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Long range interactions and Dark Matter

Dark Side of the Universe
LAPTh, Annecy
26/06/2018

Motivations

Long range interactions arise for $M_{DM} >> M_{mediator}$

- beyond usual WIMP contact interactions

  e.g. TeV scale EW-charged WIMPS. Here the light mediators are the SM gauge bosons
  Co-annihilations with colored/charged particles

- Hidden sector DM

  e.g. scenarios with Mirror symmetry, e.g. Twin Higgs models.

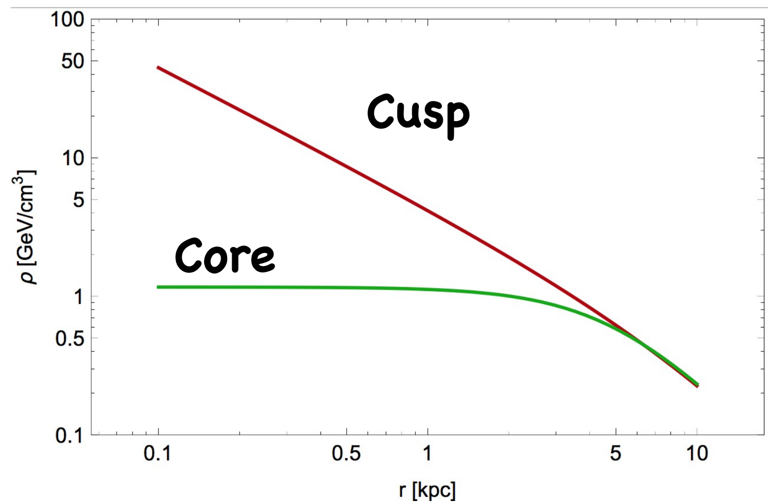
  Simple recipe to obtain **Self-interacting DM**

  Motivated by astrophysical anomalies

Collisionless CDM anomalies

Potential discrepancies between observations and predictions of Collisionless CDM at galactic and sub-galactic scales

- Core vs Cusp problem
- "Too big too fail" problem
- Missing satellites problem
- Diversity problem



Possible solutions:

- Include baryonic physics in CDM simulations: large baryonic feedback processes, like SN explosions

- Change the DM properties: Warm DM or **Self-Interacting Dark Matter (SIDM)**

Spergel, Steinhardt (2000)

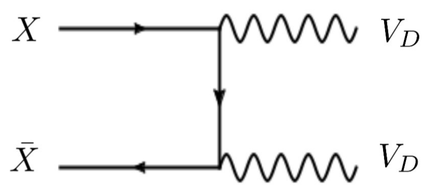
Need large cross-sections:

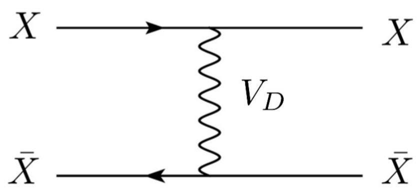
$$\sigma_{\chi\chi}/M_{DM} \sim few \times 0.1 - 1\ \mathrm{cm}^2/g$$

Dark QED

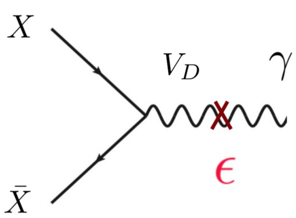
$$\mathcal{L} = \bar{X}(i\not{D} - M_{\rm DM})X - \frac{1}{4}F_{D\,\mu\nu}F_{D}^{\mu\nu} - \frac{1}{2}m_{V_D}^2 V_{D\,\mu}V_D{}^{\mu} - \frac{\epsilon}{2c_w}F_{D\,\mu\nu}F_{Y}^{\mu\nu}$$

Thermal production and scattering



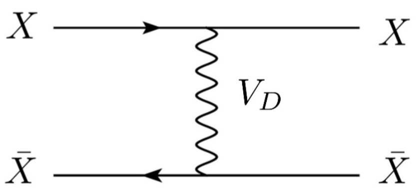


Dark Matter – SM portal



Self scattering

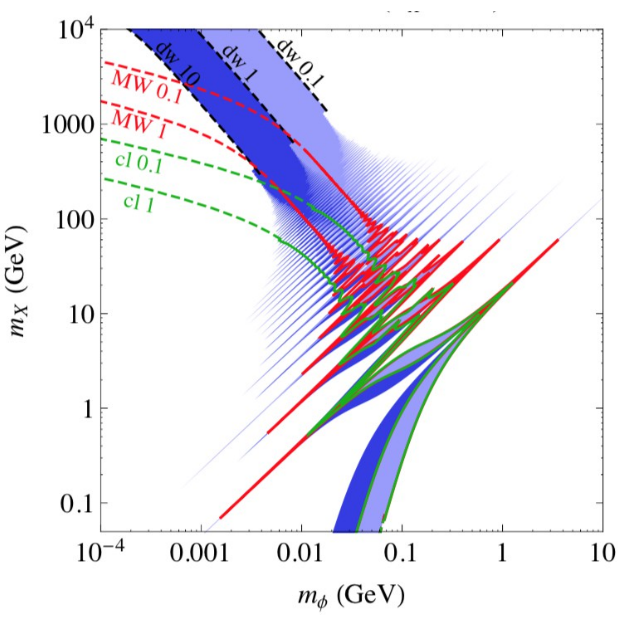
$$\mathcal{L} = \bar{X}(i\not{D} - M_{\rm DM})X - \frac{1}{4}F_{D\mu\nu}F_D^{\mu\nu} - \frac{1}{2}m_{V_D}^2 V_{D\mu}V_D{}^{\mu} - \frac{\epsilon}{2c_w}F_{D\mu\nu}F_Y^{\mu\nu}$$



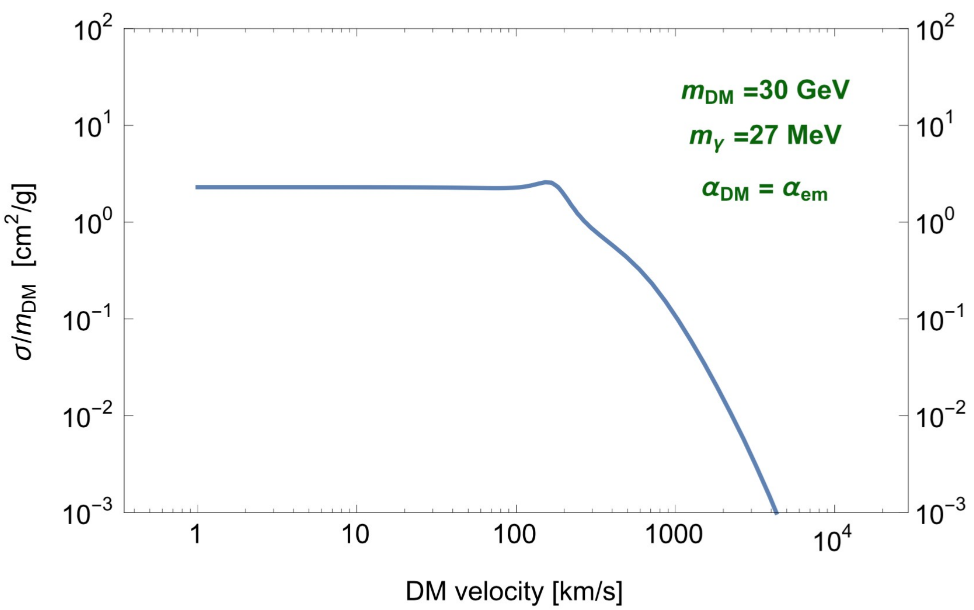
Velocity dependent cross-section

M v << mγ : contact limit and σ is v-independent

Mv >> mγ : Rutherford limit σ ~ $1/v^4$



Tulin, Yu, Zurek (2014)

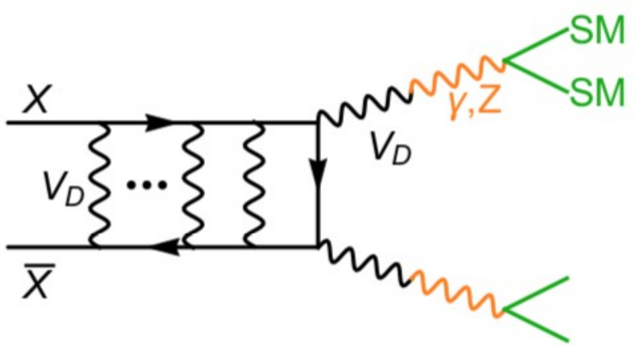


dwarfs LSB clusters

Annihilations and bound states

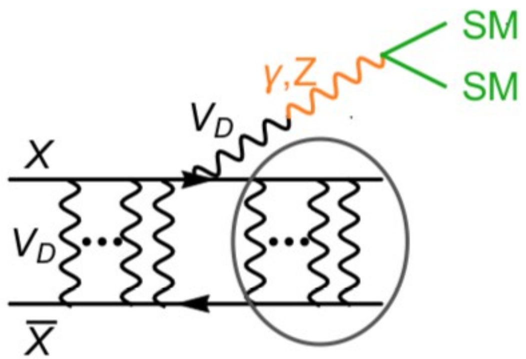
Annihilation processes are Sommerfeld enhanced

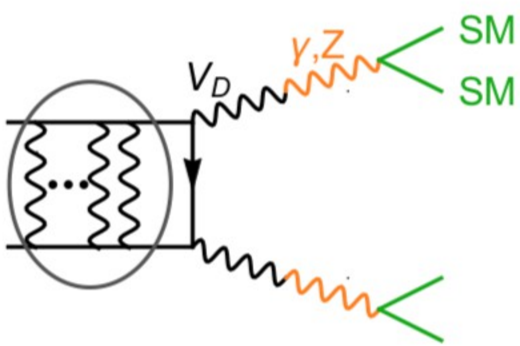
Annihilation cross section boosted at
low DM velocities

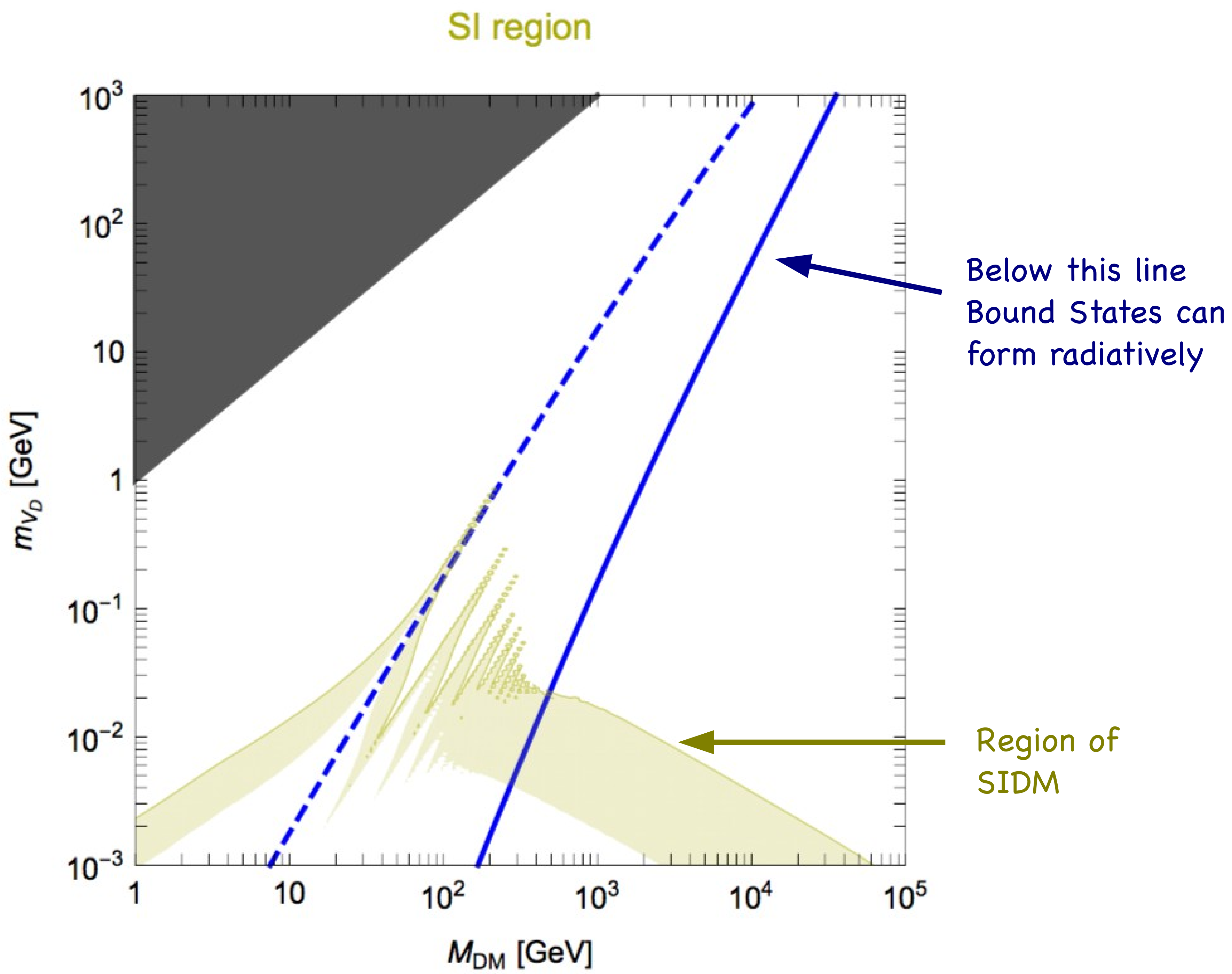


Formation of DM (unstable) bound states

In the coulomb limit this process is
a factor 3 larger than annihilations.

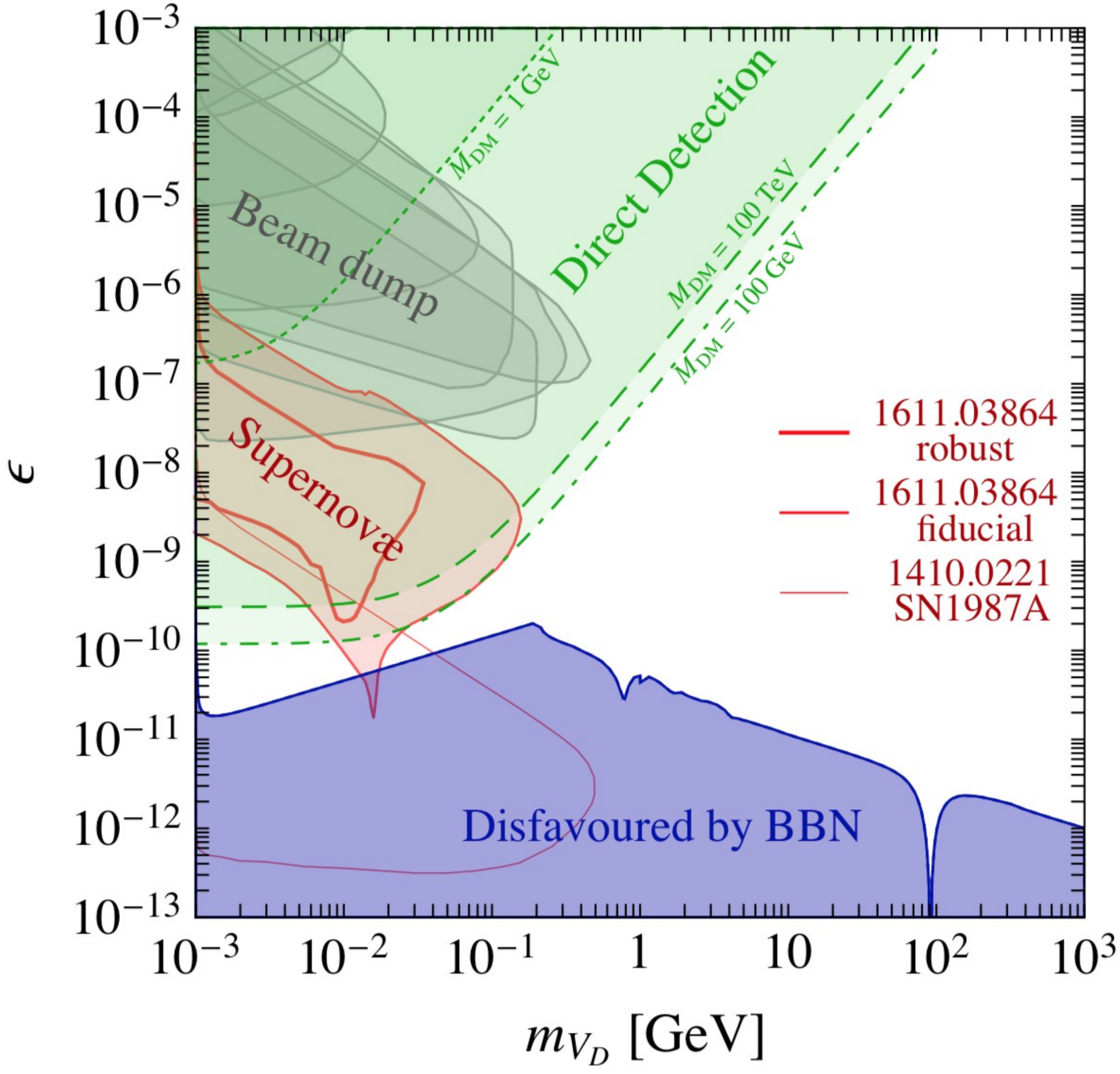






SI region
m_{V_D} [GeV]
M_{DM} [GeV]
10³
10²
10
1
10⁻¹
10⁻²
10⁻³
1
10
10²
10³
10⁴
10⁵
Below this line
Bound States can
form radiatively
Region of
SIDM

Bounds on kinetic mixing



Indirect detection

Signals produced by the decays of the light mediator into SM particles via the kinetic mixing

Indirect detection limits

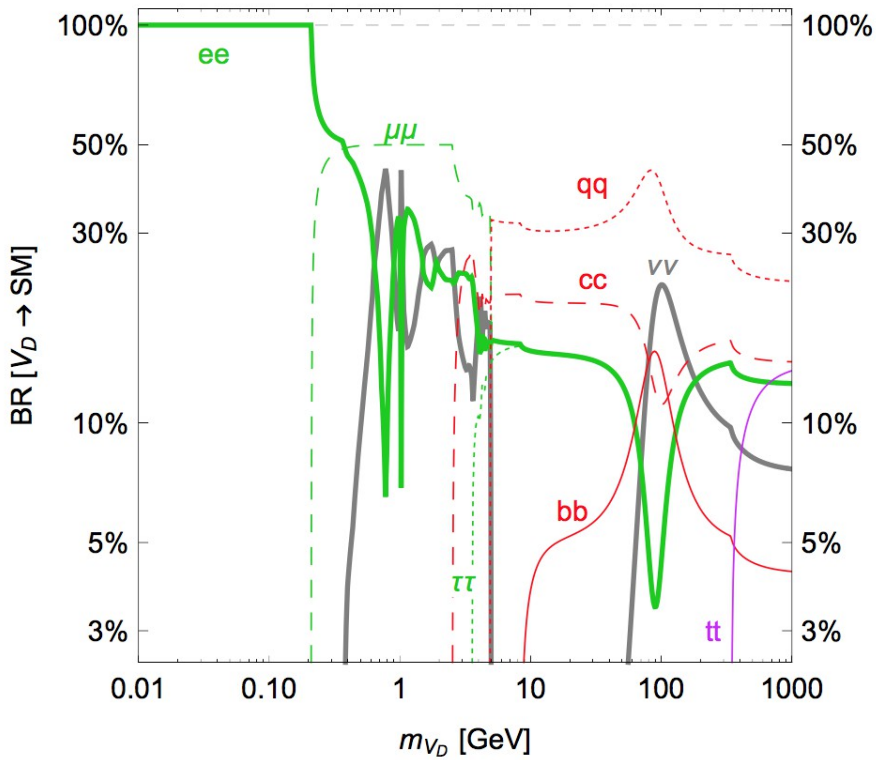
- CMB: Planck constraints

- Fermi Dwarfs

- Galactic Halo gamma-rays

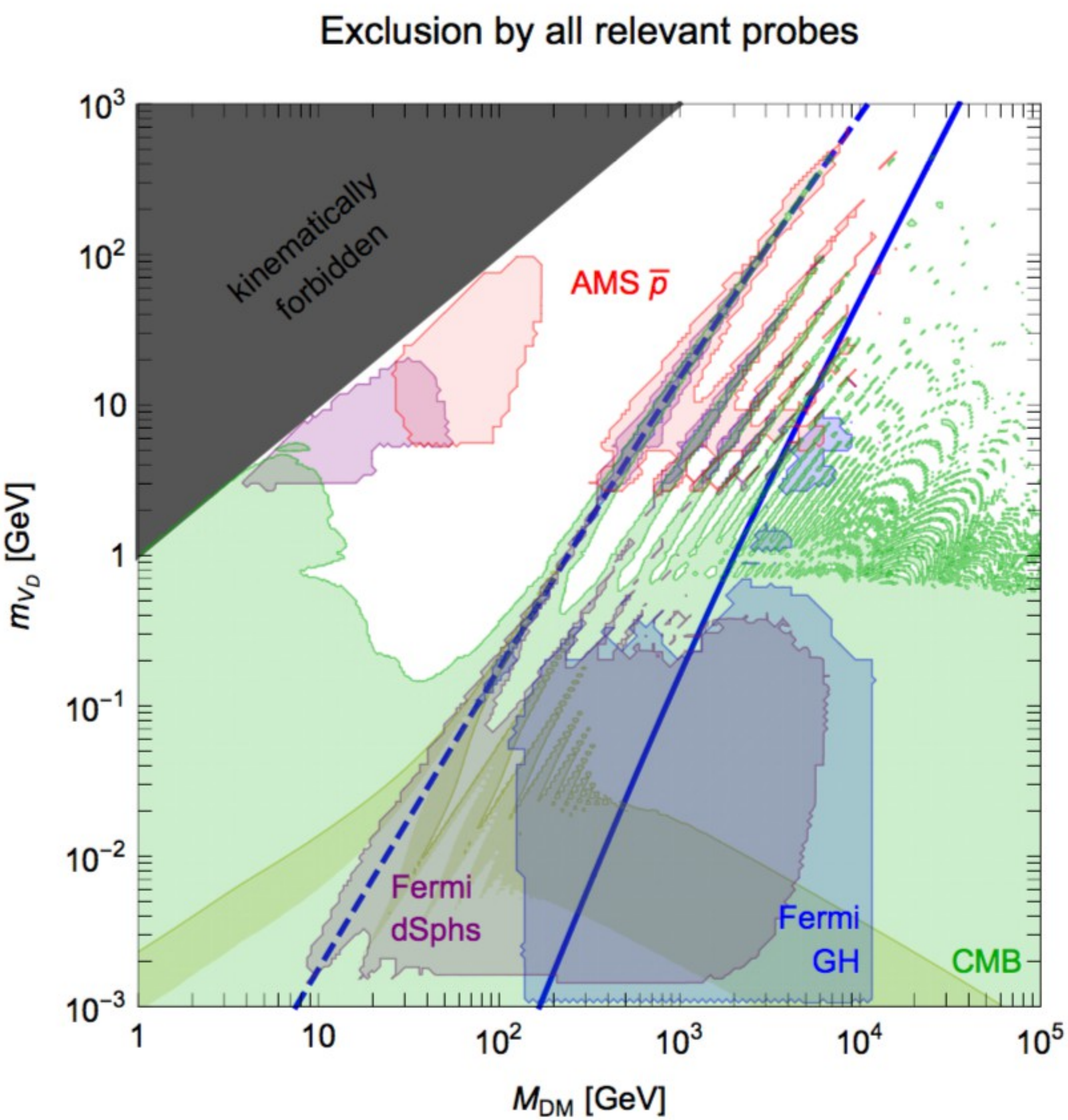
- AMS anti-protons

- ANTARES neutrinos



The decays are suppressed by the kinetic mixing but they are still prompt for astrophysical scales for values of the kinetic mixing allowed by the constraints

Summary plot



Cirelli, Panci, Petraki, Sala, M.T. (2016)

See also Kahlhoefer et al. 2016

Other possibilities for SI DM

Strong bounds on minimal models of self interacting DM from DM searches + cosmological considerations

Other possibilities:

- more complex dark sectors
- mediator decays into light hidden particles
- ...
- **Asymmetric Dark Matter**

Kaplinghat et al. 1310.7945
Kainulainen et al 1507.04931
Bernal et al. 1510.08063
Blennow et al. 1612.06681
Kahlhoefer et al. 1704.02149
Ma 1704.04666
Duerr et al. 1804.10385
+ ...

Asymmetric Dark matter

Like for the baryonic sector the DM density can be set by a primordial asymmetry

$$Y_X = \frac{n_X}{s} \qquad Y_D \equiv Y_+ - Y_- \qquad r_\infty \equiv (Y_-/Y_+)_{t\to\infty}$$

$$M_{p_D} = m_p \frac{Y_B}{Y_D} \frac{\Omega_{\rm DM}}{\Omega_{\rm B}} \left(\frac{1-r_\infty}{1+r_\infty}\right)$$

Need sufficiently large DM annihilations to wash out symmetric population of DM

→ large DM-mediator coupling to light mediator

→ large self interactions can be realized

→ Sommerfeld enhanced cross sections: indirect detection signals could be relevant

<u>Quantify how large the DM asymmetry should be</u>

Dark electrons

For an unbroken U(1) more than one specie is required in order to generate the asymmetry in a gauge invariant way

For example **dark protons** and **dark electrons**

For a broken U(1) similar conclusion

We assume dark electron much lighter than Dark proton

Role of dark electrons

- extra annihilation channel for DM and decays of the DM bound state

- in some region of parameter space dark atoms can form

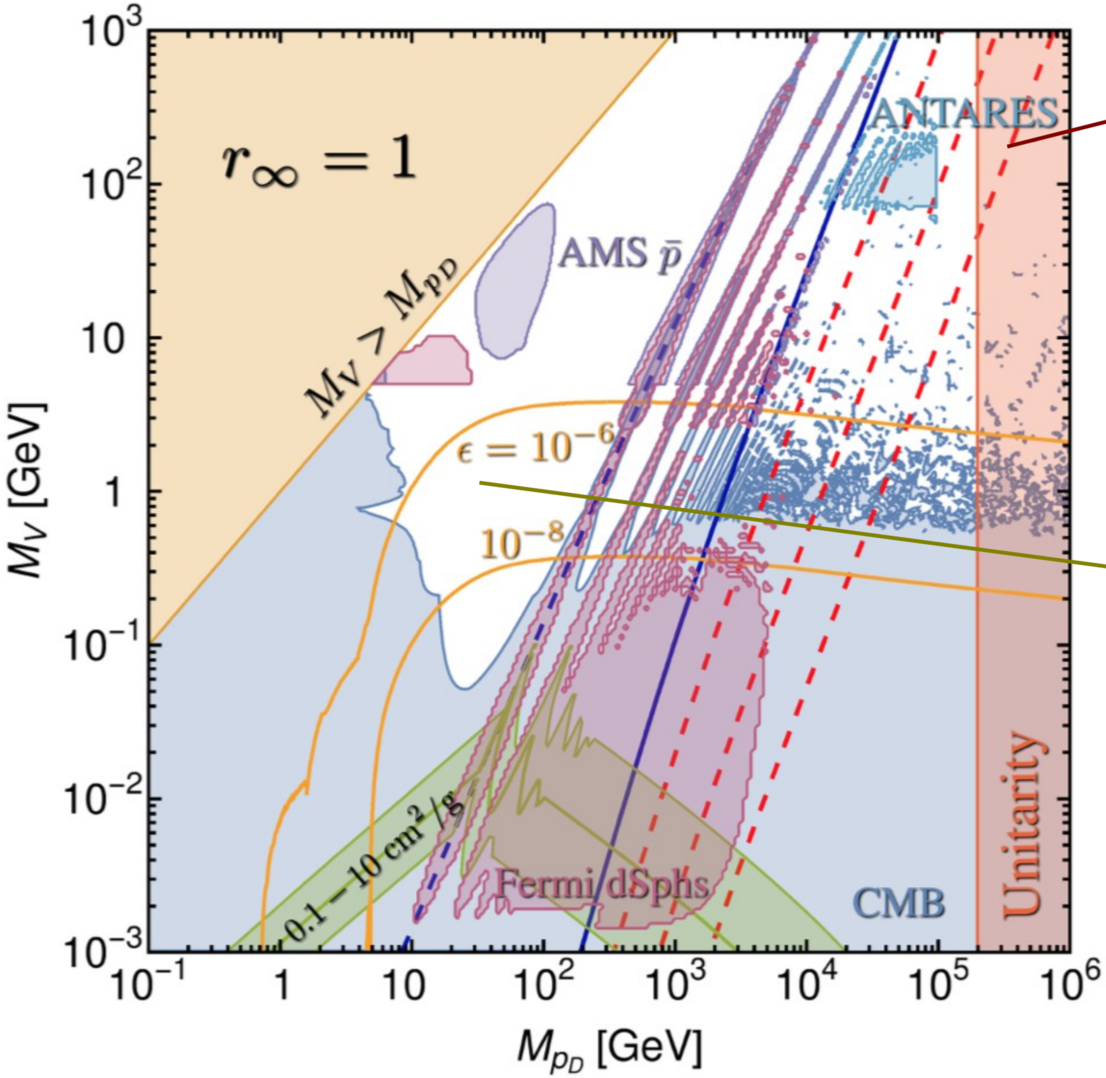
  For a massless mediator see e.g. Racine, Sigurdson 1209.5752

- Contribution to self-interaction processes from dark-p dark-e interactions

Indirect detection of Asymmetric DM

$$\sigma_{\rm ID}\, v_{\rm rel} \equiv \frac{n_\infty^+ n_\infty^-}{(n_\infty^{\rm sym})^2}\sigma_{\rm inel}\, v_{\rm rel} = \frac{4 r_\infty}{(1+r_\infty)^2}\,\sigma_{\rm inel}\, v_{\rm rel}$$

$$r_\infty \equiv (Y_-/Y_+)_{t\to\infty}$$



Dark atoms can form below the lines. NOT included here

Direct detection

Baldes Cirelli, Panci, Petraki, Sala, M.T. (2017)

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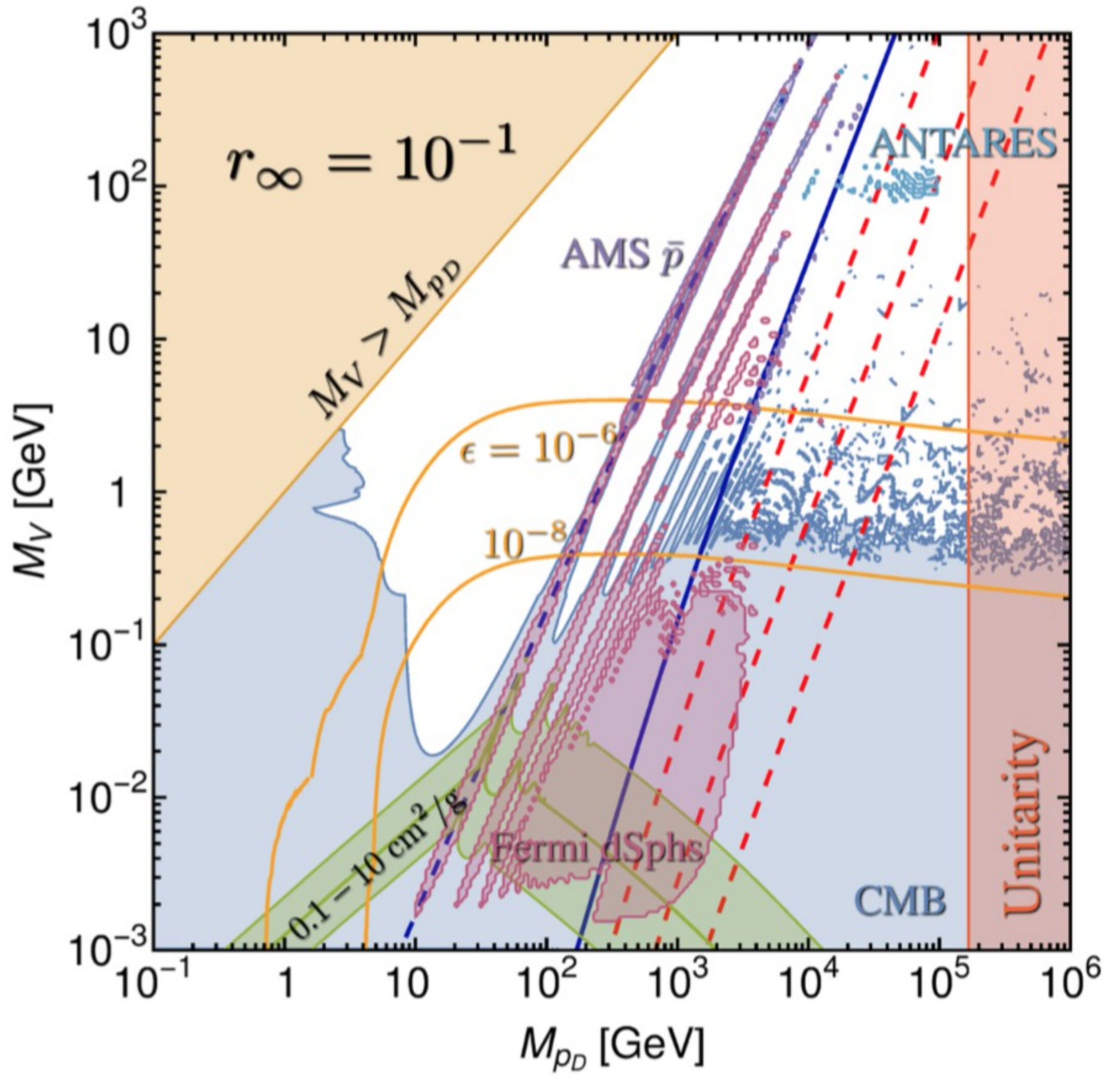

Baldes Cirelli, Panci, Petraki, Sala, M.T. (2017)

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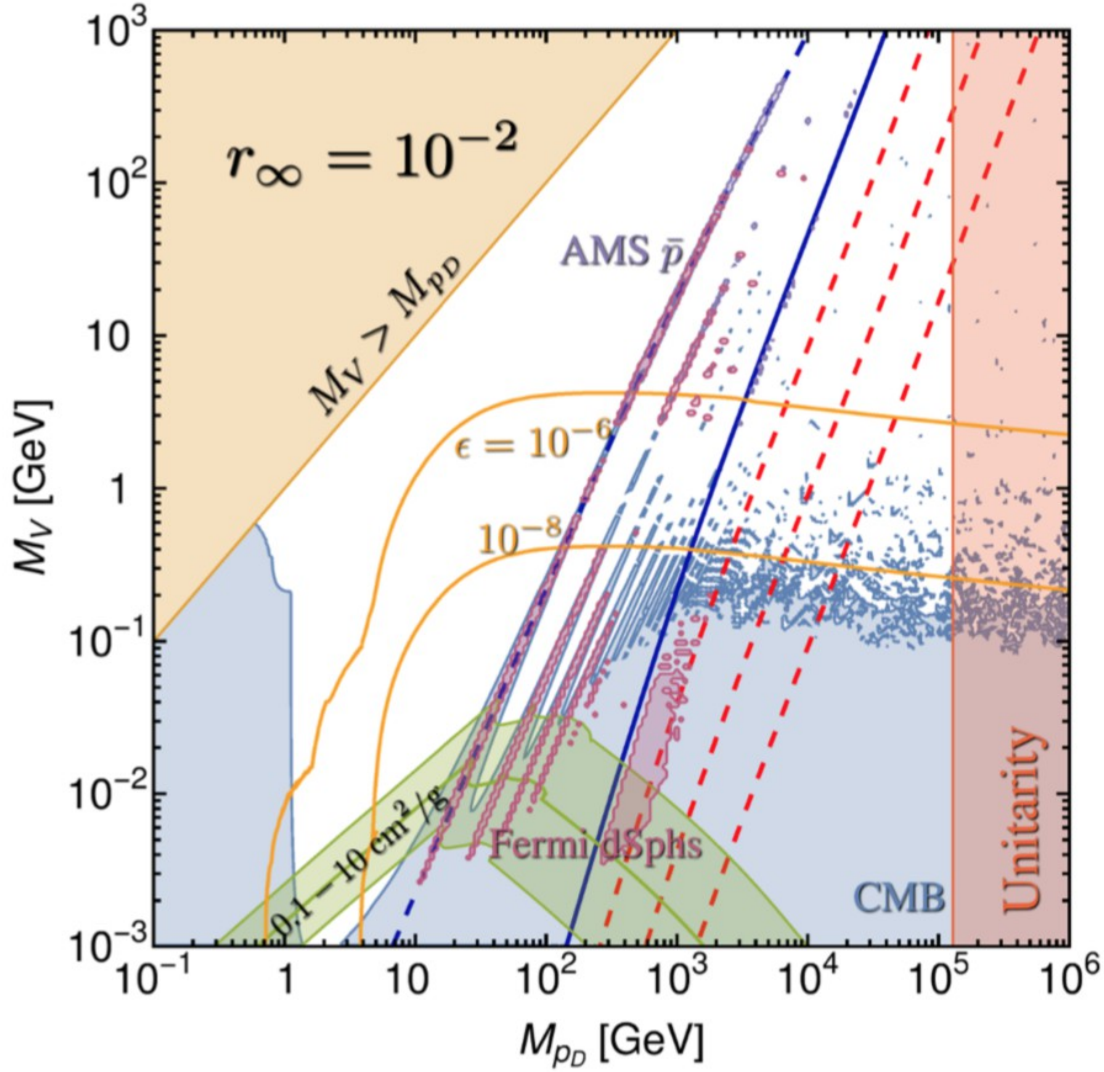

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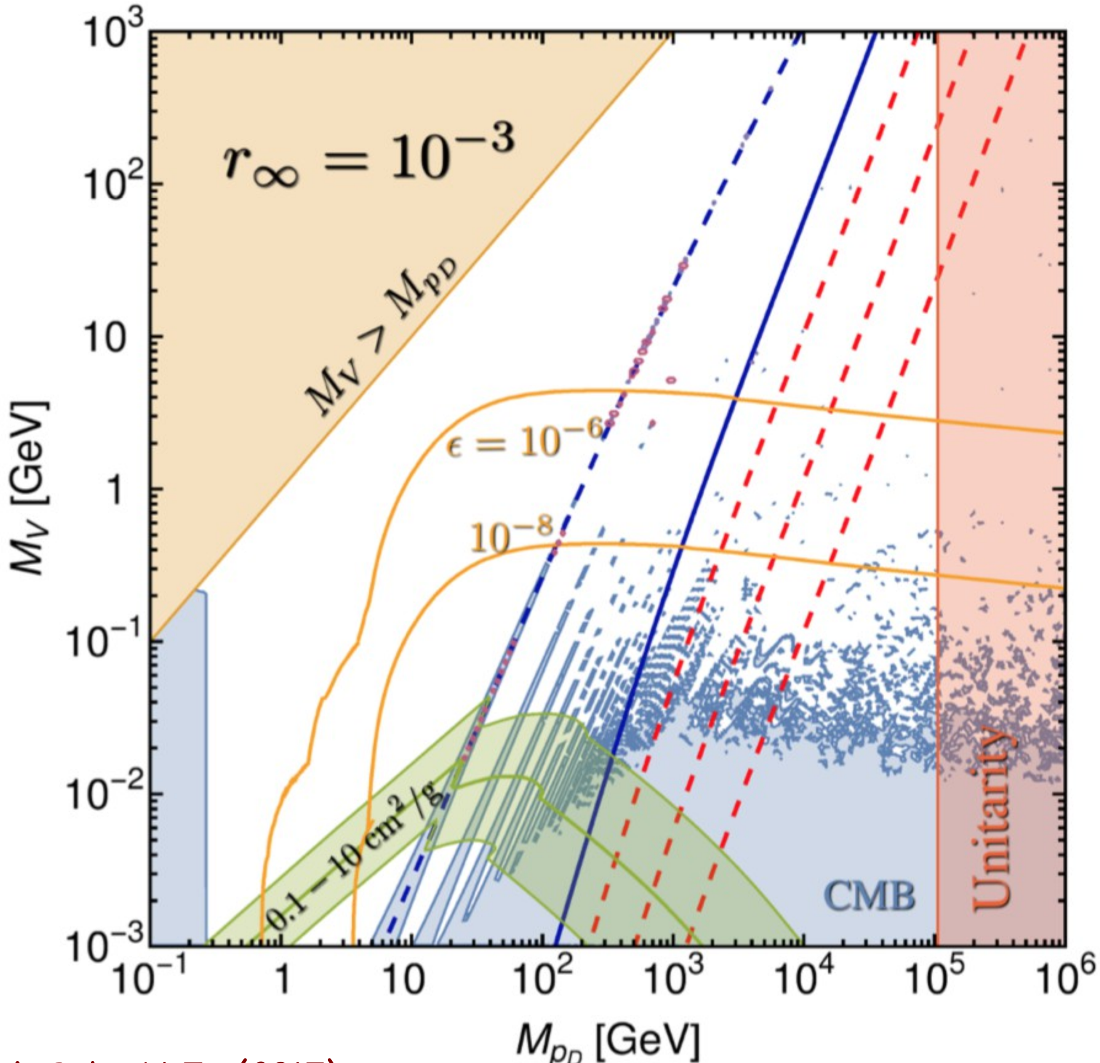

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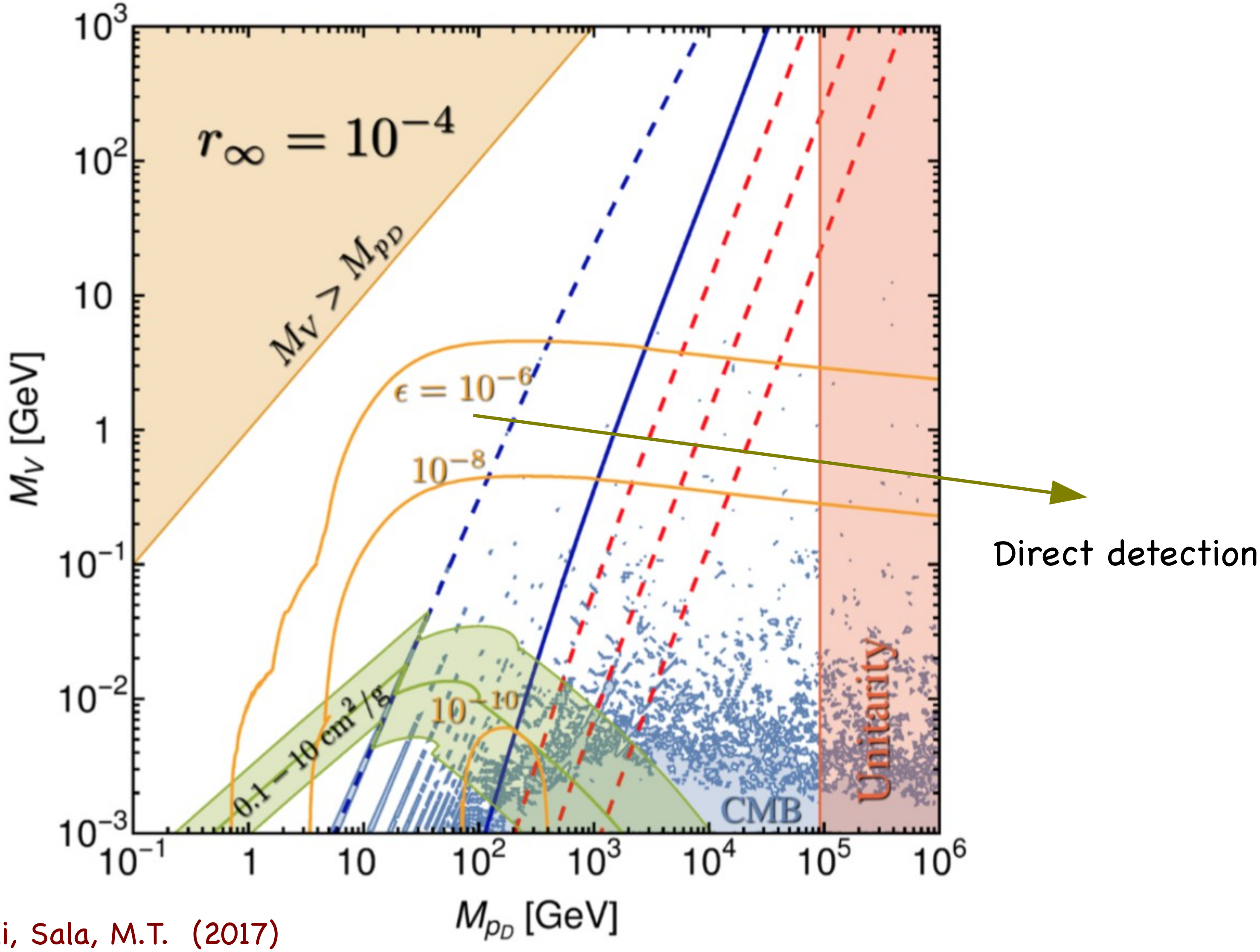

Baldes Cirelli, Panci, Petraki, Sala, M.T. (2017)

Summary

Simple dark sector model: a dark U(1) sector

Symmetric case strongly constrained for light mediators

Asymmetric dark matter scenario :

- viable option for self interacting DM

  Probes: direct detection and - for not too large asymmetries - even indirect detection

- dark sector can be complex: multicomponent

  Need to include formation of dark atoms

THANKS