Analytic model for CMB temperature angular power spectrum from cosmic (super-)strings

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- PRD82, 063518 (2010), 1006.0687[astro-ph.CO]
- JCAP10,003 (2009), 0811.4698 [astro-ph]
- JCAP05,033 (2010), 1004.0600[astro-ph,CO]

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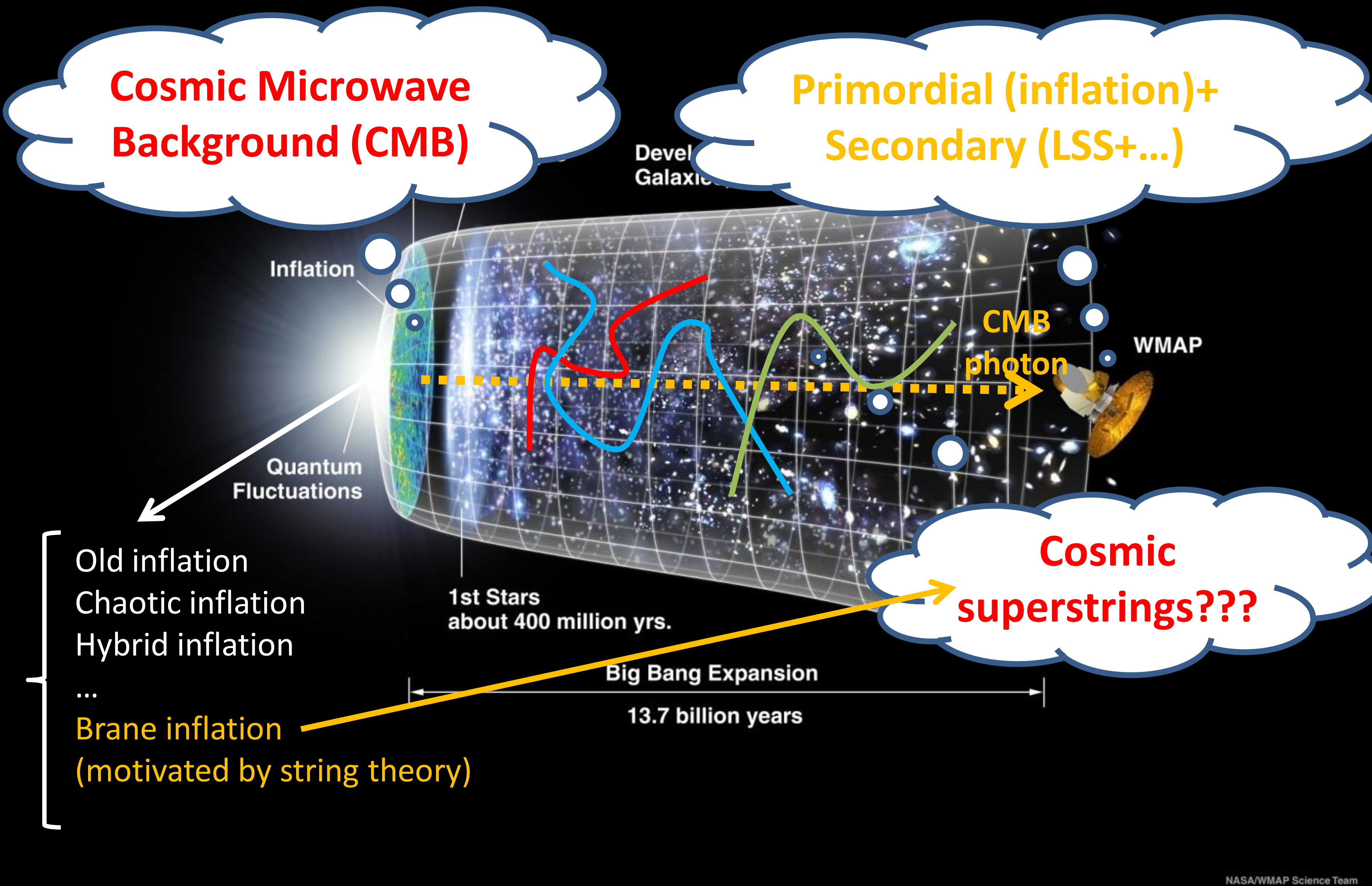
0. : Standard cosmological model

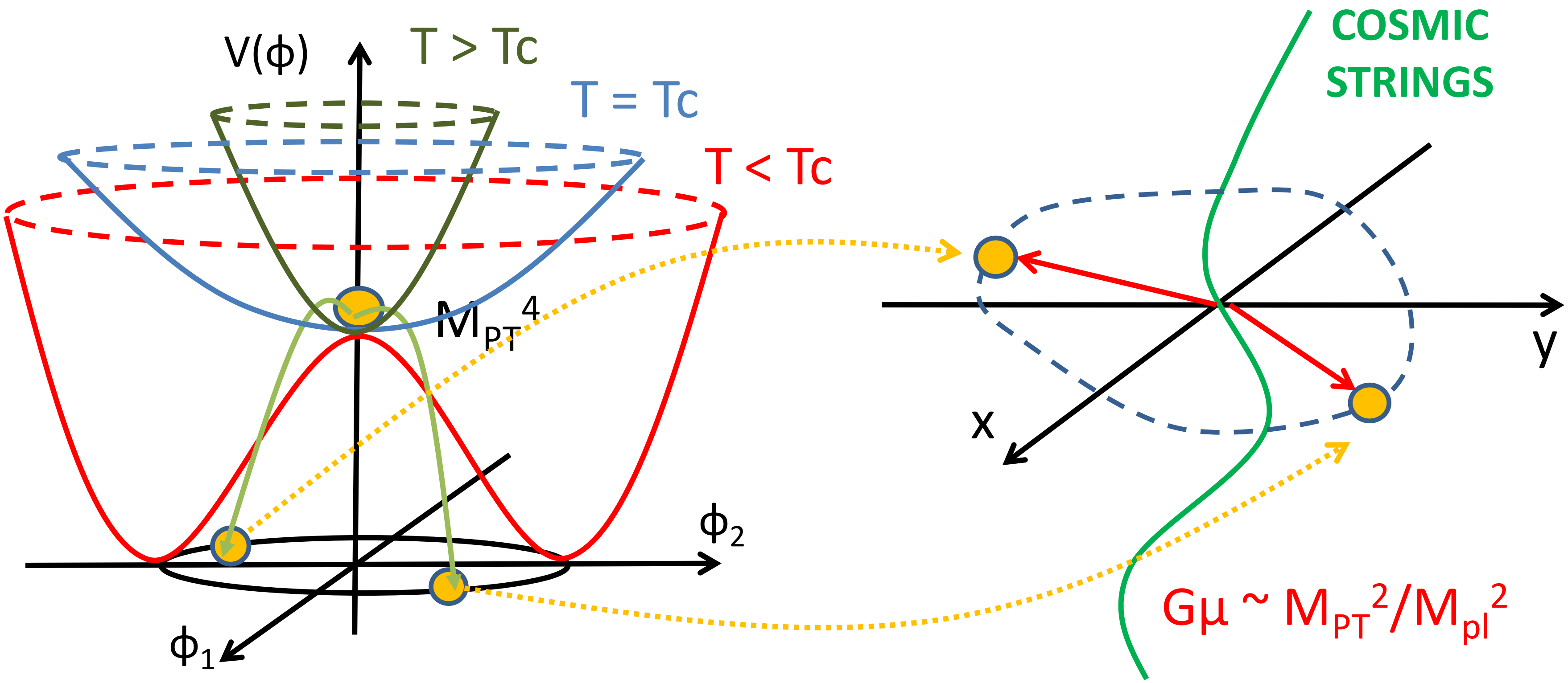


Old inflation
Chaotic inflation
Hybrid inflation
…
Brane inflation
(motivated by string theory)

1.1 : Conventional (field theoretic) cosmic strings

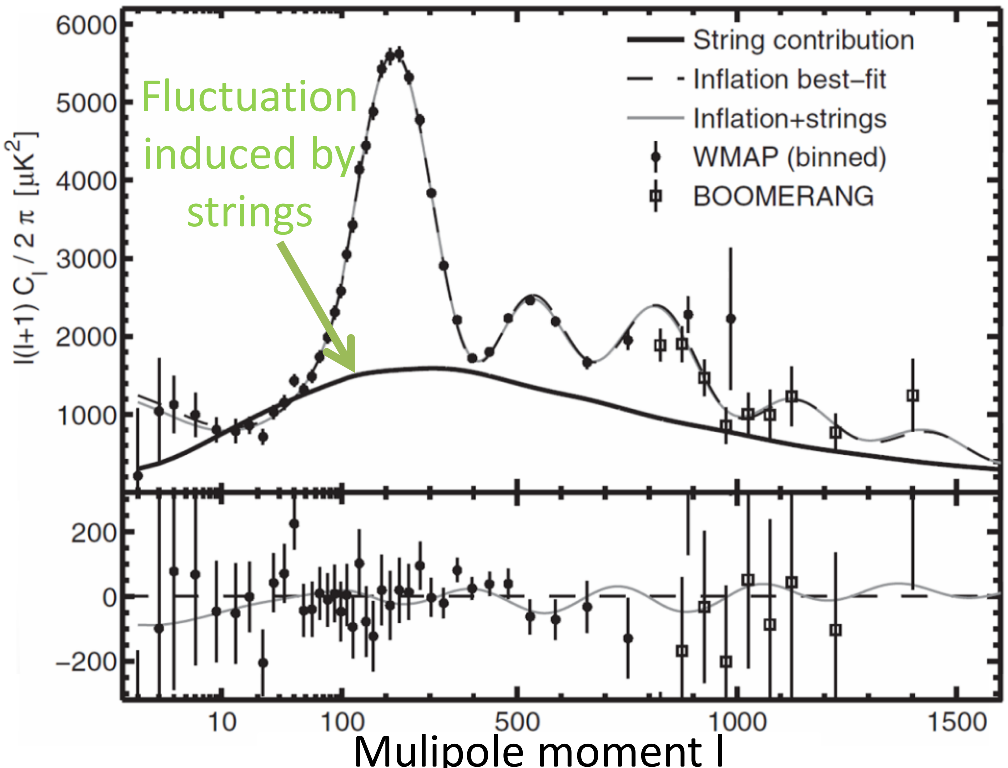
are line-like object formed in the early universe through spontaneous symmetry breaking. [Kibble ('76)]

→The non-trivial phase mapping from the internal space[left] to the physical space[right] leads to the formation of a cosmic string.



Observational verification of the existence of cosmic strings will have profound implications to unified theories !

1.2 : CMB constraints for standard cosmic strings



[Bevis, Hindmarsh, Kunz and Urrestilla, PRL100, 021301 ('08)]

Cf. [Pogosian, Tye, Wasserman and Wyman, JCAP 02 ('09) 013, etc...]

- Cosmic strings are excluded as a dominant source of the observed large-angular-scale anisotropy.

$$G\mu < 0.7 \times 10^{-6} \text{ (95\% C.L.)}$$

- Cosmic strings could still be observable at small scales with future arcmunutes experiments such as

✓**A**tacama **C**osmology **T**elescope (ACT : Fowler et al., 1001.2934)

✓**S**outh **P**ole **T**elescope (SPT : Lueker et al., 0912.4317).

1.3 : COSMIC SUPERSTRINGS

Fundamental strings and D-branes can be seen in the sky !?

- Naively,

$$G_4\mu_s \approx \mathcal{O}\left(\frac{M_s^2}{M_{\rm pl}^2}\right)$$

[cf. Witten, 1985]

$$\longleftrightarrow \quad G\mu_{\rm obs} < 0.7 \times 10^{-6}$$

- The "warping" naturally leads to low tension cosmic strings:

[e.g. Randall-Sundrum('99), Giddings, Kachru, Polchinski('02),...]

$$ds^2 = e^{2A(y)} g^{(4)}_{\mu\nu}(x)dx^\mu dx^\nu + e^{-2A(y)} g^{(6)}_{mn}(y)dy^m dy^n$$

$$\Rightarrow \quad T_{\mu\nu} = -\mu_s e^{2A(y)} g^{(4)}_{\mu\nu}\delta^8(x,y)$$

In a more general point of view, COSMIC SUPERSTRINGS are reasonably plausible (e.g. if a tachyonic phase transition occurs).

➢ Recent developments in string cosmology suggest that inflation may be due to motions of branes in higher dimensions and various new types of strings, called **COSMIC SUPERSTRINGS**, may be formed at the end of inflation.

One of the differences between **COSMIC SUPERSTRINGS** and conventional **FIELD-THEORETIC STRINGS** is the value of

THE INTERCOMMUTING PROBABILITY P !

- field theoretic strings (v<<1)

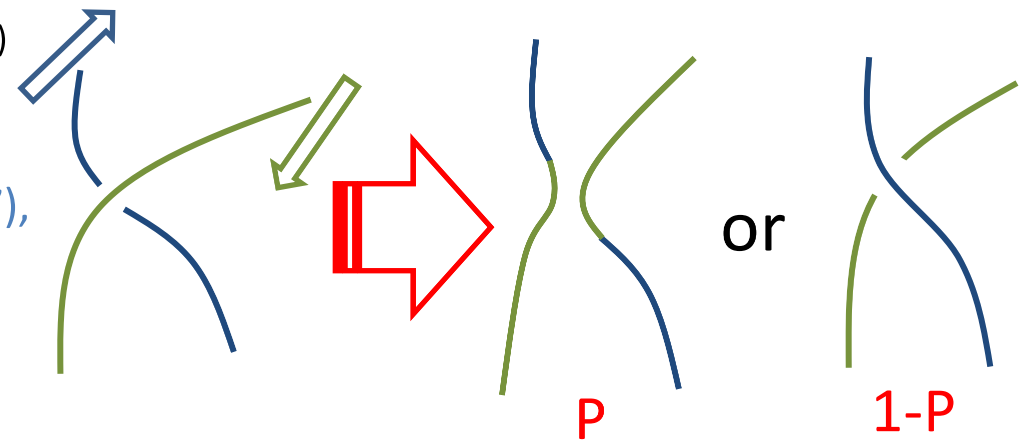
  : P = 1

  [Hashimoto, Tong('05), Eto et al.('07), and many numerical simulation]

- cosmic superstrings

  : P << 1

  [Jackson, Jones and Polchinski ('05), Hanany and Hashimoto ('05)]



Goal

✓We present a new analytic method to calculate the small scale CMB temperature power spectrum due to field-theoretic cosmic strings/cosmic superstrings.

✓ We clarify the dependence on the intercommuting probability P, namely COSMIC SUPERSTRINGS.

✓We estimate the upper bound of the dimensionless tension of the string "$G\mu$" for various value of P.

2.1 : Evolution of cosmic (super-)string network

➢ A string network is assumed to consist of string segment with the correlation length ξ , and the root-mean-square velocity v_{rms} :

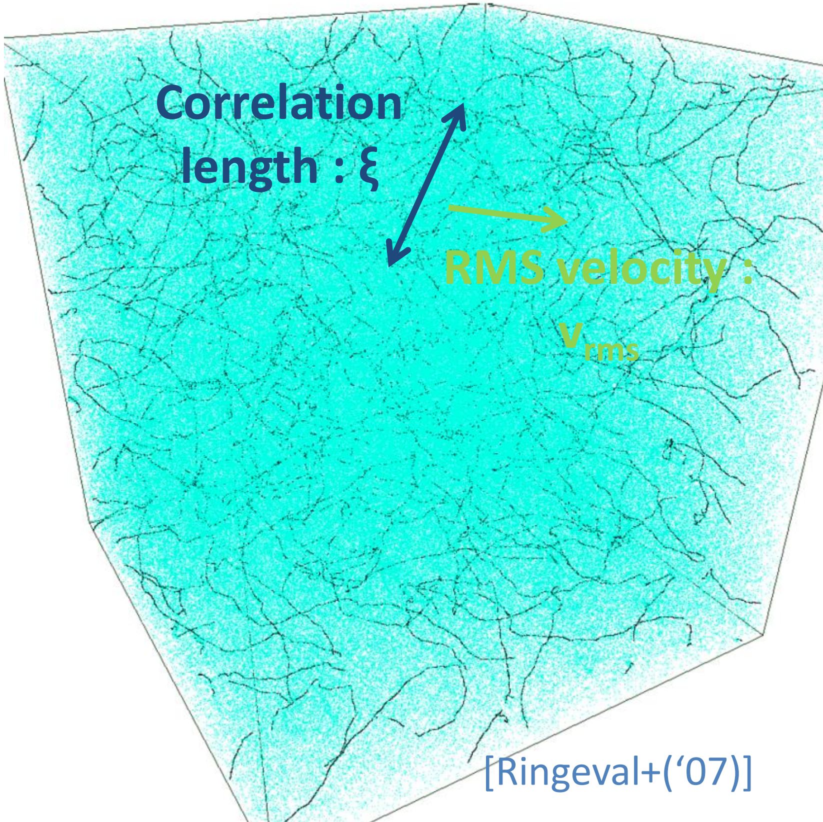
$$\rho_{\rm str} = \frac{1}{\xi^3} \times \mu\xi = \frac{\mu}{\xi^2} \qquad \xi = \frac{1}{H\gamma}$$

➢ The characteristic time scale of the interval of the loop formation :

create a loop with length cξ

collision rate

$$\frac{\Delta\rho_{\rm str}}{\Delta t} \approx -\frac{\mu\tilde{c}\xi \times (P v_{\rm rms}/\xi)}{\xi^3}$$



[Ringeval+('07)]

✓ Velocity dependent one-scale model (VOS)

$$\begin{cases} \dfrac{t}{\gamma}\cancel{\dfrac{d\gamma}{dt}}^{\,0} = \dfrac{1}{3}\left[\left(1 - v_{\rm rms}^2\right) - \underbrace{\tilde{c} P v_{\rm rms} \gamma}_{\text{Loop formation}}\right] & \text{: Energy conservation} \\ \cancel{\dfrac{d v_{\rm rms}}{dt}}^{\,0} = \left(1 - v_{\rm rms}^2\right) H \left[\underbrace{k(v_{\rm rms})}_{\text{Curvature acceleration}}\gamma - 2 v_{\rm rms}\right] & \text{: EOM} \end{cases}$$

$$k(v_{\rm rms}) = \frac{2\sqrt{2}}{\pi}\frac{1 - 8v_{\rm rms}^6}{1 + 8v_{\rm rms}^6}$$

Assuming the SCALING (scale∝1/H) is already realized by the last scattering surface, **γ** and **v_{rms}** are asymptotically constant in time:

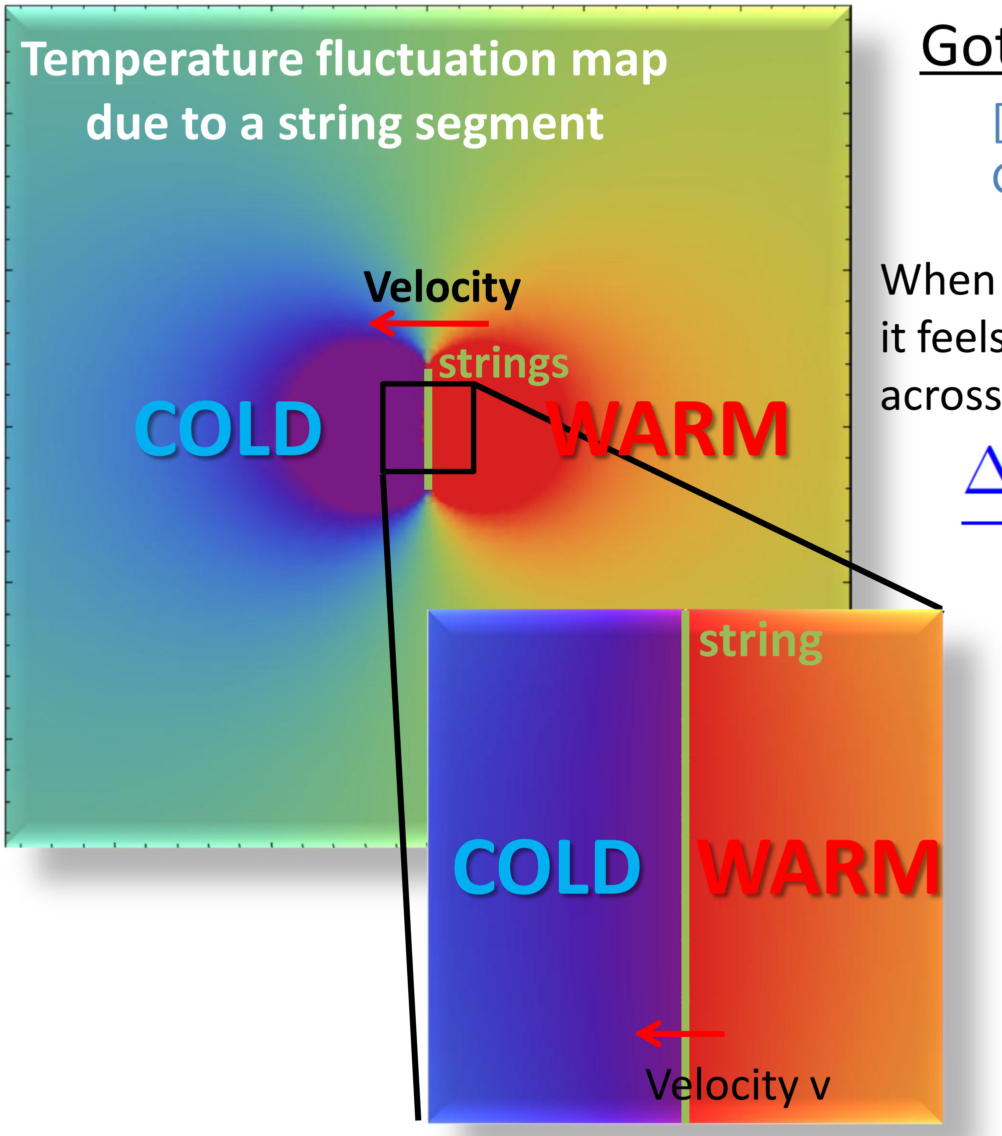
$$\gamma \approx \sqrt{\frac{\pi\sqrt{2}}{3\tilde{c}P}} \quad \Longrightarrow \quad \rho_{\rm str} = \frac{\mu}{\xi^2} = \frac{\mu}{H^2}\gamma^2 \propto \frac{1}{P}$$

: Scaling solution incorporating P

[Takahashi,***DY*** +(‘09), **DY** +(‘10)]]

[see also Martins+Shellard (’96, ’02), Avgoustidis+Shellard (‘06)]

2.2 : Signal from straight strings



Gott-Kaiser-Stebbins (GKS) effect

[Kaiser, Stebbins, Nature 310 (‘84)391,
Gott III, ApJ 288, 422 (‘85)]

When a photon passes by a moving straight string, it feels a discontinuities of gravitational potential across the string segment :

$$\frac{\Delta T_{\rm GKS}}{T} = 4\pi \frac{v}{\sqrt{1-v^2}} \alpha_{\rm seg} G\mu$$

➢The CMB photons are scattered by a number of moving string segments, hence the observed fluctuations appears as a superposition of the discontinuities.

$$\frac{\Delta T_{\rm total}}{T} = \sum_i \left(\frac{\Delta T_{\rm GKS}}{T} \right)_{(i)}$$

i :segment index

3.1 : Analytic model for power spectrum due to CS

[***DY***, Takahashi, Sendouda, Yoo, Sasaki, 1006.0687]

In order to compute the angular power spectrum due to CS, we use what we call the *SEGMENT FORMALISM*, by adapting from the halo formalism for the Sunyaev-Zel'dovich effect :

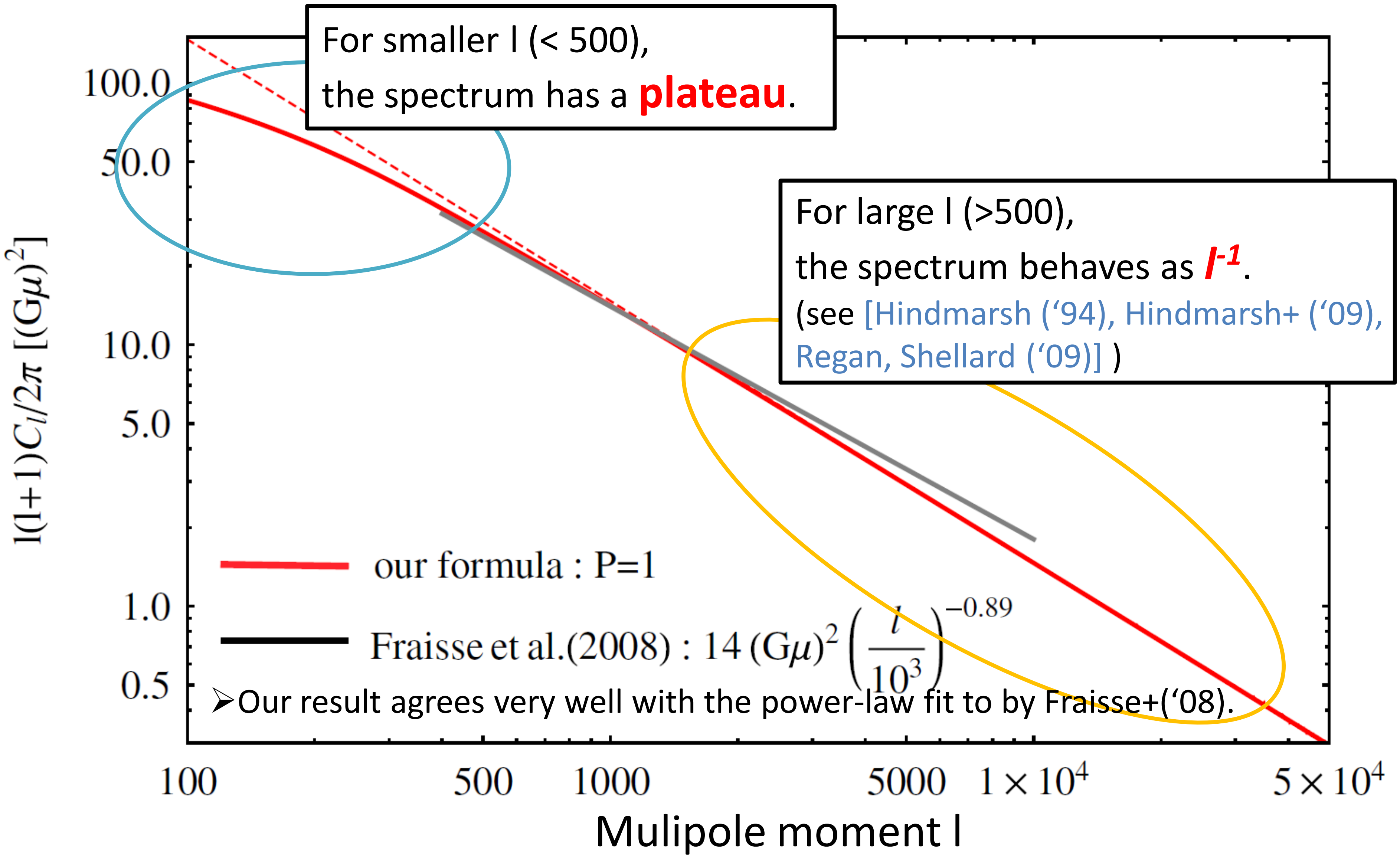
[cf . Komatsu, Seljak (2002), Komatsu, Kitayama (1999),...]

$$C_\ell \approx \int_0^{z_{\rm LSS}} \underbrace{dz \frac{dV}{dz}}_{\text{: differential comoving volume element at redshift z}} \int \underbrace{d\boldsymbol{\Theta} \cdot \frac{dn}{d\boldsymbol{\Theta}}}_{\text{: comoving number density of segments with the configuration parameter } [\boldsymbol{\Theta},\, \boldsymbol{\Theta}+d\boldsymbol{\Theta}]} \mathcal{G}_\ell(\boldsymbol{\Theta}, z)$$

with $\mathcal{G}_\ell(\boldsymbol{\Theta}, z) = \int \frac{d\hat{\varphi}_\ell}{2\pi} \left| a_\ell(\boldsymbol{\Theta}, z) \right|^2$

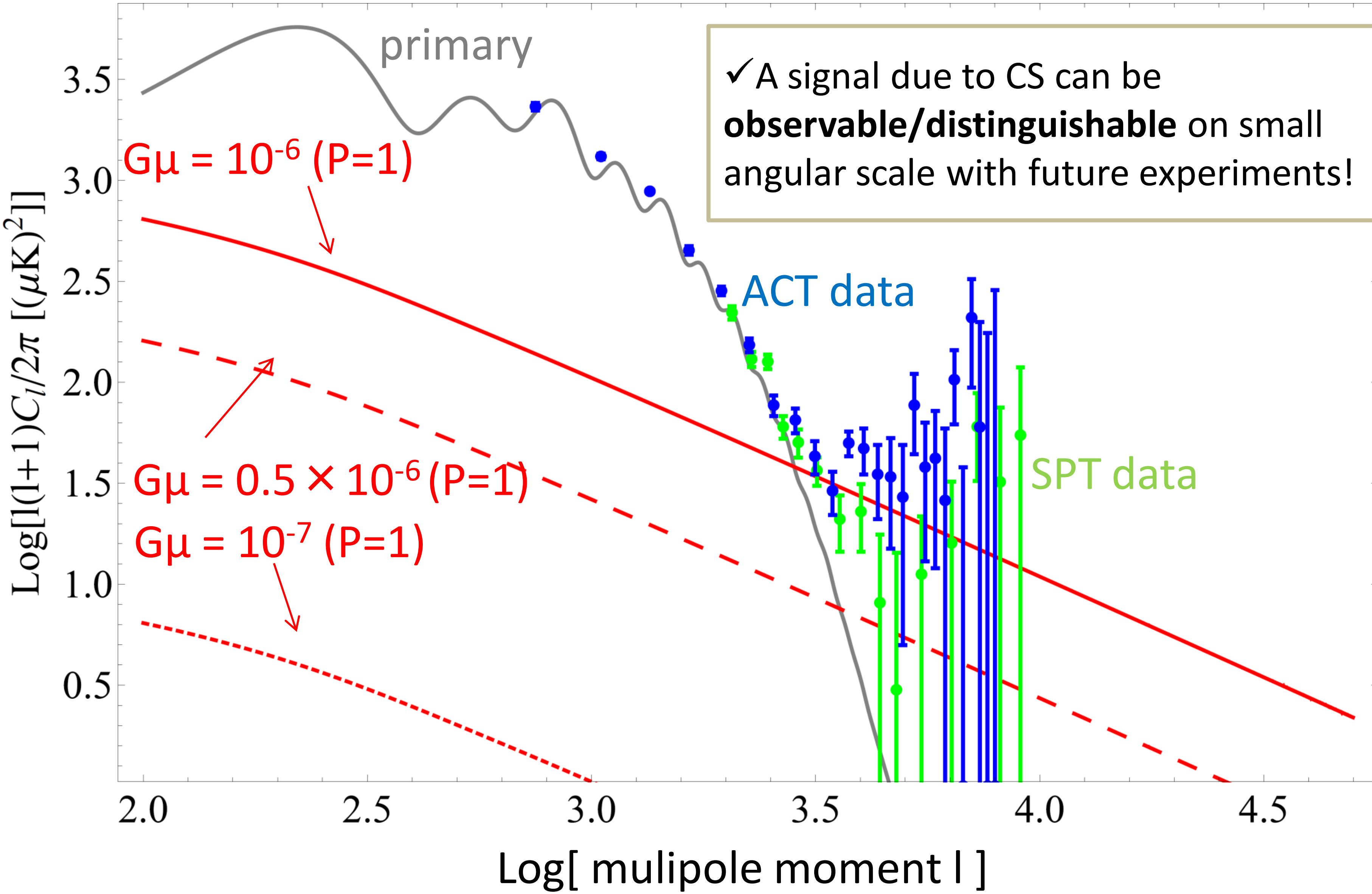
: power spectrum due to a string with configuration parameter vector **Θ** and redshift z

3.2 : Spectrum due to CONVENATIONAL STRINGS



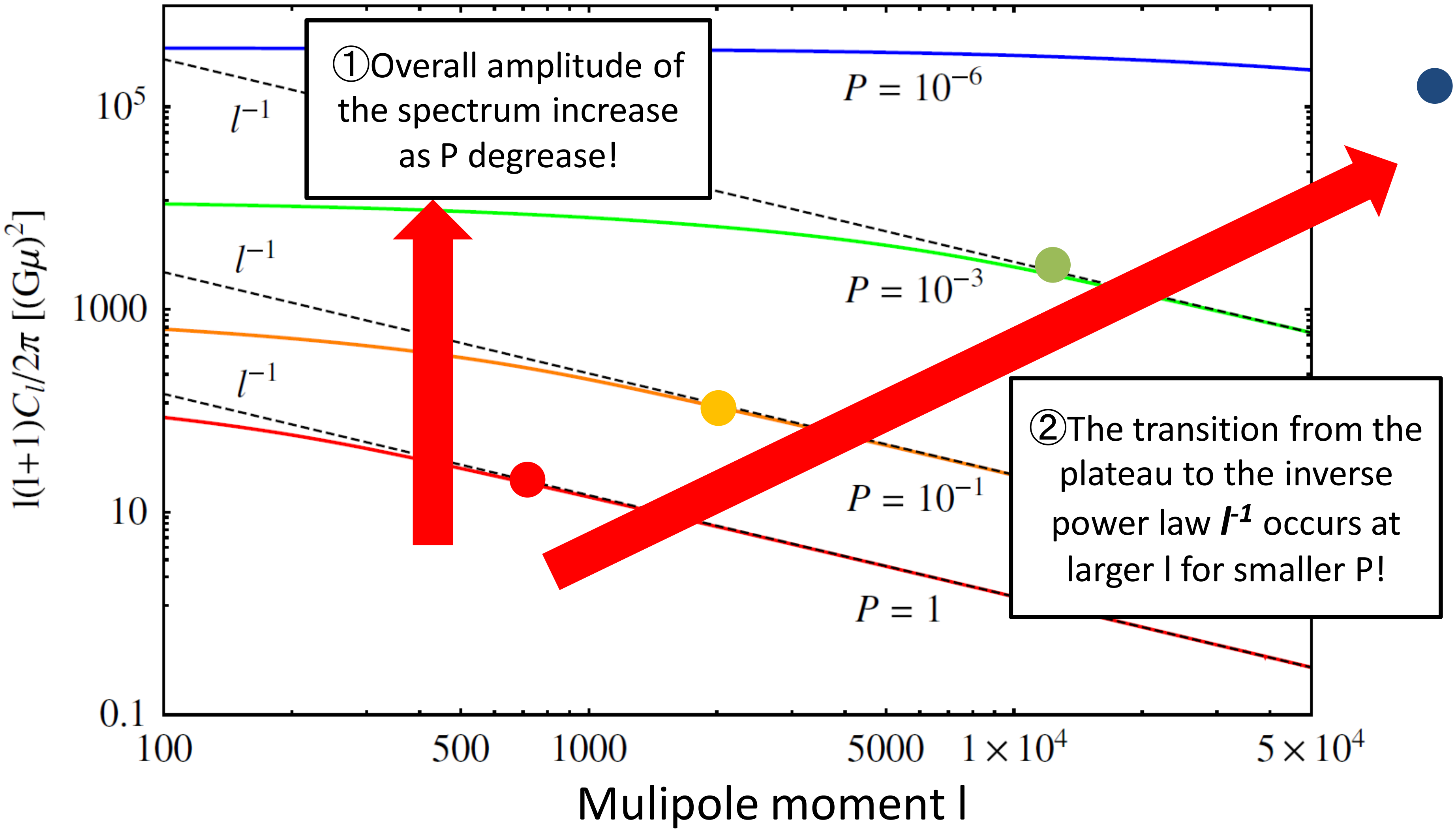
➢Our result agrees very well with the power-law fit to by Fraisse+('08).

3.2 : Spectrum due to CONVENATIONAL STRINGS



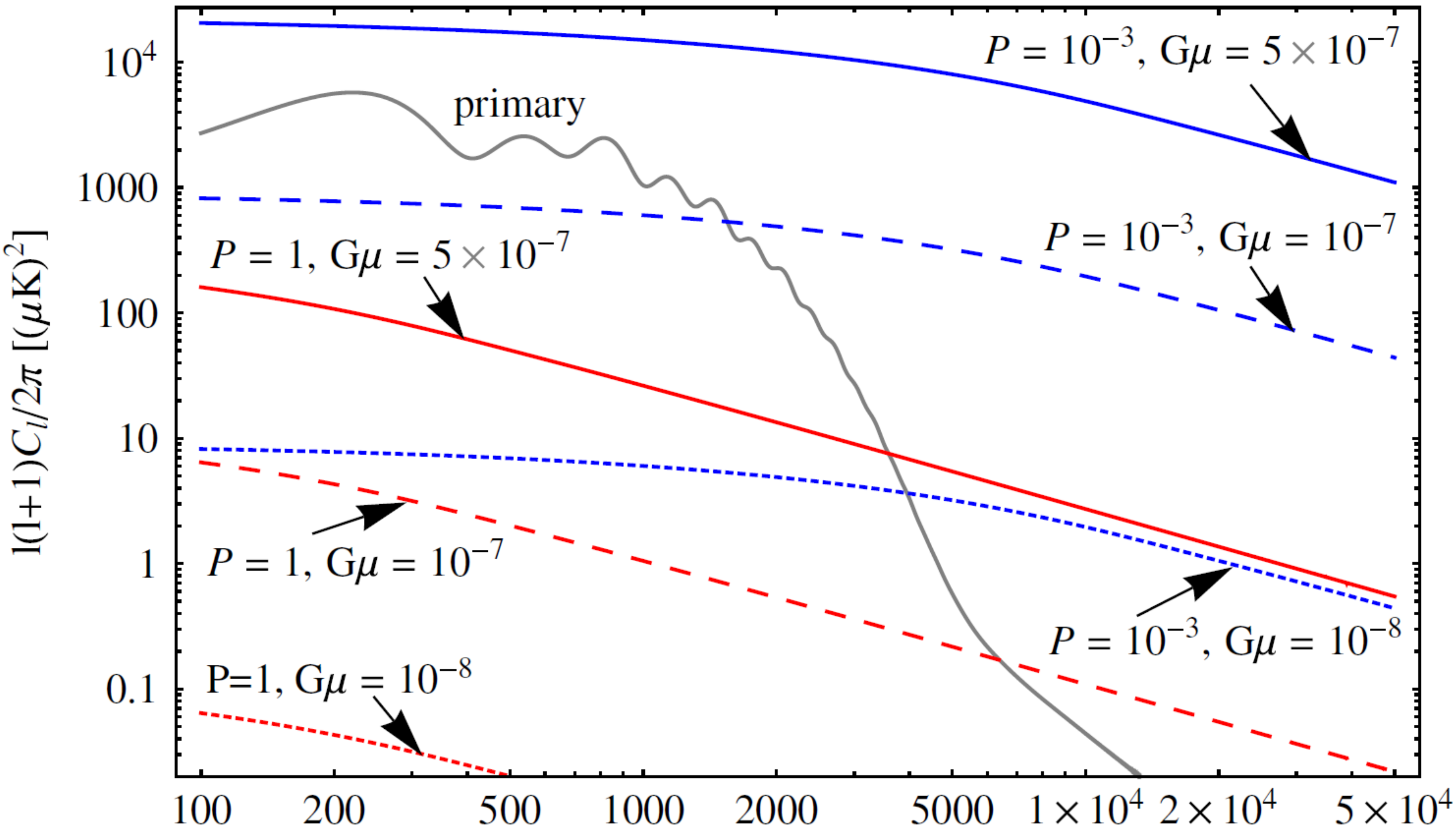
✓A signal due to CS can be **observable/distinguishable** on small angular scale with future experiments!

3.3 : Spectrum due to COSMIC SUPERSTRINGS



These properties of the power spectrum may becomes a useful tool to distinguish the value of P, namely COSMIC SUPERSTRINGS, in future experiments !

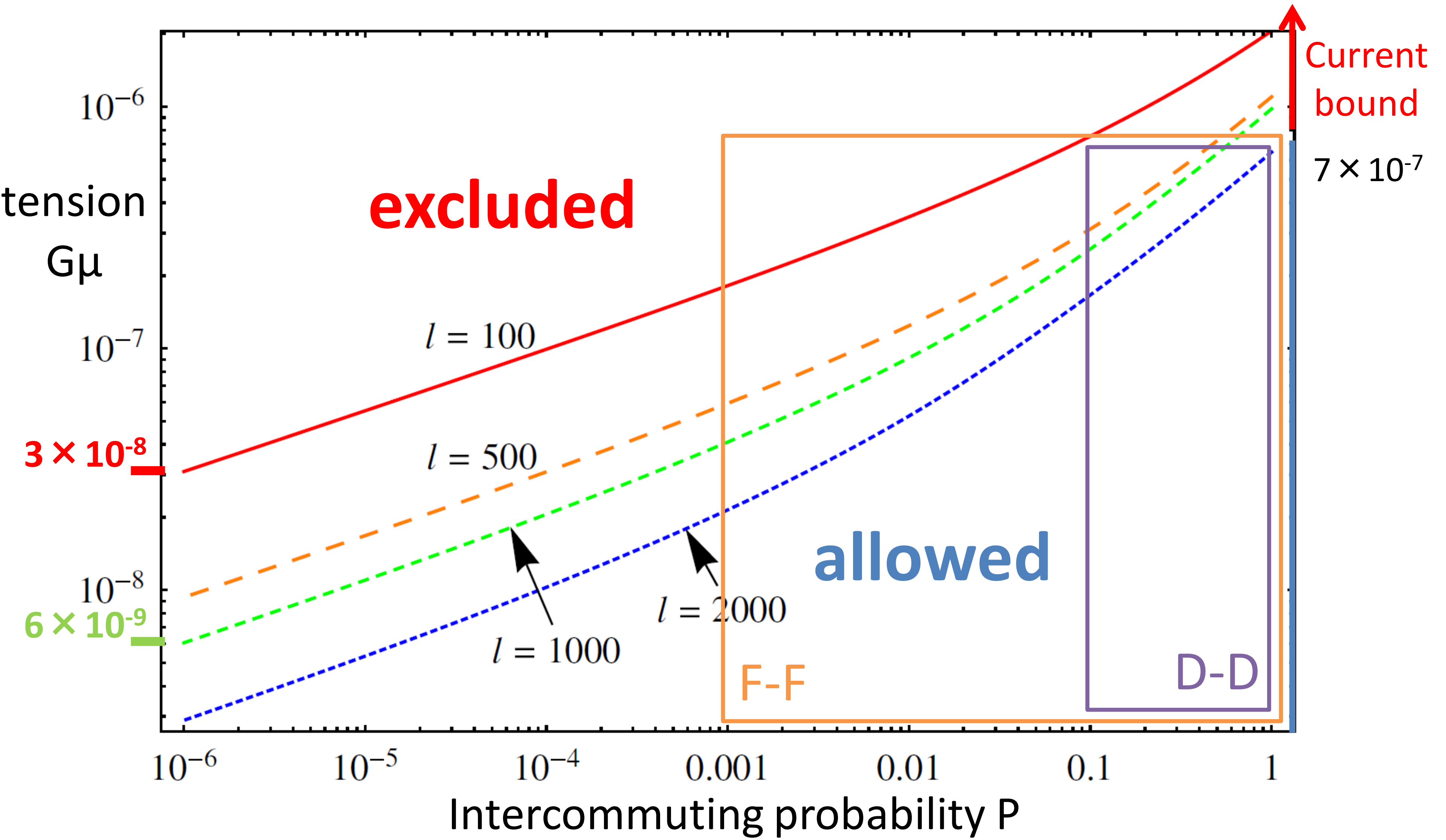
3.3 : Spectrum due to COSMIC SUPERSTRINGS



✓As P degreases the amplitude due to strings increases, hence the tension of strings with smaller P is tightly constrained !

3.4 : Constraints on string tension Gμ

➢Assuming that the fraction of the spectrum due to strings is less than 10% at various l,



4 : Summary

- We presented a new analytic method to calculate the small angle CMB temperature power spectrum due to cosmic (super-)strings, and investigated the dependence of the power spectrum on the intercommuting probability P.

- The small angle power spectrum is found to behave as l^{-1} for large l and have a plateau for small l.

- Using our result, we discussed an upper bound on the dimensionless tension Gμ as a function of P. Assuming that the fraction of the CMB spectrum due to strings is less than 10%, strings with small P are more tightly constrained.

- These properties of the power spectrum are distinguishable features of cosmic superstrings.