QCD-Collapsed Domain Walls

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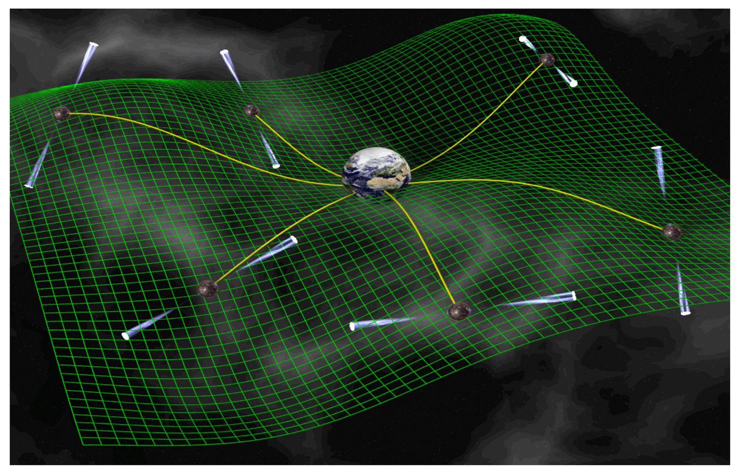
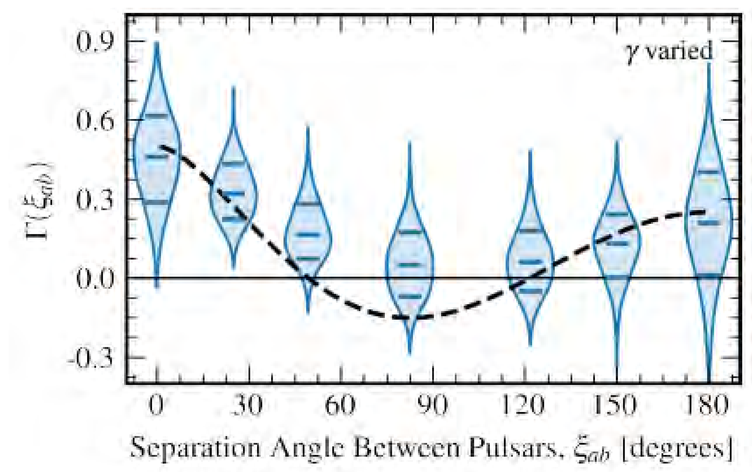
This research was supported by Award #$ 2020275

Motivation

- Era of GW astronomy with ground-based detectors (Hz-KHz) and pulsar timing array (PTA) experiments (nHZ – 100 nHZ).

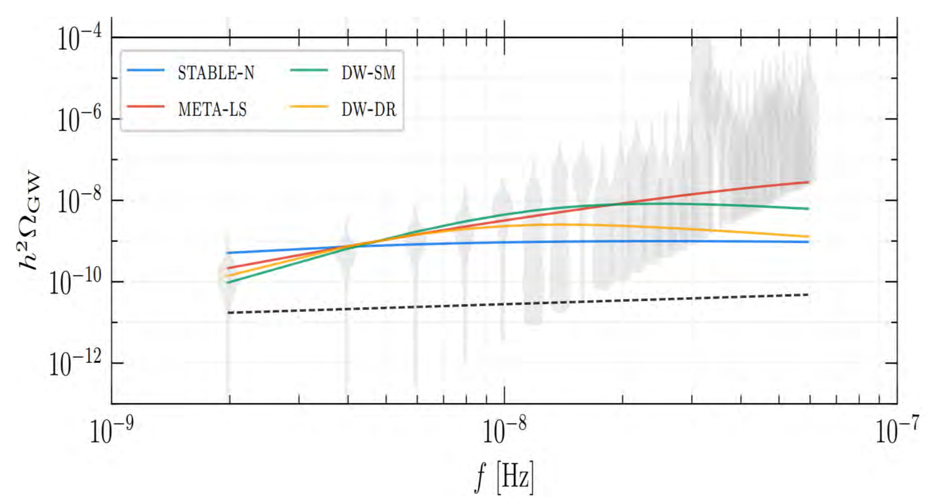


- PTA detect Stochastic GW Background (SGWB) which result in Hellings-Downs correlation observed at around 3 to 4-sigma by NANOGrav, EPTA, PPTA, CPTA, InPTA.



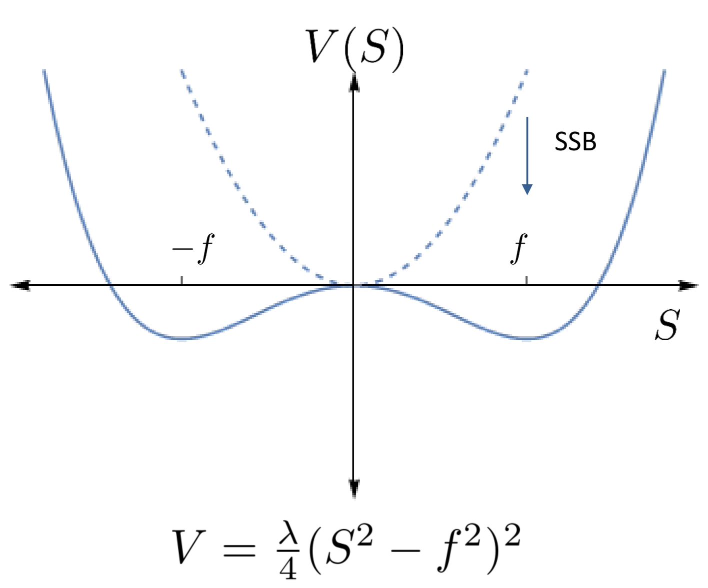
- Q: What is the source of this SGWB?

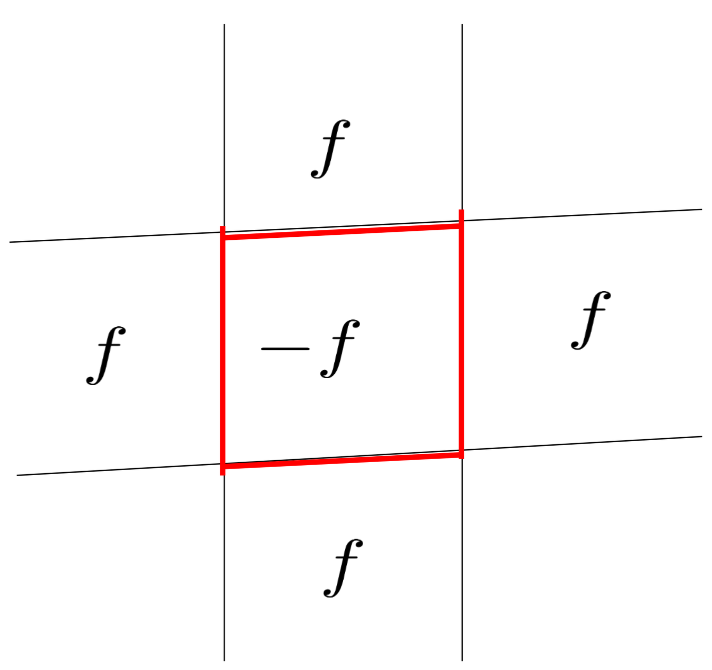
  A: 1) SM BH binary merger
  2) FOPT
  3) Inflation
  4) Cosmic Stings
  5) Domain Walls



Domain Walls

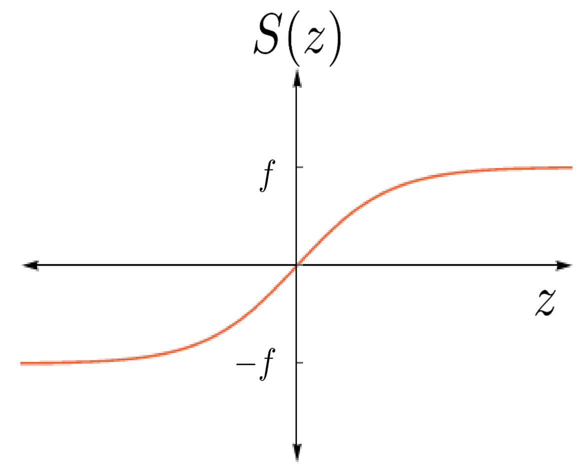
- Cosmic defects produced from SSB of discrete symmetry $\mathbb{Z}_2$





- Energy density of domain walls

$$\rho_{\rm DW} = \sigma/L$$
$$\sigma \approx \sqrt{\lambda} f^3 (\text{surface tension})$$
$$L = \text{domain size}$$



- Evolution of DW:

Scaling Solution $\quad \rho_{\rm DW} = \sigma/L = \mathcal{A}\sigma/t$

$L = L_0 t, v = v_0 \quad \mathcal{A} \approx 0.4N$

- DW are problematic as they dominate energy density of the universe, as $\rho_R \sim T^4 \propto 1/t^2$

$$T_{\rm dom} \approx 45\,\text{MeV}\left(\frac{\mathcal{A}}{0.8}\right)^{1/2}\left(\frac{\sigma}{10^{16}\,\text{GeV}^3}\right)^{1/2}\left(\frac{g_*(T_{\rm dom})}{10}\right)^{-1/4}$$

- Q: How do we get rid of DWs in early universe?
  A : Break the discrete symmetry to create a bias between degenerate vacua

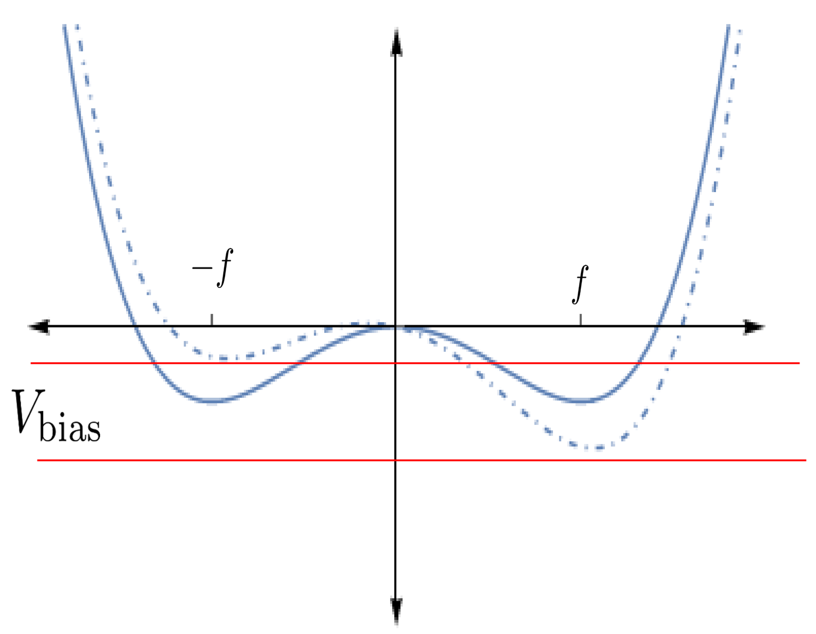
Domain Wall Collapse and GWs

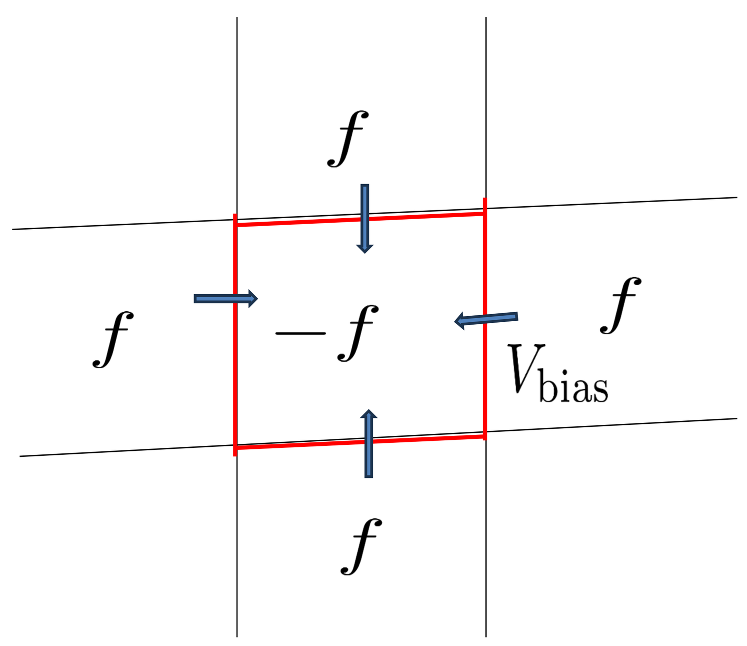
- Make discrete symmetry anomalous under QCD

$\mathcal{L}_{\rm Yukawa} = y S \bar{Q}_L Q_R$ Q vector like quarks (3,1,0)

$$\mathcal{L}_\theta = -\frac{\theta}{32\pi^2} G_{\mu\nu}\tilde{G}^{\mu\nu} \quad \text{where } \theta = \arg(\text{S})$$

$$V_{\rm bias}(\theta) = -m_\pi^2 f_\pi^2 \sqrt{1 - \frac{4\, m_u\, m_d}{(m_u + m_d)^2}\,\sin^2\left(\frac{\theta}{2}\right)}$$





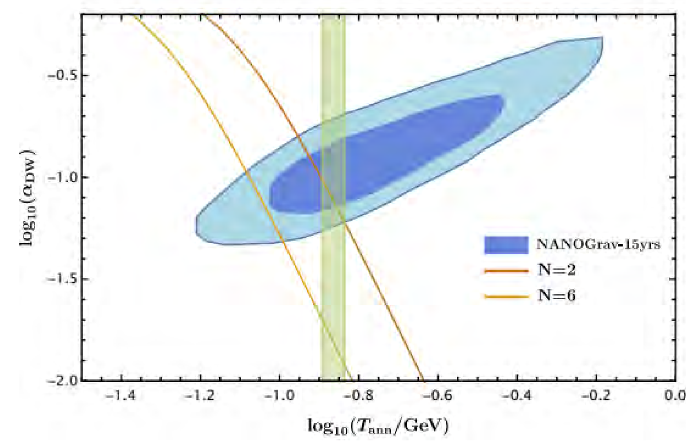
- Biased potential cause DW collapse

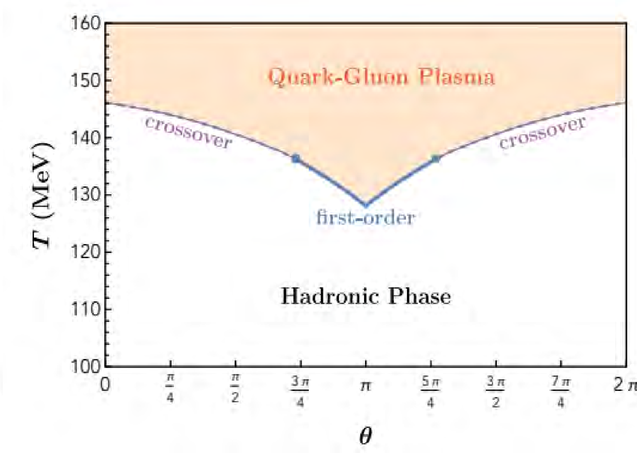
$$T_{\rm ann} \approx 120\,\text{MeV}\left(\frac{V_{\rm bias}}{(100\,\text{MeV})^4}\right)^{1/2}\left(\frac{\sigma}{10^{16}\,\text{GeV}^3}\right)^{-1/2}$$

- DW collapse generate GWs

$$f_{\rm peak} \approx 1.1 \times 10^{-8}\,\text{Hz}\left(\frac{T_{\rm ann}}{100\,\text{MeV}}\right)$$

$$\Omega_{\rm GW} h^2(t_0)\Big|_{\rm peak} \approx 3 \times 10^{-8}\left(\frac{\tilde{\epsilon}_{\rm GW}}{0.7}\right)\left(\frac{\sigma}{10^{16}\,\text{GeV}^3}\right)^2\left(\frac{T_{\rm ann}}{100\,\text{MeV}}\right)^{-4}$$

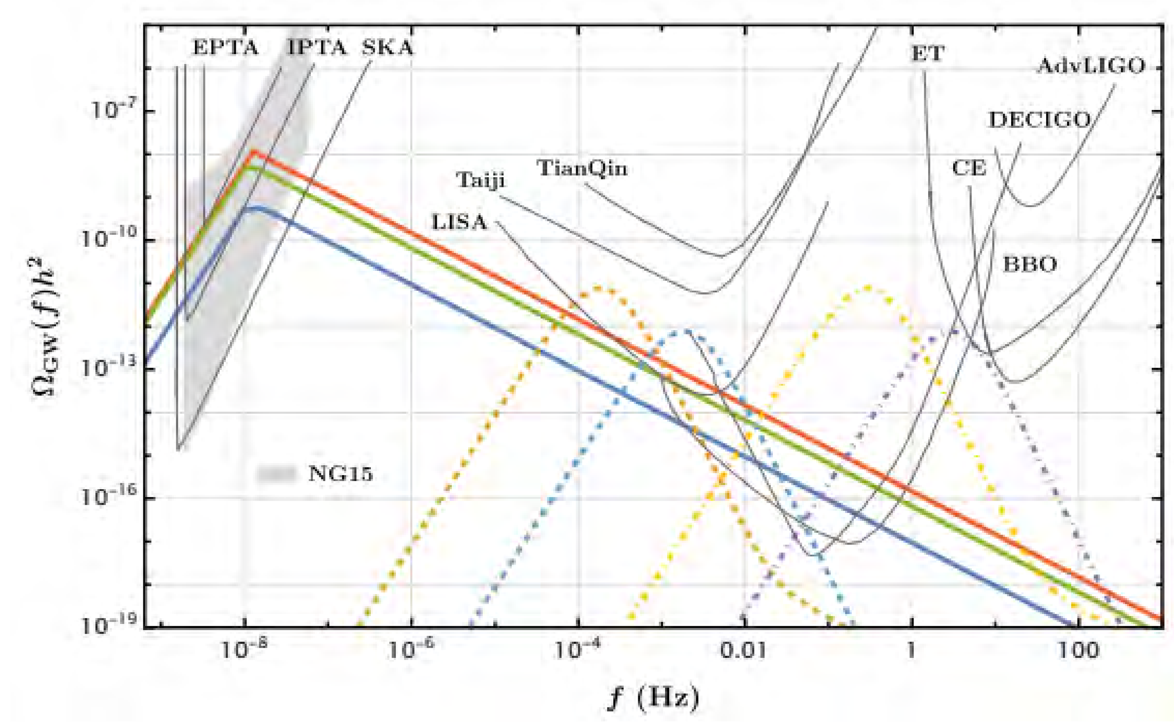




- We get QCD FOPT in the region with non-zero theta values. Obtained using LSMq. This gives new GW signature in LISA

GW Spectroscopy

- Three different sources of GW expected



References

1. YB, MK, TC'23 – 2306.17160
2. NANOGrav Collab.'23 – 2306.16213/16219
3. Pisarski'96 – hep-ph/9601316
4. Saikawa'17 – 1703.02576
5. Preskill et al.'91, Vecchia et al.' 80