Minimal self-interacting dark matter models with light mediator

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Université Libre de Bruxelles

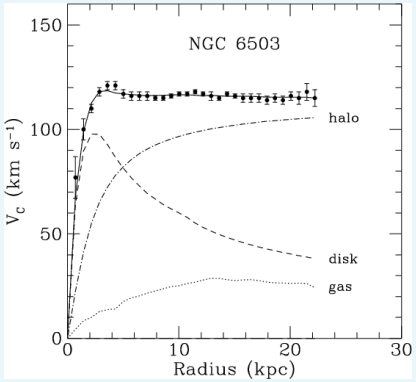
Based on
JCAP 05 (2020) 001 - [1912.11708]
T. Hambye and LV

Why do we study DM ?

Galaxies collisions

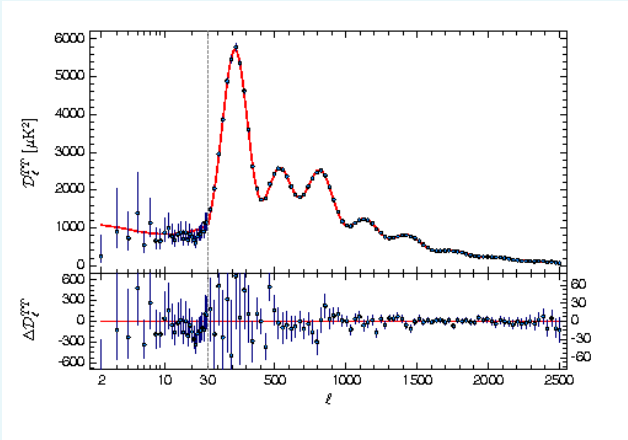
[M.Markevitch et al., 2006]

Rotations curves



[K.G. Begeman et al., 1991]

CMB anisotropies

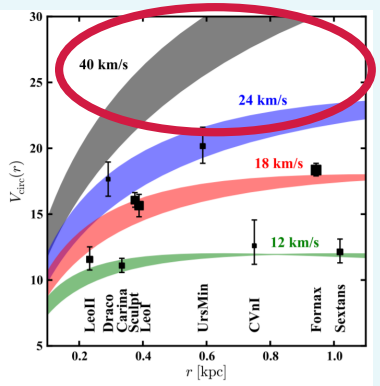


CMB anisotropies show that $\underline{\Omega_{DM}h^2 \simeq 0.1188}$

[Planck Collaboration, 2015]

Small scale crisis

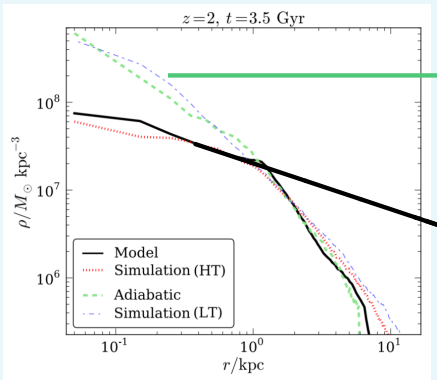
Too-big-to-fail



Missing massive subhaloes

[M. Baylan et al., 2011]

Core-vs-cusp

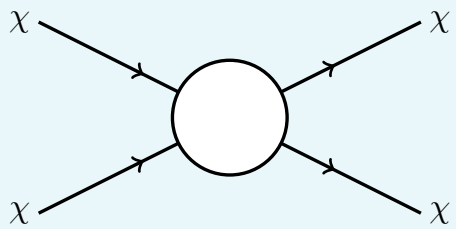


Collisionless DM

Observation

[A. Pontzen and F. Governato., 2011]

Self-interacting DM



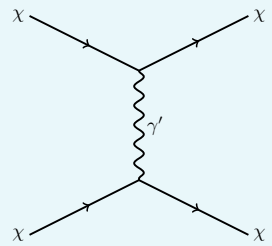
$$\Longrightarrow \sigma_T/m_{DM} \sim \mathrm{cm}^2/\mathrm{g}$$

Simple models with a light mediator

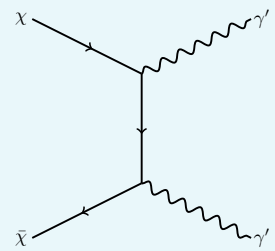
Kinetic mixing

$$\mathcal{L} \ni -g_{\gamma'} \bar{\chi} \gamma^\mu \chi A'_\mu + h.c.$$
$$-\frac{\epsilon}{2} F^Y_{\mu\nu} F'^{\mu\nu}$$

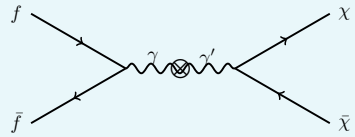
SI process



FO process



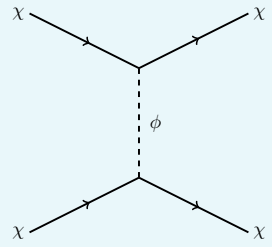
Portal



Scalar mixing

$$\mathcal{L} \ni -y_\phi \phi \bar{\chi} \chi + h.c.$$
$$-\lambda \phi^\dagger \phi H^\dagger H$$

SI process



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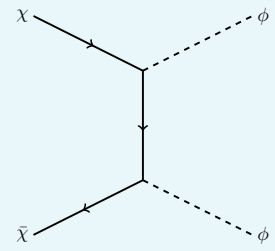

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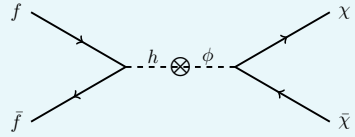
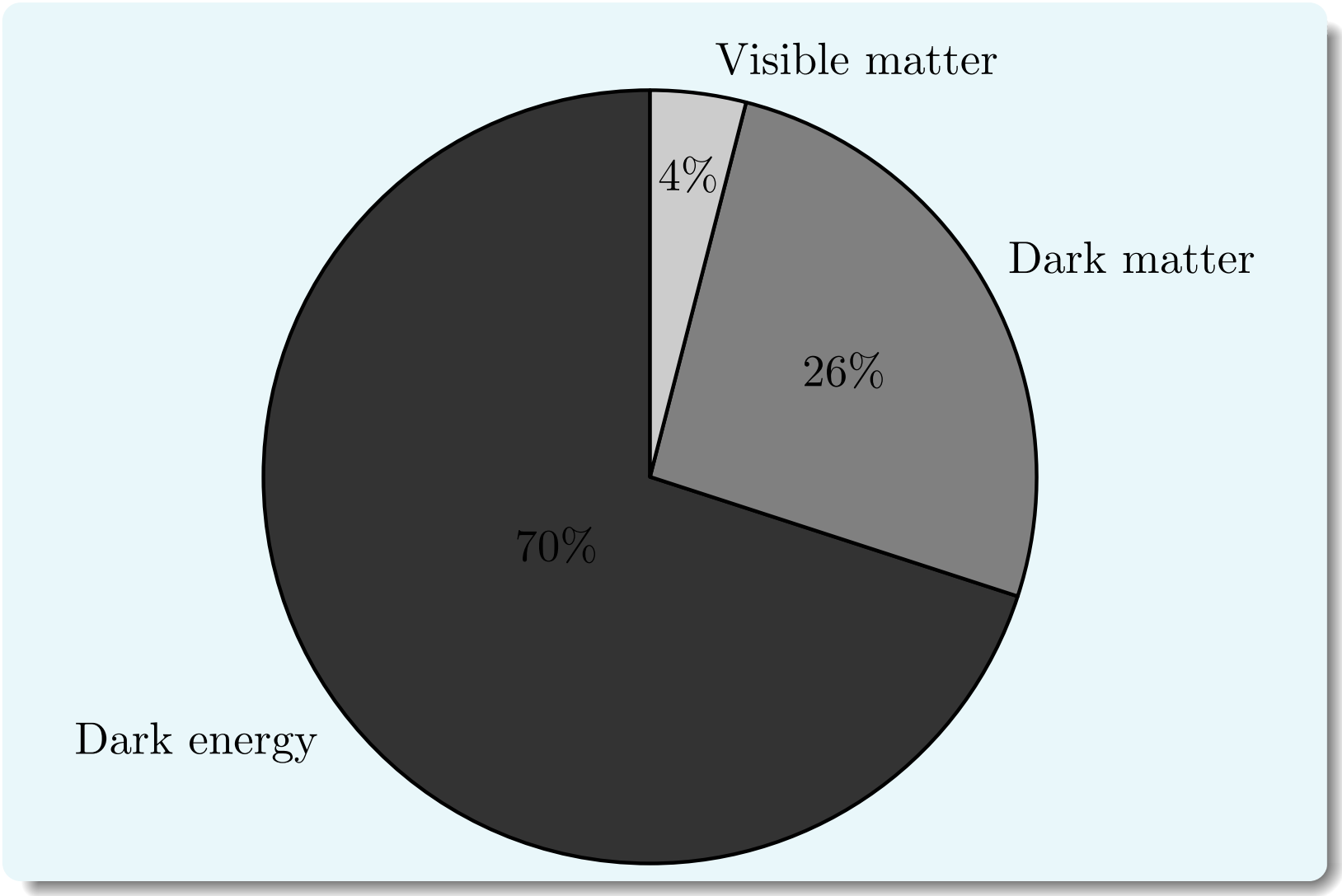


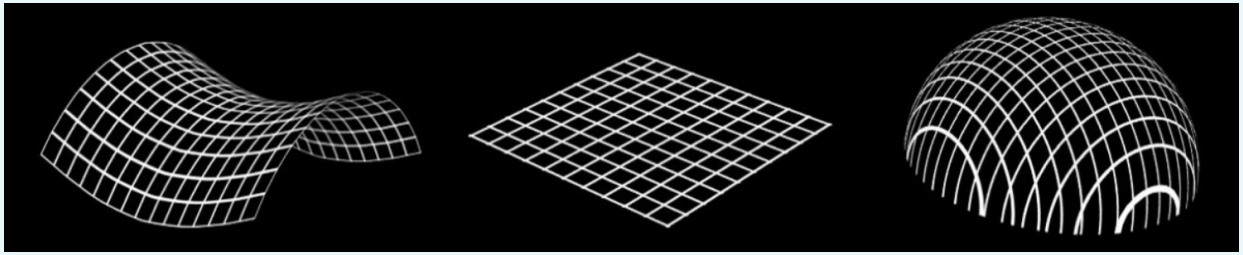
Constraints on SIDM with light mediator

DM relic density



$$\Omega_{DM} = 0.2645 \pm 0.0050$$

Non overclosure of the Universe by the light mediator



Open Universe :
$\Omega < 1$

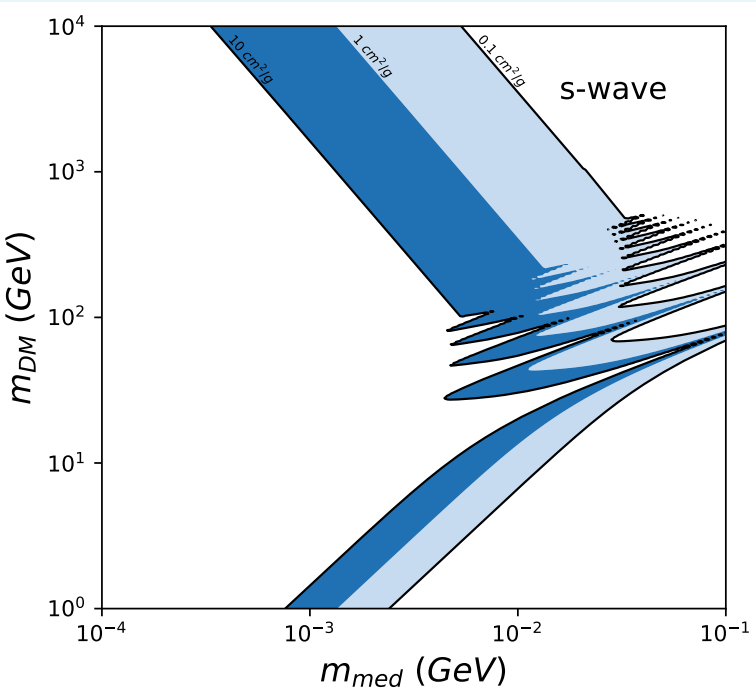
Flat Universe :
$\Omega = 1$
$\Downarrow$
$\Omega_{med} \ll 1$

Closed Universe :
$\Omega > 1$

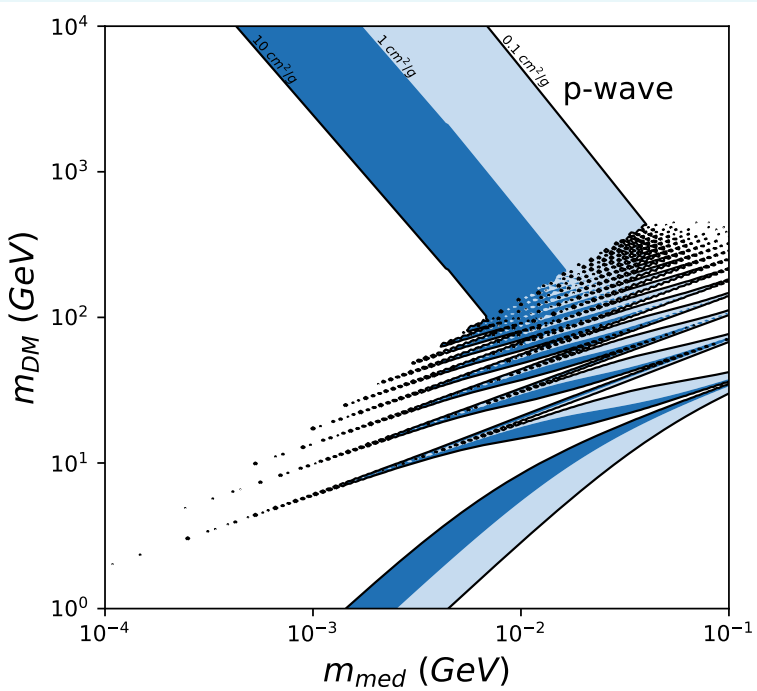
Small scale structure

$$0.10\ \mathrm{cm}^2/\mathrm{g} < \sigma_T/m_{DM} < 0.47\ \mathrm{cm}^2/\mathrm{g}$$

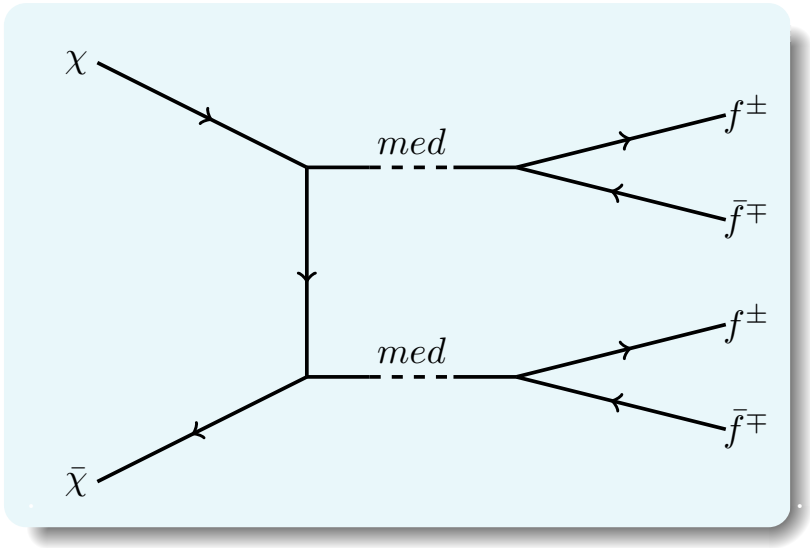
Kinetic mixing portal



Higgs portal



CMB (1) : constraint on DM annihilation rate



Production of
charged particles

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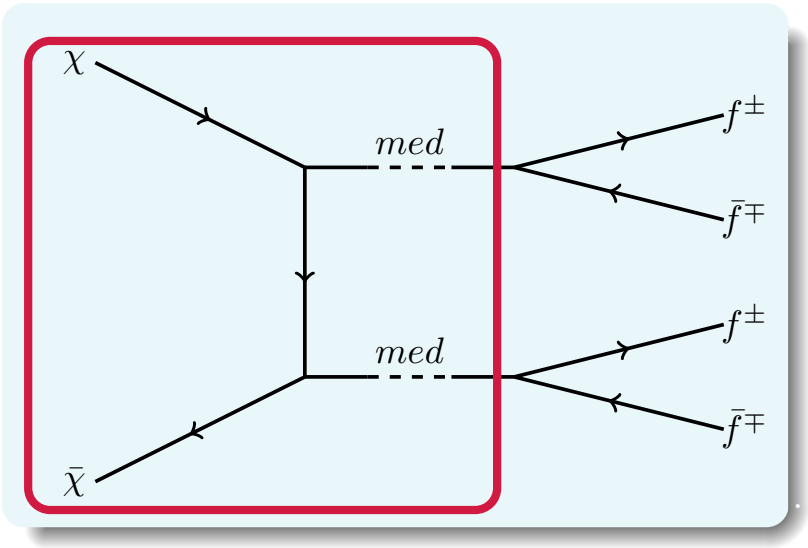

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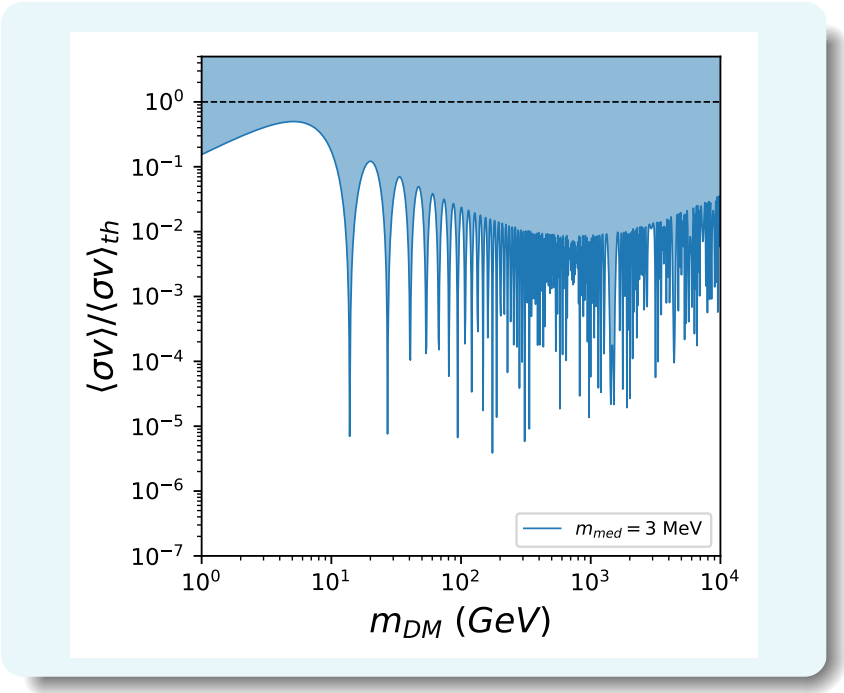
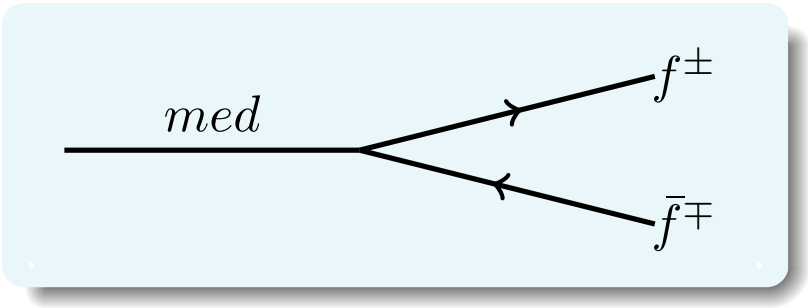


[N. Bernal et al., 2015] [T. Bringmann et al., 2016]

CMB (2) : constraints on mediator decay



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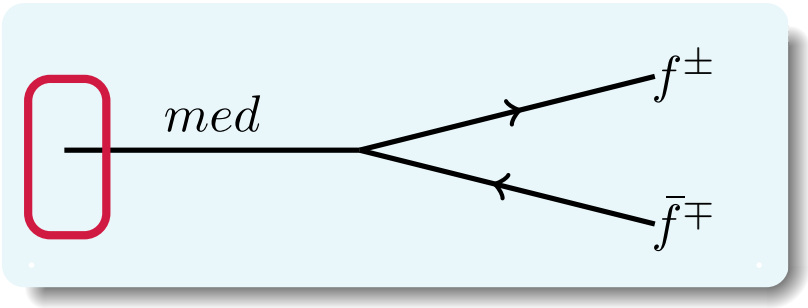

Production of
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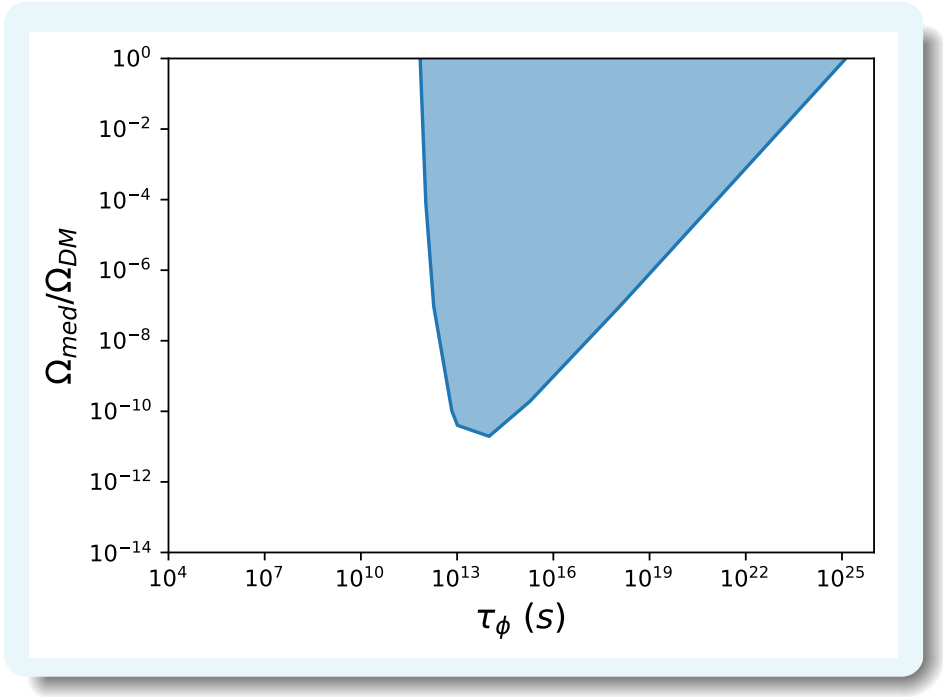

[V. Poulin et al., 2016]

CMB (3) : constraint on N_{eff}

med

Additional
relativistic d.o.f.

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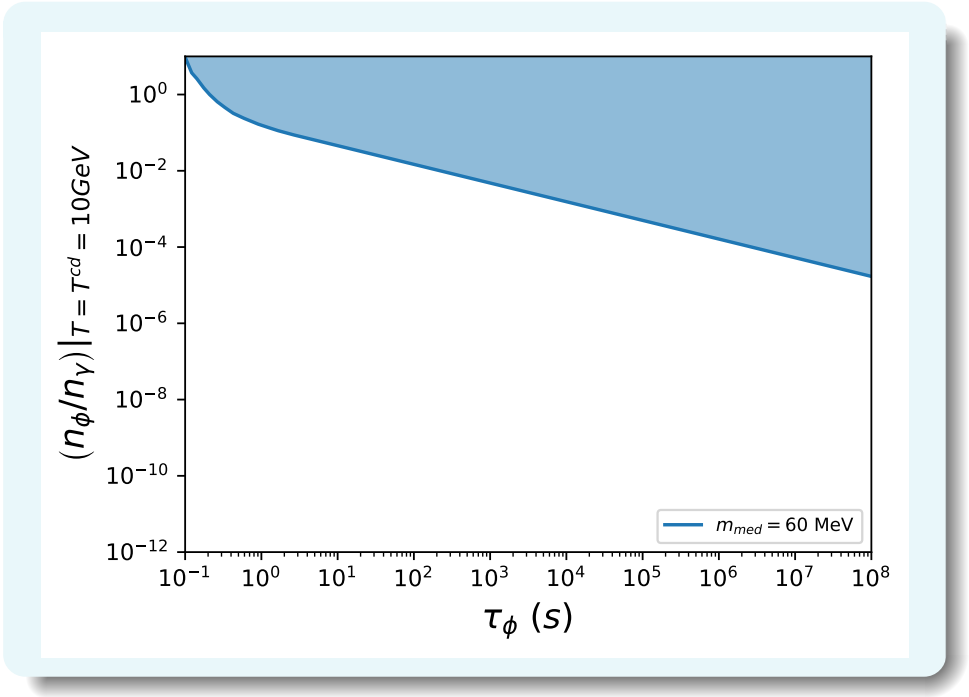
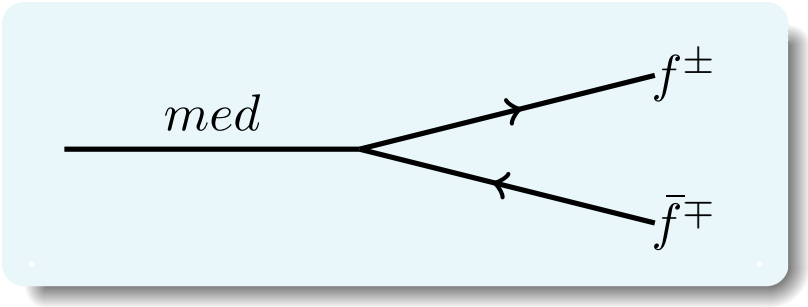


[M. Hufnagel et al., 2018]

BBN (1) : Photodisintegration



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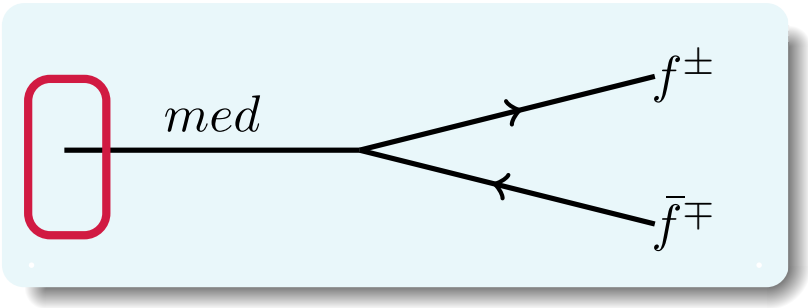

Production of
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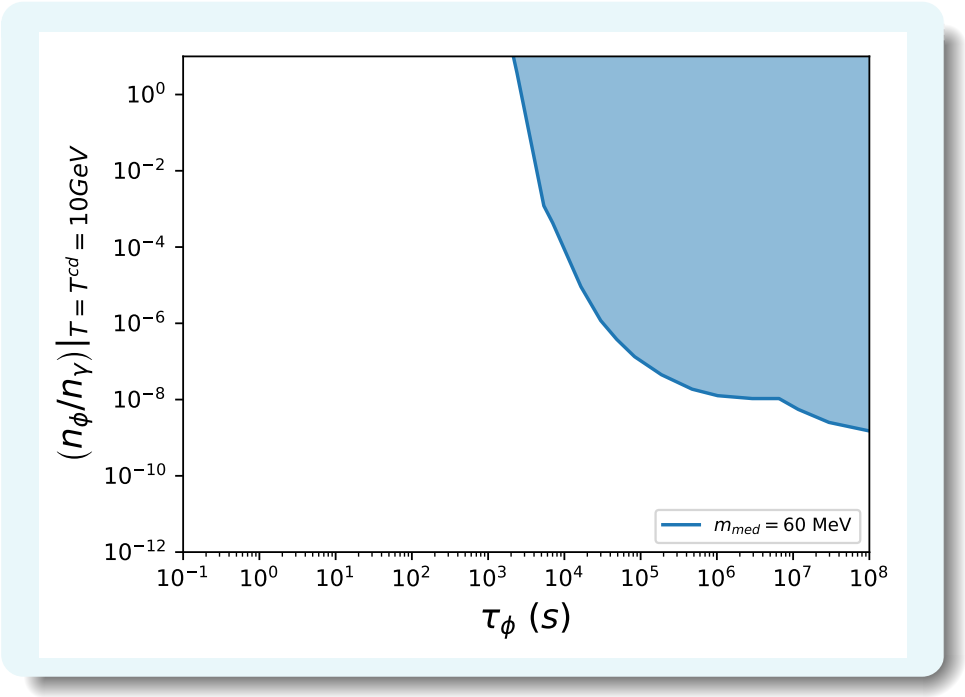
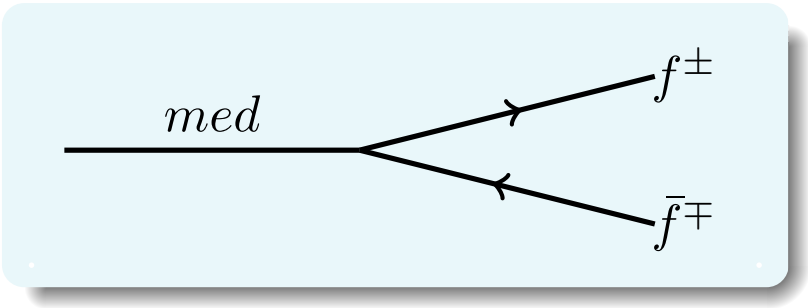


[M. Hufnagel et al., 2018]

BBN (2) : Hubble constant and entropy injection



Modification of $H(t)$
and
Entropy injection

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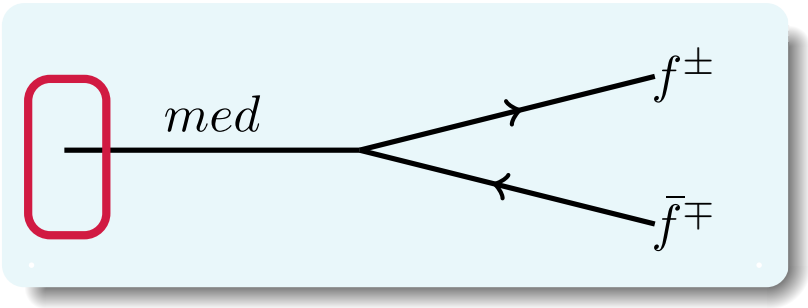

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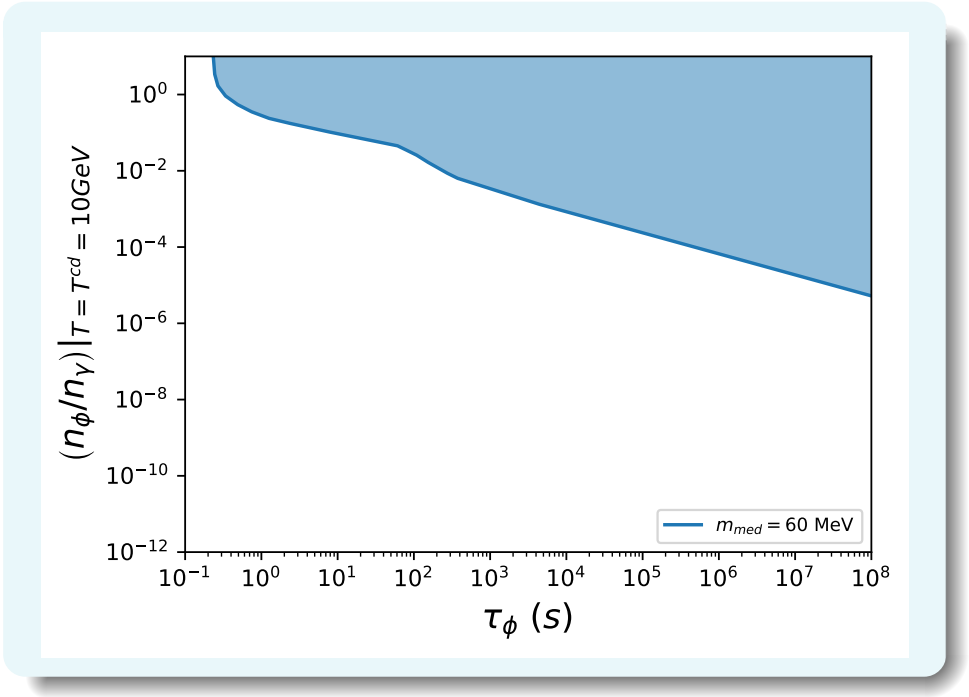
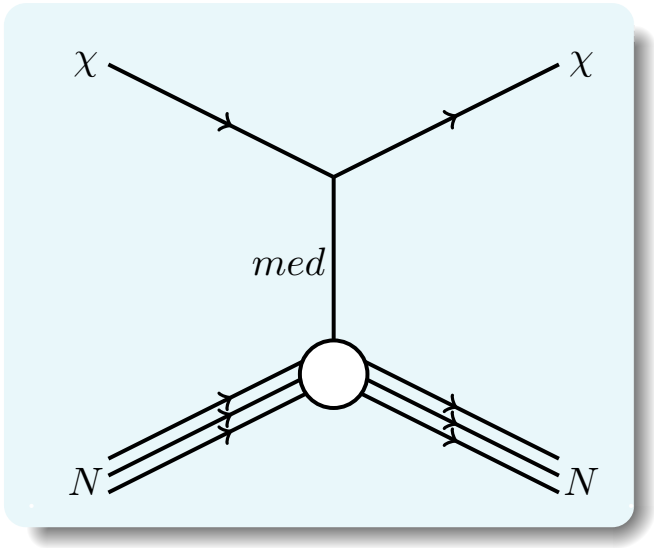


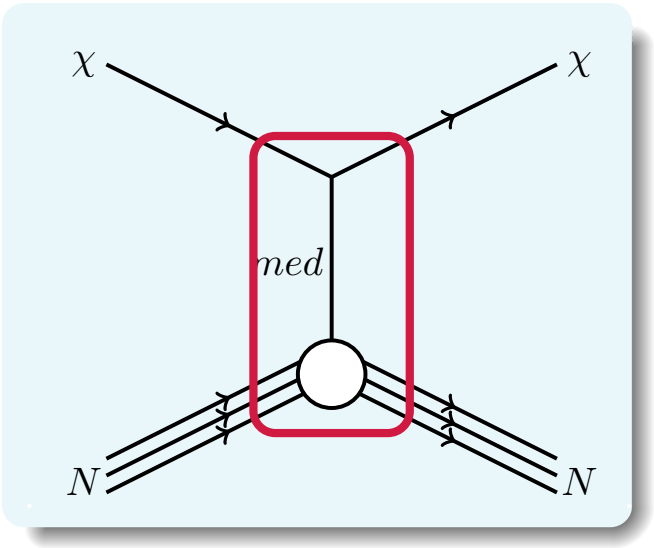
[M. Hufnagel et al., 2018]

Direct detection

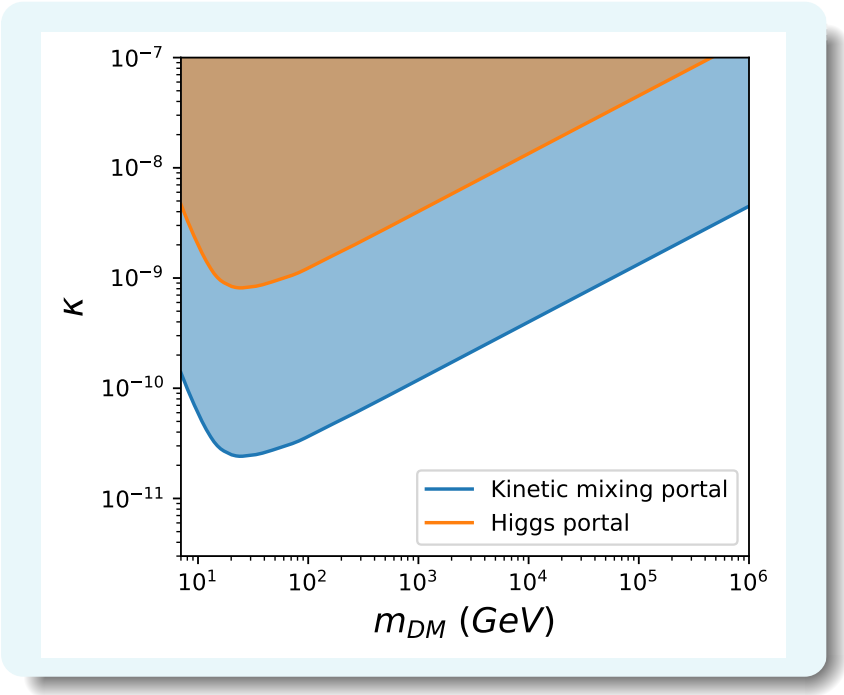


DM scatters on nucleon

Direct detection

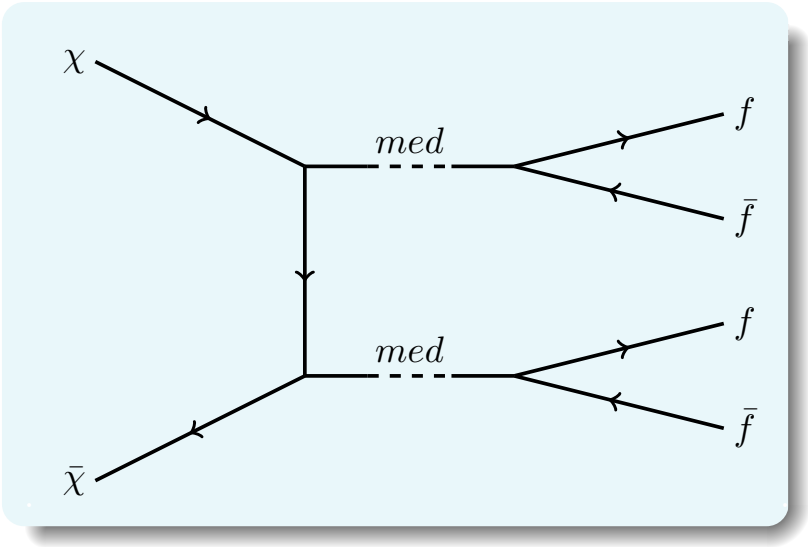


DM scatters on nucleon



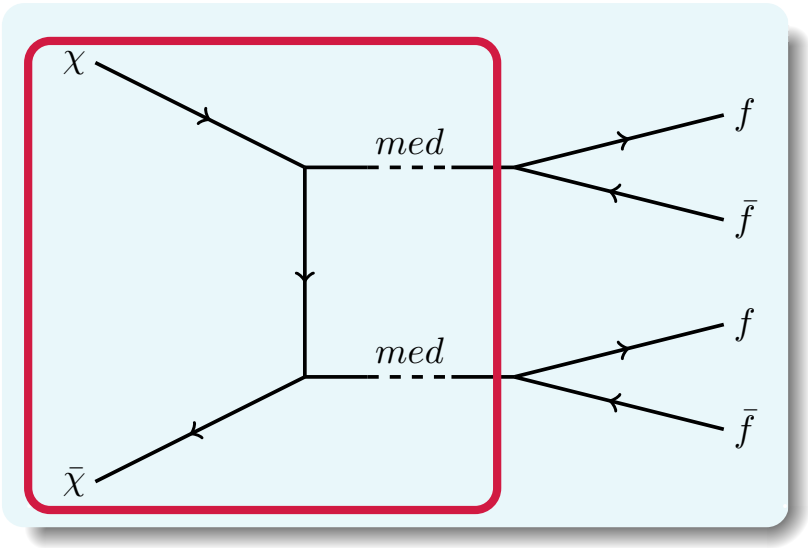
[T. Hambye et al., 2018] [T. Hambye and LV, 2019]

Indirect detection



Production of
SM particles

Indirect detection



Production of
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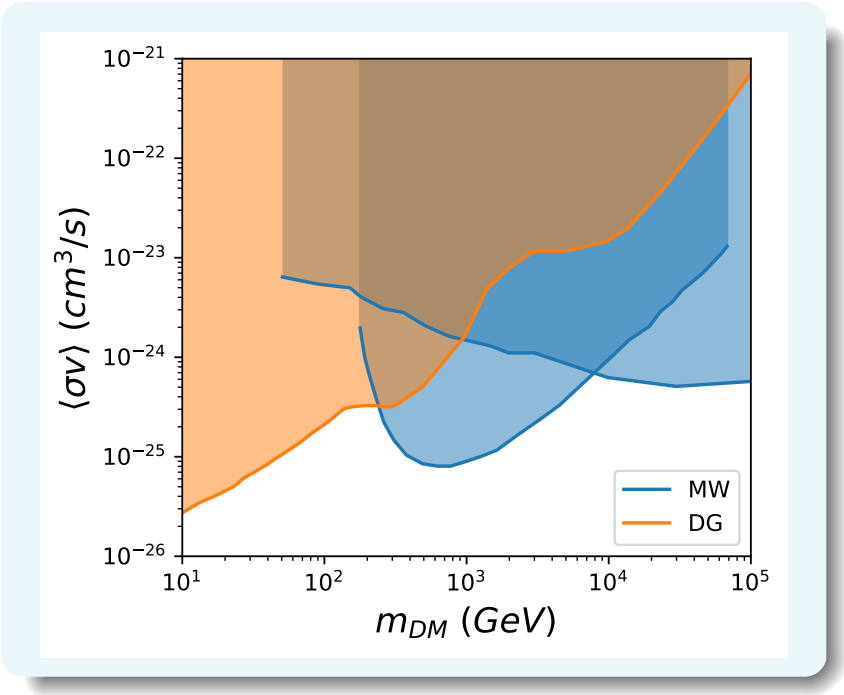
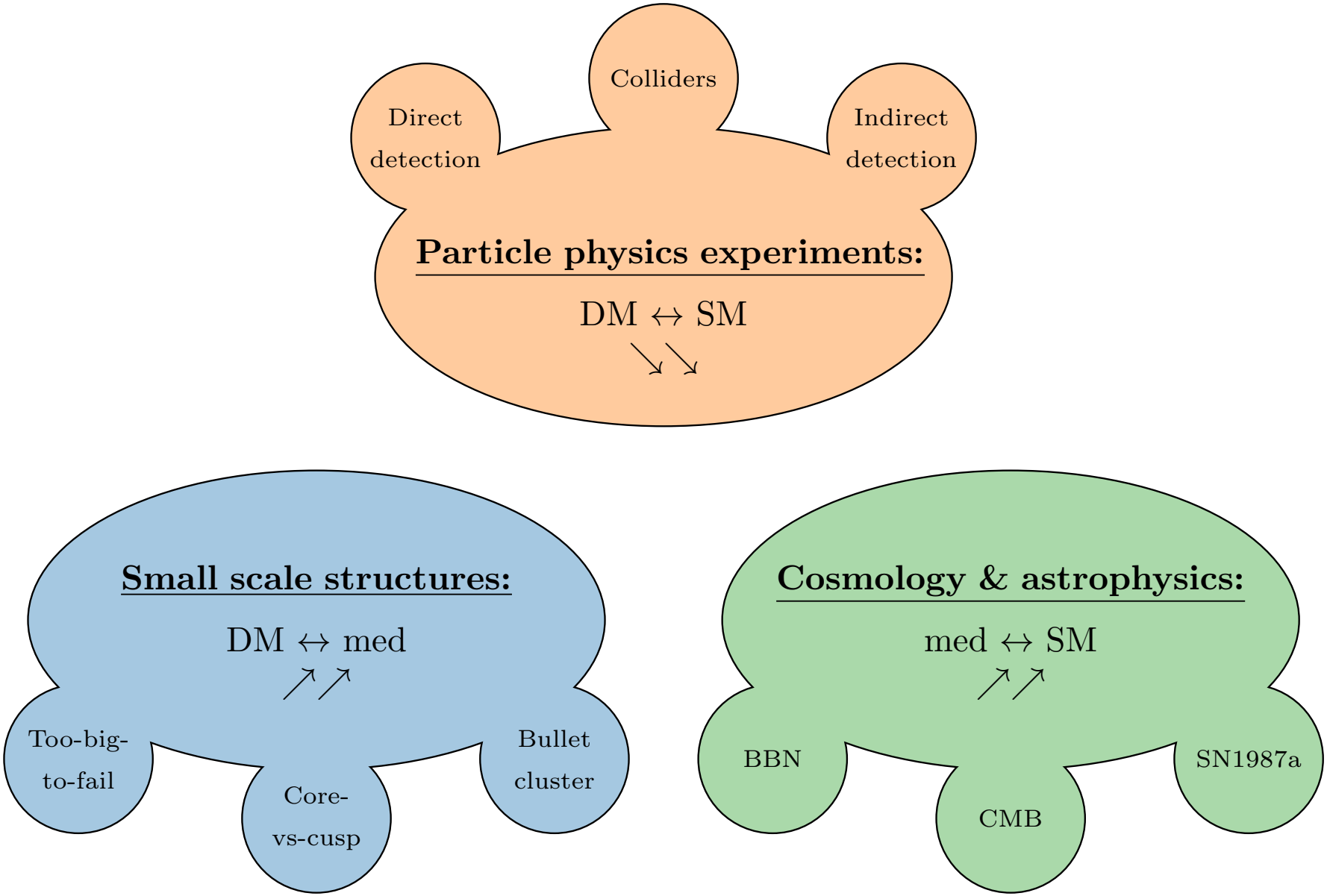


[MAGIC, FERMI-LAT collaborations, 2016]
[H.E.S.S collaboration, 2016] [ANTARES collaboration, 2016]

Highly constrained scenario



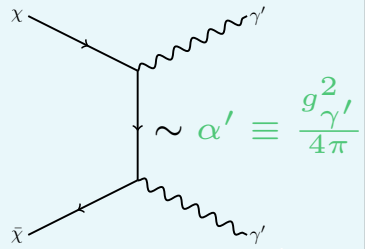
Minimal ways out

SM and HS not thermally connected : $T' < T$

Kinetic mixing portal

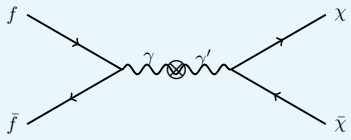
$$\mathcal{L} \ni -g_{\gamma'}\bar{\chi}\gamma^{\mu}\chi A'_{\mu} + h.c. - \frac{\epsilon}{2}F^{Y}_{\mu\nu}F'^{\mu\nu}$$

FO process

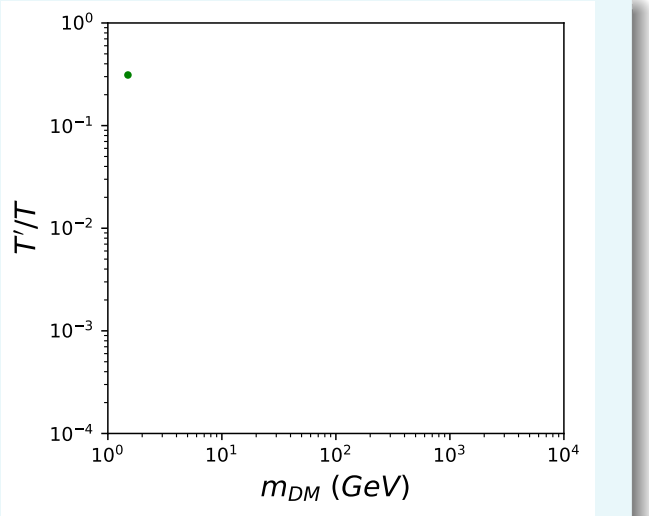


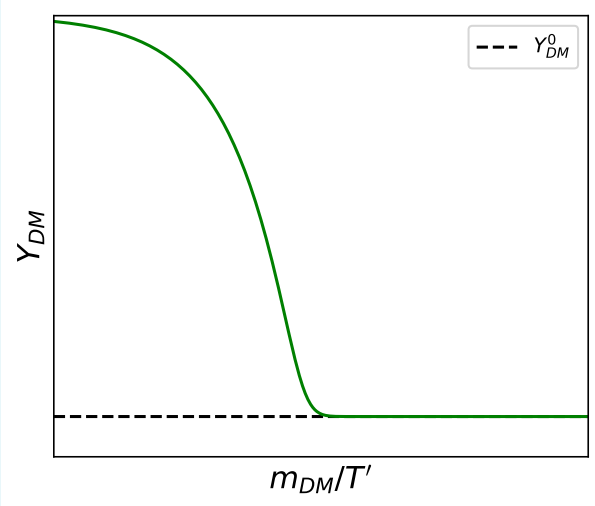
$\sim \alpha' \equiv \frac{g^2_{\gamma'}}{4\pi}$

Portal



$\sim \epsilon\sqrt{\alpha'}$





Fixing $\alpha' = 10^{-5}$ (and $\epsilon = 10^{-12}$)

SM and HS not thermally connected : $T' < T$

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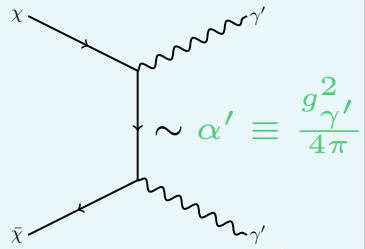

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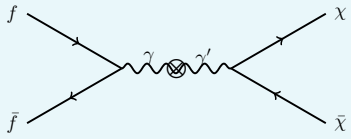
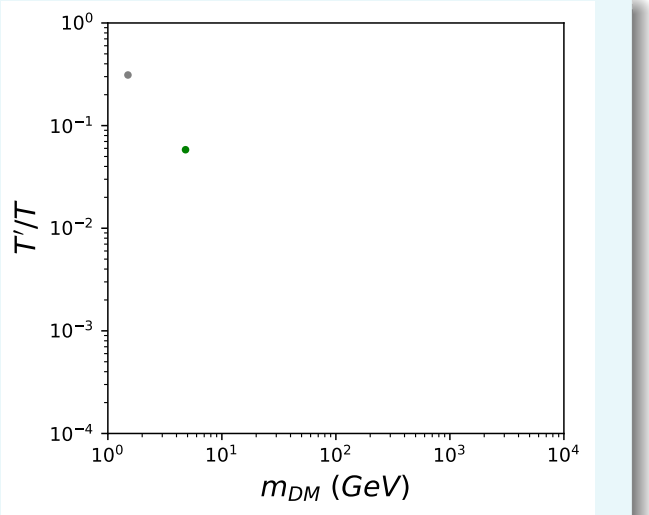
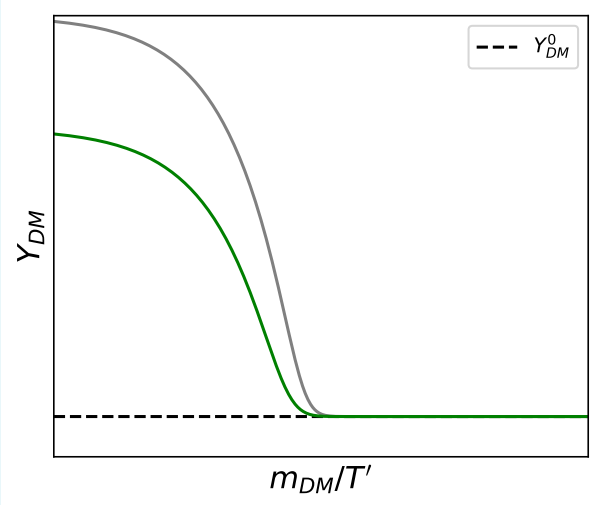
Portal



$\sim \epsilon\sqrt{\alpha'}$





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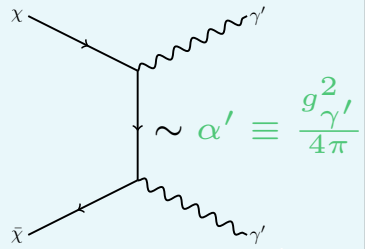

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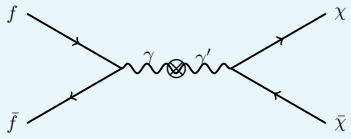

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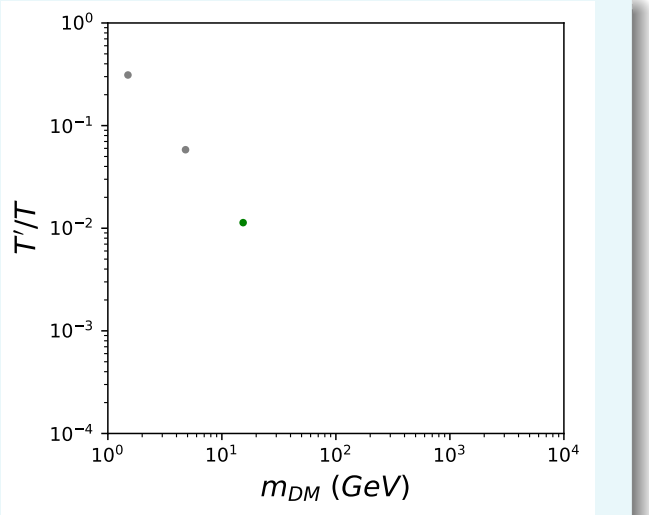

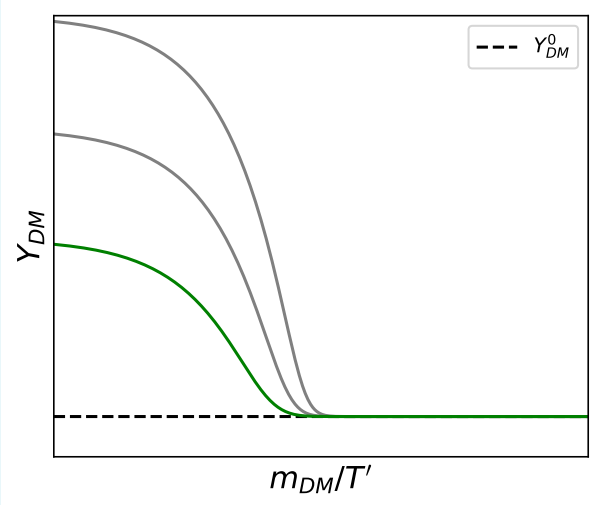

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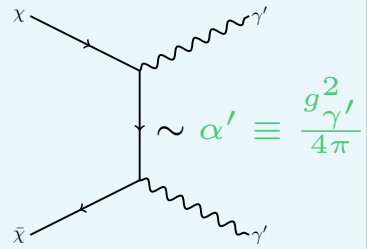

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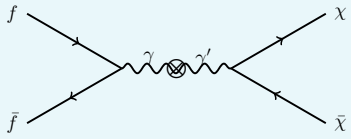
Portal



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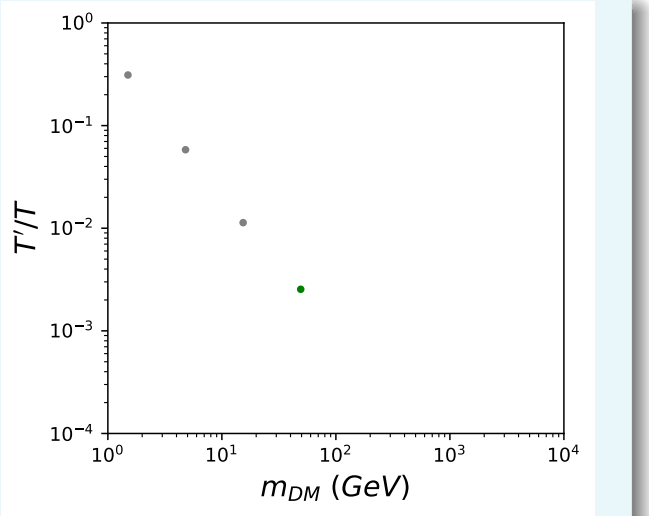

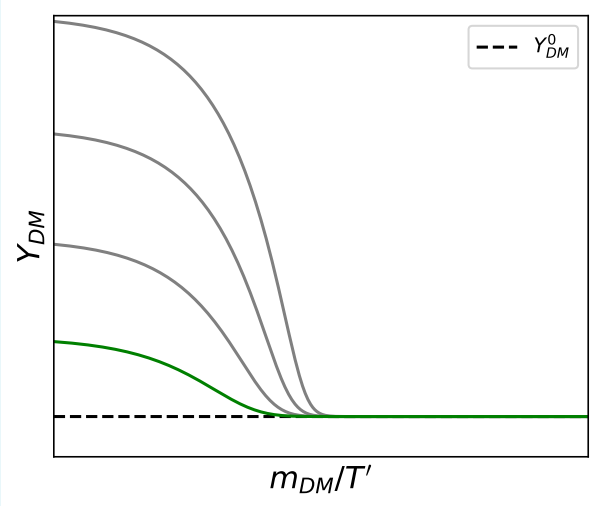

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Kinetic mixing portal

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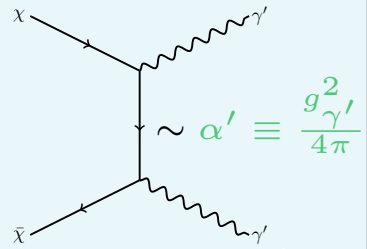

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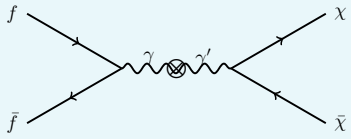

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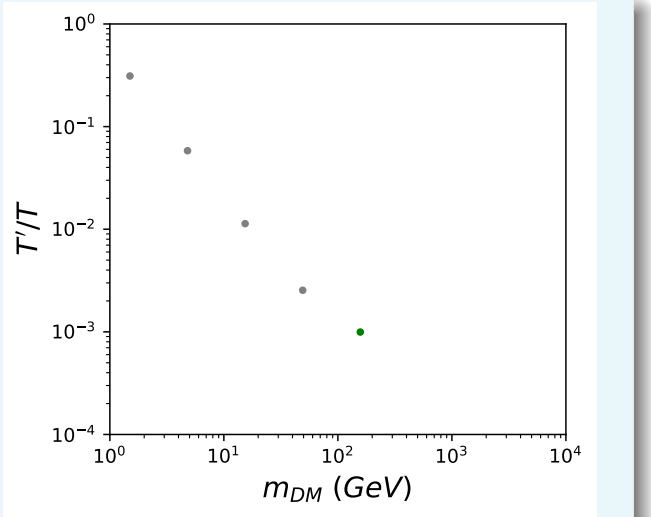

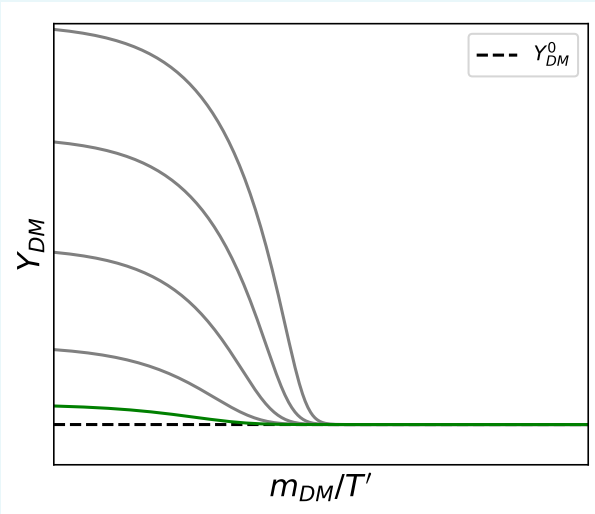

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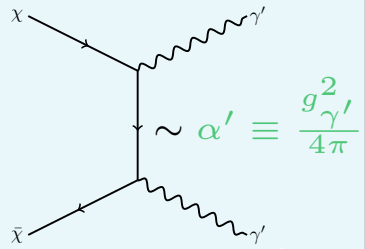

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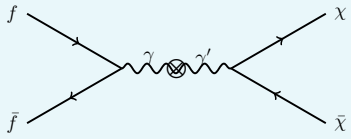

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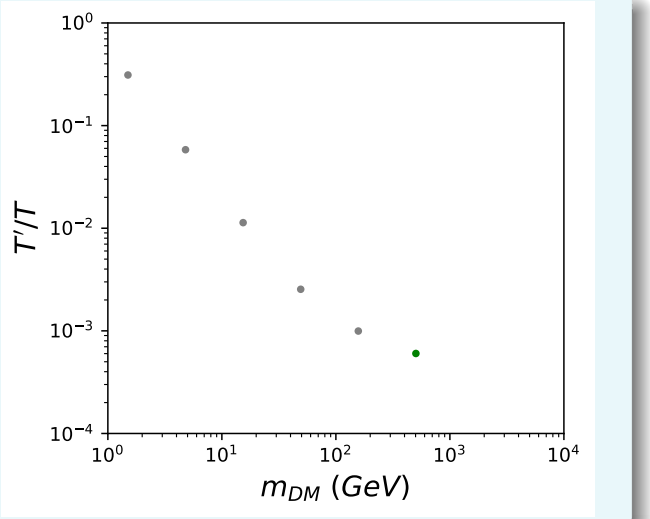

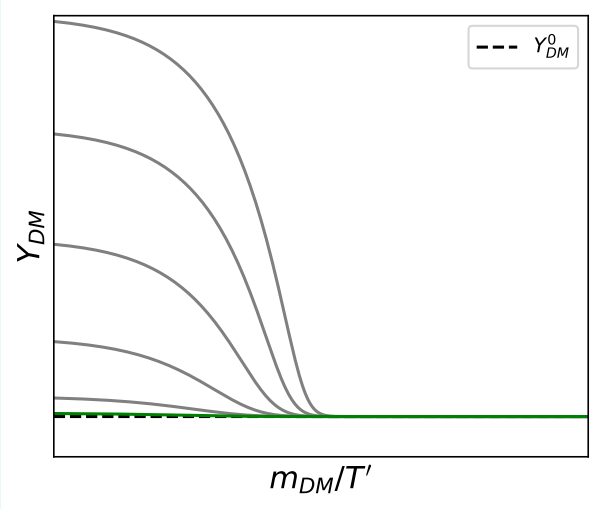

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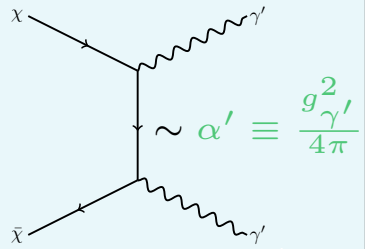

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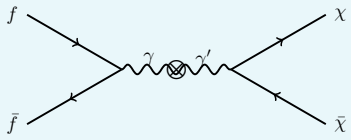

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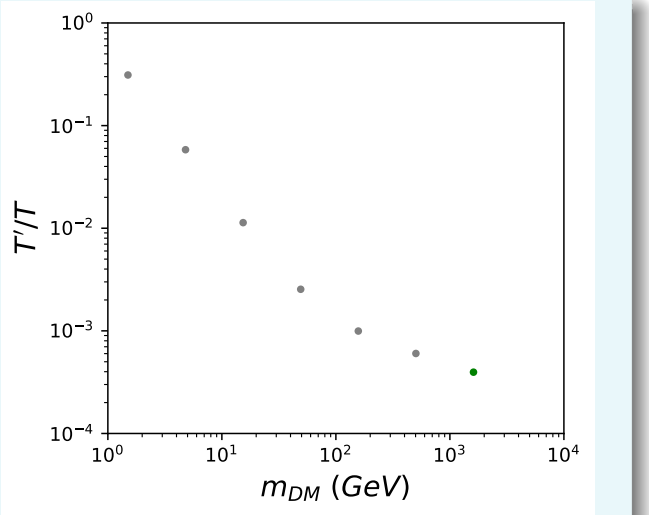

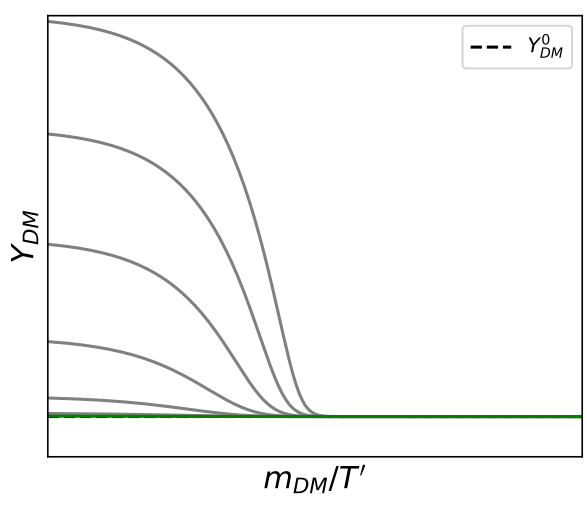

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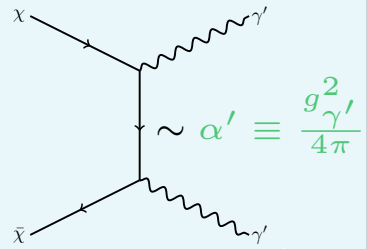

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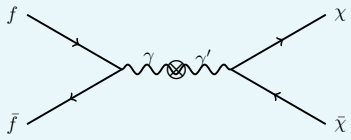

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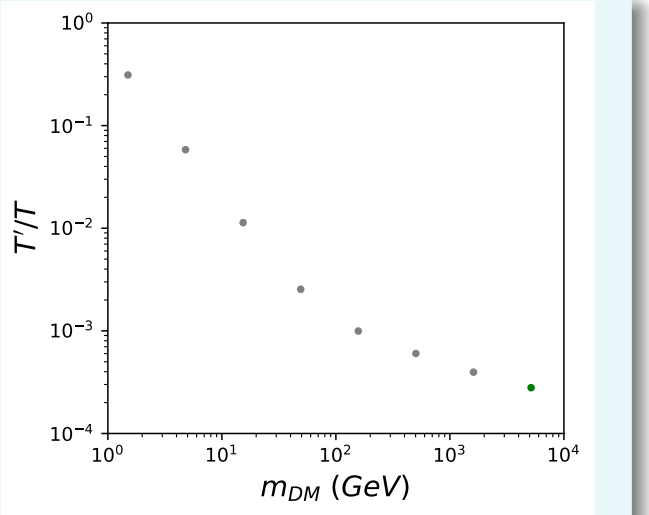

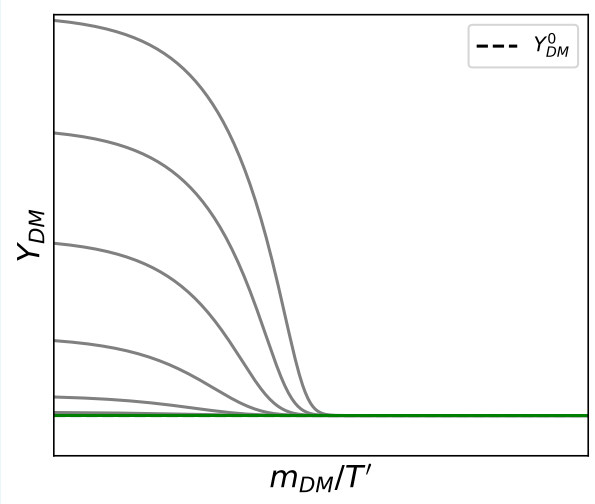

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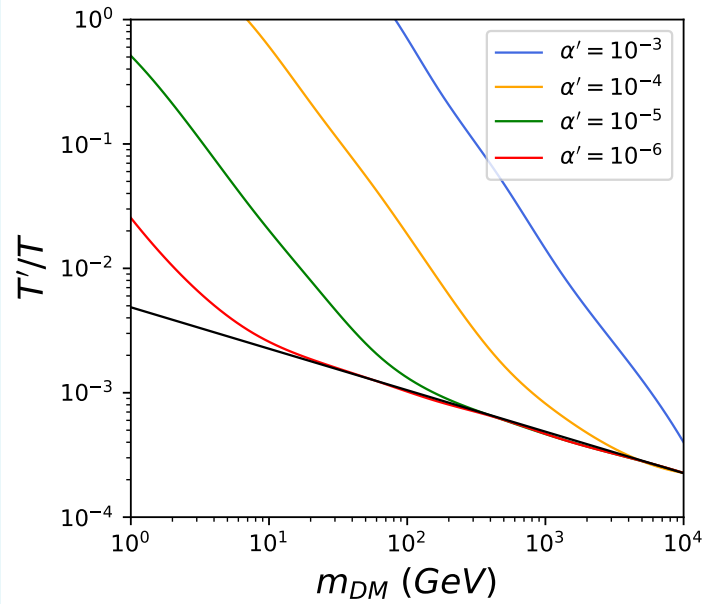

[T. Hambye and LV, 2019]

Relativistic decoupling :

$$n_{DM} \sim T'^3 \text{ and } \Omega_{DM} \sim \left(\frac{T'_{dec}}{T_{dec}}\right)^3 \left(\frac{m_{DM}}{1 \text{ TeV}}\right)$$

$$\Downarrow$$

$$\frac{T'}{T} \geqslant 2.46 \times 10^{-4} \cdot \left(\frac{100 \text{ GeV}}{m_{DM}}\right)^{1/3} \cdot \left(\frac{g_\star^S(T_{dec})}{g_{DM}}\right)^{1/3}$$

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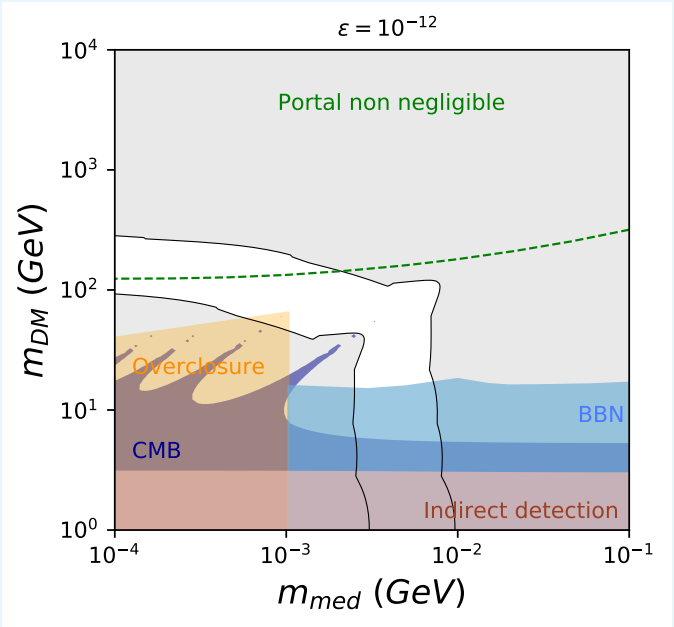

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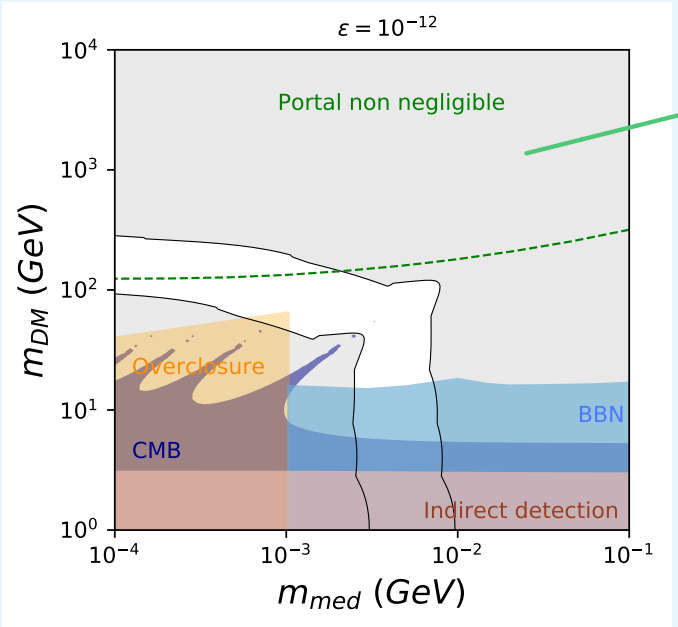

[T. Hambye and LV, 2019]

(Sequential) Freeze-In non negligible

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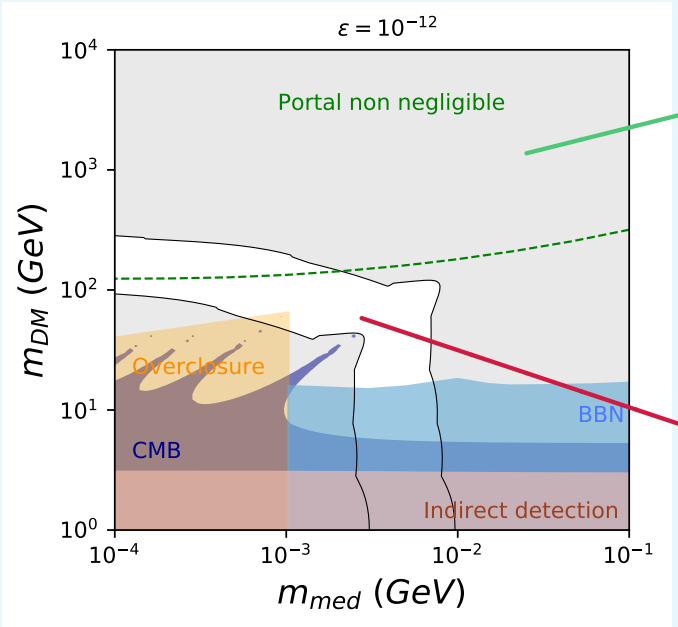
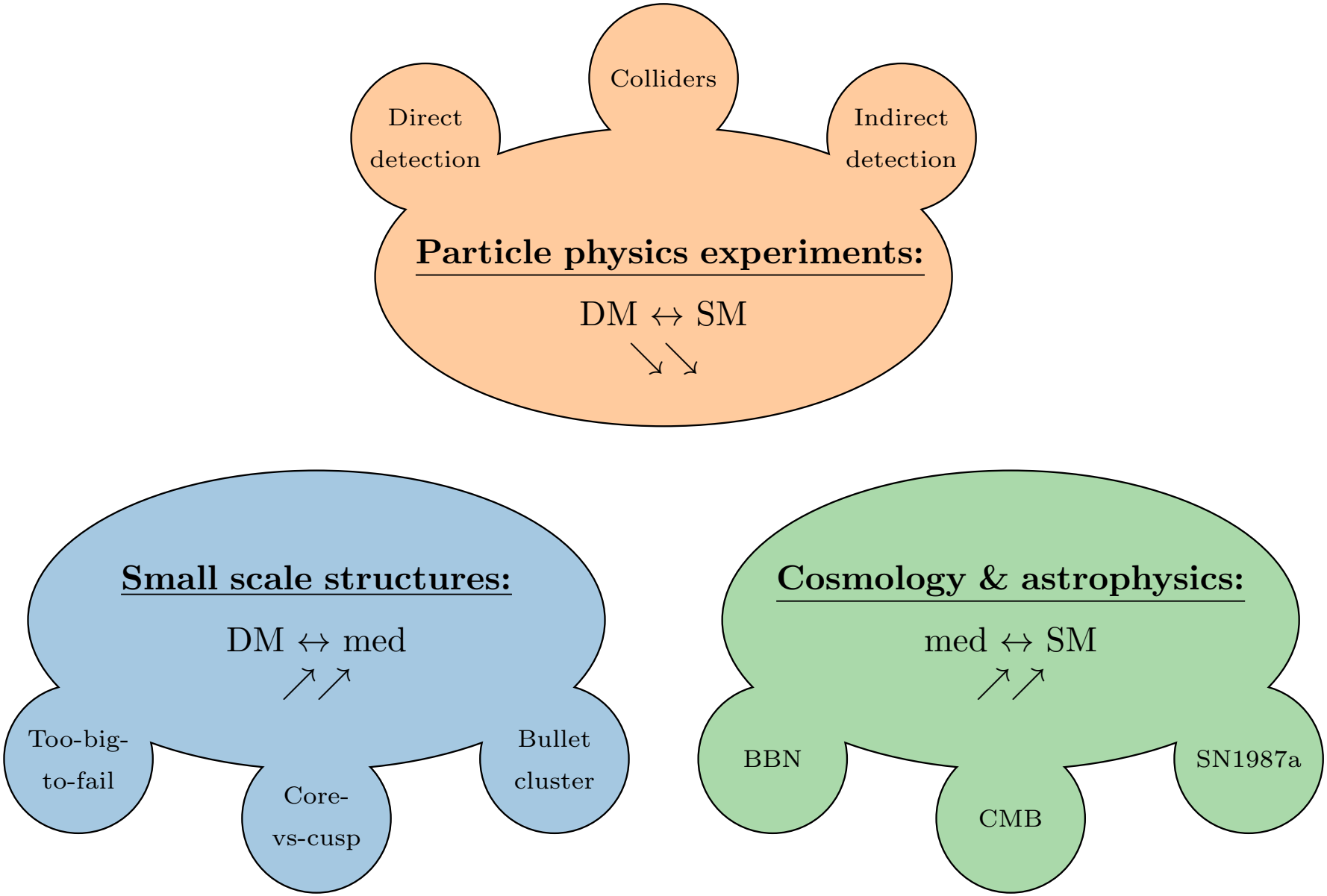


[T. Hambye and LV, 2019]

(Sequential) Freeze-In non negligible

SIDM with light mediator allowed for a large region of the parameter space !

Highly constrained scenario



Other minimal ways out

- Subleading DM annihilation into light mediators
- P-wave annihilation and decay of the light mediator into extra hidden sector particles
- Stable mediator with annihilation into hidden sector particles
- Neutrino option
- ...

Conclusion

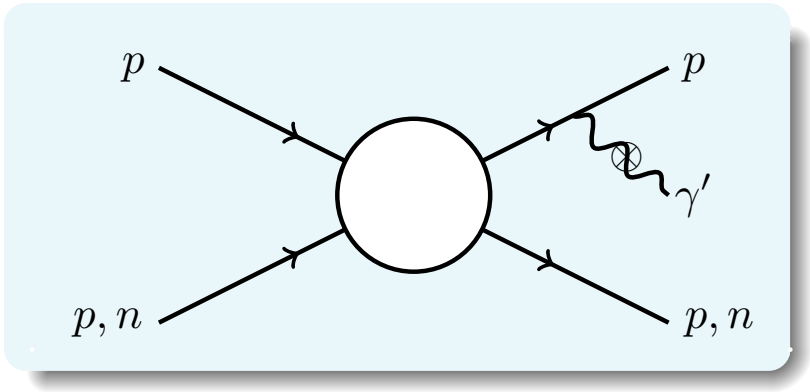
Self-interacting Dark Matter with a light mediator is an attractive possible answer to the small scale crisis. Even if this scenario seems to be highly constrained by Cosmology, Astrophysics and Particle Physics, several very simple ways out can be built in order to alleviate the various tensions.

- DM annihilation into light mediator in a hidden sector with $T' < T$
- Subleading DM annihilation into light mediators
- P-wave annihilation and decay of the light mediator into extra hidden sector particles

Thank you !

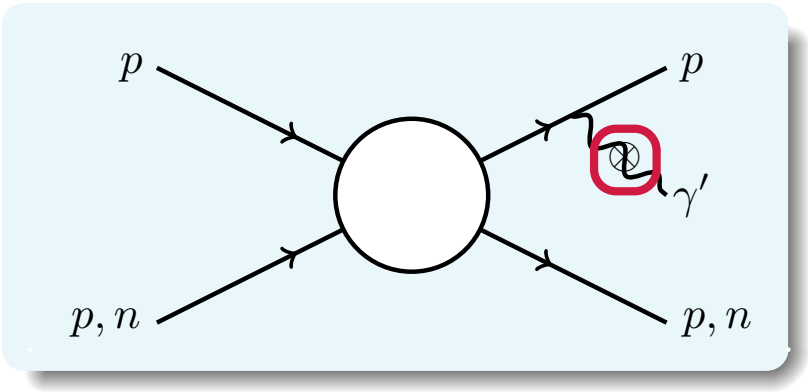
Backup slides

Supernovae - SN1987A



Luminosity argument,
Blow-away arguments
and
MeV γ-rays observations

Supernovae - SN1987A



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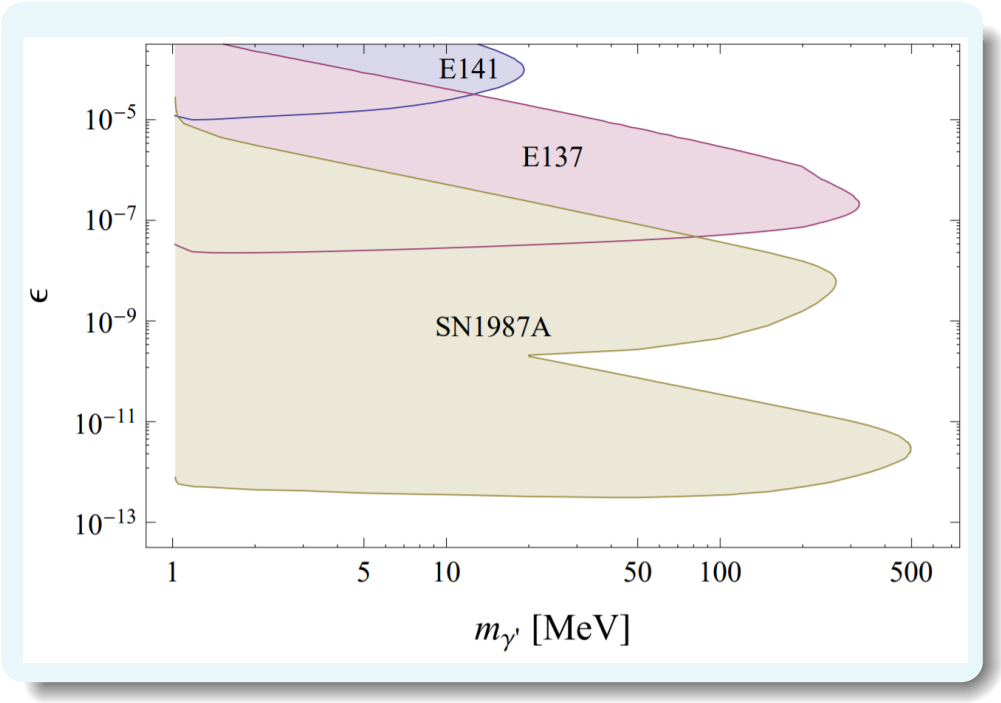
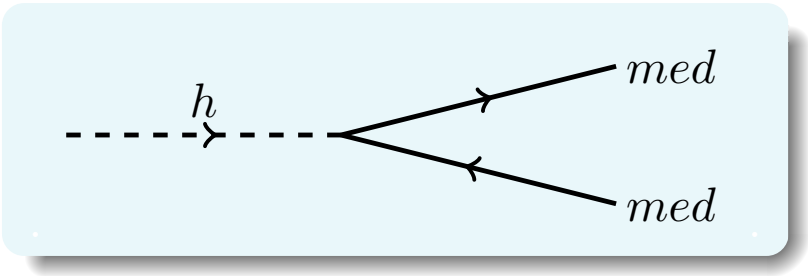


[D. Kazanas et al., 2014]

Direct limits on the size of the portals



Invisible Higgs decay width

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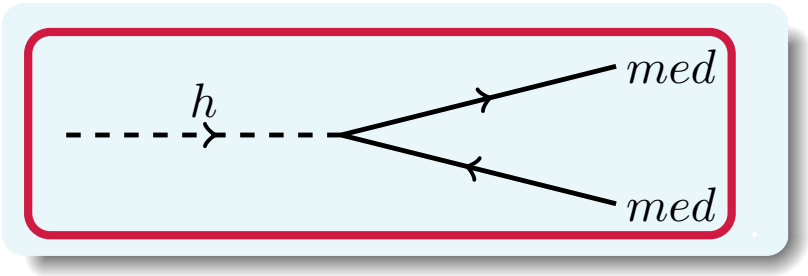

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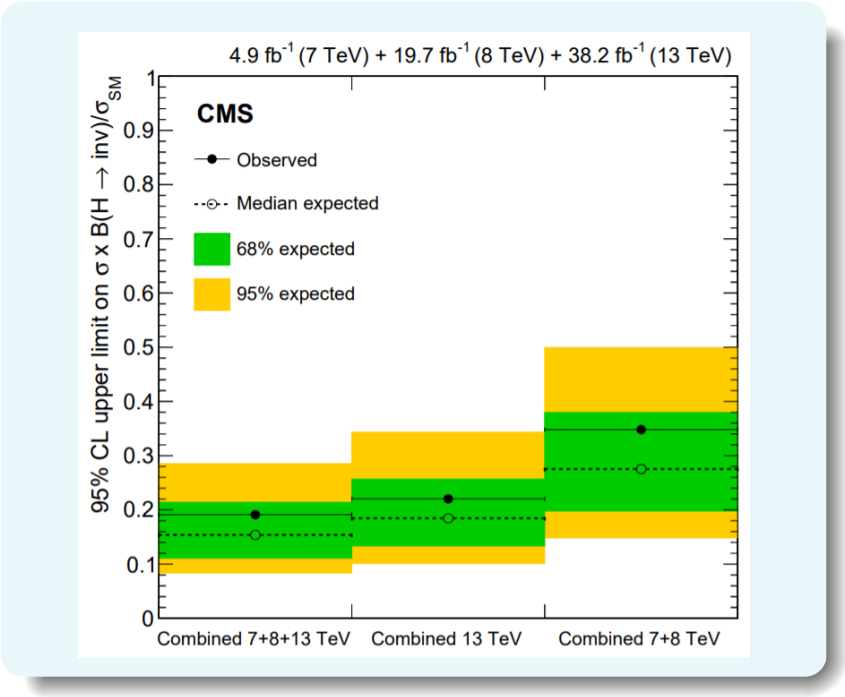

[CMS collaboration, 2018]

Minimal ways out with one extra particle

Subleading DM annihilation into light mediators

$$\mathcal{L} \ni -g_{\gamma'}\bar{\chi}\gamma^{\mu}\chi A'_{\mu} + h.c. - \frac{\epsilon}{2}F^{Y}_{\mu\nu}F'^{\mu\nu} - y_S S\bar{\chi}\chi \quad +\lambda_{HS}H^{\dagger}HS^2$$

$$\text{with } m_{\gamma'} \ll m_S < m_{DM}$$

- Light mediator γ' responsible for SI $\Rightarrow$ Alleviate tensions in the small scale crisis
- Heavy mediator S responsible for the FO process then decays quickly into SM particles

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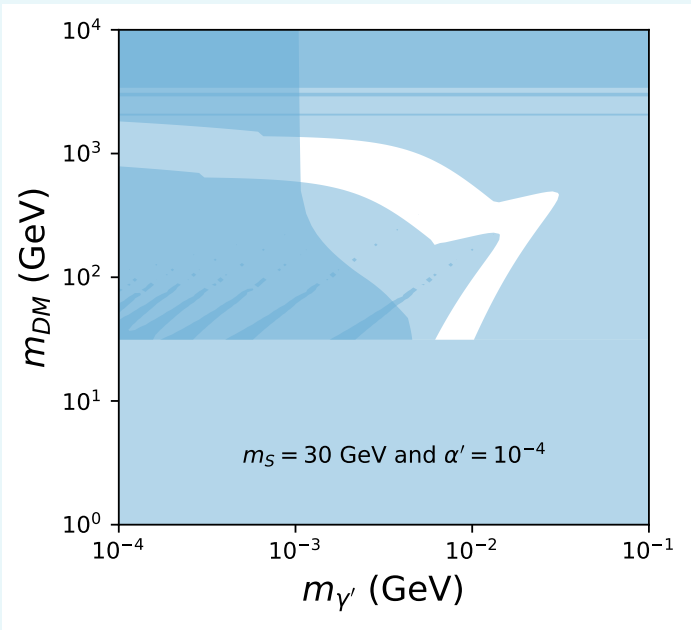

[T. Hambye and LV, 2019]

Minimal ways out with one extra particle

P-wave annihilation and decay of the light mediator into extra hidden sector particles

$$\mathcal{L} \ni -y_\phi \phi \bar{\chi}^c \chi + h.c. - \lambda_{\phi H} \phi^\dagger \phi H^\dagger H - \lambda_{\phi S} \phi^\dagger \phi S^2 - \lambda_{HS} H^\dagger H S^2$$

$$\text{with } m_S < m_\phi \ll m_{DM}$$

- "Heavy" mediator ϕ responsible for SI $\Rightarrow$ Alleviate tensions in the small scale crisis
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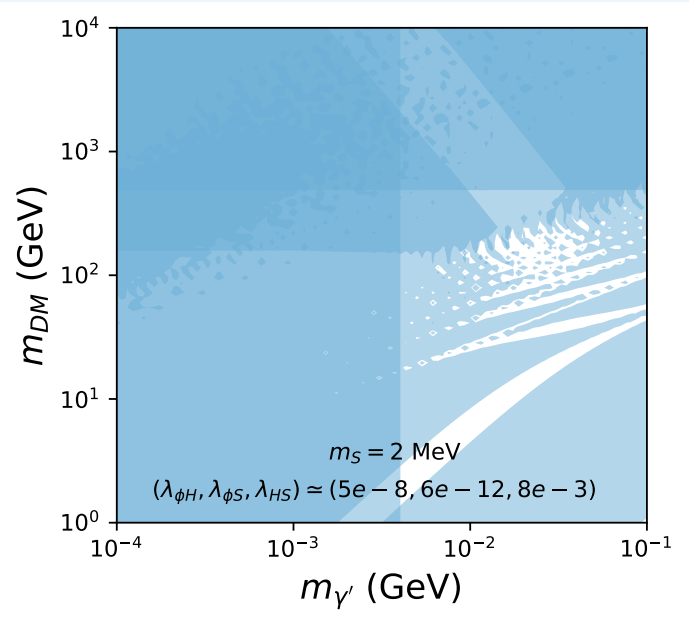
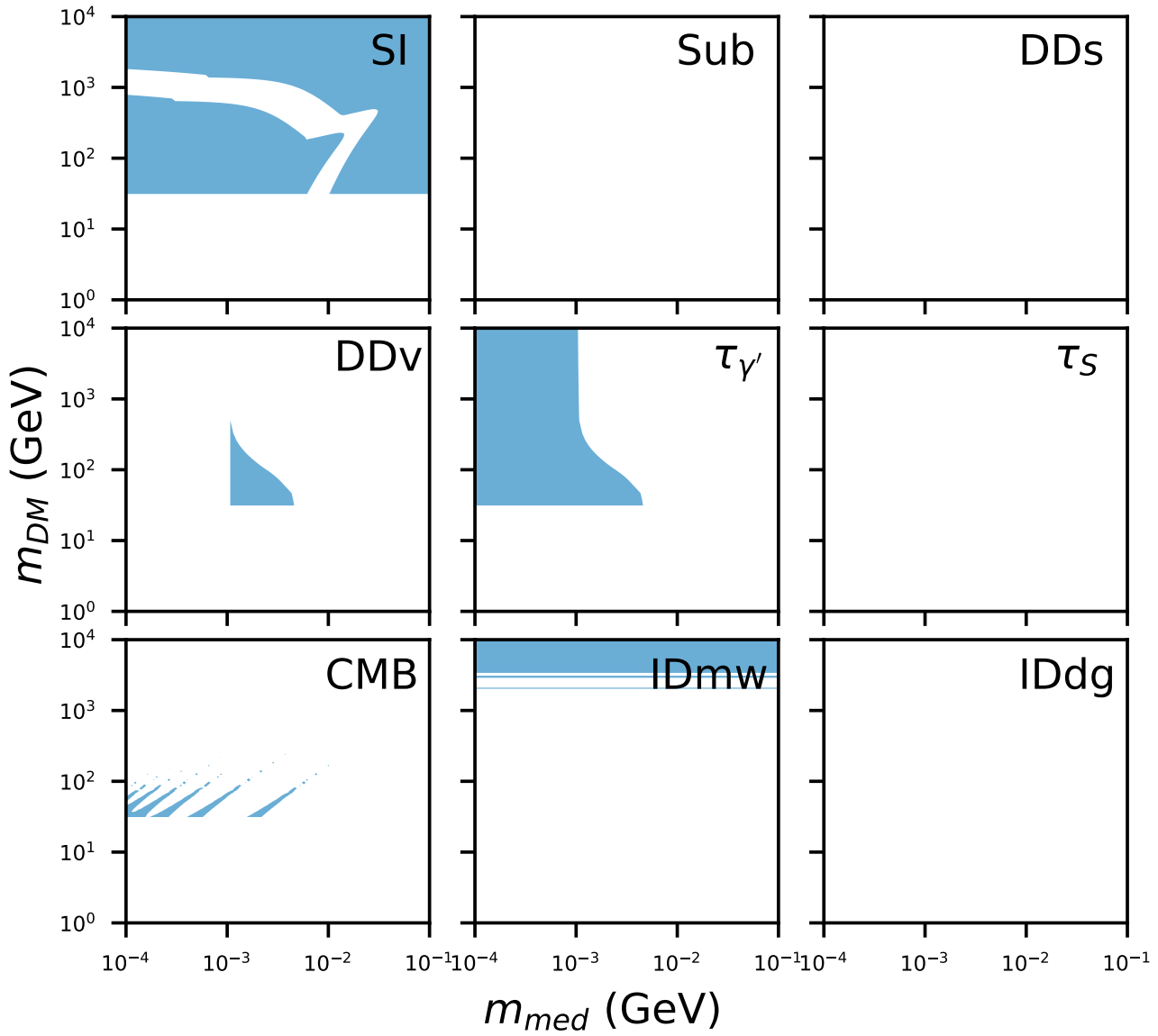
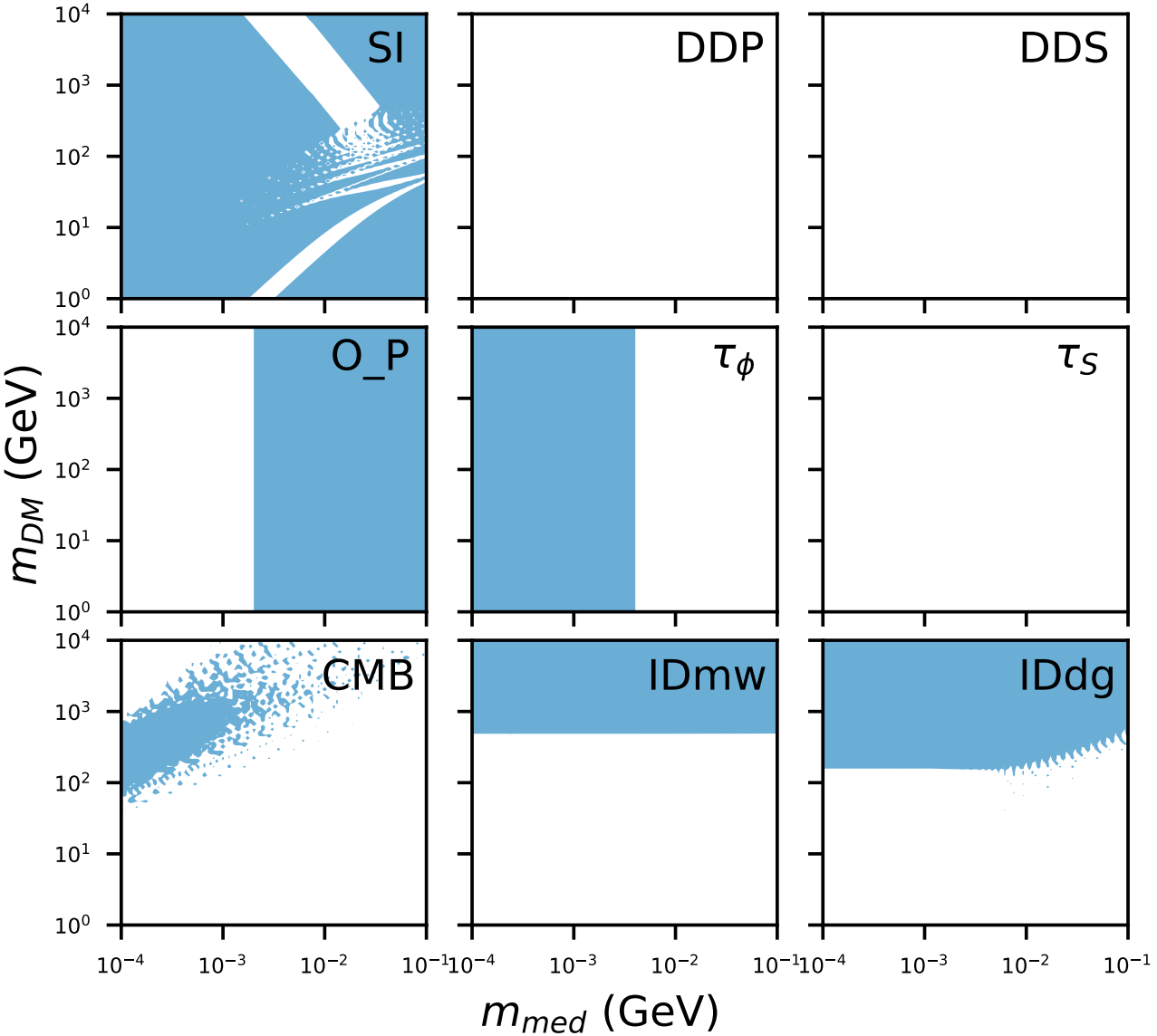


[T. Hambye and LV, 2019]

$B_{\gamma'}$


SI
Sub
DDs
DDv
$\tau_{\gamma'}$
τ_S
CMB
IDmw
IDdg
m_{DM} (GeV)
m_{med} (GeV)
10^0
10^1
10^2
10^3
10^4
10^{-4}
10^{-3}
10^{-2}
10^{-1}


SI
DDP
DDS
O_P
τ_ϕ
τ_S
CMB
IDmw
IDdg
m_{DM} (GeV)
m_{med} (GeV)
10^0
10^1
10^2
10^3
10^4
10^{-4}
10^{-3}
10^{-2}
10^{-1}