PASCOS2024
Quy Nhon, Vietnam
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Direct detection of boosted dark matter in two-component dark matter scenario

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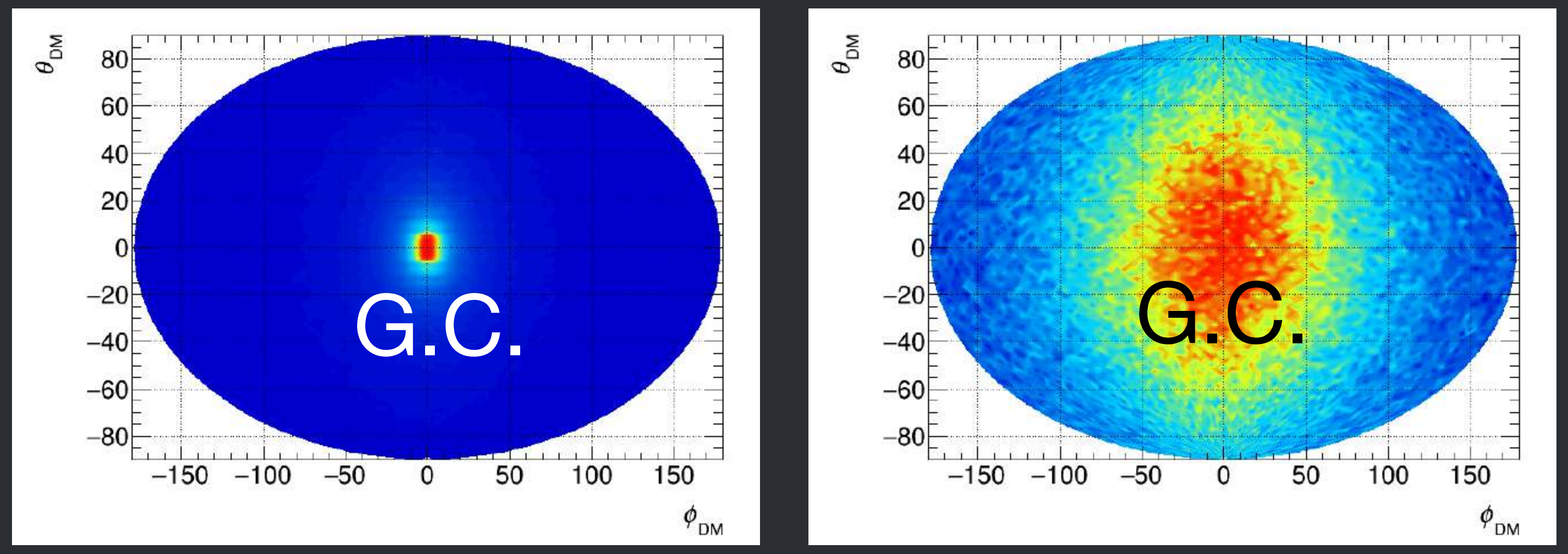
based on collaboration with T. Naka, T. Nomura (in progress)

Boosted DM

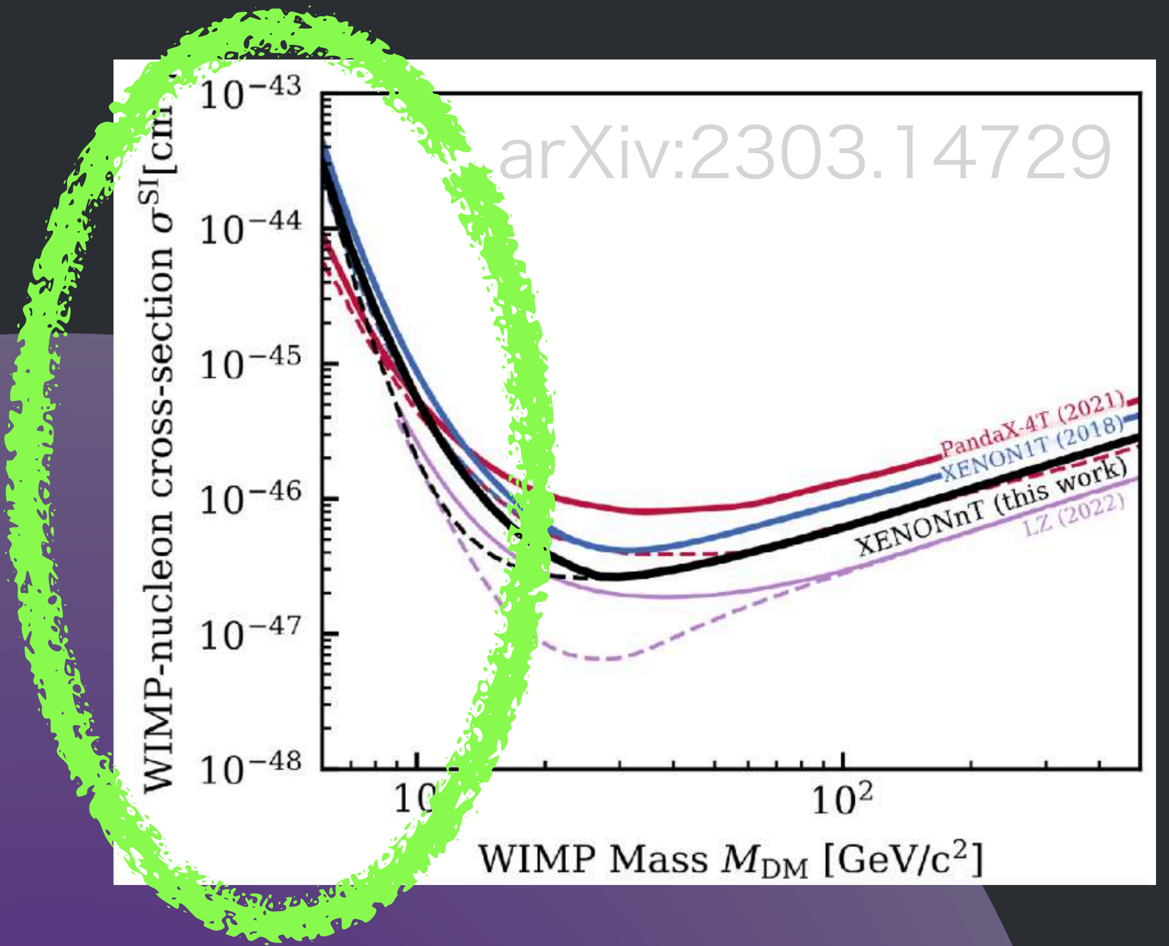
KN, S. Higashino, T. Naka, K. Miuchi
arXiv:2211.13399



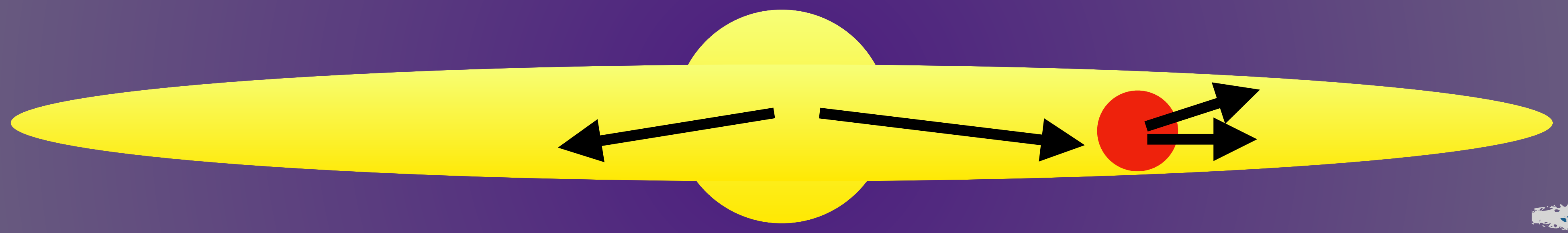
Angular distribution of nuclear recoil

- We need to consider wider range of DM

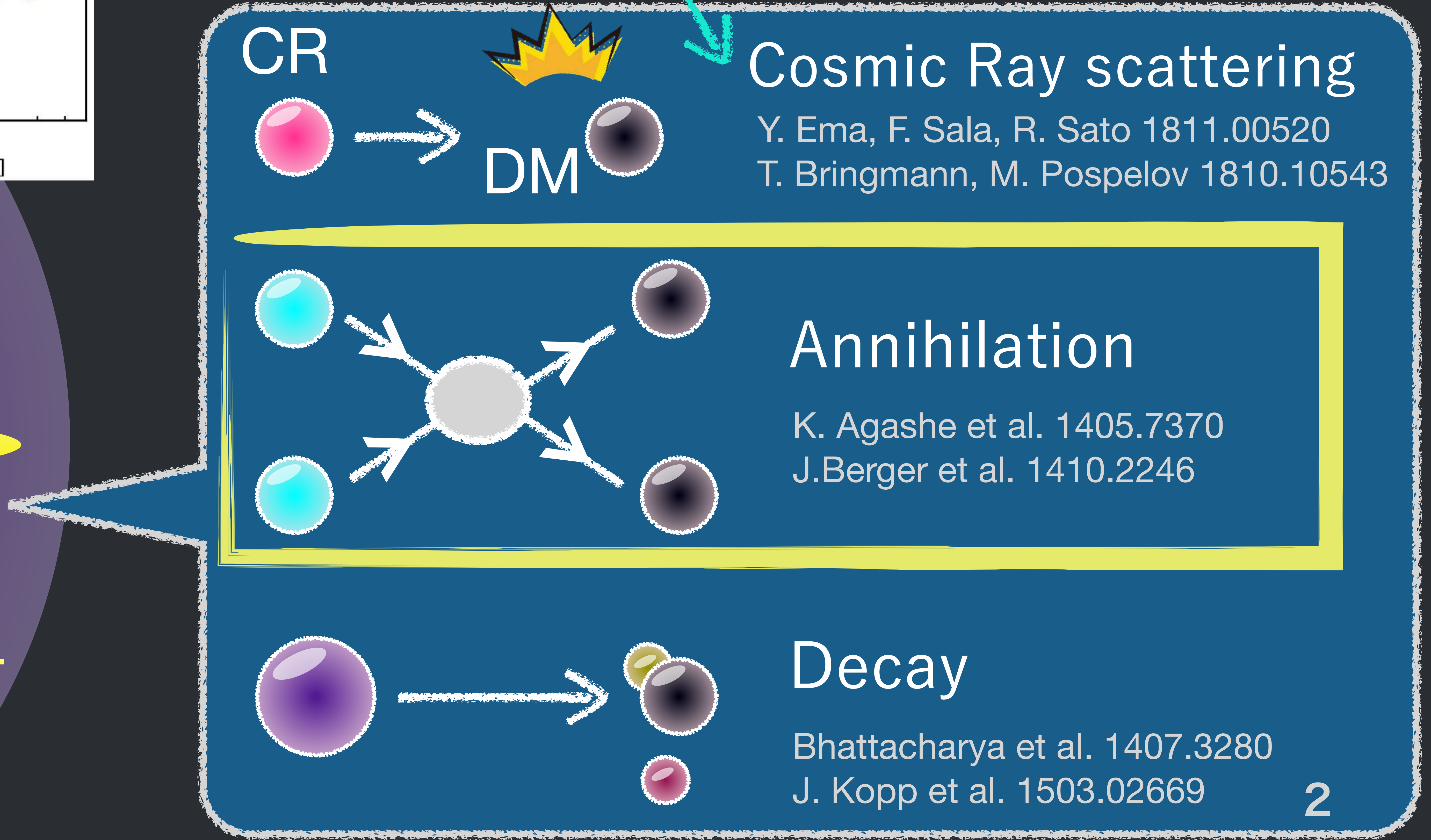
  Light DM is hard to detect in standard WIMP scenario.



- Boosted light DM

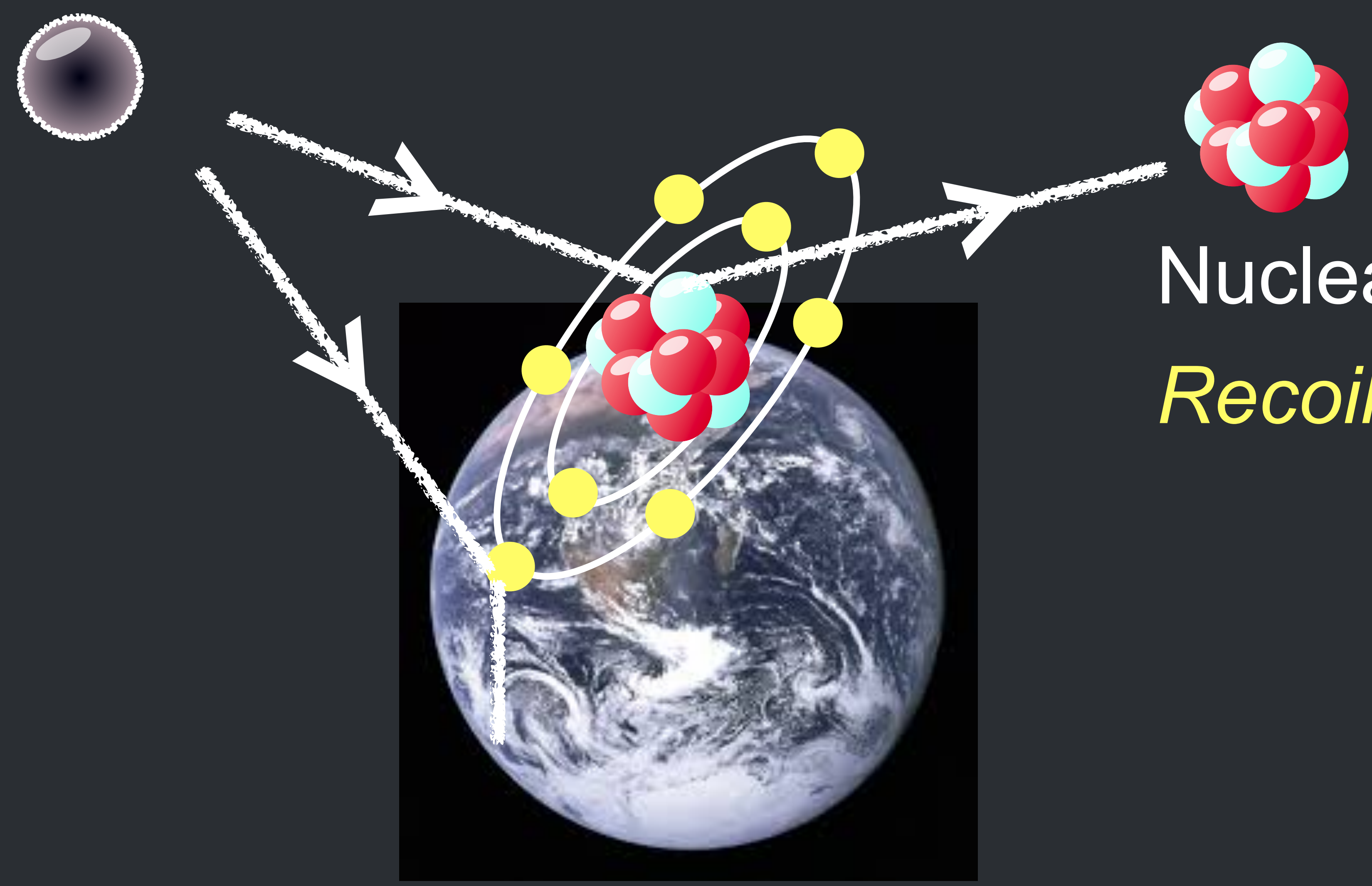


  Light DM can have enough energy to overcome the energy threshold of detectors.



Directional Detection

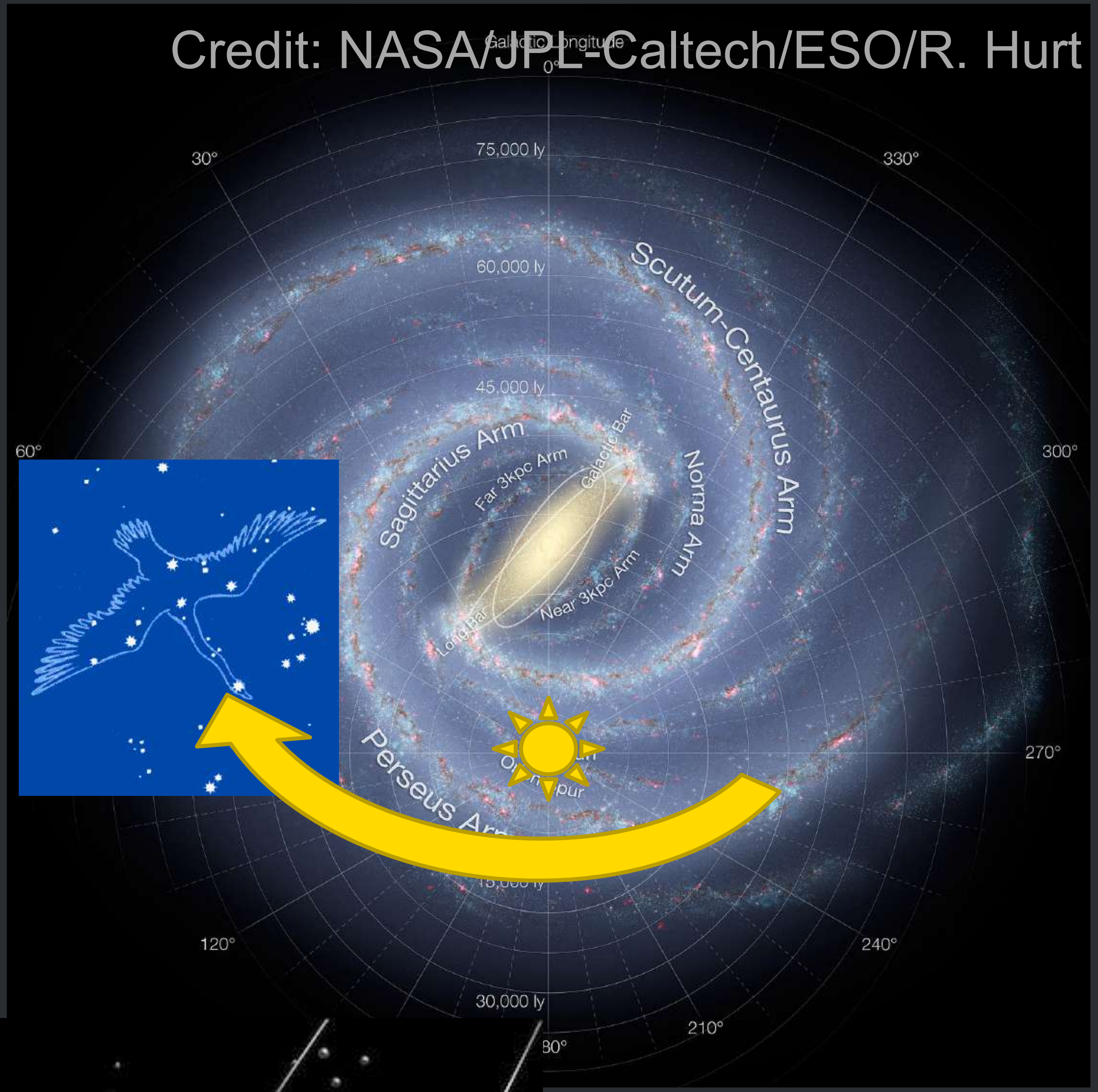
- Once DM is detected, directional detection is required.



Nuclear Recoil

Recoil Energy E_R

+ Direction!

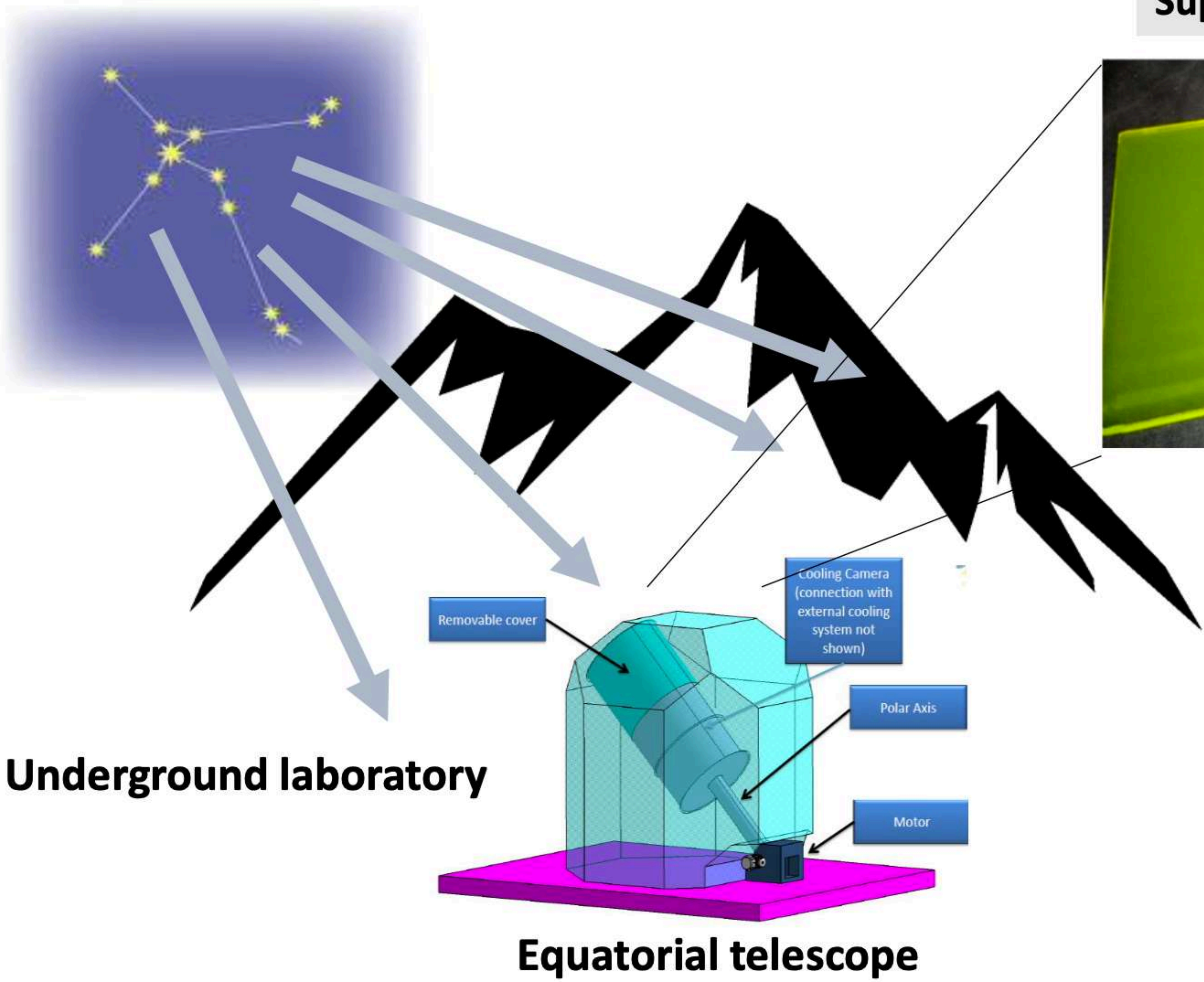


- Powerful background rejection
  - Checking DAMA/LIBRA
  - Neutrino floor

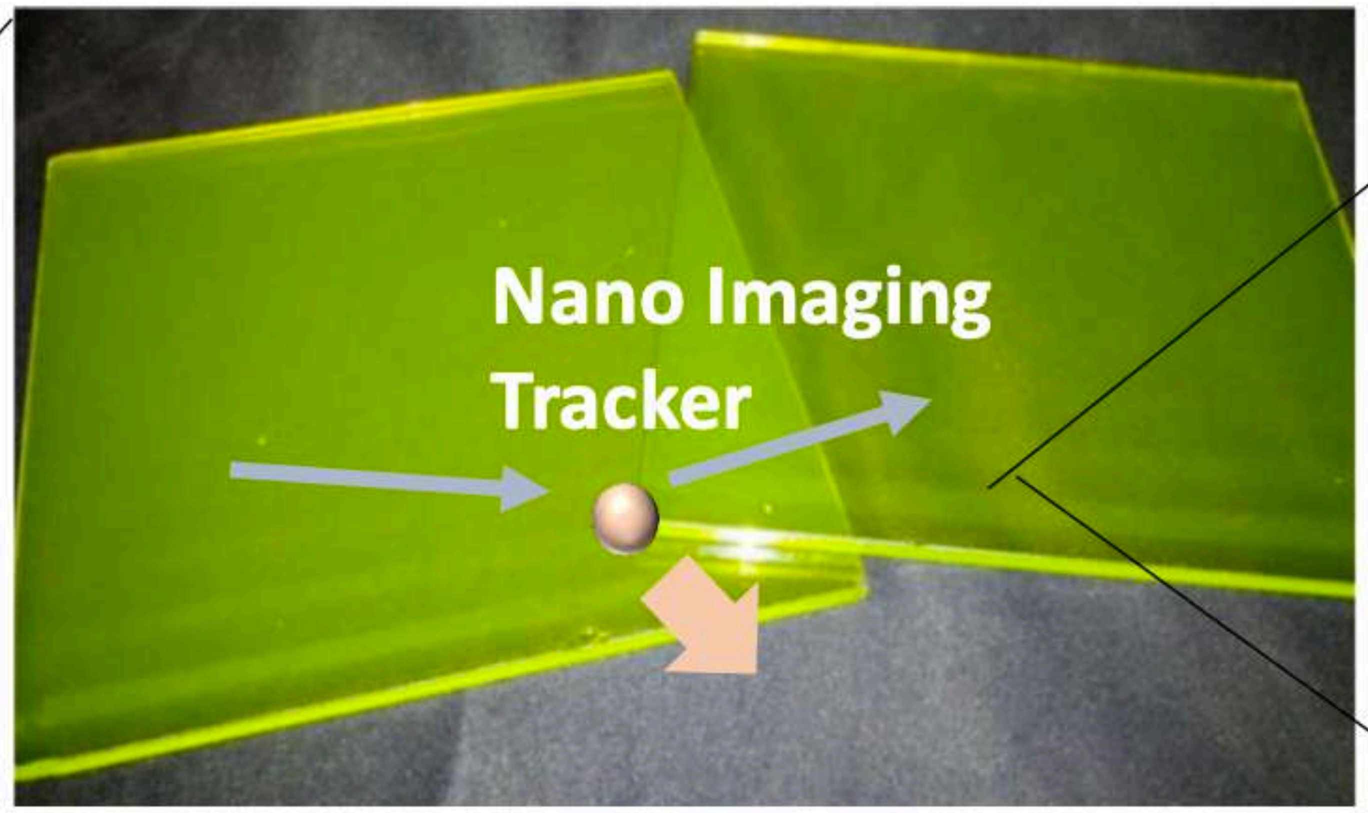
NEWSdm experiment

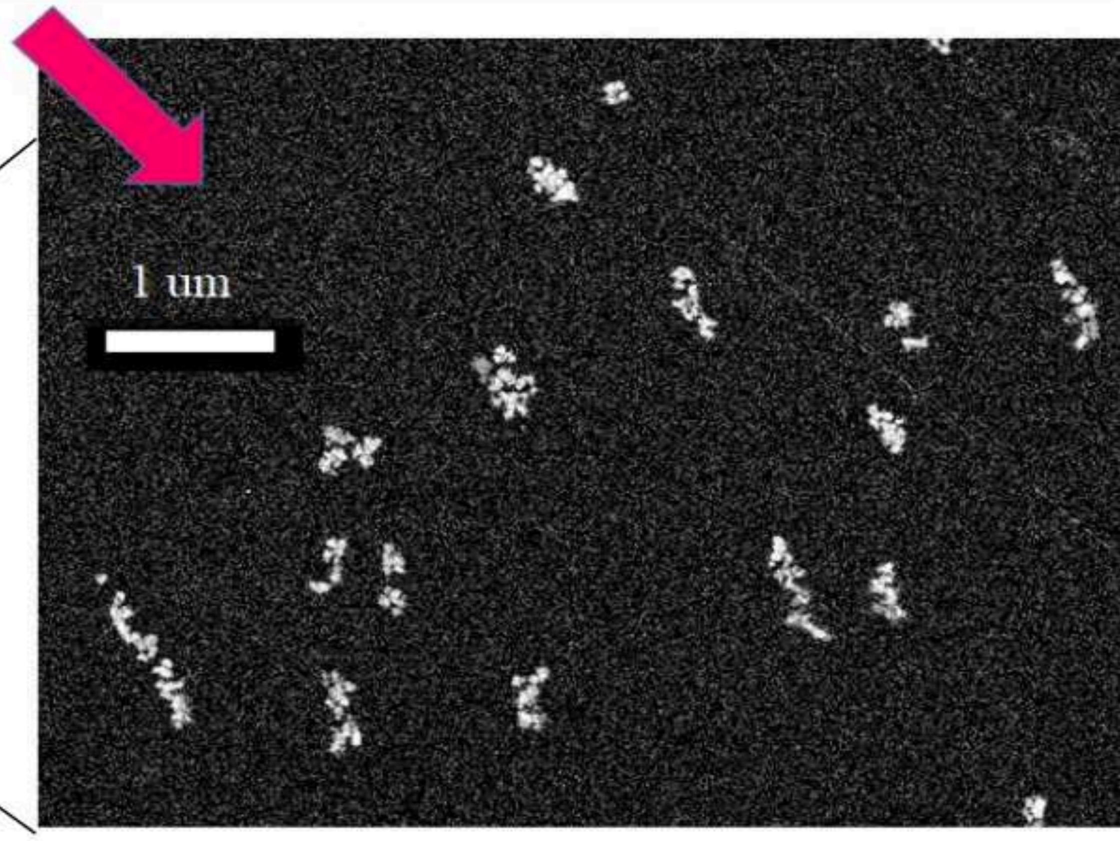
Collaborated by 5 counties, 14 institutes

Direction Sensitive Dark Matter Search with Super-high resolution nuclear emulsion



Super-resolution nuclear emulsion and sub-micron tracking



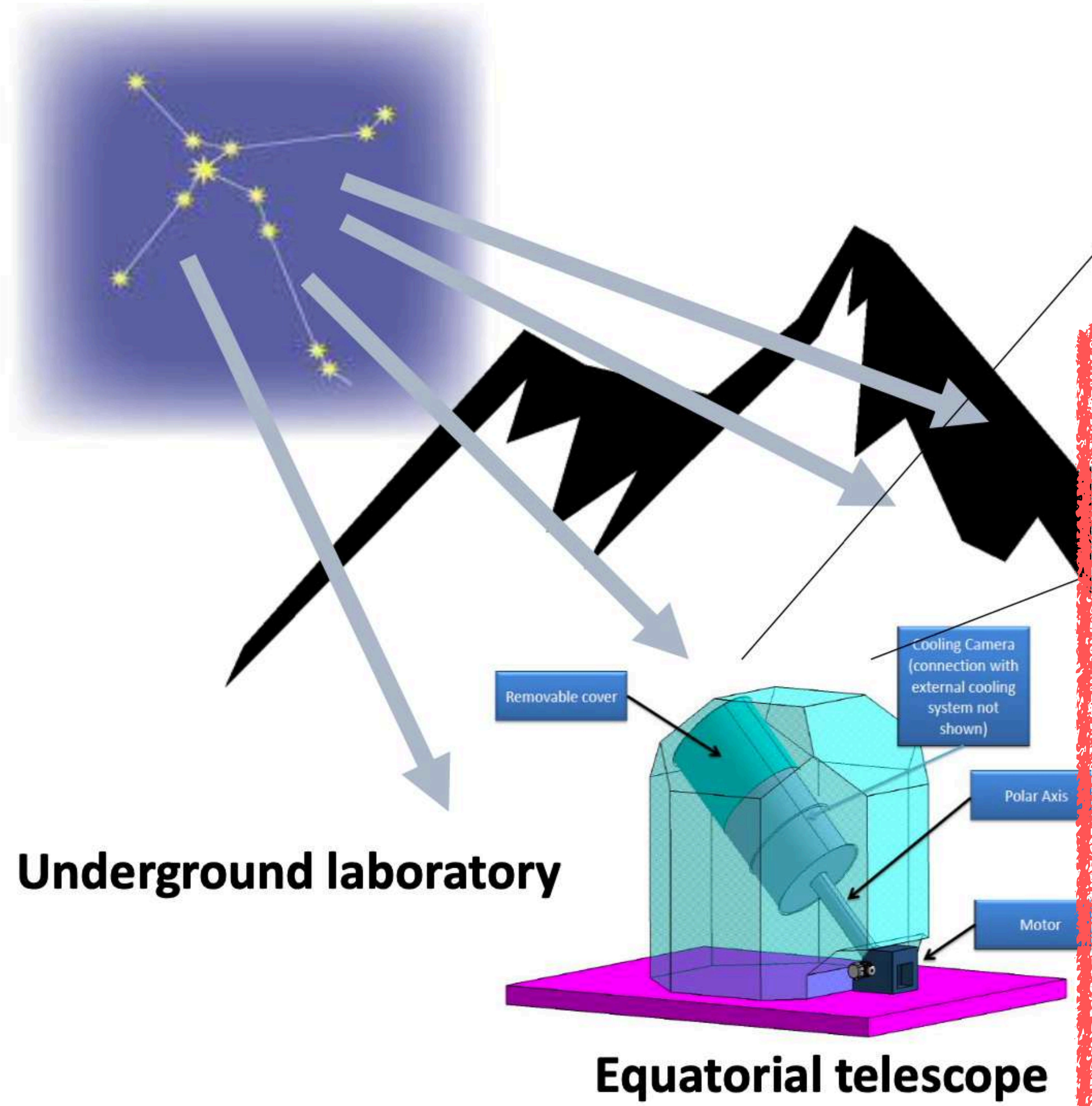


T. Naka’s slide

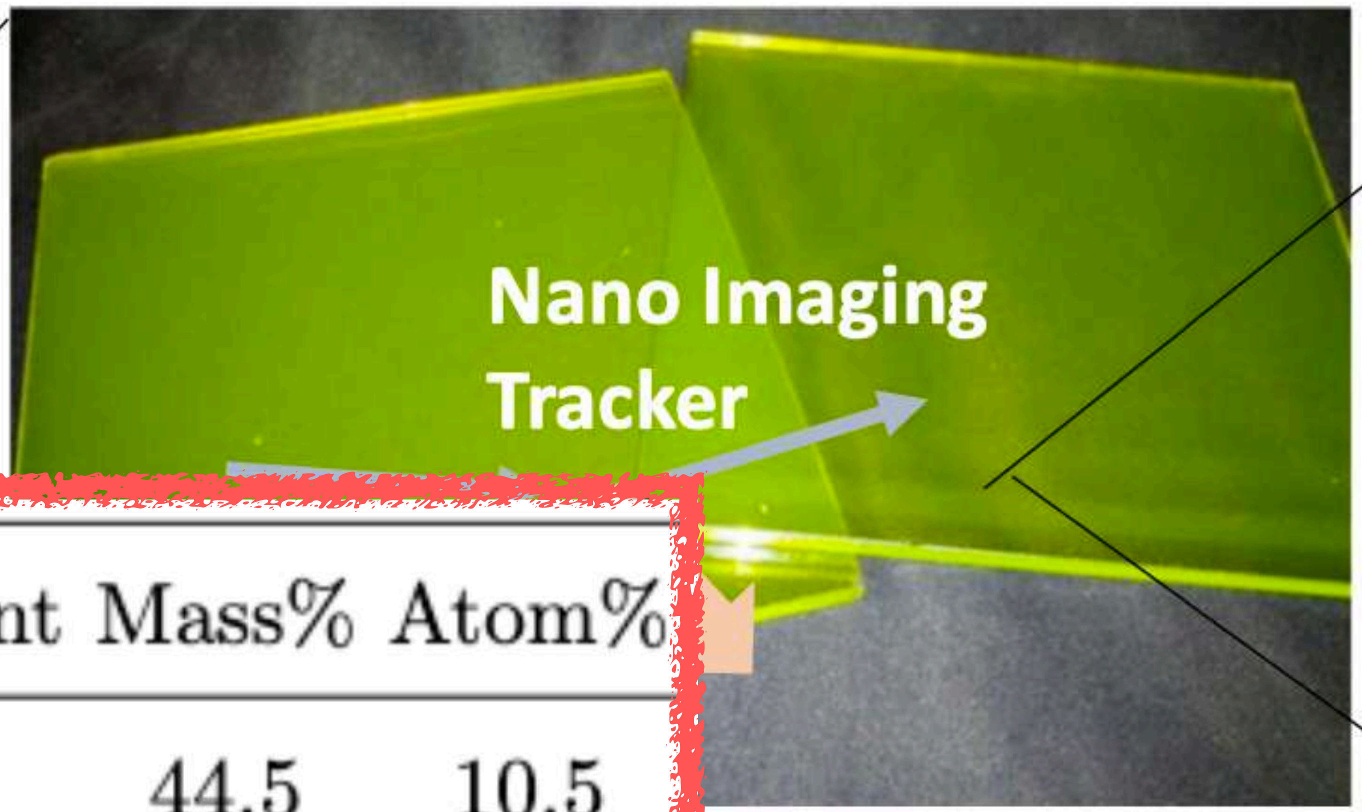
NEWSdm experiment

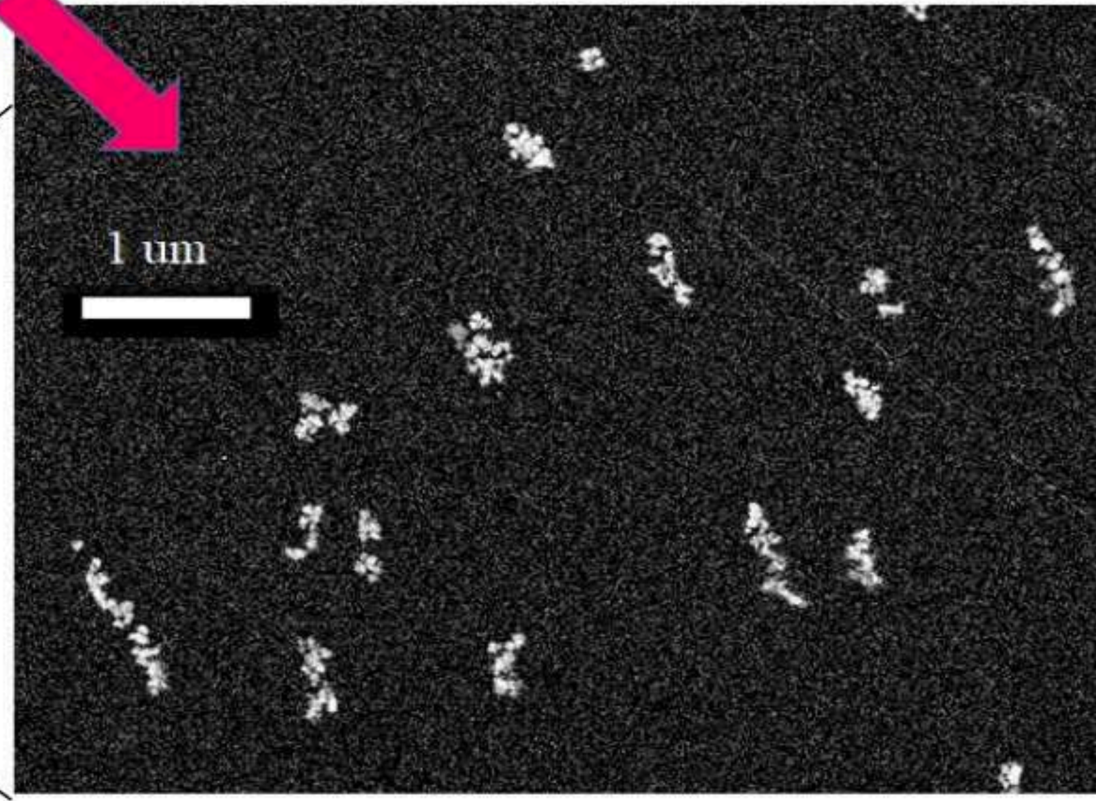
Collaborated by 5 counties, 14 institutes

Direction Sensitive Dark Matter Search with Super-high resolution nuclear emulsion



Super-resolution nuclear emulsion and sub-micron tracking





Element	Mass%	Atom%
Ag	44.5	10.5
Br	31.8	10.1
I	1.9	0.4
C	10.1	21.4
N	2.7	4.9
O	7.4	11.7
p	1.6	41.1

A two component DM Model

- Dark sector with U(1)$_D$ gauge symmetry

	Dirac Fermions		Scalar
Fields	ψ	χ	φ
U(1)$_D$ charges	Q_ψ	Q_χ	1
	Heavy DM	Light DM	$\langle\varphi\rangle$ breaks U(1)$_D$

Dominant

$|Q_\chi| \neq |Q_\psi|, |2Q_\chi| \neq 2, |2Q_\psi| \neq 2$ and $|Q_\chi \pm Q_\psi| \neq 1$ to forbid fermion mixing

- Massive extra gauge boson A' : dark photon

$$\langle\varphi\rangle = v_\varphi \Rightarrow m_{A'} = g_D v_\varphi$$

$$\mathscr{L}_{\mathrm{U(1)}} = -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}X_{\mu\nu}X^{\mu\nu} - \frac{\epsilon}{2}X_{\mu\nu}B^{\mu\nu}$$

$$\mathscr{L}_{\mathrm{A'-SM}} = e\epsilon\cos\theta_W J^\mu_{\mathrm{EM}}A'_\mu$$

tiny kinetic mixing $\epsilon \ll 1$

$B_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu$ for U(1)$_Y$

$X_{\mu\nu} = \partial_\mu A'_\nu - \partial_\nu A'_\mu$ for U(1)$_D$

DM interactions

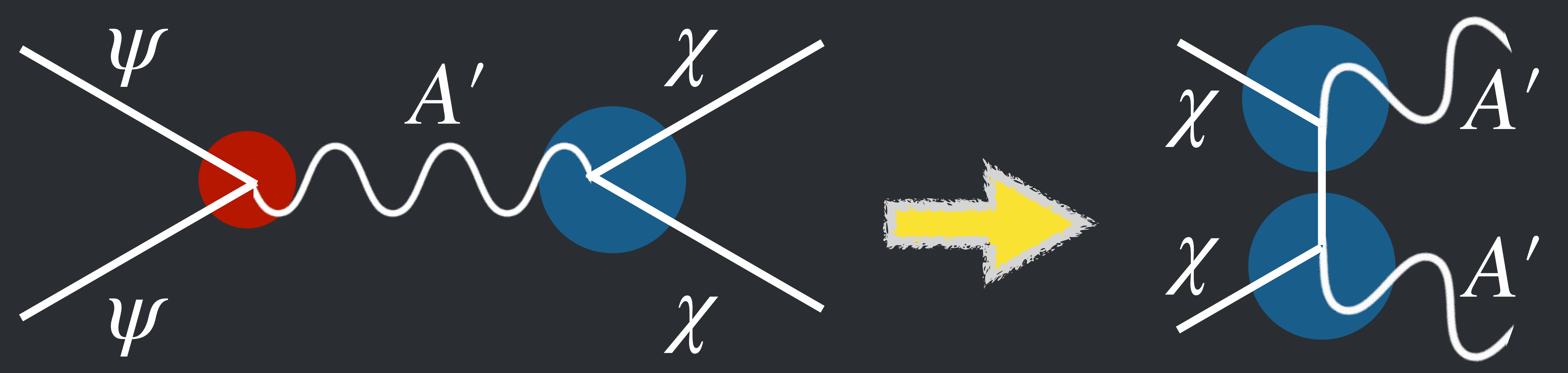
- New fermion interactions

$$\mathscr{L}_{\rm DM} = \bar{\chi}(iD_\mu\gamma^\mu - m_\chi)\chi + \bar{\psi}(iD_\mu\gamma^\mu - m_\chi)\psi$$

$$= \bar{\chi}\left[i(\partial_\mu + iQ_\chi g_D A'_\mu)\gamma^\mu - m_\chi\right]\chi + \bar{\psi}\left[i(\partial_\mu + iQ_\psi g_D A'_\mu)\gamma^\mu - m_\chi\right]\psi \supset -A'_\mu\left(g_\chi\bar{\chi}\gamma^\mu\chi + g_\psi\bar{\psi}\gamma^\mu\psi\right)$$

- Relic Abundance

$m_\psi > m_\chi \simeq m_{A'}$ $\quad g_\psi \ll g_\chi$



1. ψ freeze out =dominant DM

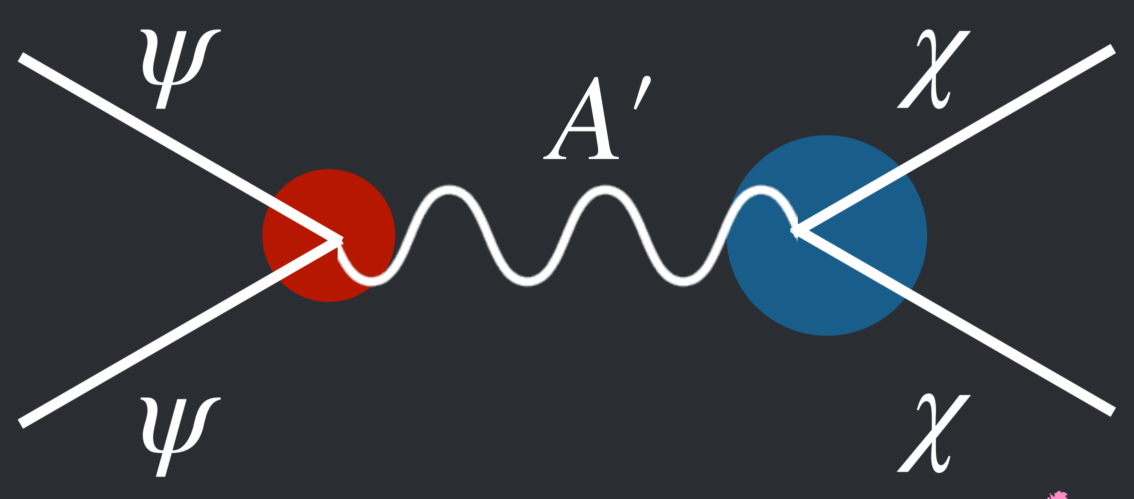
2. χ freeze out =subdominant DM

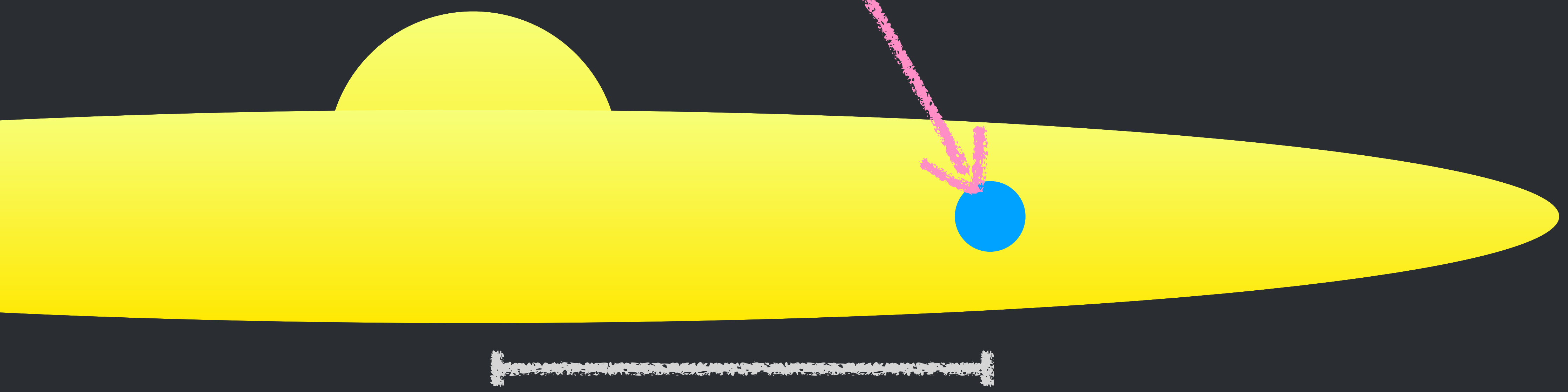
Correct abundance can be obtained if $\langle\sigma_{\psi\bar{\psi}\to\chi\bar{\chi}}v\rangle \simeq 5\times10^{-26}\ \mathrm{cm^2/s}$, achieved by tuning g_ψ.

Boosted DM from the Galactic center

Salas, Widmark
arXiv:2012.11477

- Flux of the boosted DM





$r_{\rm Sun} = 8.33\ \mathrm{kpc}$

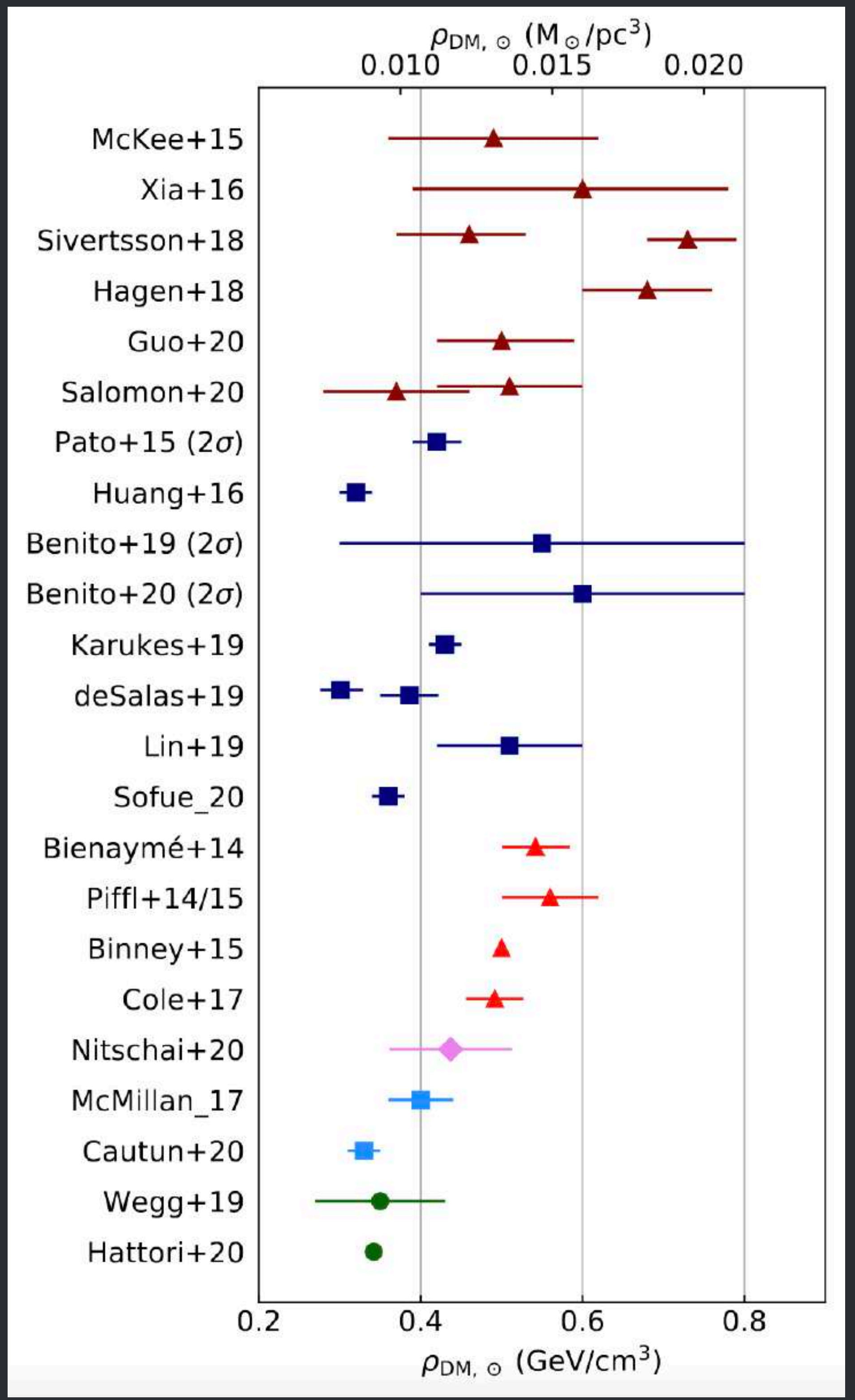
$$\frac{d\Phi_{\rm GC}}{d\Omega dE_\psi} = \frac{1}{4}\frac{r_{\rm Sun}}{4\pi}\left(\frac{\rho_{\rm local}}{m_\psi}\right)^2 J\langle\sigma_{\psi\bar\psi\to\chi\bar\chi}v\rangle_{v\to 0}\frac{dN_\chi}{dE_\chi}$$

$$\frac{dN_\chi}{dE_\chi} = 2\delta(E_\chi - m_\psi)$$

- $\rho_{\rm local} = 0.4\ \mathrm{GeV/cm^3}$
- NFW profile

J. Navarro, C. Frenk, S. White Astrophys. J. 490(1997)

$$\Phi_{\rm GC}^{10^\circ} = 9.9\times10^{-8}\mathrm{cm^{-2}s^{-2}}\left(\frac{\langle\sigma_{\psi\bar\psi\to\chi\bar\chi}v\rangle}{5\times10^{-26}\ \mathrm{cm^2/s}}\right)\left(\frac{20\ \mathrm{GeV}}{m_\psi}\right)^2$$



Expected Event Number N

- $$\frac{dN}{d\log E_R} = E_R\frac{dN}{dE_R} - \Delta N_{\rm target}\ \Phi_{\rm GC}^{10^\circ} E_R \frac{d\sigma_{\chi N\to\chi N}}{dE_R}$$

$$\Rightarrow\quad N = \Delta T\ N_{\rm target}\Phi_{\rm GC}^{10^\circ}\int dE_R \frac{d\sigma_{\chi N\to\chi N}}{dE_R}$$

- ΔT: Exposure time
- $N_{\rm target}$: #target in detector
- $d\sigma_{\chi N\to\chi N}/dE_R$
  $\simeq 2\pi m_N/E_\chi^2\ d\sigma_{\chi N\to\chi N}/d\Omega$

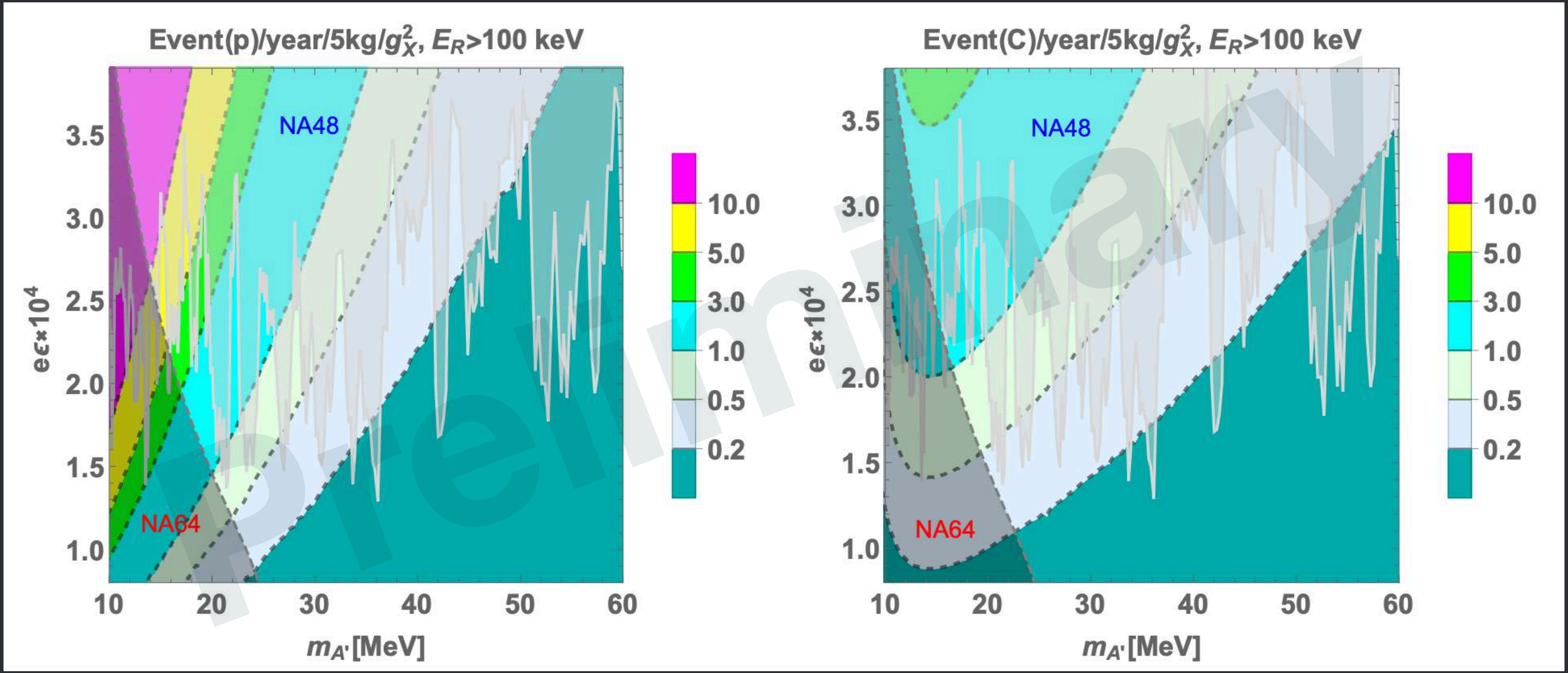
$$\frac{d\sigma_{\chi N\to\chi N}}{d\Omega} = \frac{1}{(4\pi)^2}\frac{(\epsilon e)^2 g'^2}{(q^2-m_{A'}^2)^2}\frac{p'/p}{1+(E_\chi - pE'_\chi\cos\theta/p')/m_N}$$
$$\times\left[G_E^2\frac{4E_\chi E'_\chi+q^2}{1-q^2/(4m_N^2)} + G_M^2\left((4E_\chi E'_\chi+q^2)\left(1-\frac{1}{1-q^2/(4m_N^2)}\right)+\frac{q^4}{2m_N^2}\frac{q^2m_\chi^2}{m_N^2}\right)\right]$$

$$G_E(q^2) = \frac{G_M(q^2)}{2.79} = \frac{1}{(1+q^2/(0.71{\rm GeV}^2))^2}$$

Event number

(Practical E threshold)

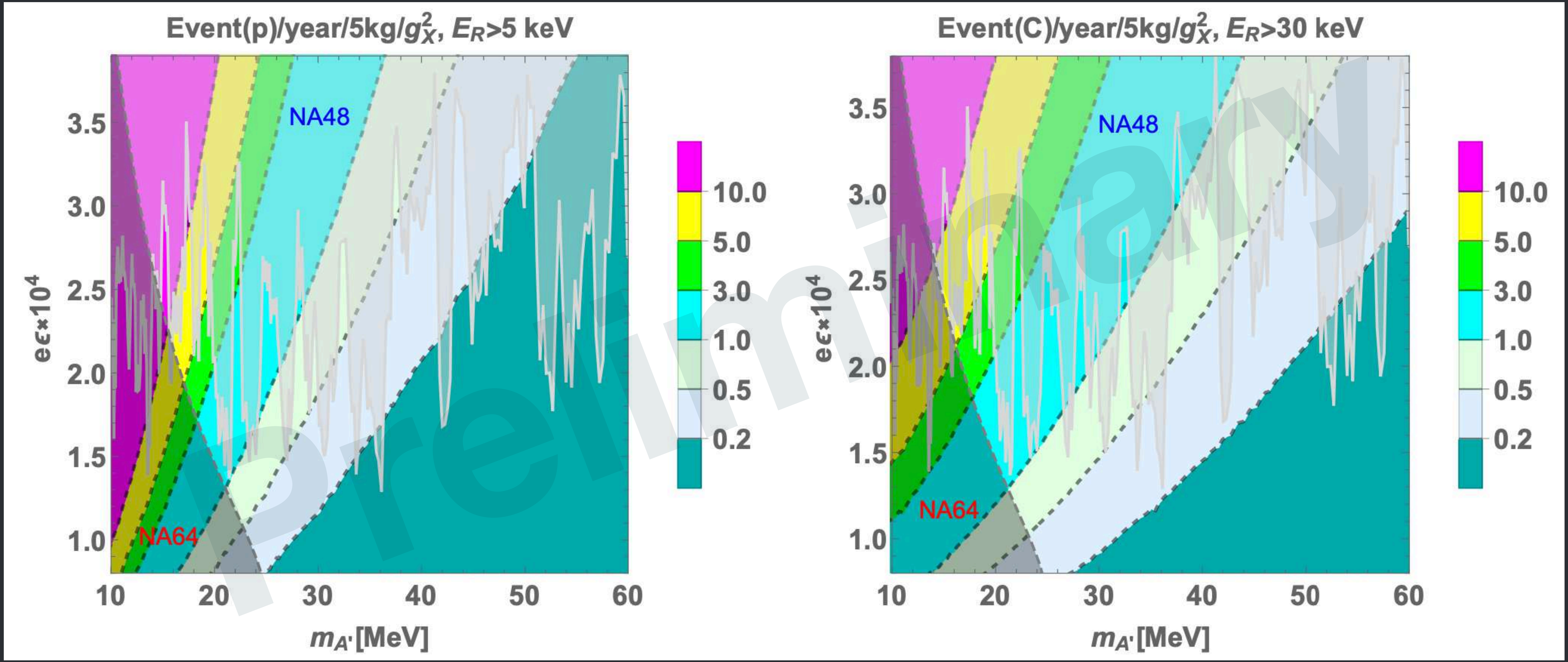
$m_\chi = m_{A'}, m_\psi = 3m_\chi$



Event number

(Ideal E threshold)

$m_\chi = m_{A'}, m_\psi = 3m_\chi$



Bench Mark Points

Ideal E threshold, 5 kg nuclear emulsion						
	$\{m_\chi/\text{MeV},\ \epsilon,\ g_\chi\}$	N_p	N_C	N_N	N_O	N_Sum
BP1	$\{24, 1.4 \times 10^{-4}, 2.5\}$	0.067	0.39	0.15	0.58	1.2
BP2	$\{18, 2.0 \times 10^{-4}, 2.0\}$	0.27	1.0	0.39	1.5	3.2
Practical E threshold, 50 kg nuclear emulsion						
	$\{m_\chi/\text{MeV},\ \epsilon,\ g_\chi\}$	N_p	N_C	N_N	N_O	N_Sum
BP1	$\{24, 1.4 \times 10^{-4}, 2.5\}$	0.50	1.4	0.48	0.17	2.6
BP2	$\{18, 2.0 \times 10^{-4}, 2.0\}$	1.7	2.6	0.88	0.30	5.5

Conclusion

- Two component DM scenario with $U(1)_D$ gauge sym.
- Light DM component is boosted in the Galactic center. Directional Detection would be suitable.
- Several events from direction of the Galactic center are expected in NEWSdm experiment in the future.