Title: Cosmology 1

Date: Jun 09, 2006 09:00 AM

URL: http://pirsa.org/06060019

Abstract:

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

Dick Bond

Inflation, Gravity Waves and the CMB

LCDM: pre-WMAP3 cf. post-WMAP3 - all observations are broadly consisten with a simple 6 basic parameter model of Gaussian curvature (adiabatic) fluctuations - so far no need for gravity waves, a running scalar index, subdominant isocurvature fluctuations, etc.

Range covered: CMB out to horizon (~ 10^{-4} Mpc^{-1}), through to ~ 1 Mpc^{-1} LSS higher k, possible deviations exist. goal - Information Compression to:

Fundamental parameters, phenomenological parameters, nuisance parameter
Bayesian framework: conditional probabilities, Priors/Measure sensitivity, .. Theory Priors, Baroqueness/Naturalness/Taste Priors, Anthropic/Environmental/broad-brush-data Priors. probability landscapes, statistical Inflation, statistics of the cosmic web, both observed and theoretical. mod functions, collective and other coordinates. 'tis all statistical physics.

Dynamical & Resolution Trajectories/Histories, for Inflation then & nov

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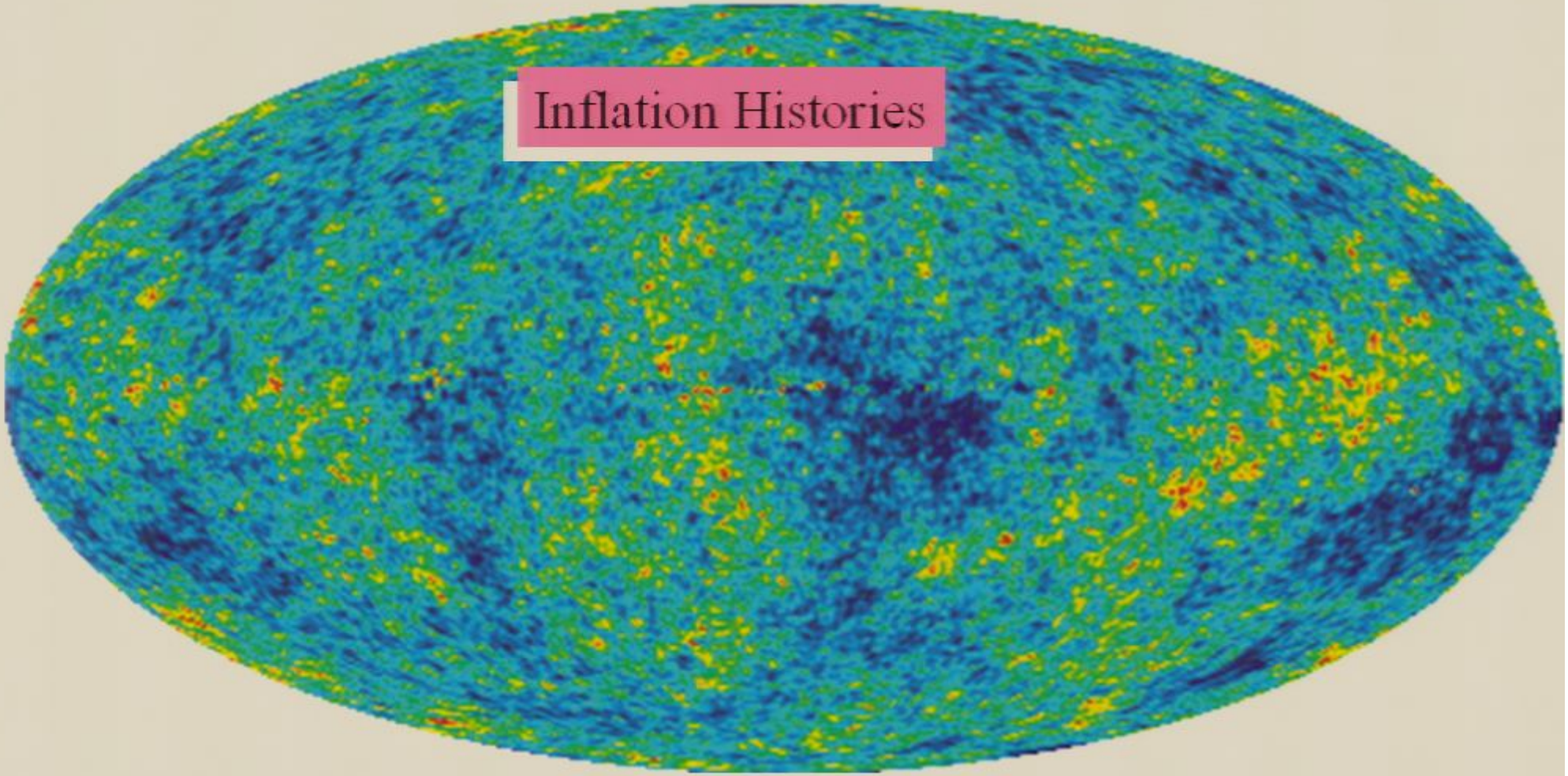
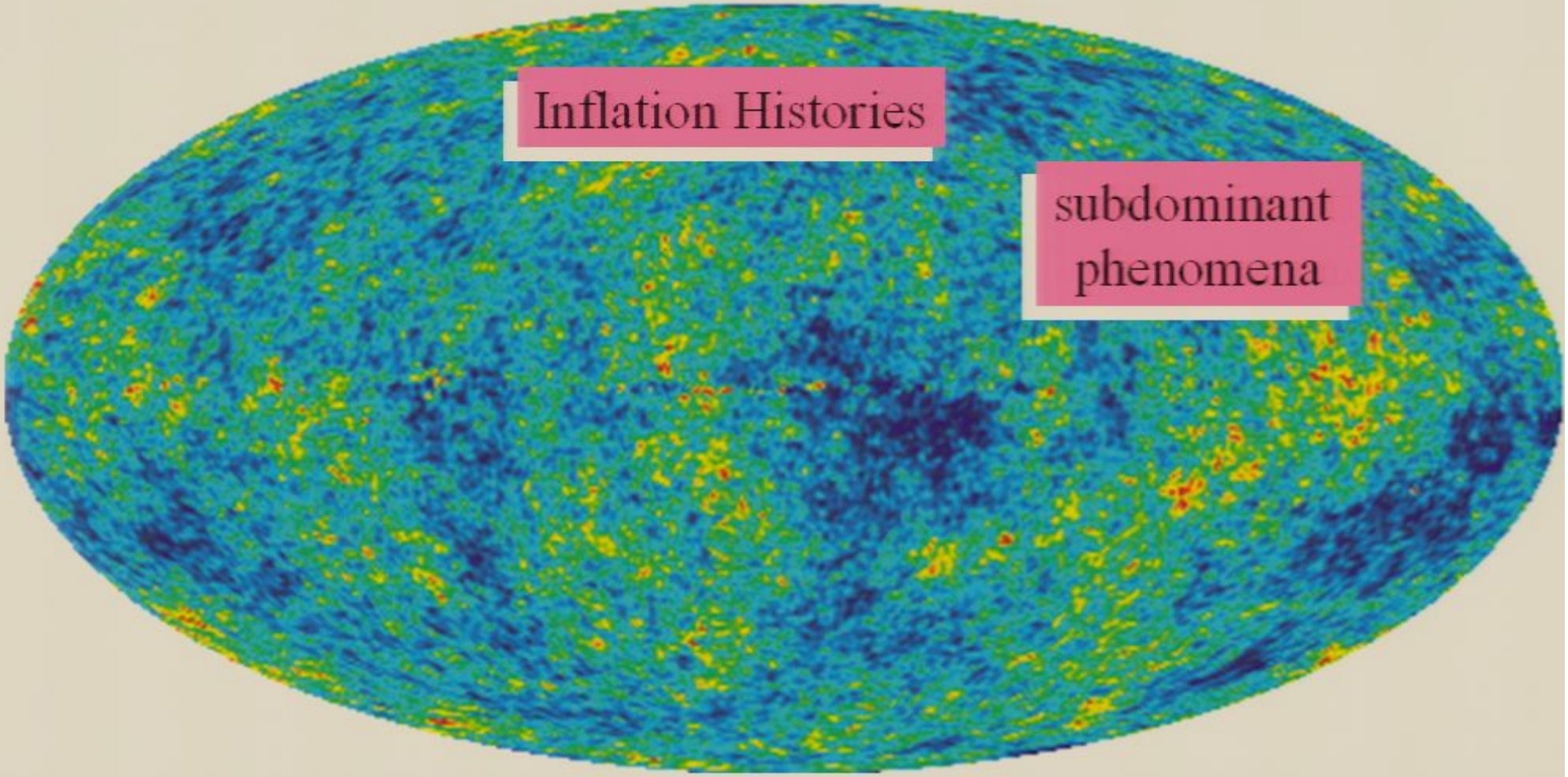
Dynamical & Resolution Trajectories/Histories, for Inflation then & now

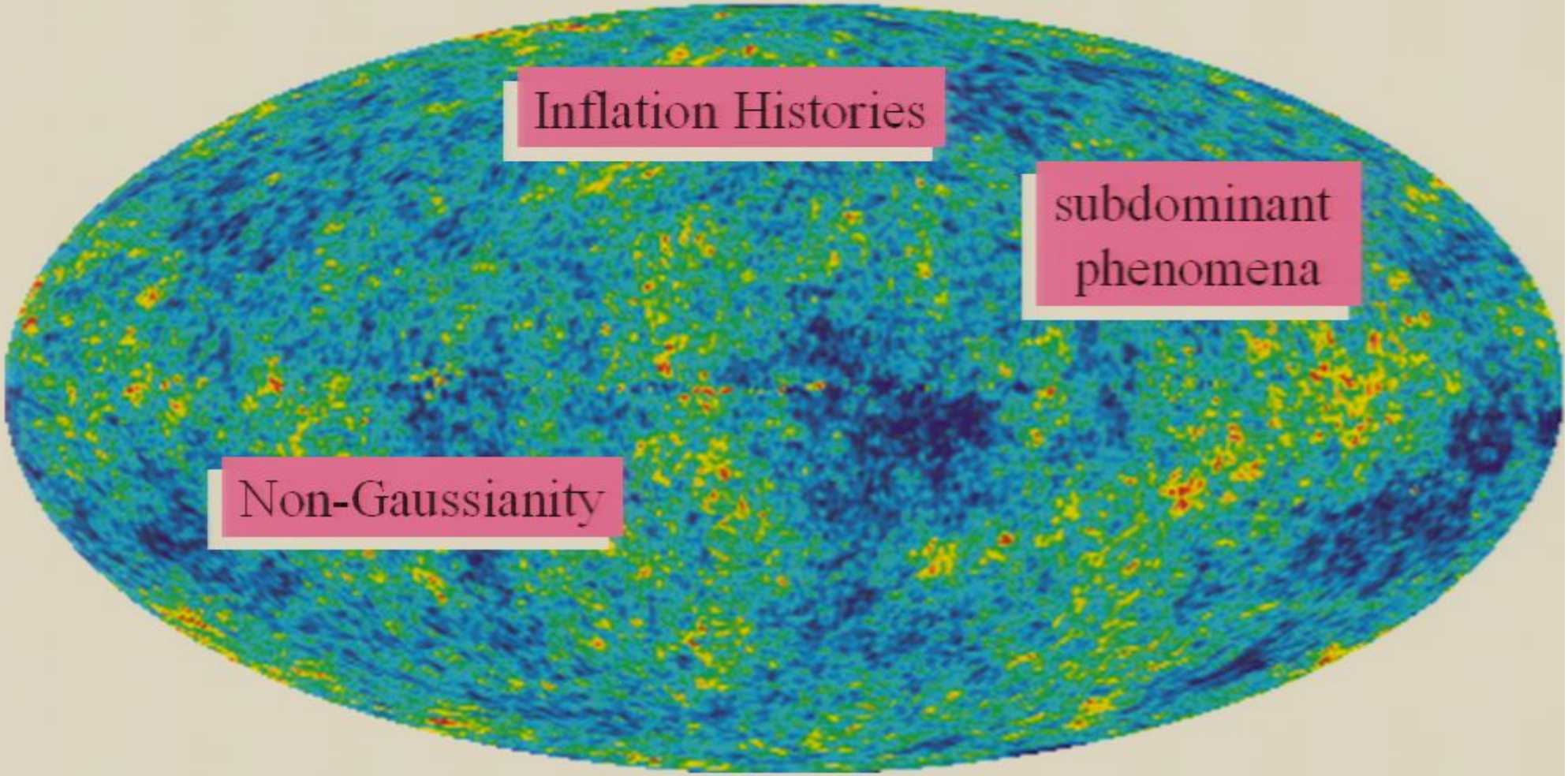
Topics



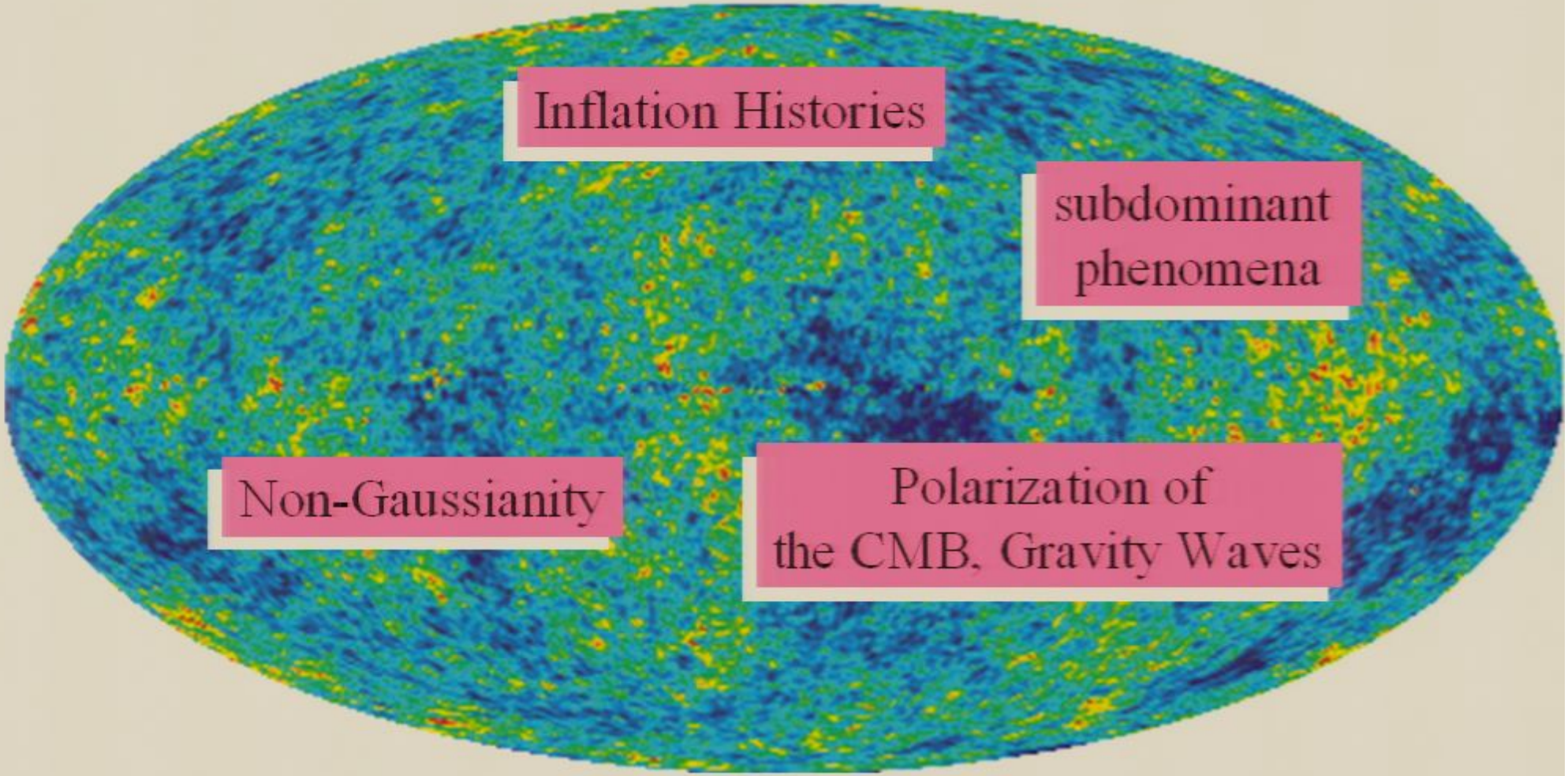
Topics



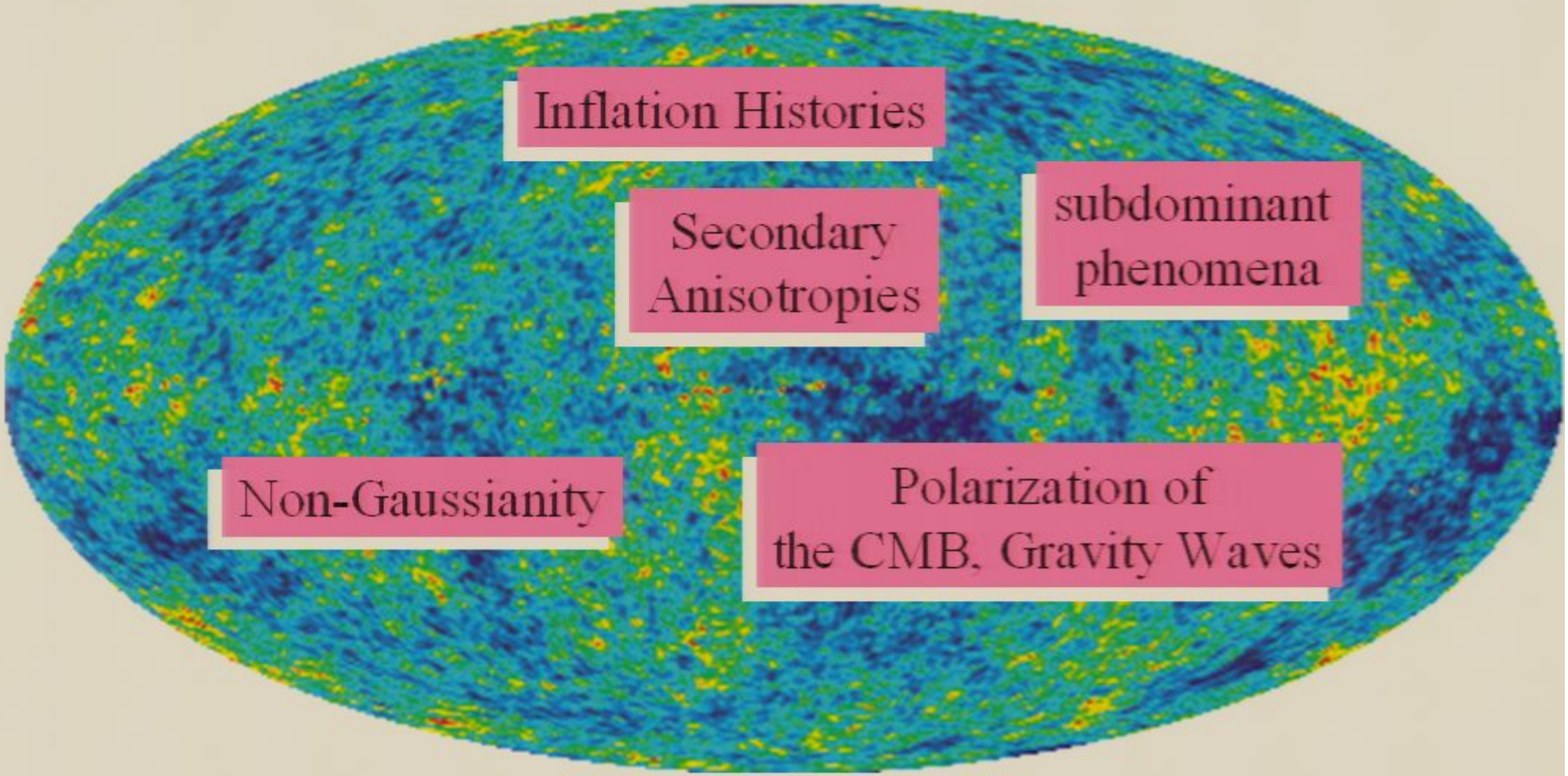
Topics


Inflation Histories
subdominant phenomena
Non-Gaussianity

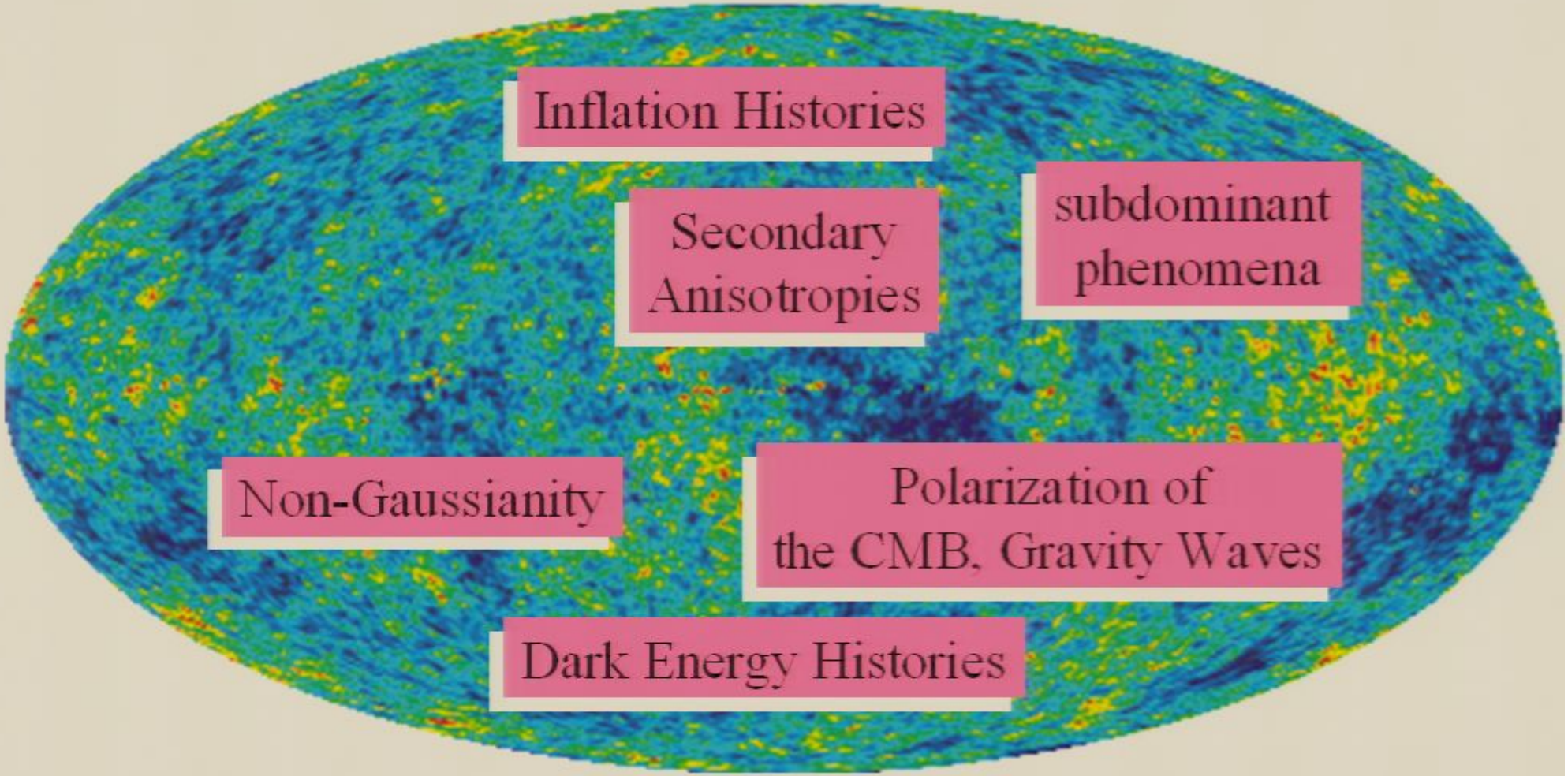
Topics


Inflation Histories
subdominant phenomena
Non-Gaussianity
Polarization of the CMB, Gravity Waves

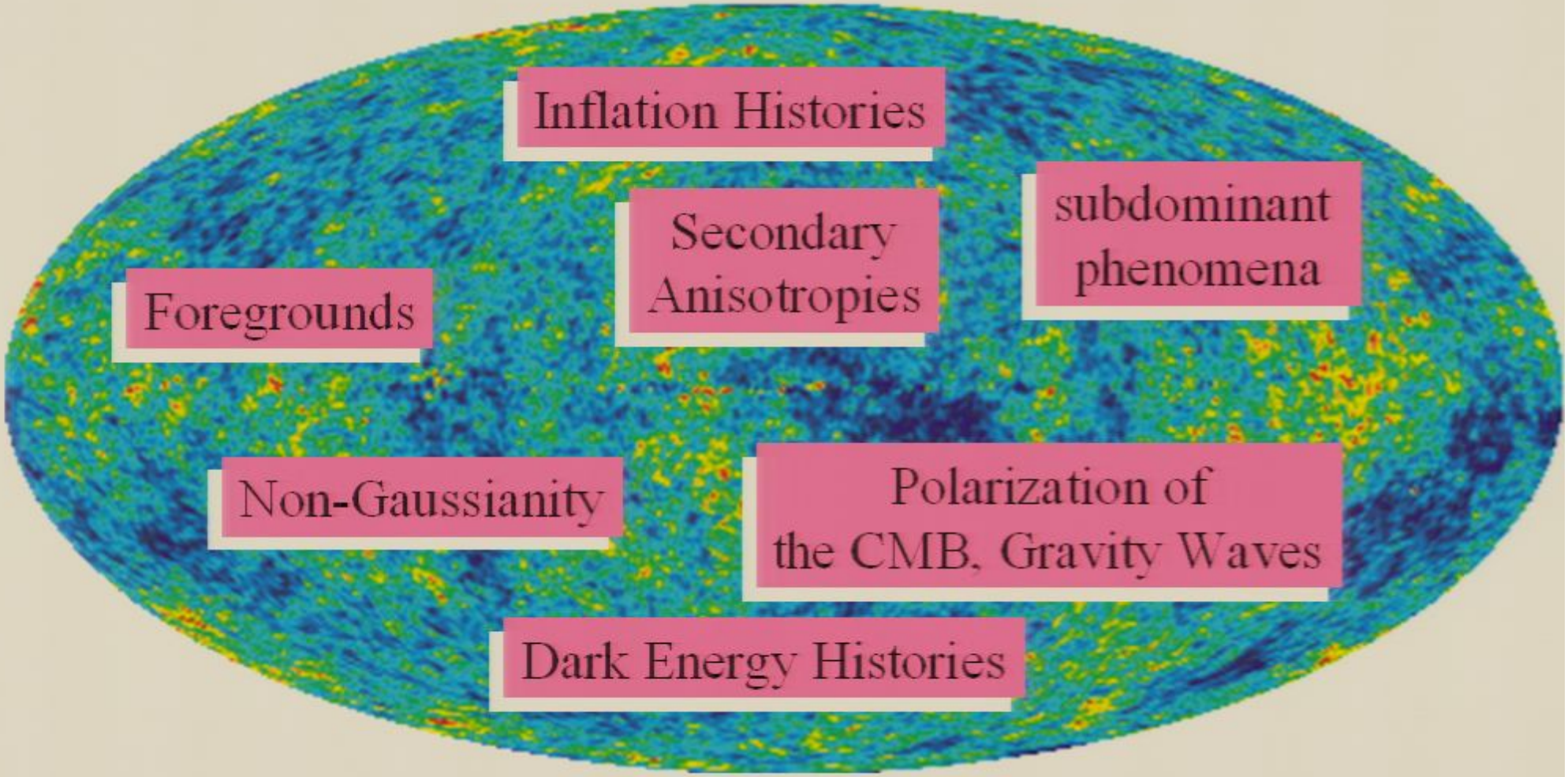
Topics

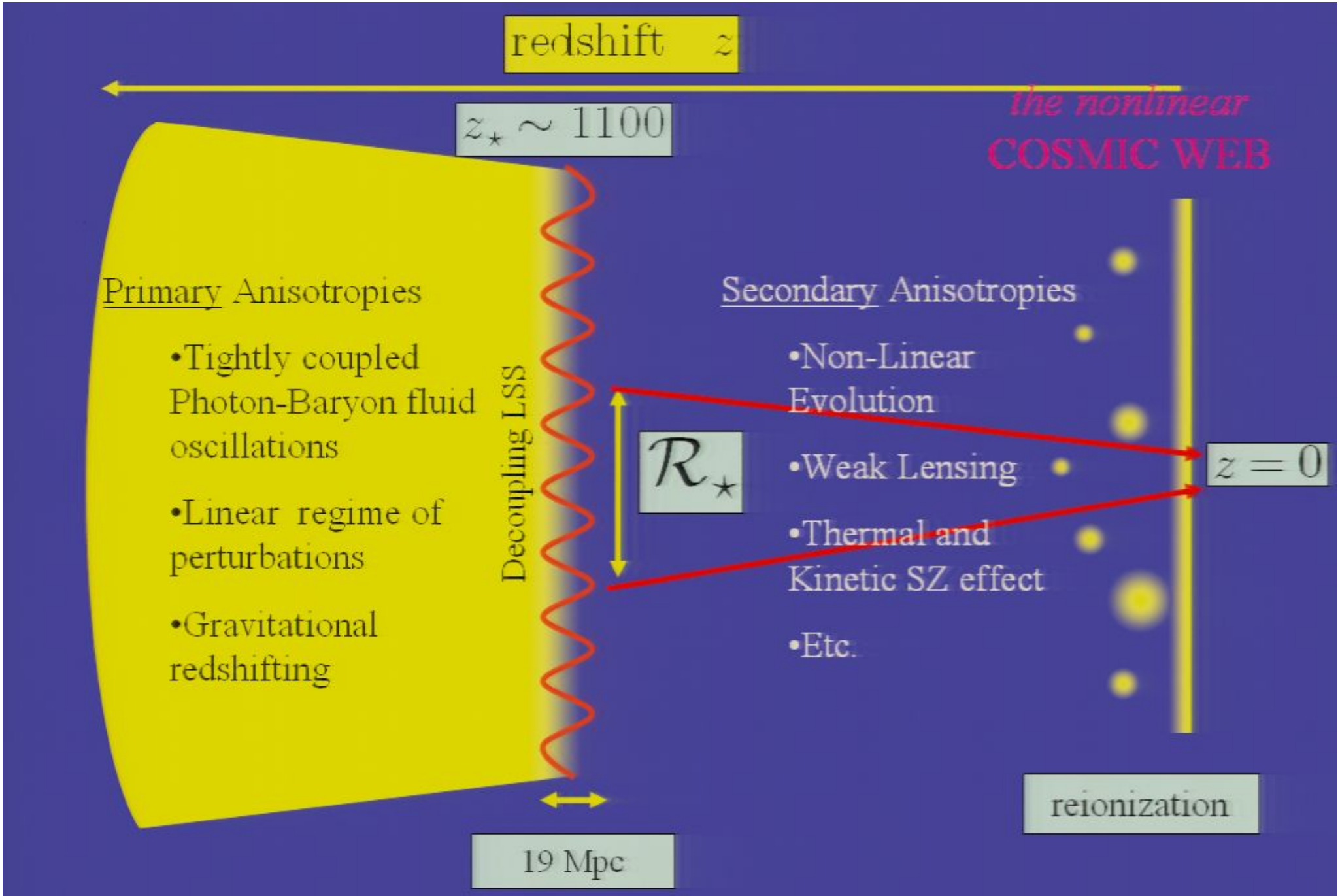

Inflation Histories
Secondary Anisotropies
subdominant phenomena
Non-Gaussianity
Polarization of the CMB, Gravity Waves

Topics


Inflation Histories
Secondary Anisotropies
subdominant phenomena
Non-Gaussianity
Polarization of the CMB, Gravity Waves
Dark Energy Histories

Topics


Inflation Histories
Secondary Anisotropies
subdominant phenomena
Foregrounds
Non-Gaussianity
Polarization of the CMB, Gravity Waves
Dark Energy Histories


redshift z
$z_\star \sim 1100$
the nonlinear
COSMIC WEB
Primary Anisotropies
•Tightly coupled Photon-Baryon fluid oscillations
•Linear regime of perturbations
•Gravitational redshifting
Decoupling LSS
$\mathcal{R}_\star$
Secondary Anisotropies
•Non-Linear Evolution
•Weak Lensing
•Thermal and Kinetic SZ effect
•Etc.
$z = 0$
reionization
19 Mpc
14Gyrs
time t
10Gyrs
today

Parameters of Cosmic Structure Formation

Ω_k $\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ τ_c n_s n_t $A_s \sim \sigma_8$ A_t

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What is the Background curvature of the universe?

- $\Omega_k > 0$ closed
- $\Omega_k = 0$ flat
- $\Omega_k < 0$ open

Parameters of Cosmic Structure Formation

Ω_k $\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ τ_c n_s n_t $A_s \sim \sigma_8$ A_t

Density of Baryonic Matter

Parameters of Cosmic Structure Formation

Ω_k $\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ τ_c n_s n_t $A_s \sim \sigma_8$ A_t

Density of non-interacting Dark Matter

Parameters of Cosmic Structure Formation

Ω_k $\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ τ_c n_s n_t $A_s \sim \sigma_8$ A_t

Cosmological Constant

Parameters of Cosmic Structure Formation

Ω_k $\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ τ_c n_s n_t $A_s \sim \sigma_8$ A_t

Optical Depth to Last Scattering Surface
When did stars reionize the universe?

Parameters of Cosmic Structure Formation

Period of inflationary expansion, quantum noise → metric perturb.

Ω_k $\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ τ_c n_s n_t $A_s \sim \sigma_8$ A_t

Spectral index of primordial scalar (compressional) perturbations

$$P_\Phi(k) \propto k^{n_s - 1}$$

Parameters of Cosmic Structure Formation

Period of inflationary expansion, quantum noise → metric perturb.

Ω_k $\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ τ_c n_s n_t $A_s \sim \sigma_8$ A_t

Spectral index of primordial tensor (Gravity Waves) perturbations

$$P_h(k) \propto k^{n_t}$$

Parameters of Cosmic Structure Formation

Period of inflationary expansion, quantum noise → metric perturb.

Ω_k $\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ τ_c n_s n_t $A_s \sim \sigma_8$ A_t

Scalar Amplitude

Parameters of Cosmic Structure Formation

Period of inflationary expansion, quantum noise → metric perturb.

Ω_k $\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ τ_c n_s n_t $A_s \sim \sigma_8$ A_t

Tensor Amplitude

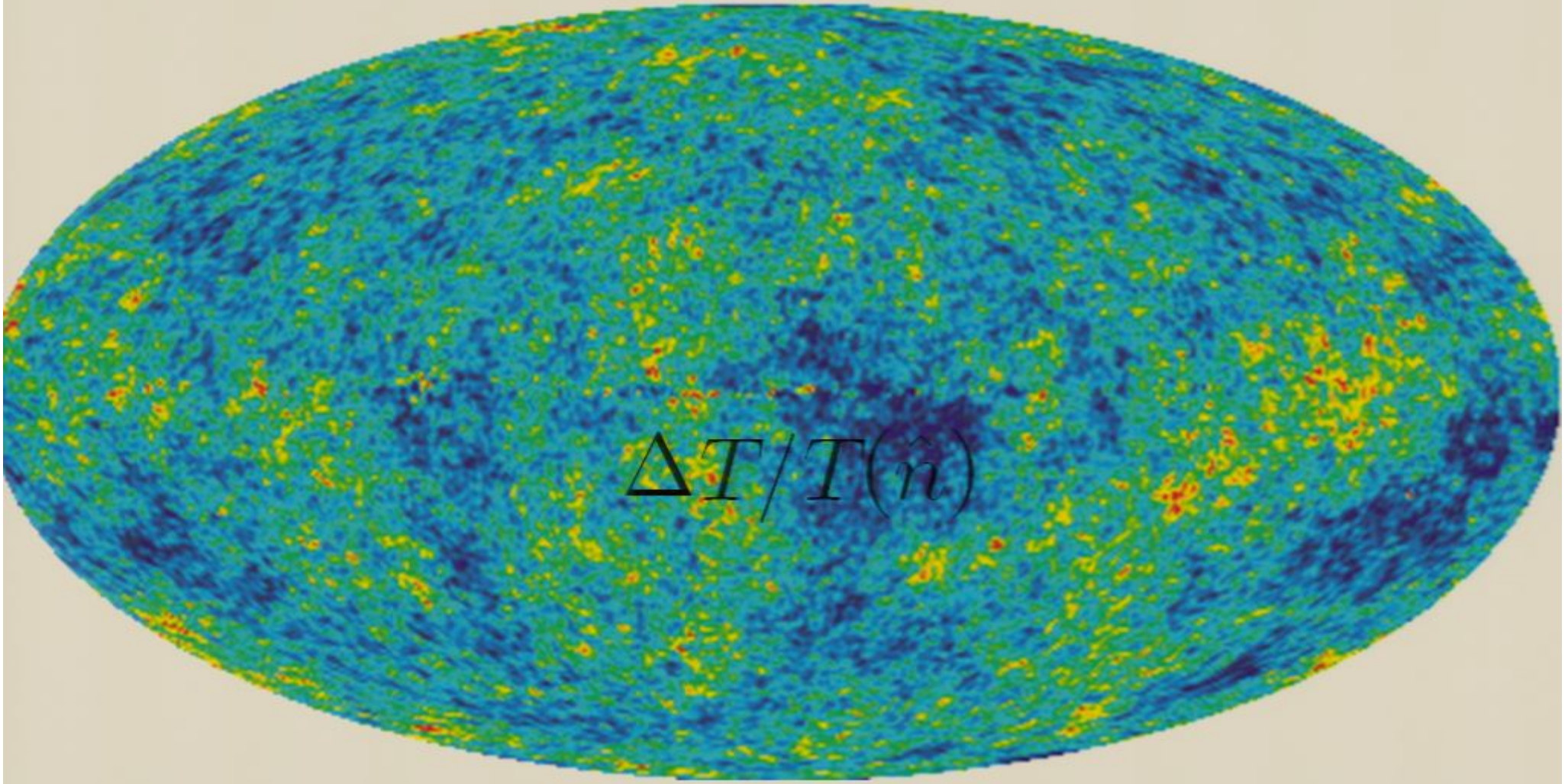
Parameters of Cosmic Structure Formation

Period of inflationary expansion, quantum noise → metric perturb.

Ω_k $\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ τ_c n_s n_t $A_s \sim \sigma_8$ A_t

- Inflation → predicts nearly scale invariant scalar perturbations and background of gravitational waves
- Passive/adiabatic/coherent/gaussian perturbations
- Nice linear regime
- Boltzman equation + Einstein equations to describe the LSS

WMAP3 thermodynamic CMB temperature fluctuations



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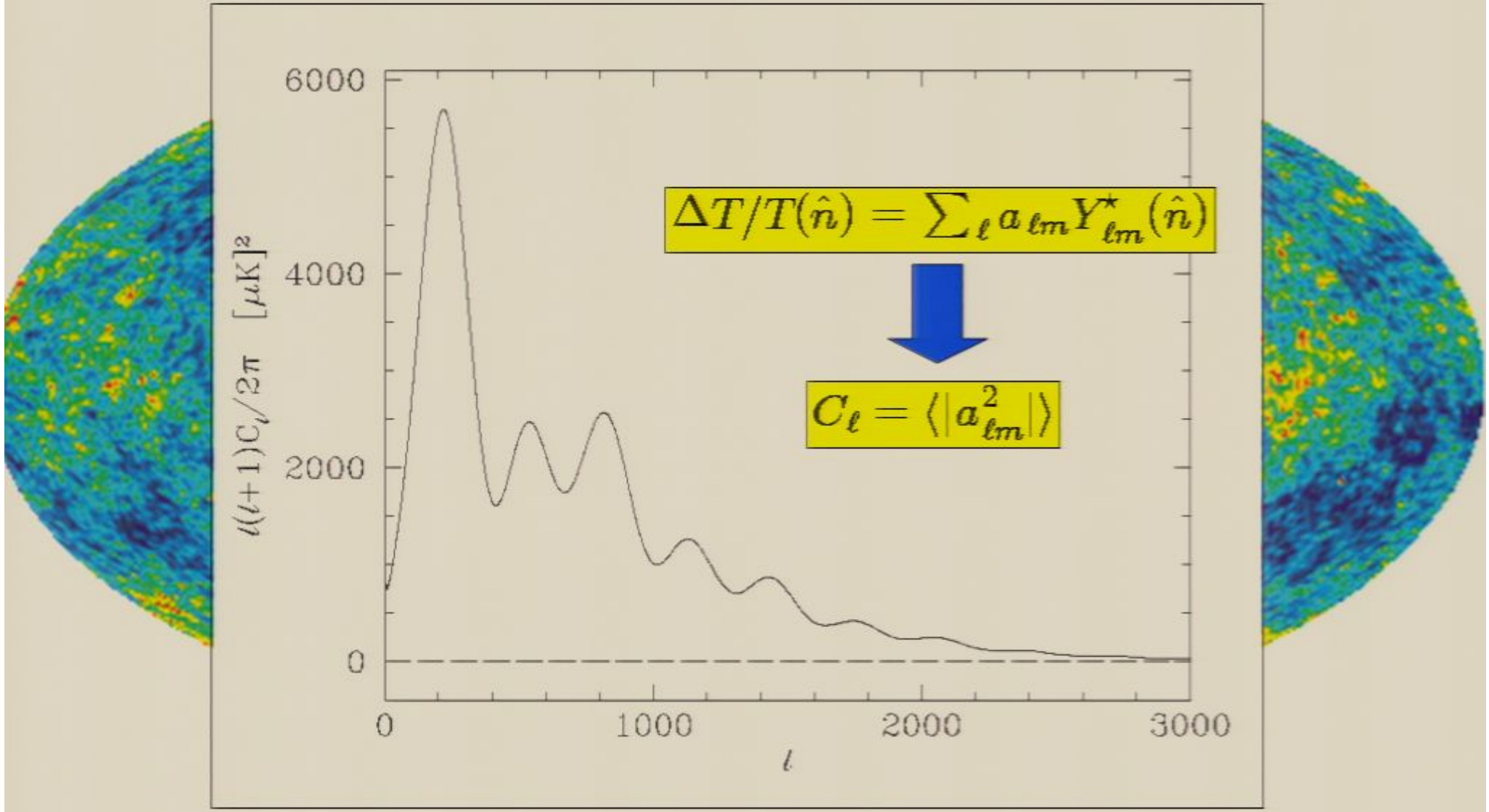

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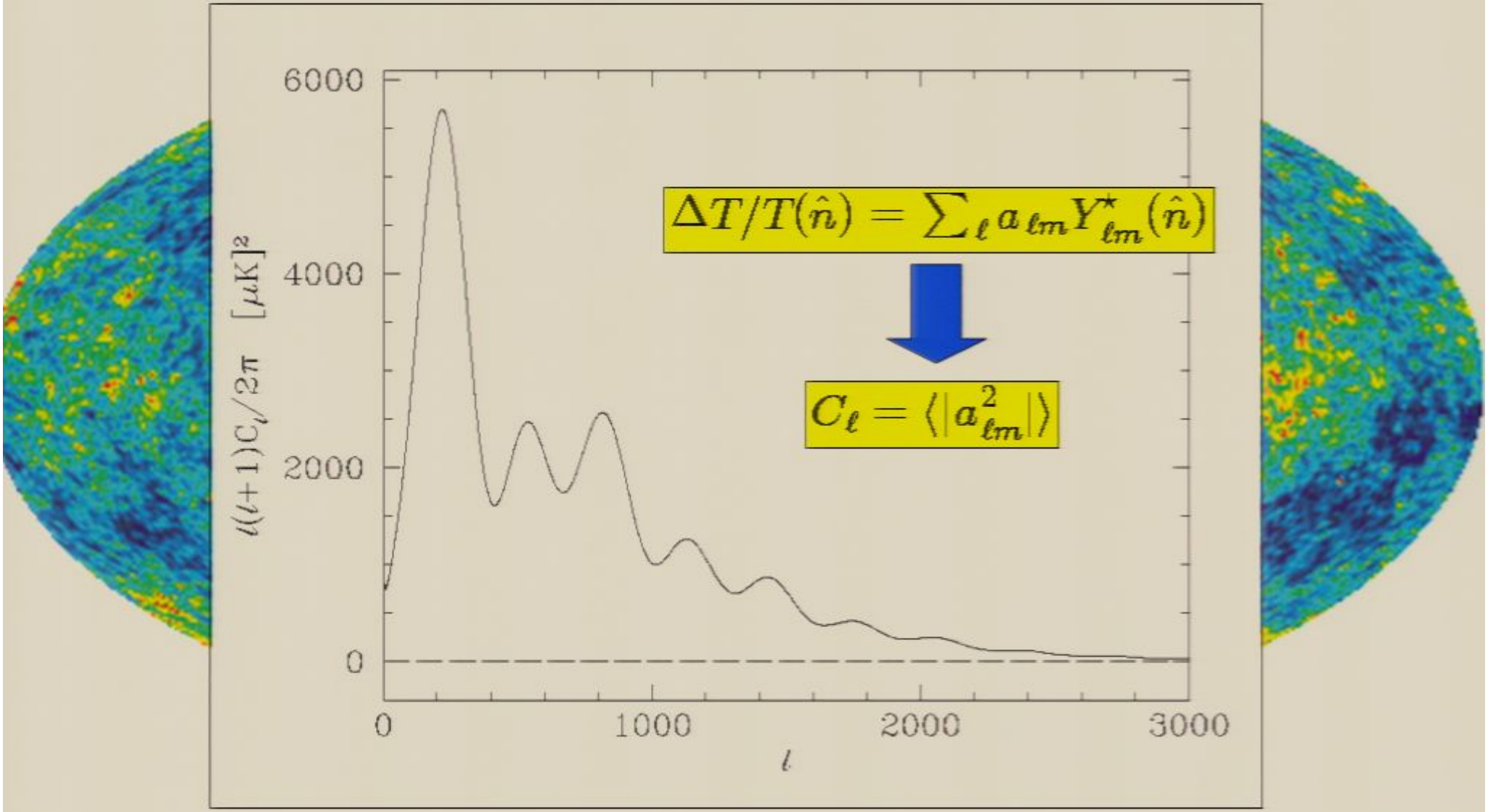
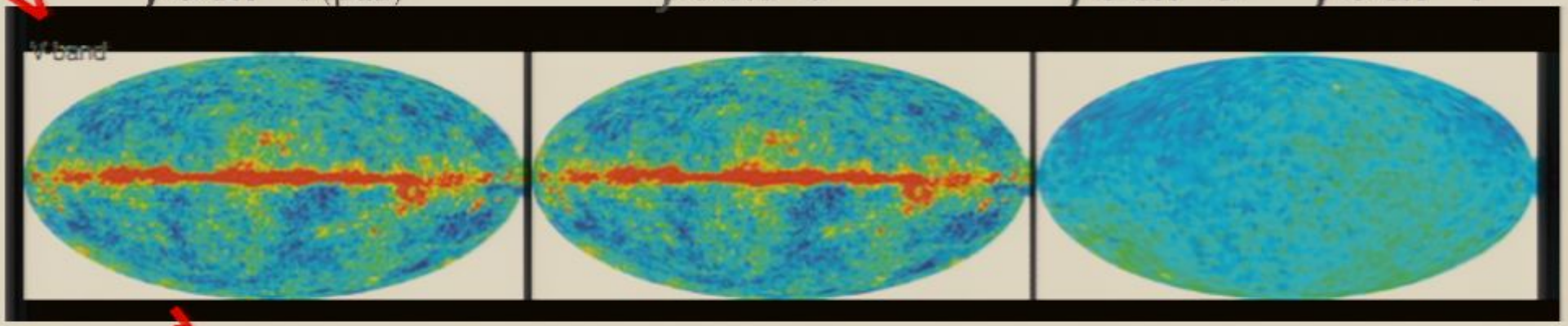


Like a 2D Fourier transform, wavenumber Q ~ L + 1/2

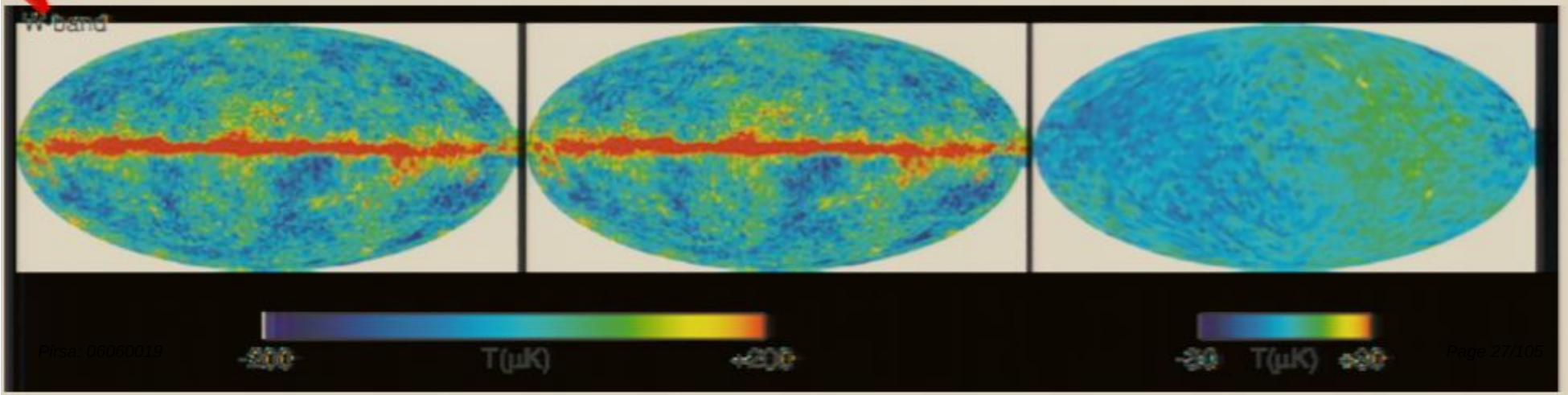
Temperature maps

V band

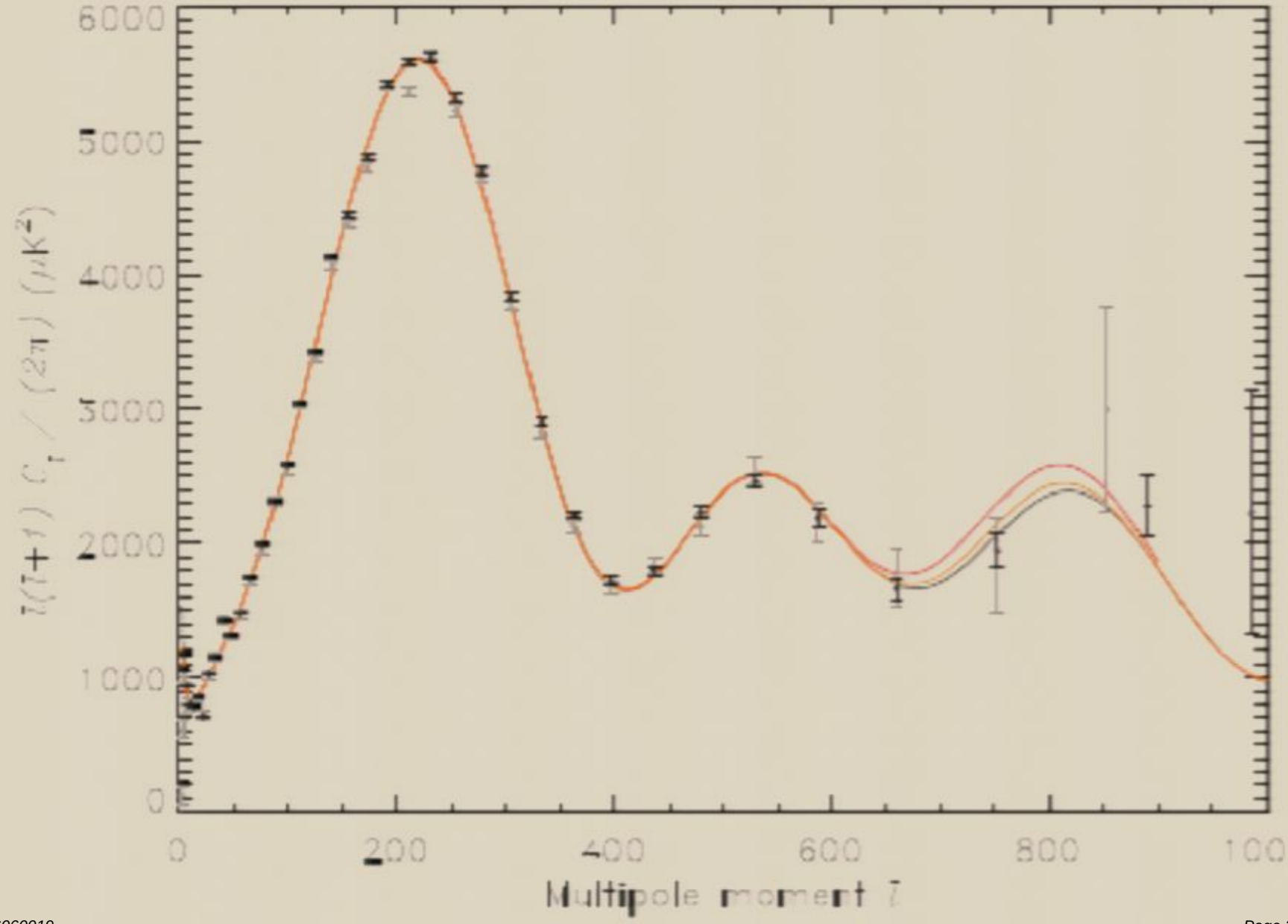
year 1 (pub) | year 3 | year 3 - year 1

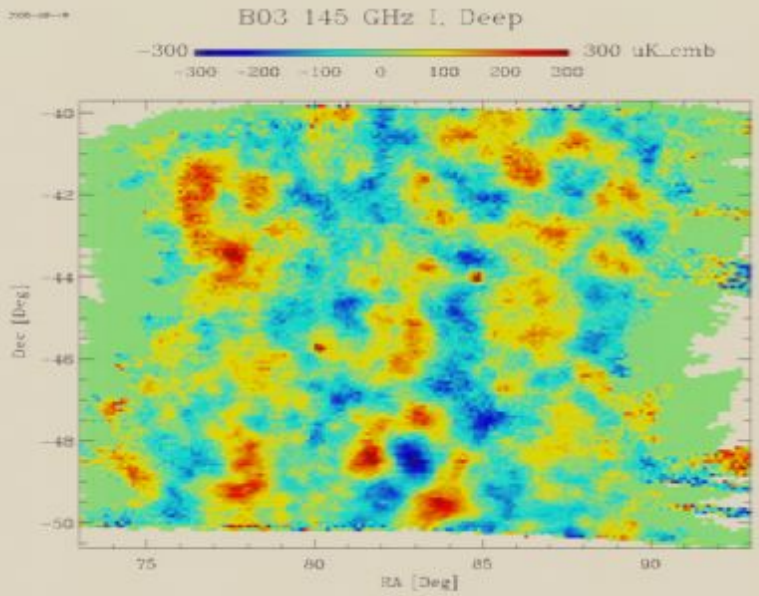


W band

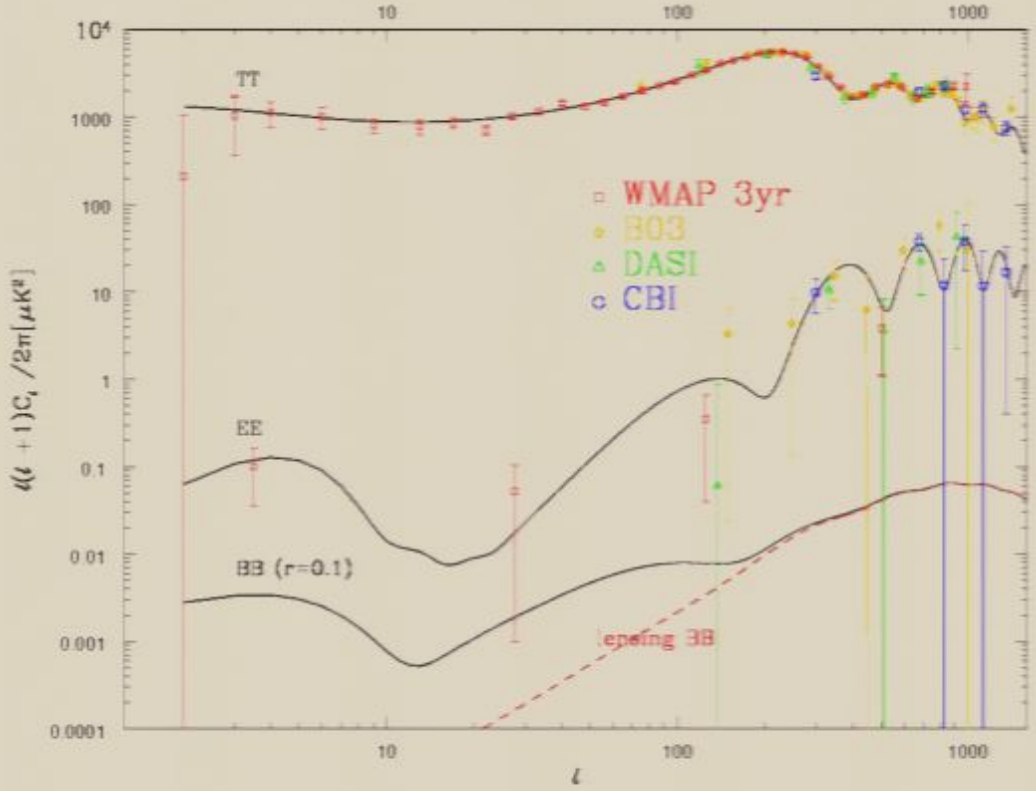


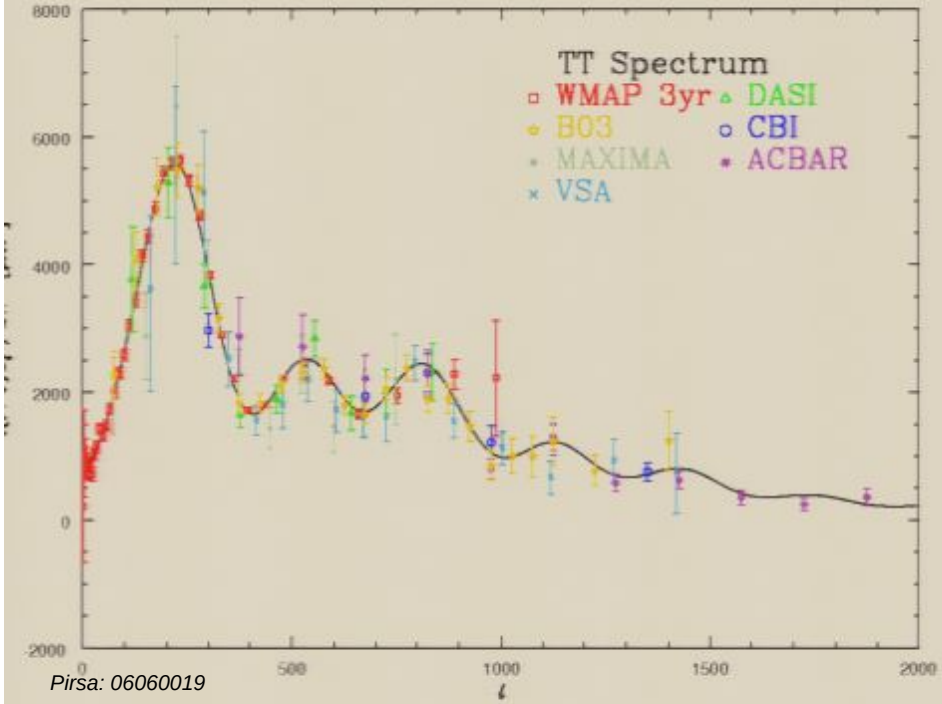
WMAP3 cf. WMAP1



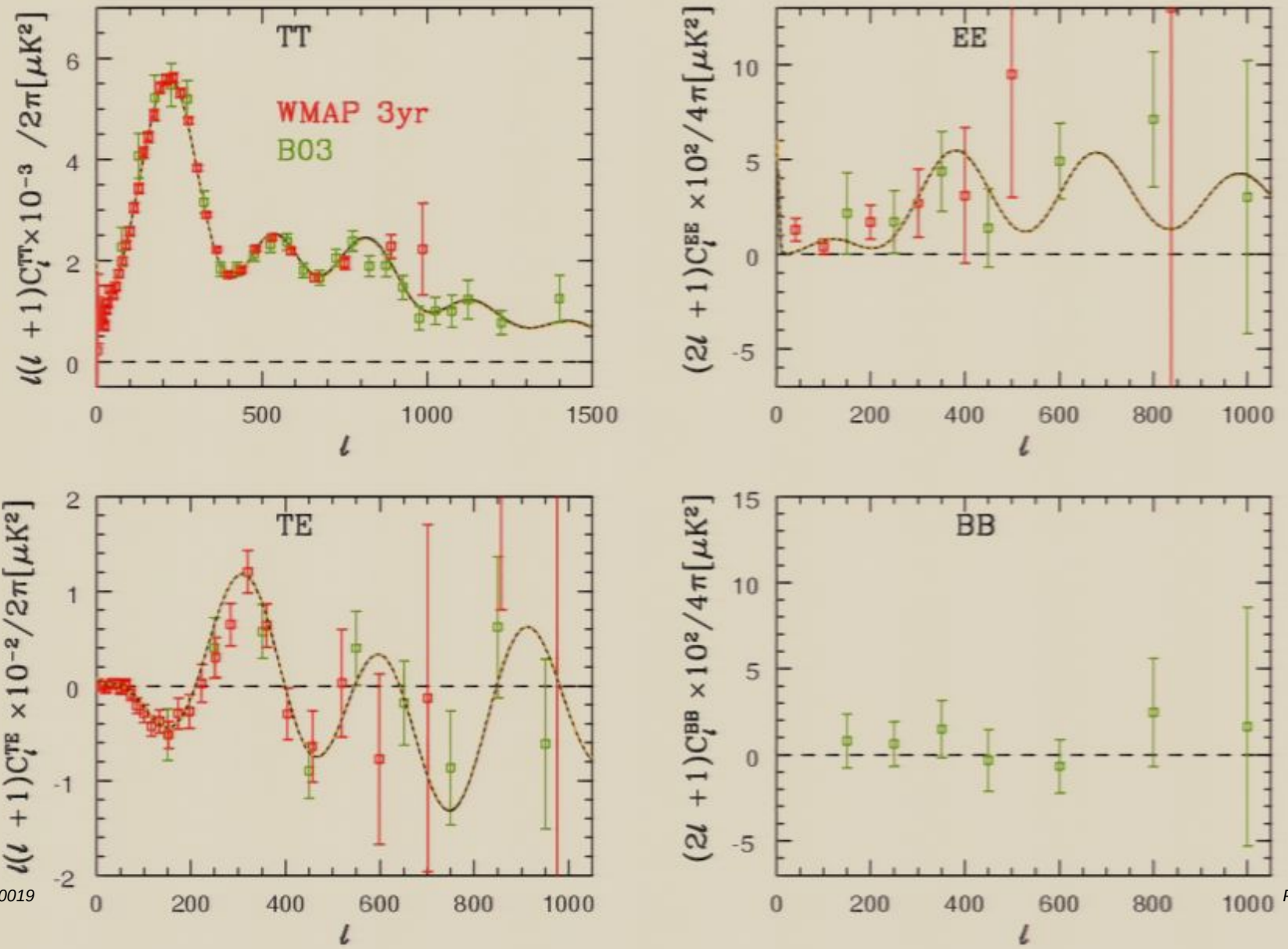


TT, EE, BB, TE, TB, EB Angular Power Spectra

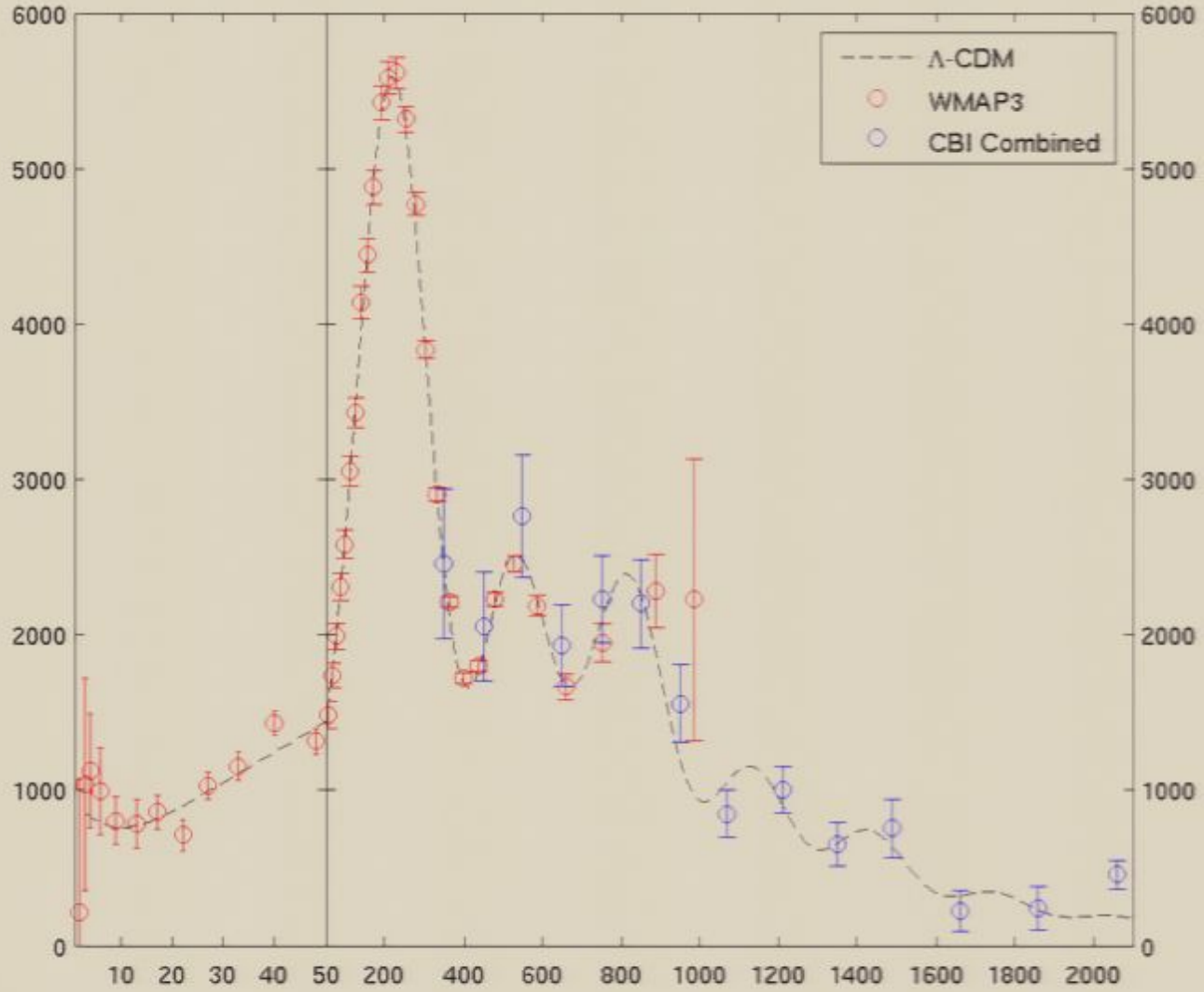




WMAP3 sees 3rd pk, B03 sees 4th



CBI combined TT sees 5th pk



CBI pol to Apr'05

Bicep

Quiet2

CBI2 to Apr'07

(1000 HEMTs)

QUaD

Quiet1 Chile

Acbar to ~Jan'06

CBI2 SCUBA2

APEX

(12000 bolometers)

(~400 bolometers)

Spider

SZA

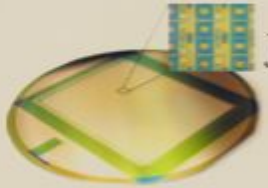
Chile

JCMT, Hawaii

(1856 bolometer LDB)

(Interferometer)

California



ACT

Clover

(3000 bolometers)

Chile

Boom03

2017

CMBpol

2003

2005

2007

2004

2006

2008

SPT

WMAP ongoing to 2009

ALMA

(1000 bolometers)

(Interferometer)

DASI

South Pole

Chile

Polarbear

CAPMAP

(300 bolometers)

Planck

California

AMI

(84 bolometers)

GBT

HEMTs L2

CMB/LSS Phenomenology

CITA/CIAR here

- Bond
- Contaldi
- Lewis
- Sievers
- Pen
- McDonald
- Majumdar
- Nolta
- Iliev
- Kofman
- Vaudrevange
- Dalal
- Dore
- Kesden
- MacTavish
- Pfrommer

UofT here

- Netterfield
- MacTavish
- Carlberg
- Yee

CITA/CIAR there

- Mivelle-Deschenes (IAS)
- Pogosyan (U of Alberta)
- Prunet (IAP)
- Myers (NRAO)
- Holder (McGill)
- Hoekstra (UVictoria)
- van Waerbeke (UBC)

& Exptal/Analysis/Phenomenology Teams here & there

- Boomerang03
- Cosmic Background Imager
- Acbar
- WMAP (Nolta, Dore)
- CFHTLS – WeakLens
- CFHTLS - Supernovae

Parameter datasets: **CMBall_pol**

SDSS P(k), 2dF P(k)

Weak lens (Virmos/RCS1; CFHTLS, RCS2)

Lya forest (SDSS)

SN1a "gold" (157, 9 z>1), CFHT

futures: ACT SZ/opt, Spider.

Parameters & Priors of the "Cosmic Standard Model"

Even for minimal Gaussian inflaton-generated fluctuations 17+, here 6+2+2+2 +2 ++

EARLY UNIVERSE: power spectra, non-Gaussian 3,4,.. Point, topology

$A_s n_s\ A_t\ n_t\ A_{iso}\ n_{iso}$ @normalization point k_n

Features & functions(k) k_{run}, $\{k_{BSI}\}$

$\Omega_b h^2\ \Omega_c h^2\ \Omega_\nu h^2\ \Omega_{er} h^2$ CMB PHOTON **TRANSPORT@Decoupling**

$\Omega_k\ \Omega_\Lambda\ (\Omega_Q\ w_Q)$ **TRANSPORT@ Late Time** ISW Effect & GEOMETRY

$k_{sound,dec}$, $k_{damp,dec}$, $k_{m\nu}$

Near Parameter Degeneracies in CMB need: LSS, SN1a,$n_{clusters}$,...

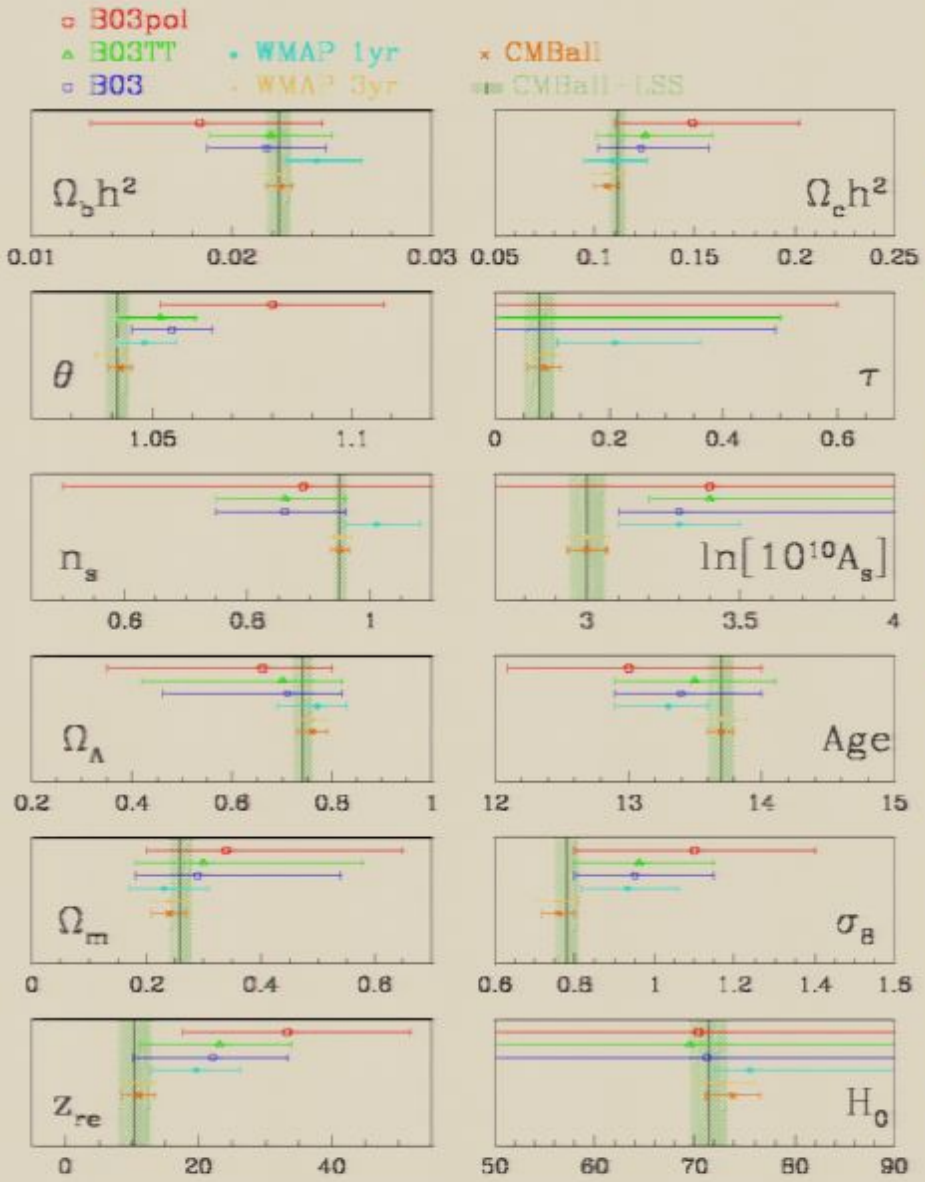
Map $L_{sound,dec}$ = **R**(z@dec) $k_{sound,dec}$, want TOMOGRAPHY **R**(z)

e.g., **R**(z) angular-diameter-distance. BROKEN by ISW. SN1a ($\mathbf{R}_L$(z) luminosity distance). z-surveys: Acoustic peaks (z). Abundances: Volume(z), perturbation growth rate (z).

τ_C z_{reh} **GASTROPHYSICS:** Compton Depth from Reionization redshift

$\sigma_8^2\ h\ \Omega_m\ \Omega_b$ **LSS:** k_{Heq} aka Γ $k_{sound,dec}$, $k_{m\nu}$

What have we learned from the CMB so far?



--> Consistent with *tilted* ΛCDM model

--> Spectral index $n_s \neq 1$!

--> Baryons, radiation, neutrinos, cold dark matter

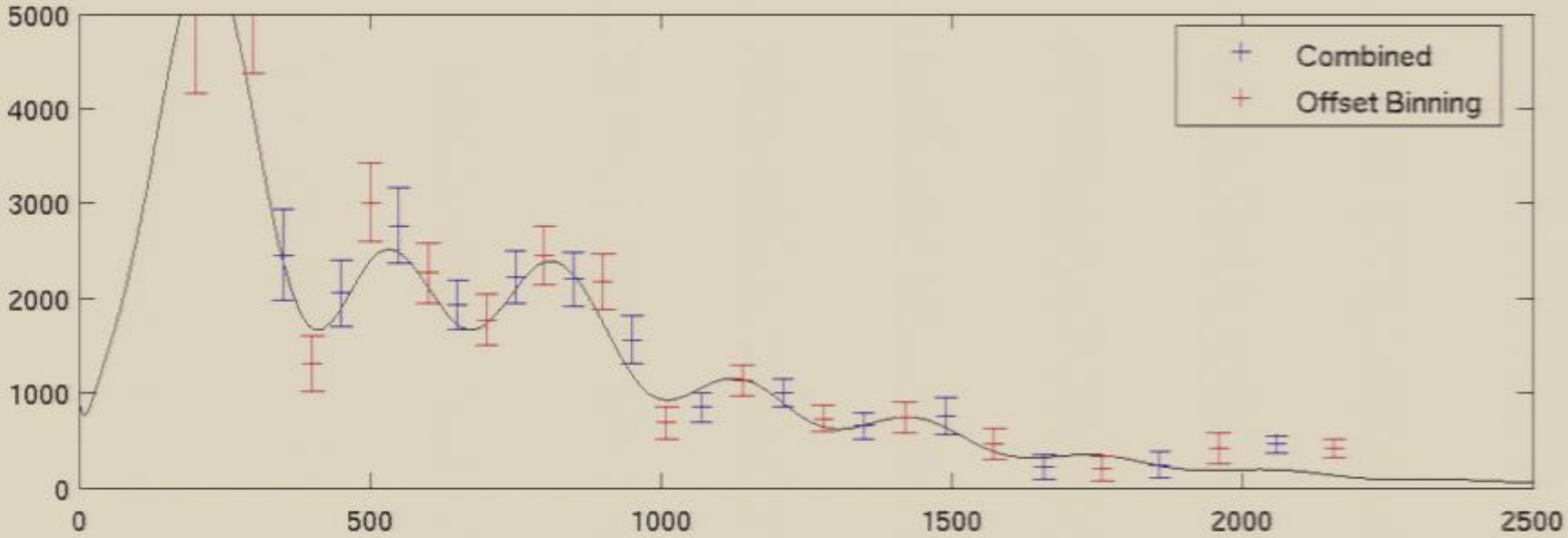
--> Dark energy in form of cosmological constant Λ

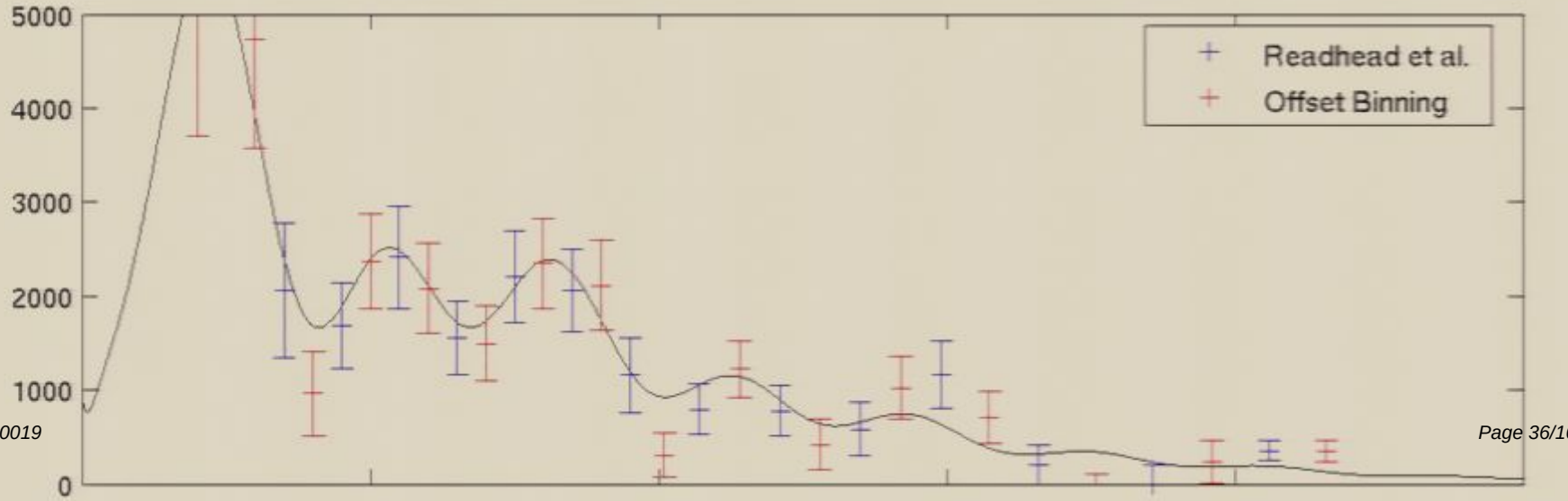
--> Initial *scalar*, adiabatic perturbation gives rise to acoustic oscillations

--> Spatially flat geometry

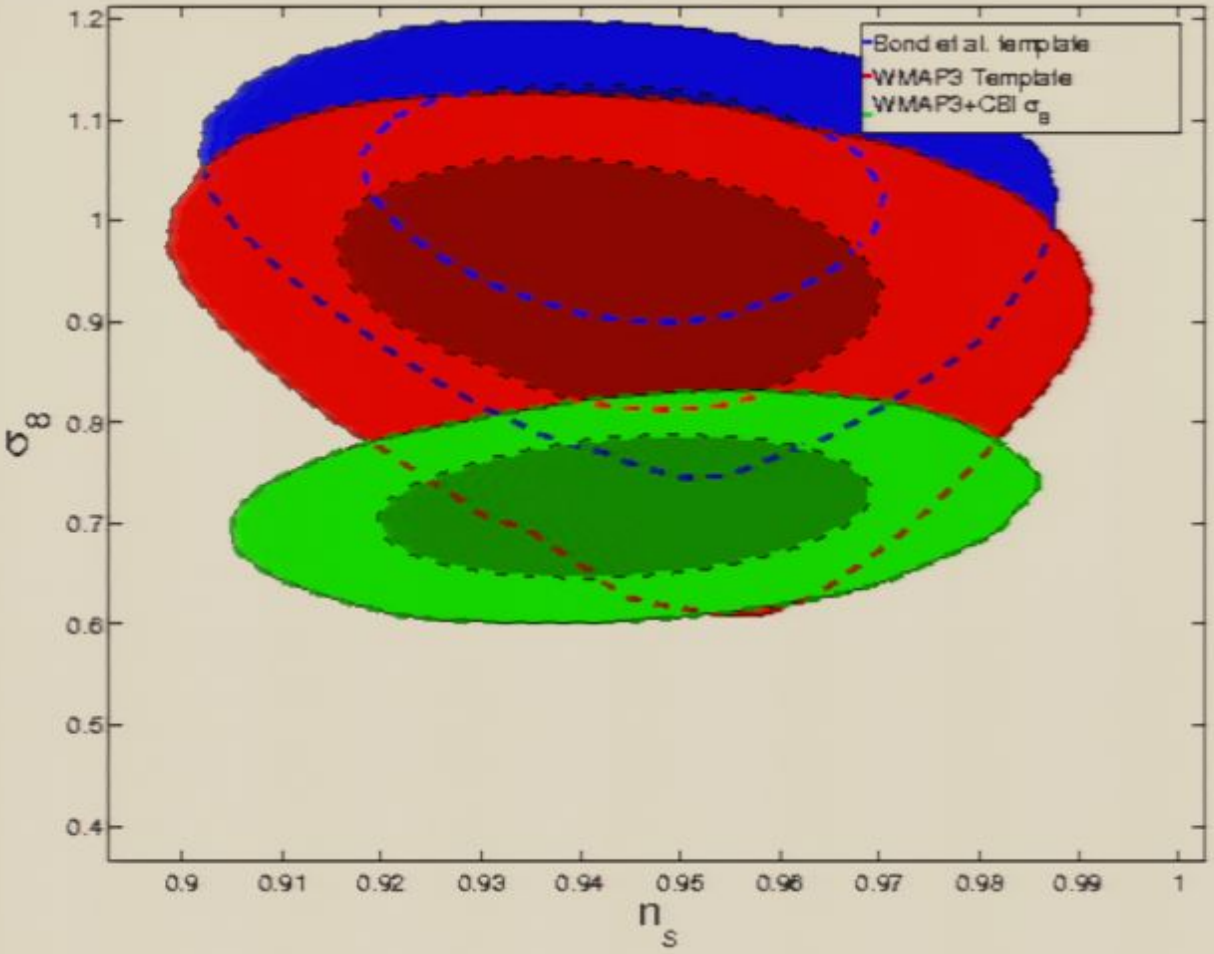
--> Agreement of all data sets (including NEW WMAP and NEW 2dF) ~1σ level

CBI combined TT data (Dec05,~Mar06)





σ_8 Tension of WMAP3 cf. WMAP1



With CBI "excess" as SZ

σ_8 for Bond et al. SZ template = 1.00±0.1, for Komatsu & Seljak SZ template = 0.93±0.1.

Komatsu & Seljak consistent with latest Chandra M-T relation (Vikhlinin et al.). Latest XMM M-T (Arnaud et al.) 50% higher than Chandra – σ_8~0.85?

Doesn't include errors from non-Gaussianity of clusters, uncertainty in faint source counts (~35% increase)

Tension with weak lensing

CBI combined TT data

$\sigma_8 = .77 +- .04$, $.72 +- .05$ (GW), $.80 +.03$ (GW+LSS)

$\sigma_8 = .80 +- .04$ run $(-0.05 +- .025)$

CSLS'05 $\sigma_8 = 0.86 +- .05$

if $\Omega_m = 0.3 +- .05$

Virmos-Descartes'05 $\sigma_8 = 0.83 +- .07$

RCS1 lens $\sigma_8 = 0.85 +- .07$

RCS1 optical $\sigma_8 = 1.05 +- .14$ (prelim)

Xray version $\sigma_8 = 0.78 +-$ larger $+-$

MacTavish etal05 B03 version $\sigma_8 = 0.85 +- .05$

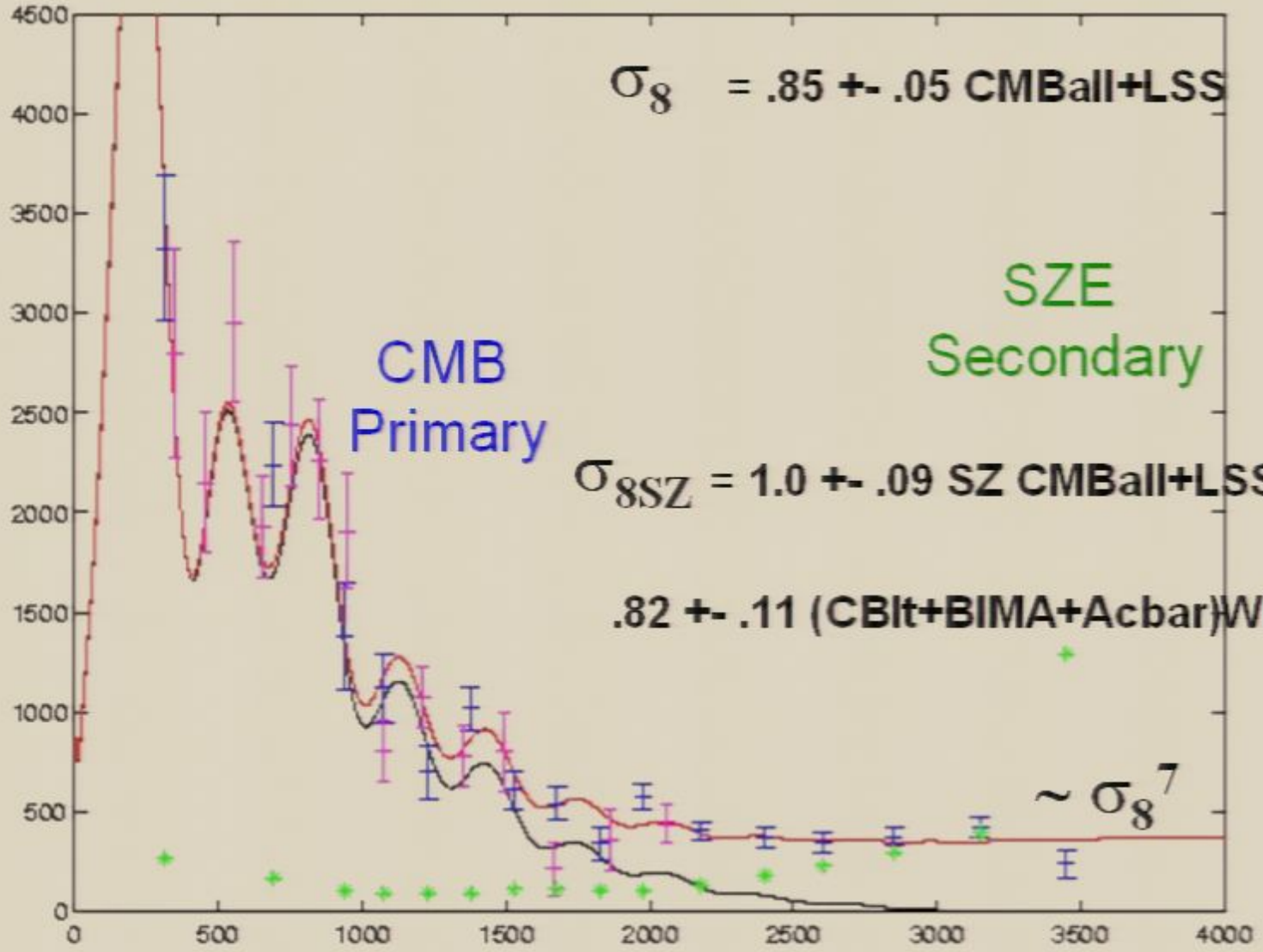
2dF version $\sigma_8 = 0.83 +- .04$

2dF version $b_g(L_*)\ \sigma_8 = 0.92 +- .04$

Van Waerbeke etal, CASCA06, slight drop because of non-Gaussian error inclusion

CBI2 "bigdish" upgrade June2006 + GBT for sources

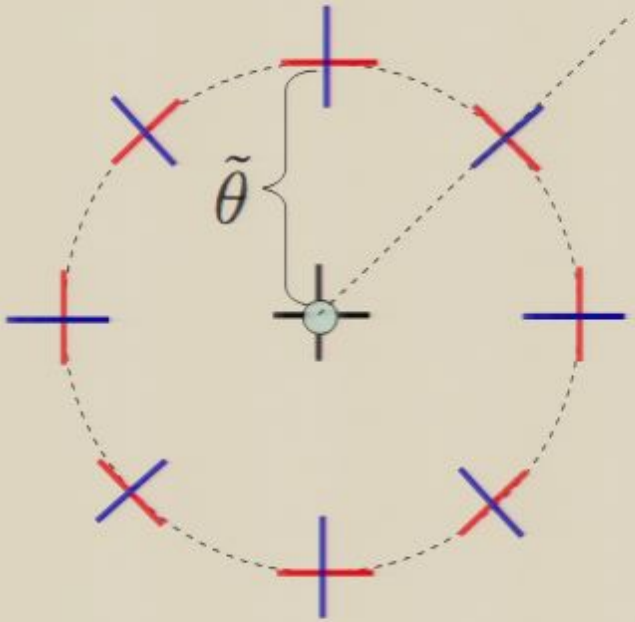
Caltech, NRAO, Oxford, CITA, Imperial by about Feb07



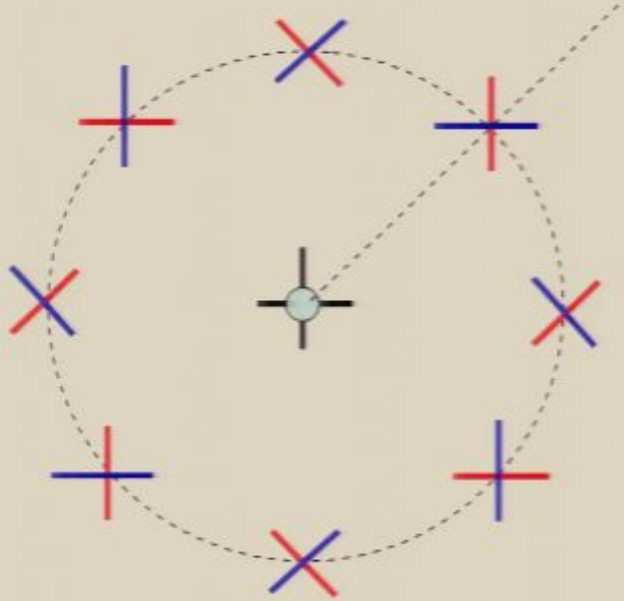
E and B mode patterns

Blue = + Red = -

"local" Q

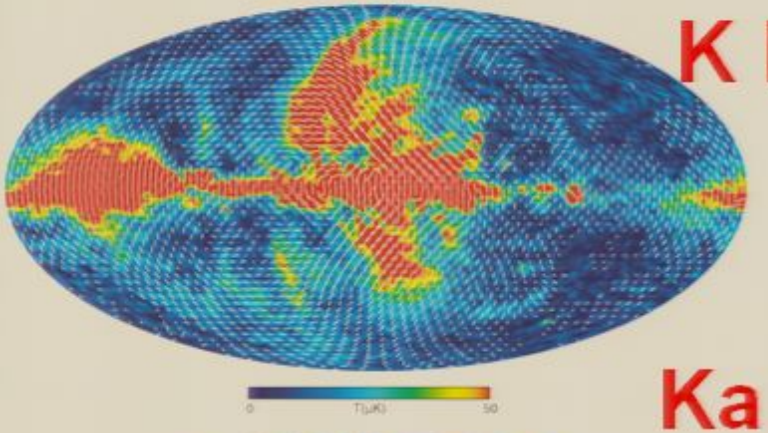


"local" U

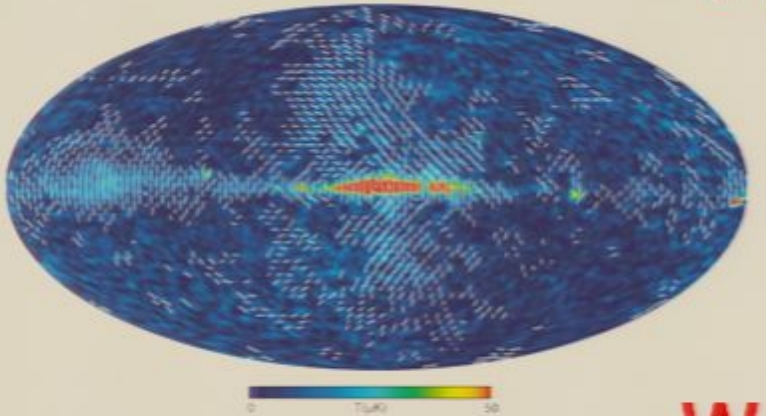


For a given circle ($\tilde{\theta}$), circumference goes as $\tilde{\theta}$, while $\omega(\tilde{\theta}) = 1/\pi\theta^2$, so the contribution of that circle goes as $1/\tilde{\theta}$.

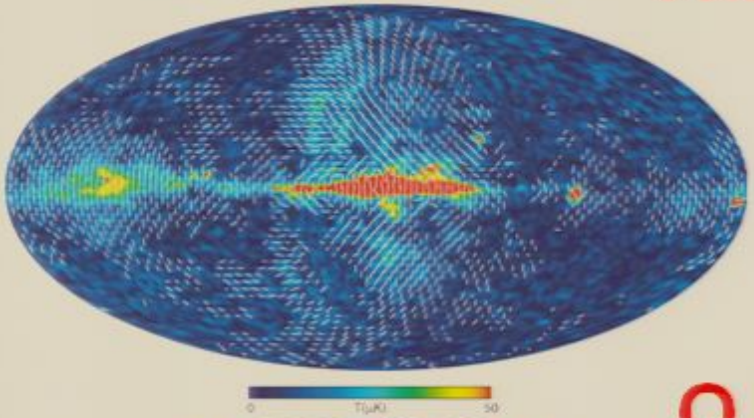
Polarization maps



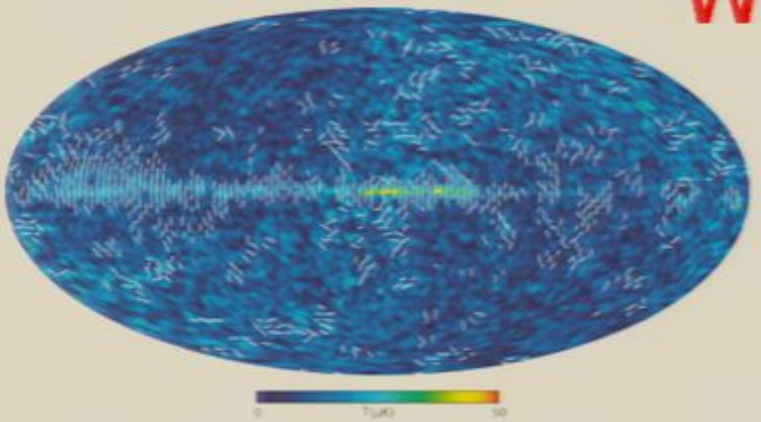
K band



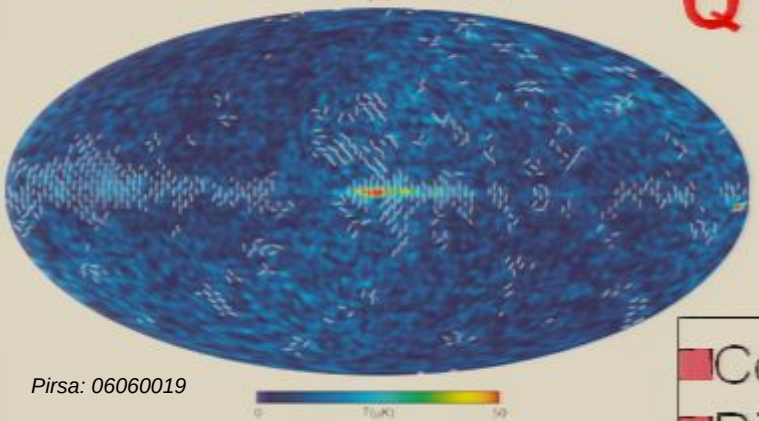
V band



Ka band



W band

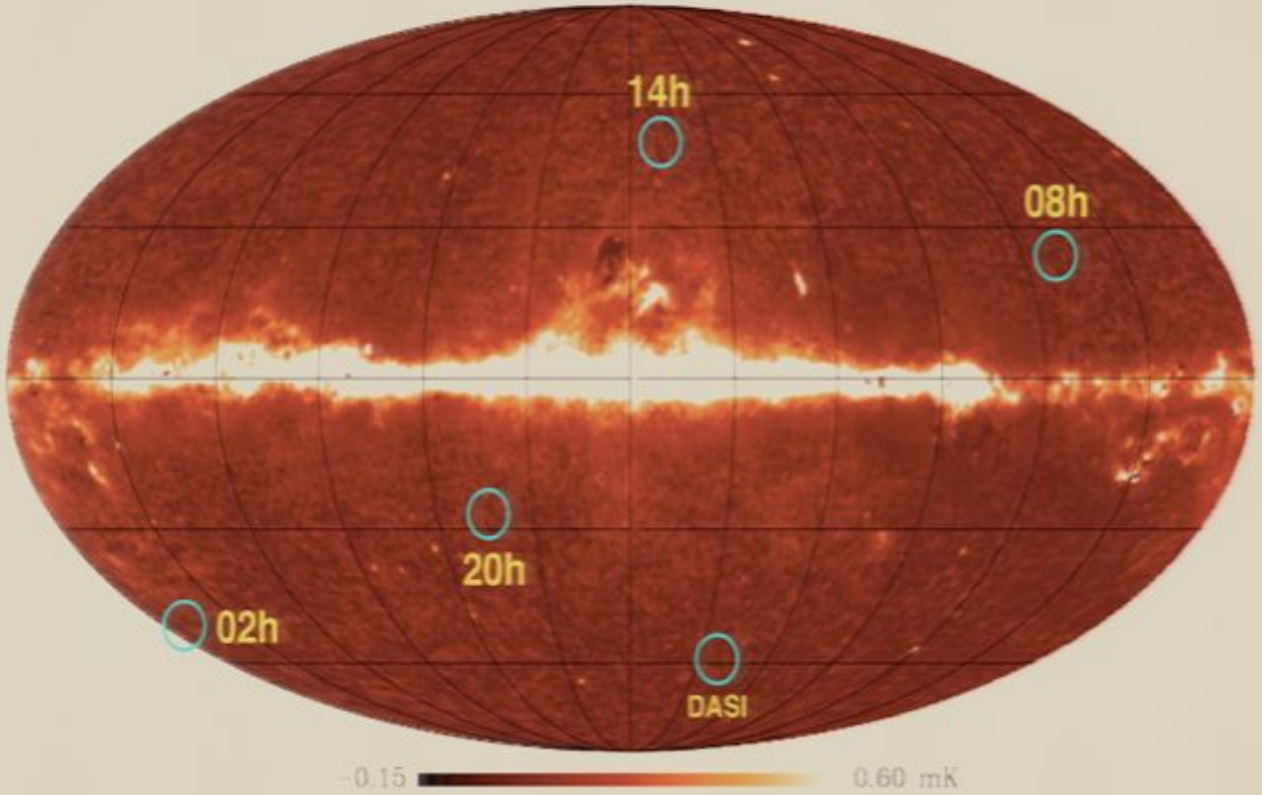


Q band

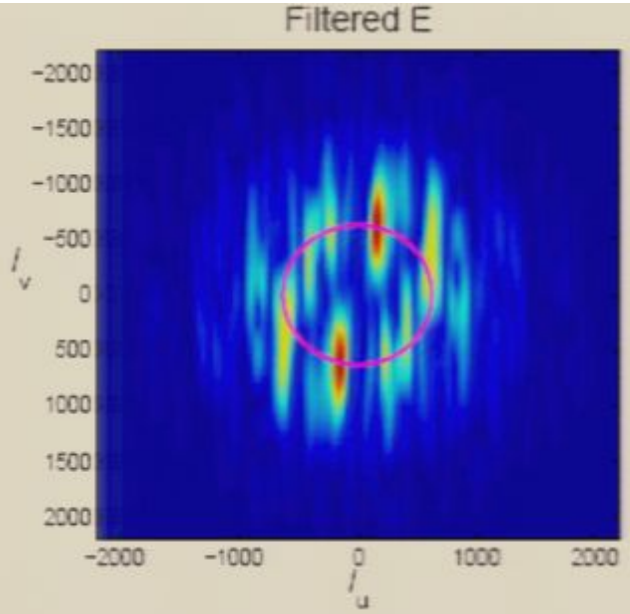
- Color code $P=(Q^2+U^2)^{1/2}$ smoothed with a 2º fwhm
- Direction shown for S/N > 1

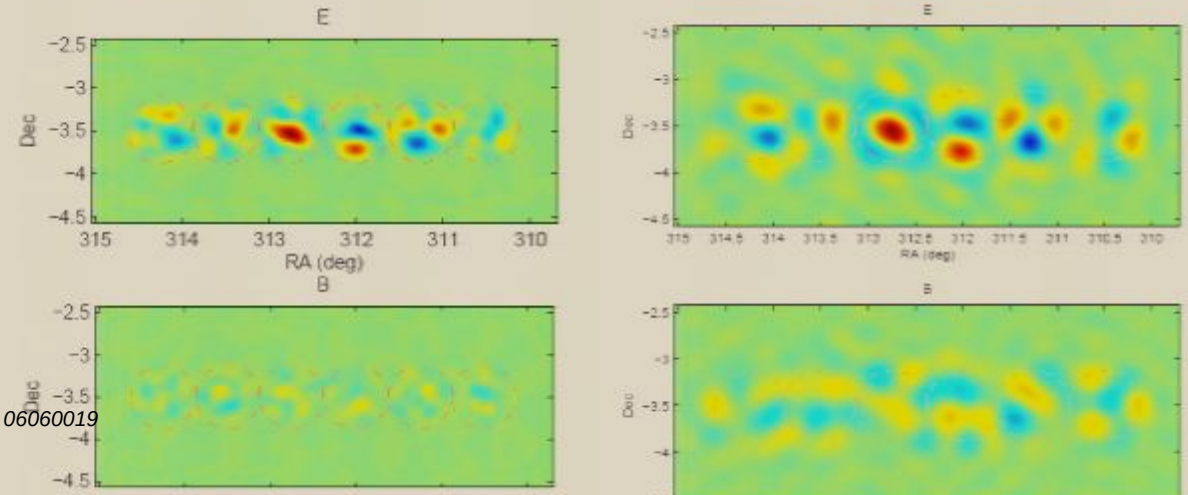
CBI Dataset

- CBI observes 4 patches of sky – 3 mosaics & 1 deep strip
- Pointings in each area separated by 45'. Mosaic 6x6 pointings, for 4.5°², deep strip 6x1.
- Lose 1 mode per strip to ground.
- 2.5 years of data, Aug 02 – Apr 05.



E/B Deep Strip signal maps cf. "raw"





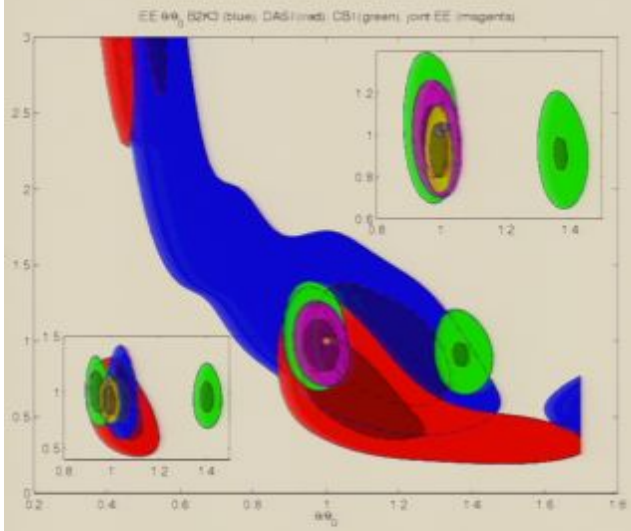
Variance of E in raw data 2.45 times B (ℓ<1000). B consistent with noise. E,B mixing ~5% in power.

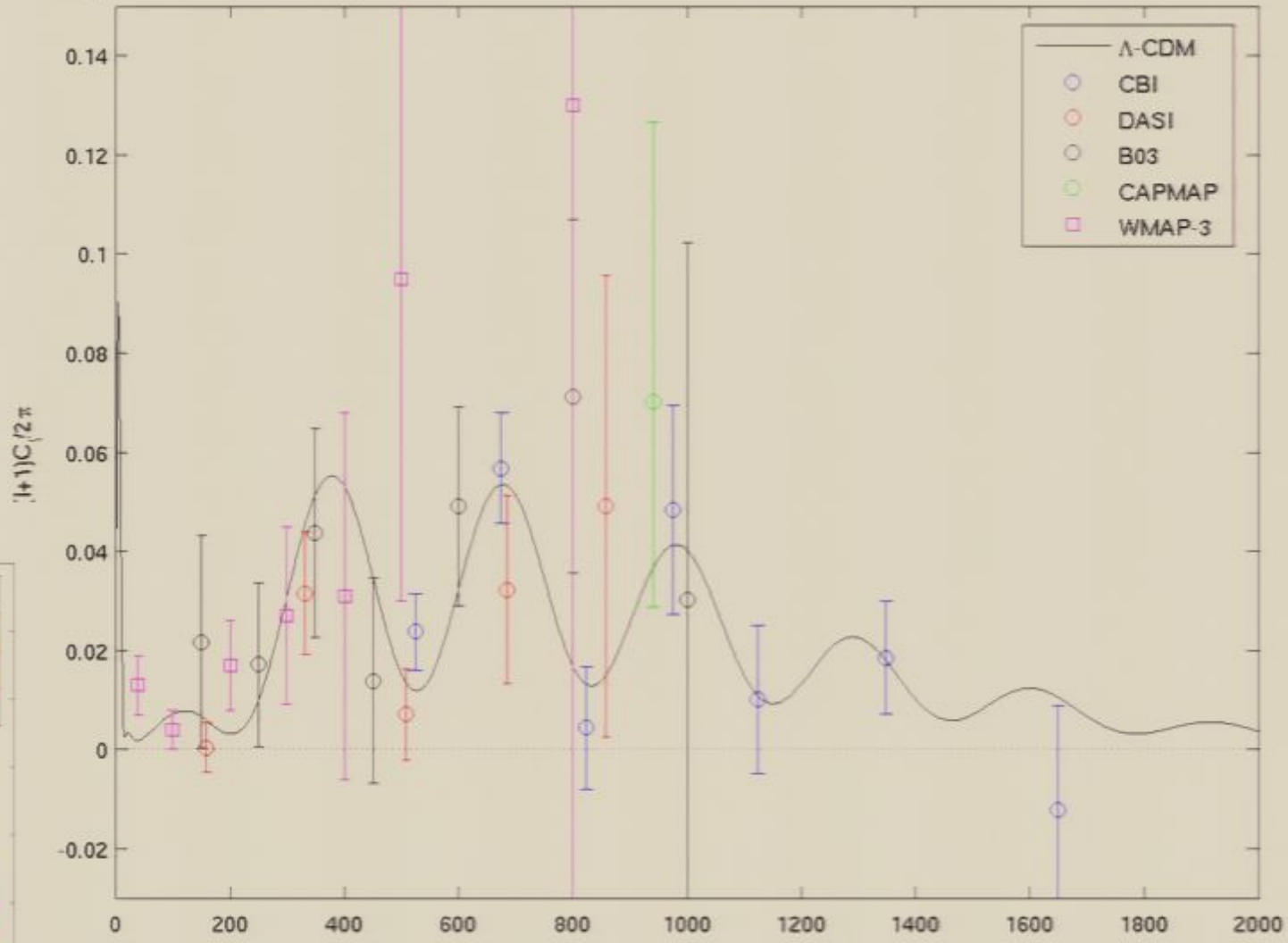
Polarization EE:2.5 yrs of CBI, Boom03,DASI,WMAP3

(CBI04, DASI04, CAPmap04 @ COSMO04) & DASI02 EE & WMAP3'06

Phenomenological parameter analysis

L_{sound}@dec vs A_s
CBI+B03+DASI
EE,TE cf. CMB TT





[Sievers et al. astro-ph/0509203]

[Montroy et al. astro-ph/0509203]

[Readhead et al. astro-ph/0409569]

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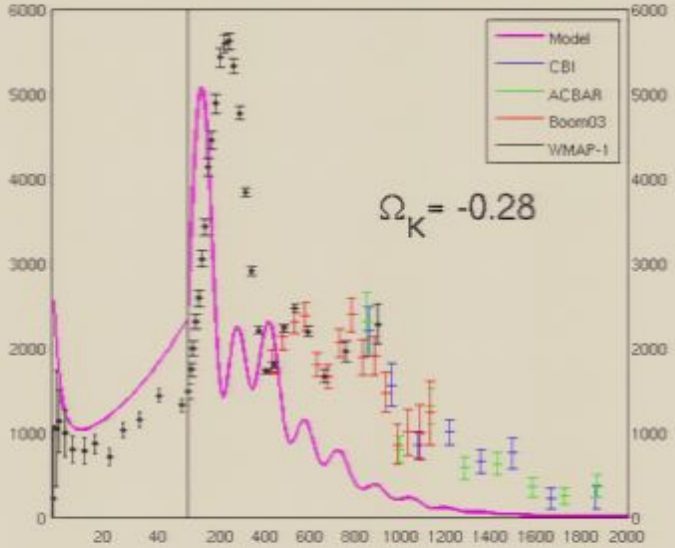

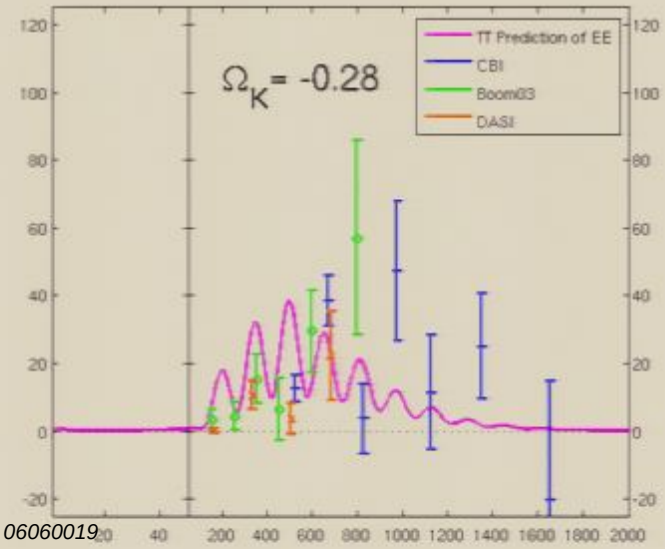

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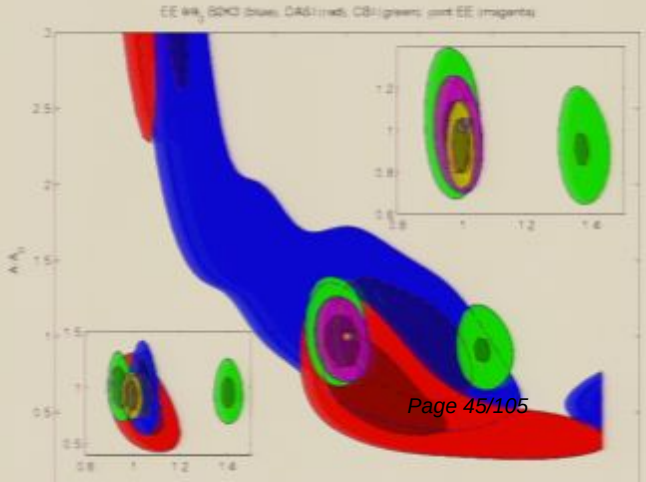

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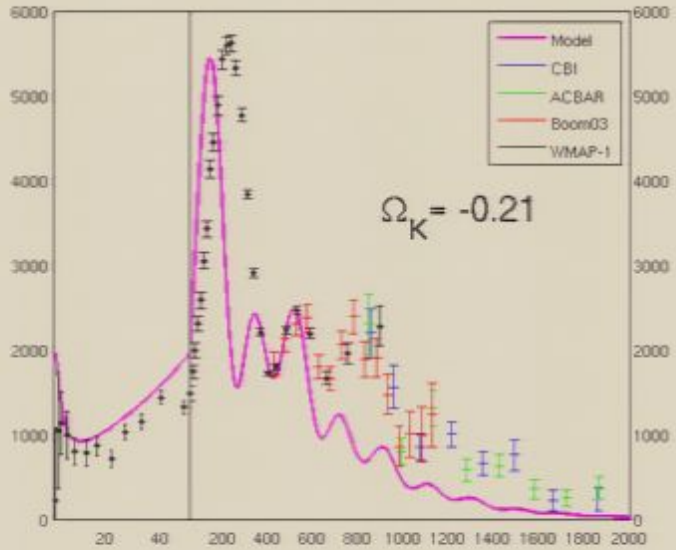

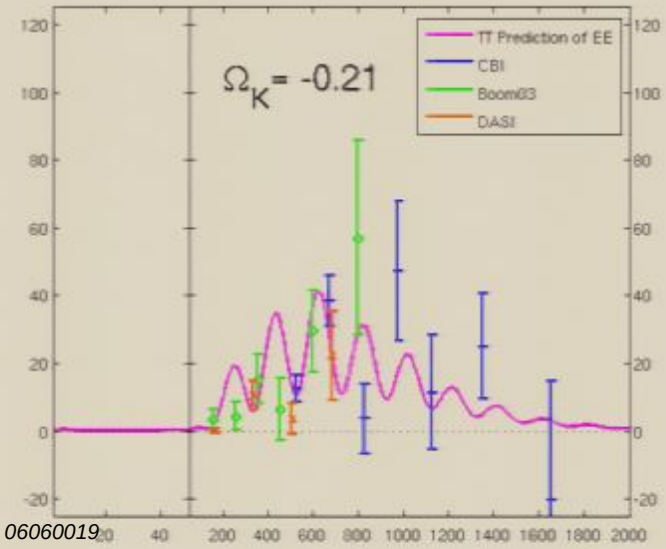

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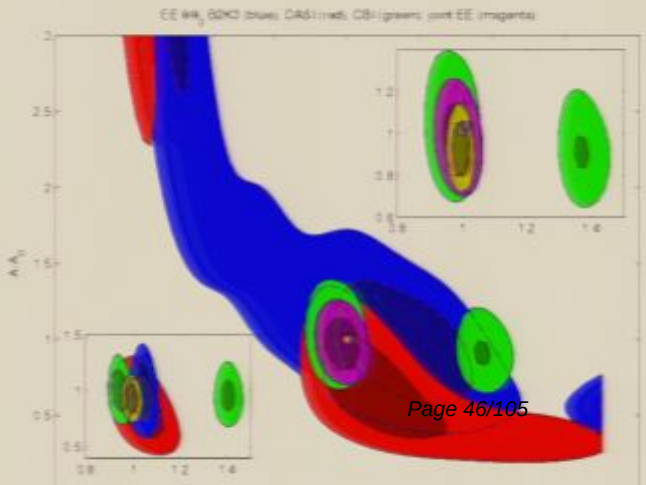

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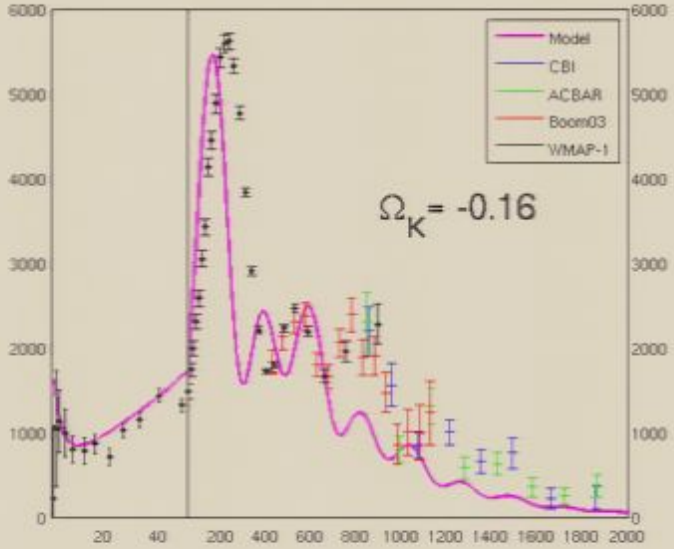

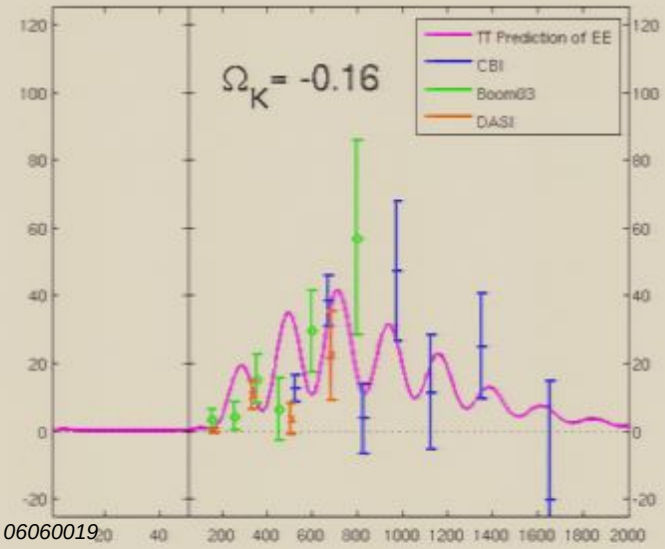

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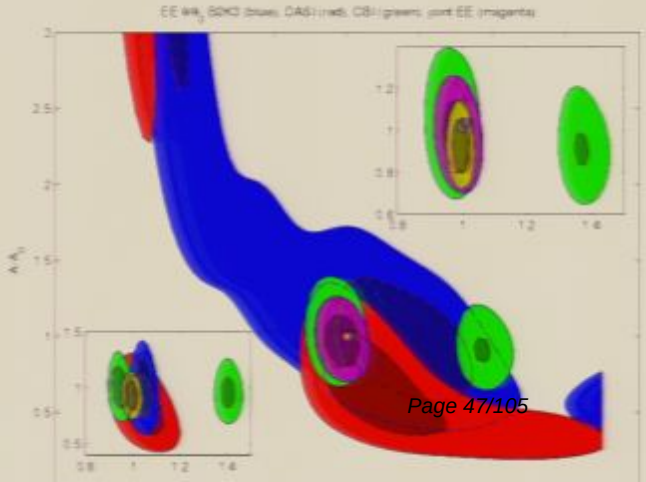

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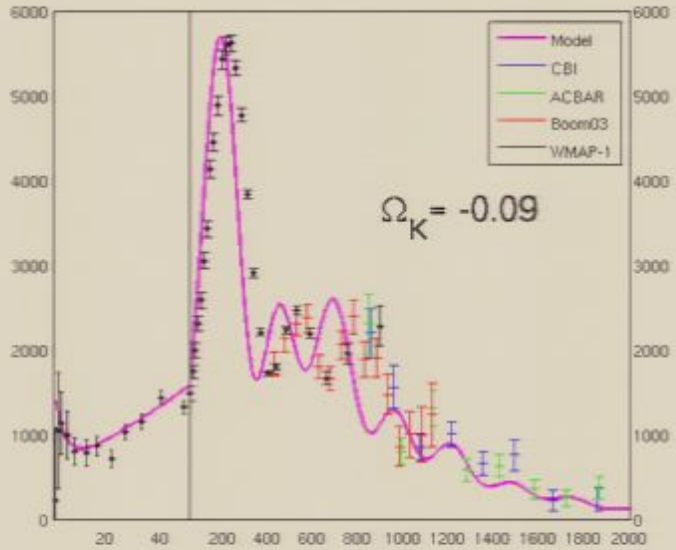

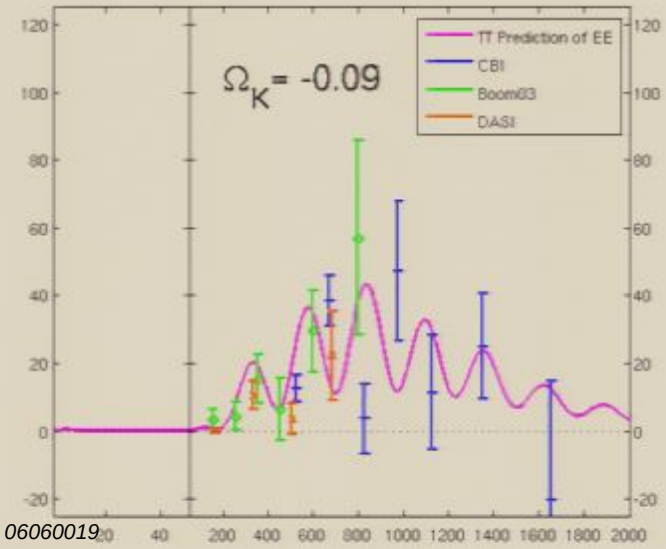

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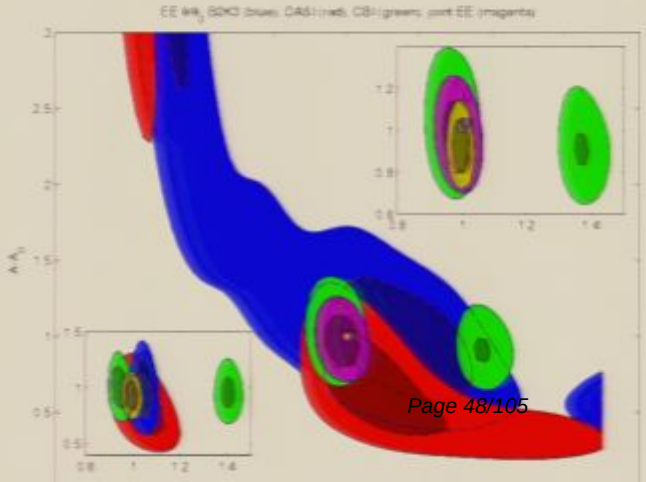

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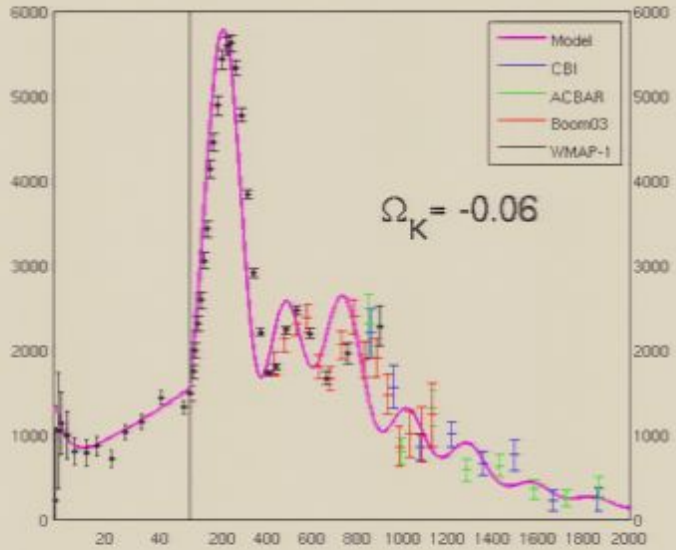

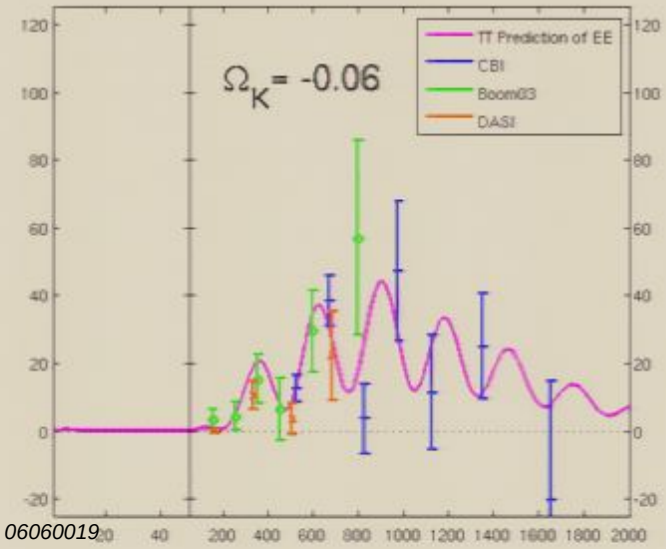

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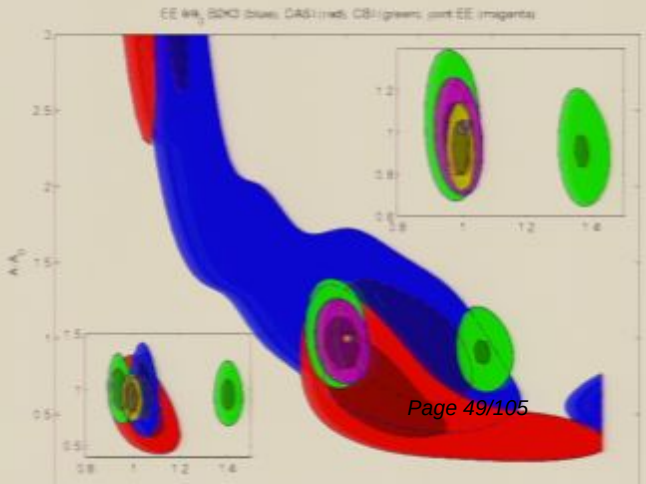

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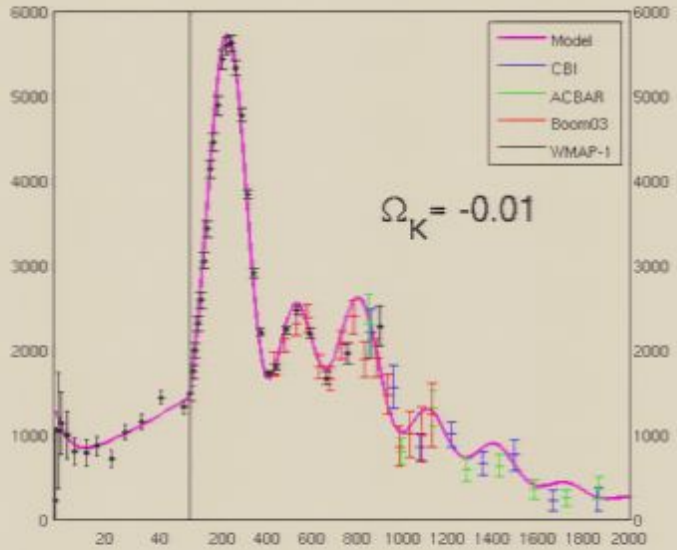

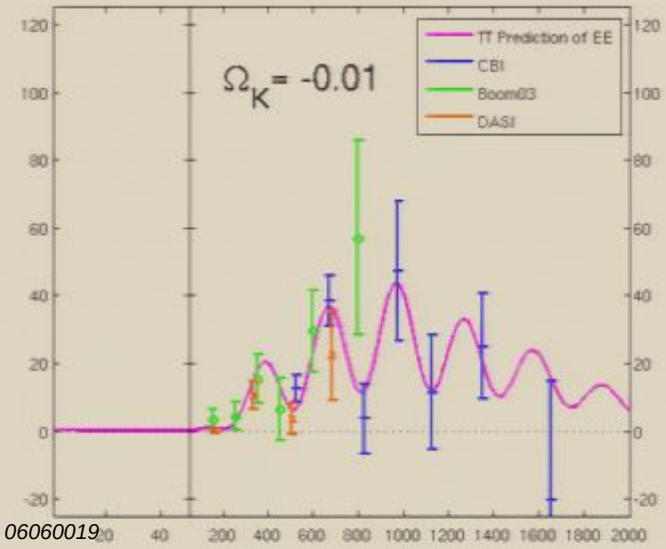

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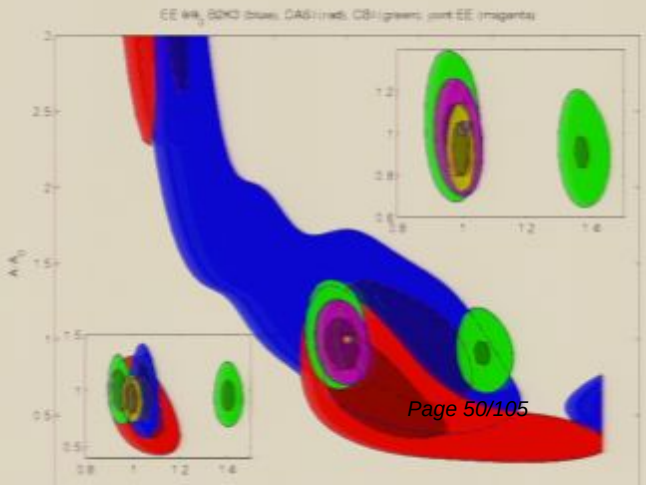

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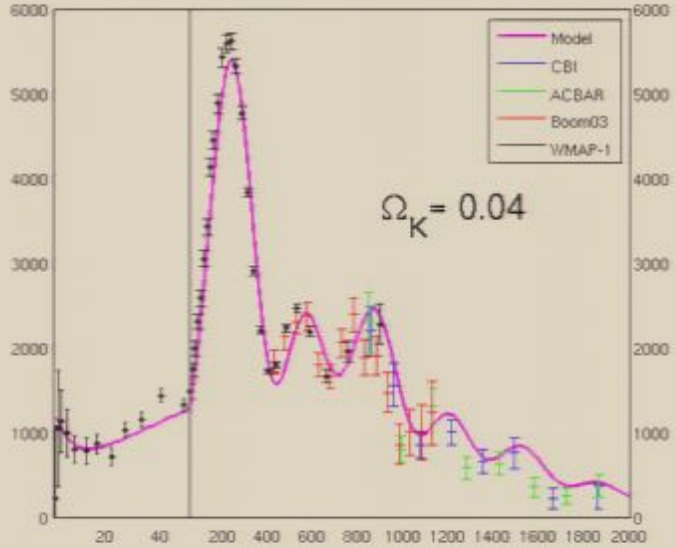

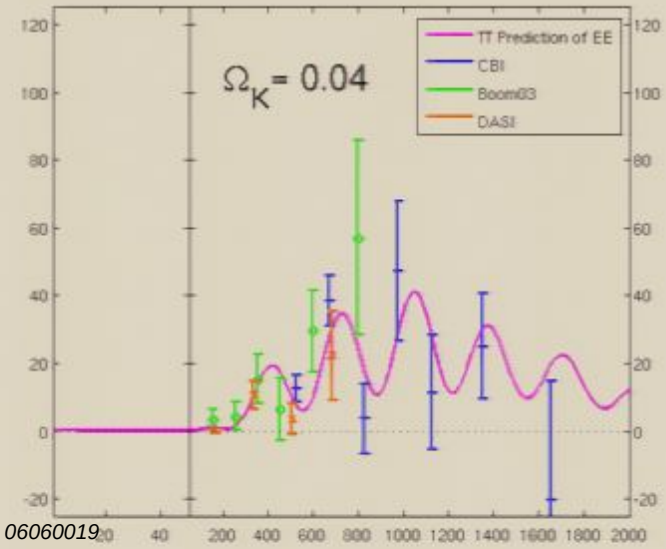

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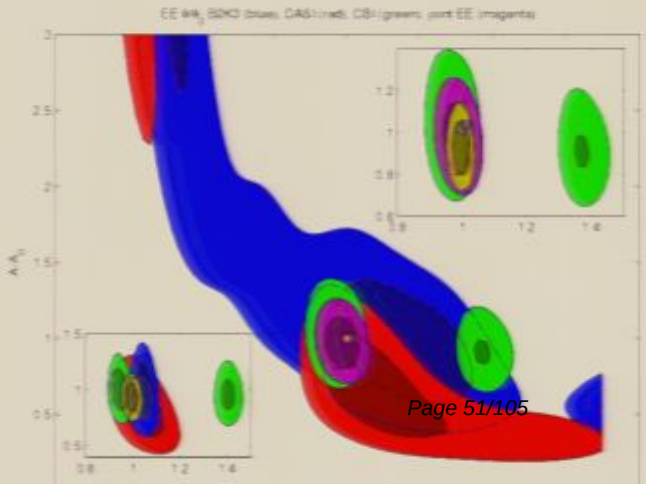

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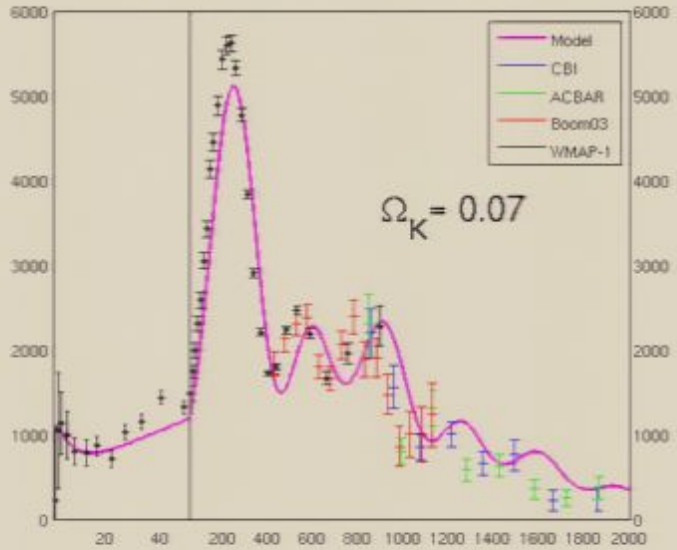

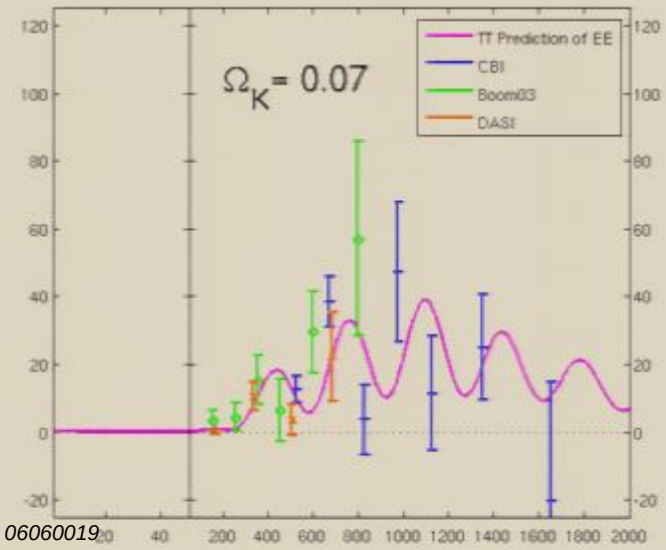

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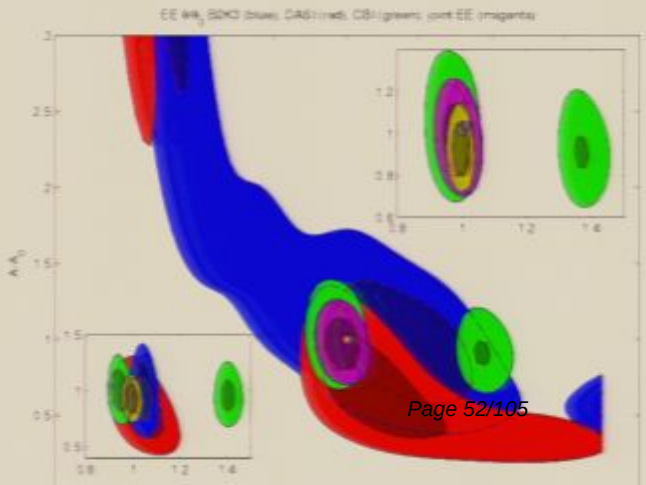

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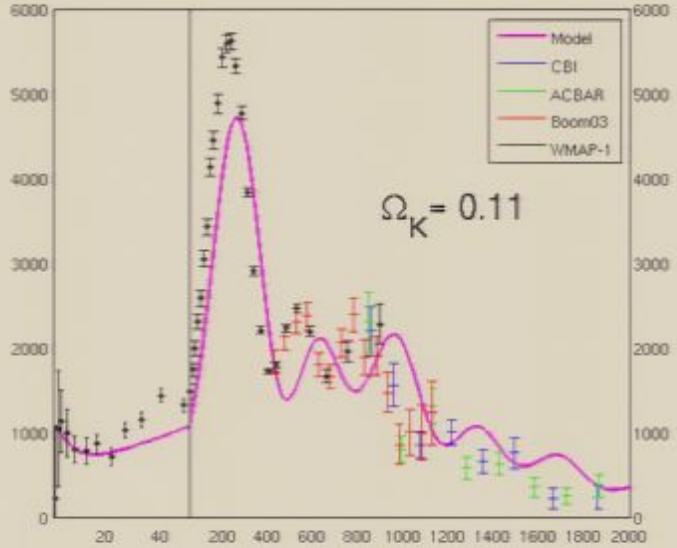

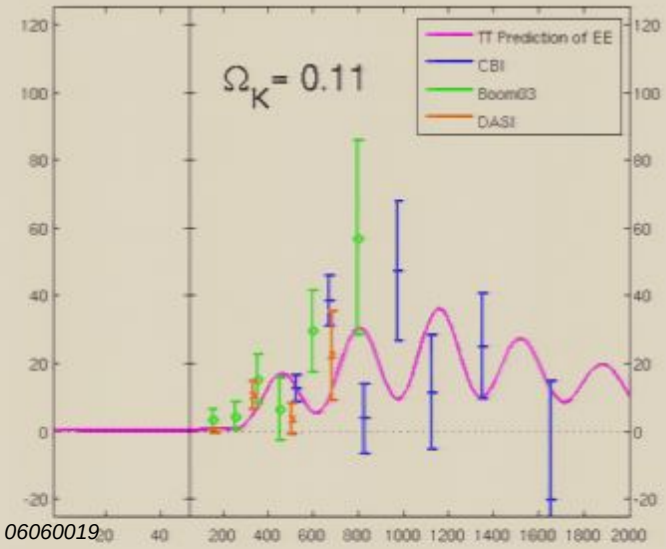

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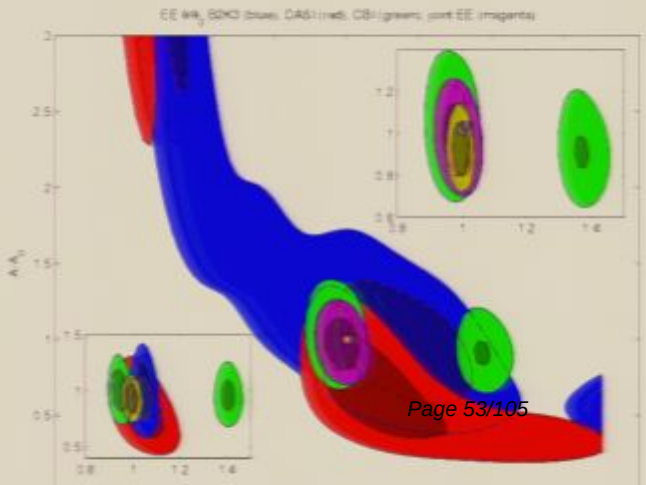

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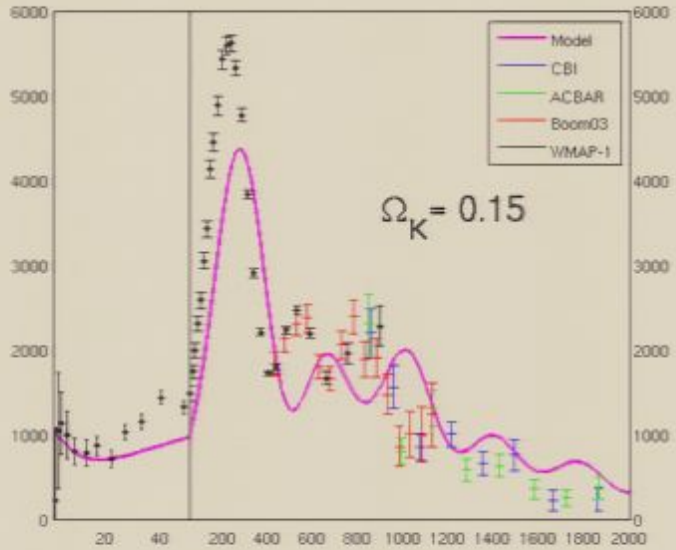

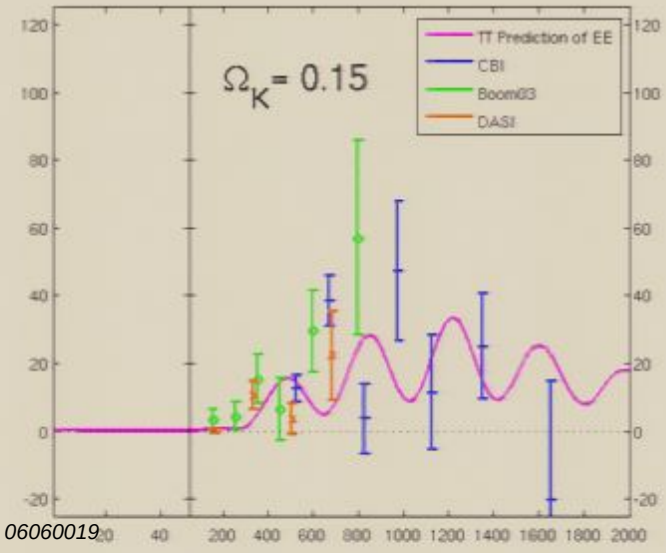

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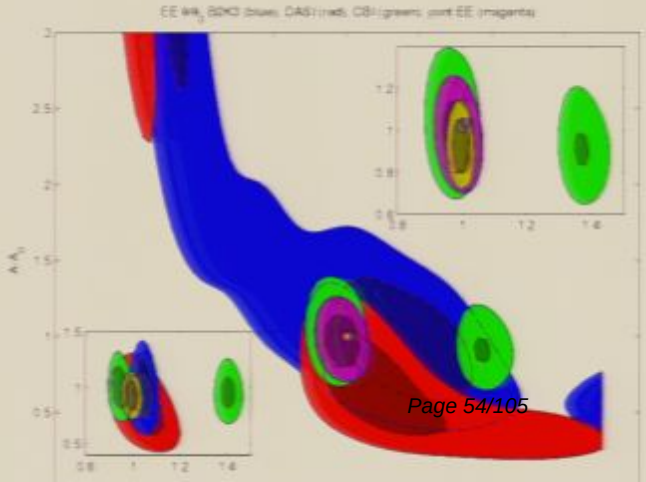

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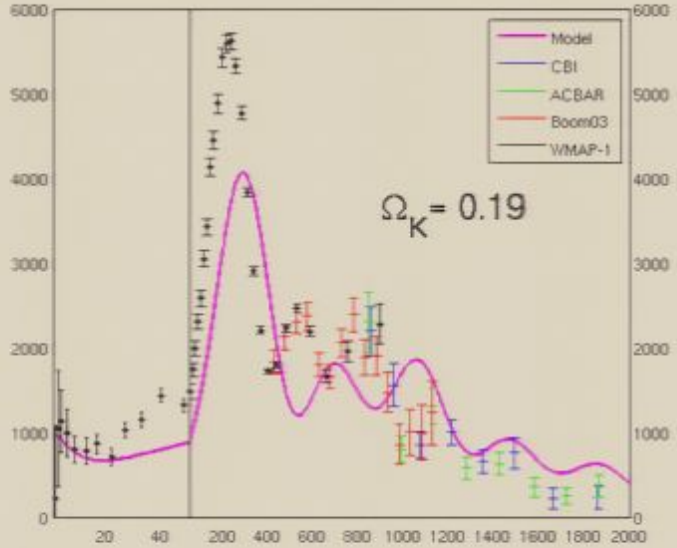

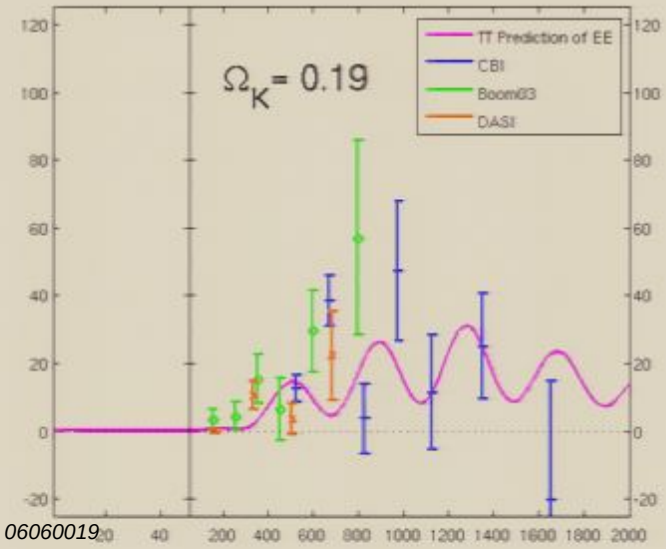

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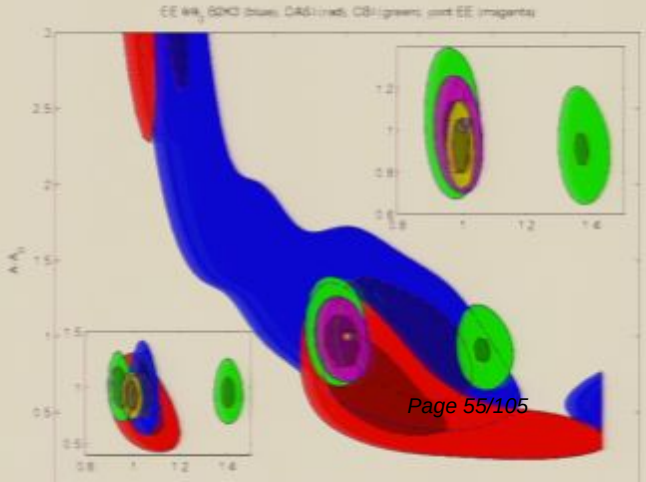

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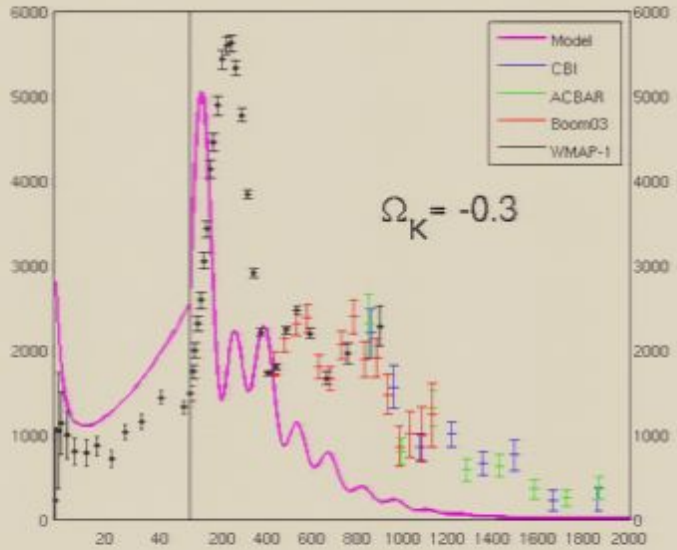

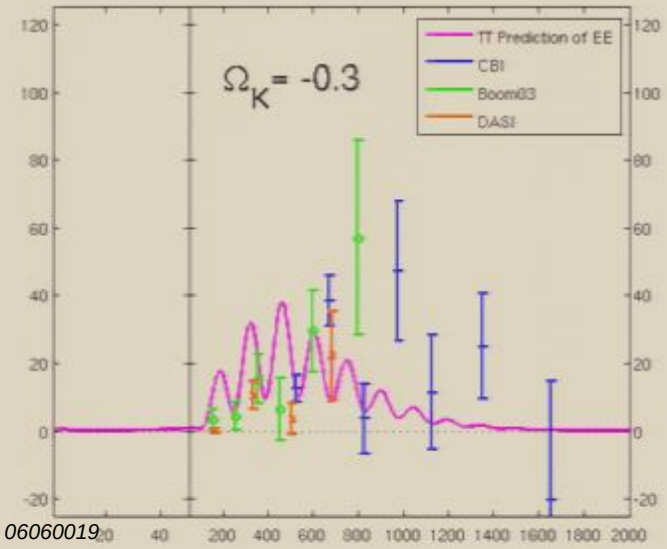

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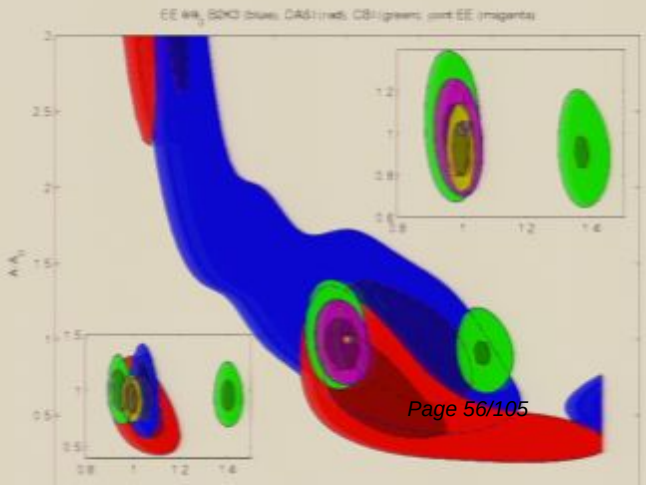

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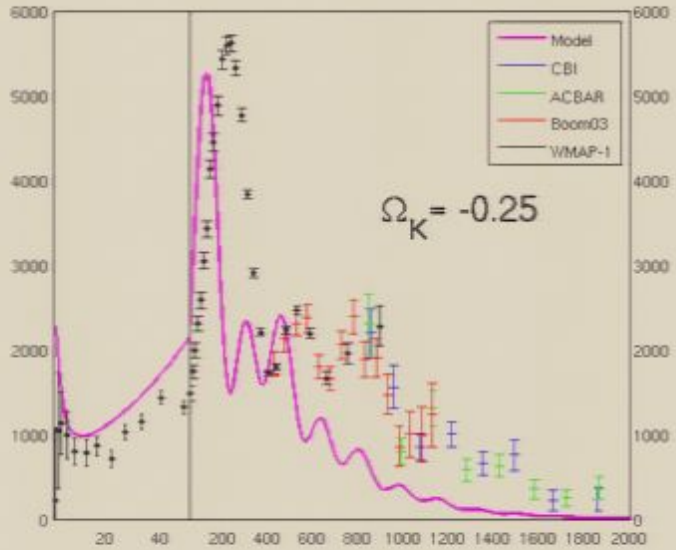

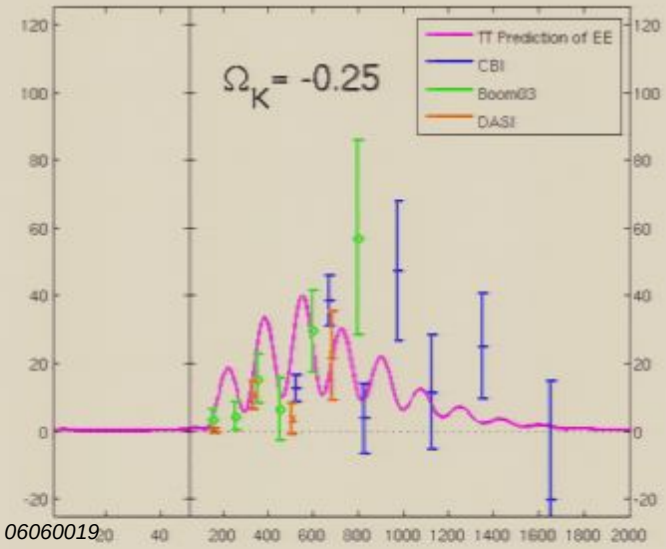

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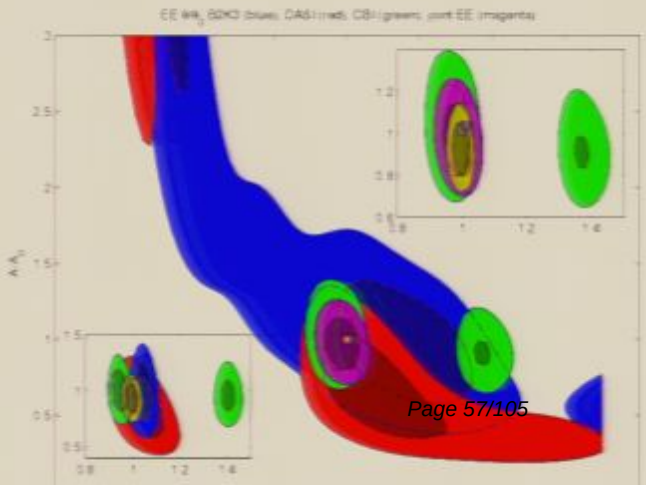

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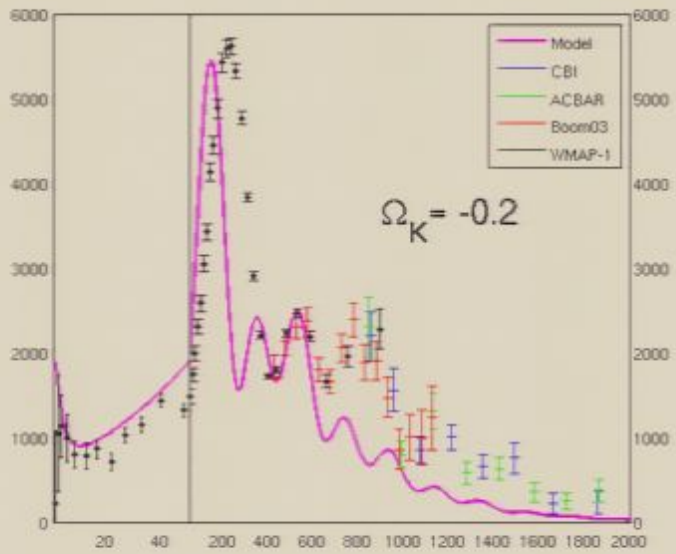

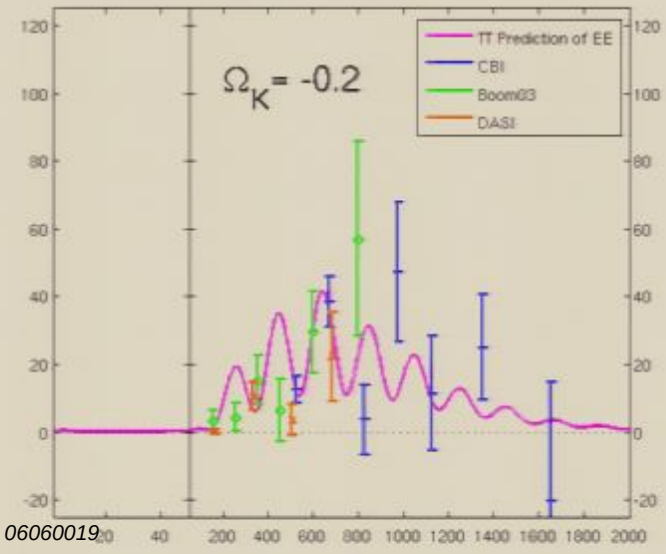

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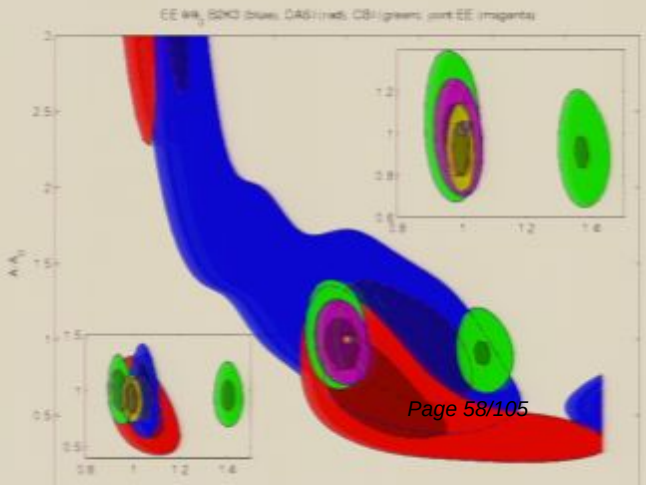

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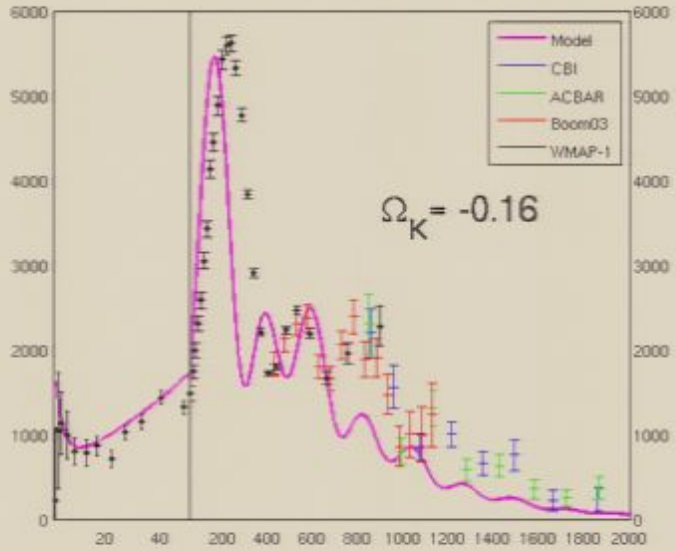

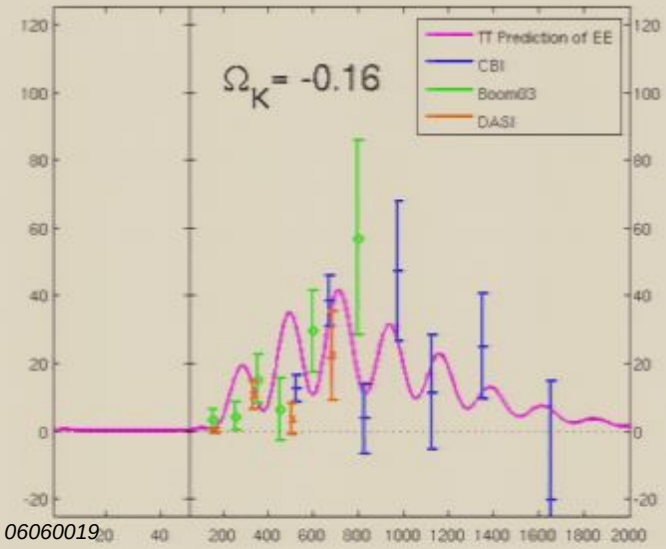

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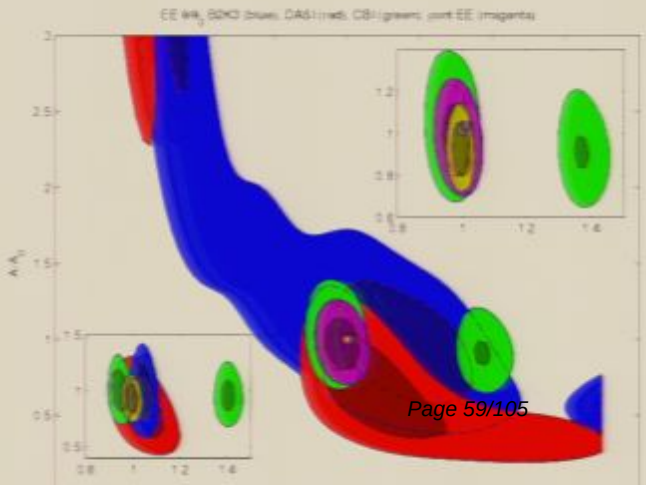

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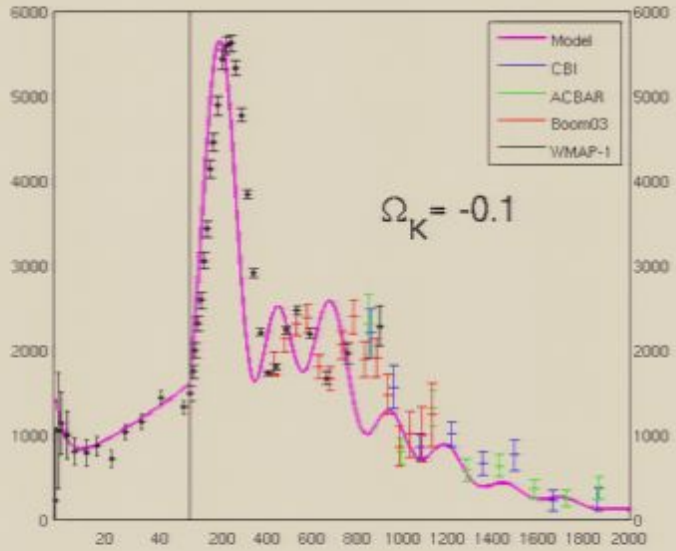

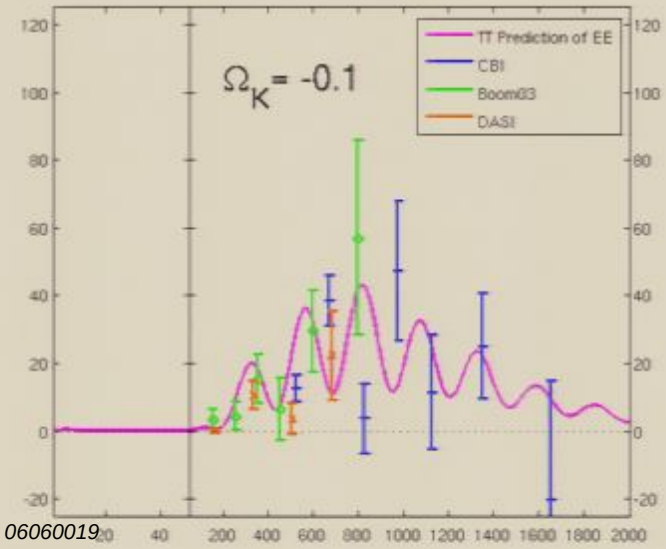

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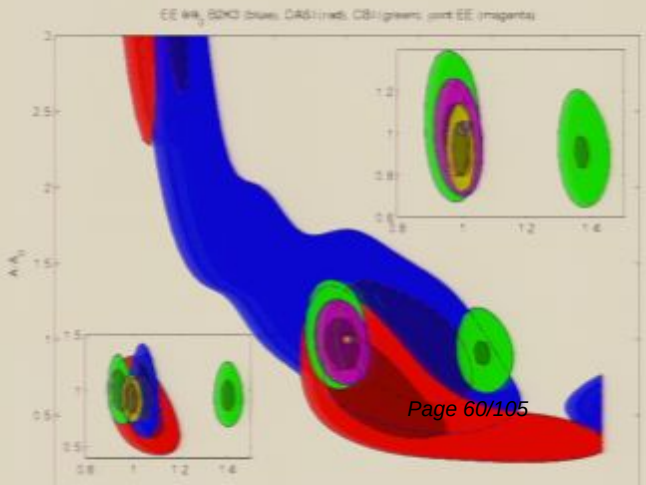

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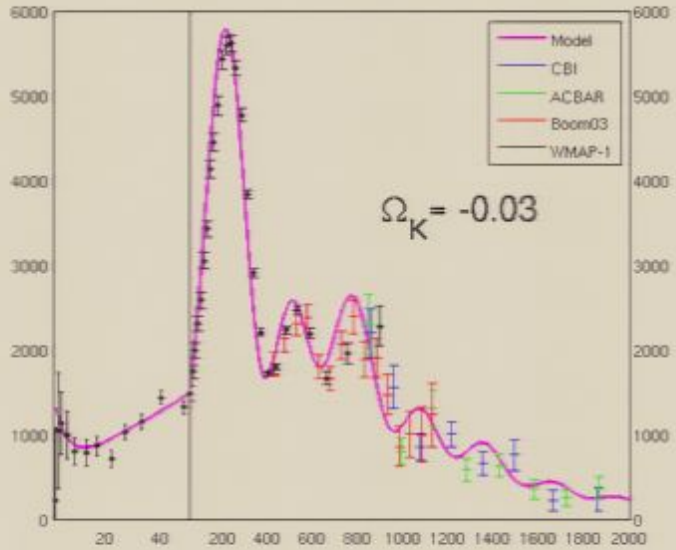

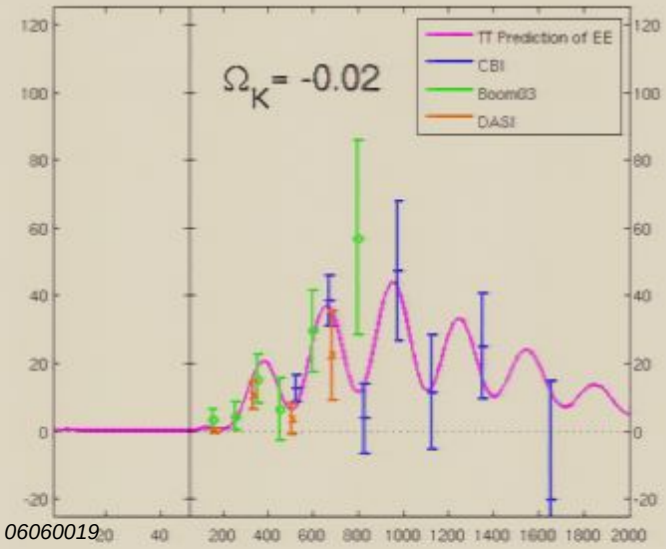

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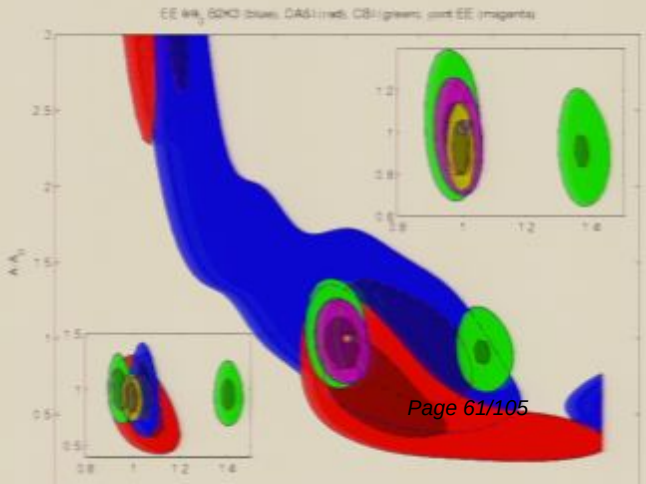

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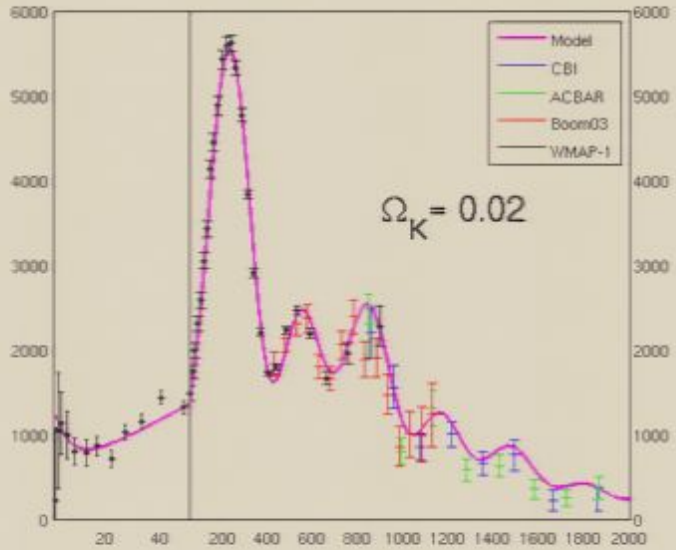

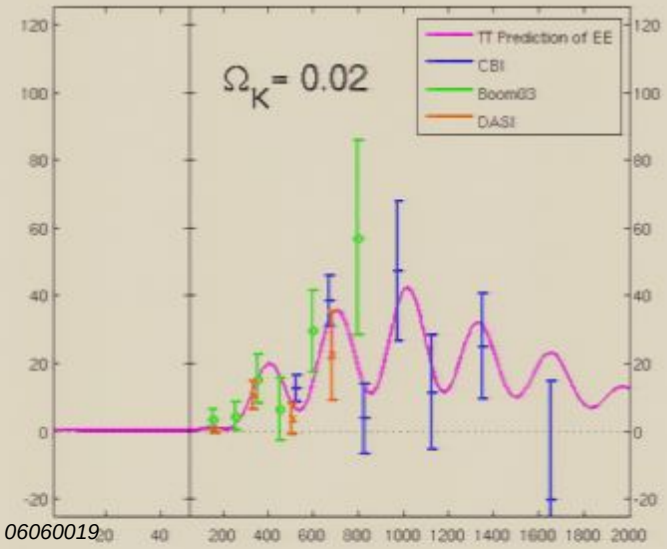

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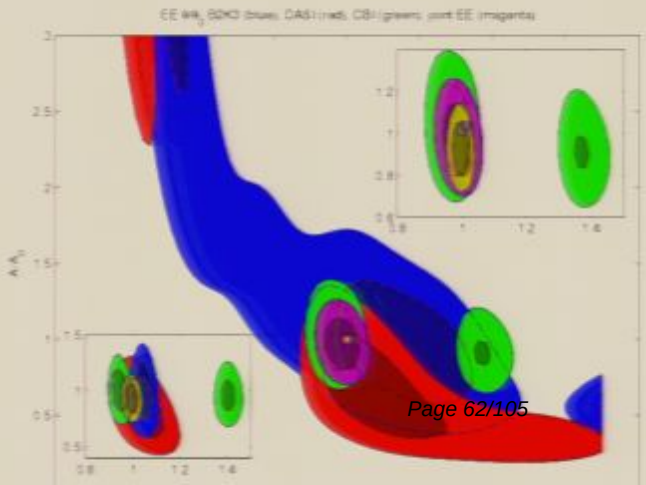

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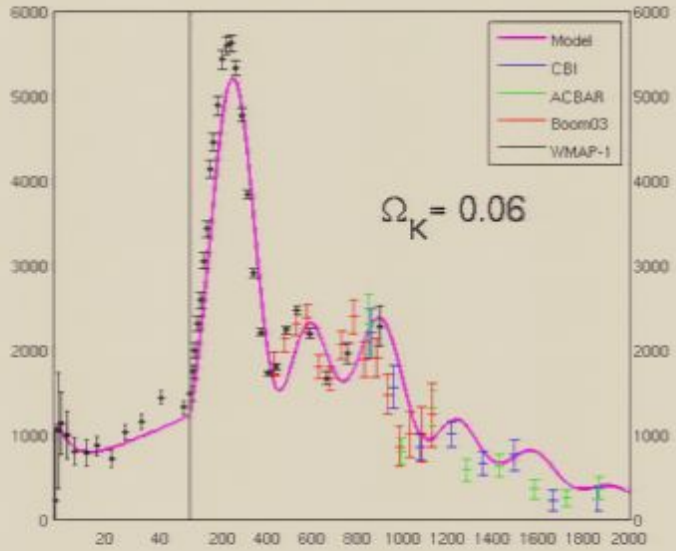

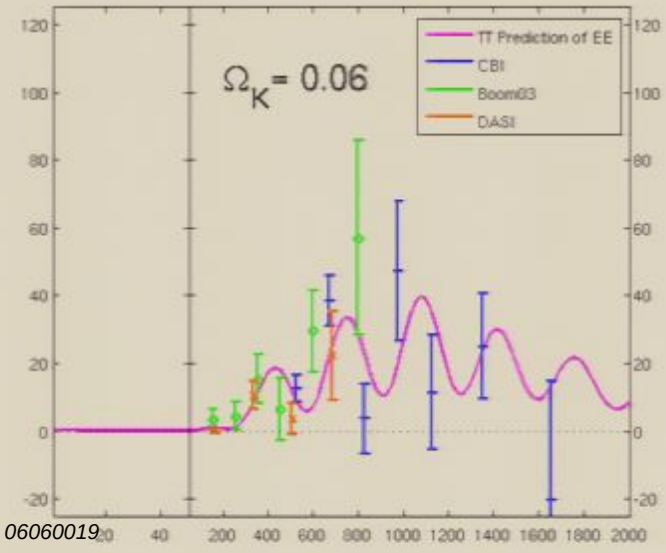

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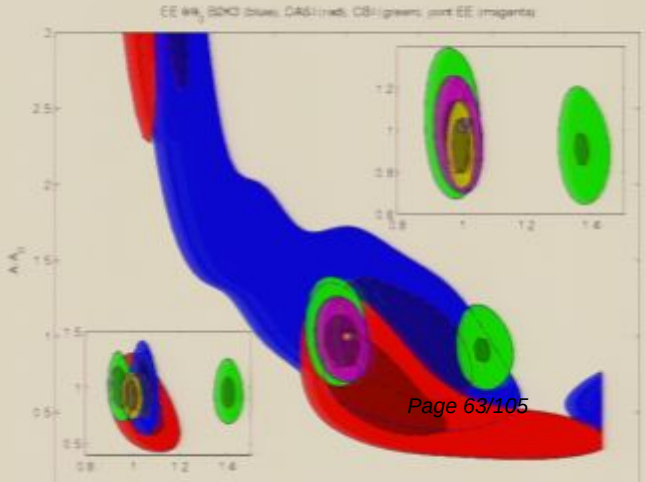

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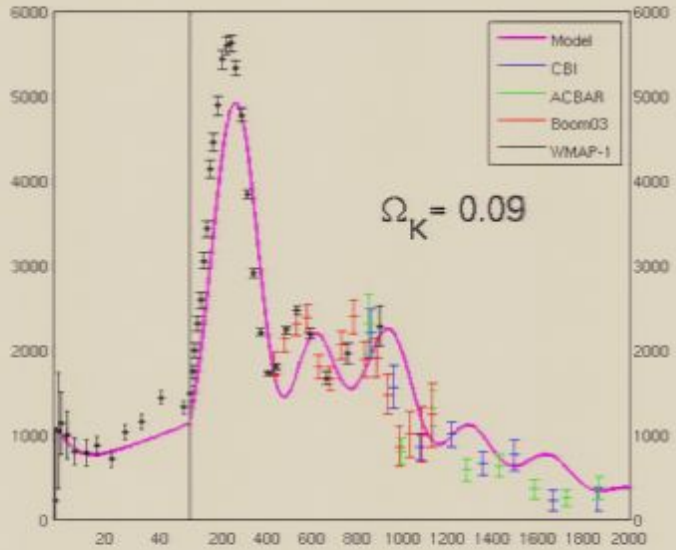

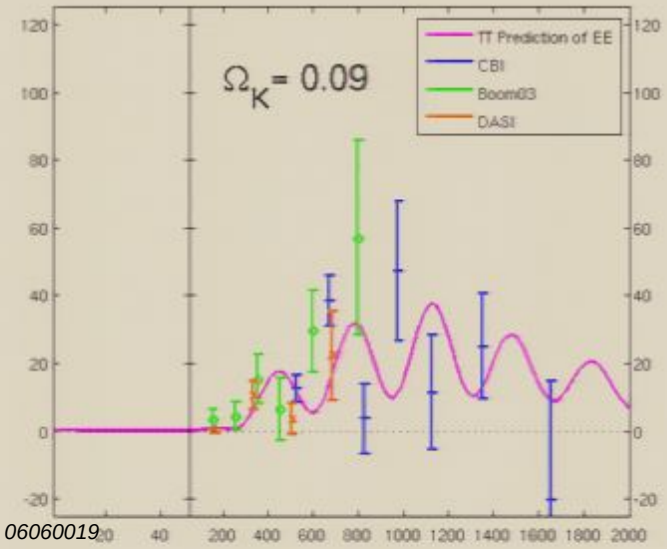

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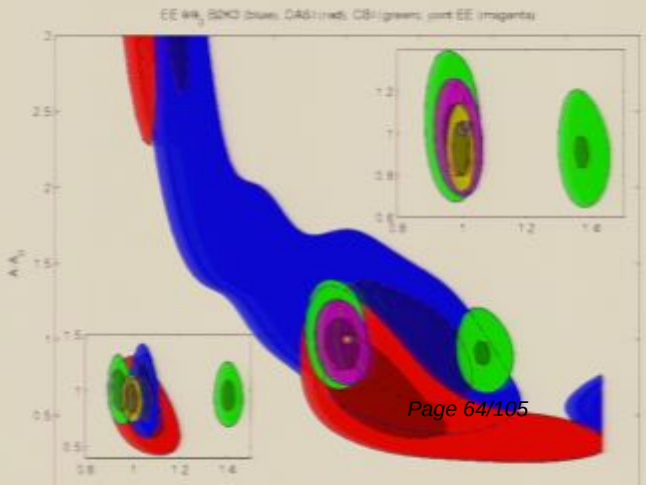

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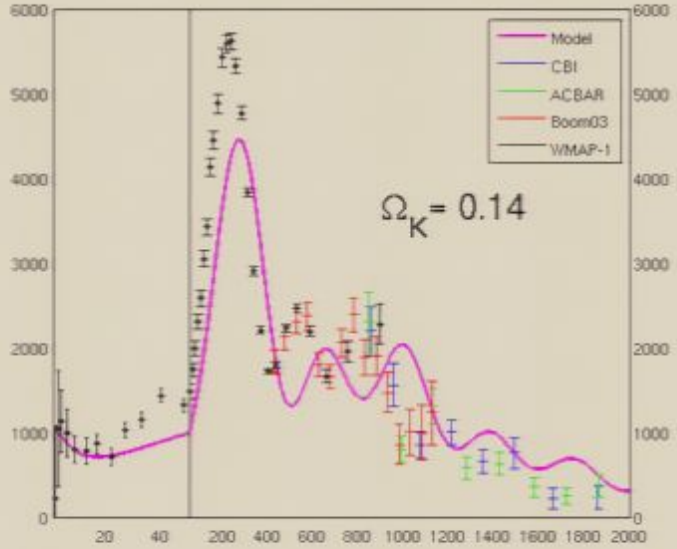

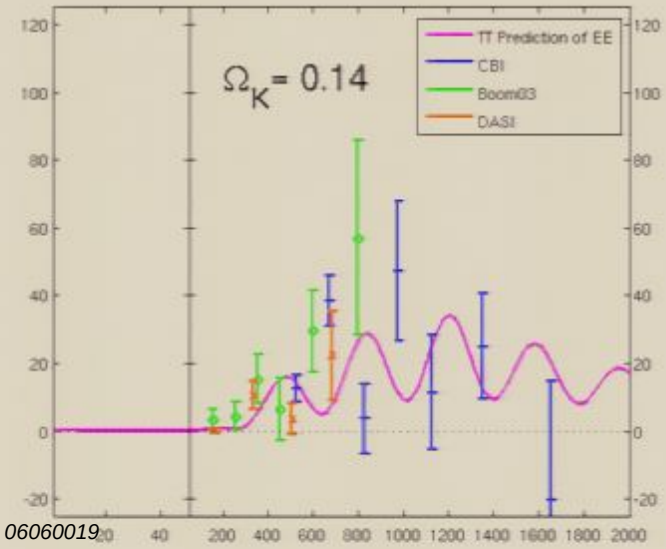

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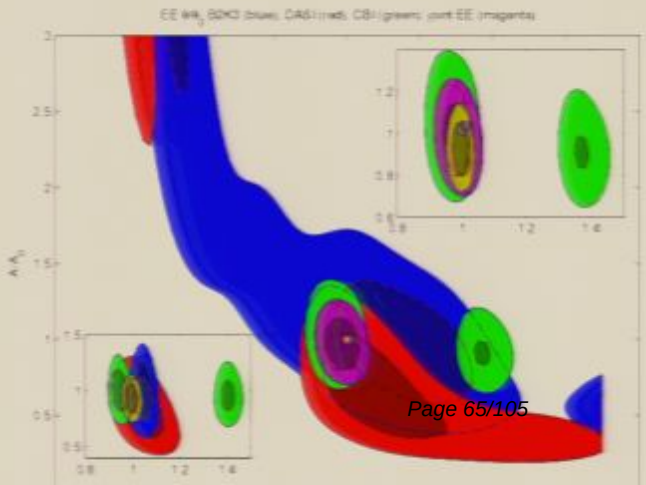
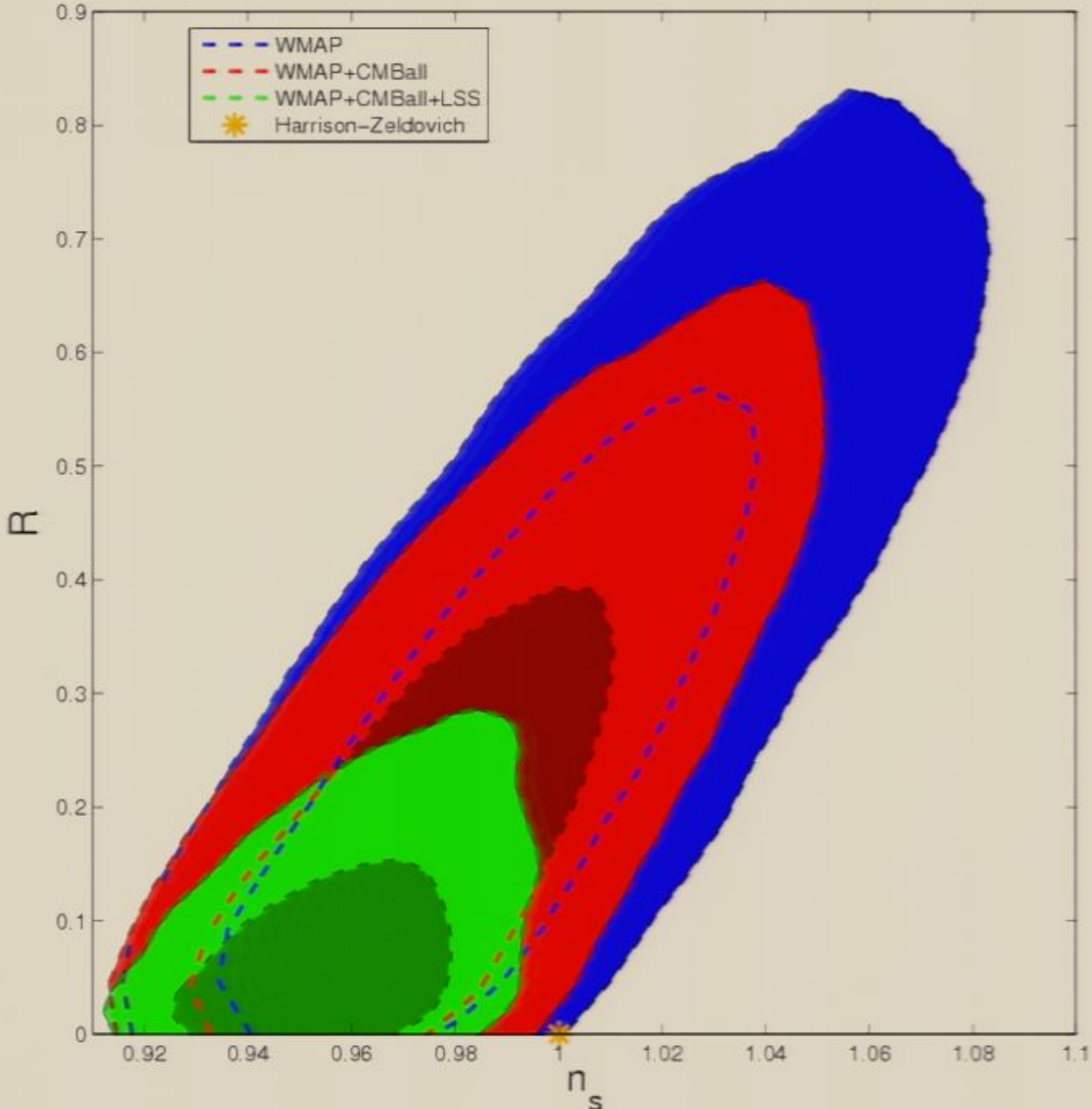


Physical cosmology Probes of Early & Late universe physics

CMB: polarization frontier (B-futures)

Inflation Then Trajectories & Primordial Power Spectrum Constraints

The Parameters of Cosmic Structure Formation



SPIDER Balloon-borne

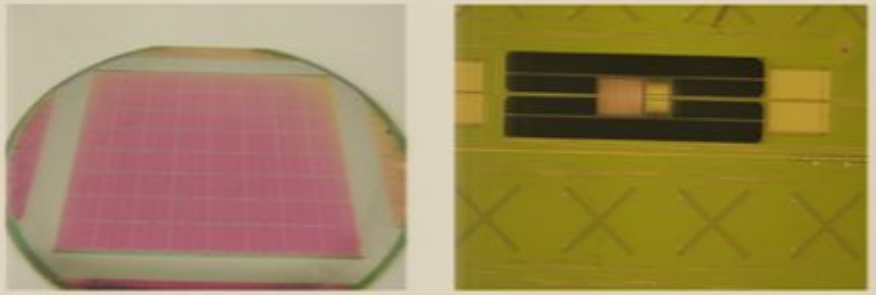
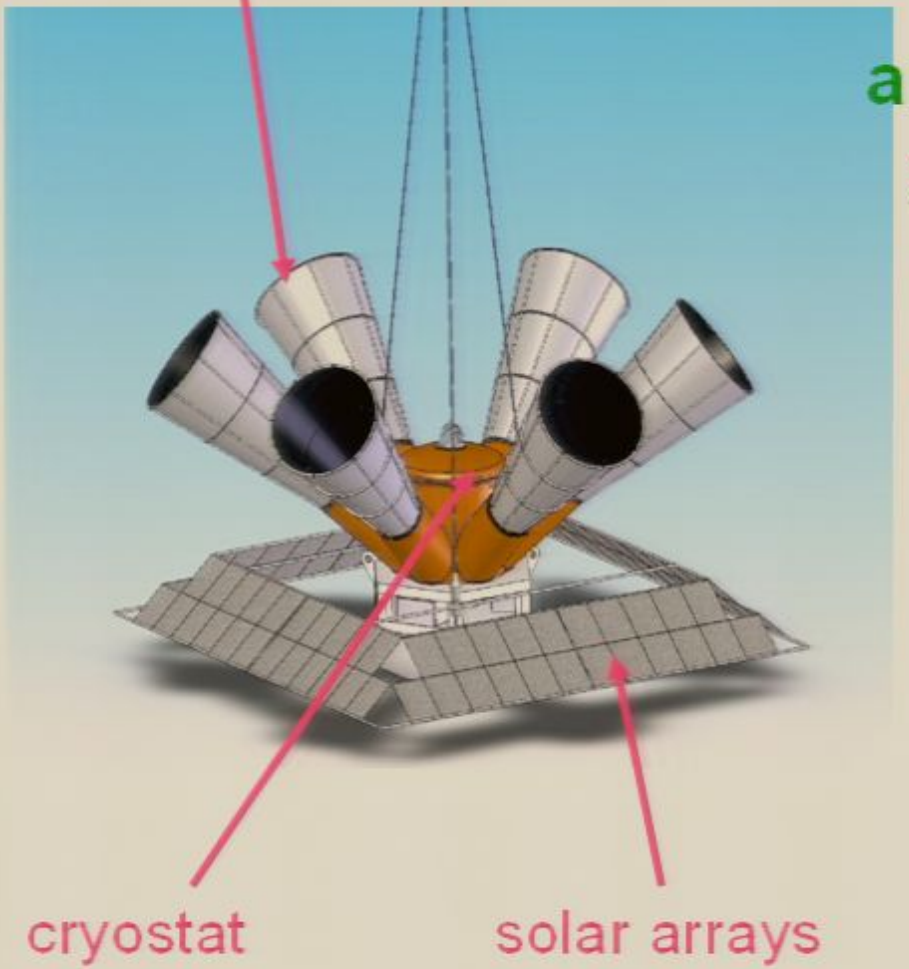


Figure 12: 4-inch-diameter wafer with 8 × 8 spatial pixels (left) and a closeup on a released TES and four antenna pairs at 50× magnification (right).



antenna-coupled bolometer array

2312 detectors cooled to 250 mK

Each pixel has two orthogonally polarized antenna

Spins in azimuth, fixed elevation (45°)

Six telescopes, five Frequencies 70 to 300 GHz

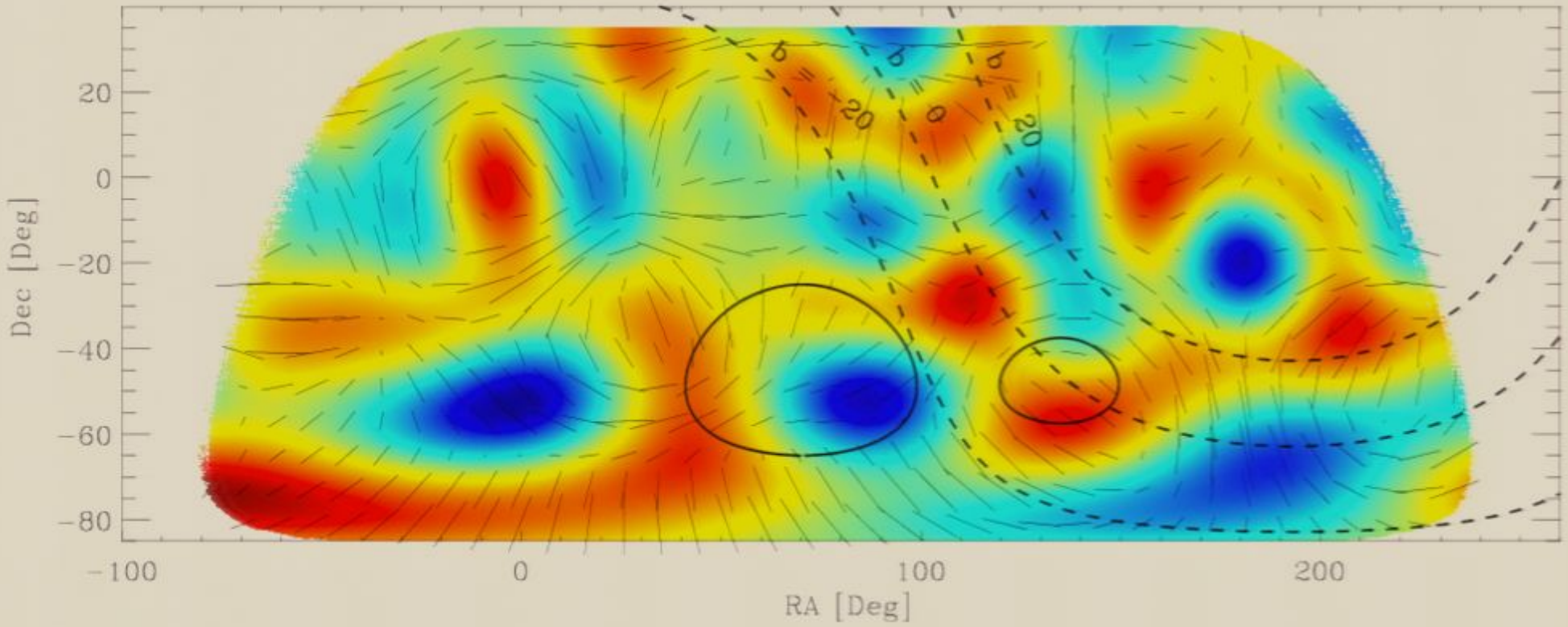
~1° resolution at 100GHz

SPIDER Tensor Signal

- Simulation of large scale polarization signal
- This is what we are after!!

$$\frac{A_T}{A_S} = 0.1$$

No Tensor



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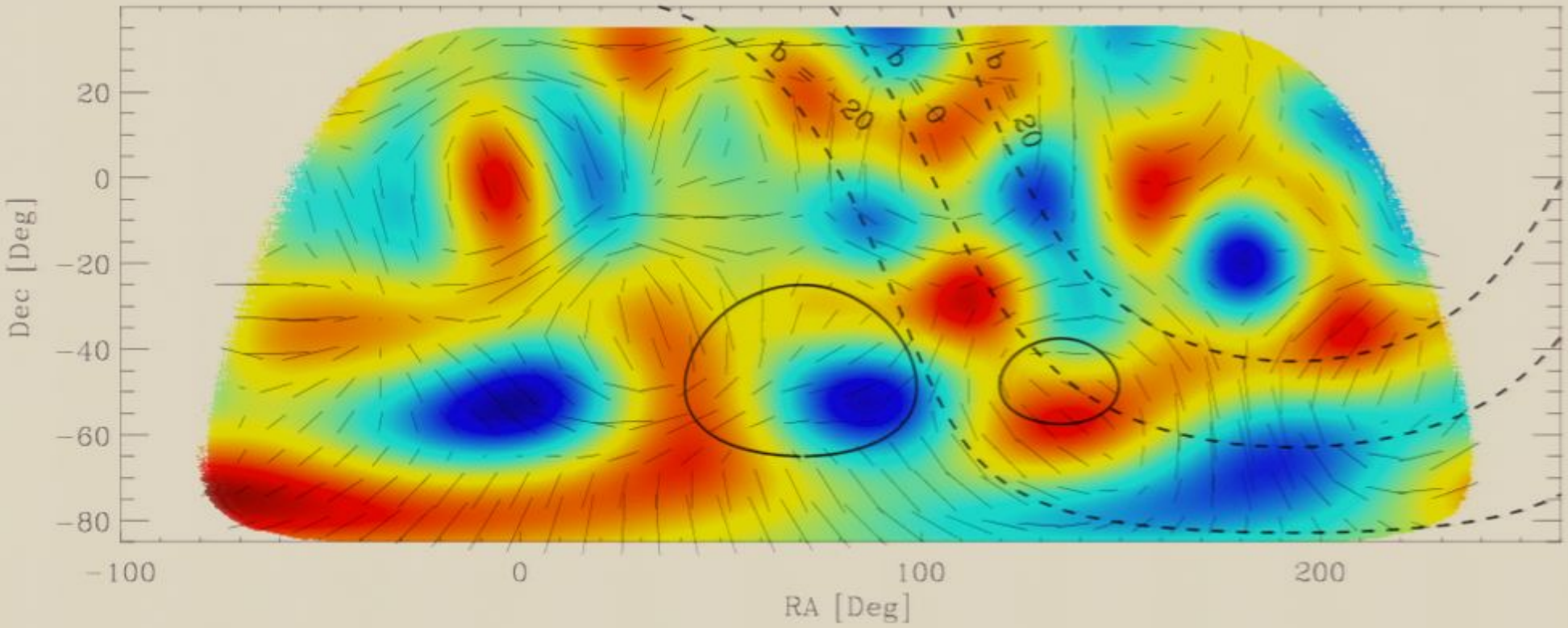

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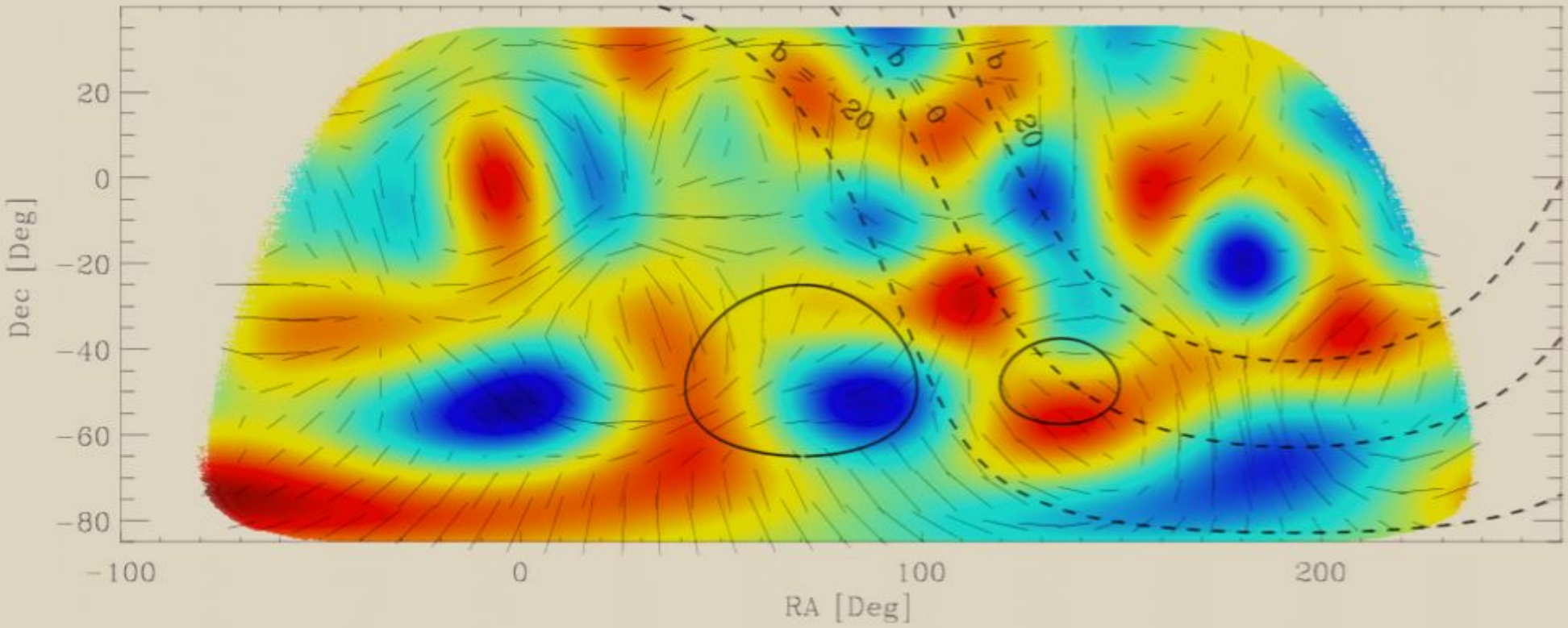

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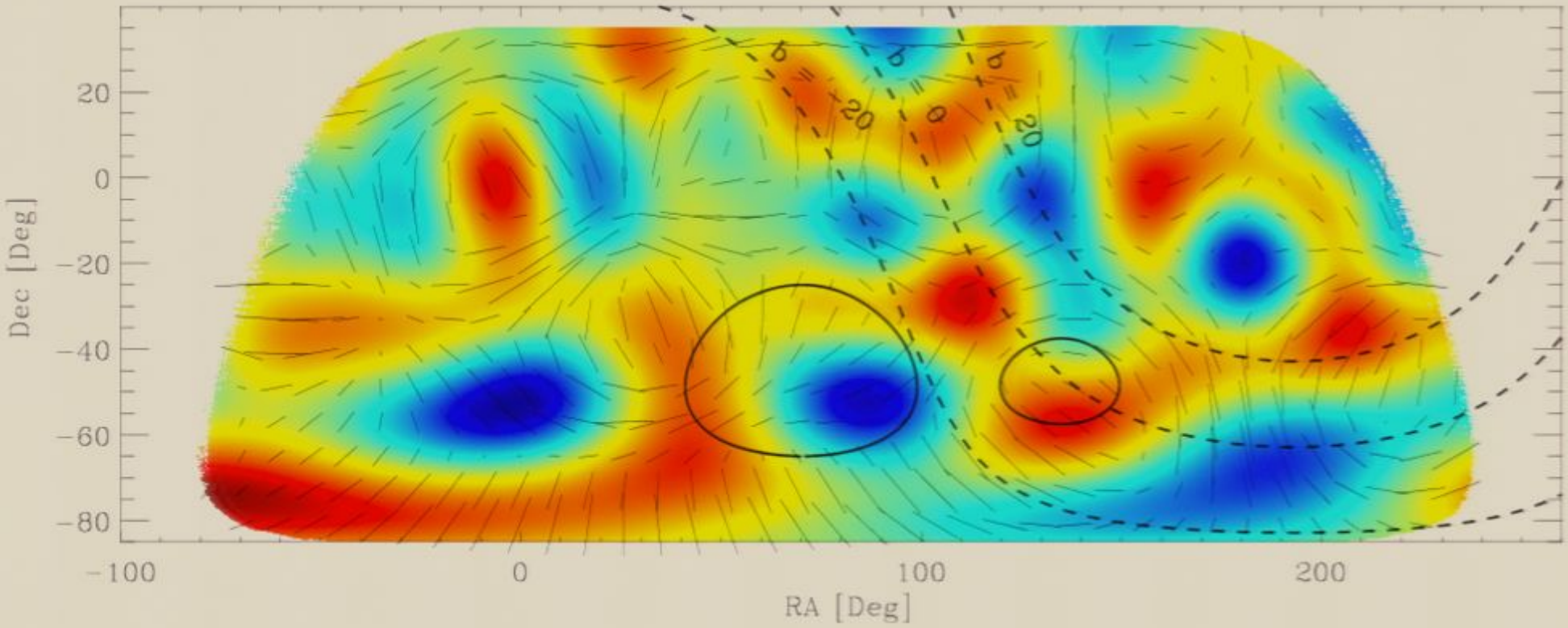

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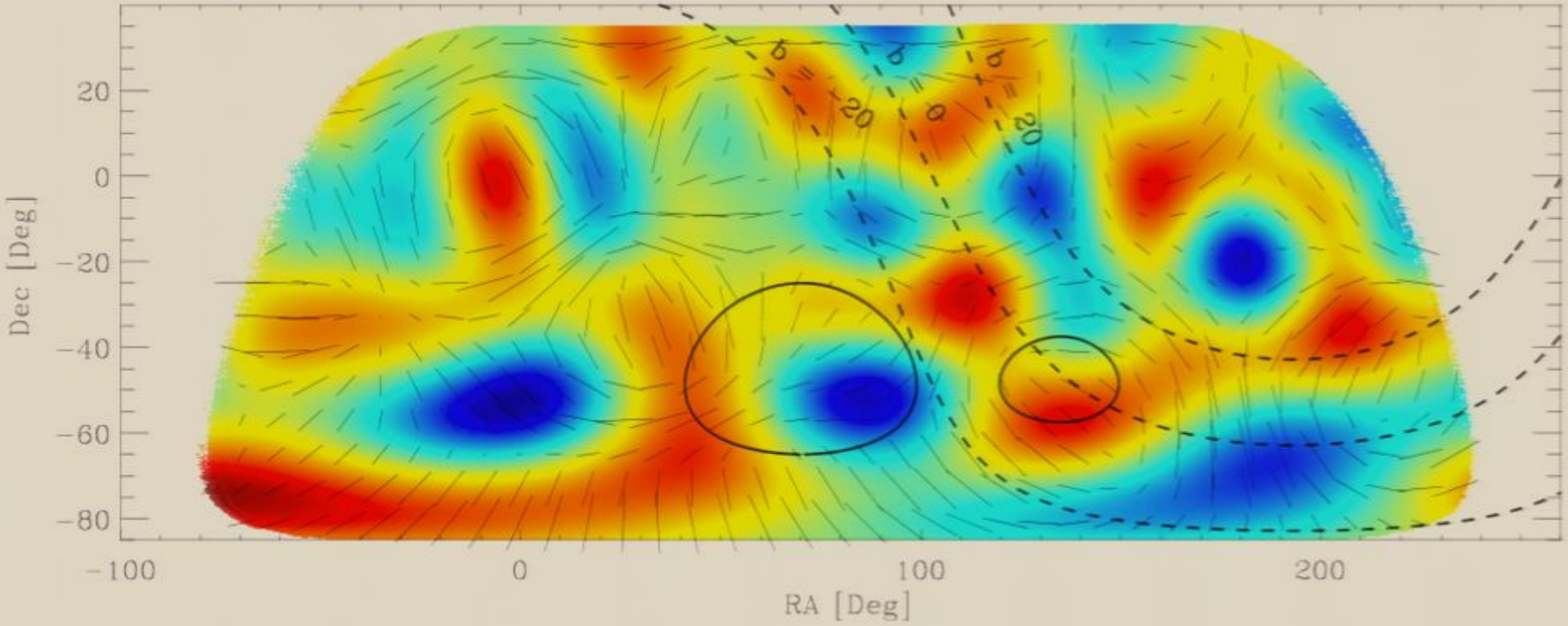

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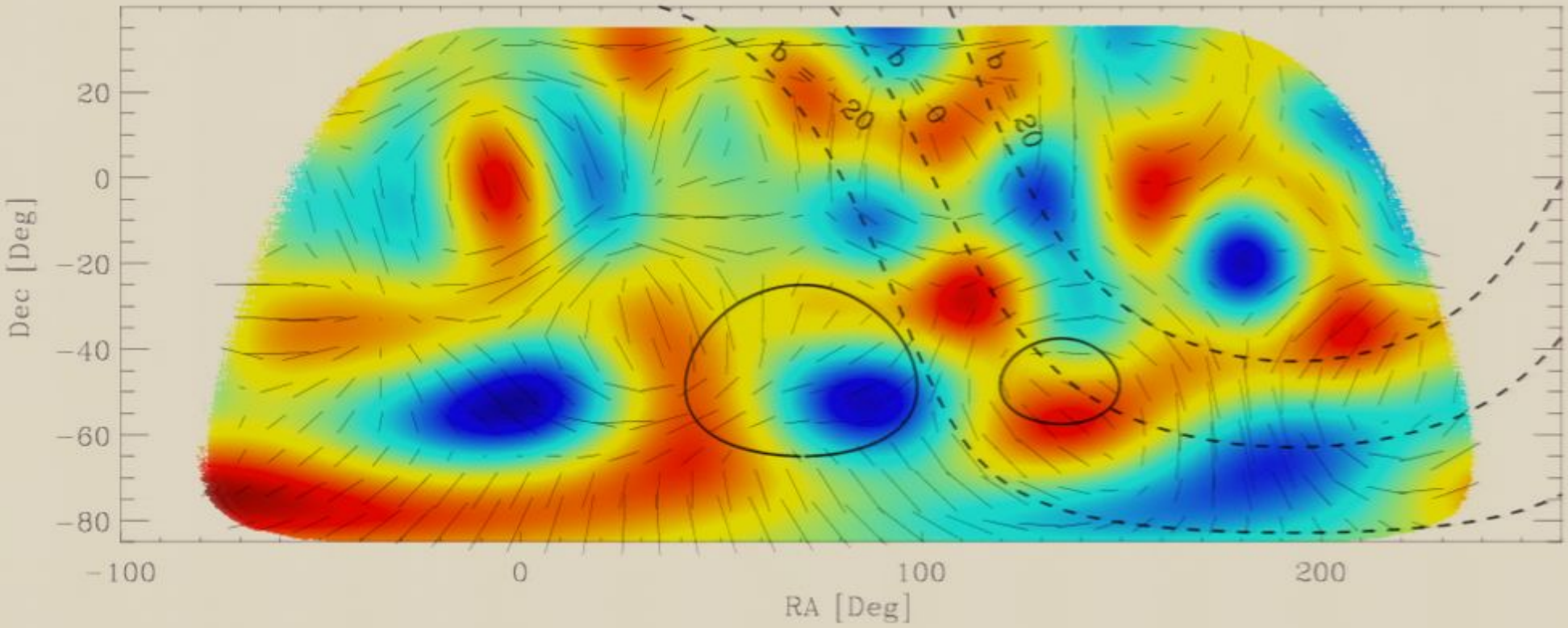

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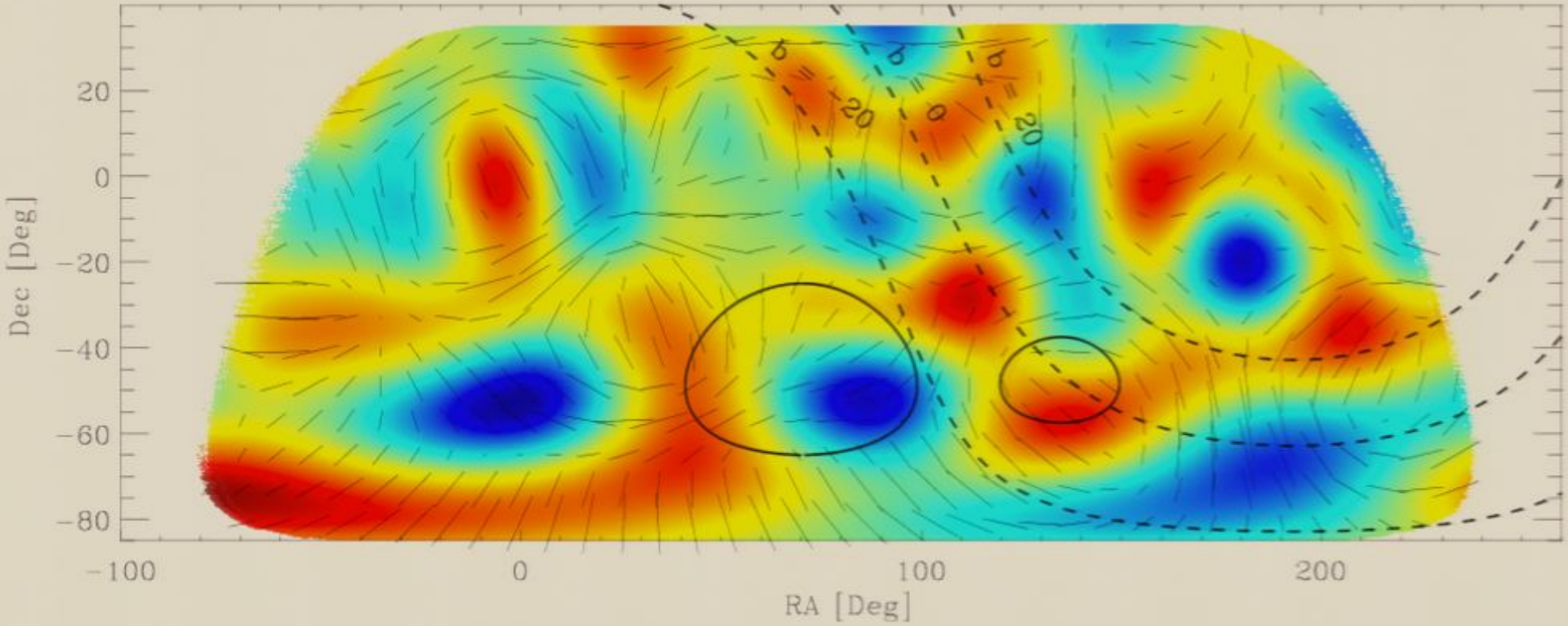
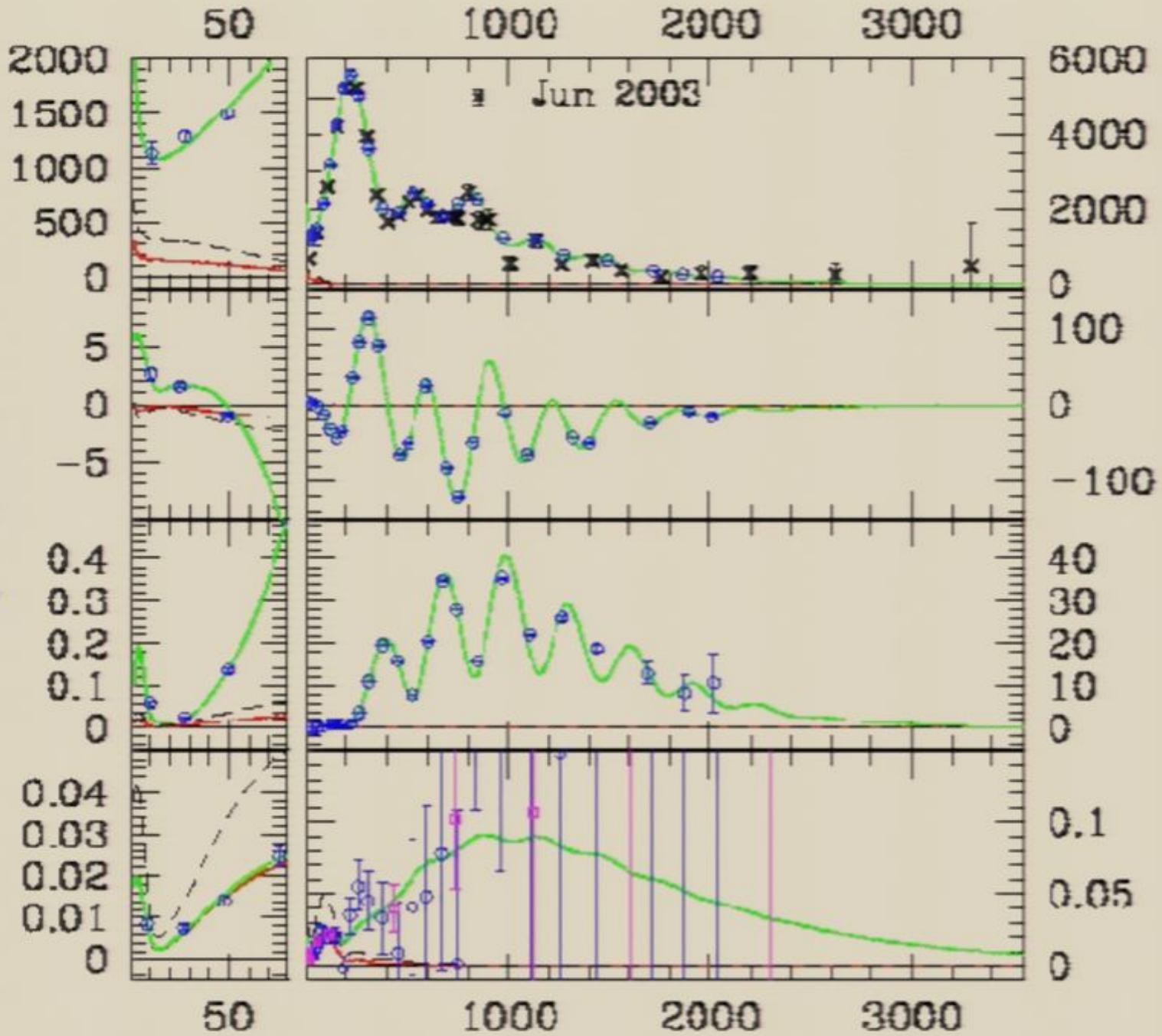


http://www.astro.caltech.edu/~lgg/spider_front.htm



forecast

Planck2.5

100&143

Spider10d

95&150

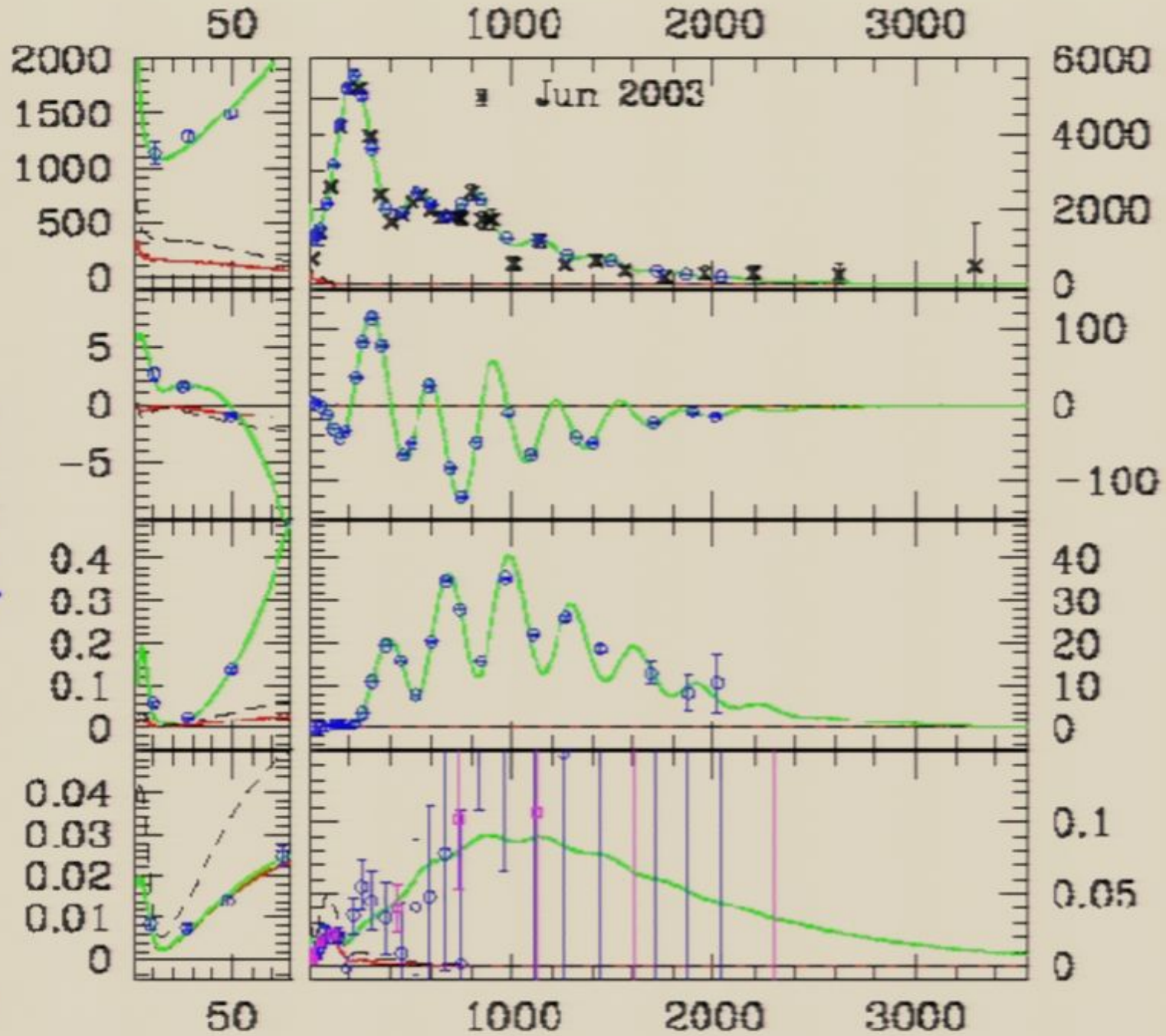
Synchrotron pol'n

< .004 ??

Dust pol'n

< 0.1 ??

Template removals from multi-frequency data



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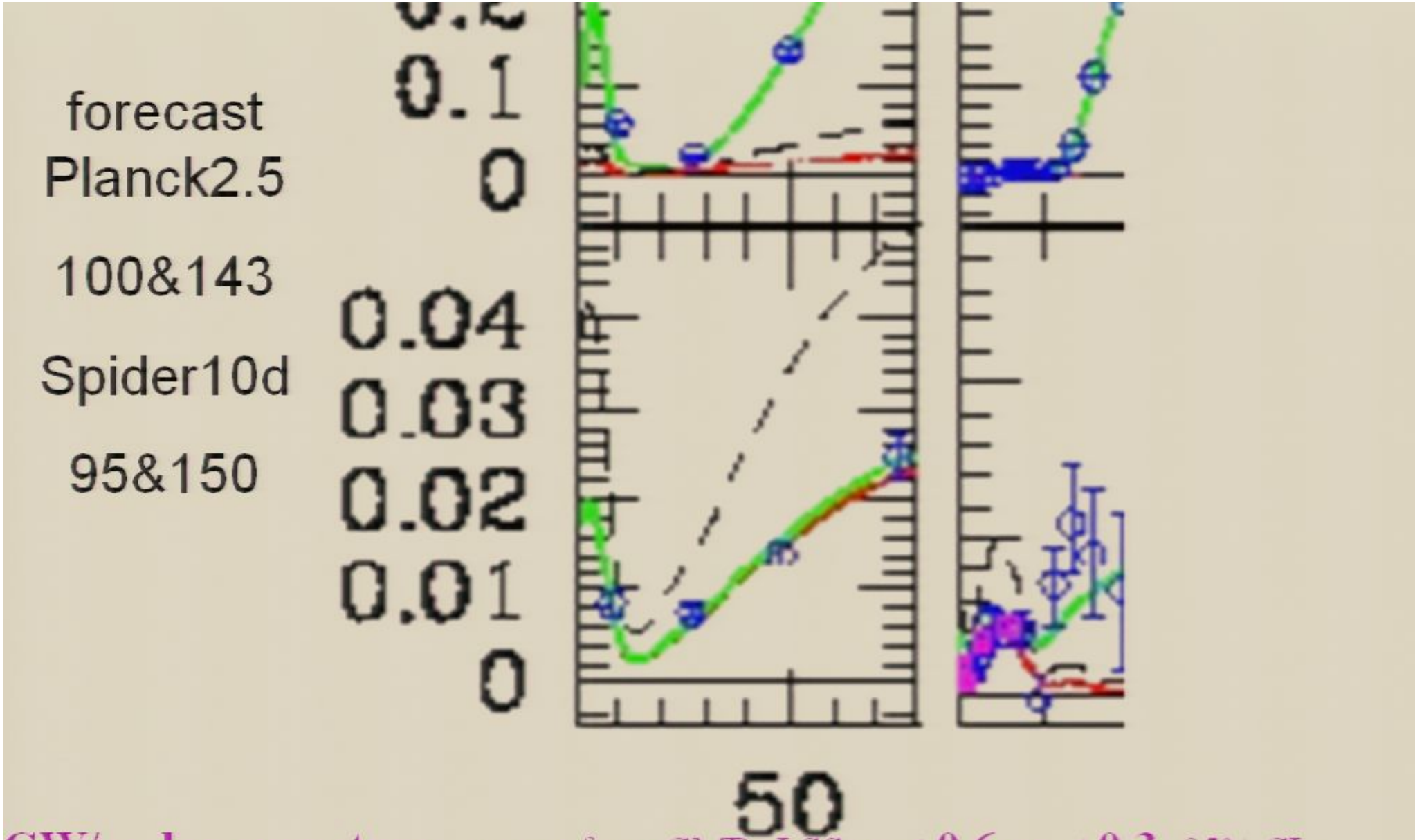


GW/scalar curvature: current from CMB+LSS: r < **0.6** or < **0.3** 95% CL; good shot at **0.02** 95% CL with **BB polarization** (+- .**02 PL2.5+Spider**)

BUT fgnds/systematics??

tensor (gravity wave) power to curvature power, r, a direct measure of ϵ = (q+1), q=deceleration parameter during inflation

q (ln Ha) may be highly complex (scanning inflation trajectories)

many inflaton potentials give the same curvature power spectrum, but the degeneracy is broken if gravity waves are measured

(**q+1**) =~ 0 is possible - low energy scale inflation – upper limit only

Very very difficult to get at this with direct gravity wave detectors – even in our dreams

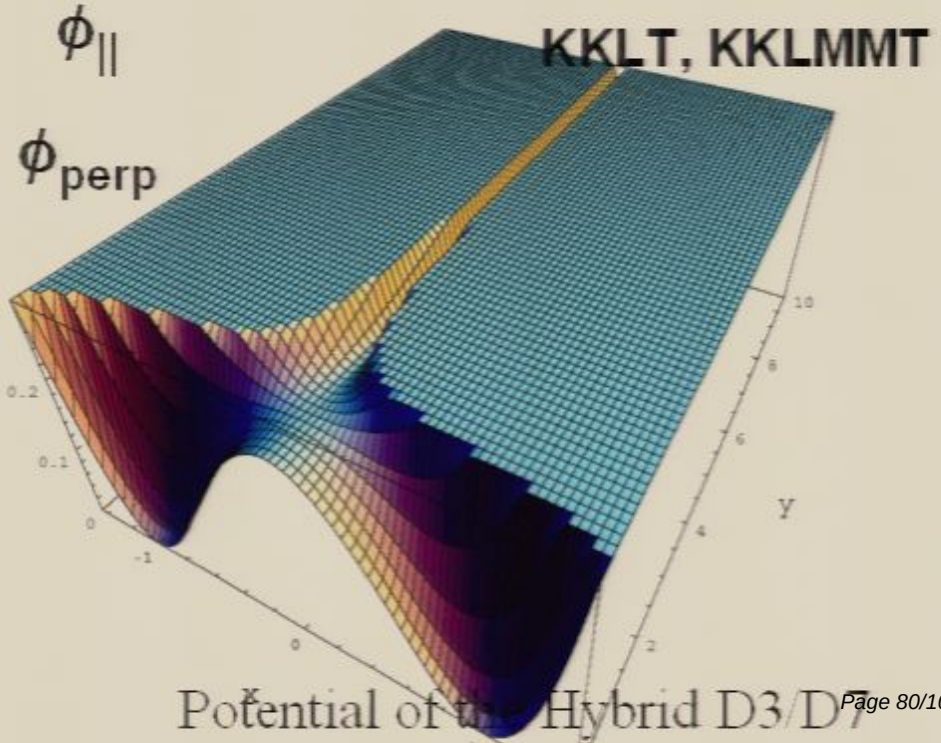
Response of the CMB photons to the gravitational wave background leads to a unique signature within the CMB at large angular scales of these GW and at a detectable level. Detecting these B-modes is the new "holy grail" of CMB science.

Inflation prior: on ϵ only 0 to 1 restriction, < 0 supercritical possible

GW/scalar curvature: current from CMB+LSS: r < **0.7** or < **0.36** 95% CL: good shot at **0.02** 95% CL with **BB polarization** (+- **.02 PL2.5+Spider**), **.01 target**

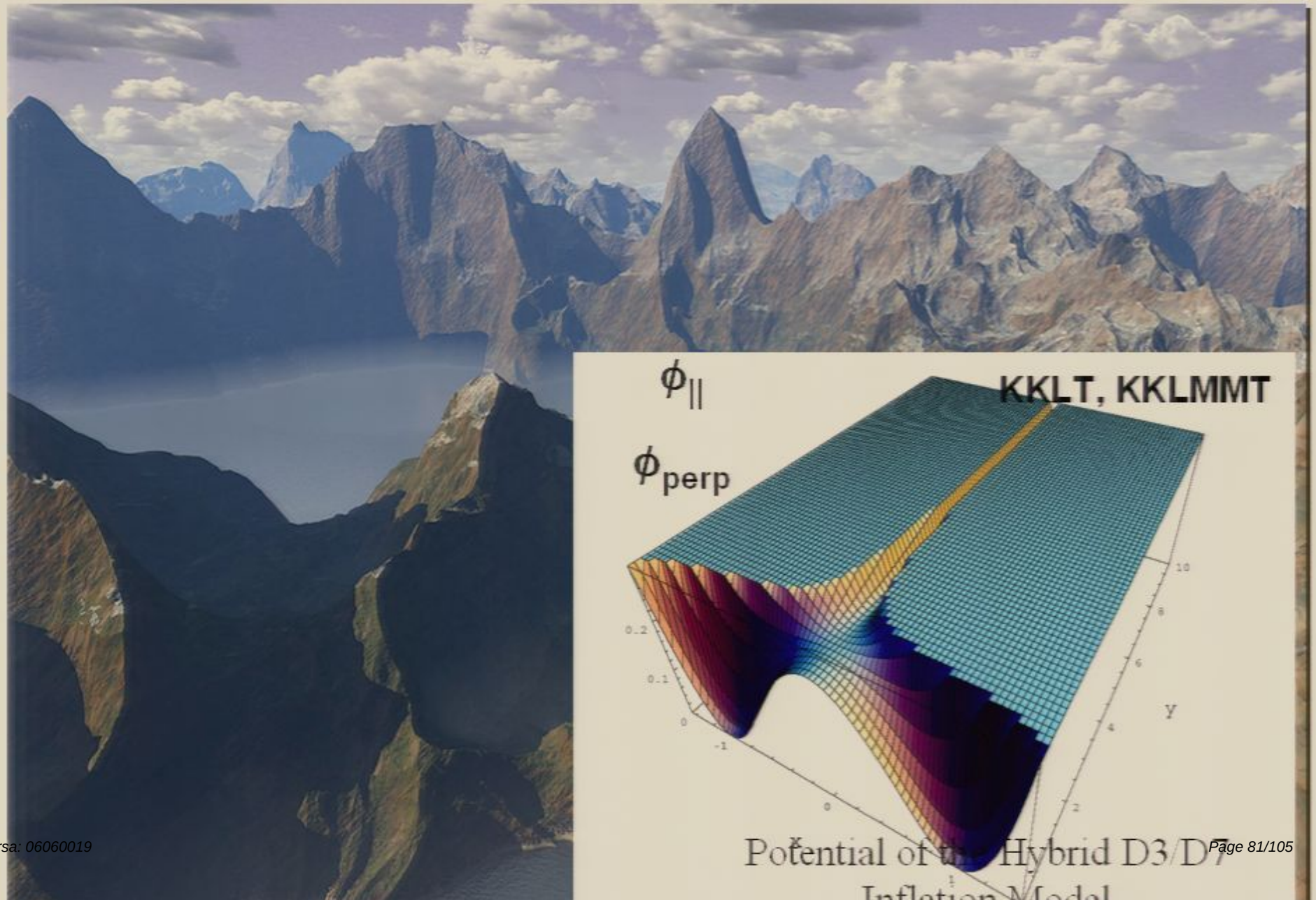
BUT fgnds/systematics?? But **r spectrum. But low energy inflation**

String Theory Landscape & Inflation++ Phenomenology for CMB+LSS



Potential of the Hybrid D3/D7 Inflation Model

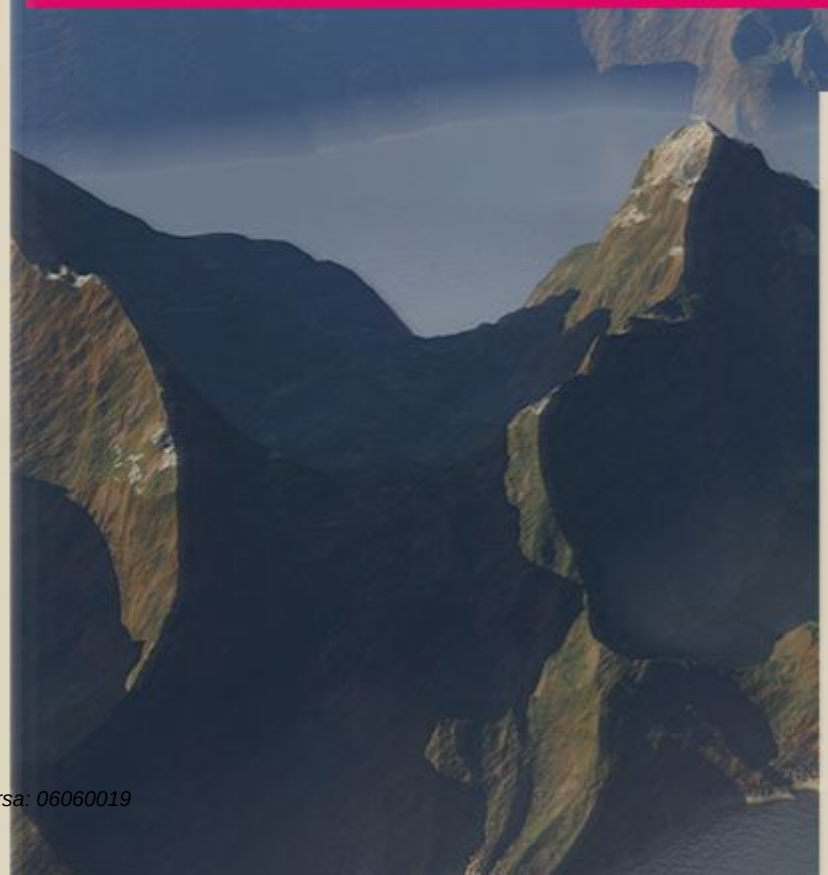
String Theory Landscape & Inflation++ Phenomenology for CMB+LSS

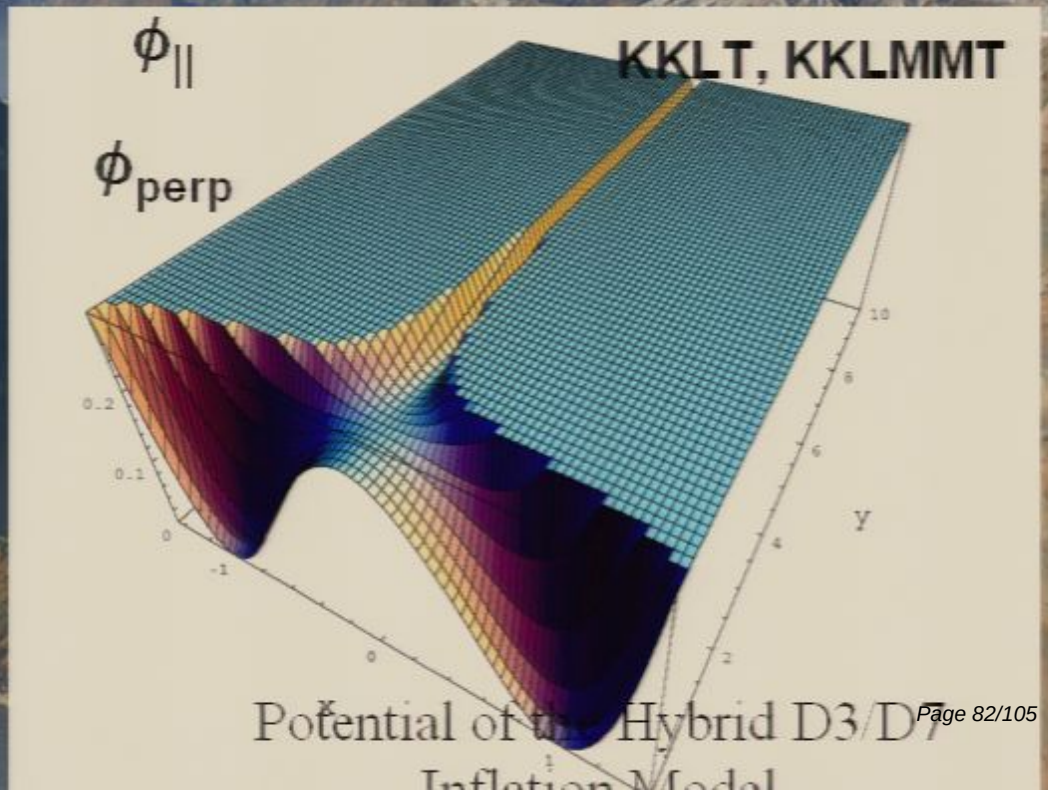


String Theory Landscape & Inflation++ Phenomenology for CMB+LSS

running index as simplest breaking, radically broken scale invariance, 2+-field inflation, isocurvatures, Cosmic strings/defects, compactification & topology, & other baroque add-ons. subdominant

String/Mtheory-motivated, extra dimensions, brane-ology, reflowering of inflaton/isocon models (includes curvaton), modified kinetic energies, k-essence, Dirac-Born-Infeld [sqrt(1-momentum**2), "DBI in the Sky" Silverstein etal 2004], etc.





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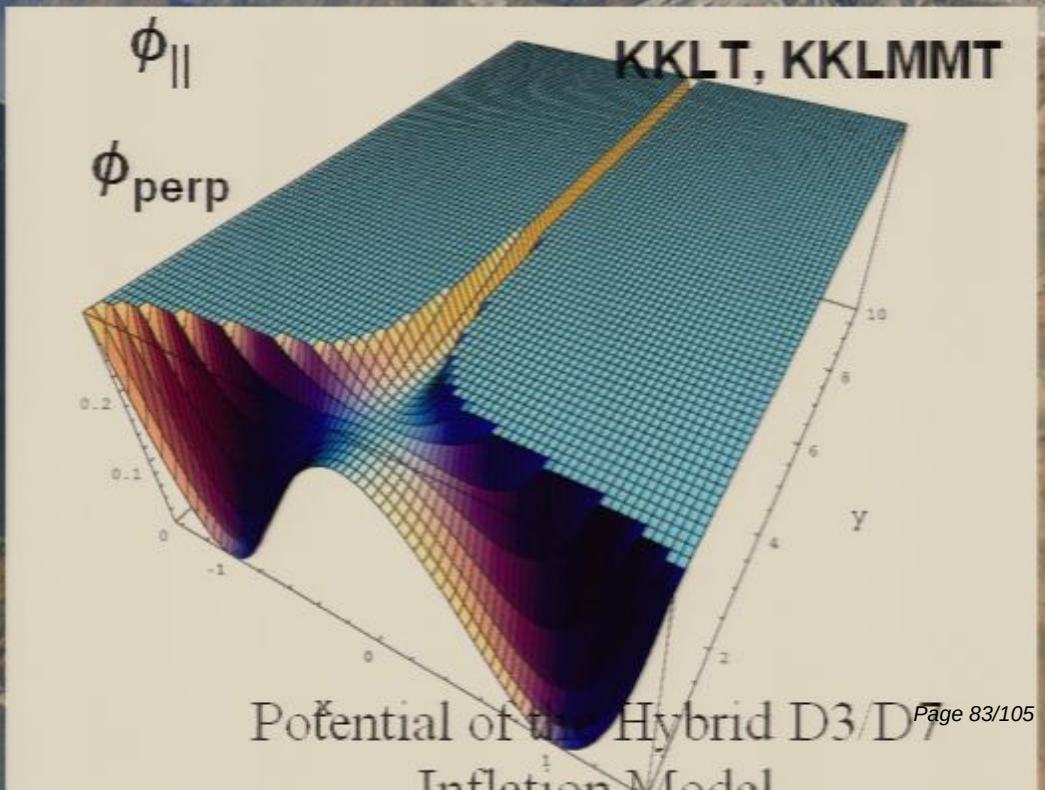

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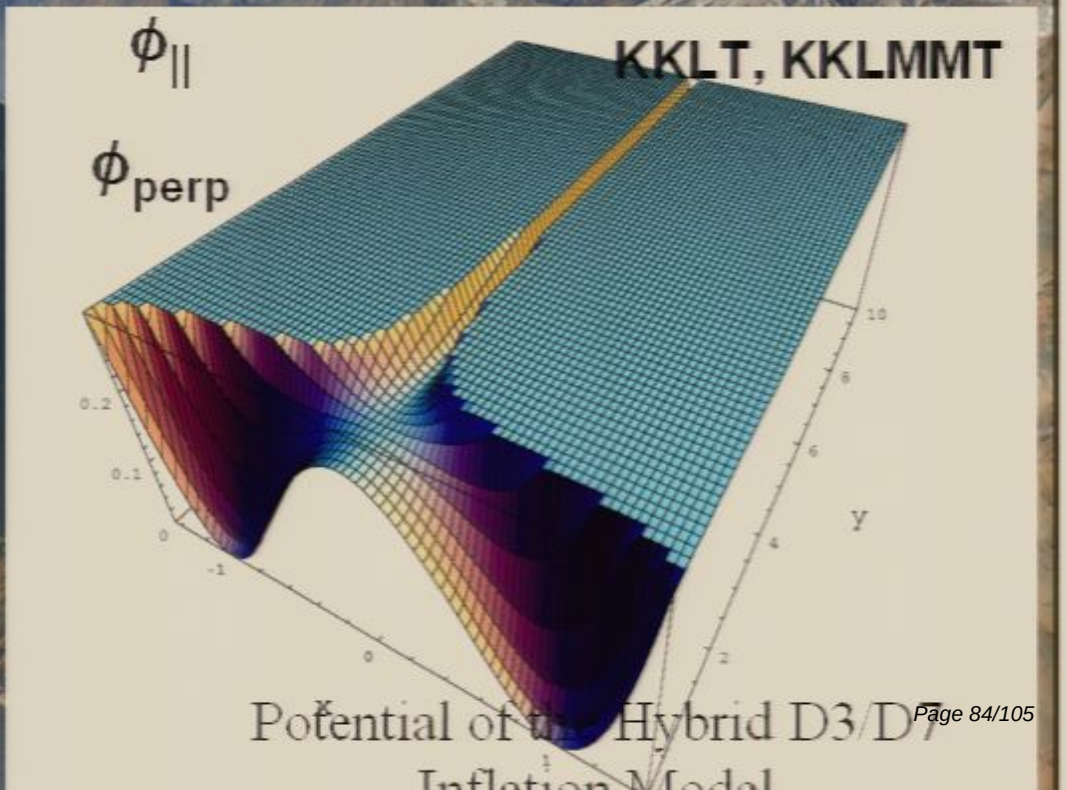
14 std inflation parameters + many many more e.g. "blind" search for patterns in the primordial power spectrum



Potential of the Hybrid D3/D7 Inflation Model

String Theory Landscape & Inflation++ Phenomenology for CMB+LSS

running index as simplest breaking, radically broken scale invariance, 2+-field inflation, isocurvatures, Cosmic strings/defects, compactification & topology, & other baroque add-ons. subdominant

String/Mtheory-motivated, extra dimensions, brane-ology, reflowering of inflaton/isocon models (includes curvaton), modified kinetic energies, k-essence, Dirac-Born-Infeld [sqrt(1-momentum**2), "DBI in the Sky" Silverstein etal 2004], etc.

14 std inflation parameters + many many more e.g. "blind" search for patterns in the primordial power spectrum

any acceleration trajectory will do??

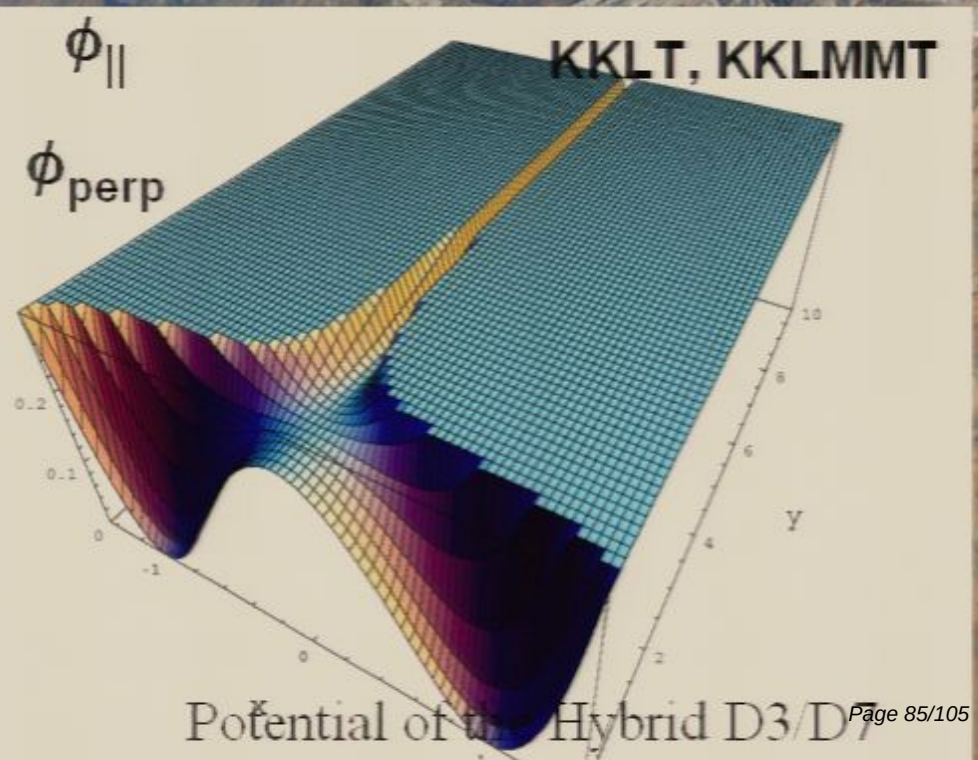
q (ln Ha)

H(ln a,...)

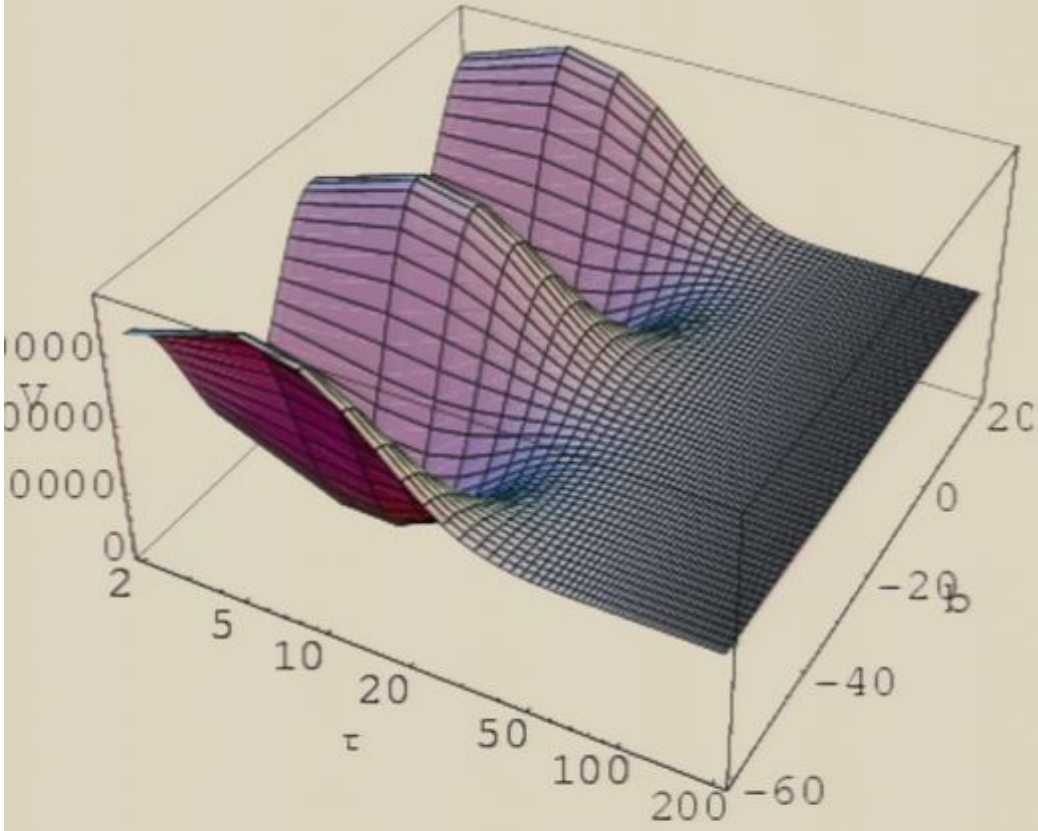
V(phi,...)

Measure??

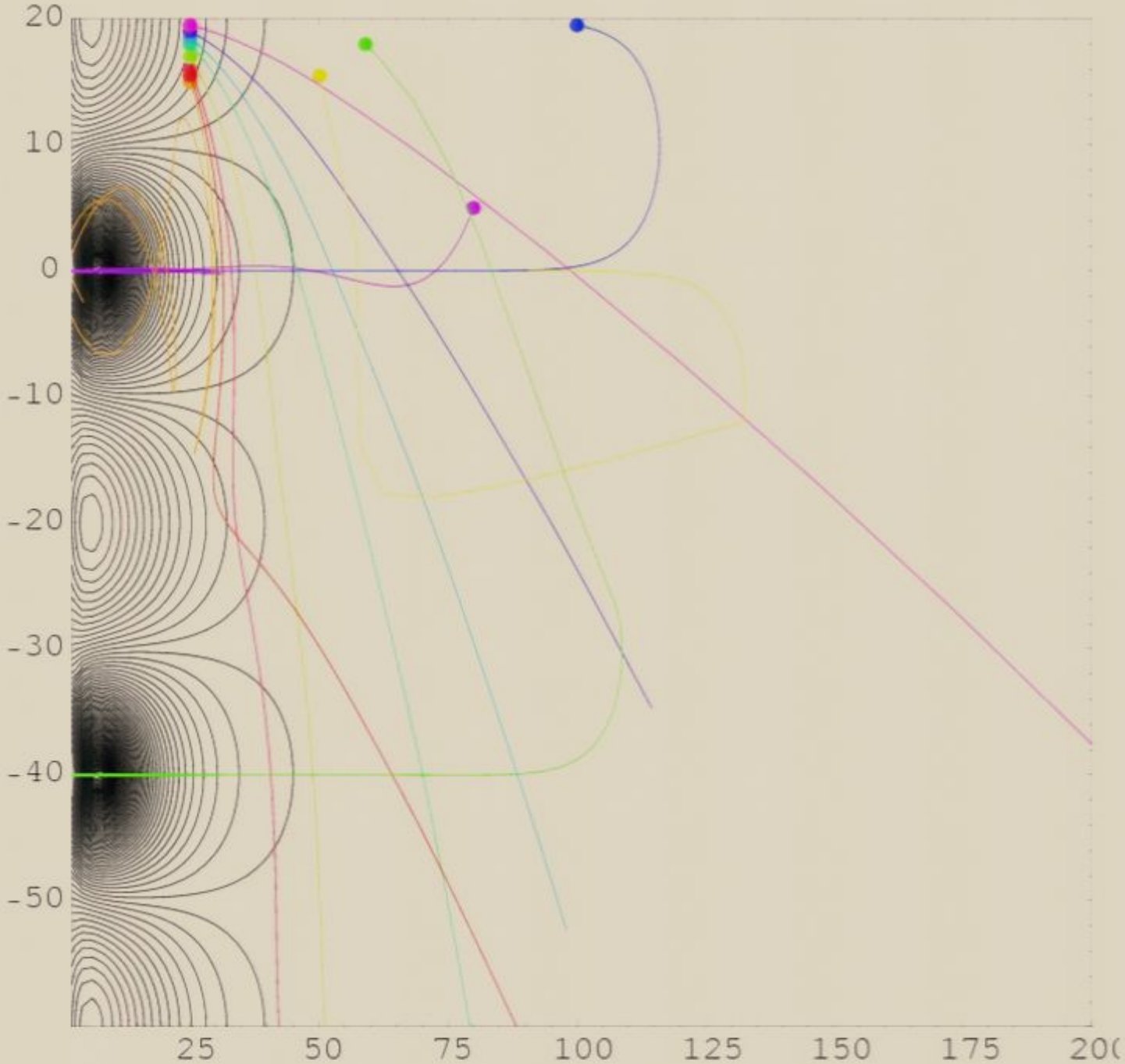
anti-baroque prior



Kahler/axion moduli Inflation
Conton & Quevedo hep-th/0509012



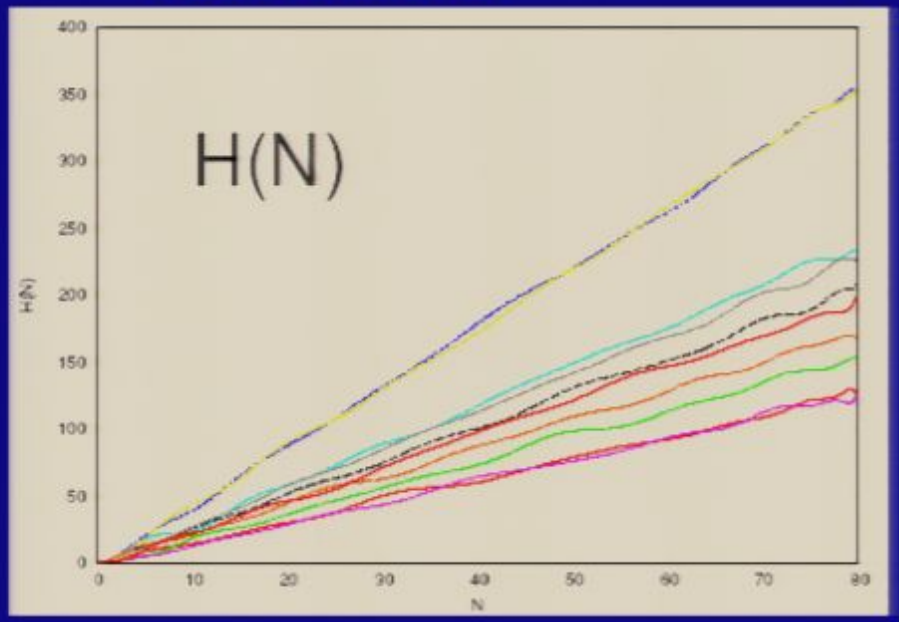
$$W = W_0 + Ae^{-aT}$$
$$K = -2\log(V + \xi/2)$$
$$T = \tau + ib$$

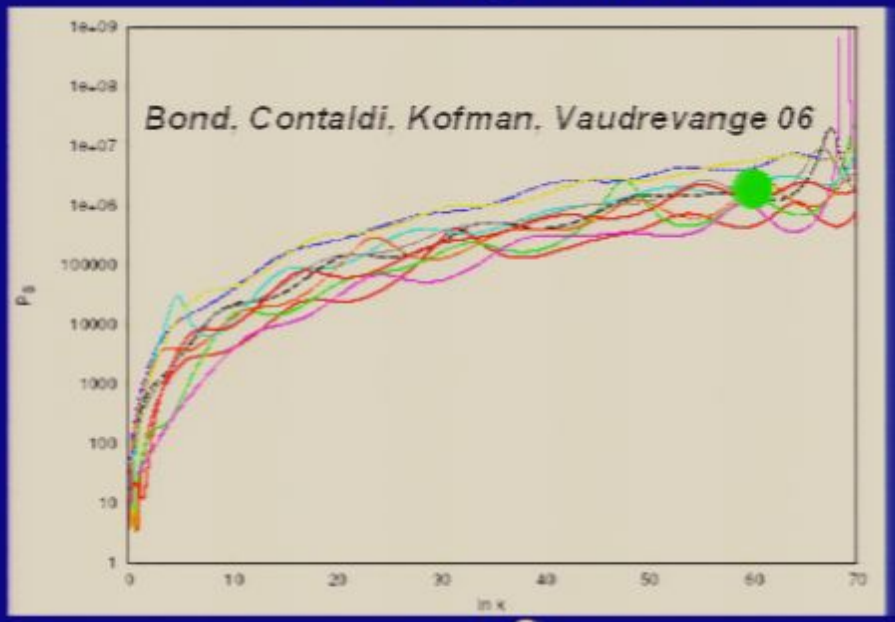

20
10
0
-10
-20
-30
-40
-50
25
50
75
100
125
150
175
200

The Eye Of The Needle

reconstruction ⟵

Acceleration | **Powerspectrum**





trajectory $H(N)$ ⟶ map ⟶ $P_S = \frac{H^2}{\epsilon}$

(natural object from Hamilton-Jacobi formalism)

(mildly broken scale invariance)

$N=-\ln(a/a_e)$, $k \sim Ha$, $\epsilon = (1+q)$, $\epsilon = d\ln H/dN$, $P_S \sim H^2/\epsilon$, $P_t \sim H^2$

$V(\phi) \sim M_{Pl}^2 H^2 (1-\epsilon/3)$, $\phi_{||}$ = inflaton collective coordinate, $d\phi_{||} \sim +\text{-} \sqrt{\epsilon}\, dN$

Beyond P(k): Inflationary trajectories

dynamical trajectory

$$u(\mathcal{T}) = \sum \phi_{\mathcal{T}\beta} q_\beta + r(\mathcal{T})$$

The mode amplitudes q_β are generalized bandpowers and the mode functions $\phi_{\mathcal{T}\beta}$ are generalized splines or

β as pairs (XP)

- Economic way to scan the space of observables
- Increasing the order of Chebyshev expansion → opening up the space of observables
- Huge degeneracy of $V(\phi)$ without data for tensor modes

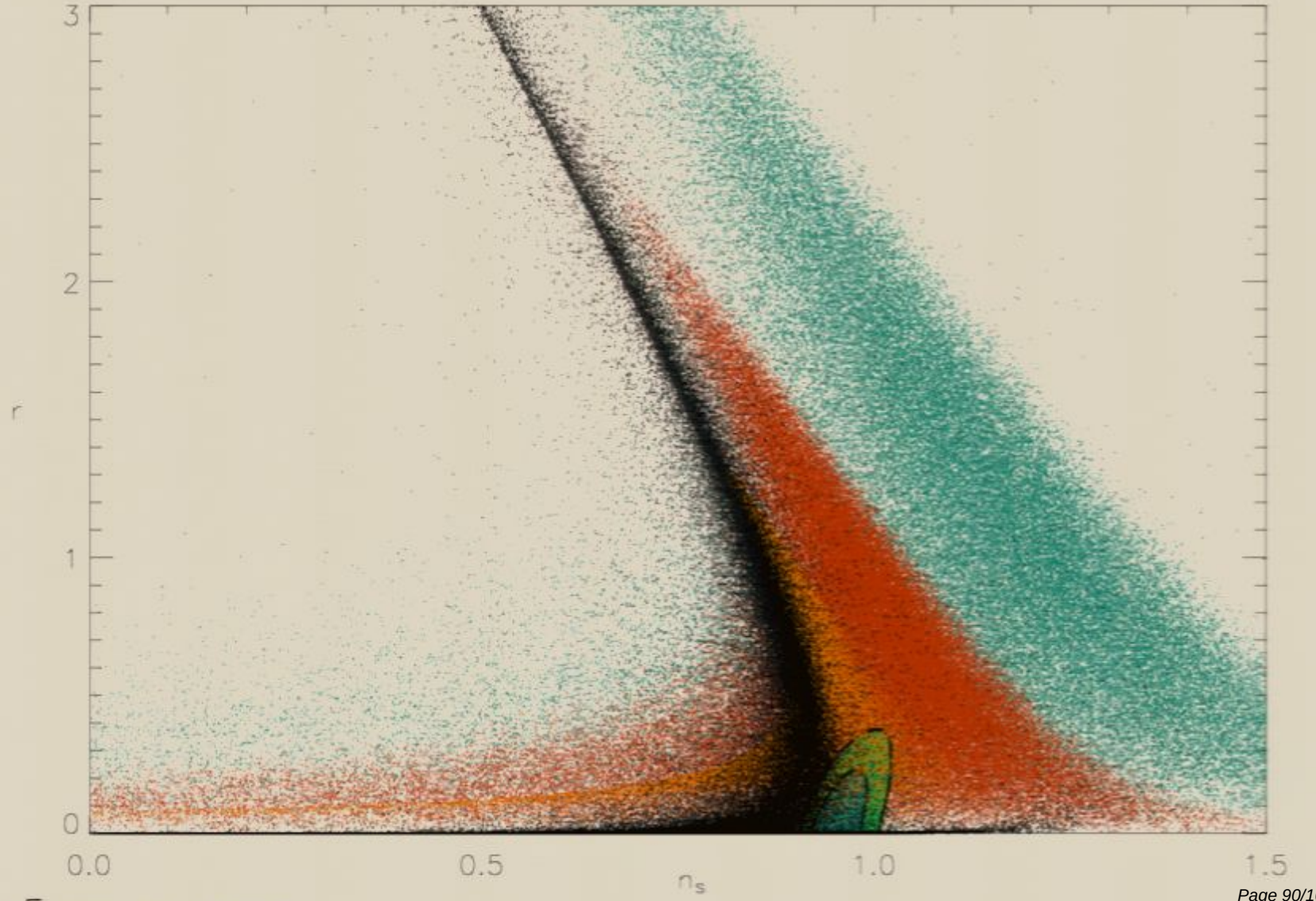
$H(\ln Ha)$

HJ + expand about uniform acceleration, 1+q, V and power spectra are derived

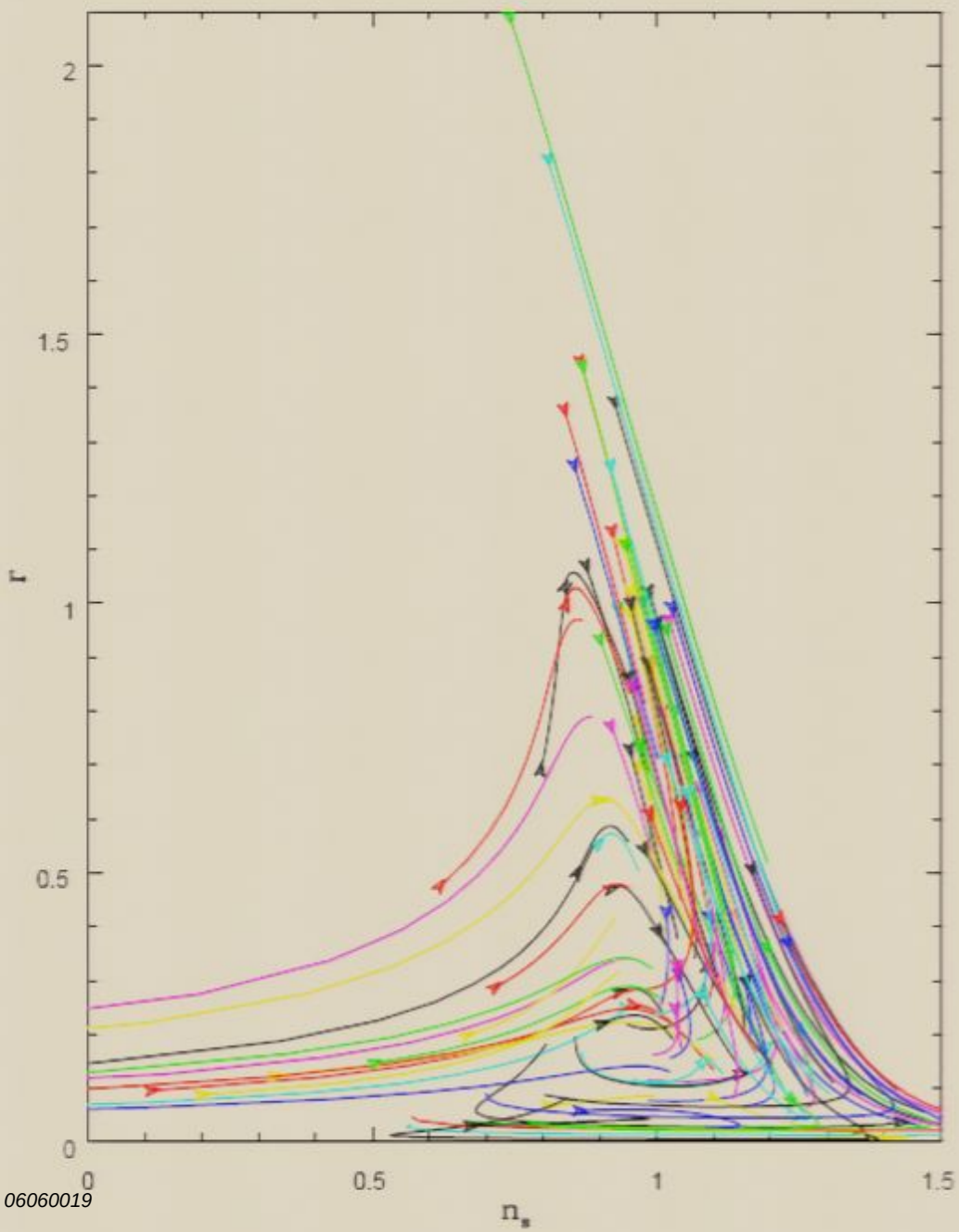
$$y_1 = \mathcal{P}_s/\mathcal{P}_s^{(s)} \quad y_2 = \mathcal{P}_t/\mathcal{P}_t^{(s)} \quad \ln k$$

Trajectories cf. WMAP1+B03+CBI+DASI+VSA+Acbar+Maxima + SDSS + 2dF

Chebyshev 7 & 10 H(N) and RG Flow



speed 10^5 up vs RGF



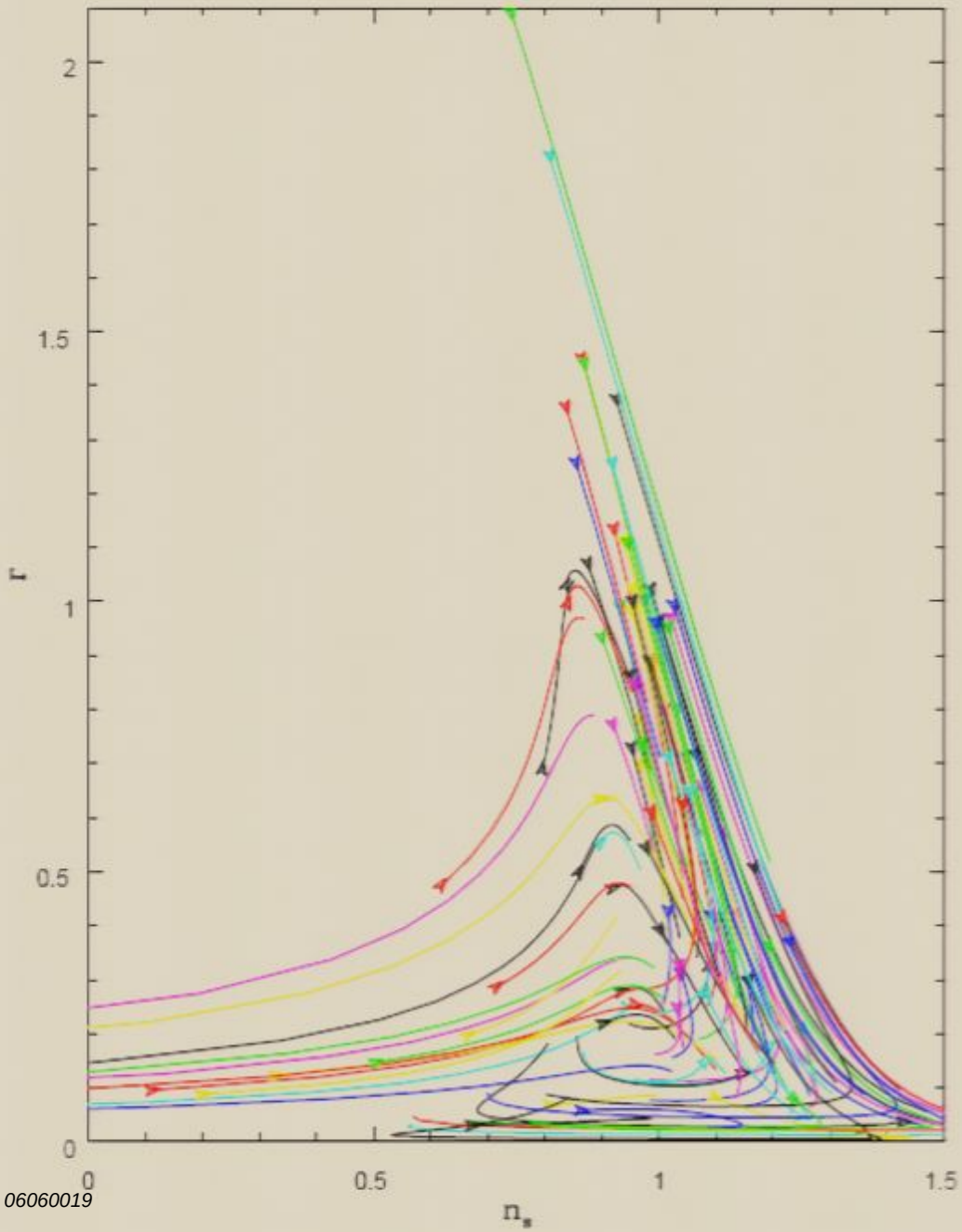
$$\epsilon, \eta \ldots$$

$$H(N) \longrightarrow P(k)$$

$$n_s, n_t, r, dn/d\ln k, A_s, \ldots$$

r(ln a)/16

= $-n_t/2$ /(1-n_t/2) + small



$\epsilon, \eta \ldots$

$H(N) \longrightarrow P(k)$

$n_s, n_t, r \ldots n_\ldots / \ln k, A_s, \ldots$

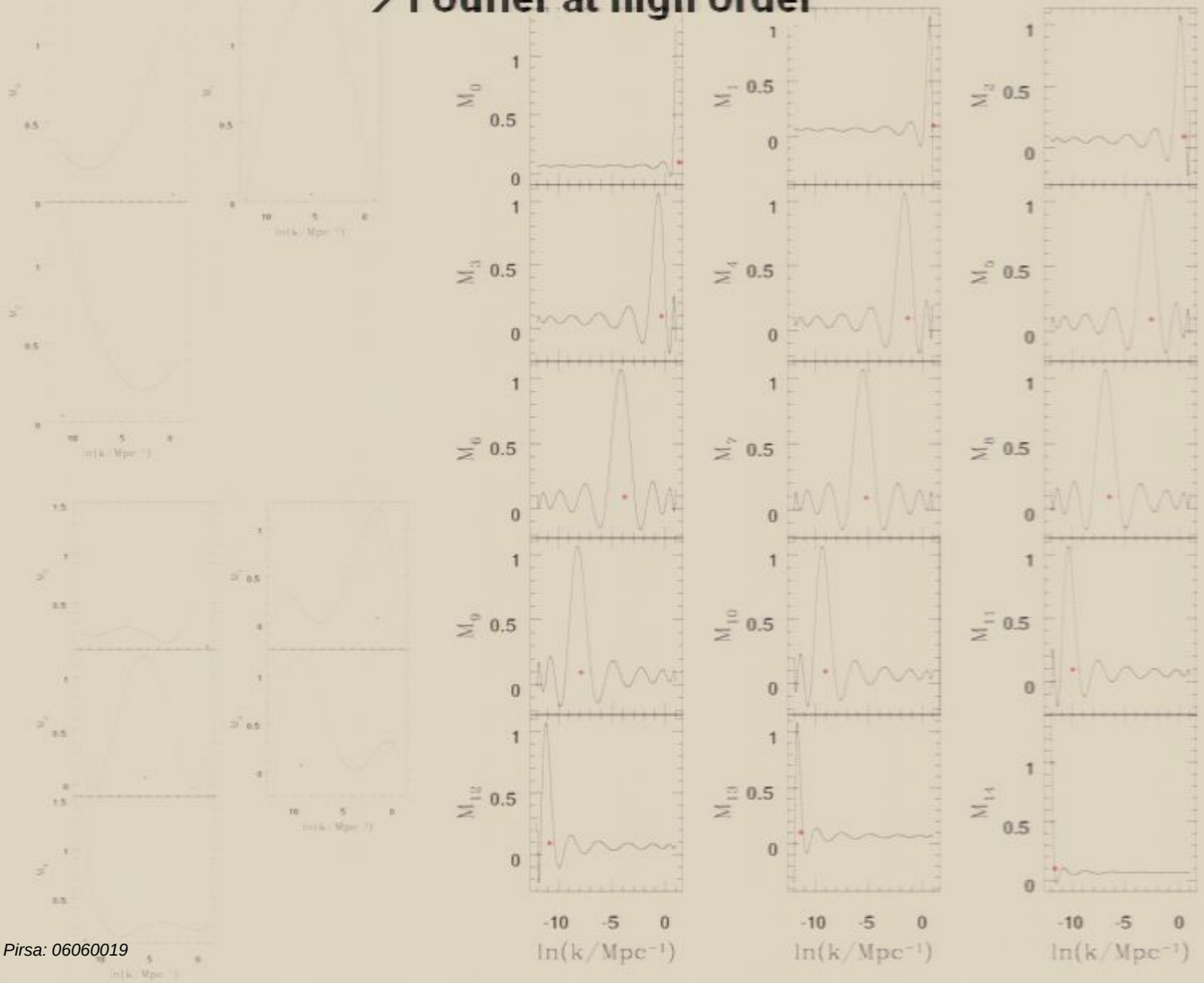
r(ln a)/16

= $-n_t/2$ /(1-n_t/2) + small

Chebyshev nodal modes (order 3, 5, 15)

Chebyshev modes are linear combinations

→ Fourier at high order



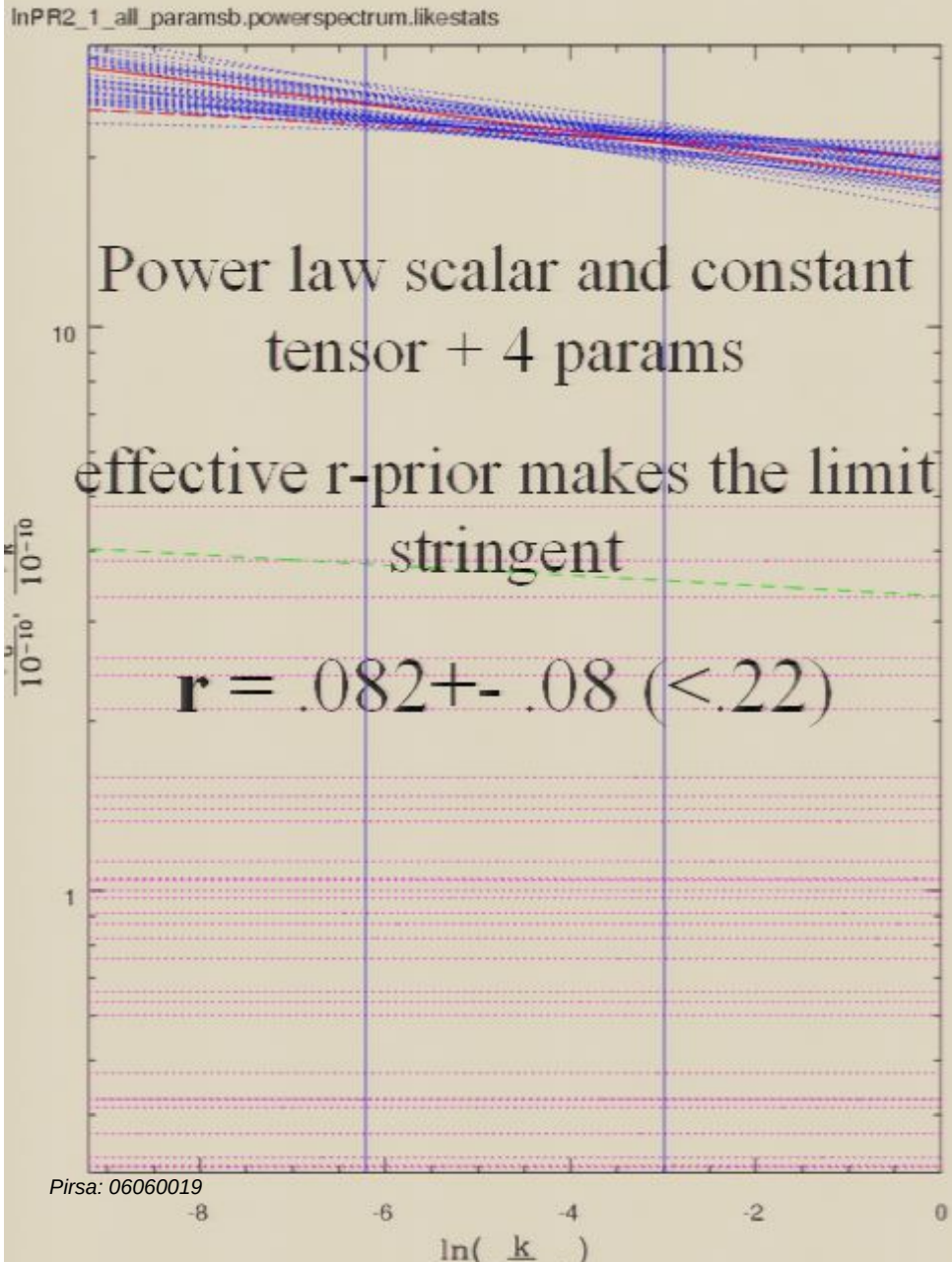
Displaying Trajectory constraints:

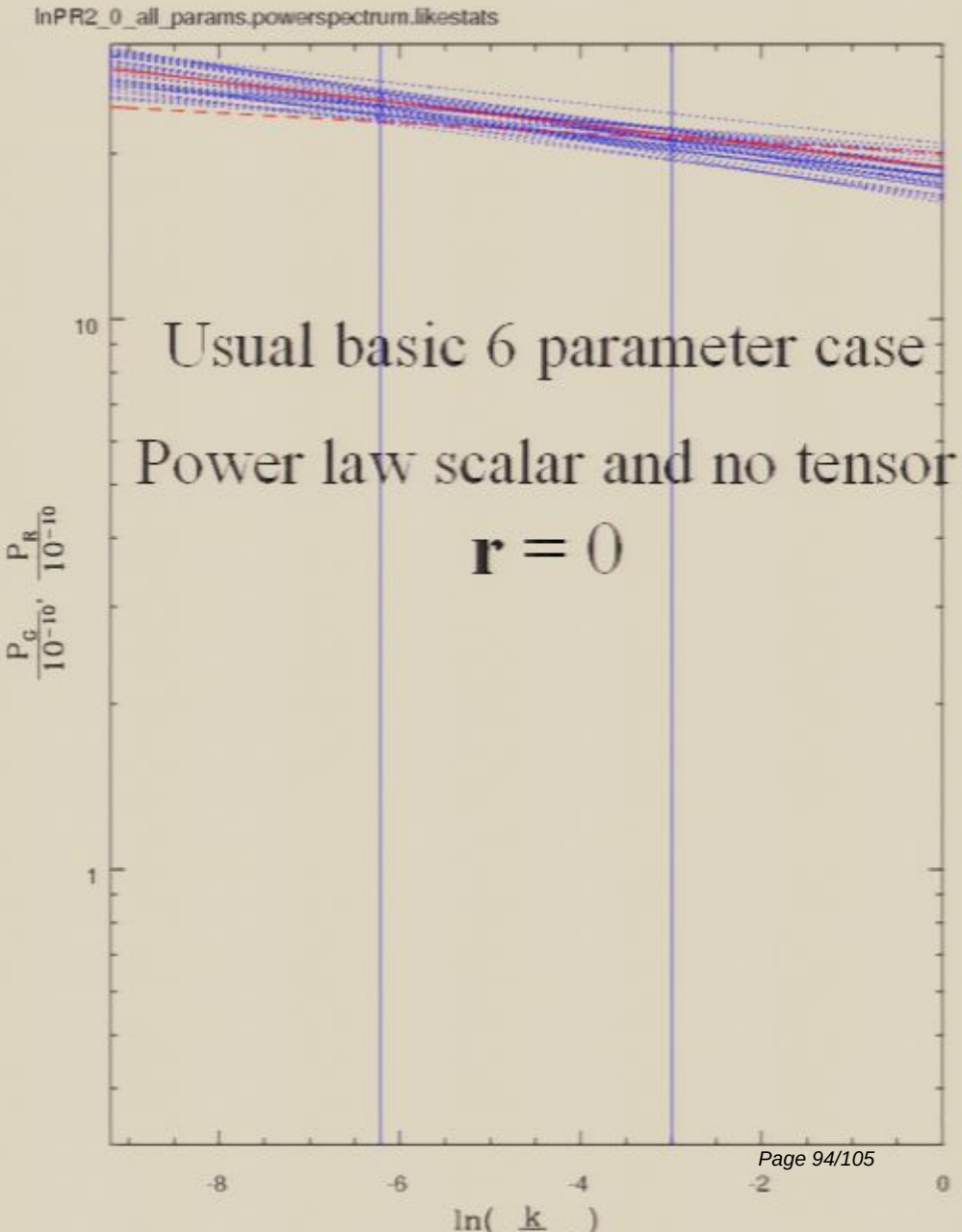
If Gaussian likelihood, compute χ^2 where **68%** probability, and follow the ordered trajectories to

$\ln L/L_m = -\chi^2/2$, displaying a uniformly sampled subset.

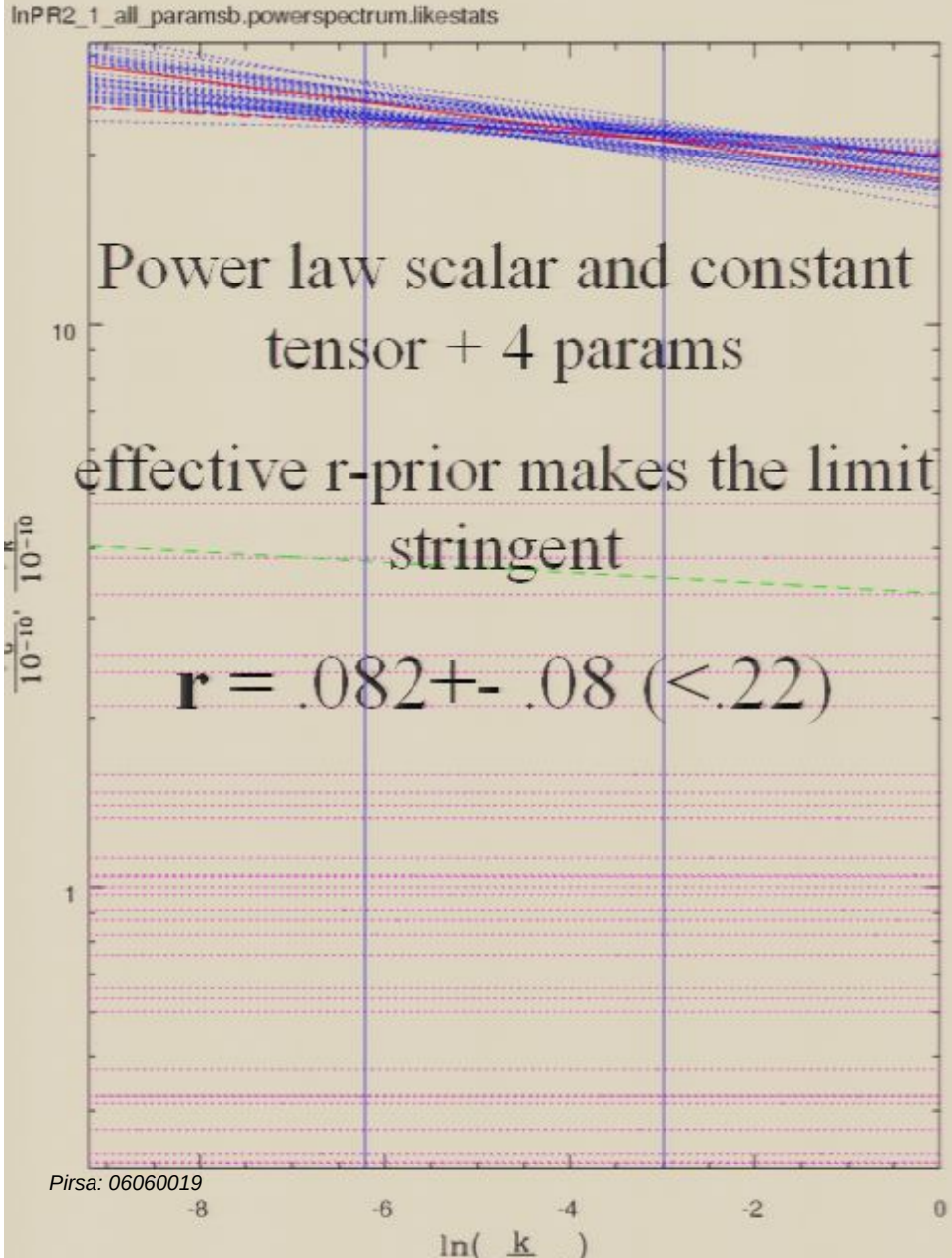
Errors at nodal points in trajectory coefficients can also be displayed.

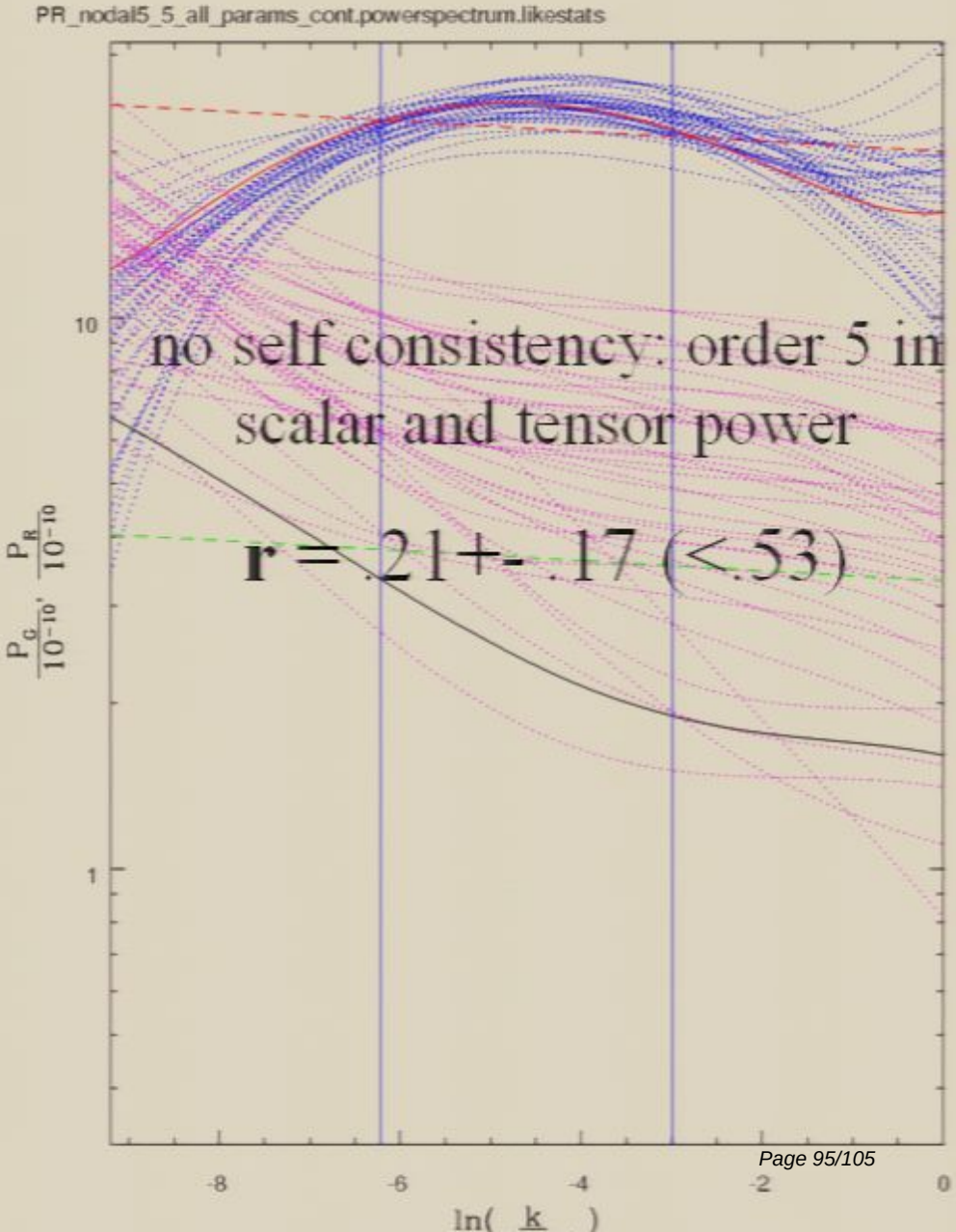
lnP_s P_t (nodal 2 and 1) + 4 params cf lnP_s (nodal 2 and 0) + 4 params reconstructed from CMB+LSS data using Chebyshev nodal point expansion & MCMC



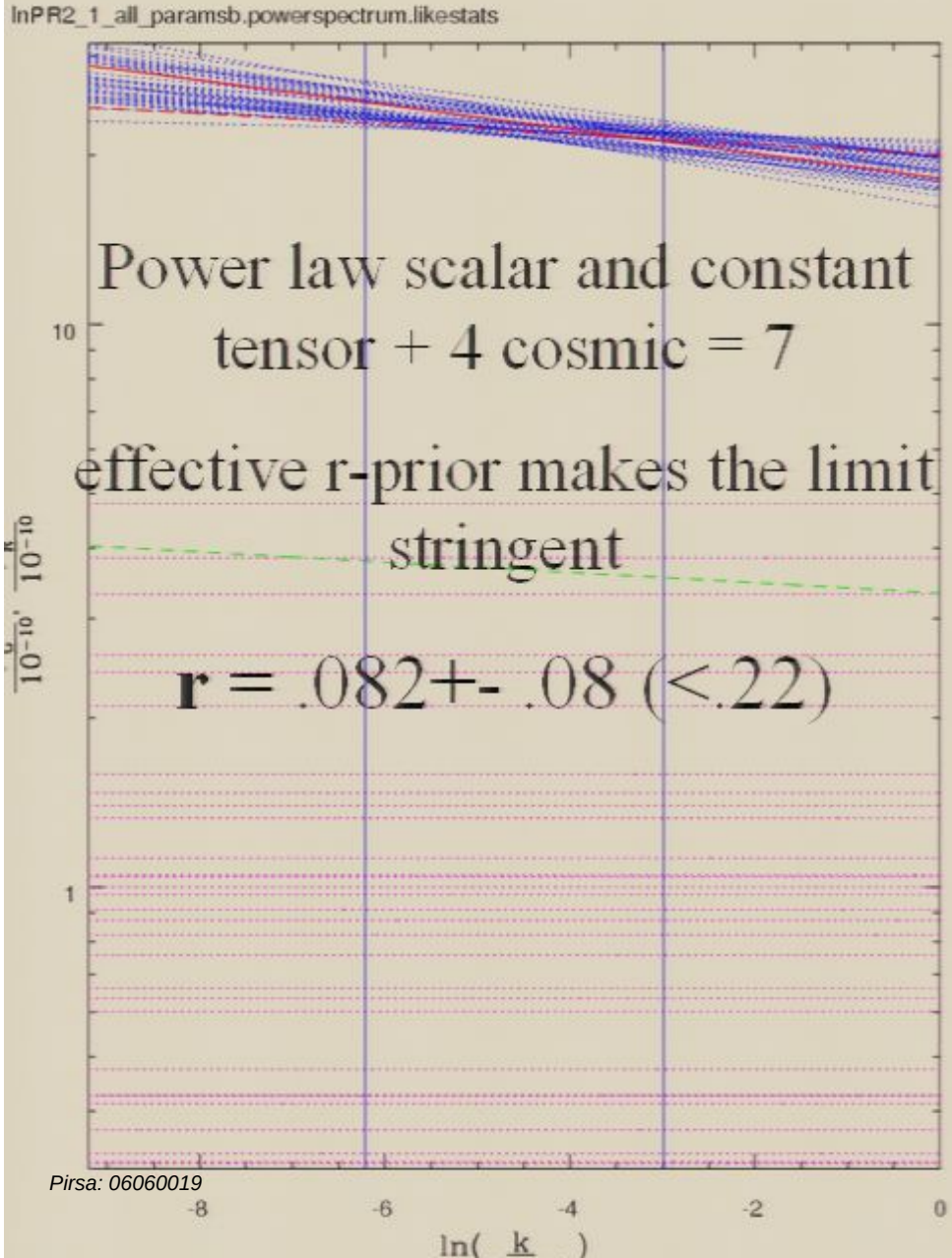


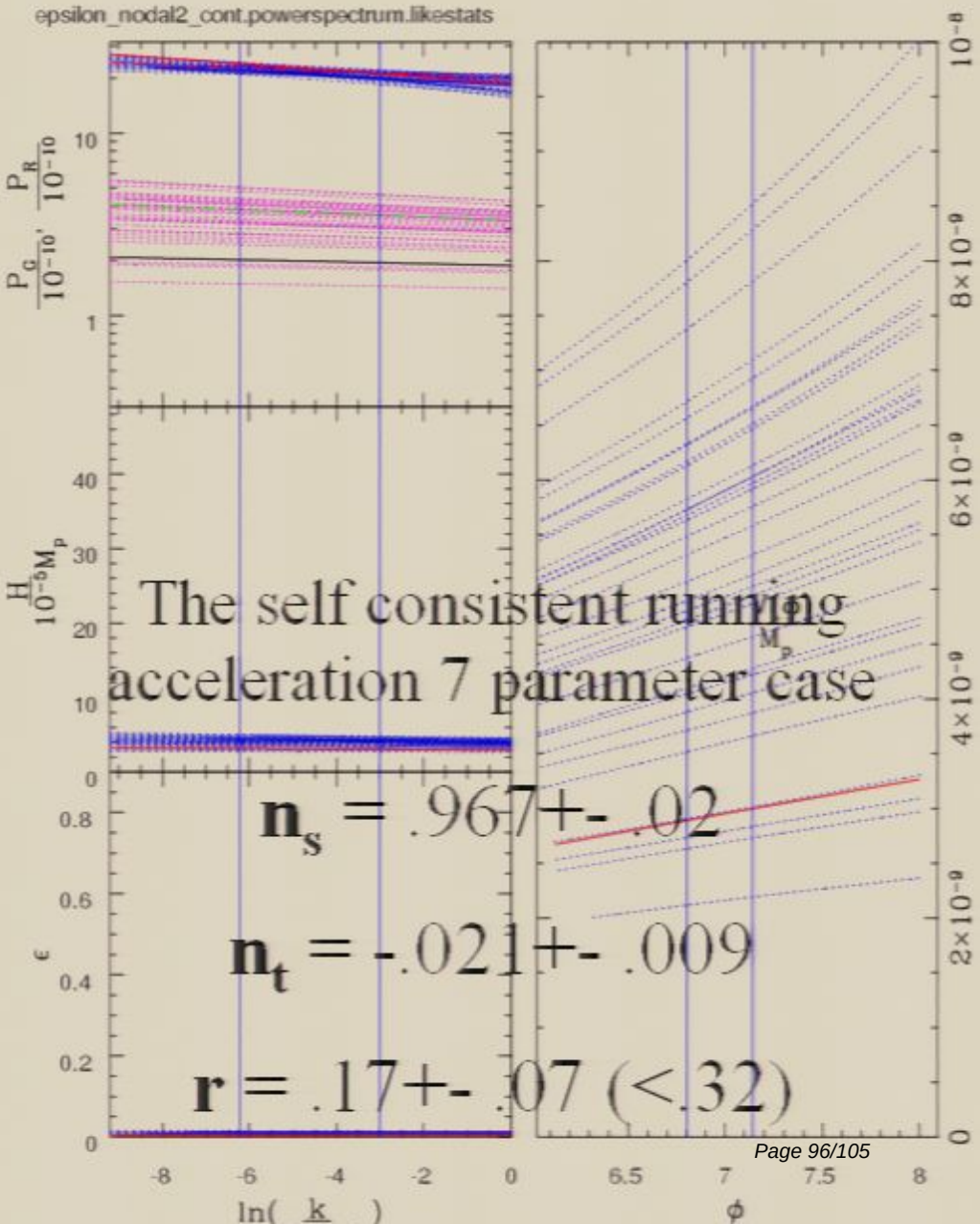
lnP_s P_t (nodal 2 and 1) + 4 params cf P_s P_t (nodal 5 and 5) + 4 params reconstructed from CMB+LSS data using Chebyshev nodal point expansion & MCMC



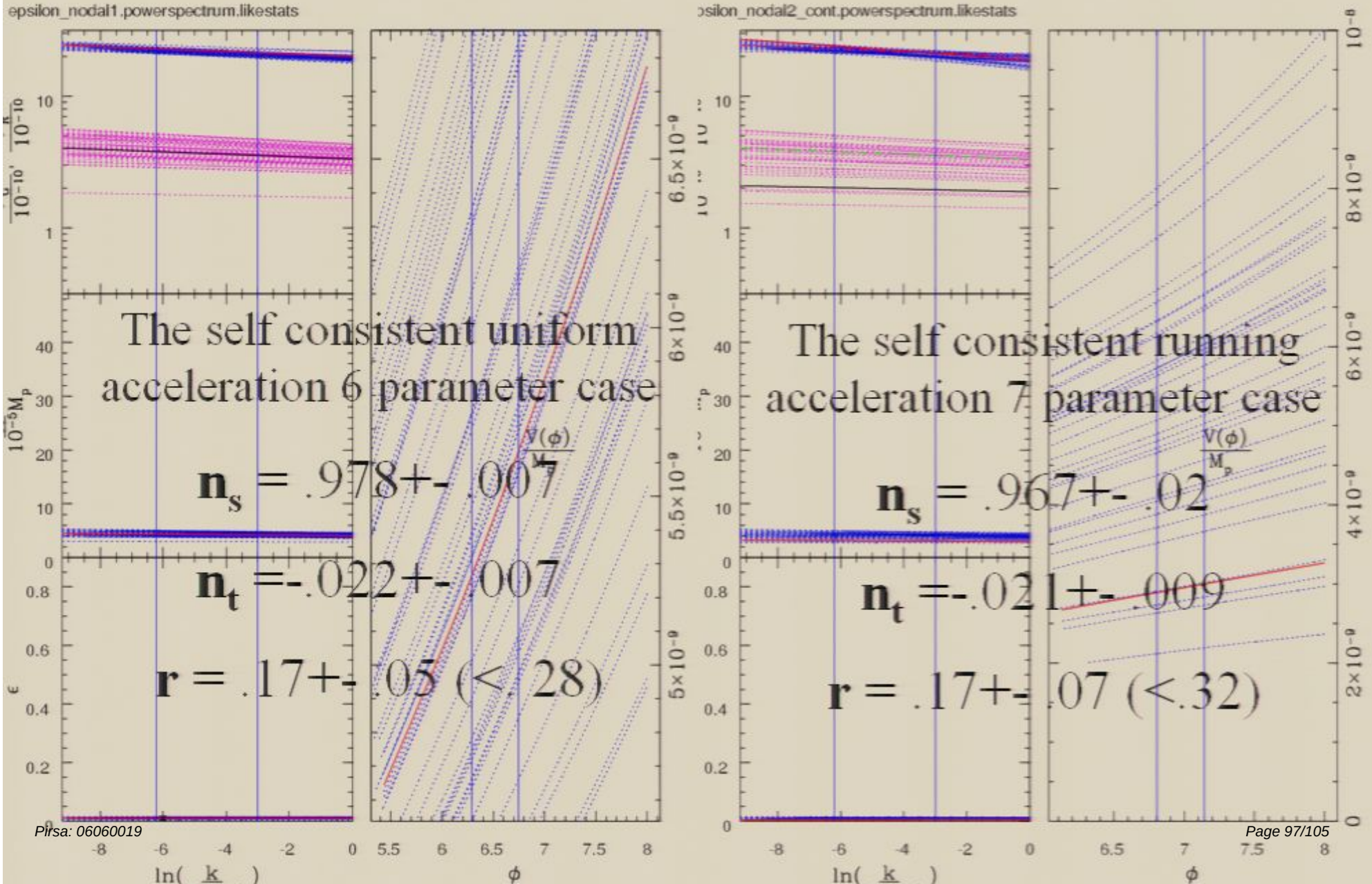


lnP_s P_t (nodal 2 and 1) + 4 params cf ϵ (ln Ha) nodal 2 + amp + 4 params reconstructed from CMB+LSS data using Chebyshev nodal point expansion & MCMC

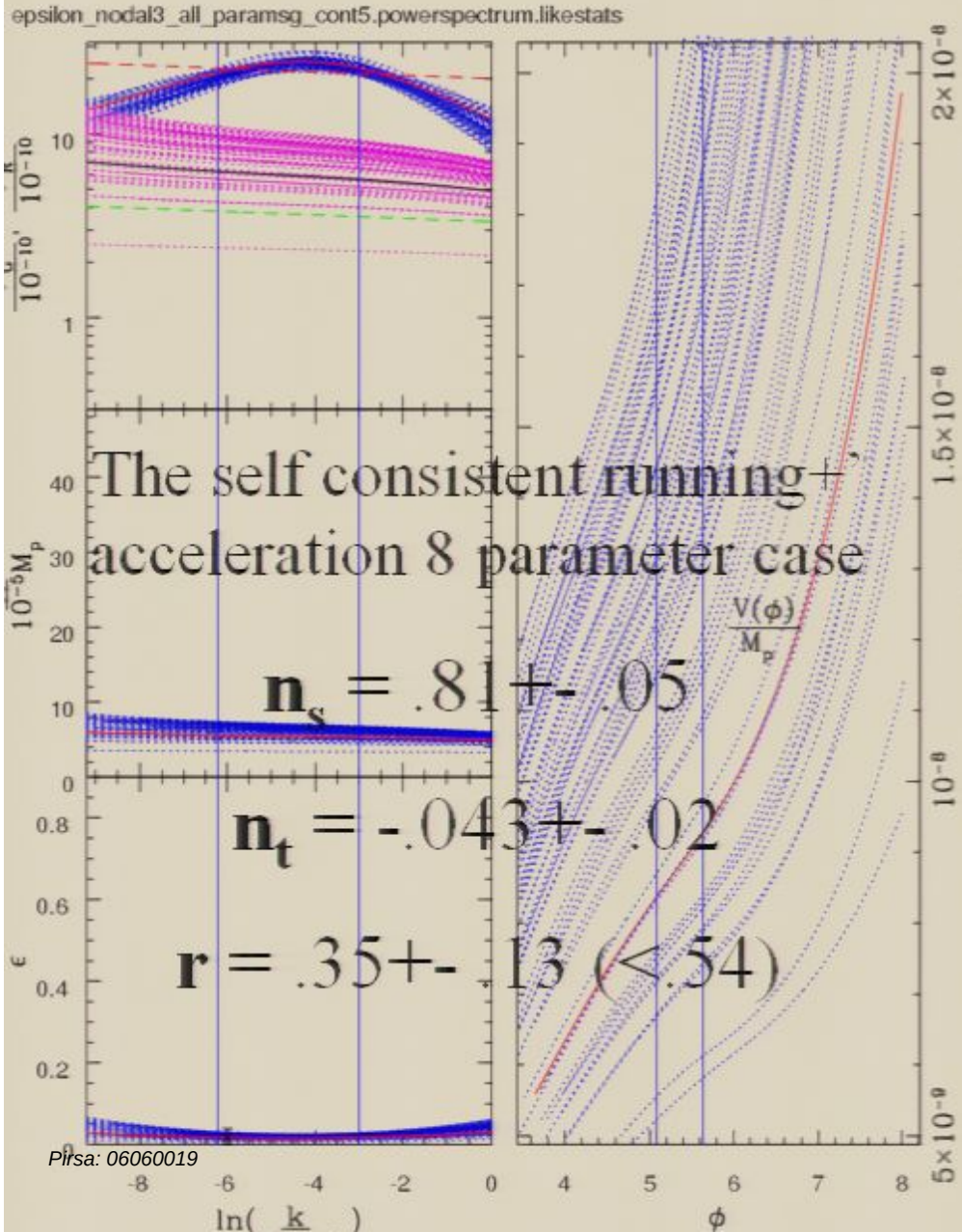


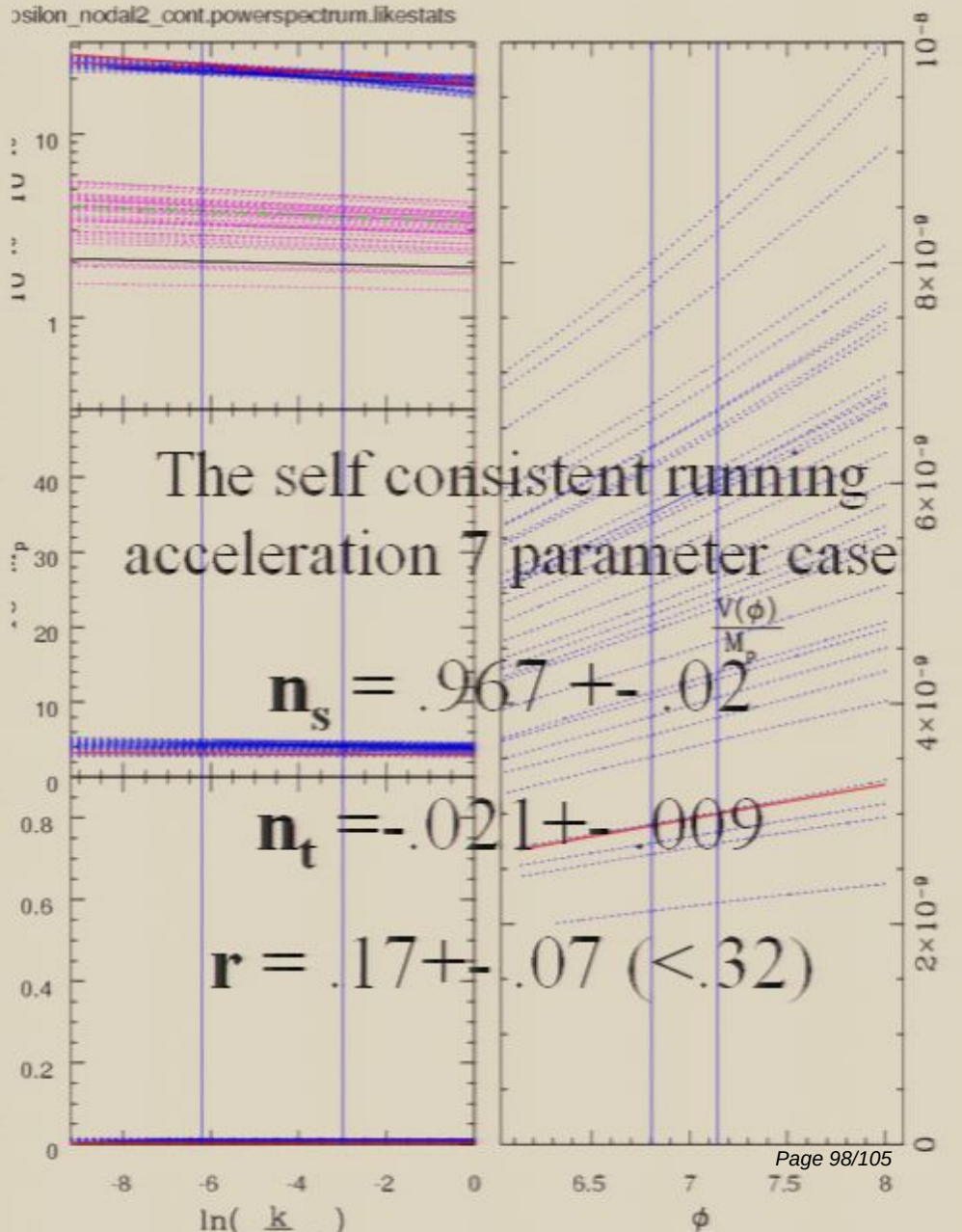


∈ **(ln Ha) order 1** + amp + 4 params cf. **order 2** reconstructed from CMB+LSS data using Chebyshev nodal point expansion & MCMC

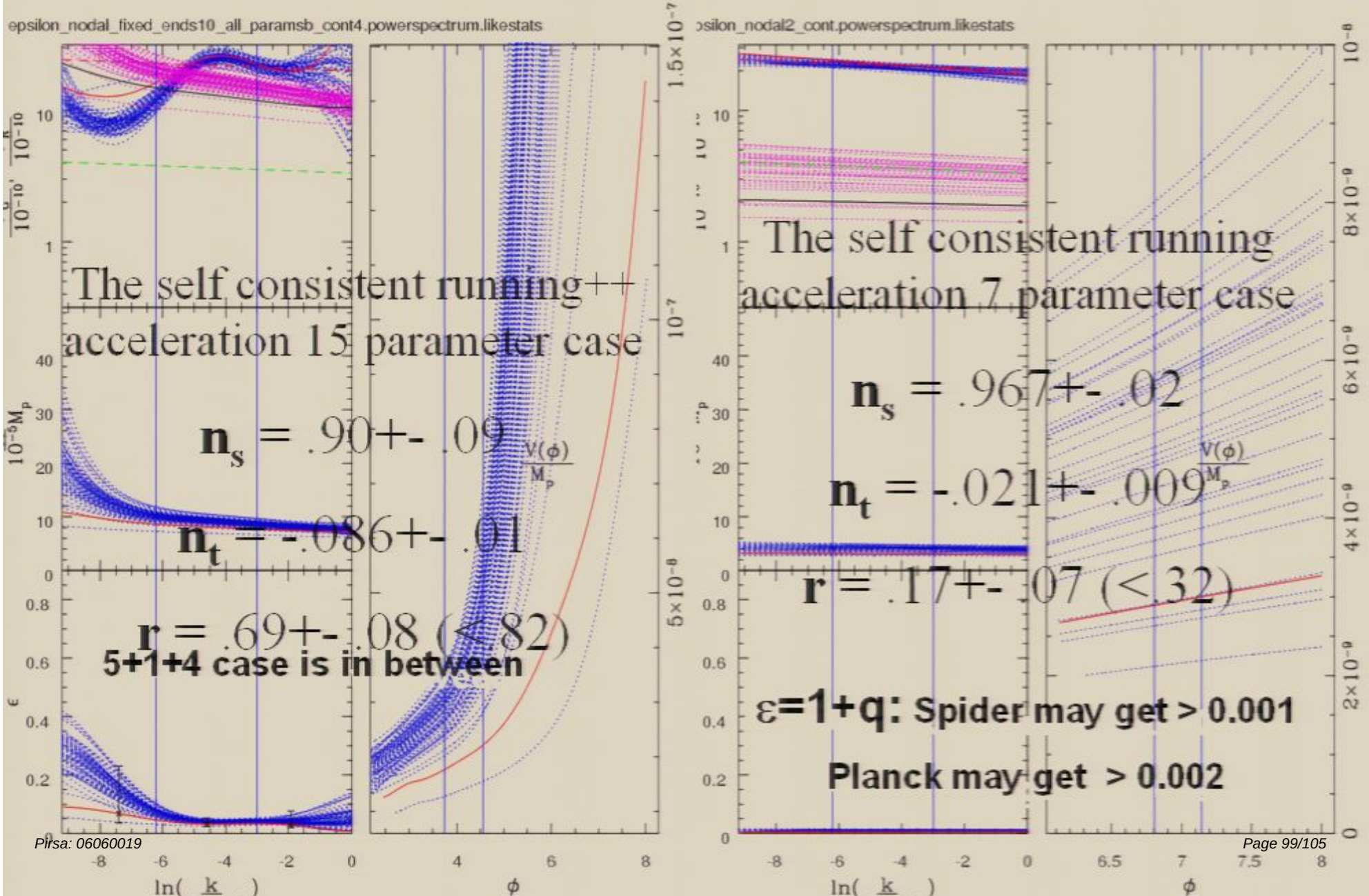


ϵ **(ln Ha) order 3** + amp + 4 params cf. **order 2** reconstructed from CMB+LSS data using Chebyshev nodal point expansion & MCMC

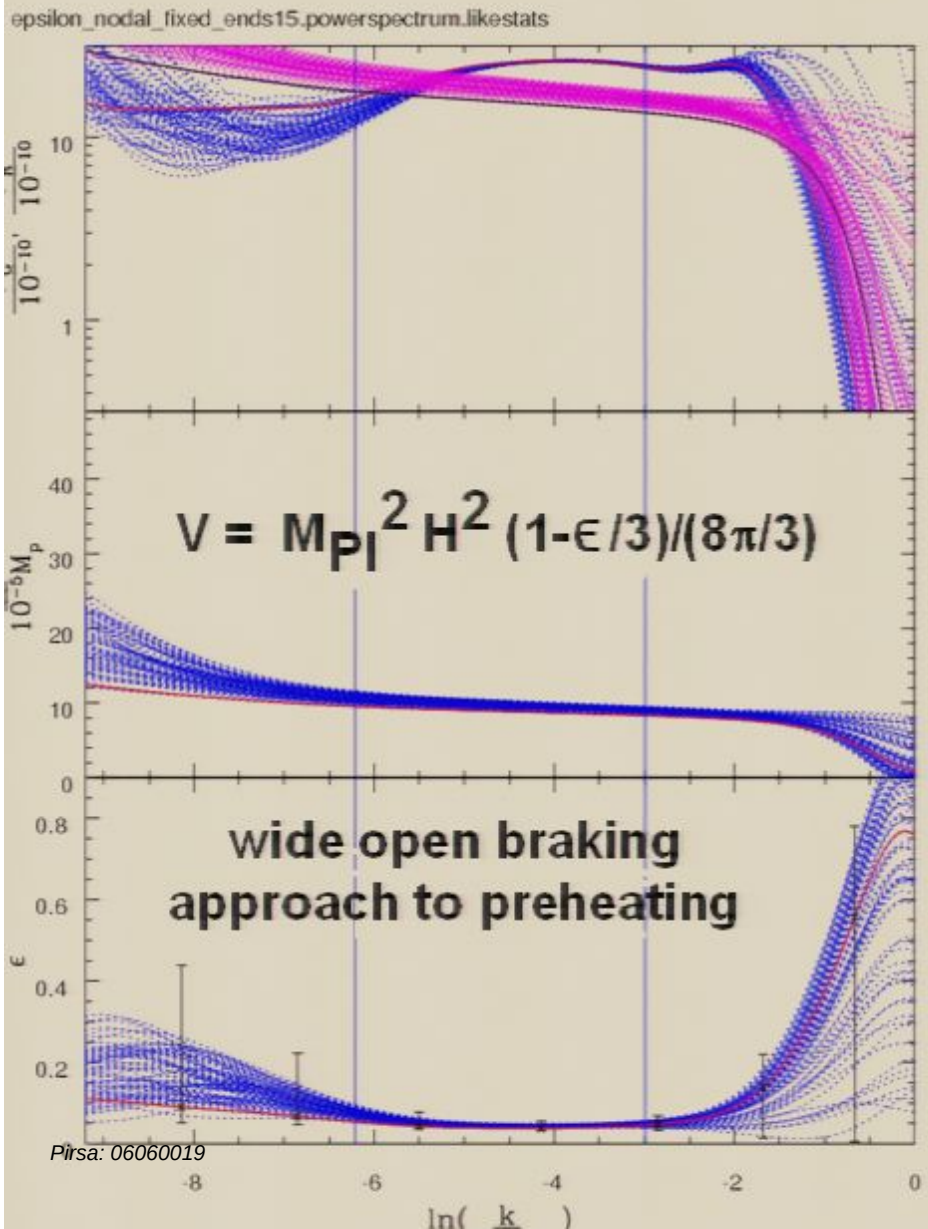


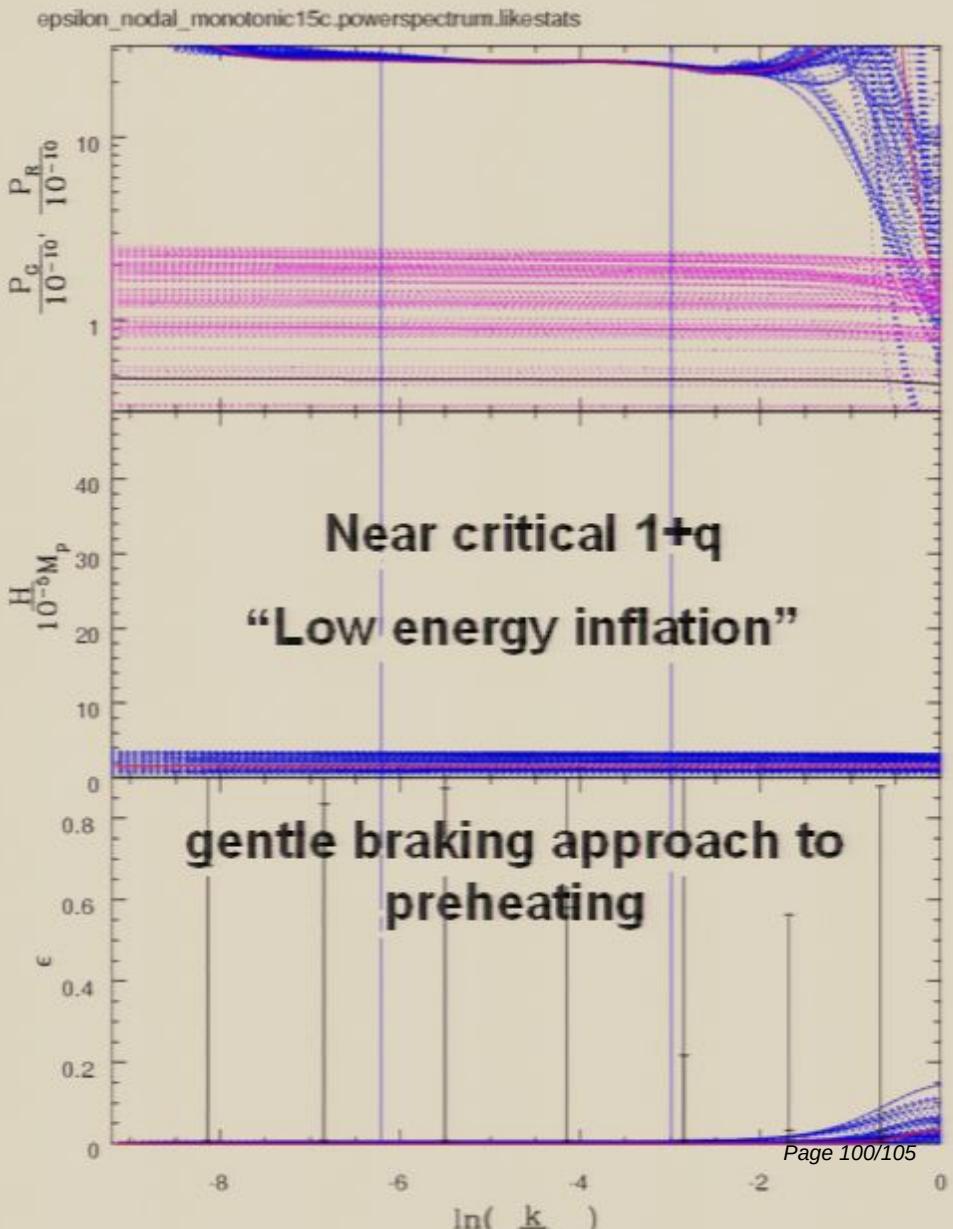


ϵ **(ln Ha) order 10** + amp + 4 params cf. **order 2** reconstructed from CMB+LSS data using Chebyshev nodal point expansion & MCMC

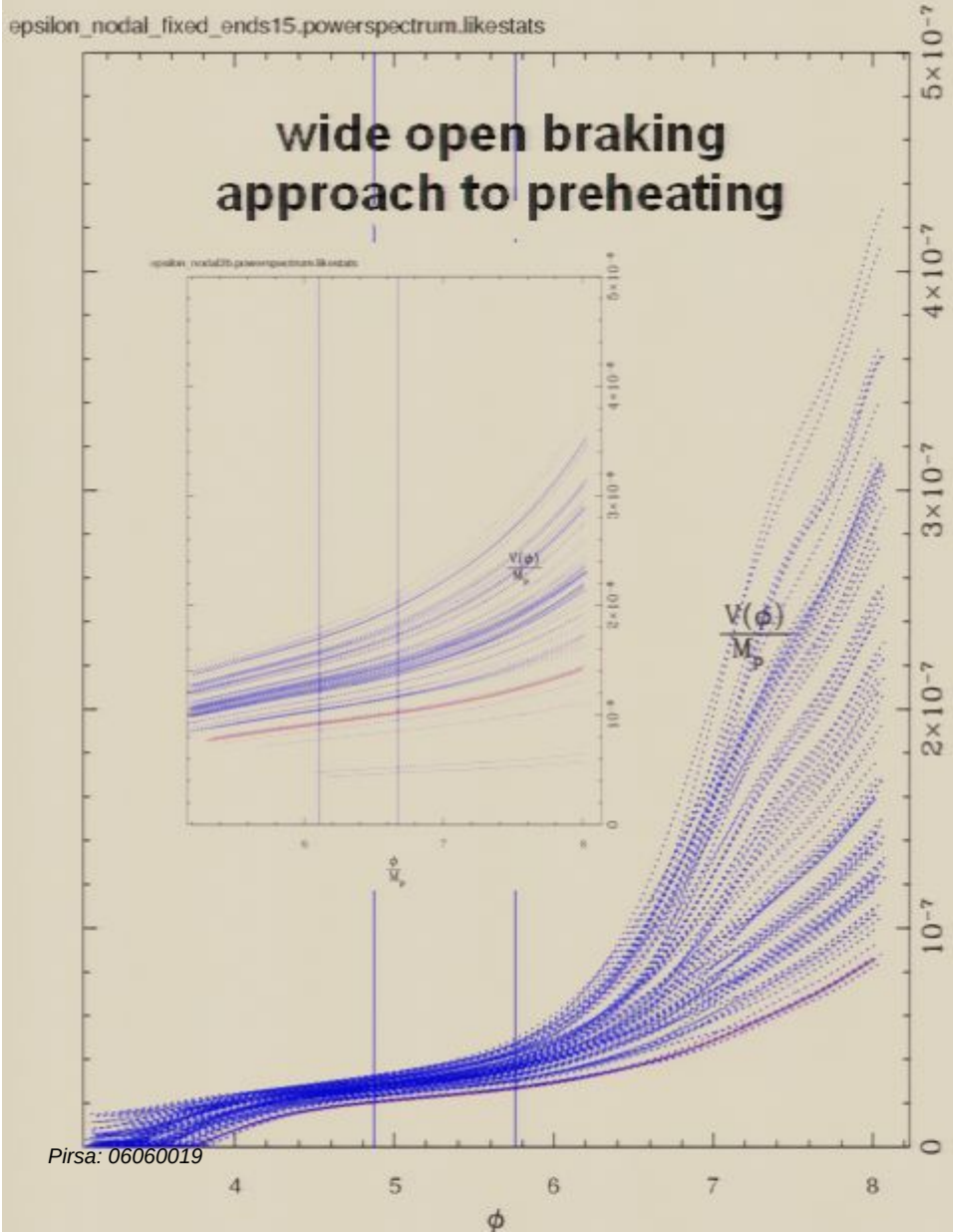


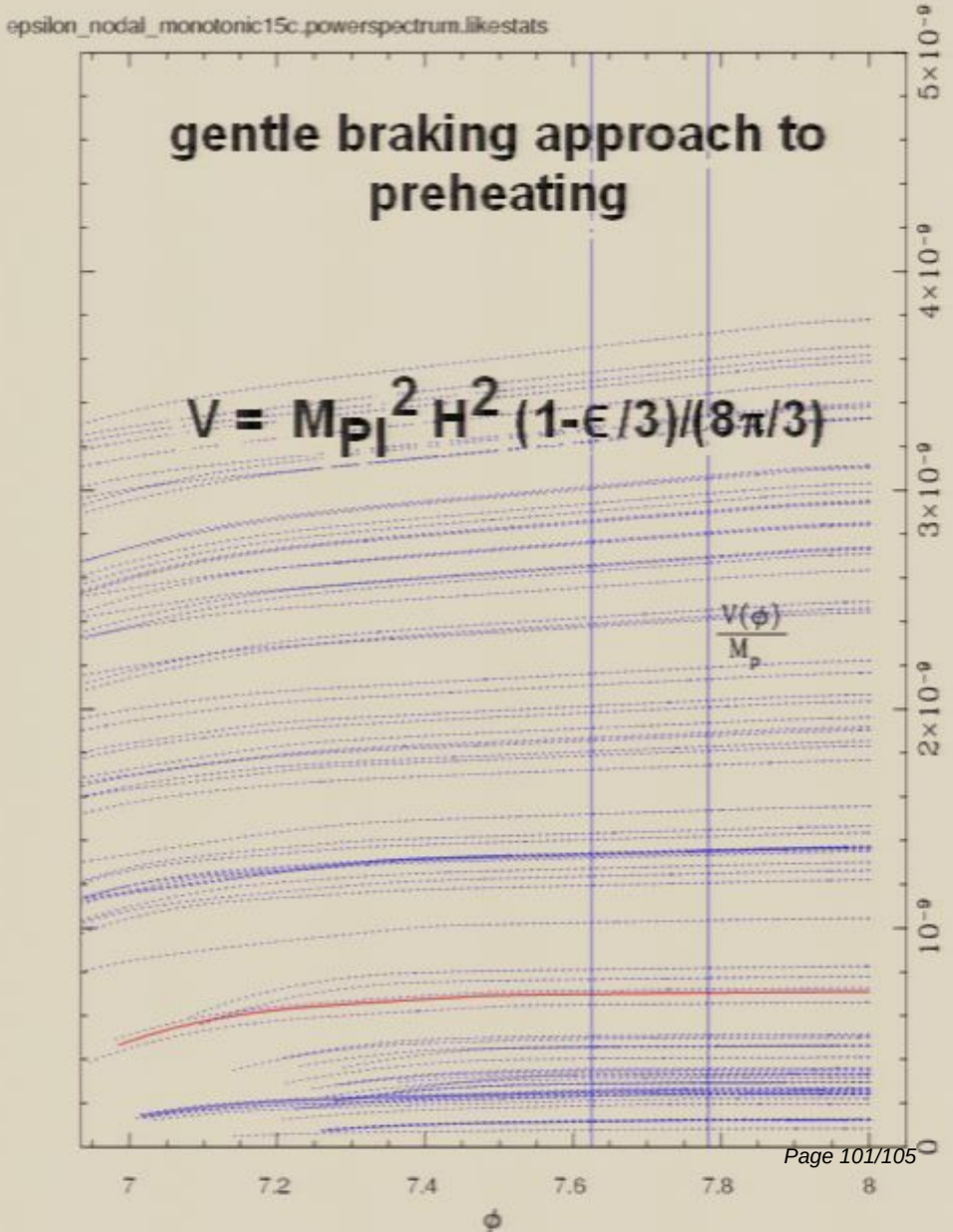
ϵ **(ln k)** reconstructed from CMB+LSS data using Chebyshev expansions **(uniform order 15 nodal point)** cf. **(monotonic order 15 nodal point)** and Markov Chain Monte Carlo methods. T/S consistency function imposed..



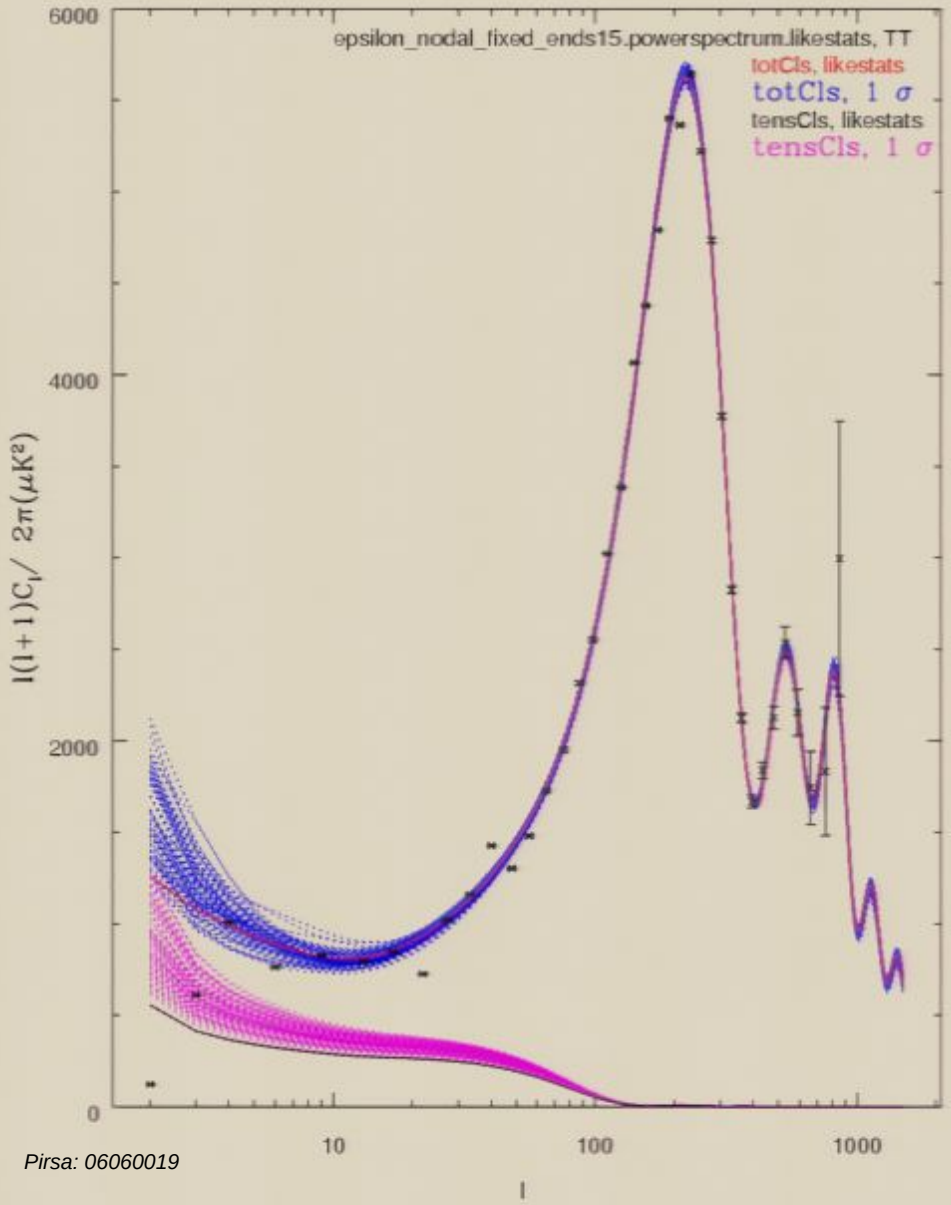


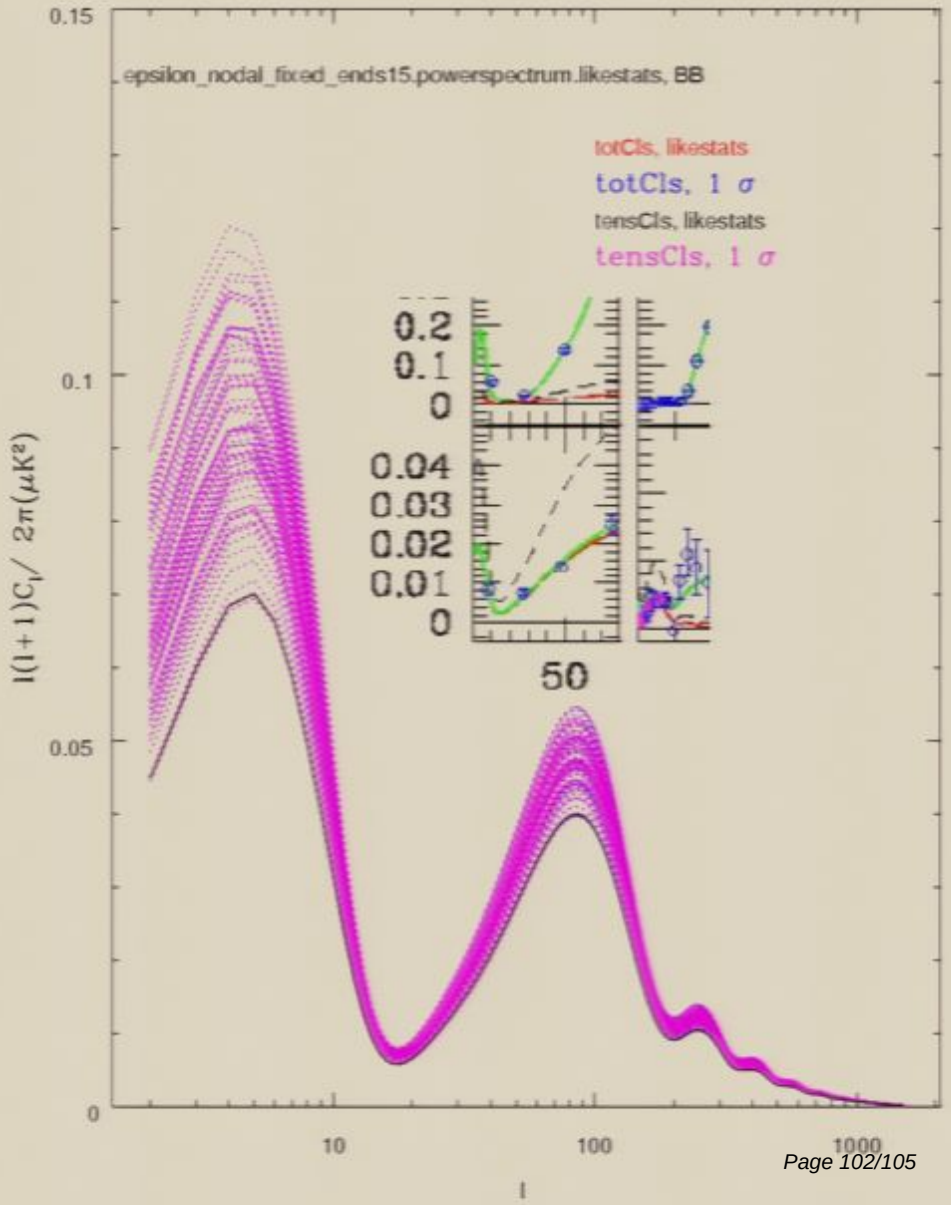
V(ϕ) reconstructed from CMB+LSS data using Chebyshev expansions **(uniform order 15 nodal point)** cf. **(uniform order 3 nodal point)** cf. **(monotonic order 15 nodal point)** and Markov Chain Monte Carlo methods...



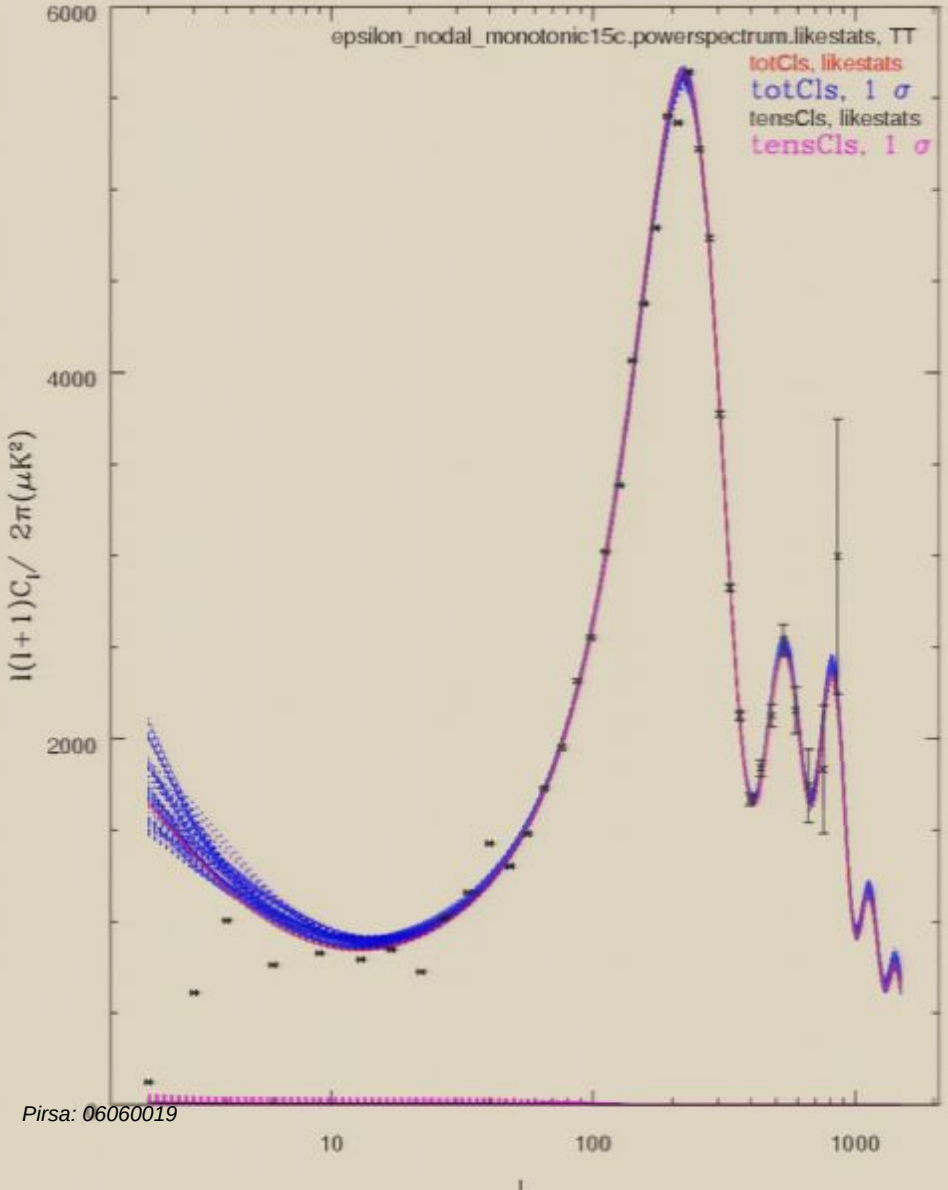


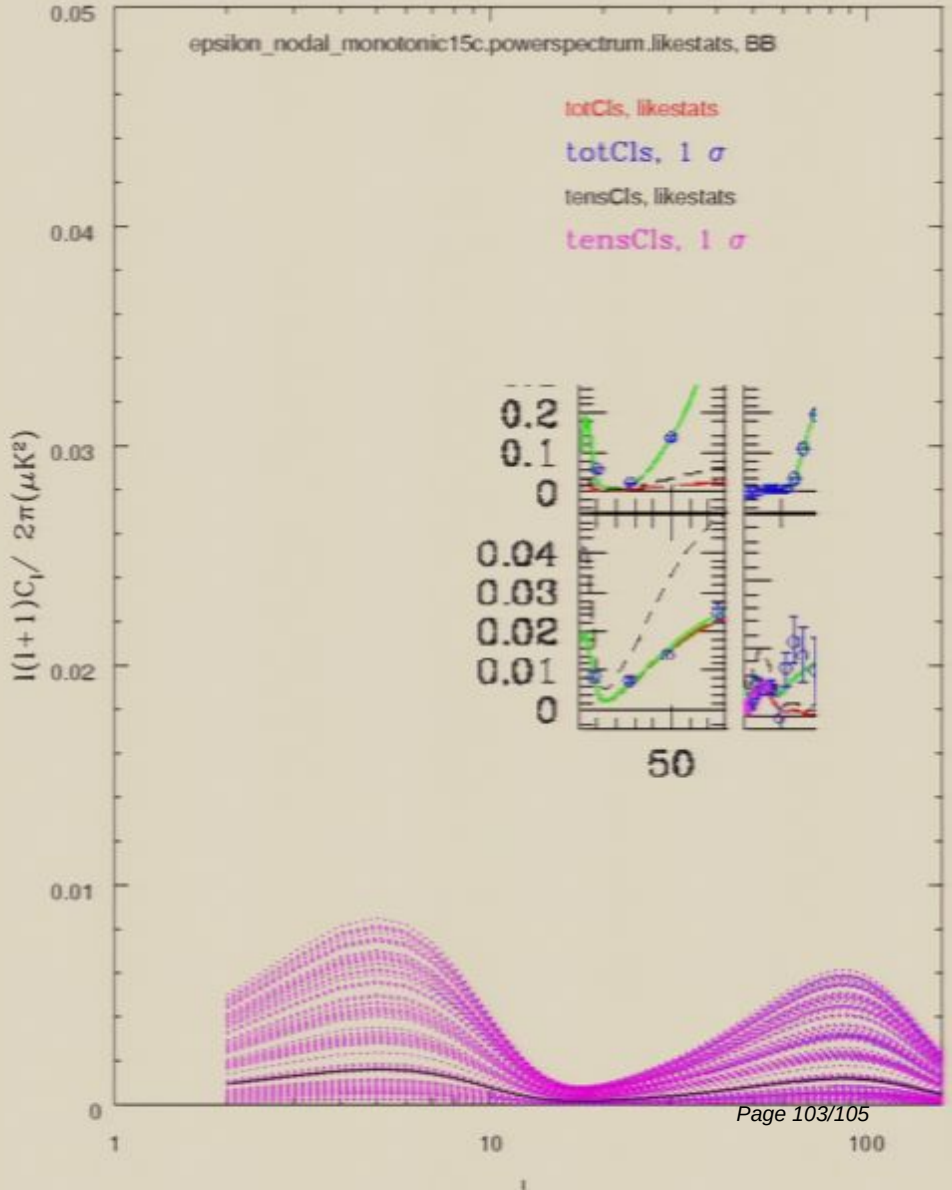
C_L **TT BB** for ε **(ln Ha)** inflation trajectories reconstructed from CMB+LSS data using Chebyshev nodal point expansion **(order 15)** & MCMC

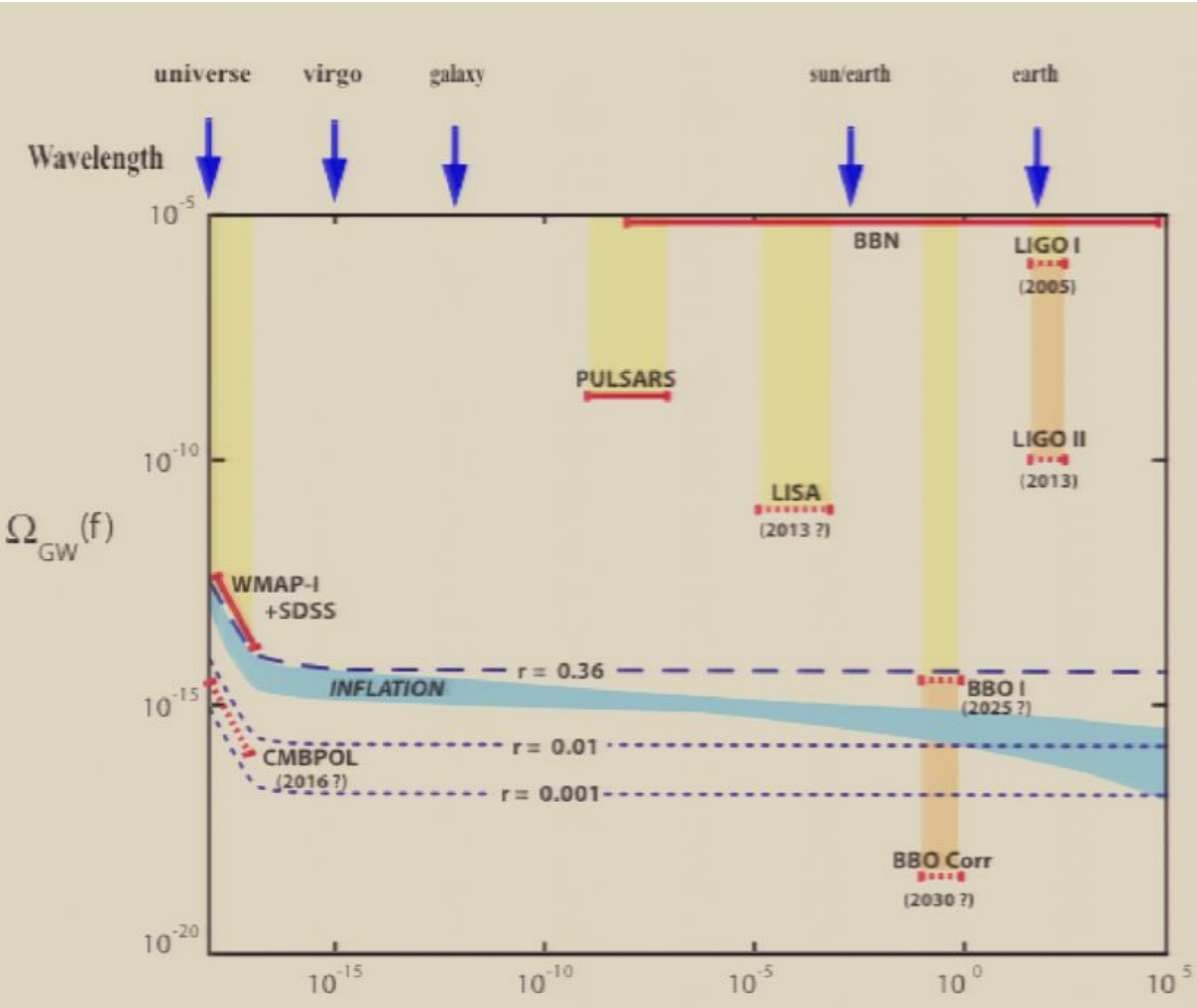




C_L **TT BB** for ε **(ln Ha) monotonic** inflation trajectories reconstructed from CMB+LSS data using Chebyshev nodal point expansion **(order 15)** & MCMC






universe
virgo
galaxy
sun/earth
earth
Wavelength
BBN
LIGO I
(2005)
PULSARS
LIGO II
(2013)
LISA
(2013 ?)
$\Omega_{GW}(f)$
WMAP-I
+SDSS
r = 0.36
INFLATION
BBO I
(2025 ?)
r = 0.01
CMBPOL
(2016 ?)
r = 0.001
BBO Corr
(2030 ?)
10^{-5}
10^{-10}
10^{-15}
10^{-20}
10^{-15}
10^{-10}
10^{-5}
10^{0}
10^{5}
Frequency (Hz)
L. Boyle & P. Steinhardt

summary

The basic 6 parameter with no allowed GW fits all of the data OK

Usual GW limits from adding r with fixed GW spectrum, no consistency (7 params)

Adding minimal consistency does not make that much difference (7 params)

r constraints come from relating high k region of s8 to low k region of GW CL

Prior probabilities on the inflation trajectories are crucial and cannot be decided at this time. Philosophy here is to be as wide open and least prejudiced about inflation as possible

Complexity of trajectories could come out of many moduli string models

Uniform prior in ε nodal point Chebyshev coefficients & Cheb coefficients give similar results, more GW allowed as the parameter space opens up. In particular scalar power downturns at low L if there is freedom in the mode expansion to do this. Adds GW to compensate.

Monotonic uniform prior in ε drives us to low energy inflation and low gravity wave content.

Even with low energy inflation prospects are good with Spider and even Planck to detect the B-mode of polarization. Both have strong Canadian roles.