# Dark Matter with $t$-channel mediators

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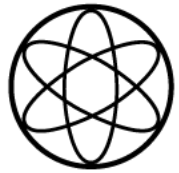

MIAPP mini-workshop on dark mediators, February 11, 2015

# Dark Matter with $t$-channel mediators: overview

**Simplified models** for Dark Matter and a $t$-channel mediator:

| | **Dark Matter** | **Mediator** | **Interaction** |
|---|---|---|---|
| (I) | Majorana fermion $\chi$ | Scalar $\eta$ | $y_{\text{yuk}}\,\chi\eta f_{\text{SM}}$ |
| (II) | Dirac fermion $\chi$ | Scalar $\eta$ | $y_{\text{yuk}}\,\chi\eta f_{\text{SM}}$ |
| (III) | Real scalar $\phi$ | Vector-like fermion $\psi$ | $y_{\text{yuk}}\,\phi\psi f_{\text{SM}}$ |

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Only three parameters $m_{\text{DM}}$, $m_{\text{mediator}}$, $y_{\text{yuk}}$ control

a) relic density
b) direct detection
c) indirect detection
d) collider phenomenology

$\Rightarrow$

- highly testable models
- ideal for complementarity studies

# Model (I): Majorana fermion Dark Matter

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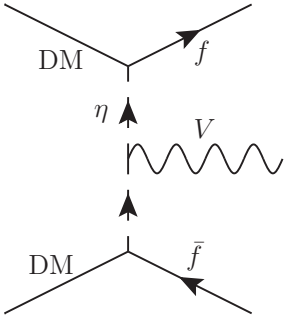
$\hookrightarrow$ see also the talk tomorrow by Mathias Garny

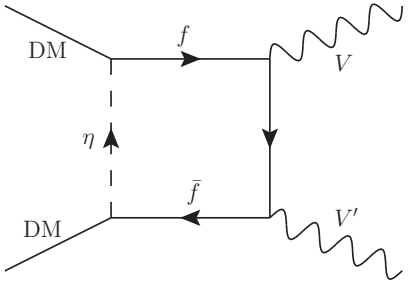
Important feature of this model: $\chi\chi \to f\bar{f}$ is **velocity or helicity suppressed**

$\hookrightarrow \langle\sigma v\rangle_{\chi\chi\to f\bar{f}} = (\dots)\cdot v^2 + (\dots)\cdot (m_f/m_\chi)^2$

$\hookrightarrow$ dominant annihilation channels for $v_\chi \simeq 0$ include higher-order effects:




virtual internal bremsstrahlung




one-loop annihilation into gauge bosons

$\hookrightarrow$ keeping the mediator in the calculation plays a crucial role!

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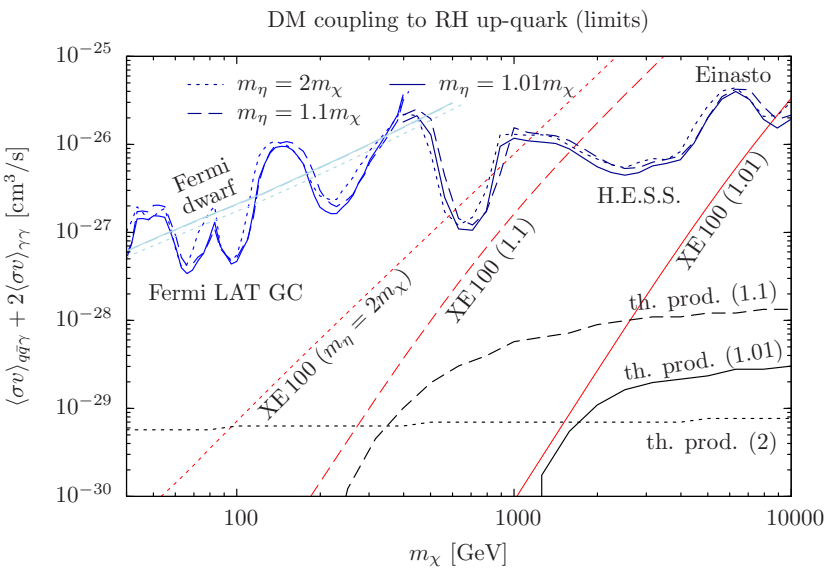
Possible **search strategies** for this model:

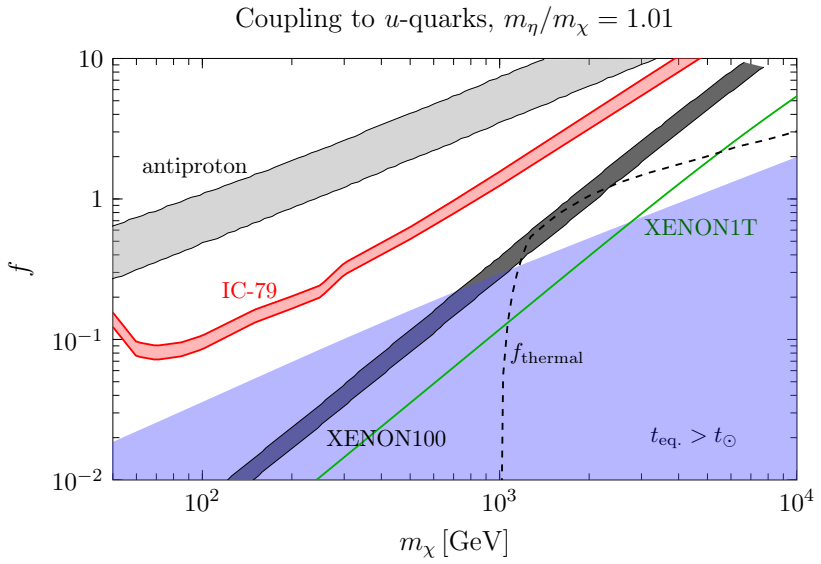
[Garny,Ibarra,Pato,Vogl 1306.6342]




$\chi\chi \to f\bar{f}\gamma$

- Search for sharp gamma-ray features with Fermi LAT, H.E.S.S.

[Ibarra,Totzauer,SW 1311.1418]




$\chi\chi \to f\bar{f}Z$

- Search for $\nu$'s from the Sun with IceCube

# Model (II): Dirac fermion Dark Matter

| | **Dark Matter** | **Mediator** | **Interaction** |
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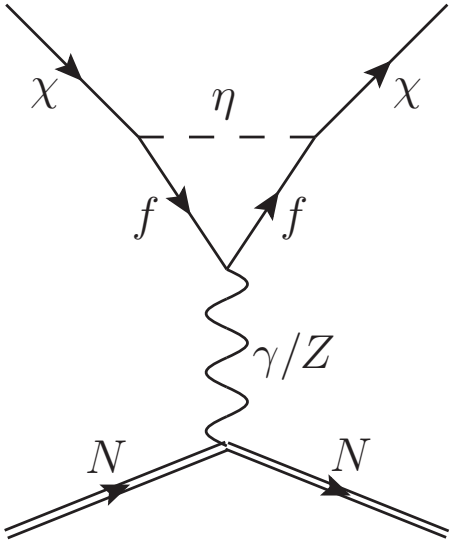
Strong limits from **direct detection** induced by one-loop diagrams:




- One-loop induced vector-vector coupling $\bar{\chi}\gamma^{\mu}\chi\bar{N}\gamma_{\mu}N$, even if DM is leptophilic or couples only to e.g. $b$-quarks
- Again, keeping explicitly the mediator $\eta$ in the calculation is crucial!

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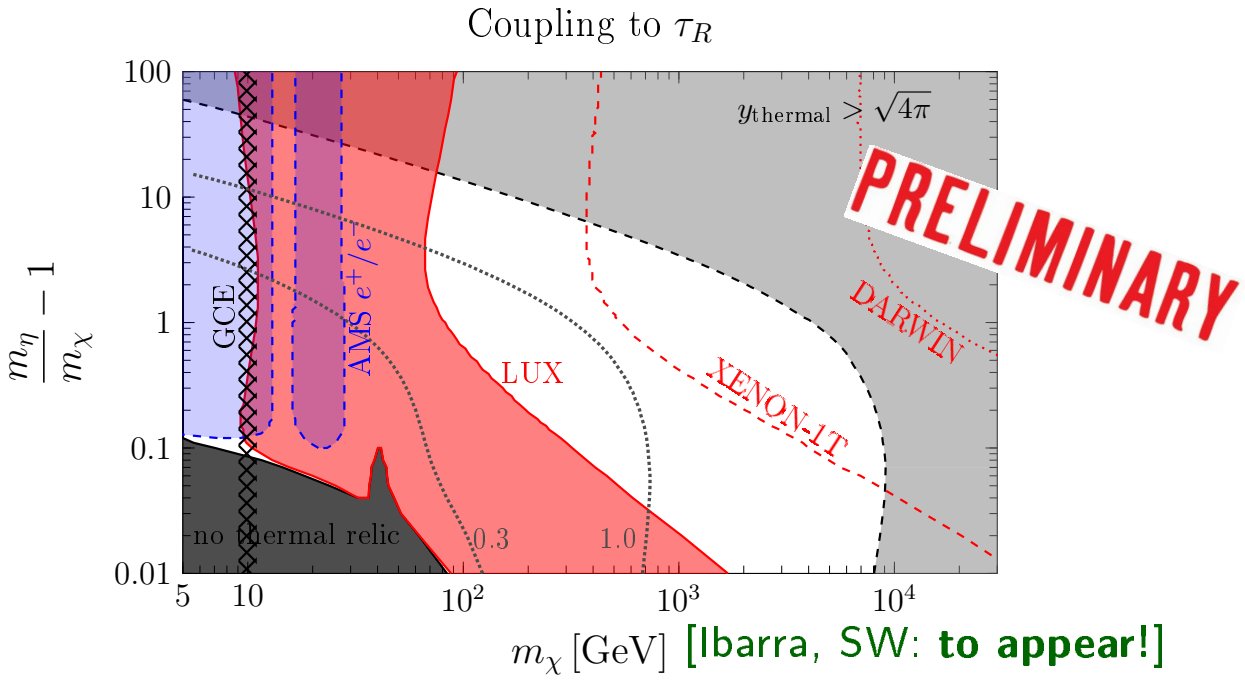

[Ibarra, SW: **to appear!**]

- Even for leptophilic scenarios, LUX already probes DM masses up to $\sim$ TeV
- The next-generation direct detection experiments will be able to probe practically the whole thermal perturbative parameter space!

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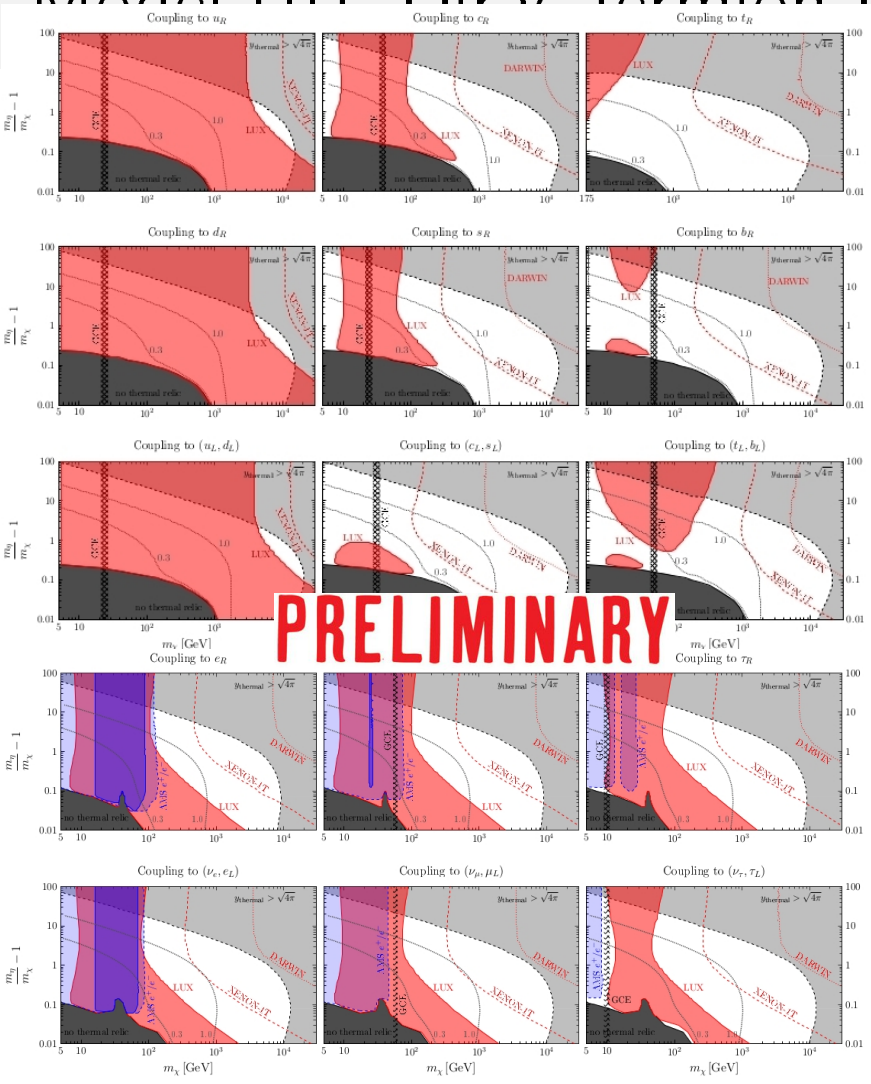
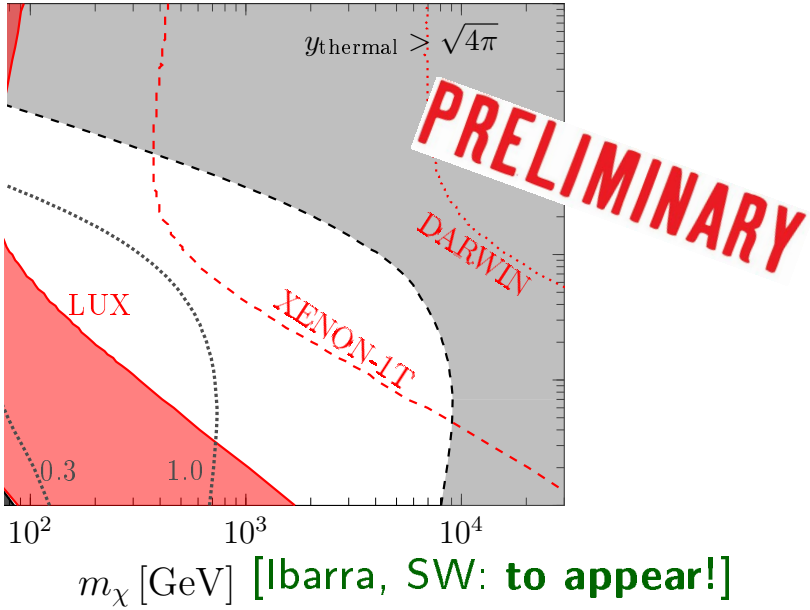



Coupling to $\tau_R$

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# Model (III): Real scalar Dark Matter

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| (III) | Real scalar $\phi$ | Vector-like fermion $\psi$ | $y_{\text{yuk}}\,\phi\psi f_{\text{SM}}$ |

This model has a unique feature: $\phi\phi \to f\bar{f}$ is **d-wave** suppressed ($\propto v^4$)

$\hookrightarrow$ large thermal value of $y_{\text{yuk}}$

$\hookrightarrow$ large indirect detection signals via $\phi\phi \to f\bar{f}\gamma$ and $\phi\phi \to \gamma\gamma$

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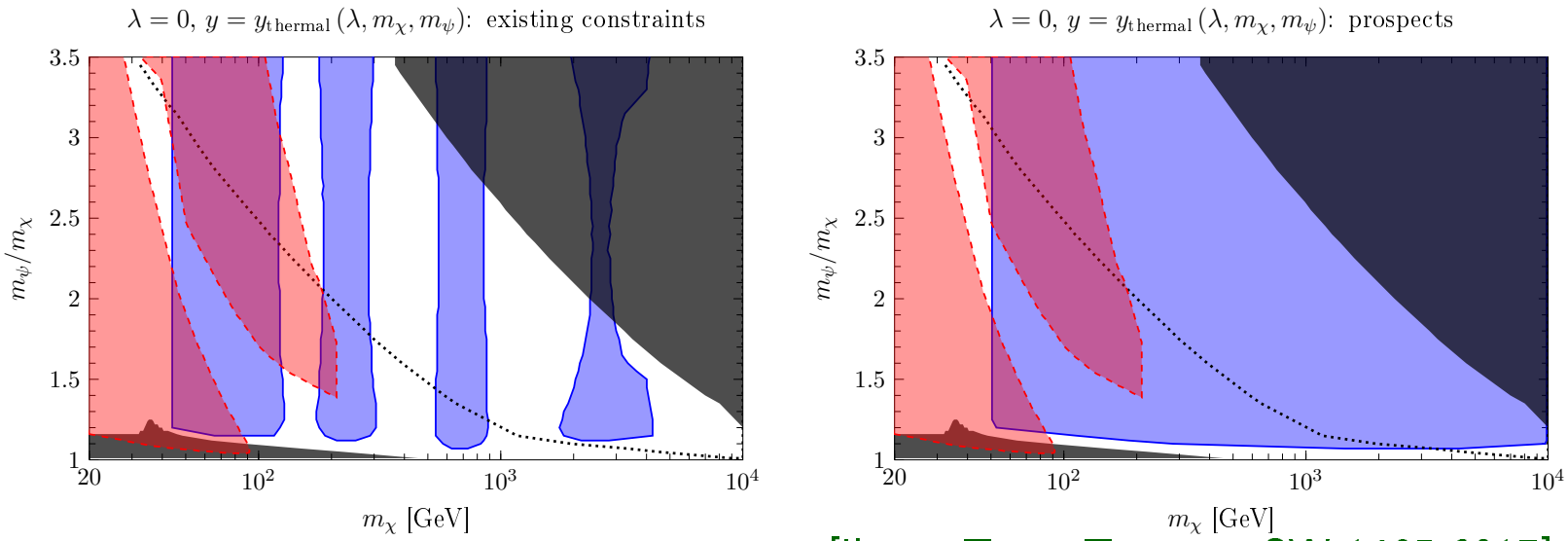



[Ibarra,Toma,Totzauer,SW 1405.6917]

- Searches for **spectral features** with FERMI and H.E.S.S. already constrain a significant part of the thermal parameter space (left plot, blue regions)
- CTA (right plot, blue region) will cover the whole thermal perturbative parameter space!

# Conclusions

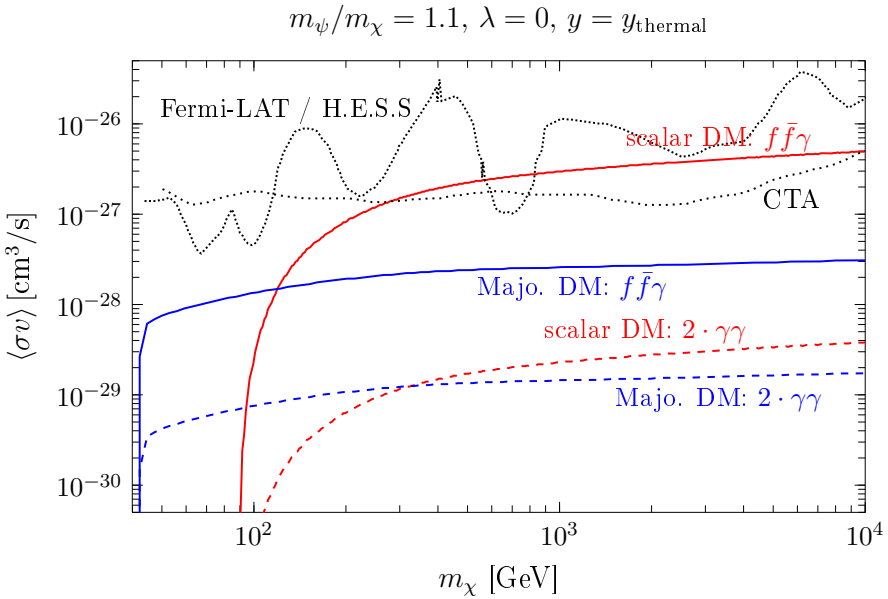
Simplified models of Dark Matter with a $t$-channel mediator have an interesting and rich phenomenology:

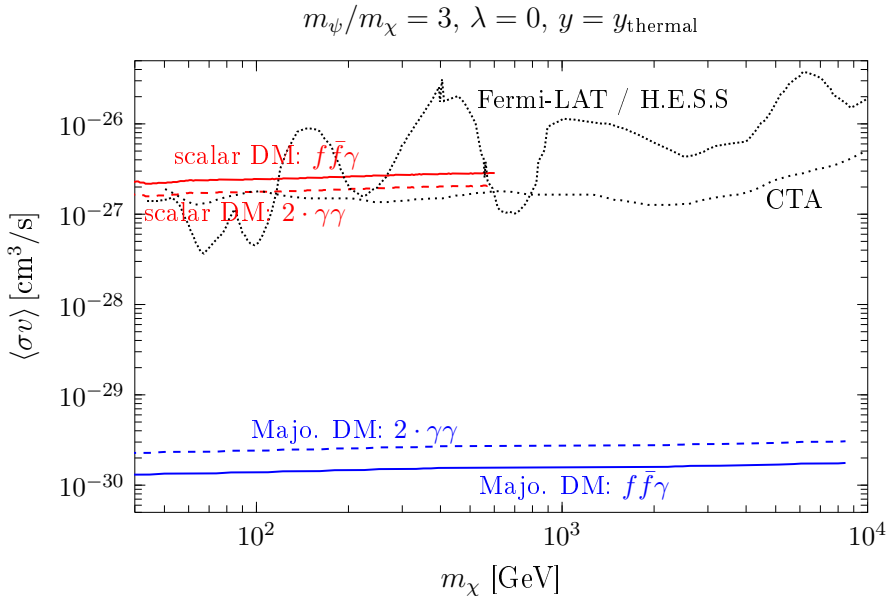
- Order-of-magnitude differences in direct and indirect detection rates, depending on nature of DM and mediator
- In practically all cases, higher-order effects can be crucial:
  $2 \to 3$ annihilations, one-loop scattering diagrams, ...
- Complementarity between
  direct & indirect searches for DM $\leftrightarrow$ collider searches for the mediator itself

In many of these models, upcoming experiments like Xenon-1T or CTA will be able to probe significant parts of the remaining thermal perturbative parameter space

# Backup slides

# Real scalar Dark Matter vs. Majorana Dark Matter



# Real scalar Dark Matter: effect of coupling to the SM Higgs