Baryon Asymmetry from Dark Matter Decay

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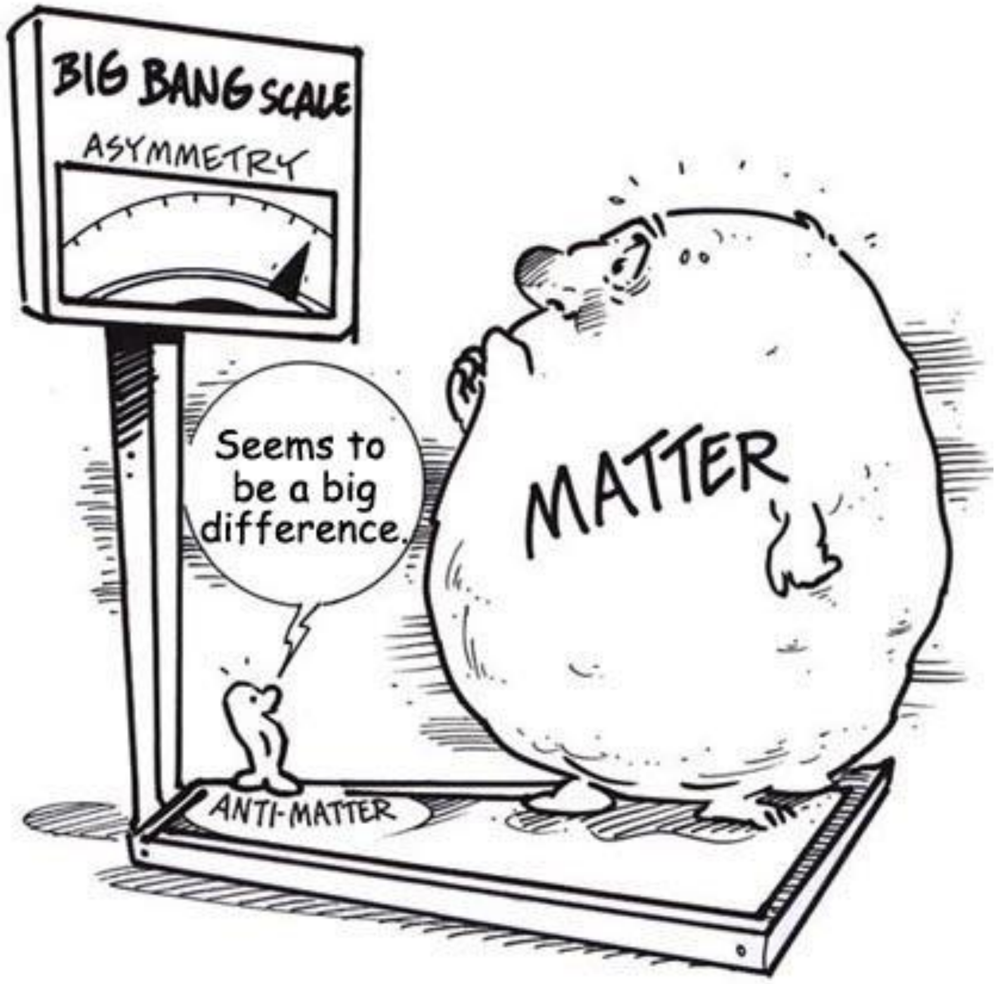
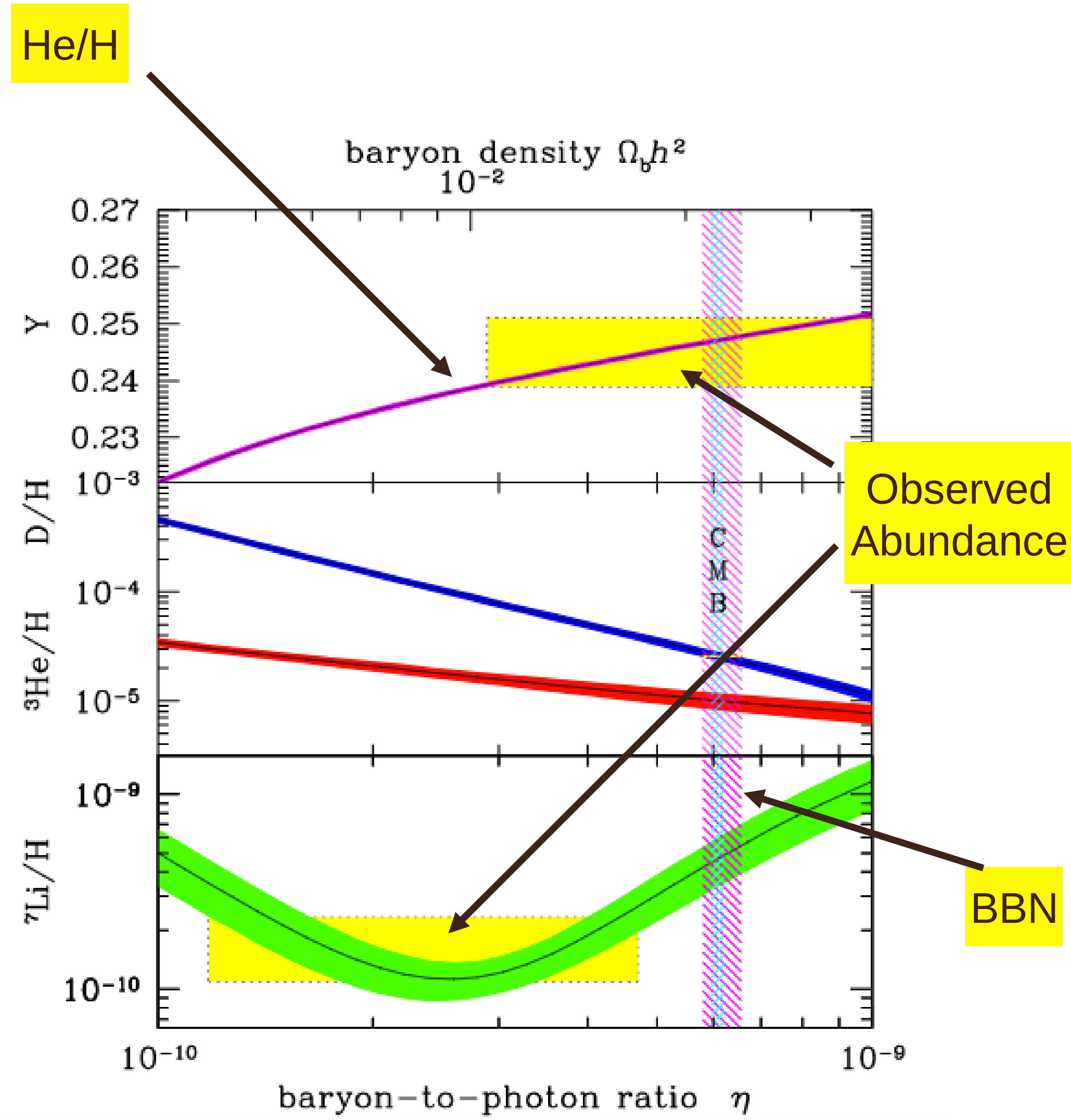
Based on arXiv:2305.13367 with Suruj Jyoti Das, Rishav Roshan

Matter-antimatter (baryon) asymmetry





Particle Data Group

- The observed BAU is often quoted in terms of baryon to photon ratio

$$\eta_B = \frac{n_B - n_{\overline{B}}}{n_\gamma} = 6.04 \pm 0.08 \times 10^{-10}$$

- The prediction for this ratio from the BBN agrees well with the observed value inferred from the CMB measurements (Planck 2018).

Sakharov's Conditions

Three basic ingredients necessary to generate a net baryon asymmetry from an initially baryon symmetric Universe (Sakharov 1967):

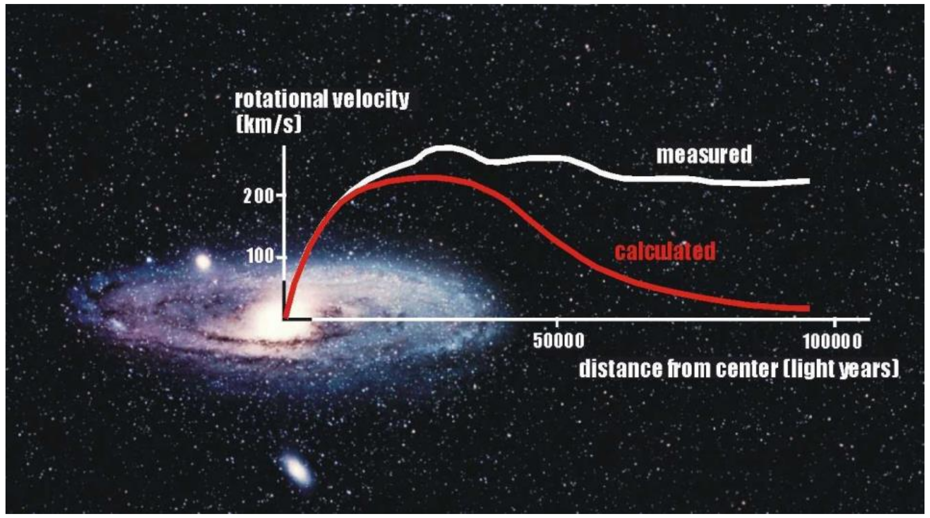
- Baryon Number (B) violation $X \to Y + B$
- C & CP violation. $\Gamma(X \to Y + B) \neq \Gamma(\overline{X} \to \overline{Y} + \overline{B})$

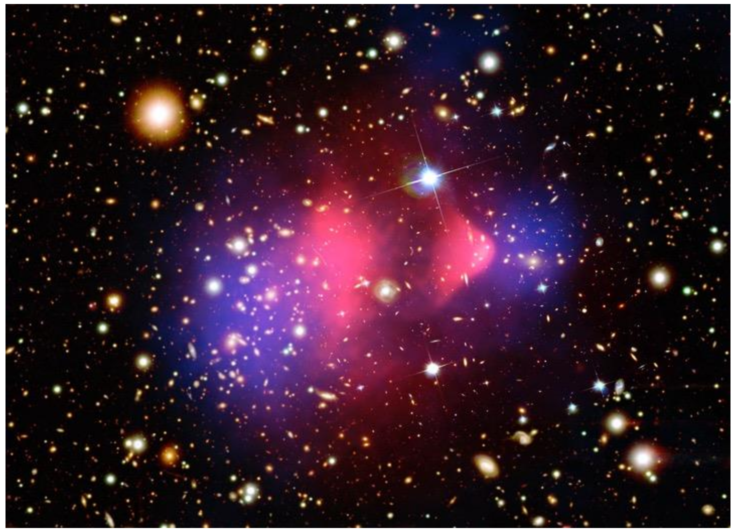
$$\Gamma(X \to q_L q_L) + \Gamma(X \to q_R q_R) \neq \Gamma(\overline{X} \to \overline{q_L} + \overline{q_L}) + \Gamma(\overline{X} \to \overline{q_R} + \overline{q_R})$$

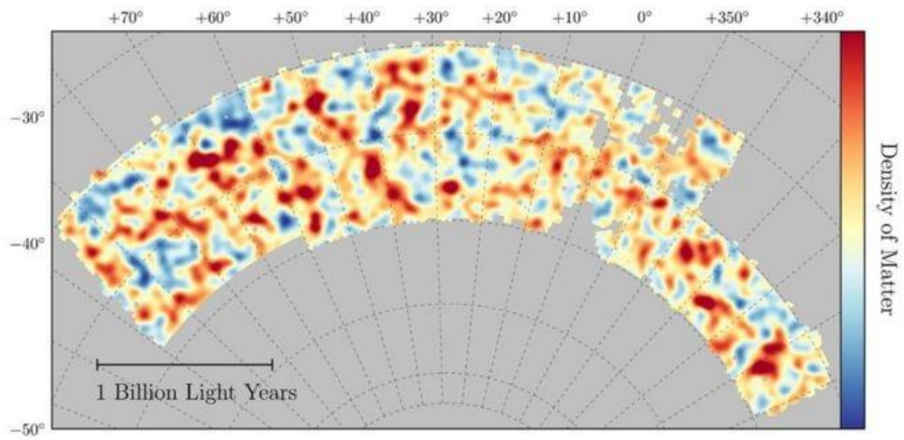
- Departure from thermal equilibrium.

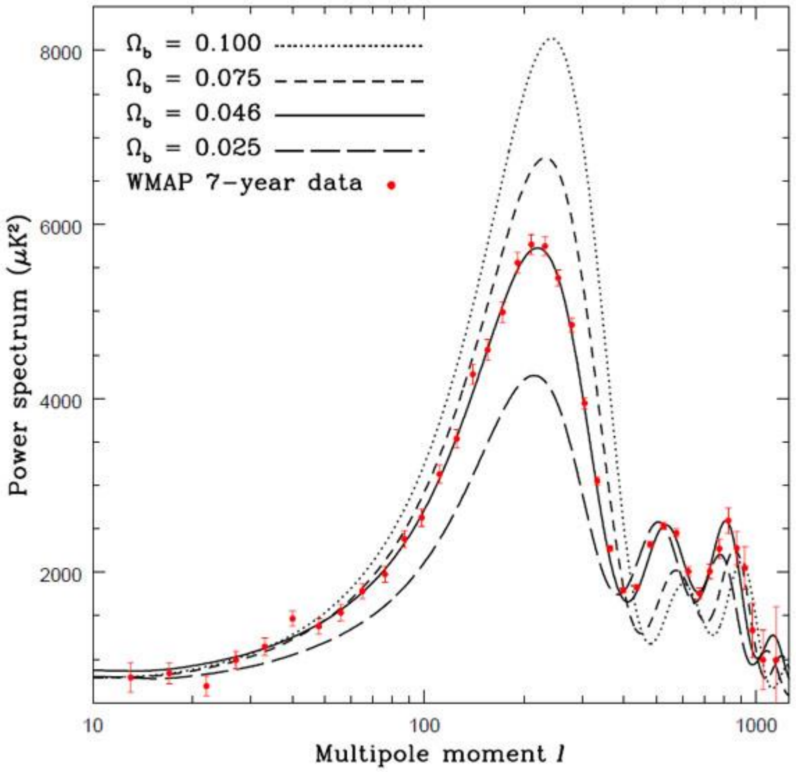
Standard Model fails to satisfy these conditions in required amount

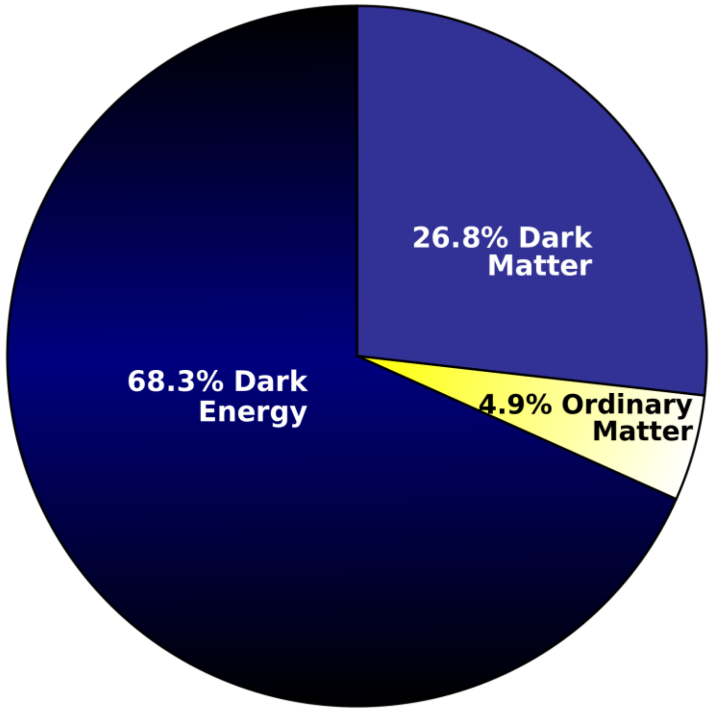
Dark Matter: Evidences

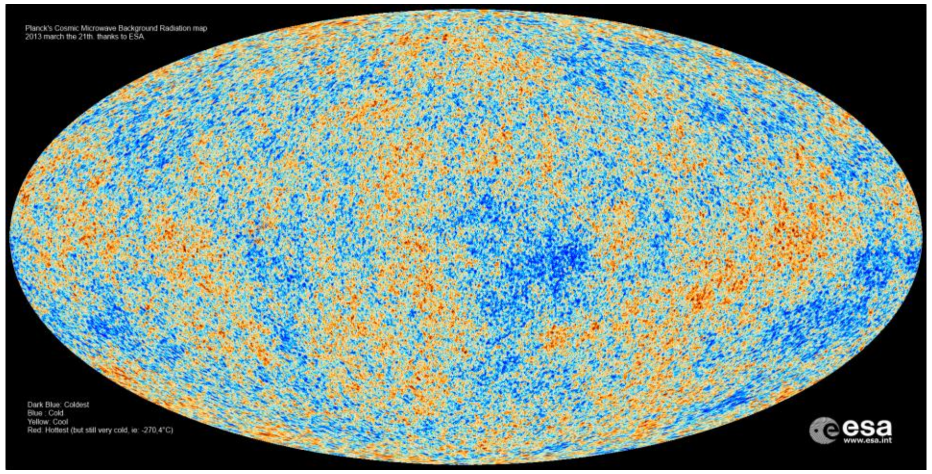








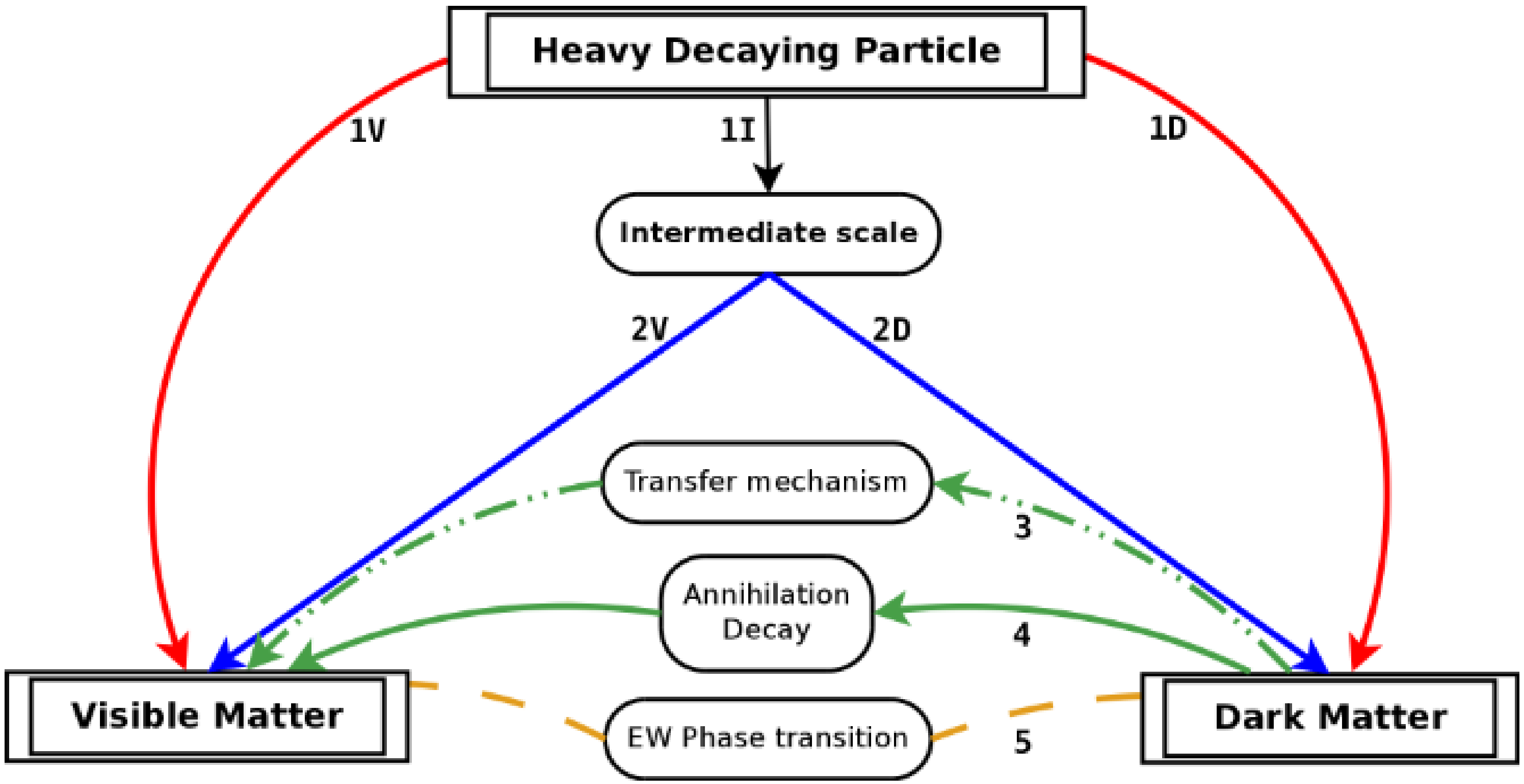




Credits: HST, Chandra, DES, WMAP, Planck

Standard Model does not have any DM candidate

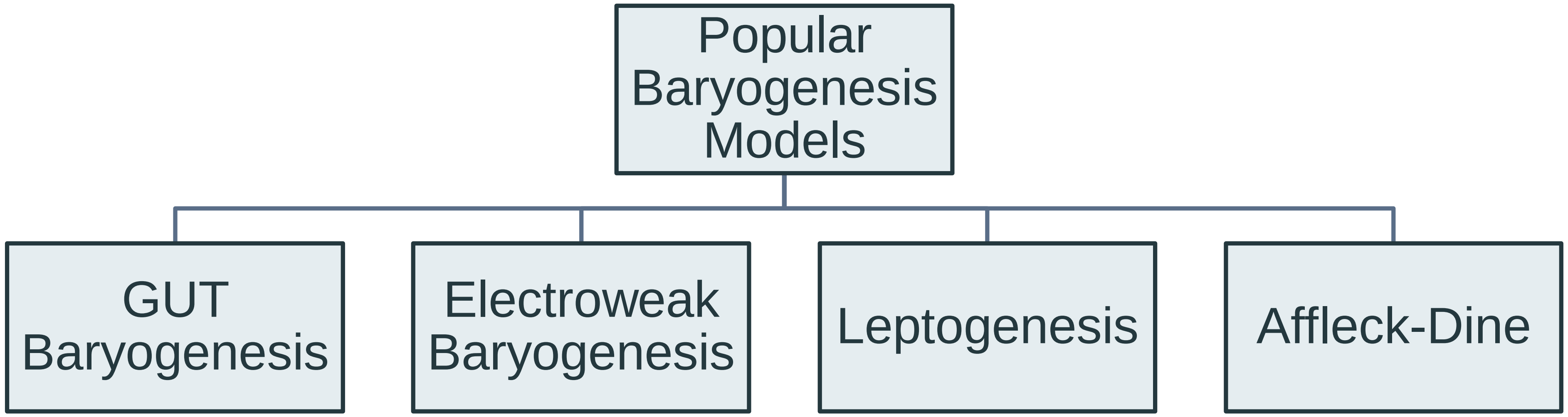
- Baryon-DM coincidence: $\Omega_{DM} \simeq 5\Omega_B$
- They could possibly have a common origin?



Schematic of popular ideas; arXiv:1310.1904

Nussinov'87; Yoshimura'78, Barr'79, arXiv:1112.2714, 1203.1247, 1305.4939, 1308.0338, 1407.4566, 2002.05170, 2112.10784++

Plenary by A. Ibarra



New Ideas

Snowmass 2021
Arxiv:2203.05010

2 New Ideas in Baryogenesis Models

Baryon Asymmetry from Dark Matter Decay

- A particle DM, cosmologically stable at low temperature, can decay at high temperatures due to finite temperature corrections to its mass: forbidden decay!

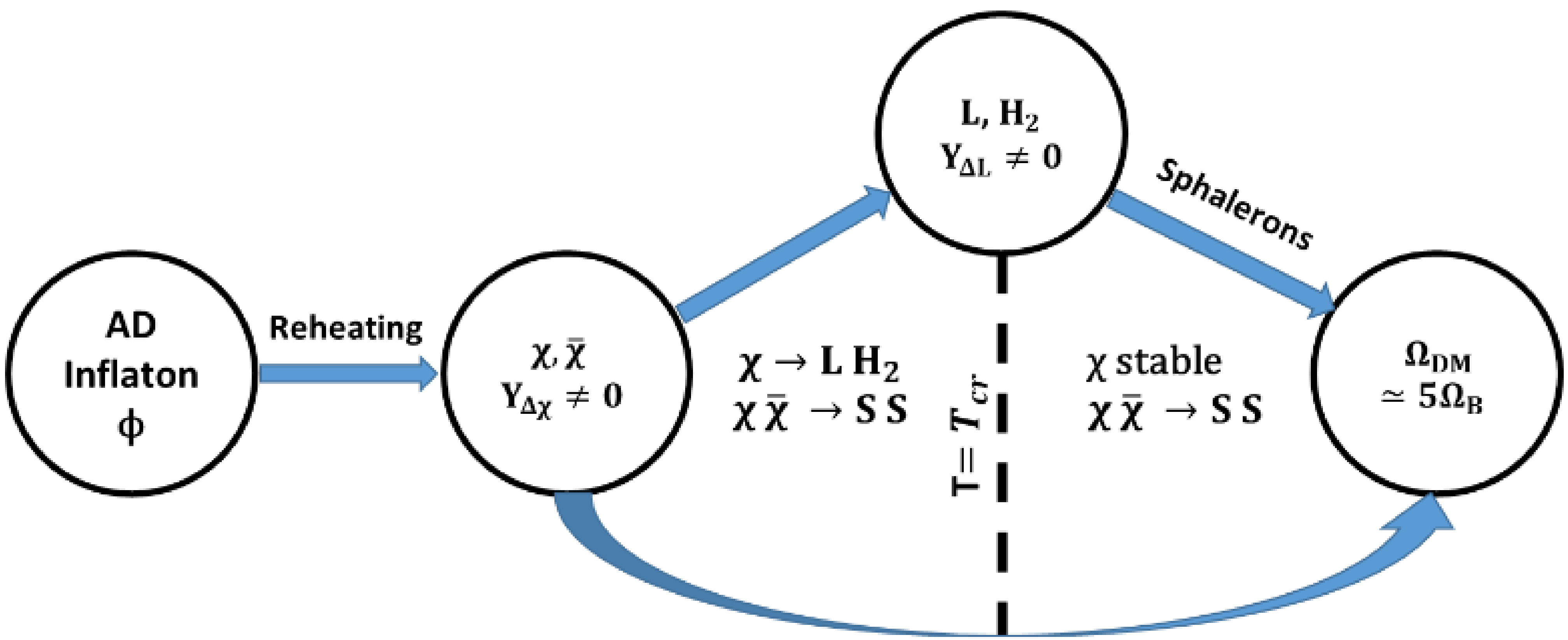
- If DM has an in-built asymmetry, it can transfer part of its symmetry into the standard model baryon/leptons (arXiv:2305:16637; DB, Suruj Jyoti Das, Rishav Roshan).

- If the DM decay can satisfy the Sakharov's conditions, baryon/lepton asymmetry can be generated in the vicinity of a first-order phase transition (arXiv:2306.05459; DB, Arnab Dasgupta, Matthew Knauss, Indrajit Saha).

The Framework

Fields	$SU(3)_c \times SU(2)_L \times U(1)_Y$	$U(1)_L$	Z_2
χ	$(1,1,0)$	1	-1
H_2	$(1,2,-1/2)$	0	-1
Φ	$(1,1,0)$	2	1
S	$(1,1,0)$	0	1

$$-\mathcal{L} \supset M_\chi \overline{\chi}\chi + Y_\nu \overline{L}\tilde{H}_2\chi_R + Y_D\overline{\chi^c}\chi\Phi^\dagger + Y_S\overline{\chi_L}\chi_R S + \text{h.c.}$$



Dark asymmetry from AD field

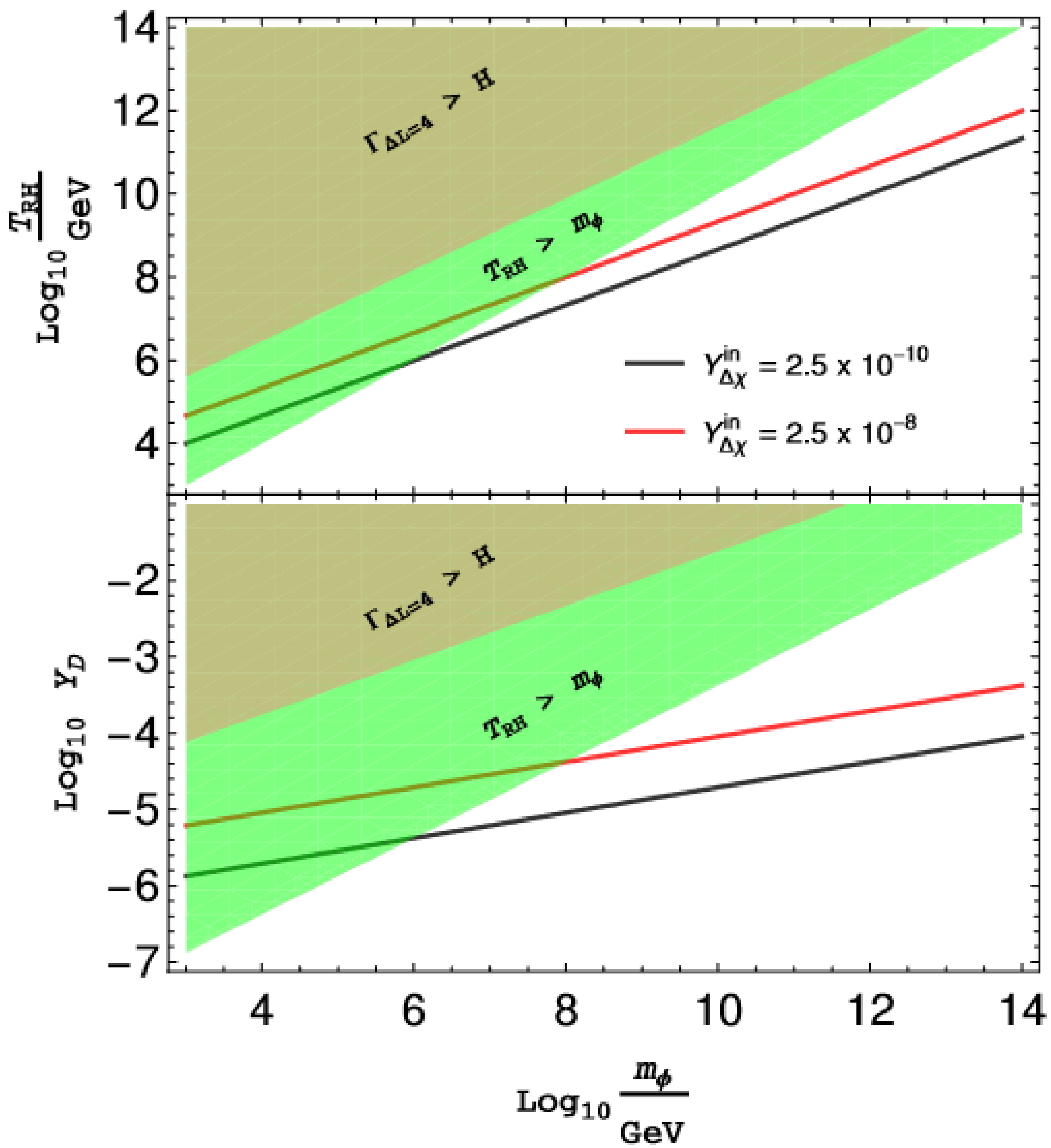
- The AD field plays the role of inflaton via $\phi^2 R$ coupling and reheats the Universe by decaying into DM χ.

- The AD field breaks L number explicitly due to the $\epsilon m_\phi^2 \phi^2$ term in the potential.

- Cosmic evolution of the AD field leads to the dark sector asymmetry given by

$$Y_{\Delta\chi}^{\rm in} = \frac{(n_\chi - n_{\bar{\chi}})^{\rm in}}{s} \simeq \frac{T_{\rm RH}^3}{\epsilon m_\Phi^2 M_P}.$$

- Dark asymmetry is partially transferred into leptons via *forbidden decay*.



Affleck and Dine 1985; also see arXiv:0802.1328, 1105.4612, 1201.2200, 1309.0007, 1309.0010, 1405.1959, 1909.12300, 2001.11505, 2008.04339 2107.01514, 2106.03381, 2201.06151, 2212.04516 ++

Thermal masses

$$
\begin{aligned}
M_\chi(T) &= \sqrt{m_\chi^2 + \Pi_{S\chi}^2(T)}, \\
M_{H_2}(T) &= \sqrt{m_{H_2}^2 + \Pi_{\text{gauge}}^2(T)}, \\
M_L(T) &= \sqrt{m_L^2 + \frac{1}{2}\Pi_{\text{gauge}}^2(T)},
\end{aligned}
$$

$$
\begin{aligned}
\Pi_{S\chi}^2(T) &= \frac{Y_S^2}{16}T^2, \\
\Pi_{\text{gauge}}^2(T) &= \left(\frac{1}{16}g'^2 + \frac{3}{16}g^2\right)T^2.
\end{aligned}
$$

Boltzmann Equations

$$
\frac{dY_\chi}{dz} = -\frac{s}{\mathbf{H}z}\left[\langle\sigma v_{\chi\bar{\chi}\to\text{SM}}\rangle(Y_\chi Y_{\bar{\chi}} - Y_\chi^{\text{eq}}Y_{\bar{\chi}}^{\text{eq}})\right] - \frac{1}{s\mathbf{H}z}\gamma(\chi \to LH_2)\left(\frac{Y_\chi}{Y_\chi^{\text{eq}}} - 1\right) + \frac{1}{s\mathbf{H}z}\gamma(H_2 \to \chi\bar{L}),
$$

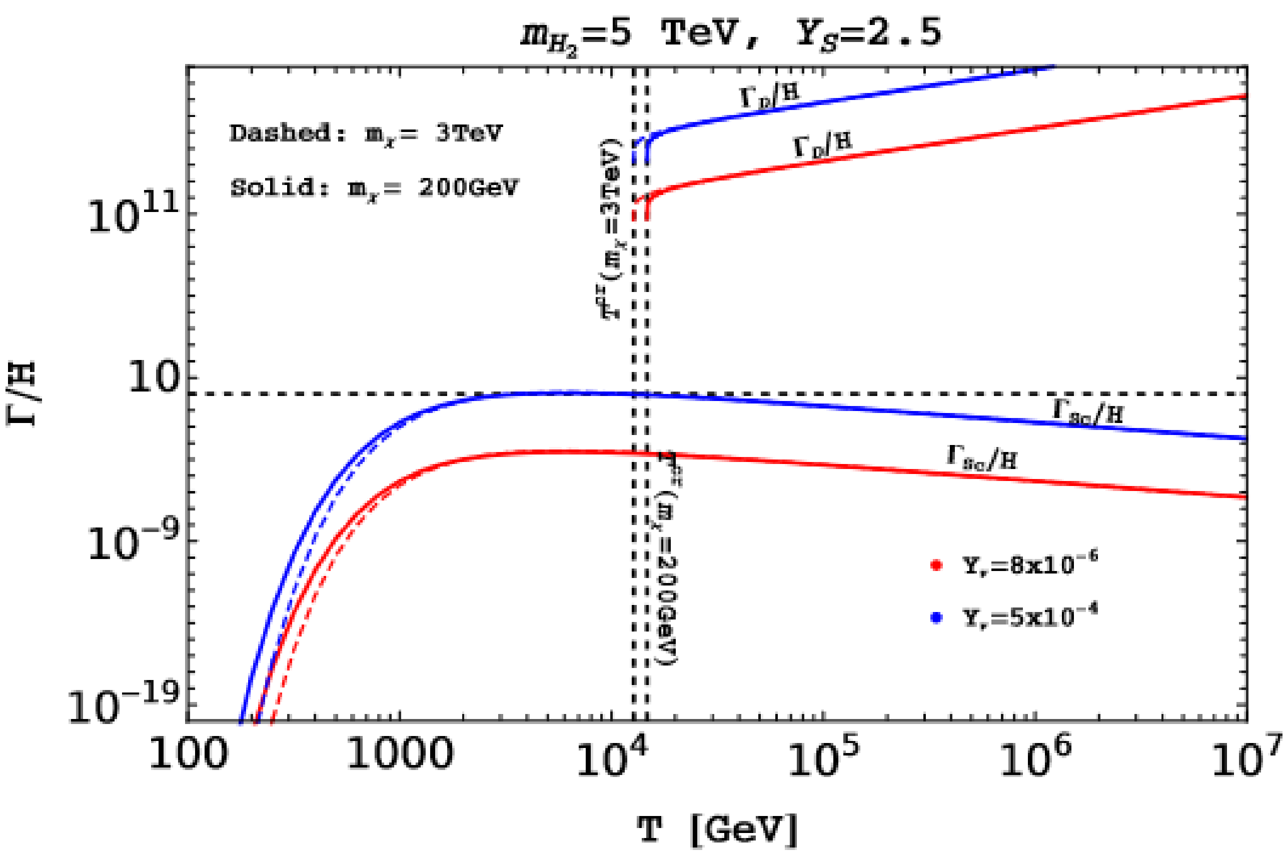
$$
\frac{dY_{\bar{\chi}}}{dz} = -\frac{s}{\mathbf{H}z}\left[\langle\sigma v_{\chi\bar{\chi}\to\text{SM}}\rangle(Y_\chi Y_{\bar{\chi}} - Y_\chi^{\text{eq}}Y_{\bar{\chi}}^{\text{eq}})\right] - \frac{1}{s\mathbf{H}z}\gamma(\bar{\chi} \to \bar{L}H_2)\left(\frac{Y_{\bar{\chi}}}{Y_{\bar{\chi}}^{\text{eq}}} - 1\right) + \frac{1}{s\mathbf{H}z}\gamma(H_2 \to \bar{\chi}L),
$$

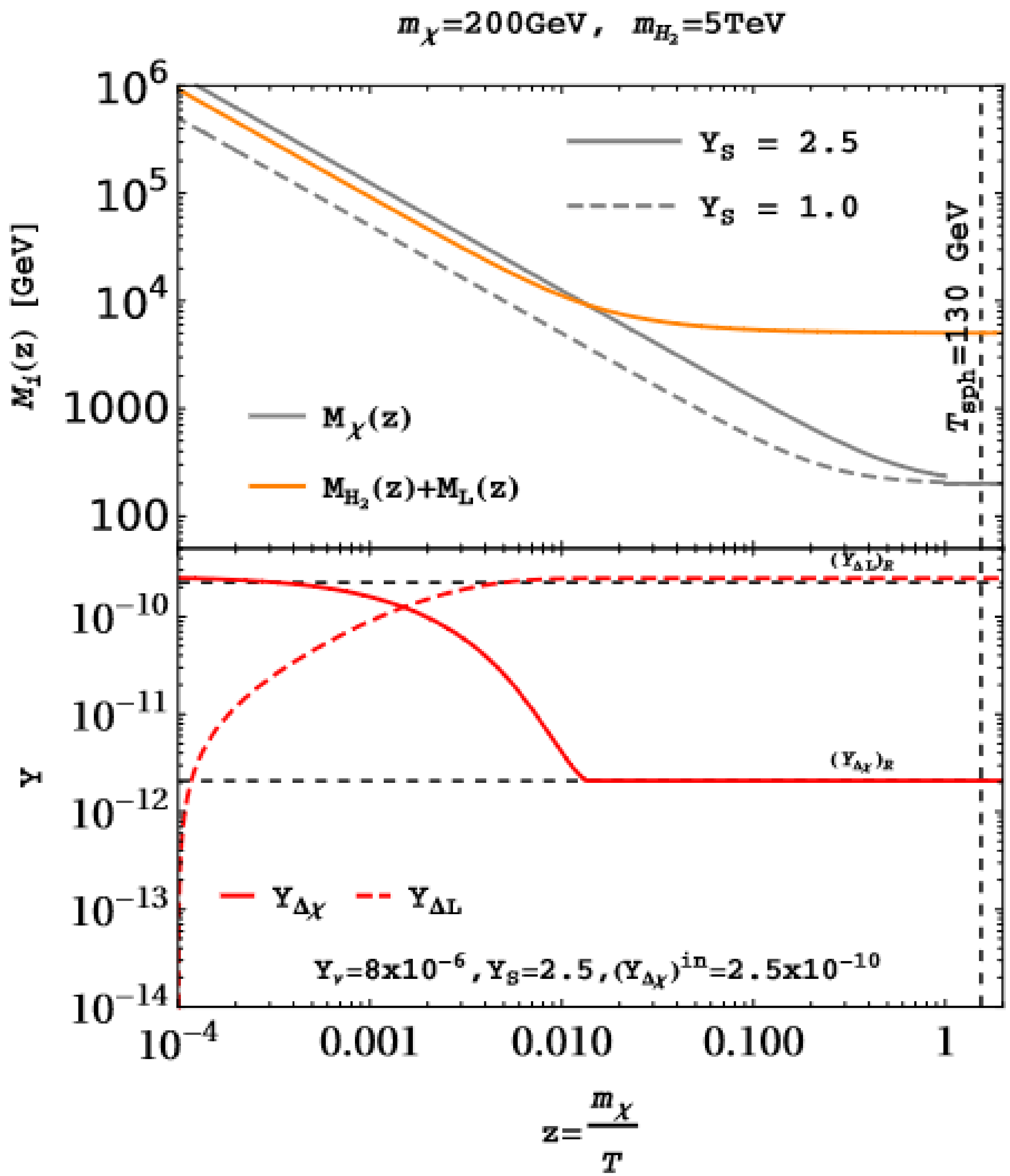
$$
\frac{dY_L}{dz} = \frac{1}{s\mathbf{H}z}\gamma(\chi \to LH_2)\left(\frac{Y_\chi}{Y_\chi^{\text{eq}}} - 1\right) + \frac{1}{s\mathbf{H}z}\gamma(H_2 \to \bar{\chi}L),
$$

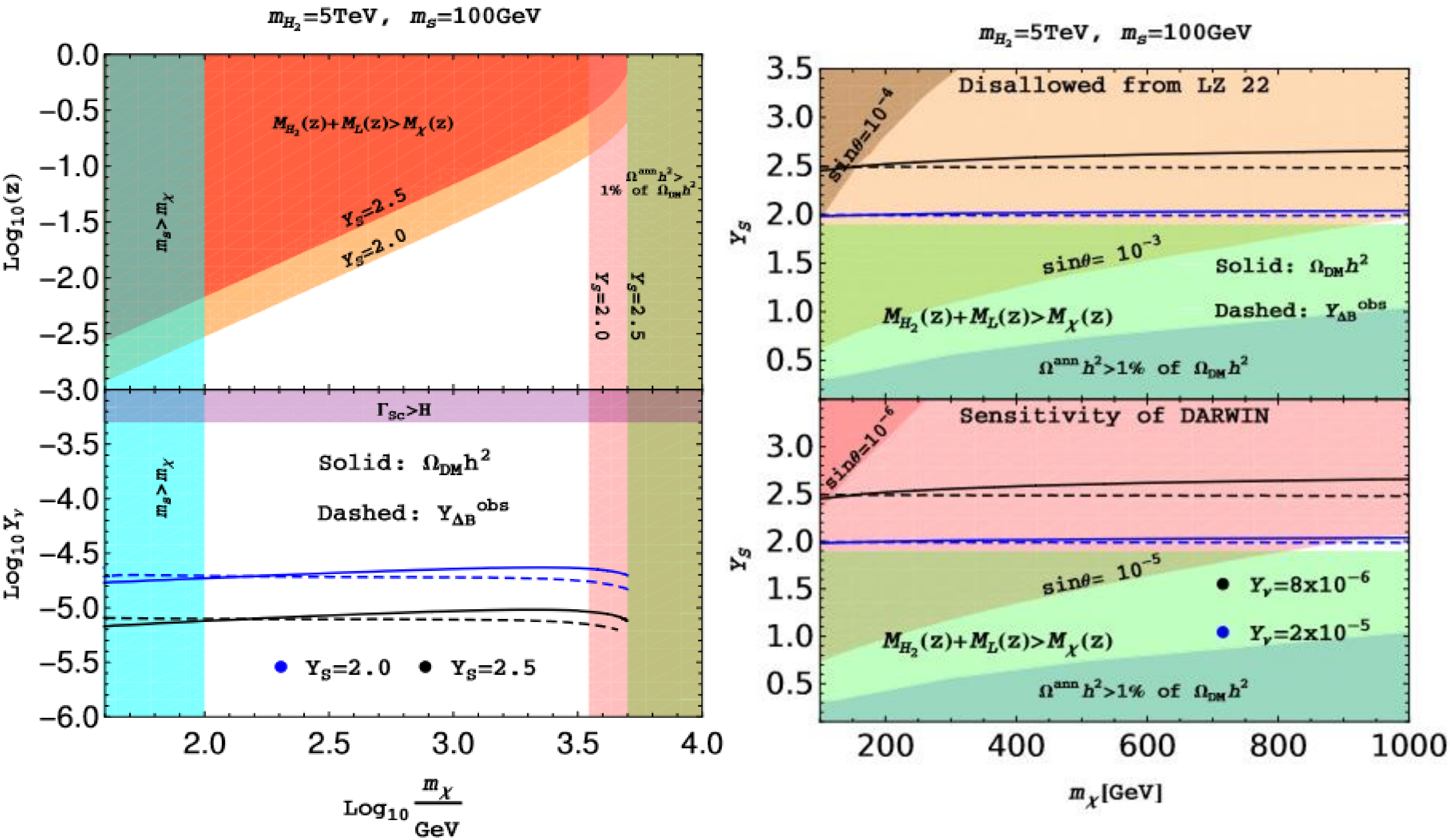
$$
\frac{dY_{\bar{L}}}{dz} = \frac{1}{s\mathbf{H}z}\gamma(\bar{\chi} \to \bar{L}H_2)\left(\frac{Y_{\bar{\chi}}}{Y_{\bar{\chi}}^{\text{eq}}} - 1\right) + \frac{1}{s\mathbf{H}z}\gamma(H_2 \to \chi\bar{L}),
$$

$$Y_\chi(0) = Y_\chi^{\rm eq},\ Y_{\bar\chi}(0) = Y_\chi^{\rm eq} - Y_{\Delta\chi}^{\rm in}$$
$$Y_L(0) = Y_L^{\rm eq},\ Y_{\bar L}(0) = Y_L^{\rm eq}$$

- The DM-lepton coupling is small such that asymmetry is transferred dominantly via decay.
- The decay $H_2 \to \chi L$ at low T can not alter asymmetries if $H_2 \leftrightarrow H_2^\dagger$ process remains efficient.







m_{H_2}=5TeV, m_s=100GeV
Log10(z)
$m_s > m_\chi$
$M_{H_2}(z)+M_L(z)>M_\chi(z)$
Y_S=2.5
Y_S=2.0
$\Omega^{ann}h^2>$ 1% of $\Omega_{DM}h^2$
$\Gamma_{Sc}>H$
Solid: $\Omega_{DM}h^2$
Dashed: $Y_{\Delta B}^{obs}$
Log10 Y_ν
Y_S=2.0 Y_S=2.5
$\mathrm{Log}_{10}\frac{m_\chi}{\mathrm{GeV}}$
Disallowed from LZ 22
$\sin\theta=10^{-4}$
$\sin\theta=10^{-3}$
$\Omega^{ann}h^2>1\%$ of $\Omega_{DM}h^2$
Y_S
Sensitivity of DARWIN
$\sin\theta=10^{-6}$
$\sin\theta=10^{-5}$
$Y_\nu=8\times10^{-6}$
$Y_\nu=2\times10^{-5}$
m_χ[GeV]

Detection Prospects

- DM-nucleon scattering can occur via mixing of singlet S and the SM Higgs.
- A light S with large coupling to DM, required for generating desired finite-T mass, can lead to large self-interactions alleviating the small-scale structure problems of Cold DM.
- A light S can be detected via Higgs invisible decay too.
- AD inflaton leads to specific predictions for inflationary observables in $n_s - r$ plane.
- The second Higgs doublet can have interesting collider signatures like dilepton/dijet plut MET.

Conclusion

- Explaining baryon asymmetry from dark matter decay also addresses the baryon-DM coincidence problem $\Omega_{DM} \simeq 5\Omega_B$, providing a new *cogenesis* possibility.
- Finite temperature effects can enable such decay of DM above a critical temperature.
- DM sector asymmetry is generated by an Affleck-Dine inflaton field.
- The mechanism can be implemented for direct baryogenesis or baryogenesis via leptogenesis, independently of the origin of neutrino mass.

Thank You