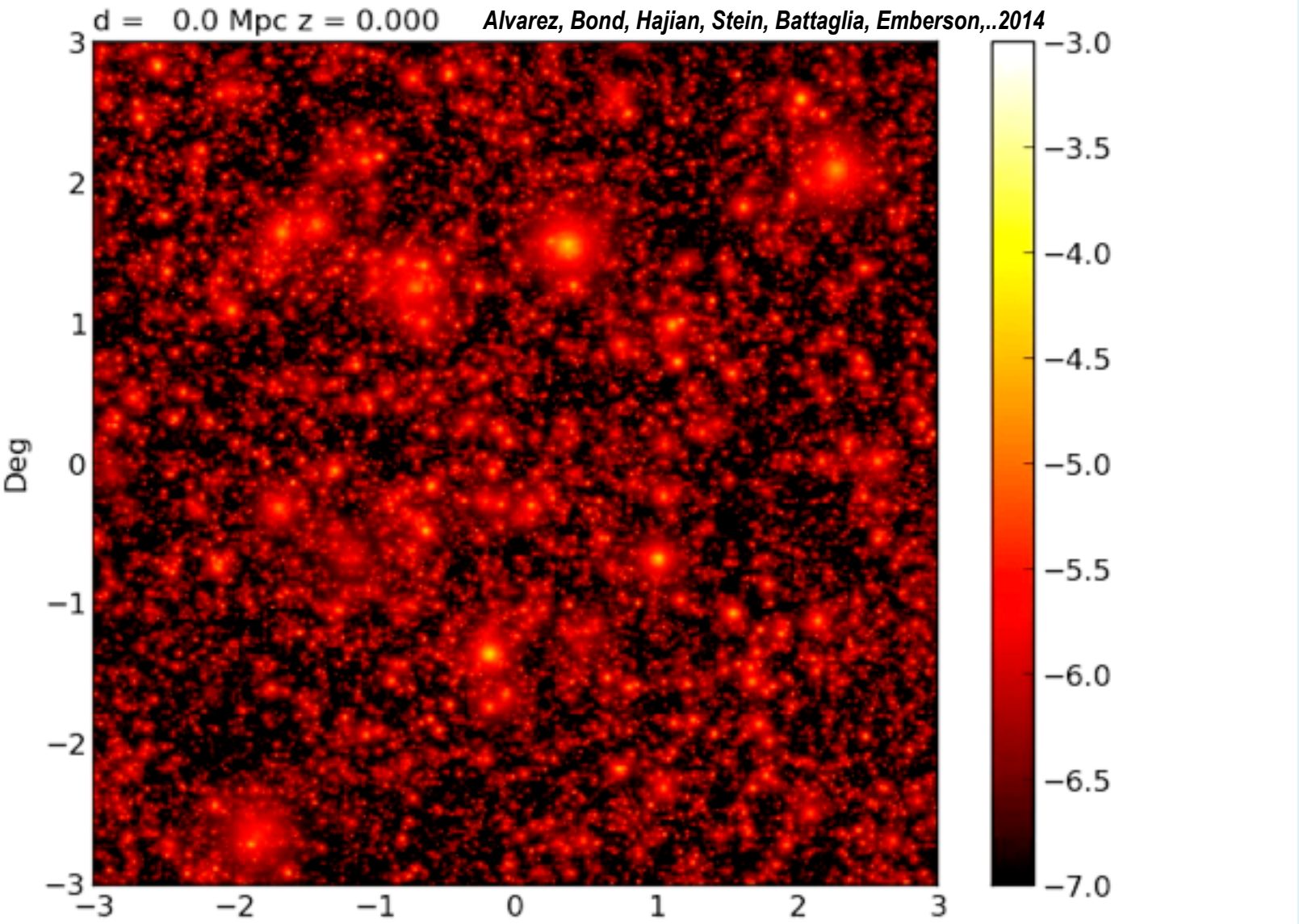




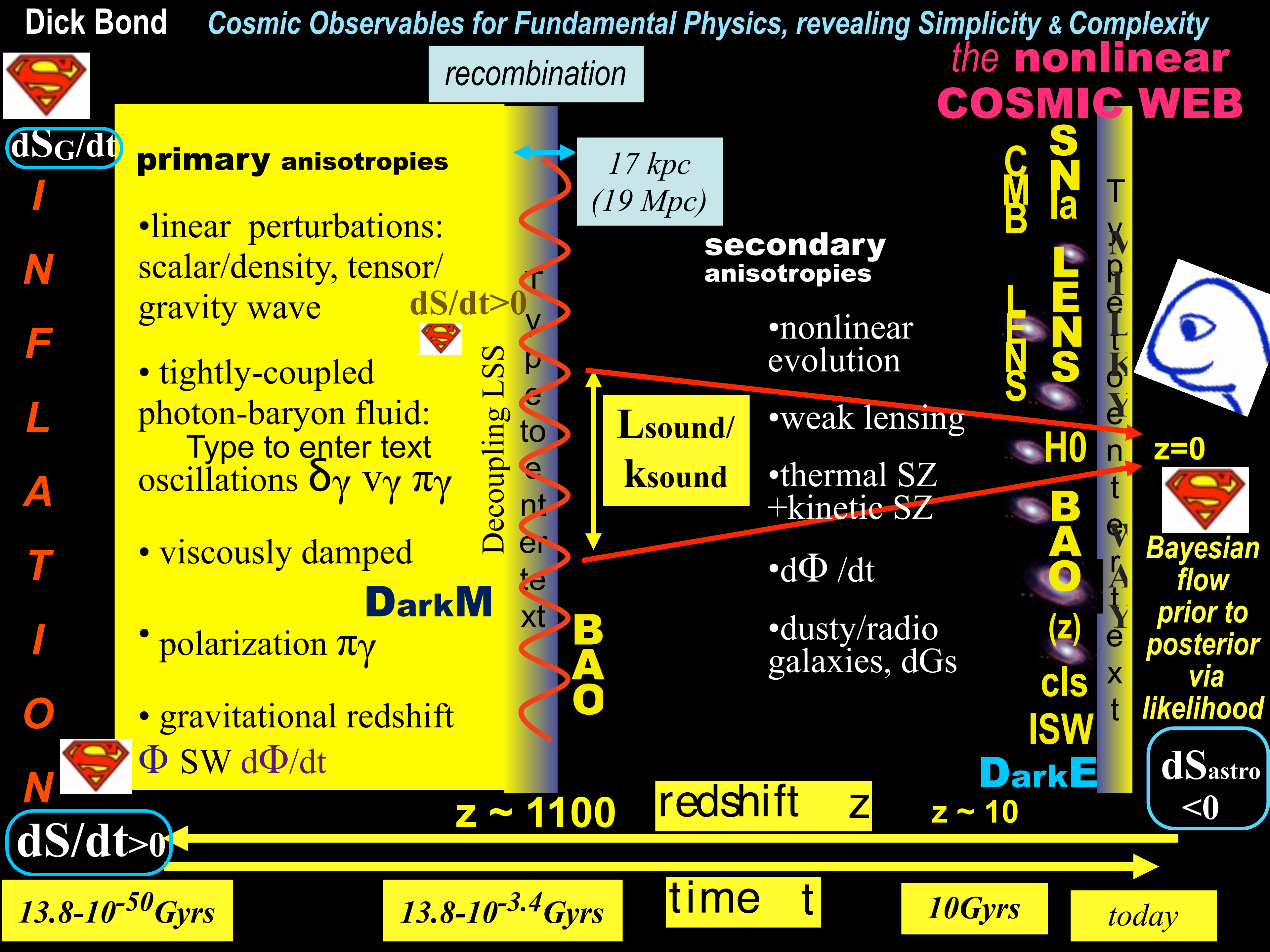


Mocking Heaven: lightcone sim for tLCDM. 36 sq deg to z=2

Planck all-sky tSZ mock 1.5 hours on 256 cores on SciNet, 30000 core IBM GPC



Planck, ACTpol, AdvACT, *ALMA, CARMA,* ***Mustang2*** *on GBT,* ***eRosita****..* ***COMA****,* ***CCAT****..* ***CHIME***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z ~ 10
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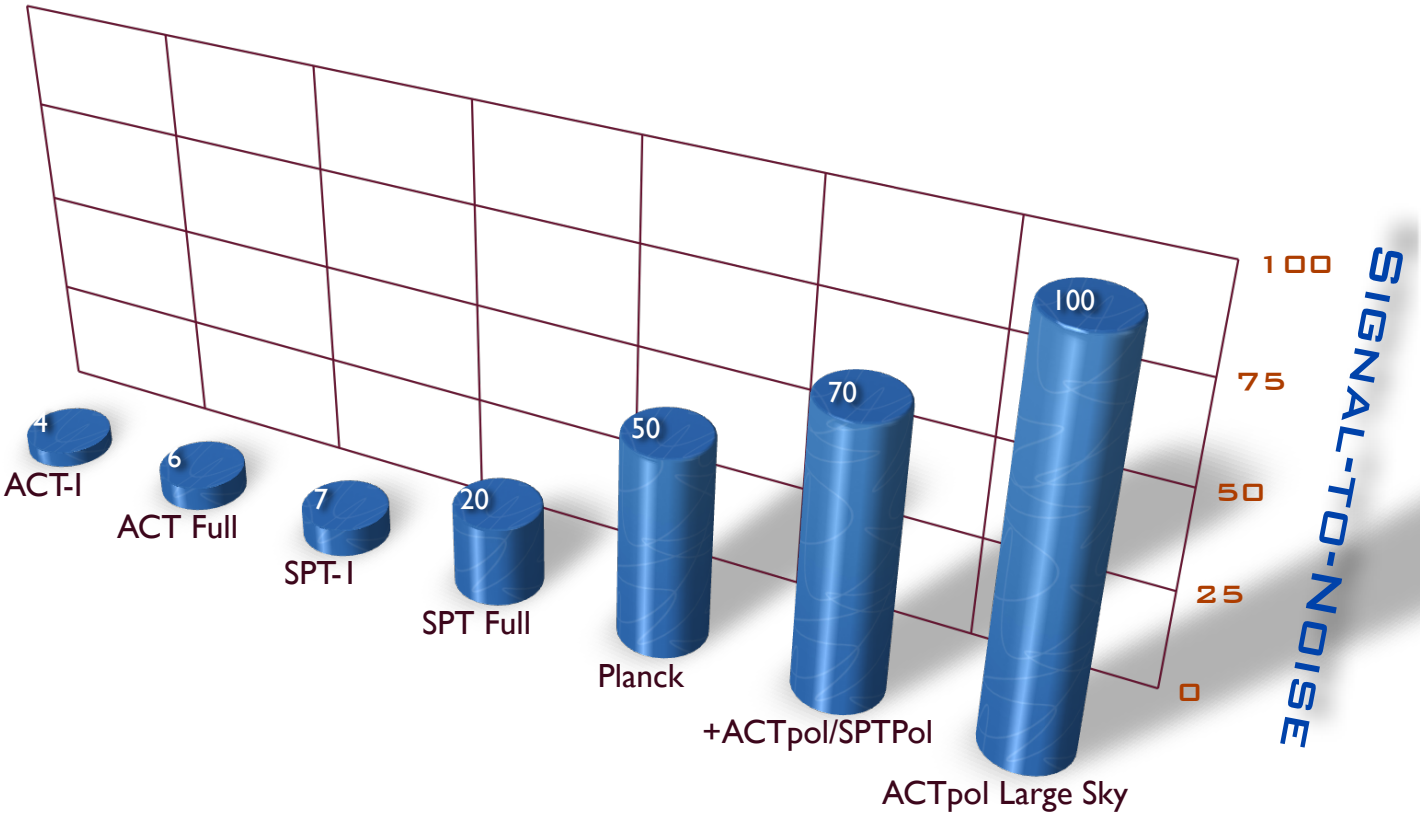
time t
13.8-10^-50 Gyrs
13.8-10^-3.4 Gyrs
10Gyrs
today

photons under strain by tides

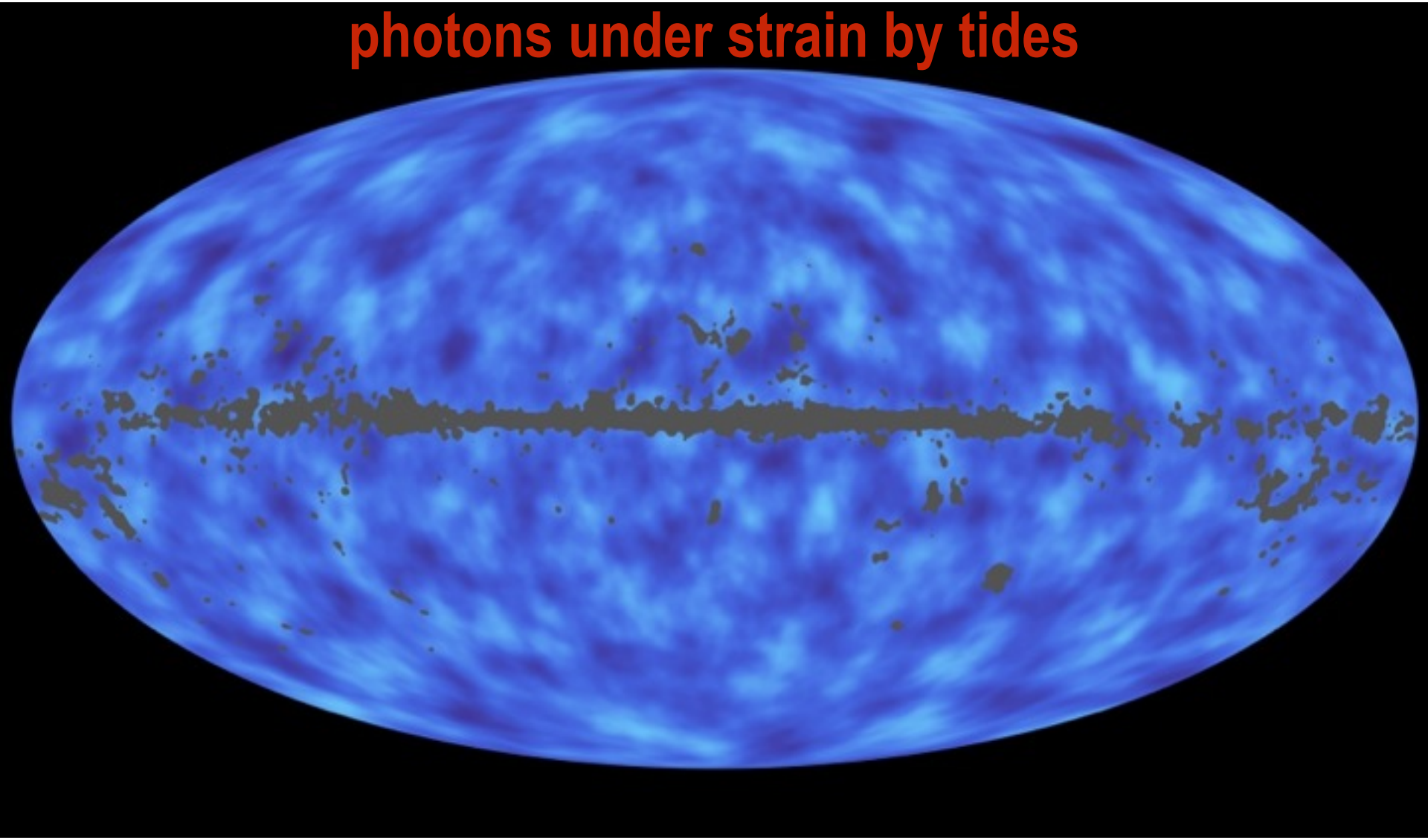
CMB Lensing is going to explode as a field in the next few years



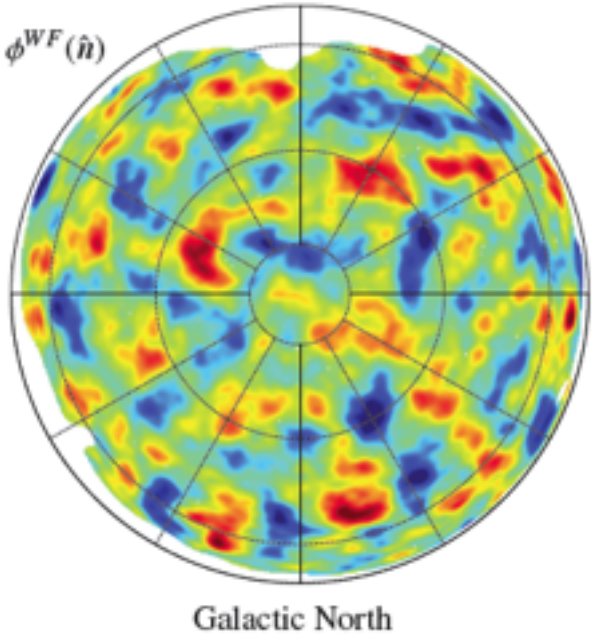
Das, pre-Planck

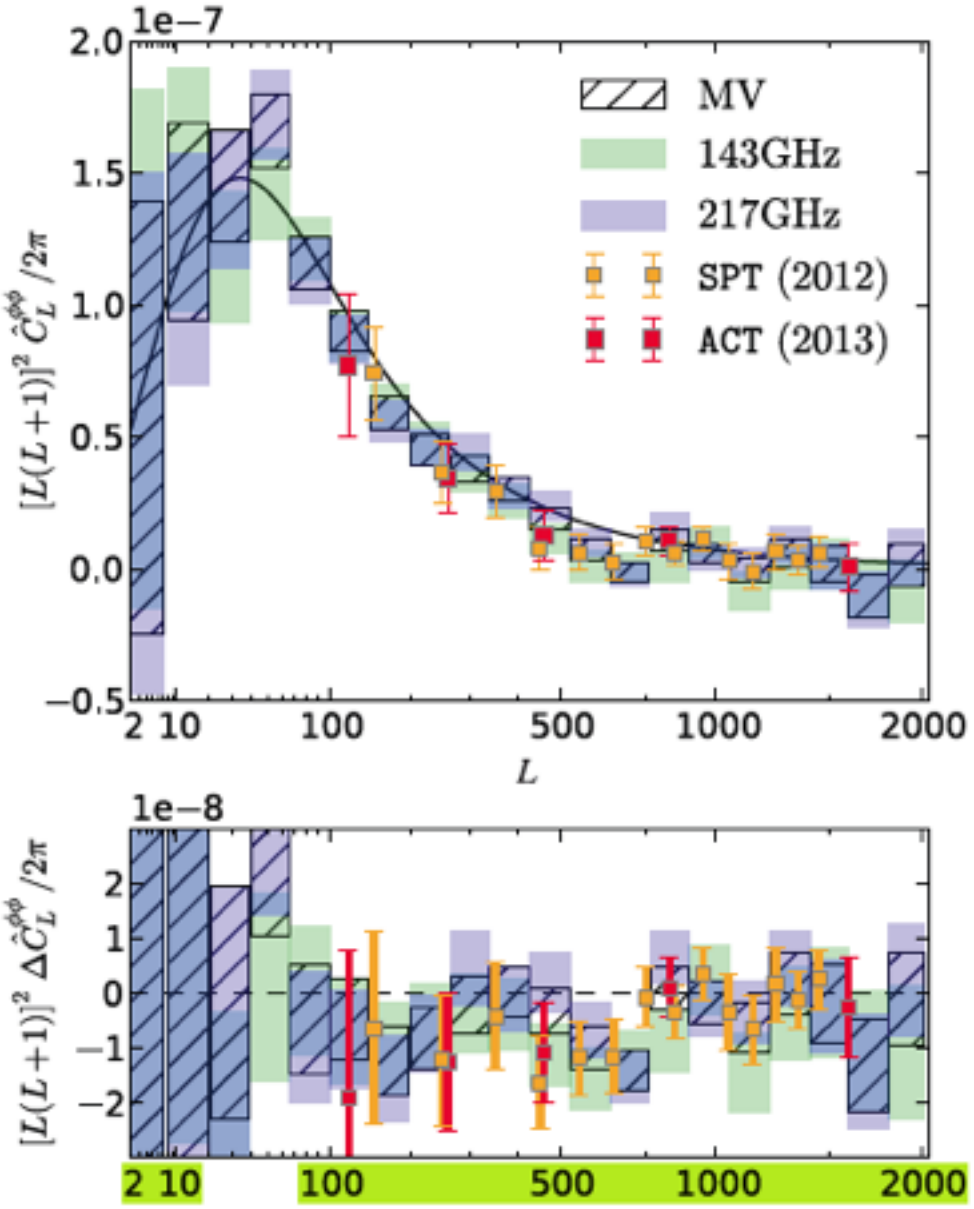
Planck1.3 CMB Lensing: reconstructed projected gravitational potential map (!)

*~ dark+baryonic matter map, mean-field map = **Wiener filter** (beware: fluctuations about mean-field)*



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



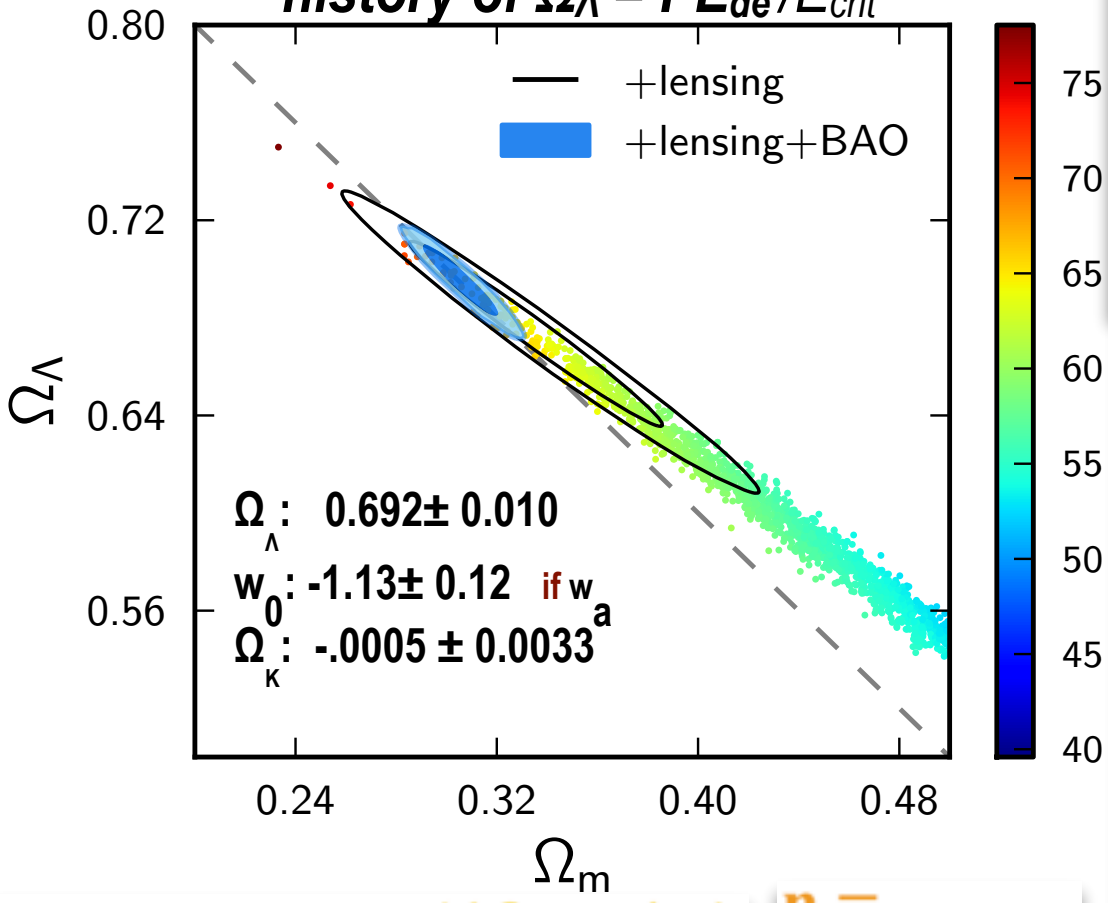


Dark Energy => inflation now

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

Planck1.3 cf. CMB+LSS

history of $\Omega_\Lambda = PE_{de}/E_{crit}$

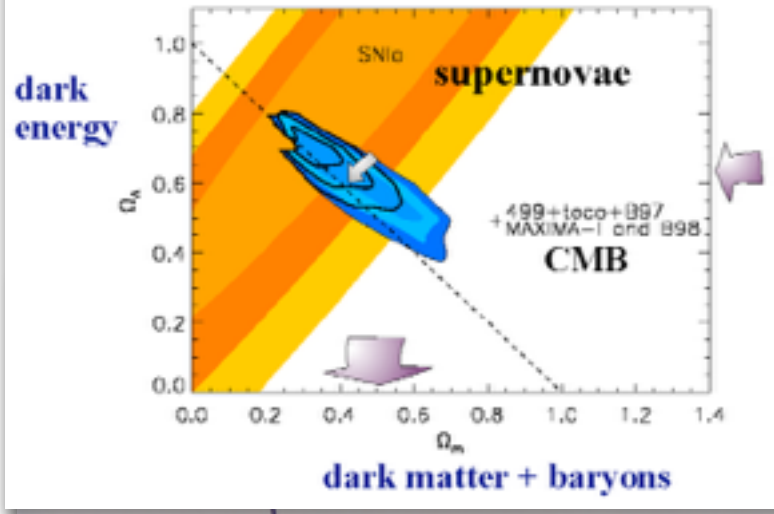


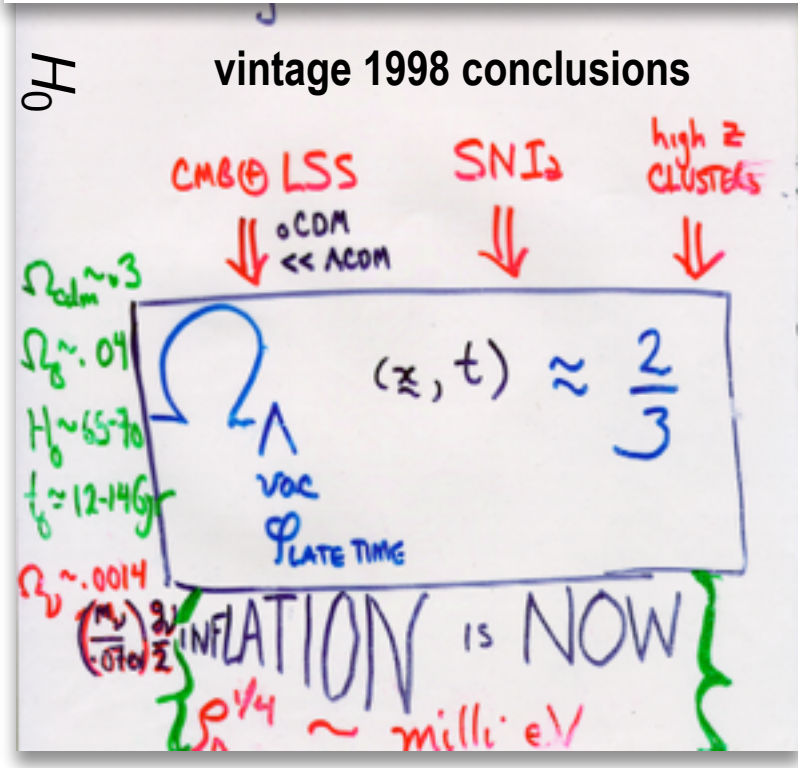
$\Omega_\Lambda \approx 2/3 \pm .07$ +LSS

B+Jaffe'96,'98

$n_s =$ .98 ± .07 .96 ± .06

BOOM 2000





SIMPLICITY

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

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

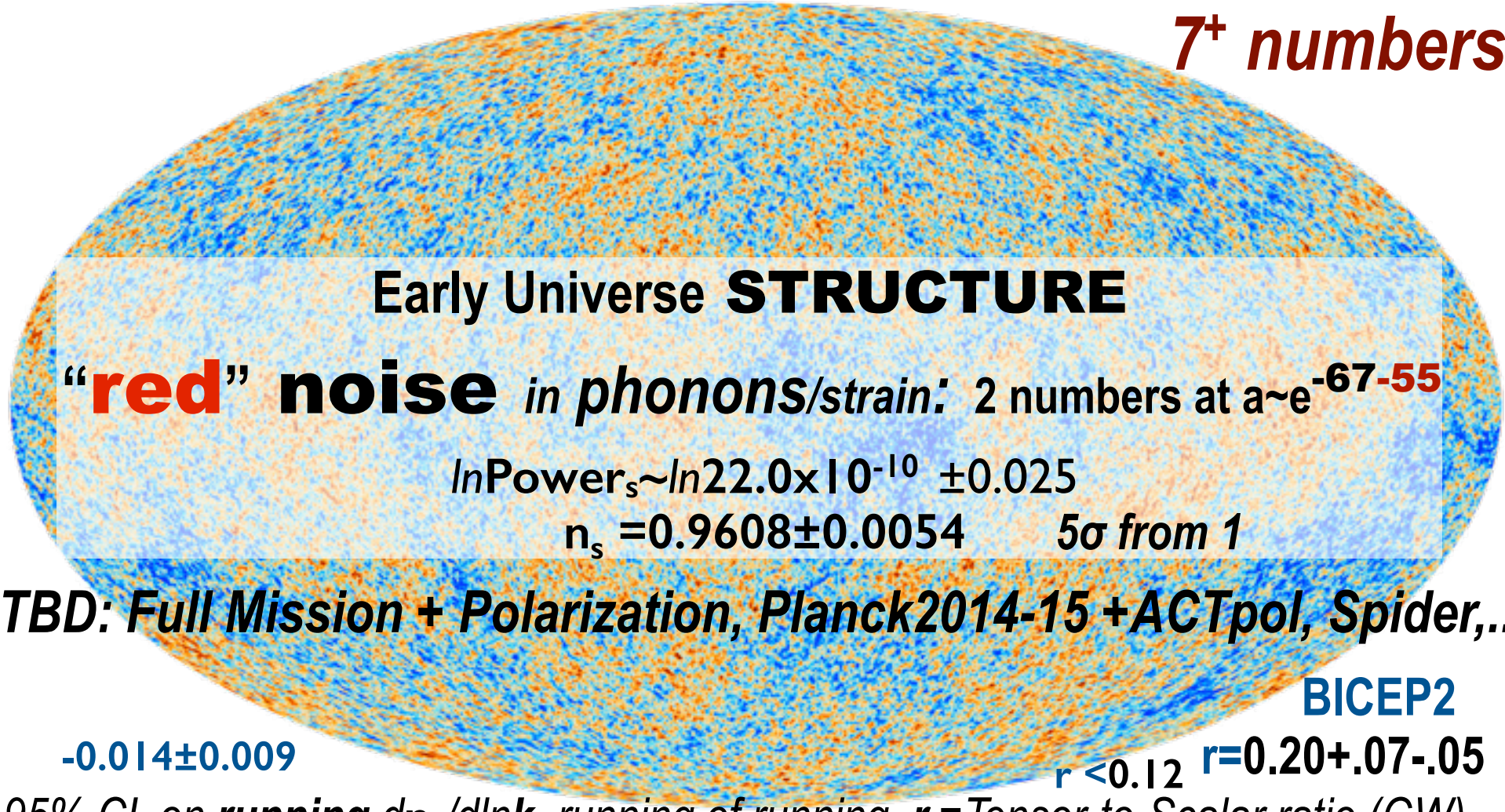
Planck2013 CMB map

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 $a \sim e^{-67-55}$

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

$n_s = 0.9608 \pm 0.0054$ *5σ from 1*

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

BICEP2

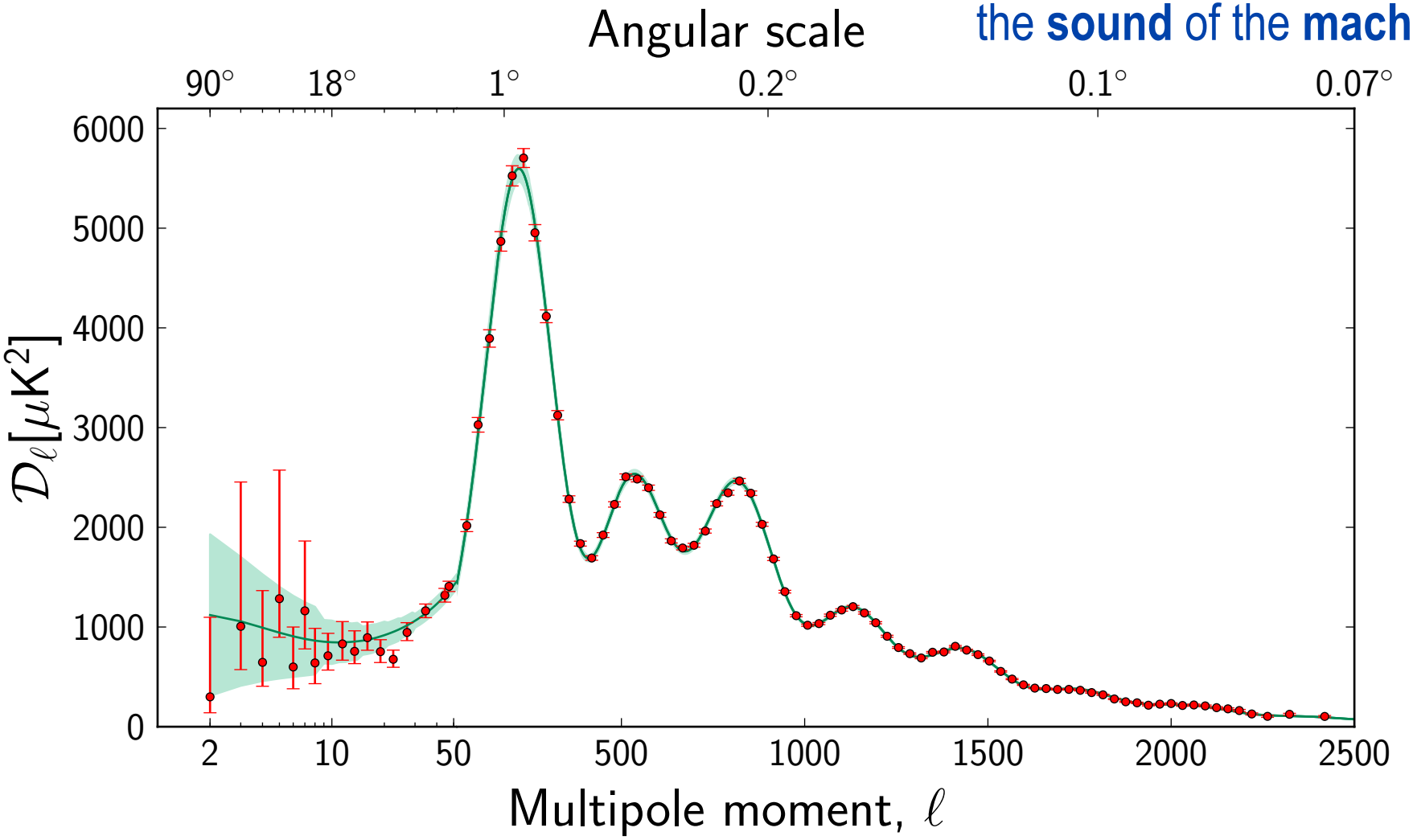
r=0.20+.07-.05

r <0.12

-0.014±0.009

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%)*

the **sound** of the **machine**

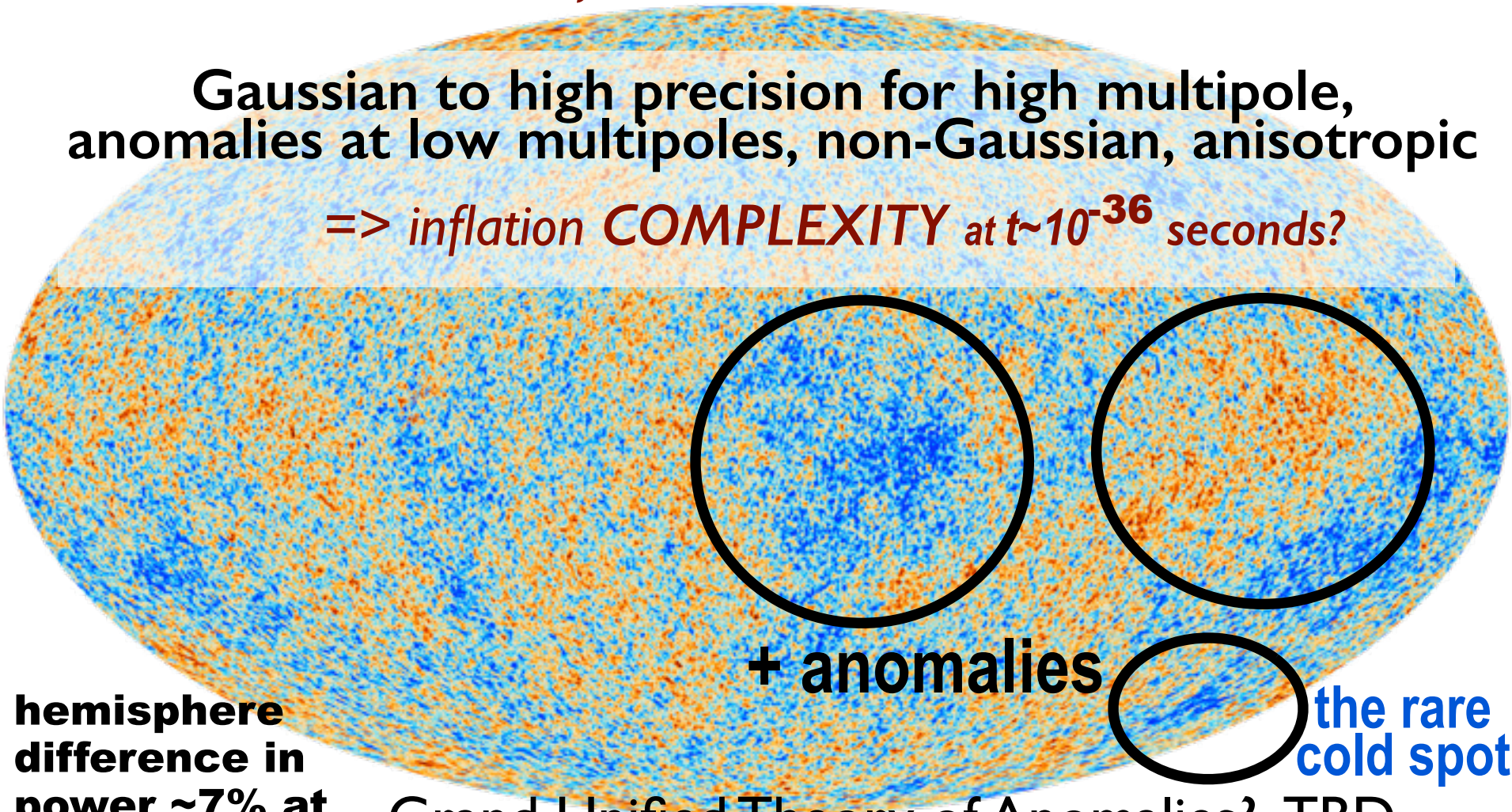


Excellent agreement between the Planck temperature spectrum at high L and the predictions of the tilted ΛCDM model.
Checks with polarization data provide full support to this conclusion.
extensive grid of cosmic models strongly constrain the x in tilted ΛCDM +x, x = subdominant deviations
Planck basic 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. *primordial fluctuation modification?*
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. no f_{NL}

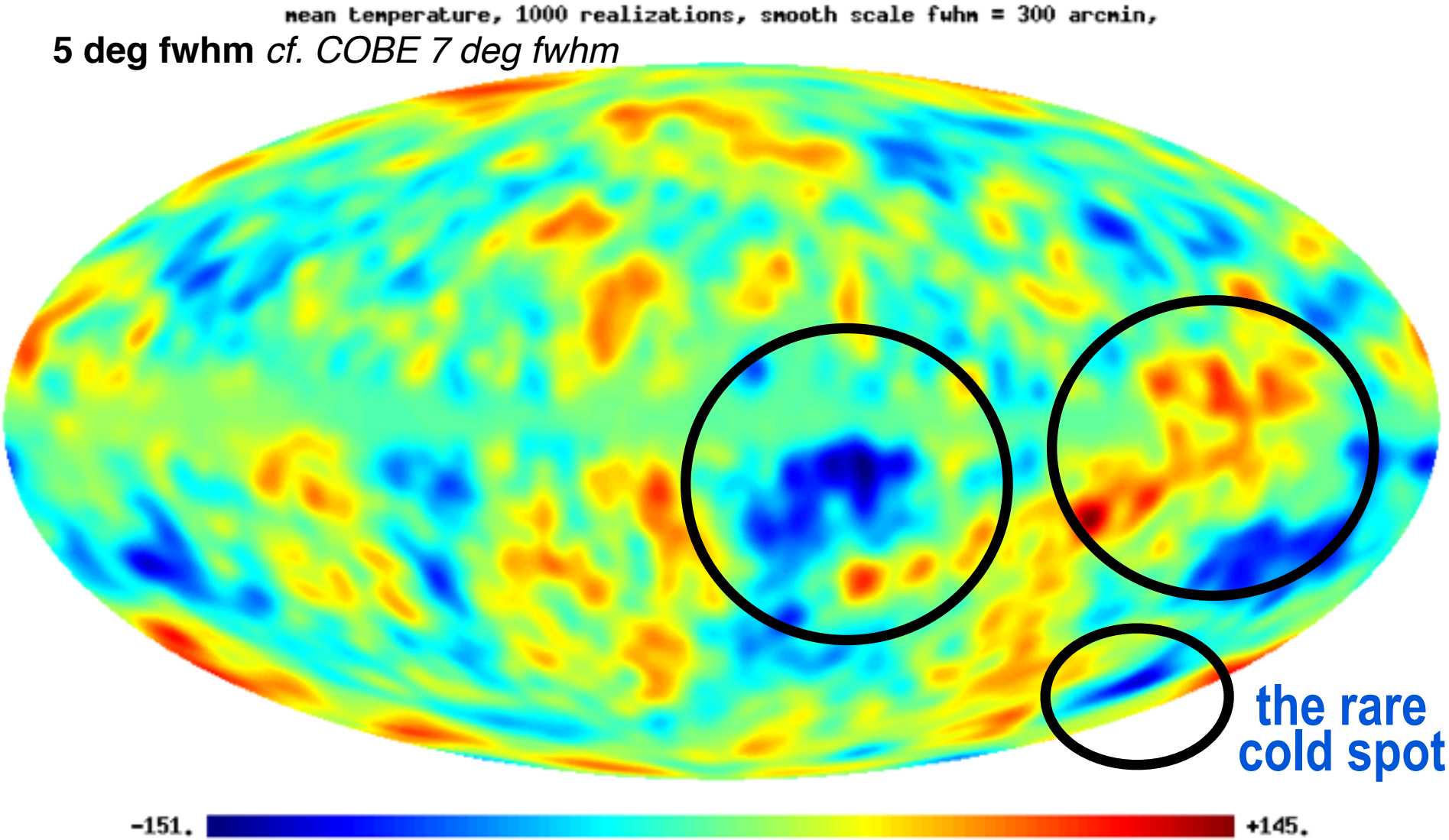
Planck's primordial light unveiled, March 21, 2013

reveals the **SIMPLICITY** of primordial cosmic structure

7^{+} numbers, 2+1 are inflation numbers



temperature map



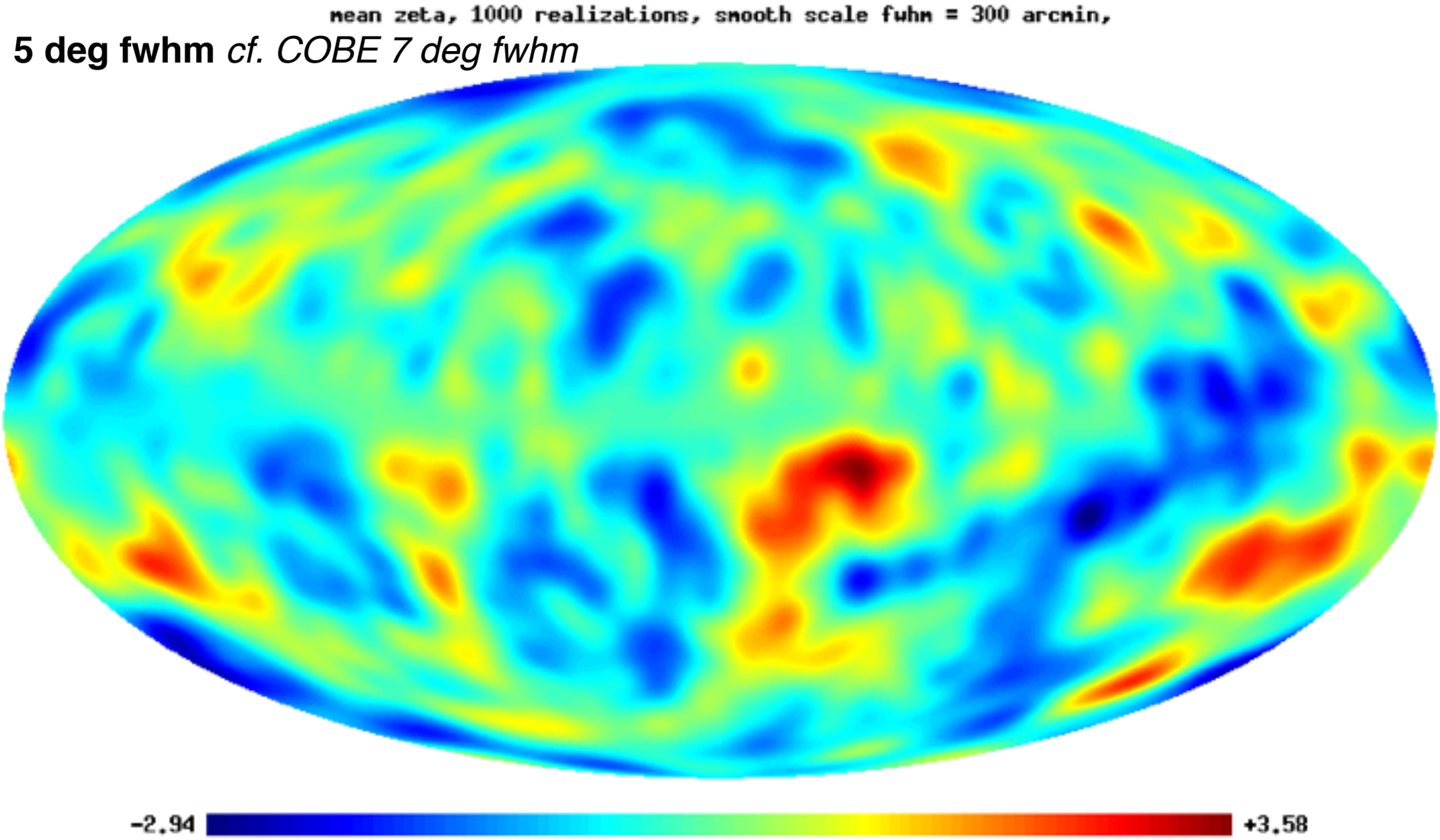
5 deg fwhm *cf. COBE 7 deg fwhm*

the rare cold spot

Temperature changes in micro-degrees

reveals map of **primordial isotropic strain /phonons**

$$\langle Trace(\alpha) | Temp \rangle$$



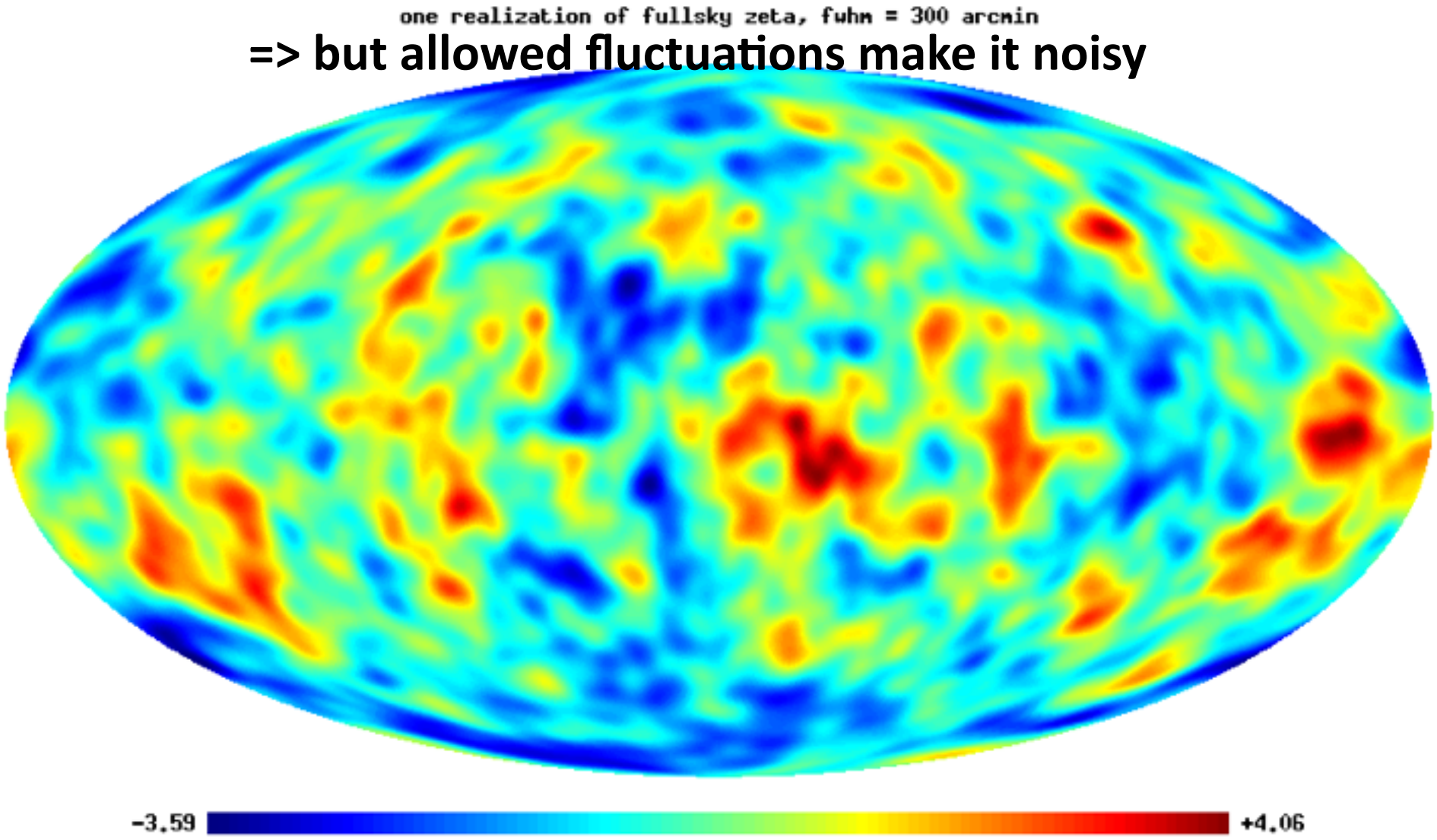
5 deg fwhm *cf. COBE 7 deg fwhm*

Reconstructing the Early Universe

visibility mask

reveals map of **primordial isotropic strain /phonons**

$$\langle \mathbf{Trace}(\boldsymbol{\alpha}) | \mathit{Temp} \rangle + \delta \mathbf{Trace}(\boldsymbol{\alpha})$$



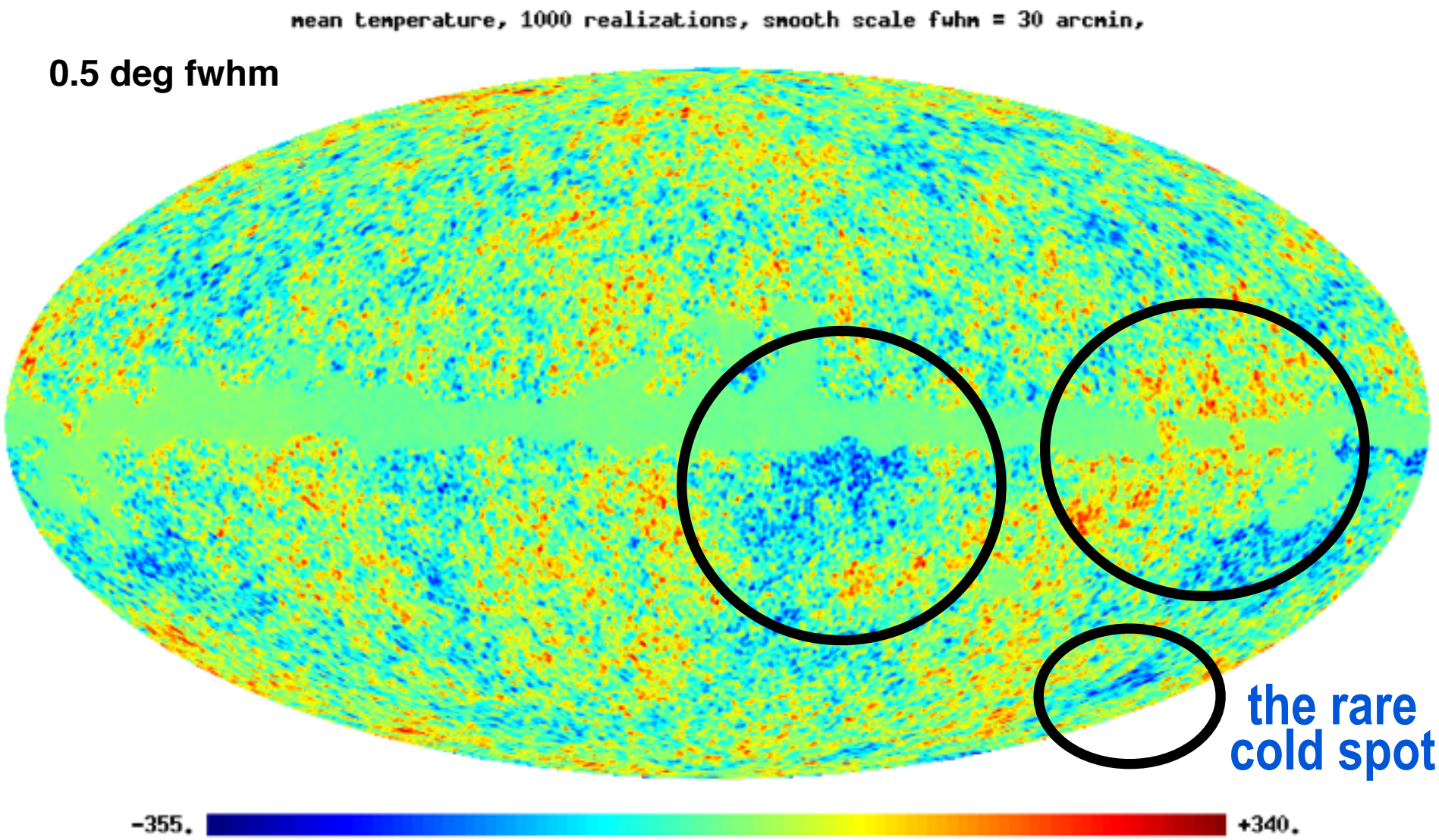
=> but allowed fluctuations make it noisy

5 deg fwhm cf. COBE 7 deg fwhm

Reconstructing the Early Universe

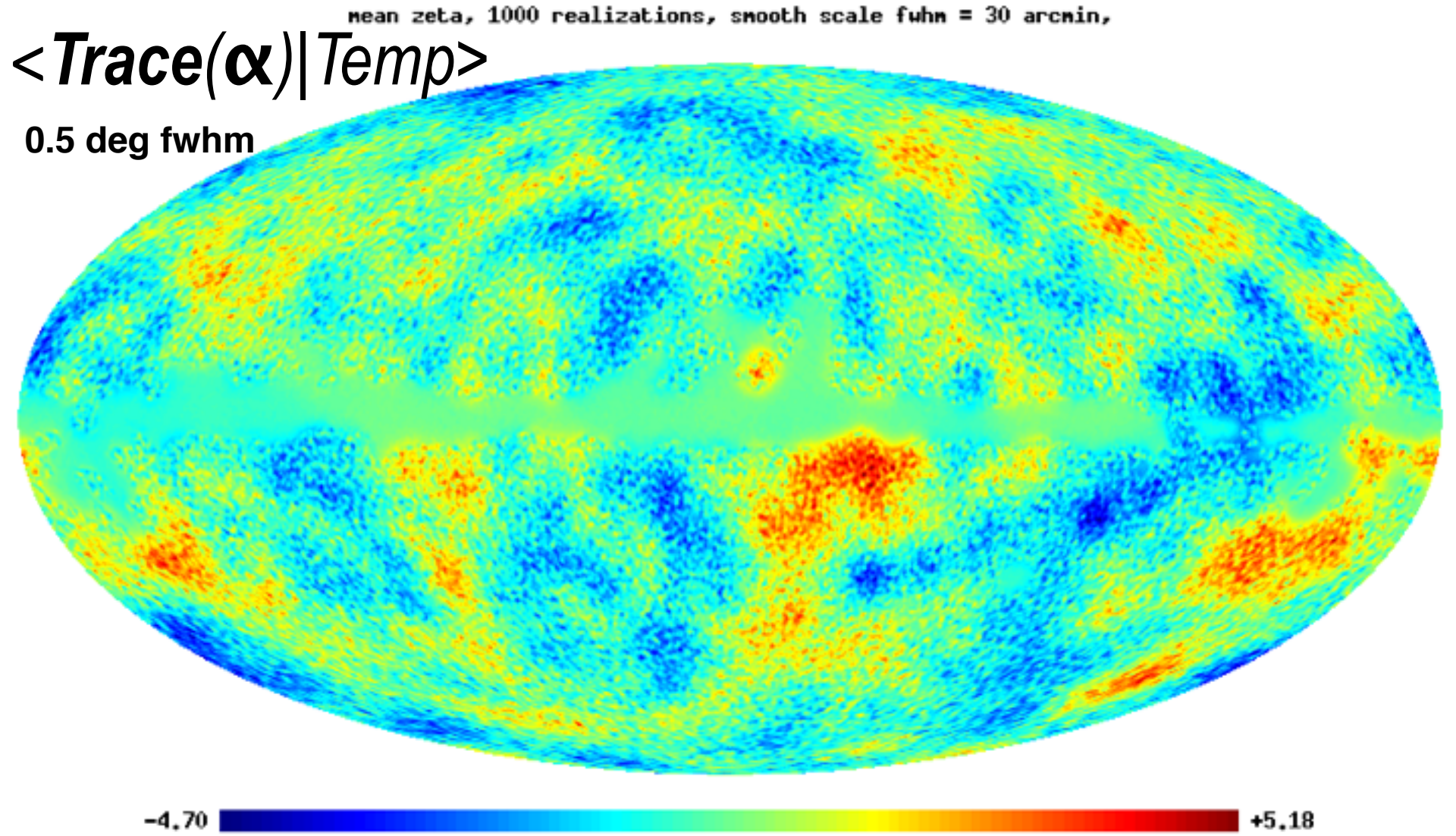
visibility mask

temperature map



reveals map of **primordial isotropic strain /phonons**

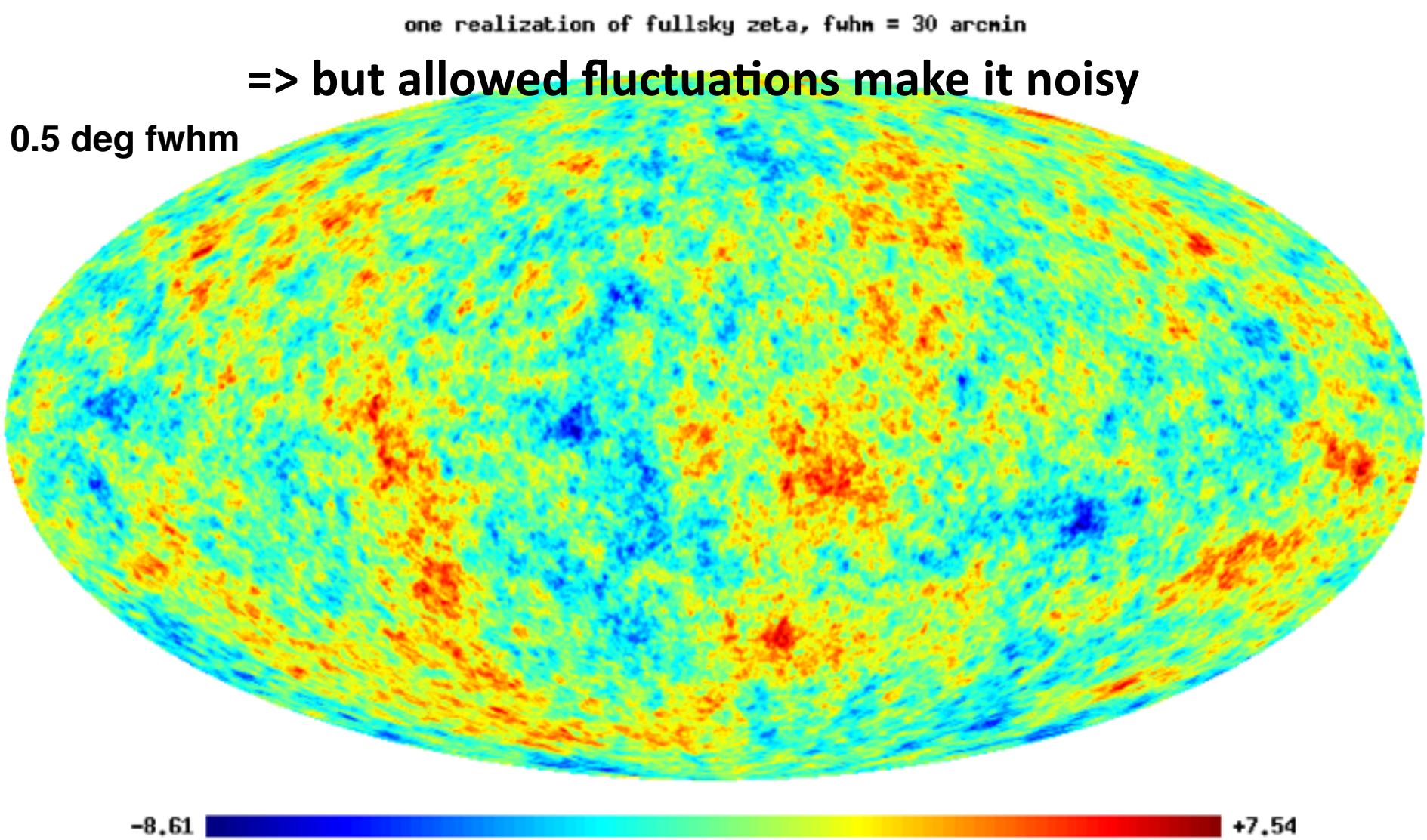
=> primordial scalar curvature map of the inflation epoch



visibility mask

reveals map of **primordial isotropic strain /phonons**

$$\langle \mathbf{Trace}(\boldsymbol{\alpha}) | \mathit{Temp} \rangle + \delta \mathbf{Trace}(\boldsymbol{\alpha})$$



visibility mask

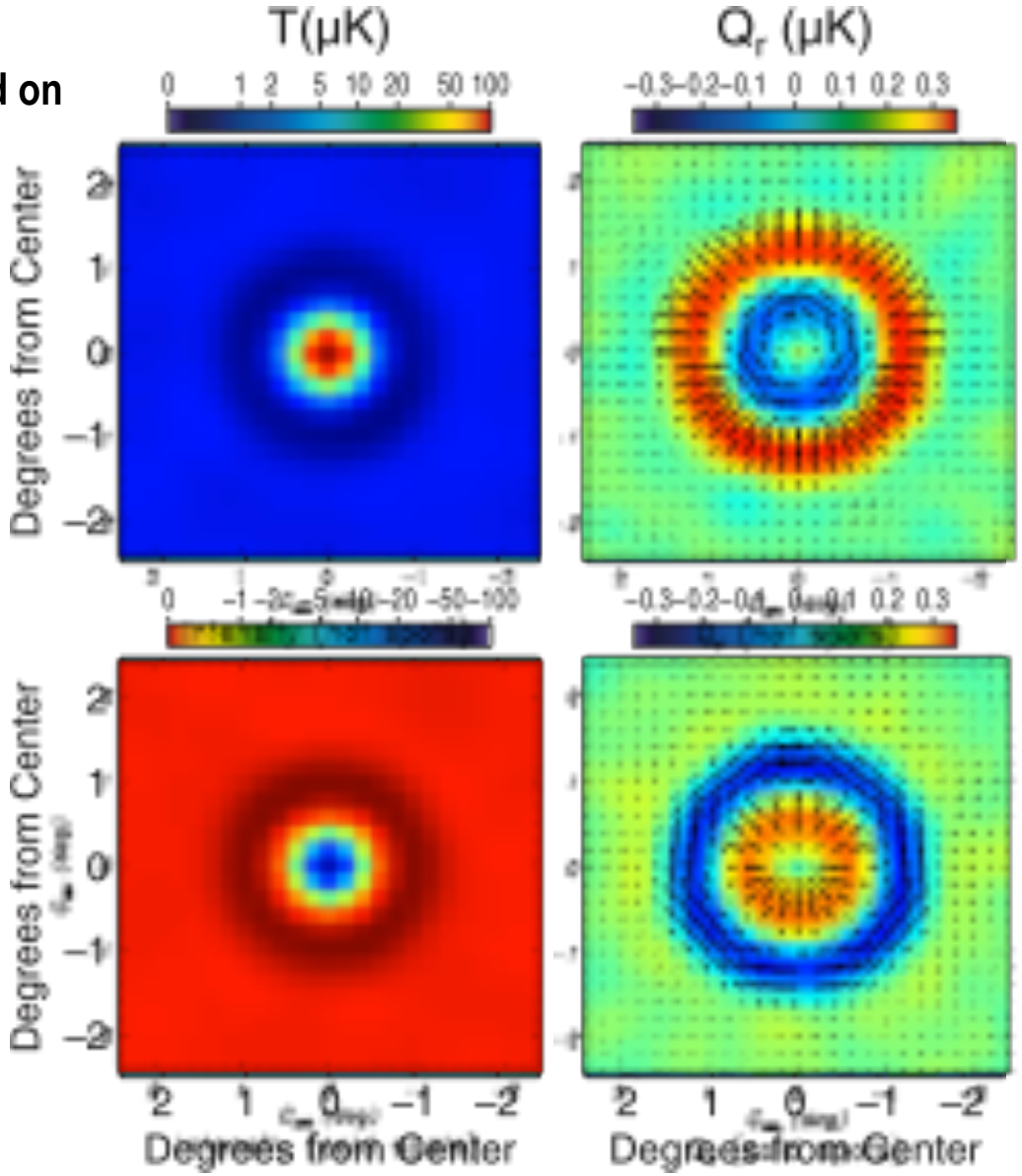
CMB Peak Statistics

temperature stacked on temperature Peaks

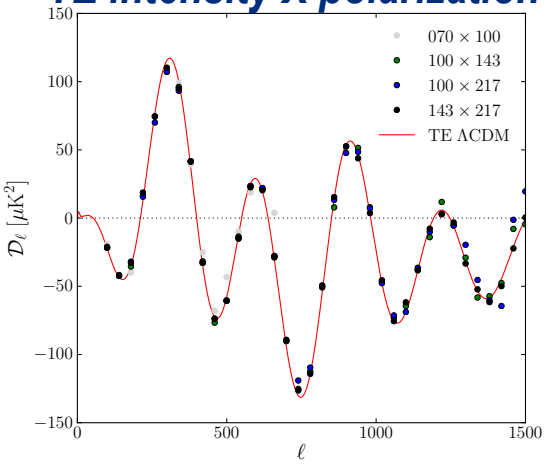
polarization rotated & stacked on temperature Peaks

CMB Polarization

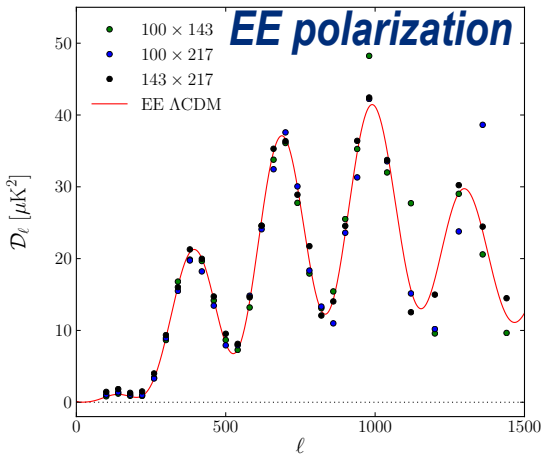
BAO in the CMB – Planck2013



TE intensity X polarization



EE polarization



Planck2013 teaser for Planck2014 polarization release

E mode patterns

no B here

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

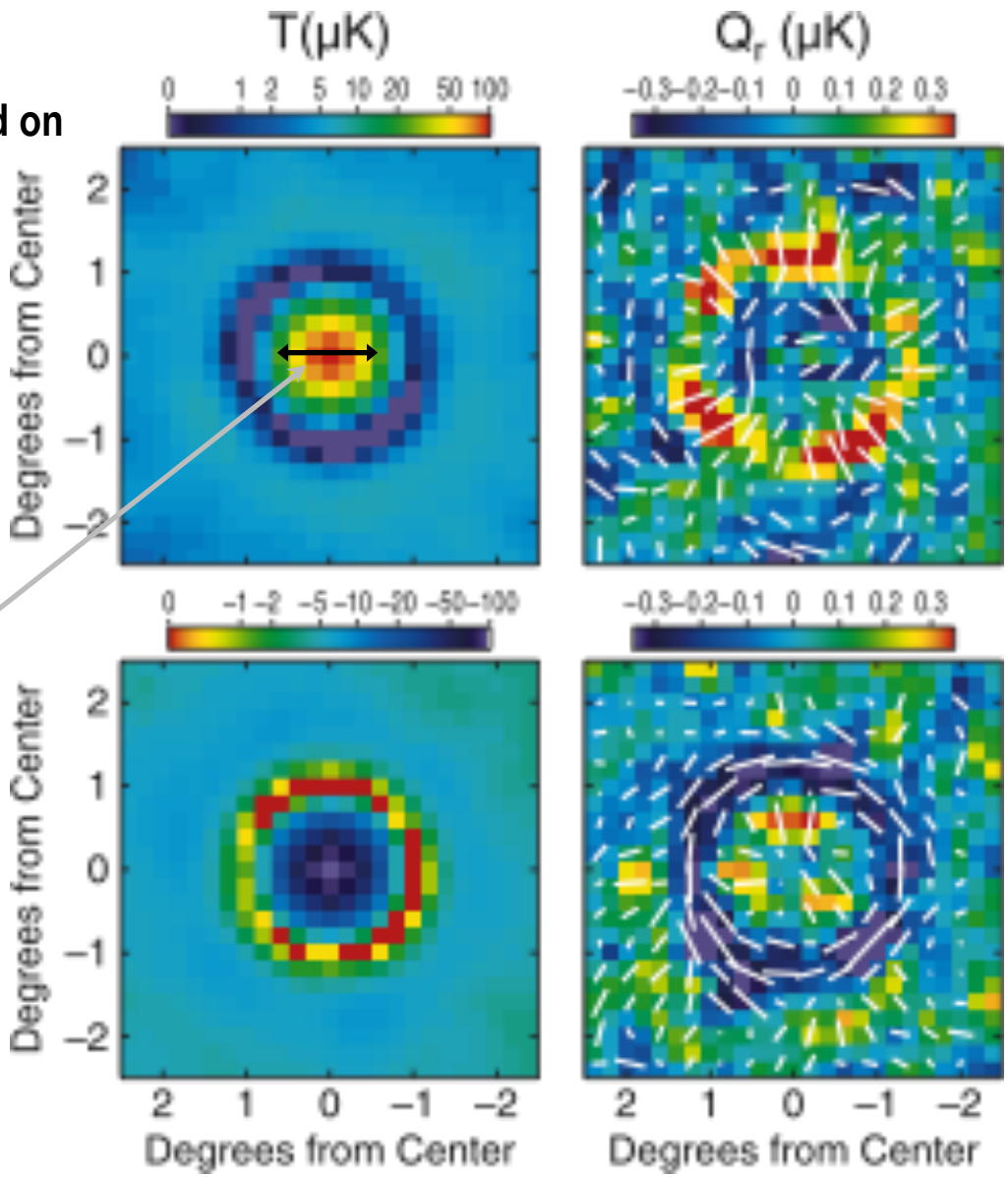
CMB Peak Statistics

temperature stacked on temperature Peaks

polarization rotated & stacked on temperature Peaks

CMB Polarization

BAO in the CMB – WMAP9



BAO scale:
145.8 ± 1.2 Mpc

B mode of polarization *cf.* E mode

linear scalar fluctuations create only E patterns

strain from CMB lensing tides distorts E pattern into a bit of B *SPT*

anisotropic strain from **gravity waves => E & B**

photons under strain

BICEP2 collaboration 2014

380 sq deg
f_{sky}=0.009

512 antenna coupled TES bolometers
150 GHz for 3 seasons
cross-correlate with BICEP1, 100 GHz,
preliminary cross-correlate with KECK

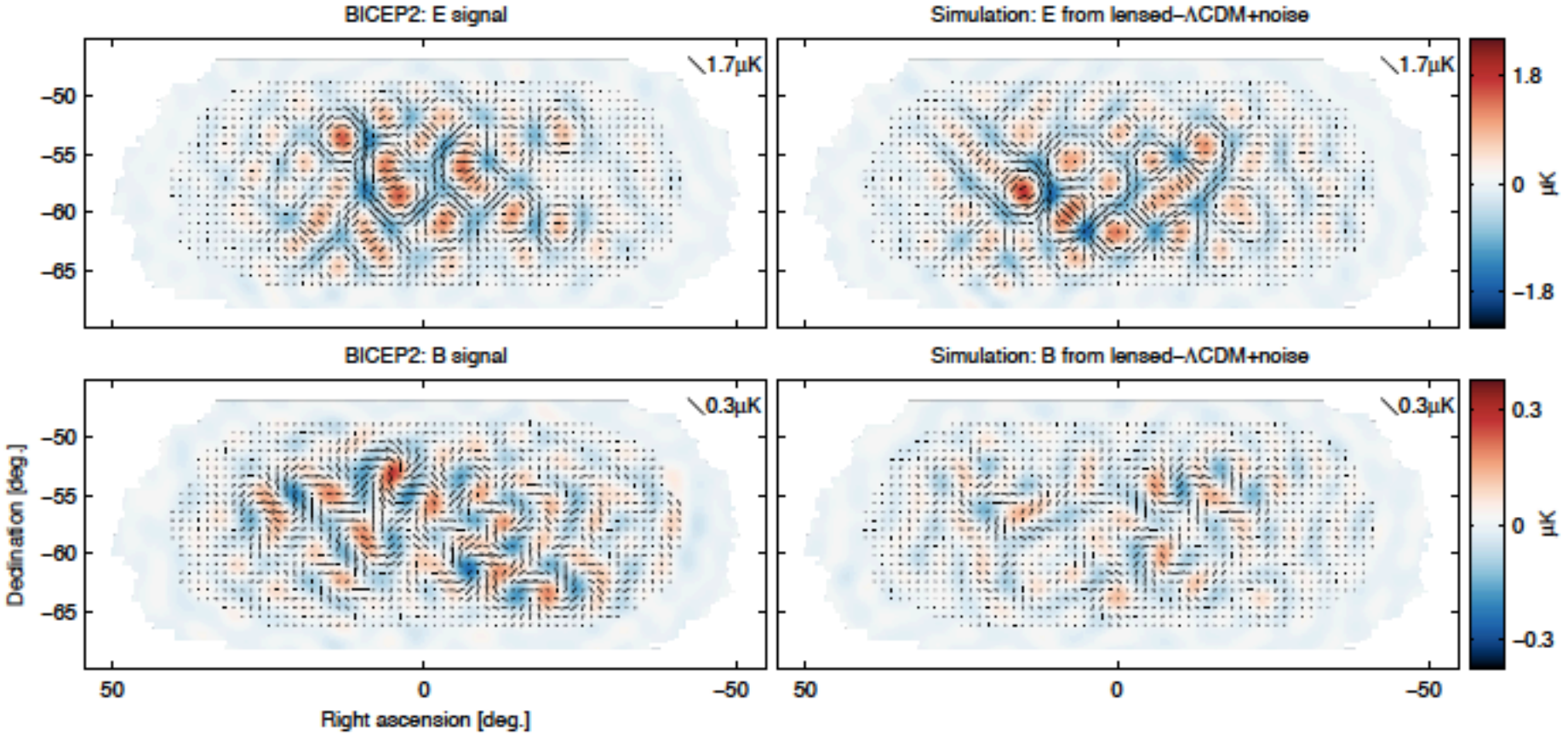
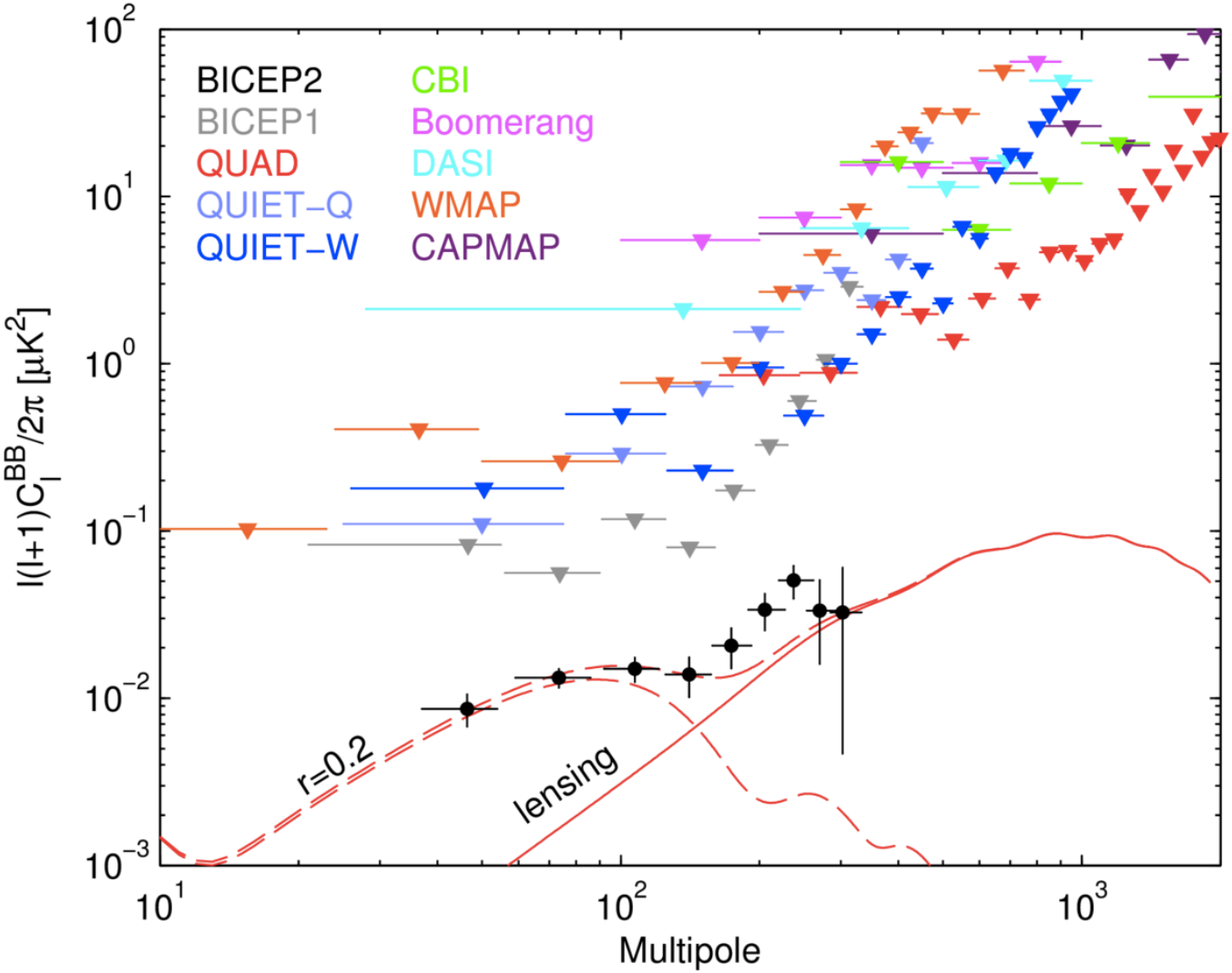


FIG. 3.— *Left:* BICEP2 apodized E-mode and B-mode maps filtered to $50 < \ell < 120$. *Right:* The equivalent maps for the first of the lensed-ΛCDM+noise simulations. The color scale displays the E-mode scalar and B-mode pseudoscalar patterns while the lines display the equivalent magnitude and orientation of linear polarization. Note that excess B-mode is detected over lensing+noise with high signal-to-noise ratio in the map ($s/n > 2$ per map mode at $\ell \approx 70$). (Also note that the E-mode and B-mode maps use different color/length scales.)

BICEP2 collaboration 2014 non-lensing B mode **=> r=0.20 +.07-.05**

cf. P13: r from TT

< 0.12 95% CL

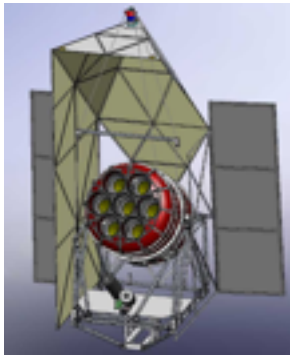


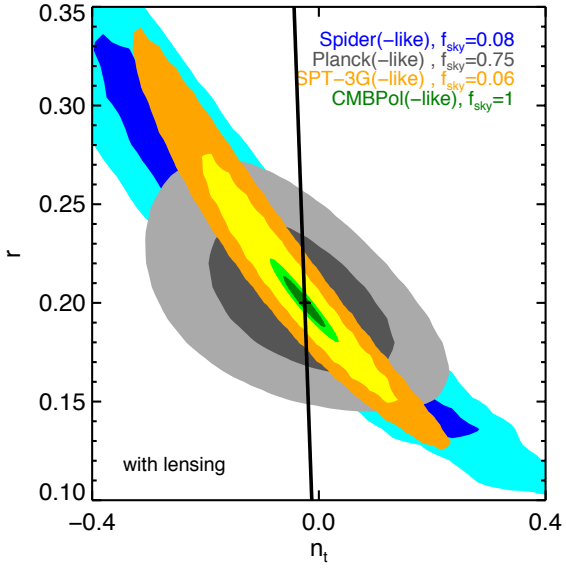
r=GW power/scalar-curvature power ≈0.13V/(2x10^{16}Gev)^4

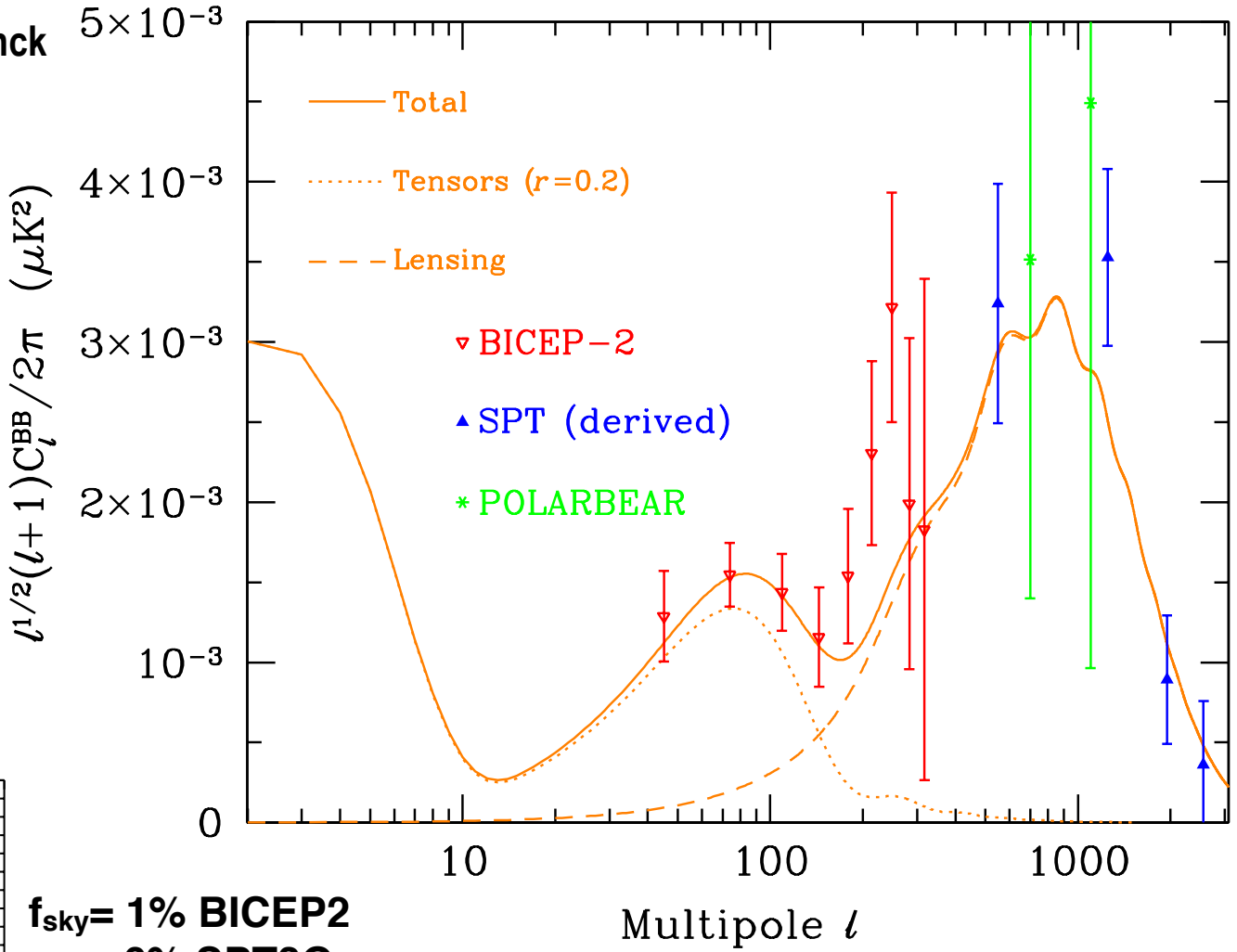
Potential Energy scale is the GUT level!

We are working heavily on Planck polarization, E Nov 2014, B ?

Spider collaboration,
LDB flight Fall 2014 +-.02
supposed to fly Fall 13, but US sequester stopped it







f_{sky}= 1% BICEP2
= 6% SPT3G
= 8% SPIDER
= 70% PLANCK

= 50% AdvACT

Spider24days+Planck2.5yr:
r-n_t *matrix*-forecast
for r=0.2 input
($2\sigma_r$ ~0.04 including fgnds)

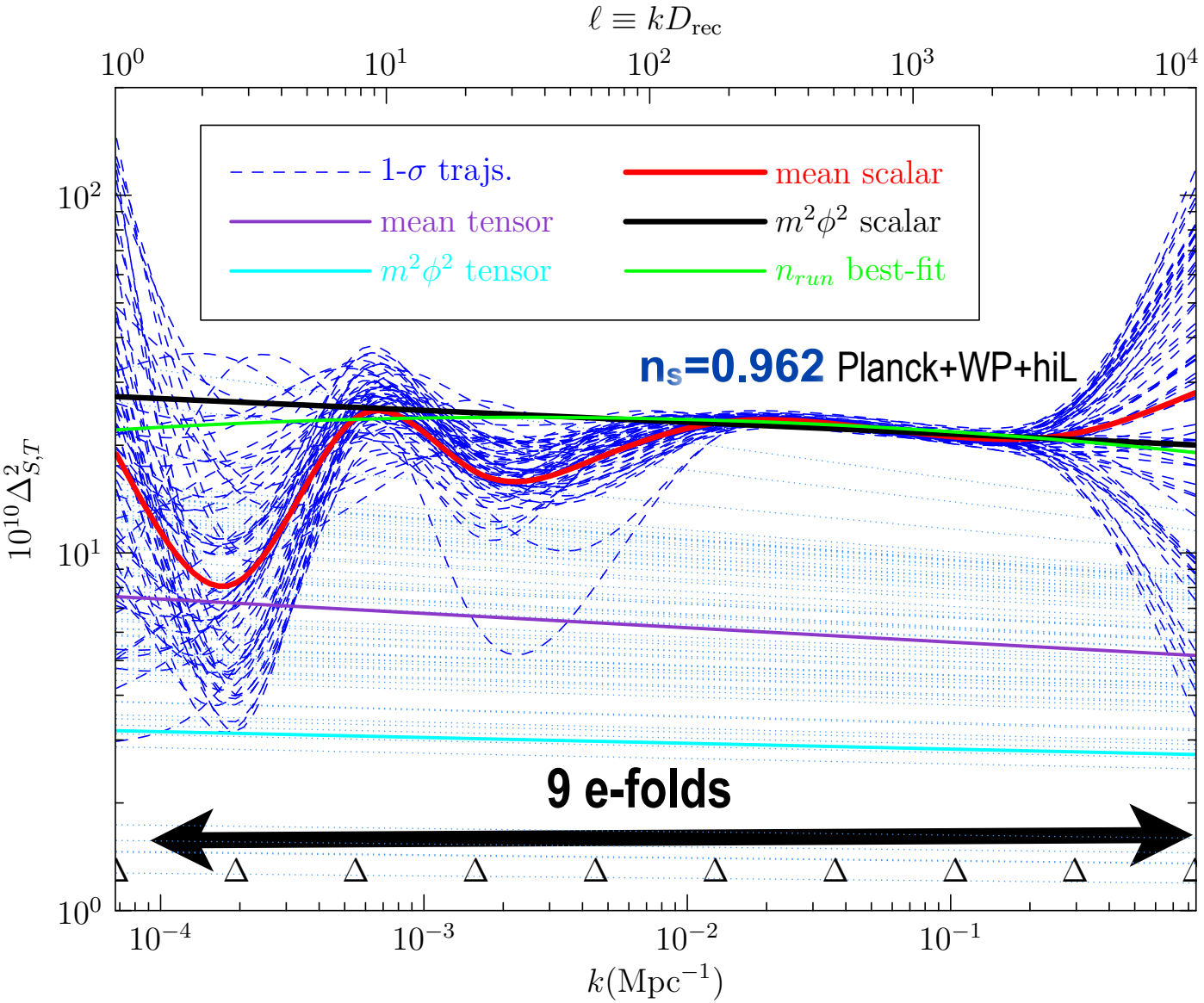
*similar r-forecasts for **ABS+, Keck, AdvACT,..***

*scan ln**P**s(lnk)/As, ln**As**=lnPs(kpivot,s), **r**(kpivot,t); consistency => reconstruct* **ε(ln*Ha*), V(ψ)**

*ln*Ps(*ln*k)

new parameters:

trajectory probabilities for early-inflatons



Bond, Braden, Huang, Frolov,2014

PS: running of PS is a bad fit

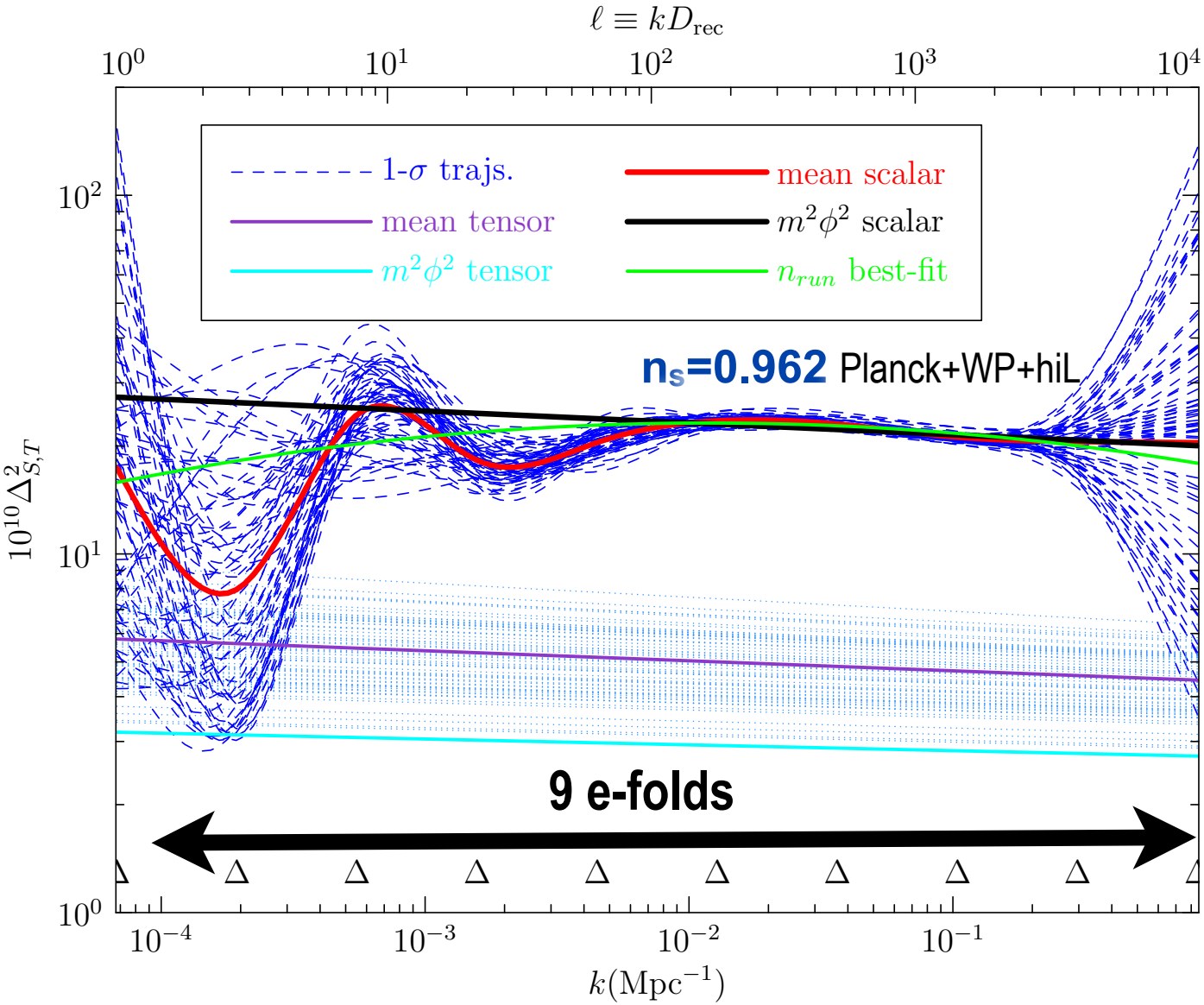
Inflation Histories
(CMBall+LSS+SN+WL)

*scan ln***P**$_s$(*ln*k)/A$_s$, *ln***A**$_s$=*ln*P$_s$($k_{pivot,s}$), ***r***($k_{pivot,t}$); *consistency => reconstruct* **ε**(*ln***Ha**), **V(ψ)**

*ln*P$_s$(*ln*k)

new parameters:

trajectory probabilities for early-inflatons



Bond, Braden, Huang, Frolov,2014

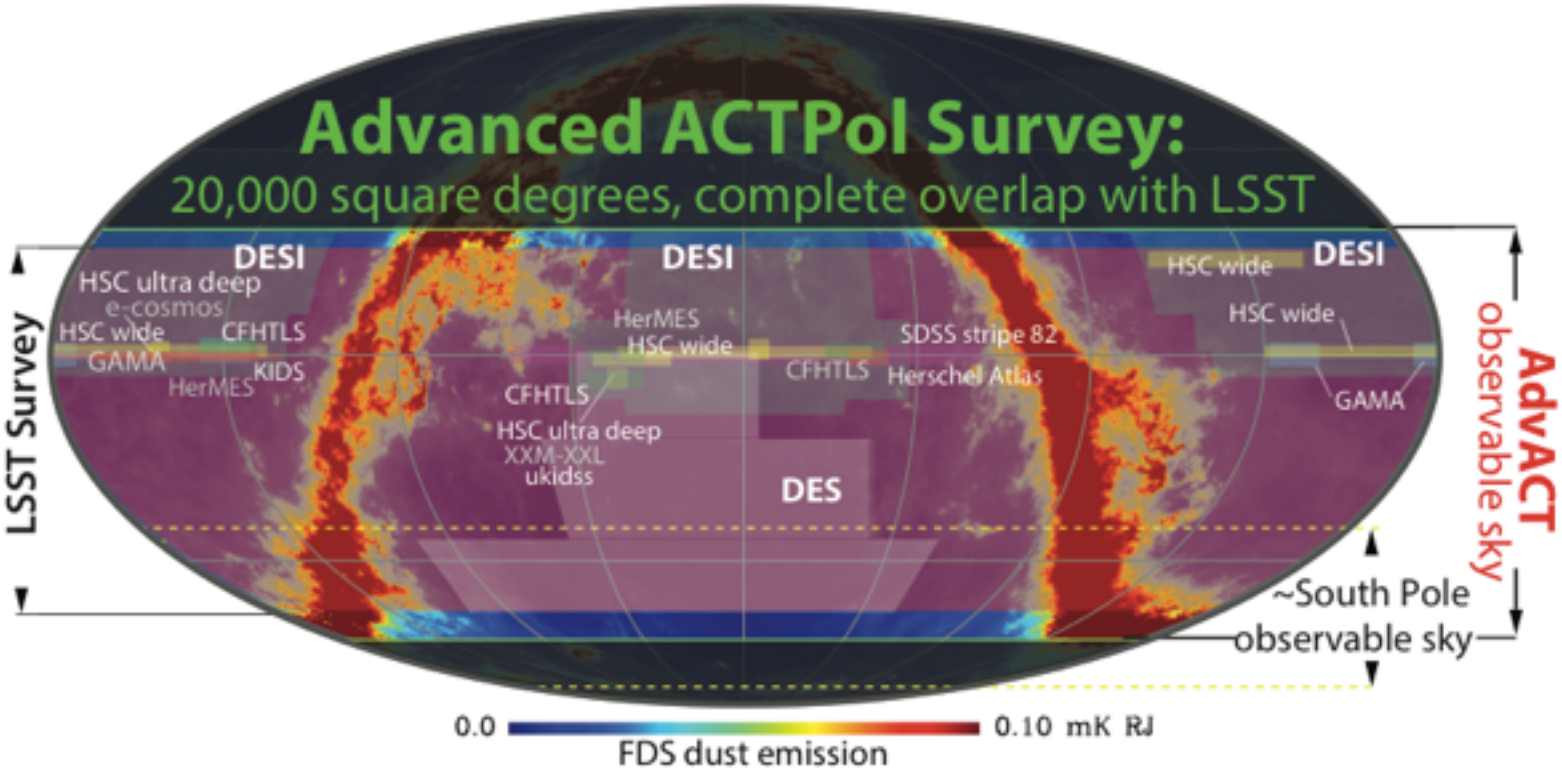
PS: running of PS is a bad fit

Inflation Histories
(CMBall+LSS+SN+WL)

The ACT Collaboration

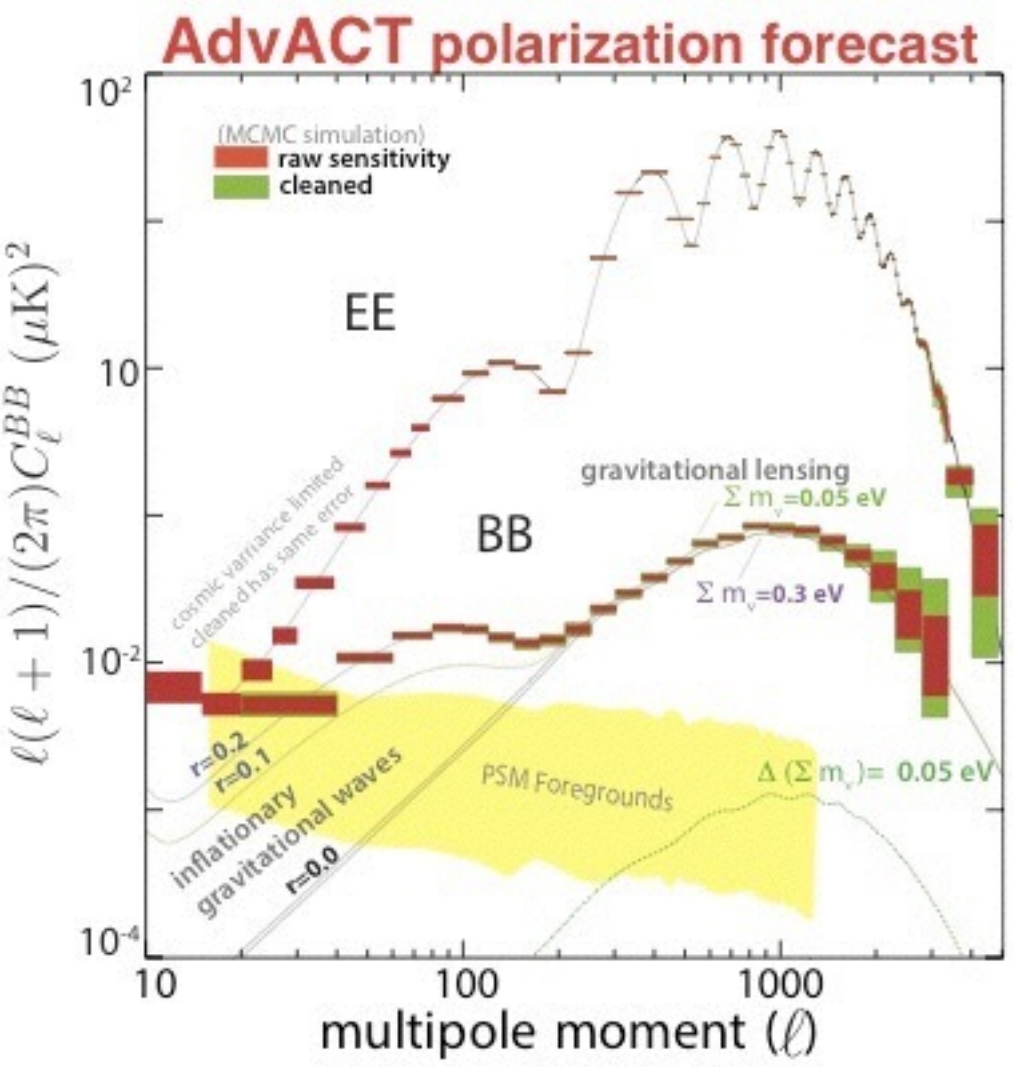
ACT, now ACTpol, => Advanced ACTpol

Advanced ACTPol (AdvACT) Observations



- ~20,000 deg^2 survey (f_{sky}~0.5) with complete LSST overlap as well as DES, ALMA, and other observatories located in Chile
- Substantial overlap with spectroscopic surveys (SDSS, PFS, DESI)

AdvACT: Power Spectra



Error bars above shown for r = 0.2

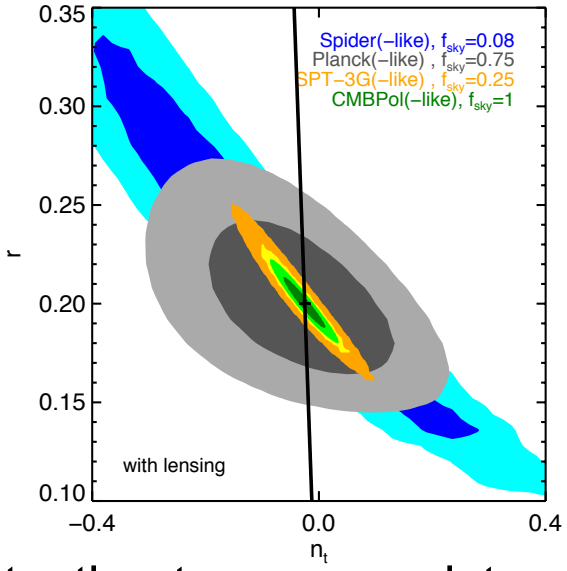
High S/N B-mode detections for r > 0.01 are measured in independent frequency bands (90 & 150 GHz) and on many patches across the sky.

This provides important cross-checks on any detected signal

Also shown:

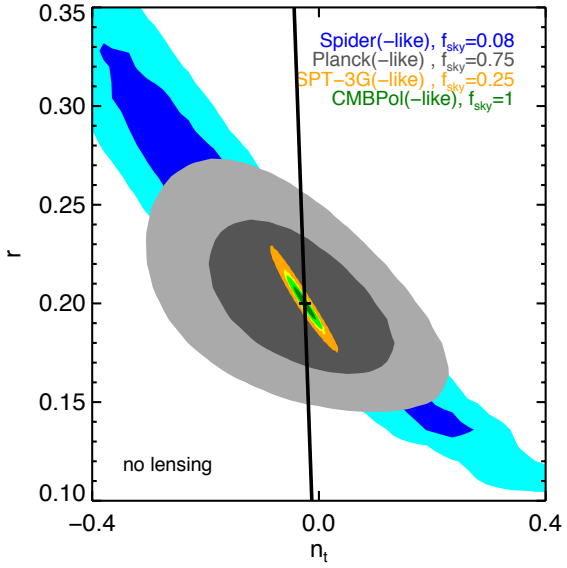
- Error bars before and after foreground cleaning
- Varying amplitudes of the gravitational lensing signal for different values of the sum of the neutrino masses
- Planck forecasts

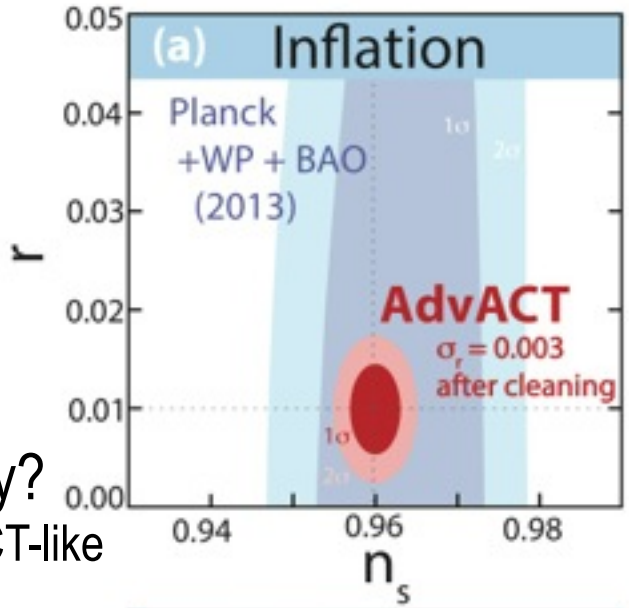
AdvACT: Cosmological Forecasts & Planck2.5, Spider, future SPT3g, CMBpol

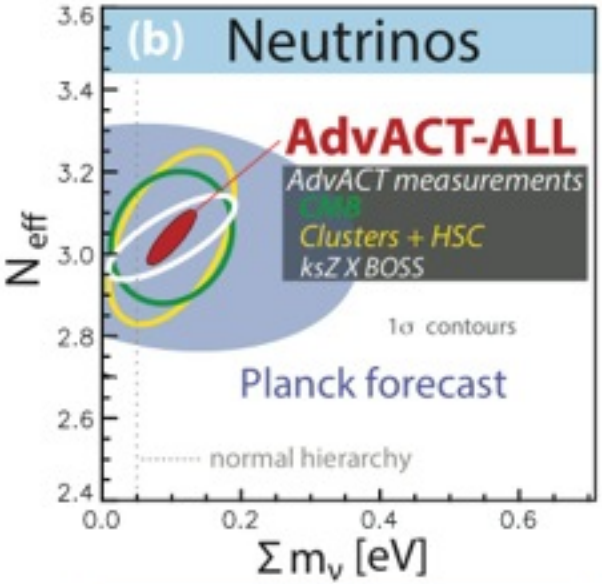


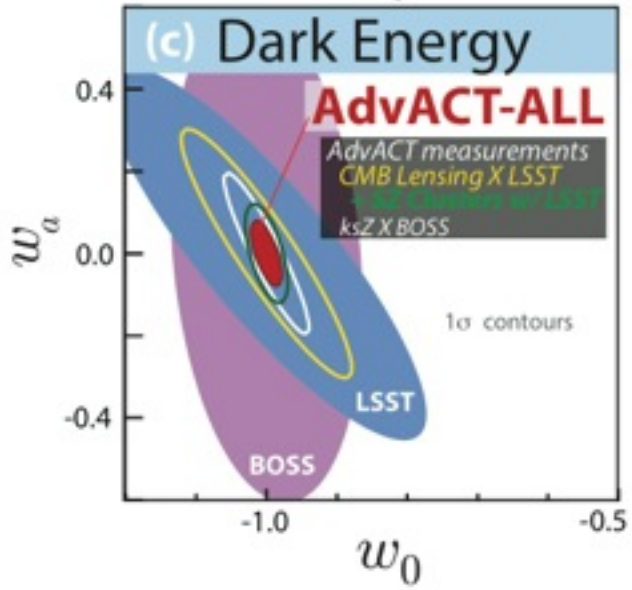
testing tensor consistency?

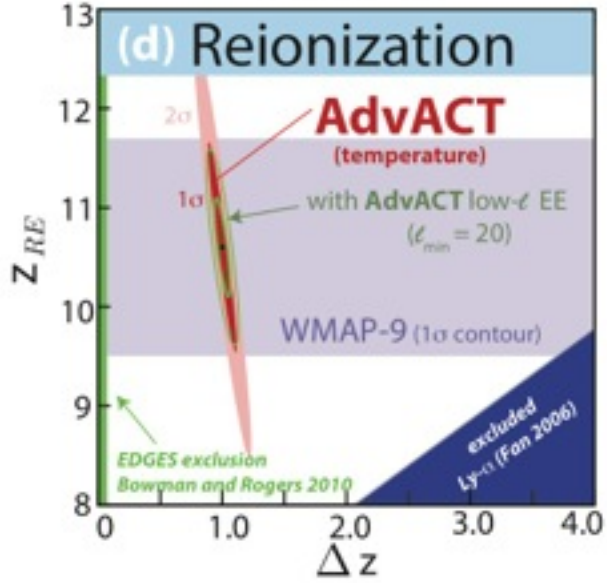
better f_{sky}=25% for spt3g/AdvACT-like than current 6% goal for spt3g





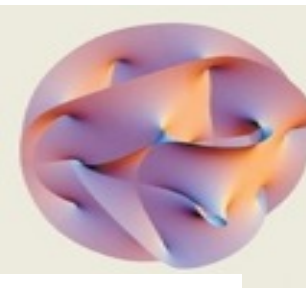




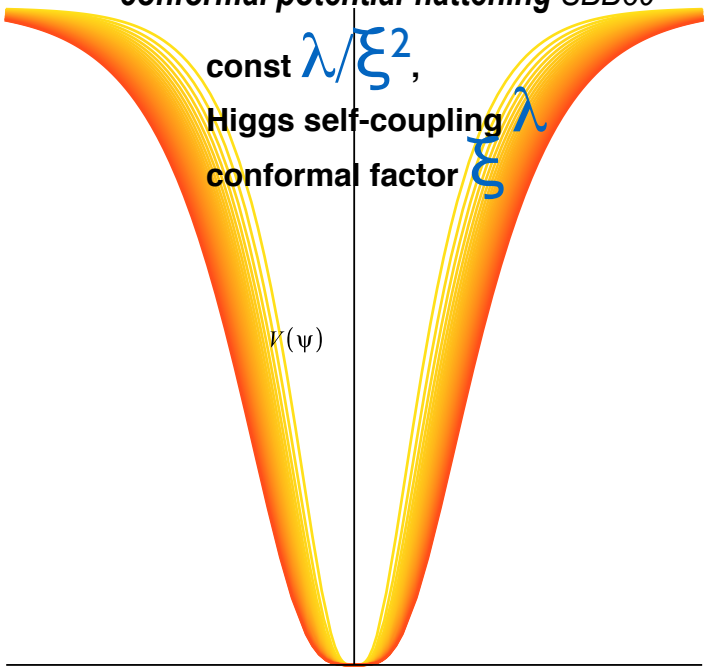


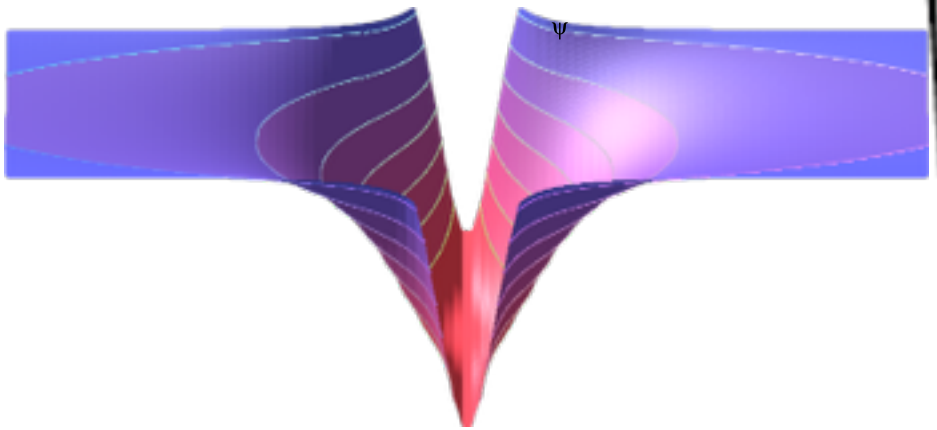
how was *matter & entropy generated at the end of acceleration = inflation*?

Relate it to the Higgs & standard model?



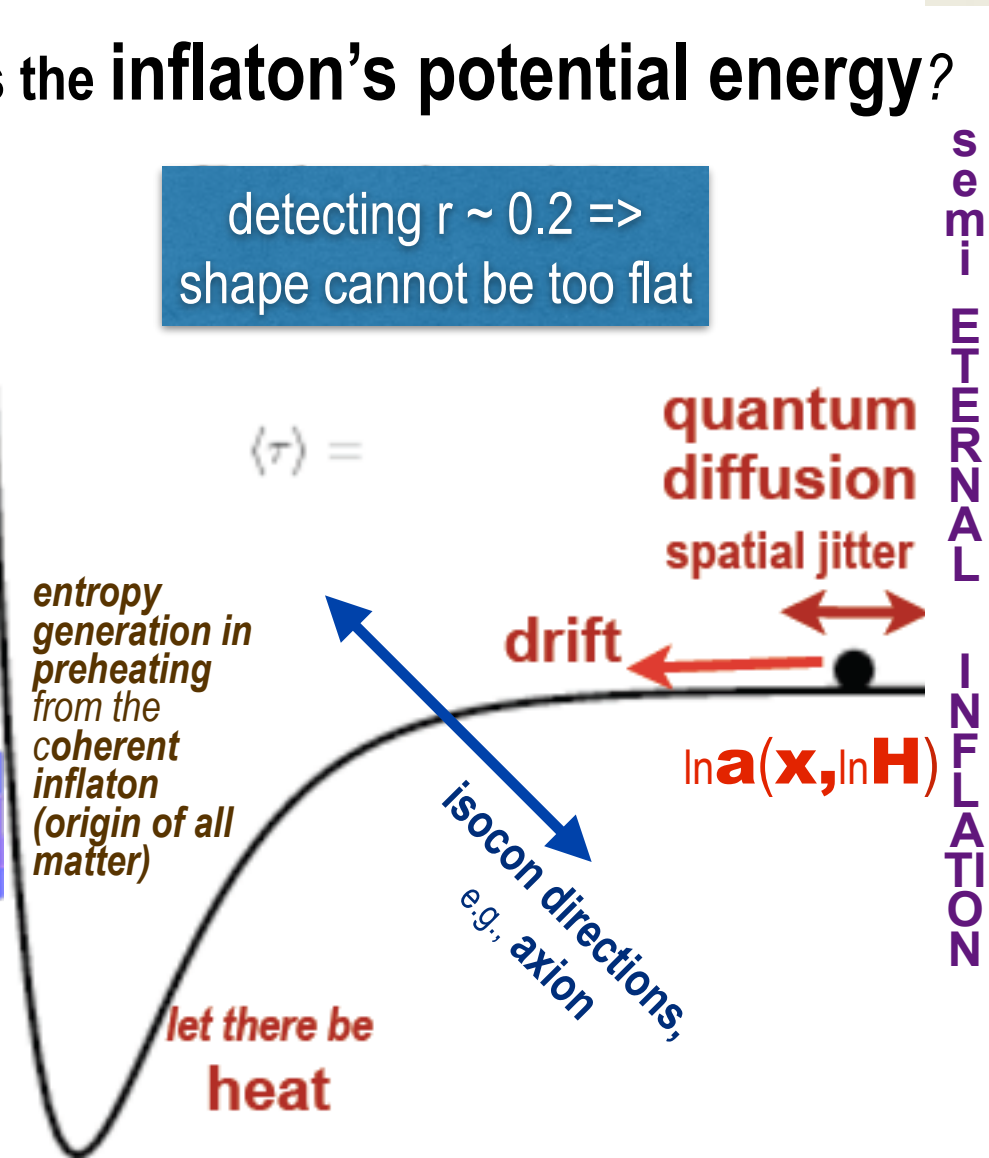
conformal potential-flattening *SBB89*





what is the **inflaton's potential energy**?

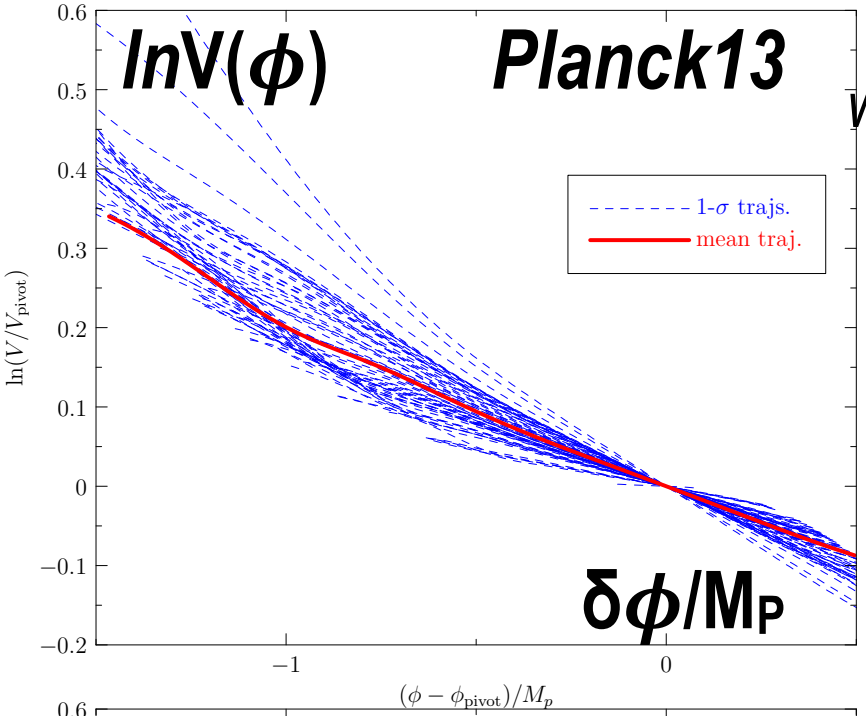
detecting r ~ 0.2 =>
shape cannot be too flat

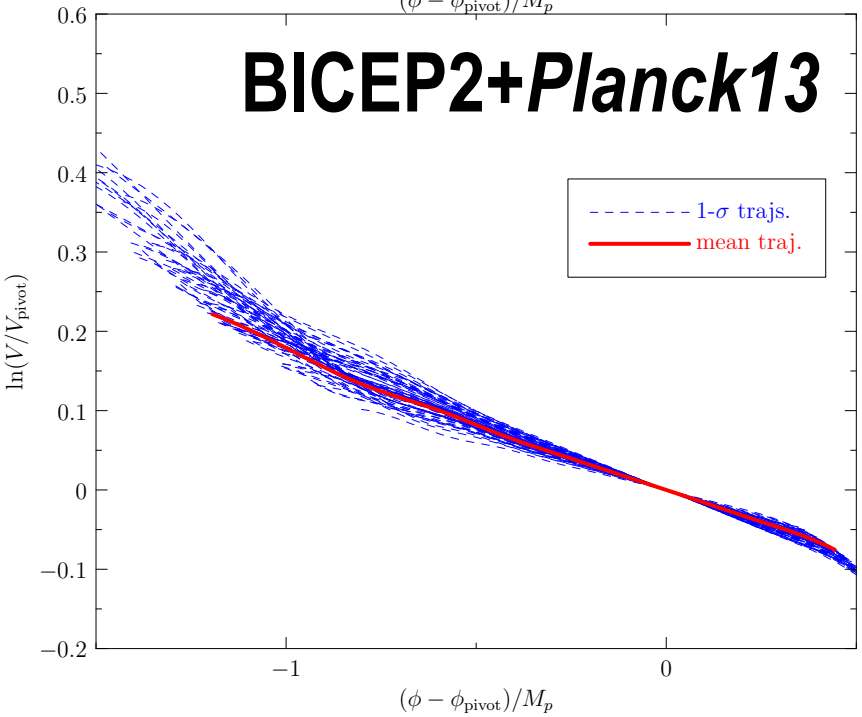


what is the inflaton's V(ϕ)?

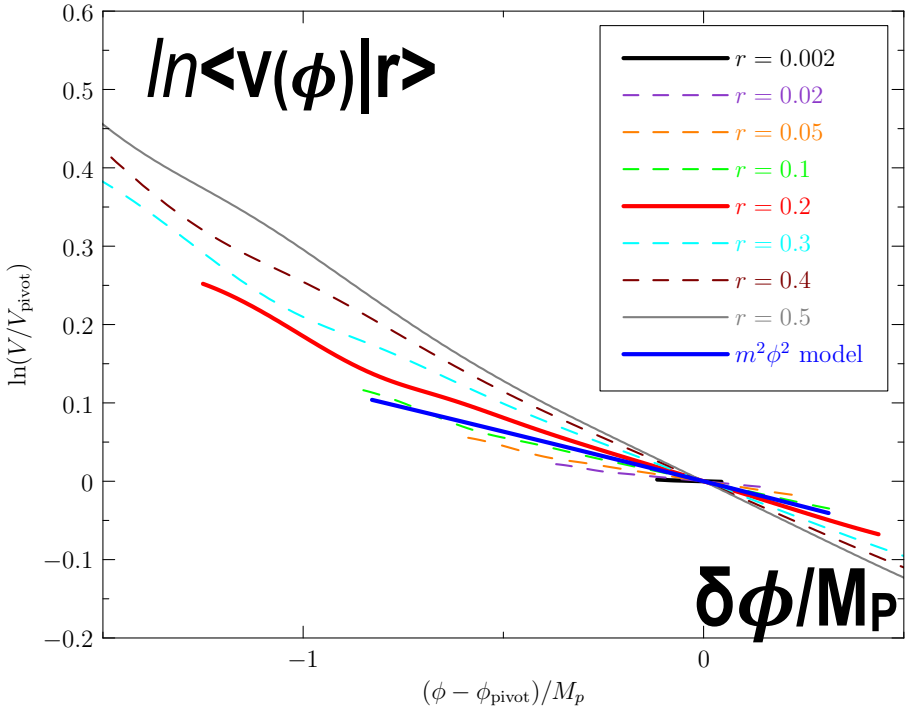
we **reconstruct** *the* ***scalar curvature power*** *(isotropic strain) & the early universe* ***acceleration histories*** *as well*

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

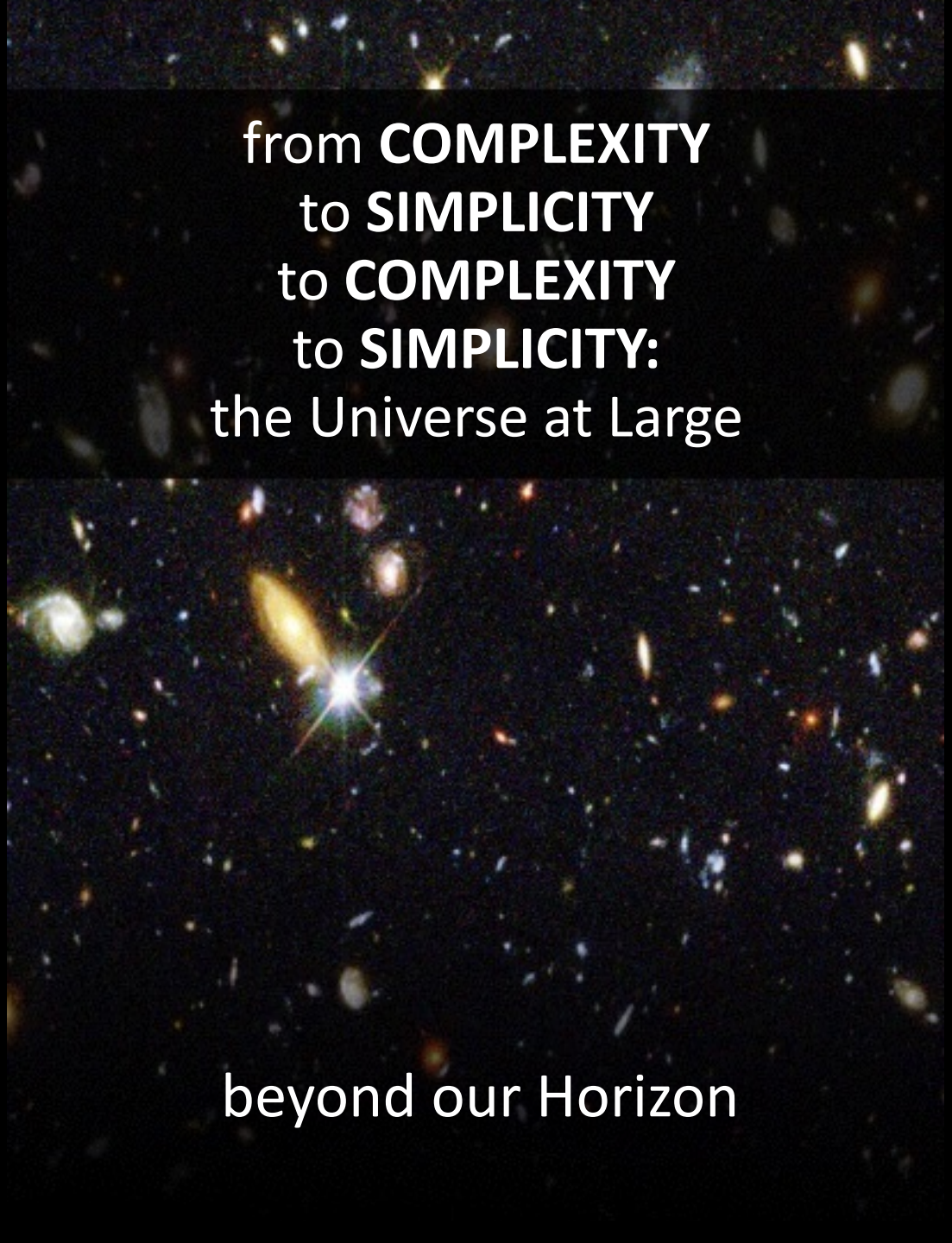




Reconstructed mean potential (without BICEP constraint)

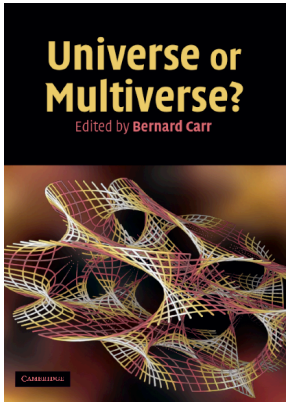


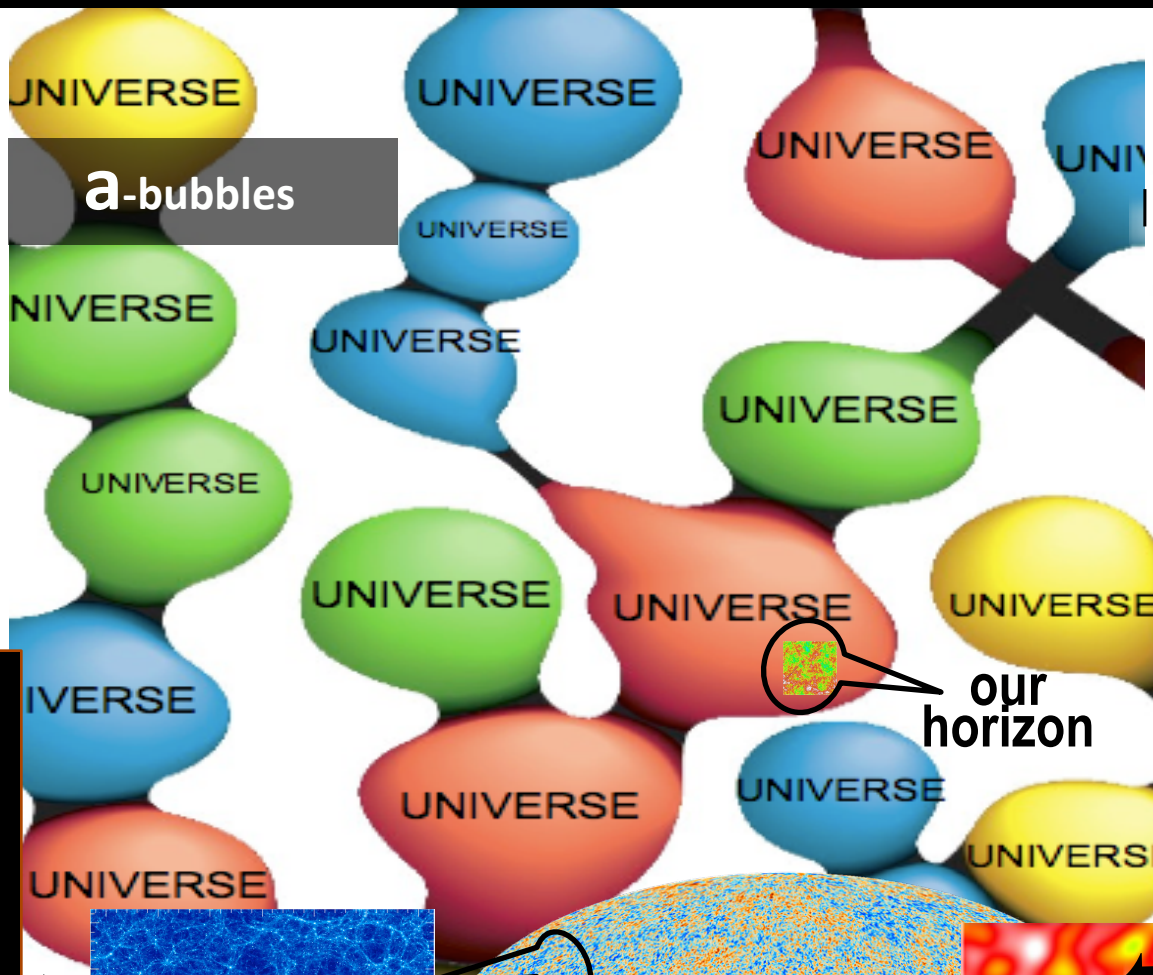
simplest is V(ϕ) ~ $m^2\phi^2$

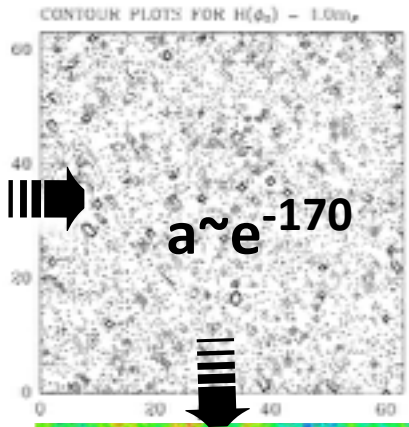

from **COMPLEXITY**
to **SIMPLICITY**
to **COMPLEXITY**
to **SIMPLICITY:**
the Universe at Large
beyond our Horizon

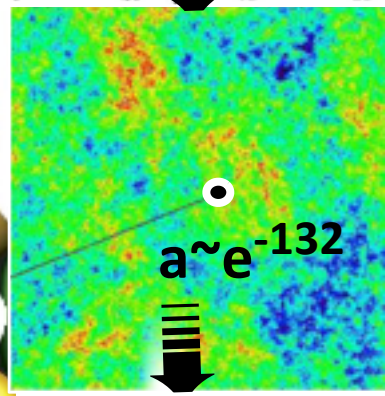
ultra-Ultra Large Scale Structure of the Universe

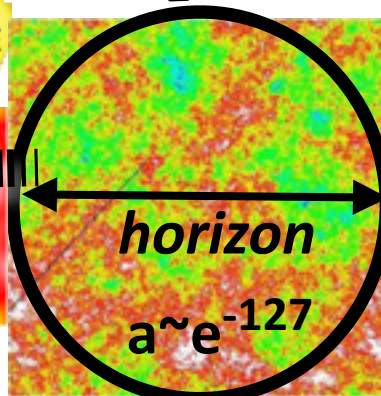
Horizons: the ultimate-speed constraint on light & information

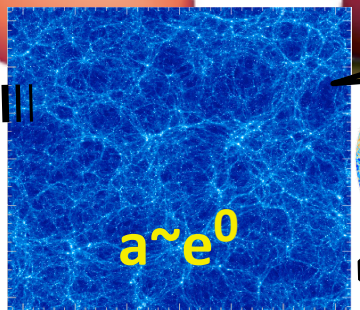


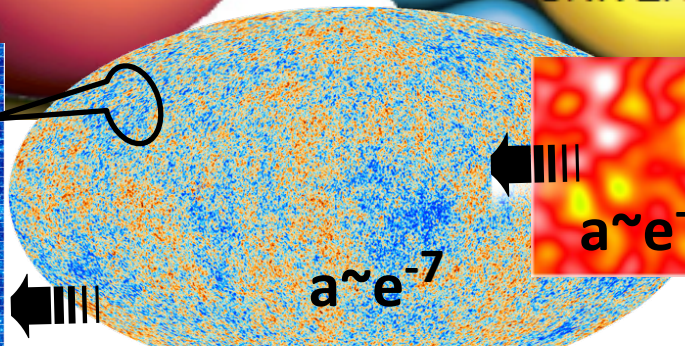


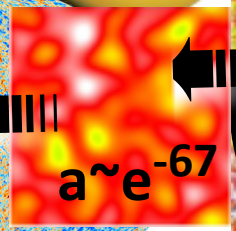












END

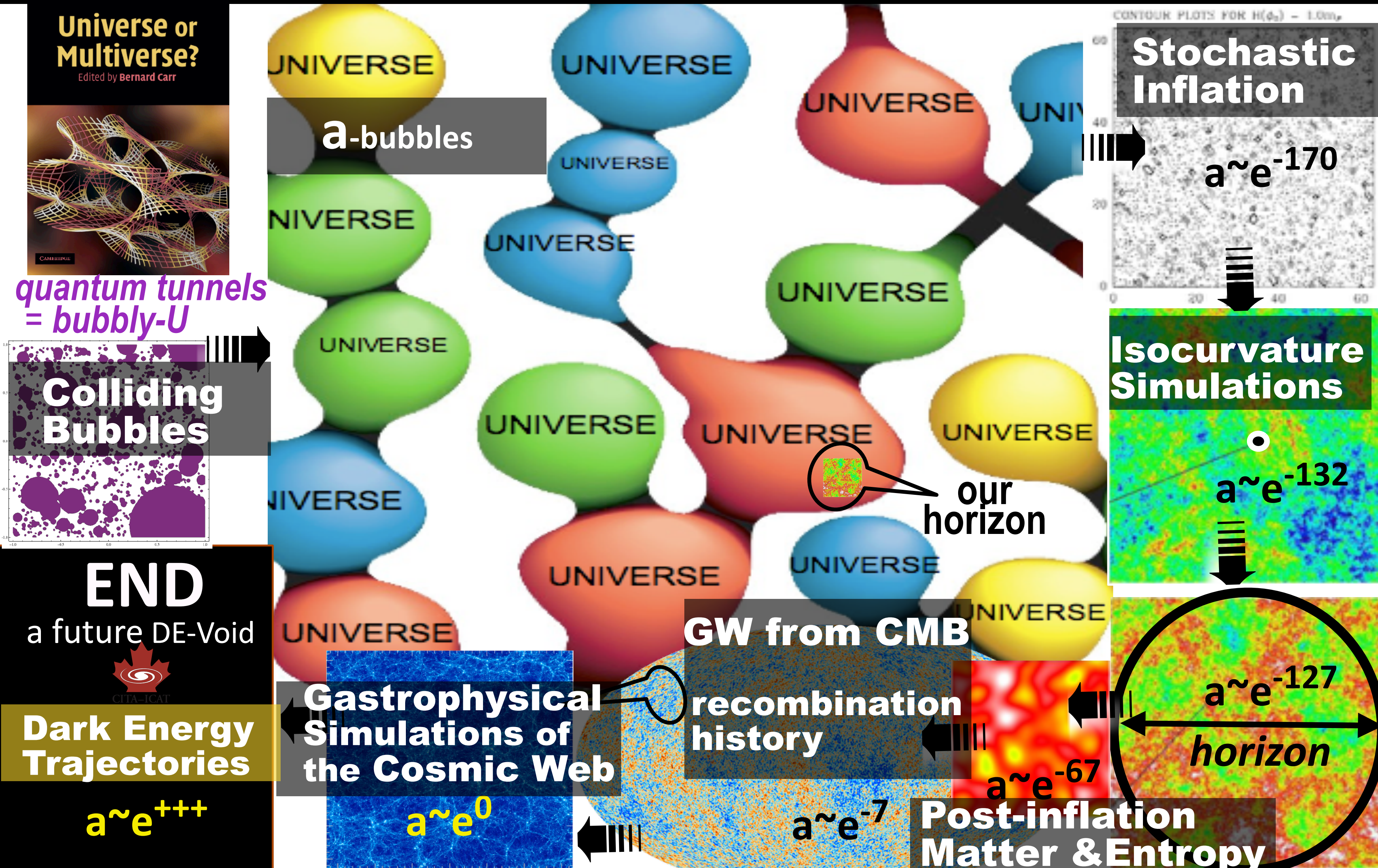
a future DE-Void

CITA–ICAT

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

ultra-Ultra Large Scale Structure of the Universe

Horizons: the ultimate-speed constraint on light & information



Let there be.....

Early **Dark Energy** from $e^{-170?}$ to e^{-67}

2+1 numbers quantum **noise** e^{-127} to e^{-67} in phonons (inflaton) & GW

Heat: matter & **radiation** $a \sim e^{-67}$

Dark Matter, light nuclei $a \sim e^{-21}$ to e^{-35}

Cosmic **Light**: 1st light released, 1st atoms $a \sim e^{-7}$

1st stars $a \sim e^{-3}$, 1st heavy nuclei (O, C, Fe,..)

Galaxies $> e^{-2.2}$

Earth $a \sim e^{-0.34}$

1st human writing $a \sim e^{-0.0000004}$

Late **Dark Energy** to e^{+++}

Let there be.....

semi **ETERNAL** Universe
most of it never Banged

Early **Dark Energy** from $e^{-170?}$ to e^{-67}

2+1 numbers quantum **noise** e^{-127} to e^{-67} in phonons (inflaton) & GW

Heat: matter & **radiation** $a \sim e^{-67}$

Our little **Big Bang**

Dark Matter, light nuclei $a \sim e^{-21}$ to e^{-35}

Cosmic **Light**: 1st light released, 1st atoms $a \sim e^{-7}$

1st stars $a \sim e^{-3}$, 1st heavy nuclei (O, C, Fe,..)

Galaxies $> e^{-2.2}$

Earth $a \sim e^{-0.34}$

1st human writing $a \sim e^{-0.0000004}$

Late **Dark Energy** to e^{+++}

Will our bit of the Universe re-Bang?
NO... maybe

END