Title: Inflation and its Cosmic Probes, Now and Then

Date: Sep 14, 2007 11:30 AM

URL: http://pirsa.org/07090050

Abstract:

CBI pol to Apr'05 @Chile

Acbar to Jan'06, 07f @SP

Bicep @SP

QUaD @SP

CBI2 to Dec'07

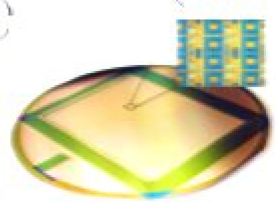
Quiet2 (1000 HEMTs)

Quiet1 @Chile

SZA (Interferometer) @Cal

APEX (~400 bolometers) @Chile

SCUBA2 (12000 bolometers)



JCMT @Hawaii

Spider 2312 bolometer @LDB

ACT (3000 bolometers) @Chile

Clover @Chile

Boom03@LDB

EBEX@LDB

2003 2005 2007 LMT@Mexico 2017

2004 2006 2008

Bpol@L

WMAP @L2 to 2009-2013?

SPT (1000 bolometers) @South Pole

DASI @SP

ALM (Interferomete @Chile

CAPMAP

Polarbear (300 bolometers) @Cal

Planck08.6

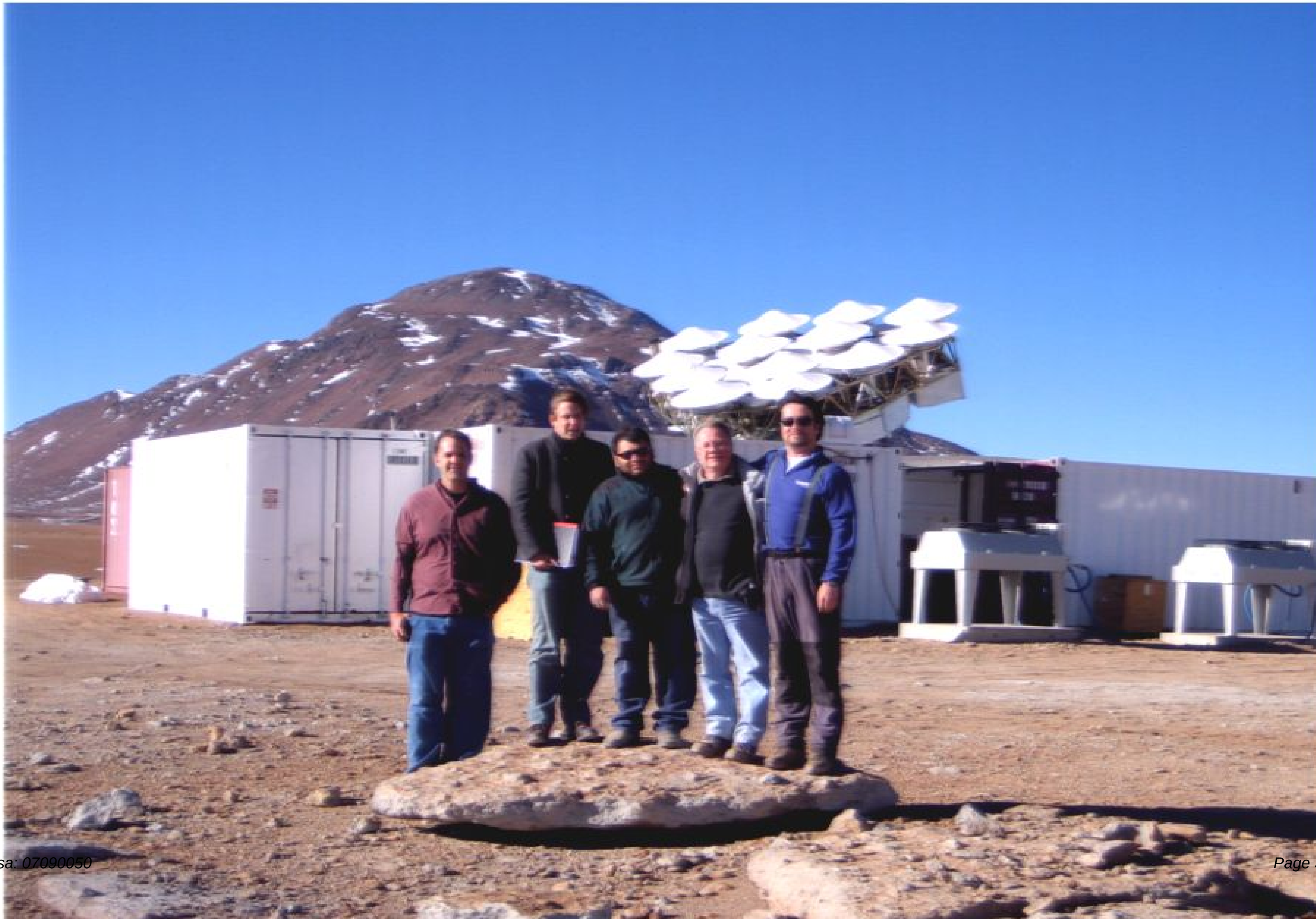
AMI

(84 bolometers) HEMTs @L2

GBT

CBI2@5040m

why Atacama? driest desert in the world. thus: cbi, toco, apex, asti, act, alma, quiet, clover



ACT@5170m

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

–Dick Bond

CIAR

25 years cifar

Inflation & its Cosmic Probes, now & then

'osmic Probes CMB, CMBpol (E,B modes of polarization)

3 from tensor: Bicep, Planck, Spider, Spud, Ebex, Quiet, Pappa, Clover, …, Bpol

'FHTLS SN(192),WL(Apr07), JDEM/DUNE BAO,LSS,Lyα

nflation Then $\varepsilon(k)=(1+q)(a)$ ~r/16 $0<\varepsilon<1$

= multi-parameter expansion in (lnHa ~ lnk)

)ynamics ~ Resolution ~ 10 good e-folds (~10^{-4}Mpc^{-1} to ~ 1 Mpc^{-1} LSS)
-10+ parameters? Bond, Contaldi, Kofman, Vaudrevange 07

'(k_p) i.e. $\varepsilon(k)$ is prior dependent now, not then. Large (uniform ε), Small
uniform lnε). Tiny (roulette inflation of moduli; almost all string-inspired models)

(KLMMT etc. Quevedo etal. Bond, Kofman, Prokushkin, Vaudrevange 07, Kallosh and Linde 07

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CIAR 25 years cifar

Inflation & its Cosmic Probes, now & then

Inflation Now $1+w(a) = \varepsilon_s f(a/a_{\Lambda eq}; a_s/a_{\Lambda eq}; \zeta_s)$

goes to $\varepsilon(a)$ x3/2 = 3(1+q)/2 ~1 good e-fold. only ~2params

Zhiqi Huang, Bond & Kofman 07 ε_s=0.0+-0.25 now, to +-0.08 Planck+JDEM SN, weak a_s

Cosmic Probes Now CFHTLS SN(192), WL(Apr07), CMB, BAO, LSS, Lyα

THEN

Standard Parameters of Cosmic Structure Formation

$\theta \sim \ell_s^{-1}, \;\; cf. \Omega_\Lambda$

r **< 0.6** or **< 0.28** 95% CL

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

$r = A_t / A$

Standard Parameters of Cosmic Structure Formation

Period of inflationary expansion, quantum noise → metric perturbations

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Scalar Amplitude

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Ω_k

New Parameters of Cosmic Structure Formation

$\Omega_b h^2$

$\theta \sim \ell_s^{-1}, \;\; cf. \Omega_\Lambda$

$\ln \mathcal{P}_t(k)$

$\Omega_{dm} h^2$

$\ln \mathcal{P}_s(k)$

τ_C

New Parameters of Cosmic Structure Formation

Ω_k

$\Omega_b h^2$

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τ_C

$\theta \sim \ell_s^{-1}, \;\; cf. \Omega_\Lambda$

$\ln \mathcal{P}_s(k)$

$\ln \mathcal{P}_t(k)$

scalar spectrum
use order N Chebyshev expansion in ln k,
N-1 parameters
amplitude(1), tilt(2), running(3), ...
(or N-1 nodal point k-localized values)

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tensor (GW) spectrum
use order M Chebyshev expansion in ln k,
M-1 parameters
amplitude(1), tilt(2), running(3),...

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use order M Chebyshev
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Dual Chebyshev expansion in ln k:

Standard 6 is Cheb=2

Standard 7 is Cheb=2, Cheb=1

Run is Cheb=3

Run & tensor is Cheb=3, Cheb=1

Low order N,M power law but high order Chebyshev is Fourier like

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$\epsilon(k), \;\; k \approx Ha$

$\ln H(k_p)$

$H(k_p)$

Ω_k

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=1+q, the deceleration parameter history

$$\mathcal{P}_s(k) \propto H^2/\epsilon, \mathcal{P}_t(k) \propto H^2$$

order N Chebyshev expansion, N-1 parameters (e.g. nodal point values)

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Hubble parameter at inflation at a pivot pt

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$-\epsilon = d \ln H / d \ln a$

Ω_k

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$\frac{-\epsilon}{1-\epsilon} = \frac{d \ln H}{d \ln k}$

Fluctuations are from stochastic kicks ~ H/2π superposed on the downward drift at Δlnk=1.

Potential trajectory from HJ (SB 90,91):

$V \propto H^2 (1 - \frac{\epsilon}{3}); \frac{d\psi_{inf}}{d \ln k} = \frac{\pm\sqrt{}}{1-}$

$\epsilon = (d \ln H / d\psi_{inf})^2$

The Parameters of Cosmic Structure Formation

Cosmic Numerology: astroph/0611198 – our Acbar paper on the basic 7+

WMAP3modified+B03+CBIcombined+Acbar06+LSS (SDSS+2dF) + DASI (incl polarization and CMB weak lensing and tSZ)

n_s = .958 +- .015

.93 +- .03 @0.05/Mpc run&tensor

$r = A_t / A_s$ < 0.28 95% CL

<.36 CMB+LSS run&tensor

dn_s /dln k = -.060 +- .022

-.038 +- .024 CMB+LSS run&tensor

A_s = 22 +- 2 x 10^{-10}

$\Omega_b h^2$ = .0226 +- .0006

$\Omega_c h^2$ = .114 +- .005

Ω_Λ = .73 +.02 - .03

h = .707 +- .021

Ω_m = .27 + .03 -.02

z_{reh} = 11.4 +- 2.5

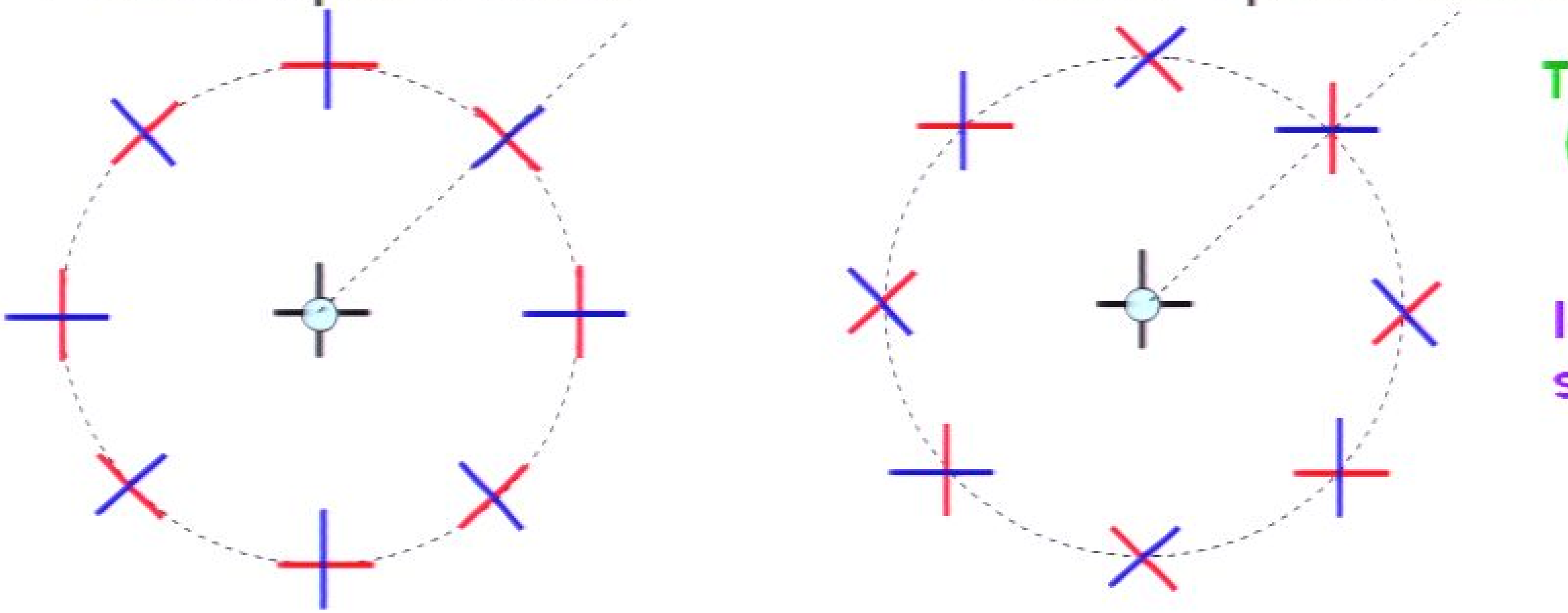
E and B polarization mode patterns

Blue = + Red = -

E="local" Q in 2D Fourier space basis

B="local" U in 2D Fourier space basis

Scalar + Tensor (GW)



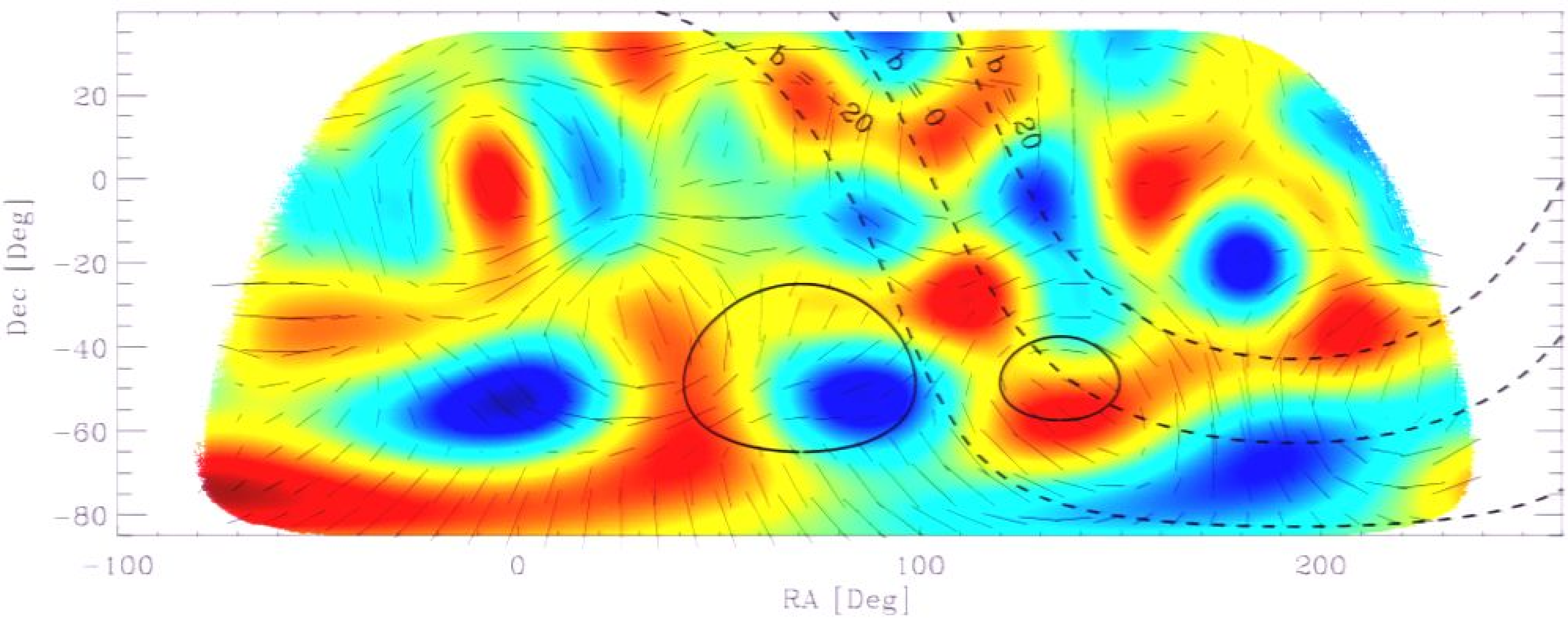
Tensor (GW) + lensed scalar

SPIDER Tensor Signal

- Simulation of large scale polarization signal

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

No Tensor



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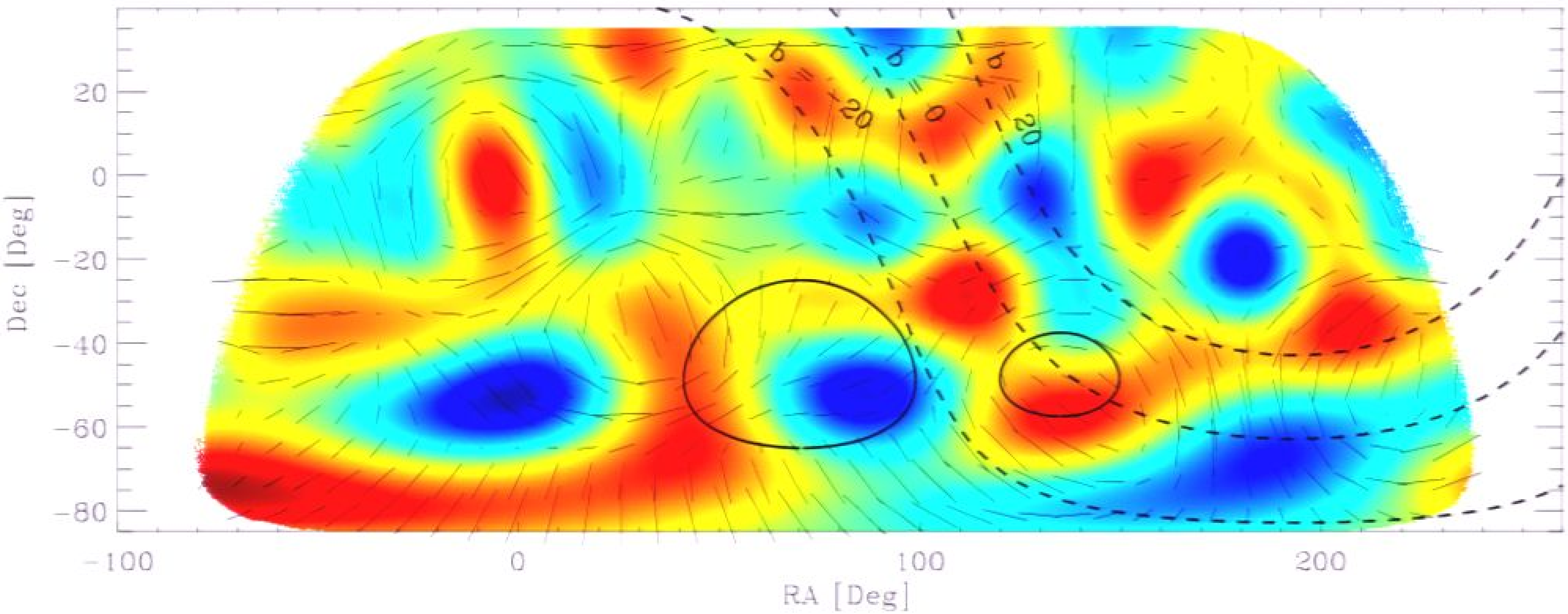

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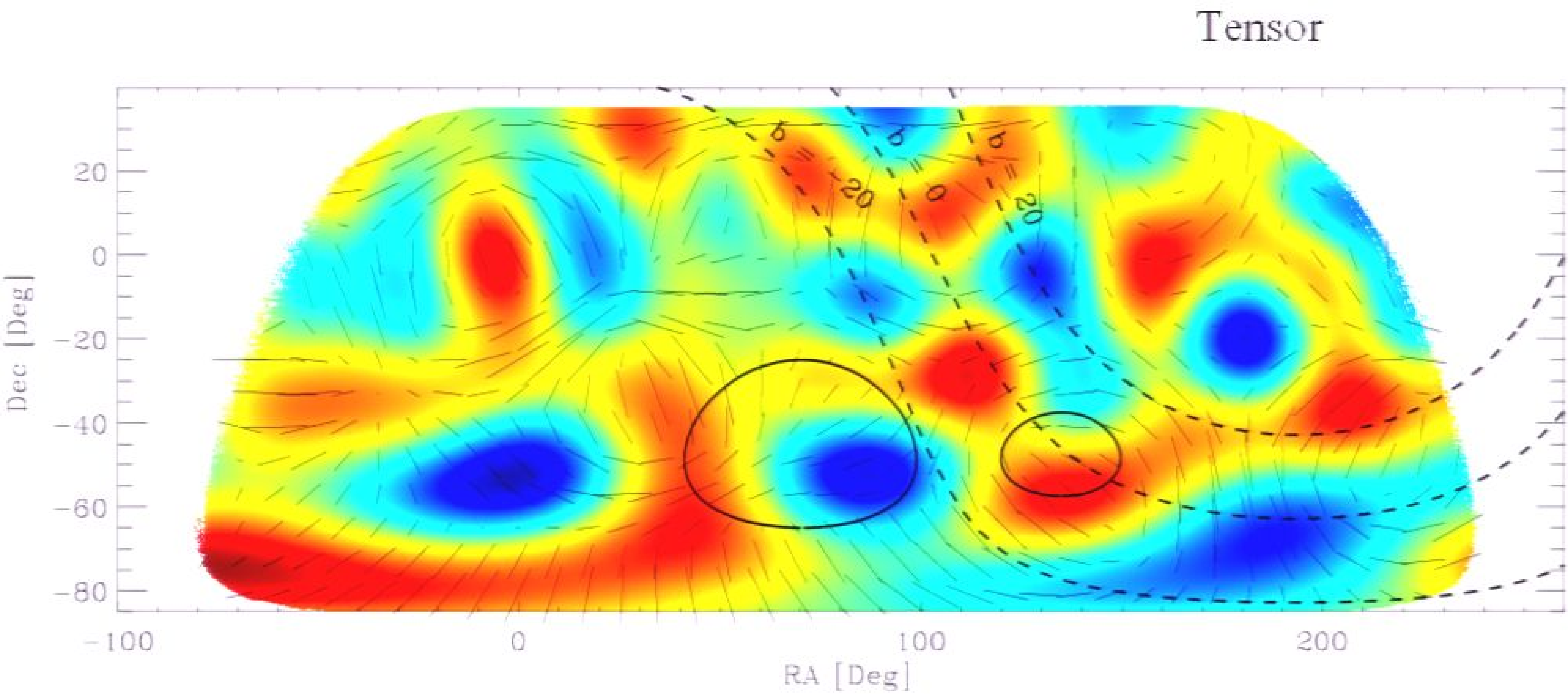

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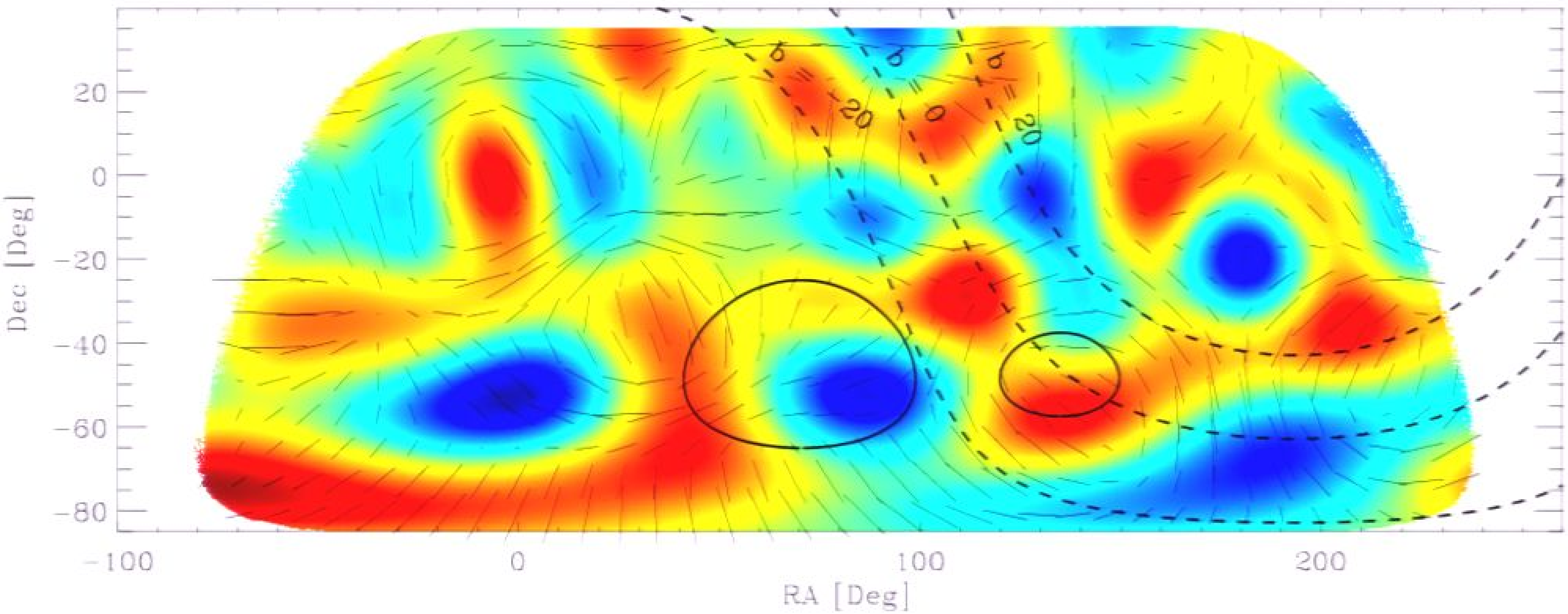

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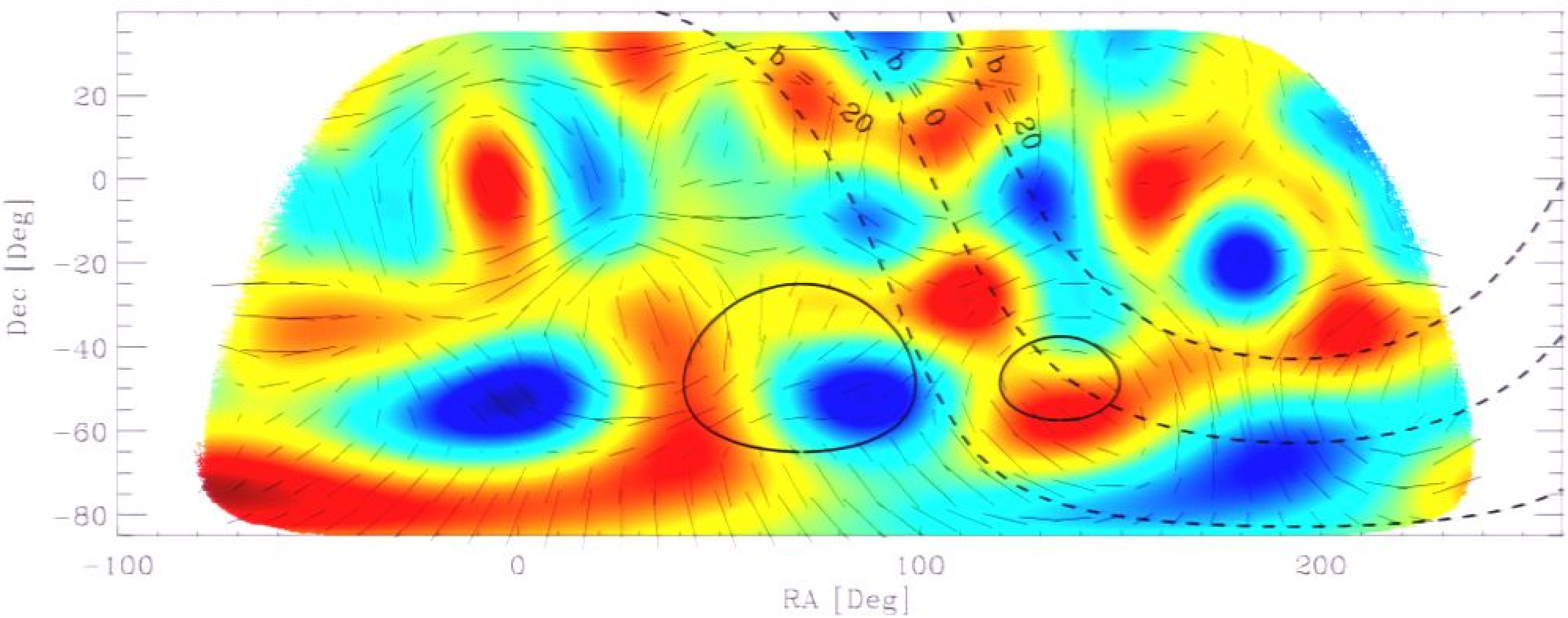

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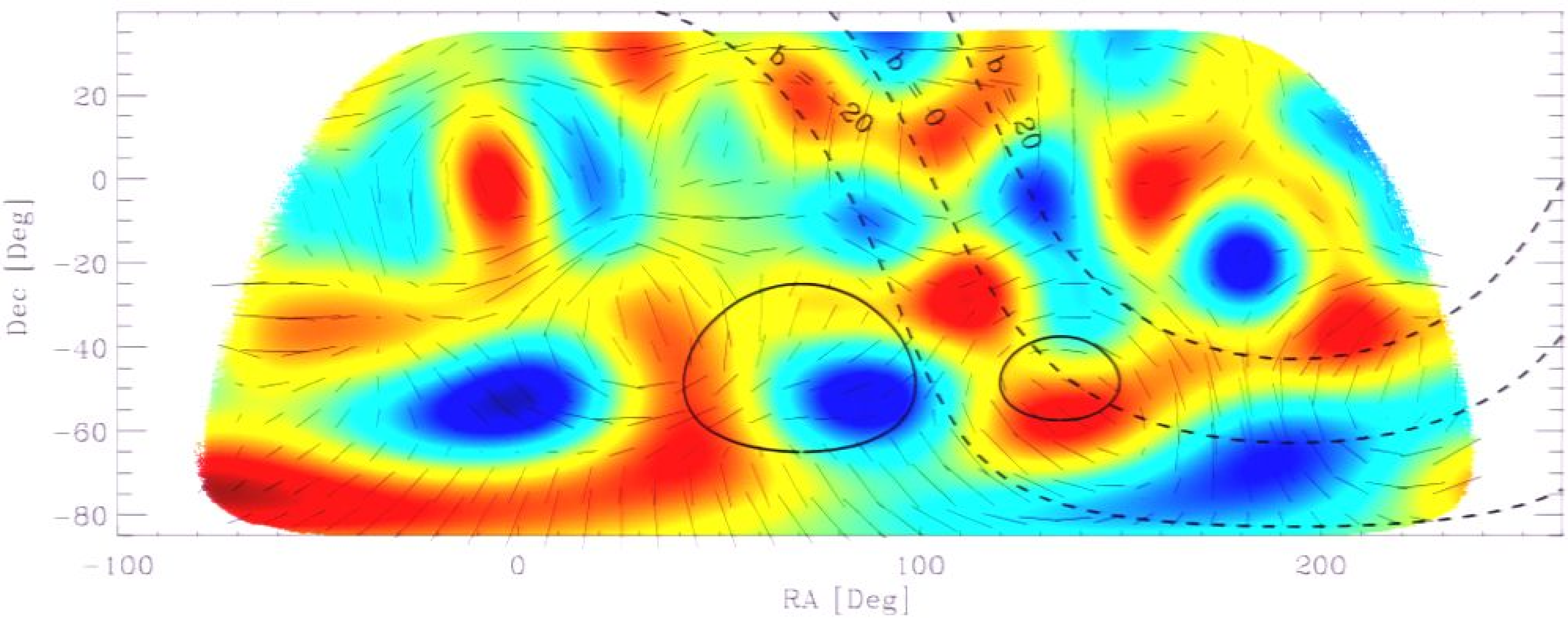

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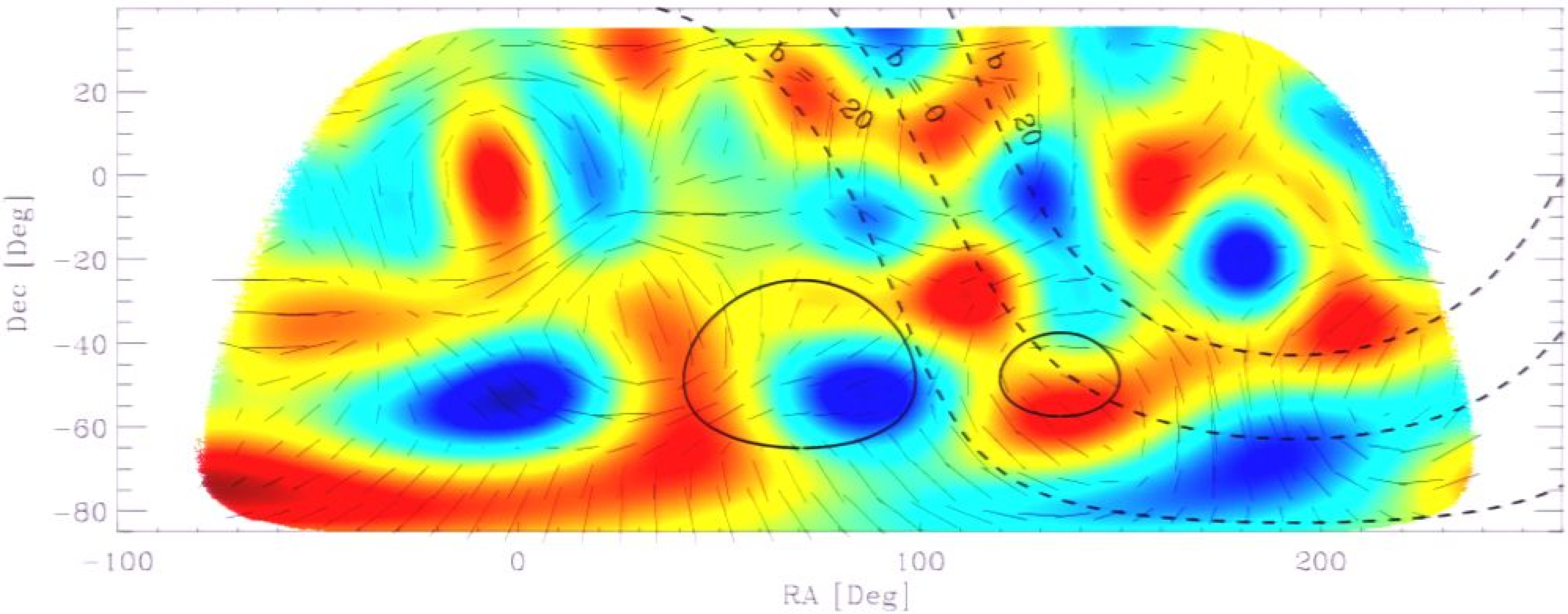

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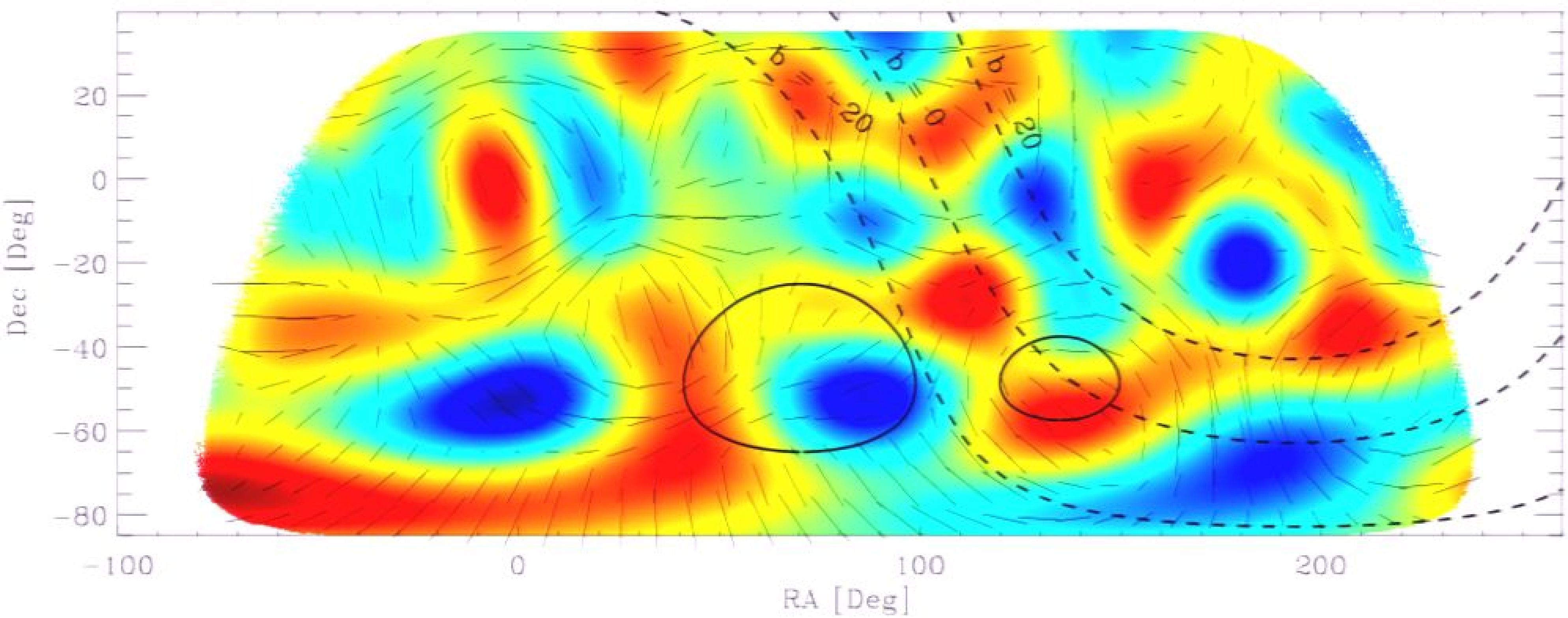

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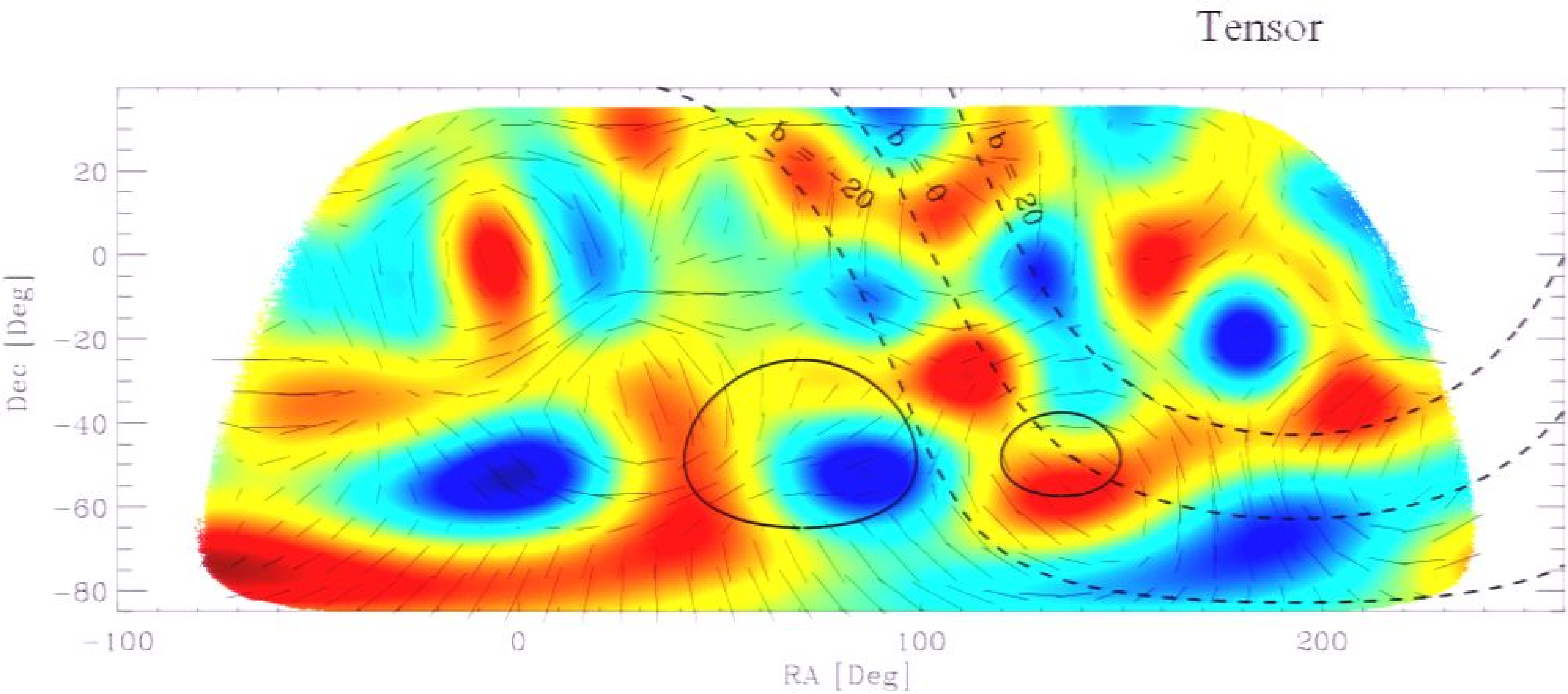

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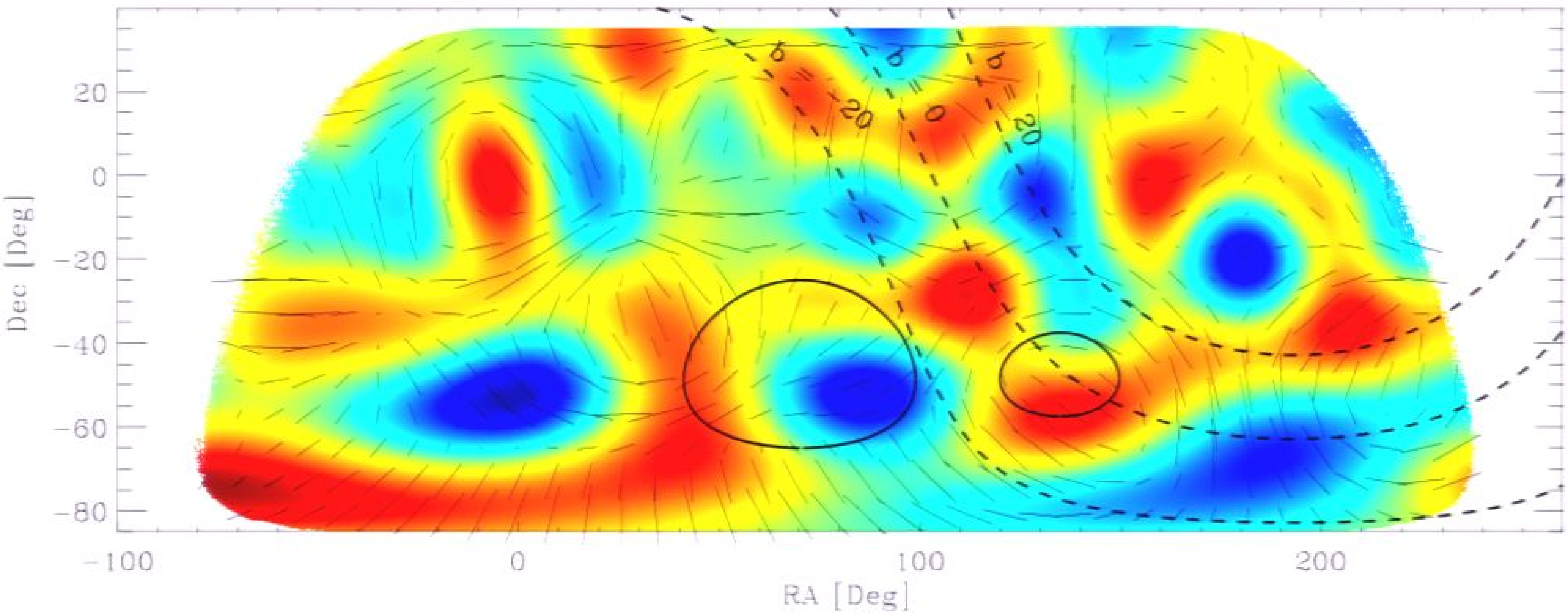

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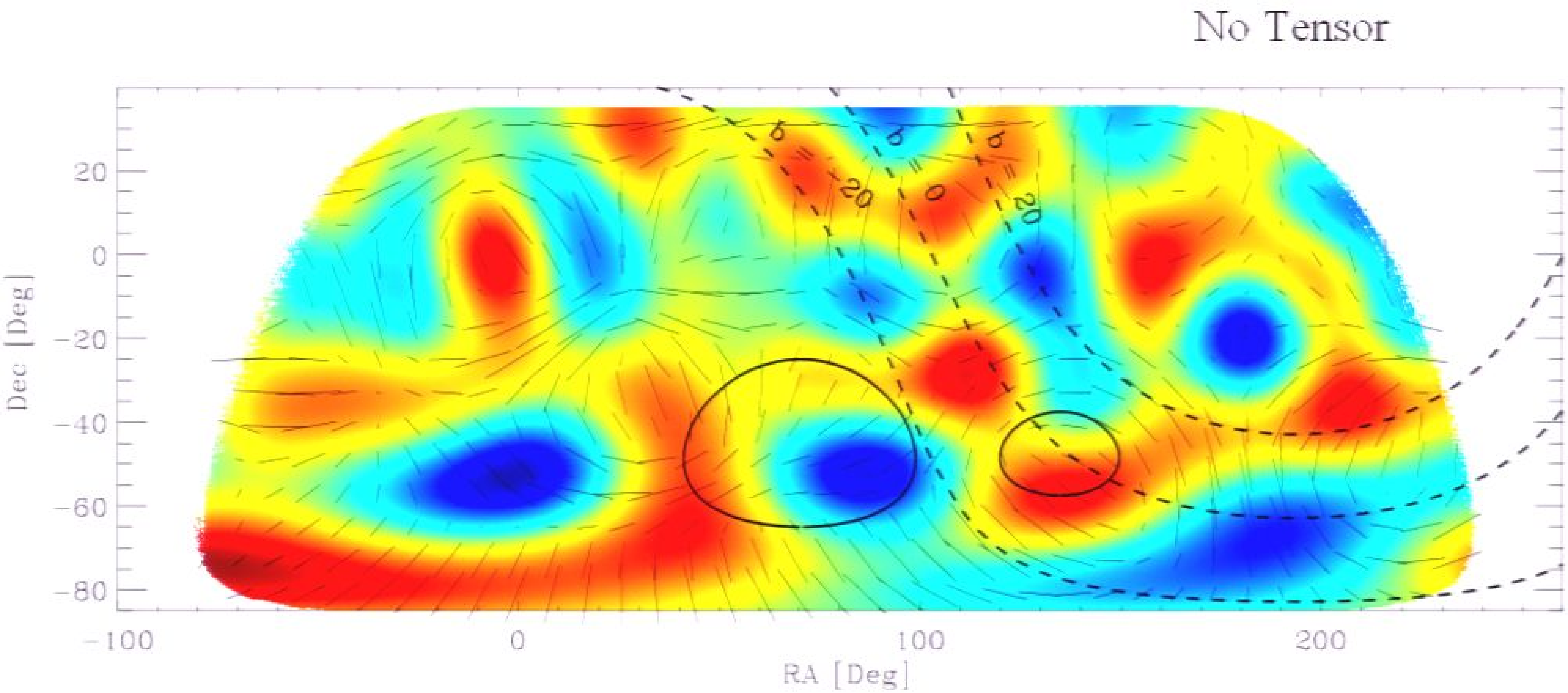

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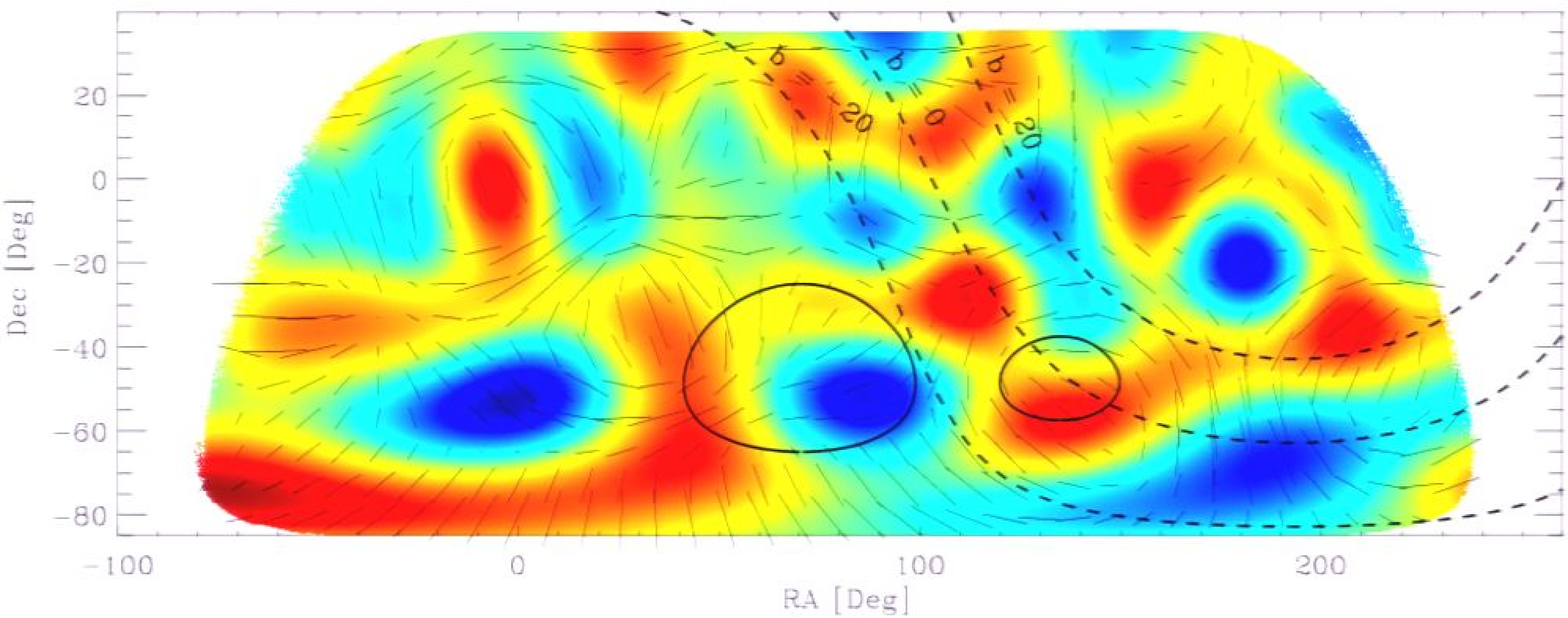

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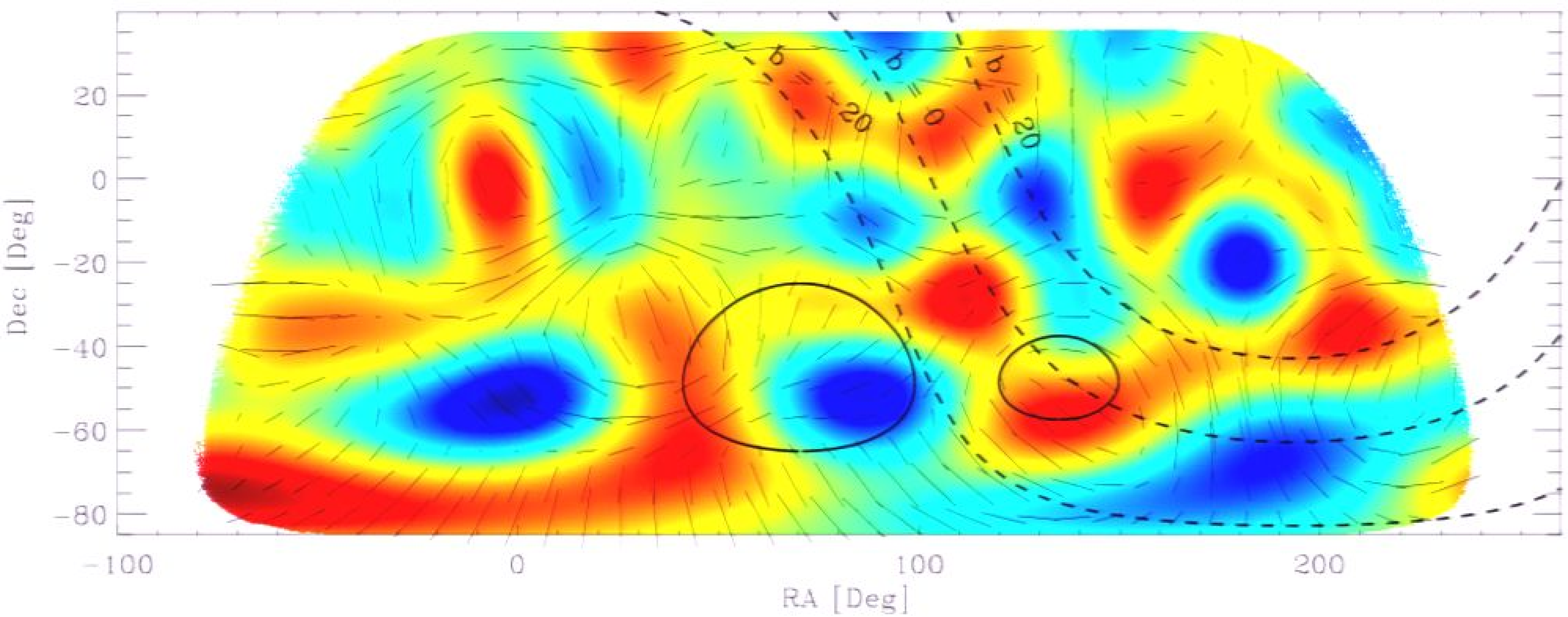

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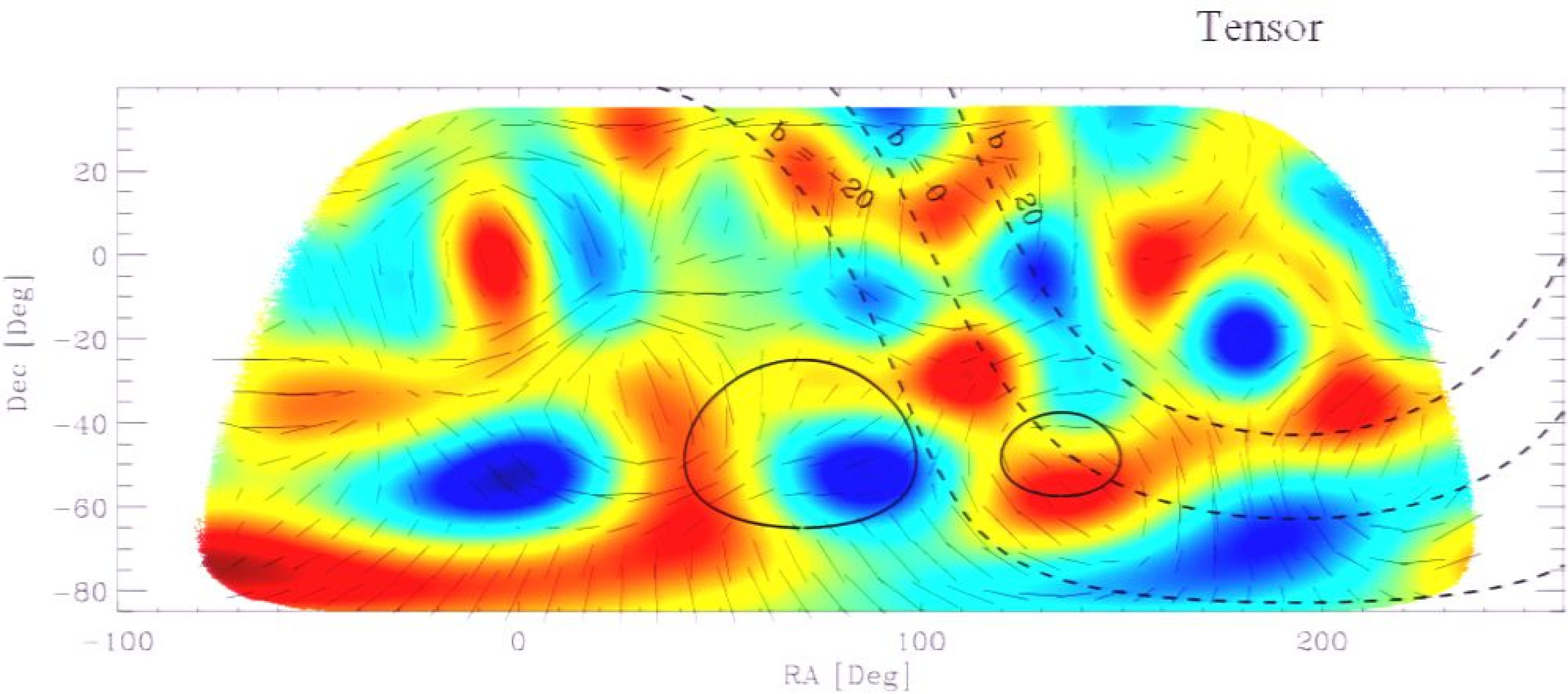

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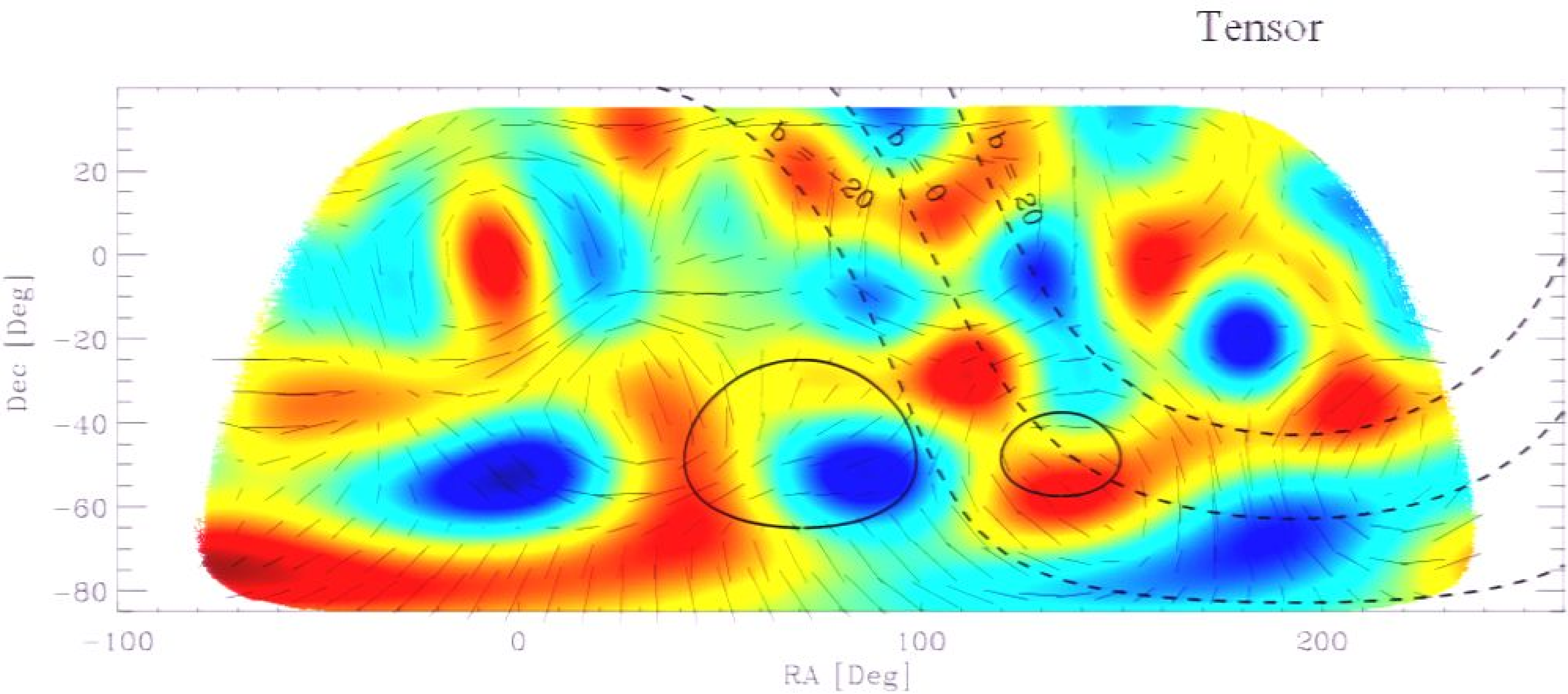

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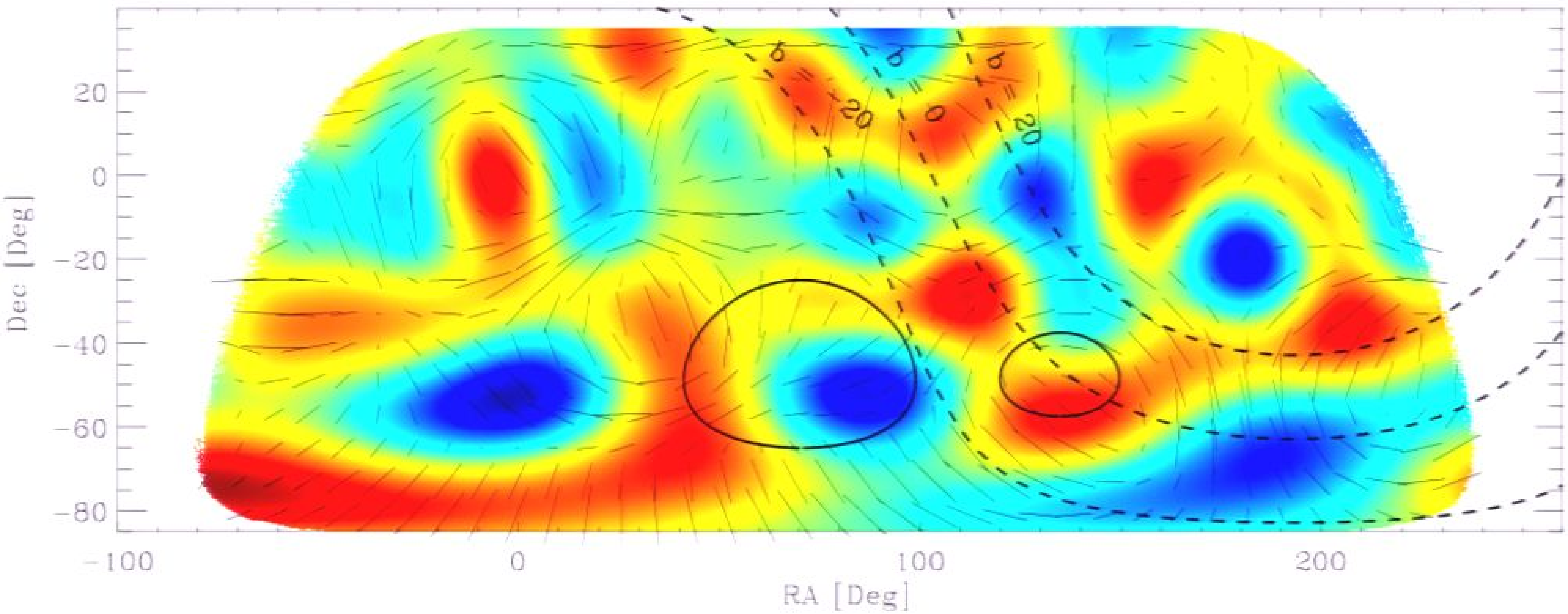

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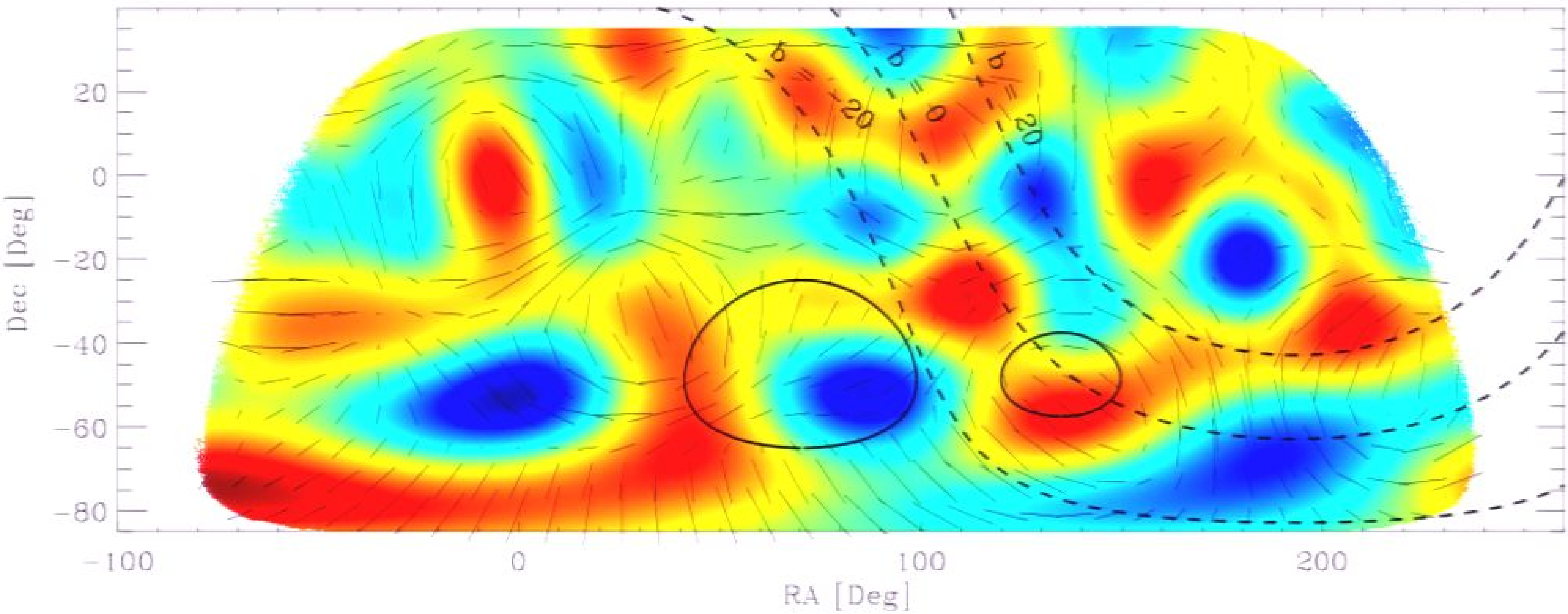

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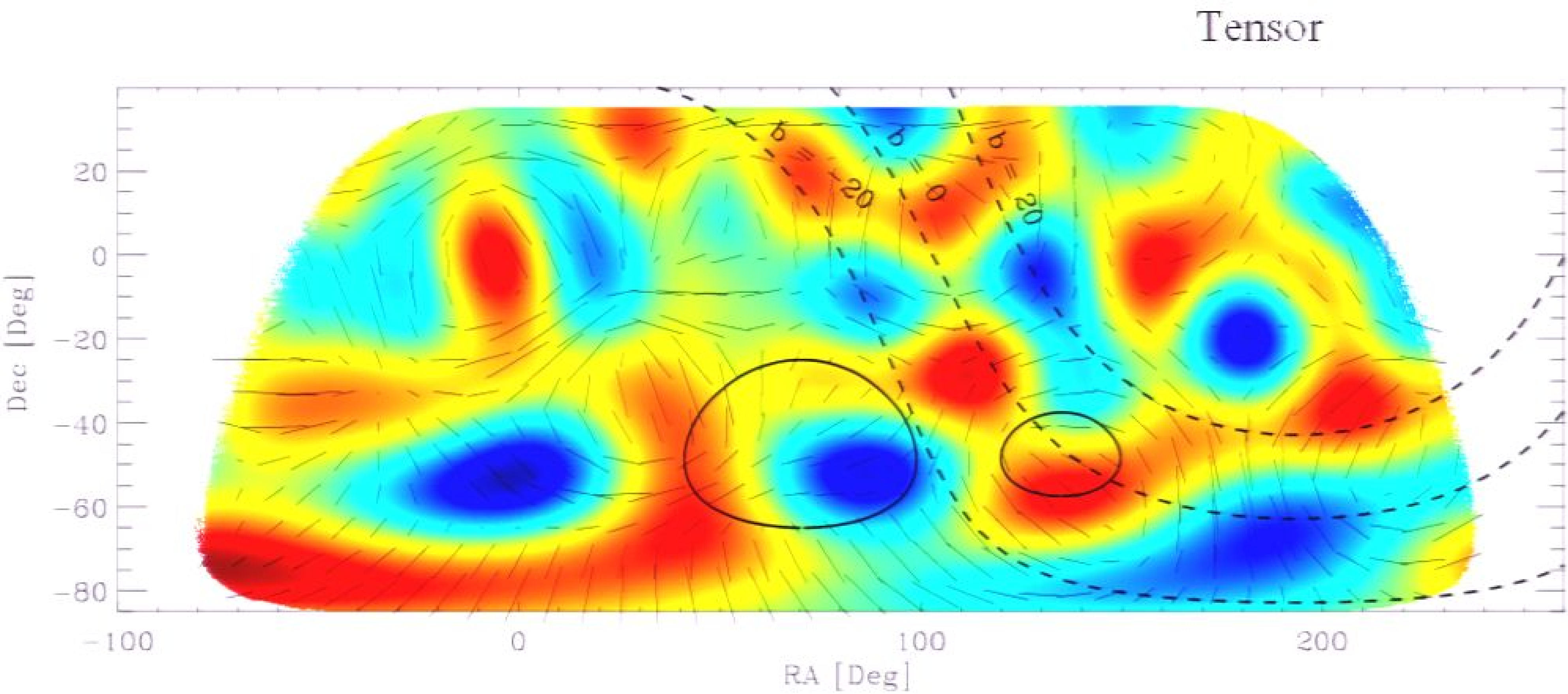

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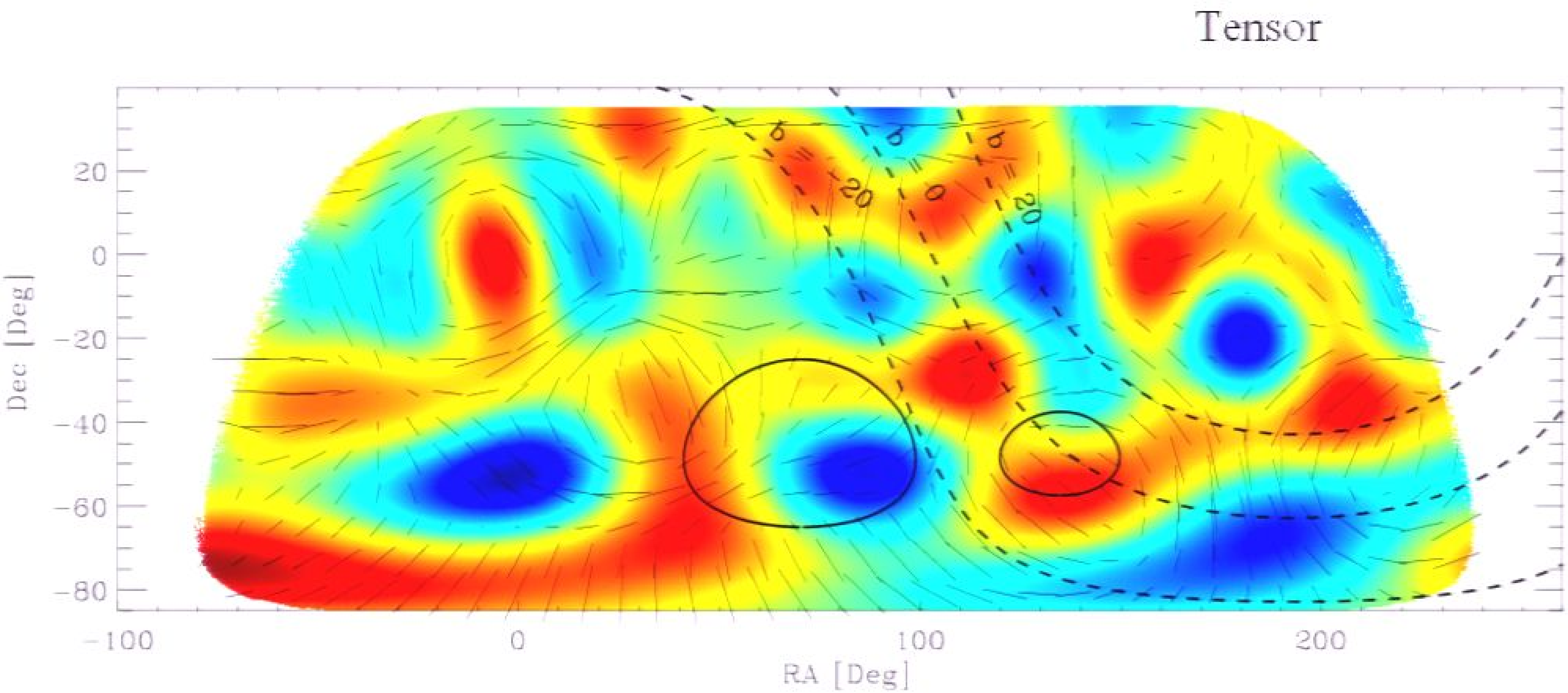


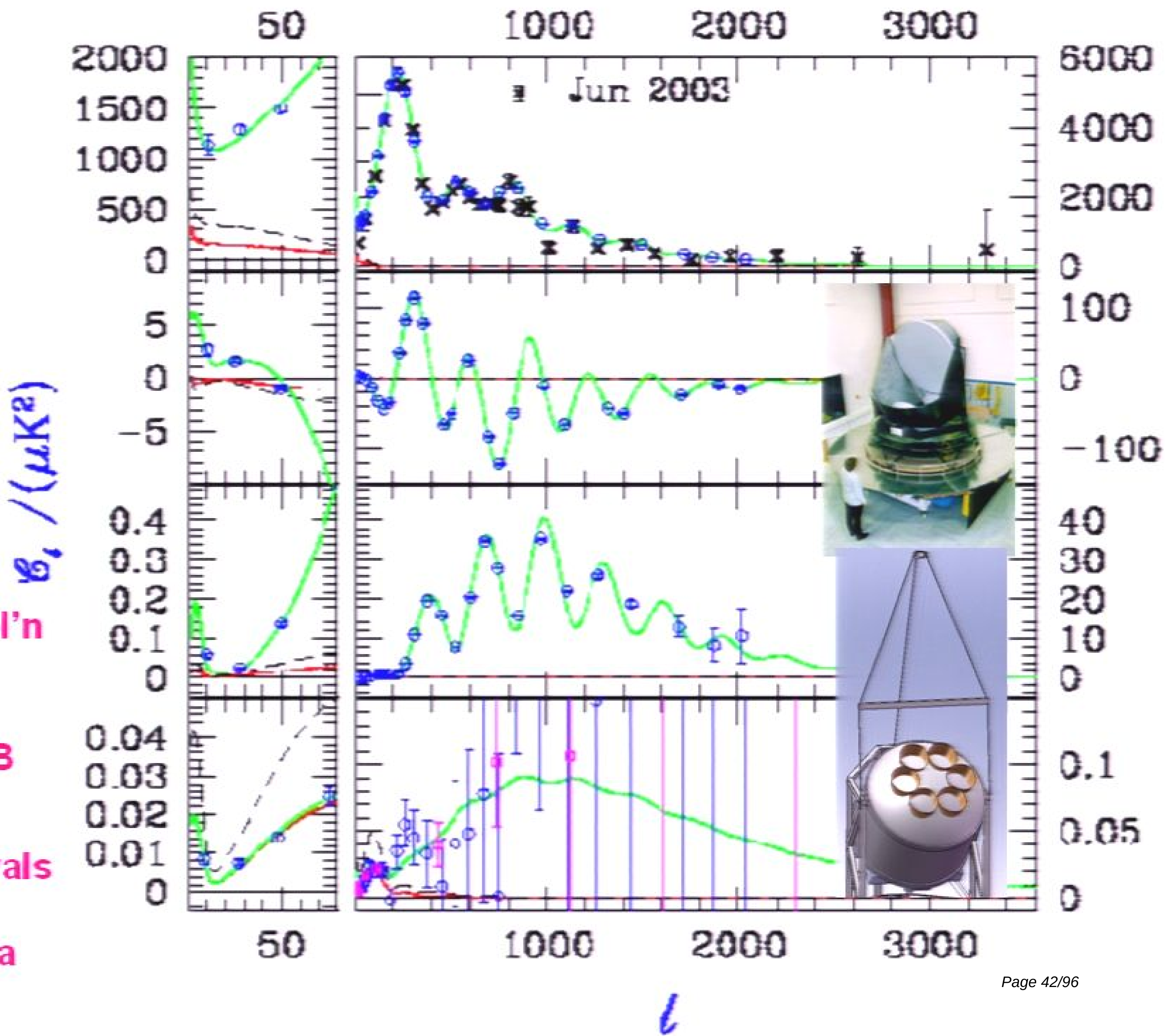
http://www.astro.caltech.edu/~lgg/spider_front.htm

forecast
Planck2.5

100&143

Spider10d

95&150



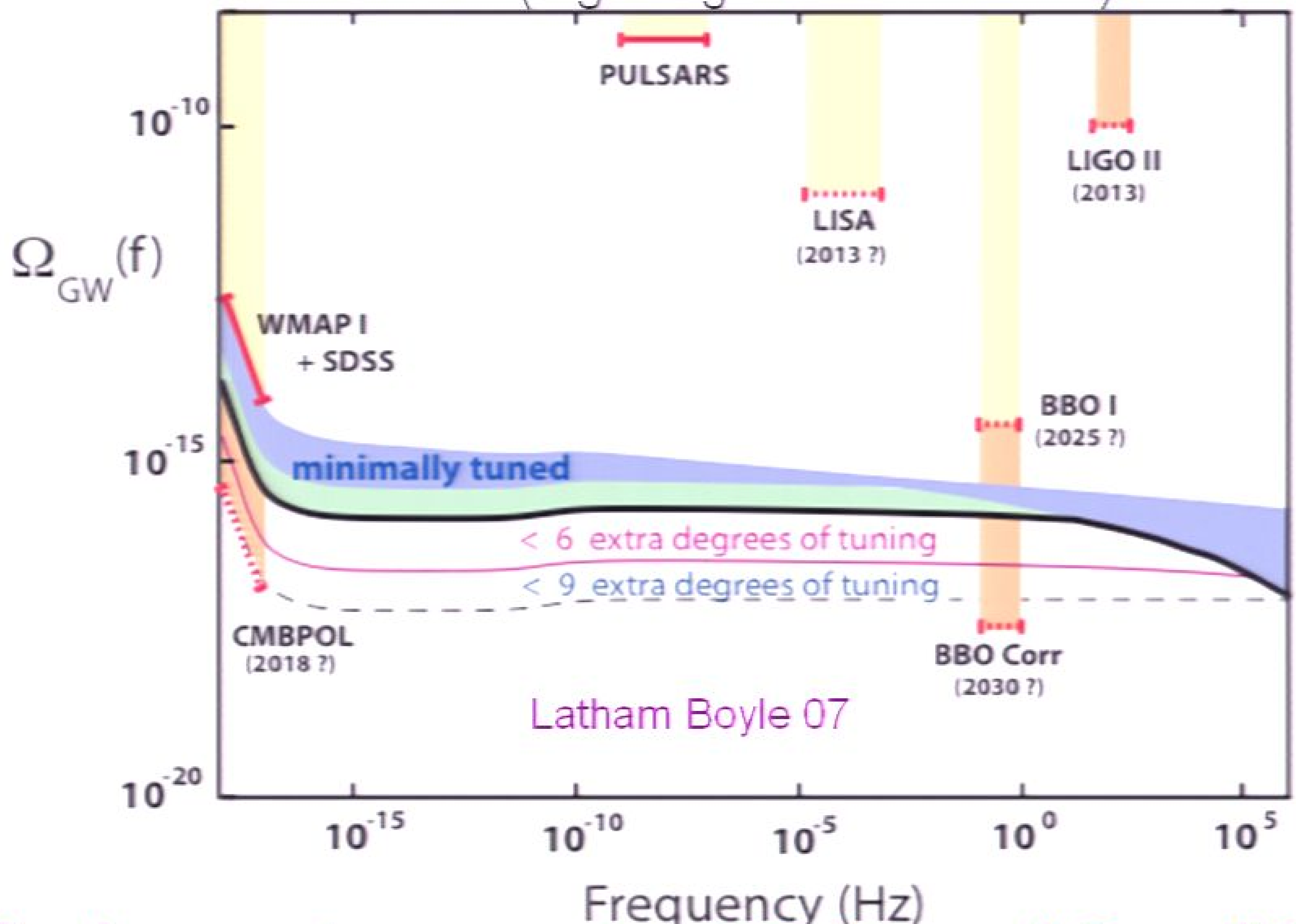
Synchrotron pol'n

Dust pol'n

are higher in B

Foreground Template removals from multi-frequency data is crucial

Very very difficult to get at with direct gravity wave detectors – even in our dreams (Big Bang Observer ~ 2030)



GW/scalar curvature: current from CMB+LSS: r < 0.6 or < 0.25 (.28) 95%;
good shot at 0.02 95% CL with BB polarization (+- .02 PL2.5+Spider), .01 target
BUT foregrounds/systematics?? But r-spectrum. But low energy inflation

Inflation in the context of ever changing fundamental theory

1980

R^2 -inflation

Old Inflation

New Inflation

Chaotic inflation

SUGRA inflation

Double Inflation

Power-law inflation

Extended inflation

1990

Natural inflation

Hybrid inflation

Assisted inflation

SUSY F-term inflation

SUSY D-term inflation

Brane inflation

2000

SUSY P-term inflation

Super-natural Inflation

K-flation

N-flation

DBI inflation

$D3-D7$ inflation

Tachyon inflation

Warped Brane inflation

Racetrack inflation

Roulette inflation Kahler moduli/axion

Power law (chaotic) potentials

$$V/M_P^4 \sim \lambda\,\psi^{2\nu},\;\; \psi = \phi/M_P\;\; 2^{-1/2}$$

$$\varepsilon = (\nu/\psi)^2,\quad \varepsilon = (\nu/2)/(N_I(k) + \nu/3),$$

$$n_s - 1 = -(\nu+1)/(N_I(k) - \nu/6),$$

$$n_t = -\nu/(N_I(k) - \nu/6),$$

$\nu=1,\ N_I \sim 60,\ \ \mathbf{r = 0.13,\ n_s = .967,\ n_t = -.017}$

$\nu=2,\ N_I \sim 60,\ \ \mathbf{r = 0.26,\ n_s = .950,\ n_t = -.034}$

$M_P^{-2} = 8\pi G$

PNGB: $V/M_P{}^4 \sim \Lambda_{red}{}^4 \sin^2(\psi/f_{red}\ 2^{-1/2})$

ABFFO93

$$n_s \sim 1 - f_{red}{}^{-2},$$

$$\varepsilon = (1-n_s)/2\ /(\exp[(1-n_s)\ N_I(k)]\ (1+(1-n_s)/6) - 1),$$

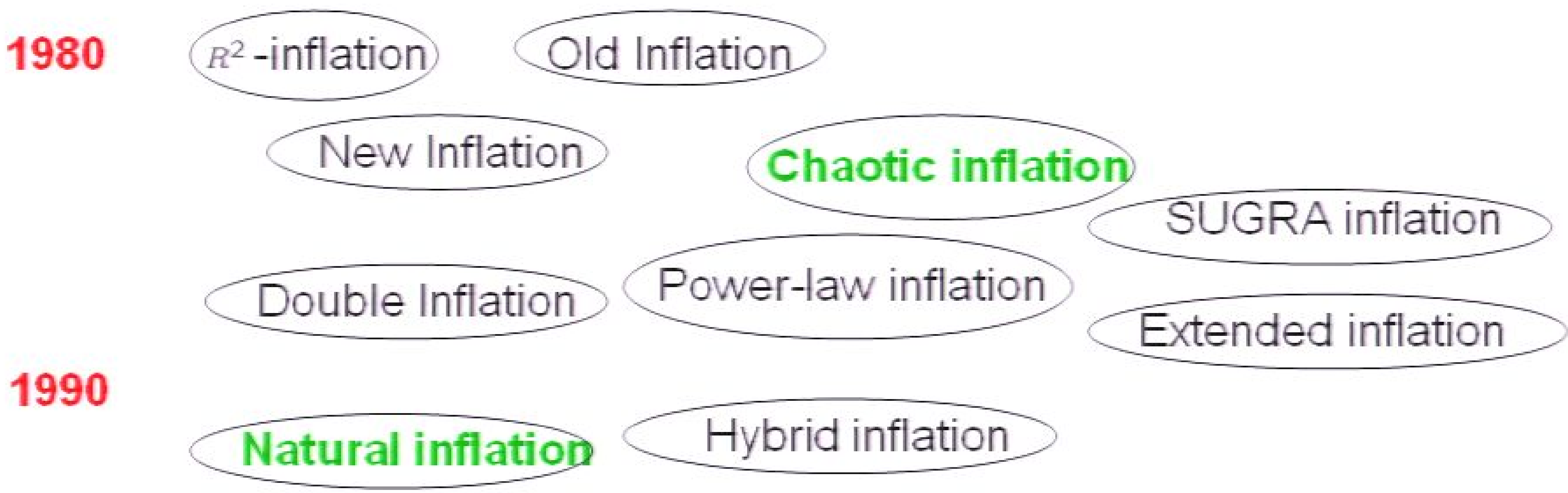
exponentially suppressed; higher **r** if lower N_I & $1-n_s$

to match $n_s = .96$, $f_{red} \sim 5$, $r \sim 0.032$

to match $n_s = .97$, $f_{red} \sim 5.8$, $r \sim 0.048$

cf. $\nu = 1$, $r = 0.13$, $n_s = .967$, $n_t = -.017$

Inflation in the context of ever changing fundamental theory



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cf. $\nu = 1$, $r = 0.13$, $n_s = .967$, $n_t = -.017$

Moduli/brane distance limitation in stringy inflation. Normalized canonical inflaton

$\Delta\psi < 1$ over $\Delta N \sim 50$, e.g. $2/n_{brane}^{1/2}$ BM06

$\varepsilon = (d\psi / d \ln a)^2$ so $r = 16\varepsilon < .007, <<?$

roulette inflation examples $r \sim 10^{-10}$ & $\Delta\psi < .002$

possible way out with many fields assisting: N-flation

$n_s = .97, f_{red} \sim 5.8, r \sim 0.048, \Delta\psi \sim 13$

cf. $\nu=1, r = 0.13, n_s = .967, \Delta\psi \sim 10$

cf. $\nu=2, r = 0.26, n_s = .95, \Delta\psi \sim 16$

energy scale of inflation & r

$$V/M_P^4 \sim P_s\, r \quad (1-\varepsilon/3)\ 3/2$$

$$V \sim (10^{16}\ \text{Gev})^4 \quad r/0.1 \quad (1-\varepsilon/3)$$

roulette inflation examples $V \sim (\text{few } x10^{13}\ \text{Gev})^4$

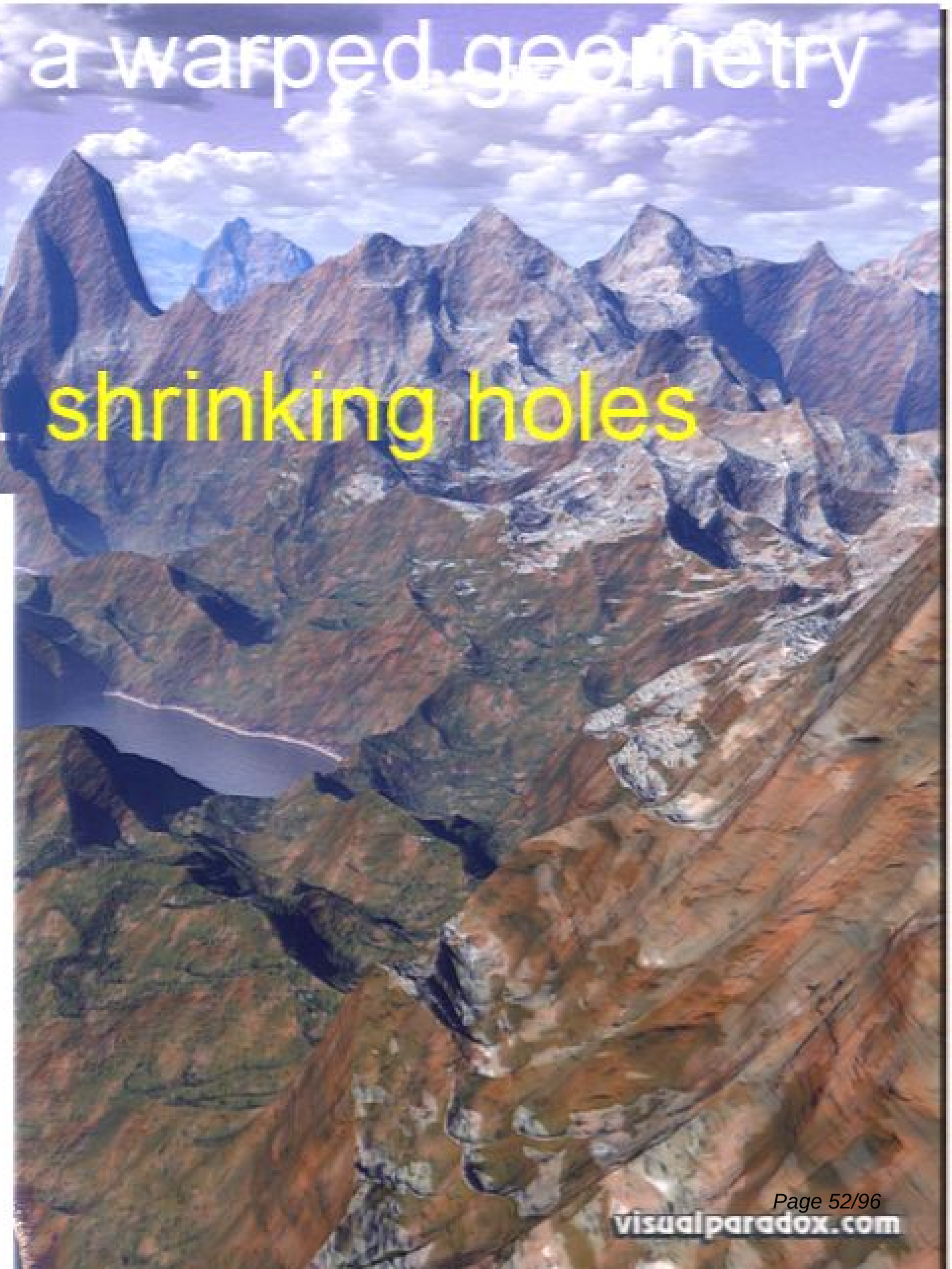
$$H/M_P \sim 10^{-5}\, (r/.1)^{1/2}$$

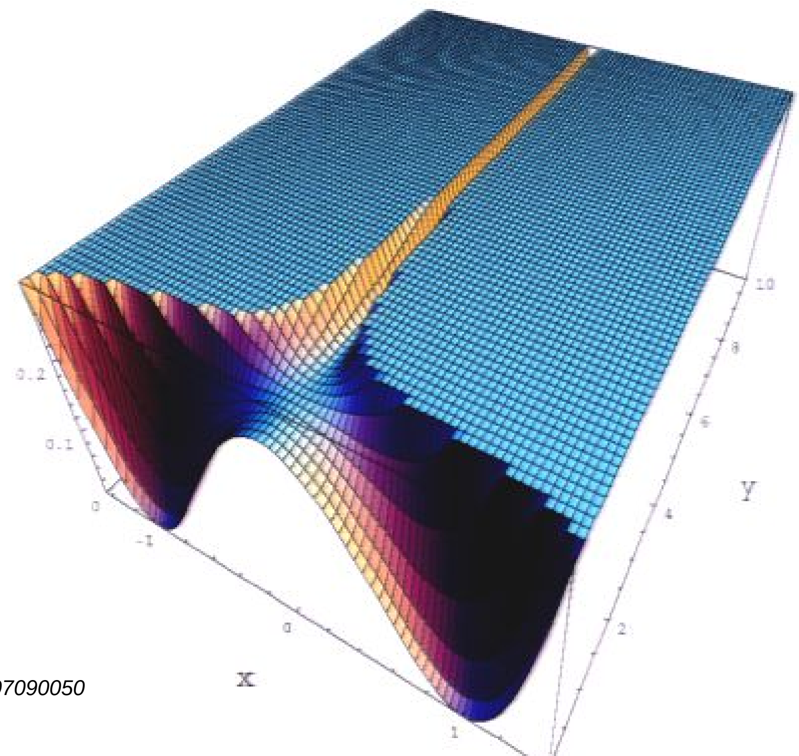
inflation energy scale cf. the gravitino mass (Kallosh & Linde 07) if a KKLT/largeV_{CY}-like generation mechanism

10^{13} Gev $(r/.01)^{1/2} \sim H < m_{3/2}$ cf. ~Tev

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

- D3/anti-D3 branes in a warped geometry
- D3/D7 branes
- axion/moduli fields ... shrinking holes





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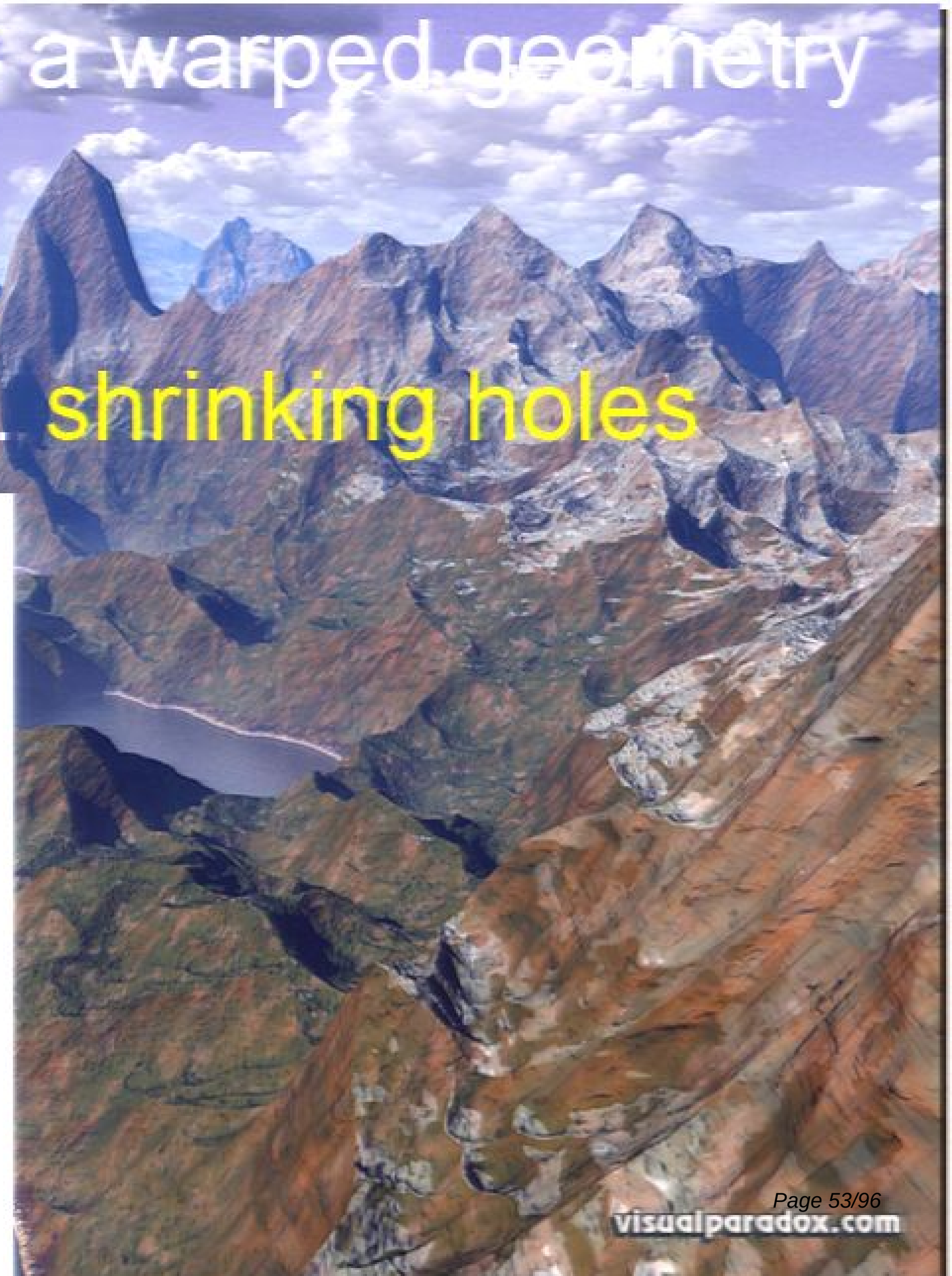
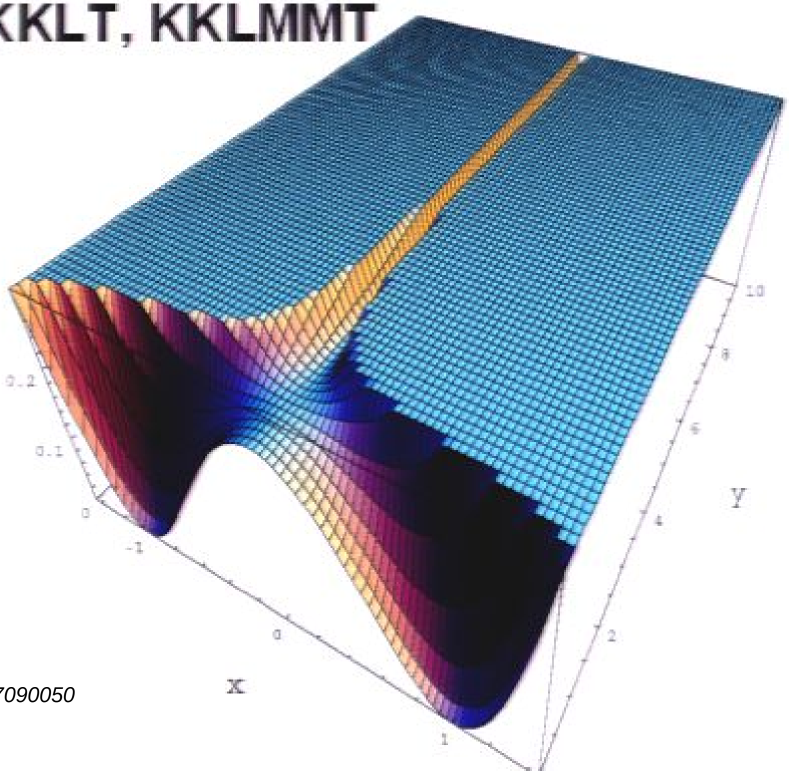


KKLT, KKLMMT



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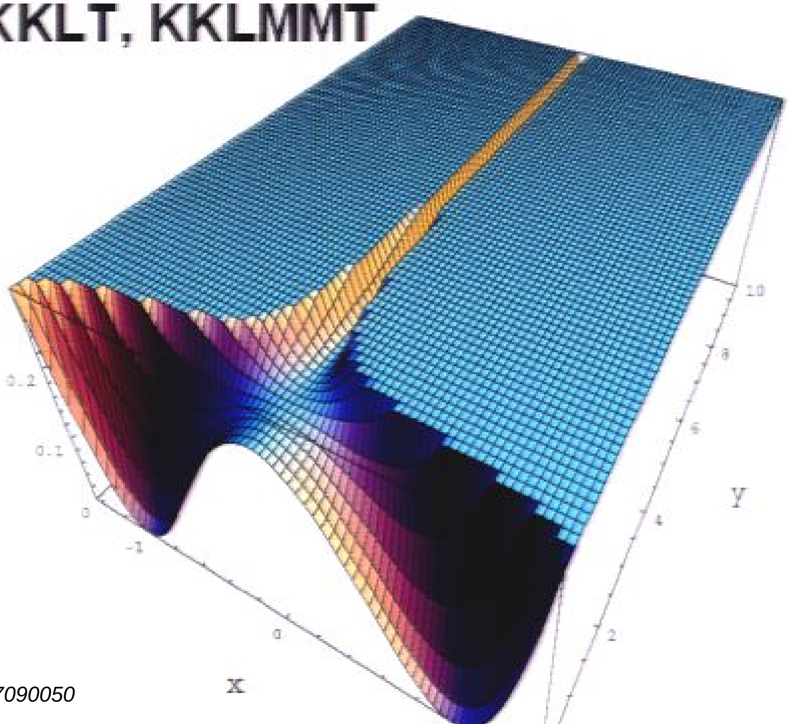

Hybrid D3/D7 Potential

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

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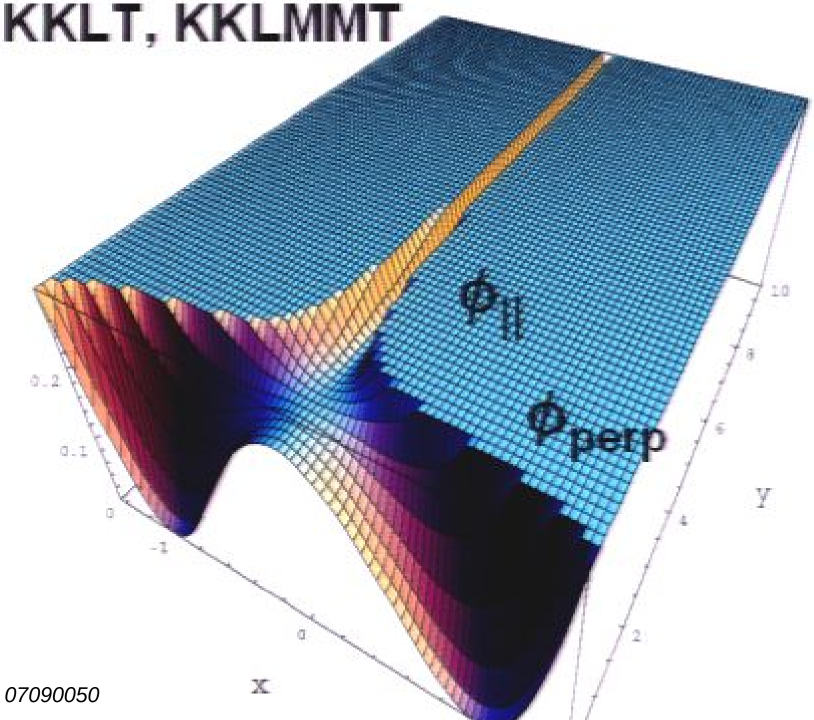

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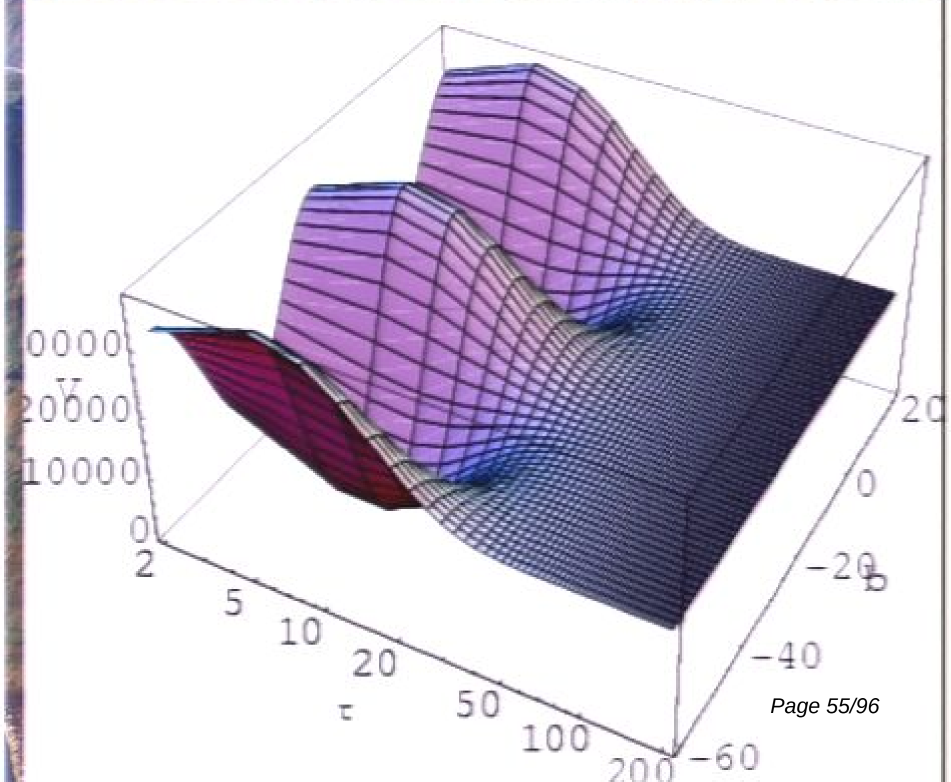

String Theory Landscape & Inflation++ Phenomenology for CMB+LSS

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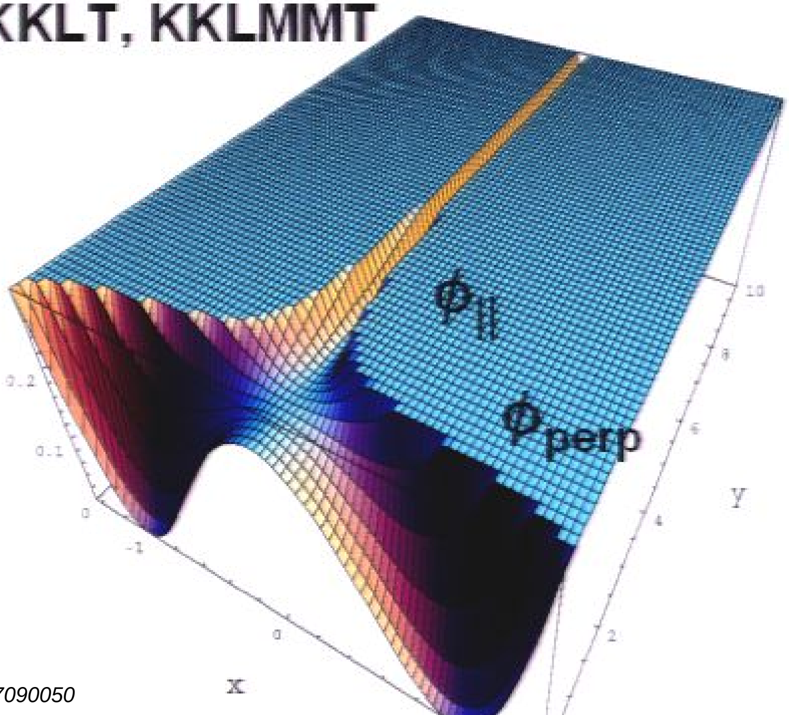

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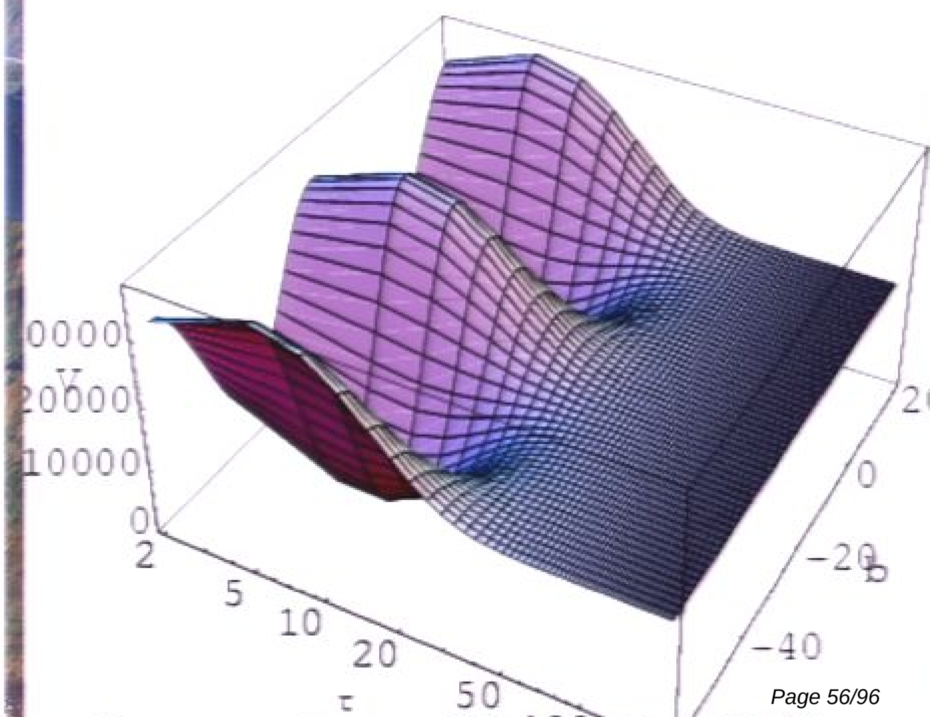

large volume 6D cct Calabi Yau

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

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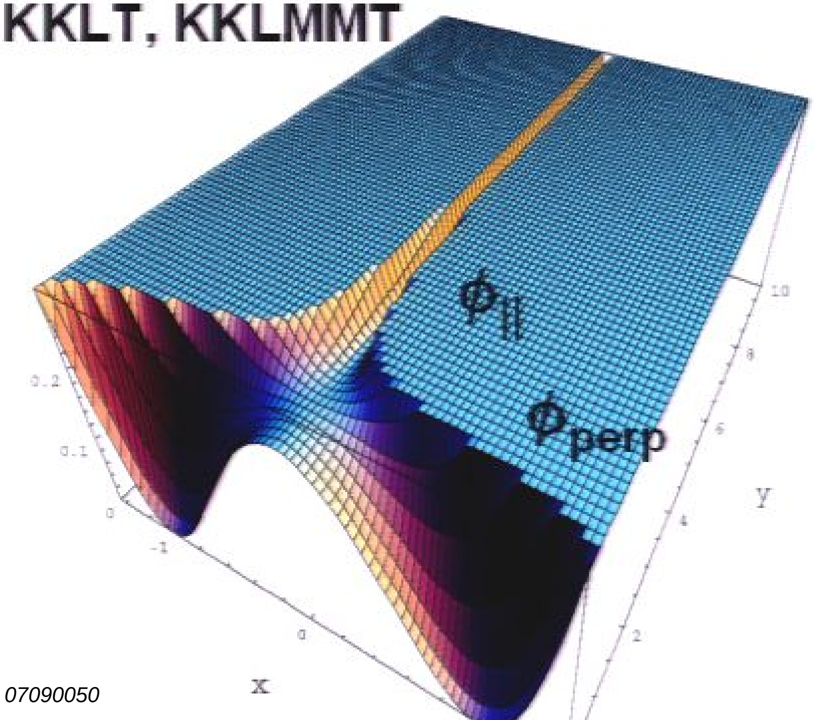
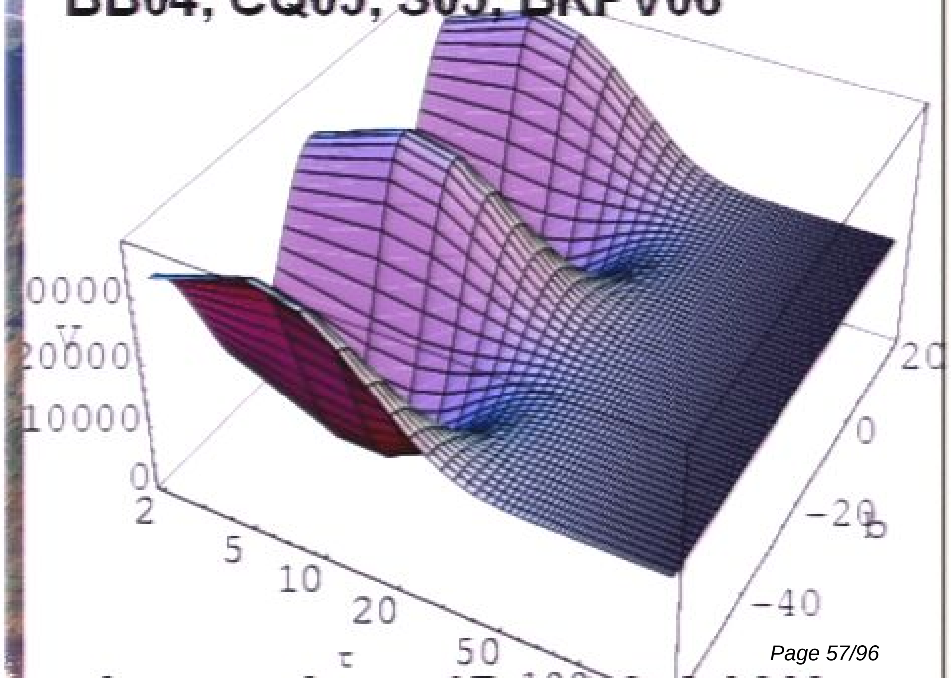


Hybrid D3/D7 Potential

BB04, CQ05, S05, BKPV06



large volume 6D cct Calabi Yau

Constraining Inflaton Acceleration Trajectories

Bond, Contaldi, Kofman & Vaudrevange 07

"path integral" over probability landscape of theory and data, with mode-function expansions of the paths truncated by an imposed smoothness (Chebyshev-filter) criterion [data cannot constrain high ln k frequencies]

$P(\text{trajectory}|\text{data, th}) \sim P(\ln H_p, \varepsilon_k|\text{data, th})$

$\sim P(\text{data}|\ln H_p, \varepsilon_k)\ P(\ln H_p, \varepsilon_k | \text{th})\quad / P(\text{data}|\text{th})$

Likelihood theory prior / evidence

Data:

CMBall

(WMAP3,B03,CBI, ACBAR,

DASI,VSA,MAXIMA)

+

LSS (2dF, SDSS, σ_8[lens])

Theory prior

uniform in $\ln H_p, \varepsilon_k$

(equal a-prior probability hypothesis)

Nodal points cf. Chebyshev coefficients (linear combinations)

uniform in / log in / monotonic in ε_k

The theory prior matters a lot for current data. Not quite as much for a Bpol future.

We have tried many theory priors

Old view: Theory prior = delta function of THE correct one and only theory

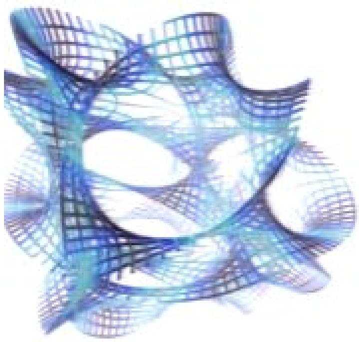
New view: Theory prior = probability distribution on an energy landscape whose features are at best only glimpsed, huge number of potential minima, inflation the late stage flow in the low energy structure toward these minima. Critical role of collective geometrical coordinates (moduli fields) and of brane and antibrane "moduli" (D3,D7).

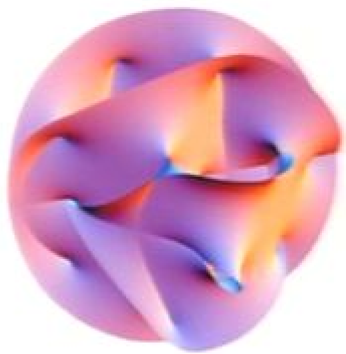
Roulette Inflation: Ensemble of Kahler Moduli/Axion Inflations

Bond, Kofman, Prokushkin & Vaudrevange 06

A Theory prior in a class of inflation theories that seem to work

Low energy landscape dominated by the last few (complex) moduli fields T_1 T_2 T_3 .. U_1 U_2 U_3 .. associated with the settling down of the compactification of extra dims





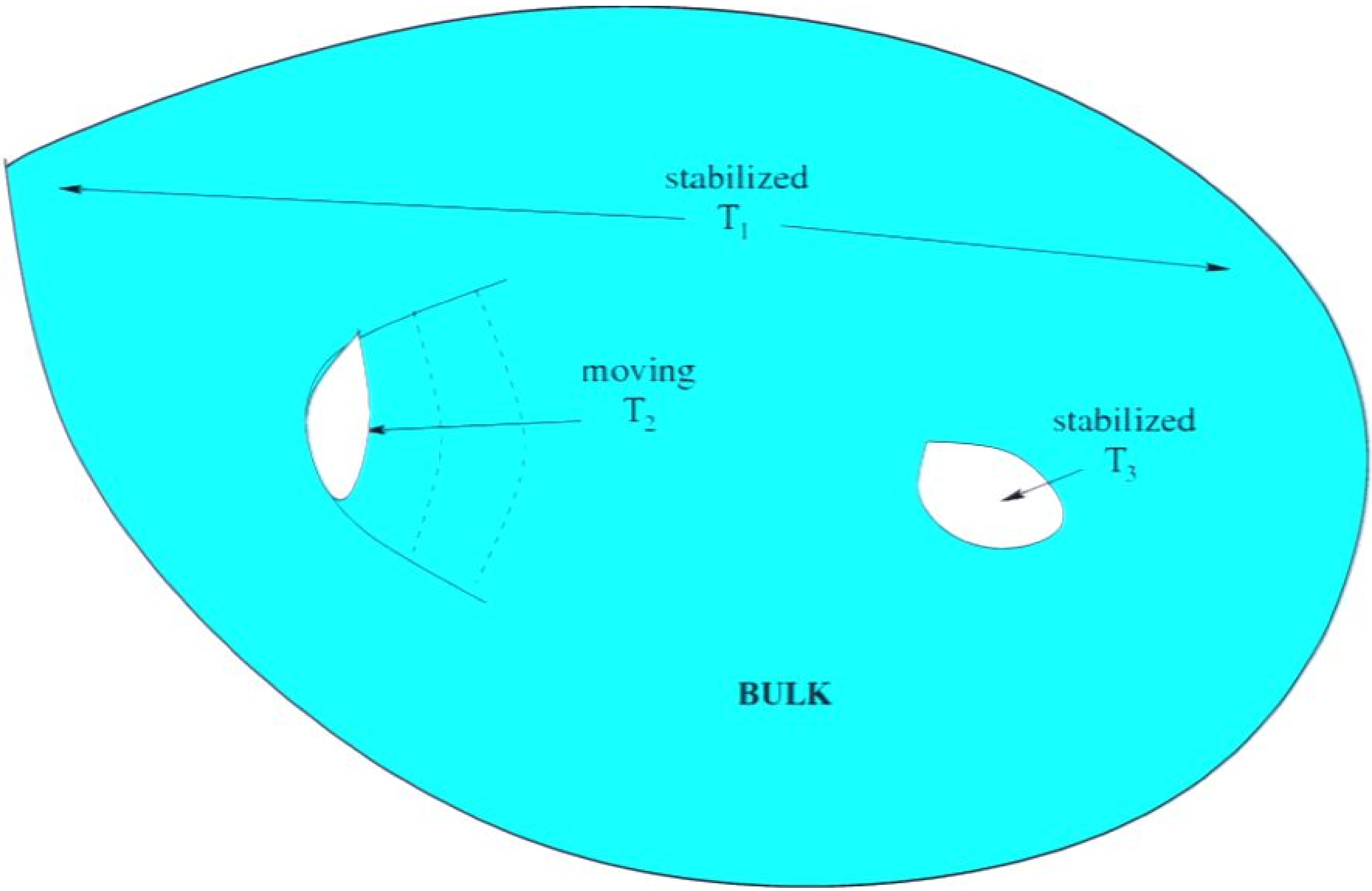
CY are compact Ricci-flat Kahler mfds

Kahler are Complex mfds with a hermitian metric & 2-form associated with the metric is closed (2nd derivative of a Kahler potential)

(complex) Kahler modulus associated with a 4-cycle volume in 6 dimensional Calabi Yau compactifications in Type IIB string theory. Real & imaginary parts are both important.

Builds on the influential KKLT, KKLMMT moduli-stabilization ideas for stringy inflation and the focus on 4-cycle Kahler moduli in large volume limit of IIB flux compactifications. Balasubramanian, Berglund 2004, + Conlon, Quevedo 2005, + Suruliz 2005 As motivated as any stringy inflation model. Many possibilities:

Theory prior ~ probability of trajectories given potential parameters of the collective coordinates X probability of the potential parameters X probability of initial conditions



Stabilization from 3rd … nth field $T_3 \ldots T_n$

$\Rightarrow$ uniform (?) distribution of initial values of (τ, θ)

. P. Conlon, C. H. Kom, K. Suruliz, B. C. Allanach, F. Quevedo

arXiv:0704.3403v1 [hep-ph] 25 Apr 2007

Sparticle Spectra and LHC Signatures for Large Volume String Compactifications

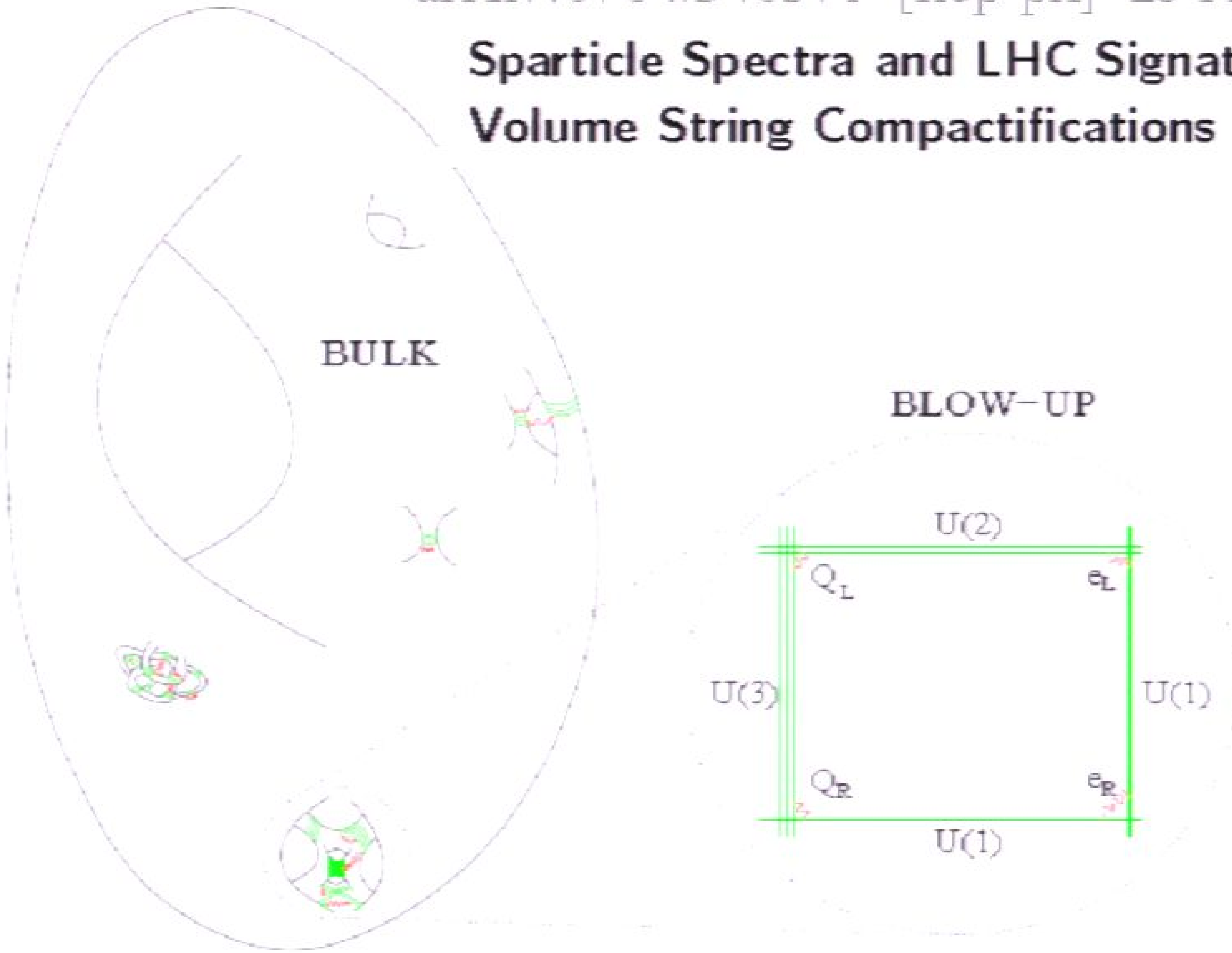
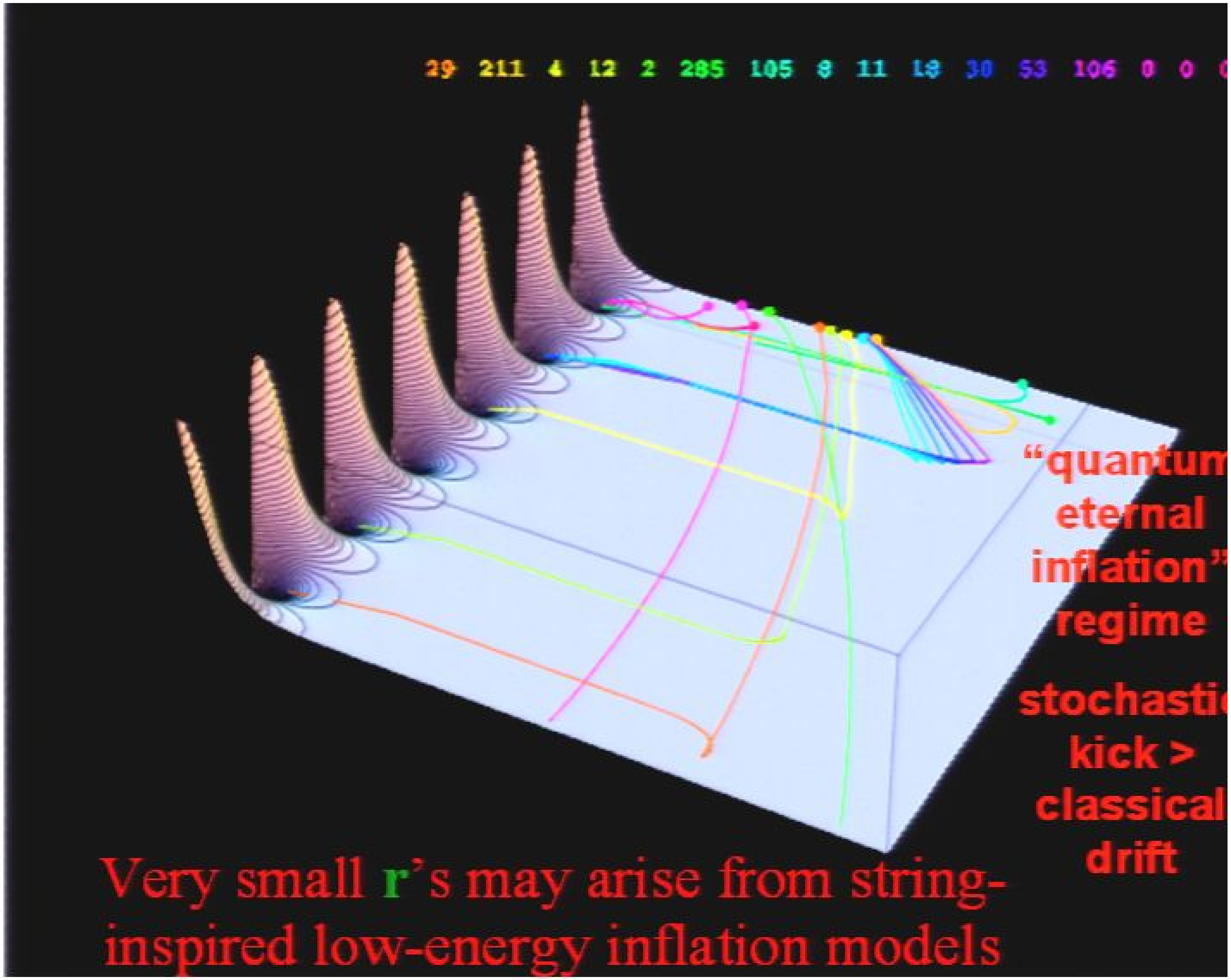


Figure 1: The physical picture: Standard Model matter is supported on a small blow-up cycle located within the bulk of a very large Calabi-Yau. The volume of the Calabi-Yau sets the gravitino mass and is responsible for the weak/Planck hierarchy.

Roulette:

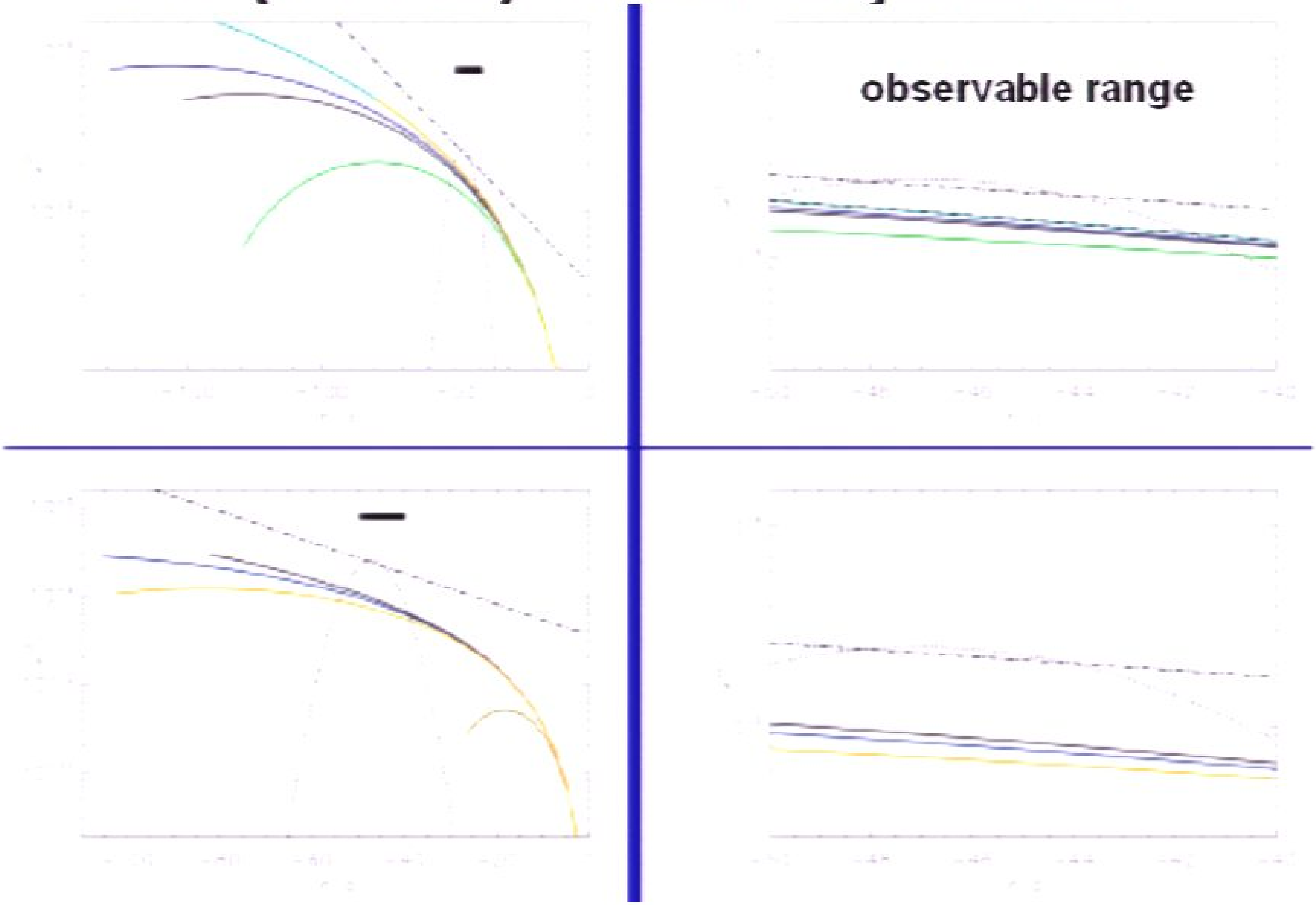
which minimum for the rolling ball depends upon the throw; but which roulette wheel we play is chance too.

The 'house' does not just play dice with the world.



$$V(\tau,\theta) = \frac{8(a_2A_2)^2\sqrt{\tau}e^{-2a_2\tau}}{3\alpha\lambda_2\mathcal{V}_s} + \frac{4W_0a_2A_2\tau e^{-a_2\tau}\cos(a_2\theta)}{\mathcal{V}_s^2} + \frac{3W_0^2\xi}{4\mathcal{V}_s^3} + V_{\rm uplift}$$

Ps (ln Ha) Kahler trajectories



Template $P_S \propto k^{n_s - 1}$ with a) dash-dot: $n_s = 0.95,\ n_{\rm run} = 0$

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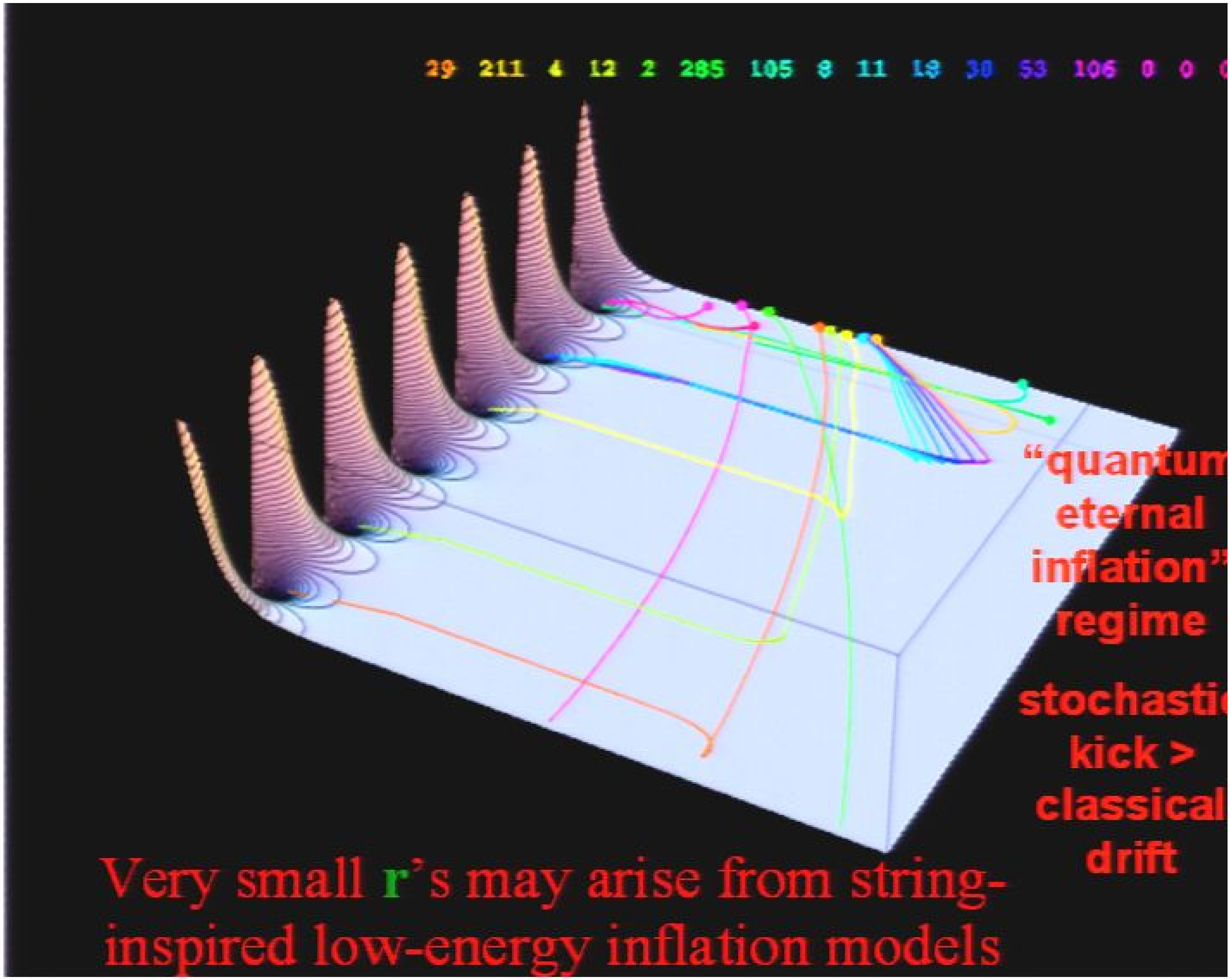

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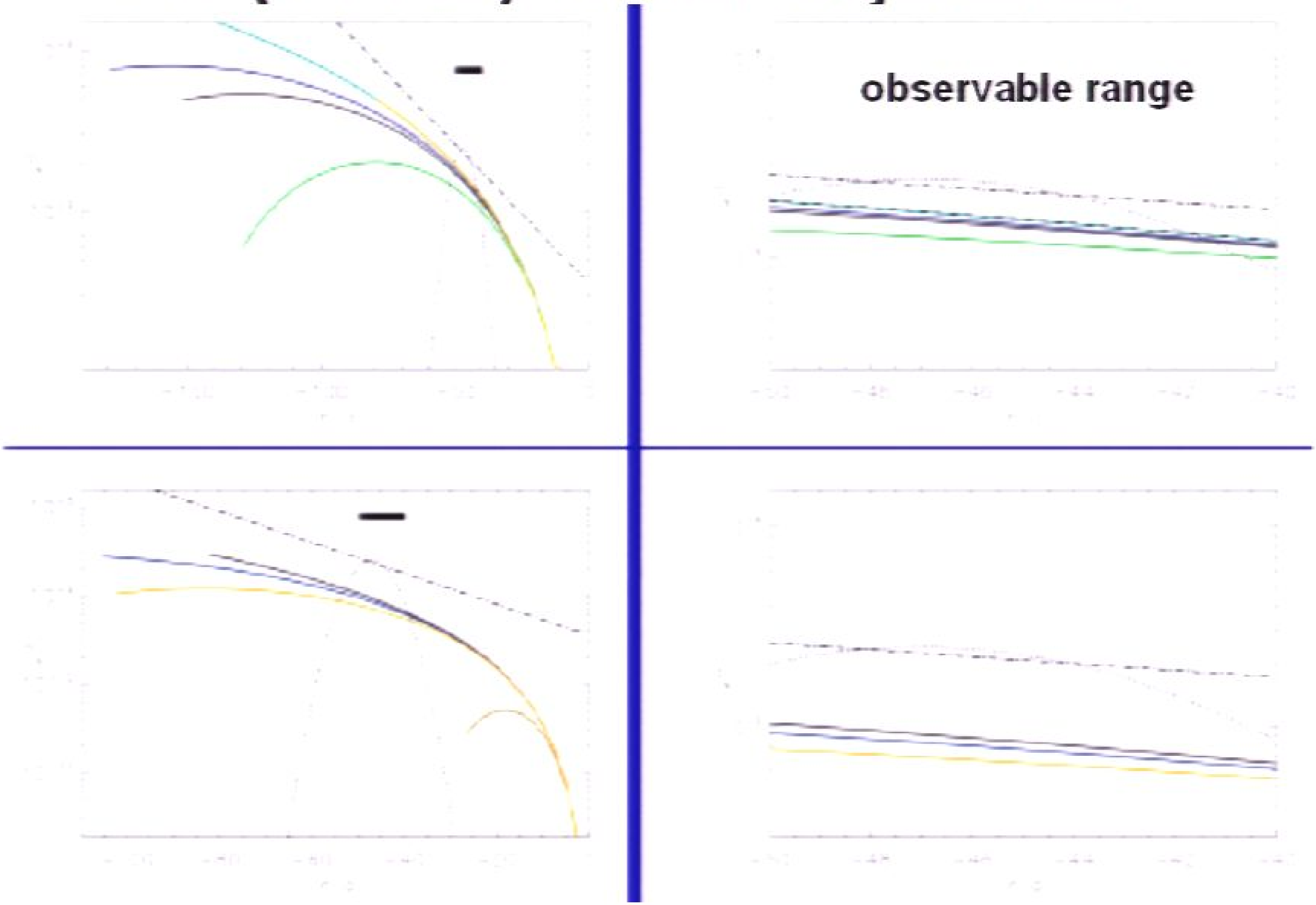
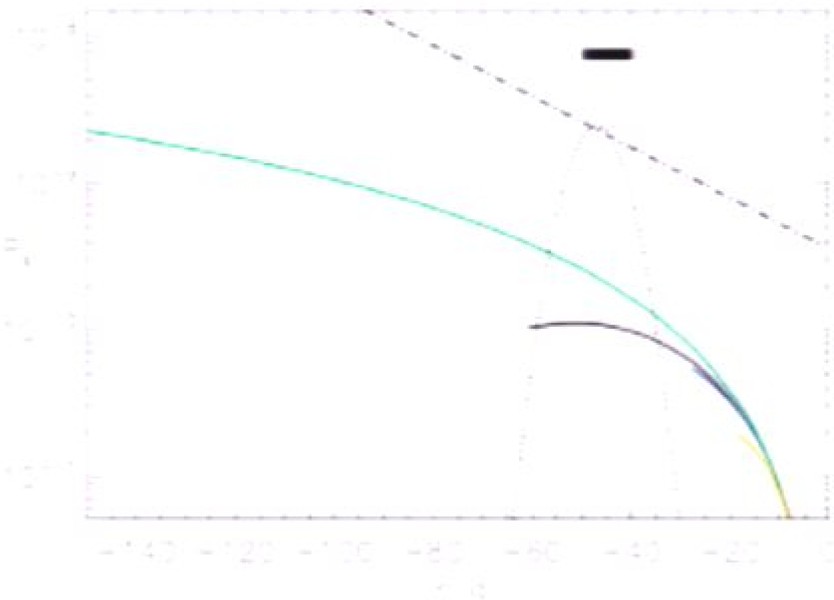
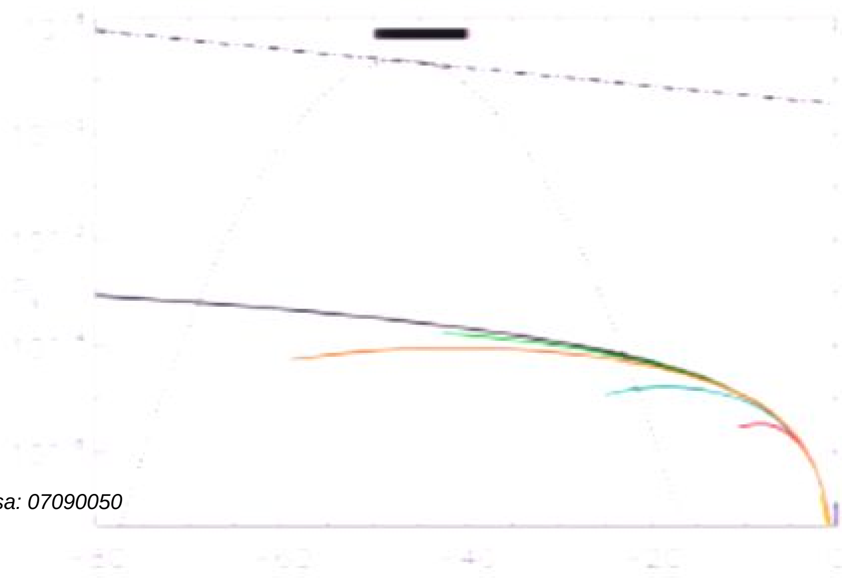
*P*s (ln Ha) Kahler trajectories



Template $P_S \propto k^{n_s-1}$ with a) dash-dot: $n_s = 0.95$, $n_{\rm run} = 0$
b) dotted:

Ps (ln Ha) Kahler trajectories





It is much easier to get models which do not agree with observations. Here the amplitude is off.

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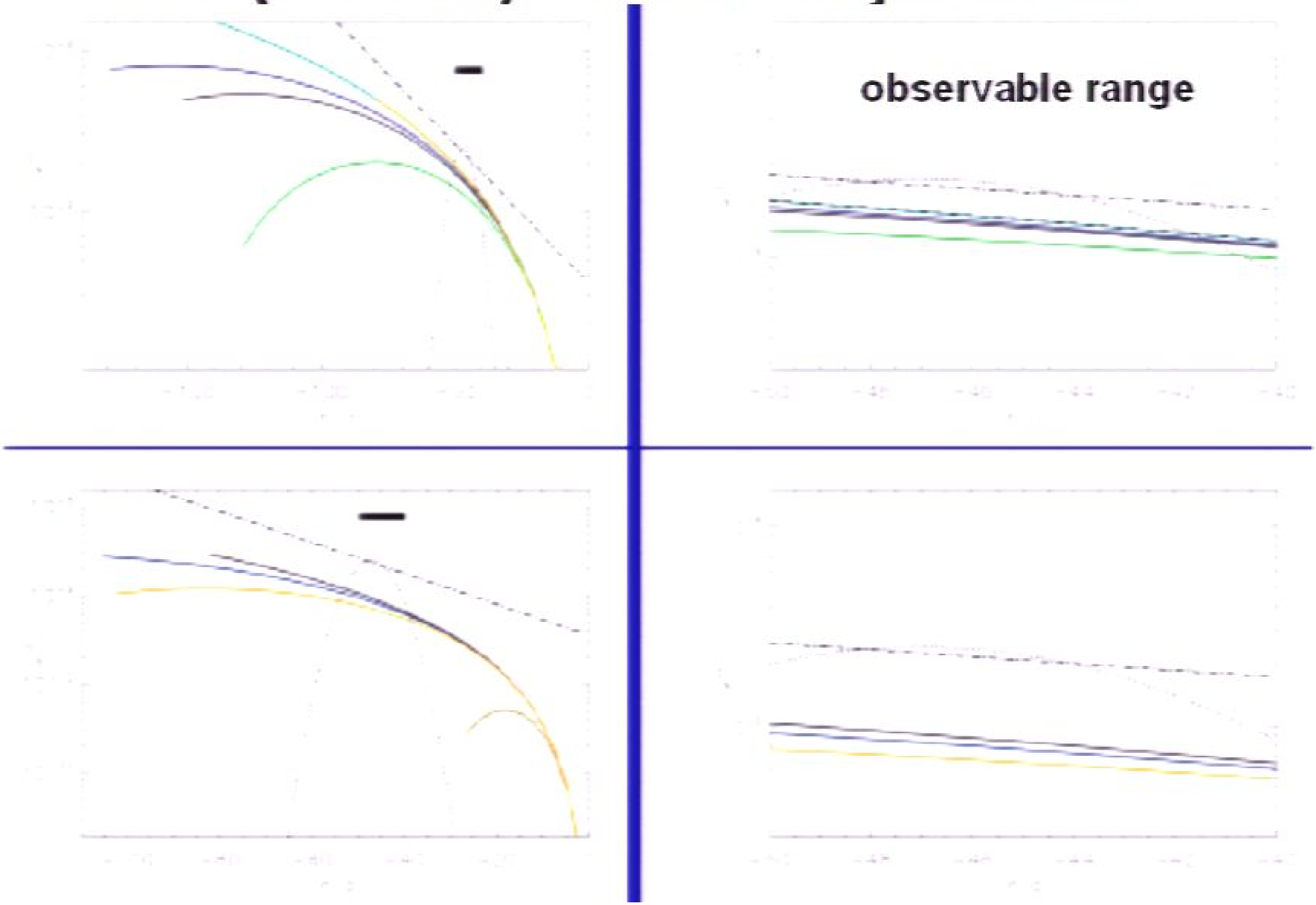

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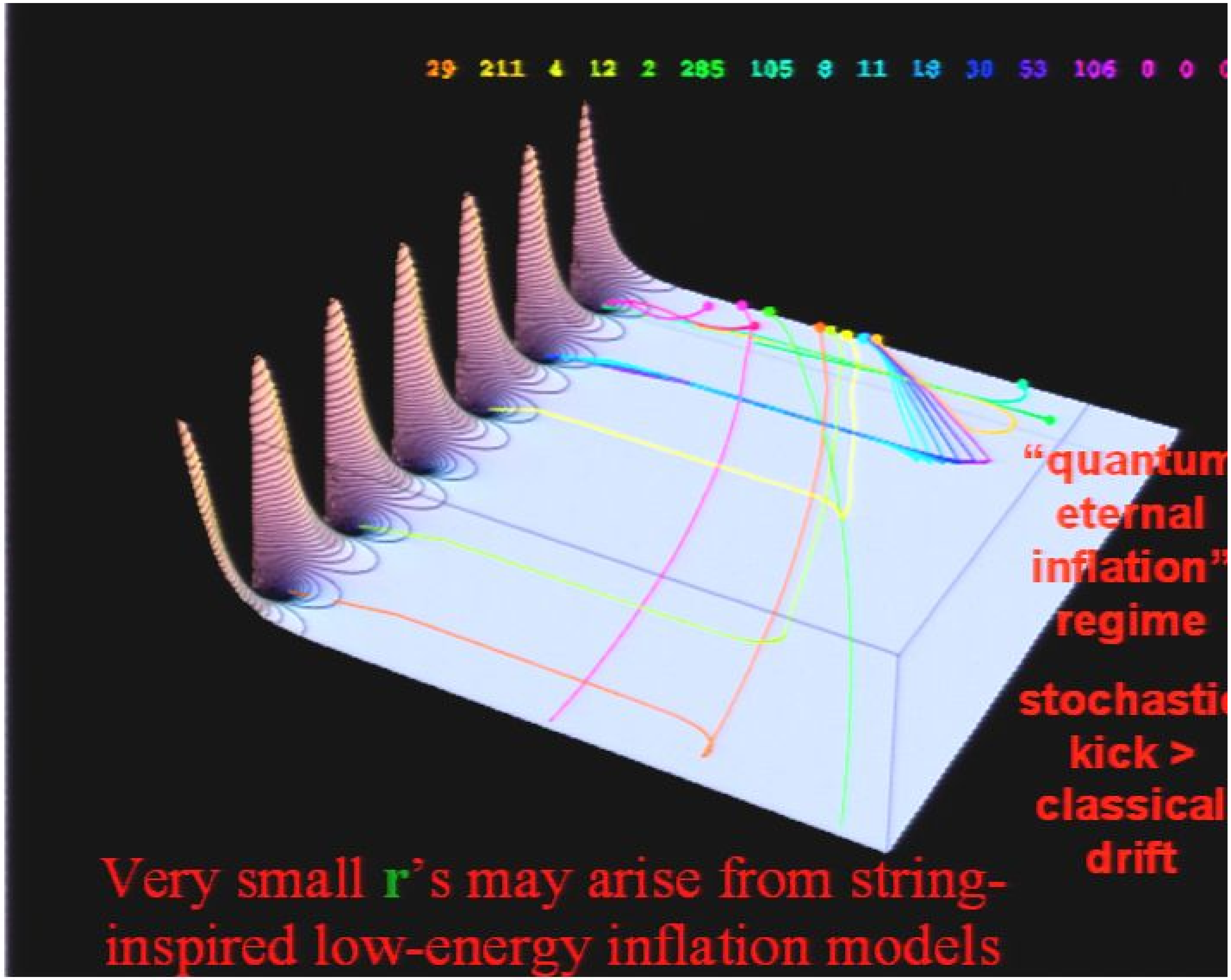

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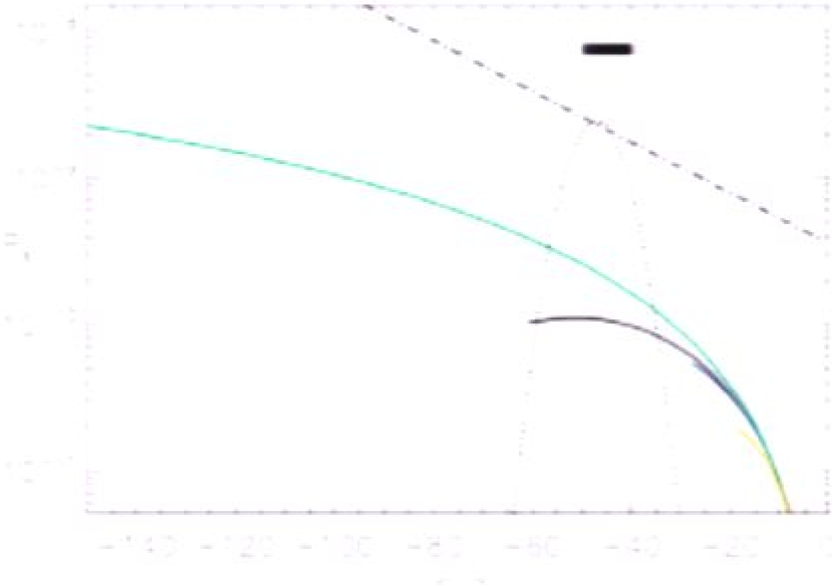
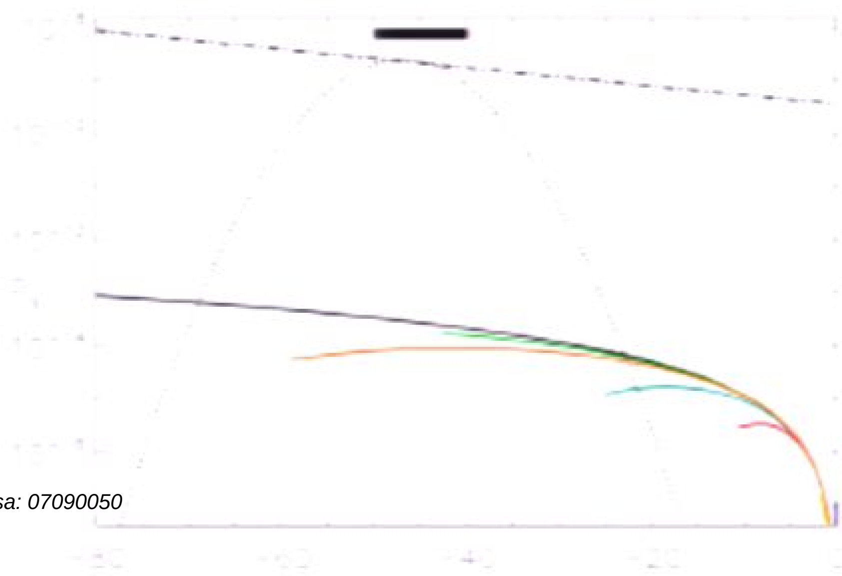
Ps (ln Ha) Kahler trajectories





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Ω_k

New Parameters of Cosmic Structure Formation

$\Omega_b h^2$

$\theta \sim \ell_s^{-1}, \;\; cf. \Omega_\Lambda$

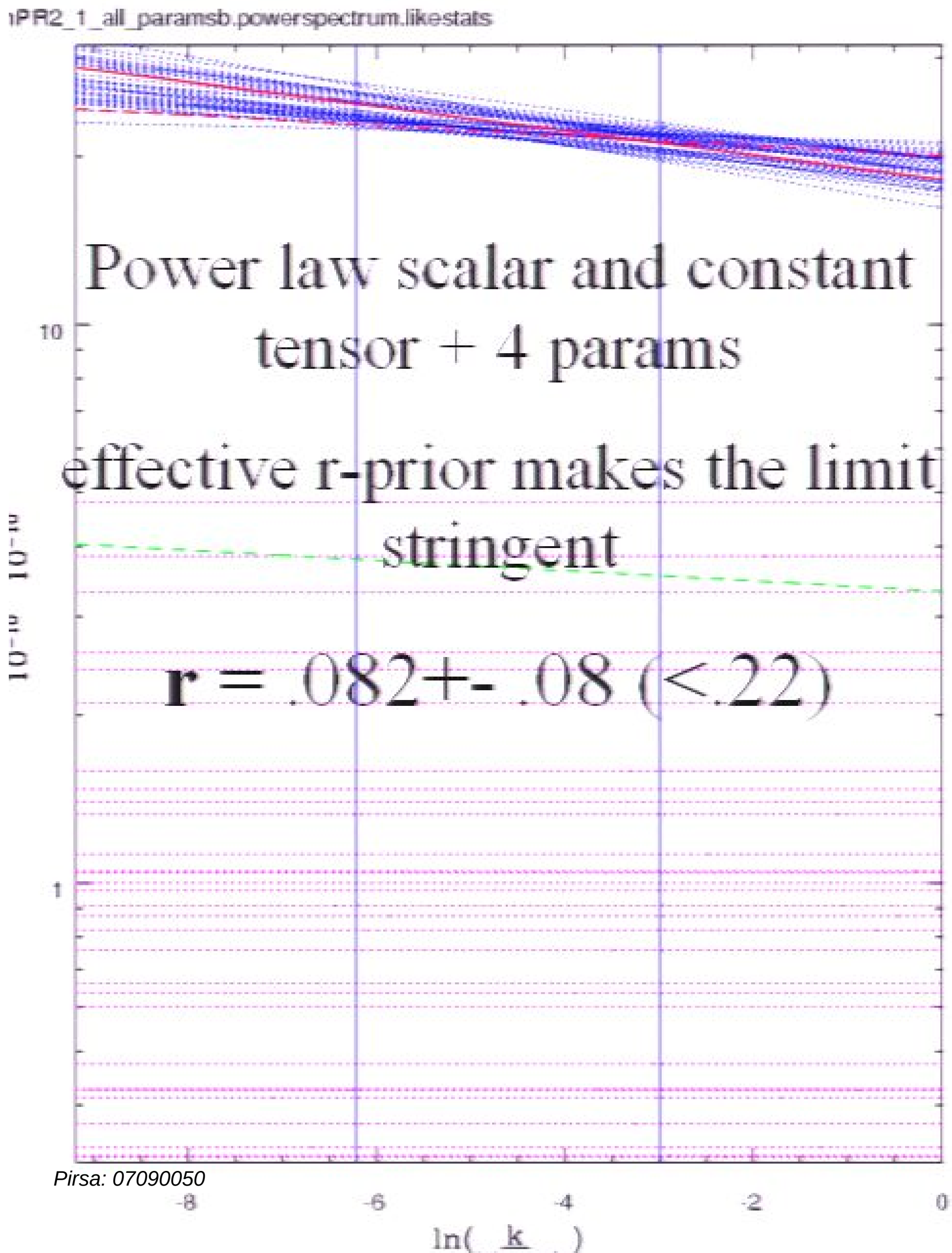
$\ln \mathcal{P}_t(k)$

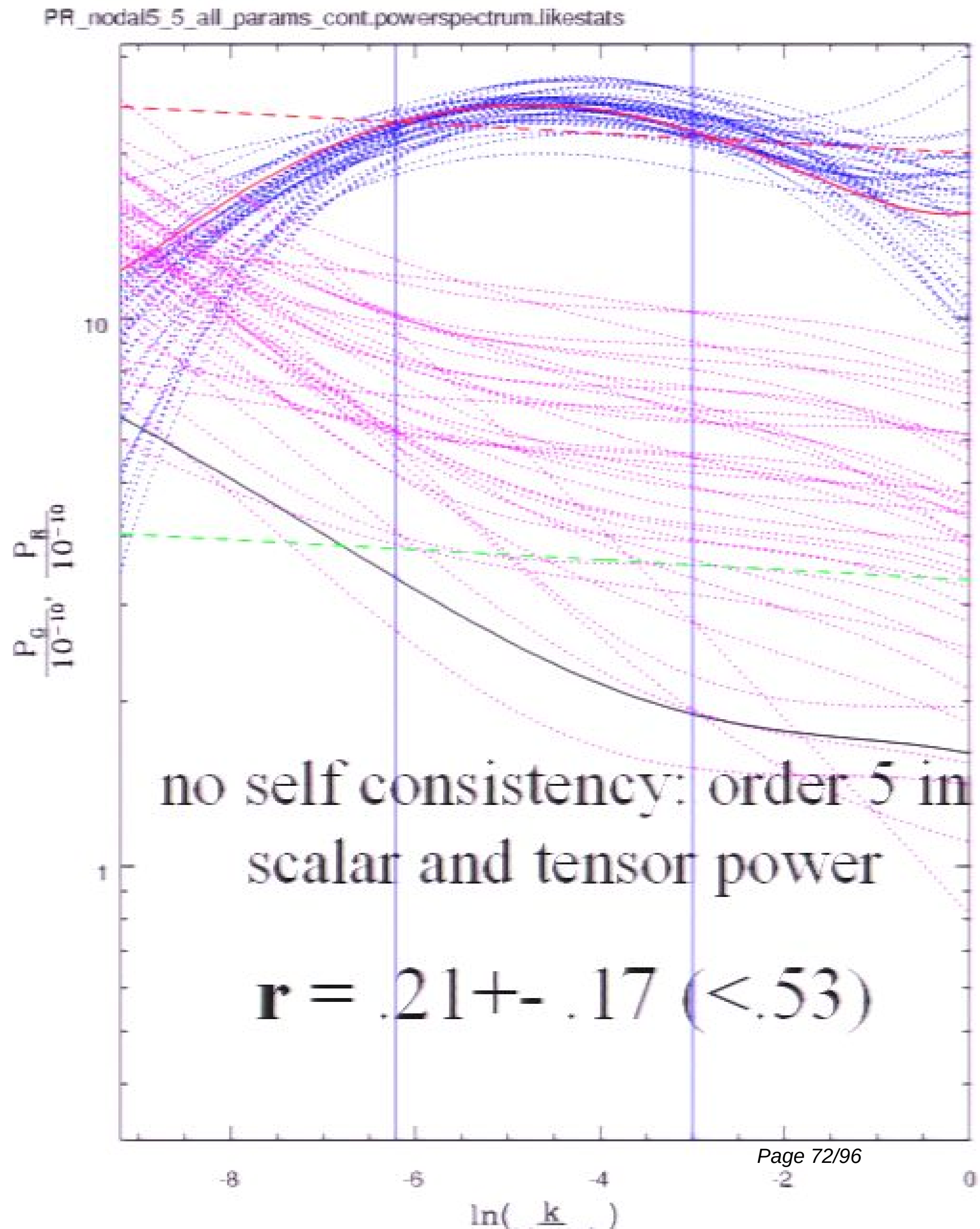
$\Omega_{dm} h^2$

$\ln \mathcal{P}_s(k)$

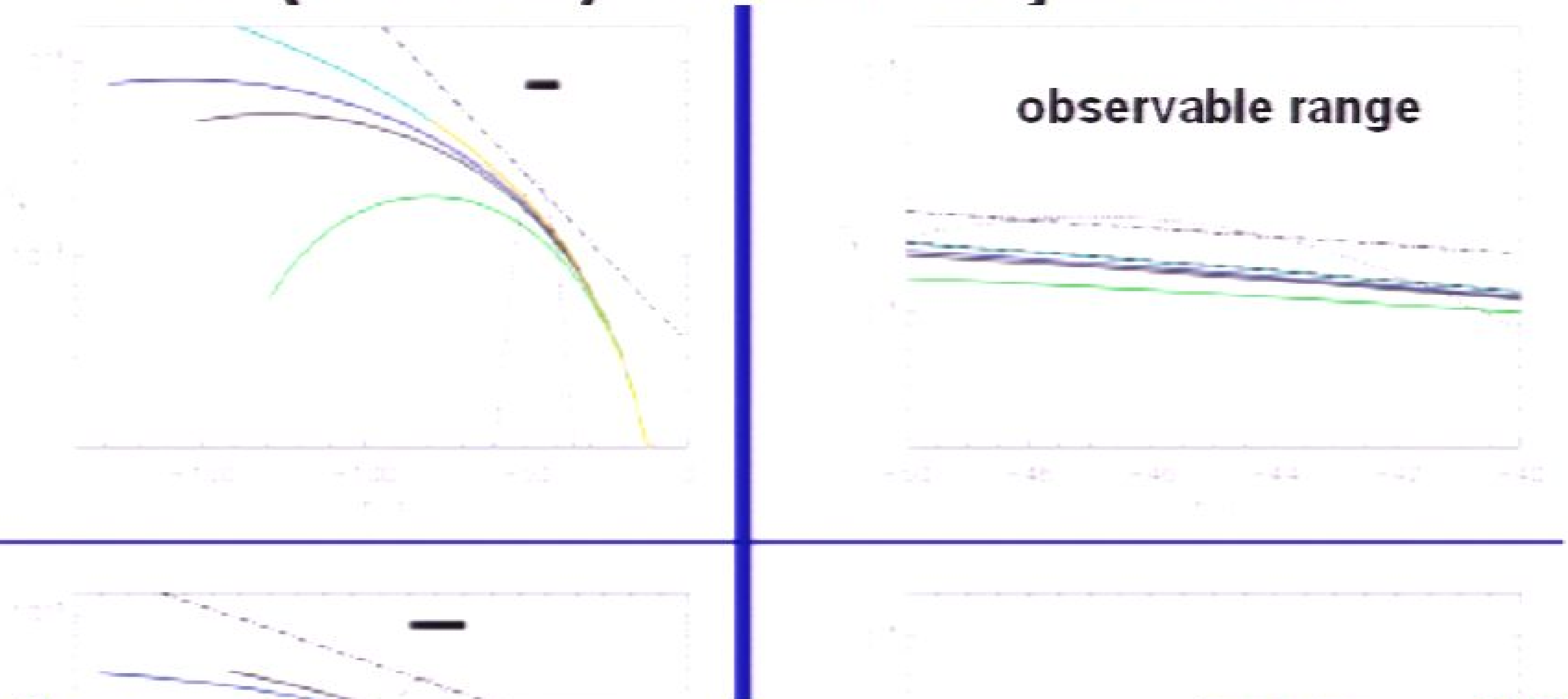
τ_C

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





*P*s (ln Ha) Kahler trajectories



play dice with the world.

drift

Very small r's may arise from string-inspired low-energy inflation models

$$V(\tau,\theta)=\frac{8(a_2A_2)^2\sqrt{\tau}e^{-2a_2\tau}}{3\alpha\lambda_2\mathcal{V}_s}+\frac{4W_0a_2A_2\tau e^{-a_2\tau}\cos(a_2\theta)}{\mathcal{V}_s^2}+\frac{3W_0^2\xi}{4\mathcal{V}_s^3}+V_{\rm uplift}$$

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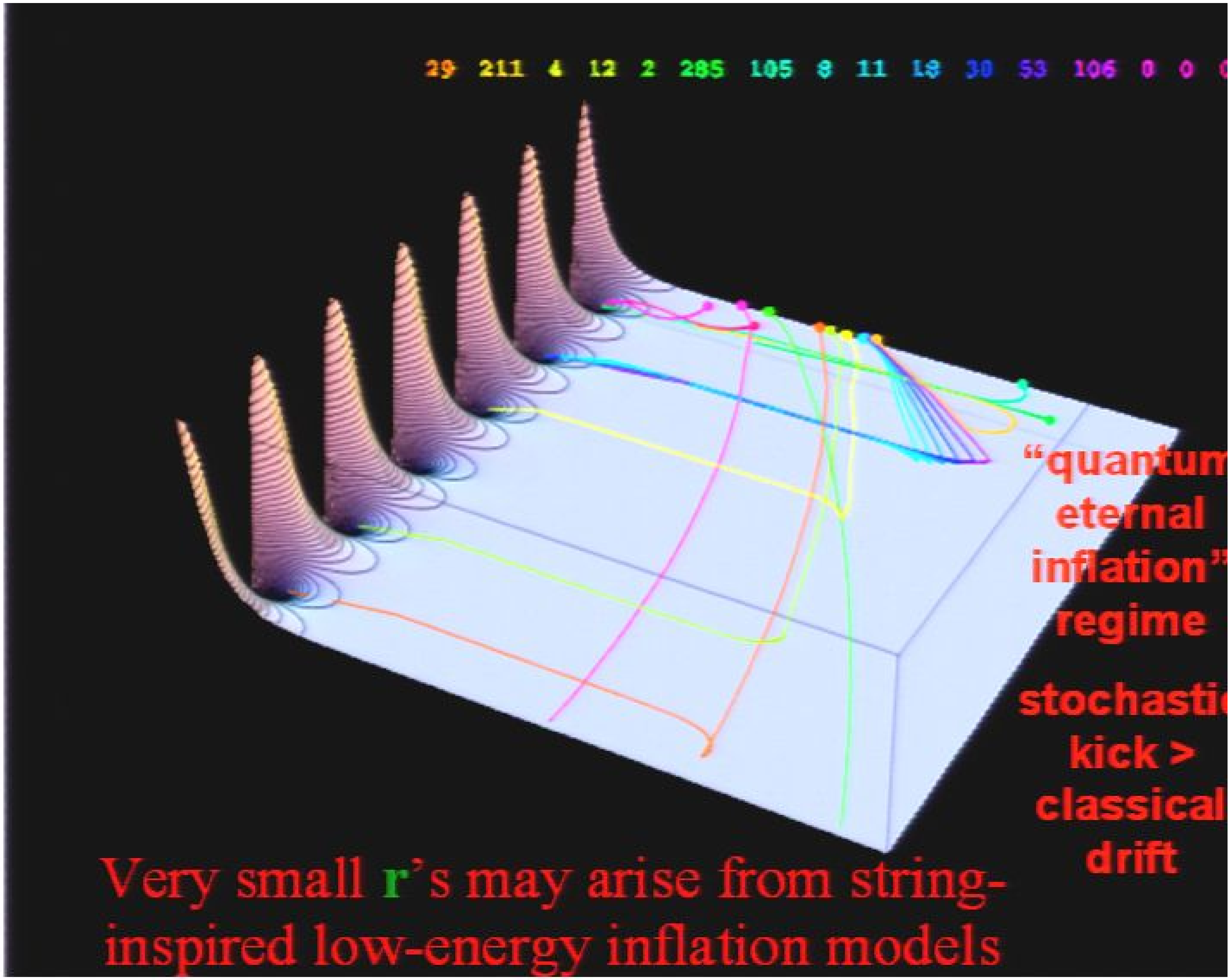

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lnP_s P_t (nodal 2 and 1) + 4 params cf **P_s P_t (nodal 5 and 5)** + 4 params
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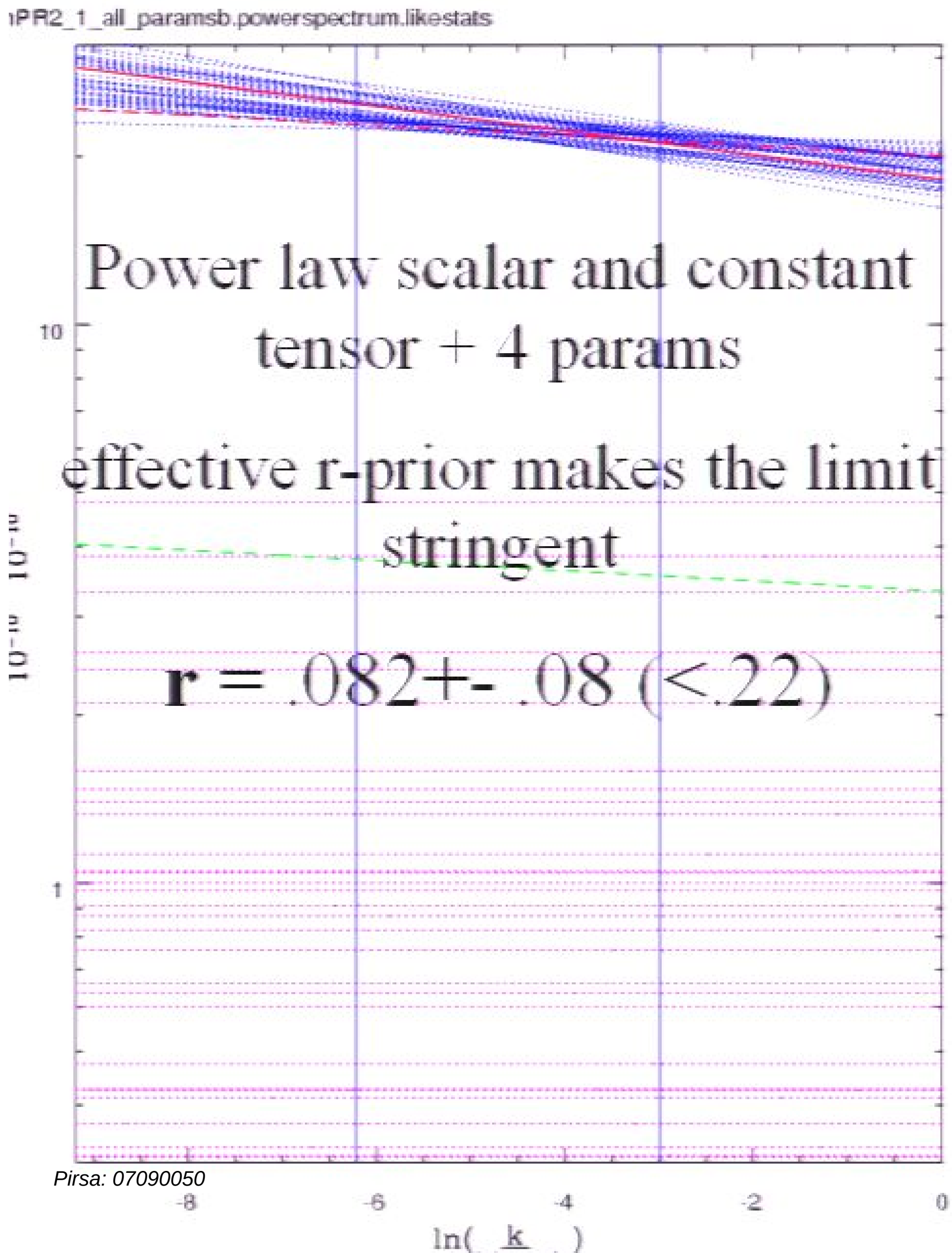

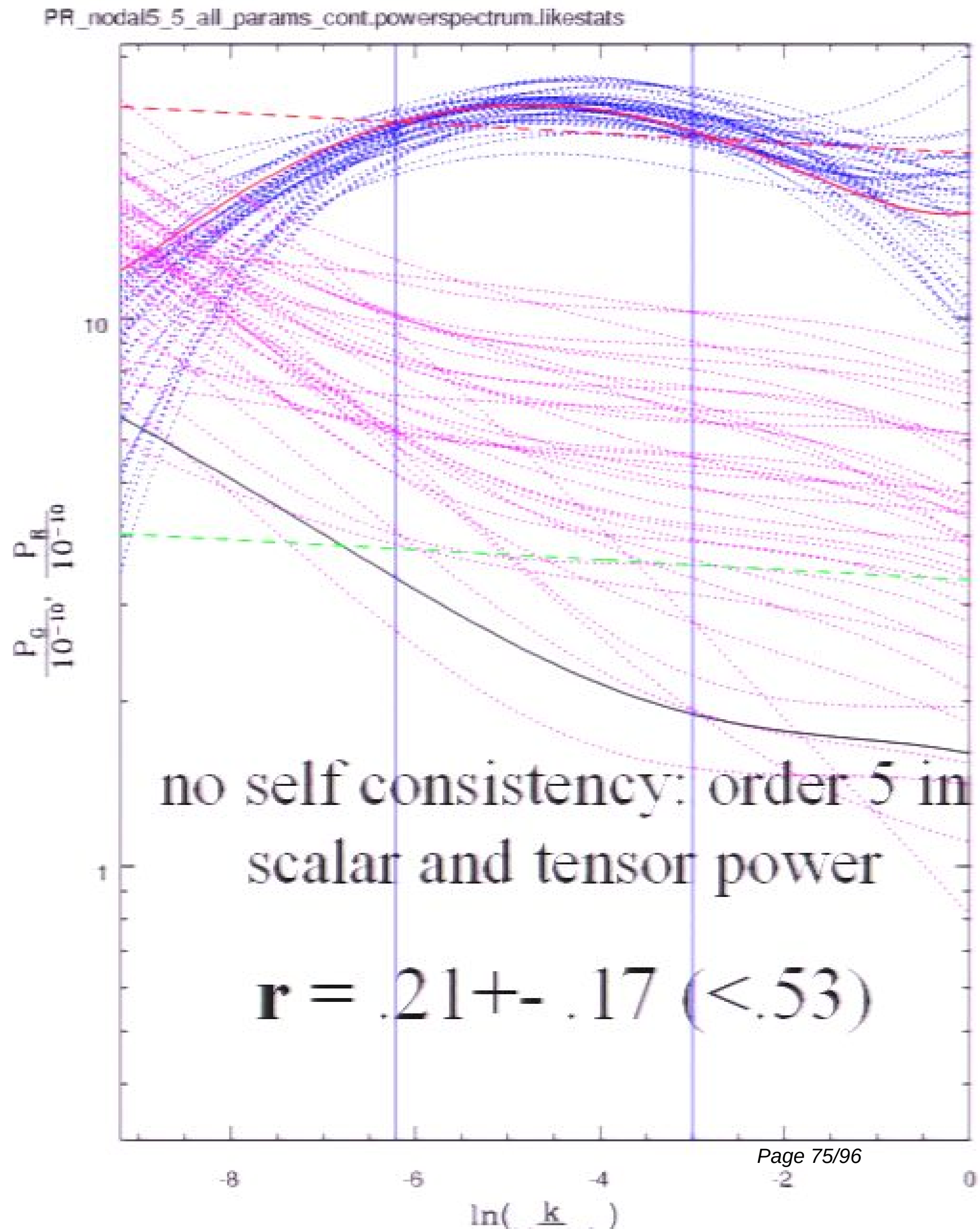

***lnP$_s$ P$_t$* (nodal 2 and 1)** + 4 params cf ***P$_s$ P$_t$* (nodal 5 and 5)** + 4 params
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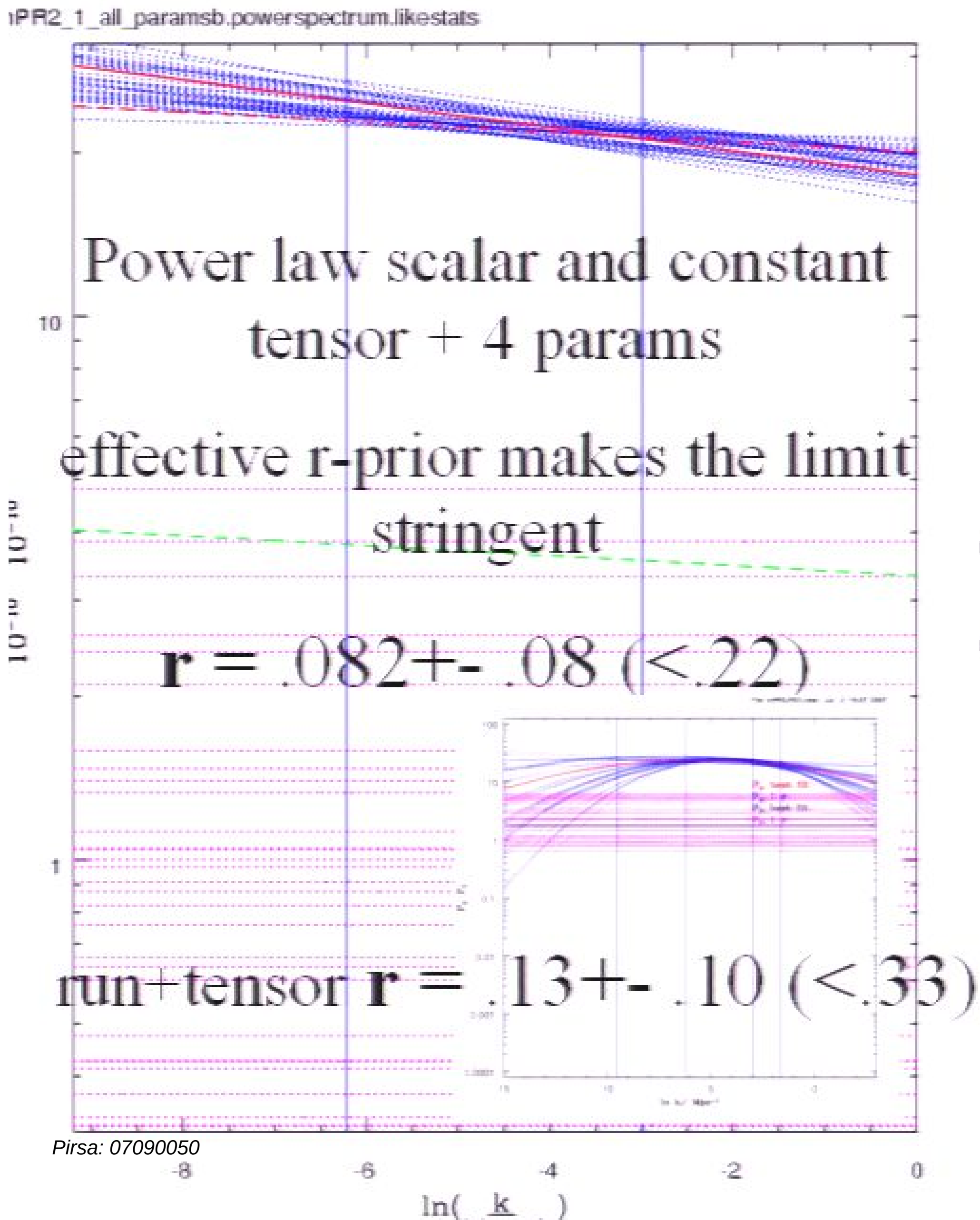
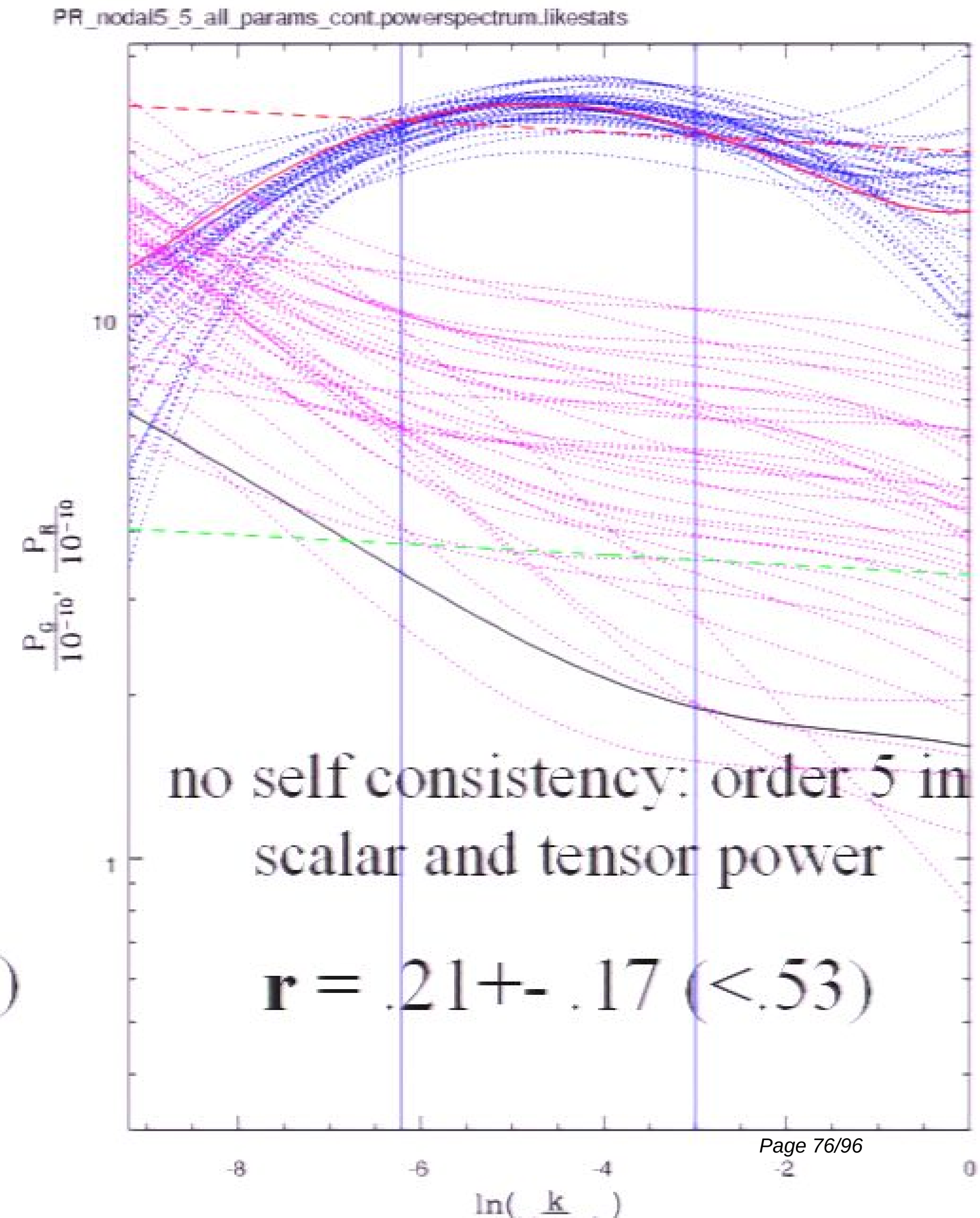
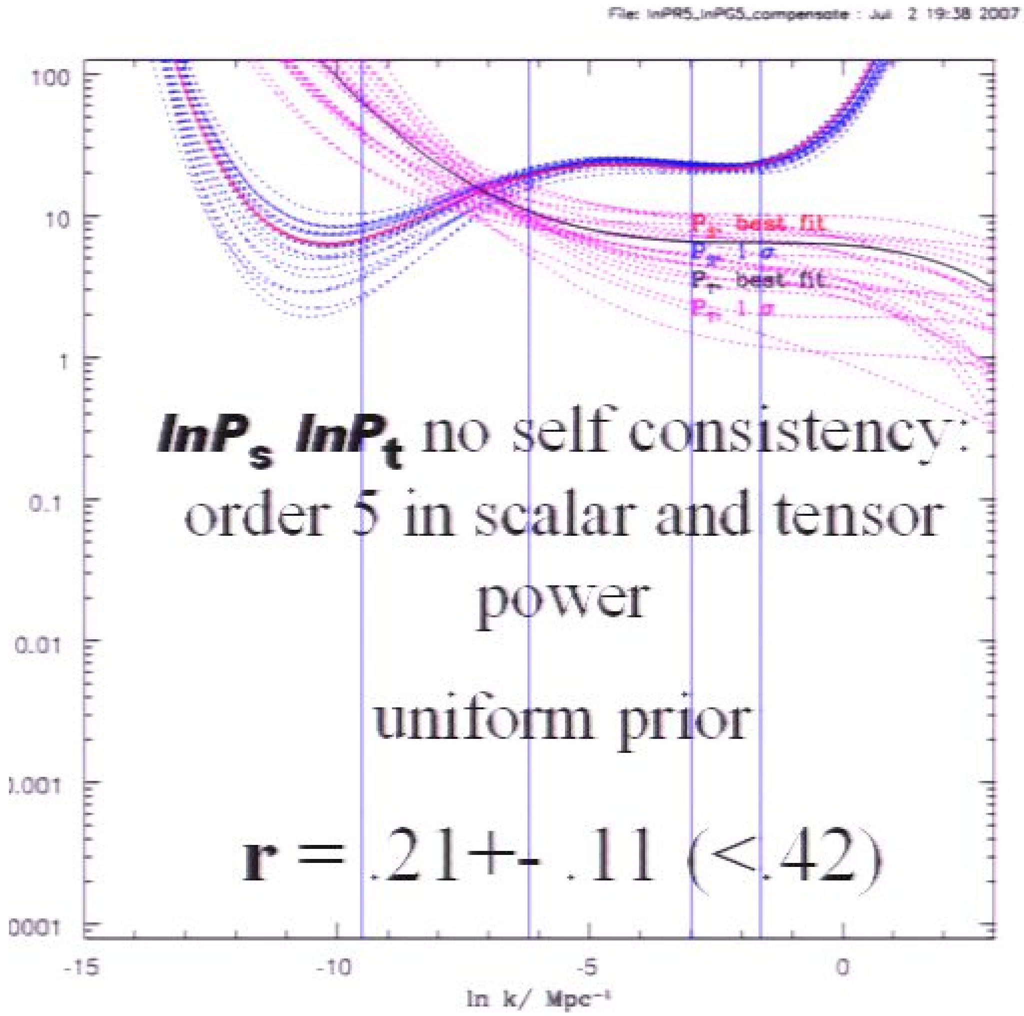
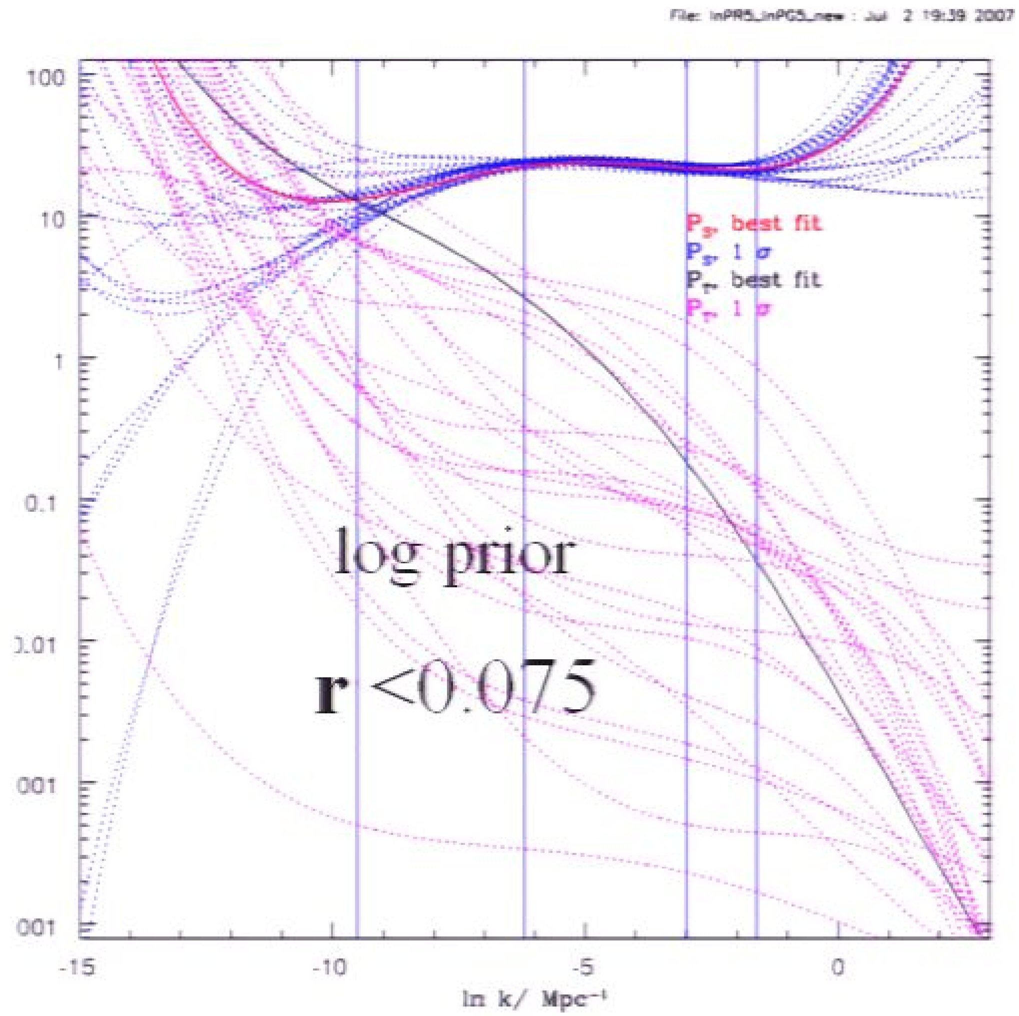


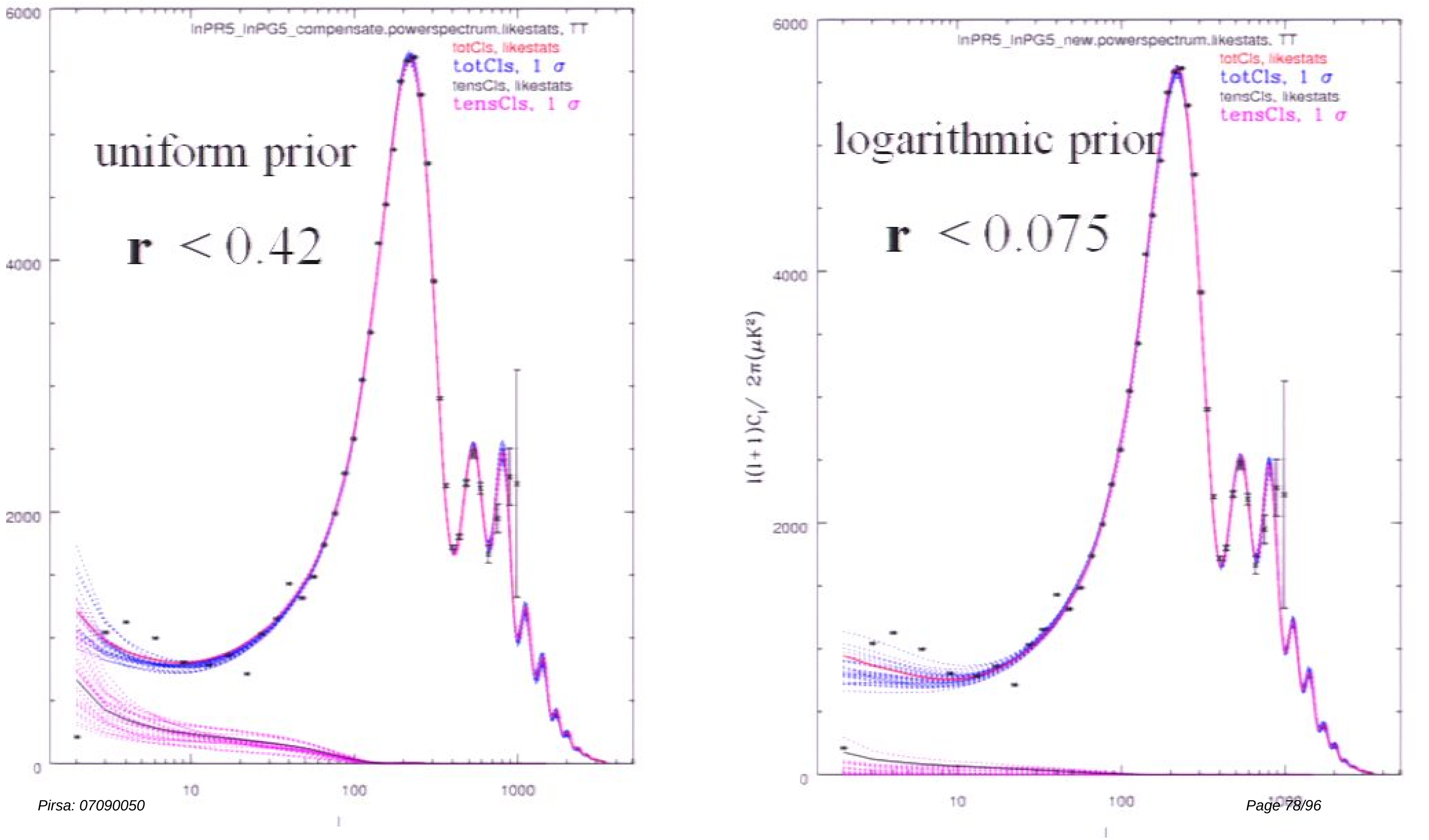


lnP$_s$ lnP$_t$ **(nodal 5 and 5)** + 4 params. **Uniform in exp(nodal bandpowers) cf. uniform in nodal bandpowers** reconstructed from April07 CMB+LSS data using Chebyshev nodal point expansion & MCMC: shows prior dependence with current data

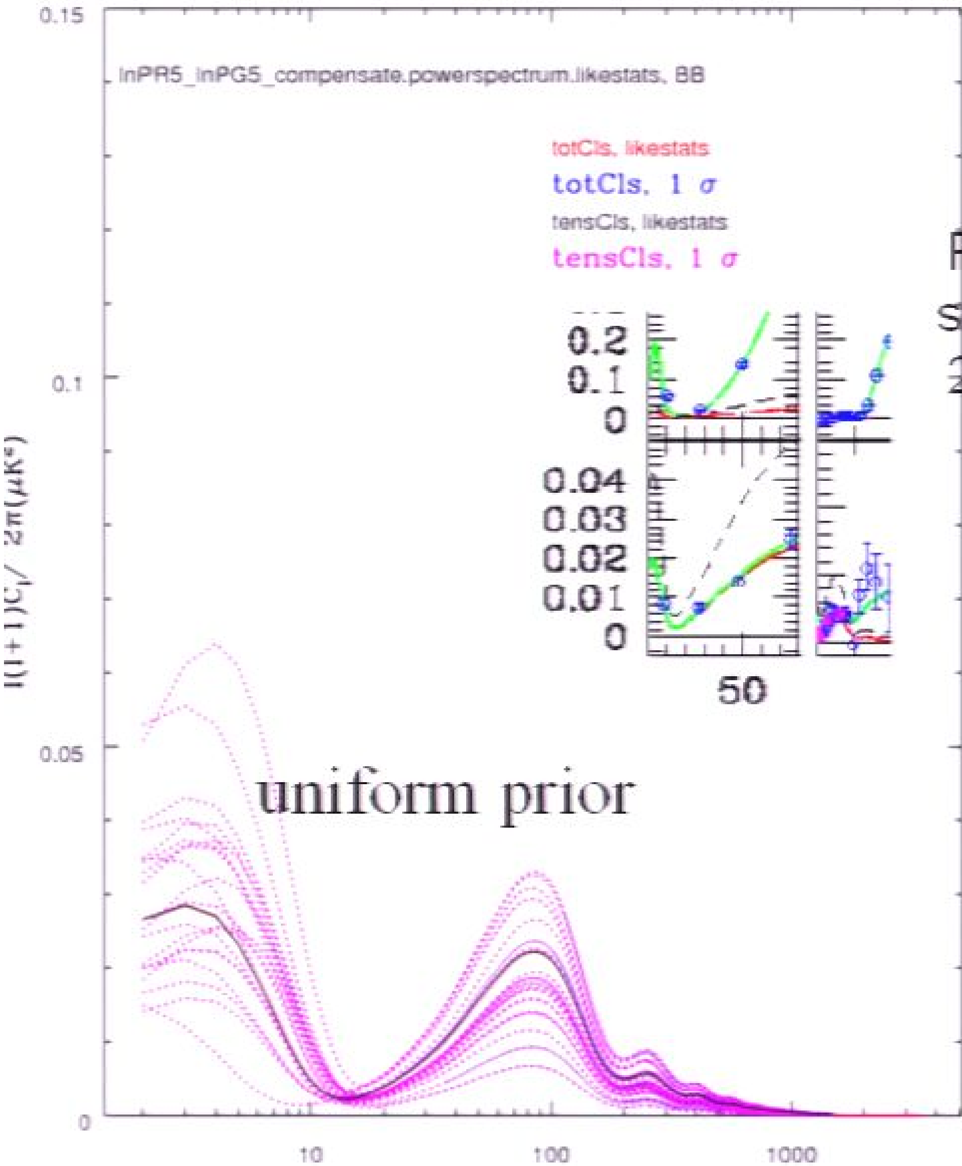


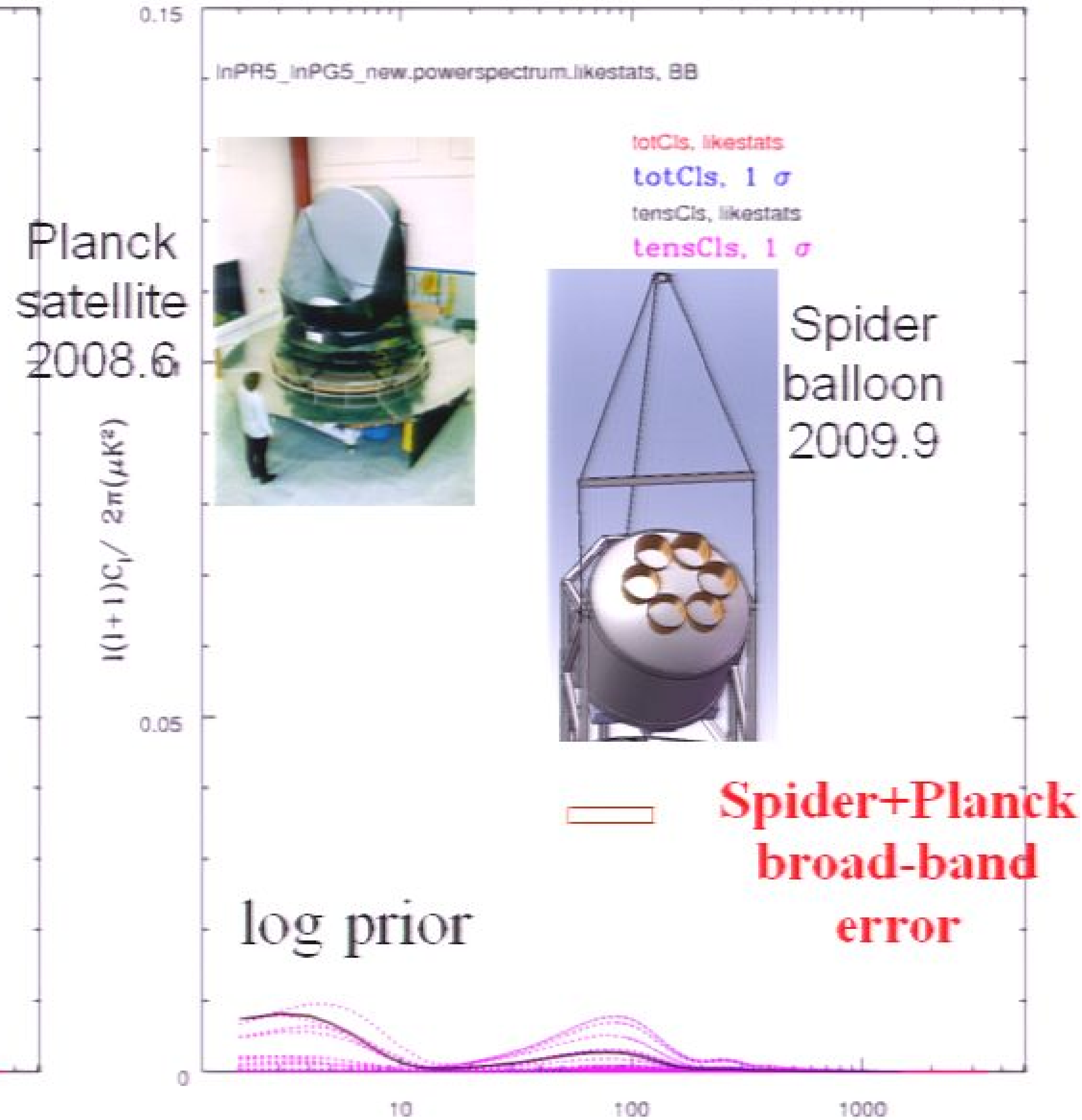


lnP_s lnP_t (nodal 5 and 5) + 4 params. Uniform in exp(nodal bandpowers) cf. uniform in nodal bandpowers reconstructed from April07 CMB+LSS data using Chebyshev nodal point expansion & MCMC: shows prior dependence with current data



C_L BB for *lnP*$_s$ *lnP*$_t$ (nodal 5 and 5) + 4 params inflation trajectories reconstructed from CMB+LSS data using Chebyshev nodal point expansion & MCMC





New Parameters of Cosmic Structure Formation

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$\Omega_{dm} h^2$

τ_c

$\theta \sim \ell_s^{-1}, \;\; cf. \Omega_\Lambda$

$\epsilon(k), \;\; k \approx Ha$

$\ln H(k_p)$

$H(k_p)$

New Parameters of Cosmic Structure Formation

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$\theta \sim \ell_s^{-1}, \;\; cf. \Omega_\Lambda$

$\ln H(k_p)$

$H(k_p)$

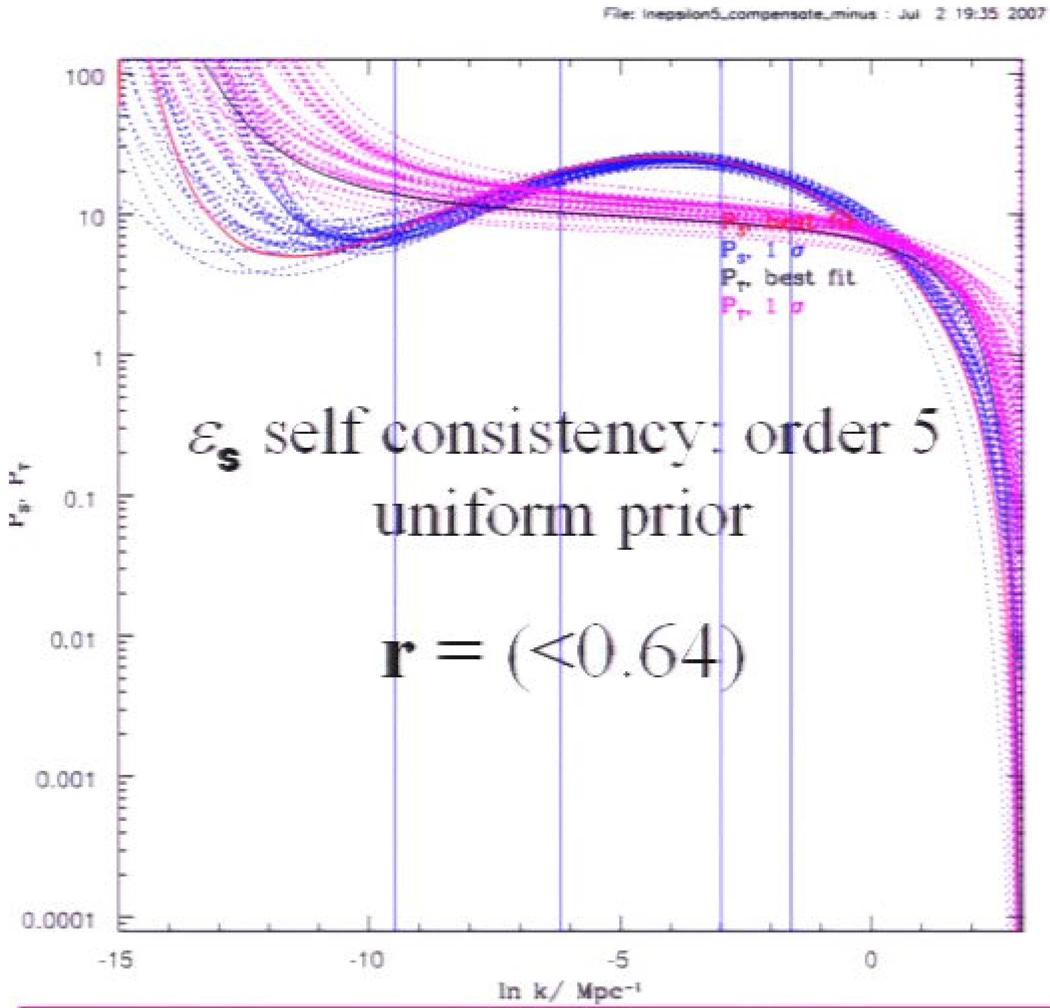
$\epsilon(k), \quad k \approx Ha$

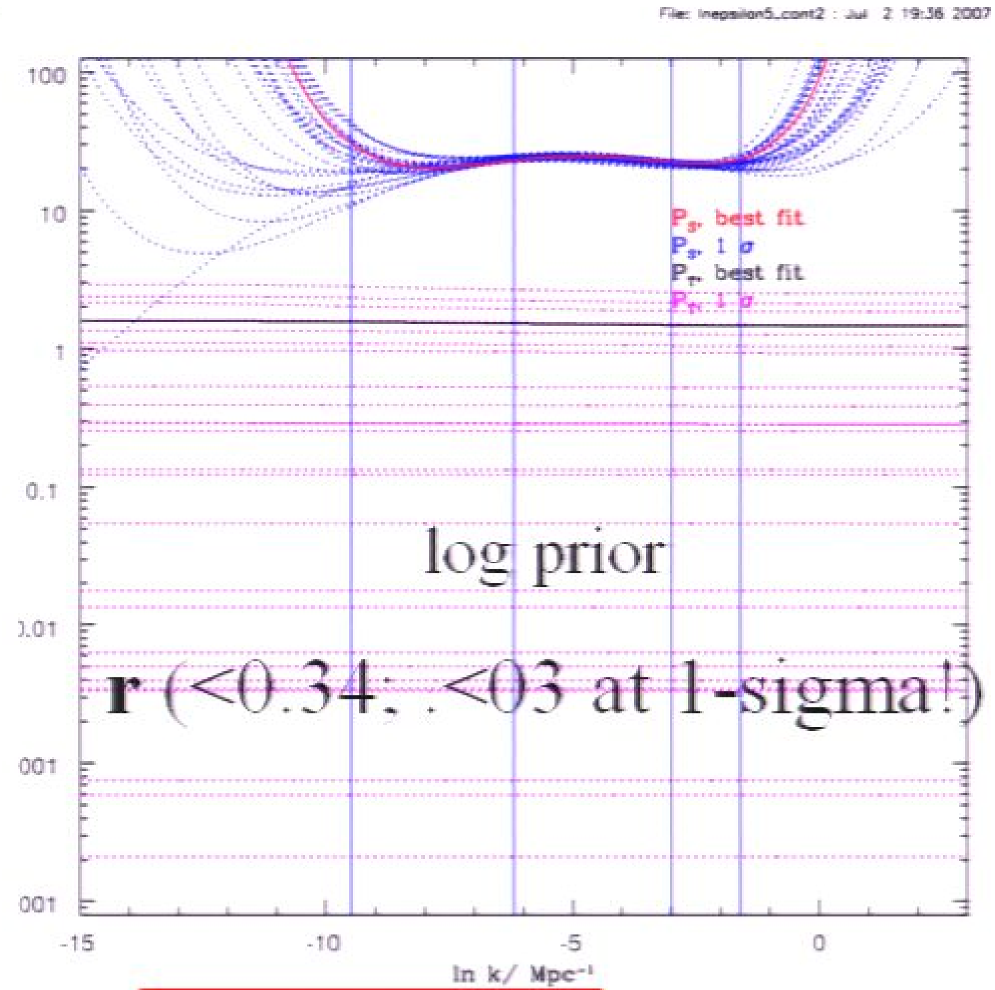
=1+q, the deceleration parameter history

$\mathcal{P}_s(k) \propto H^2/\epsilon, \mathcal{P}_t(k) \propto H^2$

order N Chebyshev expansion, N-1 parameters (e.g. nodal point values)

$ln\,\mathcal{E}_s$ **(nodal 5)** + 4 params. **Uniform in exp(nodal bandpowers) cf. uniform in nodal bandpowers** reconstructed from April07 CMB+LSS data using Chebyshev nodal point expansion & MCMC: shows prior dependence with current data



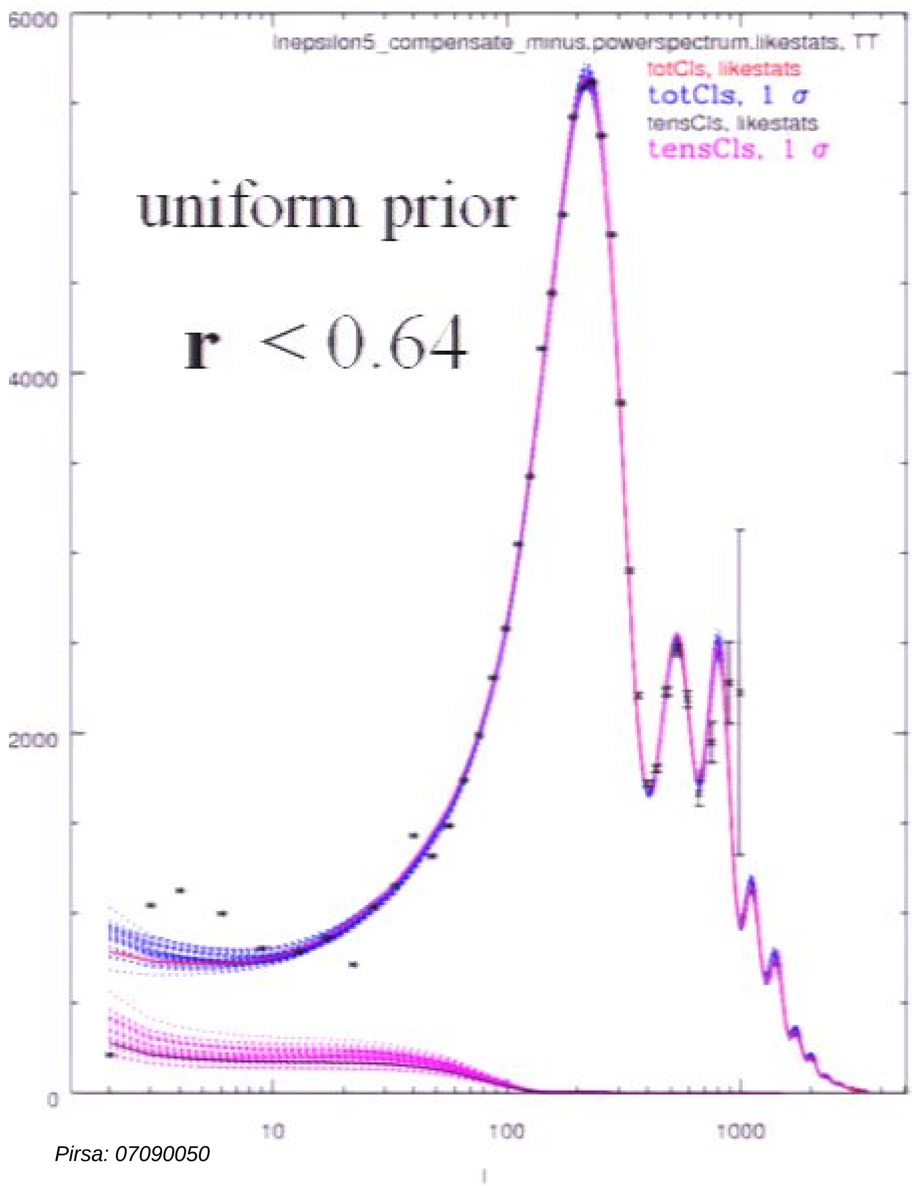


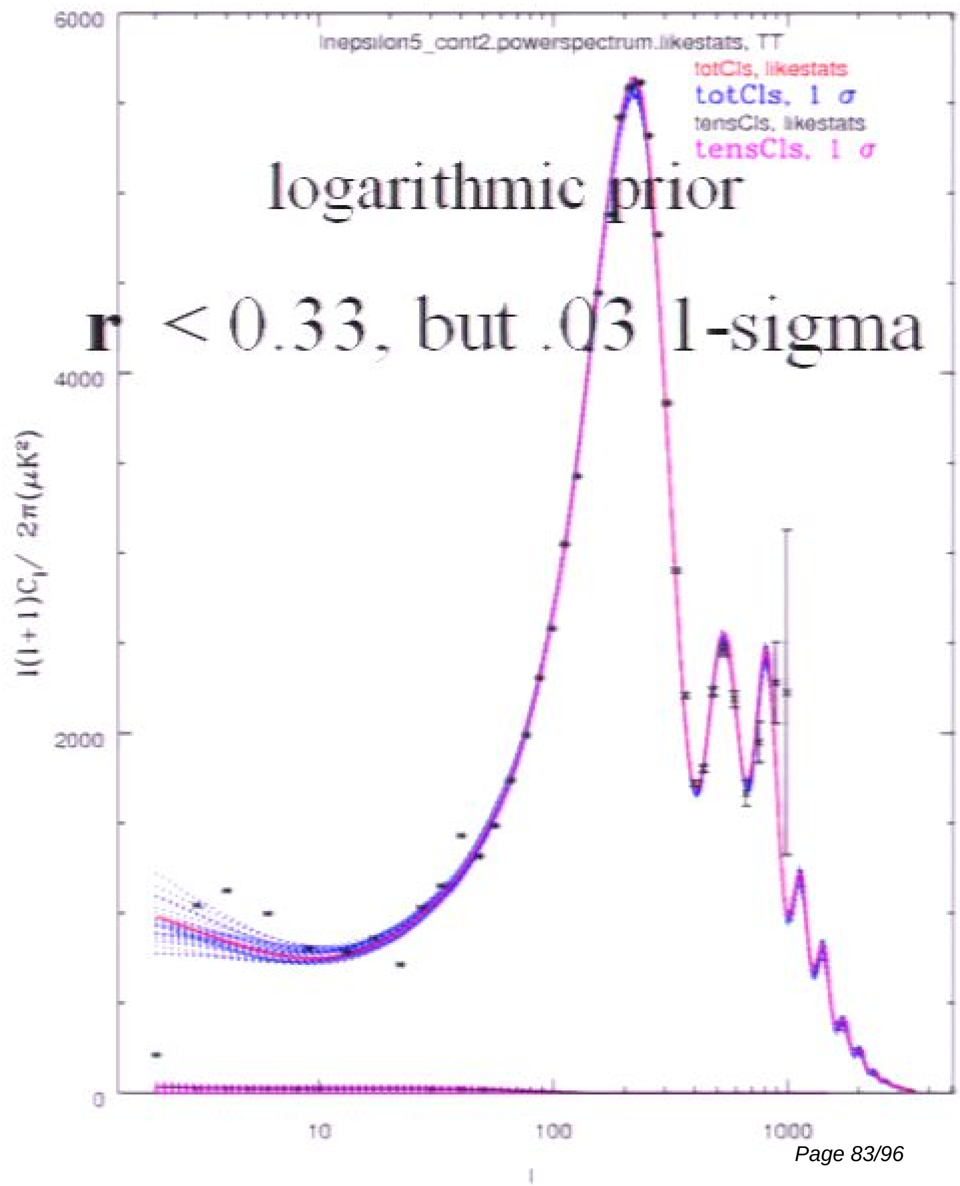
$$\mathcal{P}_{\mathbf{s}}(\mathbf{k}) \propto \mathbf{H}^2/\epsilon, \mathcal{P}_{\mathbf{t}}(\mathbf{k}) \propto \mathbf{H}^2$$

$$\frac{-\epsilon}{1-\epsilon} = \frac{\mathrm{d}\ln\mathbf{H}}{\mathrm{d}\ln\mathbf{k}}$$

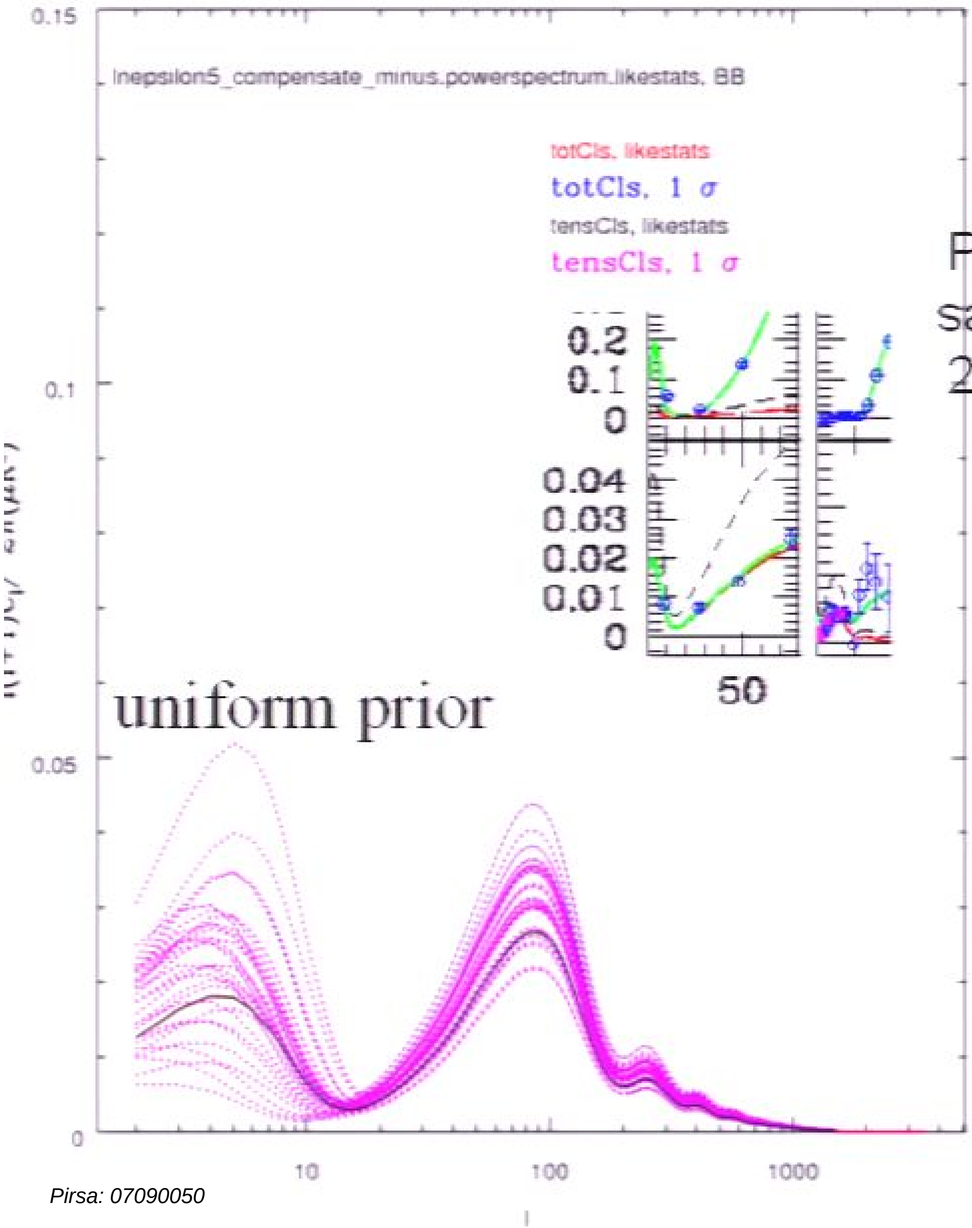
$\epsilon = (\mathrm{d}\ln\mathbf{H}/\mathrm{d}\psi_{inf})^2 \quad \mathbf{V} \propto \mathbf{H}^2(1-\frac{\epsilon}{3}); \quad \frac{\mathrm{d}\psi_{\mathbf{inf}}}{\mathrm{d}\ln\mathbf{k}} = \pm\sqrt{\ldots}$

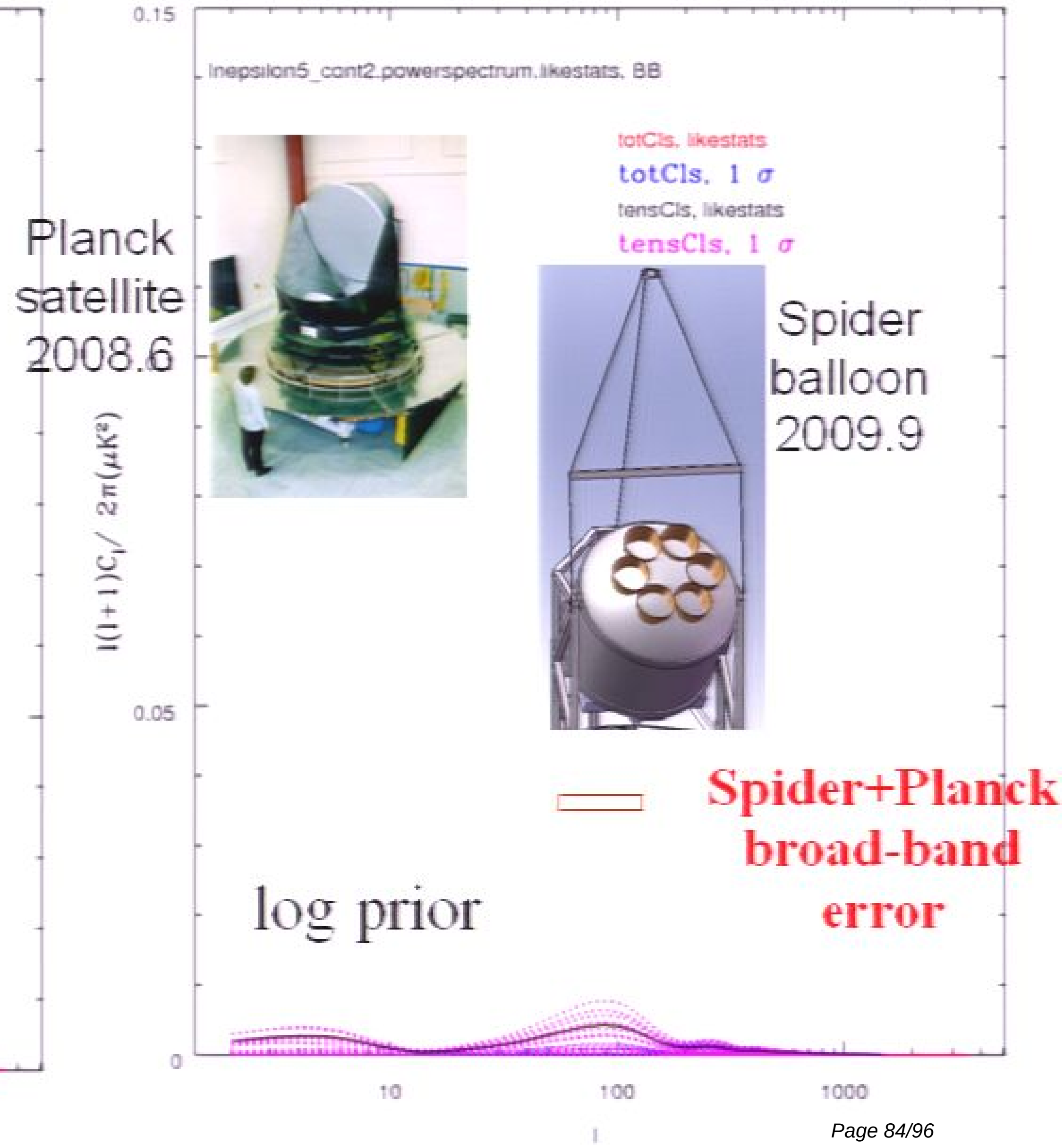
$ln\varepsilon_s$ **(nodal 5)** + 4 params. Uniform in exp(nodal bandpowers) cf. uniform in nodal bandpowers reconstructed from April07 CMB+LSS data using Chebyshev nodal point expansion & MCMC: shows prior dependence with current data



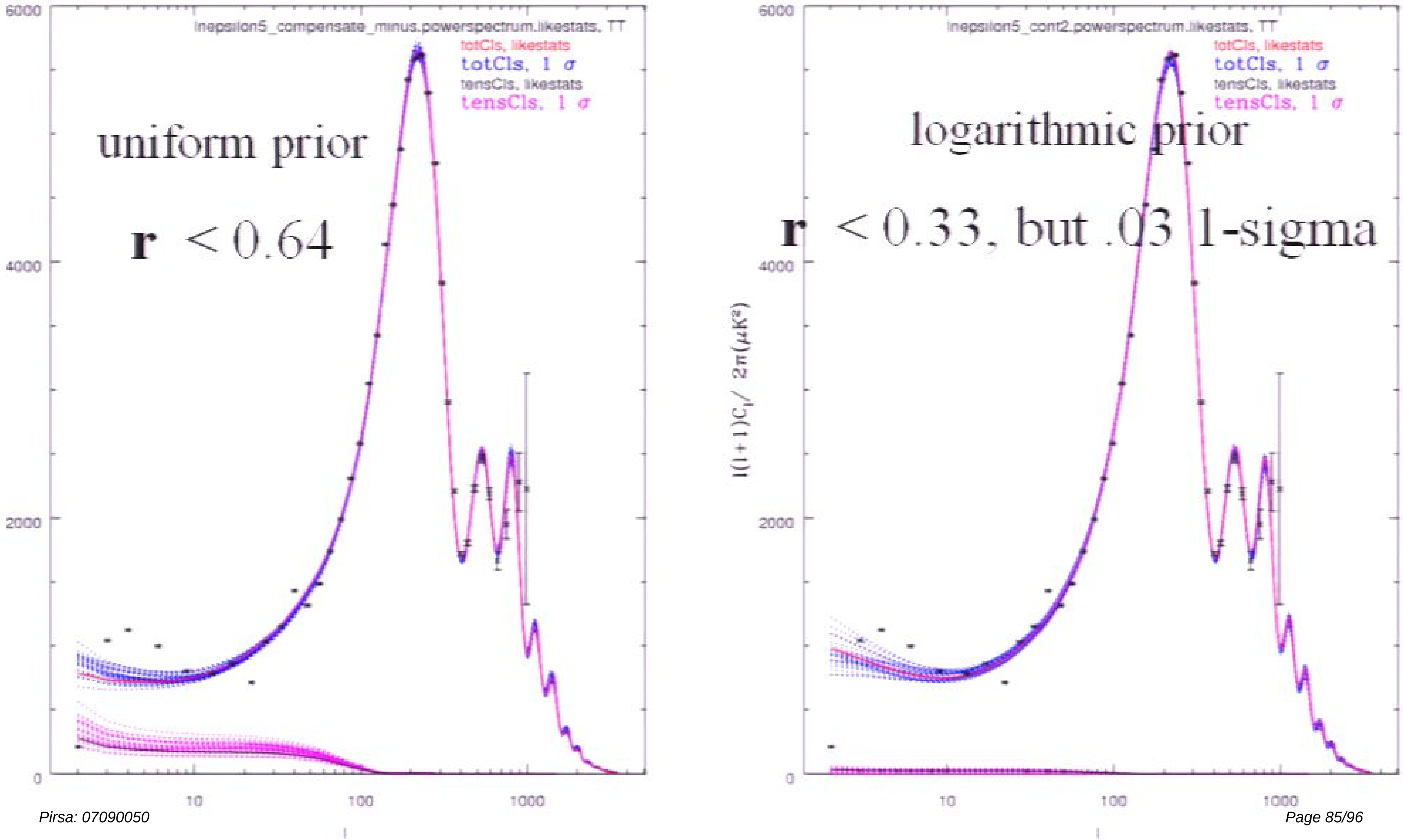


C_L BB for $ln\mathcal{E}_s$ (nodal 5) + 4 params inflation trajectories reconstructed from CMB+LSS data using Chebyshev nodal point expansion & MCMC

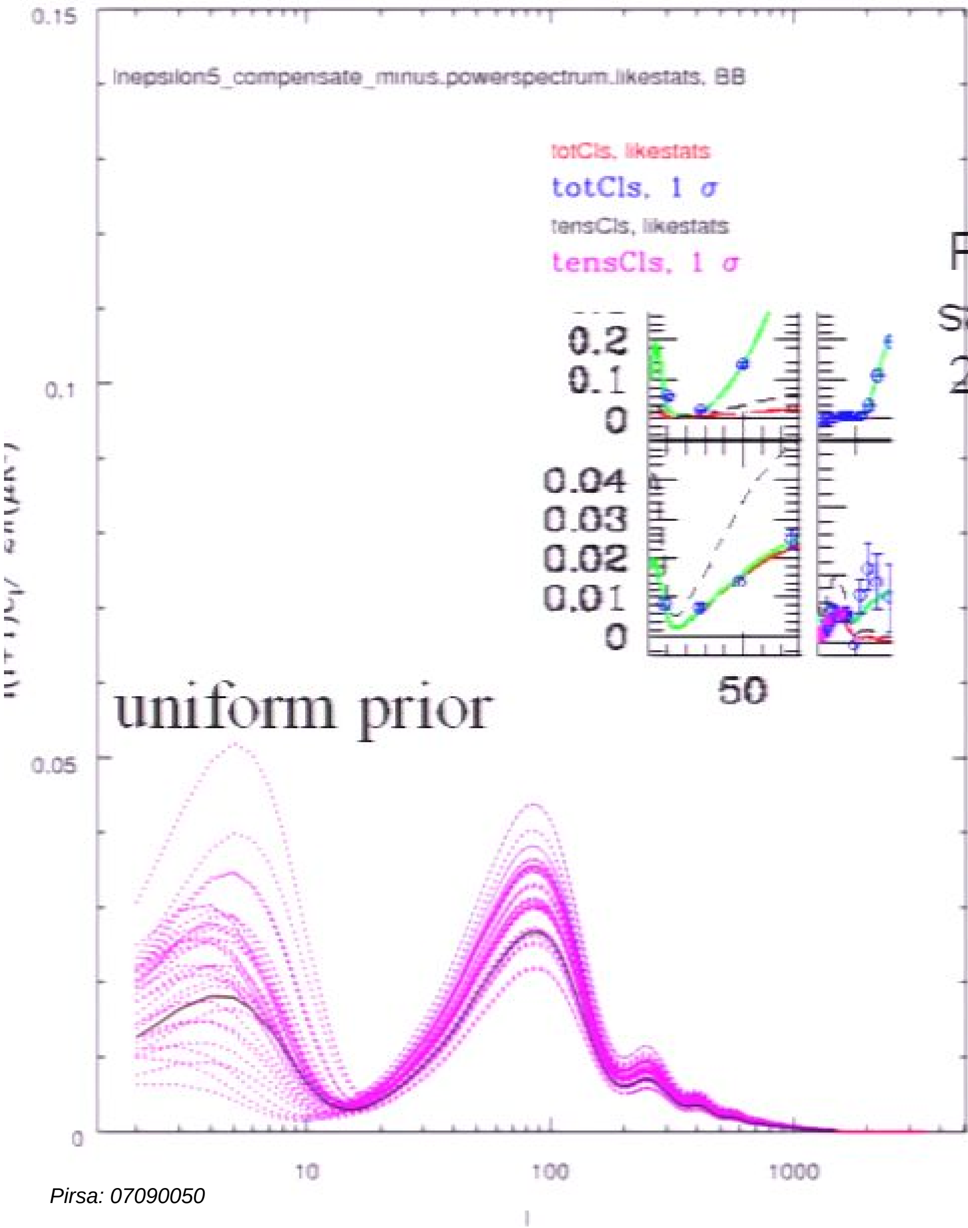


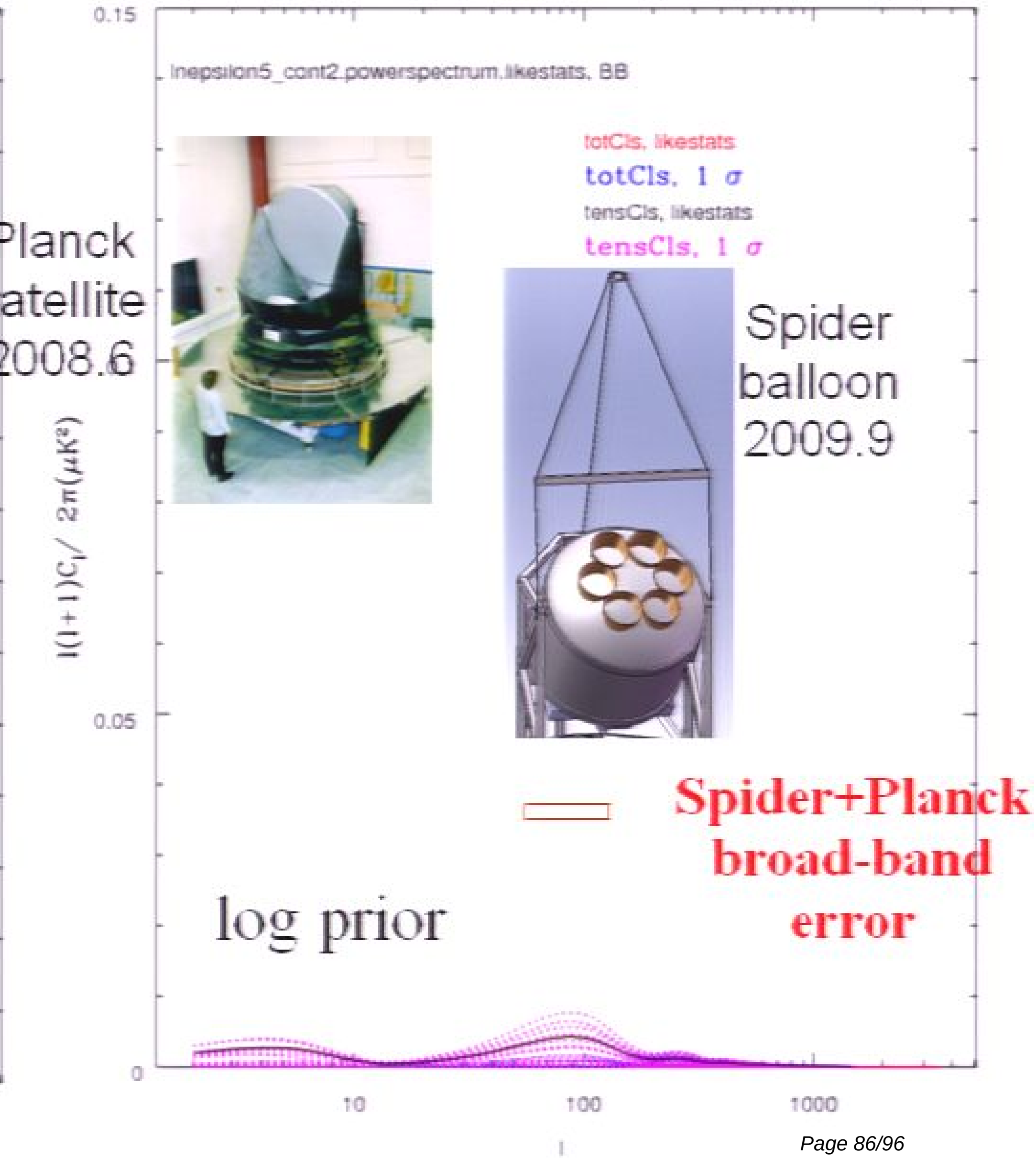


lnε_s **(nodal 5)** + 4 params. Uniform in exp(nodal bandpowers) cf. uniform in nodal bandpowers reconstructed from April07 CMB+LSS data using Chebyshev nodal point expansion & MCMC: shows prior dependence with current data

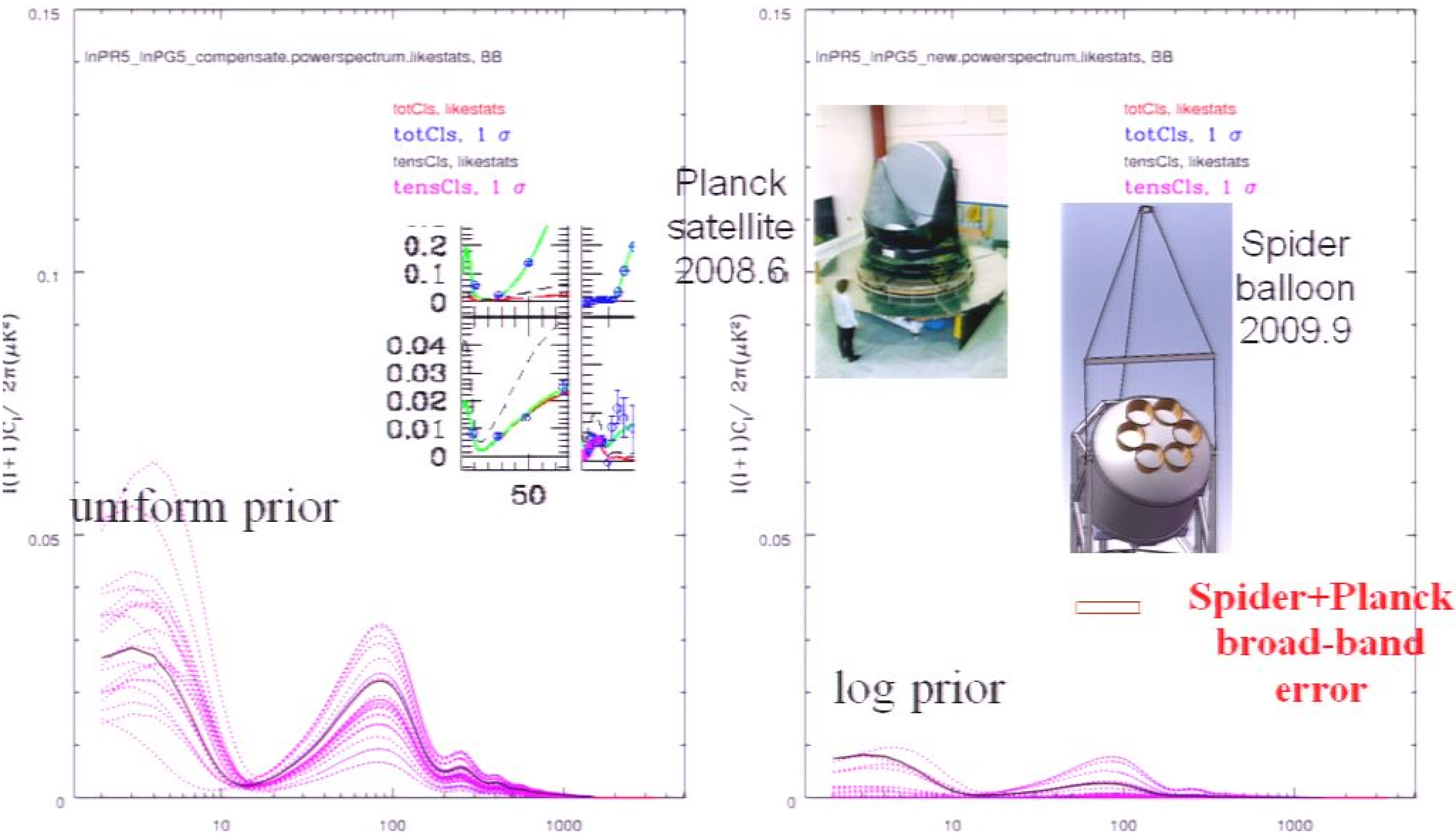


C_L BB for $ln\mathcal{E}_s$ **(nodal 5)** + 4 params inflation trajectories reconstructed from CMB+LSS data using Chebyshev nodal point expansion & MCMC

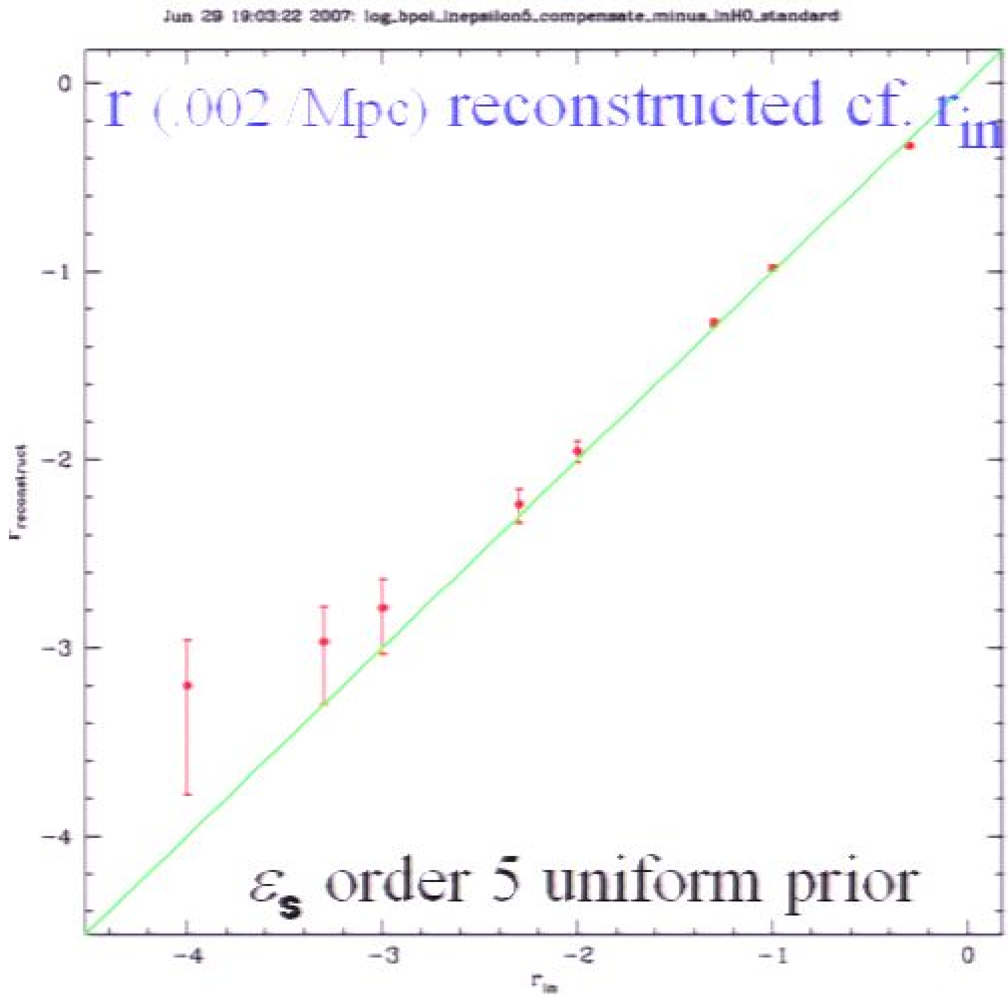


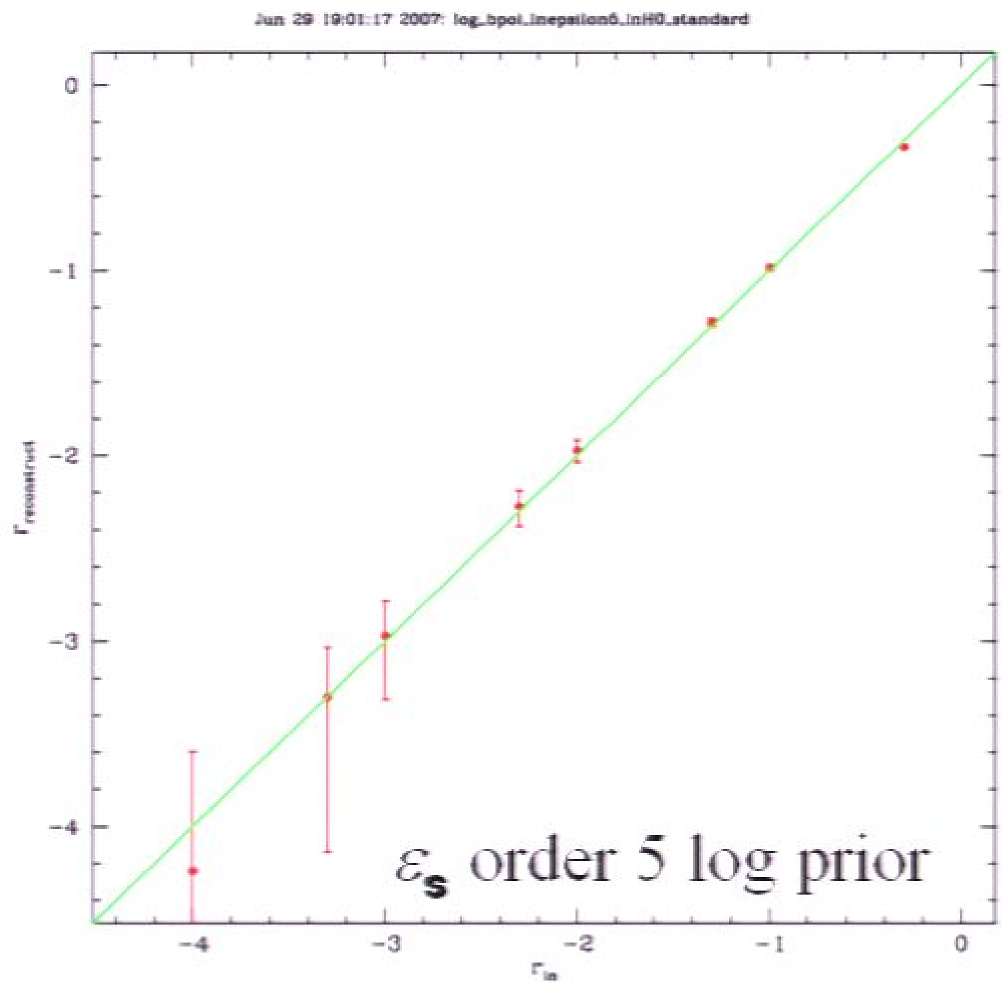


C_L **BB** for $\boldsymbol{lnP_s}$ $\boldsymbol{lnP_t}$ **(nodal 5 and 5)** + 4 params inflation trajectories reconstructed from CMB+LSS data using Chebyshev nodal point expansion & MCMC



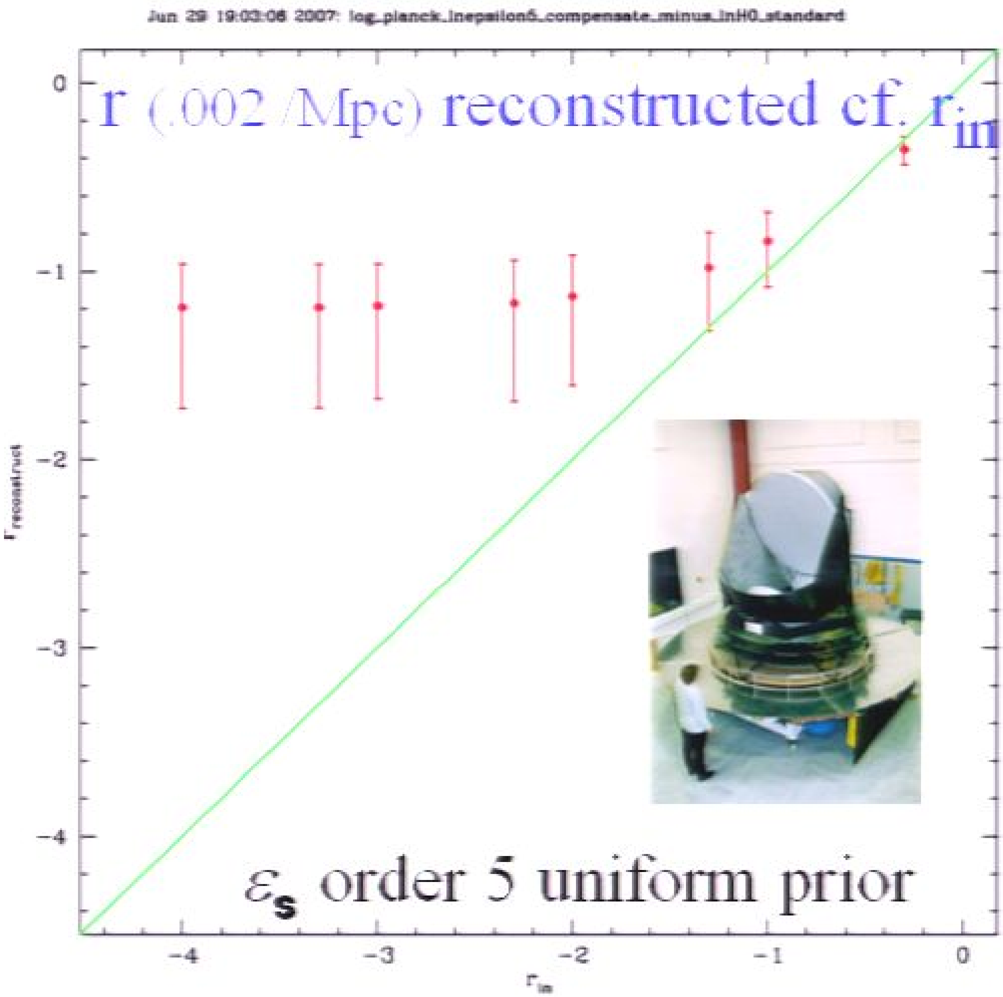
B-pol simulation: input LCDM (Acbar)+run+uniform tensor

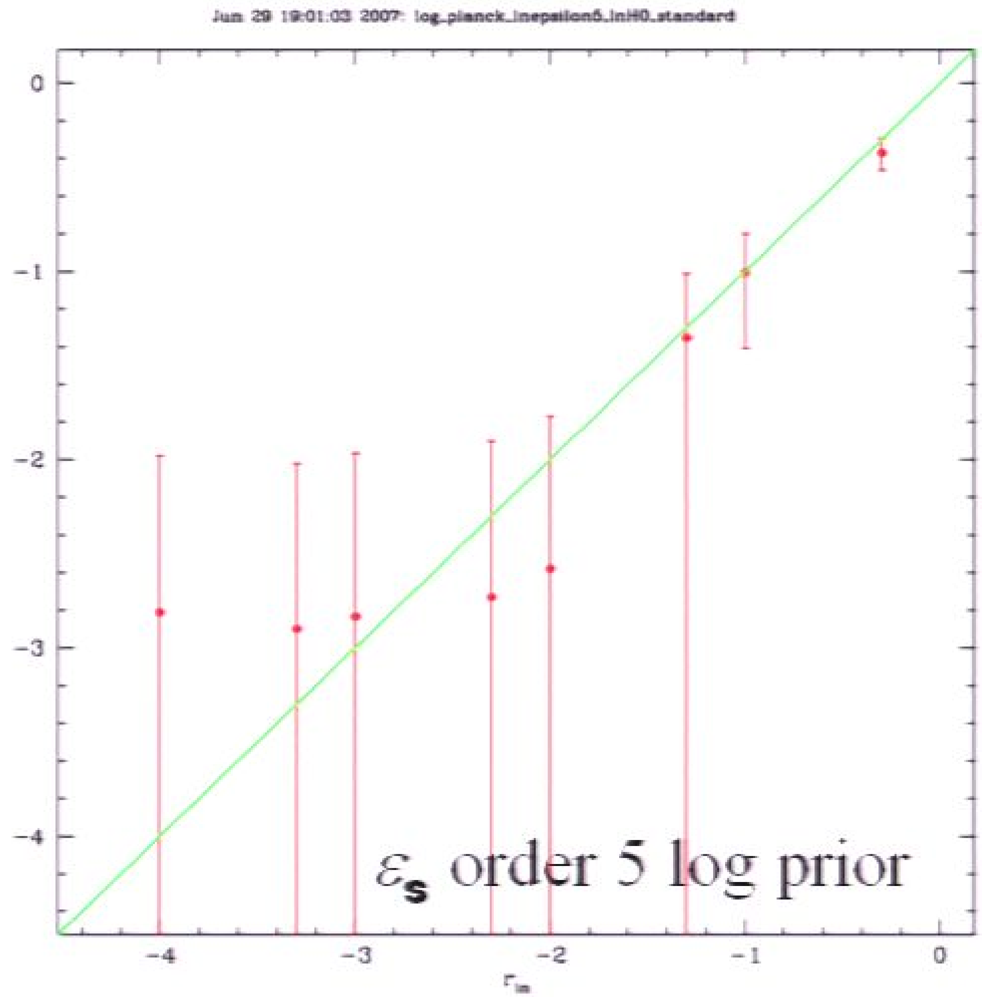




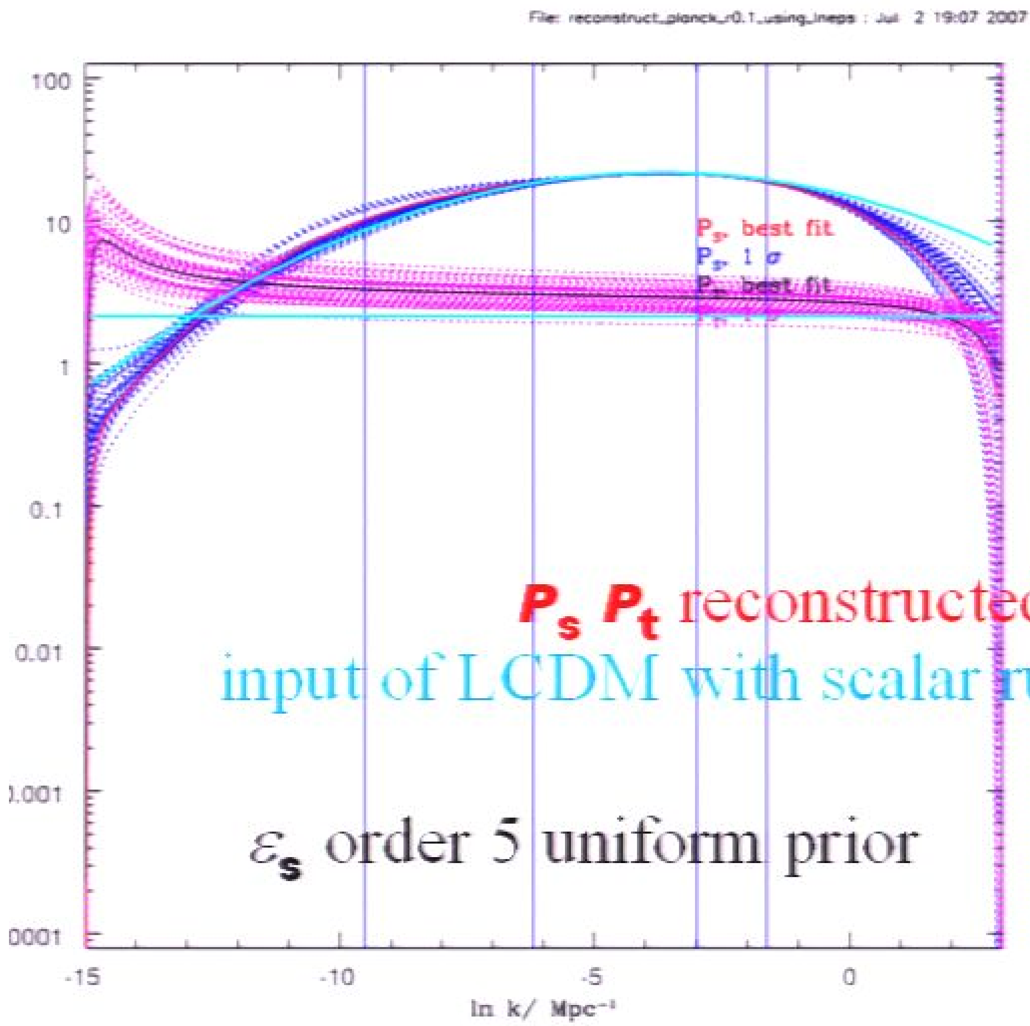
a very stringent test of the ε-trajectory methods: A+

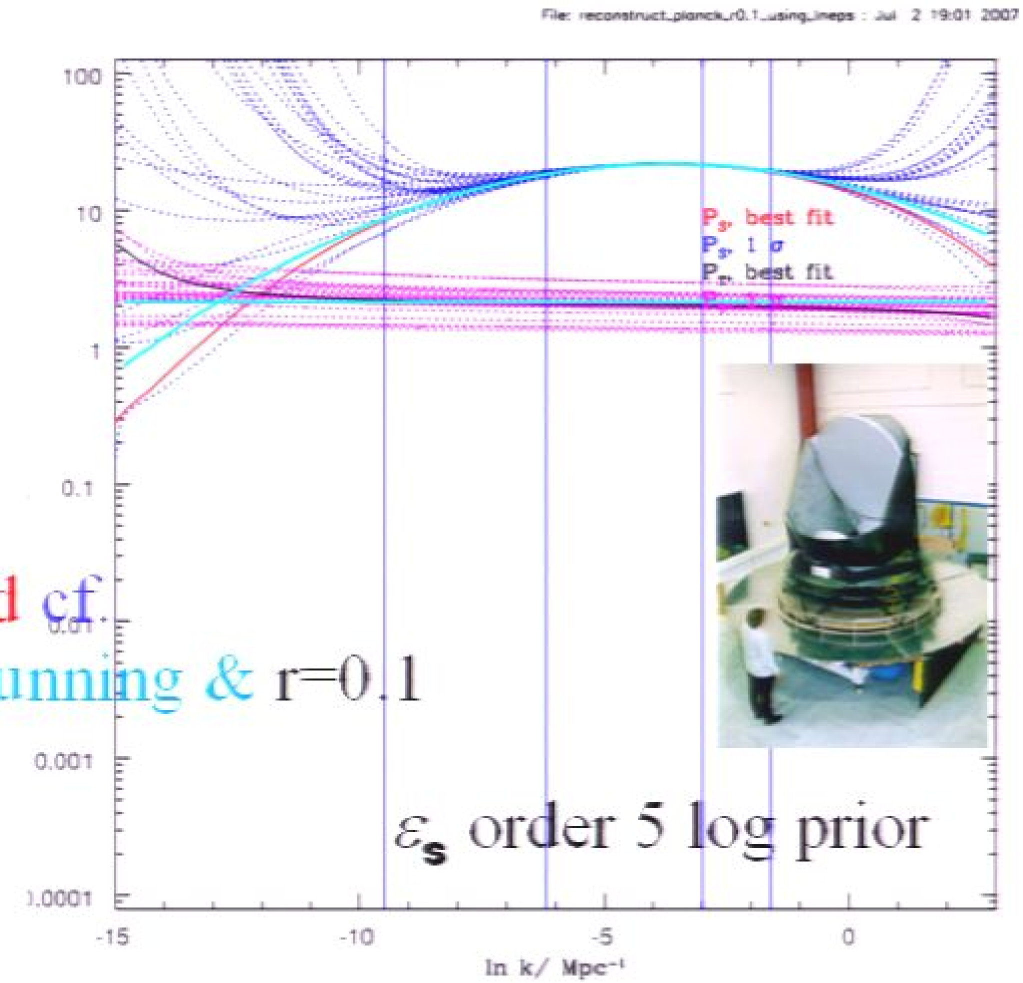
Planck1yr simulation: input LCDM (Acbar)+run+uniform tensor





Planck1 simulation: input LCDM (Acbar)+run+uniform tensor





P_s P_t reconstructed cf.

input of LCDM with scalar running & r=0.1

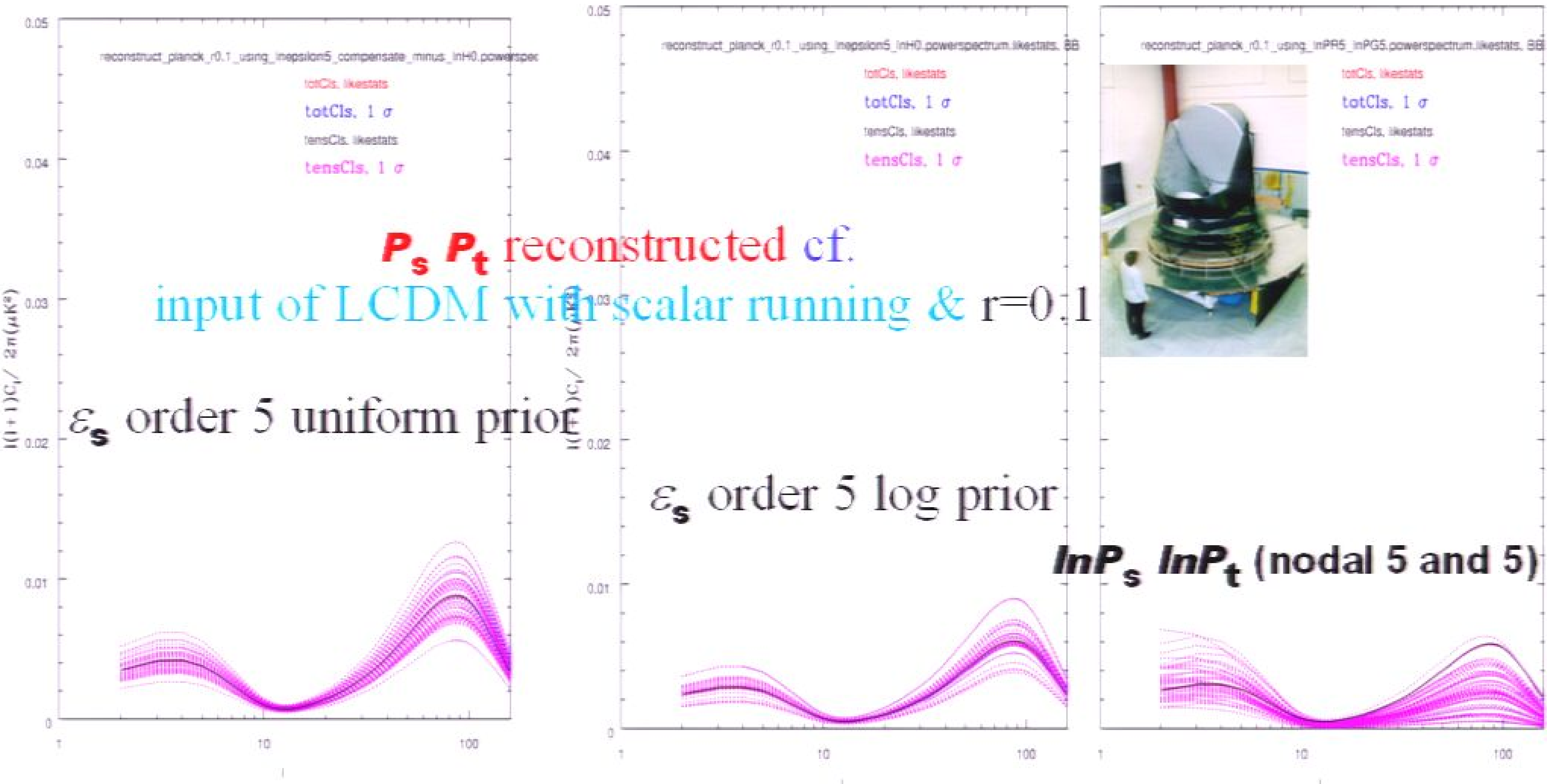
ε_s order 5 uniform prior

ε_s order 5 log prior

r=0.144 +- 0.032

r=0.096 +- 0.030

Planck1 simulation: input LCDM (Acbar)+run+uniform tensor



Inflation then summary

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

Usual GW limits come from adding r with a fixed GW spectrum and no consistency criterion (7 params). Adding minimal consistency does not make that much difference (7 params)

r (<.28 95%) limit comes from relating high k region of σ_8 to low k region of GW C_L

Uniform priors in $\varepsilon(k) \sim r(k)$: with current data, the scalar power downturns ($\varepsilon(k)$ goes up) at low k if there is freedom in the mode expansion to do this. Adds GW to compensate, breaks old r limit. T/S (k) can cross unity. But log prior in ε drives to low r. a B-pol could break this prior dependence, maybe Planck+Spider.

Complexity of trajectories arises in many-moduli string models. Roulette example: 4-cycle complex Kahler moduli in large compact volume Type IIB string theory

TINY $r \sim 10^{-10}$ if the normalized inflaton $\psi < 1$ over ~50 e-folds then $r < .007$

$\Delta\psi$ ~10 for power law & PNGB inflaton potentials

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

Even with low energy inflation, the prospects are good with Spider and even Planck to either detect the GW-induced B-mode of polarization or set a powerful upper limit against nearly uniform acceleration. Both have strong Cdn roles. CMBpol

NOW

3-parameter parameterization

$$w(a) = \quad -1 + \frac{2\epsilon_s}{3}\{\frac{(\frac{a_s}{a})^{3-3.6a_s|\epsilon_s|(1-\Omega_{m0})}}{\sqrt{1+\frac{\epsilon_s}{3|\epsilon_s|}(\frac{a_s}{a})^{6-7.2a_s|\epsilon_s|(1-\Omega_{m0})}}}\frac{1}{\sqrt{|\epsilon_s|}}$$

$$+[\sqrt{1+(\frac{a_{eq}}{a})^3} - (\frac{a_{eq}}{a})^3 \ln((\frac{a}{a_{eq}})^{\frac{3}{2}} + \sqrt{1+(\frac{a}{a_{eq}})^3})](1-\zeta_s)$$

$$+0.36\varepsilon_s(1-\Omega_{m0})\frac{(\frac{a}{a_{eq}})^2}{1+(\frac{a}{a_{eq}})^4}[0.9 - 0.7\frac{a}{a_{eq}} - 0.045(\frac{a}{a_{eq}})^2]$$

$$+\frac{2\zeta_s}{3}[\sqrt{1+(\frac{a}{a_{eq}})^3} - 2(\frac{a_{eq}}{a})^3(\sqrt{1+(\frac{a}{a_{eq}})^3} - 1)]\}^2$$

where

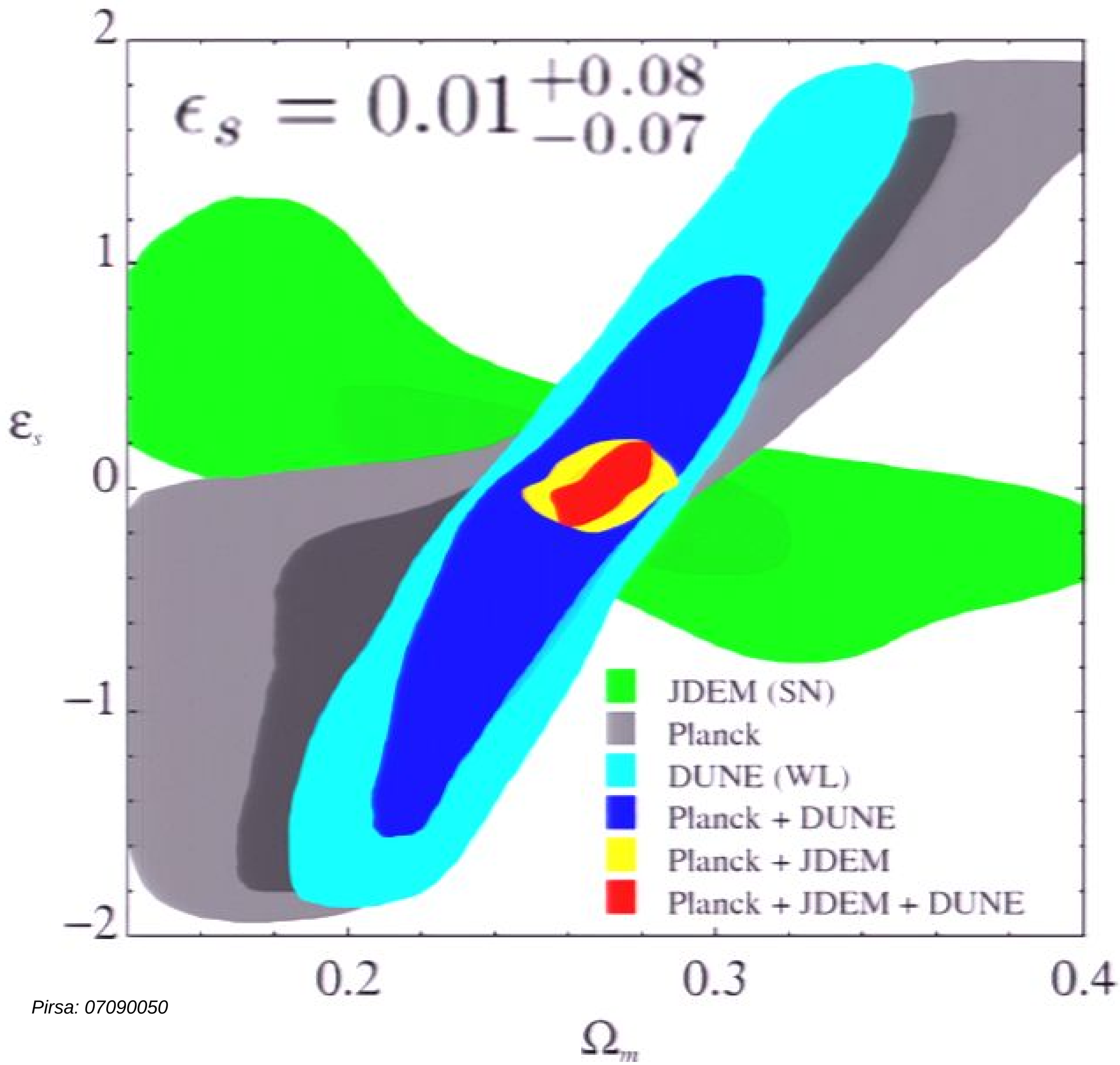
$$a_{eq} \equiv (\frac{\Omega_{m0}}{1-\Omega_{m0}})^{\frac{1}{3[1-0.36\varepsilon_s(1-\Omega_{m0})]}}$$

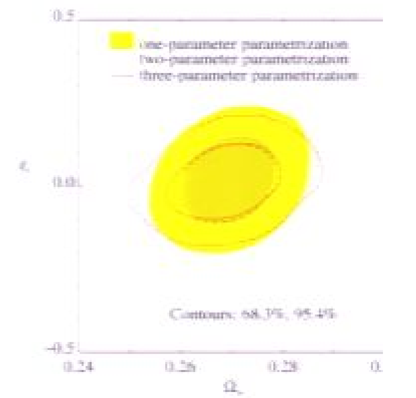
$$a_s \geq 0$$

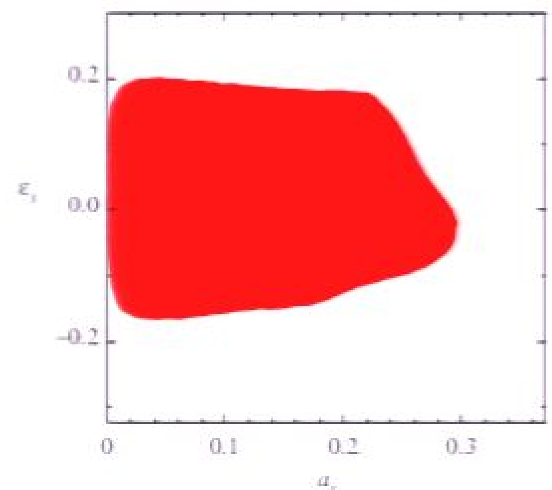
$$-1 < \zeta_s < 1$$

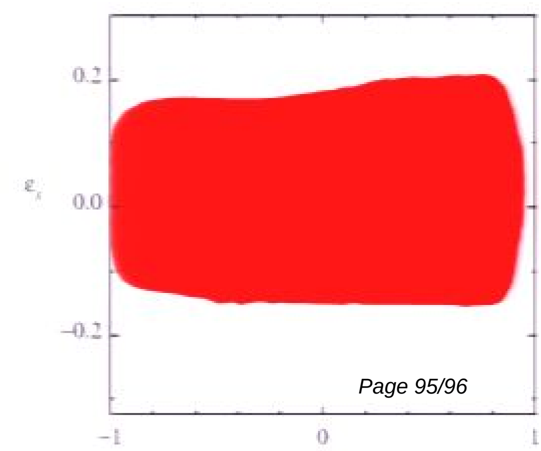
Beyond Einstein panel: LISA+JDEM

Forecast: JDEM-SN (2500 hi-z + 500 low-z) + DUNE-WL (50% sky, gals @z = 0.1-1.1, 35/min^2) + Planck1yr









Inflation now summary

the data cannot determine more than 2 w-parameters (+ csound?). general higher order Chebyshev expansion in 1+w as for "inflation-then" $\varepsilon=(1+q)$ is not that useful. Parameter eigenmodes show what is probed

The $w(a)=w_0+w_a(1-a)$ phenomenology requires baroque potentials

Philosophy of HBK07: backtrack from now (z=0) all w-trajectories arising from quintessence ($\varepsilon_s > 0$) and the phantom equivalent ($\varepsilon_s < 0$); use a 3-parameter model to well-approximate even rather baroque w-trajectories. We ignore constraints on Q-density from photon-decoupling and BBN because further trajectory extrapolation is needed.

For general slow-to-moderate rolling one needs 2 "dynamical parameters" (a_s, ε_s) & Ω_Q to describe w to a few % for the not-too-baroque w-trajectories.

a_s is not well-determined by the current data: to +-0.3 in Planck1yr-CMB+JDEM-SN+DUNE-WL future

In the early-exit scenario, the information stored in a_s is erased by Hubble friction over the observable range & w can be described by a single parameter ε_s.

a 3rd param ζ_s, (~$d\varepsilon_s$ /dlna) is ill-determined now & in a Planck1yr-CMB+JDEM-SN+DUNE-WL future

To use: given V, compute trajectories, do a-averaged ε_s & test (or simpler ε_s -estimate)

for each given Q-potential, velocity, amp, shape parameters are needed to define a w-trajectory

current observations are well-centered around the cosmological constant ε_s=0.0+-0.25

in Planck1yr-CMB+JDEM-SN+DUNE-WL future ε_s to +-0.08

but cannot reconstruct the quintessence potential, just the slope ε_s & hubble drag info

Aside: detailed results depend upon the SN data set used. Best available used here (192 SN), soon CFHT SNLS ~300 SN + ~100 non-CFHTLS. will put all on the same analysis/calibration footing – very important.

Newest CFHTLS Lensing data is important to narrow the range over just CMB and SN