Can string cosmology face the challenge of CMB anisotropies?

G. Veneziano/CERN/TH

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1. *String cosmology: a brief reminder & a small update*
2. *The blue (flat) spectrum of adiabatic (isocurvature) perturbations in S.C.*
3. *Converting IEP into ACP: is the KR axion a good "curvaton"?*
4. *The dilaton as quintessence: is Λ =0 in critical superstring theory?*
5. *Conclusions*

String cosmology: a brief reminder

(reviews : Lidsey, Wands & Copeland, hep-th/9909061,
Gasperini & GV, hep-th/0207130 ;
home page: http://www.ba.infn.it/~gasperin)

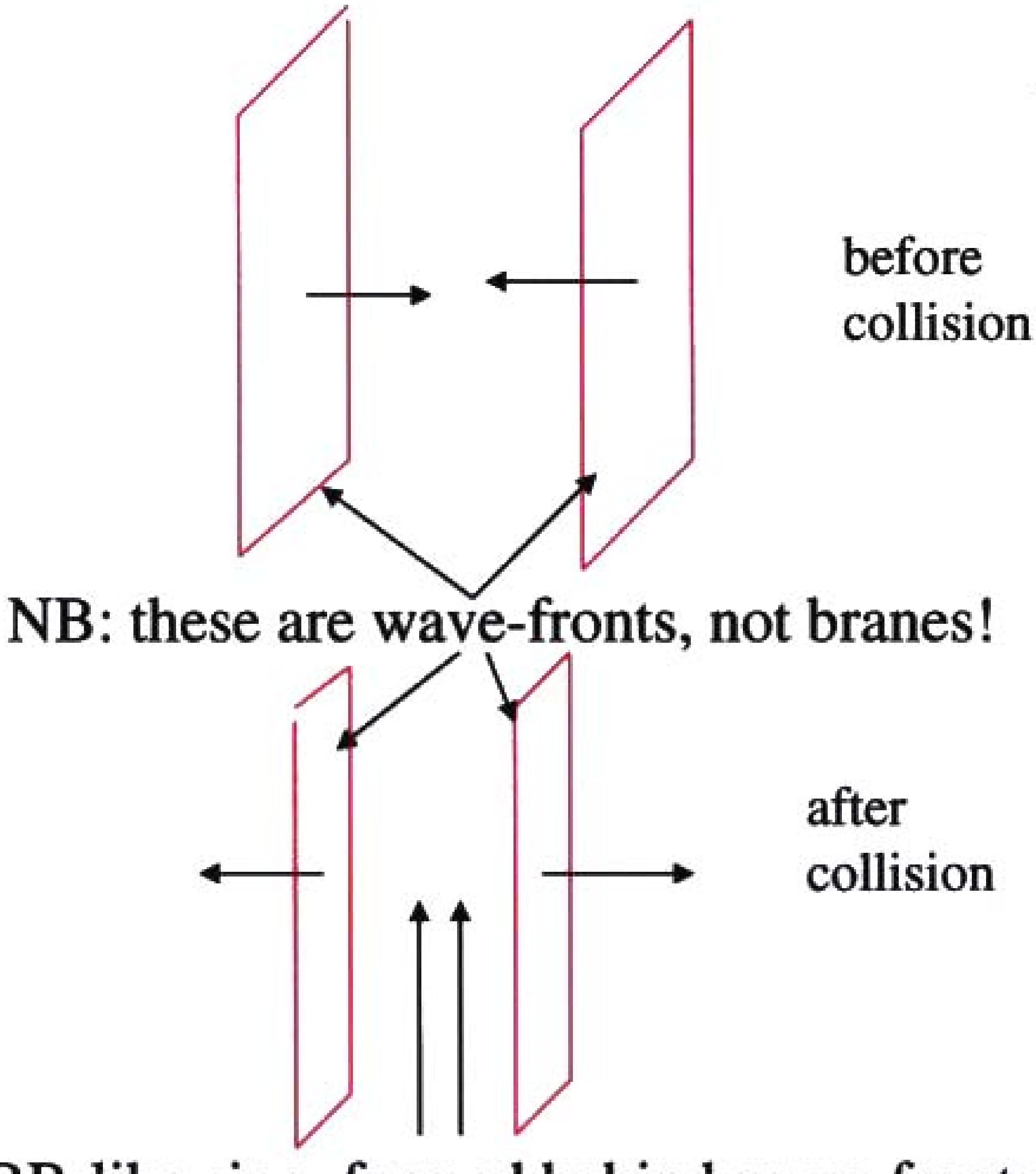
1. Evolution from APT towards BB "singularity"
   - more time available
   - accelerated (inflationary) evolution
   - grav. collapse in EF <=> Hawking-Penrose thrms.
   - PBB evolves from weak to strong coupling
   - EKP (v.2) does the opposite
2. Avoidance of singularity thanks to α'/loop corrections:
   - exit problem in PBB (can use α' & loop corrections)
   - bounce problem in EKP (only through α' corrections ?)
3. Generation of hot BB (entropy) through quantum particle production (= short wave-length perturbations)
4. Generation of large scale structure (= long wave-length perturbations) => main subject of this talk

- In order to answer better fine-tuning allegations one would like to go away from exact plane or spherical symmetry and to conside, for instance, the collision of finite-front shock waves.
- Determine whether a CTS is generically formed, estimate the mass/size of the BH, study the geometry close to the BB singularity, etc.
- Until recently, there have been just conjectures (Yurtsever, 1988) about this case. Recently, thanks to a new method by Eardley and Giddings (gr-qc/0201034), Kohlprath and myself (gr-qc/0203093) managed to find criteria for the formation of CTSs in beam-beam collisions at generic D, b, and (axisymmetric) profiles (in impulsive approximation)
- Simple example of central collision of two identical hom. beams

PBB from plane-wave collisions

(FKV-M,hep-th/0002070, BV,hep-th/0007159)

(exactly soluble model)



BB-like sing. formed behind wave-fronts

- The geometry inside the horizon is known to be cosmological and to possess a clear arrow of time towards the singularity at the centre, a space-like singularity

- The singularity inside one such BH is identified with the BB event that gave birth to our Universe, except that there is no true singularity, of course.

- To generate a big/smooth Universe like ours the BH has to be large enough, R > 1 Fermi. Is this fine-tuning (1 Fermi >> λ_s)?

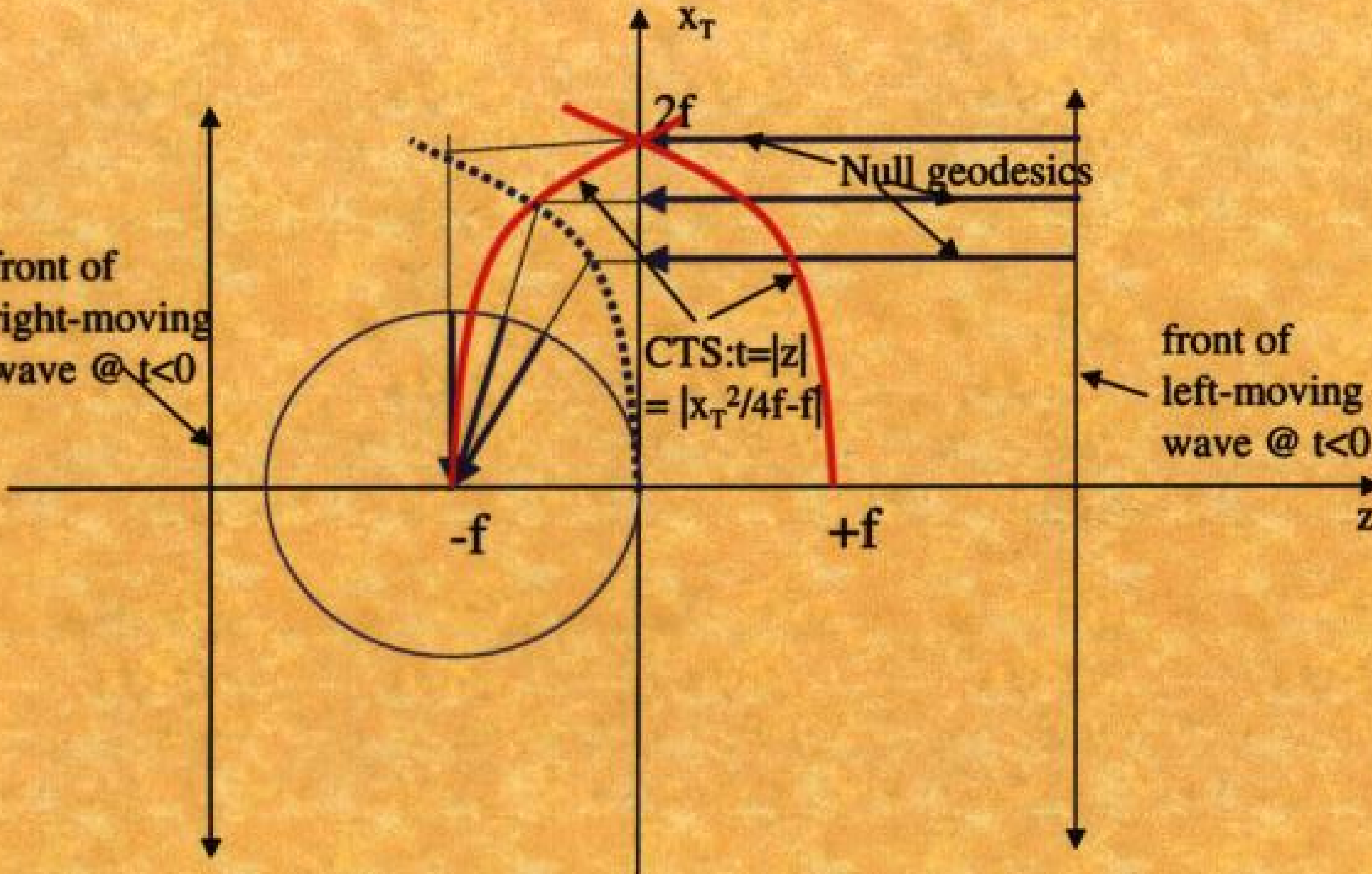
- BDV('99) studied spherical collapse criteria (using analytic results by Christodoulou).

Fine tuning in PBB?

•If we have no longer a beginning of time, how did it all start? A possibility:

•Most of the time and almost everywhere the Universe is/was/will be in a chaotic perturbative state, a superposition of waves where not even the arrow of time is well defined.

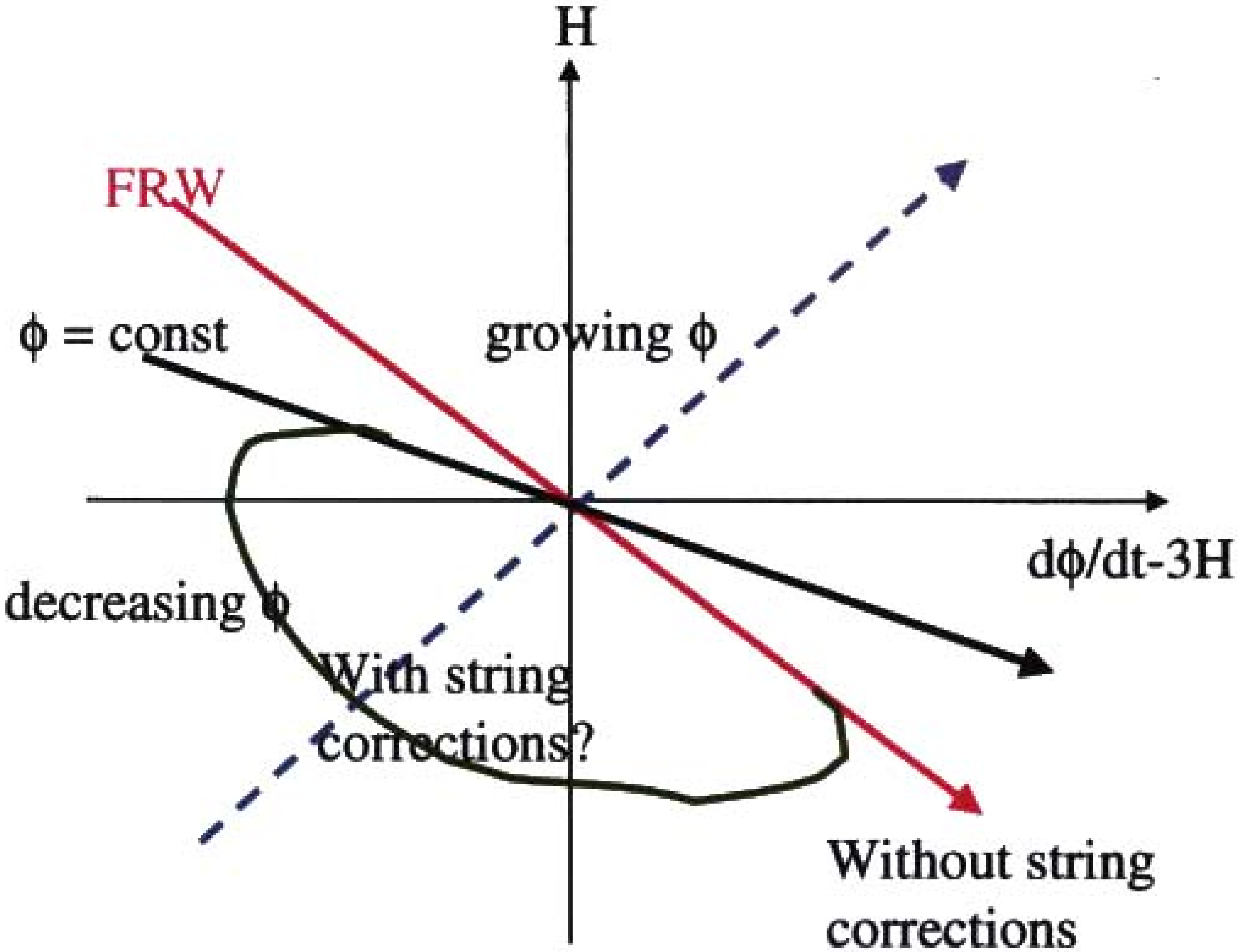
•Under some conditions a Closed Trapped Surface (CTS) may form (now or then, here or there), implying, in CGR, the onset of gravitational collapse and the formation of a black hole.



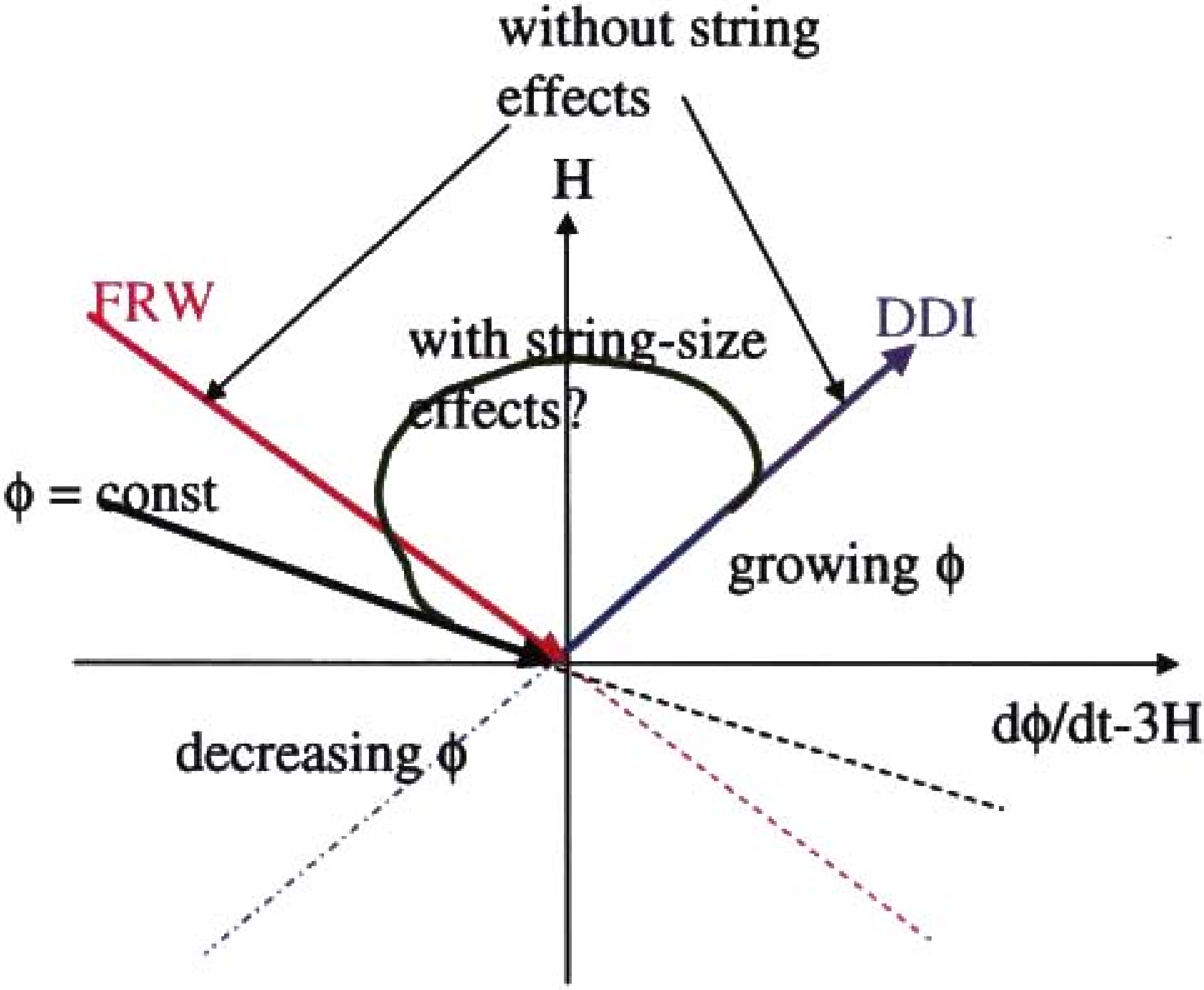
Collapse inevitable if $R_T > 2f = (D-2)\,(8\pi G_N \rho_\Sigma)^{-1}$

From Big Crunch to Big Bang

(KOSST)



PBB doc (GV '91, Gasperini & GV '93)



MAIN CONCLUSIONS

- Occurrence of gravitational collapse is generic.
- Collapse criteria involve only ratios of classical scales. e.g.

$$R_T /f, b/f$$

- No reference to λ_s or to l_P , a scale-invariant problem
- A whole distribution of collapse scales is expected, whose "tail" we can use....

NO FINE-TUNING

Perturbation spectra in string cosmology

- **Gravitational waves**: $n_T = 3$ (insensitive to extra dim.s)

  => Good for detection, irrelevant for CMB, LSS

- Adiabatic **dilaton/curvature** perturbations: $n_S = 4$? I think so!

  => Hard to detect, irrelevant for CMB, LSS

- **Photons**: not as blue, but still blue, sensitive to evolution of internal dimensions and to details of $U(1)_{em}$ embedding

  => Seeds of Cosmic Magnetic fields?

• **KR-axions**: blue, red or <u>flat</u> w/ "fixed" normalization

($H^* \sim M_s$, $\omega^* \sim M_s\, a^*/a_0 \sim 10^{11}$ Hz, σM_P = can. axion field)

$$|\delta\sigma_k|^2 = (H^*/M_P)^2\, (\omega/\omega^*)^{n_\sigma - 1};\quad 4 - 2\sqrt{3} \sim 0.53 < n_\sigma < 2$$

Flat spectrum ($n_\sigma = 1$) for symmetric 9-d evolution (mod. T-duality)

- **KR axion gives isocurvature (entropy) perturbations. Why? Its fluctuations appear <u>quadratically</u> in S_{eff} since the axion bkgnd is trivial**
  => no mixing to first order w/ metric pert.s (unlike dilaton)
- Isocurvature perturbations feed back on curvature to 2nd order but *give* "wrong" structure of acoustic peaks (DGMVV) (*Cf.* Boomerang, Maxima, ...)

However:

Converting isocurvature into adiabatic: is the KR axion a good "curvaton"?

- If V_σ generated (by PQ-symmetry breaking), and $\langle\sigma\rangle$ is <u>not</u> initially at its minimum, axion pert.s induce <u>calculable</u> metric pert.s. This "curvaton" idea (M,LWC,ES, LW, MT,BP, ...BGGV) needs (if curvaton = axion)
  - phase of axion dominance
  - axion decay before NS (m_σ > 10 TeV)
- Conversion efficiency can be computed (see e.g. BGGV, hep-ph/0206131). We find for the Bardeen potential Φ_k:

$$|\Phi_k|^2 = f^2(\sigma_i)\,|\delta\sigma_k|^2 = f^2(\sigma_i)\,(H^*/M_P)^2\,(\omega/\omega^*)^{n_\sigma-1}$$

$$f(\sigma_i) \sim (0.13\,\sigma_i + 0.18/\sigma_i) > 0.3$$

- Furthermore, temporal phase of curvature perturbations after axion decay is consistent with adiabatic initial conditions (those of standard slow-roll inflation)

$$\Phi_k(\eta) \sim -3\,\Phi_k(\eta_d)\,[\cos x/x^2 - \sin x/x^3]; \quad x = k\, c_s\, \eta\,;\ c_s \sim \sqrt{3}$$

- COBE normalization: $C_2 = (1.9 +/- 0.23)10^{-10}$ to be compared with

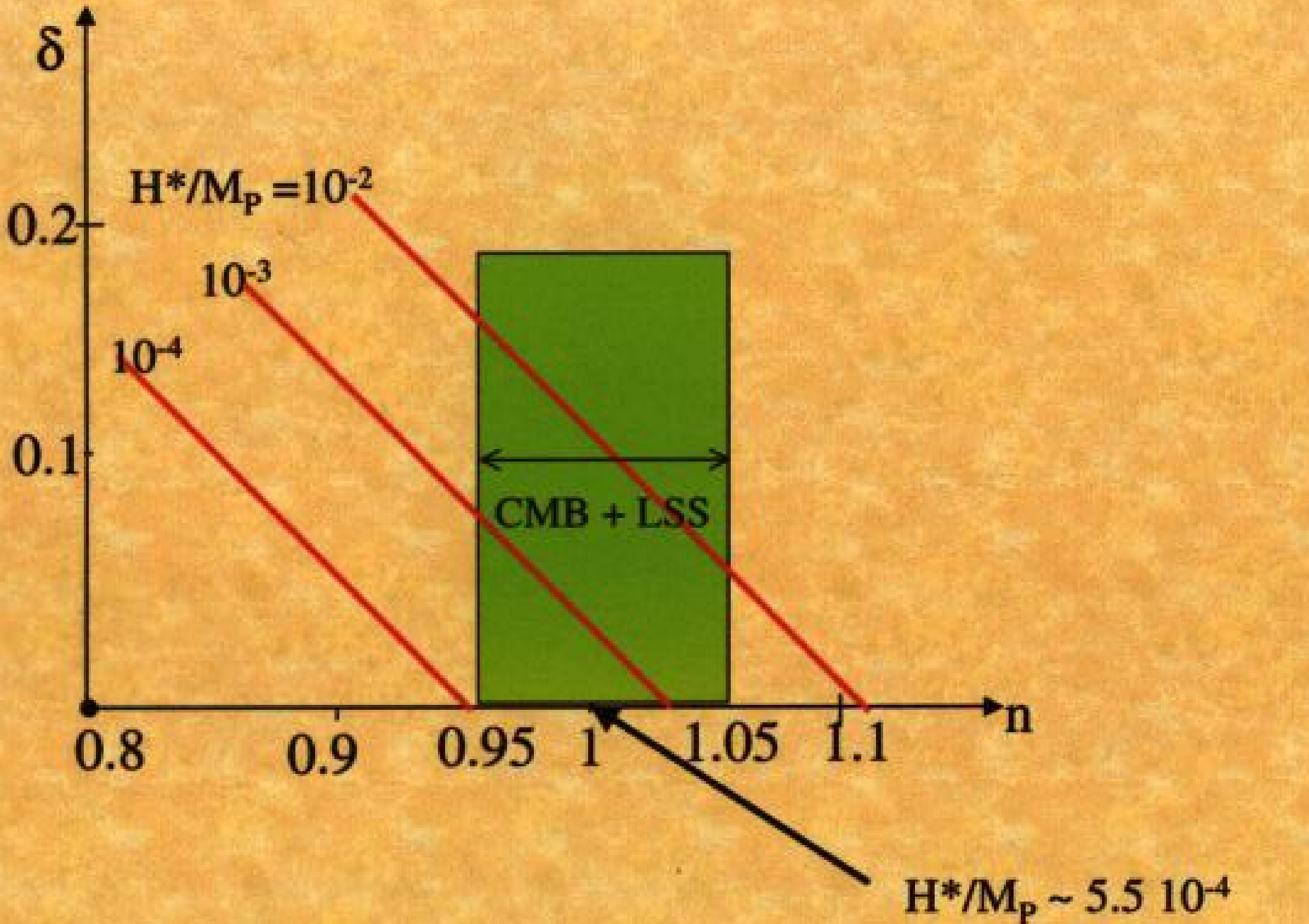
$C_2 = \alpha_n^2\, f^2(\sigma_i)\,(H^*/M_P)^2\,(\omega_0/\omega^*)^{n_\sigma - 1}$; $\alpha_n^2 \sim (1/54\pi)$; $f^2(\sigma_i) \sim 0.1$ $(n_\sigma, \sigma_i \sim 1)$

=> acoustic-peaks come out fine provided primordial axion spectrum is nearly flat ($n_\sigma \sim 1$) and appropriately normalized.

=> PBB parameter space consistent with CMB observations: see fig.
(a possible break δ in the tilt n_σ has been inserted above the AP scale)

A particularly simple case: $n_\sigma = 1$, $\delta = 0$, $(H^*/M_P) \sim 0.5\ 10^{-3}$

Q: Is standard inflation really doing better than this with its fine-tuning of inflaton potentials and an arbitrary normalization?


δ
H*/M_P =10^-2
10^-3
10^-4
0.2
0.1
CMB + LSS
n
0.8
0.9
0.95
1
1.05
1.1
H*/M_P ~ 5.5 10^-4

Conclusions

- It took many years for the original Guth idea to find a consistent framework and to become a predictive paradigm
- Until two years ago the much younger String Cosmology framework looked like a poor competitor, accused of fine-tuning and of phenomenological drawbacks
- **Recent work on collapse criteria has definitely shown that the fine-tuning allegations are unjustified**
- Recent work on conversion of isocurvature perturbations into adiabatic ones has made the phenomenological appeal of SC competitive w.r.t. standard (say chaotic) inflation (while being better motivated theoretically)
- These very encouraging developments should provide further motivation for the string community to address the fundamental questions that SC is still facing (BKL/DH chaos, (in)consistency w/ eternal acceleration, fate of BB and other singularities, etc.)