Probing *Miracle-less* Dark Matter via Gravitational Wave Spectral Shapes

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Based on arXiv:2202.10474

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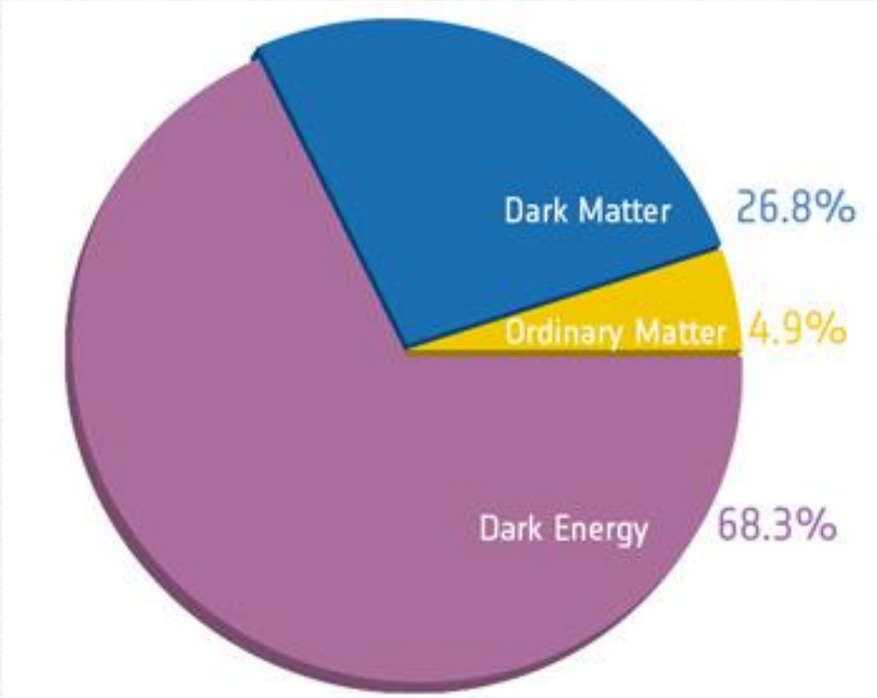
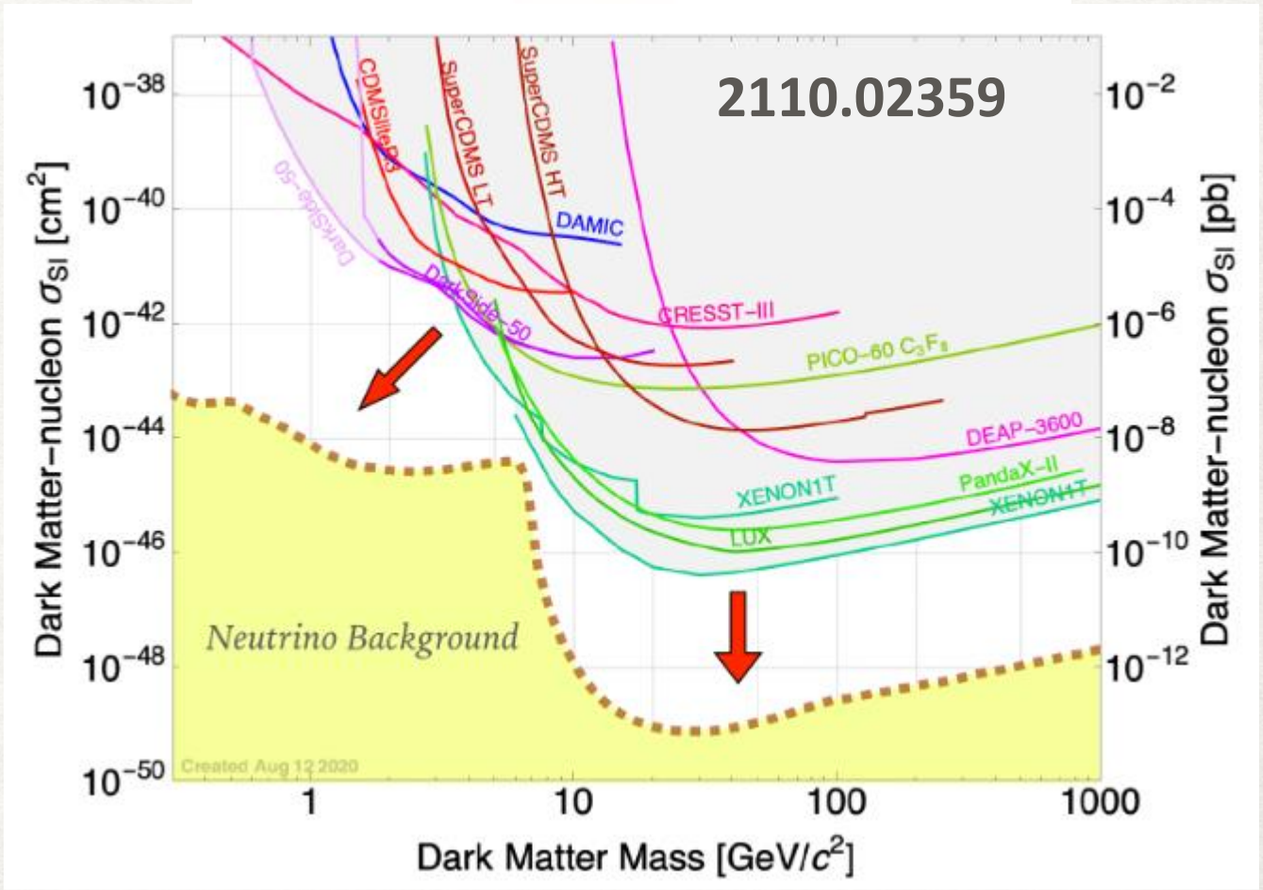
THE MOTIVATION

- The Standard Model (SM) has been very successful, but it does not have a particle dark matter (DM) candidate.
- WIMPs, the popular DM has been extensively searched for, but no positive signatures yet.
- It is motivating to consider scenarios, where DM interactions are weaker yet with complementary detection prospects.





THE FRAMEWORK

- We consider a scenario where DM mediates with the SM via superheavy mediators: naturally leading to weaker DM interactions.

- An Abelian gauge extended scenario can accommodate this possibility while ensuring DM stability simultaneously.

- As an illustrative example, we consider gauged B-L extension of SM.

	SU(3)	**SU(2)**	$\mathbf{U(1)_Y}$	$\mathbf{U(1)_{B-L}}$
Q_L	3	2	-1/6	1/3
u_R	3	1	2/3	1/3
d_R	3	1	-1/3	1/3
L	1	2	-1/2	-1
e_R	1	1	-1	-1
H_S	1	2	1/2	0
Φ	1	1	0	2
N_R	1	1	0	-1
χ	1	1	0	q_χ

Anomaly Free

Vector-like

Davidson 1979, Mohapatra & Marshak 1980

DM RELIC

- DM is produced thermally and freezes out by virtue of B-L interactions.

- DM gets thermally over-produced due to insuffic-ient annihilations media-ted by heavy B-L gauge boson.

- Correct DM relic is obtain-ed via late entropy injecti-on due to decay of one of the right handed neutrinos (RHN).

$$\mathcal{L}_{\rm fermion} = i\sum_{\kappa=1}^{3}\overline{N_{R_\kappa}}\not{D}(Q_\kappa^R)N_{R_\kappa} - \sum_{\substack{j=1\\ \alpha=e,\mu,\tau}}^{3} Y_D^{\alpha j}\ \overline{l_L^\alpha}\tilde{H}_{\rm S}N_R^j$$

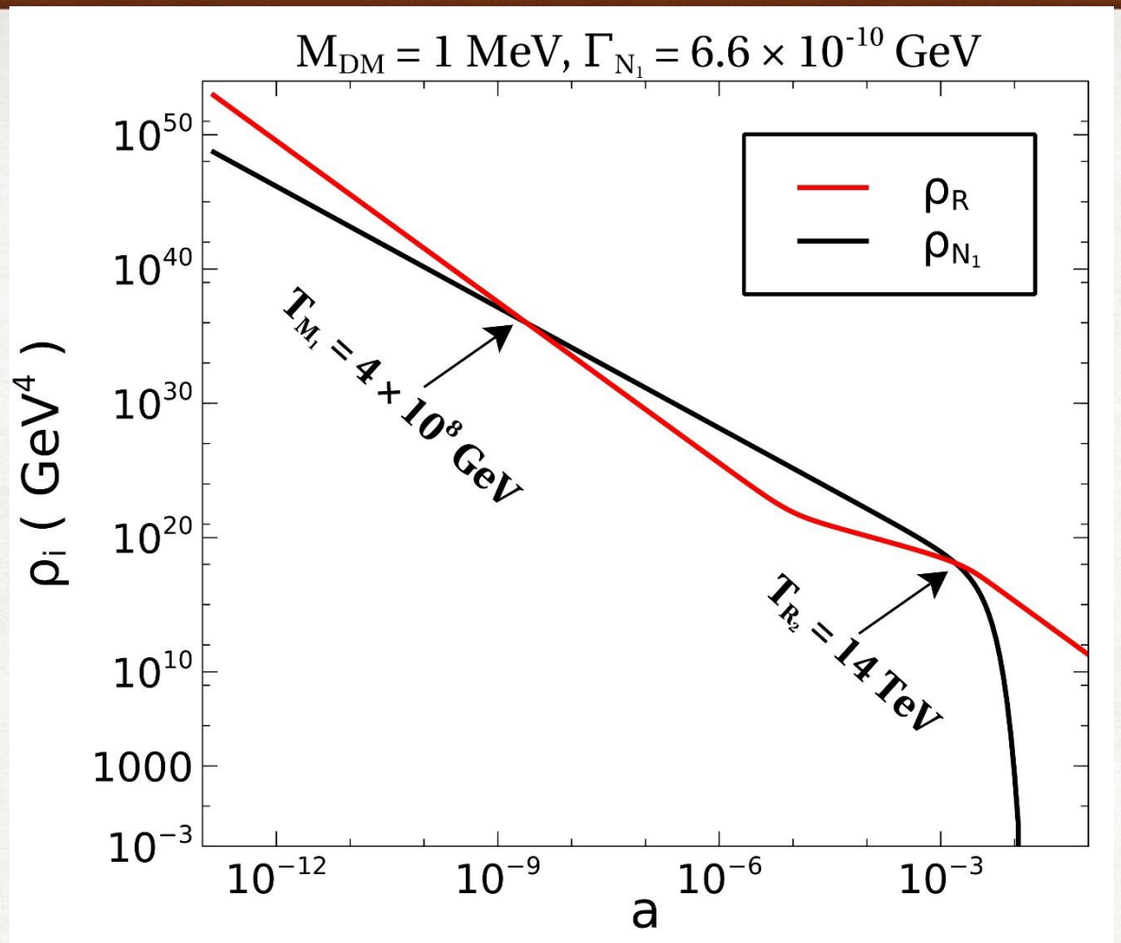
$$- \sum_{i,j=1}^{3} Y_{N_{ij}}\Phi\ \overline{N_{R_i}^C}N_{R_j} + \overline{\chi}\gamma^\mu(\partial_\mu + ig_{BL}q_\chi Z_{BL_\mu})\chi$$

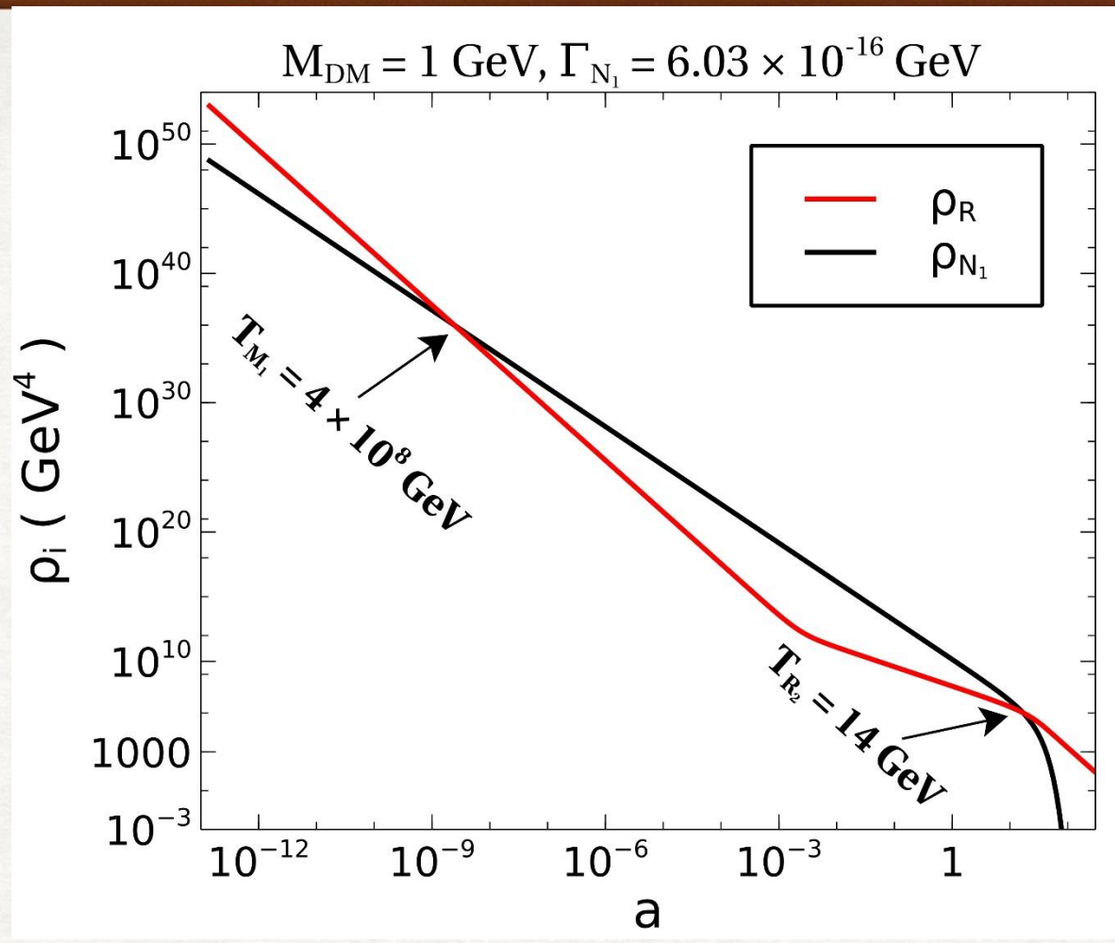
$$\frac{dE_\chi}{da} = \frac{\langle\sigma v\rangle_\chi}{Ha^4}\left((E_\chi^{\rm eq})^2 - E_{N_\chi}^2\right),$$

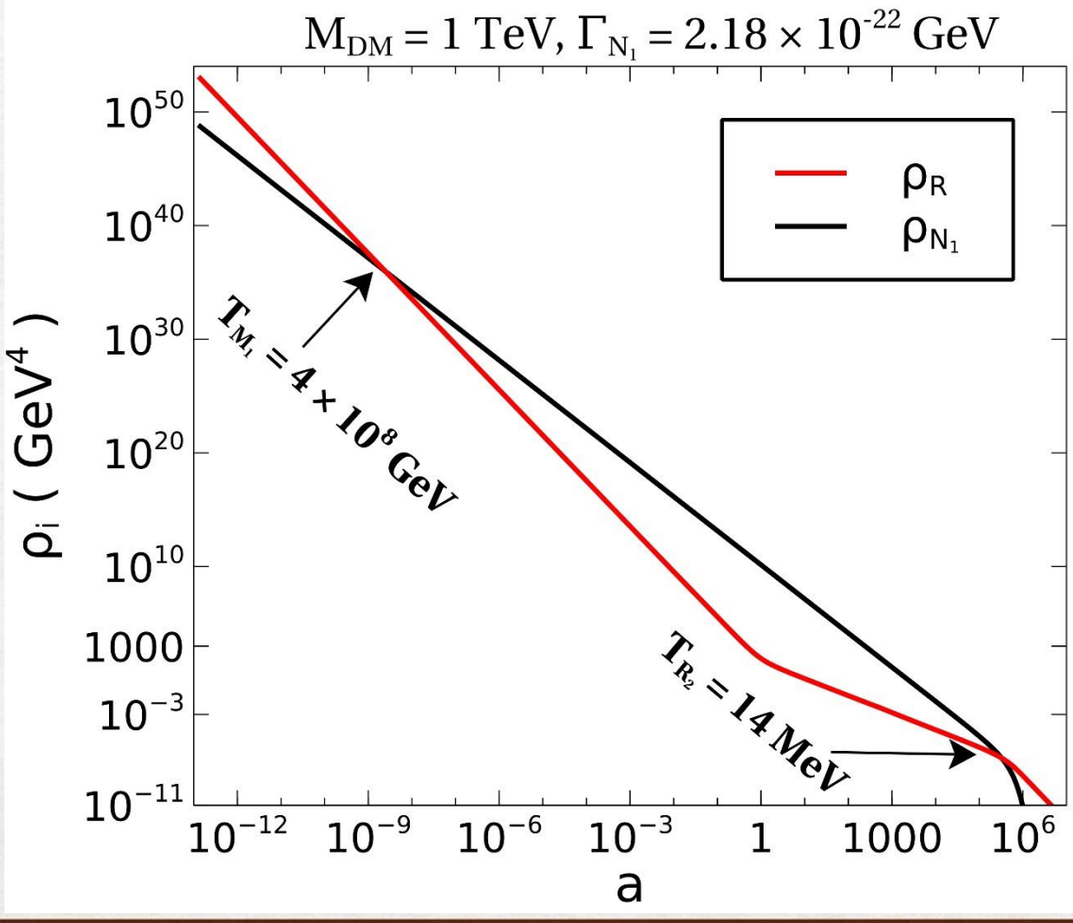
$$\frac{dE_{N_3}}{da} = \frac{\langle\sigma v\rangle_3}{Ha^4}\left((E_{N_3}^{\rm eq})^2 - E_{N_3}^2\right) - \frac{\Gamma_{N_3}}{Ha}E_{N_3},$$

$$\frac{dT}{da} = \left(1 + \frac{T}{3g_{*s}}\frac{dg_{*s}}{dT}\right)^{-1}\left[-\frac{T}{a} + \frac{\Gamma_{N_3}M_{N_3}}{3H\ s\ a^4}E_{N_3}\right]$$

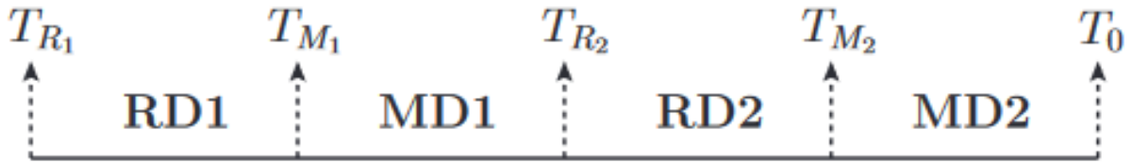
Scherrer & Turner 1985



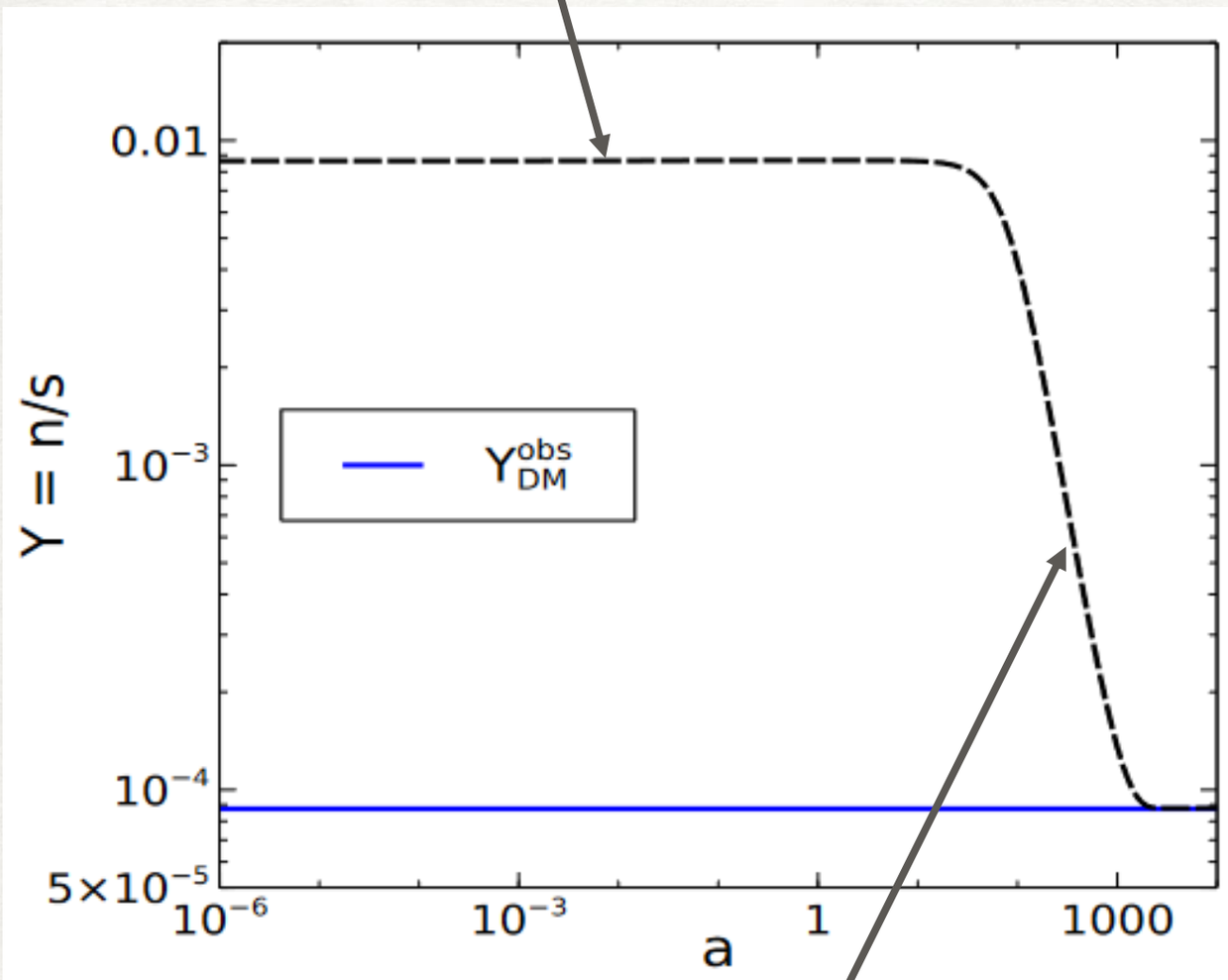


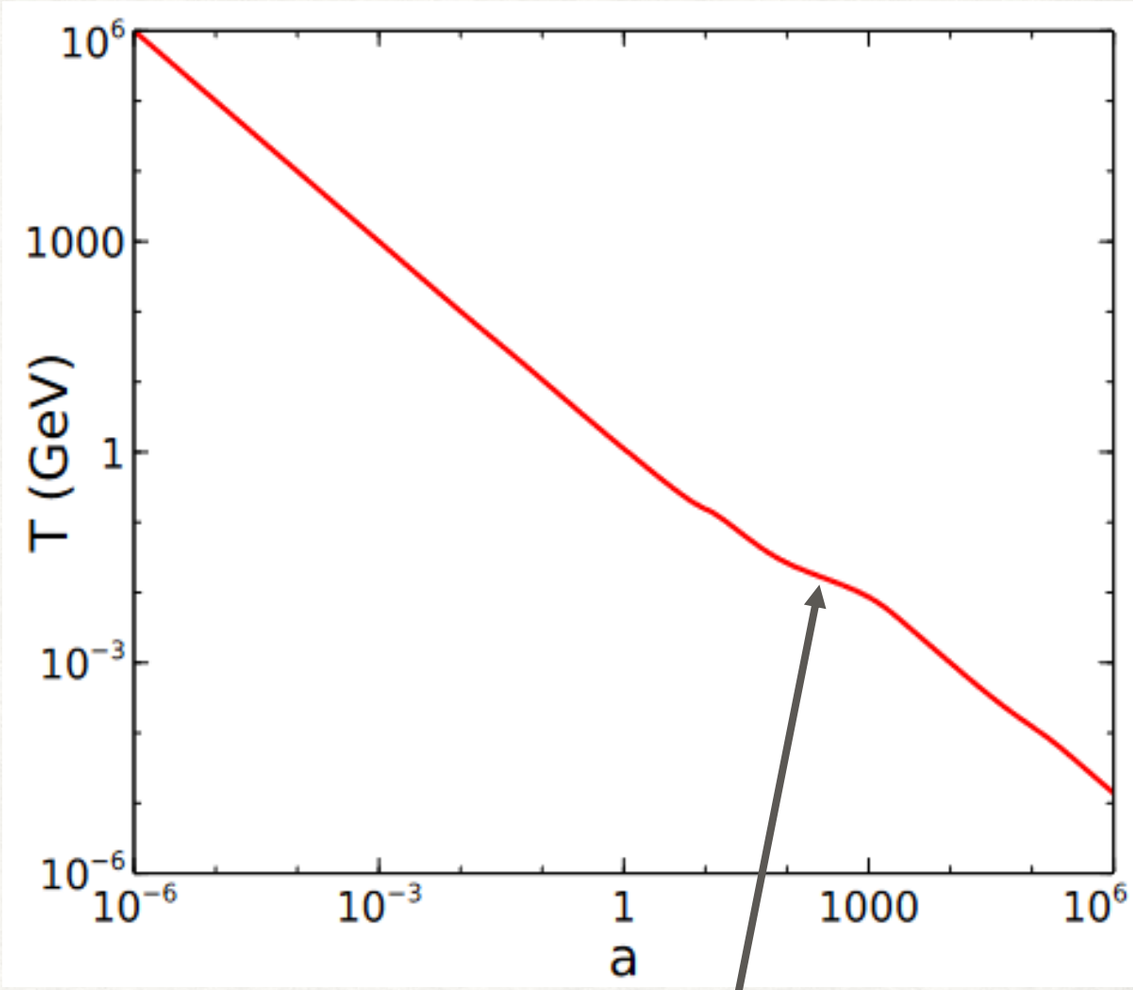


Naturally leads to non-standard cosmological history with early matter domination due to long-lived diluter



Thermally overproduced

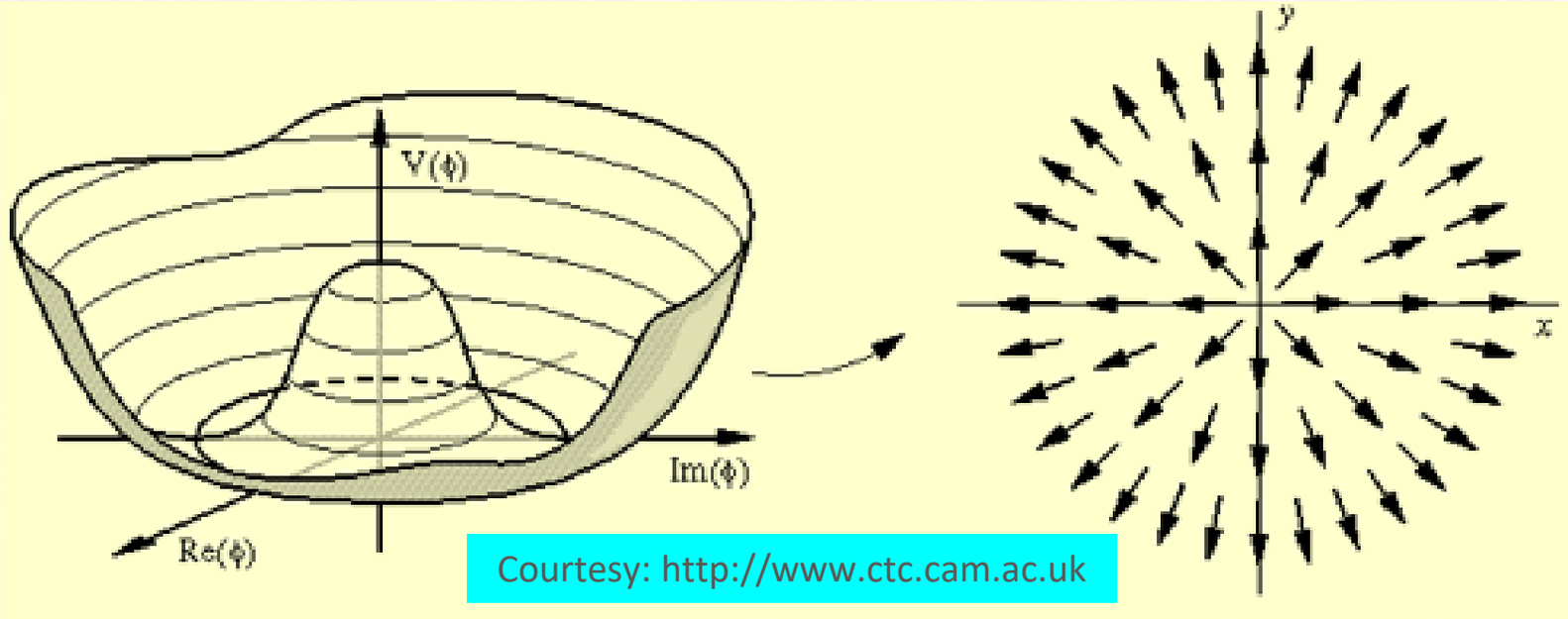




Entropy dilution

Entropy injection

COSMIC STRINGS FROM U(1) BREAKING



Courtesy: http://www.ctc.cam.ac.uk

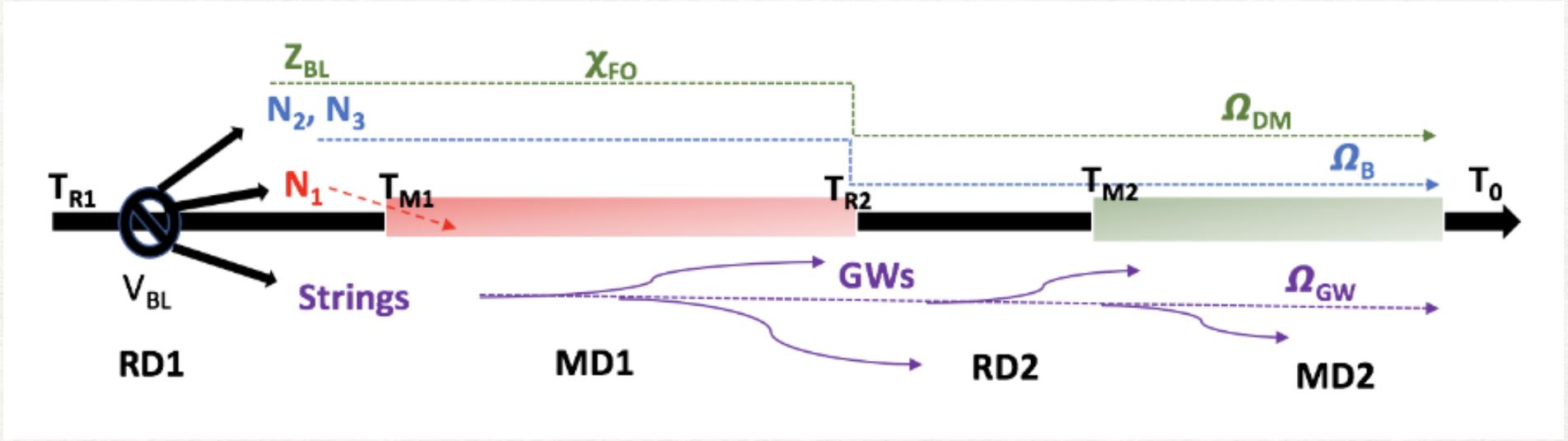
- Spontaneous breaking of U(1) can produce cosmic strings (Nielsen, Olesen 1973; Kibble 1976) which can emit GW with a characteristic spectrum (LISA Cosmology WG, arxiv:1909.00819).

- There have been some recent proposals to probe Superheavy DM which acquire mass from a high scale U(1) symmetry breaking using GW spectrum emitted from cosmic strings (see, for example, arxiv: 2107.13112).

- However, the characteristic GW spectrum from cosmic strings can arise without DM too: need some stronger connection!

- We, therefore, consider a scenario where the mechanism which guarantees correct DM abundance also leaves imprint on the GW spectrum generated by cosmic strings.

- In our setup, late entropy release required for correct DM relic, causes distortions in GW spectral shapes generated by cosmic strings.

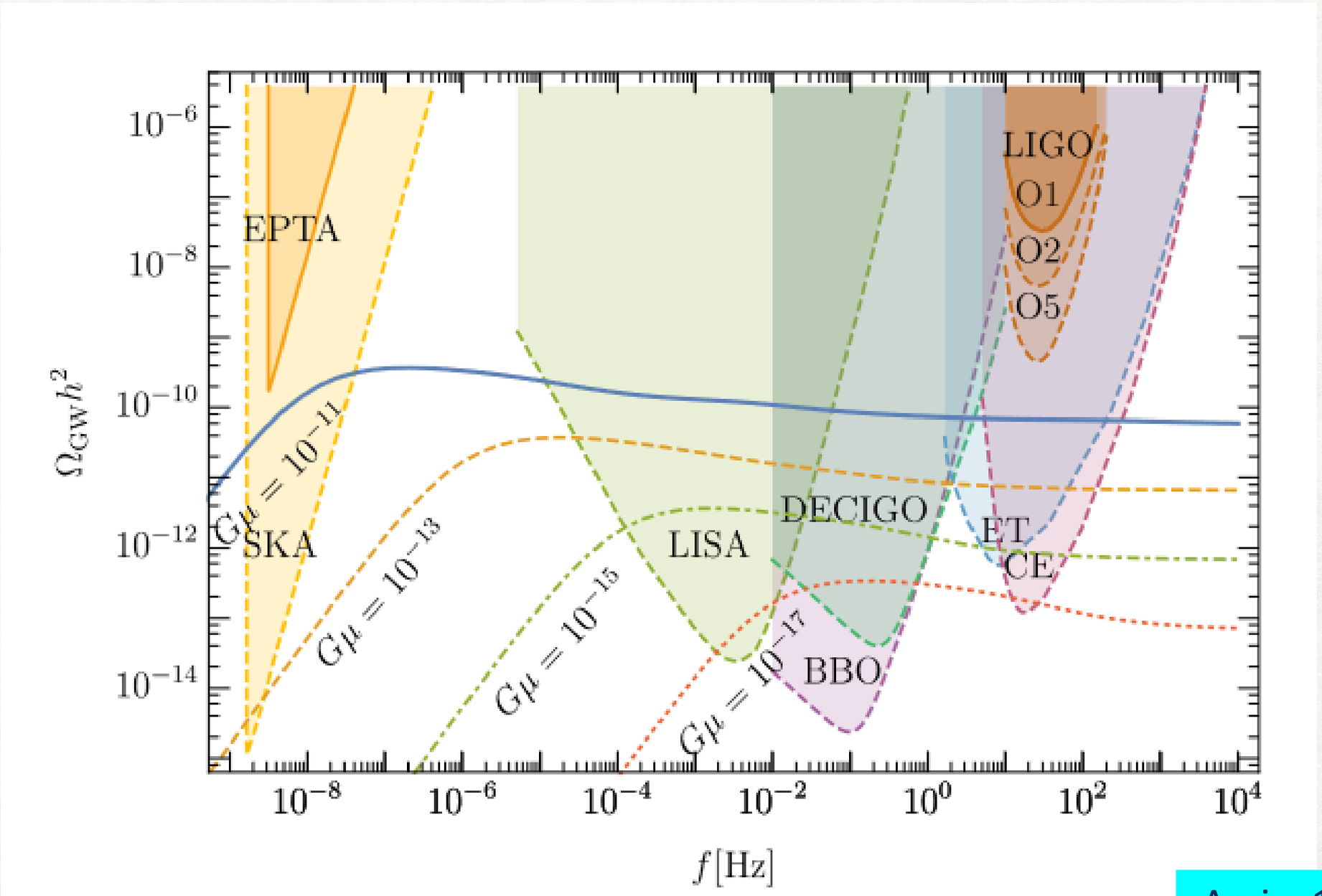


CHARACTERISTIC GW SPECTRUM

FROM COSMIC STRINGS

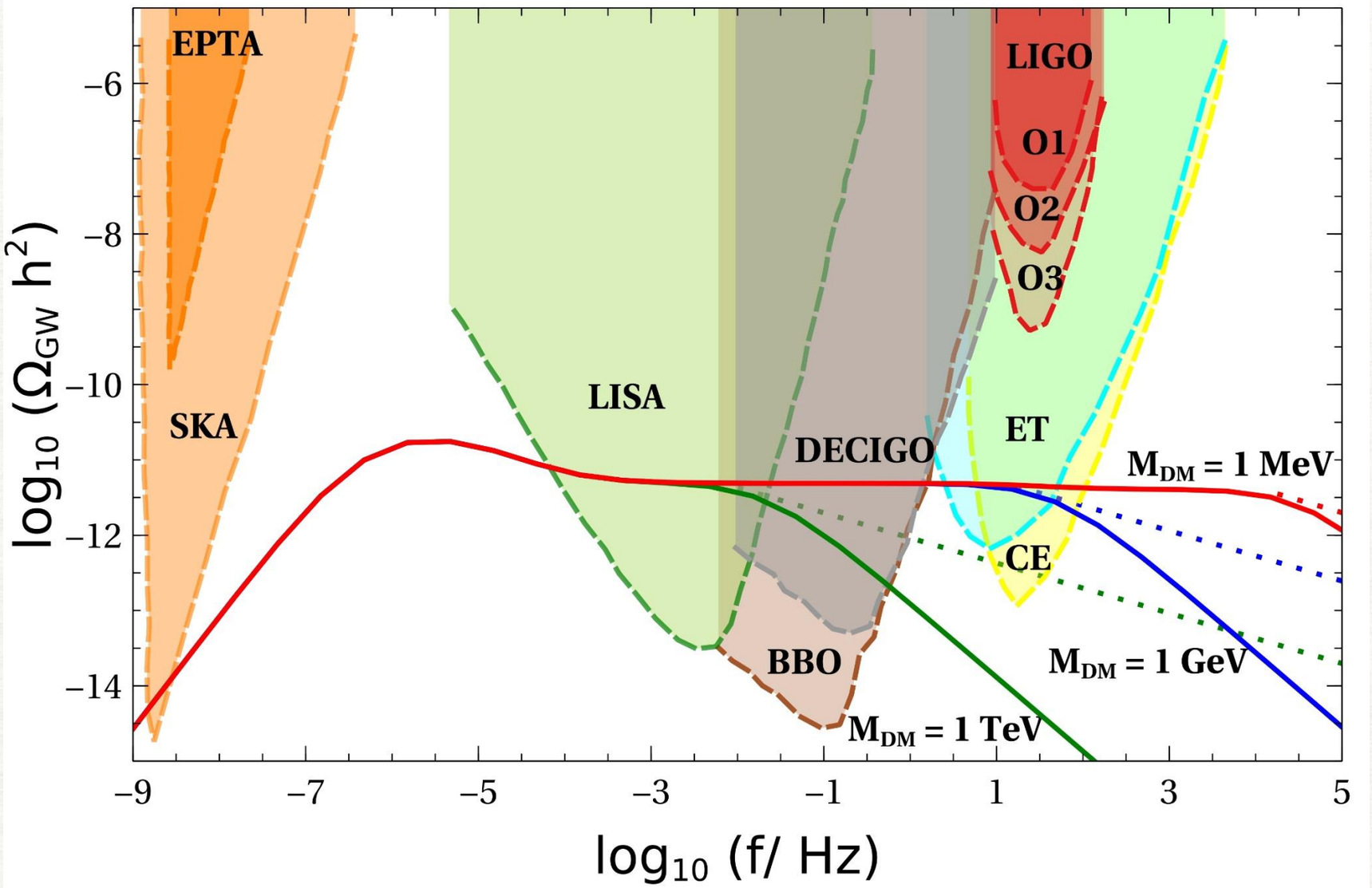
$$\Omega_{GW}^{(k=1)}(f) = \frac{128\pi G\mu}{9\zeta(\delta)} \frac{A_r}{\epsilon_r} \Omega_r \left[(1+\epsilon_r)^{3/2} - 1\right]$$

For $\epsilon_r = \frac{\alpha}{\Gamma G\mu} \gg 1, \Omega_{GW}^{k=1}(f) \approx \Lambda_{CS}$



Arxiv: 1808.08968

GW SPECTRUM WITH DM



$$f_\Delta = \sqrt{\frac{8}{\alpha\Gamma G\mu}} t_\Delta^{-1/2} t_0^{-2/3} t_{\rm eq}^{1/6}$$

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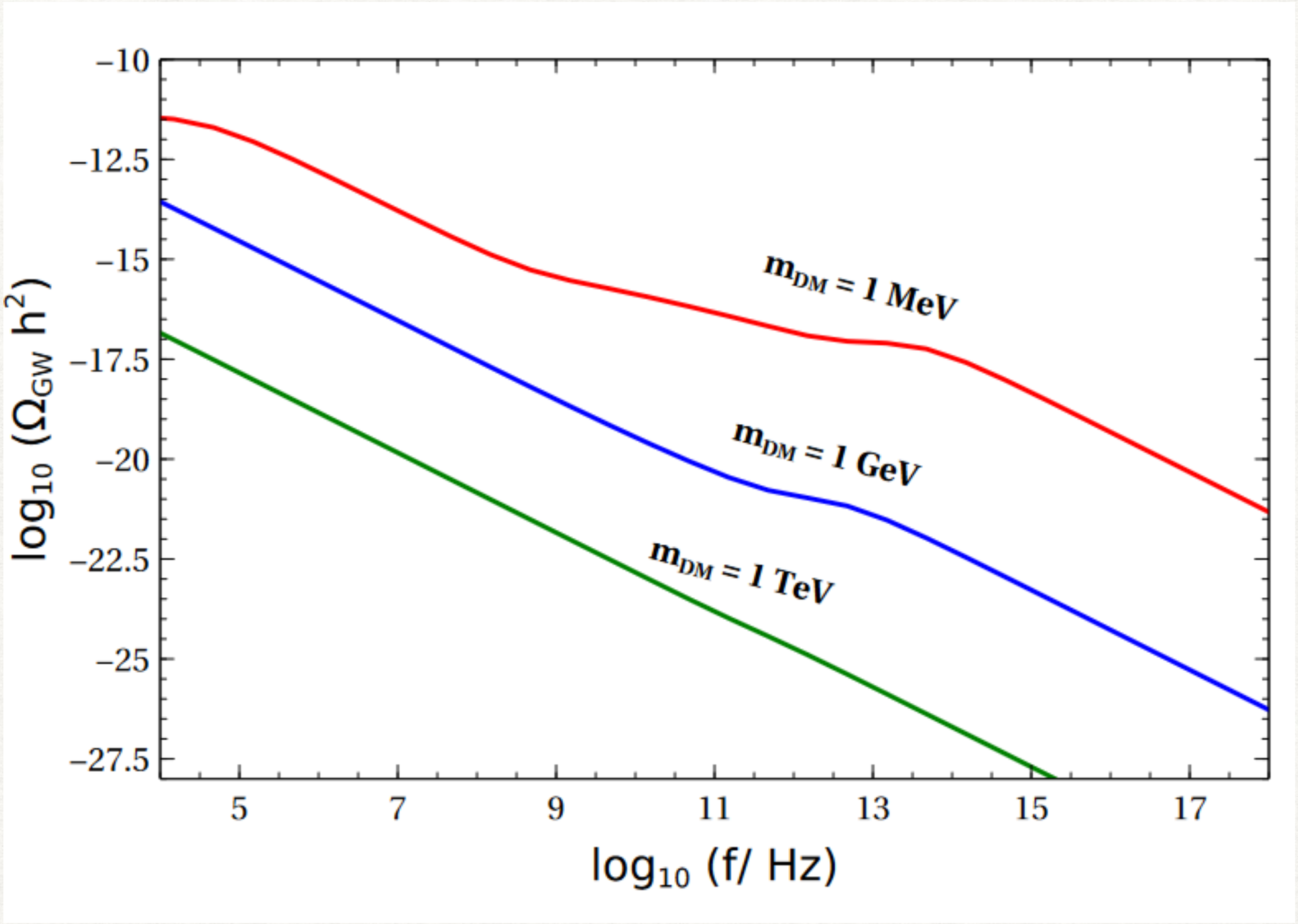

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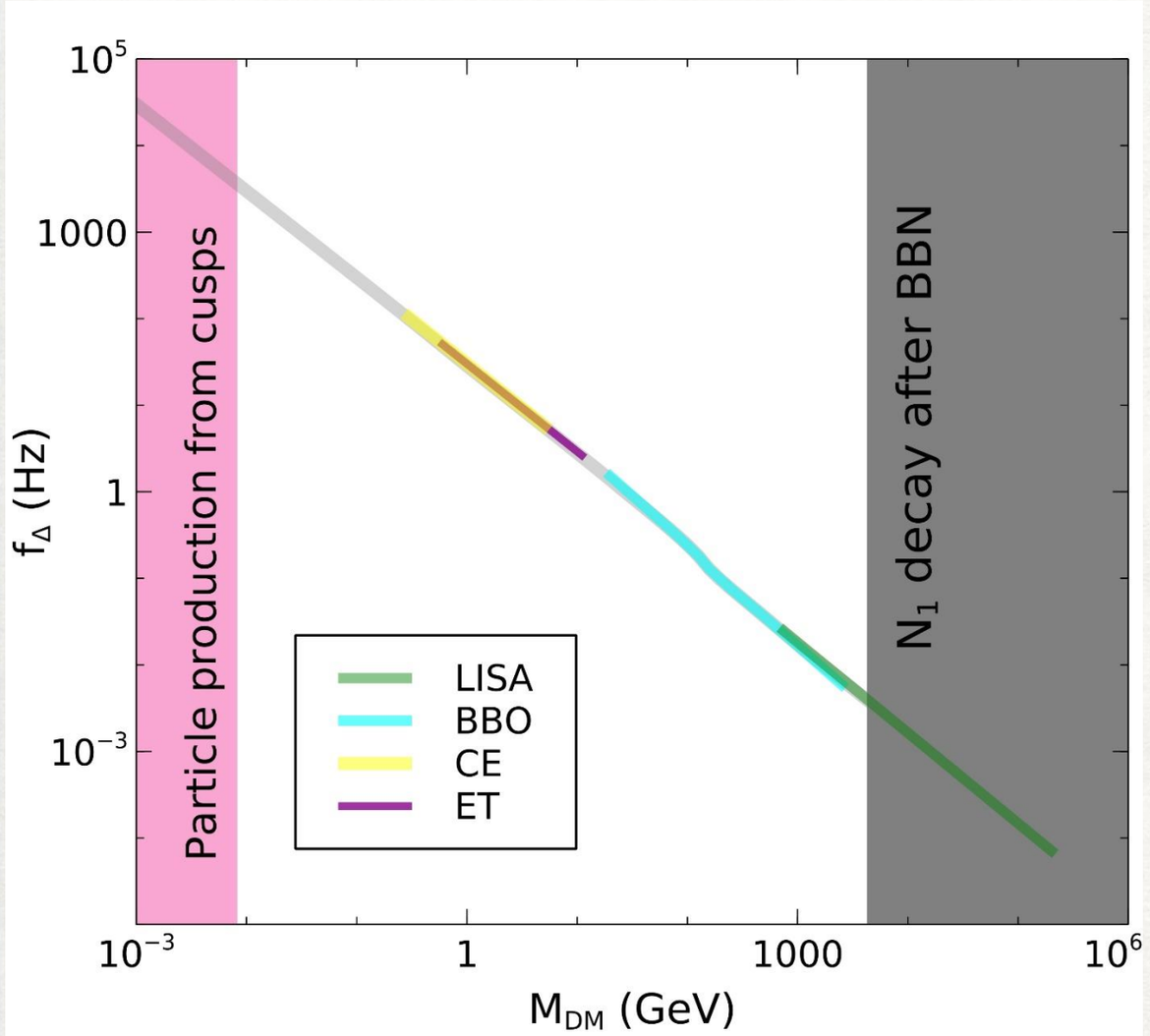

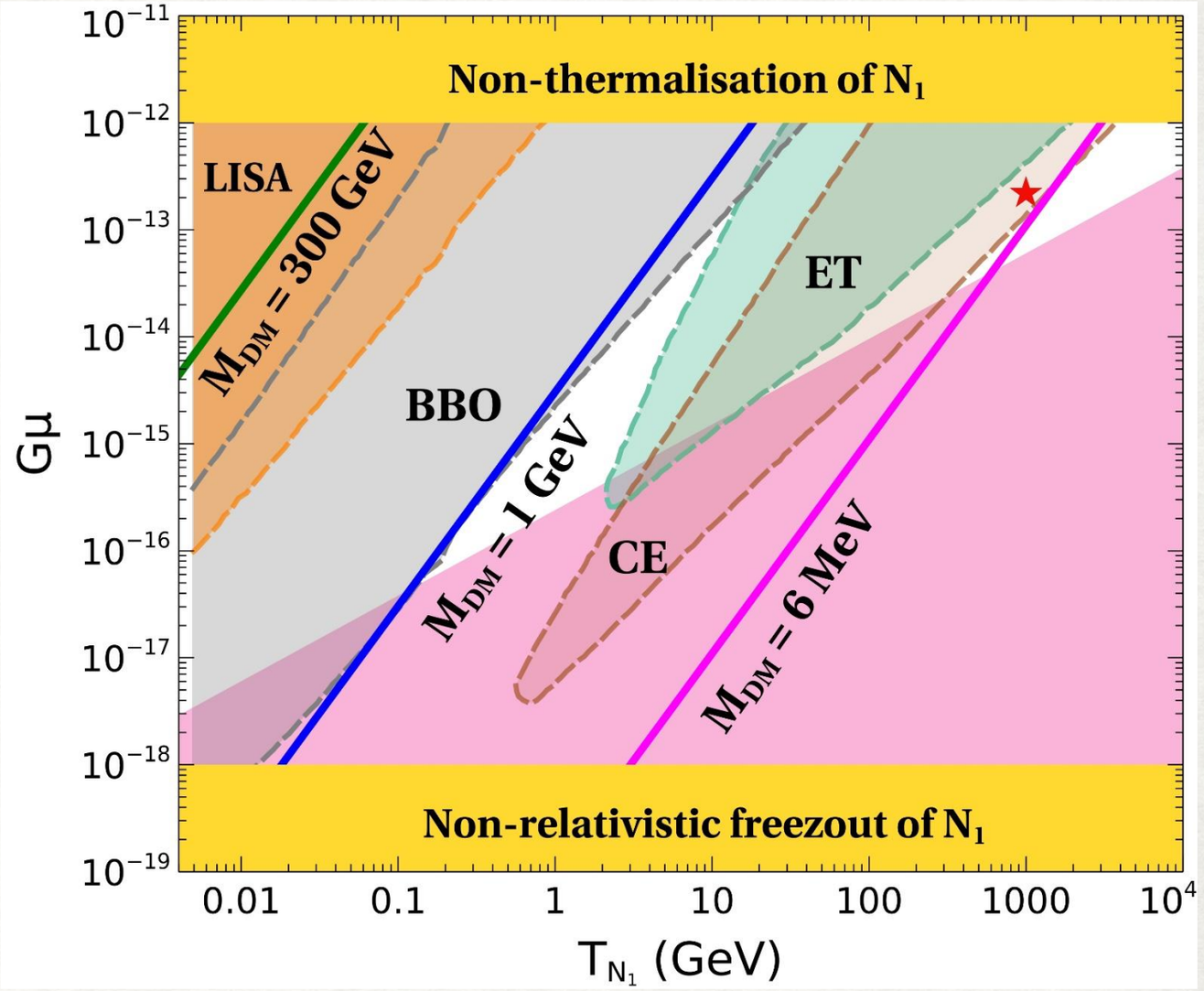

★ A benchmark consistent with successful leptogenesis.

DB, Das, Saha, Samanta'22

CONCLUSION

- *Miracle-less* WIMPs have weaker interaction rates which can be mediated by superheavy gauge bosons.
- Thermally overproduced relic can be brought within limits via late entropy dilution. Gauged B-L model naturally accommodates this.
- High scale B-L breaking can lead to observable GW background (with a scale invariant spectrum) from cosmic strings which form as a result of such symmetry breaking.
- Early matter domination due to the diluter creates GW spectral distortions at high as well as low frequencies: one of which remain within near future experimental reach.
- The model predicts vanishing lightest neutrino mass, can be falsified at tritium beta decay or neutrinoless double beta decay experiments.

THANK YOU FOR YOUR ATTENTION