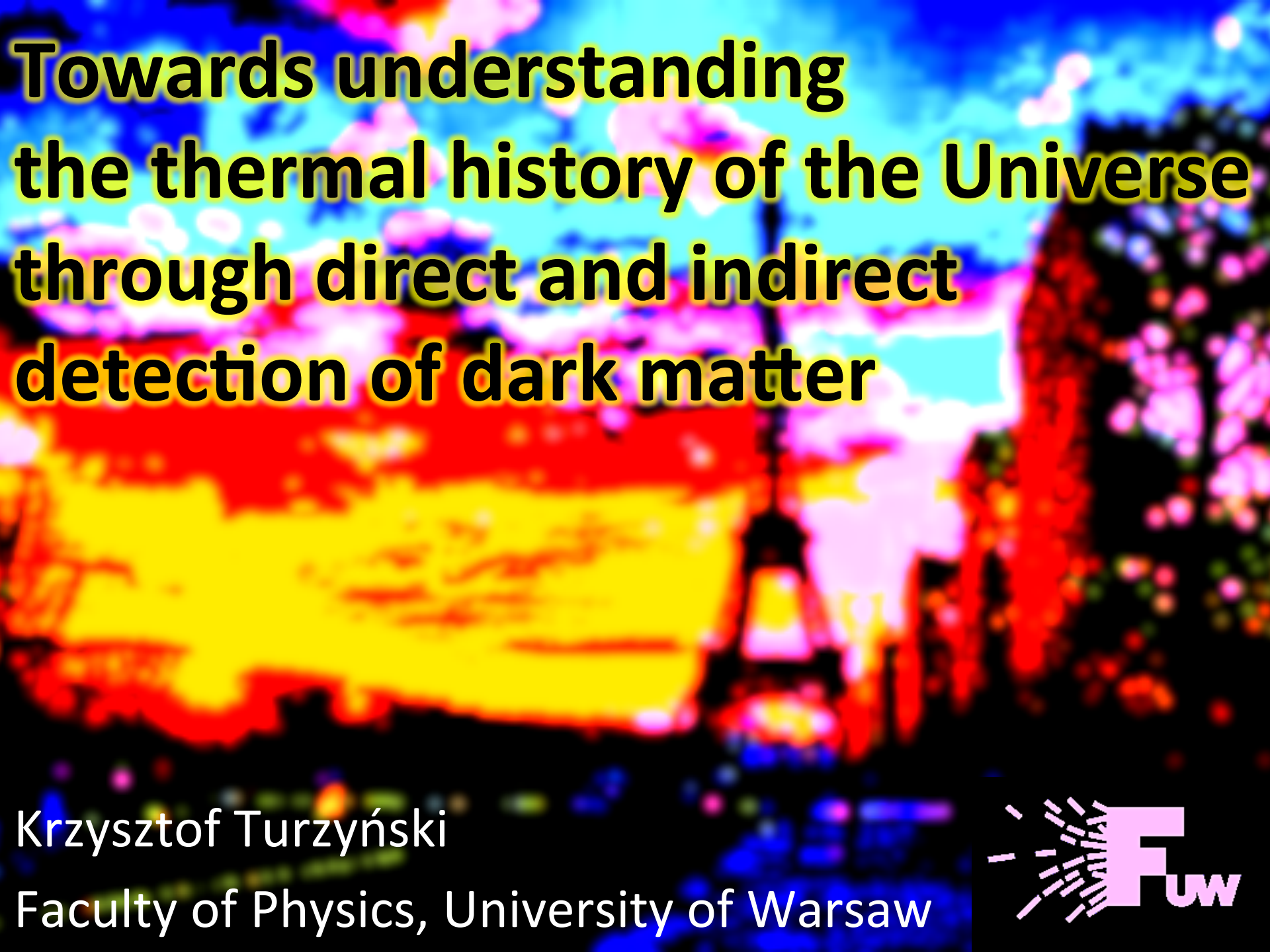
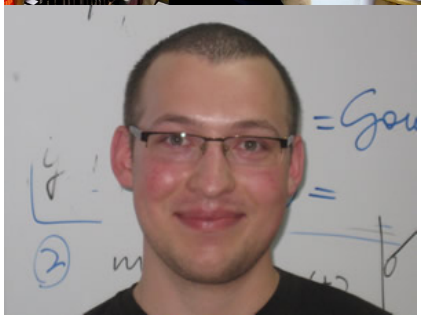
Towards understanding the thermal history of the Universe through direct and indirect detection of dark matter



Krzysztof Turzyński
Faculty of Physics, University of Warsaw

arXiv:1703.00841

Leszek Roszkowski



Sebastian Trojanowski

National Centre for Nuclear Research Świerk

University of California Irvine

support

Ministry of Science and Higher Education
Republic of Poland

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The hunt for dark matter

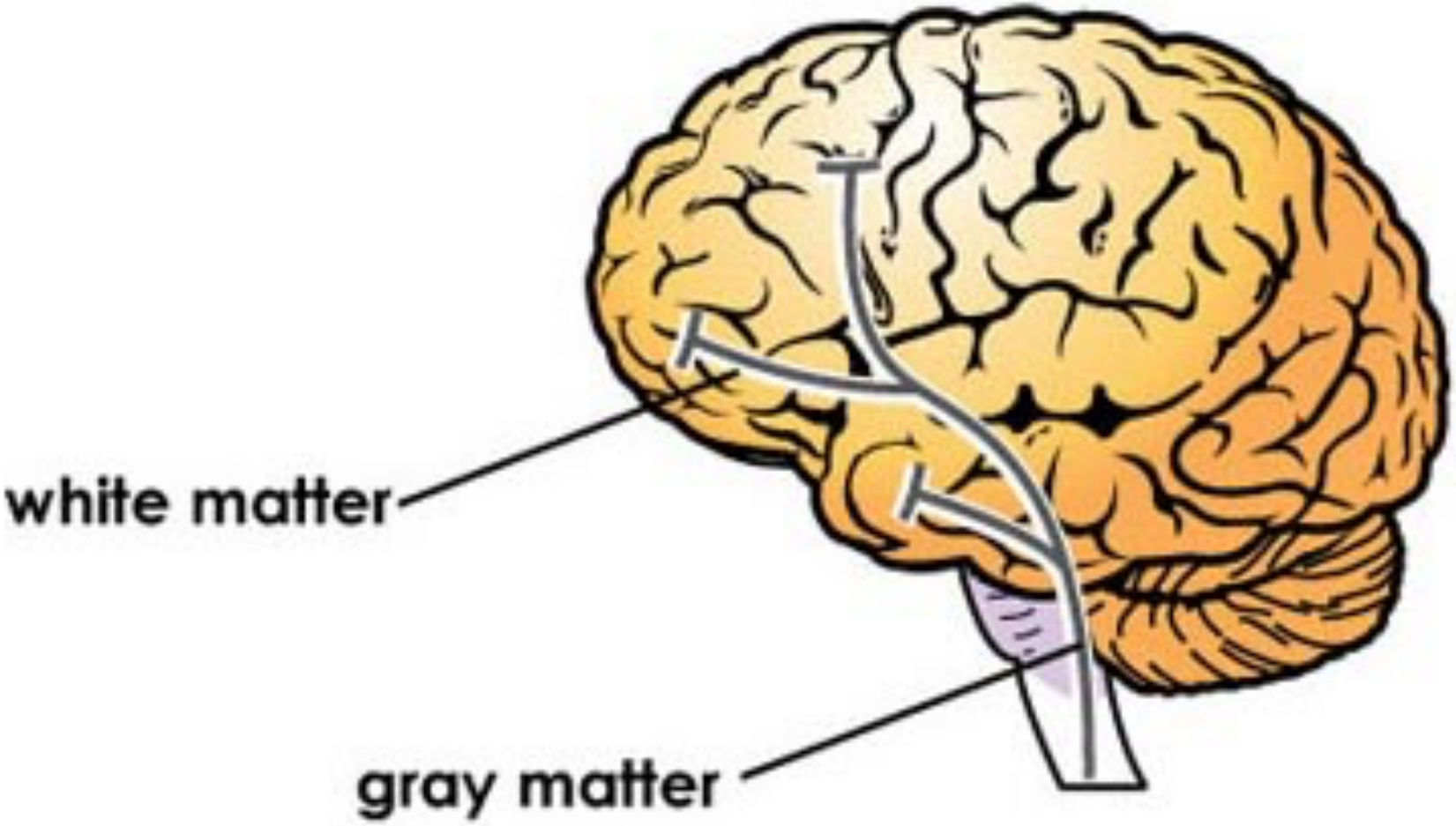
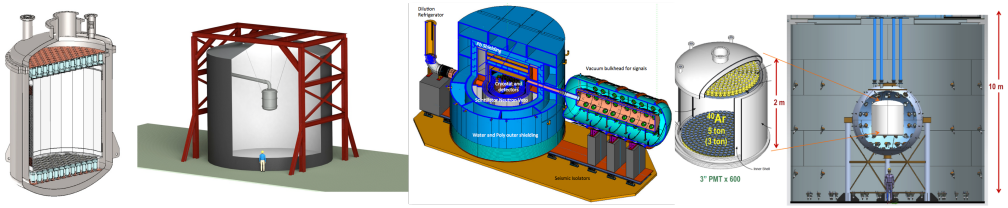


image source: howstuffworks.com

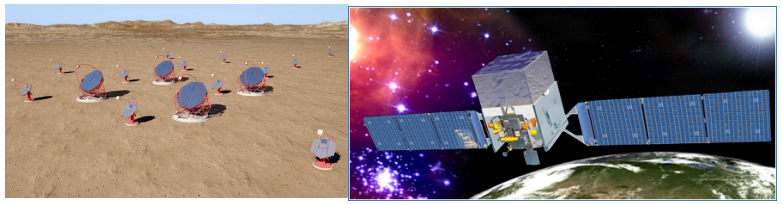
The hunt for dark matter

DIRECT DETECTION



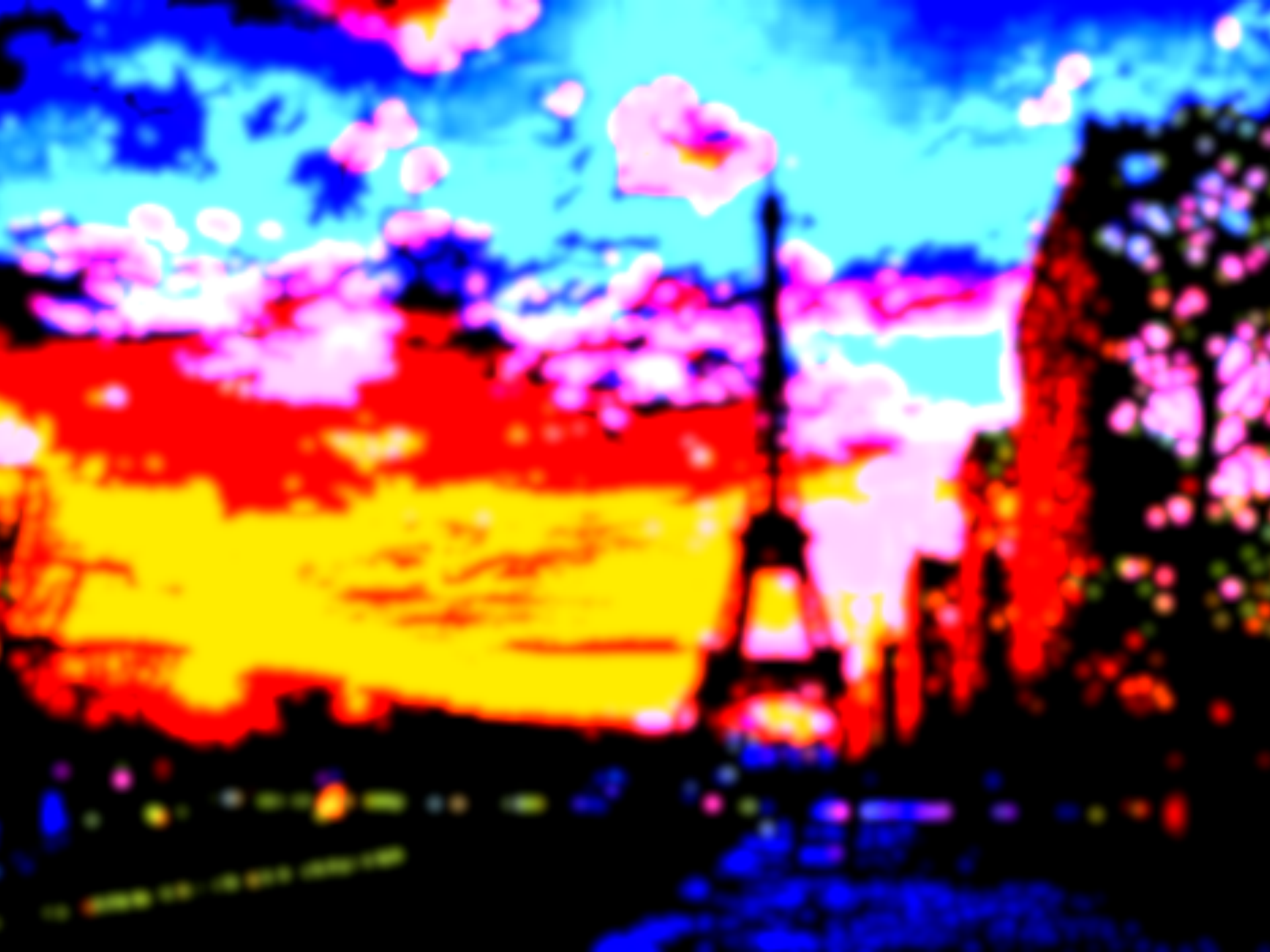
Xenon1T DarkSide-G2 Super-CDMS

INDIRECT DETECTION

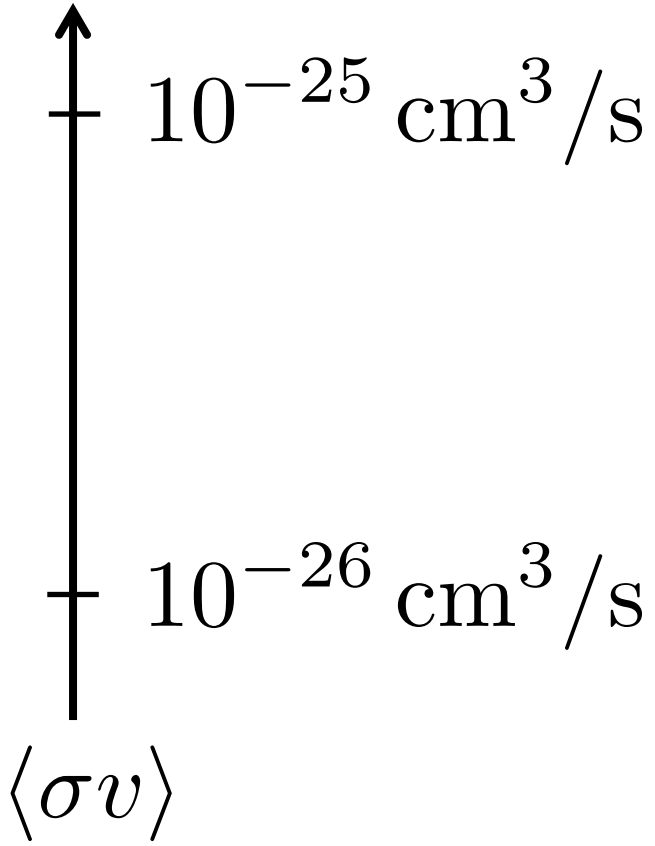


Cherenkov Telescope Array

Fermi-LAT



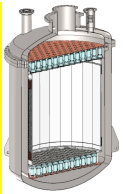
When DM signal is seen by **direct** and/or **indirect detection** (in foreseeable future), can we say if **DM has thermal origin**?

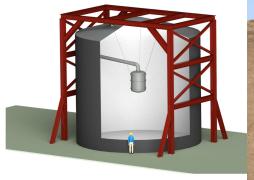


Reconstruction – methodology

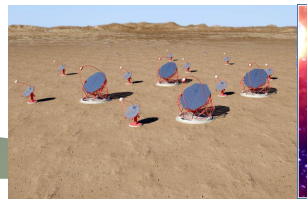
Roszkowski et al., arXiv:1603.06519

Generate mock signal for the benchmark model (above sensitivities)

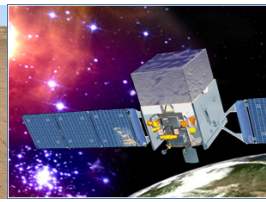




Xenon1T
(730 day•ton)



Cherenkov
Telescope Array
(500 h)



Fermi-LAT
(46 dSph
in 15 years)

Scan over model and nuisance parameters, calculate likelihood

MultiNest
MicrOMEGAs
Fermi Science Tools…

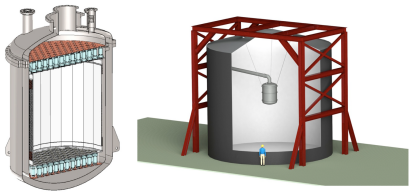
Find 2D
95% confidence regions
$\Delta\chi^2 = 5.99$

$$\Delta\chi^2 = -2\ln(\mathcal{L}/\mathcal{L}_{\max})$$

Reconstruction – methodology

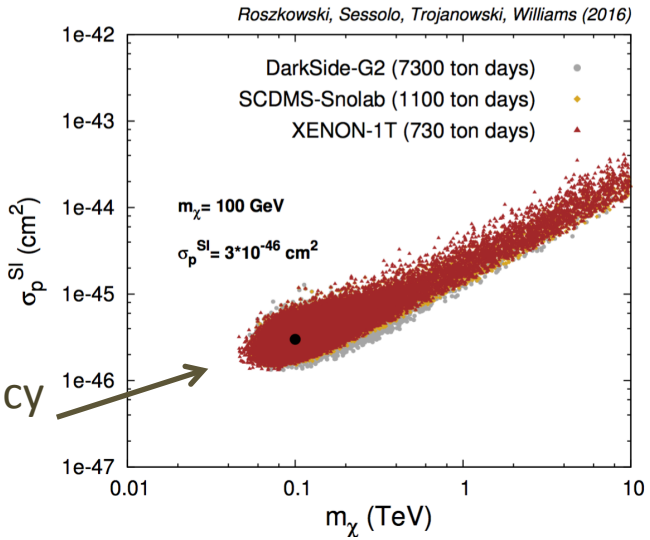
Reconstruction of DM properties based on expected positive signal from **direct** and **indirect detection** experiments.

Roszkowski, Sessolo, Trojanowski, Williams, 1603.06519

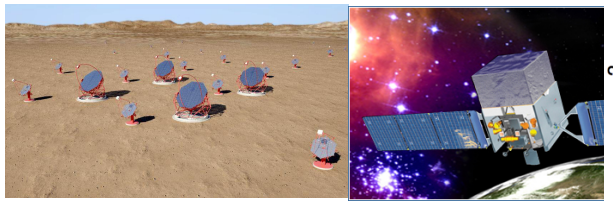


Xenon1T
(730 day•ton)

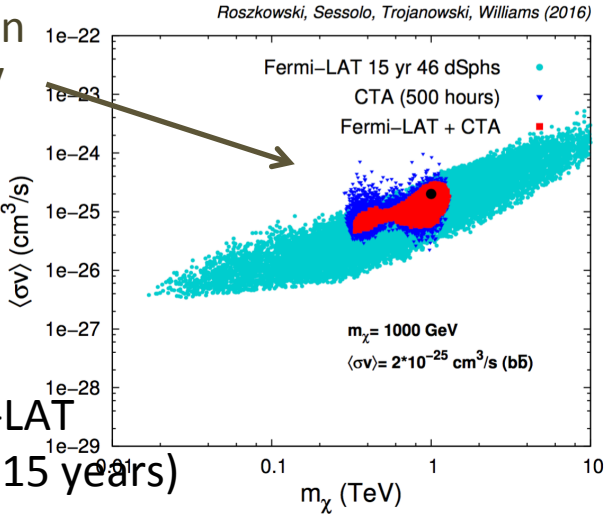
reconstruction degeneracy for DM mass **> 100 GeV**



fairly good reconstruction for DM mass > 1000 GeV



Cherenkov Telescope Array
(500 h)



Fermi-LAT
(46 dSph in 15 years)

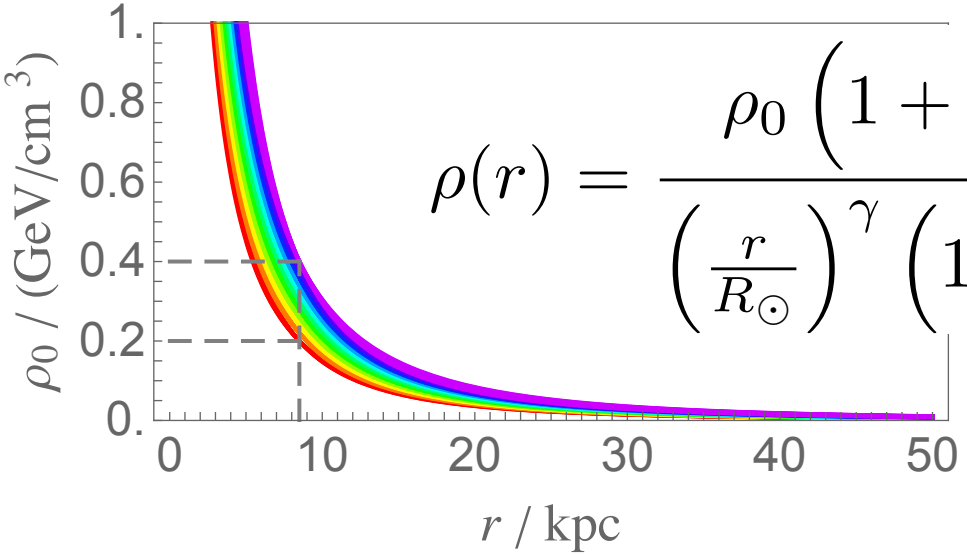
Reconstruction – astro uncertainties

DIRECT DETECTION

$$\frac{\mathrm{d}R}{\mathrm{d}E_r} = \frac{\sigma_p^{\mathrm{SI}}}{m_\chi} \cdot \frac{A^2}{2\mu_p^2} F^2(E_r)\, \rho_0 \int_{|\mathbf{v}|>v_{\mathrm{min}}}^{|\mathbf{v}|<v_{\mathrm{esc}}} \mathrm{d}^3 v\, \frac{f(\mathbf{v}, v_0)}{|\mathbf{v}|}$$

INDIRECT DETECTION

different final states



$$\rho(r) = \frac{\rho_0 \left(1 + \frac{R_\odot}{r_s}\right)^{3-\gamma}}{\left(\frac{r}{R_\odot}\right)^{\gamma} \left(1 + \frac{r}{r_s}\right)^{3-\gamma}}$$

v_0	circular velocity	$220 \pm 20\,\mathrm{km/s}$
v_{esc}	escape velocity	$544 \pm 40\,\mathrm{km/s}$
ρ_0	local DM density	$0.3 \pm 0.1\,\mathrm{GeV/cm^3}$
γ	NFW slope	1.20 ± 0.15

Gaussian priors

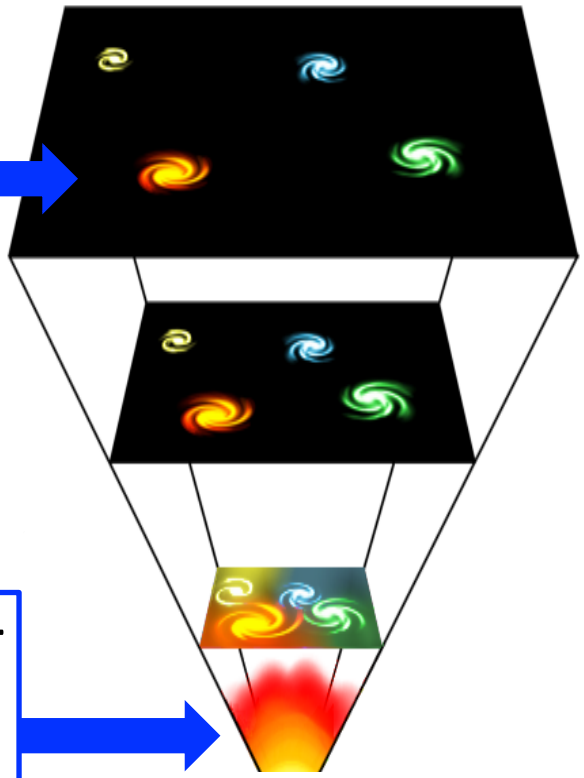
Reconstruction – cosmo uncertainties

DIRECT DETECTION

$\sigma_p^{\rm SI}$

INDIRECT DETECTION

$\langle \sigma v \rangle_0$



FREEZE-OUT

$\langle \sigma v \rangle_{\rm f.o.}$

`Model-independent' approach

$$\langle \sigma v \rangle = \frac{\alpha_s}{m_\chi^2} + \frac{\alpha_p T}{m_\chi^3}$$

$$\Downarrow$$

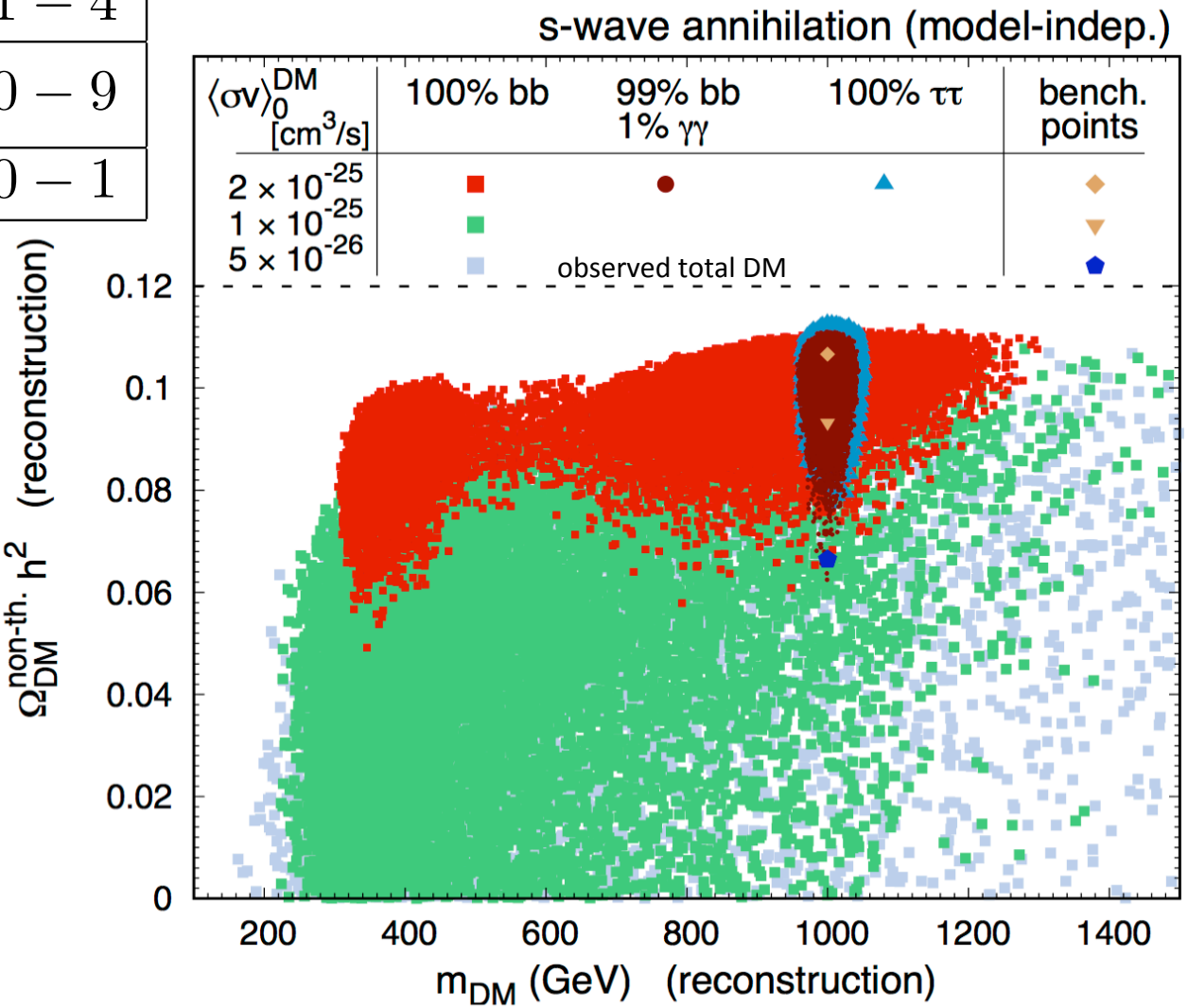
$$\langle \sigma v \rangle_{\rm f.o} \geq \langle \sigma v \rangle_0$$

$$\Omega_\chi h^2 = \Omega_\chi^{\rm f.o.} h^2 + \Omega_\chi^{\rm non\text{-}th} h^2$$

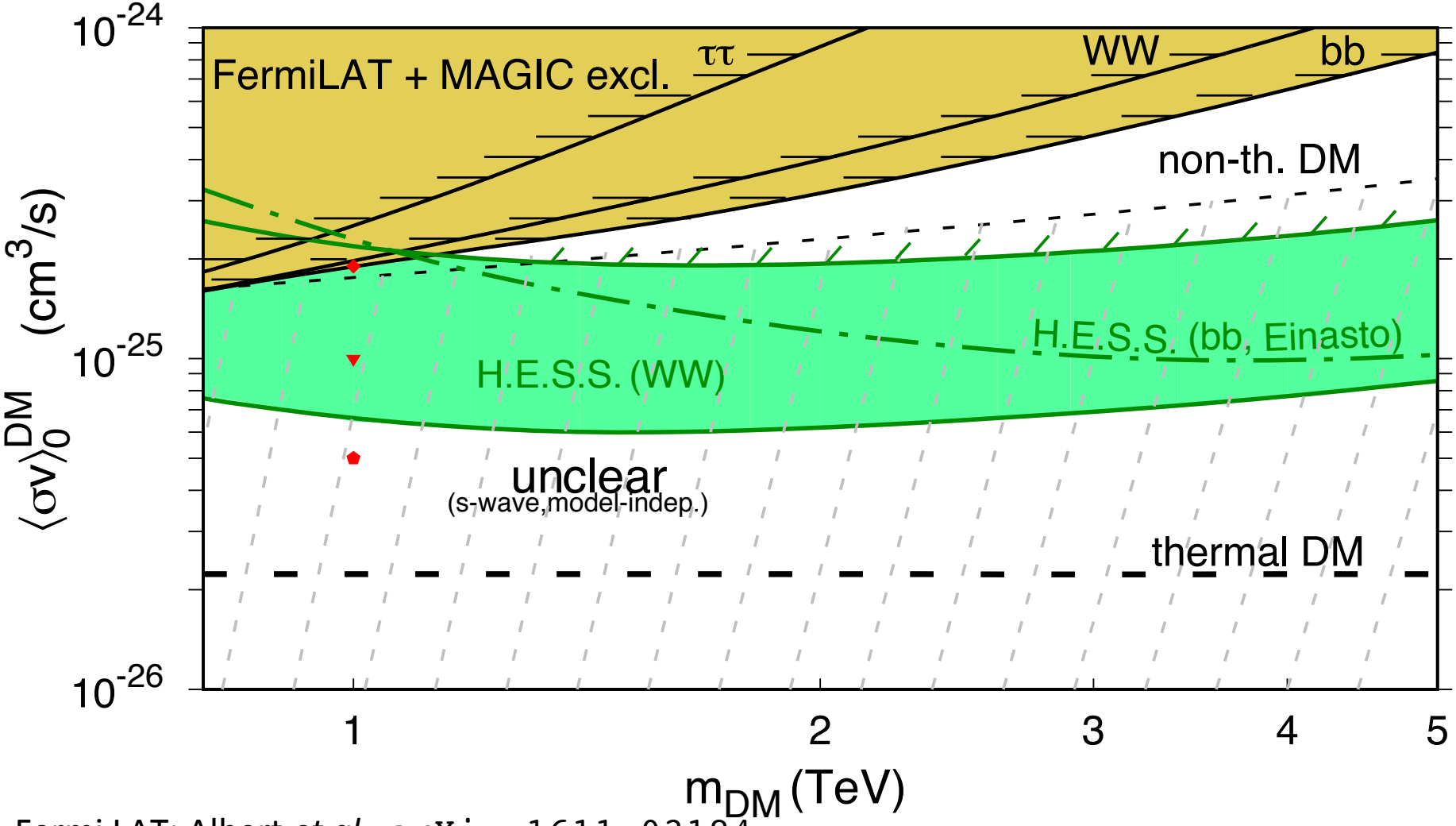
Reconstruction – `model-independent'

$\log_{10}\left(\frac{m_\chi}{\mathrm{GeV}}\right)$	$1-4$
$\log_{10}\left(\frac{\langle\sigma v\rangle_0}{10^{-30}\mathrm{cm}^3/\mathrm{s}}\right)$	$0-9$
$\mathrm{BR}_{b\bar{b},W^+W^-,\tau^+\tau^-,hh}$	$0-1$

$\langle\sigma v\rangle_0$ and σ_p^{SI} unrelated



Reconstruction – `model-independent'



Fermi LAT: Albert *et al.*, arXiv:1611.03184
MAGIC: Ahnen *et al.*, arXiv:1601.06590
H.E.S.S.: Abdallah *et al.*, arXiv:1607.08142

Reconstruction – EFT of DM

$$\mathcal{L}_{\text{eff}} = \frac{1}{\Lambda^2}(\bar{\chi}\gamma^\mu\chi)\left(c_Q\bar{Q}_L\gamma_\mu Q_L + c_U\bar{U}_R\gamma_\mu U_R + c_D\bar{D}_R\gamma_\mu D_R + c_L\bar{L}_L\gamma_\mu L_L + c_E\bar{E}_R\gamma_\mu E_R\right)$$

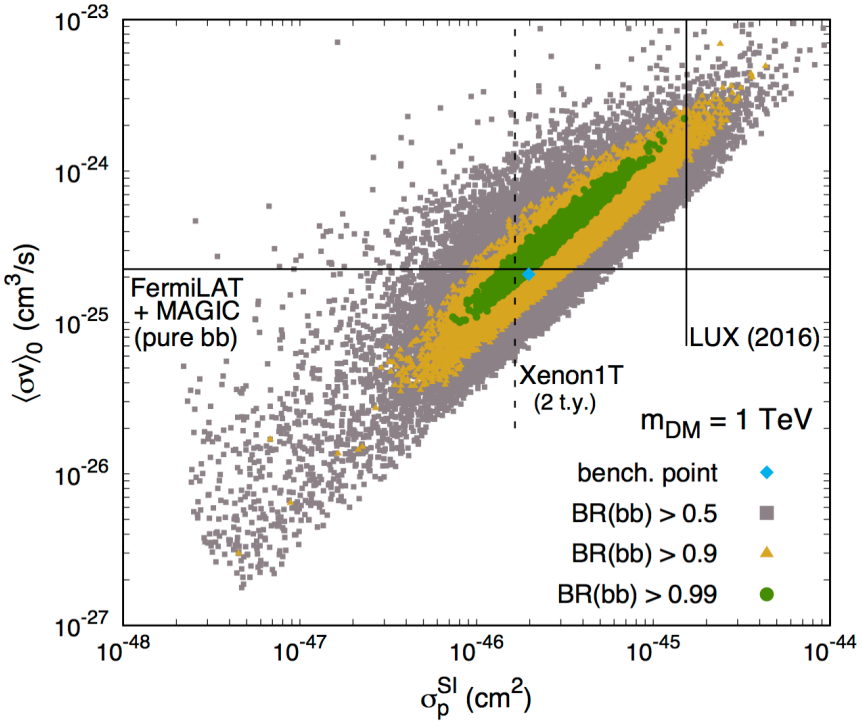
$\log_{10}(m_\chi/\text{GeV})$	$1-3.7$
Λ/TeV	$1-10$
$c_{Q,U,D,L,E}$	$0-1$

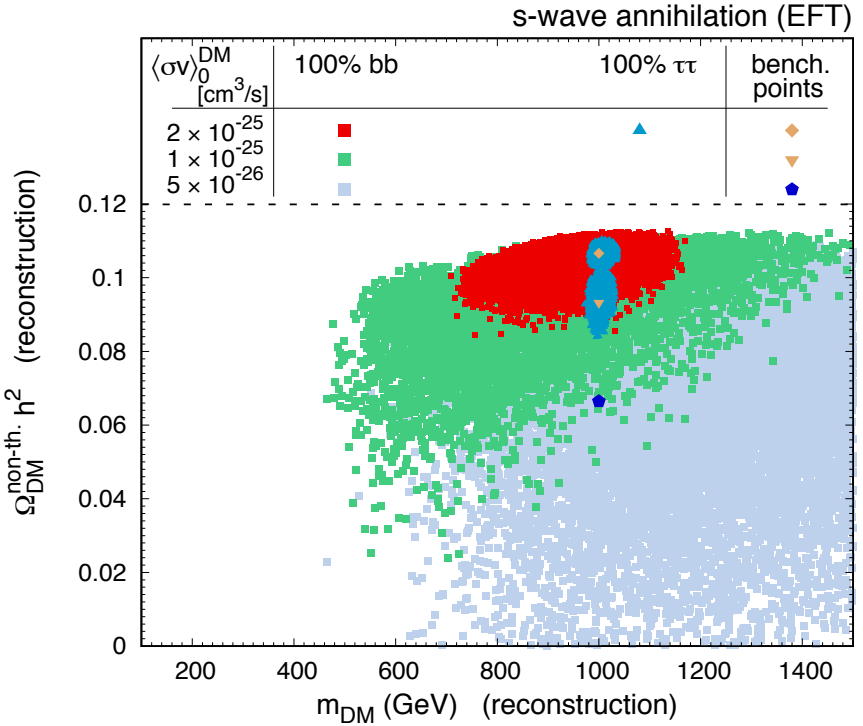
DM tree-level couplings only to 3rd generation fermions

DM coupling to 1st generation through RG running

D'Eramo *et al.*, arXiv:1411.3342, 1605.04917

$b\bar{b}, \tau^+\tau^-$ annihilation channels





Conclusions

If DM is seen in Xenon1T, Fermi-LAT and CTA:

- `model independent' DM
  almost impossible to exclude thermal-only DM despite large annihilation cross section
- EFT of DM
  better reconstruction, but still **difficult to exclude thermal-only DM**

Read on…

- `model independent' DM
  with Sommerfeld enhancement or multi-component DM – **impossible to exclude thermal-only DM**
- wino or higgsino DM
  very good reconstruction, disproving thermal-only DM possible
  nonthermal DM component form gravitino or axino decays: determination of reheating temperature