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"Weak lensing generated by vector perturbations and detectability of cosmic strings"

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Weak lensing generated by vector perturbations and detectability of cosmic strings

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- JCAP 1201 (2012) 007, arXiv:1110.1718 [astro-ph.CO]
- JCAP 1210 (2012) 030, arXiv:1205.2139 [astro-ph.CO]
- arXiv:12??.????

Vector mode in cosmology

Scalar mode

- ➢ dominant component, gravitational clustering,…

Vector mode

- ➢ very minor component and does not serve as a seed of structure formation
- ➢ In absence of sources, it decays away, and rapidly becomes negligible …

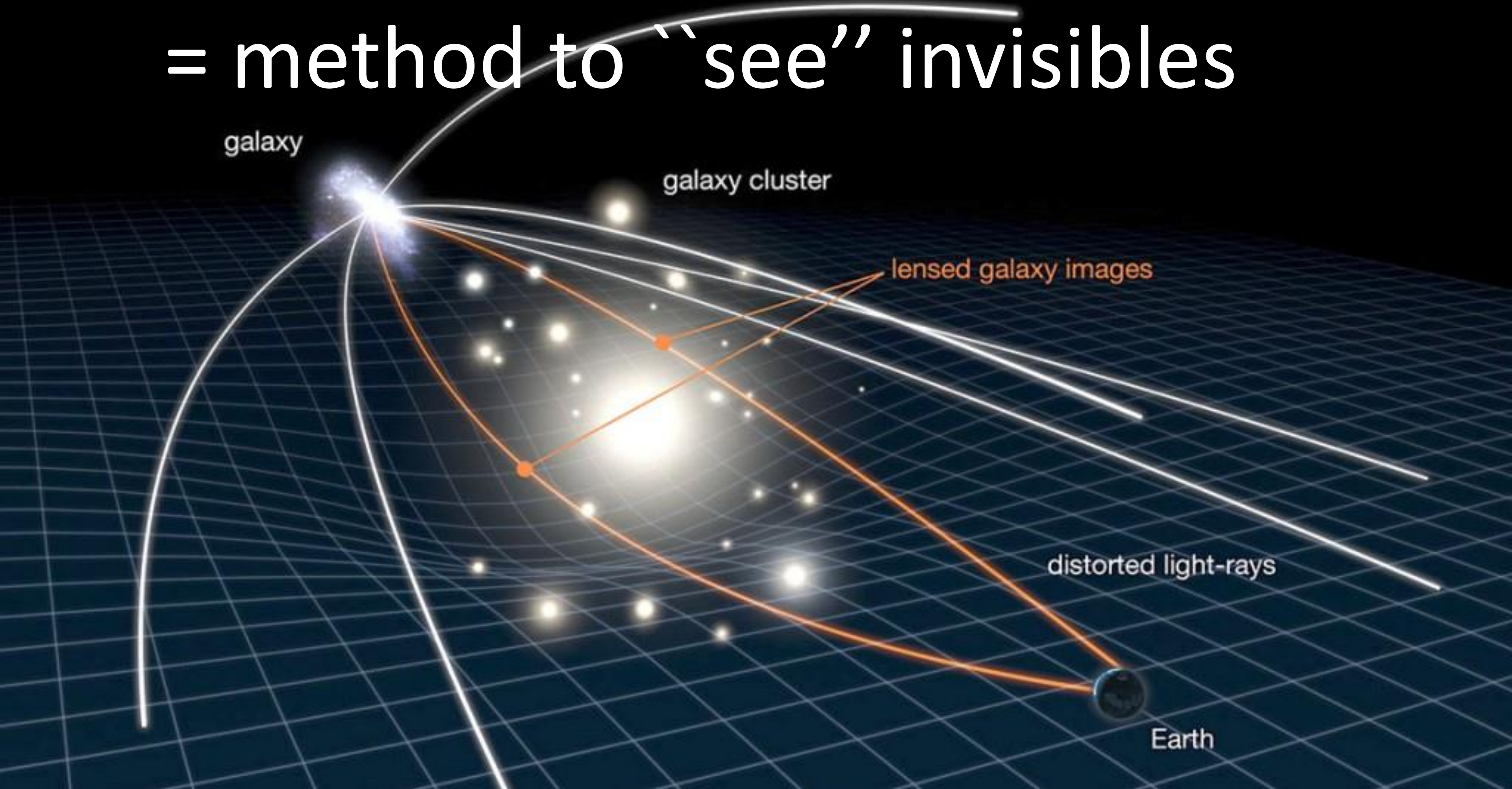
✓ BUT! It can be generated via a variety of mechanisms :

cosmic strings, magnetic fields, massive neutrinos,
2nd-order density perturbations, modification of gravity,…

…The detection/measurement of them offers an important clue to probe the unknown physics and history of the very early universe!

Gravitational Lensing
= method to ``see'' invisibles

NASA/ESA



WEAK LENSING observations can provide a direct evidence for the intervening ``VECTOR MODES'' along a line of sight by measuring the spatial patterns of the deformation of the photon path.

Main Goal

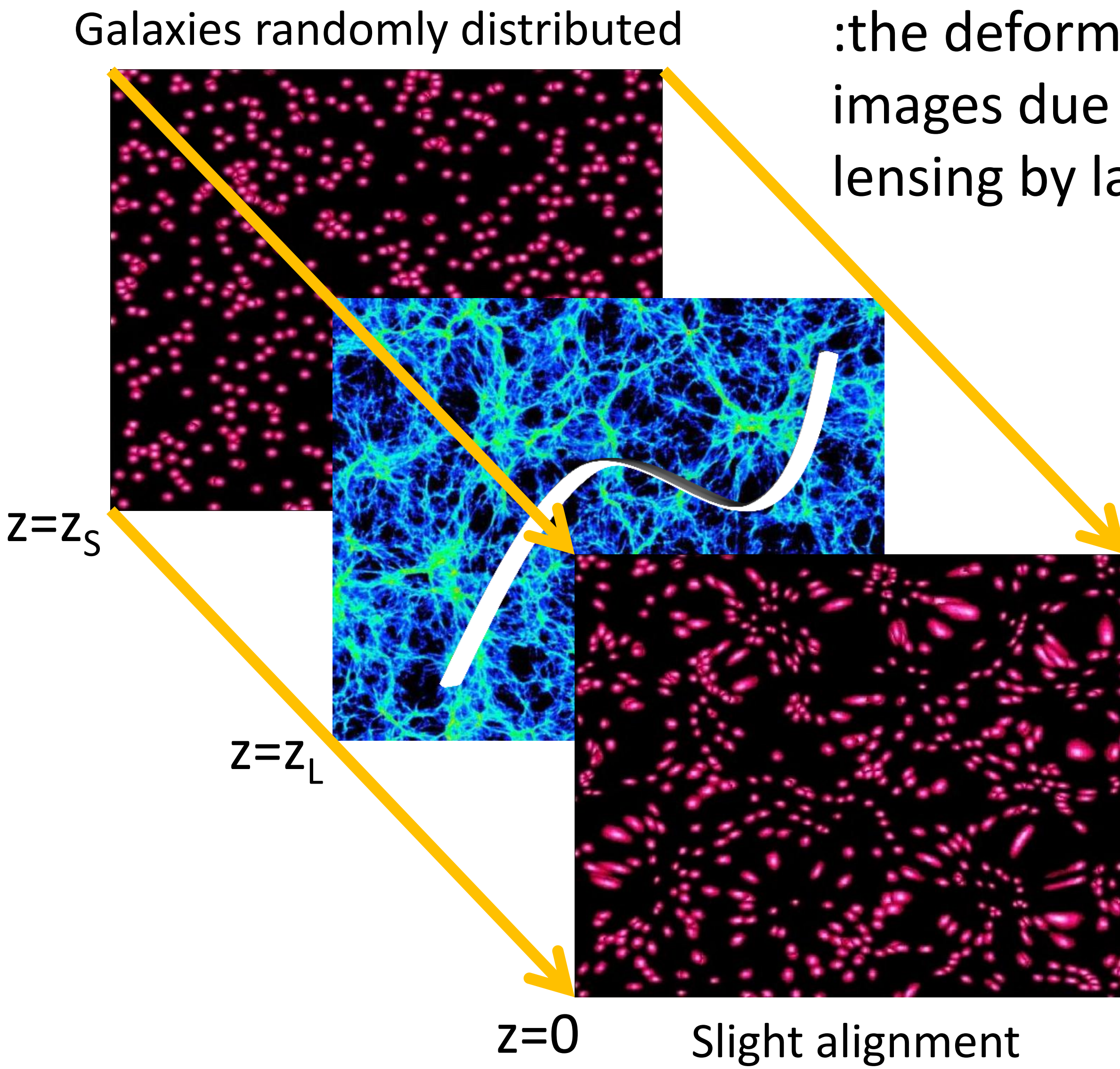
1. We derive the full-sky formulas for
   - vector-induced cosmic shear for galaxy survey
   - vector-induced deflection angle for CMB-lensing

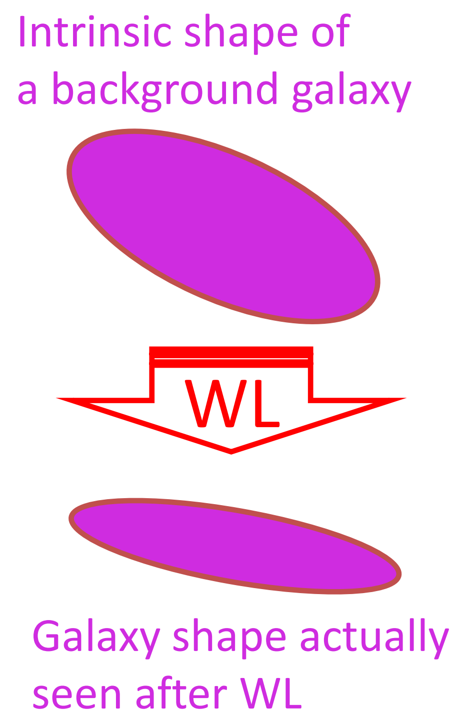
2. As a prospect for detecting shear/deflection,
   we consider a cosmic string network as
   a possible source for seeding vector perturbations.

Cosmic shear

:the deformation of distant-galaxy images due to weak gravitational lensing by large-scale structure

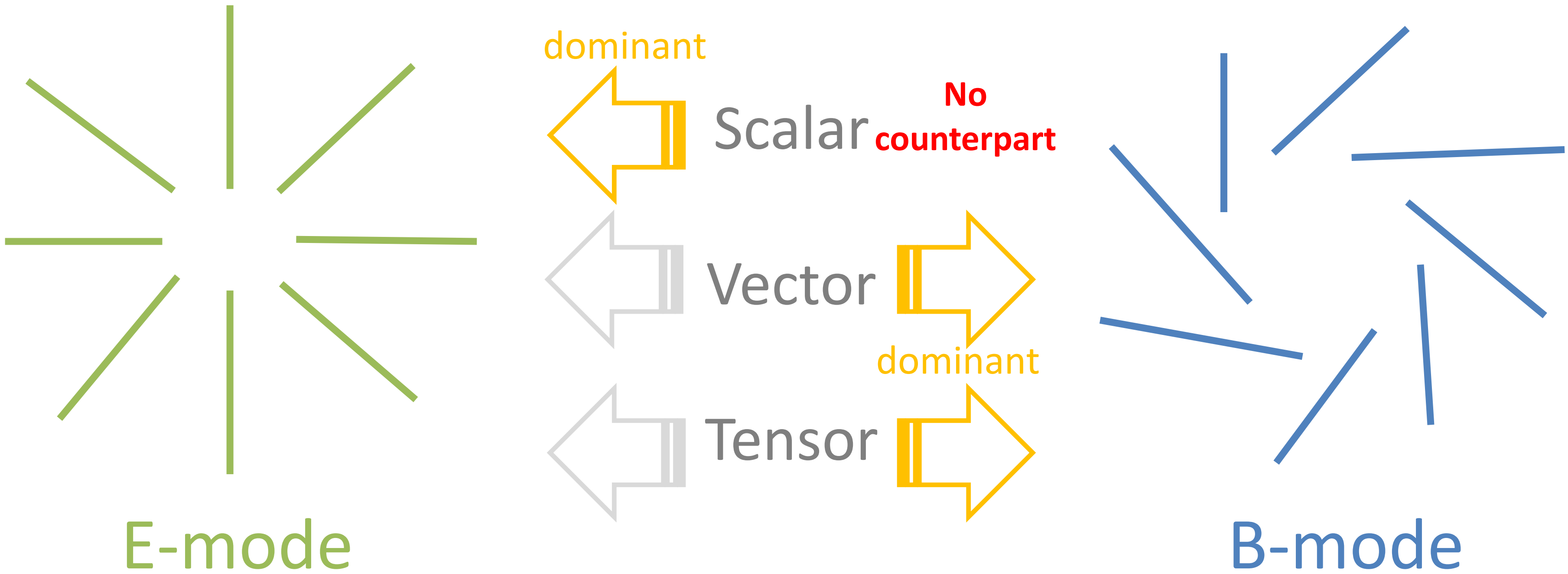
...+ exotic objects





E-/B-mode decomposition in WL

The spatial pattern of lensing shear fields can be decomposed into even-parity part (E-mode) and odd-parity part (B-mode).



The non-vanishing B-mode shear signal would be a direct evidence for non-scalar metric perturbations .

(See [Dodelson+('03), Schmidt+('12),…] for primordial GW)

Formula for vector-induced B-mode shear

[**DY**+Namikawa+Taruya, 1205.2139]

- vector perturbations

$$ds^2 = a^2(\eta)\left[-d\eta^2 + 2B_i d\eta dx^i + \left(\delta_{ij} + 2H_{(i|j)}\right) dx^i dx^j\right]$$

$$\sigma_{g,i} \equiv \dot{H}_i - B_i$$: gauge-invariant vector perturbations

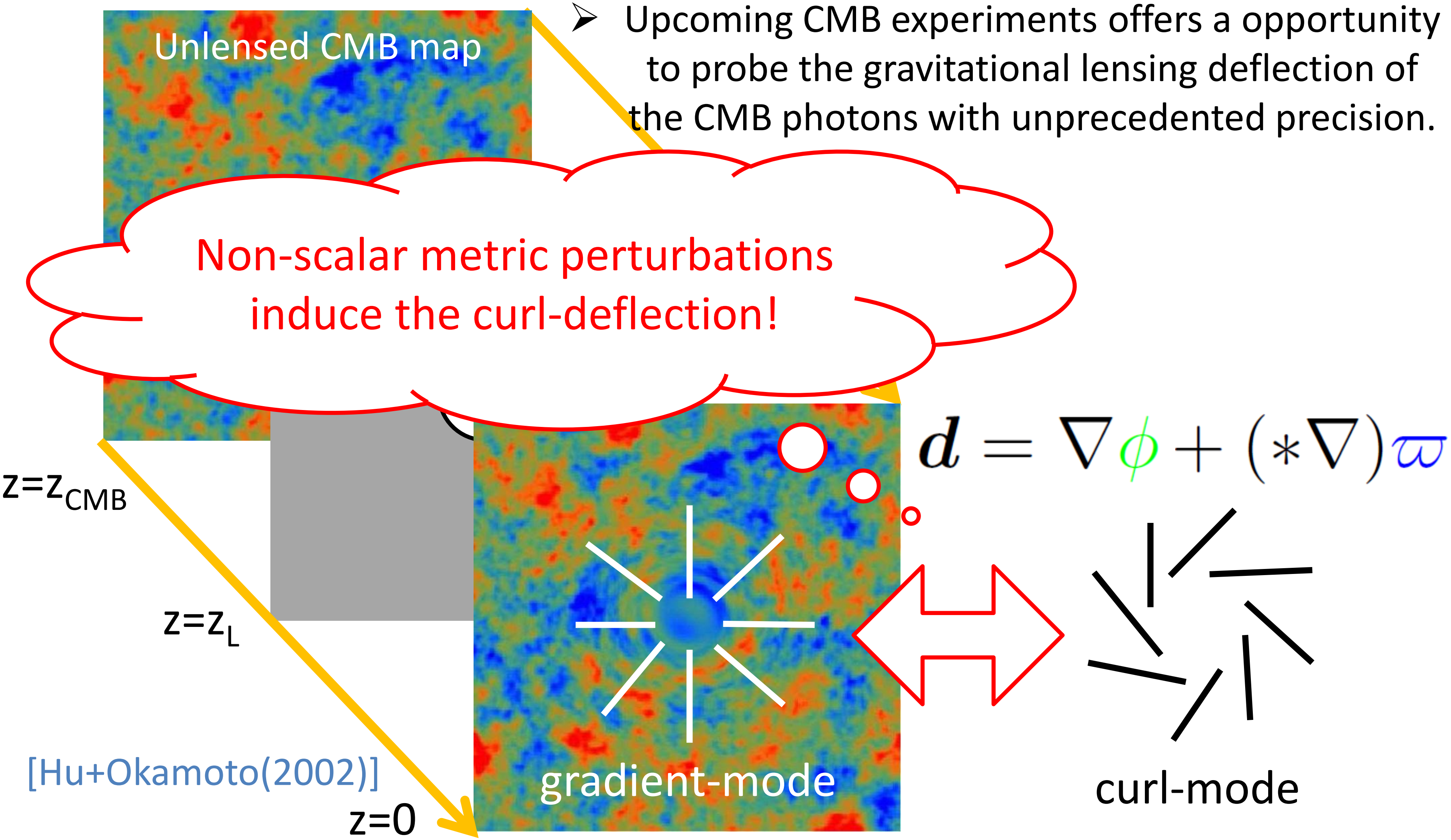
Solving the geodesic deviation equation,...

comoving distance

$$C_\ell^{BB} = \frac{1}{2\pi}\frac{(\ell-1)!(\ell+2)!}{(\ell+1)!(\ell-2)!}\int_0^\infty k^2 dk \int_0^{\chi_S} d\chi \int_0^{\chi_S} d\chi' \times \frac{j_\ell(k\chi)}{\chi}\frac{j_\ell(k\chi')}{\chi'} P_{\sigma_g\sigma_g}(k;\eta_0-\chi,\eta_0-\chi')$$

CMB lensing

- Upcoming CMB experiments offers a opportunity to probe the gravitational lensing deflection of the CMB photons with unprecedented precision.



Formula for vector-induced curl-mode

[**DY**+Namikawa+Taruya, 1205.2139]

$$\mathrm{d}s^2 = a^2(\eta)\left[-\mathrm{d}\eta^2 + 2B_i \mathrm{d}\eta \mathrm{d}x^i + \left(\delta_{ij} + 2H_{(i|j)}\right) \mathrm{d}x^i \mathrm{d}x^j\right]$$

$\sigma_{\mathrm{g},i} \equiv \dot{H}_i - B_i$: vector perturbations

$$C_\ell^{\varpi\varpi} = \frac{1}{2\pi}\frac{(\ell-1)!}{(\ell+1)!}\int_0^\infty k^2 \mathrm{d}k \int_0^{\chi_{\mathrm{CMB}}} \mathrm{d}\chi \int_0^{\chi_{\mathrm{CMB}}} \mathrm{d}\chi' \times \frac{j_\ell(k\chi)}{\chi}\frac{j_\ell(k\chi')}{\chi'} P_{\sigma_{\mathrm{g}}\sigma_{\mathrm{g}}}(k; \eta_0 - \chi, \eta_0 - \chi')$$

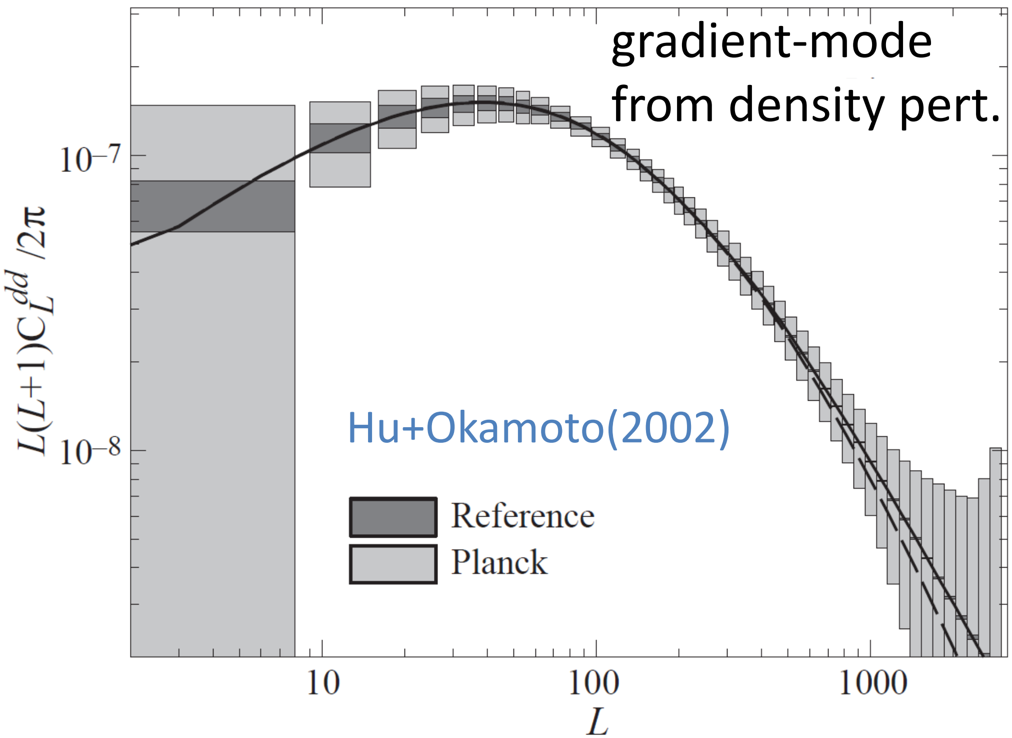
Note : Considering a single light source, we can extract the vector-induced gradient-/curl-modes from the vector-induced shear fields.

$$C_\ell^{\phi\phi} = 4\frac{(\ell-2)!}{(\ell+2)!}C_\ell^{\mathrm{EE}}, \quad C_\ell^{\varpi\varpi} = 4\frac{(\ell-2)!}{(\ell+2)!}C_\ell^{\mathrm{BB}}$$

CMB-lensing reconstruction

Lensing induces higher-order term, i.e., **non-Gaussianity**, in measured CMB anisotropies.

- NG can be used to reconstruct the lensing angular power spectrum.

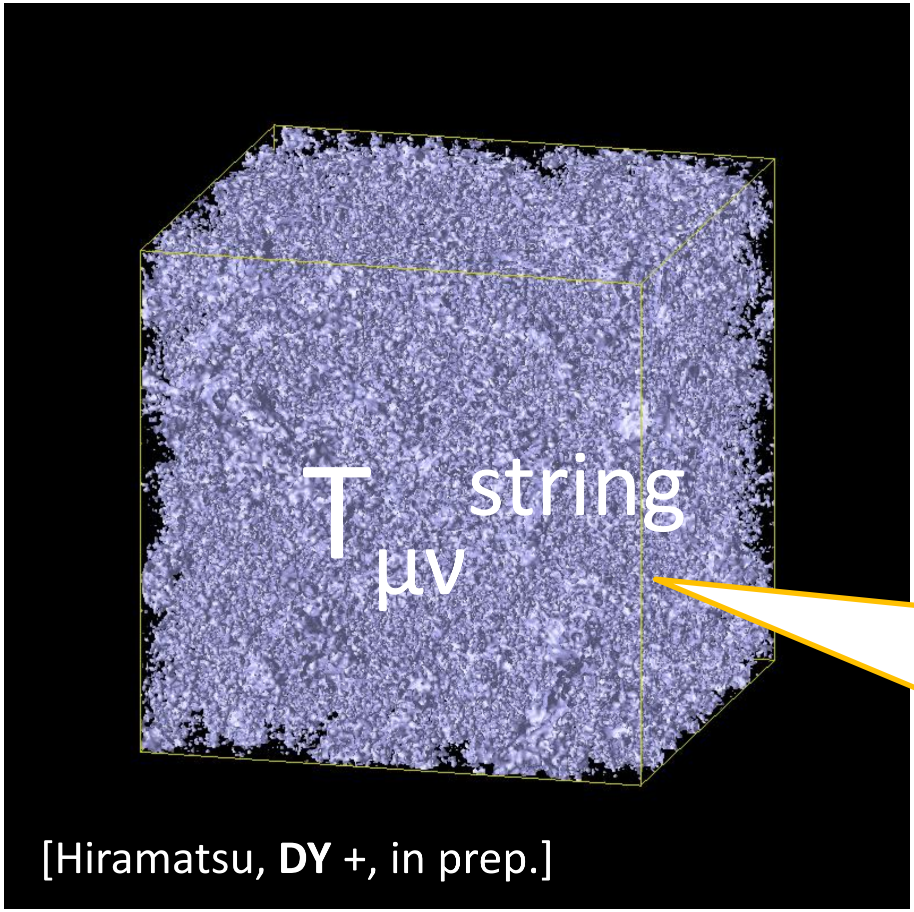


$$\boldsymbol{d} = \nabla\phi + (*\nabla)\varpi$$

✓ Gradient-mode ϕ
[Hu+Okamoto (2002),…]

✓ Curl-mode ω
[Cooray+ (2005),
Namikawa+**DY**+Taruya (2011)]

A cosmic string network
as a source of vector perturbations



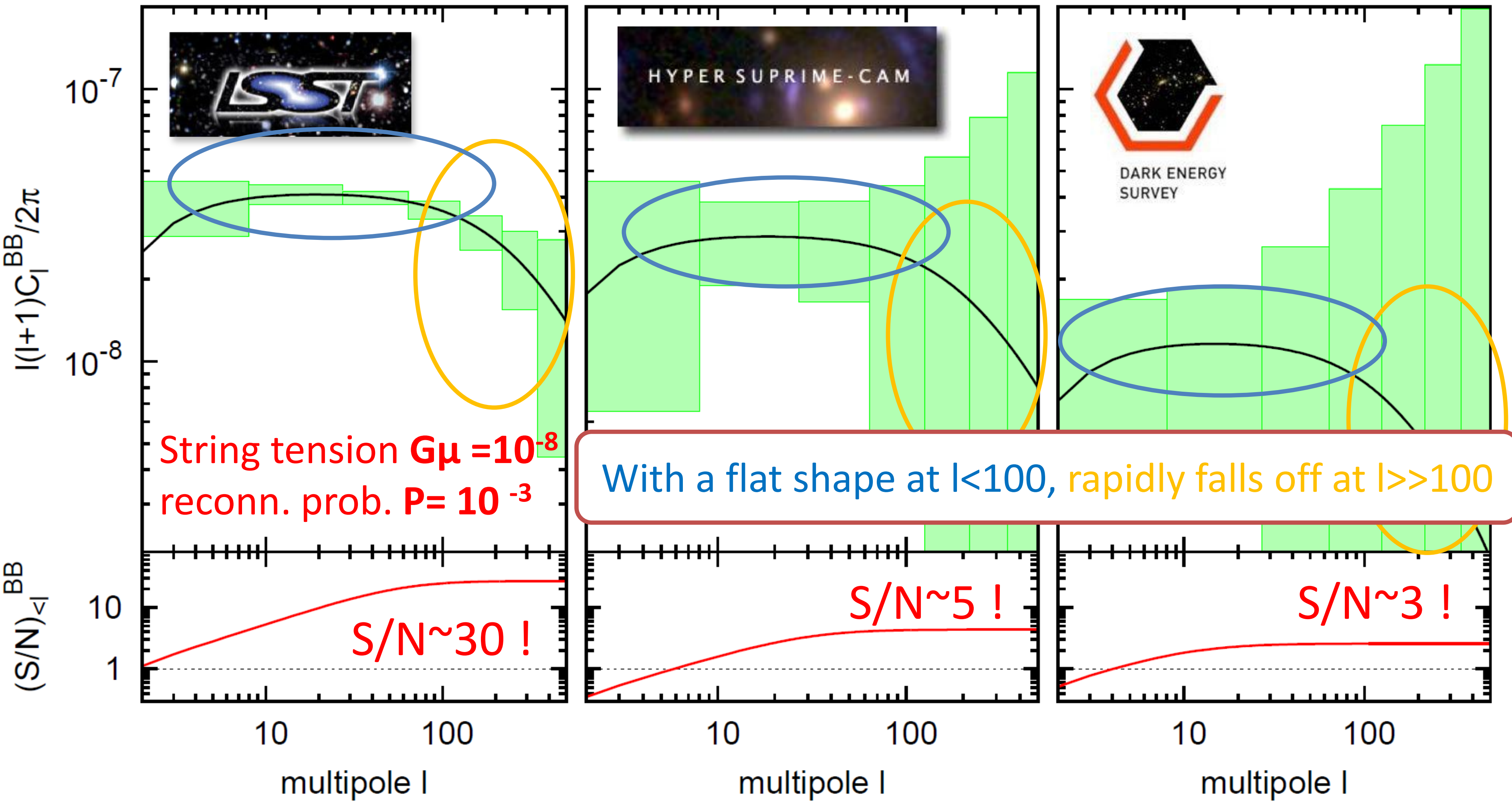
``COSMIC STRINGS'' : relics from the early universe and exist in a wide variety of particle-physics models.

The vector metric perturbations, ``$\sigma_{g,i}$'', are sourced by the non-vanishing vector mode of string stress-energy tensor.

(For convenience, we use the simple analytic model for the network evolution and the correlations.)

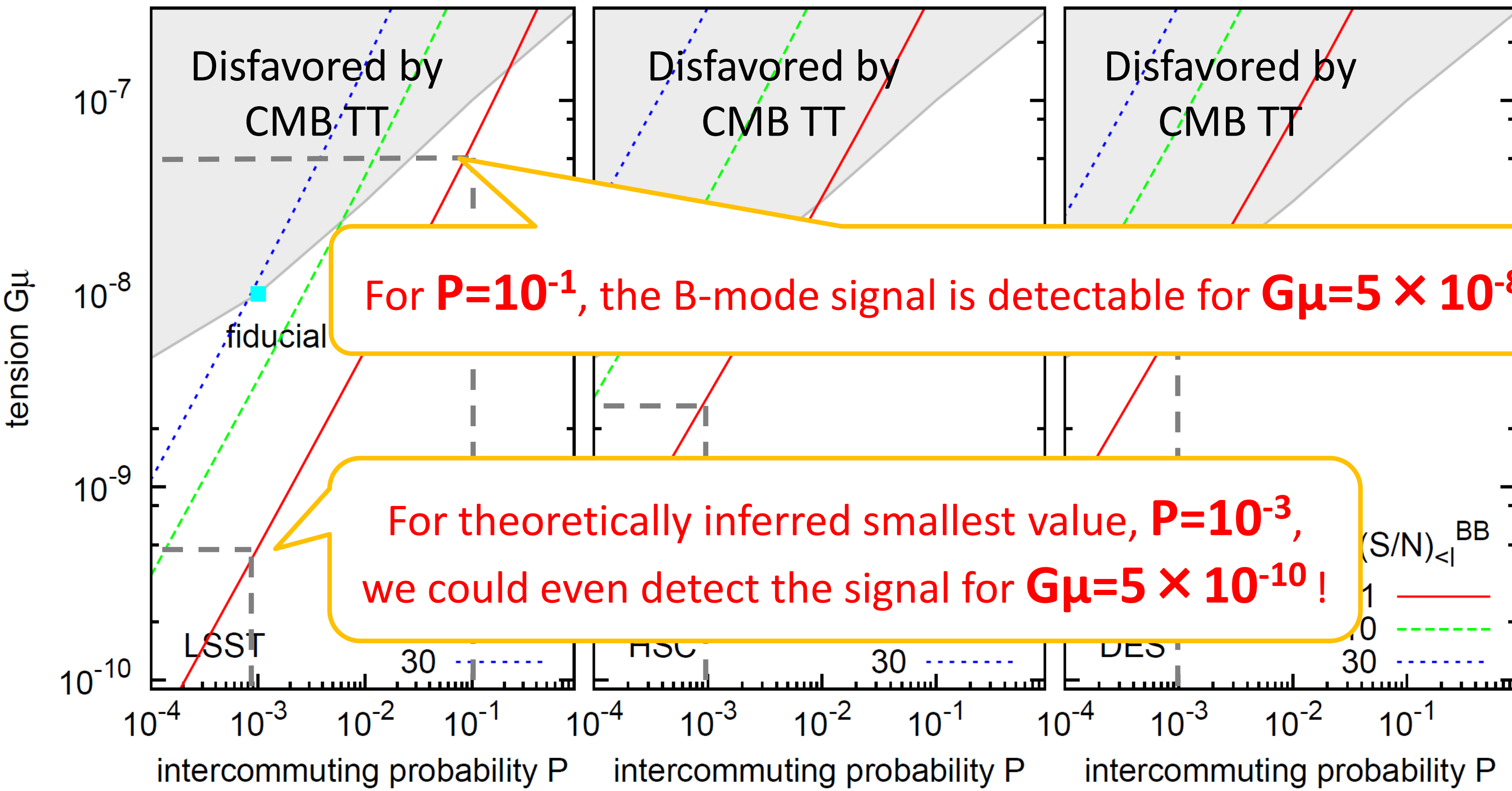
B-mode shear from cosmic strings

[**DY**+Namikawa+Taruya, 1205.2139]



[DY+Namikawa+Taruya, 1205.2139]

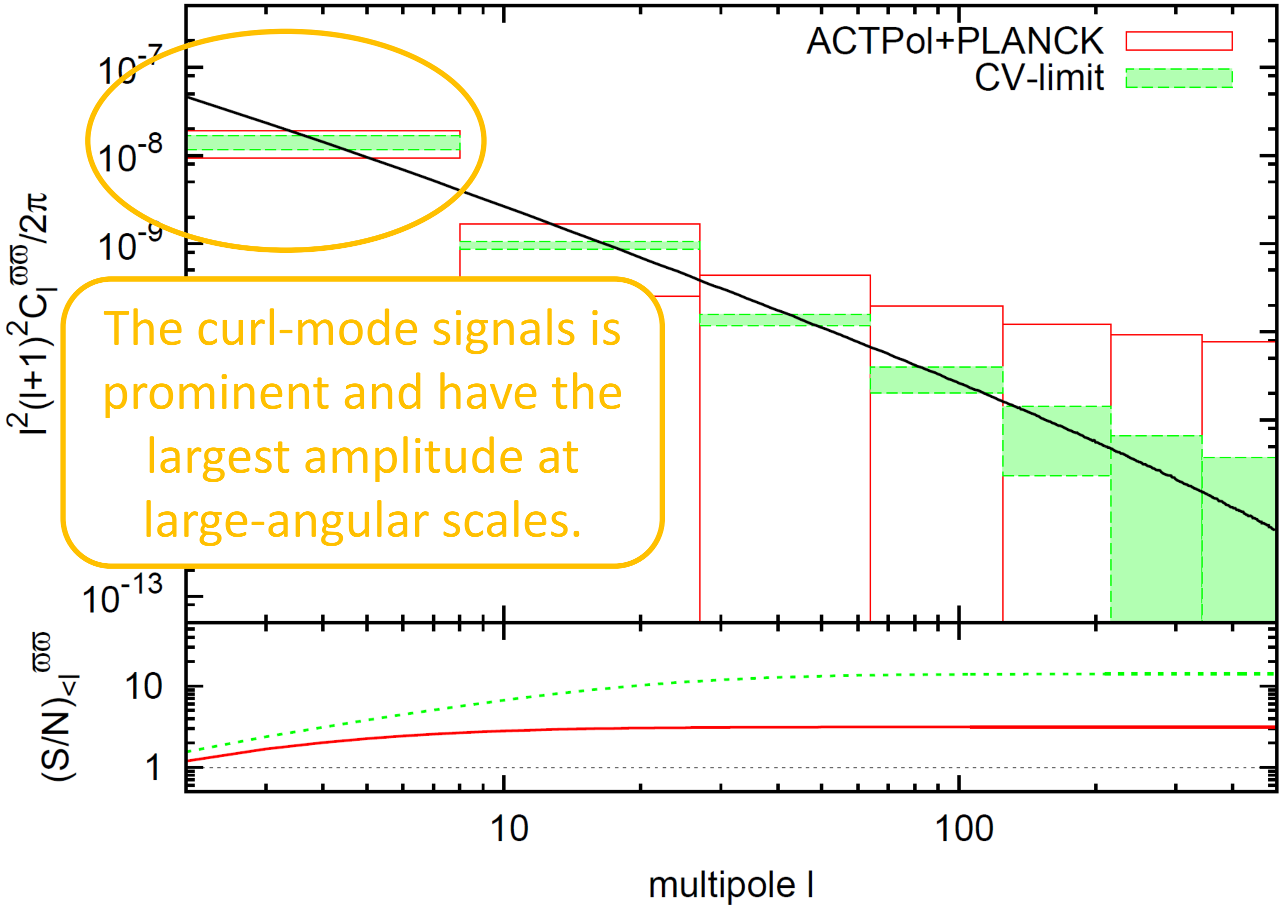
S/N for string-induced B-mode shear



For **P=10^{-1}**, the B-mode signal is detectable for **Gμ=5 × 10^{-8}**

For theoretically inferred smallest value, **P=10^{-3}**,
we could even detect the signal for **Gμ=5 × 10^{-10}** !

Curl-deflection from cosmic strings



[**DY**+Namikawa+Taruya, 1205.2139]

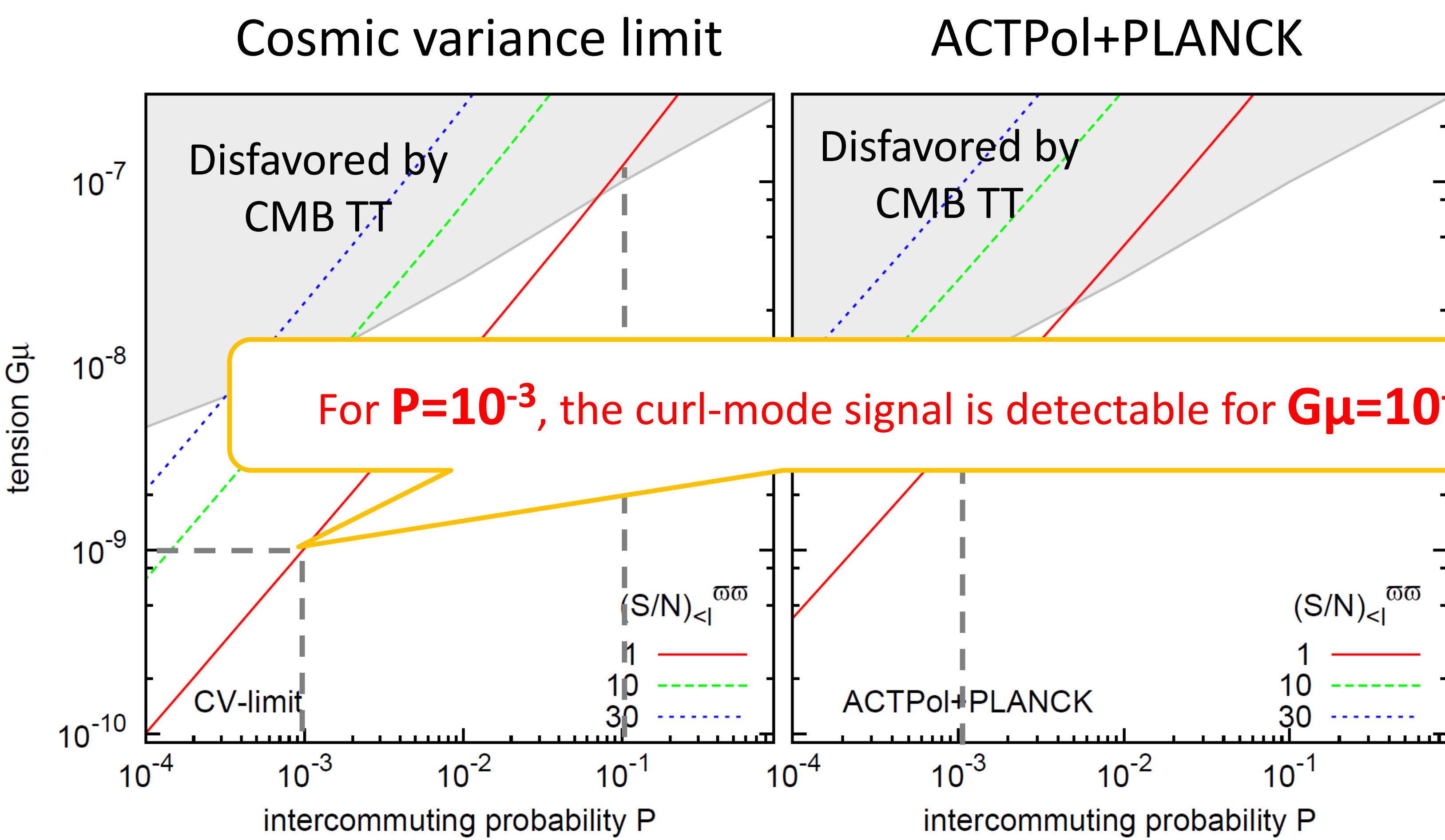
String tension **Gμ =10^{-8}**
reconn. prob. **P= 10^{-3}**

S/N ~ 10 !
S/N ~ 3 !

The CURL-MODE measurement would provide not only a direct probe of cosmic strings, but also a diagnosis helpful to check the systematics in the derived constraints from the CMB TT.

S/N for string-induced curl-deflection

[**DY**+Namikawa+Taruya, 1205.2139]



For **P=10^{-3}**, the curl-mode signal is detectable for **Gμ=10^{-9}**

Summary

- We study how vector metric perturbations affect weak gravitational lensing and possible signatures.

- As an application, we consider a cosmic string network as a possible source for seeding vector perturbations.
  - ✓ B-mode of shear fields
    - $P<10^{-1} \rightarrow G\mu > 5 \times 10^{-8}$, $P=10^{-3} \rightarrow G\mu > 5 \times 10^{-10}$
  - ✓ Curl-mode of deflection angle
    - $P<10^{-1} \rightarrow G\mu > 4 \times 10^{-9}$, $P=10^{-3} \rightarrow G\mu > 10^{-9}$

- There are several missing pieces including

  the contribution of tensor perturbations,
  the additional correlations, and the other sources

[**DY**, Namikawa, Taruya, in prep.]