Some scenarios and cosmological probes in BSM physics

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6/July/2023

Outline

- Some puzzles:
  what does constitute our universe?
  & some questions in particle physics

- Some stories from smallness: B-L model and axion

- Some cosmological Probes: CMB & GW

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Connection btw particle physics and cosmology

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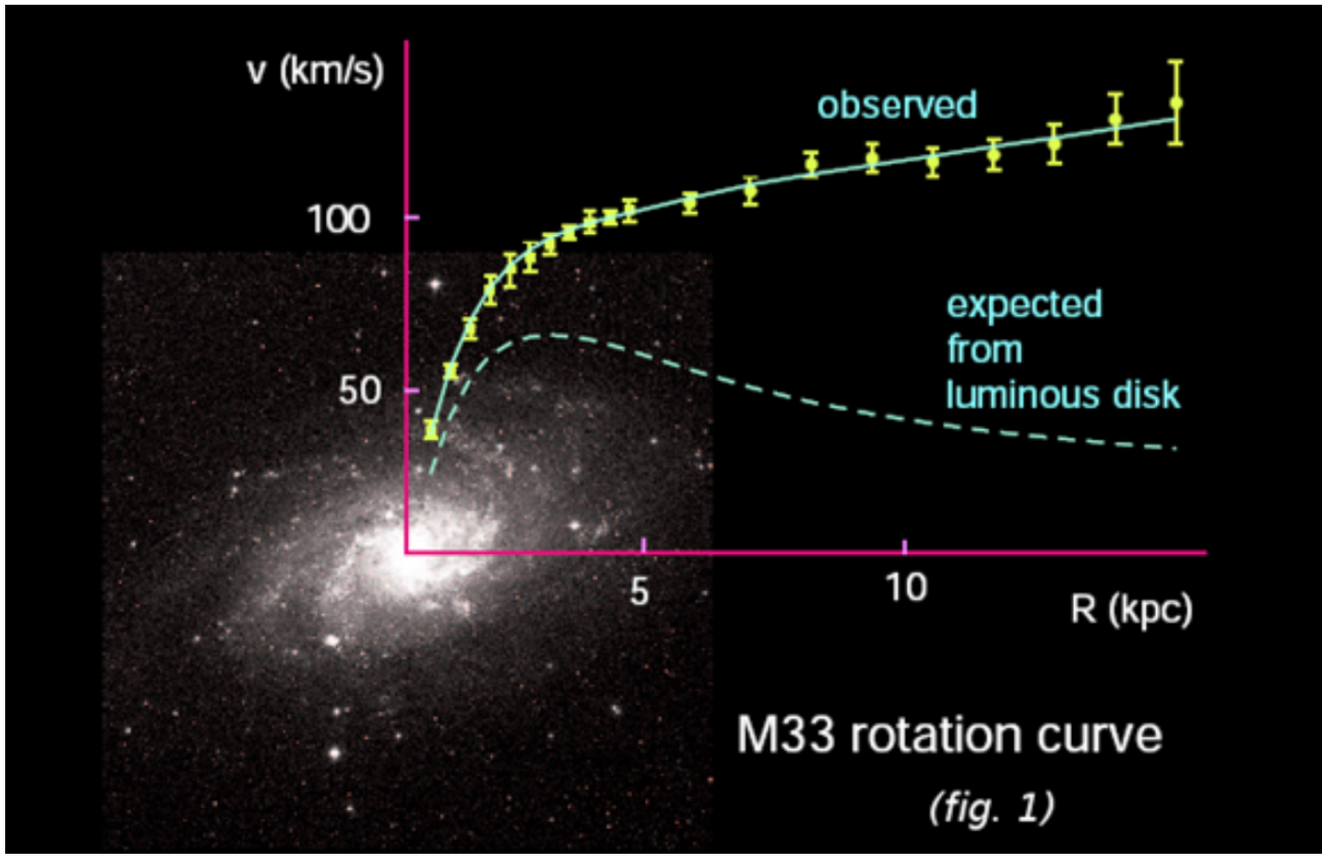
Will be very conceptual and very pictorial

Some puzzles - dark matter

- Rotation curve on galaxy, gravitational lensing by clusters, etc
  → deficit of mass (when only visible objects are counted)
  → presence of dark matter



Some puzzles - dark energy

- Observation of flux from SN (standard candle with known L)

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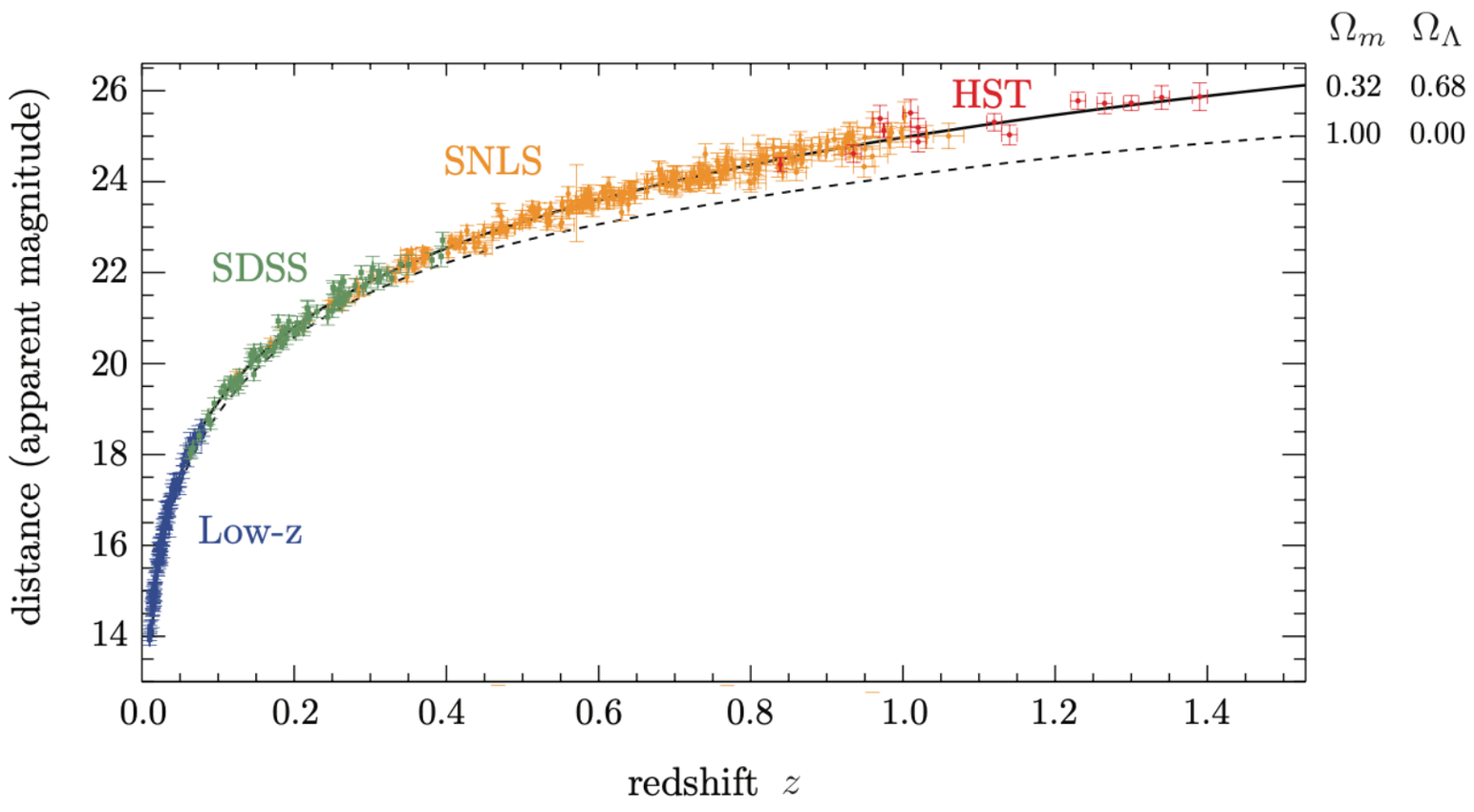

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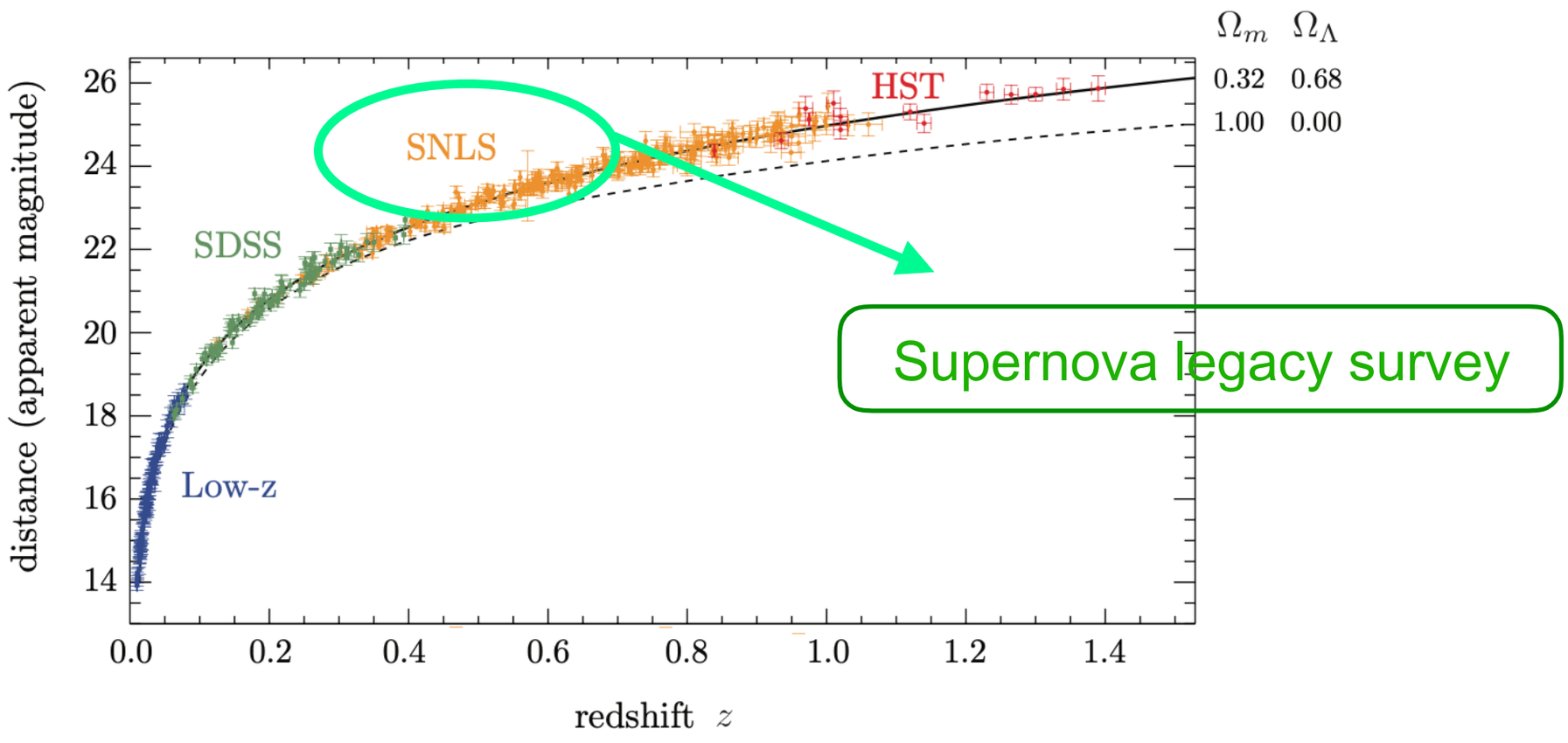

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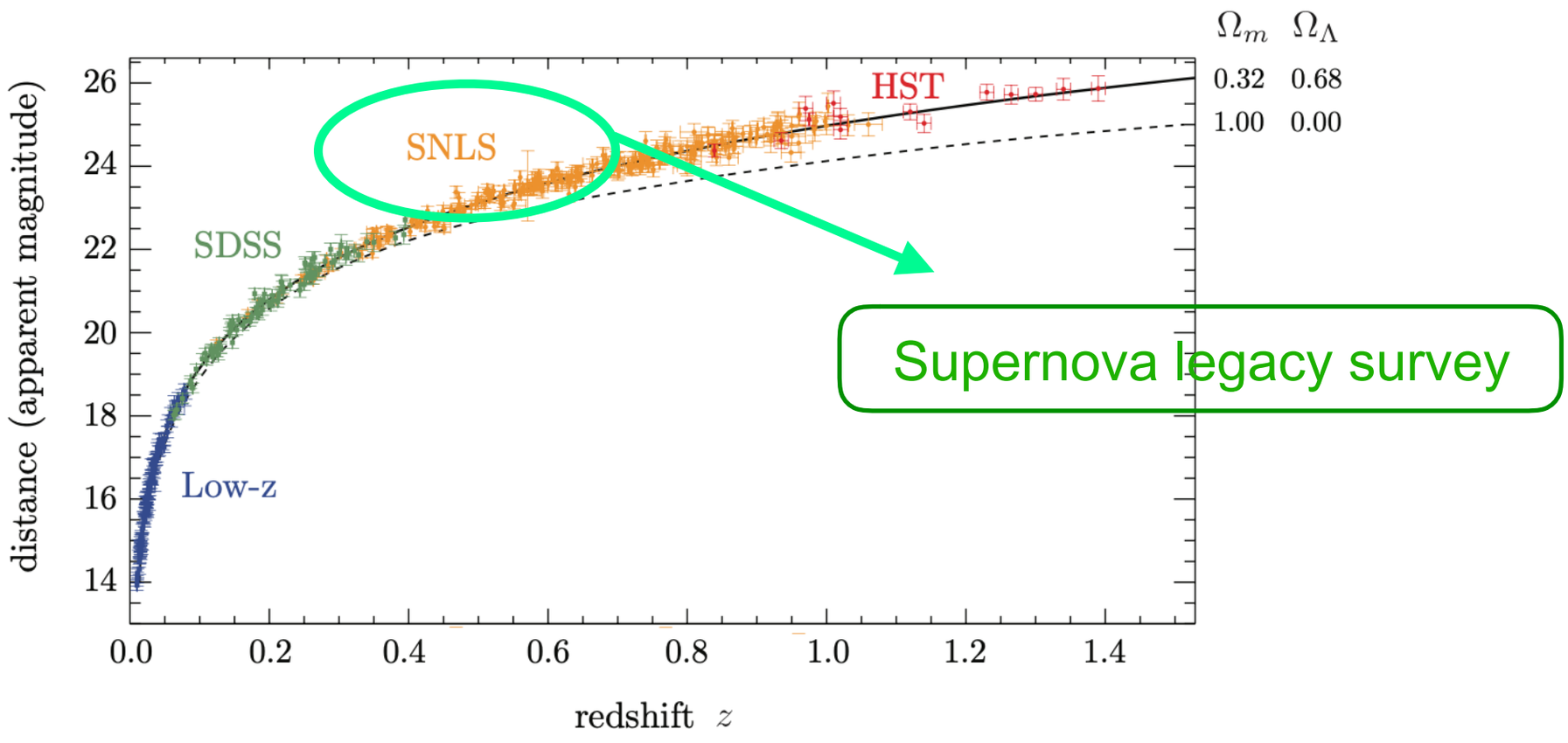
→ DM~30% and DE~70%



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- Strategy
  → one or two problems in particle physics
  & DM candidate or DE candidate simultaneously?

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B-L Model

Axion

Why so small? - ν mass

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Dark Matter Candidates in B-L models

- Additional gauge symmetry on top of SM gauge group?
  → $U(1)_{B-L}$
  → With 3 RH neutrinos, can be gauged!

- 3 RH neutrinos → 1. need for tiny active neutrino mass (seesaw mechanism)

$$\mathcal{L} \sim -\frac{1}{2}\begin{pmatrix}\overline{\nu_L} & \overline{\nu_R^c}\end{pmatrix}\begin{pmatrix}0 & m_D\\ m_D & M\end{pmatrix}\begin{pmatrix}\nu_L^c\\ \nu_R\end{pmatrix} \qquad m_\nu \approx \frac{m_D^2}{M} \qquad m_N \approx M$$

- 3 RH neutrinos → 2. the out-of-equilibrium decay of RH neutrinos (leptogenesis ΔL)
  → ΔL conversion to ΔB at EWPT by sphaleron transition
  → can explain baryon asymmetry

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No role in leptogenesis and m_ν!

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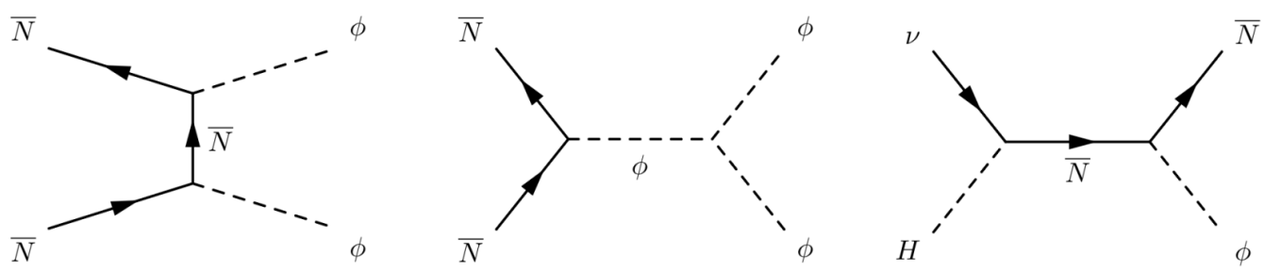

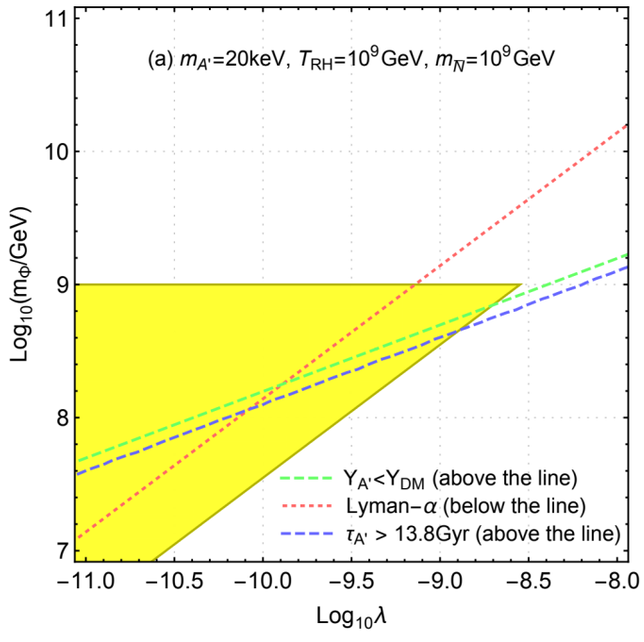

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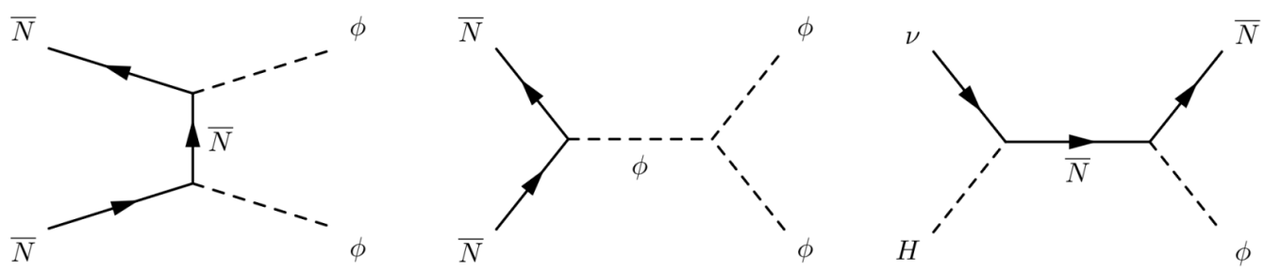

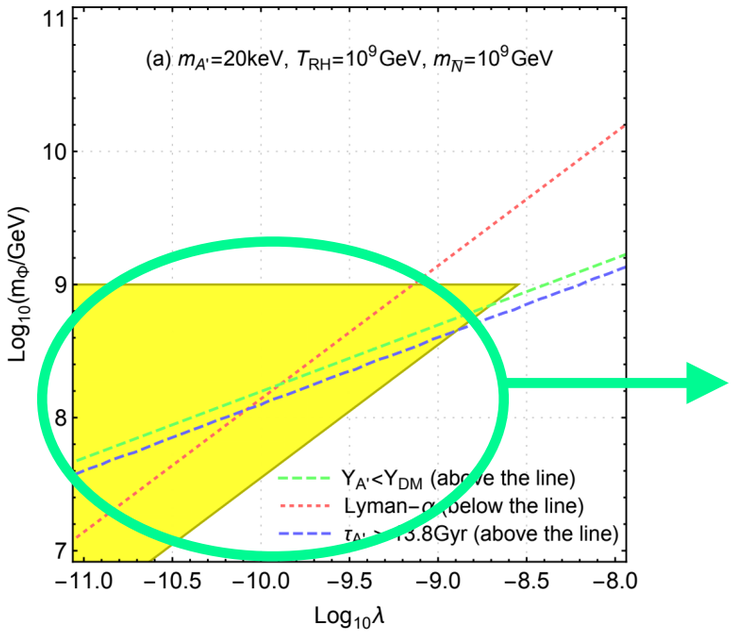

Production of Φ → Φ become non-rel
→ Φ decays to A'
→ A' free-stream to become DM

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1 RH neutrinos can be DM

Dark Matter Candidates in strong CP problem

- Non-zero neutron EDM → CP violation

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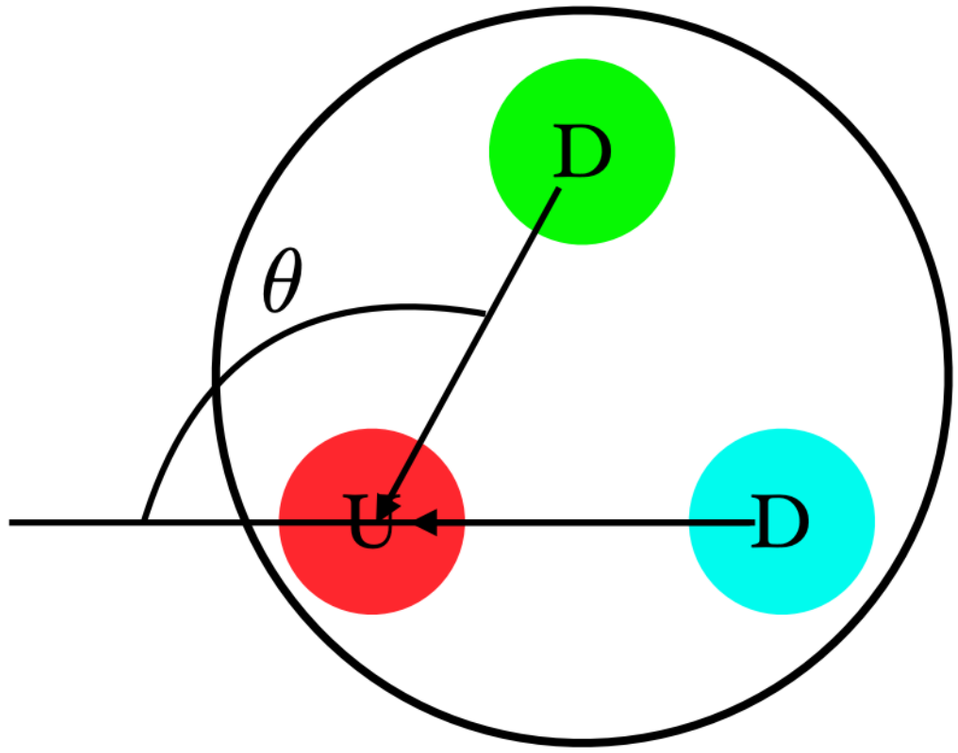

$$\vec{d} = \sum q\vec{r}. \qquad |d_n| \approx 10^{-13}\sqrt{1-\cos\theta}\, e\,\mathrm{cm}$$

From A. Hook's lecture note (1812.02669)

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- In QCD, we have ~θ F Λ F
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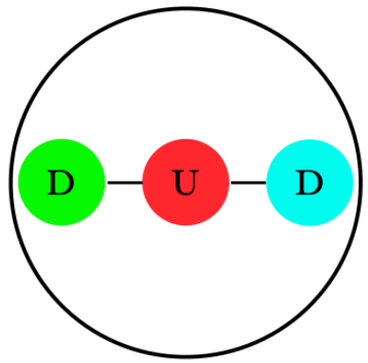

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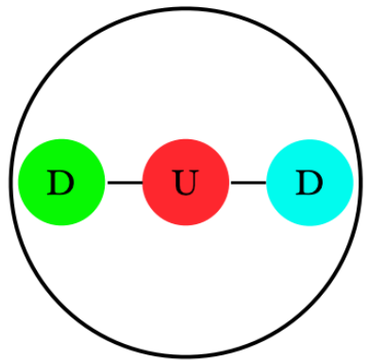

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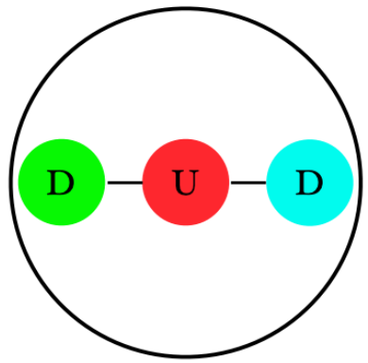

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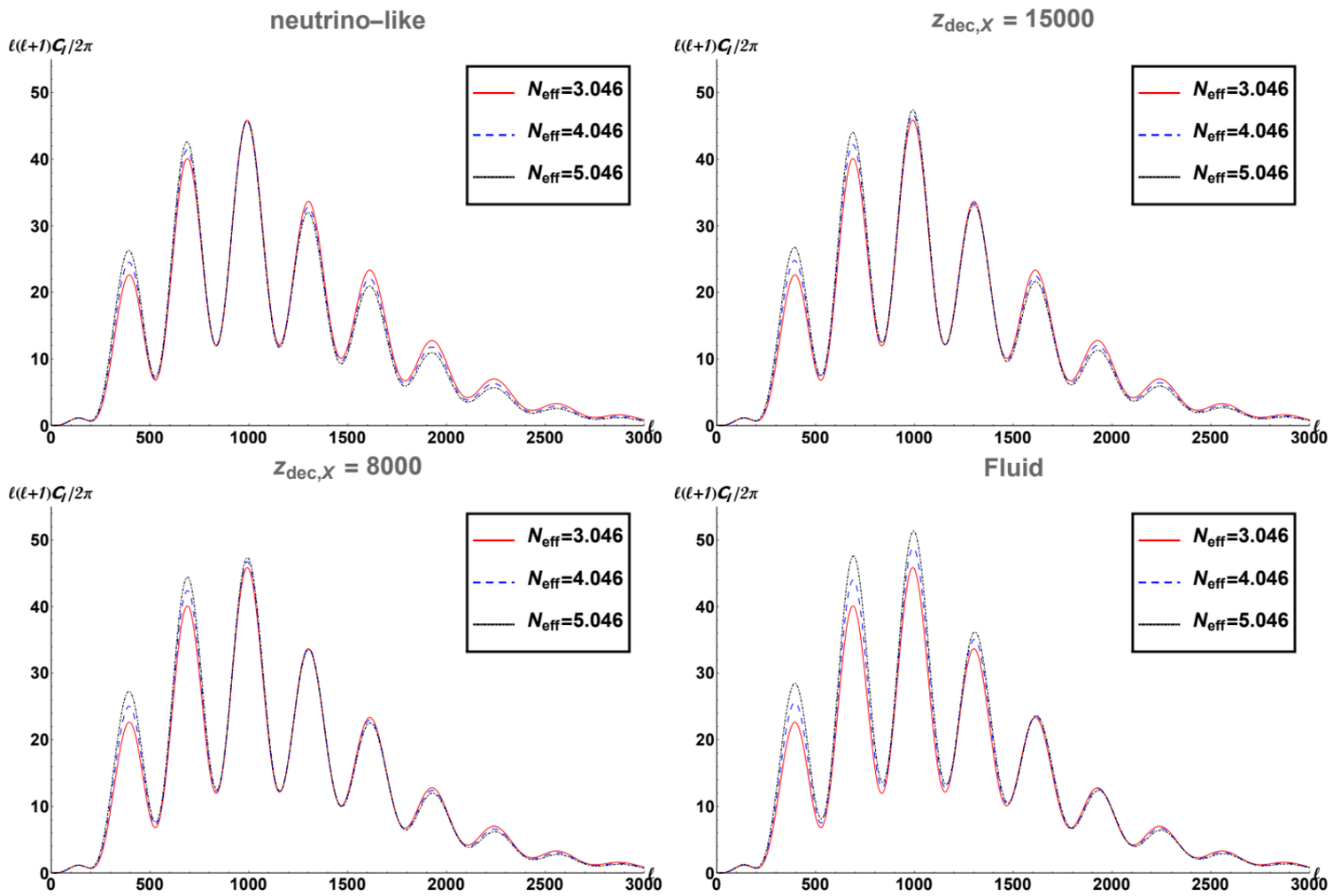
- Axion (PQ mechanism) dynamically relaxes the angle.
  → good candidate for dark matter!
  → axion energy density ~ a^{-3}

Axion as dark energy?

- $w = P/\rho = (KE\text{-}PE)/(KE+PE) \rightarrow -1$ for DE $\rightarrow$ KE~0
- If $m_q \sim H_0 \sim 10^{-33}$eV, then slow-roll today $\rightarrow$ KE~0
- Axion with $f_q \sim M_P$ can be DE
  $\rightarrow \Lambda_{DE}^2 = (2\text{meV})^2 \sim m_q f_q$
- Why so small mass?
- $\Lambda_{DE}^4 \sim (2\text{meV})4 \sim M_P^4 10^{-120}$
- For $SU(2)_L$ in SM,
  $\Lambda_a^4 \sim M_P^4 e^{-S_{inst}} \rightarrow M_P^4 e^{-(-2\pi/(1/44))} \rightarrow M_P^4 10^{-130}$

Probing dark radiation using CMB power spectrum

- Different decoupling time t_d
  → CMB phase shift at a horizon scale at t_d



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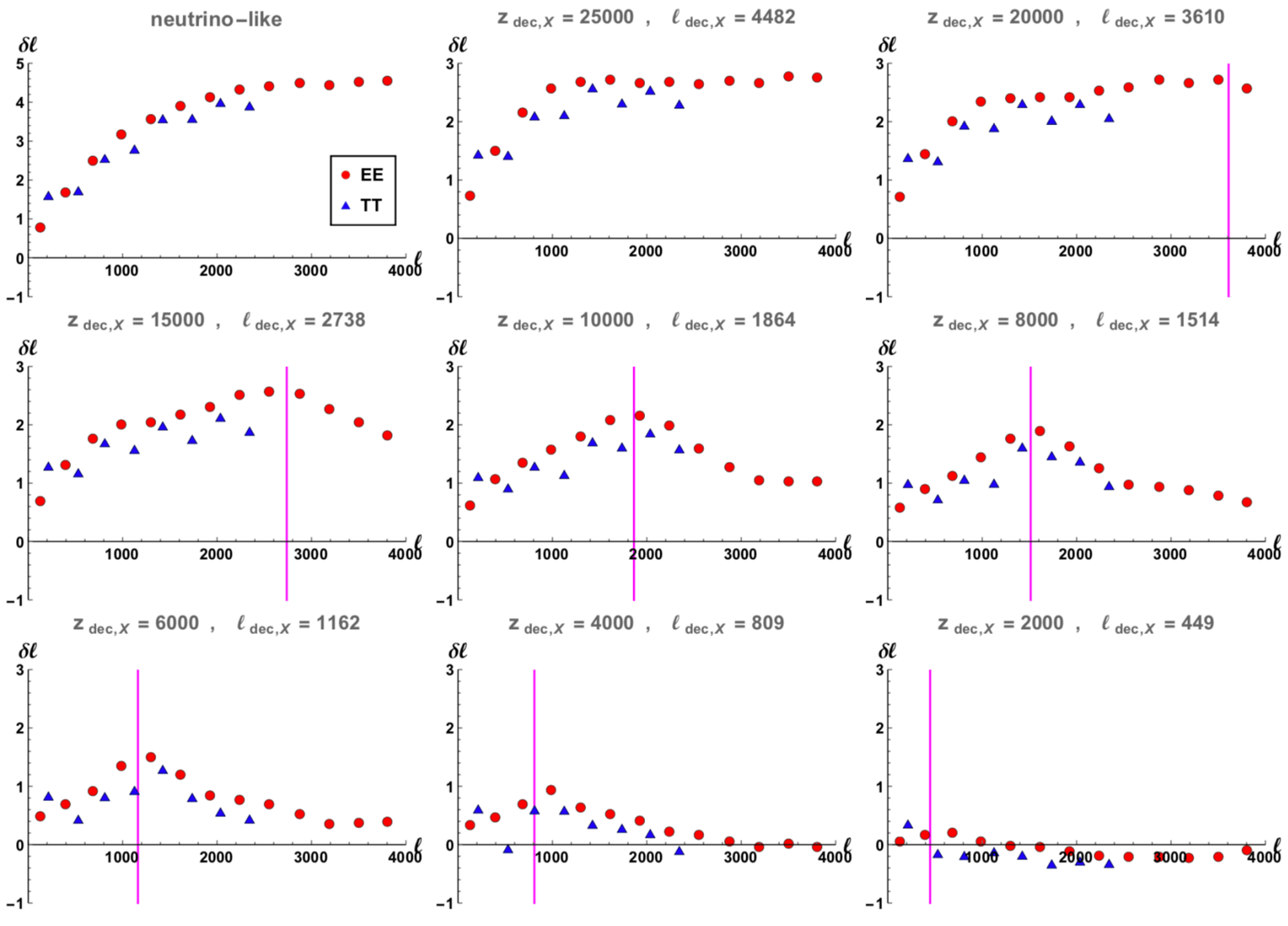

Probing BSM with GW

- Probing PeV-SUSY breaking ($m_{3/2}$~100eV-1keV)
  → too much gravitinos

$$\omega_{3/2} \equiv \Omega_{3/2} h^2 = \left(\frac{T_{3/2,0}}{T_{\nu,0}}\right)^3 \left(\frac{m_{3/2}}{94\mathrm{eV}}\right)$$
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→ Q. how to probe?

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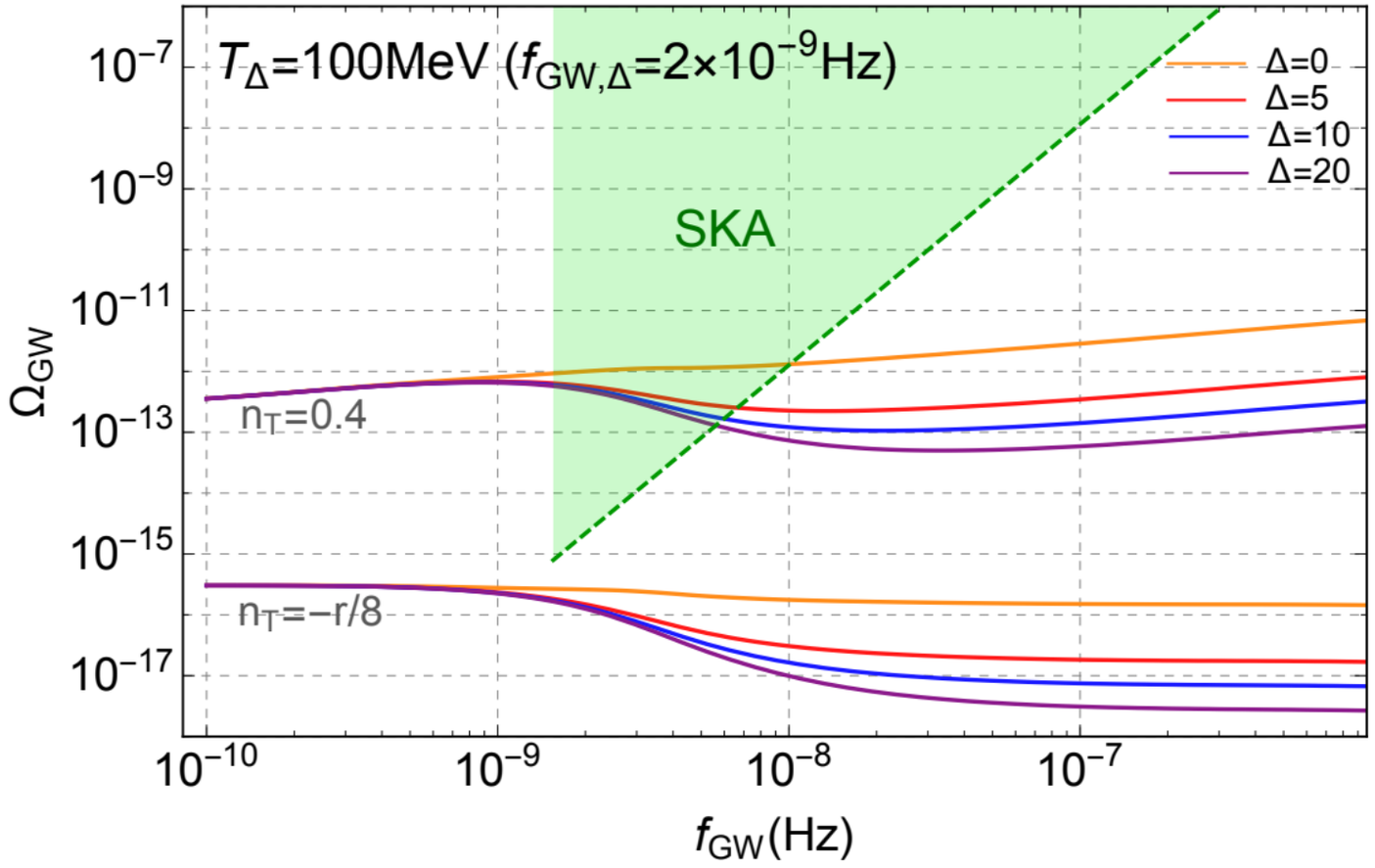
  → suppression of inflationary GW spectrum



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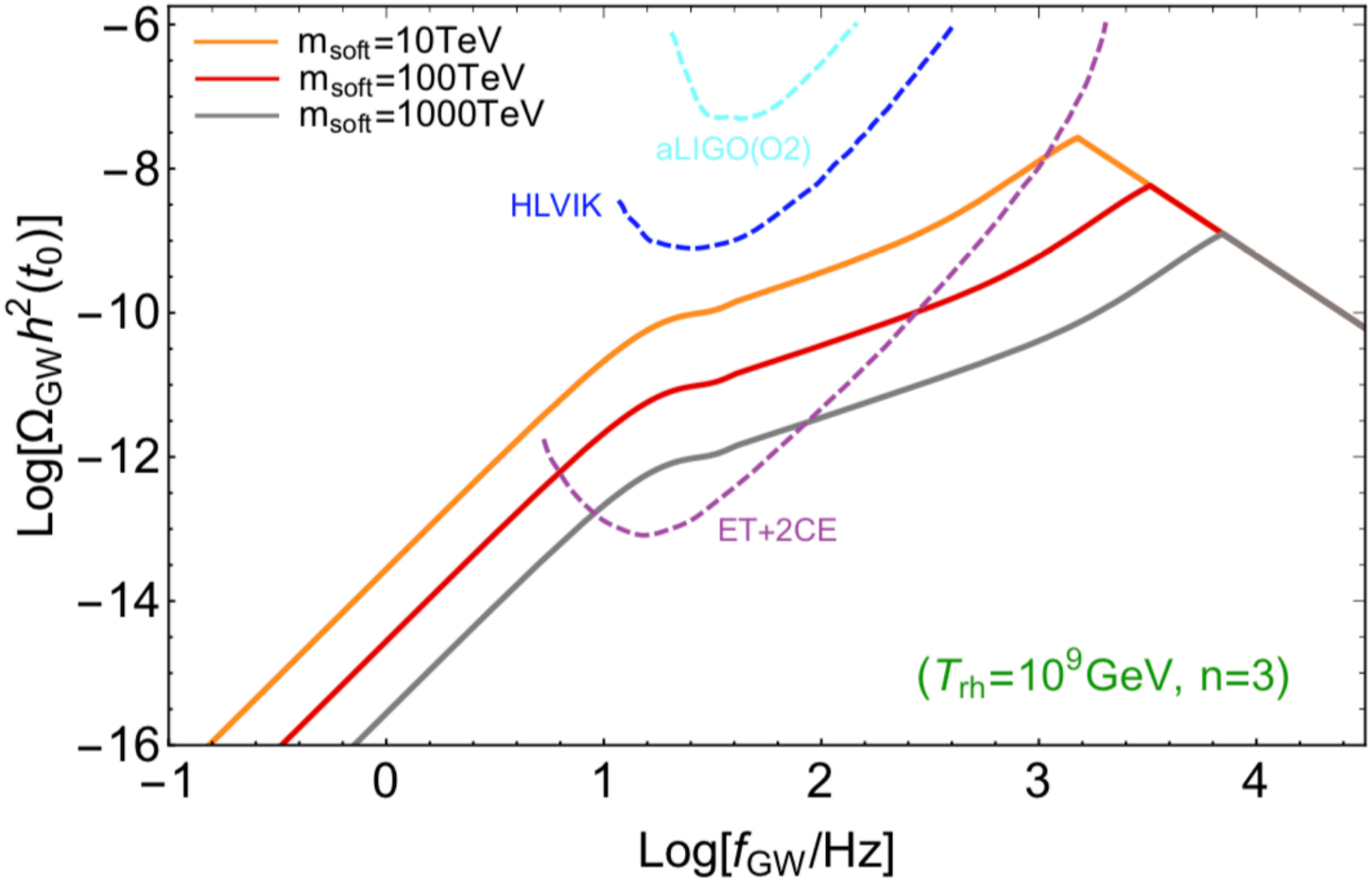

Probing BSM with GW

Higher $m_{3/2}$ → higher $\langle\chi\rangle$
→ more time for CS to decay
→ more dilution

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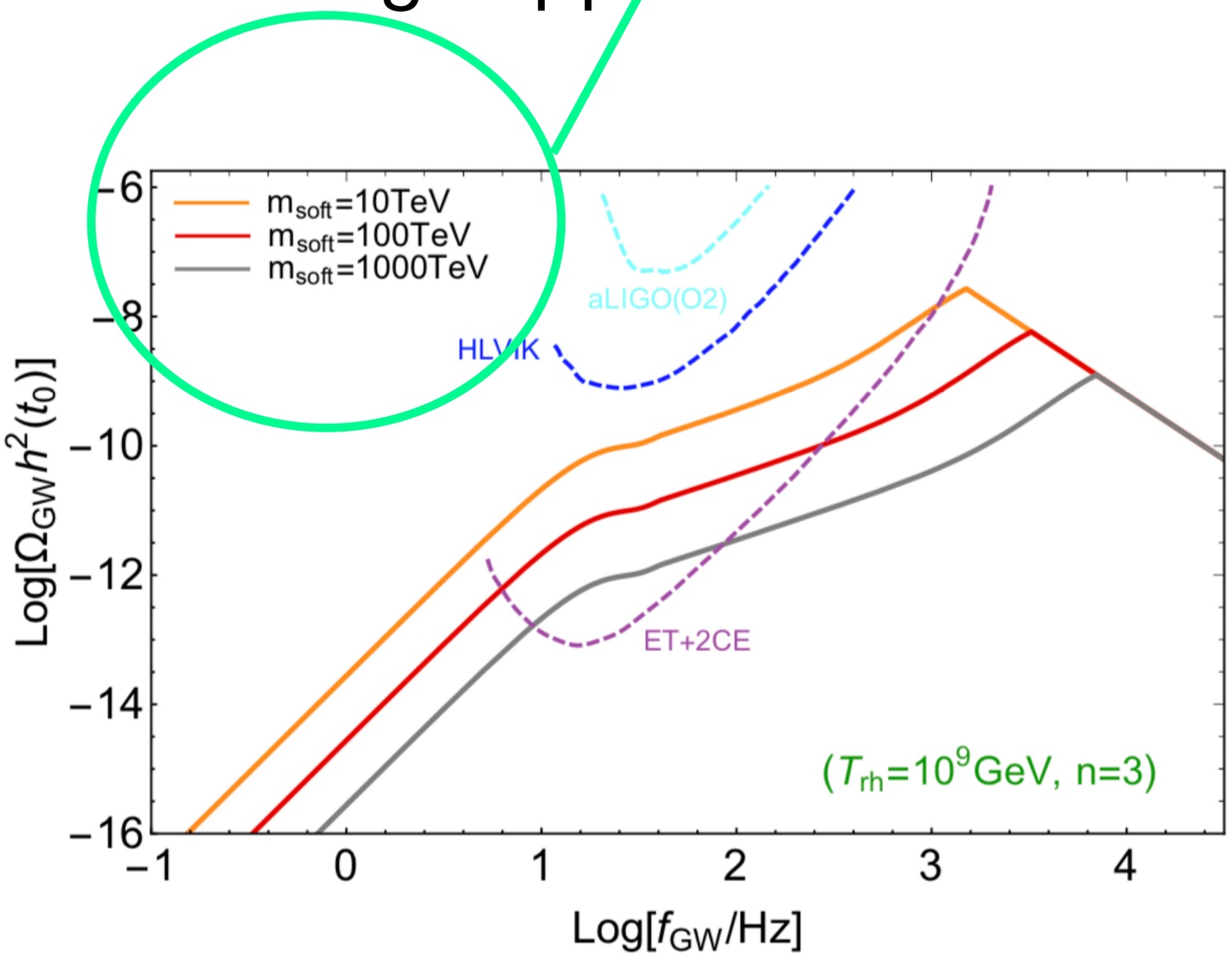

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Different slop due to different phase

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