CITA = Cosmic Information Theory & Analysis: *IT from BIT, from BITs in IT,*

Studying the Cosmic Tango** en-TANGO-ment* ***Universe=System+Res=Data+Theory **=Signal(s)+*noise*=EFT+*Hidden variables***

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

Dick Bond

25 years cifar

the Cosmotician's Agenda: Statistical Paths in Cosmic Theory & Data via the Bayesian chain

Shannon entropy $S_f(D,T) = -\int dq\, P_f \ln P_f$ = **information** **(with no Quality assurance on the bits)**

~ von-Neumann entropy= Trace $\varrho \ln \varrho^{-1}$, $\varrho(U) = \varrho(S,R) = \varrho(R|S)\, \varrho(S)$ entanglement of phase & probability

$\mathbf{s}_{Ui}$~*0;* $\mathbf{s}_{Utot,m+r}/\mathbf{n}_b$ ~***1.66x10^10*** **bits/b;** $\mathbf{s}_\gamma / \mathbf{n}_\gamma$ = ***5.2 bits/Y*** = *2130/411*; $\mathbf{s}_\nu$ =*21/22* $\mathbf{s}_\gamma$

$\mathbf{s}_m/\mathbf{n}_b$ ~190 bits/b in clusters, 19 centre of sun, 1 preSN collapse, 1 atmosphere $\mathbf{s}_{kin+th}$-$\mathbf{s}_{th}$

non-equilibrium entropy of density fluctuations & of cosmic structures $\Delta \mathbf{s}_{dm}$ ~*7 bits/DM-particle*

Studying the Cosmic Tango

en-Tango-ment, the dance of S+R=U
Universe=System(s)+Reservoir,
=Signal(s)+Residual *noise*,
=Effective Theory+*Hidden variables*,
observer(s)+observed,
ruled by (information) entropy, entangled. ***the fine grains in the coarse grains***

> ***the coherent and the entropic, in all its forms, from ultra-early-U to ultra-late-U***

the emergence of the collective from the random:
coherence from driven zero-point vacuum fluctuations ⇨ V **inflaton**, gravity waves; decohere

let there be heat: entropy generation in **preheating** from the coherent inflaton (origin of all matter)

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$P(q|D,T) = P(D|q,T)P(q|T)P(T)/P(D|T)$ D=CMB,LSS,SN,..,complexity, life

T=baryon, dark matter, vacuum mass-energy densities,...,

early & late inflation as low energy flows on a (string) landscape

(point process of vacuua, river-flow trajectories), $L(g_{\mu\nu},\phi,\chi_i,\psi,A_\mu,\rho_m,p_m)$,

structure of manifolds (compactifying extra dims 7+3+1, moduli ~ "collective coordinates" of holes, branes, fibres, coupling 'constants')

Anthrostatician=superHorizon measurer, *of the information beyond UUUULSS*

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inflation now: DarkEnergy(t,x), amplitude V_0 & slope d*ln*V/d*Inflaton* of an effective potential

inflation then: amplitude/slope of scalar-curvature & tensor-curvature (GW) fluctuations, n_s r

entropy production: ***Post-inflation shock-heat*** & weak nonGaussianity F_{NL}

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Power$_s$=25x10^{-10} *Tilt*$_s$ =0.963±0.013 **running=-0.024 ± 0.015 r=T/S<0.19** T_{cmb} **=*2.725***

Photo: Ariel Zambelich, Copyright © Nobel Media AB

Saul Perlmutter

Photo: Belinda Pratten, Australian National University

Brian P. Schmidt

Photo: Homewood Photography

Adam G. Riess

The Nobel Prize in Physics 2011 was divided, one half awarded to Saul Perlmutter, the other half jointly to Brian P. Schmidt and Adam G. Riess *"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"*.

ΛCDM was the standard "concordance" model since ~1995;

much invoked since

Peebles 85

WYSIWYG

bbe87, pr88, weinberg87, ...

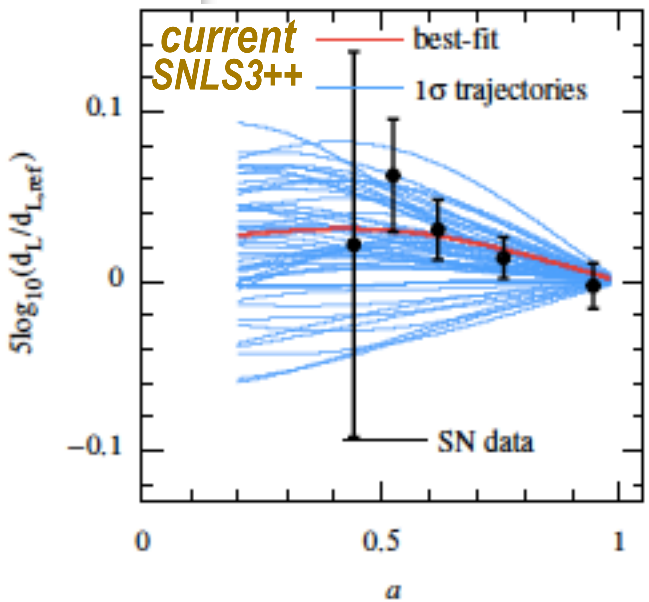
Physics Nobel Prize 2011

current Type Ia Supernova data Apr 2011

472: 123 low-z+ 242 SNLS3yr +93 SDSS1yr + 14 HST

HubbleST constraint H0 = 73.8 +-2.4 km/s/Mpc

Bond, Huang 2011



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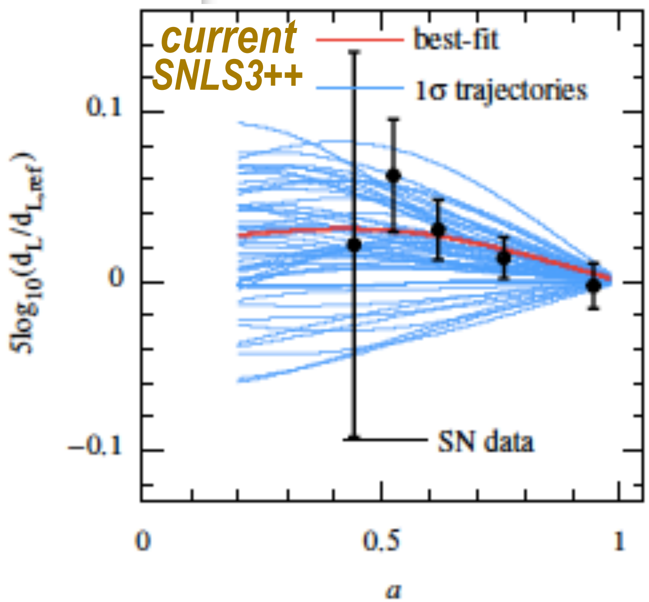
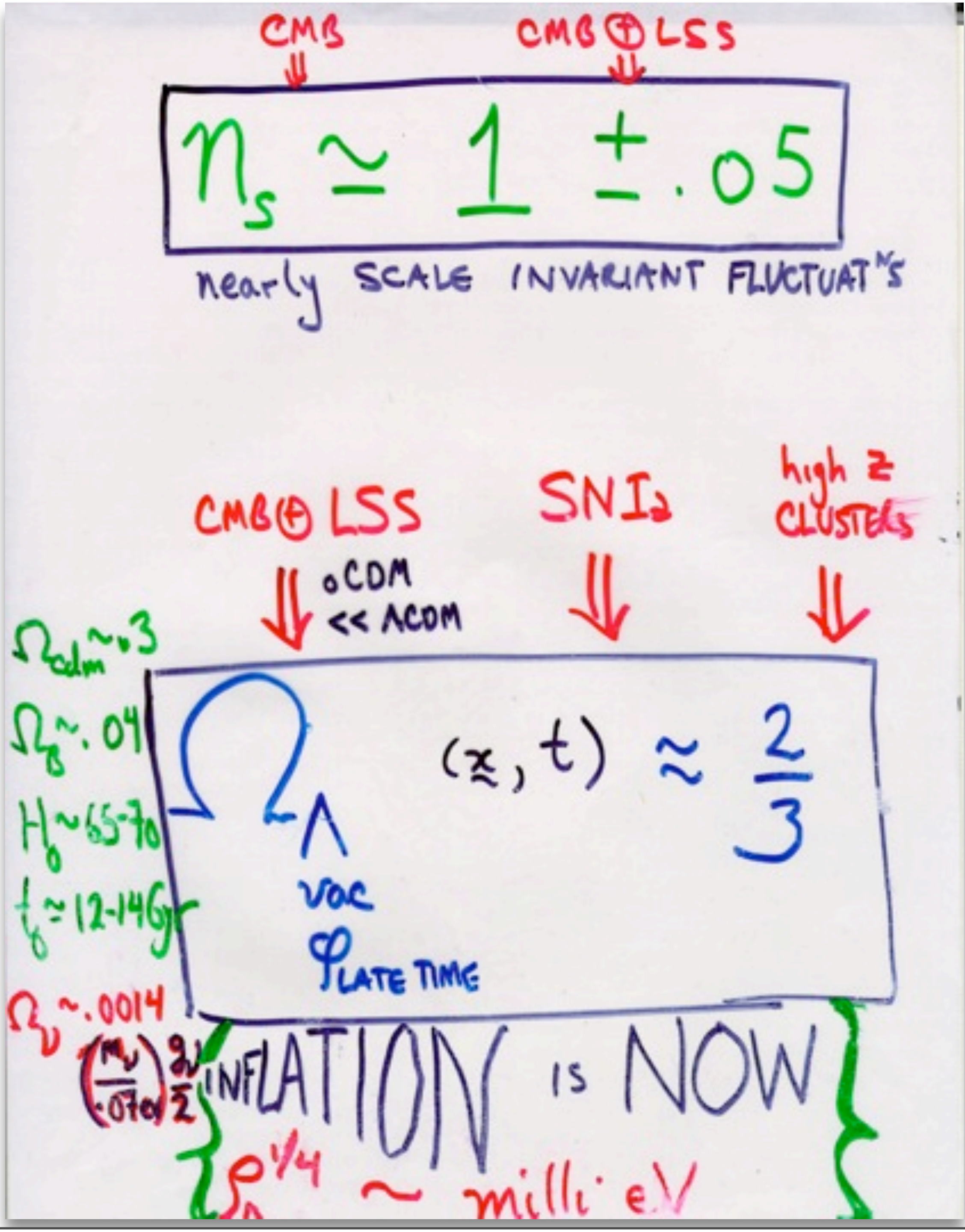


vintage 98 conclusions



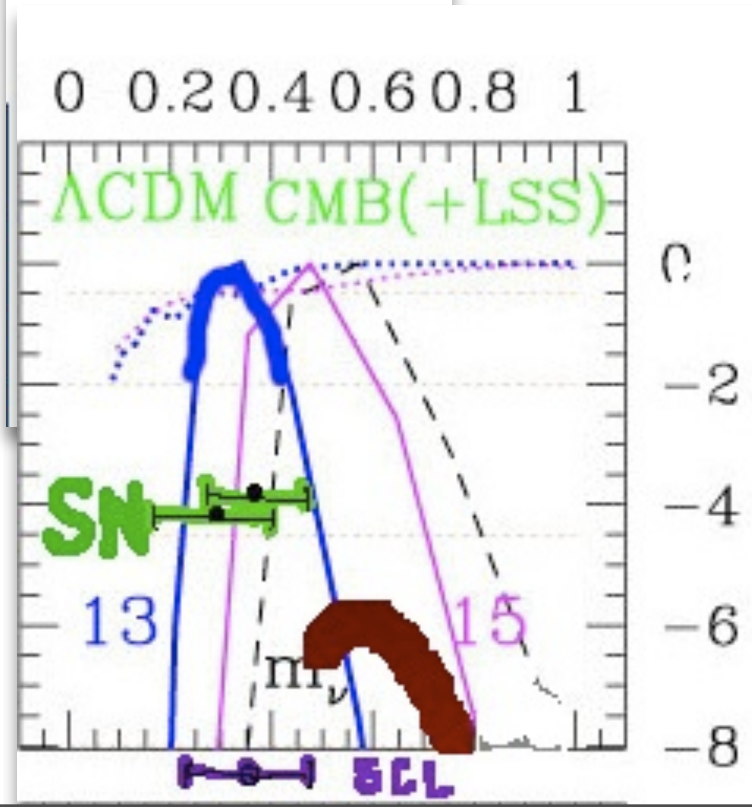
B+Jaffe'96,'98 (13Gyr/t_0)

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

$n_s =$

$.98 \pm .07$

$.96 \pm .06$



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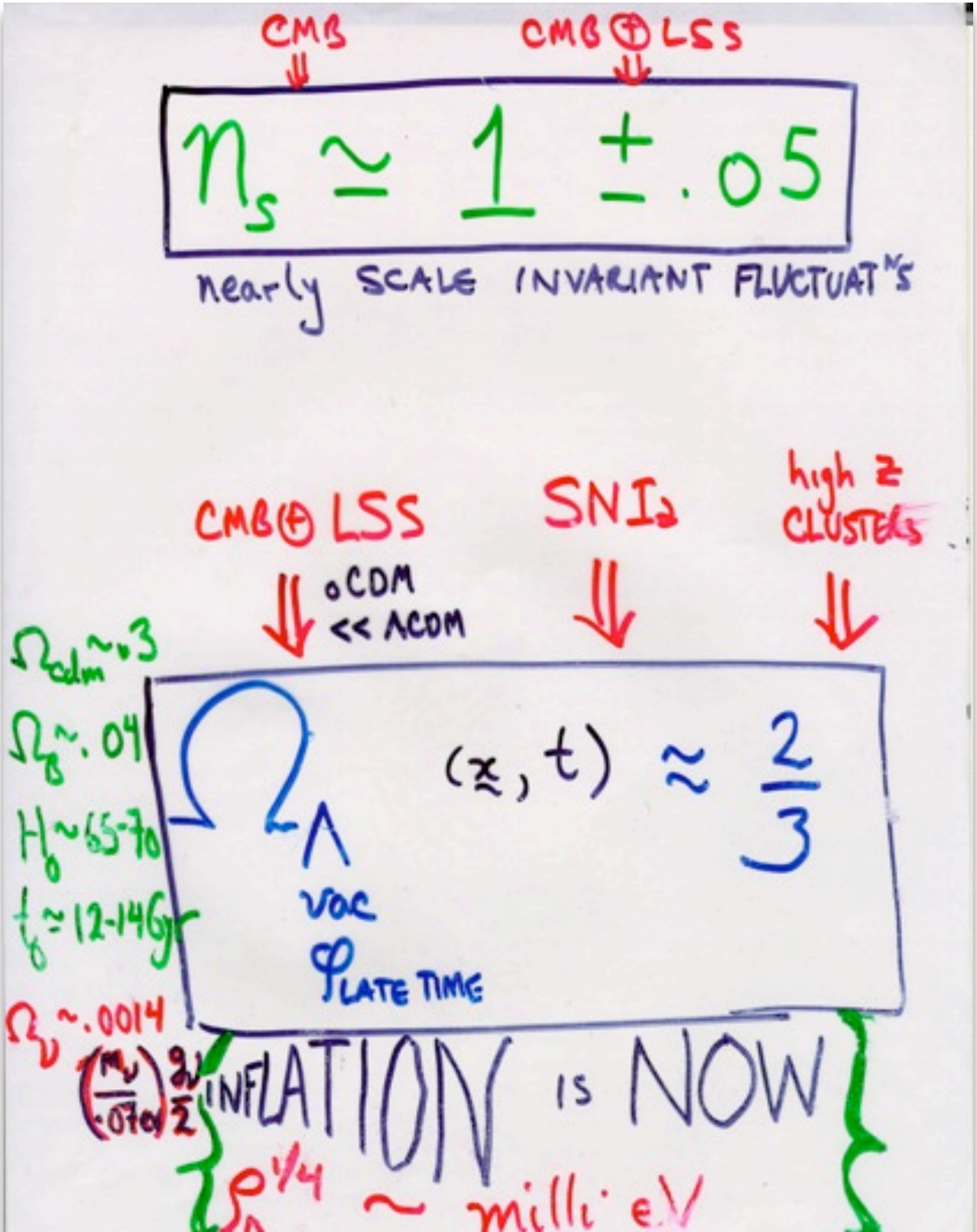

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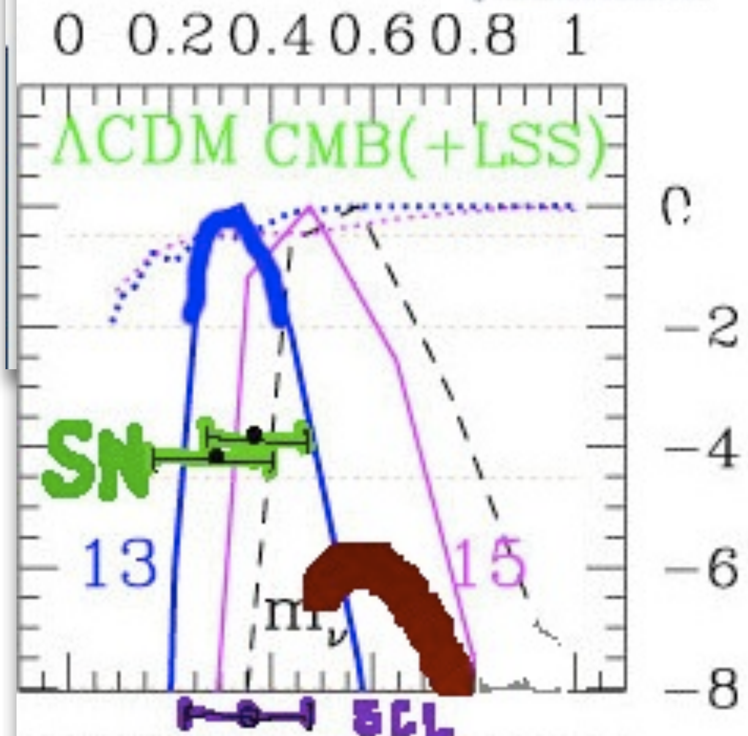
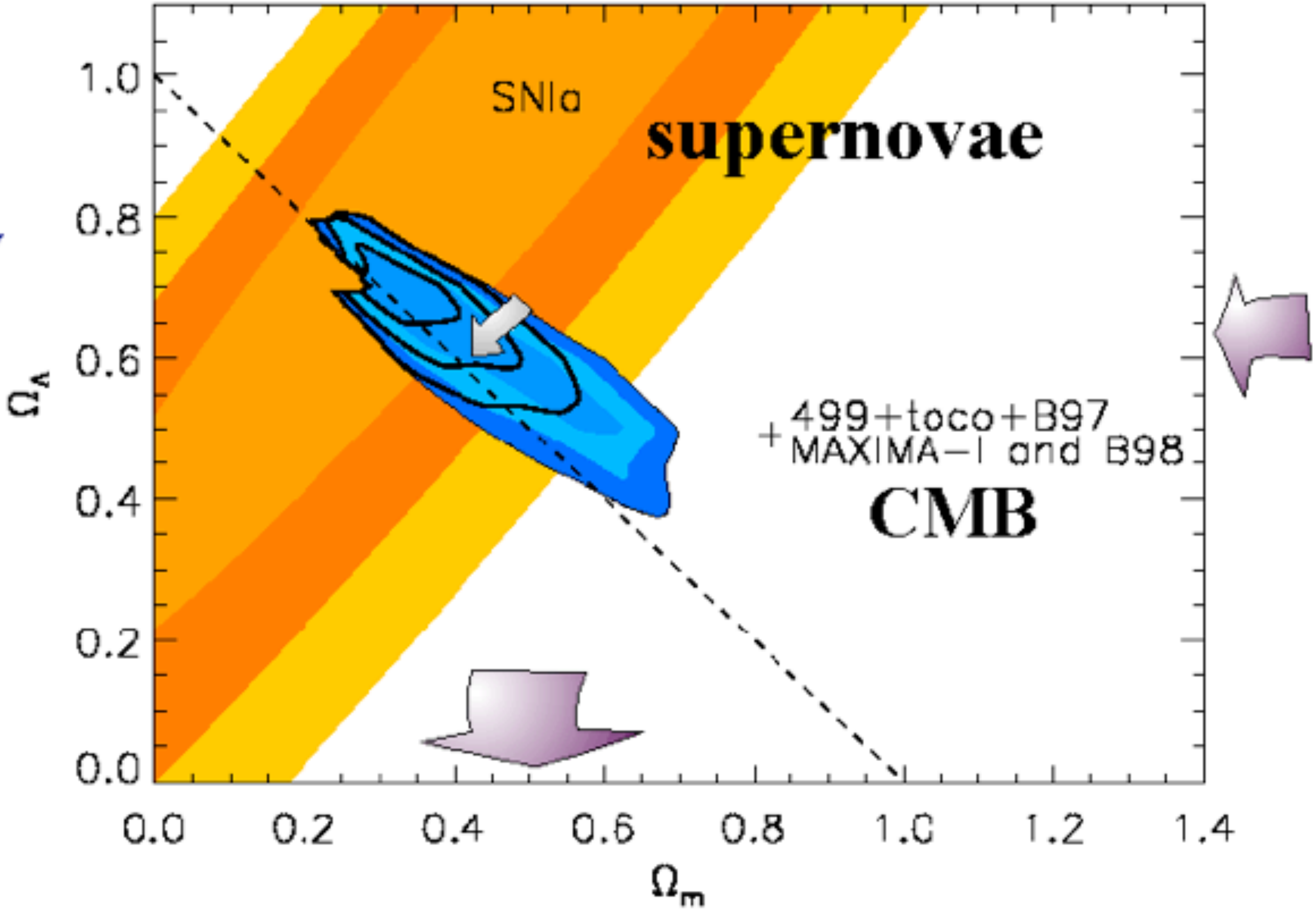


⇒evidence for **"dark energy"** aka **the cosmological constant**

BOOM 2000

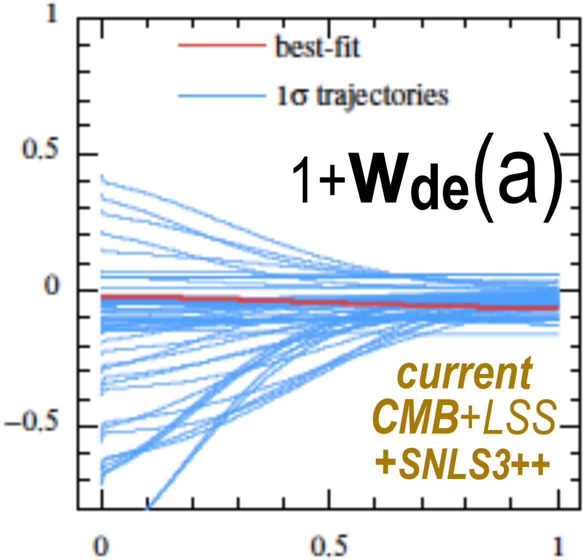
dark energy



dark matter + baryons

NOW & future DE equation of state trajectories

$(1+w_{de}) = -\, d\ln\rho_{de} / d\ln a^3 = 2/3\, \varepsilon_\psi$ & $\varepsilon = \Omega_\psi \varepsilon_\psi + \Omega_m \varepsilon_m$ & $\varepsilon_m = 3/2$



Current Data

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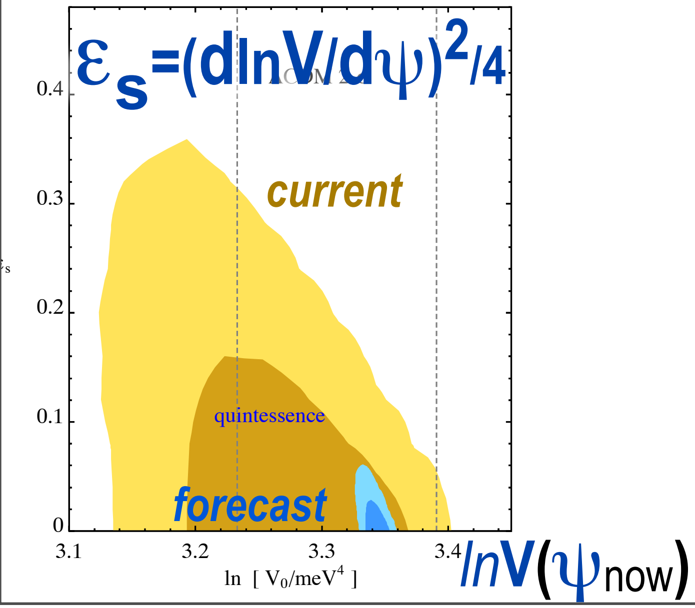
Lya Forest: SDSS

Huang, Bond, Kofman 2010; Bond, Huang 2011



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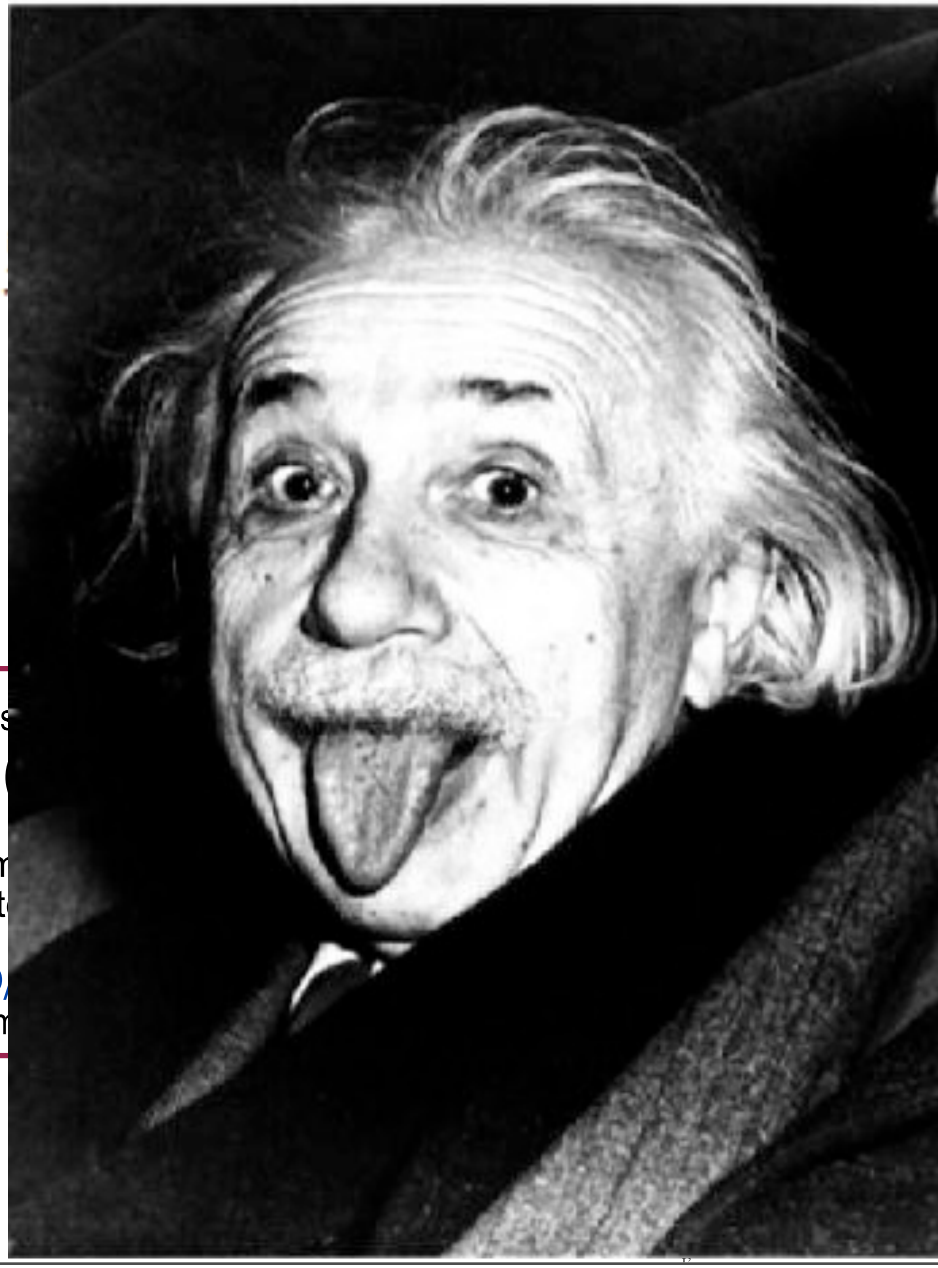

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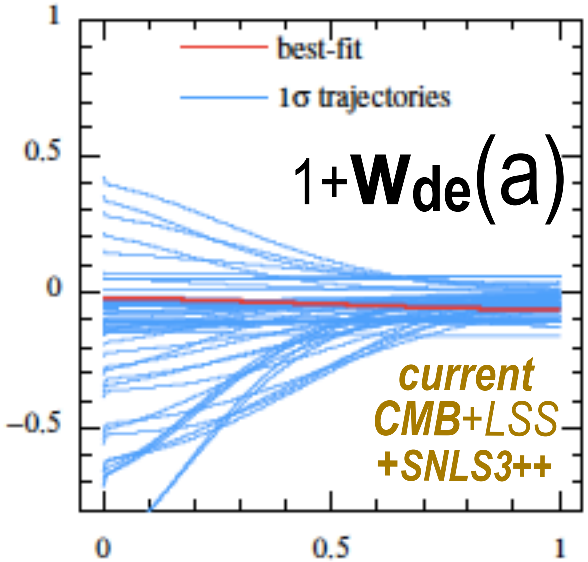

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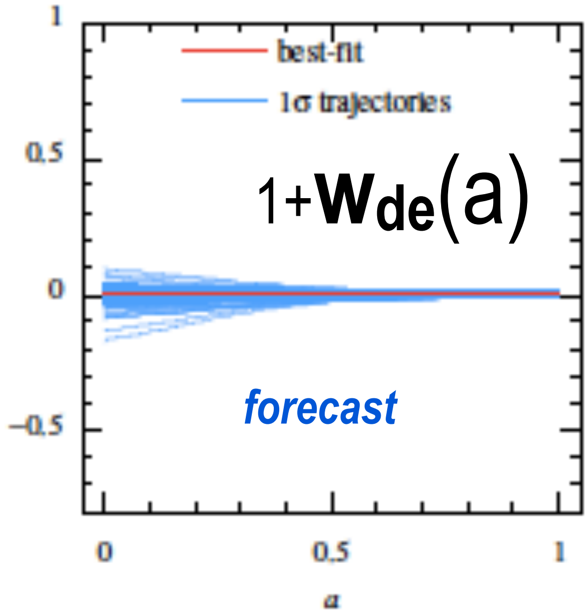


Forecast Data

CMB: Planck2.5yr,

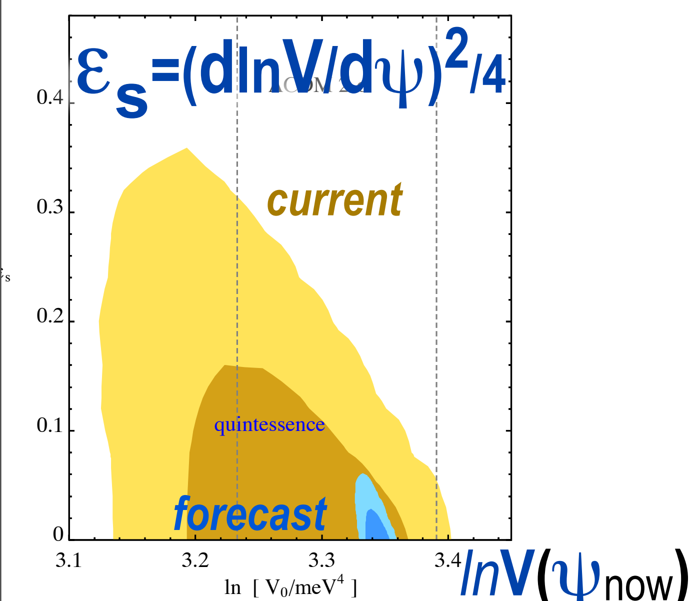
LSS:

EUCLID spectroscopic redshift survey;

21-cm CHIME BAO survey:

EUCLID weak lensing survey

Huang, Bond, Kofman 2010; Bond, Huang 2011

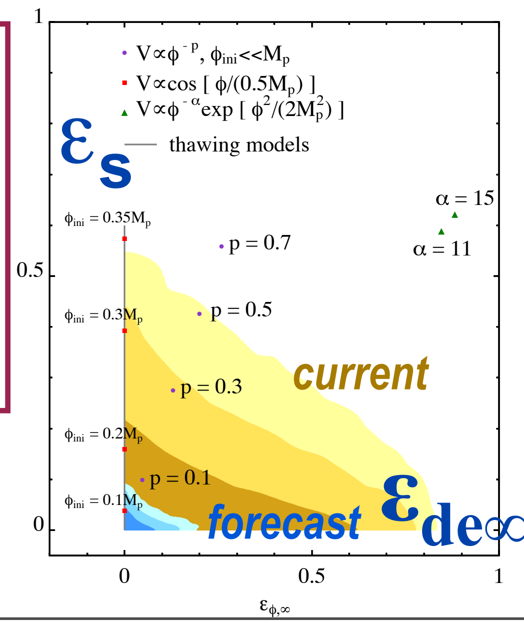


Quintessence $w_{de}(a|V(\psi),IC)$

$\Rightarrow w(a|\varepsilon_s\ \ \varepsilon_{de\infty}\ \ \varsigma_s)$

3parameter form paves even wild late-inflaton trajectories

$\psi=\phi/\sqrt{2}M_P$ = late-inflaton in Planck mass units



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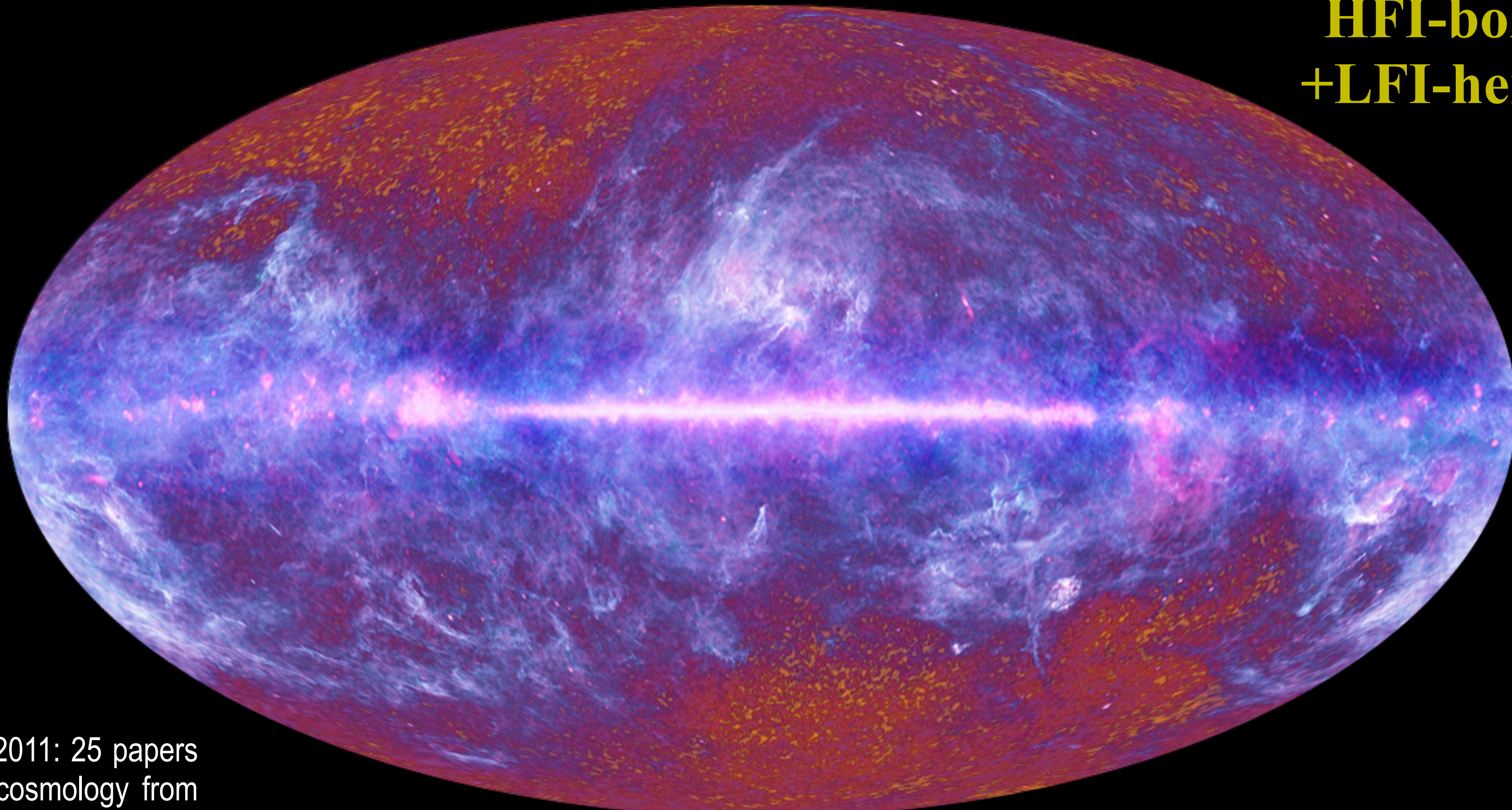
Planck & ACT

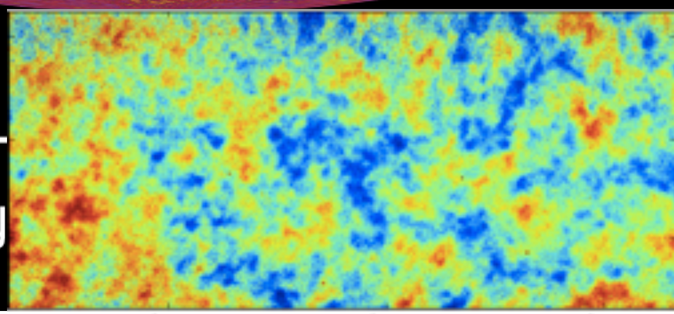
Dick Bond

7 veils(ν)+CMB

9 ν, pol,
HFI-bolos
+LFI-hemts



Jan 2011: 25 papers
first cosmology from
Planck early 2013,
major pol early 2014



ACT+WMAP7 hajian+10

The Planck one-year all-sky survey

ESA, HFI and LFI consortia, July 2010

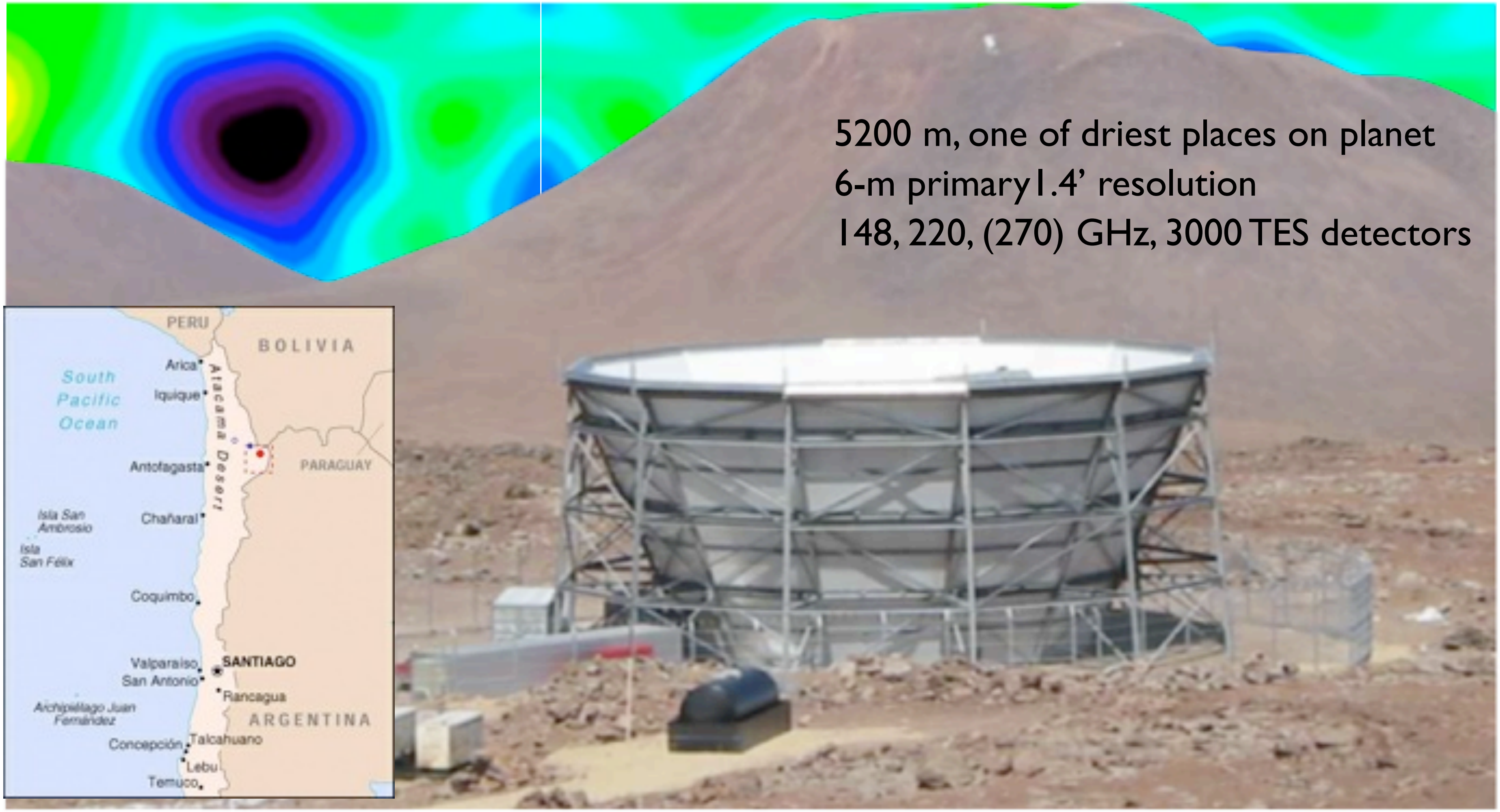
The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 50 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency -- ESA -- with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

Bond since 1993, Canada since 2001, 1st CSA pre-launch contract 2002-09, post-launch 2010-11, 2011-13

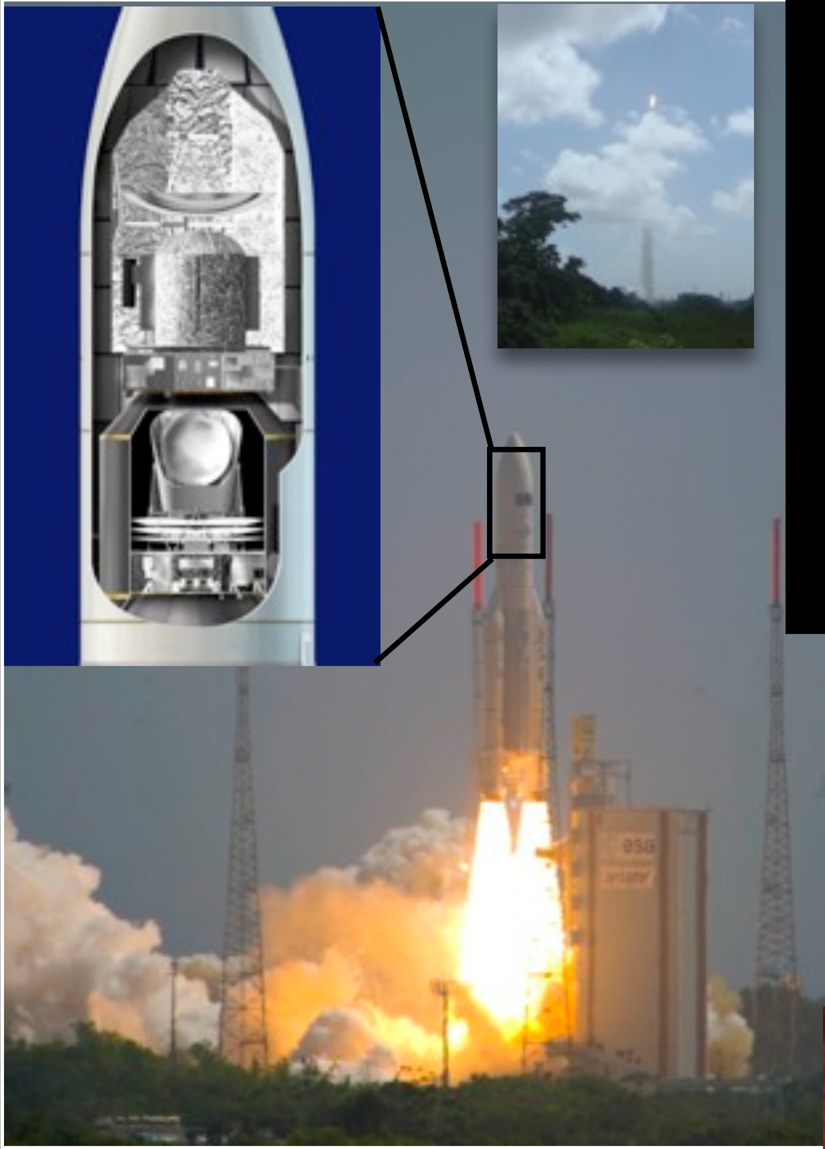
Cosmology From 5200 metres:
the Atacama Cosmology Telescope

5200 m, one of driest places on planet
6-m primary1.4’ resolution
148, 220, (270) GHz, 3000 TES detectors



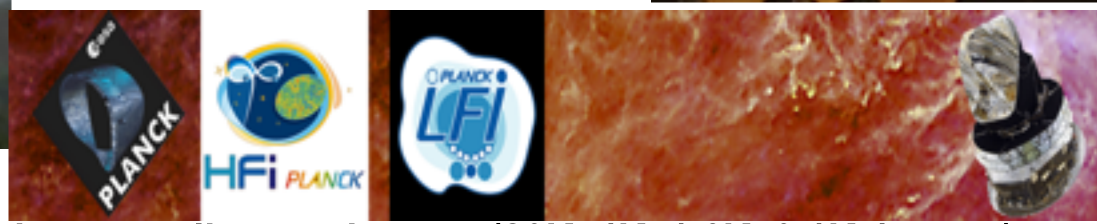
CMB@CITA: Boomerang, Acbar, CBI1,2, Planck, ACT, Spider, Blast, & ACTpol, ABS, QUIET90-2;
GBT-Mustang2, CARMA/SZA, SCUBA2, ALMA

Planck+Herschel Launch May14 09 Fr. Guiana



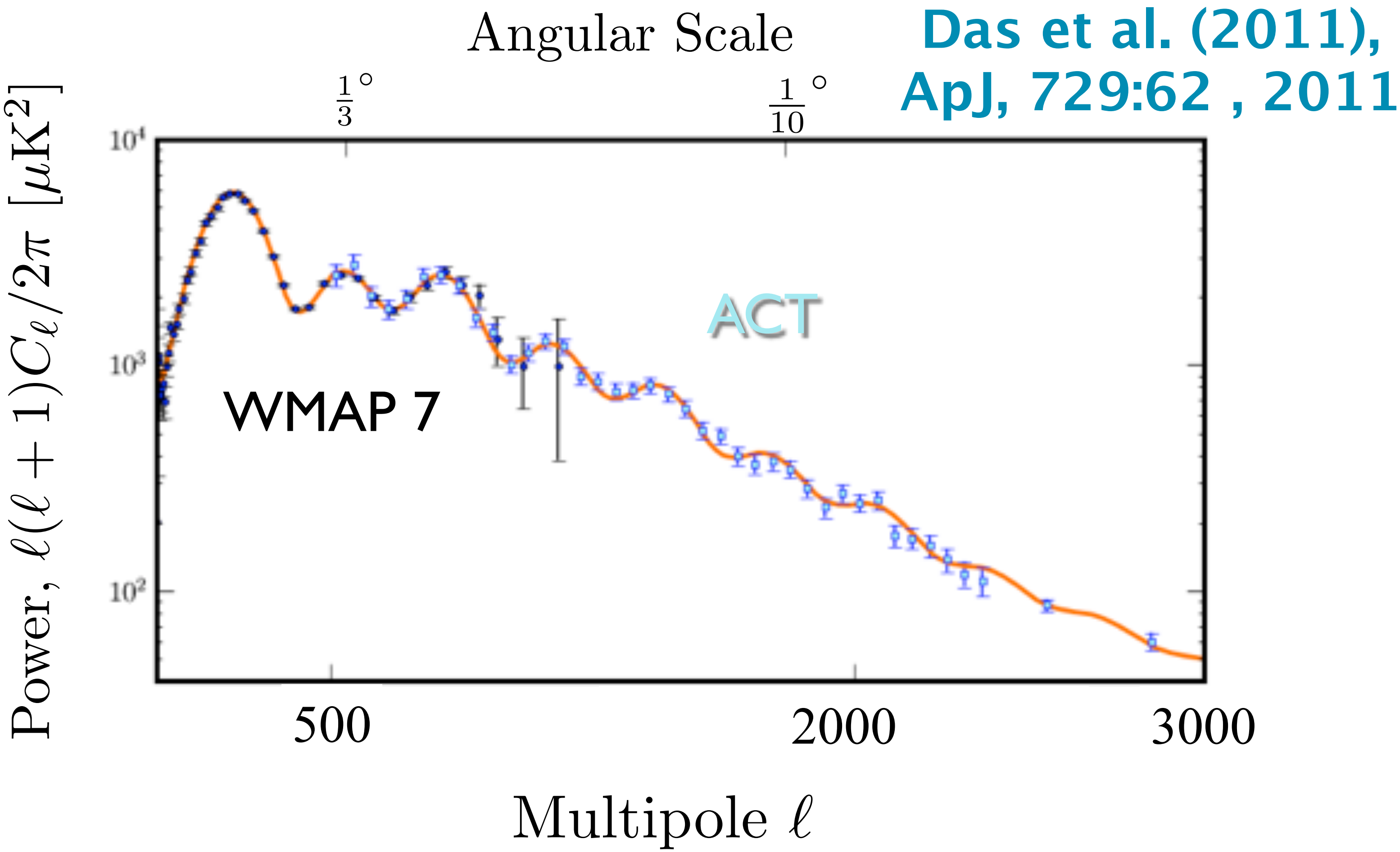
1.5m telescope, HFI bolometers @6freq <100mK, LFI HEMTs@3freq, some bolometers & all HEMTS are polarization sensitive

HFI+LFI **performance** to **spec** or better



Left earth at ~10 km/s, 1.5 million km in 45 days, cooling on the way (20K, 4K, 1.6K, 0.1K 4 stage).
@L2 on July 2 09 -almost no trajectory correction @operational temp; Survey started on Aug 13 09
spin@1 rpm, 40-50 minutes on the same circle, covers all-sky in ~6 month, ~4 surveys Aug11, ~5 total

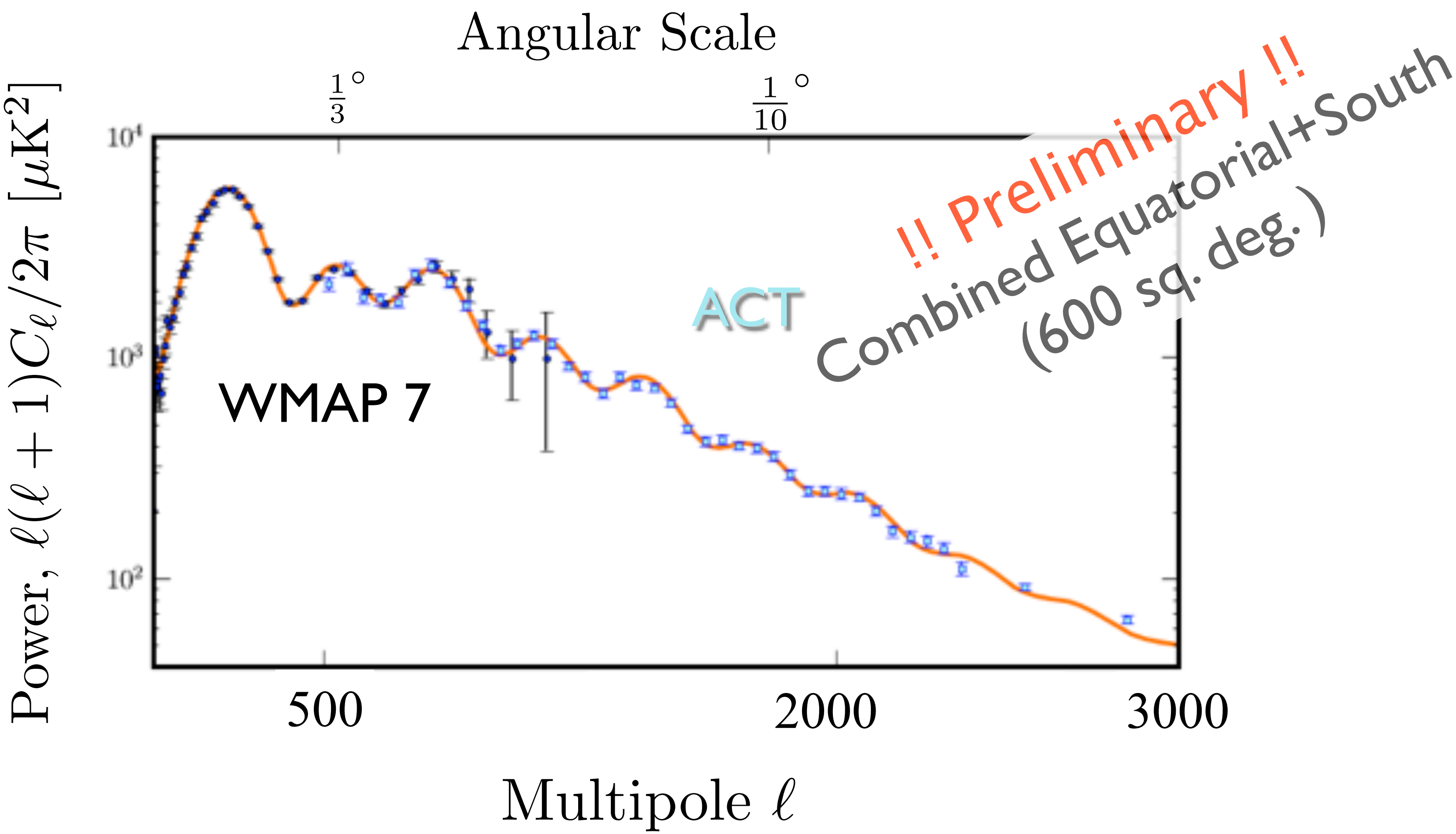
HIGH RESOLUTION POWER SPECTRUM FROM ACT



tilted ΛCDM a very good fit (n_s constant); but data are good enough to search for subdominant cosmic parameters

Dunkley+. 2010

HIGH RESOLUTION POWER SPECTRUM FROM ACT: NEW RESULT!



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Sievers+. 2011

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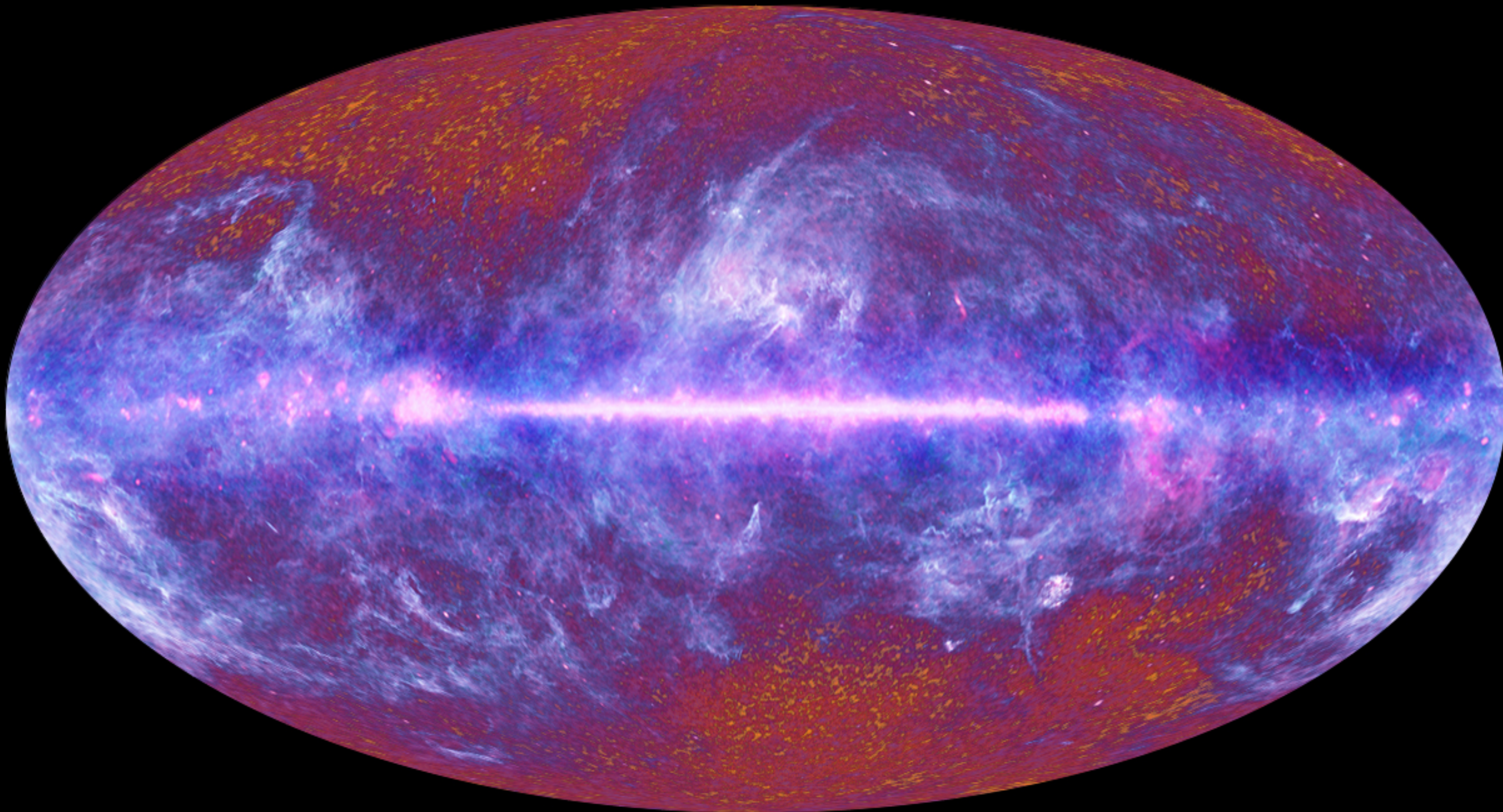
WMAP: 1.15 Tbits in 9yrs, cf. MyLifeBits, Gordon Bell, 1.28 Tbits in 9yrs, Planck 36 Tbits, ACT 304 Tbits. Radically Compress to high quality Bits. Terabit=10^{12}bits=125 GigaBytes.

Beyond the standard model: tilted ΛCDM + x

Prob (**cosmic parameters & trajectories** | CMB+LSS data, theory-framework)



morphs into the nonlinear **Cosmic Web: clusters, filaments, voids; galaxies** (SZ)

gastrophysical simulations with feedback from AGN starbursts .. confront CMB+LSS data

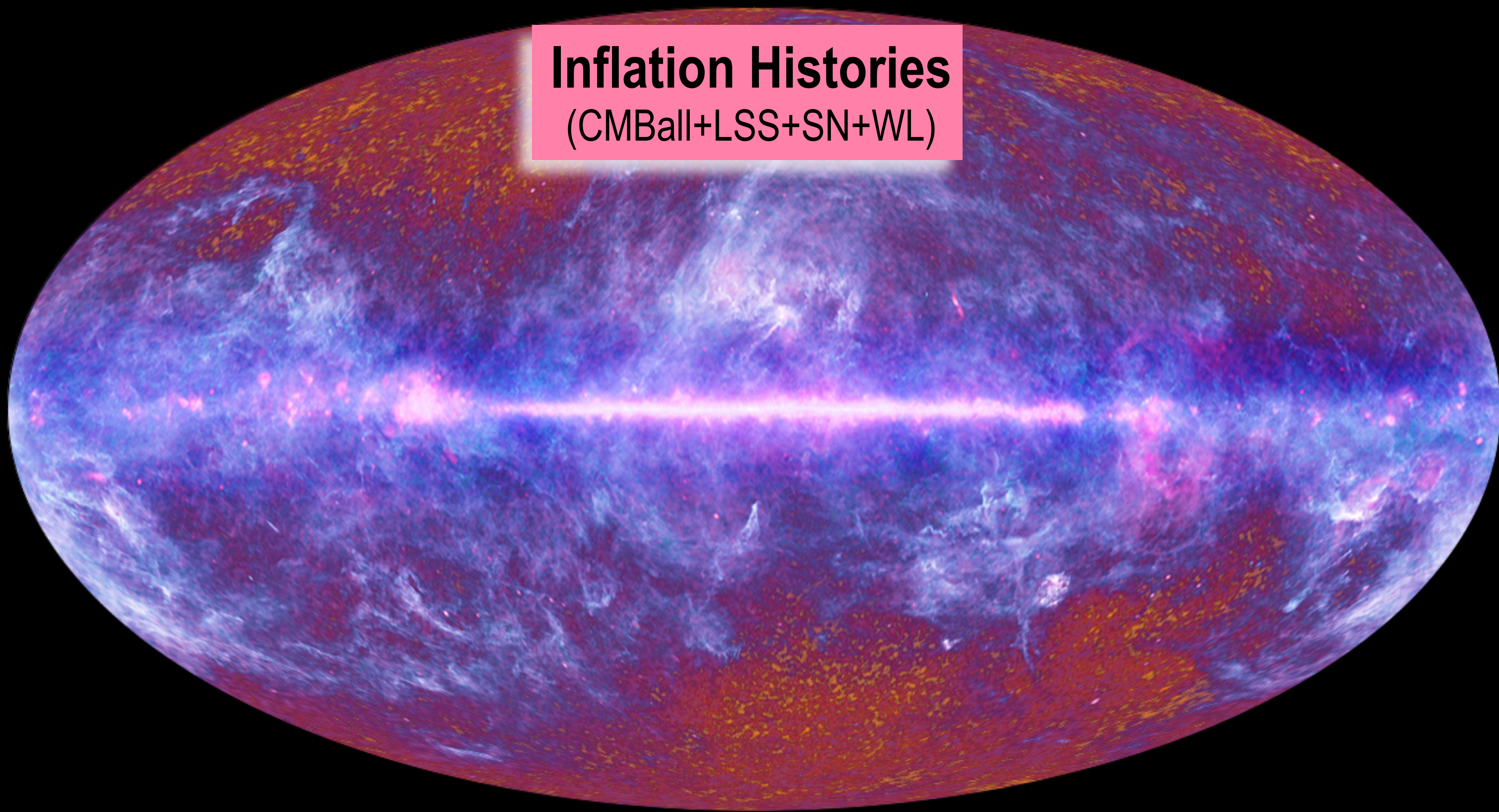
The Planck one-year all-sky survey

(c) ESA, HFI and LFI consortia, July 2010

Beyond the standard model: tilted ΛCDM + x

*Prob (**cosmic parameters & trajectories** | CMB+LSS data, theory-framework)*

Inflation Histories
(CMBall+LSS+SN+WL)



morphs *into the nonlinear* ***Cosmic Web: clusters, filaments, voids; galaxies*** **(SZ)**

gastrophysical simulations with feedback from AGN starbursts .. confront CMB+LSS data

The Planck one-year all-sky survey

esa

(c) ESA, HFI and LFI consortia, July 2010

Beyond the standard model: tilted ΛCDM + x

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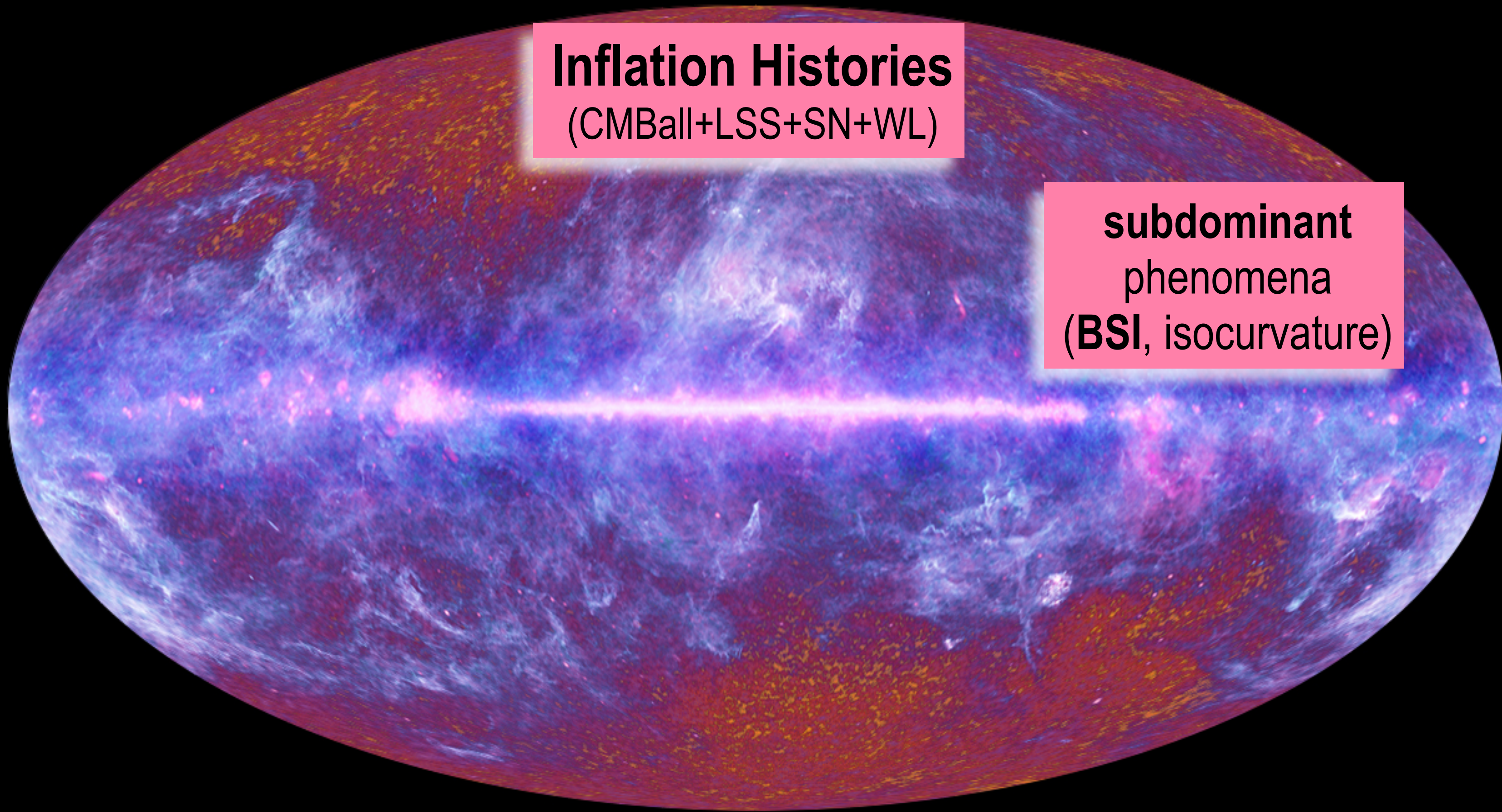

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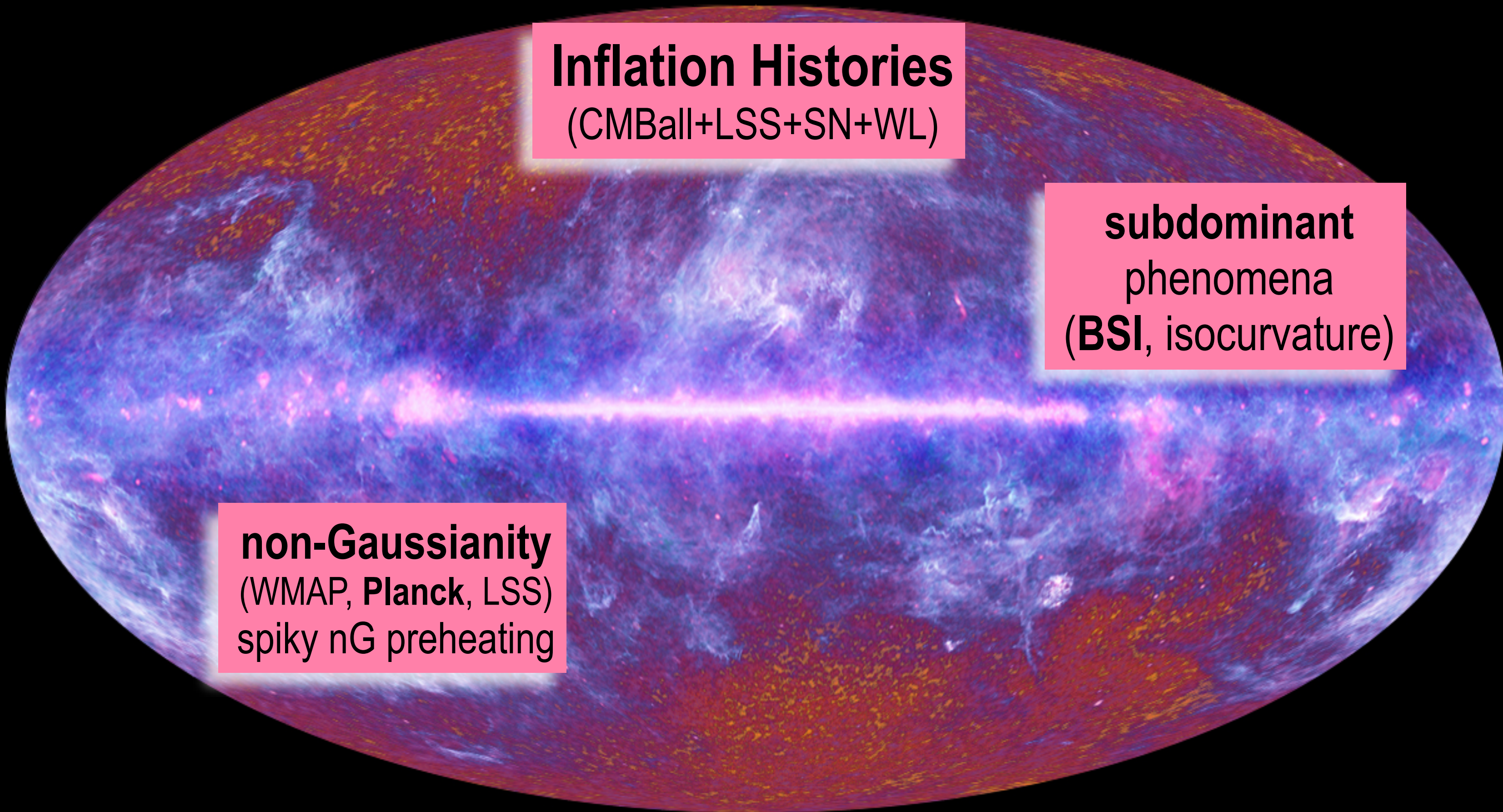

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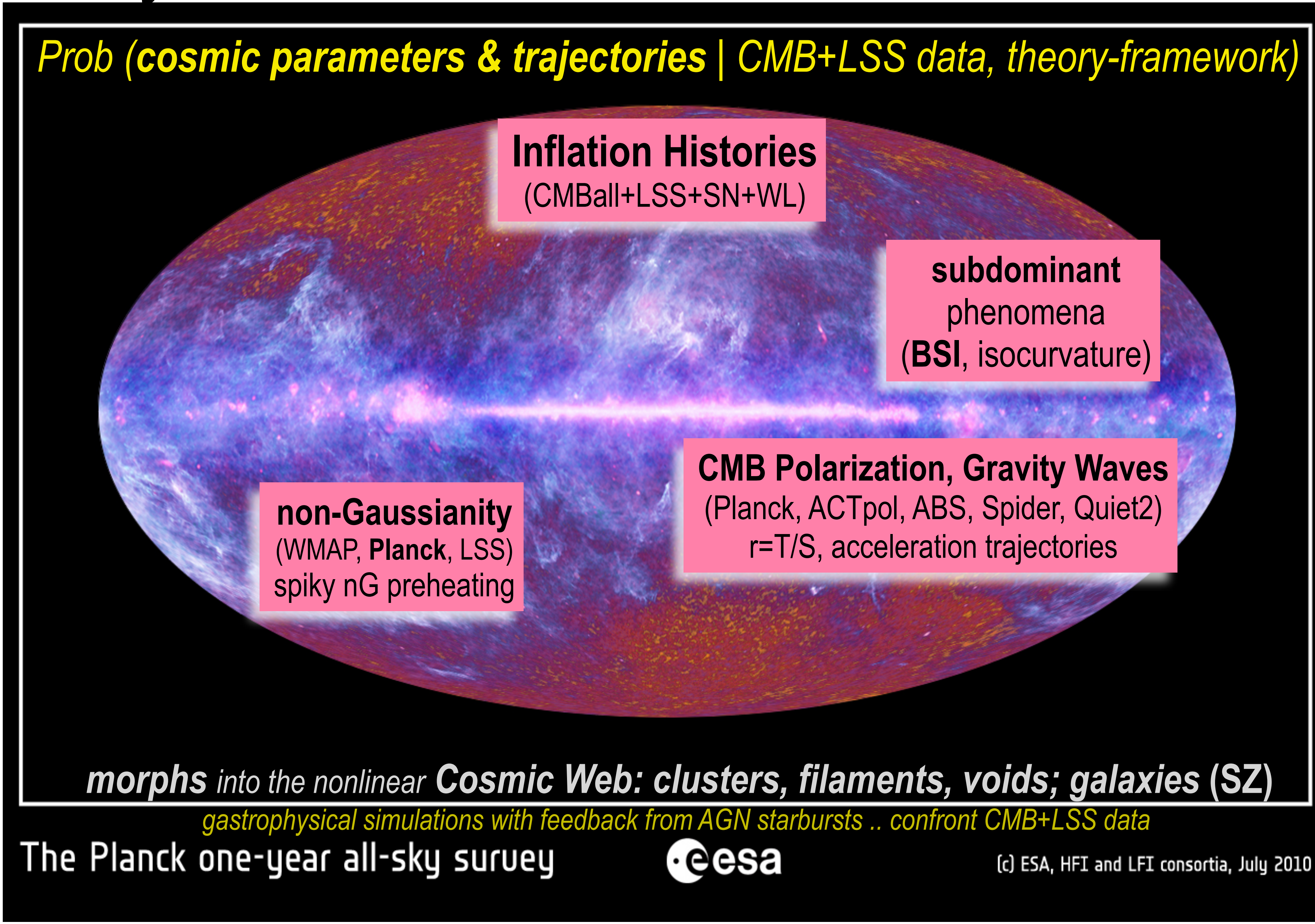

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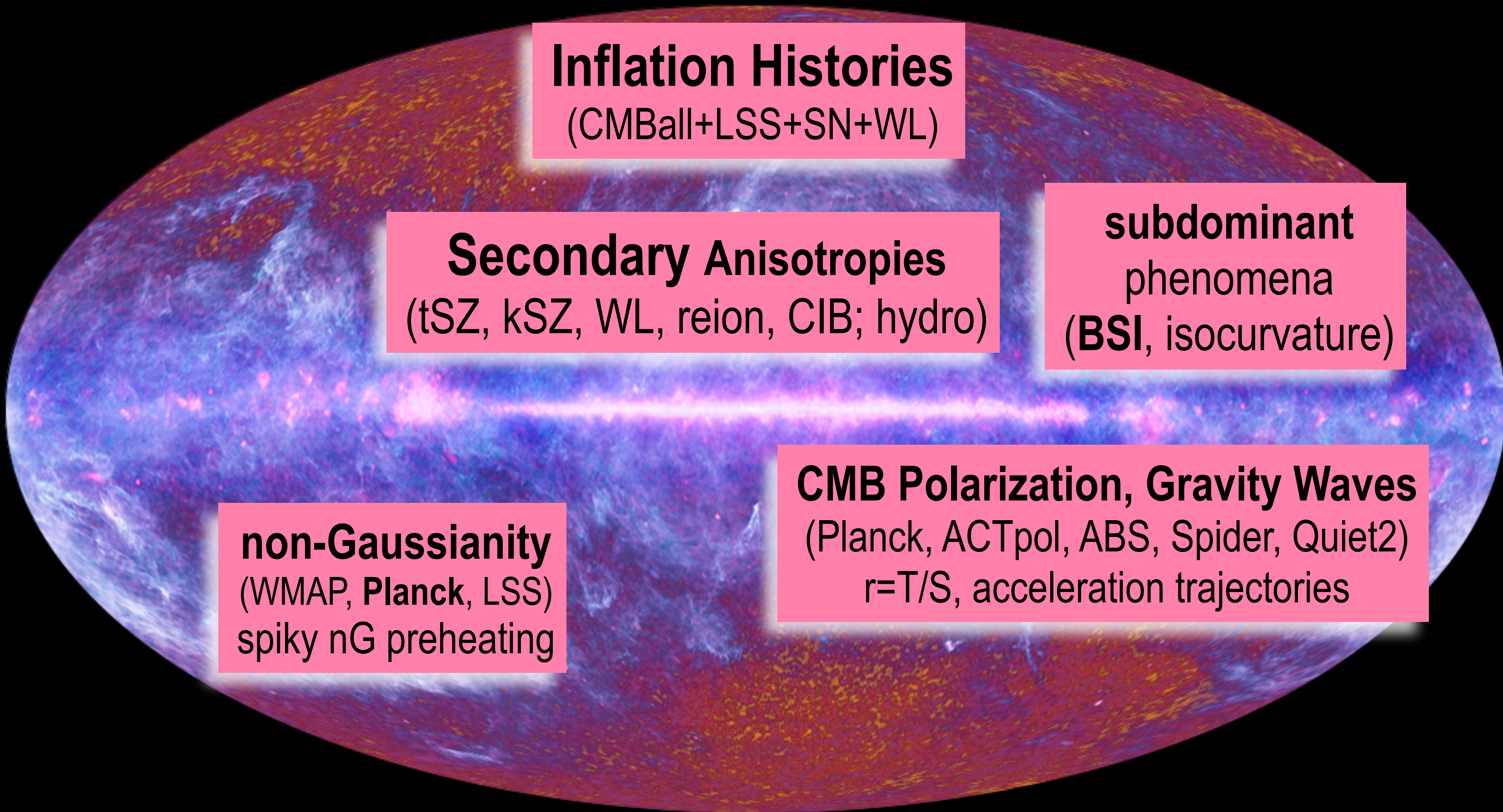

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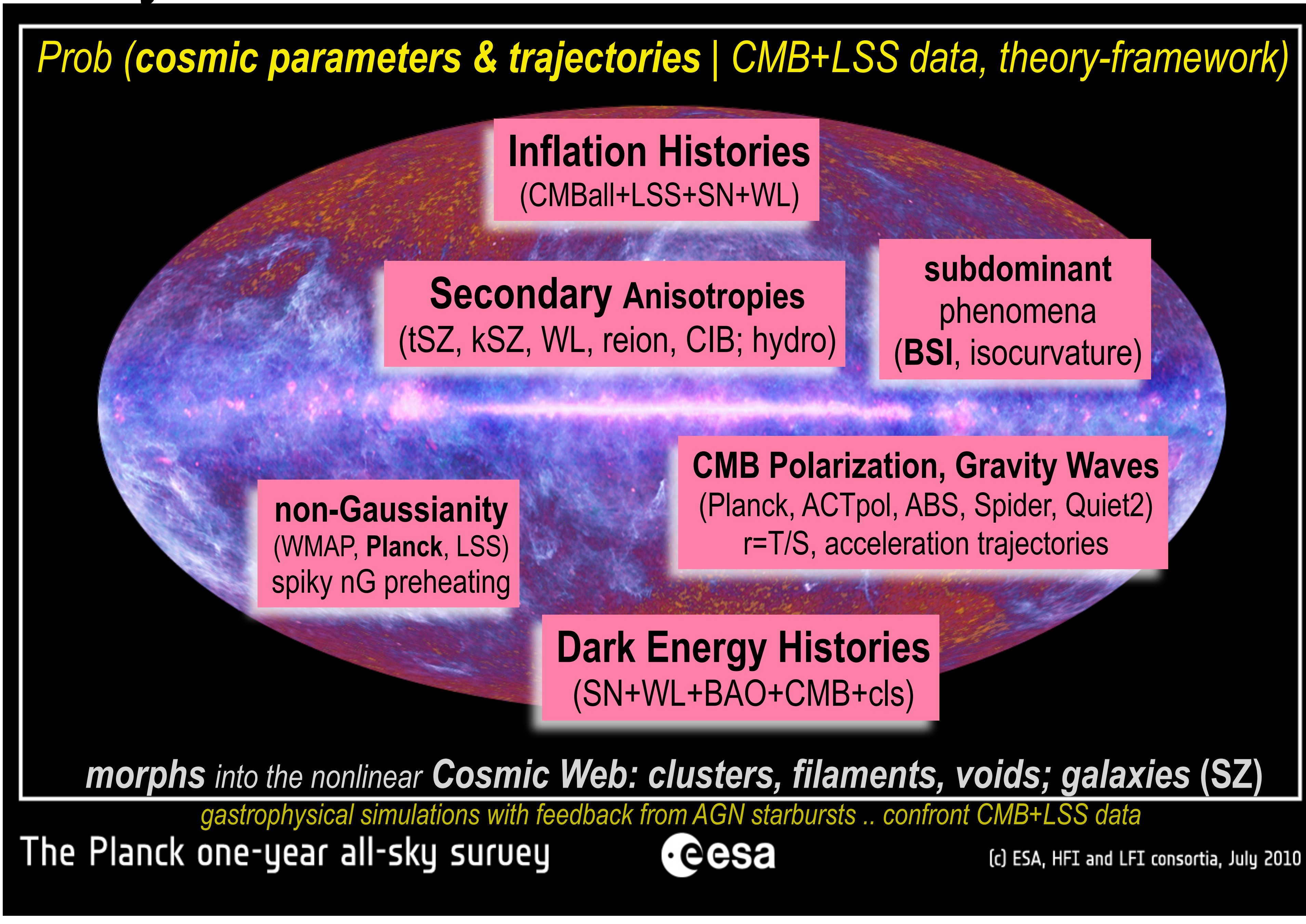

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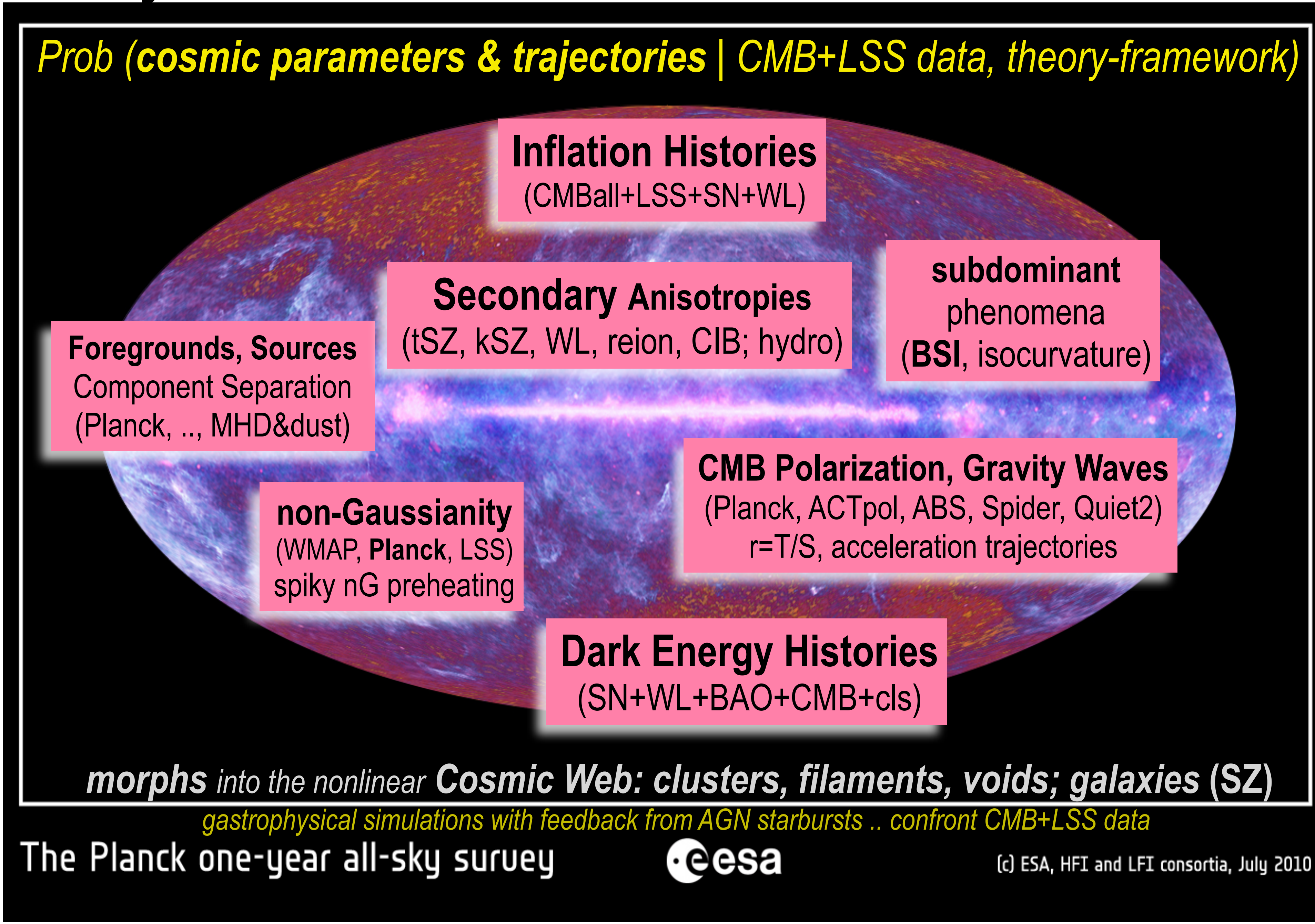


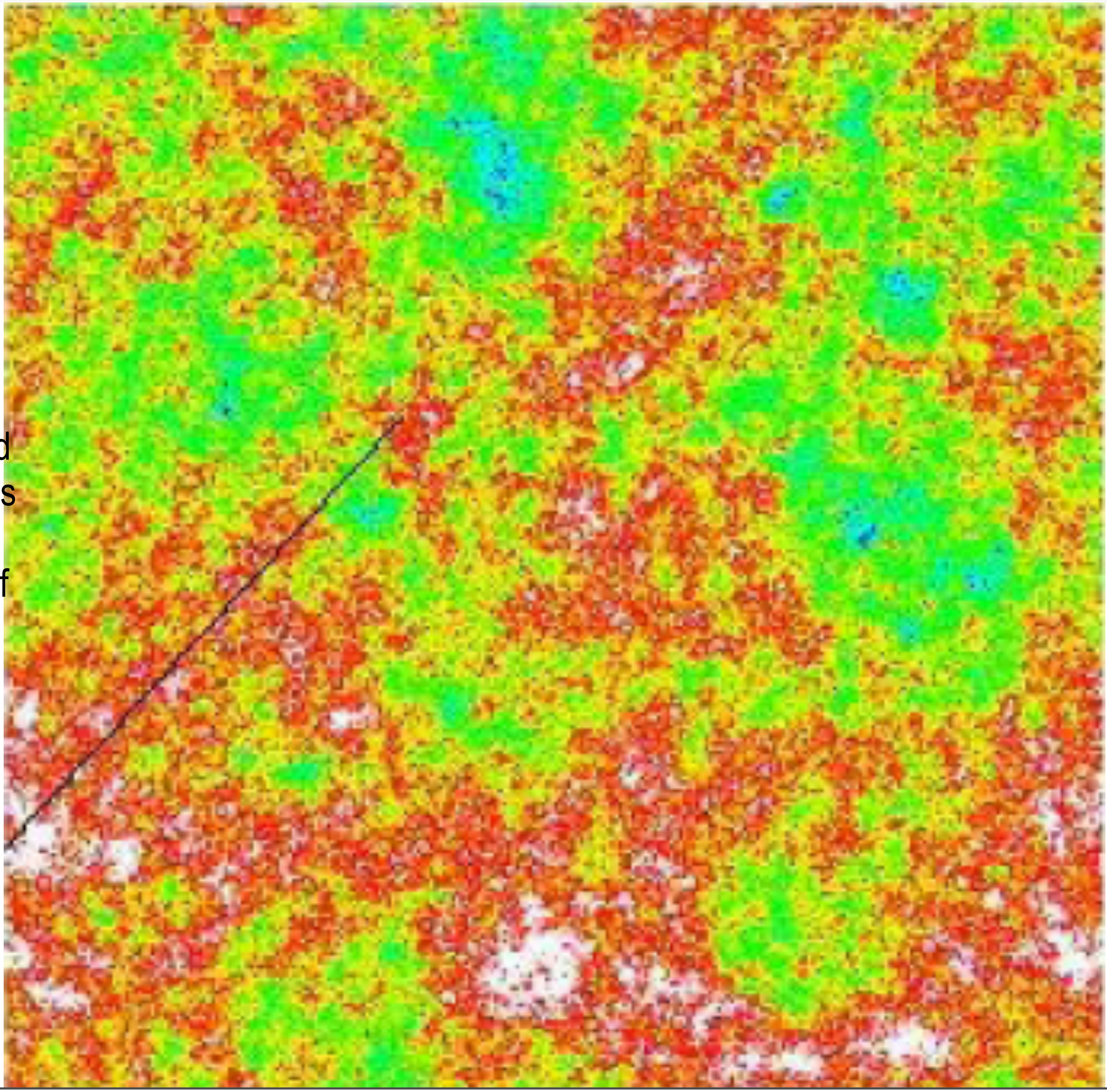
Thursday, 10 November, 11

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

χ

scalar field fluctuations in the vacuum of the ultra-early Universe

pre-heating patch (~1cm)



10 Gpc

$\chi(x,\ln a)$

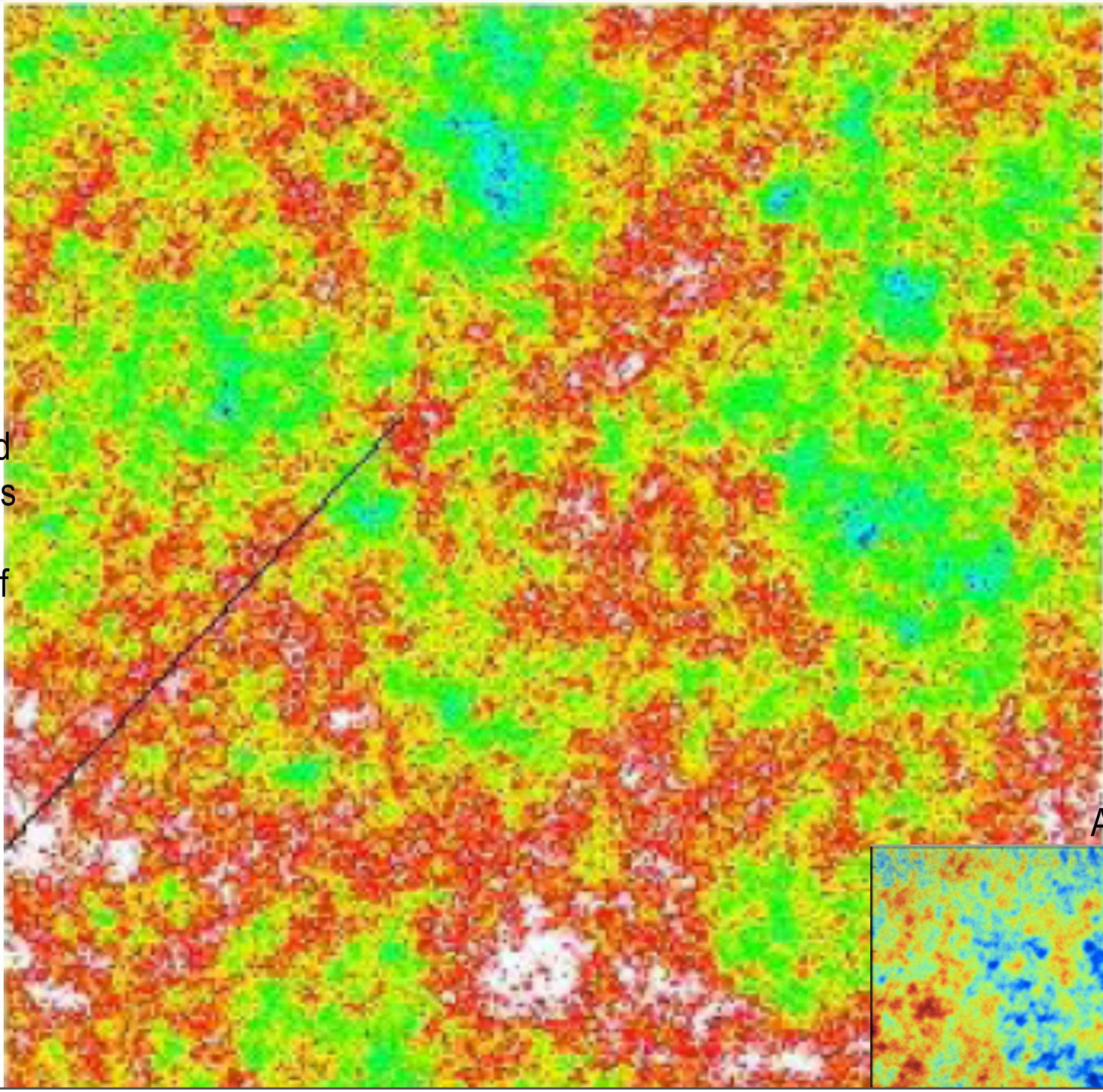
$\ln a(x,\ln H)$

evolve from early U vacuum potential and vacuum noise

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

χ

ln**a(x,**ln**H)**



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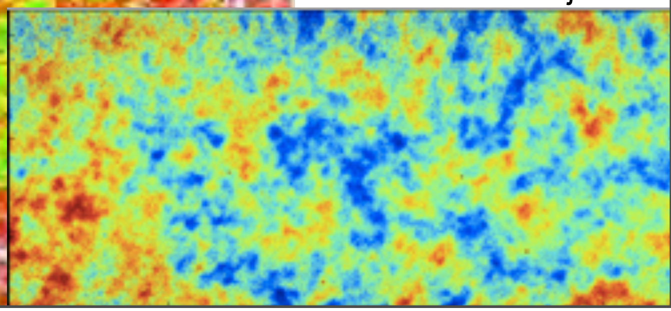
ACT+WMAP7 hajian+10



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

400 Mpc

ΛCDM

WMAP5

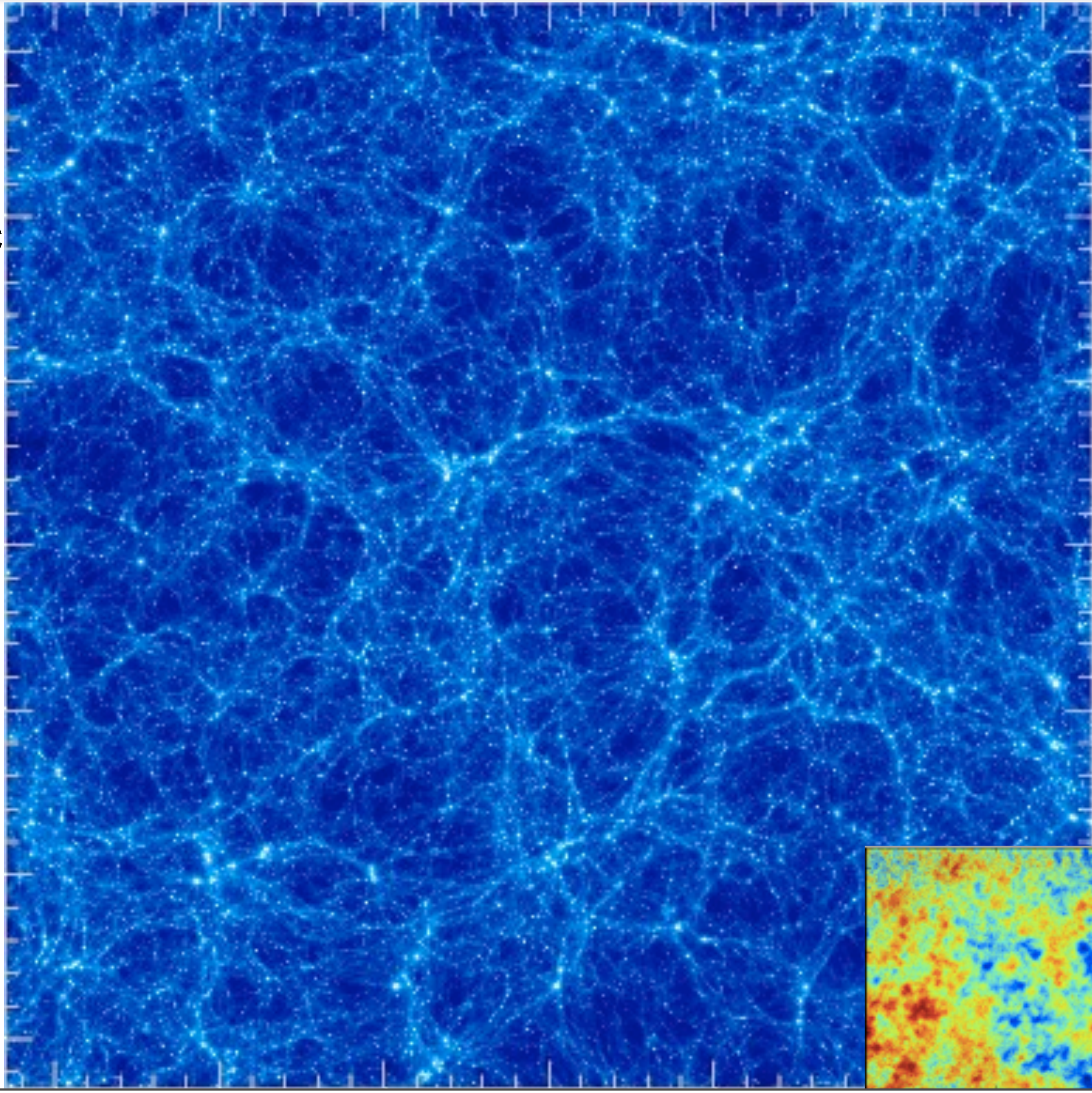
gas density

Gadget-3

SF+ SN E+ winds +CRs

512^3

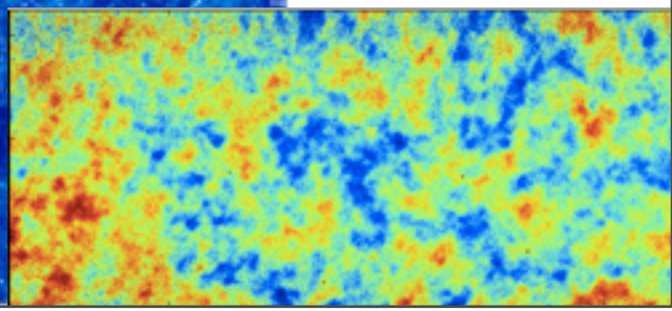
BBPSS10



$\rho_g(x,t)$

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential aka dark energy



pressure intermittency *in the cosmic web, in cluster-group concentrations probed by* **tSZ**

400 Mpc

ΛCDM

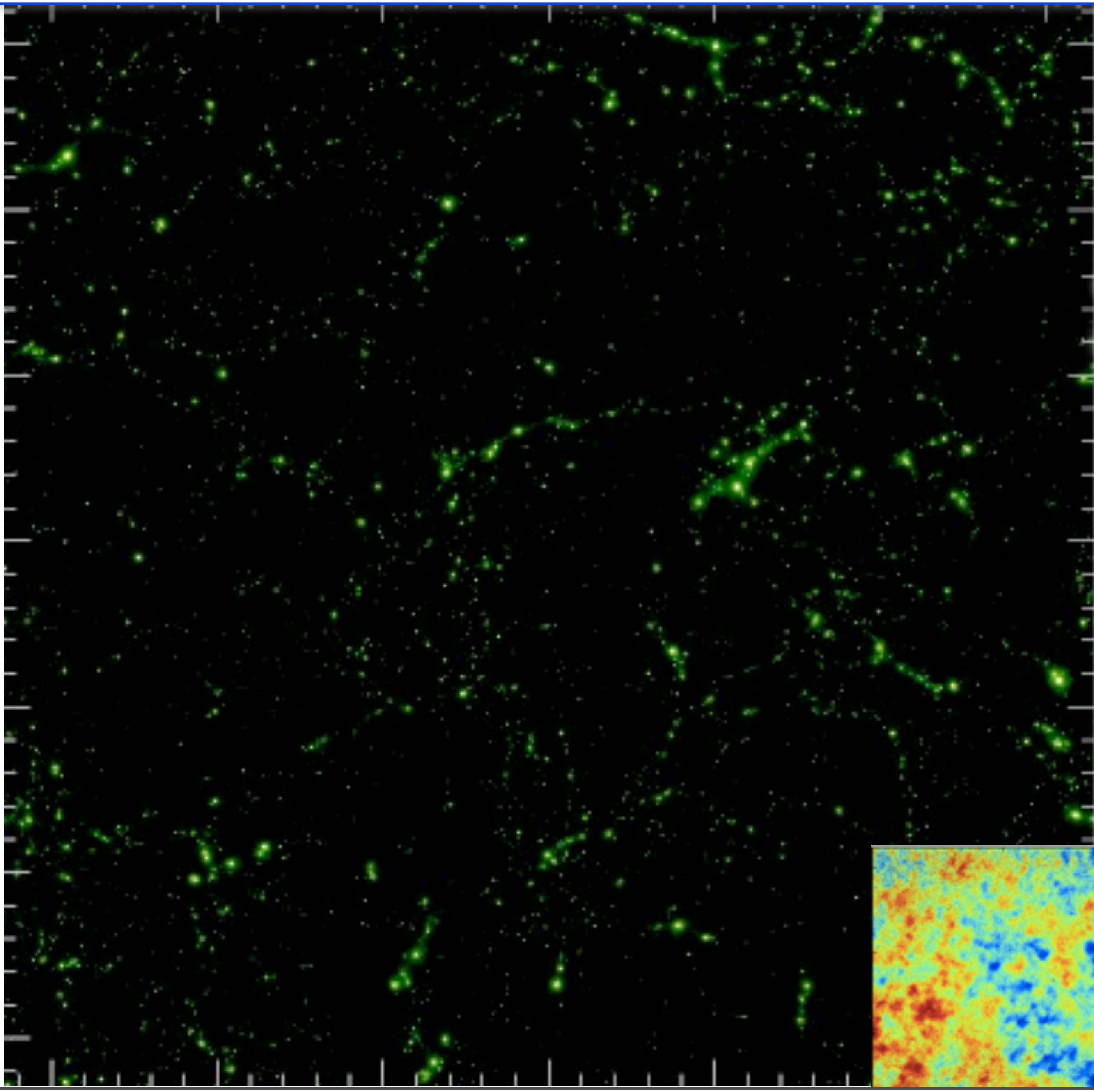
WMAP5

gas pressure

Gadget-3
SF+
SN E+
winds
+CRs

512^3

BBPSS10



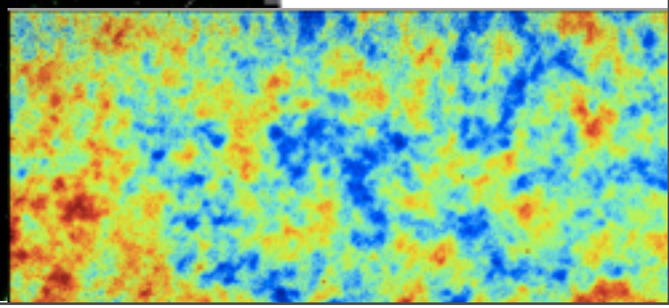
$p_e(x,t)$

CMB gets entangled in the cosmic web

descending into the real gastrophysics of cosmic weather

the energetic, turbulent, dissipative, compressive

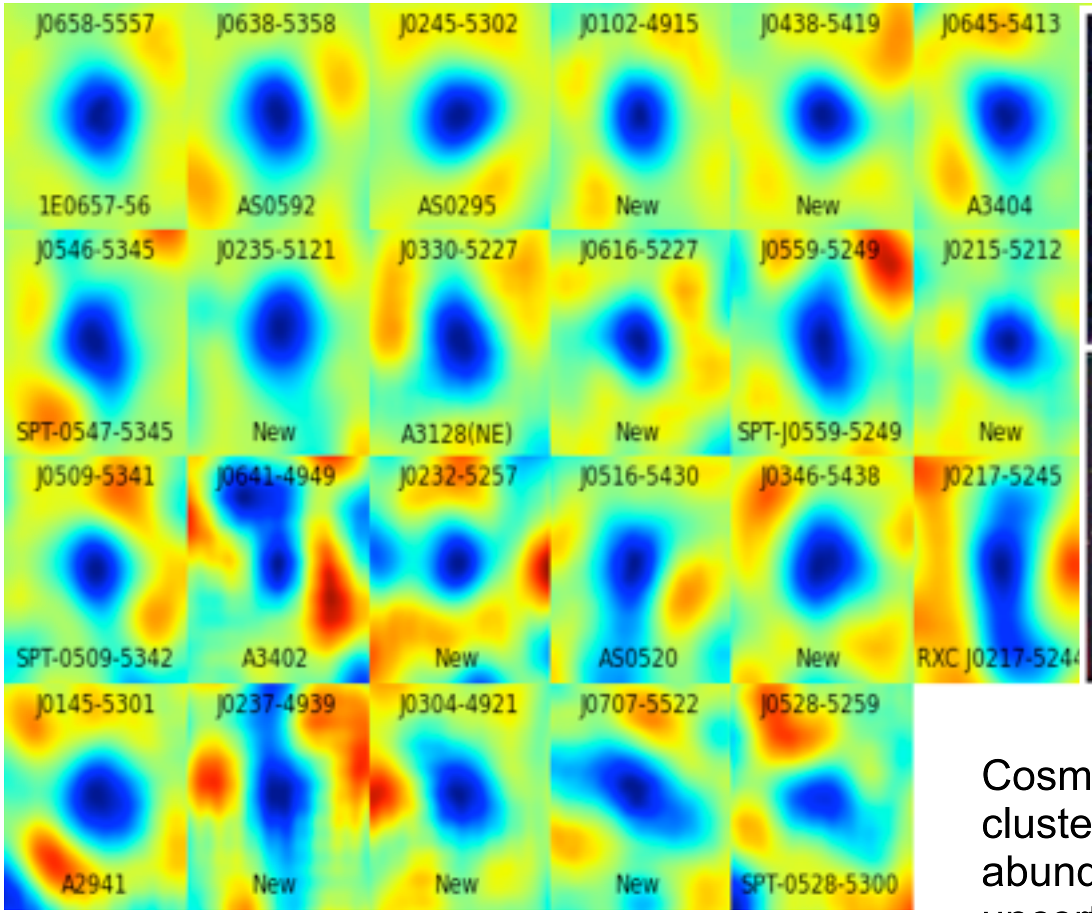
life of the IGM/ICM/ISM



23 Galaxy Clusters Found by ACT via SZ Signal

Marriage et al 2010 (1010.1065)

Optical Observations Menanteau et al 2010 (1006.5126)



Cosmic Parameters from 9 confirmed clusters (Sehgal et al.2010) using cluster abundances => mass calibration still too uncertain (e.g. σ_8=0.82±0.05 to 0.85±0.12). attempt at Dark Energy equation of state, little leverage

With the ACT equatorial strip, >50 clusters.

Menanteau+11, el Gordo, a “bullet”-like Cluster at z~0.87, discovered in 2009 data by Manenteau+10, highest SZ flux in 755 sq deg Marriage+2011, much follow-up

CBI pol to Apr'05 @Chile **CBI2**

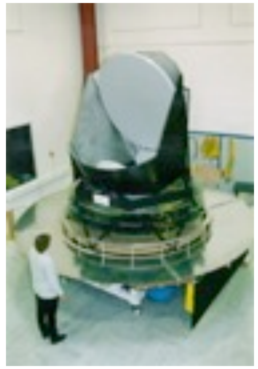
53+35 cls **(>=40)**

QUaD @SP

189 +10 **cls (>=1000)**

Planck09.4

52+ bolometers
+ HEMTs @L2
9 frequencies



WMAP @L2 **to 2010**

2004 2005 2006 2007 2008 **LHC** 2009 2011

Bpol @L2

21+26~50 (>=750)

SPT
1000 bolos
@SPole

>96

OVRO /BIMA array

38 cls

Acbar@SP
~1 blind

SZA@Cal

3 cls (z>1), x?

AMIBA

6 cls

AMI

7+1 cls >=50+25

GBT

4 cls (~25 CLASH)

APEX
~400 bolos@Chile

~25 cls

ACT **23+27~50 cls**

3000 bolos
3 freqs @Chile

SCUBA2
12000 bolos
JCMT @Hawaii

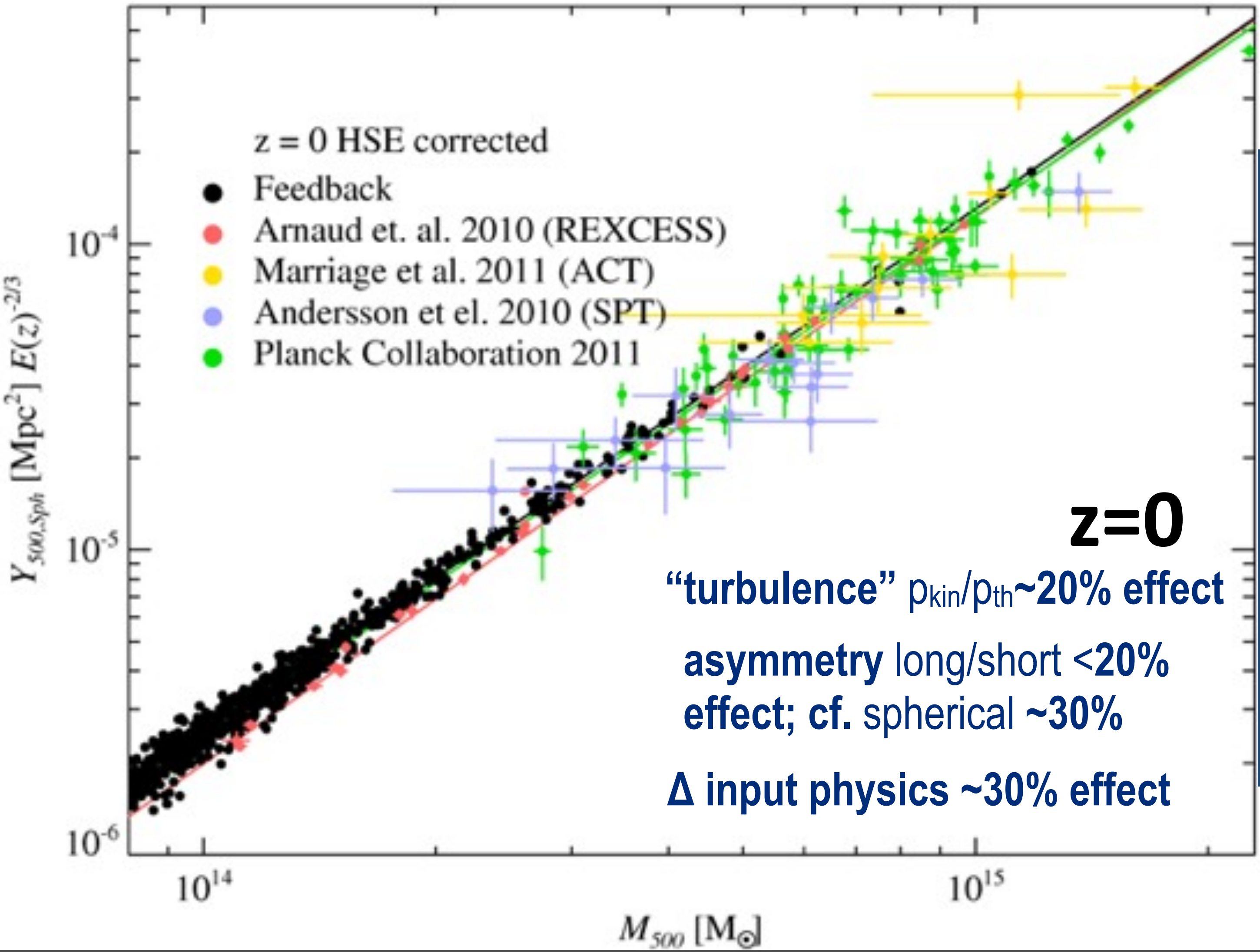
80s-90s
Ryle
OVRO

SPTpol
ACTpol
ALMA
CCAT@Chile
LMT@Mexico

$E_{e,th}(<r_\Delta)$-$M(<r_\Delta)$ relation, *where*

$M(<R_\Delta)/V(<R_\Delta)=\Delta\ \rho_{crit}$, Δ=2500, 500, 200

Battaglia, Bond, Pfrommer, Sievers 1,2, (3,4) 2011: non-eq processes, p-profiles, YM, C_L^{SZ}



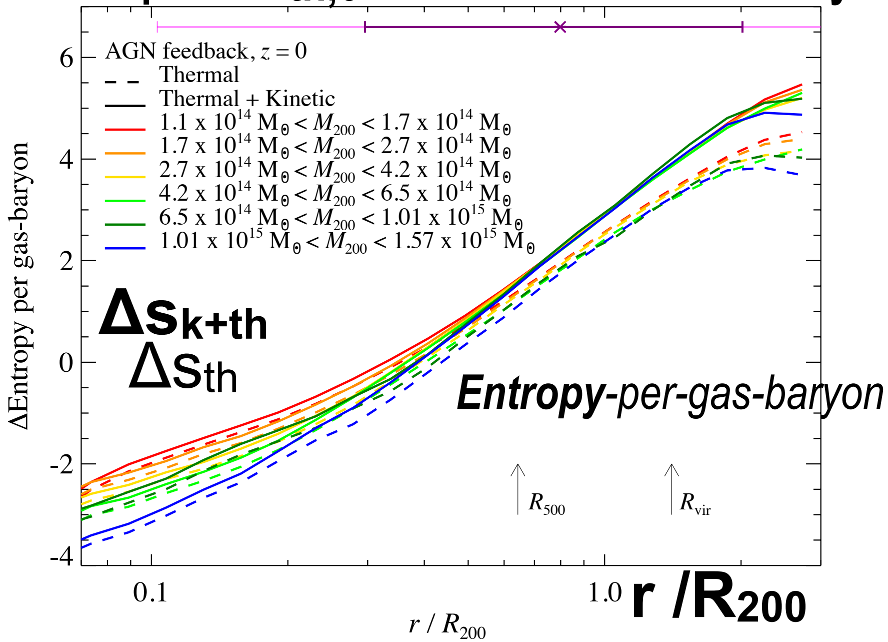
Planck-ESZ gives **Y_{5R500}**

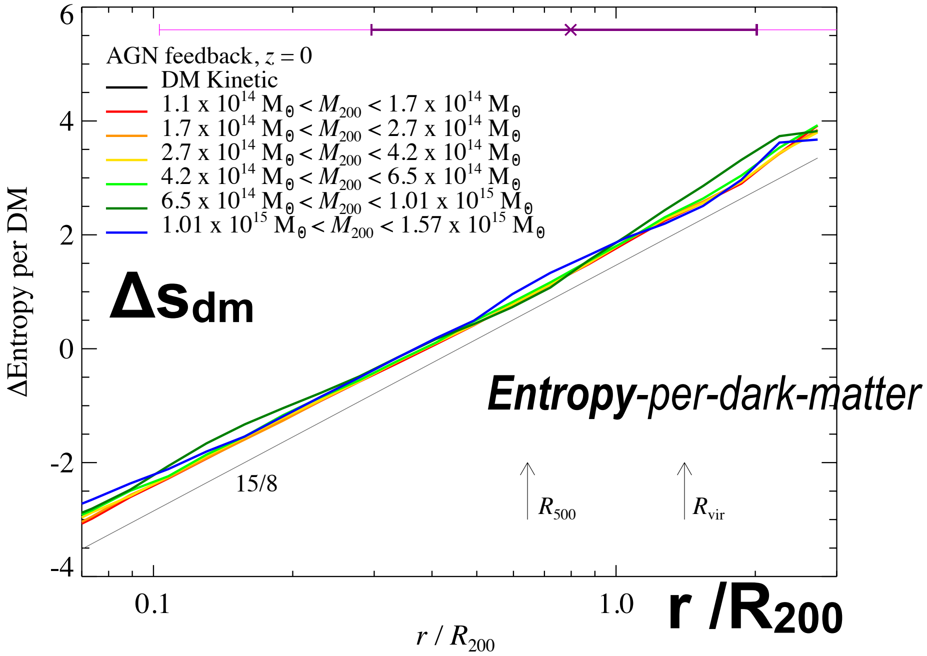
is Y_{SZ} a good mass proxy in $n_{cl}(M, z)$? even though virial theorem Y(e,K/U,...|M) => $n_{cl}(Y, z)$

Thursday, 10 November, 11

non-equilibrium and non-thermal ***Entropy Profiles (M | z=0) for Mass-binned Scaled Stacked Clusters***

zero point $S_{th,0}$ ~ 130 nats ~ 190 bits/baryon





slope~3.04 =X-ray Voit

slope~15/8 =self-similar radial infall Navarro

better-than-NFW fit to DM-only simulation density profiles.

gas/star effect affect NFW-ism.

ongoing mystery - why halos have this entropy growth law

P_{kin}/P_{th}~0.1-0.6!

$<(\Delta v)^2>/c_s^2$ affects hydrostatic equilibrium

*gps-**cls** ~150-**190 bits/baryon, Δs_{th}~12 bits/b ; s_{kin+th}-s_{th}~1bit/b***

Δs_{dm} = 1/2 Tr *ln*<(p_{kin} I + Π_{kin}) /ρ_{dm}> - *ln* ρ_{dm} *~7 bits/DM*

zero point depends on type of DM, WIMP or axion or ...

cf. **$s_{\gamma+\nu}$ / n_b ~*1.66x10^10*/(1+δ_b) bits/b**

cf. **AGN's black hole entropy $S_{bh} = M_{bh}^2/2M_P^2$** ~10^{22} **S_b;** but **τ_{bh}** ~ 10^{120}yrs

25 papers & a large fraction of the papers at Planck2011 were unveiled for 10 months & 9-freq T data, + a press conference, highlighting: **HFI & LFI work**

near-future cosmology => PlanckEXT

EXT=many observatories & expts enabling the cosmology/astro

XMM **Herschel** Fermi **WMAP GBT BLAST ACT** SPT AMI **CBI** CBASS QUIET **SDSS** IRAS CO/HI-maps,...

cosmology: **$n_s(k)$, GW $r(k)$, nonG f_{NL}++, $\rho_{de}(t)$, m_ν, strings, isocurvature,... $n_e(t)$**

ACTpol, SPTpol, eRosita, PanStarrs, DES, LSST, **GBT**, **CCAT**,

ABS, Spider, Quiet-90, *EBEX, Keck,* ***CHIME****, EUCLID, ...* $\subset$ **EXT**

CBI pol to Apr'05 @Chile CBI2

QUaD @SP

Quiet1 @Chile

Quiet2 1000 HEMTs

Boom03@LDB

Bicep @SP

Bicep2

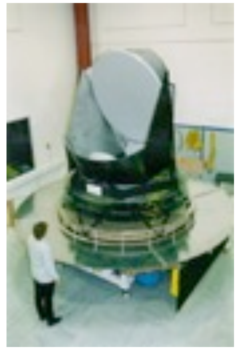
Keck@SP

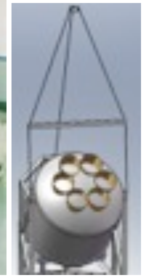
WMAP @L2 to 2010

Planck09.4

52 bolometers + HEMTs @L2

9 frequencies





ABS@ Chile

EBEX @LDB

Spider 2312 bolos @LDB

DASI @SP

CAPMAP

Herschel

BLAST

2013

Pixie/ COrE/ LiteBird @space

2004 2006 2008 LHC 2011

2005 2007 2009

Acbar to Jan'06, 08f @SP

SPT 1000 bolos @SPole

BLASTpol

Piper

SZA @Cal

ACT 3000 bolos 3 freqs @Chile

Polarbear @Chile

SPTpol

AMI

APEX ~400 bolos @Chile

ACTpol

SCUBA2

12000 bolos JCMT @Hawaii

ALMA

CCAT@Chile

GBT

LMT@Mexico

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

$\Omega_{er}h^2$ $\Omega_{m\nu}h^2$ X_{He}

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

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

(partially) blind cf. informed "theory" priors

lnPower$_s$~ln25x10^{-10} ± 0.03 Dunkley+ 2010 ACT+WMAP7

n_s = 0.963 ± 0.011 (ACT+WMAP+BAO+H0)

$dn_s/d\ln k$ = -0.024 ± 0.015 (ACT+WMAP+BAO+H0)

r < 0.19 (95% CL, ACT+WMAP+BAO+H0)

Hlozek+11 **Primordial power spectrum(k);** Bond, Contaldi, Huang, Kofman, Vaudrevange 2011 *w/o & with T-S consistency*

CITA = Cosmic Information Theory & Analysis: *IT from BIT, from BITs in IT,*

Studying the Cosmic Tango** en-TANGO-ment* **Universe=System+Res=Data+Theory =Signal(s)+*noise*=EFT+*Hidden variables

CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut canadien d'astrophysique théorique **Dick Bond** 25 years cifar

the Cosmotician's Agenda: Statistical Paths in Cosmic Theory & Data via the Bayesian chain

we compress the Petabit++ observed cosmic info into a precious few bits encoding 6+ parameters of the Minimal Cosmic Standard model (tilted ΛCDM)

ρ_{dm}/ρ_b=5.1 ρ_m/ρ_{de} =.30 Ω_m=0.268 ±.012 Ω_Λ=0.736 ±.012

Power$_s$=25x10^{-10} *Tilt*$_s$ =0.963±0.013 **running=-0.024 ± 0.015 r=T/S<0.19 T_{cmb}=*2.725***

CMB*ology* uses WMAP7+ACT (SPT), **past: Boom, CBI, Acbar,..** (QuAD, ...). **LSS*ology* BAO H0 *SN lens, clusters*.** coming: ***Planck* cosmology** Jan2013,14 **cosmic parameters** Jan11(25p), Feb12 **SZ,CIB,ISM *ACTpol, ABS, Spider, Quiet-2*,**..*CARMA, Mustang2 on GBT, CCAT, ALMA*,..CHIME, EUCLID,..

WMAP: 1.15 Tbits in 9yrs, cf. MyLifeBits, Gordon Bell, 1.28 Tbits in 9yrs, Planck 36 Tbits, ACT 304 Tbits. Radically Compress to high quality Bits. Terabit=10^{12}bits=125 GigaBytes.

now	ACT1	Mar03	Jan03	Jan02	Jan00	Jan13-15	then
ΔS_{1f} (Ω_Λ)	0	1.60	2.32	2.49	3.91	-4.00	± 0.012 => ± 0.001 (Pext)
ΔS_{1f} (w_0)	0	-	-	-	-	-2.5 (-2.2)	± 0.06 => ± 0.01 (Pext) (± 0.14 => ± 0.03)
ΔS_{1f} (V-slope^2)	0	-	-	-	-	-2.4	0.0± 0.18 => ± 0.03 (Pext)
ΔS_{1f} (n_s)	0	0.24	2.24	2.03	3.86	-2.59	0.963± 0.011 => ± 0.002 (Pext)
ΔS_{1f} (r)	0	0.92	-	-	-	-3.70	< 0.17 => < 0.007-0.013 (Pext)
ΔS_{1f} (f_{nl})	0	-	-	-	-	-4.00	-10< f_{NL} <74 => ± 5 (Pext)

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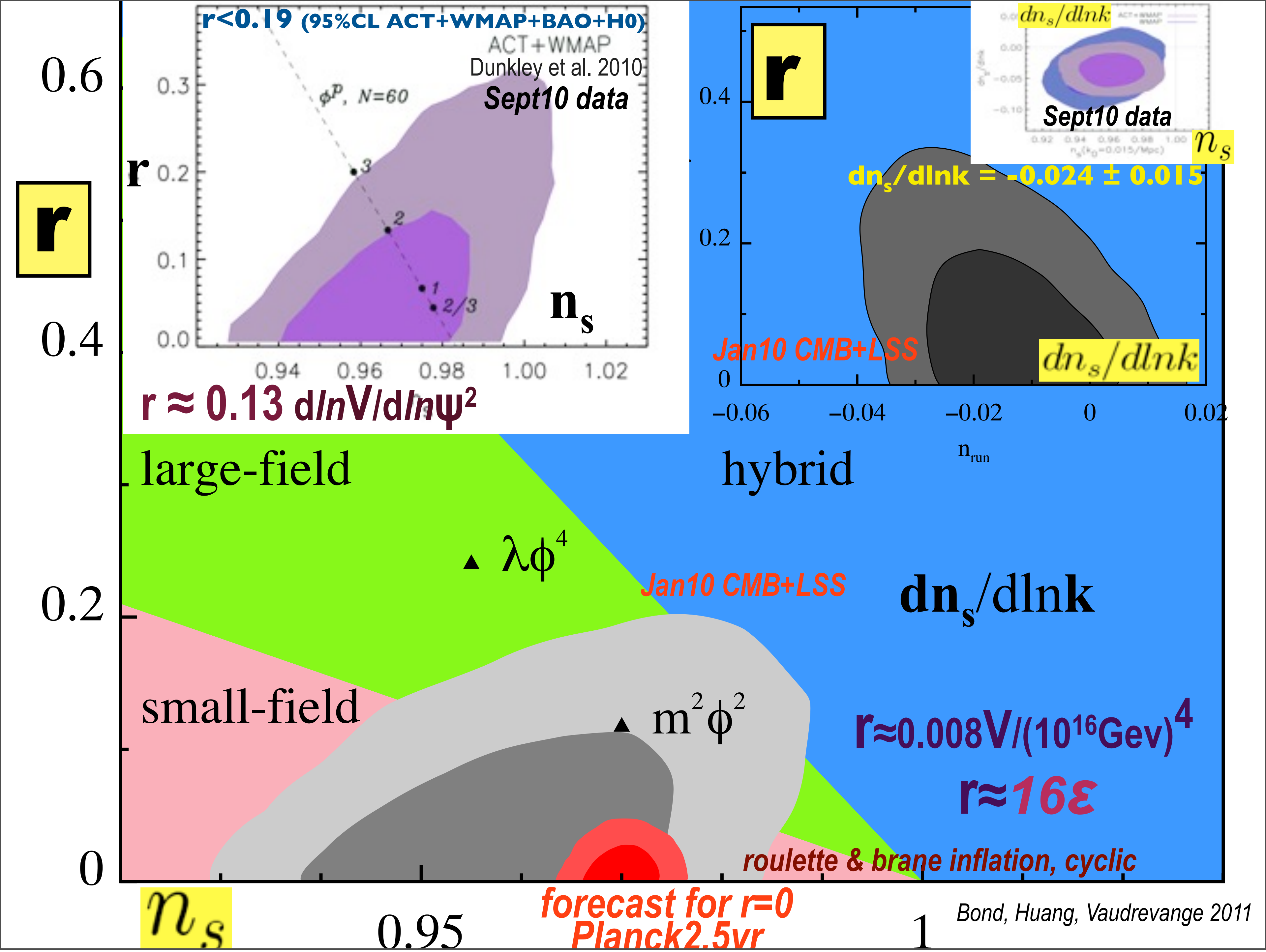
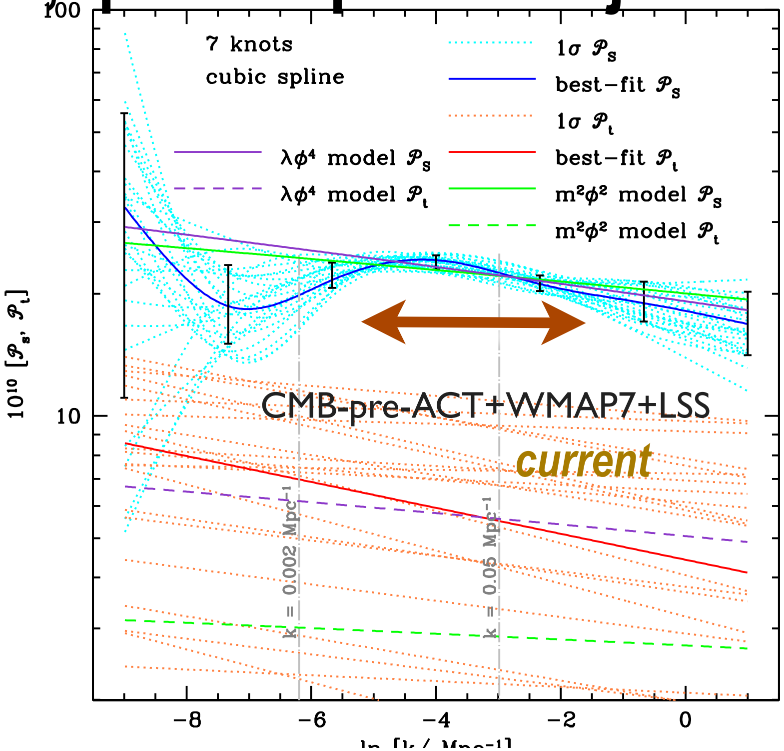
ΔS_{1f} (r)	0	0.92	-	-	-	-3.70	< 0.17 => < 0.007-0.013 (Pext)
ΔS_{1f} (f_{nl})	0	-	-	-	-	-4.00	-10< f_{NL} <74 => ± 5 (Pext)

$\Delta \sum m_\nu \sim 0.06$ eV

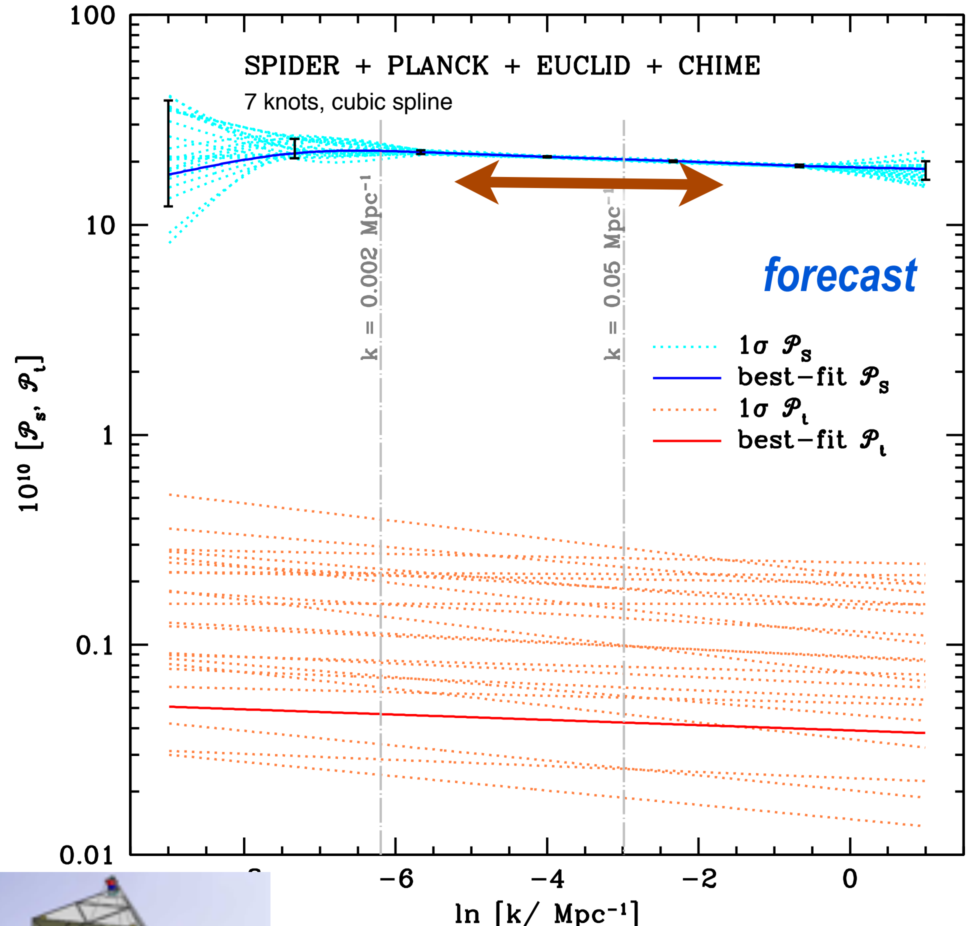

r<0.19 (95%CL ACT+WMAP+BAO+H0)
ACT+WMAP
Dunkley et al. 2010
Sept10 data
ϕ^P, N=60
r
n_s
r ≈ 0.13 dlnV/dlnψ²
r
dn_s/dlnk
Sept10 data
n_s
dn_s/dlnk = -0.024 ± 0.015
Jan10 CMB+LSS
dn_s/dlnk
n_{run}
r
large-field
hybrid
λφ⁴
Jan10 CMB+LSS
dn_s/dlnk
small-field
m²φ²
r≈0.008V/(10¹⁶Gev)⁴
r≈16ε
roulette & brane inflation, cyclic
forecast for r=0
Planck2.5yr
Bond, Huang, Vaudrevange 2011
n_s
0.95
1

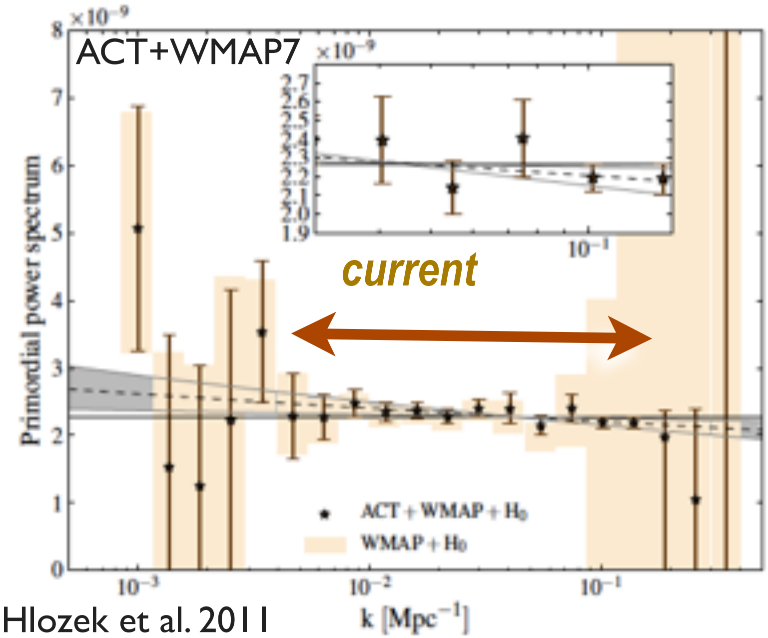
s,t power spectra trajectories: compress data onto non-top-hat k-modes

Bond, Contaldi, Huang, Kofman, Vaudrevange 2011

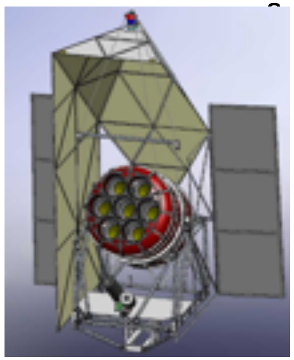


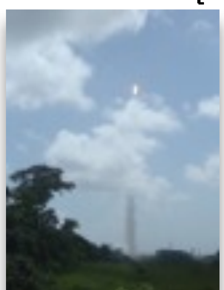
Spider-24days + Planck-2.5yr + ... 7 knot lnPs +r-nt forecast for r=0 (+ fgnds)

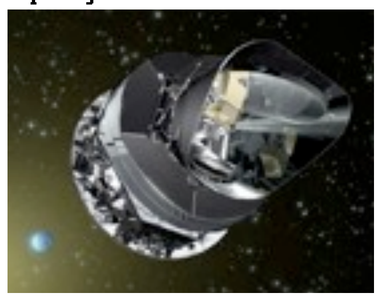




Hlozek et al. 2011

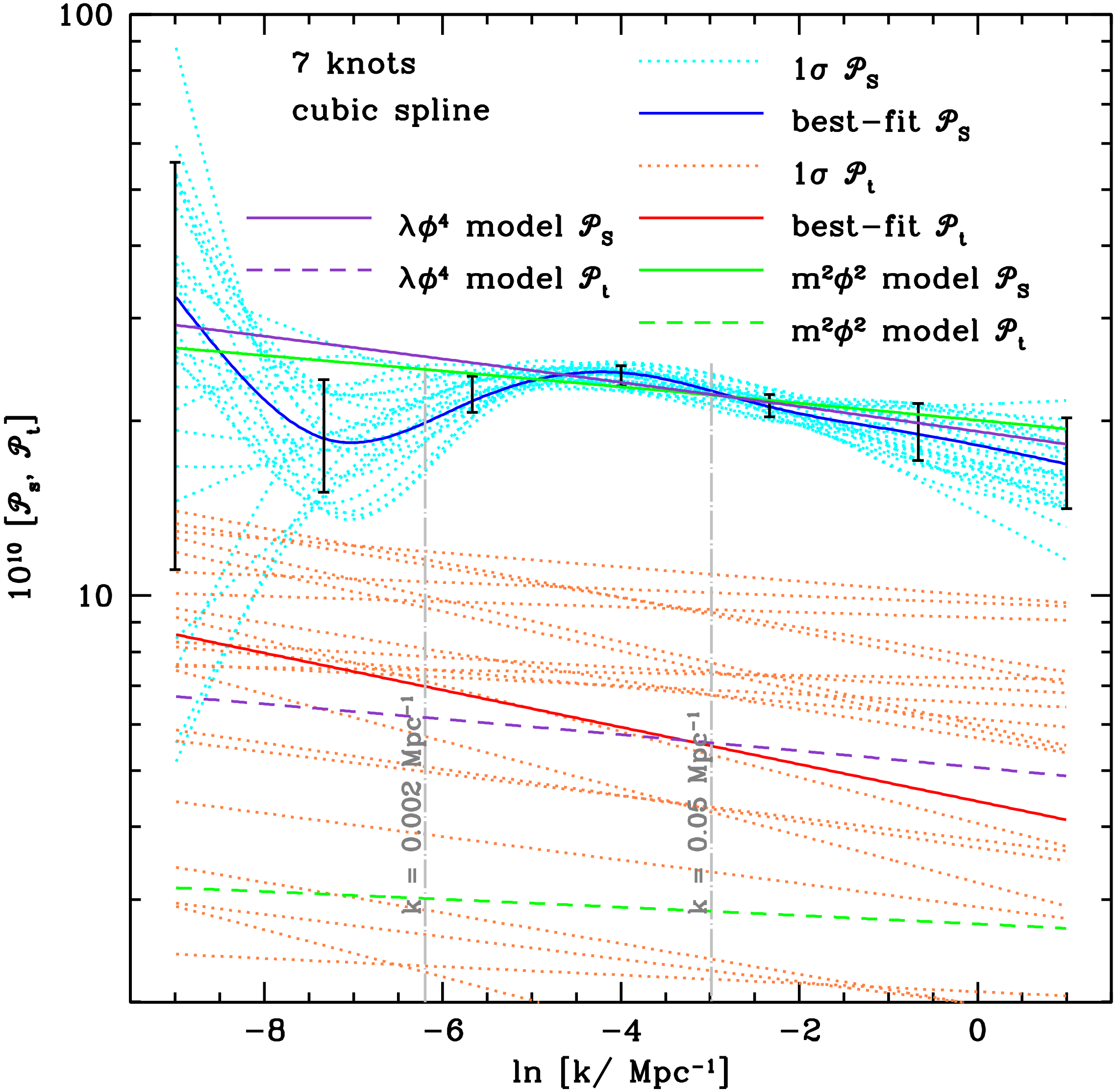




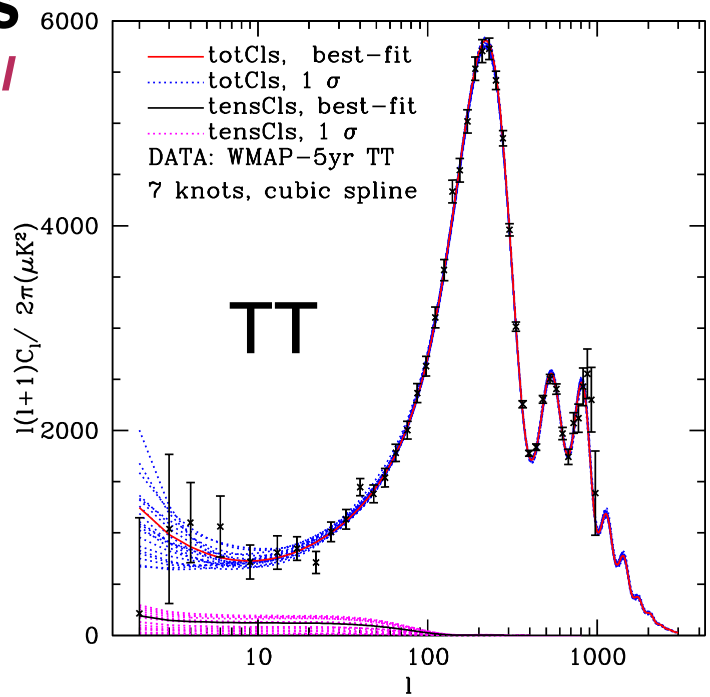


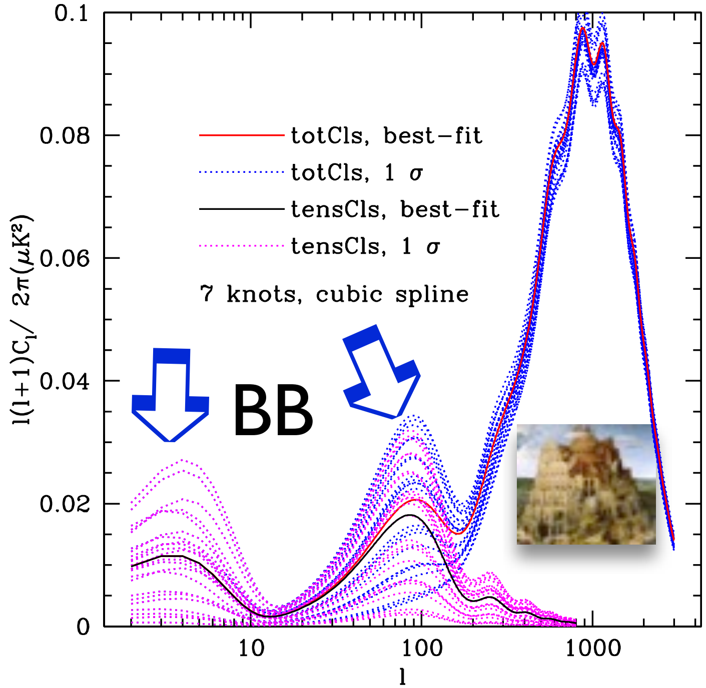
compress data onto non-top-hat k-modes

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



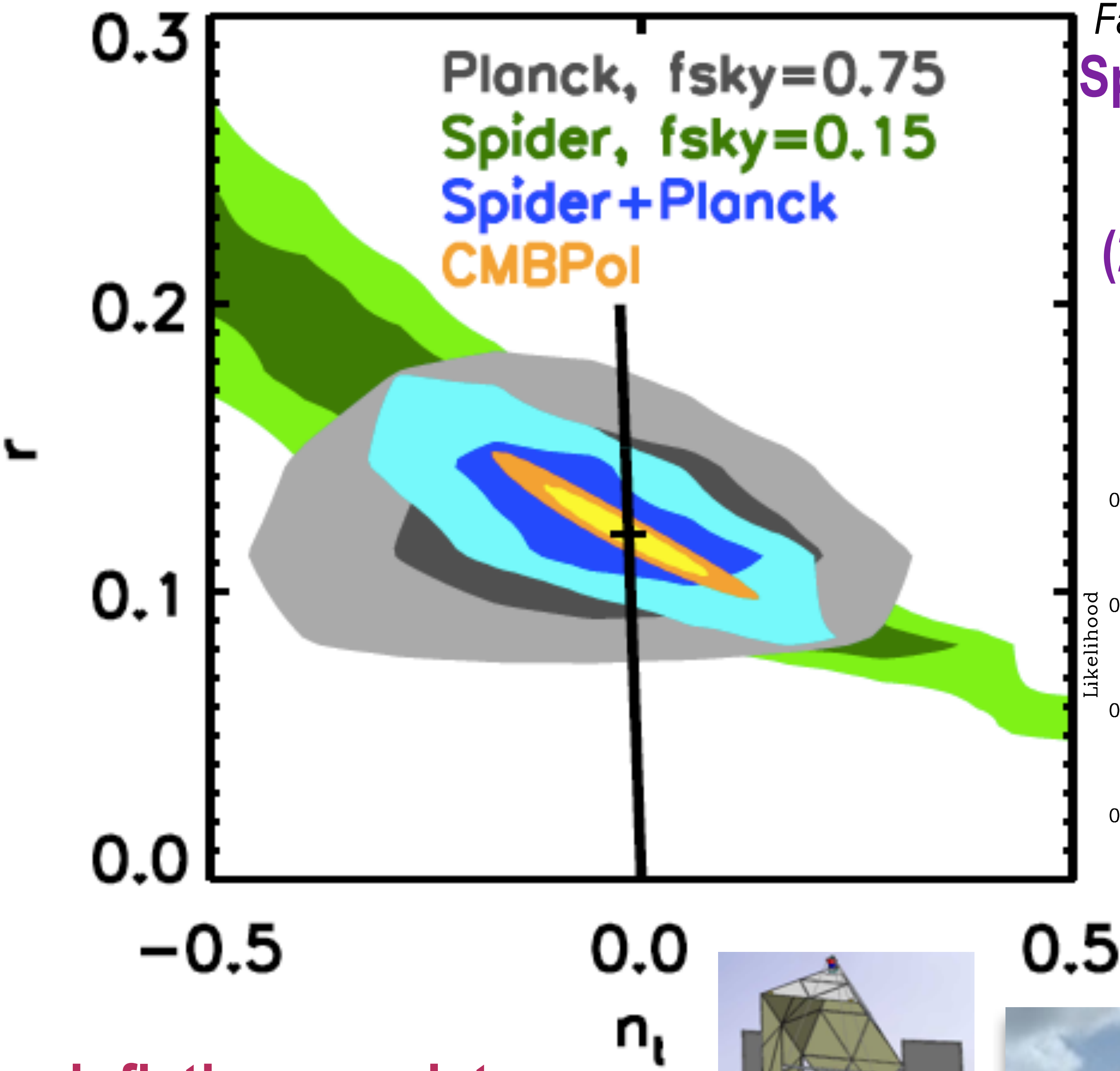
Bond, Contaldi, Huang, Kofman, Vaudrevange 2011



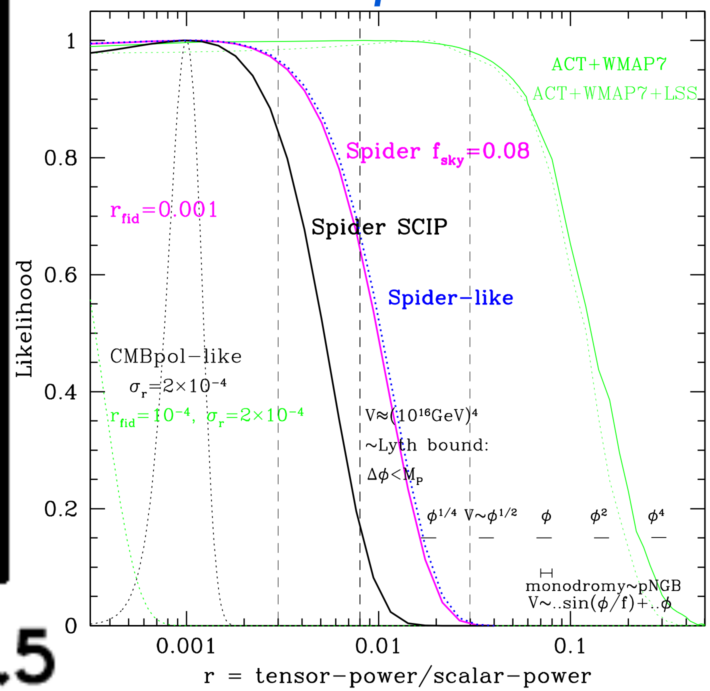


Farhang, Bond, Dore, Netterfield 2011

Spider-24days+Planck-2.5yr r-n_t forecast for r=0.12 input for $m^2\varphi^2$ ($2\sigma_r$ ~0.02 including fgnds)



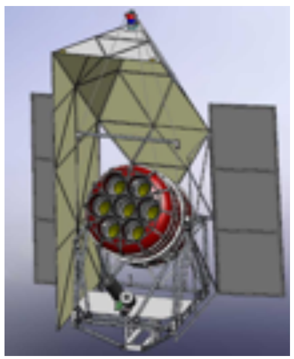
forecasted r-posterior

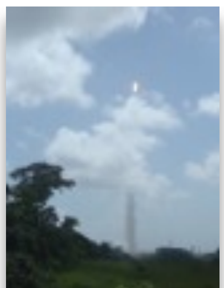


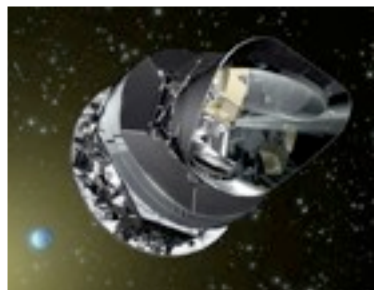
inflation consistency

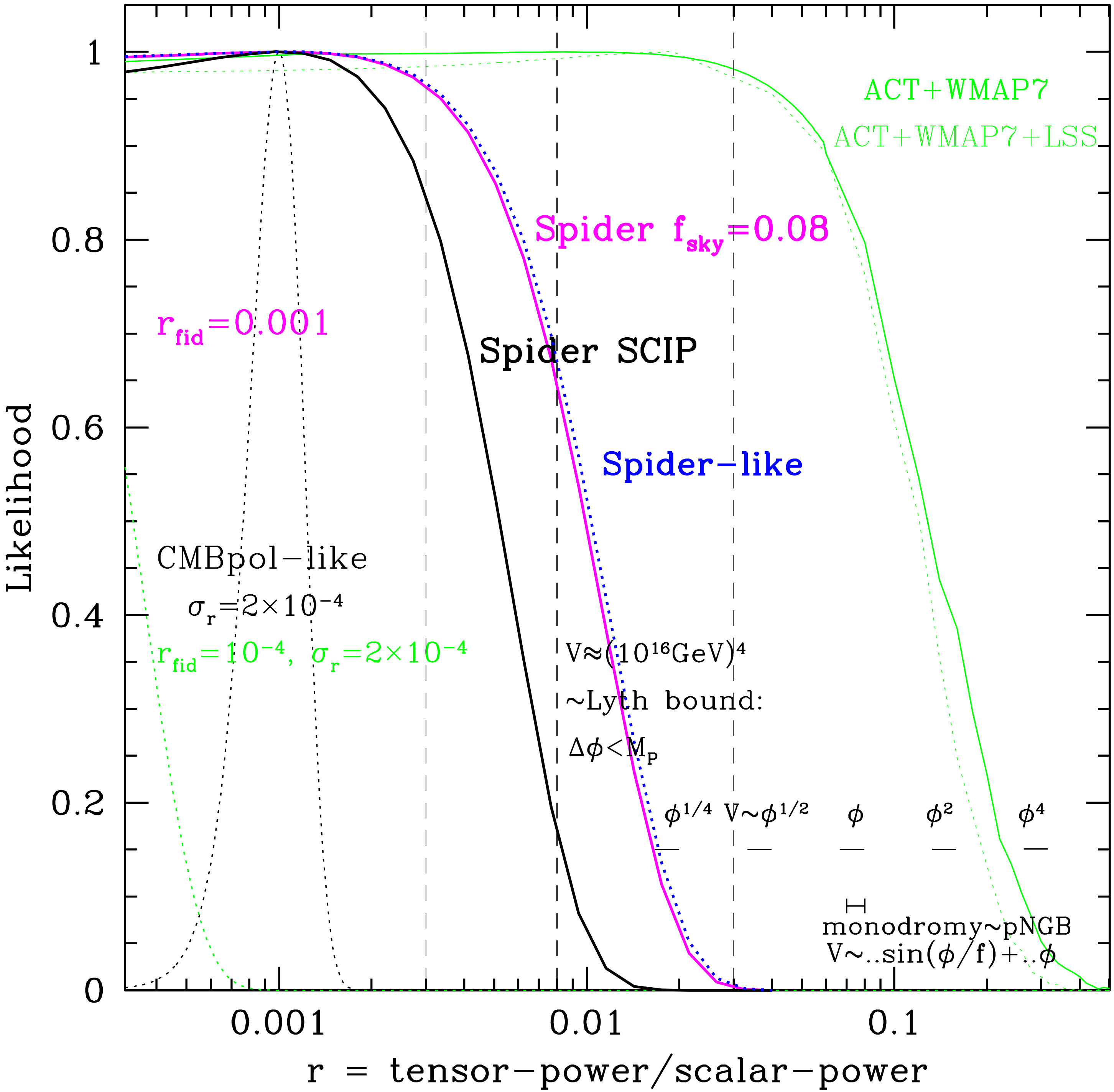
$-n_t \approx r/8 \approx 2\varepsilon(k)$

$1-n_s \approx 2\varepsilon + d\ln\varepsilon/d\ln Ha$

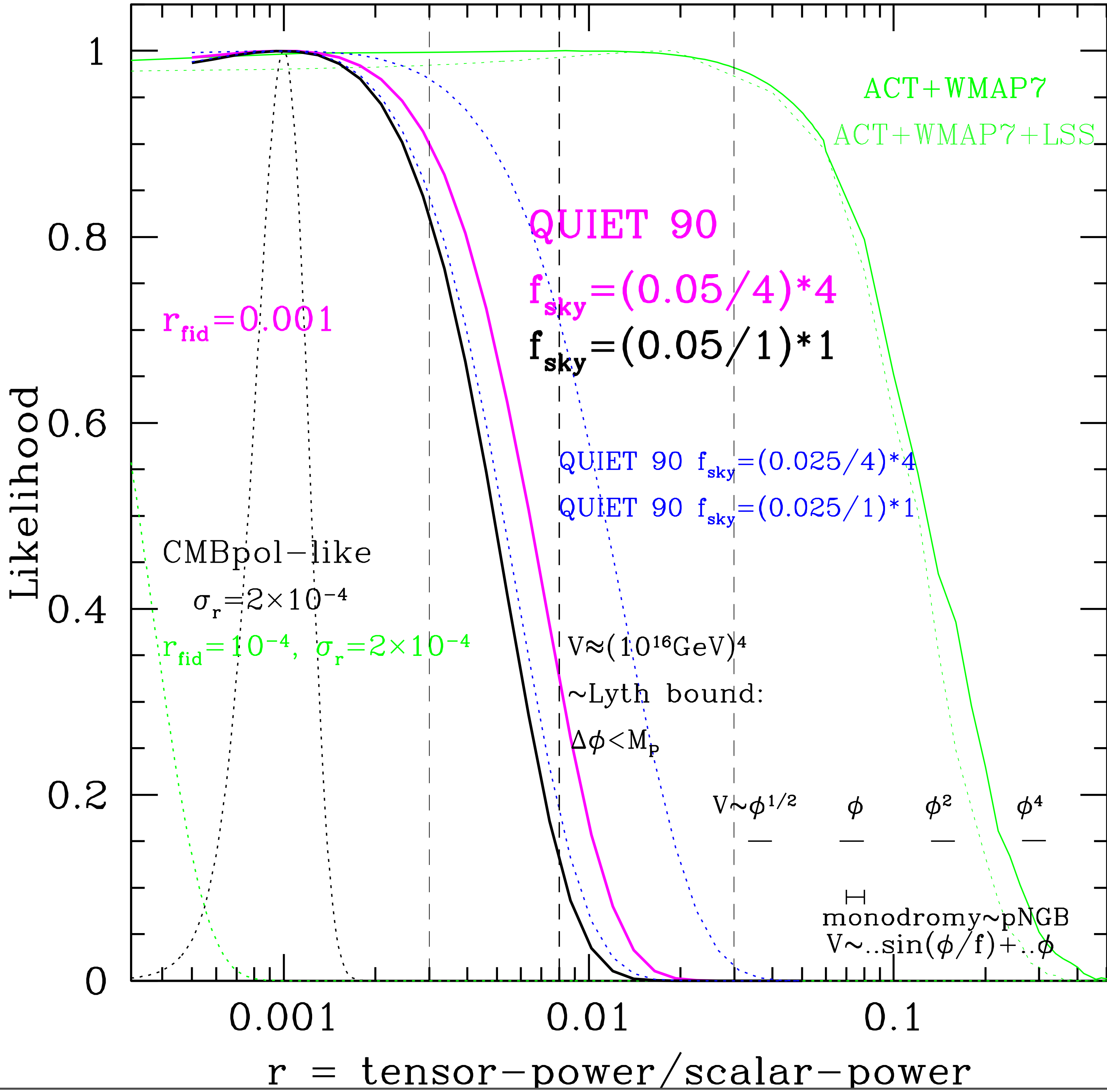




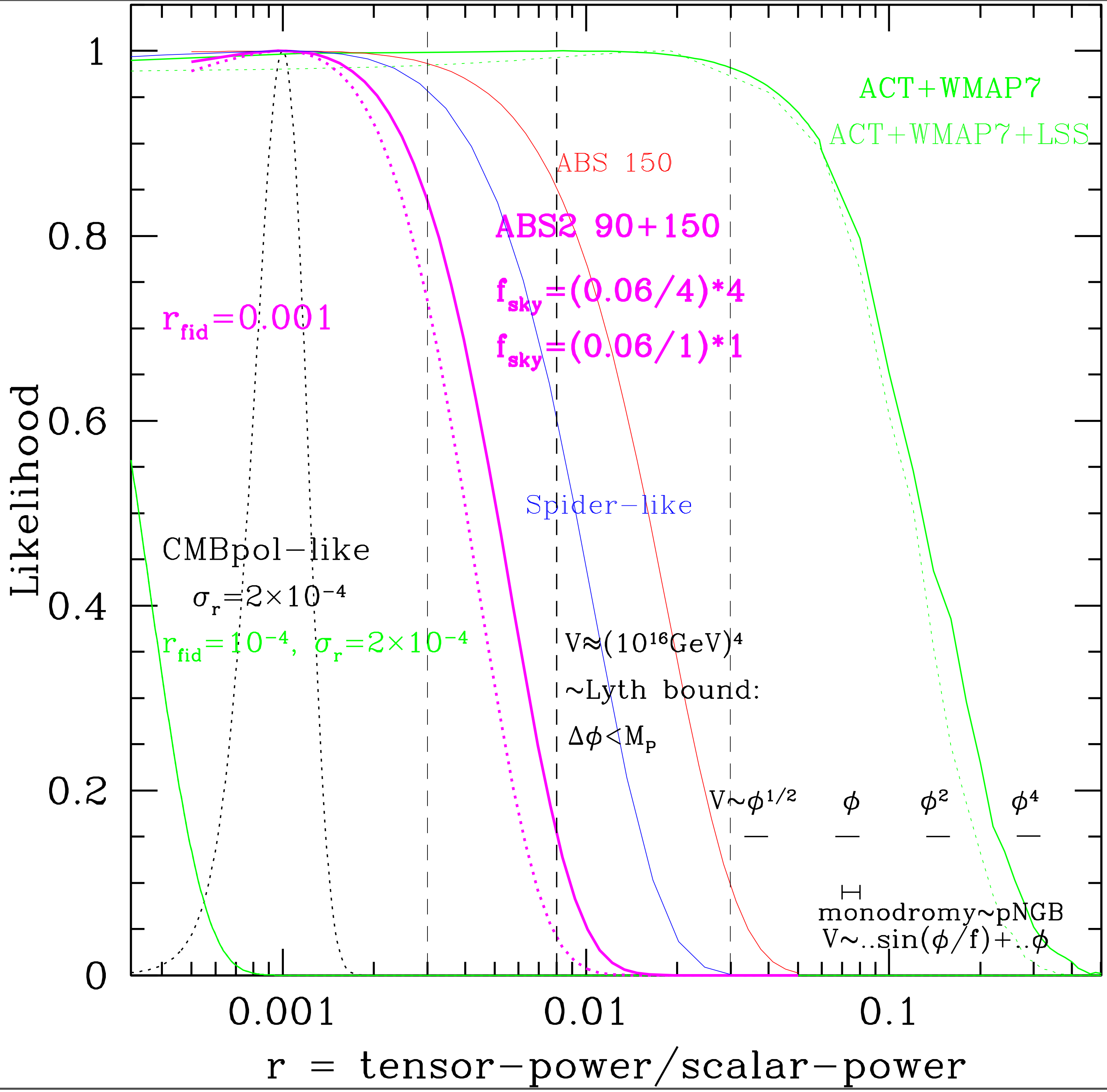




1
0.8
0.6
0.4
0.2
0
Likelihood
0.001
0.01
0.1
r = tensor−power/scalar−power
ACT+WMAP7
ACT+WMAP7+LSS
Spider f_sky=0.08
r_fid=0.001
Spider SCIP
Spider−like
CMBpol−like
σ_r=2×10^−4
r_fid=10^−4, σ_r=2×10^−4
V≈(10^16GeV)^4
~Lyth bound:
Δφ<M_P
φ^1/4 V~φ^1/2 φ φ^2 φ^4
monodromy~pNGB
V~..sin(φ/f)+..φ



ACT+WMAP7
ACT+WMAP7+LSS
QUIET 90
f_sky=(0.05/4)*4
f_sky=(0.05/1)*1
r_fid=0.001
QUIET 90 f_sky=(0.025/4)*4
QUIET 90 f_sky=(0.025/1)*1
CMBpol−like
σ_r=2×10^−4
r_fid=10^−4, σ_r=2×10^−4
V≈(10^16 GeV)^4
~Lyth bound:
Δφ<M_P
V~φ^1/2
φ
φ^2
φ^4
monodromy~pNGB
V~..sin(φ/f)+..φ
Likelihood
r = tensor−power/scalar−power
0.001
0.01
0.1
0
0.2
0.4
0.6
0.8
1

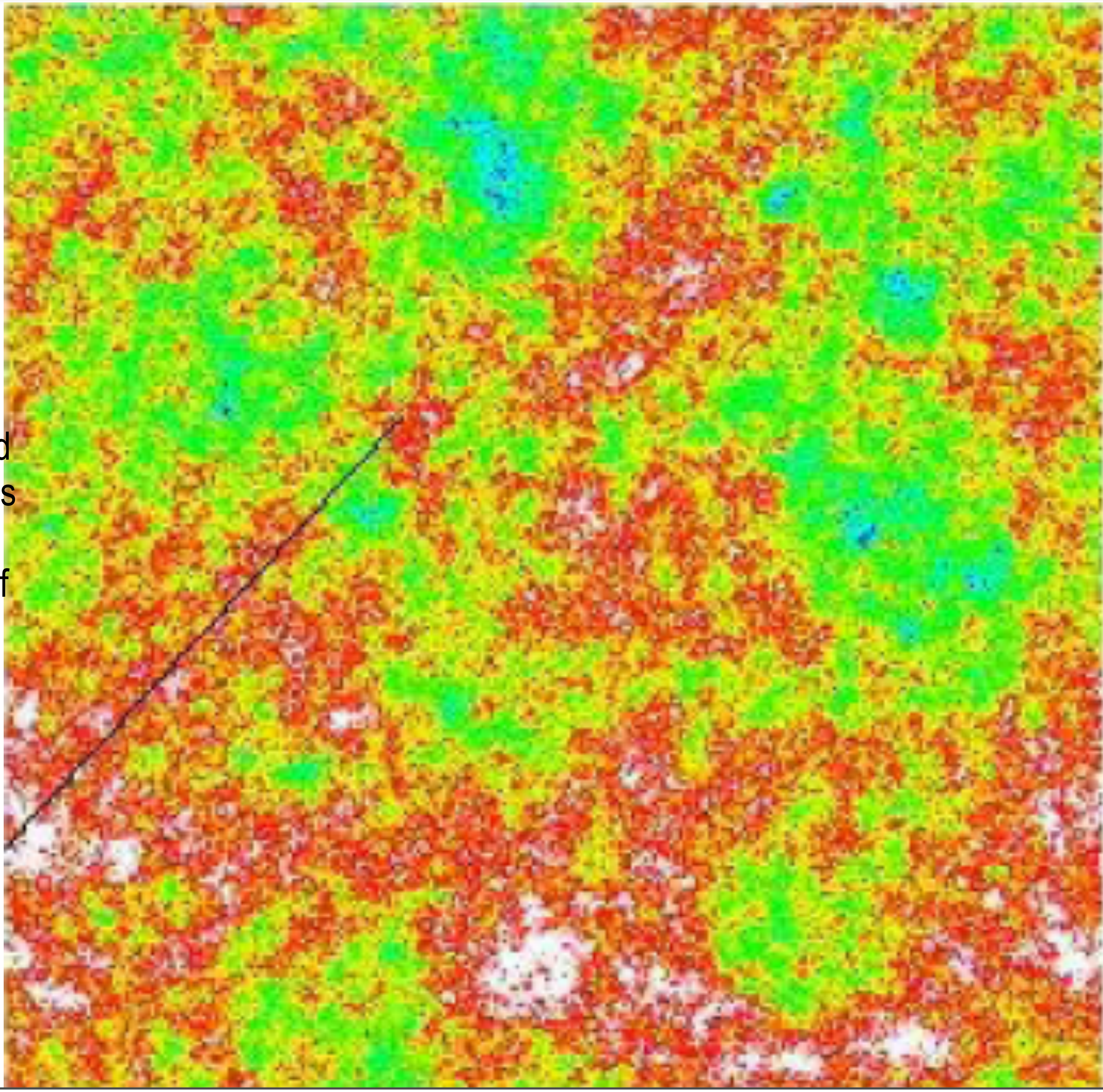

1
0.8
0.6
0.4
0.2
0
0.001
0.01
0.1
Likelihood
r = tensor−power/scalar−power
ACT+WMAP7
ACT+WMAP7+LSS
ABS 150
ABS2 90+150
f_{sky}=(0.06/4)*4
f_{sky}=(0.06/1)*1
r_{fid}=0.001
Spider−like
CMBpol−like
$\sigma_r=2\times10^{-4}$
$r_{fid}=10^{-4}$, $\sigma_r=2\times10^{-4}$
V≈$(10^{16}$GeV$)^4$
~Lyth bound:
$\Delta\phi<M_P$
$V\sim\phi^{1/2}$
ϕ
ϕ^2
ϕ^4
monodromy~pNGB
$V\sim..\sin(\phi/f)+..\phi$

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

χ

scalar field fluctuations in the vacuum of the ultra-early Universe

pre-heating patch (~1cm)



10 Gpc

$\chi(x, \ln a)$

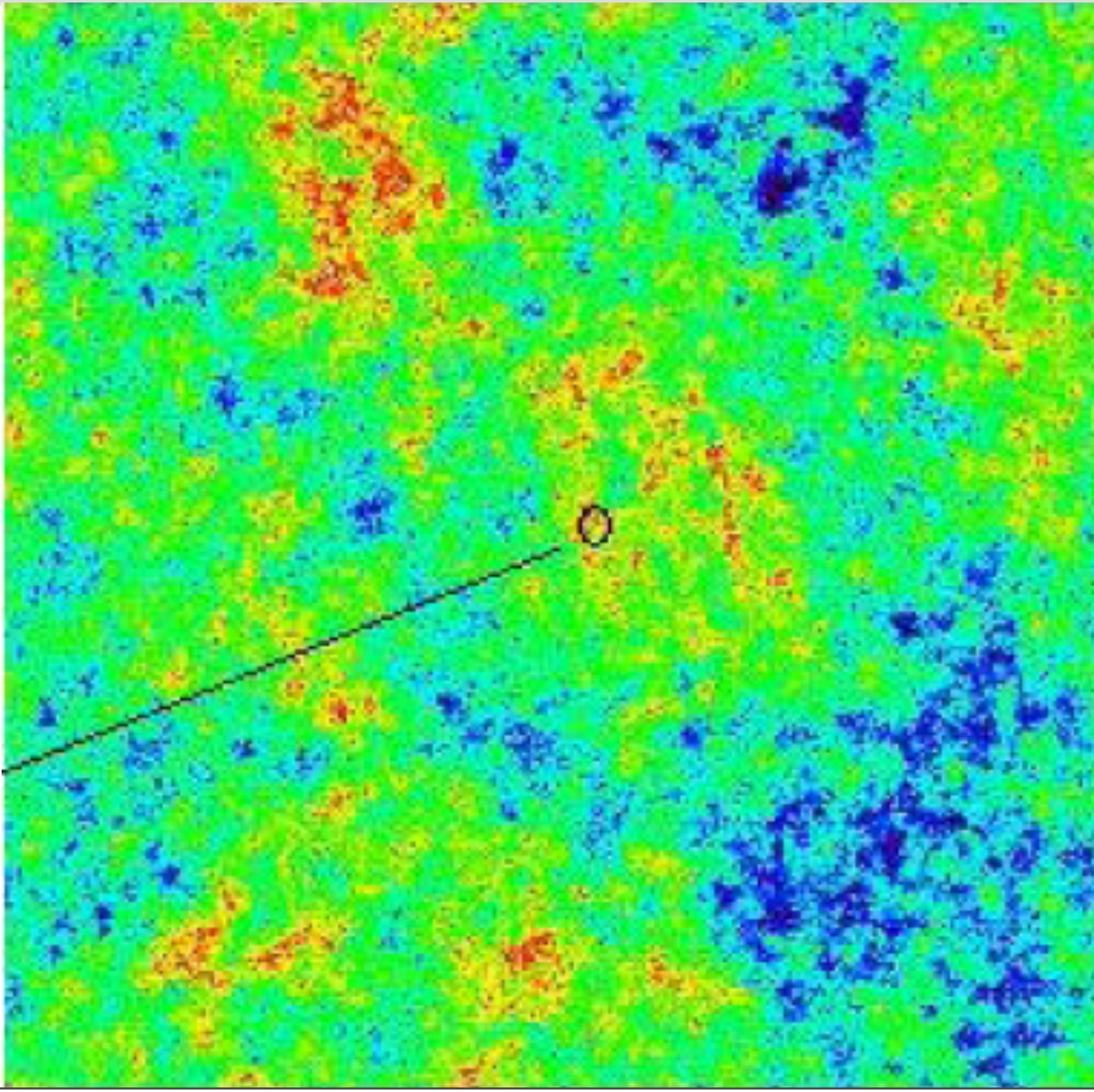
$\ln a(x, \ln H)$

evolve from early U vacuum potential and vacuum noise

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

ln a(x,ln H)

χ



current Hubble patch ~10 Gpc

speed limit horizon

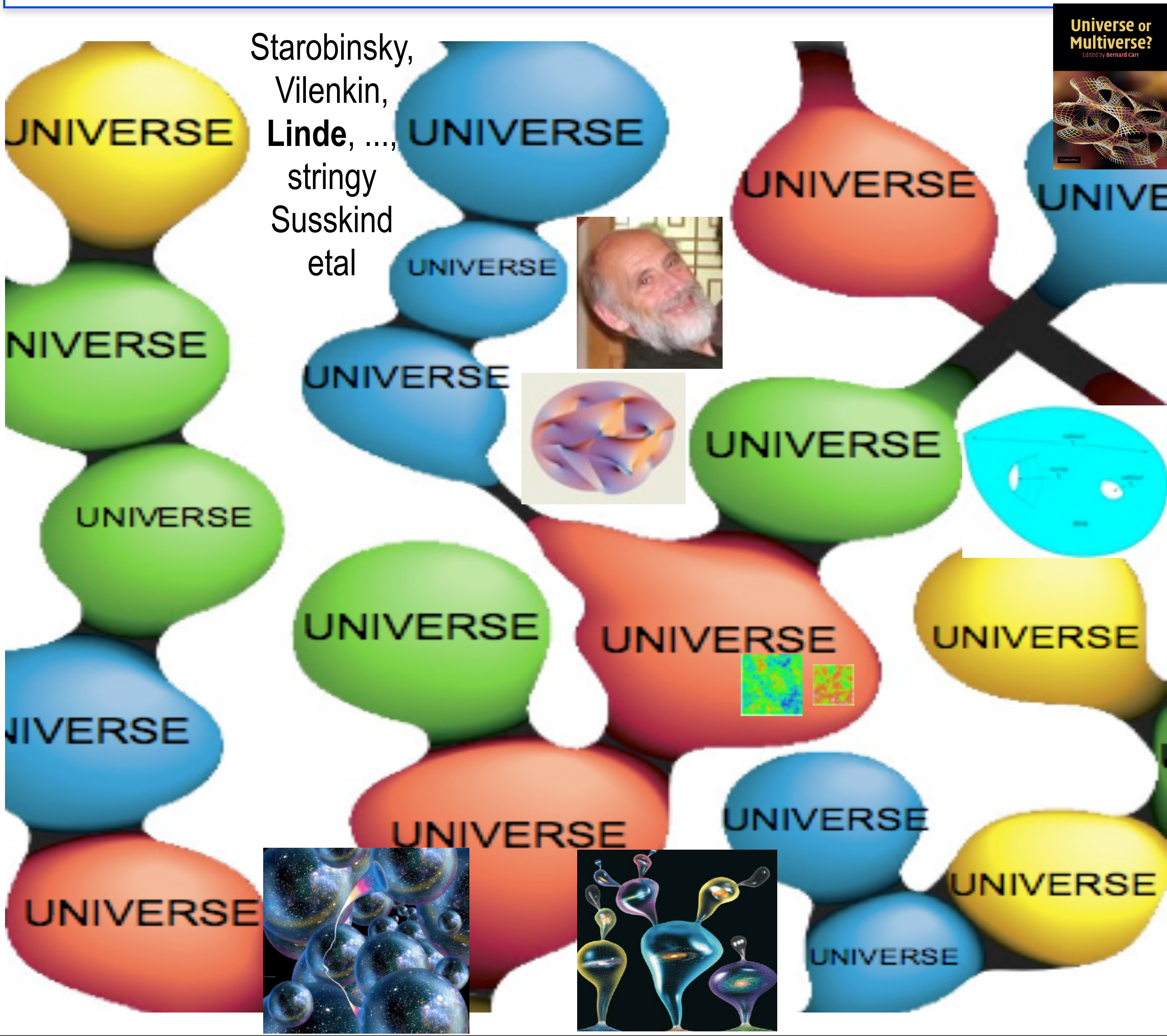
patterns in the quantum jitter evolve under gravity

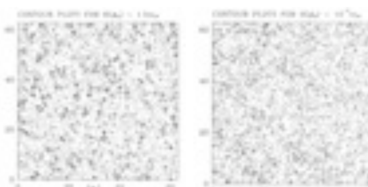
(& gas dynamics)

1000 Gpc

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

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





ln a(x, ln H)

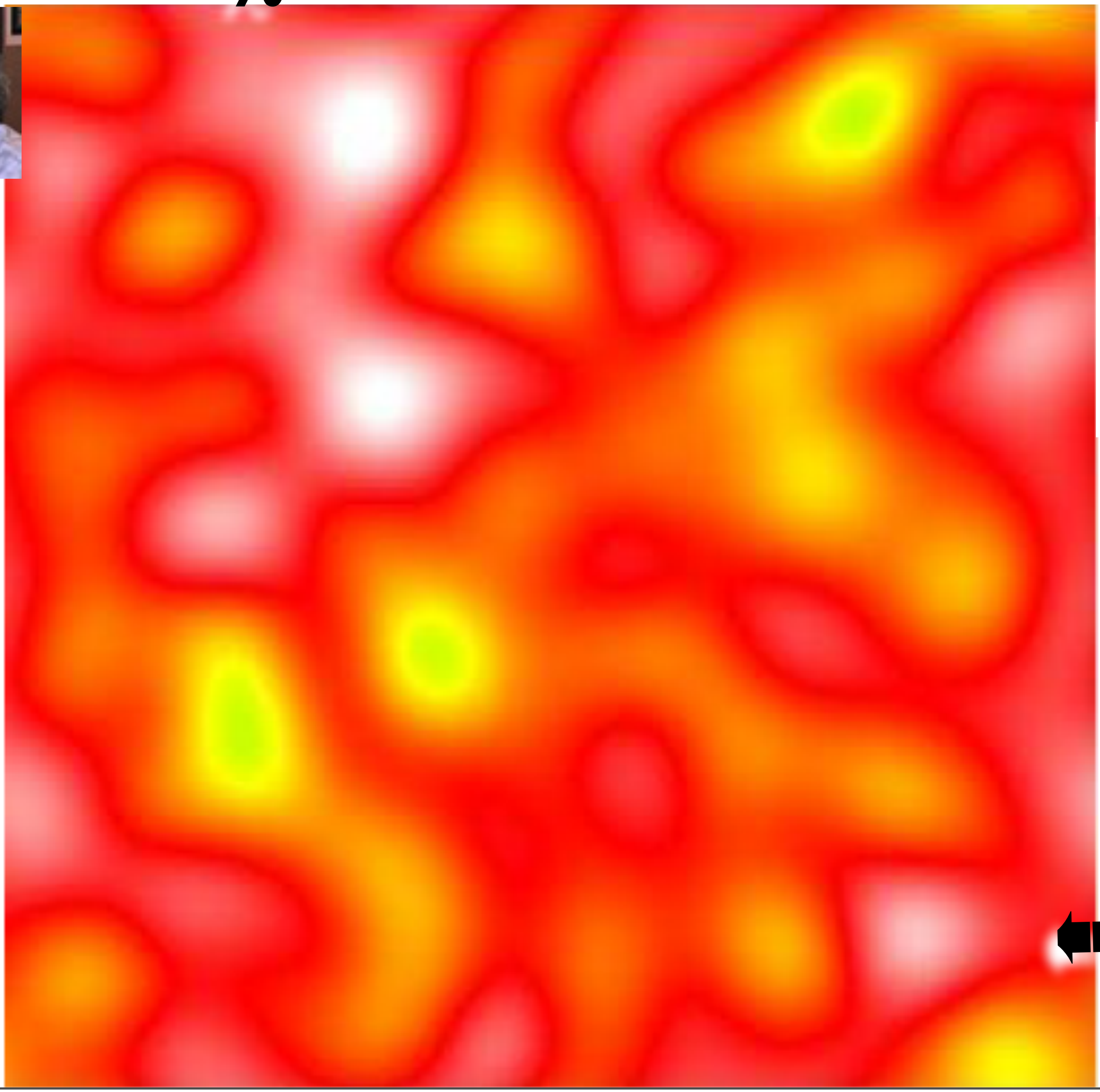
SB91: non-G *on uniform Ha-hypersurfaces from a simple exponential potential* ***via quantum kicks > drift at high $H_I \sim m_P$ uuUULSS*** *cf. observable nearly-* ***Gaussian at low $H_I \sim 10^{-5} m_P$***

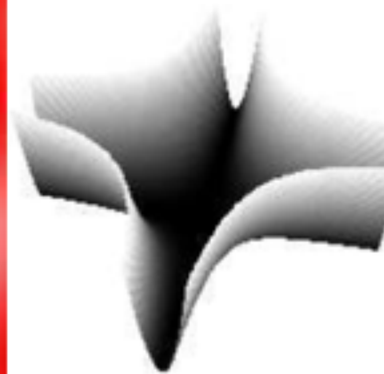
asymptotic flat eternal inflation V has similar behaviour

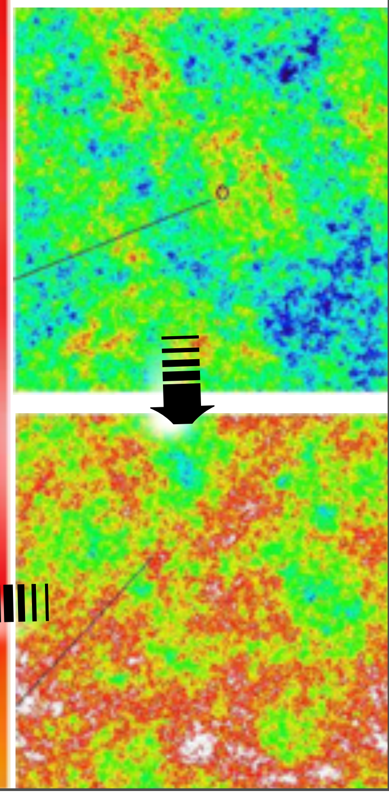
ϕ inflaton χ isocon $V(\phi,\chi) = 1/4\ \lambda\ \phi^4 + 1/2\ g^2\ \phi^2\ \chi^2$

Parametric Resonance

$g^2/\lambda \sim 1$







pre-heating patch (~1cm)

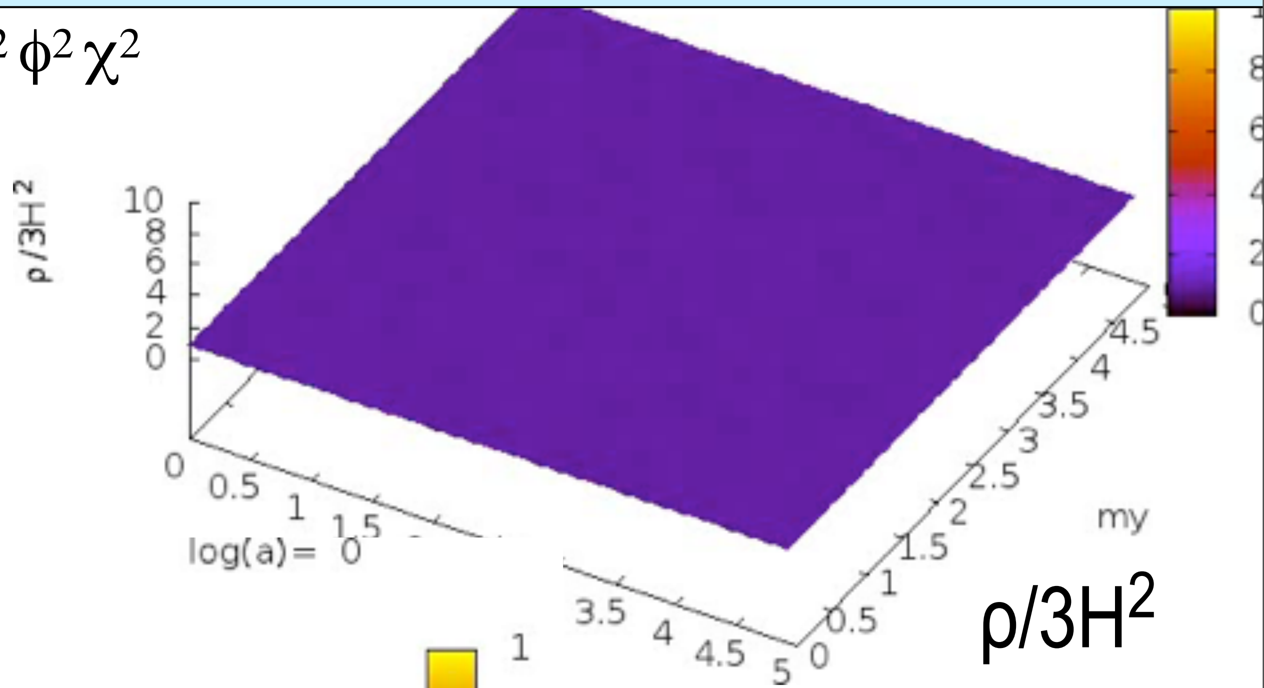
coherent inflaton => incoherent mode cascade of fields thru a shock-in-time to thermal equilibrium

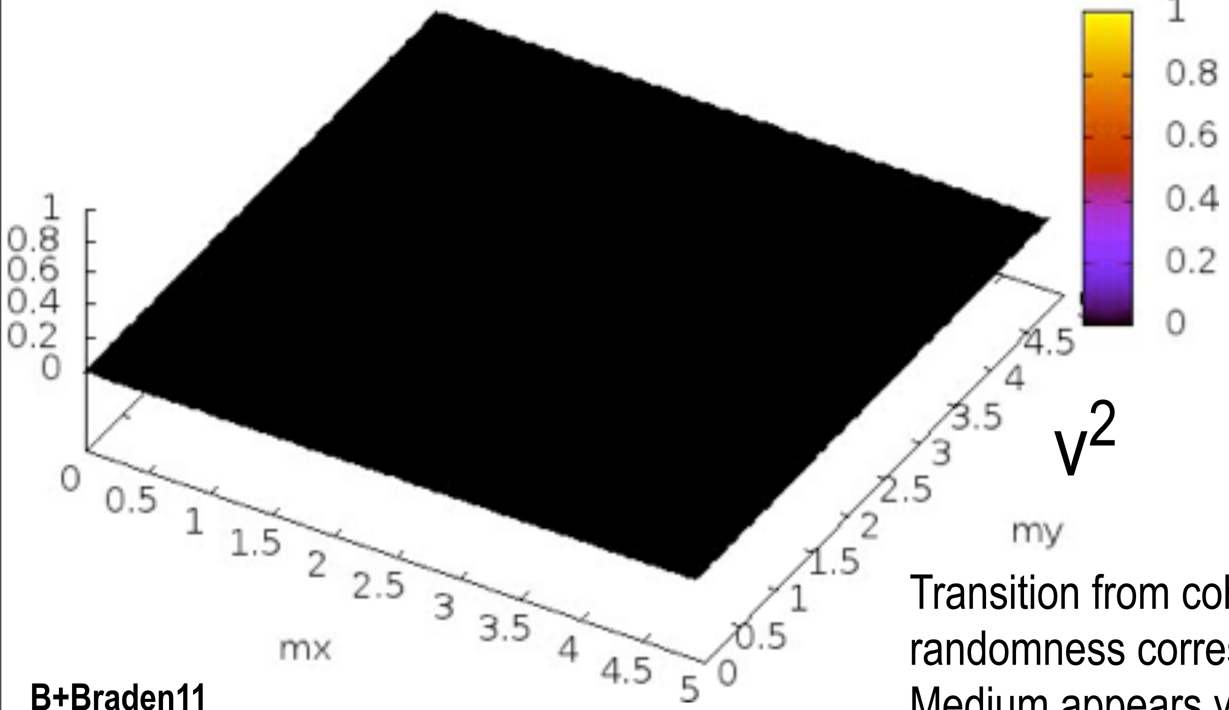
$V(\phi,\chi) = 1/4\ \lambda\ \phi^4 + 1/2\ g^2\ \phi^2\ \chi^2$

Slow Dynamics of IR Modes ⇒
Hydrodynamic Description

$\rho = -T^0{}_0 \quad P = -T^i{}_i$

$v^i = a T^i{}_0 / (\rho + P)$

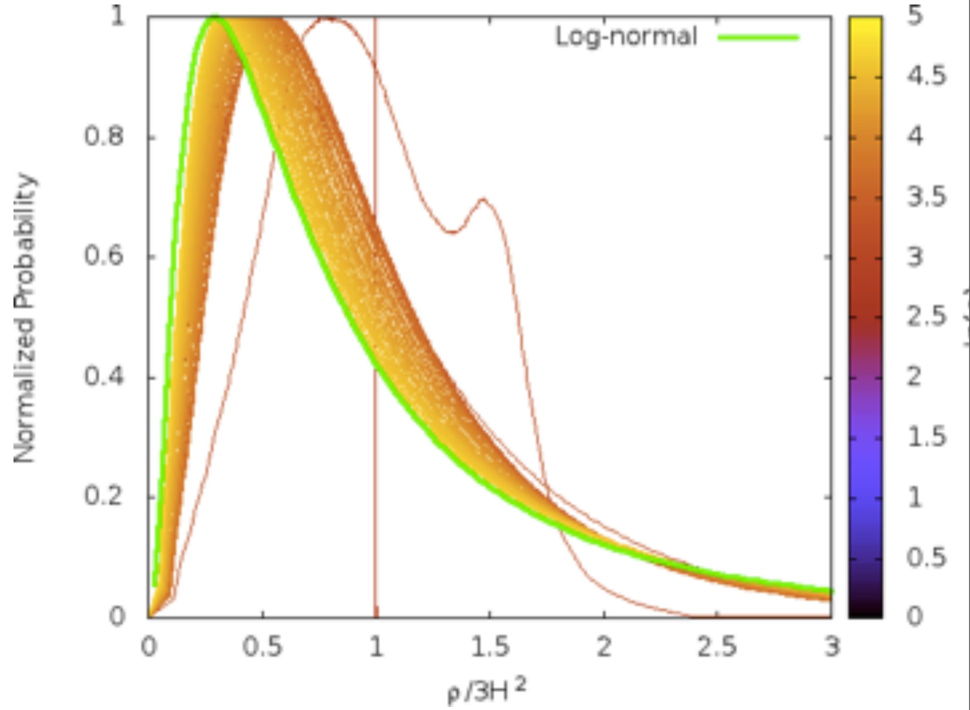




Transition from coherent wall-like structures to randomness corresponds to the shock-in-time.
Medium appears very complex in space and time, but ...

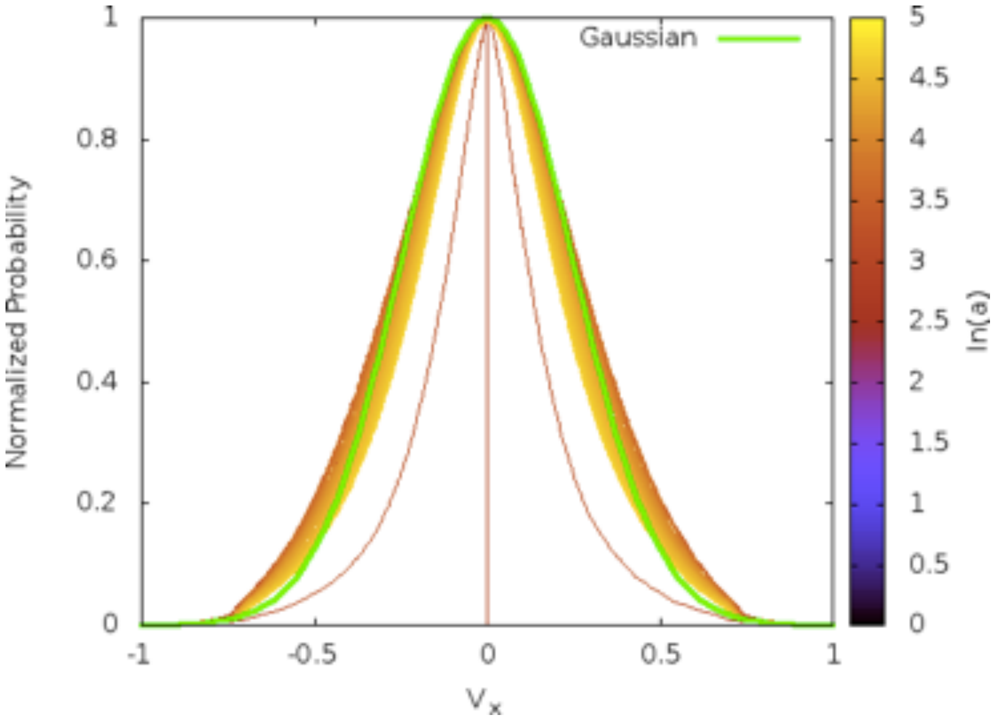
B+Braden11

but Statistical Simplicity



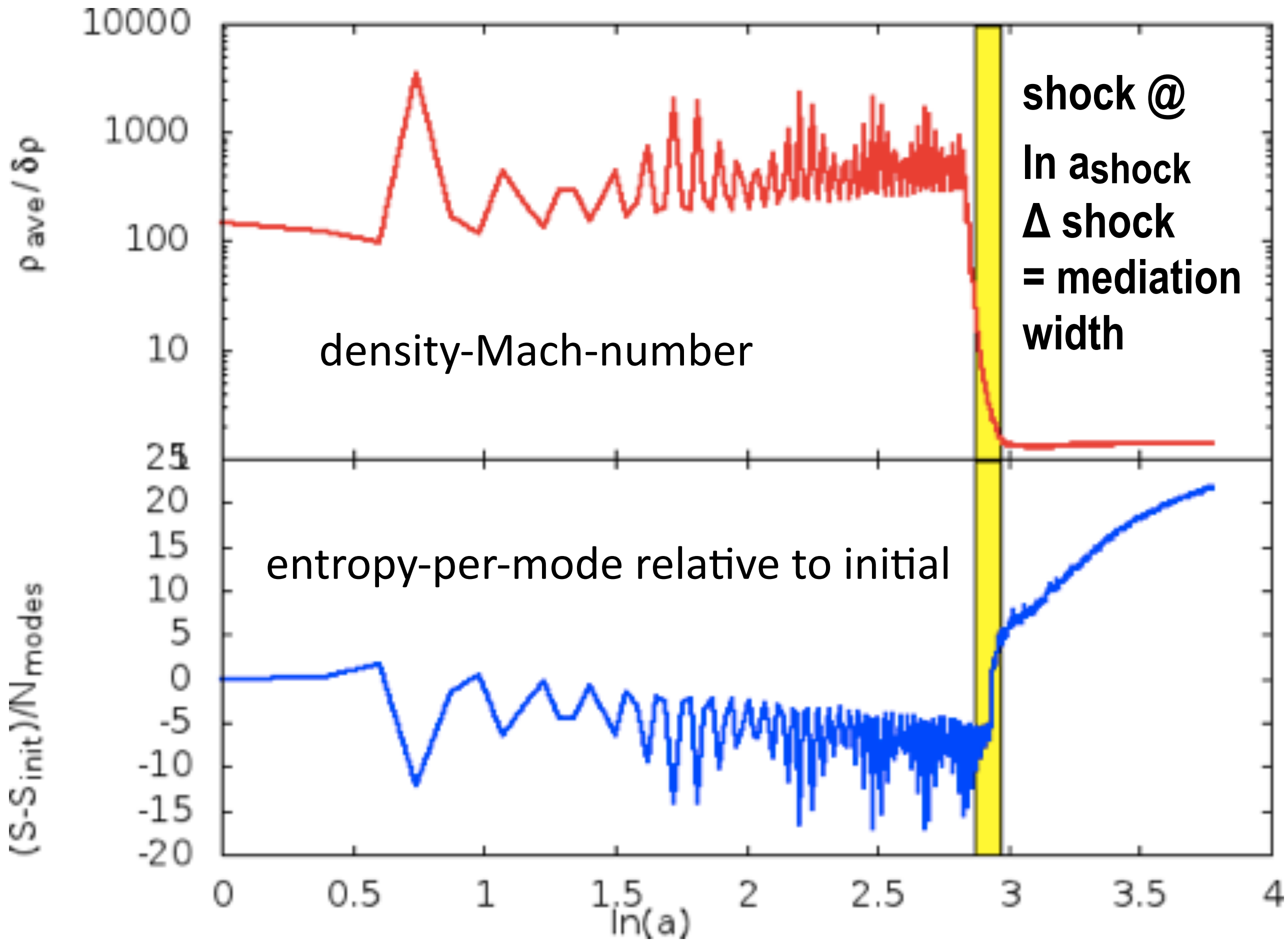
Density PDF~ log-normal after initial transient Frolov

Velocity components ~ Gaussian PDF



B+Braden11

Entropy Production & the Shock-in-time



true thermal equilibrium far off

& on to coupling to standard model degrees of freedom

constrained coarse-grained Shannon entropy is taken relative to the initial entropy with its Gaussian random field entropy from band-limited quantum fluctuations

there is indeed a spike of entropy production at the shock front.

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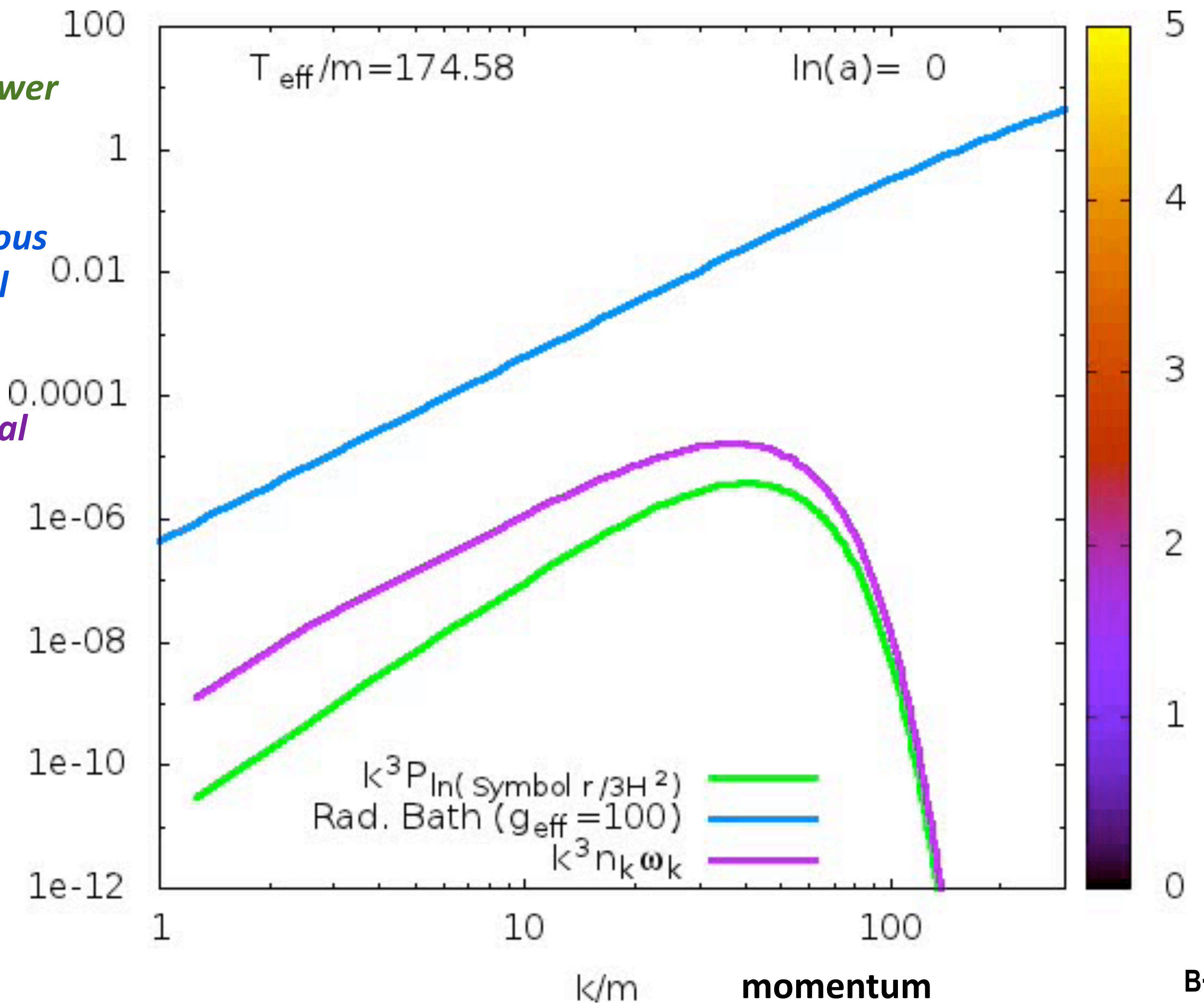
coherent inflaton => incoherent mode cascade of fields thru a shock-in-time to thermal equilibrium

s_{Ui}~0; $s_{Utot,m+r}/n_b$ ~1.66x10^{10} bits/b; s_γ / n_γ = 5.2 bits/Υ = 2130/411; s_ν =21/22 s_γ

ln ρ/3H^2 power spectrum

cf. instantaneous full thermal spectrum

cf. conventional energy spectrum using a pseudo particle occupation number



momentum

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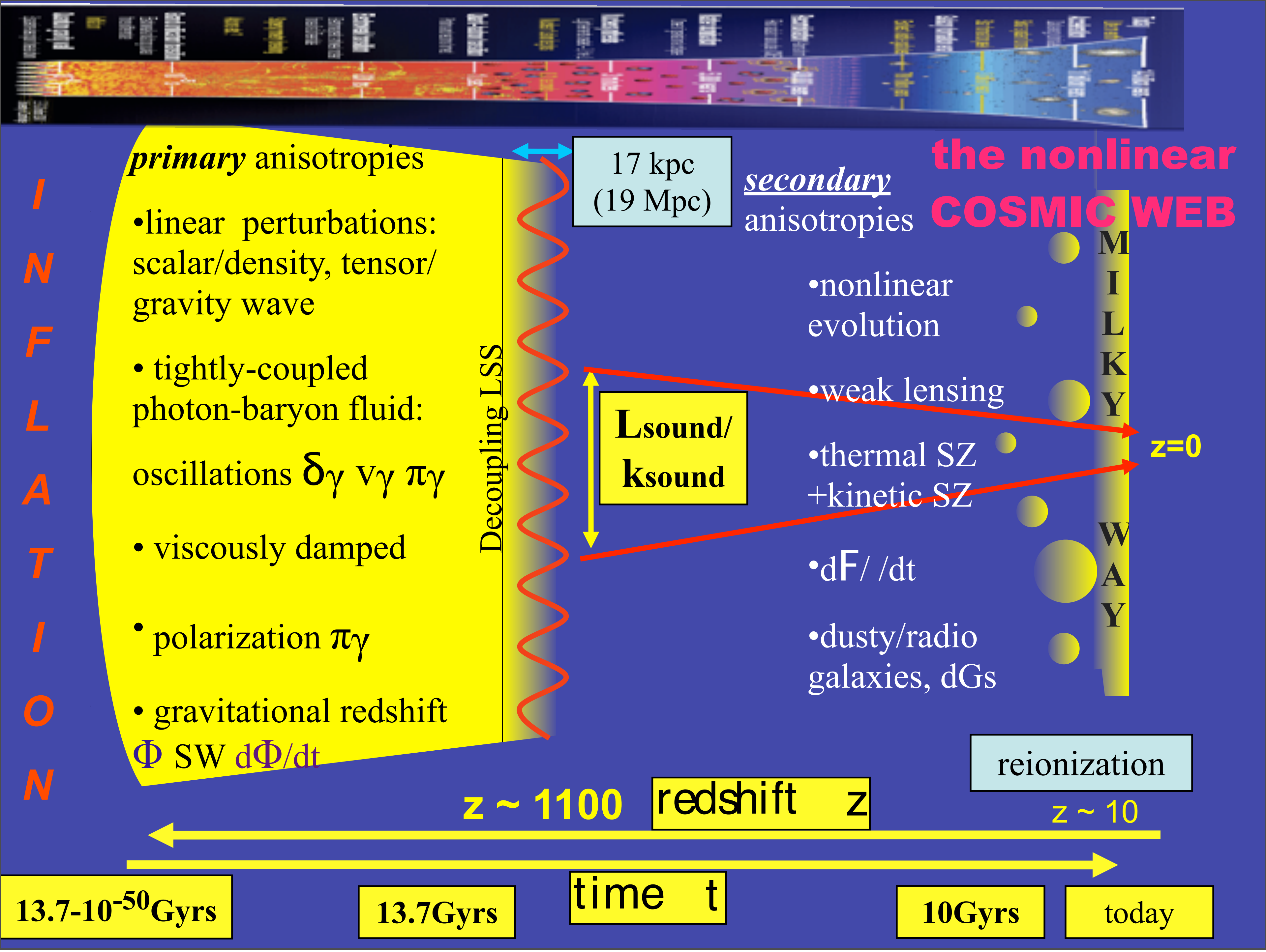

Thursday, 10 November, 11

end

cosmology forecasts for PlanckEXT

$n_s(k)$, GW $r(k)$, nonG f_{NL}++, $\rho_{de}(t)$, m_ν, strings, isocurvature, ...

current CMB+LSS+WL+SN1a+Lyα **PEXT=**Planck2.5yr + low-z-BOSS + CHIME + Euclid-WL + JDEM-SN

Huang, Bond, Kofman 2010, Bond, Huang 2011

$$n_s = 0.963 \pm 0.011 \Rightarrow \pm 0.002 \text{ (Pext)}$$

Power$_s$~25x10^{-10} $\ln A_s = \pm 0.03 \Rightarrow \pm 0.008$ (Pext)

Farhang, Bond, Dore, Netterfield 2011 ***forecasting QU not EB***

Spider $2\sigma_r$~0.013 => ~0.02 for 0.02 < f_{sky} < 0.15

Planck2.5yr $2\sigma_r$~0.02 => ~0.05 (foregrounds)

quadratic local nonG -10< f_{NL} <74 (+- 5 Planck)

$\Omega_m = \pm 0.012 \Rightarrow \pm 0.001$ (Pext) $1-\Omega_{\Lambda de}$ ie, V_{de}

$w_0 = \pm 0.06 \Rightarrow \pm 0.01$ (Pext) if w_a=0 $\pm 0.14 \Rightarrow \pm 0.03$ $w_a \neq 0$

DEslope $(d\ln V/d\psi)^2/4$ @pivot a_{eq} $= 0.0 \pm 0.18 \Rightarrow \pm 0.03$ (Pext)

$z_{re} = \pm 1.2 \Rightarrow \pm 0.3$ (Pext)

$\sigma_8 = \pm 0.016 \Rightarrow \pm 0.002$ (Pext)

$\Delta \sum m_\nu \sim 0.06$ eV

Planck + ACTPol

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

25 years cifar

CITA = Cosmic Information Theory & Analysis:

IT from BIT, from BITs in IT, *Studying the Cosmic Tango*

Dick Bond CIAR

Universe=System+Res =Data+Theory ***en-TANGO-ment***

the ***Cosmotician's*** *Agenda: Statistical Paths in Cosmic Theory & Data*

We consider the Universe to be fundamentally quantum and statistical, the many-paths/many-worlds information-theoretic story. This lecture uses Cosmic Information Theory and Analysis, CITA, as a unifying theme to explore the vast sweep of our current ideas of the Universe and the experiments we use to probe them, ranging from the ultra-early beginnings to our far-future fate. I describe the intimate entanglement of theory with precision "first-light" and other cosmic data, in particular from the satellite Planck and the Andes-based ACT. Such data are the BITs in IT informing us of the physics that defines the BIT of the Universe accessible to us from which we hope to learn of that vast IT which encodes all Cosmic Information.