WARSAW WORKSHOP
ON NON-STANDARD DARK MATTER:
MULTICOMPONENT SCENARIOS AND BEYOND

Self-Interactions of out-of-equilibrium Dark Matter

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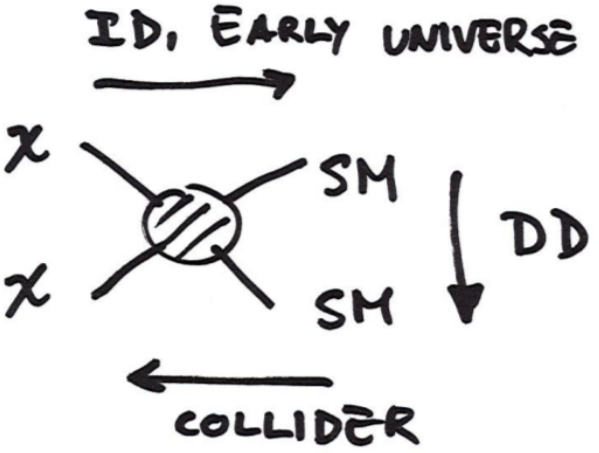
Based on: JCAP 1603 (2016) no.3, 018, **[arXiv: 1510.08063]**
In collab. with Bernal, Chu, Garcia and Hambye

DM Searches

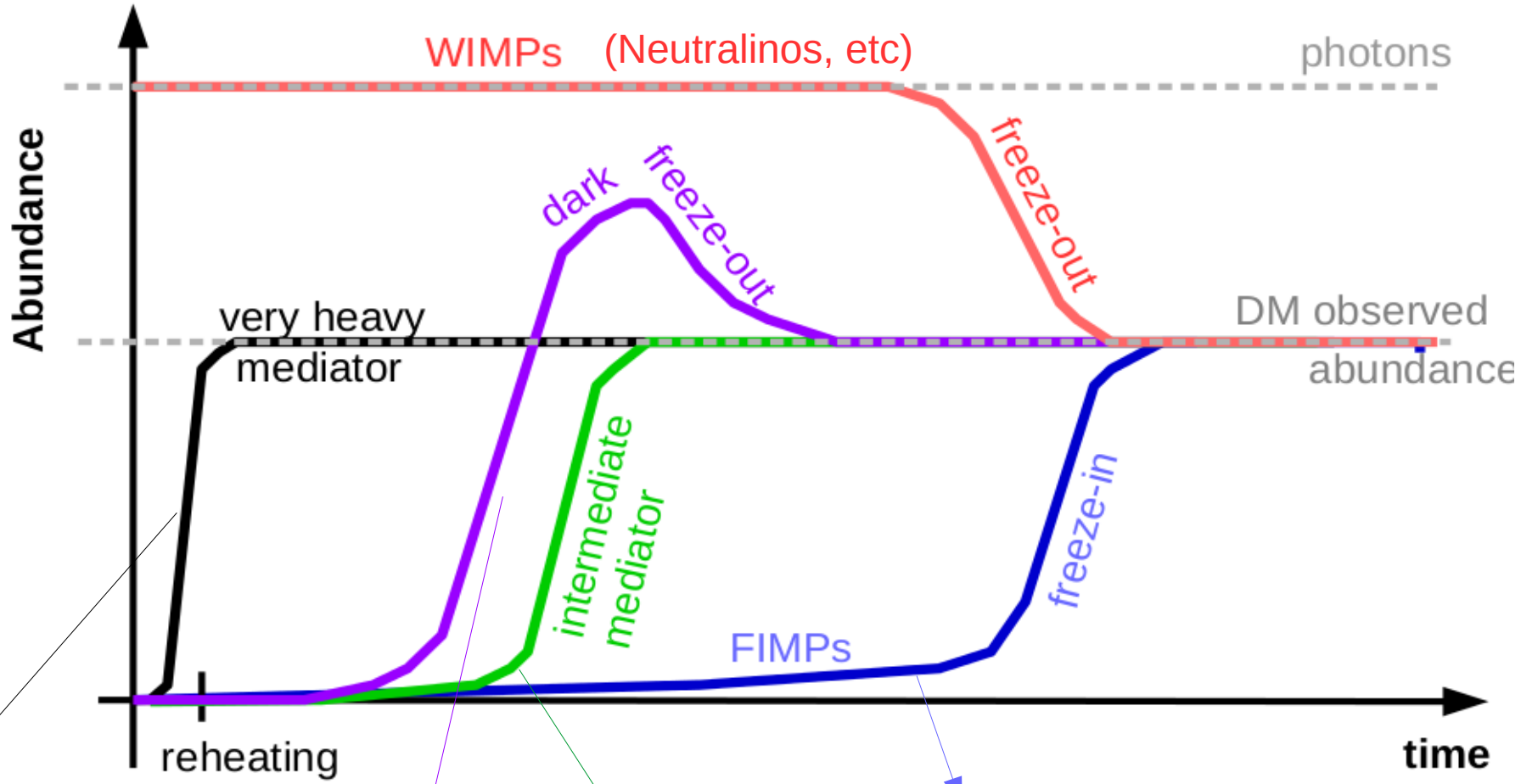
- Lead by WIMP searches
- No signals so far
- It may not be consistent with all astro data



Strategies:

- Keep searching (good luck to us)
- Expand to other parameter regions (sub-GeV or multi-TeV)
- Study other candidates with different pheno (like “SIMPs”, like Self-Interactions)

Different thermal histories



Gravitinos,
Axions,
NETDM, ...

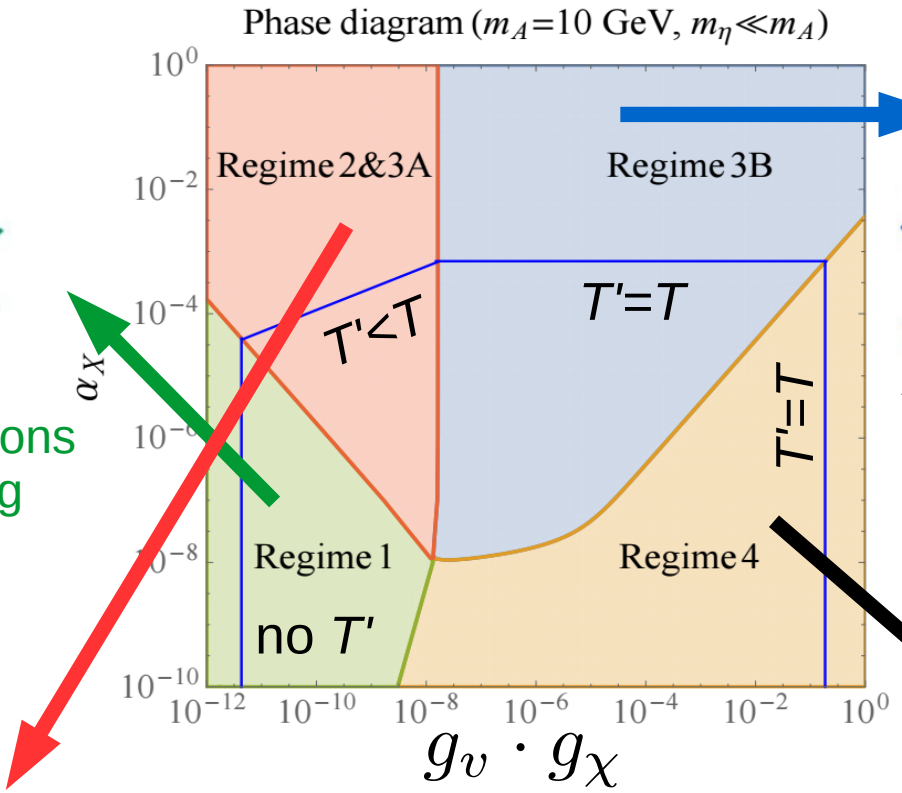
(secluded dark sectors)

(Non-thermal Z', …)

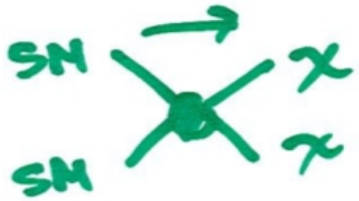
(light-mediator, 2-to-2 production,
Stau-friend DM, etc)

Different thermal histories

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{HS}\left(\chi\chi \xrightarrow{g_\chi} \eta\eta \;+\; SM\,SM \xrightarrow{g_v} \eta\eta \right)$$



Freeze-in



- good self-interactions
- OK with everything

Dark Freeze-out (T' = T)

- good self-interactions
- problematic early universe

Dark Freeze-out (T' < T)

- Freeze-in production **+** dark annihilation
- good self-interactions
- can be OK with early universe

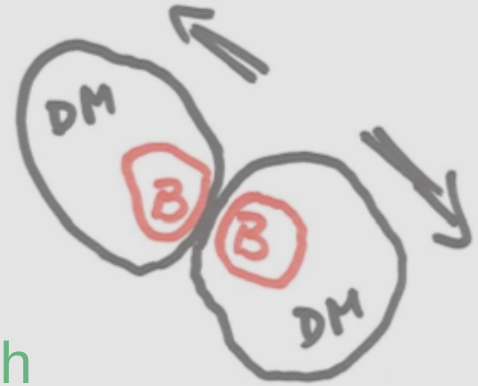
Freeze-out standard

- rich pheno
- not good self-interactions

Brief reminder of self-interactions

- Astro observations are able to predict and/or Constrain self-interacting cross sections

$$\frac{\sigma}{m} \lesssim \mathcal{O}(1)\ \mathrm{cm}^2/\mathrm{g}$$ (cluster scale)



- Colliding clusters
- DM halos may have some friction consistent with non-gravitational interactions

- Simulations in tension with cold dark matter paradi

$$0.1 \lesssim \frac{\sigma}{m} \lesssim 10\ \mathrm{cm}^2/\mathrm{g}$$ (gal

- Core-vs-cusp problem
- Too-big-to-fail problem

I'm not going over this again (see previous talks)

MP cross sections
orders of magnitude smaller!!

Alternatives so far

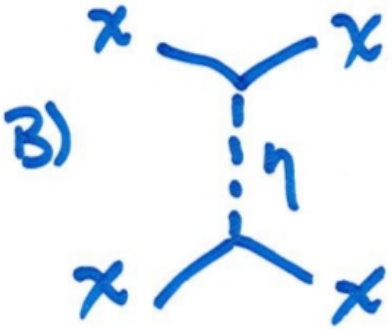
$$\sigma \sim \frac{\alpha_\chi^2}{m_\chi^2} \mathcal{O}(1)$$

O(100 MeV)

(Volansky et al, 2014)

Implies:

Dominant Freeze-out process (SIMP Miracle)



e.g. O(EW)

$$\sigma \sim \frac{\alpha_\chi^2}{m_\chi^2} f(m_\chi, m_\eta, \alpha_\chi, v)$$

Wide range

$$f \gg 1$$

long range interactions

$$m_\eta \ll \alpha_\chi \cdot m_\chi$$

- **Non-perturbative enhancements**
- **Schrödinger equation**

Problems:

A) DM sector reheats itself (structure formation)

Coupling sometimes too large

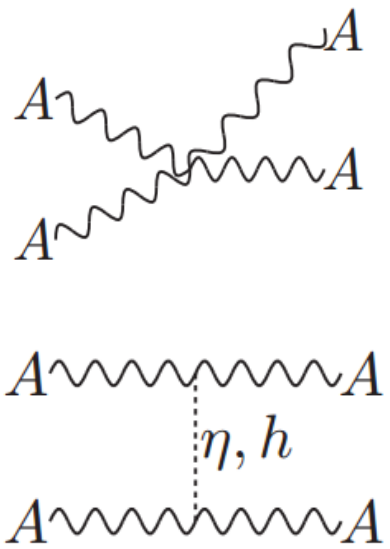
B) Direct Detection and other early universe constraints

The model

$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{4}\underbrace{F'^{\mu\nu} \cdot F'_{\mu\nu}}_{SU(2)_X} + (D_\mu \phi)^\dagger (D^\mu \phi) - \mu_\phi^2 \, \phi^\dagger \phi - \lambda_\phi \, (\phi^\dagger \phi)^2 - \lambda_m \, \phi^\dagger \phi \, H^\dagger H$$

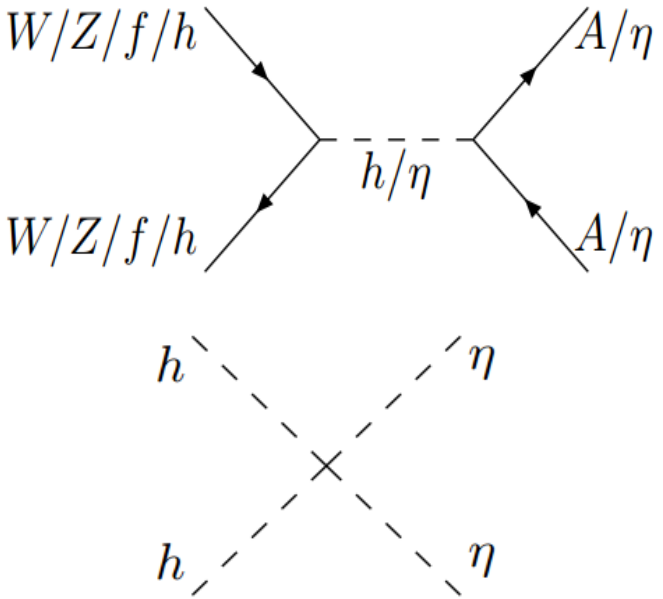
- **Gauge bosons: DM candidates** (degenerated, Custodial symmetry)
- **Real Scalar boson**, Higgs portal

Self-Interactions



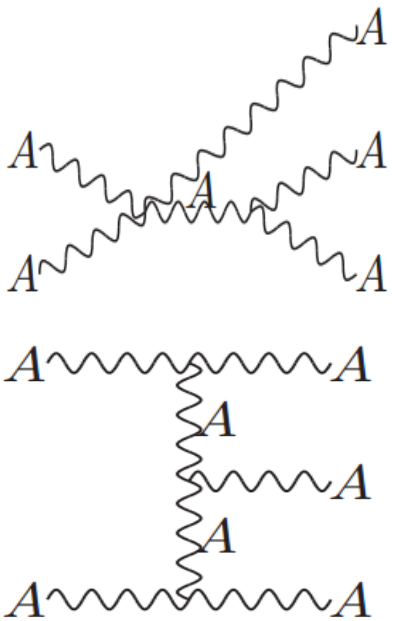
(plus some others...)

Production from SM



(plus some others...)

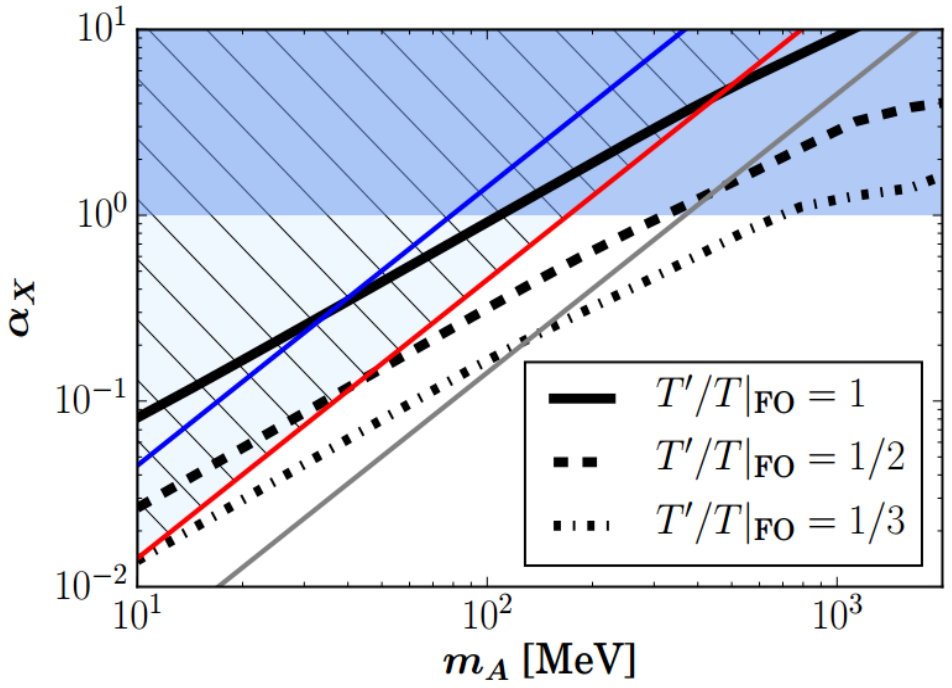
3-to-2 processes



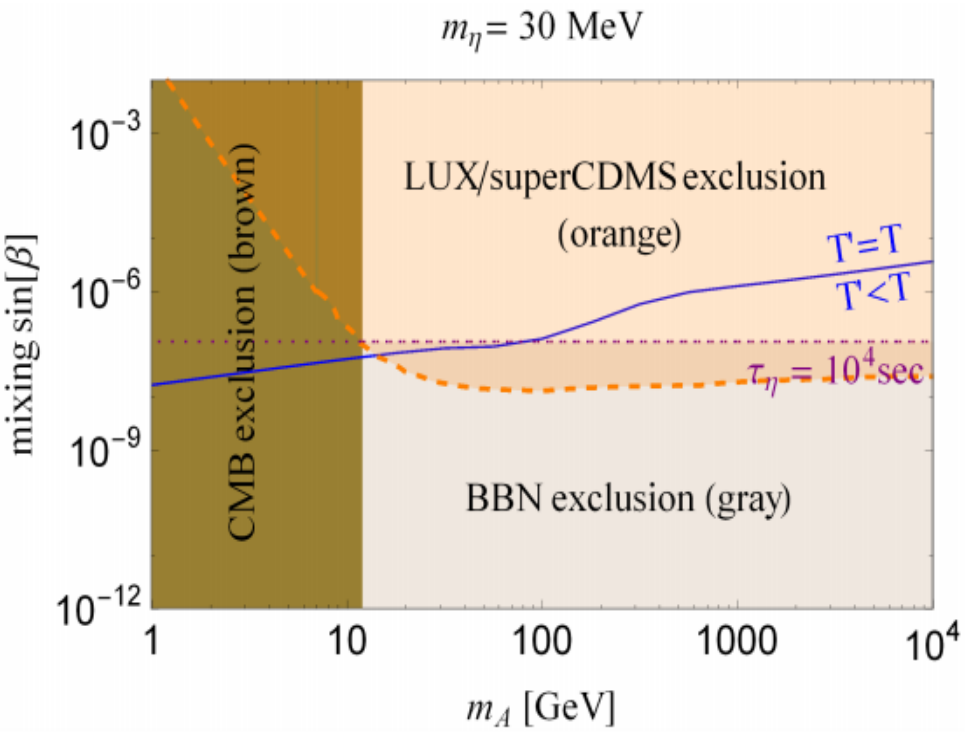
(plus some others...)

back into the problems

Contact interaction



Long-range interaction



Also:

Difficult to maintain kinetic equilibrium with SM, without being excluded by Invisible Higgs decays

$$h \to \eta\eta$$

DM reheats too much,
wiping out Structure formation

This case is excluded

Limits get stronger for lighter mediator

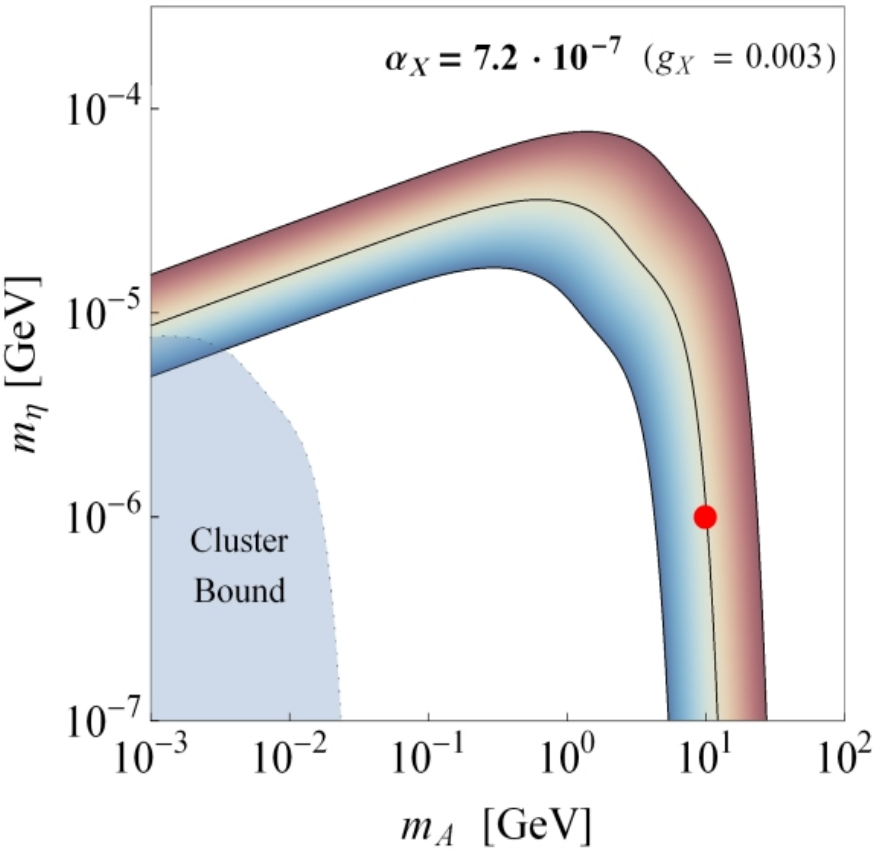
Difficult for Self-Int to cope with heavier mediator

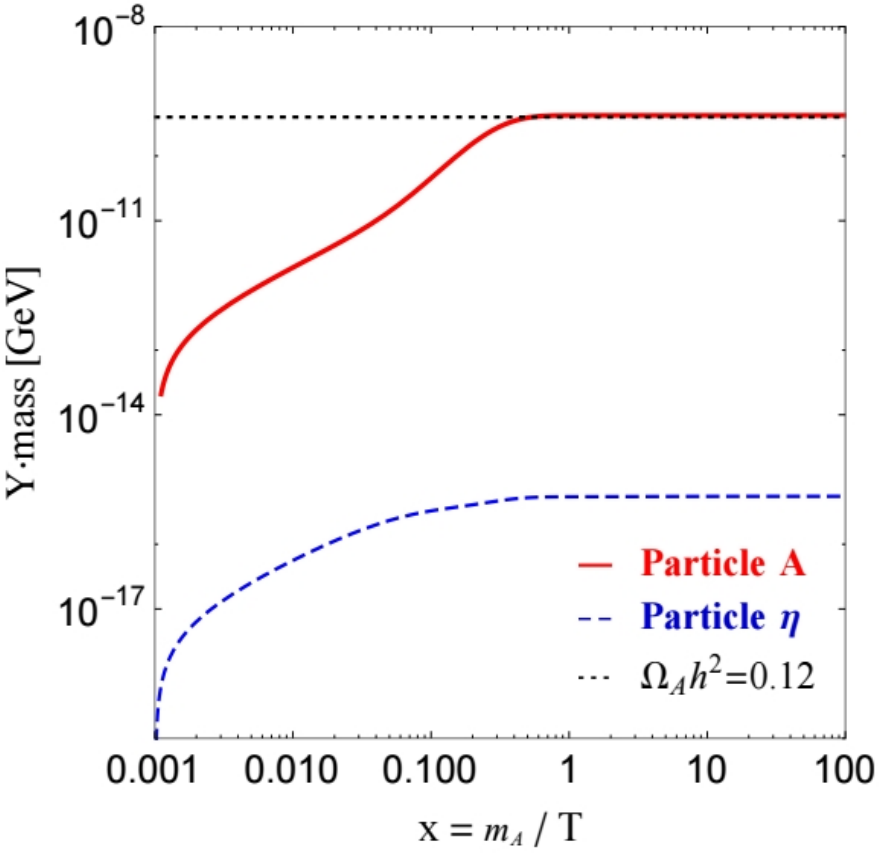
Proposal:

Relax the equilibrium condition with the visible sector

	Lighter mediator $(m_\eta \ll m_\chi)$	Heavier mediator $(m_\eta \gtrsim m_\chi)$
Freeze-In (no T')	$Y_\eta \sim Y_A$ (same creation from SM)  $\Omega_\eta \ll \Omega_\chi$ (ok with BBN) $g_\chi \sim 10^{-3}$ (ok with Self-Int)	$g_\chi \ll 1$ (No Self-Int)  or $m_\eta \sim \mathcal{O}(\mathrm{keV})$ (watch-out Hot DM)
Dark Freeze-out (T' < T)	$Y_\eta \gg Y_A$ (from eq.)  Life-time < 10^4 s : Direct Det. Life-time < 10^{12} s : BBN/Self-Int Life-time > 10^{12} s : CMB/Self-Int	3-to-2 dominates over 2-to-2 (requiring self-int and Small connector couplings)  Ok with Structure Form. Smaller g_χ (ok with perturb.)

Lighter mediator & Freeze-In



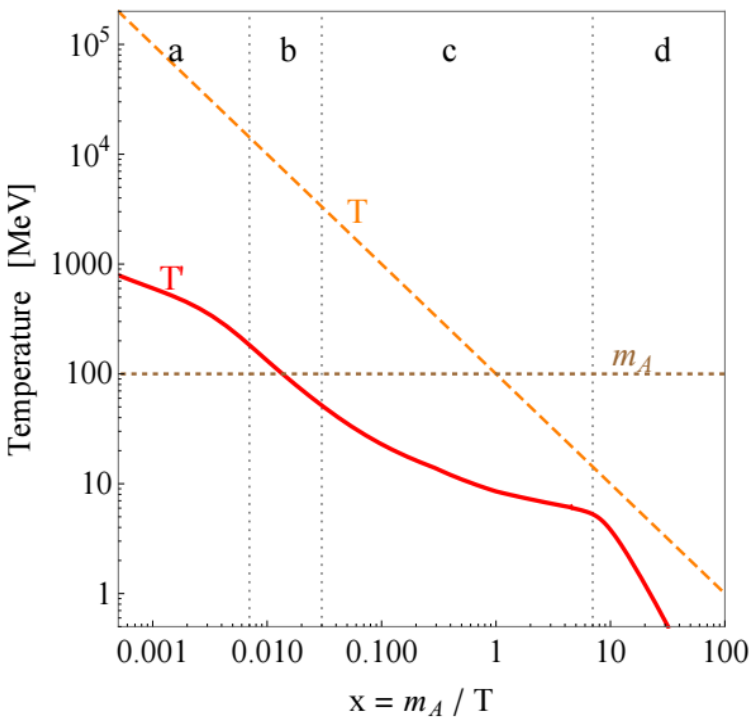


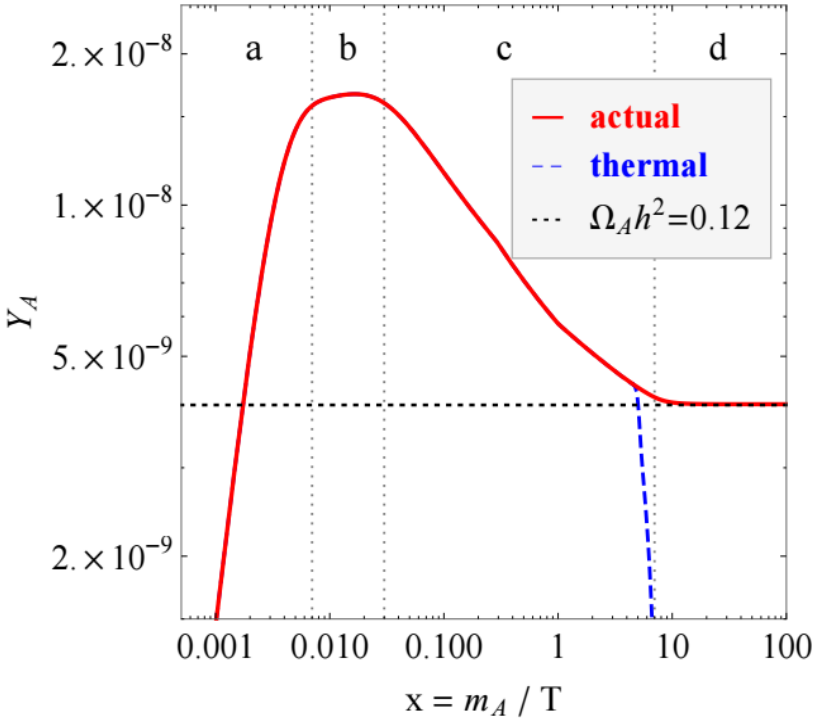
From Self-Interactions

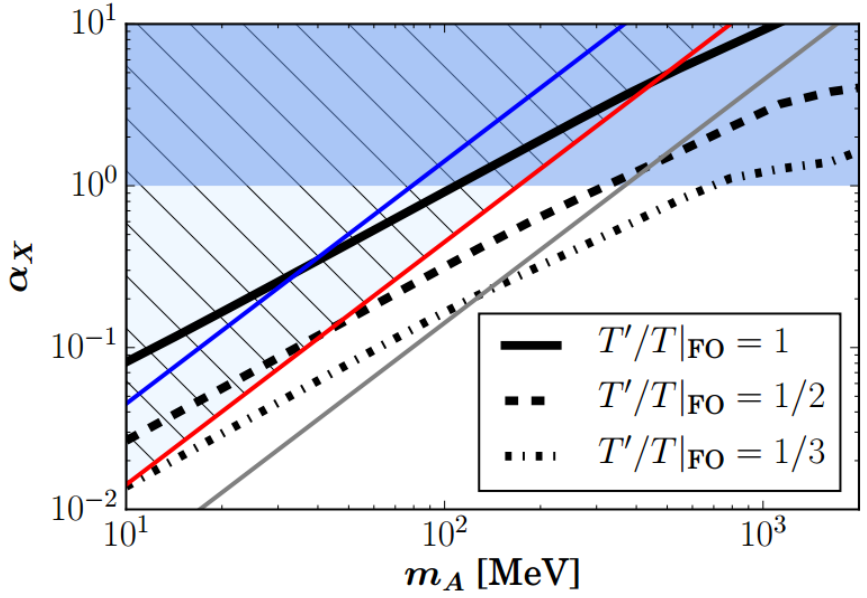
From relic abundance

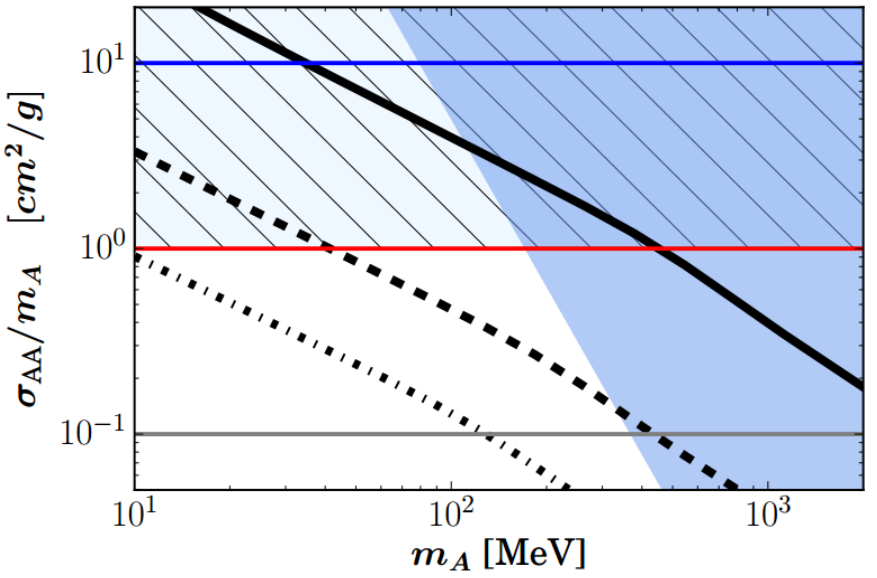
OK with all the rest of constraints

Heavier mediator & colder freeze-out









Summary

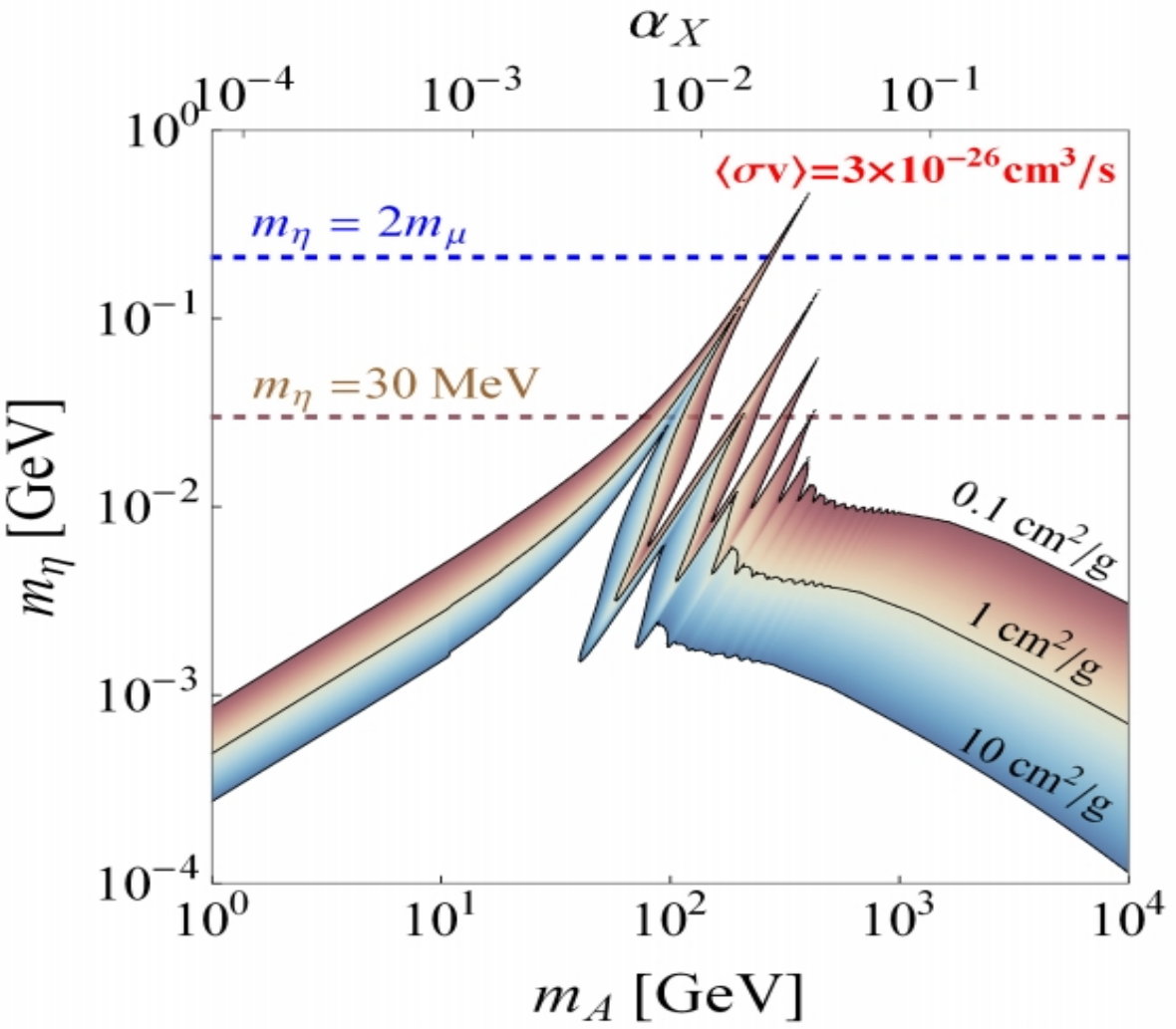
- Non-standard (non-WIMPy) dark matter candidates are very motivated given the null results of experimental searches
- SIDM may be the solution to the small scale issues of the CDM scenario
- SIDM coming from equilibrium with the SM poses a variety of phenomenological problems (BBN, structure formation, Direct Detection, etc)

Solution: go out of equilibrium with the visible sector

- DM mediated by light portals can have a Freeze-in genesis compatible with self-interactions
- DM mediated by (not so) heavier portals can have a colder Freeze-out compatible with self-interactions


Thanks

bckp


α_X
10^{-4}
10^{-3}
10^{-2}
10^{-1}
$\langle\sigma v\rangle = 3\times10^{-26}\,\mathrm{cm}^3/\mathrm{s}$
$m_\eta = 2m_\mu$
m_η =30 MeV
0.1 cm^2/g
1 cm^2/g
10 cm^2/g
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
m_η [GeV]
10^0
10^1
10^2
10^3
10^4
m_A [GeV]