

A FEEBLE WINDOW ON LEPTOPHILIC DARK MATTER

Based on arXiv:1904.07513 in collaboration
with Laura Lopez Honorez and Alberto Mariotti

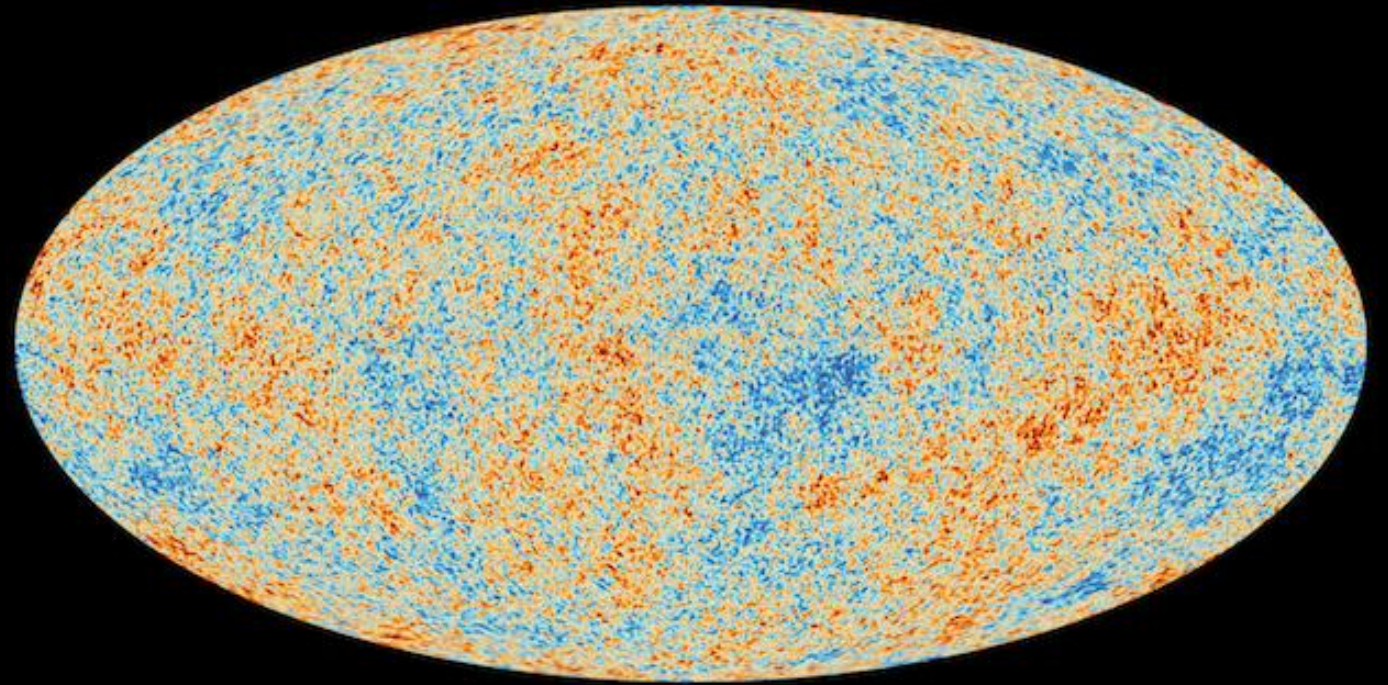
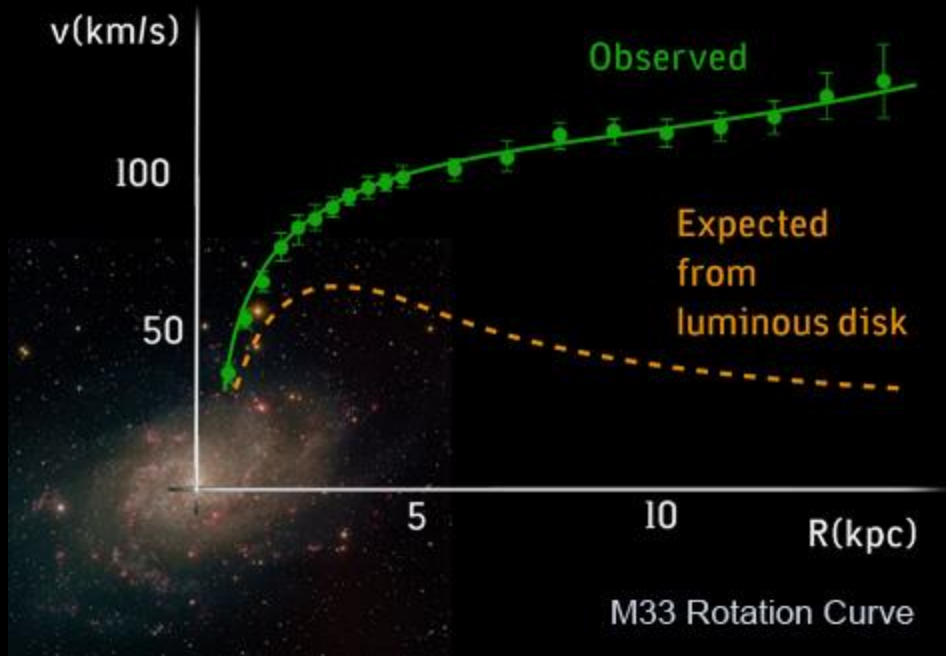
ULB

SAM JUNIUS

EPS-HEP CONFERENCE – 12/07/2019

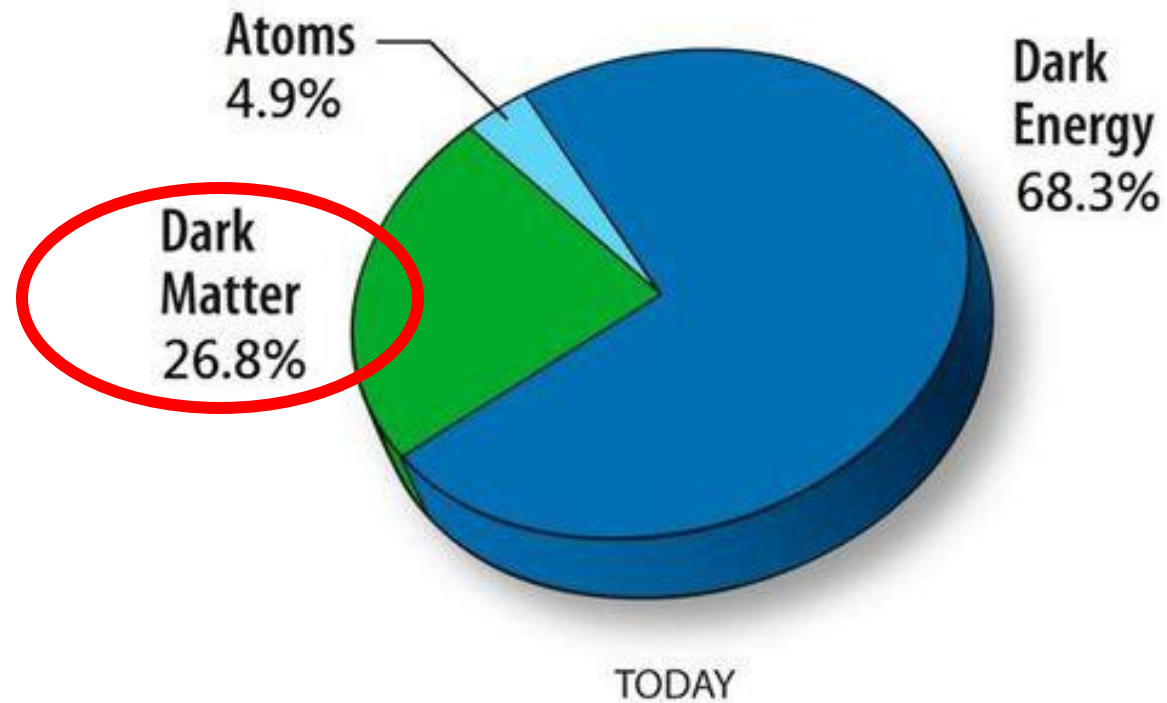
VUB

COMPELLING EVIDENCE FOR THE EXISTENCE OF DARK MATTER



Only gravitational evidence

AMOUNT OF DARK MATTER IN THE UNIVERSE TODAY



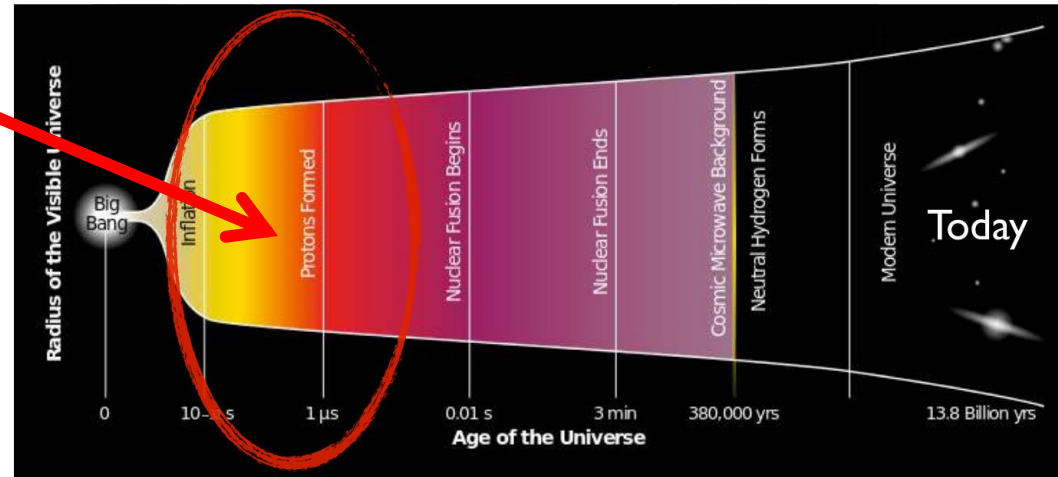
Dark matter relic abundance

$$\Omega_{DM} h^2 = 0.12$$

PRODUCTION OF DARK MATTER IN EARLY UNIVERSE

**Thermal
Bath**

Expansion with Hubble rate H



Boltzmann equation
for $a + b \rightarrow c + d$:

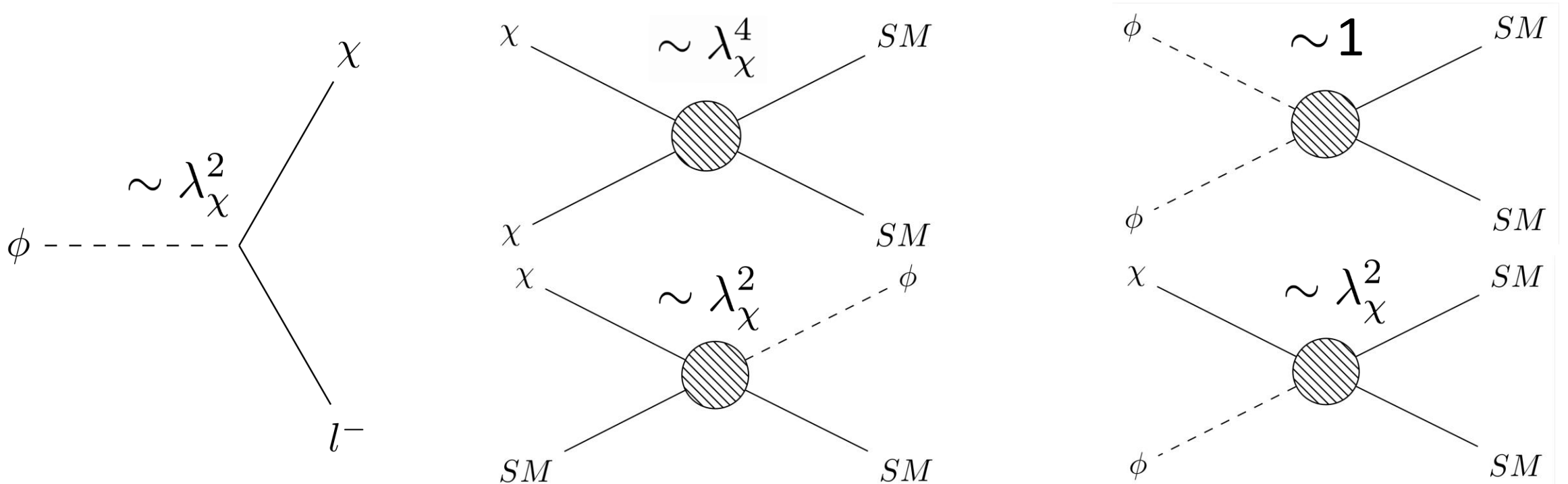
$$\frac{dn_a}{dt} + 3Hn_a = \Gamma_{ab \rightarrow cd} \left\{ \frac{n_c n_d}{n_c^{eq} n_d^{eq}} - \frac{n_a n_b}{n_a^{eq} n_b^{eq}} \right\}$$

SIMPLIFIED LEPTOPHILIC DM MODEL

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{2}\bar{\chi}\gamma^\mu\partial_\mu\chi - \frac{m_\chi}{2}\bar{\chi}\chi + (D_\mu\phi)^\dagger D^\mu\phi - m_\phi^2|\phi|^2 - \lambda_\chi\phi\bar{\chi}l_R - \lambda_H H^\dagger H\phi^\dagger\phi + h.c.$$

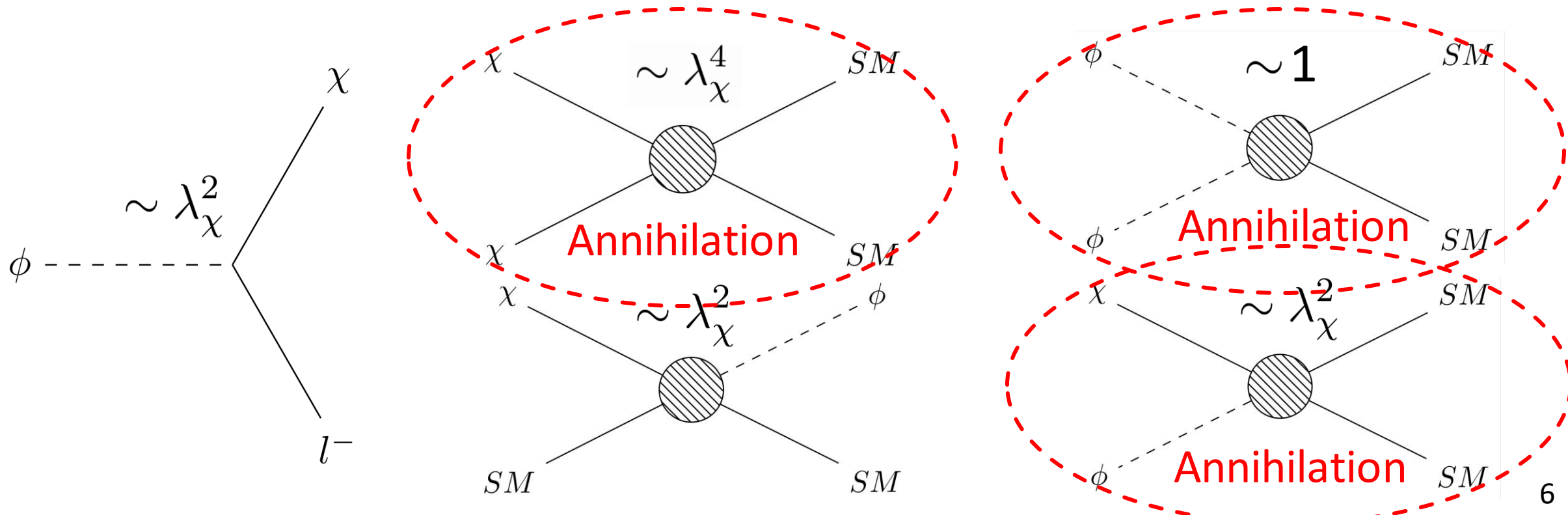
SIMPLIFIED LEPTOPHILIC DM MODEL

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{2}\bar{\chi}\gamma^\mu\partial_\mu\chi - \frac{m_\chi}{2}\bar{\chi}\chi + (D_\mu\phi)^\dagger D^\mu\phi - m_\phi^2|\phi|^2 - \lambda_\chi\phi\bar{\chi}l_R - \lambda_H H^\dagger H\phi^\dagger\phi + h.c.$$



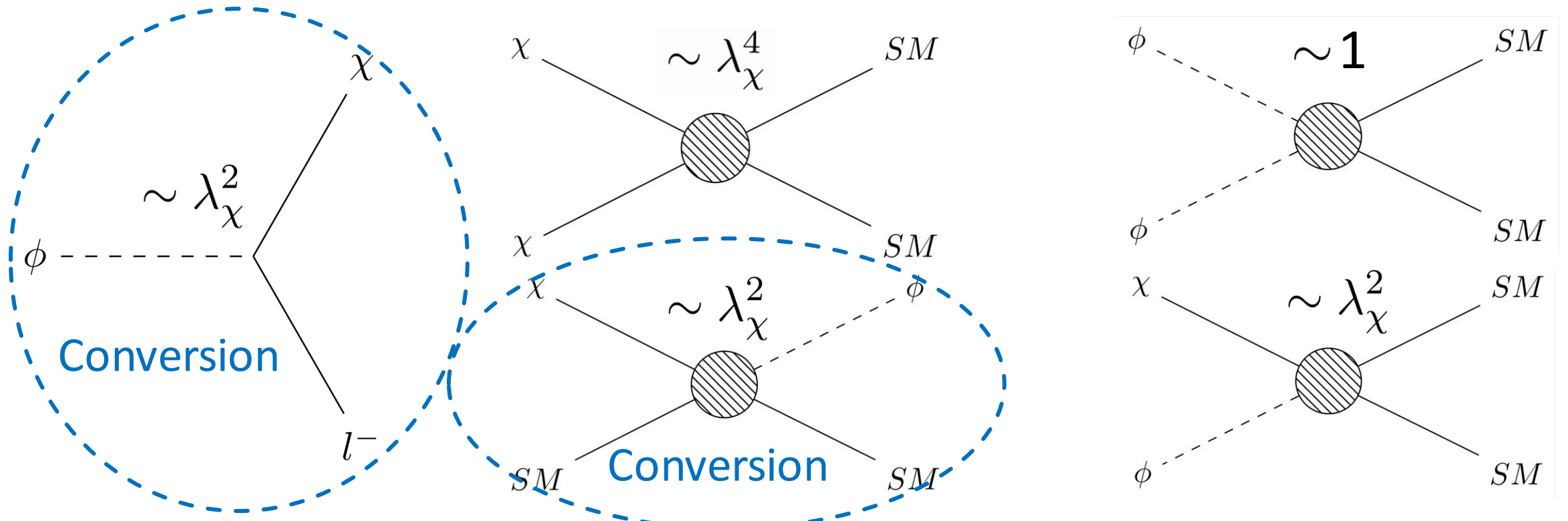
SIMPLIFIED LEPTOPHILIC DM MODEL

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{2}\bar{\chi}\gamma^\mu\partial_\mu\chi - \frac{m_\chi}{2}\bar{\chi}\chi + (D_\mu\phi)^\dagger D^\mu\phi - m_\phi^2|\phi|^2 - \lambda_\chi\phi\bar{\chi}l_R - \lambda_H H^\dagger H\phi^\dagger\phi + h.c.$$



SIMPLIFIED LEPTOPHILIC DM MODEL

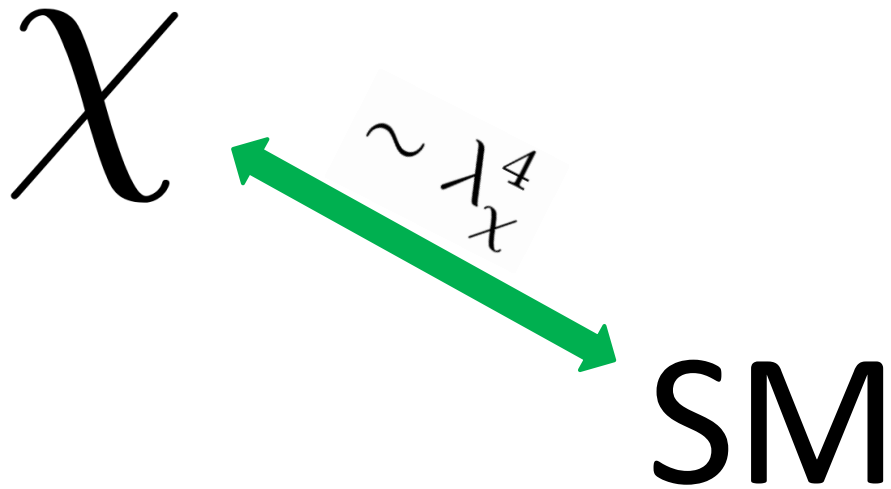
$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{2}\bar{\chi}\gamma^\mu\partial_\mu\chi - \frac{m_\chi}{2}\bar{\chi}\chi + (D_\mu\phi)^\dagger D^\mu\phi - m_\phi^2|\phi|^2 - \lambda_\chi\phi\bar{\chi}l_R - \lambda_H H^\dagger H\phi^\dagger\phi + h.c.$$



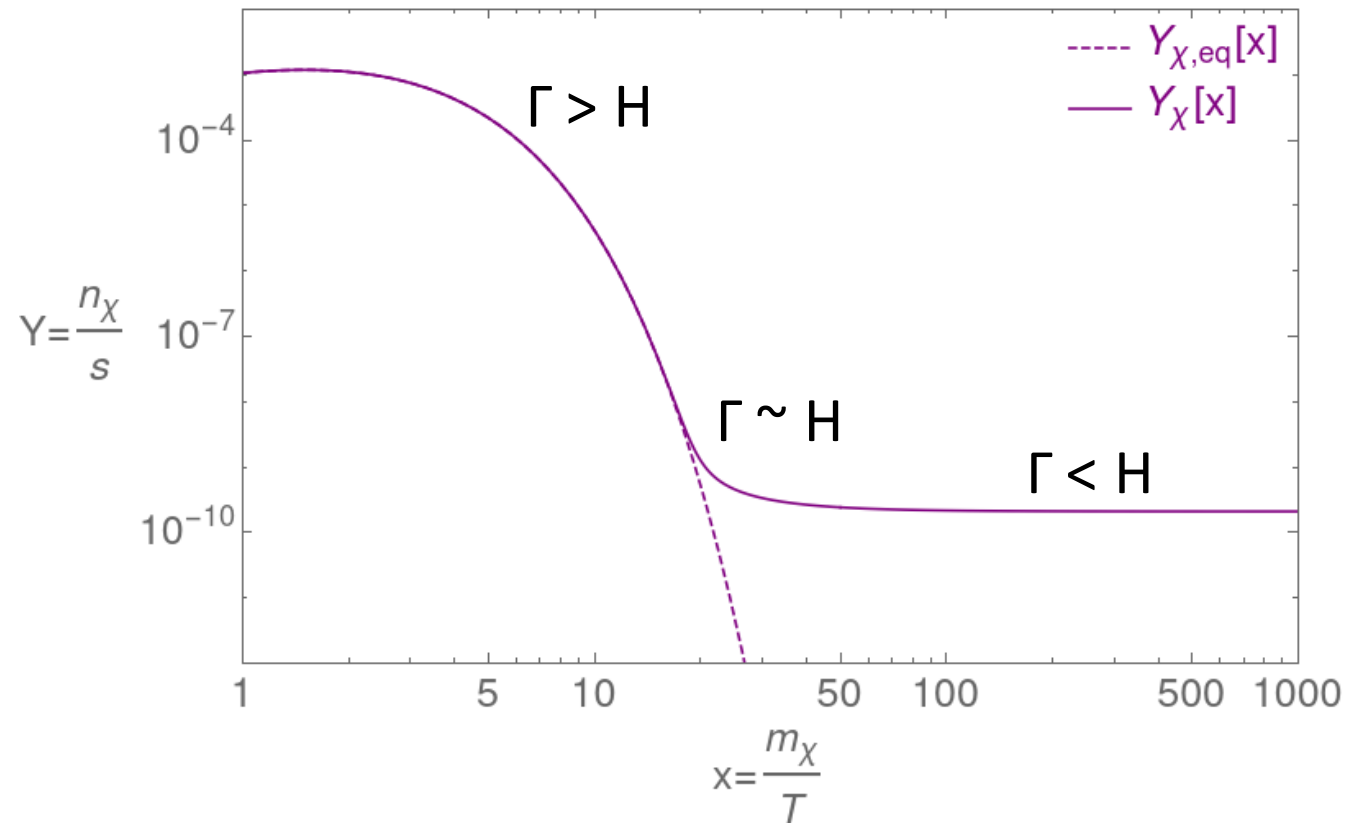
The background is a dark blue field filled with various circular and semi-circular patterns. These include concentric circles, dashed lines, and scales with numerical markings. Some scales are labeled with numbers like 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, and 260. There are also curved arrows and partial circles scattered throughout the design.

DARK MATTER PRODUCTION MECHANISMS

DARK MATTER FREEZE-OUT

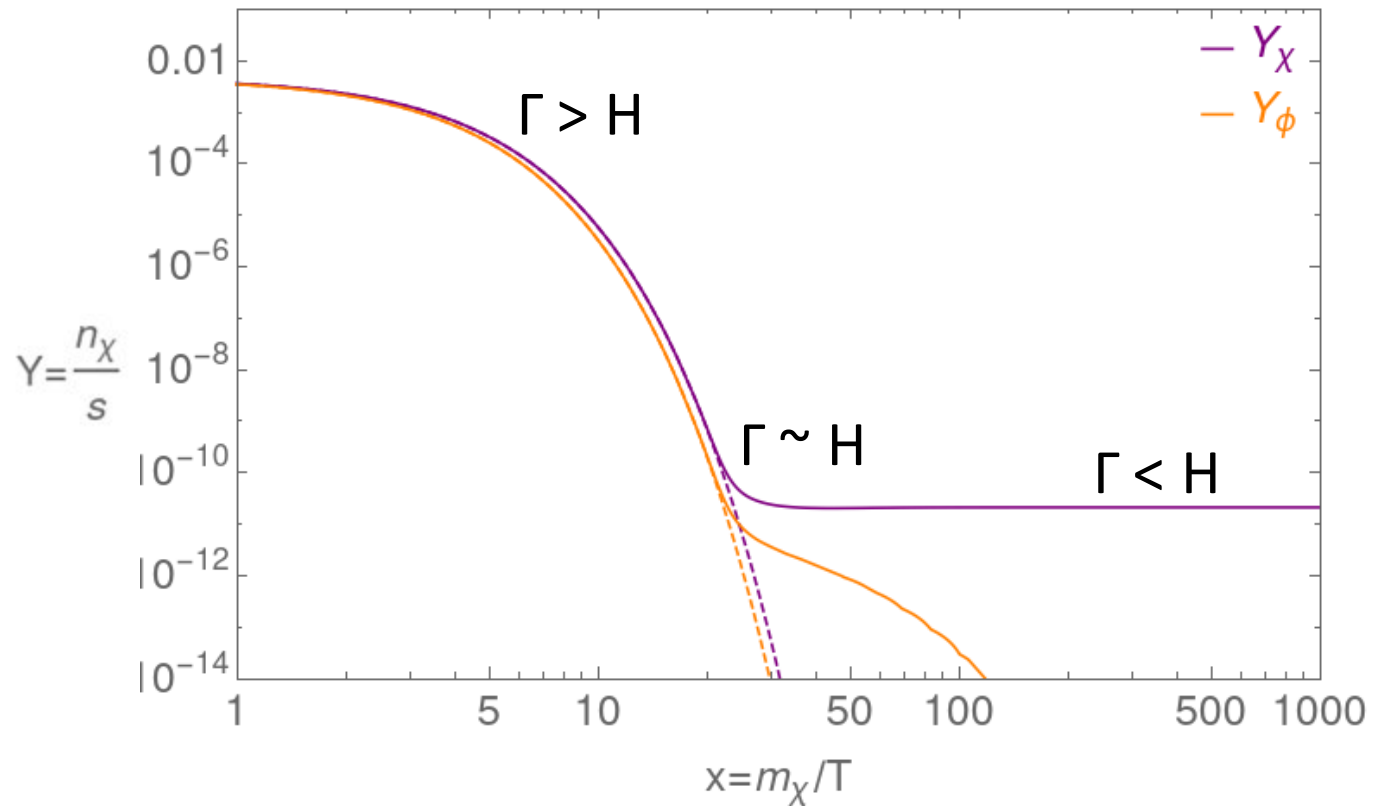
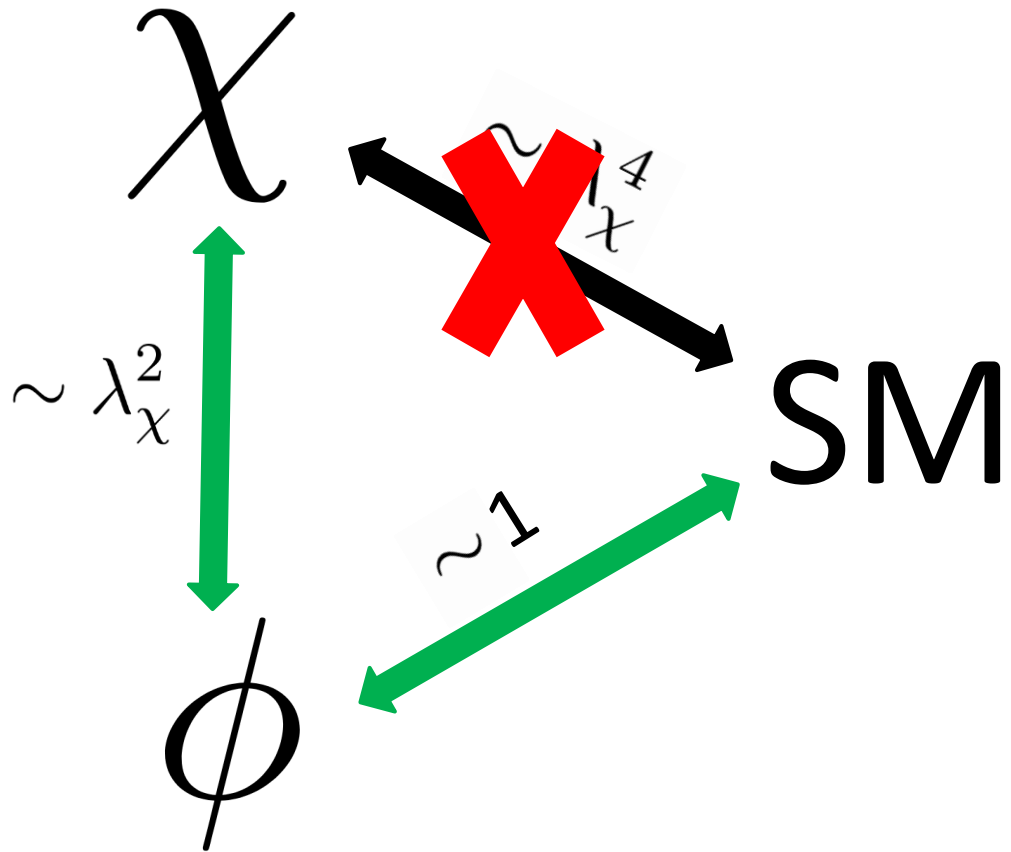


$$\lambda_\chi = 5 \cdot 10^{-1}$$

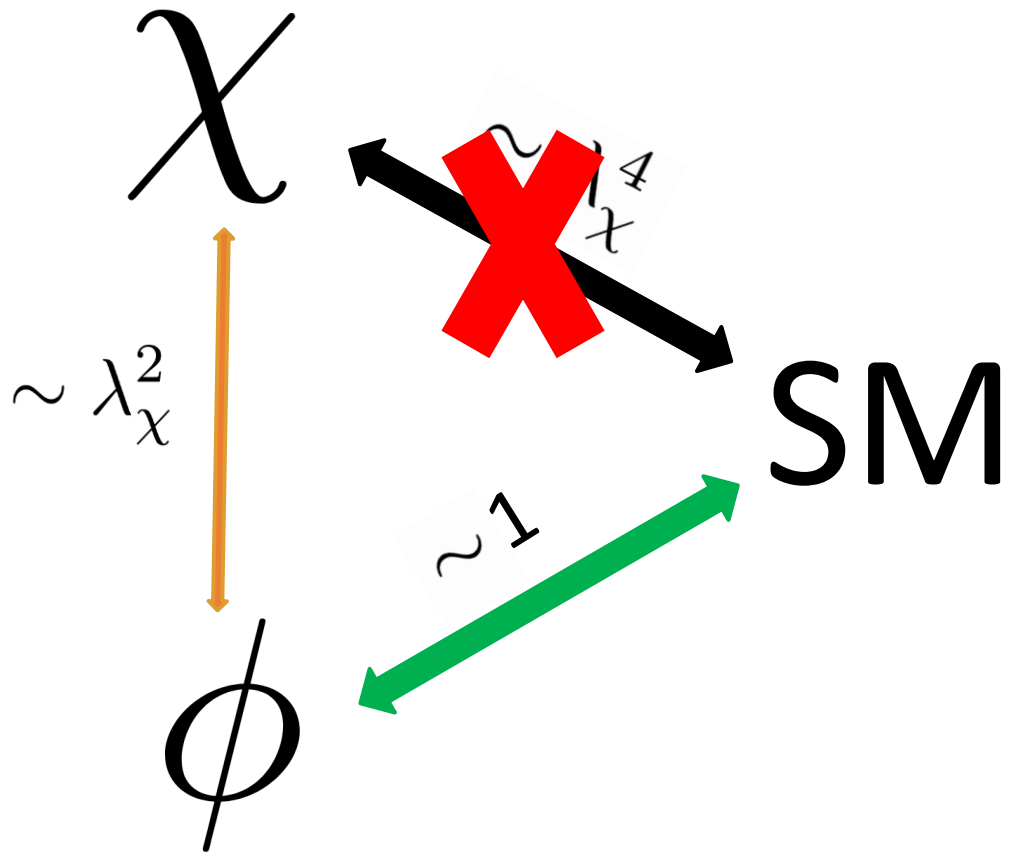


MEDIATOR DRIVEN FREEZE-OUT

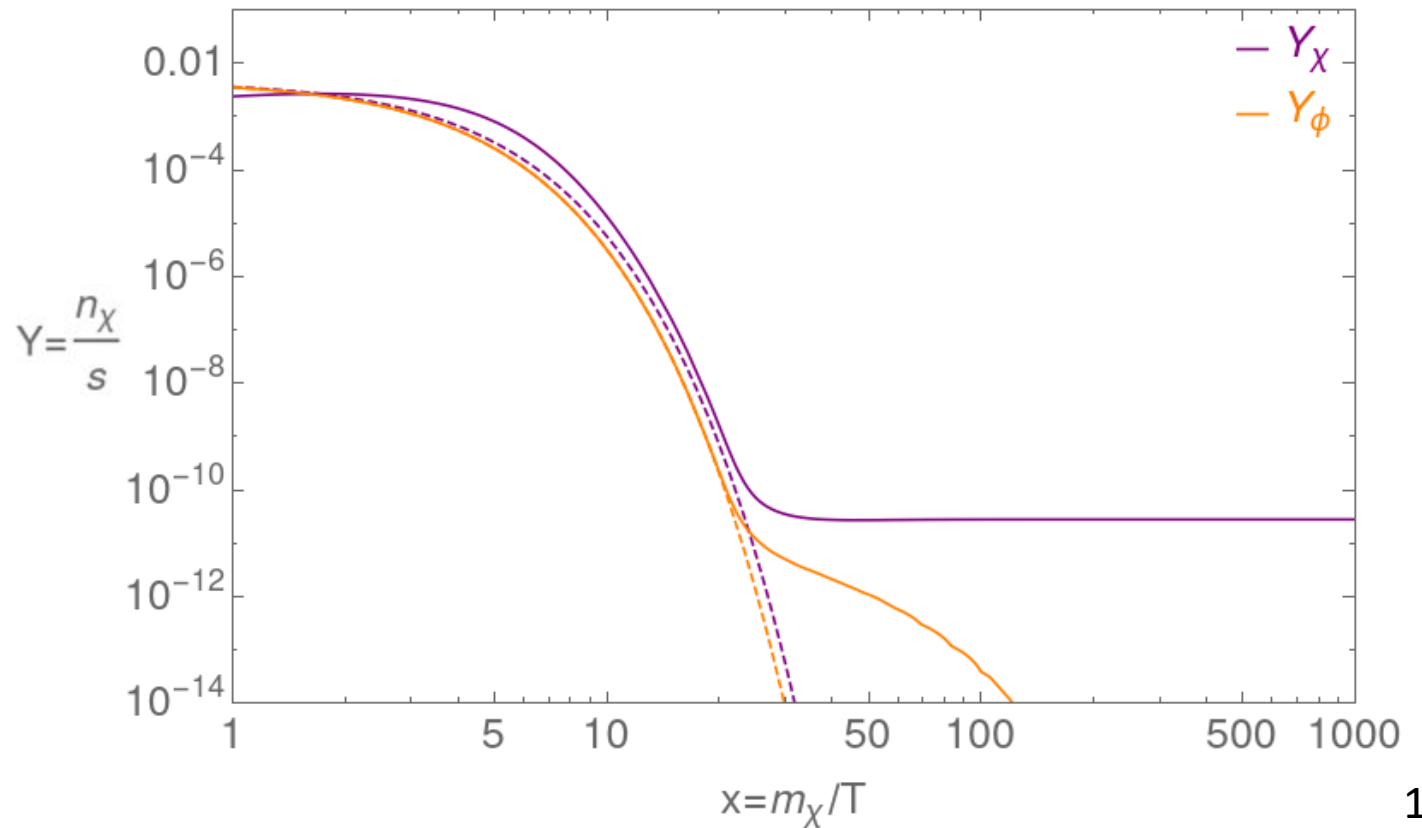
$$\lambda_\chi = 10^{-4}$$



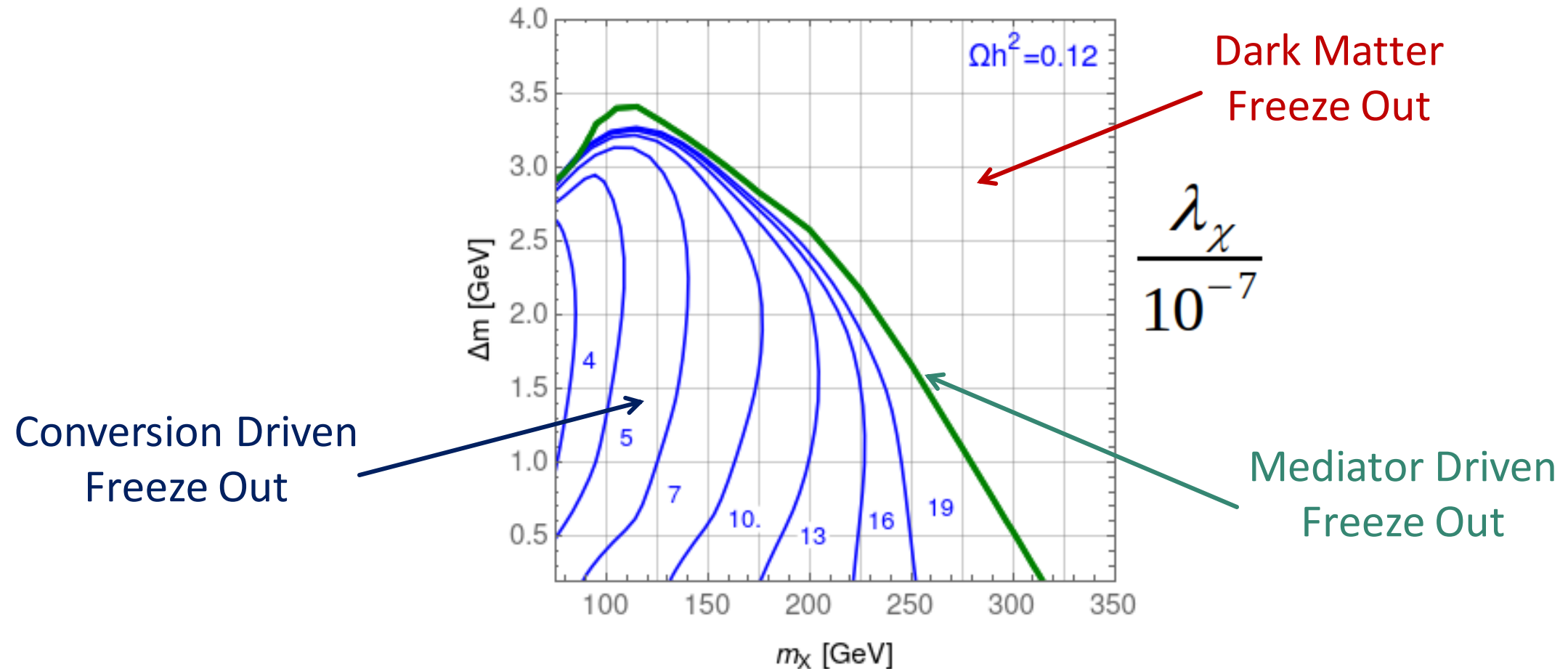
CONVERSION DRIVEN FREEZE-OUT



$$\lambda_\chi = 5 \cdot 10^{-7}$$



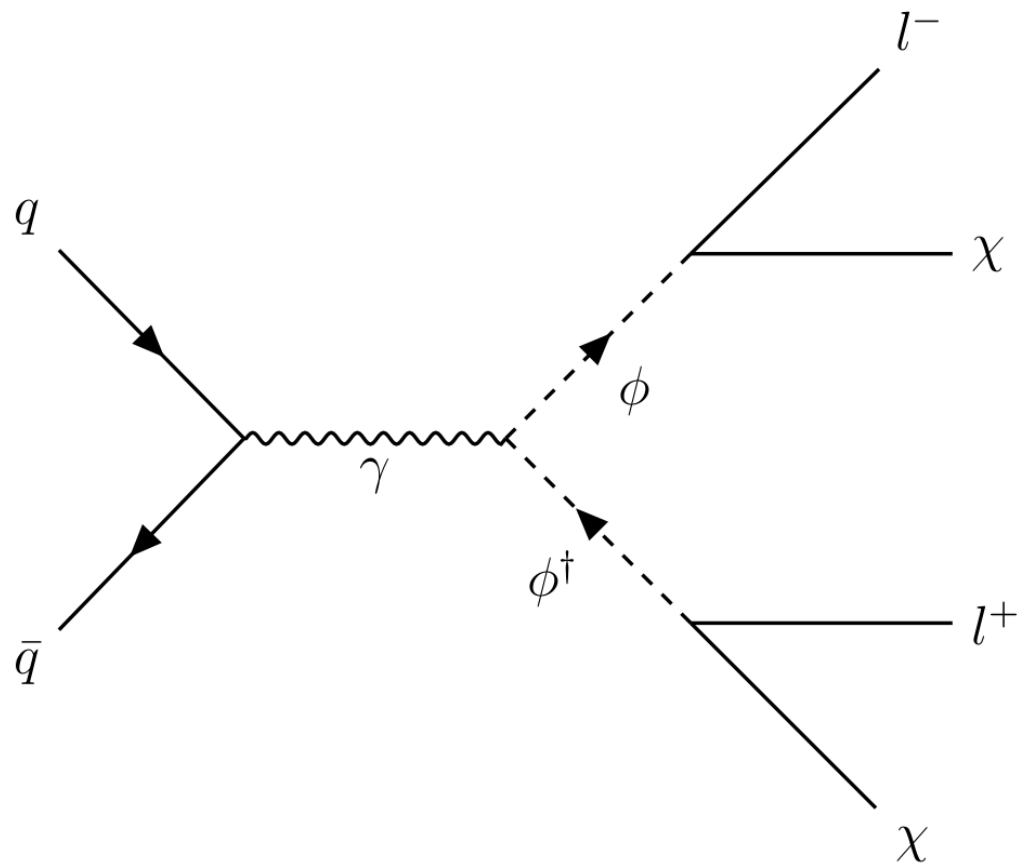
VIABLE PARAMETER SPACE FOR CONVERSION DRIVEN FREEZE OUT



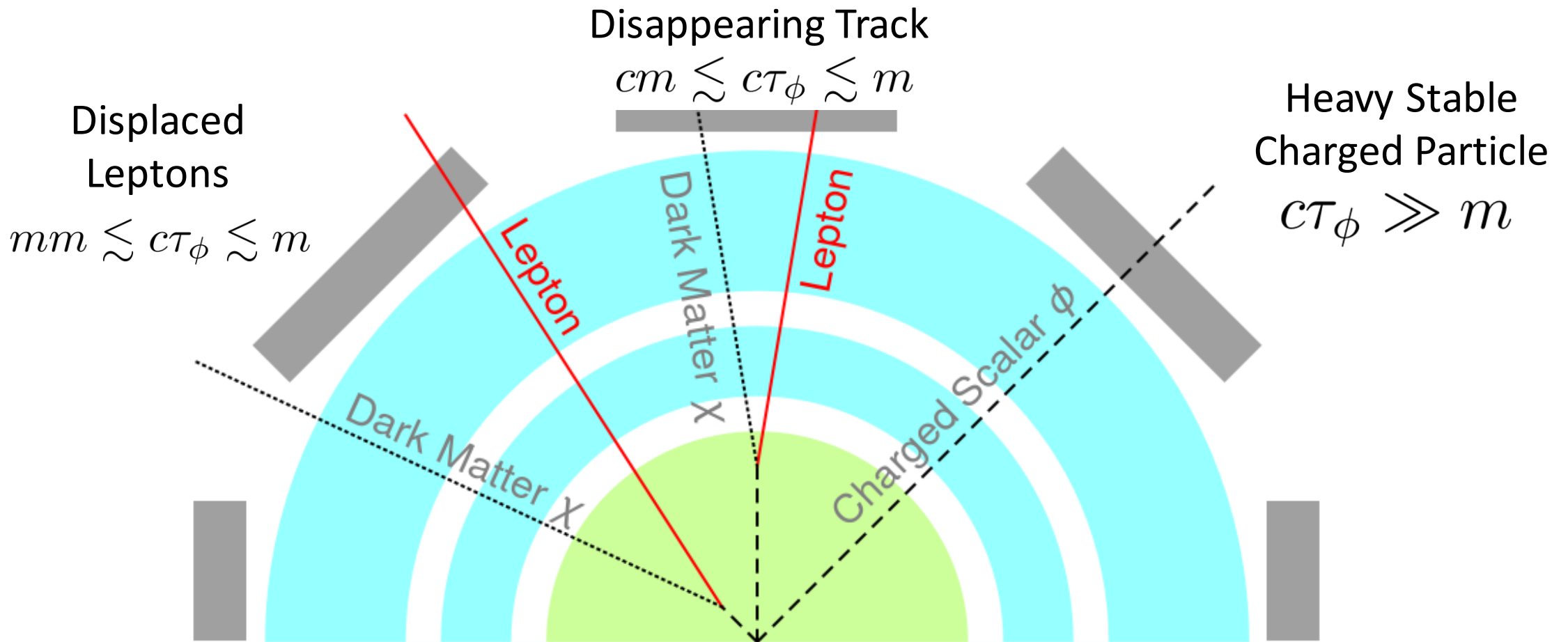
The background is a dark blue field filled with various white and light blue circular diagrams. These diagrams represent particle detector components, including circular tracks with arrows indicating direction, concentric circles, and segments with numerical labels (e.g., 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260).

LONG LIVED COLLIDER SIGNATURES

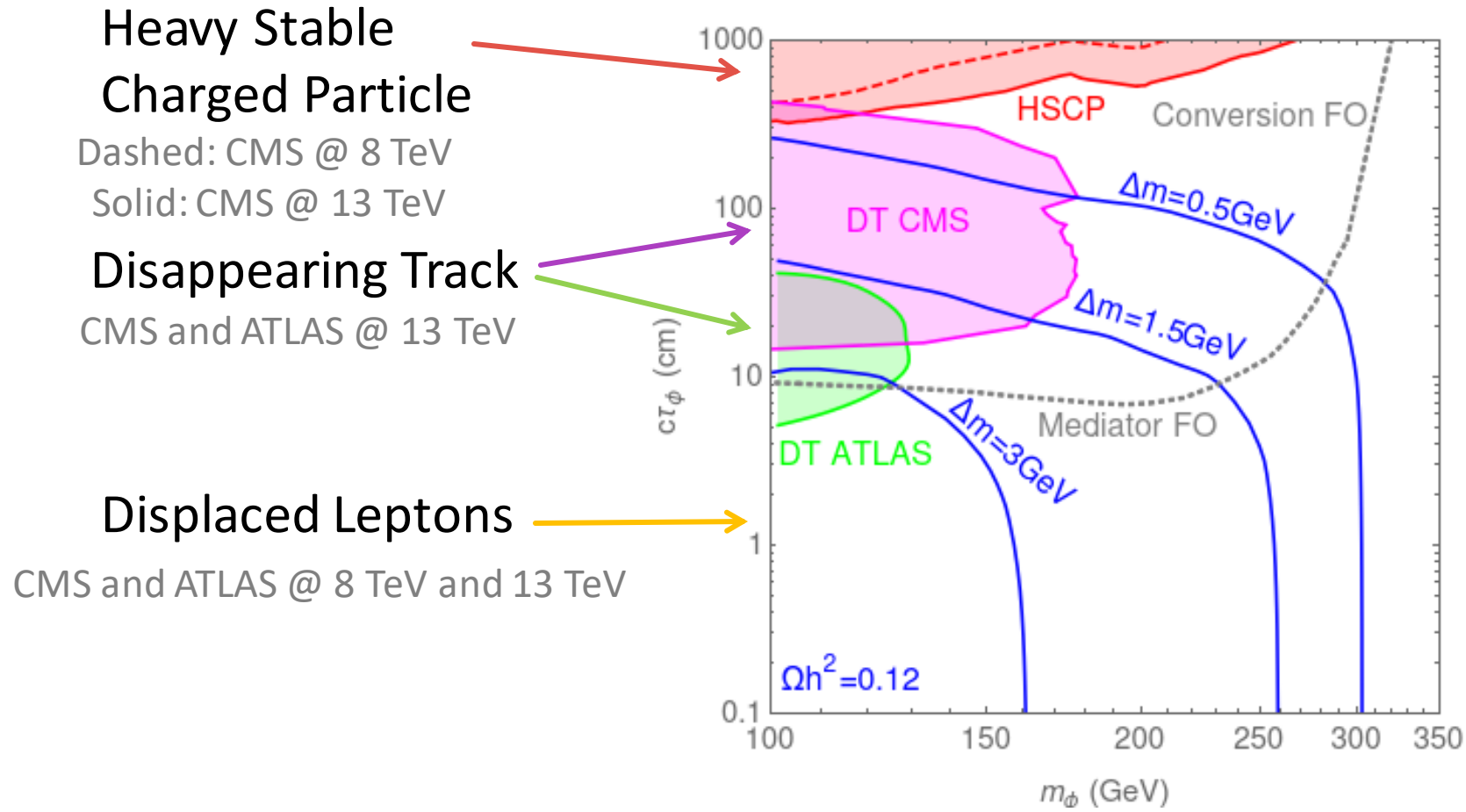
LONG LIVED COLLIDER SIGNATURES



LONG LIVED COLLIDER SIGNATURES

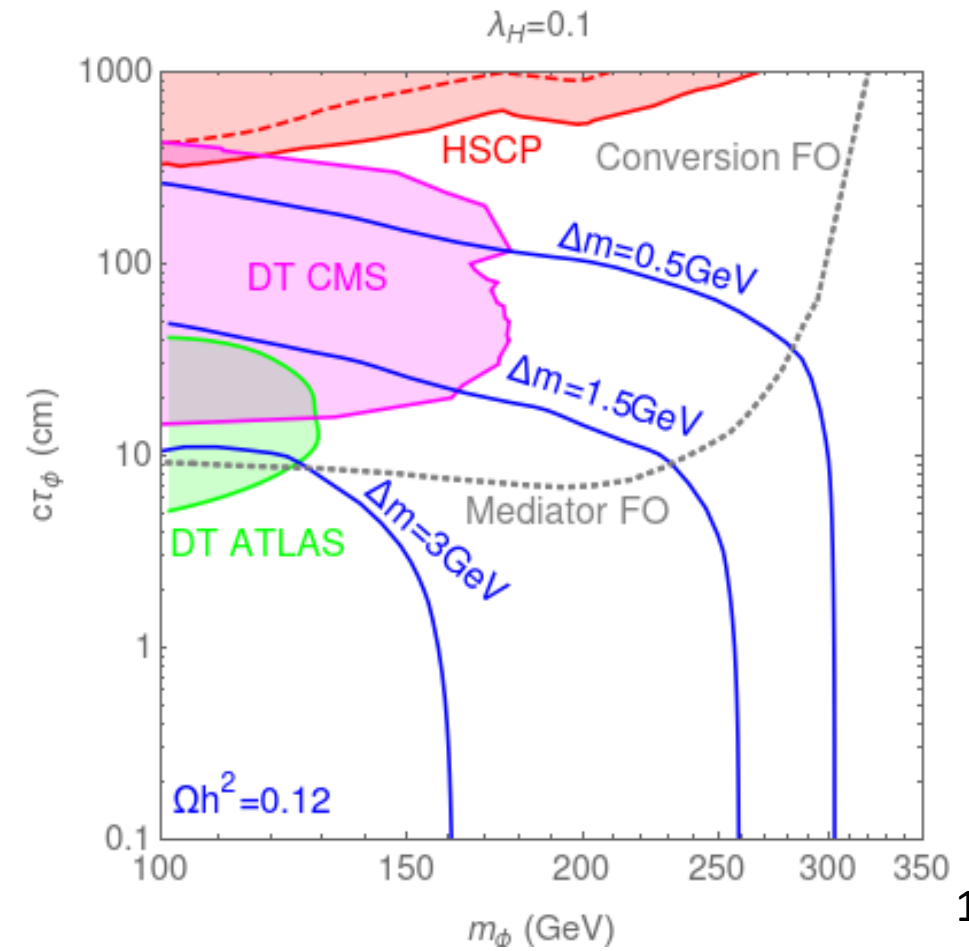


COLLIDER CONSTRAINTS



SUMMARY

- Leptophilic dark matter model
- Feebly interacting dark matter
- Novel production mechanism
- Long lived particle signatures at colliders

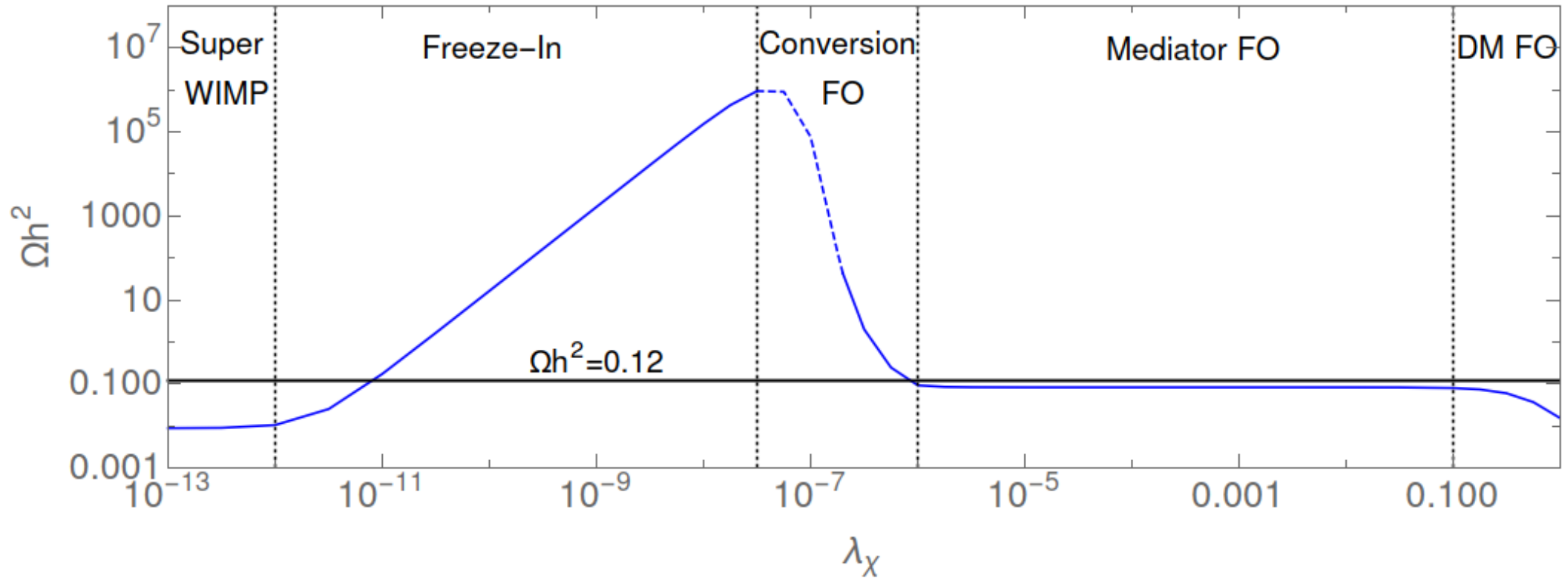


The background is a dark blue color with several faint, light blue circular patterns. These patterns include concentric circles, dashed lines, and solid lines, some with arrows indicating a clockwise direction. There are also degree markings around the perimeter of some of these circles, ranging from 0 to 260 in increments of 10. The overall aesthetic is technical and geometric.

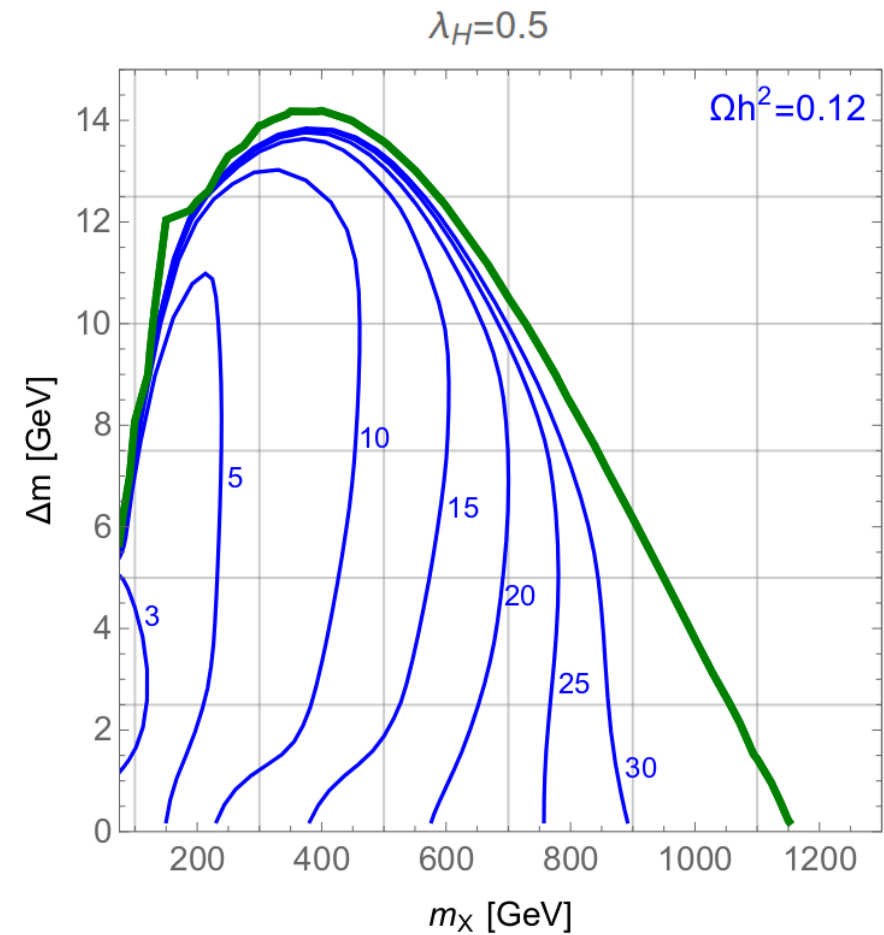
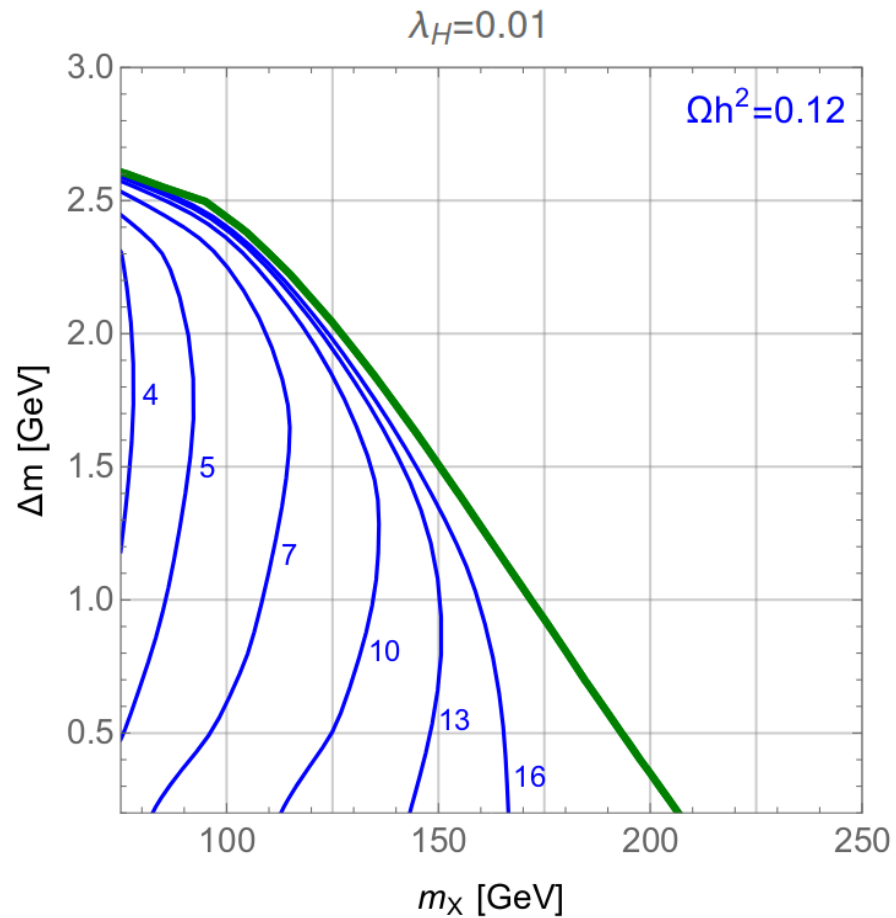
BACK-UP SLIDES

DARK MATTER PRODUCTION

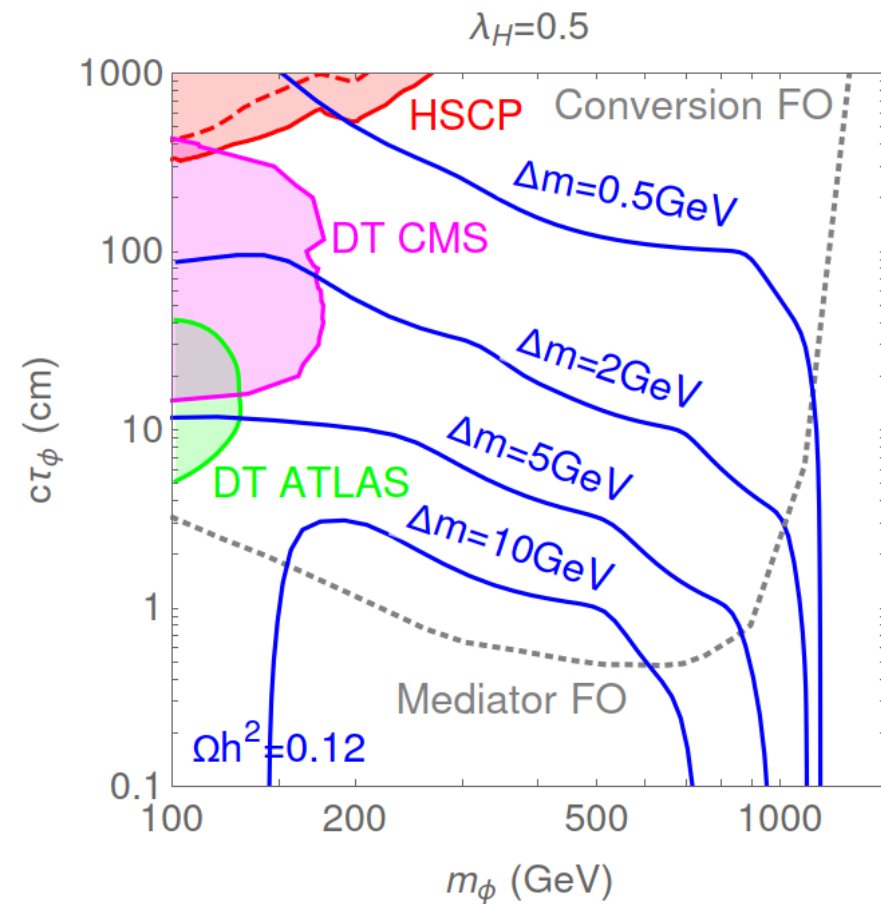
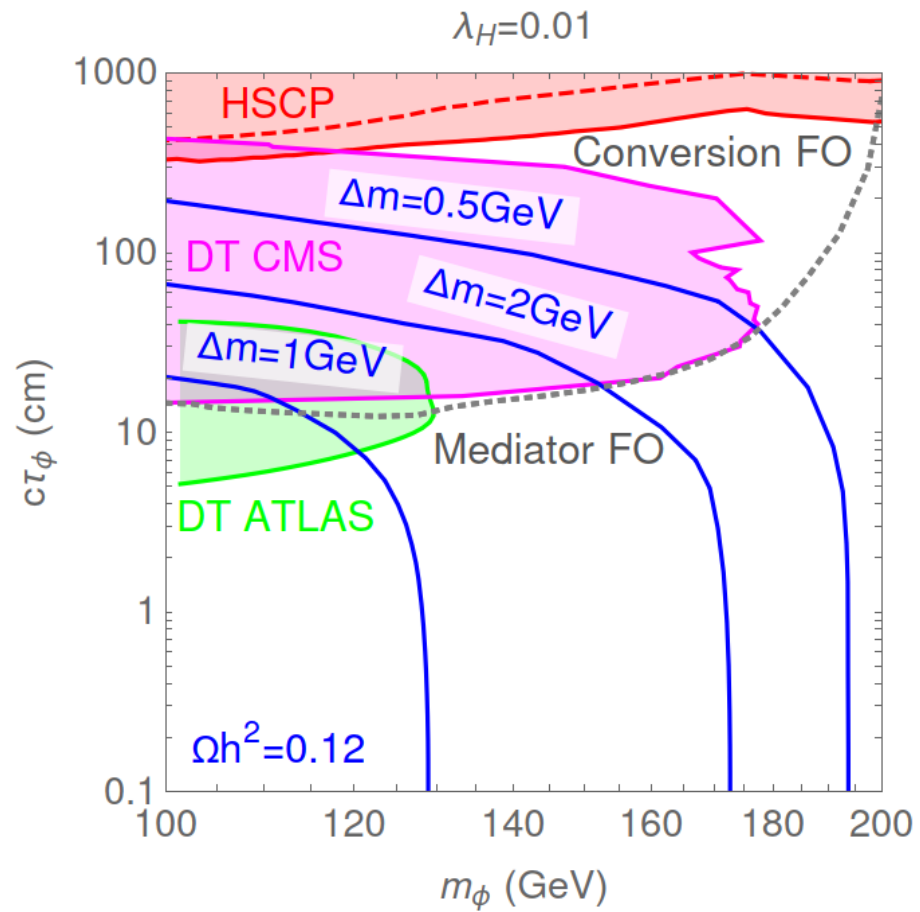
$m=150\text{GeV}, \Delta m=2\text{GeV}, \lambda_H=0.1$



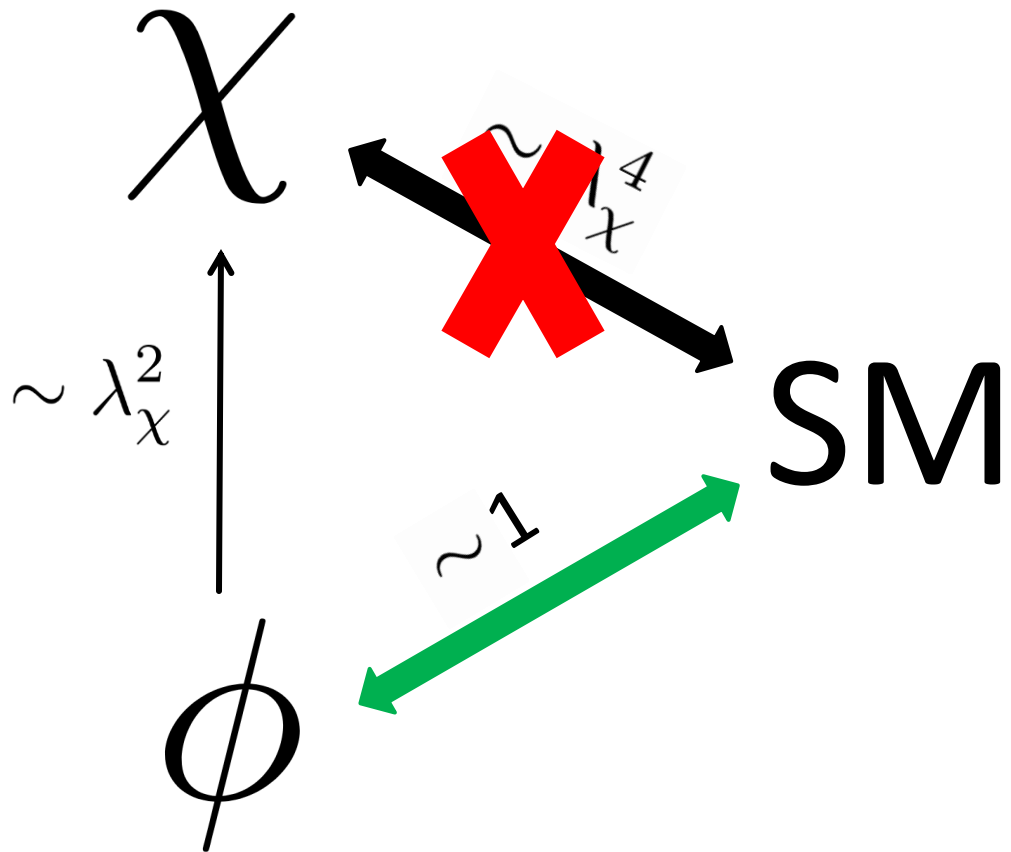
VIABLE PARAMETER SPACE FOR CONVERSION DRIVEN FREEZE OUT



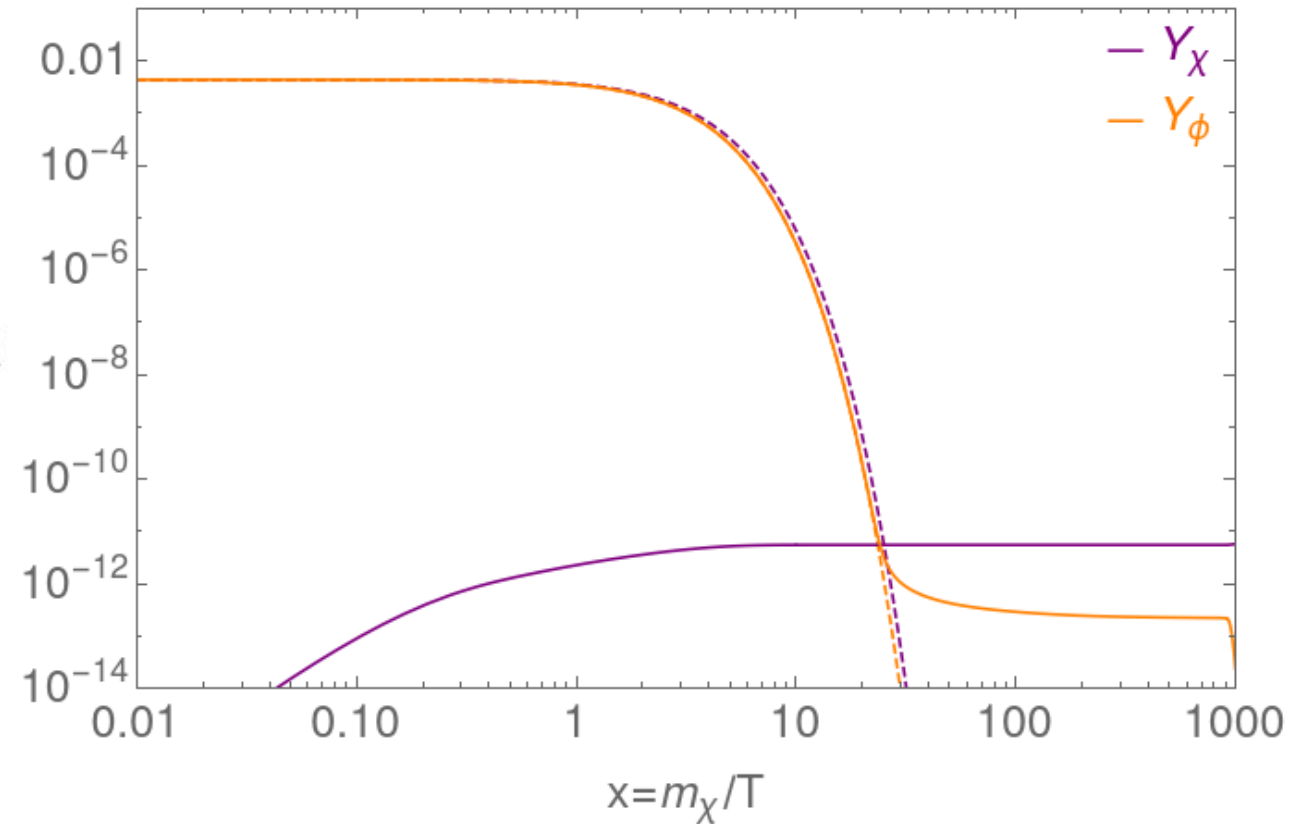
COLLIDER CONSTRAINTS



FREEZE-IN

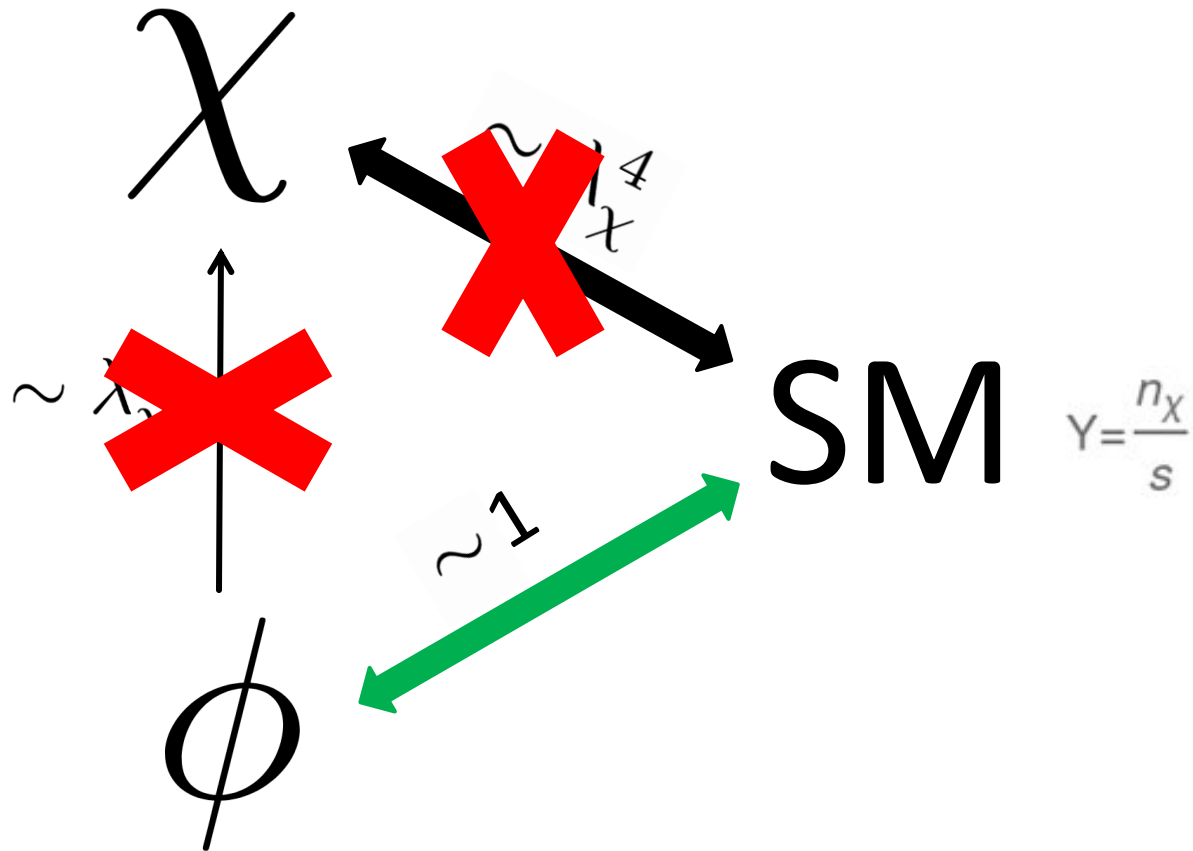


$$Y = \frac{n_\chi}{s}$$

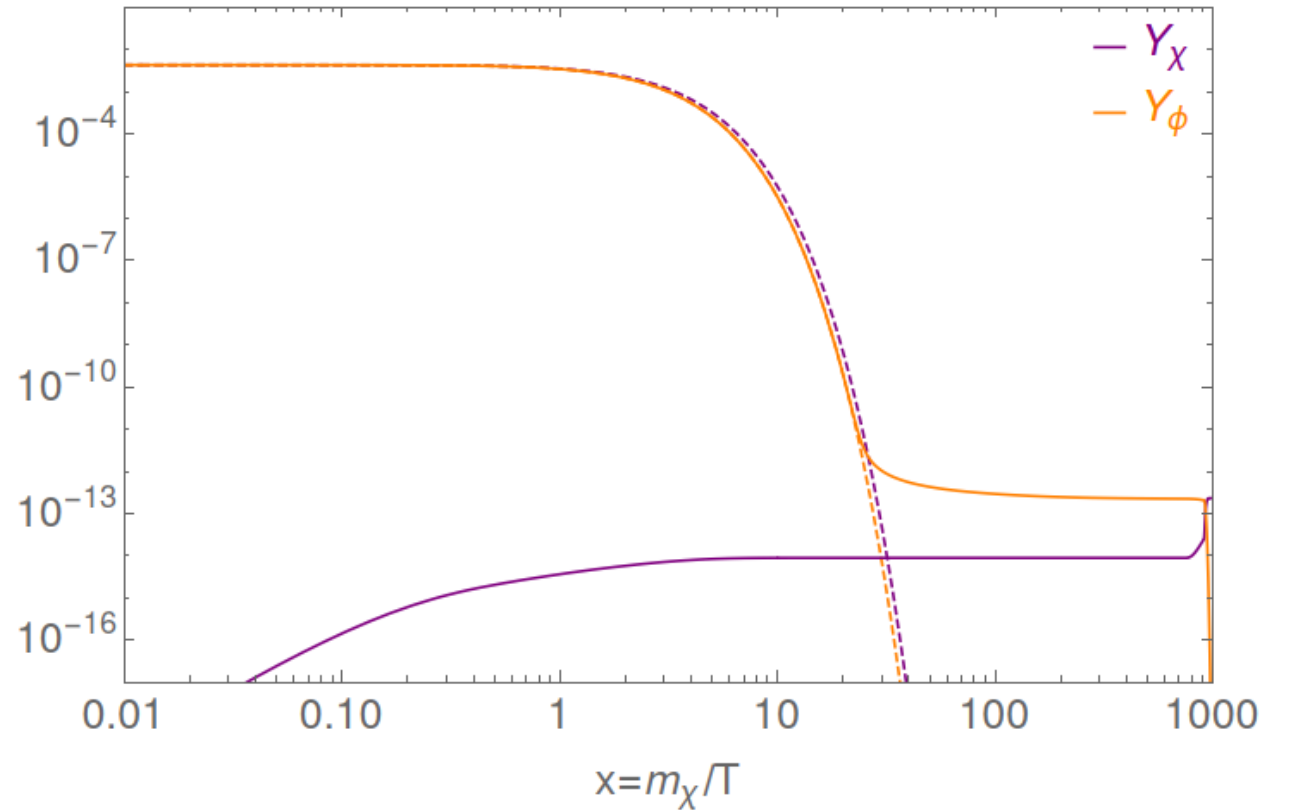


SUPERWIMP

$$\lambda_\chi = 10^{-13}$$



$$Y = \frac{n_\chi}{s}$$



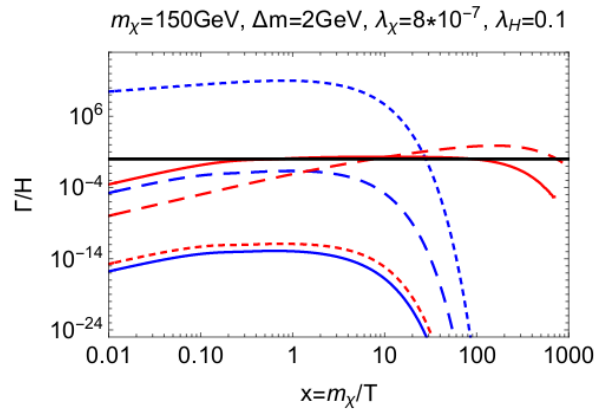
COANNIHILATION DRIVEN FREEZE-OUT

$$\frac{dY_{DM}}{dx} = \frac{s\langle\sigma v_{\text{eff}}\rangle}{Hx} (Y_{DM}^2 - Y_{DM,eq}^2)$$

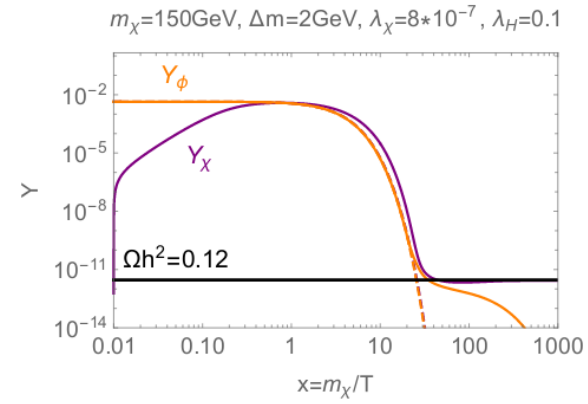
$$\langle\sigma v_{\text{eff}}\rangle \simeq \frac{1}{g_{\text{eff}}^2} \sum_{ij} r_i r_j \langle\sigma v\rangle_{ij} \quad \text{with} \quad g_{\text{eff}} = \sum_i r_i$$

$$\text{and} \quad r_i = g_i (1 + \Delta_i)^{3/2} \exp(-x_f \Delta_i).$$

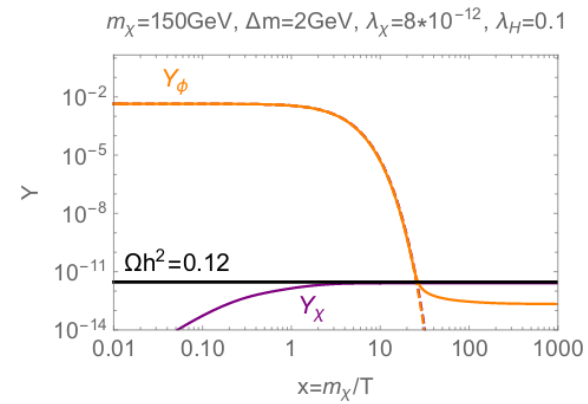
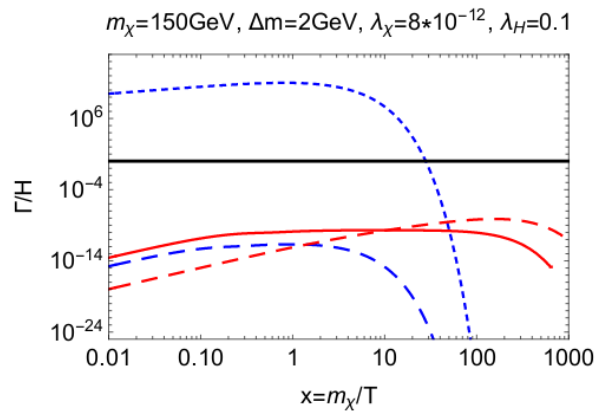
RATE COMPARISON



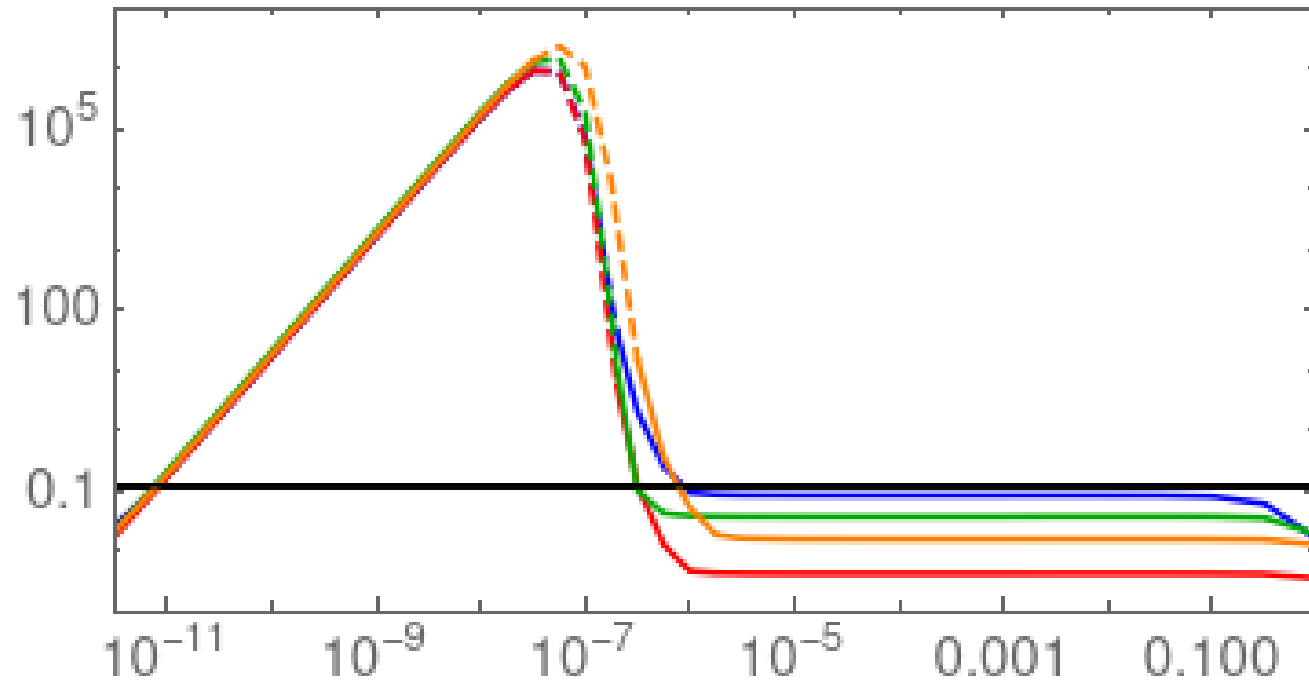
(a)



(b)



DEPENDENCE ON PARAMETERS



— $m=150\text{ GeV}, \Delta m=2\text{ GeV}, \lambda_H=0.1$

— $m=150\text{ GeV}, \Delta m=2\text{ GeV}, \lambda_H=0.5$

— $m=150\text{ GeV}, \Delta m=8\text{ GeV}, \lambda_H=0.5$

— $m=300\text{ GeV}, \Delta m=2\text{ GeV}, \lambda_H=0.5$

BOLTZMANN EQUATIONS

$$\frac{dY_\chi}{dx} = \frac{-2}{Hxs} \left[\gamma_{\chi\chi} \left(\frac{Y_\chi^2}{Y_{\chi,eq}^2} - 1 \right) + \gamma_{\chi\phi} \left(\frac{Y_\chi Y_\phi}{Y_{\chi,eq} Y_{\phi,eq}} - 1 \right) + \gamma_{\chi \rightarrow \phi} \left(\frac{Y_\chi}{Y_{\chi,eq}} - \frac{Y_\phi}{Y_{\phi,eq}} \right) + \gamma_{\chi\chi \rightarrow \phi\phi^\dagger} \left(\frac{Y_\chi^2}{Y_{\chi,eq}^2} - \frac{Y_\phi^2}{Y_{\phi,eq}^2} \right) \right]$$

$$\frac{dY_\phi}{dx} = \frac{-2}{Hxs} \left[\gamma_{\phi\phi^\dagger} \left(\frac{Y_\phi^2}{Y_{\phi,eq}^2} - 1 \right) + \gamma_{\chi\phi} \left(\frac{Y_\chi Y_\phi}{Y_{\chi,eq} Y_{\phi,eq}} - 1 \right) - \gamma_{\chi \rightarrow \phi} \left(\frac{Y_\chi}{Y_{\chi,eq}} - \frac{Y_\phi}{Y_{\phi,eq}} \right) - \gamma_{\chi\chi \rightarrow \phi\phi^\dagger} \left(\frac{Y_\chi^2}{Y_{\chi,eq}^2} - \frac{Y_\phi^2}{Y_{\phi,eq}^2} \right) \right]$$

COLLIDER SEARCHES

- Heavy Stable Charged Particles: CMS @ 13 TeV and 12.9 fb⁻¹
- Disappearing Tracks: CMS @ 13 TeV and 38.4 fb⁻¹
- Disappearing Tracks: ATLAS @ 13 TeV and 36.1 fb⁻¹
- Displaced Leptons: CMS @ 8 TeV and 19.7 fb⁻¹
- Displaced Leptons: CMS @ 13 TeV and 2.6 fb⁻¹