INDIRECT DETECTION OF DARK PHOTONS

SEARCHES FROM CELESTIAL CAPTURE

Flip Tanedo

UC IRVINE
UNIVERSITY OF CALIFORNIA

arXiv:1508.soon & work in progress

with J. Feng and J. Smolinsky

SUSY 2015 Conference, August 2015

MAD LIBS™ (UCI version)

Indirect detection of dark matter

Dark Matter annihilates in **the Galactic Center** to

A PLACE

photons, which are detected by **Fermi-LAT**.

SOME PARTICLE(S) AN EXPERIMENT

Adapted from J. Feng, AMS Days at CERN 2015

Summary of this talk

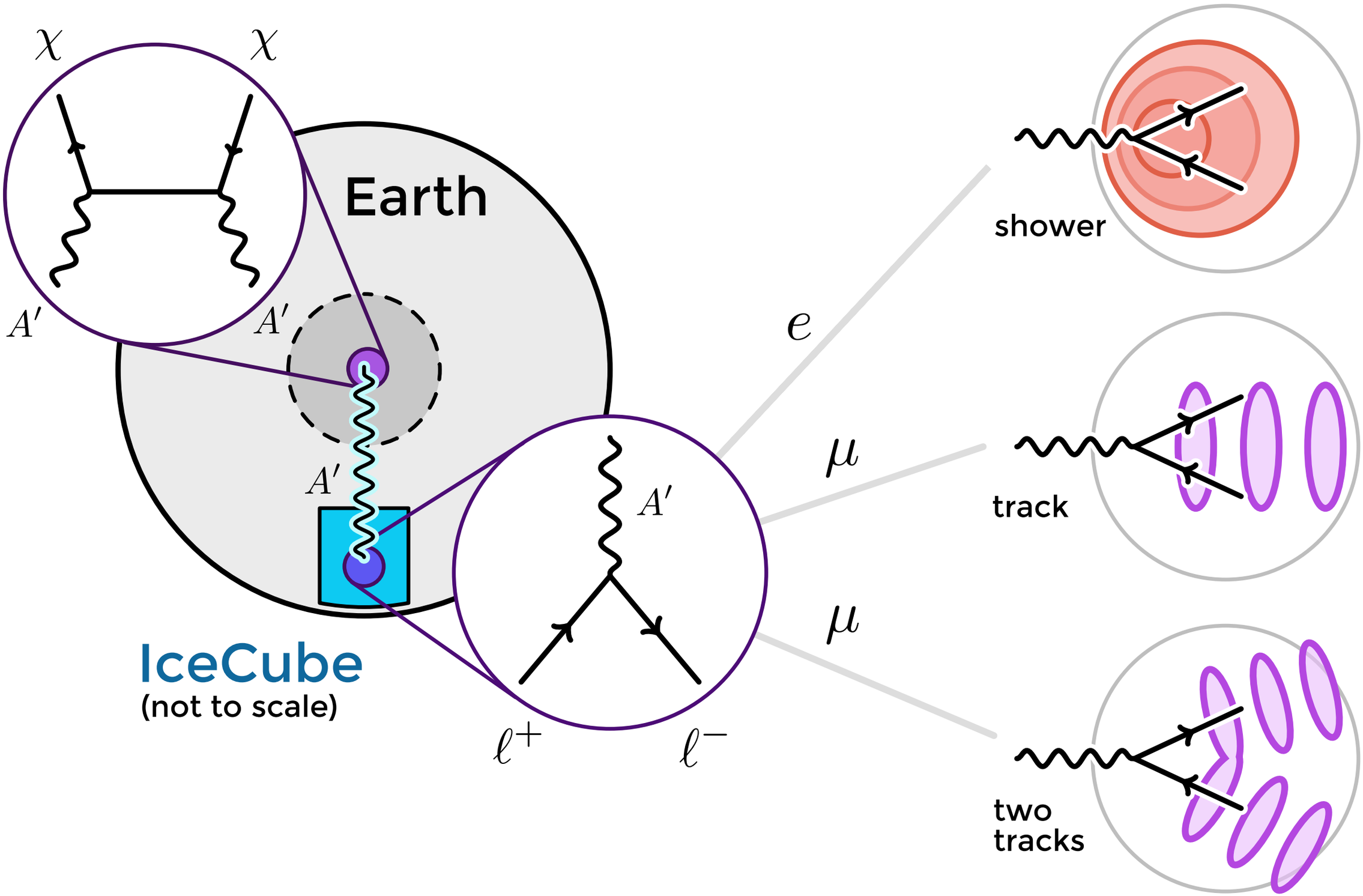
Indirect detection of dark matter

Dark Matter annihilates in the Earth (or the Sun) to dark photons, which are detected by IceCube (or AMS).

(A PLACE; SOME PARTICLE(S); AN EXPERIMENT)

EARLIER WORK: Delaunay, Fox, Perez (0812.3331); Schuster, Toro, Yavin (0910.1602, 0910.1839); Meade, Nussinov, Papucci, Volansky (0910.4160)

Summary: dark photons from Earth



Feng, Smolinsky, FT (2015, to appear)

Dark Photon Minimal Model

dark U(1)

$$\mathcal{L}_{\rm dark} = -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + i\bar{\chi}(\not{\partial} + ig_\chi \not{A}')\chi$$

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

$$\mathcal{L}_{\rm mix} = \frac{\epsilon}{2}F^{(0)}_{\mu\nu}F'^{(0)\mu\nu}$$

Kinetic Mixing

dark coupling α_χ s.t.

$\langle\sigma v\rangle_{\rm ann} = 2.1\times10^{-26}\ {\rm cm}^3/{\rm s}$

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

Kobzarev et al. (*Sov J. Nucl. Phys* **3**1966), Holdom (*PLB* **166** 1986)

Dark Photon Bounds

dark U(1)

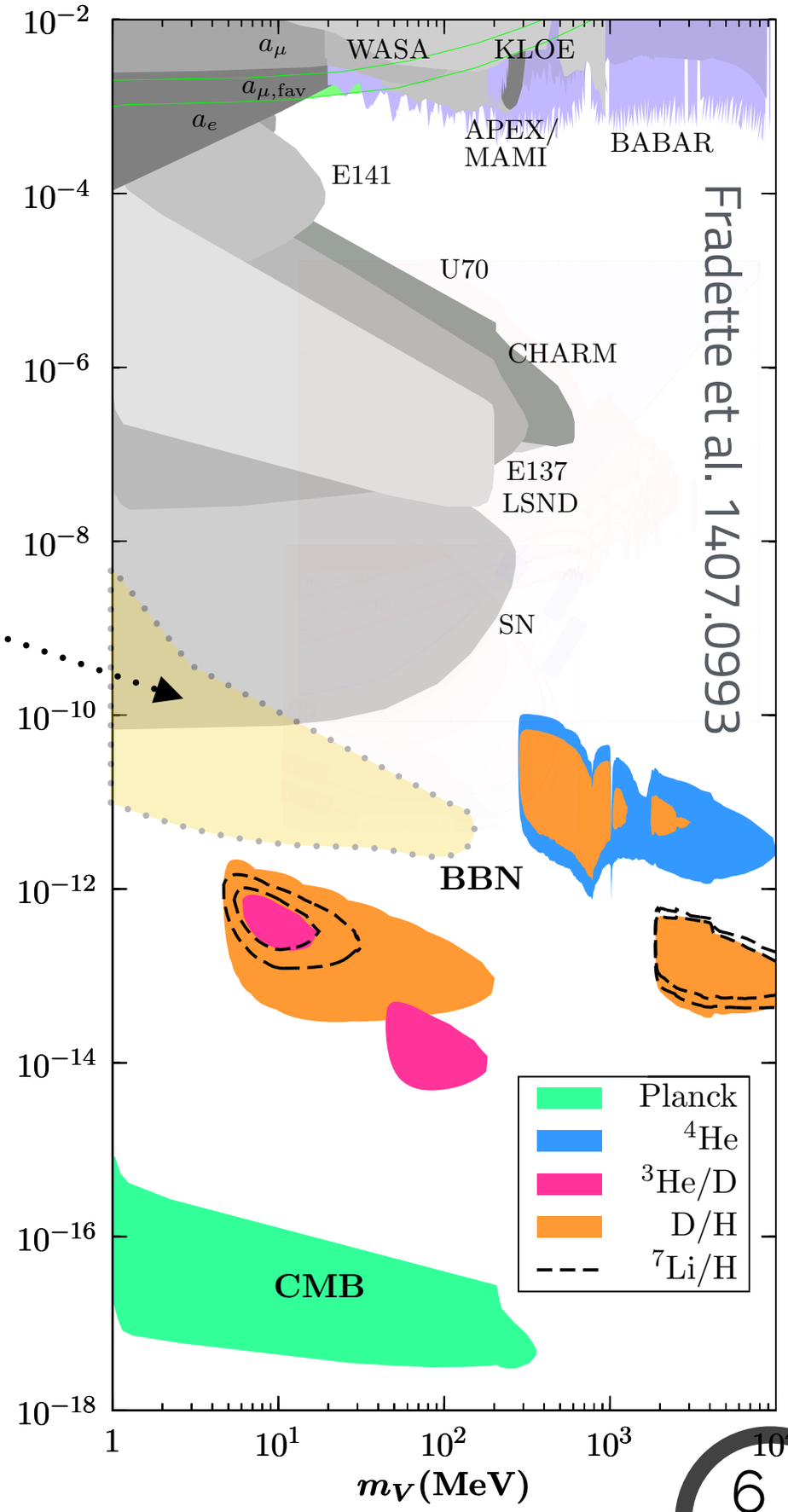
$$\mathcal{L}_{\rm dark} = -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - m_{A'}A'^2$$

$$\mathcal{L}_{\rm mix} = \frac{\epsilon}{2}F^{(0)}_{\mu\nu}F'^{(0)\mu\nu}$$

Kinetic Mixing

Beam Dumps

SN Blow Away
Kazanas et al.
1410.0221



Fradette et al. 1407.0993

Snowmass Review: 1311.0029

Dark Photon Minimal Model

dark U(1)

$$\mathcal{L}_{\rm dark} = -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + i\bar{\chi}(\not{\partial} + ig_\chi \not{A}')\chi - m_{A'}A'^2 - m_\chi\bar{\chi}\chi$$

$$\mathcal{L}_{\rm mix} = \frac{\epsilon}{2}F^{(0)}_{\mu\nu}F'^{(0)\mu\nu}$$

Kinetic Mixing

dark coupling α_χ s.t.

$$\langle\sigma v\rangle_{\rm ann} = 2.1\times10^{-26}\ {\rm cm}^3/{\rm s}$$

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

When the χ properties matter

example: direct detection of dark U(1) model

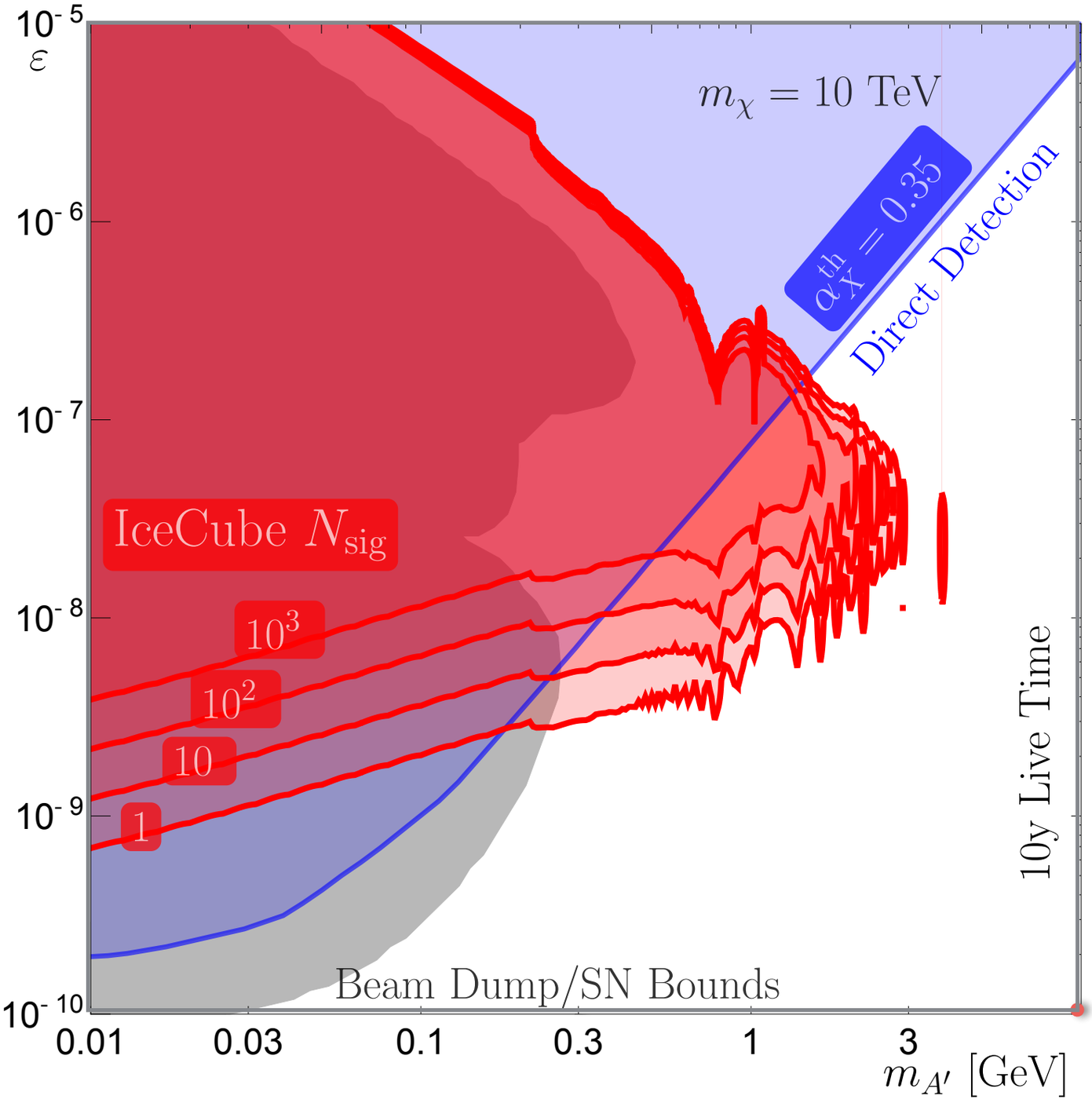
m_χ

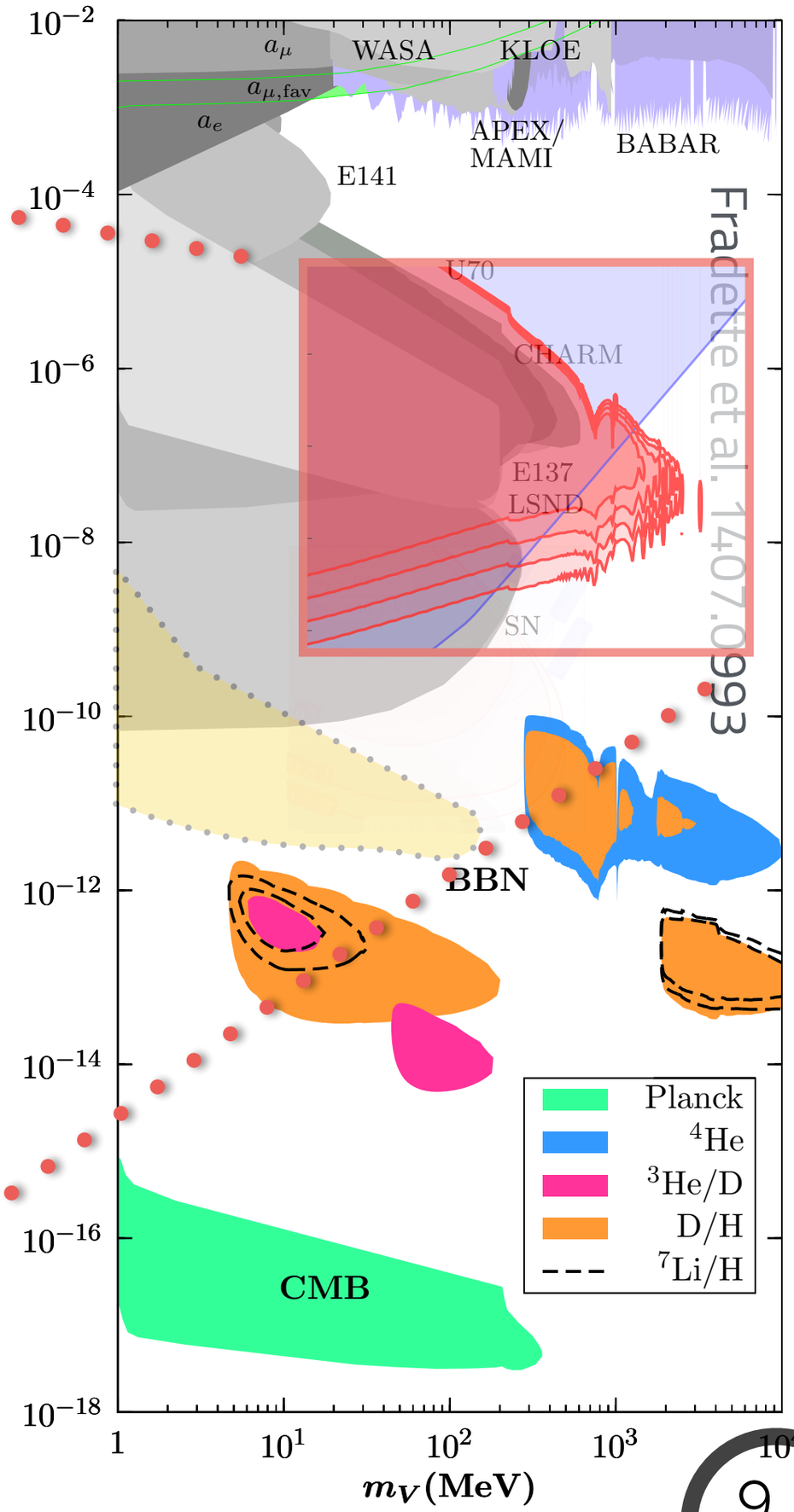
$\alpha = 0.01$

$$\sigma_i = \frac{16\pi\varepsilon^2\alpha_X\alpha Z_i^2 m_{ri}^2}{(2\mathbf{p}_{\rm CM}^2(1-\cos\theta_{\rm CM})+m_{A'}^2)^2}$$

Courtesy of E. del Nobile, M. Kaplinghat, H.B. Yu (1507.04007)

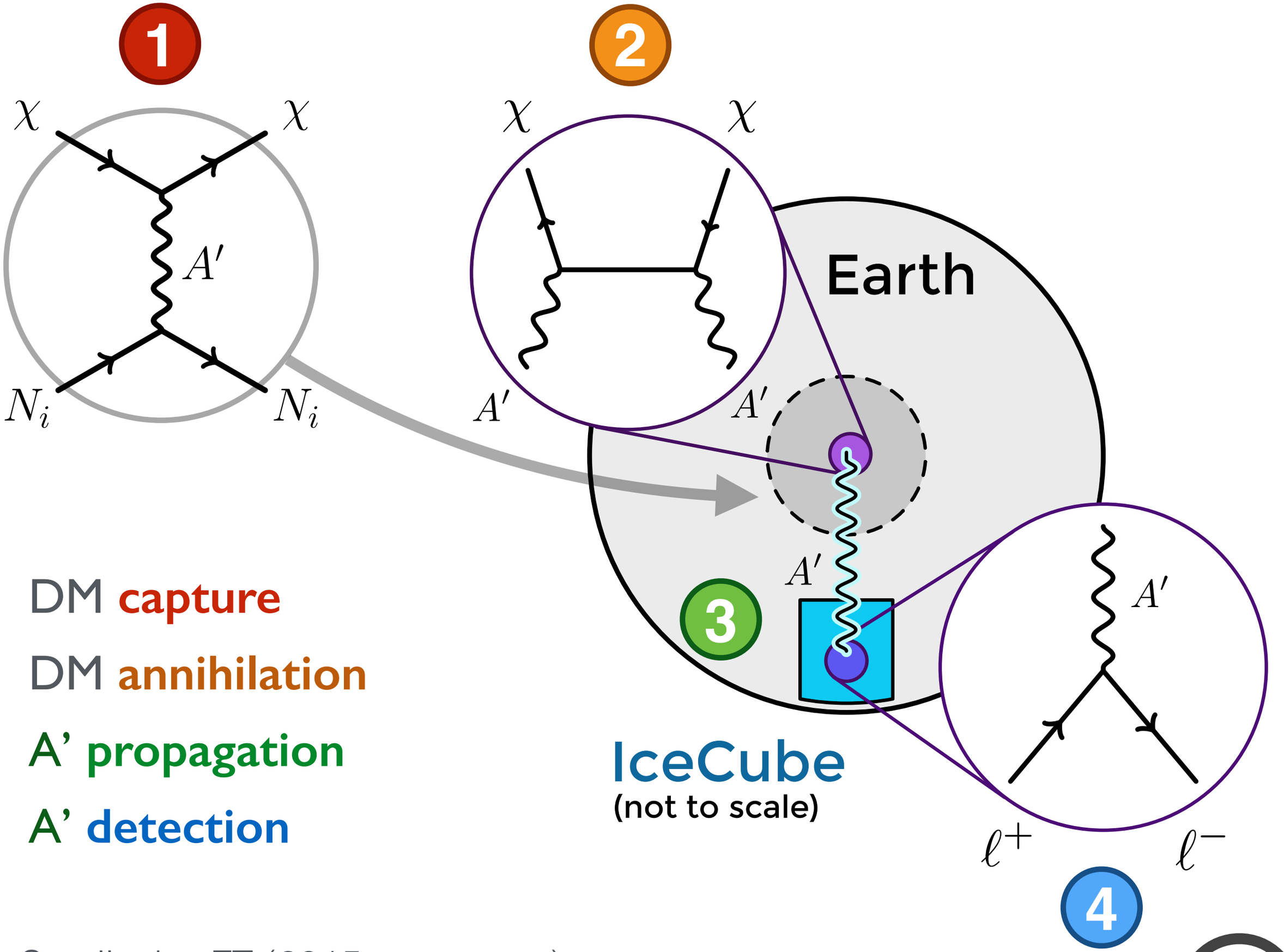
Dark Photon Reach





Fradette et al. 1407.0993

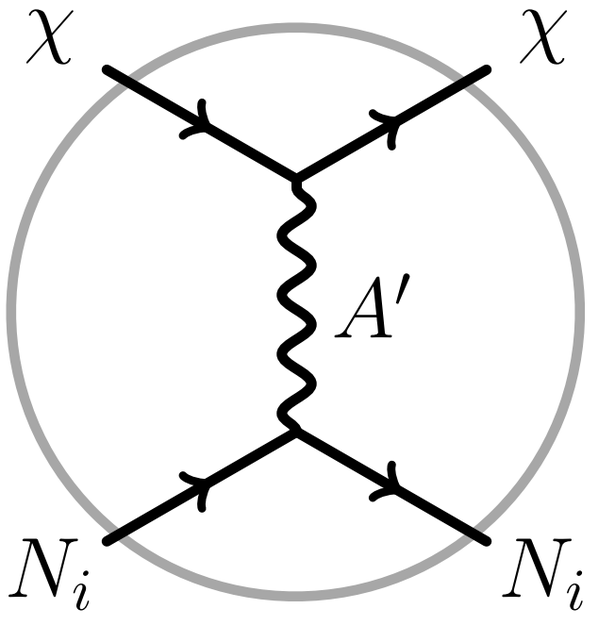
Feng, Smolinsky, FT (2015, to appear)



1. DM **capture**
2. DM **annihilation**
3. A' **propagation**
4. A' **detection**

Feng, Smolinsky, FT (2015, to appear)

Capture of Dark Matter



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

"Direct Detection" in space

$$\Gamma^i_{\rm cap} = n_\chi \int \underbrace{d^3r\; n_i(r)}_{\text{EARTH}} \times \int \underbrace{d^3u\; f(u) \frac{u^2+v^2}{u}}_{\text{VELOCITY}} \times \int \underbrace{dE_R\; \frac{d\sigma_i}{dE_R} F(E_R)\Theta}_{\text{RECOIL ENERGY}}$$

ESCAPE VELOCITY

ASYMP. VELOCITY

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

KINEMATICS

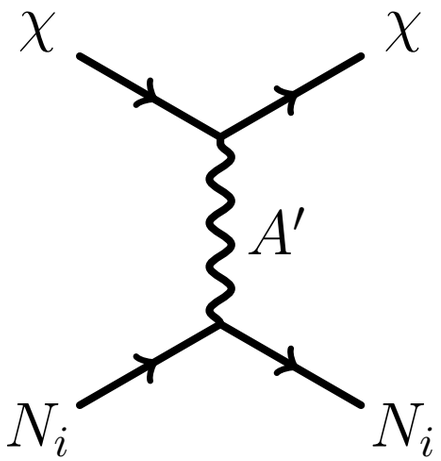
Press & Spergel (85), Krauss, Srednicki, Wilczek (86), Gould (87, 92), PPPCν (1312.6408)

Filling the Earth with Dark Matter

CAPTURE

ANNIHILATION

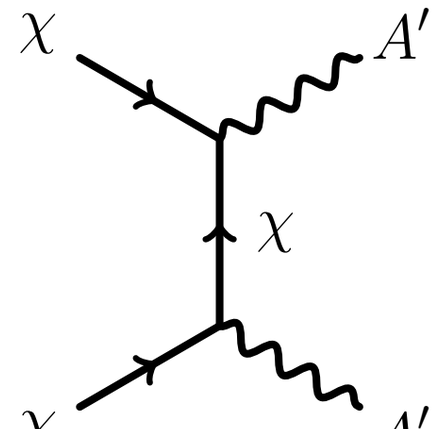
$$\dot{N}_\chi = C_{\rm cap} + (C_{\rm self} - C_{\rm evap})N_\chi - C_{\rm ann}N_\chi^2$$



MORE ON THIS LATER

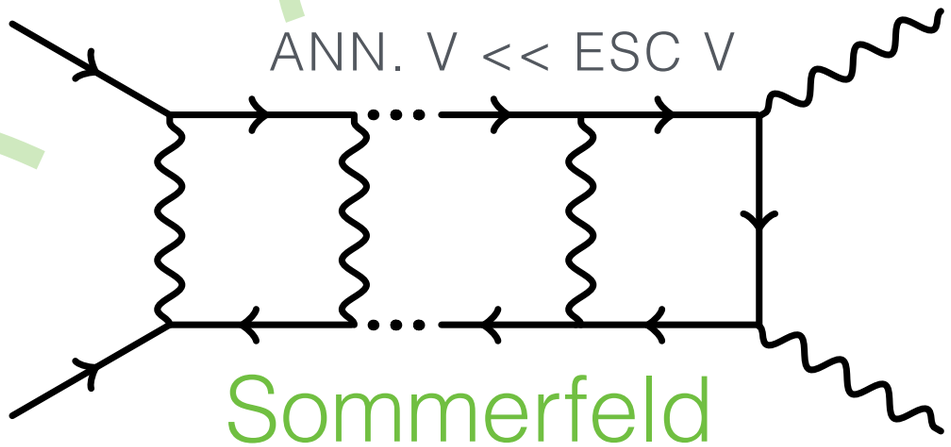
ONLY RELEVANT FOR LIGHT DM

(ONLY FOR SMALL ε)



EQUILIBRIUM TIME

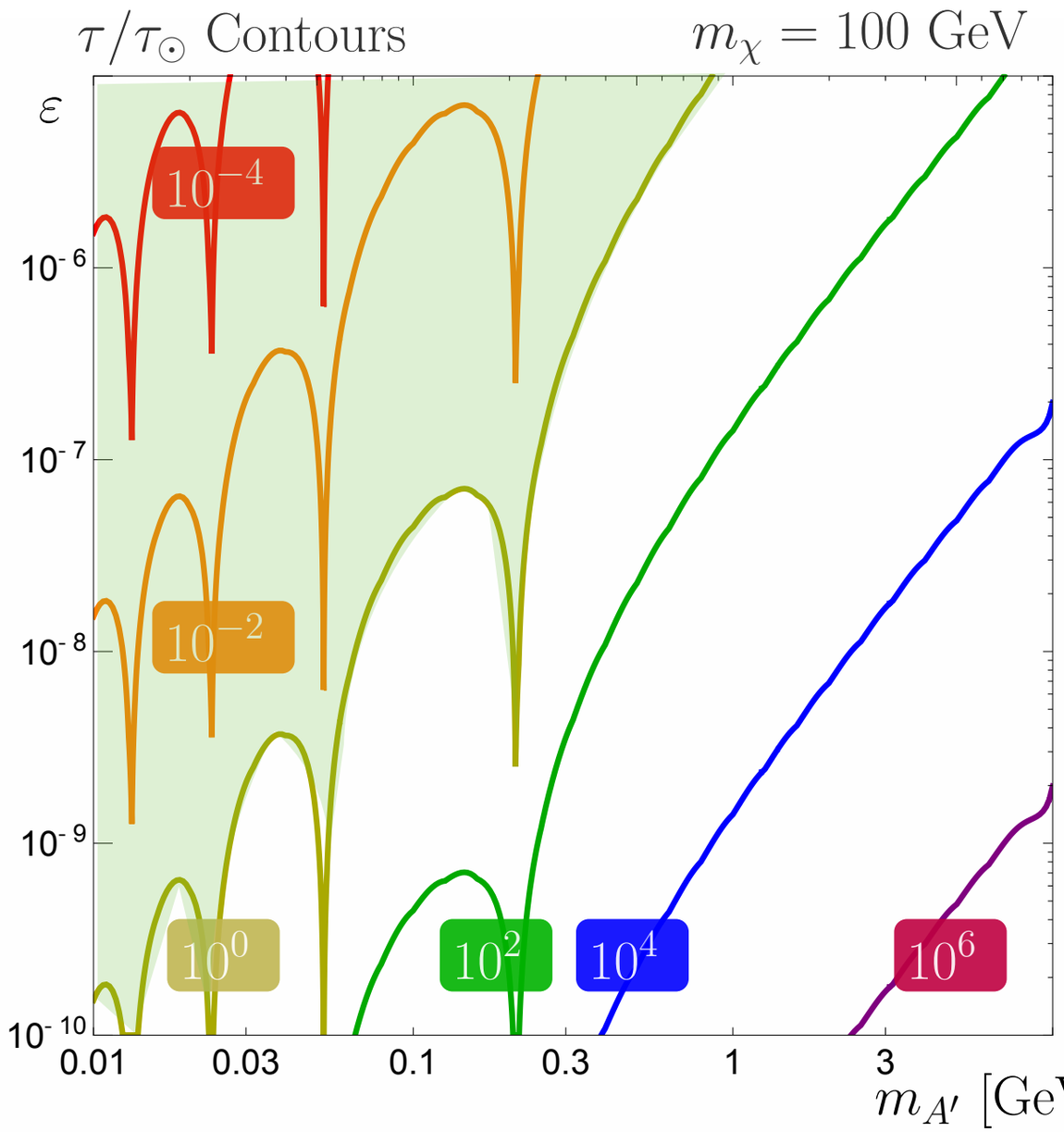
$$\tau = \frac{1}{\sqrt{C_{\rm cap}C_{\rm ann}}}$$

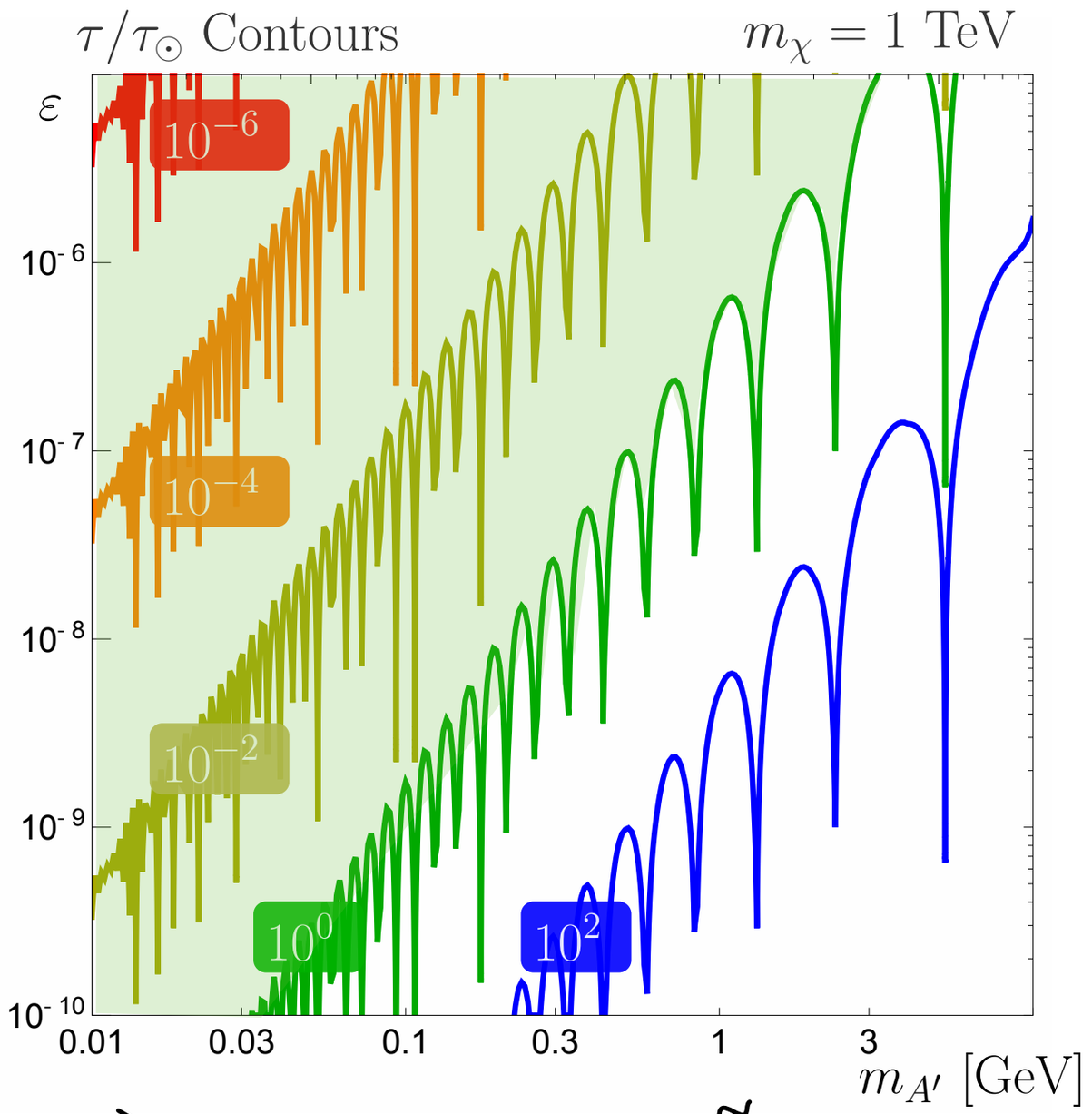


Sommerfeld
HAS RESONANCES
see, e.g. 1302.3898

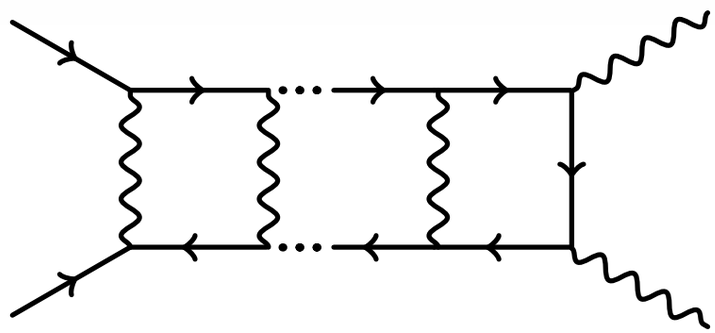
Press & Spergel (85), Krauss, Srednicki, Wilczek (86), Gould (87, 92), Zentner (0907.3448)

Filling the Earth with Dark Matter





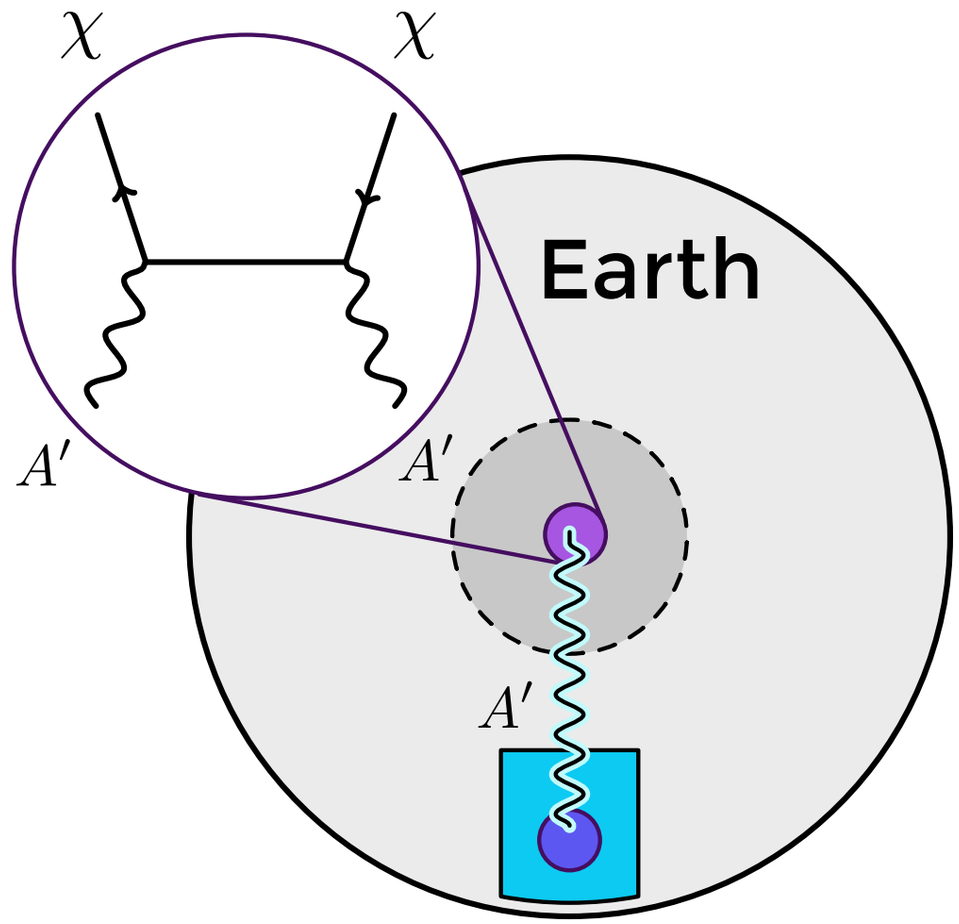
Shaded: Earth is DM “full”



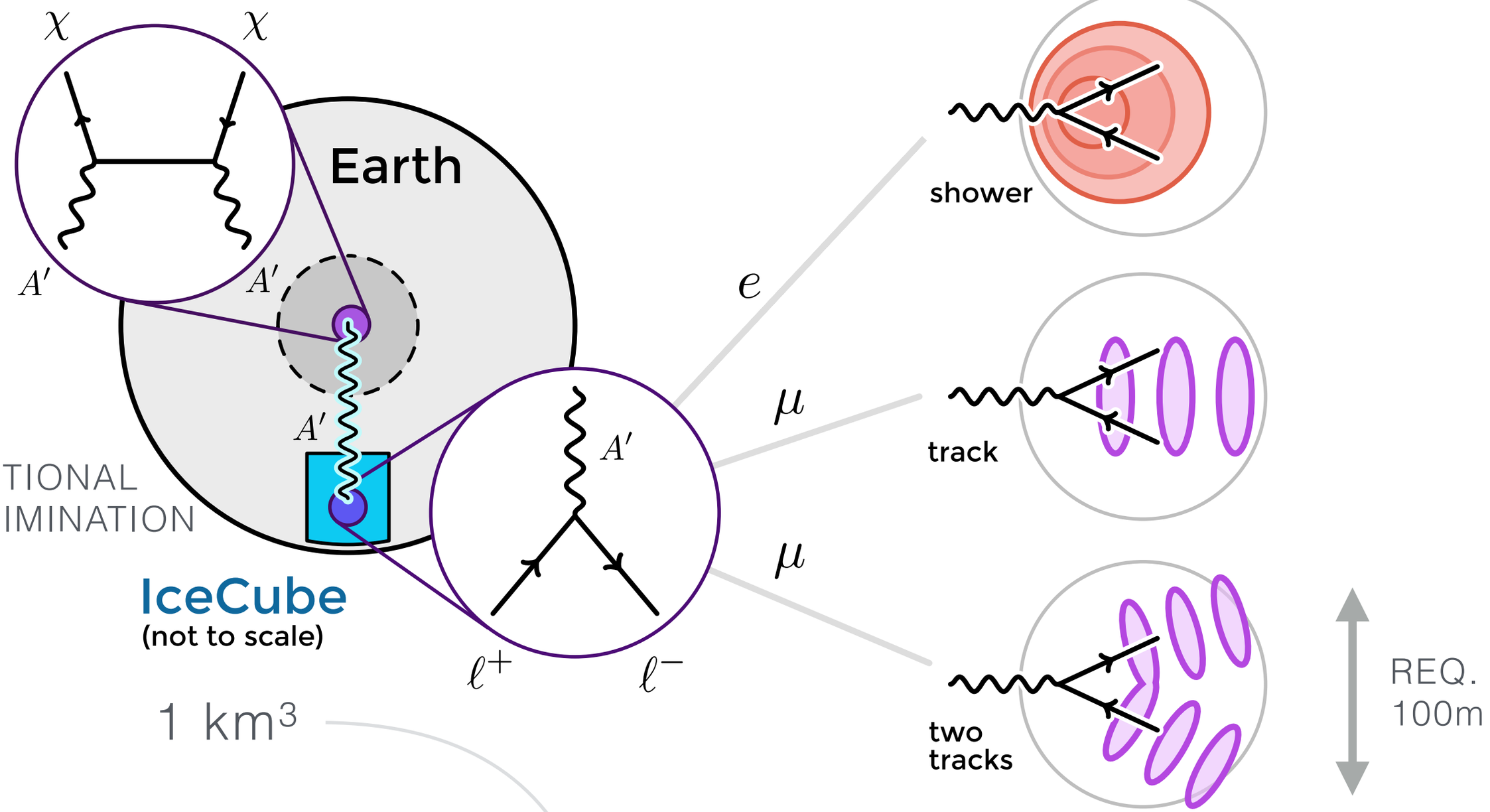
Annihilation from Capture

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

Indirect detection,
but no J factors.

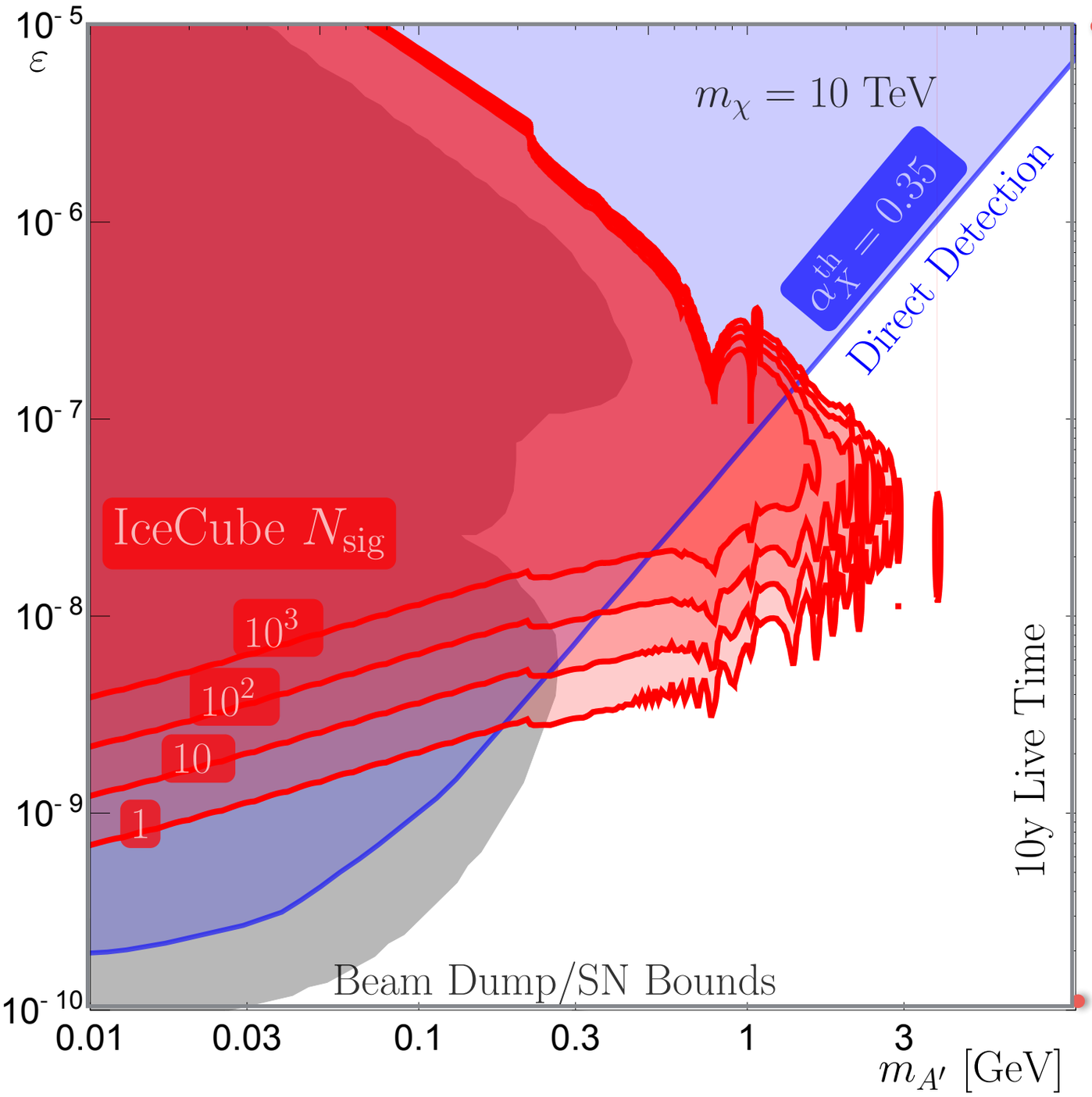


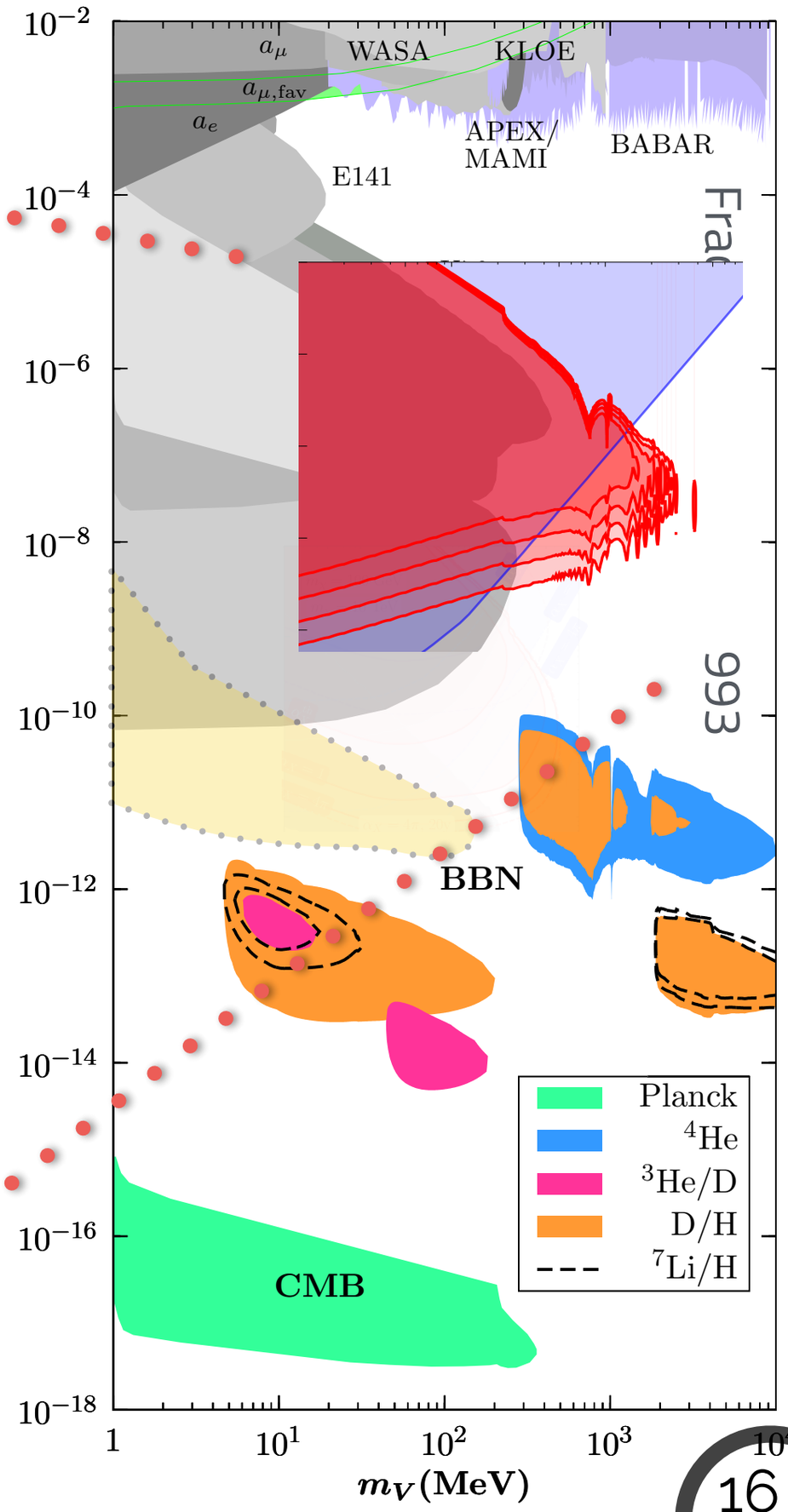
Detection in IceCube



$$\Gamma_{\rm sig} = 2\Gamma_{\rm ann}\frac{1\ {\rm km}^2}{4\pi R_\oplus^2}\left[e^{-(R_\oplus+\delta r)\Gamma_{\rm tot}\frac{m_{A'}}{m_\chi}} - e^{-R\Gamma_{\rm tot}\frac{m_{A'}}{m_\chi}}\right]{\rm Br}(A'\to\ell^+\ell^-)$$

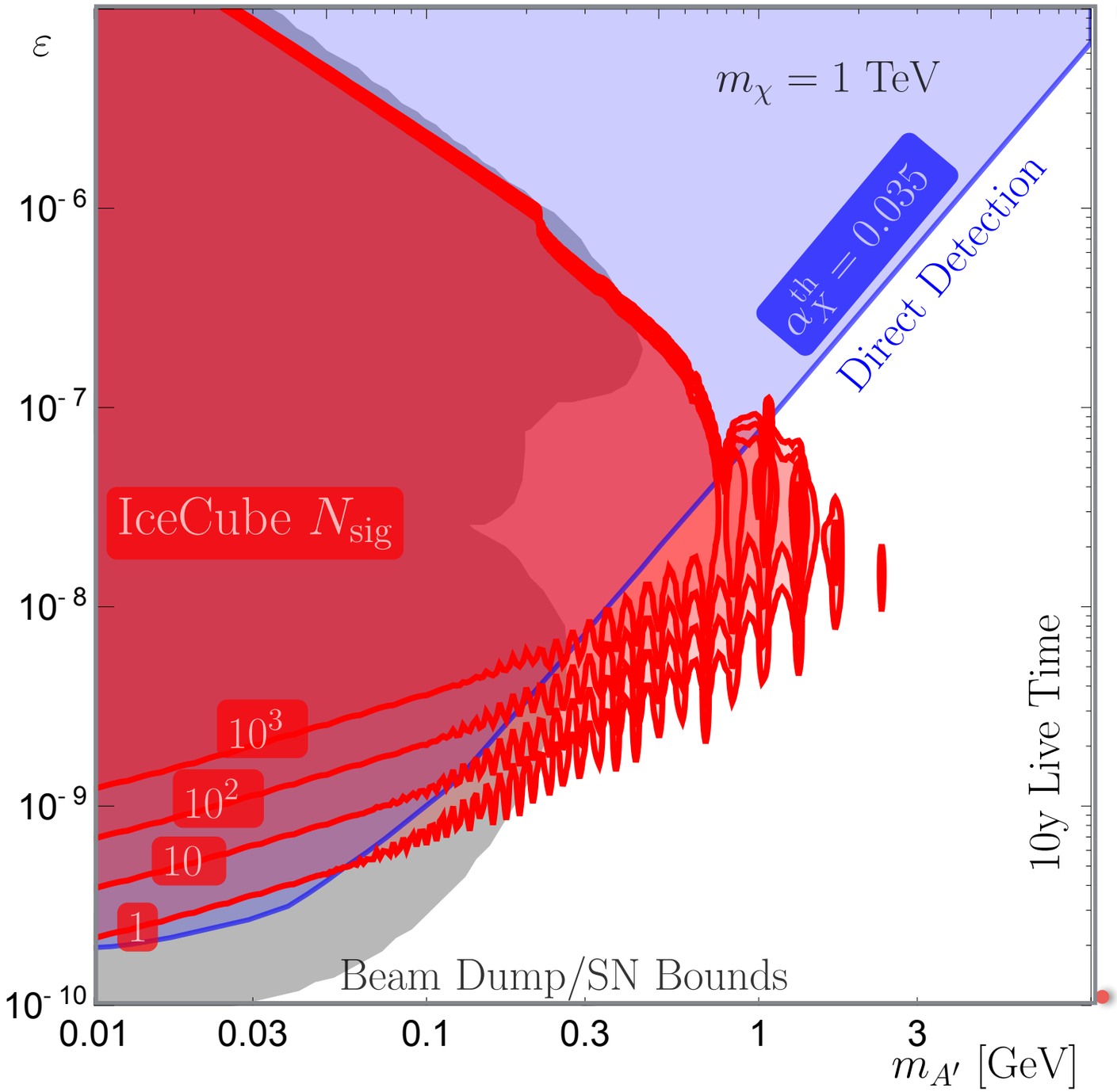
Reach: $m_\chi = 10$ TeV

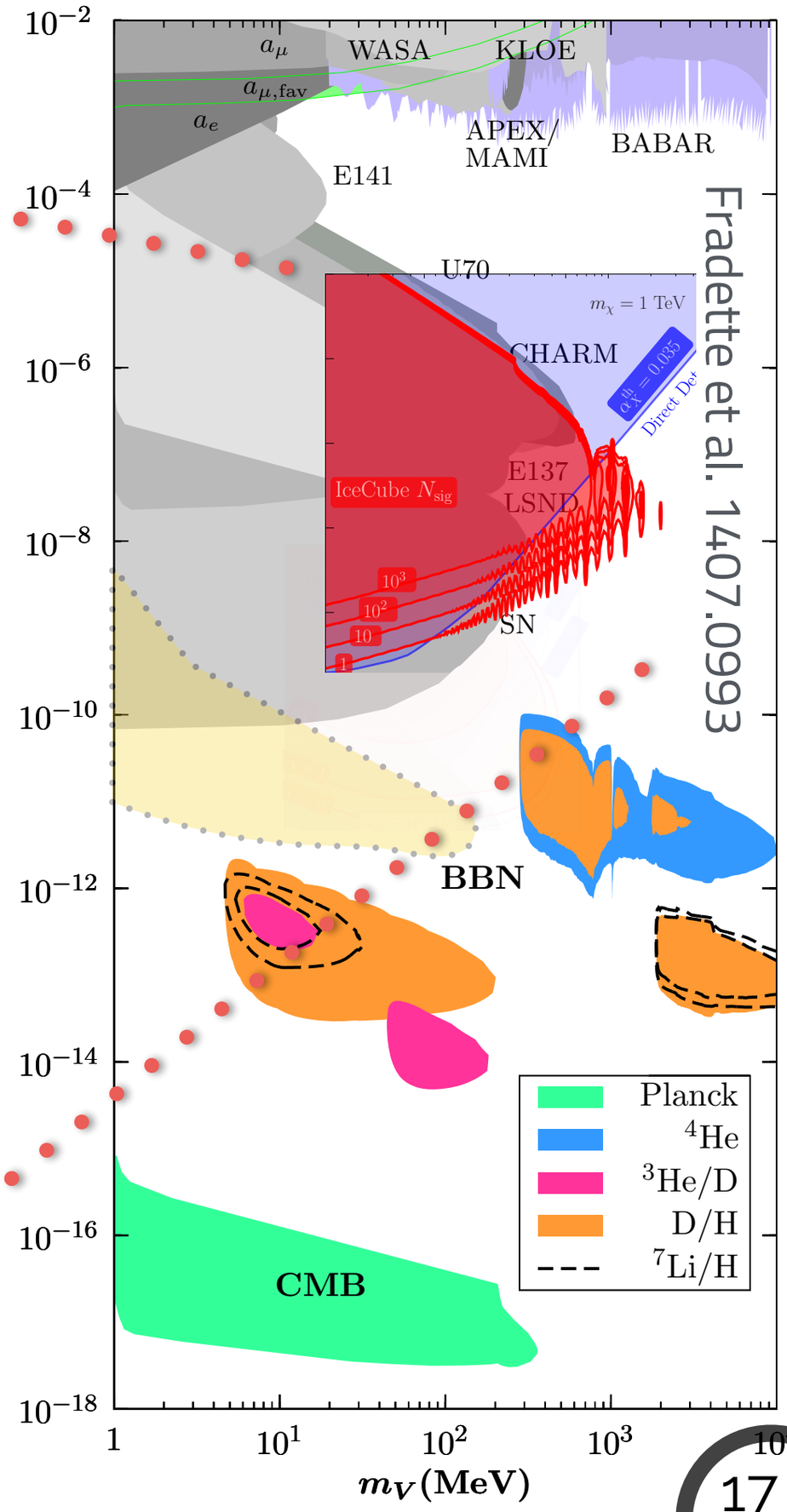




Feng, Smolinsky, FT (2015, to appear)

Reach: m_χ = 1 TeV

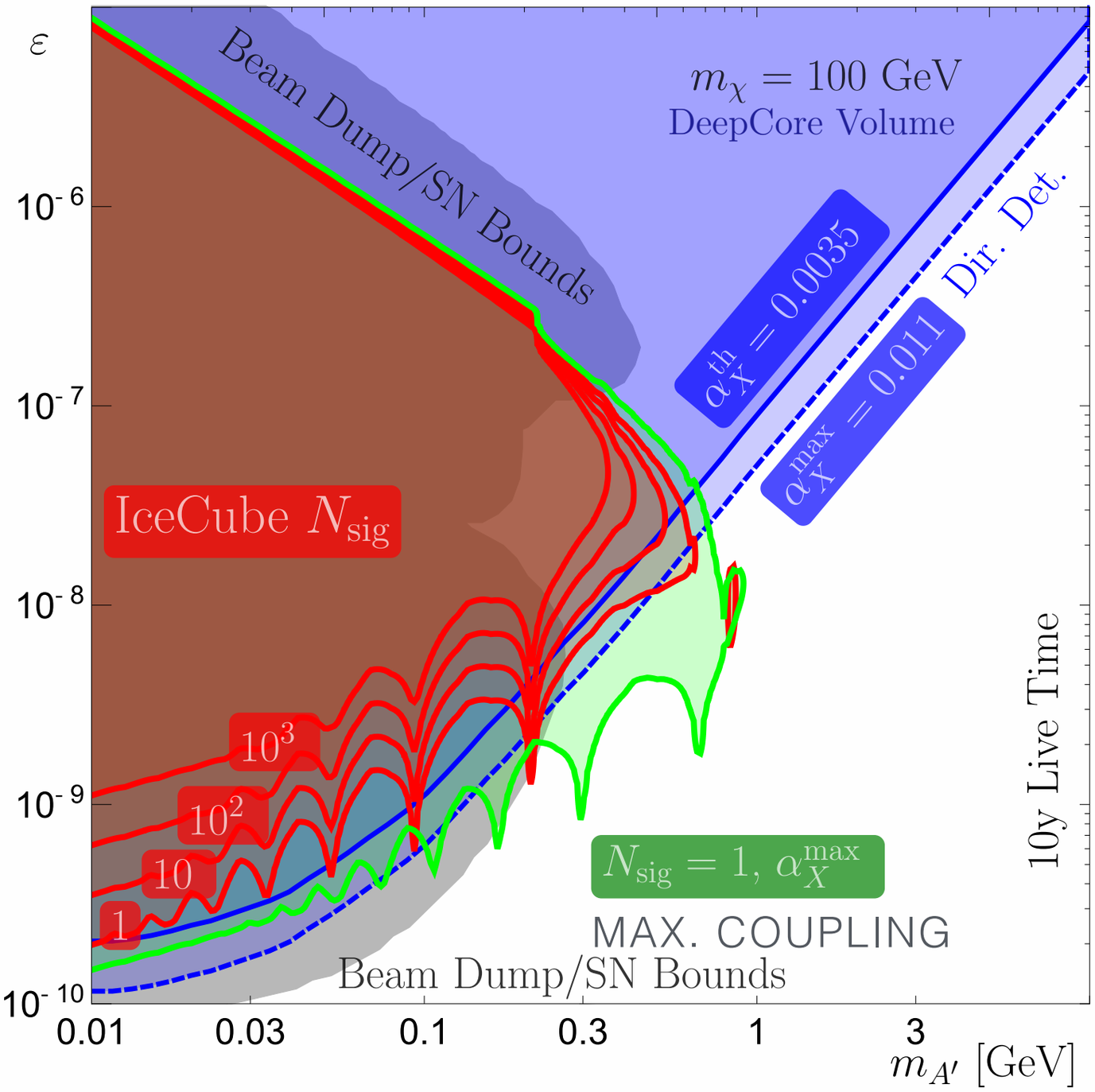


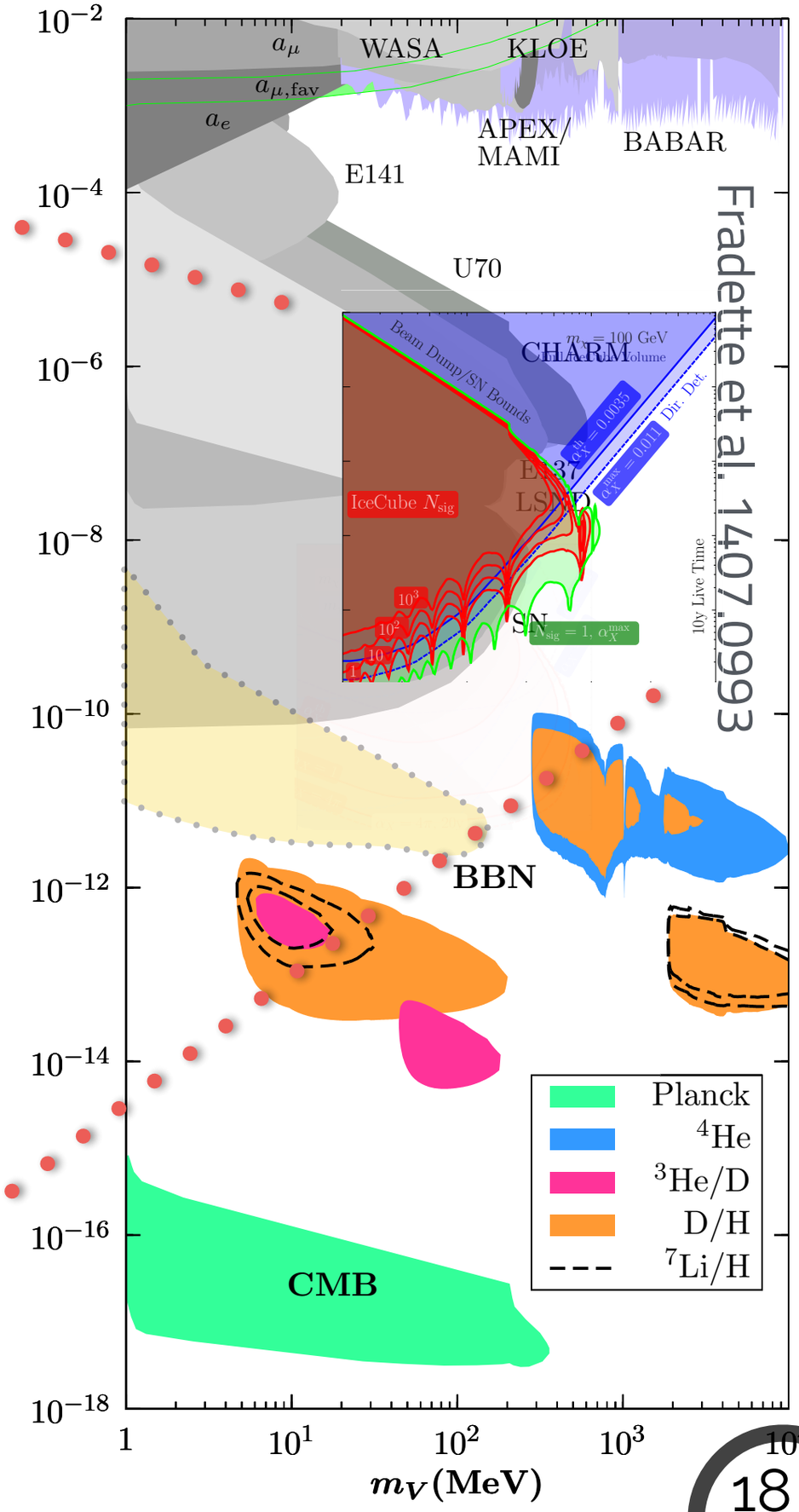


Fradette et al. 1407.0993

Feng, Smolinsky, FT (2015, to appear)

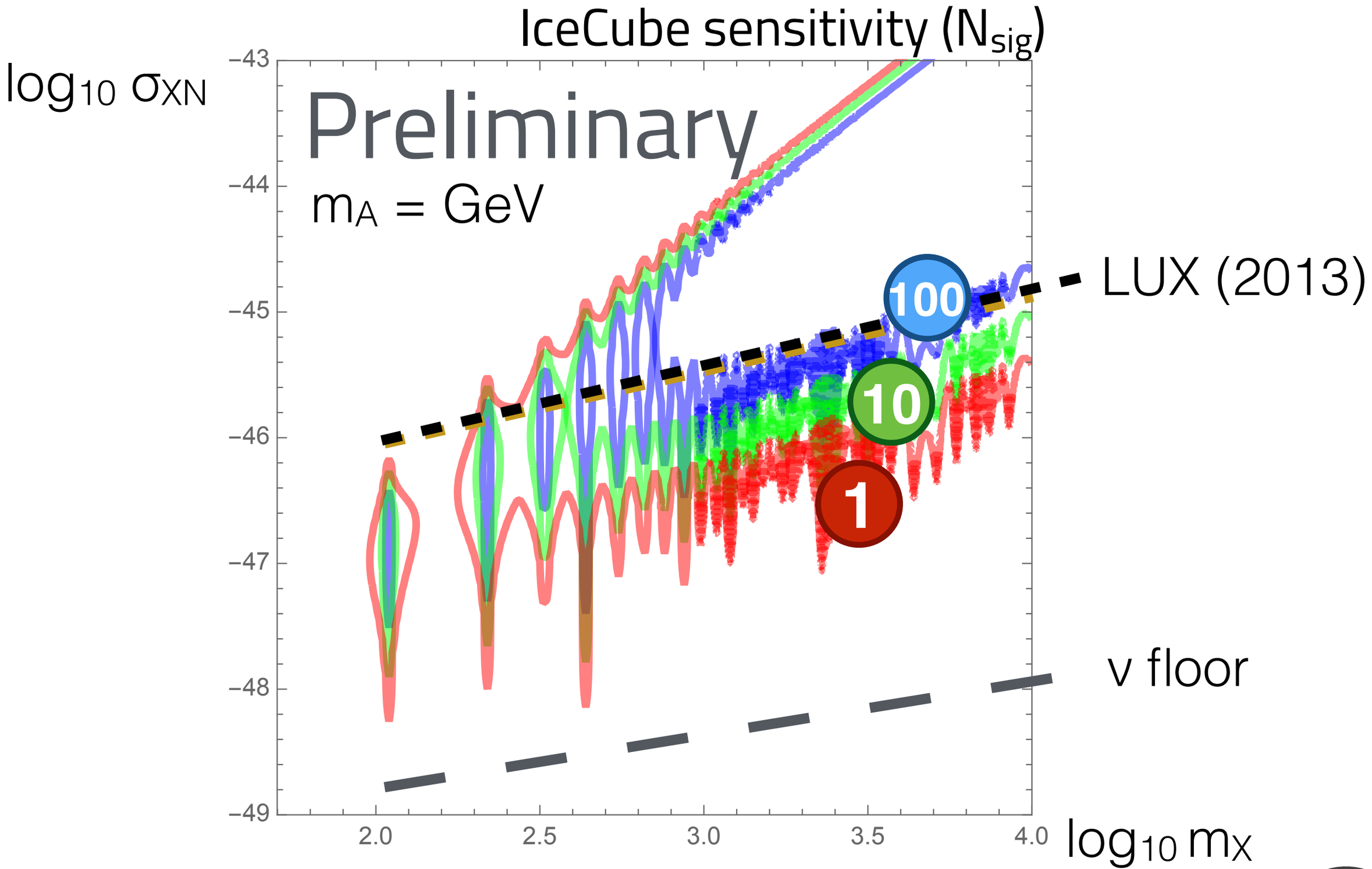
Reach: $m_\chi = 100$ GeV





Feng, Smolinsky, FT (2015, to appear)

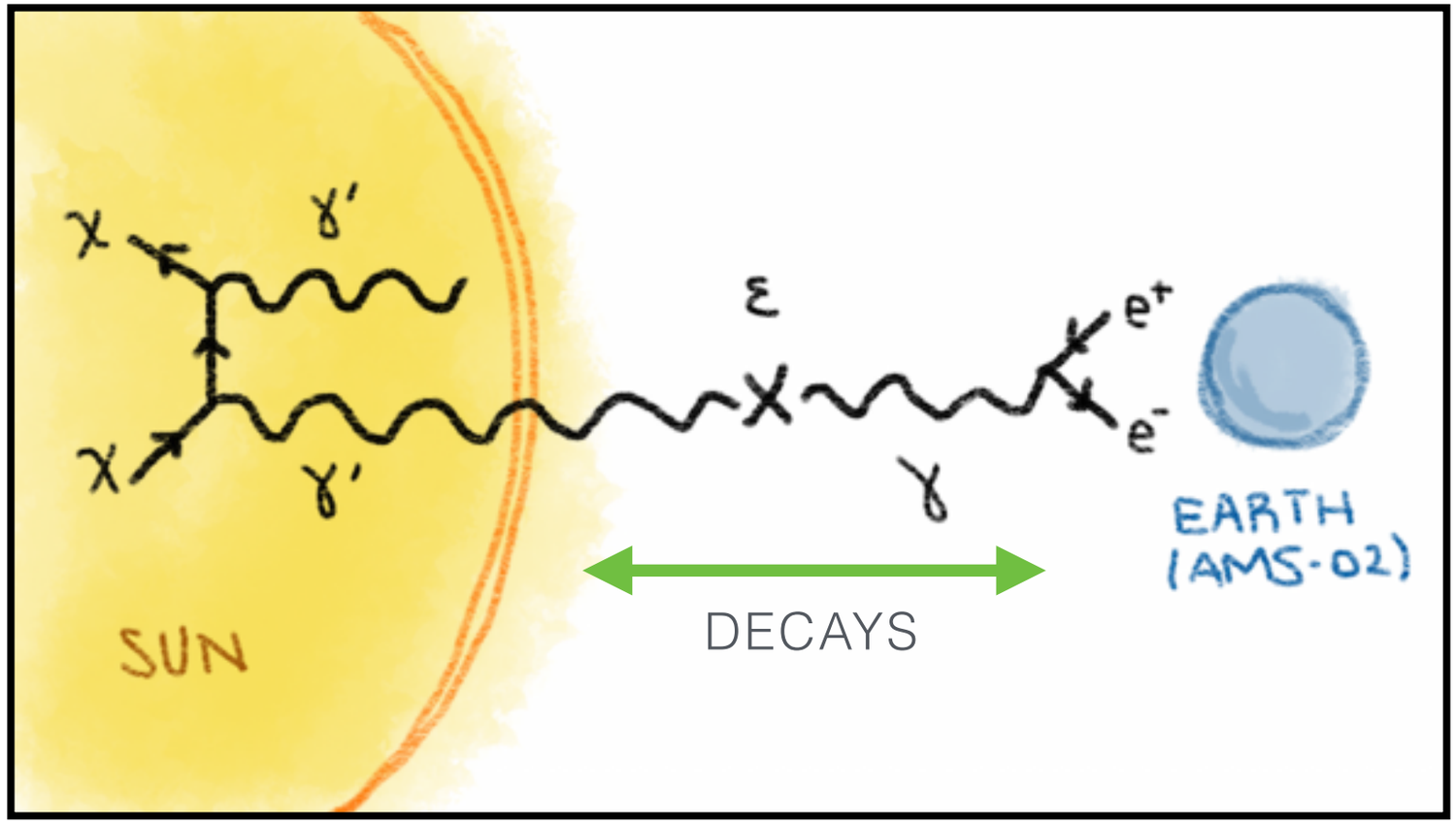
Direct Detection Plane



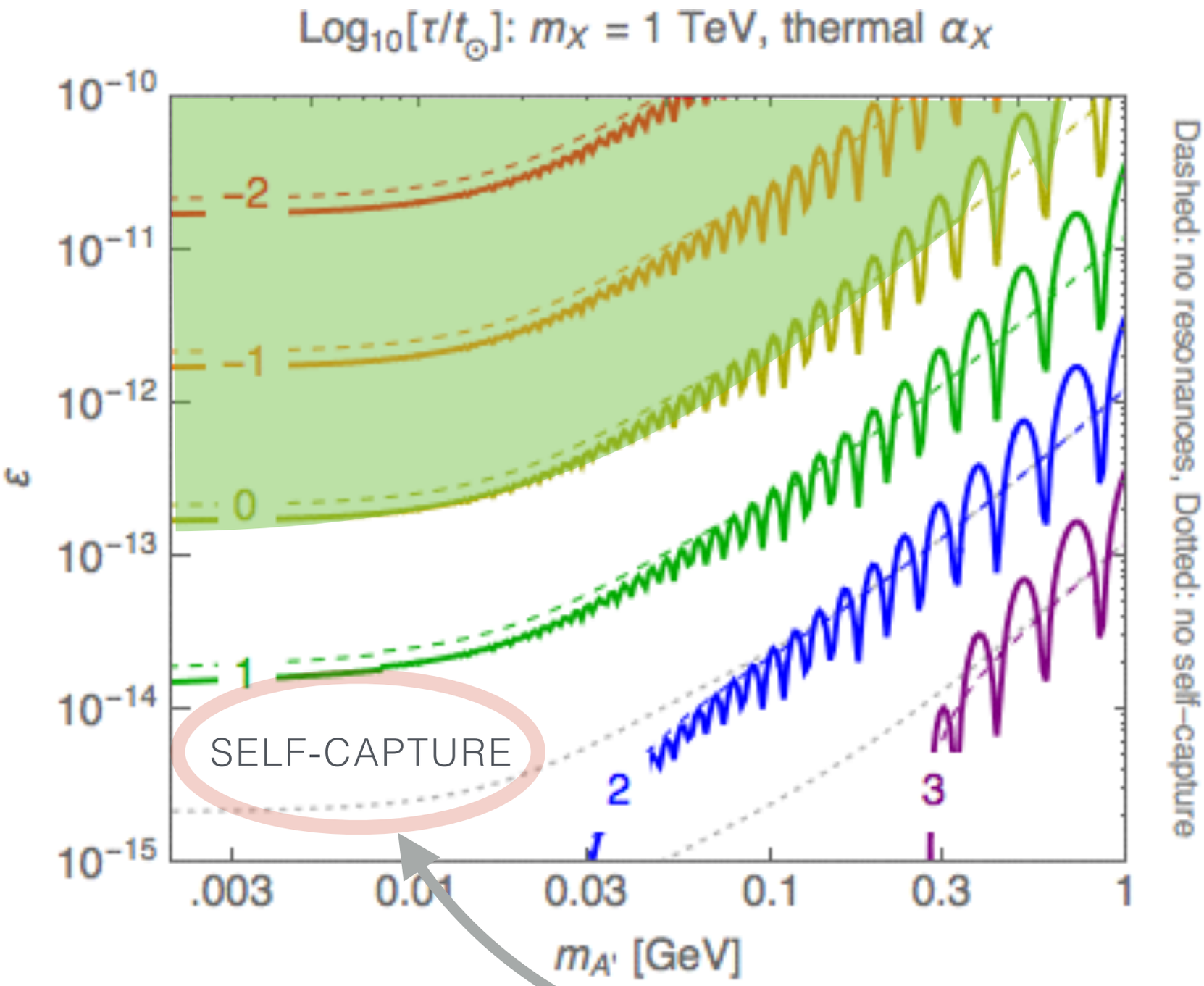
Feng, Smolinsky, FT (2015, to appear)

Quick Comparison: Sun

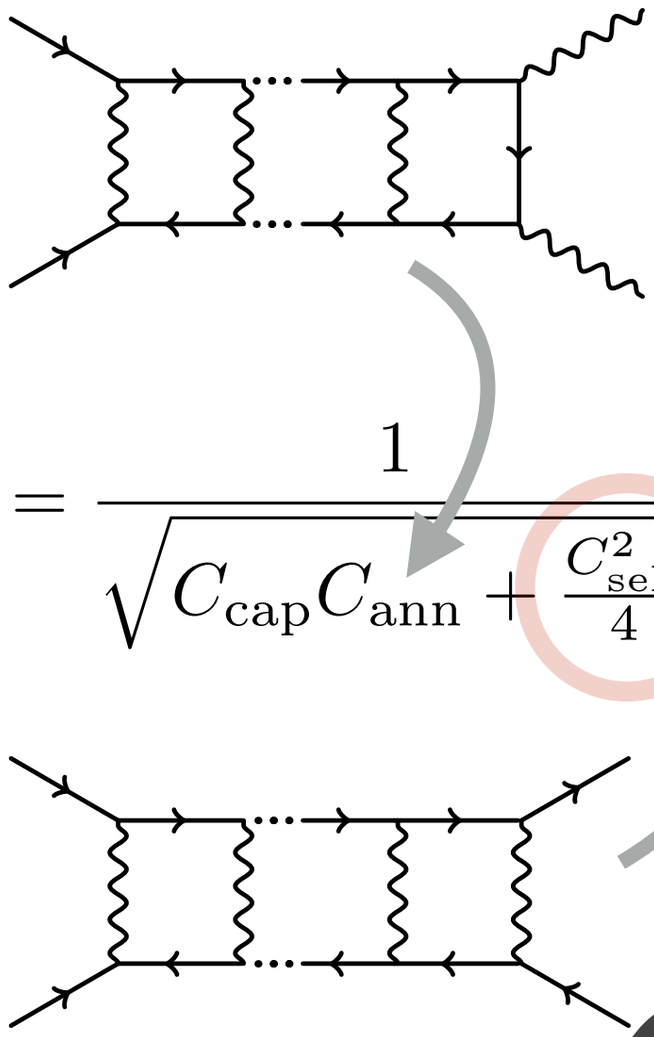
Dark Matter annihilates in the Earth (or the Sun) (A PLACE) to dark photons (SOME PARTICLE(S)), which are detected by IceCube (or AMS) (AN EXPERIMENT).



Equilibrium time in the sun



SOMMERFELD ENHANCEMENT OF ANNIHILATION

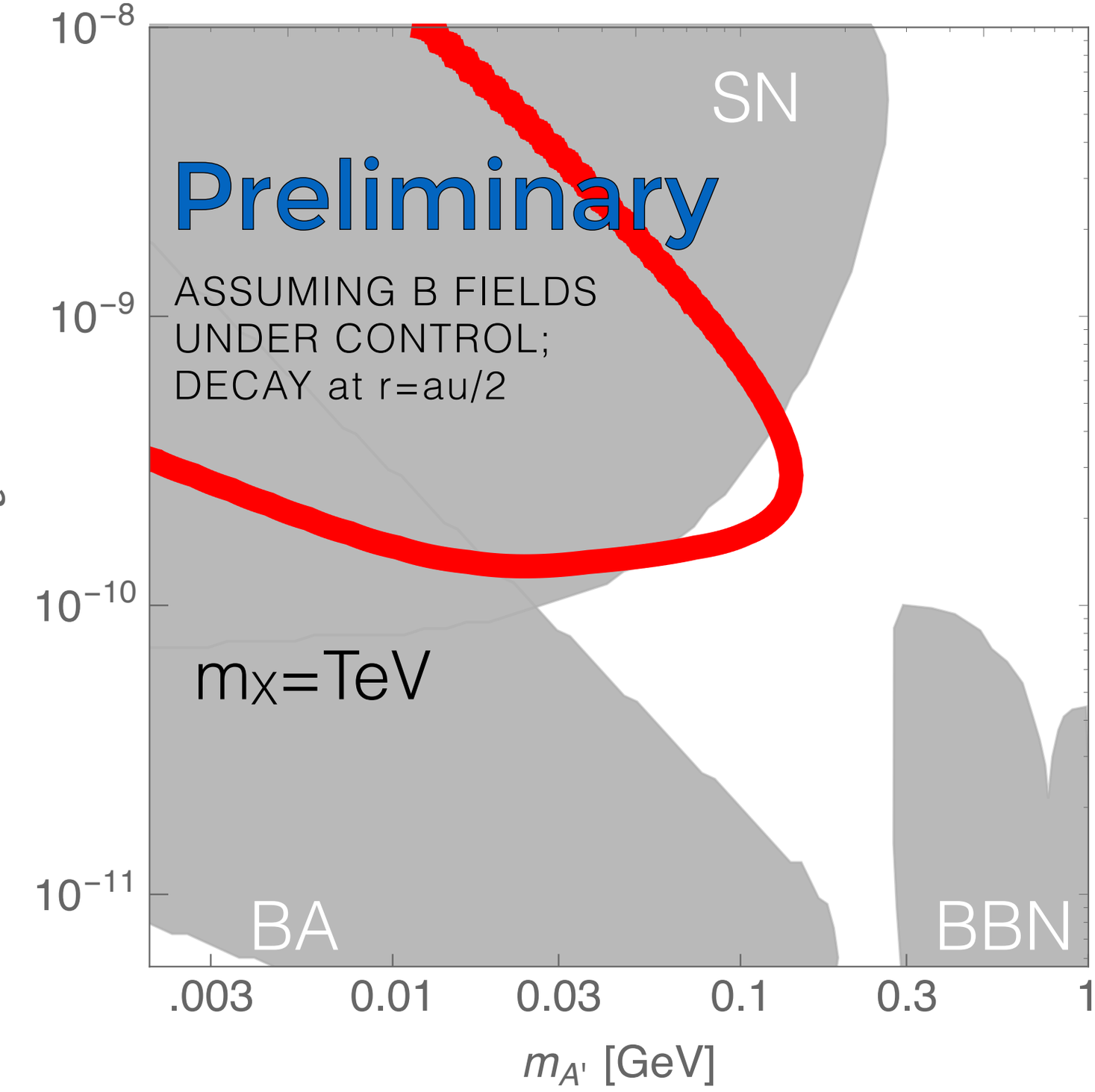


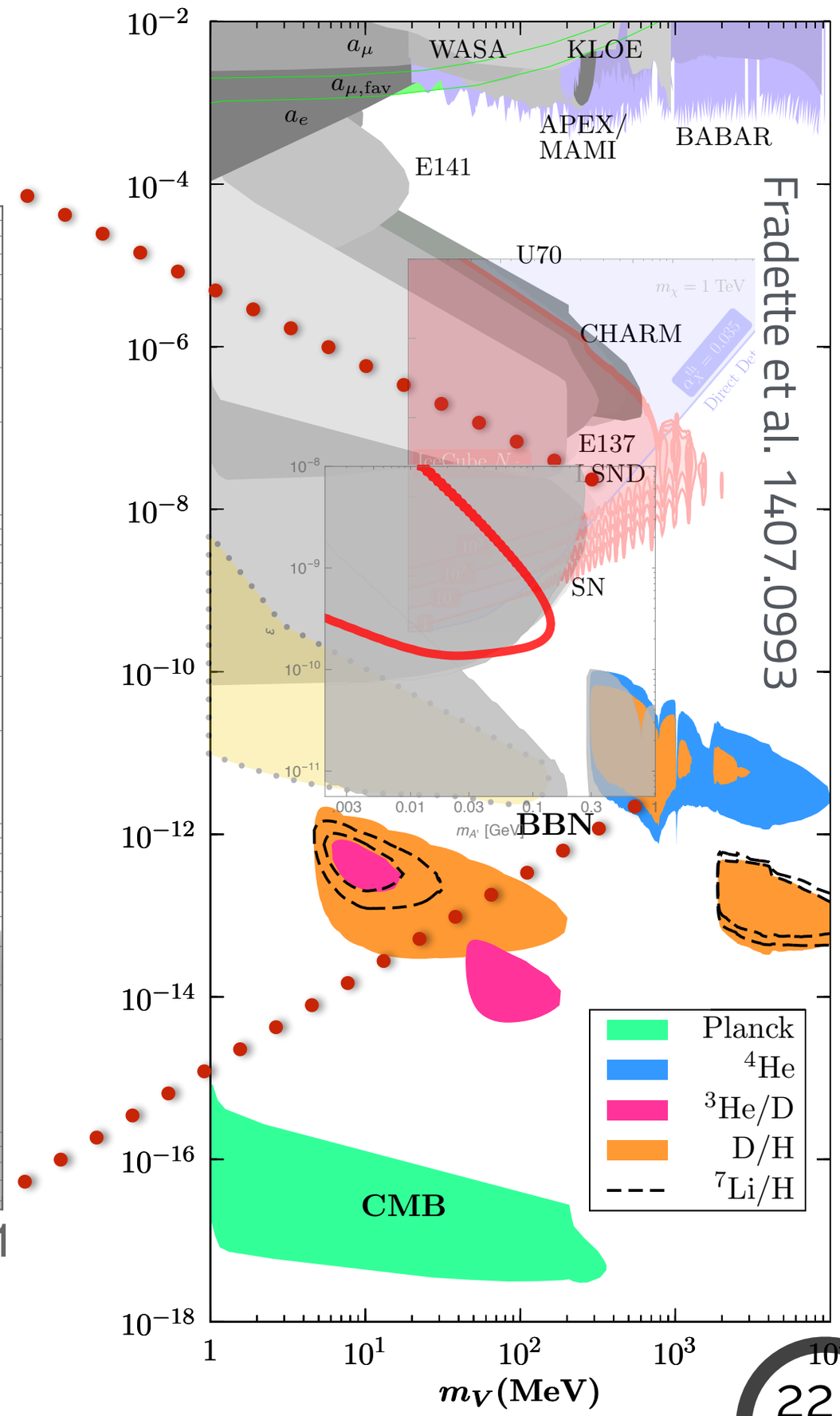
$$\tau = \frac{1}{\sqrt{C_{\rm cap} C_{\rm ann} + \frac{C_{\rm self}^2}{4}}}$$

Feng, Smolinsky, FT (2015, to appear)

AMS-02 Reach

Preliminary N_{sig}=1, $B_{\odot}$=0, t=3y





Feng, Smolinsky, FT (2015, to appear)

Solar Dark Photons with AMS-02

- Novel way to search for DM with AMS-02:
  controlled astrophysical background
  REMARK: AMS HAS FANTASTIC ANGULAR RESOLUTION!

- Magnetic field of the Sun/Earth smears out signal;
  But can be modeled at solar minimum

- Self-capture rate too small to be probed,
  esp. with Sommerfeld enhancement of annihilation
  PERHAPS OTHER TARGETS? (e.g. “If AMS-02 were at Pluto..”)

Summary of this talk

Dark Matter annihilates in the Earth (or the Sun) to dark photons, which are detected by IceCube (or AMS).

(A PLACE; SOME PARTICLE(S); AN EXPERIMENT)

- Directional information gives background rejection
- Earth/Sun is cold: Sommerfeld resonances
- Interesting but difficult to reach:
  Double muon track in IceCube, self-interaction effects