宇宙の進化と素粒子模型

2024 年度宇宙線研究所共同利用研究成果発表会

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2024 年度 業績一部

(1) Comprehensive Bayesian Exploration of Froggatt-Nielsen Mechanism

Masahiro Ibe, Satoshi Shirai Keiichi Watanabe
e-Print: 2412.19484 [hep-ph]

(2) Curvaton distribution from stochastic inflation
Koki Tokeshi e-Print: 2411.15849 [astro-ph.CO]

(3) Gravitational Waves from Metastable Cosmic Strings in Supersymmetric New Inflation Model
Akifumi Chitose (Tokyo U., ICRR), Masahiro Ibe (Tokyo U., ICRR and Tokyo U., IPMU), Shunsuke Neda (Tokyo U., ICRR), Satoshi Shirai (Tokyo U., IPMU) e-Print: 2411.13299 [hep-ph]

(4) Nucleon Decay as a Probe of Flavor Symmetry: The Case of Fake Unification
Masahiro Ibe (Tokyo U., ICRR and Tokyo U., IPMU), Satoshi Shirai (Tokyo U., IPMU and Tokyo U., ICRR), Keiichi Watanabe (Tokyo U., ICRR) e-Print: 2411.05398 [hep-ph]

(5) Exactly solvable stochastic spectator
Masazumi Honda (Tokyo U. and Wako, RIKEN), Ryusuke Jinno (Kobe U.), Koki Tokeshi (Tokyo U., ICRR)
e-Print: 2409.16272 [astro-ph.CO]
DOI: 10.1088/1475-7516/2024/12/044
Published in: JCAP 12 (2024), 044

(6) Dark photon pair production via off-shell dark Higgs at FASER
Takeshi Araki (Koriyama Women's U.), Kento Asai (Tokyo U., ICRR), Yohei Nakashima (Kyushu U., Fukuoka (main)), Takashi Shimomura (Miyazaki U.)
e-Print: 2406.17760 [hep-ph] DOI: 10.1007/JHEP12(2024)124
Published in: JHEP 12 (2024), 124

(7) Supermassive black hole formation from Affleck-Dine mechanism with suppressed clustering on large scales
Kentaro Kasai (Tokyo U., ICRR), Masahiro Kawasaki (Tokyo U., ICRR and Tokyo U., IPMU), Kai Murai (Tohoku U.), Shunsuke Neda (Tokyo U., ICRR)
e-Print: 2405.09790 [astro-ph.CO]

(8) Small instanton effects on composite axion mass
Takafumi Aoki (Tokyo U., ICRR), Masahiro Ibe (Tokyo U., ICRR and Tokyo U., IPMU), Satoshi Shirai (Tokyo U., IPMU and Tokyo U., ICRR), Keiichi Watanabe (Tokyo U., ICRR)
e-Print: 2404.19342 [hep-ph]
DOI: 10.1007/JHEP07(2024)269
Published in: JHEP 07 (2024), 269

(9) MeV gamma rays from Q-ball decay
Shinta Kasuya (Kanagawa U.), Masahiro Kawasaki (Tokyo U., IPMU and Tokyo U., ICRR), Naomi Tsuji (Kanagawa U. and Wako, RIKEN)
e-Print: 2403.01675 [hep-ph]
DOI: 10.1103/PhysRevD.109.083039 (publication)
Published in: Phys.Rev.D 109 (2024) 8, 083039

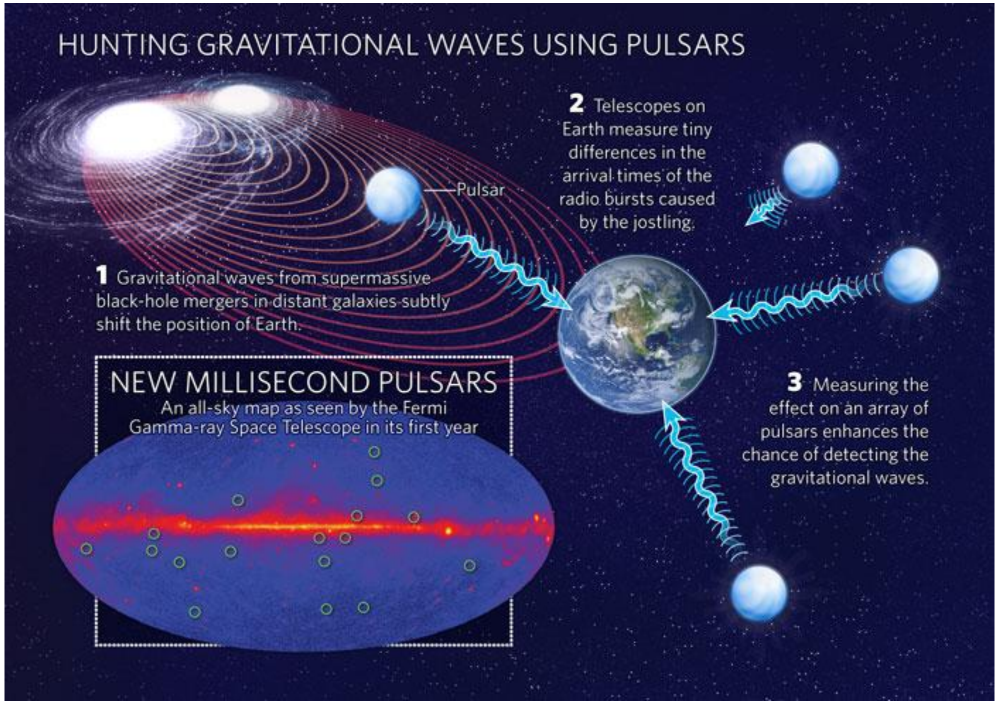
Gravitational Waves from Metastable Cosmic Strings in Supersymmetric New Inflation Model

Akifumi Chitose, MI, Sunsuke Neda, Satoshi Shirai *arXiv: 2411.13299*

Pulsar Timing Array : Gravitational Wave (GW) signal?

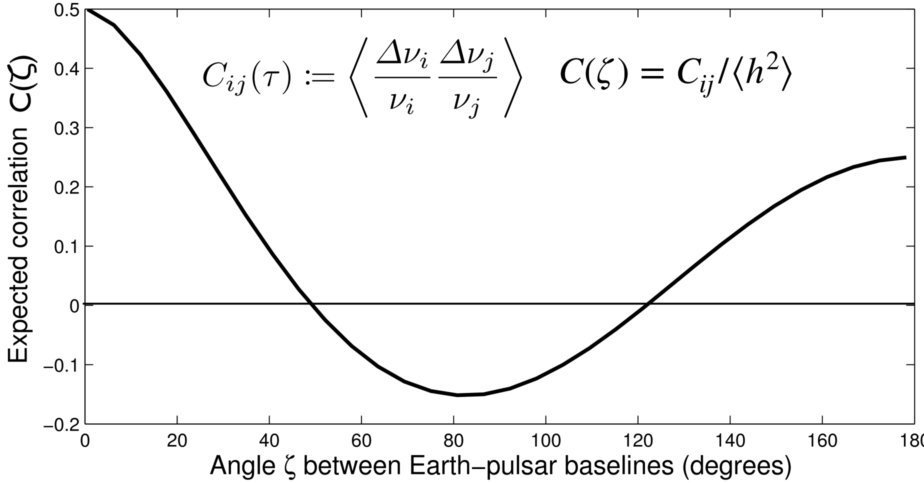
- **Millisecond pulsars:** incredibly stable clocks in space.
- **GWs** passing through spacetime slightly alter the arrival times of the pulses.
- **Timing analysis:** PTAs can detect correlations in the difference between the observed and predicted arrival times from many pulsars for many that are indicative of GWs.

[**NANOGrav** has observes radio waves from the 67 pulsars for **15 years ~ 5 x 10^8 sec**]



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

Helling-Downs curve:



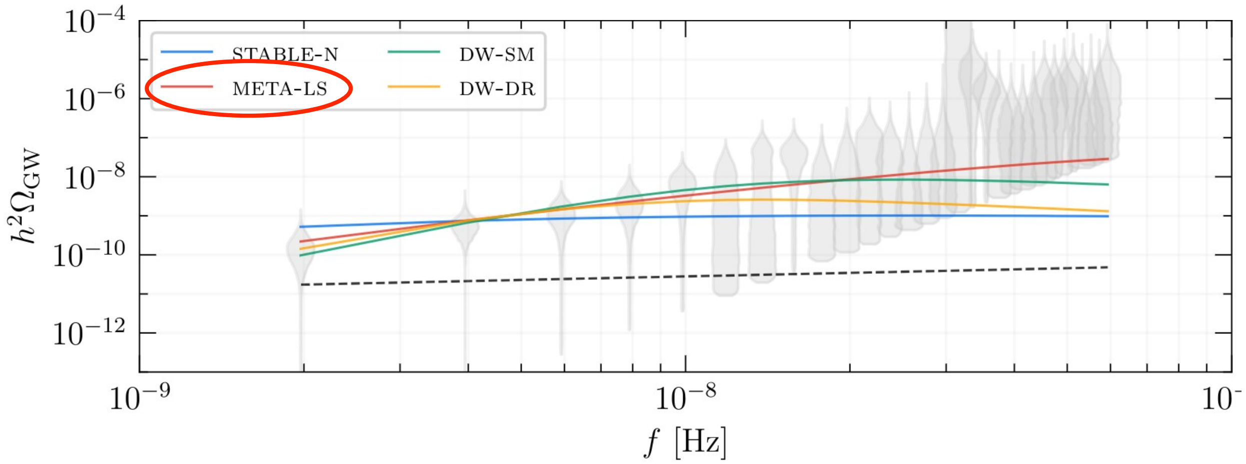
The correlation of a GW signal for pulsars separated by ζ .

PTA can detect the stochastic GWs !

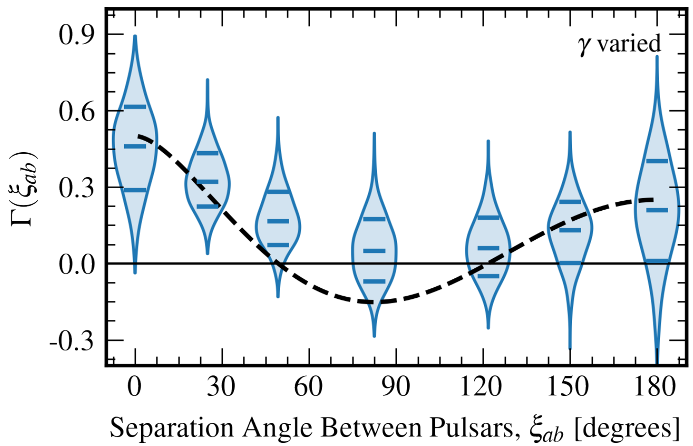
Figure taken from https://nanograv.github.io/metronomedemo/

Pulsar Timing Array : Gravitational Wave (GW) signal?

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

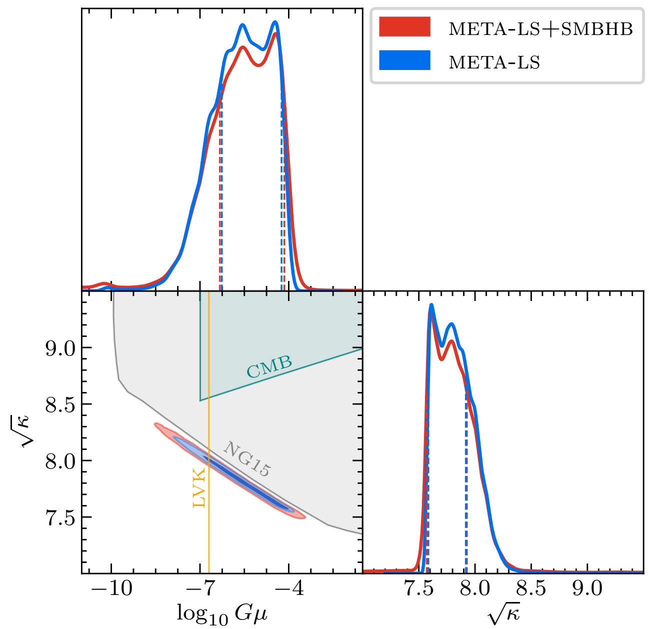


[NANOGrav 2306.16213]



Approx. 3σ excess compared with uncorrelated noise

[NANOGrav 2306.16219]



Metastable Cosmic String well fits the signal !

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

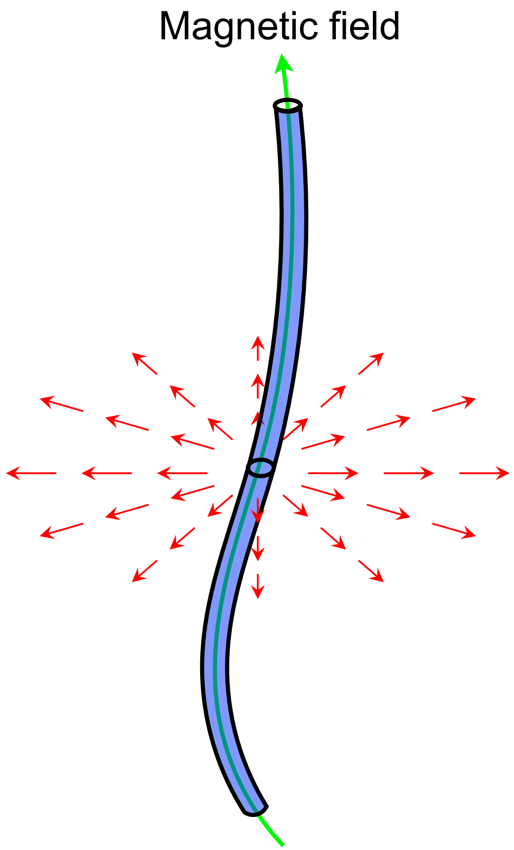
$$G_N\mu \sim 10^{-8} - 10^{-4}$$
$$(\ \mu^{1/2} \sim 10^{15} - 10^{17}\,\text{GeV}\ )$$

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 $\Gamma_d = \frac{\mu}{2\pi}e^{-\pi\kappa}$:

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.)

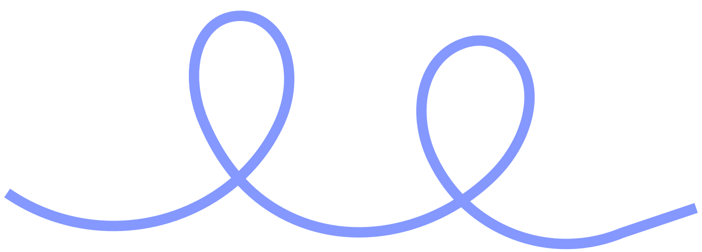
Loop strings shrink by emitting GWs and disappear.

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

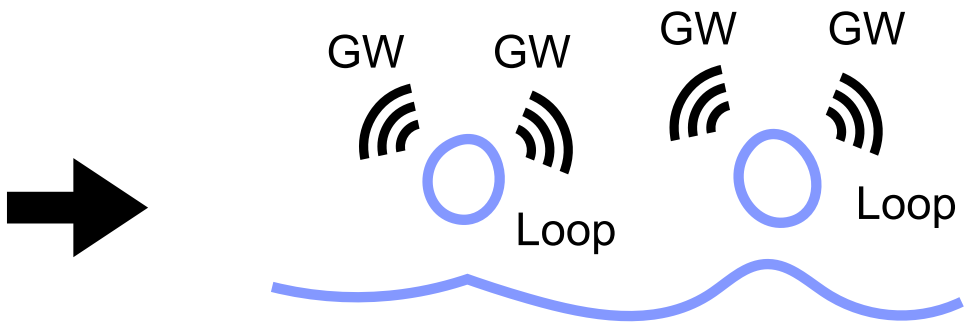
(It costs infinite of energy to make the long string disappear)

GW wave length ~ string loop size ~ Hubble^{-1}

Typical Size ~ Hubble^{-1}



Long strings self-intersect/reconnect

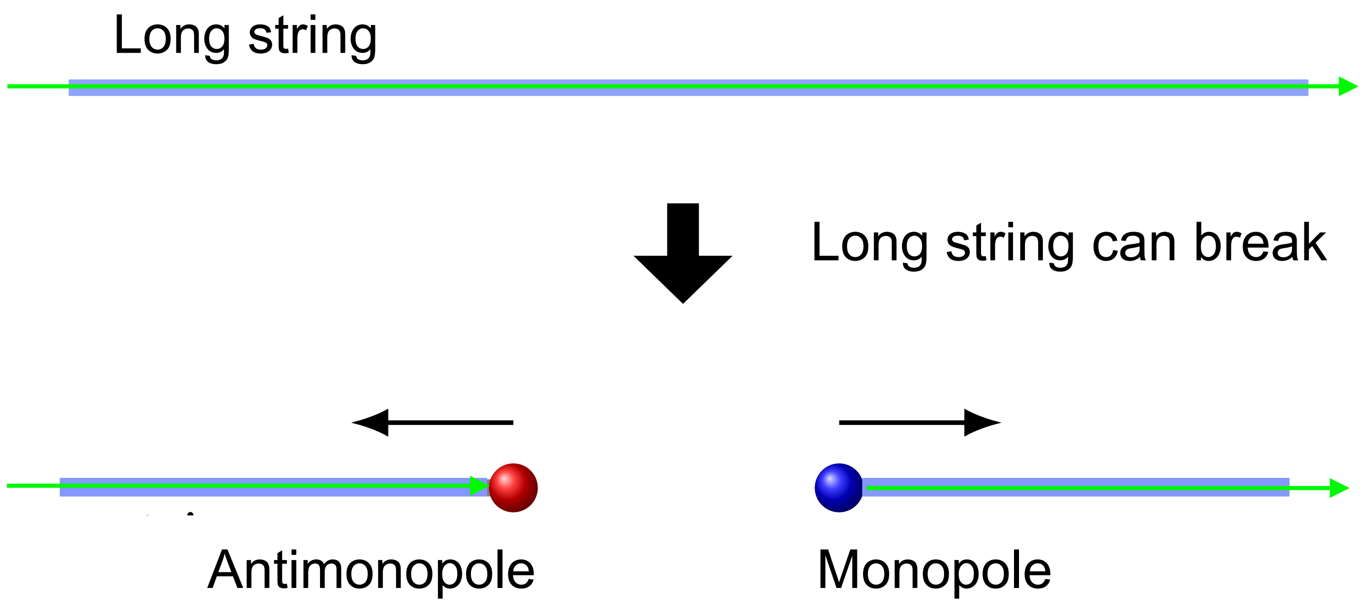


Long strings remain in the Universe and keep generating loop strings.

PTA signal requires metastable string

(Long strings should also disappear at some point !)

With magnetic monopole, strings can be broken ! [Vilenkin 1982]



(Pair creation inside the string)

Metastable String appears in model with **2-step phase transition!**

SU(2) → U(1) → No symmetry

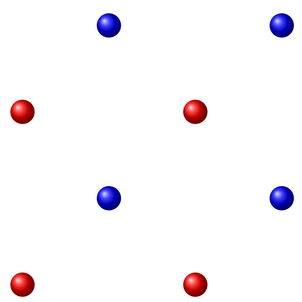
"Monopole" "string"

PTA signal also requires

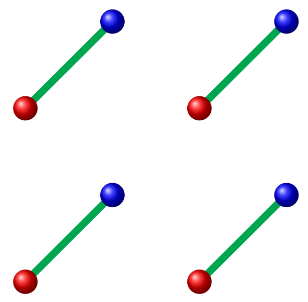
SU(2) breaking scale ~ U(1) breaking scale…

Can an inflation model produce the expected GW signal?

For SU(2) breaking scale ~ U(1) breaking scale…



@ SU(2) breaking
= many monopoles



@ U(1) breaking
= strings are formed

Most strings are formed connecting a monopole and an antimonopole.

Can we expect long strings ?

PTA signal also requires

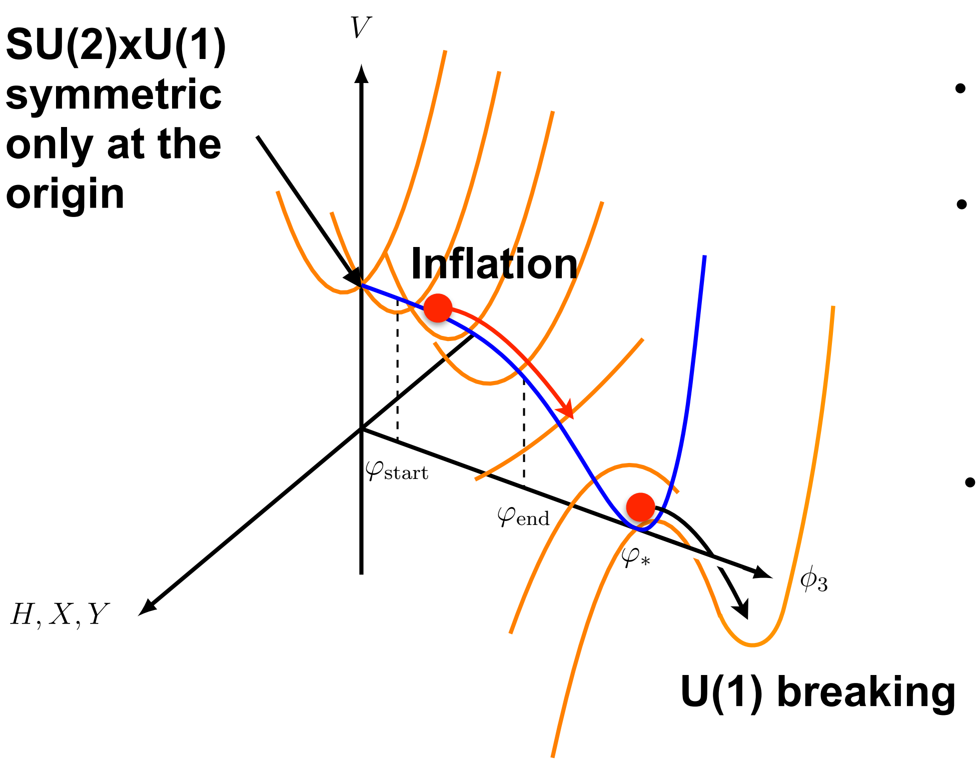
SU(2) breaking scale ~ U(1) breaking scale…

Can an inflation model produce the expected GW signal?

Supersymmetric New Inflation Model !

Why supersymmetric ? ∵ We need very flat potential.

Why New Inflation ? ∵ SU(2) symmetry is broken at the on-set of inflation (avoid too many monopoles)



- Inflation occurs along blue potential
- On the blue potential U(1) is symmetric while SU(2) is broken

  (no monopoles after inflation)
- U(1) breaking takes place after inflation.

  → **Long strings are formed !**

Supersymmetric New Inflation Model with symmetry breaking

Gravitinos are produced by the decays of inflaton sector fields

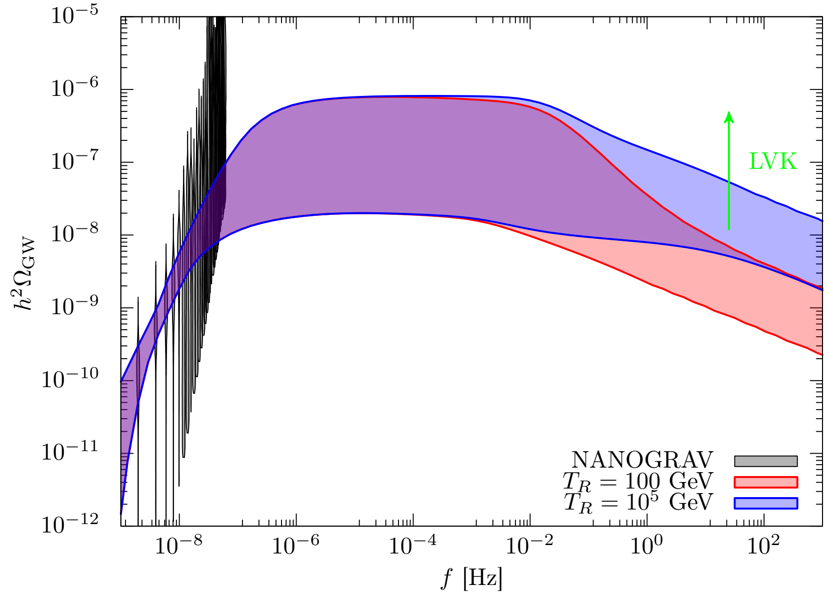
To avoid too many gravitinos, low reheating temperature is required

$\boldsymbol{T_R < 10^{4\text{-}5}}$ **GeV**

Low $\boldsymbol{T_R}$ suppresses GW spectrum @ $\boldsymbol{f = O(10)}$**Hz**

→ consistent with the current LIGO–Virgo–KAGRA (LVK) Limit @ **25Hz**

GW from later Universe GW from earlier Universe



Model can be further tested by PTA experiments ($\boldsymbol{f \sim 10^{-9}}$**Hz**)

and interferometer experiments ($\boldsymbol{f \sim O(1\text{-}100)}$**Hz**) !

2025 年度もサポートよろしくお願いいたします。