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Catastrogenesis: ALP or PBH Dark Matter

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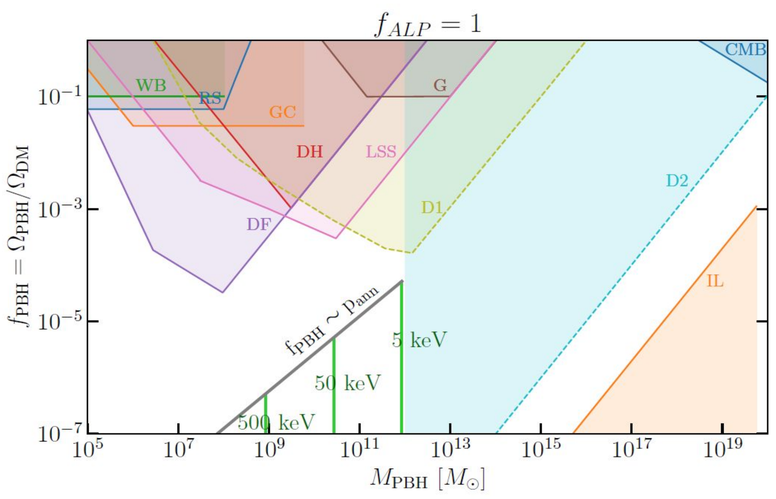
Based on hep-ph 2103.07625, 2207.07126, and 2303.14107 (with G. Gelmini and E. Vitagliano)

Stable ALPs

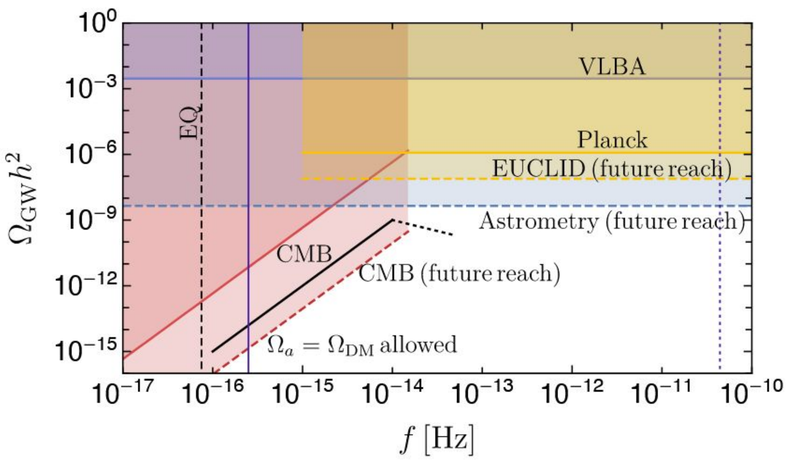
- *ALPs can make up the bulk of the DM*
- *Wall annihilation produces GWs* $\sim 10^{-15}\,\mathrm{Hz}$ *(possibly detectable by CMB/astrometry probes) for* $m_a < 10^{-3}\,\mathrm{GeV}$
- *Could produce small amount of supermassive PBHs*

PBHs



Gray line: $\alpha = 7$; larger values of α below
Green vertical lines: annihilation temperatures

GW Spectrum



Black slanted lines: Spectrum for $T_{\rm ann} = 100\,\mathrm{eV}$
Black dashed line: GW frequency at matter-radiation equality
Purple vertical line: leftmost limit for where ALPs can be all the DM (due to CMB bounds alone)

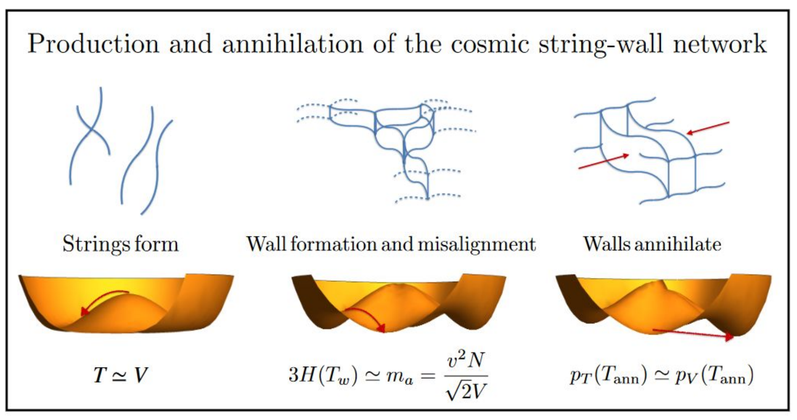
Catastrogenesis: The production of axion-like particles (ALPs), gravitational waves (GWs), and primordial black holes (PBHs) by the annihilation of a cosmic string-wall system.

(from the Greek καταστροφή, "annihilation")

Generic Potential (Lagrangian)

$$V(\phi) \supset \underbrace{\frac{\lambda}{4}\left(|\phi|^2 - V^2\right)^2}_{\text{Spontaneous symmetry breaking}} + \underbrace{\frac{v^4}{2}\left(1 - \frac{|\phi|}{V}\cos\left(N\theta\right)\right)}_{\text{Explicit breaking}} - \underbrace{\epsilon_b v^4 \frac{|\phi|}{V}\cos(\theta - \delta)}_{\text{Bias}}$$

Fields: $\phi = |\phi|e^{i\theta};\ \ a = \theta V$
Consistency conditions: $v \ll V;\ \ \epsilon_b \ll 1$
The field a may be any pseudo-Goldstone boson, but we refer to it as an ALP.



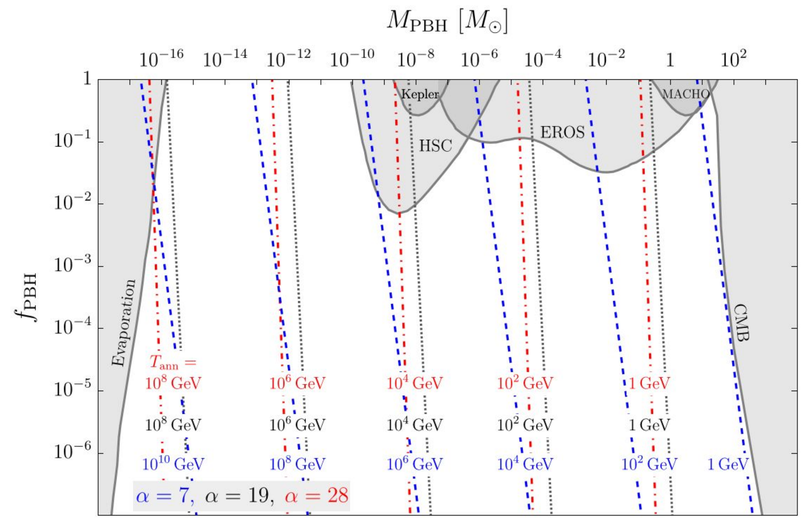
Cosmology

1. The global U(1) symmetry is spontaneously broken, leading to the formation of cosmic strings, which shortly after enter into a "scaling" regime.
2. Domain walls form due to the explicit U(1) breaking in the 2nd term, forming a string-wall system (another scaling regime).
3. Domain walls annihilate due to the small bias $\sim \epsilon_b v^4$ between adjacent vacua.
4. PBHs may form at the end of the annihilation process from spherically symmetric collapse of closed walls (Ferrer et al. 2019, 1807.01707).

Unstable ALPs, PBH DM

- *ALPs decay into SM products that thermalize*
- *Lab limits require* $m_a > 1\,\mathrm{GeV} - 1\mathrm{TeV}$ *(depending on coupling)*
- *Could produce asteroid-mass PBHs that can be all the DM* $(10^{-16} - 10^{-10} M_\odot)$
- *Could produce GWs* $> 10^{-6}\,\mathrm{Hz}$ *(possibly detectable by future GW detectors)*

PBHs

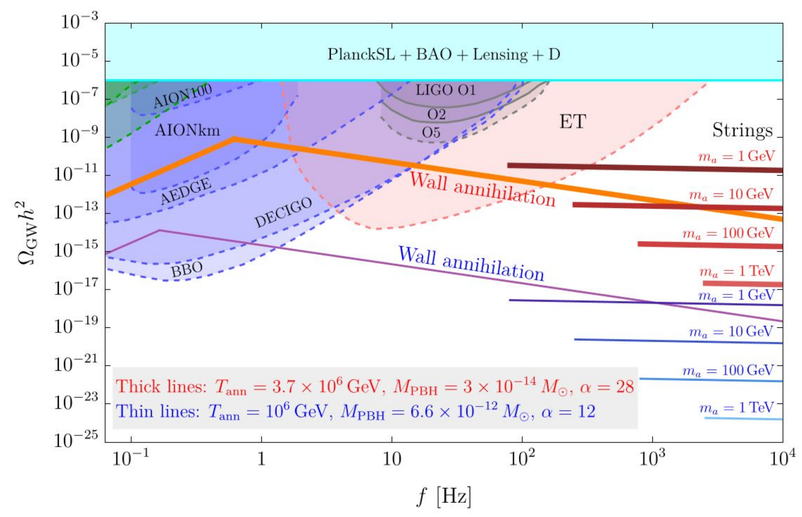


After annihilation starts,

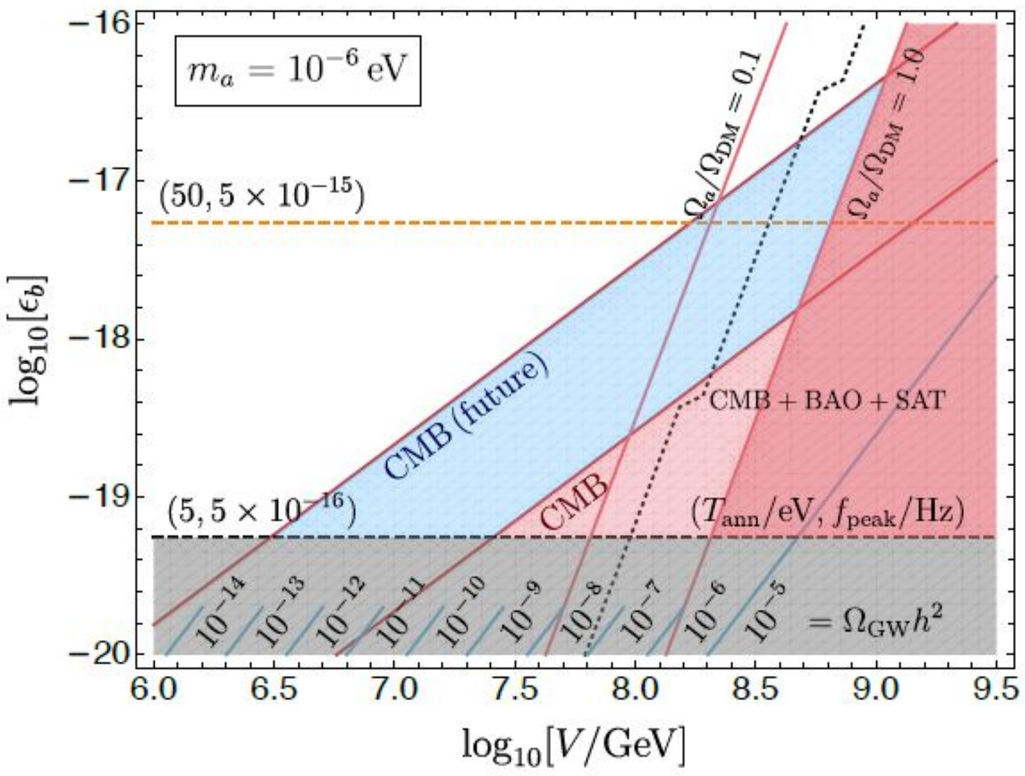
$$\frac{\rho_{\rm wall}(T)}{\rho_{\rm wall}(T_{\rm ann})} = \left(\frac{T}{T_{\rm ann}}\right)^{\alpha}$$

(Simulations: Kawasaki et al. 2015, 1412.0789)

GW Spectrum

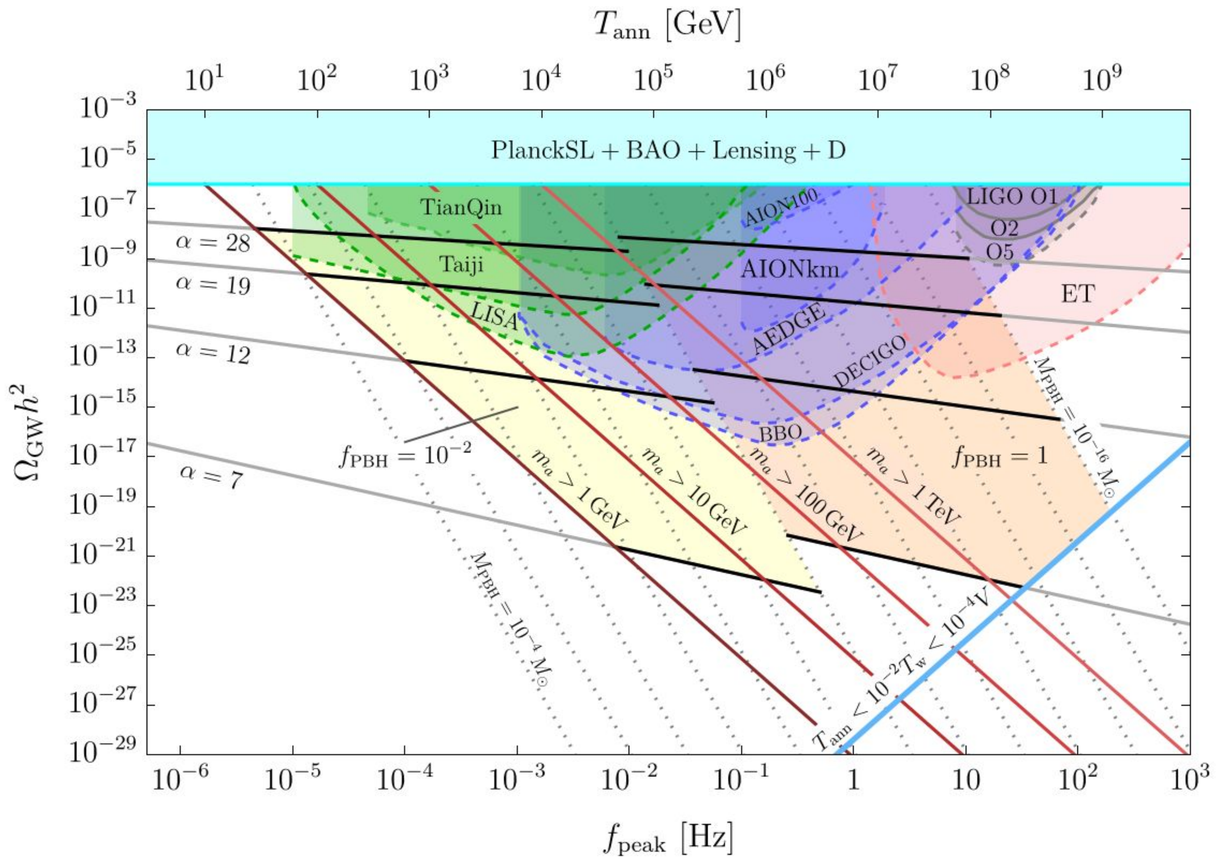


Regions of Interest



Blue: Observable in future CMB probes and astrometry
Red: Excluded by CMB limits or because $\Omega_a/\Omega_{\rm DM} > 1$
Gray: Excluded because $T_{\rm ann} < 5\,\mathrm{eV}$
Right of black dotted line: Region subject to structure formation bounds

Regions of Interest



$$f_{\rm peak} \simeq 1.6\,\mathrm{Hz}\,\frac{T_{\rm ann}}{10^7\,\mathrm{GeV}}$$

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