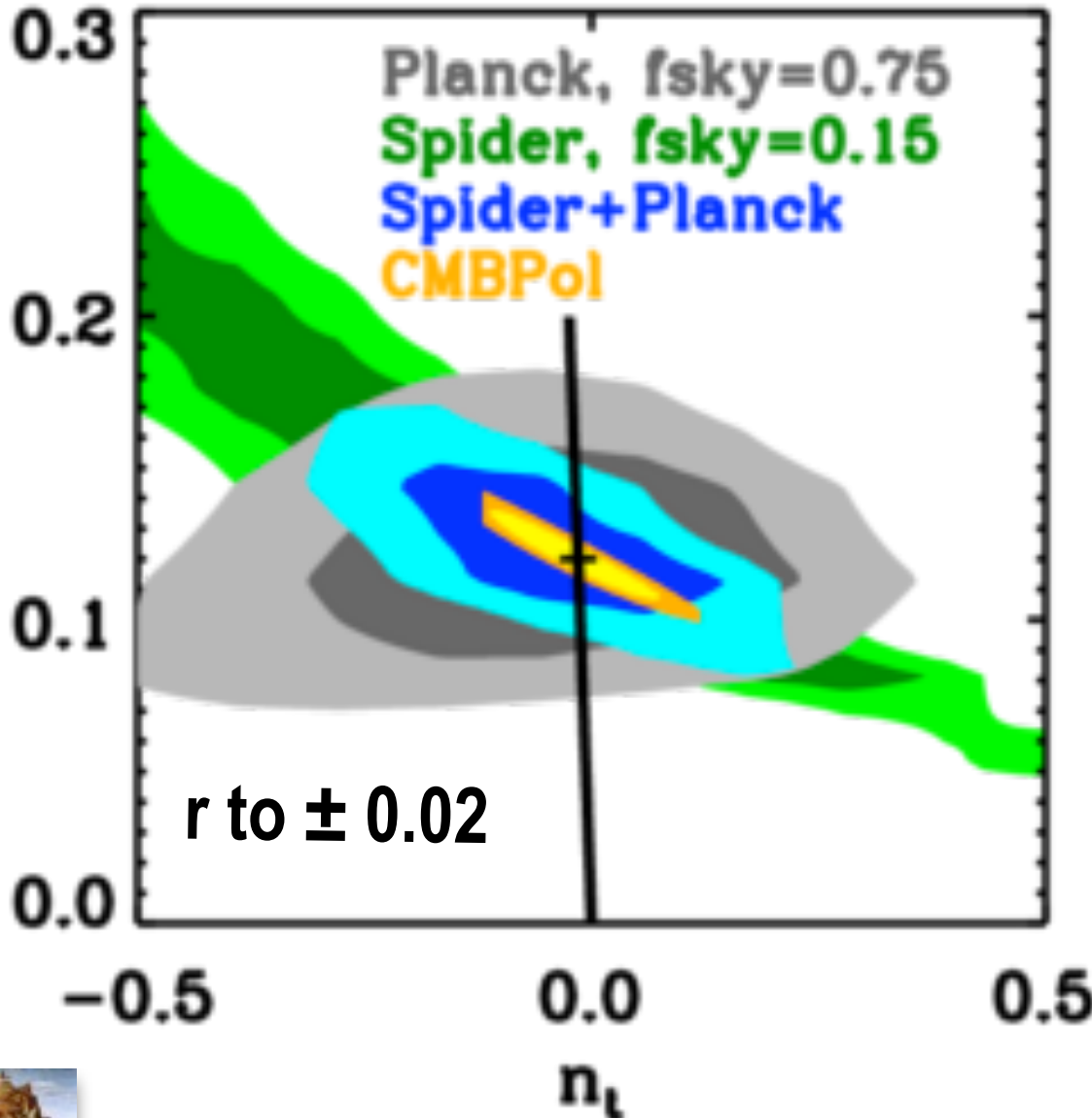


PRIMARY @ 2012?



CMB ~2012: Planck2.5+WMAP9+SPT/ACT/Quiet+Bicep/QuAD/Keck/ABS +Ebex/Spider



Pillar 7? Gravity Waves
 $r \approx 0.1 V / (10^{16} \text{Gev})^4$

$$r \approx 16\epsilon \approx -8n_t$$

nearly uniform acceleration

$$r \approx 0.13 \frac{d \ln V}{d \ln \psi^2}$$

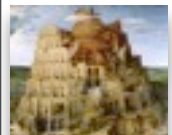
$\sim 0.03-0.3$ 80s-90s-03

string-based many-moduli
 inflation: roulette (hole sizes in a
 compactifying manifold) & brane
 inflation (separations), cyclic
 ensemble of trajectories

r tiny $< 10^{-10}$, but some
 models give $\sim .03-.05$

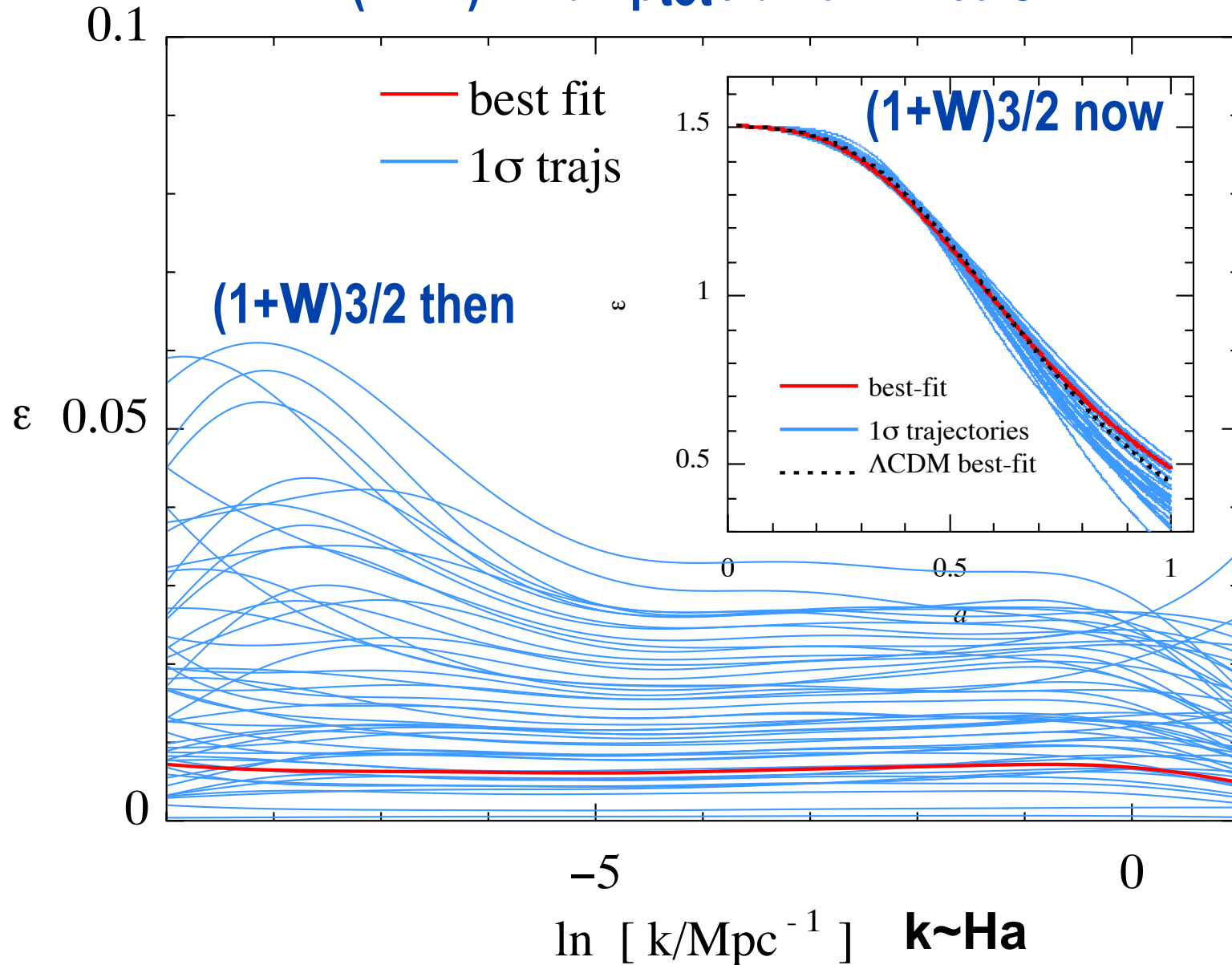
$r < 0.02$ 95% CL

+ Pillar 4: primordial non-Gaussianity $-9 < f_{NL} < 111$ (+- 5-10 Planck1)

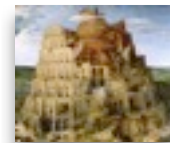


acceleration trajectories then & now

$$(1+W) = - d \ln p_{\text{tot}} / d \ln a^3 = 2/3 \epsilon$$

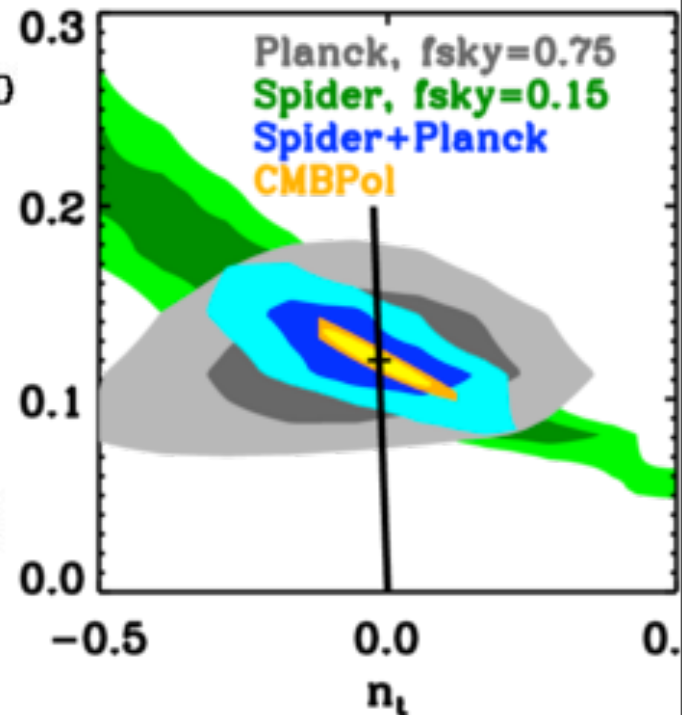
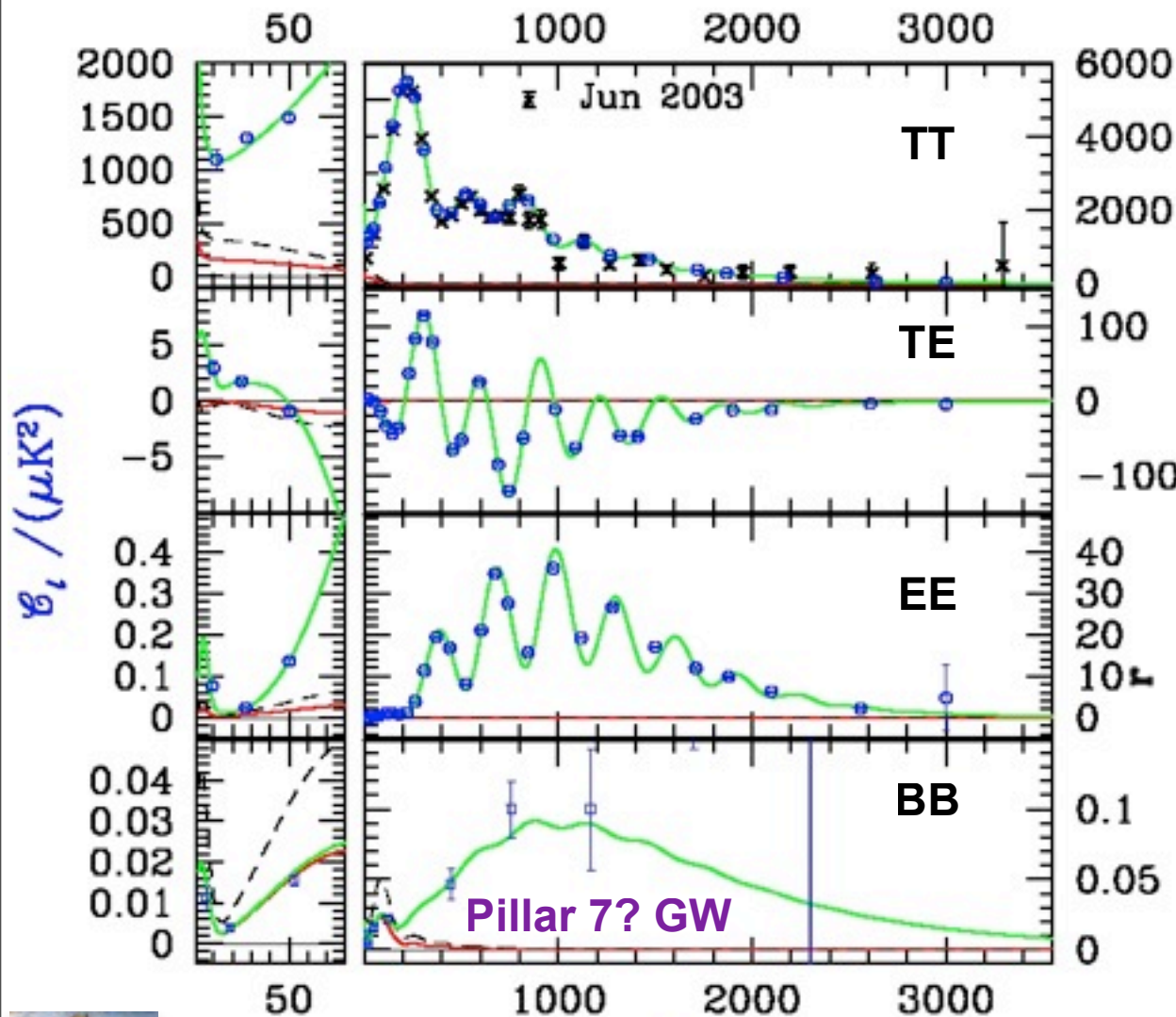


PRIMARY END @ 2012?



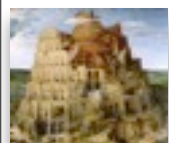
CMB ~2011+ Planck1+WMAP9+SPT/ACT/Quiet+Bicep/QuAD/Quiet +Spider

Pillar 7? Gravity Waves



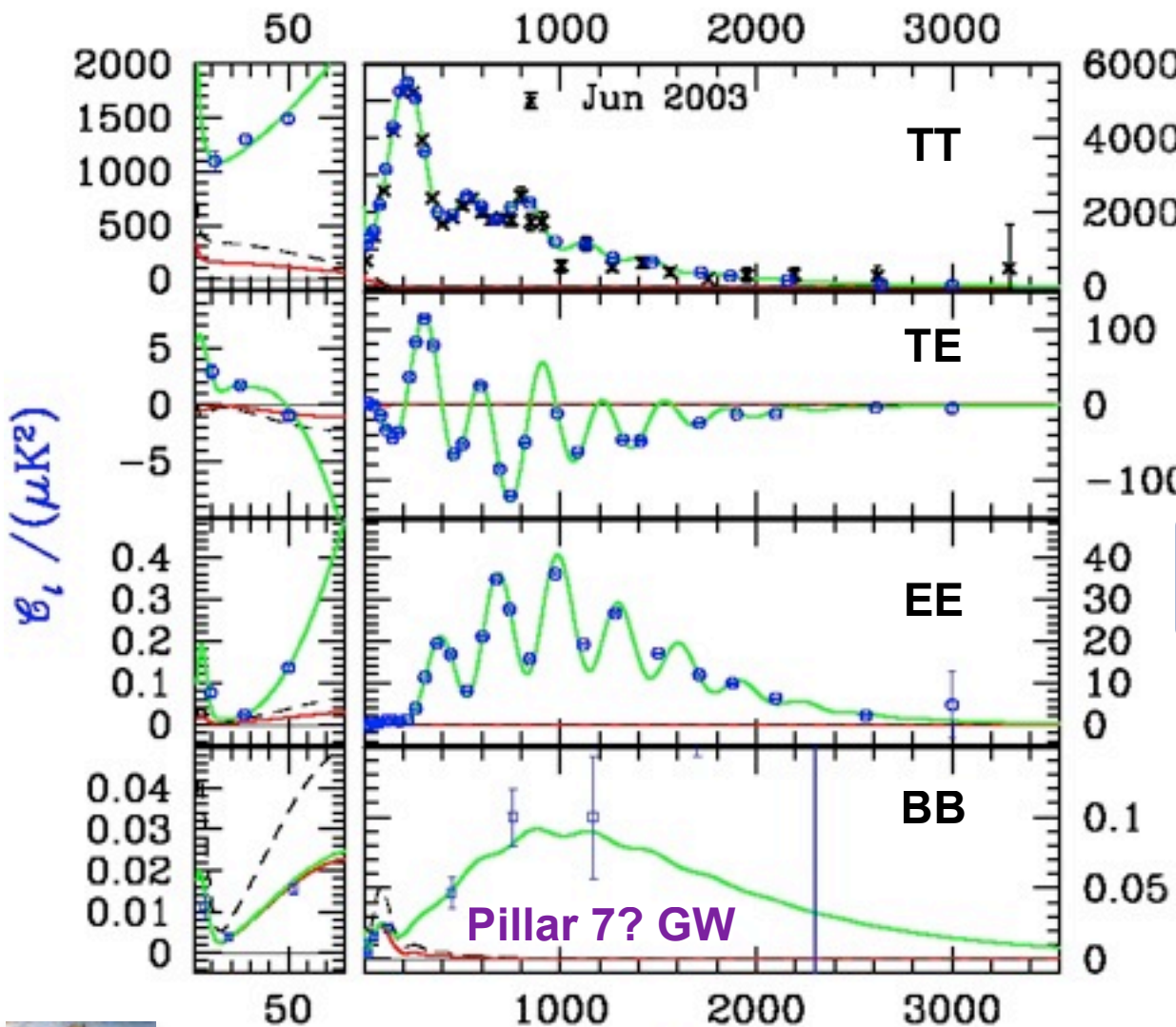
+ Pillar 4: primordial non-Gaussianity

$-9 < f_{NL} < 111$ (+- 5-10 Planck1)



PRIMARY END @ 2012?

CMB ~2009+ Planck1+WMAP8+SPT/ACT/Quiet+Bicep/QuAD/Quiet +Spider+Clover



Pillar 7? Gravity Waves

An ensemble of trajectories arises in many-moduli string models, whether braney or holey. Roulette inflation: complex hole sizes in 6D TINY $r < 10^{-10}$ & n_s from data-selected braking! ('theorem': $\Delta\psi < 1 \rightarrow r < .007$)

nearly uniform acceleration (power law, exp, PNGB, ..potentials) $r \sim .03-.3!$ is $\Delta\psi \sim 10$ deadly?

Even with low energy inflation, the prospects are good with Spider plus Planck to either detect the GW-induced B-polarization or set a strong blind upper limit $r < 0.02$ indicating stringy or other exotic models. Both experiments have strong Cdn roles. Bpol 2020?, to $r \sim 0.002$

+ Pillar 4: primordial non-Gaussianity

$-4 < f_{NL} < 80$ (+- 5-10 Planck1)

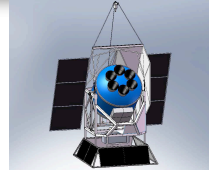
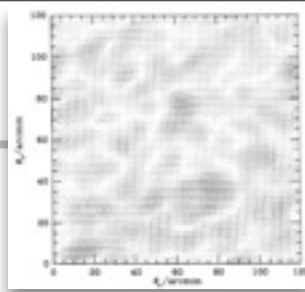
SPIDER Tensor Signal

Gravity Waves from Inflation

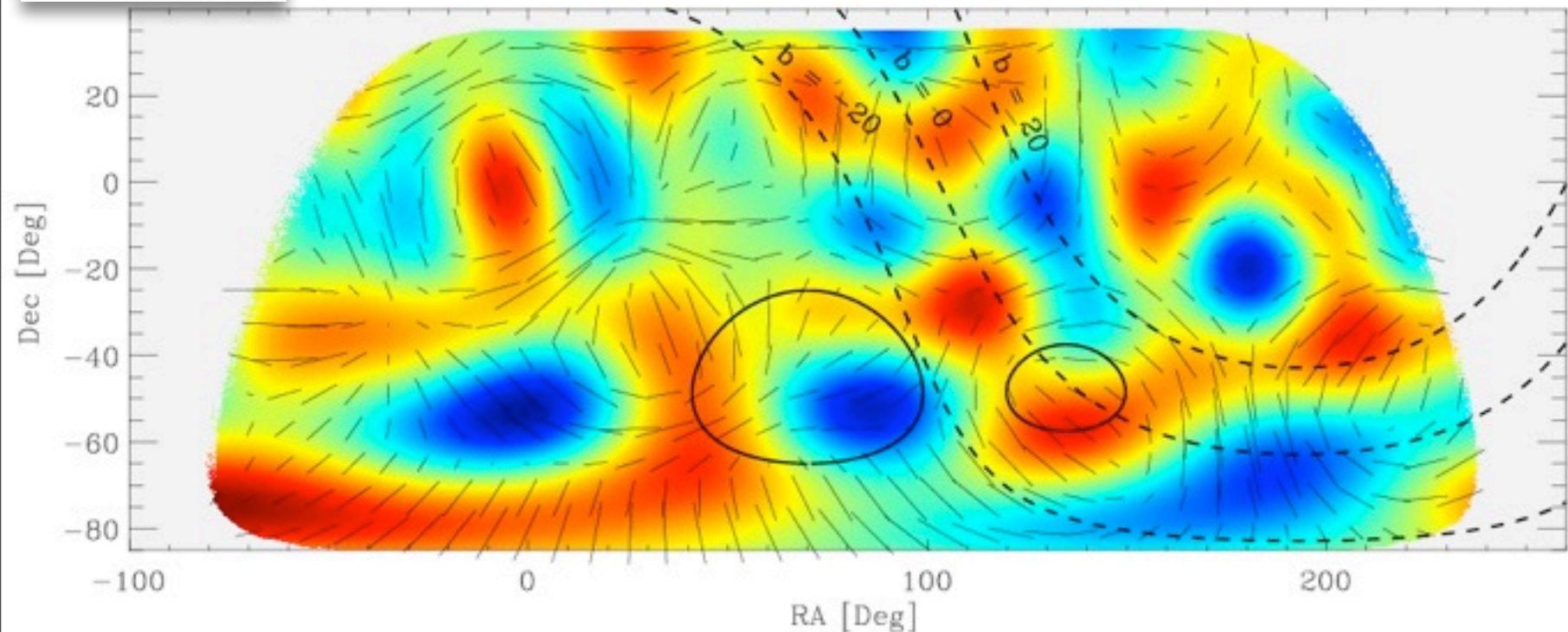
- Simulation of large scale polarization signal

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

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



Tensor



GW/scalar curvature: current from CMB+LSS: $r < 0.3$ 95%; good shot at 0.02 95% CL with BB polarization (+- .02 PL2.5+Spider), .01 target; Bpol .001 BUT foregrounds/systematics? But $r(k)$, low Energy inflation

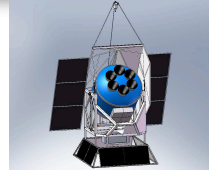
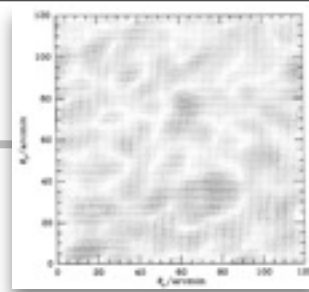
SPIDER Tensor Signal

Gravity Waves from Inflation

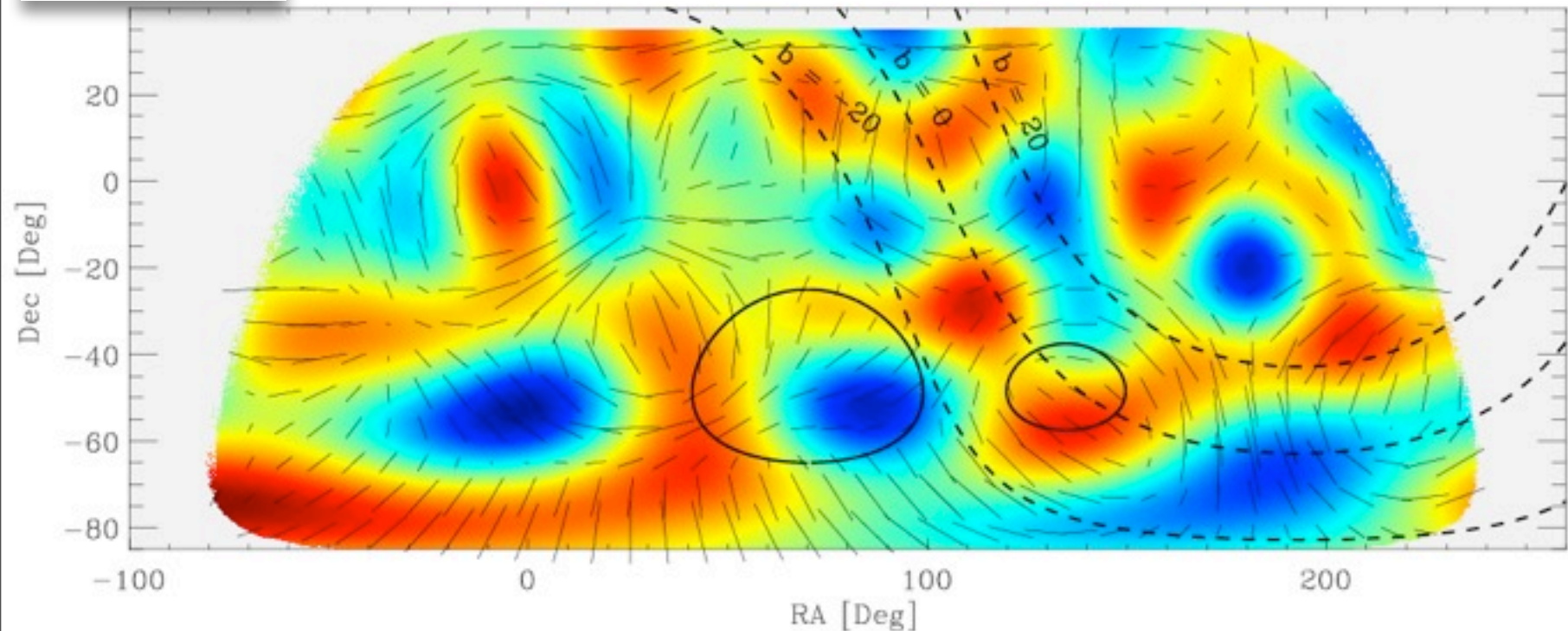
- Simulation of large scale polarization signal

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

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



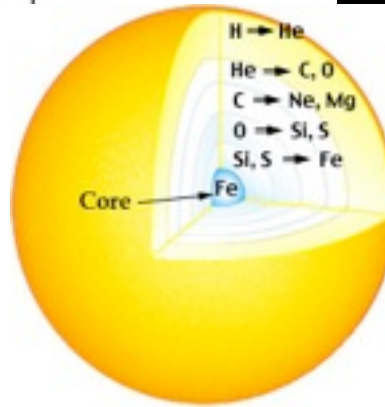
No Tensor



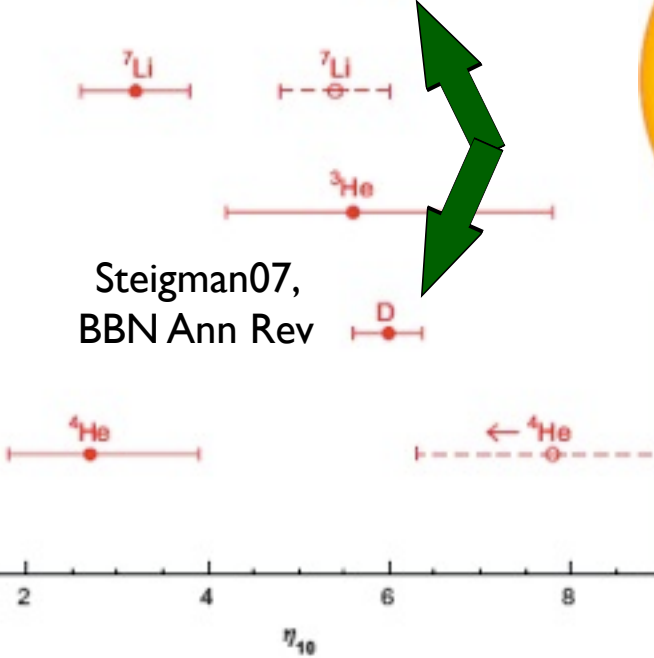
GW/scalar curvature: current from CMB+LSS: $r < 0.3$ 95%; good shot at 0.02 95% CL with BB polarization (+- .02 PL2.5+Spider), .01 target; Bpol .001 BUT foregrounds/systematics? But $r(k)$, low Energy inflation

Baryometers

CMB/LSS



Nobel Prize 84
Willy Fowler + Chandrasekhar



Steigman07,
BBN Ann Rev

$$\eta_{10} \equiv 10^{10} (n_B/n_\gamma) \equiv 274 \Omega_B h^2$$

$\Omega_b h^2$	January 2000	January 2002	June 2002	January 2003	March 2003
	$0.0339^{+0.0443}_{-0.0246}$	$0.0222^{+0.0025}_{-0.0021}$	$0.0221^{+0.0024}_{-0.0020}$	$0.0221^{+0.0023}_{-0.0018}$	$0.0233^{+0.0013}_{-0.0013}$

0.0223 ± 0.0007 0.0226 ± 0.0006 wmap3+acbar+cbi+... LSS

0.0233 ± 0.0005 wmap5+acbar+cbi+b03+.+WL+LSS+SNI+Lya
 cosmic baryon number $n_b = 0.261 \pm 0.005 / m^3$
 $\Omega_{dm} h^2 = 0.1145 \pm 0.0023$ $\Omega_m = 0.268 \pm 0.012$ $\Omega_\Lambda = 0.736 \pm 0.012$

How the First Cosmic Light Illuminates the Dark Universe

the dark seen from the 70s, 80s, 90s, 00s

** the high resolution frontier: the insides of clusters via SZ (SuZie,..., Acbar, QUaD, ... CCAT, CARMA++,ALMA,GBT,... ACT, SPT, Planck)

the polarization frontier: down the damping tail, through Planck (and ACTpol, SPTpol, ...)

the CMB computational horizon: simulations & Monte Carlos

the CMB computational horizon: optimal de-nuisanced maps from large-format arrays; algorithmic advances, foreground/source issues

** Theory of inflation & dark energy: the non-Gaussian frontier (beyond f_{NL} templates $-4 < f_{NL} < 80$ now to $f_{NL} \sim \pm 5$ Planck; will Gravity Wave B be big enough to detect $r(k)$? DE w $(z|V(\psi),IC)$ trajectories

beyond the SM: in quest of the sub-dominant & the anomalous

** the polarization frontier: the quest for B-modes and primordial gravity waves - small-sky (Bicep, KECK, Spider), Planck+small-sky, need for a CMBpol??

CBI pol to Apr'05 @Chile CBI2

Boom03@LDB

WMAP @L2 to 2010

DASI @SP

CAPMAP

QUaD @SP

Bicep @SP

Planck09.4

52 bolometers
+ HEMTs @L2

9 frequencies
Herschel

BLAST

Quiet1

@Chile

Bicep2



Quiet2

1000 HEMTs

Keck/Spud@SP

EBEX @LDB **ABS@Chile**

Spider

2312 bolos
@LDB



CHIP

2004

2006

2008

LHC

2011

Bpol @L2

2005

2007

2009

Acbar to Jan'06, 08f @SP

SPT

1000 bolos
@SPole

ACT

3000 bolos
3 freqs @Chile

BLASTpol

Clover @Chile

Polarbear

300 bolos
@Cal/Chile

SPTpol

ACTpol

ALMA

CCAT@Chile

LMT@Mexico

SZA @Cal



APEX

~400 bolos
@Chile

AMI



GBT

SCUBA2

12000 bolos
JCMT @Hawaii



2002

NSF/Caltech
/CITA/CIAR

May 23, 2002

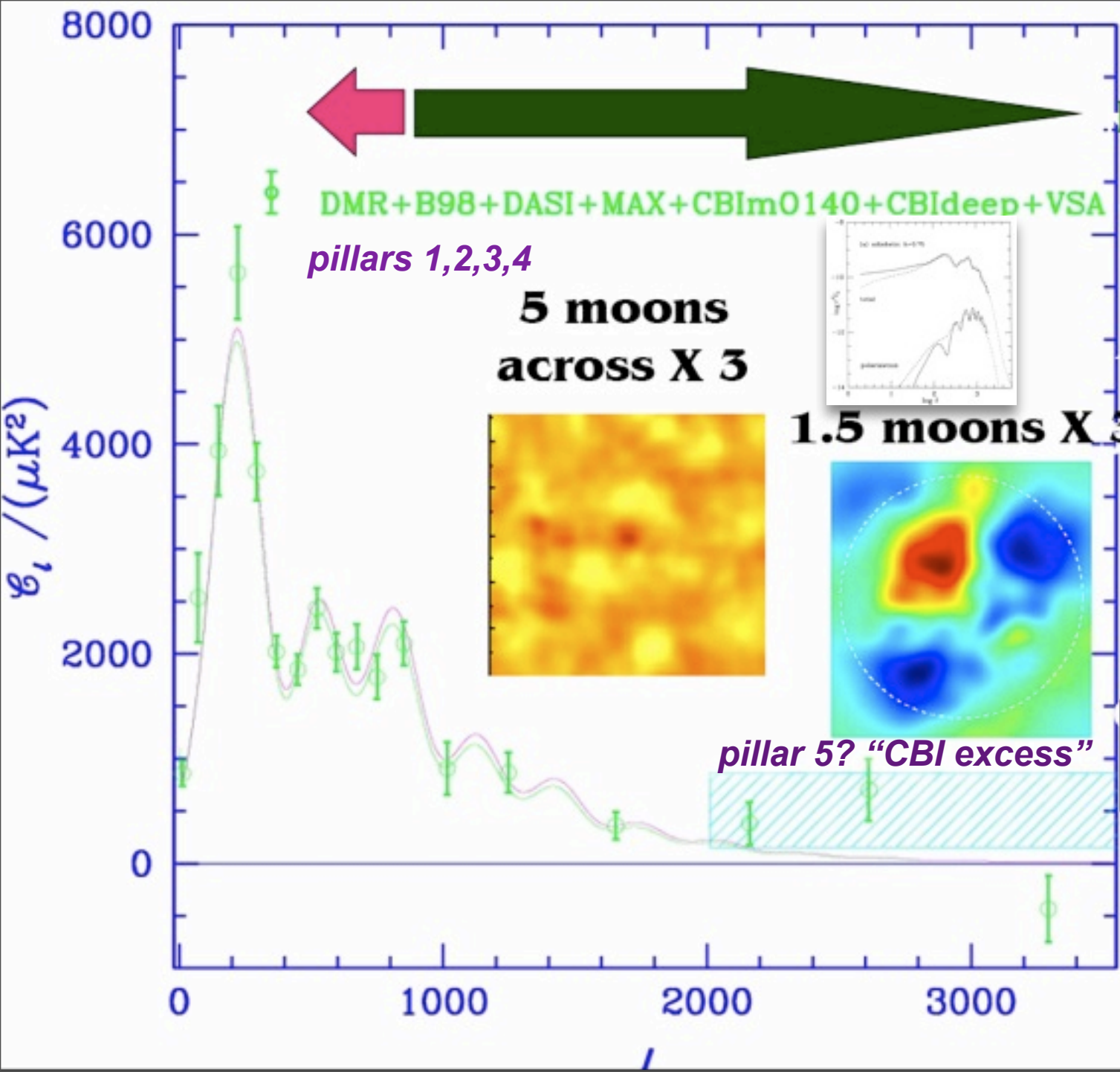
AAS Jun02

Grand
unified
spectrum

Adds

CBI mosaic
+ CBI deep

+ VSA



⇒ exquisite & increasingly precise determination of cosmic parameters

dark matter abundance $\Omega_m = 0.268 +0.012 -0.012$

	January 2000	January 2002	June 2002	January 2003	March 2003
$\Omega_{\text{cdm}} h^2$	$0.198^{+0.088}_{-0.080}$	$0.130^{+0.031}_{-0.028}$	$0.124^{+0.026}_{-0.025}$	$0.125^{+0.021}_{-0.022}$	$0.111^{+0.010}_{-0.010}$

CMB-only history (weak-h prior). LSS-then drove to near current

$\Omega_{\text{dm}} h^2$ **0.1145 ± 0.0023** CMBall+WL+LSS+SN+Lya
 $\Omega_{\text{b}} h^2$ **0.0233 ± 0.0005** ordinary matter abundance (baryons)

⇒ $\rho_{\text{dm}}/\rho_{\text{b}} = 5.1$

Ω_{Λ}	$0.34^{+0.28}_{-0.24}$	$0.52^{+0.17}_{-0.20}$	$0.53^{+0.17}_{-0.19}$	$0.57^{+0.14}_{-0.19}$	$0.73^{+0.06}_{-0.10}$
--------------------	------------------------	------------------------	------------------------	------------------------	------------------------

CMB-only history (weak-h prior). LSS-then drove to near current value

dark energy abundance $\Omega_{\Lambda} = 0.736 +0.012 -0.012$

& $H_0 = 72 \pm 1$ CMBall+WL+LSS+SN+Lya

⇒ $\rho_{\text{m}}/\rho_{\text{de}} = 0.30$

$\epsilon = -d \ln H / d \ln a = 1 + q$: now $= 3/2 [\Omega_{\text{m}0} + (1+w)(1-\Omega_{\text{m}0})]$ ~0.40?, to 0?

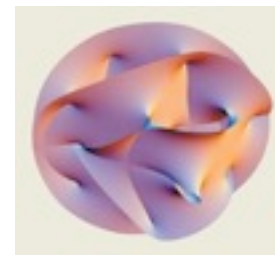
standard inflation space: n_s $dn_s/d\ln k$ $r = T/S$ @k-pivots

WHAT IS PREDICTED?

Smoothly broken scale invariance
by nearly uniform braking (standard
of 80s/90s/00s) $r \sim 0.03-0.5$

large field inflation (field moves $>$ Planck mass)
or highly variable braking r tiny

(stringy cosmology) $r < 10^{-10}$



small field inflation (field moves $<$ Planck mass $\Rightarrow r < .007$)

Bond, Kofman, Prokushkin, Vaudrevange 07, Roulette Inflation with Kahler Moduli and their Axions

Barnaby, Bond, Zhiqi Huang, Kofman 09, Preheating after Modular Inflation

monodromy (V=cosine+linear) & fibre inflation give larger r

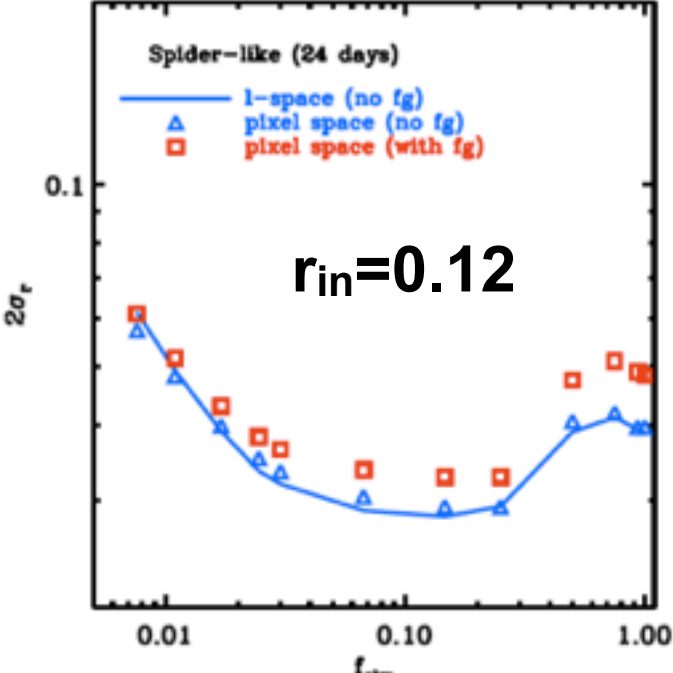
current r constraints (95%CL) - prior sensitive

$r < 0.16$ (no running, all data sets)

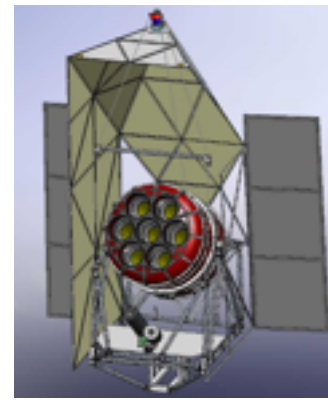
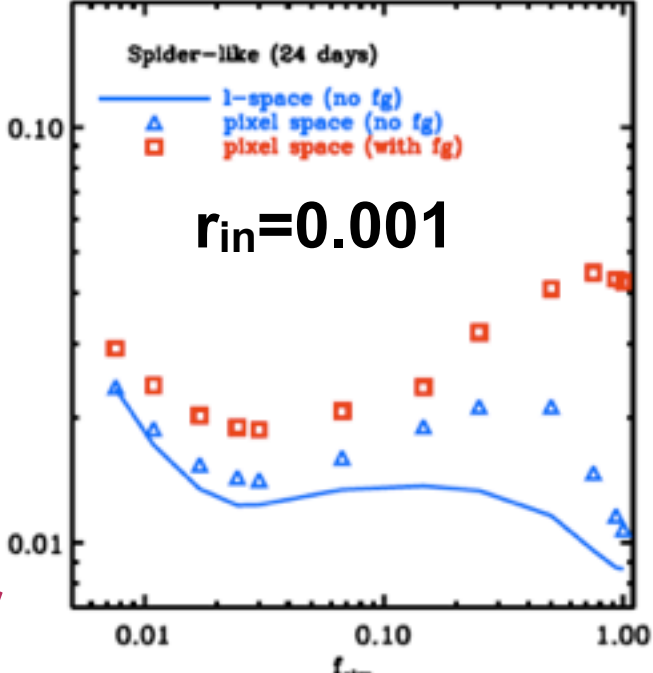
$r < 0.32$ (no running, CMB-only data sets)

$r < 0.27$ (with running, all data sets)

inflation consistency
 $-n_t \approx r/8 \approx 2\varepsilon(k)$
 $1-n_s \approx 2\varepsilon + d\ln\varepsilon/d\ln H a$

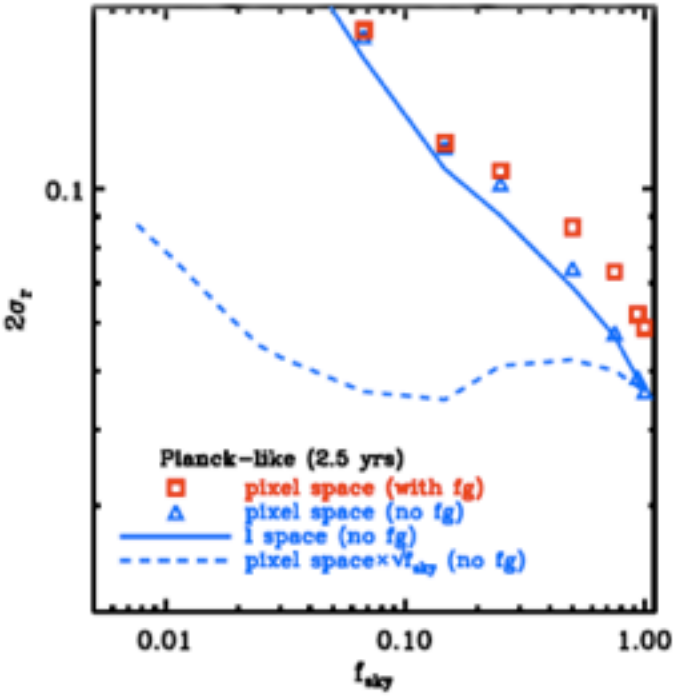


$2\sigma_r$
VS
 f_{sky}
via
QU
direct
to r
Spider

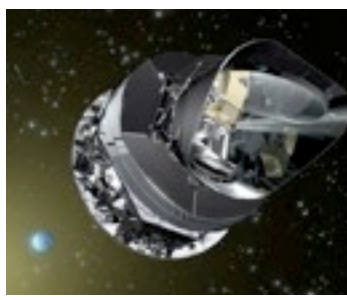
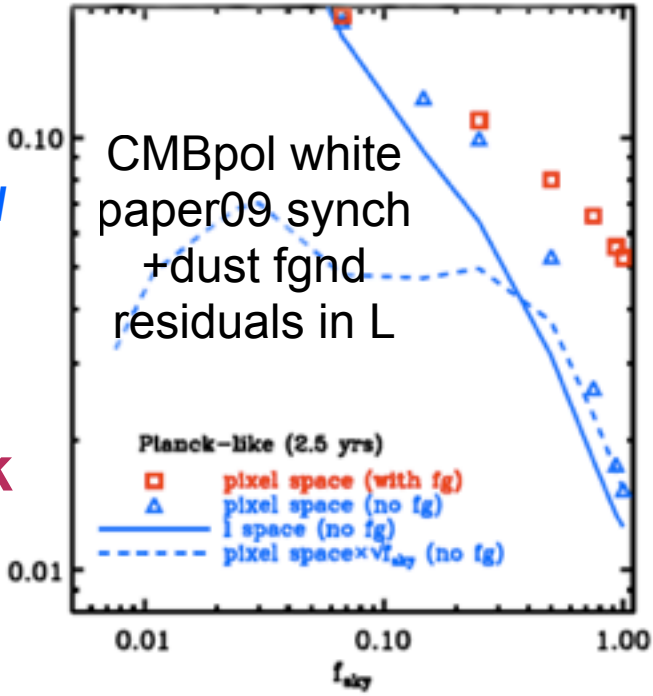


Spider
96+150 GHz
~2000 bolos
24 days LDB

PRIMORDIAL GRAVITATIONAL WAVE DETECTABILITY WITH DEEP SMALL-SKY CMB EXPERIMENTS

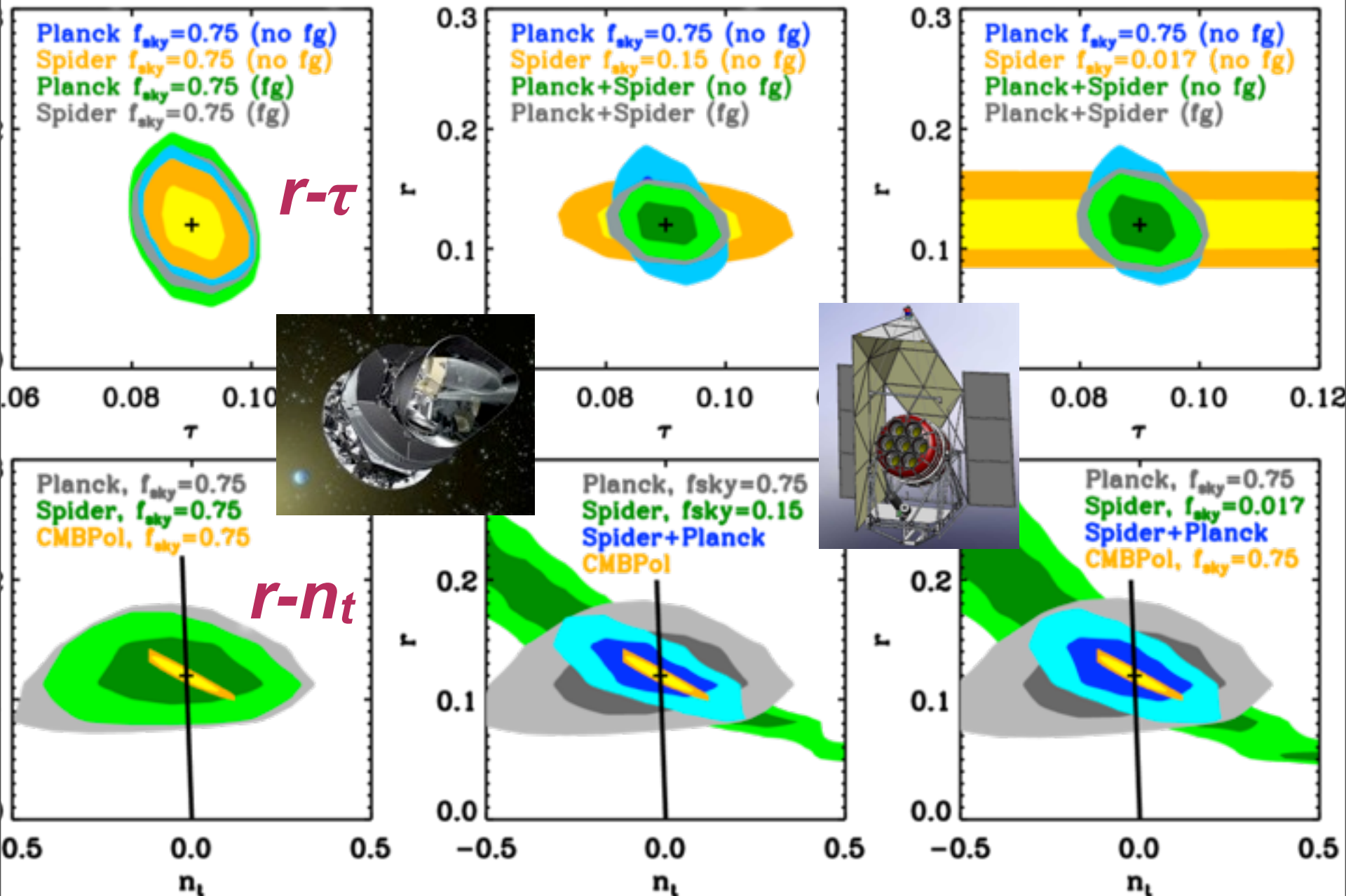


Farhang,
Bond,
Dore &
Netterfield
2010
Planck



Planck
100+143 GHz
16 PSB+8 SWB
of 32PSB+20SWE
2.5 yrs@L2

Spider-24d (fsky) cf. Planck-2.5yr. QUIET/KECK/ABS/EBEX... similar



forecasting QU not EB $2\sigma_r \sim 0.02$ for $0.02 < f_{\text{sky}} < 0.15$

standard inflation space: n_s $dn_s/d\ln k$ $r = T/S$ @k-pivots

What can be observed?

forecasting QU not EB

Spider $2\sigma_r \sim 0.02$ for $0.02 < f_{\text{sky}} < 0.15$

Planck 2.5yr $2\sigma_r \sim 0.02 \Rightarrow \sim 0.05$ (foregrounds)

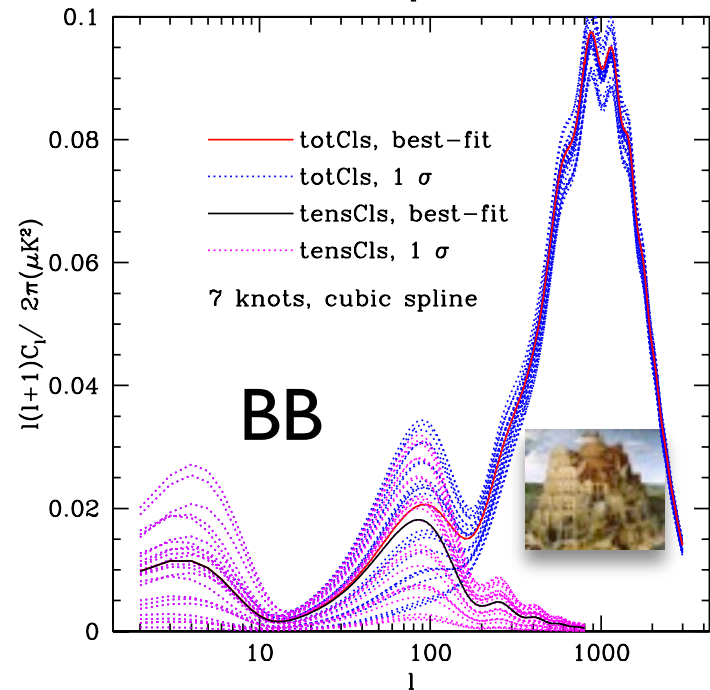
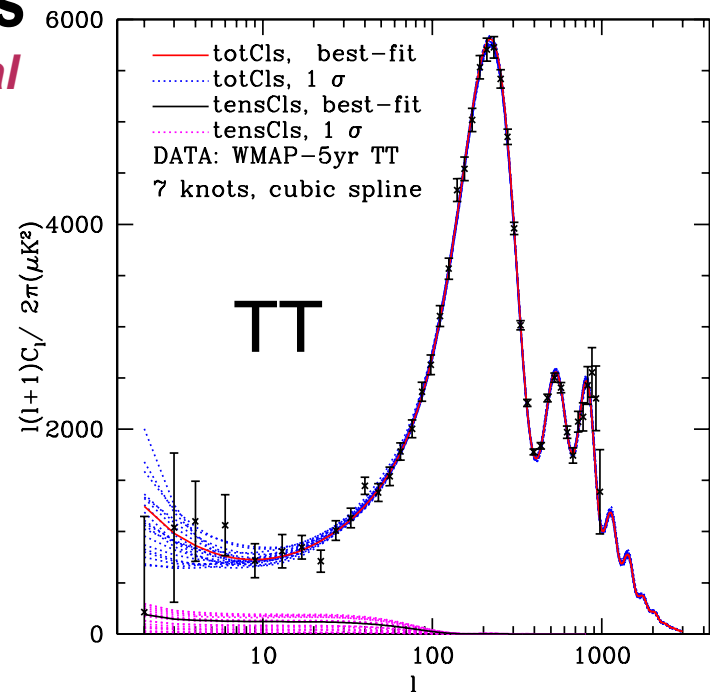
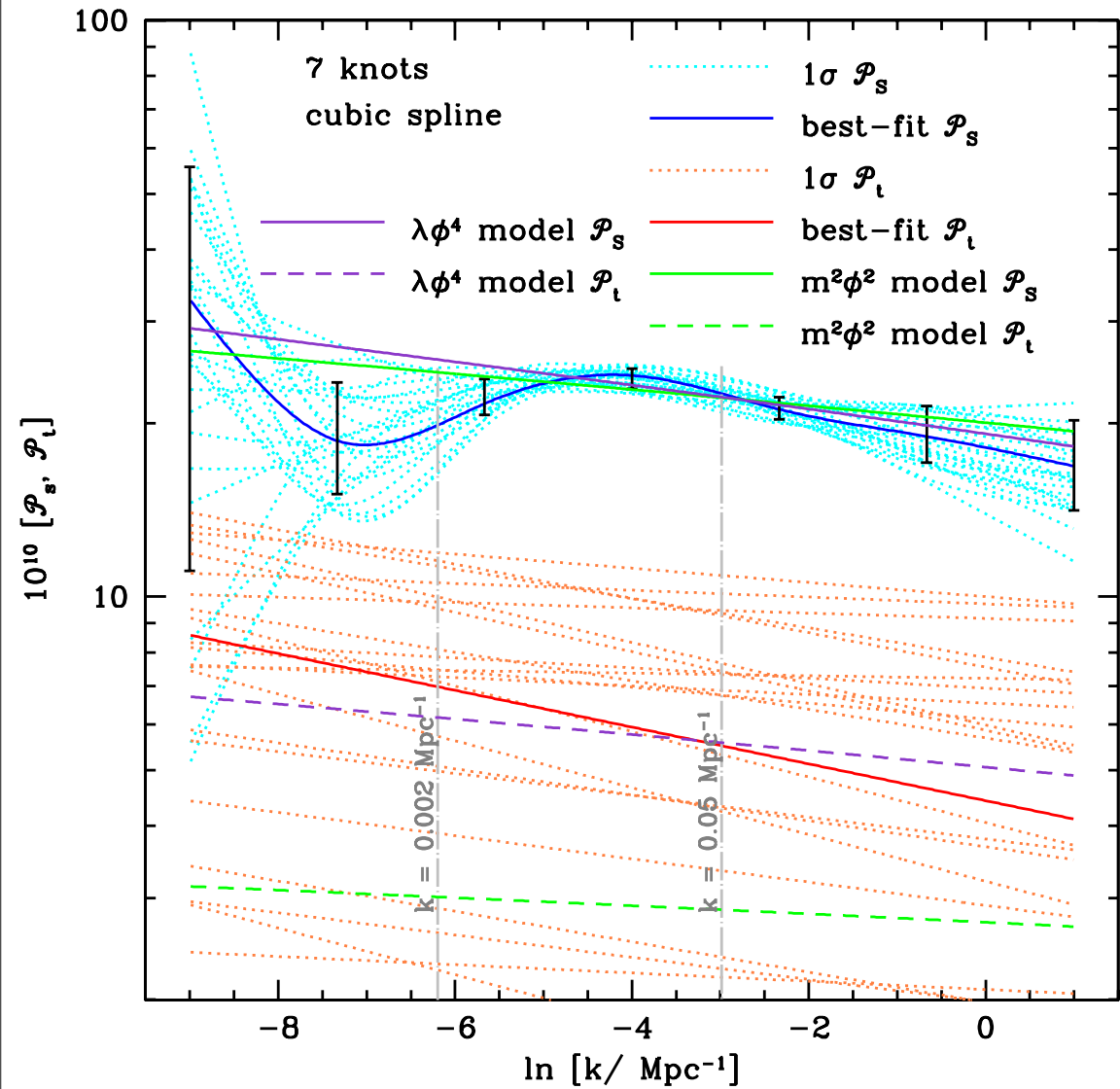
Marzieh Fahrang, Bond, Dore & Netterfield 2010

What is predicted? ???

$0 < r < 0.5$, $-12 < \log(r) < -0.3$

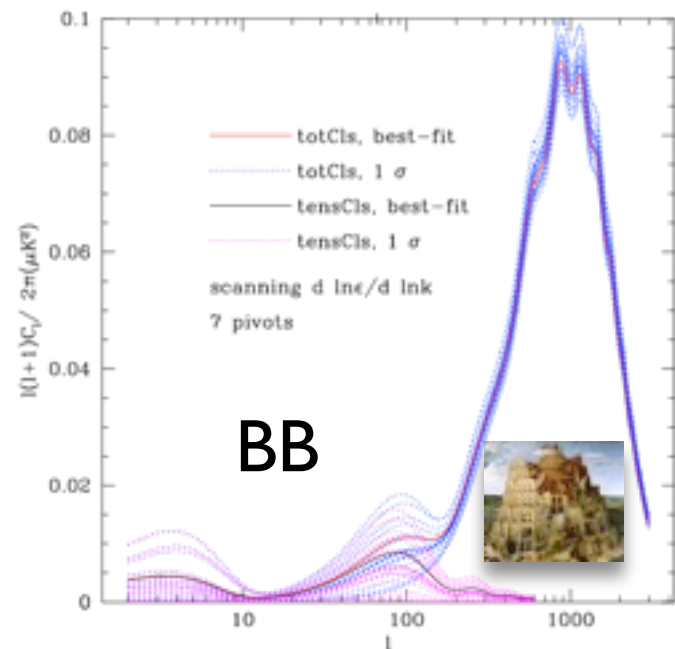
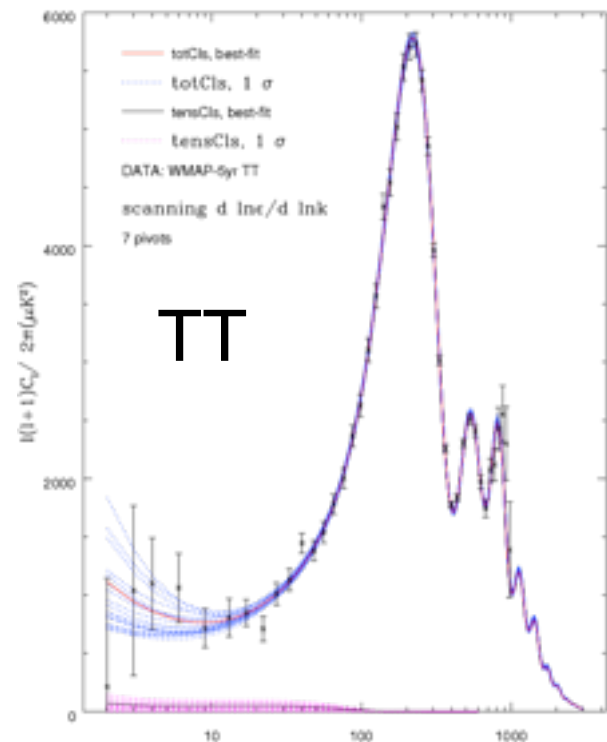
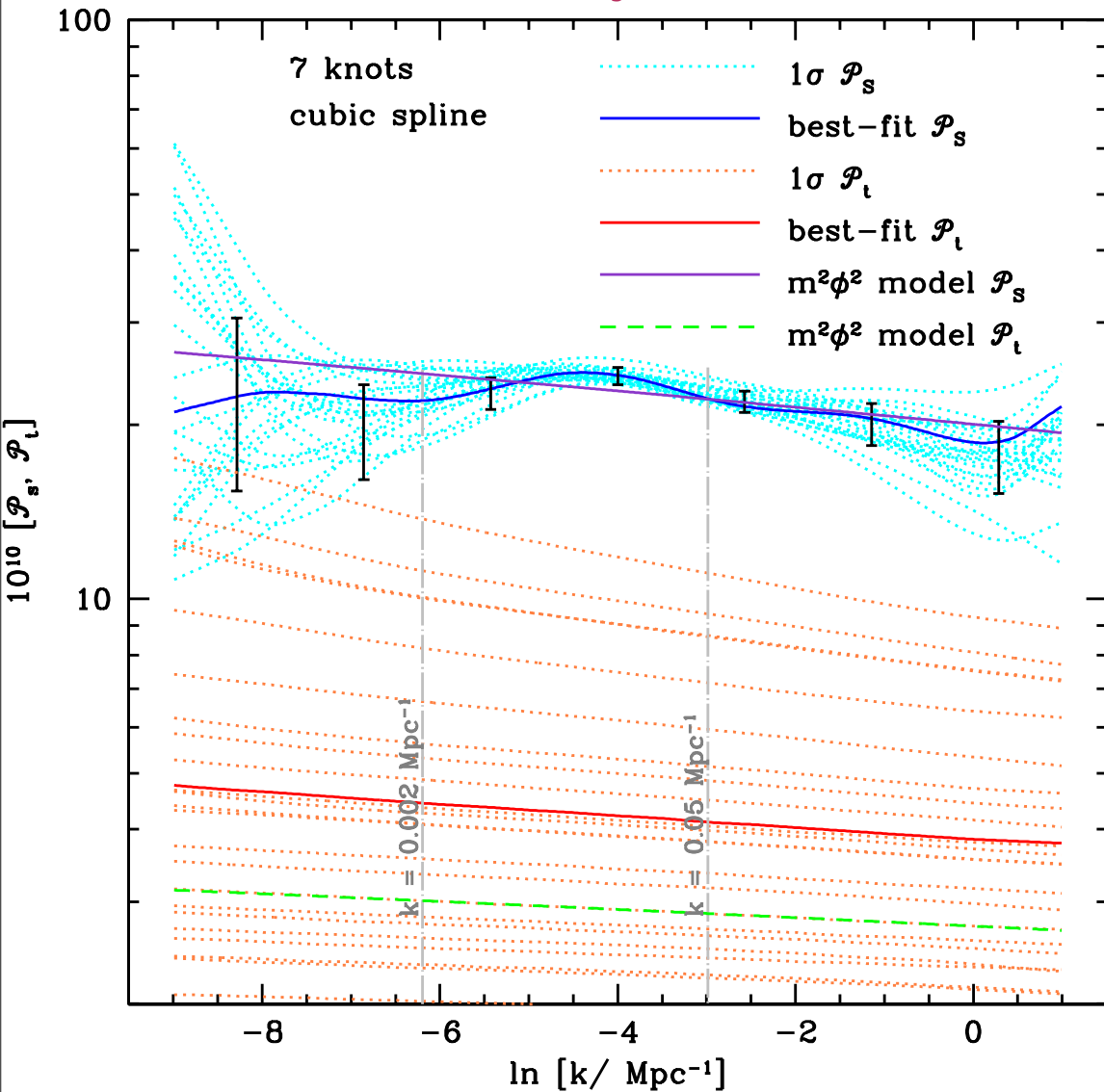
compress data onto non-top-hat k-modes

partially-blind scalar \ln -power trajectories & usual r - n_t tensor - no consistency relation. Nov09 data



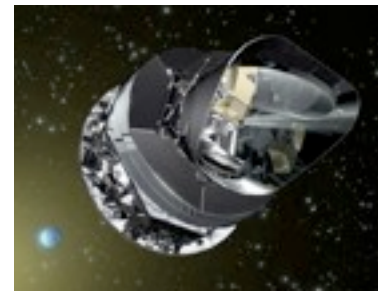
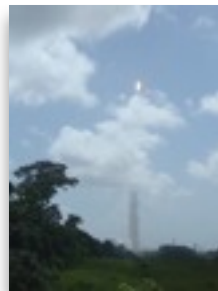
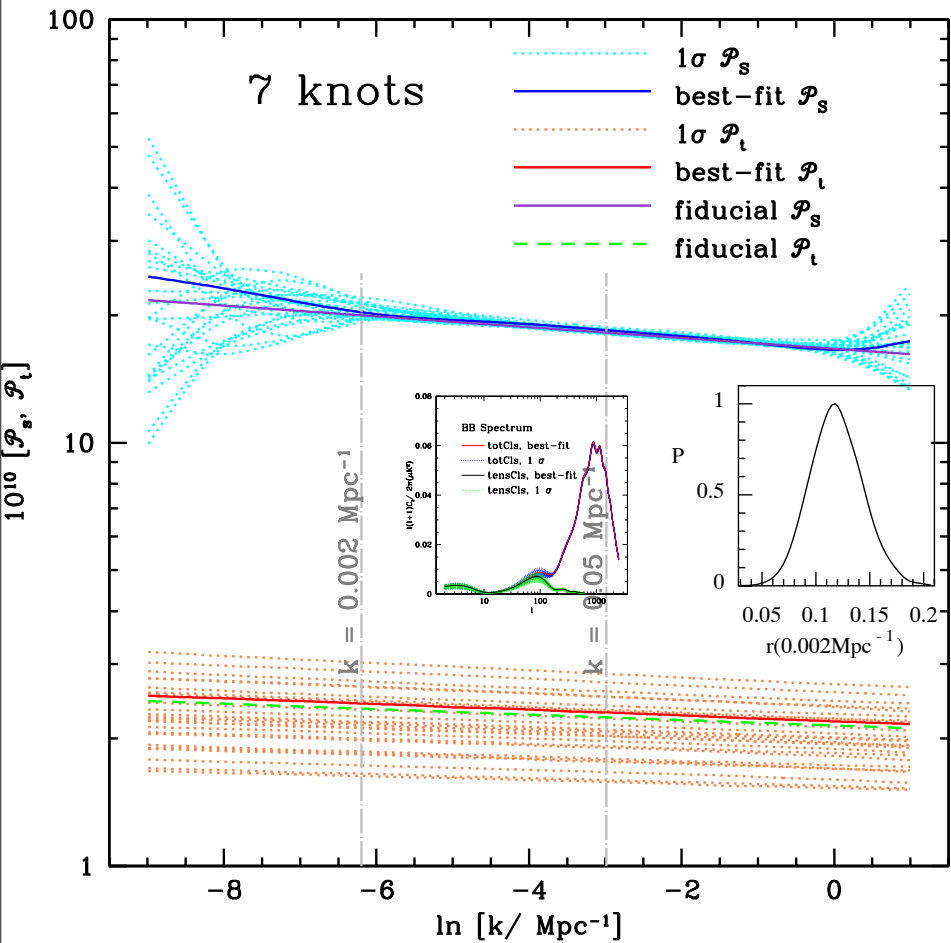
compress data onto non-top-hat k-modes

partially-blind acceleration trajectories obeying tensor/scalar consistency relation. Nov09 data



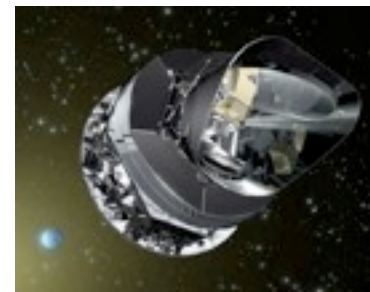
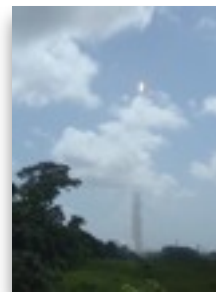
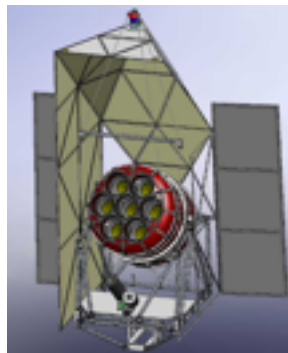
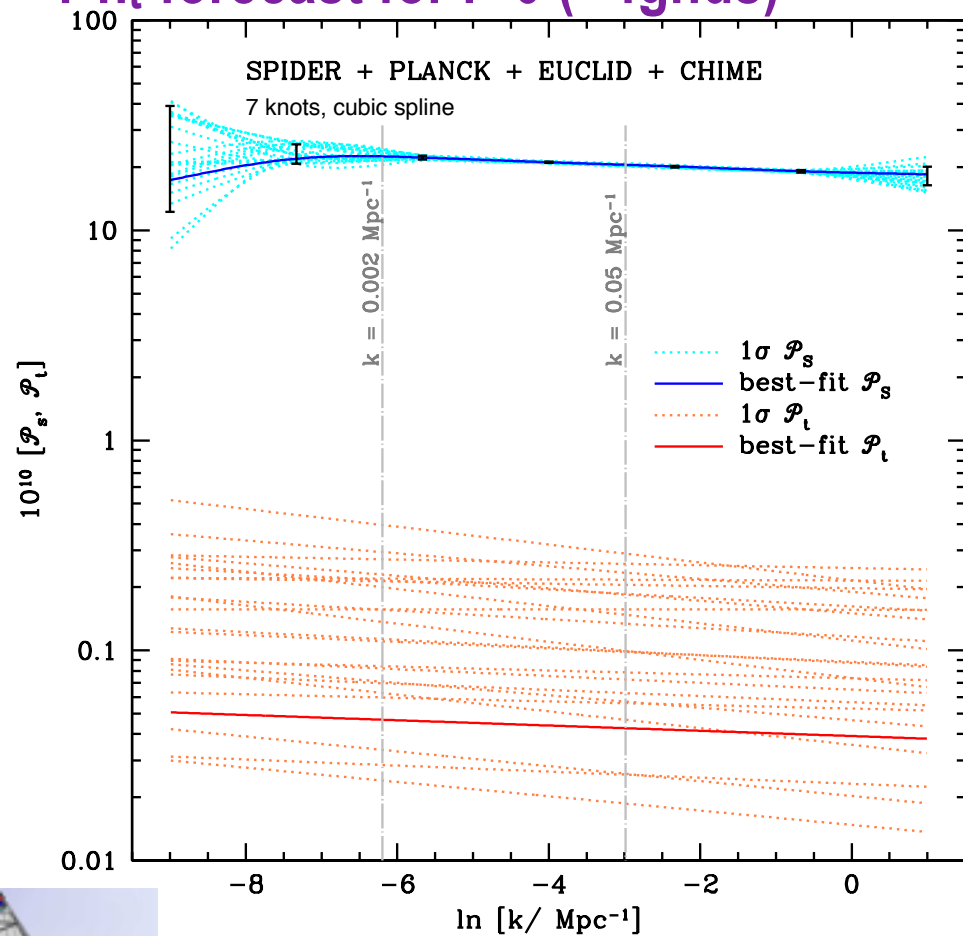
compress data onto non-top-hat k-modes

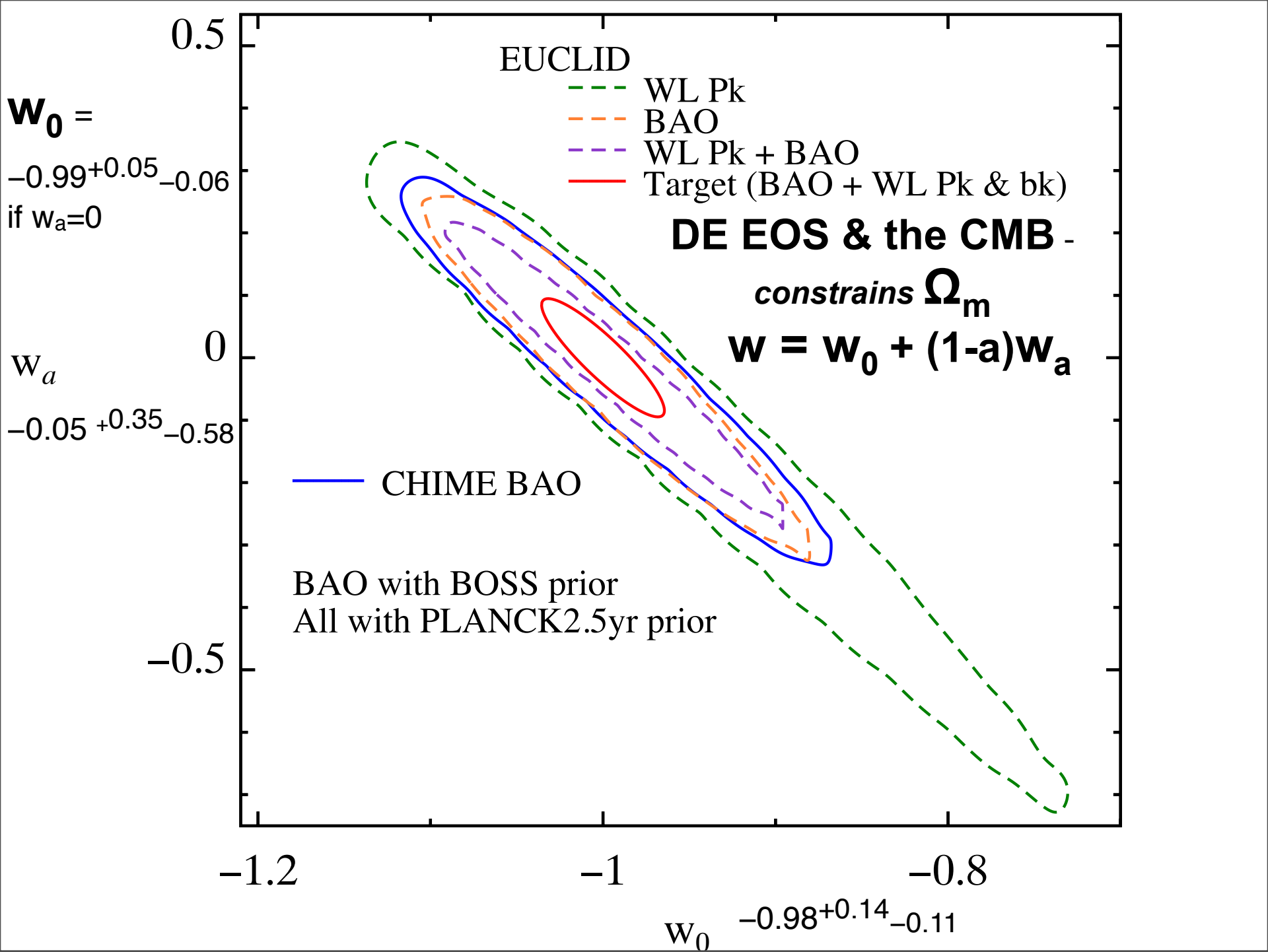
Planck2.5 7 knot forecast with inflation consistency; input $r=0.12 m^2\phi^2$



compress data onto non-top-hat k-modes

Spider-24days + Planck-2.5yr + ... 7 knot InPs
+r-n_t forecast for r=0 (+ fgnds)





Quintessence $V(\psi)$

& $KE < 0$ Phantom?

3-parameter paving of trajectories

$$w(z | \epsilon_s, \alpha_t, \zeta_s)$$

Huang, Bond, Kofman 10

$$\epsilon_s = (d \ln V / d\psi)^2 / 4 \text{ @pivot } a_{eq}$$

$= .00 + .18 - .17$ current

to $= .005 + .031 - .025$ future

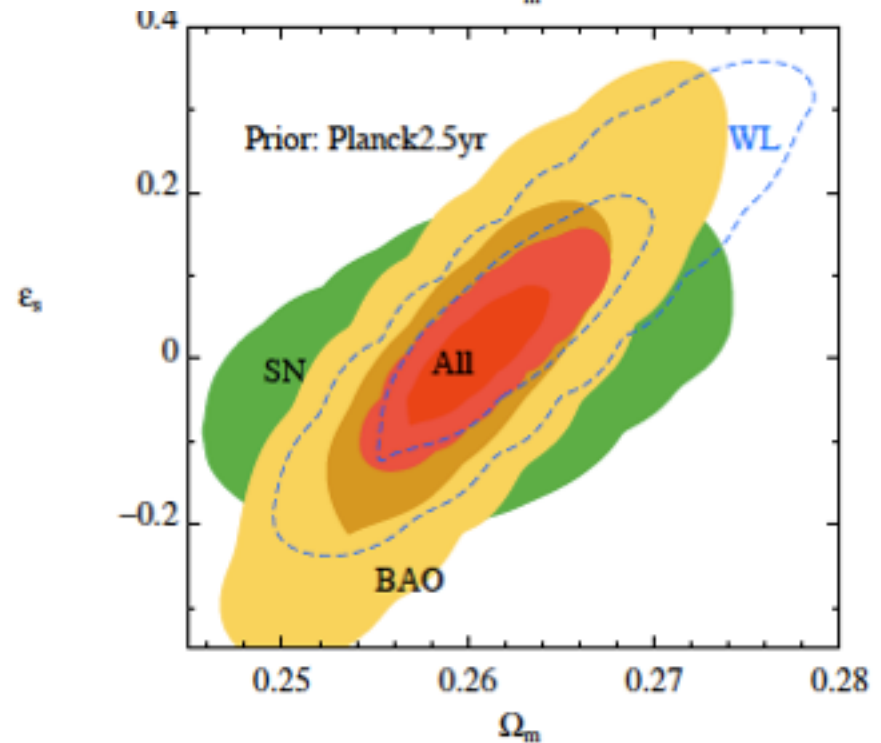
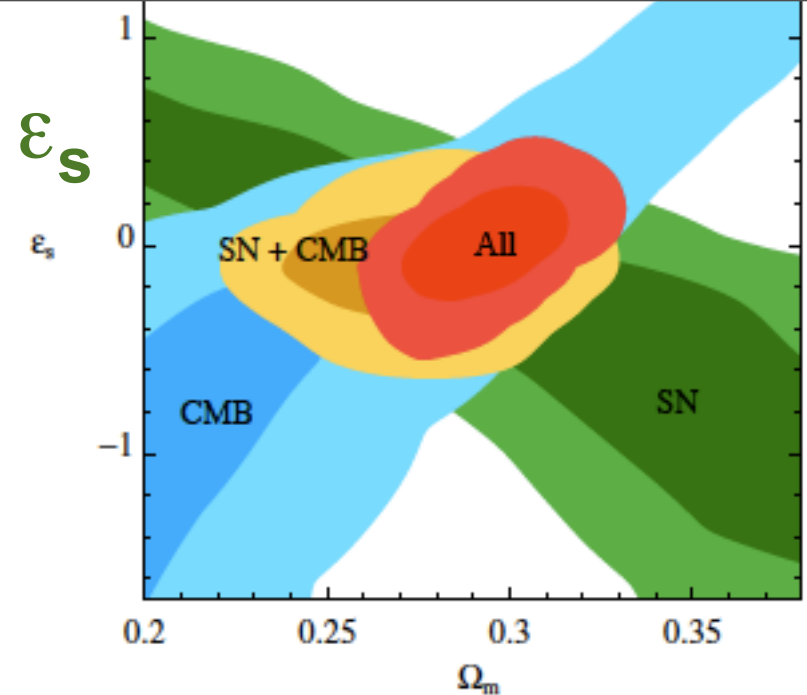
α_t ~tracking parameter

$= .00 + .21 + .58$ current

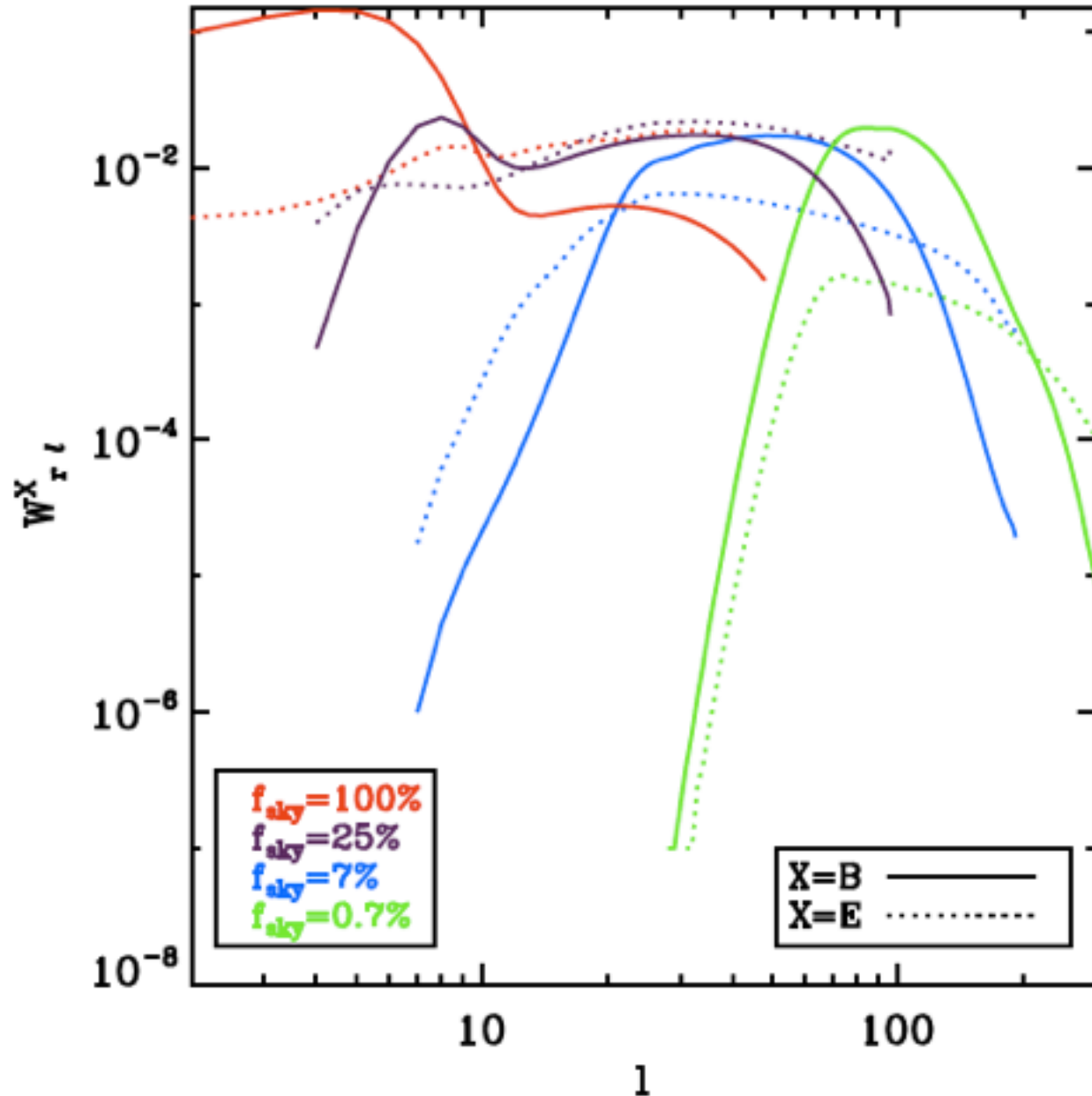
to $= .00 + .034 + .093$ future

$$\zeta_s \sim d^2 \ln V / d\psi^2$$

~ not constrained



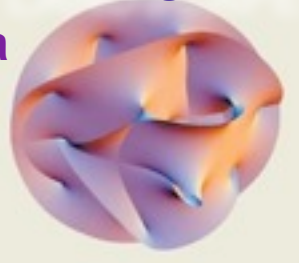
Window functions for the $\delta r/r^*$ response to relative uncertainties in EE, BB power spectra: complementarity of Planck & small-sky Spider *etal*



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

New: Theory prior = probability distribution of late-flows on an energy LANDSCAPE

6/7 tiny extra dimensions



1980

R^2 -inflation

Old Inflation

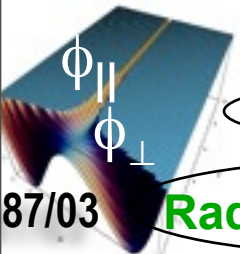
Chaotic inflation

New Inflation

Double Inflation

Power-law inflation

SUGRA inflation



87/03

Radical BSI inflation

running (nee variable M_p) inflation

Extended inflation

1990

Natural pMGB inflation

Hybrid inflation

KLS94 preheating

SUSY F-term inflation

SUSY D-term inflation

Assisted inflation

Brane inflation

2000

SUSY P-term inflation

Super-natural Inflation

K-flation



N-flation

D3,D7 brane inflation

DBI inflation

ekpyrotic/
cyclic

moving brane separations

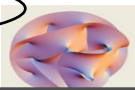
Racetrack inflation

Tachyon inflation

Warped Brane inflation

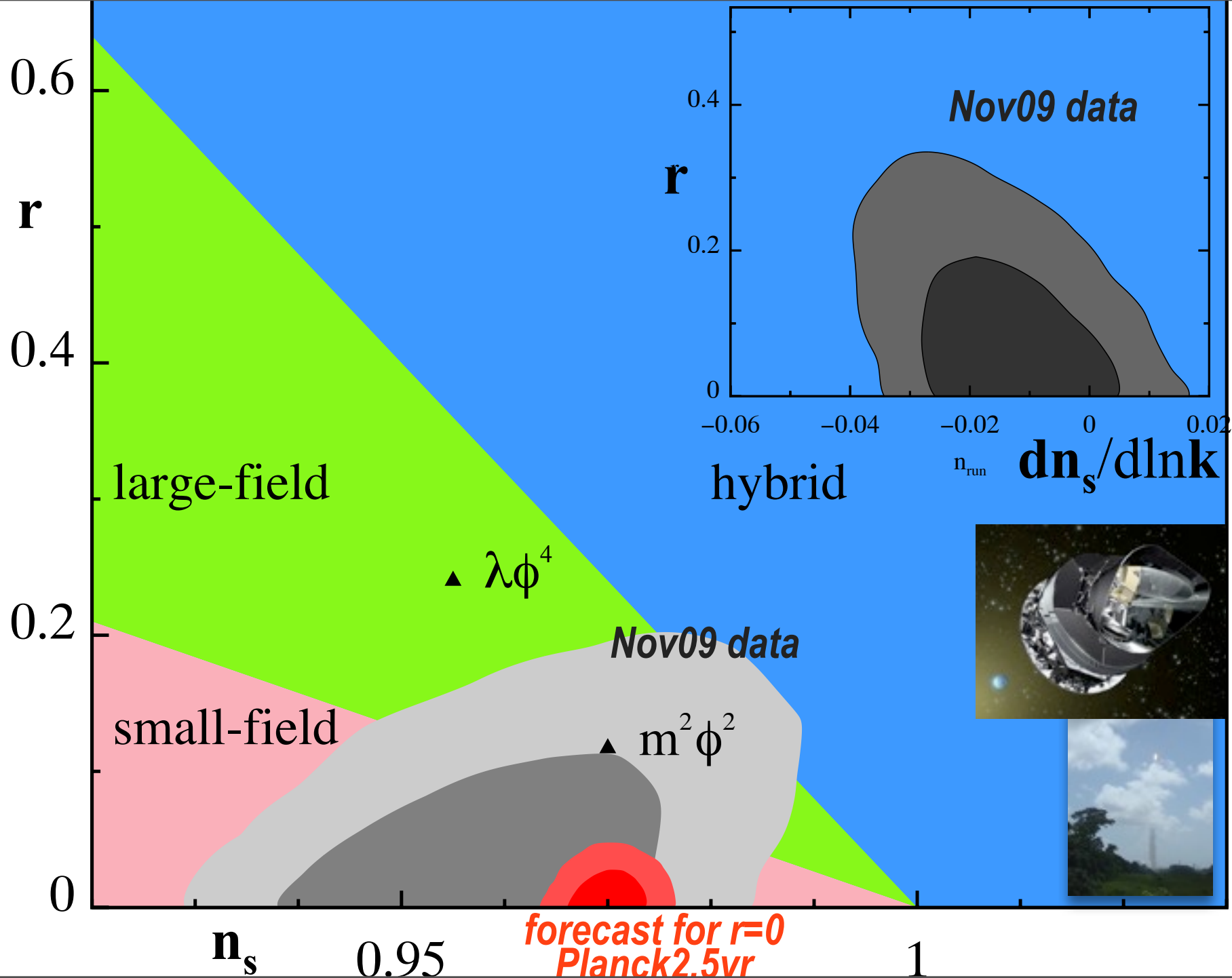
moduli fields

monodromy

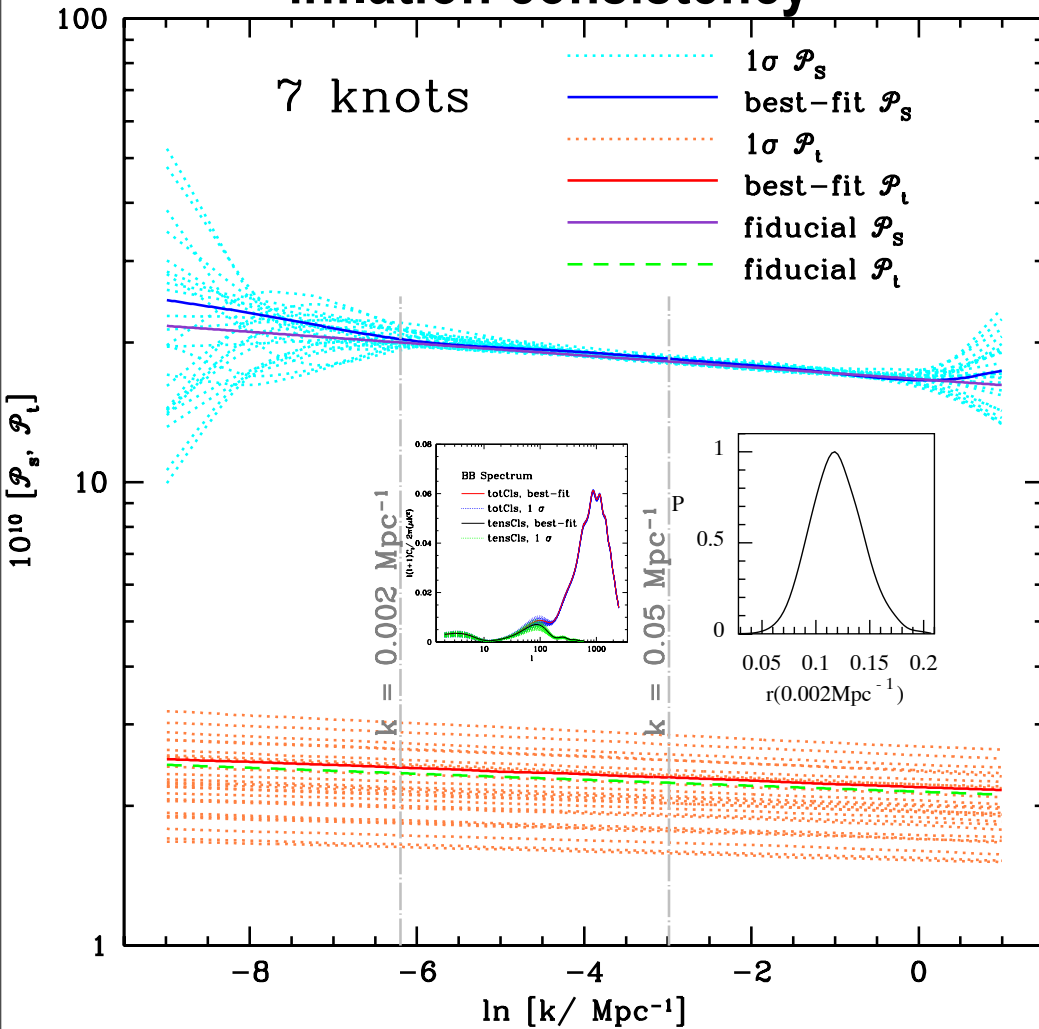


Roulette inflation Kahler moduli/axion

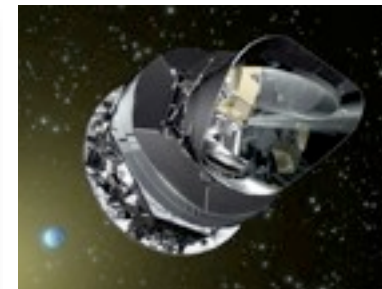
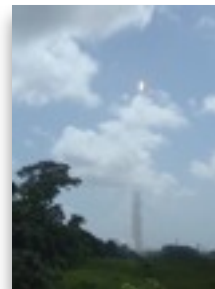
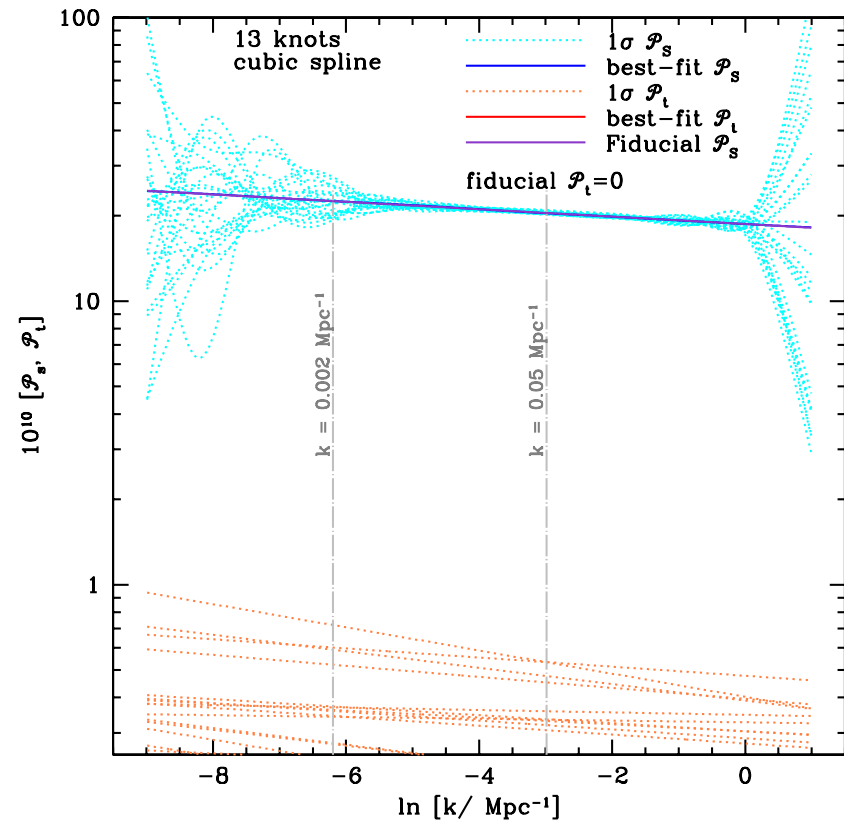
fibre inflation



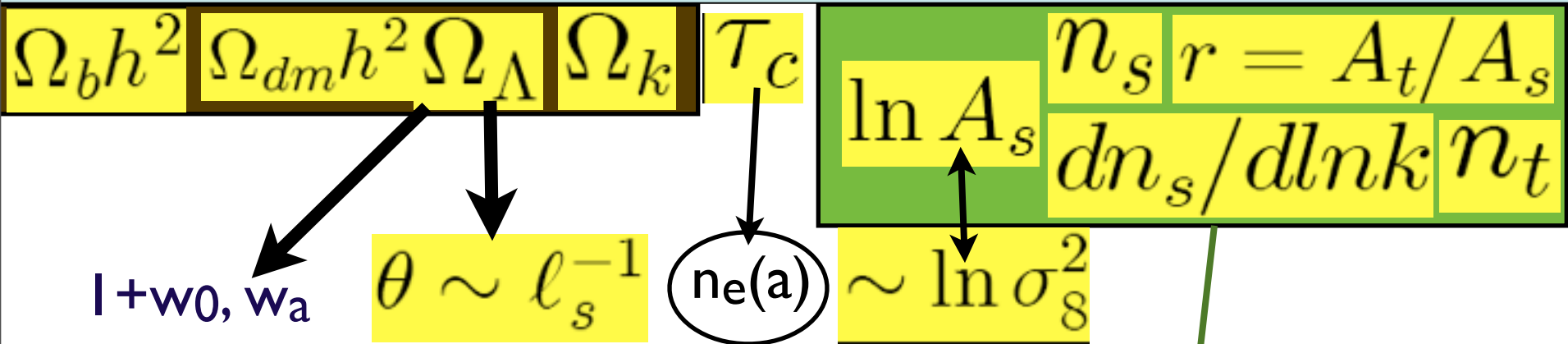
Planck2.5 forecast with inflation consistency



Planck2.5 r=0 forecast for 13 knot semi-blind $\mathcal{P}_s + r\text{-}n_t$



Standard Parameters of Cosmic Structure Formation



new parameters: trajectory probabilities for early-inflatons & late-inflatons (partially) blind cf. informed "theory" priors

primordial non-Gaussianity
 $\Phi(\mathbf{x}) = \Phi_G(\mathbf{x}) + \mathbf{f}_{NL} (\Phi_G^2(\mathbf{x}) - \langle \Phi_G^2 \rangle)$
 local smooth

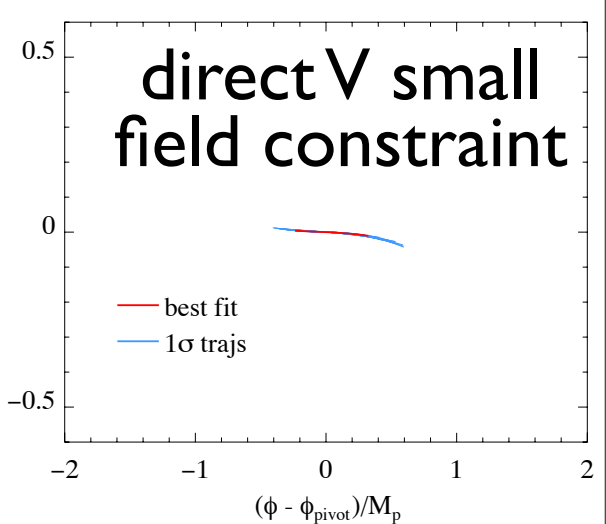
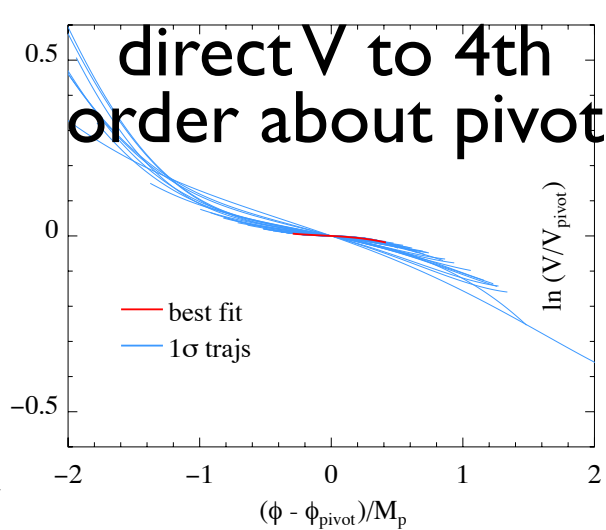
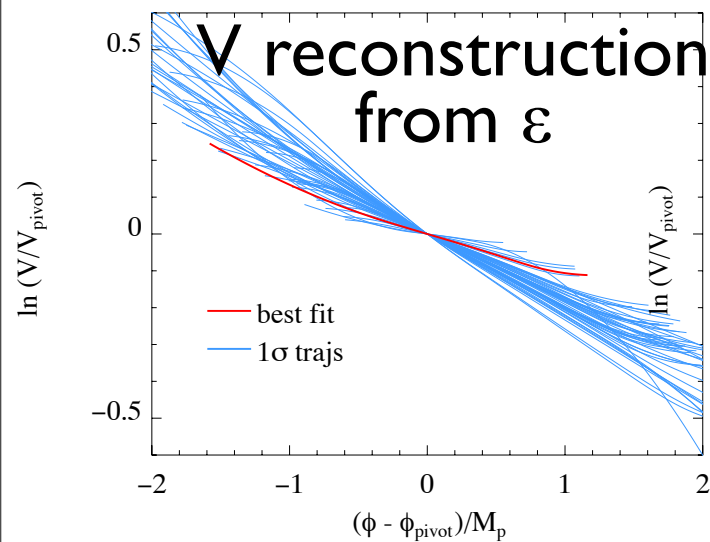
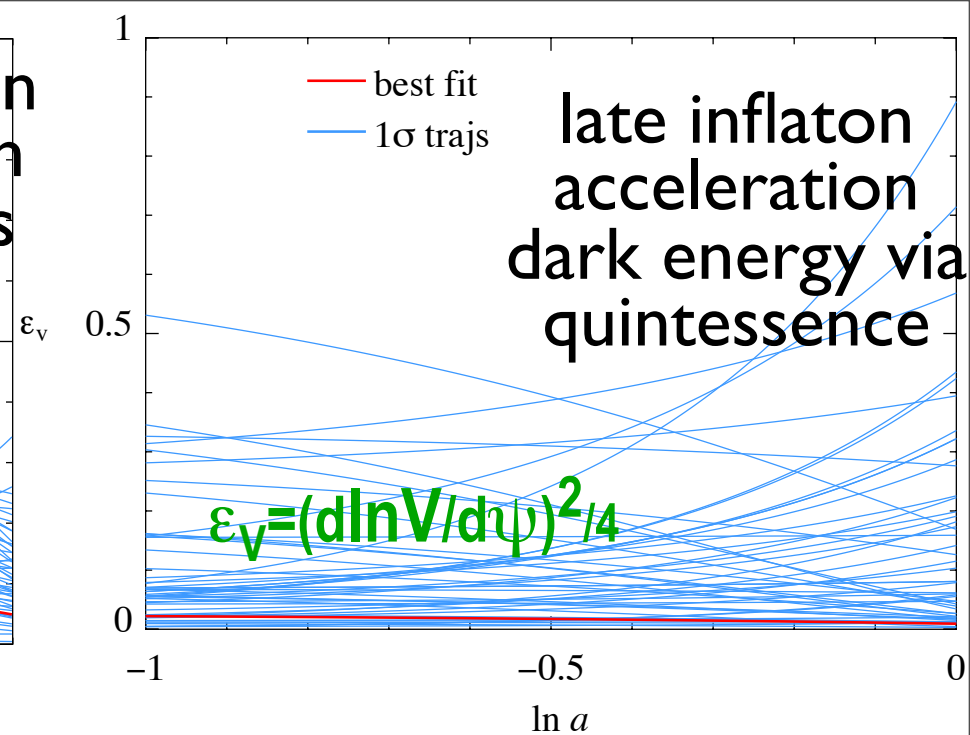
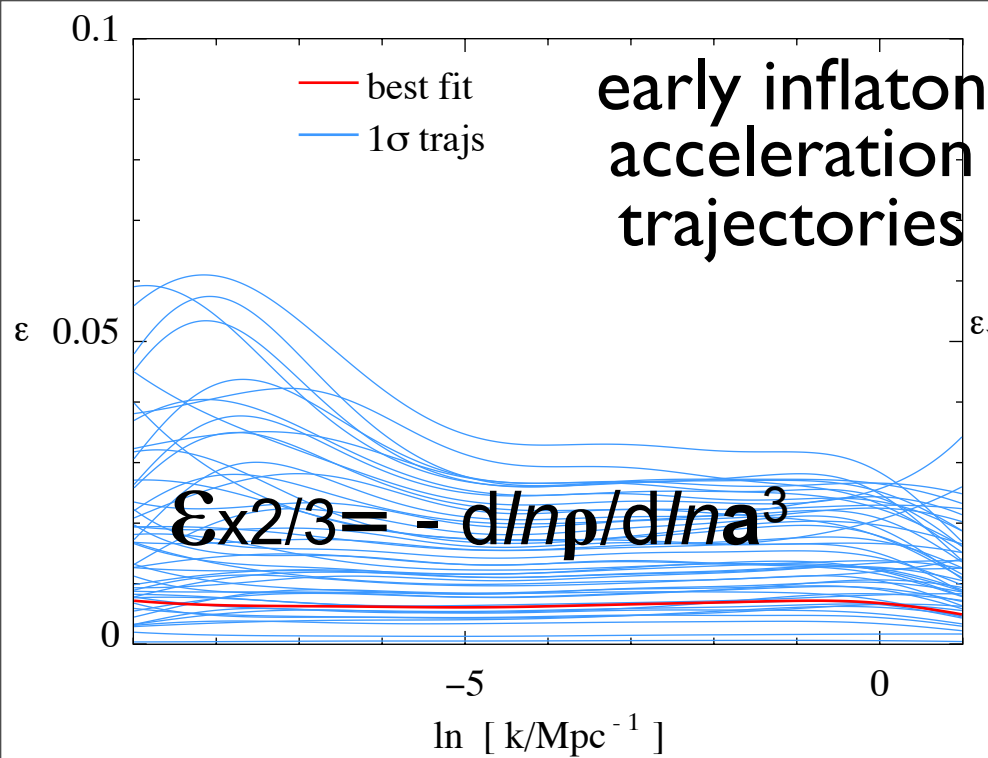
DBI inflation: non-quadratic kinetic energy
 cosmic/fundamental strings/defects
 from end-of-inflation & preheating

$\Phi(\mathbf{x}) = \Phi_G(\mathbf{x}) + F_{NL}(\chi_b) - \langle F_{NL} \rangle$
 resonant preheating

$\ln P_s(\ln k)$ & $\ln P_t(\ln k)$
 & $r(k_p)$

$\epsilon_\phi \times 2/3 = 1 + w(a)$
 $= - d \ln p_\phi / d \ln a^3$

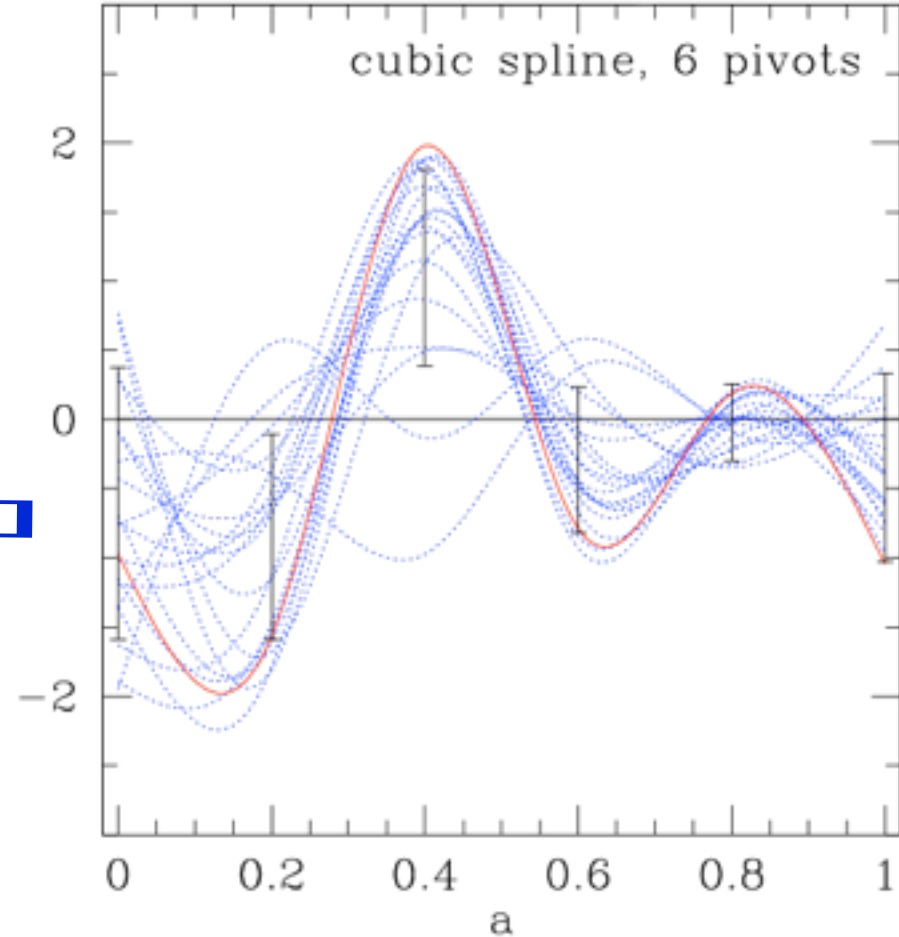
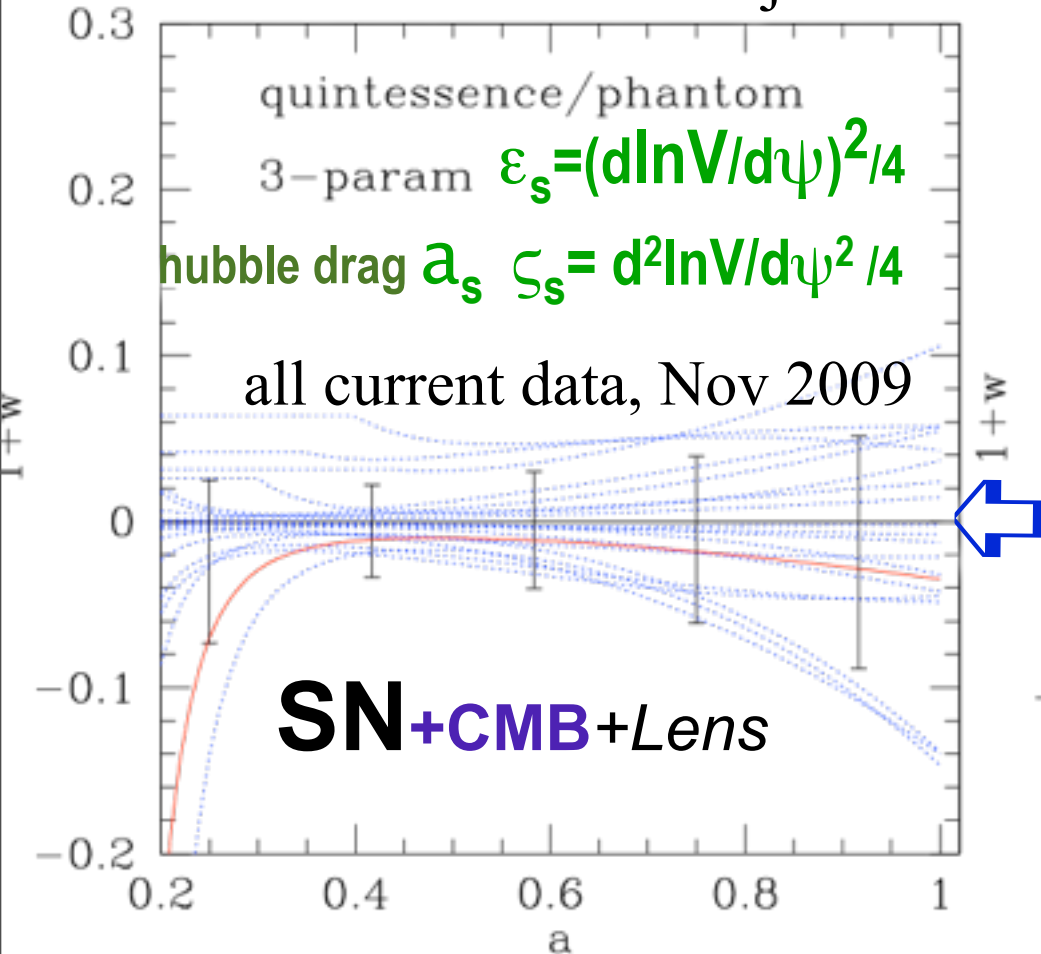
+ subdominant
 isocurvature, cosmic string,
 & *fgnds, tSZ, kSZ, ...*



is the dark energy “vacuum potential energy” ?

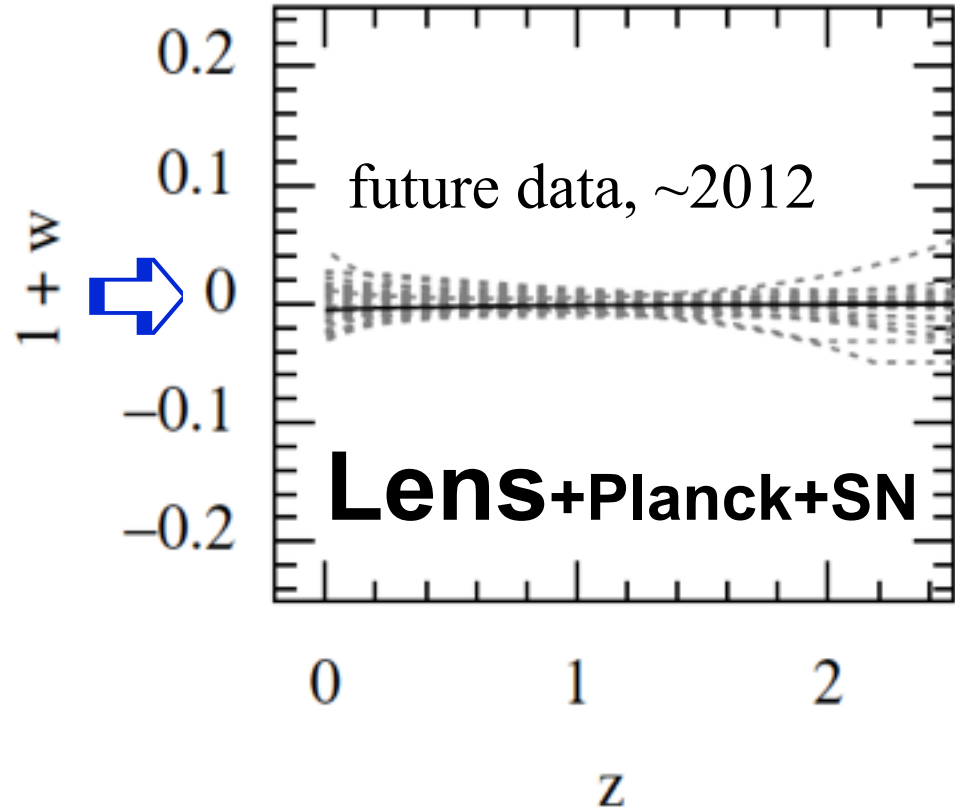
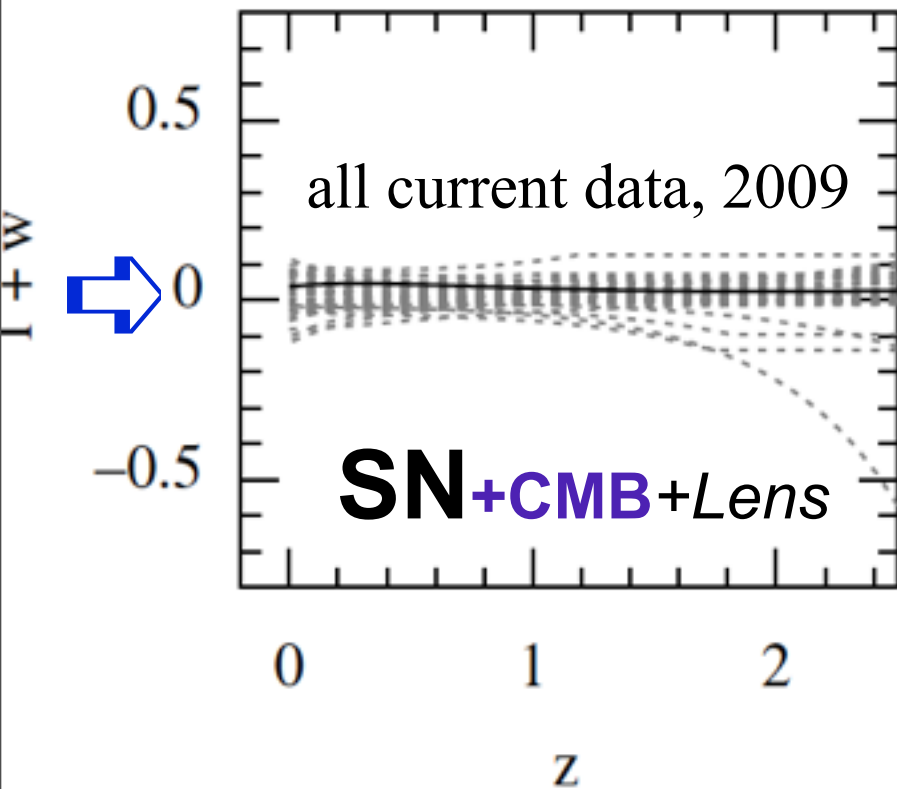
a 3-parameter expansion paves even wild late-inflaton trajectories

semi-blind mode expansion

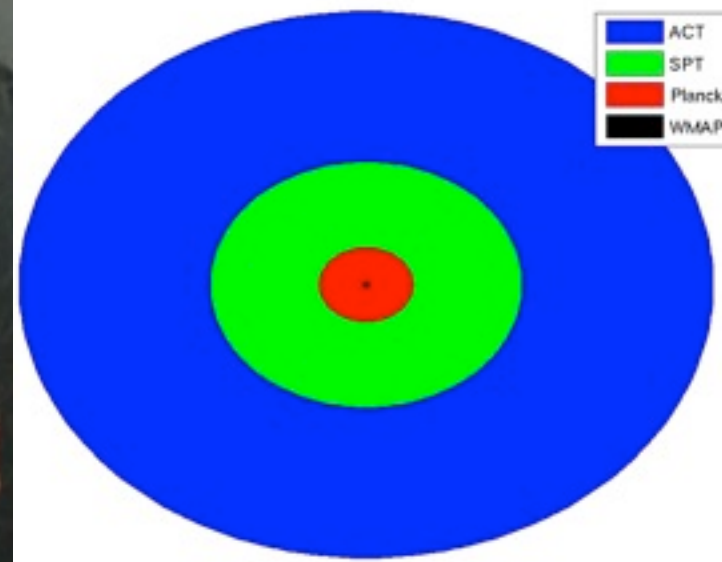


TEST: within errors, energy-density does not change with expansion \Rightarrow Einstein's cosmological constant is best fit so far
 cannot reconstruct the quintessence potential, just the slope ϵ_s & \sim hubble drag

is the **dark energy** “vacuum potential energy” ?



TEST: within errors, energy-density does not change with expansion \Rightarrow Einstein's cosmological constant is best fit so far



CMB DATA ANALYSIS

**Computing Life with
~3000 detectors
ACT ~200 GB/night
WMAP - 50 GB/7 yrs,
Planck 2-4 TB total
2 weeks of ACT=all of
Planck
+ huge Monte Carlo
simulation needs
hydro etal
25M+5M hours/year**

**GPC: 3780 nehalem nodes=30240 cores
306 TFlops debut as #16 in Top500**

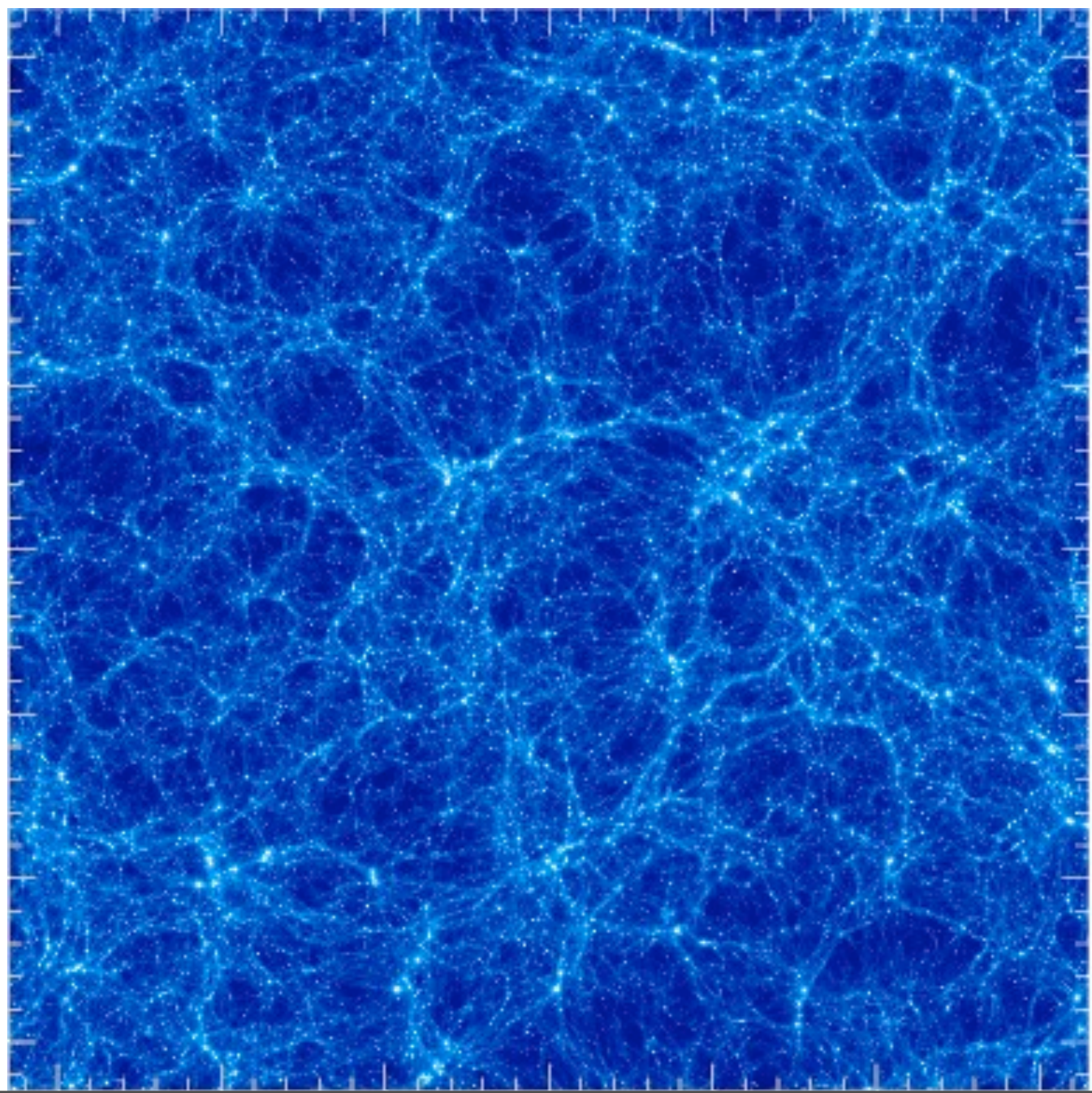
**TCS: 104 P6 nodes=3328 cores
60 TFlops debut as #53 in Top500 ->80**

1.4 Pbytes storage GPUs@UofT & CMB?

NERSC > 100000 cores (DOE Planck access)

NCSA > 300000 IBM cores

400
Mpc
 Λ CDM
WMAP5
gas
density
Gadget-3
SF+
SN E+
winds
+CRs
512³



**CMB gets
entangled
in the
cosmic web**

**aka the
descent
into the
real
astronomy
of**

**IGM/ISM
weather,
dust
storms**

**&
turbulent
times**

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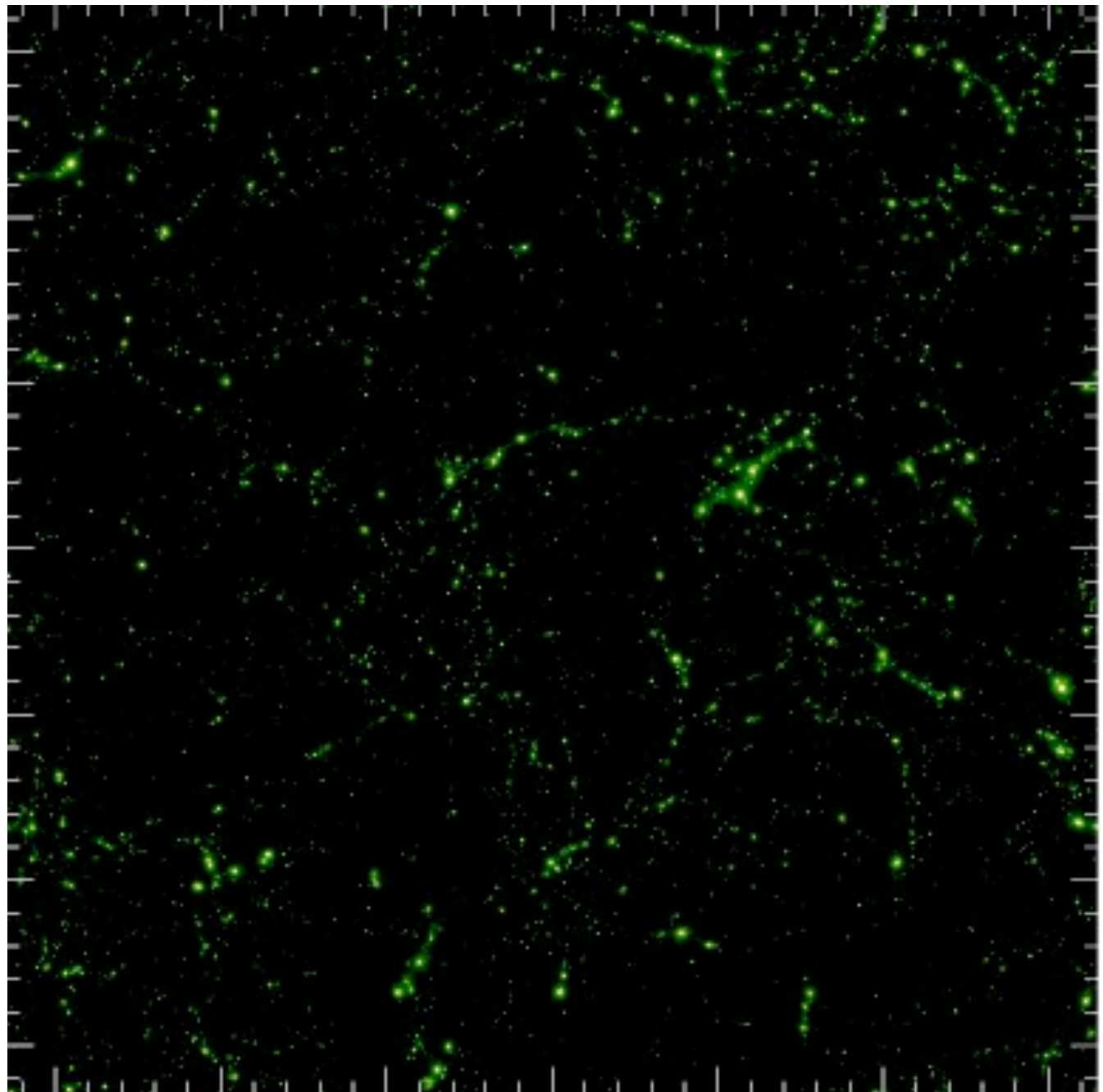
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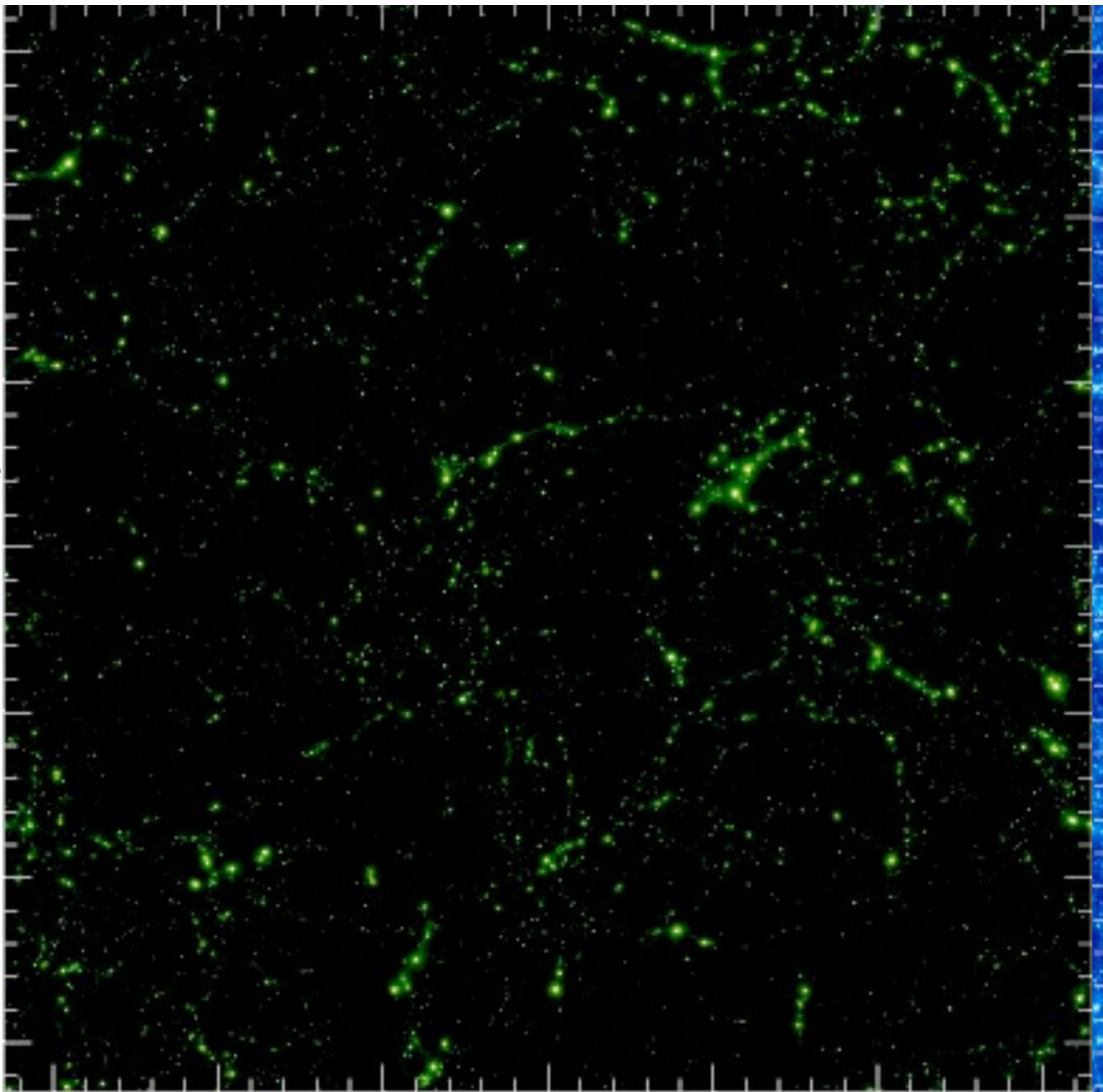
Λ CDM

WMAP5

gas
pressure

Gadget-3
formation
shocks
only aka
adiabatic

512^3



Variations in SZ with cooling and feedback

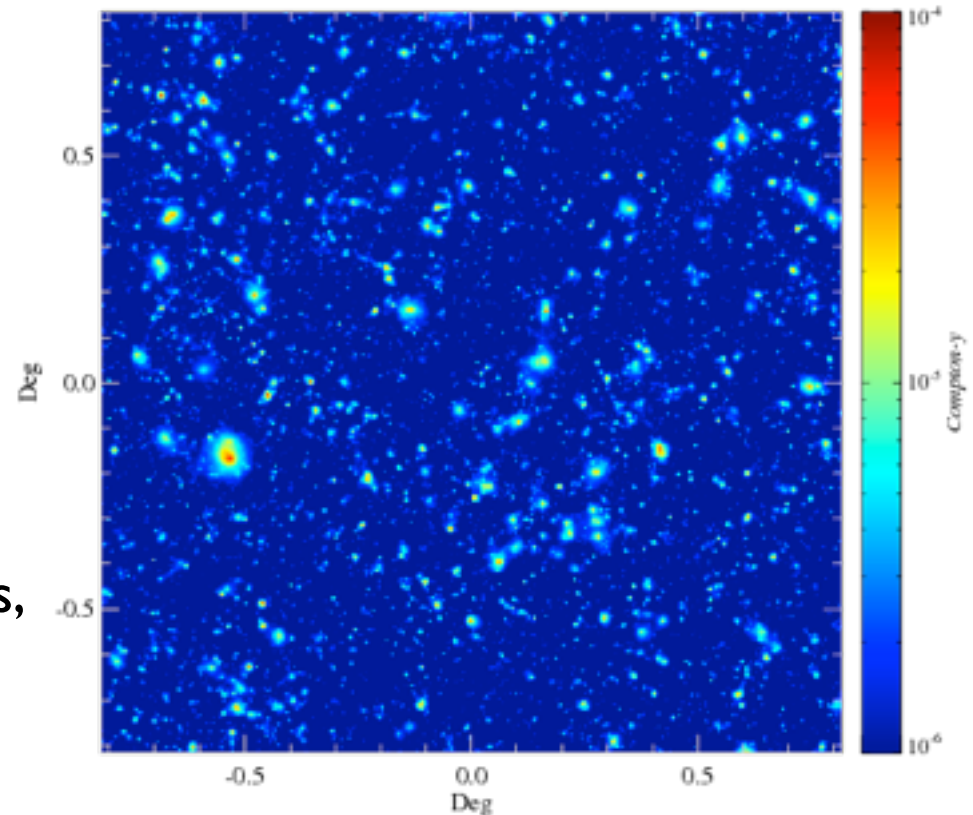
- 1st - adiabatic (no star formation).
- 2nd - + gas cooling + star formation +CR
- 3rd - + “AGN” feedback as well. Note pushing out of gas, softening of cluster cores

Cooling+SFR+Feedback 2×256^3 ~20 hours on 96 cores (out of 30240)

All 3 prescriptions have the same basic KE/Thermal Energy content ~20%

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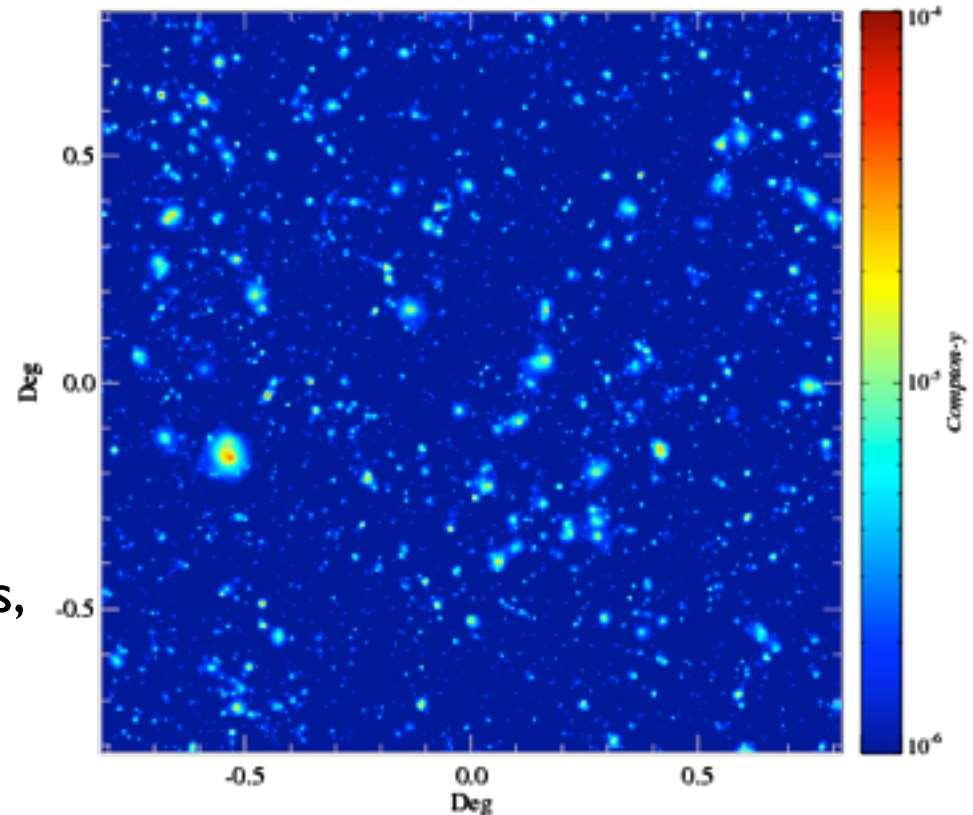


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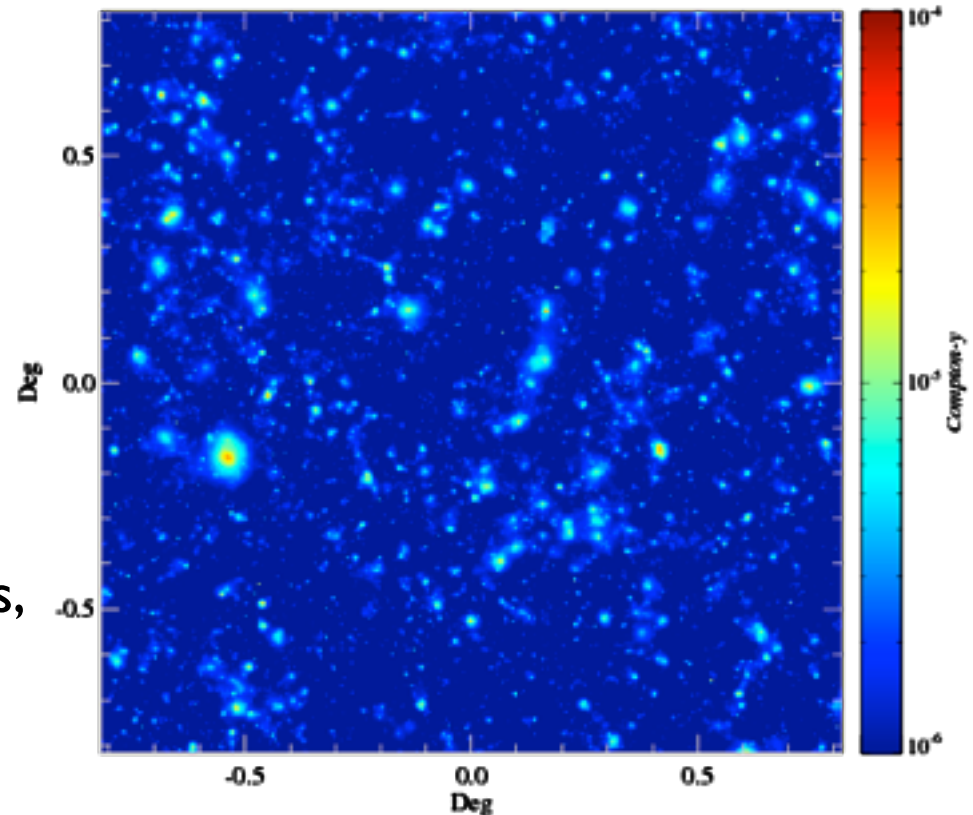


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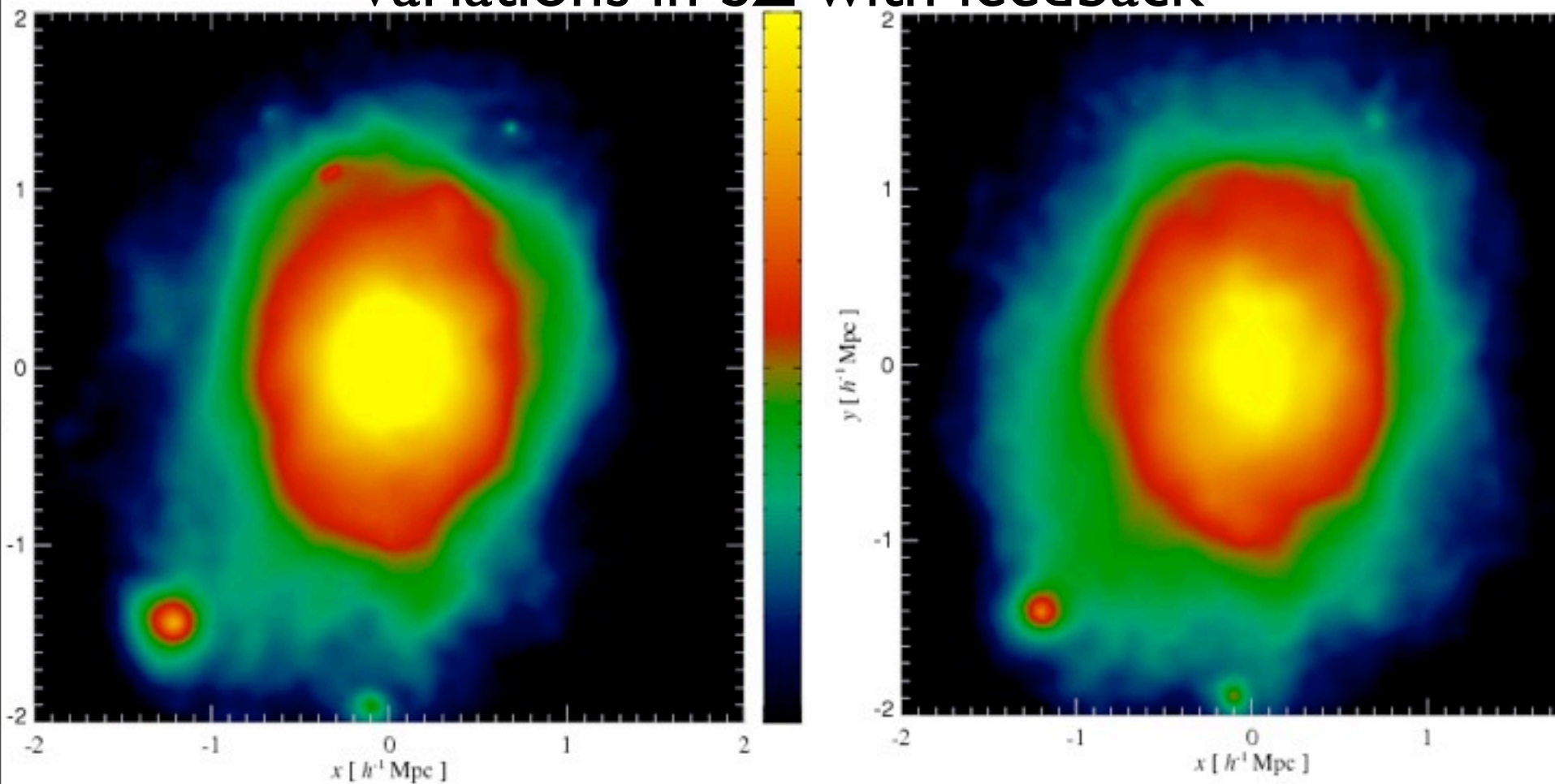
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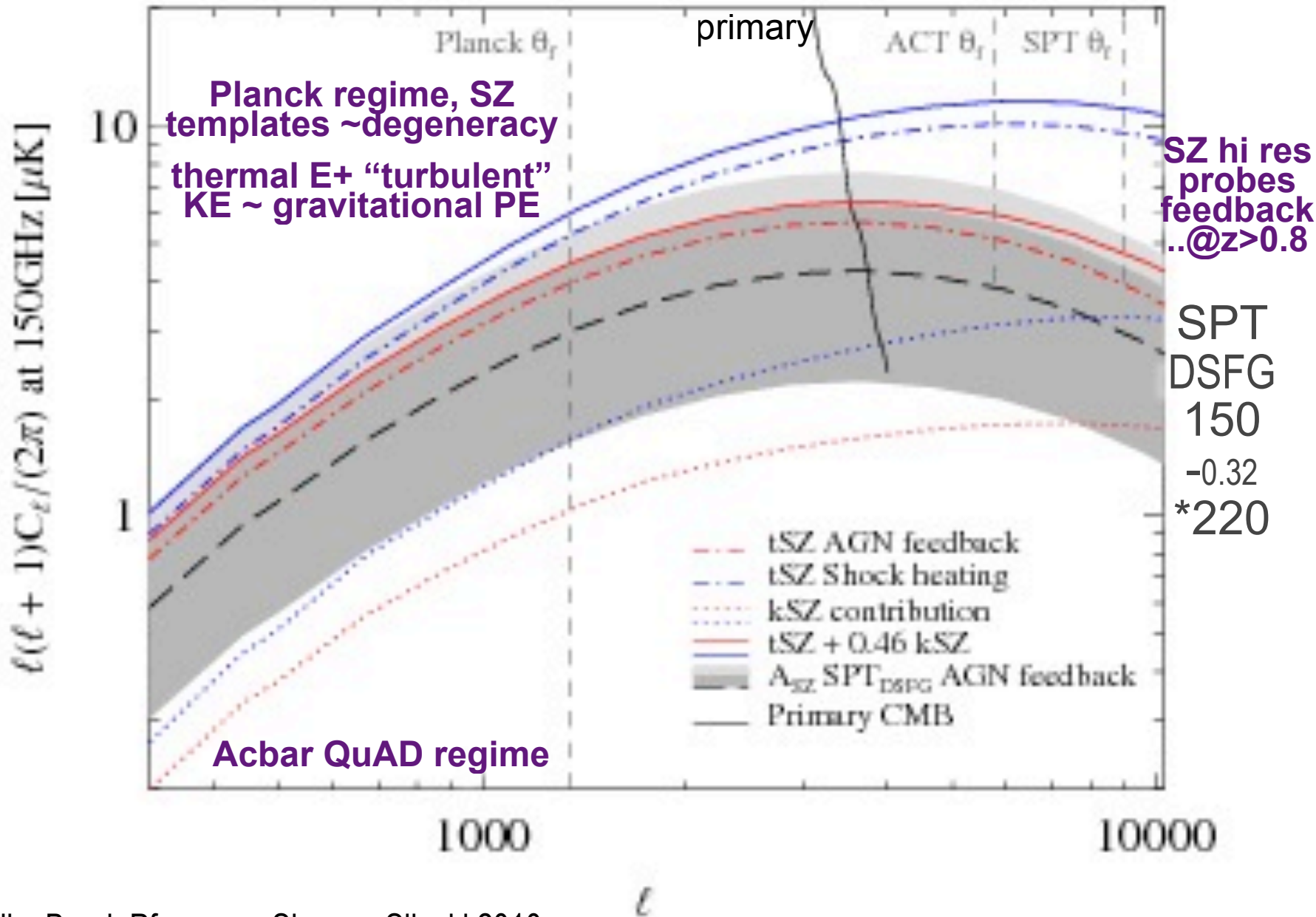
+ gas cooling + star formation + CR

+ "AGN" feedback

high res ICM follow-ups are essential to make a robust
cluster catalogue for cosmology ...

Battaglia, Bond, Pfrommer, Sievers, Sijacki 2010

the high resolution frontier: SZ power spectra



ACT@5170m



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

CBI2@5040m





Fermilab's

Primordial SOUP

INGREDIENTS

Quarks	98%
Force Carriers	20%
Electron-like Particles	3%
Neutrinos	2%
Higgs Bosons	1%

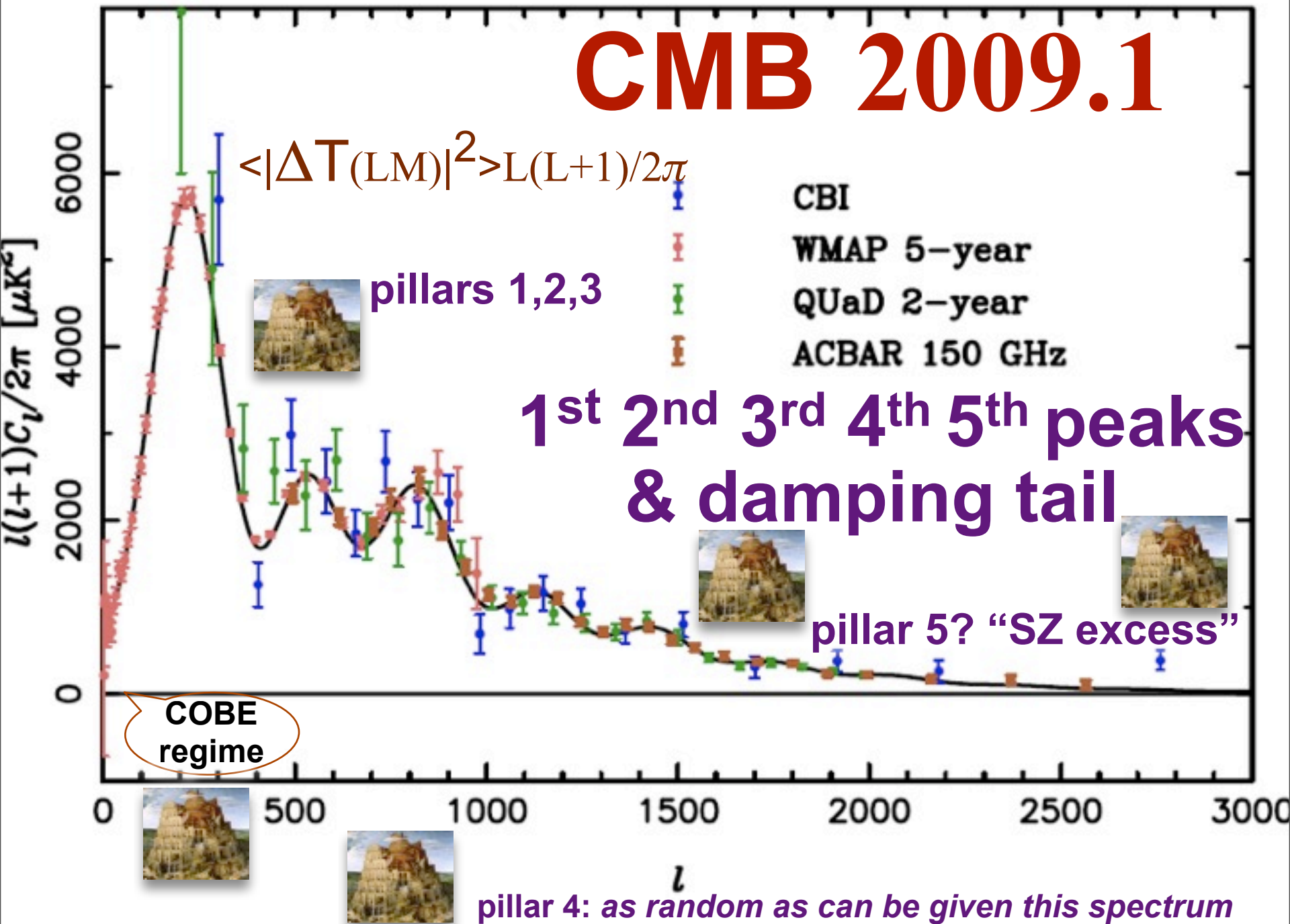
INSTRUCTIONS
Heat ingredients to 3,000,000,000,000,000 degrees, stirring occasionally if you wish.

CAUTION
Contents are extremely dense and are under enormous pressure.

MADE IN U.S.A.

Provides 100% of the maximum daily requirements for a healthy, expanding and expanding known universe.

CMB 2009.1



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