**Dark Universe working group, IRN**

# Groupement de Priorités Scientifiques (GPS) on Dark Matter


**Coordinators**

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Kallia Petraki (LPTHE)
Vincent Poireau (LAPP)

**Direction**

Marco Cirelli (LPTHE), Emmanuel Moulin (IRFU/DPhP)


Durham, 05 September 2018

# GPS participants

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- Julien Billard
- Mathieu Boudaud
- Marco Cirelli
- Pierre Fayet
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- Andreas Goudelis
- Julia Harz
- Lucien Heurtier
- Cyril Hugonie
- Nazila Mahmoudi
- Julien Masbou
- Dimitri Misiak
- Emmanuel Moulin
- Emmanuel Nezri
- Karl Nordstrom
- Eric Nuss
- Kallia Petraki
- Tilman Plehn
- Vincent Poireau
- Peter Reimitz
- Michel Tytgat

# Discussion plan

- 09:30 – 10:30 Indirect detection of multi-TeV DM: annihilation and radiative level transitions
- 10:30 – 11:00 Break
- 11:00 – 12:00 Long-lived mediators at direct detection experiments
- 12:00 – 12:30 Free-form discussion

# Indirect detection of multi-TeV DM

## Long-range interactions – motivation

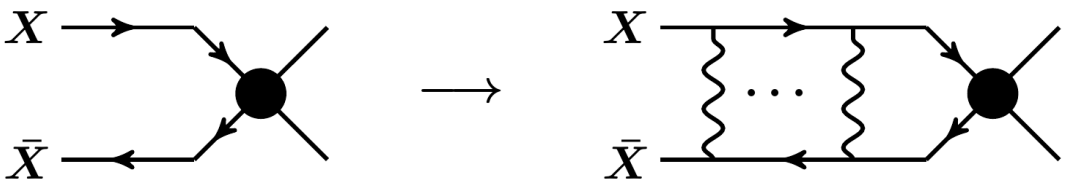
$$m_{\text{mediator}} \lesssim \alpha\, m_{\text{DM}}$$

- WIMPs (≡ particles coupled to EW interactions): $\alpha_W\, m_W \sim$ few TeV.
- Self-interacting DM, motivated by observed galactic structure:
  $\sigma_{\text{elastic}} v_{\text{rel}} \sim$ barn / GeV ⇒ light mediators (and not too heavy DM).
- Hidden-sector DM (≡ particles with non-SM interactions):
  $m_{\text{mediator}} \ll m_{\text{DM}}$ as generic as $m_{\text{mediator}} \gtrsim m_{\text{DM}}$ .
- For very heavy DM, any significant interaction is mediated by particles with $m_{\text{mediator}} \ll m_{\text{DM}}$ and/or large α.
- *S*-matrix unitarity: $\sigma_{\text{inelastic}}\, v_{\text{rel}} \leq 4\pi\,(2J+1) / (m_{\text{DM}}^2\, v_{\text{rel}})$ [*J*: partial wave]
  Thermal-relic DM requires sufficient annihilation ⇒ $m_{\text{DM}} \lesssim$ few × 100 TeV.
  Parametric dependance of $\sigma_{\text{inelastic}}$ implies that the unitarity limit can be realised or approached only by interactions that manifest as long range.

# Indirect detection of multi-TeV DM

## Long-range interactions – what happens

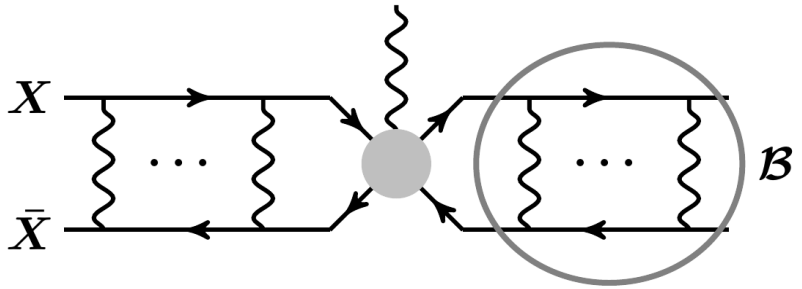
### The Sommerfeld effect




enhances/suppresses cross-sections at low velocities
for attractive/repulsive interactions

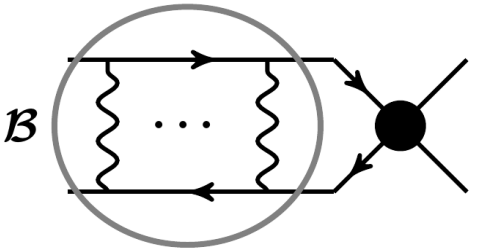
### Bound-state formation

$X + \bar{X} \to \mathcal{B}(X\bar{X}) + \text{radiation}$




note: also affected by Sommerfeld

### $\mathcal{B}(X\bar{X})$ decays via the same diagrams $X + \bar{X}$ annihilate



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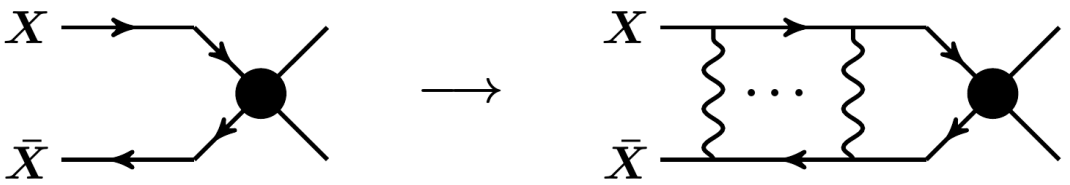


enhances/suppresses cross-sections at low velocities
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High energy ID signals
$E \sim m_{DM}$

Low energy ID signals
$E \sim m_{DM} \alpha^2 / 4$

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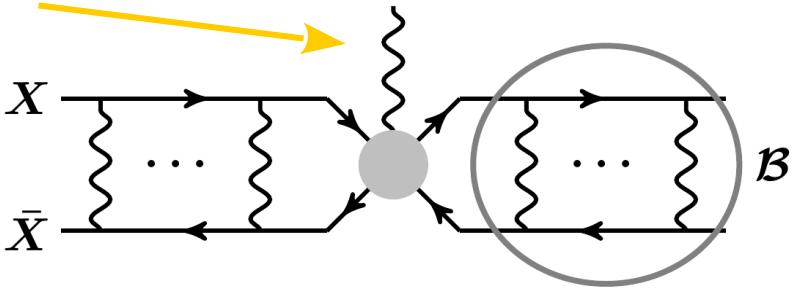


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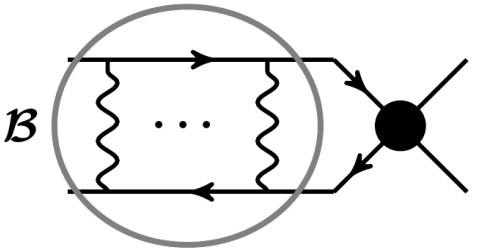


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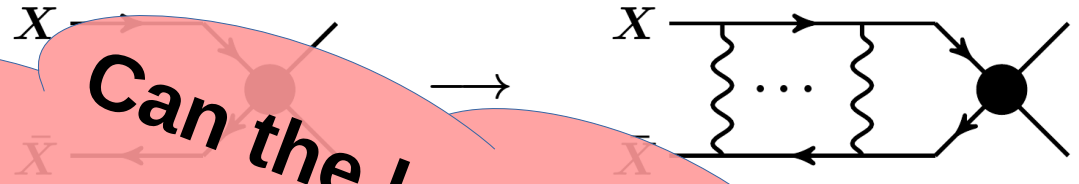


enhances/suppresses cross sections at low velocities for attractive/repulsive interactions

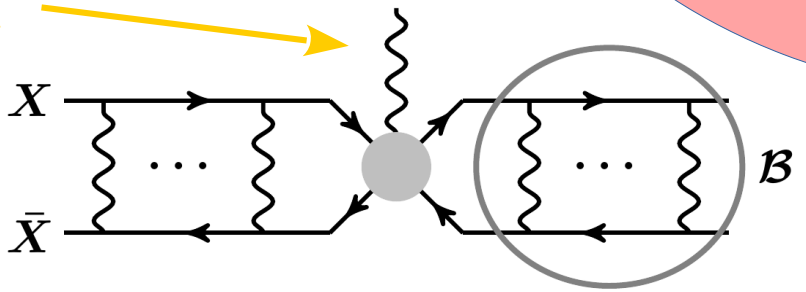
Can the lower energy radiation improve our ability to probe heavy DM?

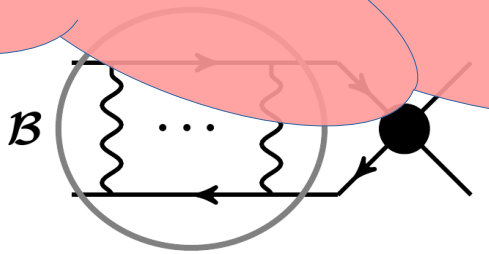
High energy ID signals
$E \sim m_{DM}$

Low energy ID signals
$E \sim m_{DM} \alpha^2 / 4$

Bound-state formation $X + \bar{X} \to \mathcal{B}(X\bar{X}) + \text{radiation}$

$\mathcal{B}(X\bar{X})$ decays to the same channels as $X + \bar{X}$ annihilate

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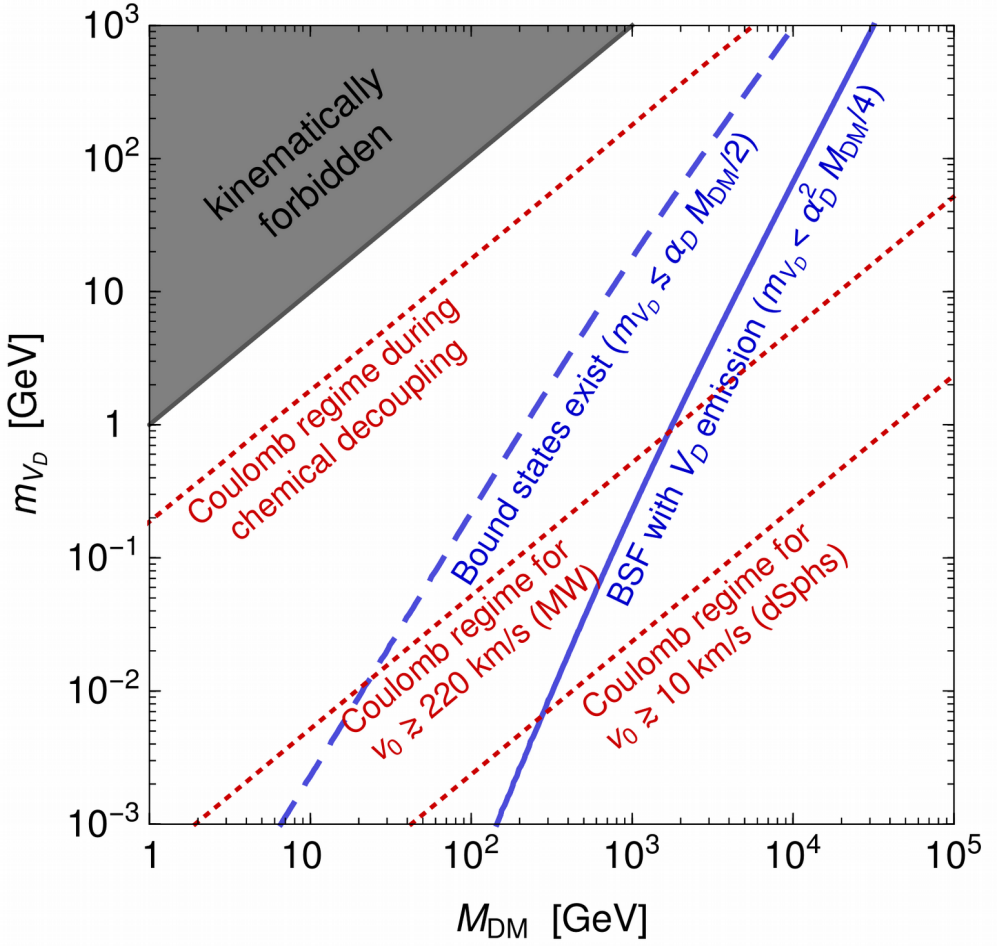
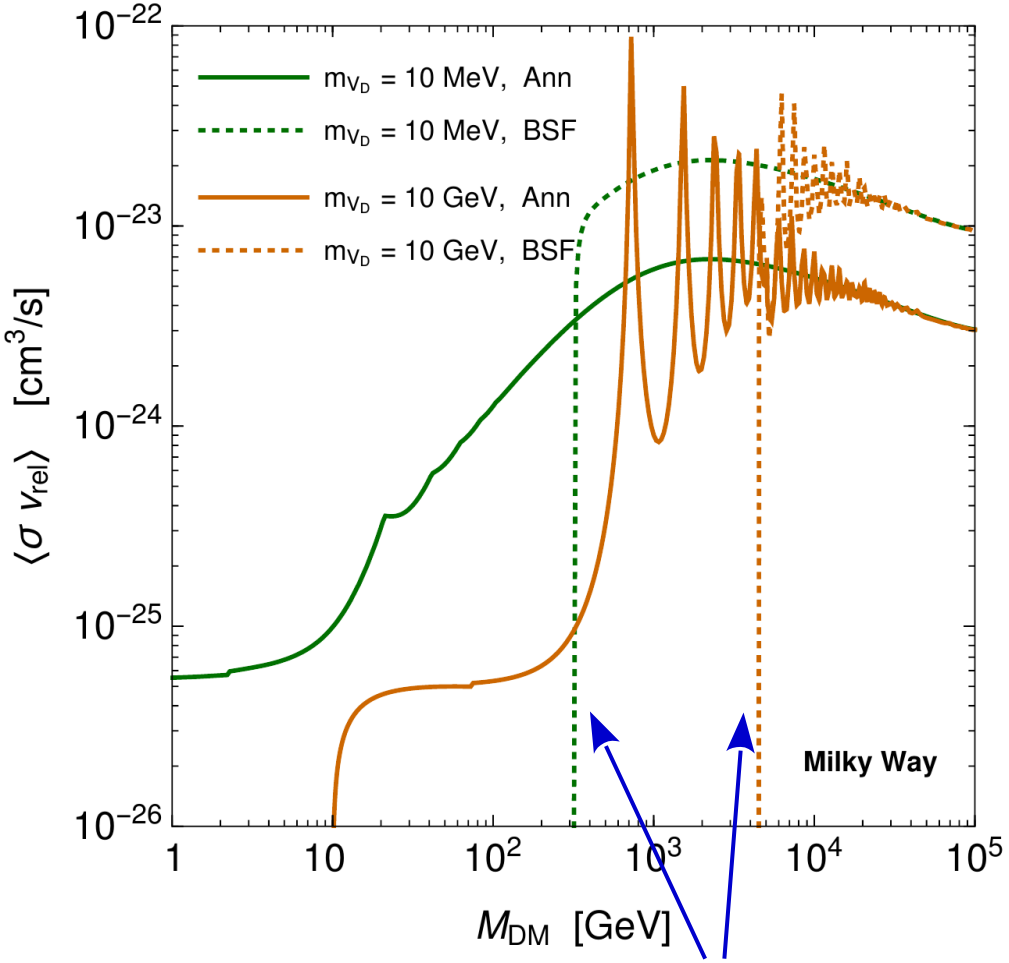
# Indirect detection of multi-TeV DM

## parameter space of a dark U(1) sector




**BSF cross-section produces both high-energy ($E \sim M_{DM}$) and low-energy ($E \sim M_{DM}\, \alpha^2/4$) signals**

From Cirelli et al 1612.07295

# Indirect detection of multi-TeV DM
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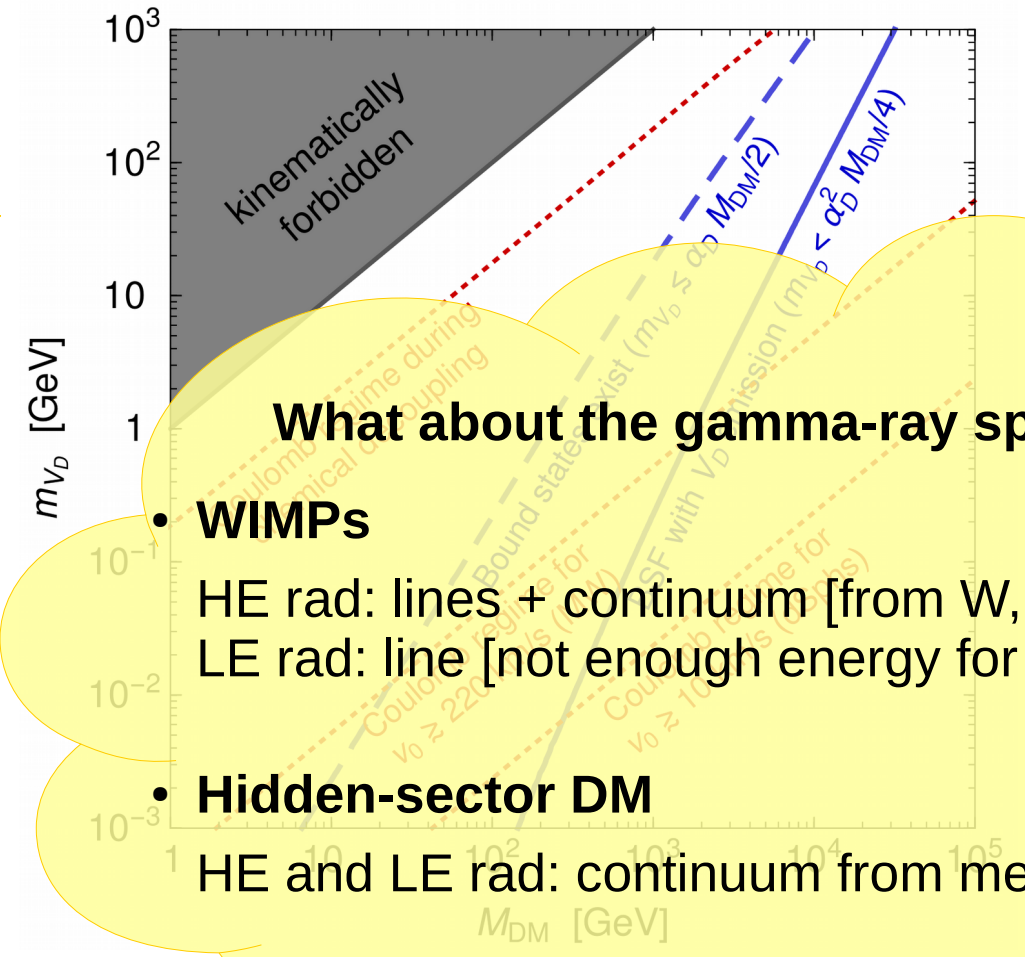


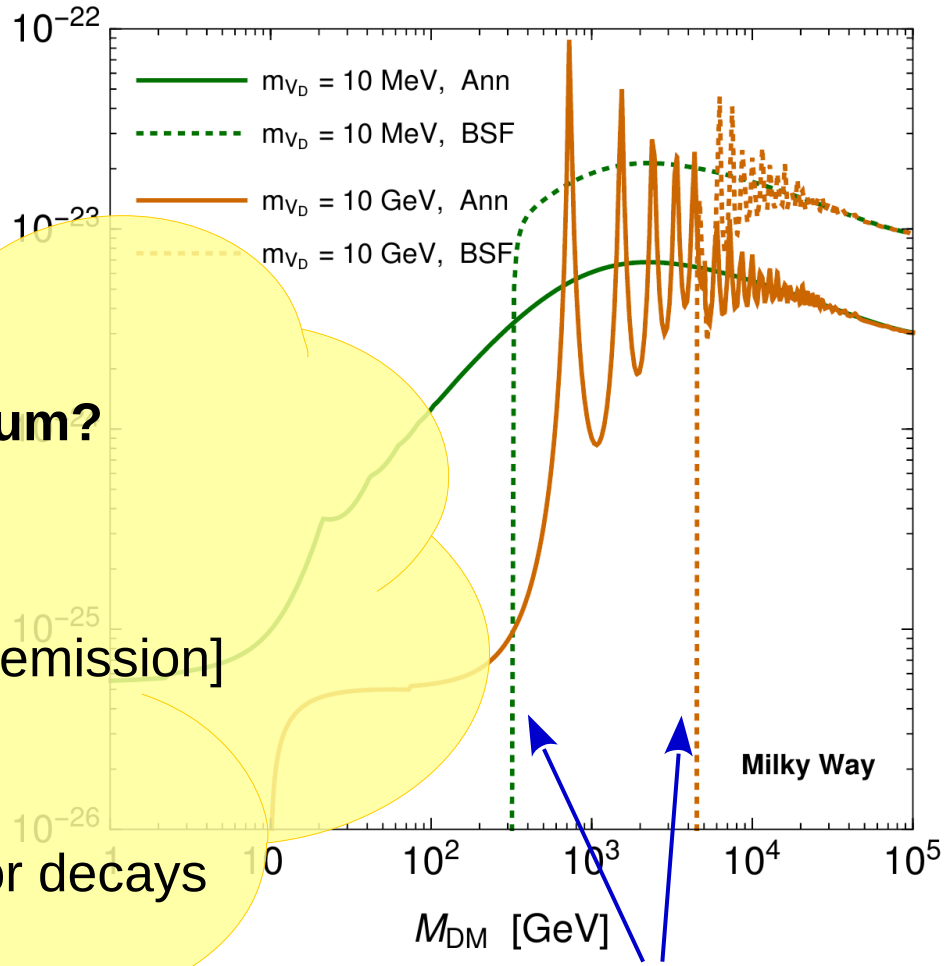


**What about the gamma-ray spectrum?**

- **WIMPs**

  HE rad: lines + continuum [from W, Z]
  LE rad: line [not enough energy for W,Z emission]

- **Hidden-sector DM**

  HE and LE rad: continuum from mediator decays

**BSF cross-section produces both high-energy ($E \sim M_{DM}$) and low-energy ($E \sim M_{DM}\, \alpha^2/4$) signals**

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# Indirect detection of multi-TeV DM

## What can we do?

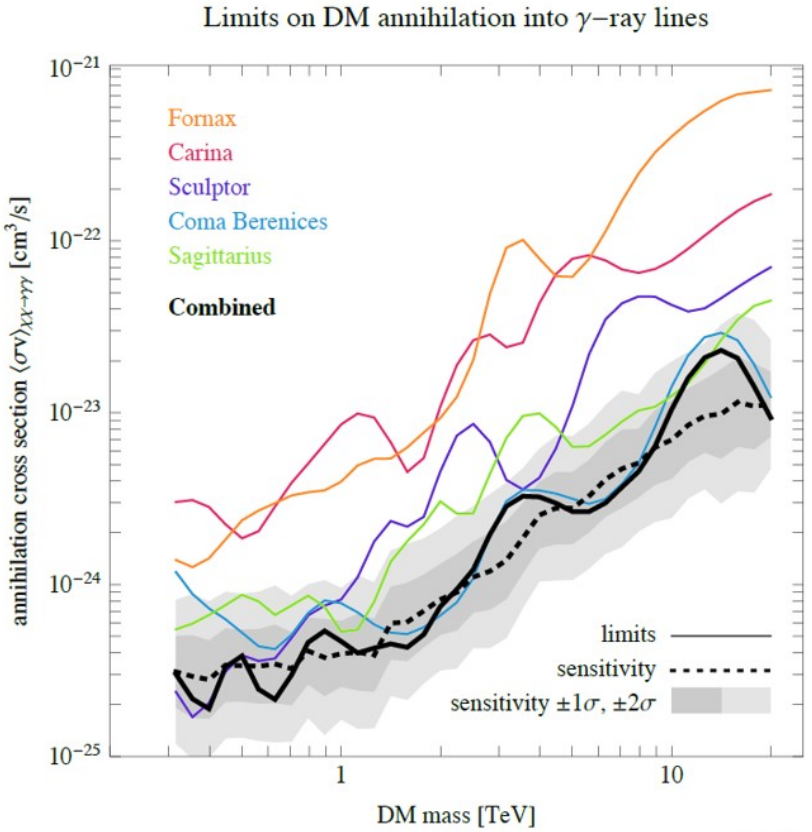
Model-independent study of
the experimental sensitivity to the
combined low-energy + high-energy radiation

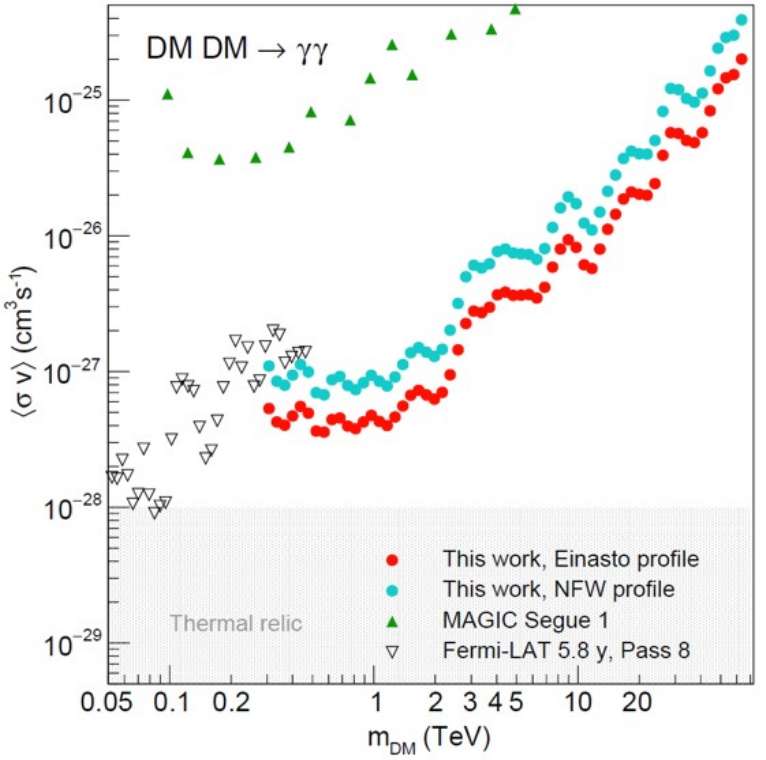
**Parametrisation**

| DM mass | Total cross-section of processes producing high-energy signals | Total cross-section of processes producing low-energy signals | Ratio of low and high energies |
|---|---|---|---|
| $m_{\mathrm{DM}}$ | $\sigma_{\mathrm{HE}} v_{\mathrm{rel}}$ | $\sigma_{\mathrm{LE}} v_{\mathrm{rel}}$ | $\epsilon \equiv E_{\mathrm{LE}}/E_{\mathrm{HE}}$ |

# Existing constraints on gamma-ray lines

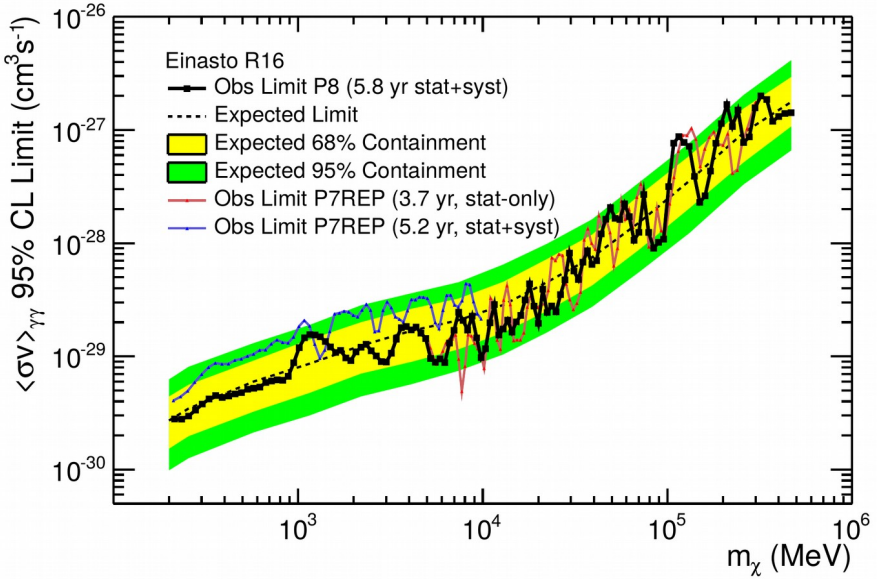
HESS, Dwarfs




HESS, Milky Way

Fermi pass 8 (Milky Way)
1506:00013



# Indirect detection of multi-TeV DM

## Some immediate tasks

- Recast existing constraints (which assume $E \sim m_{DM}$) for low energy radiation
  - For line emission [WIMPs]: $(\sigma v_{rel})_{max}\ [m_{DM}] \rightarrow (\sigma v_{rel})_{max}\ (m_{DM}/E)^2$
  - For continuous spectrum [hidden sector DM]: detailed analysis required
- Predictions for annihilation and BSF in SU(N) theories
  - Analytical formulas for very heavy DM [unbroken SU(N) approximation]
  - Numerical code when above approximation breaks down [perhaps separate project]
- Literature search: Constraints from CMB