Imprints of cosmic strings in late-time scaling scenario

based on: KK, Y. Miyamoto, D. Yamauchi & J. Yokoyama, arXiv:1407.2951

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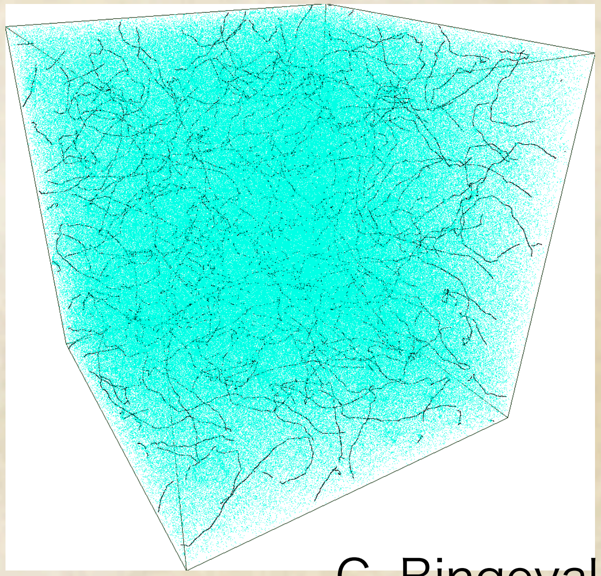
SEWM14, 17/7/2014, EPFL

Courtesy H.Oide

Introduction

Cosmic string...

- Line-like topological defect associated with symmetry breaking.
- Almost unavoidably produced when GUT breaks down to the Standard Model gauge group.



C. Ringeval+ ('07)

e.g.) R. Jeannerot+ ('03)

$$
4_{\rm C}\ 2_{\rm L}\ 2_{\rm R}
\begin{cases}
\xrightarrow{1}\ 3_{\rm C}\ 2_{\rm L}\ 2_{\rm R}\ \underline{1_{\rm B-L}}
\begin{cases}
\xrightarrow{1}\ 3_{\rm C}\ 2_{\rm L}\ 1_{\rm R}\ \underline{1_{\rm B-L}} \xrightarrow{2\ (2)} {\rm G_{SM}}\ (Z_2) \\
\xrightarrow{2'\ (2)}\ {\rm G_{SM}}\ (Z_2)
\end{cases} \\
\xrightarrow{1}\ 4_{\rm C}\ 2_{\rm L}\ 1_{\rm R}
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\xrightarrow{1\ (1,2)}\ {\rm G_{SM}}\ (Z_2)
\end{cases}
$$

cosmic strings

Study of cosmic string can lead to the understanding of the nature of the Standard Model and possibly the electroweak and strong forces.

Courtesy H.Oide

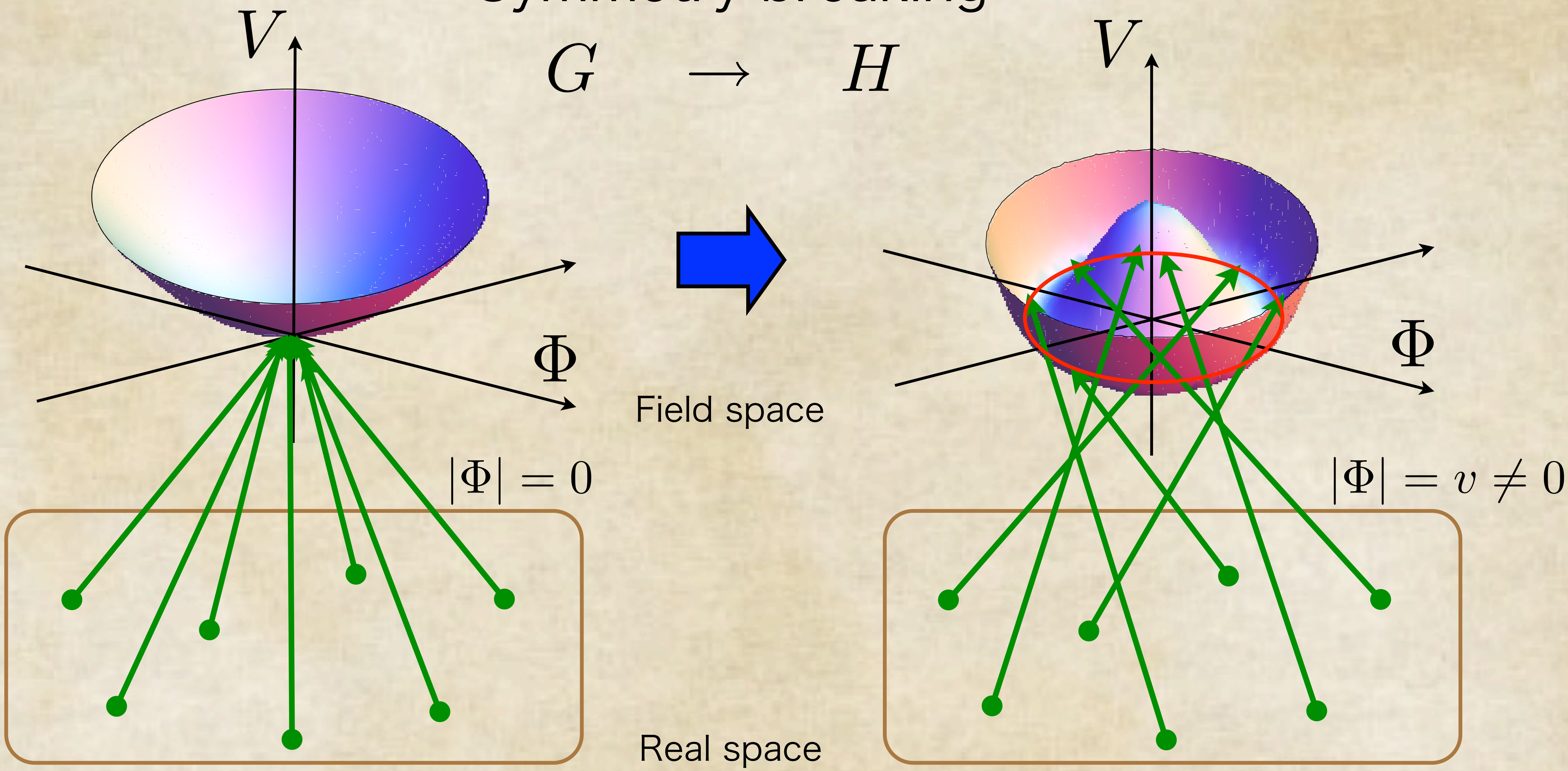
Cosmic string formation

Kibble mechanism (Kibble '76)

Symmetries can be restored in the early Universe,
and broken down during the course of cosmic history.

Symmetry breaking

$$G \quad \rightarrow \quad H$$

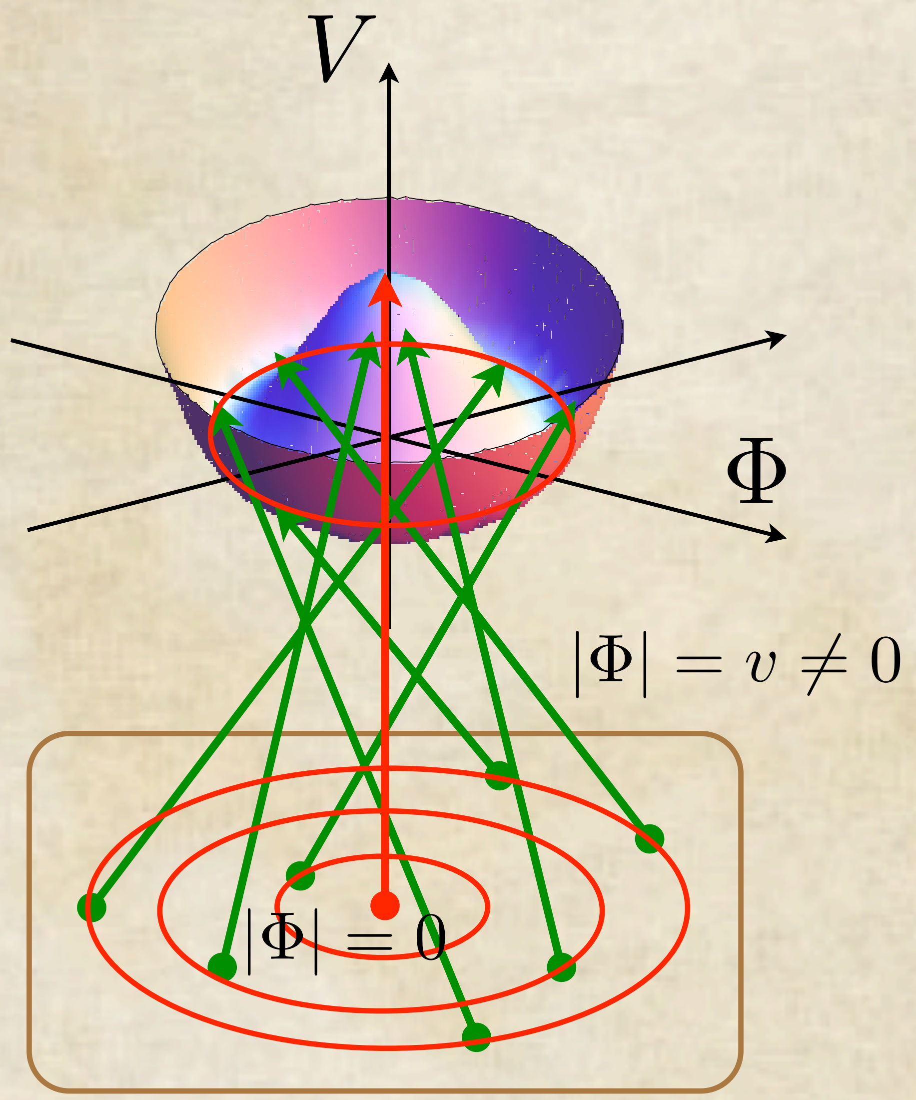


Courtesy H.Oide

When a symmetry is broken, cosmic strings are formed
if the vacuum manifold is S^1 or $\pi_1(G/H) \neq 0$.

(or when U(1) symmetry is broken)

Kibble mechanism (Kibble '76)



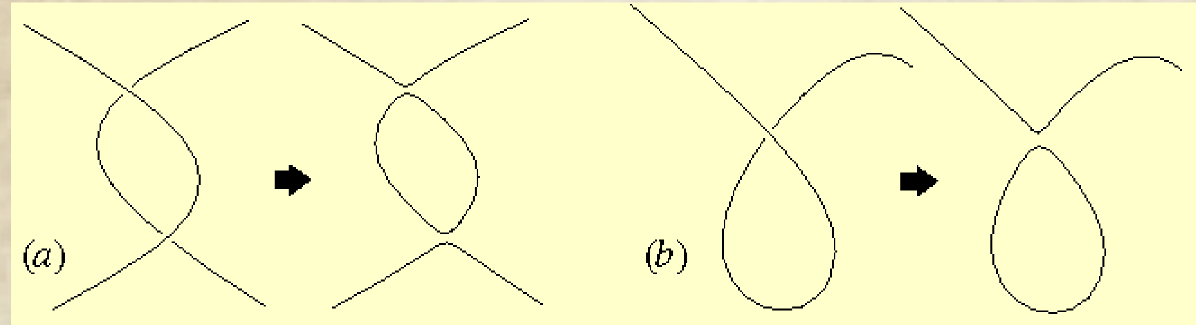
Higgs field in the vacuum manifold distributes randomly at the scale larger than the correlation scale.

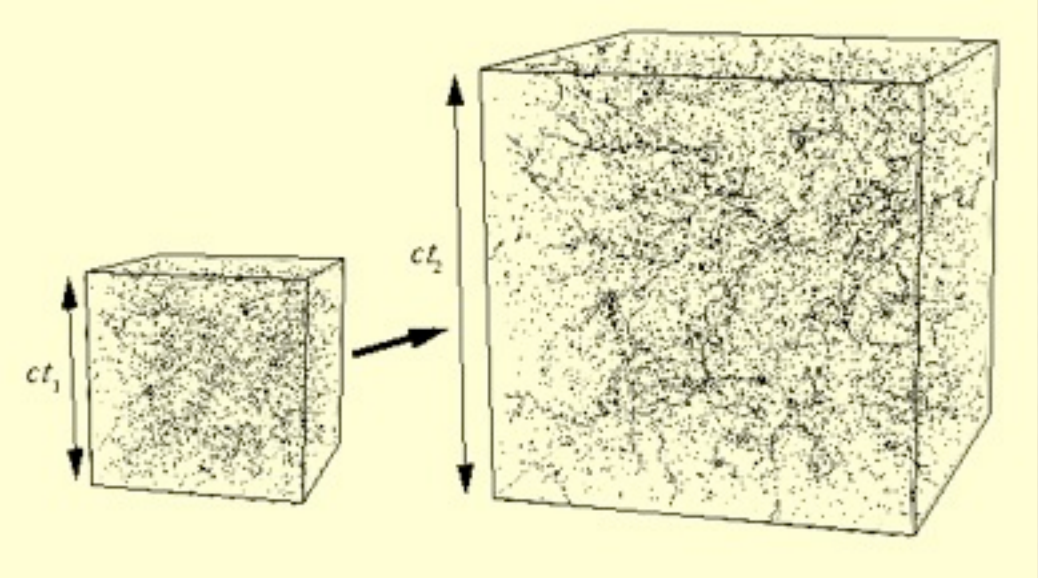
There must be line-like points in the real space where Higgs field cannot fall down to the vacuum, $|\Phi| = 0$, from the topological reason. (At that point, the energy density remains high.)

Such field configuration is topologically stable and hence we call it "topological defects".

Scaling behavior of the cosmic string network (Kibble '85)

The energy density of cosmic strings decays as a^{-2} and hence they may overclose the Universe if they are produced in the early Universe...





However, cosmic string network forms loops when they intersect, and hence its characteristic scale remains constant relative to the Hubble length.

-> They do not overclose the Universe!

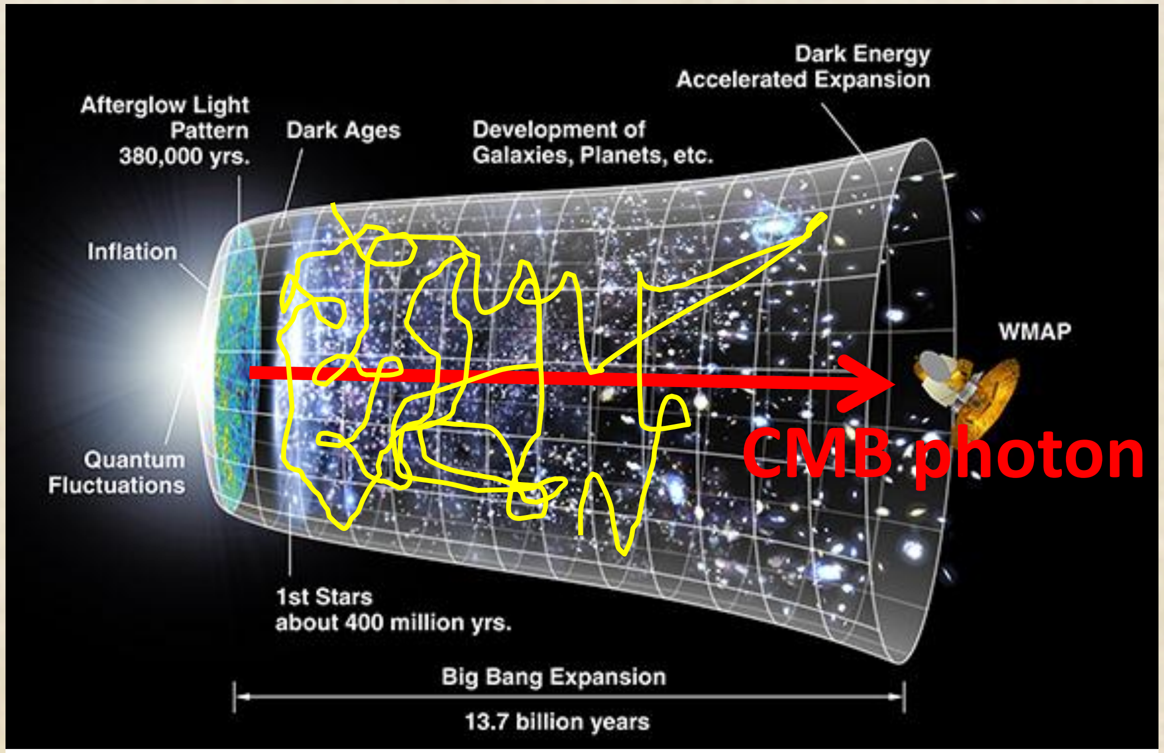
=> They are still in our Universe, and it is possible to observe their traces in CMB, GWB, or cosmic rays.

Traces of cosmic strings in CMB

(Albrecht+ '97; Seljak+ '97)

cosmic strings between the last scattering surface and us generates the fluctuation of CMB temperature/polarization.

From slide of T.Suyama



From WMAP homepage

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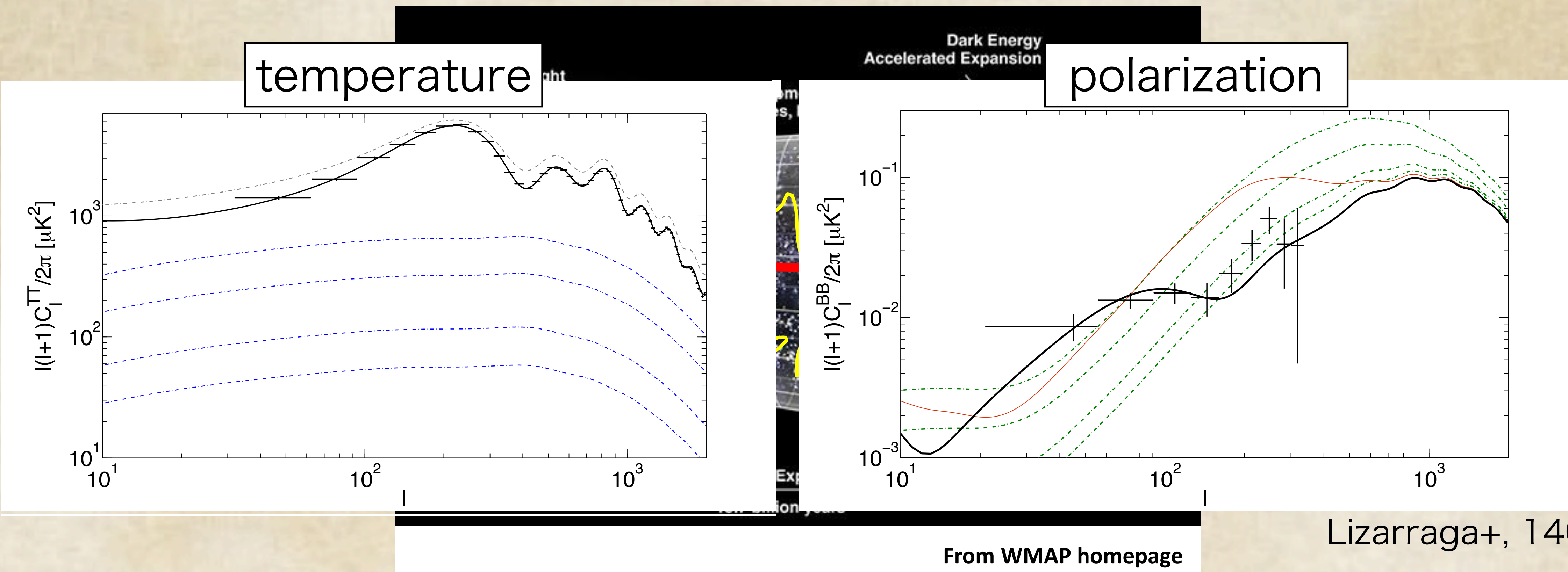

Lizarraga+, 1403.4924

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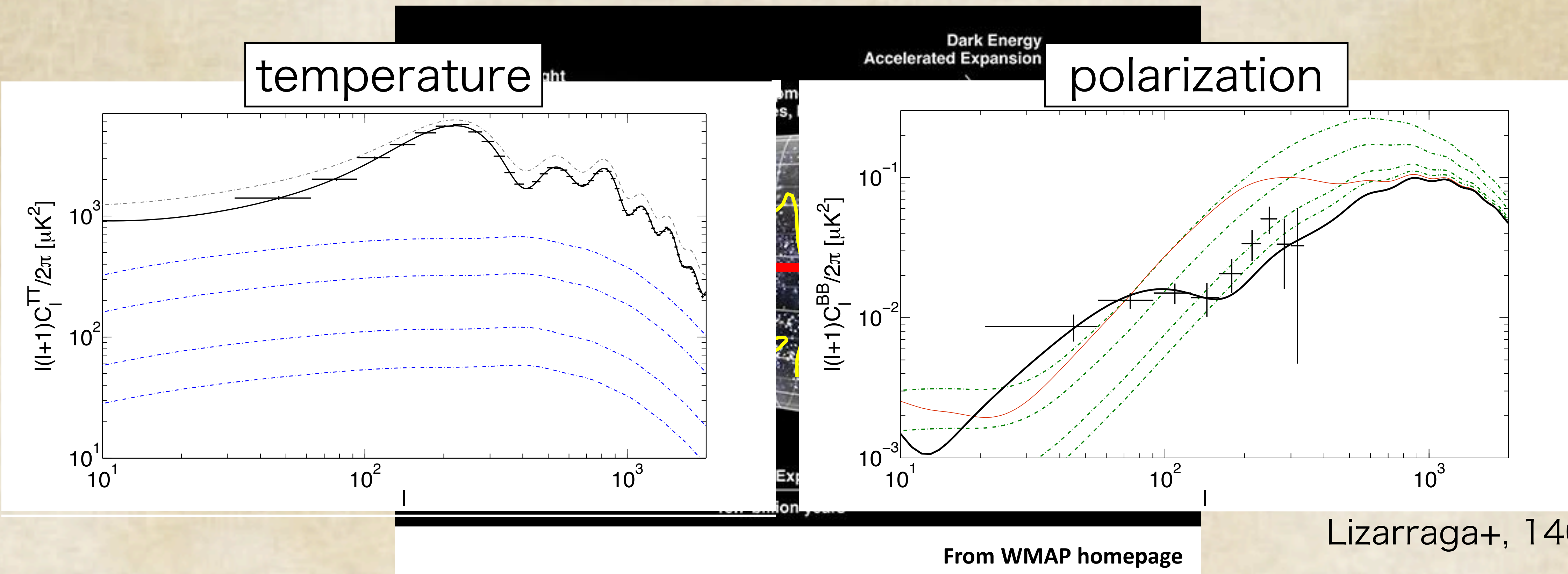

Lizarraga+, 1403.4924

Planck temperature observation gives the strong constraint on the cosmic string tension; $G\mu \lesssim (1-3)\times 10^{-7}$ (Planck collaboration, 1303.5085)

Related to the symmetry breaking scale.
#CMB can see them only through gravity.

There are uncertainties in the model of cosmic string.

Delayed scaling scenario

(Lazarides+ ’84; Vishniac+ ’87; Yokoyama, ’88; KK+ ’12)

The discussion for the effect on CMB is based on the assumption that the cosmic string entered the scaling regime well before recombination.

-> Observational predictions are very generic.

It is true for the case of hybrid inflation or thermal-mass triggered phase transition.

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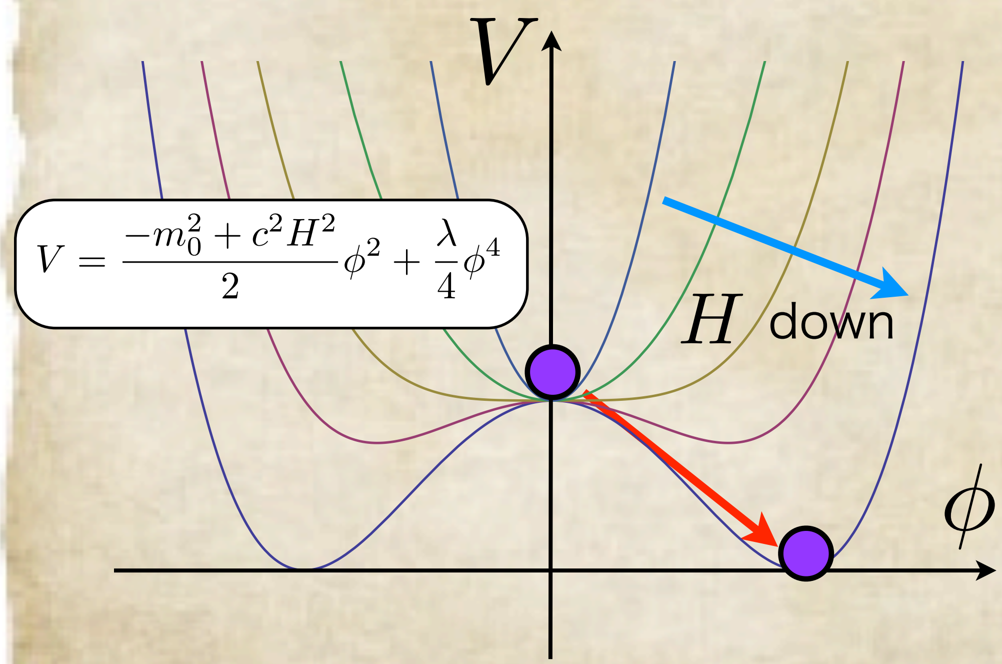
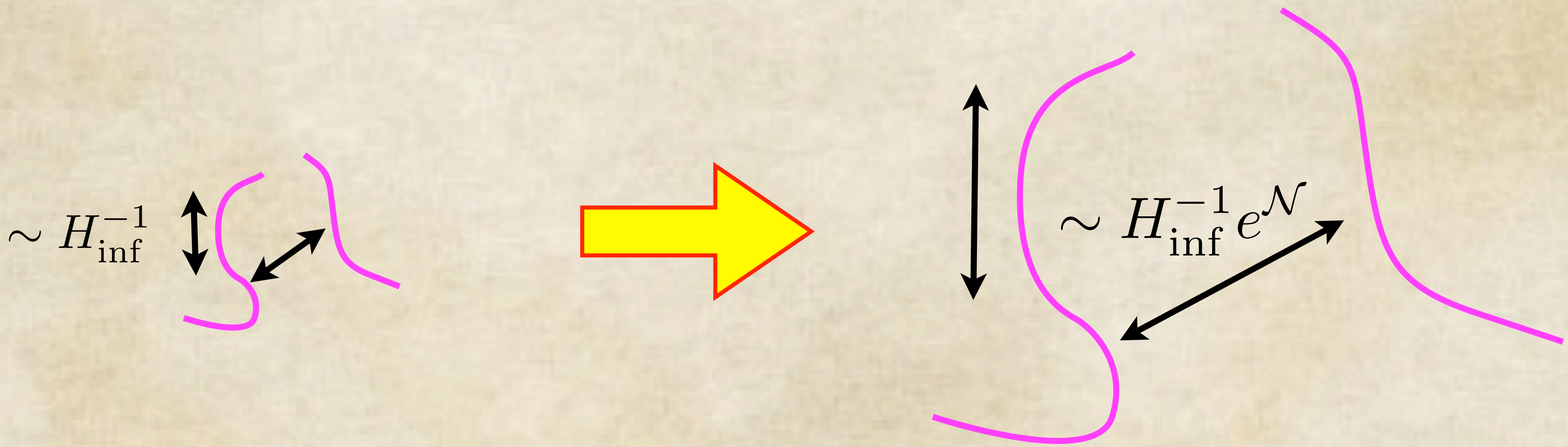
However, it is possible for the phase transition to take place DURING inflation, since the symmetry is naturally restored during inflation due to the "Hubble-induced" mass, $c^2H^2\phi^2$ coming from

- non minimal coupling to gravity: $\xi\phi^2R$
- direct coupling between inflaton and Higgs: $\kappa\phi_{\rm inf}^2\phi^2$
- gravitational coupling in SUSY F-term inflation: $e^{|\phi|^2/M_{\rm Pl}^2}V_{\rm inf}$
- and so on...



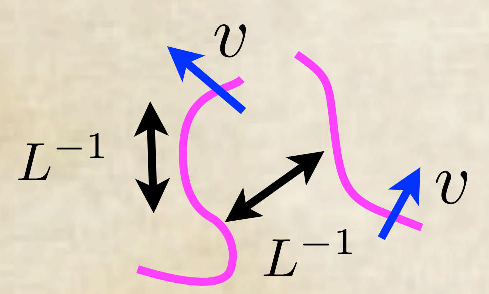
If the Hubble-induced mass and zero-temp. mass are comparable and Hubble parameter decreases relatively largely, cosmic string can be formed during inflation.

The characteristic length, which would be the Hubble length at CS formation, gets exponentially long at the end of inflation.



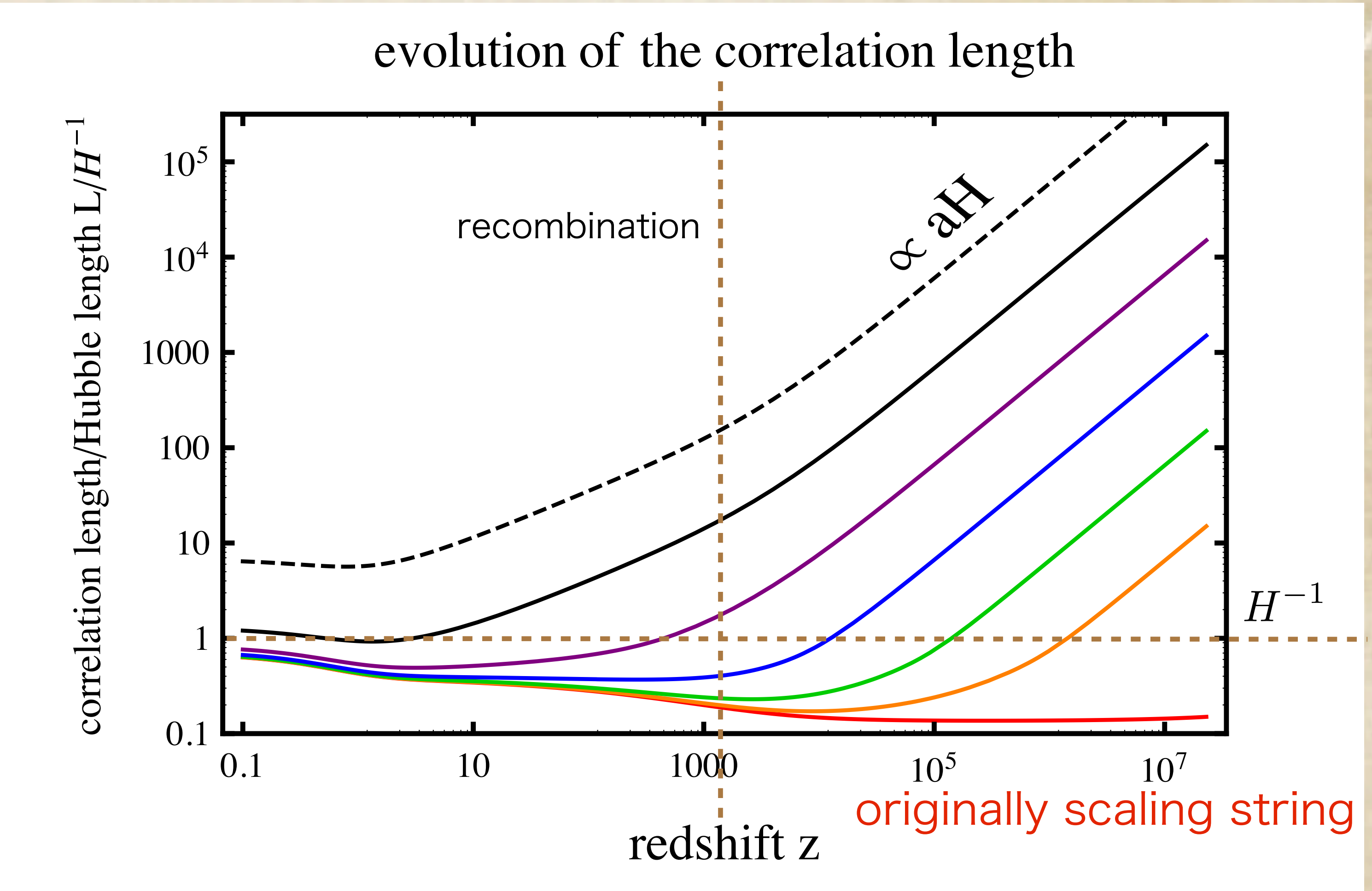
At the end of inflation, CSs are distributed at the superhorizon scales, and characteristic length evolves just $\propto a$ after that.

Adopting velocity-dependent one-scale model (approximation), we find the typical evolution of the correlation length of CS network and how the system would approach the scaling regime. (Martins+ '96, '00)



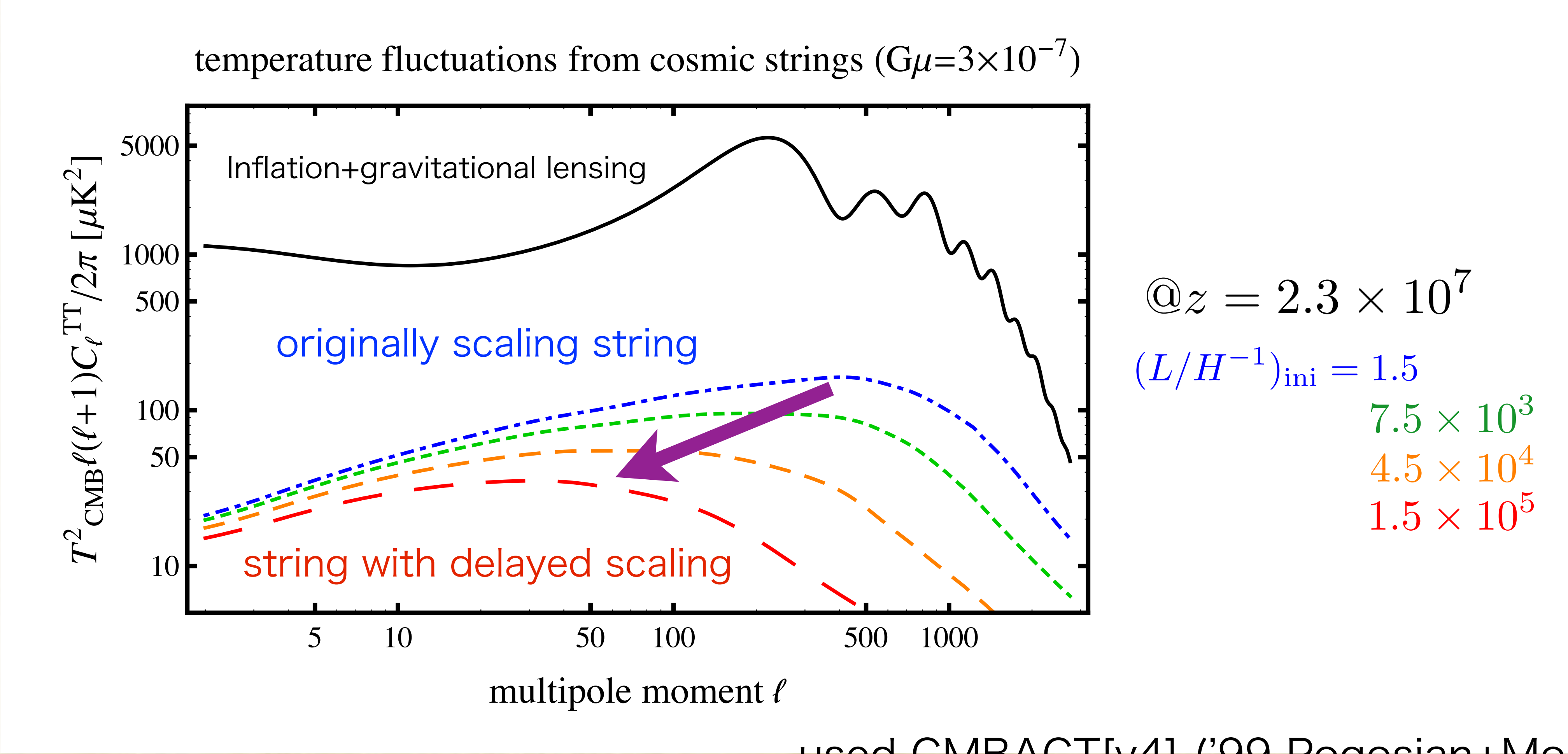
$$\frac{dL}{dt} = (1+v^2)HL + \frac{1}{2}\tilde{c}v$$

$$\frac{dv}{dt} = (1-v^2)\left(\frac{\tilde{k}(v)}{L} - 2Hv\right)$$



It takes a few orders of redshift for the system to enter the scaling regime after the characteristic length comes to subhorizon scales.

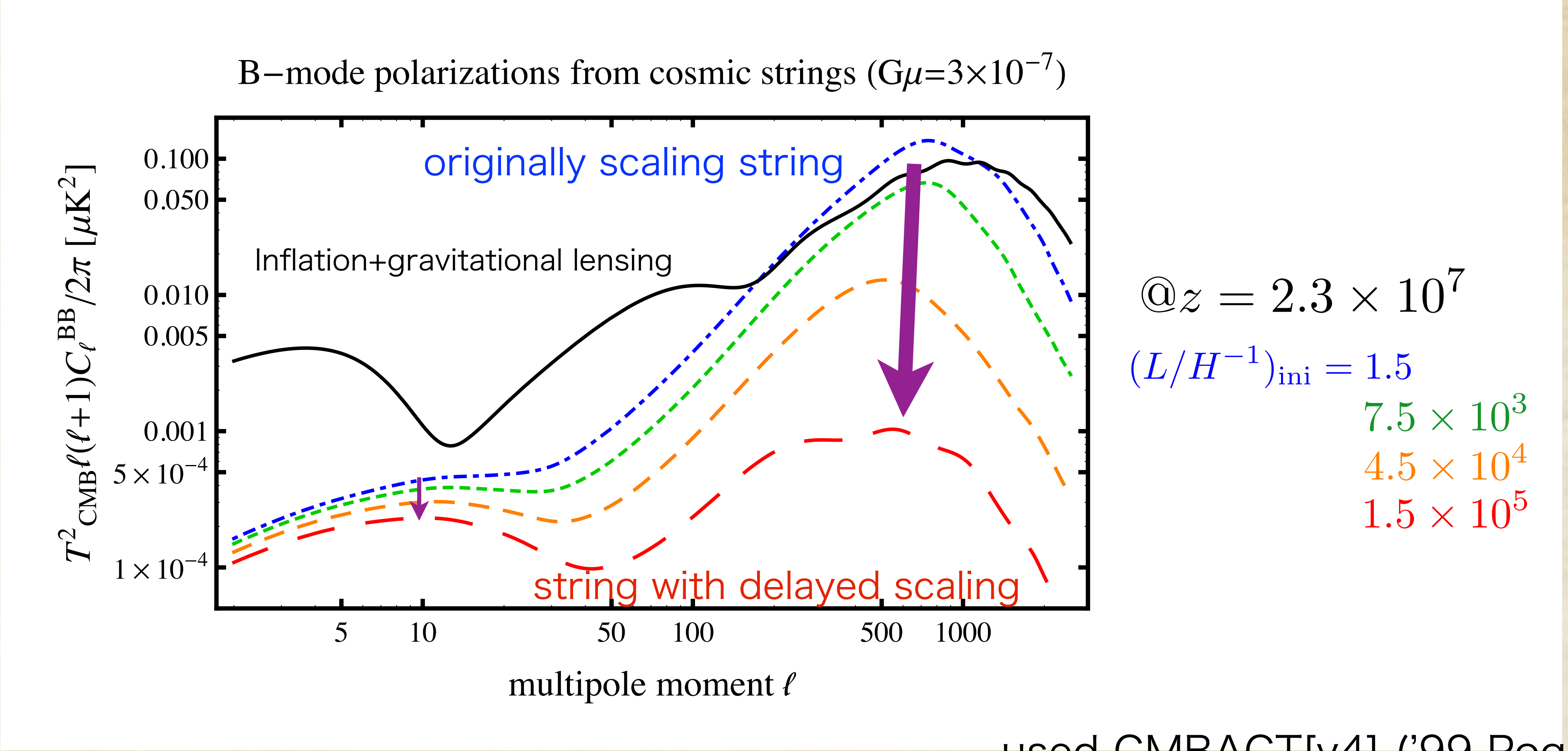
String-induced CMB temperature fluctuations



used CMBACT[v4] ('99 Pogosian+Moss)

The position of the peak is determined by the time when the network enters the scaling regime.

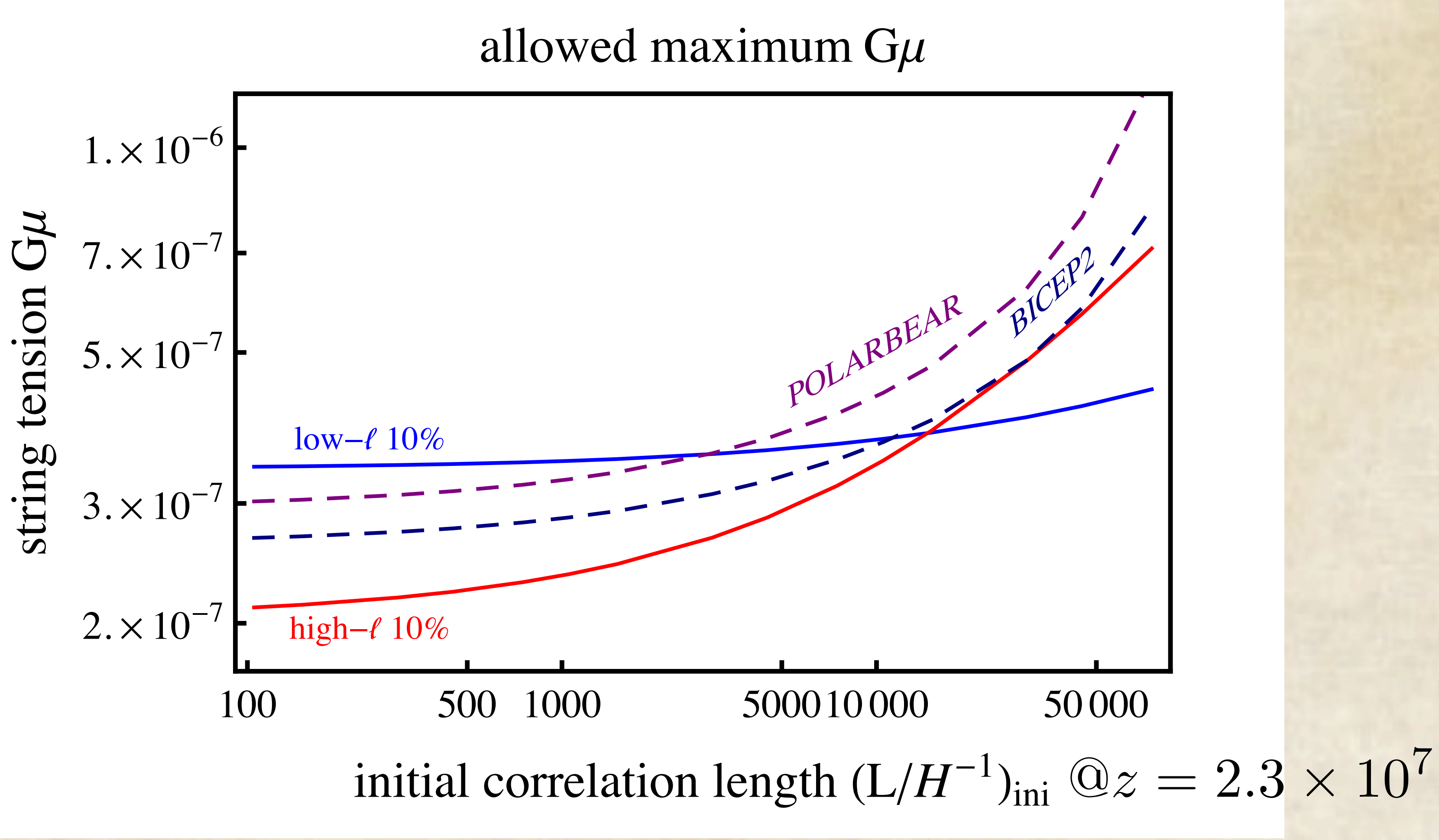
String-induced CMB polarization fluctuations



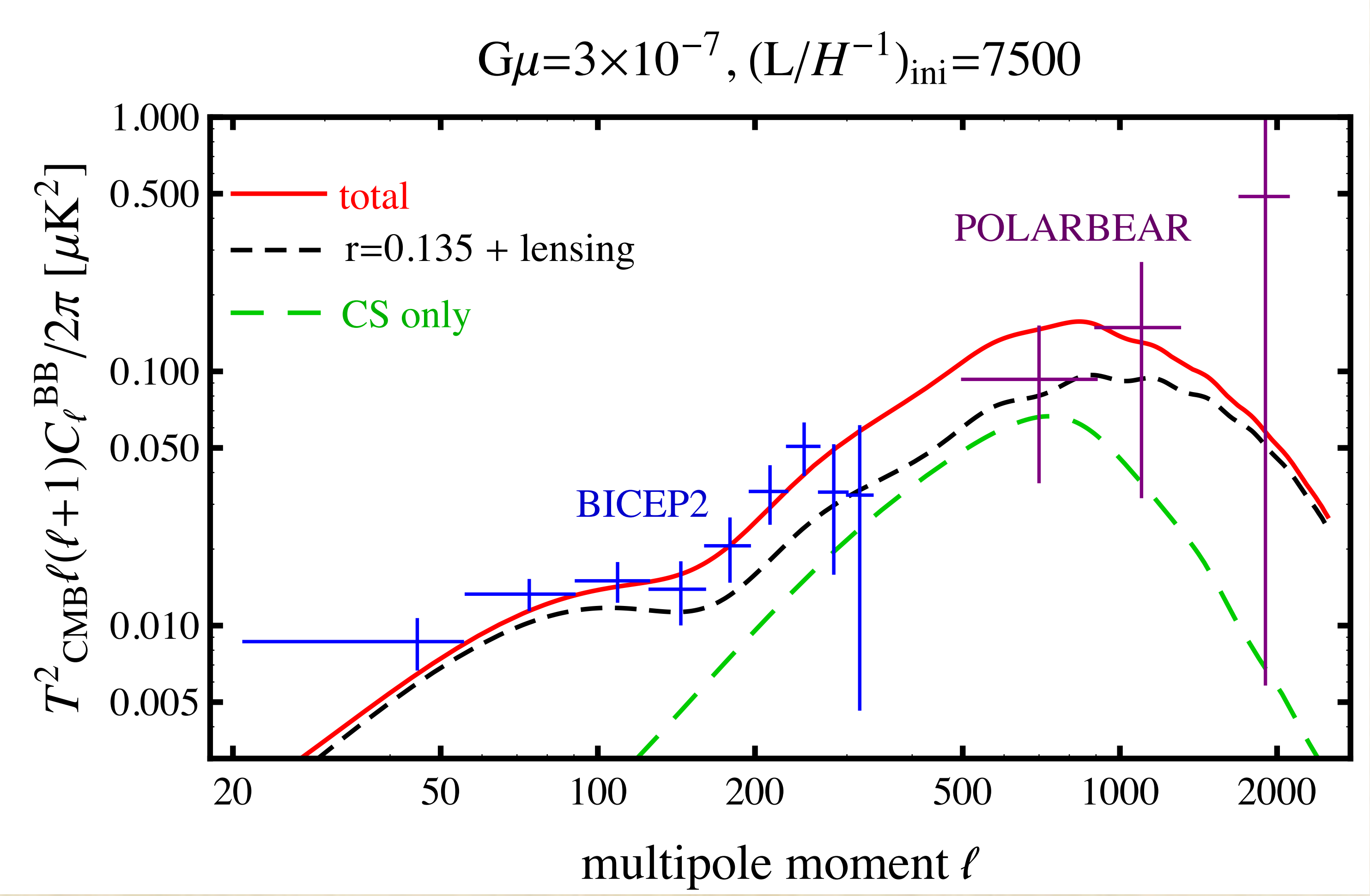
used CMBACT[v4] ('99 Pogosian+Moss)

The position of the peak is determined by recombination and reionization. Their amplitude is determined by the number of strings at that time.

Constraint on the string tension



BICEP2?



$\Delta\chi^2 \sim -9$ for GW (r=0.2)+GL vs GW (r=0.135)+CS+GL

Summary

- Cosmic strings are key ingredients for both cosmology and high energy physics.
- Their formation during inflation is an interesting possibility.
- The string network enters scaling regime later in this case, which can reduce the high multipole moment of both CMB temperature and polarization fluctuations.

Open issues

- We assumed several idealization, such as one-scale model.
  -> need numerical simulations.
- We gave just qualitative constraints.
  -> Combined analysis of Planck temperature/polarization data and other experiments (including BICEP2) is needed to give a precise constraint.