Primordial gravitational waves revealed by a spinning axion

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(Based on the work in progress: to appear…)

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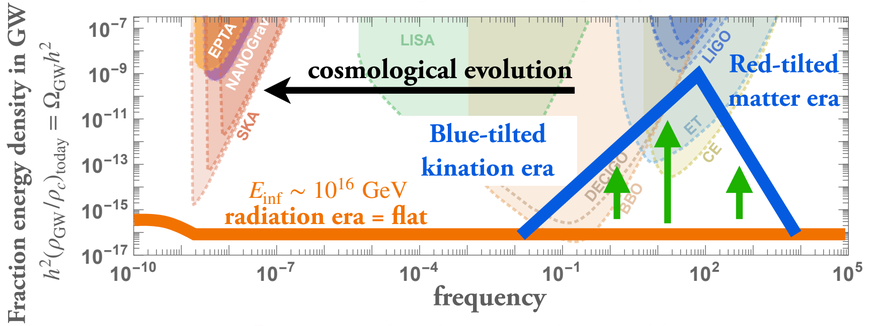
Abstract. A fast-spinning axion can dominate the Universe at early times and generates the so-called kination era. The presence of kination imprints a smoking-gun spectral enhancement in the primordial gravitational-wave (GW) background. Current and future-planned GW observatories could constrain particle theories that generate the kination phase. Surprisingly, the viable parameter space allows for a kination era at the PeV-EeV scale and generates a peaked spectrum of GW from either cosmic strings or primordial inflation, which lies inside ET and CE windows.

I. Motivation.

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

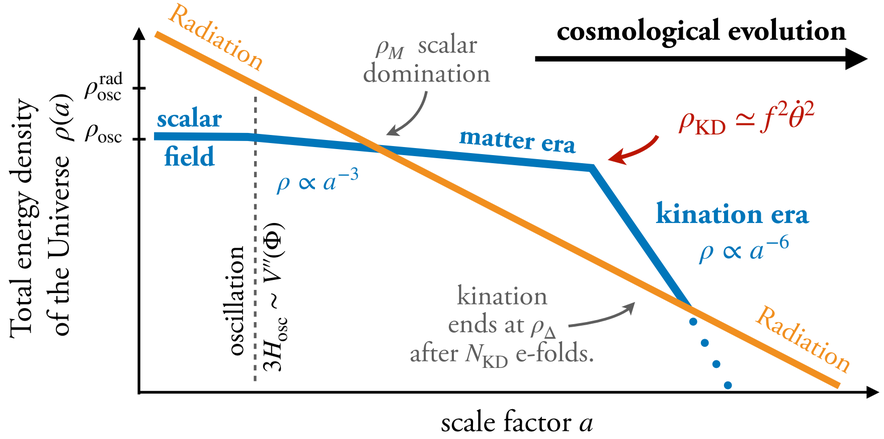


Cosmological evolution can be traced by GW spectral distortion from high-to-low frequencies.
ΛCDM model: "radiation era" at early times ⇒ "flat" GW spectrum

$$\Omega_{GW,flat}h^2 \simeq 10^{-17}(E_{inf}/10^{16}\ \text{GeV})^4$$

With a non-standard cosmological history (beyond the ΛCDM model),
"Kination era" ⇒ Blue-tilted, "Matter era" ⇒ Red-tilted
(due to the relative fraction of GW energy density to the total energy density.)

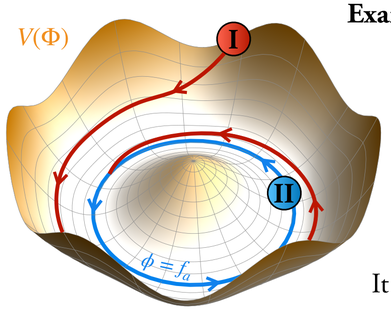
Too long kination ⇒ too large GW signal?
The extra radiation (N_{eff}) bound: $h^2\Omega_{GW,0} \lesssim 10^{-6}$



II. Kination from a spinning axion.

Going beyond the assumption of vanishing velocity of axion.

e.g. Kinetic-misalignment (Axiogenesis / Trapped-misalignment)
[Harigaya et al, '19 '20] [Chang & Cui, '19] [Di Luzio, Gavela, Quilez, Ringwald, '21]



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

Radial mode ϕ oscillates inside potential.

Angular mode: "axion" θ spins and stores large kinetic energy.

Stage 1. Field has a large VEV and is frozen due to Hubble friction. It starts to oscillate when $3H \sim \partial^2 V/\partial\Phi^2$.

Stage 2. The explicit $U(1)$-breaking term (wiggles along angular direction) generates a rotation.

Stage 3. "Matter era" from oscillation & rotation on potential

Scalar-field equation-of-state: $\omega_\Phi = P_\Phi/\rho_\Phi = \dfrac{KE - PE}{KE + PE}$

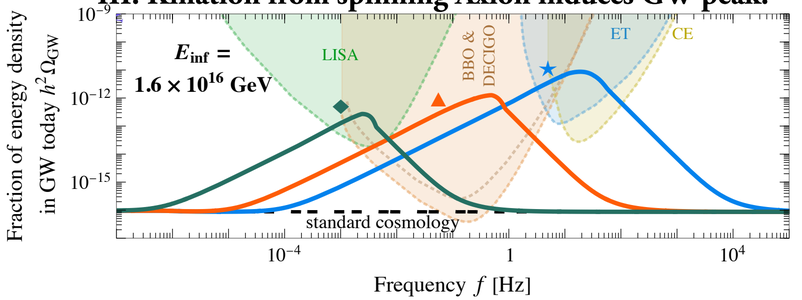
$KE = PE$: balance of the centrifugal force and potential gradient. $\omega_\Phi = 0$

Stage 4. "Kination era" starts when field reaches the bottom $\phi \to f$.

Kinetic energy density dominates with $\rho_\Phi = KE \simeq f^2\dot{\theta}^2 \propto a^{-6}$, $\omega_\Phi = 1$.

Kination era starts and lasts for $N_{KD} = \log(a_\Delta/a_{KD})$
until the radiation becomes dominant again at ρ_Δ.

III. Kination from spinning Axion induces GW peak.

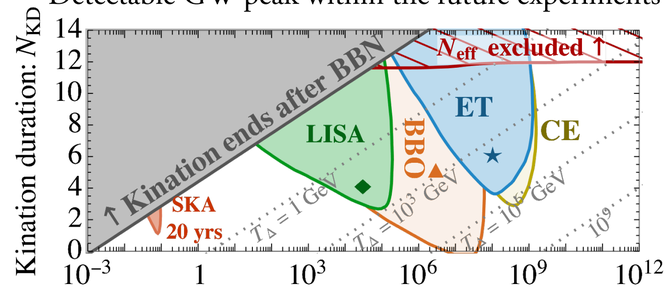


Peak tells us the energy scale $\sqrt{f\dot{\theta}}$ and duration N_{KD} of kination era.

Peak frequency: $f_{peak} \approx 10\ \text{Hz} \left(\dfrac{\sqrt{f\dot{\theta}}}{10^8\ \text{GeV}}\right)\left[\dfrac{\exp(N_{KD}/2)}{10}\right]$

Peak amplitude: $\Omega_{peak}h^2 \approx 10^{-12}\left(\dfrac{E_{inf}}{1.6\times10^{16}\ \text{GeV}}\right)^4\left[\dfrac{\exp(2N_{KD})}{10^4}\right]$

Detectable GW peak within the future experiments



Kination starts: $E_{KD} \simeq \sqrt{f\,\dot{\theta}}$ [GeV]

Take-home messages:

A spinning axion e.g. from complex scalar field (generic in SM extensions) can dominate the universe and generate a short kination era. (Axion kinetic misalignment or Affleck-Dine mechanism)

The observable inflationary-GW peak can be induced, e.g. ET & CE ~ 10^8 GeV kination, LISA ~ 10 TeV kination.