Primordial gravitational waves boosted by the axion

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based on 2108.10328 & 2111.01150

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Universität Hamburg
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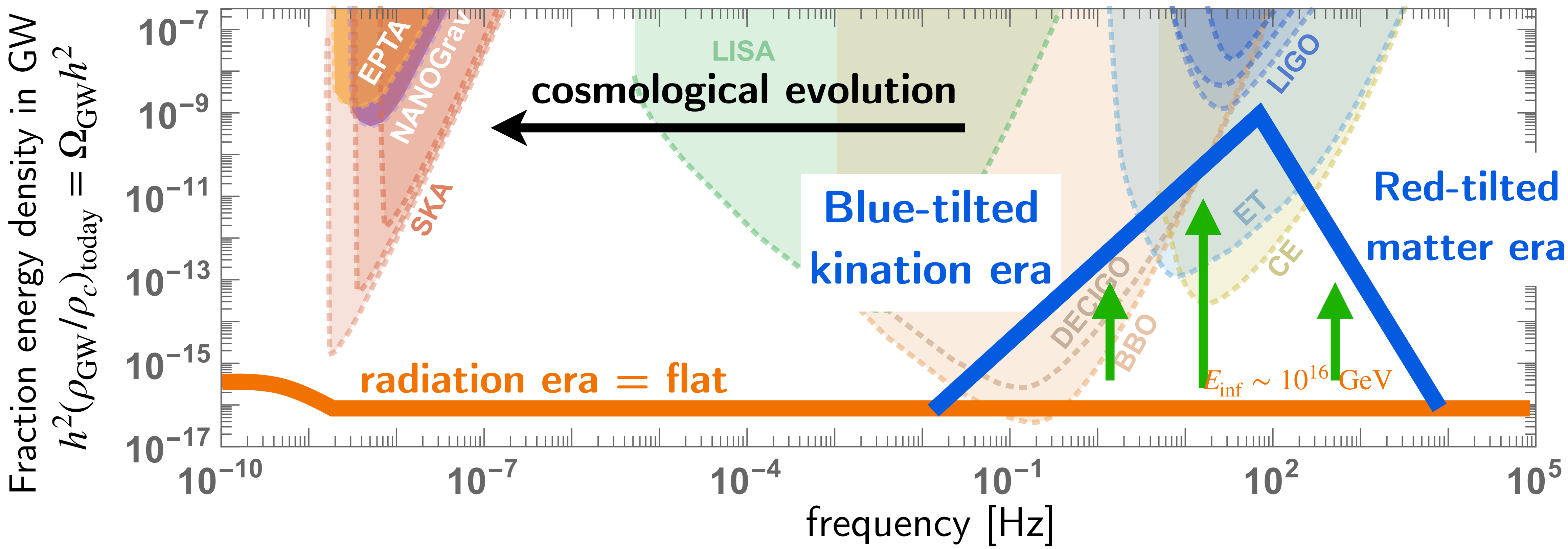
DESY.

Irreducible GW background from quantum fluctuation during **inflation** is **typically small.**

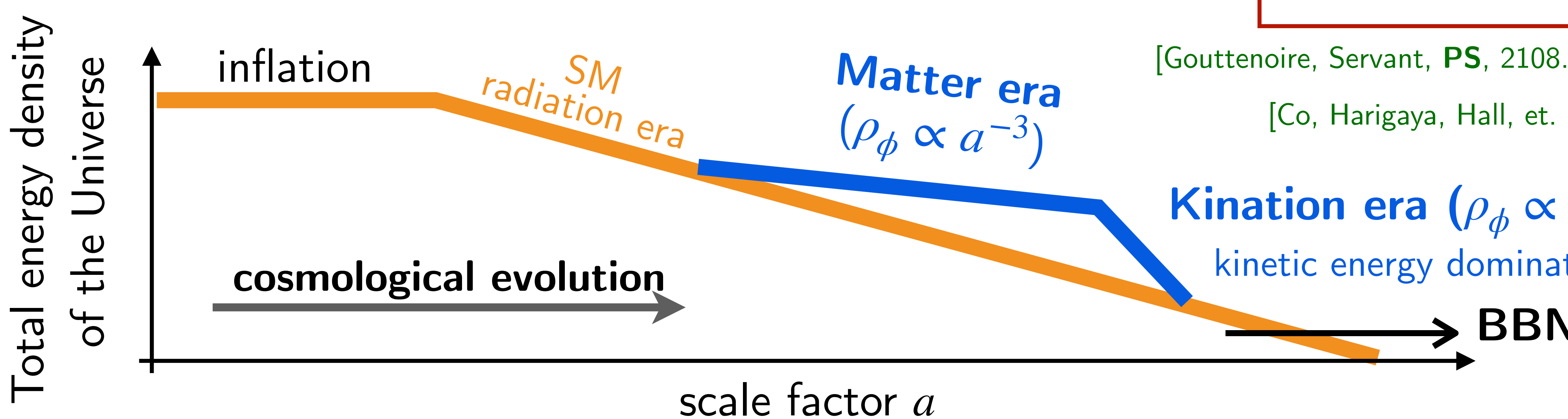


Spectral distortion of the primordial GW provide a hint of **the cosmological history.**

Spinning axion!

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

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

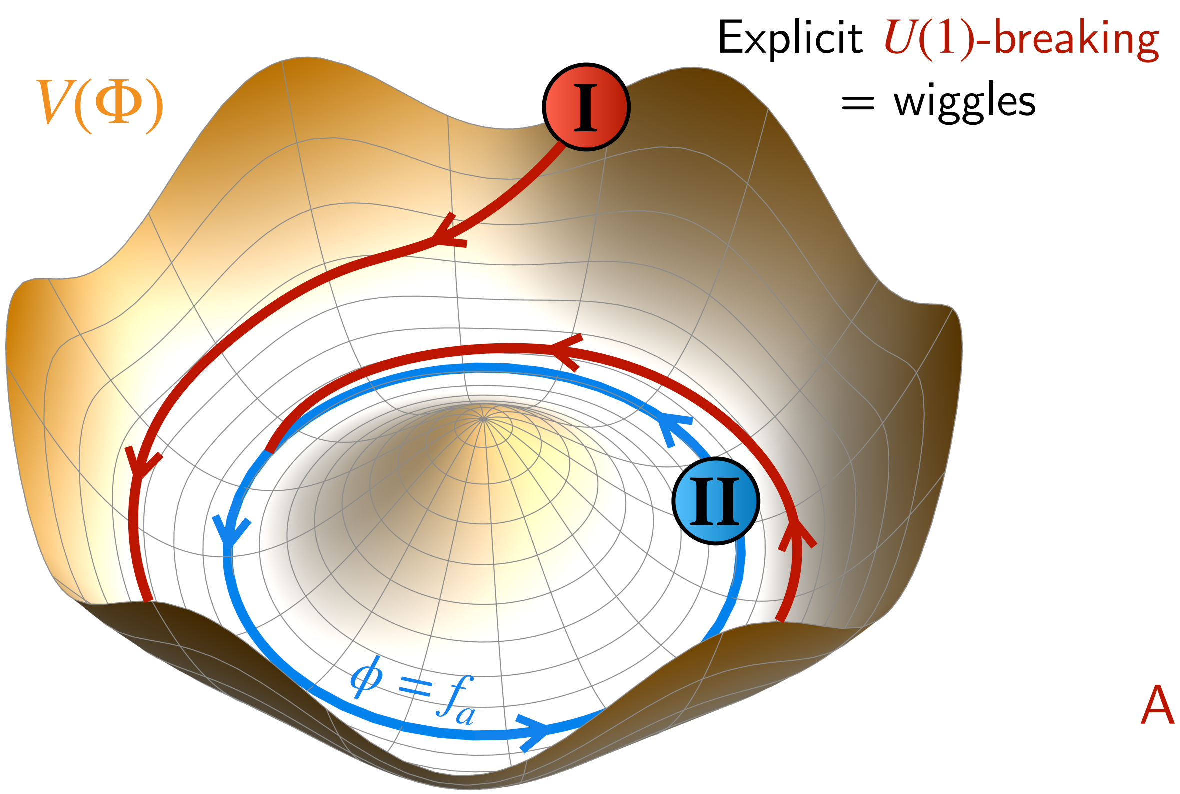


"Spinning axion"

Going beyond the assumption of vanishing velocity of axion.

e.g. **Kinetic-misalignment** & **axion fragmentation**.

[Co, Harigaya, Hall, '19 & Chang, Cui, '19] [Fonseca, Morgante, Sato, Servant, '19] [Morgante, Ratzinger, Sato, Stefanek, '21]



Example: Complex scalar field

"Axiogenesis" Co, Harigaya, '19

"Affleck-Dine Baryogenesis" Affleck, Dine, 1985

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

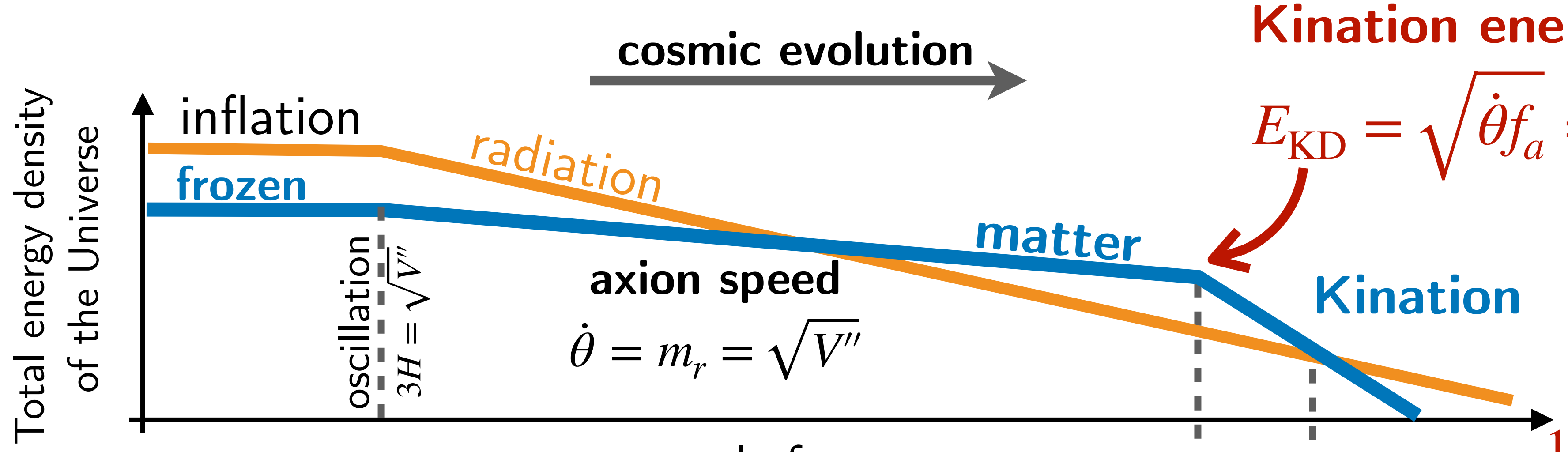
Radial mode ϕ oscillates with mass $m_r = \sqrt{V''(\Phi)}$.

Angular mode θ "axion" spins, with large kinetic energy.

when $\phi \to f_a$

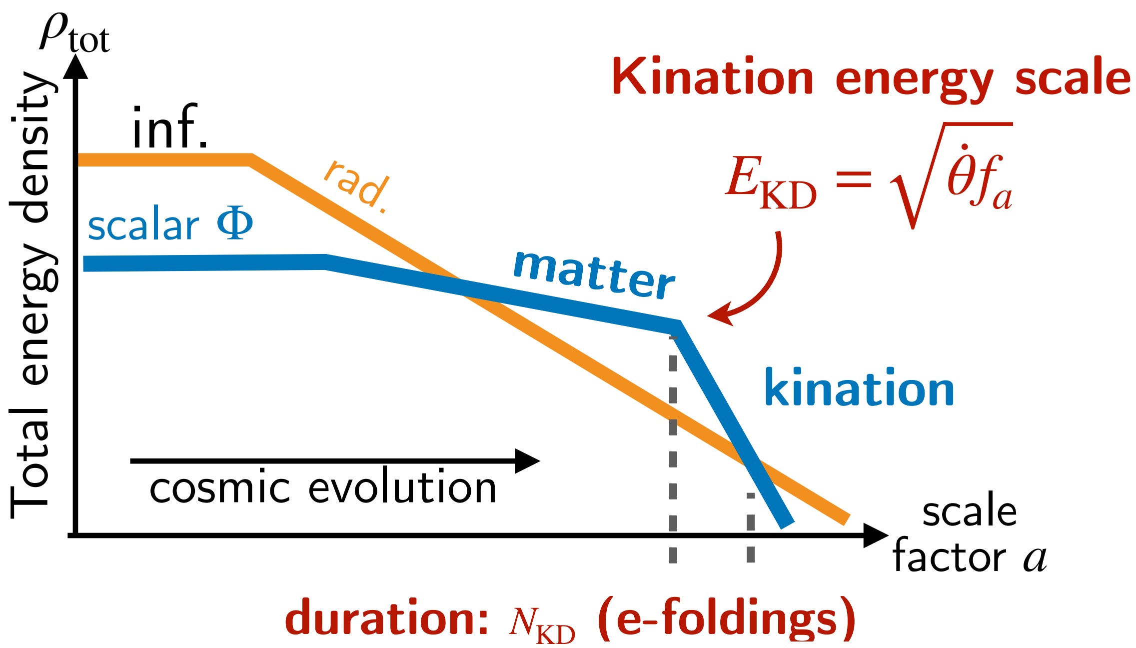
Kination energy scale

$E_{\rm KD} = \sqrt{\dot{\theta} f_a} = \sqrt{m_r f_a}$



Duration: $N_{\rm KD} = \frac{1}{6} \log \left(\rho_{\rm MD}/\rho_{\rm KD}\right)$

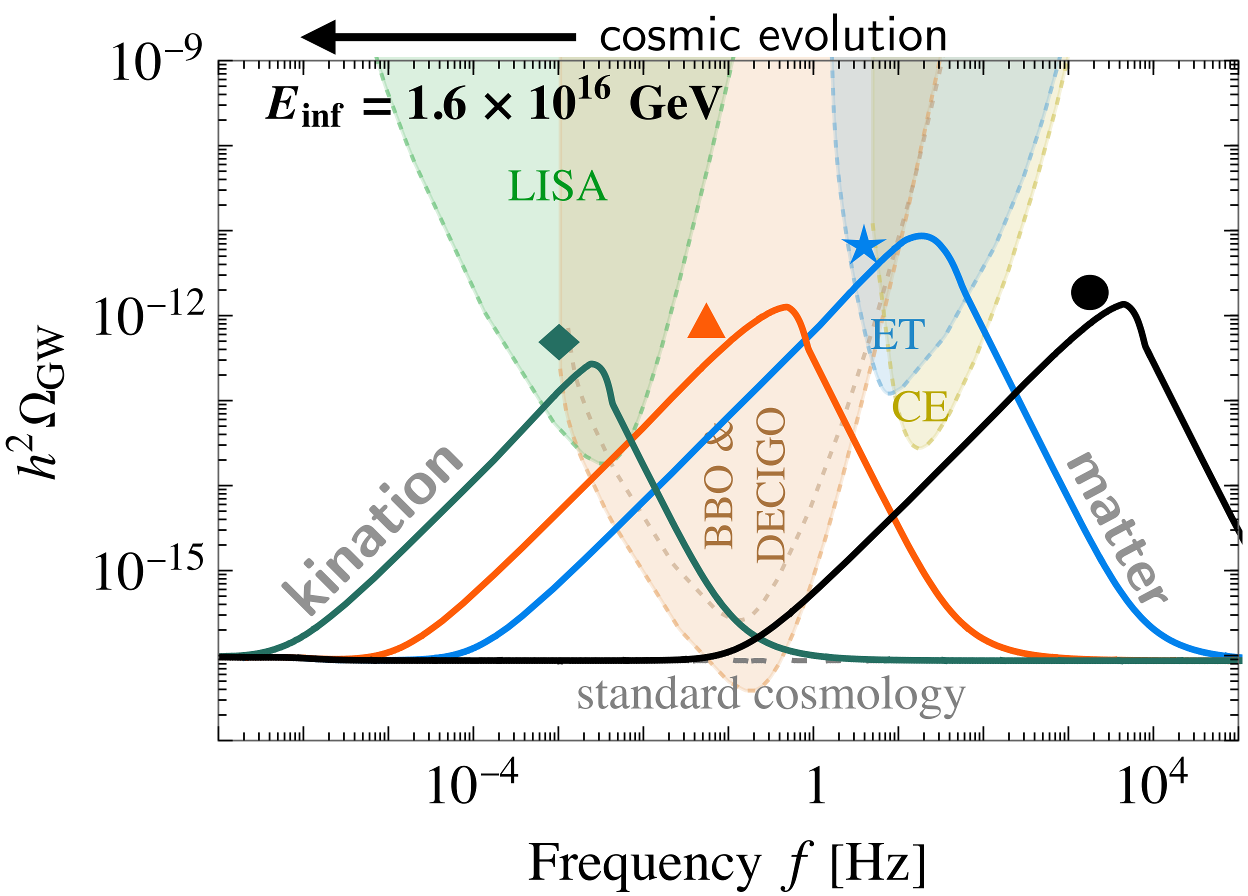
GW signature: a "Peak"



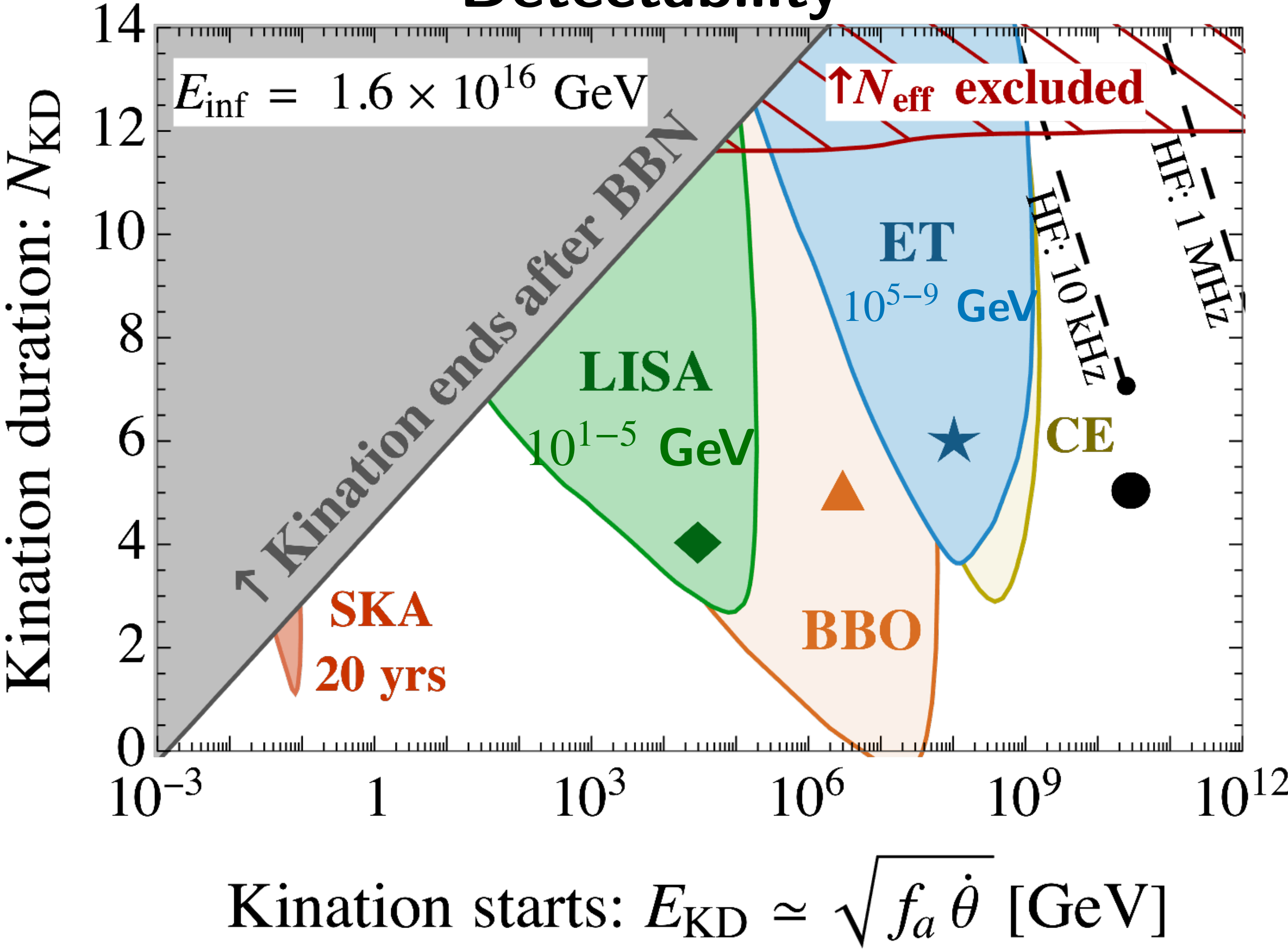
Peak position for GW from inflation.

$$f_{\rm peak} \approx 10\ \text{Hz} \left(\frac{E_{\rm KD}}{10^8\ \text{GeV}}\right) \left[\frac{\exp(N_{\rm KD}/2)}{10}\right]$$

$$\Omega_{\rm peak} h^2 \approx 10^{-12} \left(\frac{E_{\rm inf}}{1.6\times 10^{16}\ \text{GeV}}\right)^4 \left[\frac{\exp(2N_{\rm KD})}{10^4}\right]$$

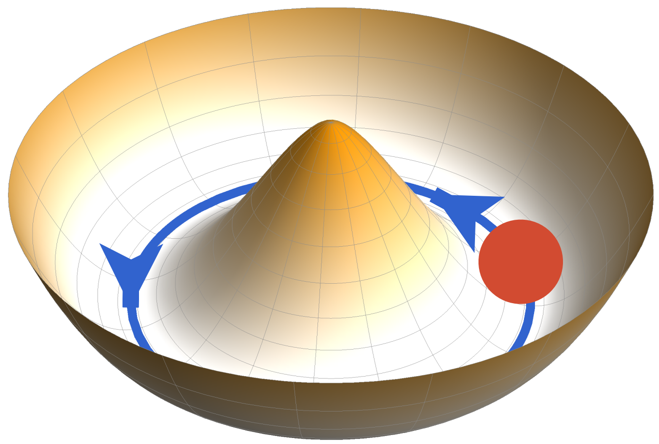


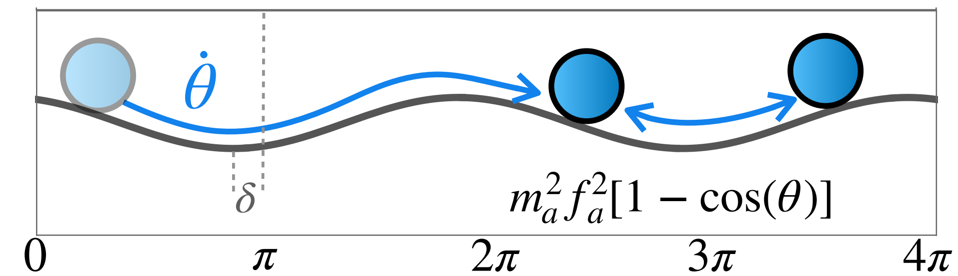
Detectability



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

Axion Dark Matter





Kinetic energy red-shifts $\dot\theta^2 f_a^2 \propto a^{-6}$ until $\dot\theta^2 f_a^2 \simeq m_a^2 f_a^2$.

PQ charge in the spinning axion transfers to the axion number density via kinetic misalignment & axion fragmentation

[Co, Harigaya, Hall, '19]
[Chang, Cui, '19]
[Fonseca, Morgante, Sato, Servant, '19]
[Morgante, Ratzinger, Sato, Stefanek, '21]

$$\boxed{\left.\frac{n_a}{s}\right|_0 \simeq \left.\frac{n_\theta}{s}\right|_{\rm KD} \equiv \frac{f_a^2\dot\theta_{\rm KD}}{s_{\rm KD}} \sim \frac{f_a E_{\rm KD}^2}{T_{\rm KD}^3}} \quad \Rightarrow \quad E_{\rm KD} \simeq 10^9\ {\rm GeV}\left(\frac{f_a m_a}{1\ {\rm GeV}}\right)\left(\frac{\Omega_{\rm DM,0}}{\Omega_{a,0}}\right) e^{-3N_{\rm KD}/2}$$

QCD Axion Dark Matter

$$\left.\frac{n_a}{s}\right|_0 \simeq \left.\frac{n_\theta}{s}\right|_{\rm KD} \equiv \frac{f_a^2\dot\theta}{s_{\rm KD}}$$

via kinetic misalignment & axion fragmentation

[Co, Harigaya, Hall, '19]
[Chang, Cui, '19]

[Fonseca, Morgante, Sato, Servant, '19]
[Morgante, Ratzinger, Sato, Stefanek, '21]

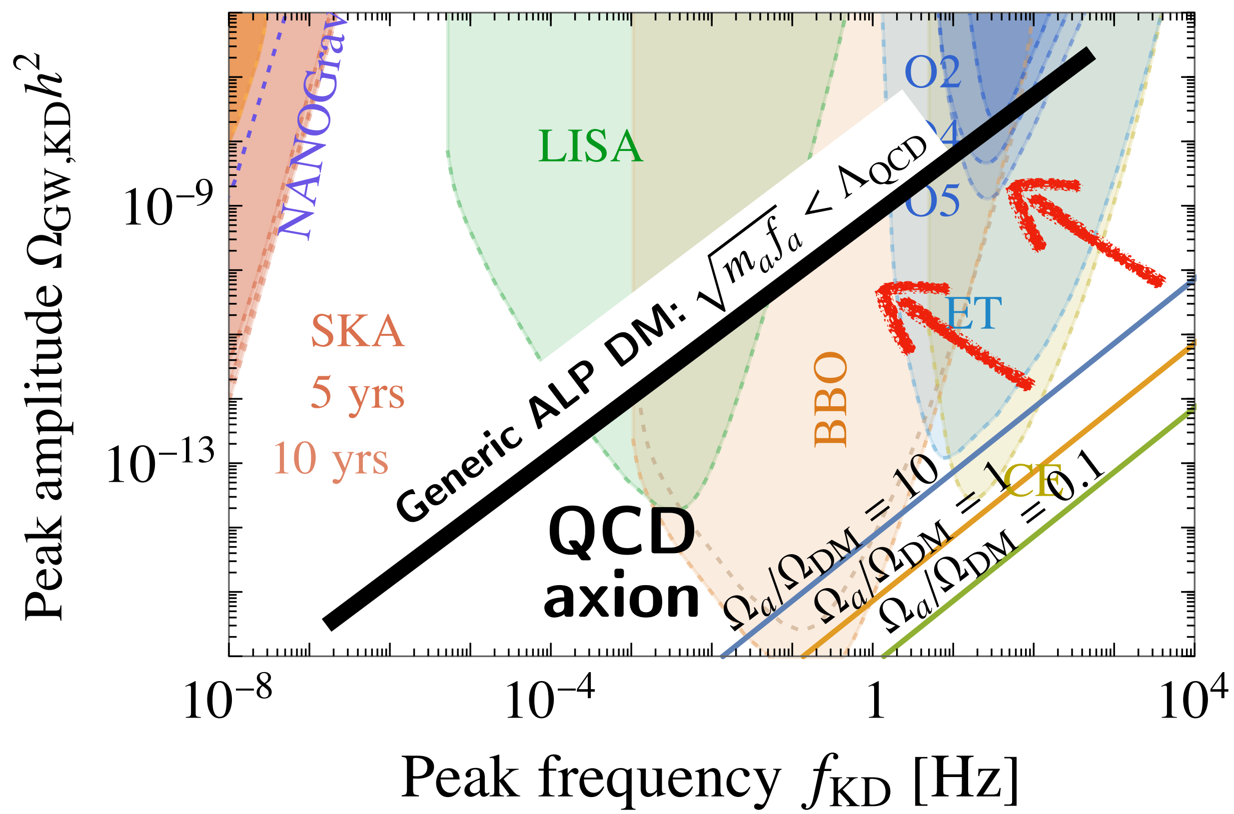
$$E_{\rm KD} \simeq 10^9 \text{ GeV} \left(\frac{f_a m_a}{1 \text{ GeV}}\right)\left(\frac{\Omega_{\rm DM,0}}{\Omega_{a,0}}\right) e^{-3N_{\rm KD}/2}$$

GW peak & Axion abundance

$$f_{\rm peak} \approx 10 \text{ kHz} \left(\frac{\sqrt{m_a f_a}}{100 \text{ MeV}}\right)^2 \left(\frac{E_{\rm KD}}{10^9 \text{ GeV}}\right)^{4/3} \left(\frac{\Omega_{a,0}}{\Omega_{\rm DM,0}}\right)^{1/3}$$

$$\Omega_{\rm peak} h^2 \approx 10^{-15} \left(\frac{f_{\rm peak}}{\rm Hz}\right) \left(\frac{E_{\rm inf}}{10^{16} \text{ GeV}}\right)^4 \left(\frac{100 \text{ MeV}}{\sqrt{m_a f_a}}\right)^2 \left(\frac{\Omega_{a,0}}{\Omega_{\rm DM,0}}\right)$$

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



The conventional QCD axion DM has no observable peak,
except at BBO or high-frequency experiments.

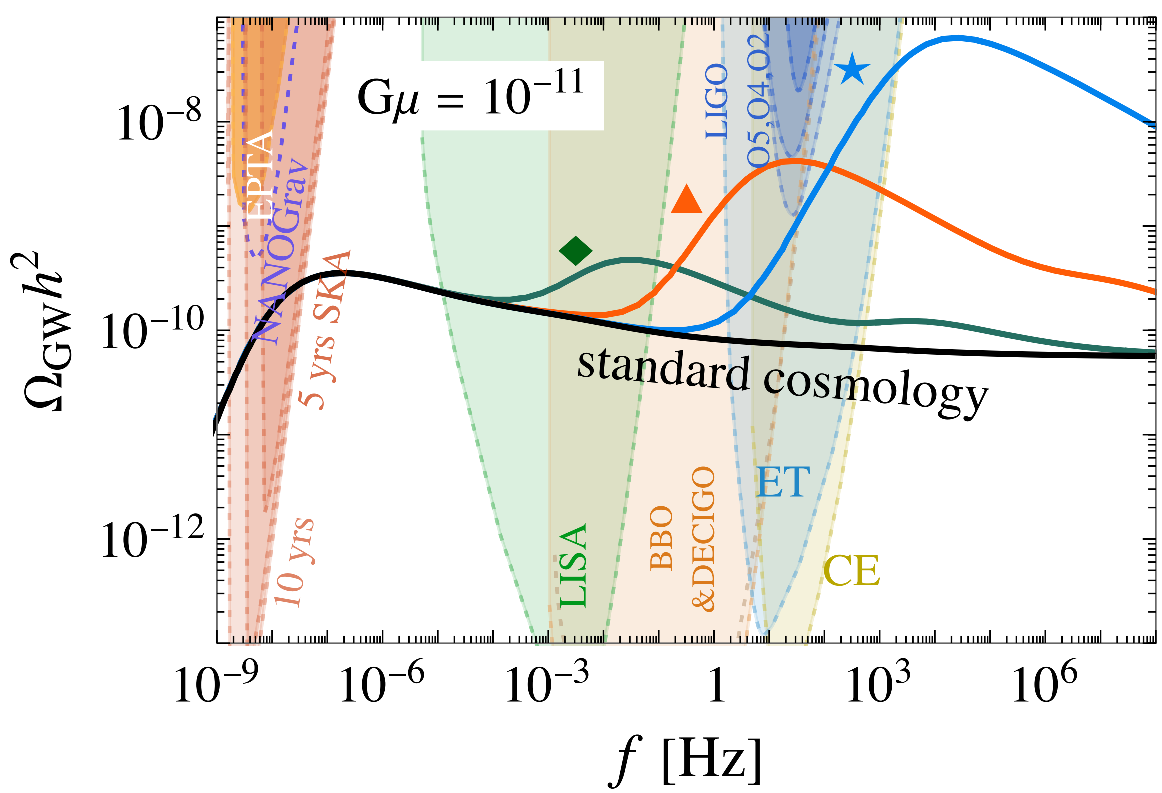
Observable signals for generic ALP DM and
QCD axion DM with lighter mass, e.g., from the $\mathbb{Z}_N$-axion.

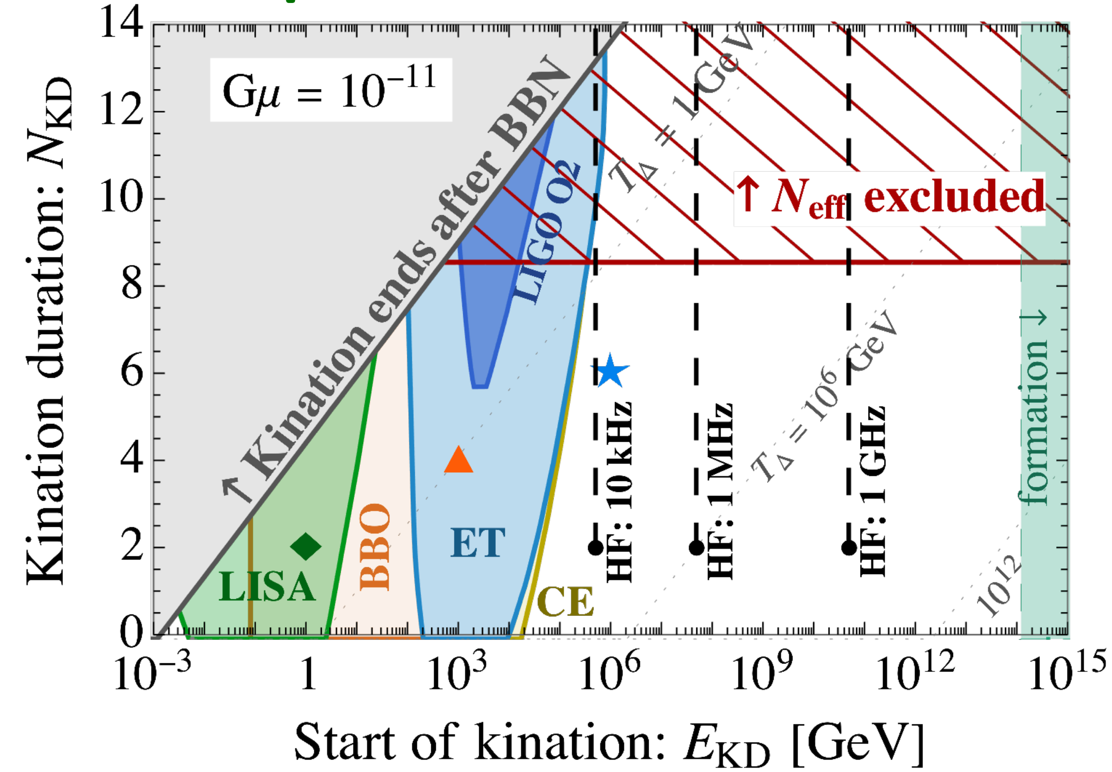
[Hook, '18]
[Di Luzio, Gavela, Quilez, Ringwald, '21]

Local cosmic strings   symmetry breaking scale $\simeq M_{\rm pl}\sqrt{G\mu}$

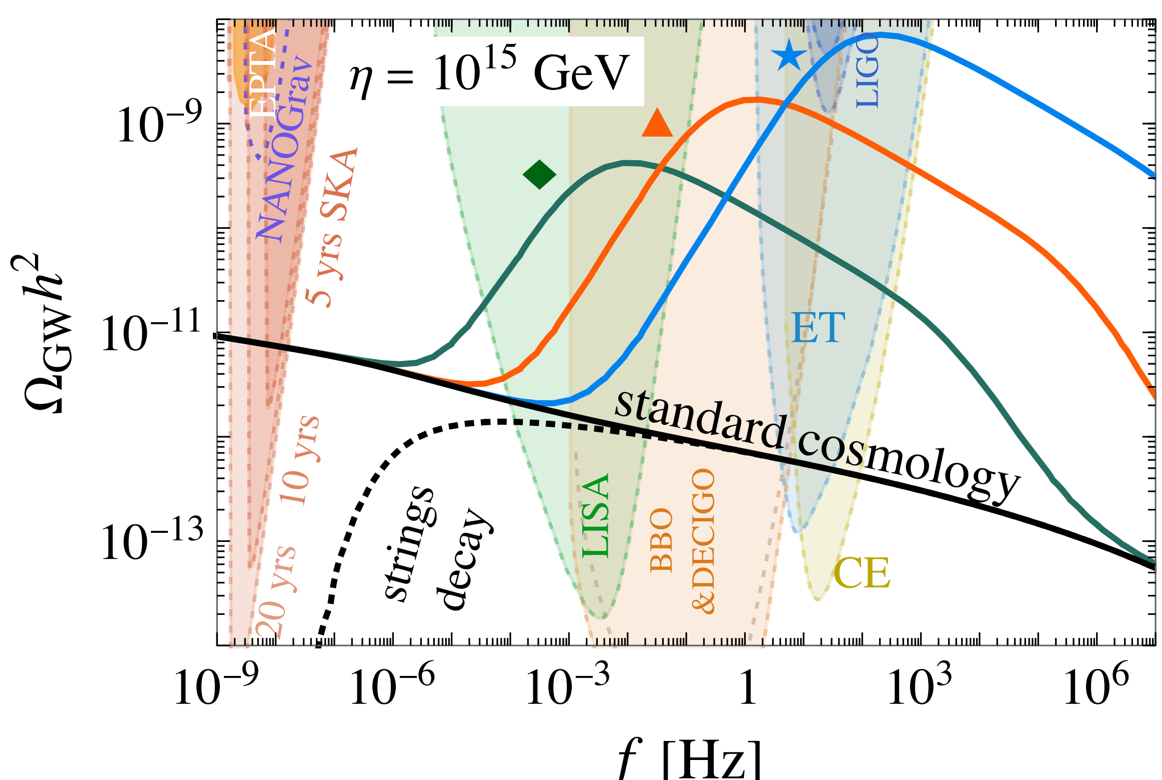
Gouttenoire, Servant, **PS,** 2111.01150

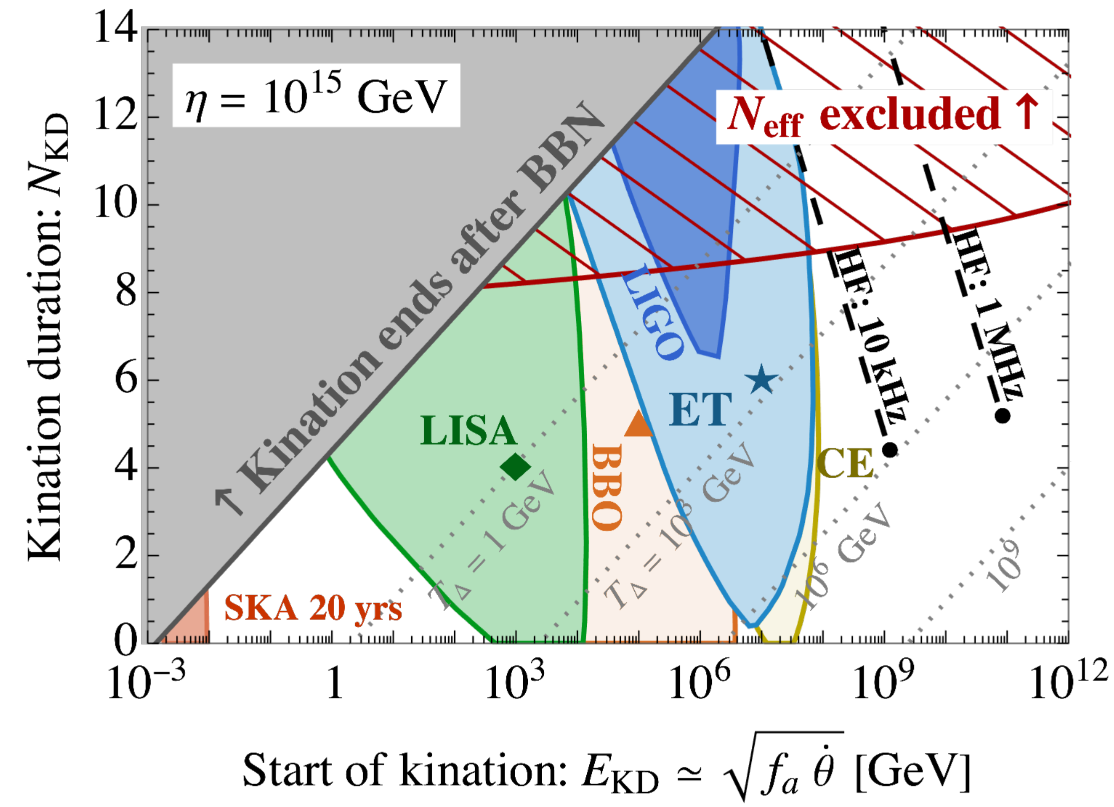
LISA probes down to MeV scales



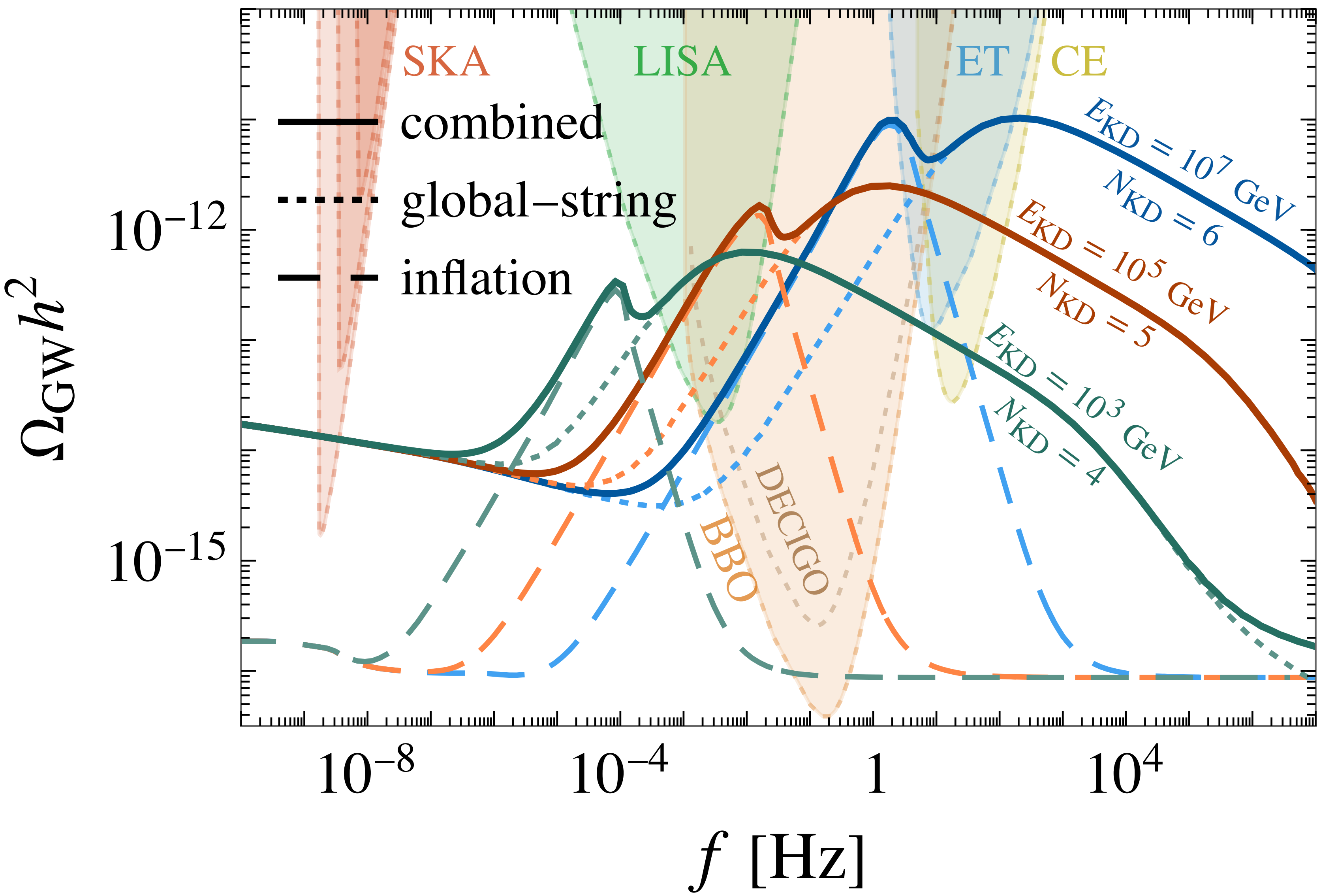


Global cosmic strings   symmetry breaking scale $\simeq \eta$





GW peaks from inflation + global cosmic strings



"Two-peak signature"

Fixed peak separation: $f_{\rm inf}/f_{\rm glob} = \mathcal{O}(10^{-2})$

[assuming loops' size: $(0.1)H^{-1}$]

Conclusion

Primordial GW is enhanced by

"Kination" — the kinetic energy of scalar field dominates the Universe.

A spinning axion

e.g. from complex scalar field (generic in SM extensions)

can generate a matter-kination era during the pre-BBN epoch.

(Axion kinetic misalignment or Affleck-Dine mechanism)

leads to an observable "GW peak", ∝ energy scale and duration of kination.

$$\textbf{LISA for } E_{\rm KD} \sim \begin{cases} 10^{1-5}\ \text{GeV, (inflation)} \\ 10^{(-3)-3}\ \text{GeV, (local strings)} \\ 10^{0-4}\ \text{GeV, (global strings)} \end{cases}$$

GW peak & axion abundance.

No observable for standard QCD axion DM, except at BBO.

LISA can probe GW peak for generic ALP dark matter

with lighter mass than the standard QCD axion.

For more detail, [Gouttenoire, Servant, PS, 2108.10328 & 2111.01150]
[Co, Harigaya, Hall, et. al., 2108.09299]

Stay safe and healthy, thank you!