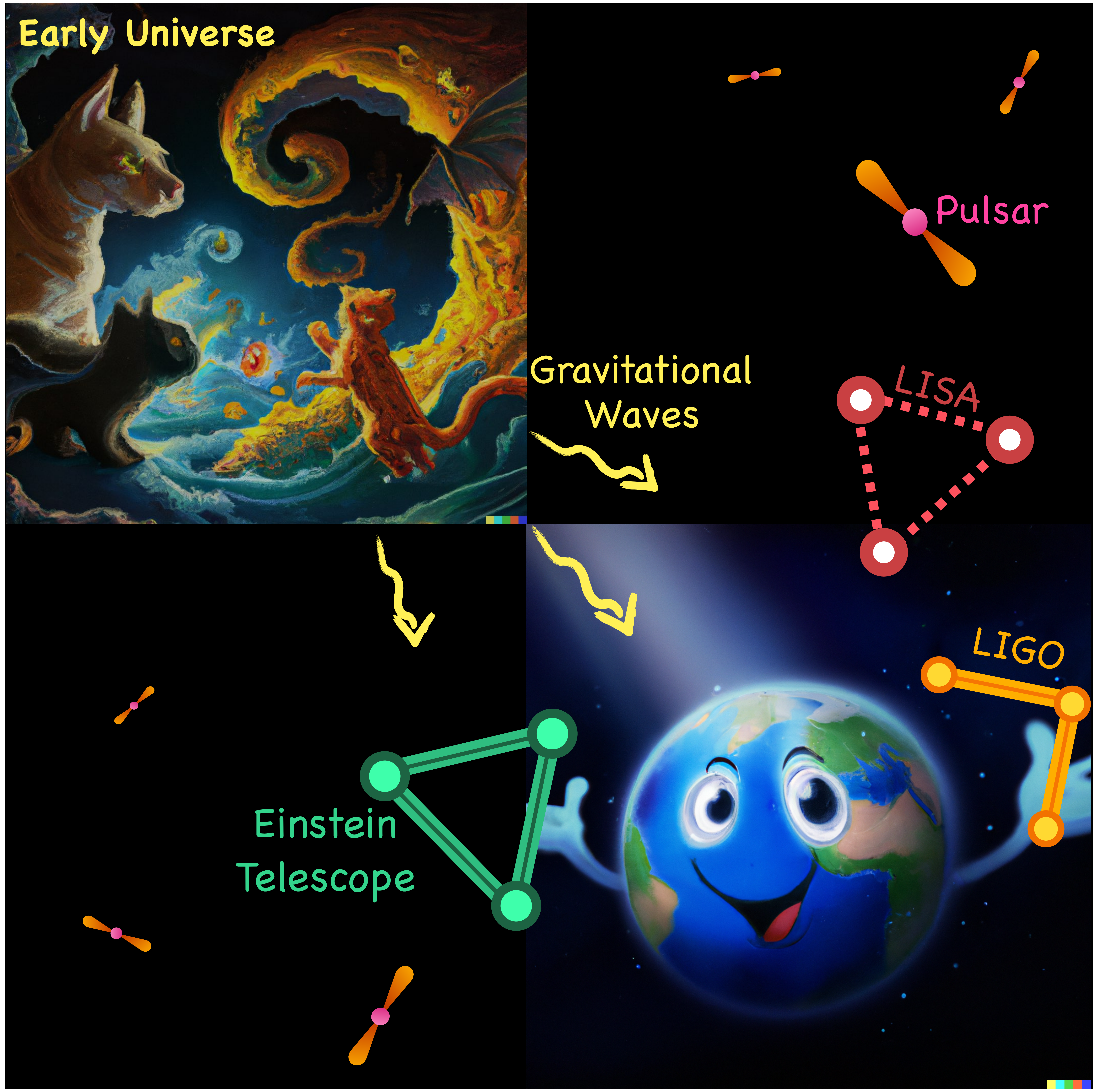


Modified from arts generated by artificial intelligence

Charting Cosmological History and New Particle Physics with Primordial Gravitational Waves

Strategic Advisory Board Meeting
of the Research Field "Matter"
DESY, 3rd May 2023

Peera Simakachorn
(IFIC postdoc)

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

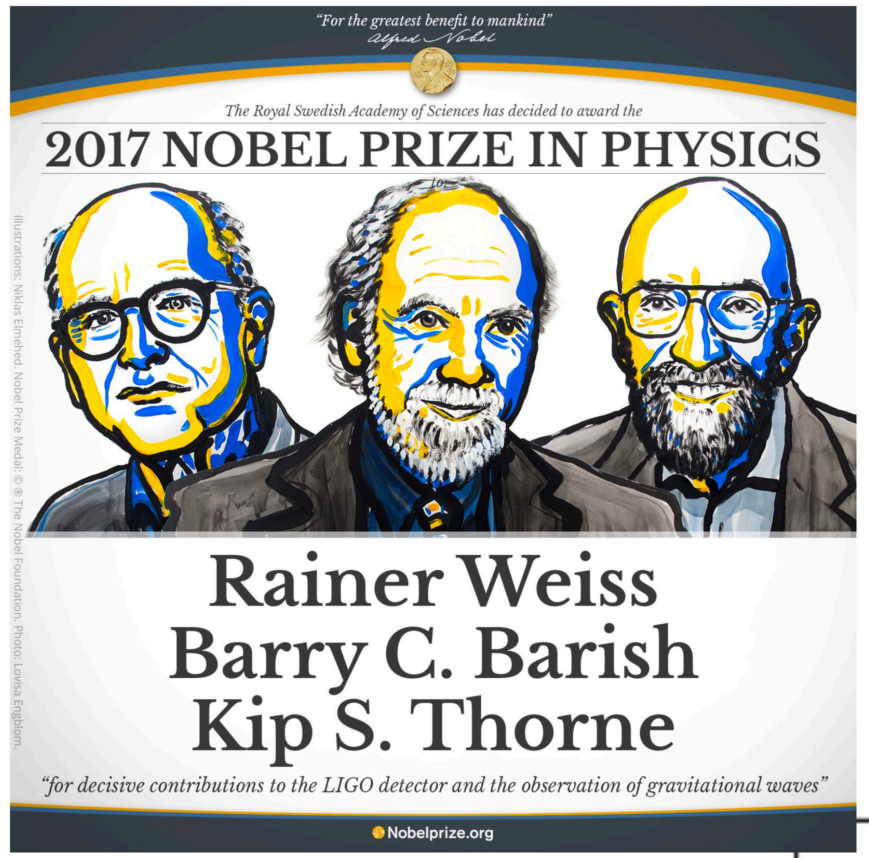
CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

DESY.

VNIVERSITAT DE VALÈNCIA

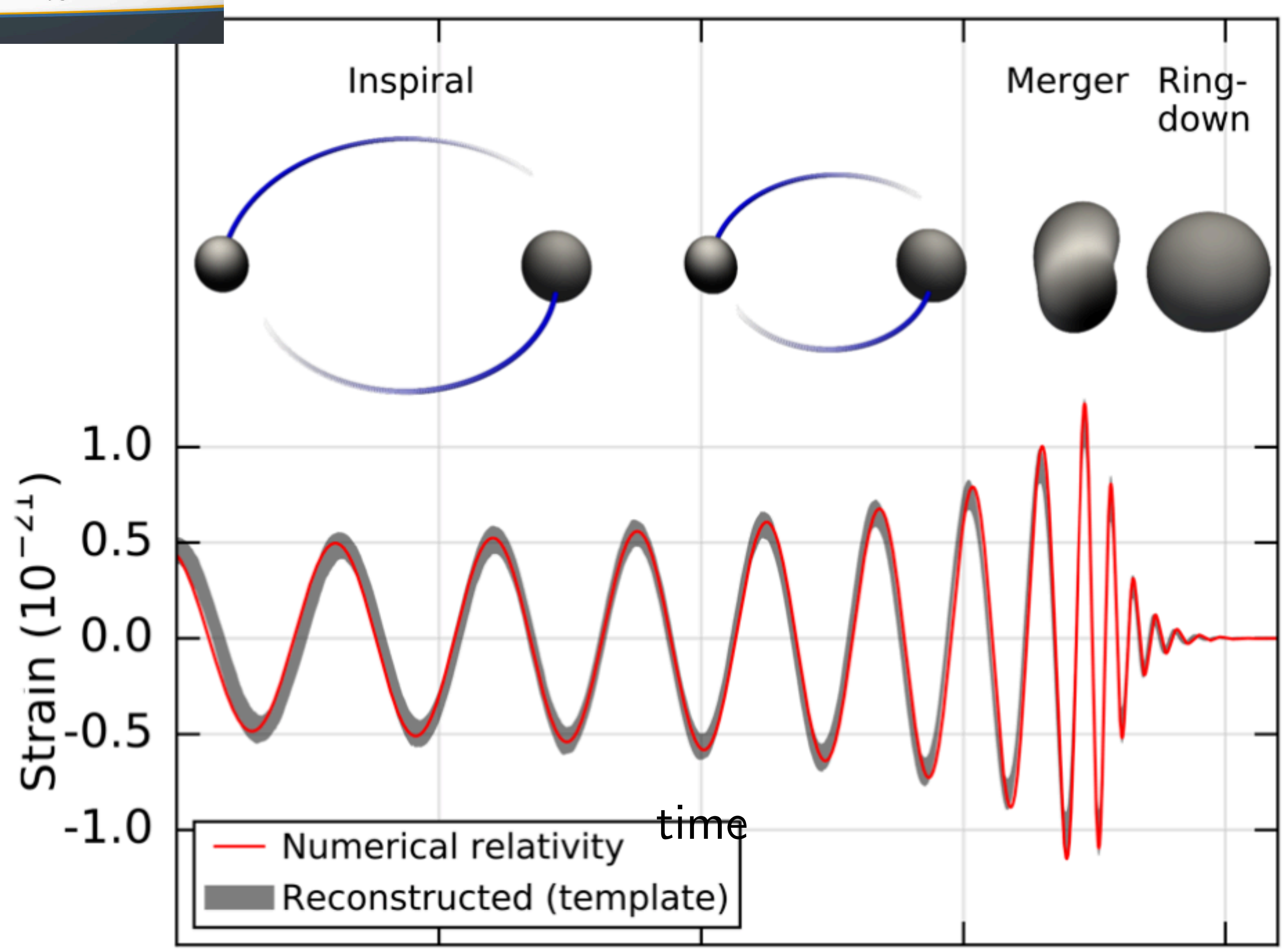
IFIC
INSTITUT DE FÍSICA CORPUSCULAR

2 types of gravitational-wave (GW) signals



- **Astrophysical** signals (in the late universe)

✔ Detected

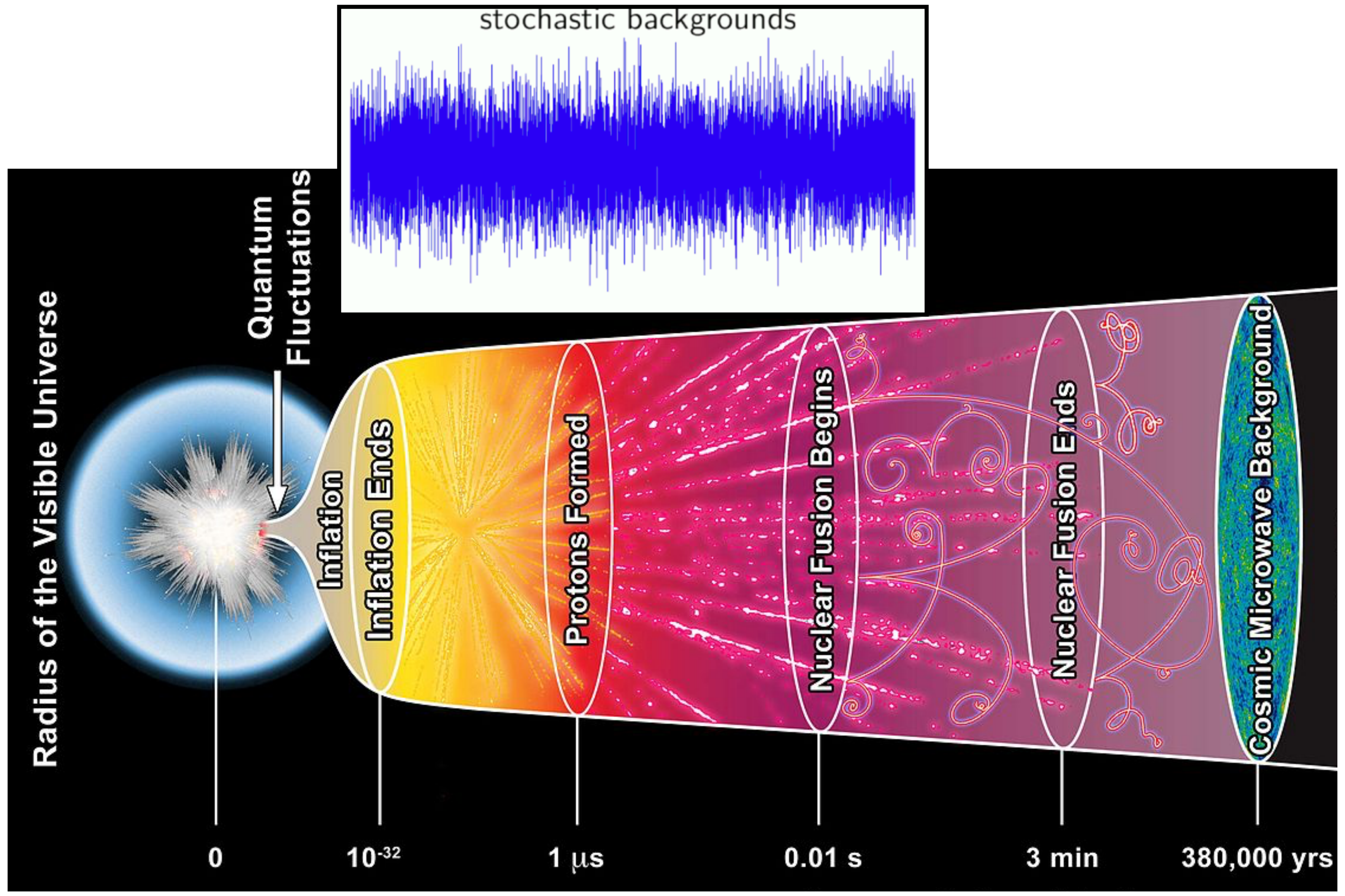


[LIGO & Virgo Scientific Collaborations (arXiv:1602.03841)]

- **Cosmological** background filling the whole Universe

A noisy signal from the early or "*primordial*" Universe.

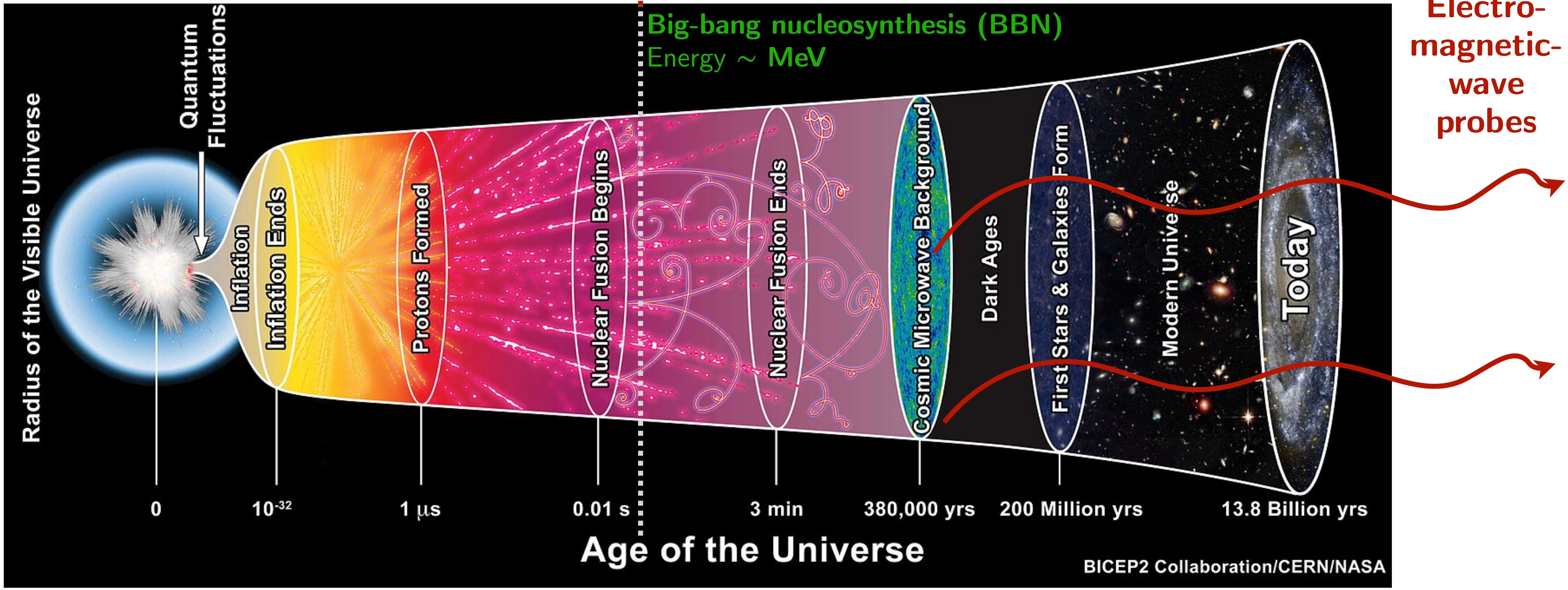
✘ Not yet detected



Note: Astrophysics background can lead to stochastic background if it is unresolvable.

high energies ⟵ low energies

Universe younger than 1 sec is unconstrained ⟵ ⟶ well-tested (age $\gtrsim 1$ sec)



Electro-magnetic-wave probes

high energies ⟵ low energies

Universe younger than 1 sec is unconstrained ⟵ ⟶ well-tested (age $\gtrsim 1$ sec)

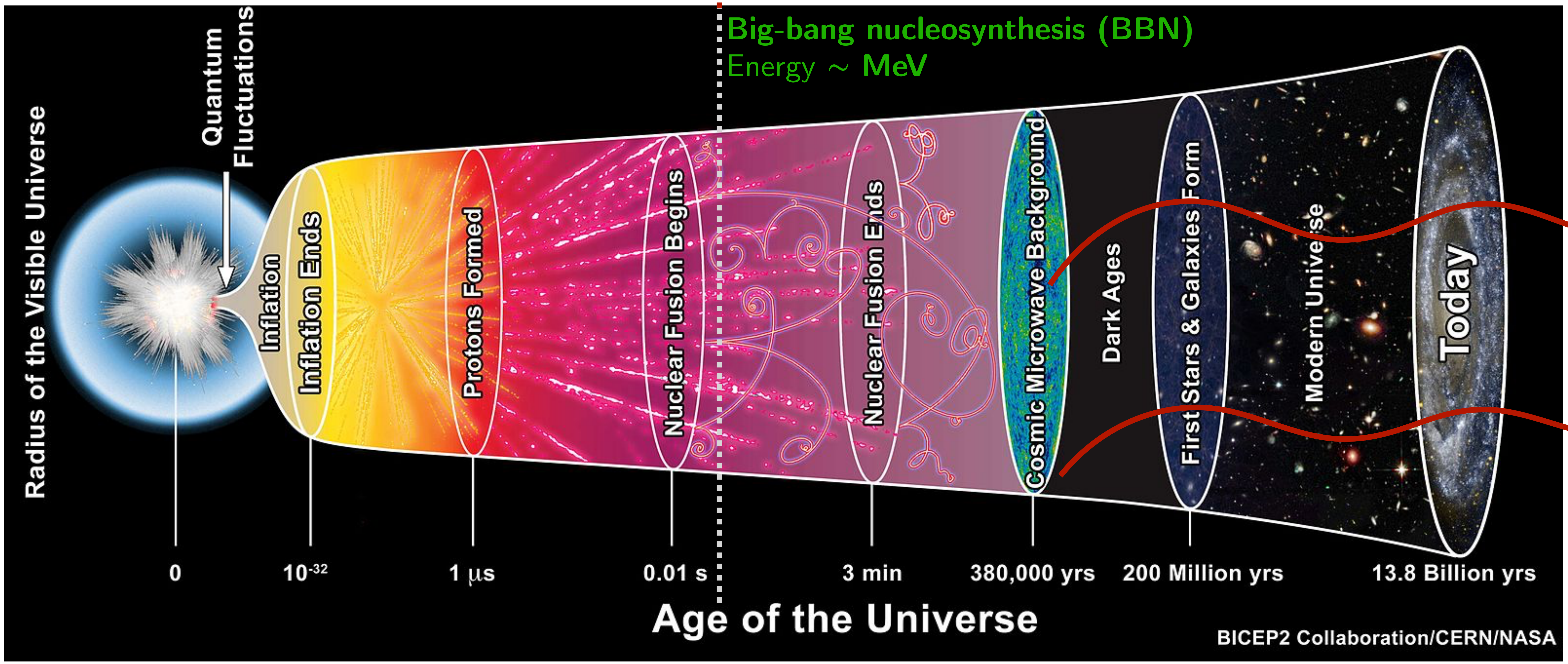
Dark matter production

Matter-antimatter Asymmetry

Primordial Inflation

Origin of Higgs mass

⋮



Electro-magnetic-wave probes

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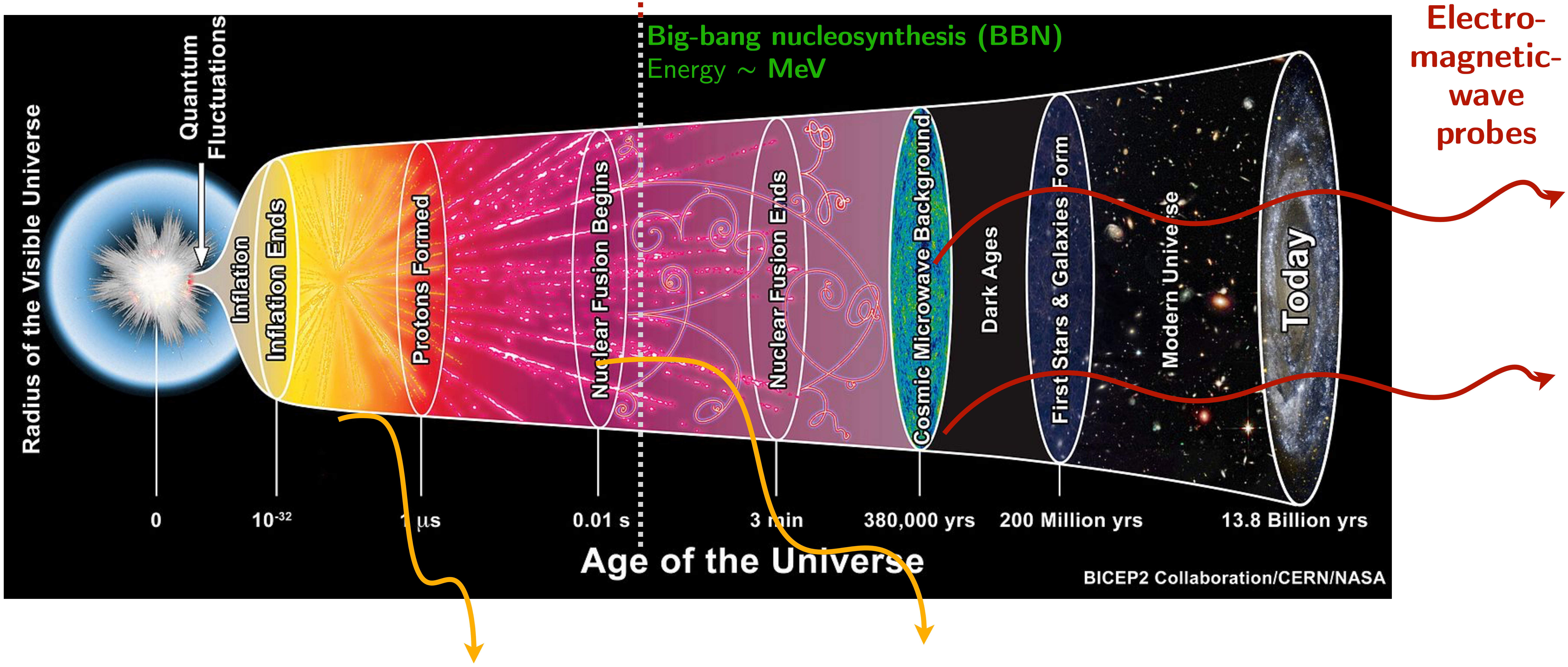


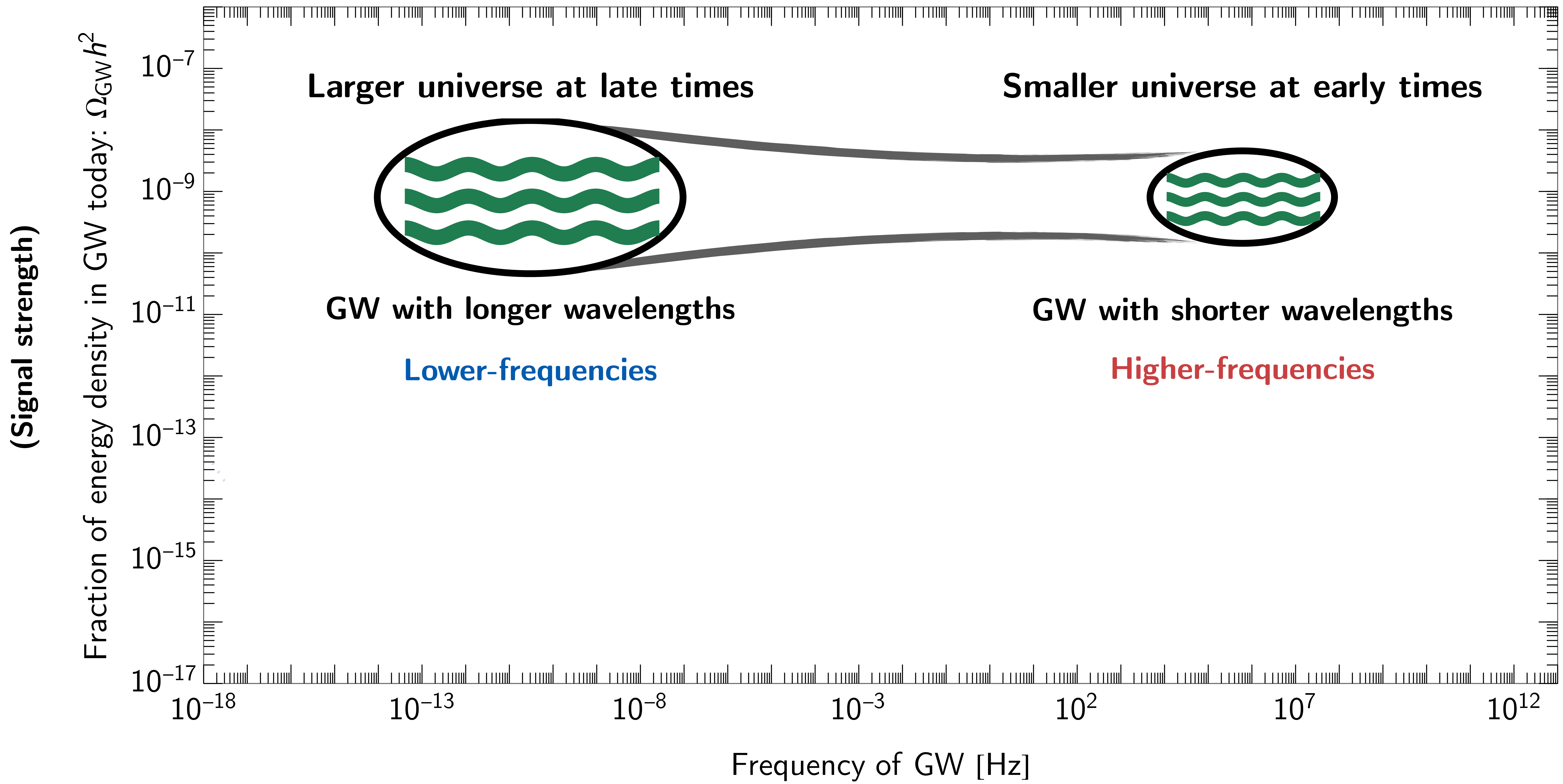
Electro-magnetic-wave probes

GW propagates freely and carries information about the Universe when it is produced.

Primordial GW as probes of the early Universe (age $\lesssim 1$ sec)

& high-energy physics (energy $\gtrsim$ MeV)

Landscape of Primordial Gravitational Waves



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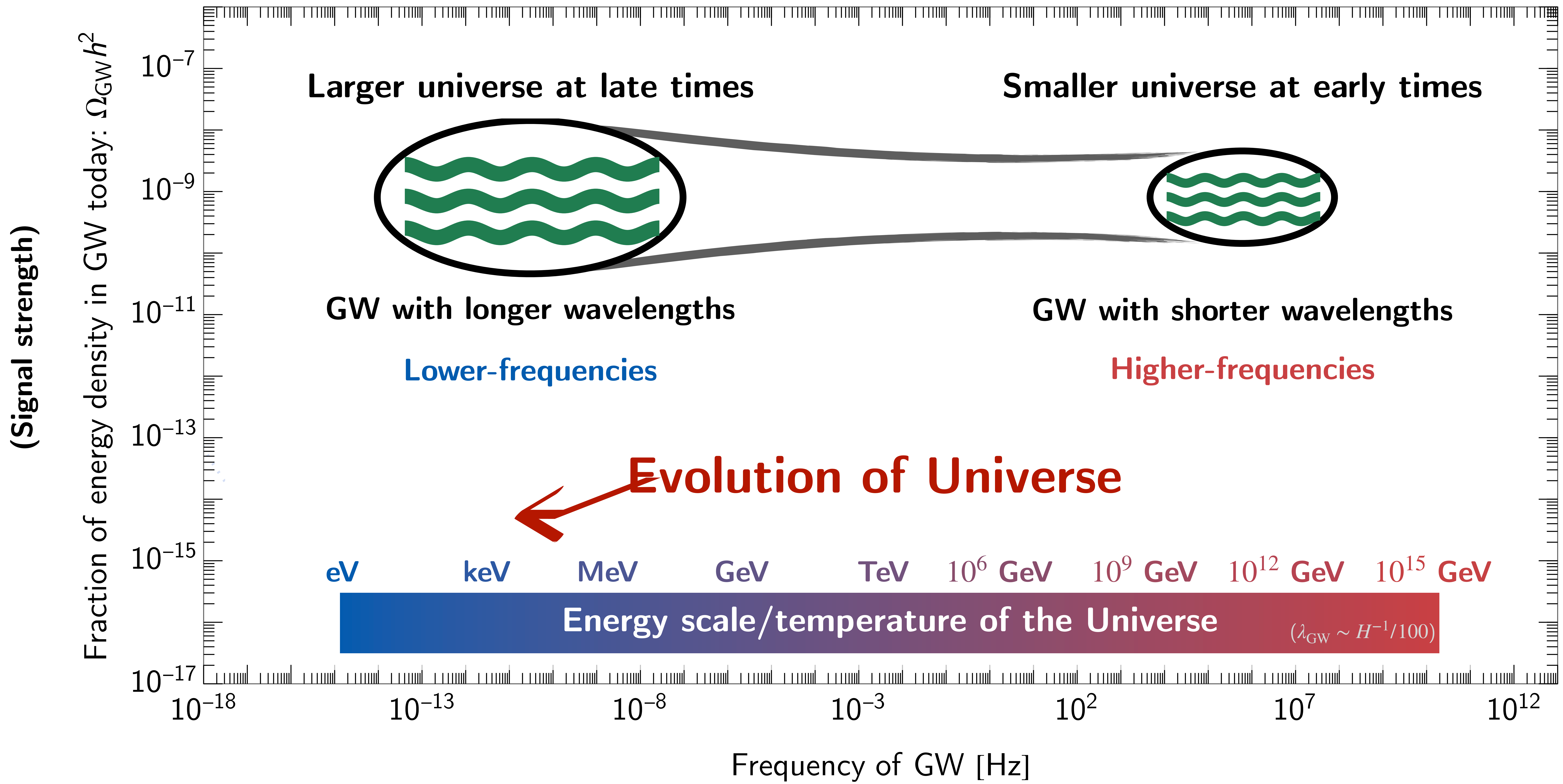
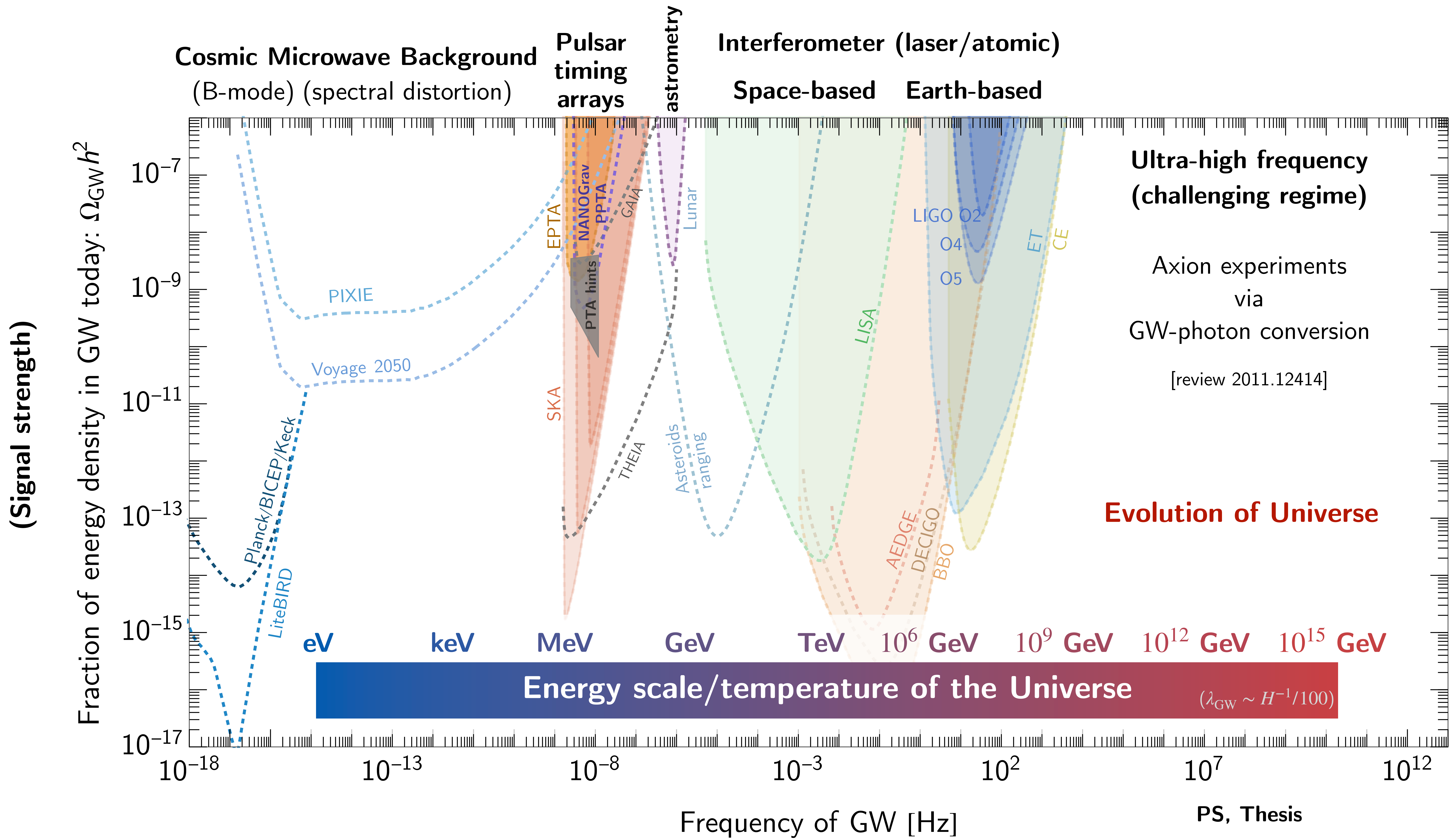


Current and Future Gravitational-Wave Experiments



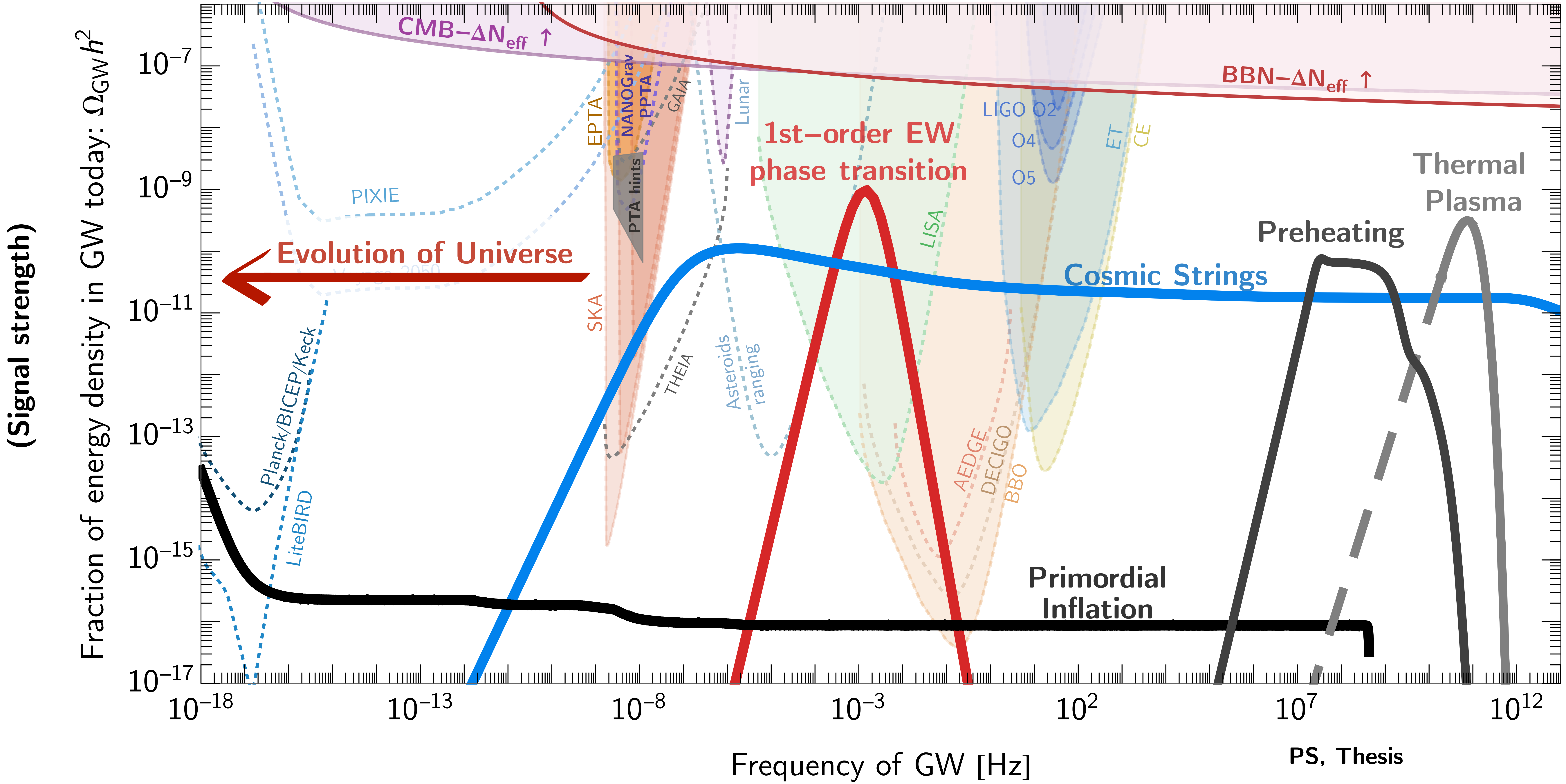
Sources of Primordial Gravitational Waves

Standard-Model sources

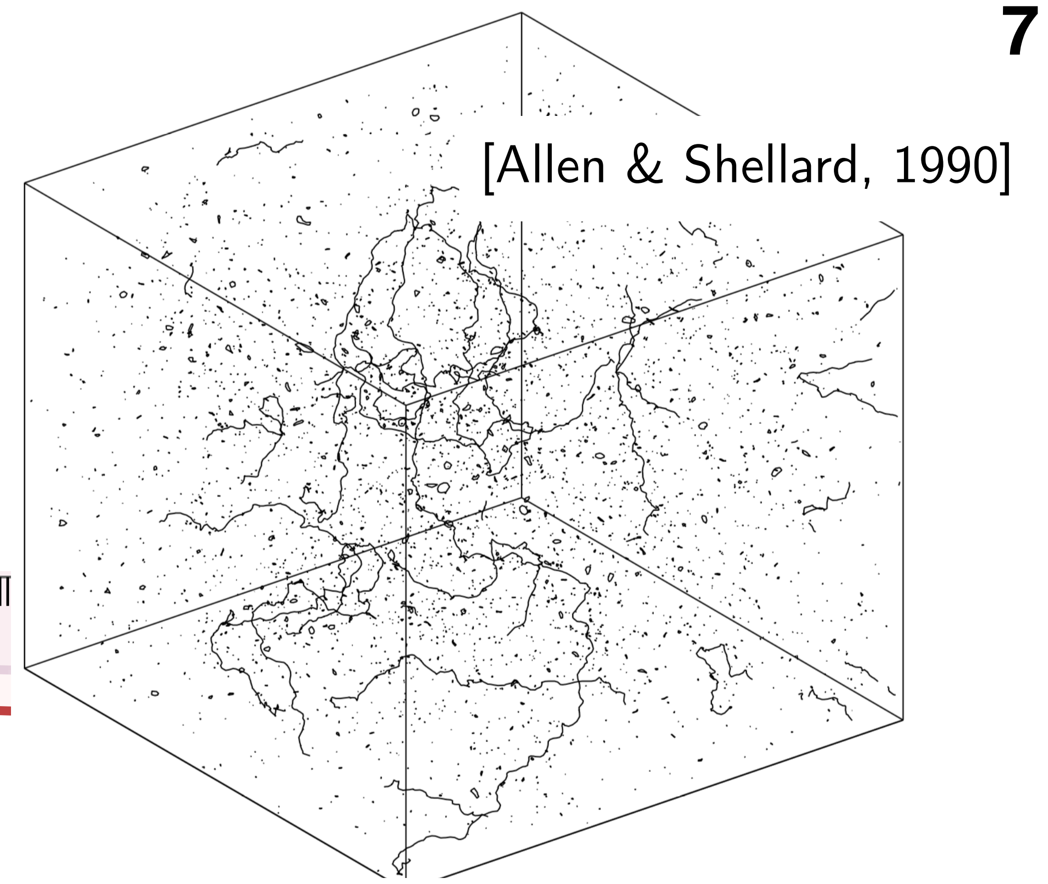
Thermal plasma, Primordial inflation

Particle physics beyond the Standard-Model

Preheating, First-order Phase Transitions, Cosmic strings
(Topological defects)



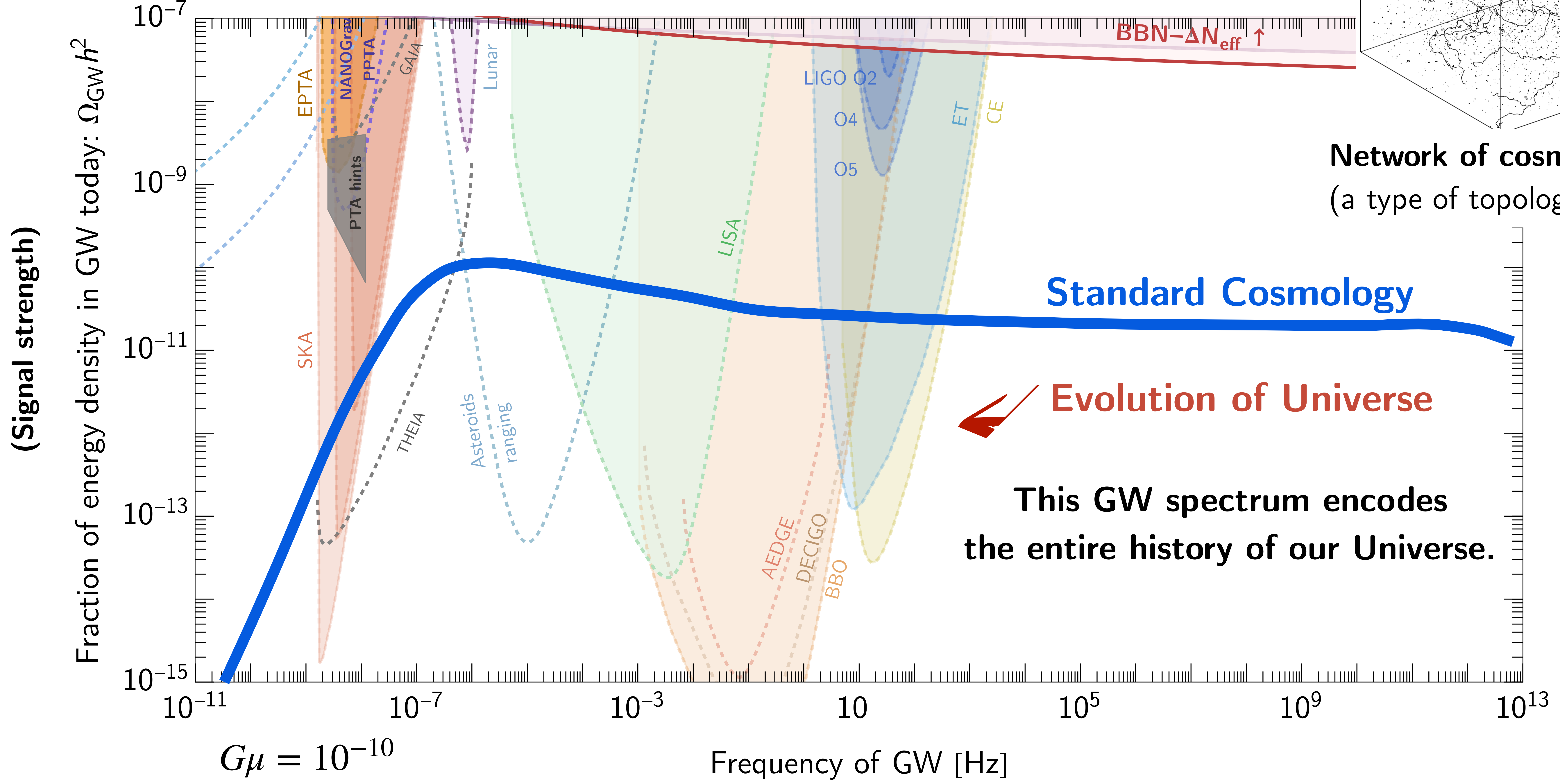
Learning about high-energy phase transitions



Network of cosmic strings
(a type of topological defects)

Beyond the Standard Models with Cosmic Strings **JCAP 07 (2020) 032, [1912.02569].**

Gouttenoire, Servant, PS



This GW spectrum encodes the entire history of our Universe.

Learning about high-energy phase transitions

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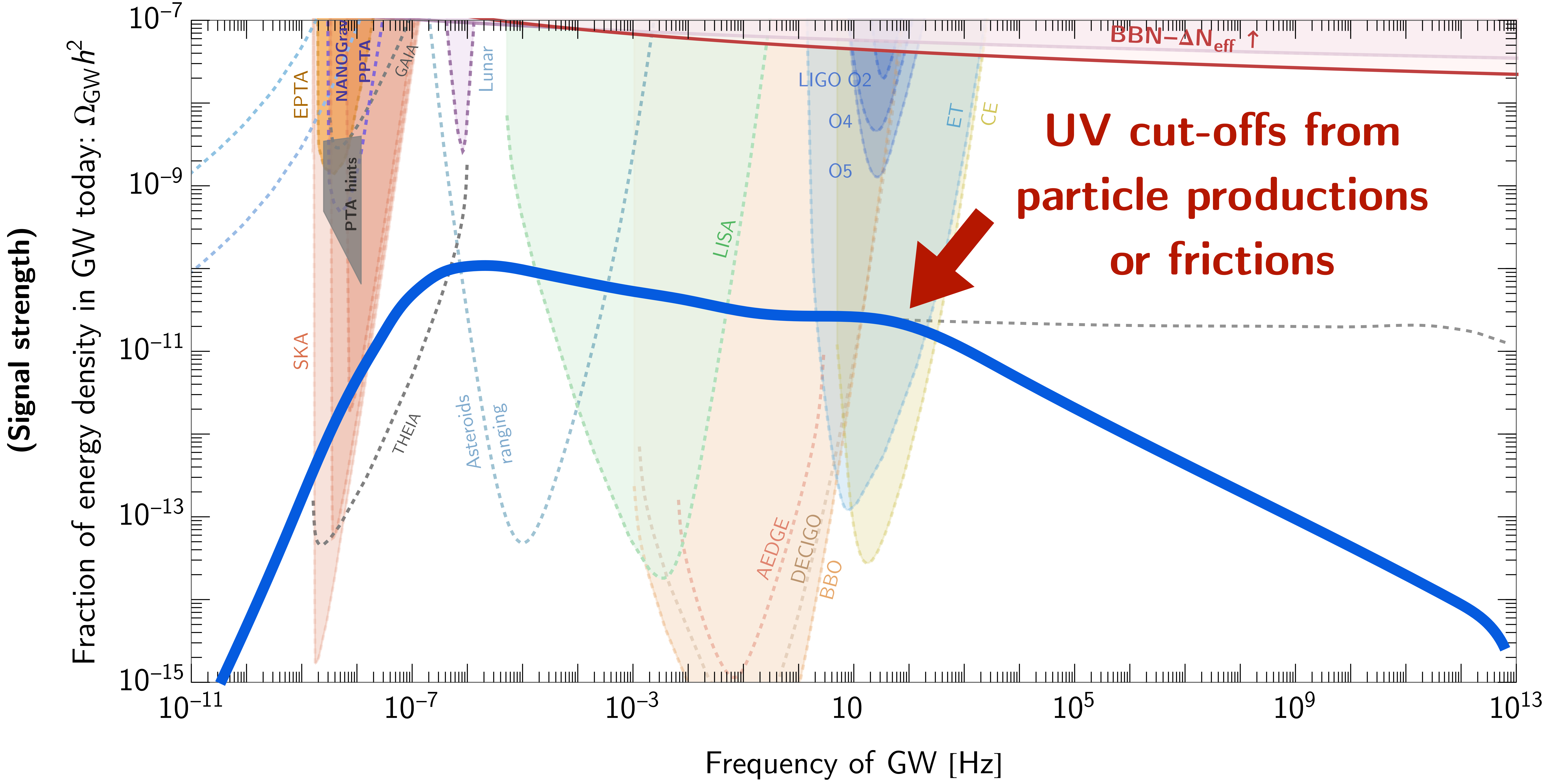

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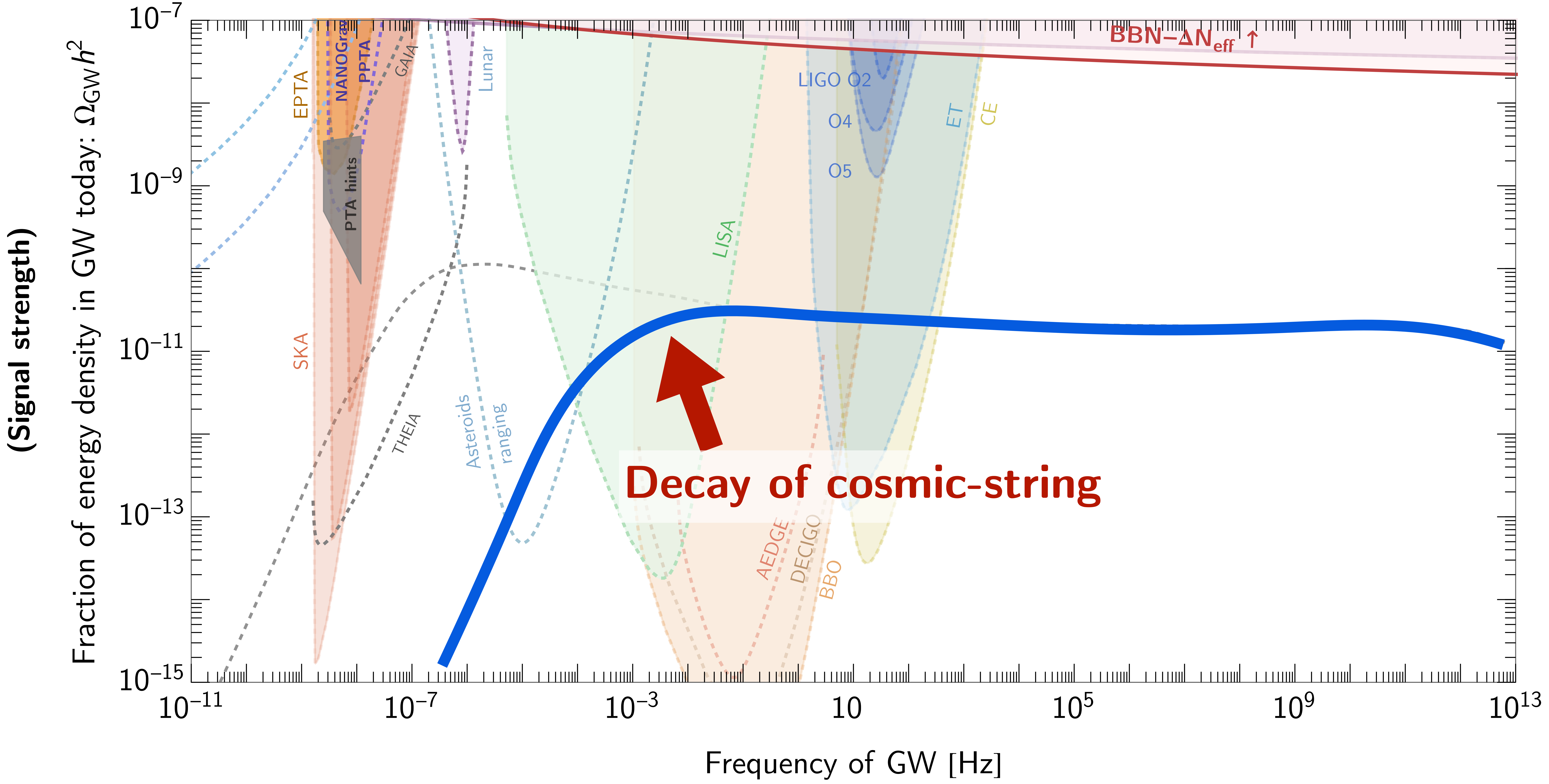

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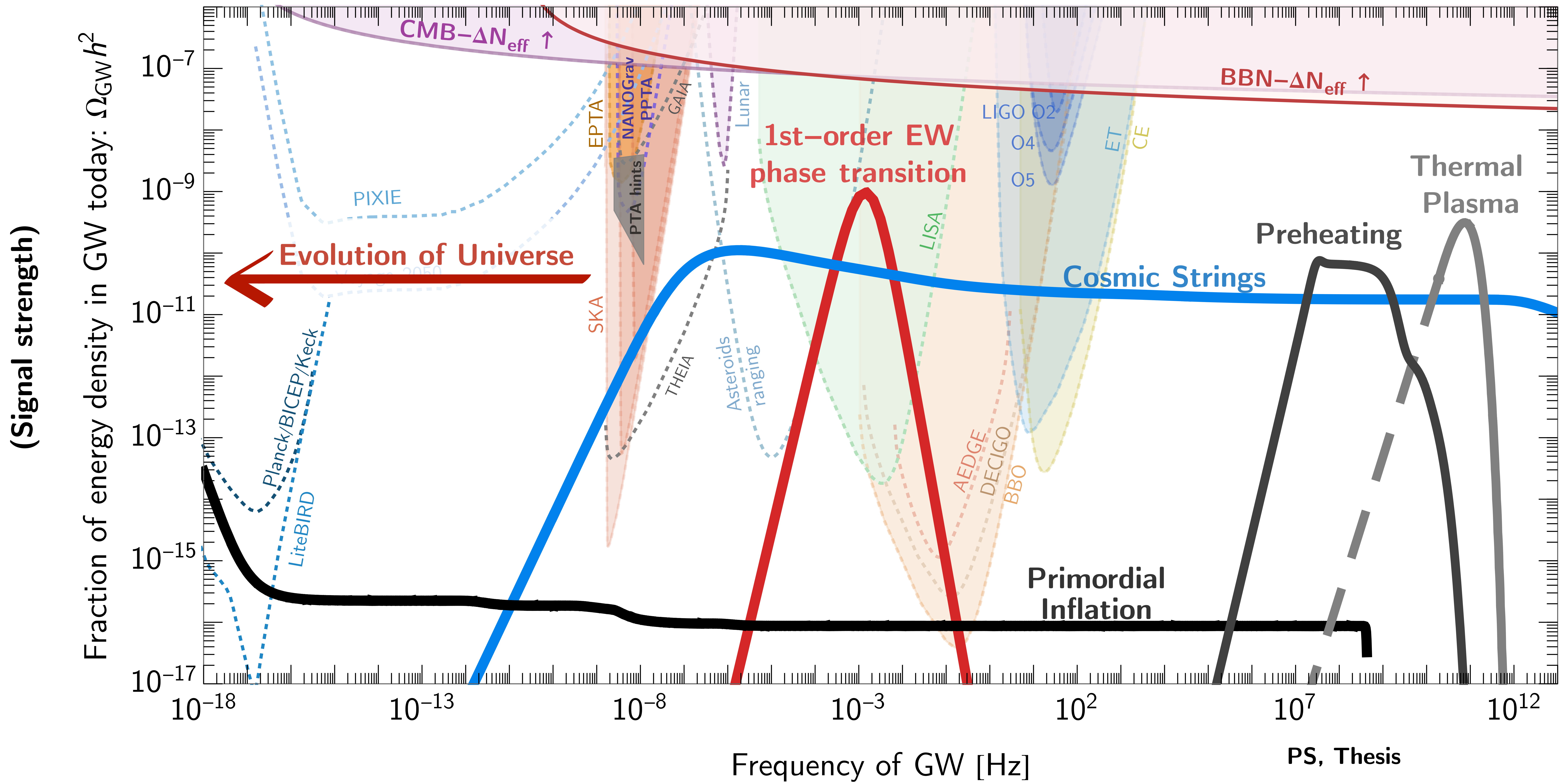

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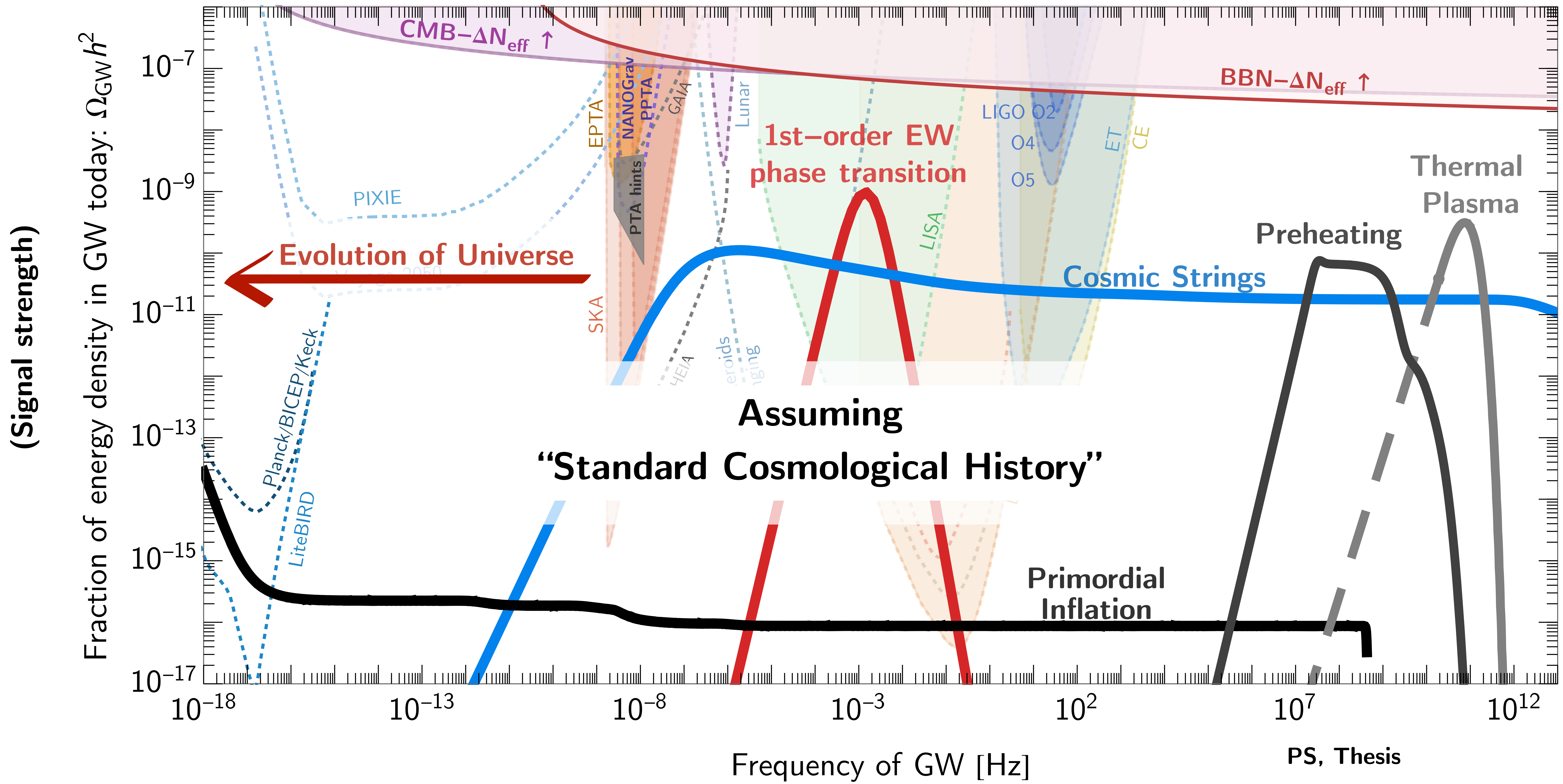

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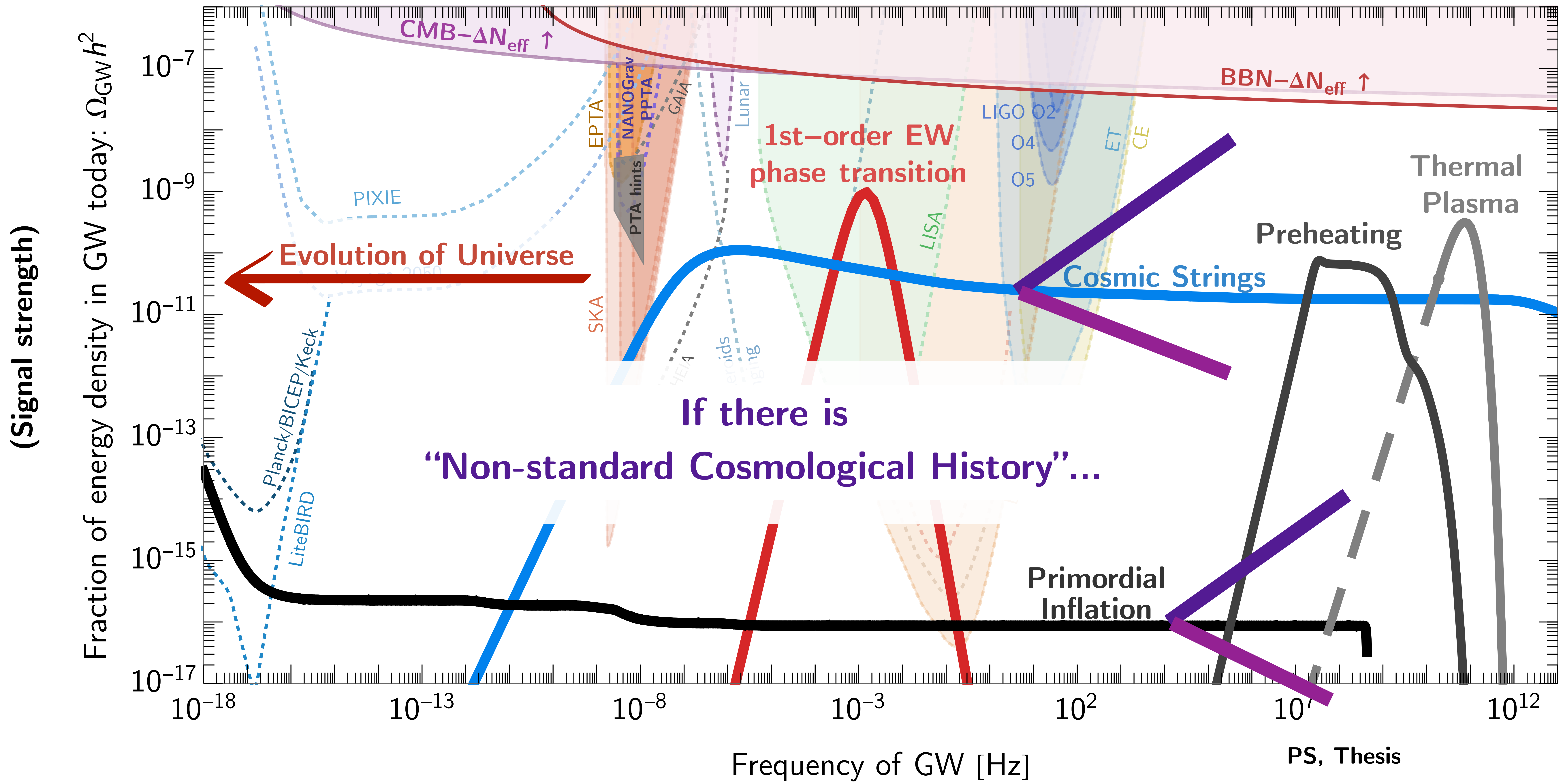
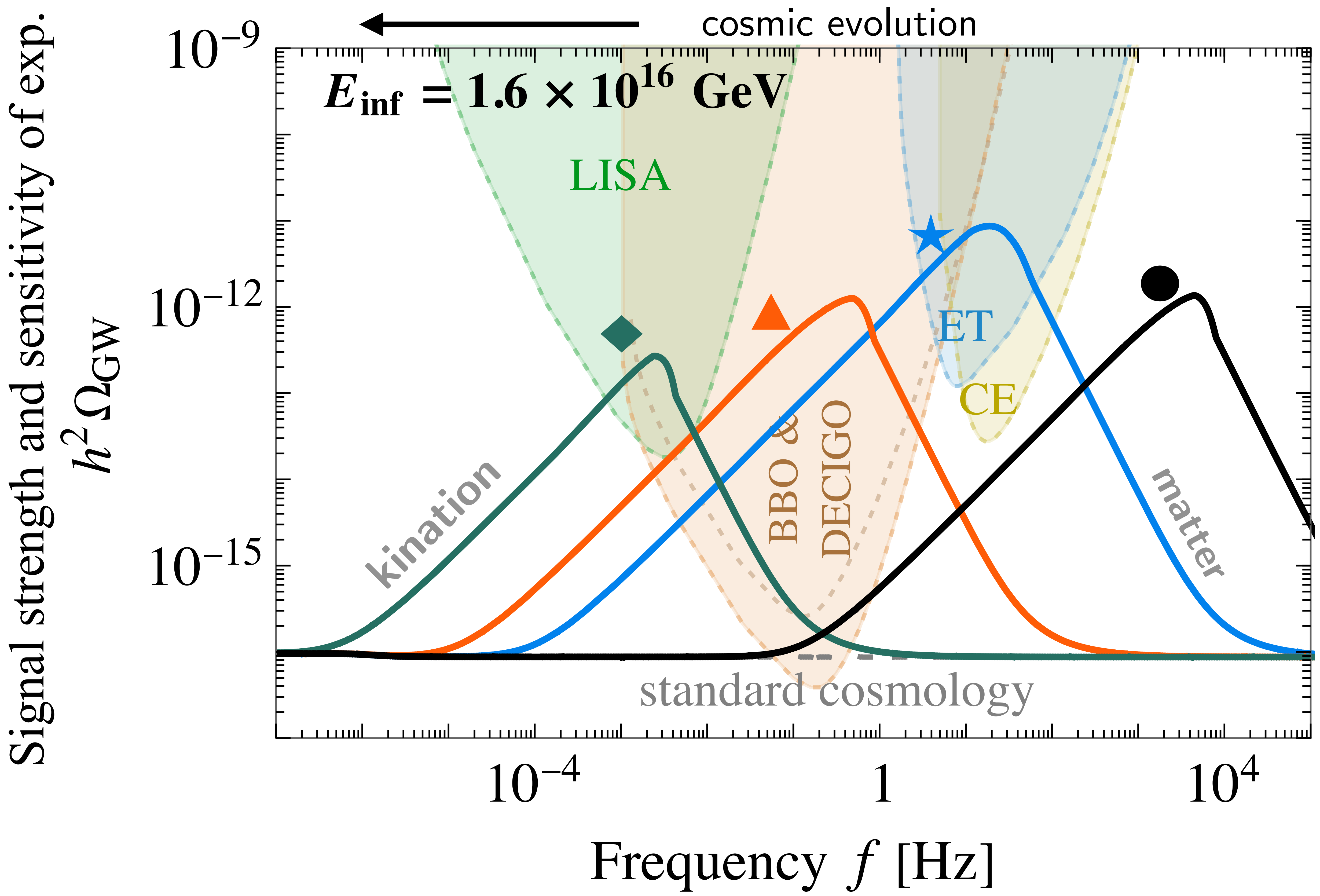
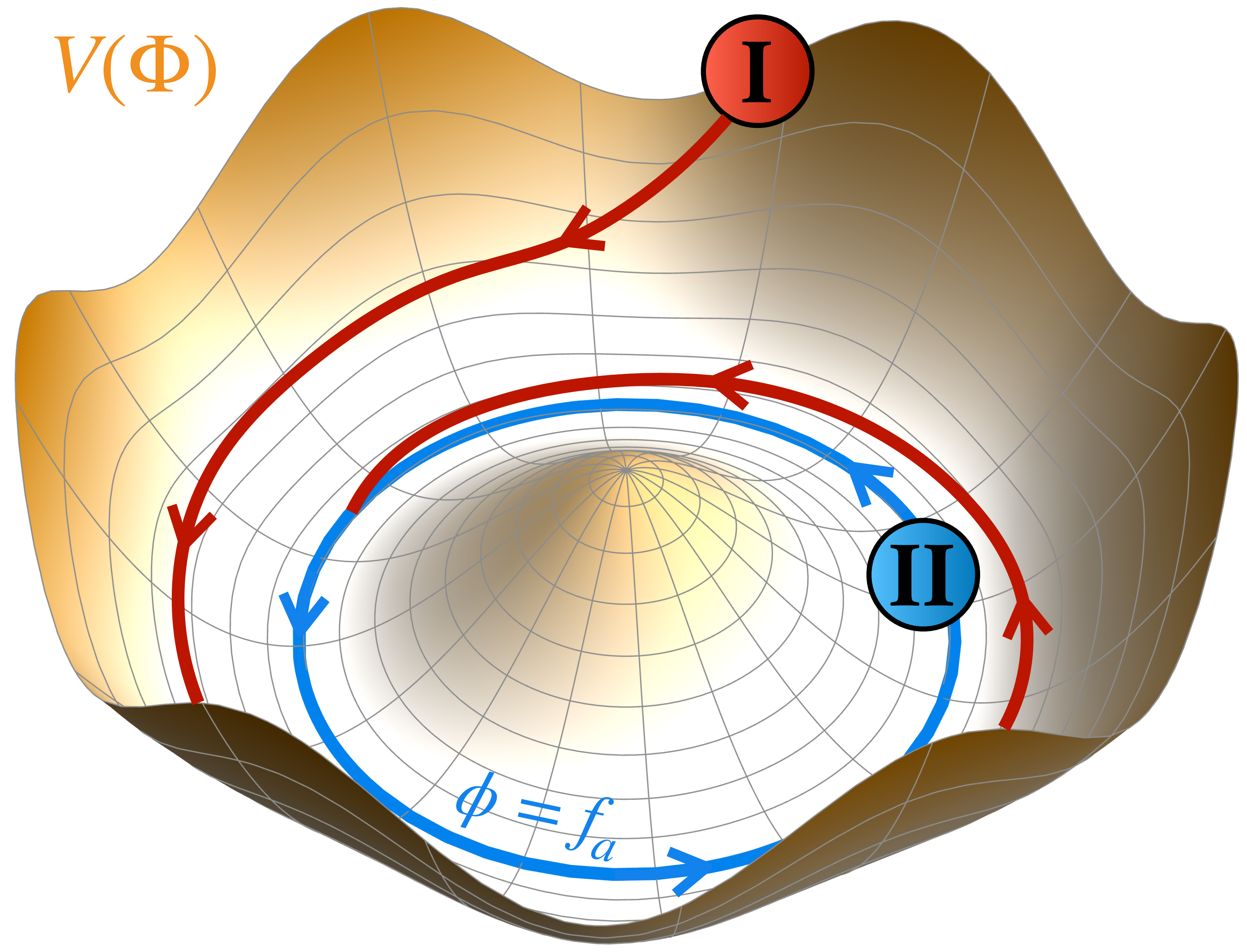


Non-standard cosmology from the "rotating" axion.

[Gouttenoire, Servant, **PS**, 2108.10328 & 2111.01150]

[Co, Harigaya, Hall, et. al., 2108.09299]





Discovery of a new signature of axion physics in gravitational waves.

Complementary to the very active field of laboratory axion searches.

Collaborations

LISA White paper: Cosmology with the Laser Interferometer Space Antenna

LISA
CosWG-22-03

arXiv:2204.05434v1 [astro-ph.CO]

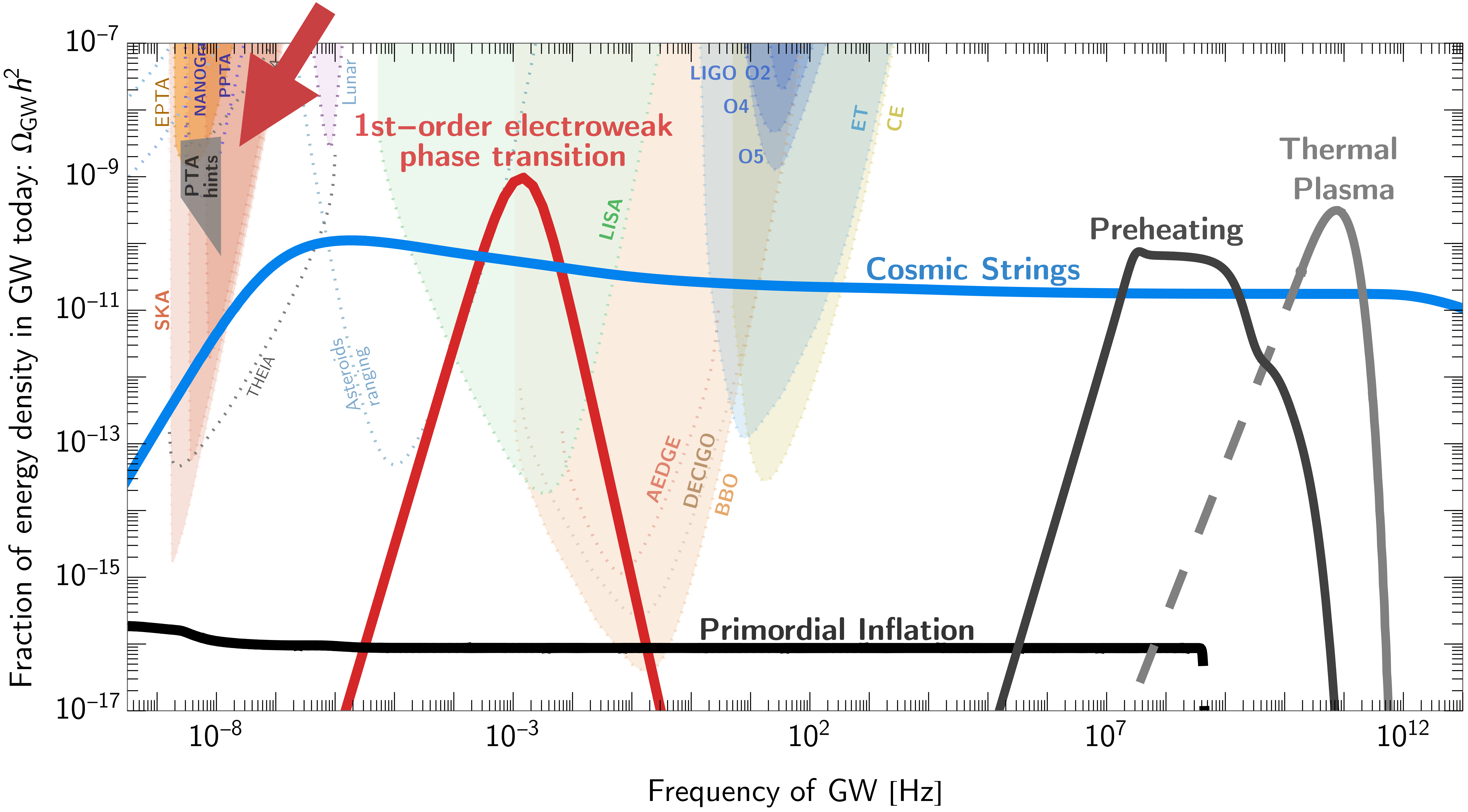
A comprehensive 176-page summary of the state of the art in LISA cosmology, theory and methods, and of the new opportunities to use gravitational wave observations by LISA to probe the universe.

Contents

Present and future plans

I. Investigation of potential interpretations of GW signal at pulsar timing arrays

II. Science case of high-frequency GW experiments Related to axion experiments @ DESY

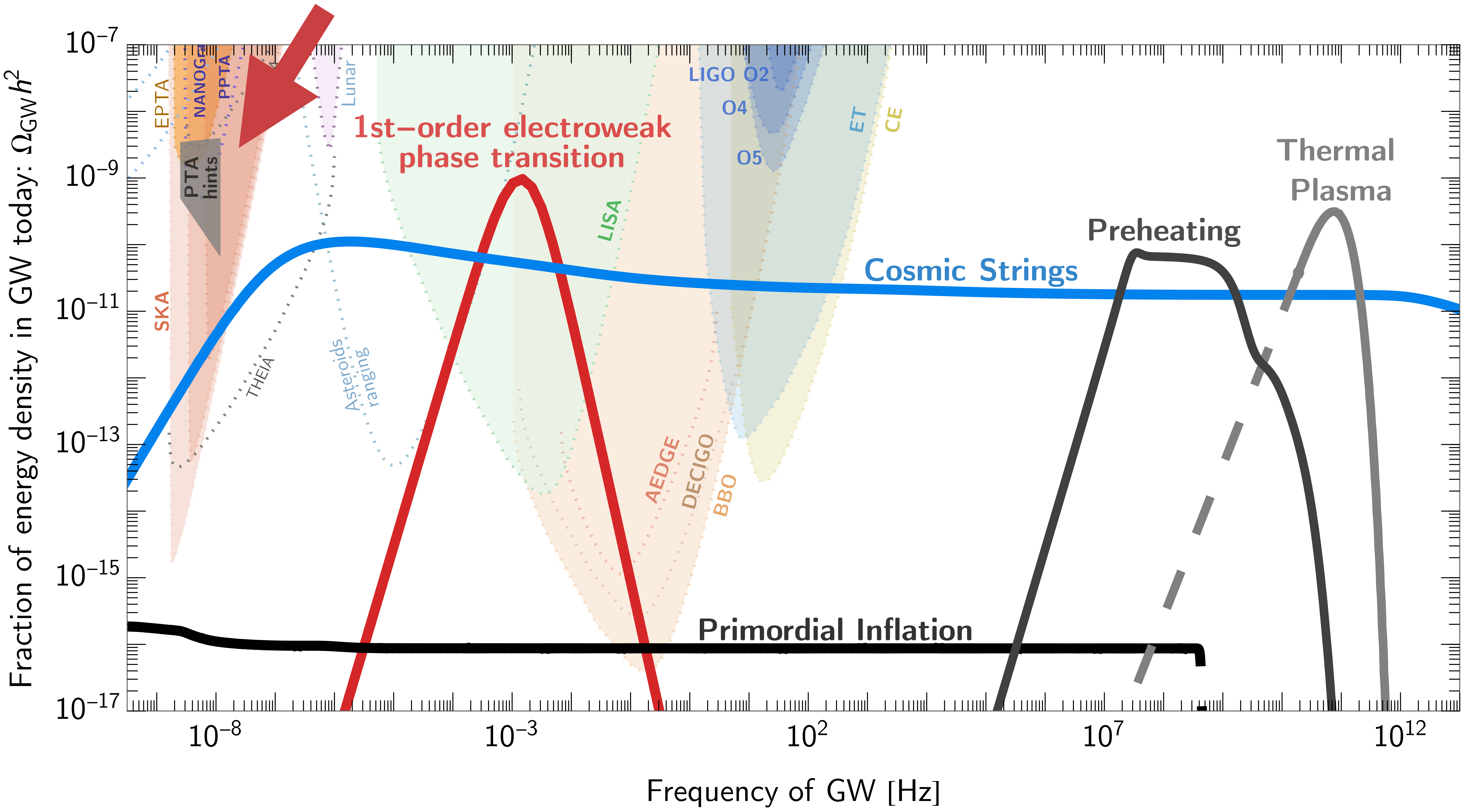


Present and future plans

Thank you!

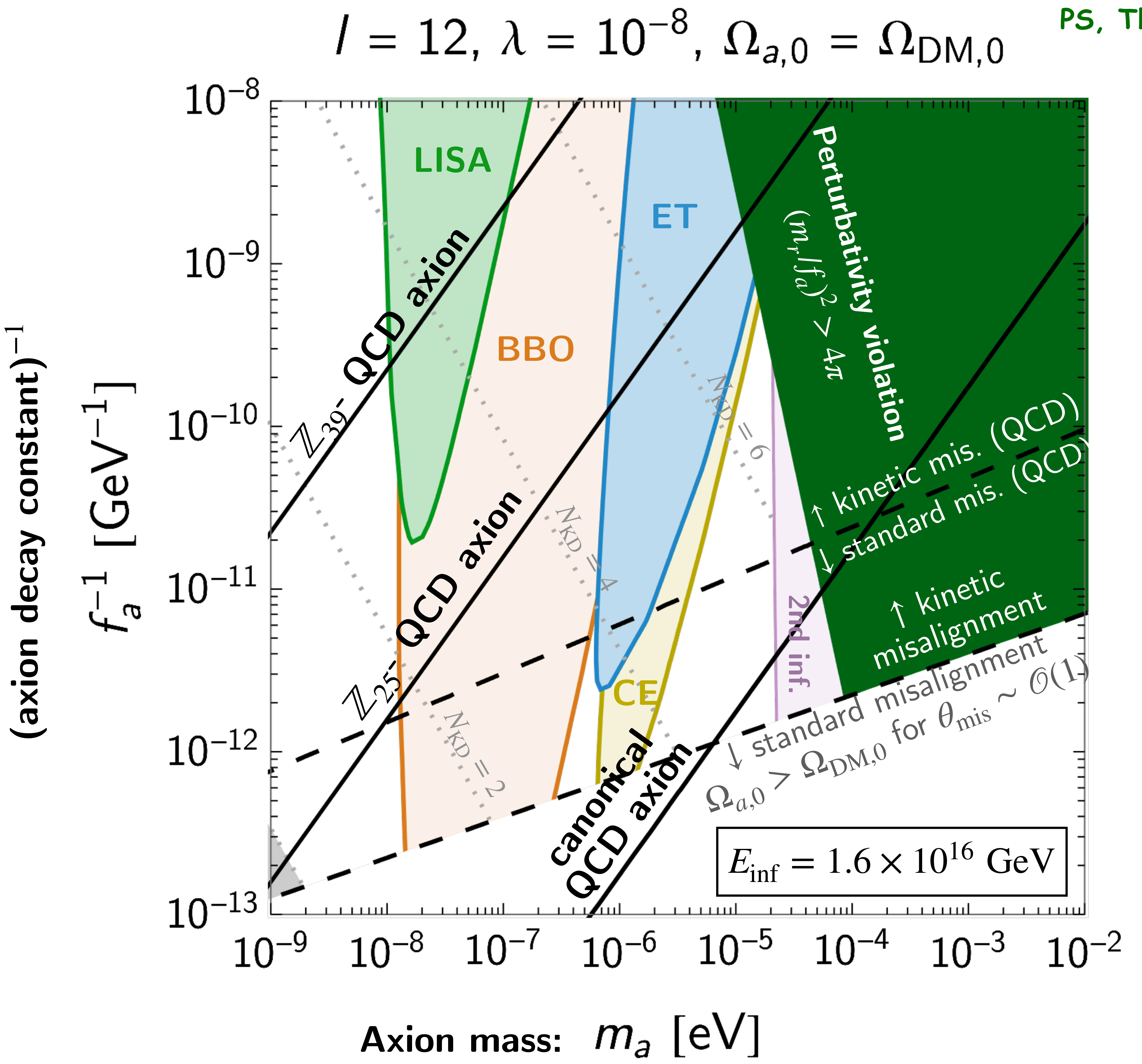
I. Investigation of potential interpretations of GW signal at pulsar timing arrays

II. Science case of high-frequency GW experiments Related to axion experiments @ DESY

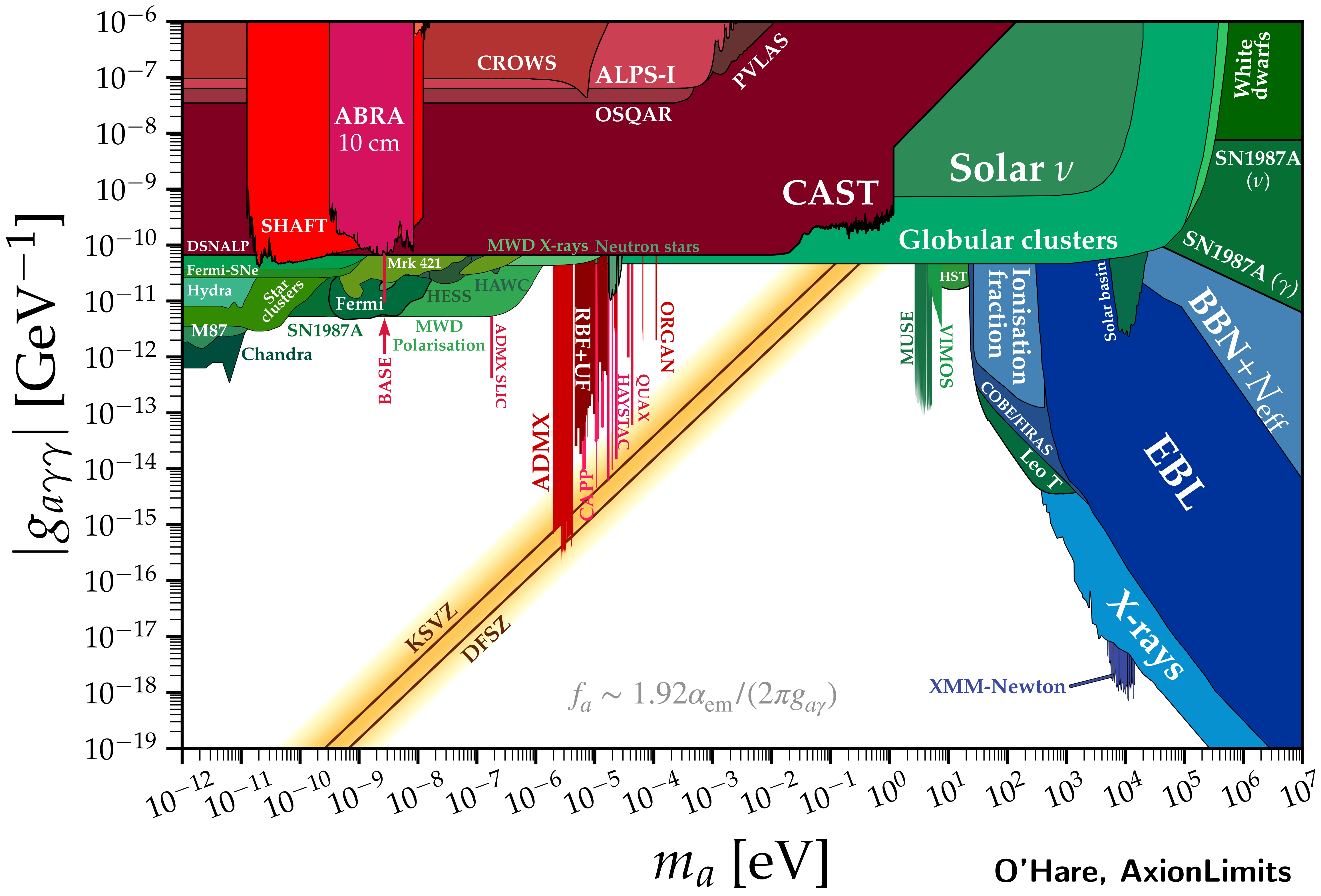


Dark matter from the rotating axion & GW signature.

PS, Thesis



GW as a complementary probe to other axion searches!



Tracing the history of the Universe

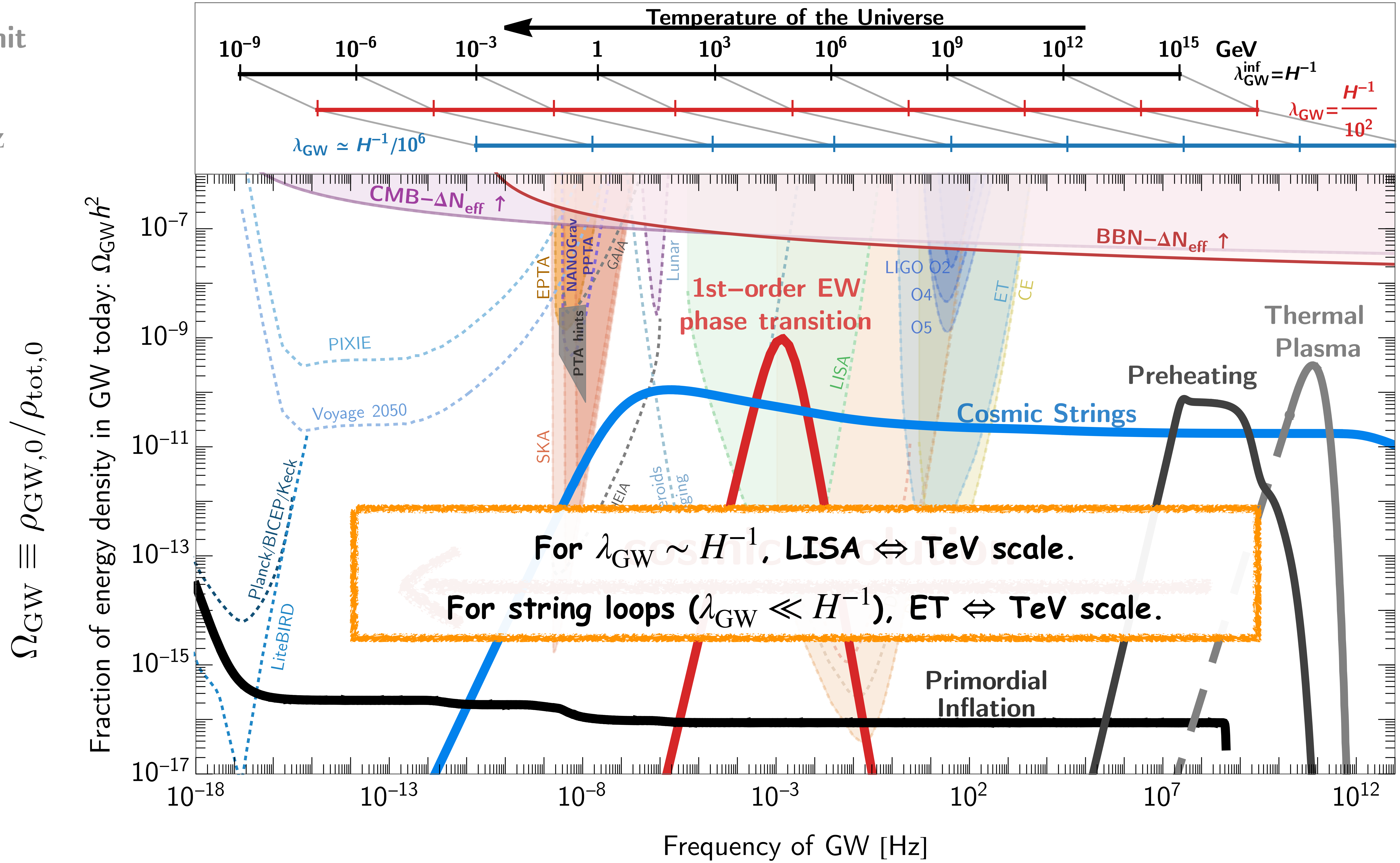
GW frequency observed today: $f_{\mathrm{GW},0} \simeq \lambda_{\mathrm{GW}}^{-1}(a_{\mathrm{prod}}/a_0) \simeq 10^{-6}\ \mathrm{Hz} \left[\frac{H_{\mathrm{prod}}^{-1}}{\lambda_{\mathrm{GW}}}\right] \left[\frac{T_{\mathrm{prod}}}{100\ \mathrm{GeV}}\right]$ $[H \simeq T^2/M_{\mathrm{pl}}]$

Low-freq. limit

$f_{\mathrm{GW}}^{\mathrm{min}} \simeq H_0^{-1} \simeq 10^{-18}$ Hz

High-freq. limit

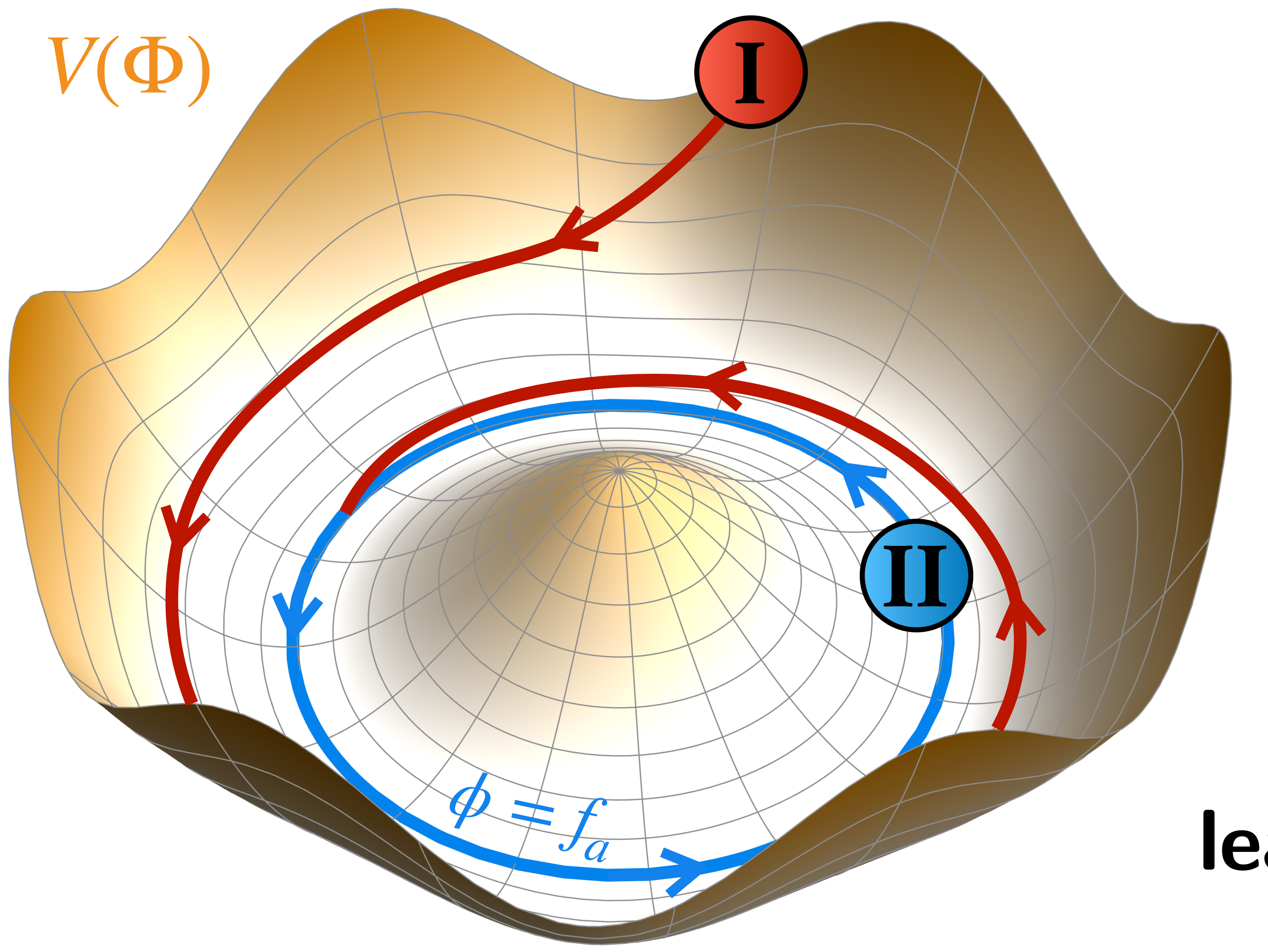
$f_{\mathrm{GW}}^{\mathrm{max}} \simeq 10^{13}$ Hz $(\lambda_{\mathrm{GW}} \sim H^{-1} \sim M_{\mathrm{pl}}^{-1})$



For $\lambda_{\mathrm{GW}} \sim H^{-1}$, LISA ⇔ TeV scale.

For string loops ($\lambda_{\mathrm{GW}} \ll H^{-1}$), ET ⇔ TeV scale.

Rotating Axion.



$\Phi \sim \phi e^{i\theta}$ with global $U(1)$-symmetry

Angular mode θ: "axion" (Goldstone boson)

Radial mode ϕ with mass $m_r \simeq \sqrt{V'/\phi}$

§1: Difference from the usual axion cosmology!

The usual axion cosmology with $\langle \Phi \rangle = 0$
where only axion matters,

In our case, $\langle \Phi \rangle \gg f_a$ the radial/axion interplay
leads to large kinetic energy in the axion, allowing for kination.

§2: Difference from other rotating complex field!

Rotating complex scalar is not new.

"Affleck-Dine Baryogenesis" (Affleck, Dine, 1984)
"Spontaneous Baryogenesis" (Cohen, Kaplan, 1987)
"Spintessence" (Boyle, Caldwell, Kamionkowski, 2001)
"Affleck-Dine Magnetogenesis" (Kamada, Shin, 2019)
"Axiogenesis" (Co, Harigaya, 2019)

What's new in our case:
the rotating axion survives until late times,
generating kination era and explaining DM.

Nothing exotic and could be QCD axion!

My few pages on GW from cosmic strings

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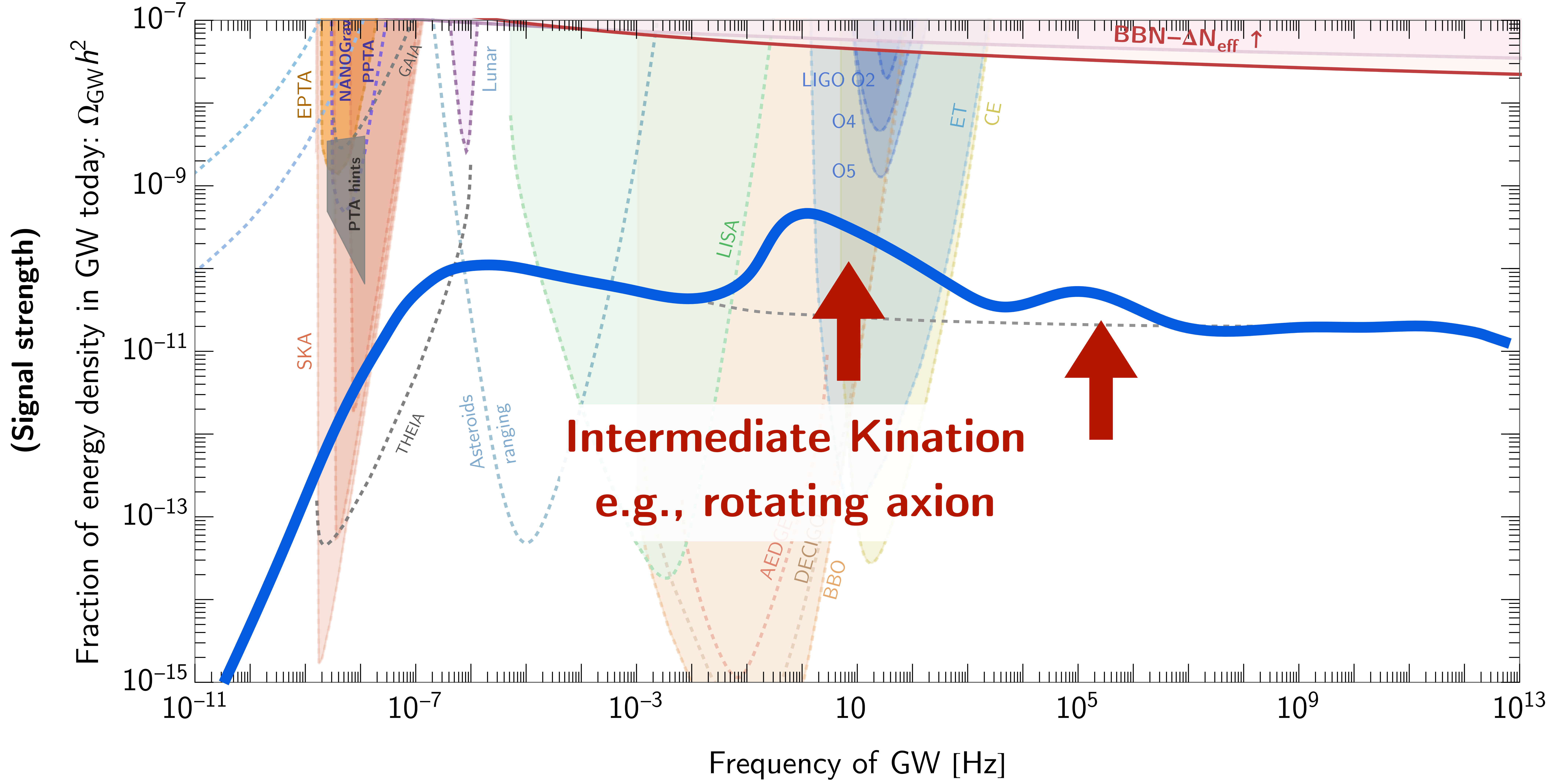

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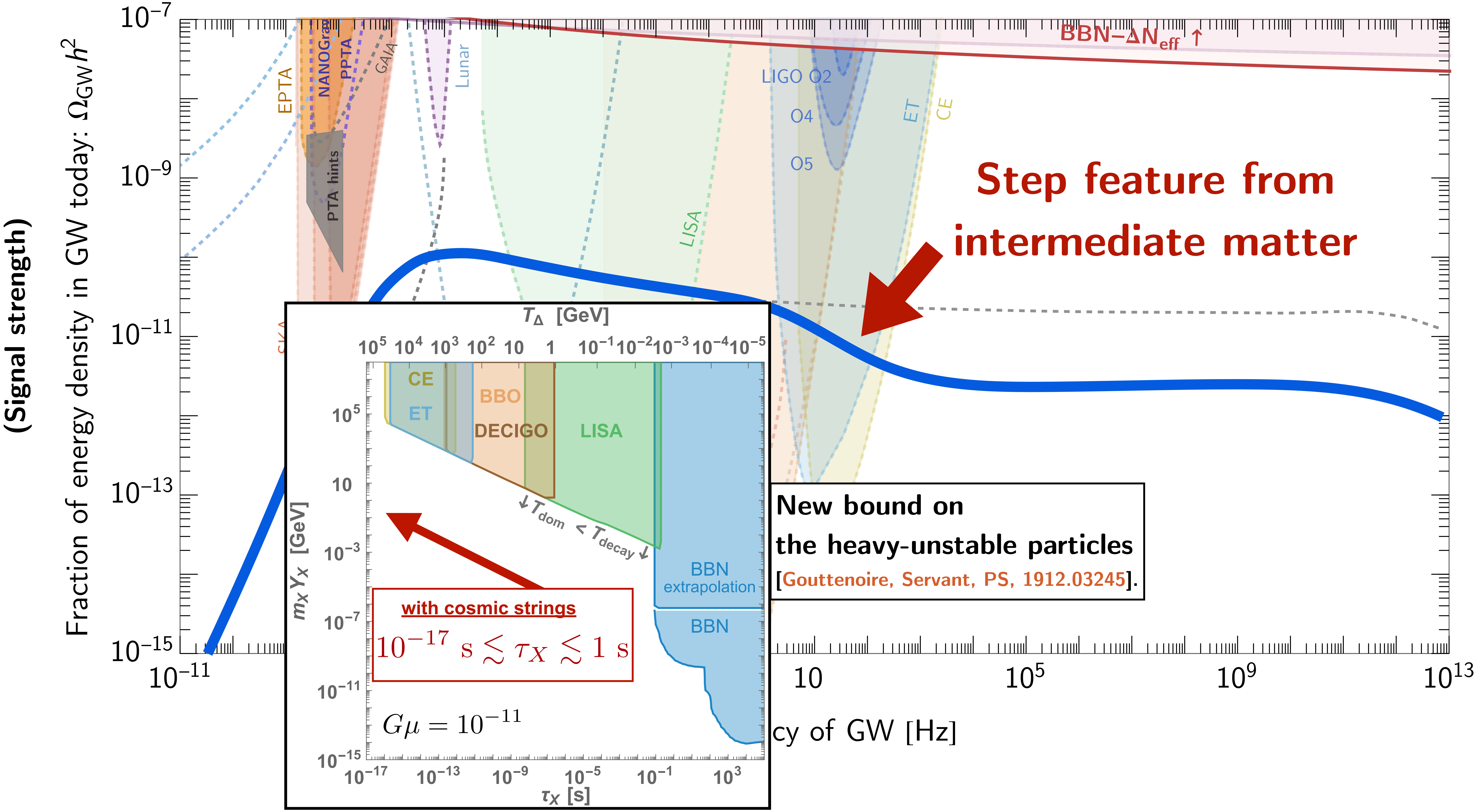

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