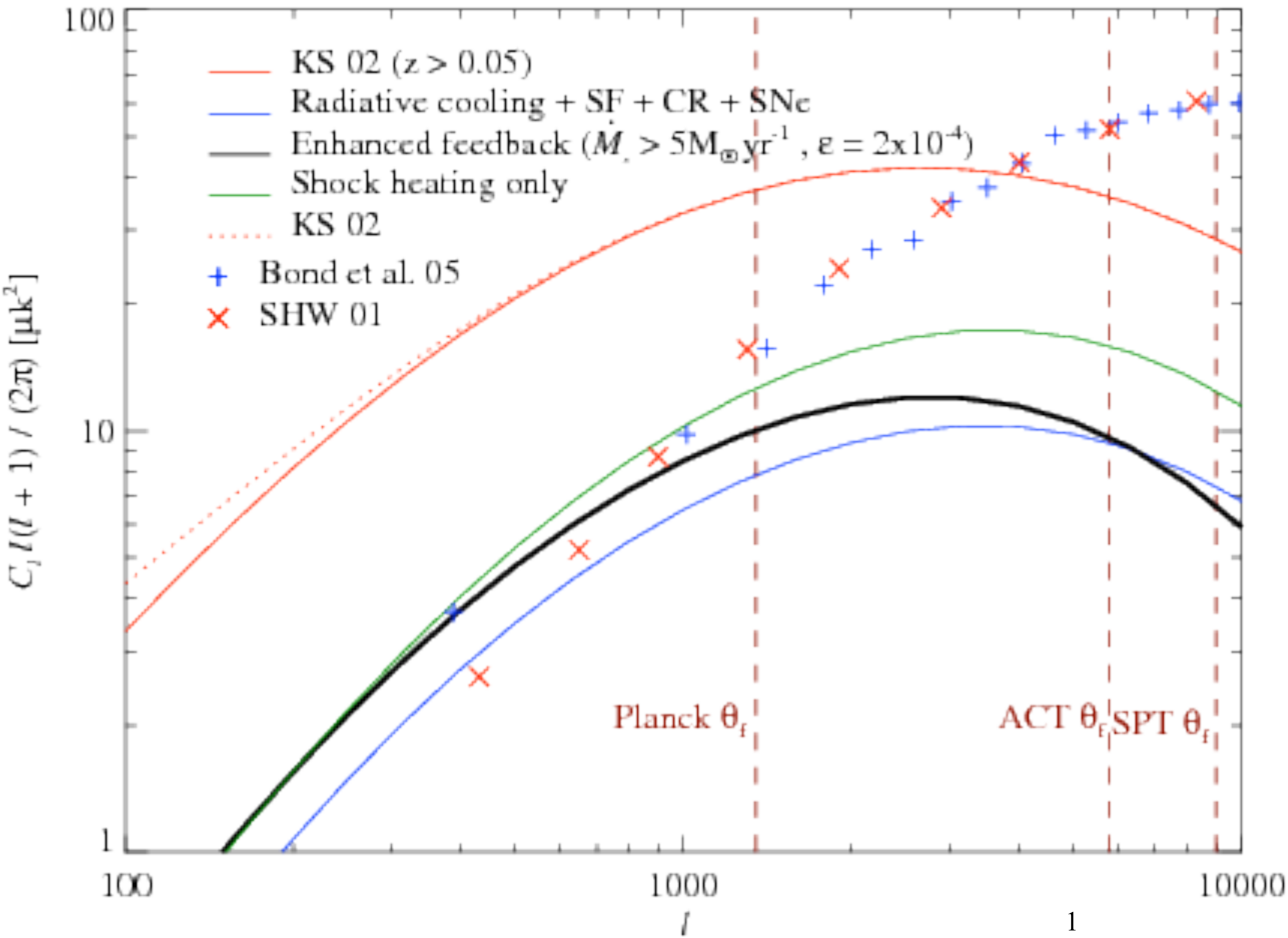
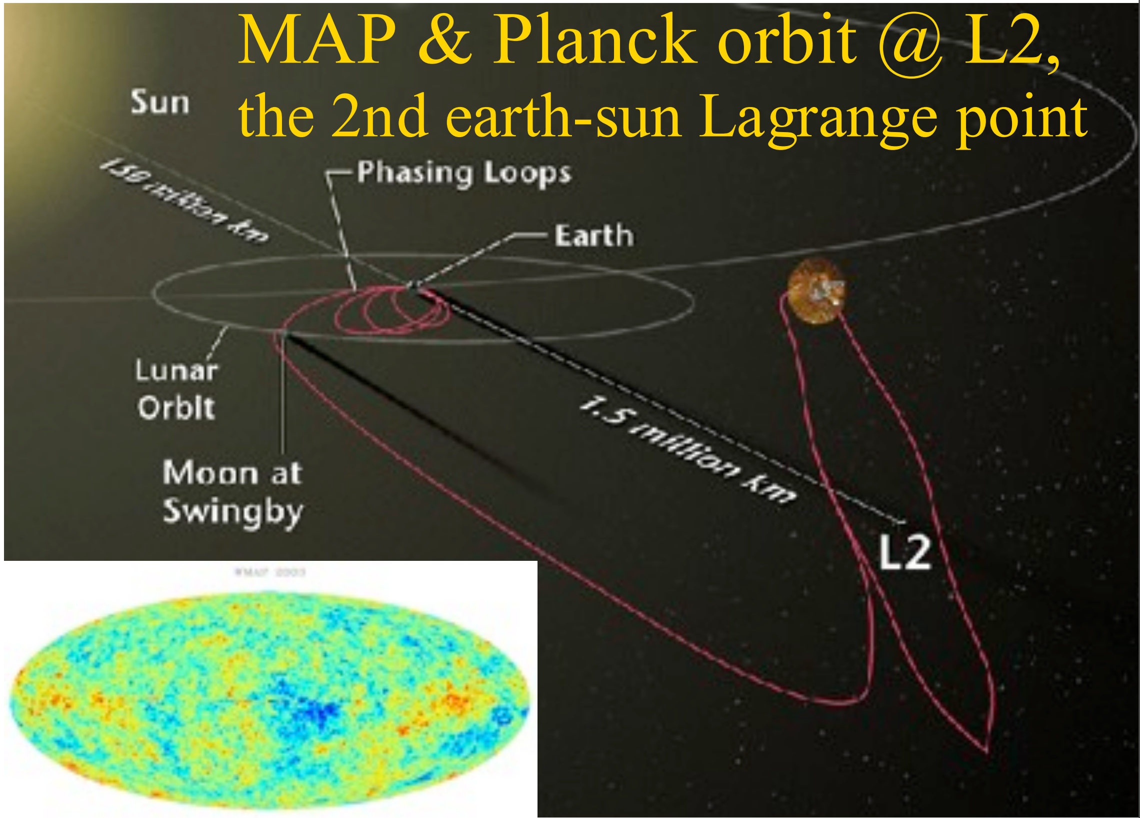
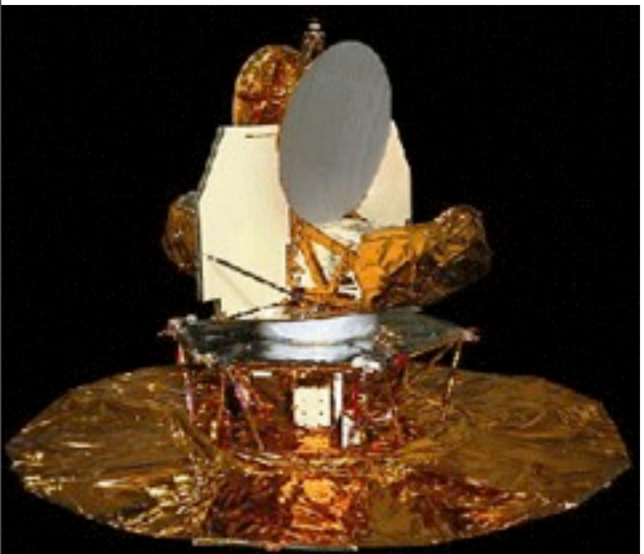


KS 02 (z > 0.05)
Radiative cooling + SF + CR + SNe
Enhanced feedback ($\dot{M}_* > 5M_\odot yr^{-1}$, $\varepsilon = 2x10^{-4}$)
Shock heating only
KS 02
Bond et al. 05
SHW 01
Planck θ_f
ACT θ_f
SPT θ_f
$C_l\, l(l+1) / (2\pi)$ [μk^2]
l
100
10
1
100
1000
10000

Nasa's WMAP satellite @ L2: launch 2001.5, 1yr data 2003.2, 3yr 2006.3, 5yr 2008.3, funded for 9 years

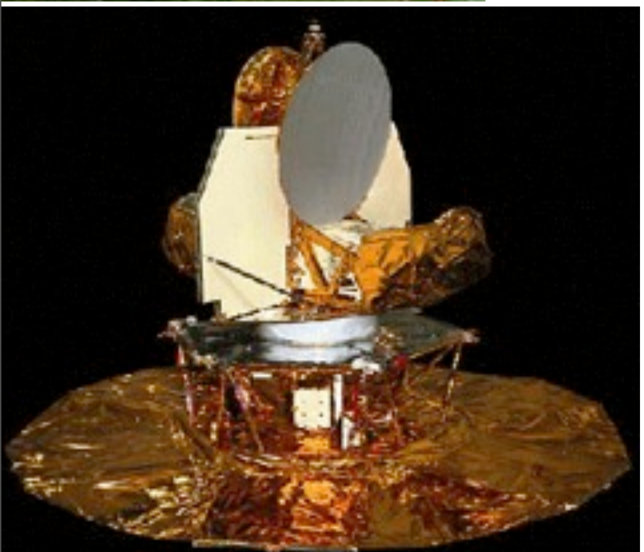
MAP & Planck orbit @ L2, the 2nd earth-sun Lagrange point

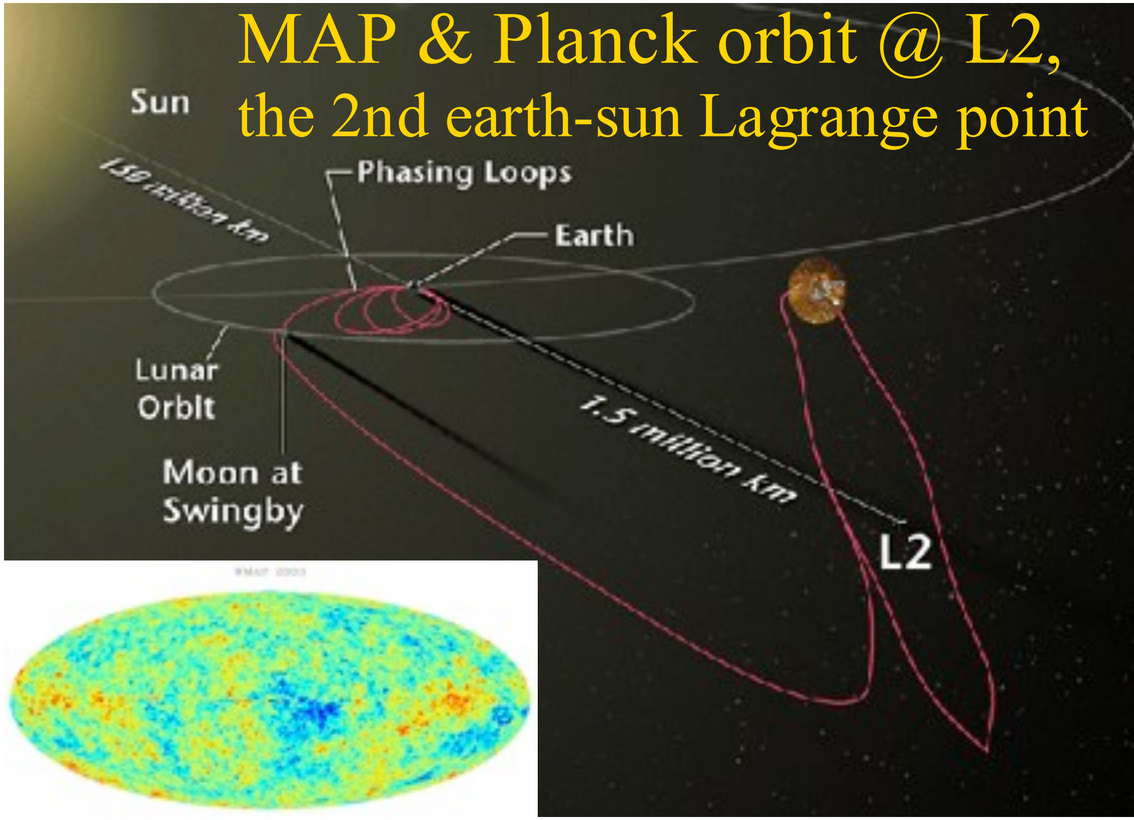


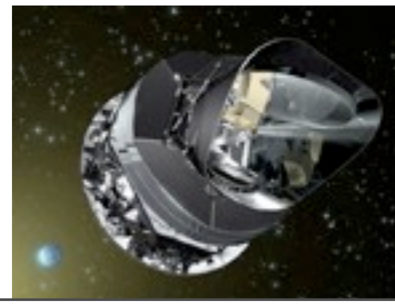


Planck satellite @ L2: launch 2009.4
ESA+NASA+ Cdn Space Agency

Nasa's WMAP satellite @ L2: launch 2001.5, 1yr data 2003.2, 3yr 2006.3, 5yr 2008.3, funded for 9 years







Planck satellite @ L2: launch 2009.4
ESA+NASA+ Cdn Space Agency

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

400
Mpc

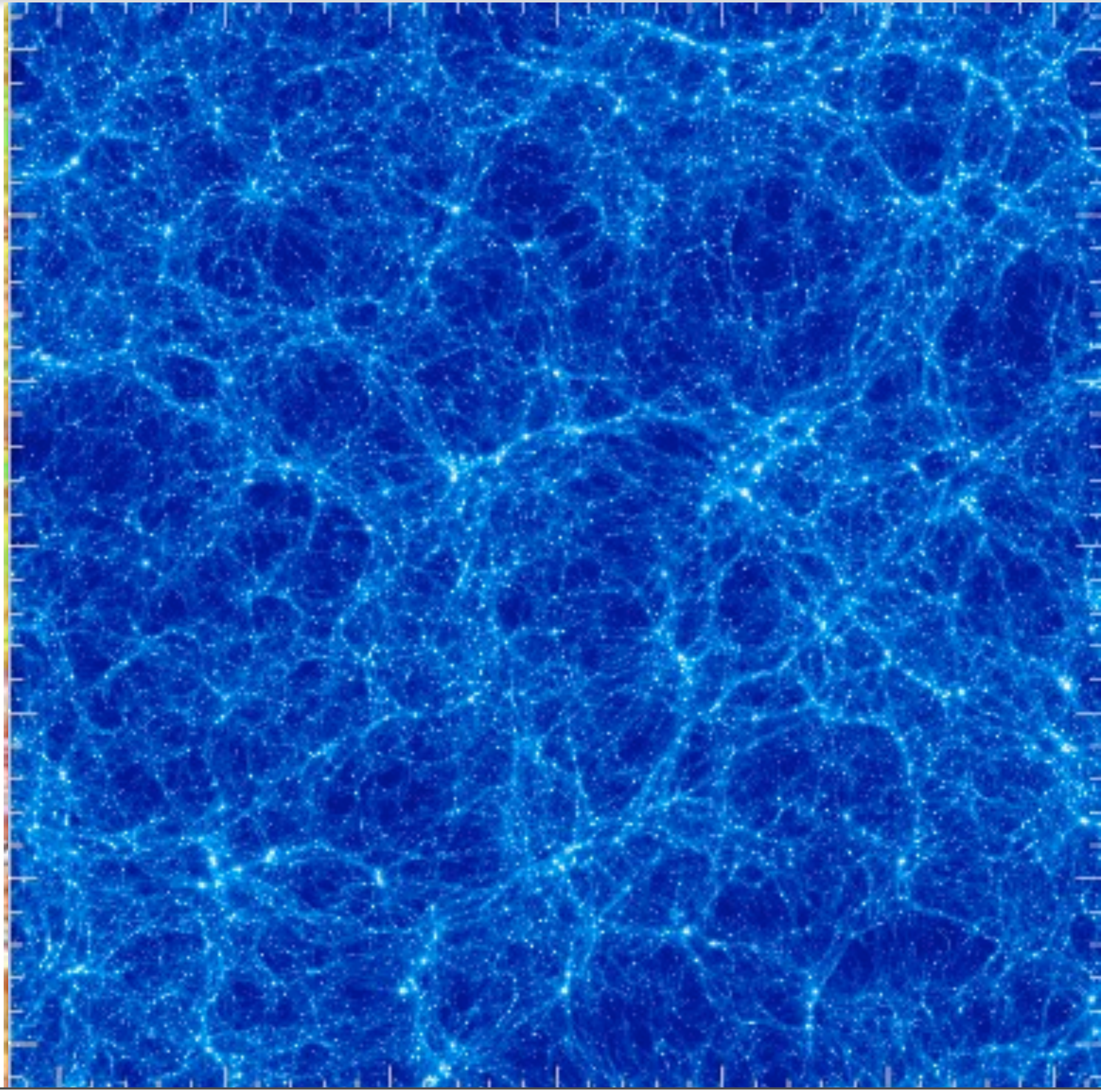
ΛCDM

WMAP5

gas
density

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!

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

400 Mpc

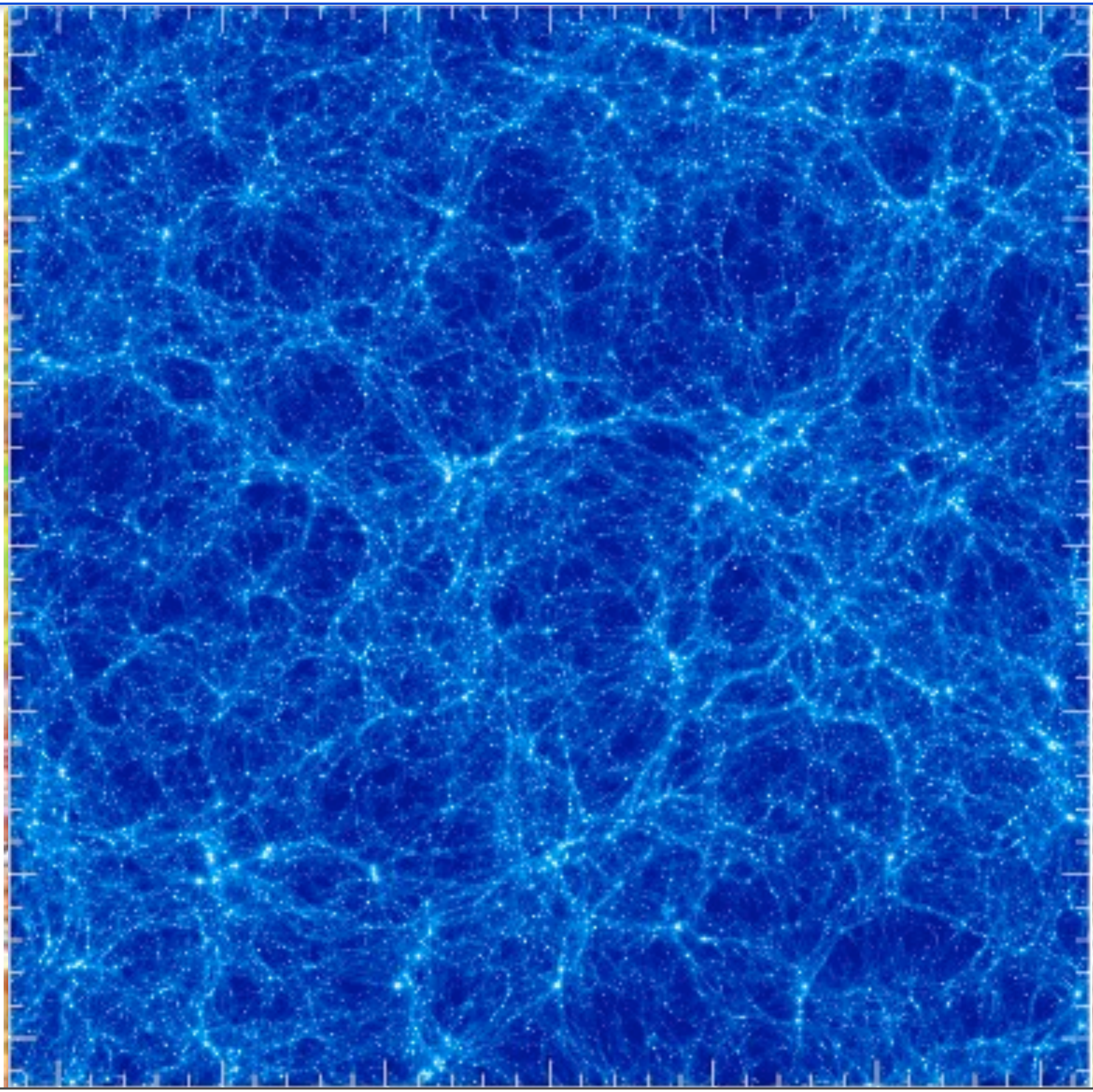
ΛCDM

WMAP5

gas density

Gadget-3 SF+ SN E+ winds +CRs

512^3



all this can

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential

aetherial!

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

400 Mpc

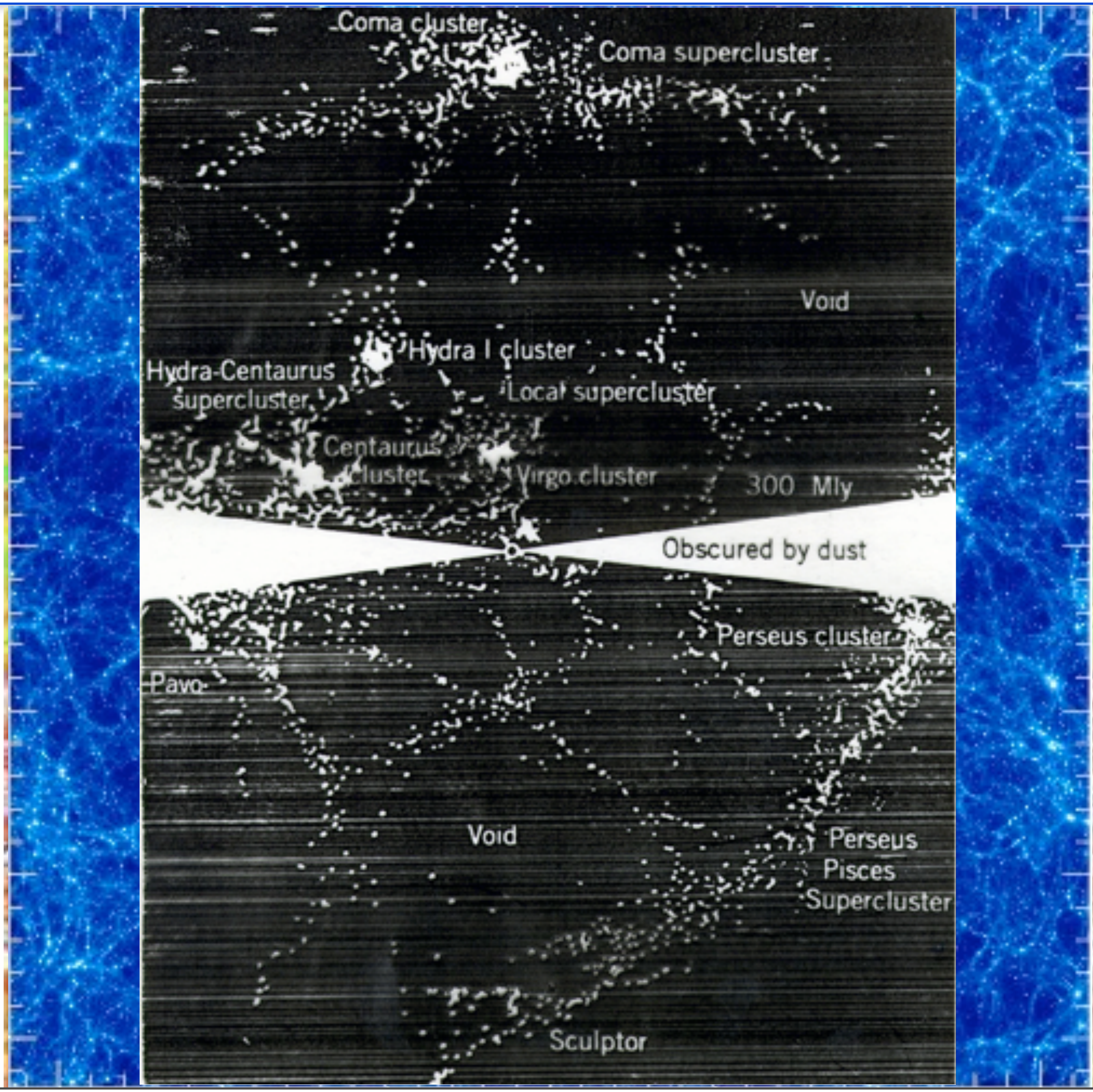
ΛCDM

WMAP5

gas density

Gadget-3 SF+ SN E+ winds +CRs

512^3



all this can

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential

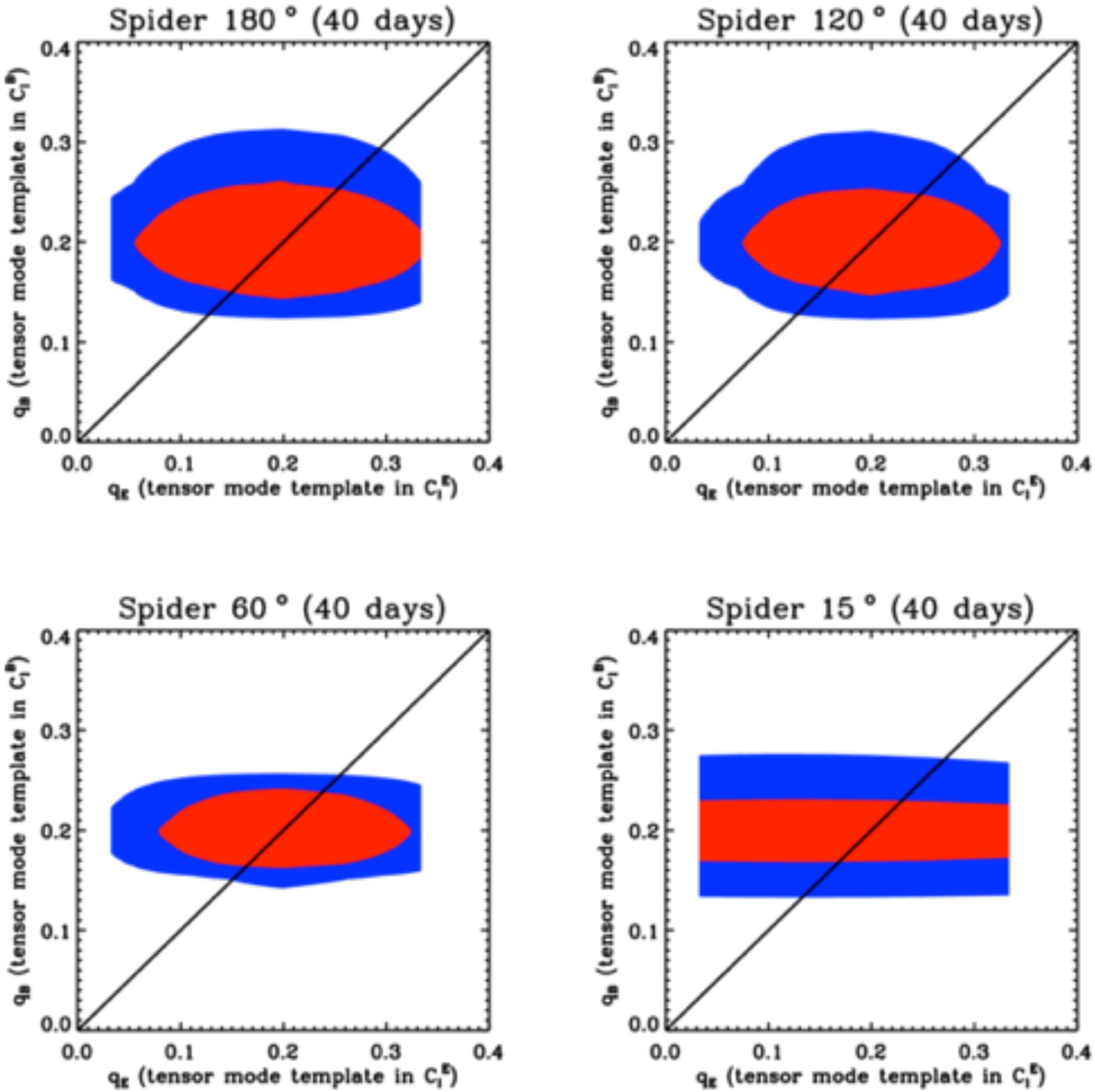
aetherial!

end

BB/EE

gravity wave template amplitude can be partly

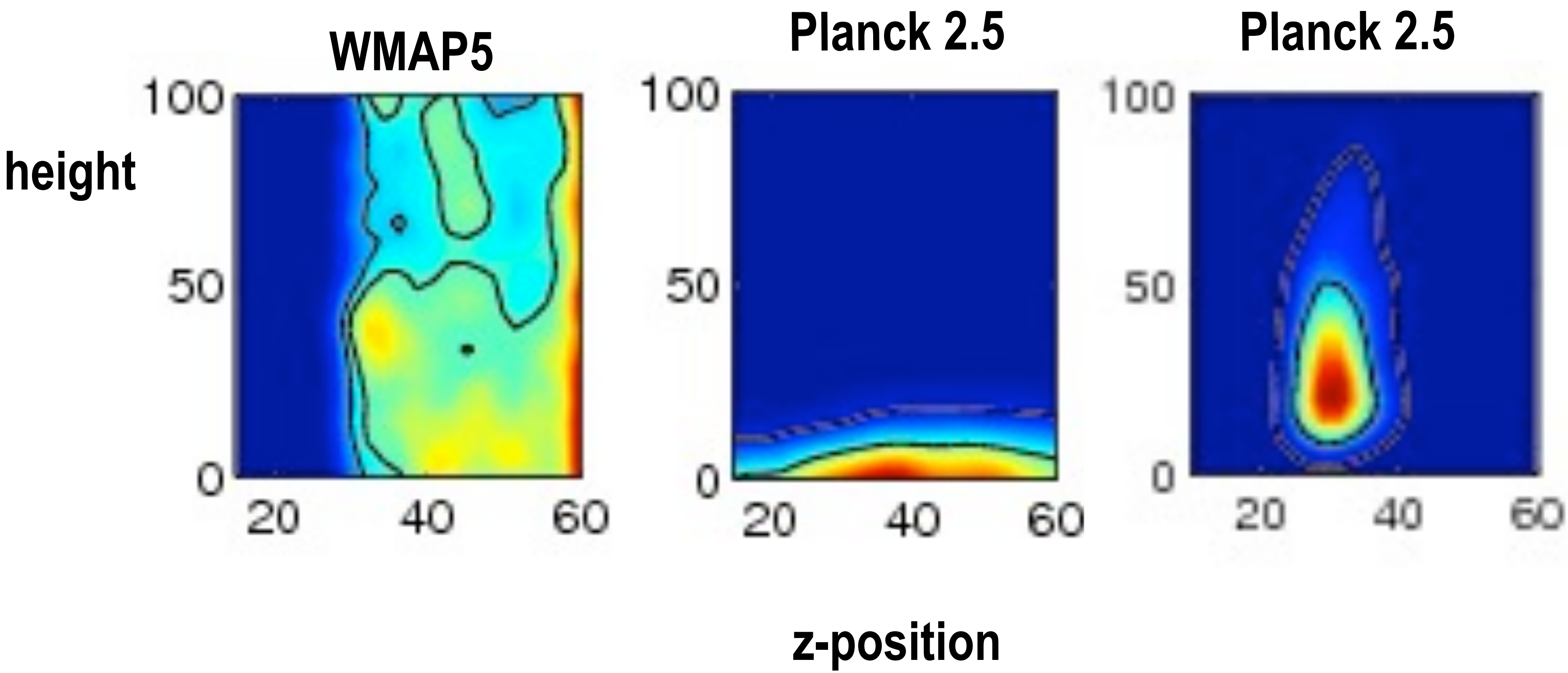
checked



reionization trajectories: expansions in modes, eigenmodes

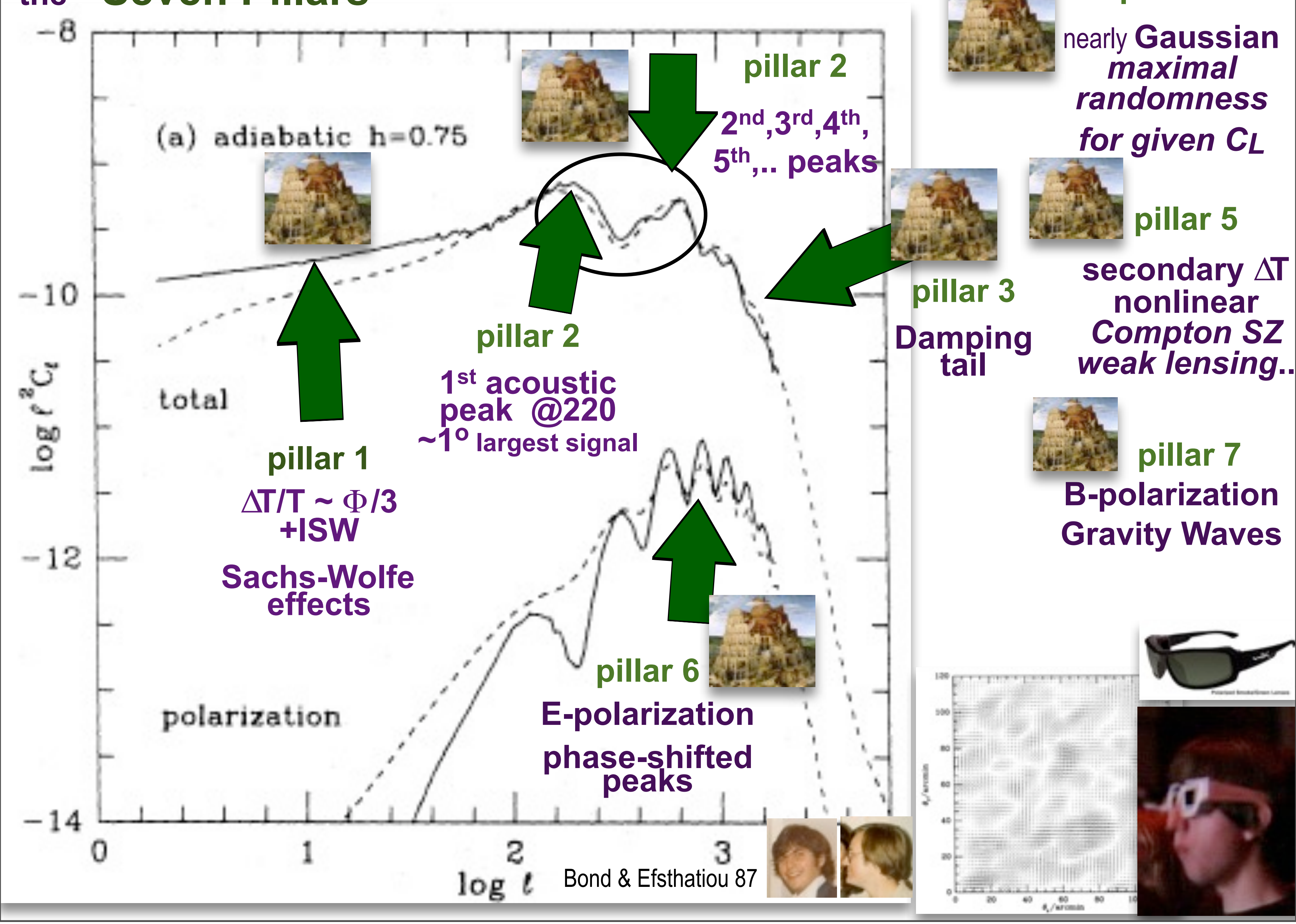
can we detect an early reionization bump in Compton depth?
yes with Planck, no with WMAP

test case: height, z-position, width



end

the "Seven Pillars"



CBI pol to Apr'05 @Chile

QUaD @SP

Quiet1 @Chile

Quiet2 1000 HEMTs

Boom03@LDB

Bicep @SP

Bicep2

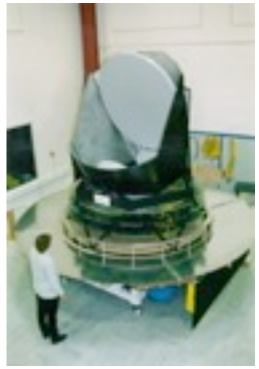
Keck/Spud

WMAP @L2 to 2009-2013?

Planck09.4

(52 bolometers) + HEMTs @L2

9 frequencies



EBEX @LDB

Spider 2312 bolos @LDB

CHIP

DASI @SP

CAPMAP

2004 2005 2006 2007 2008 2009 2011

LHC

Bpol @L2

BLASTpol

Clover @Chile

Polarbear 300 bolos @Cal/Chile

SPTpol

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.999 &** $r \sim 16\varepsilon_s$ **slow roll**

2 solutions: nearly uniform acceleration & small ζ_s

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

low energy inflation with tiny ε_s

$2\varsigma_s \sim .017 \pm .007$

errors go to $\pm .0012$ Planck+JDEM+DUNE

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

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

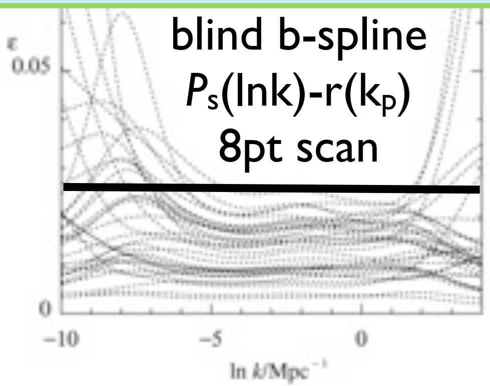
to $\pm .07$ Planck+JDEM+DUNE

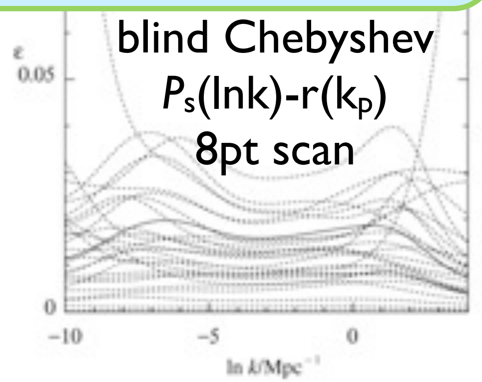
$\varsigma_s = \pm 1.001\, d^2\ln V/d\psi^2/4$ @a_{eq}

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

to $+.6-.7$ Planck+JDEM+DUNE **LCDM**

to $+.3-.3$ steep-ish $\exp[-\psi]$





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

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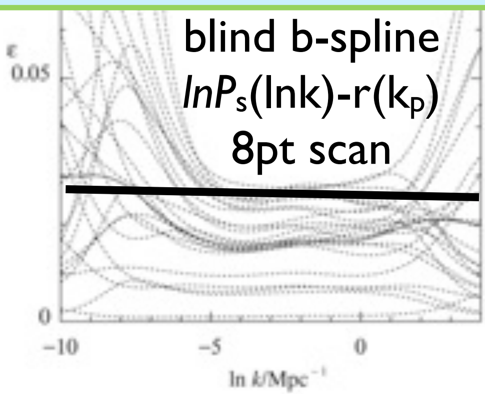
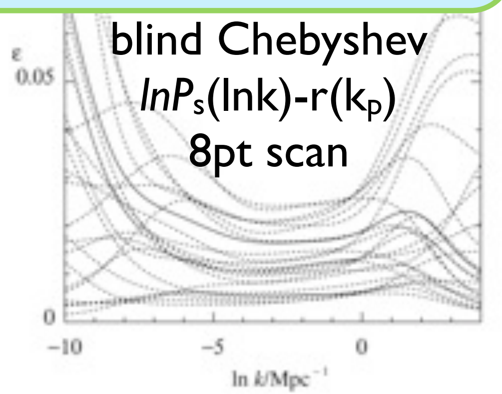
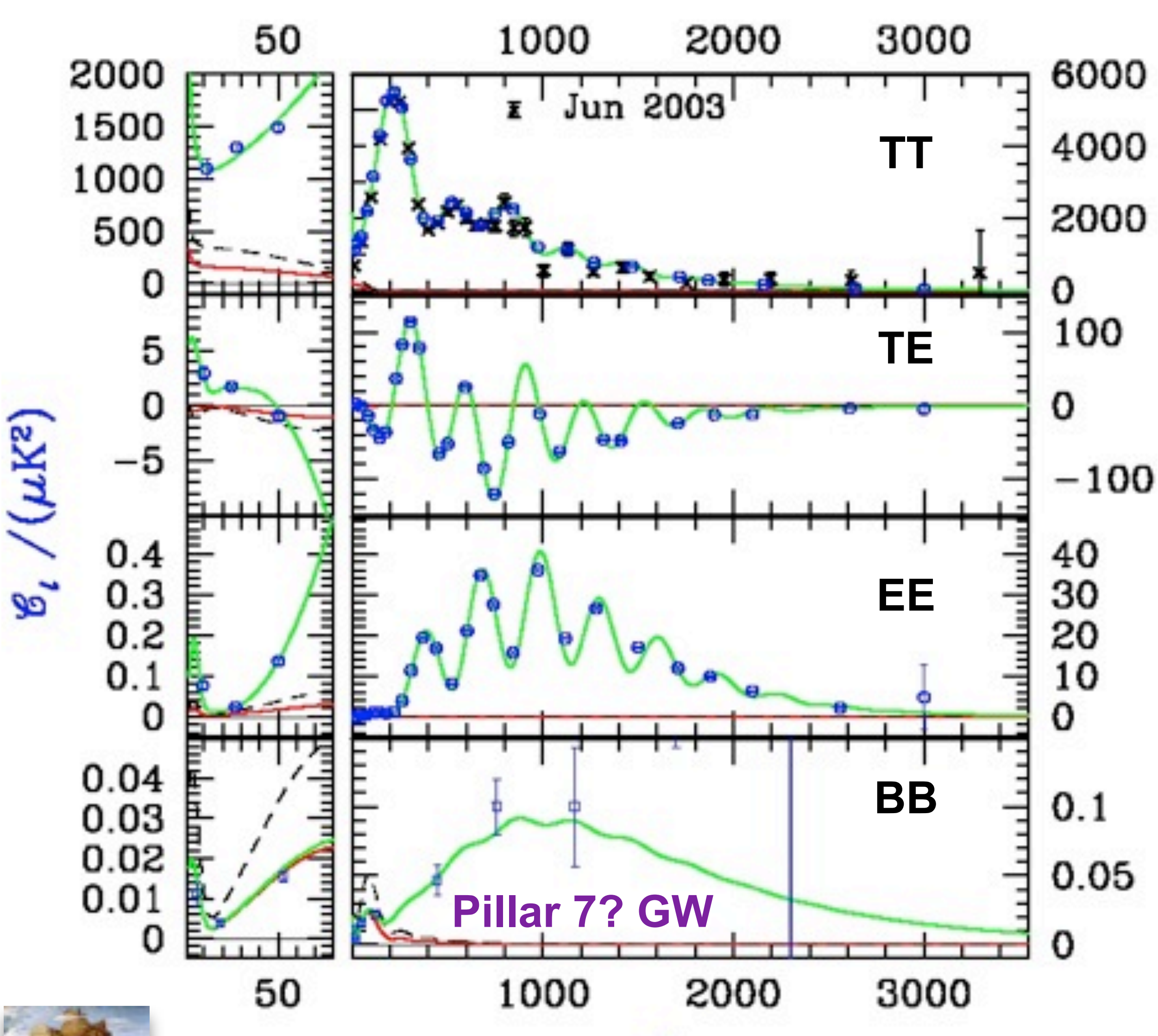




PRIMARY END @ 2012?

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

Pillar 7? Gravity Waves



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

PRIMARY END @ 2012?

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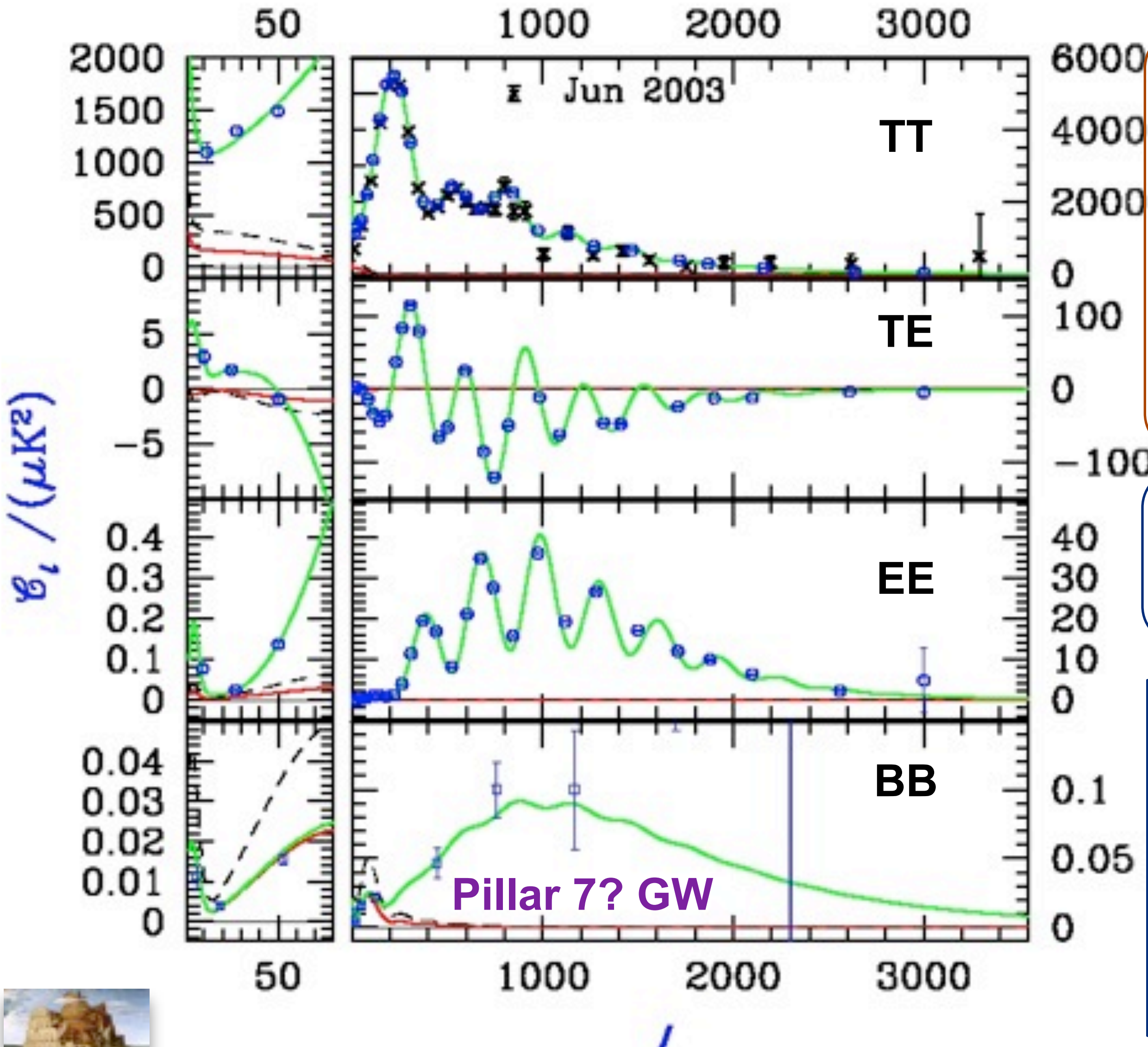


Pillar 7? Gravity Waves

An ensemble of trajectories arises in many-moduli string models, whether braney or holey. **Roulette inflation:** *complex hole sizes in 6D* TINY **$r<10^{-10}$** *& n_s from data-selected braking!*

(‘theorem’: $\Delta\psi< 1$ -> **$r<.007$**)

nearly uniform acceleration

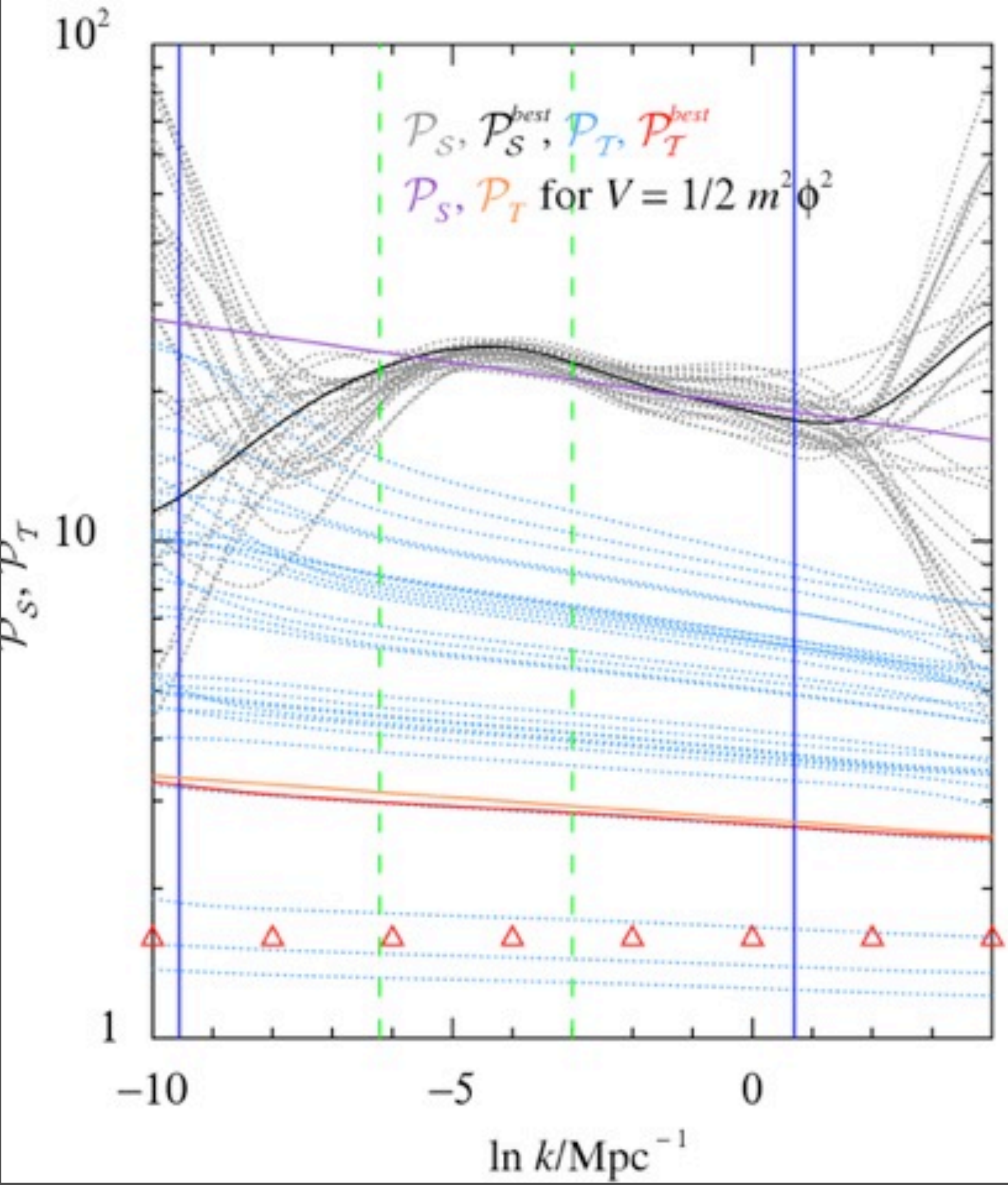
(power law, exp, PNGB, ..potentials)

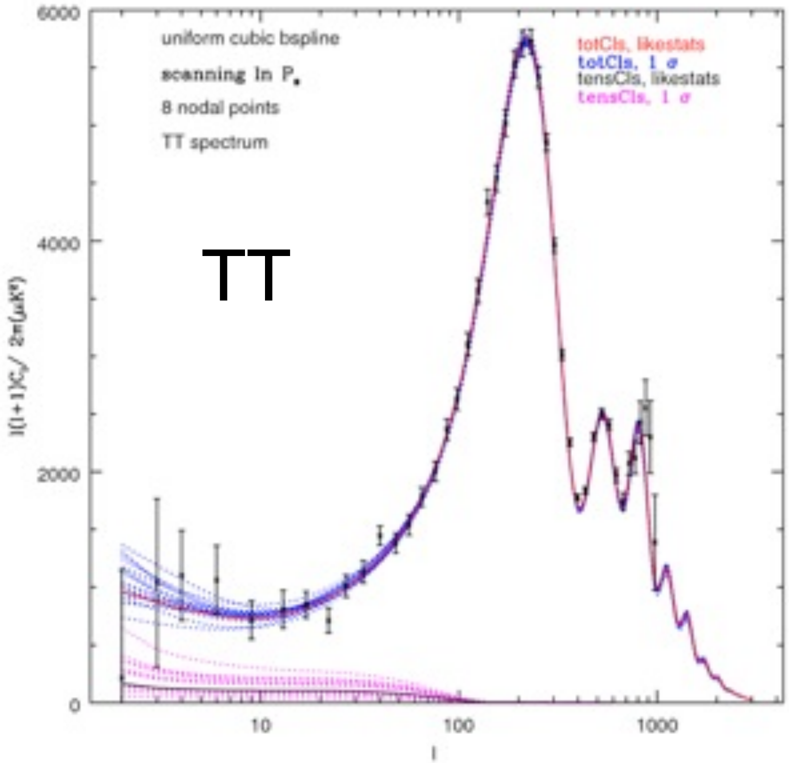
$r\sim.03$-$.3$! is $\Delta\psi\sim10$ deadly?

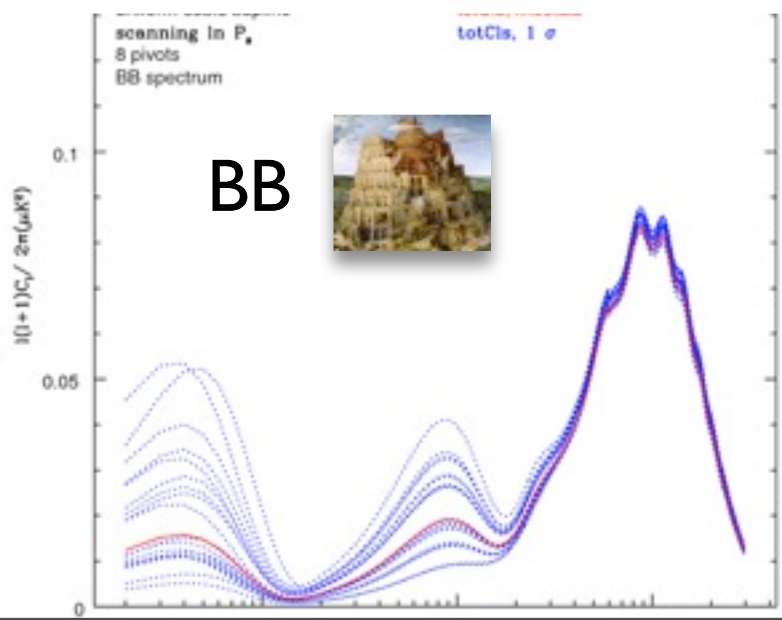
Even with low energy inflation, the prospects are good with ***Spider*** *plus* ***Planck*** *to either detect the GW-induced B-polarization or set a strong blind upper limit* ***$r<0.02$*** *indicating stringy or other exotic models. Both experiments have strong Cdn roles.* ***Bpol 2020?, to $r\sim0.002$***

+ Pillar 4: primordial non-Gaussianity **$-4< f_{NL}<80$ (+- 5-10 Planck1)**

partially-blind acceleration trajecteries obeying tensor/scalar consistency relation. May08 data







Nongaussianity from Preheating

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

Preheating After Roulette Inflation

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

DEFROST: $V = \frac{1}{2} m^2 \varphi^2 + \frac{1}{2} g^2 \varphi^2 \psi^2$: Density ρ

http://www.youtube.com/watch?v=3xySN-gcbxg&feature=related

DEFROST: $V = \frac{1}{2} m^2 \varphi^2 + \frac{1}{2} g^2 \varphi^2 \psi^2$: Potential Ψ

http://www.youtube.com/watch?v=YahXIBEkXPQ&NR=1

DEFROST: $V = \frac{1}{2} m^2 \varphi^2 + \frac{1}{2} \sigma \varphi \psi^2 + \frac{1}{4} \lambda \psi^4$: Composite ρ & Ψ

http://www.youtube.com/watch?v=rBizdnSaBoA&feature=related

Observables and conclusions

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

local quadratic non-G constraint: $-9 < f_{NL} < 111 \Rightarrow -4 < f_{NL} < 80$ WMAP5 ($\pm$ 5-10 Planck1yr)

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

resonant preheating form

modulated curvature fluctuations from preheating are superimposed on the usual curvature fluctuations from the inflaton

the peak values have $\delta \ln a \sim 10^{-5} \Rightarrow$ comparable to standard Gaussian

temperature fluctuations, but spiky $F_{NL} \Rightarrow$ non-Gaussian?

As long as $g^2/\lambda \leq O(1)$, the χ field has very long wavelength perturbations (similar to, but uncorrelated with, the inflaton field)

Large Scale Structure statistics of spiky F_{NL} mapping: under investigation

Rich possibilities in theory space & on the sky

e.g., $F_{NL}(\chi) \sim \sum_p F_p \exp(-(\chi_p - \chi)^2/2\gamma_p{}^2) \Rightarrow$ e.g., $\langle \square F_{NL}|\chi_{LF}\rangle \sim \beta_\chi\, \chi_{LF} + f_\chi\, \chi_{LF}{}^2$

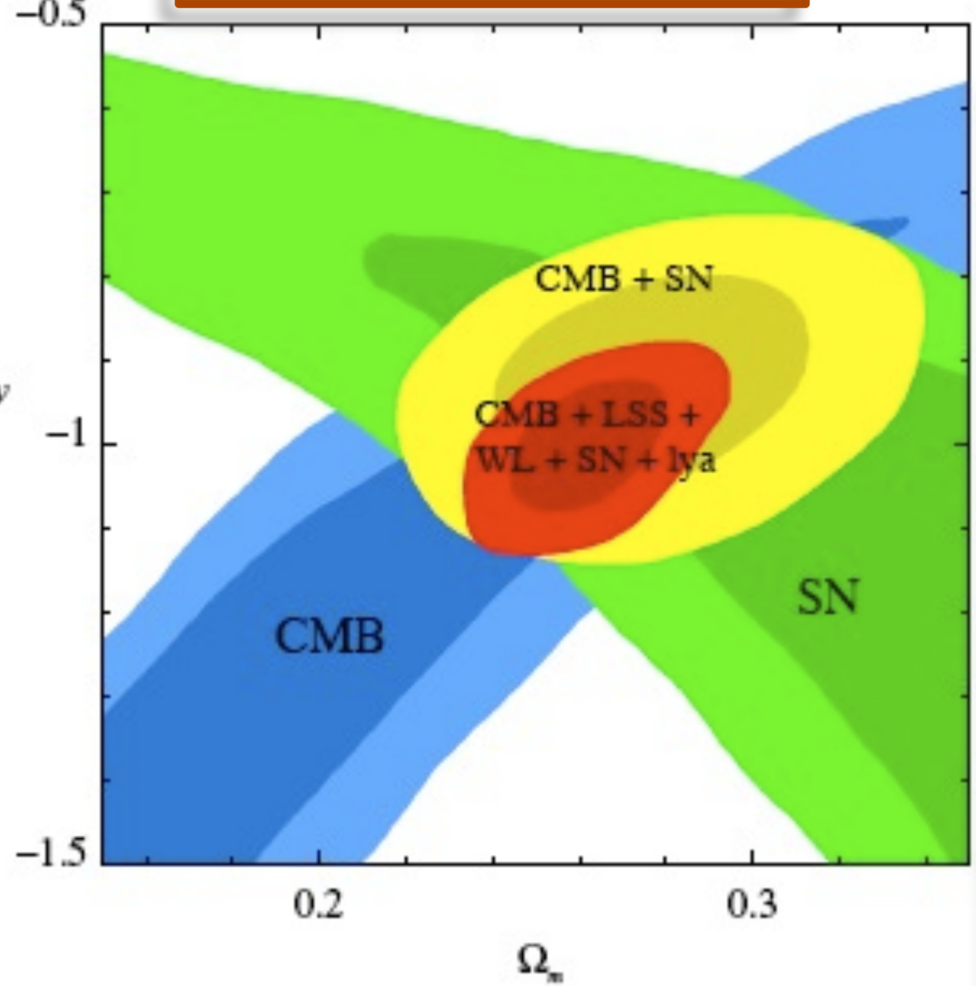
non-G & rare spot non-G

end

INFLATION NOW PROBES NOW

$$w(a) \equiv \frac{p(a)}{\rho(a)}$$

$1+\mathbf{w_0} = -0.0 +/- 0.06$



w(a)=w$_0$+w$_a$(1-a)

$1+\mathbf{w_0} = -0.01 +/- 0.19$

$\mathbf{w_a} = 0.0 +0.6-0.8$

piecewise parameterization

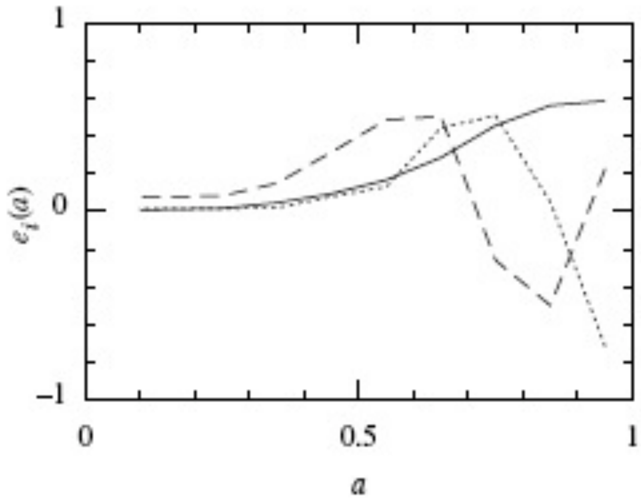
4,9,40 modes in redshift

9 & 40 into Parameter eigenmodes

data cannot determine >2 EOS parameters

DETF Albrecht etal06, Crittenden etal06, hbk08

σ_1**=0.13** σ_2**=0.33** σ_3**=0.58**



. $\varepsilon_{\phi 0}$ = 0.0 +/- 0.09 if constant, $\varepsilon_{\phi 0}$ = -0.015 +/- 0.3 if a-linear model

- **Cosmological Constant (w=-1)**
- **Quintessence**

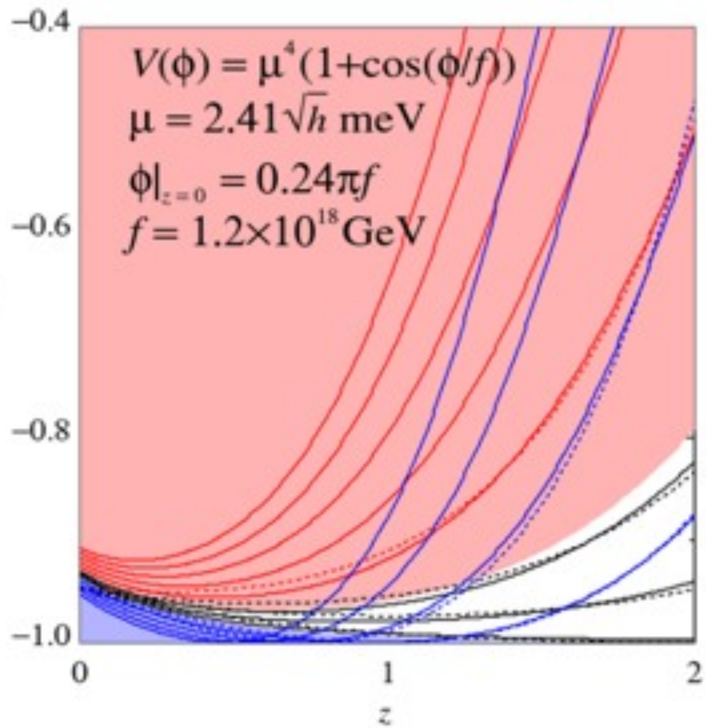
(-1≤w≤1)

- **Phantom field (w≤-1)**
- **Tachyon fields (-1 ≤ w ≤ 0)**
- **K-essence**

(no prior on w)

INFLATION NOW

PROBES NOW



trajectory probability: ~1 e-fold => blind is bad => slow-to-moderate roll ++

$-d\ln\phi/d\ln a\ /2$

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

$=\varepsilon_s f(a/a_{\Lambda eq};a_s/a_{\Lambda eq};\zeta_s)$

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

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

$\zeta_s = d\ln\varepsilon_s/d\ln a$ x1/2 @pivot a_{eq}

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 /Eucid

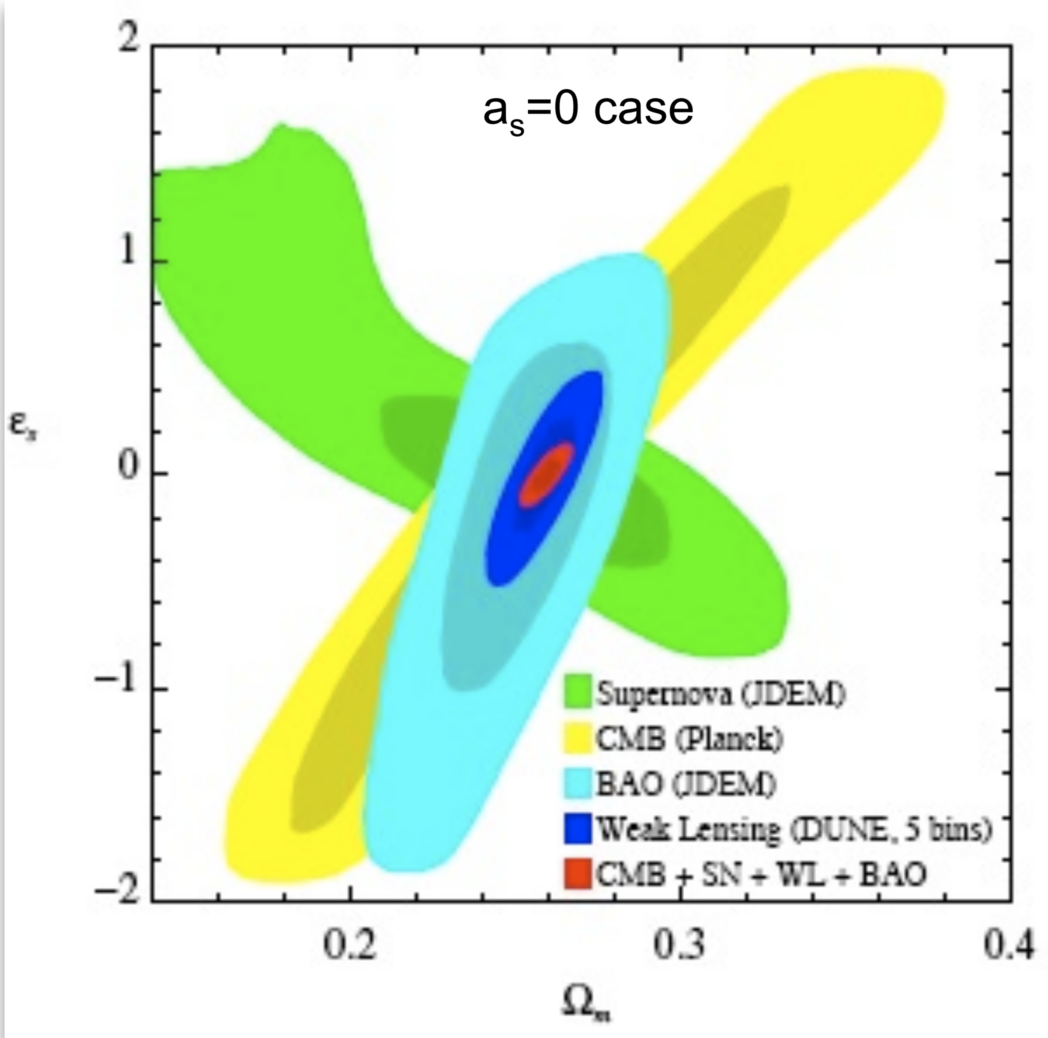
ESA (+NASA/CSA)

INFLATION NOW

PROBES THEN

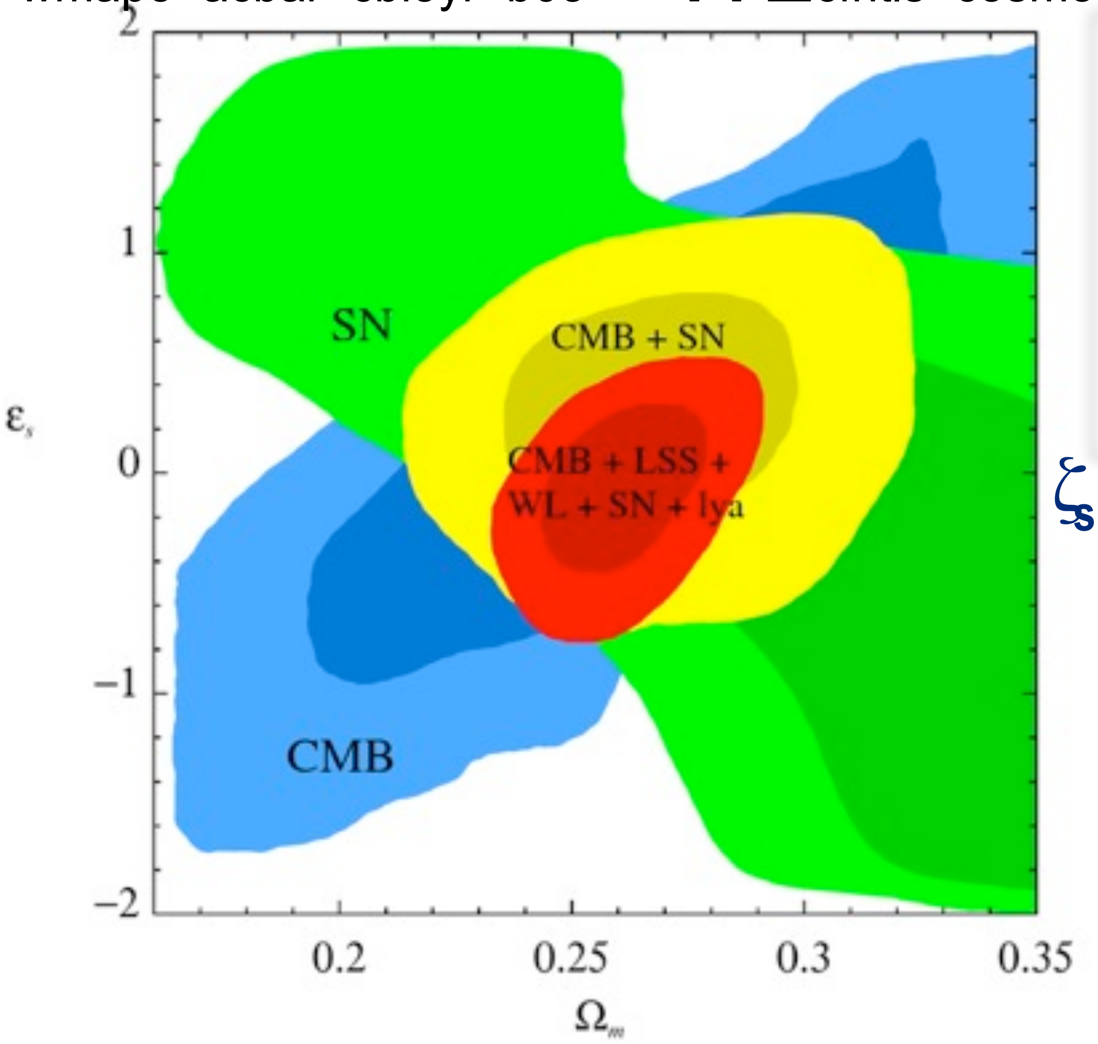
$\varepsilon_s = 0.00^{+0.07}_{-0.06}$

$\zeta_s \sim d\ln\varepsilon_s / d\ln a /2$ $\quad 0.1^{+0.6}_{-0.7}$



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

measuring ε_s ζ_s a_s=0 tracking (SNe$_{union}$+CMB$_{wmap5+acbar+cbi5yr+b03}$+WL$_{cfhtls+cosmos}$+LSS$_{sdssRG+2dF}$+Lya)



ε_s= (dlnV/dψ)^2/4 @pivot a_{eq}

ε_s .01 + .25 -.28 1

-.03 + .21 -.25 3

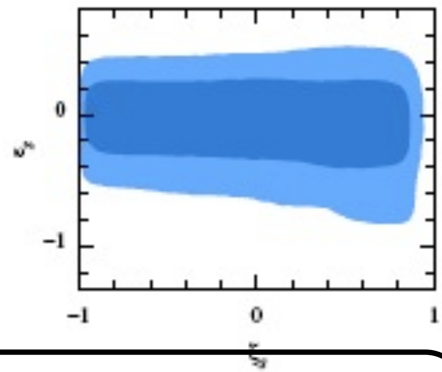
-.03 + .26 -.30 2

ζ_s= +-1.001d^{2}lnV/dψ^2 /4 @pivot a_{eq}

ζ_s =dlnε_s /dlna x1/2 @pivot a_{eq}

ill-determined now

$0.1^{+0.6}_{-0.7}$



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

CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut canadien d'astrophysique theorique – Dick Bond CIAR 25 years cifar

Constraining Trajectories of Dark Energy Inflatons

Inflation Now $\varepsilon_\phi(a) = \varepsilon_s f(a/a_{\Lambda eq}; a_s/a_{\Lambda eq}; \zeta_s)$

$\varepsilon_\phi = -d\ln\square_\phi/d\ln a\ /2$ ~0 now, to $\varepsilon = -d\ln\square_{tot}/d\ln a\ /2$ ~0 to 2, 3/2, ~.4

cf. w(a): w0,wa; w in z-bands or z-modes; $\varepsilon(a)$: in modes, jerk

~1 good e-fold. only ~2 params. priors matter

Inflation Then $\varepsilon(k) = (1+q)(a)$ **= mode expansion in resolution (lnHa ~ lnk)**

~r/16 (Tensor/Scalar Power & gravity waves) ~ 10 good e-folds CMB+LSS

Cosmic Probes Now CMB(Apr08), CFHTLS SN(Union 307),WL, LSS/BAO, Lyα

Cosmic Probes Then JDEM-SN + DUNE-WL + Planck1

Zhiqi Huang, Bond & Kofman 09 $\varepsilon_s = -0.03 \pm 0.28$ now, inflaton (potential gradient)^2

to +-0.07 then Planck1+JDEM SN+DUNE WL, weak a_s < 0.36 now <0.21 then

3-parameter formula

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

+ Friedmann Eqn+DM+B

$$\theta \equiv \begin{cases} \sin^{-1} \frac{\dot{\phi}}{\sqrt{2\rho_\phi}} \\ \sinh^{-1} \frac{\dot{\phi}}{\sqrt{2\rho_\phi}} \end{cases}$$

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

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

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

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

accurate fits to slow-to-moderate roll & even wild rising baroque late-inflaton trajectories + thawing & freezing trajectories. *non-oscillating*

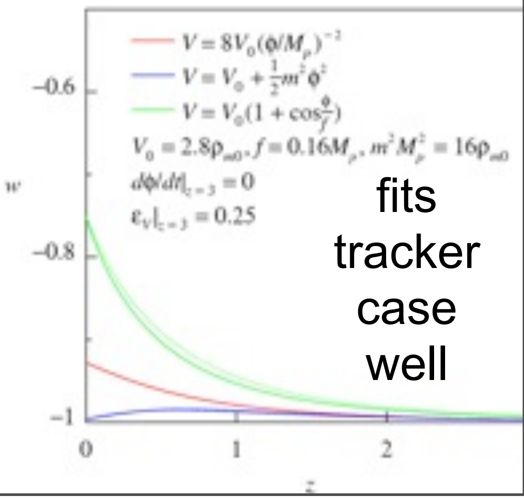
where

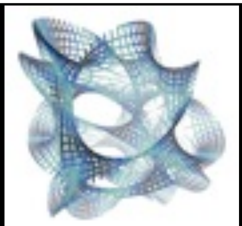
$$a_{eq} \equiv (\frac{\Omega_{m0}}{1-\Omega_{m0}})^{\frac{1}{3[1-0.36\varepsilon_s(1-\Omega_{m0})]}}$$

$$a_s \geq 0$$

$$\sqrt{|\epsilon_V|} = \sqrt{|\epsilon_s|}[1+\zeta_s((\frac{a}{a_{eq}})^{\frac{3}{2}} - 1)] \quad -1 < \zeta_s < 1$$

- ~15% thawing, 8% freezing, with flat priors





"To me every hour of the light and dark is a miracle. Every cubic inch of space is a miracle."
– Walt Whitman

In every cubic centimetre

- **cosmic radiation 412 cm^{-3}**
- **dark matter ~amu m^{-3} ~ compressed in MW to ~0.1 amu cm^{-3} for LHC-type DM, ~ 1 every 10 cm**
- **dark energy ~4 keV cm^{-3} ~(milli-eV)^4**
- **neutrinos ~ CMB photons**
- **gravity waves**
- **virtual particles - vacuum fluctuations**
- **vacuum potentials - Higgs origin of mass**
- **extra dimensions here, now?**

detect Ω_{dm} in lab; annihilation in space; early U Ω_{GW} via CMB

ρ_{Λ} **(time,space) vacuum E**

Then (10^{-37}s) inflation

Now (13.7×10^{9} yr)

=dark energy mysteries

in a **landscape** of

different vacuua

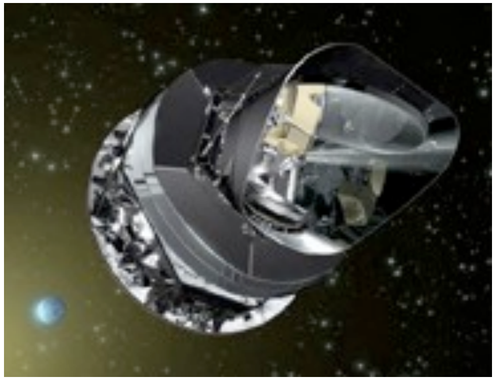
our CIfAR future: to the early & late Universe thru

Theory+Experiment (CMB+Lens+SN+clusters

+ LIGO,LISA,BBO for gravity waves +

SNOlab,CERN,..,Planck,Fermi,.. for dark matter)

detect $\Omega_{\mathbf{dm}}$ in lab; annihilation in space; early U $\Omega_{\mathbf{GW}}$ via CMB



ρ_Λ **(time,space)** **vacuum E**

Then (10^{-37}s) inflation

Now (13.7 x 10^9 yr)

=dark energy mysteries

in a **landscape** of

different vacuua

our CIfAR future: to the early & late Universe thru

Theory+Experiment (CMB+Lens+SN+clusters

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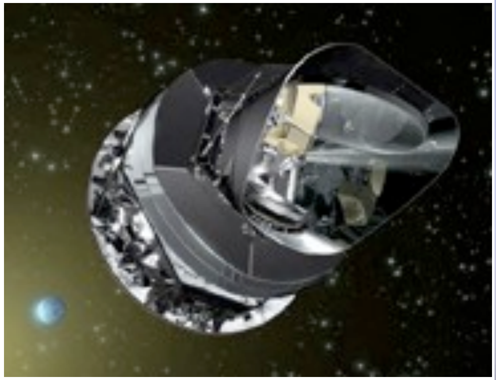
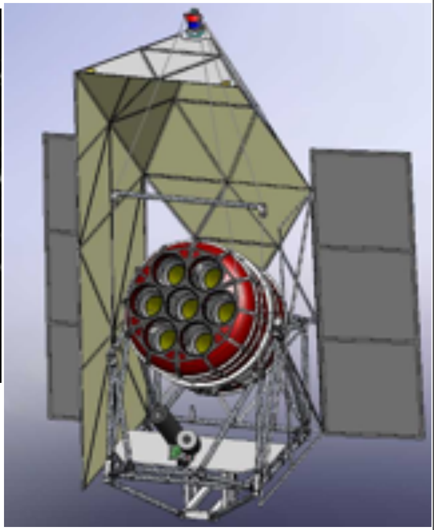
detect Ω_{dm} in lab; annihilation in space; early U Ω_{GW} via CMB





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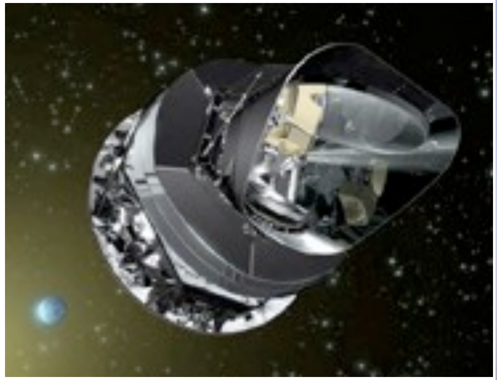

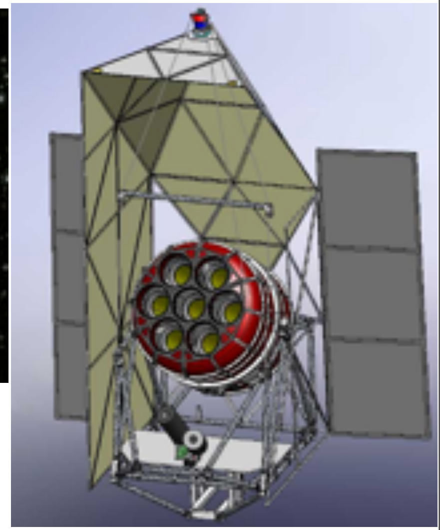

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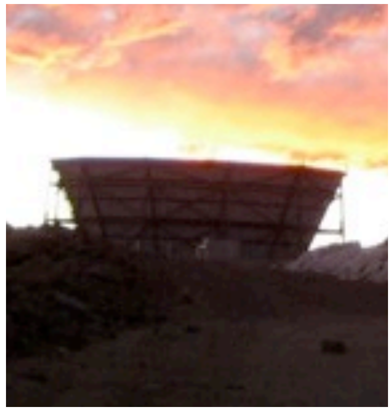

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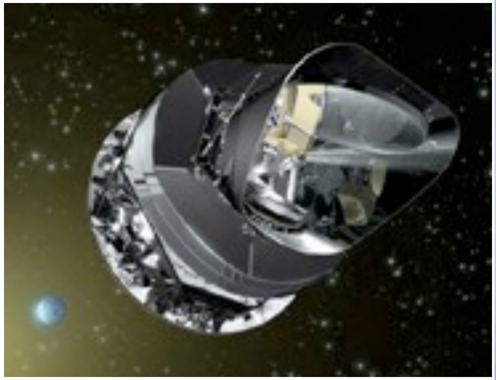

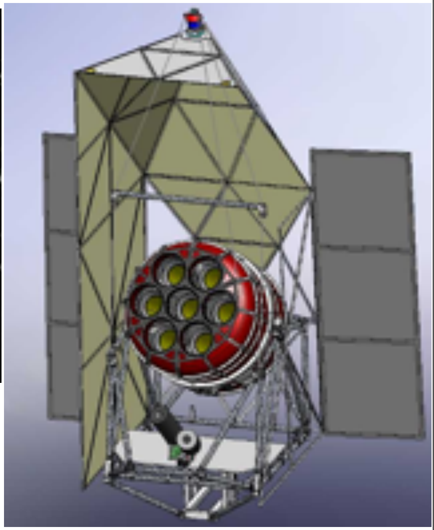

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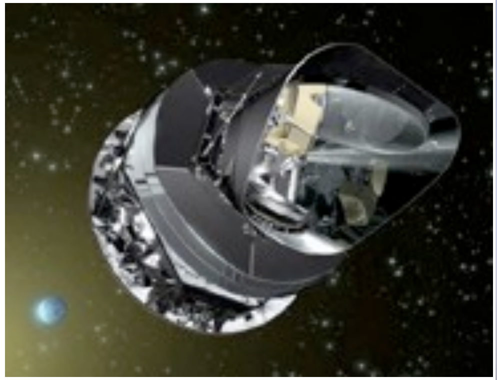

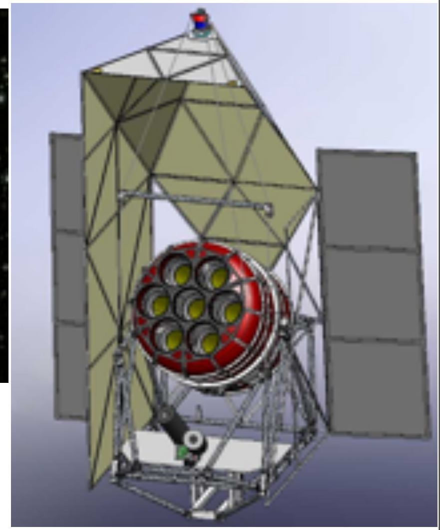

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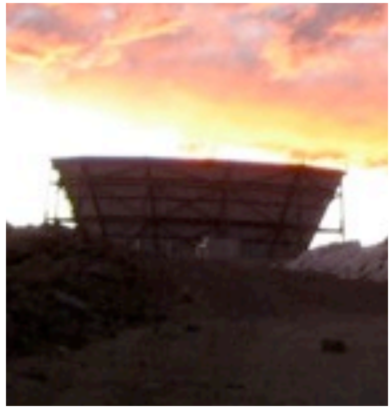

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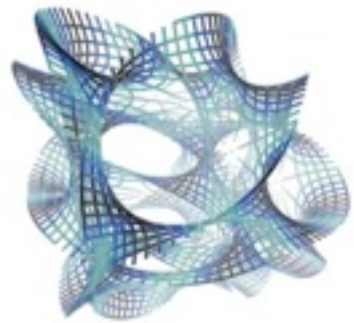


CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut canadien d'astrophysique theorique

CIAR 25 years cifar

Planck satellite, CMB all-sky, 9 frequencies, & polarization: *B+ Nolta (SrRA), Netterfield (Prof), Marzieh Farhang (GS), Miville-Deschenes (SrRA), Peter Martin, Francine Marleau (CLTA) + Contaldi, MacTavish, Crill (ex-CITAzens)*

Early Universe non-Gaussianity: *B+ Zhiqi Huang (GS), Kofman (Prof), Frolov ex-CITAzen*

probing CMB non-Gaussianity: *B+ Zhiqi Huang (GS), Kofman (Prof), Nolta, Frolov*

Cosmic Background Imager, CMB@ hi res: *B+ Sievers (SrRA)*

Acbar, CMB @ hi res: *B+ Contaldi - completed*

Atacama Cosmology Telescope, CMB@very hi res: *B+ Nolta, Sievers, Hajian (PDF)*

Clusters & Cosmic Web Gasdynamical Simulations, & the Intracluster Radio Web: *B+ Nick Battaglia (GS), Pfrommer (SrRA), Sievers*

Spider, a balloon-borne CMB expt targetting primordial gravity waves and the universe's ionization history: *B+ Netterfield, Farhang (GS) + Contaldi, MacTavish*

Boomerang (first high precision CMB expt): *B+ Netterfield, Contaldi, MacTavish still papers*

GW and Inflation Trajectories: *B+ Zhiqi Huang (GS), Kofman (Prof), Vaudrevange (ex-GS), Contaldi*

Preheating in Stringy Roulette Inflation: *B+ Zhiqi Huang (GS), Neil Barnaby (PDF), Kofman*

Late-time Inflation Trajectories and Dark Energy: *B+ Zhiqi Huang (GS), Kofman*

Chime, Baryon Acoustic Oscillations & Dark Energy: *B+ Gojko Vujanovic (GS), Ue-Li Pen (Prof), ...*

CMB Polarization, Past, Present & Future

Dick Bond   Canadian Institute for Theoretical Astrophysics, University of Toronto

theory of CMB polarization

E/B modes

detection history

future CMB polarization experiments

reionization ‘trajectories’

inflation & forecasts of the gravity wave level: is the energy scale of inflation high (80s/90s) or low (00s)?

the quest for gravity wave induced B-modes

Standard Parameters of Cosmic Structure Formation

$\theta \sim \ell_s^{-1}$ $\sim \ln \sigma_8^2$

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

1+w0, wa $dn_s/d\ln k$ n_t

New Parameters of Cosmic Structure Formation: early-inflaton & late-inflaton trajectories

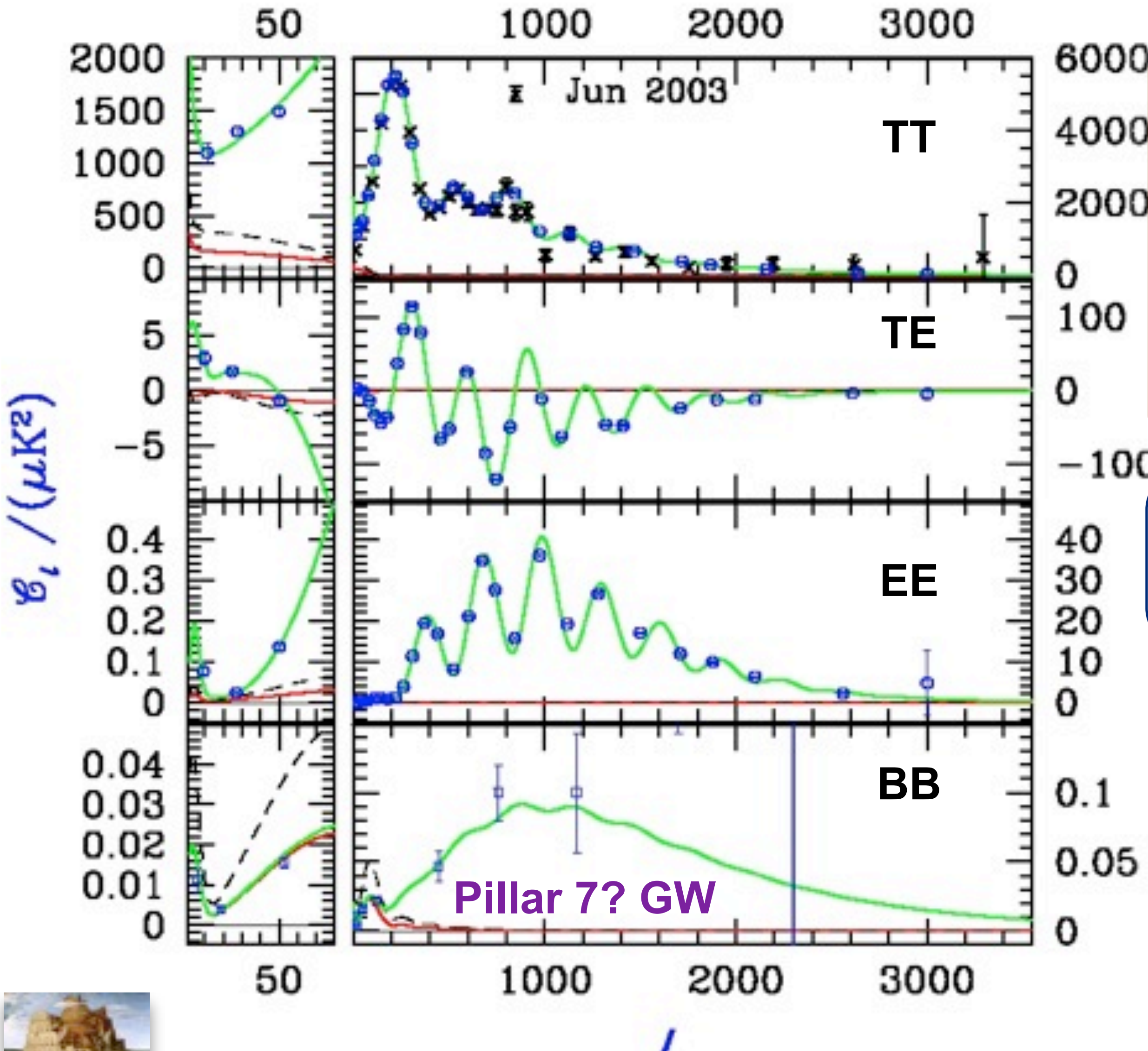
$\Box_\phi = (1+w(a)) \times 3/2$ $\epsilon(k), \quad k \approx Ha$ $\ln H(k_p)$

$\varepsilon_s f(a/a_{\Lambda eq}; a_s/a_{\Lambda eq}; \zeta_s)$ $\ln P_s(k)$ $\ln P_t(k)$

+ subdominant isocurvature/cosmic string/ tSZ ...

PRIMARY END @ 2012?

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



Pillar 7? Gravity Waves

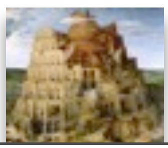
An ensemble of trajectories arises in many-moduli string models, whether braney or holey. **Roulette inflation:** *complex hole sizes in 6D* TINY **$r<10^{-10}$** *& n_s from data-selected braking!*

('theorem': $\Delta\psi < 1$ -> **$r<.007$**)

nearly uniform acceleration (power law, exp, PNGB, ..potentials)

$r\sim.03$-$.3$! is $\Delta\psi\sim10$ deadly?

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

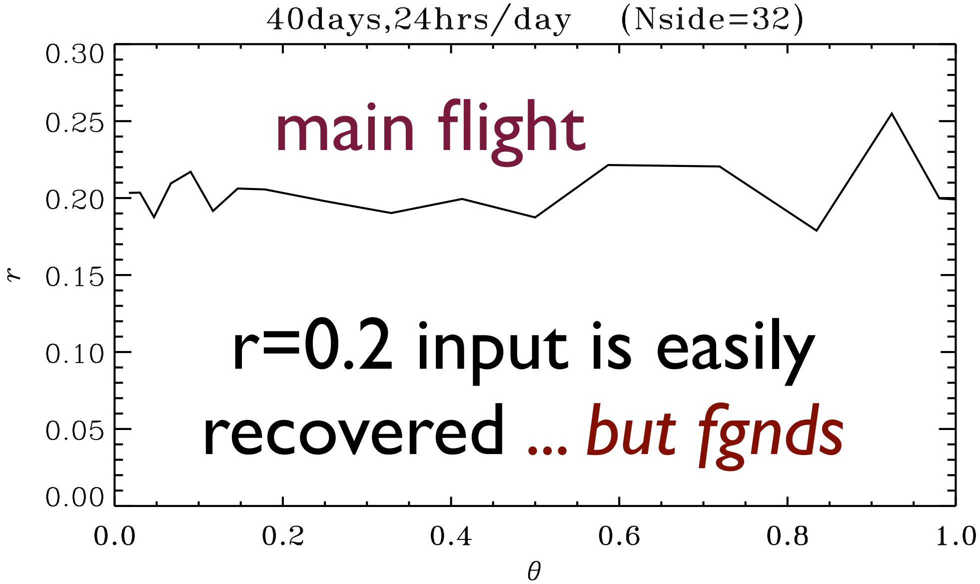


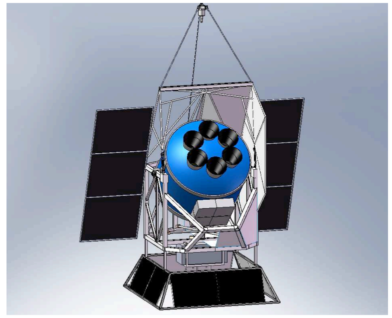
+ Pillar 4: primordial non-Gaussianity **$-9 < f_{NL} < 111$ (+- 5-10 Planck1)**

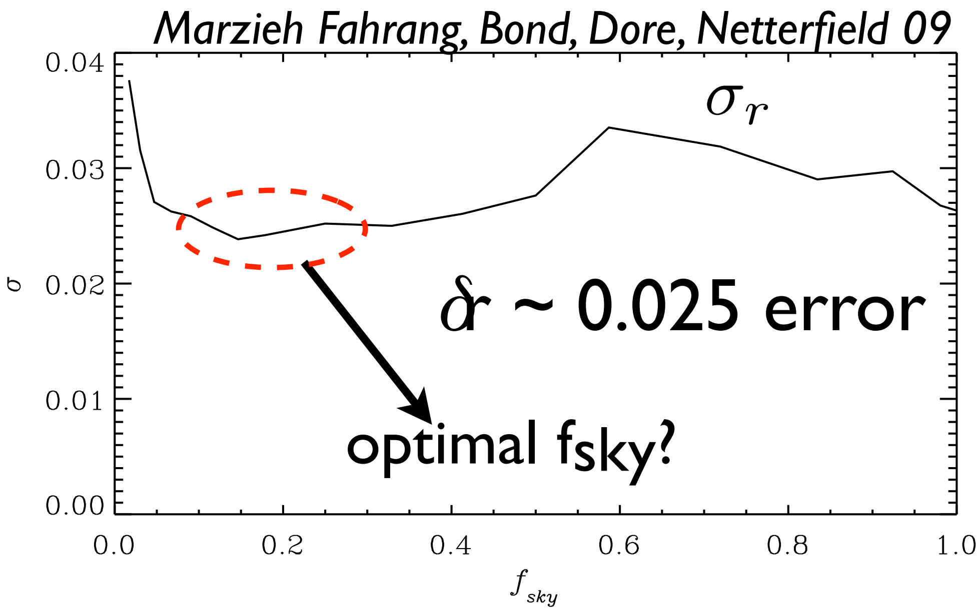
Spider/Keck: best f_{sky} for E/B-demixing via direct max-L filters for **r** τ

- test LDB flight: 2-6 days, 10.3 Alice Springs
- **main LDB flight: 20-40 days, 11.9 Antarctica**

N_t~2.5 Tbytes, N_p~10 Mb







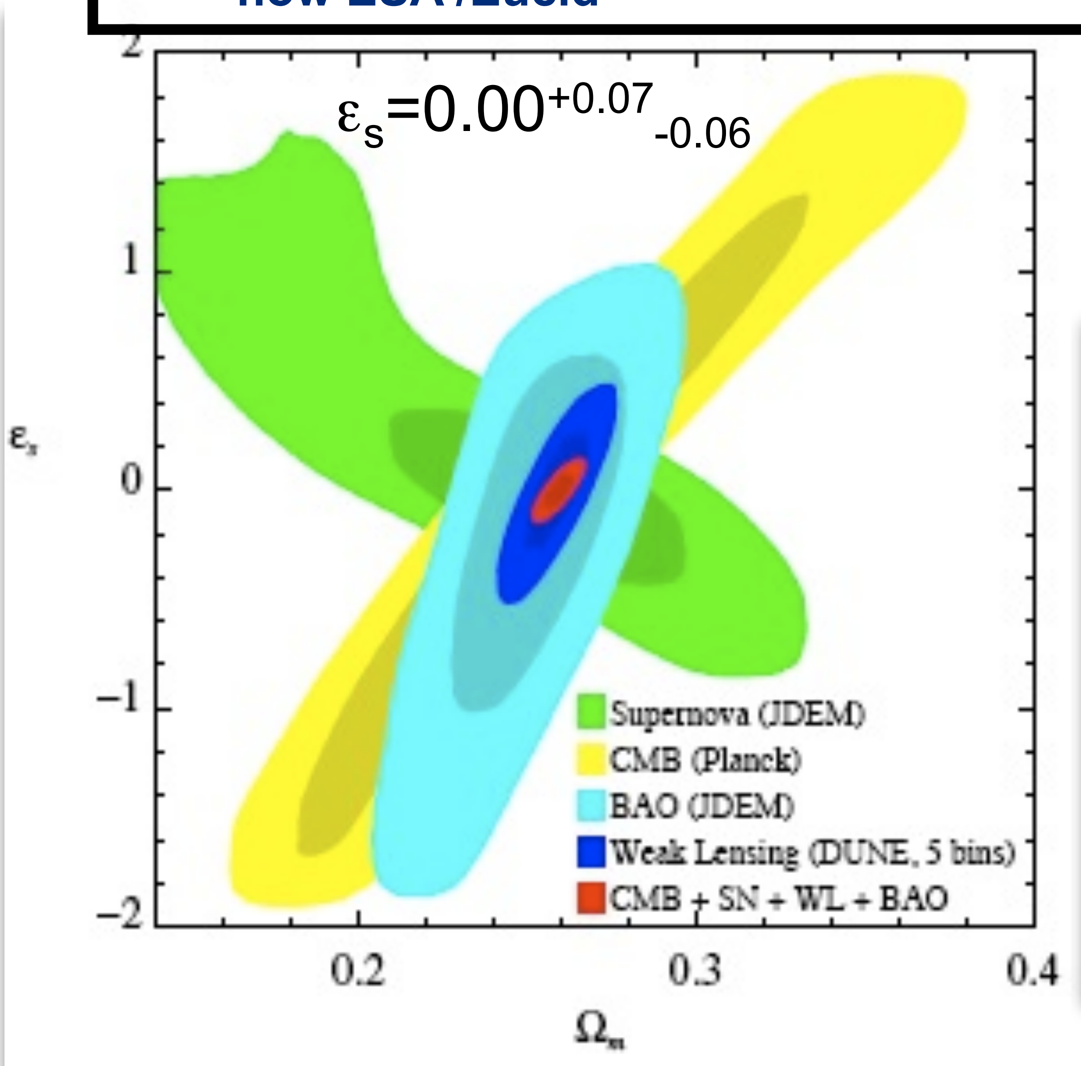
Beyond Einstein panel: LISA+JDEM

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 /Eucid

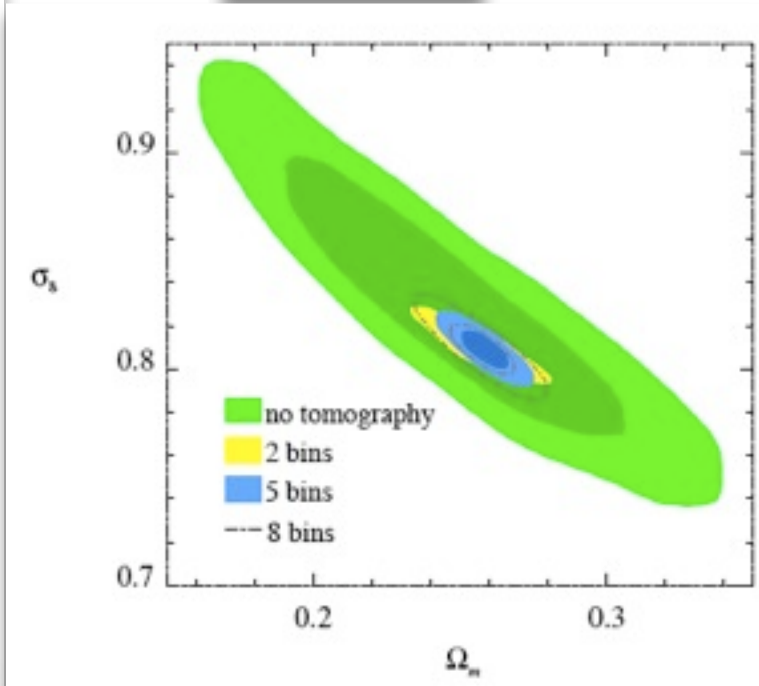
ESA (+NASA/CSA)



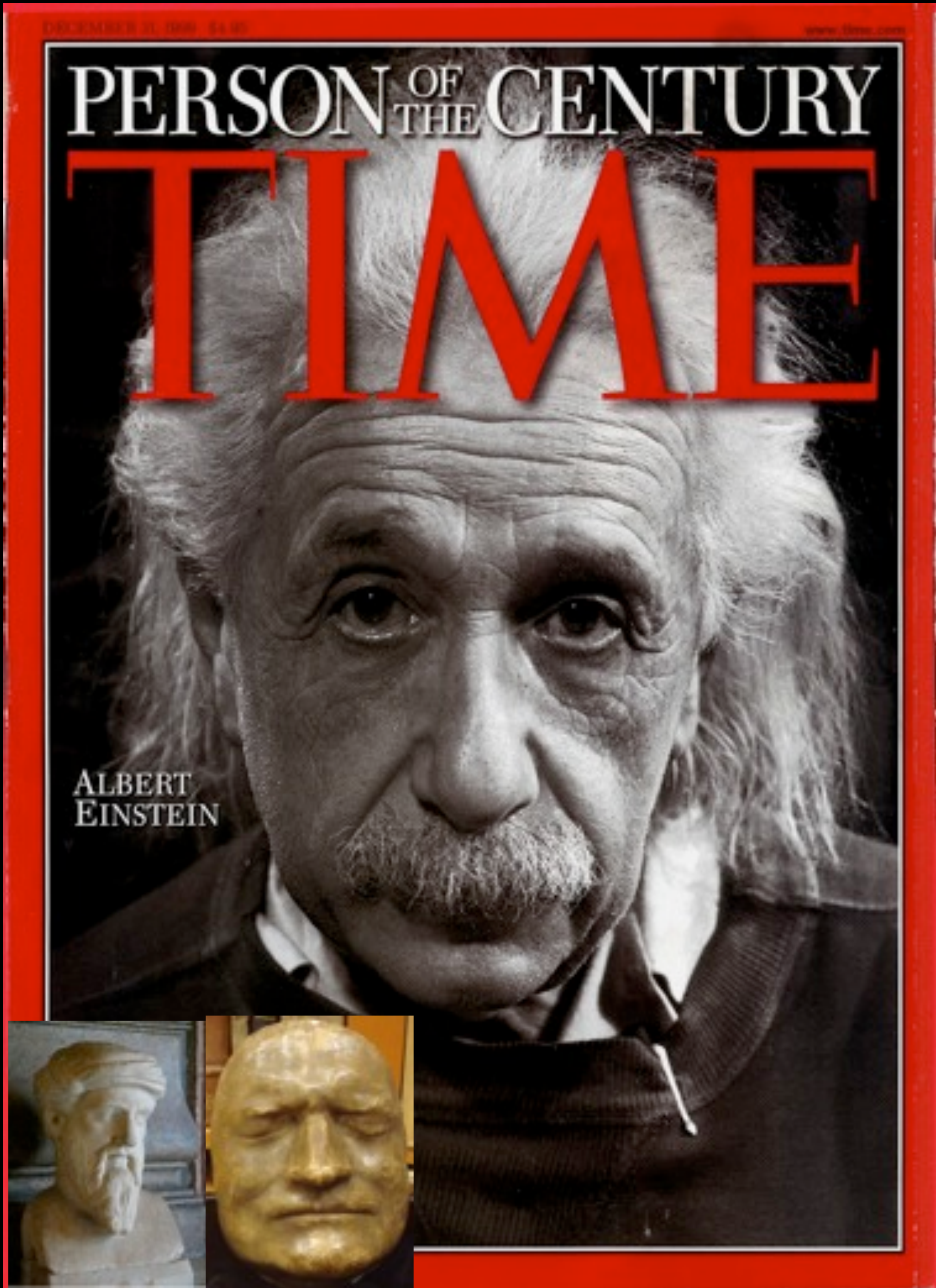
a_s=0 case

ζ_s ~dlnε_s /dlna /2 ill-determined

$0.1^{+0.6}_{-0.7}$



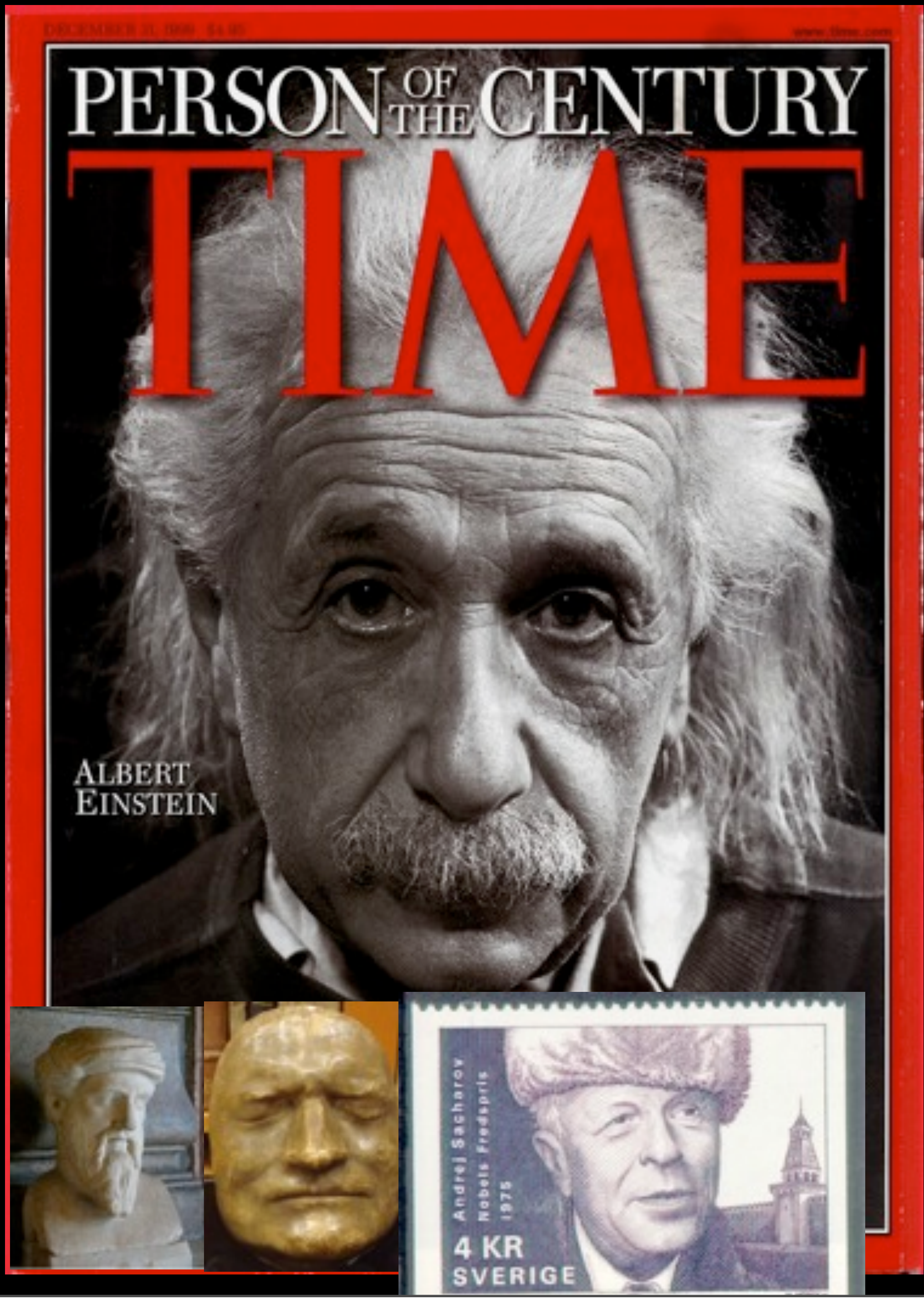
cannot reconstruct the quintessence potential, just the slope ε_s & ~hubble drag



"The most beautiful thing we can experience is the mysterious. It is the source of all true art and all science. Those to whom this emotion is a stranger, who can no longer pause to wonder and stand rapt in awe, are as good as dead: their eyes are closed."

Albert Einstein

Beyond Einstein in the Final Frontier



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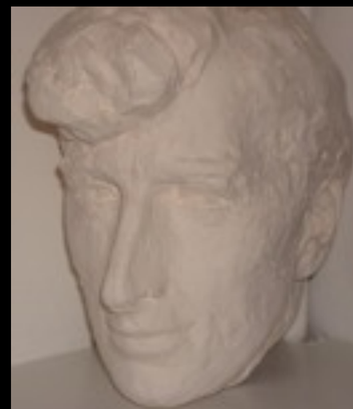

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