Dark matter spikes with strongly Self-interacting particles

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In collaboration with Boris Betancourt, Motoko Fujiwara and Takashi Toma
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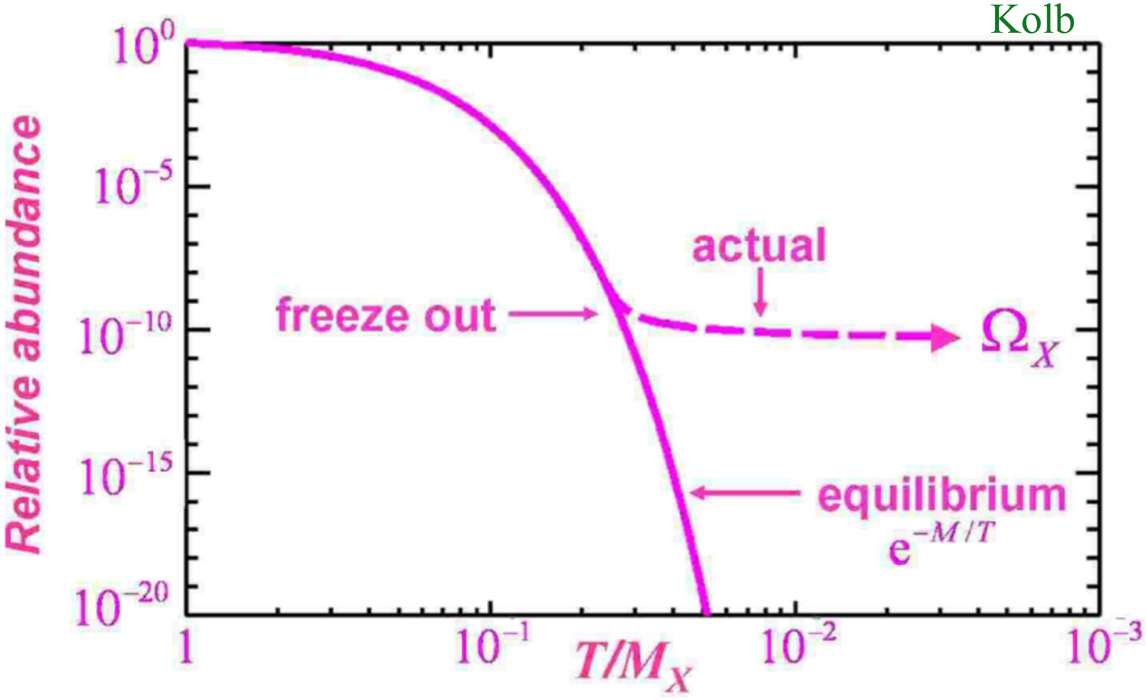
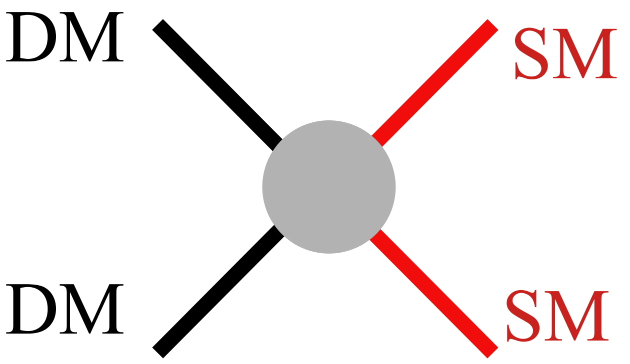
Introduction

Thermal freeze-out stands out as a plausible mechanism to generate the DM in our Universe (analogous to photon decoupling, neutron decoupling)

Kolb





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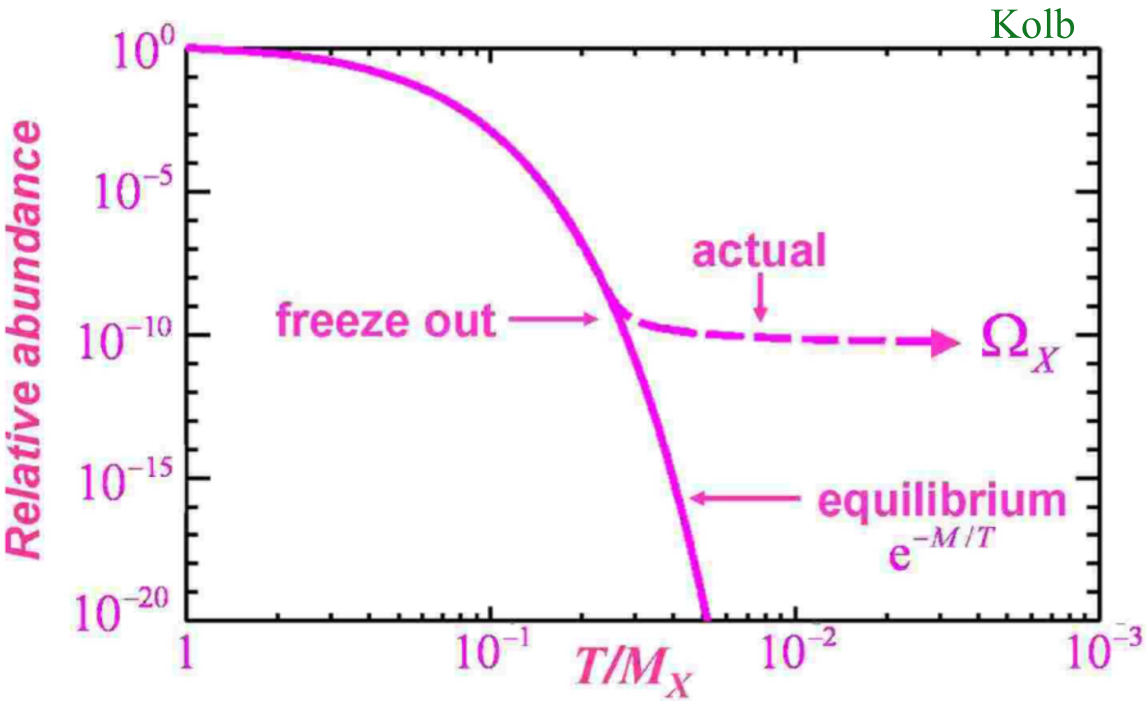

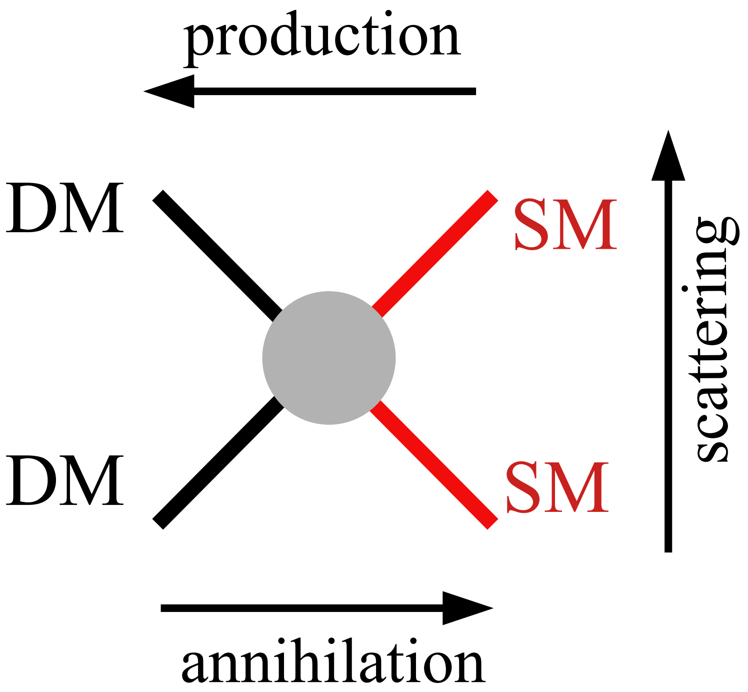

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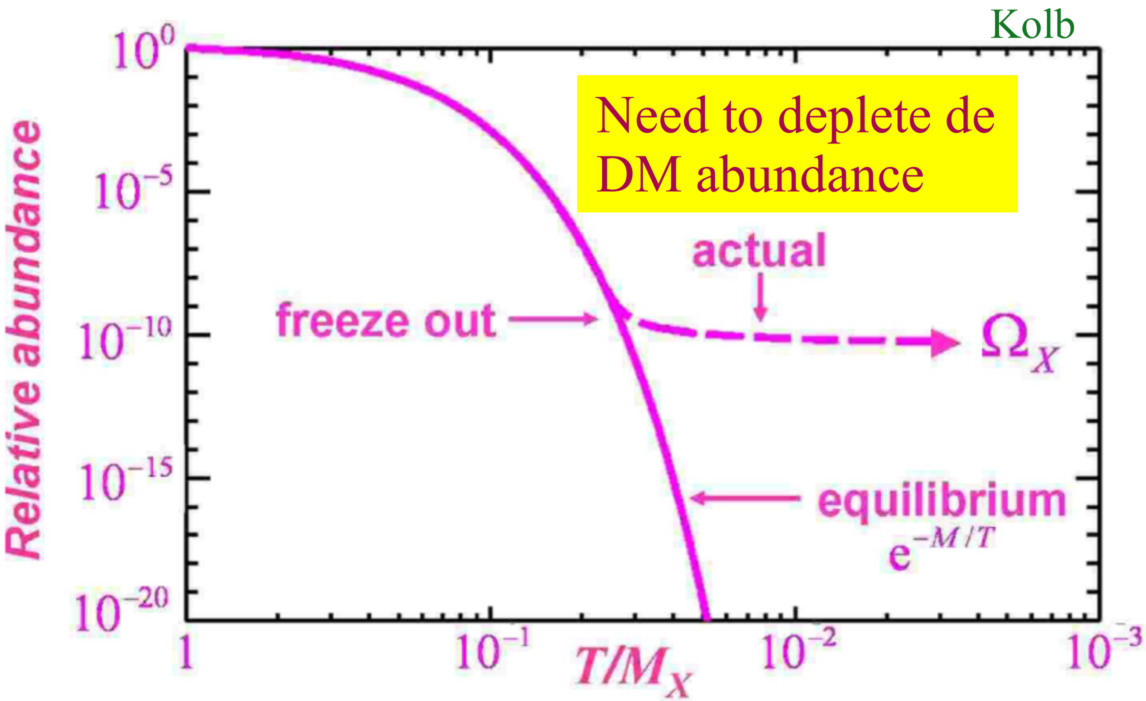

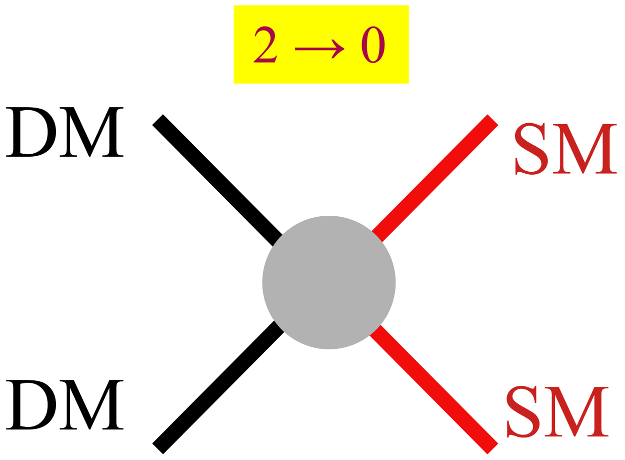

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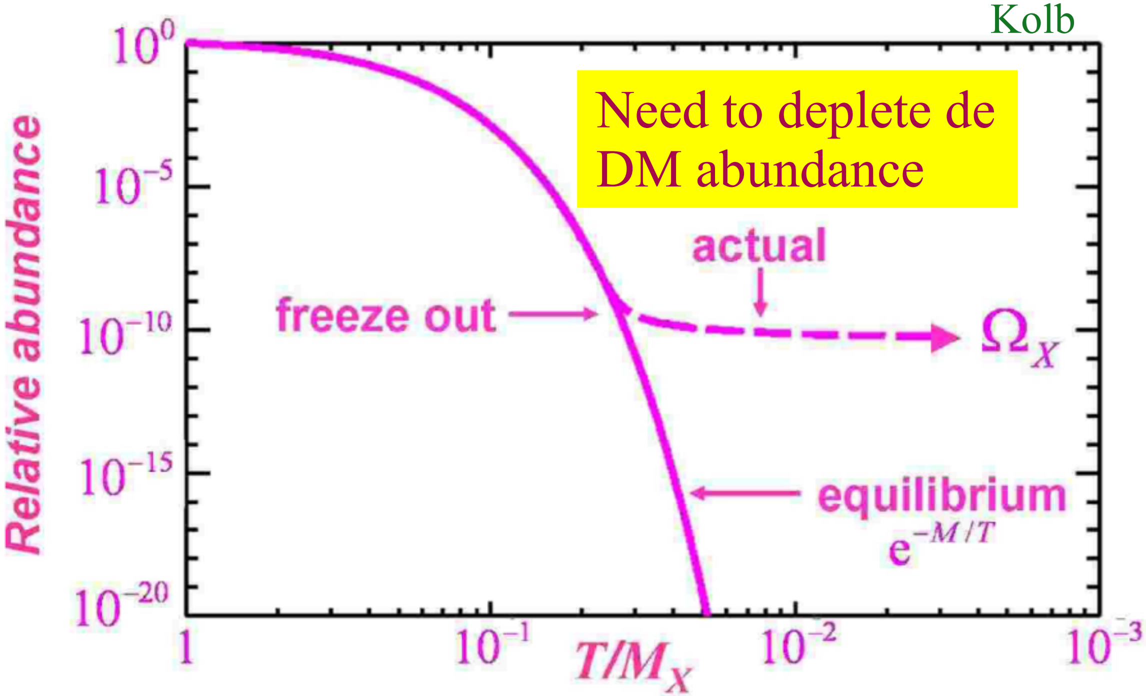

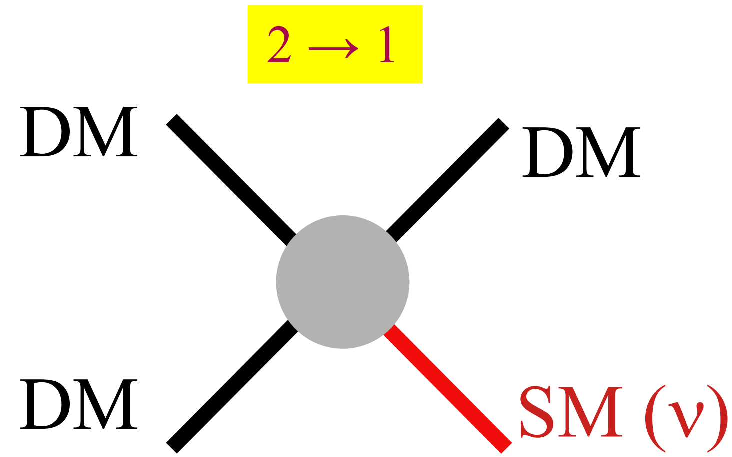

Hambye et al.
D'Eramo, Thaler

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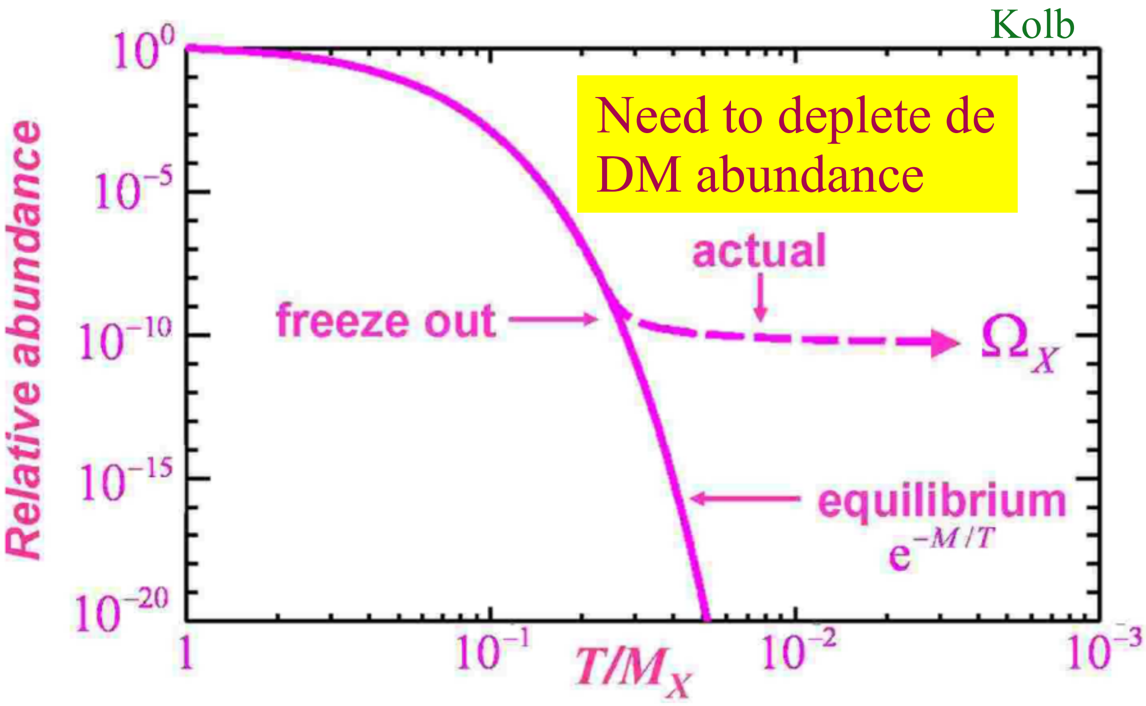

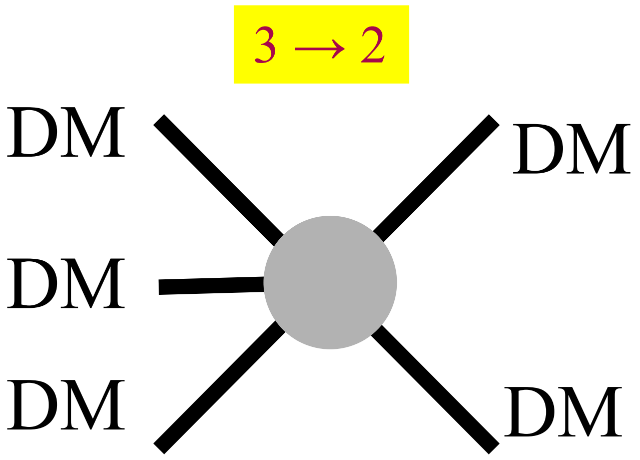

Carlson, Machacek, Hall
Hochberg, Kuflik, Volansky, Wacker

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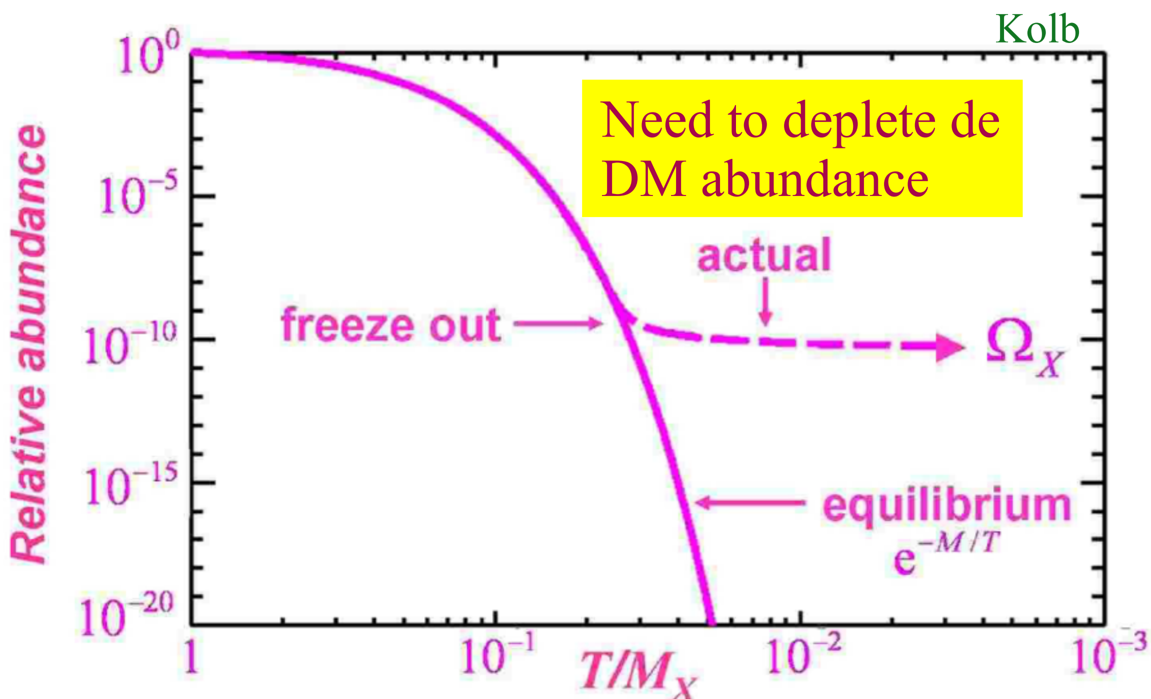

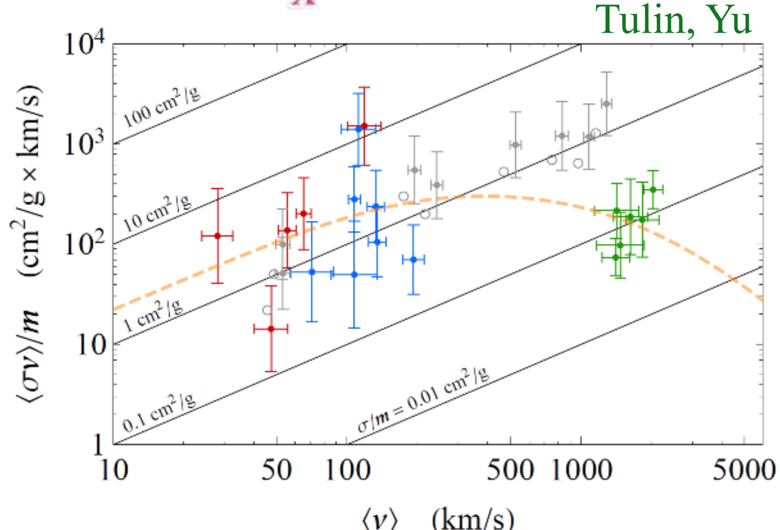

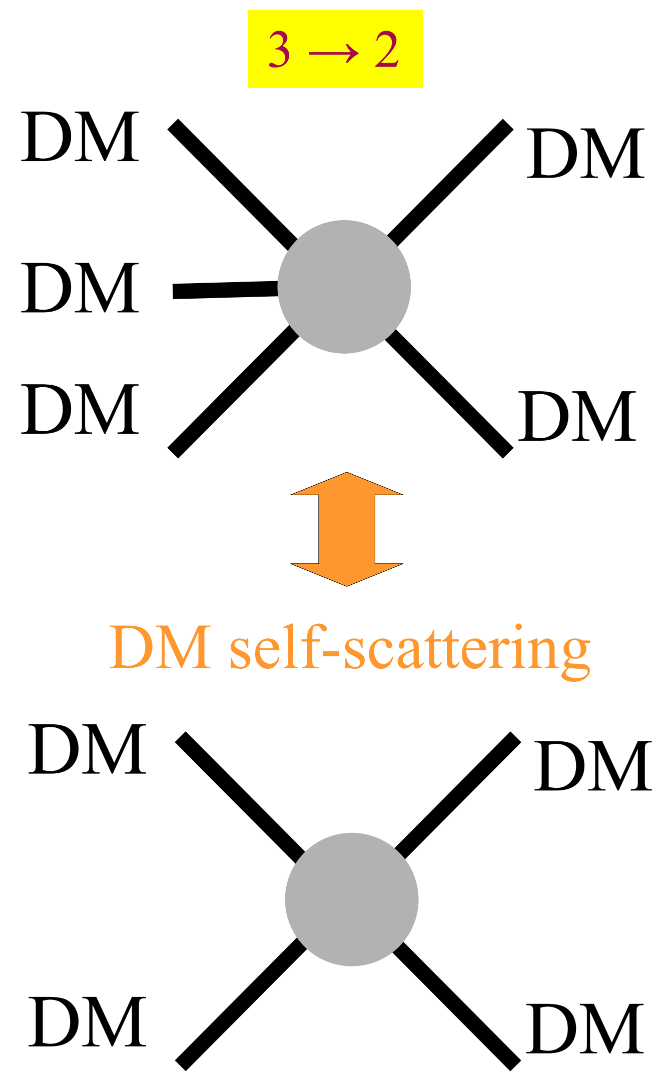

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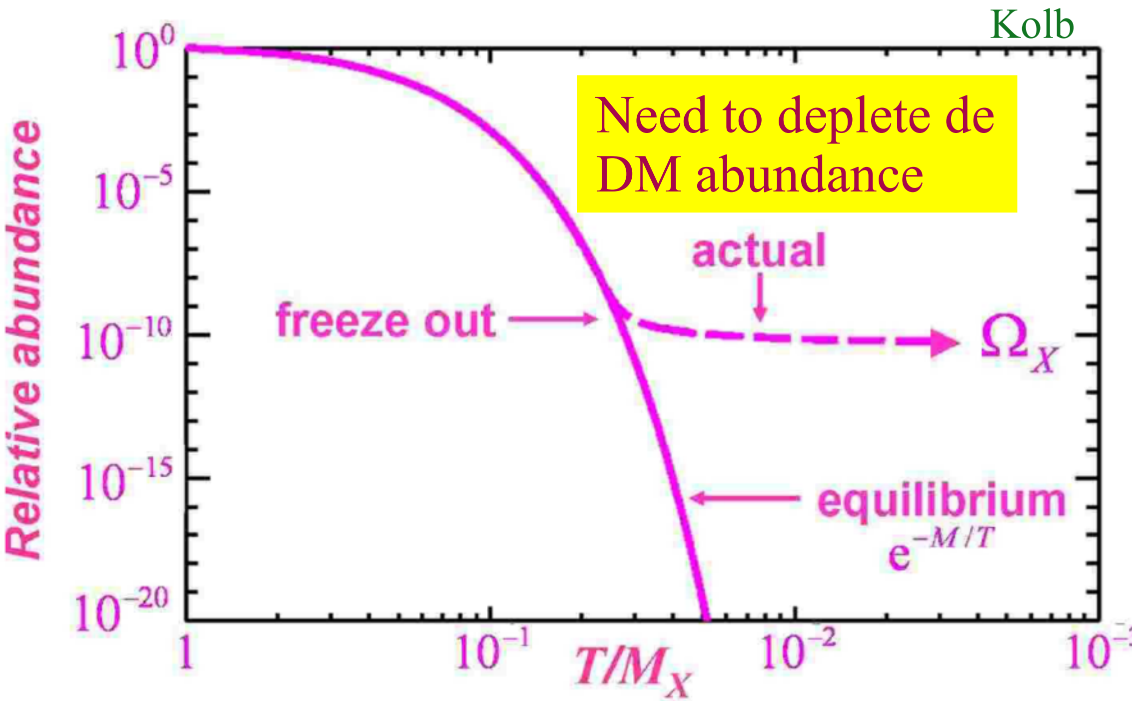

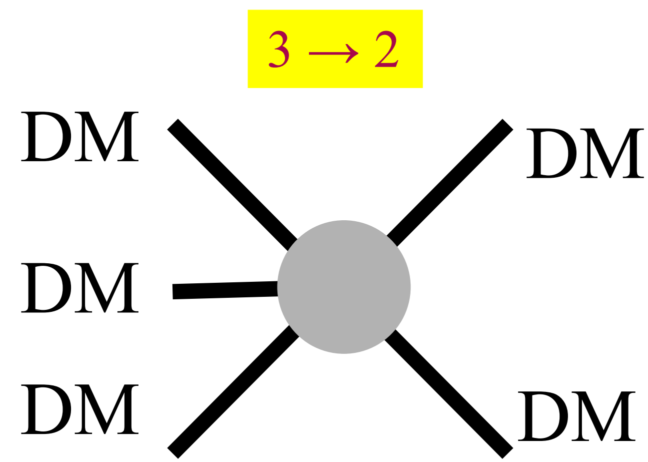

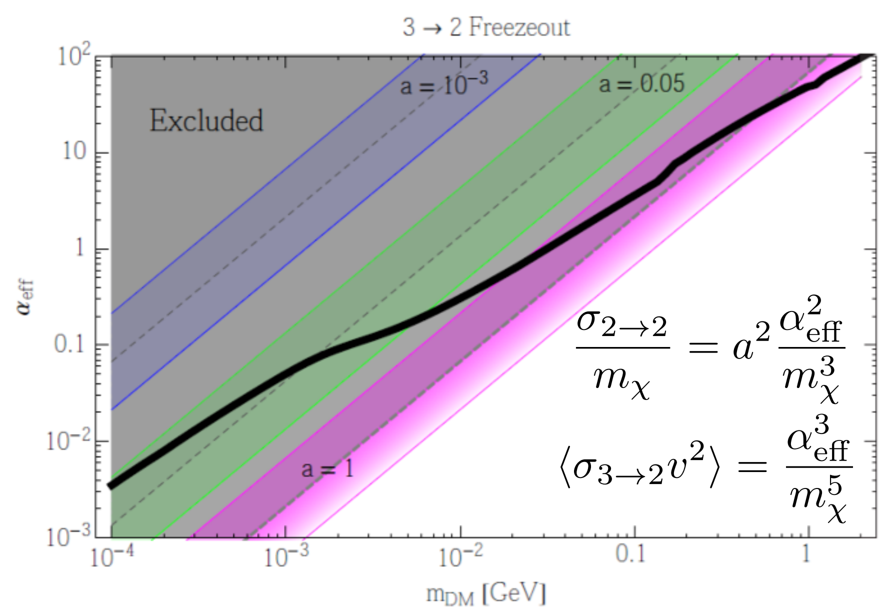

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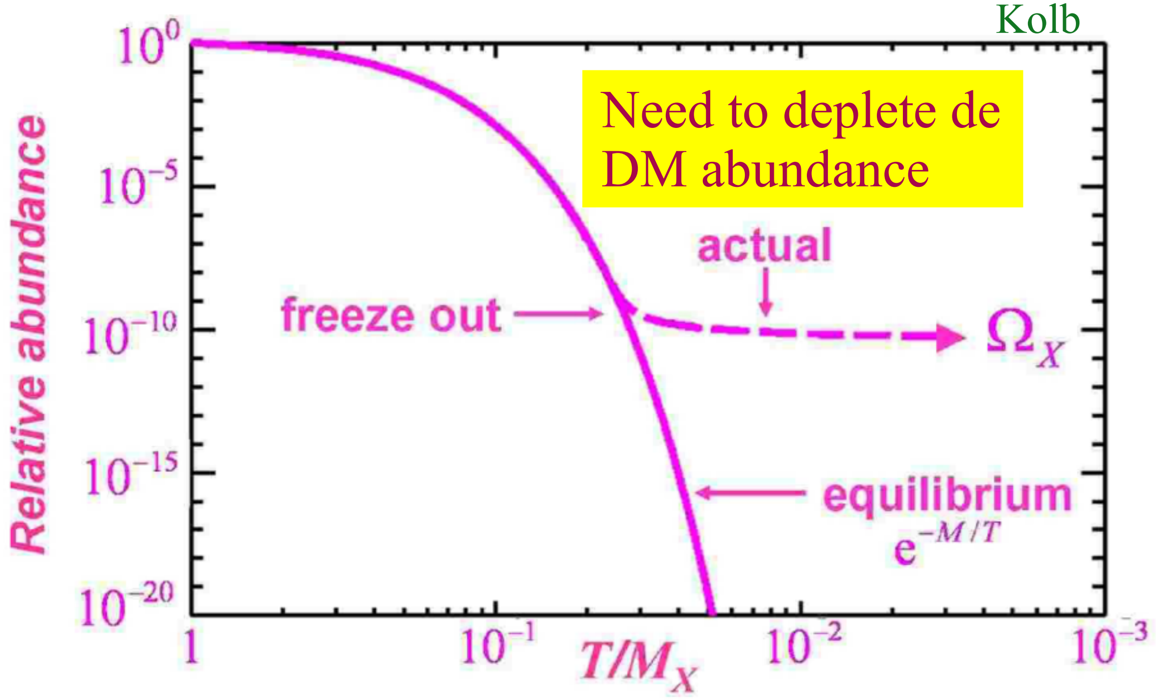
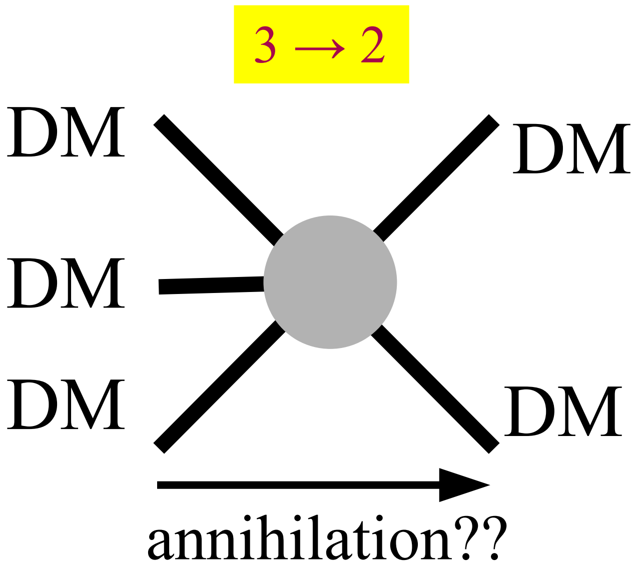




DM density at freeze-out

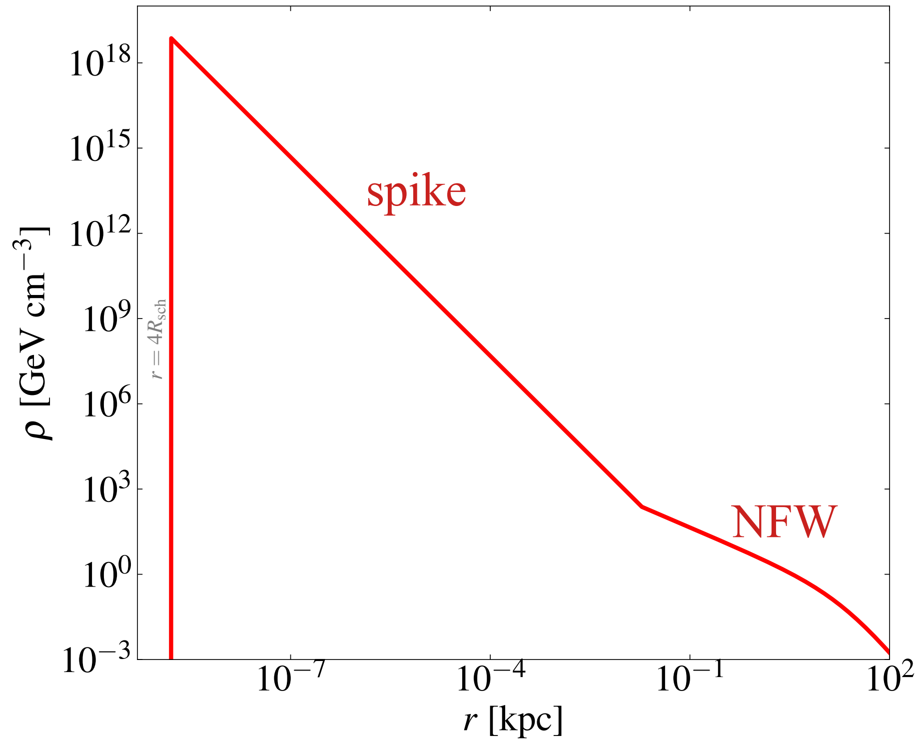
$$\rho_\chi \sim 6 \times 10^{22}\,\mathrm{GeV/cm^3} \left(\frac{m_\chi}{100\,\mathrm{MeV}}\right)^{-3} \left(\frac{\alpha_{\rm eff}}{0.1}\right)$$

The DM spike around supermassive black holes

In the center of the Milky Way it is located a supermassive black hole, with mass ~ 4×10^6 M_{sun}.

The adiabatic growth of the black hole produces a "spike" in the dark matter distribution Gondolo, Silk'99, Peebles '72, Quinlan, Hernquist, Sigurdsson '95

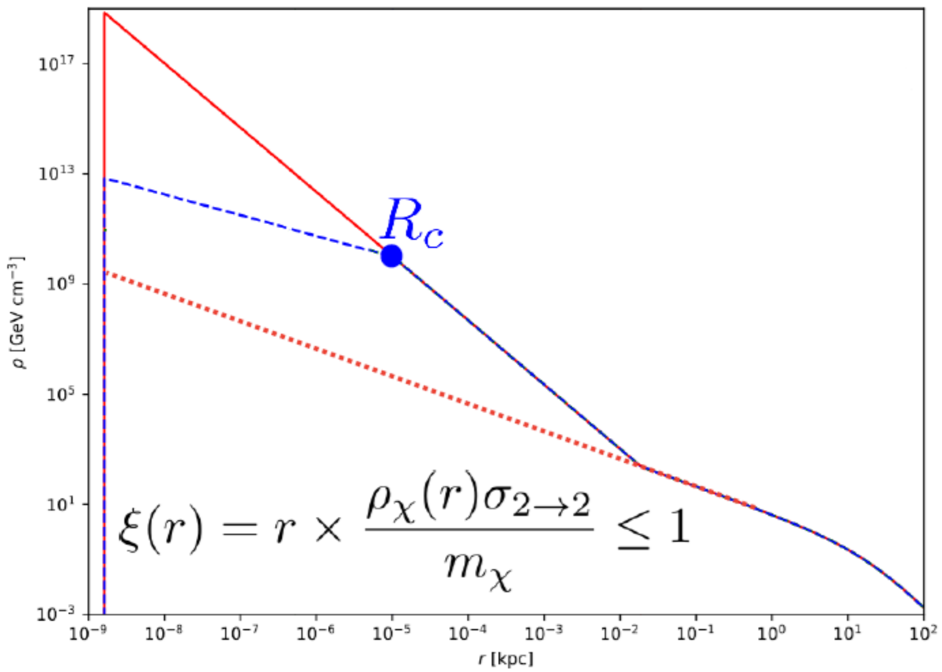
$$\rho(r) = \rho_0 \left(\frac{r_0}{r}\right) \longrightarrow \rho_{\rm sp} \sim \rho_R \left(\frac{R_{\rm sp}}{r}\right)^{7/3}$$



The DM spike around supermassive black holes

Different effects can soften the spike:

- Self-interactions: momentum exchange produce a core (depends on $\sigma_{2\to 2}$)



The DM spike around supermassive black holes

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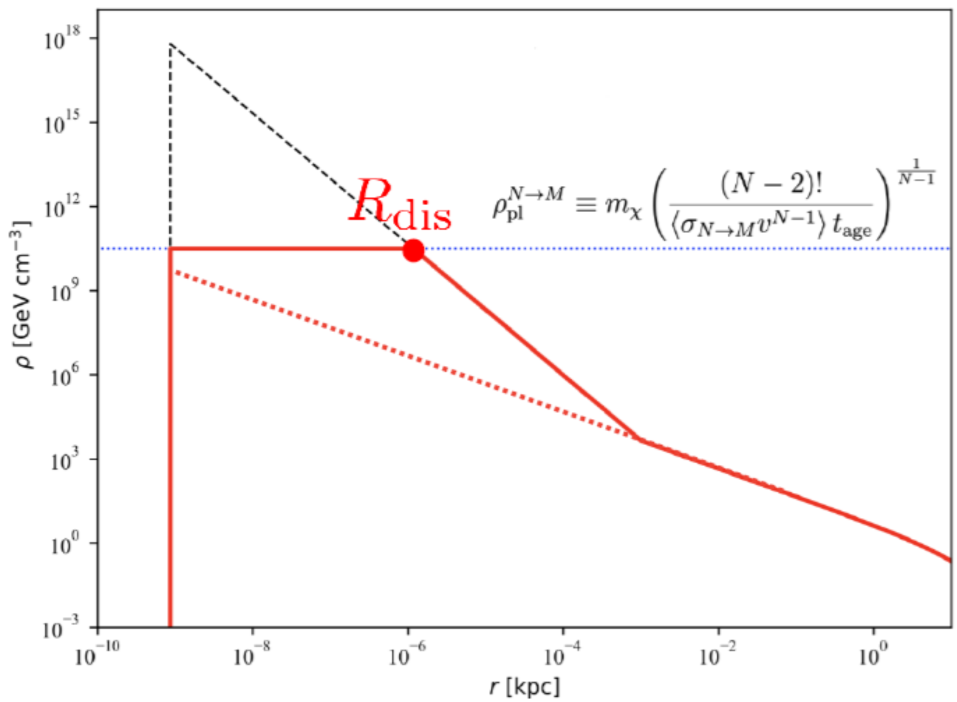
- Self-interactions: momentum exchange produce a core (depends on $\sigma_{2\to 2}$)

- n→m processes (n>m): deplete the number of DM particles in the spike (depends on $\sigma_{n\to m}$)

$$\dot{n}_\chi(r,t) = -\langle\sigma_{2\to 0}v\rangle\,(n_\chi(r,t))^2 - \frac{n}{n!}\left\langle\sigma_{n\to m}v^{n-1}\right\rangle(n_\chi(r,t))^n$$



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- n→m processes (n>m) produce energetic DM particles. If they scatter, they heat-up the spike and produce a core (depends on $\sigma_{n\to m}$ and $\sigma_{2\to 2}$)

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- n→m processes (n>m): deplete the number of DM particles in the spike (depends on $\sigma_{n\to m}$)
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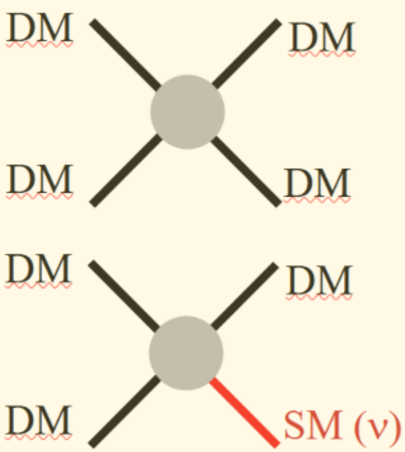
The n→m process produces a highly boosted DM particle.

Implications for direct DM searches?

The DM spike around supermassive black holes

Large parameter space: $\{m_\chi, \sigma_{2\to2}/m_\chi, \langle\sigma_{2\to0}v\rangle, \langle\sigma_{2\to1}v\rangle, \langle\sigma_{3\to2}v^2\rangle, \ldots\}$

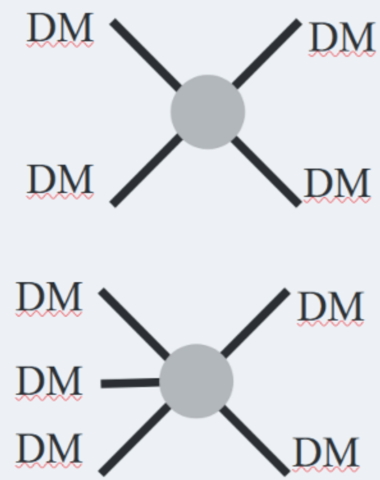
- Example 1: Only 2→2 and 2→1



$$\sigma_{2\to2}/m_\chi = \frac{\alpha_{2\to2}^2}{m_\chi^3}$$

$$\langle\sigma_{2\to1}v\rangle = \frac{\alpha_{2\to1}^2}{m_\chi^2}$$

- Example 2: Only 2→2 and 3→2

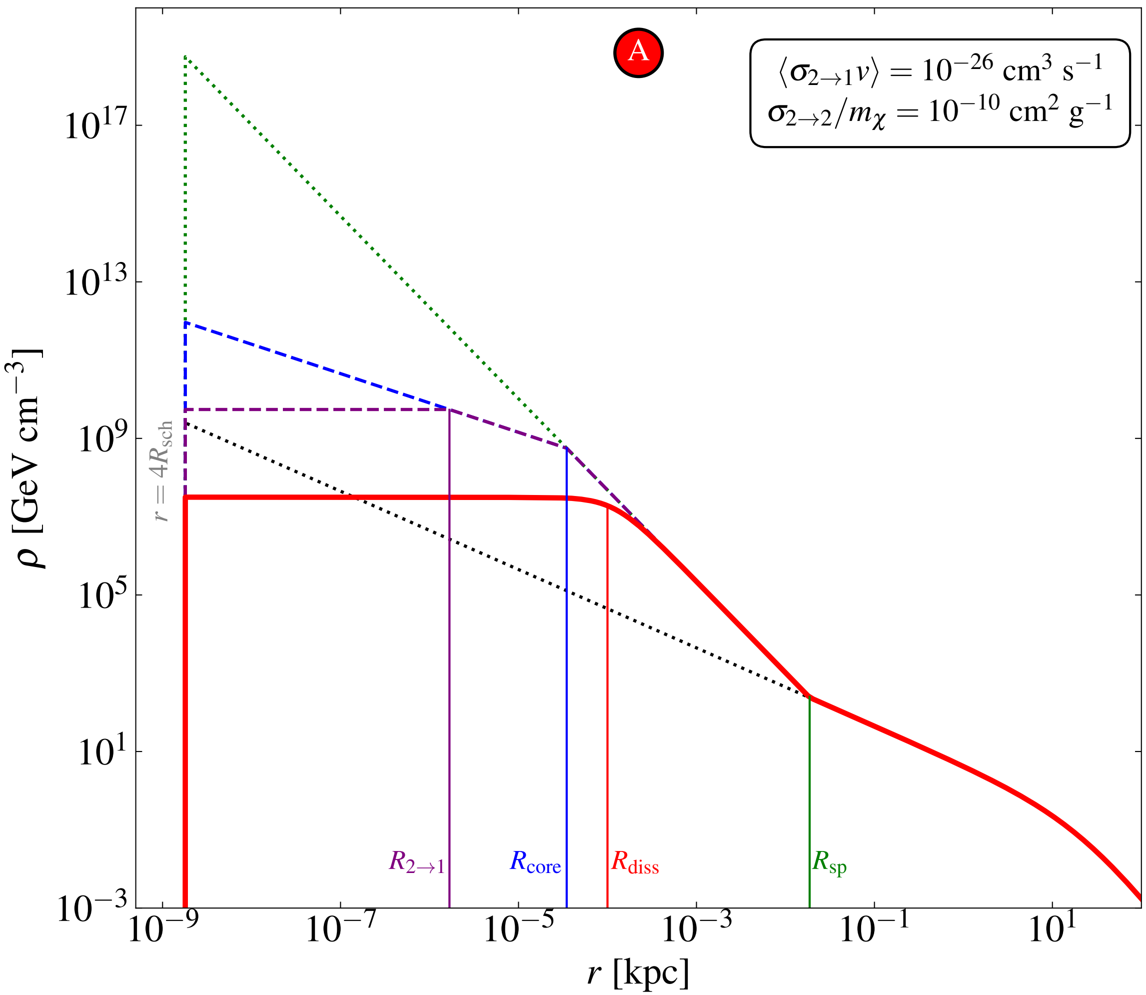


$$\sigma_{2\to2}/m_\chi = \frac{\alpha_{2\to2}^2}{m_\chi^3}$$

$$\langle\sigma_{3\to2}v^2\rangle = \frac{\alpha_{3\to2}^3}{m_\chi^5}$$

The fate of the DM spike

- Example 1: Only 2→2 and 2→1



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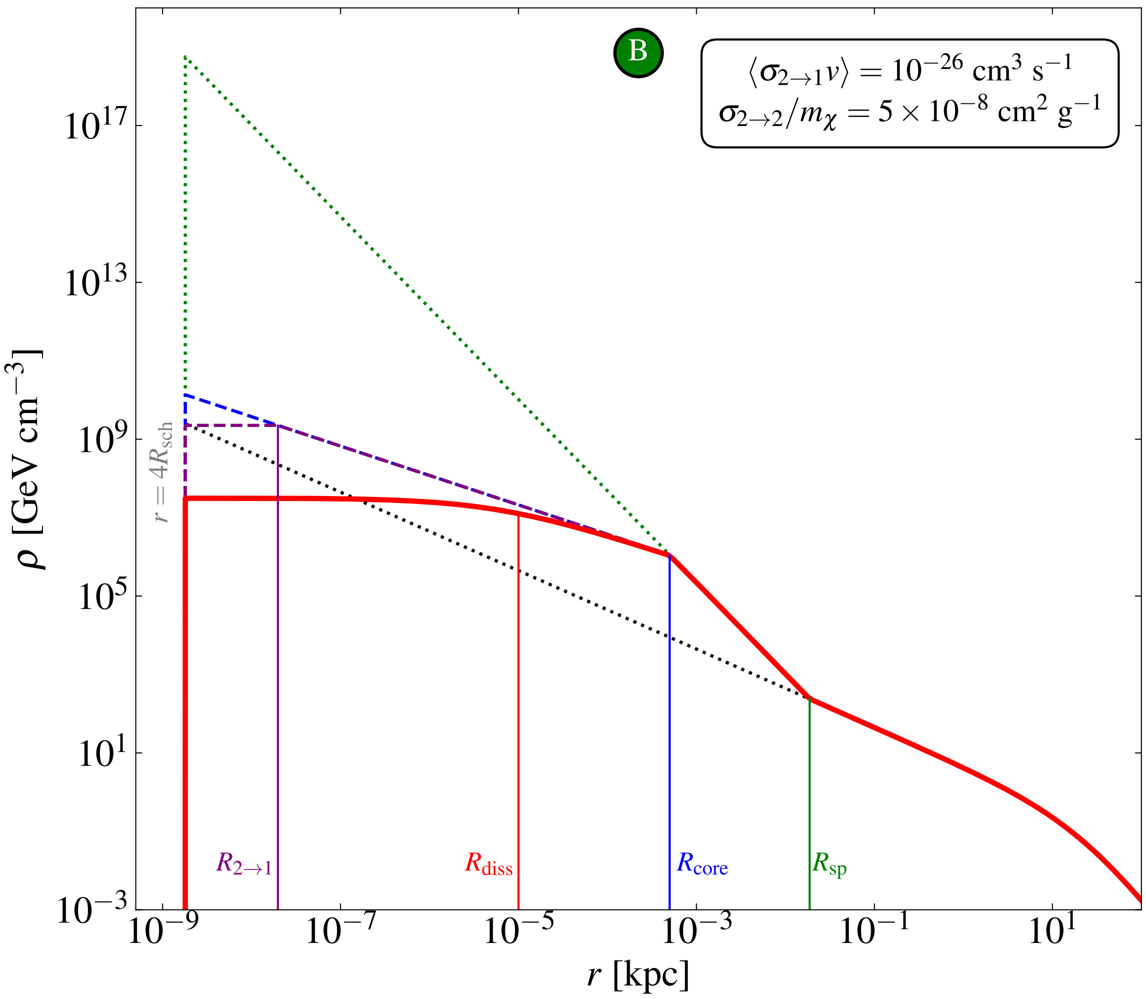

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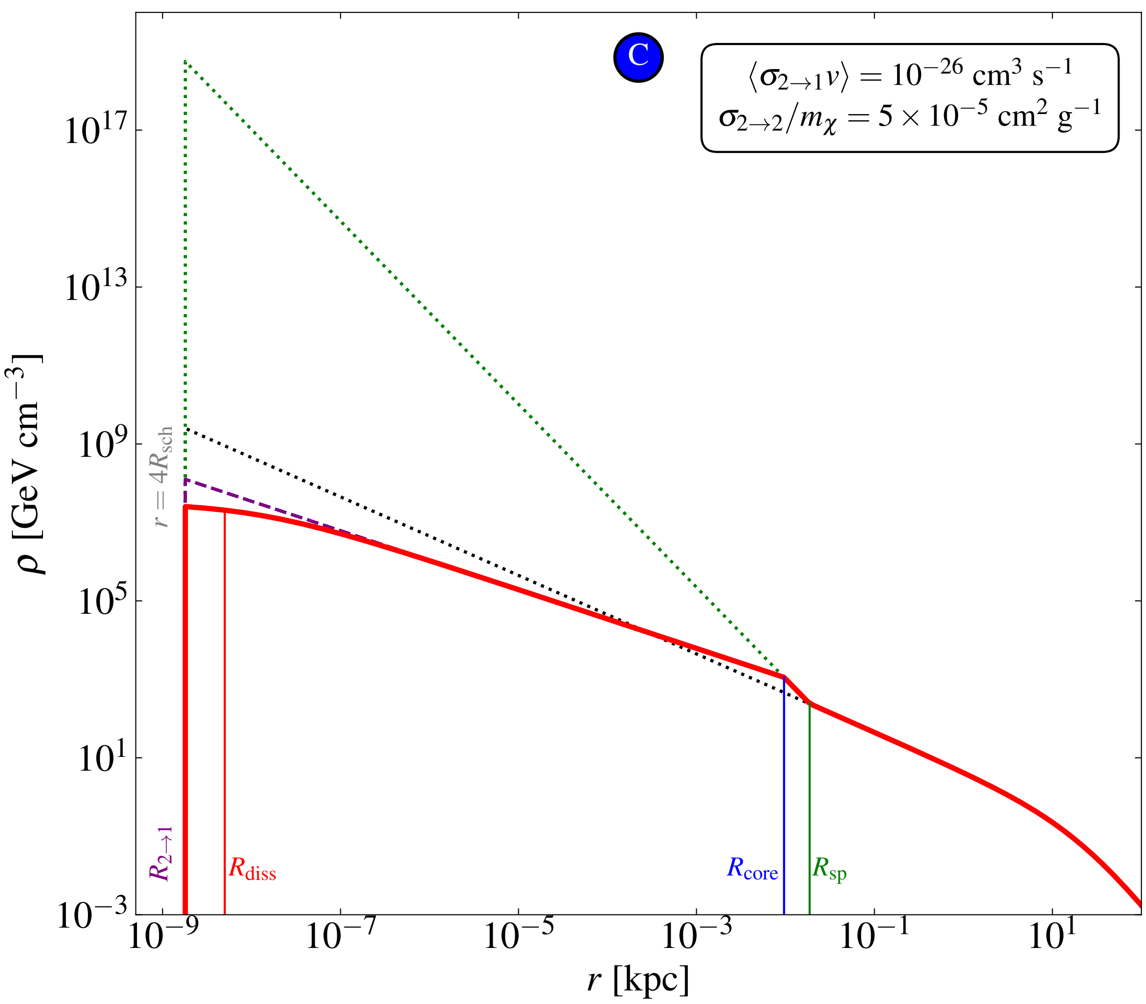

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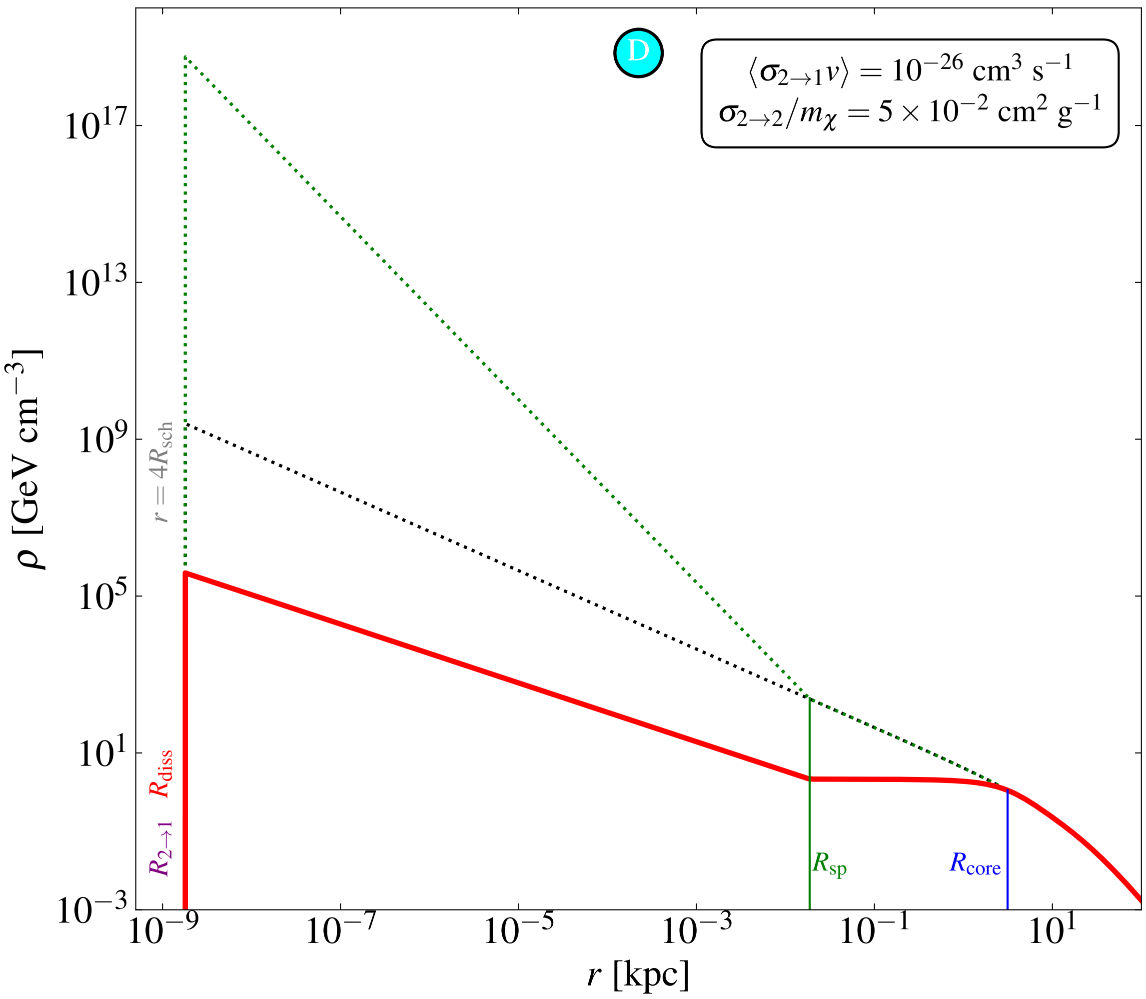
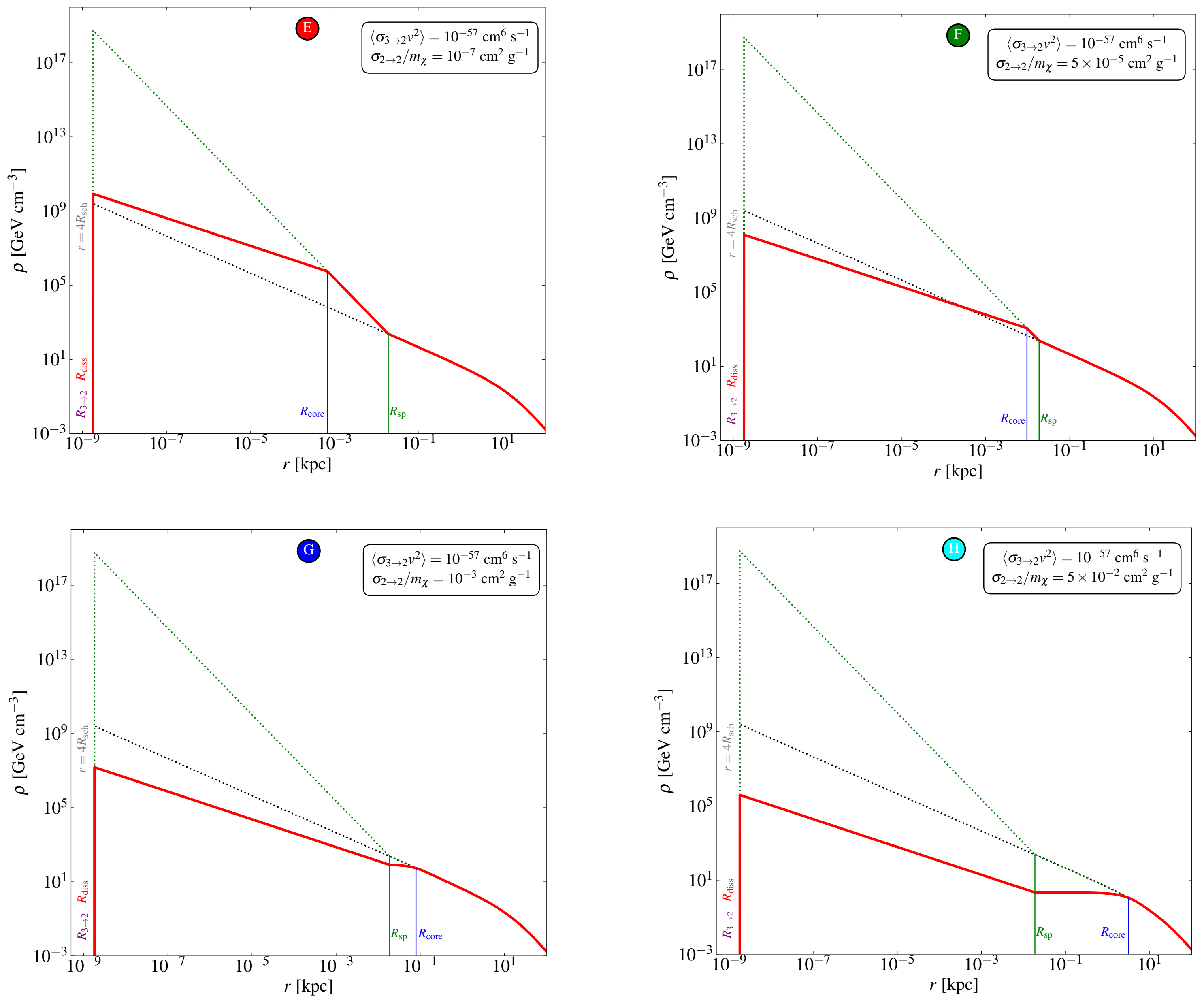
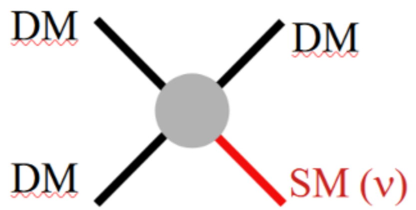


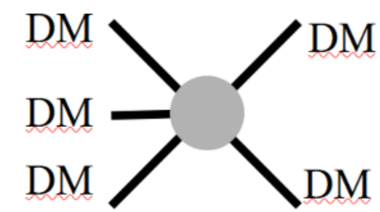
The fate of the DM spike

- Example 2: Only 2→2 and 3→2



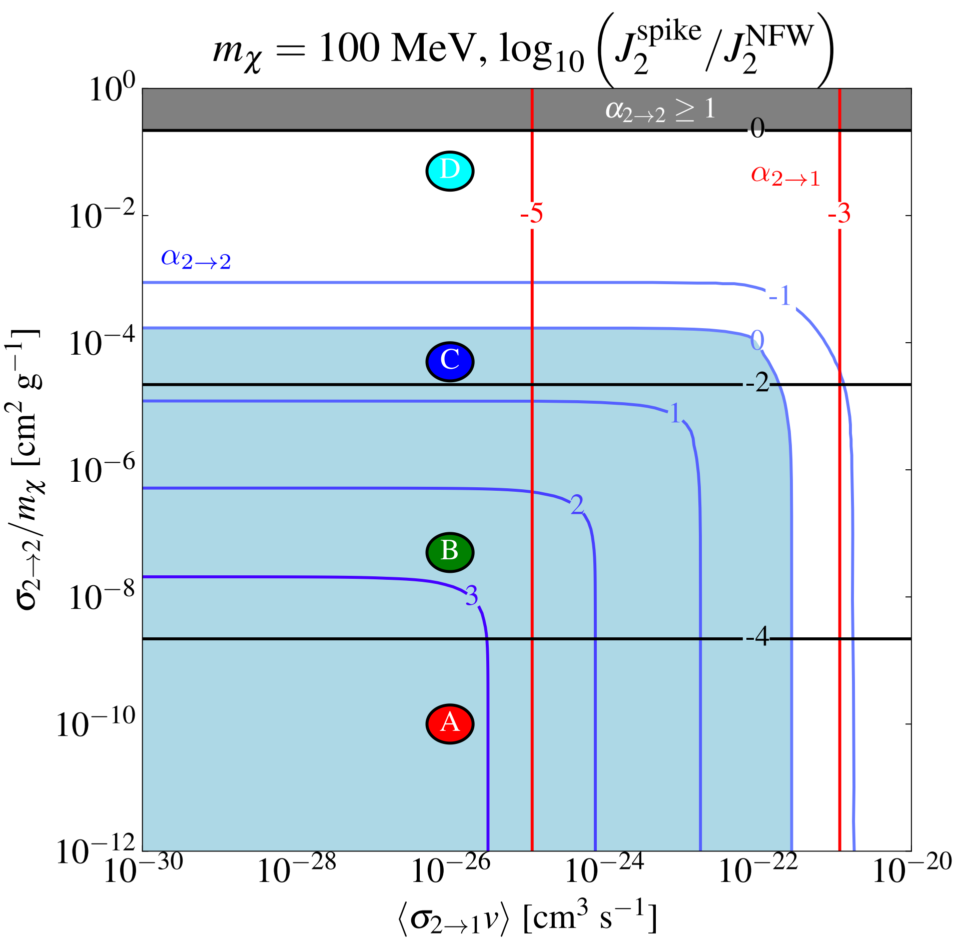
Implications for J-factors

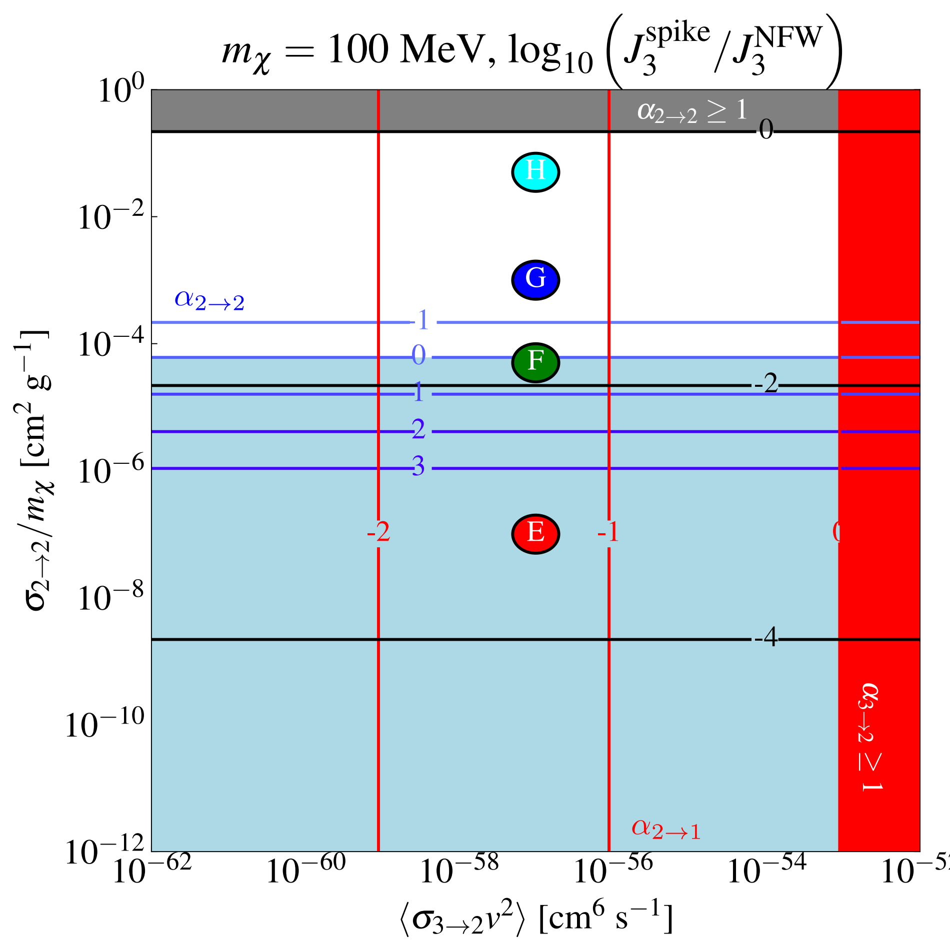




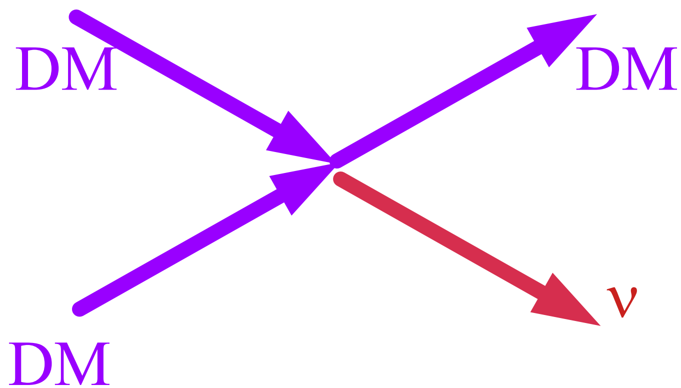
$$J_2^{\rm spike} \equiv 4\pi \int_0^{R_{\rm sp}} dr\ r^2 \big(\rho_\chi(r)/m_\chi\big)^2 .$$

$$J_3^{\rm spike} \equiv 4\pi \int_0^{R_{\rm sp}} dr\ r^2 \big(\rho_\chi(r)/m_\chi\big)^3$$



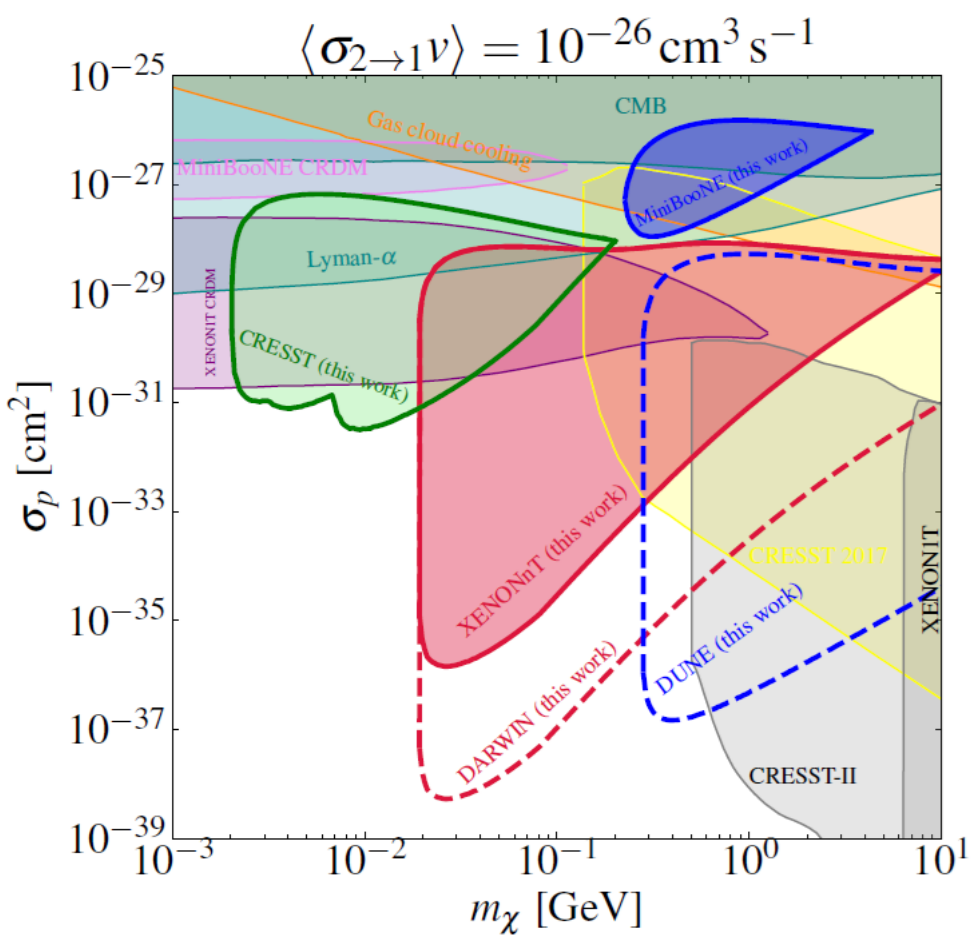


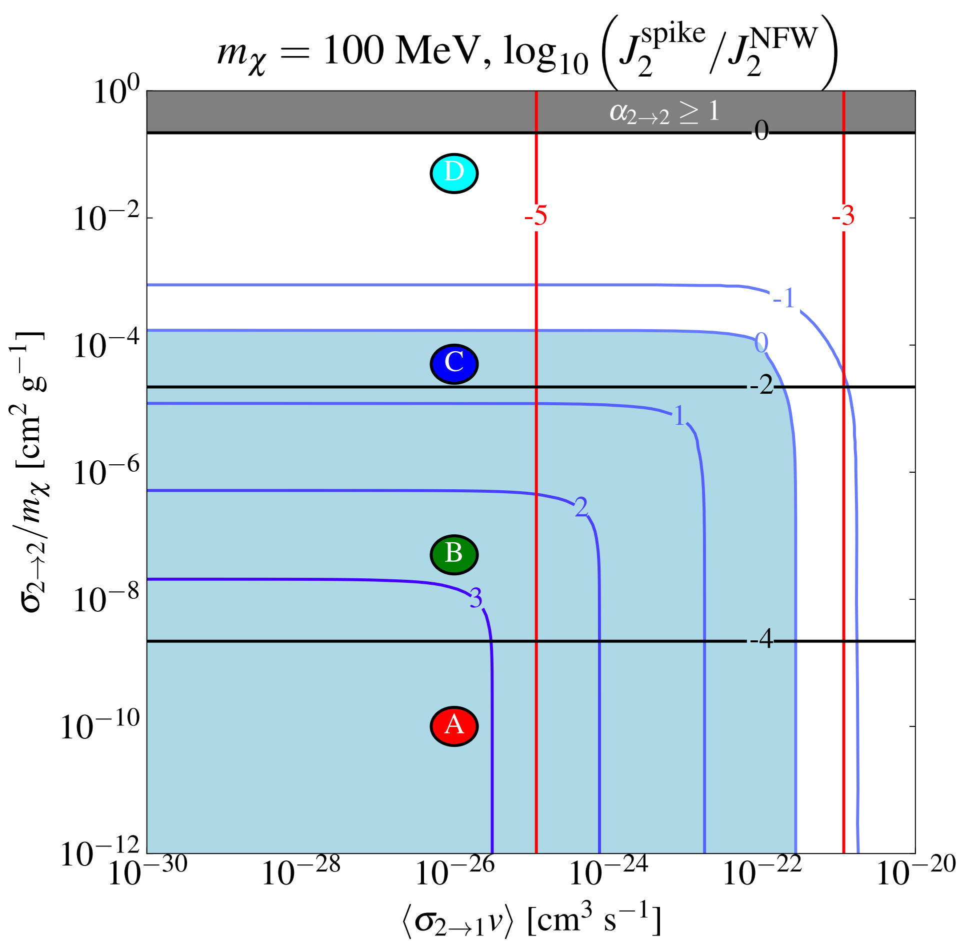
Implications for direct detection experiments



Flux of boosted DM particles, with $T_\chi = m_\chi/4$

$$\Phi_{\rm BDM} \simeq 3.2 \times 10^{-3}\ {\rm cm}^{-2}\ {\rm s}^{-1}\ \left(\frac{m_\chi}{100\,{\rm MeV}}\right)^{-2} \left(\frac{\langle\sigma_{2\to1}v\rangle}{10^{-26}\ {\rm cm}^3{\rm s}^{-1}}\right)$$





Conclusions

- The structure of the dark matter spike surrounding a black hole can be significantly affected by dark matter processes (scatterings, annihilations, semi-annihilations, $3\rightarrow2$ processes, etc.)
- The rate for annihilations and semi-annihilations in the spike can be significantly modified by the existence of self-interactions. Implications for indirect searches.
- The rate for semi-annihilations and $3\rightarrow2$ processes in the spike can be significantly modified by the existence of self-interactions. Implications for direct searches.

Back-up

Benchmark	$\langle \sigma v \rangle_{2\to1}$ $[\frac{cm^3}{s}]$	$\frac{\sigma_{2\to2}}{m_\chi}$ $[\frac{cm^2}{g}]$	$\langle \sigma v^2 \rangle_{3\to2}$ $[\frac{cm^6}{s}]$	$\alpha_{2\to2}$	$\alpha_{2\to1}$	$\alpha_{3\to2}$
A	10^{-26}	10^{-10}	0	2.14×10^{-5}	2.93×10^{-6}	0
B	10^{-26}	5×10^{-8}	0	4.78×10^{-4}	2.93×10^{-6}	0
C	10^{-26}	5×10^{-5}	0	1.51×10^{-2}	2.93×10^{-6}	0
D	10^{-26}	5×10^{-2}	0	4.78×10^{-1}	2.93×10^{-6}	0
E	0	10^{-7}	10^{-57}	6.77×10^{-4}	0	4.81×10^{-2}
F	0	5×10^{-5}	10^{-57}	1.51×10^{-2}	0	4.81×10^{-2}
G	0	10^{-3}	10^{-57}	6.77×10^{-2}	0	4.81×10^{-2}
H	0	5×10^{-2}	10^{-57}	4.78×10^{-1}	0	4.81×10^{-2}