Anisotropies in the gravitational wave background as a probe of the cosmic string network

based on arXiv:1604.00332

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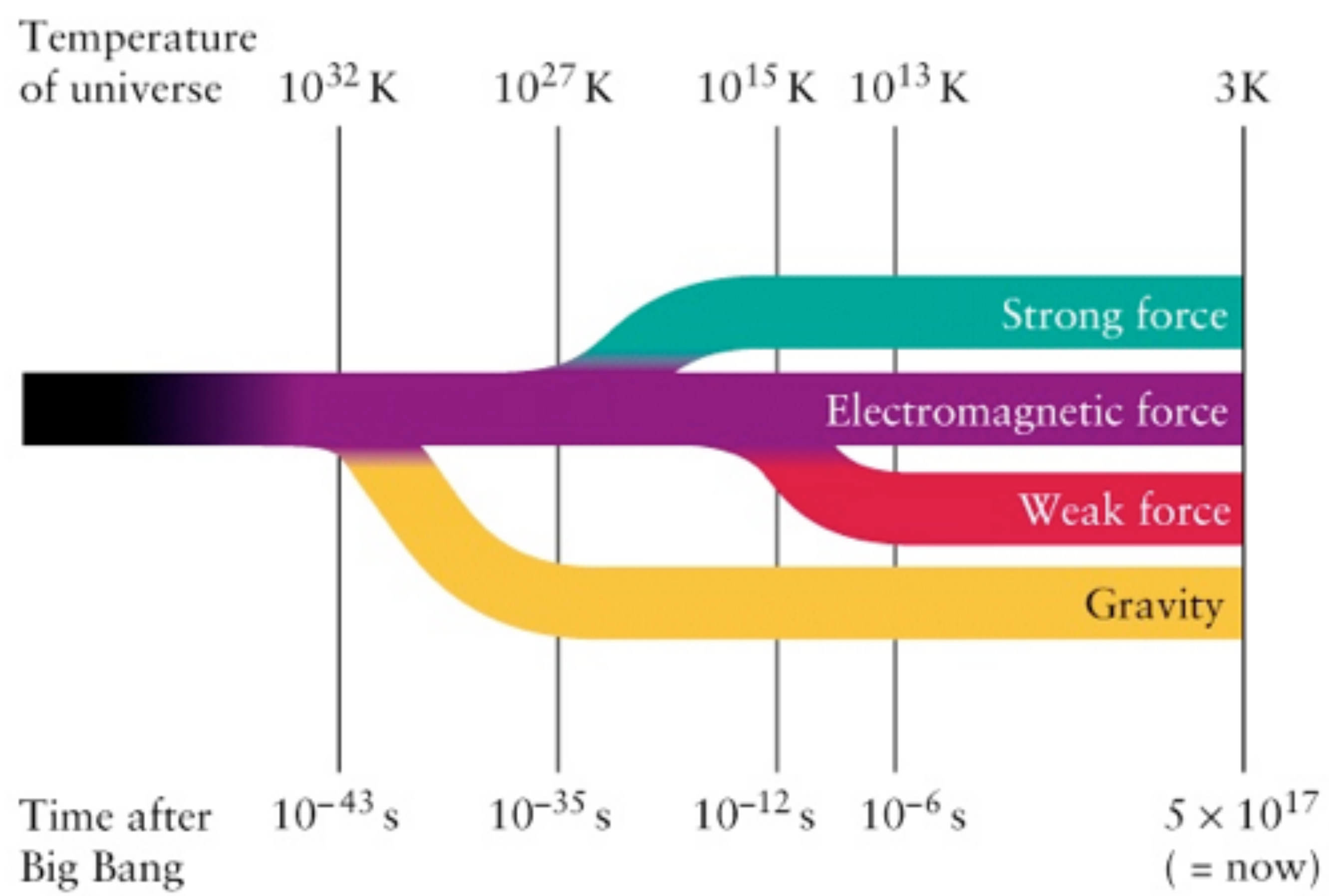
Cosmic string ?

One dimensional topological defect
generated in the early universe

<u>Generation mechanism</u>

1: Phase transition

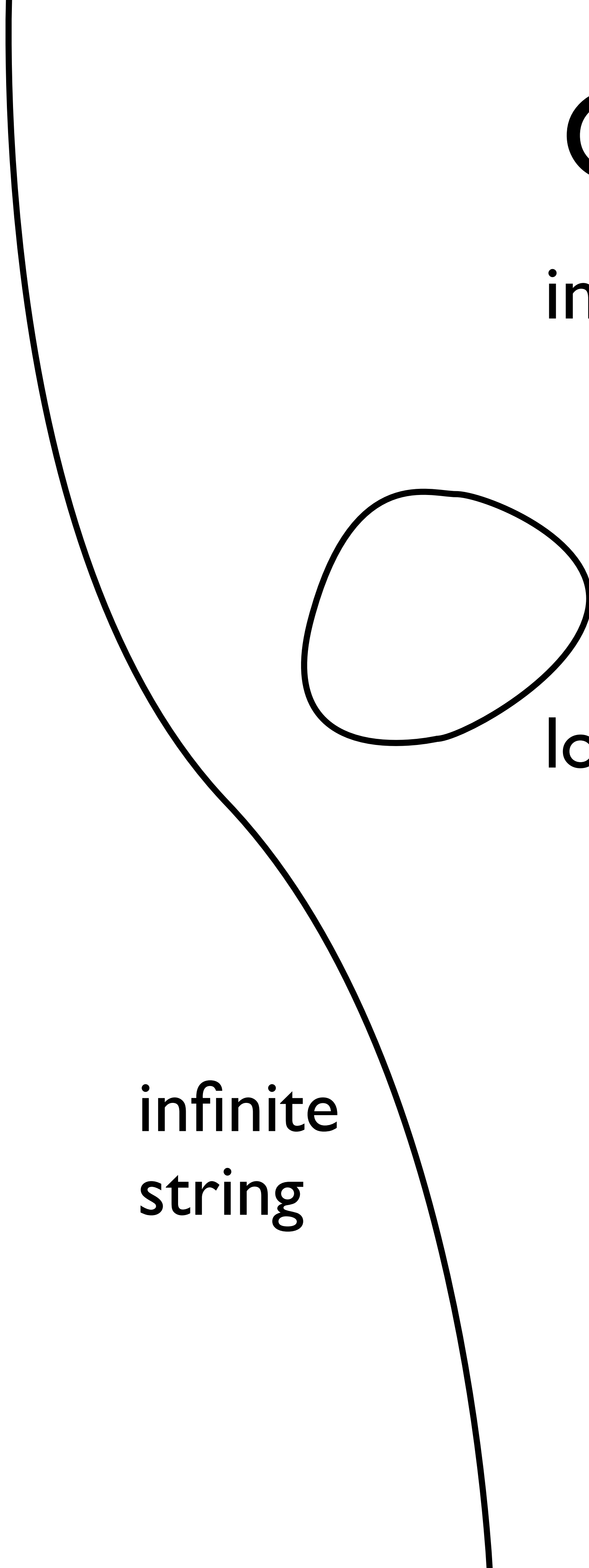


2: Cosmic superstrings

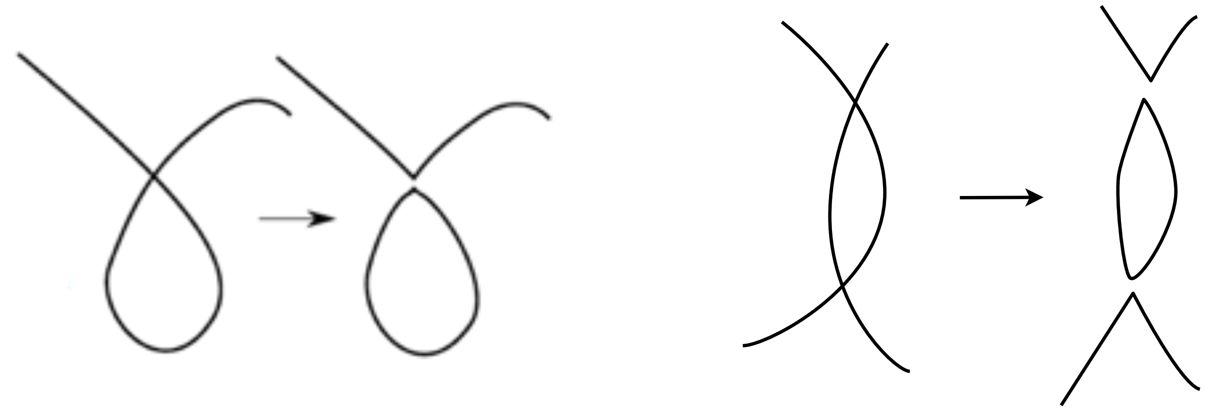
Cosmological size strings remains after inflation

→ **could provide some insights into fundamental physics**

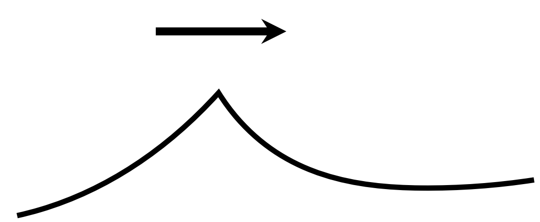
Cosmic string ?

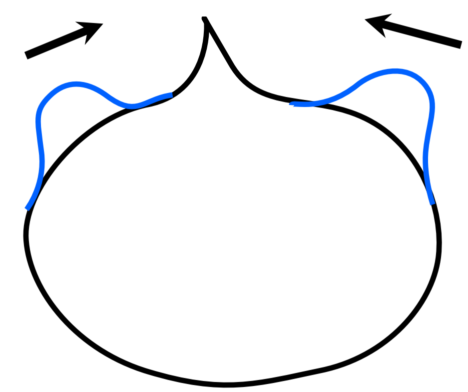


infinite string becomes a loop by reconnection



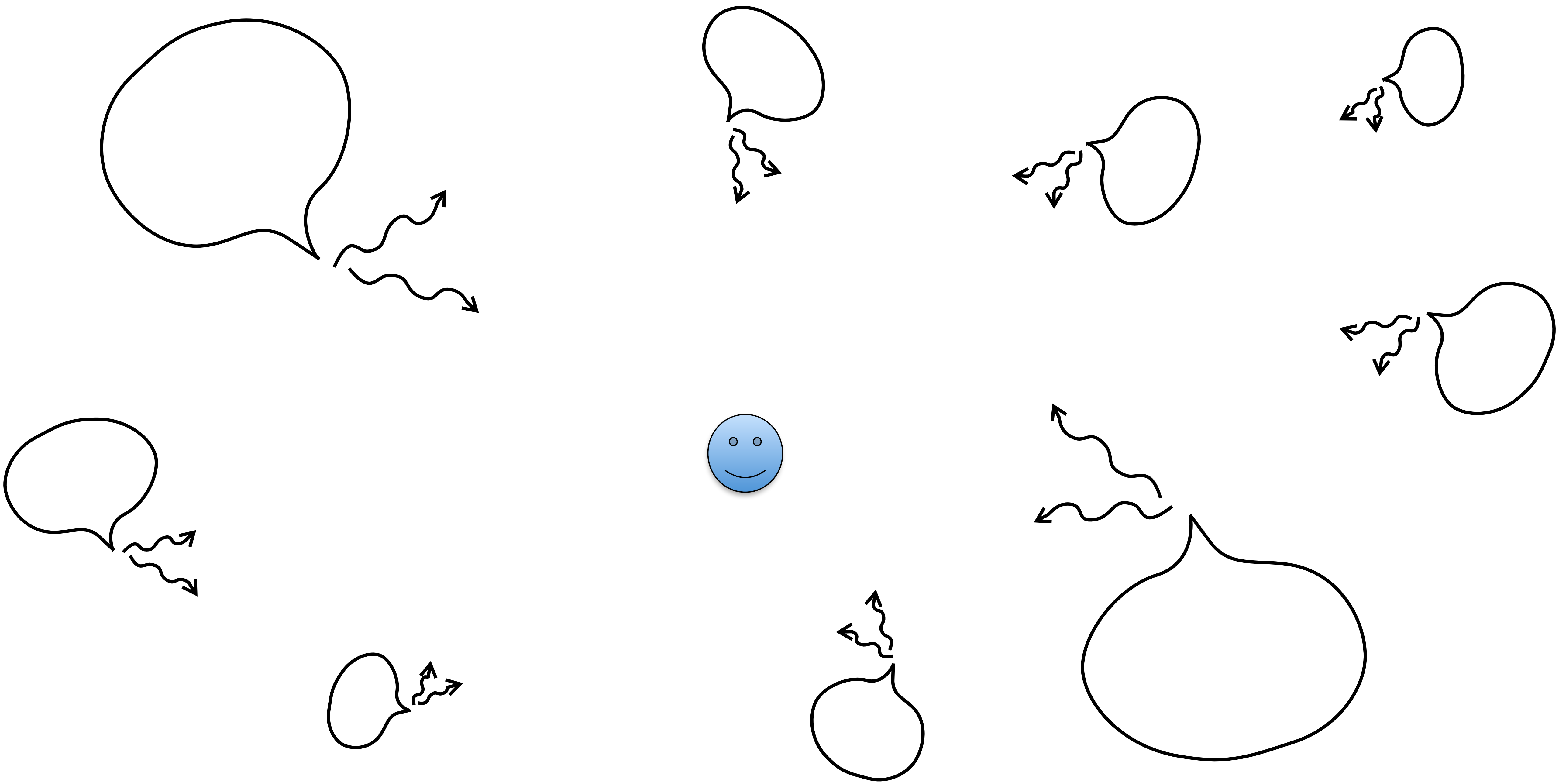
strings emit gravitational waves
especially from singular structures





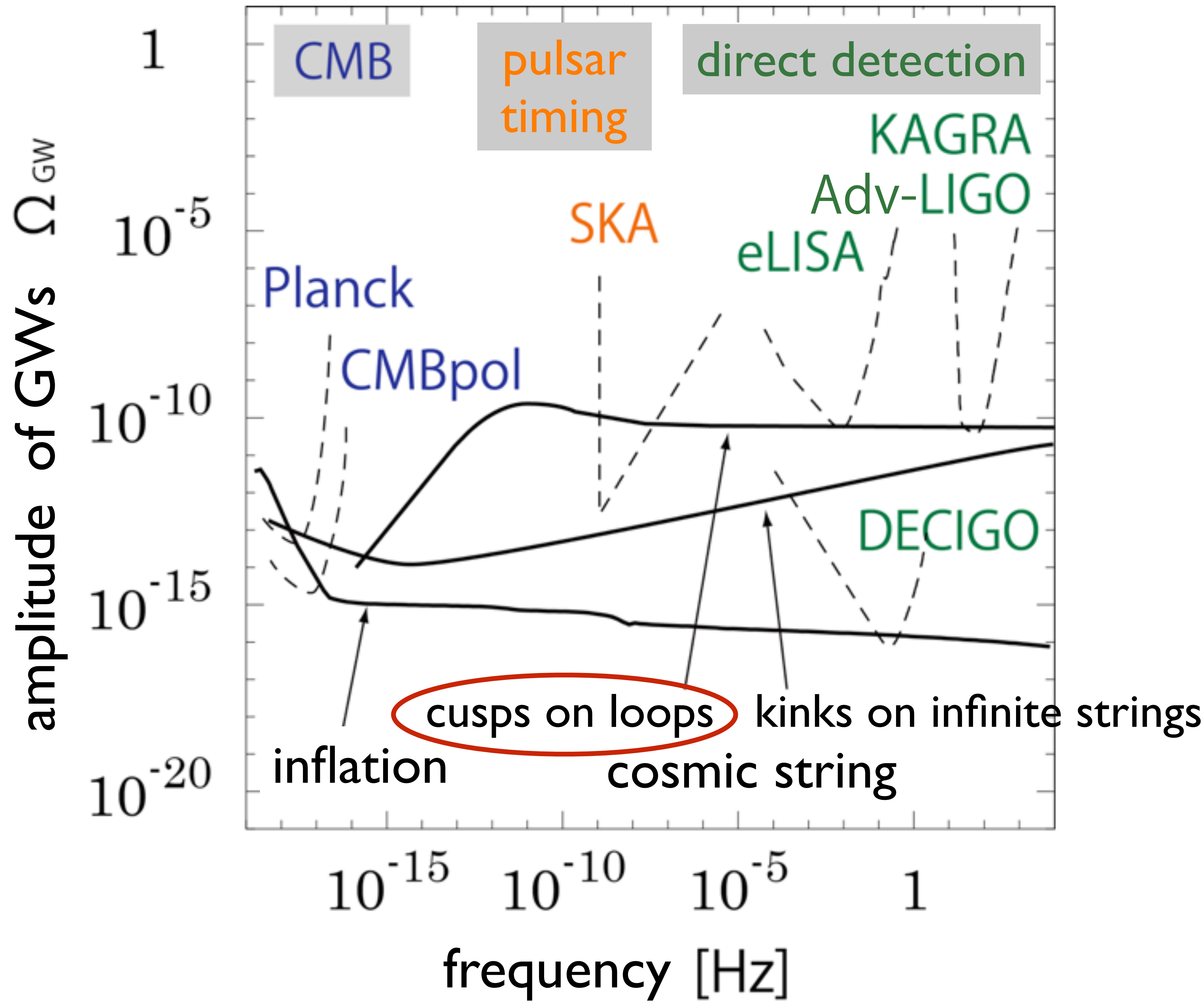
loops lose energy and shrink by emitting
gravitational waves and eventually evaporate

Gravitational waves from cosmic string loops



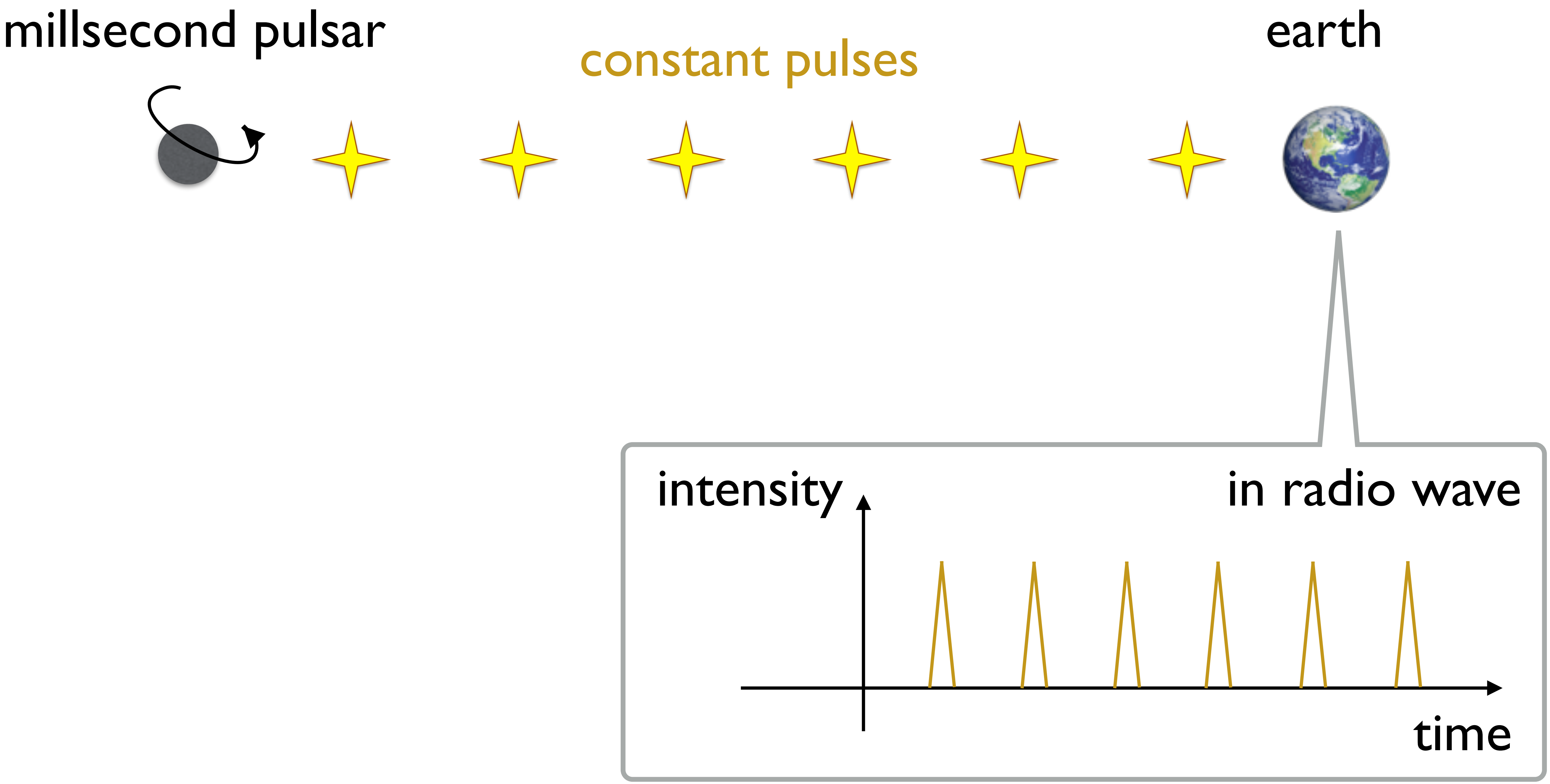
Gravitational waves coming from different directions overlap each other and form gravitational wave background

Spectrum and Sensitivities



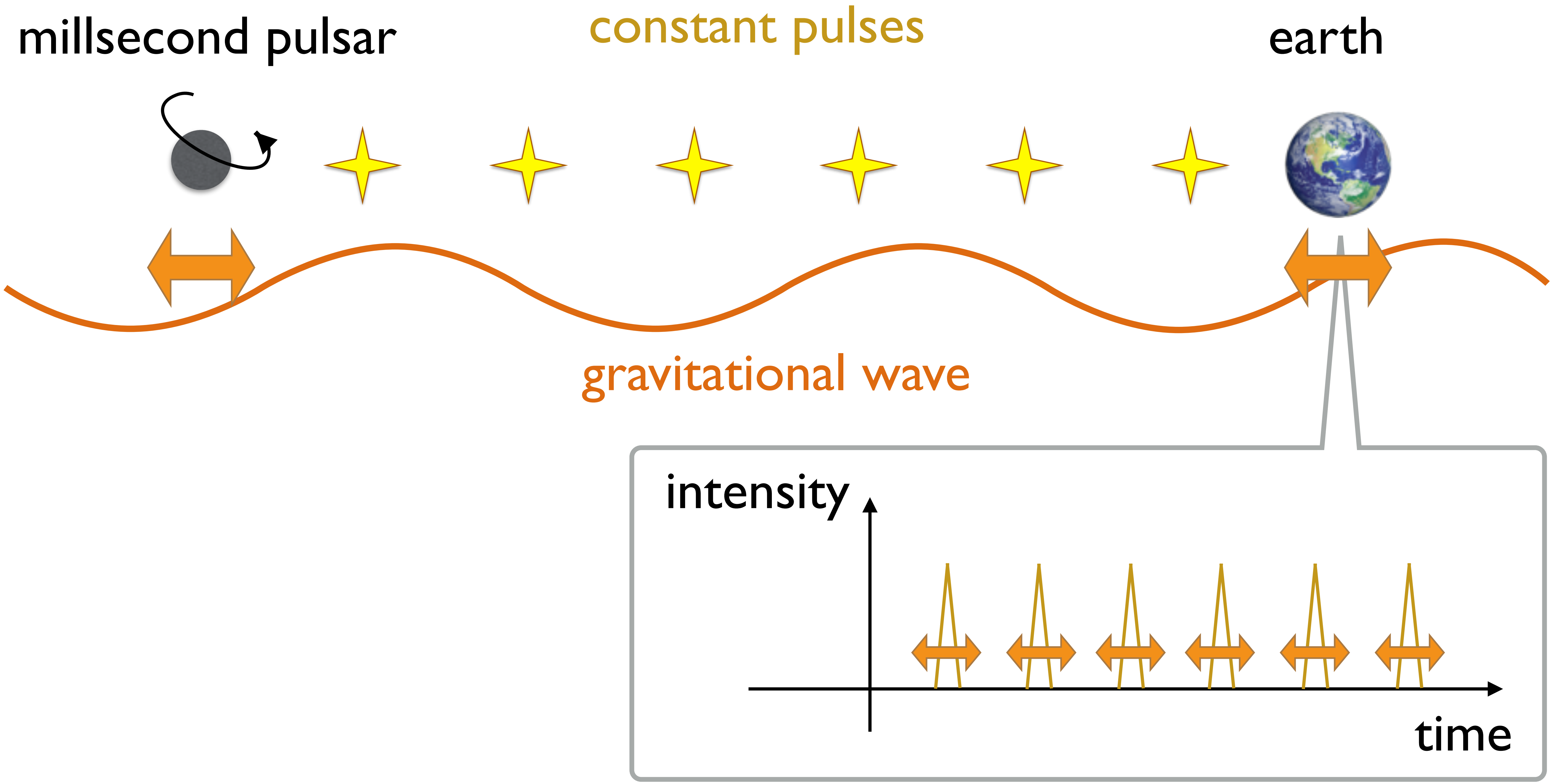
Pulsar timing array

- Robust and unique test of gravitational waves

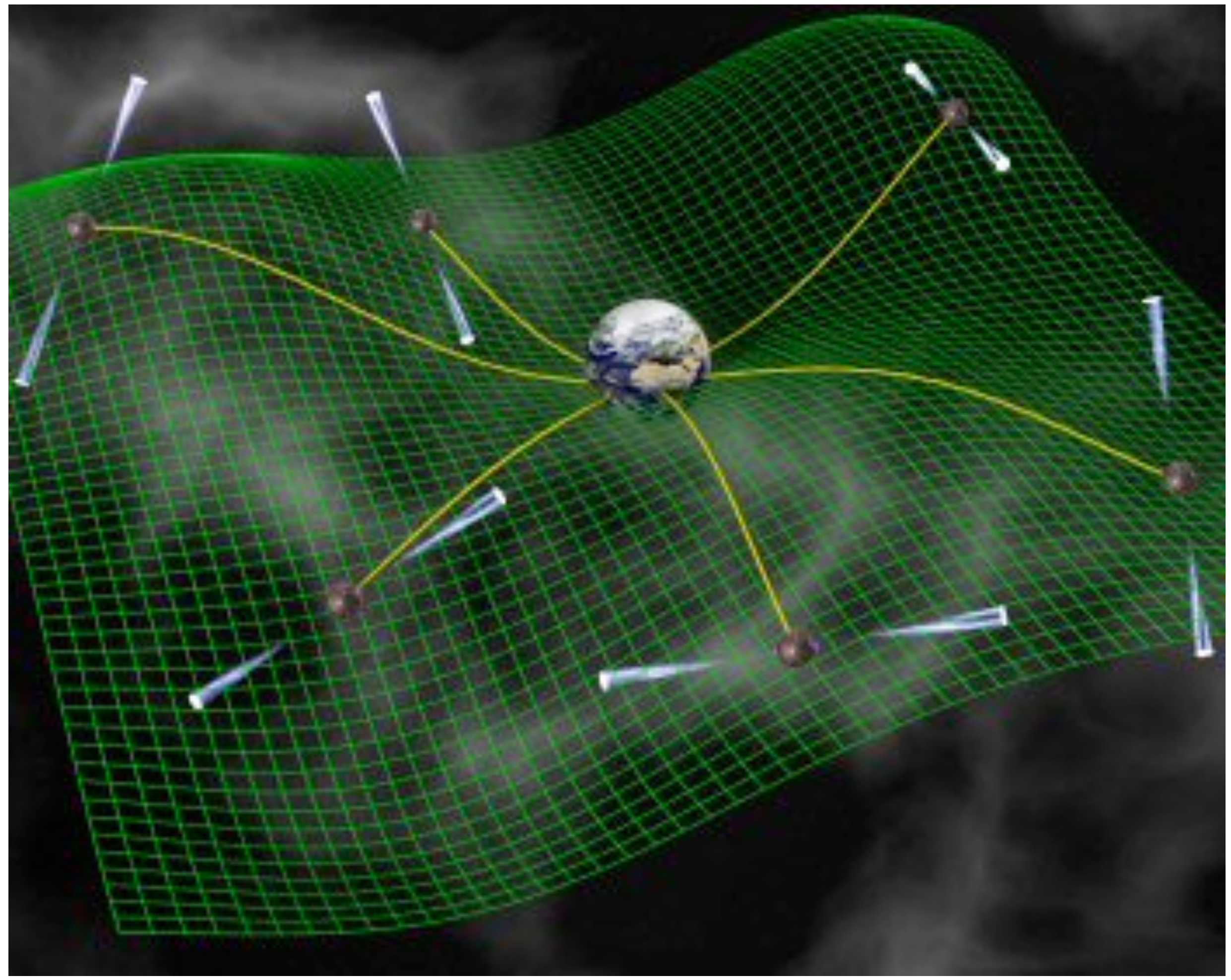


Pulsar timing array

- Robust and unique test of gravitational waves

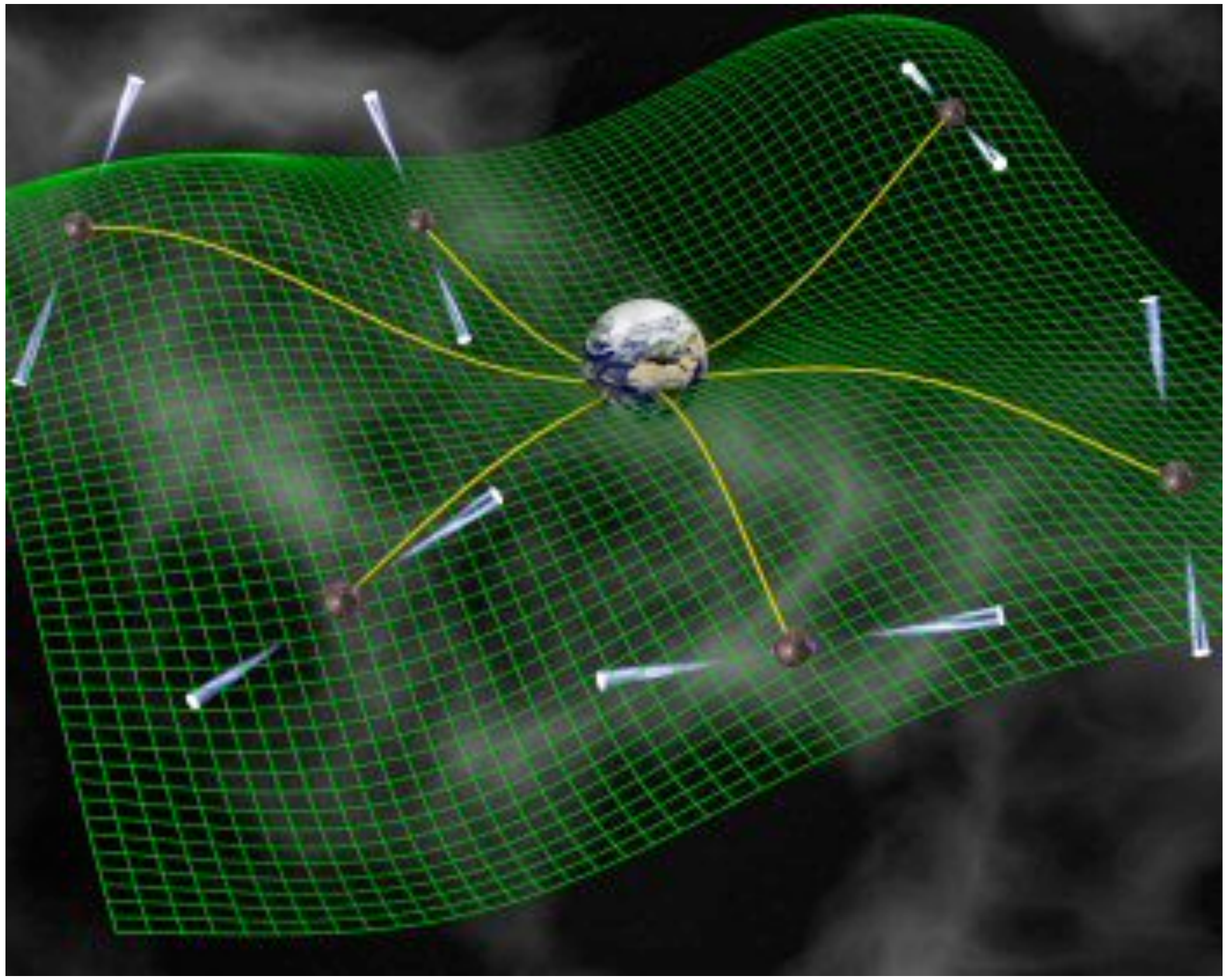


Pulsar timing array



- Correlation analysis with multiple pulsars to remove noises associating with individual pulsars
- Frequency $\propto$ (Observation time)$^{-1}$

Pulsar timing array



- expected to detect gravitational waves from super massive black hole binaries or maybe from exotic sources (e.g. cosmic strings)

3 main parameters to characterize cosmic string

$G\mu$: tension = line density

Generation mechanism

α : initial loop size $L \sim \alpha H^{-1}$

Network evolution

p : reconnection probability

Phase transition origin: p=1

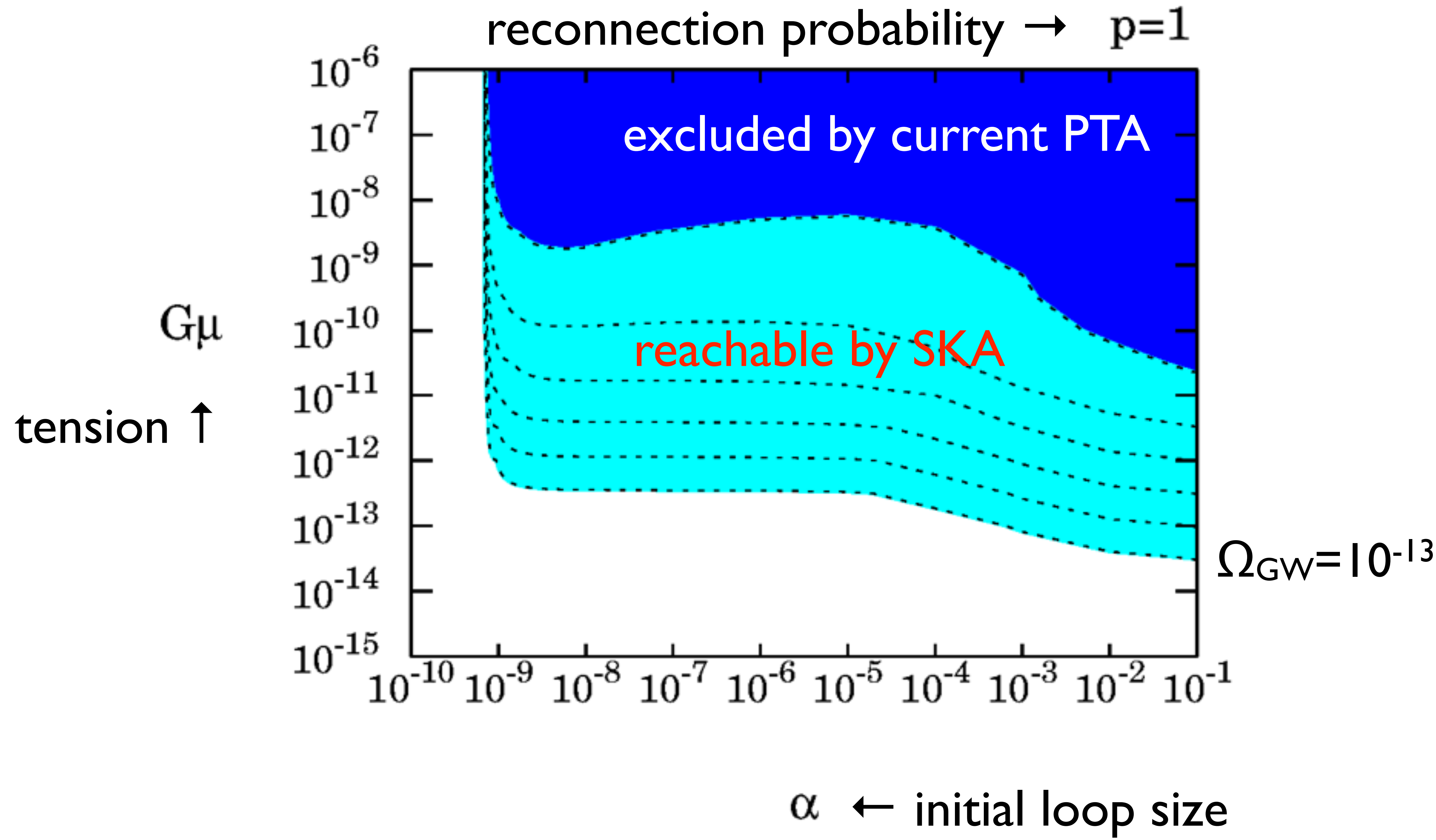
Cosmic superstring: p<<1

determines

amplitude of a single burst

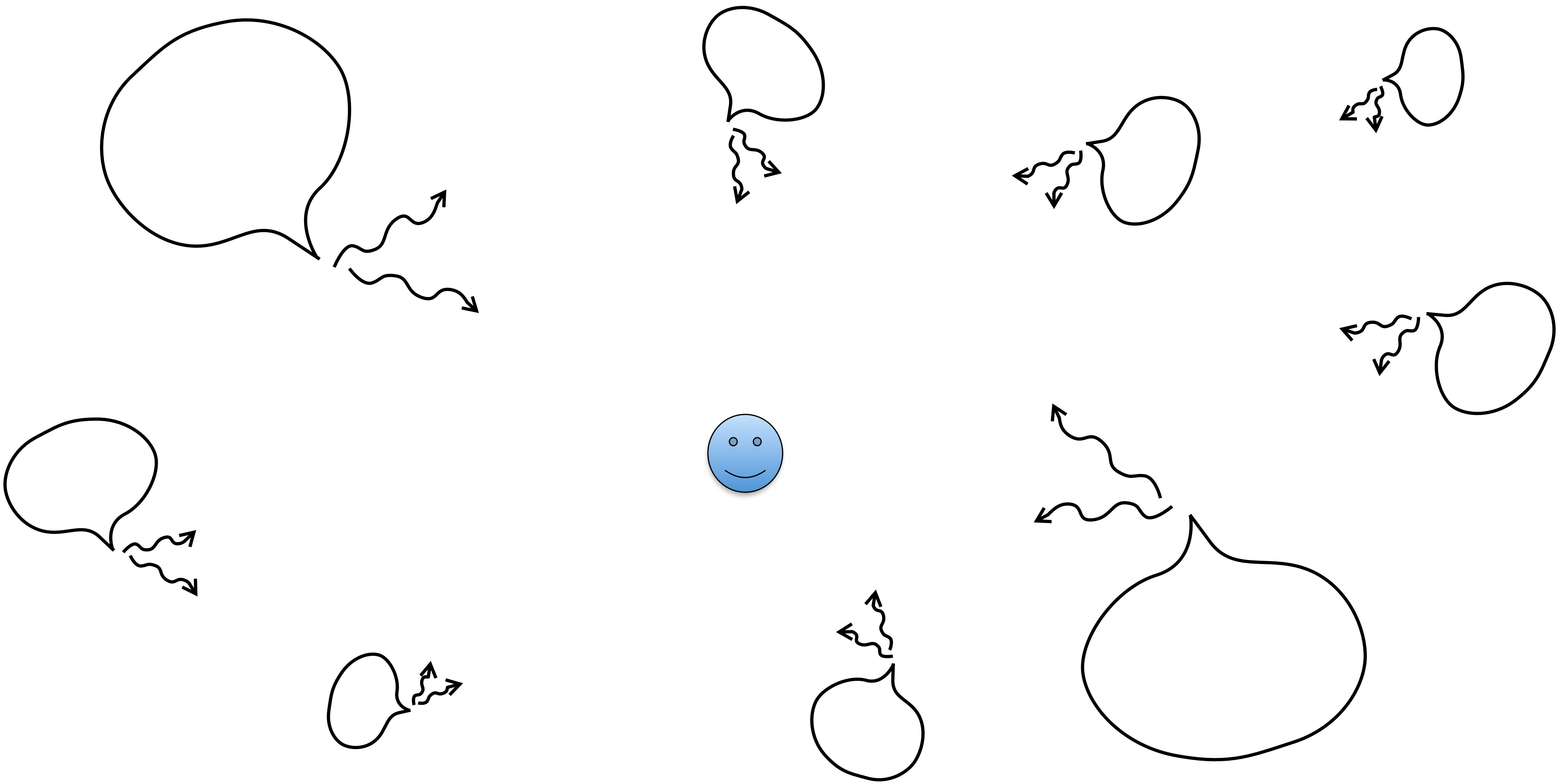
number density of loops

Detectability in Gμ - α plane



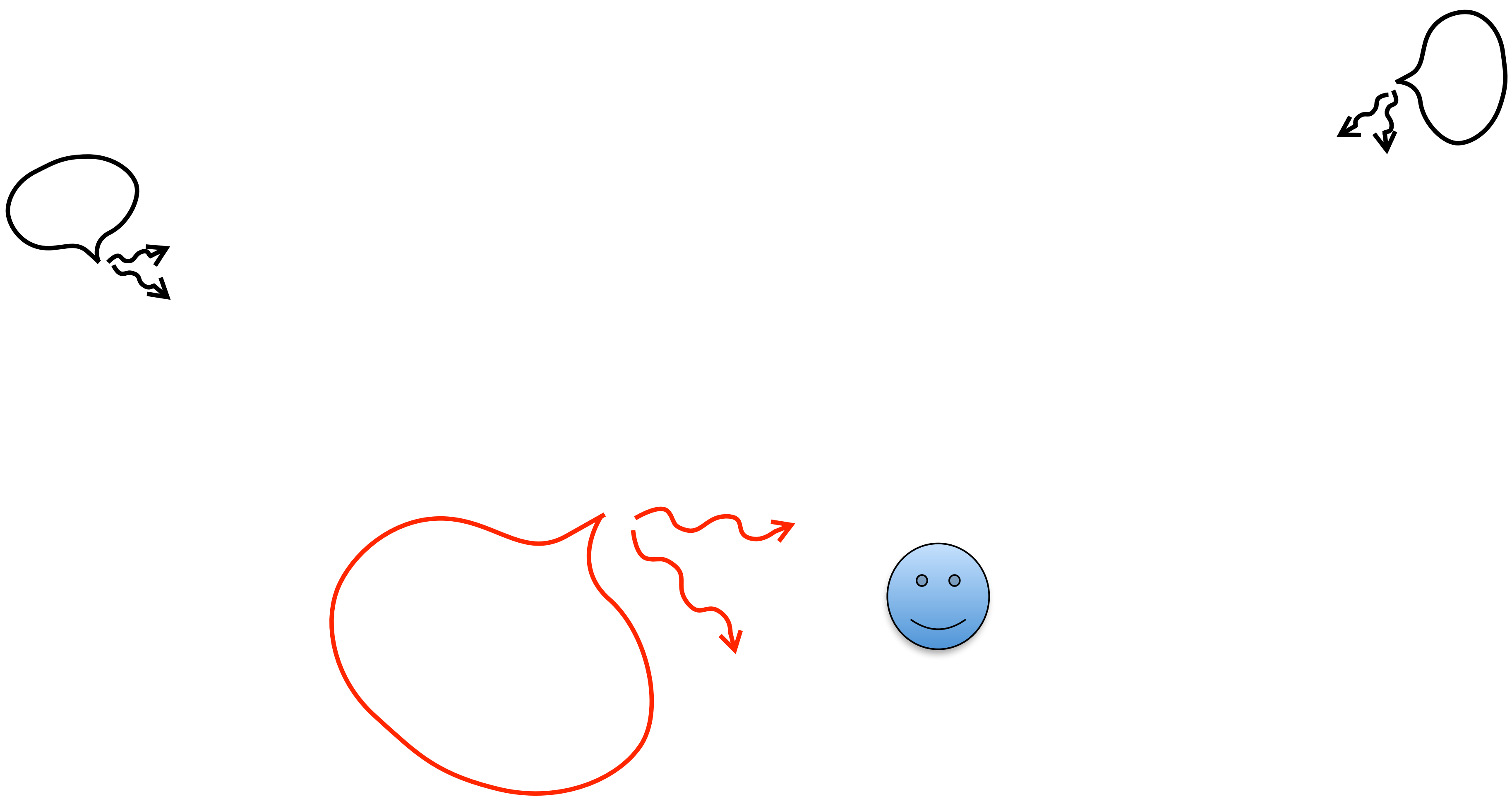
SKA will cover a large parameter space of cosmic string parameters

Gravitational waves from cosmic string loops



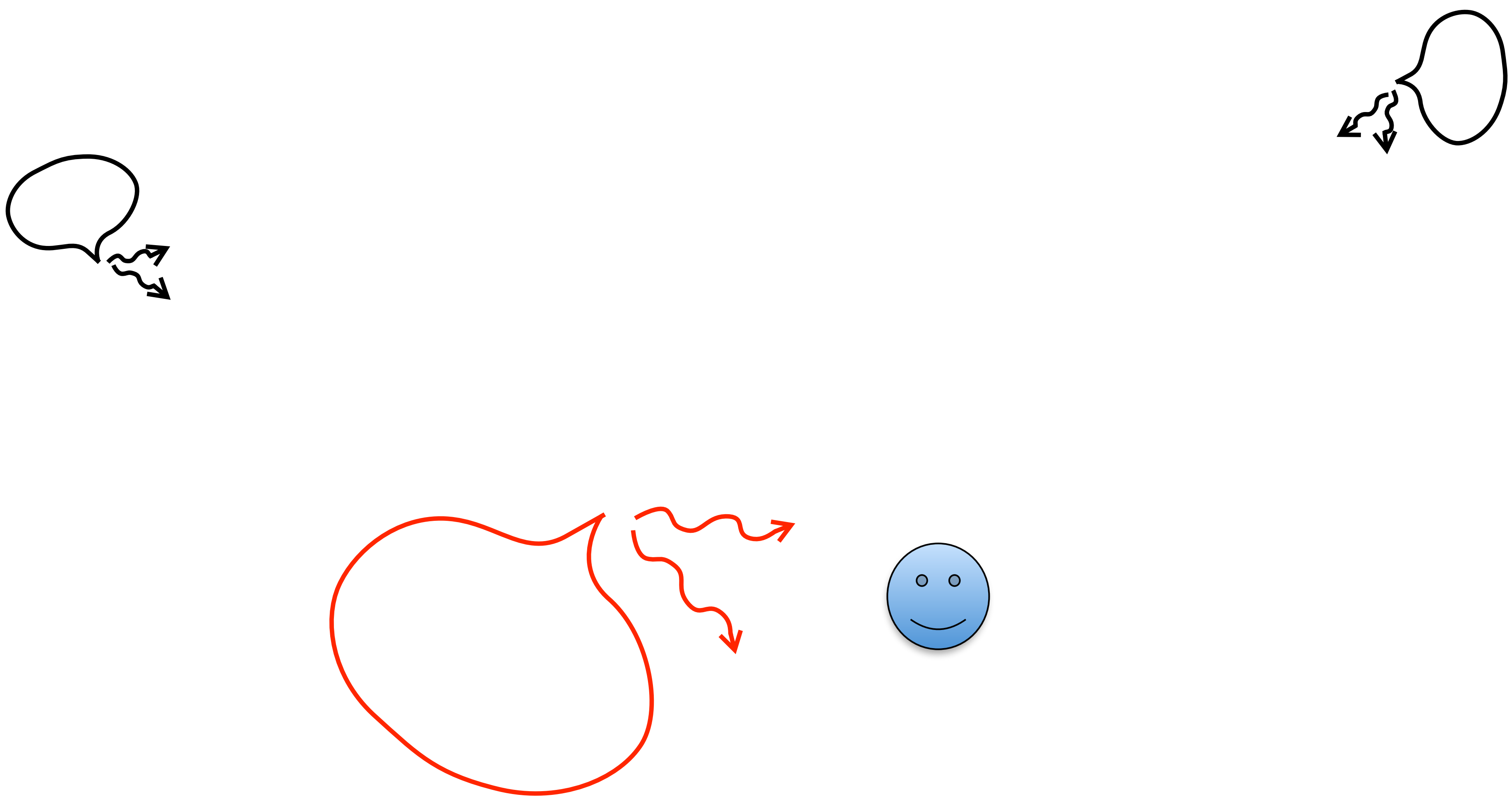
Gravitational waves coming from different directions overlap each other and form gravitational wave background

Anisotropy of gravitational wave background



If only a few loops contributes to the GW background,
it becomes anisotropic

Anisotropy of gravitational wave background



initial loop size α

↑

We can extract information of <u>loop number density</u>
from anisotropy of the gravitational wave background

Anisotropy test

- Formulations are constructed by

  Mingarelli et. al., PRD 88, 062005 (2013)

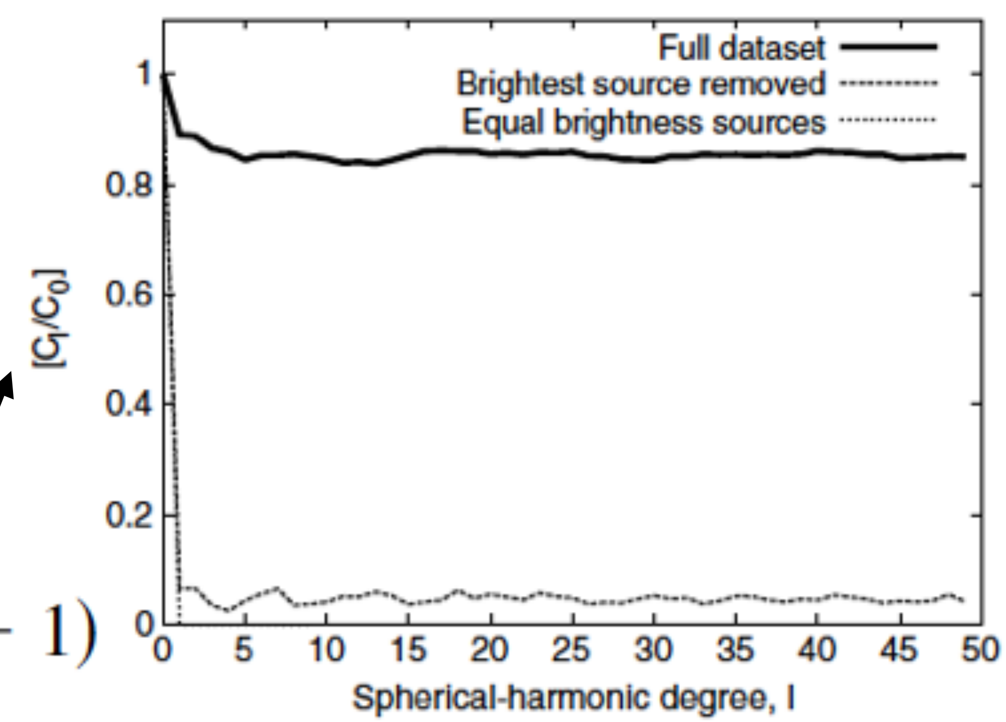
GW amplitude: $\Omega_{\mathrm{gw}}(f) = \frac{8\pi^2}{3H_0^2} f^3 H(f) \int d\hat{\Omega} P(\hat{\Omega})$

$P(\hat{\Omega}) \equiv \sum_{lm} c_l^m Y_l^m(\hat{\Omega})$ ← Spherical harmonic expansion

- Simulation study in a context of GWs from SMBH binaries

  Taylor & Gair, PRD 88, 084011 (2013)

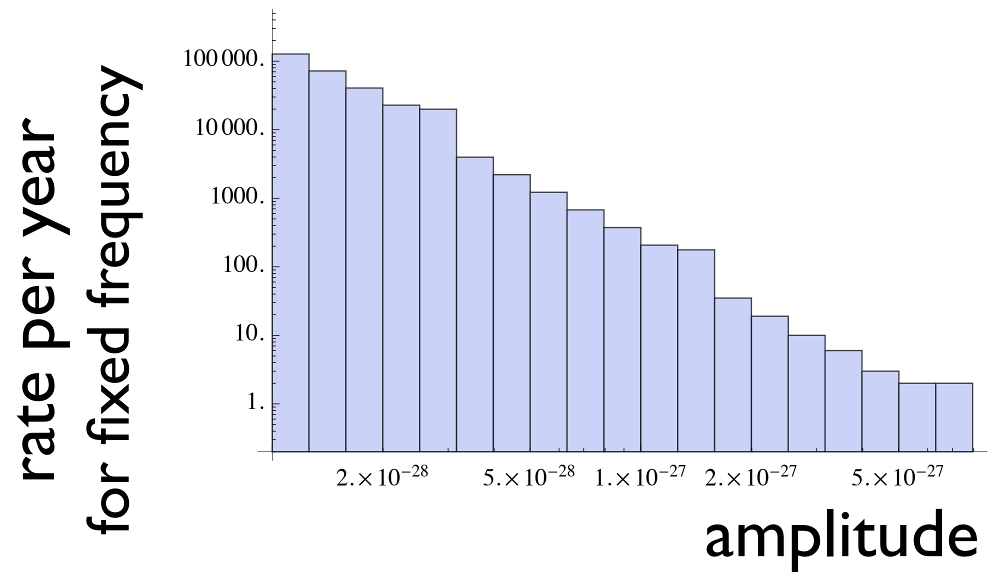
Anisotropy test is possible
for detection with SN>10



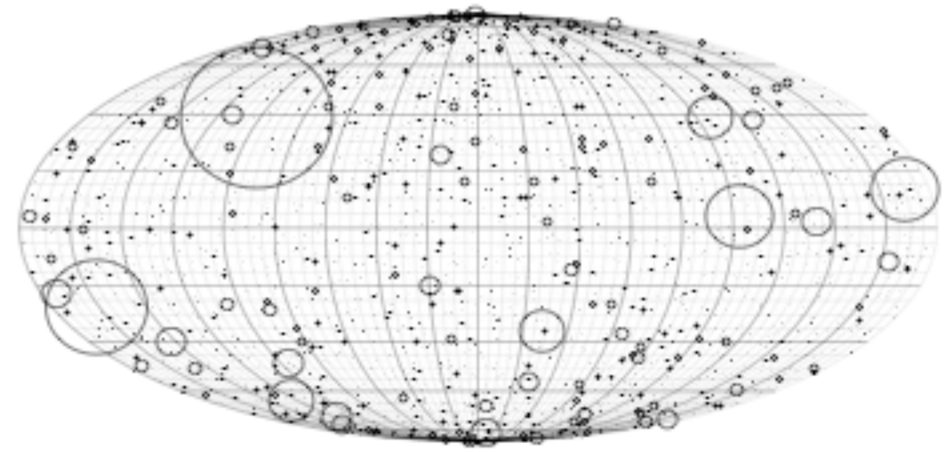
angular power spectrum: $C_l = \sum_m |c_{lm}|^2/(2l+1)$

Predictions for cosmic strings

1. predict rate of GW bursts



2. randomly distribute the source

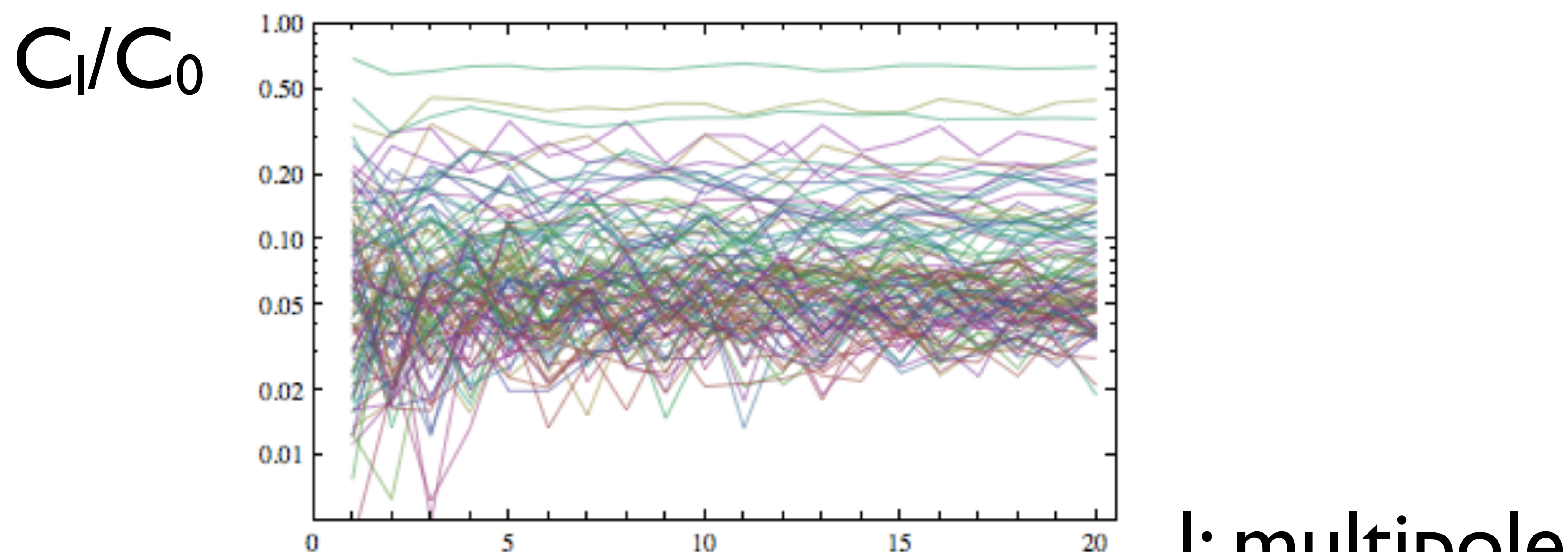


$$c_{lm} = \sum_{i=1}^{N} \rho_i Y_{lm}(\hat{\Omega}_i)$$

3. make100 realizations

$$C_l = \sum_m |c_{lm}|^2/(2l+1)$$

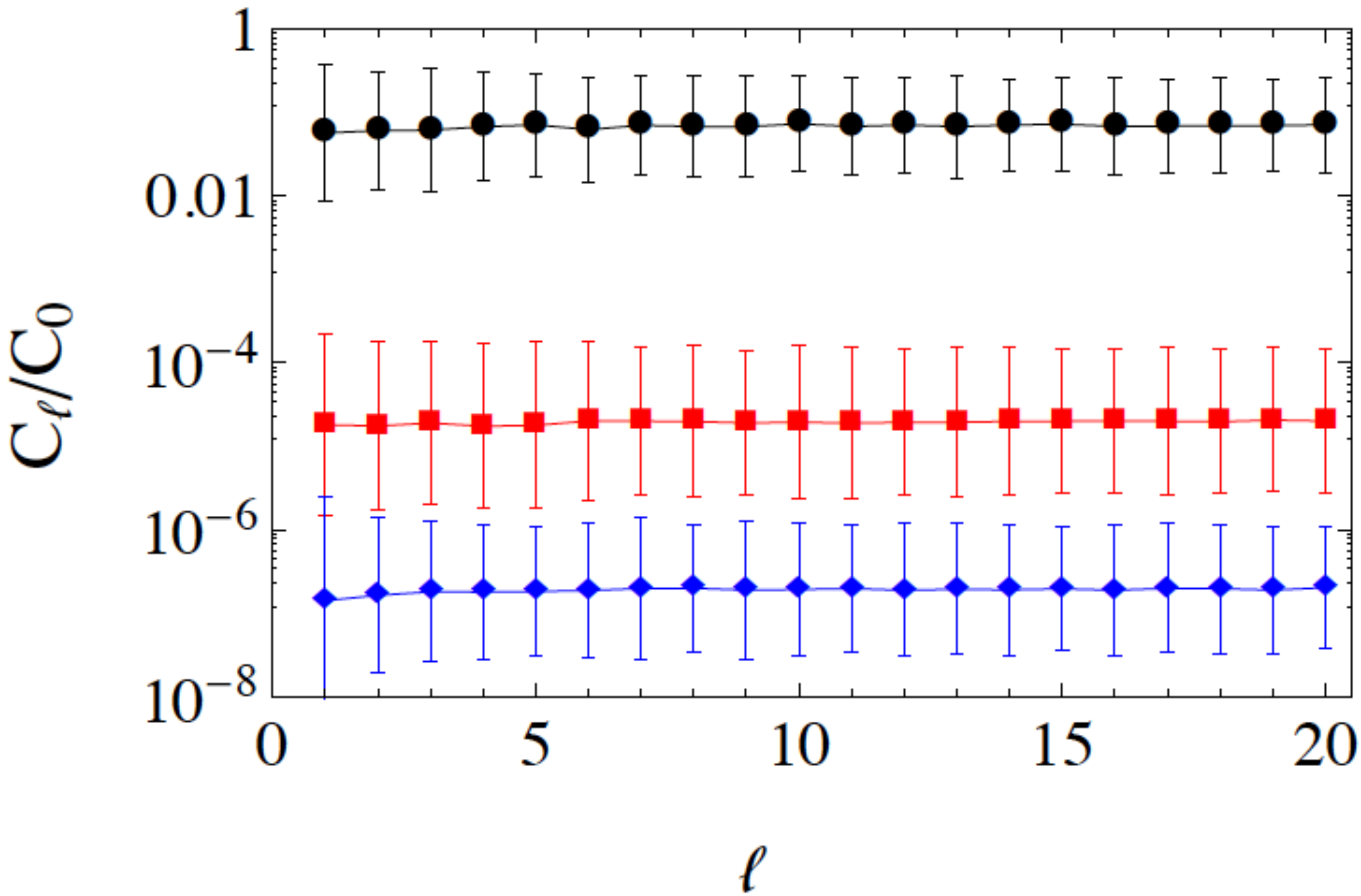
4. calculate anisotropy levels



assumed $f=(10\mathrm{yr})^{-1}$
$G\mu=10^{-11}$, $p=1$

Anisotropy level

with 2σ error bar



$\alpha=7.26\times10^{-10}$

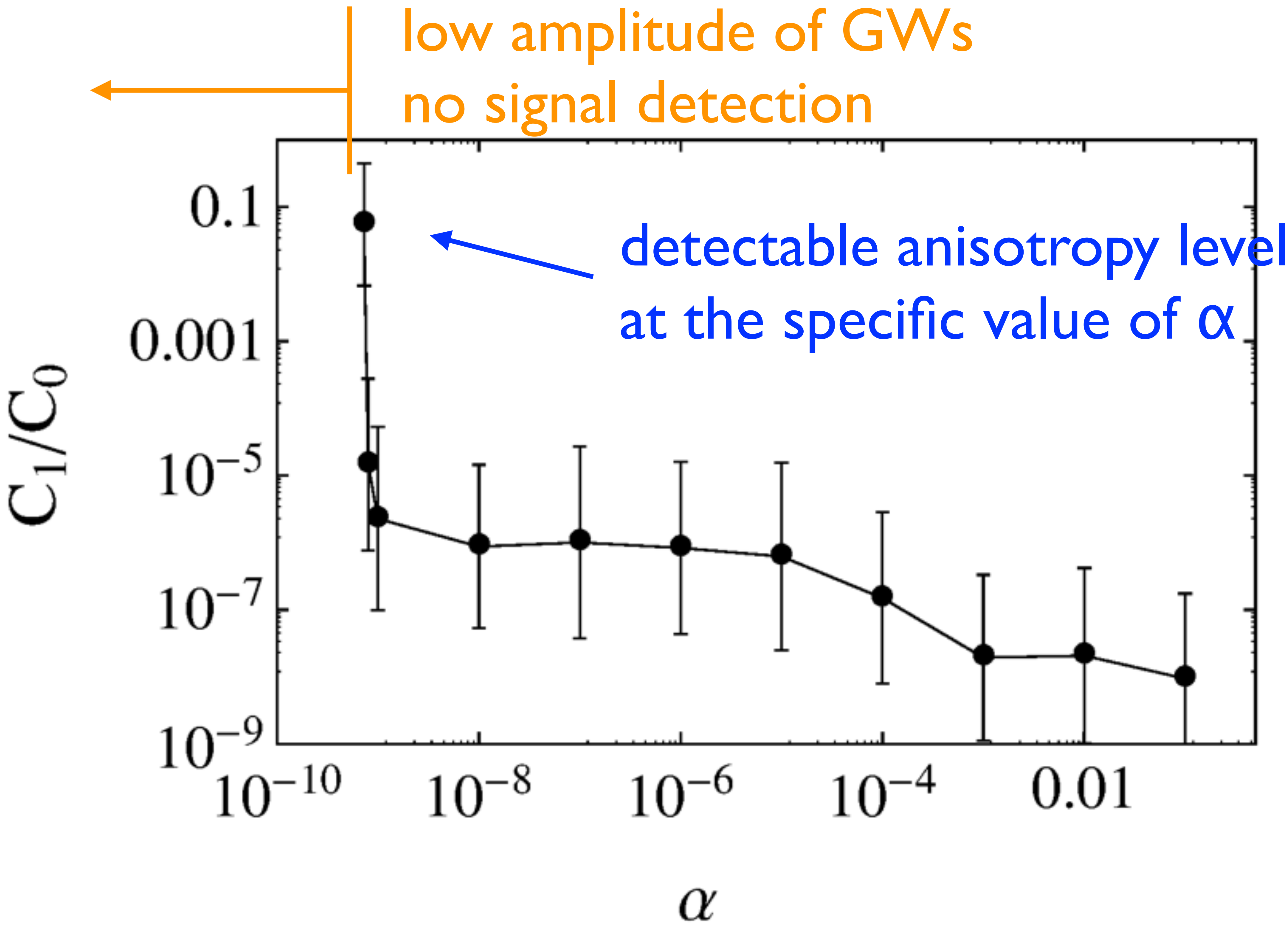
$\alpha=8\times10^{-10}$

$\alpha=10^{-4}$

We get large anisotropy for smaller value of α

(smaller initial loop size)

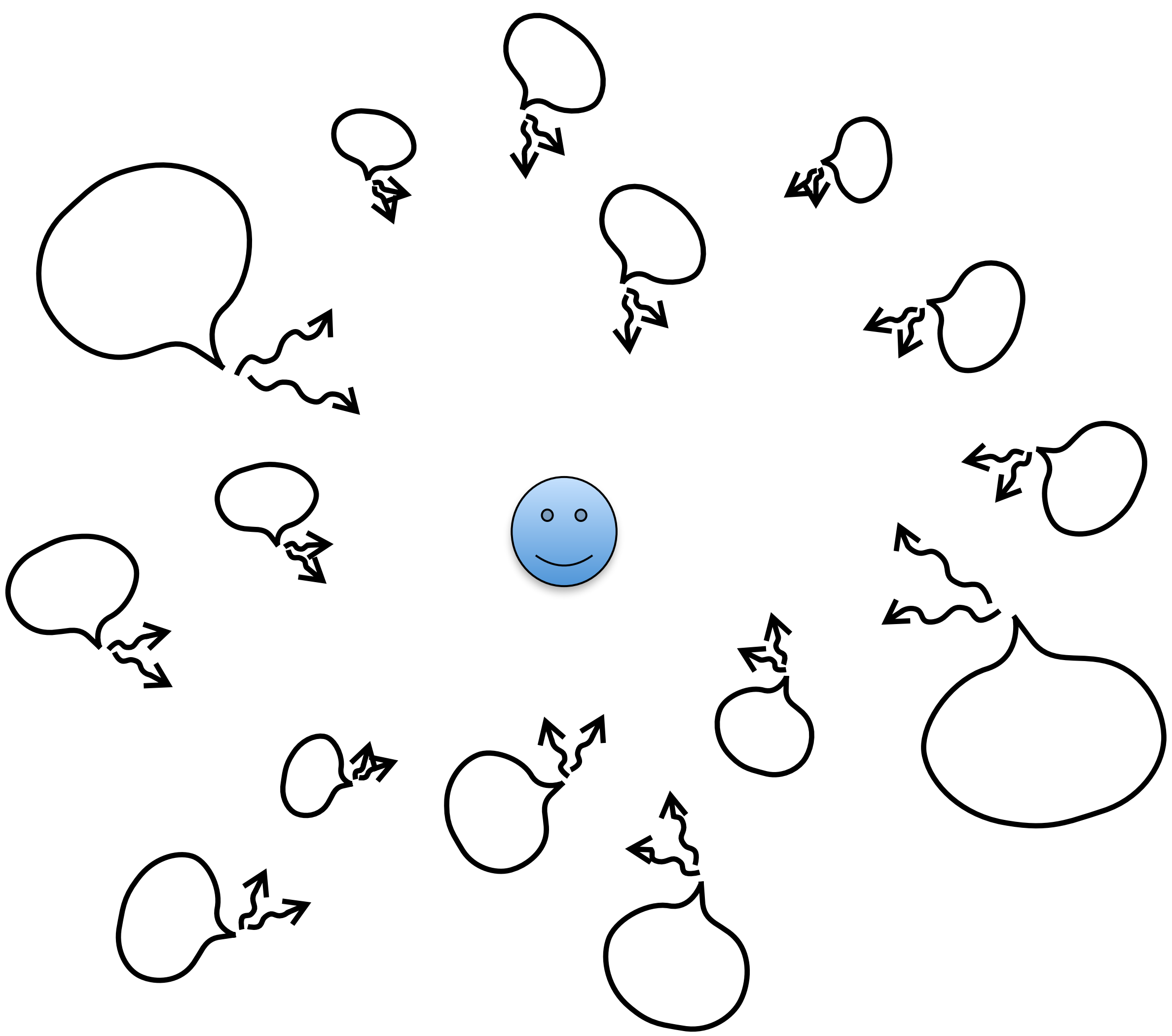
Dipole component α dependence



Interpretation

large α = long lifetime

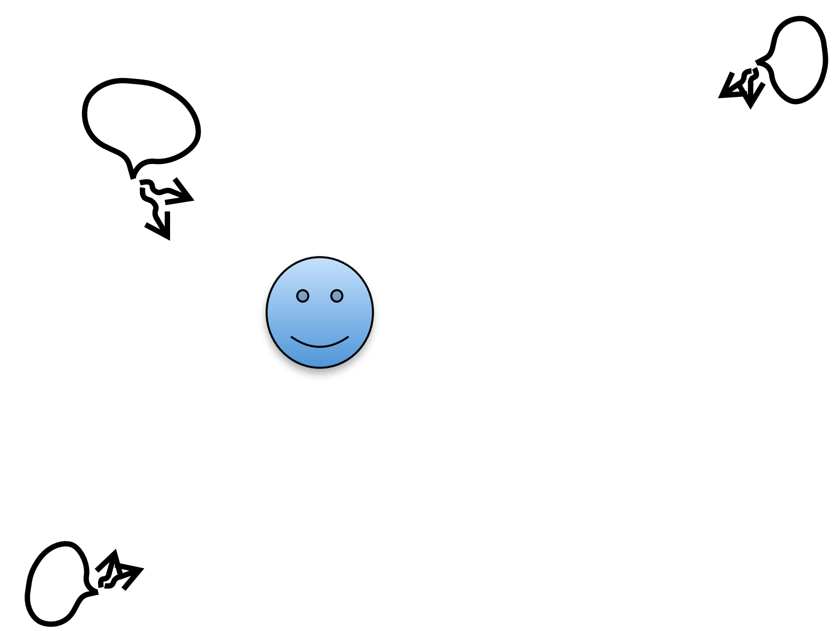
network consists of mixture of old and new loops



→ **isotropic GWs**

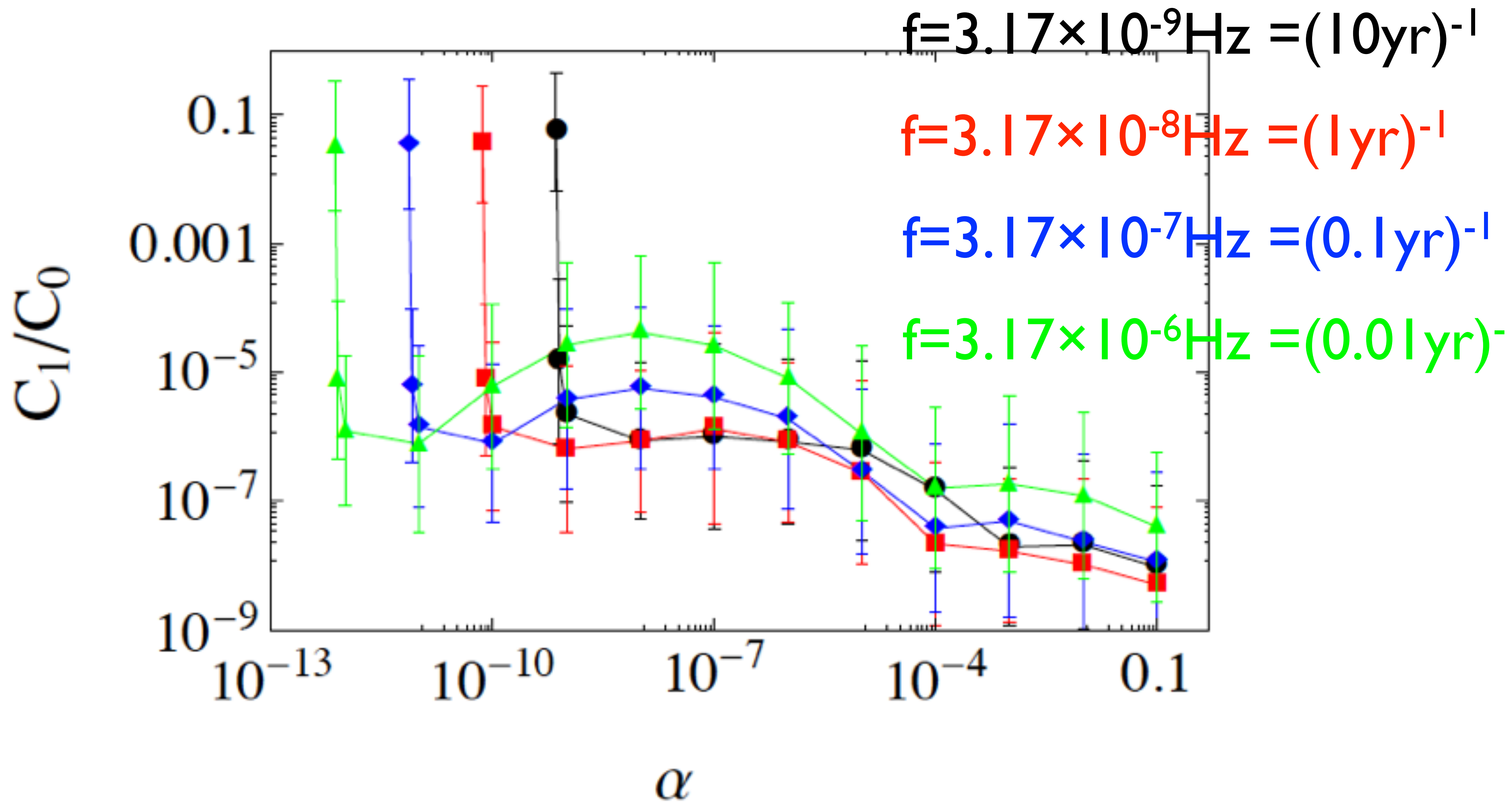
small α = short lifetime

loops evaporate soon after their formation



→ **anisotropic GWs**

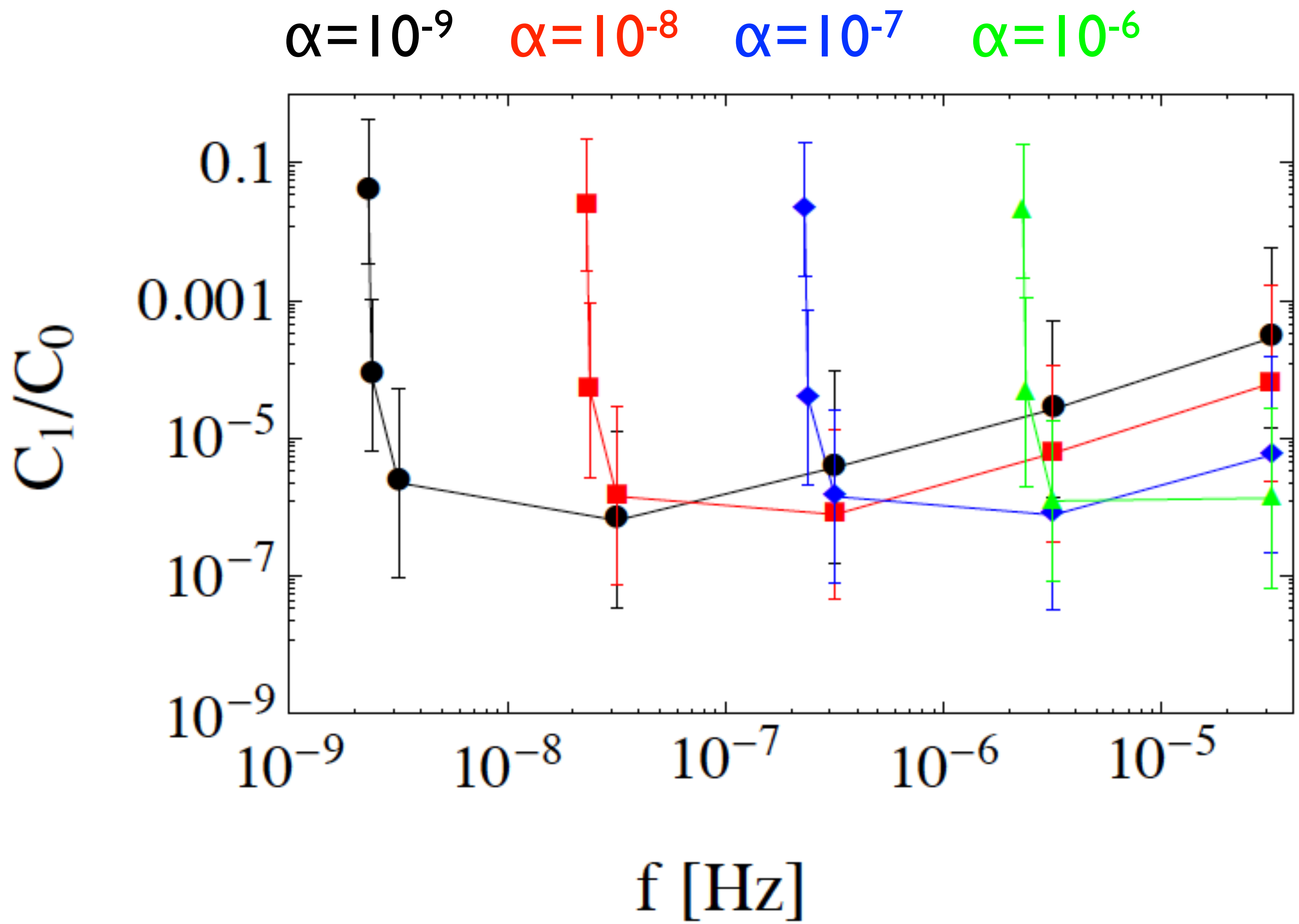
Observation frequency dependence



The peak position changes for different observation frequency

frequency of GWs ~ (initial loop size)$^{-1}$ ∝ α^{-1}

Observation frequency dependence



By checking anisotropy for different frequency bands, it may be possible to obtain implication on the value of α

Summary

- Testing the existence of cosmic string by PTA is important for obtaining implication on fundamental physics.
- SKA will cover a large parameter space of cosmic string parameters.
- Anisotropy of the gravitational wave background can be used to extract information on the initial loop size, which is important for understanding cosmic evolution of string network.