Celestial bodies as WIMPs detectors

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Based on:

S. Kang, A. Kar, S.S., "*Halo-independent bounds on the non-relativistic effective theory of WIMP-nucleon scattering from direct detection and neutrino observations*", JCAP 03 (2023), 011 (2212.05774)

S. Kang, A. Kar, S.S., "*Halo-independent bounds on Inelastic Dark Matter*", JCAP 11 (2023), 077 (2308.13203)

A. Biswas, A. Kar, H. Kim, S.S., L. Velasco-Sevilla, "*Improved white dwarves constraints on inelastic dark matter and left-right symmetric models*", Phys.Rev.D 106 of (2022) 8, 083012 (2206.06667)

A. Kar, H. Kim, S. P. Kim, S.S., "*WIMP constraints from black hole low--mass X-ray binaries*", *JCAP 03 (2024) 030* (2311.16539)

K. Choi, I. Jeong, S.Kang, A. Kar and S.S., "Sensitivity WIMP bounds on the velocity distribution in the limit of a massless mediator", JCAP 01 (2025) 007 (2408.09658)

2025 CAU-IBS Beyond the Standard Model Workshop
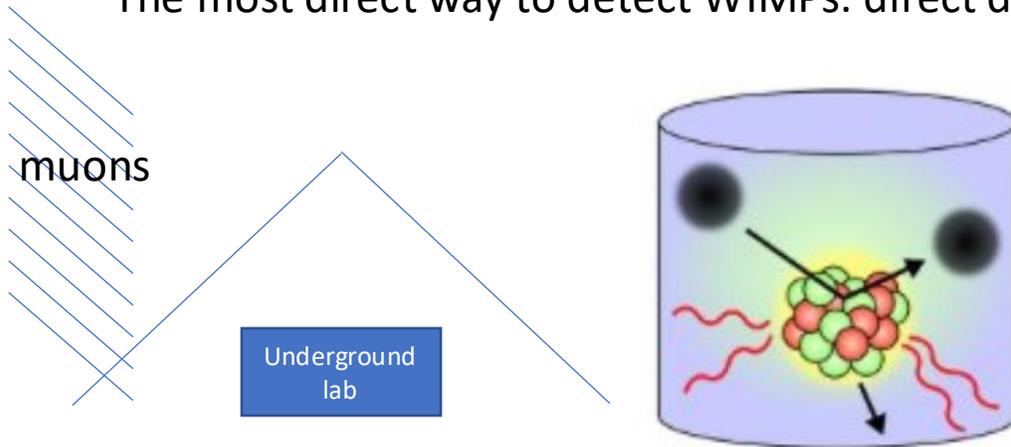
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The visible part of Galaxies (including ours) is strongly believed to be embedded in a halo of invisible Dark Matter particles (the only alternative: modify gravity)

WIMPS (Weakly Interacting Massive Particles) are the most popular Dark Matter candidates (but many other possibilities...):

- few GeV < WIMP mass< few TeV
- No electric charge, no colour
- Weak-type interactions with ordinary matter keep WIMPS in thermal equilibrium in the early Universe and can provide the correct relic abundance through thermal decoupling ("WIMP miracle")
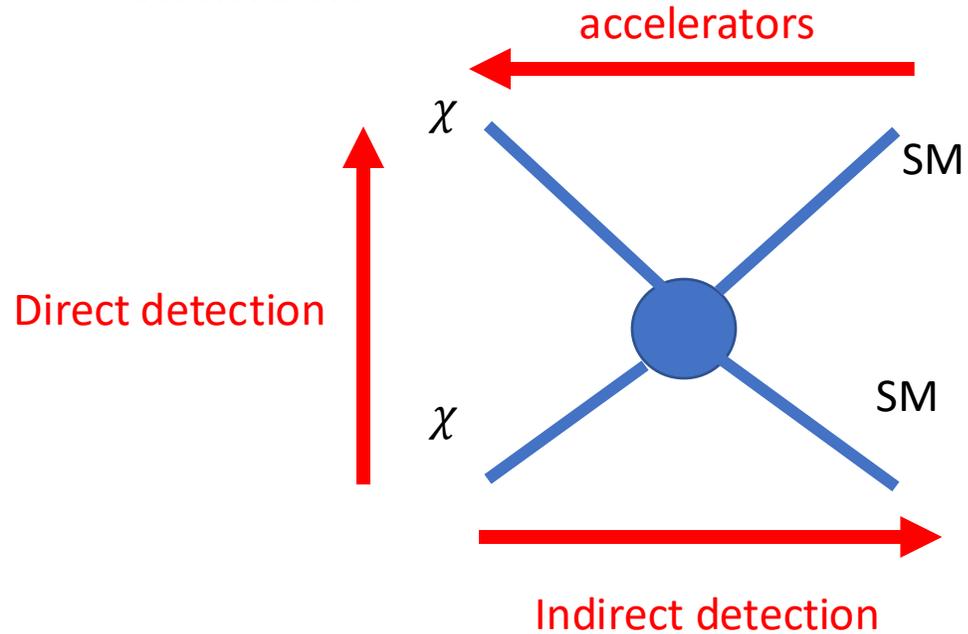

Dark Halo

Disk

Earth (not in scale!)

The most direct way to detect WIMPs: direct detection of its interaction with ordinary matter (it's all in the name!)

muons

Underground lab

Measure nuclear recoil (~ keV range) from WIMP-nucleus elastic scattering in ionizator, scintillator, bolometer, bubble chamber, etc.

WIMP searches:
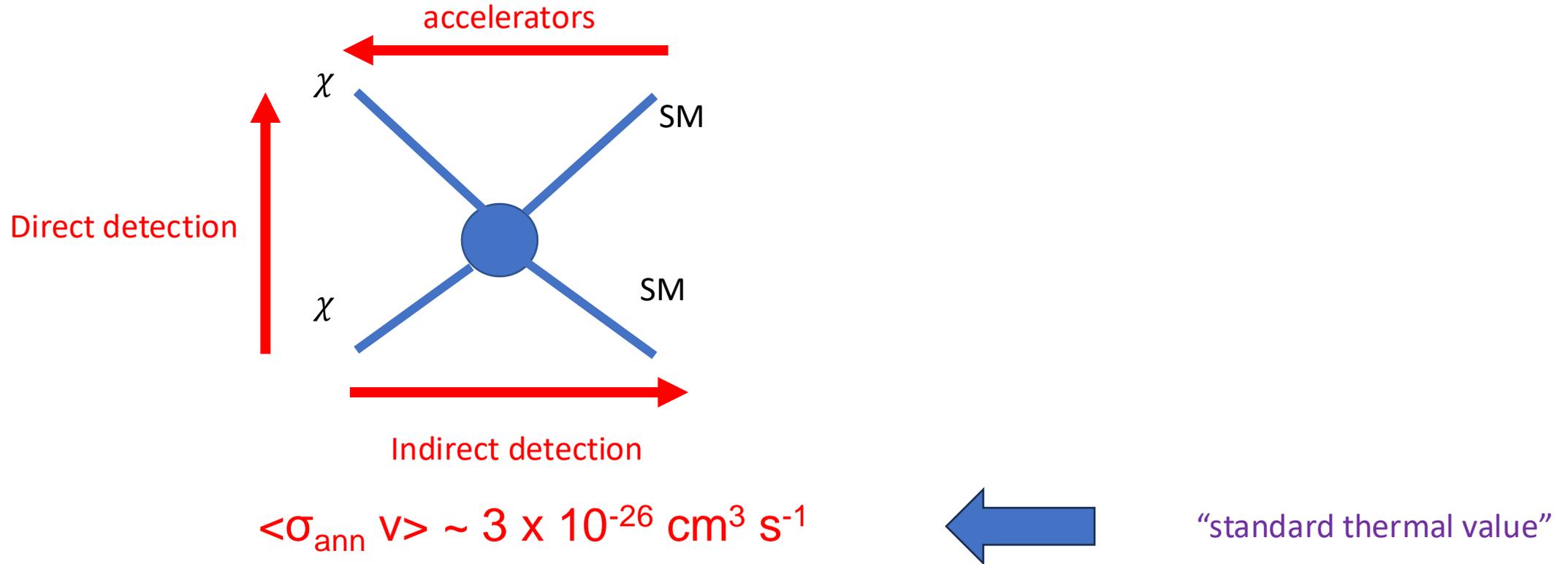- Direct detection
- Indirect detection
- accelerators

accelerators

χ

SM

Direct detection

χ

SM

Indirect detection

Indirect detection:
- WIMP annihilation to photons/neutrinos/antiprotons/positrons in tha halo of our Galaxy
- Enhanced wherever the DM density is large (e.g. Galactic Center)
- Celestial bodies can accumulate WiMPs in their interior through their gravitational potential
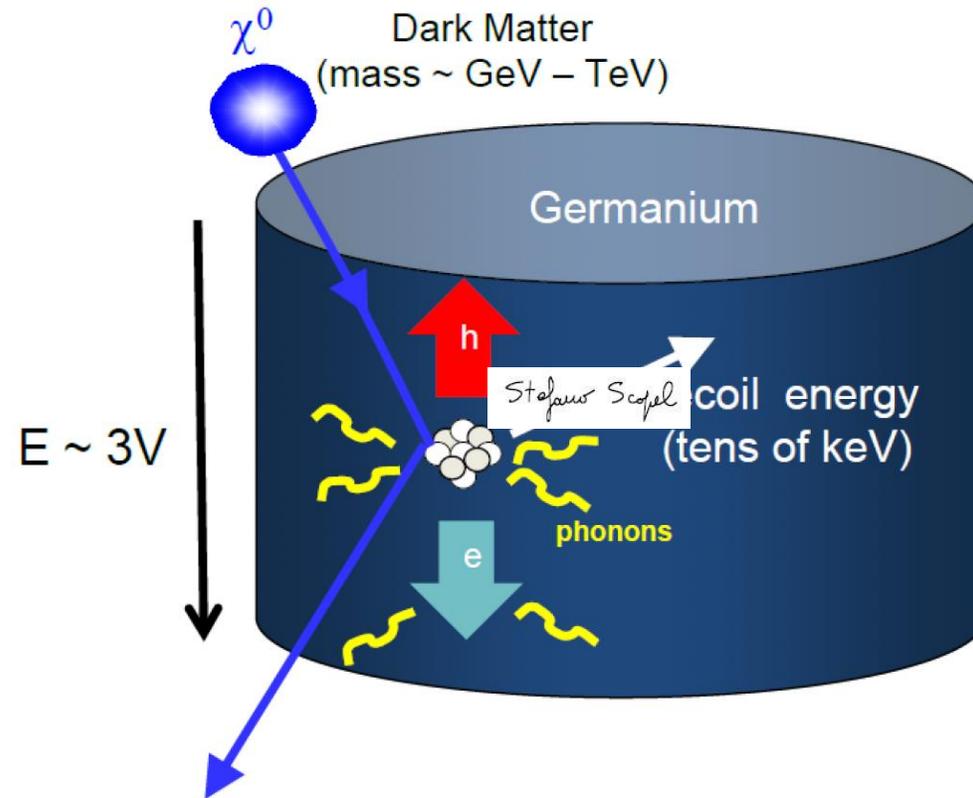
WIMP searches:
- Direct detection
- Indirect detection
- accelerators

accelerators

χ

SM

Direct detection

χ

SM

Indirect detection

$$<\sigma_{ann} v> \sim 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}$$

"standard thermal value"

Indirect detection:
- WIMP annihilation to photons/neutrinos/antiprotons/positrons in tha halo of our Galaxy
- Enhanced wherever the DM density is large (e.g. Galactic Center)
- Celestial bodies can accumulate WiMPs in their interior through their gravitational potential
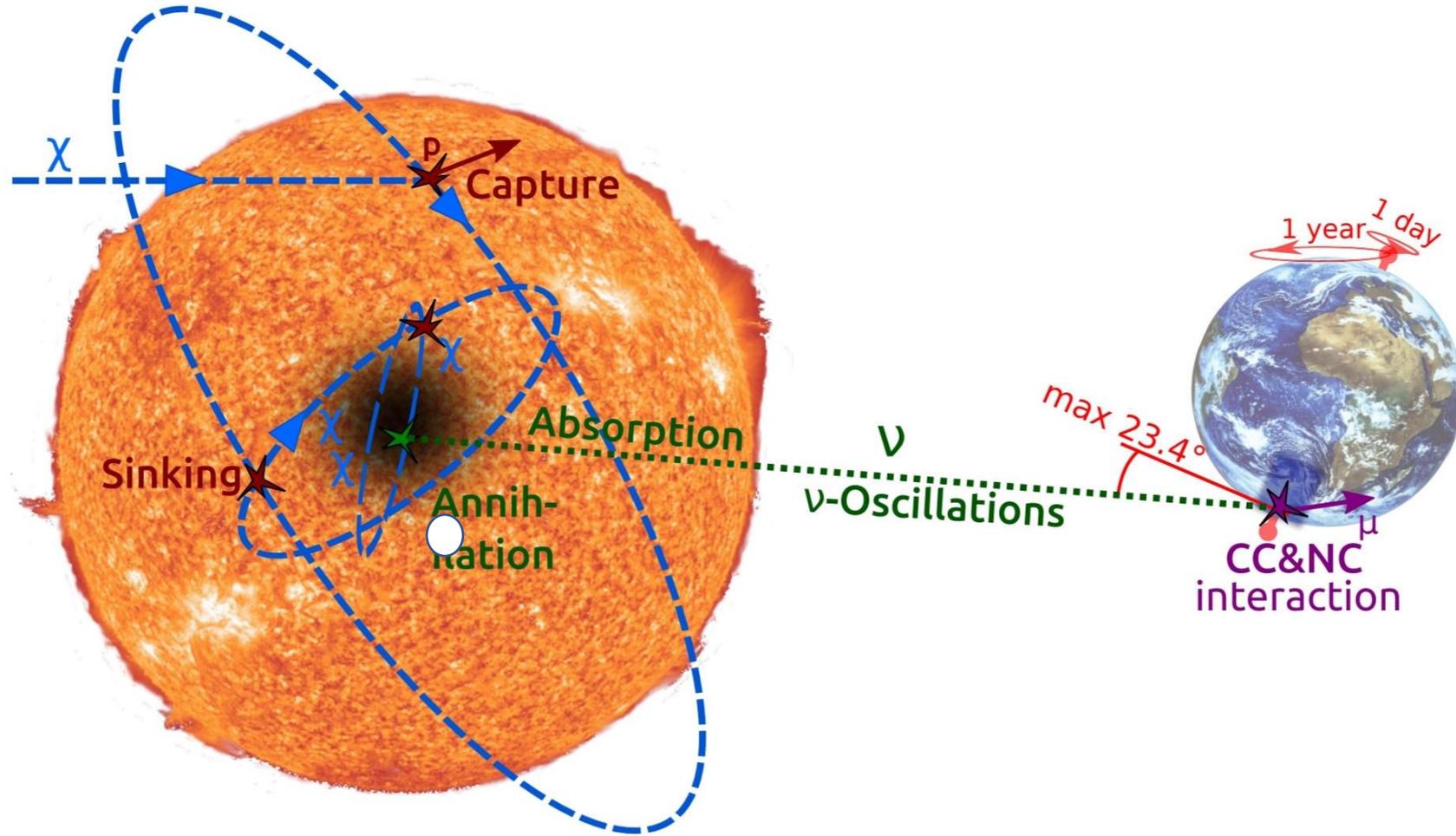
WIMP direct detection

Incoming WIMP non-relativistic (v ~ 1^{-3} c) → nuclear recoil energy in the keV range

Indirect detection: **enhanced wherever the density is high**
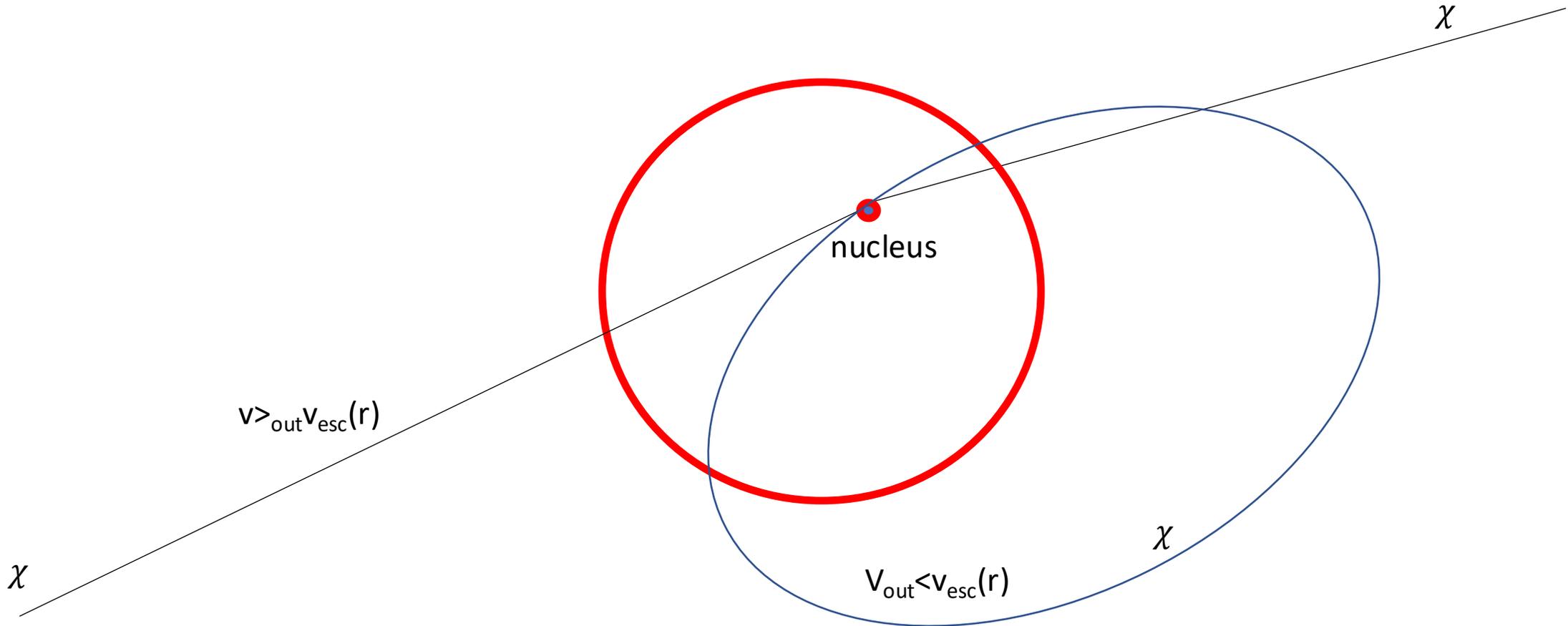EXAMPLE: WIMP capture in the Sun

Only neutrinos can escape -> up-going muons detected on Earth by Cherenkov detectors (Super-K, IceCube)

NB: same WIMP-nucleus scattering process entering direct detection

Capture mechanism:
- WIMP scatters off nucleus at distance r inside celestial body (same interaction probed by Direct Detection)
- If its outgoing speed v_{out} is below the escape velocity $v_{esc}(r)$ gets locked into gravitationally bound orbit
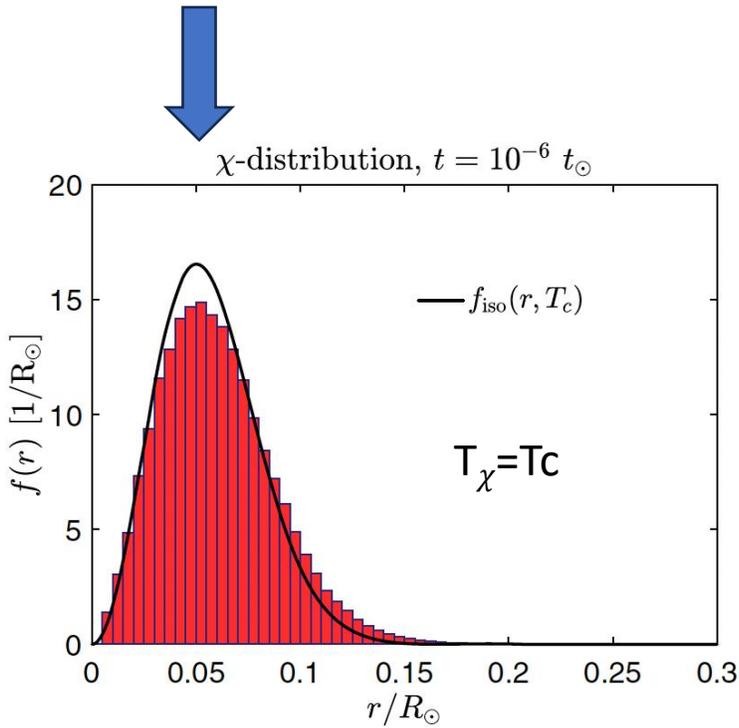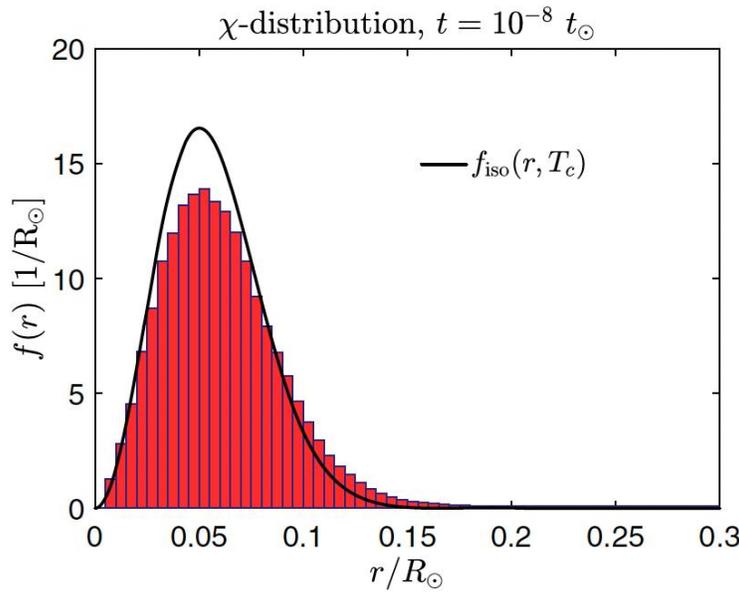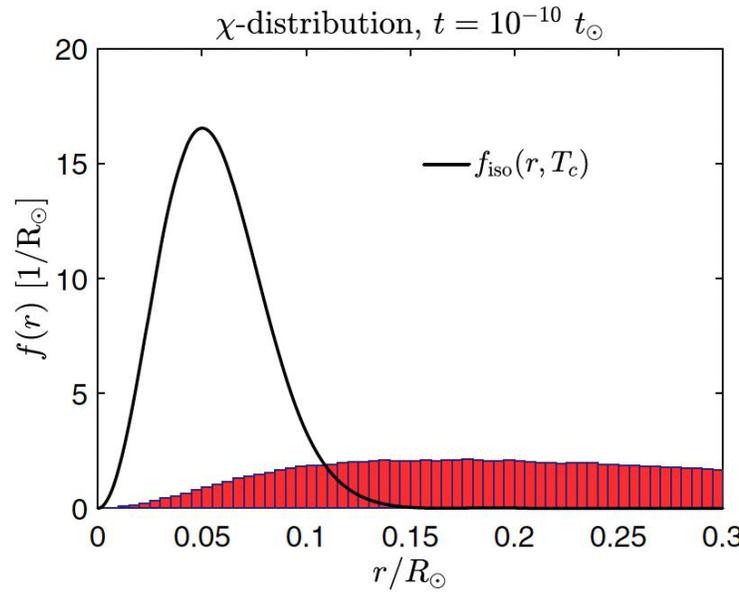- Keeps scattering again and again until it settles down in the stellar core

Thermalization of Dark Matter within the Sun: confirmed by **numerical simulations**

$$n_\chi(r) = n_0 e^{-m_\chi \phi(r)/T_c}$$

T_c = central Sun temperature

WIMP distribution at central temperature of the Sun

N.B. : WIMP-nuclei elastic scattering

M. Blennow, S. Clementz, J. Herrero-Garcia, Eur. Phys. J. C (2018) 78, arXiv:1802.06880

very high density of WIMPs localized at the center of the Sun → enhanced annihilation signal

The WIMP direct detection signal can be written in the form:

$$R_{\mathrm{DD}} = \int_0^{u_{\mathrm{max}}} du\, f(u)\, H_{\mathrm{DD}}(u)$$

velocity distribution — — — — — — — — — — — response function

if:

$$H_{DD}(u) = c^2 \tilde{H}_{DD}(u)$$

is it possible to get a bound on the coupling for any velocity distribution f(u) with the only condition:

$$\int_{u=0}^{\infty} f(u)du = 1 \quad ? \quad \boxed{\textbf{NO}}$$

Due to the energy threshold **WIMP direct detection alone does not probe the full velocity range of the velocity distribution** → combine with capture in the Sun (F. Ferrer, A. Ibarra, S. Wild, JCAP 09 (2015), 052, [1506.03386])
Also in this case:

$$C_{\odot} = \int_0^{\infty} du f(u) H_C(u) \qquad\qquad H_C(u) = c^2 \tilde{H}_C(u)$$

The velocity range probed by capture is <u>complementary </u>to direct detection

writing:

$$H(c_i^2, u) = c_i^2 H(c_i = 1, u)$$

an experimental upper bond implies:

$$R(c_i^2) = \int_0^{u_{\max}} du f(u) \frac{c_i^2}{c_{i\,\max}^2(u)} H(c_{i\,\max}^2(u), u) = \int_0^{u_{\max}} du f(u) \frac{c_i^2}{c_{i\,\max}^2(u)} R_{\max} \leq R_{\max}$$
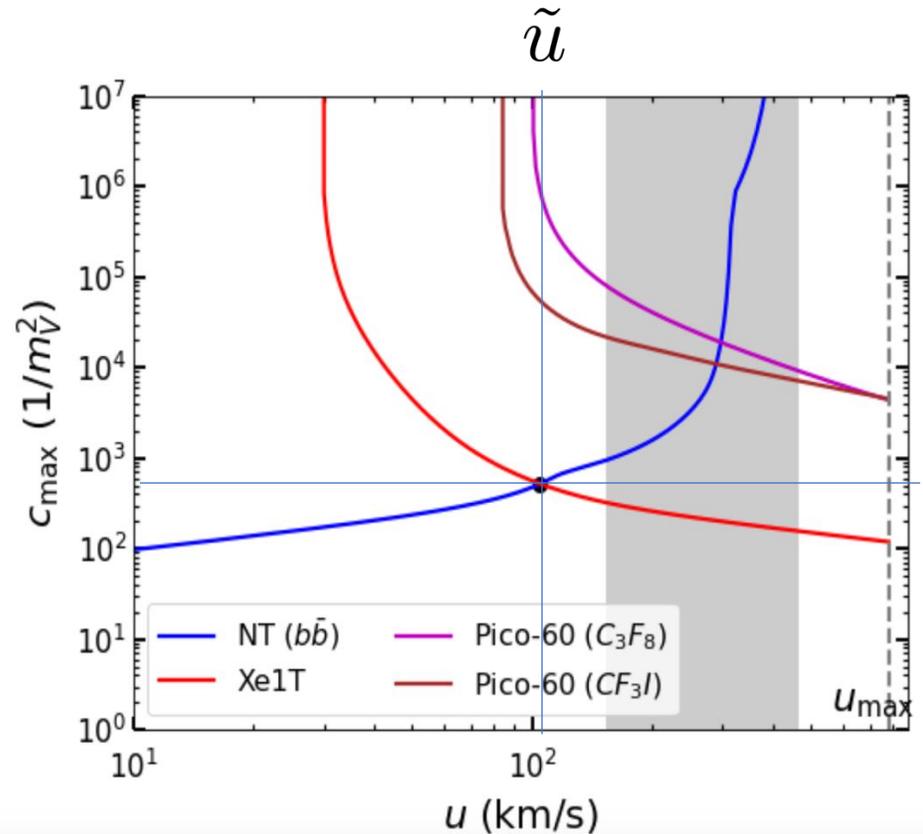
with:

$$H(c_{i\,\max}^2(u), u) = c_{i\,\max}^2(u) H(c_i = 1, u) = R_{\max}$$

one gets the upper bound on c_i^2:

$$c_i^2 \leq \left[\int_0^{u_{\max}} du \frac{f(u)}{c_{i\,\max}^2(u)} \right]^{-1}$$

$c_{i\,max}(u)$ is a function of u that can be bounded combining DD and Capture in the sun:

$$\tilde{u}$$

$$c_{i\,max}(u) \leq c_*$$
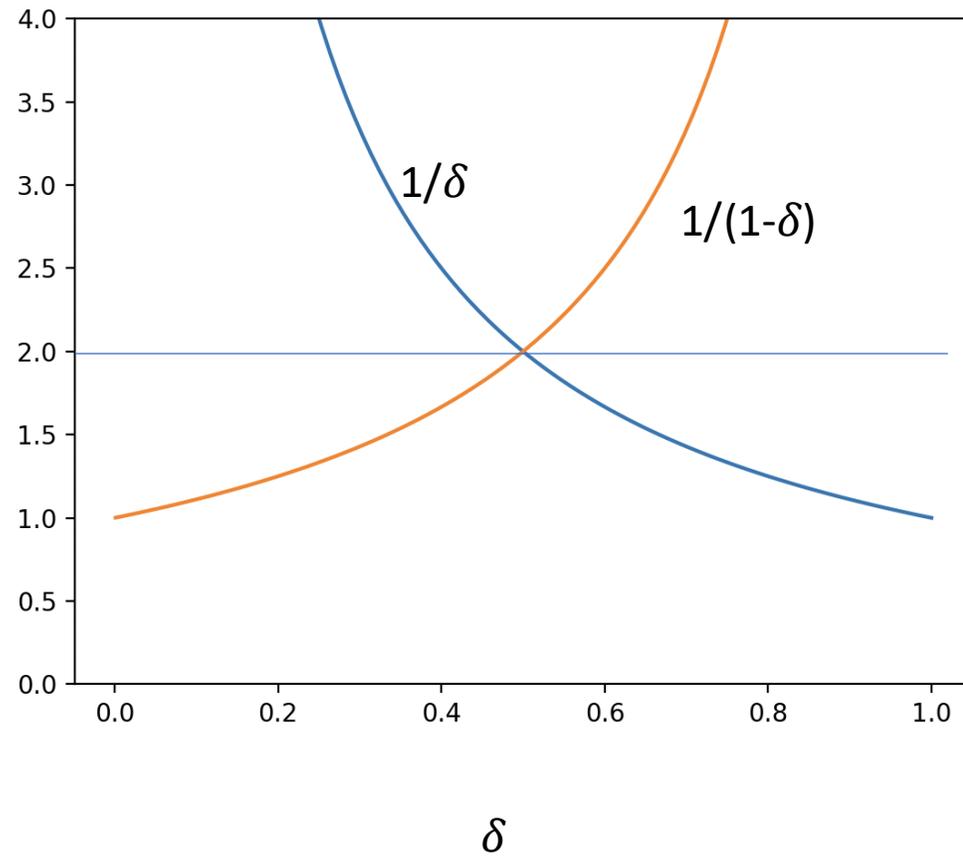
now c* can be pulled out from the rate formula:

$$c^2 \leq c_*^2 \left[\int_0^{\tilde{u}} du f(u) \right]^{-1} = \frac{c_*^2}{\delta},$$

with

$$\delta \equiv \int_0^{\tilde{u}} f(u)\, du$$

$$c^2 \leq c_*^2 \left[\int_{\tilde{u}}^{u_{\max}} du f(u) \right]^{-1} = \frac{c_*^2}{1-\delta}.$$

$$\max(1/\delta, 1/(1-\delta)) = 2$$

$$c^2 \leq c_*^2 \left[\int_0^{\tilde{u}} du f(u) \right]^{-1} = \frac{c_*^2}{\delta},$$

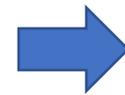$$c^2 \leq c_*^2 \left[\int_{\tilde{u}}^{u_{\max}} du f(u) \right]^{-1} = \frac{c_*^2}{1-\delta}.$$

$$c \leq 2c_*$$

F. Ferrer, A. Ibarra, S. Wild, JCAP09(2015)052

Sensitivity of WIMP bounds on the velocity distribution in the limit of a massless mediator

Assume effective Hamiltonian for Spin Independent and Spin Dependent interactions + a massless mediator

$$\mathcal{H} = \sum_{\tau=0,1} \left(\frac{\alpha_{SI}^\tau}{q^2 + M_0^2} 1_\chi 1_N t^\tau + \frac{\alpha_{SD}^\tau}{q^2 + M_0^2} \vec{S}_\chi \cdot \vec{S}_N t^\tau \right)$$

$$\alpha_j^0 = \alpha_j^p + \alpha_j^n$$
$$\alpha_j^1 = \alpha_j^p - \alpha_j^n$$

The usual case is recovered when $M_0 \gg q$:

$$\lim_{M_0 \to \infty} \frac{\alpha_{SI}^\tau}{q^2 + M_0^2} \to \frac{\alpha_{SI}^\tau}{M_0^2} \equiv c_{SI}^\tau$$

$$\lim_{M_0 \to \infty} \frac{\alpha_{SD}^\tau}{q^2 + M_0^2} \to \frac{\alpha_{SD}^\tau}{M_0^2} \equiv c_{SD}^\tau$$

WIMP-nucleus cross section in the limit $M_0 \to 0$:

$$\frac{d\sigma_T}{dE_R}(q^2) = \frac{2m_T}{4\pi w^2} \left[\frac{1}{2j_\chi + 1} \frac{1}{2j_T + 1} |\mathcal{M}_T(q^2)|^2 \right]$$

with scattering amplitude:

$$\frac{1}{2j_\chi + 1} \frac{1}{2j_T + 1} |\mathcal{M}_T(q^2)|^2 = \frac{4\pi}{2j_T + 1} \sum_{\tau,\tau'=0,1} \left\{ \frac{\alpha_{SI}^\tau \alpha_{SI}^{\tau'}}{q^4} W_{TM}^{\tau\tau'}(q) + \frac{j_\chi(j_\chi + 1)}{12} \frac{\alpha_{SD}^\tau \alpha_{SD}^{\tau'}}{q^4} \left[W_{T\Sigma'}^{\tau\tau'}(q) + W_{T\Sigma''}^{\tau\tau'}(q) \right] \right\}$$

Problem: scattering amplitude diverges for $q \to 0$ (effective model requires ultraviolet completion to restore Unitarity!)

For Direct Detection signals the infrared divergence is not a problem, thanks to the energy threshold

$$R_{\mathrm{DD}} = M_{\mathrm{exp}}\tau_{\mathrm{exp}} \left(\frac{\rho_\odot}{m_\chi} \right) \sum_T N_T \int du\, f(u)\, u \int_0^{E_R^{\mathrm{max}}} dE_R\, \zeta_T(E_R, E_1', E_2') \frac{d\sigma_T}{dE_R}$$

Window function specifying the energy bin and including convolution with experimental efficiency/acceptance:

$$\zeta_T = \int_{E_1'}^{E_2'} dE'\, \mathcal{G}_T \left[E', Q(E_R)E_R \right] \epsilon(E') \rightarrow \epsilon(E_R)\Theta(E_{R,2} - E_R)\Theta(E_R - E_{R,1})$$

lower cut-off in momentum integration due to the energy threshold E_t^{th} for nuclear target T:

$$q_T^{\mathrm{th}} = \sqrt{2 m_T E_T^{\mathrm{th}})}$$

Instead, for Capture in the Sun the momentum integration extends to q→0

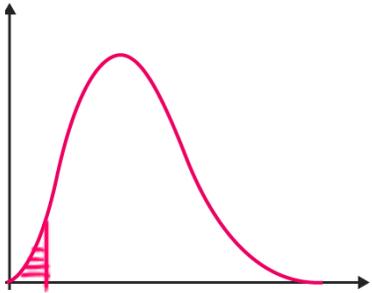At face value the capture rate **<u>diverges</u>**

$$C_\odot = \left(\frac{\rho_\odot}{m_\chi}\right) \int du\, f(u)\, \frac{1}{u} \int_0^{R_\odot} dr\, 4\pi r^2\, w^2 \sum_T \eta_T(r)\, \Theta(E_{max}^C - E_{min}^C) \int_{E_{min}^C}^{E_{max}^C} dE\, \frac{d\sigma_T}{dE}$$

$$E_{max}^C = 2\mu_{\chi T}^2 w^2 / m_T = 2\mu_{\chi T}^2 (u^2 + v_{esc}^2(r))/m_T$$

$$E_{min}^C = \frac{1}{2} m_\chi u^2$$

For u→0 the capture rate diverges

Actually, the capture rate is totally dominated by the low-speed tail of the velocity distribution!
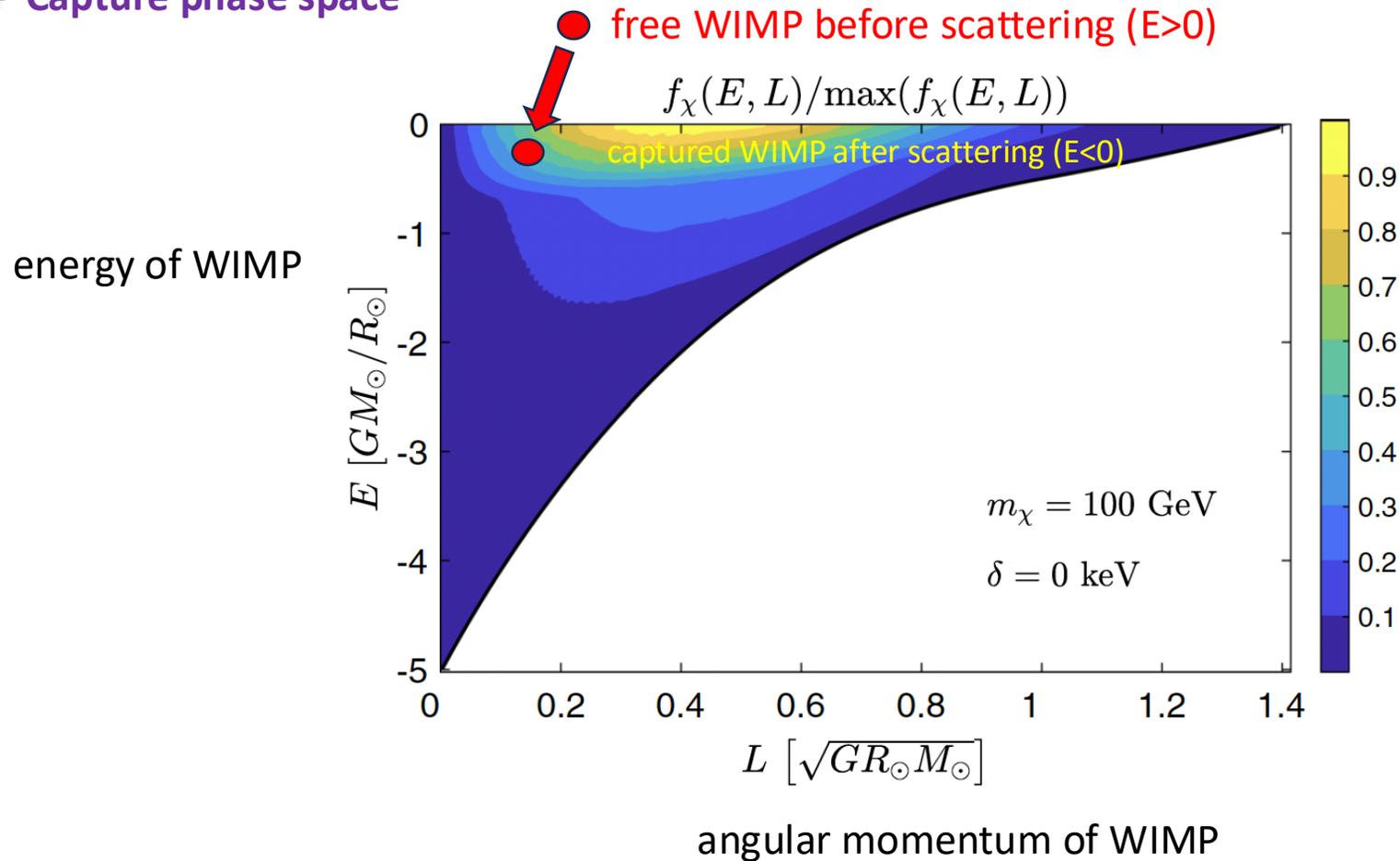
- in the Sun reference frame, they are WIMPs <u>corotating</u> with the Sun
- dark streams or a dark disk may be suggested by recent data from Gaia

➡️ **for a massless mediator the WIMP Capture rate in the Sun is extremely sensitive to a poorly known component of the dark halo**
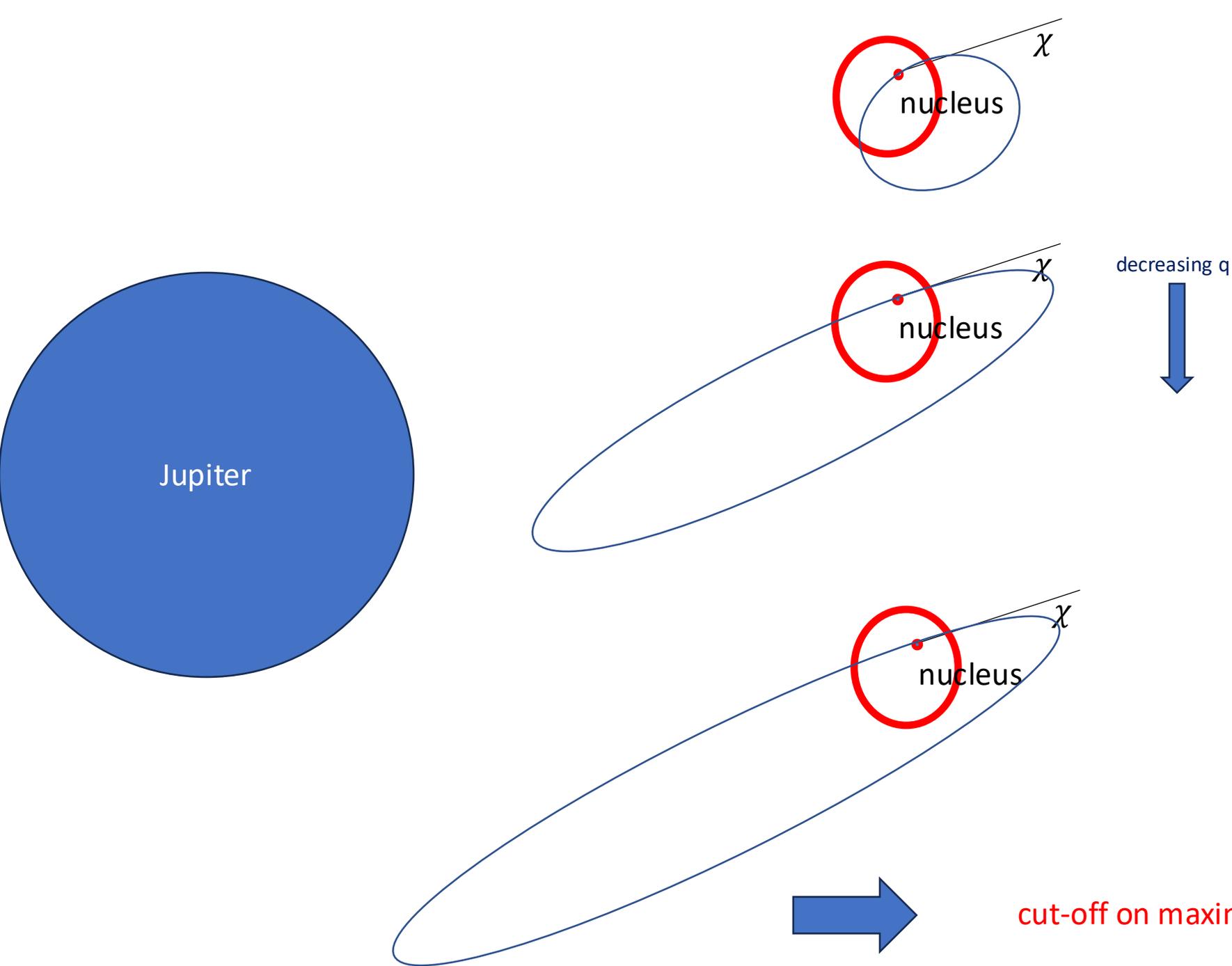
K. Choi, I. Jeong, S.Kang, A. Kar and S.S., JCAP 01 (2025) 007, 2408.09658

A closer look to the Capture rate divergence

WIMP Capture phase space

free WIMP before scattering (E>0)

$$f_\chi(E, L)/\max(f_\chi(E, L))$$

captured WIMP after scattering (E<0)

energy of WIMP

$E \left[GM_\odot / R_\odot \right]$

$m_\chi = 100 \text{ GeV}$

$\delta = 0 \text{ keV}$

$L \left[\sqrt{GR_\odot M_\odot} \right]$

angular momentum of WIMP

WIMPs with very small positive energy (u→0) can be captured (driven to negative energies) by arbitrarily small momentum transfer (q→0). Not a problem for a contact interaction, but for a massless mediator the cross section for these events <u>dominates</u> the total capture rate

However, on the boundary (|E|→ 0 with E<0) the aphelion of the captured WIMP orbit diverges (the WIMP is *barely* captured)

- as q →0 the WIMP trajectory eventually reaches other planets, and eventually the boundary of the Solar System!
- after being locked into a bound orbit by a first scattering event, the WIMP is assumed to scatter again many times during the age of the Solar System and to eventually thermalize at the center of the Sun
- this picture assumes that the WIMP-Sun system is isolated, and breaks down in presence of external disturbances that can drive the WIMP away from the Sun

decreasing q

cut-off on maximal size of the orbit

The Jupiter cut

in the Literature a cut is assumed on the maximal distance r_0 of the WIMP bound trajectory in order to assume that it is captured

- usual assumption: a WIMP is captured if the outgoing speed after scattering is below the escape velocity:

$$v_{out} < v_{esc}(r) \qquad\qquad (r=\text{position of nucleus inside the Sun})$$
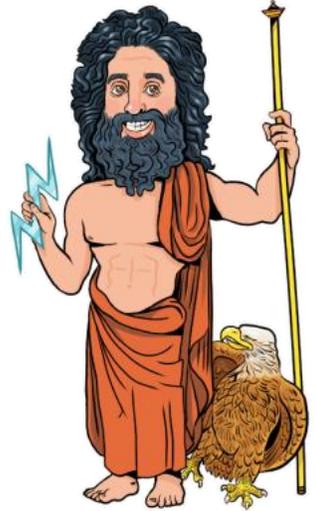
- Jupiter cut: a WIMP needs a minimal speed:

$$v_e(r)^2 = v_{esc}(r)^2 - v_{esc}(r_0)^2$$

in order to reach the maximal distance r_0

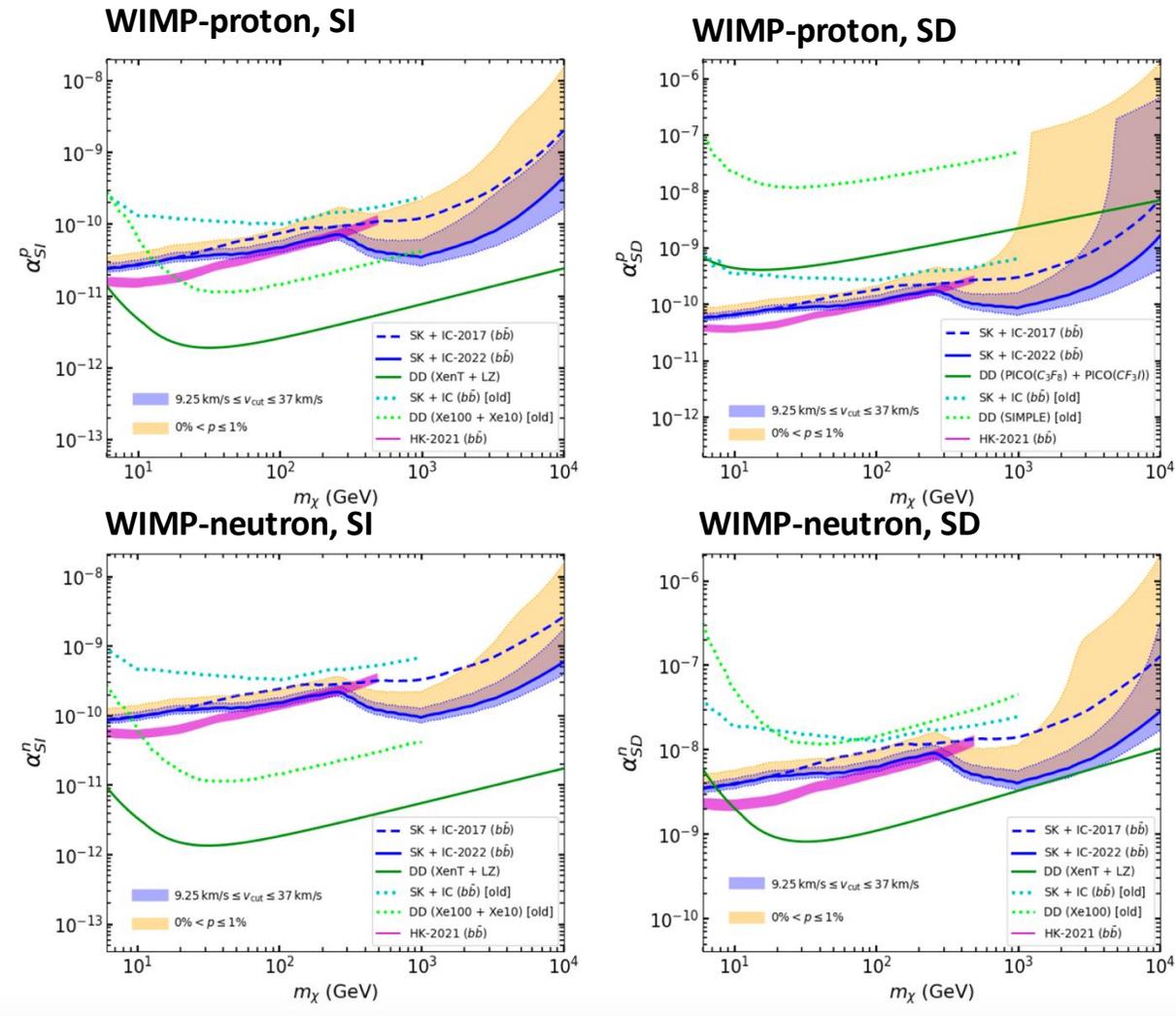since $v_e(r) < v_{esc}(r)$ this is a stronger condition for Capture → corresponds to assuming that all WIMPs with bound trajectories reaching Jupiter are lost. For the Sun-Jupiter distance:

$$v_{esc}(r_0) = v_{cut} \simeq 18.5\,\text{km/s}$$

In this way the capture rate no longer diverges, but the procedure appears *arbitrary* and does not really remove the sensitivity of the rate on the low-speed tail of the velocity distribution → **halo-independent approach!**

Long-range interaction: **Maxwellian bounds**

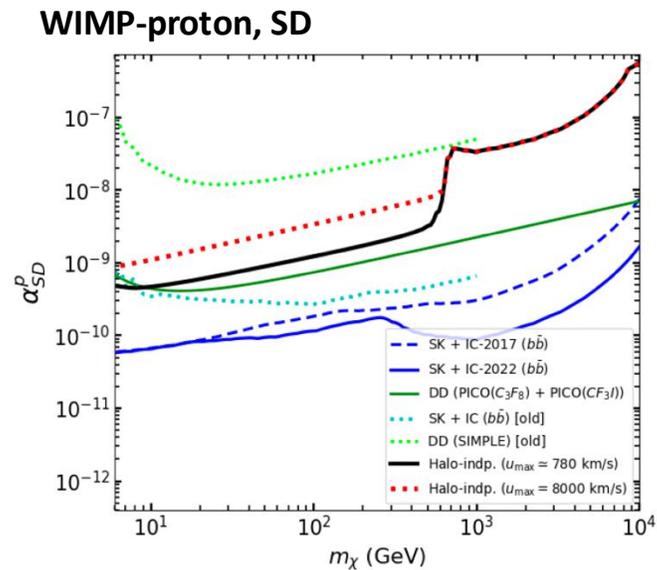**WIMP-proton, SI**

WIMP-proton, SD
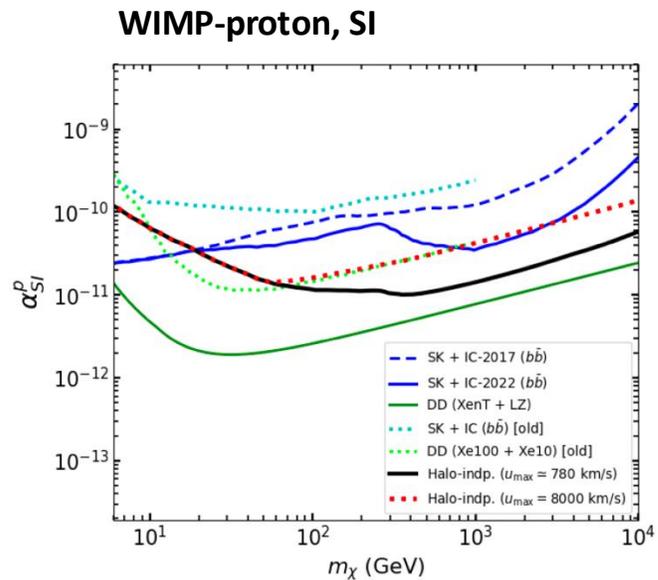
WIMP-neutron, SI

WIMP-neutron, SD

uncertainty due to Jupiter's bound
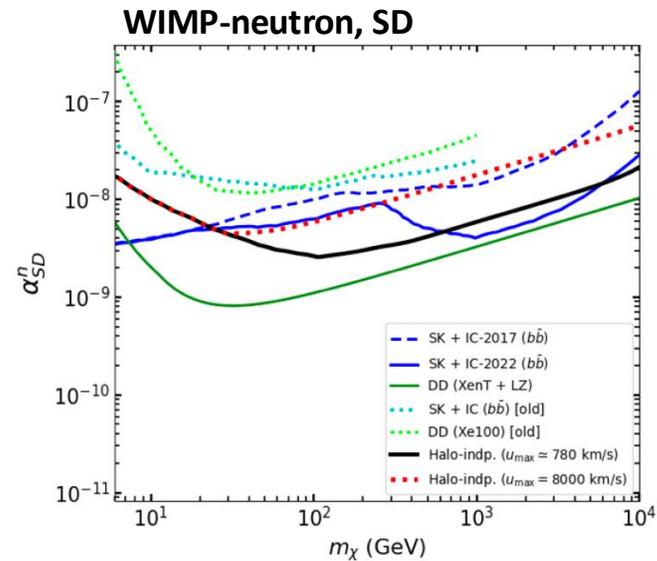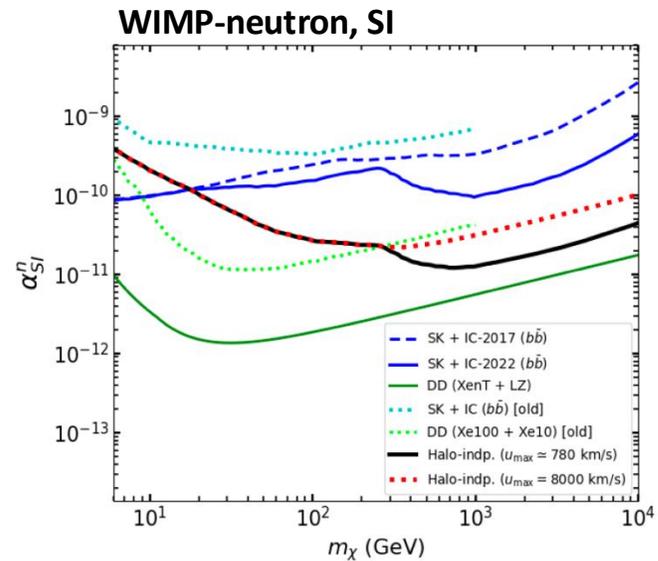
sensitivity to <1% low speed tail of Maxwellian distribution

In all cases the bounds are driven by direct detection

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Long-range interaction: **Halo-independent bounds**
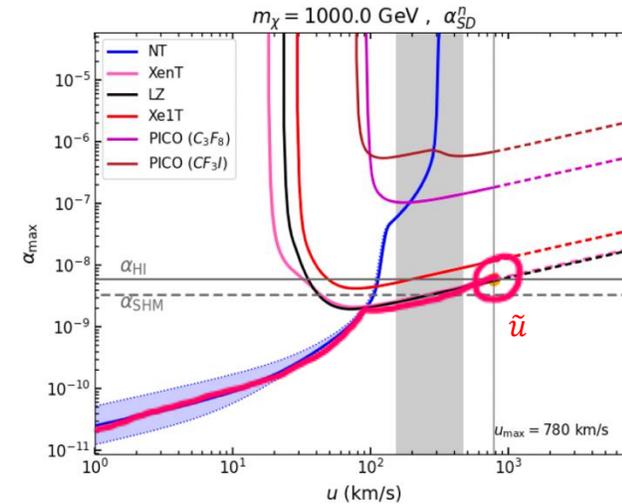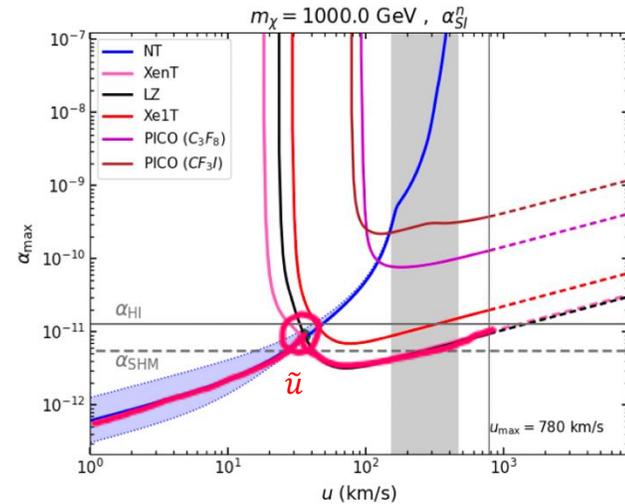

WIMP-proton, SI

WIMP-proton, SD
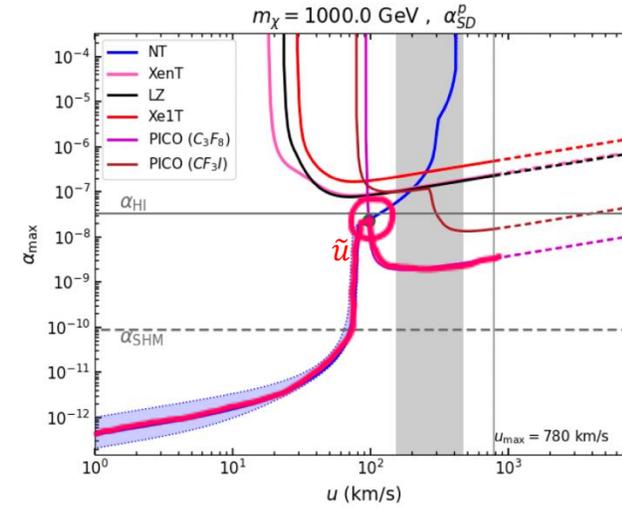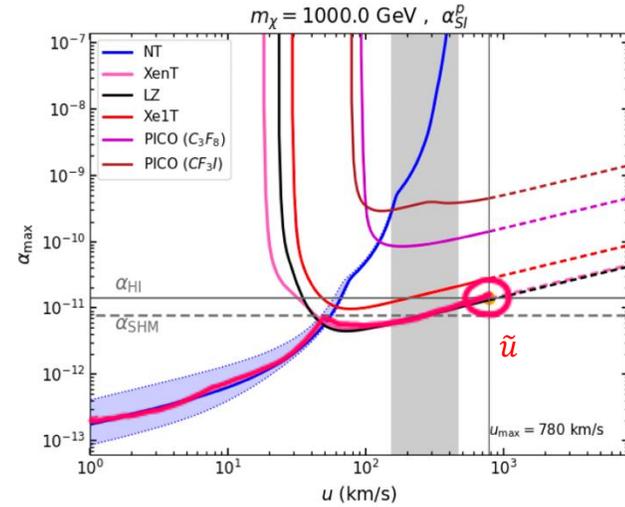
WIMP-neutron, SI

WIMP-neutron, SD

halo-independent bound

Long-range interaction: **Halo-independent bounds**

N.B. the halo-independent bound is determined by the largest value of the function $\alpha_{max}(u)$ in the full range of incoming WIMP speeds. Such maximum occurs at a speed value $\tilde{u}$ which is far from the velocity range affected by the Jupiter cut uncertainty
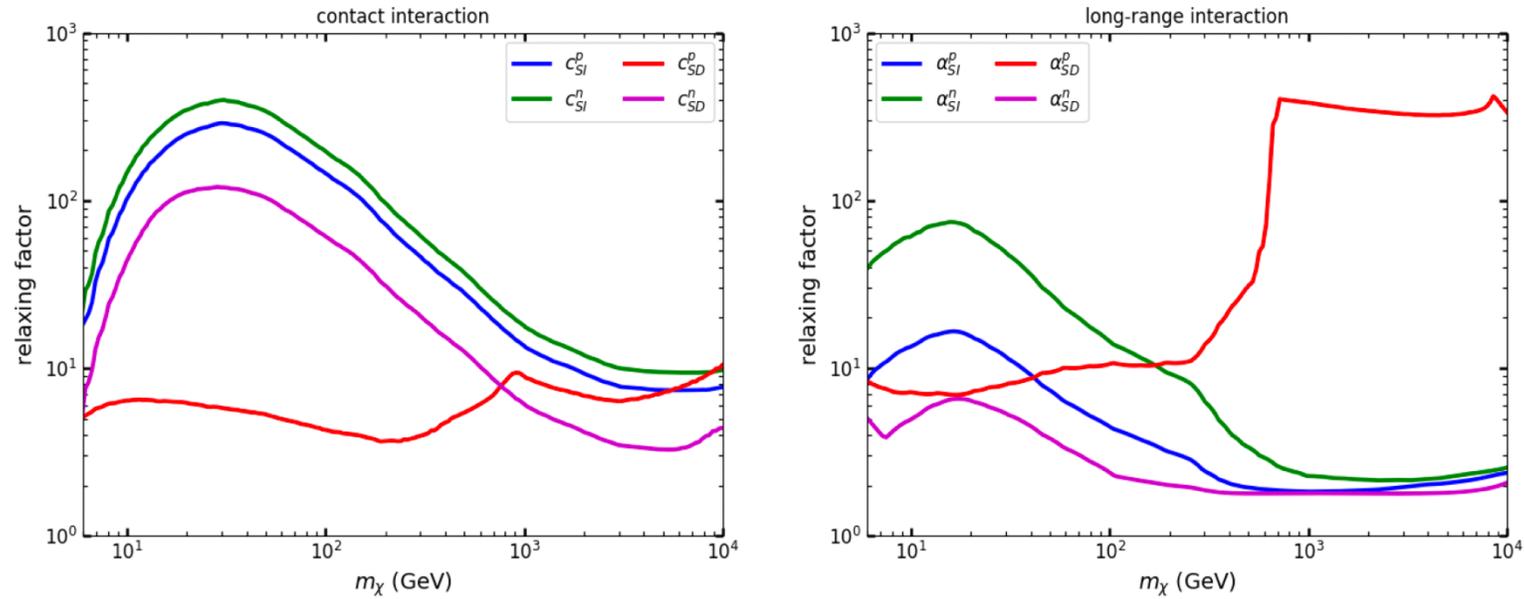
→ the halo-independent bound does not depend on the Jupiter cut

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Long-range interaction: relaxing factor

of the same order of contact interaction, with the exception of $\alpha_{SD}{}^p$ that is extremely sensitive to Hydrogen in the Sun. At large WIMP masses capture on Hydrogen is kinematically not accessible and the signal drops by orders of magnitude.

Searching for WIMPs with solar-mass black holes in low--mass X-ray binaries (LMXB)
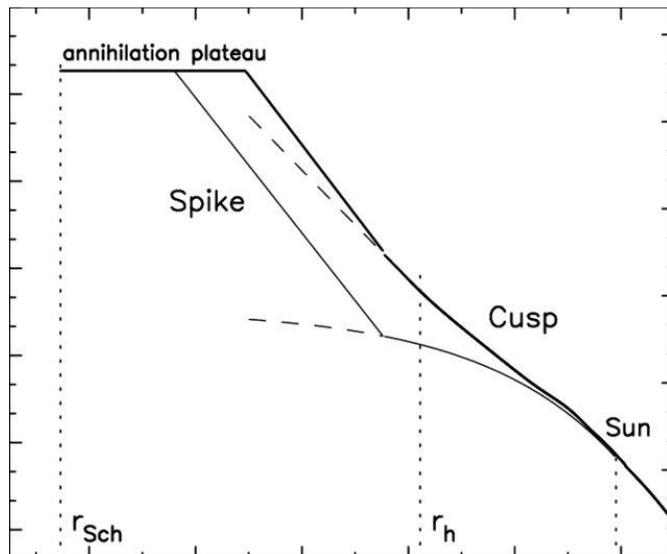
In cosmological simulations of cold and collisionless dark matter, a dark matter halo has a density profile that rises toward the center with a power index of −1 to −1.5 → cusp
This is not observed (cusp-core problem) but simulations do not include the effect of baryons.

Supermassive black hole (SMBH) with mass $M_{BH} \sim 3 \times 10^6\, M_\odot$ located very close to the dynamical center of the Galaxy, and most likely associated to the compact radio source labeled Sgr A

The dark matter at the galactic center can be redistributed by the black hole into a cusp with density profile $r^{\gamma_{sp}}$ and $1.5 \lesssim \gamma_{sp} \lesssim 2.5$ (adiabatic compression, Gondolo, Silk, PRL83(1999)1719)
→ stong enhancement of the WIMP annihilation signal very sensitive on the cups index γ_{sp}

Dark Matter Spike density profile

$$\rho_{\mathrm{DM}}(r) = \begin{cases} 0 & \text{for } r \leq 2R_s, \\[2mm] \dfrac{\rho_{\mathrm{sp}}(r)\,\rho_{\mathrm{sat}}}{\rho_{\mathrm{sp}}(r) + \rho_{\mathrm{sat}}} & \text{for } 2R_s < r \leq r_{\mathrm{sp}} \\[2mm] \rho_0 & \text{for } r > r_{\mathrm{sp}}, \end{cases}$$

horizon radius:
$$R_s = 2GM_{\mathrm{BH}}/c^2$$

spike radius:
$$r_{\mathrm{sp}} = 0.2\,r_{\mathrm{in}}$$

radius of influence r_{in} defined by the relation:
$$M_{\mathrm{DM}}(r \leq r_{\mathrm{in}}) = \int_0^{r_{\mathrm{in}}} dr\, 4\pi r^2\, \rho_{\mathrm{DM}} = 2\,M_{\mathrm{BH}}$$

with:

$$\rho_{\mathrm{sp}}(r) = \rho_0 \left(\frac{r}{r_{\mathrm{sp}}}\right)^{-\gamma_{\mathrm{sp}}}$$

⟵ spike index

and

$$\rho_{\mathrm{sat}} = \frac{m_\chi}{\langle \sigma v \rangle\, t_{\mathrm{BH}}}$$

⟵ constant value of the annihilation plateau

WIMP annihilation signals are extremely sensitive to the spike index γ_{sp}.

What is the value of the spike index γ_{sp}?

Beyond the influx of the Black Hole the DM density profile is predicted by models of Galaxy formation (NFW, Moore, Einasto, etc). Suppose that:

$$\rho(r) = \rho_0 \left(\frac{r}{r_0}\right)^{-\gamma}$$

$$0<\gamma<2$$

corresponding to the phase distribution f(E,L) (E=energy, L=angular momentum)

Locally, the presence of the BH redistributes the DM density as:

$$\rho'(r) = \int_{E'_m}^{0} dE' \int_{L'_c}^{L'_m} dL' \frac{4\pi L'}{r^2 v_r} f'(E',L')$$

with

$$v_r = \left[2\left(E' + \frac{GM}{r} - \frac{L'^2}{2r^2}\right)\right]^{1/2},$$
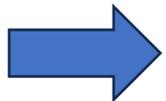
$$E'_m = -\frac{GM}{r}\left(1 - \frac{4R_S}{r}\right),$$

$$L'_c = 2cR_S,$$

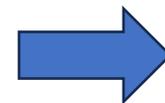$$L'_m = \left[2r^2\left(E' + \frac{GM}{r}\right)\right]^{1/2}.$$

(all particles with L<L$_c$' are captured by the BH)

Adiabatic assumption: f'=f, L'=L, E=E'
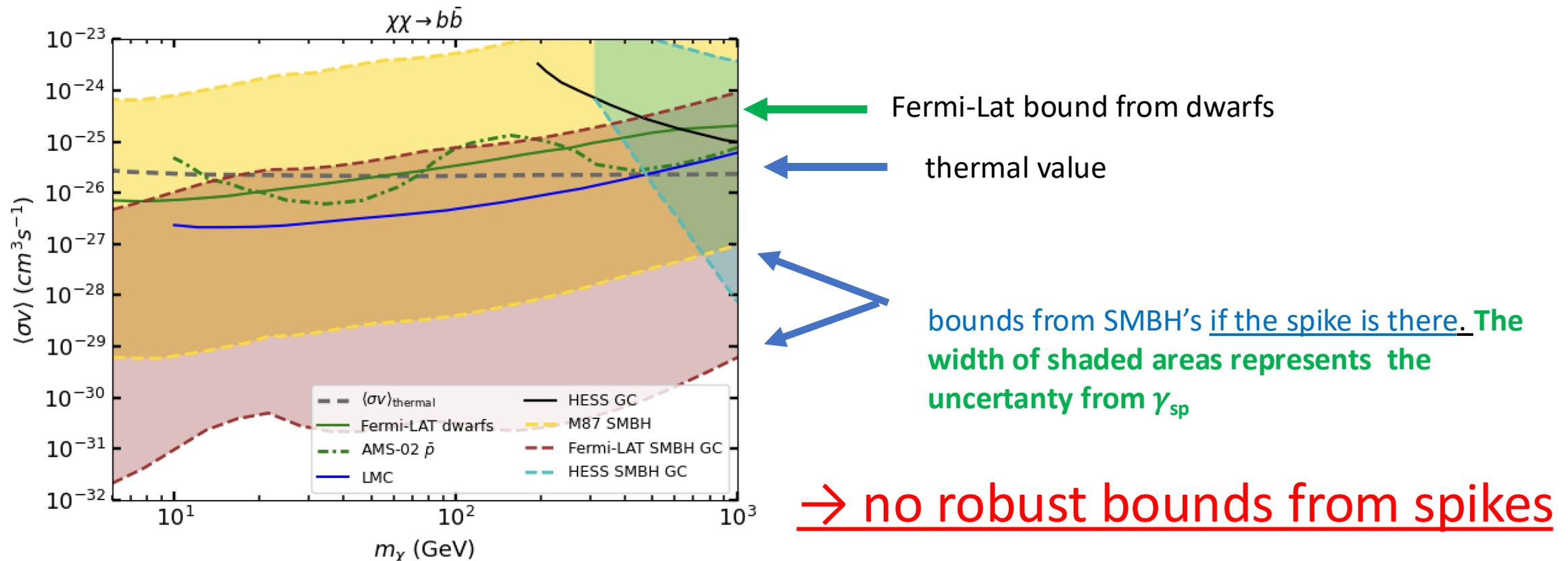
$$\gamma_{sp} = \frac{9 - 2\gamma}{4 - \gamma}$$

$$2.25<\gamma_{sp}<2.5$$

Very uncertain.

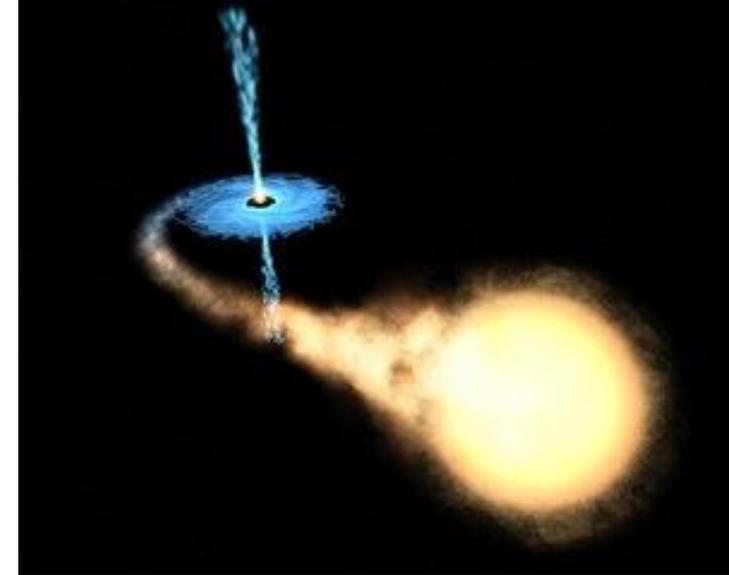1. No cusp → no spike
2. Even if the cusp is there, the spike could not have been formed (BH or hosting galaxy experienced a non-adiabatic merger, or BH not exactly at the center)
3. Even if the spike is initially formed, it can be smoothed out by DM scattering off stars

In the literature, <u>very strong</u> bounds on $\langle\sigma v\rangle$ have been published from the Super Massive Black Holes at the center of our Galaxy, or of the Large Magellanic Cloud, when the existence of the cusp is assumed, but they don't even reach the thermal value $\langle\sigma v\rangle_{thermal}$ ~ 2.2 x 10^{26} cm³s⁻¹ when the the uncertainty on δ_{sp} is taken into account

Fermi-Lat bound from dwarfs

thermal value

bounds from SMBH's <u>if the spike is there.</u> **The width of shaded areas represents the uncertanty from γ_{sp}**

→ no robust bounds from spikes

XTE J1118+480: a low-mass X-ray binary in the constellation Ursa Major. Made of a Black Hole and a rotating star.
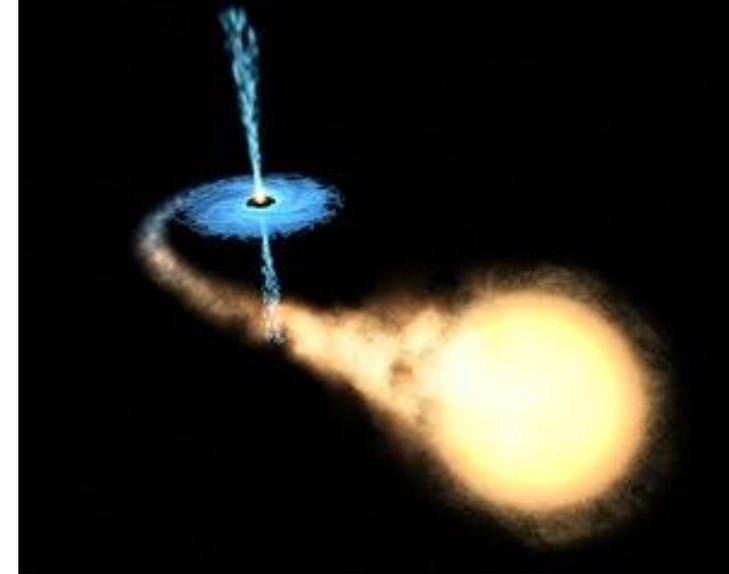The study of the motion of the visible star allows an accurate measurement of the parameters of the system

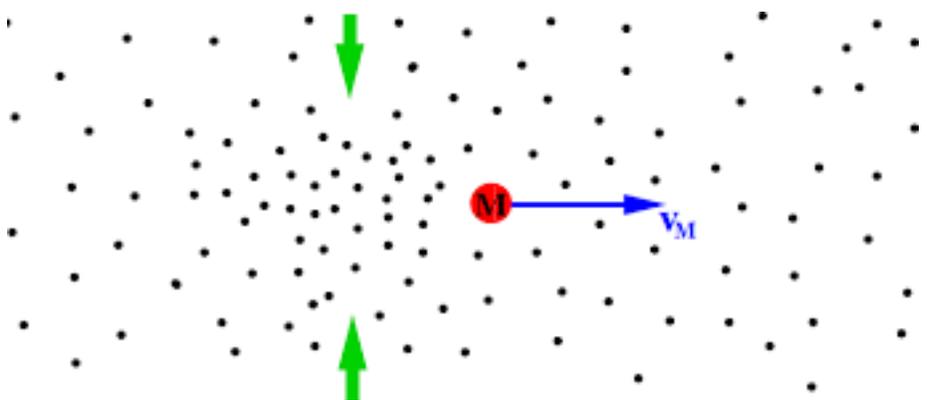|	
M_{BH}	$7.46^{+0.34}_{-0.69}M_\odot$ (Gonzalez Hernandez et al. 2014)
q =m_{star}/M_{BH}	0.024 ± 0.009 (Khargharia et al. 2013)
K (km s^{-1})	708.8 ± 1.4 (Khargharia et al. 2013)
i	$73°5 \pm 5°5$ (Khargharia et al. 2013)
P (day)	$0.16993404(5)$ (Gonzalez Hernandez et al. 2014)
$\dot{P}$ (ms yr^{-1})	-1.90 ± 0.57 (Gonzalez Hernandez et al. 2014)
d (kpc)	1.70 ± 0.10 (Gonzalez Hernandez et al. 2011)

low-mass black hole (few solar masses) + visible star ~2% of that

Change of rotational period abnormally high: -1.9 ms/year

- Difficult to explain $\dot{P}$ = -1.9 ms/year in XTE J1118+480, **2 orders of magnitude larger** than the one expected with gravitational-wave radiation
- Two possible explanations:
  - ❑ orbital period reduced by coupling between the magnetic field and the winds from the companion star through tidal torques. However, there should be a significant mass loss from the binary system, which has not been observed
  - ❑ the tidal torque between the circumbinary disk and the binary can efficiently extract the orbital angular momentum from the binary to cause the orbital decay. However, simulations show that the predicted mass transfer rate and the circumbinary disk mass should be much greater than the inferred values from observations

Alternative explanation: the star is slowed down by the dynamical friction with a steep dark matter density spike close to the Black Hole
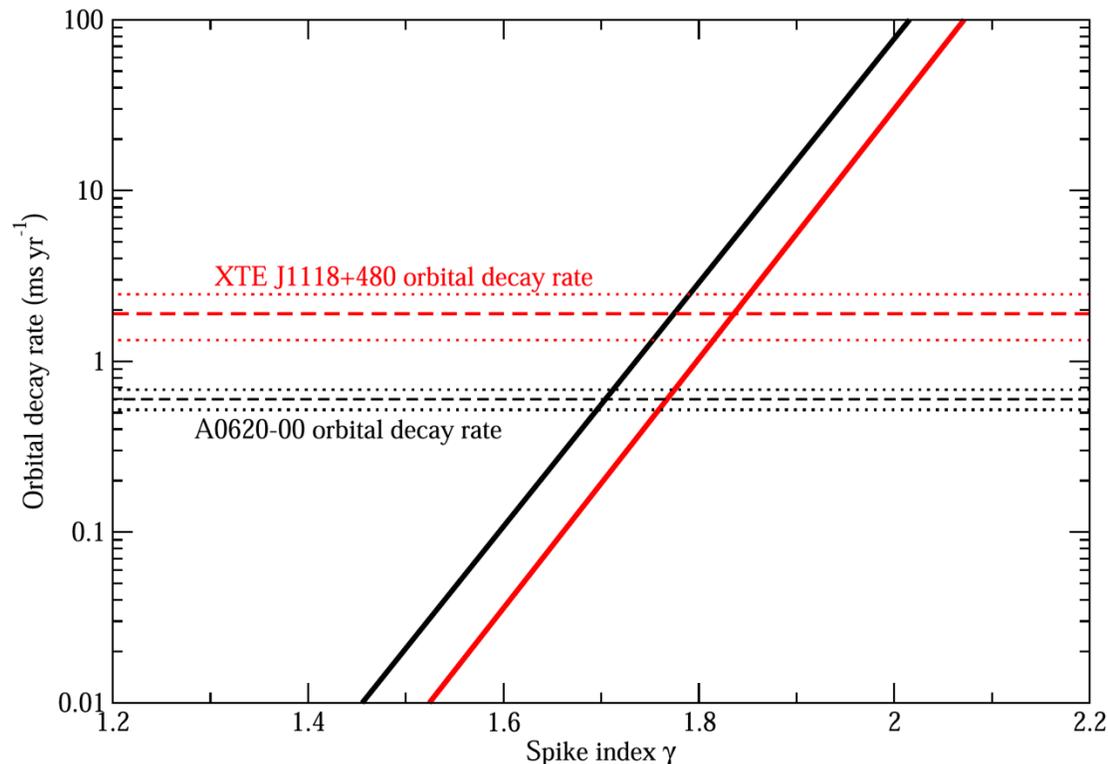
Dynamical friction: if the star is crossing a very dense spike of DM particles, a concentration of DM particles develops behind the rotating star, slowing it down

Orbital decay due to dynamical friction between DM and the star

$$\dot{P} = -\frac{12\pi qGP\ln\Lambda}{(1+q)^2(K/\sin i)}\left[\frac{GM_{\mathrm{BH}}(1+q)P^2}{4\pi^2}\right]^{1/3}\rho_{\mathrm{DM}}$$

depends on the observed parameters of the BH–LMXB and the spike density. The only free parameter is the spike index γ_{sp} → **can determine γ_{sp} from observation**

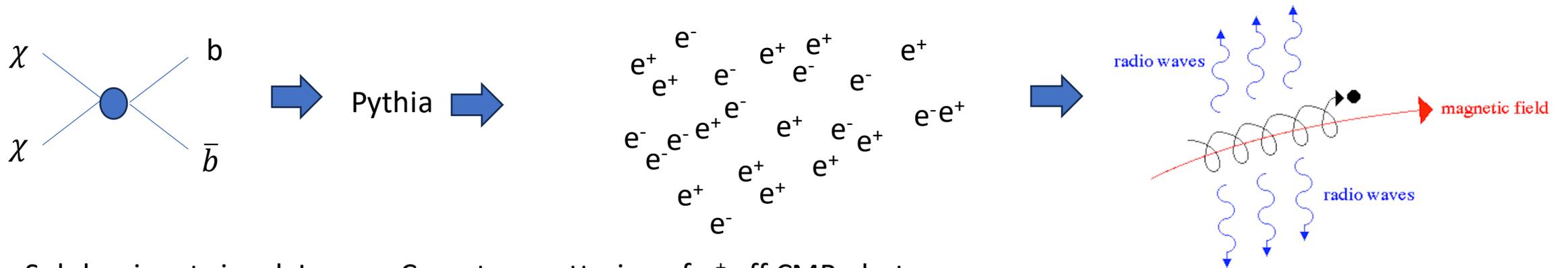**M.H.Chan and C.M.Lee, Astrophys. J. Lett. 943, no.2, L11 (2023)**

using observed value of $\dot{P}$:

$$\gamma_{\mathrm{sp}} = 1.85 \pm 0.04 \quad \text{for XTE J1118+480}$$

at variance with SMBH in the Galactic Center, or in LMC very small uncertainty → **much smaller uncertainty in the calculation of DM signals**

DM signal from XTE J1118+480

Main source of signal: syncrotron radiation from $e^\pm$ produced from DM annihilation in BH magnetic field

Subdominant signal: Inverse Compton scattering of $e^\pm$ off CMB photons

Solve diffusion equation (f=density of $e^\pm$ assumed in equilibrium) :

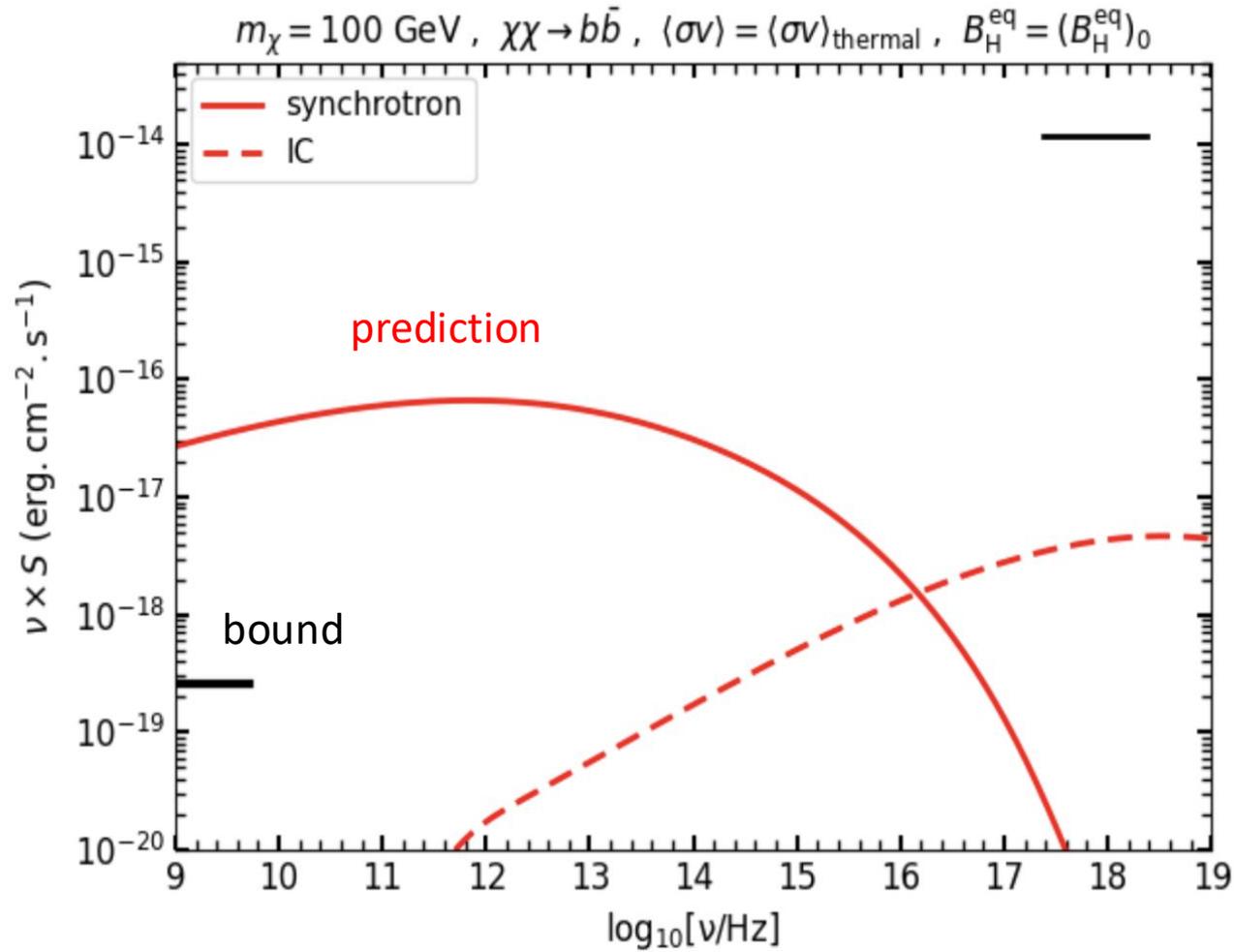$$-\frac{1}{r^2}\left[r^2 D \frac{\partial f}{\partial r}\right] + \frac{1}{p^2}\frac{\partial}{\partial p}(\dot{p}p^2 f) = q(r,p)$$

diffusion coefficient

source from DM annihilation

D(r,p)=(1/3) $r_g v_e$ with r_g=E/(eB) (the $e^\pm$ gyroradius and v_e ~c the electron velocity (assuming Bohm diffusion, i.e. that the coherence length of the magnetic field is comparable or greater that r_g)

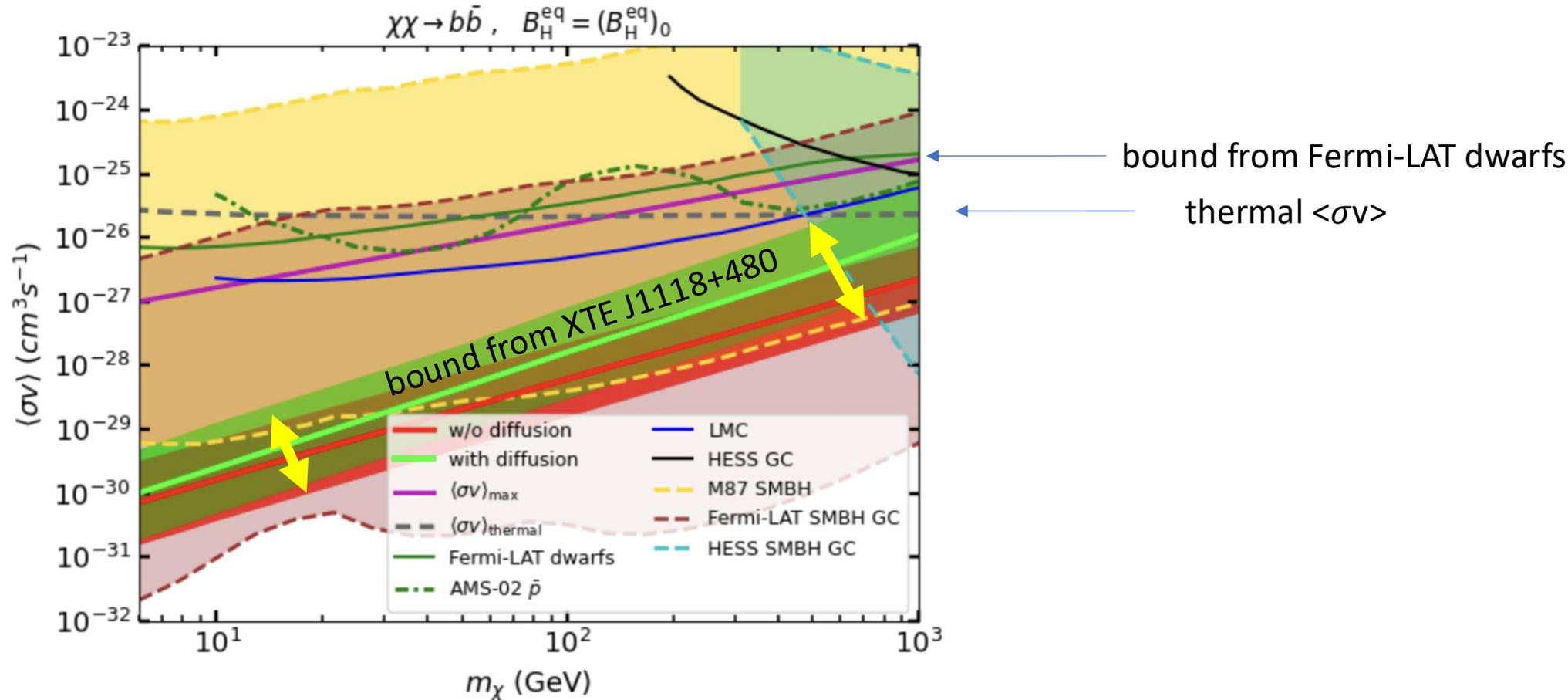# DM signal from XTE J1118+480

$m_\chi = 100$ GeV , $\chi\chi \to b\bar{b}$, $\langle\sigma v\rangle = \langle\sigma v\rangle_{\text{thermal}}$, $B_H^{eq} = (B_H^{eq})_0$

- synchrotron
- IC

prediction

bound

strong constraint!

DM signal from XTE J1118+480

$$\chi\chi \to b\bar{b}, \quad B_H^{eq} = (B_H^{eq})_0$$

bound from Fermi-LAT dwarfs

thermal $\langle\sigma v\rangle$

bound from XTE J1118+480

Legend:
- w/o diffusion
- with diffusion
- $\langle\sigma v\rangle_{max}$
- $\langle\sigma v\rangle_{thermal}$
- Fermi-LAT dwarfs
- AMS-02 $\bar{p}$
- LMC
- HESS GC
- M87 SMBH
- Fermi-LAT SMBH GC
- HESS SMBH GC

strong constraint, small uncertainty!

A. Kar, H. Kim, Sang Pyo Kim, S.S, JCAP 03 (2024) 030

uncertainty in the DM signal calculation from the magnetic field

$m_\chi = 100$ GeV, $\chi\chi \to b\bar{b}$, $\langle\sigma v\rangle = \langle\sigma v\rangle_{\text{thermal}}$

Axis labels: $L_{\text{DM}} / L_{\text{obs}}$ versus B_H^{eq} (μG)

Legend:
- Radio (w/o diffusion)
- X-ray (w/o diffusion)
- Radio (with diffusion)
- X-ray (with diffusion)

no diffusion — diffusion — estimated $[(B_H^{\text{eq}})_0]$ — equipartition

$$B(r) = \begin{cases} B^{\text{eq}}(r) & \text{for} \quad r_H \leq r < r_{\text{acc}} \\ B^{\text{eq}}(r_{\text{acc}}) \left(\frac{r}{r_{\text{acc}}}\right)^{-2} & \text{for} \quad r \geq r_{\text{acc}}, \end{cases}$$

$$B^{\text{eq}}(r) = B_H^{\text{eq}} \left(\frac{r}{r_H}\right)^{-5/4},$$

No direct access to B^{eq}_H parameter. Assuming equipartition of energy:

$$B_H^{\text{eq}} \simeq 4 \times 10^{14} \, \dot{m}^{1/2} \left(\frac{M_{\text{BH}}}{10 M_\odot}\right)^{-1/2} \, [\mu G].$$
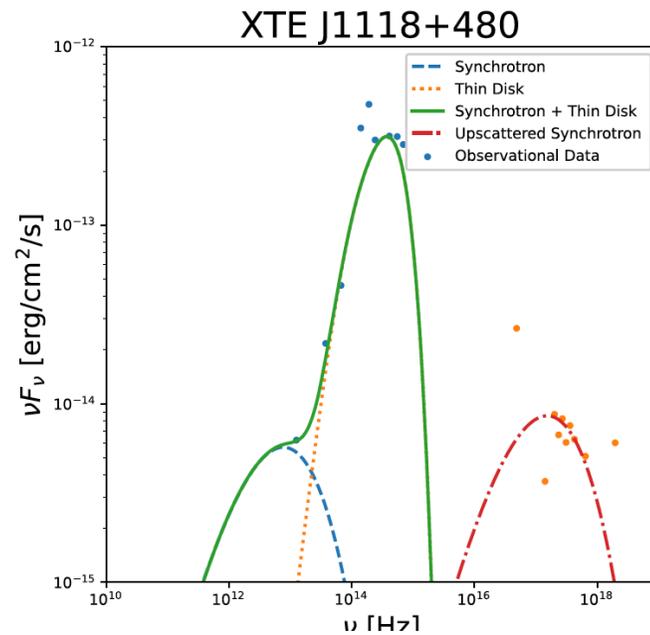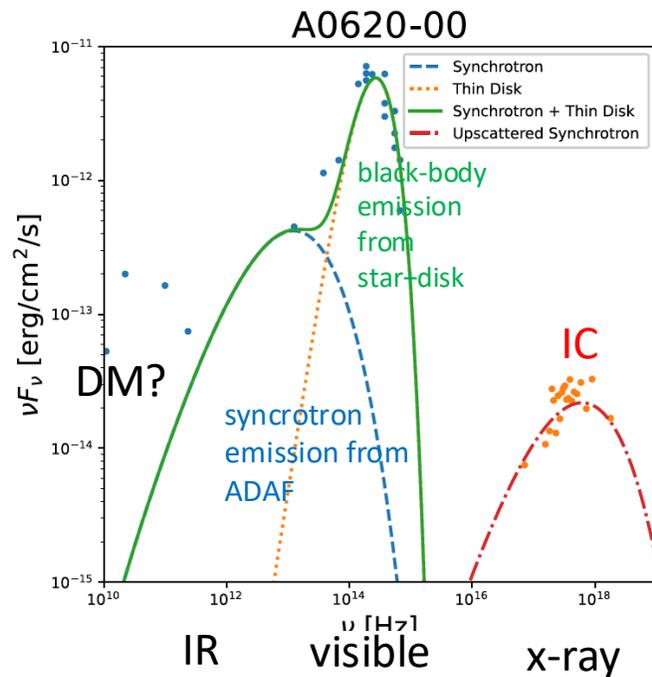
with $\dot{m} \sim 10^{-4}$

On general grounds B~10^{10} µG for supermassive black hole ($M_{\text{BH}} \simeq 10^9 M_\odot$) and B~$10^{14}$ µG for a stellar mass one (as in XTE J1118+480)

predictions are sensitive to the intensity of the magnetic field when the effect of diffusion is included

the bottom line: we have traded the uncertainty on the spike profile index for another one: the intensity of the magnetic field….
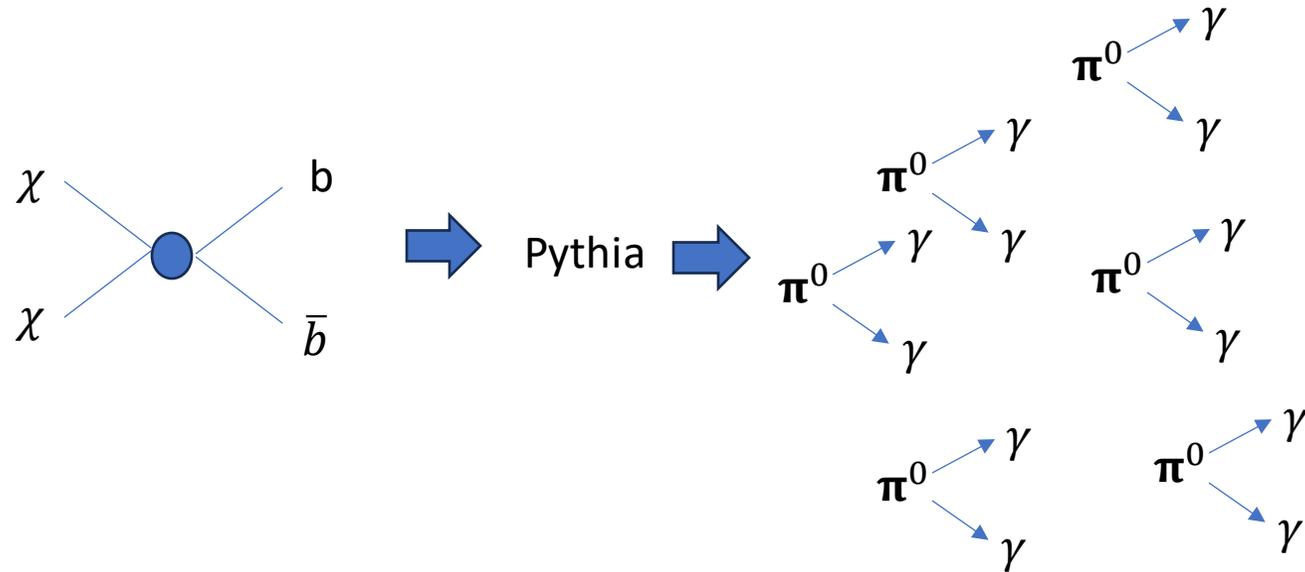
can we better estimate the magnetic field from the data? work in progress…
(spoiler: need a comprehensive fit where the DM spike is added to the other components, i.e. including emissions from accretion disk + companion star emission + DM spike

P. Gondolo, A. Kan, S. Kang, H. Kim, SS, work in progress

comment: looking directly for a signal in the gamma spectrum (~ tens of GeV) would be the simplest way to look for DM
- no dependence on the accretion disk details
- including no dependence on the magnetic field
- present bounds very weak (astronomers do not allocate telescope time to this part of the spectrum!)

continuum spectrum, up to $E = m_{DM}$

Conclusions

- Combining WIMP direct detection and capture in the Sun it is possible to obtain bounds that do not depend on the WIMP velocity distribution (different cases: elastic, inelastic, long-range)
- The Dark Matter cusp in Low-Mass X-ray binaries can potentially put constraints on the WIMP annihilation cross section times velocity $<\sigma v>$ that exceed existing ones by several orders of magnitude (but we need to better understand the intensity and coherence of the magnetic field)