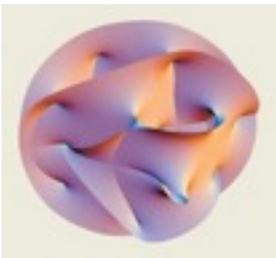
Paths in the Early and Late Universe with Lev Kofman



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

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

6/7 tiny extra dimensions

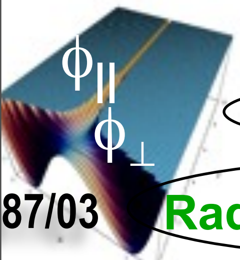
1980

R^2-inflation

Old Inflation

Chaotic inflation

New Inflation



Double Inflation

Power-law inflation

SUGRA inflation

87/03

Radical BSI inflation

running (nee variable M_P) inflation

Extended inflation

1990

Natural pNGB inflation

Hybrid inflation

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

Roulette inflation Kahler moduli/axion

fibre inflation

INFLATION THEN

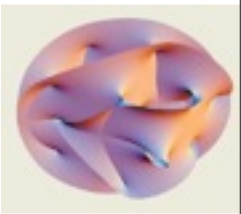
"standard inflation space": n_s $dn_s/d\ln k$ r @k-pivots

WHAT IS PREDICTED?

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

large field inflation (field moves > Planck mass)

or highly variable braking r tiny



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

small field inflation (field moves < Planck mass)

Bond, Kofman, Prokushkin,Vaudrevange 2007, Roulette Inflation with Kahler Moduli and their Axions

Neil Barnaby, Bond, Zhiqi Huang, Kofman, hep-th/0909.0503, Preheating after Modular Inflation

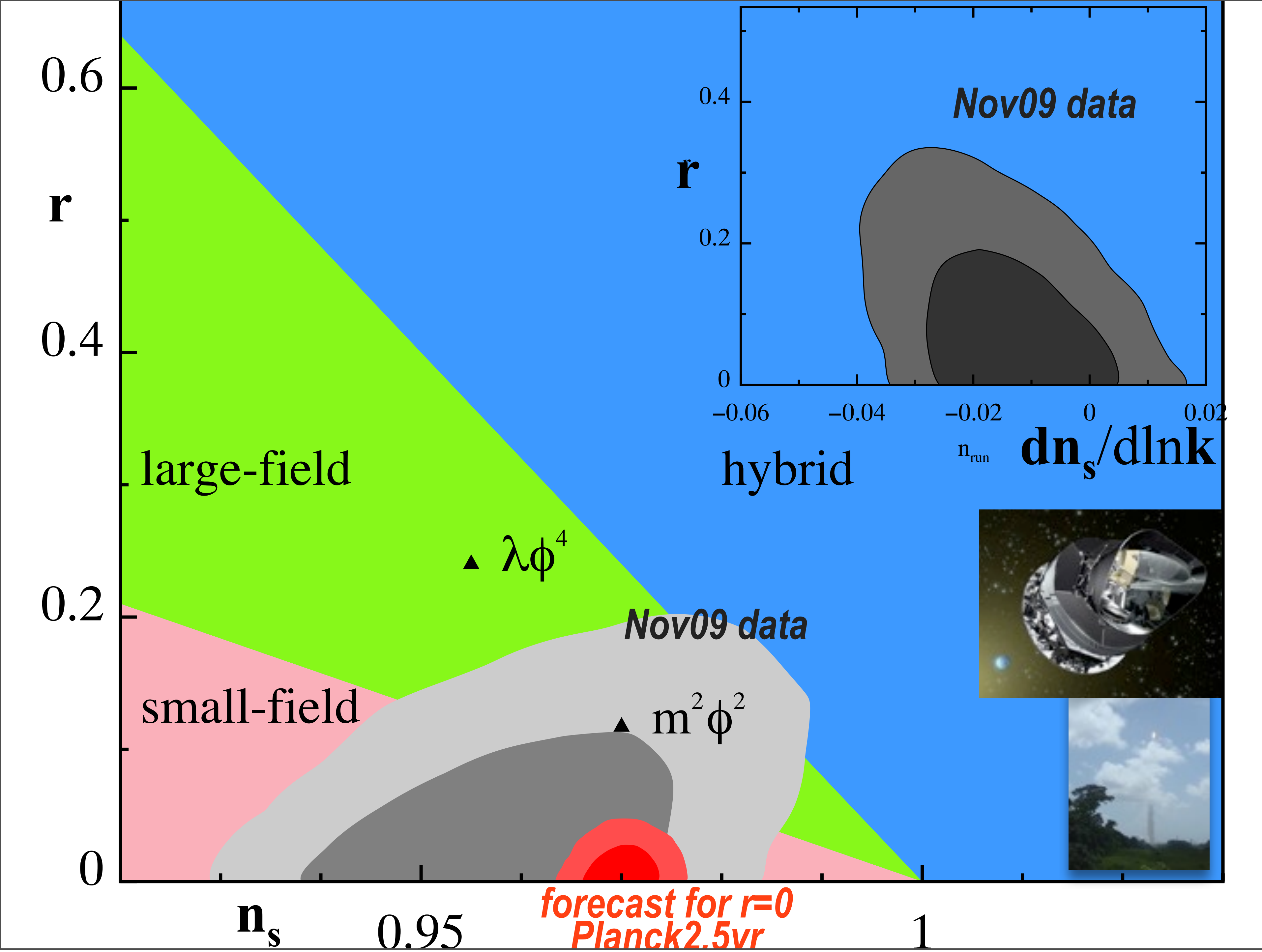
monodromy & fibre inflation give larger r

current constraints on r (95%CL) - prior sensitive

r < 0.16 (no running, all data sets)

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

r < 0.27 (with running, all data sets)


0.6
r
0.4
0.2
0
large-field
small-field
hybrid
λφ⁴
m²φ²
Nov09 data
n_s
0.95
1
forecast for r=0
Planck2.5yr
r
0.4
0.2
0
−0.06
−0.04
−0.02
0
0.02
n_run
dn_s/dlnk
Nov09 data

Standard Parameters of Cosmic Structure Formation

$\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ Ω_k τ_c

$\ln A_s$ n_s $r = A_t / A_s$ $dn_s / d\ln k$ n_t

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

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

(partially) blind cf. informed "theory" priors

primordial non-Gaussianity

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

local smooth

DBI inflation: non-quadratic kinetic energy

cosmic/fundamental strings/defects

from end-of-inflation & preheating

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

resonant preheating

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

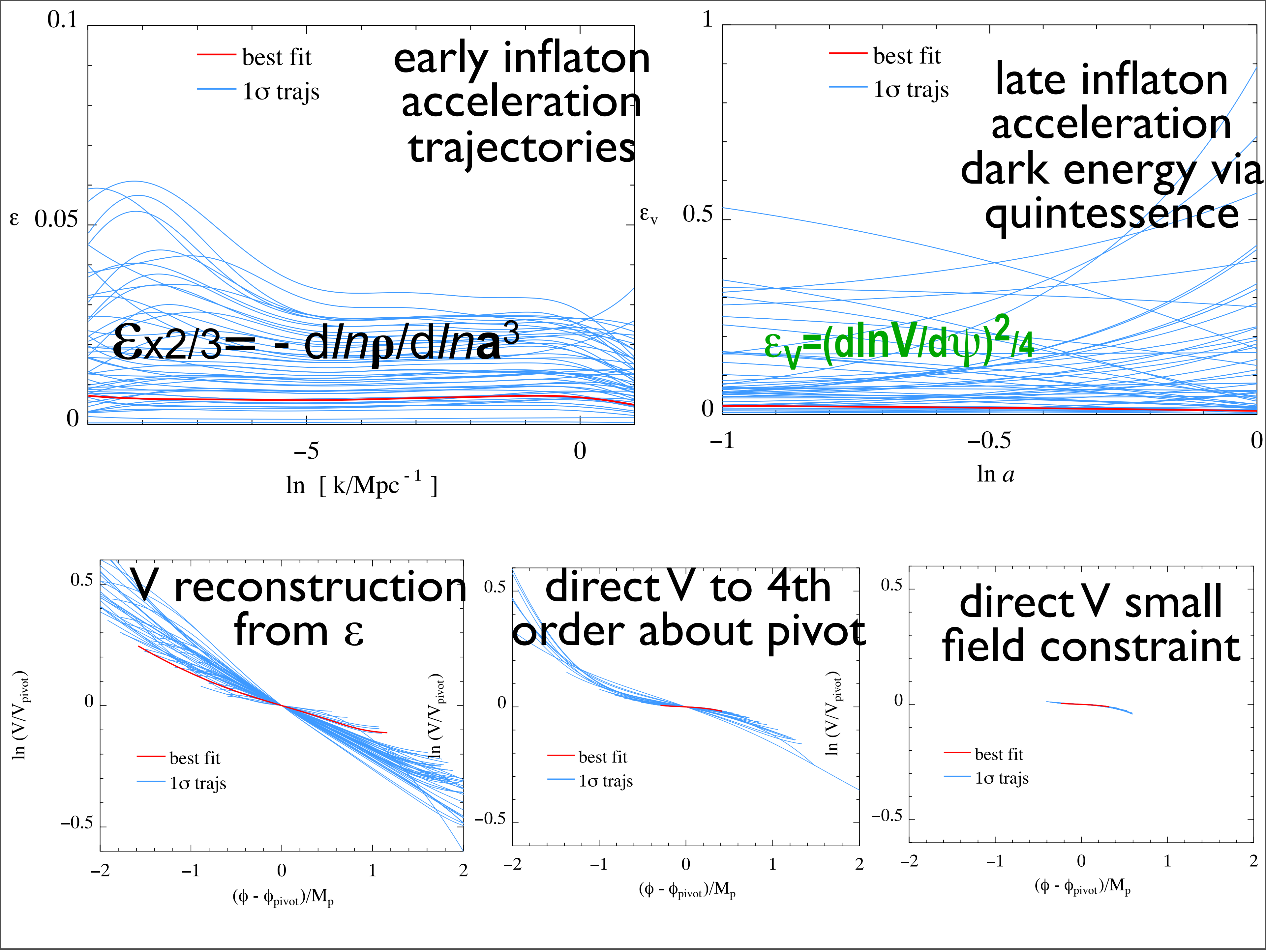
& $\ln P_t(\ln k)$

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

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

+ subdominant isocurvature, cosmic string,

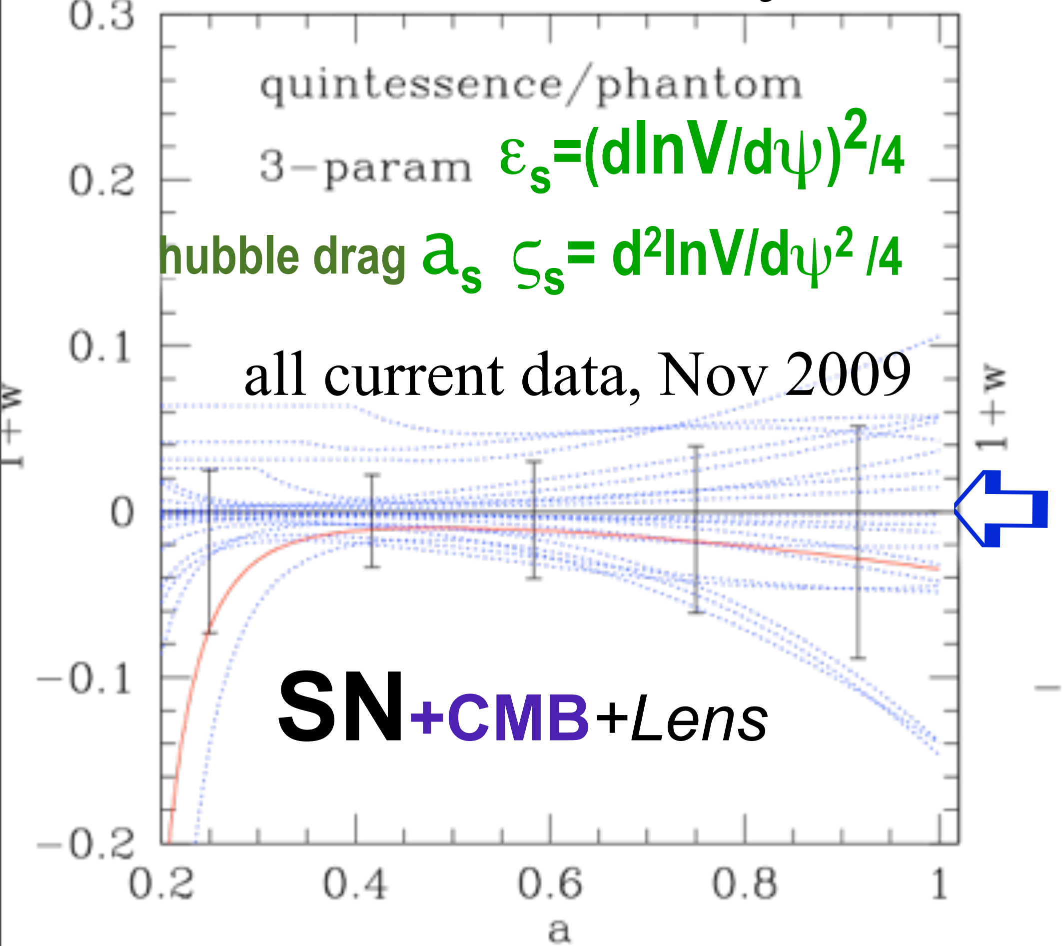
& fgnds, tSZ, kSZ, ...



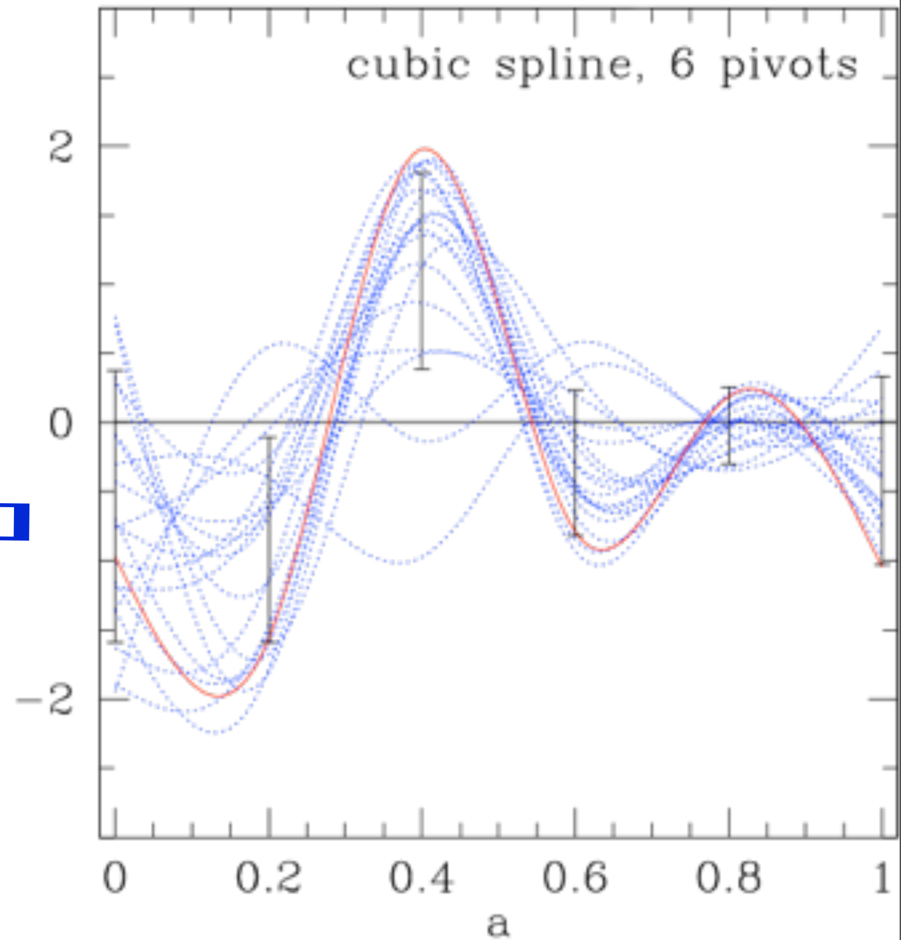
Monday, February 22, 2010

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

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



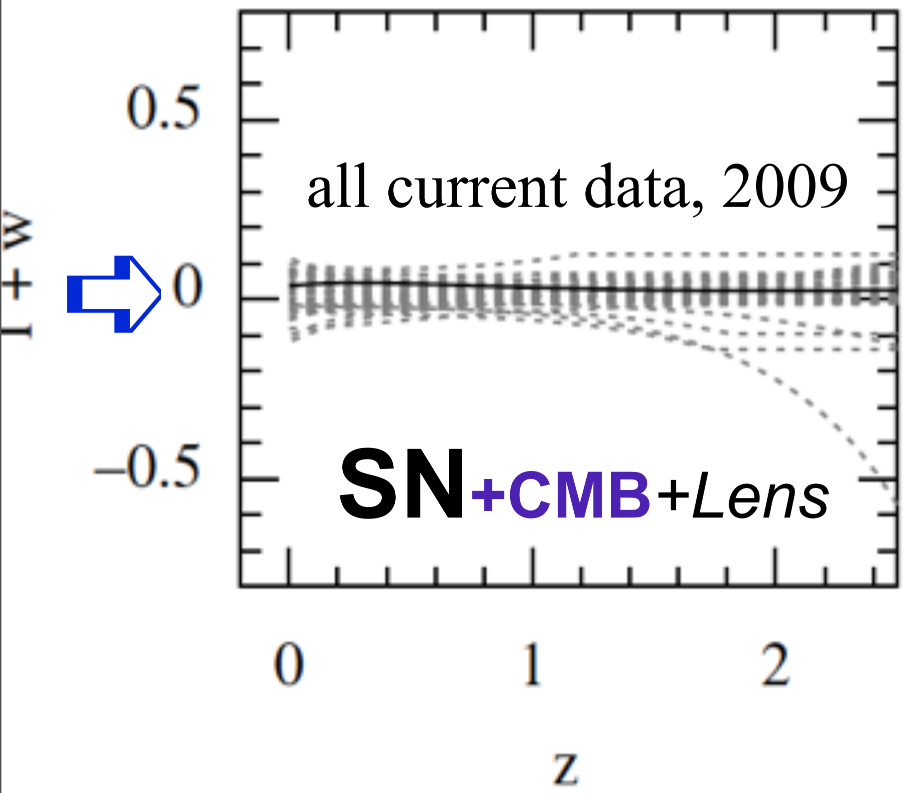
semi-blind mode expansion

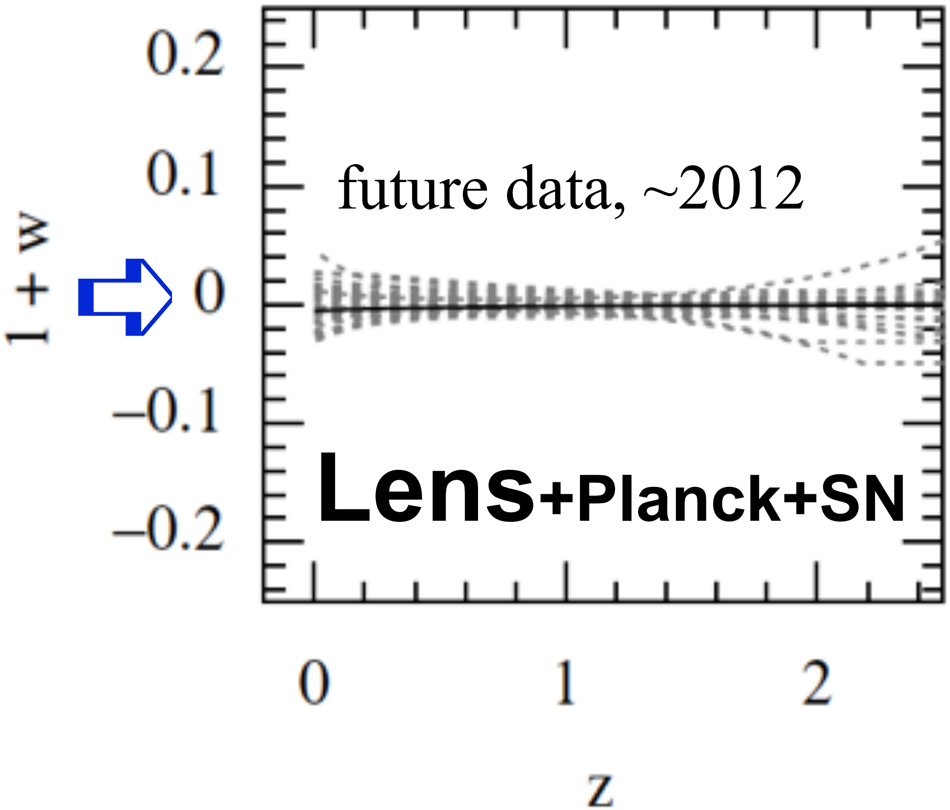


TEST: within errors, energy-density does not change with expansion ⇨Einstein's cosmological constant is best fit so far

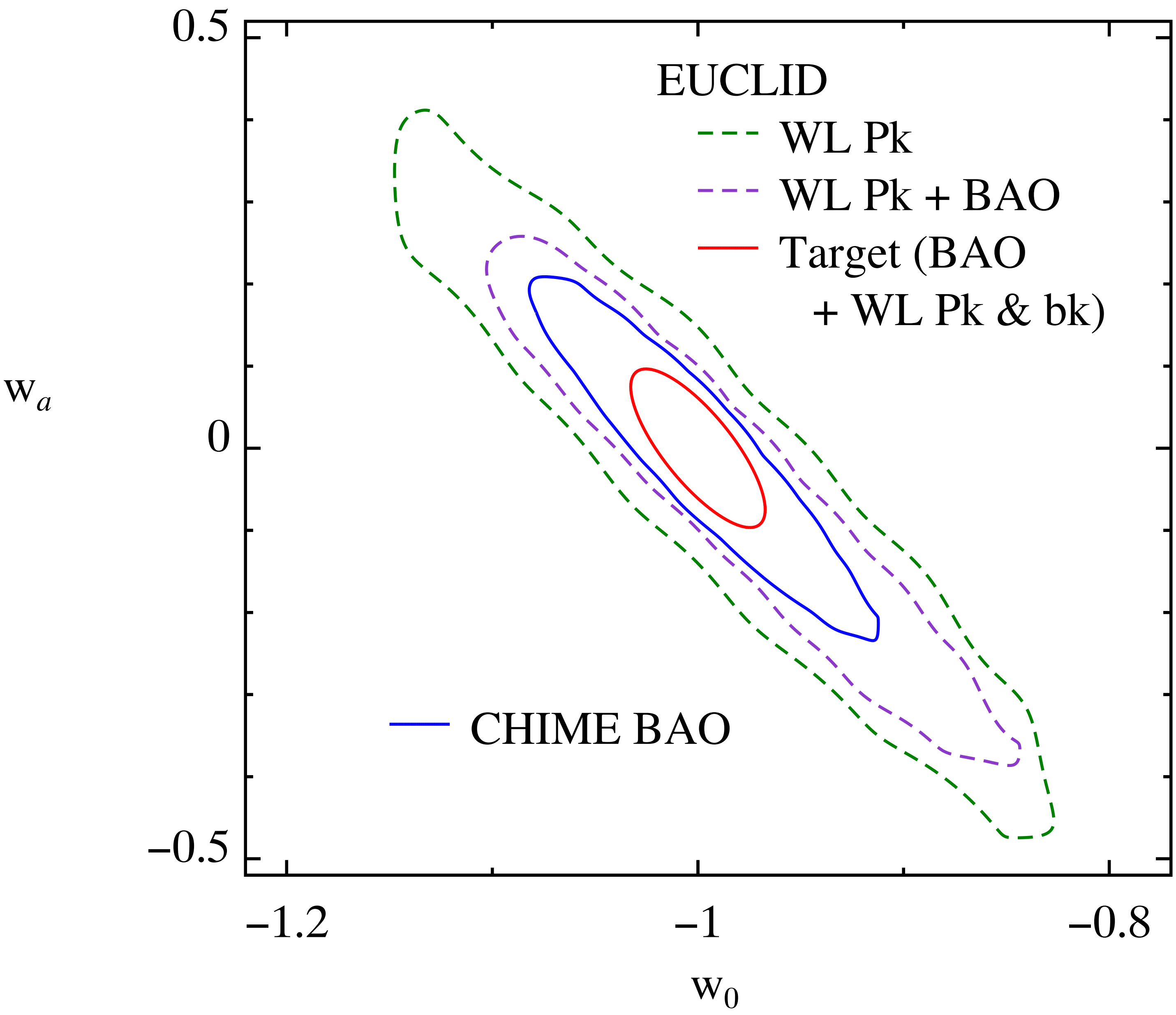
cannot reconstruct the quintessence potential, just the slope ε_s & ~hubble drag

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

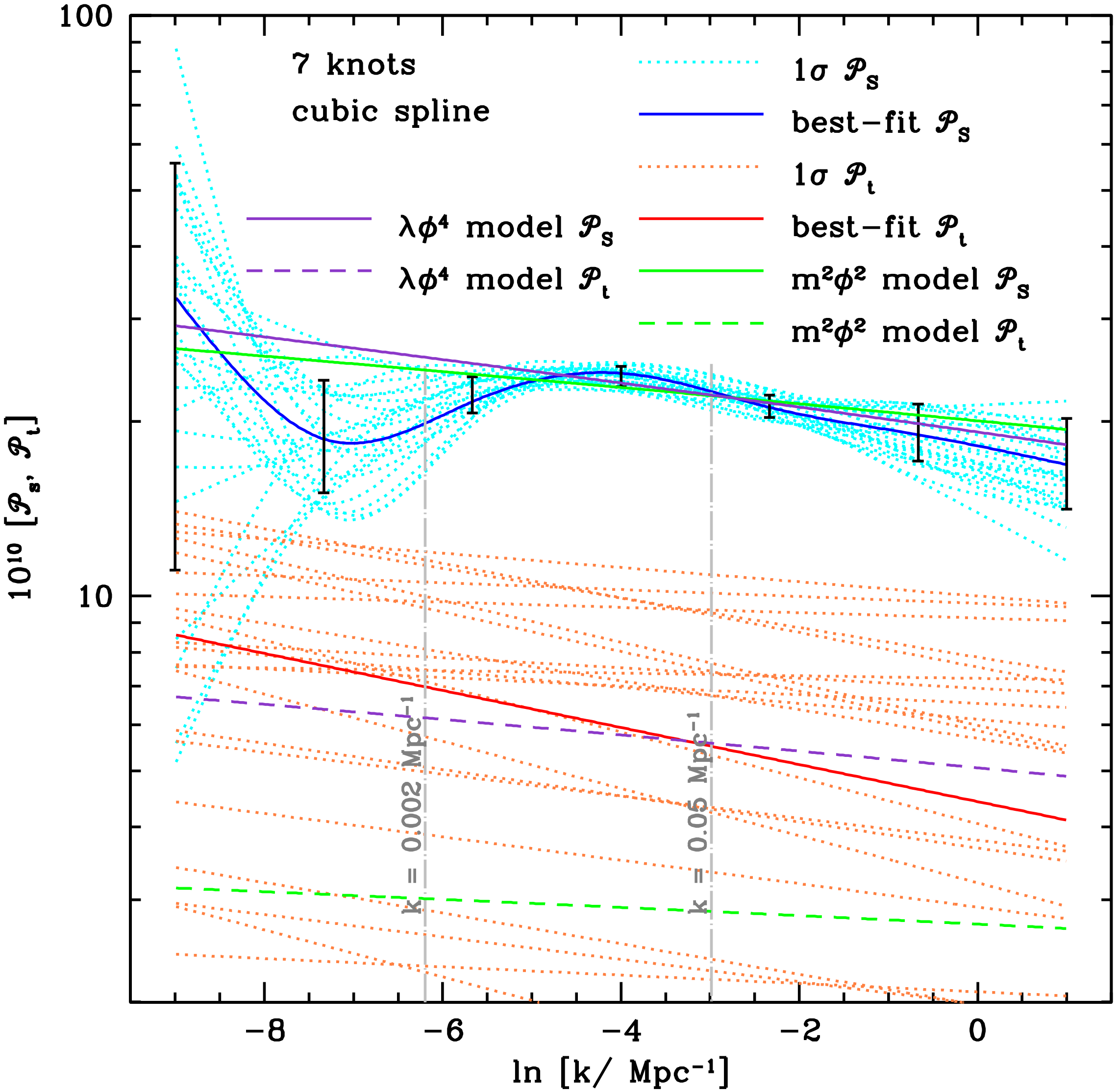


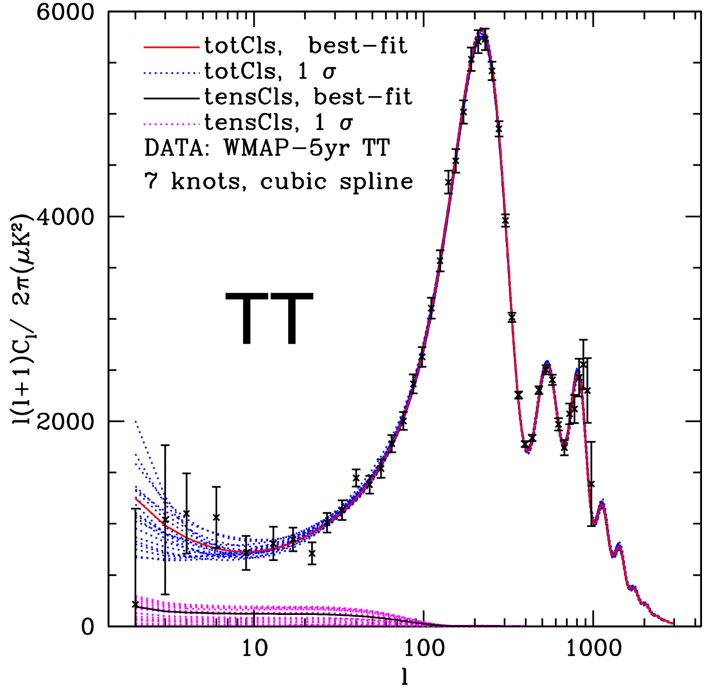


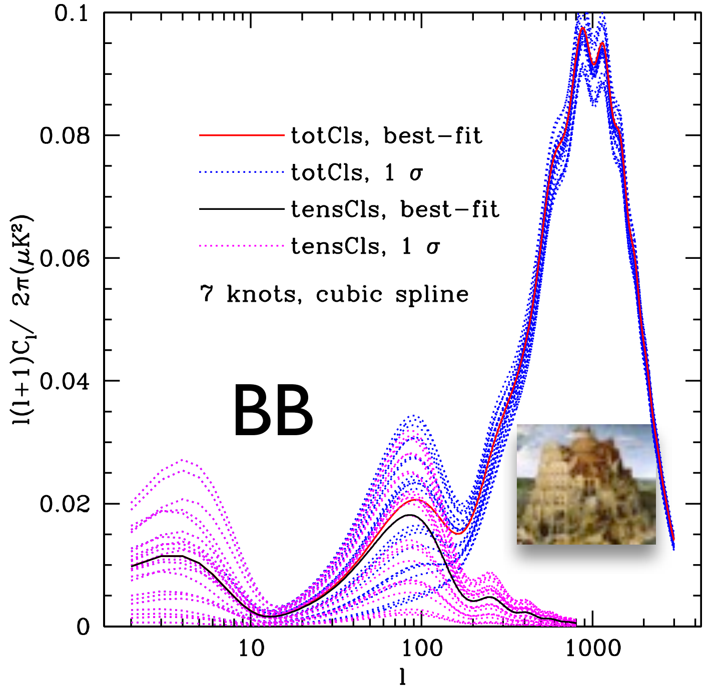
TEST: within errors, energy-density does not change with expansion ➪Einstein's cosmological constant is best fit so far


EUCLID
WL Pk
WL Pk + BAO
Target (BAO
+ WL Pk & bk)
CHIME BAO
0.5
0
−0.5
−1.2
−1
−0.8
w_a
w_0

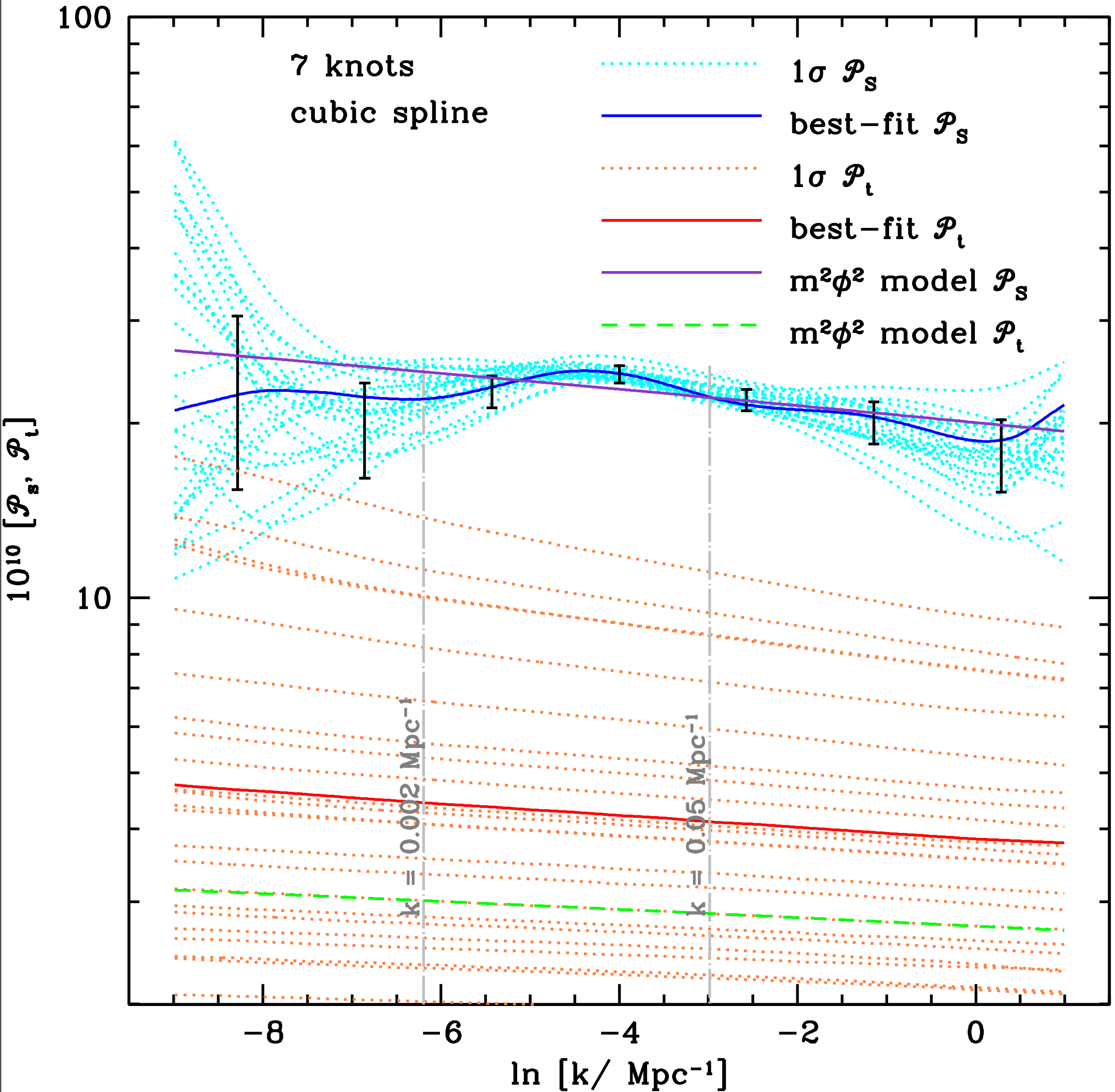
partially-blind scalar power trajecteries & usual r-n_t tensor - no consistency relation. Nov09 data

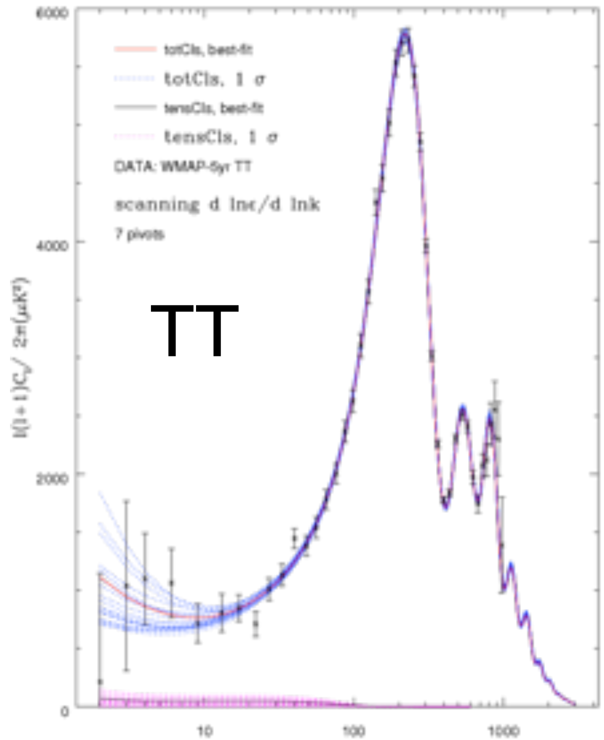


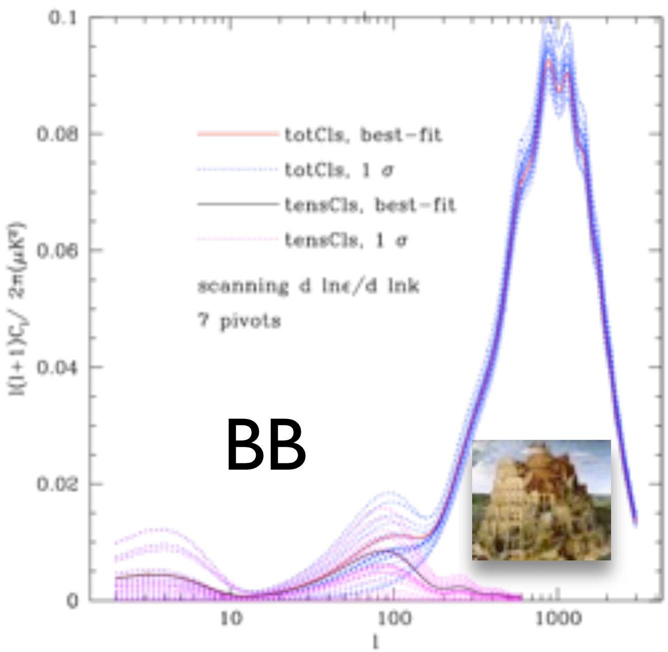




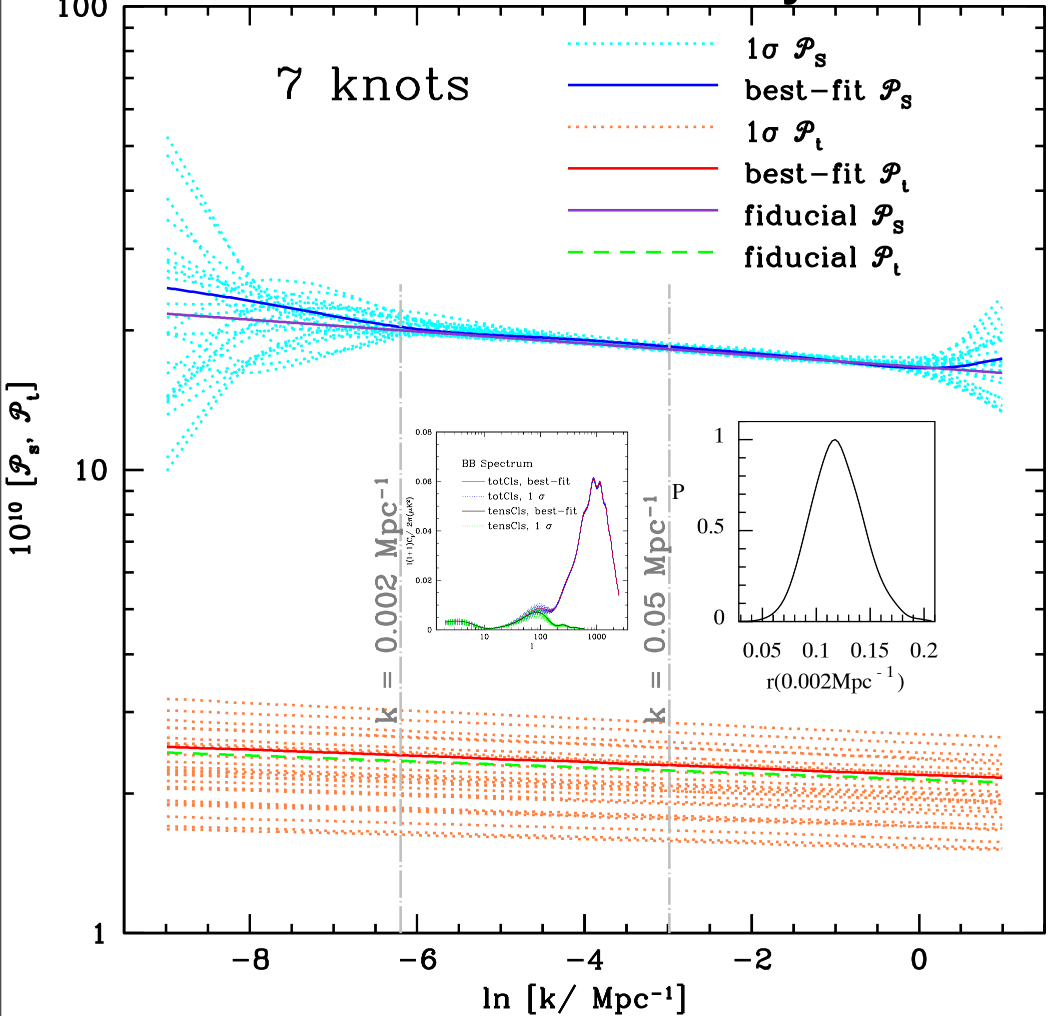
partially-blind acceleration trajecteries obeying tensor/scalar consistency relation. Nov09 data



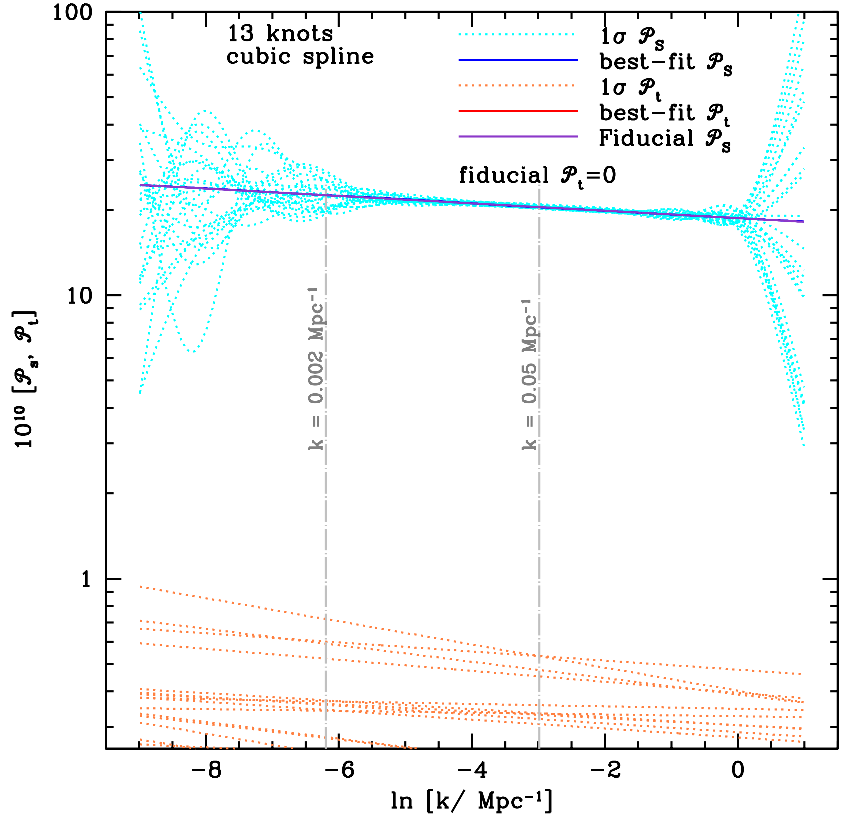


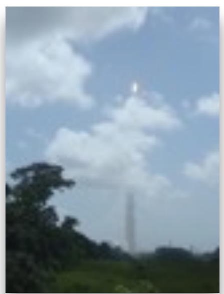


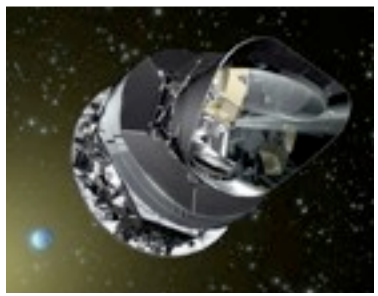
Planck2.5 forecast with inflation consistency

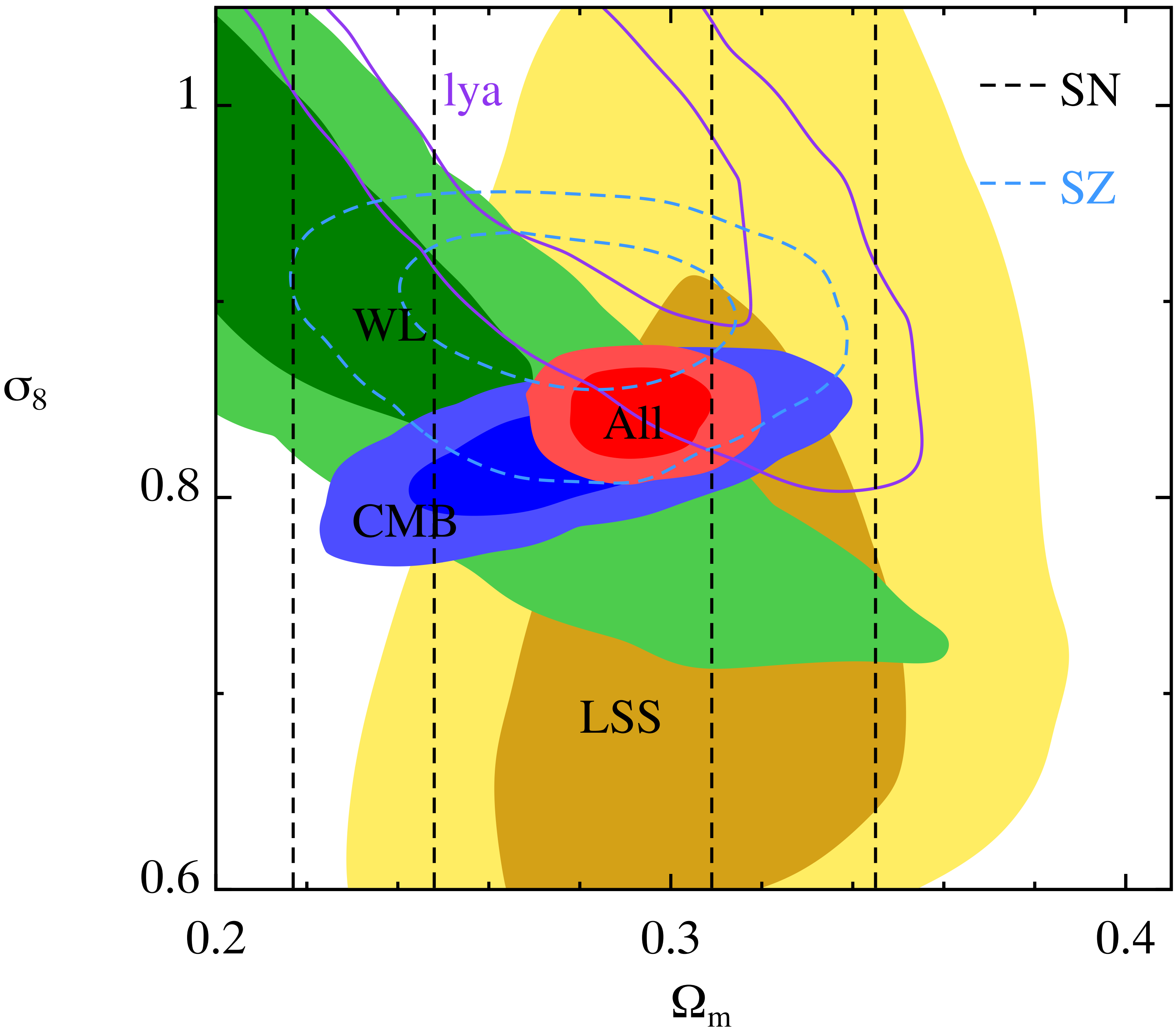


Planck2.5 r=0 forecast for 13 knot semi-blind P_s +r-n_t

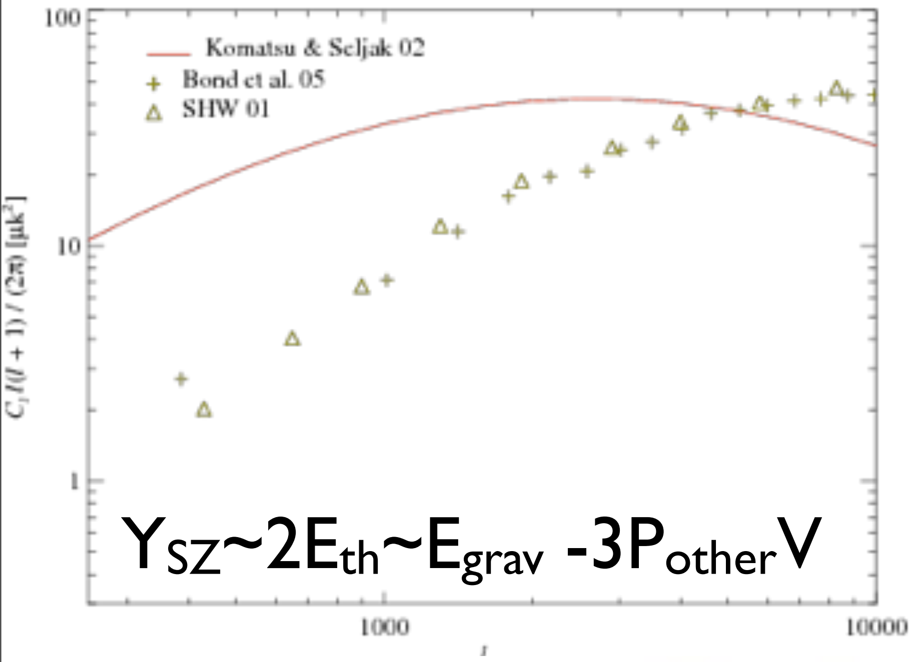




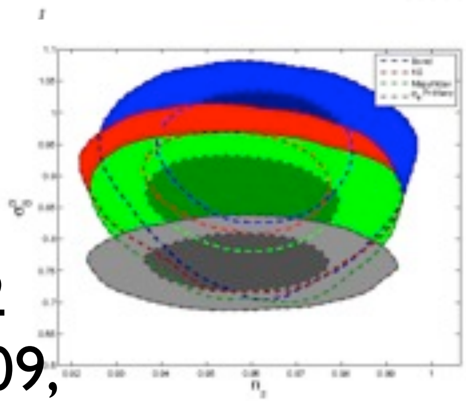


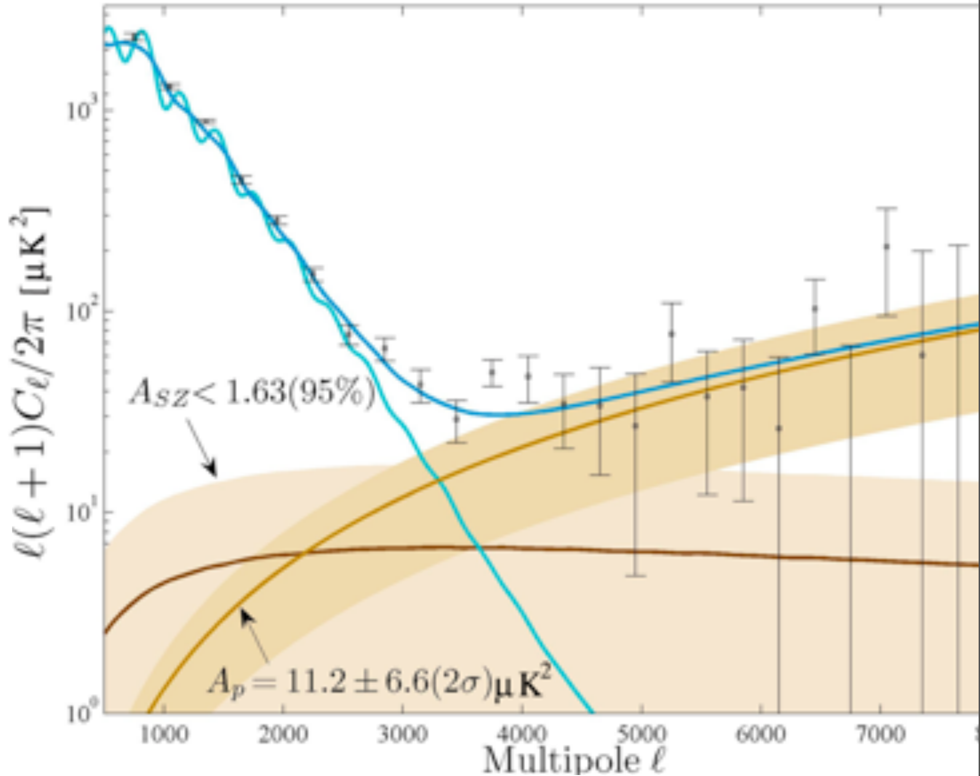

1
0.8
0.6
0.2
0.3
0.4
σ_8
Ω_m
lya
SN
SZ
WL
All
CMB
LSS

Feedback Simulations, SZ Power Spectra & σ_8^{SZ}



$Y_{SZ} \sim 2E_{th} \sim E_{grav} - 3P_{other}V$

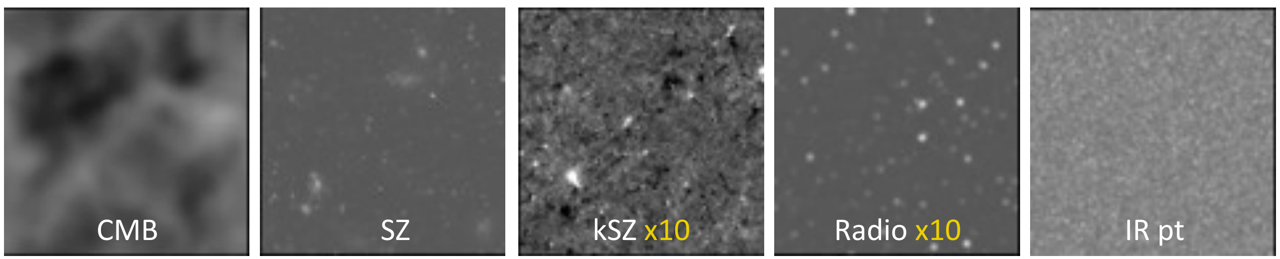


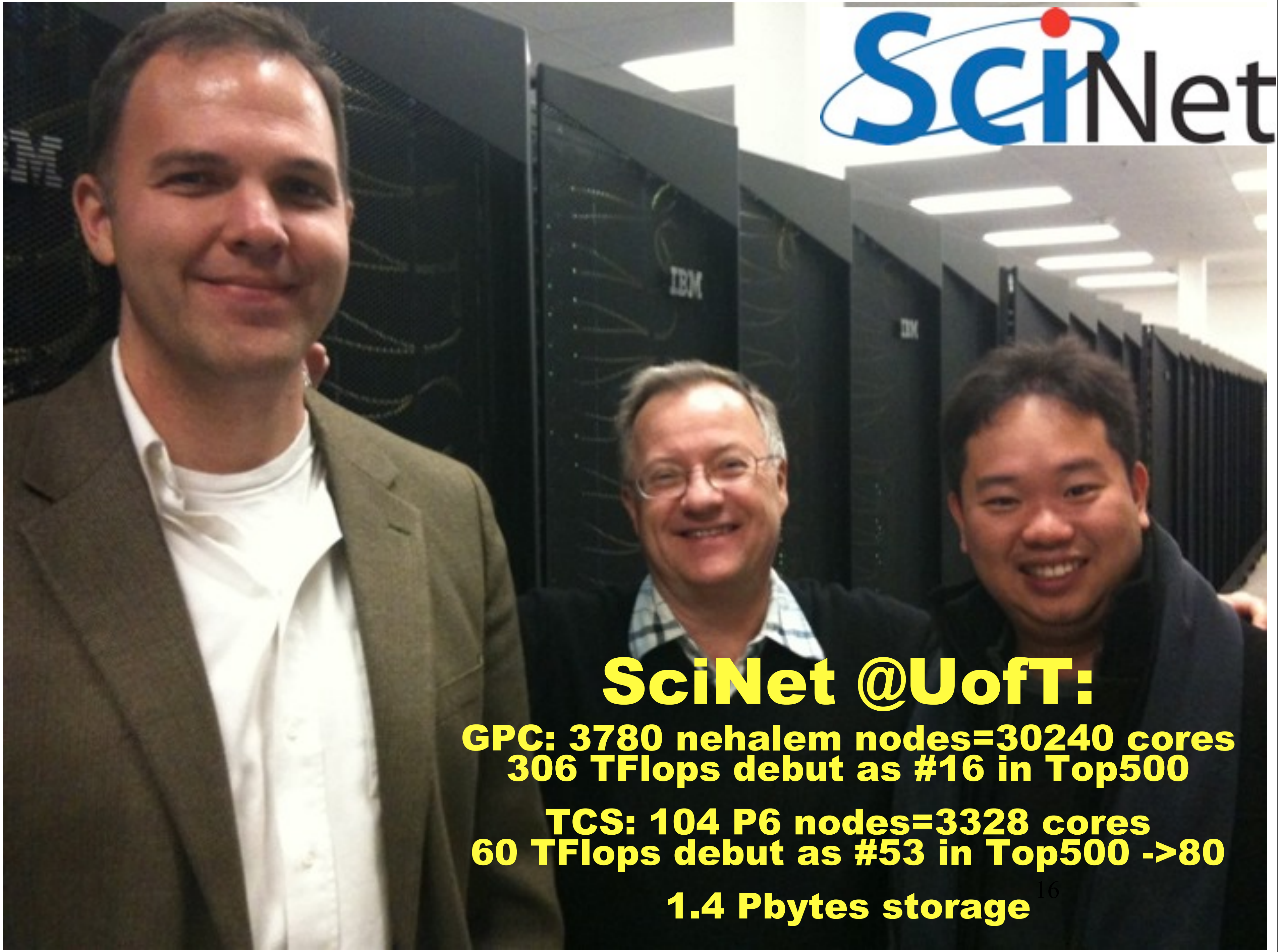


$$\mathcal{B}_\ell^{\rm th} = \mathcal{B}_\ell^{\rm CMB} + A_{\rm SZ}\mathcal{B}_\ell^{\rm SZ} + A_p\left(\frac{\ell}{3000}\right)^2 + \mathcal{B}_\ell^{\rm corr}$$

brwg02, cbi 02 (05), 04, 05, 07, 09, acbar 03, 07, 09 used brwg02-SPH, later in cbi KS as well since WMAP used it

Simulations : Sehgal et al, arxiv:0908.0540




SciNet
IBM
SciNet @UofT:
GPC: 3780 nehalem nodes=30240 cores
306 TFlops debut as #16 in Top500
TCS: 104 P6 nodes=3328 cores
60 TFlops debut as #53 in Top500 ->80
1.4 Pbytes storage

400
Mpc

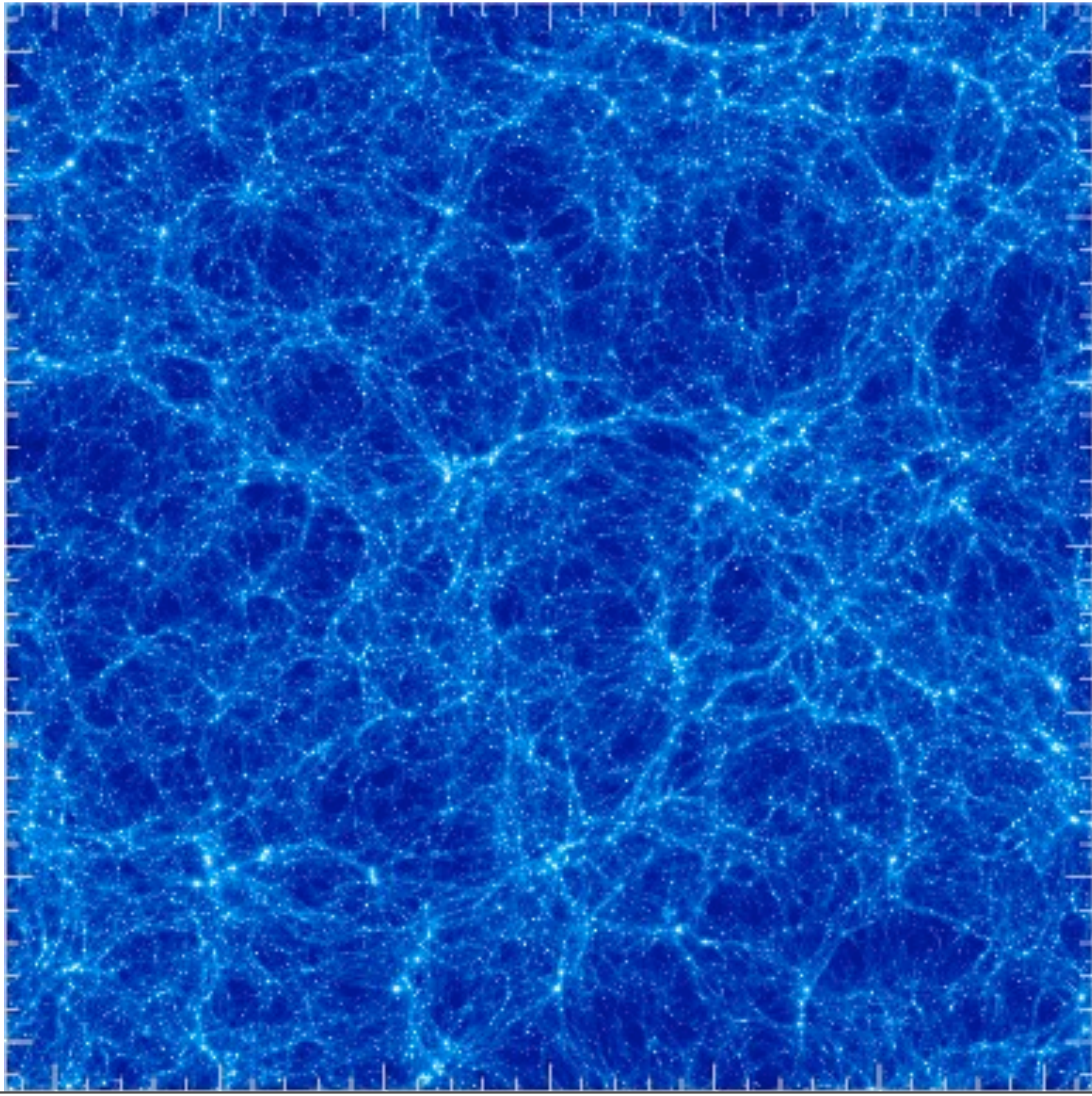
ΛCDM

WMAP5

gas
density

Gadget-3
SF+
SN E+
winds
+CRs

512^3



400
Mpc

ΛCDM

WMAP5

gas
pressure

Gadget-3
SF+
SN E+
winds
+CRs

512^3

400
Mpc

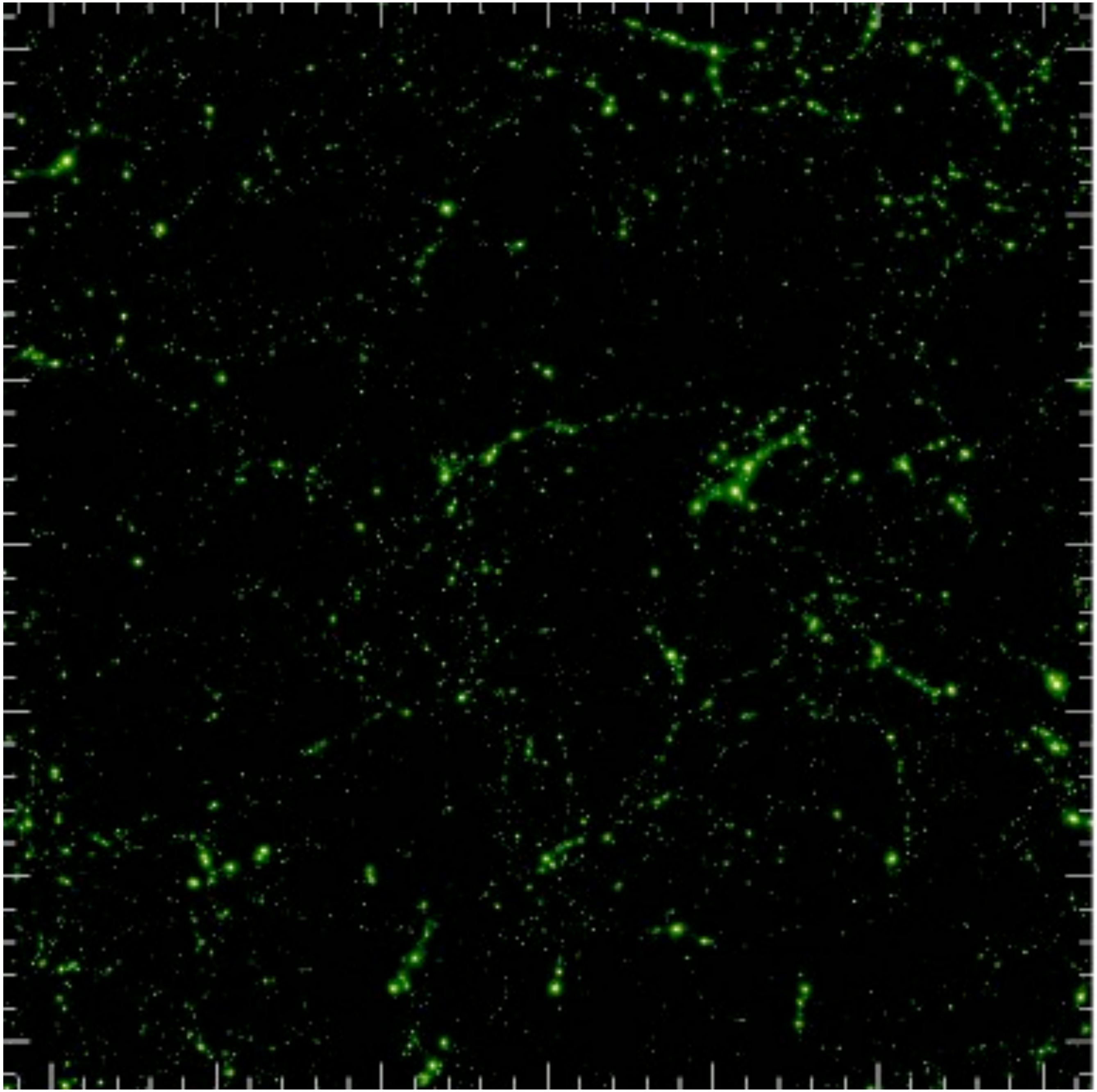
ΛCDM

WMAP5

gas
pressure

Gadget-3
SF+
SN E+
winds
+CRs

512^3



400 Mpc

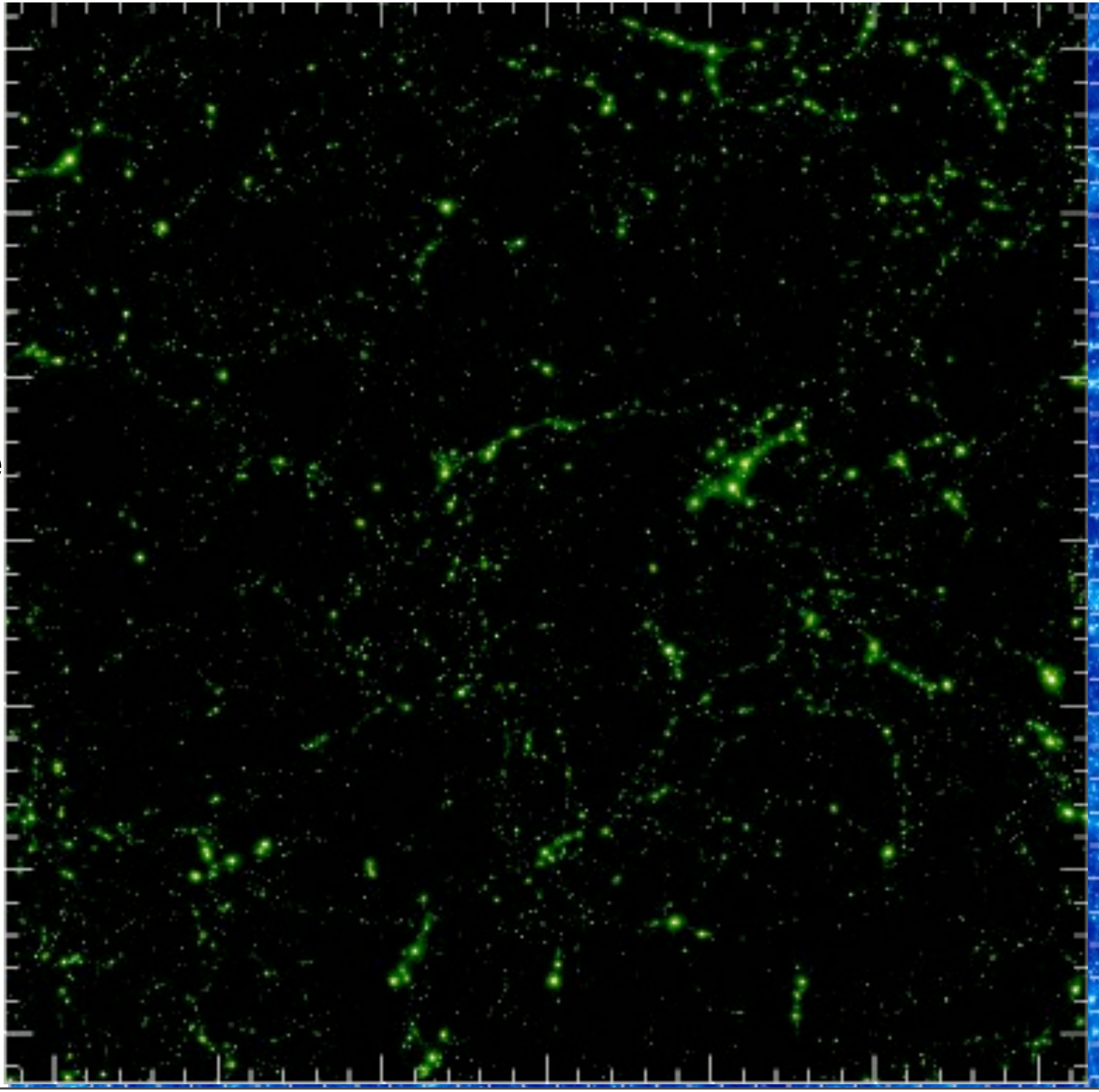
ΛCDM

WMAP5

gas pressure

Gadget-3 formation shocks only aka adiabatic

512^3

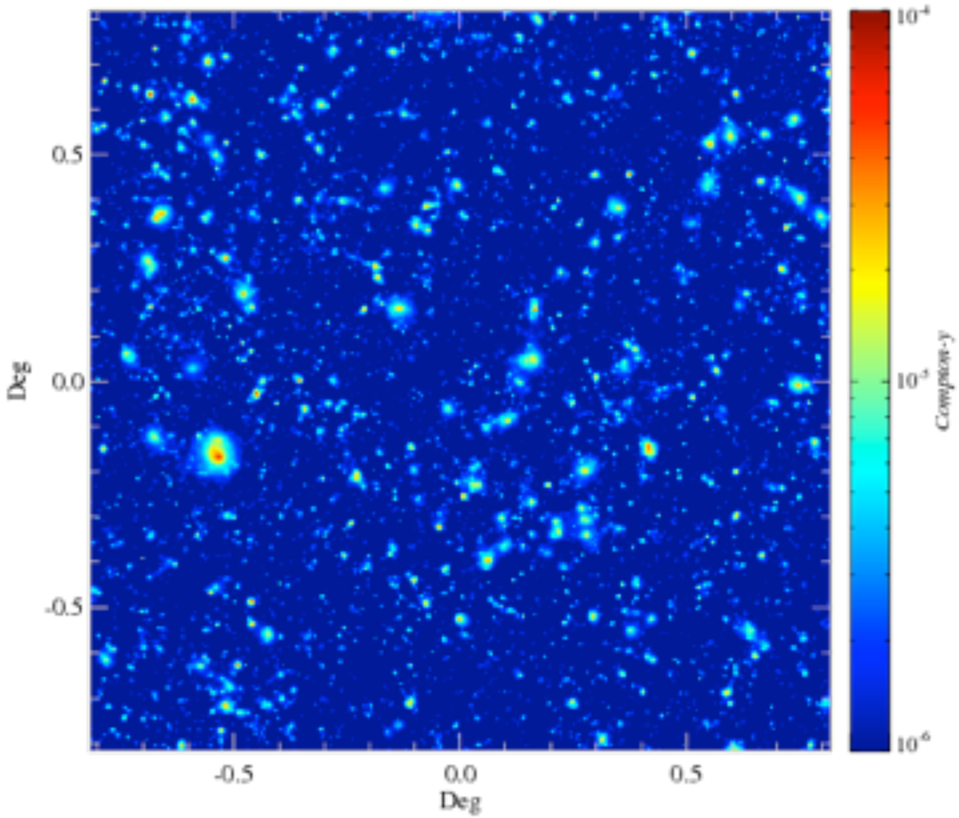


Variations in SZ with feedback

- 1st - adiabatic (no star formation).
- 2nd - gas cooling + star formation +CR
- 3rd - w/ feedback as well. Note pushing out of gas, softening of cluster cores.
- Cooling+SFR +Feedback $2*256^3$ ~20 hours on 8 nodes.

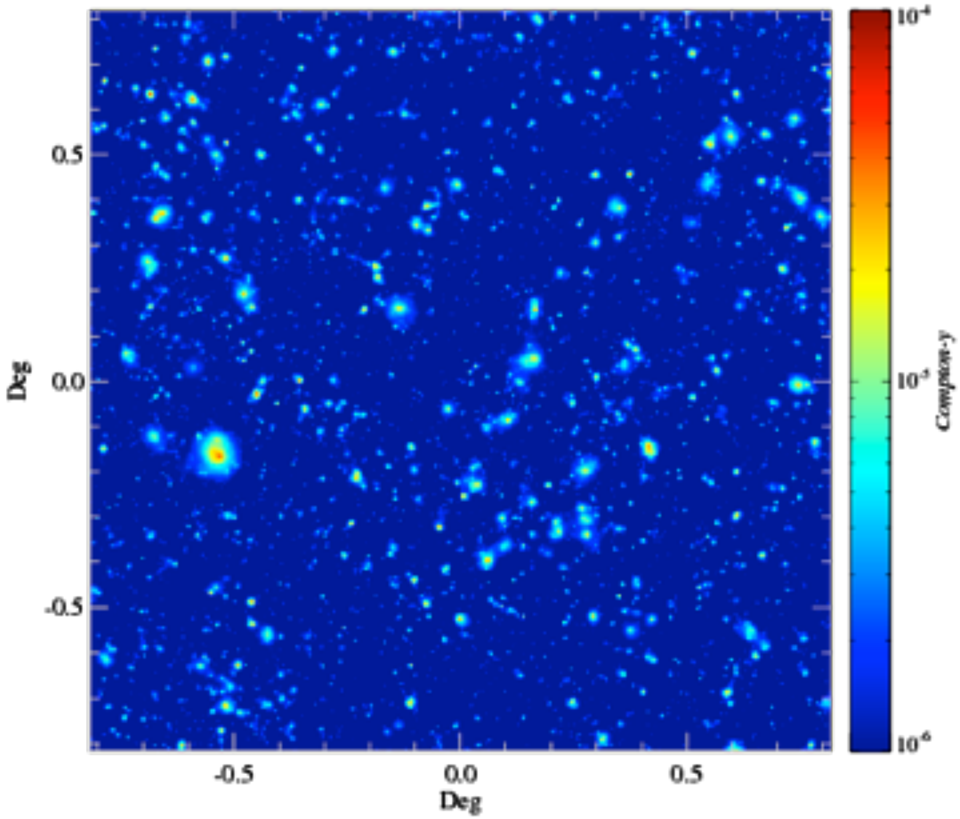
Variations in SZ with feedback

- 1st - adiabatic (no star formation).
- 2nd - gas cooling + star formation +CR
- 3rd - w/ feedback as well. Note pushing out of gas, softening of cluster cores.
- Cooling+SFR +Feedback $2*256^3$ ~20 hours on 8 nodes.



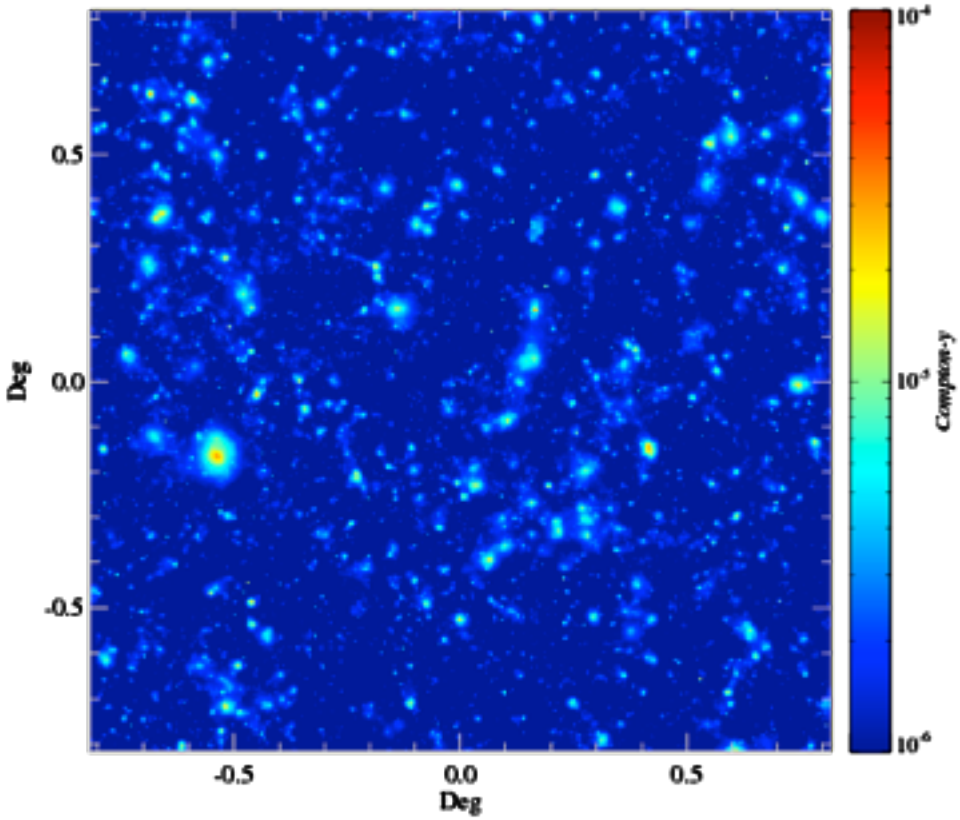
Variations in SZ with feedback

- 1st - adiabatic (no star formation).
- 2nd - gas cooling + star formation +CR
- 3rd - w/ feedback as well. Note pushing out of gas, softening of cluster cores.
- Cooling+SFR +Feedback $2*256^3$ ~20 hours on 8 nodes.

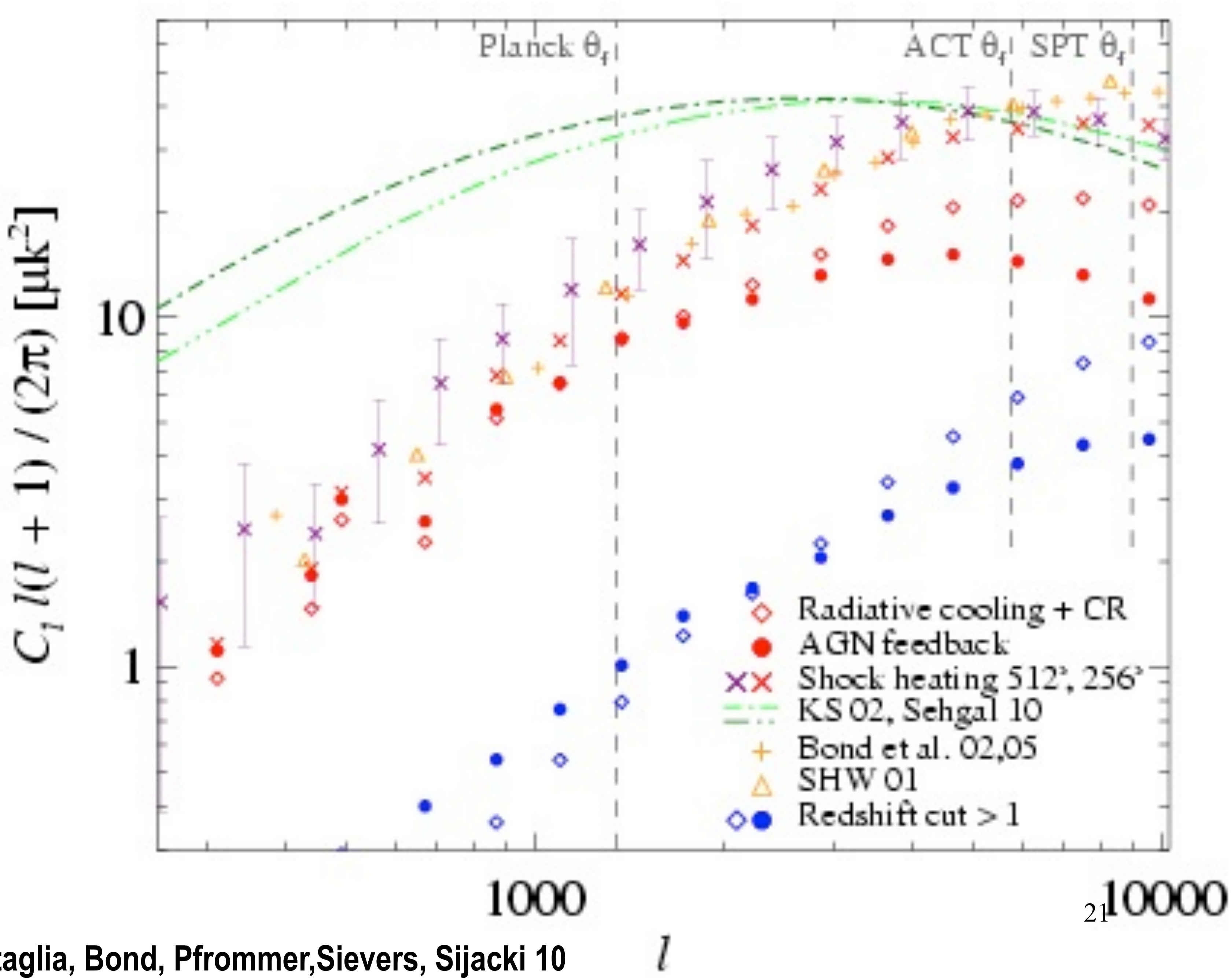


Variations in SZ with feedback

- 1st - adiabatic (no star formation).
- 2nd - gas cooling + star formation +CR
- 3rd - w/ feedback as well. Note pushing out of gas, softening of cluster cores.
- Cooling+SFR +Feedback $2*256^3$ ~20 hours on 8 nodes.



C_L^{SZ} & σ_8^{SZ} theoretical uncertainties & impact on ACT



Battaglia, Bond, Pfrommer,Sievers, Sijacki 10

C_L^{SZ} systematic uncertainties, effect on σ_8^{SZ} from ACT

$C_L^{SZ} \sim [\sigma_8^{SZ}]^7$ x SZ template (cosmic parameters)

$\sigma_8^{SZ} <$ .87 @2-sigma for KS ACT, 0.77 +- 0.25 SPT

SPH gives $\sigma_8^{SZ} < 0.96$ adiabatic, < 0.99 cool+SN

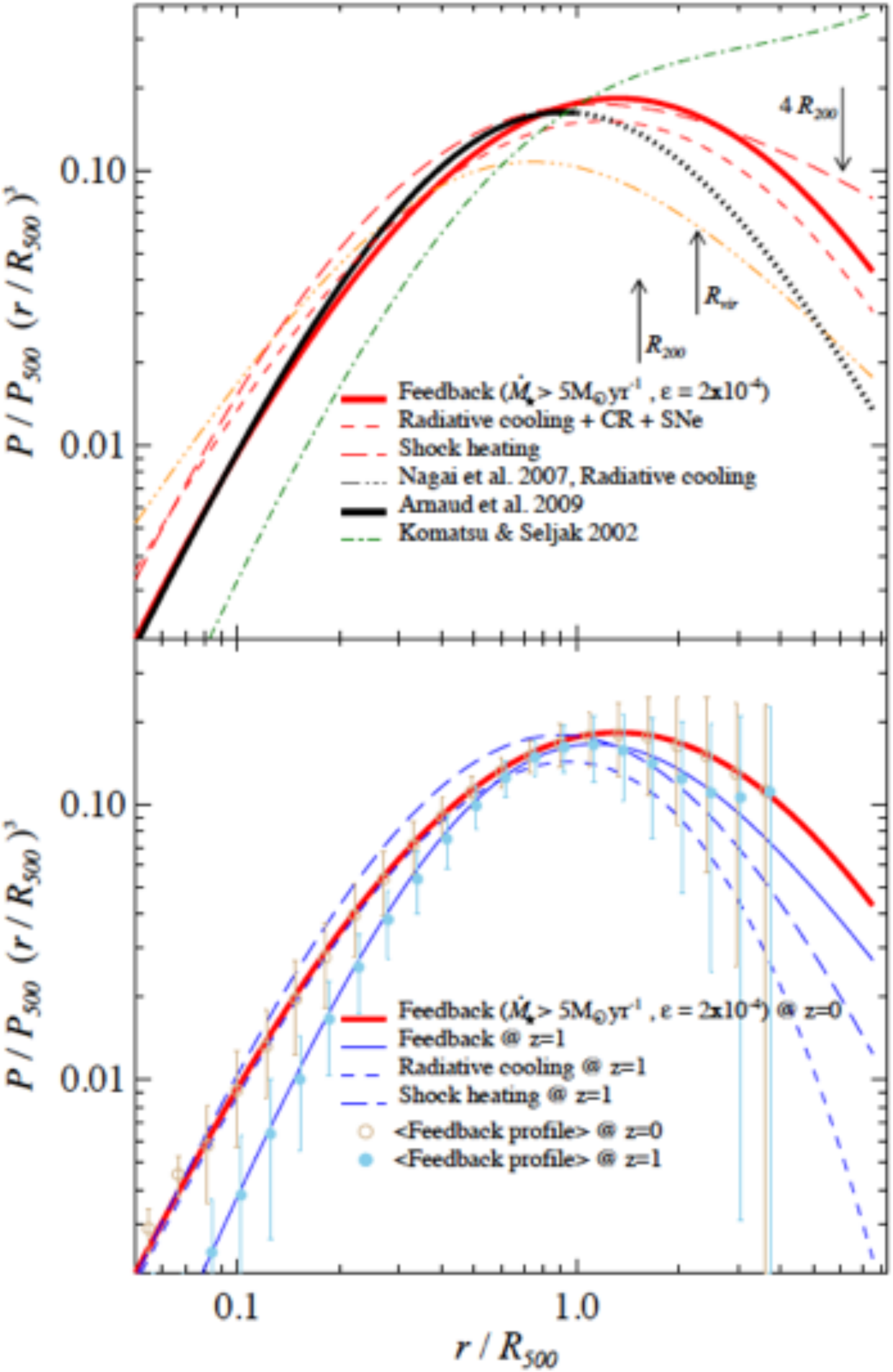
AGN feedback+cool+SN-E+CR: $\sigma_8^{SZ} < 1.00$, & mean σ_8^{SZ}= x

Feedback tied to star formation via injection in halo cores - good agreement with Sijacki et al. high-res AGN feedback sims; untuned pressure profiles match X-ray (Arnaud et al.09) very well to r_{500} (limit of data) & Y-M

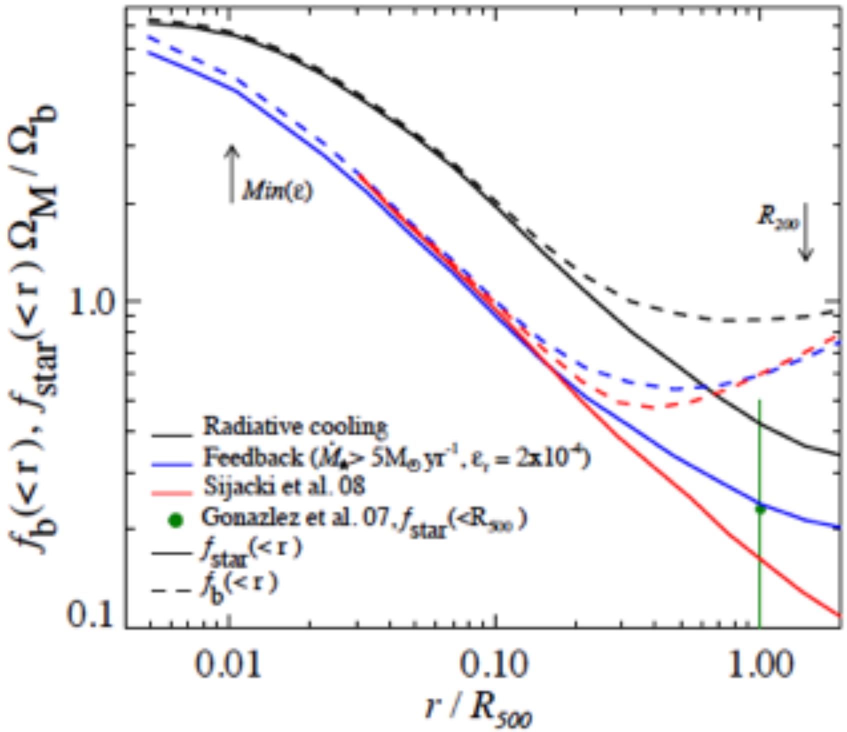
a 16% variation in σ_8^{SZ} between KS and hydro sims!!

this agrees with the variations depending upon template used in Bond etal 05 CBI, ACBAR. not surprising because the 02 simulations are similar to the 09 simulations, when scaled for WMAP5 parameters, in particular σ_8^{SZ}

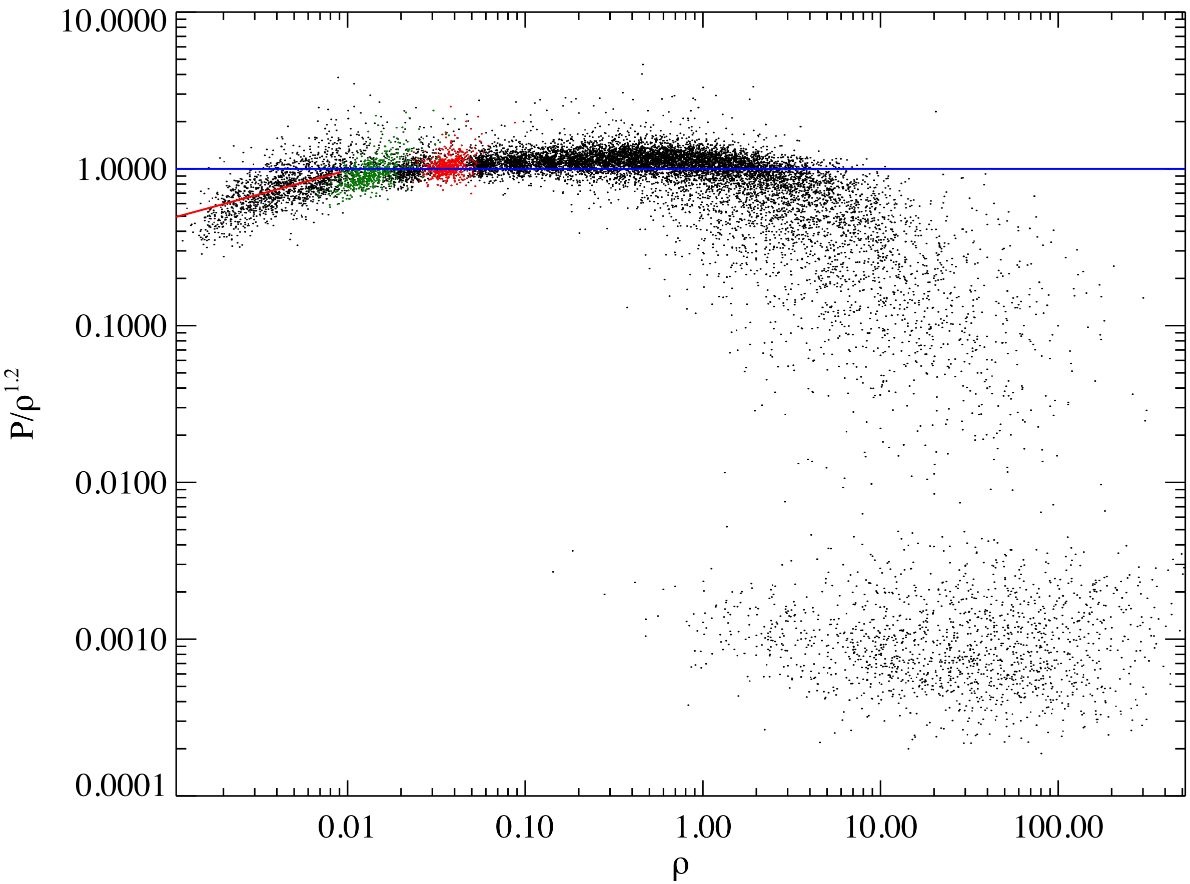
end



P / P500 (r / R500)^3
0.10
0.01
4 R200
R200
Rvir
Feedback (Ṁ• > 5M⊙yr⁻¹ , ε = 2x10⁻⁴)
Radiative cooling + CR + SNe
Shock heating
Nagai et al. 2007, Radiative cooling
Arnaud et al. 2009
Komatsu & Seljak 2002
Feedback (Ṁ• > 5M⊙yr⁻¹ , ε = 2x10⁻⁴) @ z=0
Feedback @ z=1
Radiative cooling @ z=1
Shock heating @ z=1
<Feedback profile> @ z=0
<Feedback profile> @ z=1
0.1
1.0
r / R500



fb(< r), fstar(< r) ΩM / Ωb
1.0
0.1
Min(ε)
R200
Radiative cooling
Feedback (Ṁ• > 5M⊙yr⁻¹ , εr = 2x10⁻⁴)
Sijacki et al. 08
Gonazlez et al. 07, fstar(<R500)
fstar(< r)
fb(< r)
0.01
0.10
1.00
r / R500


10.0000
1.0000
0.1000
0.0100
0.0010
0.0001
P/ρ^1.2
0.01
0.10
1.00
10.00
100.00
ρ