

PASCOS 18/06/2021 - PARALLEL 13A - COSMOLOGY

Lower Mass Bounds on FIMP Dark Matter.

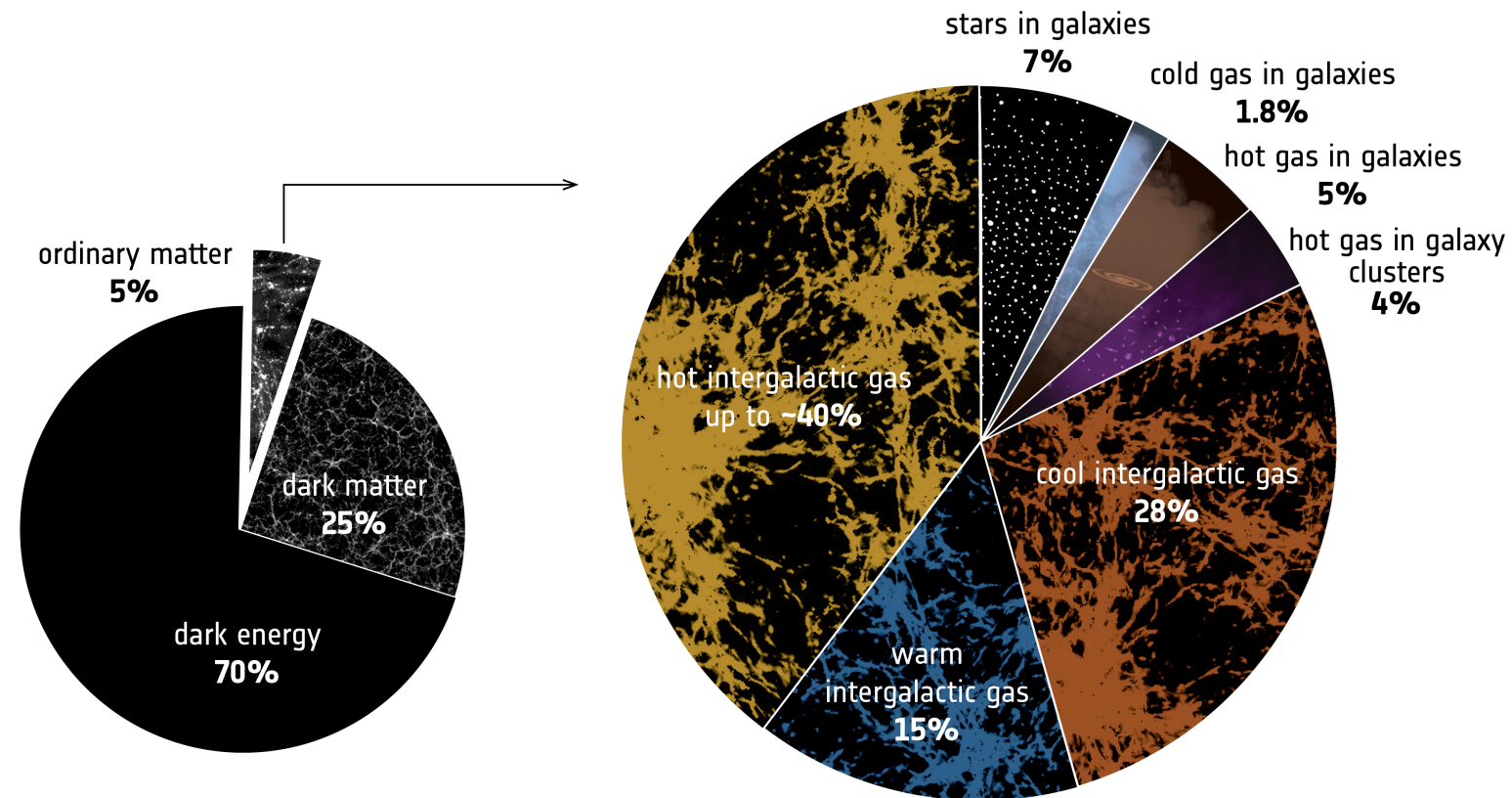
Alessandro Lenoci



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2012.01446



The cosmic pie: DM and Lyman- α forest.



$$\Omega_{\text{DM}}(t_0)h^2 = 0.120 \pm 0.001$$

Planck CMB TT+EE+lensing

Thermal Warm Dark Matter Lyman- α constraints

$$m_{\text{WDM}} > \begin{cases} 3.5 \text{ keV} \\ 5.3 \text{ keV} \end{cases}$$

M. Viel et al. 1702.01764

Our framework.

1. **Homogeneous and isotropic** FRW expanding Universe
2. **Standard model of particle physics** for $g_{\star}(T)$ and $g_{\star s}(T)$
3. DM is produced via **freeze-in** IR dominated at $T \sim M$
4. Single FIMP non-CDM particle χ
 - mass m_{χ}
 - g_{χ} internal degrees of freedom
 - **non-thermal** phase space distribution (PSD) $f_{\chi}(p)$
 - **Maxwell-Boltzmann (MB) statistics** (excellent approximation)
5. DM produced in **radiation-dominated era** $H(T) \propto \frac{M_{\text{Pl}}}{T^2}$

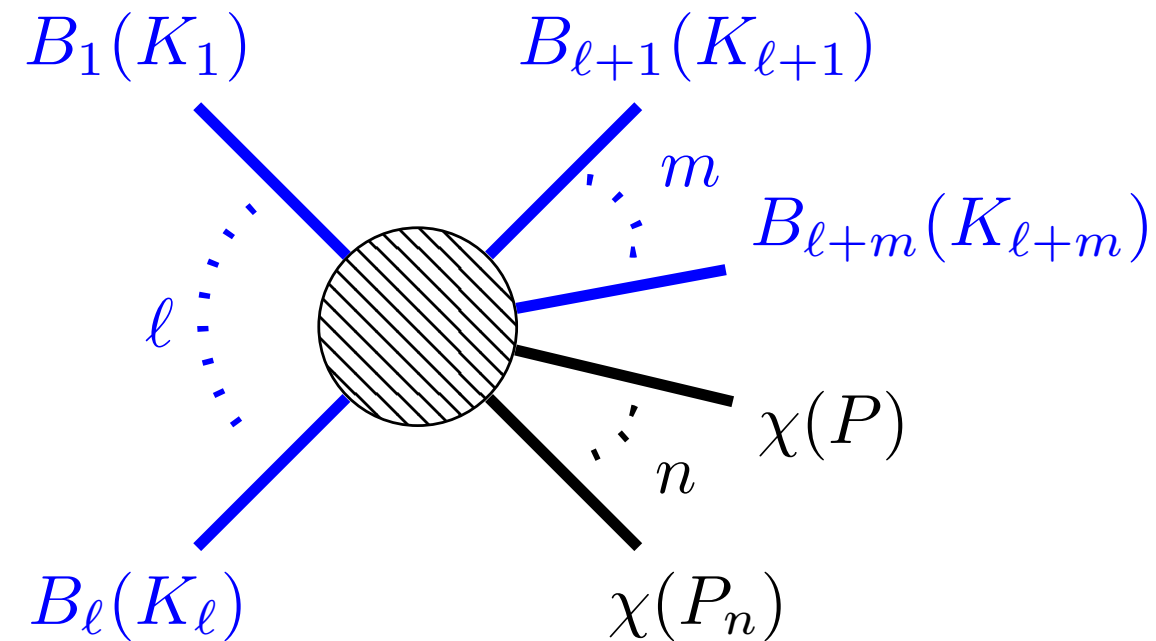
Boltzmann Equation for FIMPs.

$$x = \frac{M}{T}$$

$$q = \frac{p}{M} \frac{a(T)}{a(M)}$$

$$T_\chi = \frac{p}{q}$$

$$\frac{df_\chi}{dt} = C[f_\chi]$$

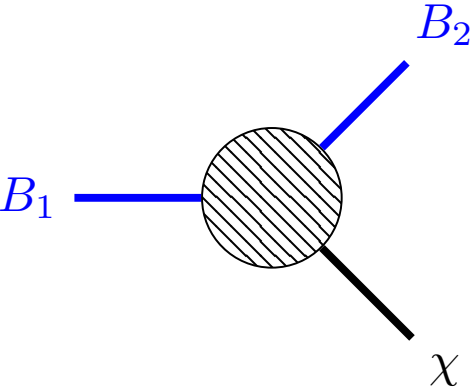
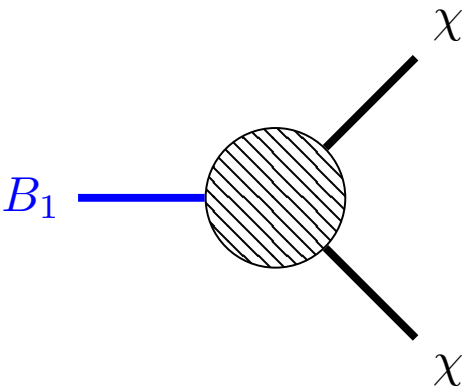
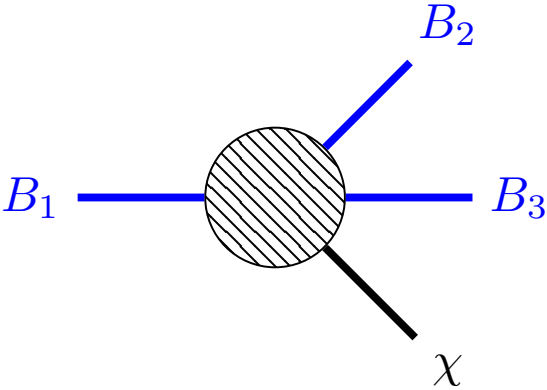
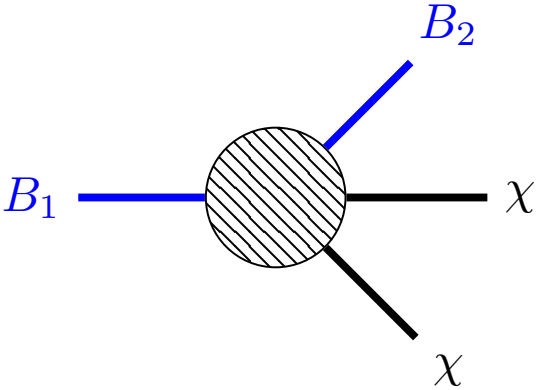
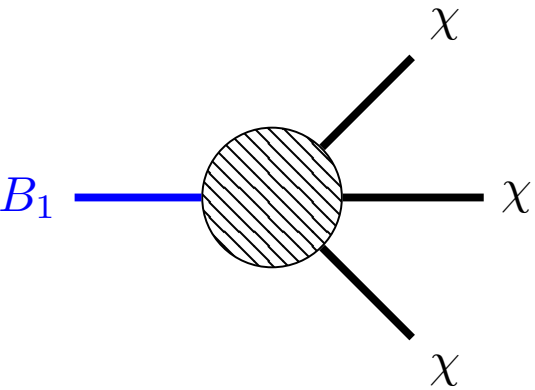
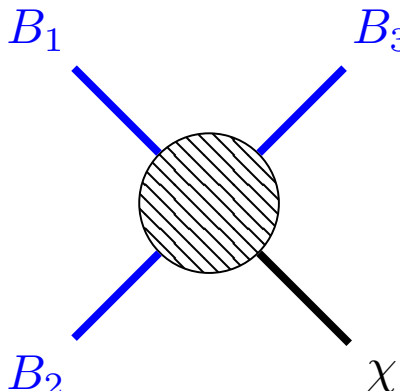
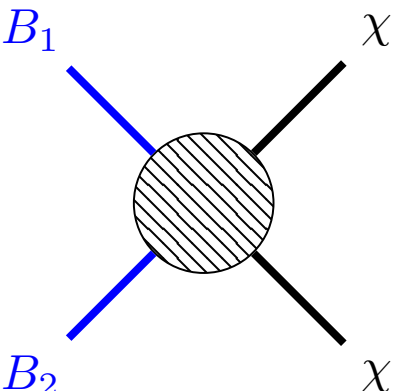


$$g_\chi f_\chi(q) = \int_0^\infty d \log x \frac{1}{H(x)} \left(1 - \frac{1}{3} \frac{d \log g_\star}{d \log x} \right) \frac{\mathcal{C}(x, q)}{E}$$

$$\mathcal{C}(T, p) \equiv \frac{n}{2} \int \prod_{i=1}^{\ell+m} d\mathcal{K}_i \prod_{i=2}^n d\Pi_i (2\pi)^4 \delta^{(4)}(P_f - P_i) |\mathcal{M}|^2 \prod_{i=1}^{\ell} f_i(k_i)$$

In our work we consider $|\mathcal{M}|^2 = \text{const.}$ since Freeze-in is IR dominated.
(Excellent approximation)

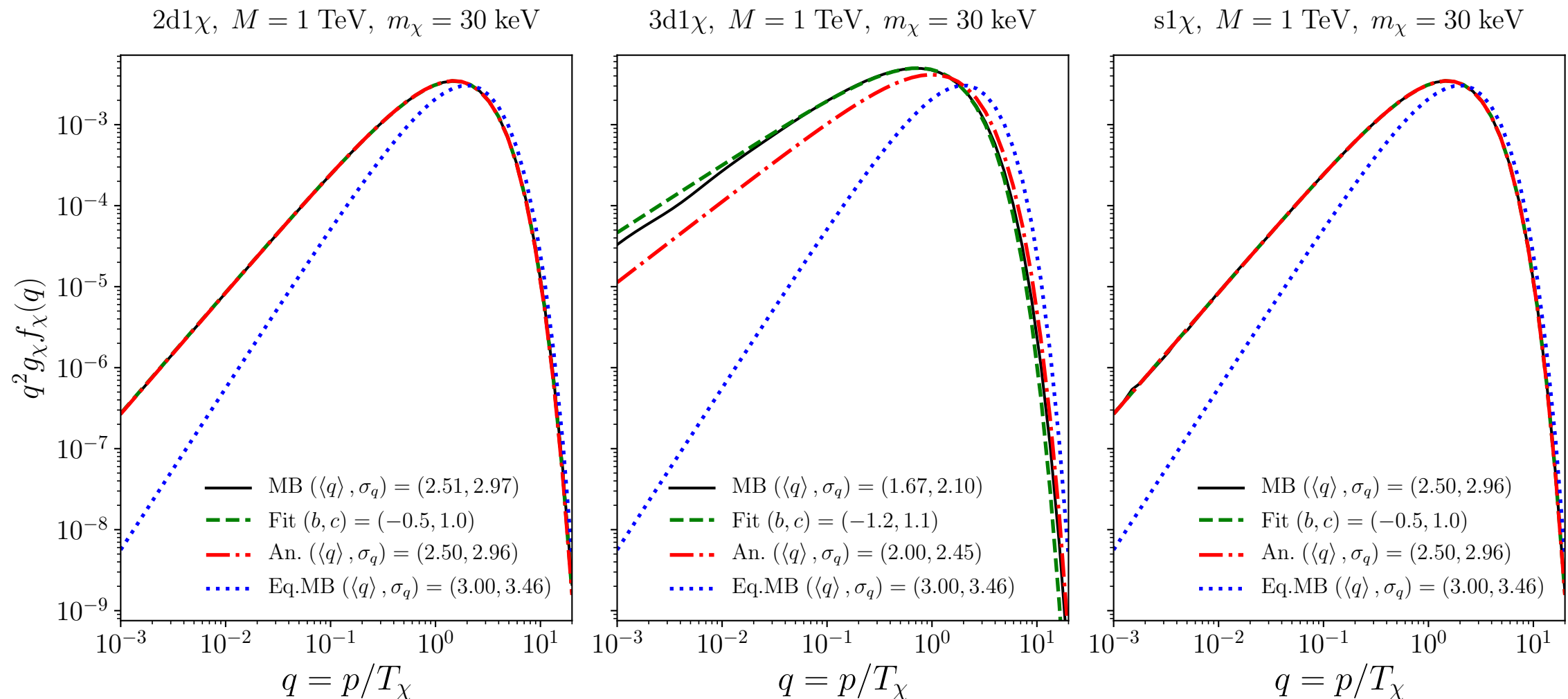
Our topologies.

	Single production	Pair production	Triple production
FIMP DM Two-body decays			
FIMP DM Three-body decays			
FIMP DM Scatterings			

Chosen benchmarks.

Benchmark	Topology	(m_1, m_2, m_3) [TeV]	Analytical $f_\chi(q)$
2d1 χ		$(M, 0, -)$	$\propto \frac{\Gamma_1 M_{\text{Pl}}}{M^2} \frac{1}{\sqrt{q}} e^{-q}$
2d2 χ		$(M, -, -)$	
3d1 χ		$(M, 0, 0)$	$\propto \frac{\Gamma_1 M_{\text{Pl}}}{M^2} \frac{1}{q} e^{-q}$
3d2 χ		$(M, 0, -)$	
3d3 χ		$(M, -, -)$	
s1 χ		$(M, 0, 0)$	$\propto \sigma^{\text{FI}} M M_{\text{Pl}} \frac{1}{\sqrt{q}} e^{-q}$
s2 χ		$(M, M, -)$	

PSDs for benchmarks.



$$g_\chi f_\chi(q) \propto q^b e^{-cq}$$

$$\langle q \rangle = \frac{b+3}{c}$$

$$\sigma_q = \sqrt{\langle q^2 \rangle} = \frac{\sqrt{(b+3)(b+4)}}{c}$$

Warmness constraints.

- Free-streaming length

$$\lambda_{\text{FS}}(m_\chi, M, f_\chi) = \int_{t_{\text{prod}}}^{t_{\text{equality}}} dt \frac{\langle v(t) \rangle}{a(t)} < \lambda_{\text{WDM}}(m_{\text{WDM}})$$

- Momentum dispersion $W_\chi = \sqrt{\langle p^2 \rangle / m_\chi^2} < W_{\text{WDM}}$ Kamada, Yanagi - [1907.04558]

$$m_\chi > 19 \text{ keV} \left(\frac{m_{\text{WDM}}}{5.3 \text{ keV}} \right)^{4/3} \left(\frac{\sigma_q}{3.6} \right) \left(\frac{106.75}{g_{\star s}(M)} \right)^{1/3}$$

- Linear matter power spectrum $P(k)$ computed with CLASS

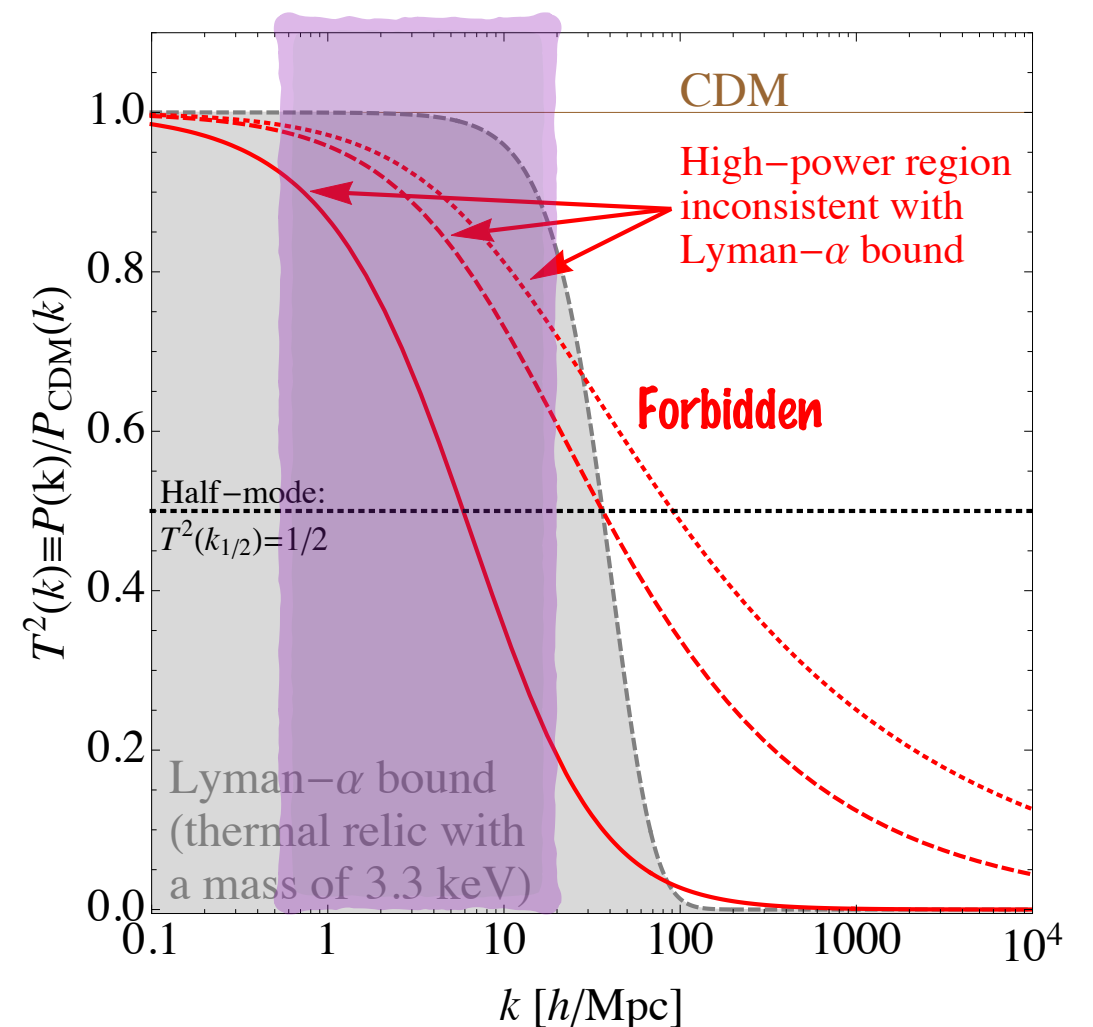
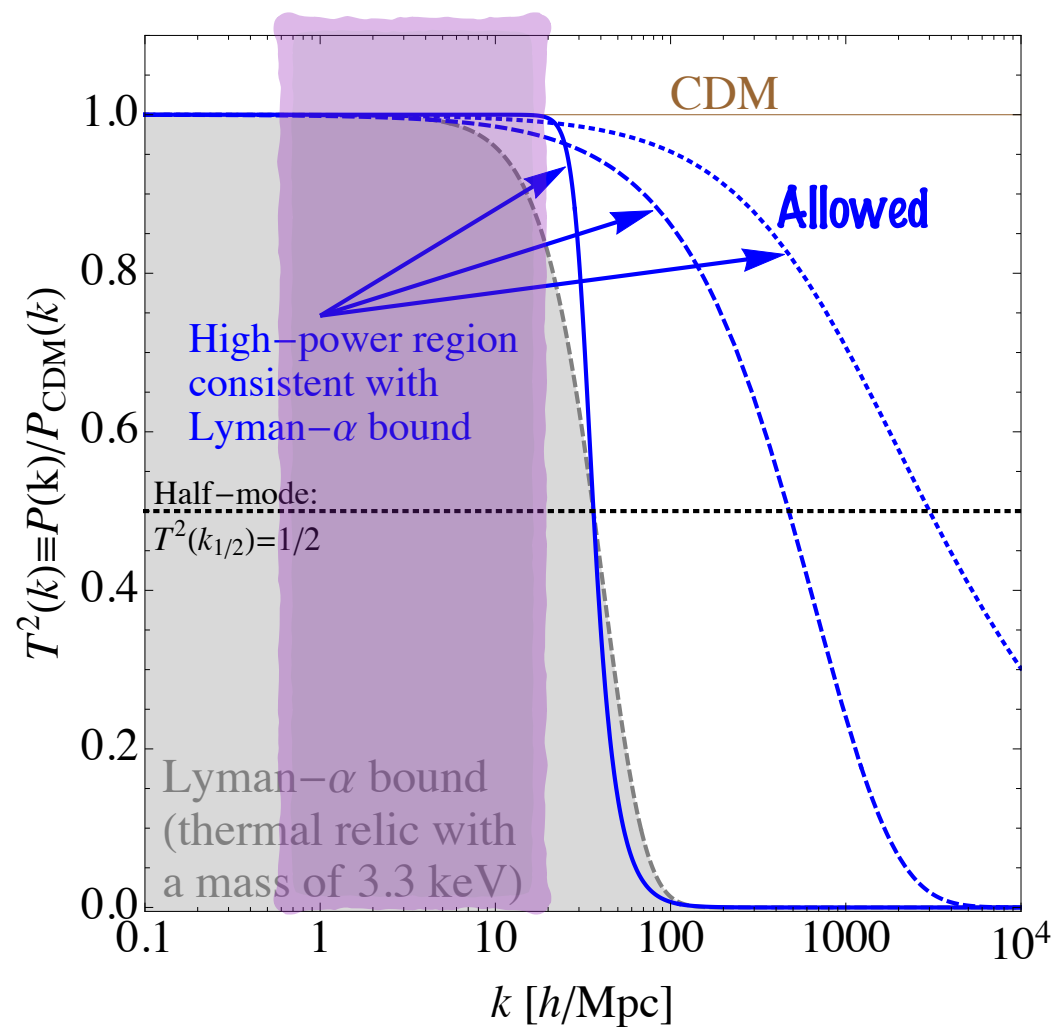
1. Relative transfer function $\mathcal{T}_{3\text{D}}^2(k) = P/P_{\text{CDM}} : k_{1/2} > k_{1/2}^{\text{WDM}}$

2. Relative 1D transfer function $\mathcal{T}_{1\text{D}}^2(k) = P^{1\text{D}}/P_{\text{CDM}}^{1\text{D}} : \delta A < \delta A_{\text{WDM}}$

3. Number of Milky way satellites $N_{\text{sat}} \propto \int \frac{dM_{\text{sub}}}{M_{\text{sub}}^2} \frac{M_{\text{halo}}}{R_{\text{sub}}^3} \frac{P(1/R_{\text{sub}})}{\sqrt{2\pi(S_{\text{sub}} - S_{\text{halo}})}} \gtrsim 57 - 63$

Relative transfer functions.

1609.01289



$$k_{1/2} : \mathcal{T}_{3D}^2(k_{1/2}) = \frac{1}{2}$$

$$\delta A = 1 - \int_{k_{\min}}^{k_{\max}} dk' \frac{\mathcal{T}_{1D}^2(k')}{k_{\max} - k_{\min}}$$

Lower Mass Bounds on FIMP DM

$$k_{1/2} > k_{1/2}^{\text{WDM}}$$

$$\delta A < \delta A_{\text{WDM}}$$

MIKE/HIRES+XQ-100

$$k_{\max} = 20 \text{ h/Mpc}$$

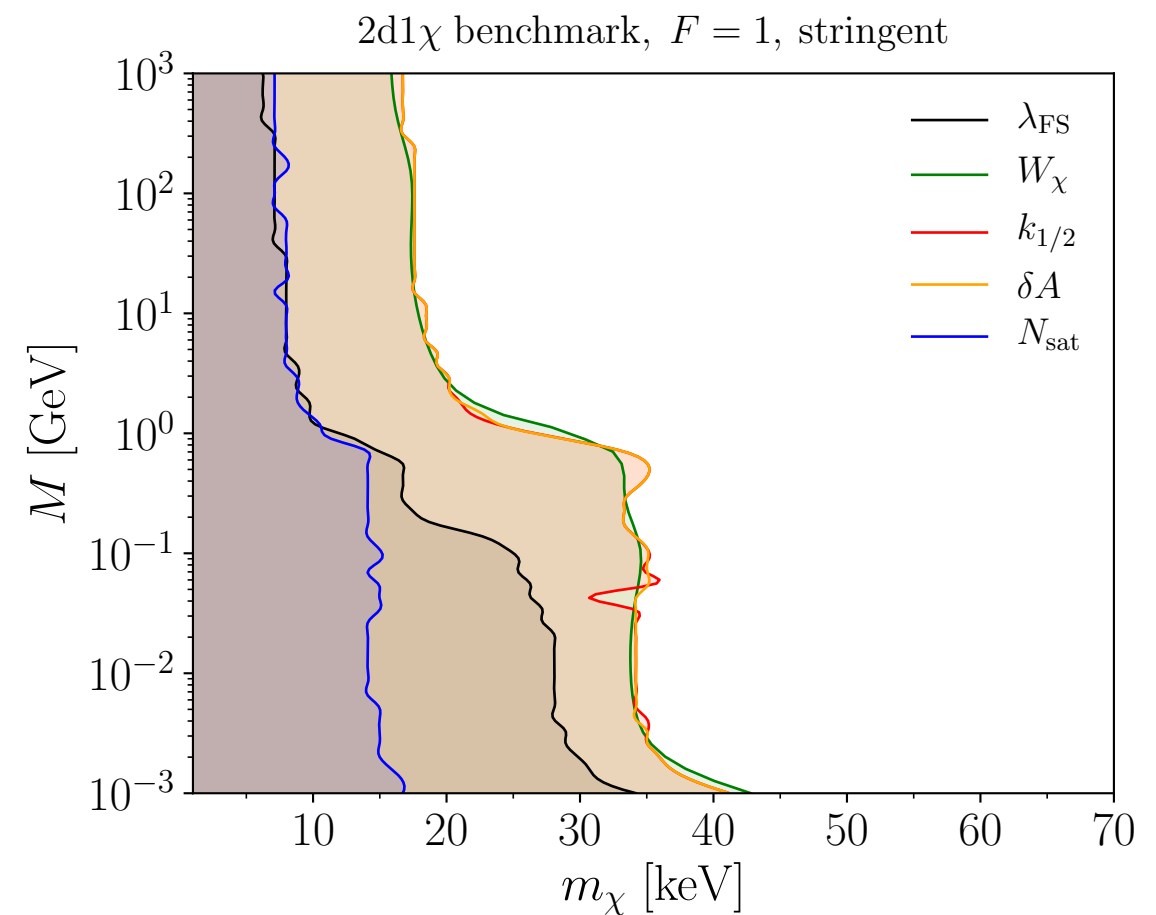
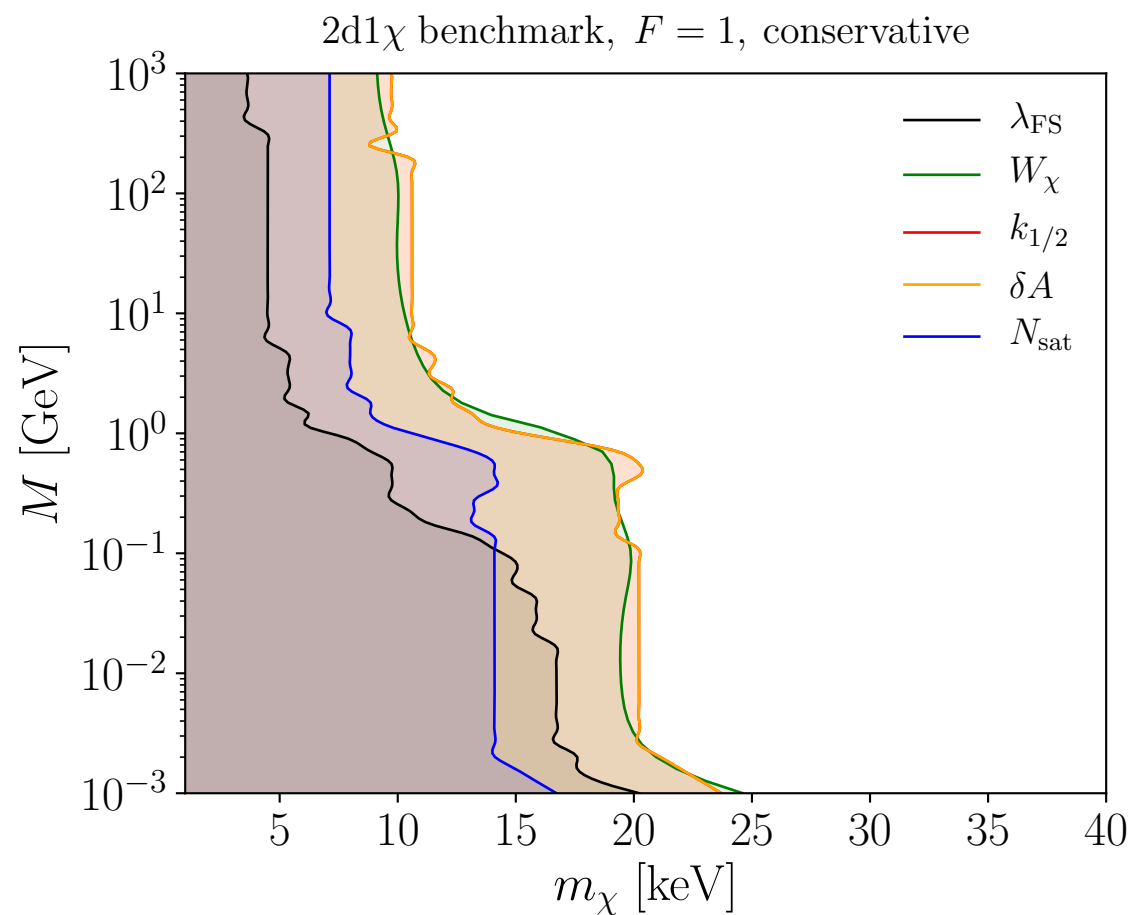
$$k_{\min} = 0.5 \text{ h/Mpc}$$

FIMP DM bounds: (m_χ, M) plane.

$$\left(m_1 = M, m_\chi, F = \frac{\Omega_\chi}{\Omega_{\text{DM}}}, r_2 = \frac{m_2}{m_1} \right)$$

$$m_{\text{WDM}} = 3.5 \text{ keV}$$

$$m_{\text{WDM}} = 5.3 \text{ keV}$$

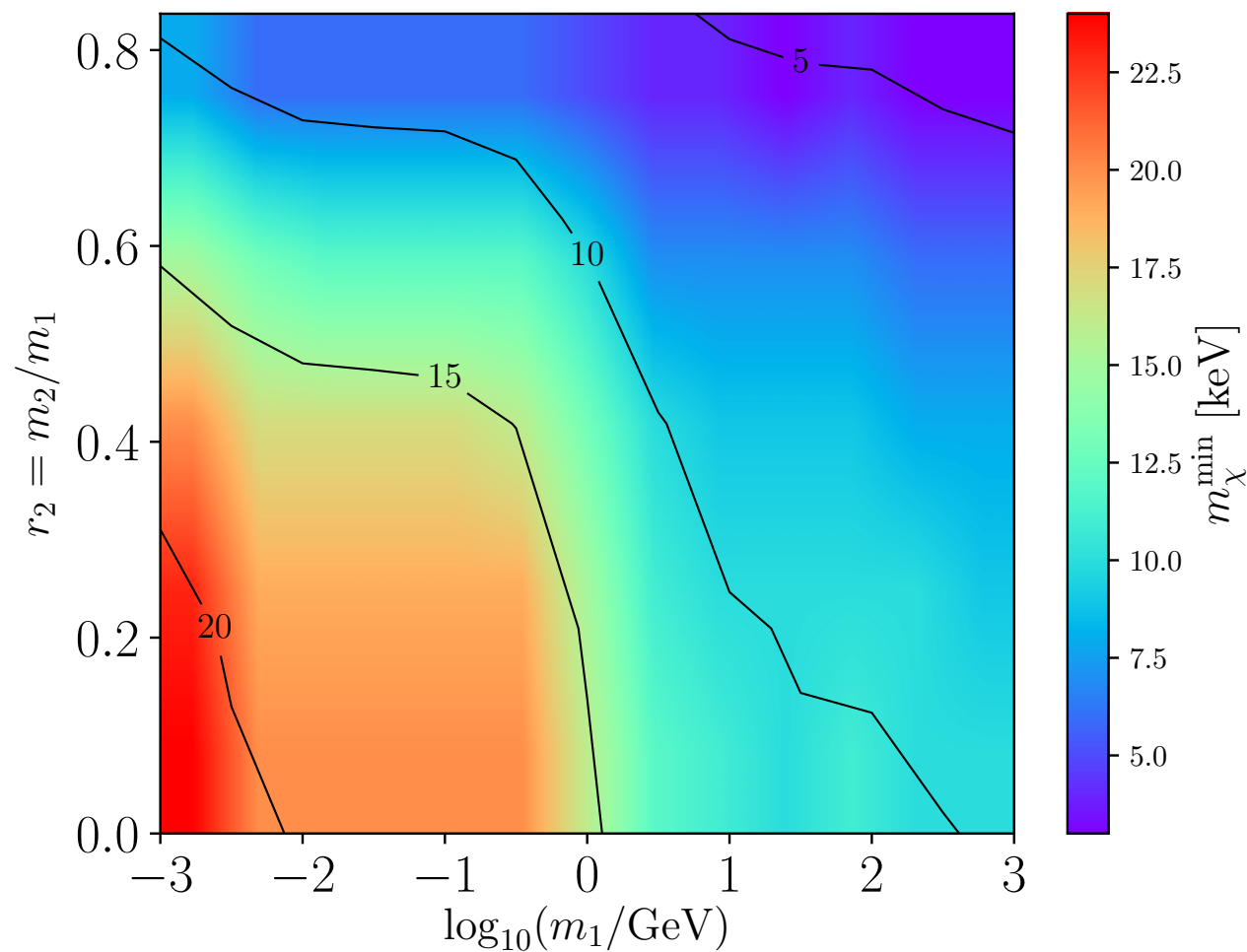


FIMP DM mass bounds: (m_1, r_2) plane.

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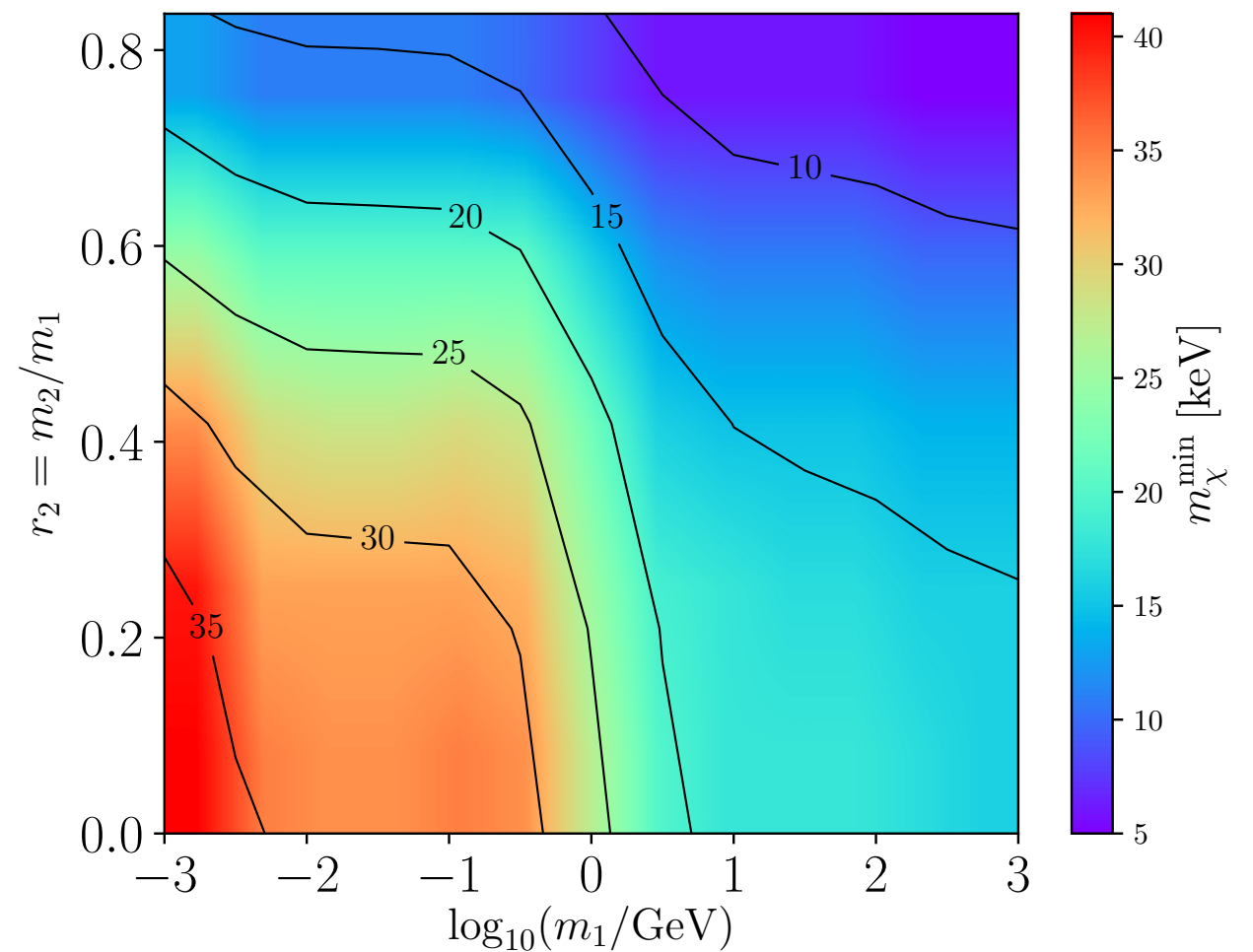
$m_{\text{WDM}} = 3.5 \text{ keV}$

2d1 χ , $F = 1$, conservative



$m_{\text{WDM}} = 5.3 \text{ keV}$

2d1 χ , $F = 1$, stringent

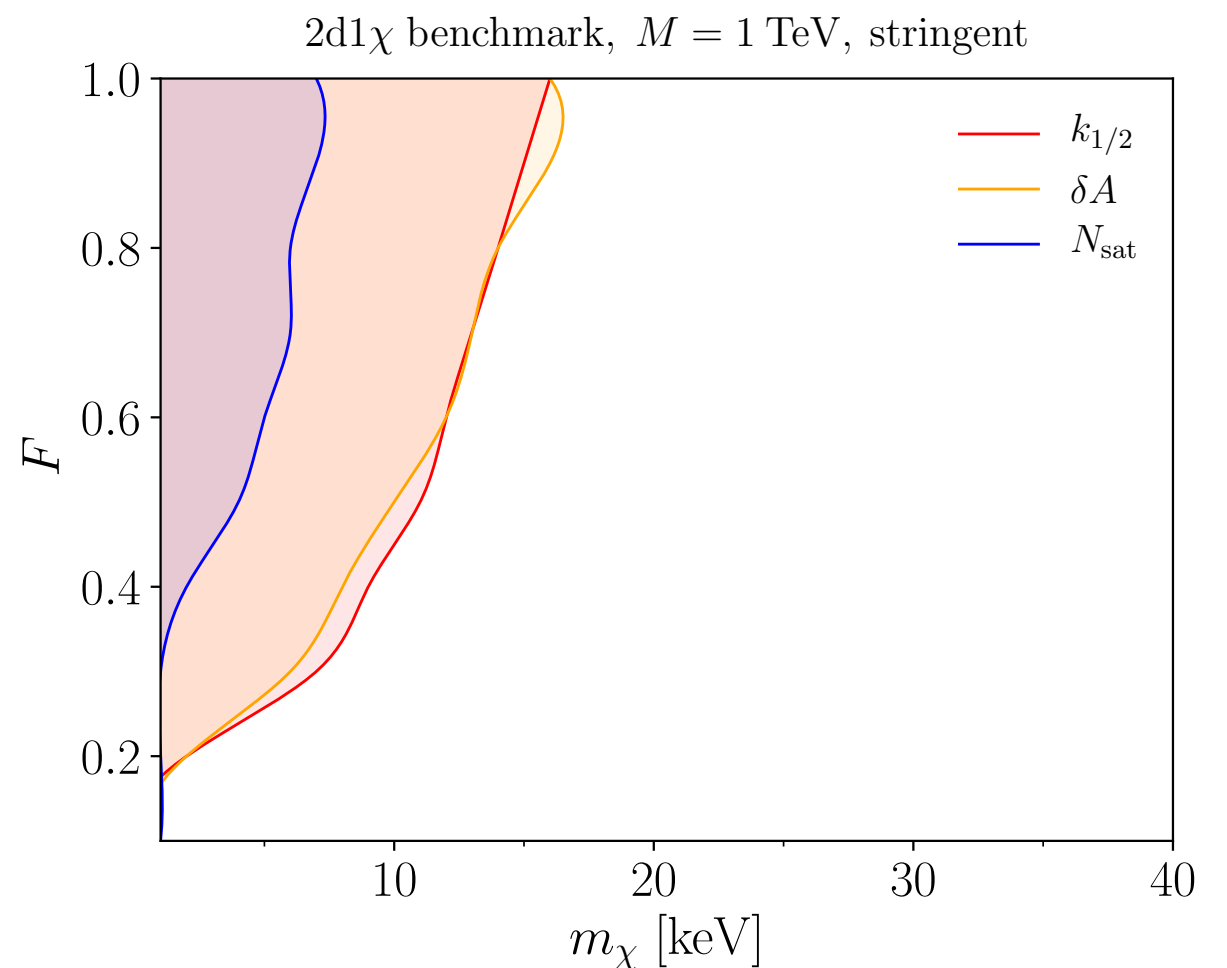
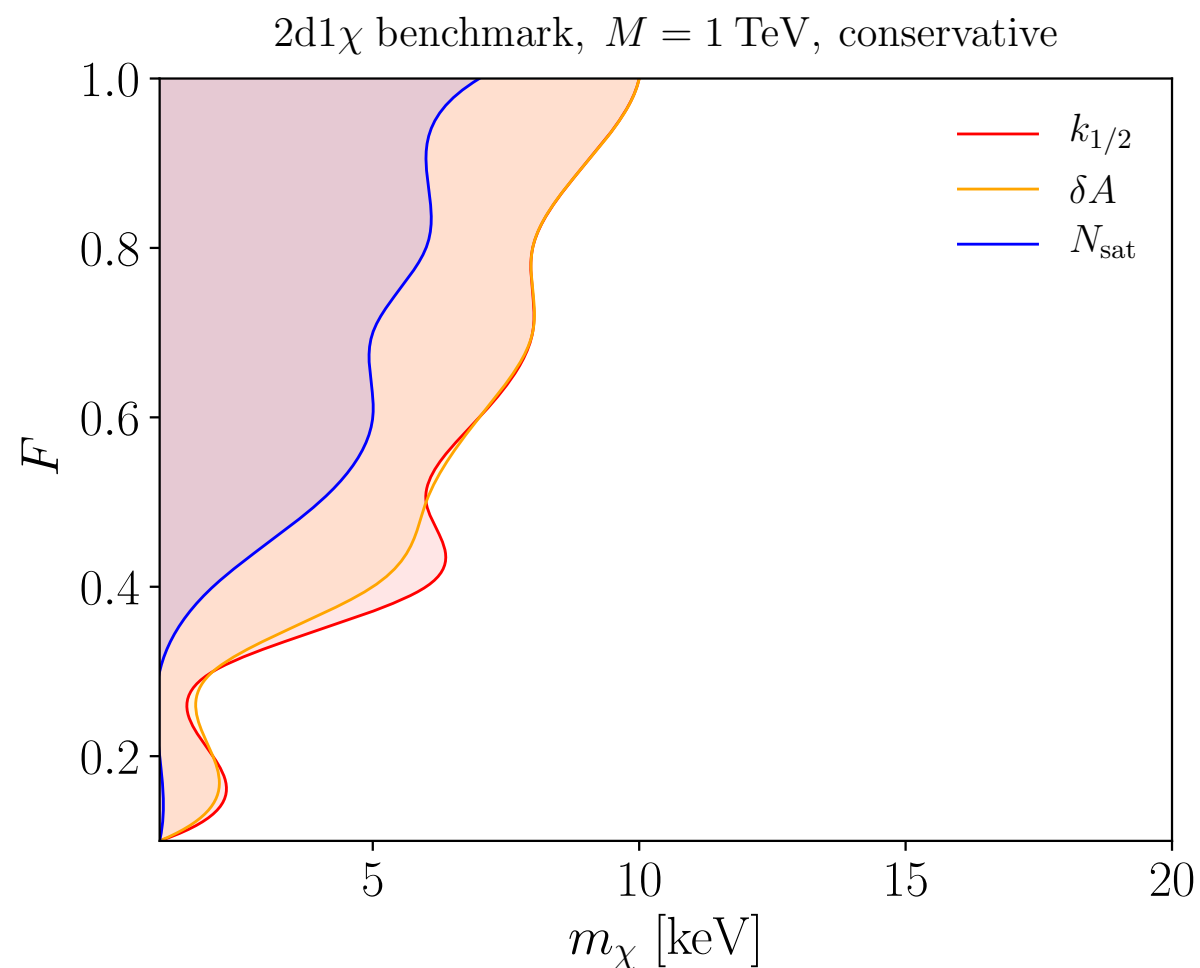


Subdominant FIMP DM bounds: (m_χ, F) plane.

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$$m_{\text{WDM}} = 3.5 \text{ keV}$$

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Further developments.

1. We can change the **cosmological background up to BBN**

- Early matter domination
- Inflationary reheating (non adiabatic evolution)
- Fast expanding universe: new species with $\rho \propto a^{-(4+n)}$

$$H(T) \propto \frac{M_{\text{Pl}} M^{n/2}}{T^{2+n/2}}$$

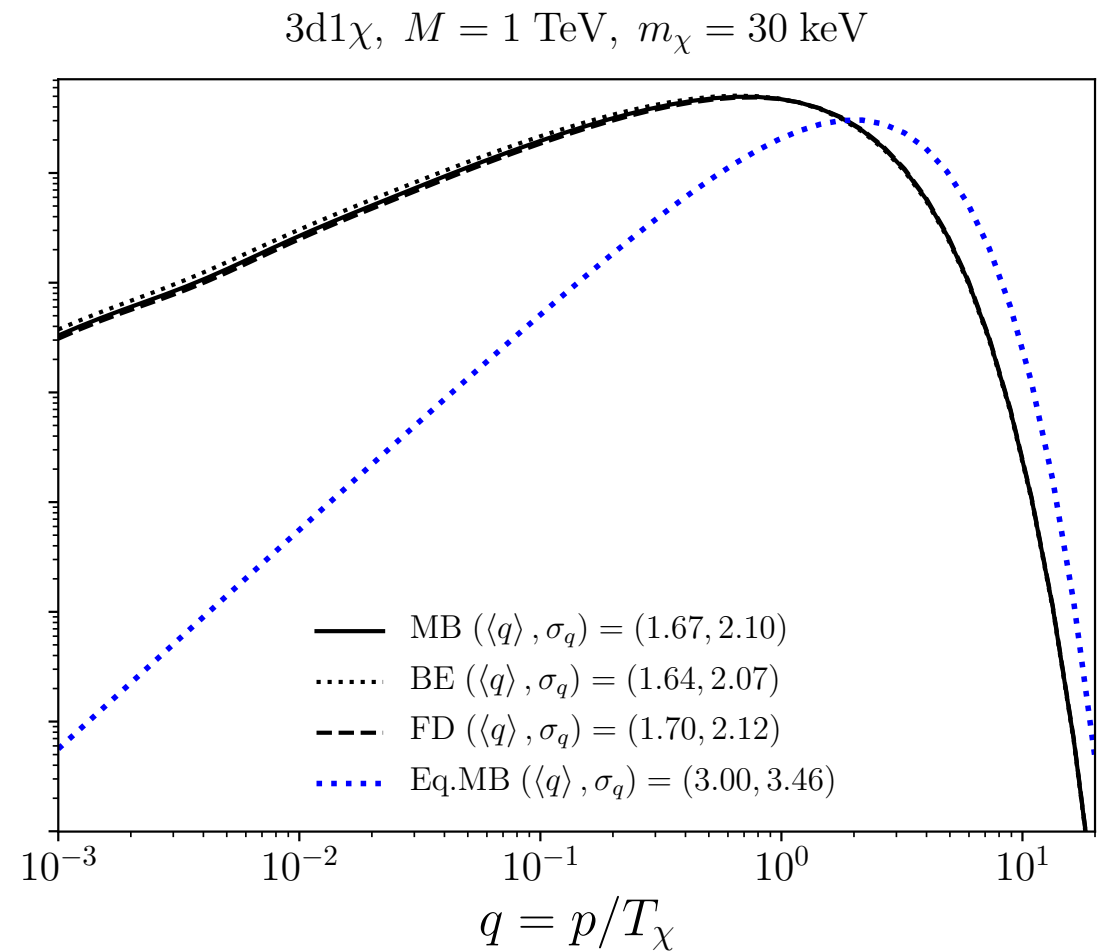
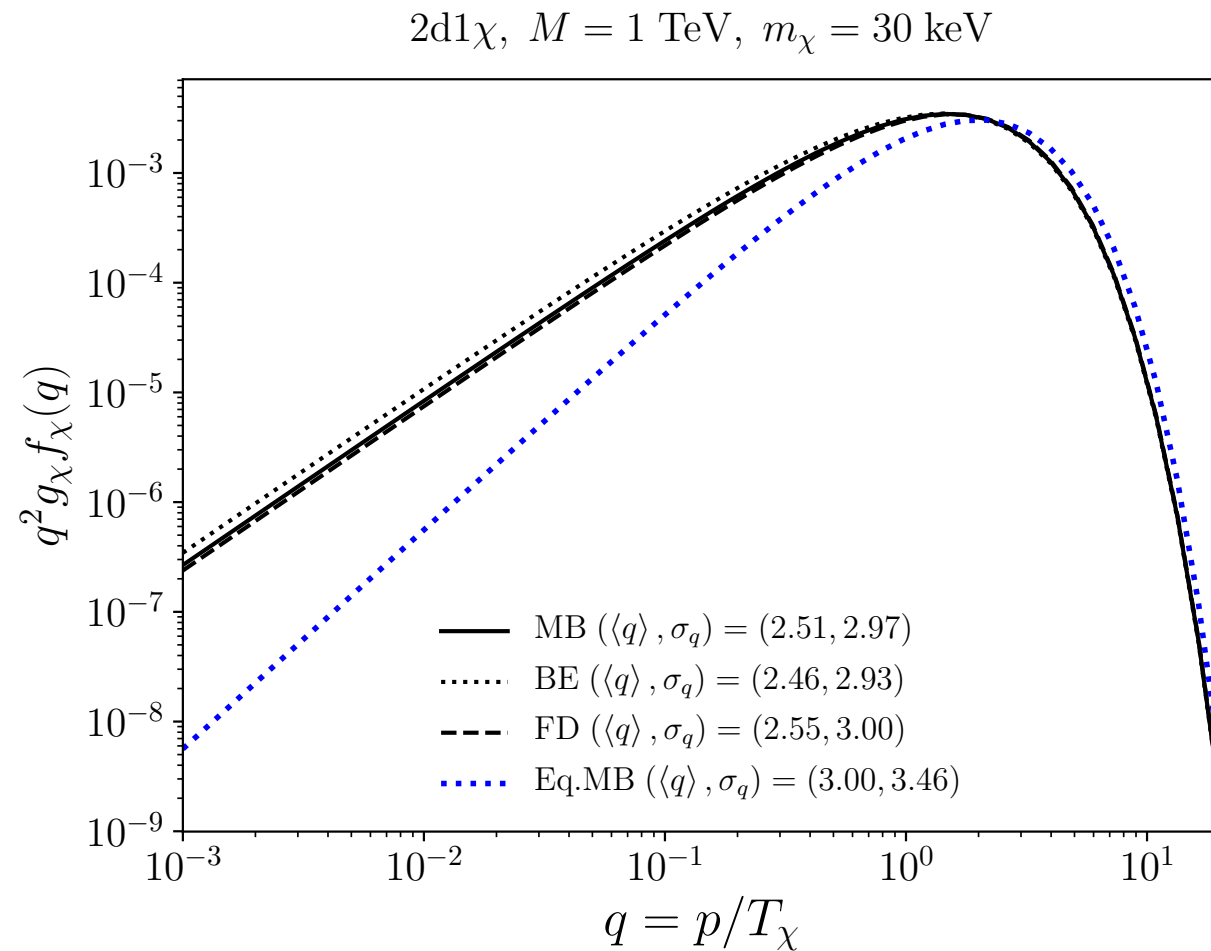
2. Specific **microscopic realisations**

- Portal models: dark photon, Higgs portal
- UV-dependent freeze-in

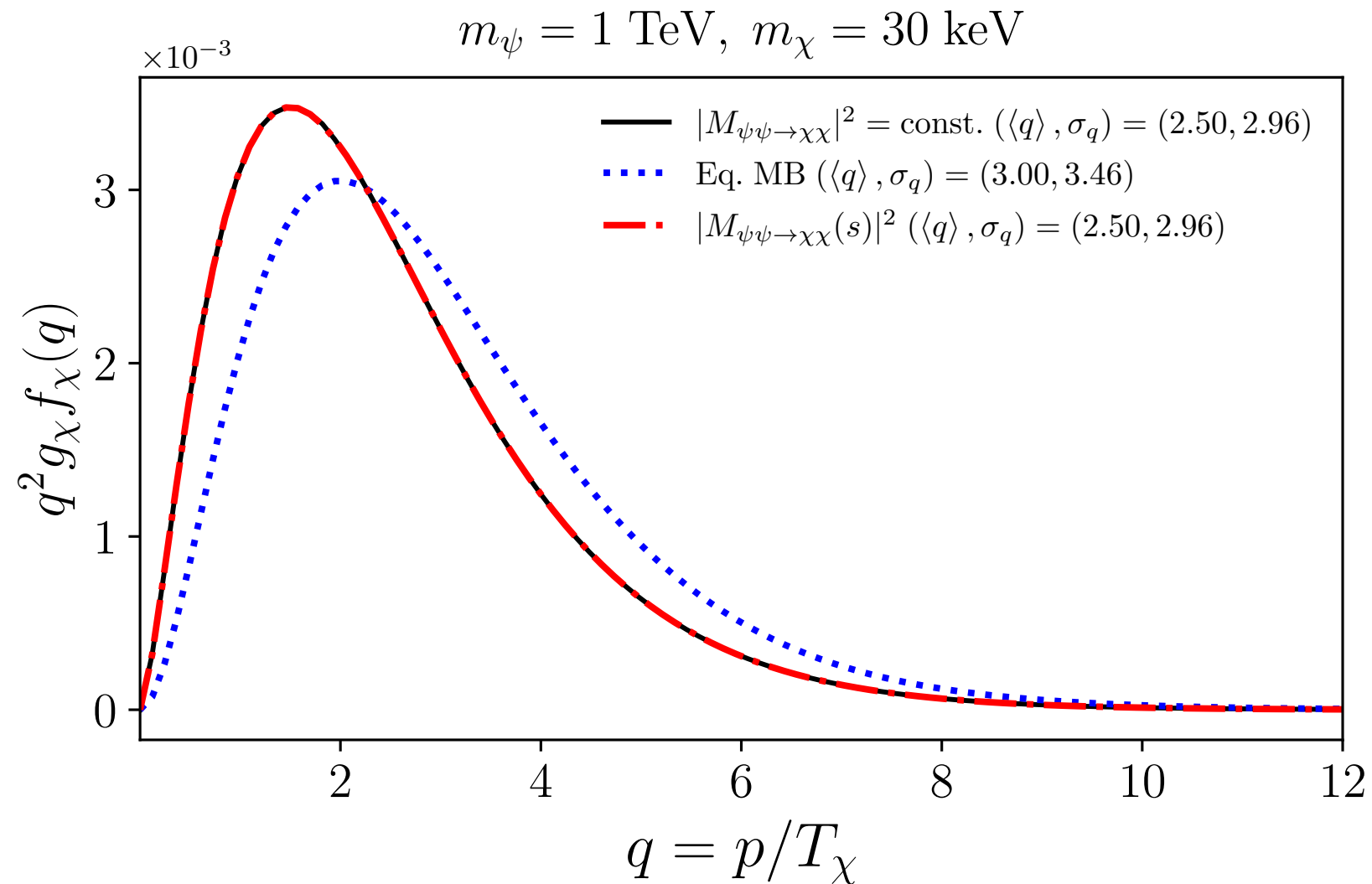
FIMP model $\longrightarrow$ our methodology + **CLASS $\longrightarrow$ constraints on FIMP parameters**

Thanks for listening!

The MB approximation.



The $|\mathcal{M}|^2 = \text{const.}$ approximation.



Specific simple model : fermion thermal bath ψ annihilation into χ DM through a scalar mediator ϕ

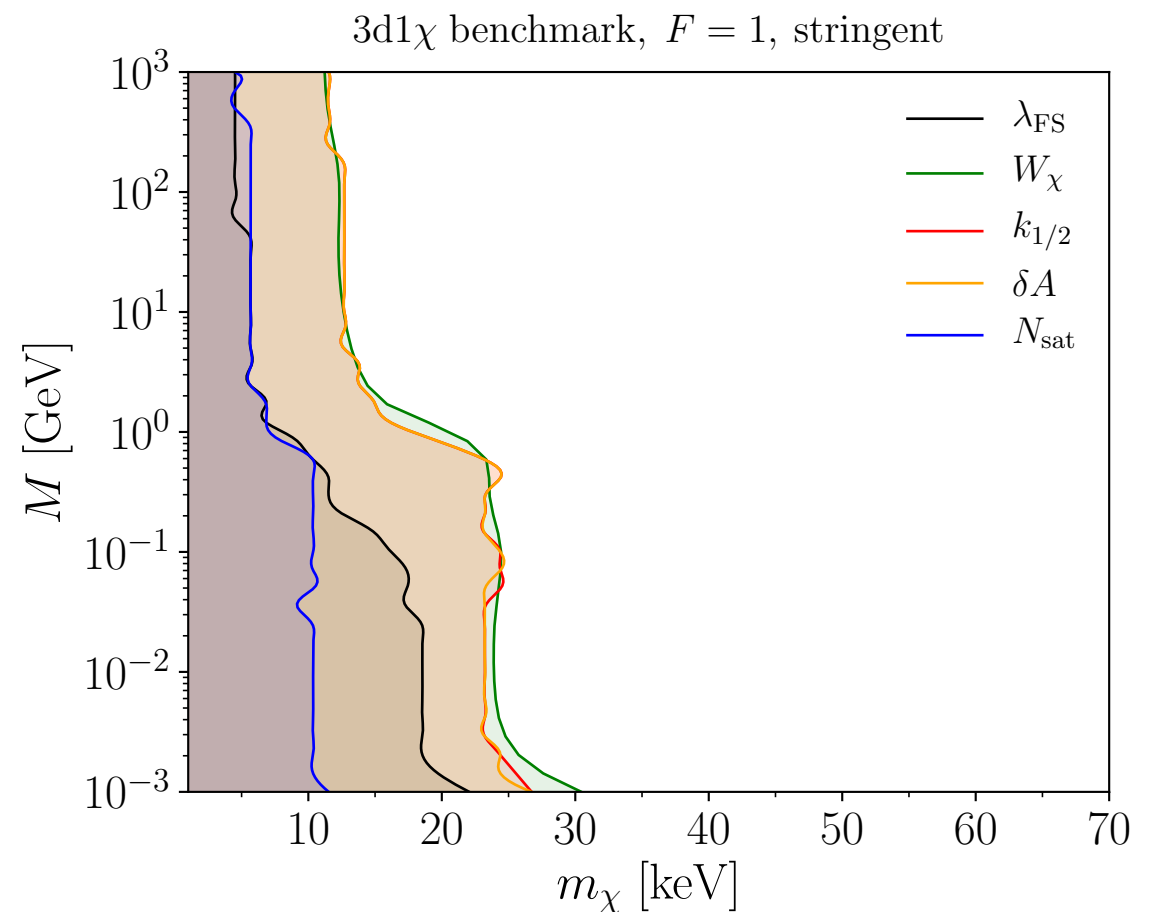
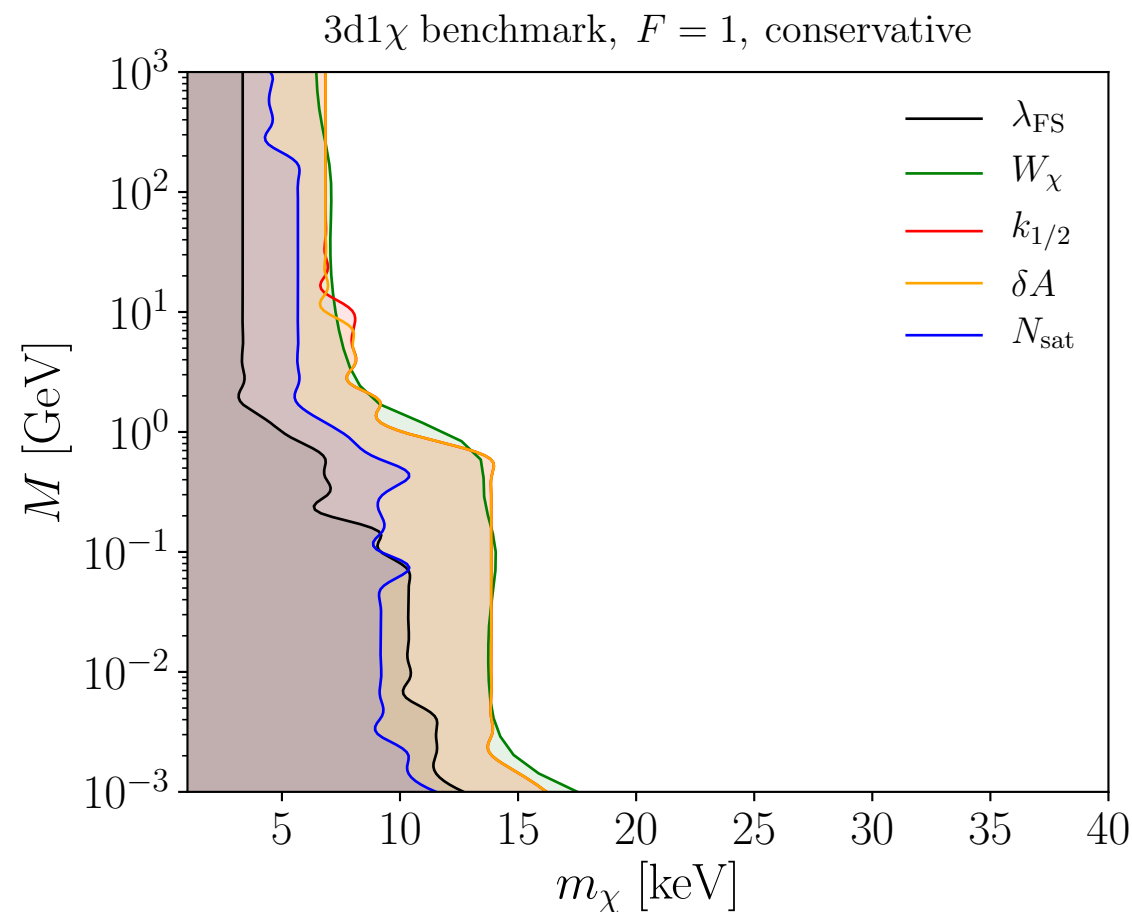
$$\mathcal{L} \supset y_\psi \phi \bar{\psi} \psi + y_\chi \phi \bar{\chi} \chi$$

FIMP DM bounds: (m_χ, M) plane.

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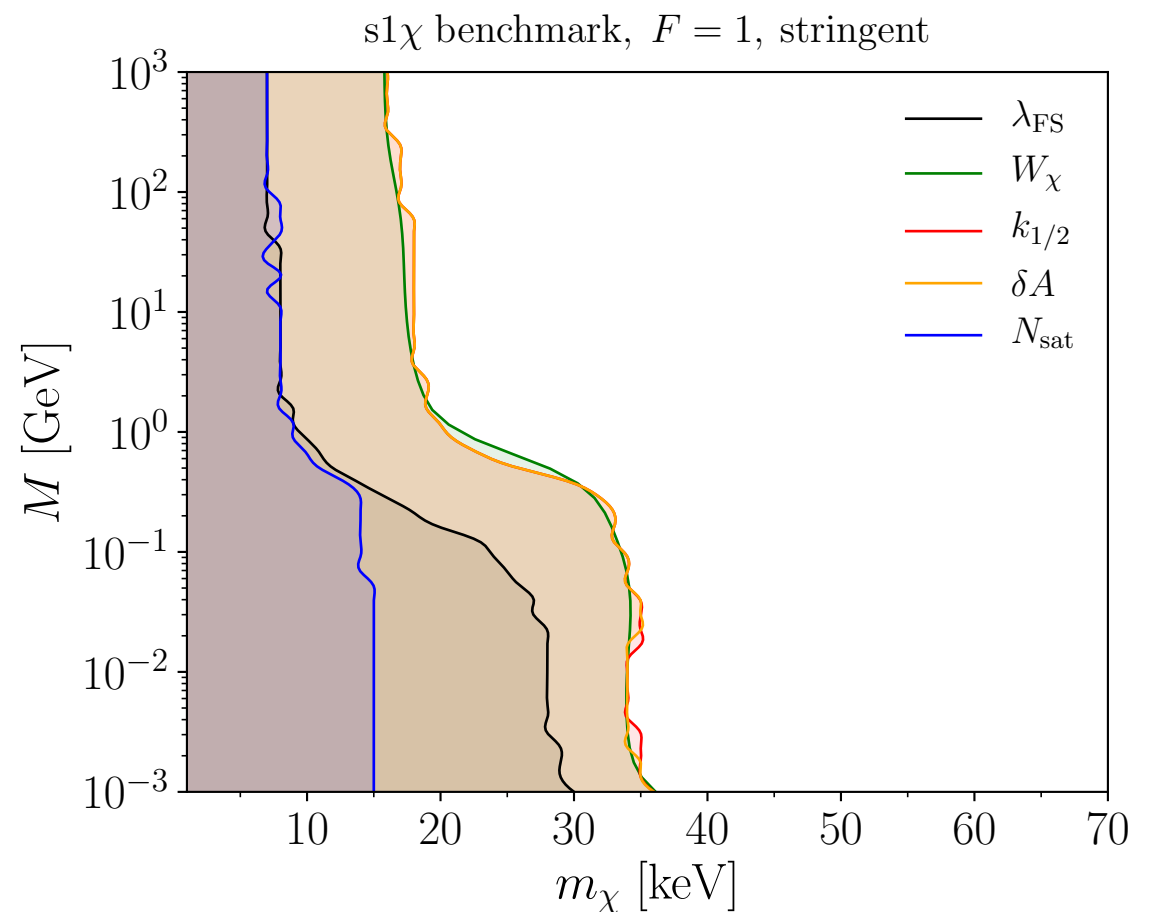
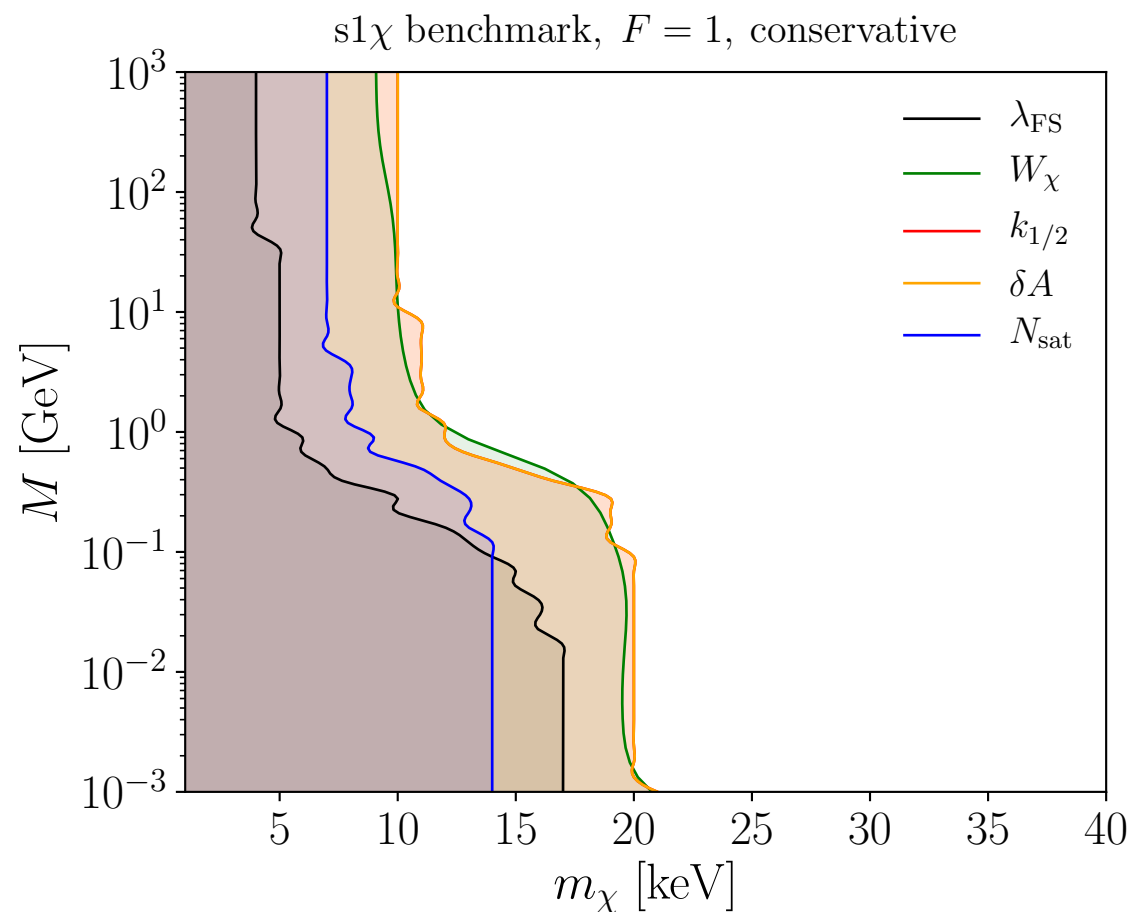


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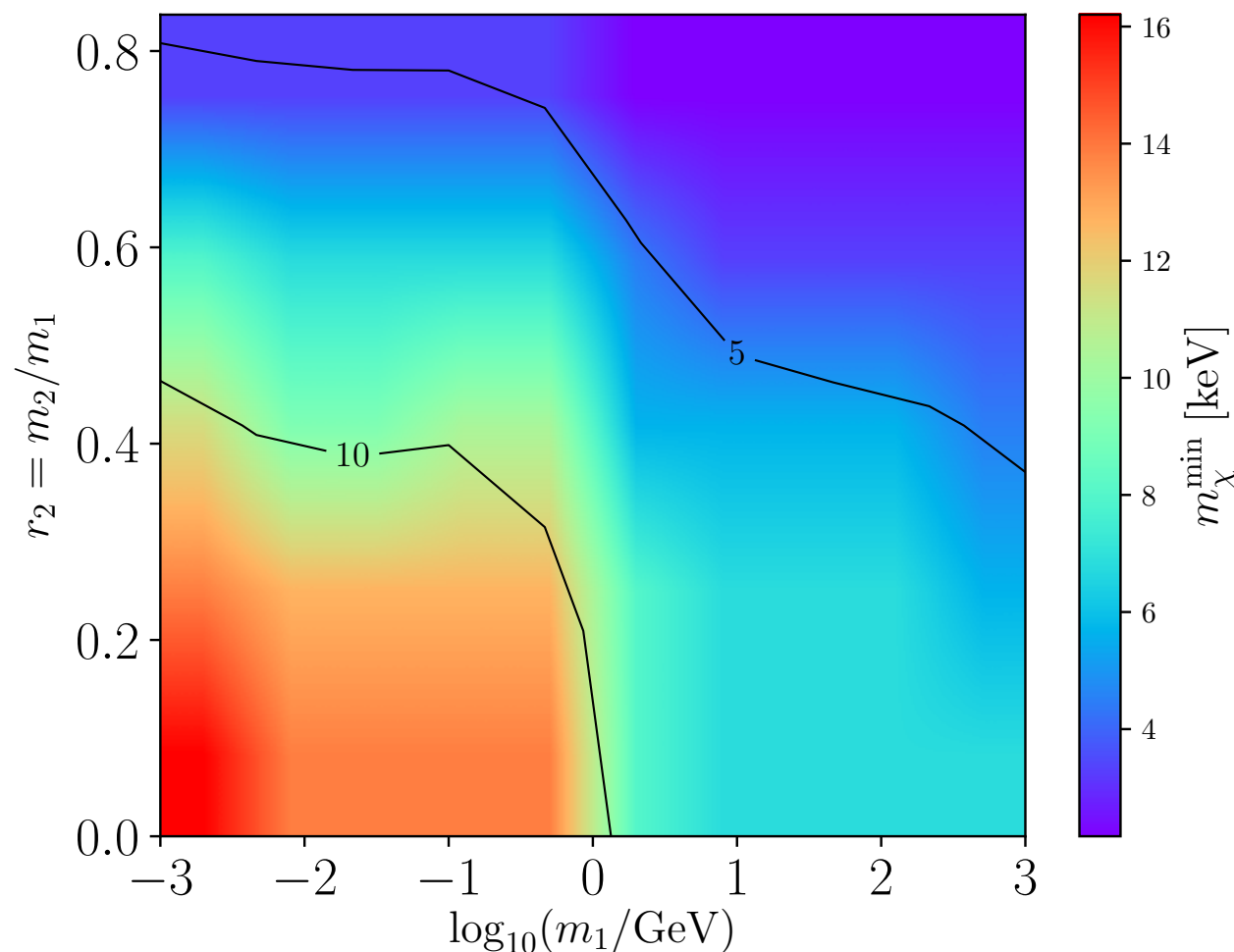
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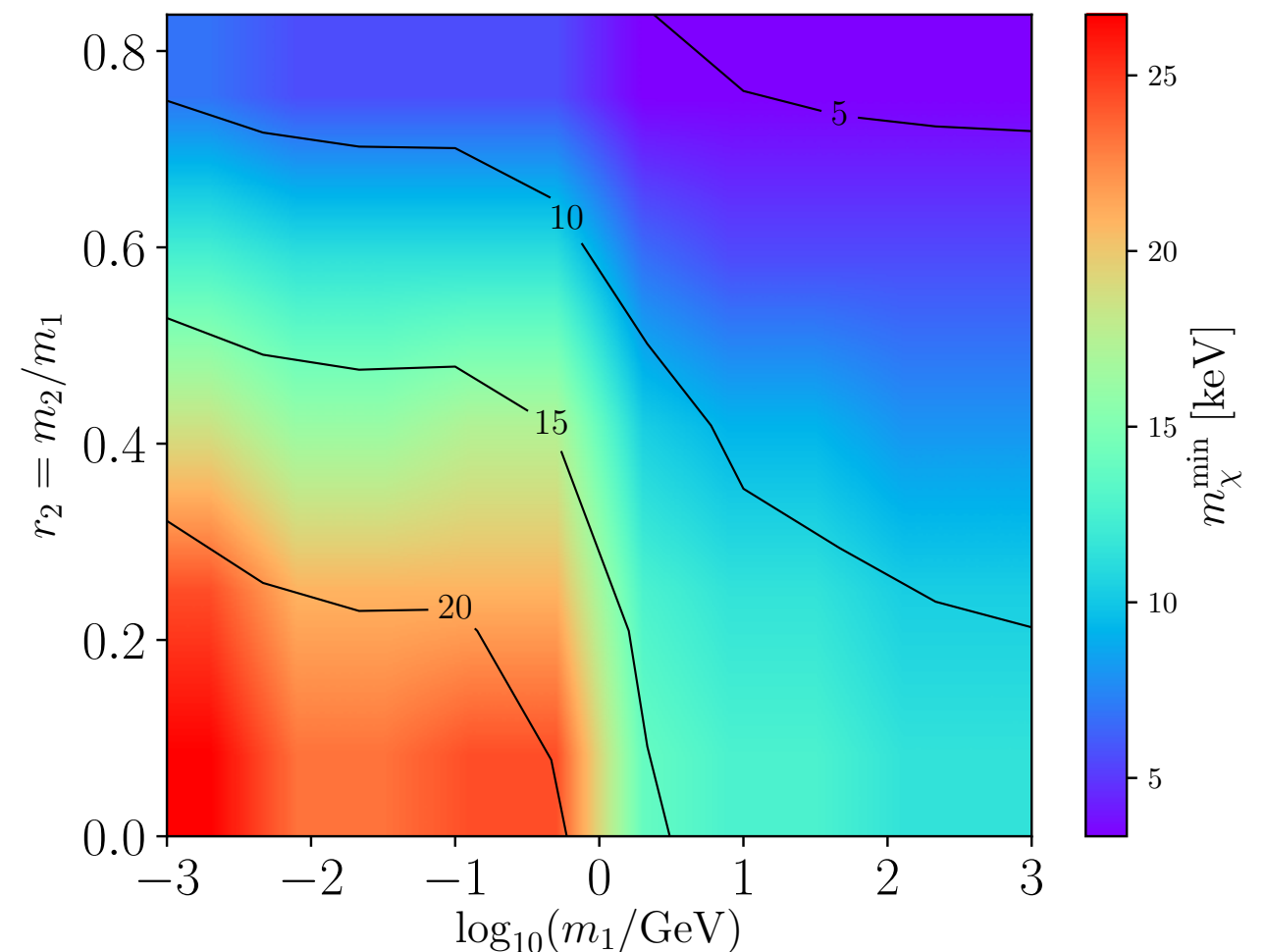
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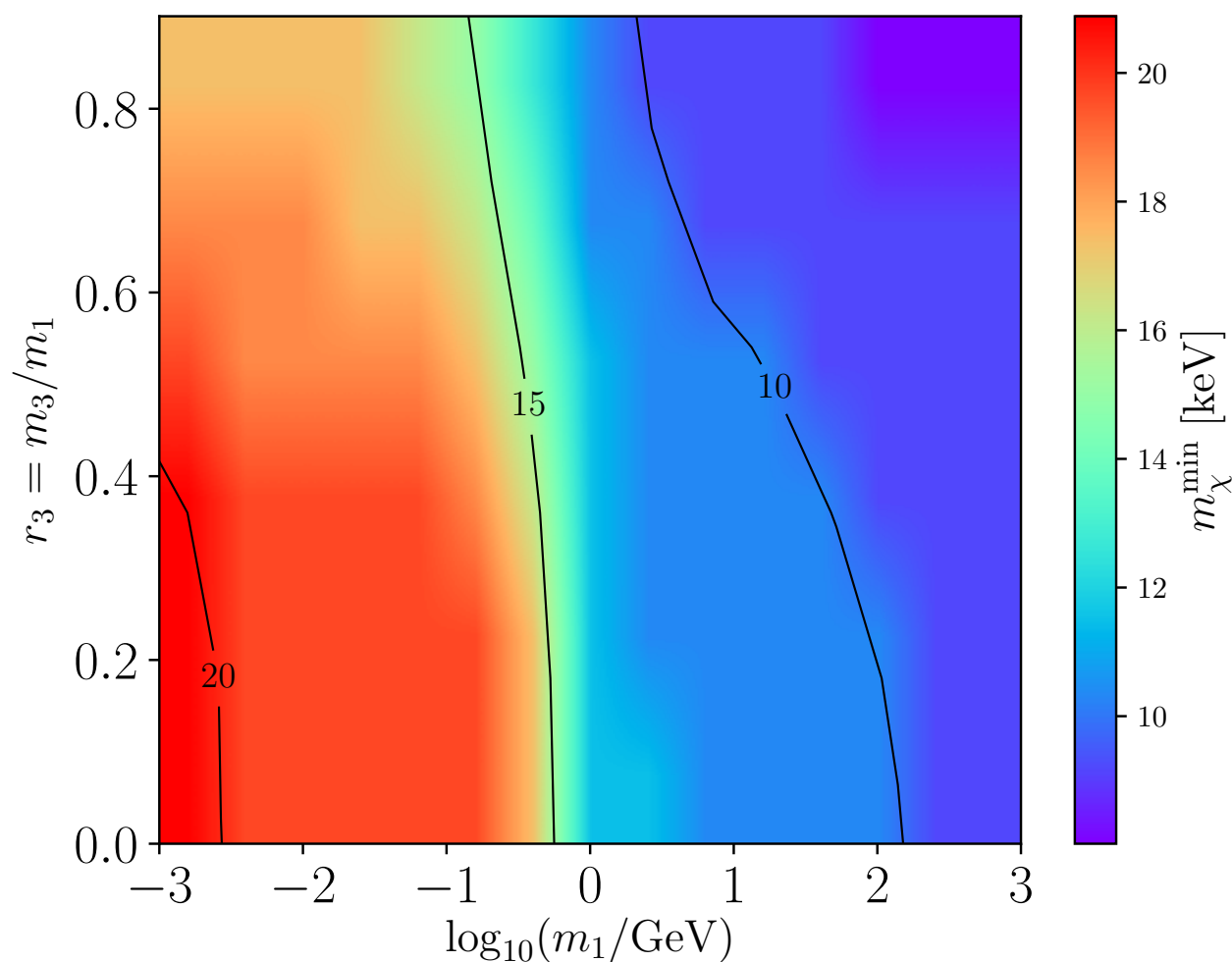
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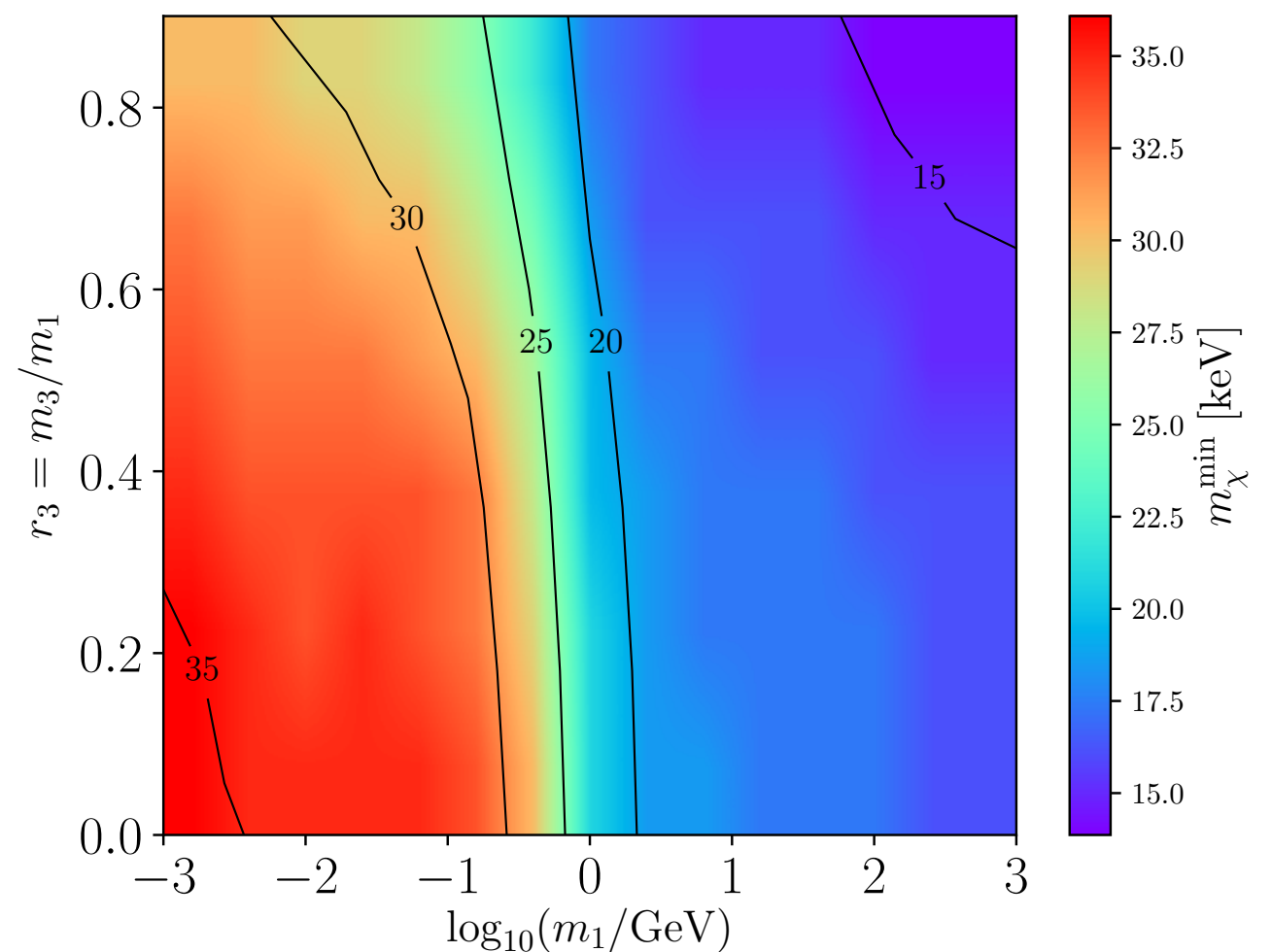
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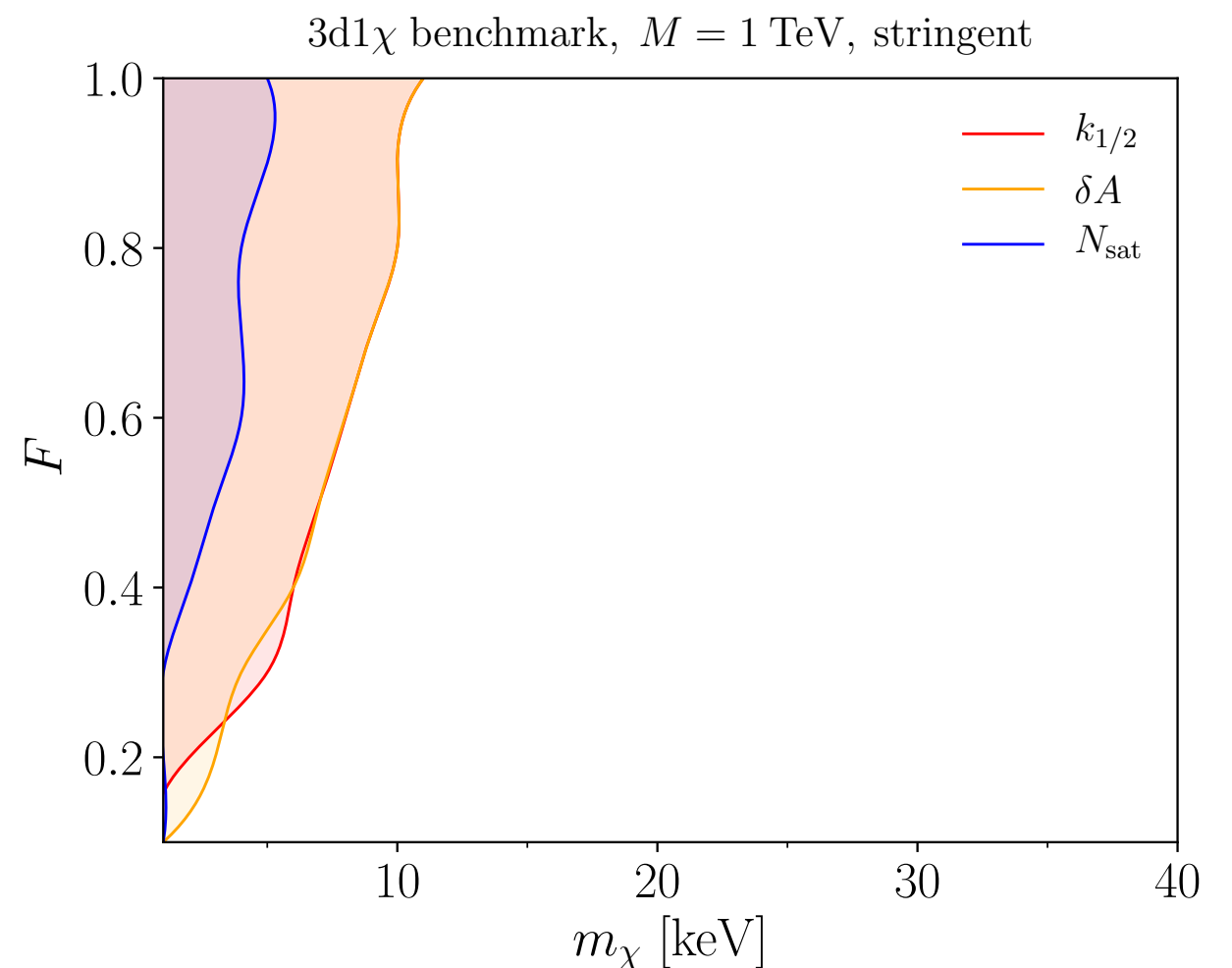
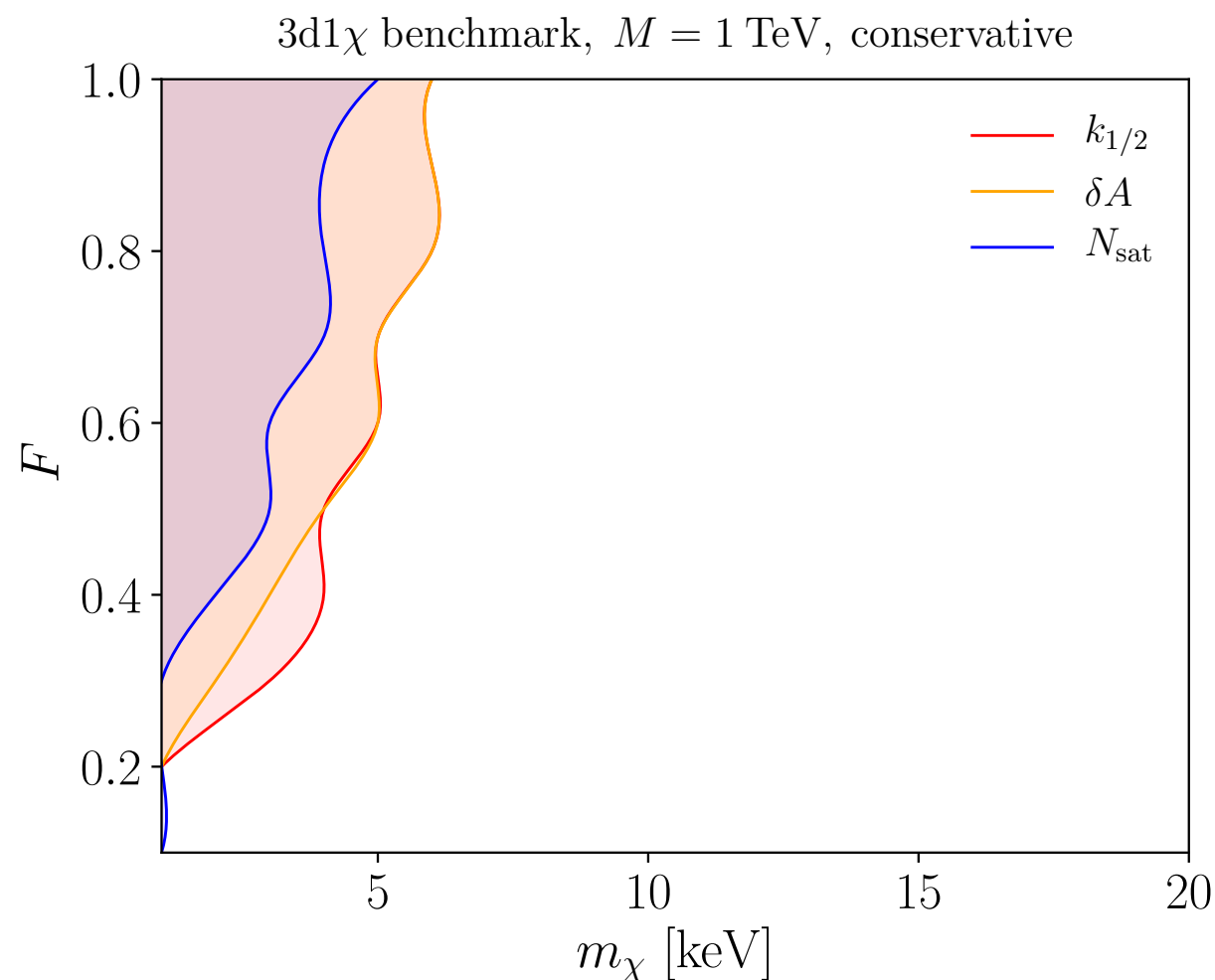


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