INFLATION

primary anisotropies

•linear perturbations: scalar/density, tensor/ gravity wave

• tightly-coupled photon-baryon fluid:

oscillations $\delta\gamma$ $v\gamma$ $\pi\gamma$

• viscously damped

• polarization $\pi\gamma$

• gravitational redshift

Φ SW $d\Phi/dt$

DarkM

Decoupling LSS

17 kpc (19 Mpc)

Lsound/ ksound

secondary anisotropies

the nonlinear COSMIC WEB

dS/dt

•nonlinear evolution

•weak lensing

•thermal SZ +kinetic SZ

•$d\Phi$ /dt

•dusty/radio galaxies, dGs

MILKY WAY

DarkE

z=0

reionization

z ~ 10

z ~ 1100

redshift z

dS/dt

time t

13.7-10^{-50}Gyrs

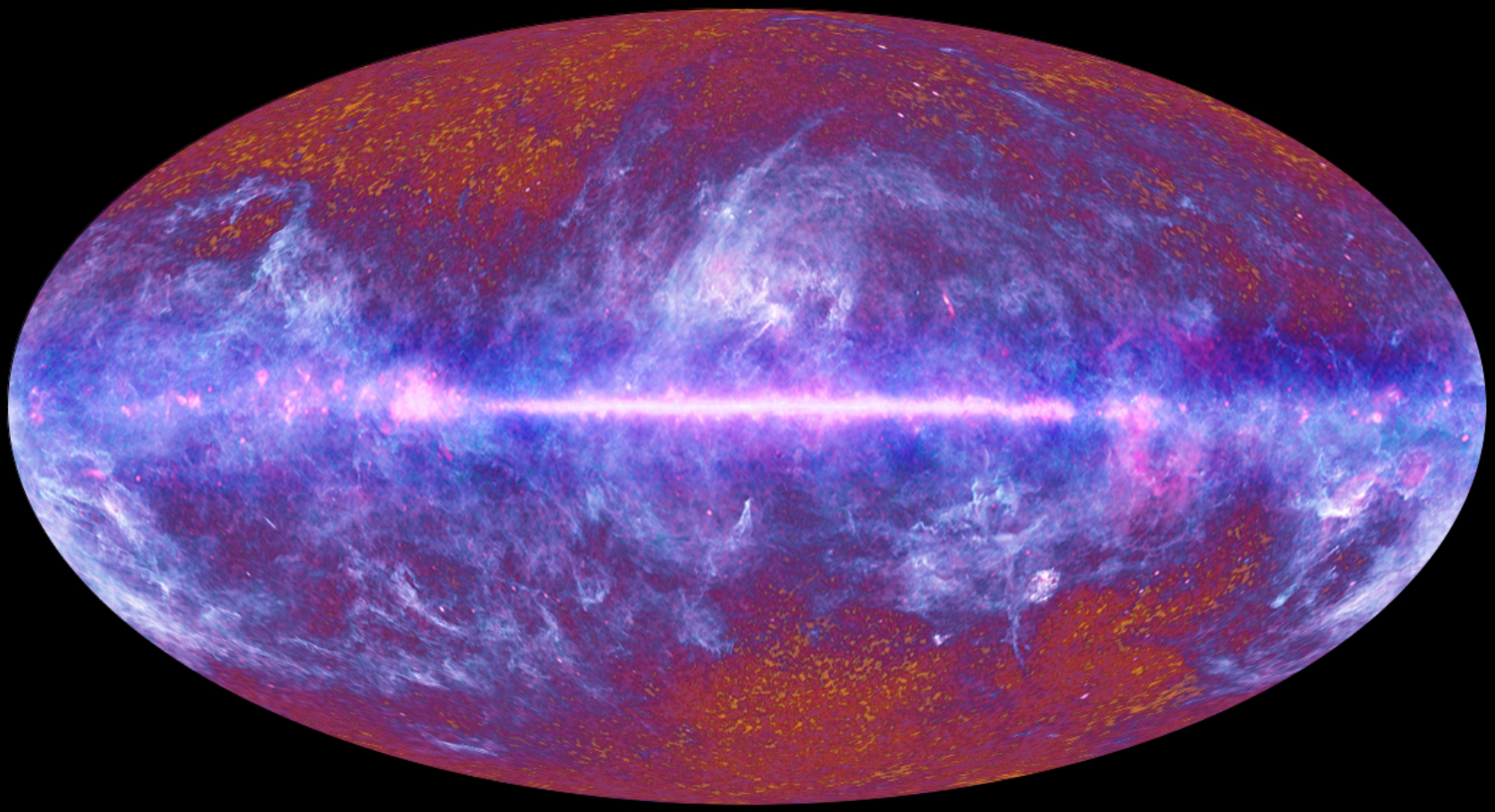
13.7Gyrs

10Gyrs

today

Dick Bond+cast of 1000s *Probing the Cosmic Theory of* **Early&Late Universe** *Physics*

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



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The Planck one-year all-sky survey

esa

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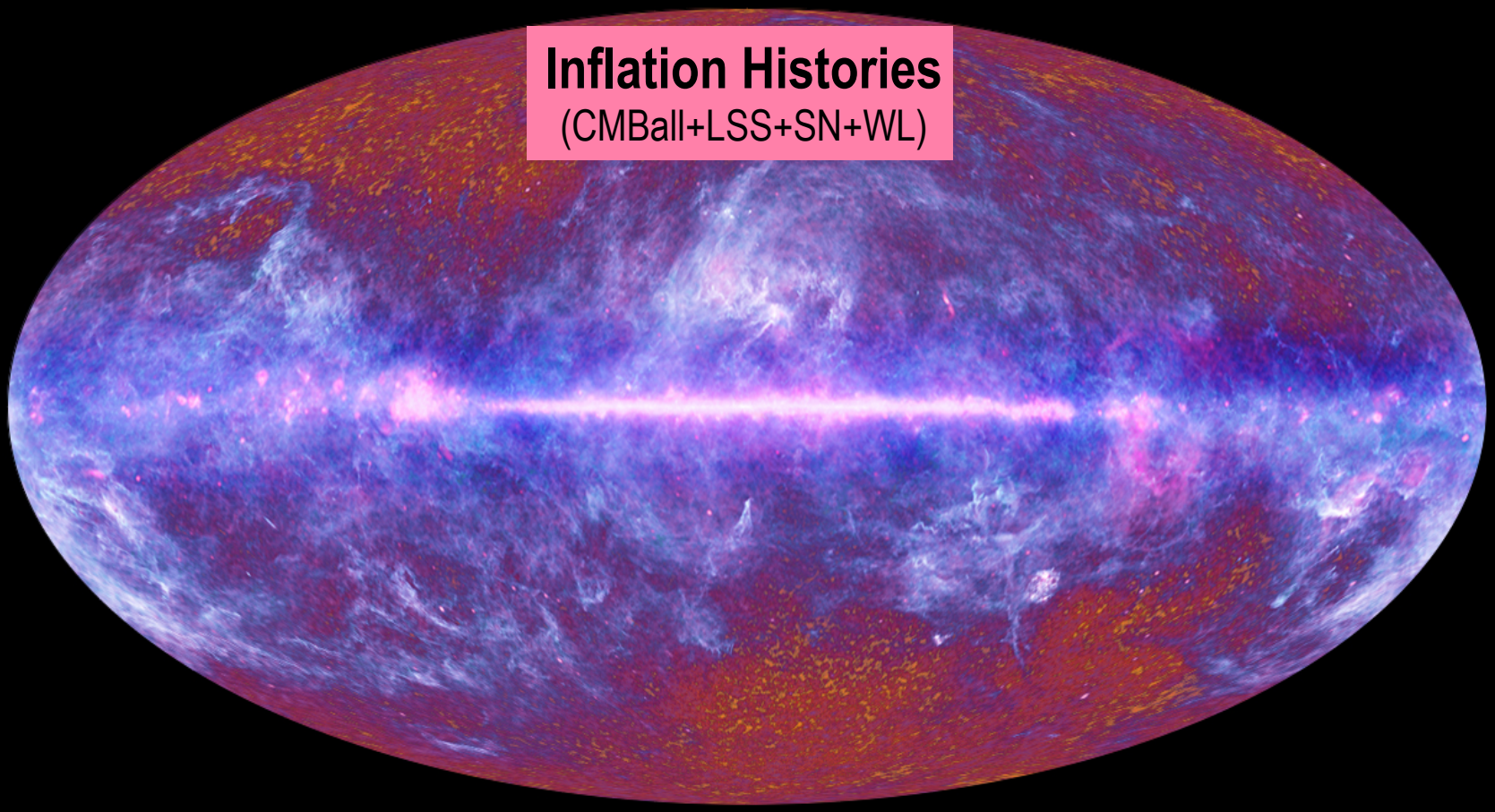

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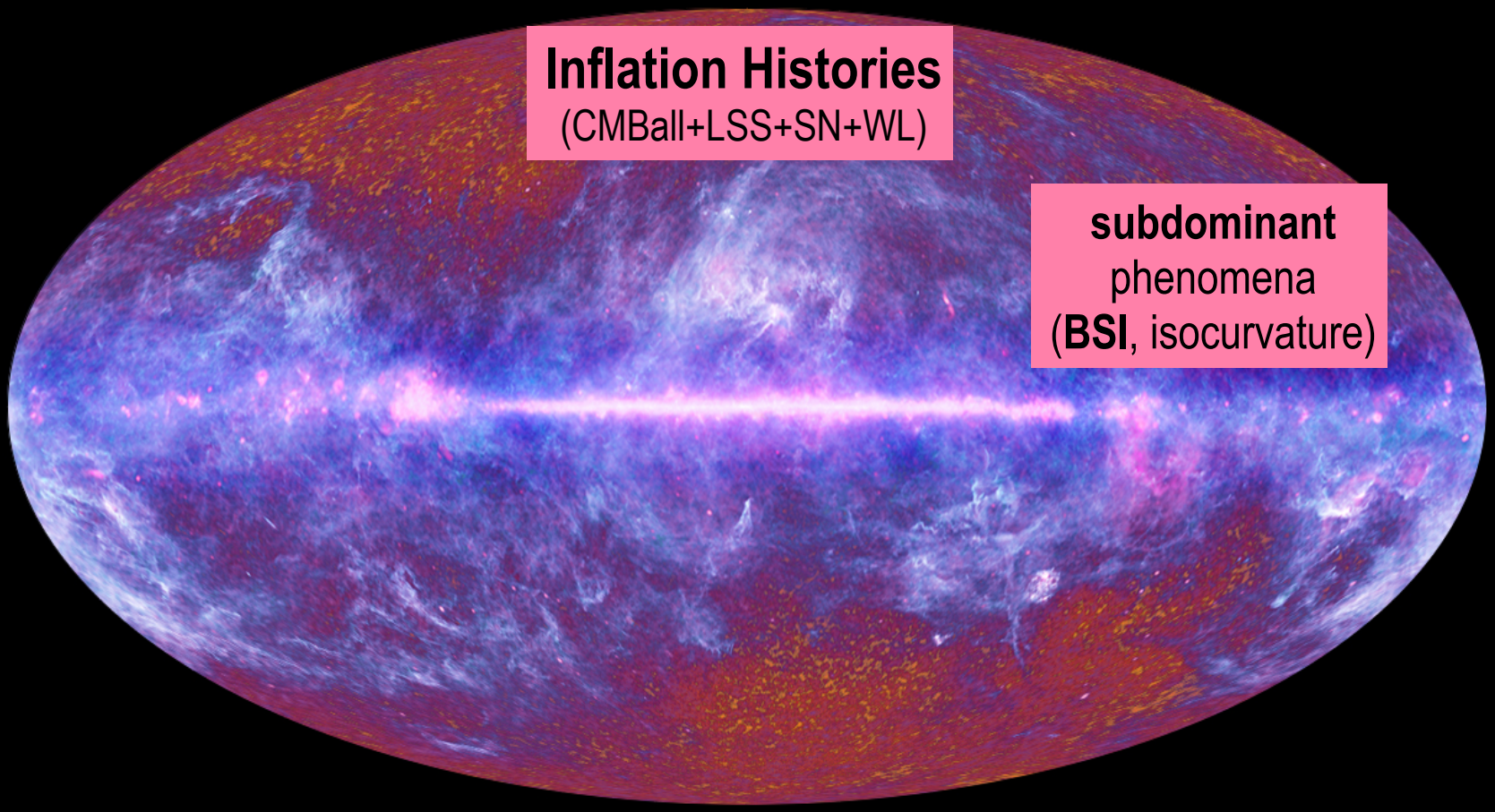

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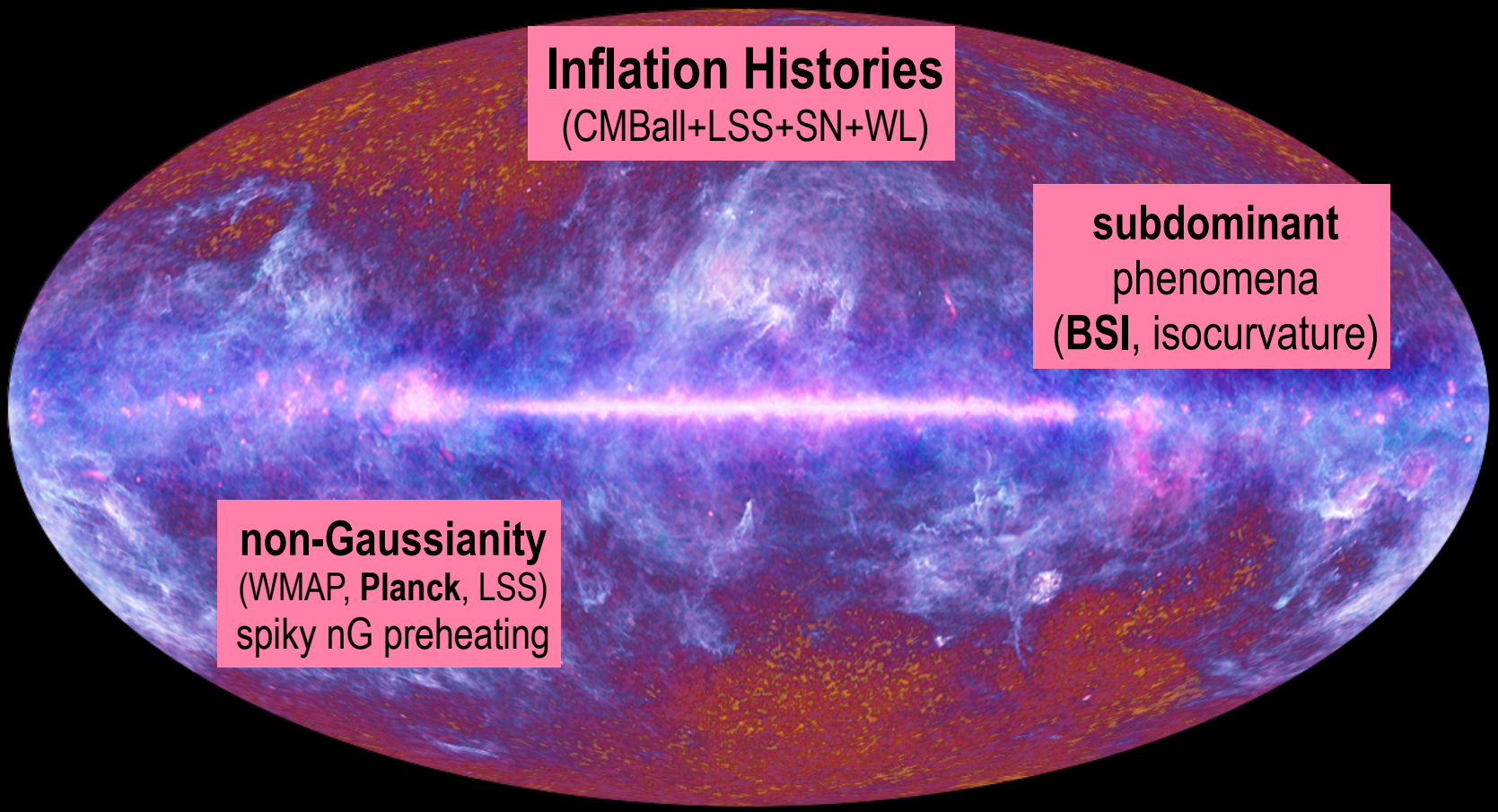

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(c) ESA, HFI and LFI consortia, July 2010

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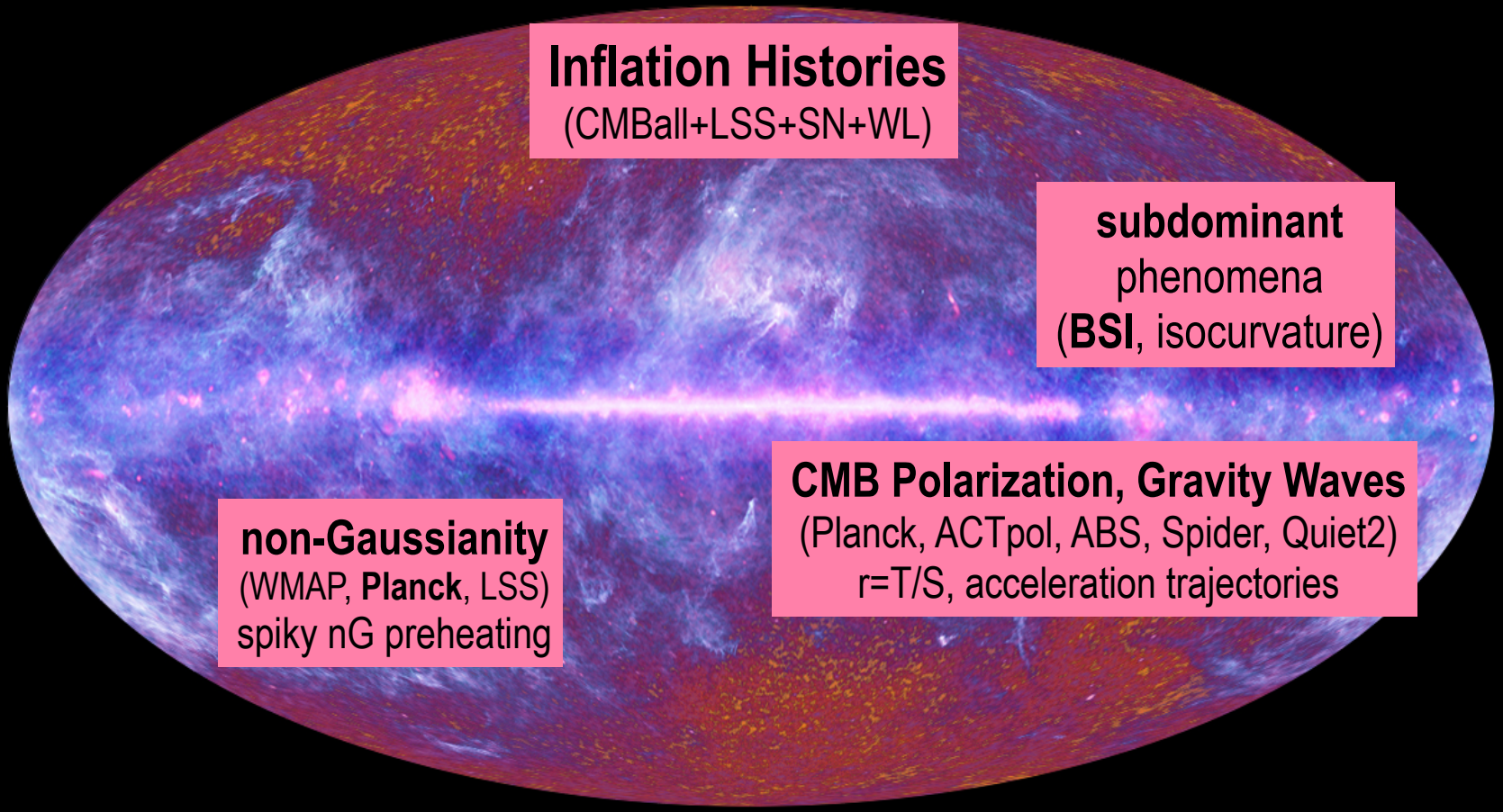

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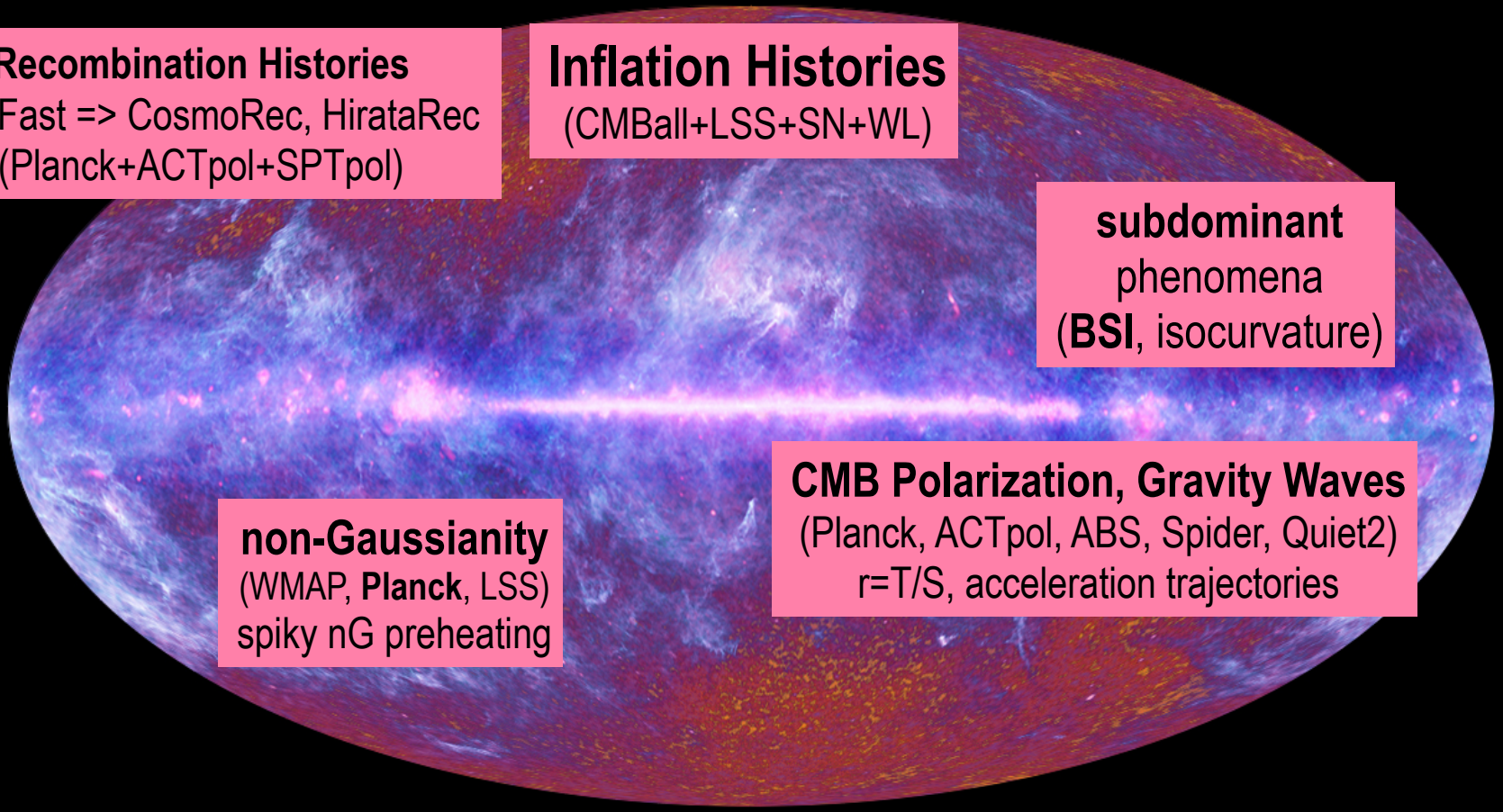
Recombination Histories
(RecFast => CosmoRec, HirataRec
(Planck+ACTpol+SPTpol)

Inflation Histories
(CMBall+LSS+SN+WL)

subdominant
phenomena
(**BSI**, isocurvature)



CMB Polarization, Gravity Waves
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r=T/S, acceleration trajectories

non-Gaussianity
(WMAP, **Planck**, LSS)
spiky nG preheating

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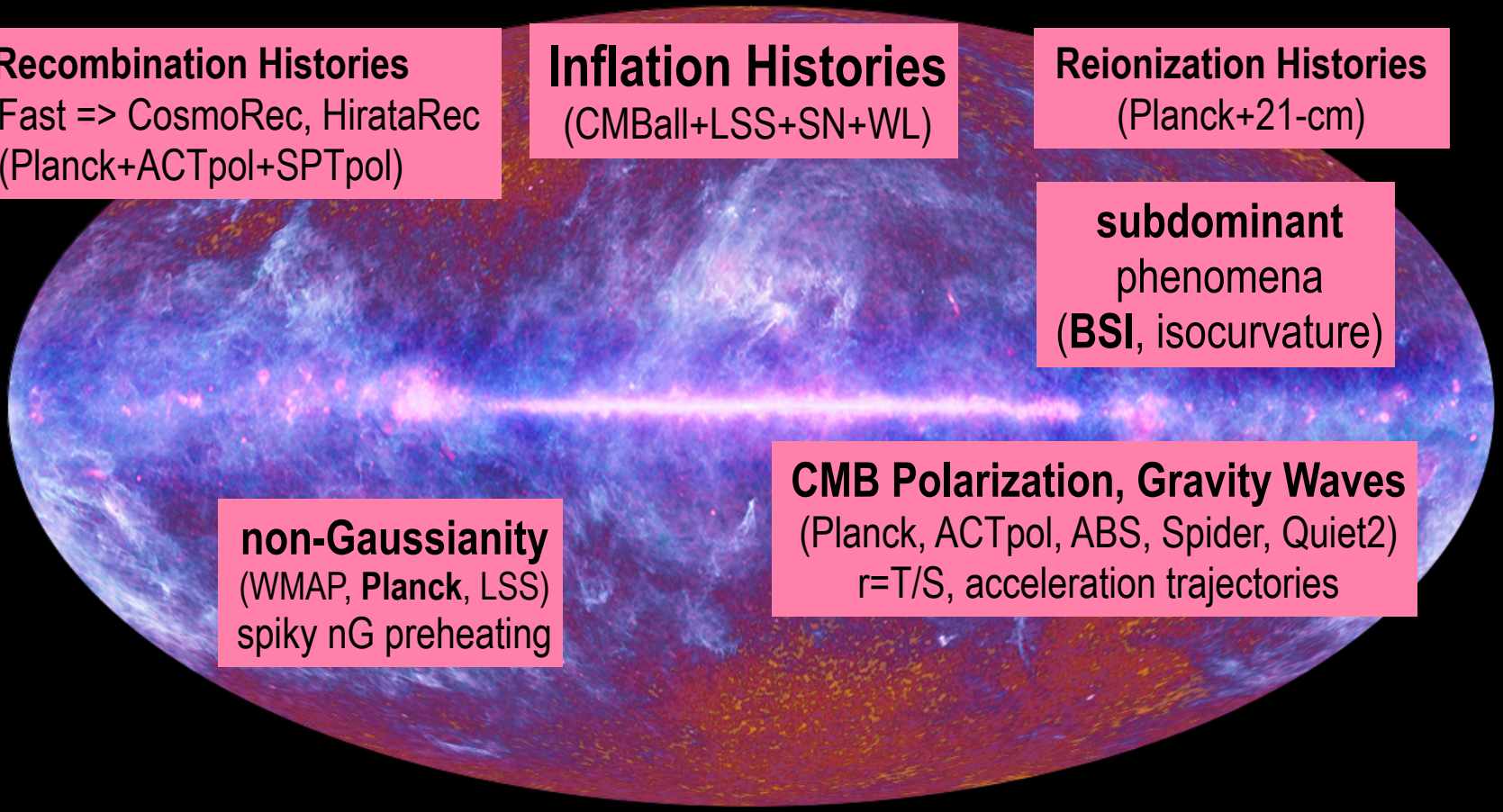

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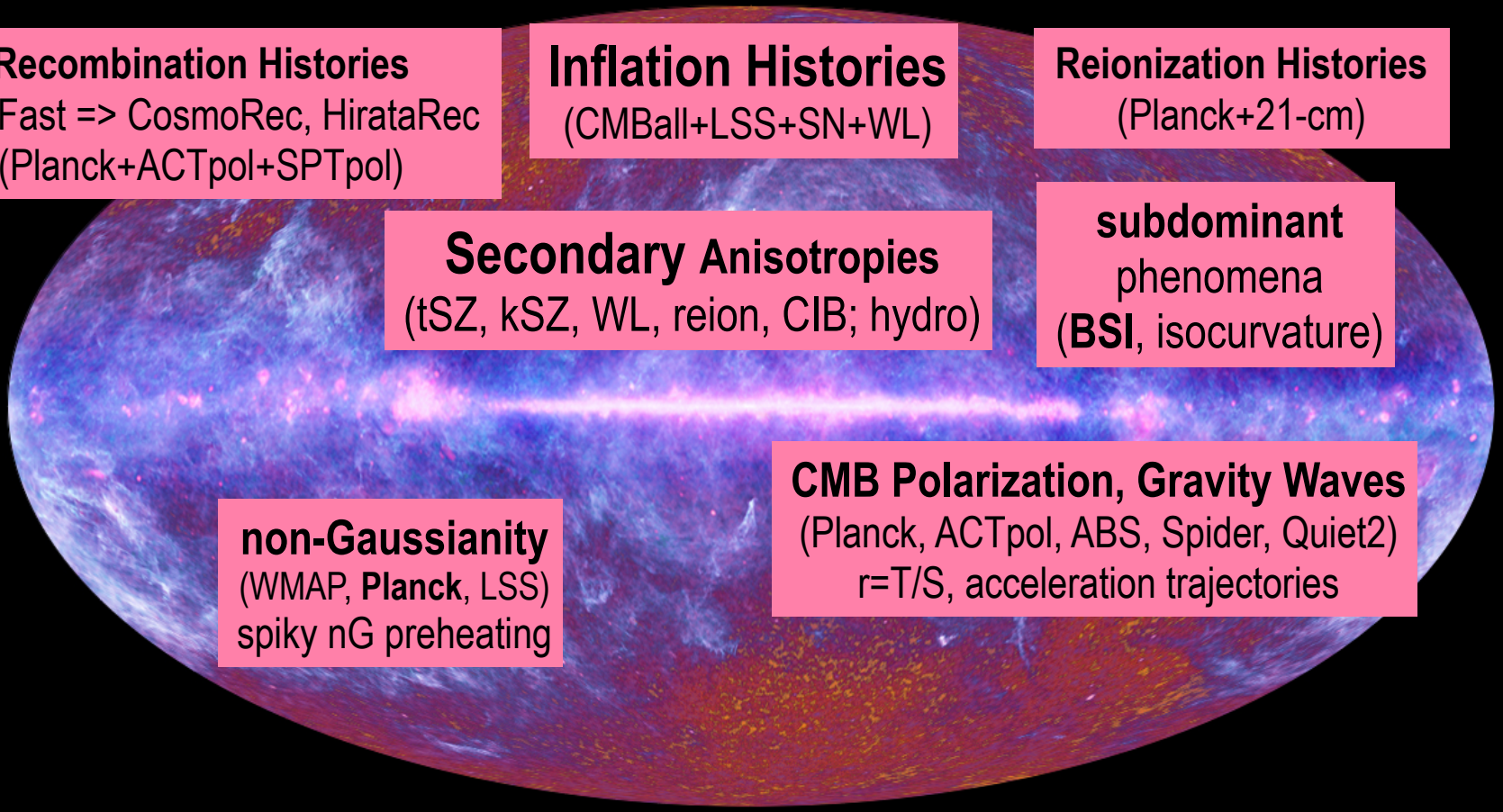

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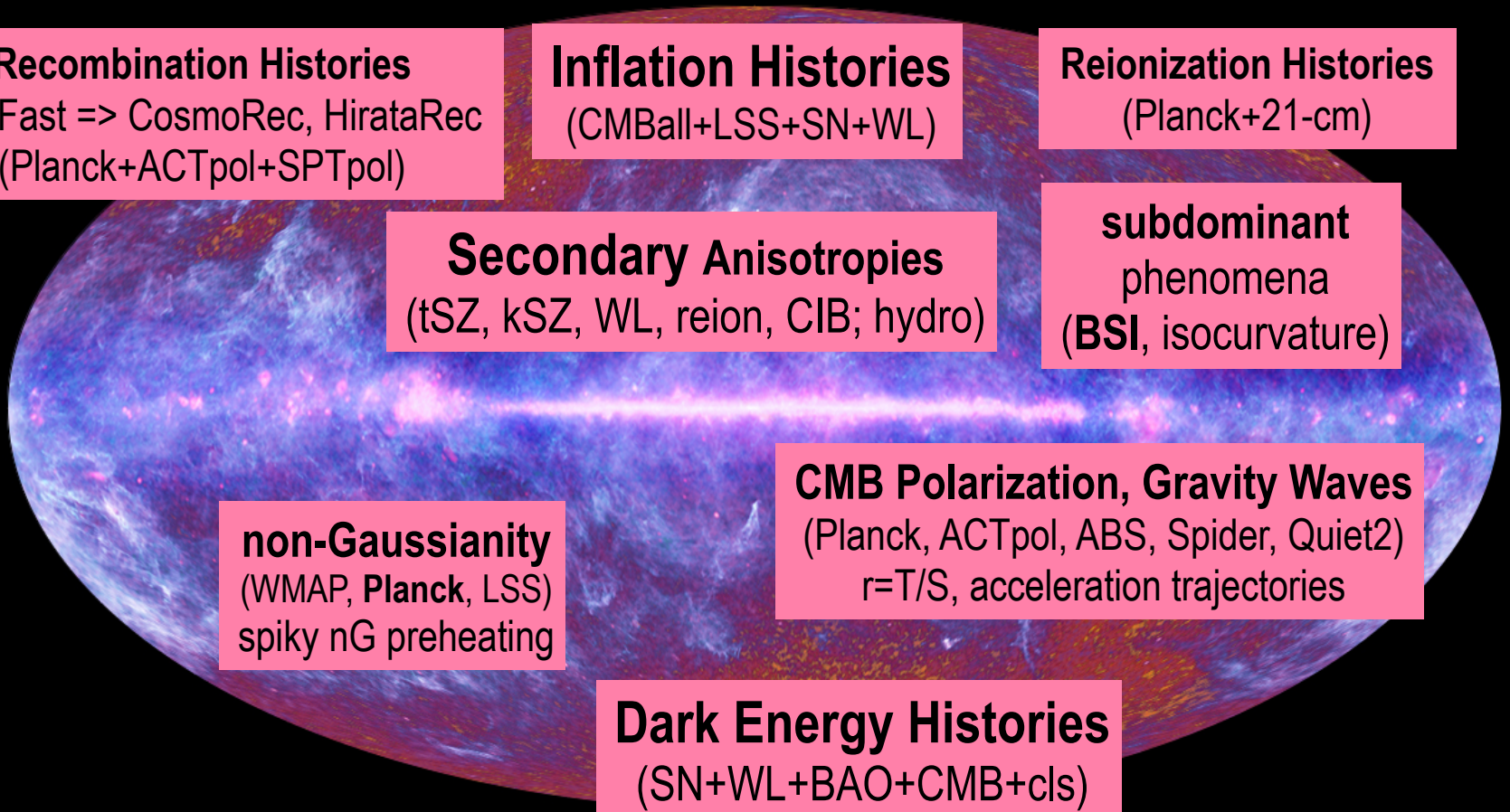

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(SN+WL+BAO+CMB+cls)

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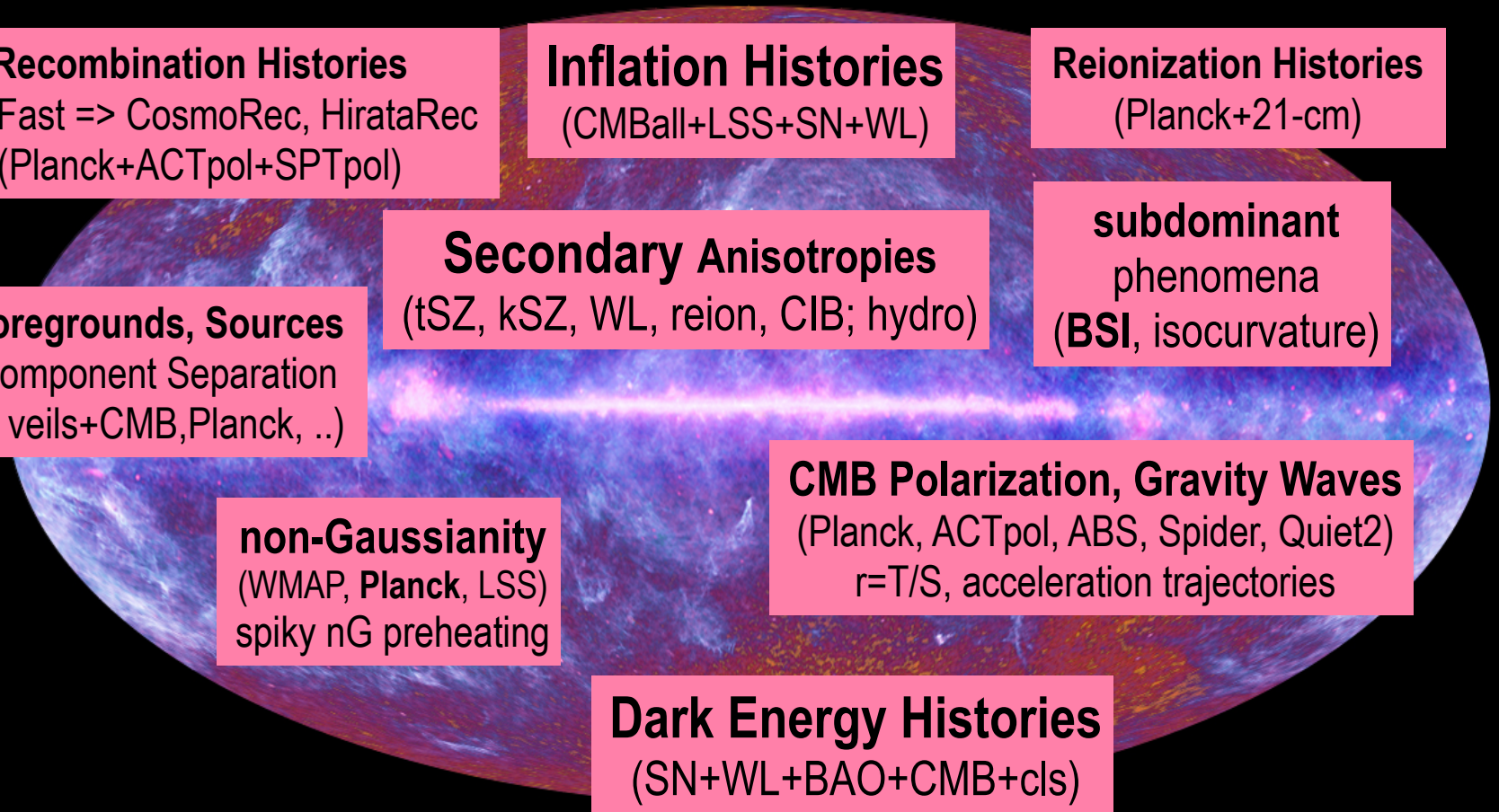

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Foregrounds, Sources
Component Separation
(7 veils+CMB,Planck, ..)

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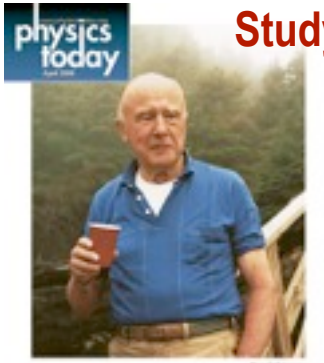


Studying the Cosmic Tango

en-TANGO-ment U=S+R

Boltzmann

$S = k_B \ln N_{states}$

$dS/dt > 0$

$S_{U,m+r} \sim 10^{88.6}$

information-content =entropy **Quantity not Quality** Shannon 1948

the coherent and the entropic, in all its forms, from ultra-early-U to ultra-late-U *cf.* $S_G \sim 10^{121.9}$ *asymptotic DE*

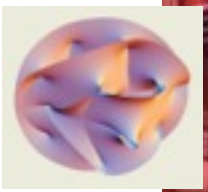
our Cosmoticians' Agenda: Statistical Paths in Cosmic Theory & Data via the Bayesian chain drawing what we know of It from Its Bits

$P(q|D,T) = P(D|q,T)P(q|T)P(T)/P(D|T)$ Shannon $S_f(D,T) = \int dq\, P_f \ln P_f^{-1}$

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

Old: Theory prior = delta function of THE correct one&only



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

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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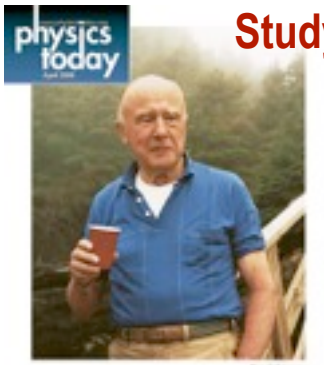

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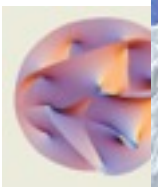

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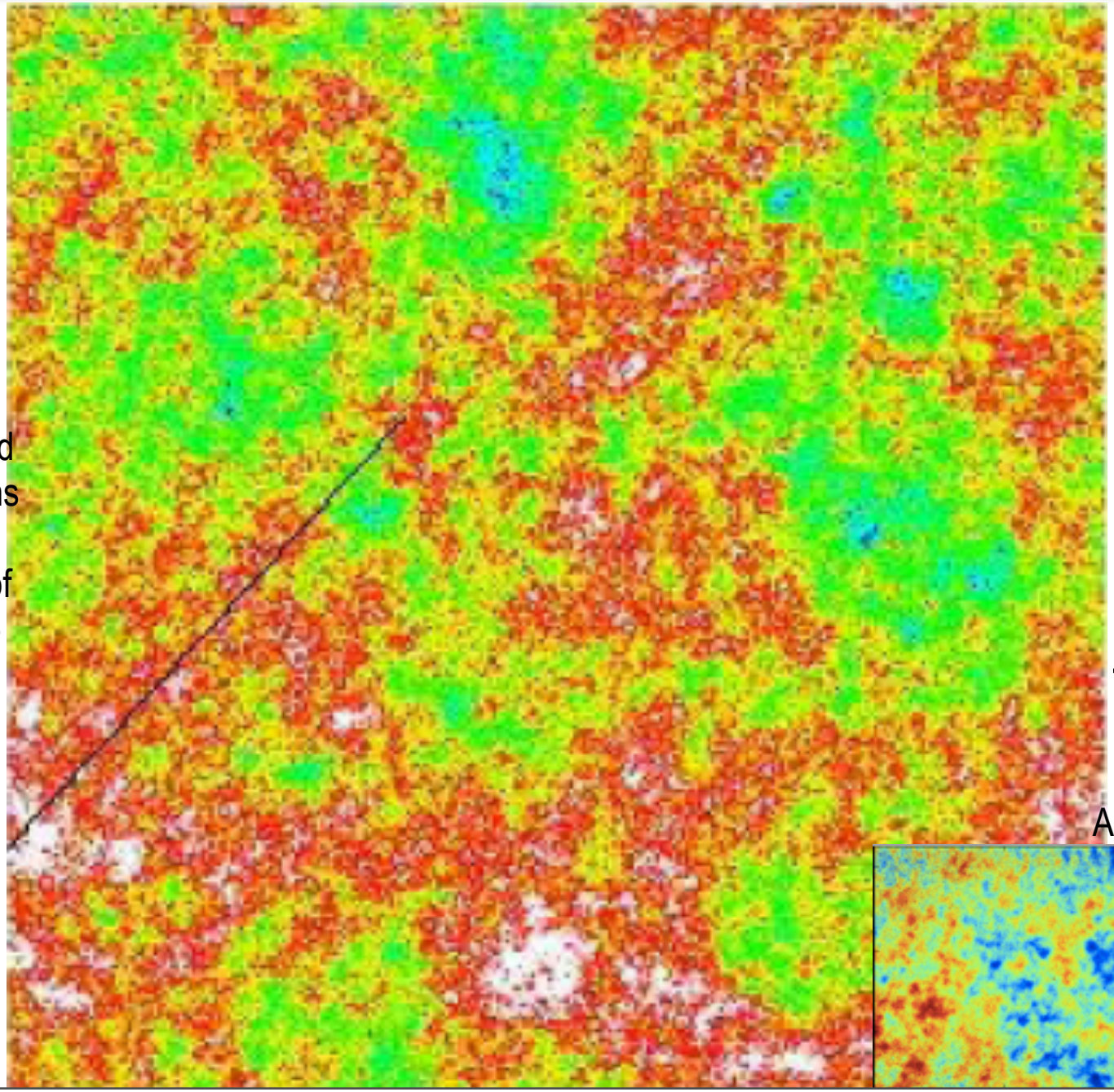
SciNet
Simulate Universes from ultra-early beginnings to the ultimate end. turning 6 parameter theories into Petabits. Fields on a lattice, Linear Theory, Linear perturbation evolution for primary CMB, pure N-body, Gastrophysical complexity, feedback, transport
Process Data compressing the Petabit+ raw observed CMB+LSS information into high quality bits
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**

χ



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

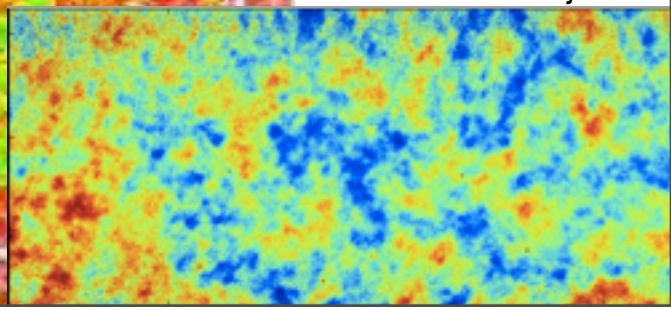
scalar field fluctuations in the vacuum of the ultra-early Universe

pre-heating patch (~1cm)

evolve from early U vacuum potential and vacuum noise

10 Gpc

ACT+WMAP7 hajian+10



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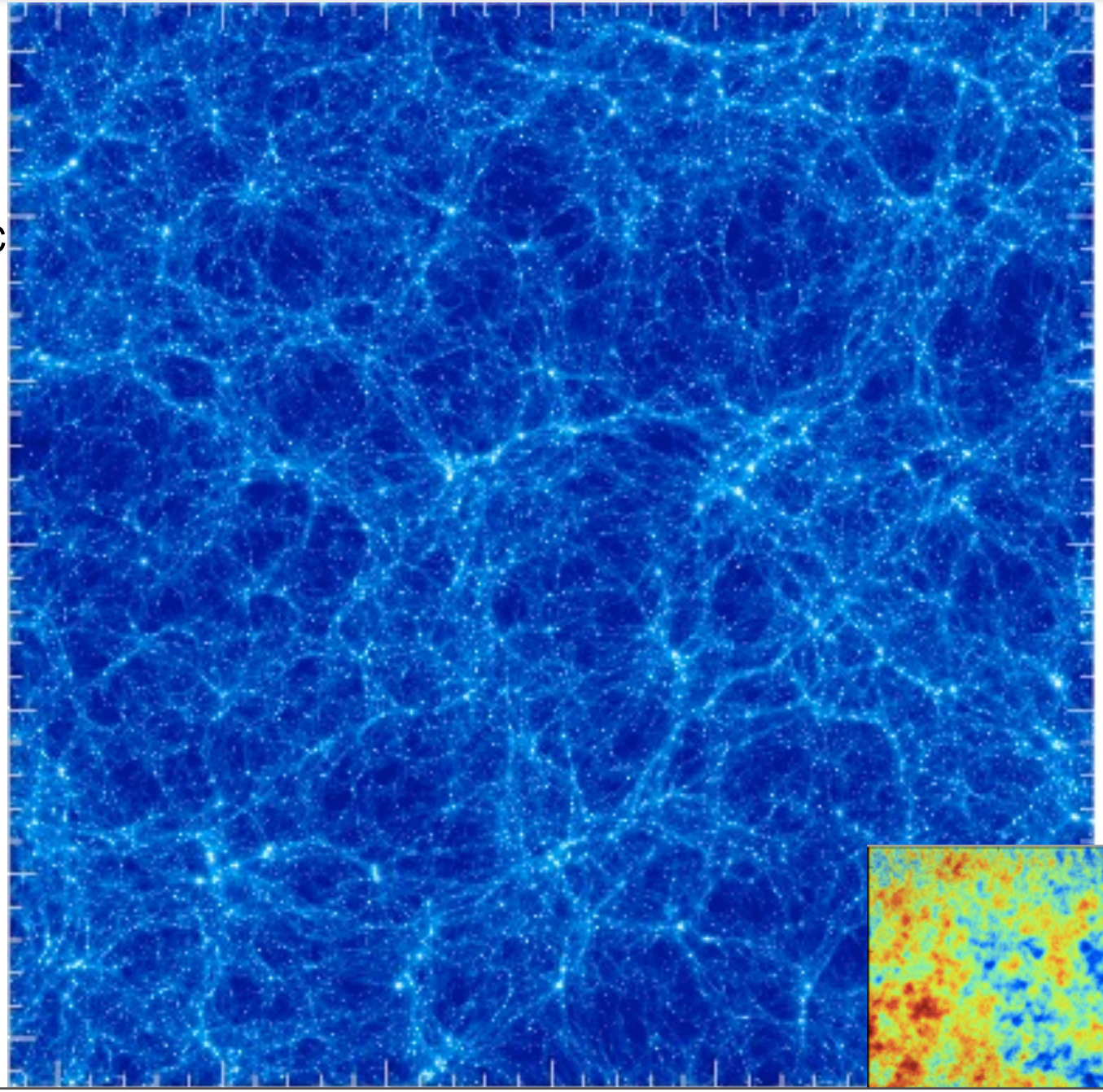


400 Mpc

ΛCDM

WMAP5

gas density

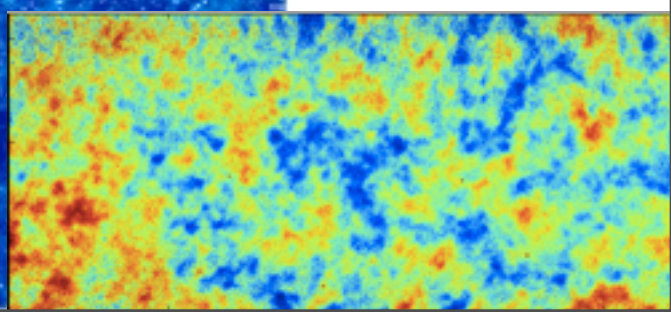
Gadget-3

SF+ SN E+ winds +CRs

512^3

BBPSS10

BBPS1,2,3,4



$\rho_g(x,t)$

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential aka dark energy

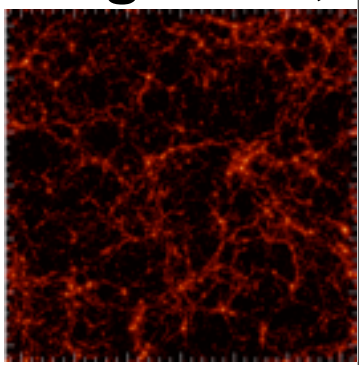
dS/dt 2

how most of the entropy in baryons & dark matter was generated

strain waves break => clusters/groups (galaxies/dwarfs) in the cosmic web collapse => shocked gas & extreme nonlinear phase space entanglement of dark matter / stars

then the baryons feed back entropy: exploding stars, accreting black holes, dusty radiation,

... who, what, where,when, why?



Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

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

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entropy intermittency *in the cosmic web, via gravitation-induced shocks (then E/S-feedback)*

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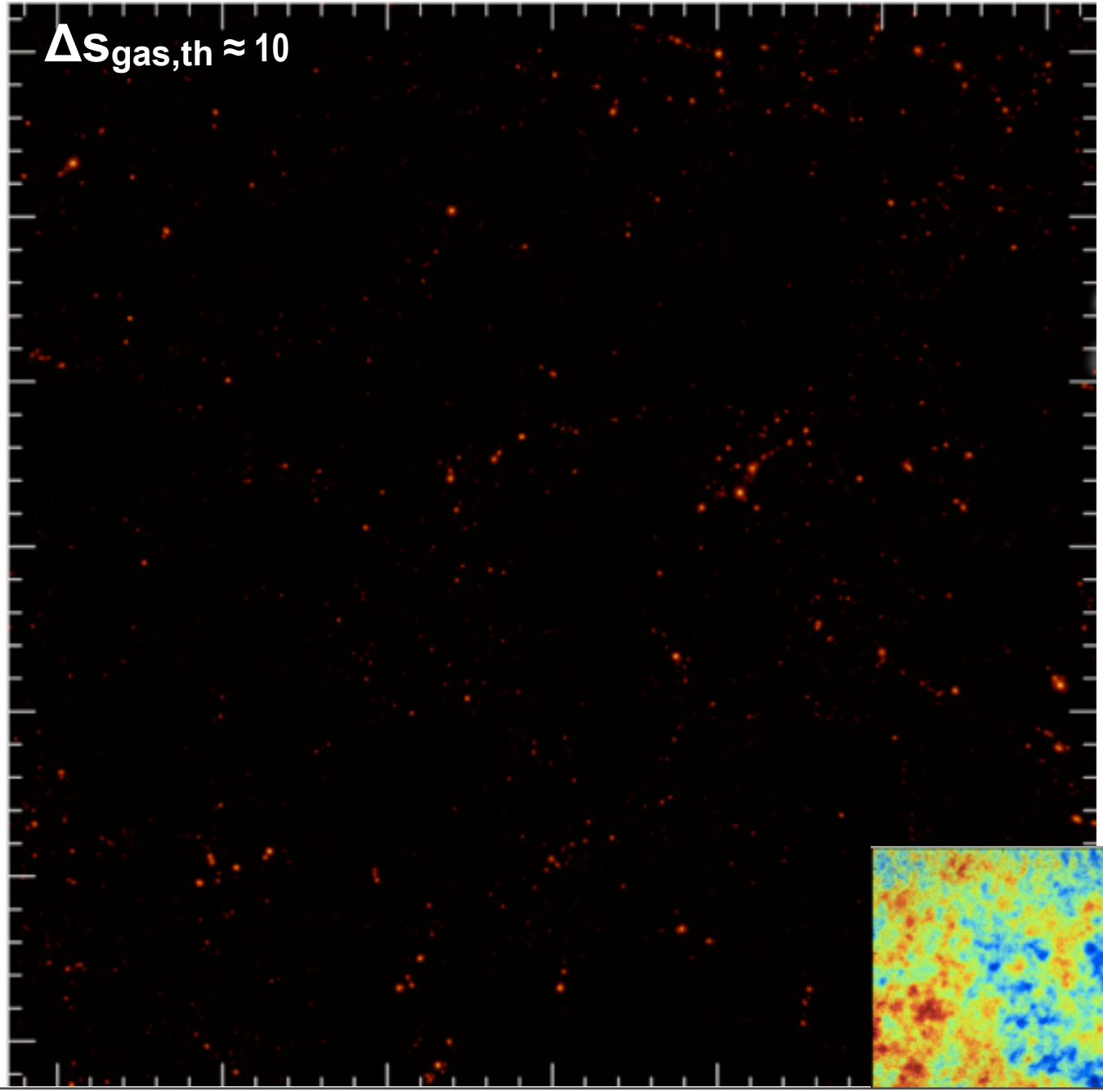
$s_{b,th}(x,t)$



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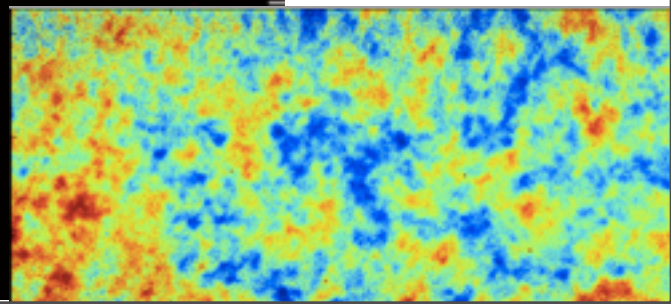
CMB gets entangled in the cosmic web

descending into the real gastrophysics of cosmic weather

the energetic, turbulent, dissipative, compressive

life of the IGM/ICM/ISM



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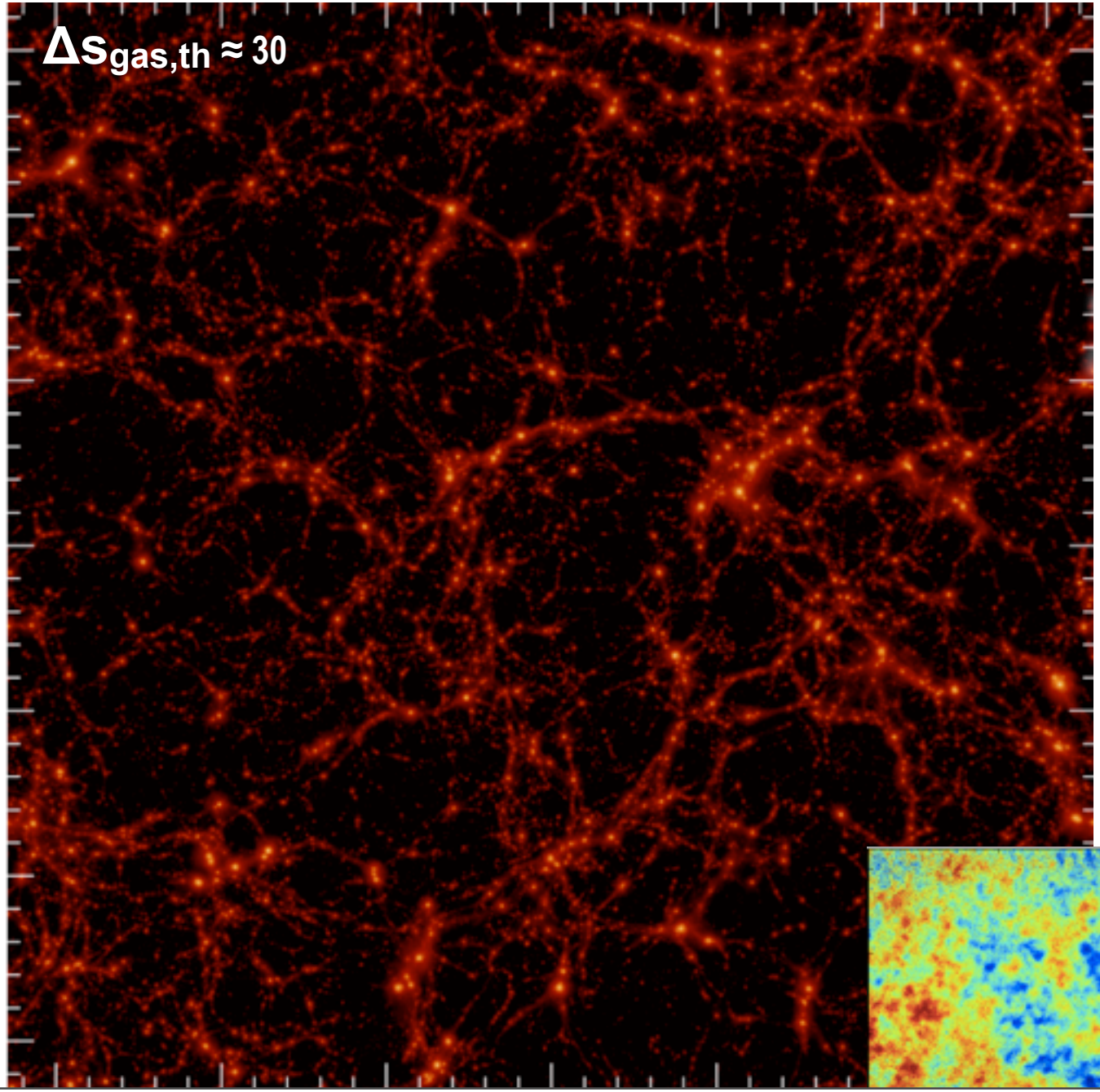

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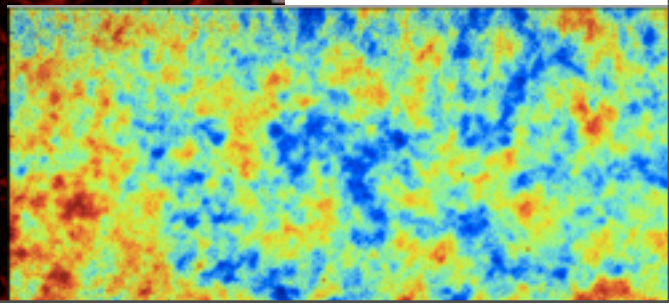

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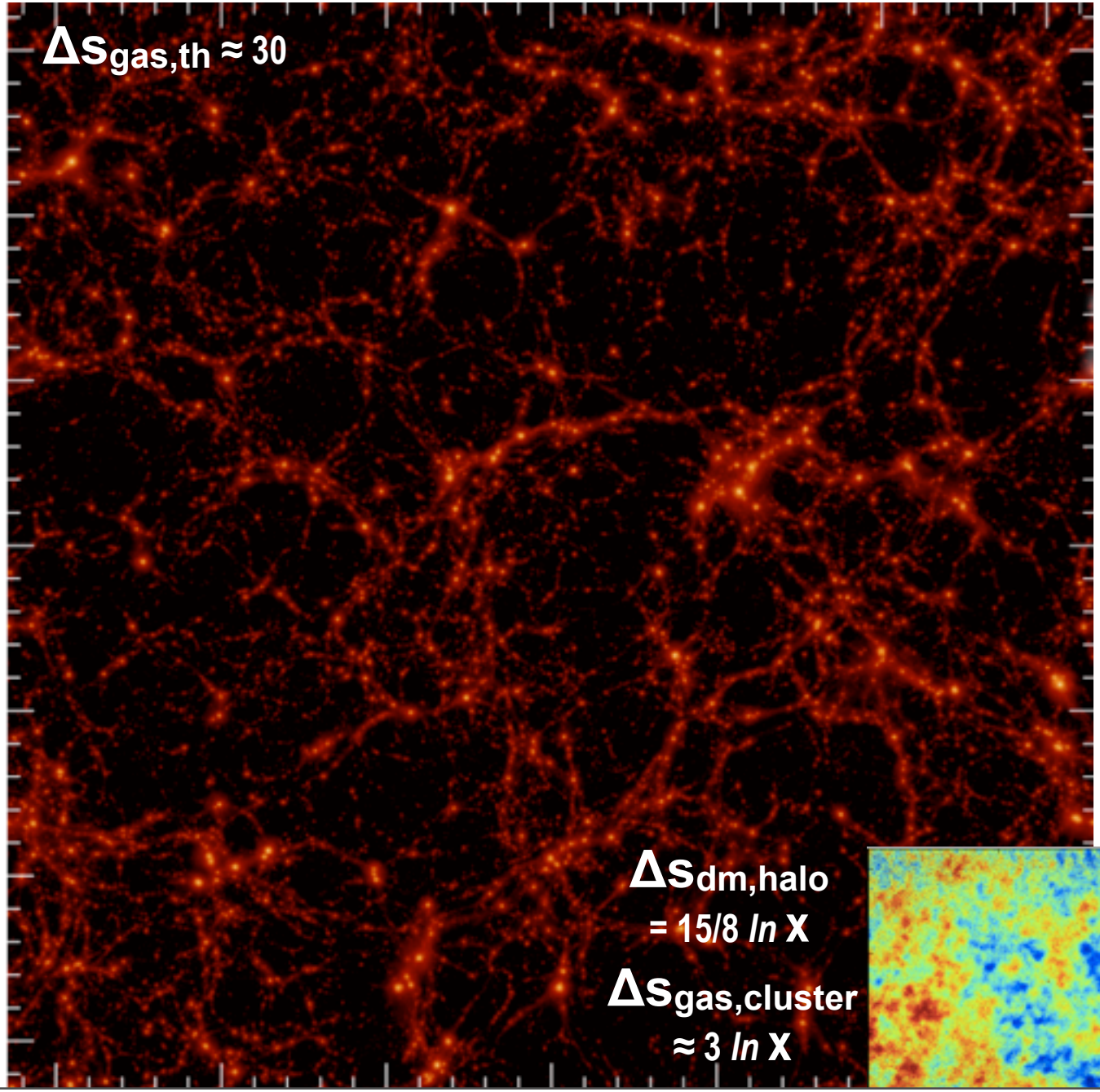

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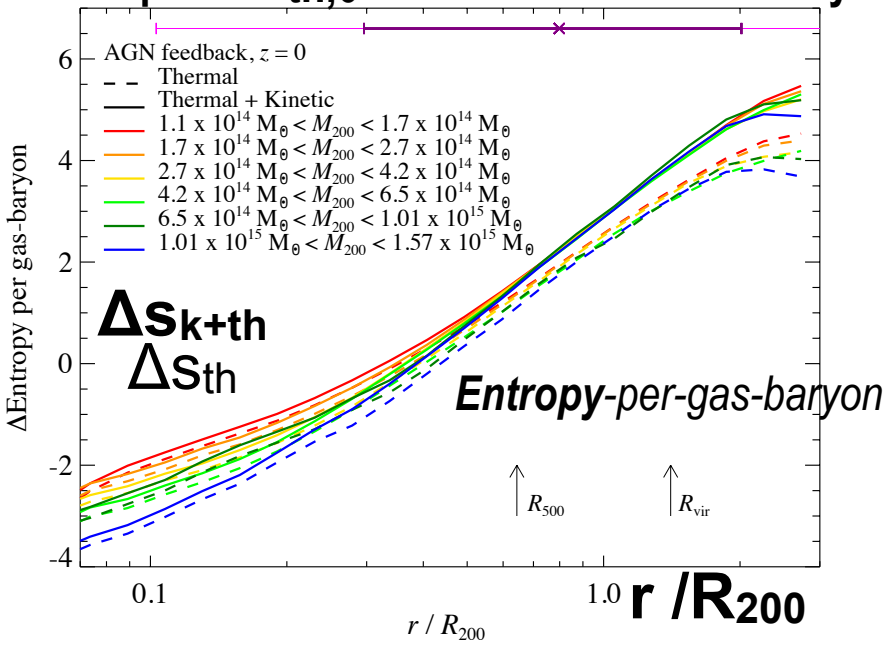
non-equilibrium and non-thermal ***Entropy Profiles (M | z=0) for Mass-binned Scaled Stacked Clusters***

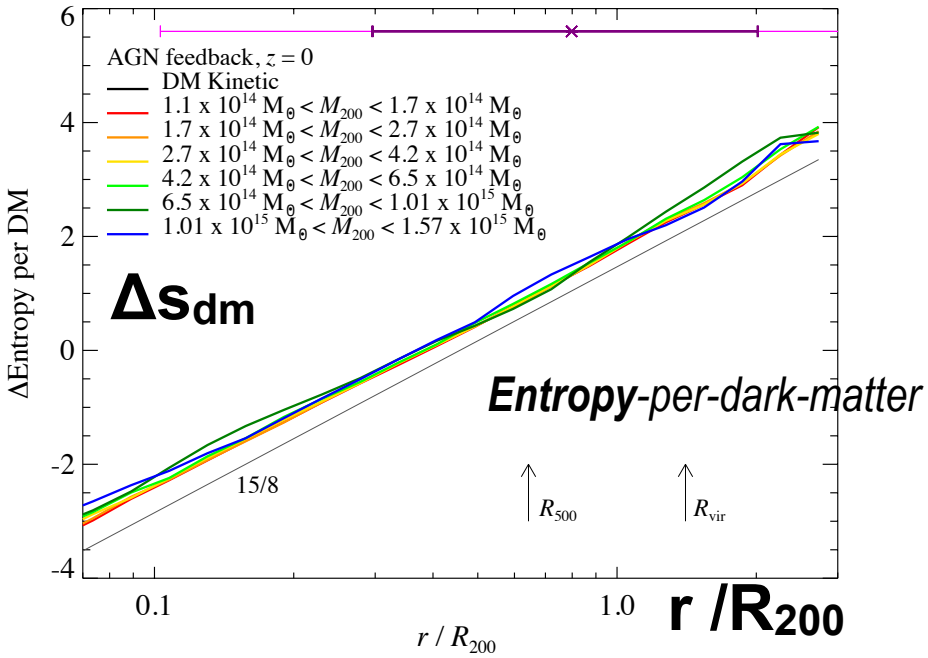
zero point $S_{th,0}$ ~ 130 nats ~ 190 bits/baryon



slope~3.04 =X-ray Voit

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

$\langle(\Delta v)^2\rangle/c_s^2$ affects hydrostatic equilibrium



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

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

$$\Delta s_{dm} = 1/2\ \mathrm{Tr}\ ln\langle(p_{kin}\, I + \Pi_{kin})/\rho_{dm}\rangle - ln\ \rho_{dm} \quad \sim 7\ bits/DM$$

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

cf. $s_{\gamma+\nu}/n_b \sim 1.66\times10^{10}/(1+\delta_b)$ **bits/b**

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

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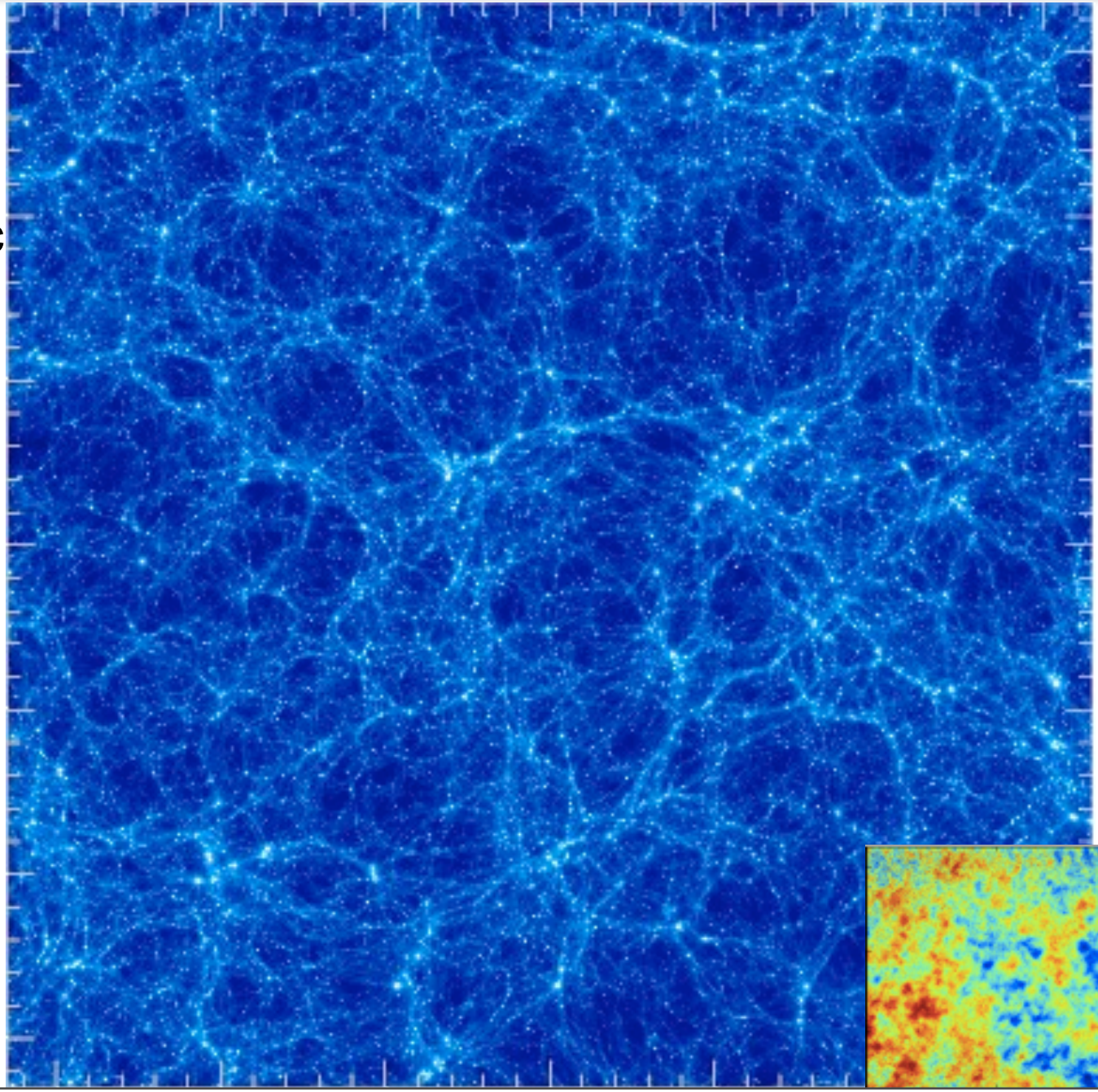
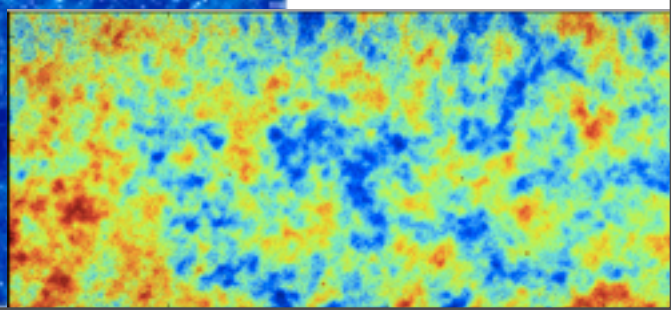
BBPSS10

BBPS1,2,3,4





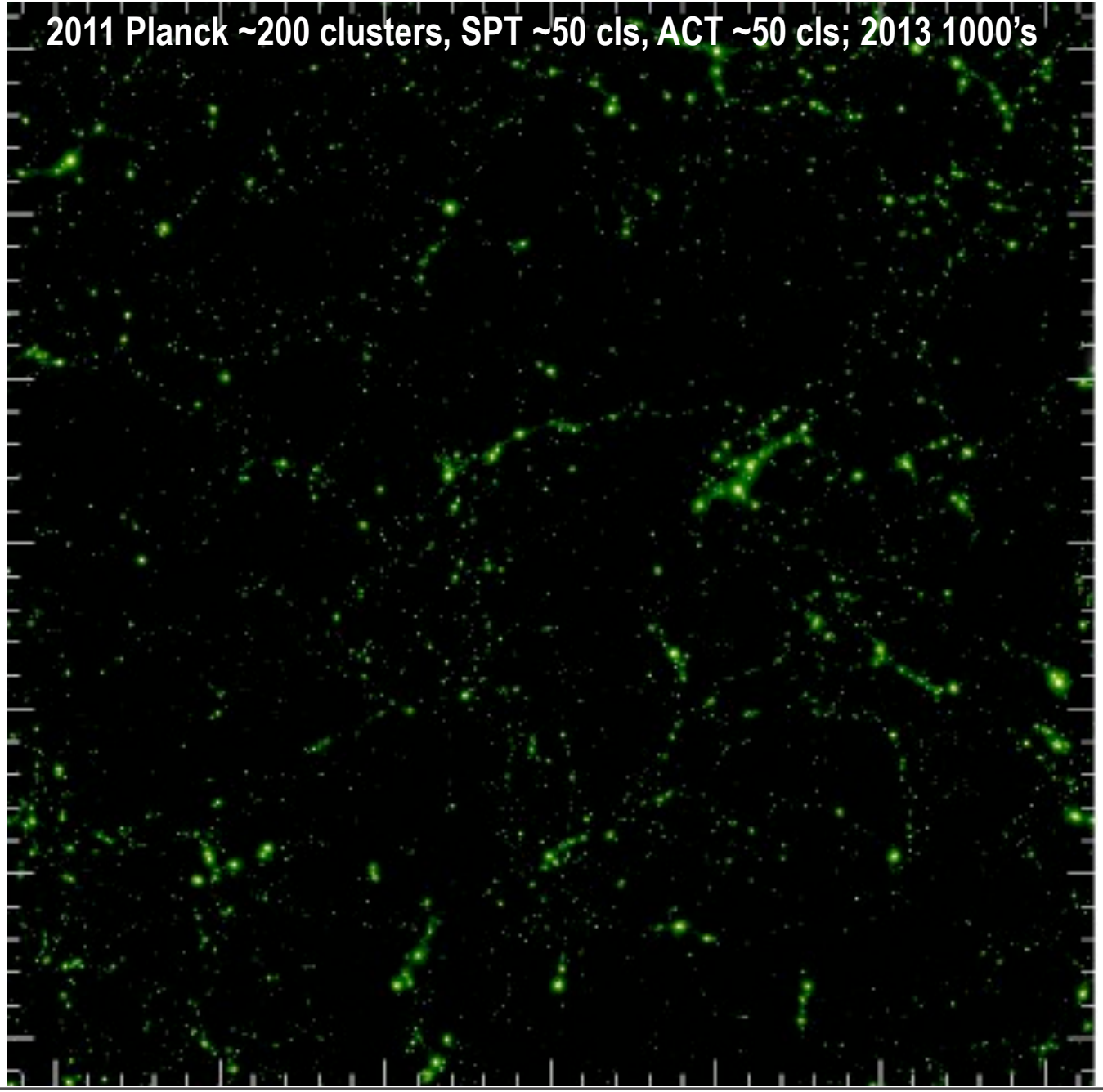
$\rho_g(x,t)$

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**

Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)



400 Mpc

ΛCDM

WMAP5

gas pressure

Gadget-3 SF+ SN E+ winds +CRs

512^3

BBPSS10

BBPS1,2,3,4

$p_e(x,t)$

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

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

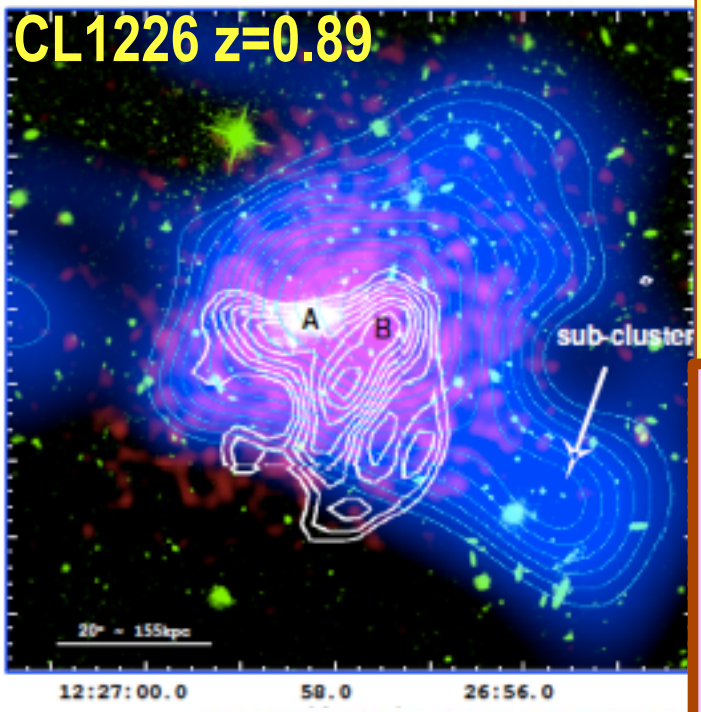
tSZ: 2011 Planck ~200 clusters, SPT ~50 cls, ACT ~50 cls; 2013 1000's

Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

$p_e(x,t)$

CMB gets entangled in the cosmic web

descending into the real gastrophysics of cosmic weather the energetic, turbulent, dissipative, compressive IGM/ICM/ISM life



Red X-ray **Chandra**
Blue/cyan weak lens Σ
Green optical
White MUSTANG **SZ>3σ**
A BCG ~ X-ray peak
B Dark Matter peak
~ lobe of SZ ridge

theory & observations agree (broadly) iff feedback & non-equilibrium processes SIMULATE *MonteCarlo* (+calibrated analytics)

400 Mpc

ΛCDM

WMAP5

gas pressure

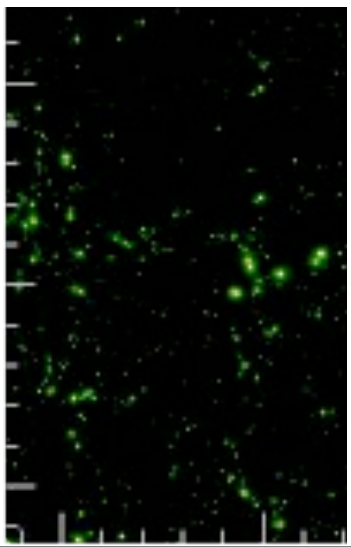
Gadget-3

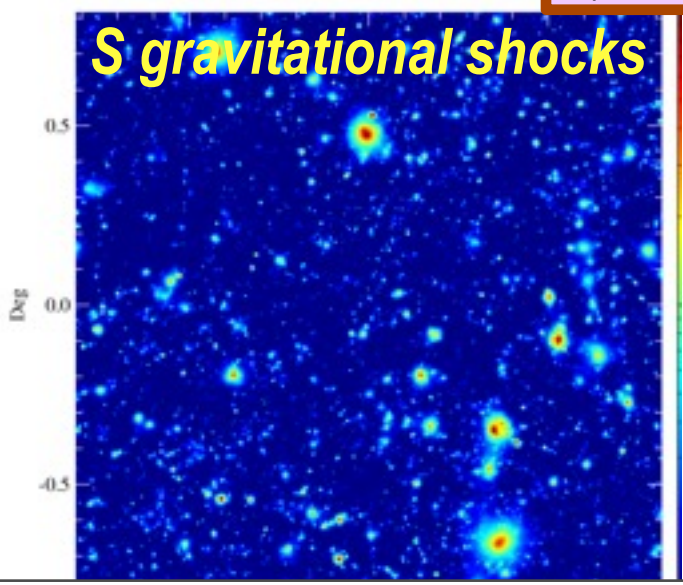
SF+ SN E+ winds +CRs

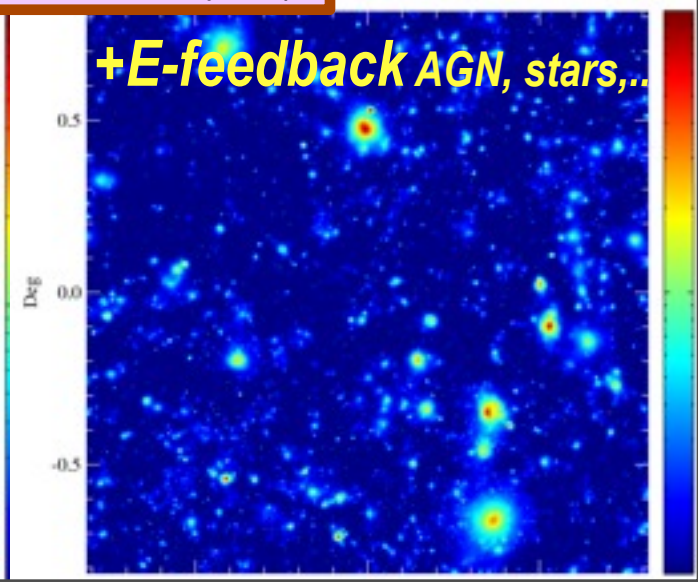
512^3

BBPSS10

BBPS1,2,3,4



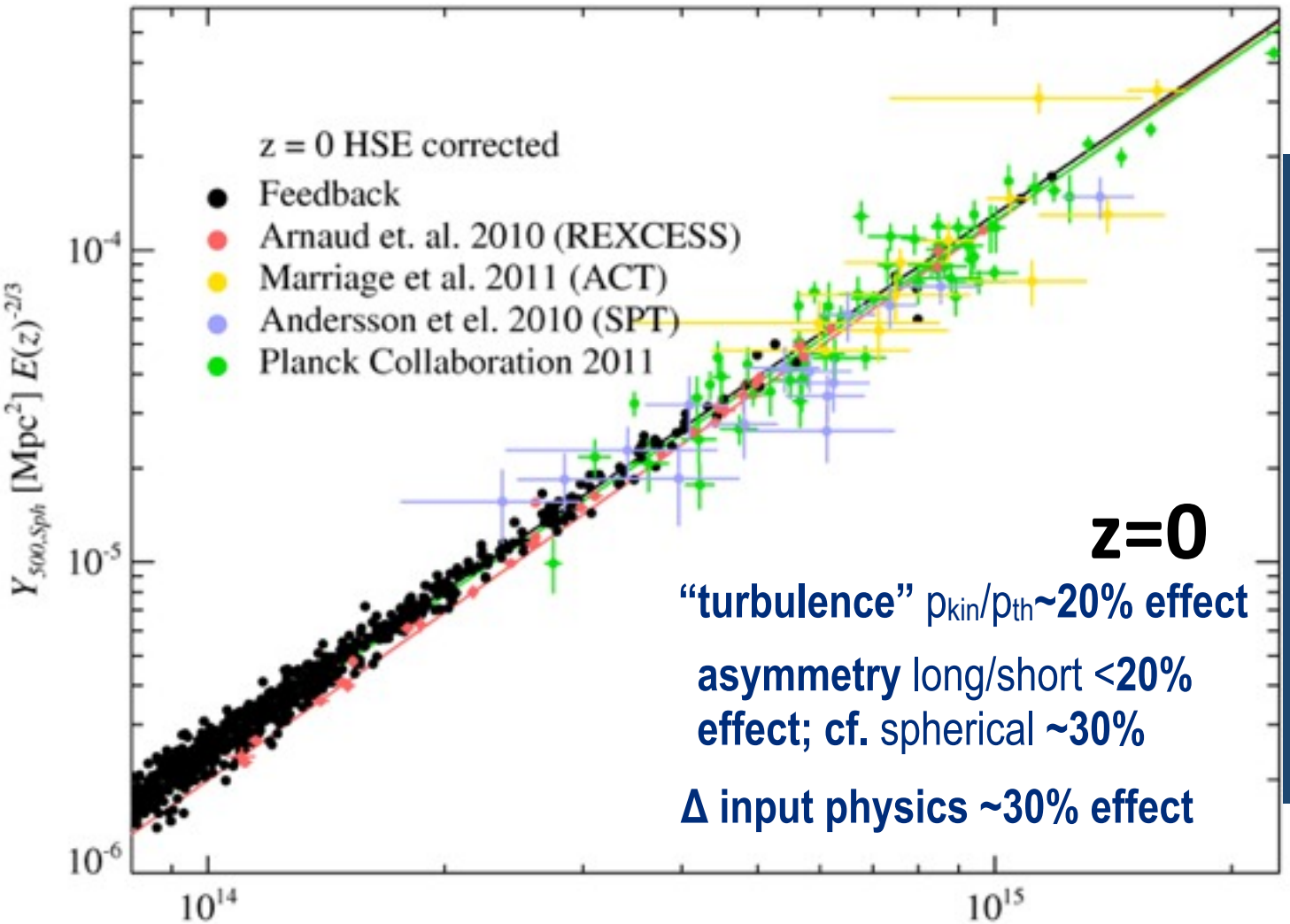




$E_{e,th}(<r_\Delta)$-$M(<r_\Delta)$ *aka* $Y_{SZ,X}$-M relation, *where*

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

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



z=0

"turbulence" p_{kin}/p_{th}**~20% effect**

asymmetry long/short **<20% effect; cf.** spherical **~30%**

Δ input physics ~30% effect

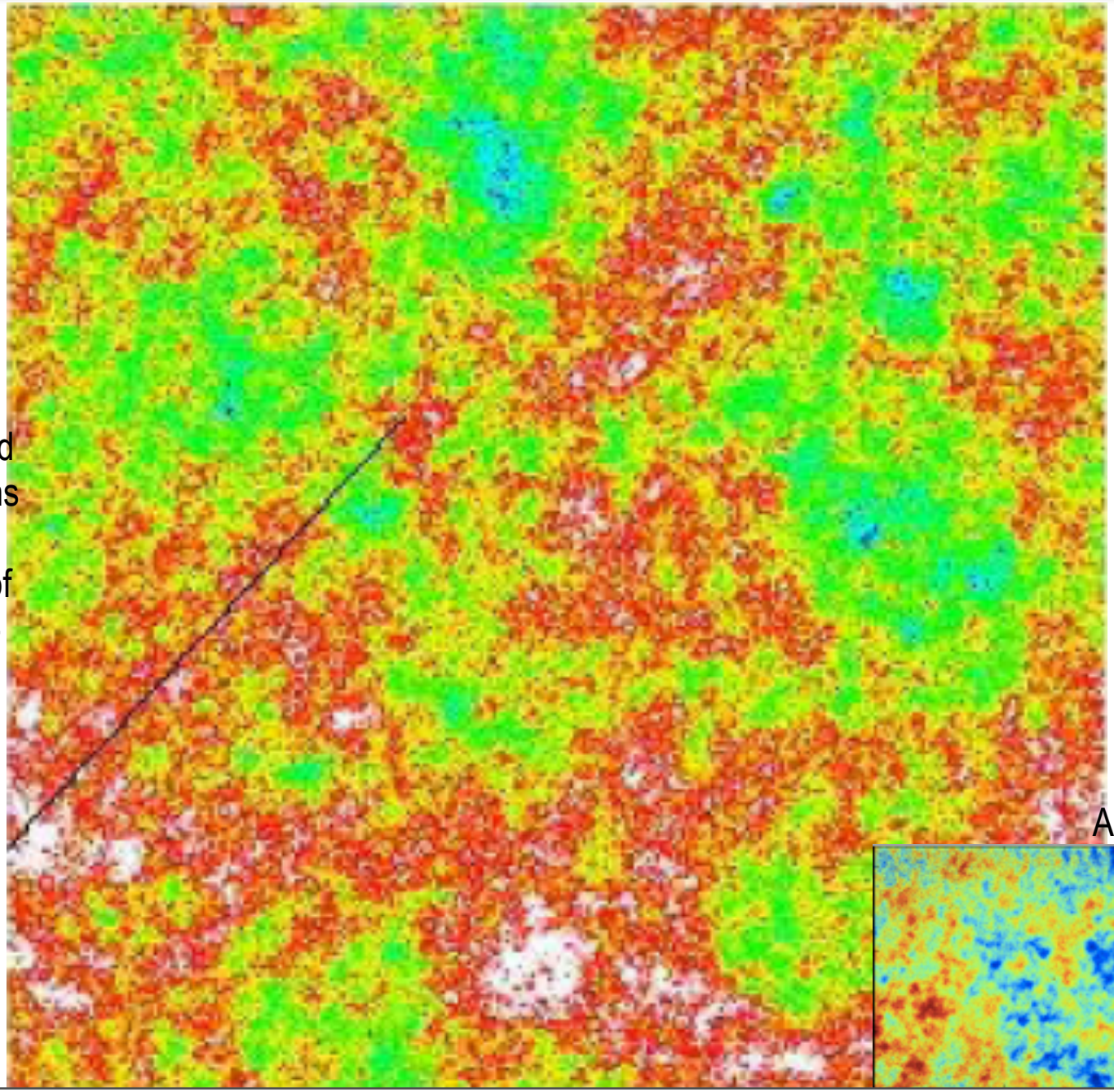
Planck-ESZ gives Y_{5R500}

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

ACTers Sehgal+10: mass calibration still too uncertain for σ_8 *& DE*

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

χ



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

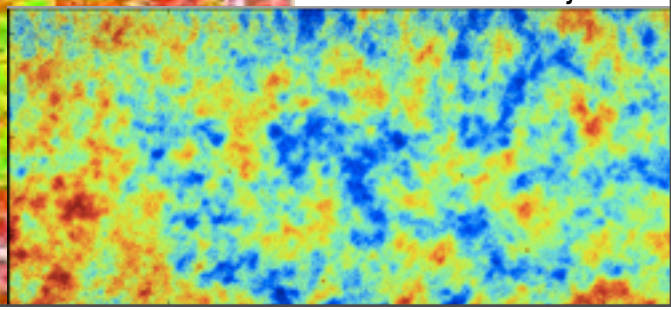
complex patterns *evolve from early U vacuum potential and vacuum noise*

10 Gpc

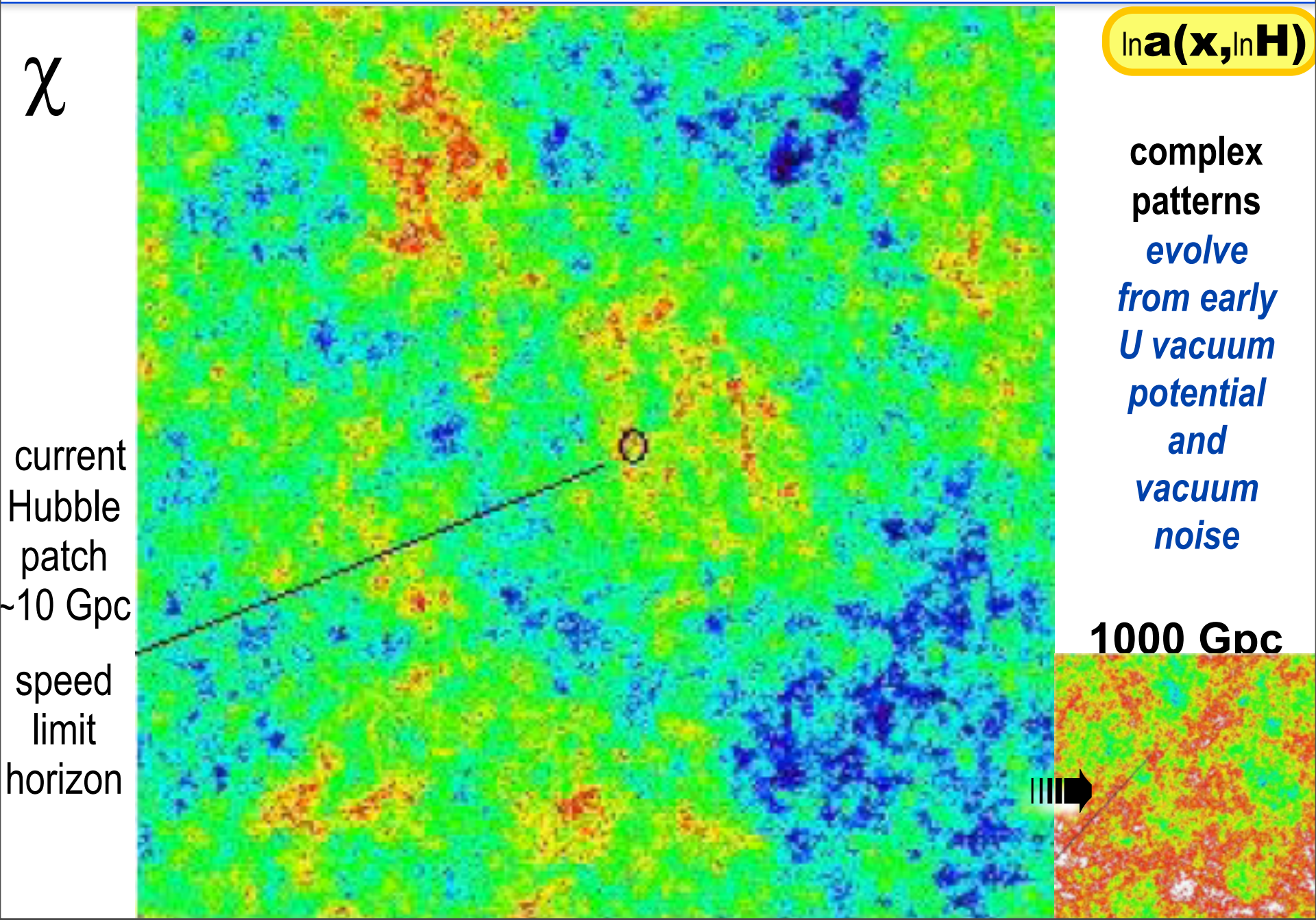
scalar field fluctuations in the vacuum of the ultra-early Universe

pre-heating patch (~1cm)

ACT+WMAP7 hajian+10



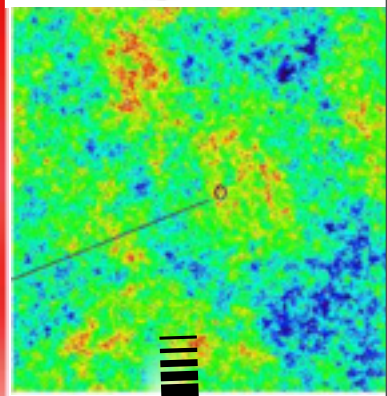
fluctuations in the **early universe "vacuum" grow** to *all* **structure**

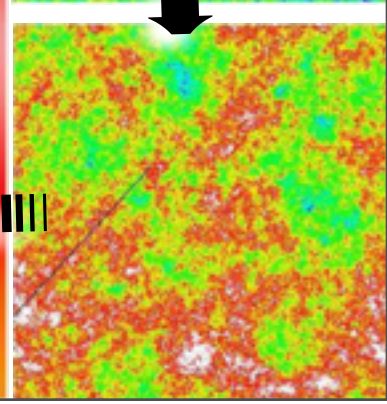


ϕ inflaton χ isocon $V(\phi,\chi)=1/4\ \lambda\ \phi^4 + 1/2\ g^2\ \phi^2\ \chi^2$

Parametric Resonance

$g^2/\lambda \sim 1$





pre-heating patch (~1cm)

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**

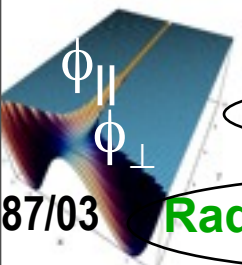
6/7 tiny extra dimensions

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

Higgs inflation

Extended inflation

1990

Natural pNGB 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

ekpyrotic/ cyclic

2003 KKLT

D3,D7 brane inflation

DBI inflation

moving brane separations

Racetrack inflation

Tachyon inflation

Warped Brane inflation

moduli fields

monodromy

Higgs inflation

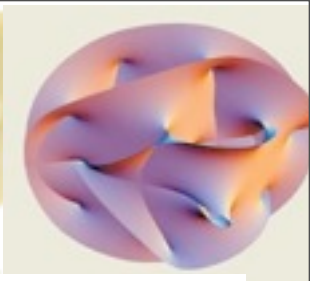
Roulette inflation **Kahler moduli/axion**

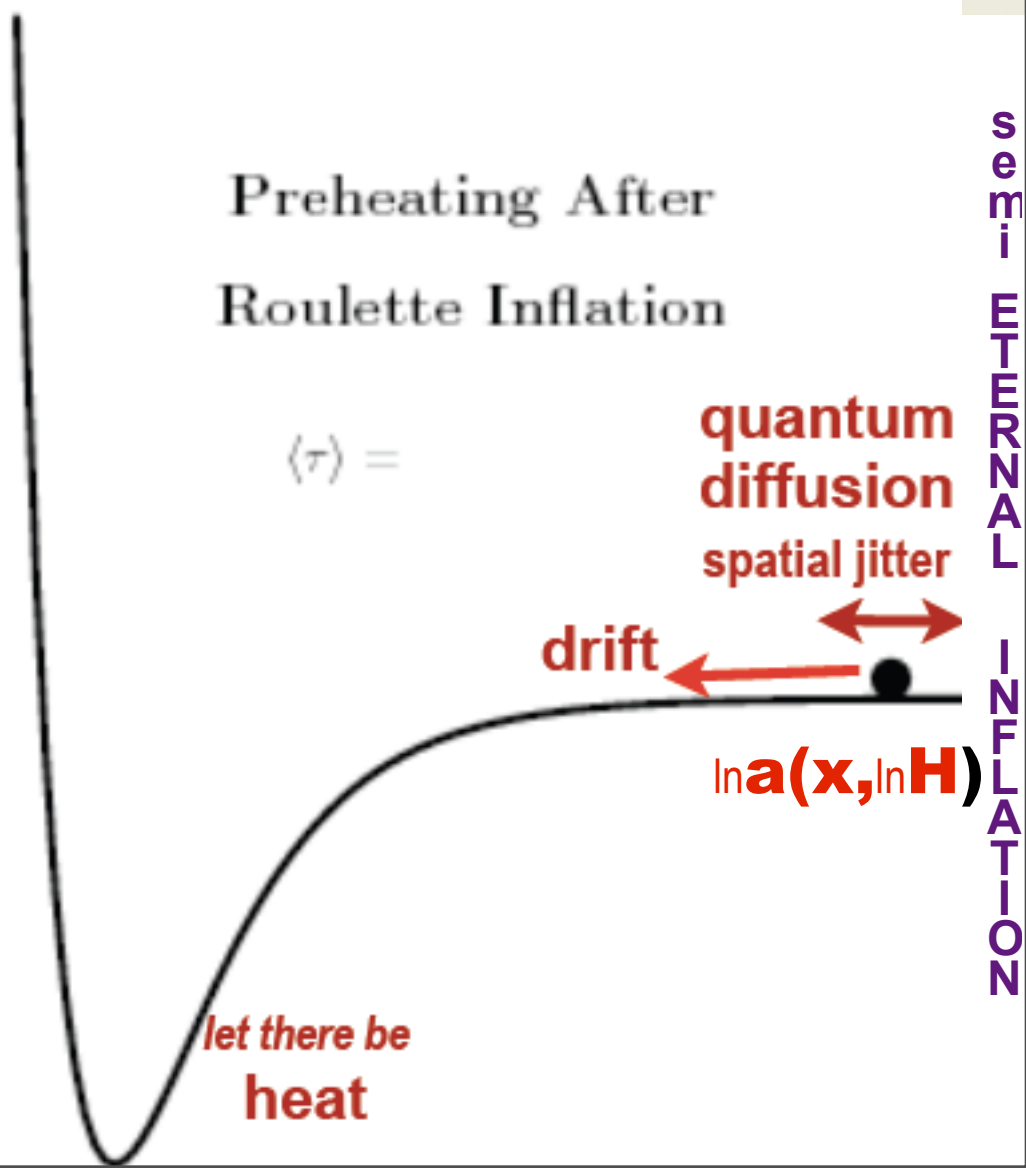
fibre inflation

Roulette Inflation: ***a statistical mini-landscape (one of very many) of the early U origins of observed cosmic structure:***

holey U: **sizes/shapes of geometrical structures such as holes in a dynamical extra-dimensional (6-7D) space settling into a stable bit of extra-dim at each point in our 3D space;**

braney U: *motions of lower-dimension subspaces*





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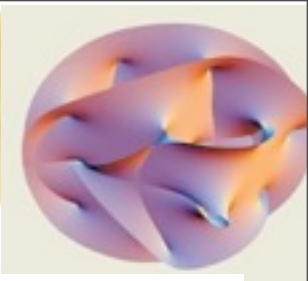


holey U: sizes/shapes of geometrical structures such as holes in a dynamical extra-dimensional (6-7D) space settling into a stable bit of extra-dim at each point in our 3D space;

braney U: *motions of lower-dimension subspaces*

kick: $\Delta\varphi/M_P \sim H/M_P \; sqrt(\Delta ln a)$ *grd*

beats

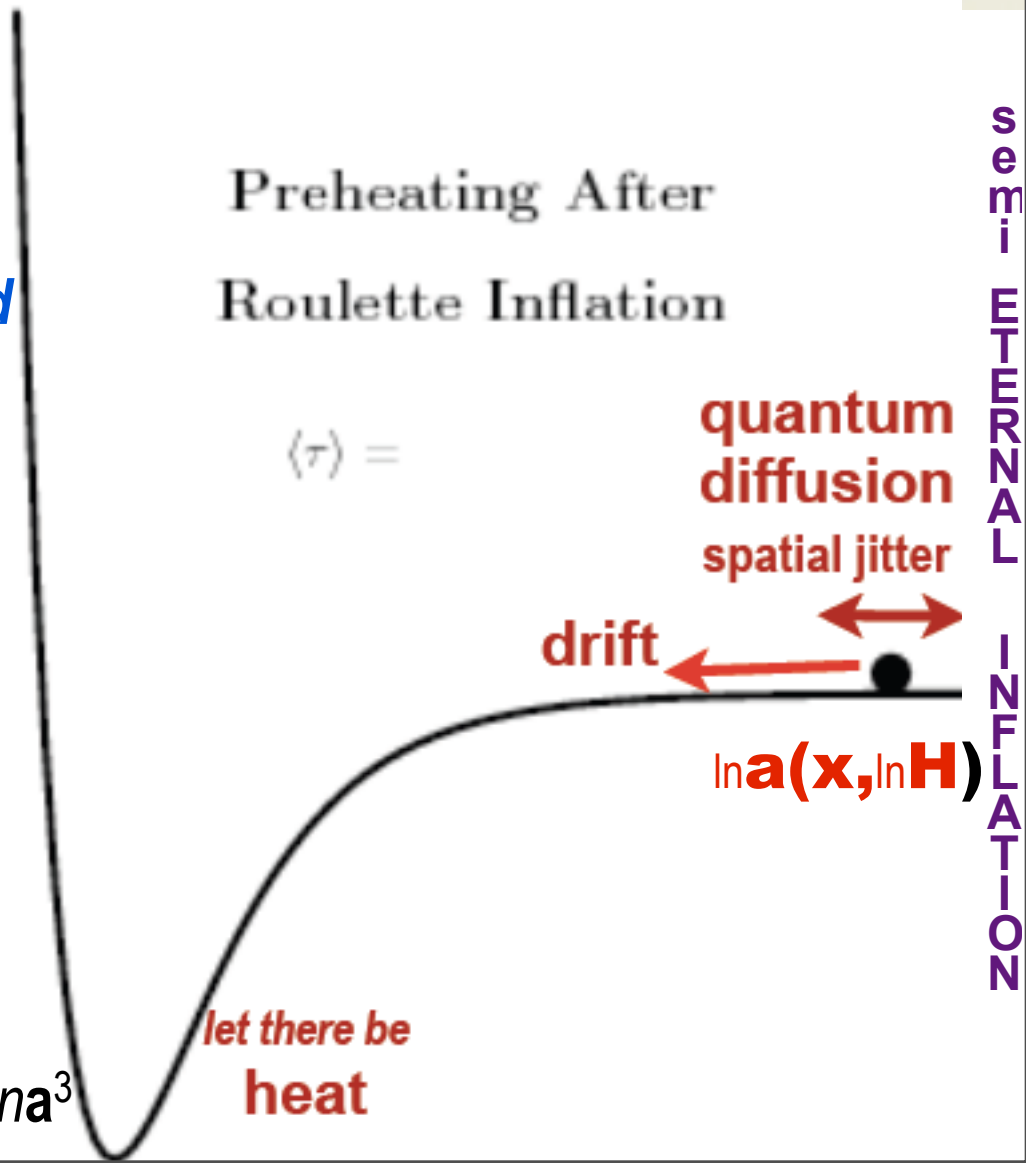
drift: $\Delta\varphi/M_P \sim sqrt(\varepsilon)\, \Delta ln a$

in semi-ETERNAL INFLATION regime

at **high H ~M_P**

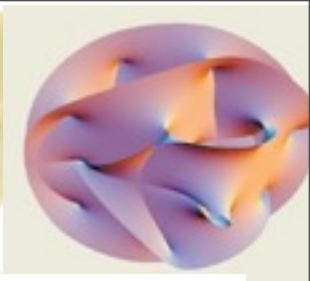
or at **low H $\ll M_P$** *with a*

very flat potential & tiny **ε**



$\varepsilon_\phi = 1+q = 3/2(1+w_{de}(a)) = -3/2 d ln \rho_\phi / d ln a^3$

Roulette Inflation: *a statistical mini-landscape (one of very many) of the early U origins of observed cosmic structure:*



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in semi-ETERNAL INFLATION regime

at **high H ~M_P**

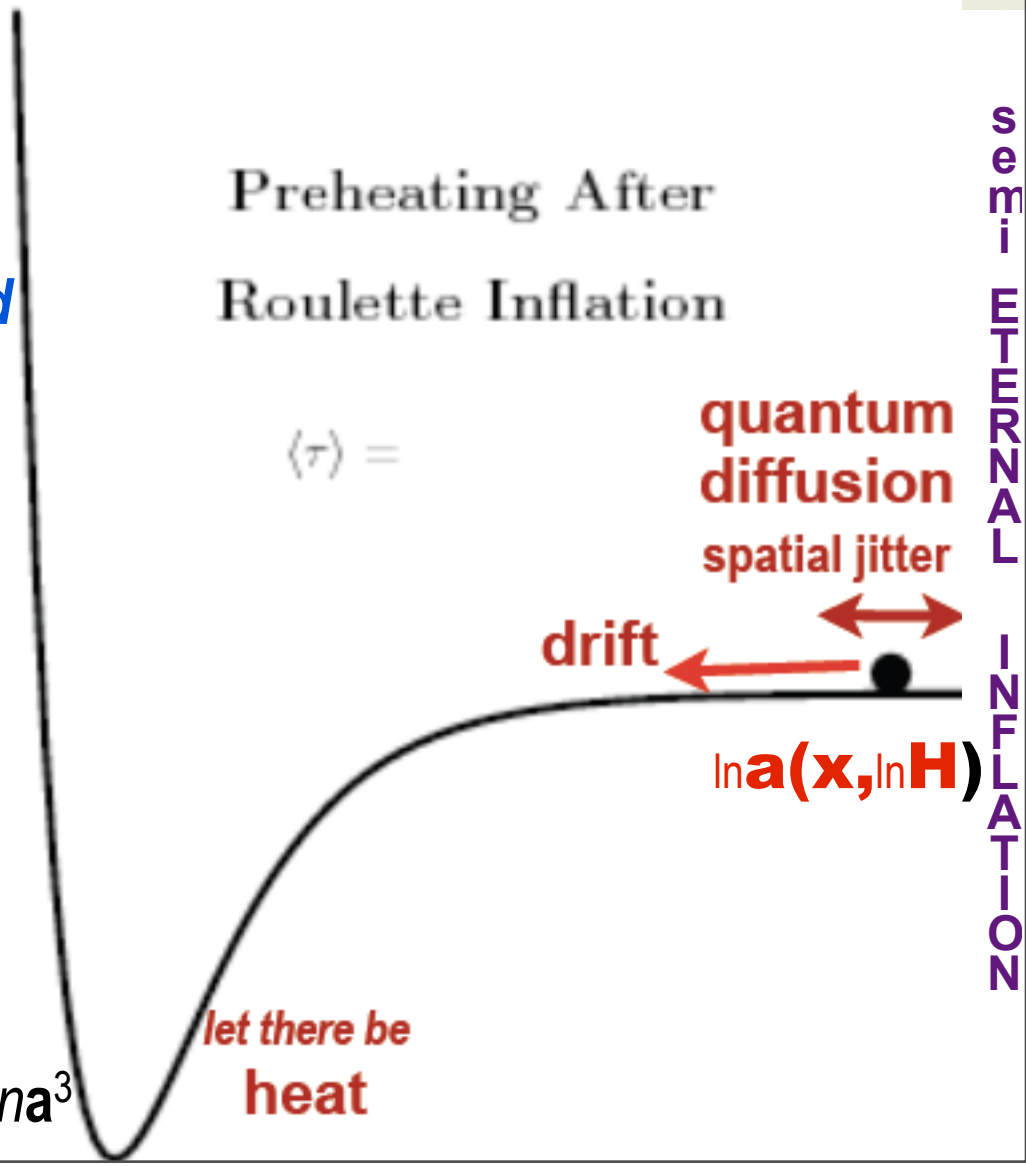
or at **low H ≪M_P** *with a*

very flat potential & tiny **ε**

or thru tunnelling between potential minima

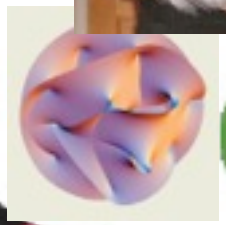
deSitter(x,t) .. *beyond horizon measurement*

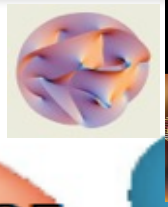
$\varepsilon_\phi = 1+q = 3/2(1+w_{de}(a)) = -3/2 d ln\rho_\phi / d ln a^3$

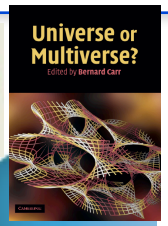


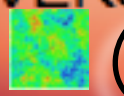
quantum stochastic *non-Gaussian* time landscape cf. stringy landscape

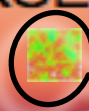
multiverse
Starobinsky, Vilenkin, ***Linde****, SB, Rees, ..., stringy: Susskind etal*



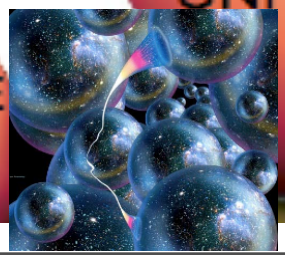


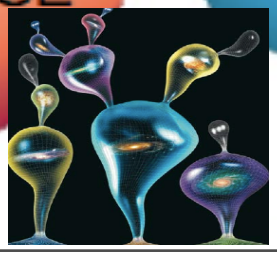






our horizon





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

a "natural" consequence of quantum mechanics of the U's uuUULSS on ln*a*(*x*, ln*Ha*)

***if quantum diffusion > 'classical' drift at* high H**

cf. our ***observable horizon (patch) at* low H**

this eternal inflation can happen even at low H

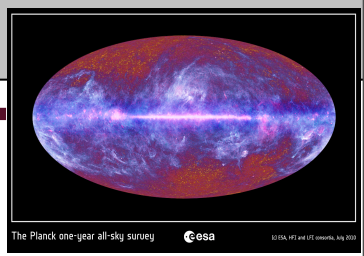
Salopek & Bond 1991

the gatherers of cosmic information

Cosmic **M**icrowave **B**ackground +

Large **S**cale **S**tructure experimental probes

then & now & then



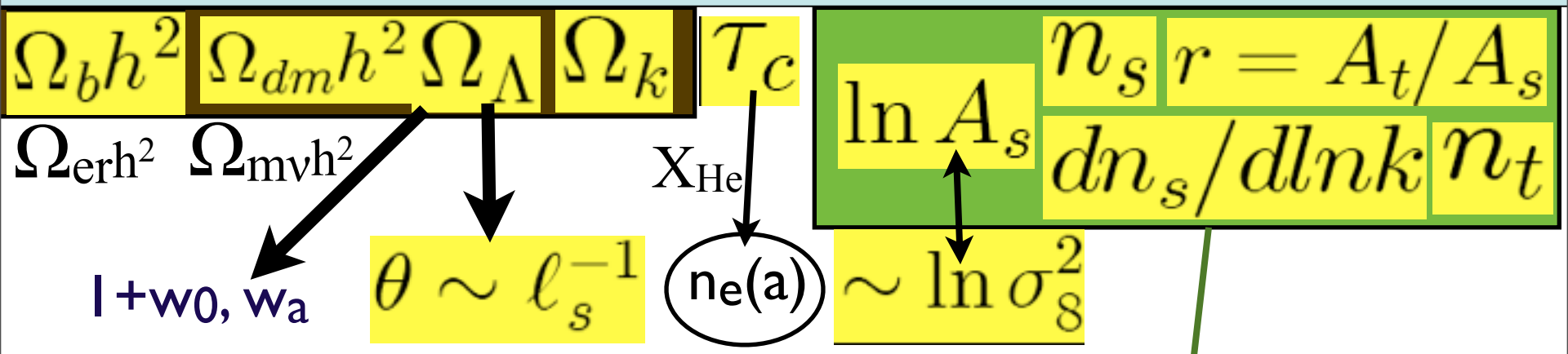
near-future cosmology => PlanckEXT

EXT=many observatories & expts enabling the cosmology/astro

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

ACTpol, SPTpol, ***ABS, Spider, Quiet-90,*** *EBEX, Keck,* **GBT**, **CCAT**,
eRosita, PanStarrs, DES, HSC, LSST, ***CHIME***, ***EUCLID***, ... ⊂ **EXT**

Standard Parameters of Cosmic Structure Formation



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

(partially) blind cf. informed "theory" priors

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

Dunkley+ 2010 ACT+WMAP7

Keissler+ 2011 SPT+WMAP7

$\ln$Power$_s$~$\ln 25 \times 10^{-10} \pm 0.03$

$n_s = 0.963 \pm 0.011$ (ACT+WMAP+BAO+H0)

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

r < 0.19, 0.17 (95% CL, ACT+WMAP+BAO+H0, SPT+...)

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

Inflation Histories
(CMBall+LSS+SN+WL)

h_{+x} gravitons generated as acceleration-driven zero point fluctuations during early universe inflation induce CMB (B + E) polarization

r=GW power/scalar-curvature power $\approx 0.008 V/(10^{16}\text{Gev})^4$

r < 0.19, 0.17 (95% CL, ACT+WMAP+BAO+H0, SPT+...)

What is Predicted?

Smoothly broken scale invariance by nearly uniform braking (std of 80s/90s/00s)
r~0.03-0.5, but could get much lower r as well

or highly variable braking (stringy cosmology, branes & holes) $r<10^{-10}$

monodromy (V=cosine+linear) & fibre inflation => larger r~.03; superconformal supergravity r ~.003-.3

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

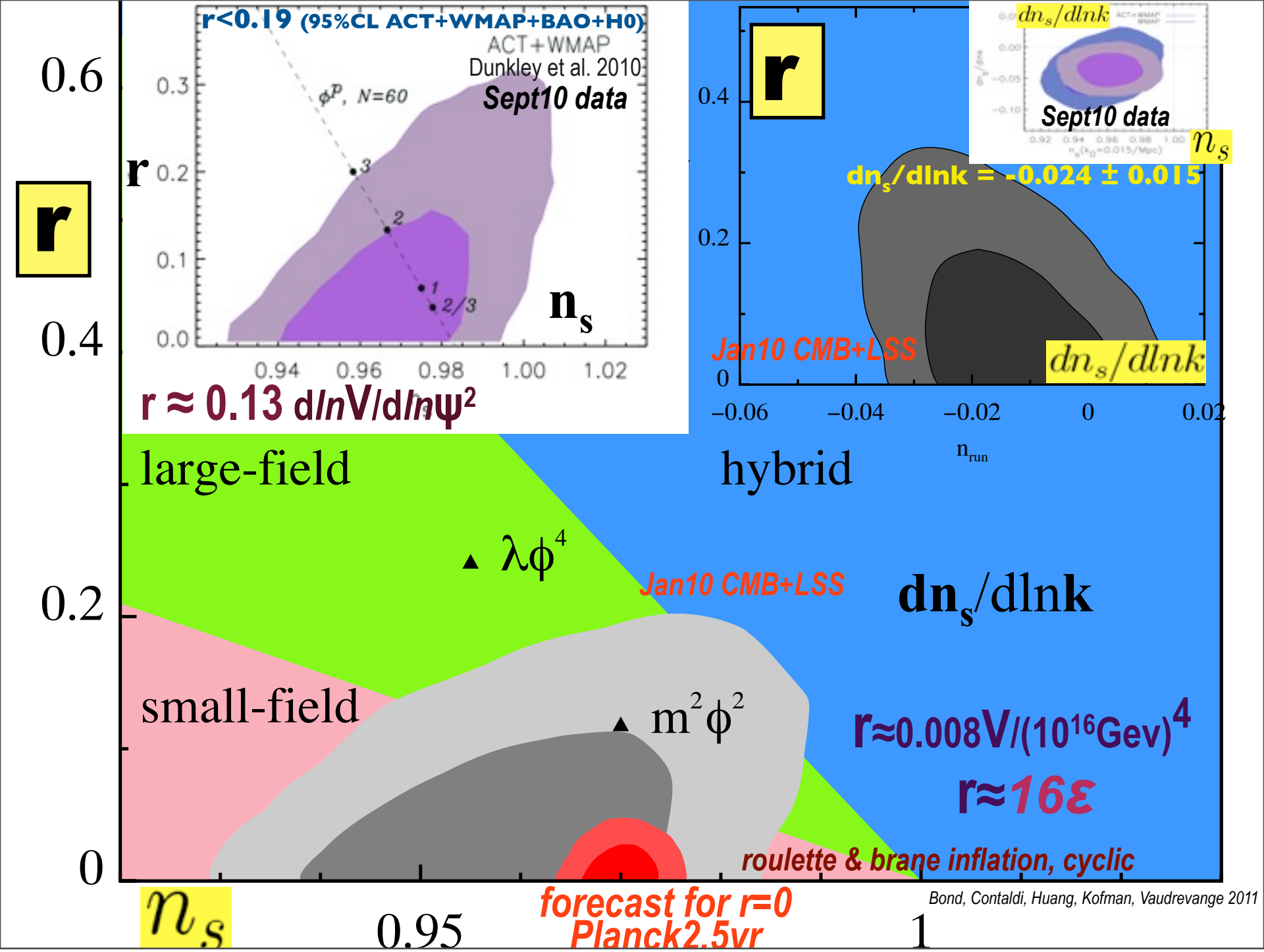
$$(1+W_t) = -\, d\ln\rho_t / d\ln a^3 = 2/3\, \varepsilon$$

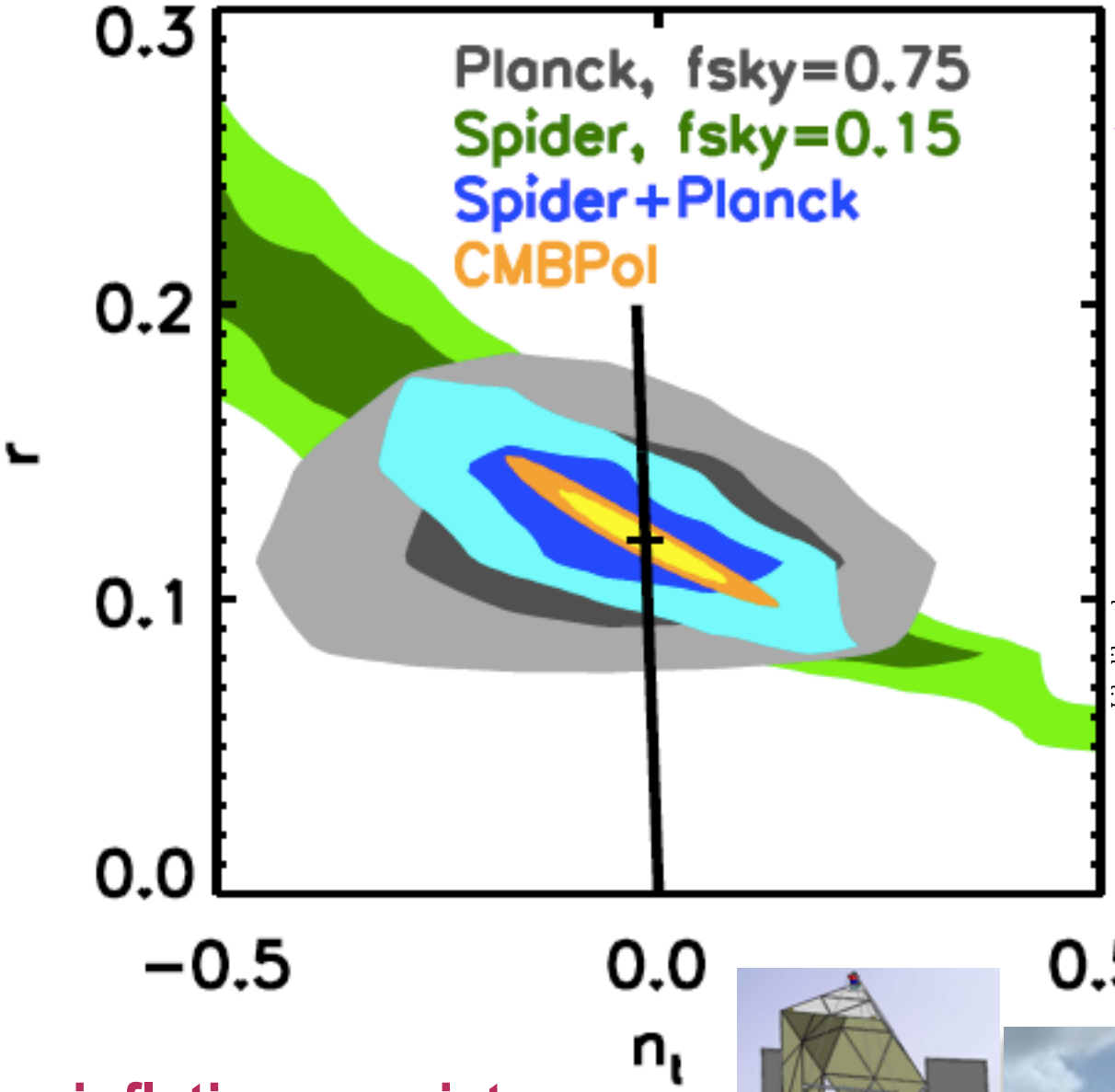
CMB Polarization, Gravity Waves
(Planck, ACTpol, ABS, Spider, Quiet2)
r=T/S, acceleration trajectories

inflation consistency

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

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

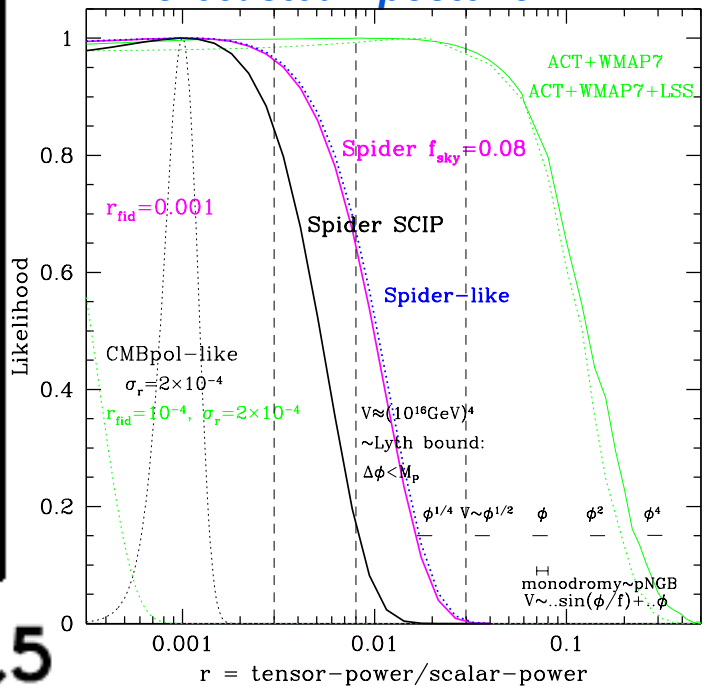

r<0.19 (95%CL ACT+WMAP+BAO+H0)
ACT+WMAP
Dunkley et al. 2010
Sept10 data
ϕ^p, N=60
r
n_s
r ≈ 0.13 d*ln*V/d*ln*ψ²
r
Sept10 data
$dn_s/dlnk$
n_s
$dn_s/dlnk$ = -0.024 ± 0.015
Jan10 CMB+LSS
$dn_s/dlnk$
n_{run}
large-field
hybrid
$\lambda\phi^4$
Jan10 CMB+LSS
$dn_s/dlnk$
small-field
$m^2\phi^2$
$r \approx 0.008 V/(10^{16}\text{Gev})^4$
$r \approx 16\varepsilon$
roulette & brane inflation, cyclic
forecast for r=0
Planck2.5yr
Bond, Contaldi, Huang, Kofman, Vaudrevange 2011
r
n_s



Farhang, Bond, Dore, Netterfield 2011

Spider24days+Planck2.5yr: r-n_t forecast for r=0.12 input for $m^2\varphi^2$ ($2\sigma_r$ ~0.02 including fgnds)

forecasted r-posterior



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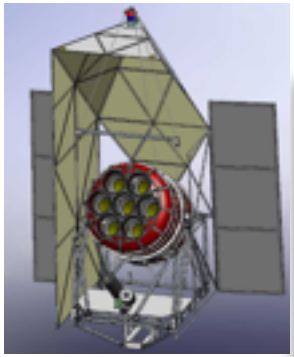
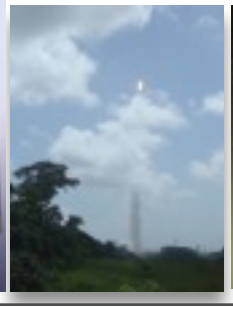
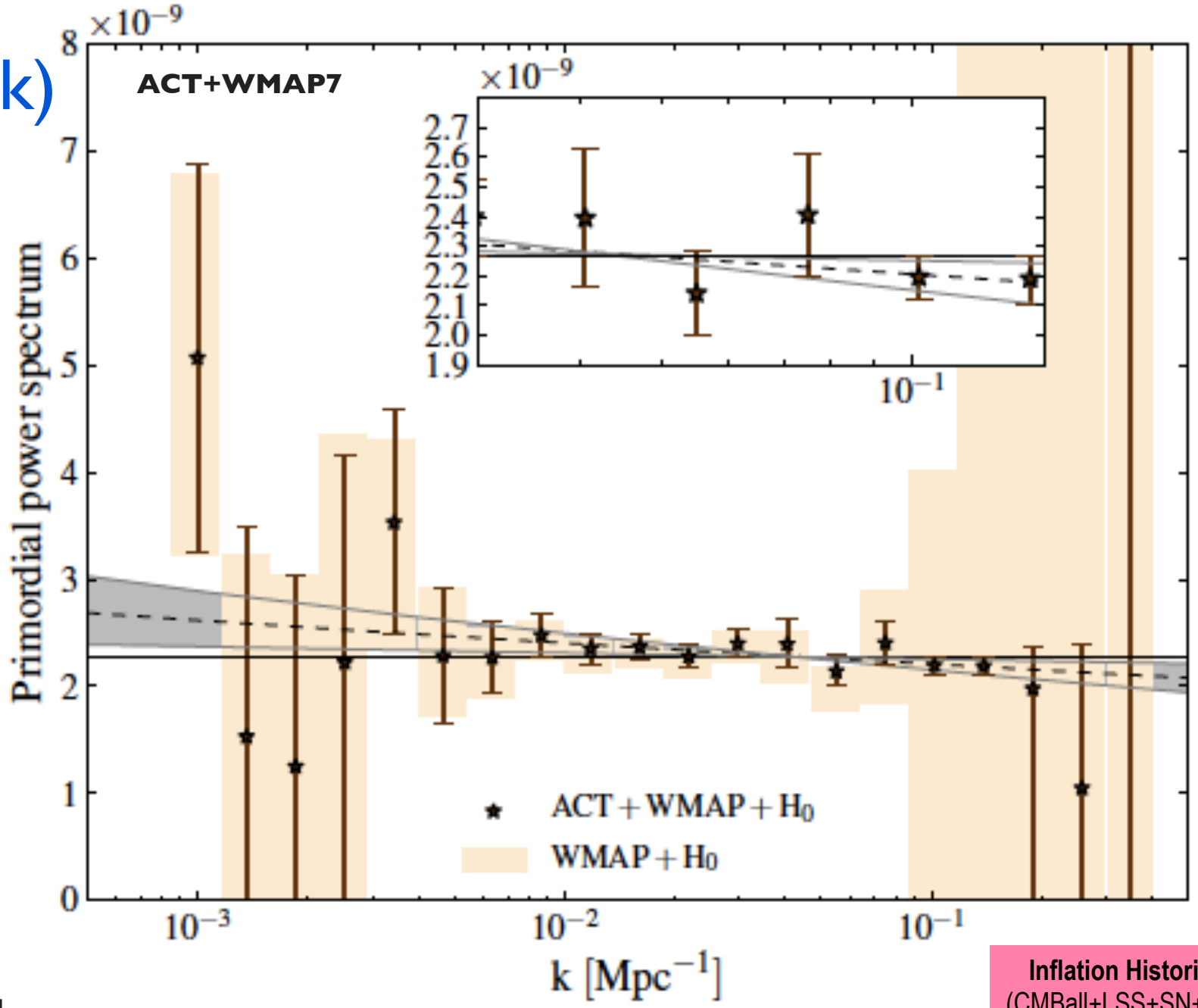




Inflation Histories
(CMBall+LSS+SN+WL)

s-power spectrum trajectories: compress data onto k-modes *cubic splines*

$\ln P_s(\ln k)$

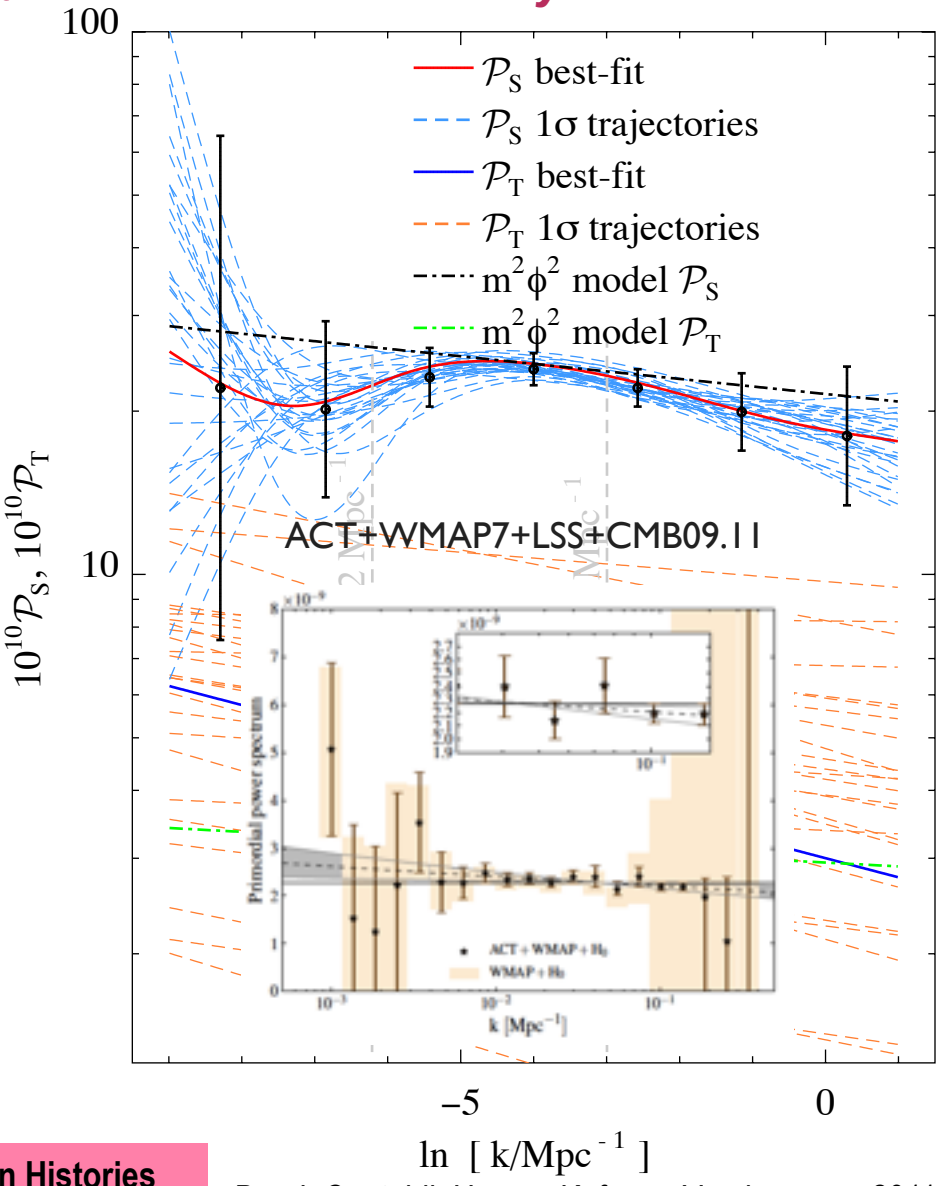


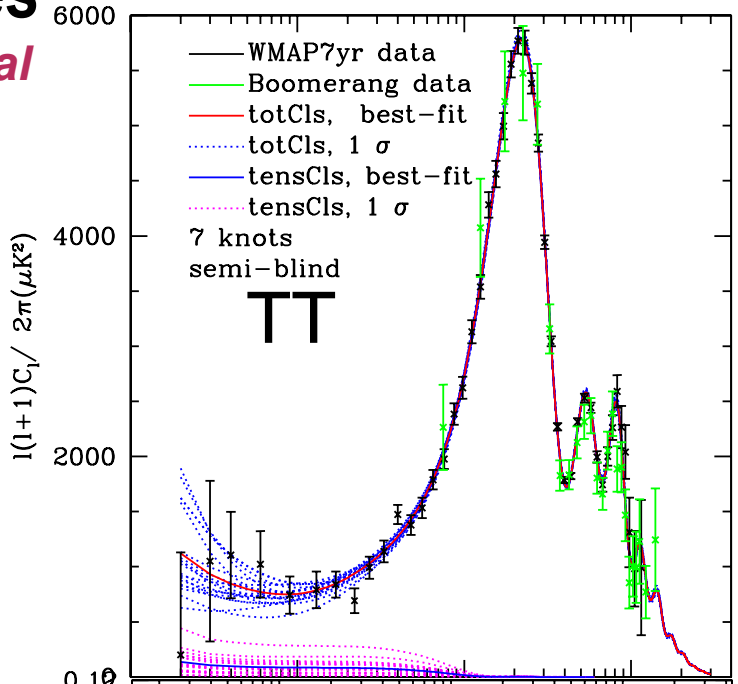
Hlozek et al. 2011

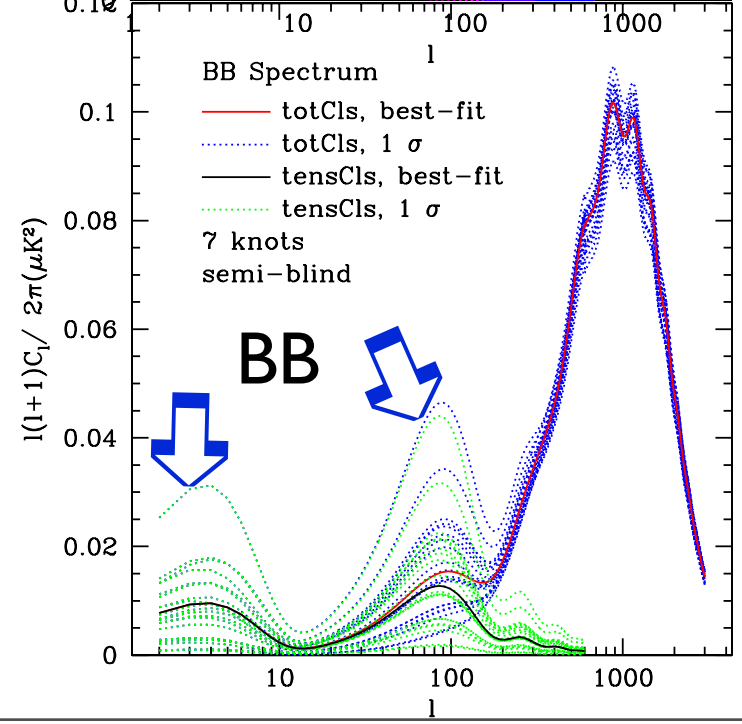
Inflation Histories
(CMBall+LSS+SN+WL)

compress data onto non-top-hat k-modes

partially-blind scalar ln-power trajecteries & usual r-n_t tensor - no consistency relation. 10.09 data





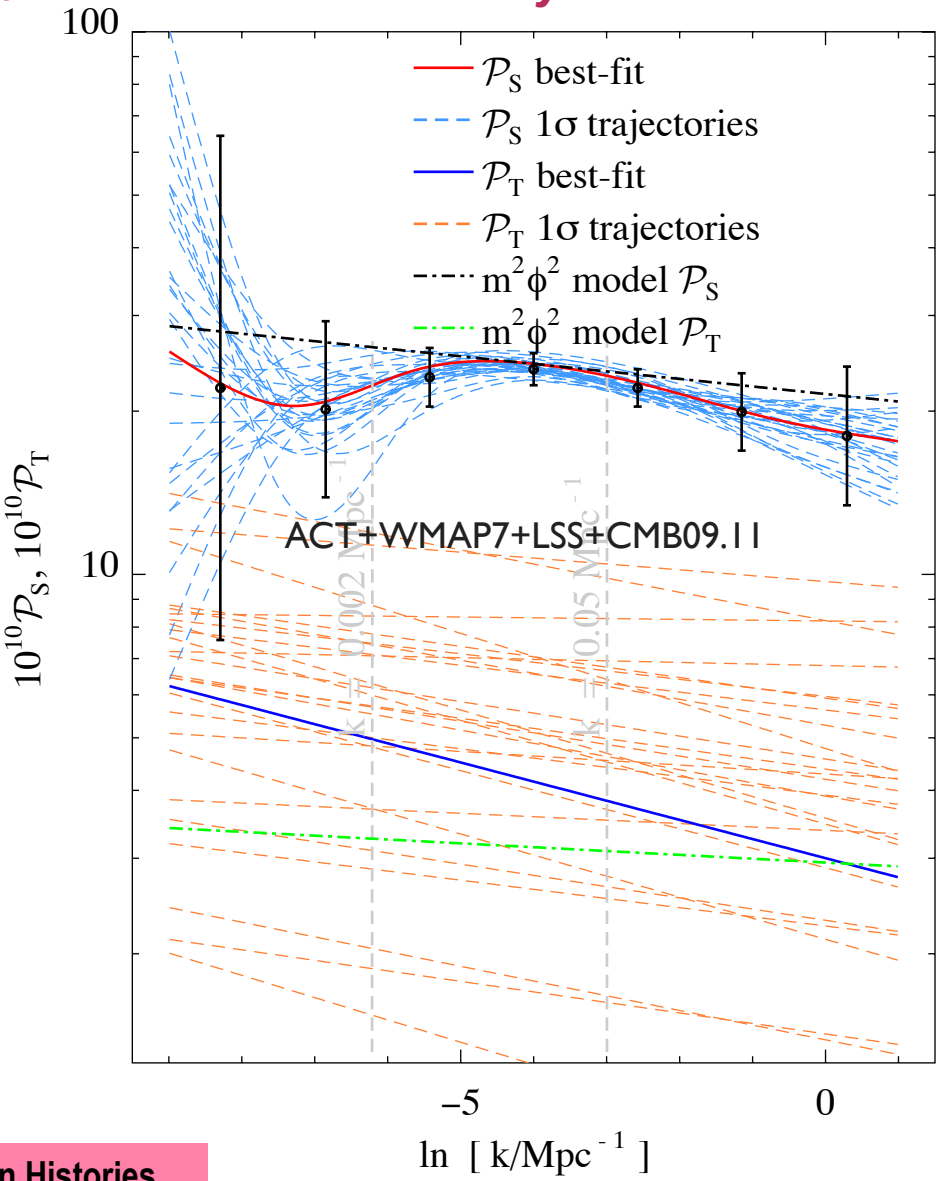


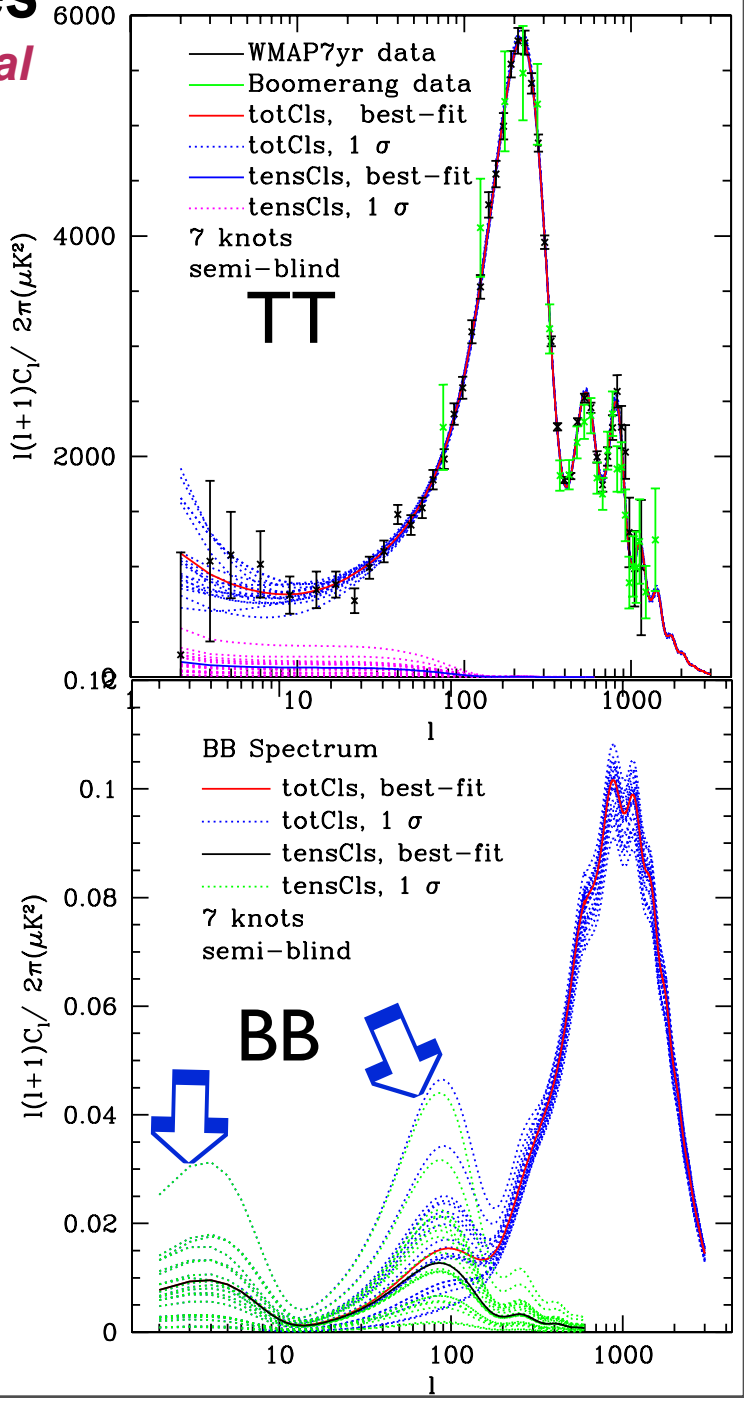
Inflation Histories
(CMBall+LSS+SN+WL)

Bond, Contaldi, Huang, Kofman, Vaudrevange 2011

compress data onto non-top-hat k-modes

partially-blind scalar ln-power trajecteries & usual r-n_t tensor - no consistency relation. 10.09 data



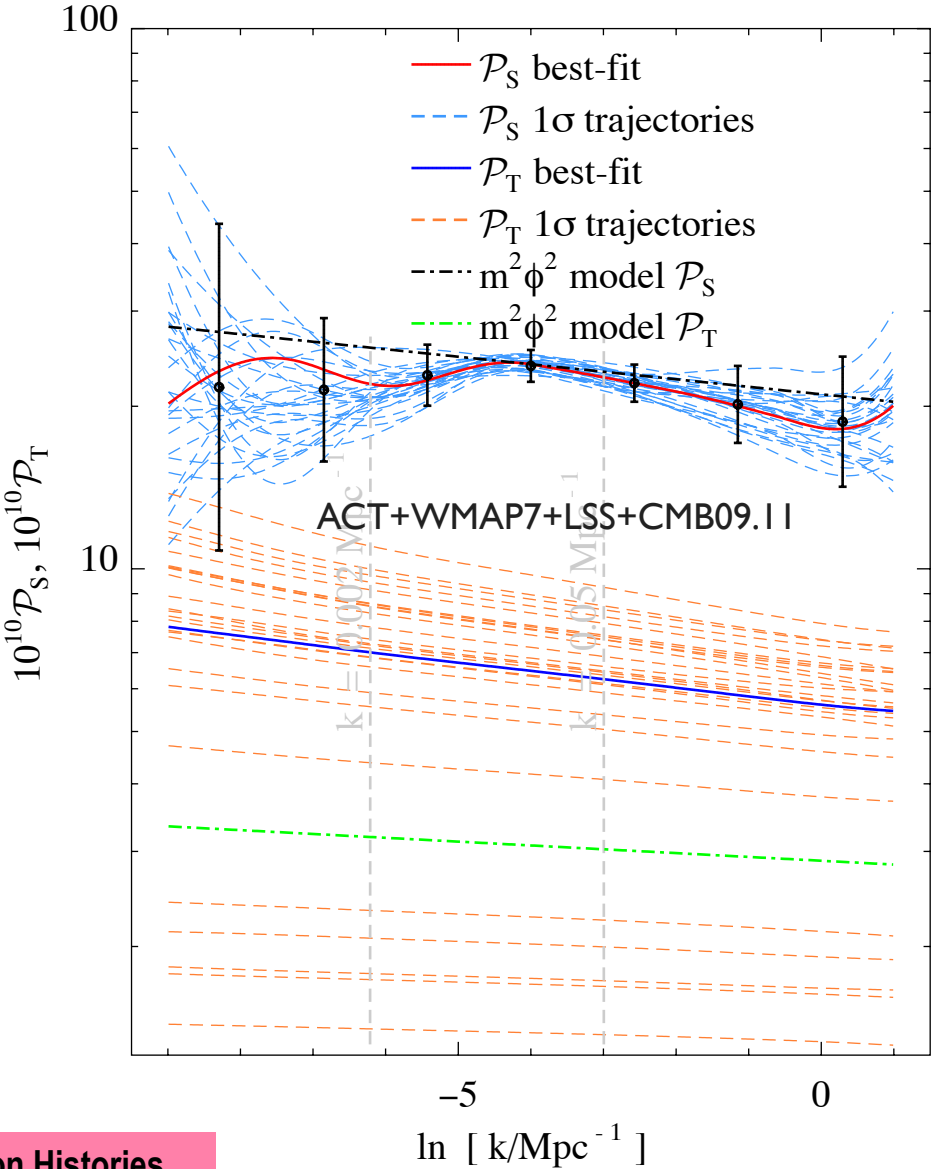


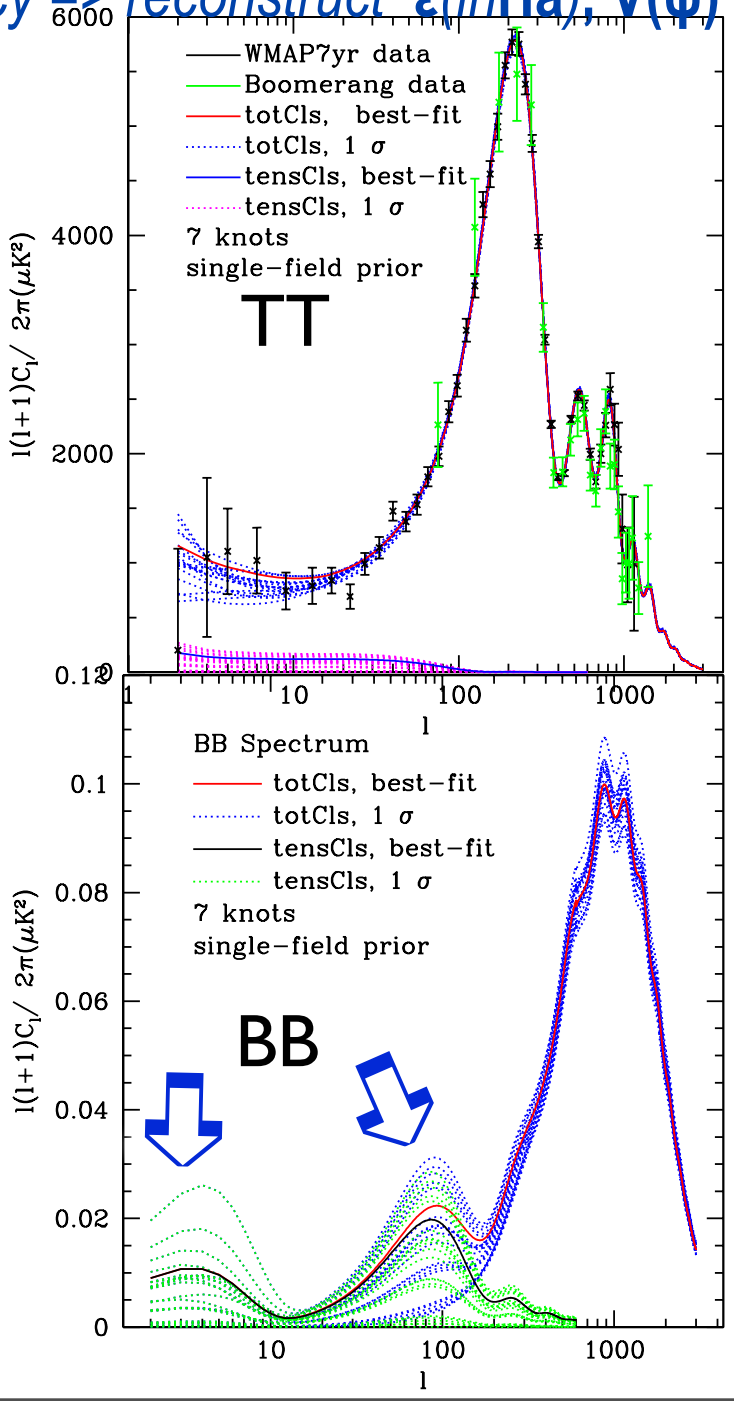
Inflation Histories
(CMBall+LSS+SN+WL)

Bond, Contaldi, Huang, Kofman, Vaudrevange 2011

scan $\mathbf{n_s}(\mathit{lnk})$, $\mathit{ln}\mathbf{A_s}=\mathit{ln}P_s(k_{pivot,s})$, $\mathbf{r}(k_{pivot,t})$; *consistency* => *reconstruct* $\boldsymbol{\varepsilon}(\mathit{ln}\mathbf{Ha})$, $\mathbf{V}(\boldsymbol{\psi})$

partially-blind acceleration trajectories obeying tensor/scalar/ε consistency relation. 10.09 data





Inflation Histories
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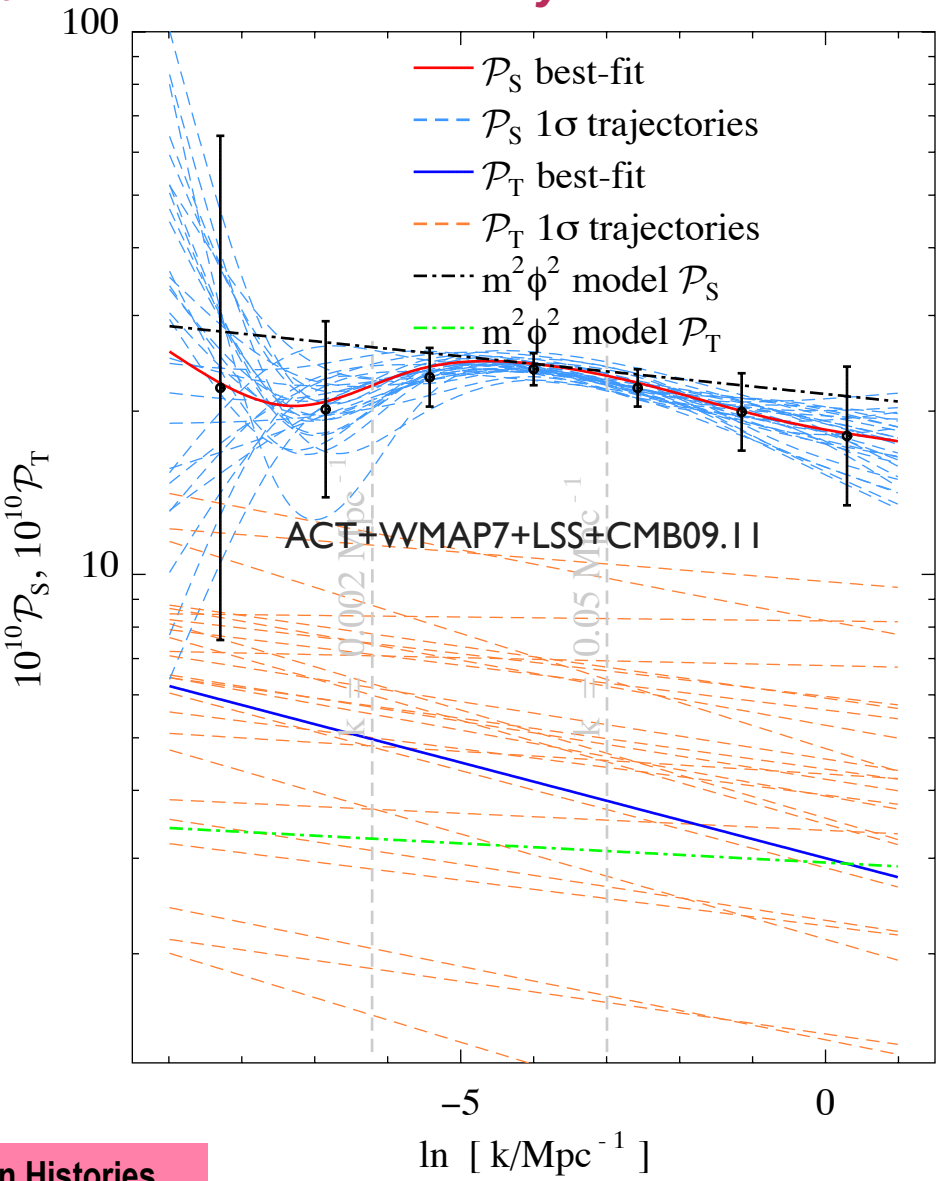
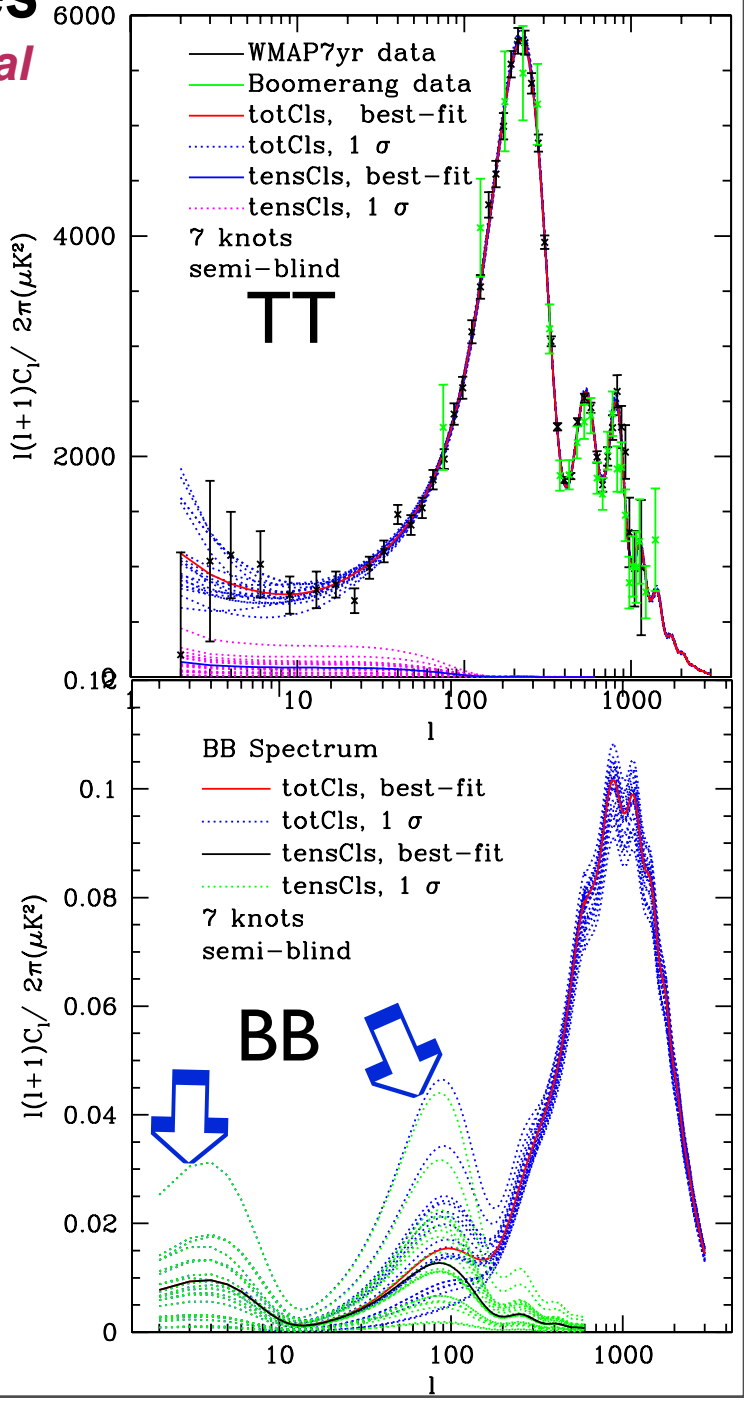




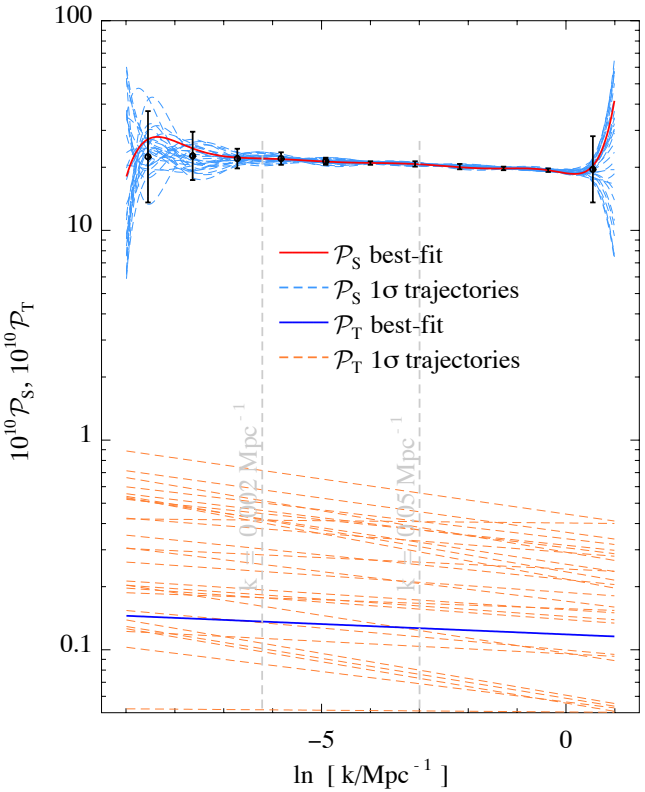
Inflation Histories
(CMBall+LSS+SN+WL)

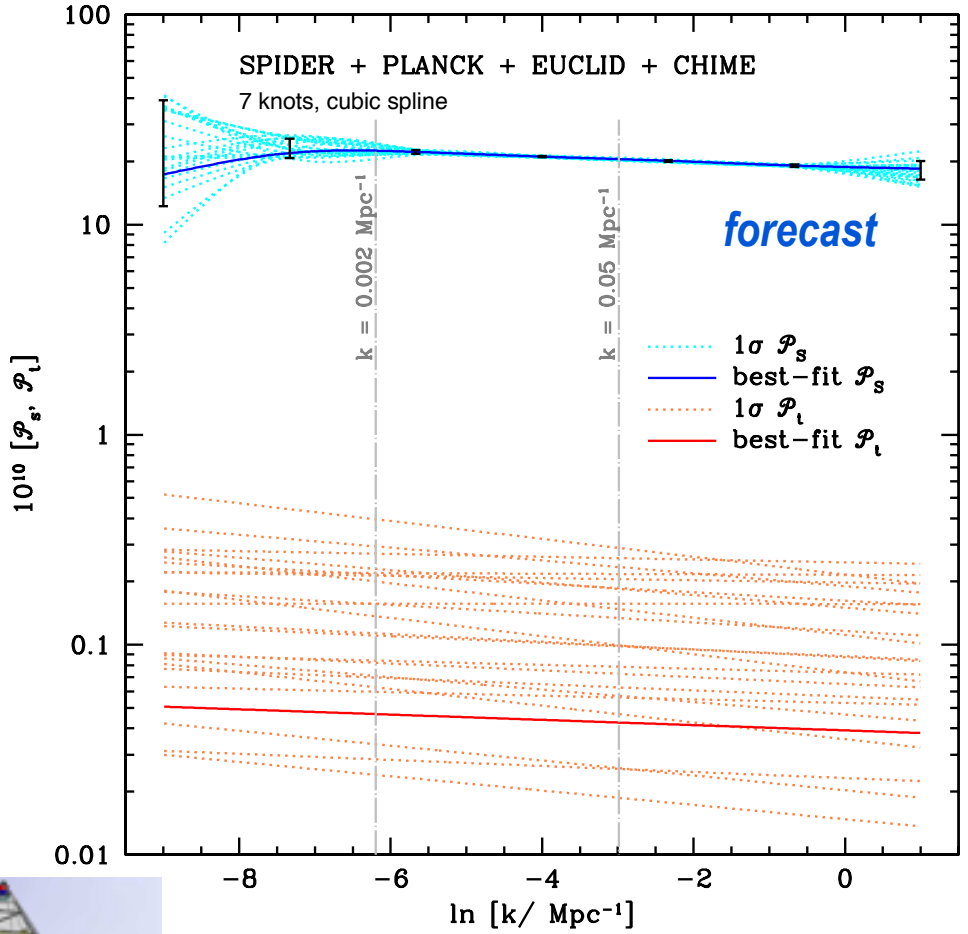
Bond, Contaldi, Huang, Kofman, Vaudrevange 2011

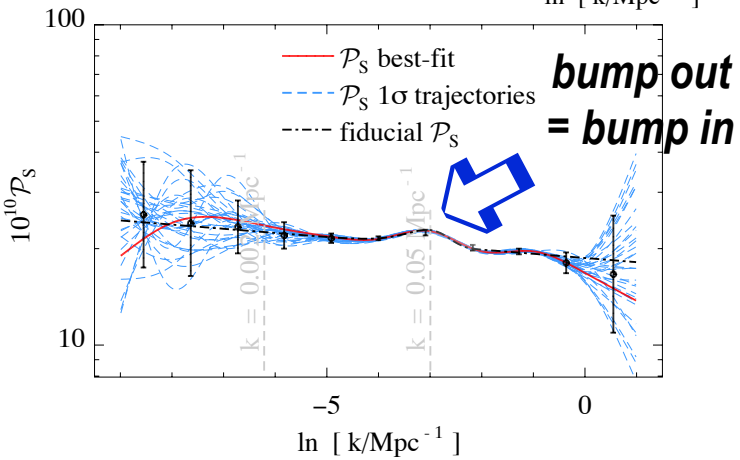
s,t power spectra trajectories: compress data onto non-top-hat k-modes

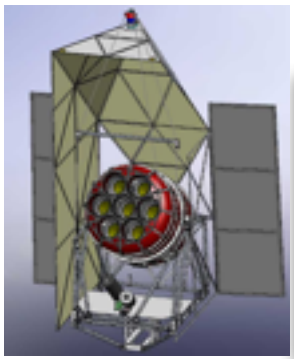
Bond, Contaldi, Huang, Kofman, Vaudrevange 2011

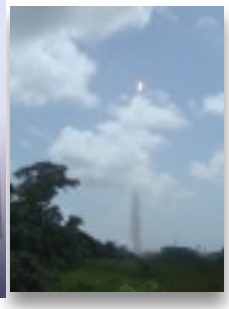
Spider-24days + Planck-2.5yr + ... 11/7 knot $\ln P_S$ +r-n_t forecast for r=0 (+ fgnds)

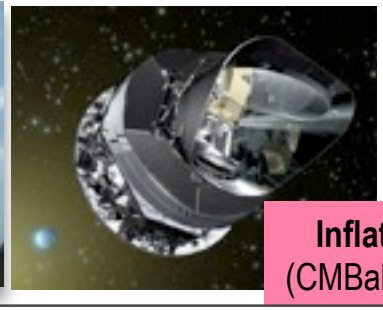












Inflation Histories
(CMBall+LSS+SN+WL)

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

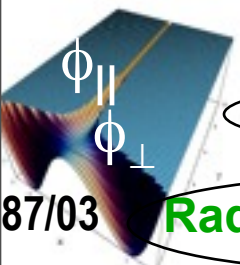
Chaotic inflation

New Inflation

Power-law inflation

SUGRA inflation

Double Inflation



87/03 Radical BSI inflation

running (nee variable M_P) inflation

Higgs inflation

Extended inflation

1990

Natural pNGB 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

2003 KKLT

N-flation

ekpyrotic/ cyclic

D3,D7 brane inflation

DBI inflation

moving brane separations

Racetrack inflation

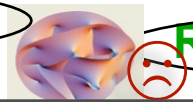
Tachyon inflation

Warped Brane inflation

moduli fields

monodromy

Higgs inflation



Roulette inflation Kahler moduli/axion

fibre inflation

Coherent Inflation with Quantum Jitter to Hot Big Bang, an Incoherent Particle Soup

how (most of) the entropy in matter

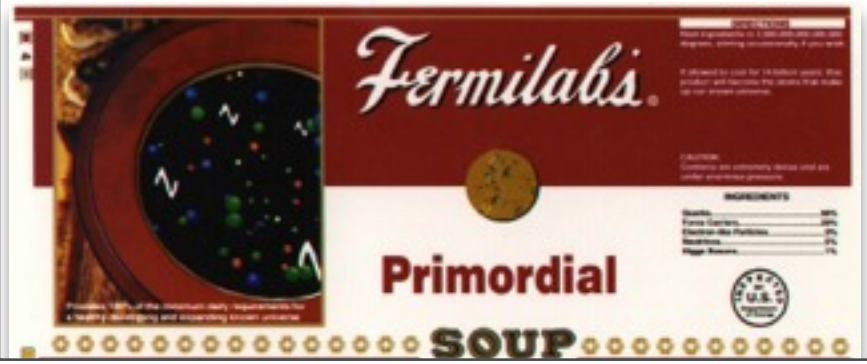
=> *GUT plasma/quark soup* => $S(\gamma,\nu)$ was generated *(through a shock-in-time)*

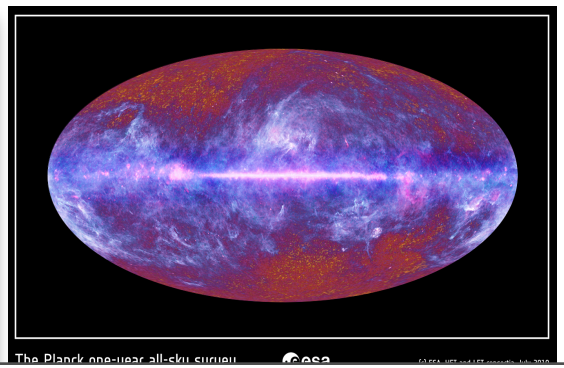
via nonlinear coupling of the inflaton to new interaction channels g,χ_a *ultimately to standard model degrees of freedom*

∃ a role for *decaying particles, 1st order phase transitions?*

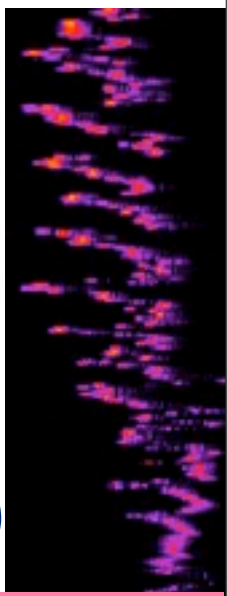
exactly who, what, where, when, why?

we search for fossil "non-Gaussian" structures from this period with Planck +WMAP9





$a_{Shock}(g)$

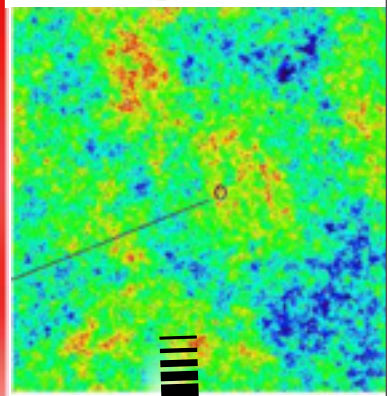


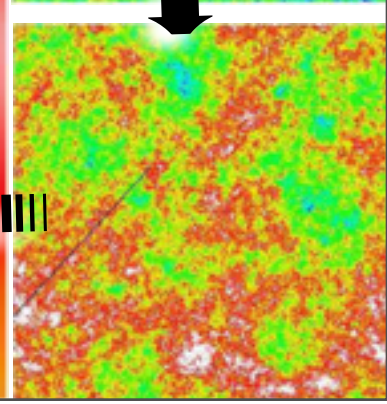
non-Gaussianity
(WMAP, **Planck**, LSS)
spiky nG preheating

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

Parametric Resonance

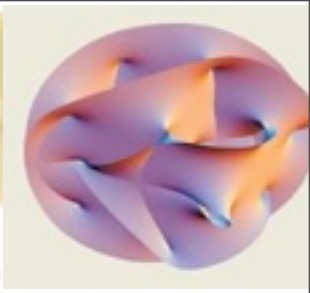
$g^2/\lambda \sim 1$





pre-heating patch (~1cm)

Roulette Inflation: ***a statistical mini-landscape (one of very many) of the early U origins of observed cosmic structure:***



holey U: **sizes/shapes of geometrical structures such as holes in a dynamical extra-dimensional (6-7D) space settling into a stable bit of extra-dim at each point in our 3D space;**

braney U: *motions of lower-dimension subspaces*

pre-heating patch (**<1cm**-now, **<10^{-30} cm**-then)

semi ETERNAL INFLATION

quantum diffusion

spatial jitter

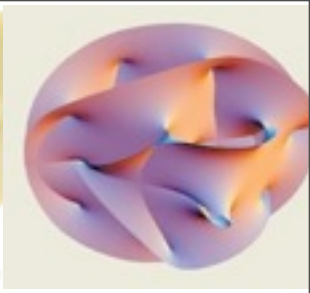
drift

let there be

heat

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

Roulette Inflation: ***a statistical mini-landscape (one of very many) of the early U origins of observed cosmic structure:***



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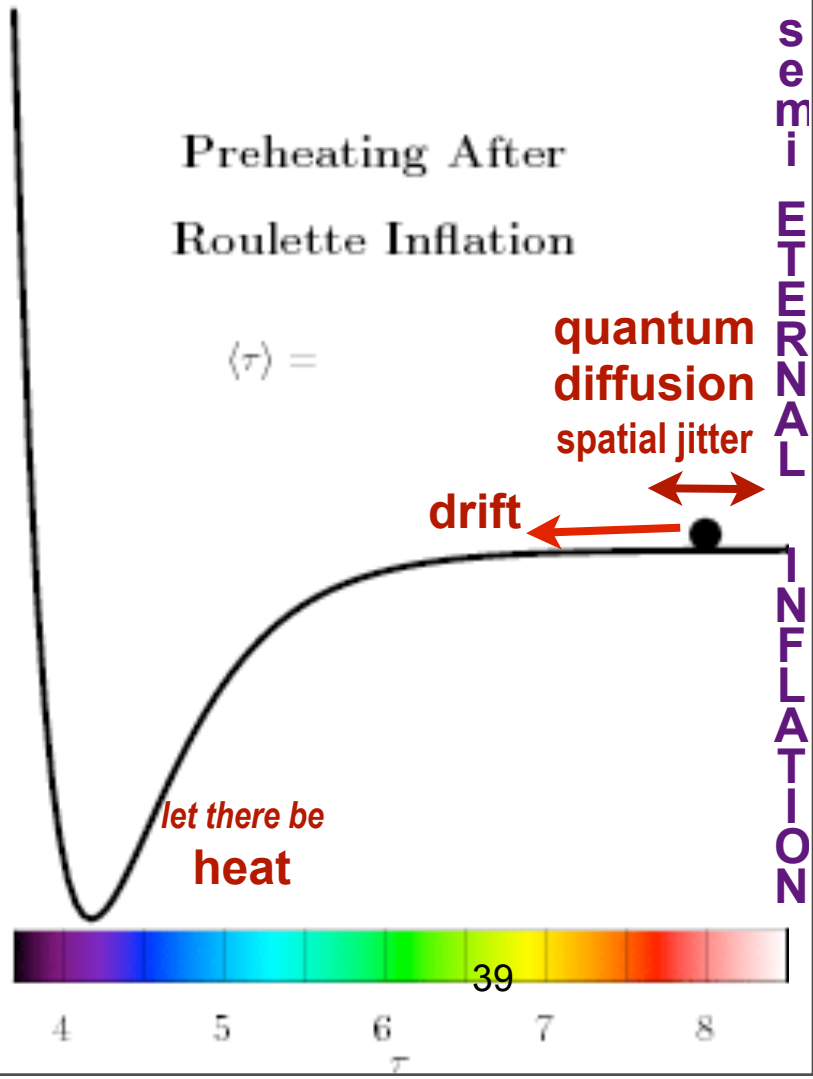
braney U: *motions of lower-dimension subspaces*

pre-heating patch (**<1cm**-now, **<10^{-30} cm**-then)

A visualized 2D slice

in lattice simulation

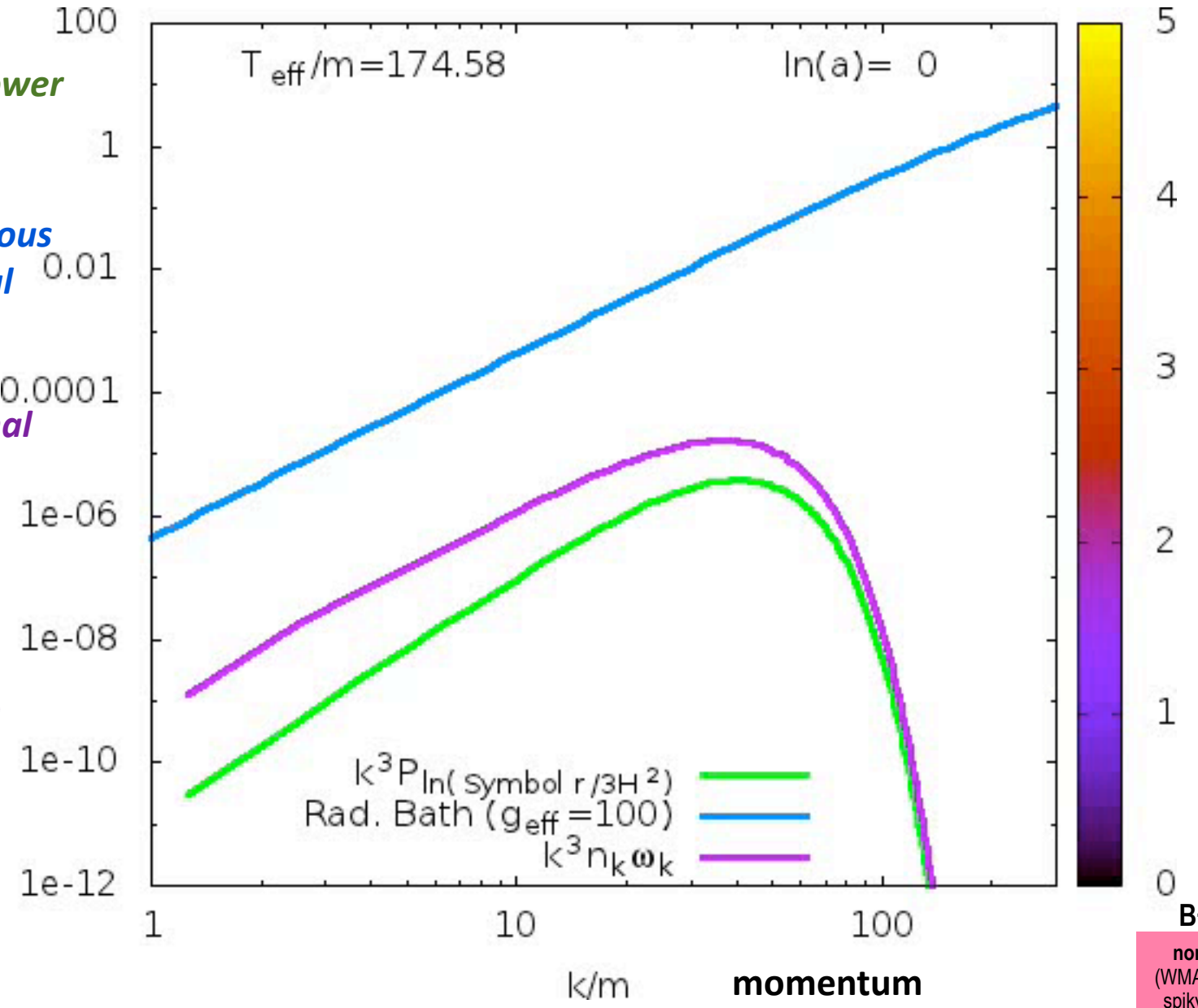


www.youtube.com/watch?v=FW__su-W-ck&NR=1

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

$s_{Ui\sim 0}$; $s_{Utot,m+r}/n_b \sim 1.66\times10^{10}$ bits/b; $s_\gamma / n_\gamma = 5.2$ bits/Υ = 2130/411; s_v = 21/22 s_γ

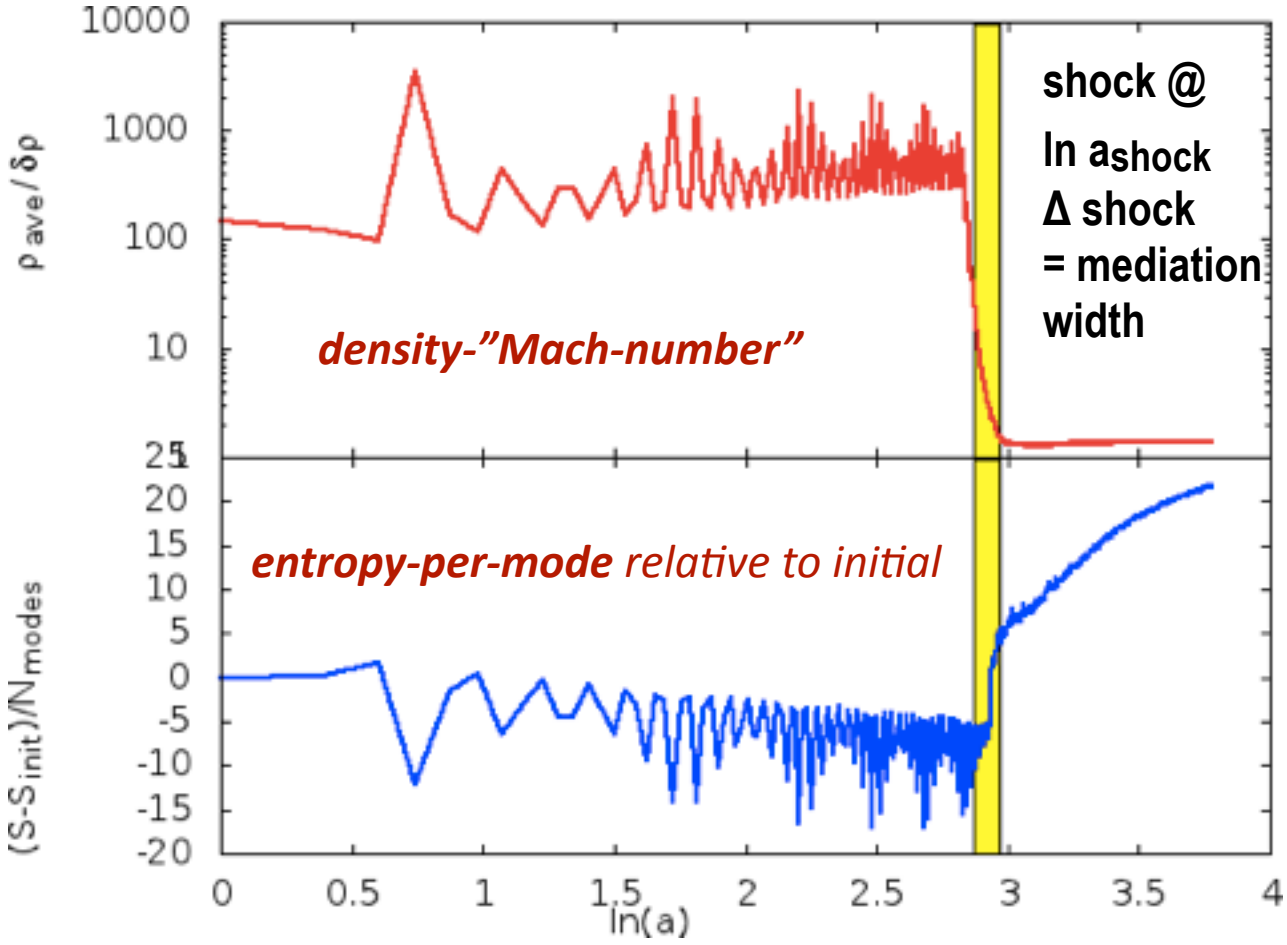
ln ρ/<ρ> power spectrum cf. instantaneous full thermal spectrum cf. conventional energy spectrum using a pseudo particle occupation number



B+Braden11

non-Gaussianity (WMAP, **Planck**, LSS) spiky nG preheating

the Shock-in-time: entropy production & (density-contrast)$^{-1}$



true thermal equilibrium far off

➤

& on to coupling to standard model degrees of freedom

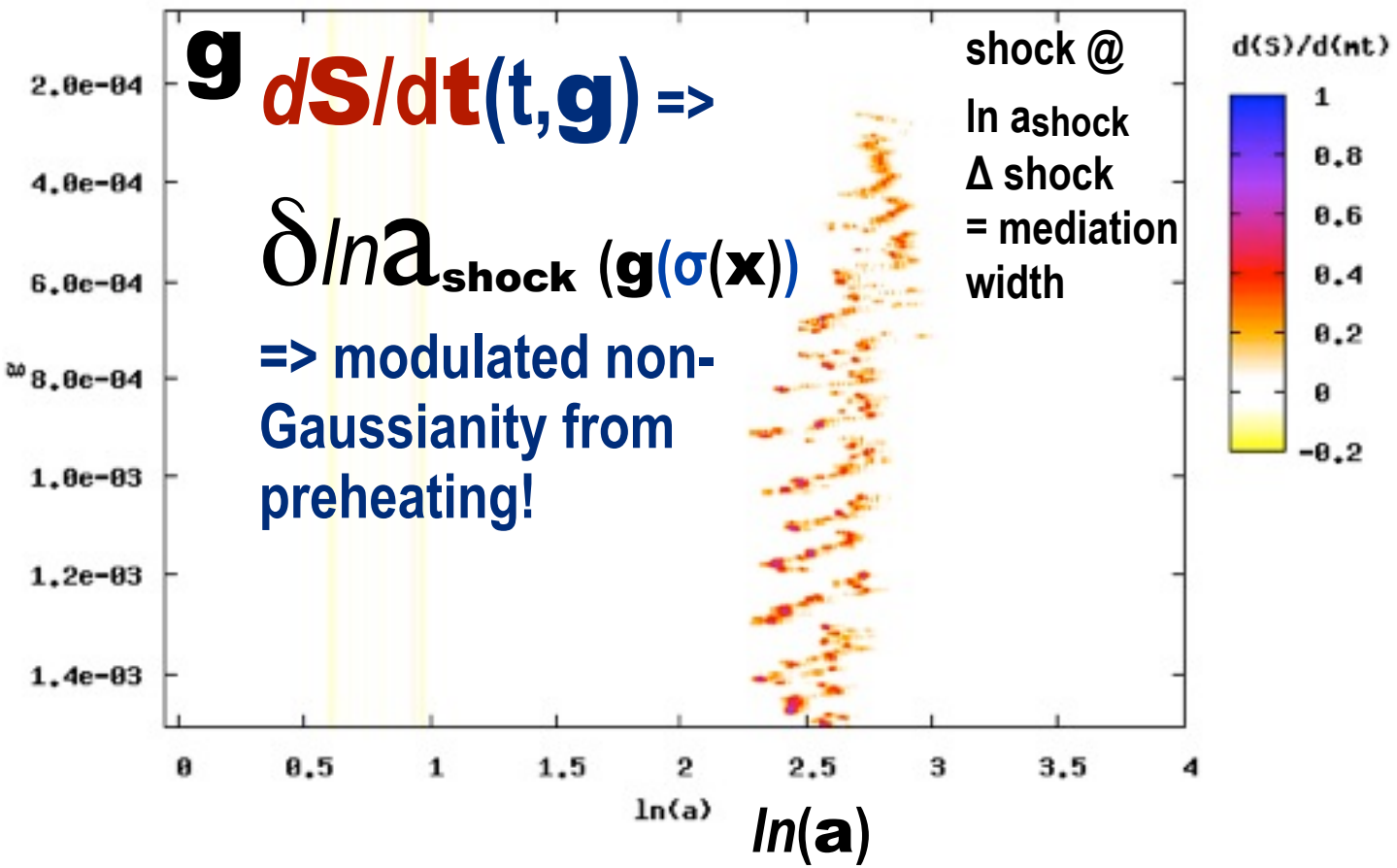
$$V(\phi,\chi)=1/2\ m^2\ \phi^2 + 1/2\ g^2\ \phi^2\ \chi^2$$

constrained coarse-grained ***Shannon-entropy(ln a)*** minus the initial Gaussian random field entropy (from band-limited quantum fluctuations)

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

non-Gaussianity
(WMAP, **Planck**, LSS)
spiky nG preheating
B+Braden11

the Shock-in-time: entropy production rate



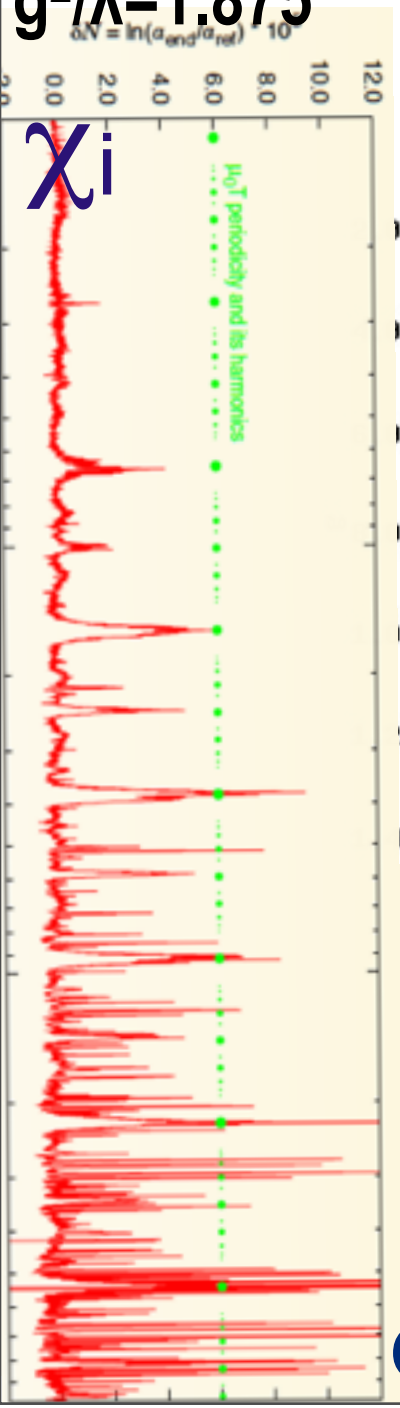
$$V(\phi,\chi)=1/2\ m^2\ \phi^2+1/2\ g^2\ \phi^2\ \chi^2$$

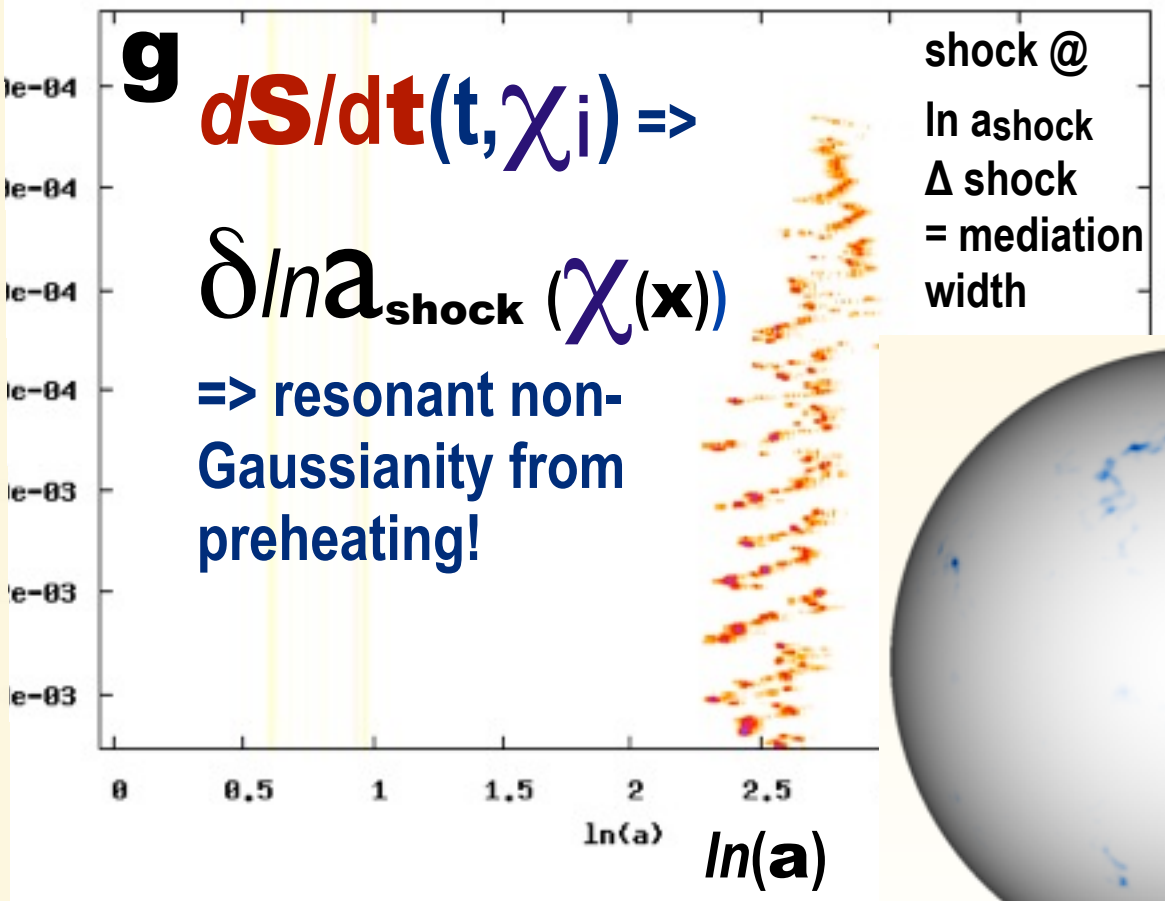
non-Gaussianity
(WMAP, **Planck**, LSS)
spiky nG preheating

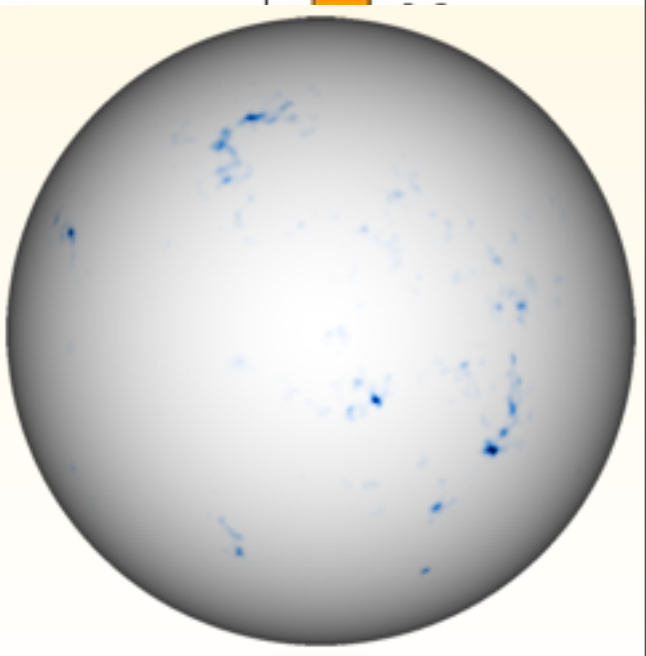
modulated non-G **Kofman03**
B+Braden11

$g^2/\lambda=1.875$

the Shock-in-time: entropy production rate







& f_{NL}^{equiv}

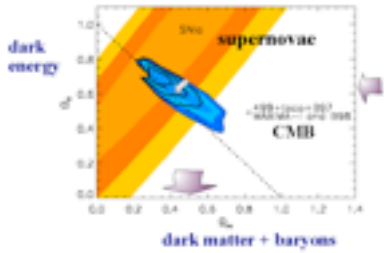
Chaotic Billiards: NonGaussianity from Parametric Resonance in Preheating

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

$\delta ln a\ (\chi_i(x,t))$

B+Frolov, Huang, Kofman 09
B+Braden, Frolov, Huang 12

non-Gaussianity
(WMAP, **Planck**, LSS)
spiky nG preheating



Dark Energy Histories
(SN+WL+BAO+CMB+cls)

future fate?

the **cold-death** of the **Universe** (cf. 1800s heat-death)

coherence (dark energy $\rho_{de}(t,x) \Rightarrow V_{de} \sim \Lambda$)

beats **incoherence** (Υ,ν,h_{+x},..p,n,e)

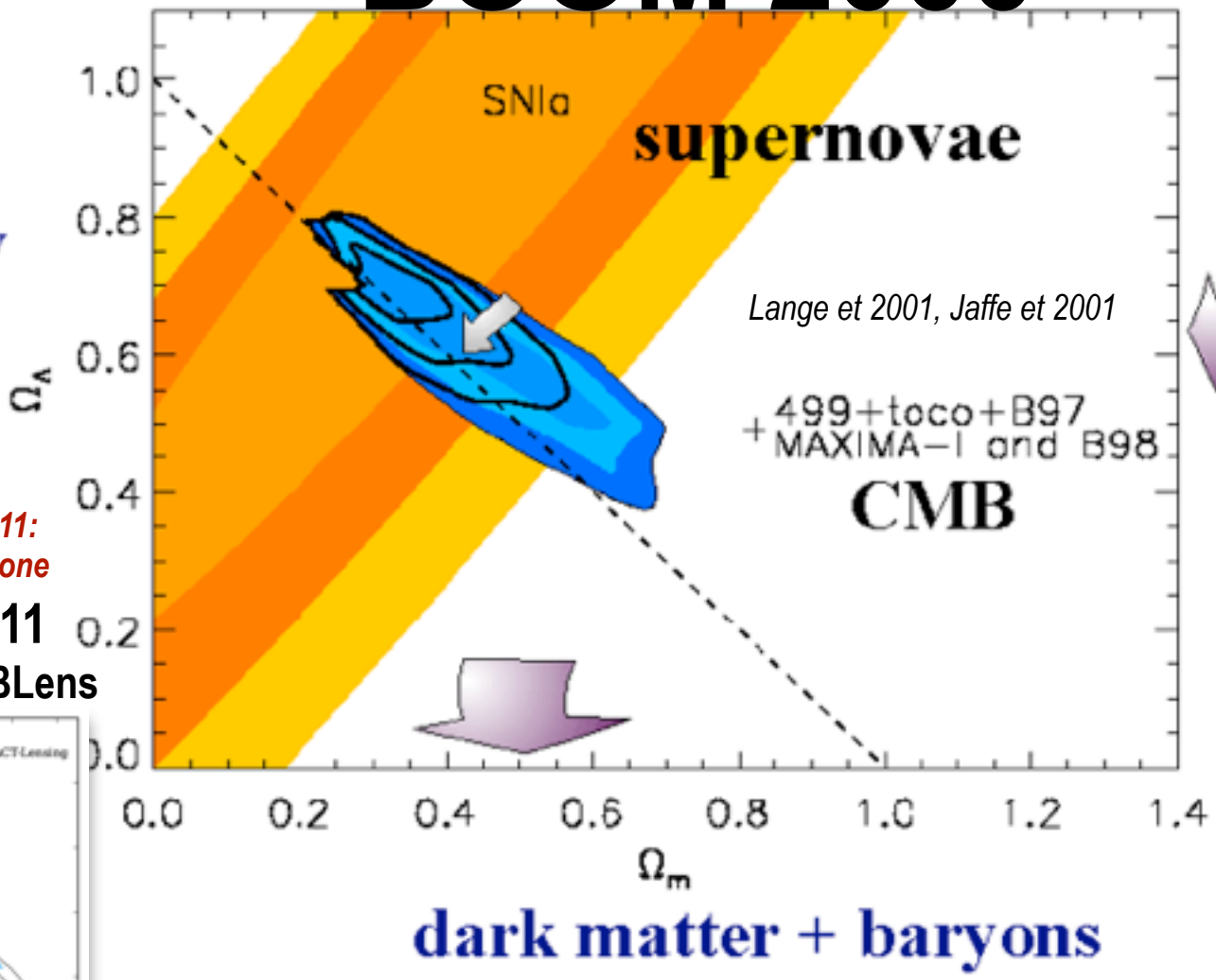
but **entropy/particle**

remains *(for those particles that survive)*

...nce for "dark energy" aka the cosmological constant

dark energy

BOOM 2000



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

much invoked since

Peebles 1985

a neo-Lemaitrian

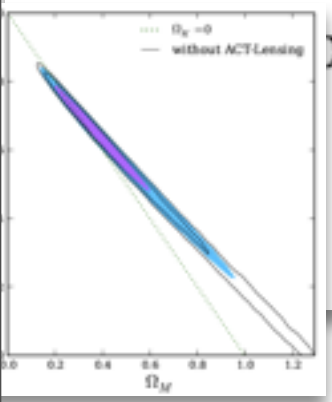
WYSIWYG

BBE87, PR88, Weinberg87, ...

Sherwin et 2011: Λ from CMB alone

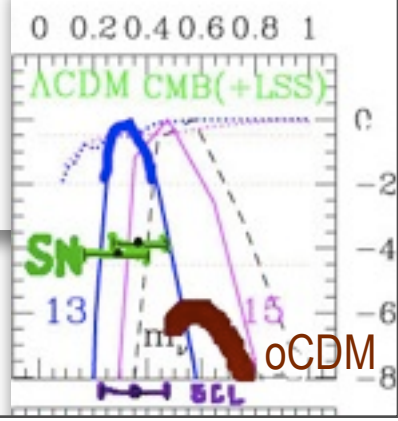
ACT 2011

DE from CMBLens



CMB+LSS 1996/98

DE w/o SN



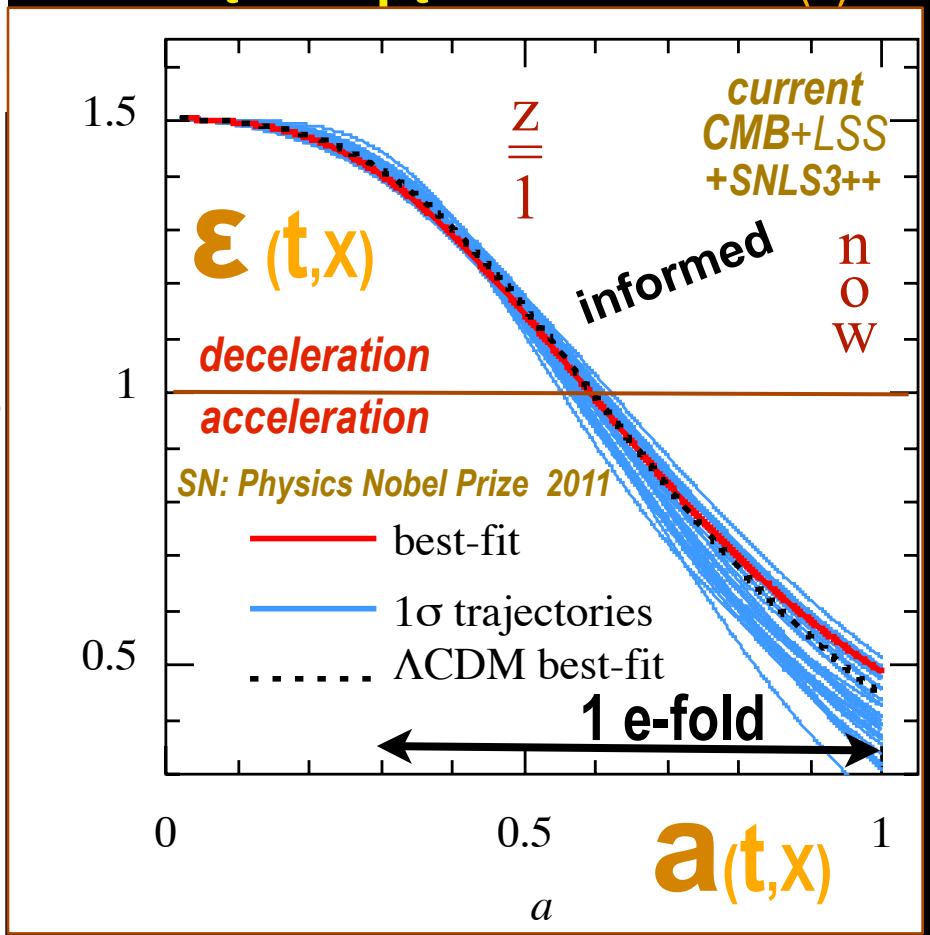
Dunkley et 2011 cosmic parameters

Ω_Λ=0.736 ±.012 =>± 0.001 (Pext) B+Huang 2011

2011: WMAP7+ACT+BAO+H0

Dark Energy Histories (SN+WL+BAO+CMB+cls)

$1+W_t=-d\ln\rho_t / d\ln a^3=2/3\,\varepsilon(t)$



informed=

3-parameter

w_ϕ

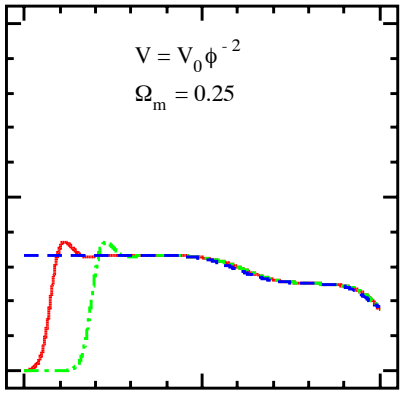
$W_{de}(a|V(\psi),IC)$

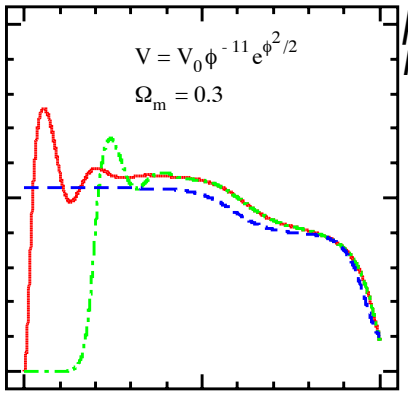
$= w(a|\varepsilon_s \varepsilon_{de\infty} \varsigma_s)$

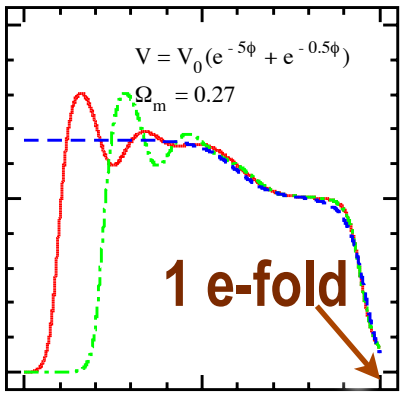
paves even wild late-inflaton trajectories

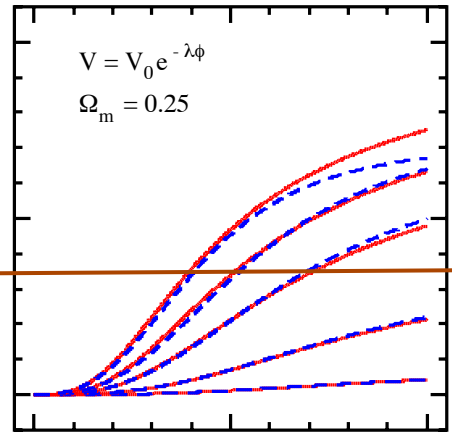
cf. w_ϕ

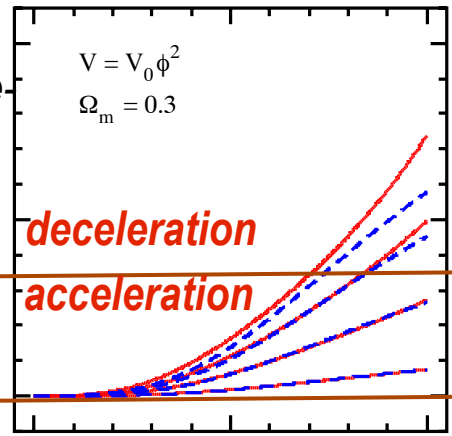
semi-blind eigen-analysis



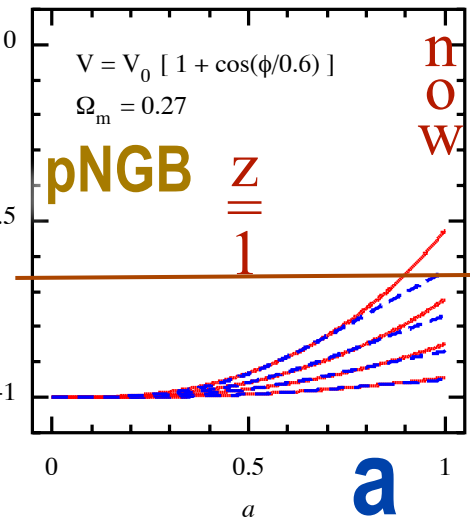




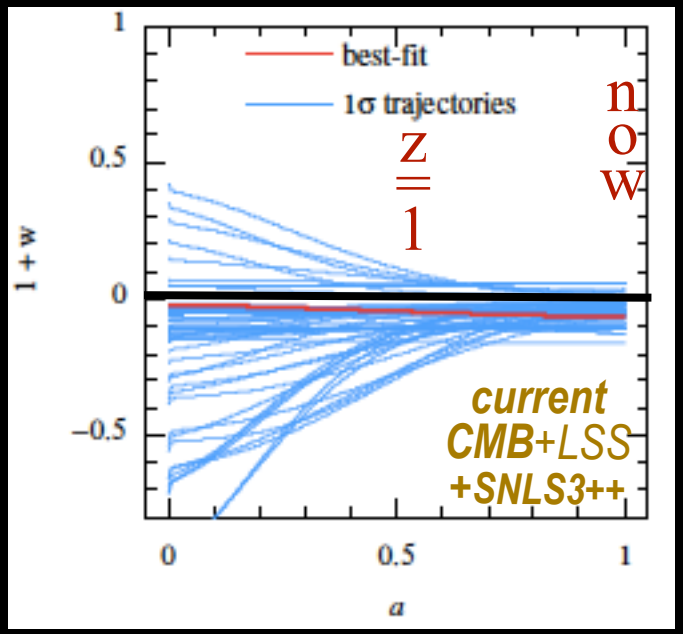




W_{de}

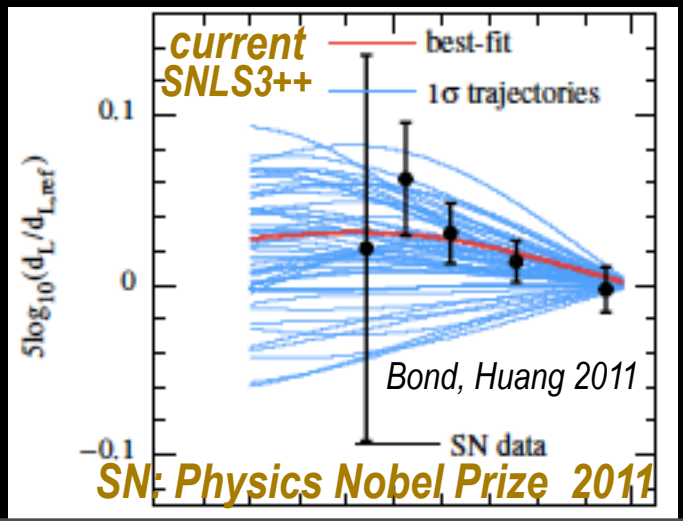


$1+w_{de}=-d\ln\rho_{de} / d\ln a^3=2/3\,\varepsilon_{de}(t)$



$a(t,x)\ H(t,x)\ \varepsilon(t,x)$

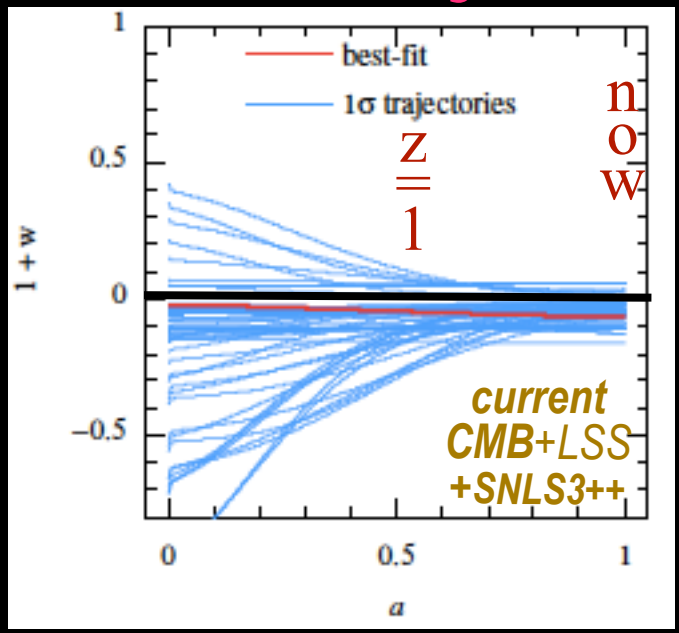
acceleration < 1

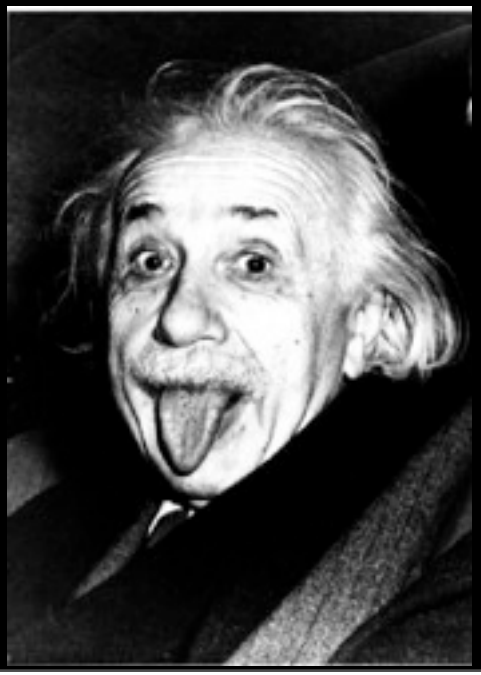


to DE (t,x)
or not
to DE (t,x)
that is the
question

CITA ICAT

late-inflaton DE trajectories





to DE (t,x)
or not
to DE (t,x)
that is the
question

modify
Einstein
equations?!
nein

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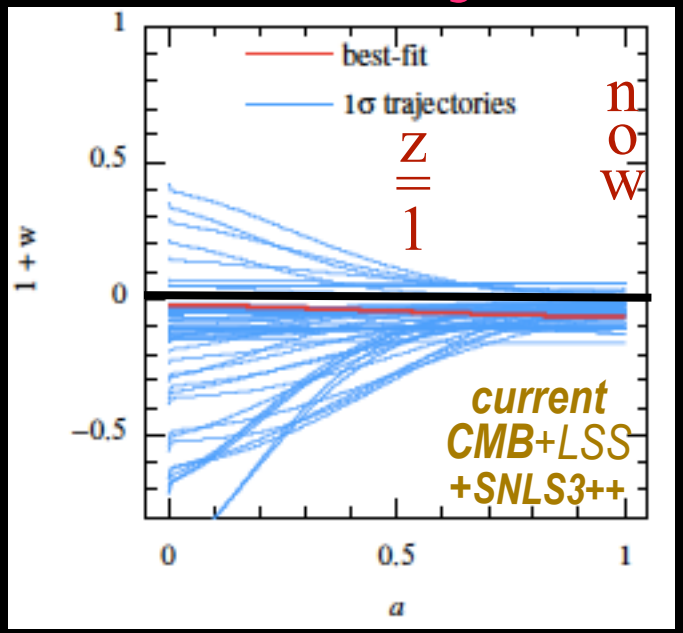
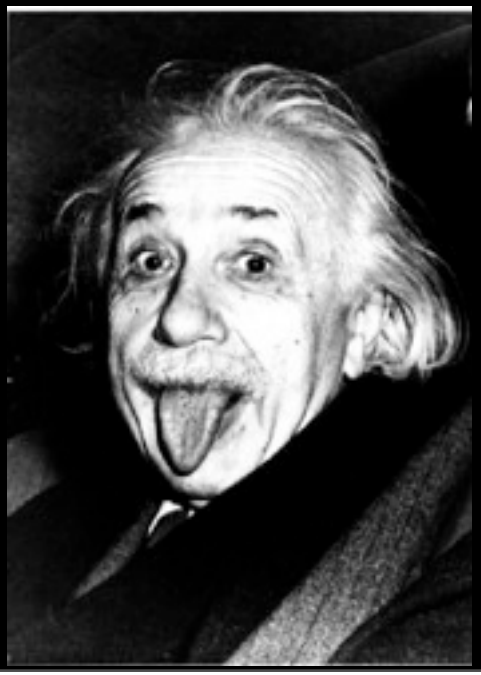
cifar 25 years

late-inflaton DE trajectories





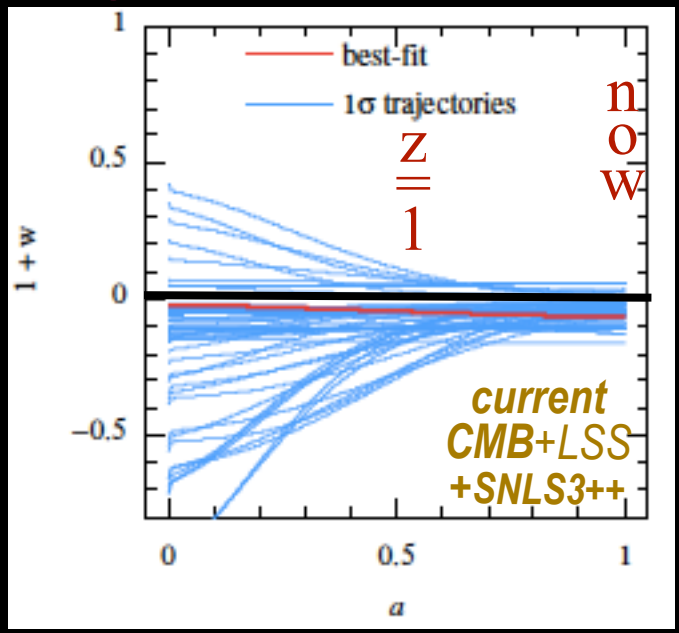
Beyond Einstein

to DE (t,x)
or not
to DE (t,x)
that is the
question

modify
Einstein
equations?!
~~nein~~ ja

conformal factor dynamics

g_E/g_{JBD}~
(dL_G/dR)

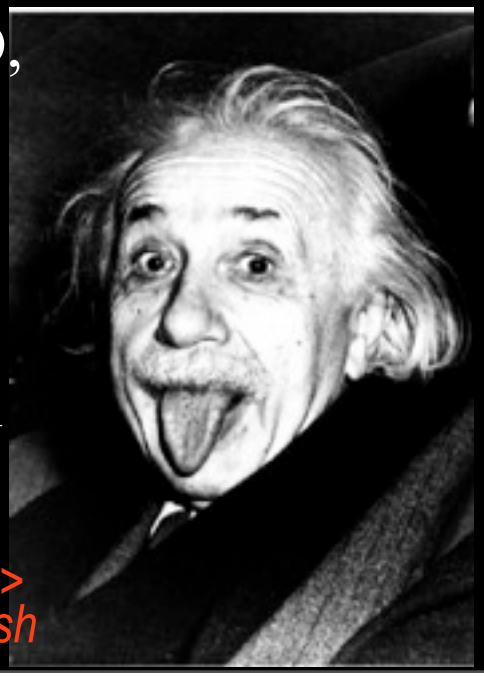


generalized JBD,
$G_N(\varphi)$ f(R) etc
aka $L_G(R,\varphi)$

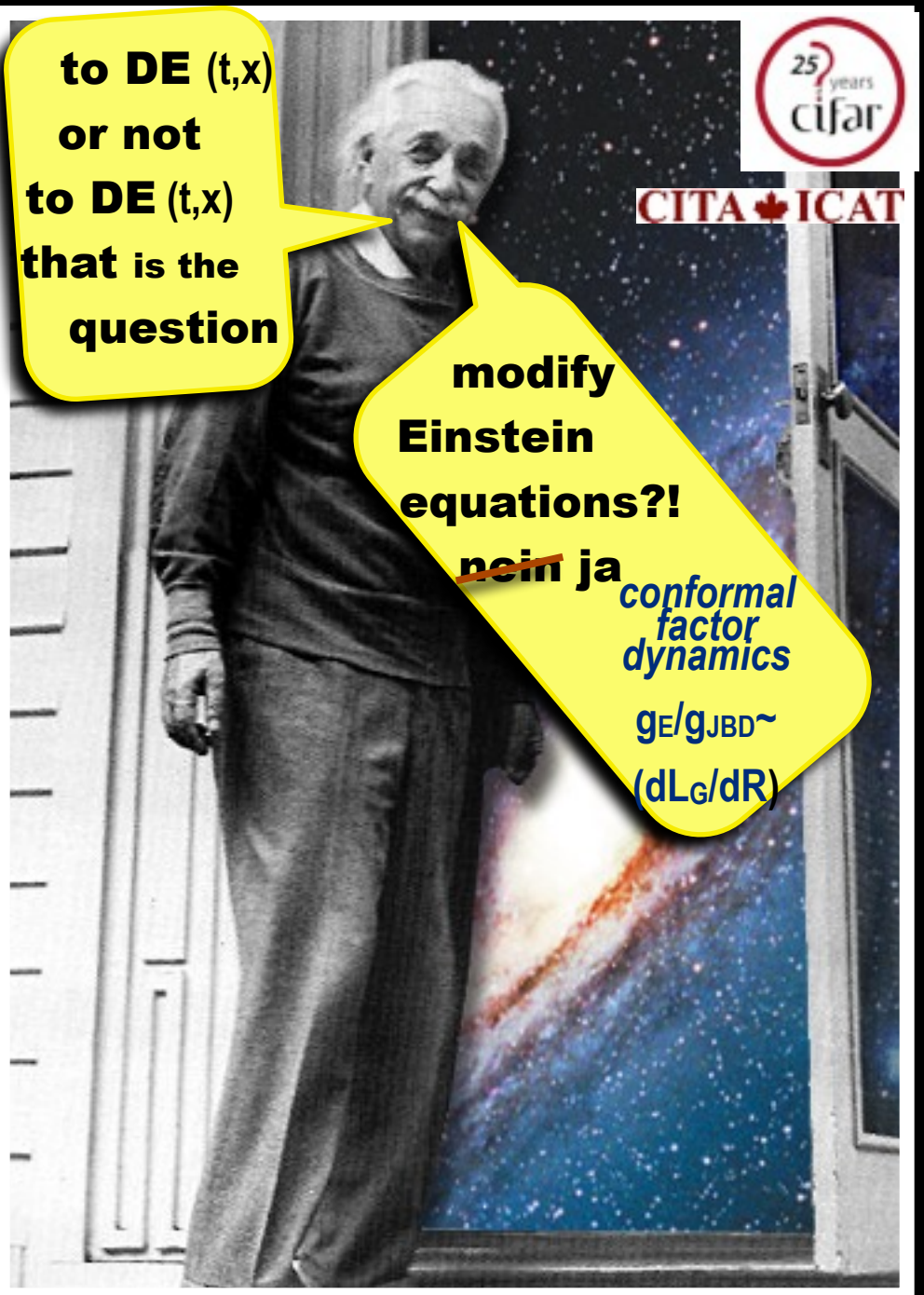
aha

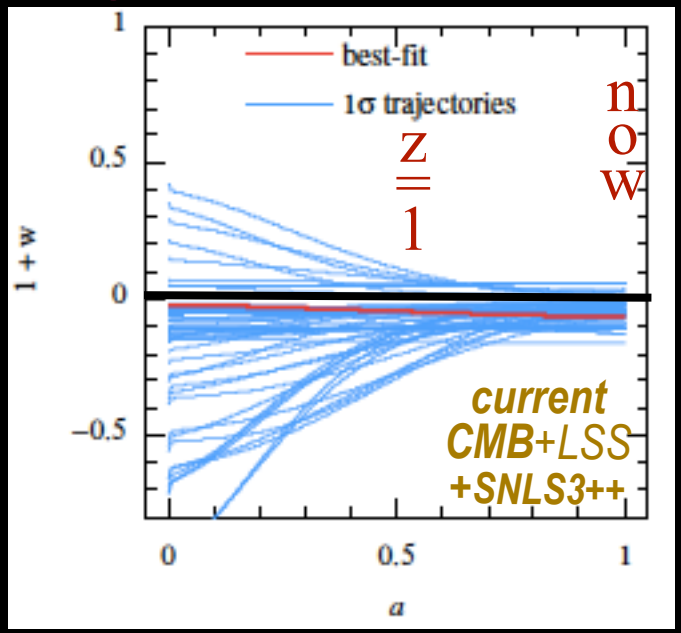
fifth+ forces in
Einstein frame

& matter-interaction =>
exciting!! *chameleon-ish*



Beyond Einstein





$L_{GE} = M_P^2\, R/2$ scale$\sim R^{-1/2}$:

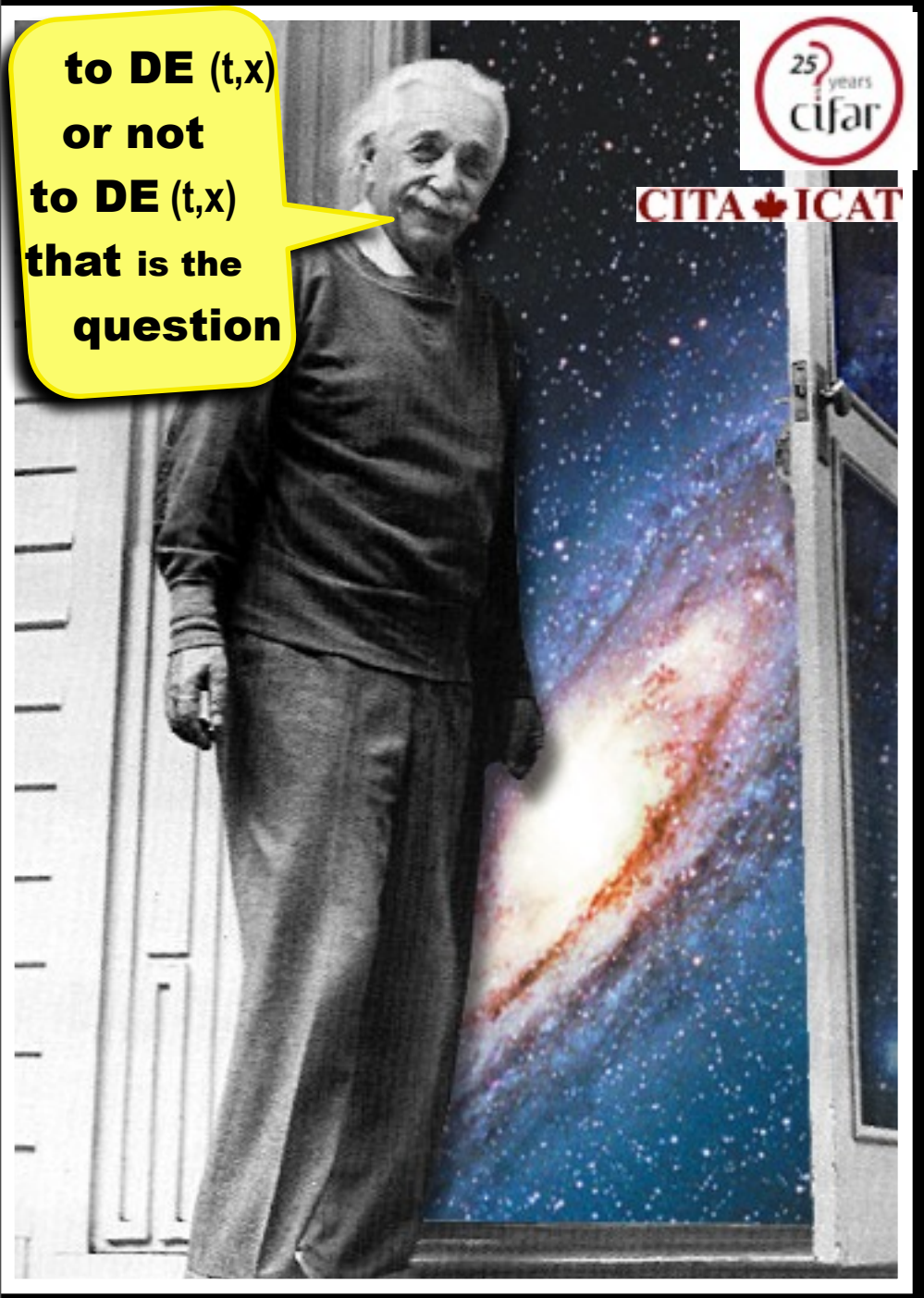
$M_P^2 G^{\mu\nu} = (dL_G/dL_{GE})^2 T_m^{\mu\nu} + T_\chi^{\mu\nu}$

& scalar: $\chi(x,t|R) \sim -ln(dL_G/dL_{GE})$

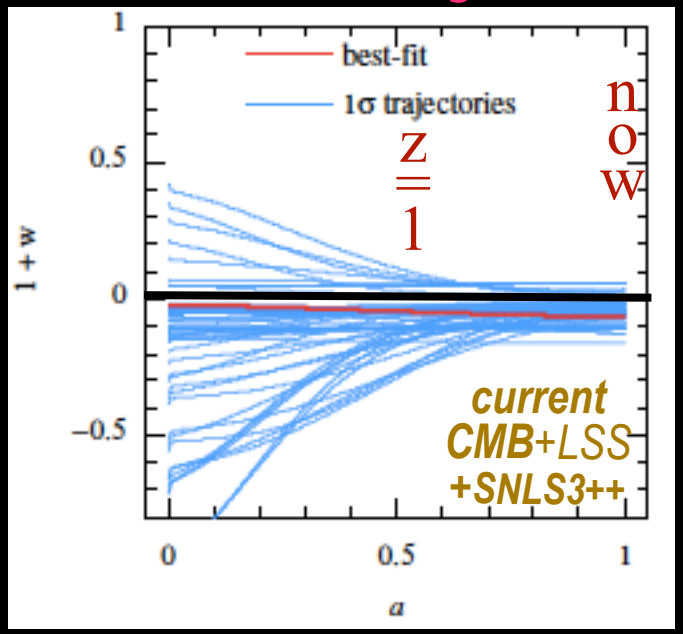
$U(\chi) = (dL_G/dL_{GE})^2\, [(\rho_m - 3p_m)/4$

$+ L_{GE}\, d(L_G/L_{GE})/d\,lnR]$

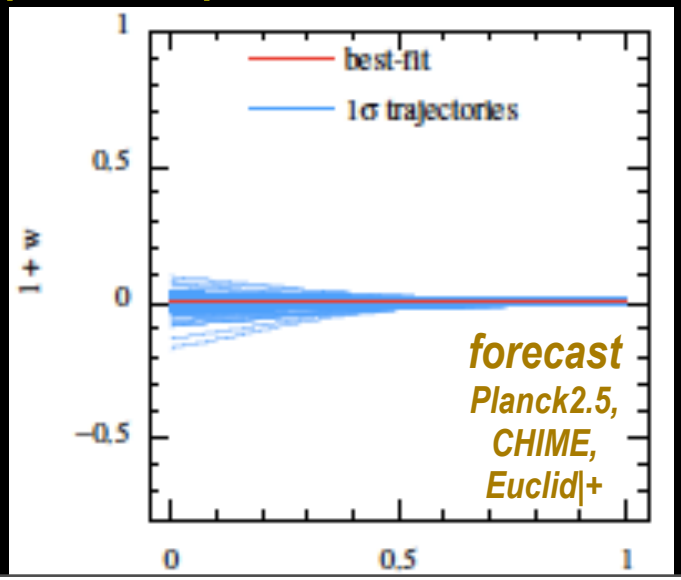
the dance: pass solar system/BBN/CMB+ tests

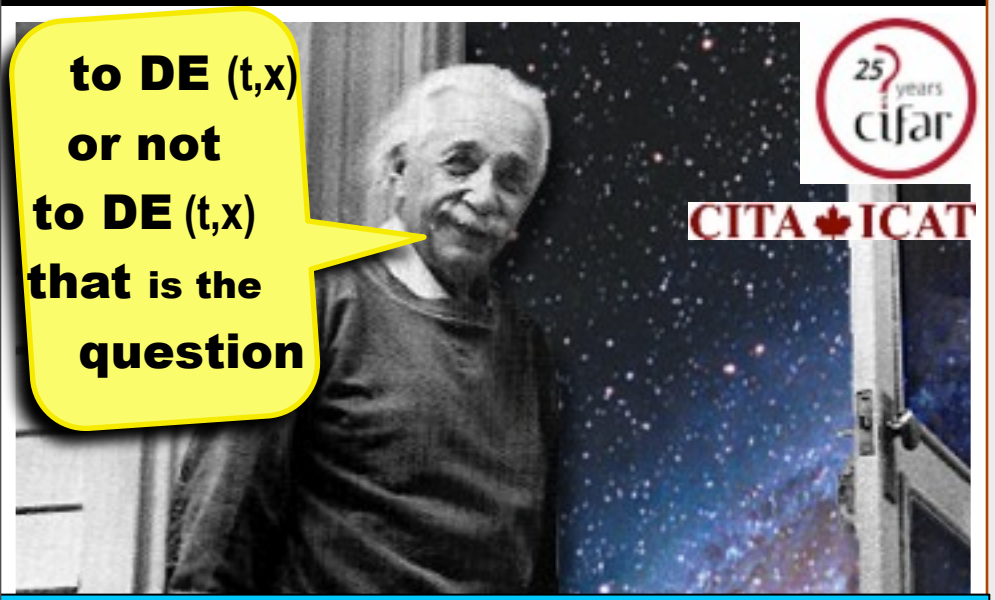


late-inflaton DE trajectories

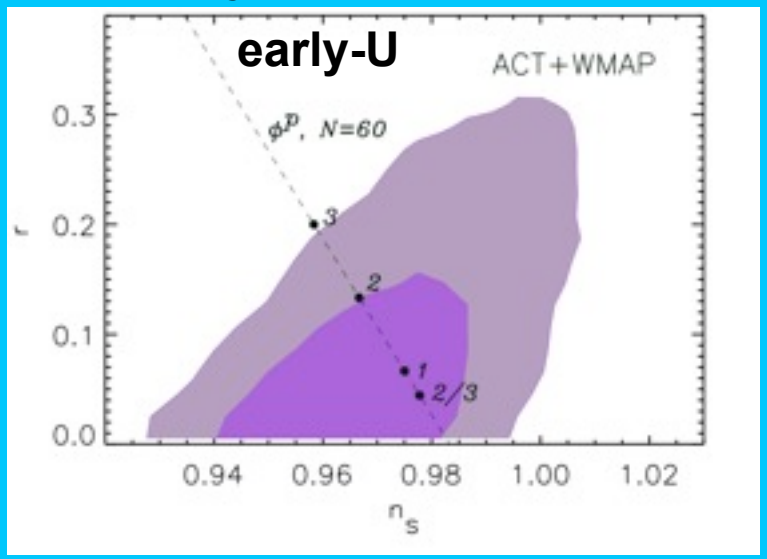


$$(1+W_{de}) = - d\ln\rho_{de} / d\ln a^3$$

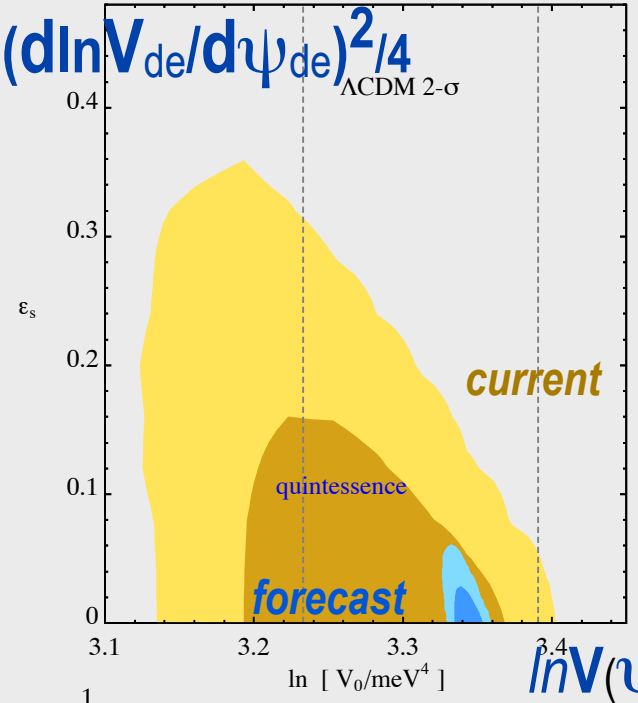




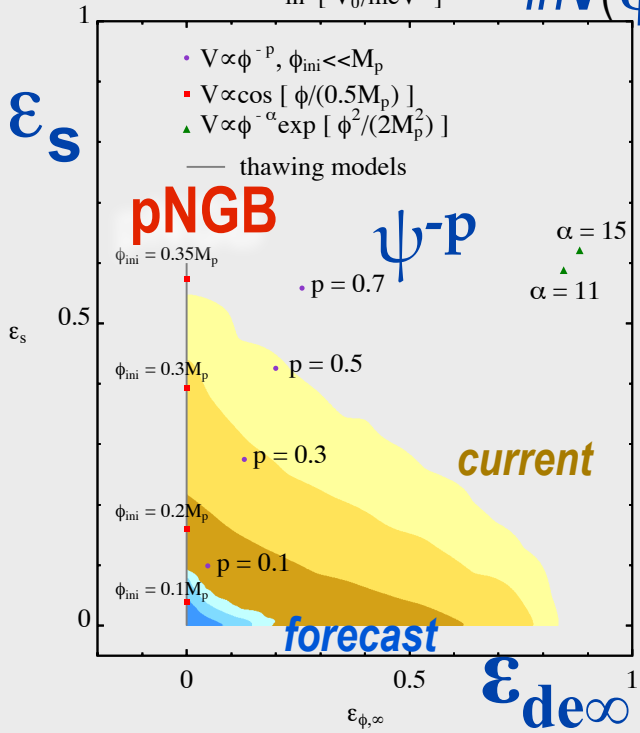
introduce a late-U DE plot littered with theory models similar to the early-U r-n_s plot. with HBK10/BH11 parameterization of the DE trajectories this can be done.



$\varepsilon_s=(d\ln V_{de}/d\psi_{de})^2/4$



$\ln V(\psi_{de,now})$



SUGRA-inspired

INFLATION

primary anisotropies

•linear perturbations: scalar/density, tensor/ gravity wave

• tightly-coupled photon-baryon fluid:

oscillations $\delta\gamma$ $v\gamma$ $\pi\gamma$

• viscously damped

• polarization $\pi\gamma$

• gravitational redshift

Φ SW $d\Phi/dt$

DarkM

Decoupling LSS

17 kpc (19 Mpc)

Lsound/ ksound

secondary anisotropies

the nonlinear COSMIC WEB

dS/dt

•nonlinear evolution

•weak lensing

•thermal SZ +kinetic SZ

•$d\Phi$ /dt

•dusty/radio galaxies, dGs

MILKY WAY

DarkE

z=0

reionization

z ~ 10

z ~ 1100

redshift z

dS/dt

time t

13.7-10^{-50}Gyrs

13.7Gyrs

10Gyrs

today