Title: Light mediators and terrestrial dark matter capture

Date: Jul 20, 2017 04:25 PM

URL: http://pirsa.org/17070013

Abstract:

LIGHT MEDIATORS & DARK MATTER CAPTURE

Flip Tanedo

UC Riverside Particle Theory

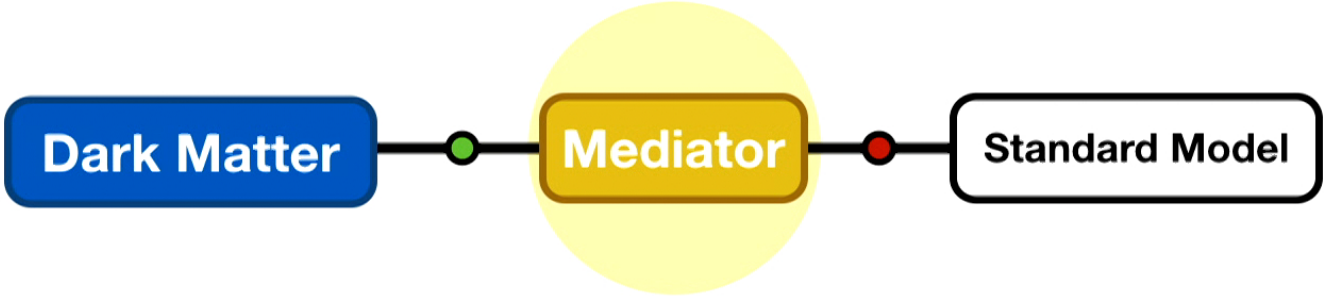
1509.07525 & 1602.01465

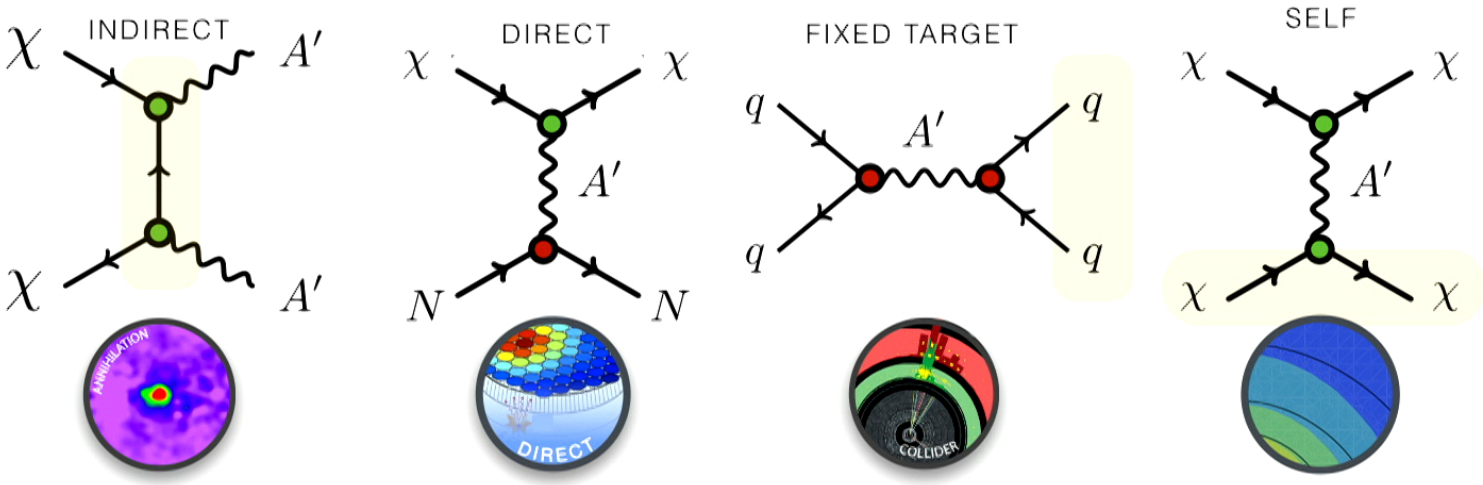
w/ Jonathan Feng, Jordan Smolinsky, Adam Green

PERIMETER PI INSTITUTE FOR THEORETICAL PHYSICS

New Directions in DM & Neutrino Physics (20 July 2017)

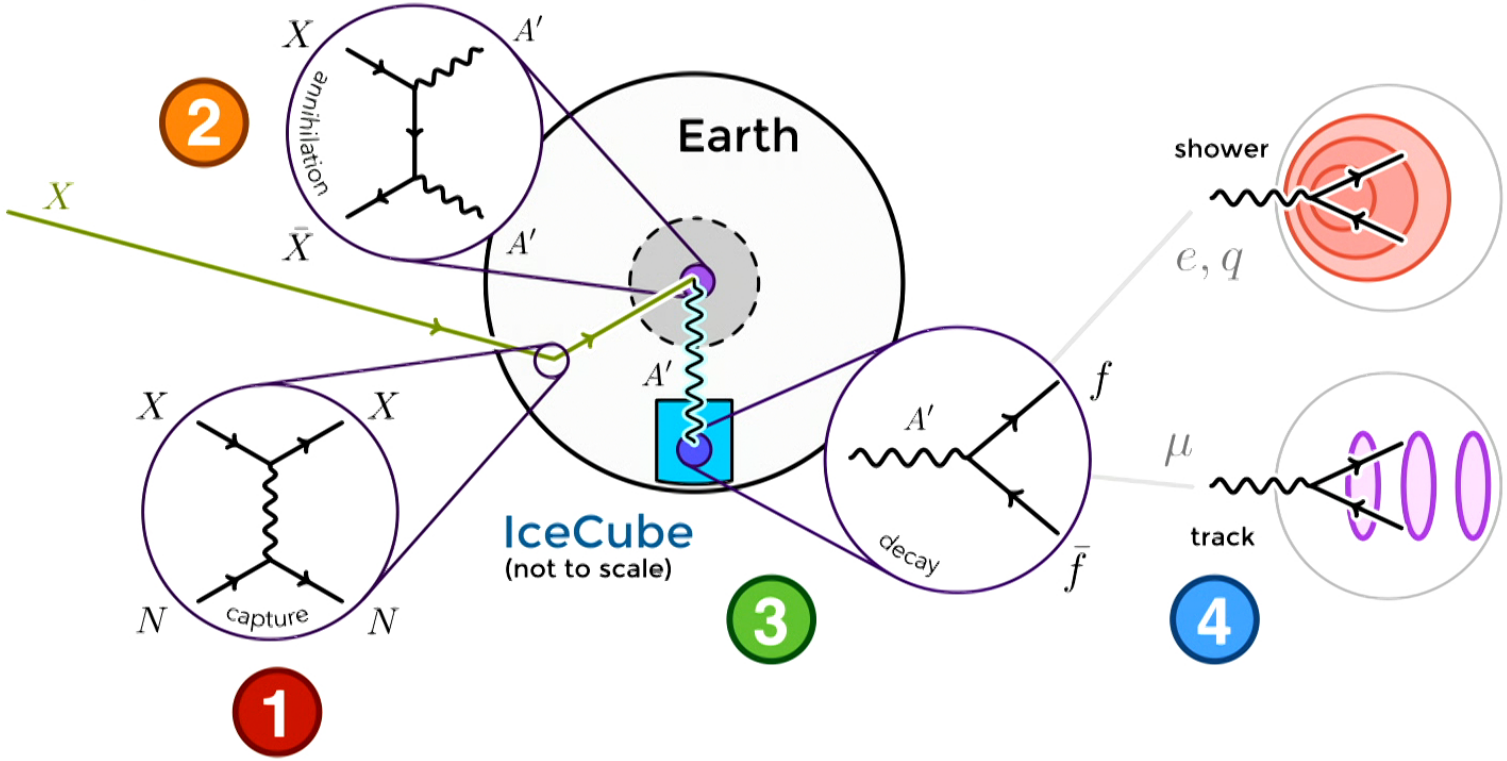
Dark Matter, Light Mediators





can be thermal relic

Capture and Annihilation, Redux



CAPTURE& ANNIHILATION: Press & Spergel '85; Krauss, Srednicki, Wilczek '86; Freese '86; Griest & Seckel '87; Gaisser, Steigman, Tilav '86; Gould ('87,'88,'92)

DARK PHOTONS: Batell, Pospelov, Ritz, Shang (0910.1567) Delaunay, Fox, Perez (0812.3331); Schuster, Toro, Yavin (0910.1602, 0910.1839); Meade, Nussinov, Papucci, Volansky (0910.4160);

3/24
Reebok

Dark Matter + Dark Photons

dark U(1)

$$\mathcal{L}_{\rm dark} = -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + i\bar{\chi}(\partial\!\!\!/ + ig_\chi A\!\!\!/')\chi$$

~GeV

$$+m_{A'}^2 A'^2 - m_\chi \bar{\chi}\chi$$

$$\mathcal{L}_{\rm mix} = \frac{\epsilon}{2}F_{\mu\nu}F'^{\mu\nu}$$

Kinetic Mixing

$\epsilon \sim 10^{-9} - 10^{-7}$

THERMAL RELIC

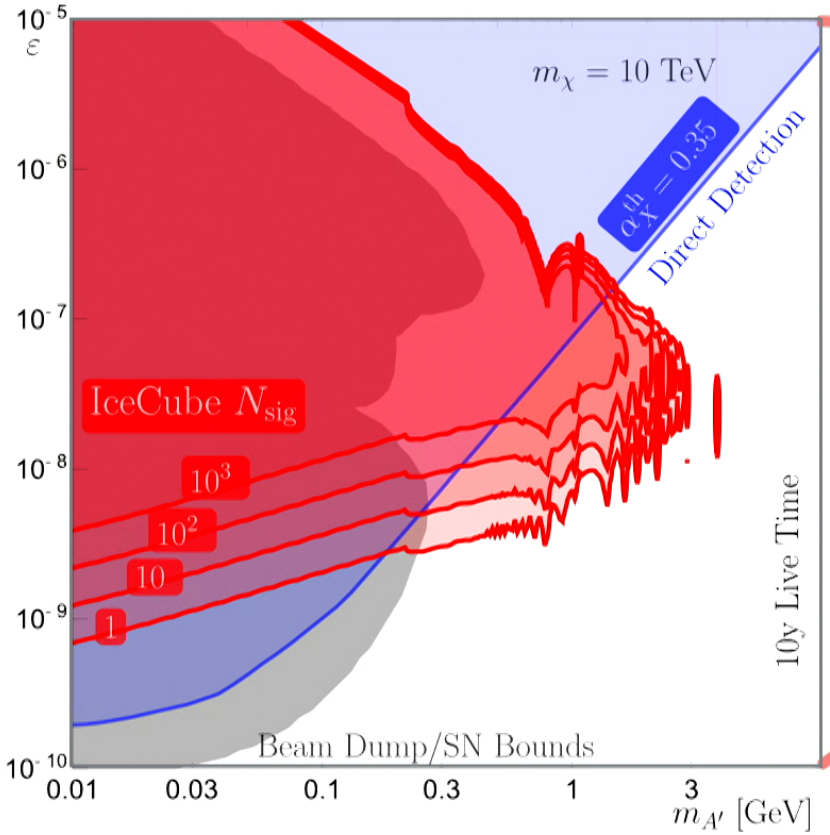
α_χ s.t. $\langle\sigma v\rangle_{\rm ann} = 2.1 \times 10^{-26}\ {\rm cm}^3/{\rm s}$

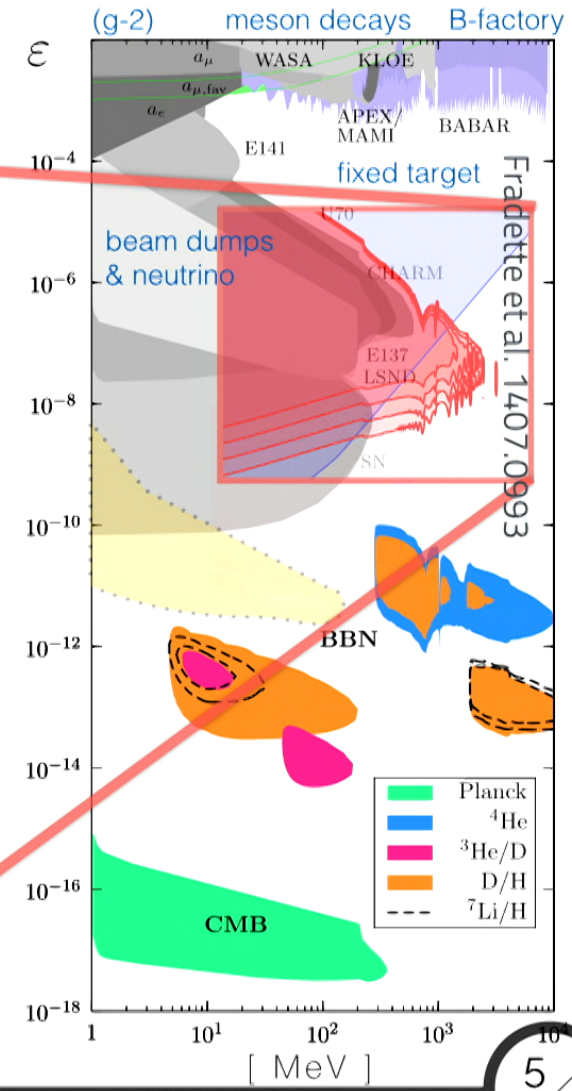
$100\ {\rm GeV} \lesssim m_\chi \lesssim 10\ {\rm TeV}$

WEAK-SCALE DM MASSES

Dark Photon Reach

DEPENDS ON MASS OF DARK MATTER





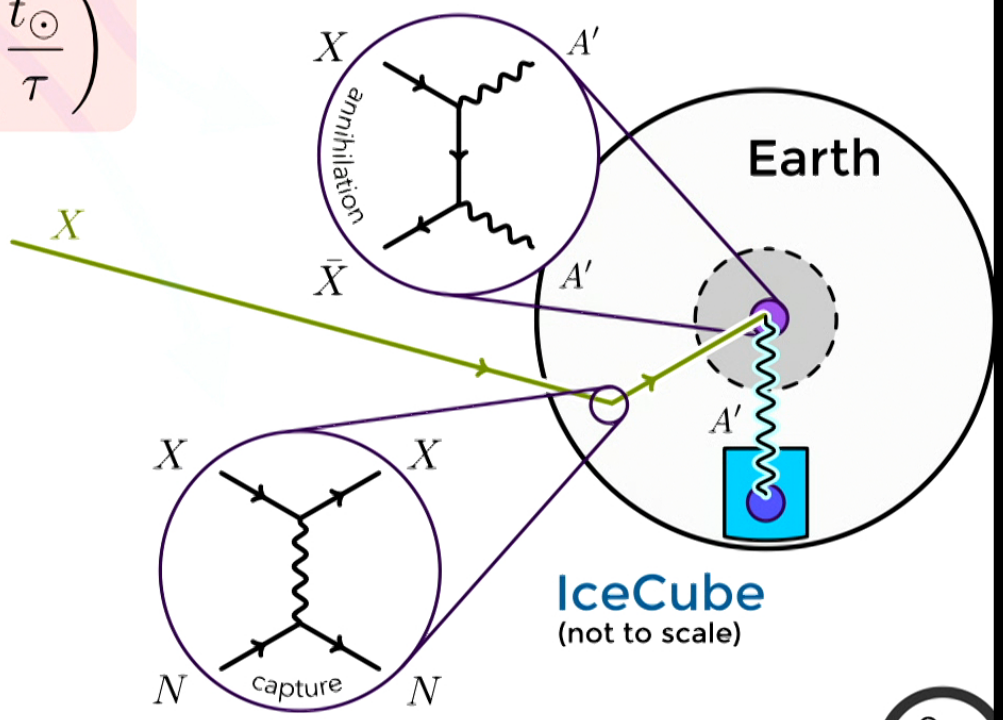
Dark Matter Capture

$$\dot{N}_\chi = C_{\rm cap} - C_{\rm ann} N_\chi^2$$

EQUILIBRIUM TIME

$$\tau = \frac{1}{\sqrt{C_{\rm cap} C_{\rm ann}}}$$

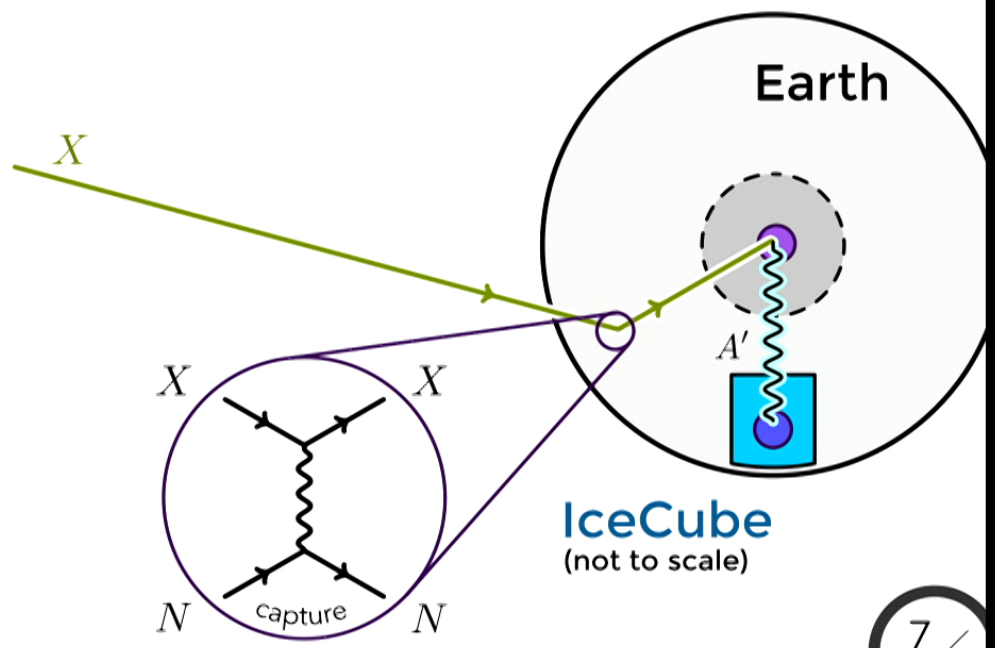
$$\Gamma_{\rm ann} = \frac{\Gamma_{\rm cap}}{2} \tanh^2\left(\frac{t_\odot}{\tau}\right)$$



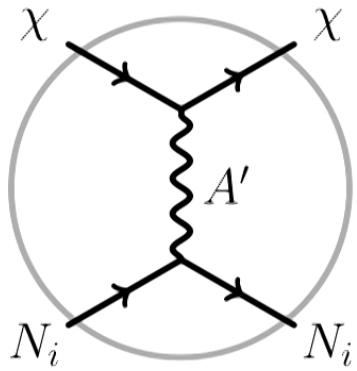
Dark Matter Capture

DM is captured when elastically scattered dark matter has velocity less than the Earth's escape velocity

CAPTURE PROCESS ~ DIRECT DETECTION



Capture of Dark Matter



DM capture when $v_\chi < v_{esc}$

"Direct Detection" in space

EARTH

$$\Gamma^i_{\rm cap} = n_\chi \int d^3r\, n_i(r)$$

VELOCITY

ESCAPE VELOCITY

$$\times \int d^3u\, f(u) \frac{u^2+v^2}{u}$$

ASYMP. VELOCITY

RECOIL ENERGY

$$\frac{d\sigma_i}{dE_R} = \frac{8\pi m_i^2 E_X^2 \alpha_x \varepsilon^2 Z^2 \alpha}{m_i p_X^2 (2m_i E_R + m_{A'}^2)^2}$$

$$\times \int dE_R \frac{d\sigma_i}{dE_R} F(E_R)\Theta$$

KINEMATICS

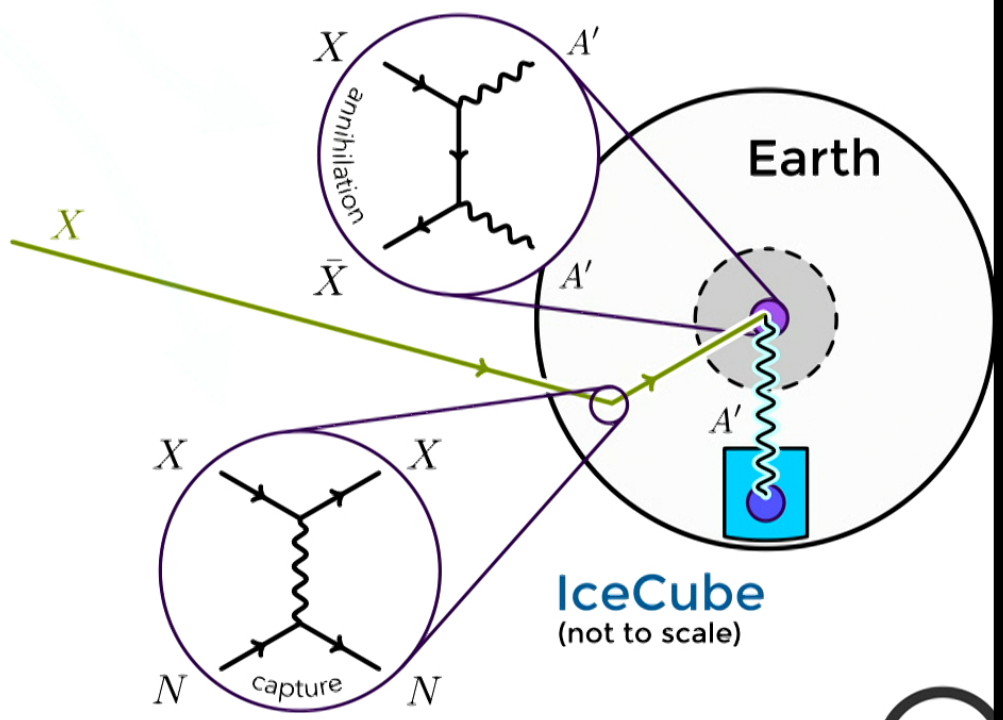
Press & Spergel (85), Krauss, Srednicki, Wilczek (86), Gould (87, 92), PPPCv (1312.6408)

Dark Matter Capture

$$\dot{N}_\chi = C_{\rm cap} - C_{\rm ann} N_\chi^2$$

EQUILIBRIUM TIME

$$\tau = \frac{1}{\sqrt{C_{\rm cap} C_{\rm ann}}}$$



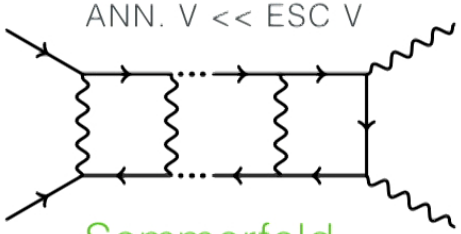
Dark Matter Capture

$$\dot{N}_\chi = C_{\rm cap} - C_{\rm ann} N_\chi^2$$

EQUILIBRIUM TIME

$$\tau = \frac{1}{\sqrt{C_{\rm cap} C_{\rm ann}}}$$

ANN. V << ESC V



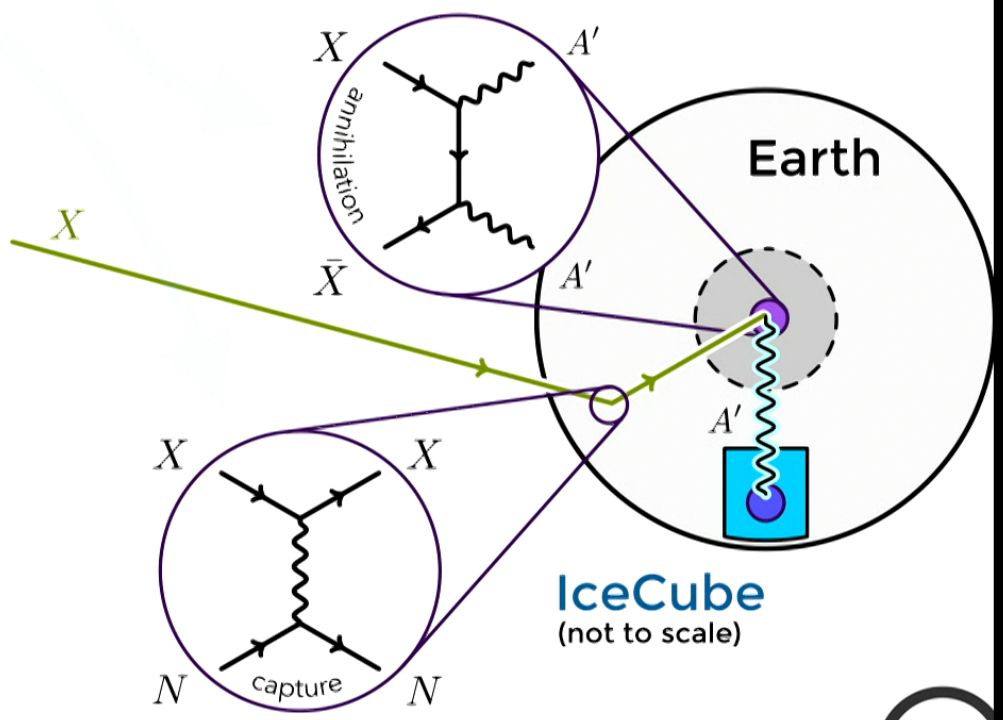
Sommerfeld

HAS RESONANCES

see, e.g. 1302.3898

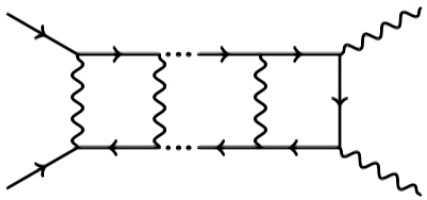
$$v_0 \approx 10^{-6} \sqrt{\frac{\rm TeV}{m_X}}$$

5700 K



Sommerfeld Enhancement

$$S_0 = \frac{2\pi\,\alpha_X/v}{1-e^{-2\pi\alpha_X/v}}$$



$m_{A'} \ll \alpha_X m_X$

GENERAL, valid for finite mediator mass

$$S_S = \frac{\pi}{a}\frac{\sinh(2\pi ac)}{\cosh(2\pi ac)-\cos(2\pi\sqrt{c-a^2c^2})}$$

$a = v/(2\alpha_X)$ $\quad$ $c = 6\alpha_X m_X/(\pi^2 m_{A'})$

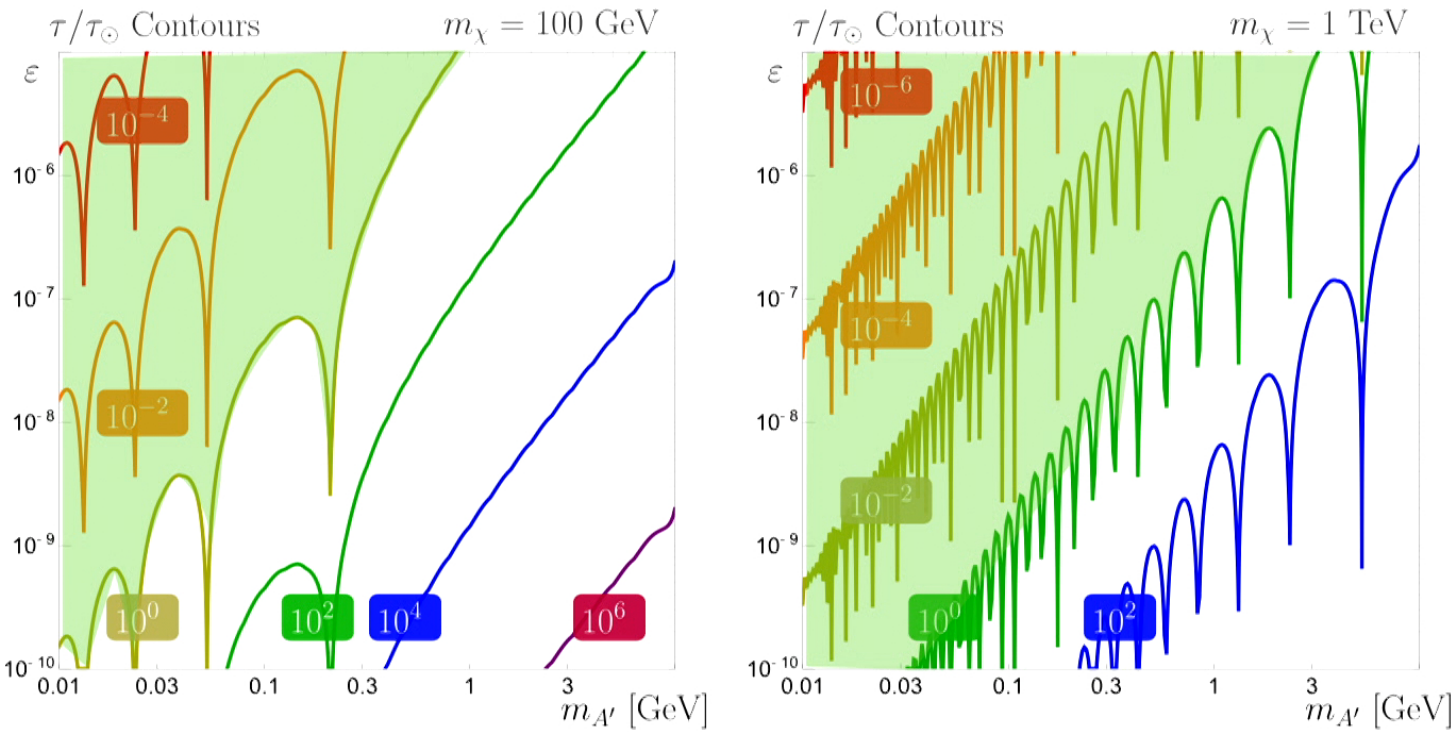
$$\langle S_S\rangle = \int \frac{d^3v}{(2\pi v_0^2)^{3/2}}\, e^{-\frac{1}{2}v^2/v_0^2}\, S_S$$

$$v_0 \approx 10^{-6}\sqrt{\frac{\text{TeV}}{m_X}}$$

5700 K

Feng, Kaplinghat, Yu (1005.4678)

Filling the Earth with Dark Matter



Shaded: Earth is saturated with dark matter

Annihilation from Capture

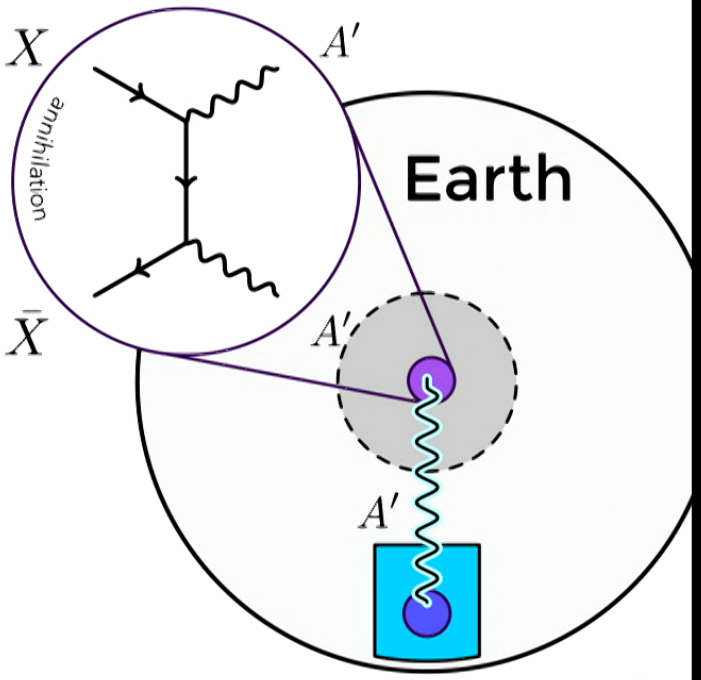
$$\dot{N}_\chi = C_{\rm cap} - C_{\rm ann} N_\chi^2$$

$$\Gamma_{\rm ann} = \frac{\Gamma_{\rm cap}}{2} \tanh^2\left(\frac{t_\odot}{\tau}\right)$$

Indirect detection,
but no J factors.

EQUILIBRIUM TIME

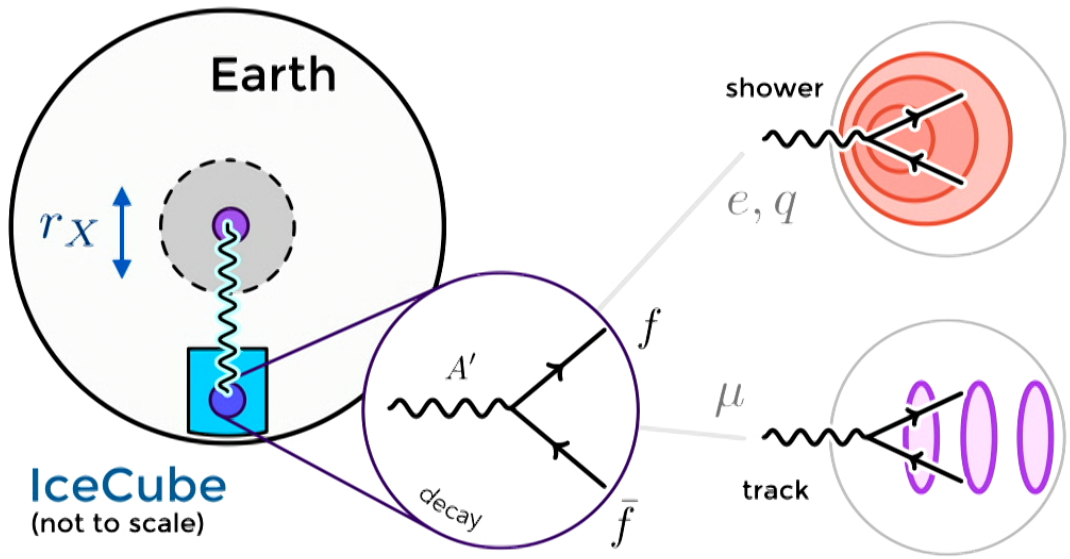
$$\tau = \frac{1}{\sqrt{C_{\rm cap} C_{\rm ann}}}$$



Detection in IceCube

$$r_X = \left(\frac{3T_\oplus}{2\pi G_N \rho_\oplus m_X}\right)^{1/2} \approx 150\ \text{km}\sqrt{\frac{\text{TeV}}{m_X}}$$

DIRECTIONAL DISCRIMINATION



km²

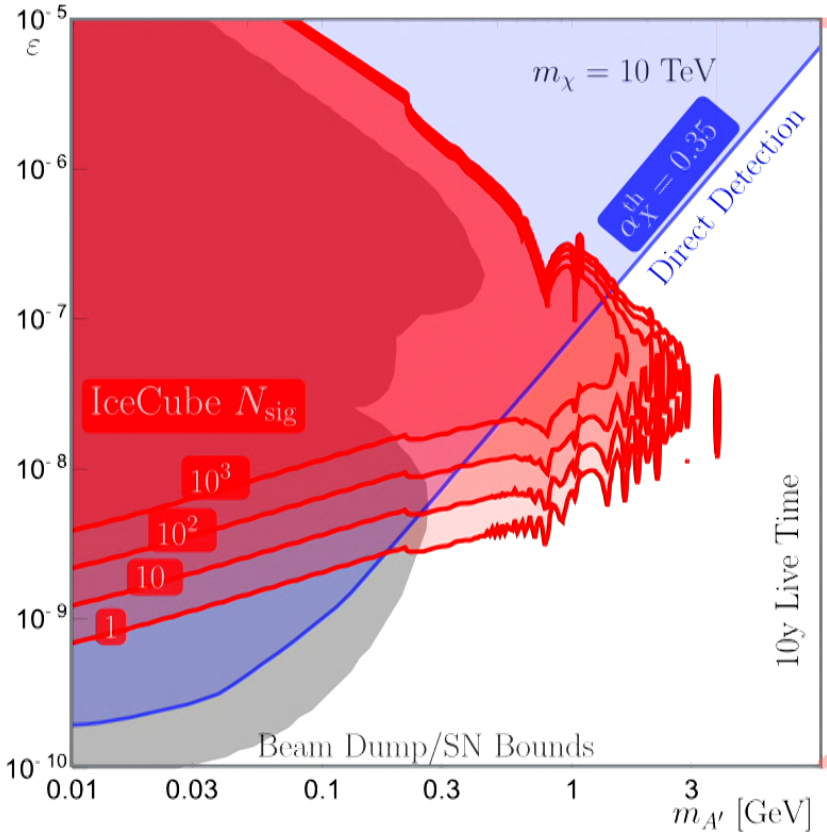
$e^{-R_\oplus/L} - e^{-(R_\oplus+D)/L}$

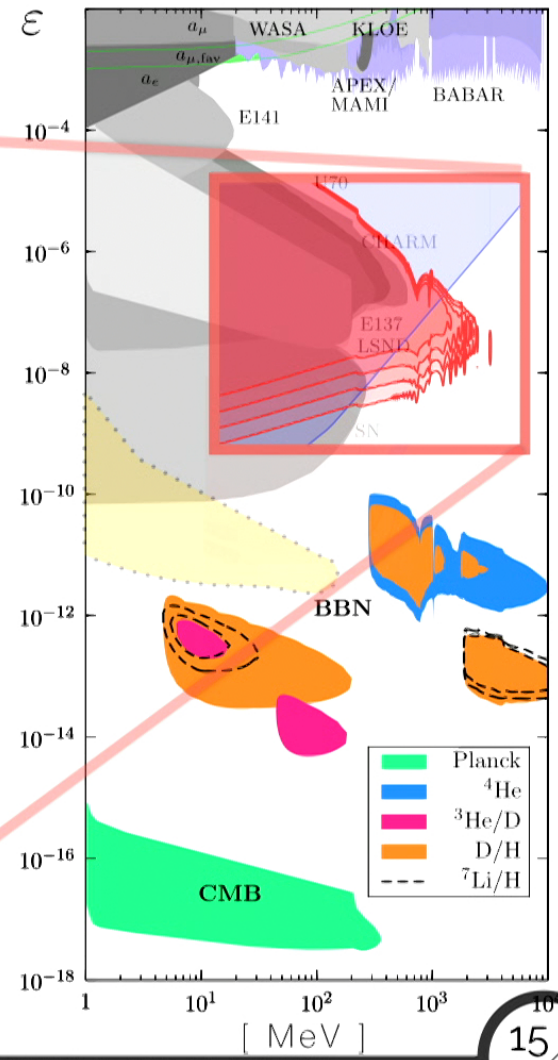
$$N_{\text{sig}} = 2\,\Gamma_{\text{ann}}\,\frac{A_{\text{eff}}}{4\pi R_\oplus^2}\,\epsilon_{\text{decay}}\,T$$

6400 km

10 y

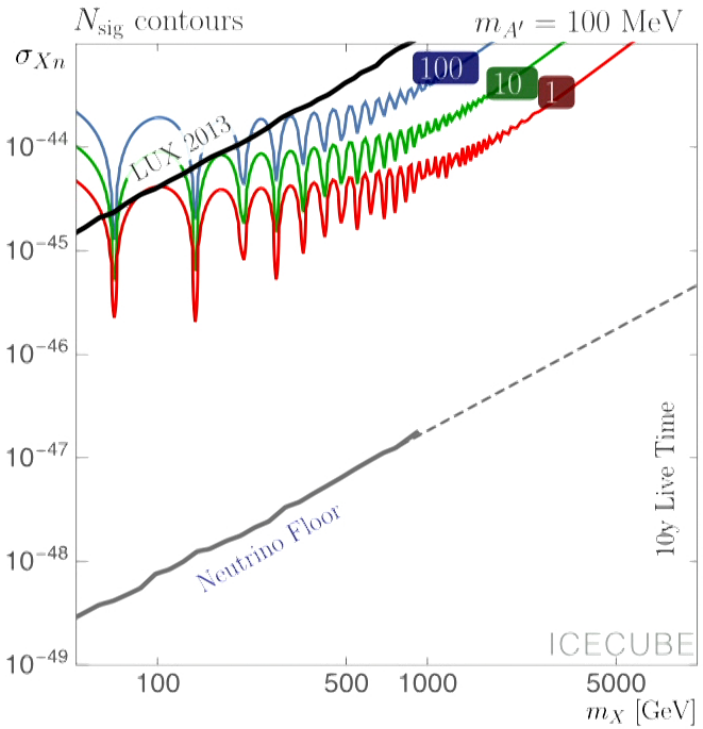
Reach: m_χ = 10 TeV

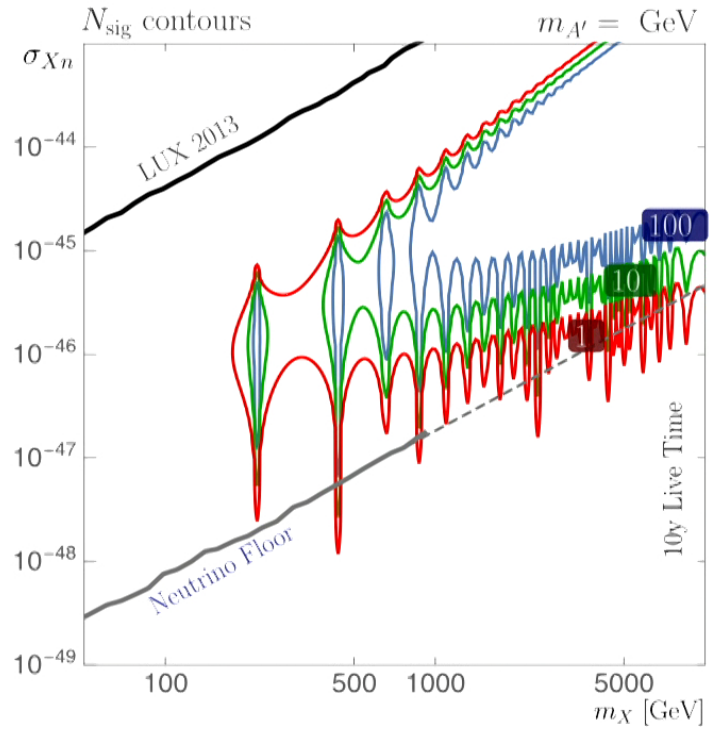




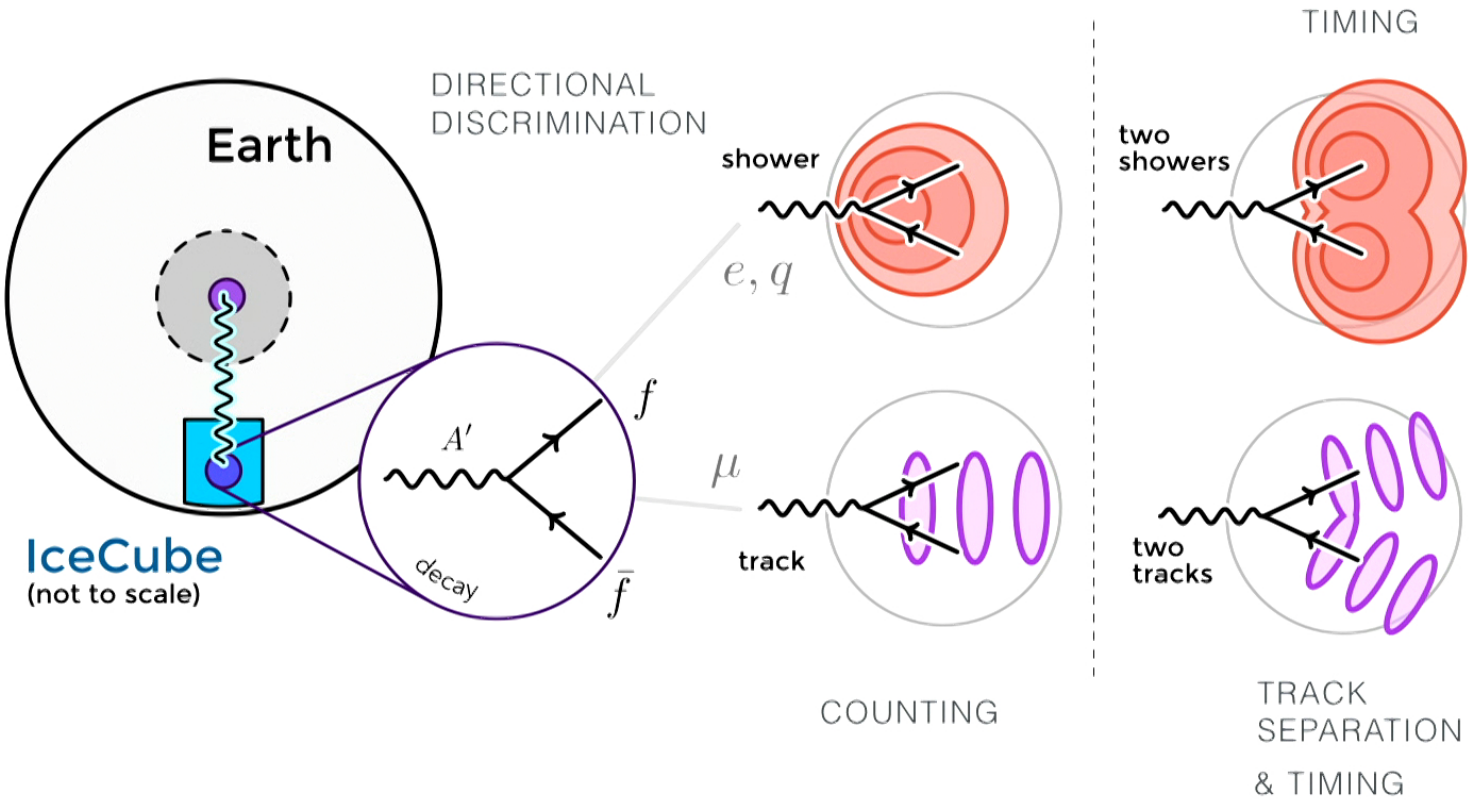
Direct Detection: del Nobile, Kaplinghat & Yu: 1507.04007

Direct Detection Plane

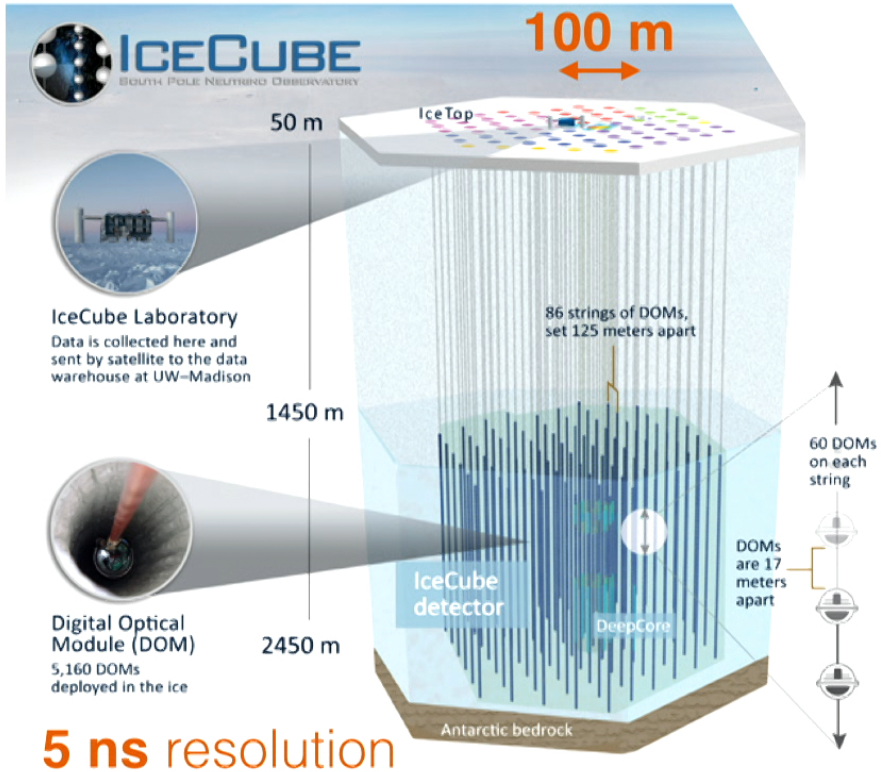




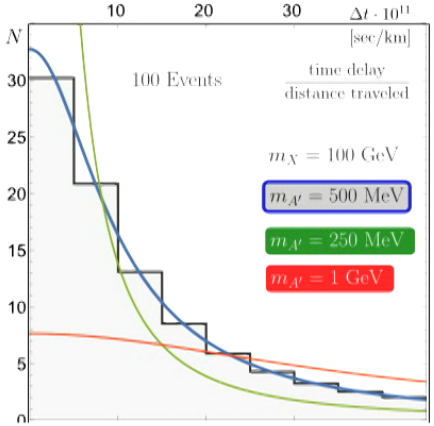
Detection in IceCube



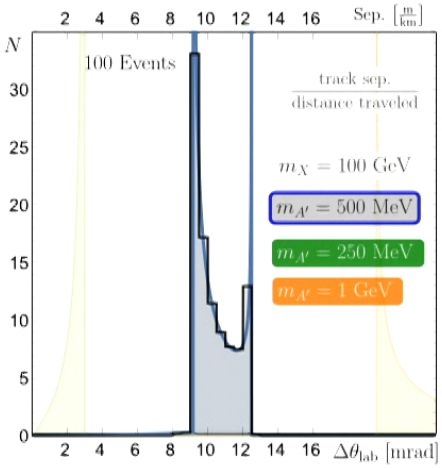
Just out of reach



5 ns resolution



time delay ~ 0.1 ns



separation ~ 10 m

IceCube Collaboration website

All sorts of capture targets?

EARTH

MOON

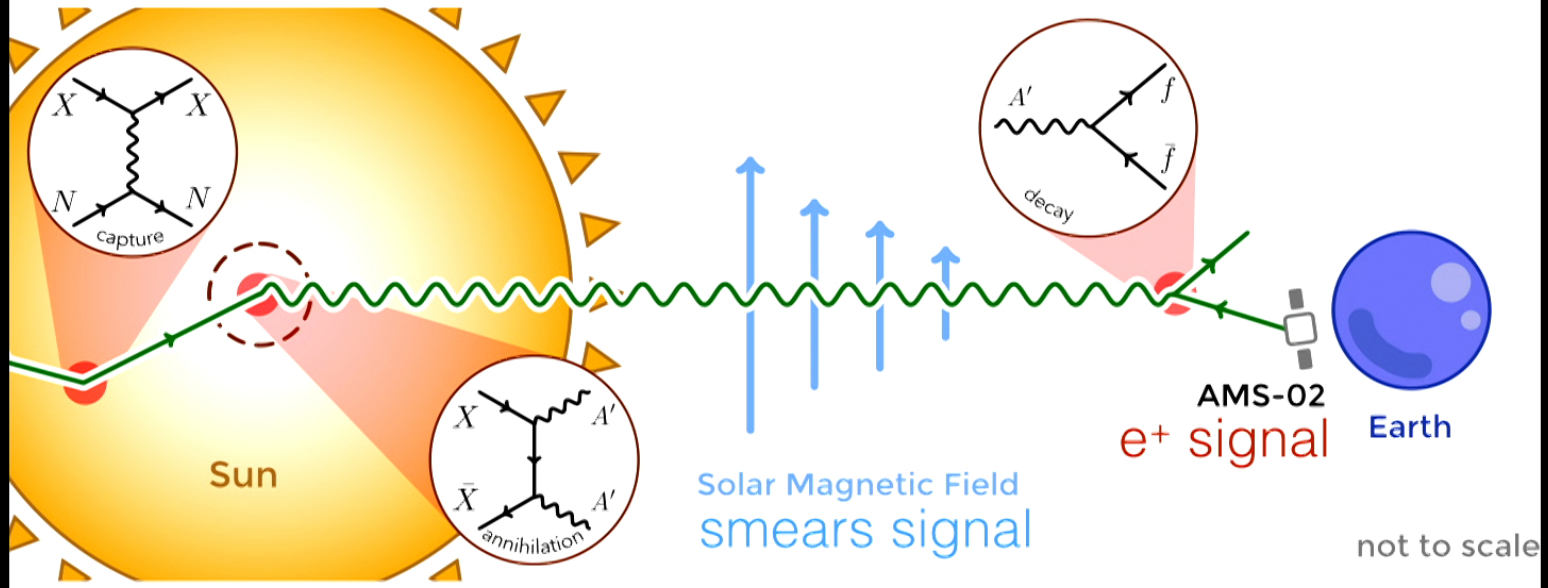
too small

SUN

favorite for
WIMP capture

JUPITER

Accumulation in the Sun



Capture & Annihilation

ANALOGOUS TO EARTH

Rule of thumb: sun is always in equilibrium.

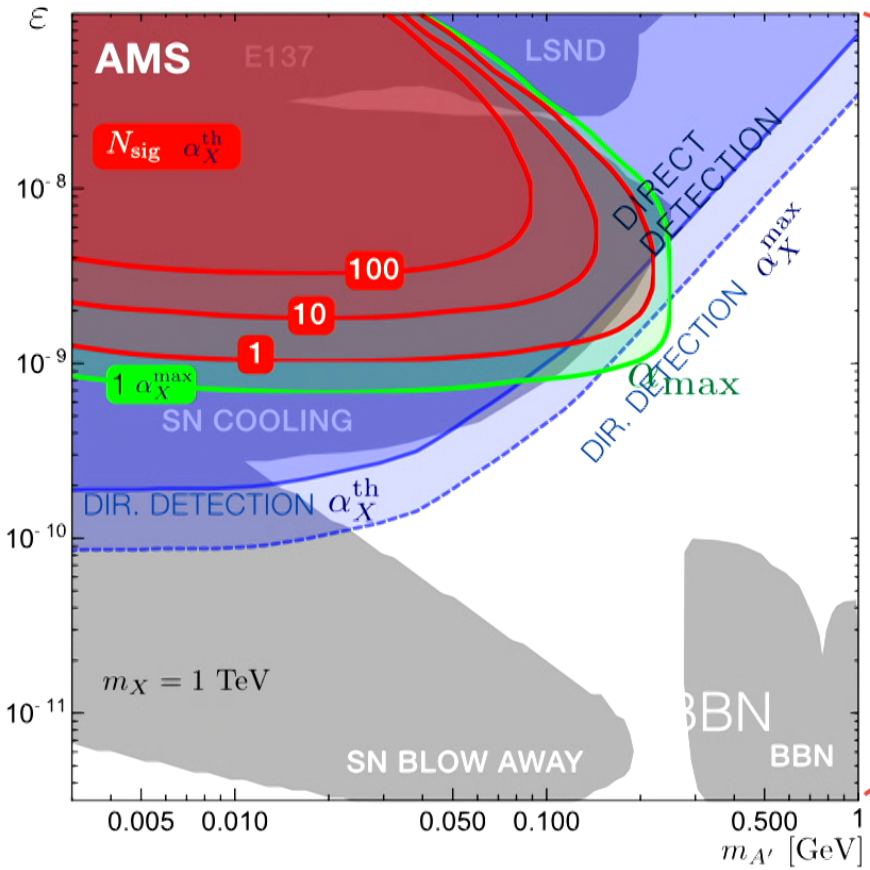
$$B_\phi = \left(\frac{3.3\ \mathrm{nT}}{\sqrt{2}}\right)\frac{\mathrm{au}}{r}$$

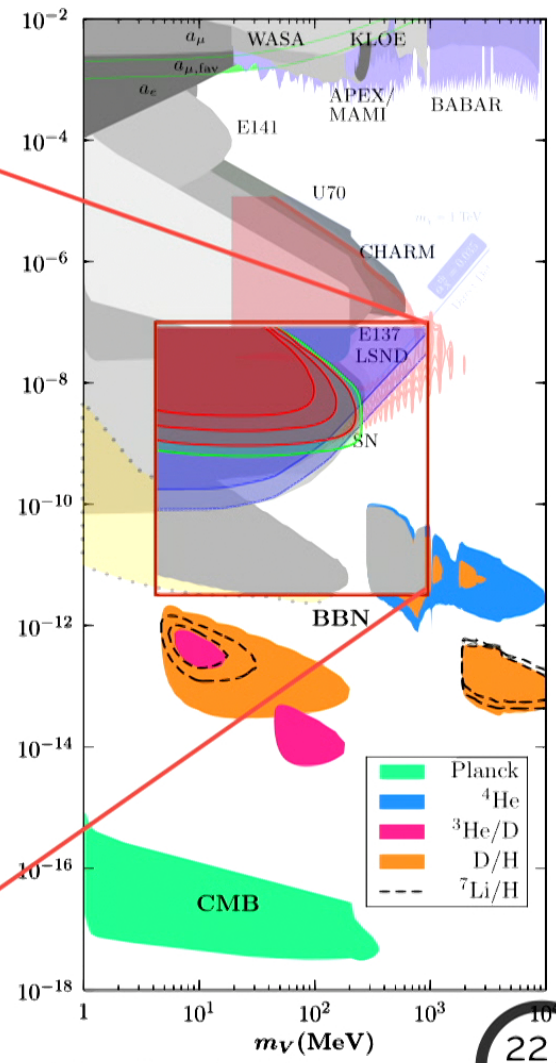
PARKER SPIRAL

J. Feng, J. Smolinsky, FT 1602.01465

AMS-02 Reach

3 year live time, 1 BG event

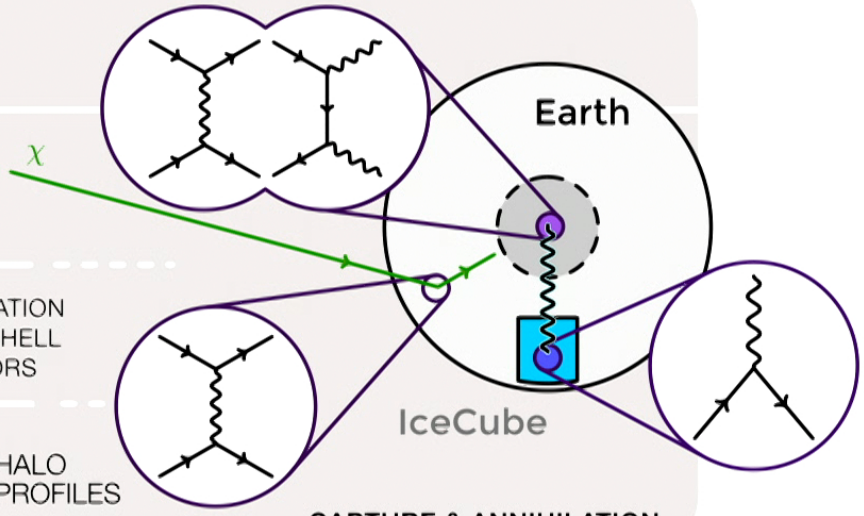




Feng, Smolinsky, FT (1602.01465)

Complementarity Remix

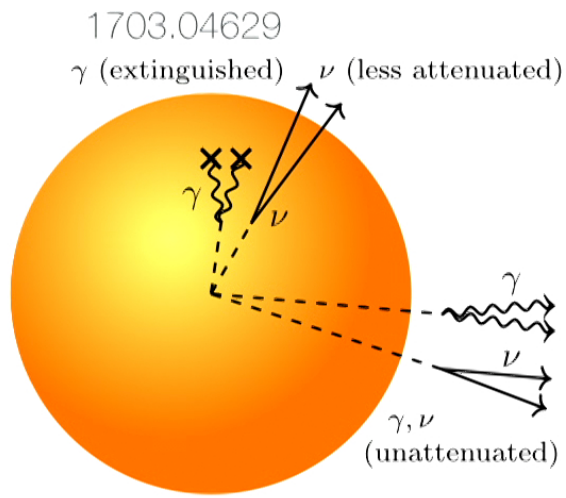
INTERACTION	WIMP SEARCH	STANDARD SEARCHES FOR LIGHT MEDIATORS	THIS PROPOSAL NEW & REVISED SEARCHES
PRODUCTION	COLLIDER: MISSING ENERGY	BEAM DUMP & FIXED-TARGET	
SCATTERING	DIRECT DETECTION	UNCHANGED	
ANNIHILATION	INDIRECT DETECTION	ANNIHILATION TO ON-SHELL MEDIATORS	
SELF-INT.	N/A	HALO PROFILES	



Neat Recent Work

Neutron Star Heating
(Nirmal's Talk)

Baryakhtar, Bramante, Li, Linden, Raj
(1704.01577)



Long-lived mediators

Gamma Ray Searches

Batell, Pospelov, Ritz, Shang (0910.1567)
Leane, Ng, Beacom (1703.04629)