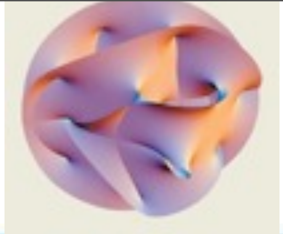
Lev Kofman June 17, 1957 - November 12, 2009

Ph.D 1984, Inst Ap & Atmos Phys, Tartu, Estonian Acad Sci & Landau Institute, Moscow. Advisor: Alexei Starobinsky

2008-09 CITA Acting Director
2006-08 CITA Associate Director
1998-2009 CITA & UofT Professor
CIFAR Fellow
1993-98 Inst for Astronomy, U of Hawaii, Associate Professor, CIFAR Associate
1992-93 CITA Sr RA, CIFAR Scholar
1992 Princeton U, Ap Sci, Lecturer
1991 CITA Postdoctoral Fellow
1987-90 Senior Fellow, 83-87 Fellow, Estonian Acad Sci, Tartu

2007 Fellow American Physical Society
2006 Humboldt Award, Germany
2006 FInstPhys
1999 Premier Research Excellence Award ON
1998 FCIFAR
1993-98 ACIFAR
1992 SCIFR
1987 Medal, Soviet Acad Sci in Phys (<35)



Lev Kofman June 17, 1957 - November 12, 2009

Zhiqi Huang, Pascal Vaudrevange

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

CIAR 25 years cifar

Cosmology & Fundamental Physics aka Prob(*Theory|Data)*

Dick Bond Canadian Institute for Theoretical Astrophysics, University of Toronto

Cosmotician *P(cosmic parametersID,T), P(DIT) D=CMB,LSS,SN,..,complexity, life T=baryon, dark matter, vacuum mass-energy densities,...,early and late inflation,structure of manfolds (extra compactifying 7 + 3+1), holes, branes, fibres, strings,vacuua landscape, physical coupling 'constants'* **Anthrostician**

Cosmic history: what is U made of? $\Rightarrow \rho_{dm}/\rho_b = 5.1 \Rightarrow \rho_m/\rho_{de} = .30$ **and** $\Omega_m = 0.268 \pm .012$, $\Omega_\Lambda = 0.736 \pm .012 \Rightarrow (0.294 \pm .011, 0.706 \pm .011)$

How Structure in the Universe Arose?: ***from nearly Gaussian early Inflation vacuum fluctuations in curvature, isocurvature & Gravity Wave fields morphs into the nonlinear Cosmic Web: clusters, filaments, voids; galaxies***

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

CMB*ology* & *x*CDM, *x*=Λ+*tilt*: the cosmic standard model, status@Nov09:

Boomerang, CBI, Acbar, WMAP, DASI, QuAD, .. P(D|T) paths for early & late inflation

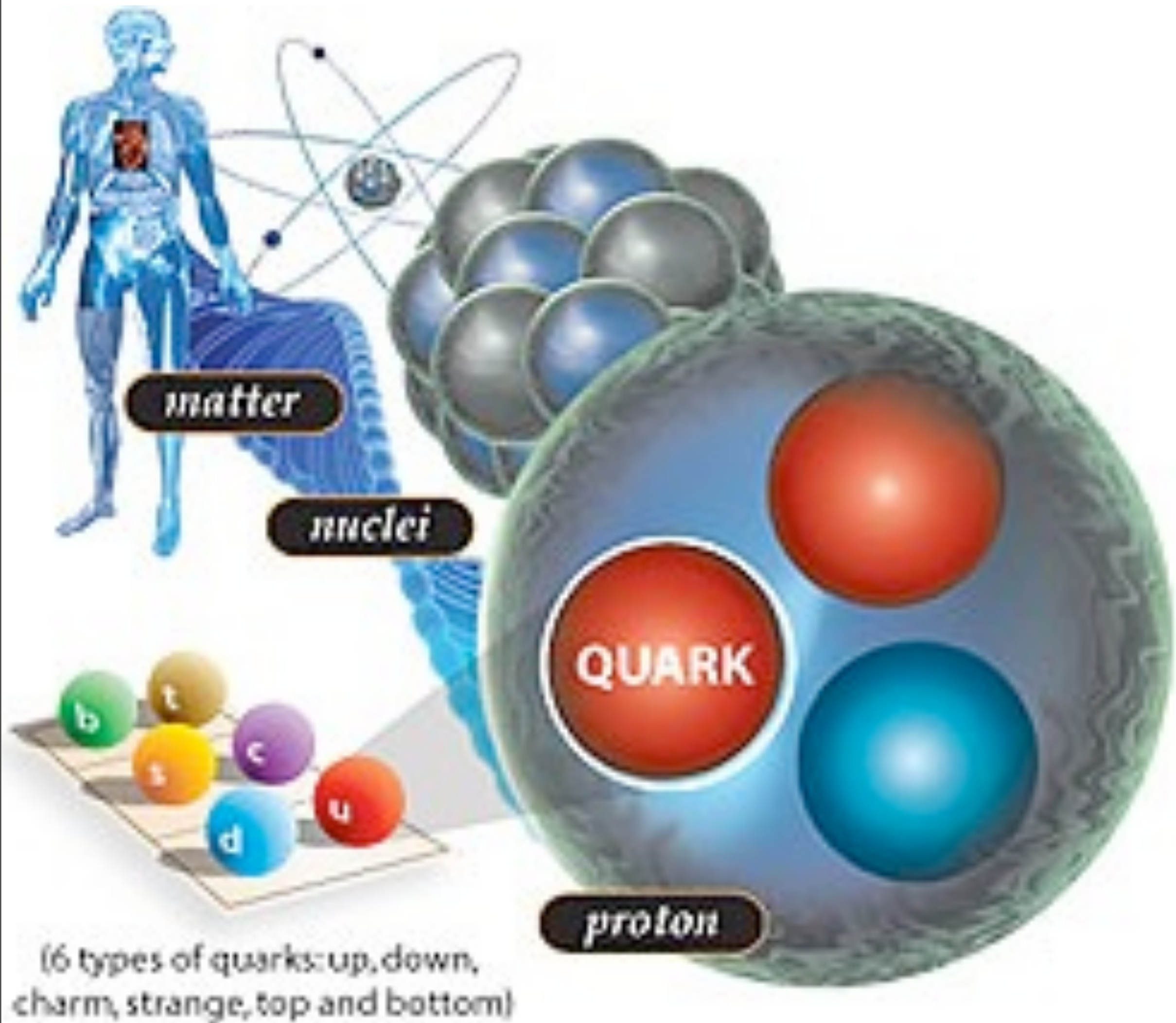
is there a y to x? @2011-12 from new expts: ***ACT, Planck,*** **Spider, Keck, ACTpol**

SPT, EBEX, Bicep, Quiet, SPTpol,.. acceleration paths for B-modes, dark energy probes

the Weighty Matter of the Cosmos: *what is the Universe made of?*

Greek GUT: 4 elements/ 4 qualities+ 5th element: quintessence aether

water (Thales), air (Anaximenes), earth (Xenophanes), and fire (Heraclitus). Empedocles unified theory of all 4. Plato 4 of 5 geometrical crystal-like solids as atoms. Aristotle prevailed: elements as combinations of qualities

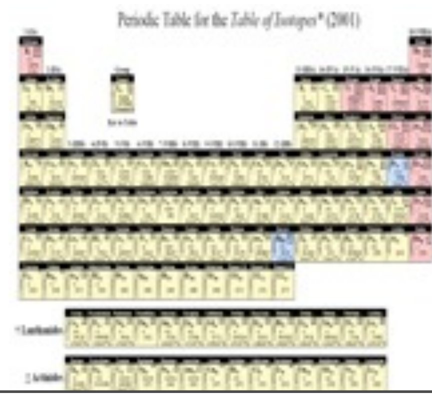


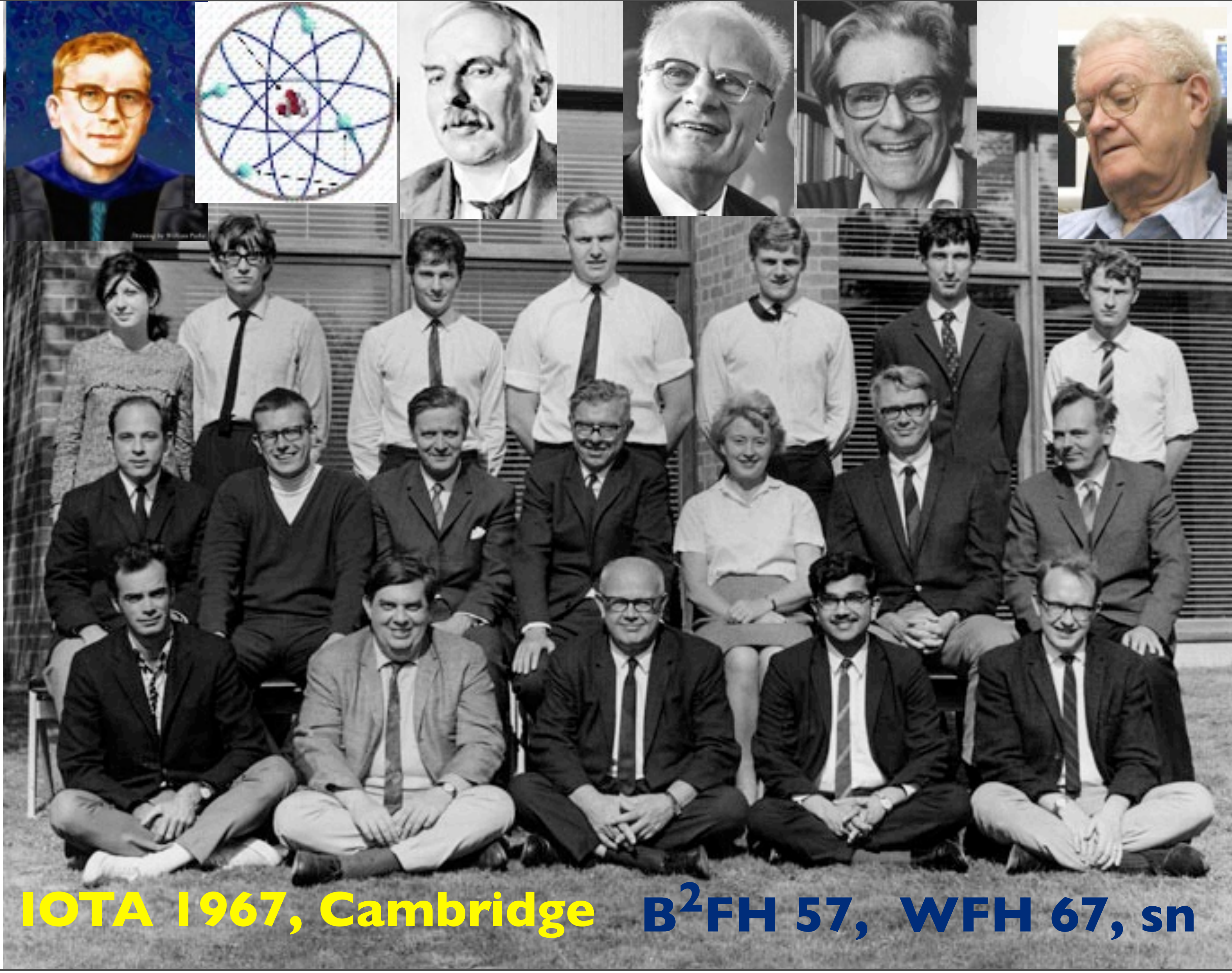
- ✓ **GAMOW (40s, early 50s) HOT BIG BANG**
- ✓ **Hoyle etal (40s, ...) SSM**

Eternal Inflation with PreHeating BANGs

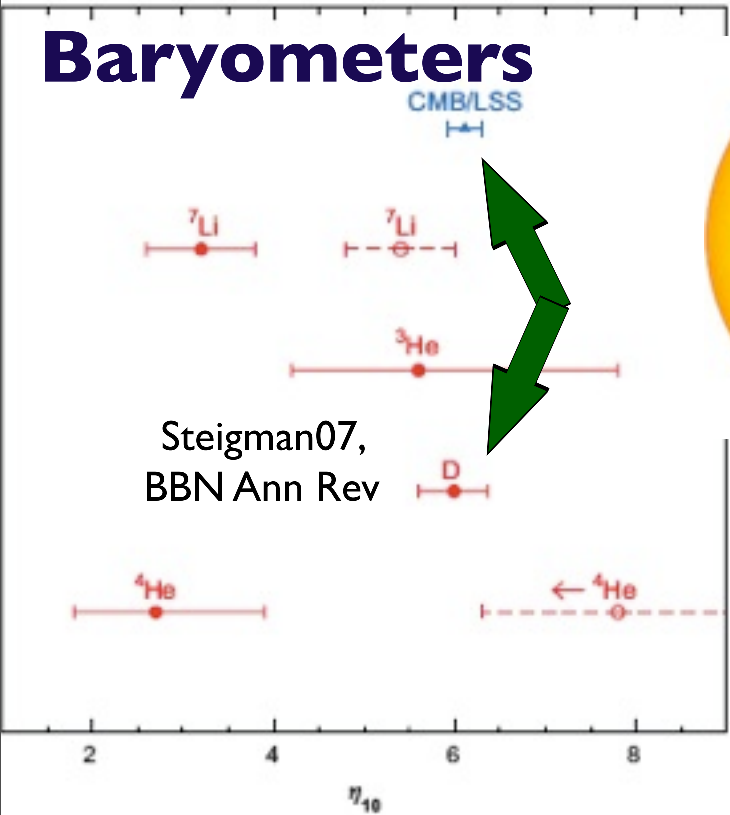
Nuclear Fundamental Physics:

40s-80s.. *Hydrogen (75%) & Helium (25%) Deuterium, Lithium from the first minutes; Carbon, Oxygen, Iron,.. from exploding stars*

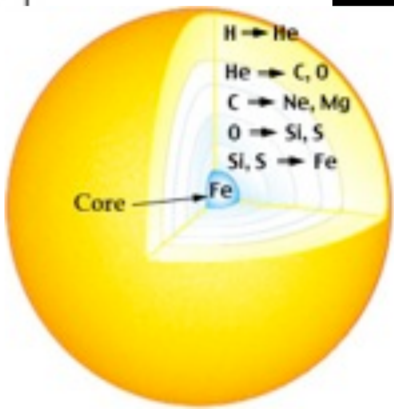



IOTA 1967, Cambridge
B2FH 57, WFH 67, sn

Baryometers



Steigman07, BBN Ann Rev



Nobel Prize 84 Willy Fowler + Chandra -sekhar

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

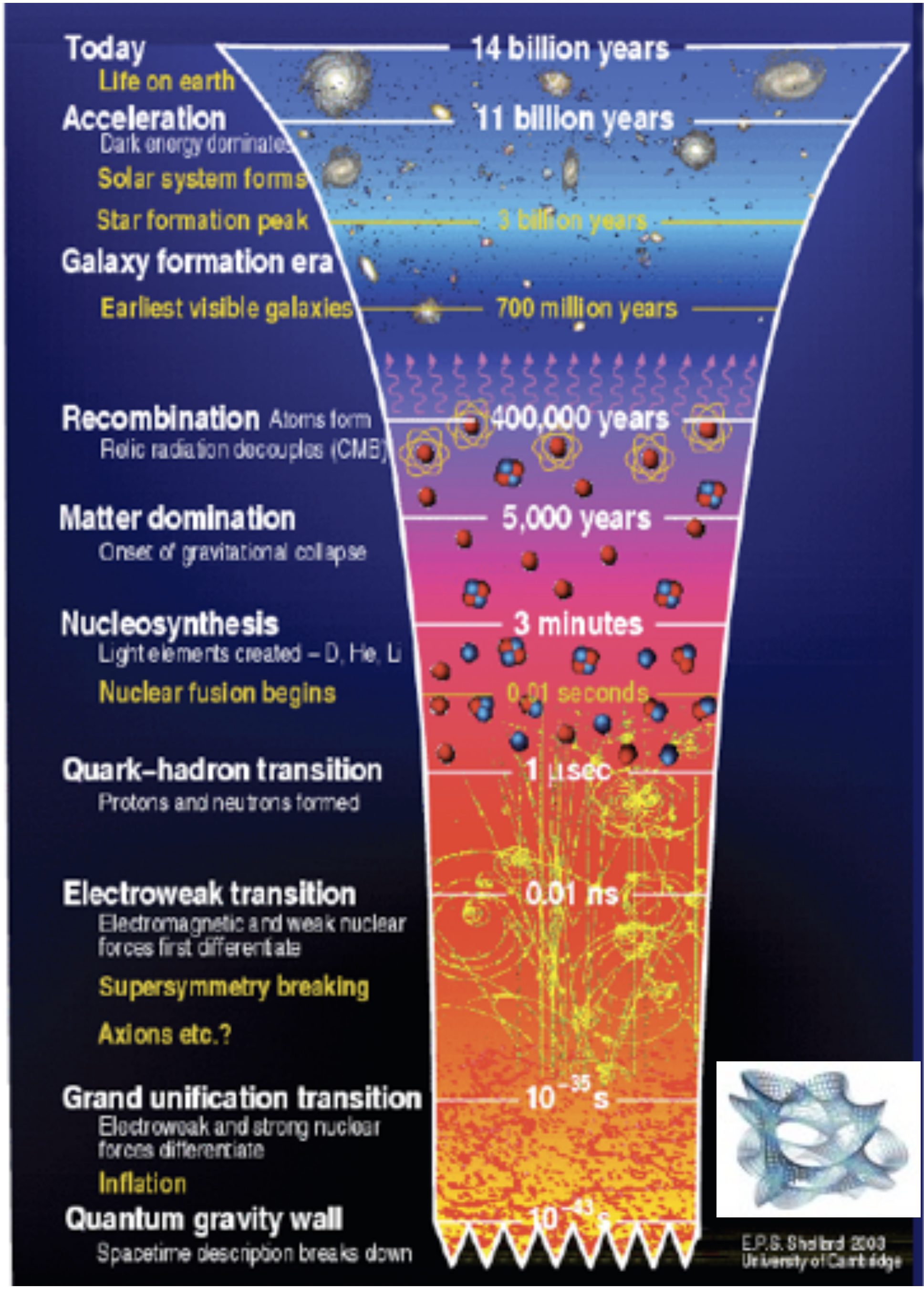
	January 2000	January 2002	June 2002	January 2003	March 2003
$\Omega_b h^2$	$0.0339^{+0.0443}_{-0.0246}$	$0.0222^{+0.0025}_{-0.0021}$	$0.0221^{+0.0024}_{-0.0020}$	$0.0221^{+0.0023}_{-0.0018}$	$0.0233^{+0.0013}_{-0.0013}$

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

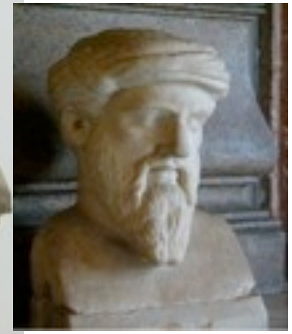
0.0233 +- 0.0005 wmap5+acbar+cbi+b03+.+WL+LSS+SN1+Lya

cosmic baryon number $\mathbf{n_b}$=0.261 ±.005 /m^3

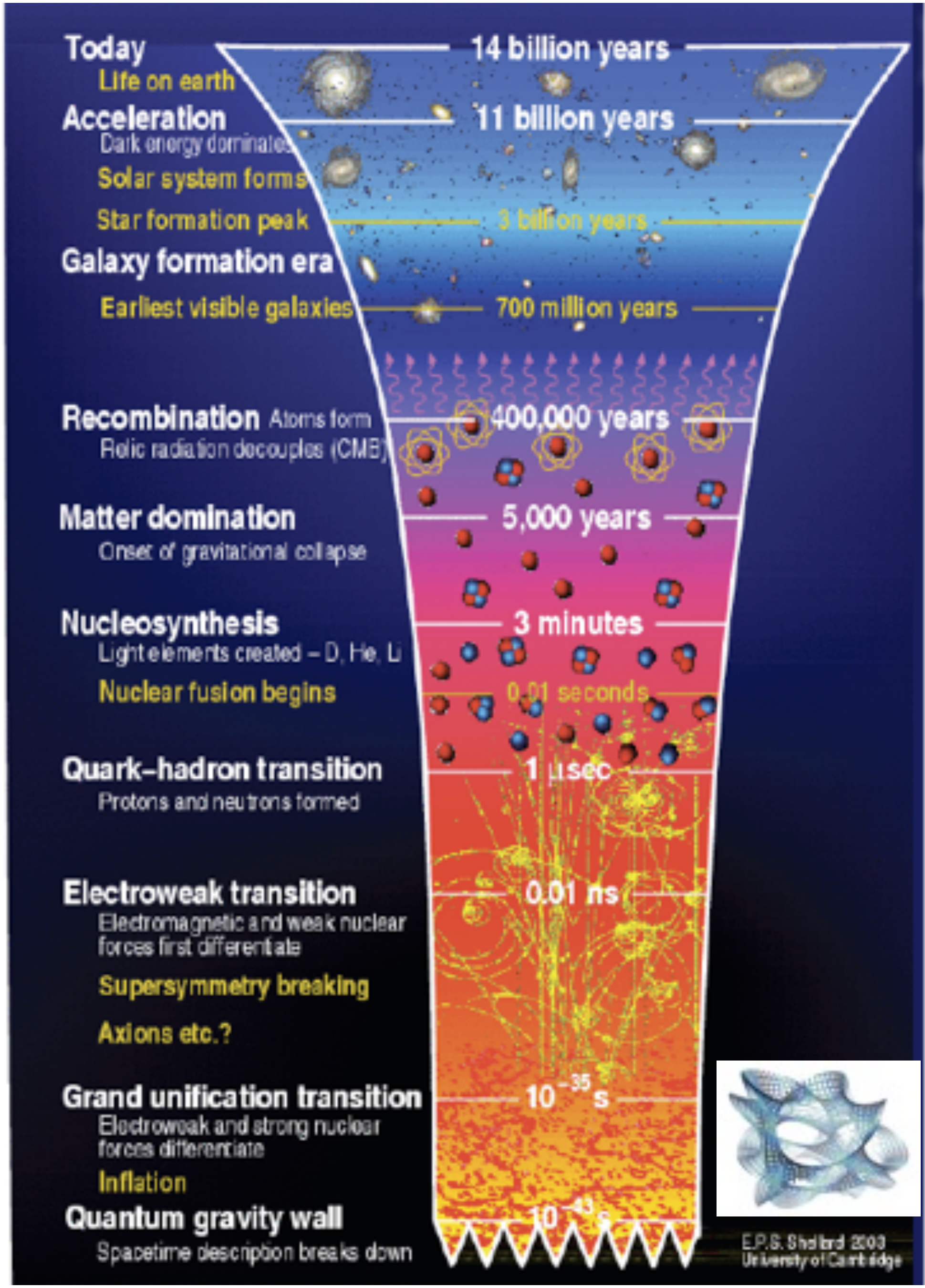
$\Omega_{dm}h^2$=0.1145 ±0.0023 Ω_m=0.268 ±.012 Ω_Λ=0.736 ±.012



IT
from
BIT



the Meaning may change but the Facts will remain



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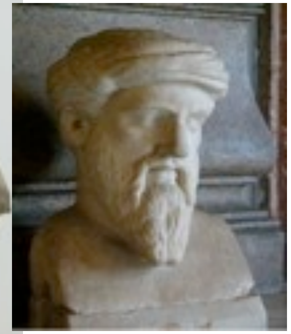
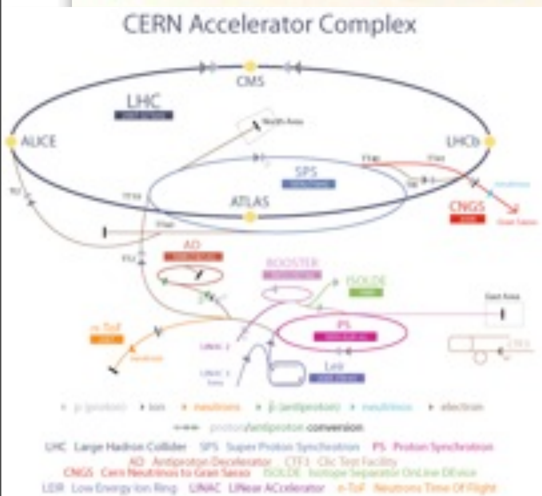


the Meaning may change but the Facts will remain

ρ_{Λ} =vacuum potential energy density Sakharov~67

extra-“ordinary” matter



what is **mass?**

vacuum potential

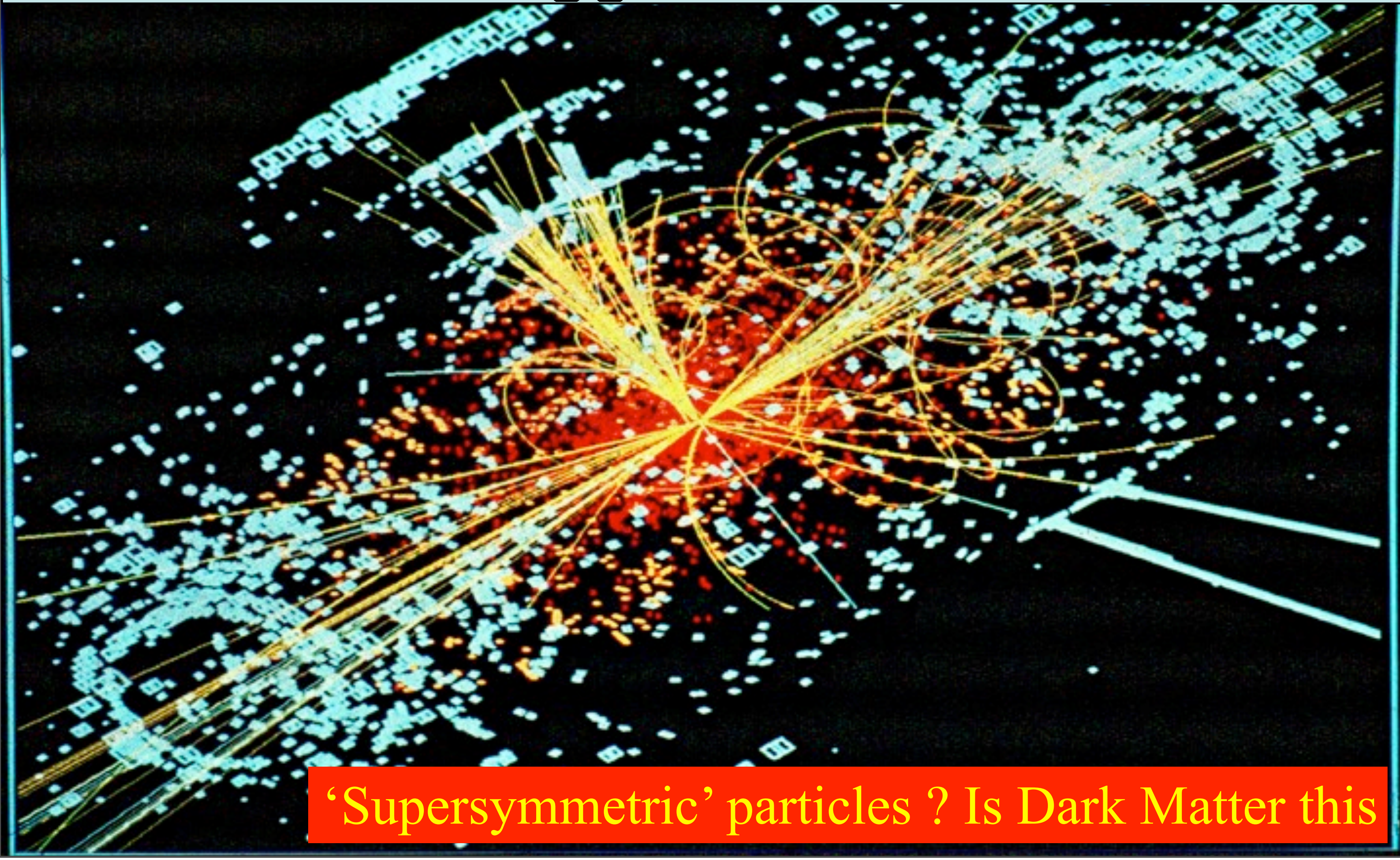
dark matter

antimatter asymmetry

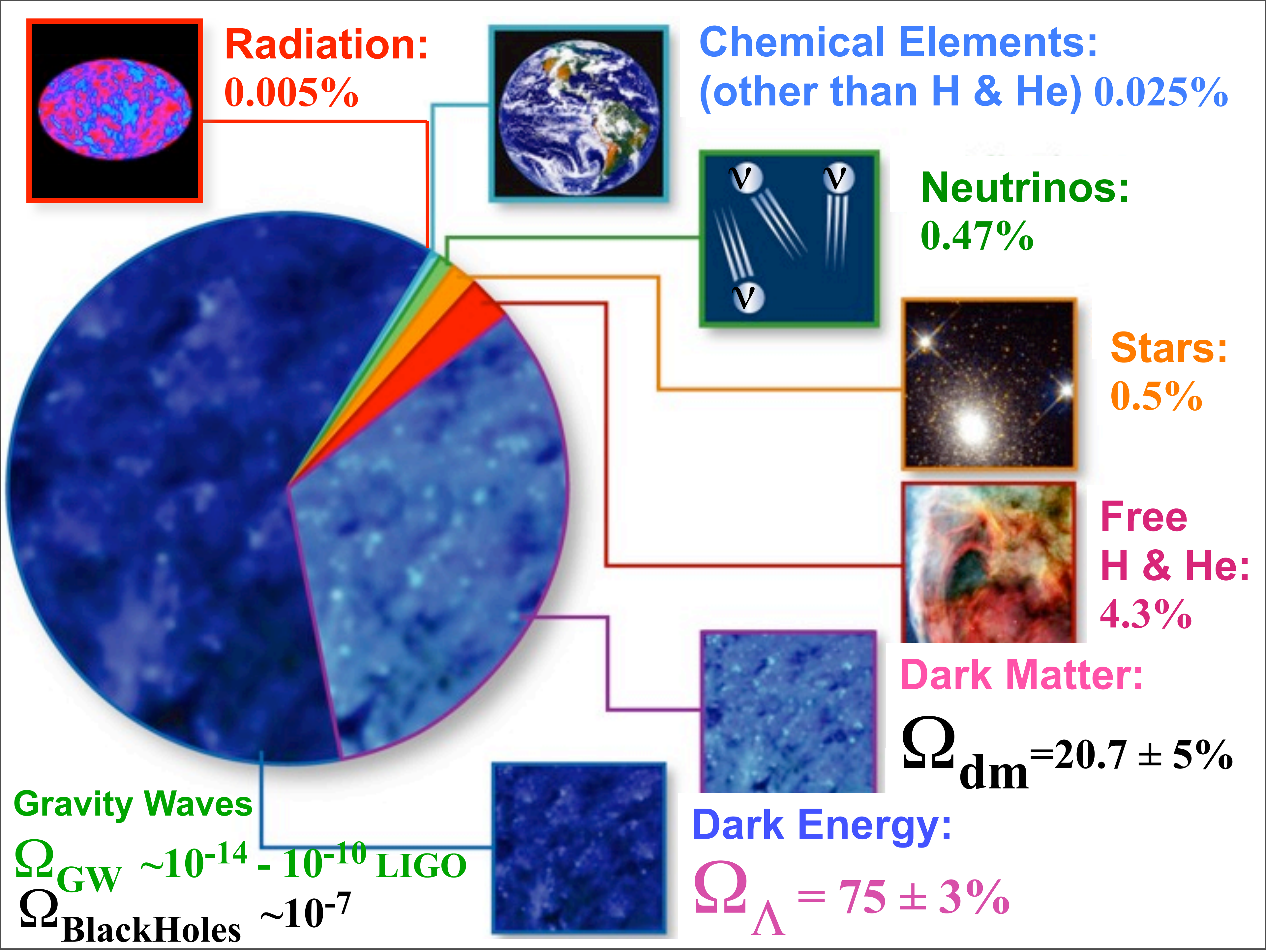
extra dimensions

If Dark Matter interacts with ordinary matter by more than gravity, we may "see" it at the Large Hadronic Collider 2009+ or at SNOlab 2010+ in Sudbury Canada

A Simulated Higgs Event in CMS: LHC



'Supersymmetric' particles ? Is Dark Matter this


Radiation:
0.005%
Chemical Elements:
(other than H & He) 0.025%
Neutrinos:
0.47%
Stars:
0.5%
Free
H & He:
4.3%
Dark Matter:
Ω_{dm}=20.7 ± 5%
Dark Energy:
Ω_{Λ} = 75 ± 3%
Gravity Waves
Ω_{GW} ~10^{-14} - 10^{-10} LIGO
$\Omega_{BlackHoles}$ ~10^{-7}
ν
ν
ν

What is the Universe made of?

NOW: ***baryons + (cold-ish) dark matter + dark energy/inflaton + tiny curvature energy*** *(+light neutrinos+photons). ??a bit of strings/textures/PBHs??* ***web of galaxies/clusters***

THEN: coherent inflaton /**"vacuum" energy** plus **zero-point fluctuations** in all fields (≈*Gaussian RF*) & then preheat via mode coupling to incoherent cascade to thermal equilibrium aka **quark-gluon plasma**

& how was it, is it & will it be distributed?

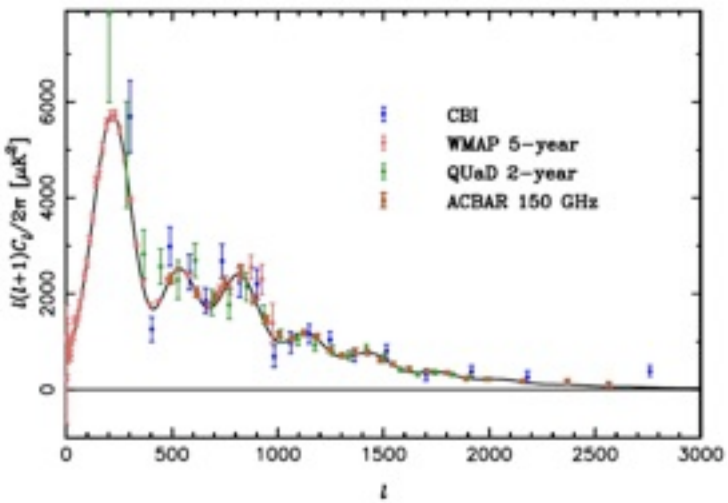
very early U early to middle to now U **very late U**

string theory/landscape/higher dimensions

inflation cyclic baryogenesis dark matter BBN γdec **dark energy**

$V_{eff}(\psi_{inf})$?

$K_{eff}(\psi_{inf})$?



$V_{eff}(\psi_{inf})$?

$K_{eff}(\psi_{inf})$?

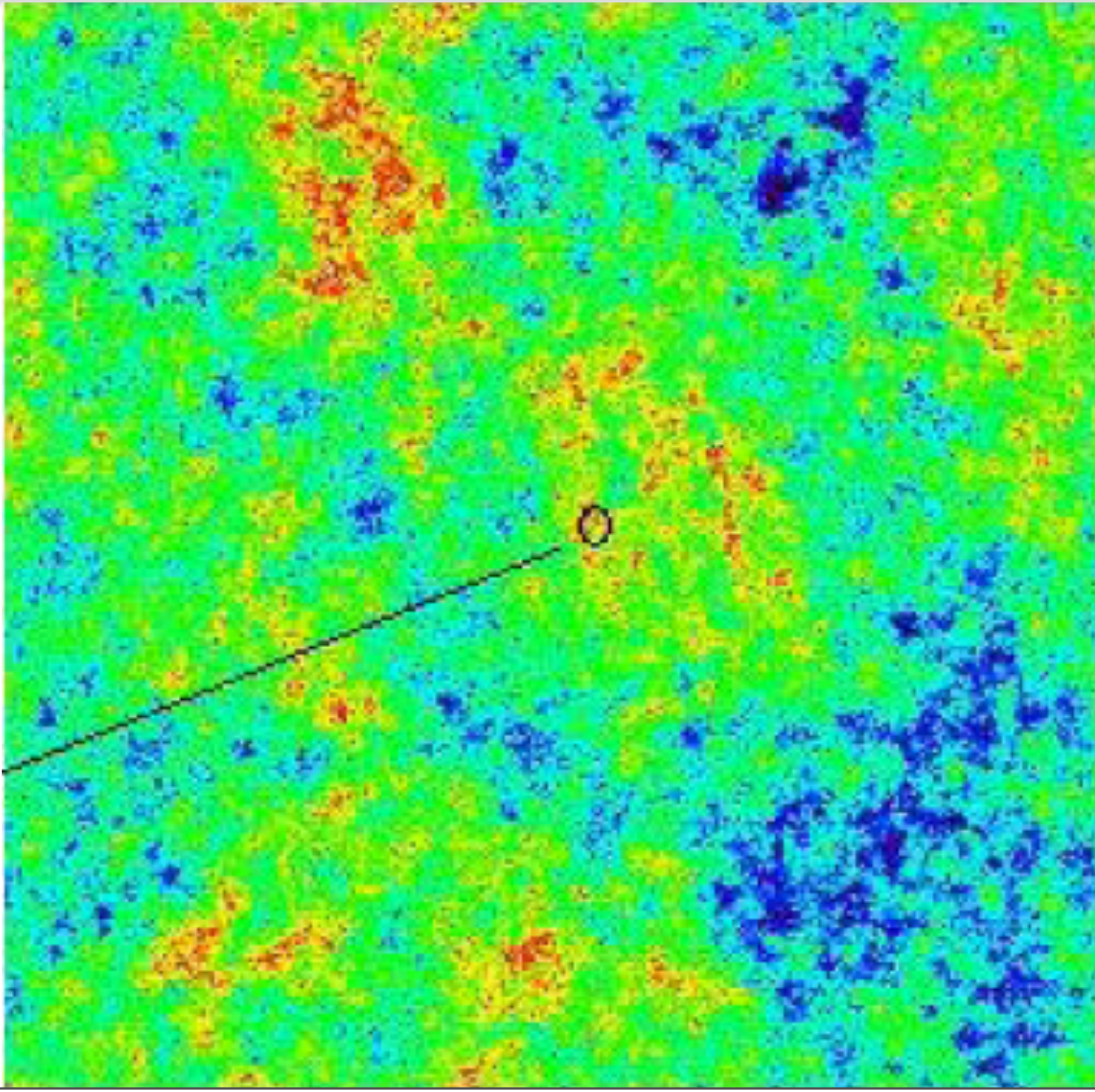
cosmic mysteries

n_b/n_γ ρ_{dm}/ρ_b z_{eq}/z_{rec} ρ_{curv} ρ_{de}/ρ_{dm} $\rho_{de} \sim H^2 M^2_{Planck}$ $\rho_{m\nu}/\rho_{stars}$

fluctuations in the **early universe "vacuum" grow** to *all* **structure**

current
Hubble
patch
~10 Gpc

speed
limit
horizon

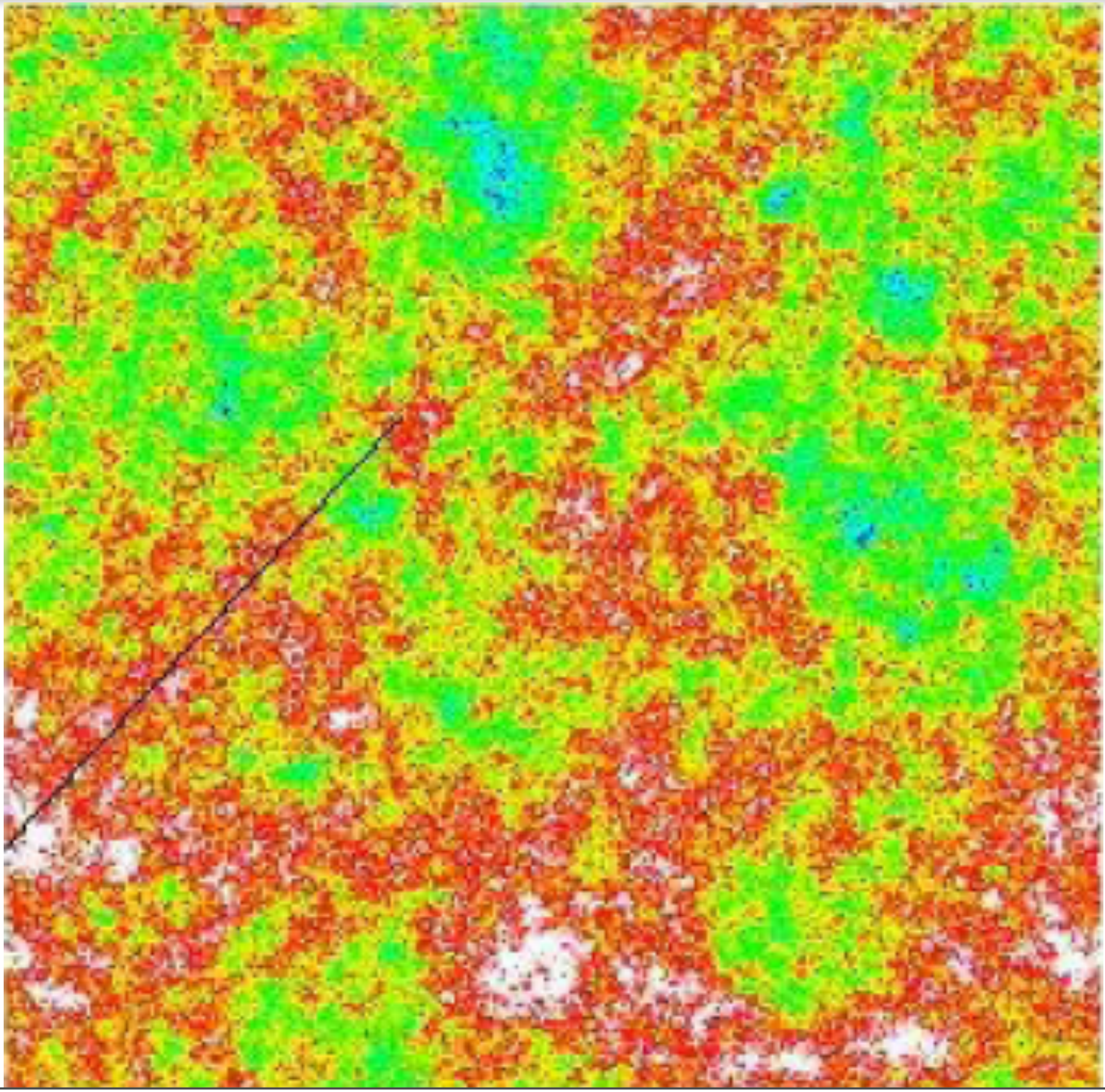


patterns
in the
quantum
jitter
evolve
under
gravity

(& gas
dynamics)

1000 Gpc

fluctuations in the **early universe "vacuum" grow** to *all* **structure**



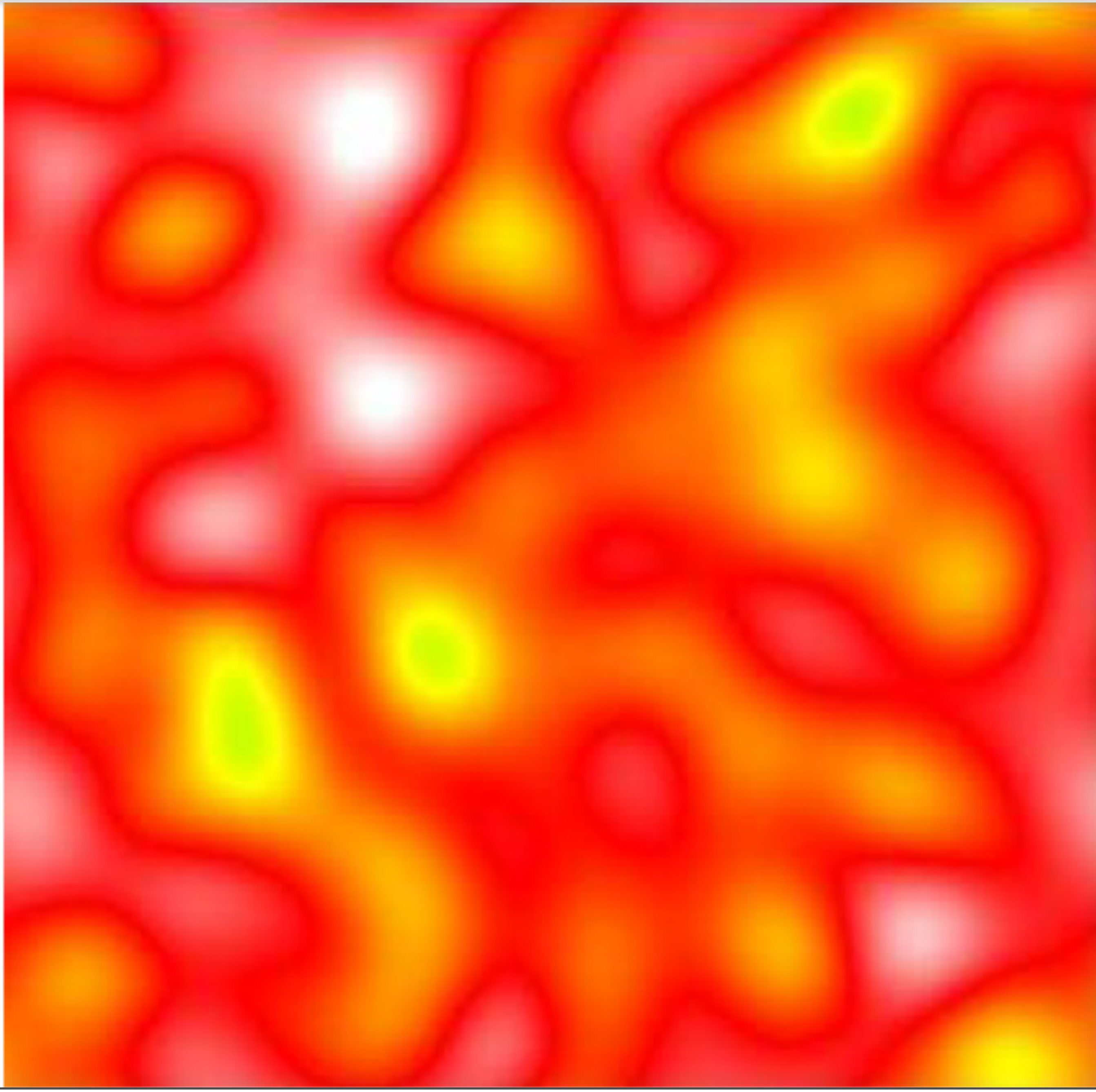
pre-heating patch (~1cm)

patterns in the quantum jitter evolve under gravity

(& gas dynamics)

10 Gpc

fluctuations in the **early universe "vacuum" grow** to *all* **structure**



patterns in the quantum jitter evolve under gravity

(& gas dynamics)

pre-heating patch (~1cm)

~1 cm

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**

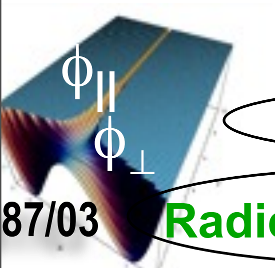
6/7 tiny extra dimensions

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 pNGB inflation

Hybrid inflation

KLS preheating

SUSY F-term inflation

SUSY D-term inflation

Assisted inflation

Brane inflation

2000

SUSY P-term inflation

Super-natural Inflation

K-flation

2003 KKLT

N-flation

ekpyrotic/ cyclic

D3,D7 brane inflation

DBI inflation

moving brane separations

Racetrack inflation

Tachyon inflation

Warped Brane inflation

moduli fields

monodromy

Roulette inflation Kahler moduli/axion

fibre inflation

fluctuations in the **early universe "vacuum" grow** to ***all*** **structure**

current
Hubble
patch
~10 Gpc

speed
limit
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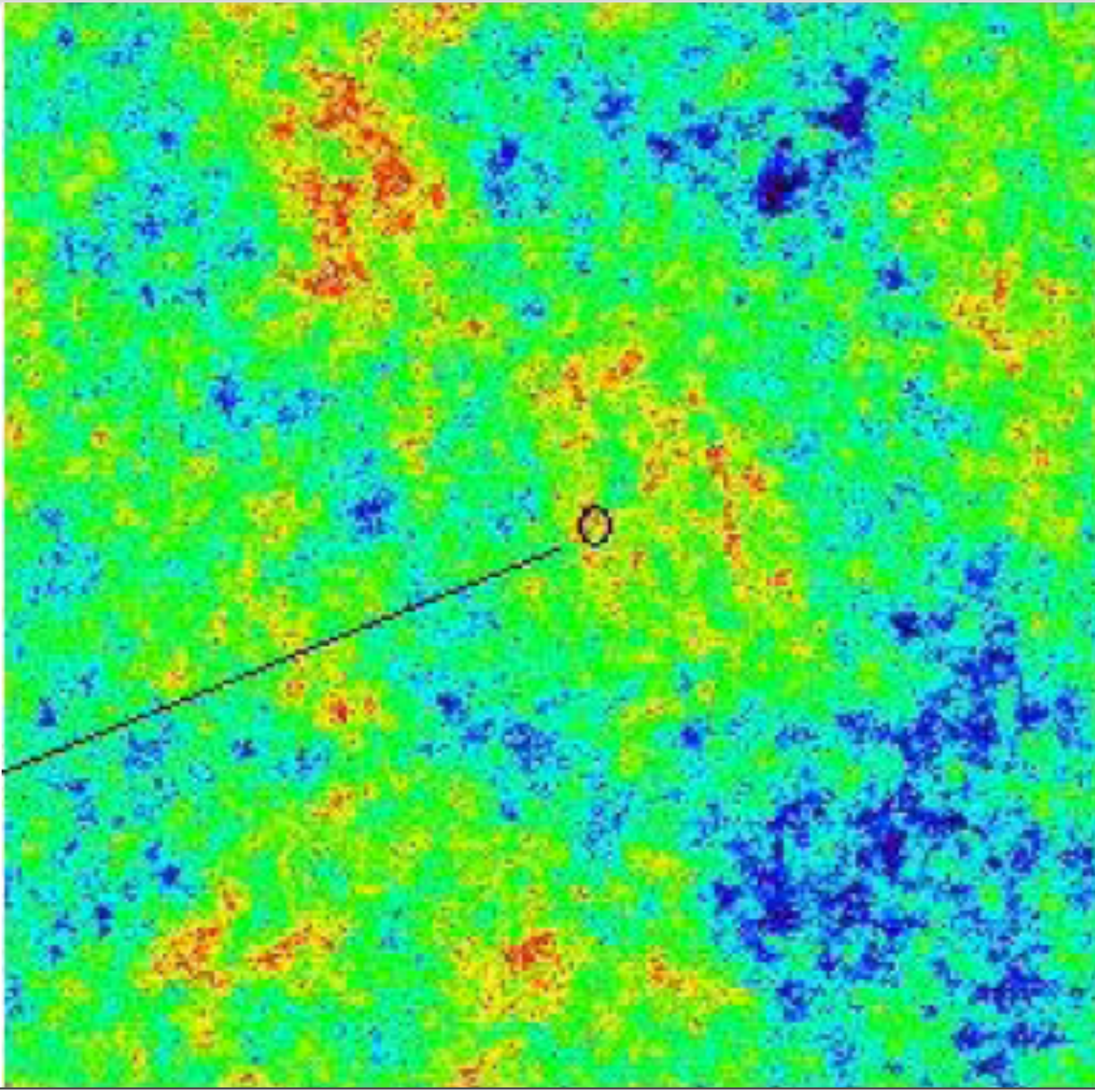

patterns
in the
quantum
jitter
evolve
under
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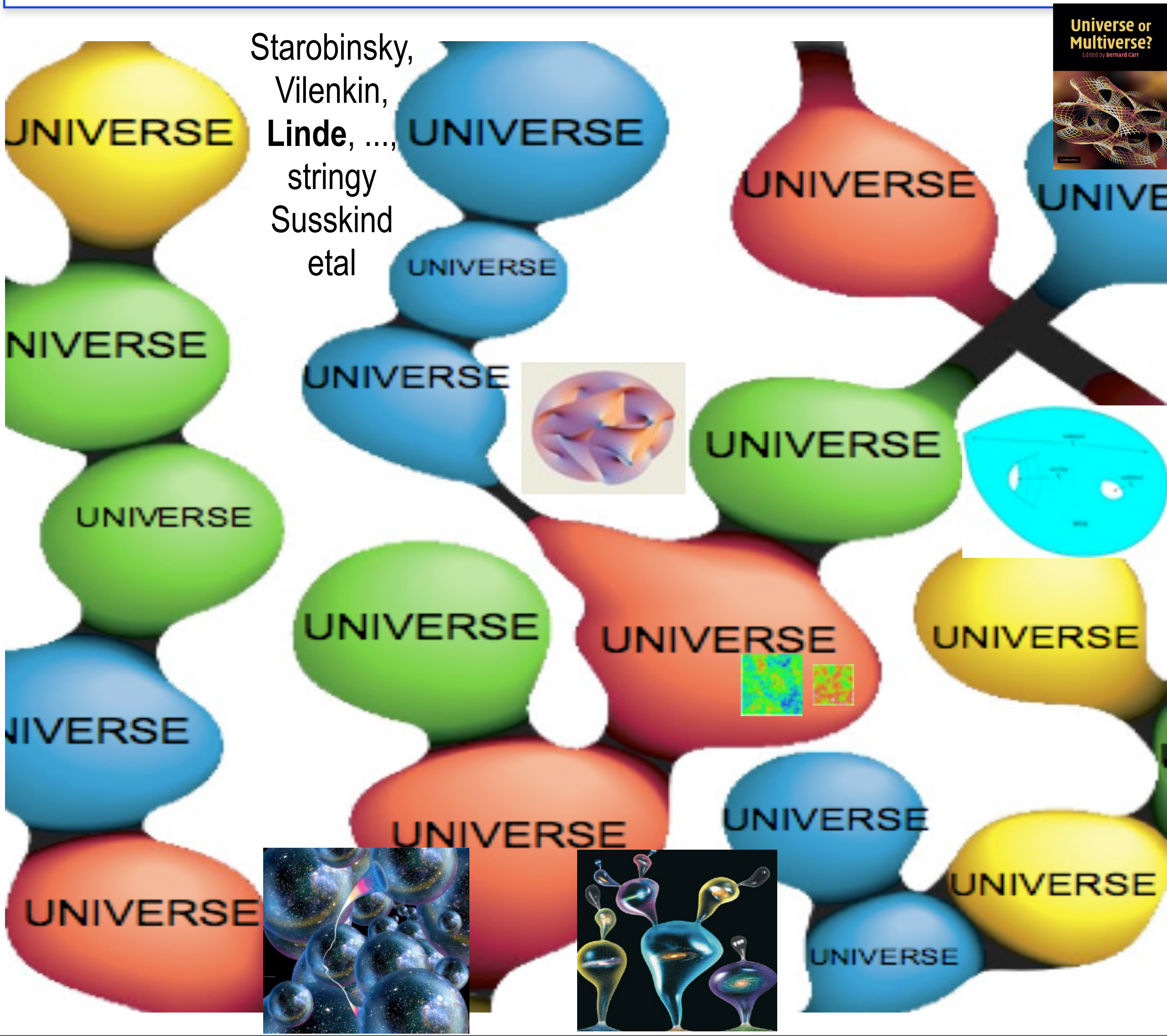
(& gas
dynamics)

1000 Gpc

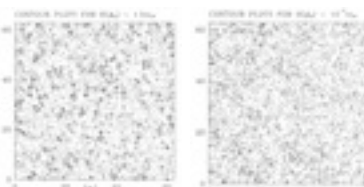
the **quantum stochastic non-G landscape** cf. the **stringy landscape**

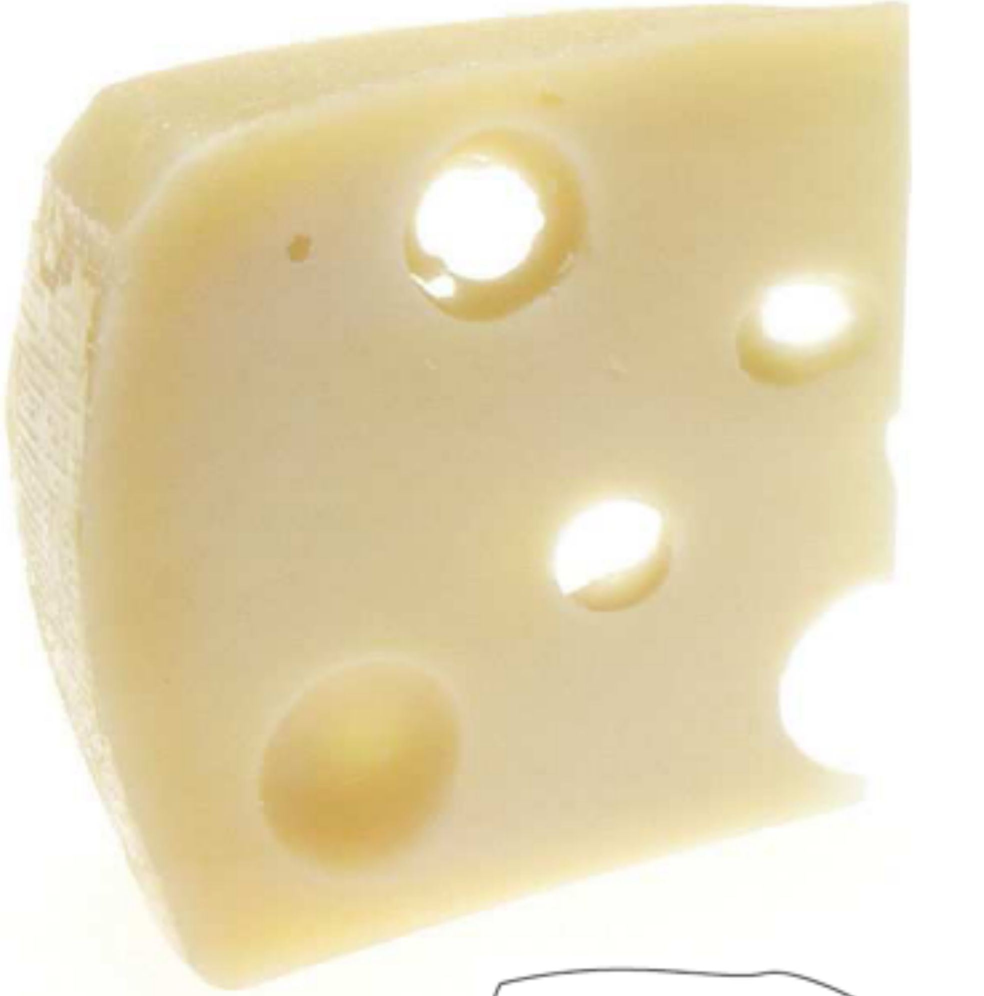
Starobinsky, Vilenkin, **Linde**, ..., stringy Susskind etal

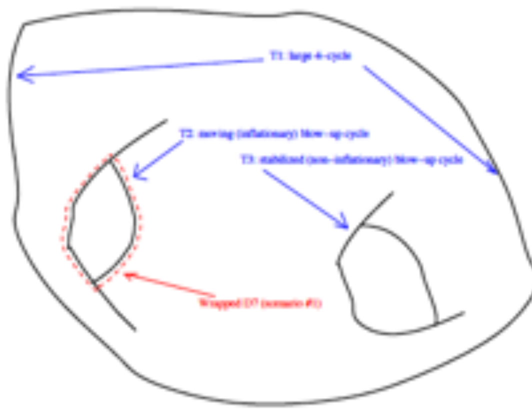


SB91: non-G on uniform Ha-hypersurfaces from a simple exponential potential via quantum kicks > drift at high $H_i \sim m_p$ uuUULSS cf. observable nearly-Gaussian at low $H_i \sim 10^{-5} m_p$

asymptotic flat eternal inflation V has similar behaviour



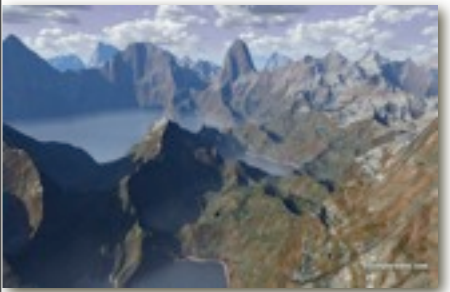


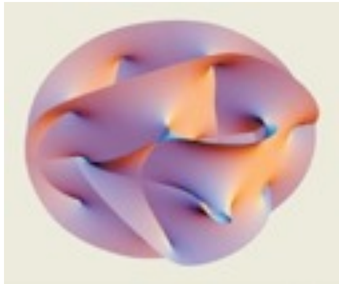


Balasubramanian, Berlund, Conlon, Quevedo, · · ·

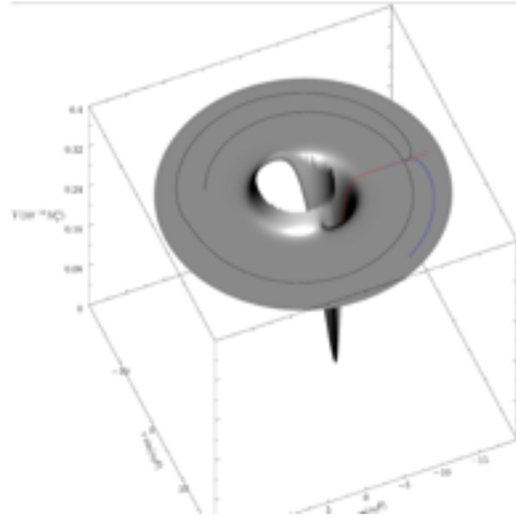
Neil Barnaby, J. Richard Bond, Zhiqi Huang & Lev Kofman,
"Preheating After Modular Inflation," arXiv:0909.0503.

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





The 'house' plays roulette as well as dice with the world.

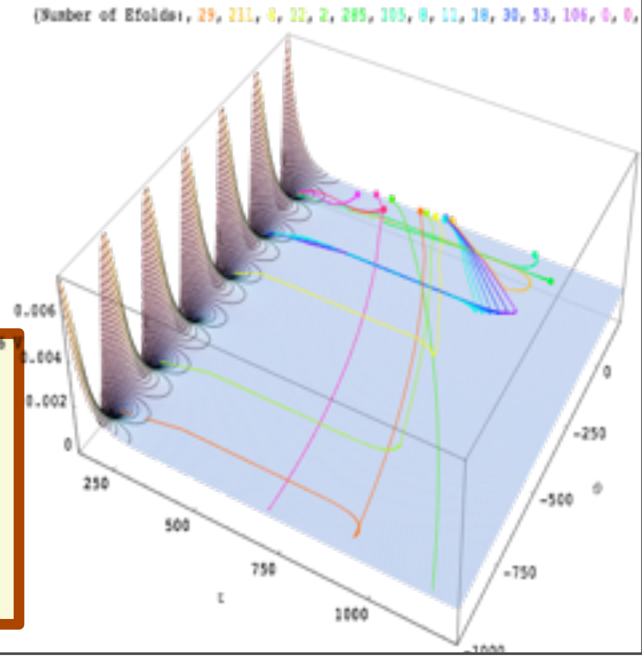


Roulette inflation
Kahler moduli/axion

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 coordinates in the low energy landscape:

moving brane/antibrane separations (D3,D7)
moduli fields, sizes and shapes of geometrical structures such as holes in a dynamical extra-dimensional (6D) manifold approaching stabilization

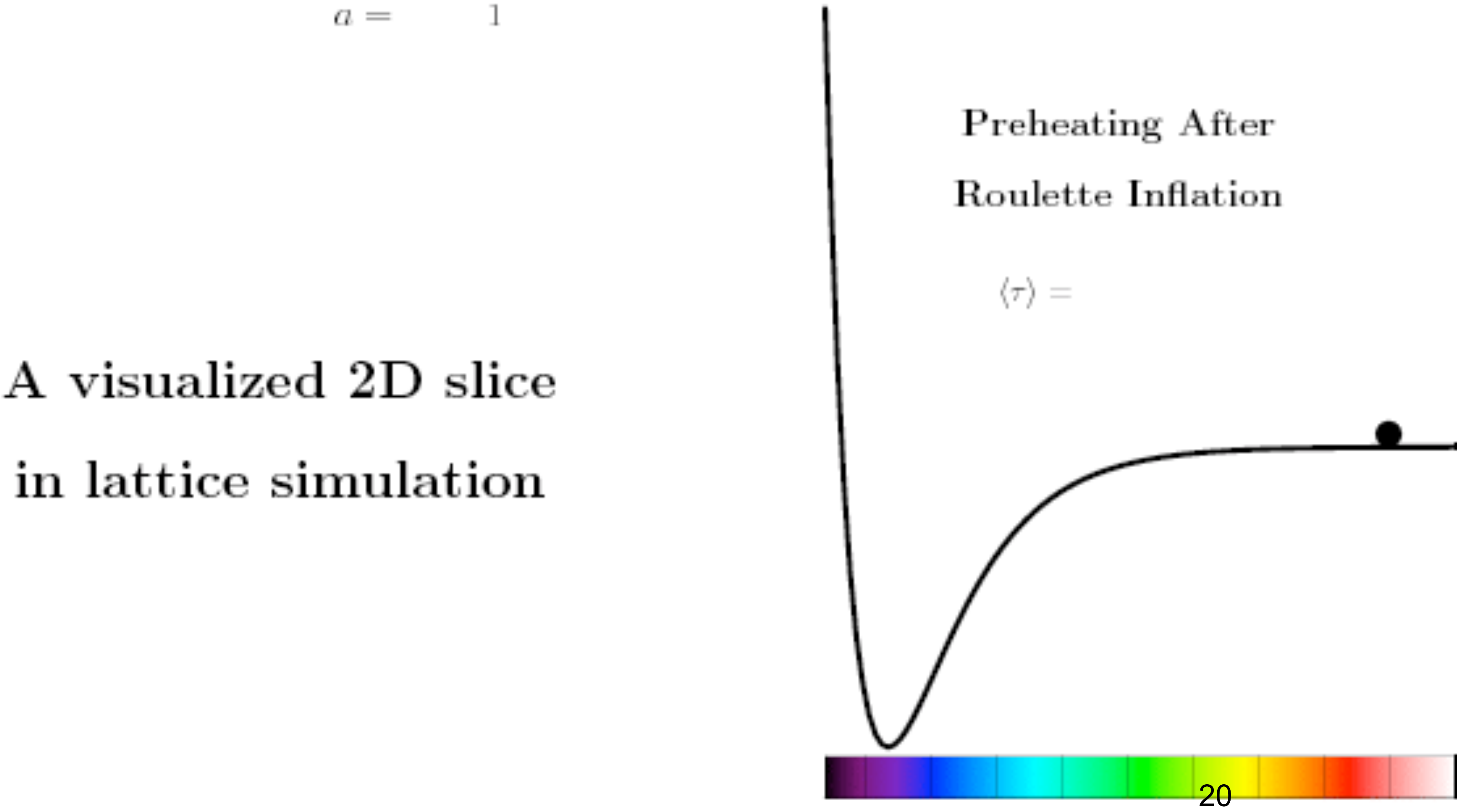


theory prior ~ probability of trajectories given potential parameters of the collective coordinates X probability of the potential parameters X probability of initial conditions

Barnaby, Bond, Huang, Kofman 2009

Preheating After Roulette Inflation

HLattice code: arbitary number of fields,
hybrid symplectic, to ~ trillionth accuracy!

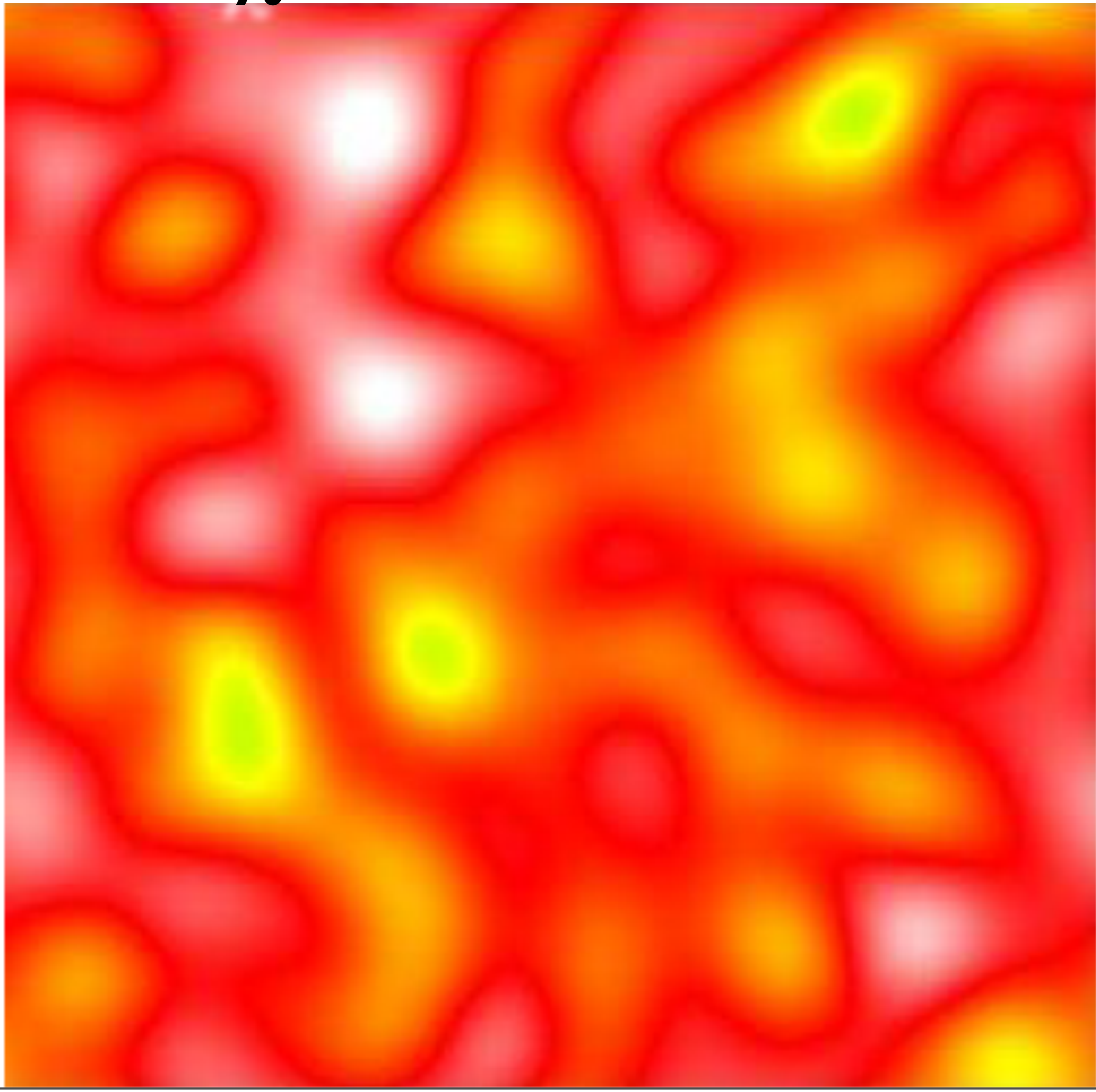


4 5 6 7 8

τ

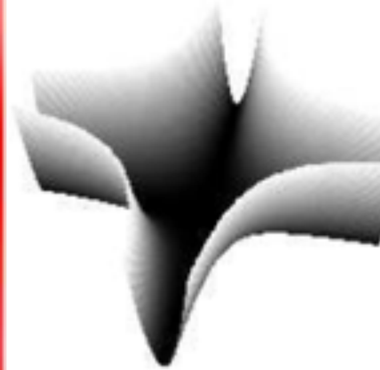
www.youtube.com/watch?v=FW__su-W-ck&NR=1

ϕ inflaton χ isocon $V(\phi,\chi)=1/4\ \lambda\ \phi^4 + 1/2\ g^2\ \phi^2\ \chi^2$



Parametric Resonance

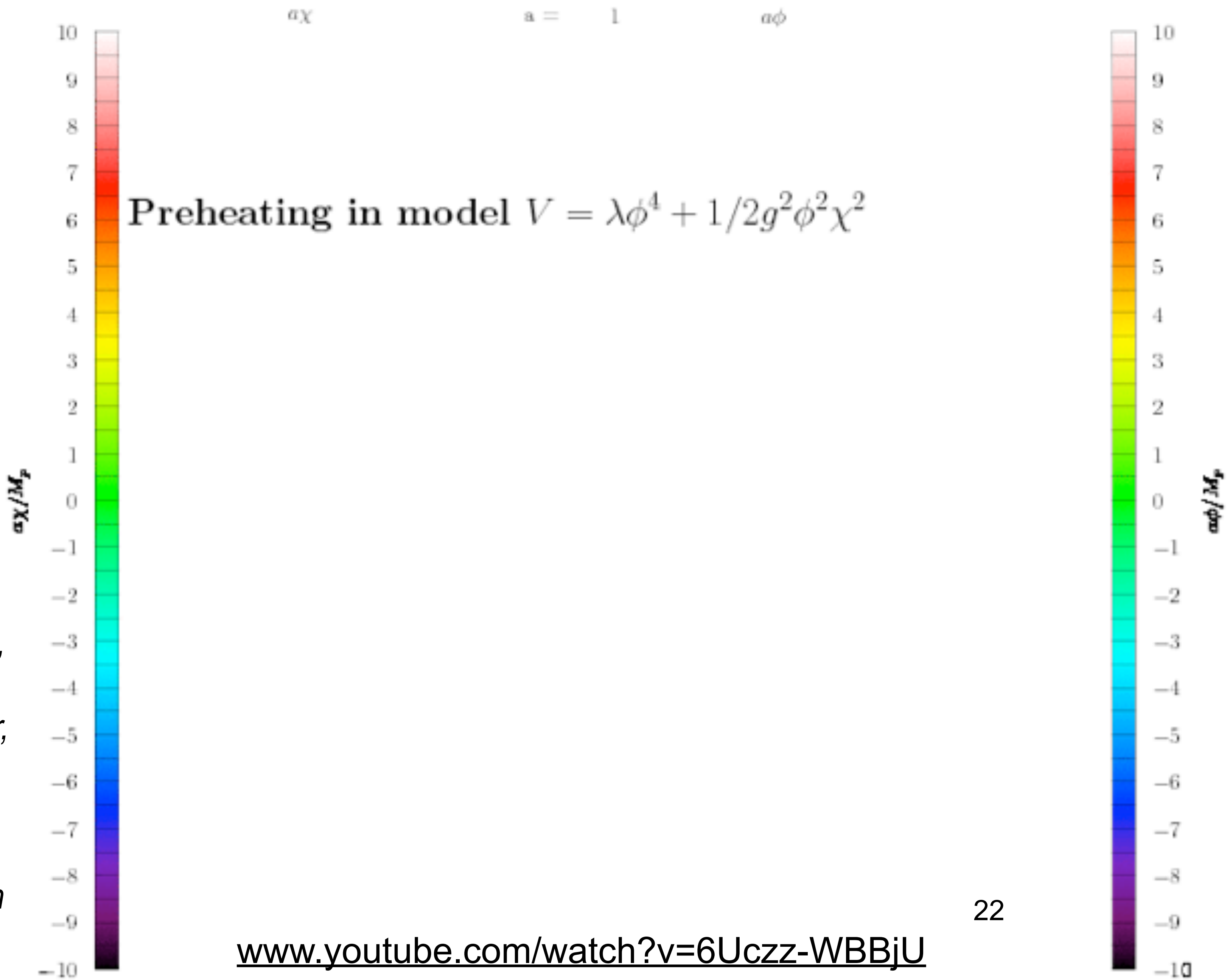
$g^2/\lambda \sim 1$



pre-heating patch (~1cm)

~1 cm

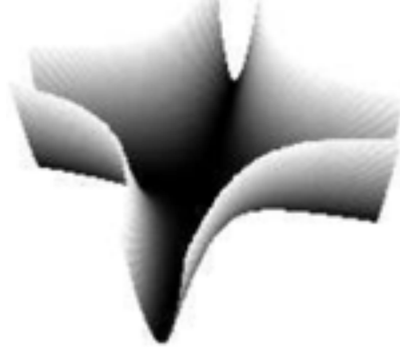
Cosmic Chaotic Billiards: Nongaussianity from Parametric Resonance in Preheating

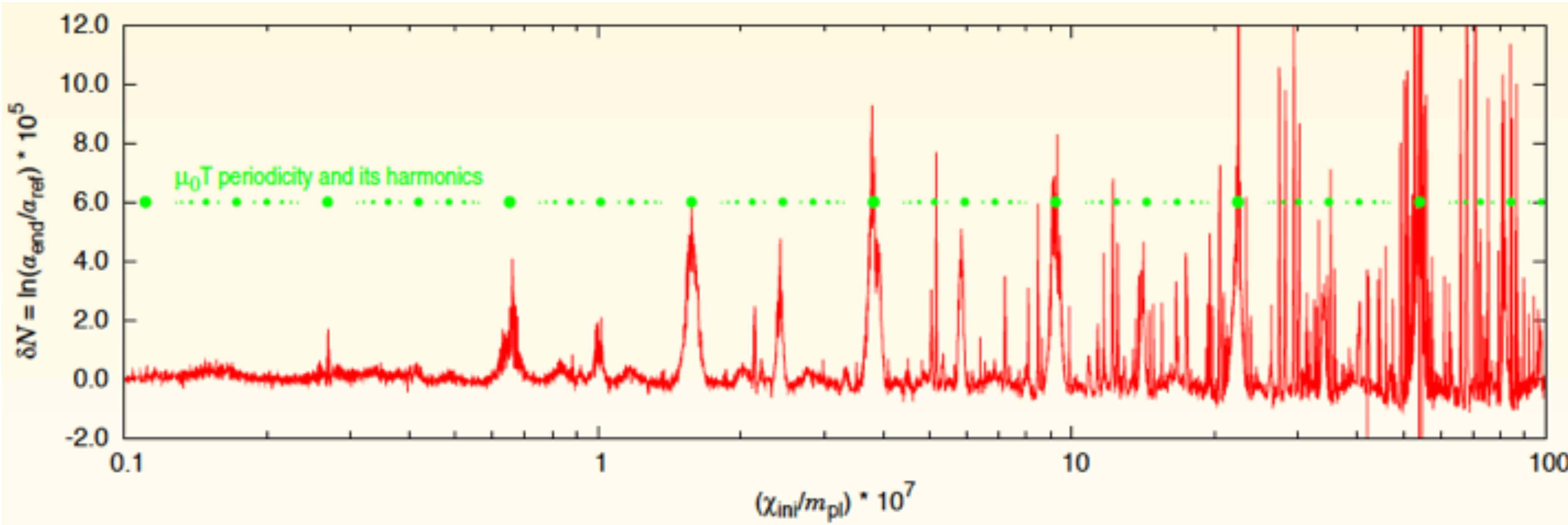


***preheating ideas**: 90s Kofman, Linde, Starobinsky, .., Greene, Felder, Frolov, ...*

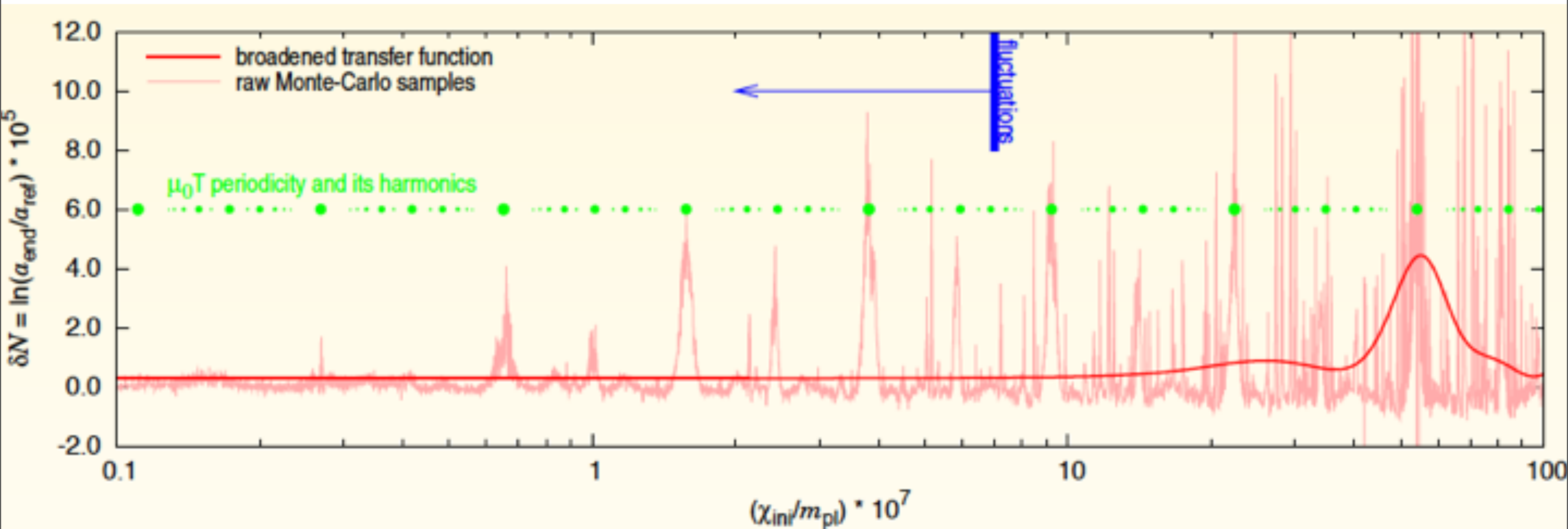
***nonG ideas** Bond, Frolov, Huang, Kofman 2009*

www.youtube.com/watch?v=6Uczz-WBBjU





12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
δN = ln(a_end/a_ref) * 10^5
μ0T periodicity and its harmonics
0.1
1
10
100
(χ_ini/m_pl) * 10^7



broadened transfer function
raw Monte-Carlo samples
fluctuations
μ0T periodicity and its harmonics
δN = ln(a_end/a_ref) * 10^5
(χ_ini/m_pl) * 10^7
12.0
10.0
8.0
6.0
4.0
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-2.0
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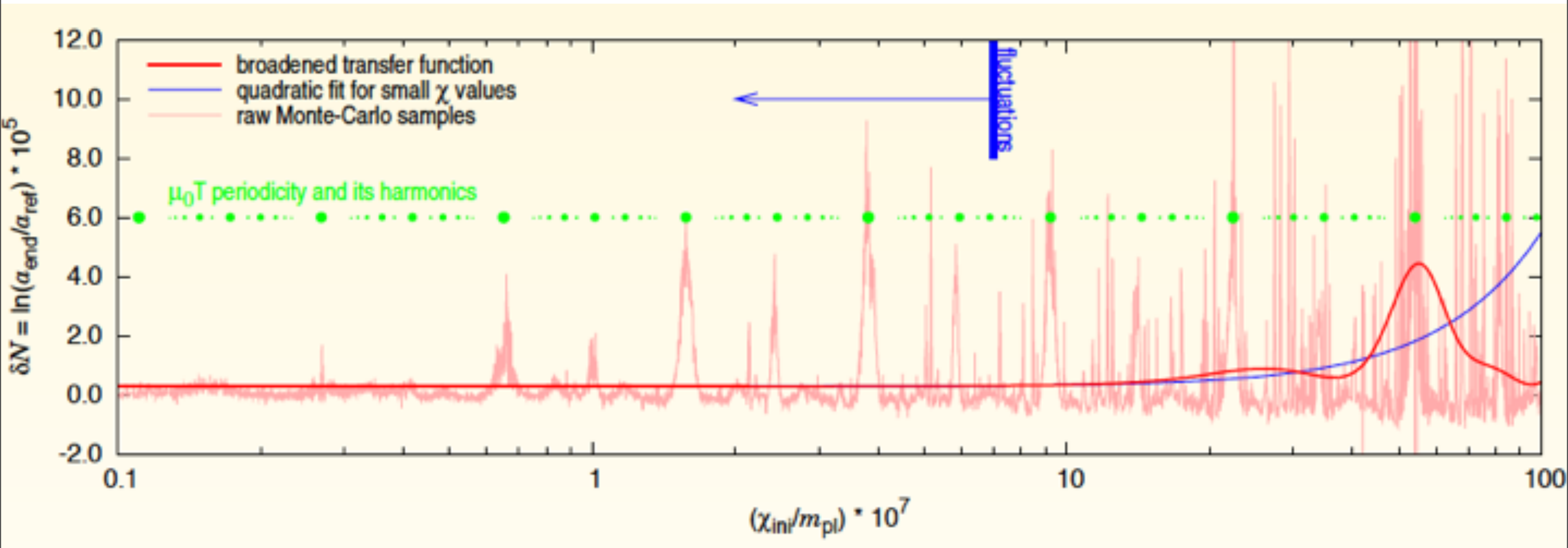
1
10
100



broadened transfer function
quadratic fit for small χ values
raw Monte-Carlo samples
fluctuations
μ0T periodicity and its harmonics
δN = ln(a_end/a_ref) * 10^5
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12.0
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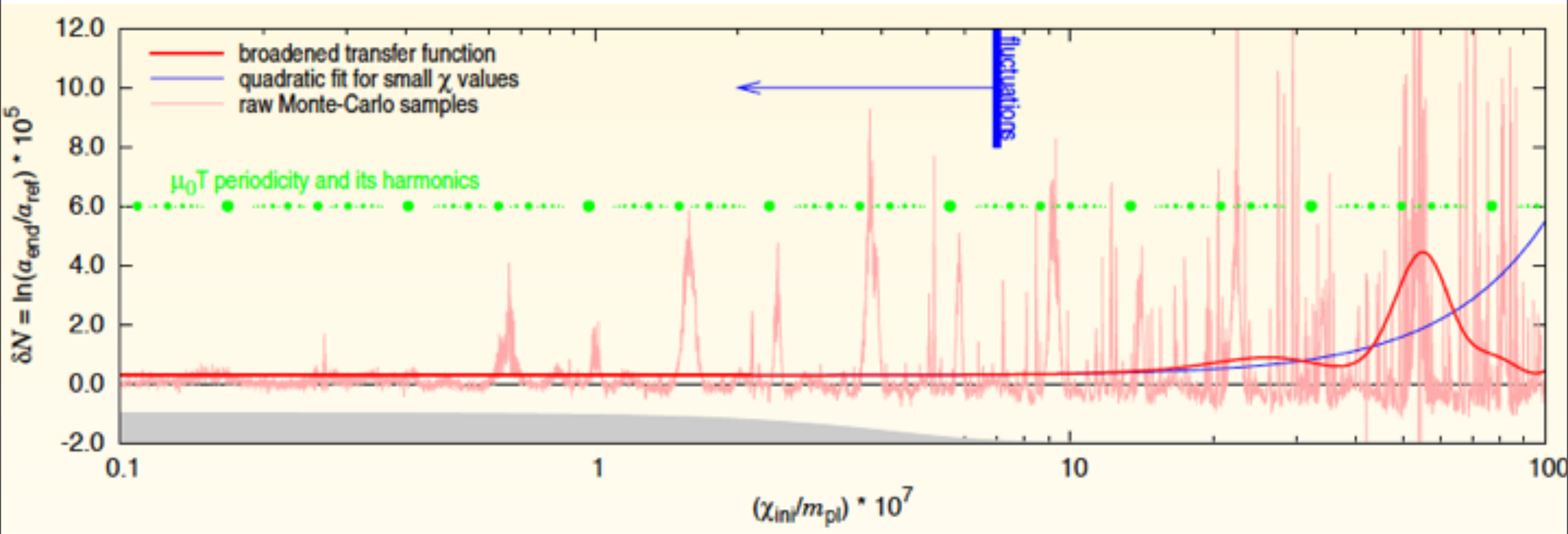

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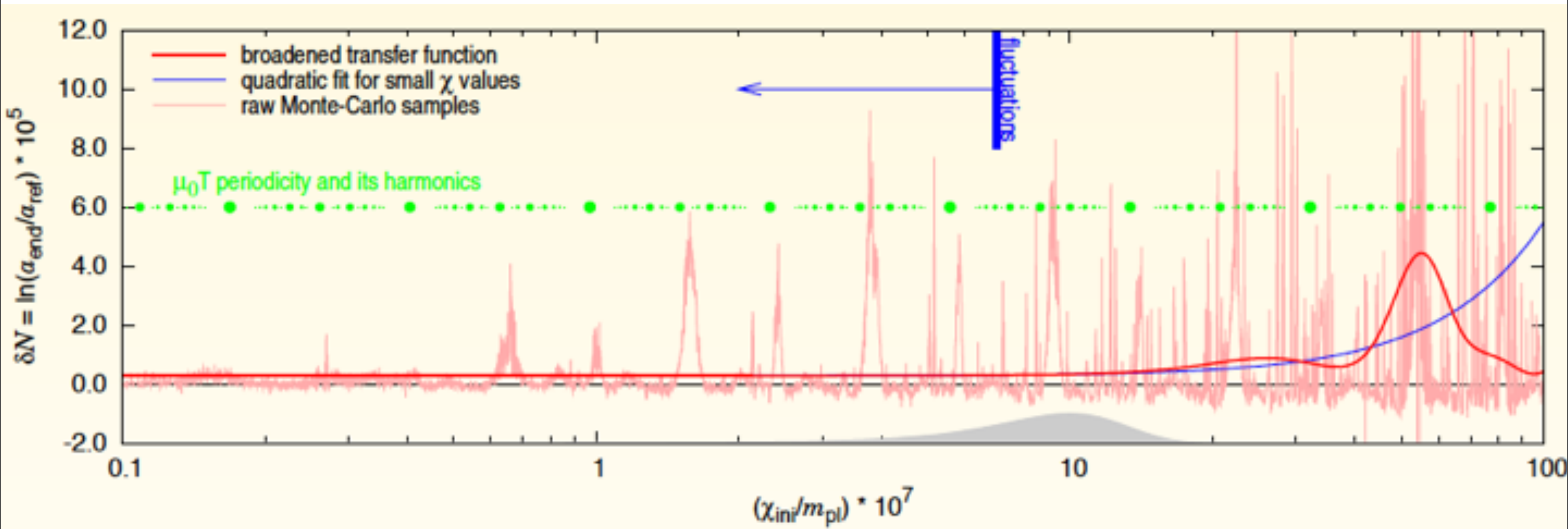

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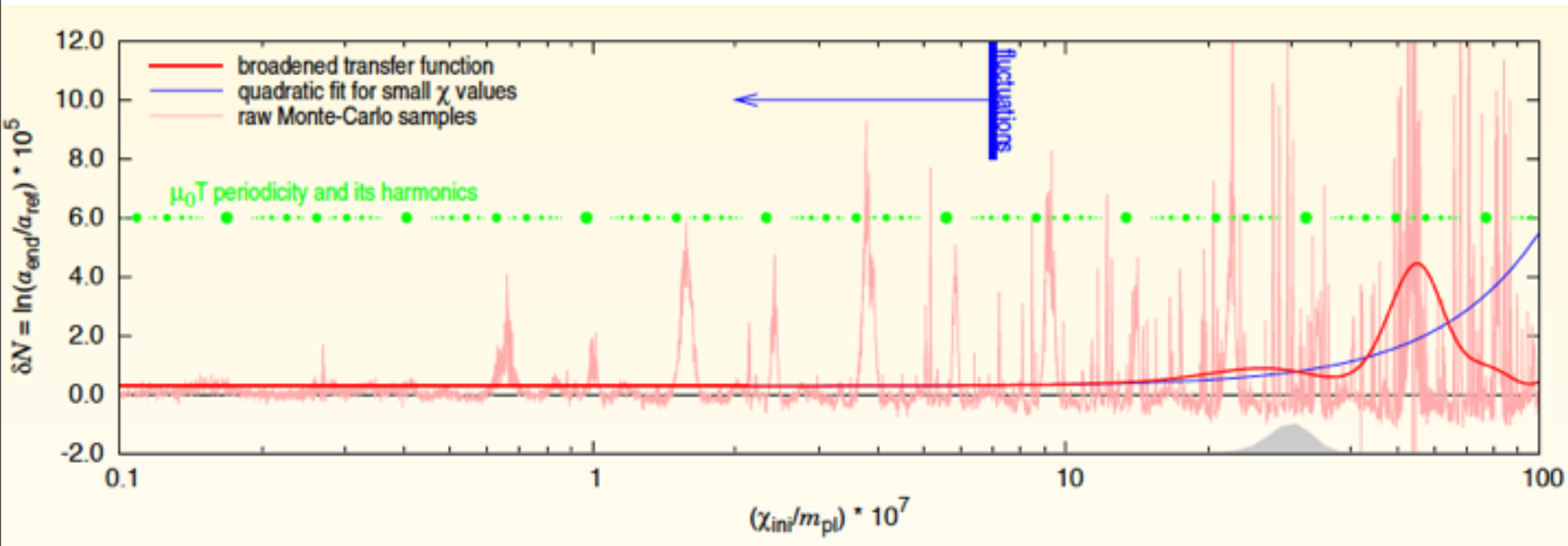

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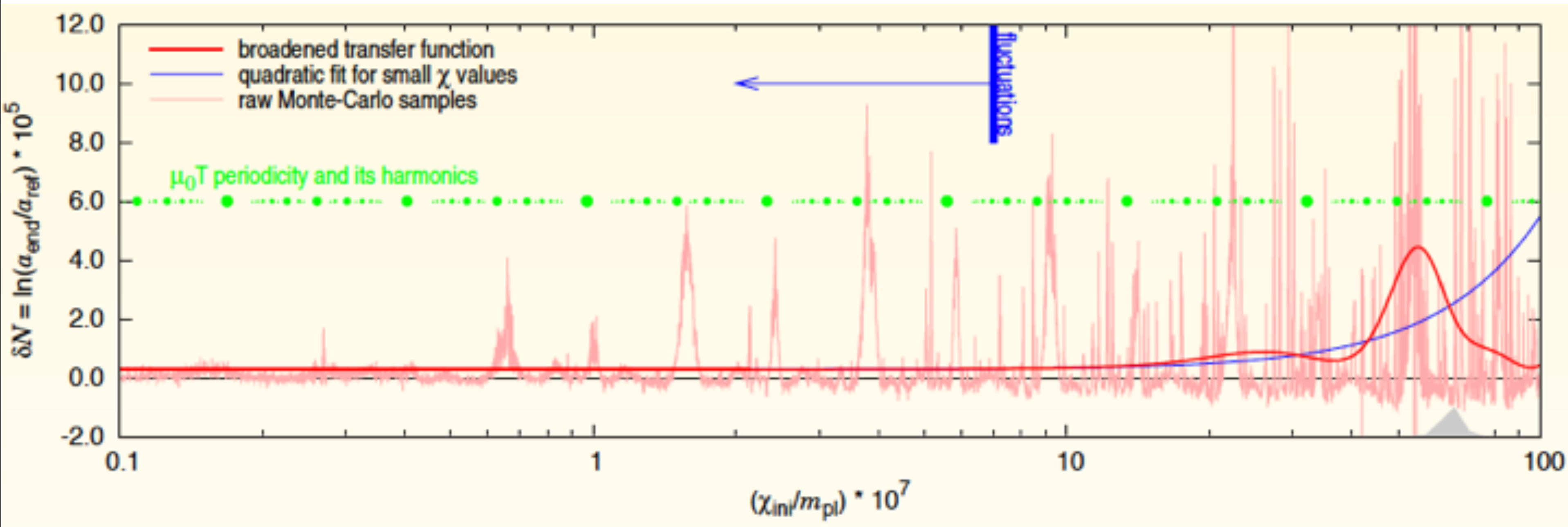

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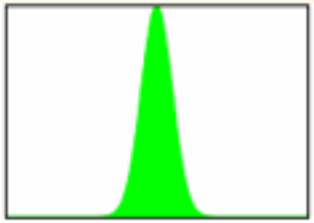

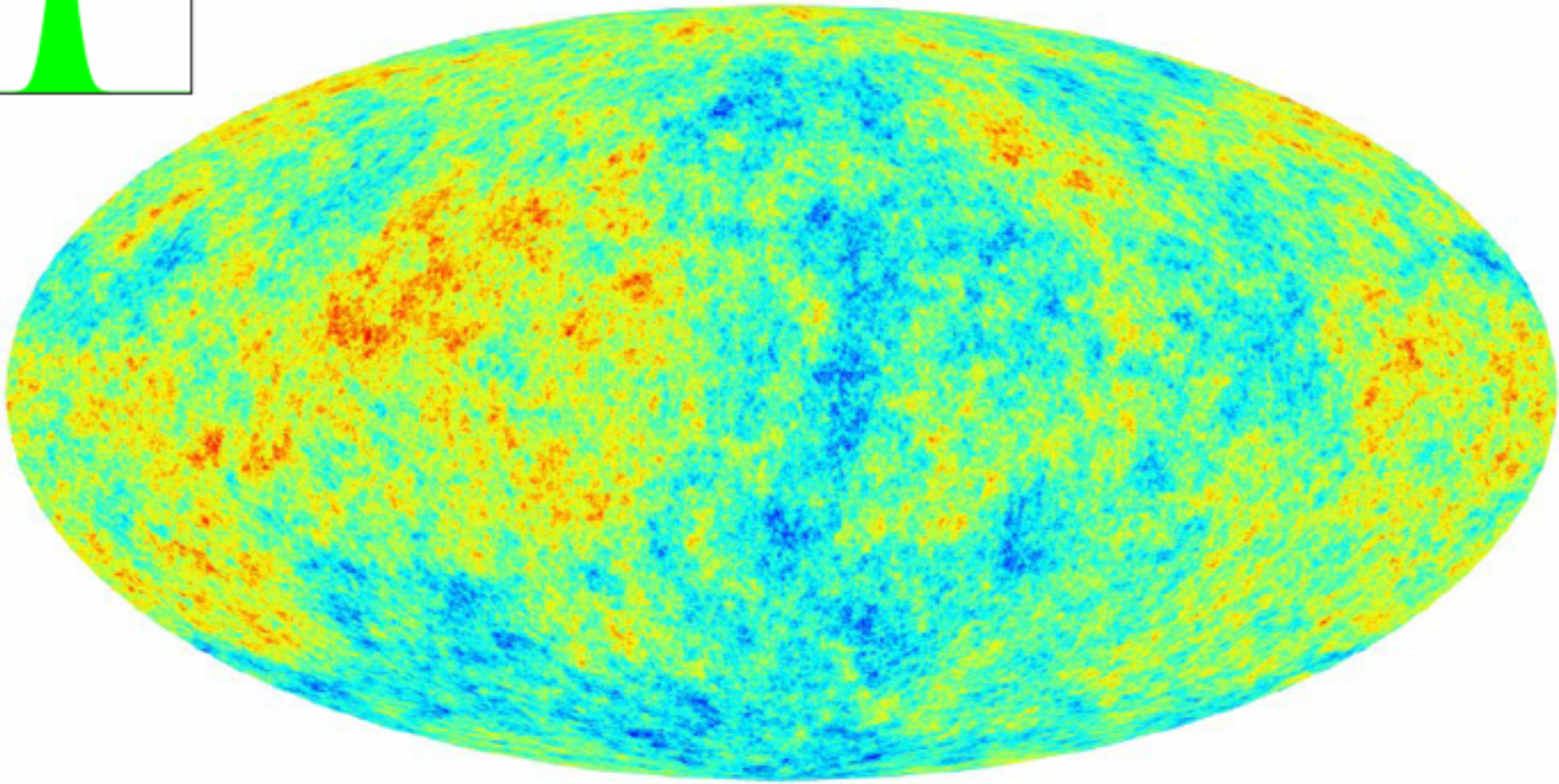

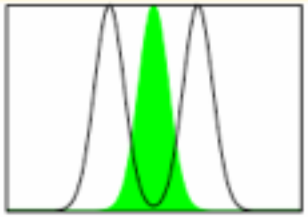

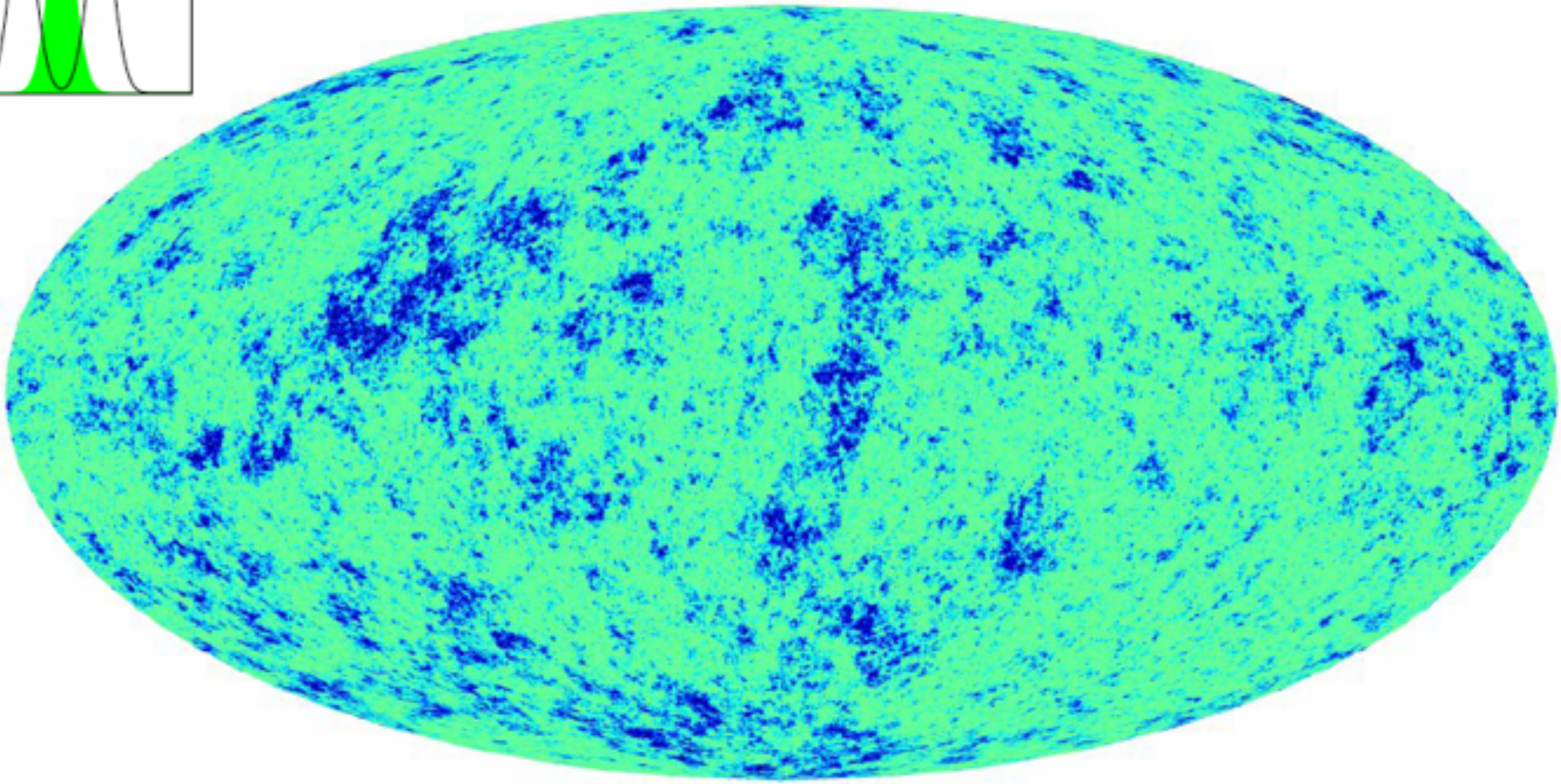

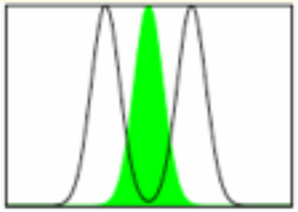

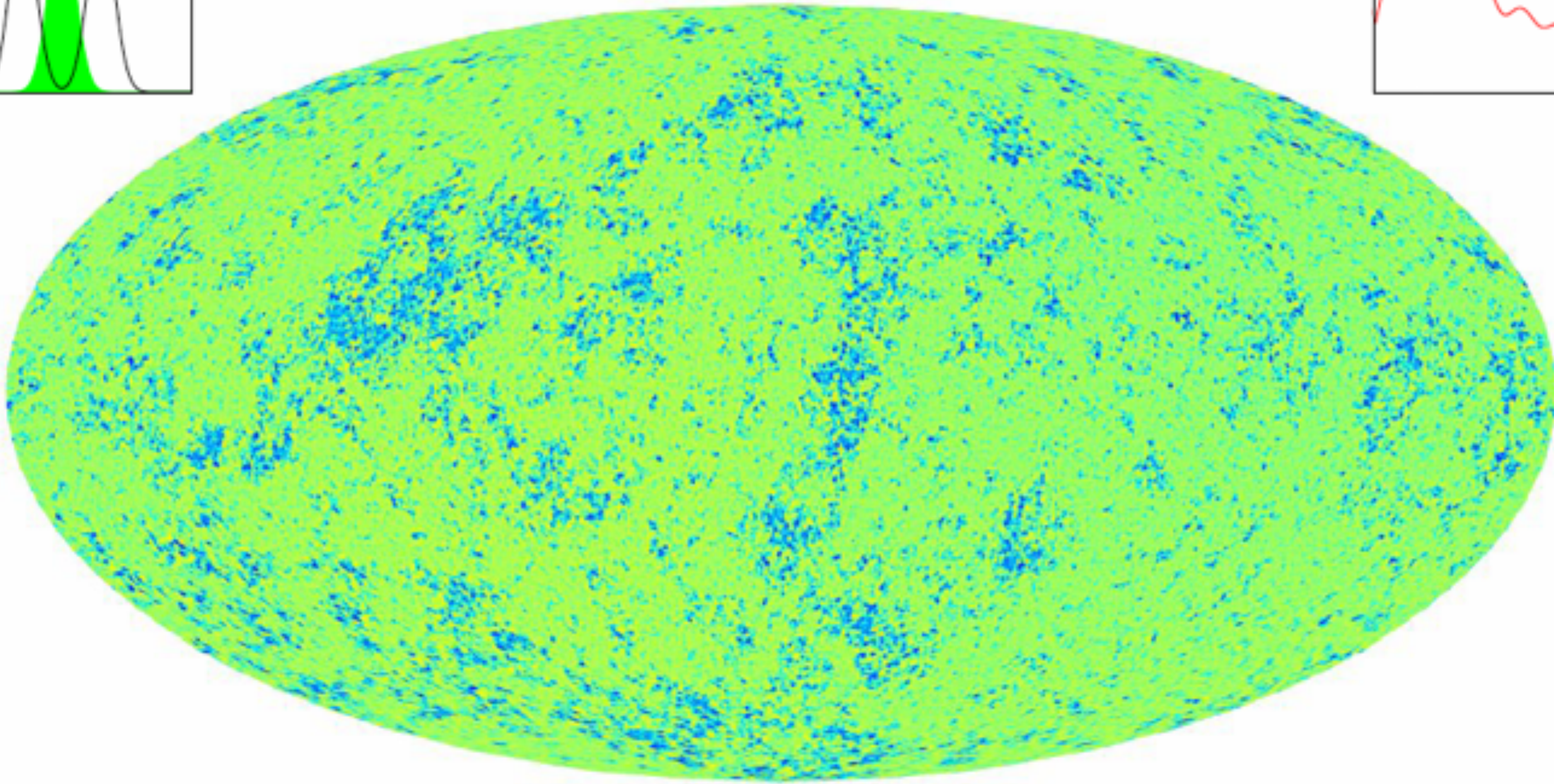

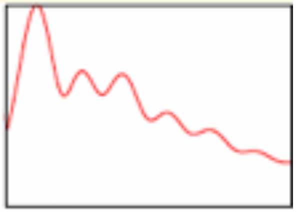

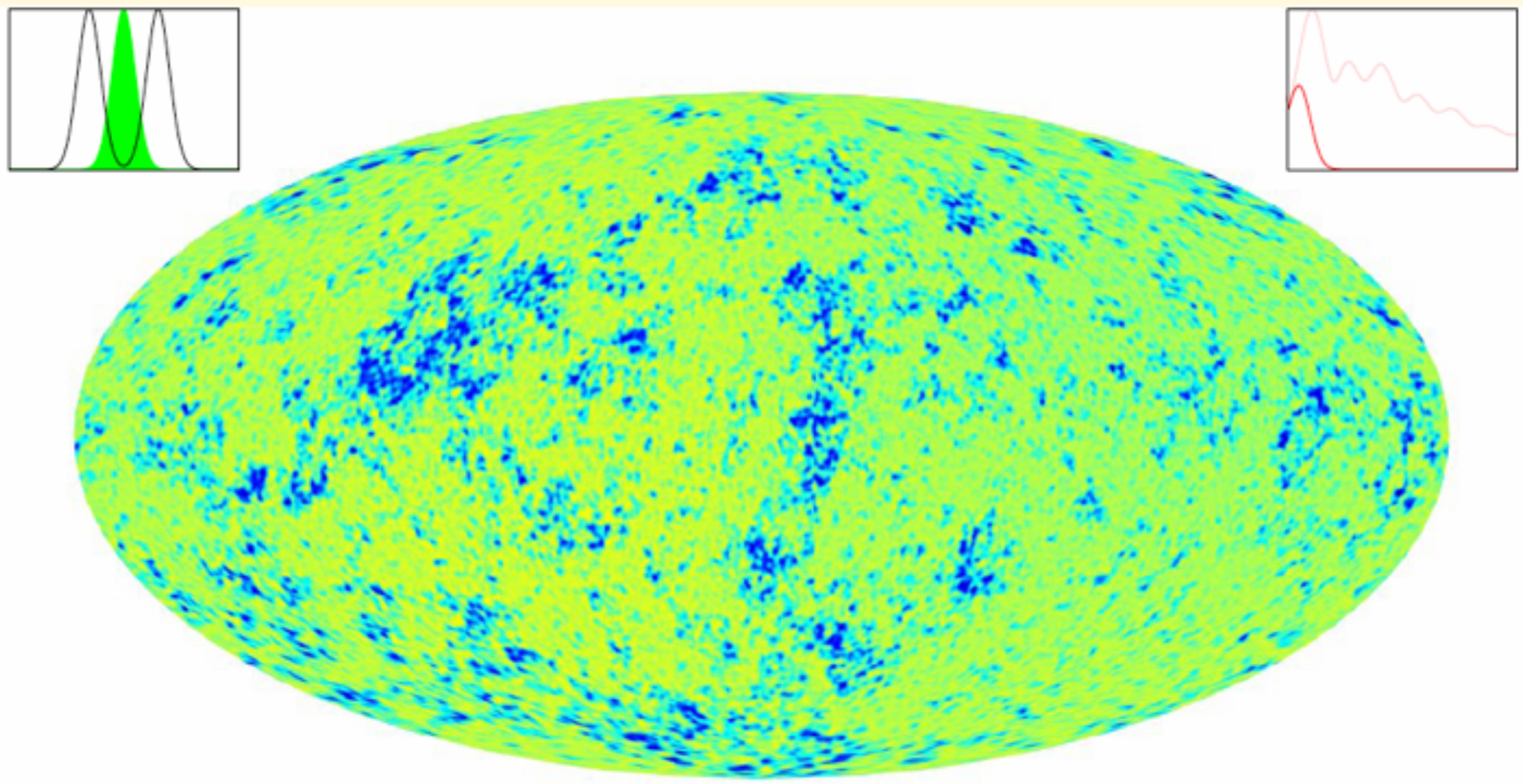

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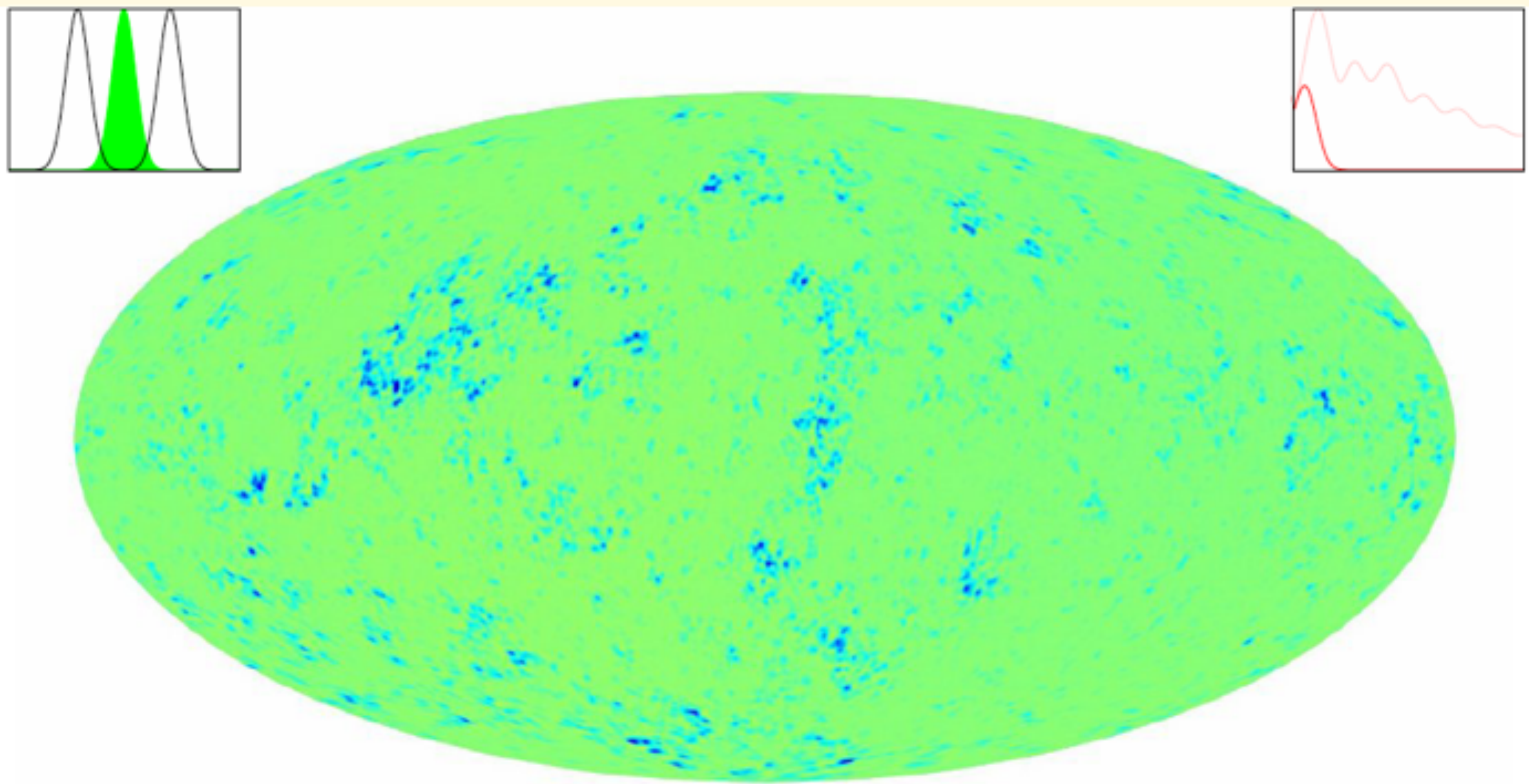
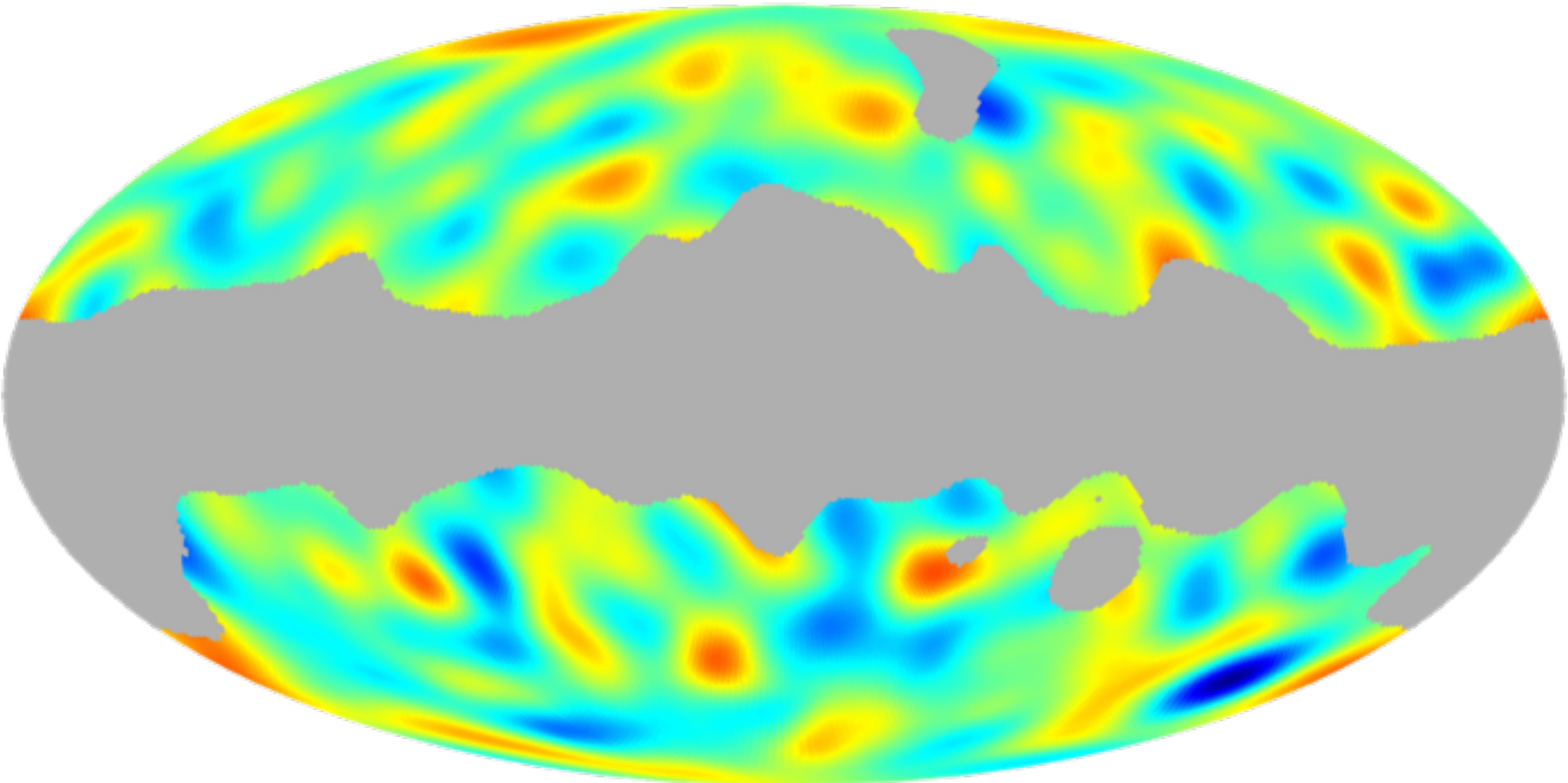
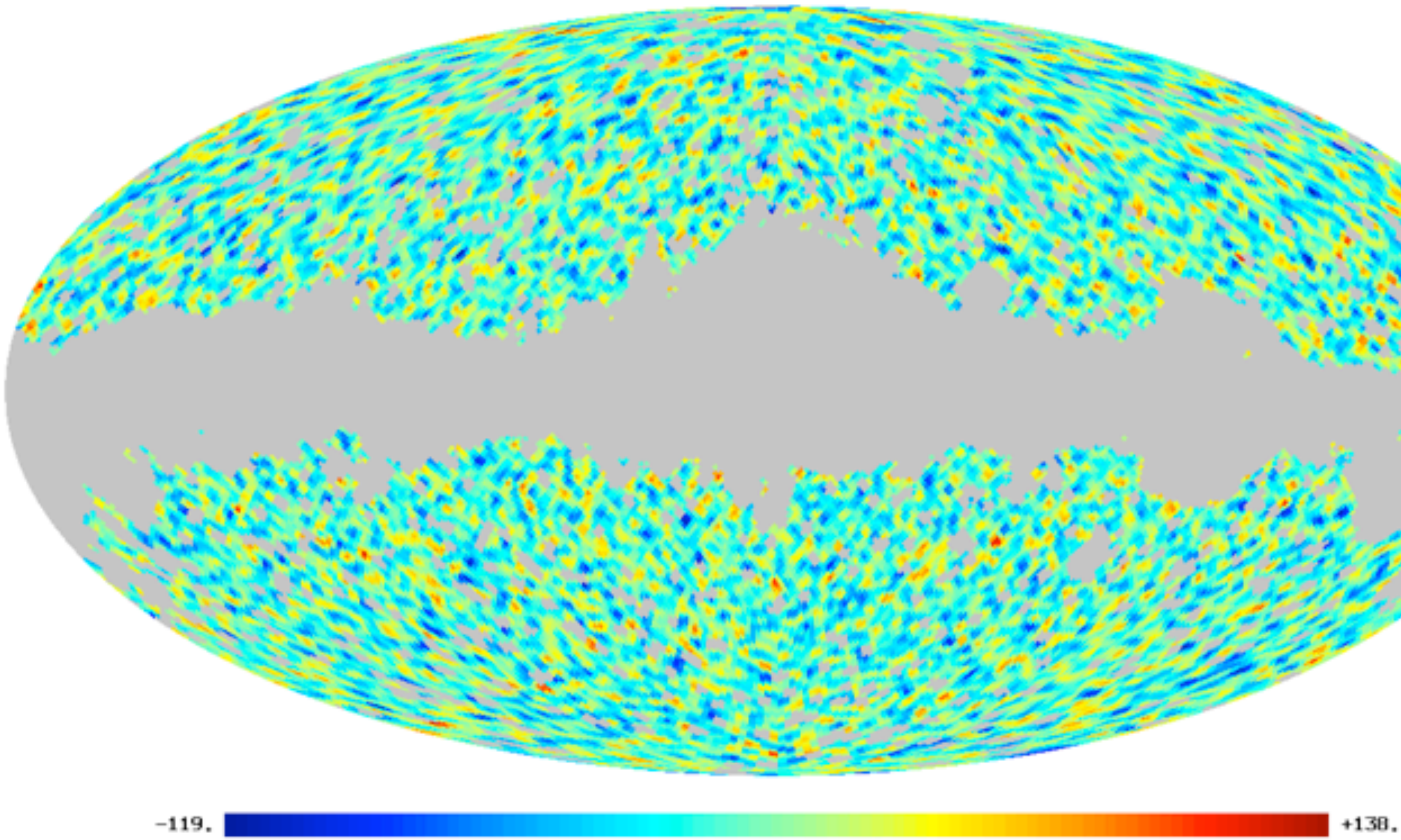


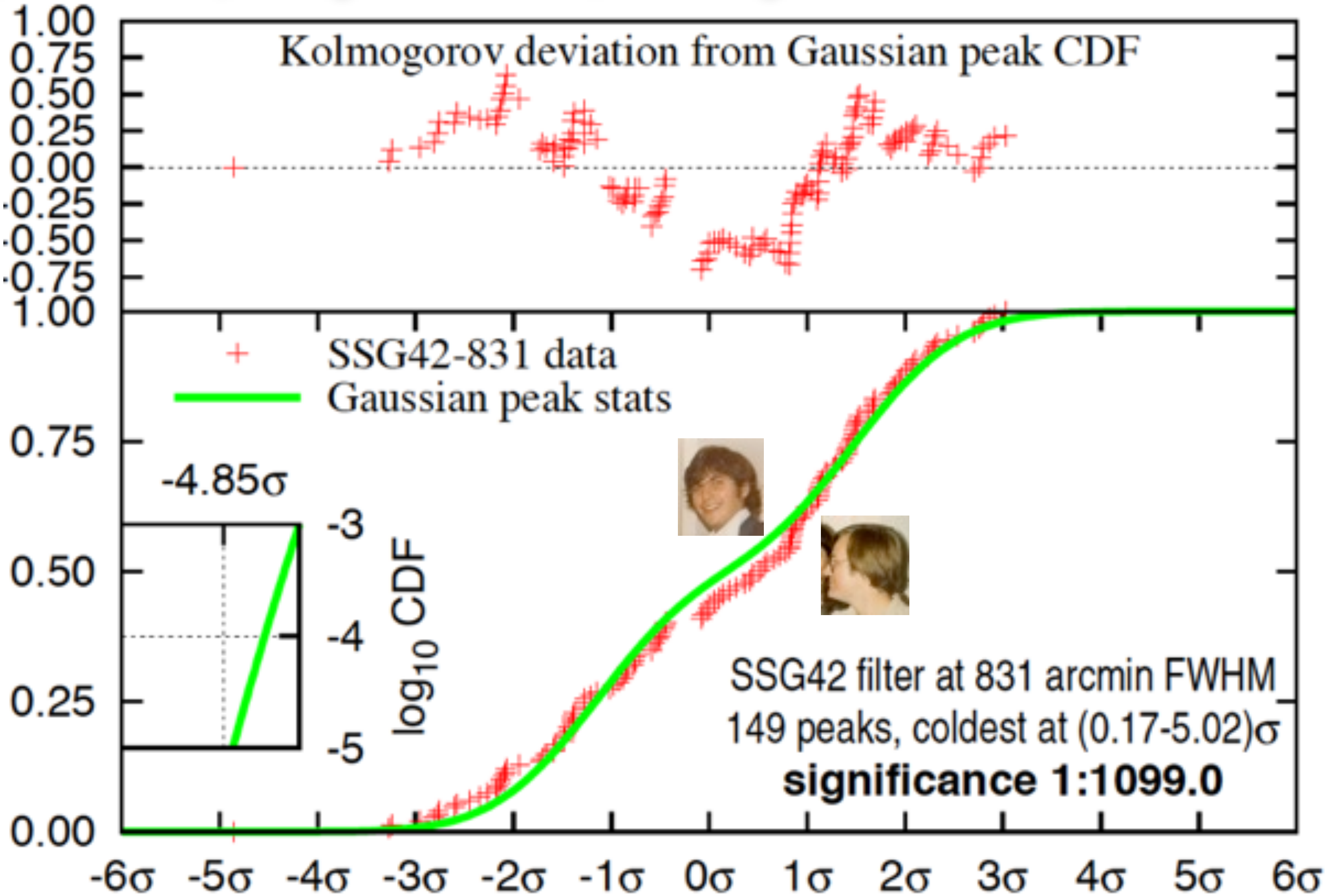
the WMAP Cold Spot: Vielva, Martinez-Gonzalez, Barr, Sanz, Cayon 2004 wavelets in WMAP1, ... Cruz etal 07 in WMAP3, & in WMAP5: needlets, steerable wavelets: ~4.5σ, others ~3σ; Zhang & Huterer 09, not as significant with other filters 20%



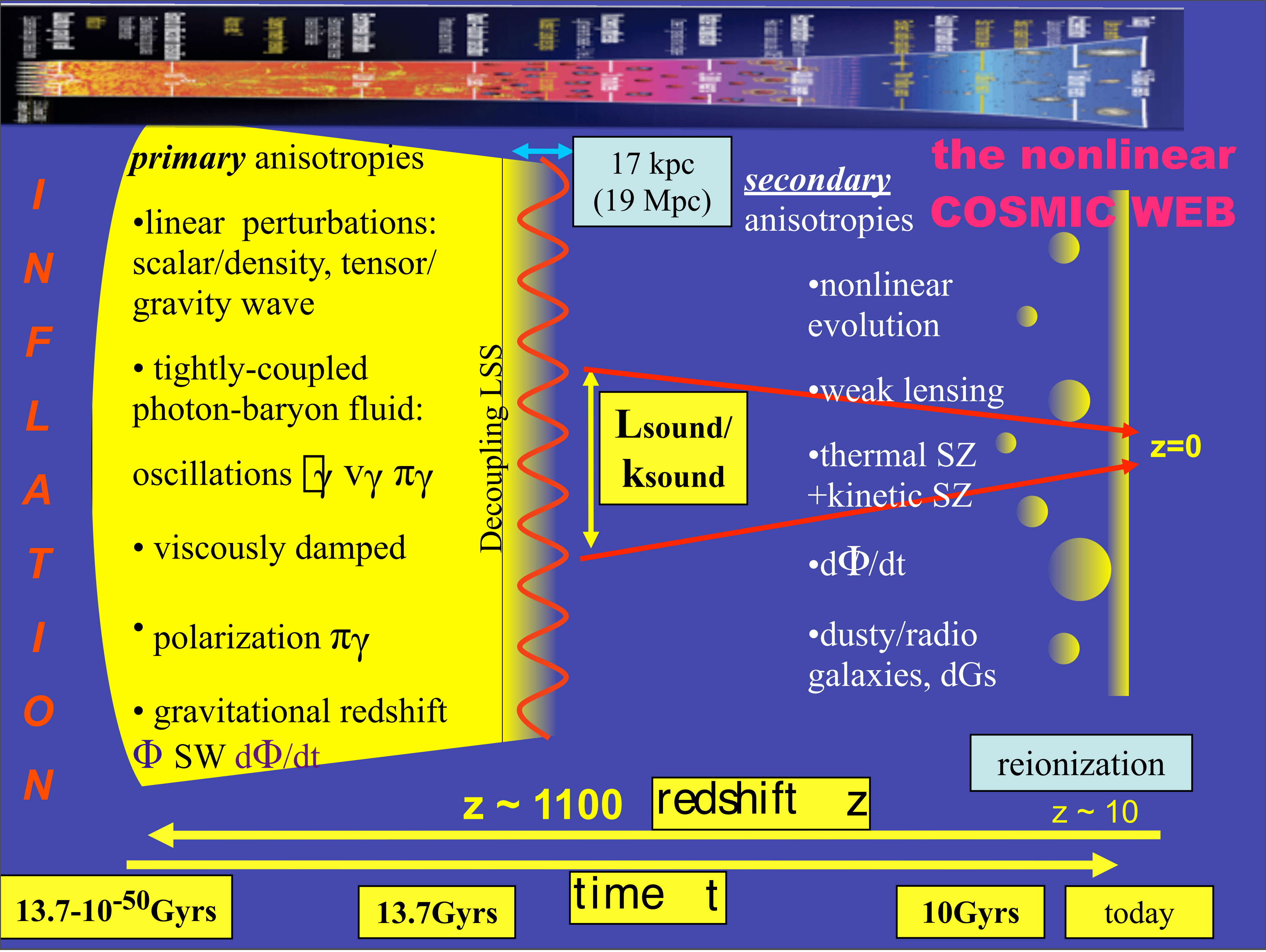
Bond, Frolov, Huang, Kofman, Nolta: Cold Spot testing: spherical SavitzkyGolay filters (compact polynomials) on pre-whitened WMAP5 data: -5.02σ, at 831 arcmin fwhm, 149 peaks, 1/1099 significance

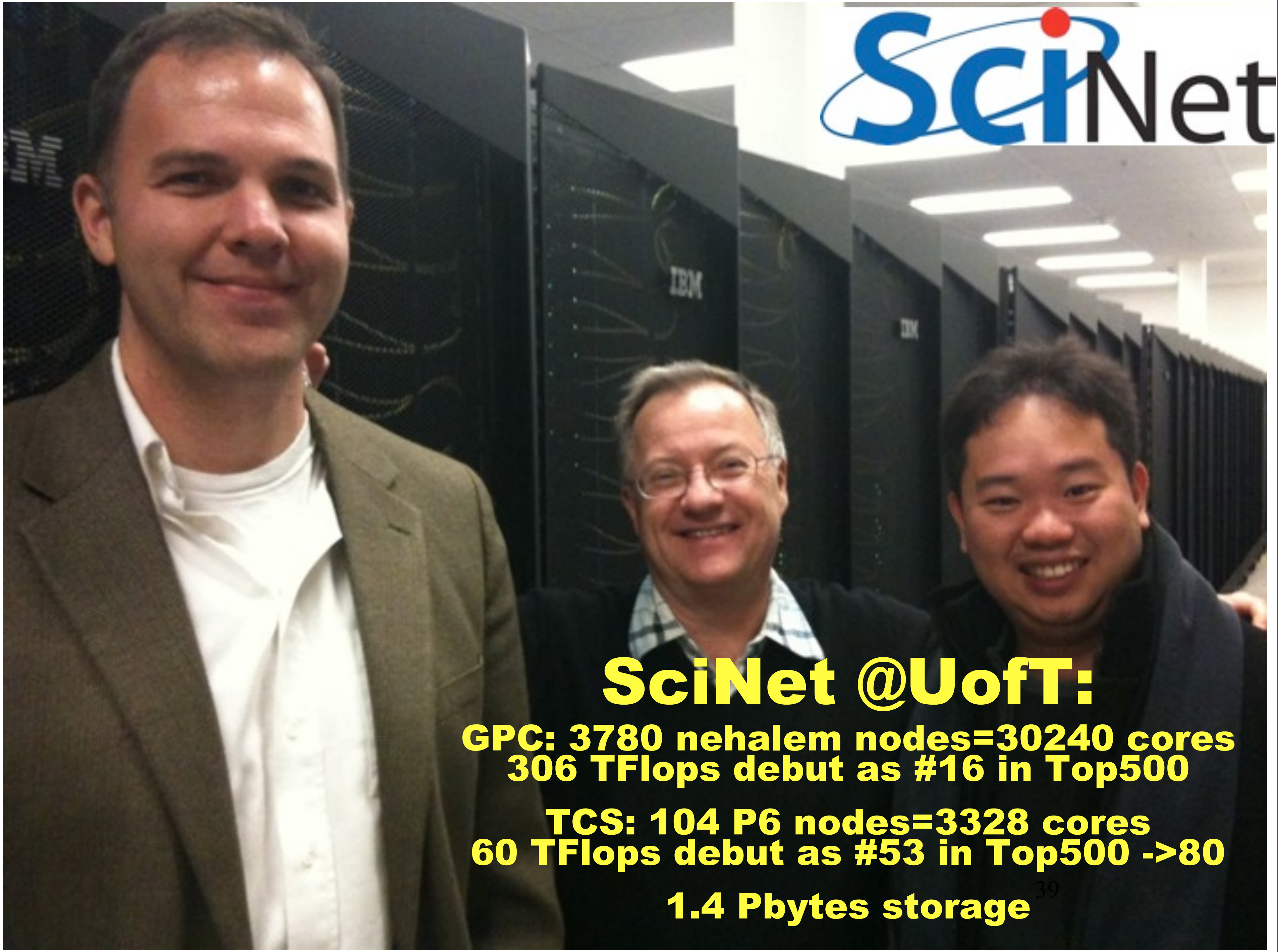

-119.
+138.

the WMAP Cold Spot: Vielva, Martinez-Gonzalez, Barr, Sanz, Cayon 2004 wavelets in WMAP1, ... Cruz etal 07 in WMAP3, & in WMAP5: needlets, steerable wavelets: ~4.5σ, others ~3σ; Zhang & Huterer 09, not as significant with other filters 20%



Bond, Frolov, Huang, Kofman, Nolta 09


INFLATION
primary anisotropies
•linear perturbations: scalar/density, tensor/ gravity wave
• tightly-coupled photon-baryon fluid:
oscillations □γ vγ πγ
• viscously damped
• polarization πγ
• gravitational redshift
Φ SW dΦ/dt
Decoupling LSS
17 kpc
(19 Mpc)
Lsound/
ksound
secondary
anisotropies
the nonlinear
COSMIC WEB
•nonlinear evolution
•weak lensing
•thermal SZ
+kinetic SZ
•dΦ/dt
•dusty/radio galaxies, dGs
z=0
reionization
z ~ 10
z ~ 1100
redshift z
time t
13.7-10^-50 Gyrs
13.7Gyrs
10Gyrs
today


SciNet
IBM
SciNet @UofT:
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

fluctuations in the **early universe "vacuum" grow** to *all* **structure**

400 Mpc

ΛCDM

WMAP5

gas density

Gadget-3

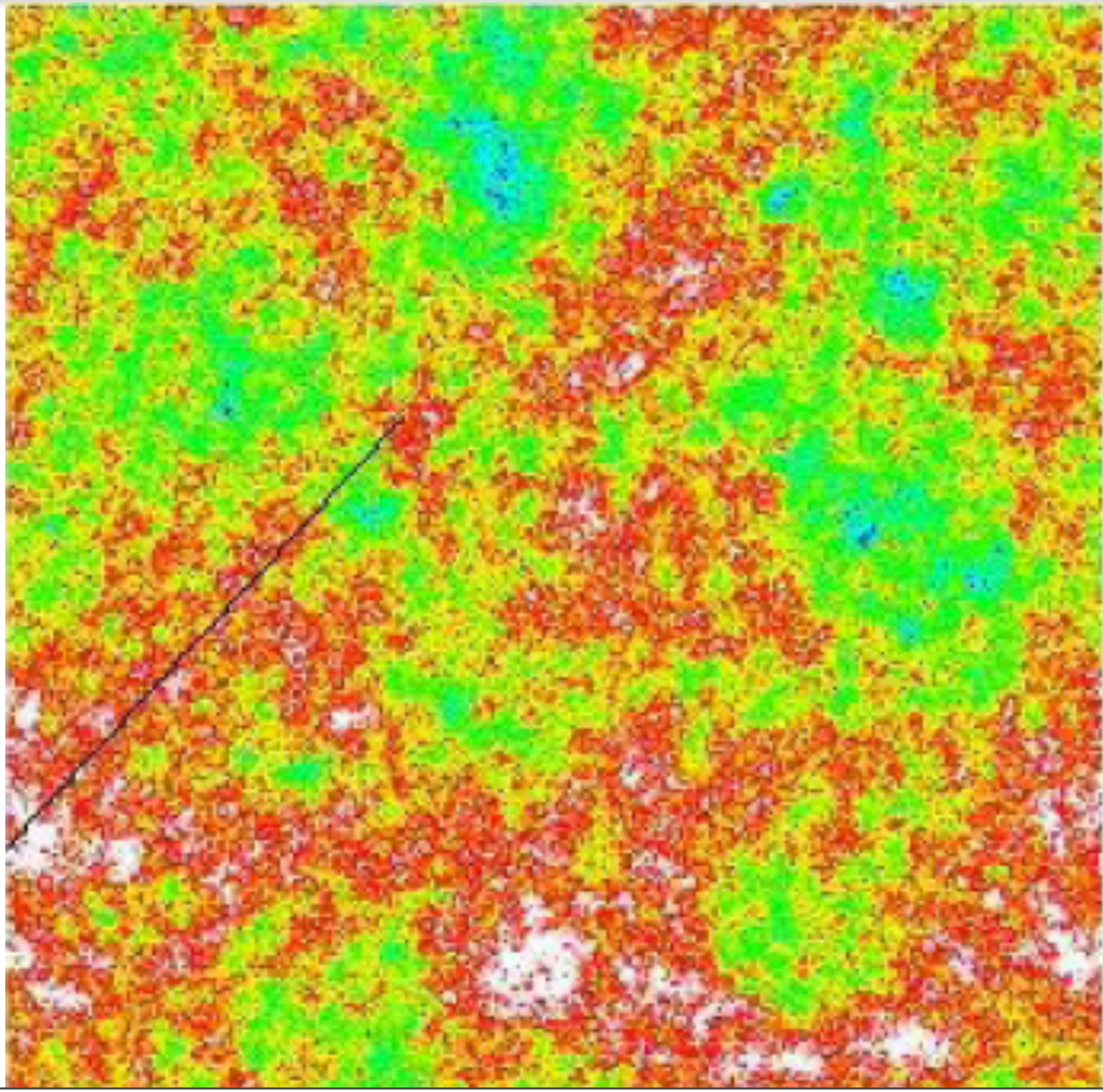
SF+

SN E+

winds

+CRs

512^3



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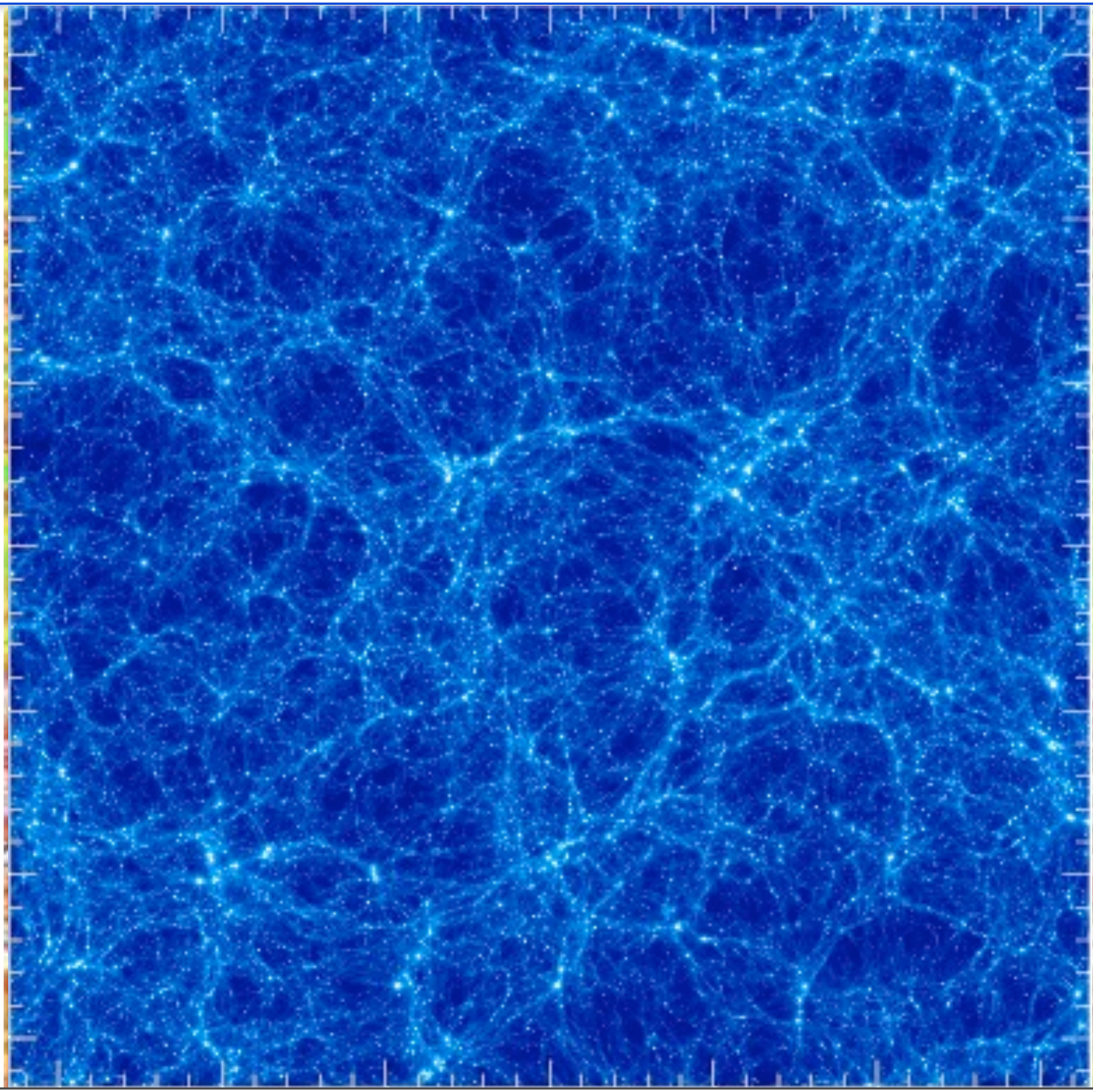

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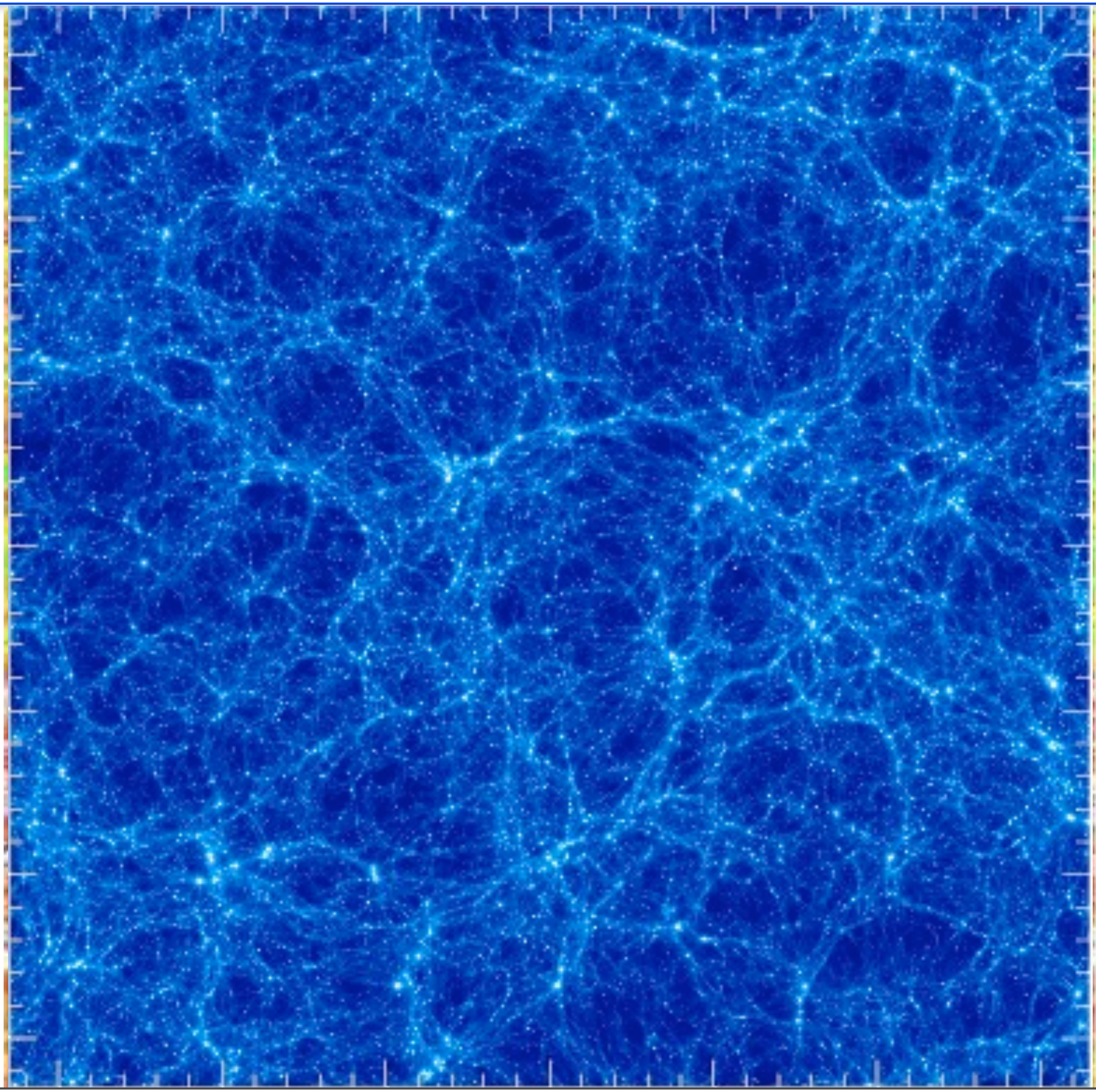


all this can

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential

aetherial!

CBI pol to Apr'05 @Chile

CBI2

QUaD @SP

Quiet1 @Chile

Quiet2 1000 HEMTs

Boom03@LDB

Bicep @SP

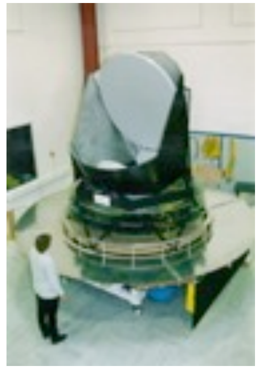
Bicep2

Keck/Spud

WMAP @L2 to 2010

Planck09.4

(52 bolometers)
+ HEMTs @L2
9 frequencies



EBEX @LDB

Spider 2312 bolos @LDB

DASI @SP

CAPMAP

Herschel

BLAST

CHIP

2004 2006 2008 LHC 2011 Bpol @L2

2005 2007 2009

Acbar to Jan'06, 08f @SP

SPT
1000 bolos
@SPole

BLASTpol

Clover @Chile

SZA
@Cal

ACT
3000 bolos
3 freqs @Chile

Polarbear
300 bolos
@Cal/Chile

SPTpol

ACTpol

AMI

GBT

APEX
~400 bolos
@Chile

SCUBA2

12000 bolos
JCMT @Hawaii

ALMA
@Chile

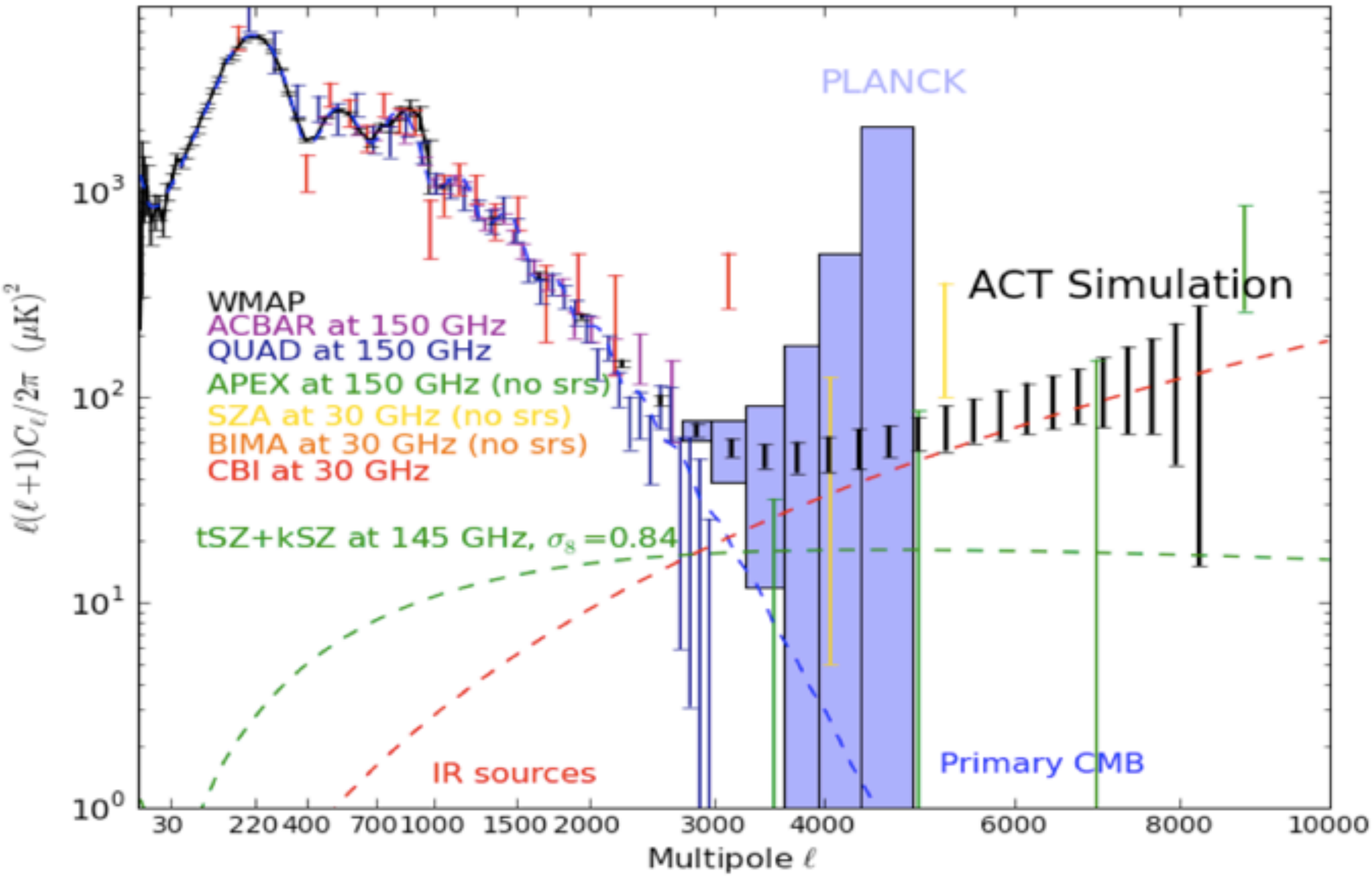
LMT@Mexico

V. Acquaviva [1,2]
P. Ade [3]
P. Aguirre [4]
M. Amiri [5]
J. Appel [6]
E. Battistelli [7,5]
J. R. Bond [8]
B. Brown [9]
B. Burger [5]
J. Chervenak [10]
S. Das [6,1]
M. Devlin [2]
S. Dicker [2]
W. B. Doriese [11]
J. Dunkley [12,6,1]
R. Dunner [4]
T. Essinger-Hileman [6]
R.P. Fisher [6]
J.W. Fowler [6]
A. Hajian [6]
M. Halpern [5]
M. Hasselfield [5]
C. Hernandez-Monteagudo [13,2]
G. Hilton [11]
M. Hilton [14,15]
A. D. Hincks [6]
R. Hlozek [12]
K. Huffenberger [16,6]
D. Hughes [17]
J. P. Hughes [18]
L. Infante [4]
K.D. Irwin [11]
N. Jarosik [6]
R. Jimenez [19]
J.B. Juin [4]
M. Kaul [2]
J. Klein [2]
A. Kosowsky [9]
J.M. Lau [20,6]
M. Limon [21]
Y.T. Lin [22,1,4]
R.H. Lupton [1]
T.A. Marriage [1,6]
D. Marsden [2]
K. Martocci [23,6]
P. Mauskopf [3]
F. Menanteau [18]
K. Moodley [14]
H. Moseley [10]
B. Netterfield [24]
M.D. Niemack [11,6]
M.R. Nolta [8]
L.A. Page (PI) [6]
L. Parker [6]
B. Partridge [25]
H. Quintana [4]
B. Reid [19,1]
N. Sehgal [20,18]
J. Sievers [8]
D. Spergel [1]
S.T. Staggs [6]
O. Stryzak [6]
D. Swetz [2]
E. Switzer [23,6]
R. Thornton [26,2]
H. Trac [27,1]
C. Tucker [3]
L. Verde [19]
R. Warne [14]
G. Wilson [28]
E. Wollack [10]
Y. Zhao [6]

the ACTers

[1] Princeton University Astrophysics (USA)
[2] University of Pennsylvania (USA)
[3] Cardiff University (UK)
[4] Pontifica Universidad Catolica de Chile (Chile)
[5] University of British Columbia (Canada)
[6] Princeton University Physics (USA)
[7] University of Rome "La Sapienza" (Italy)
[8] CITA, University of Toronto (Canada)
[9] University of Pittsburgh (USA)
[10] NASA Goddard Space Flight Center (USA)
[11] NIST Boulder (USA)
[12] Oxford University (UK)
[13] Max Planck Institut fur Astrophysik (Germany)
[14] University of KwaZulu-Natal (South Africa)
[15] South African Astronomical Observatory
[16] University of Miami (USA)
[17] INAOE (Mexico)
[18] Rutgers (USA)
[19] ICCUB (Spain)
[20] KIPAC, Stanford (USA)
[21] Columbia University (USA)
[22] IPMU (Japan)
[23] KICP, Chicago (USA)
[24] University of Toronto (Canada)
[25] Haverford College (USA)
[26] West Chester University of Pennsylvania (USA)
[27] Harvard-Smithsonian CfA (USA)
[28] University of Massachusetts, Amherst (USA)

Power Spectrum



fluctuations in the **early universe "vacuum" grow** to ***all* structure**

400 Mpc

ΛCDM

WMAP5

gas pressure

Gadget-3

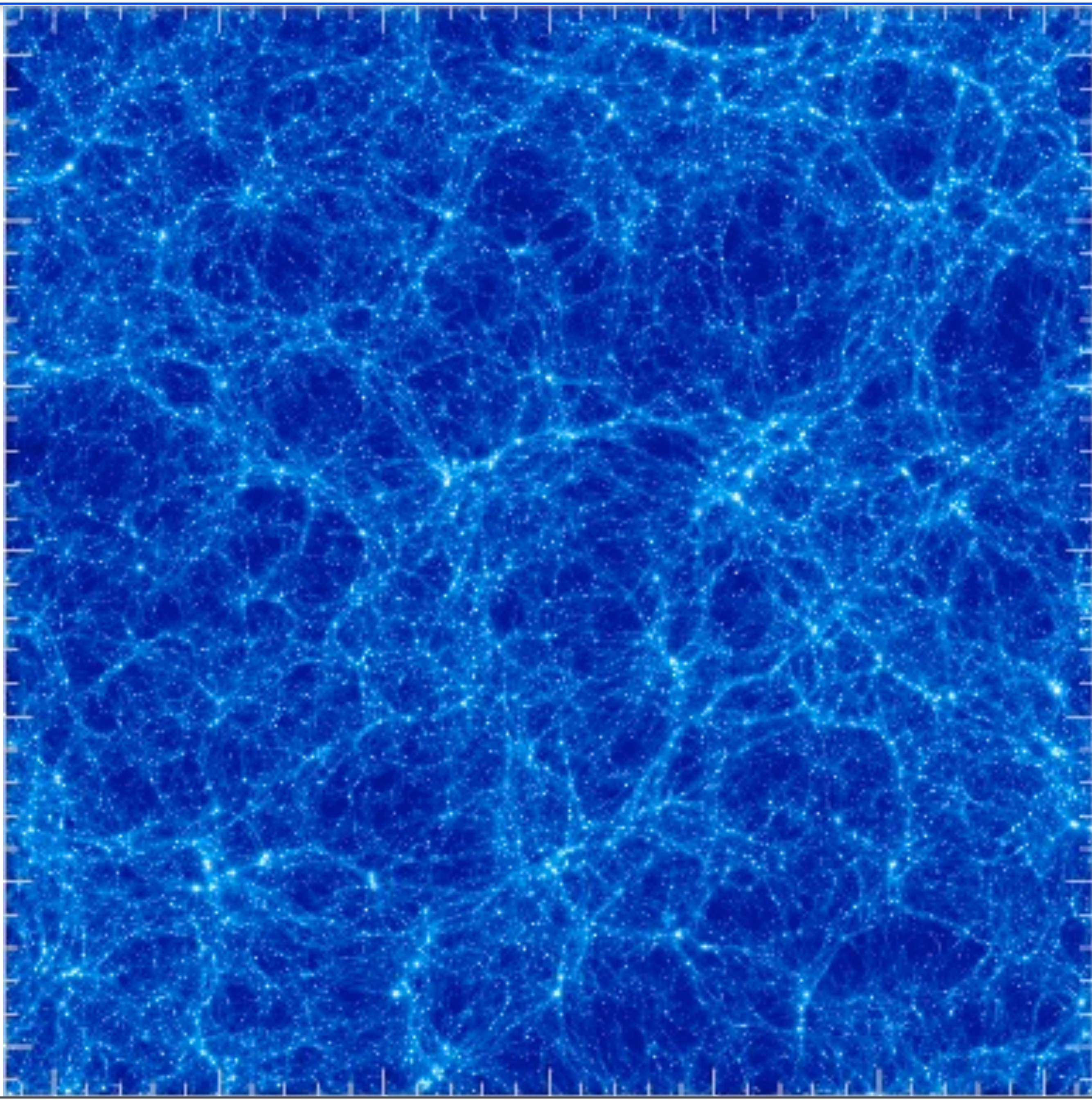
SF+

SN E+

winds

+CRs

512^3



all this can

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential

aetherial!

Saturday, November 21, 2009

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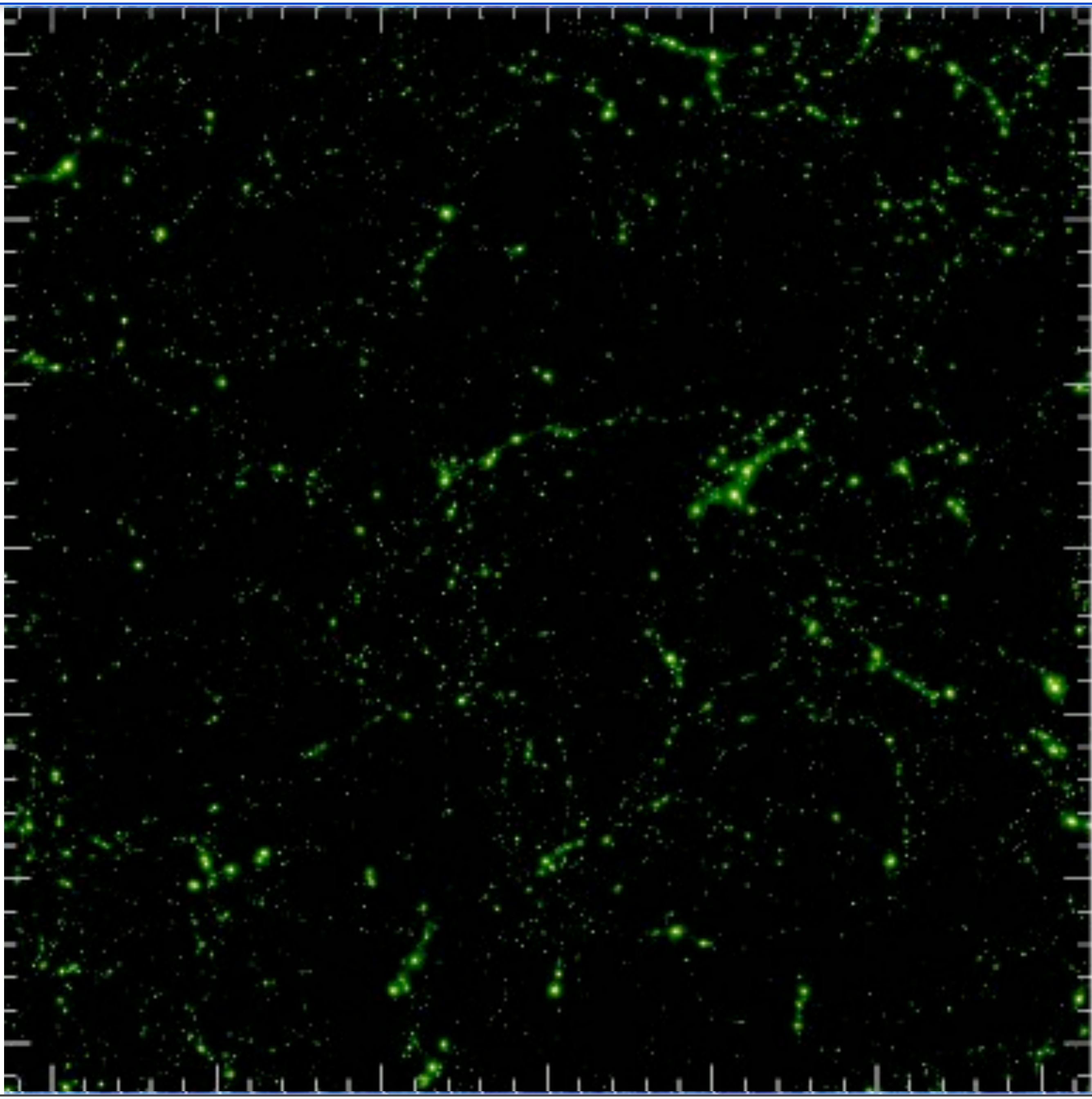

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fluctuations in the **early universe "vacuum" grow** to *all* **structure**

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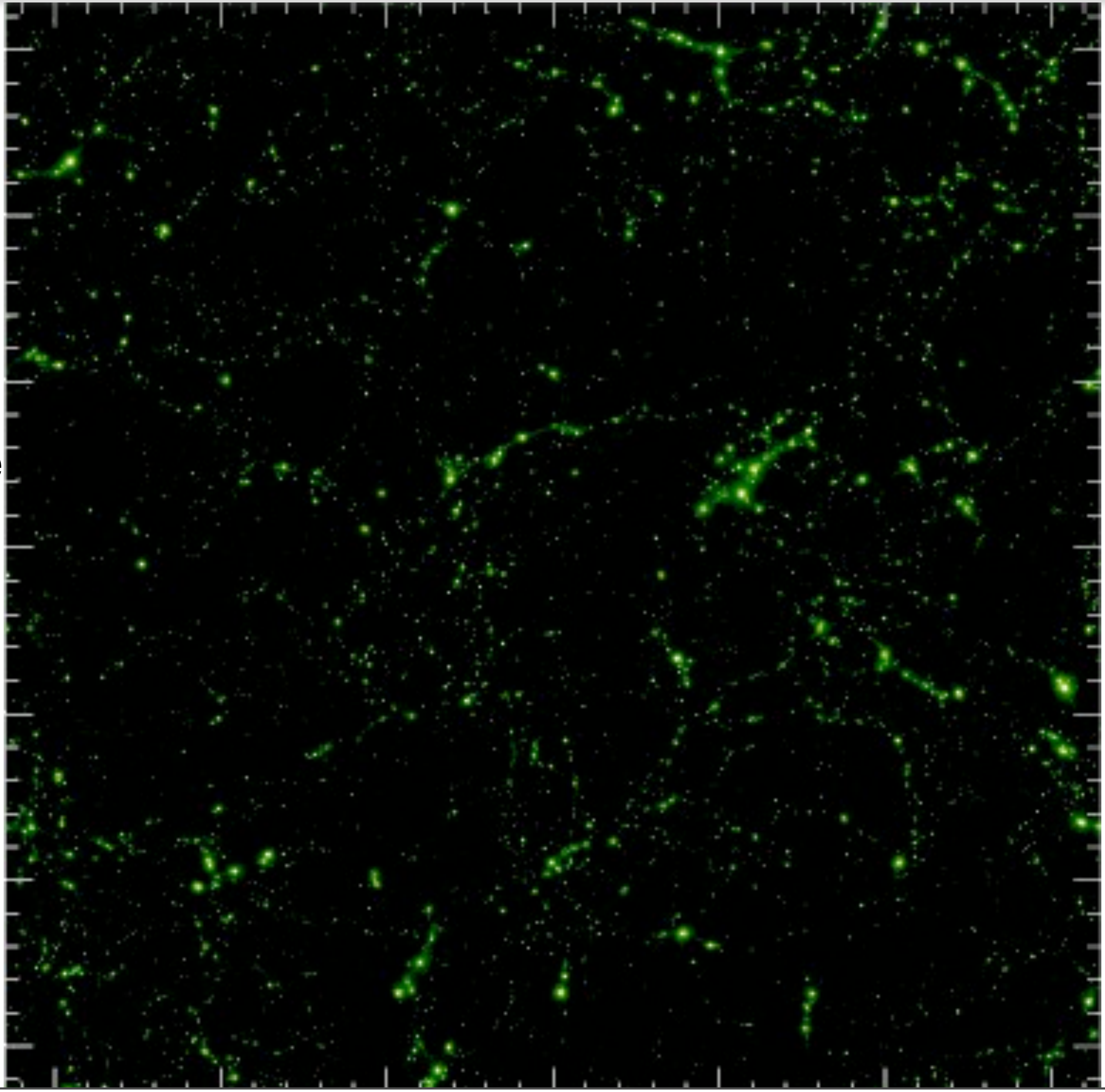
WMAP5

gas pressure

Gadget-3 formation shocks only aka adiabatic

512^3



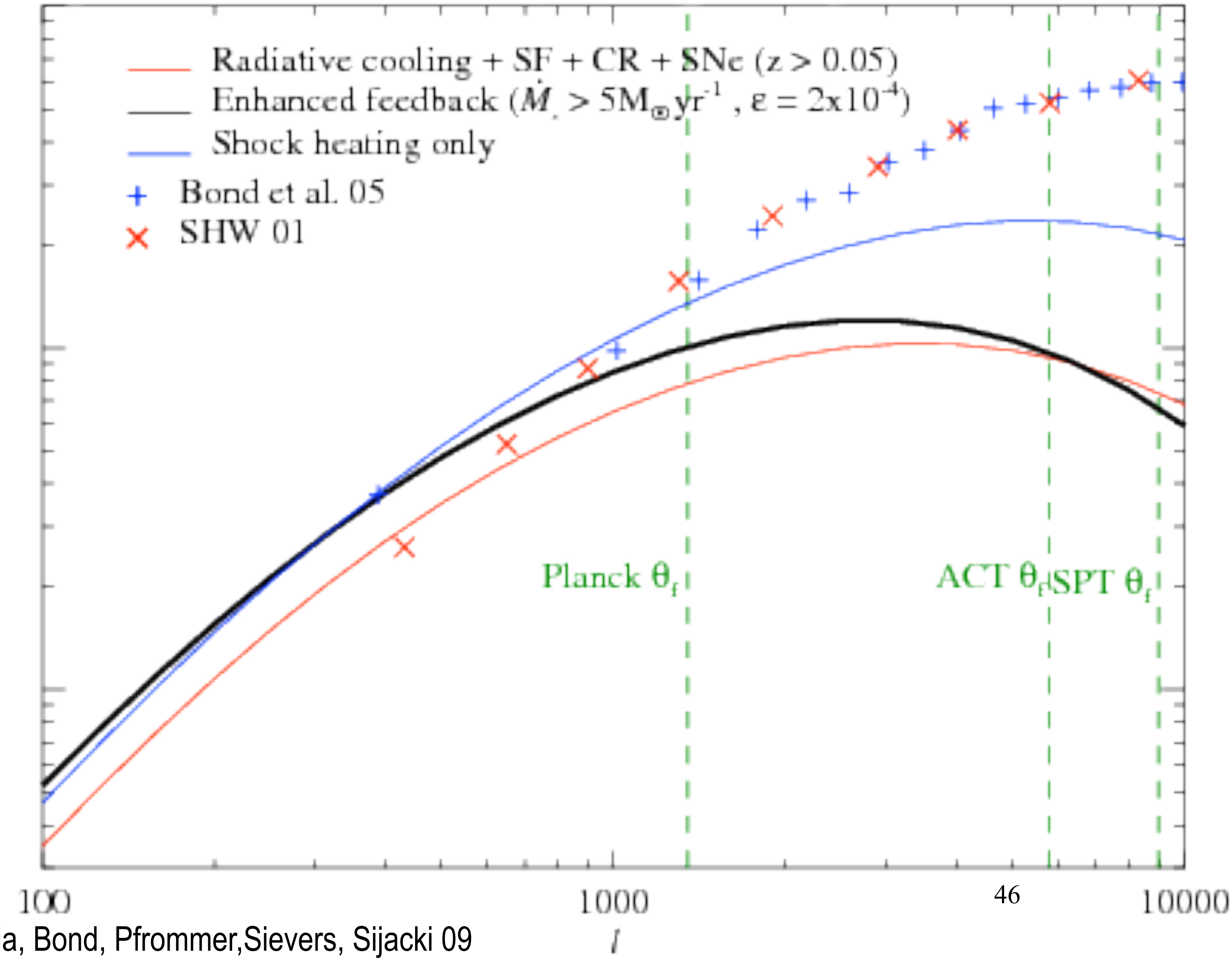
all this can

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential

aetherial!

C_L^{SZ} systematic uncertainties, via large computer simulations

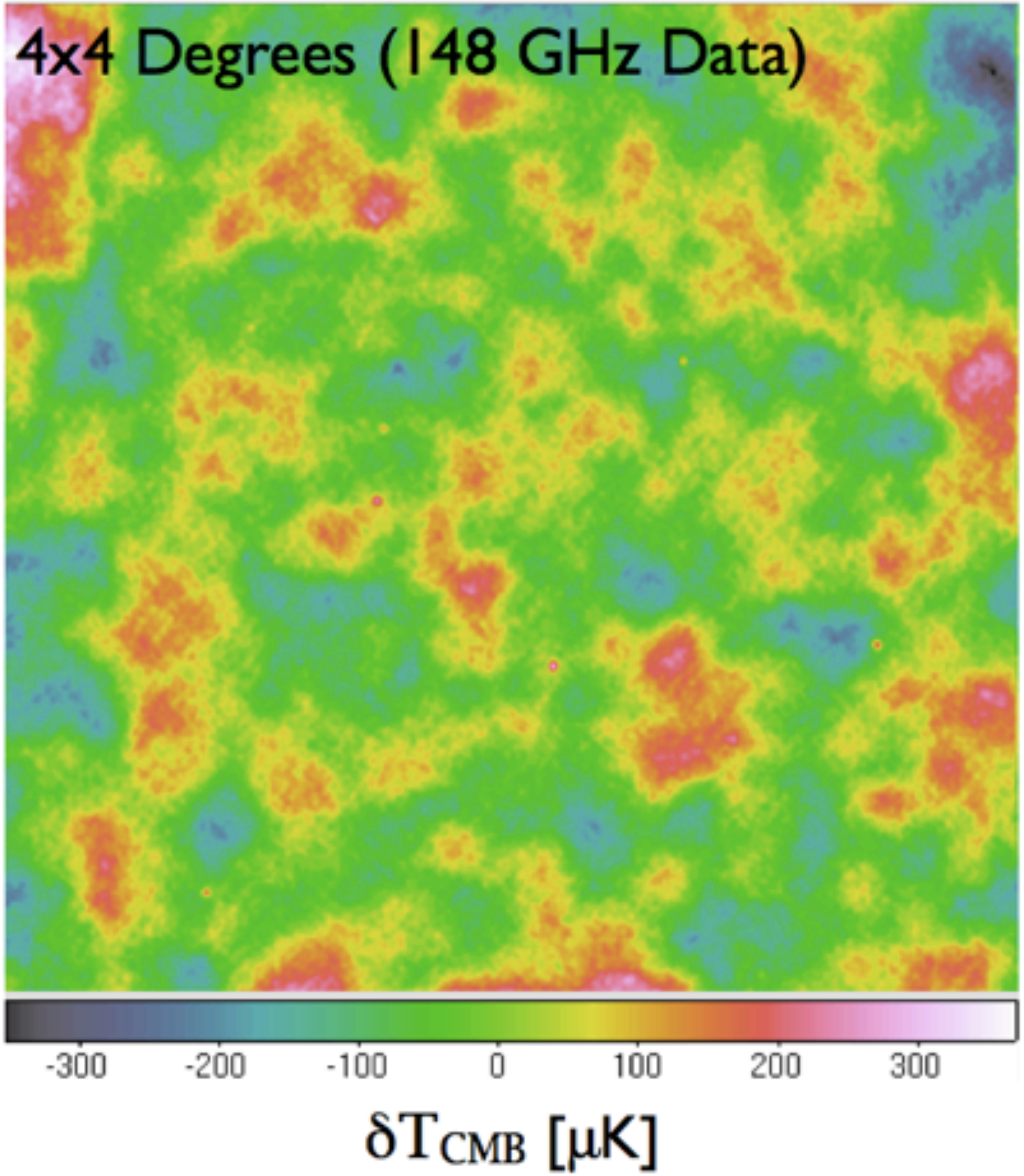


Battaglia, Bond, Pfrommer,Sievers, Sijacki 09

Mapping

Jon Sievers etal ACTers

- Input data: 5 TB
- ML map solved iteratively
- ~1000 iterations
- 4000 CPU Cores for 1.5 days
- ~20 CPU years for one map
- Unbiased estimate of all modes from *ell* ~ 100 - 10000



ACT Maps are made at U. Toronto's Scinet cluster, ranked in top 20 fastest.

Mapping

Jon Sievers etal ACTers

Unbiased estimate of all modes from *ell* ~ 100 - 10000

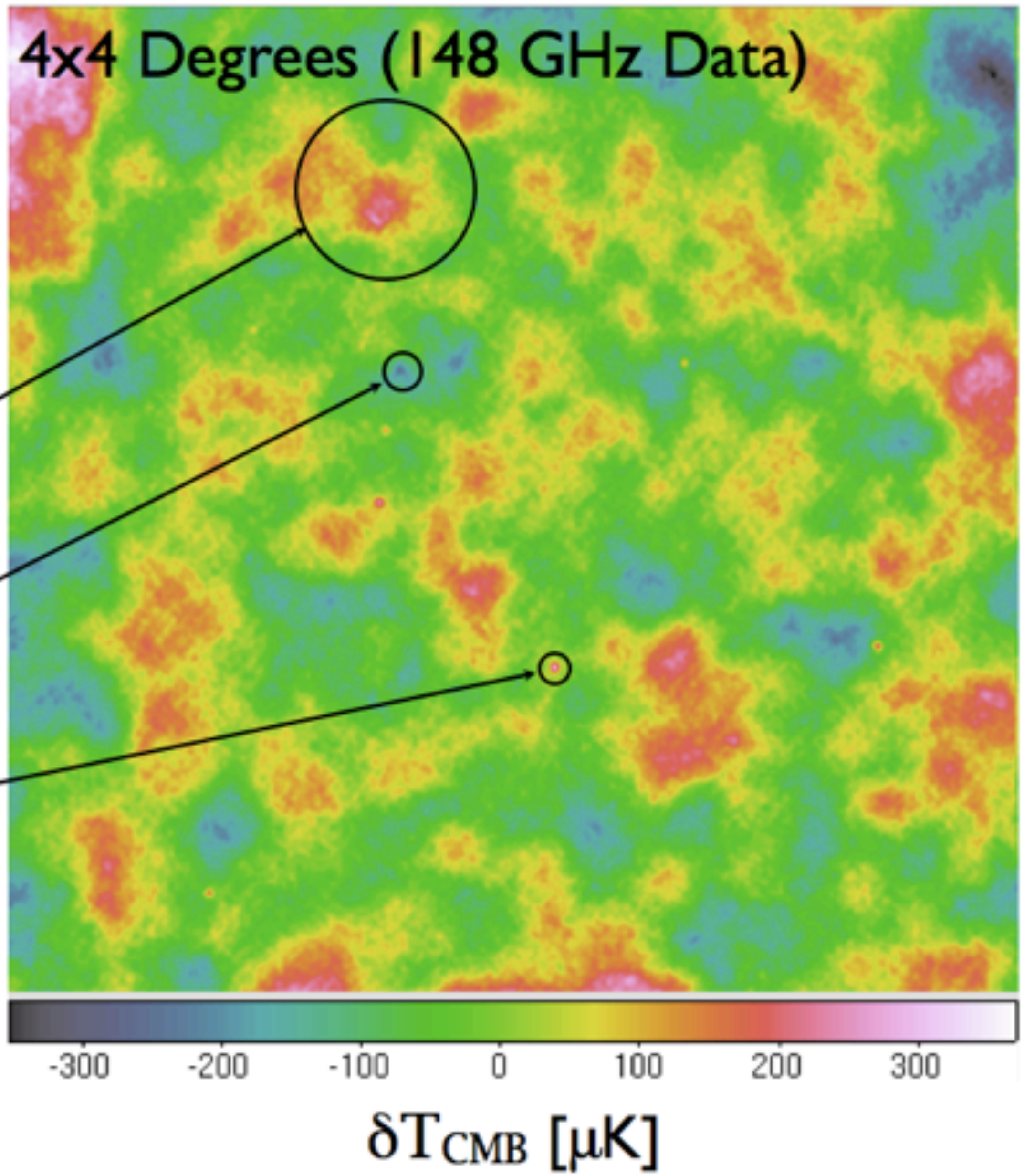
Atmosphere: 2 deg
(Filtered Here)

CMB: 1 deg

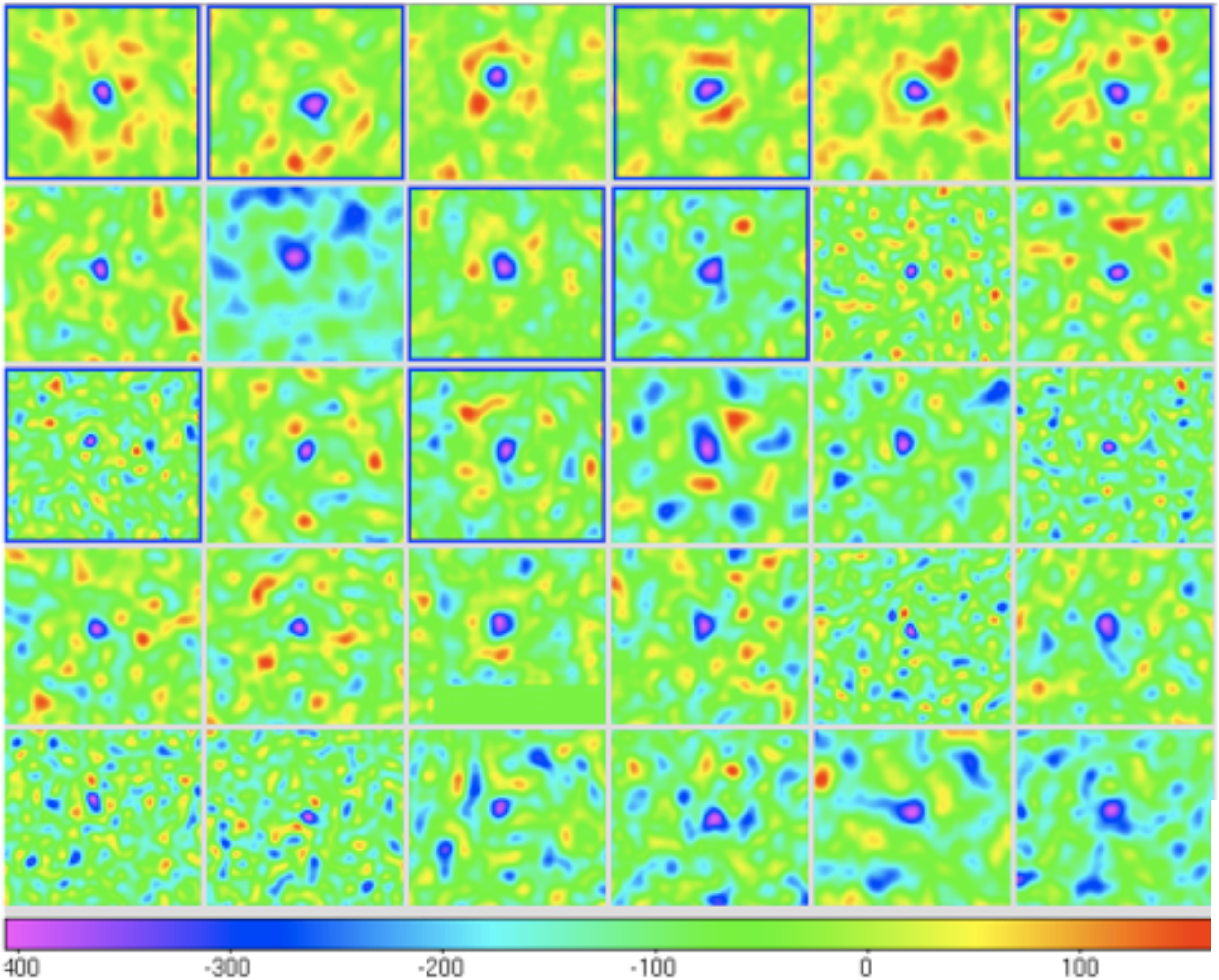
Clusters*: (>1.4')-4'

Sources*: 1.4'

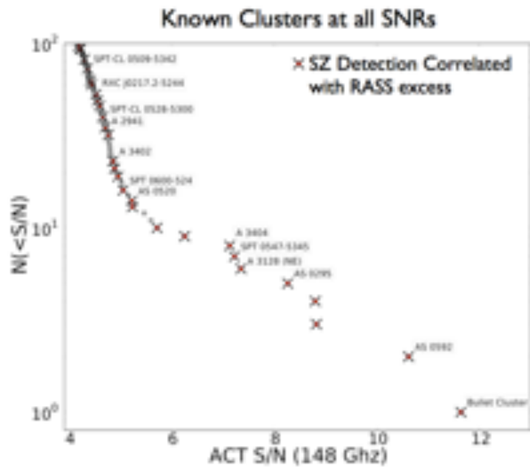
* Minimum size set by beam



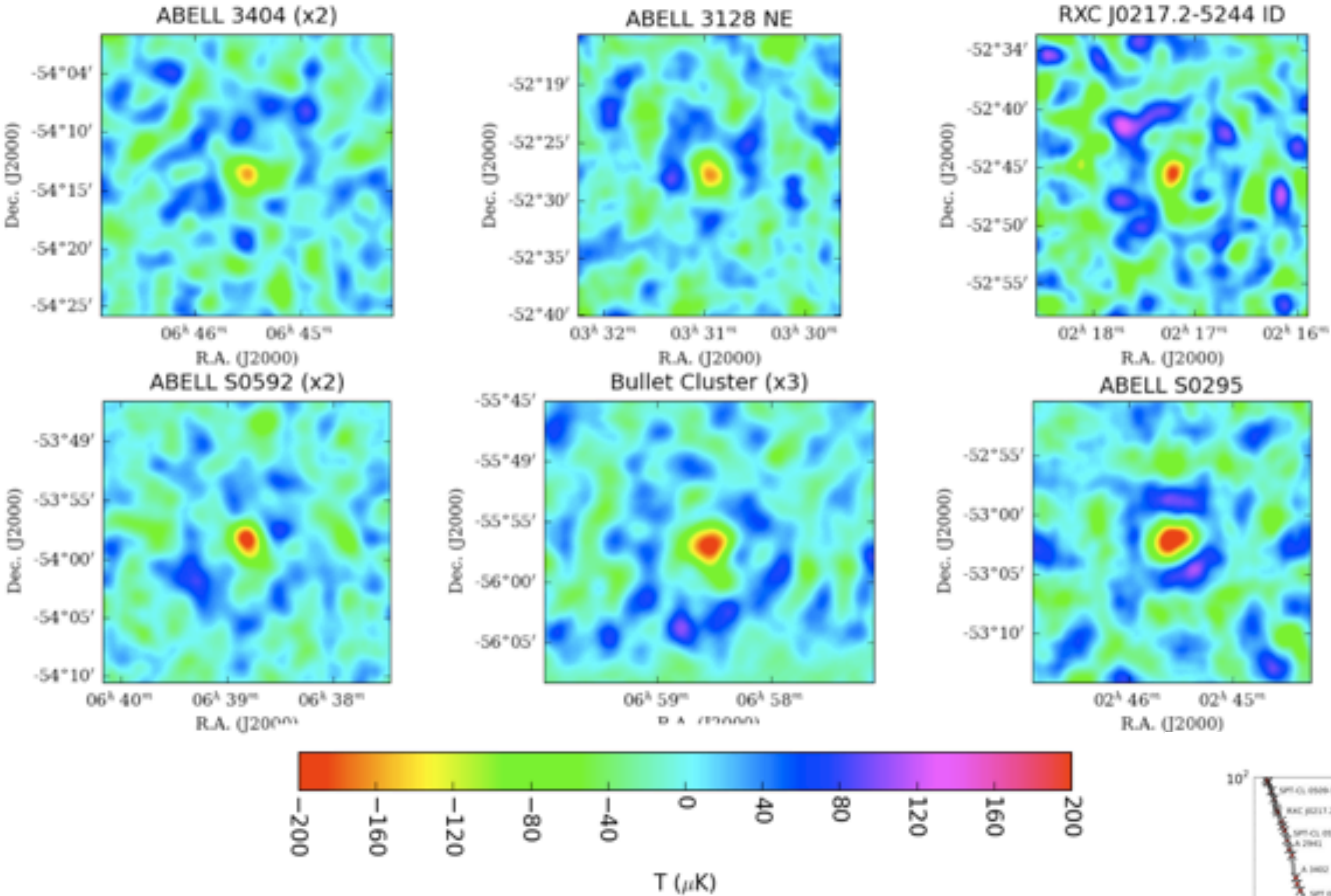
148 GHz SZ Decrements   : Previously Known

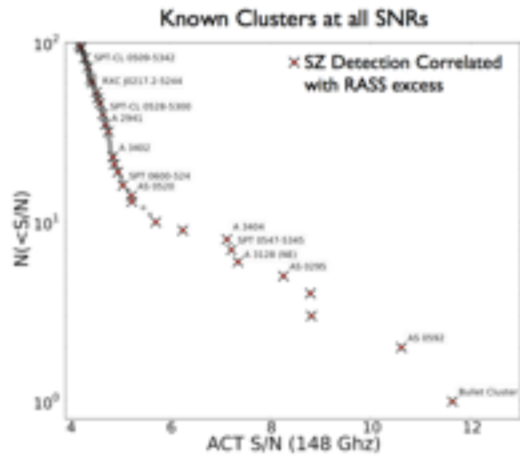


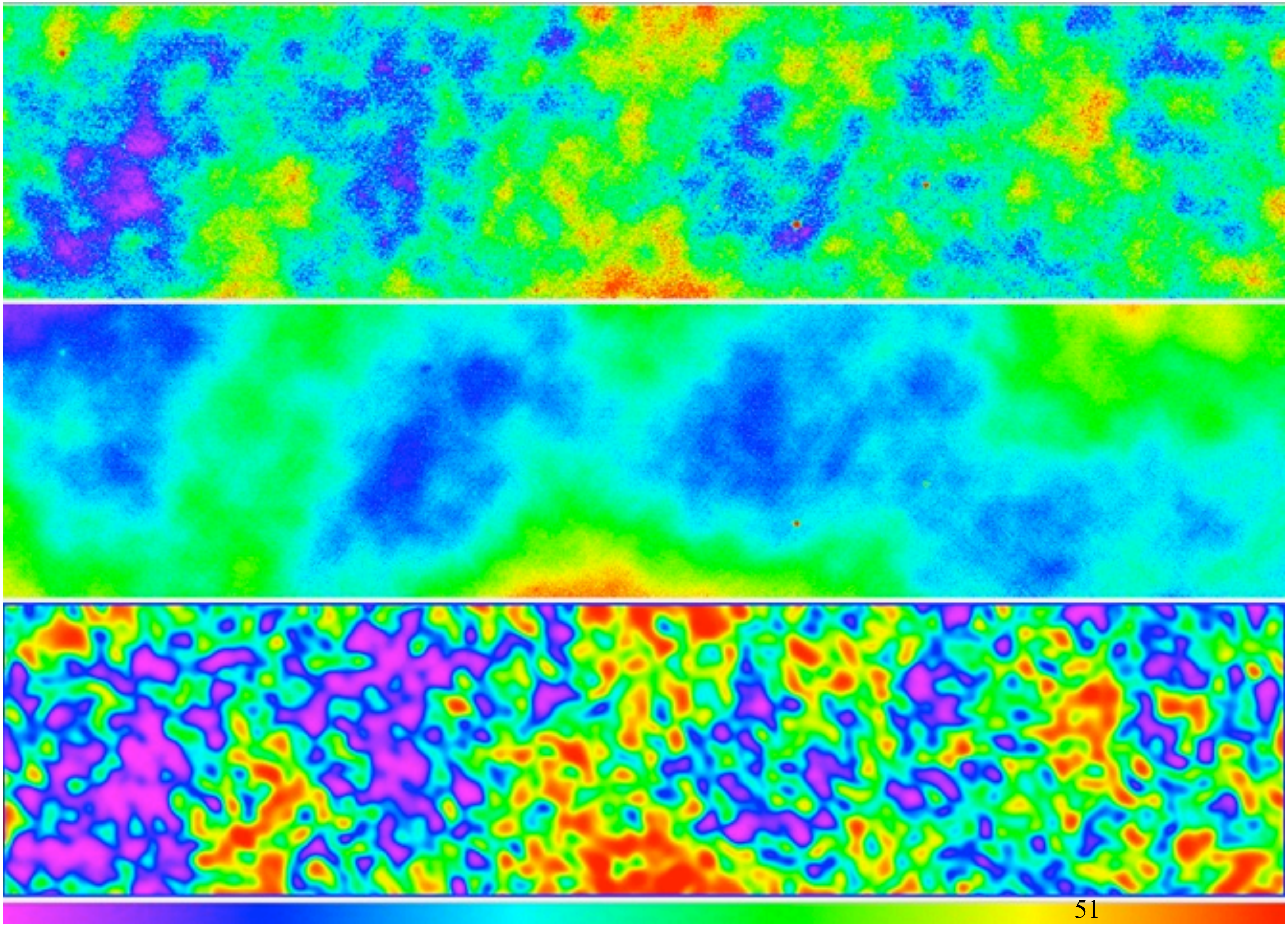
δT_{CMB} [μK] (Only for top left candidate)

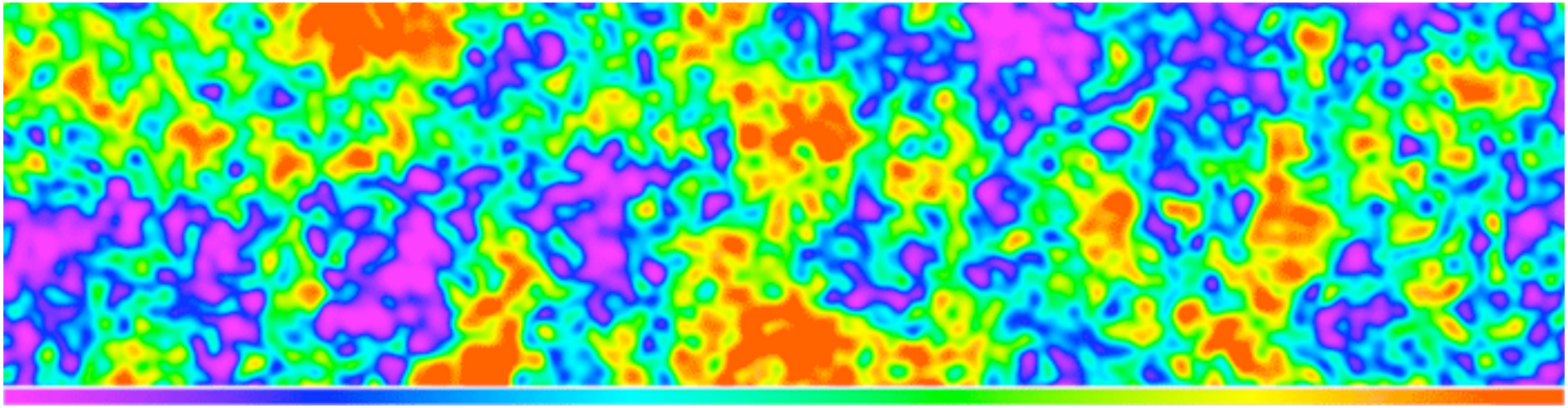


Some Known Clusters

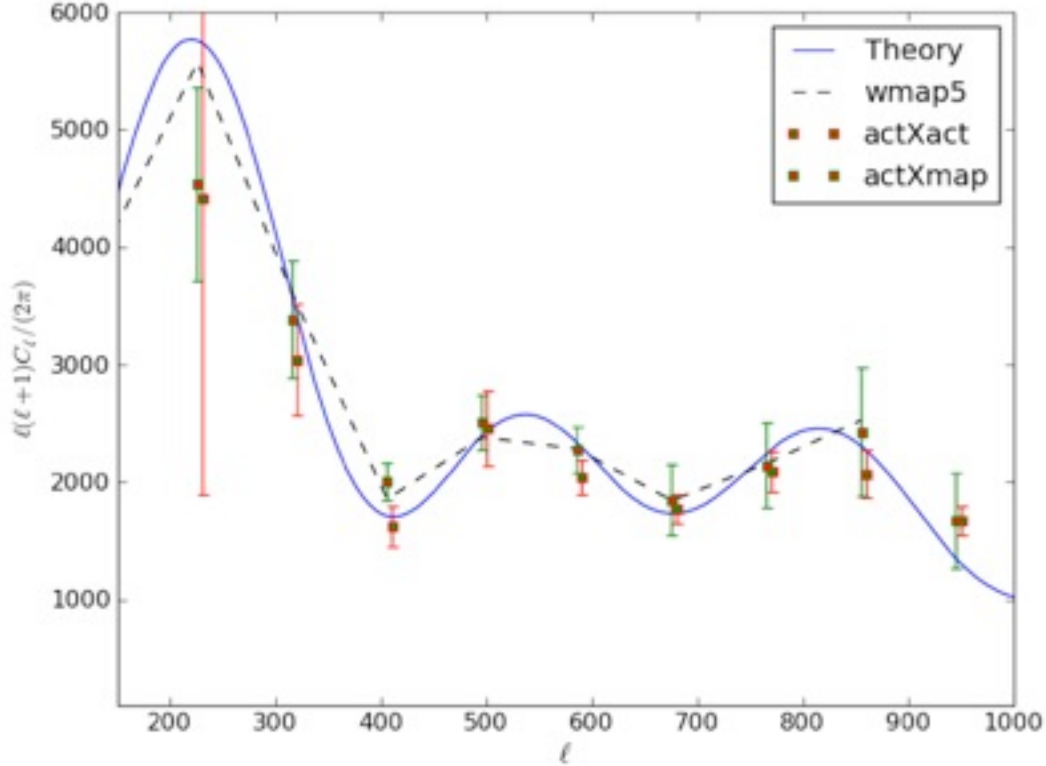


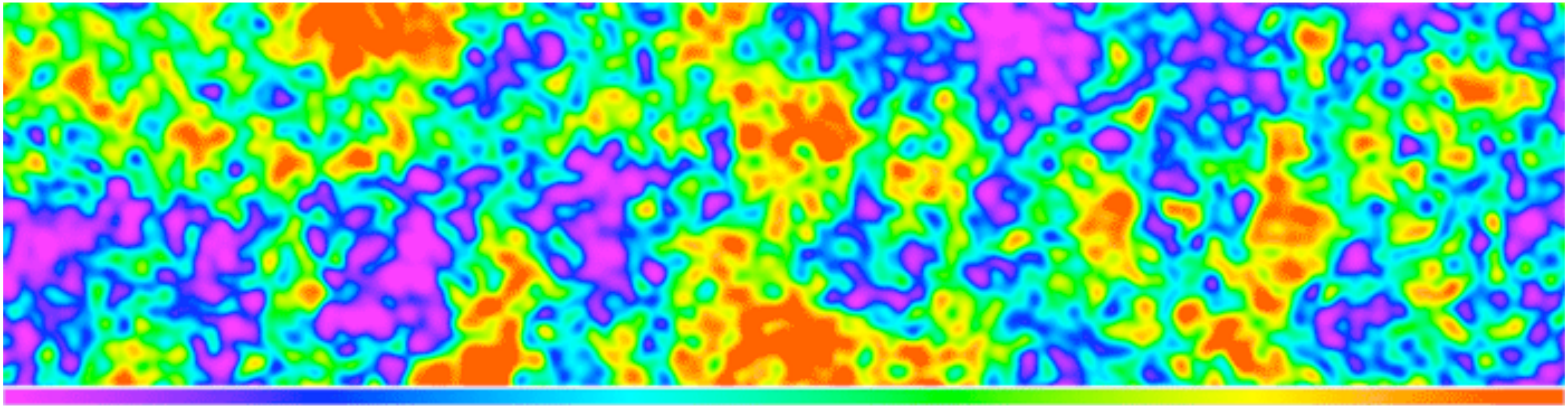




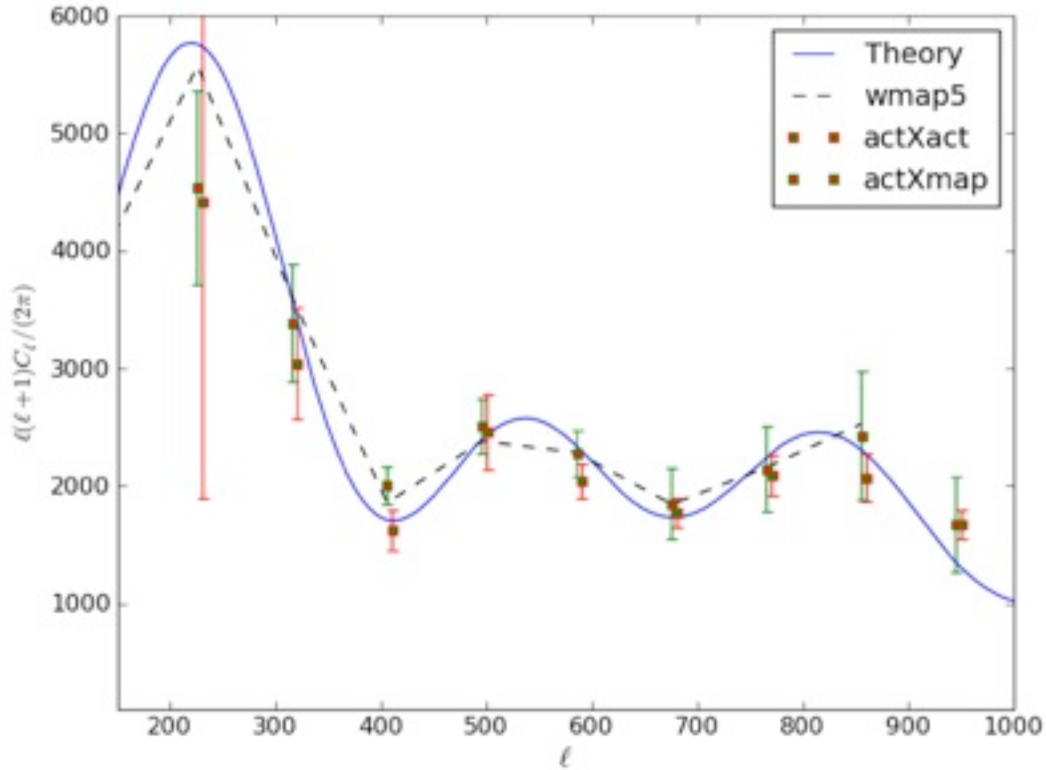


Amir Hajian etal ACTers





Amir Hajian etal ACTers



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

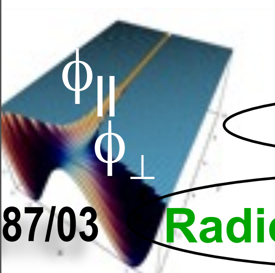
1980

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 pNGB inflation

Hybrid inflation

KLS preheating

SUSY F-term inflation

SUSY D-term inflation

Assisted inflation

Brane inflation

2000

SUSY P-term inflation

Super-natural Inflation

K-flation

2003 KKLT

N-flation

ekpyrotic/cyclic

D3,D7 brane inflation

DBI inflation

moving brane separations

Racetrack inflation

Tachyon inflation

Warped Brane inflation

moduli fields

monodromy

Roulette inflation **Kahler moduli/axion**

fibre inflation

Standard Parameters of Cosmic Structure Formation

$\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ Ω_k τ_c $\ln A_s$ n_s $r = A_t/A_s$ $dn_s/d\ln k$ n_t

$1+w_0, w_a$ $\theta \sim \ell_s^{-1}$ $n_e(a)$ $\sim \ln \sigma_8^2$

new parameters: **trajectory probabilities for early-inflatons & late-inflatons**

(partially) blind cf. informed "theory" priors

primordial non-Gaussianity

$\Phi(x) = \Phi_G(x) + \mathbf{f_{NL}} (\Phi_G^2(x) - \langle\Phi_G^2\rangle)$

local smooth

DBI inflation: non-quadratic kinetic energy

cosmic/fundamental strings/defects

from end-of-inflation & preheating

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

resonant preheating

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

& $\ln P_t(\ln k)$

$\varepsilon_\phi \times 2/3 = 1 + w(a)$

$= - d\ln \rho_\phi / d\ln \mathbf{a}^3$

+ subdominant isocurvature, cosmic string,

& fgnds, tSZ, kSZ, ...

INFLATION THEN

PROBES NOW

“standard inflation space”: n_s $dn_s/d\ln k$ r @k-pivots

$n_s(k_p)$=.962 +-.013 (+-.005 Planck1) .959 +- .011 all data

$r=P_t/P_s(k_p')$ < 0.40$_{cmb}$ 95% CL (+-.03 P1, +- .01 Spider+P2.5)

$dn_s/d\ln k$ (k_p) =-.016 +- .019 (+-.005 Planck1)

(partially) blind trajectories e.g., $n_s(k)$ and $r(k_p)$, *are better*

local quadratic non-G constraint: -9< f_{NL}<111 ⇒ -4< f_{NL}<80 WMAP5 (± 5-10 Planck1yr)

CBI10: add a cosmic string template ⇒ n_s<1 @2σ &string tension limit $G\mu < 2.8 \times 10^{-7}$

INFLATION THEN

"standard inflation space": $\mathbf{n_s}$ $\mathbf{dn_s/dlnk}$ $\mathbf{r}$ **@k-pivots**

WHAT IS PREDICTED?

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

large field inflation (field moves > Planck mass)

or highly variable braking r tiny

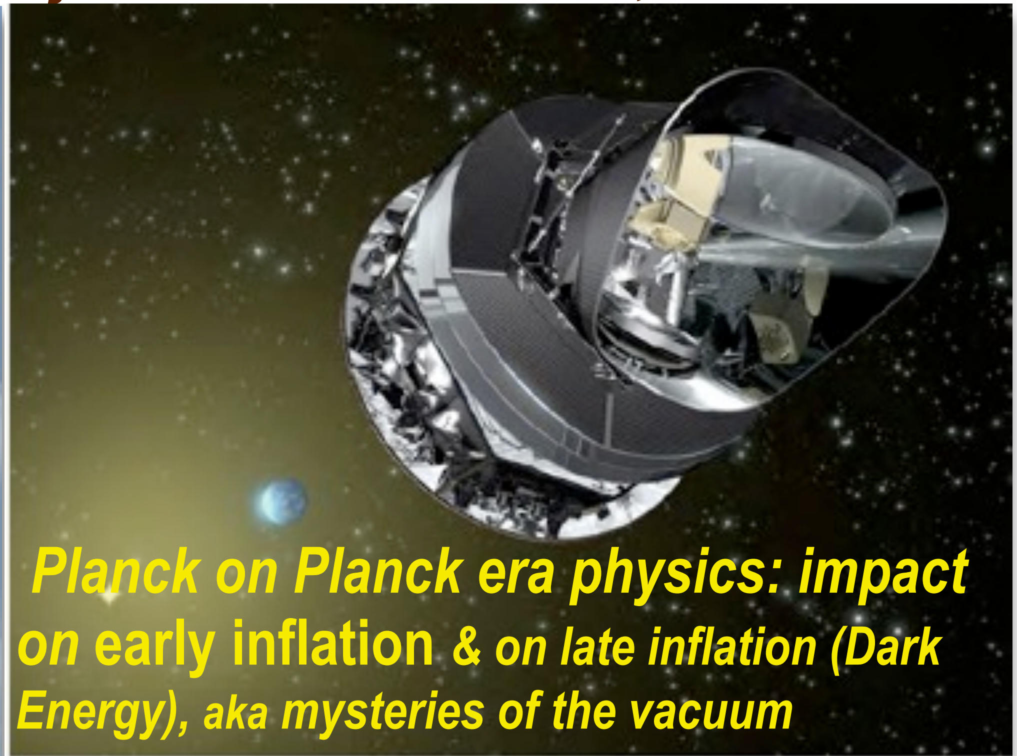
(stringy cosmology) $r<10^{-10}$

small field inflation (field moves < Planck mass)

monodromy & fibre inflation give larger r

Entering the Planck Era > May 14, 2009

status A-OK, first all sky survey finishes Feb 2010; 5 in all



$n_s(k)$, GW: Tensor(k)

subdominant isocurvature, cosmic strings, textures,

nonGaussian **F_{NL} (x)**

ESA /NASA /CSA Toronto HFI QLA/KST, TA, ... *Barth & Dick, Marc-Antoine Miville-Deschenes,*

Carrie MacTavish, Brendan Crill, Olivier Dore, Carlo Contaldi, Mike Nolta, Peter Martin, Francine Marleau, UBC LFI

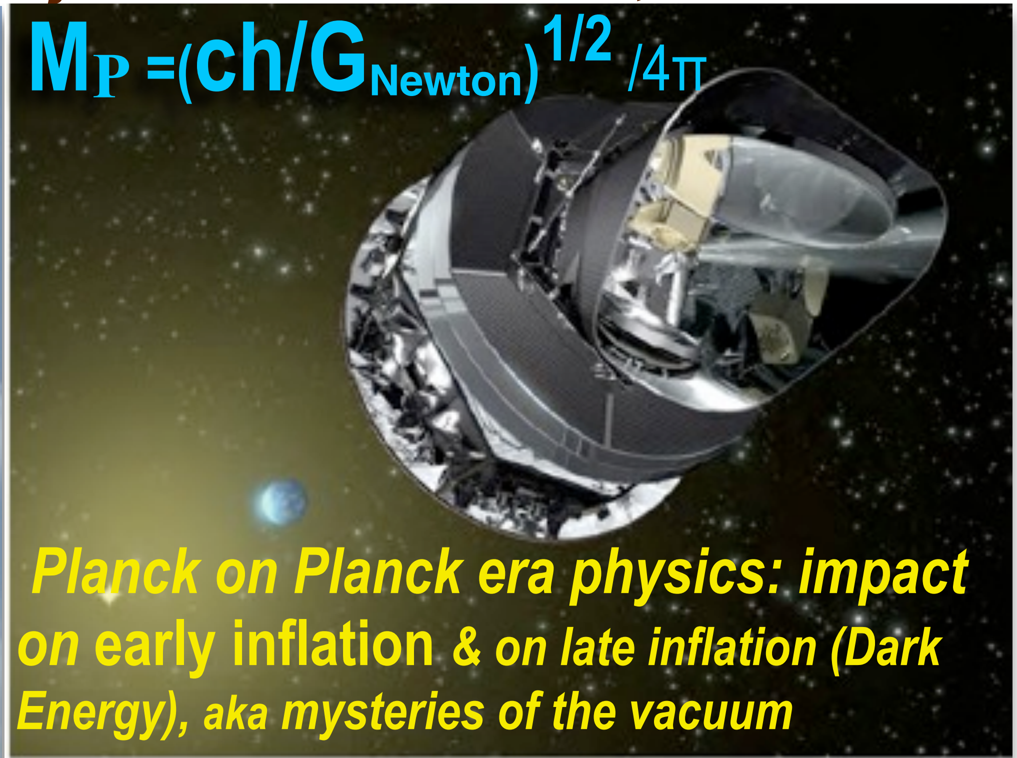
Entering the Planck Era > May 14, 2009

status A-OK, first all sky survey finishes Feb 2010; 5 in all

Launch May 14, 2009

FrenchGuiana, @L2 early July,

Survey Began Aug 09



$M_P = (ch/G_{Newton})^{1/2} / 4\pi$

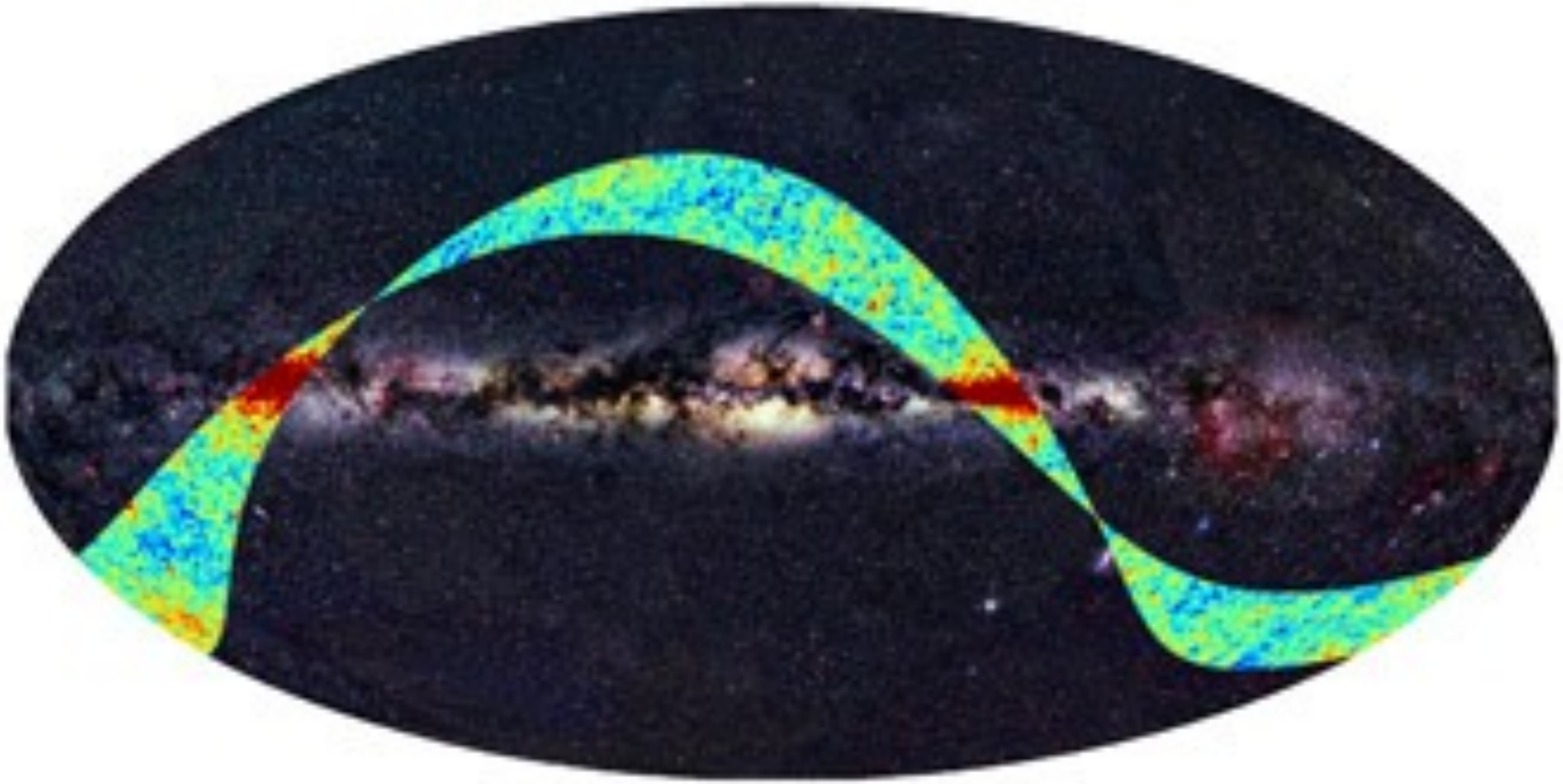
Planck on Planck era physics: impact on early inflation & on late inflation (Dark Energy), aka mysteries of the vacuum

$n_s(k)$, GW: Tensor(k)

subdominant isocurvature, cosmic strings, textures,

nonGaussian F_{NL} (x)

ESA /NASA /CSA Toronto HFI QLA/KST, TA, ... *Barth & Dick, Marc-Antoine Miville-Deschenes, Carrie MacTavish, Brendan Crill, Olivier Dore, Carlo Contaldi, Mike Nolta, Peter Martin, Francine Marleau,* UBC LFI



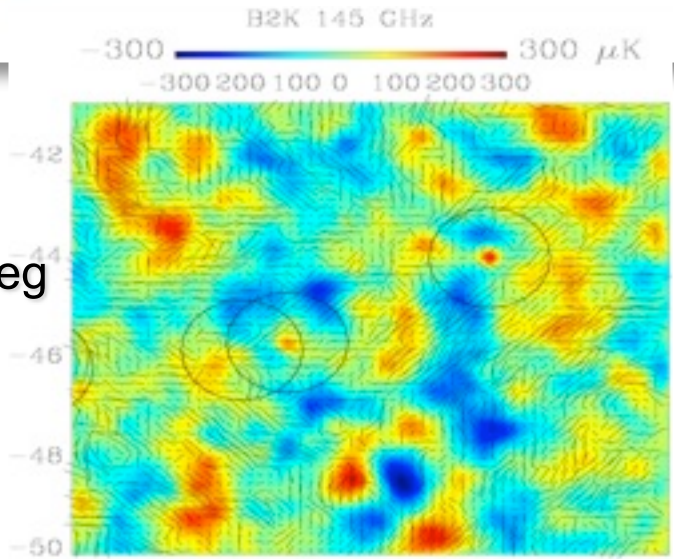
Planck “First Light” Survey Aug 2009

BoomPol deep

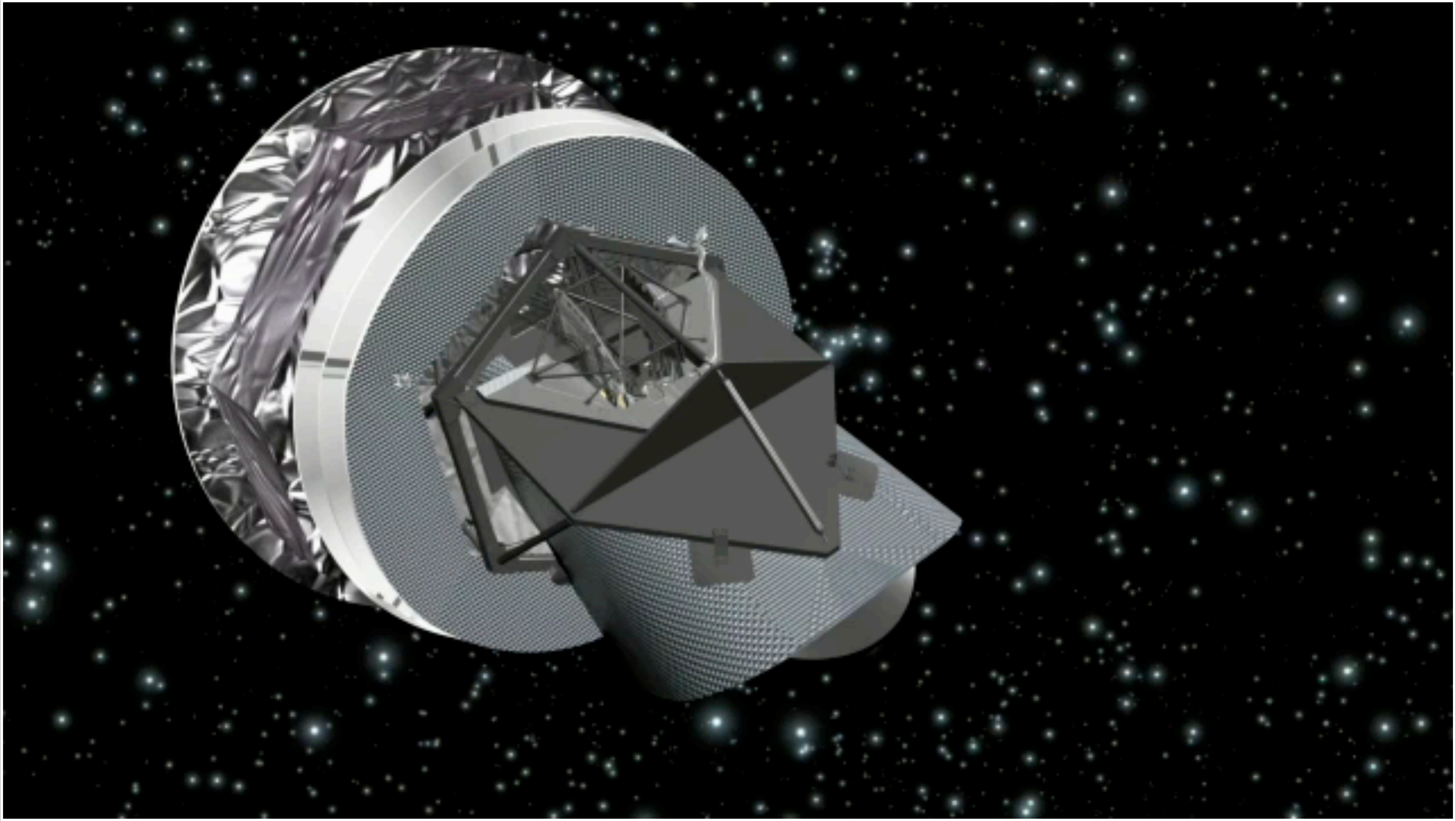
2003.1, Jul05, Nov09

125 hours, fsky=0.28% 115sq deg

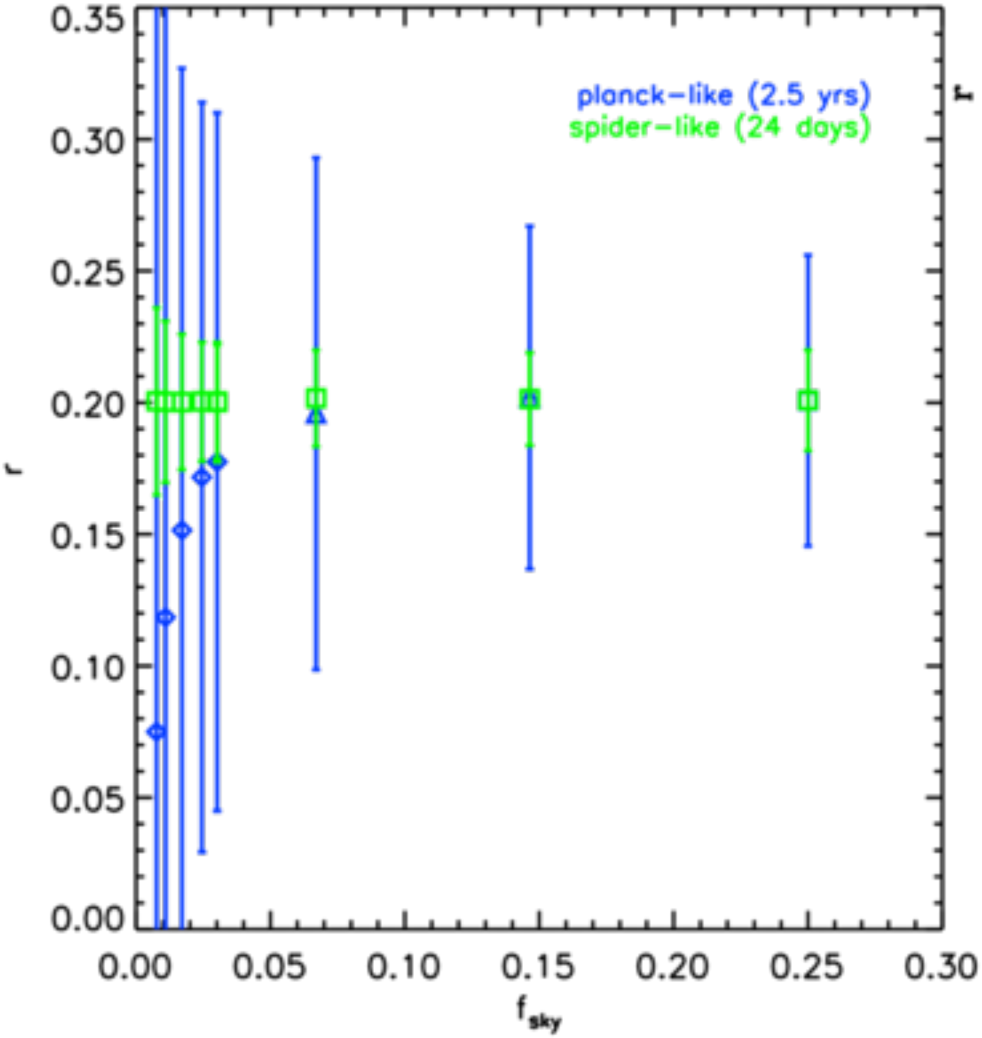
Planck is ~ as deep, but all sky, with similar bolometers (but more) and better resolution

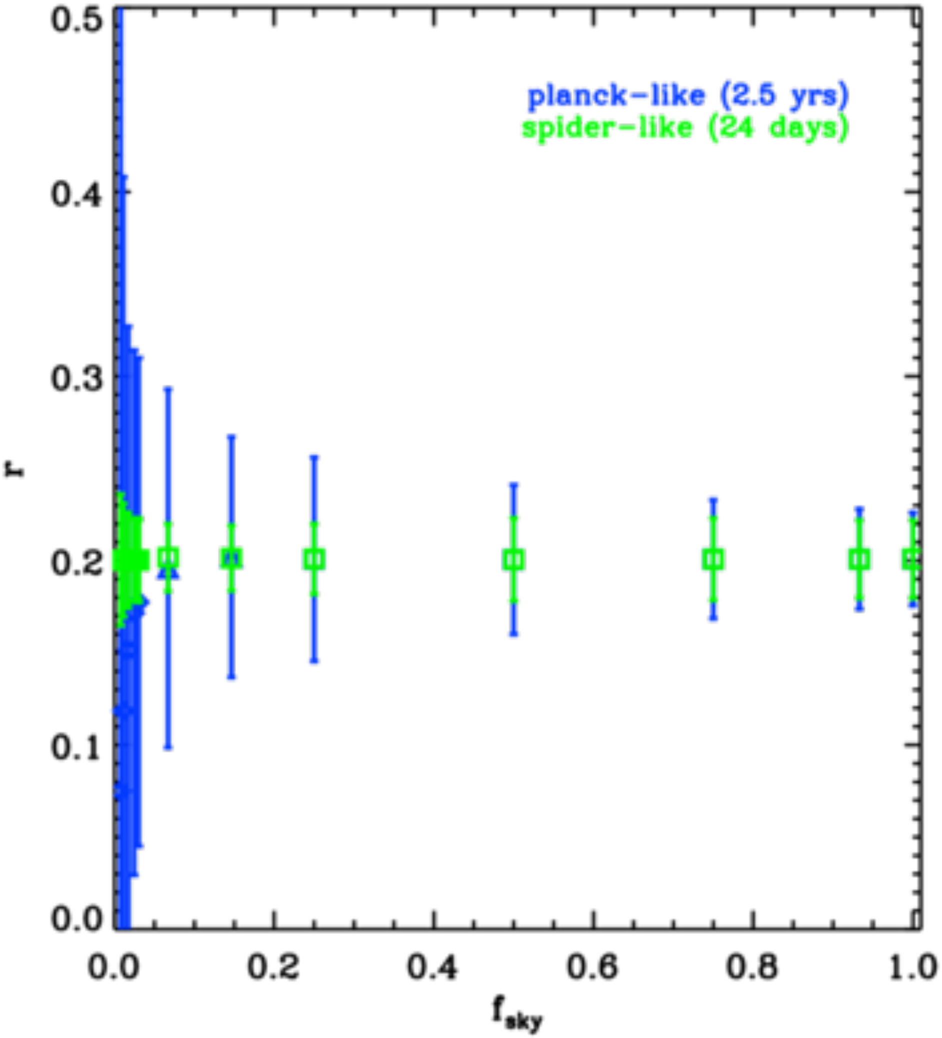


Planck 1st of 5 all Sky Surveys 09.7-10.1



how do errors in r vary with sky fraction? (disentangle E/B mixing by direct Likelihood in Q,U)





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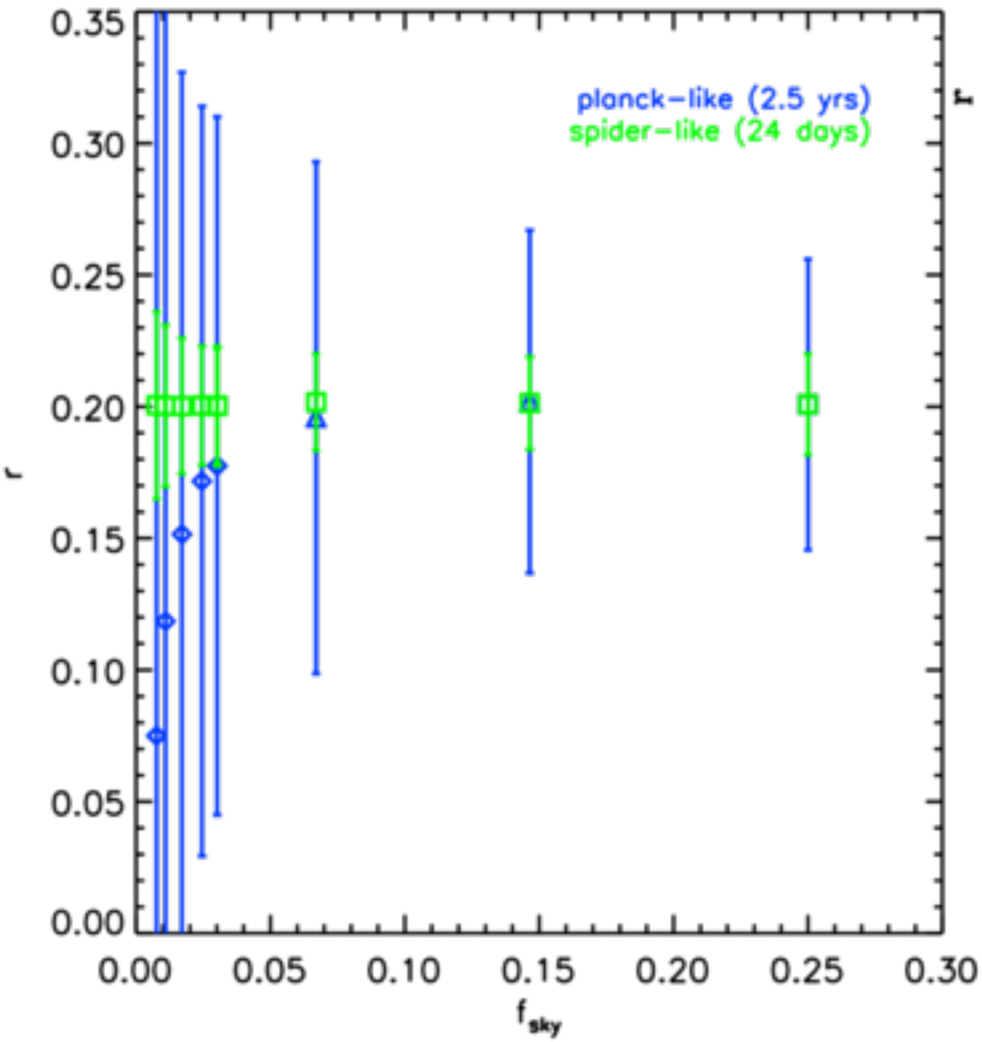

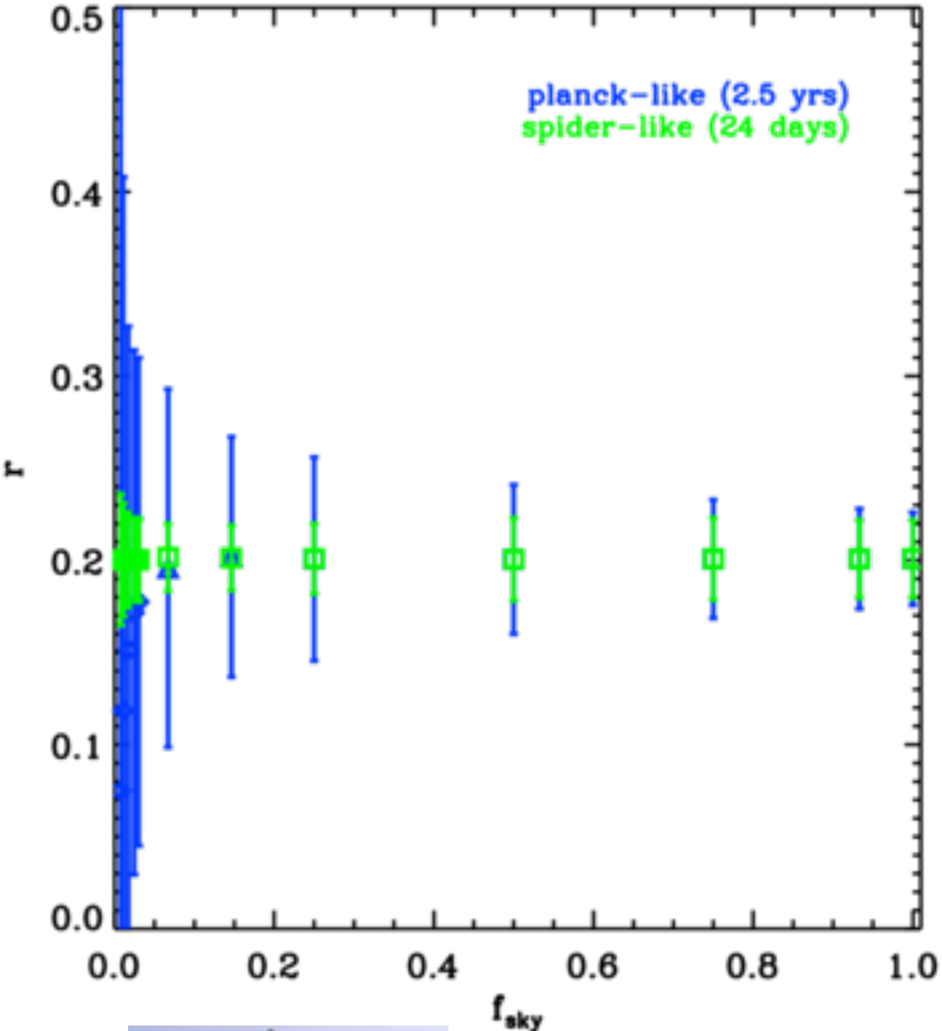

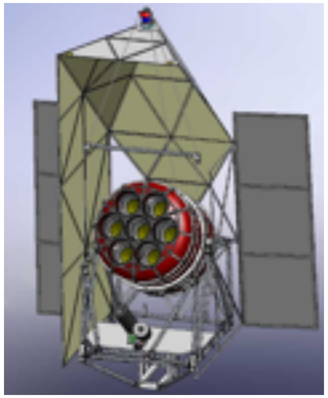

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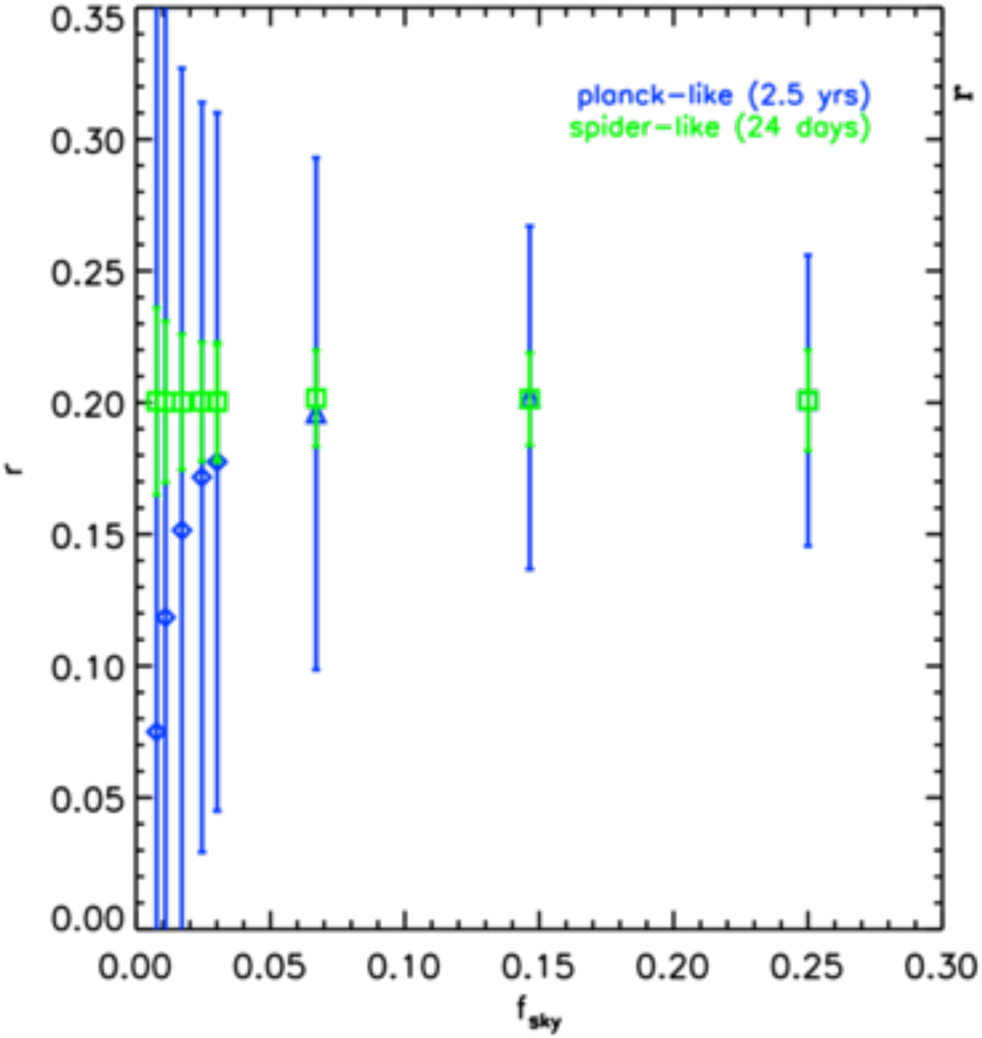
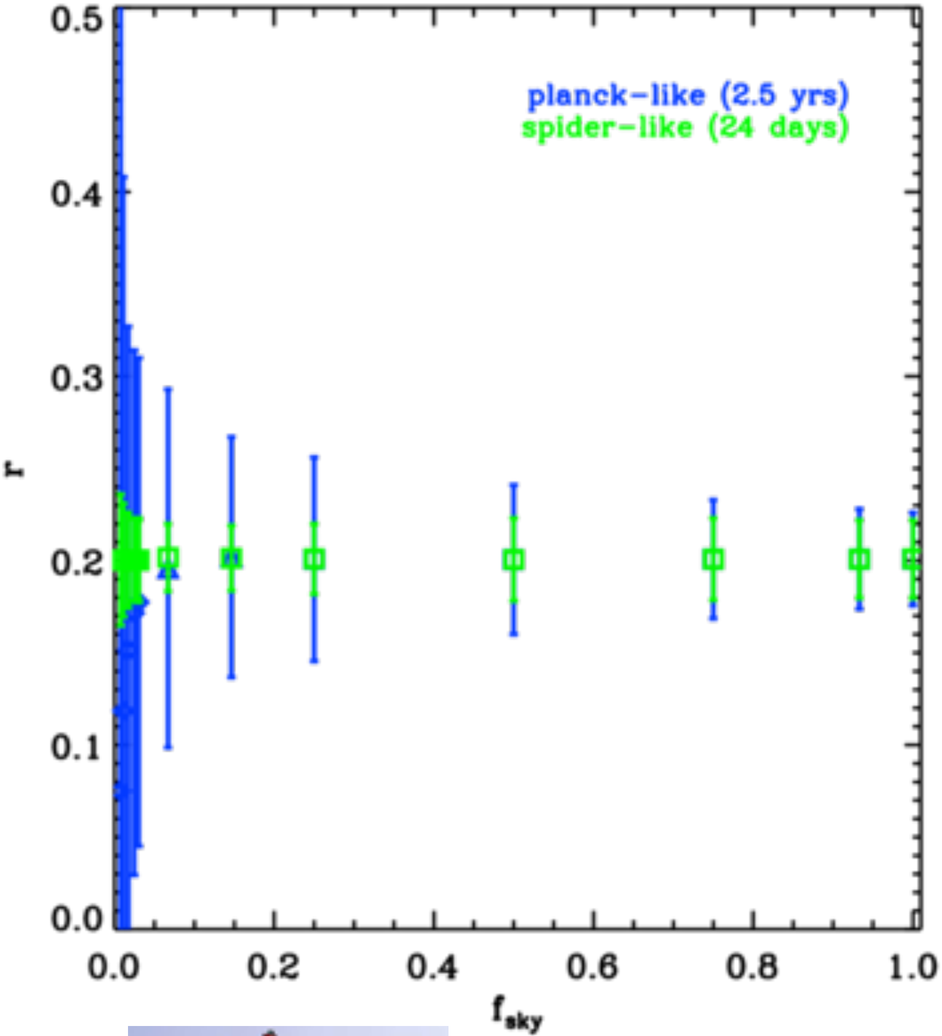
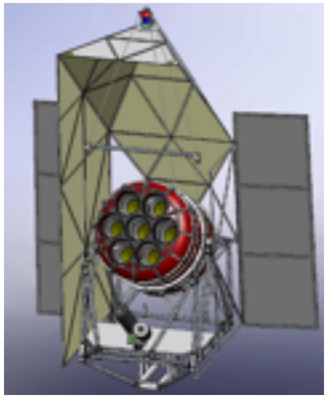
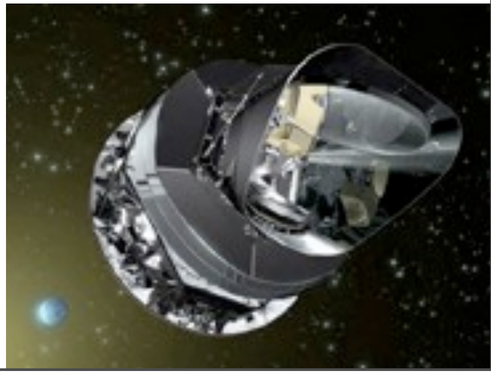




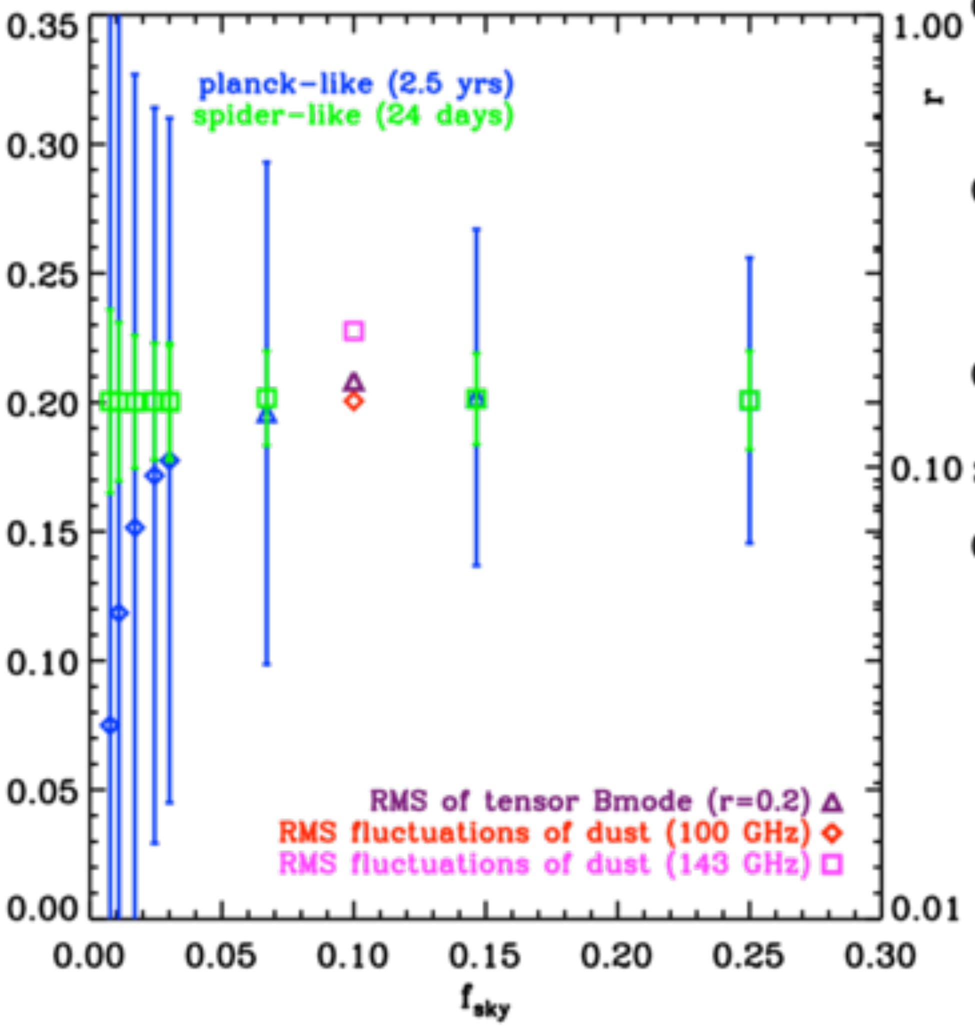


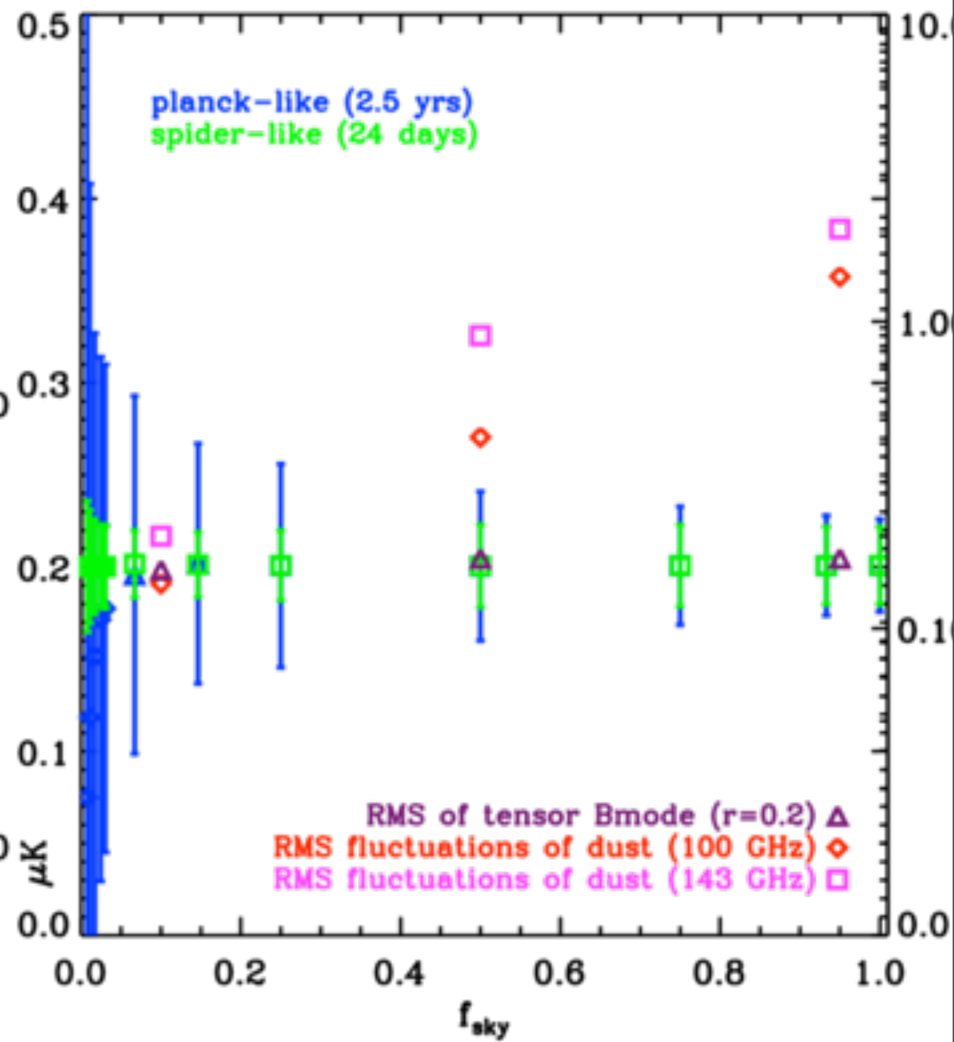


go for low dust patches of sky - from ground, e.g., Keck/spud

or balloons Spider deep/shallow

Planck can use almost all sky and low-dust patches





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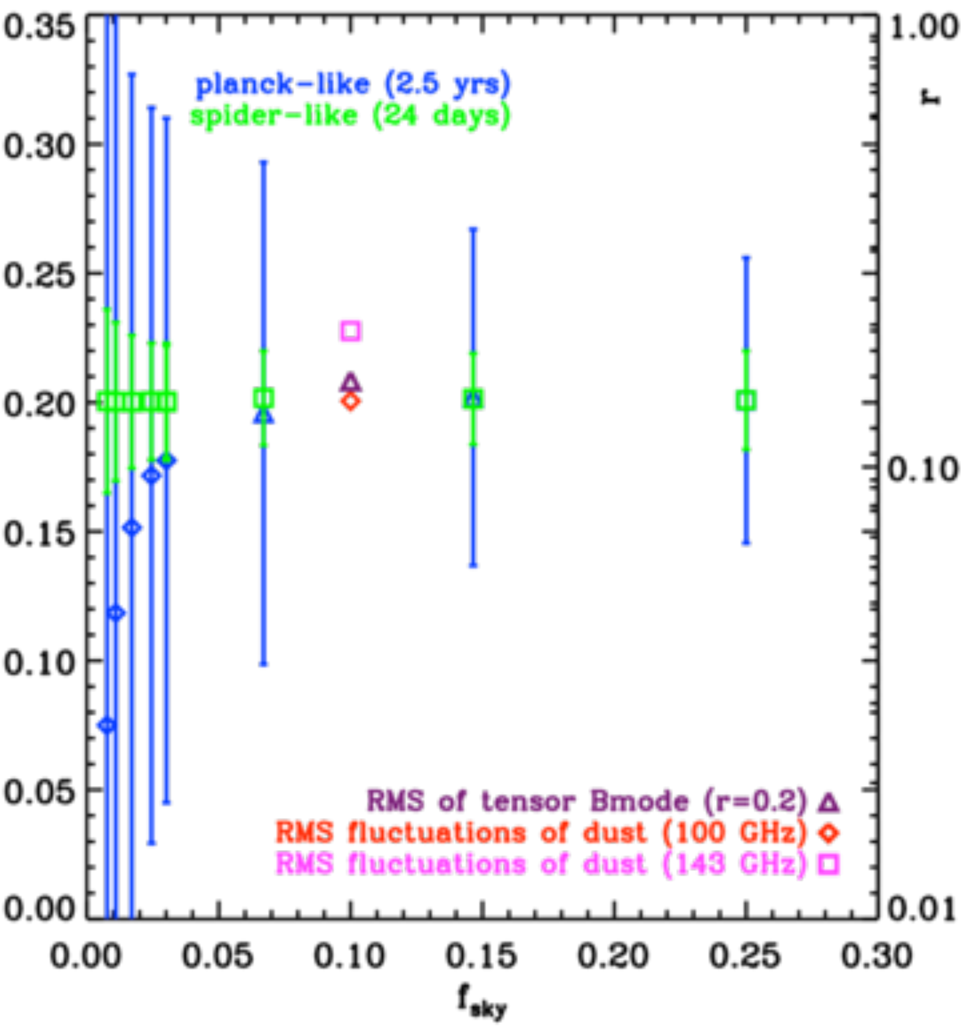

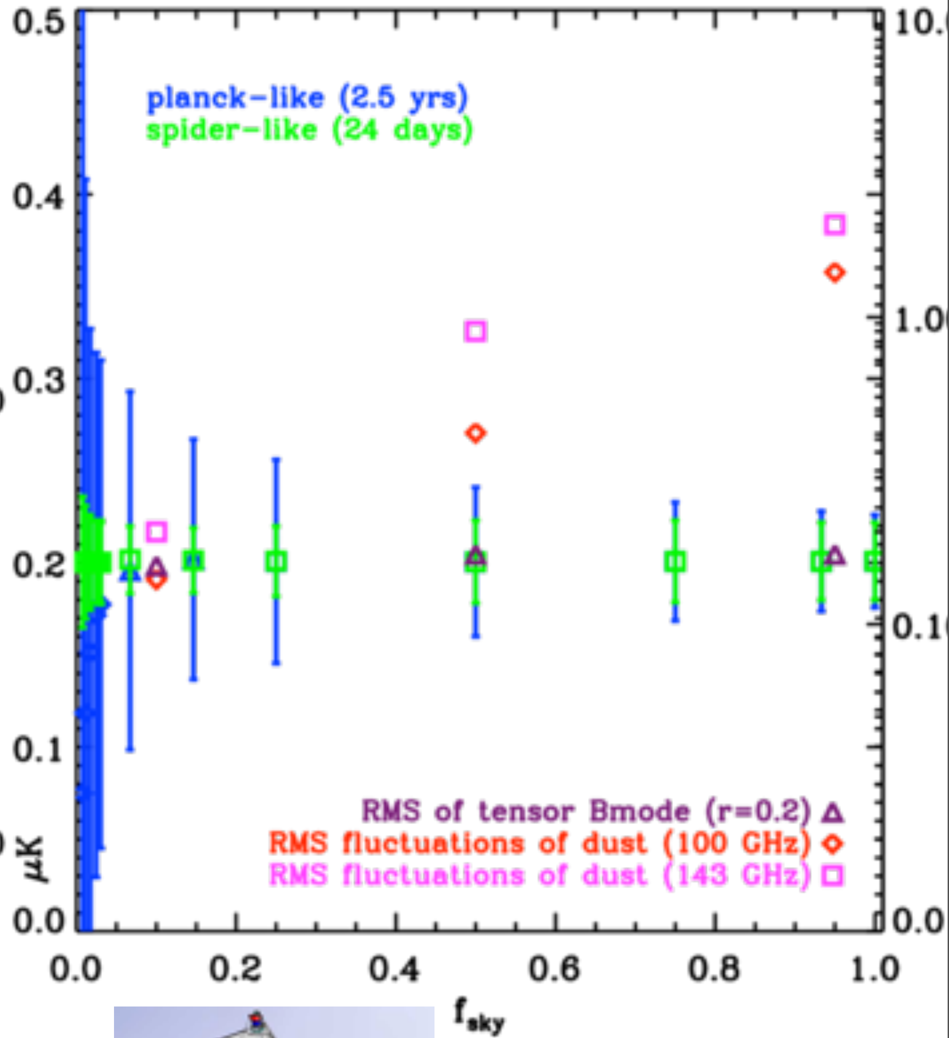

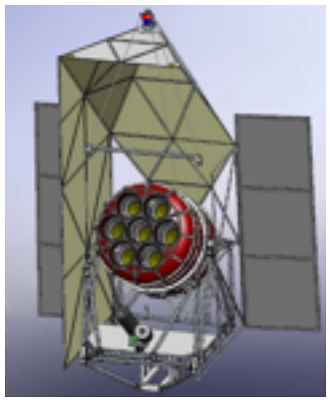

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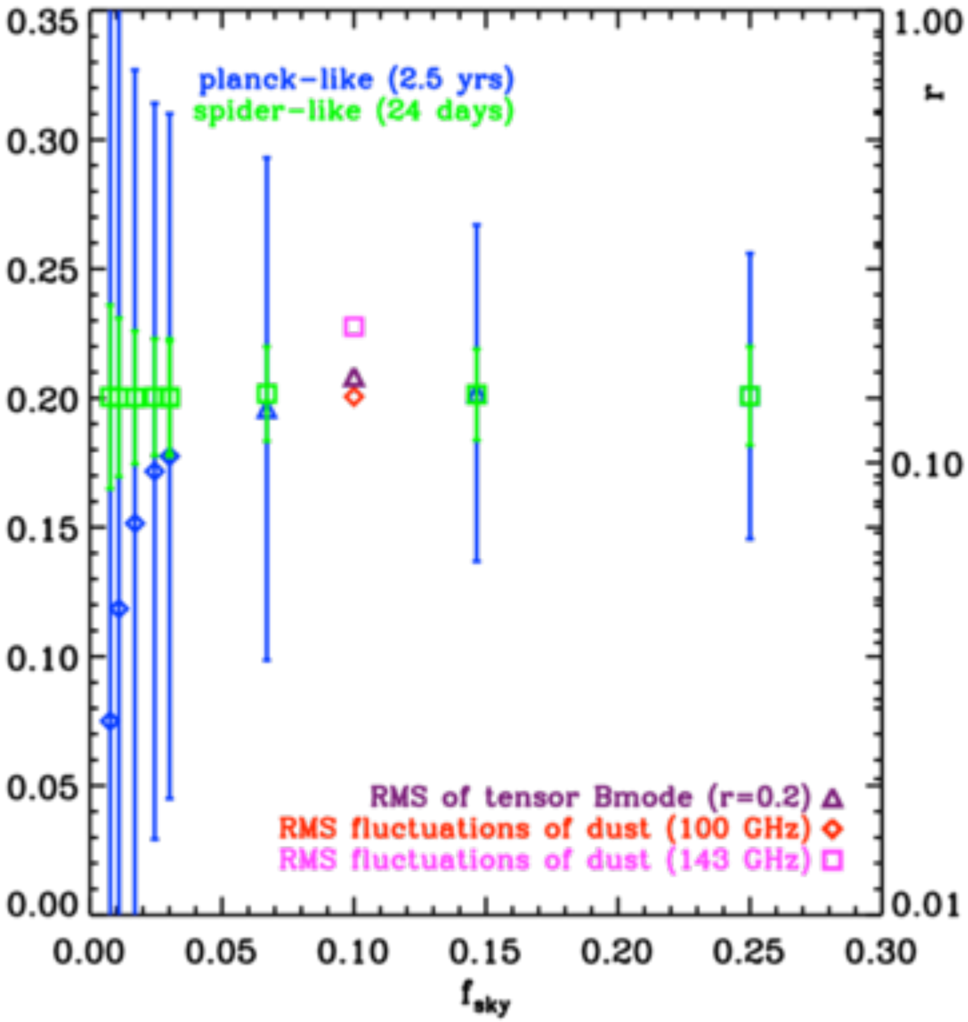
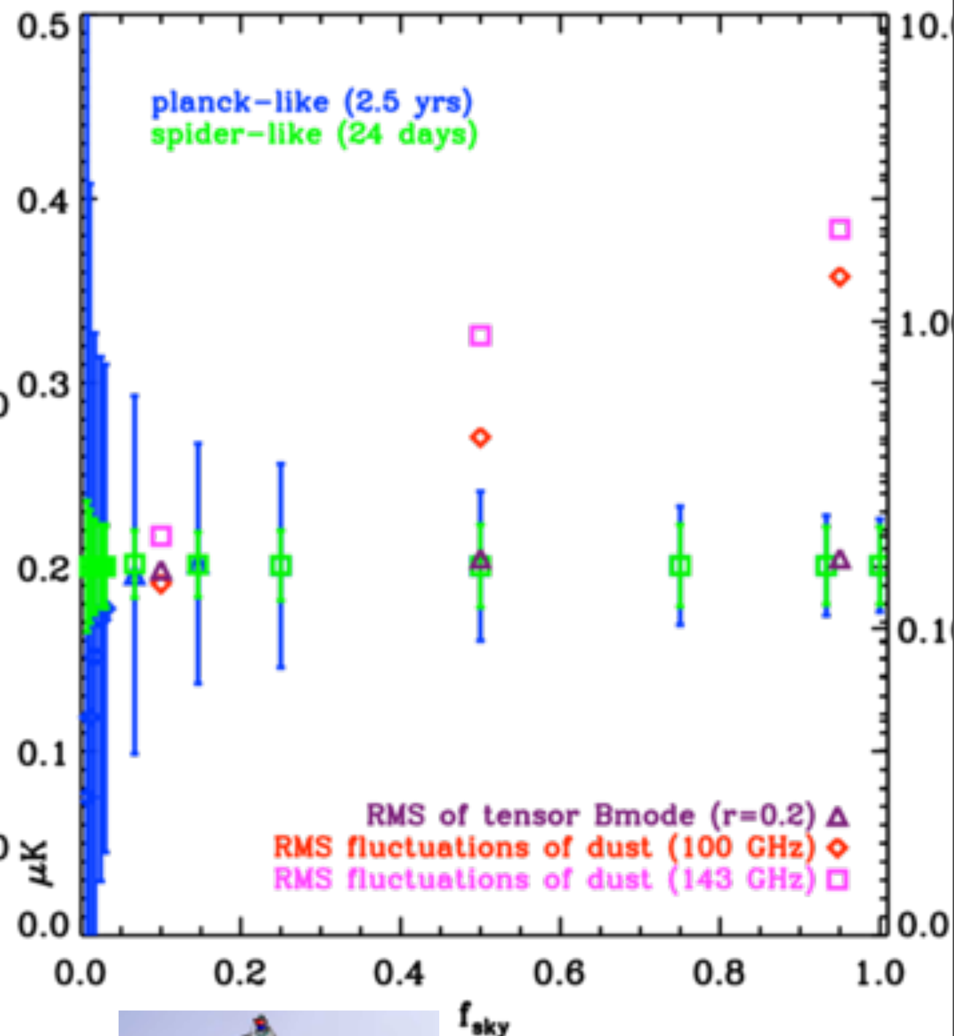
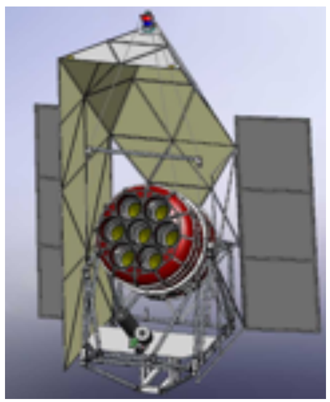
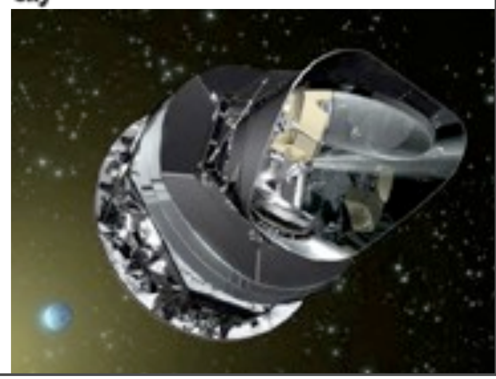








trajectory probabilities for early-inflatons & late-inflatons

very early U	early to middle to now U	**very late U**
inflation	*string theory/landscape/higher dimensions*	**dark energy**
$V_{eff}(\psi_{inf})$? $K_{eff}(\psi_{inf})$?	partial shape reconstruction	reconstruct gradient $V_{eff}(\psi_{inf})$? $K_{eff}(\psi_{inf})$?
		$1+\mathbf{w_0} = -0.0 \pm 0.06$

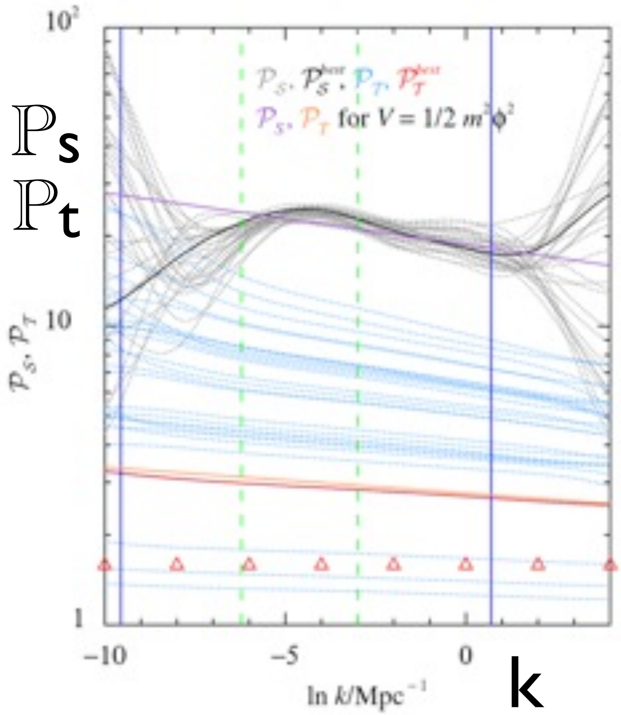
trajectory probability

$-d\ln\rho_{tot}/d\ln a\ /2$

$=\varepsilon(k)=1+q,\ k\sim Ha$

$\Rightarrow \mathbb{P}_s, \mathbb{P}_t$

$\mathbb{V}_{eff}(k)$, $\psi_{inf}(k)$



trajectory probability

$-d\ln\rho\psi\ /d\ln a\ /2$

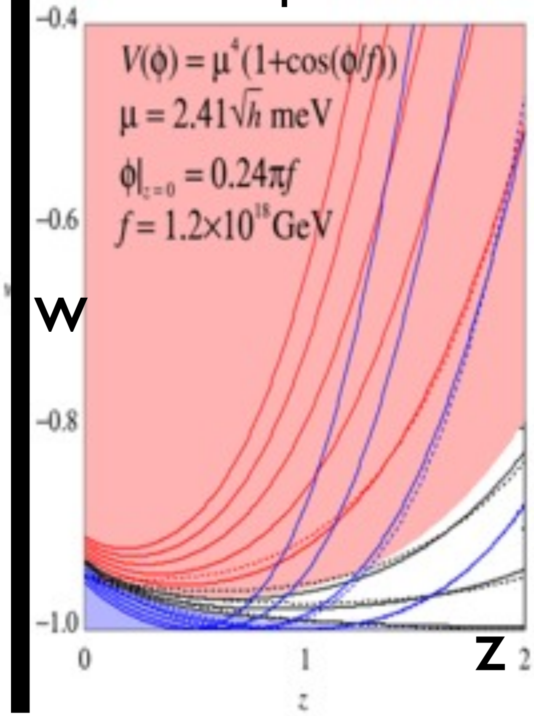
$=\varepsilon\psi(a)=(1+w)2/3$

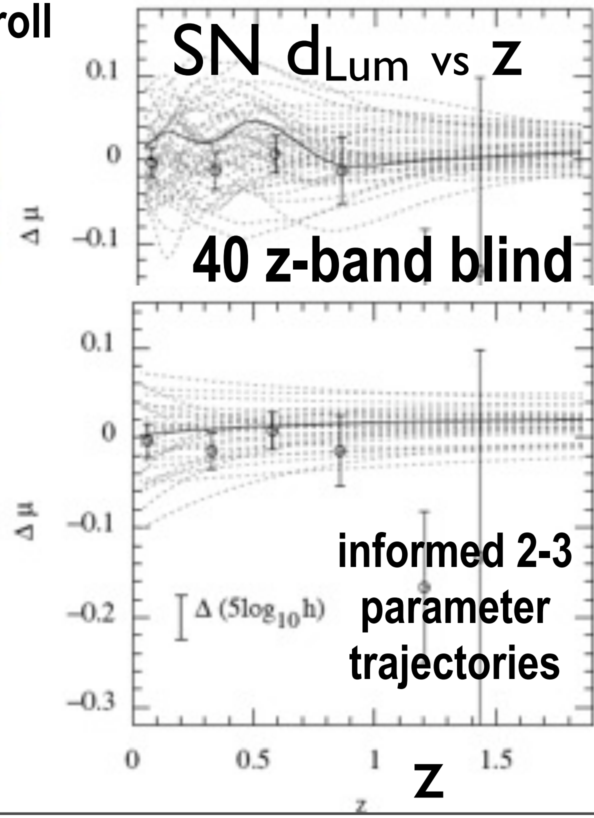
$\Rightarrow$

$\varepsilon_s=(d\ln V/d\psi)^2/4$ @pivot a_{eq} **yes**

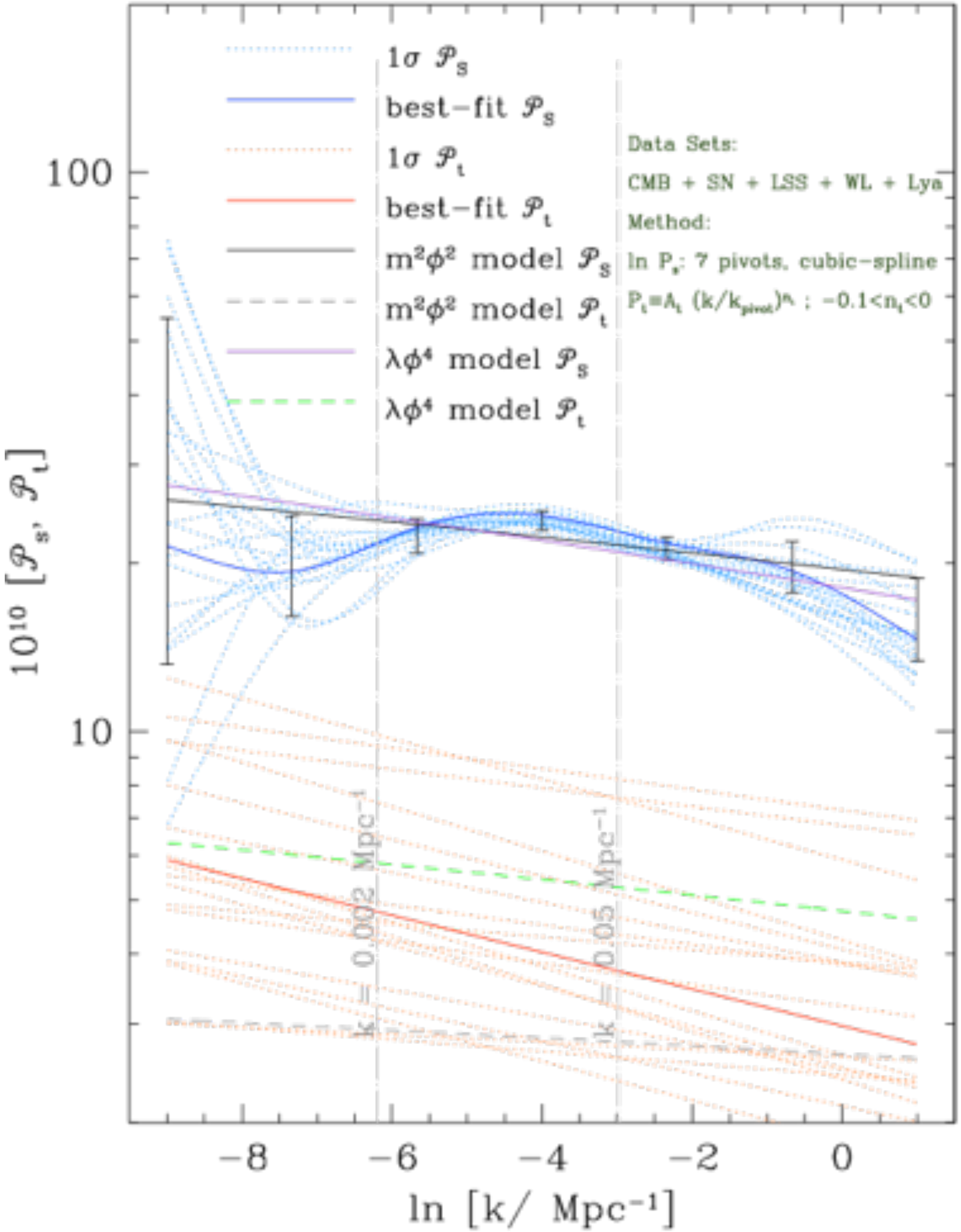
$d^2\ln V/d\psi^2\ /4$ **no**

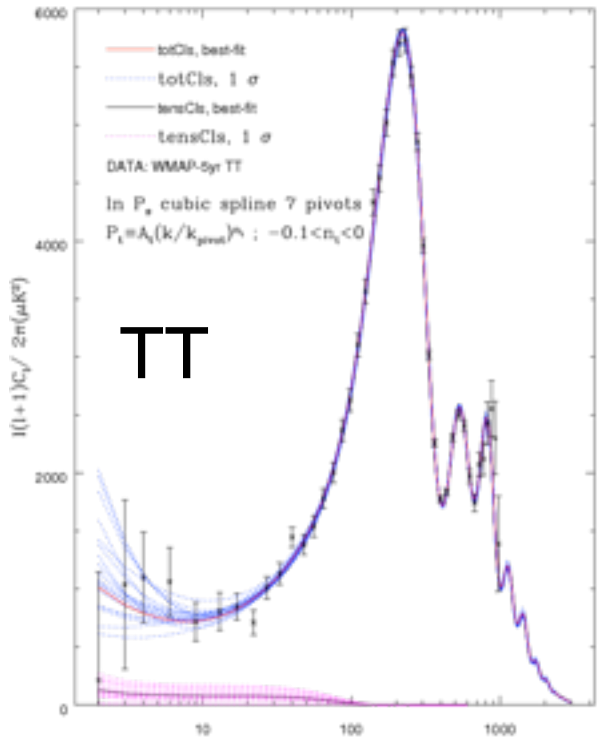
slow-to-moderate roll quintessence

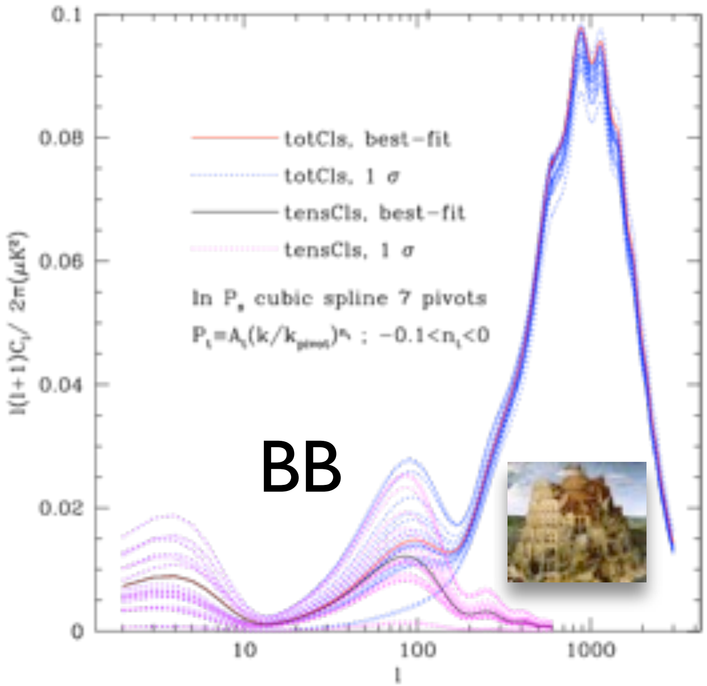




partially-blind scalar power trajecteries & usual r-n_t tensor - no consistency relation. Nov09 data



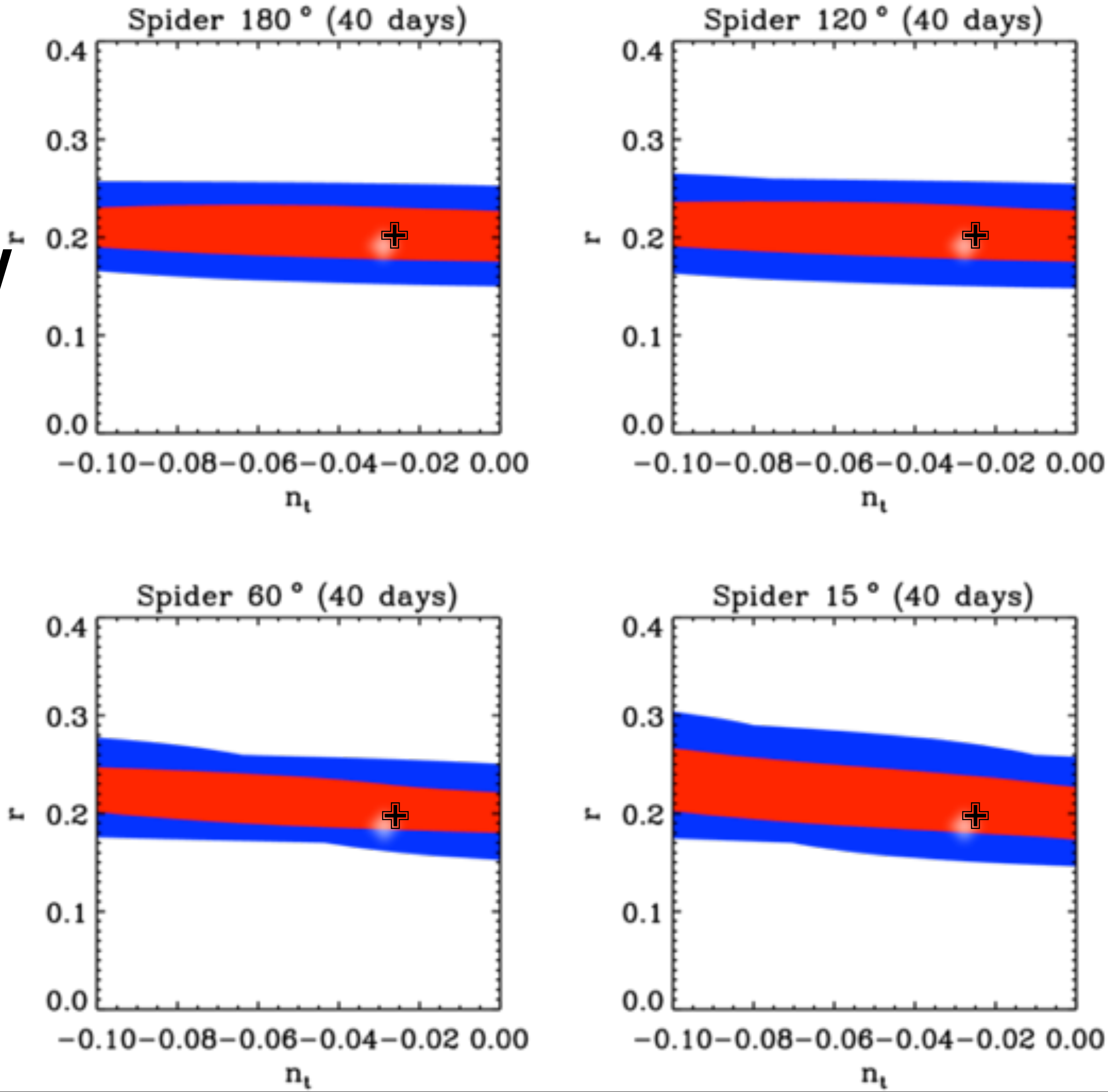




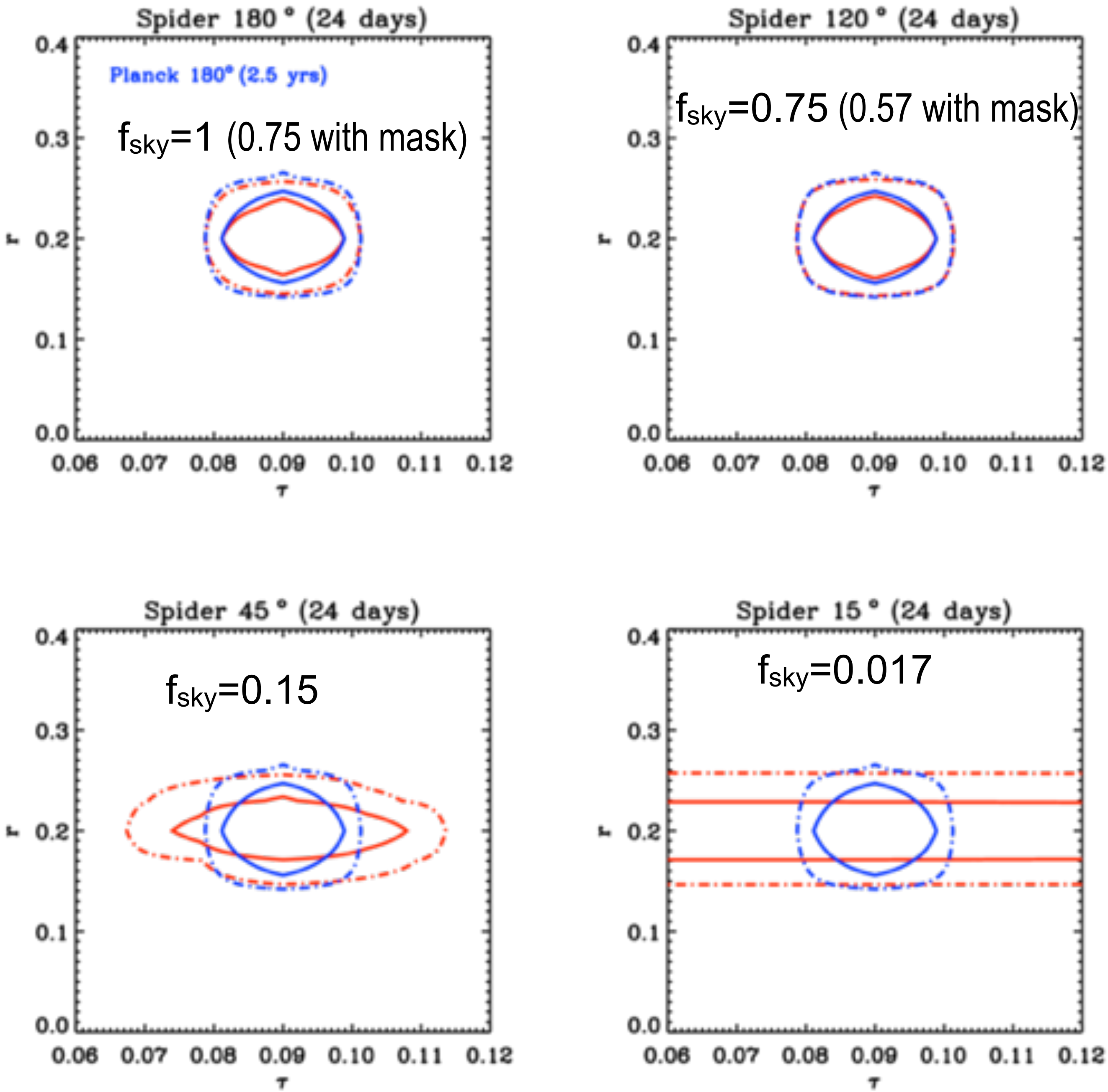
$r \approx -8n_t$

inflation consistency cannot be checked

- poor n_t

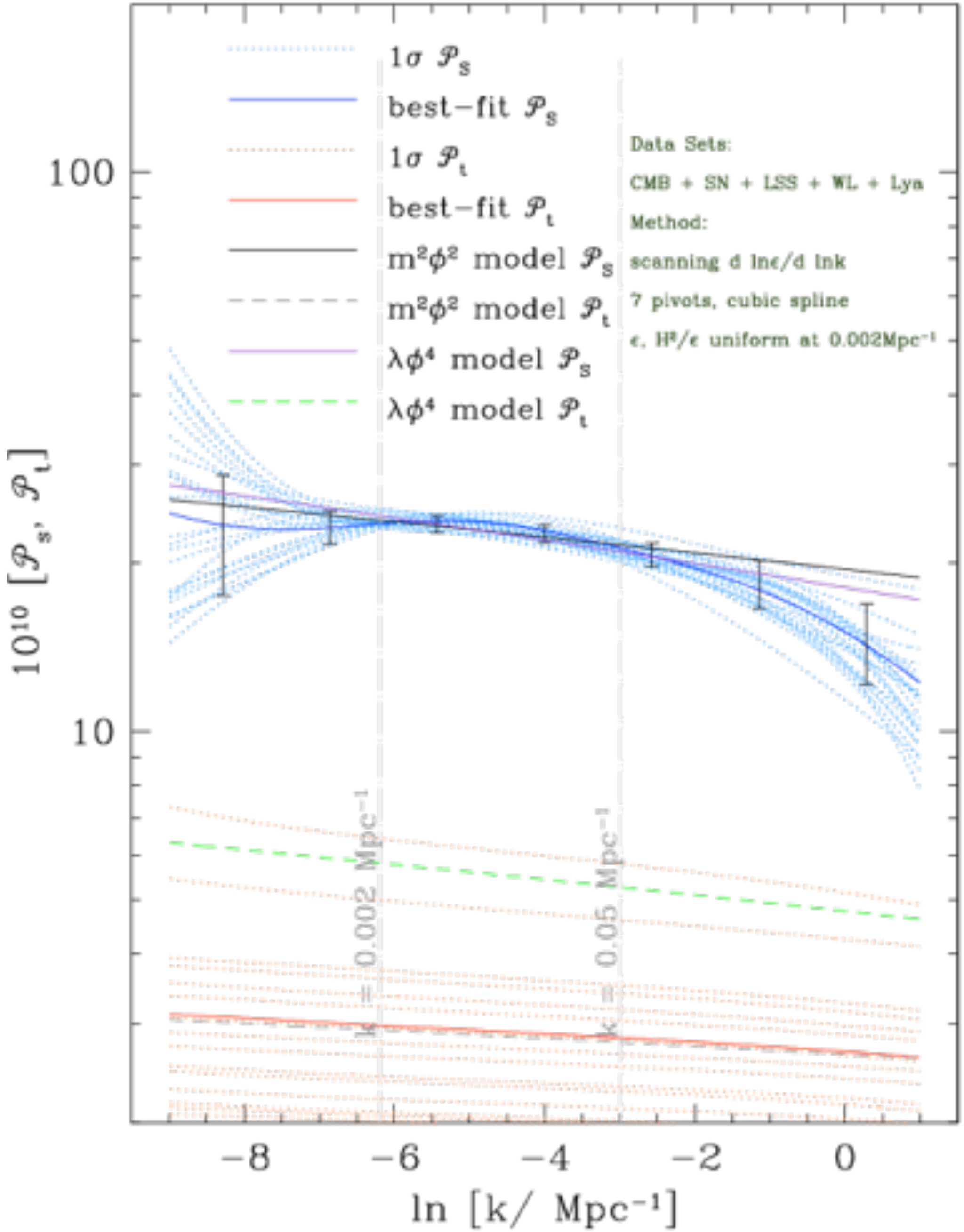


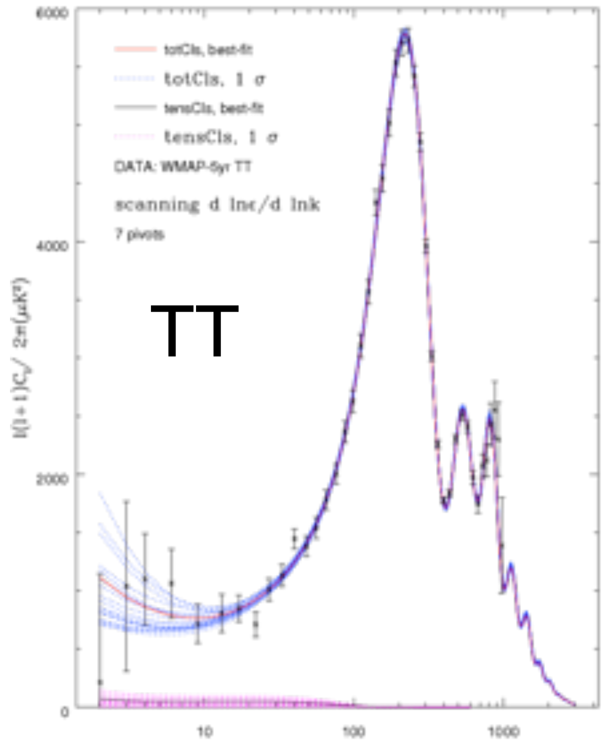
r-τ

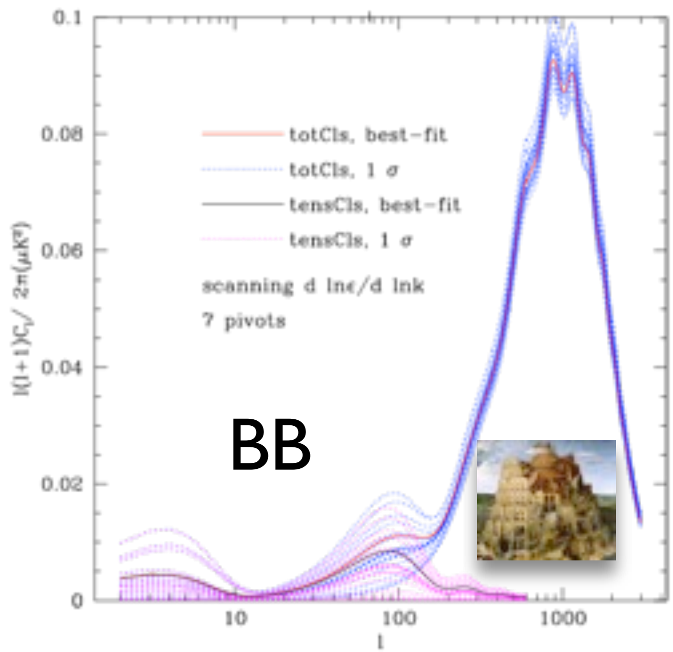


Spider 180 ° (24 days)
Planck 180° (2.5 yrs)
fsky=1 (0.75 with mask)
Spider 120 ° (24 days)
fsky=0.75 (0.57 with mask)
Spider 45 ° (24 days)
fsky=0.15
Spider 15 ° (24 days)
fsky=0.017
r
τ
0.0
0.1
0.2
0.3
0.4
0.06
0.07
0.08
0.09
0.10
0.11
0.12

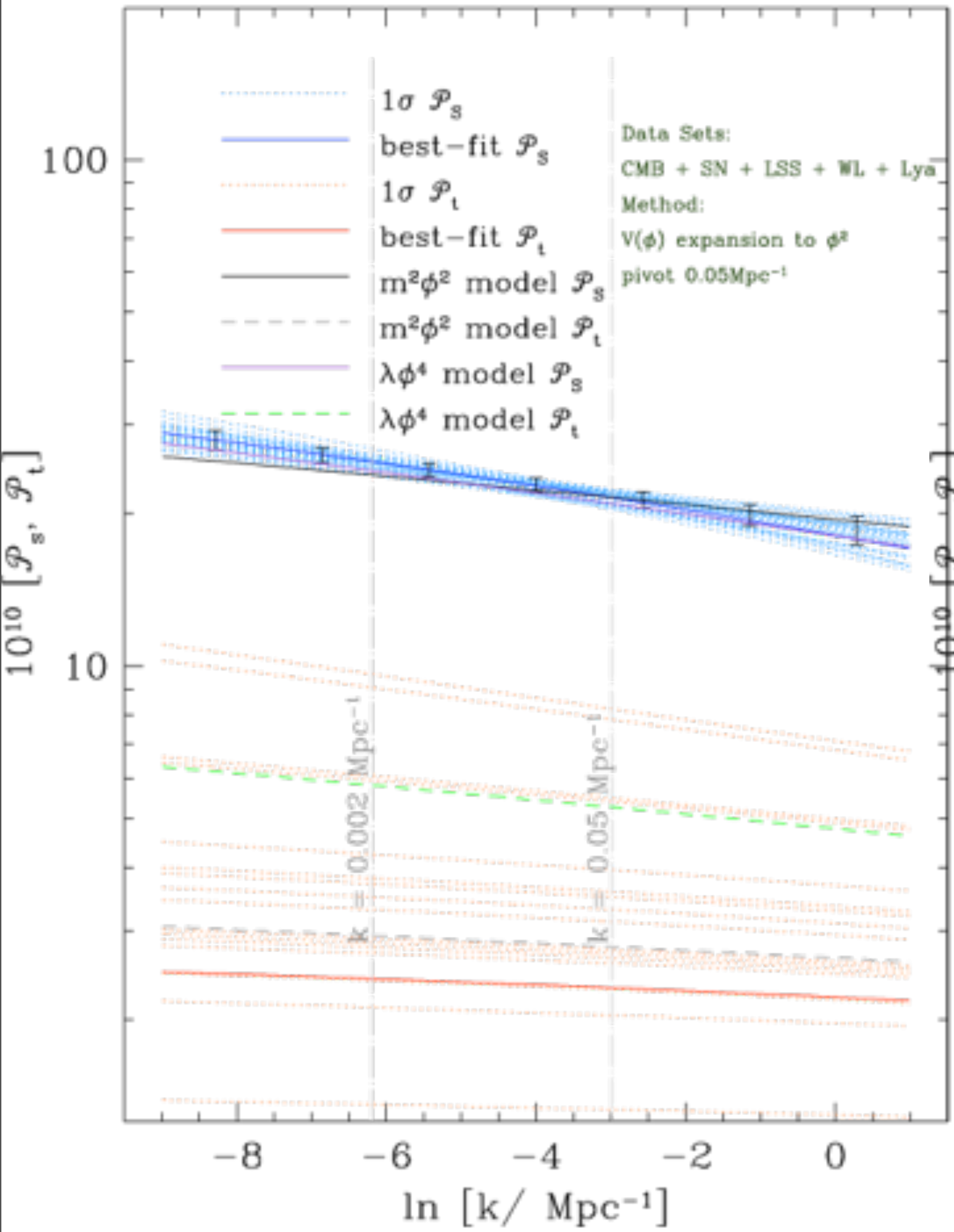
partially-blind acceleration trajecteries obeying tensor/scalar consistency relation. Nov09 data

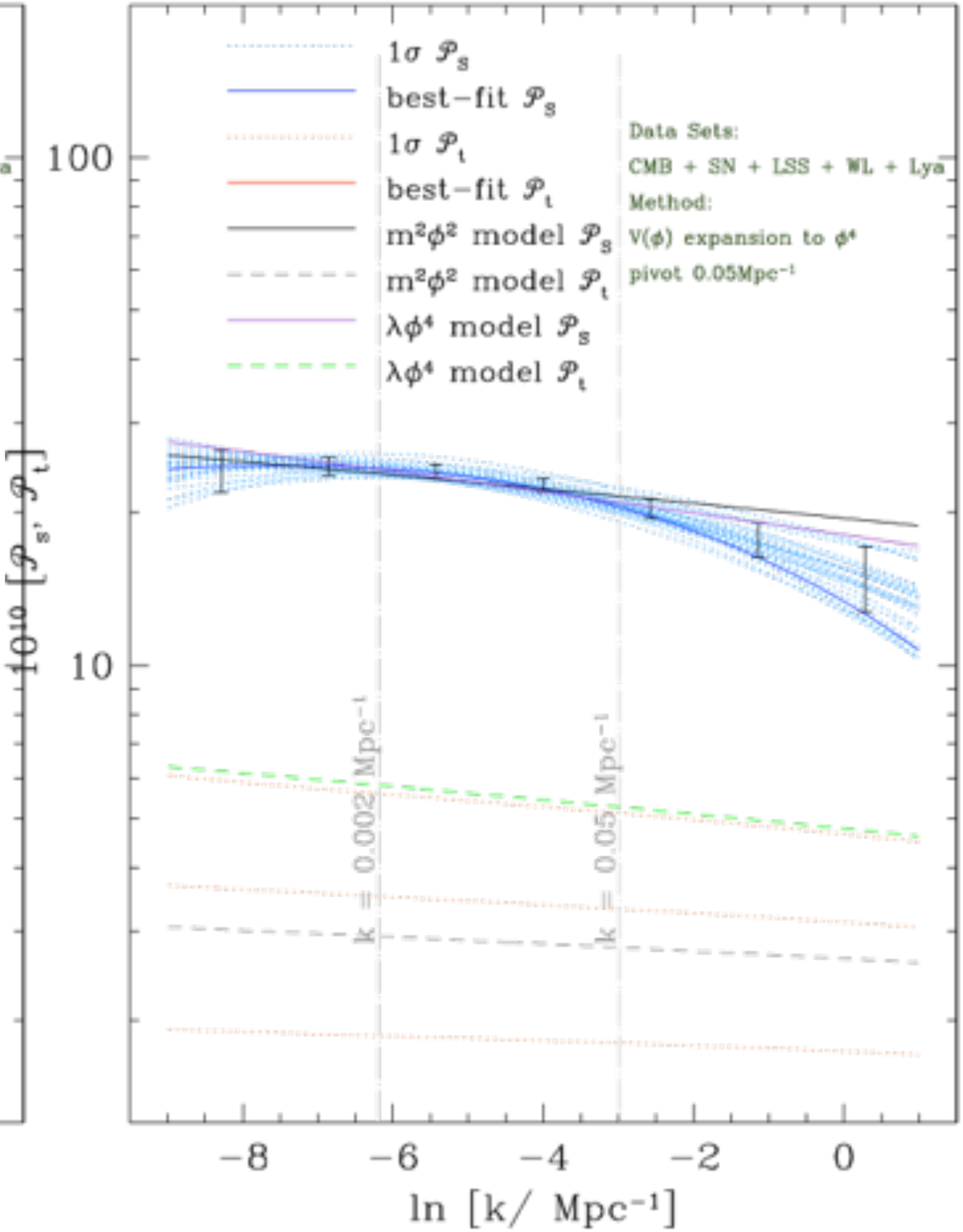






quadratic potential about a pivot point **quartic potential about a pivot point**





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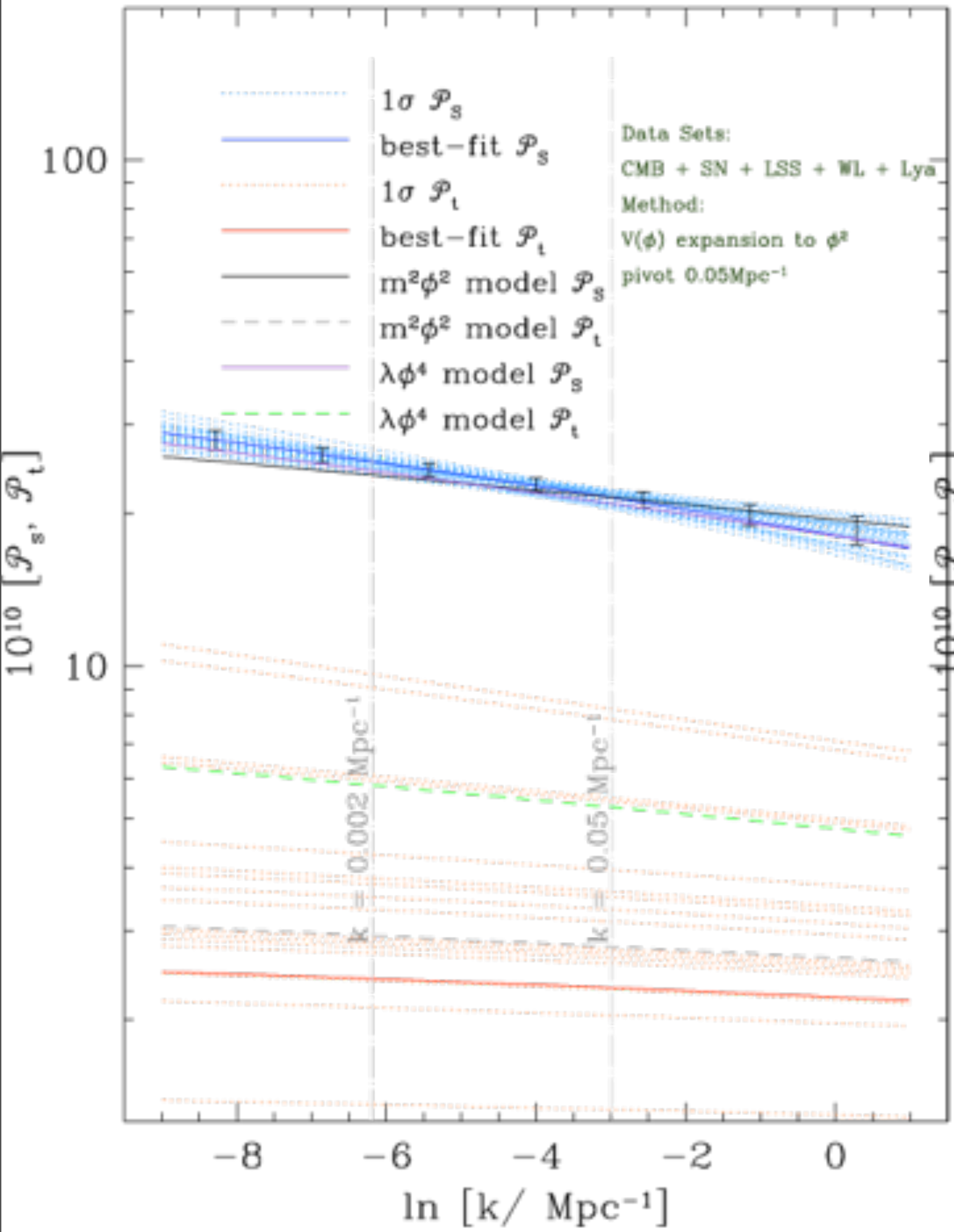
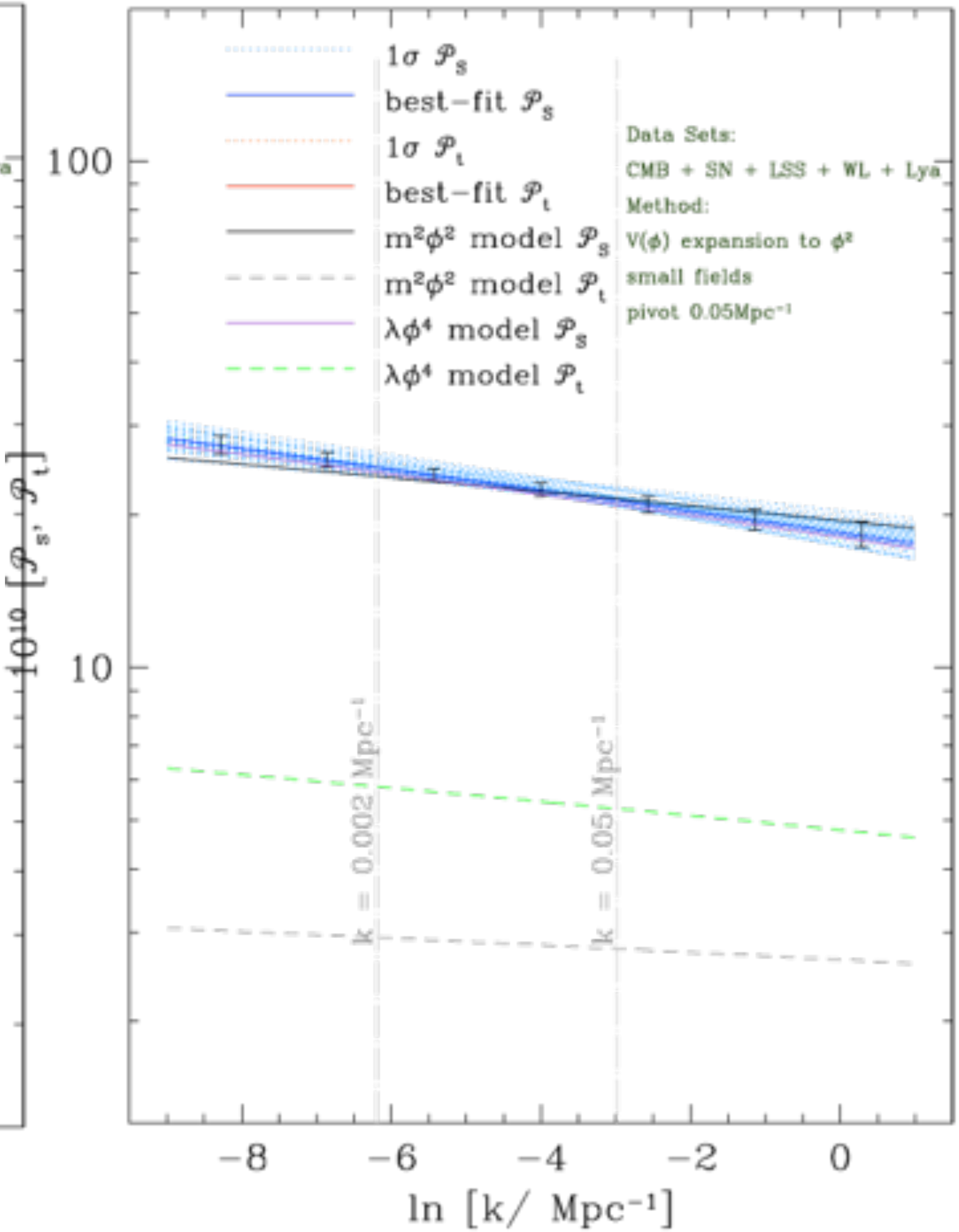


same, with a small field constraint

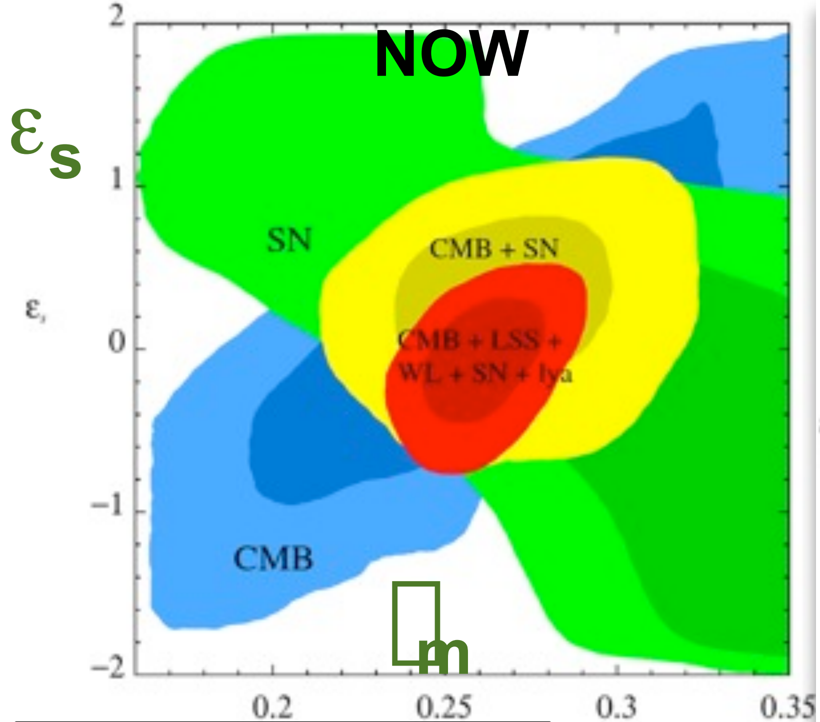


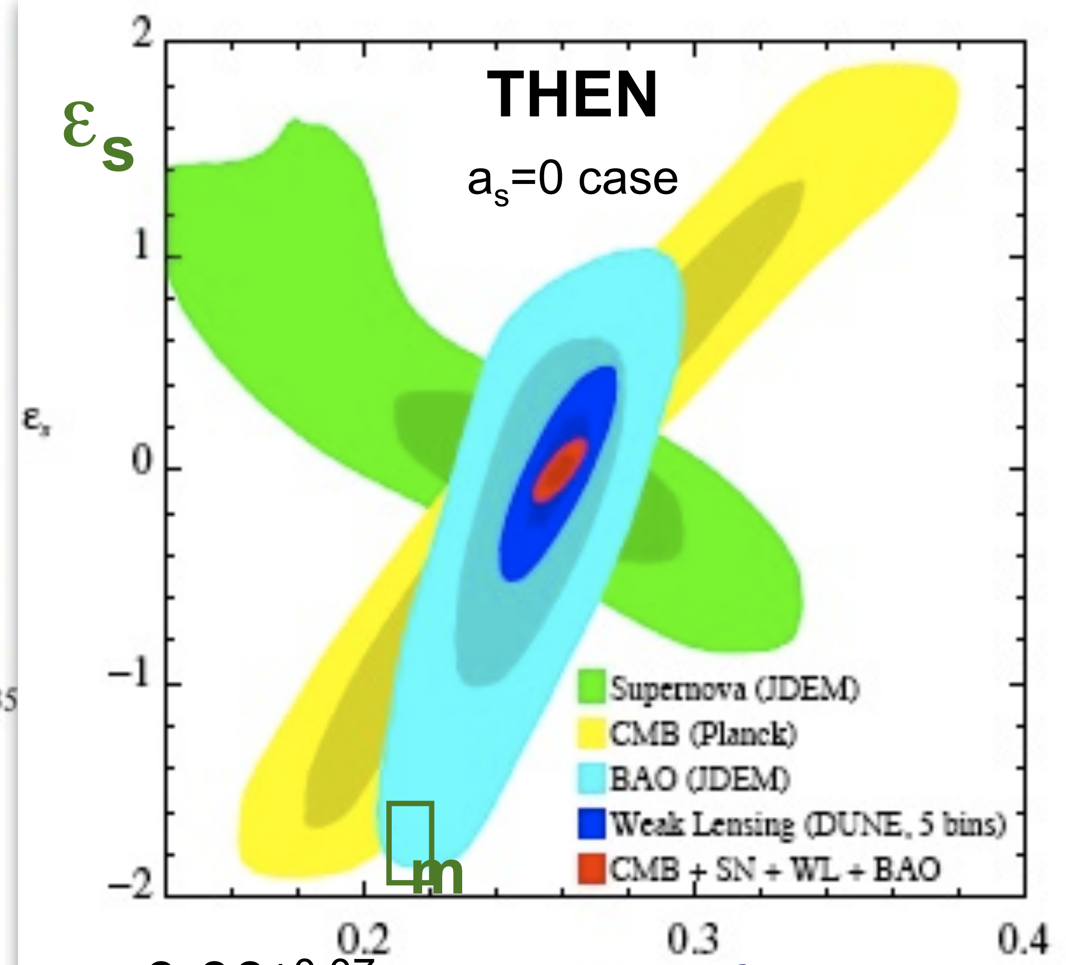
Beyond Einstein panel: LISA+JDEM

Forecast: JDEM-SN (2500 hi-z + 500 low-z)

+ DUNE-WL (50% sky, gals @z = 0.1-1.1, 35/min^2) + Planck1yr

now ESA /Euclid ESA (+NASA/CSA)





$1+w_0 = -0.0 \pm 0.06$

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

$= -.03 + .26 -.30$ 2

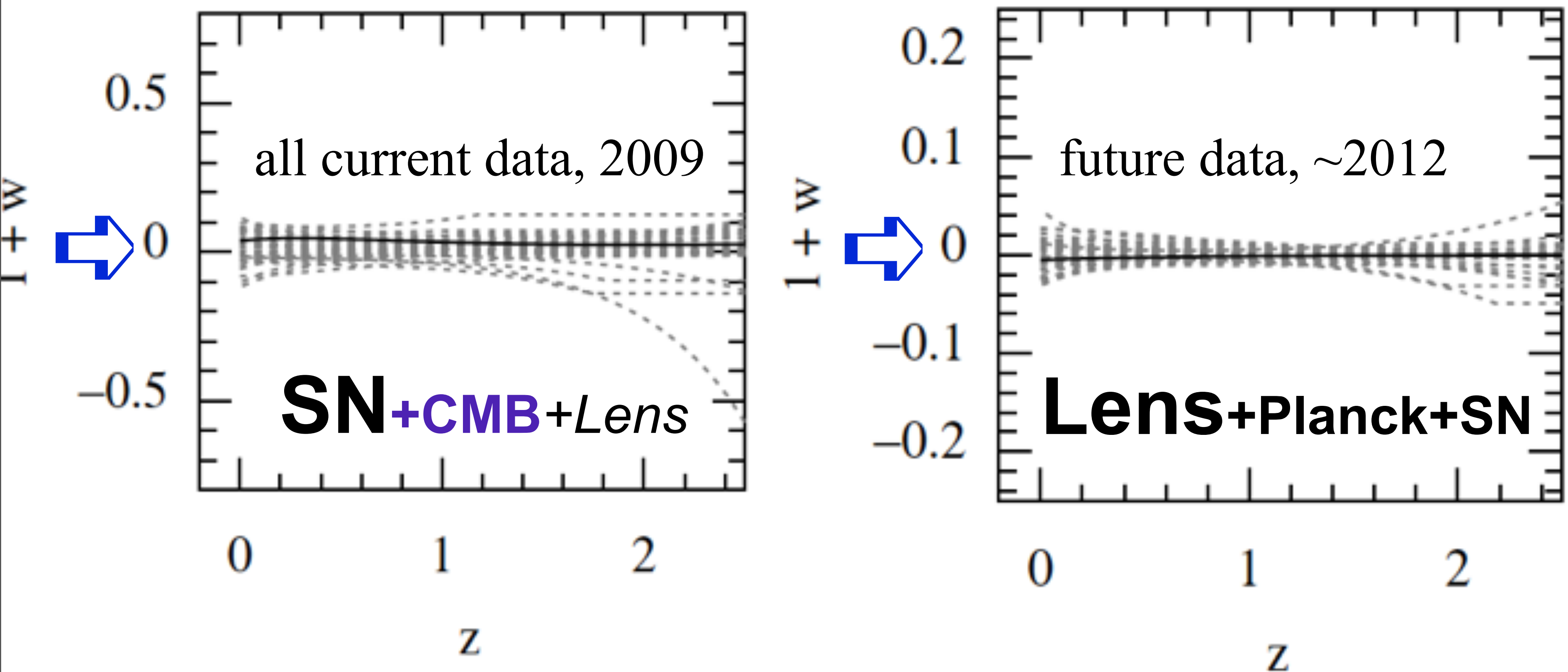
$\varsigma_s = \pm 1.001 d^2 \ln V/d\psi^2 /4$ $= 0.1 \pm 0.7$

$\varepsilon_s = 0.00^{+0.07}_{-0.06}$ Ω_m $\zeta_s = 0.1 \pm 0.7$

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

ρ_Λ(time,space) ?

is the **dark energy** "vacuum potential energy" ?



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

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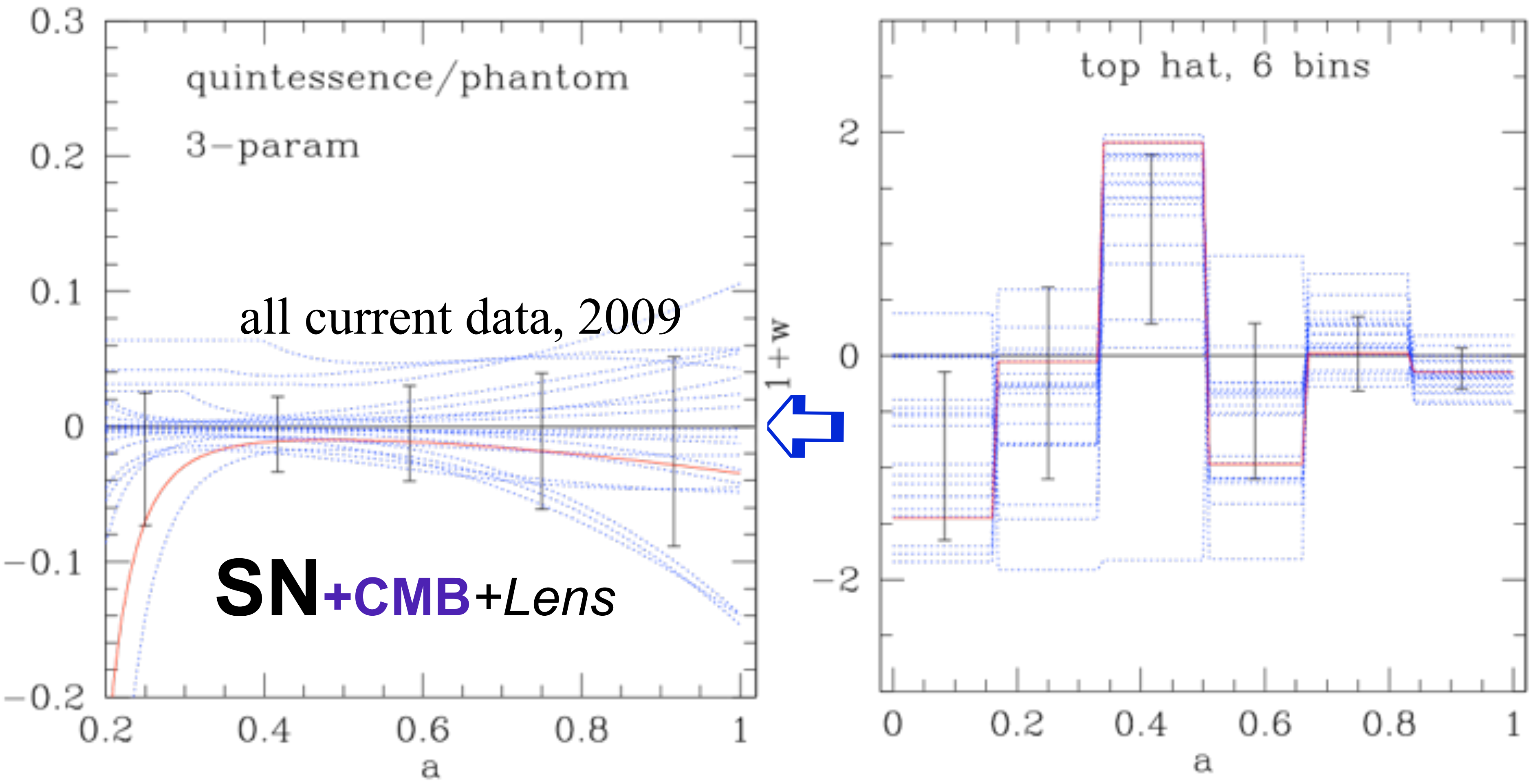

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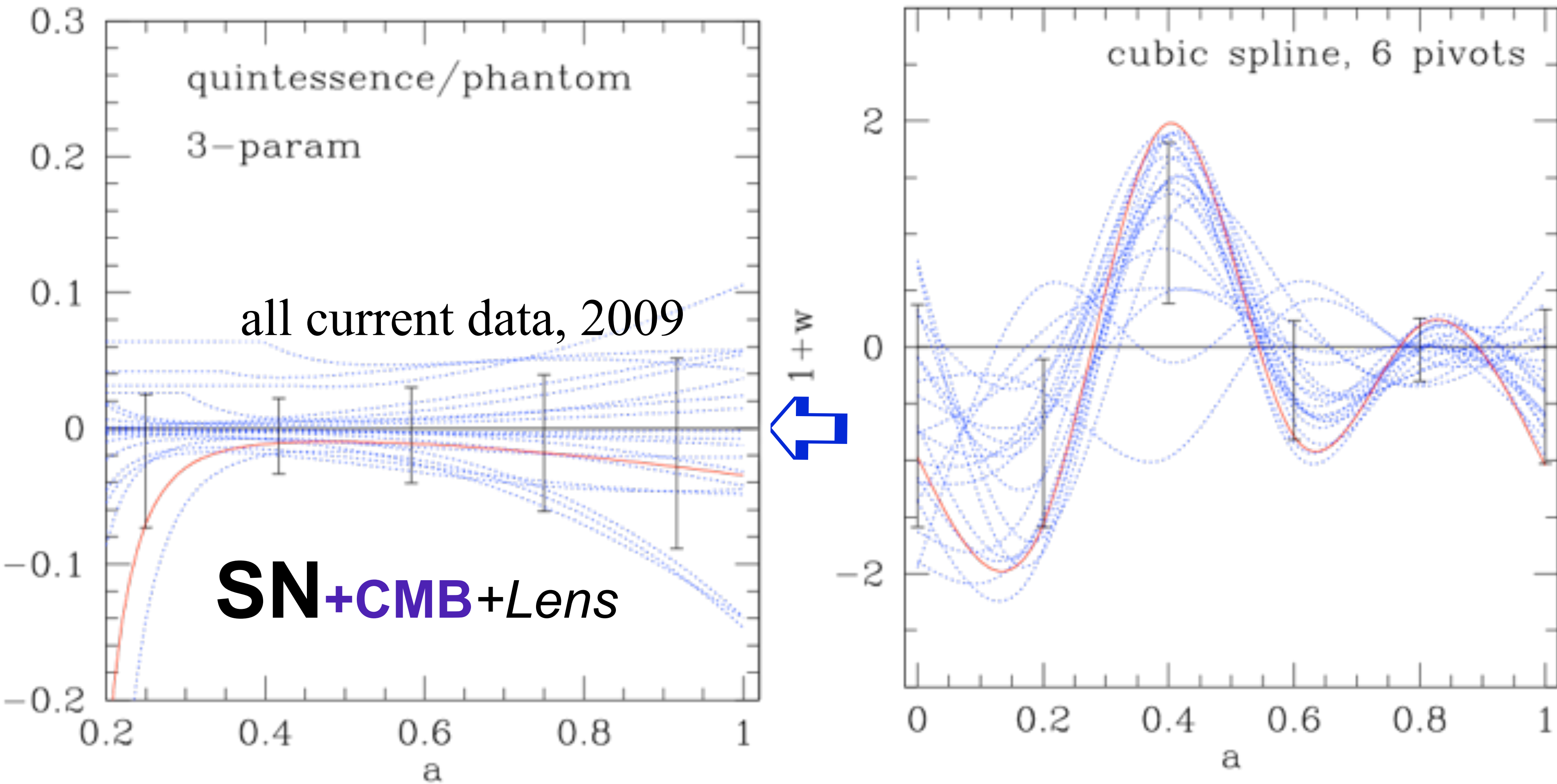

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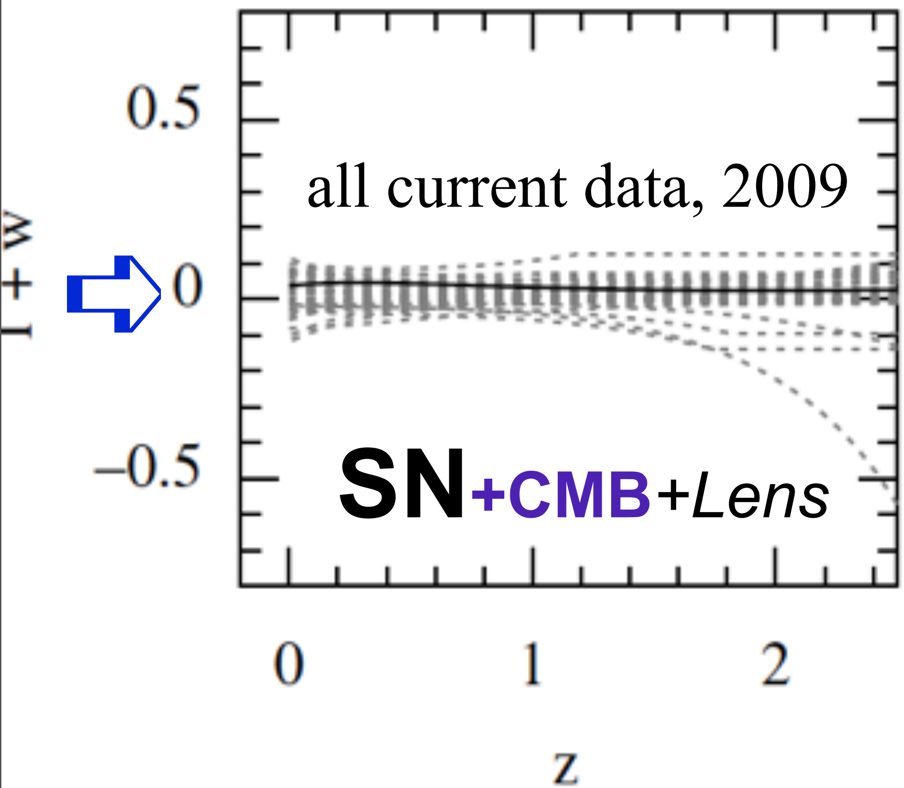

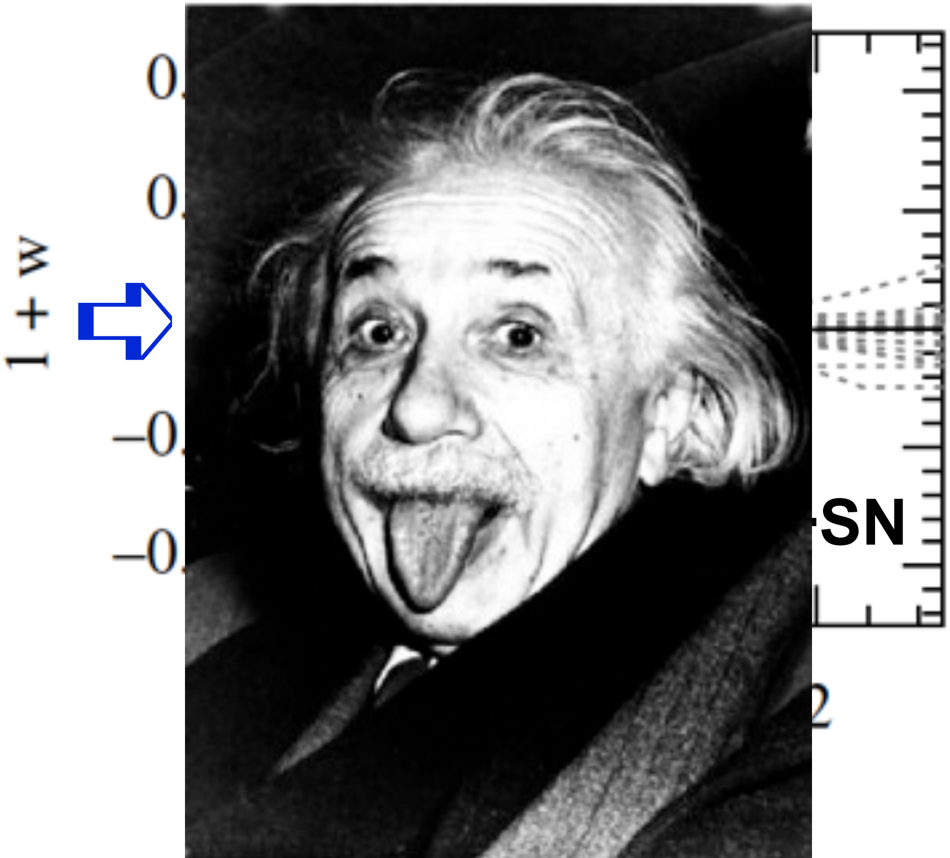

TEST: within errors, energy-density does not change with expansion ➪Einstein's cosmological constant is best fit so far

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very early U — early to middle to now U — very late U

inflation — *string theory/landscape/higher dimensions* — dark energy

$V_{eff}(\psi_{inf})$? partial shape reconstruction — reconstruct gradient $V_{eff}(\psi_{inf})$?

$K_{eff}(\psi_{inf})$? — $K_{eff}(\psi_{inf})$?

$1-n_s \sim 2\varepsilon_s + 4\varsigma_s$ x.9999 & $r \sim 16\varepsilon_s$ slow roll

2 solutions: nearly uniform acceleration & small ς_s

$\varepsilon_s \sim .017 +- .007$; $\varepsilon_s < .025$ 95% from r

\

low energy inflation with tiny ε_s

$2\varsigma_s \sim .017 +- .007$

errors go to $+-$ .0012 Planck+JDEM+DUNE

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

$\varepsilon_s \sim$ -.03 + .26 -.30

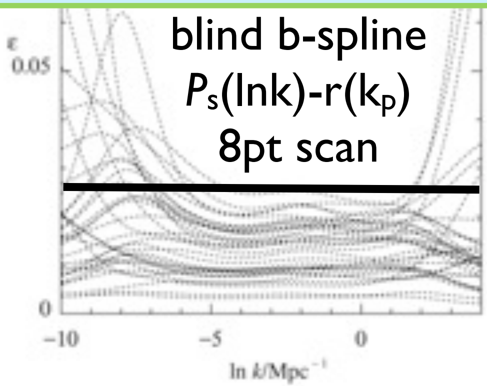
to +− .07 Planck+JDEM+DUNE

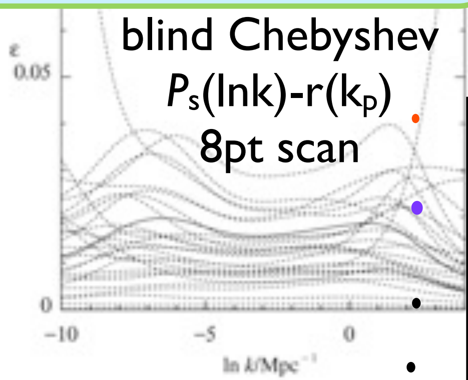
$\varsigma_s =_{+-1.001} d^2\ln V/d\psi^2/4$ @a_{eq}

$\varsigma_s \sim$ 0.1 +.6 -.7

to +.6-.7; +-.3 Planck+JDEM+DUNE

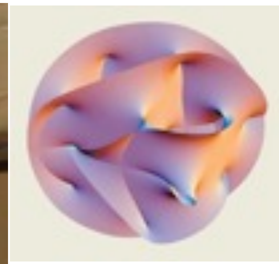
a_s < 0.36 (z_s >2.0) • to a_s to <0.21 (z_s >3.7)





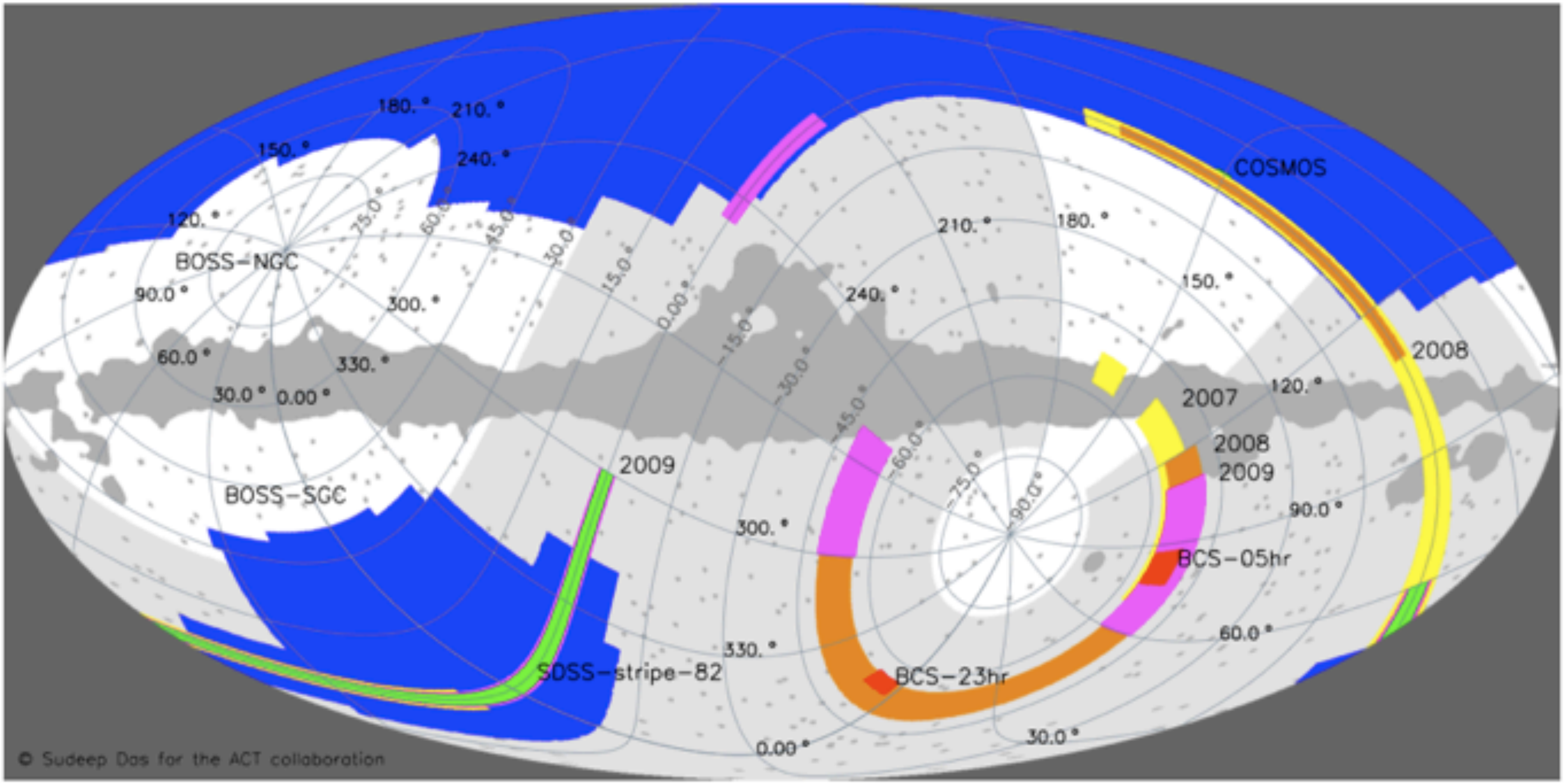
- we ignore z_dec and z_bbn constraints on Ω_Q (a) *much further trajectory extrapolation needed.*
- prior sensitivity sqrt(ε): ε=0.00 +.09-.13 & ε>0 (since phantom is ~ baroque): ε=0.00+.20
- late-inflaton field is < Planck mass
- *coupled-DE 5th force constraints are strong*

Lev Kofman June 17, 1957 - November 12, 2009



end

ACT Survey Coverage



2007	2009	Stripe 82	BCS
2008	ACT Range	BOSS	Masked

Tobias A. Marriage etal ACTers

Fall 2009

Known Clusters at all SNRs