宇宙の進化と素粒子模型

2023 年度宇宙線研究所共同利用研究成果発表会

宇宙線研究所理論グループ　伊部昌宏

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2023 年度 業績一部

(1) Affleck-Dine leptogenesis scenario for resonant production of sterile neutrino dark matter
Kentaro Kasai, Masahiro Kawasaki, Kai Murai
e-Print: 2402.11902 [hep-ph]

(2) New Constraints on Gauged U(1)$_{L_\mu-L_\tau}$ Models via $Z-Z'$ Mixing
Kento Asai, Coh Miyao, Shohei Okawa, Koji Tsumura
e-Print: 2401.17613 [hep-ph]

(3) Revisiting Metastable Cosmic String Breaking
Akifumi Chitose, Masahiro Ibe, Yuhei Nakayama, Satoshi Shirai, Keiichi Watanabe
e-Print: 2312.15662 [hep-ph](4) Revisiting sterile neutrino dark matter in gauged $U(1)_{B-L}$ model

(4) Precise Estimate of Charged Higgsino/Wino Decay Rate
Masahiro Ibe, Yuhei Nakayama, Satoshi Shirai
e-Print: 2312.08087 [hep-ph]

(5) Primordial Origin of Supermassive Black Holes from Axion Bubbles
Kentaro Kasai, Masahiro Kawasaki, Naoya Kitajima (Tohoku U.),
Kai Murai (Tohoku U.), Shunsuke Neda, Fuminobu Takahashi (Thohoku U)
e-Print: 2310.13333 [astro-ph.CO]

(6) Axion curvaton model for the gravitational waves observed by pulsar timing arrays
Keisuke Inomata (Johns Hopkins U. and Chicago U., EFI and Chicago U., KICP), Masahiro Kawasaki, Kyohei Mukaida (KEK), Tsutomu T. Yanagida (Tokyo U., IPMU and Shanghai Jiaotong U.)
e-Print: 2309.11398 [astro-ph.CO]

(7) Contribution of Majoron to Hubble tension in gauged $U(1)_{L_\mu-L_\tau}$ Model
Kento Asai, Tomoya Asano (Saitama U.), Joe Sato (Yokohama Natl. U.), Masaki J.S. Yang (Saitama U.)
e-Print: 2309.01162 [hep-ph] DOI: 10.1088/1475-7516/2022/07/046

(8) Enhancement of gravitational waves at Q-ball decay including non-linear density perturbations
Masahiro Kawasaki (Tokyo U., ICRR and Tokyo U., IPMU), Kai Murai (Tohoku U.)
e-Print: 2308.13134 [astro-ph.CO] DOI: 10.1088/1475-7516/2024/01/050

(9) New constraint on dark photon at T2K off-axis near detector
Takeshi Araki (Koriyama Women's U.), Kento Asai , Tomoya Iizawa (KEK, Tsukuba), Hidetoshi Otono (Kyushu U.), Takashi Shimomura (Miyazaki U. and Kyushu U., Fukuoka (main)) et al.
e-Print: 2308.01565 [hep-ph] DOI: 10.1007/JHEP11(2023)056

(10) Probing for chiral Z' gauge boson through scattering measurement experiments
Kento Asai, Arindam Das (Hokkaido U.), Jinmian Li (Sichuan U.), Takaaki Nomura (Sichuan U.), Osamu Seto (Hokkaido U.)
e-Print: 2307.09737 [hep-ph]

(11) Hill-top inflation from Dai-Freed anomaly in the standard model
Masahiro Kawasaki, Tsutomu T. Yanagida (Tsung-Dao Lee Inst., Shanghai and Tokyo U., IPMU)
e-Print: 2306.14579 [hep-ph] DOI: 10.1088/1475-7516/2024/01/014

(12) Clustering of primordial black holes from QCD axion bubbles
Kentaro Kasai, Masahiro Kawasaki, Naoya Kitajima, Kai Murai, Shunsuke Neda et al.
e-Print: 2305.13023 [astro-ph.CO] DOI: 10.1088/1475-7516/2023/10/049

(13) Model building by coset space dimensional reduction scheme using eight-dimensional coset spaces
Kento Asai, Joe Sato (Yokohama Natl. U.), Ryosuke Suda (Saitama U.), Yasutaka Takanishi (Saitama U.), Masaki J.S. Yang (Saitama U.)
e-Print: 2305.01421 [hep-ph] DOI: 10.1007/JHEP11(2023)213

(14) Dai-Freed anomaly in the standard model and topological inflation
Masahiro Kawasaki, Tsutomu T. Yanagida (Shanghai Jiao Tong U. and Tokyo U., IPMU)
e-Print: 2304.10100 [hep-ph] DOI: 10.1007/JHEP11(2023)106

(15) Interactions of electrical and magnetic charges and dark topological defects
Akifumi Chitose (Tokyo U., ICRR), Masahiro Ibe (Tokyo U., ICRR)
e-Print: 2303.10861 [hep-ph] DOI: 10.1103/PhysRevD.108.035044 (publication)

(16) Muon g − 2 and non-thermal leptogenesis in $U(1)_{L_\mu-L_\tau}$ model
Shintaro Eijima, Masahiro Ibe, Kai Murai,
e-Print: 2303.09751 [hep-ph] DOI: 10.1007/JHEP05(2023)010

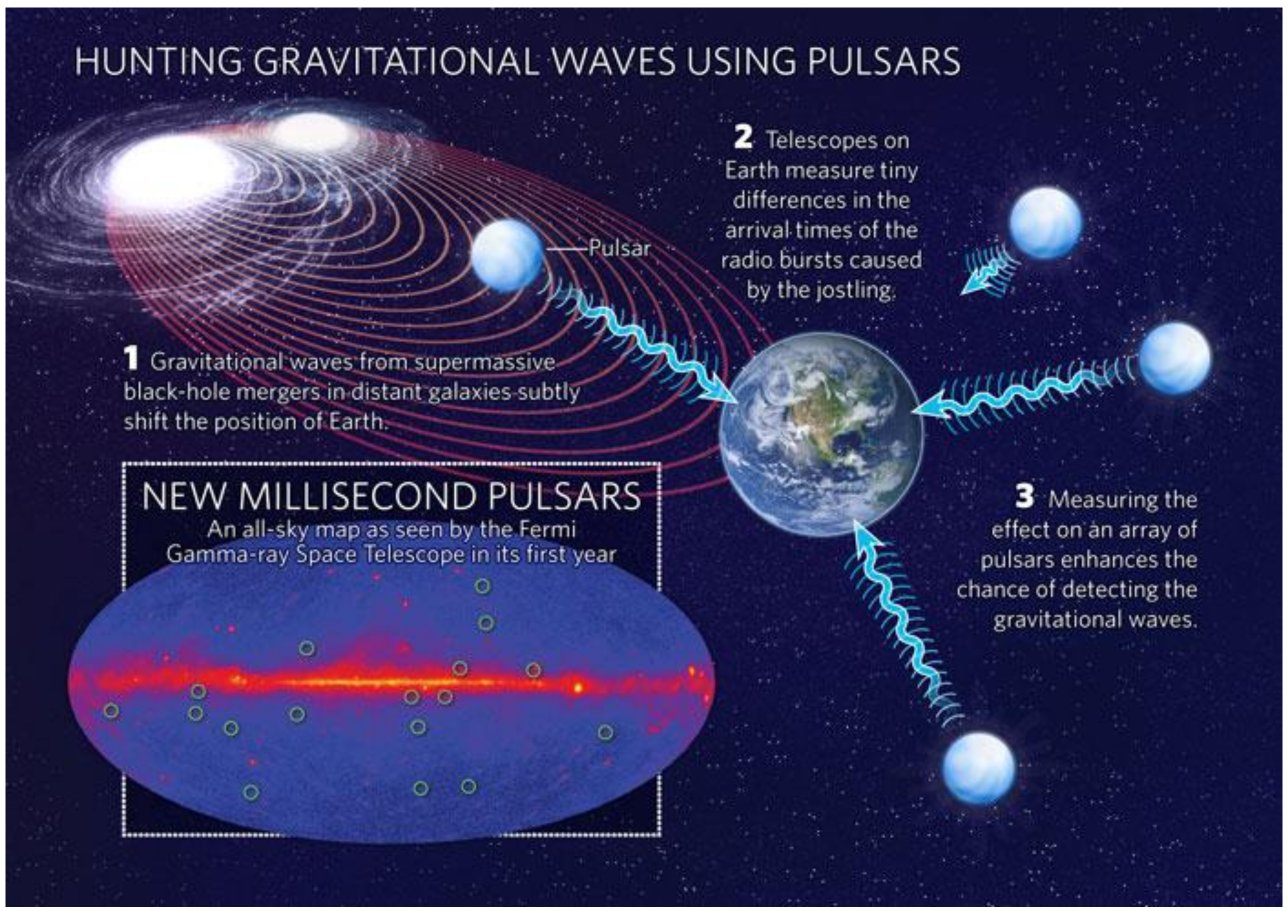
Revisiting Metastable Cosmic String Breaking

arXiv: 2312.15662

Akifumi Chitose, MI, Yuhei Nakayama, Satoshi Shirai, Keiichi Watanabe

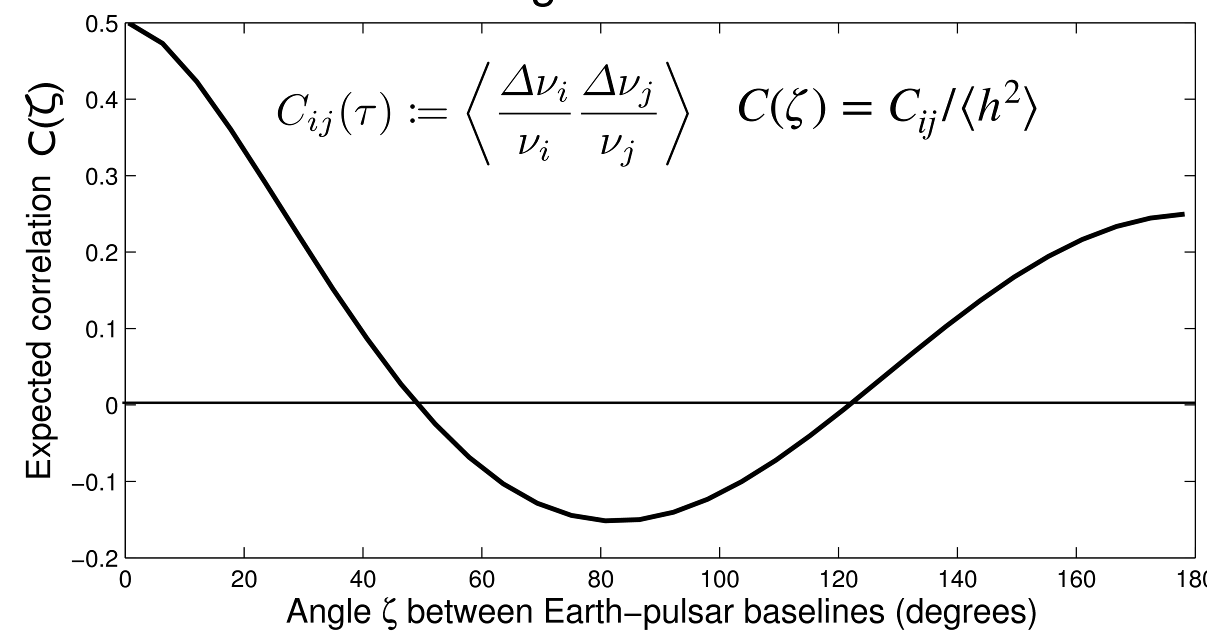
Pulsar Timing Array : Gravitational Wave (GW) signal?

- **Millisecond pulsars:** incredibly stable clocks in space.
- **GWs** passing through spacetime slightly alter the arrival times of the pulses.
- **Timing analysis:** PTAs can detect correlations in the difference between the observed and predicted arrival times from many pulsars for many that are indicative of GWs.
  [**NANOGrav** has observes radio waves from the 67 pulsars for 15 years ~ 0.5 x 10^8 sec]



(Credit: NASA/DOE/Fermi LAT Collaboration via Nature)

Helling-Downs curve:



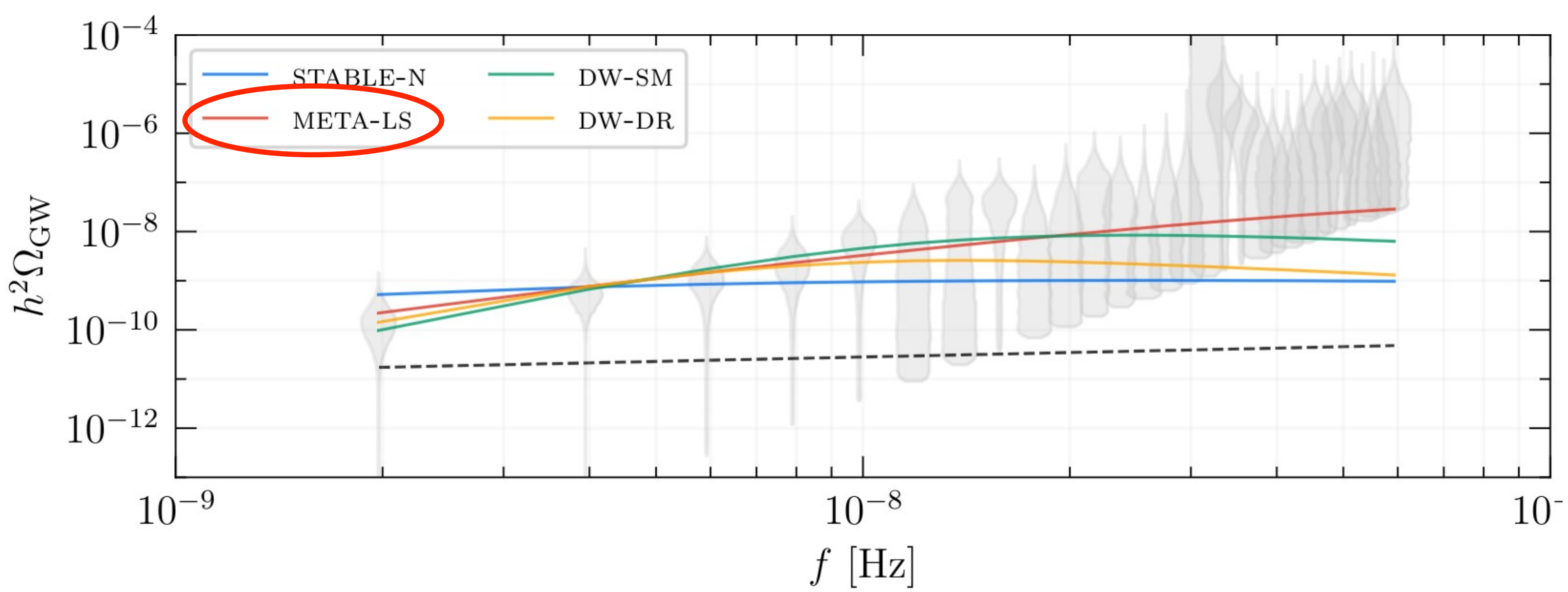
The correlation of a GW signal for pulsars separated by ζ .

PTA can detect the stochastic GWs !

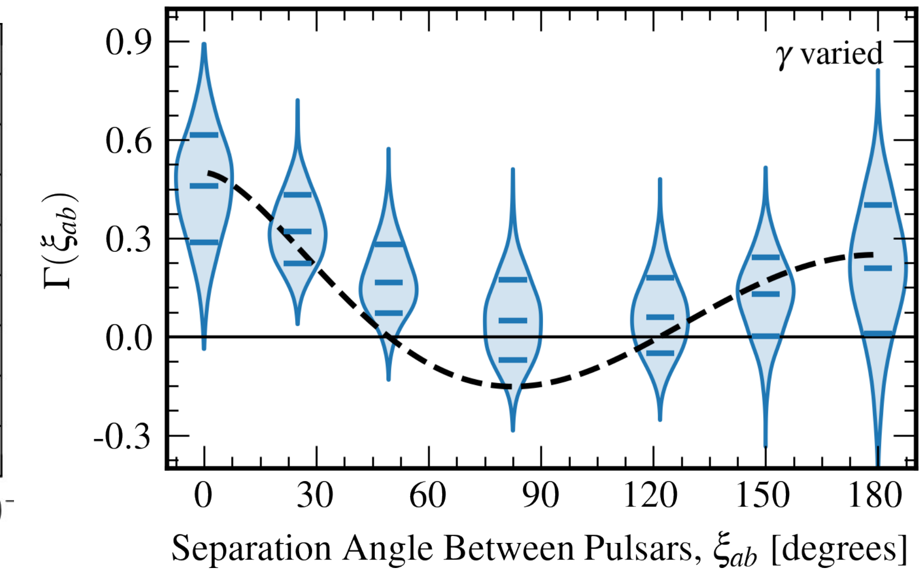
Figure taken from https://nanograv.github.io/metronomedemo/

Pulsar Timing Array : Gravitational Wave (GW) signal?

[NANOGrav 2306.16219] $\Omega_{\rm GW}(f) \equiv \frac{f}{\rho_c}\left|\frac{d\rho_{\rm GW}}{df}\right|$

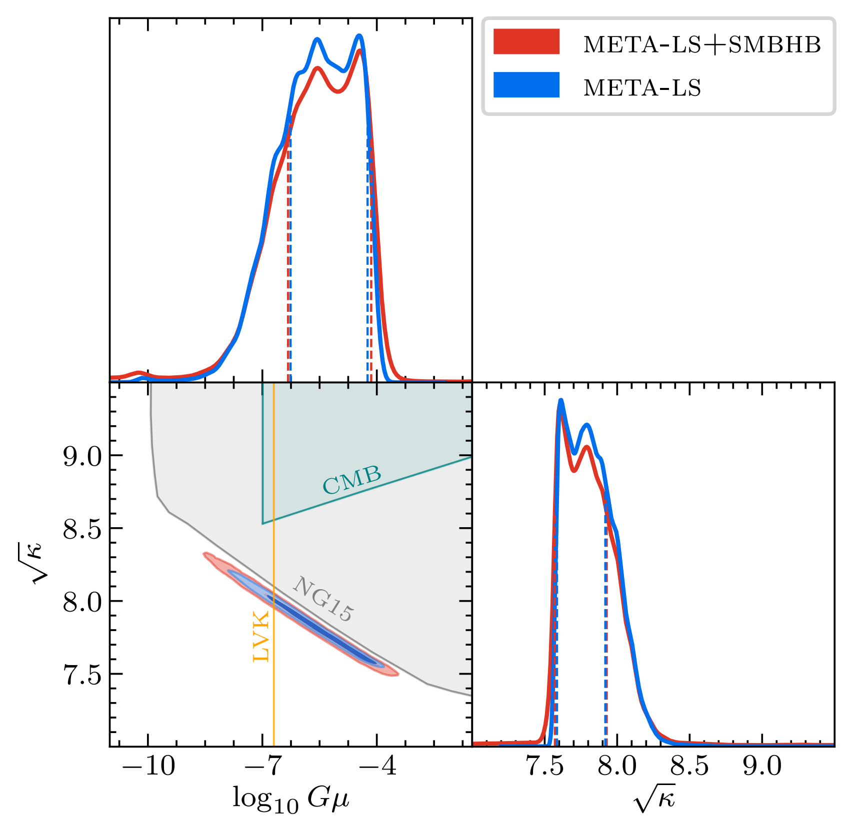


[NANOGrav 2306.16213]



Approx. 3σ excess compared with uncorrelated noise

[NANOGrav 2306.16219]



Metastable Cosmic String well fits the signal !

Tension (mass per unit length) μ **:**

$$G_N\mu \sim 10^{-8} - 10^{-4}$$

$$(\ \mu^{1/2} \sim 10^{15} - 10^{17}\,\text{GeV}\ )$$

Breaking @ cosmic time $t_s \sim \Gamma_d^{-1/2}$

$$t_s \sim 10^3\,\text{sec}, \quad (G_N\mu \sim 10^{-4})$$

$$t_s \sim 10^6\,\text{sec}, \quad (G_N\mu \sim 10^{-8})$$

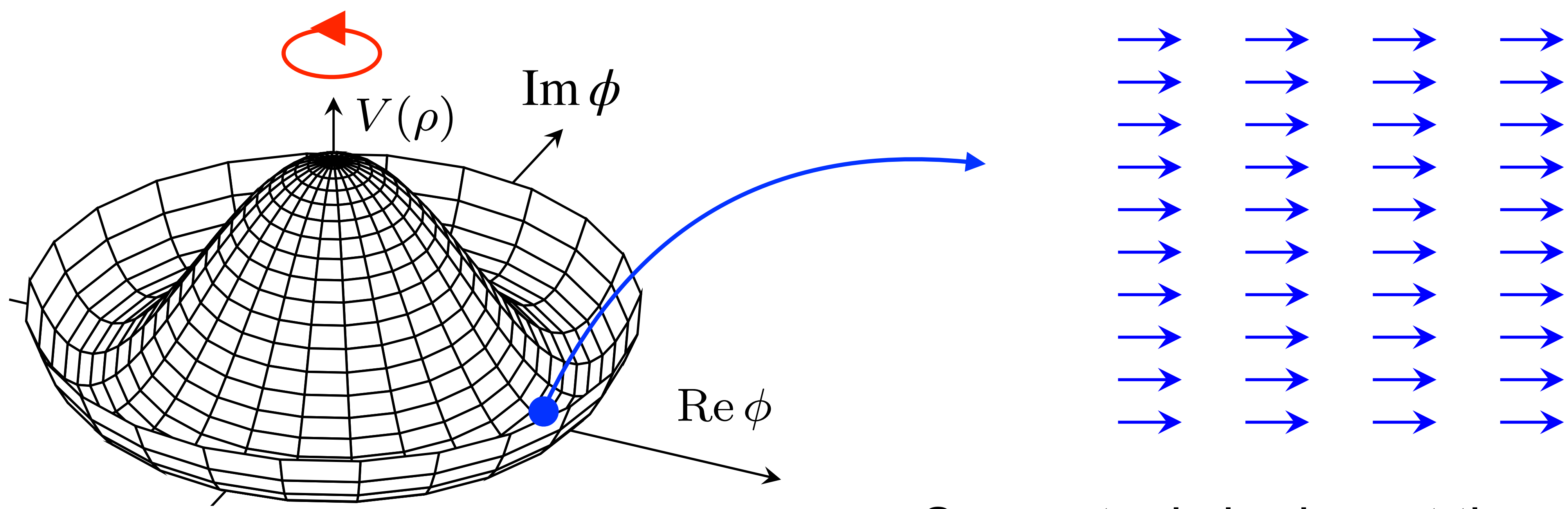
Decay width per unit length $\Gamma_d = \frac{\mu}{2\pi}e^{-\pi\kappa}$:

What is Cosmic String ?

Spontaneous Symmetry Breaking (Higgs Mechanism)

U(1) Rotation Invariant Potential

Direction of symmetry breaking on xy-plane



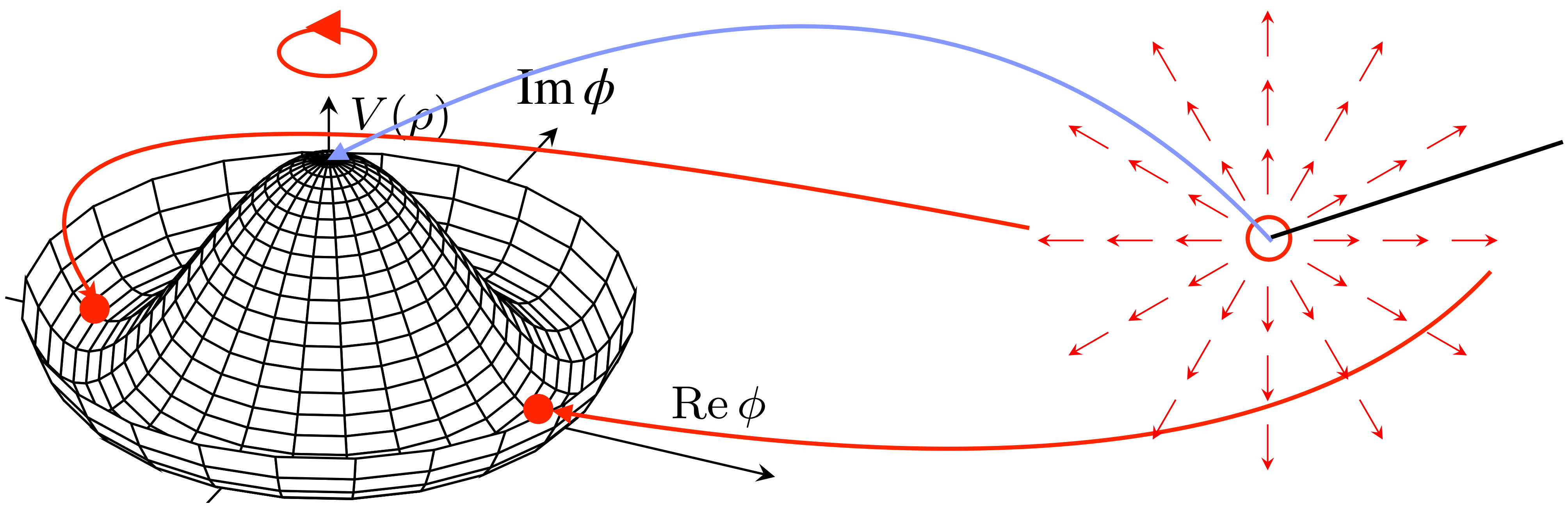
Symmetry is broken at the vacuum homogeneously

What is Cosmic String ?

Spontaneous Symmetry Breaking (Higgs Mechanism)

U(1) Rotation Invariant Potential

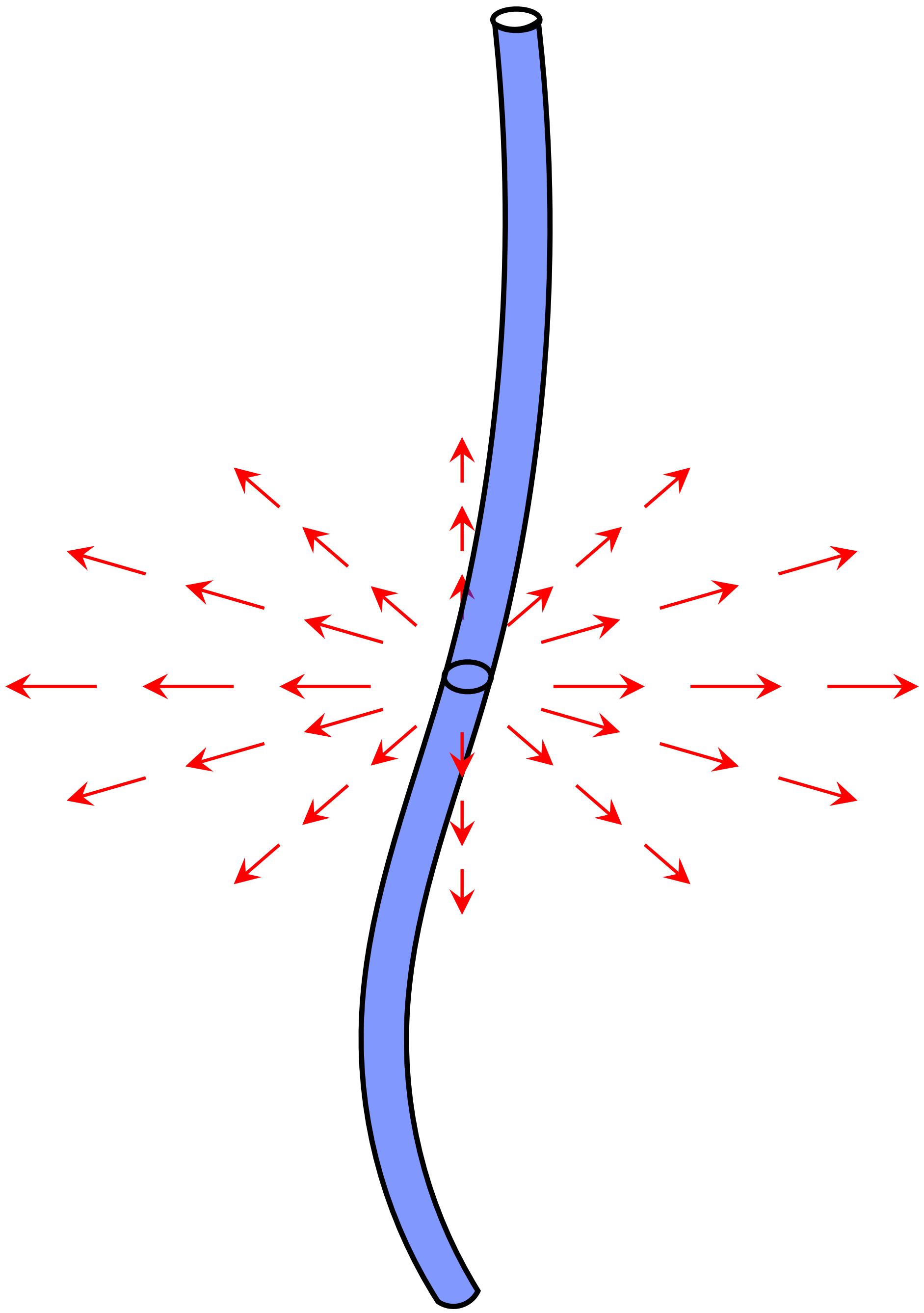
Direction of symmetry breaking on xy-plane



Symmetry is broken at the vacuum but leaves a defect (= symmetry enhanced point)

In the early Universe non-trivial structures often appear at the phase transition of the spontaneous symmetry breaking.

What is Cosmic String ?

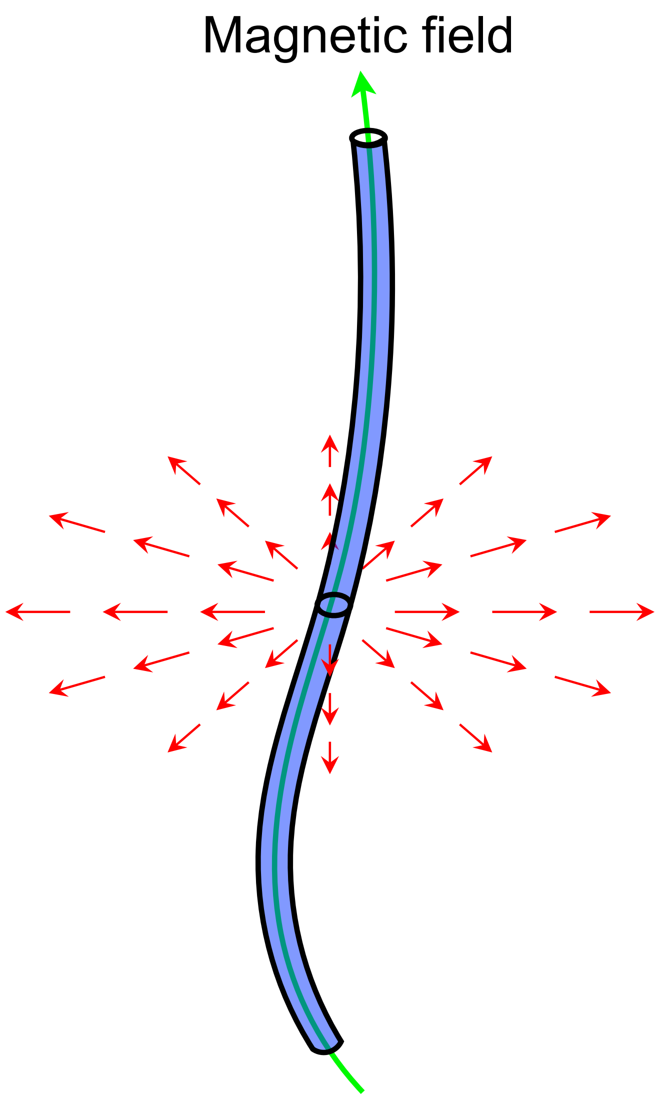


Along the defect (= symmetry restored point) string-like object is formed

Cosmic String !

New physics models which predict cosmic strings are quite common!

Physics of Cosmic String in minutes



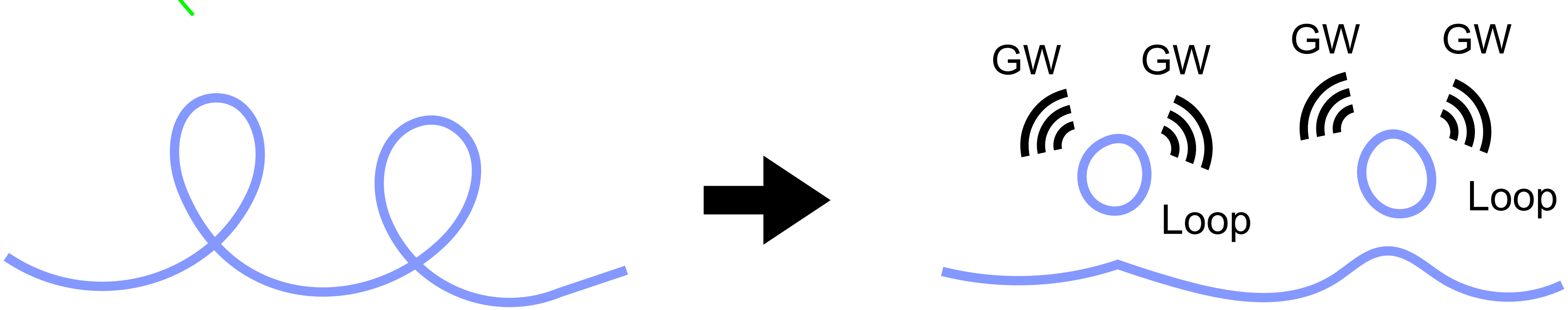
Non-QED Magnetic field is going through the cosmic string.

Long strings keep generating loop strings.
(Reconnections and self intersections etc.)

Loop strings shrink by emitting GWs and disappear.

Long strings do not disappear from the Universe, i.e. stable.

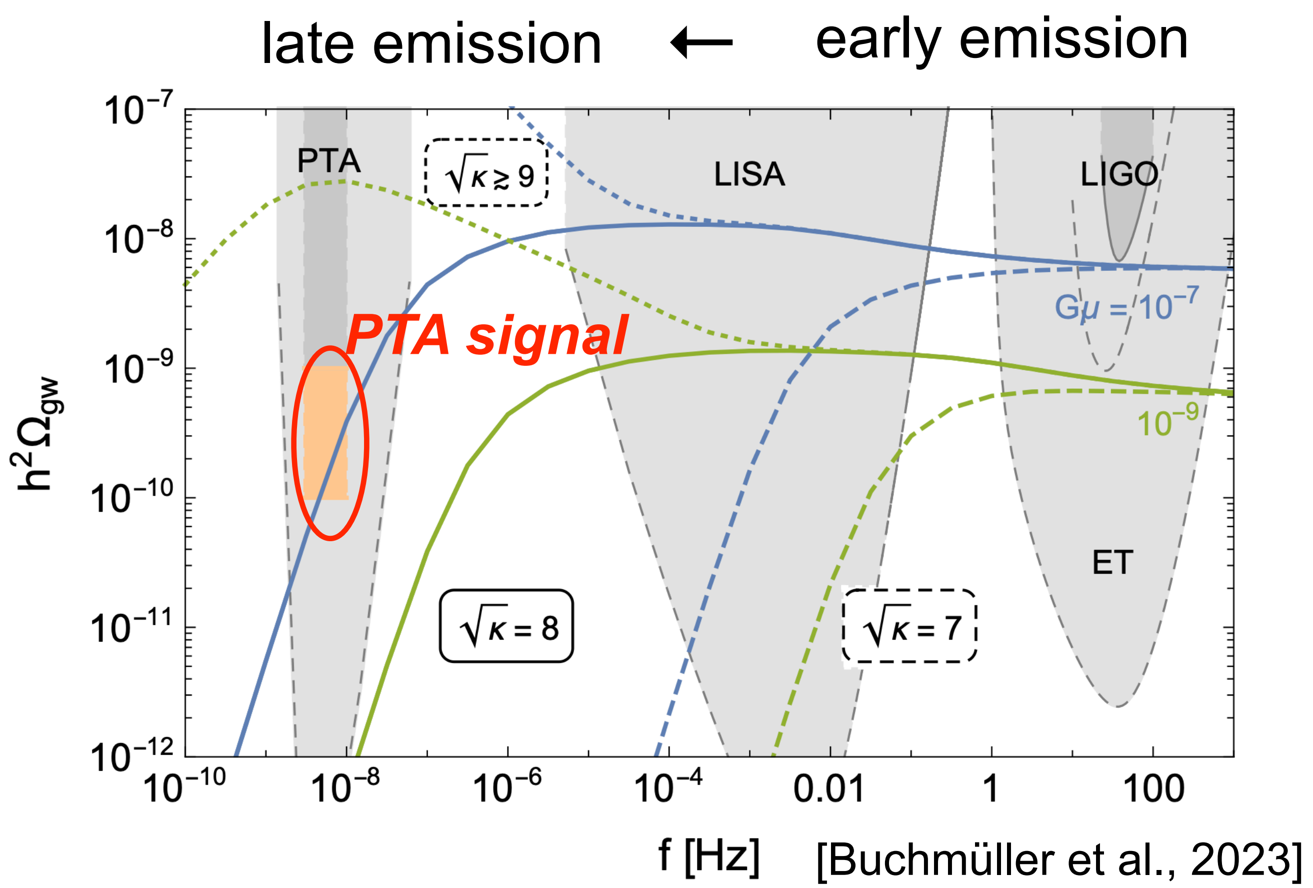
(It costs infinite of energy to make the long string disappear)



Long strings self-intersect/reconnect

Long strings remain in the Universe
and keep generating loop strings.

Metastable String ?



Dotted ~ stable,
Solid ~ metastable,
Dashed ~ more fragile

Cosmic String with stable long string cannot explain the PTA results…

(String loops generated at the late time makes the GW spectrum inconsistent)

We need to make the long string disappear from the Universe

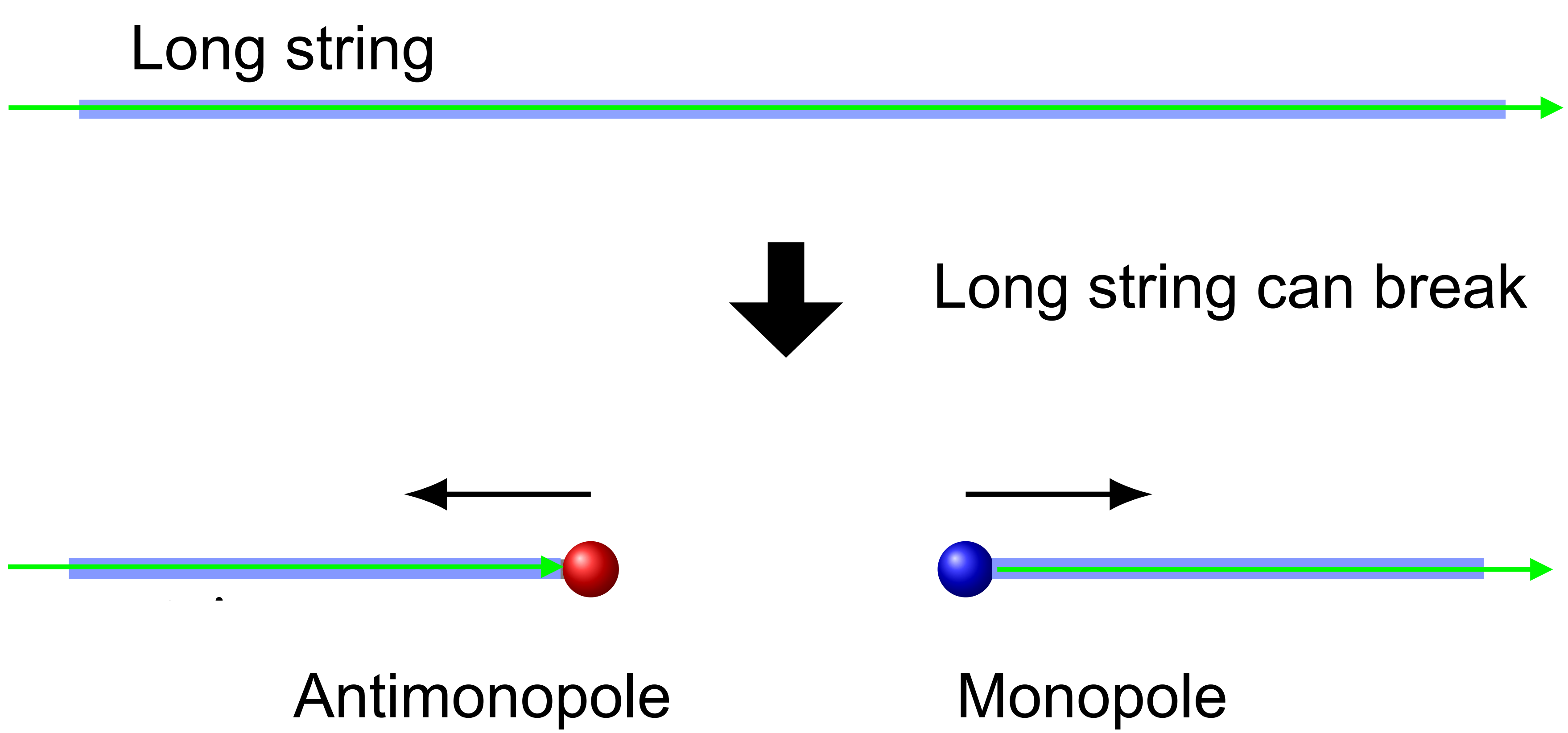
→ Make strings metastable

How to make strings metastable ?

Key : Magnetic field

Assume U(1) symmetry breaking model possesses Magnetic monopole.
→ The string can break by creating monopole-antimonopole pair !

[Vilenkin 1982]



This type of the system is ubiquitous in Grand Unified Theory such as SO(10) model.

How to make strings metastable ?

How about the breaking rate ?

Preskill Vilenkin approximation of decay rate per unit string length (1992)

$$\Gamma_d = \frac{\mu}{2\pi} e^{-\pi\kappa}\,, \quad \kappa = \frac{M_M^2}{\mu}$$

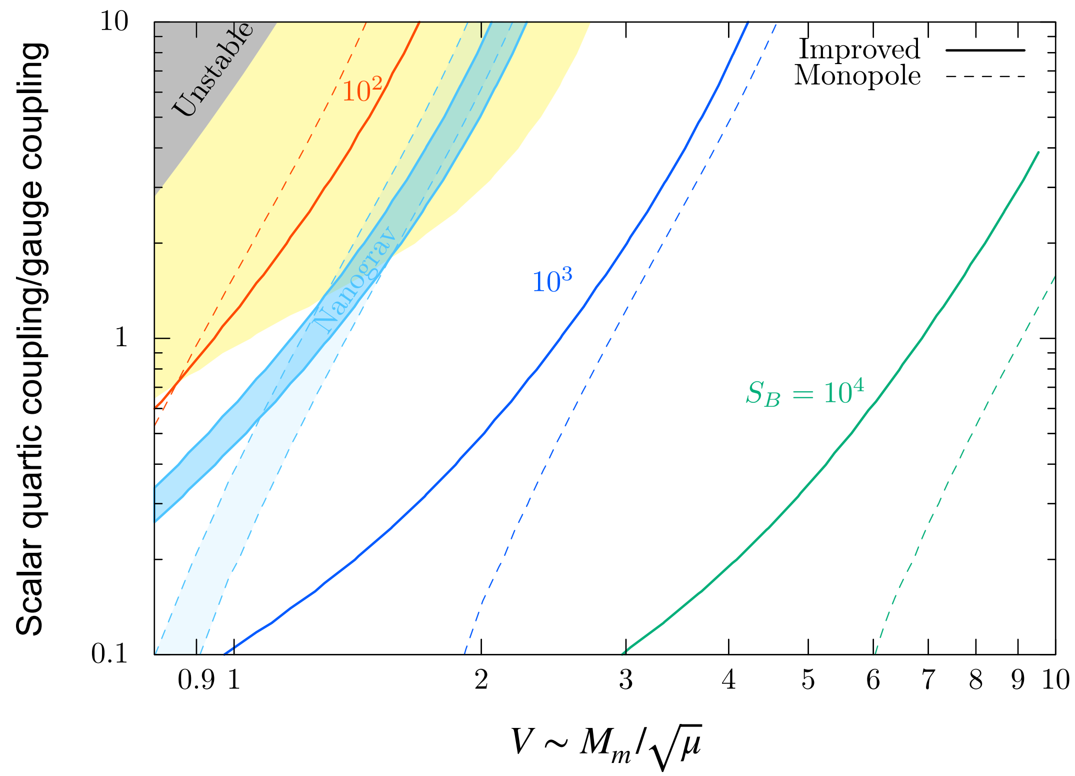
μ : string tension, M_M : Monopole Mass

This estimate is valid when we neglect the string width and the monopole size.

How to make strings metastable ?

How about the breaking rate ?

In our work, we performed numerical estimate of the string decay rate by taking into account the finite thicknesses of strings and monopoles. (Based on a proposal by Shifman&Yung 2002)



arXiv: 2312.15662 (our work)

In the yellow shaded region, the string decay can be much faster than the prediction of the Preskill-Vilenkin approximation.

Our result provides important information to pin down the parameters of the model, such as SO(10) GUT settings!