WIMP Benchmarks & the Neutrino Floor

Giorgio Arcadi

University of Messina

Based on
G.A., M. Lindner and S. Profumo
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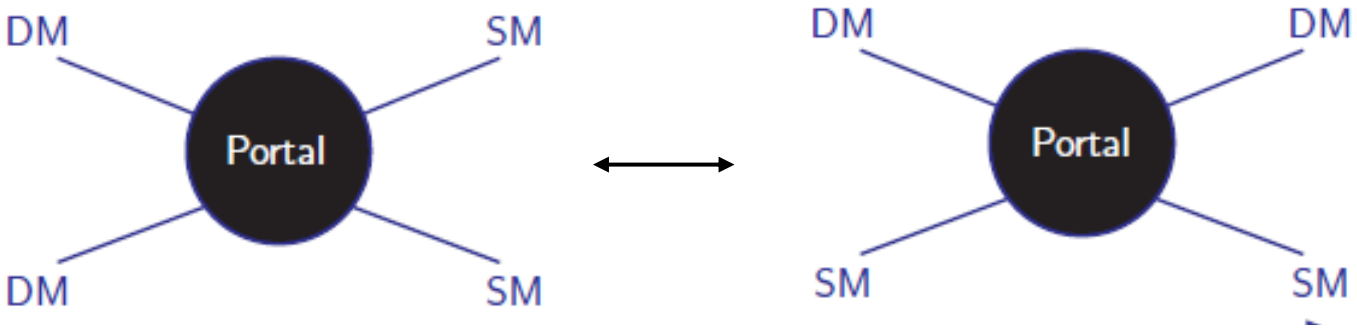
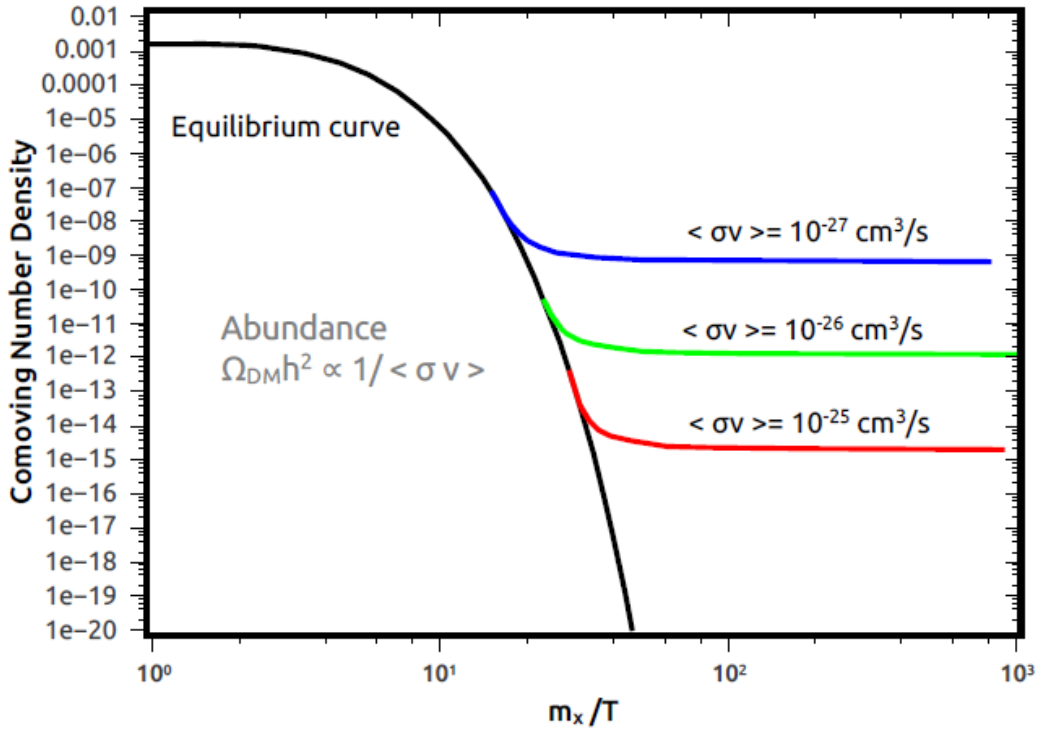
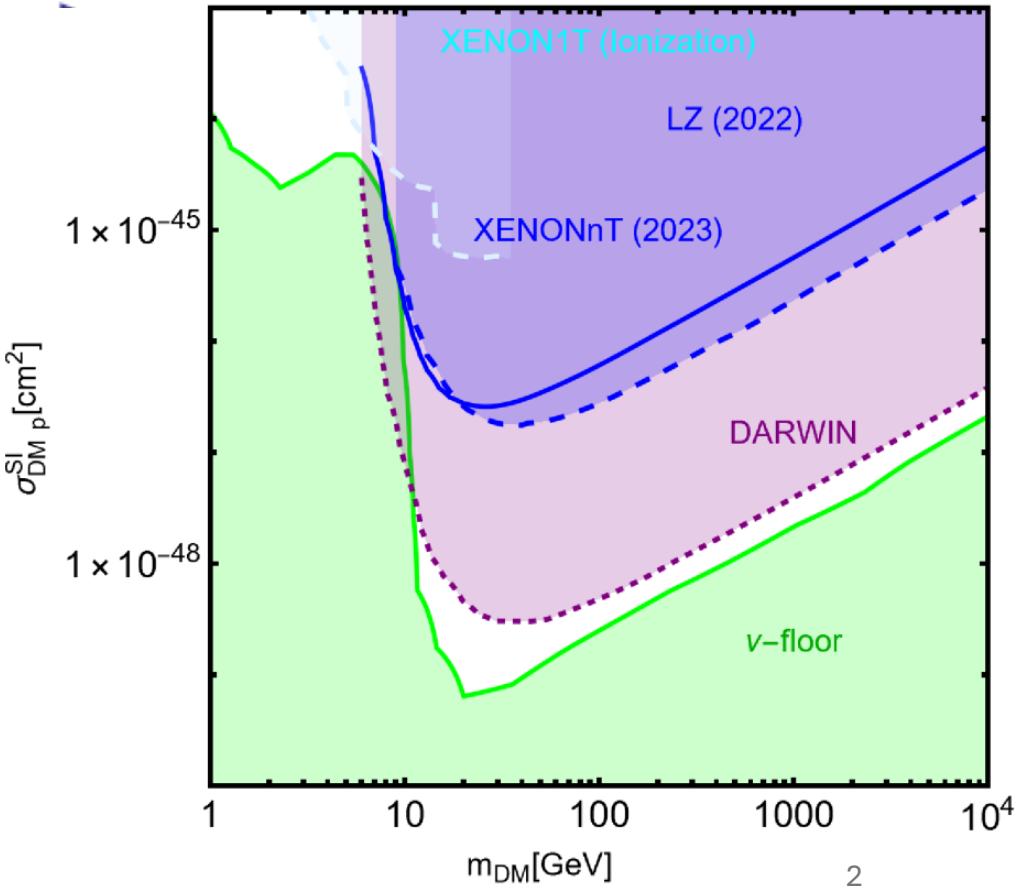
Relic Density vs DD



Relic Density

Direct Dection





DM Models

$$L = \mu_\chi^S \lambda_\chi^S \chi\chi S + \frac{1}{2}\left(\lambda_\chi^S\right)^2 \chi^2 S^2 + \frac{c_S}{\sqrt{2}} \bar{f} f S$$ Scalar spin-0 Portal

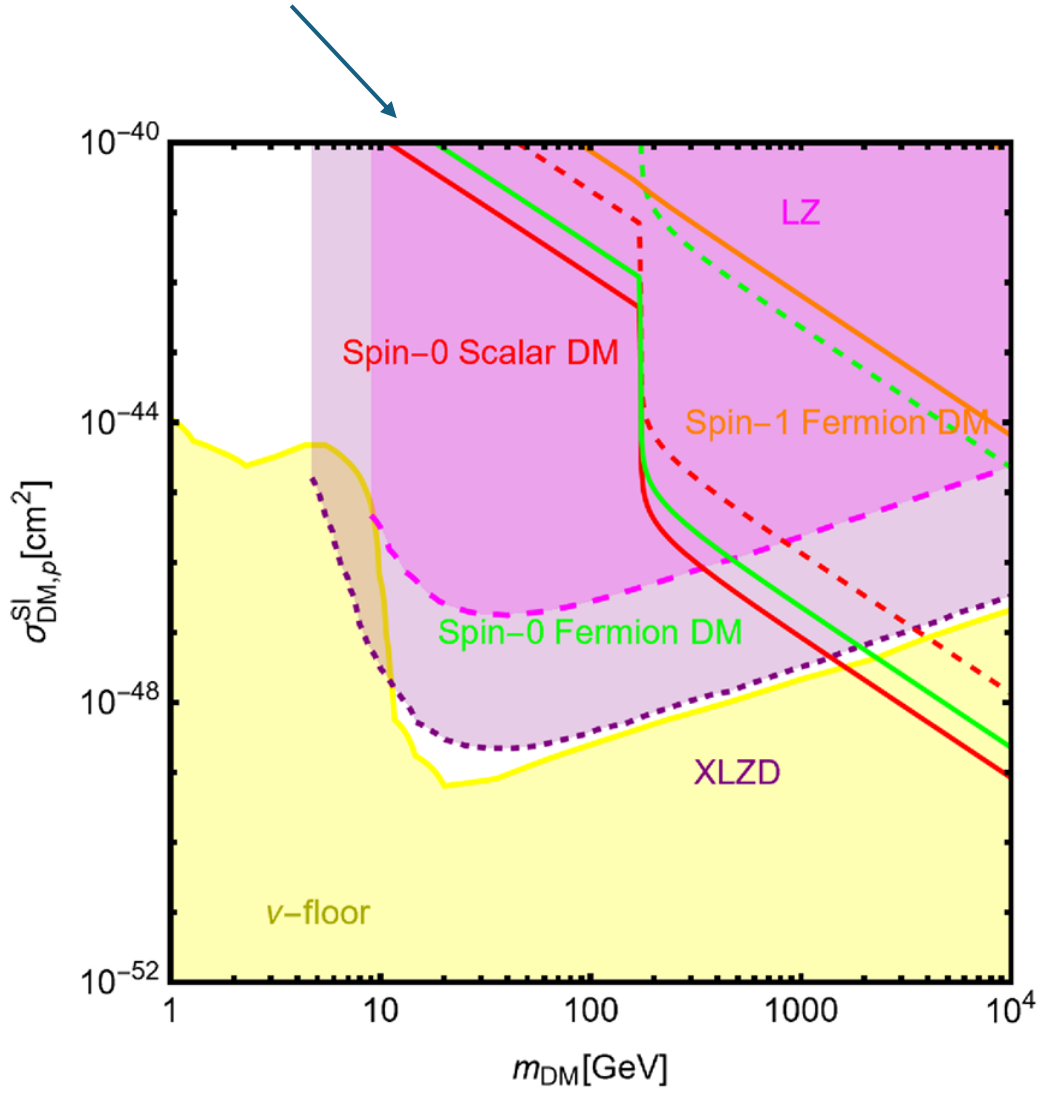
$$L = g_\psi \bar{\psi}\psi S + \frac{c_S}{\sqrt{2}} \bar{f} f S$$ Fermion spin-0 Portal

$$L = g_\psi^V \bar{\psi}\gamma^\mu \psi Z'_\mu + \mathrm{g}_\mathrm{f}^\mathrm{V} \bar{f}\gamma^\mu f Z'_\mu$$ Spin-1 Portal

$$L = \lambda_\chi \bar{f} P_R \Phi\chi + h.c.$$ t-channel Portal

$$L = \frac{g_2}{4}\sqrt{n^2-(2Y+1)^2}\,\bar{\chi}\gamma^\mu \psi^- W_\mu^+ + \frac{g_2}{4}\sqrt{n^2-(2Y-1)^2}\,\bar{\chi}\gamma^\mu \psi^+ W_\mu^- - \frac{i g_2 Y}{cos\theta_W}\bar{\chi}\gamma^\mu \eta Z_\mu$$ EW DM

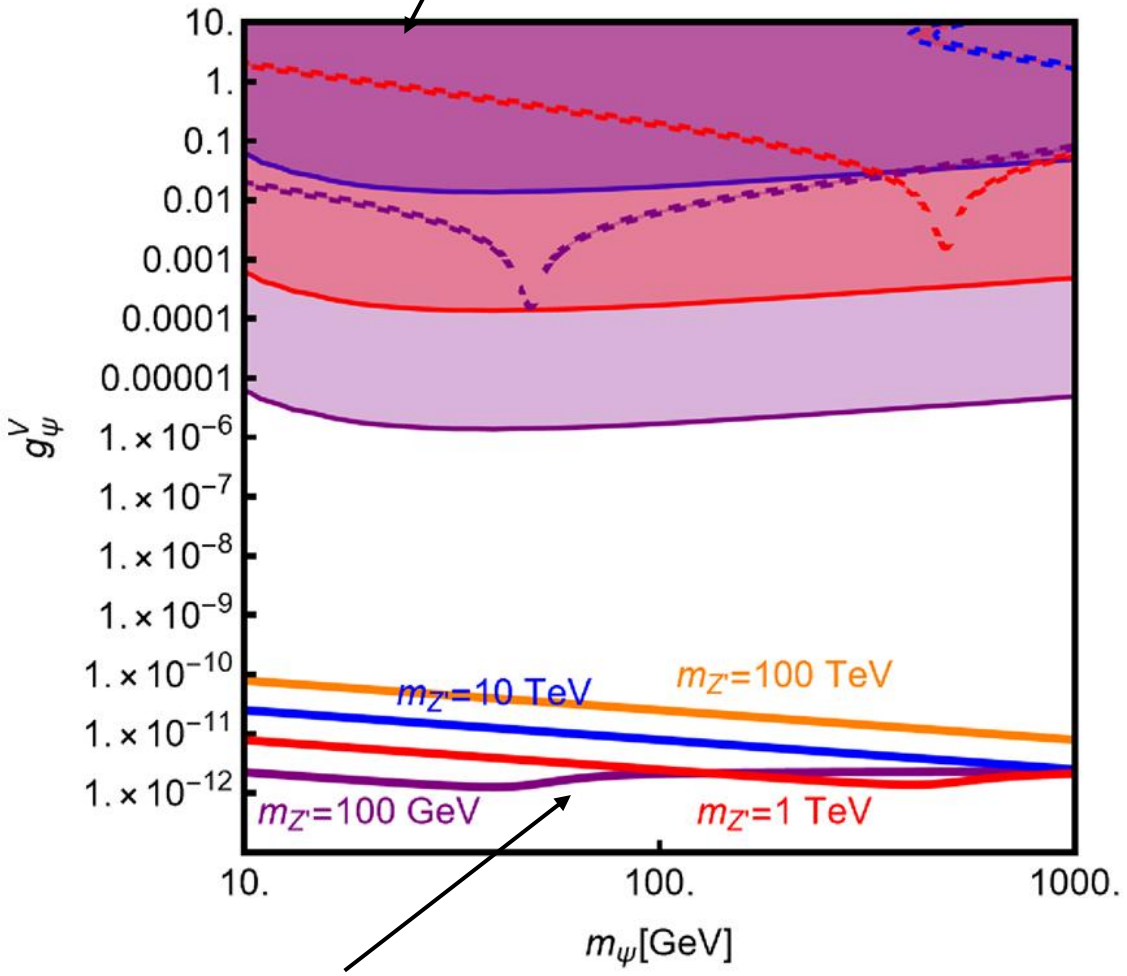
Minimal value of the couplings ensuring thermal equilibrium



Solid lines $\frac{m_{DM}}{m_{med}} = \frac{1}{3}$

Dashed lines $\frac{m_{DM}}{m_{med}} = \frac{1}{5}$

Thermal freeze-out



«Conventional» freeze-in

Purpose of this study:

Investigate how the parameter space to be probed through Direct Detection is affected by non-standard Cosmology/non-thermal DM production.

DM production in non-standard Cosmology

$$\frac{d\rho_\Phi}{dt} + 3\,(1+\omega)H\,\rho_\Phi = -\Gamma_\Phi \rho_\Phi$$

$$\frac{ds}{dt} + 3Hs = \frac{\Gamma_\Phi \rho_\Phi}{T}\left(1 - b_{DM}\frac{E_{DM}}{m_\Phi}\right) + 2\frac{E_{DM}}{T}\langle\sigma v\rangle\left(n_{DM}^2 - n_{DM,eq}^2\right)$$

$$\frac{dn_{DM}}{dt} + 3Hn_{DM} = \frac{b_{DM}}{m_\Phi}\Gamma_\Phi \rho_\Phi - \langle\sigma v\rangle\left(n_{DM}^2 - n_{DM,eq}^2\right)$$

$$\Phi = \rho_\Phi a^3 \Lambda^{-1} \qquad N_{DM} = n_{DM} a^{-3} \qquad A = a/a_I \qquad \widetilde{H} = (a_I A)^{3/2} H = \left(\frac{\Lambda\Phi + \rho_R(T) A^3 a_I^3 + E_{DM} N_{DM}}{3 M_{Pl}^2} \right)^{1/2}$$

$$\frac{d\Phi}{dA} = -\frac{\Gamma_\Phi}{\widetilde{H}} A^{1/2} a_I^{3/2} \Phi$$

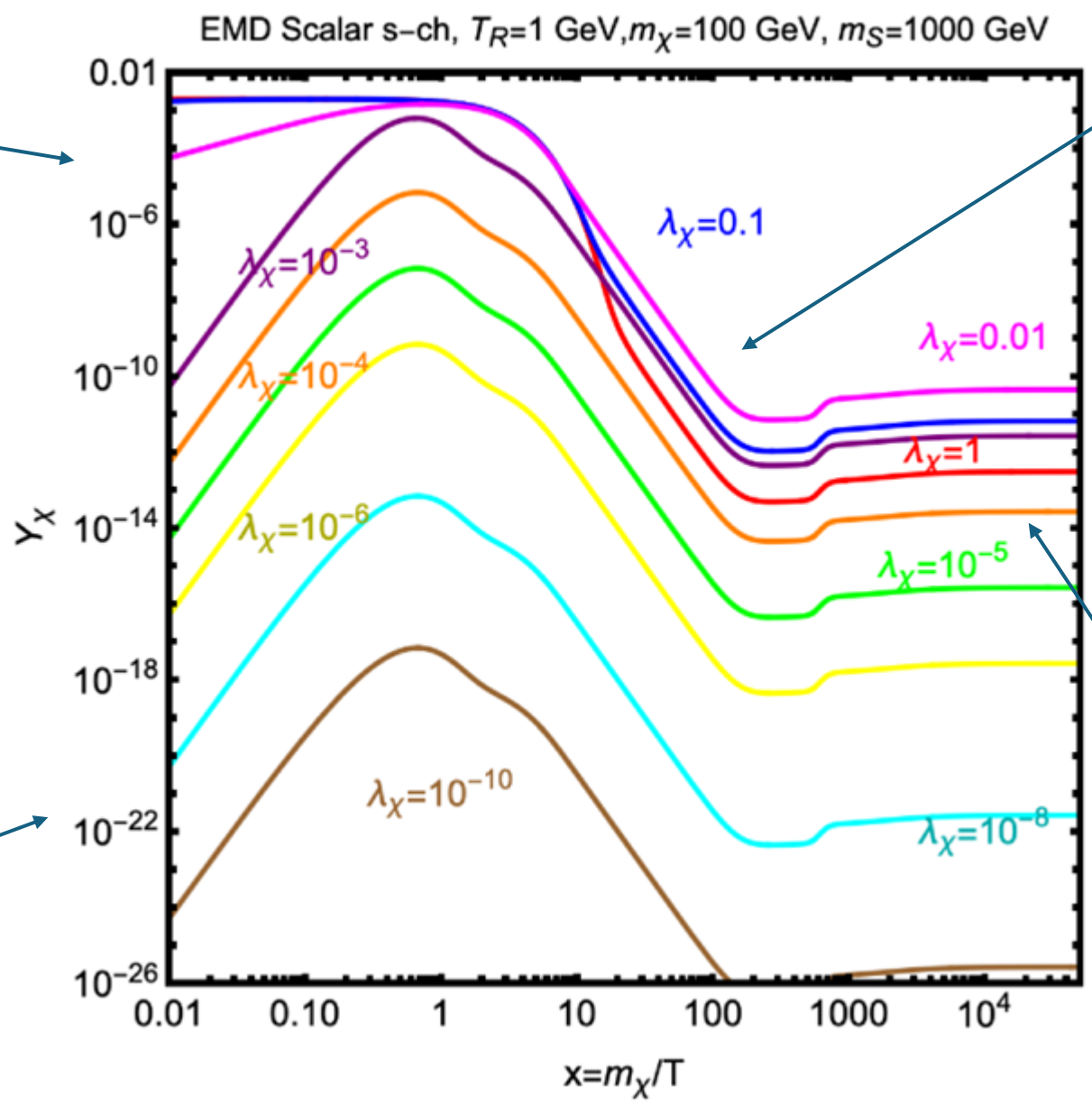
$$\frac{dN_{DM}}{dA} = \frac{A^{1/2} a_I^{3/2}}{\widetilde{H}} \Lambda \frac{b_{DM}}{m_\Phi} \Gamma_\Phi \Phi - \frac{\langle \sigma v \rangle}{\widetilde{H}} A^{-5/2} a_I^{-3/2} \left(N_{DM}^2 - N_{DM,eq}^2 \right)$$

$$\frac{dT}{dA} = \left(1 + \frac{T}{3} \frac{dh_{eff}}{dT} \right)^{-1} \left\{ -\frac{T}{A} + \frac{\Gamma_\Phi \Lambda}{m_\Phi} \left(1 - \frac{b_{DM} E_{DM}}{m_\Phi} \right) \frac{T}{s\widetilde{H}} A^{-5/2} a_I^{-3/2} \Phi + 2 \frac{E_{DM}}{s\widetilde{H}} A^{-11/2} a_I^{-9/2} \langle \sigma v \rangle \left(N_{DM}^2 - N_{DM,eq}^2 \right) \right\}$$

Case $b_{DM} = 0$

(thermal production of DM during non-standard cosmological evolution)

At high coupling the DM enters in chemical equilibrium at Early times



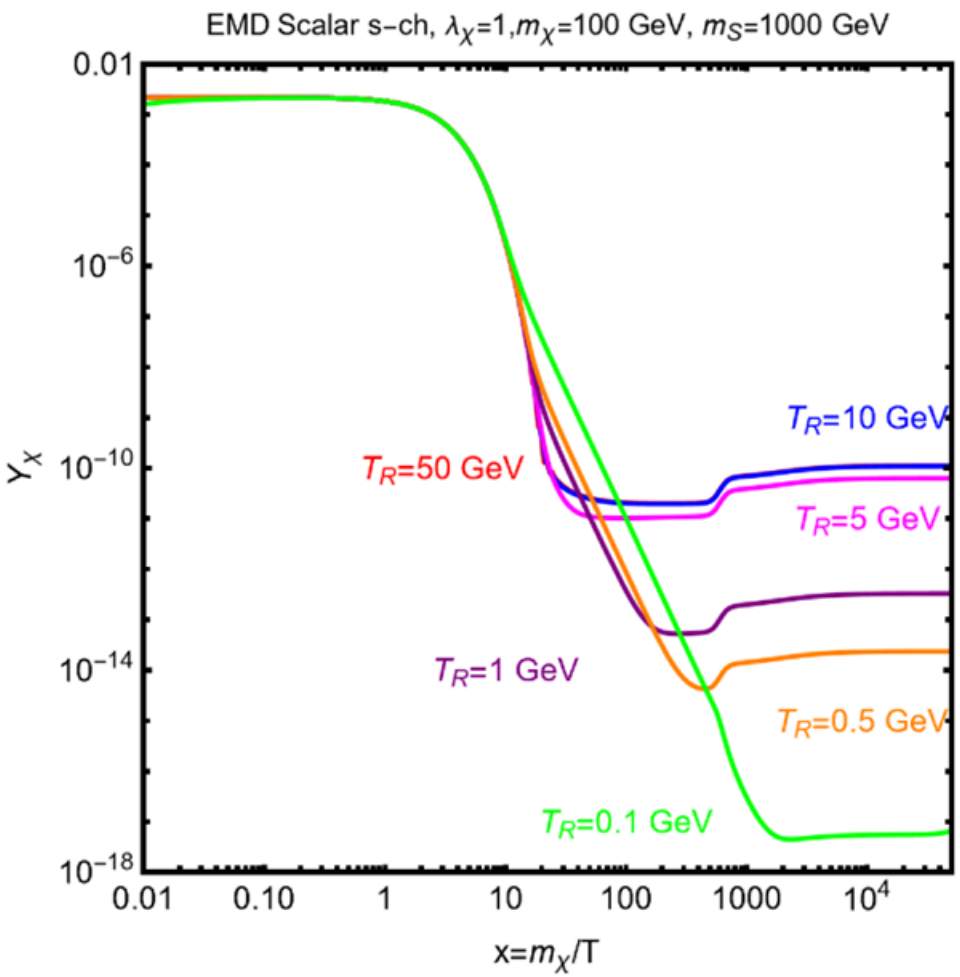
Dilution from entropy injection

At low couplings the DM never comes into thermal equilibrium

Final relic density

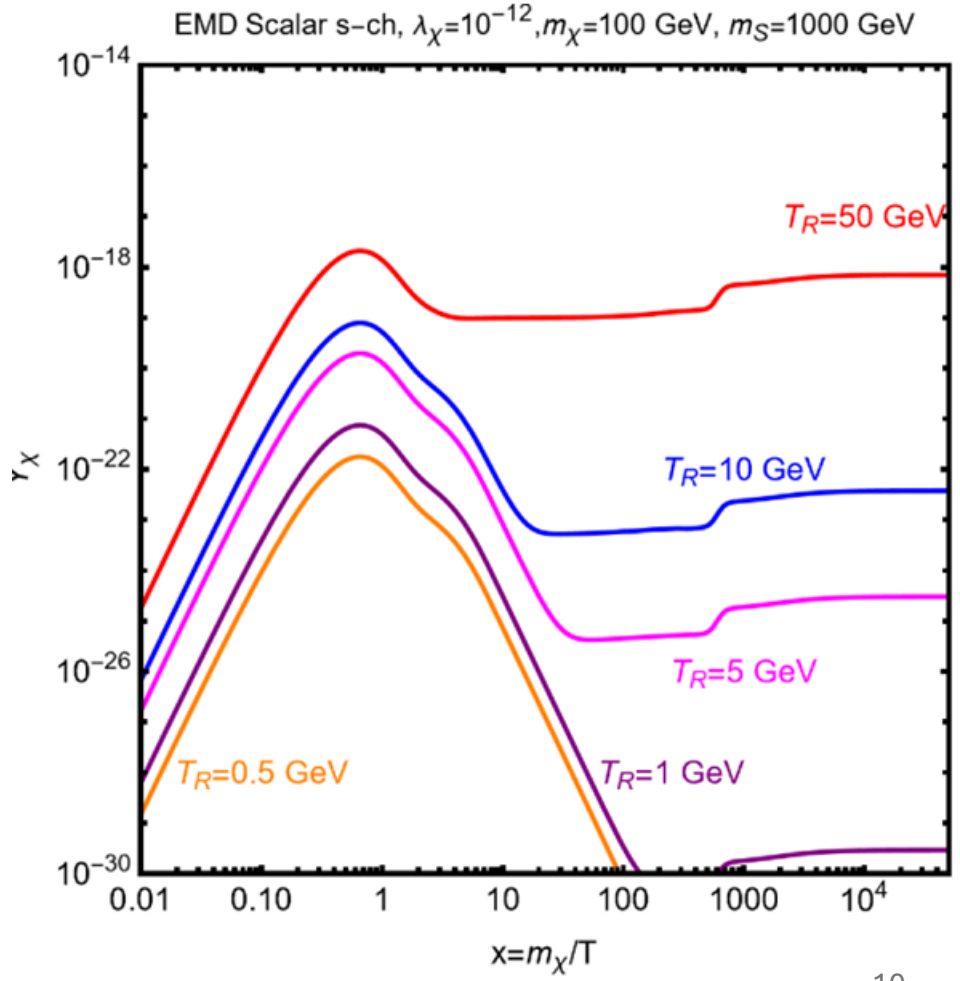
Production with chemical equilibrium

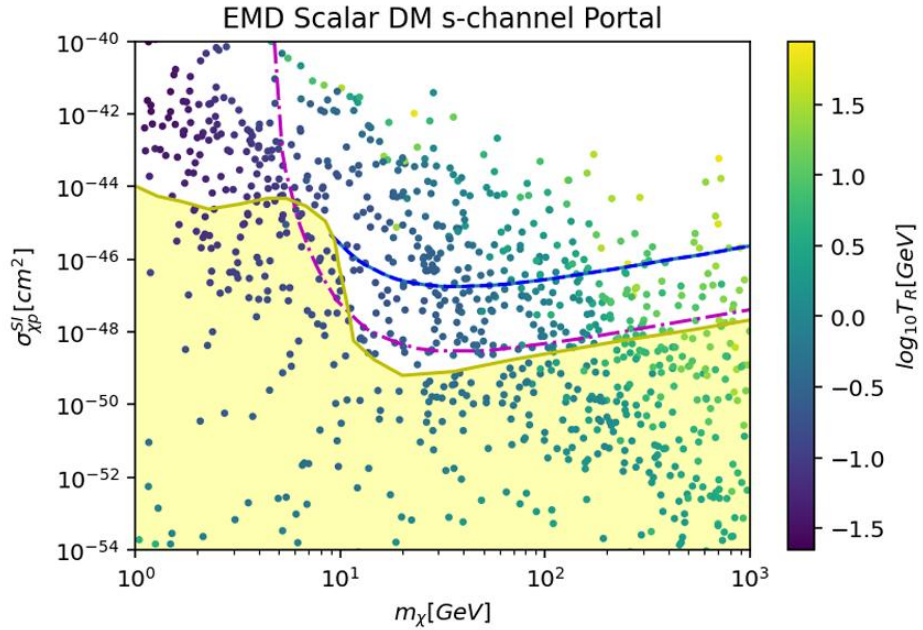
$$\Omega_{DM}^{EMD} = \frac{T_R^3 T_{s.f.o.}}{T_{f.o.}^4}\Omega_{DM}^{T}$$

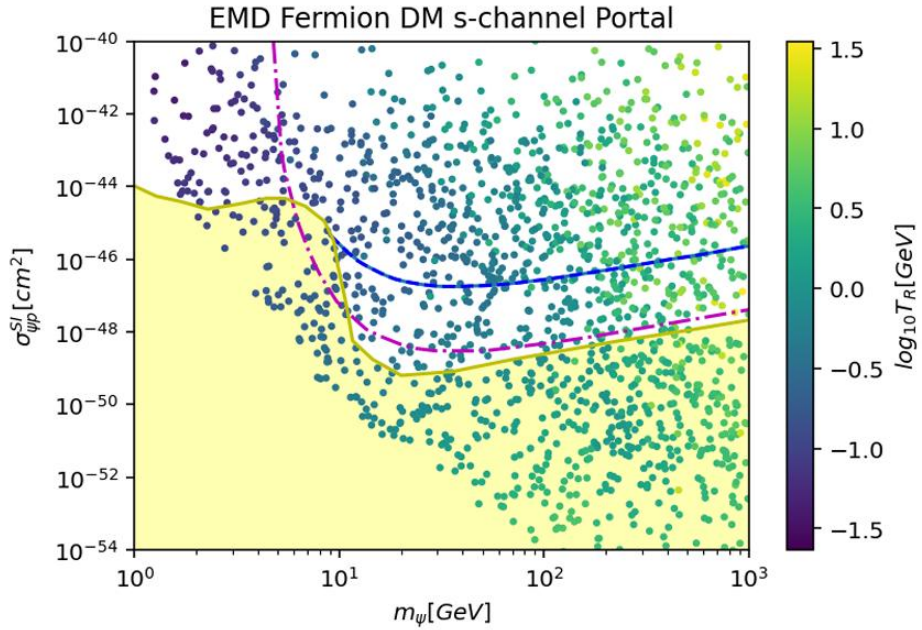


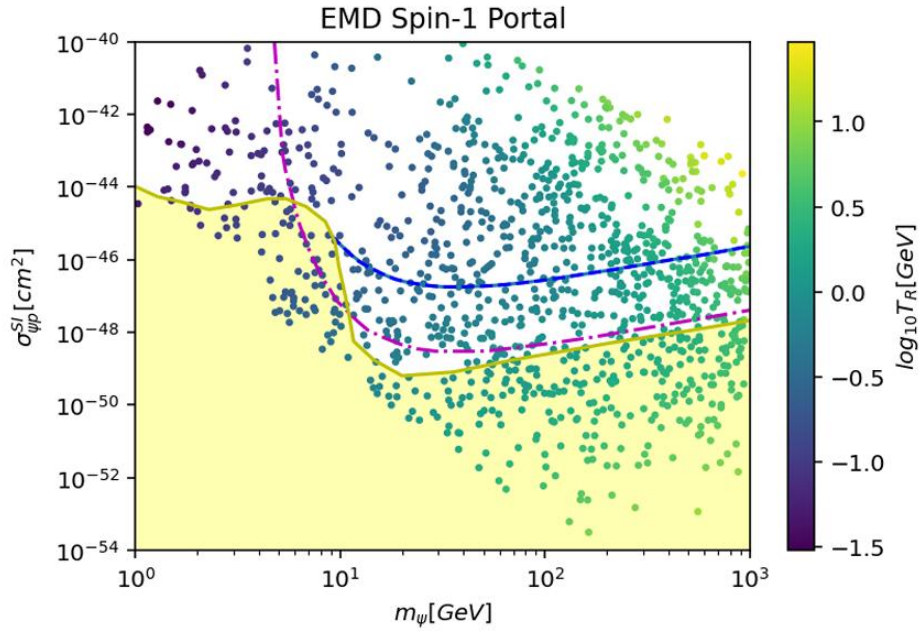
Production without chemical equilibrium

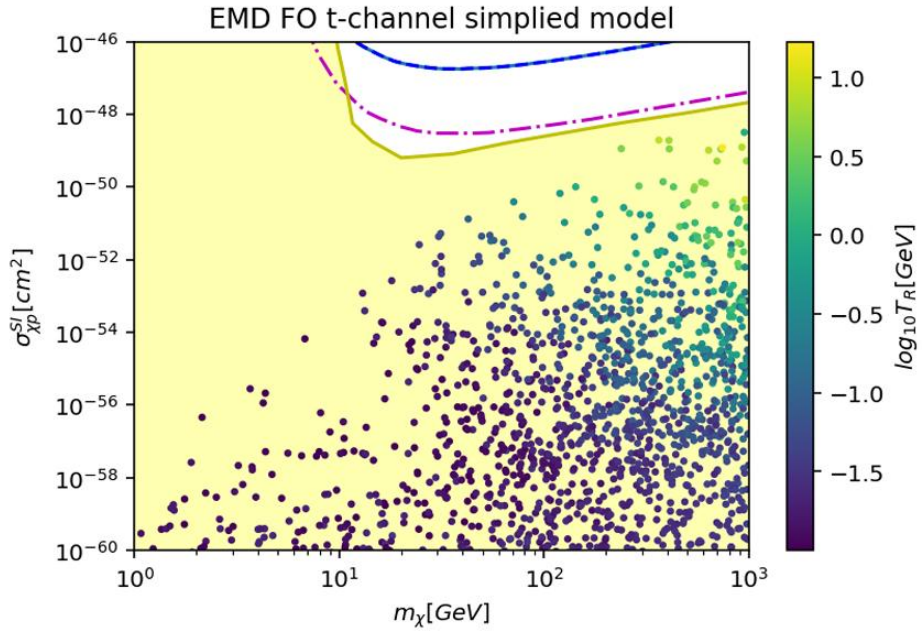
$$\Omega_{DM}^{EMD} = 0.12\,\frac{\langle\sigma v\rangle}{10^{-16}GeV^{-2}}\left(\frac{100\ GeV}{m_{DM}}\right)\left(\frac{T_R}{1\ GeV}\right)^7$$




EMD Scalar DM s-channel Portal
$\sigma^{SI}_{\chi p}[cm^2]$
$m_\chi[GeV]$
$log_{10}T_R[GeV]$


EMD Fermion DM s-channel Portal
$\sigma^{SI}_{\psi p}[cm^2]$
$m_\psi[GeV]$
$log_{10}T_R[GeV]$


EMD Spin-1 Portal
$\sigma^{SI}_{\psi p}[cm^2]$
$m_\psi[GeV]$
$log_{10}T_R[GeV]$

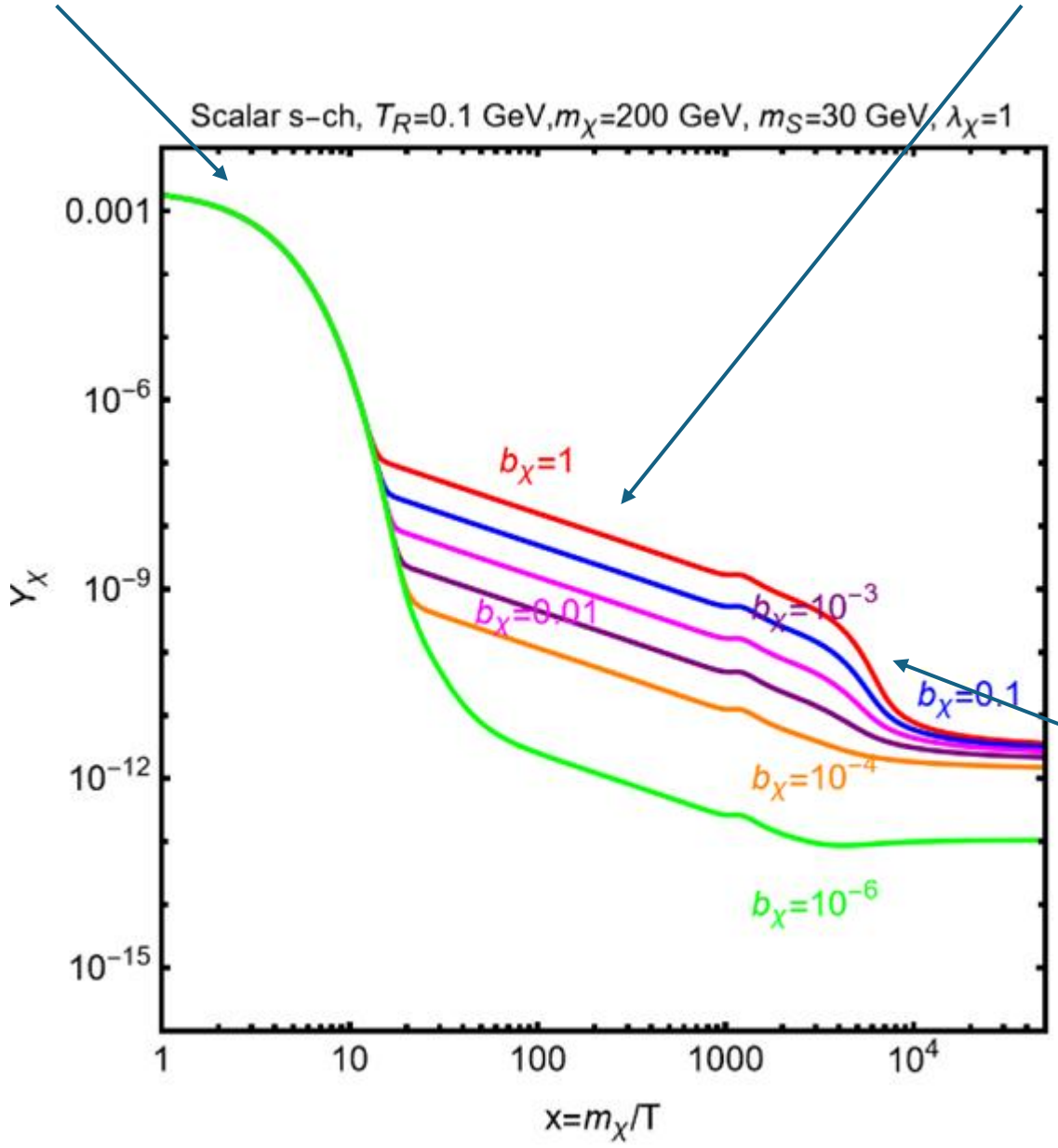

EMD FO t-channel simplied model
$\sigma^{SI}_{\chi p}[cm^2]$
$m_\chi[GeV]$
$log_{10}T_R[GeV]$

Case $b_{DM} \neq 0$

(non-thermal production of DM during non-standard cosmological evolution)

Thermal equilibrium at Early times

Dilution from entropy injection.



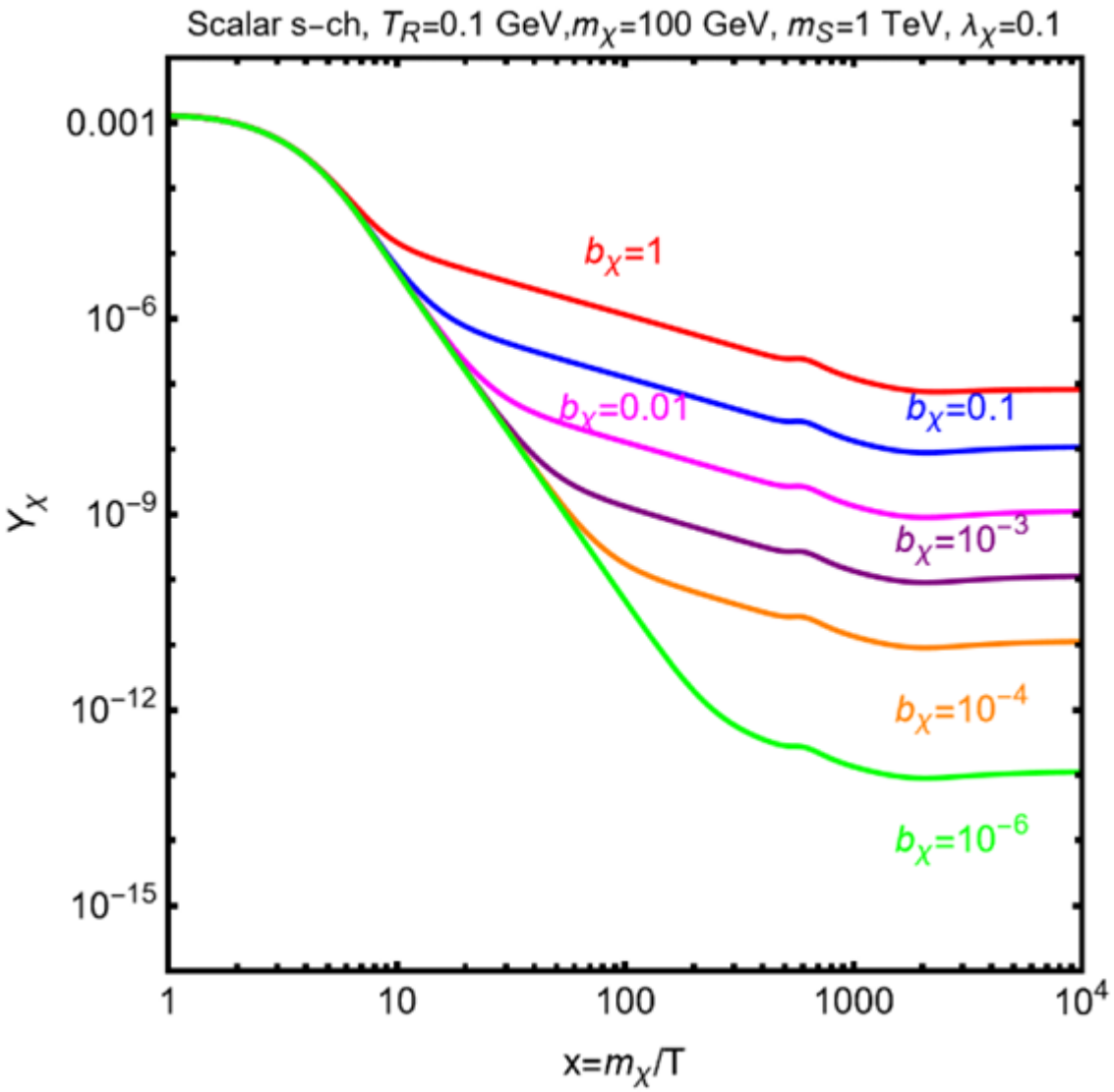
$$\Omega_{DM}^{NT} h^2 \simeq \frac{T_{s.f.o.}}{T_R} \Omega_{DM}^{T} h^2$$

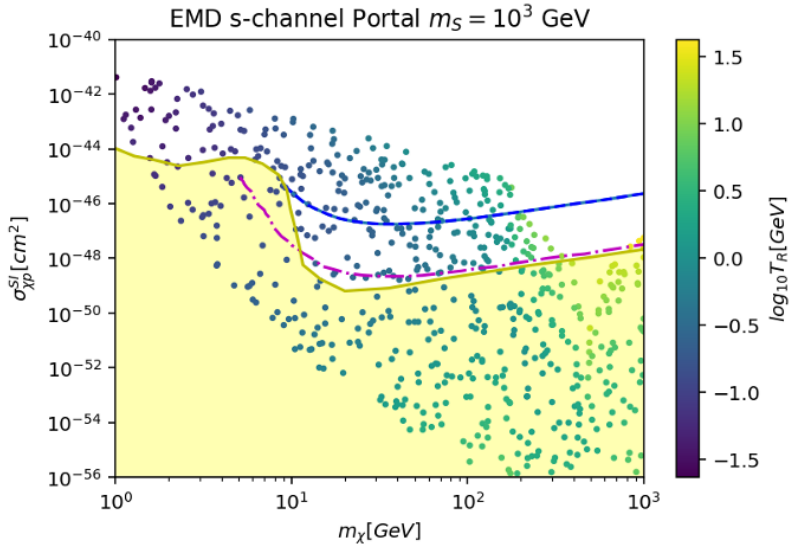
Reannihilation phase

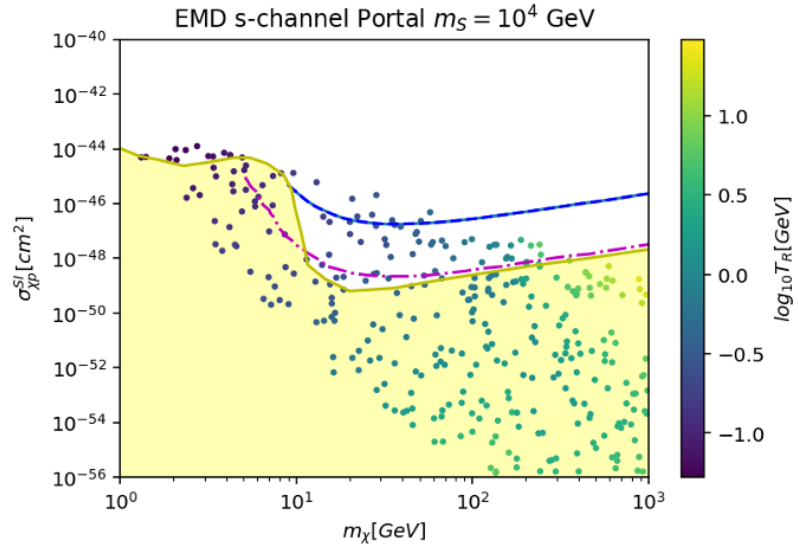
Direct production regime

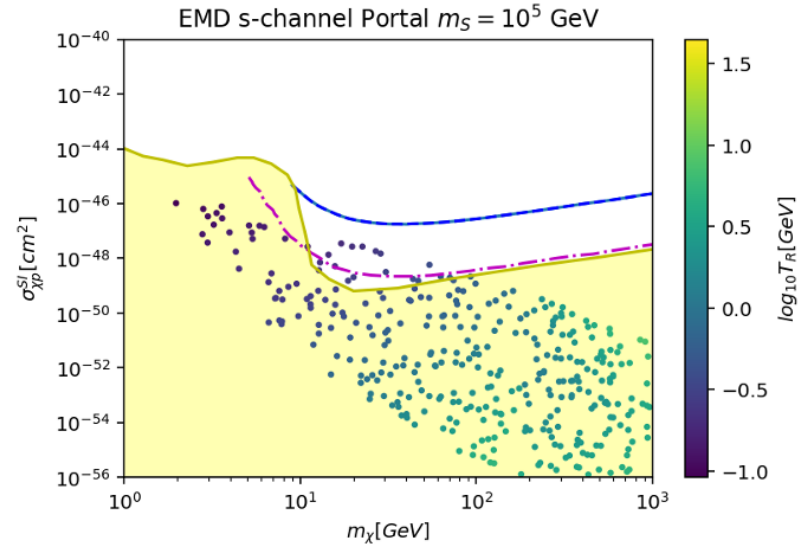
$$Y_{DM}(T_R) \simeq \frac{b_{DM}\rho_\phi(T_R)}{m_\phi s(T_R)}$$

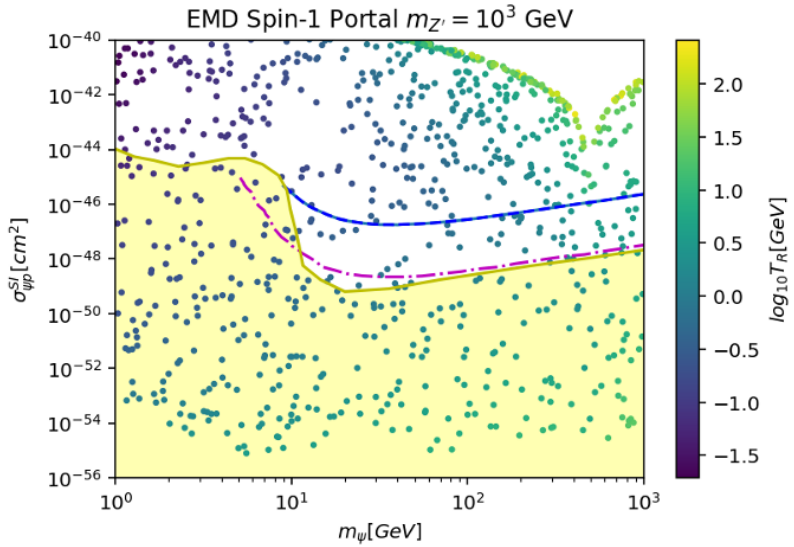
$$\rightarrow \Omega_{DM}^{NT}h^2 \simeq 0.2\times 10^4 b_{DM}\frac{10\ TeV}{m_\phi}\frac{T_R}{1\ MeV}\frac{m_{DM}}{100\ GeV}$$

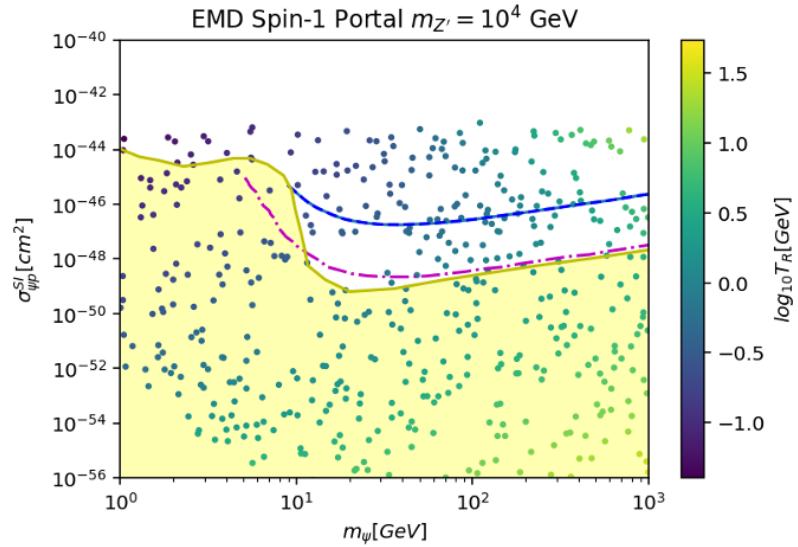


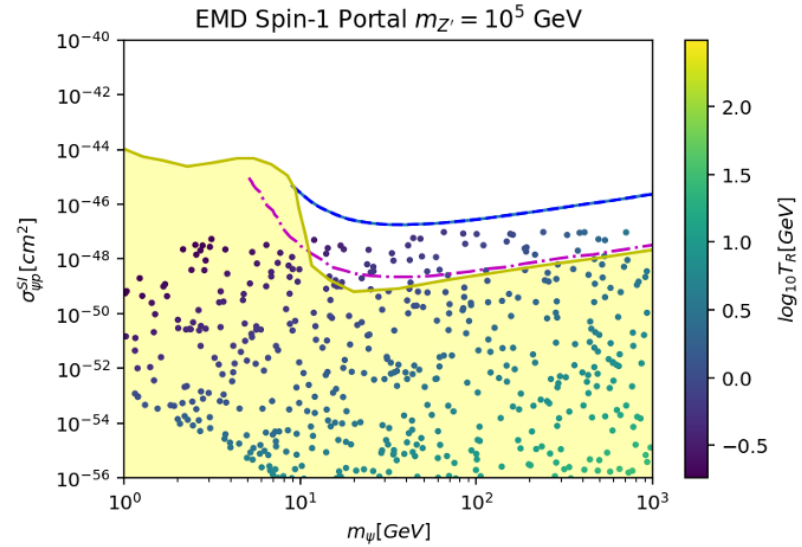

EMD s-channel Portal $m_S = 10^3$ GeV
$\sigma^{SI}_{\chi p}[cm^2]$
$m_\chi[GeV]$
$log_{10}T_R[GeV]$

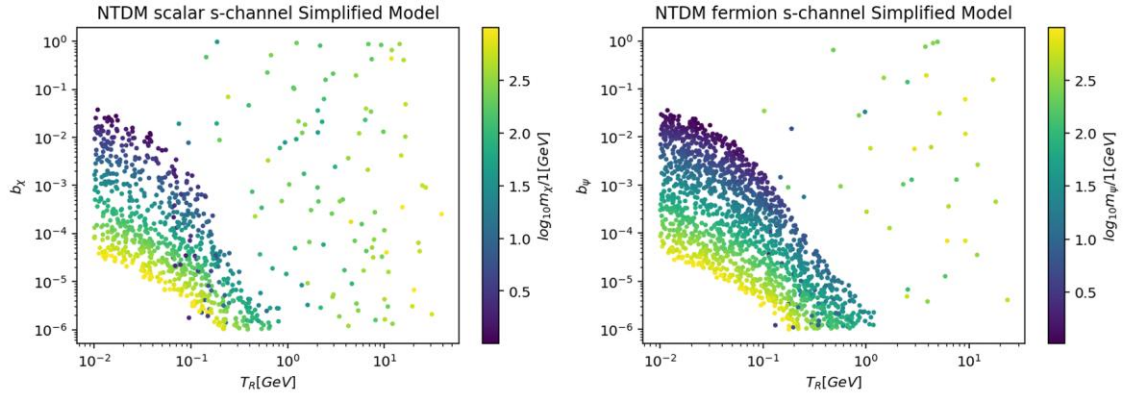

EMD s-channel Portal $m_S = 10^4$ GeV
$\sigma^{SI}_{\chi p}[cm^2]$
$m_\chi[GeV]$
$log_{10}T_R[GeV]$


EMD s-channel Portal $m_S = 10^5$ GeV
$\sigma^{SI}_{\chi p}[cm^2]$
$m_\chi[GeV]$
$log_{10}T_R[GeV]$

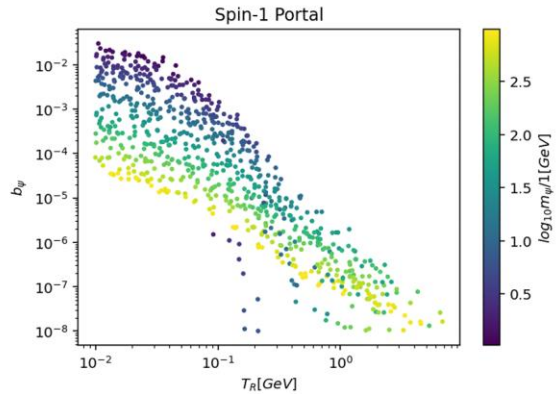

EMD Spin-1 Portal $m_{Z'} = 10^3$ GeV
$\sigma^{SI}_{\psi p}[cm^2]$
$m_\psi[GeV]$
$log_{10}T_R[GeV]$

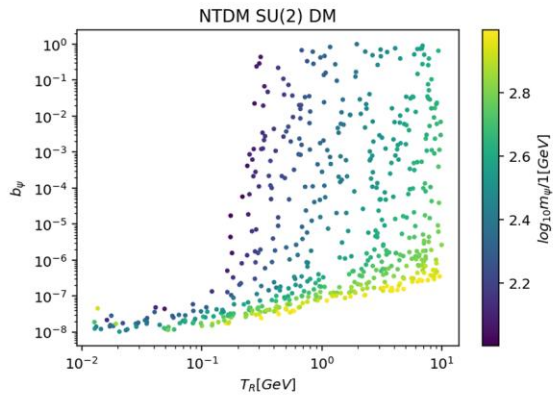

EMD Spin-1 Portal $m_{Z'} = 10^4$ GeV
$\sigma^{SI}_{\psi p}[cm^2]$
$m_\psi[GeV]$
$log_{10}T_R[GeV]$

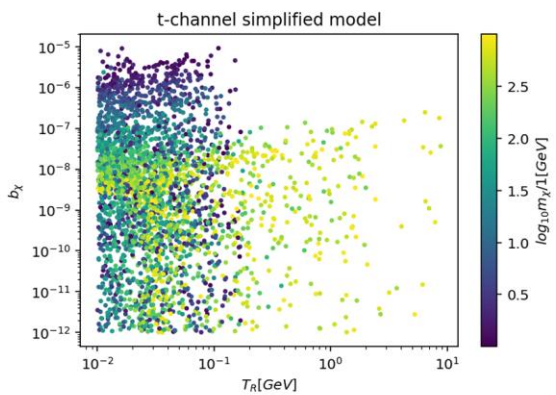

EMD Spin-1 Portal $m_{Z'} = 10^5$ GeV
$\sigma^{SI}_{\psi p}[cm^2]$
$m_\psi[GeV]$
$log_{10}T_R[GeV]$


NTDM scalar s-channel Simplified Model
b_χ
$T_R[GeV]$
$log_{10}m_\chi/1[GeV]$

NTDM fermion s-channel Simplified Model
b_ψ
$T_R[GeV]$
$log_{10}m_\psi/1[GeV]$

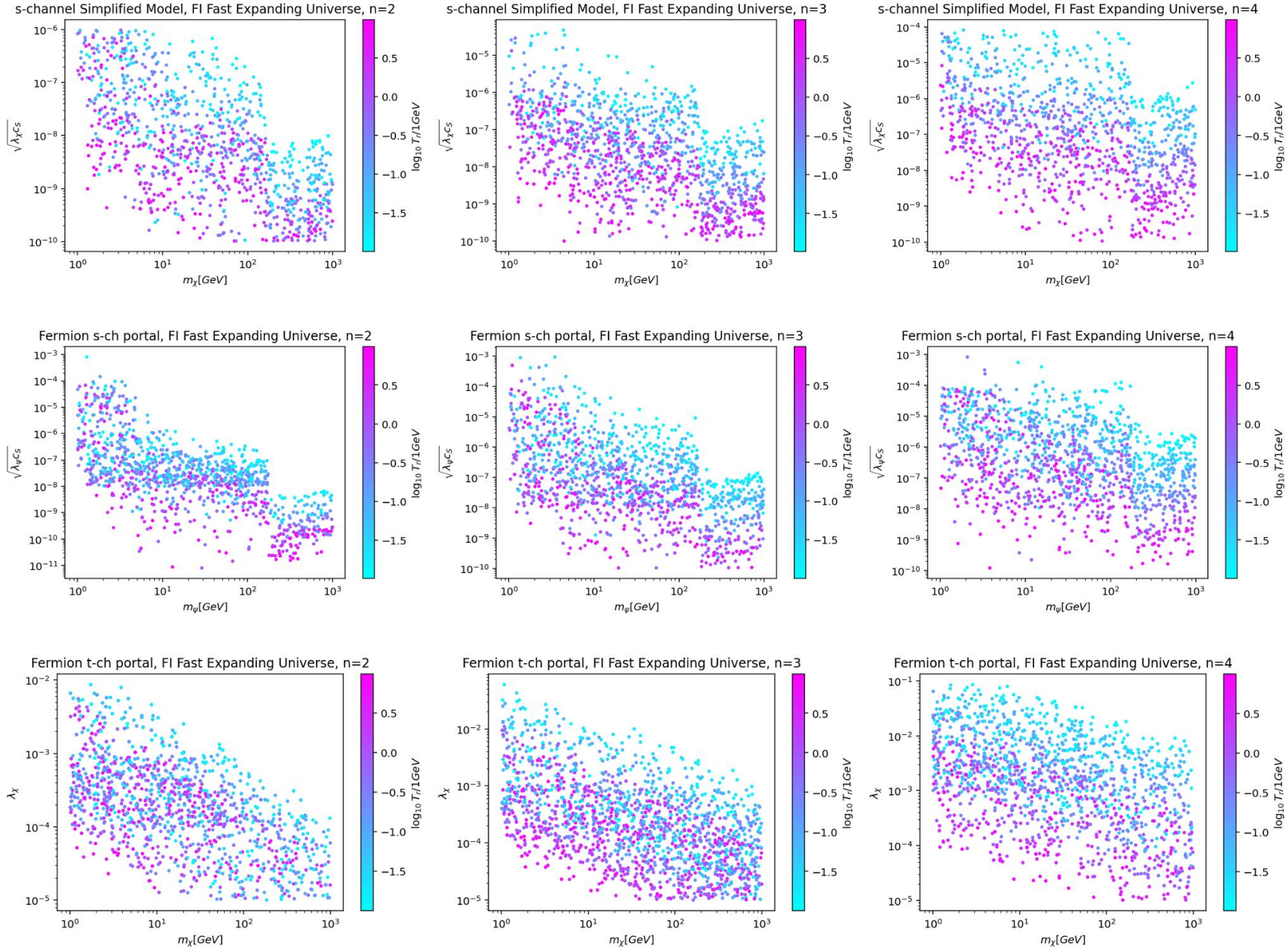

Spin-1 Portal
b_ψ
$T_R[GeV]$
$log_{10}m_\psi/1[GeV]$


NTDM SU(2) DM
b_ψ
$T_R[GeV]$
$log_{10}m_\psi/1[GeV]$


t-channel simplified model
b_χ
$T_R[GeV]$
$log_{10}m_\chi/1[GeV]$

Production during Early Accelerated Rates

$$\rho_{\Phi} \propto a^{-(4+n)}$$


s-channel Simplified Model, FI Fast Expanding Universe, n=2
s-channel Simplified Model, FI Fast Expanding Universe, n=3
s-channel Simplified Model, FI Fast Expanding Universe, n=4
Fermion s-ch portal, FI Fast Expanding Universe, n=2
Fermion s-ch portal, FI Fast Expanding Universe, n=3
Fermion s-ch portal, FI Fast Expanding Universe, n=4
Fermion t-ch portal, FI Fast Expanding Universe, n=2
Fermion t-ch portal, FI Fast Expanding Universe, n=3
Fermion t-ch portal, FI Fast Expanding Universe, n=4
m_χ[GeV]
m_ψ[GeV]
$\sqrt{\lambda_\chi c_S}$
$\sqrt{\lambda_\psi c_S}$
λ_χ
$\log_{10} T_r/1\mathrm{GeV}$

Conclusions

WIMPs still retain theoretical motivation even in light of the increasing experimental tensions.

We have determined a series of theoretical benchmark to continue the quest of the DM beyond the neutrino floor.