Coloured coannihilations

Dark matter phenomenology meets non-relativistic EFTs

Stefan Vogl

based on
JHEP 1902 (2019) 016 [arxiv:1811.02581]
and work in progress

in collaboration with:
S. Biondini

MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK

Where does is come from?

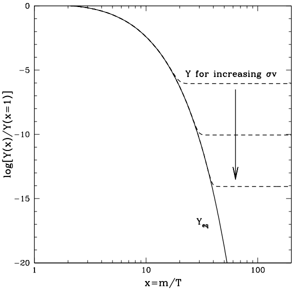
Thermal Relics

- dark matter was in thermal equilibrium
- abundance decreases with T

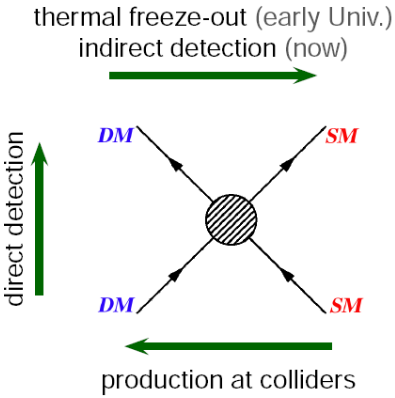
$$\frac{dn_\chi}{dt} + 3Hn_\chi = -\sigma v \left[n_\chi^2 - (n_\chi^{EQ})^2 \right]$$

- interaction rate becomes small compared to expansion of universe; freeze-out

$$\rightarrow \Omega h^2 \simeq 0.1 \frac{2 \times 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1}}{\sigma v_{\mathrm{thermal}}}$$



Thermal dark matter

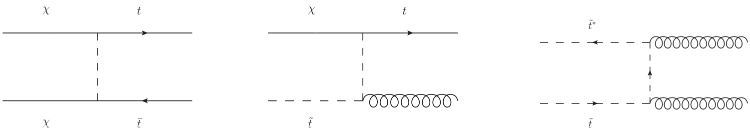


Direct detection limits very stringent. Models with simple crossing symmetry are getting in trouble.

$\Rightarrow$ break crossing symmetry

Coannihilations

For light mediators ($\Delta m_{med} \leq 1.2 m_{DM}$) coannihilation matters during freeze-out



$$\sigma v \to \sigma v_{eff} \approx \sigma_{\chi\chi} v + \sigma_{\chi\tilde{t}} v\, e^{-\Delta m/T} + \sigma_{\tilde{t}\tilde{t}} v\, e^{-2\Delta m/T}$$ Griest Seckel 1991

- want big cross sections for coannihilation partners $\rightarrow$ colour charge them

Models for coloured coannihilations

- Majorana fermion dark matter χ and scalar quark partner η

$$\begin{aligned}\mathcal{L} &= \mathcal{L}_{SM} + \frac{1}{2}\bar{\chi}\left(i\partial\!\!\!/ - M_\chi\right)\chi + (D_\mu\eta)^\dagger D^\mu\eta - M_\eta^2\,\eta^\dagger\eta - \lambda_2(\eta^\dagger\eta)^2 \\ &- \lambda_3\,\eta^\dagger\eta\,H^\dagger H - y\,\eta^\dagger\bar{\chi}P_R q - y^*\bar{q}P_L\chi\,\eta\,,\end{aligned}$$

- simplified t-channel model with fermionic mediator

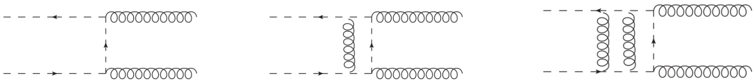
$$\begin{aligned}\mathcal{L} &= \mathcal{L}_{SM} + \frac{1}{2}\partial_\mu S\partial^\mu S - \frac{M_S^2}{2}S^2 - \frac{\lambda_2}{4!}S^4 - \frac{\lambda_3}{2}S^2\,H^\dagger H \\ &+ \bar{F}\left(iD\!\!\!\!/ - M_\chi\right)F - y\,S\bar{F}P_R q - y^*S\bar{q}P_L F\quad,\end{aligned}$$

- fermionic dark matter with color octet fermion partner

$$\mathcal{L} = ...$$

- ...

non-perturbative effects



need to treat long range interactions in thermal background

- Sommerfeld enhancement Hisano et al '05
- bound state formation von Harling, Petraki '14
- thermal background

complicated problem but similarities with heavy quarkonium in medium

$\rightarrow$ re-purpose tools for quarkonium at finite temperature
use non-relativistic effective field theories (NREFT)

NREFT for coannihilations in a nutshell

non-relativistic EFT

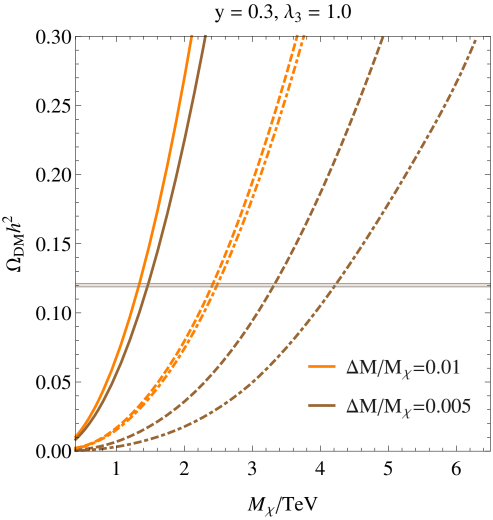
- factorize hard process from initial state effects (non-relativistic EFT)
- $\sigma v \propto \langle \mathcal{O}_i \rangle$ (thermal expectation value of NREFT operators)
- $\langle \mathcal{O}_i \rangle$ can expressed in terms of spectral functions ρ

Kim, Laine '16, Biondini, Laine '18

spectral functions

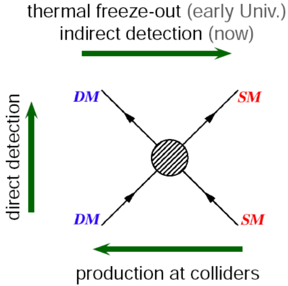
- spectral function can be exacted from solution of plasma modified Schrödinger equation
- thermal potentials and interaction rates with plasma constituents for static

Relic density



NREFT meets pheno

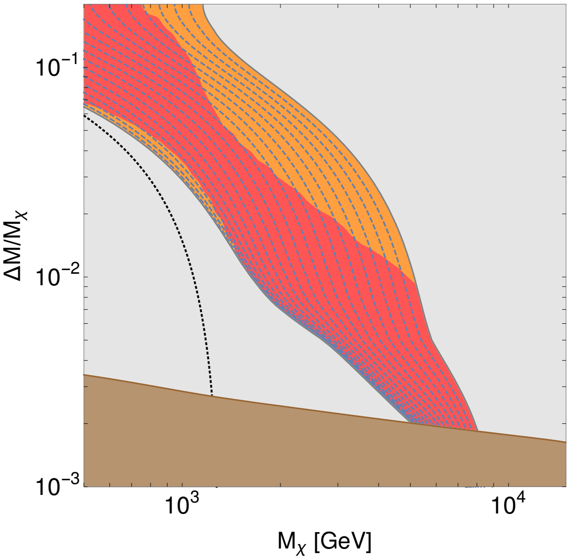
use precise prediction for thermal production to predict experimental signatures



Test it with

- ID: suppressed σv ✗
- LHC searches:
  fermionic mediators ✓
  scalar mediators ✗ (✓)
- DD: guaranteed for
  colored mediators ✓

Impact on parameter space



Conclusions

- Coannihilations are attractive possibility to accommodate thermal production and direct detection
- non-perturbative/in-medium effects matter for colored coannihilation
- NREFT methods available
- explore connection between freeze-out and direct detection (models testable with future experiments)