Implications of Dark Matter Bound States

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Goal

Bound states of Dark Matter particles can form in models where the Dark Matter interacts through a light or massless mediator. The aim of this work is:

- Compute the effect of bound states on the Dark Matter thermal relic density (Ω_{DM}).
- Estimate the indirect detection signal induced by formation and decay of bound states.

Long range interactions

In the non-relativistic limit, non-abelian interactions mediated by a vector of mass M_V give rise to the potential

$$V(r) = -\alpha_{eff}\frac{e^{-M_V r}}{2r}$$

The effective coupling, α_{eff}, encodes the group theory structure of the interaction. If two Dark Matter particles in the representations R and R' form a two particles state in the representation J we have:

$$\alpha_{eff} = \lambda_J \alpha \qquad \text{with} \qquad \lambda_J = \frac{C_R - C_{R'} - C_J}{2}$$

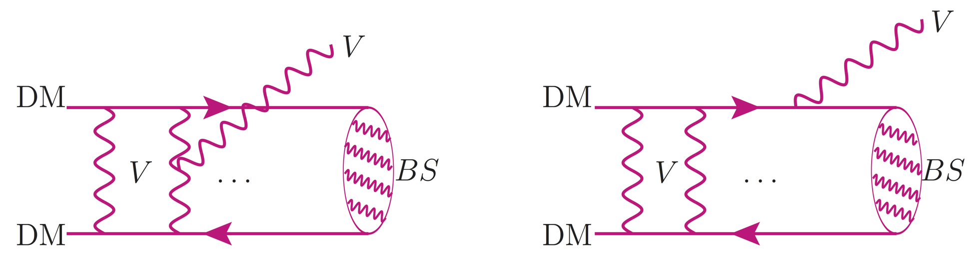
where the C's are the quadratic Casimirs for the various representations.

Sommerfeld enhancement

The long range potential deforms the initial state wave function enhancing the tree level annihilation cross section by a factor S:

$$S \overset{v_{rel}\to 0}{\simeq} \frac{2\pi^2\alpha_{eff}M_{DM}}{M_V}\left(1-\cos 2\pi\sqrt{\frac{\alpha_{eff}M_{DM}}{M_V}}\right)^{-1}$$

Bound state formation



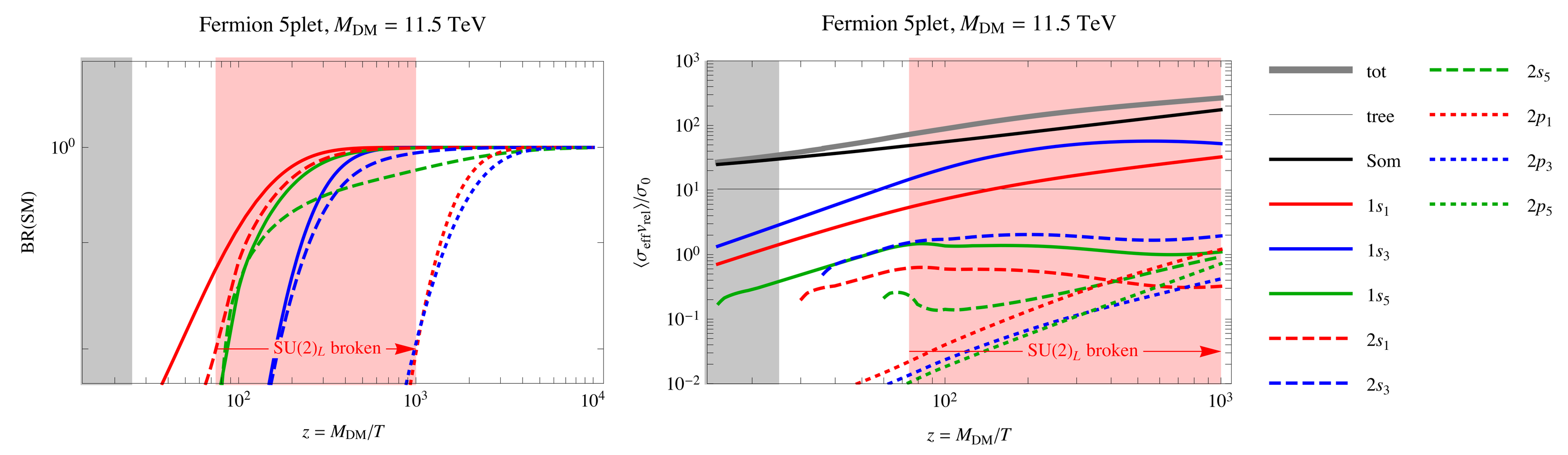
Bound states can form when:

- the range of the potential is larger than the Bohr radius: $1/M_V \gtrsim \alpha_{eff}M_{DM}$
- the sum of the bound state binding energy and the initial state kinetic energy is bigger than the mediator mass: $M_{DM}(\alpha_{eff}^2 + v_{rel}^2) \gtrsim M_V$

If both these requirements are satisfied, bound states can form with a cross section given by

$$(\sigma v_{rel})_{bsf} \simeq \sigma_0 \underbrace{\frac{2S+1}{g_\chi^2}}_{\text{BS d.o.f.}} \frac{2^{11}\pi}{3} \underbrace{\sum_{aMM'}\left|C_{\mathcal{J}}^{aMM'} + \frac{1}{\lambda_f}C_{\mathcal{T}}^{aMM'}\right|^2}_{\text{Group theory structure}} \underbrace{\frac{\lambda_i^3\alpha}{\lambda_f v_{rel}}e^{-4\lambda_i/\lambda_f}}_{\text{Low } v \text{ enhancement}}$$

The fate of a bound state



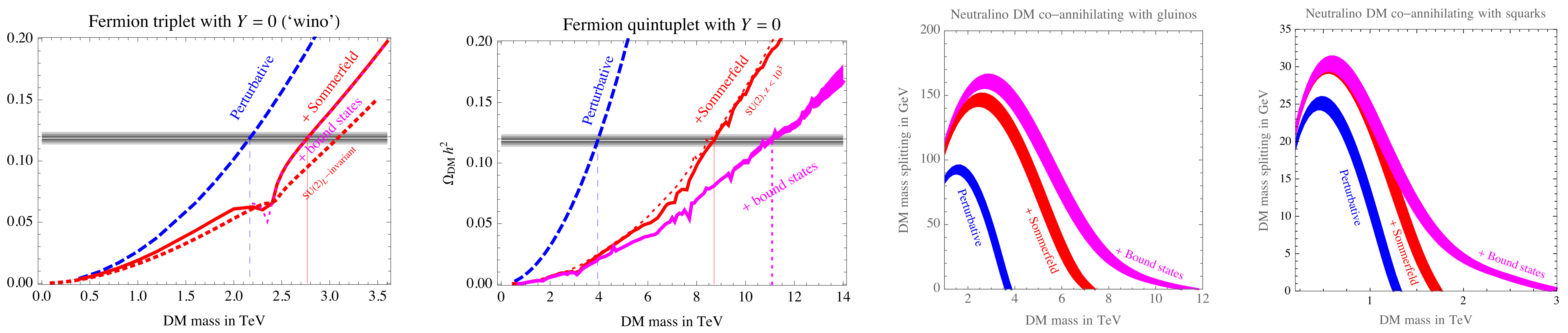
Once formed a bound state can

- Decay into Standard Model particles, giving rise to an additional annihilation channel.
- Be ionized back into free Dark Matter particles by interactions with the plasma.

Because of this, bound states contribute to the annihilation of DM particles with an effective cross section given by

$$\sigma_{eff} \equiv \sigma_{bsf} \times BR \qquad \text{where} \qquad BR = \frac{\langle\Gamma_{dec}\rangle}{\langle\Gamma_{dec} + \Gamma_{ion}\rangle}$$

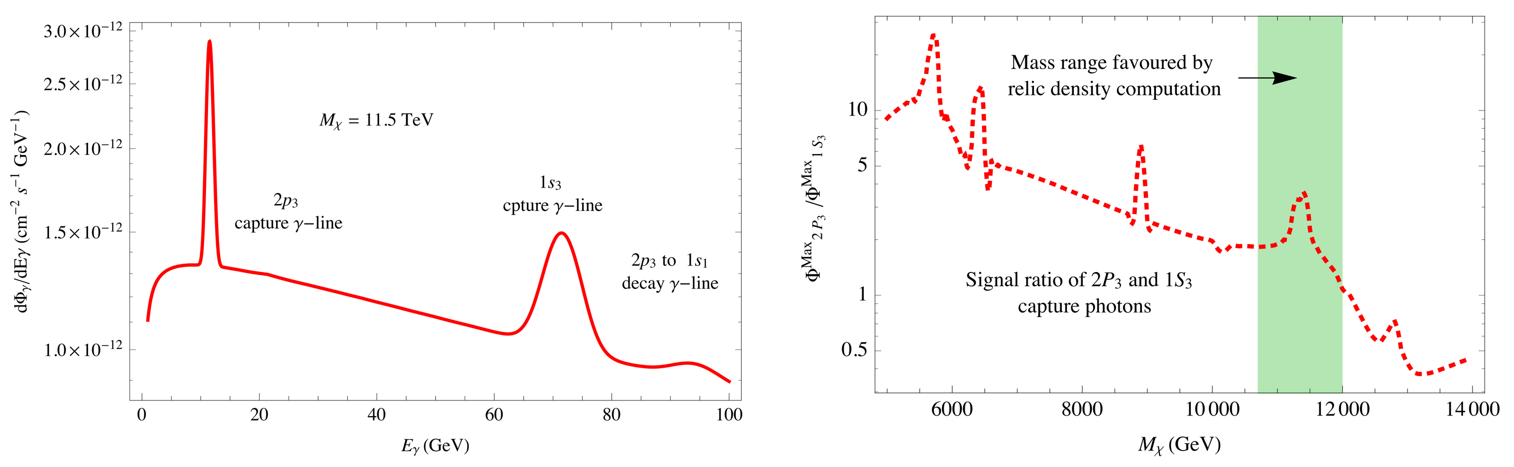
Correction to the relic density



We studied the impact of bound states in two kind of Dark Matter model:

- Models where the Dark Matter is an automatically stable SU(2) multiplet. In this case we found no effect for the triplet and a **30% effect for the quintuplet**.
- Models where the Dark Matter is a neutralino co-annihilating with a colored partner. Here we found a correction of few % at large mass splitting and a **100% correction at small mass splitting**.

Indirect detection signatures



Photons emitted during formation or de-excitation of bound states lead to **monochromatic gamma lines** over the continuum astrophysical background.

Conclusions

We found that:

- **Bound states can significantly enhance the annihilation of Dark Matter particles leading to sizable corrections to the thermal relic density.**
- **Bound states can lead to interesting indirect detection signatures, namely emission of monochromatic photons.**

References

[1] A. Mitridate, M. Redi, J. Smirnov, A. Strumia, *"Cosmological Implications of Dark Matter Bound States"* [arXiv:1702.01141].