# Stefano Profumo

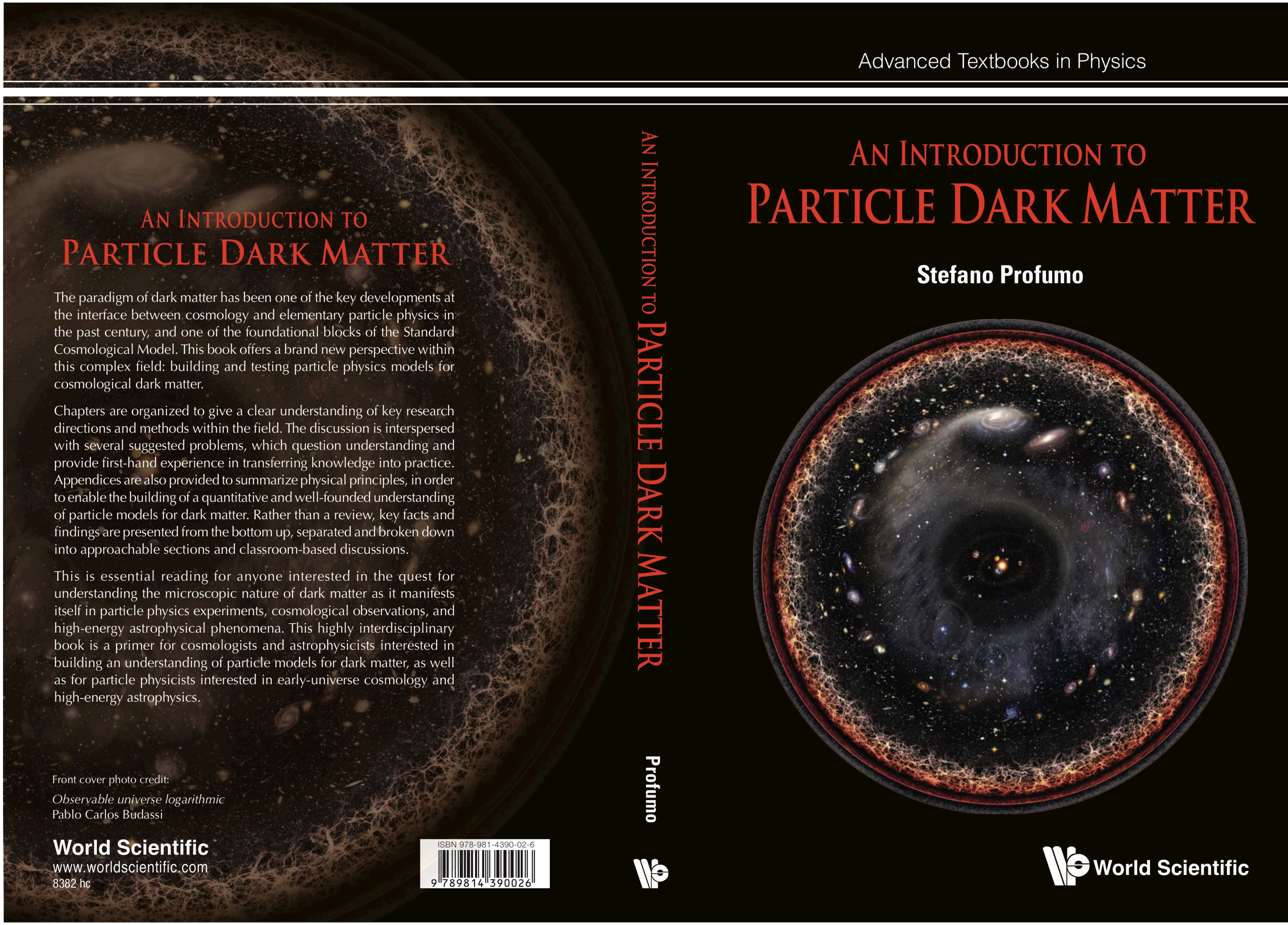
Santa Cruz Institute for Particle Physics
University of California, Santa Cruz

# An Introduction to Particle Dark Matter

## Lecture 3

## **Key ideas** from last lecture

- ✓ Cold relic density: **Boltzmann** equation, still $\Omega \sim 1/\sigma$, but potentially with **caveats** (resonances, coannihilation, thresholds)
- ✓ Modified **expansion rate** at DM freeze-out = big deal!
- ✓ Following chemical decoupling, **kinetic decoupling** sets the **cutoff** to the matter power spectrum
- ✓ Cut off **tiny** for cold relics, **too big** for hot relics, ~OK for warm
- ✓ DM doesn't need to be **coupled** to **ordinary matter** (other than gravitationally) but if thermal relic works, then it is
- ✓ **Direct detection** hard, but possible; keV-scale energy deposited, GeV-scale DM masses




* to appear end of 2016/beginning 2017

# Direct detection **event rates**

$$\frac{\mathrm{d}R}{\mathrm{d}E_R} = N_T\, n_\chi\, \langle v_\chi \frac{\mathrm{d}\sigma}{\mathrm{d}E_R} \rangle$$

$$E_R = \frac{q^2}{2m_T} = \frac{\mu_T^2}{m_T} v_\chi^2 (1 - \cos\theta)$$

$$\mathrm{d}E_R = (\mathrm{d}\cos\theta)(\mu_T^2/m_T)v^2$$

$$\frac{\mathrm{d}R}{\mathrm{d}E_R} = N_T \frac{\rho_{\mathrm{DM}} m_T}{m_\chi \mu_T^2} \int_{v_{\min}}^{v_{\mathrm{esc}}} \mathrm{d}^3 v \frac{f(v)}{v} \frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta}$$

How do we calculate the scattering **cross section**?

**Non-relativistic** limit, the scattering **matrix element** is the Fourier transform of WIMP-nucleus potential

$$\mathcal{M}(q^2) \sim \int \langle f | V(\vec{r}) | i \rangle e^{i\vec{q}\cdot\vec{r}} \mathrm{d}\vec{r},$$

to the lowest order in velocity, the potential is just a **contact interaction** of spin-independent and axial terms

$$V(\vec{r}) = \sum_{\text{nucleons } n} \left( G_s^n + G_a^n \vec{\sigma}_\chi \cdot \vec{\sigma}_n \right) \delta(\vec{r} - \vec{r}_n)$$

where the ***G***'s are the effective DM-nucleon couplings for **scalar** and **axial** interactions

**Coherence** requires the nucleus size to be much smaller than the momentum transfer wavelength (*1/q*)

$$qR_{\mathrm{nucleus}} \ll 1$$

Loss of coherence is phenomenologically accounted for by introducing **form factors** describing the nucleus response

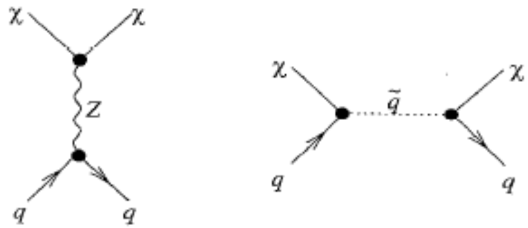
$$\mathcal{M}(q^2) = T(0)F(q^2)$$

Given a **microscopic** theory of dark matter,

how does one get to the **DM-nucleus cross section**?

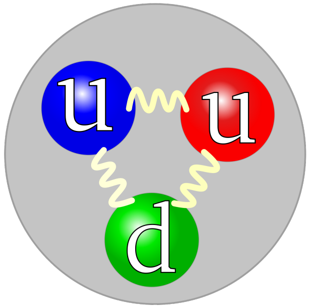
An interesting **multi-layered** problem in **effective field theory**!

**Dark Matter-quark**



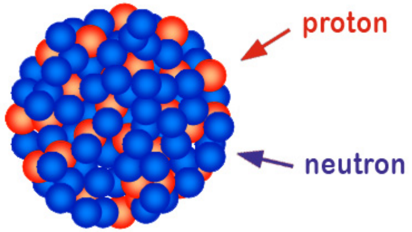

**Low-energy EFT**

**Nucleon matrix elements**




**Dark Matter-nucleon**

**Form factors**

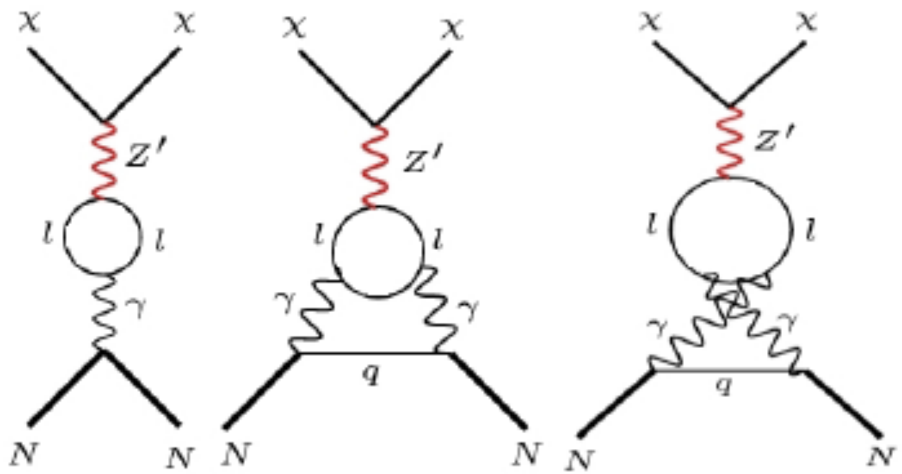


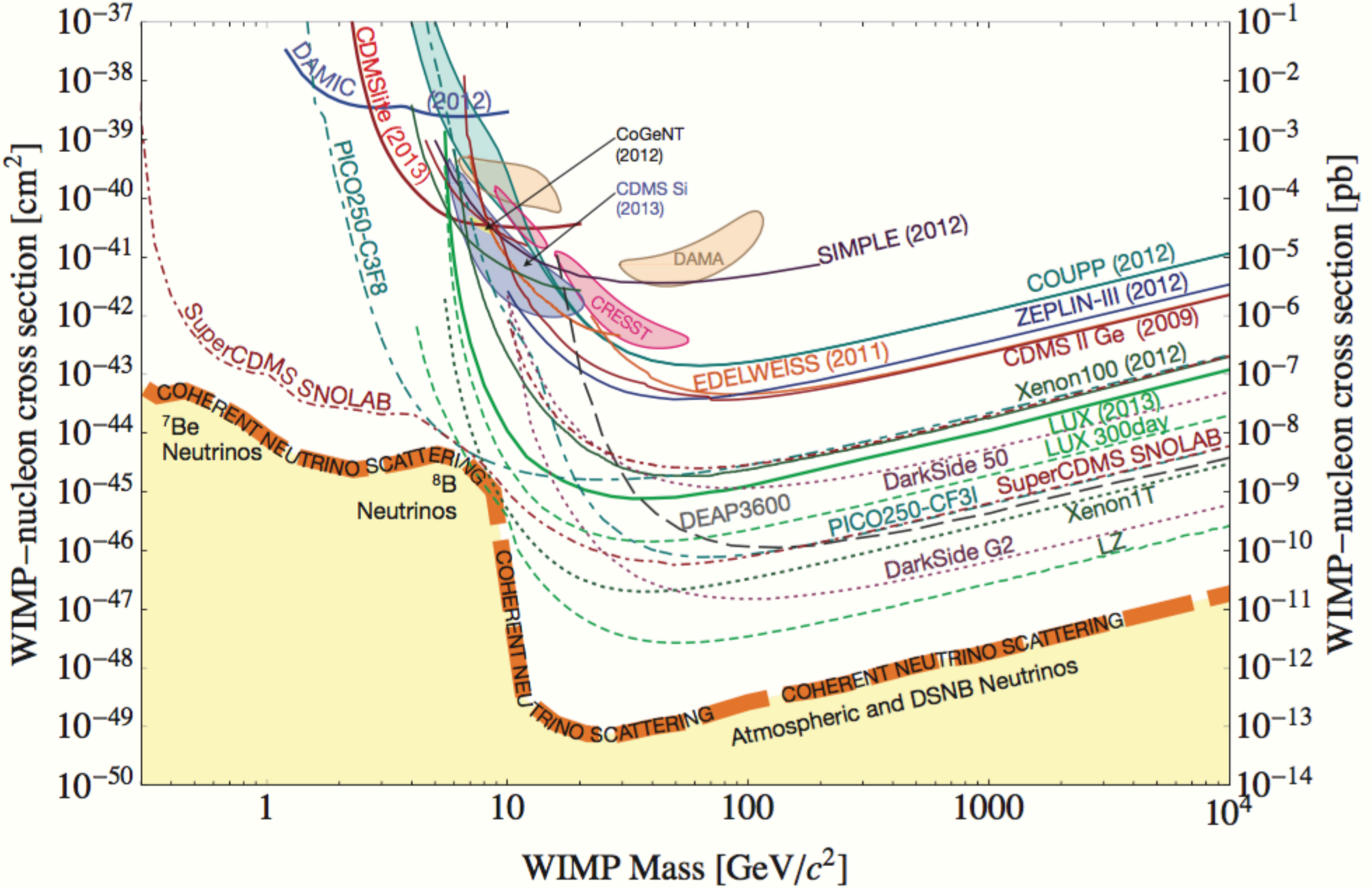

**Dark Matter-nucleus**

Sometimes life is simpler, e.g. if DM is (**milli**-electric-)**charged**

$$\sigma_N = \frac{16\pi\alpha^2\varepsilon^2 Z^2 \mu_N^2}{q^4}$$

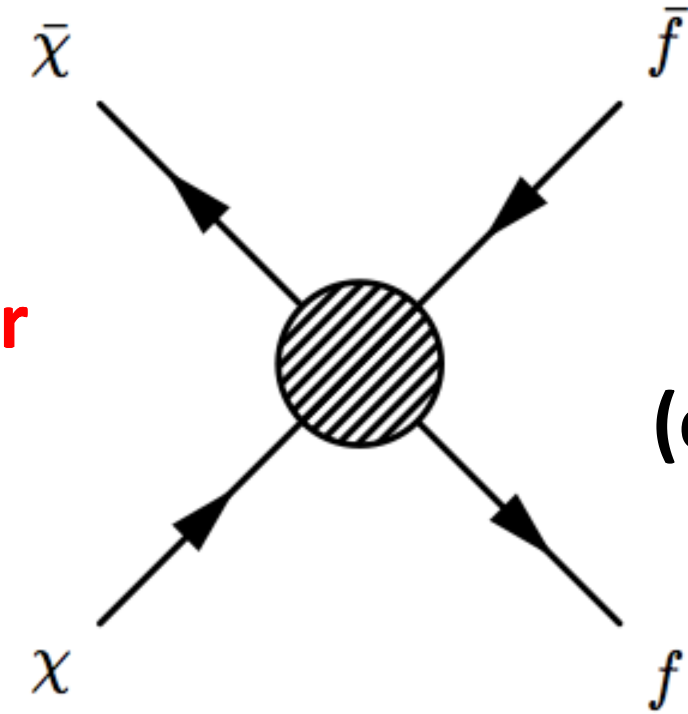
Sometimes life is nastier, e.g. if DM is **lepto-philic**





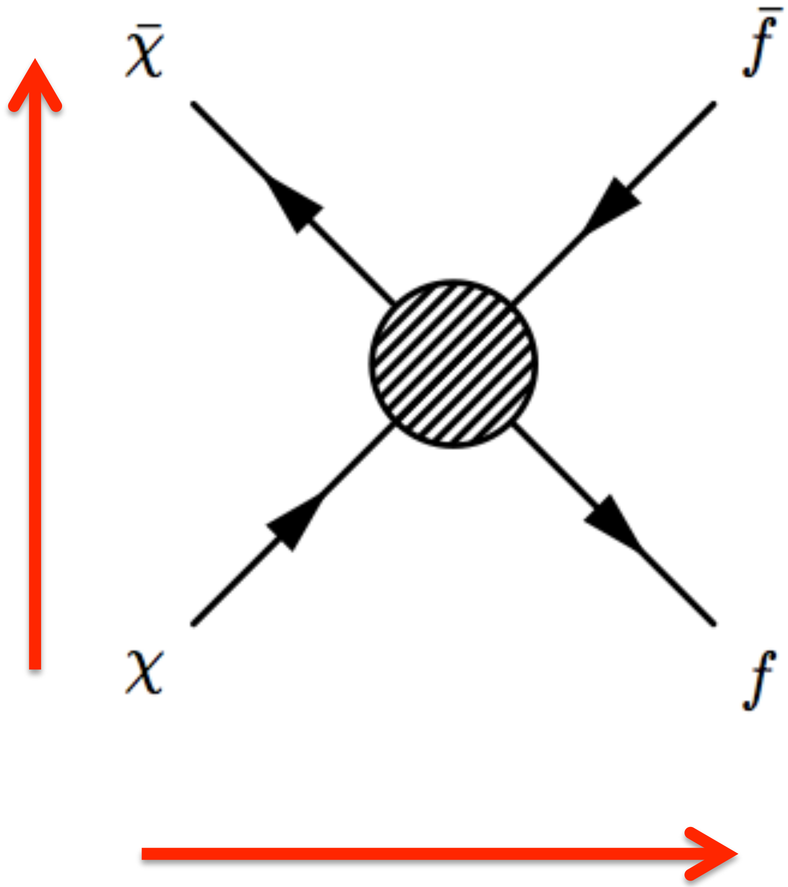
WIMP–nucleon cross section [cm^2]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c^2]
DAMIC
CDMSlite (2013)
(2012)
PICO250-C3F8
CoGeNT (2012)
CDMS Si (2013)
DAMA
SIMPLE (2012)
CRESST
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
Xenon100 (2012)
LUX (2013)
LUX 300day
SuperCDMS SNOLAB
DarkSide 50
DEAP3600
PICO250-CF3I
Xenon1T
DarkSide G2
LZ
SuperCDMS SNOLAB
COHERENT NEUTRINO SCATTERING
7Be Neutrinos
8B Neutrinos
Atmospheric and DSNB Neutrinos

**Dark Matter**
**Particles**




**Standard Model**
**(ordinary) Particles**

direct detection




**thermal equilibrium**

**[pair annihilation, “indirect” detection]**

Idea: use the **debris** of DM **pair-annihilation** (likely large if thermal relic) or **decay**

$$\Gamma_{\rm SM,\ ann} \sim \left(\int_V \frac{\rho_{\rm DM}^2}{m_\chi^2} {\rm d}V\right) \times (\sigma v) \times (N_{\rm SM,\ ann})\,,$$

$$\Gamma_{\rm SM,\ dec} \sim \left(\int_V \frac{\rho_{\rm DM}}{m_\chi} {\rm d}V\right) \times \left(\frac{1}{\tau_{\rm dec}}\right) \times (N_{\rm SM,\ dec})$$

What do we know about these **rates**?
$\sigma$v from **thermal production** (with caveats!)

How about **decay rate**?

Suppose DM decay mediated by **high-scale** physics at scale ***M***

$$\Gamma_5 \sim \frac{1}{M^2} m_\chi^3$$

$$\tau_5 \sim 1 \text{ s} \left(\frac{1 \text{ TeV}}{m_\chi}\right)^3 \left(\frac{M}{10^{16} \text{ GeV}}\right)^2$$

Dimension-5 operator doesn't work – would be too **short lived**!

$$\Gamma_6 \sim \frac{1}{M^4} m_\chi^5,$$

**Interesting**, well motivated!

$$\tau_6 \sim 10^{27} \text{ s} \left(\frac{1 \text{ TeV}}{m_\chi}\right)^5 \left(\frac{M}{10^{16} \text{ GeV}}\right)^4$$

What about annihilation **final state**?

Very **model-dependent**

1. if DM belongs to an SU(2) **multiplet**, then well-defined combination of *ZZ*, *WW* final states...

2. In UED, DM is KK-1 mode of **hypercharge gauge boson**, thus

$|M|^2 \propto |Y_f|^4$ $Y_{u_L} = 4/3$ $Y_{e_R} = 2$

3. Special "**selection rule**", e.g. helicity suppression for Marjorana fermion (analogous to charged pion decay)

$$|M|^2 \propto m_f^2$$

**Annihilation** (or decay) of DM can be **detected** or **constrained** in a variety of ways

Here's one possible **classification**:

1. **Very Indirect**: effects induced by dark matter on **astrophysical objects** or on **cosmological observations**

2. **Pretty Indirect**: probes that don't "trace back" to the annihilation event, as their trajectories are bent as the particles propagate: **charged cosmic rays**

3. **Not-so-indirect**: **neutrinos** and **gamma rays**, with the great added advantage of traveling in straight lines

**Very indirect** probes include e.g.

- **Solar Physics** (dark matter can affect the Sun's core temperature, the sound speed inside the Sun,...)
- **Neutron Star Capture**, possibly leading to the formation of black holes (notably e.g. in the context of asymmetric dark matter)
- **Supernova** and **Star** cooling
- **Protostars** (e.g. WIMP-fueled population-III stars)
- **Planets warming**
- **Big Bang Nucleosynthesis**, on the **cosmic microwave background**, on **reionization**, on **structure formation**…

**Pretty Indirect** Probes: **charged cosmic rays**

Good idea is to use **rare** cosmic rays, such as **anti-matter**

**antiprotons**, **positrons** relatively abundant
(mostly from inelastic processes CR p on ISM p)

Interesting probe: **antideuterons** (or even **anti-$^3$He** !!)

$$\bar{D}: \quad p+p \to p+p+\bar{p}+p+\bar{n}+n$$

**large** energy **threshold** (~17 GeV), so typically large momentum, while from DM produced at very low momentum! Select **low-energy antideuterons**

**positrons** (and in part antiprotons) have attracted attention because of "**anomalies**" reported by PAMELA, AMS-02

general scheme for Galactic CR's: **diffusion** (leaky-box) models

$$\frac{\mathrm{d}n}{\mathrm{d}E} = \psi\left(\vec{x}, E, t\right)$$

$$\frac{\partial}{\partial t}\psi \;=\; D(E)\Delta\psi \;+\; \frac{\partial}{\partial E}\left(b(E)\;\psi\right) \;+\; Q\left(\vec{x}, E, t\right)$$

Things can be made arbitrarily more **complicated/sophisticated**:

- *Cosmic-ray convection*; recipe: add: $\frac{\partial}{\partial z}(v_c \cdot \psi)$;
- *Diffusive re-acceleration*; recipe: add: $\frac{\partial}{\partial p}\, p^2\, D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \psi$;
- *Fragmentation and decays*; recipe: add: $-\frac{1}{\tau_{\mathrm{f,d}}}\psi$.

**Boundary** conditions:
$$R \sim \mathcal{O}(1) \times 10 \text{ kpc},$$
$$h \sim \mathcal{O}(1) \times 1 \text{ kpc}.$$

$$D(E) \sim D_0 \left(\frac{E}{E_0}\right)^{\delta}$$

Useful to **simplify** the diffusion equation assuming steady-state, using typical diffusion and energy loss **time-scales**, defined by

$$\tau_{\text{diff}} \sim \frac{R^2}{D_0} \cdot E^{-\delta}, \qquad \tau_{\text{loss}} \sim \frac{E}{b(E)}$$

Diff. Eq. then looks like
$$0 = -\frac{\psi}{\tau_{\text{diff}}} - \frac{\psi}{\tau_{\text{loss}}} + Q$$

with **solution**
$$\psi \sim Q \cdot \min[\tau_{\text{diff}}, \tau_{\text{loss}}]$$

If the source is cosmic rays accelerated via a **Fermi mechanism**,

$$Q \sim E^{-2} \longrightarrow \psi \sim E^{-2} \cdot E^{-\delta} \sim E^{-2.7}$$

…in agreement with **CR protons** (where en. losses are irrelevant)

For CR **electrons**, energy losses are efficient above a certain **energy**,

$$b_e(E) \simeq b^0_{\rm IC} \left(\frac{u_{\rm ph}}{1\ {\rm eV/cm^3}}\right) \cdot E^2 + b^0_{\rm sync} \left(\frac{B}{1\ \mu{\rm G}}\right)^2 \cdot E^2$$

$$b^0_{\rm IC} \simeq 0.76, \qquad b^0_{\rm sync} \simeq 0.025\ \ 10^{-16}\ {\rm GeV/s}$$

Therefore (as observed) we expect a **broken power-law**

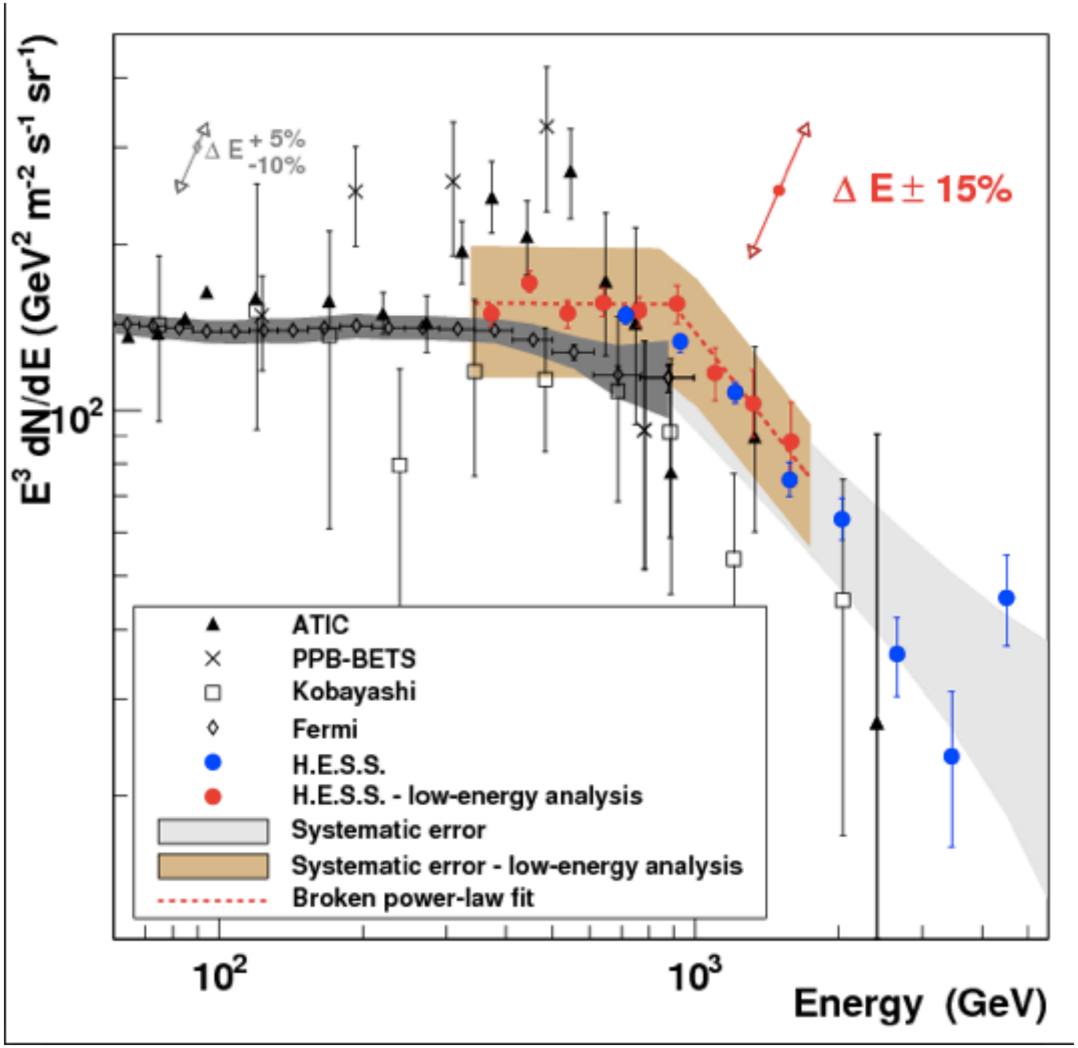
$$\psi_{\rm primary,\ low-energy} \sim Q \cdot \tau_{\rm diff} \sim E^{-2} \cdot E^{-\delta} \sim E^{-2.7}$$

$$\psi_{\rm primary,\ high-energy} \sim Q \cdot \tau_{\rm loss} \sim E^{-1} \cdot \frac{E}{E^2} \sim E^{-3}$$

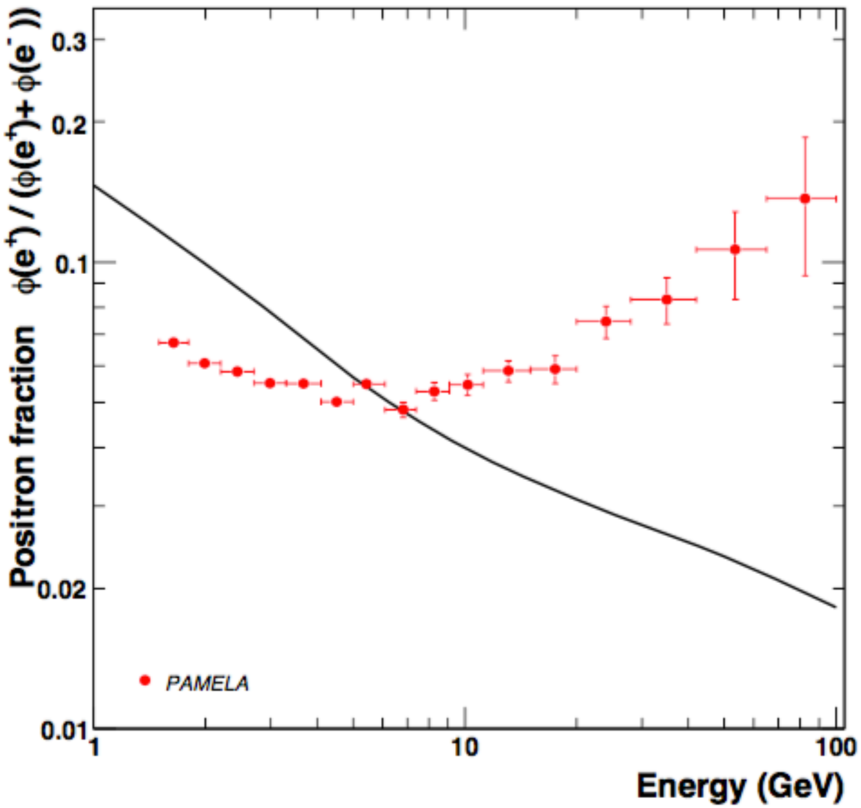
Also, **secondary-to-primary** ratios are generically

$$\frac{\psi_{e^+}}{\psi_{e^-}} \sim E^{-\delta}.$$

# Electron spectrum looks pretty good



but the **secondary-to-primary ratio** prediction is at **odds** with observed rising positron fraction




Much **hype** about this possibly being from **DM** – but very **problematic**

- No excess **anitprotons** – must be "leptophilic" (possible but not generic)

- No observed **secondary radiation** from brems or IC

- Needed **pair-annihilation rate** very large for thermal production, leads to unseen gamma-ray or radio emission

$$\langle \sigma v \rangle \sim 10^{-24} \frac{\text{cm}^3}{\text{s}} \cdot \left( \frac{m_\chi}{100 \text{ GeV}} \right)^{1.5}$$

Alternate explanation: nearby **point source** injecting a burst of **positrons** (a.k.a. Green's function, a.k.a. **PSR**)

$$\psi \propto Q \cdot \exp\left(-\left(\frac{r}{r_{\rm diff}}\right)^2\right)$$

Estimate **Age** and **Distance** of putative source

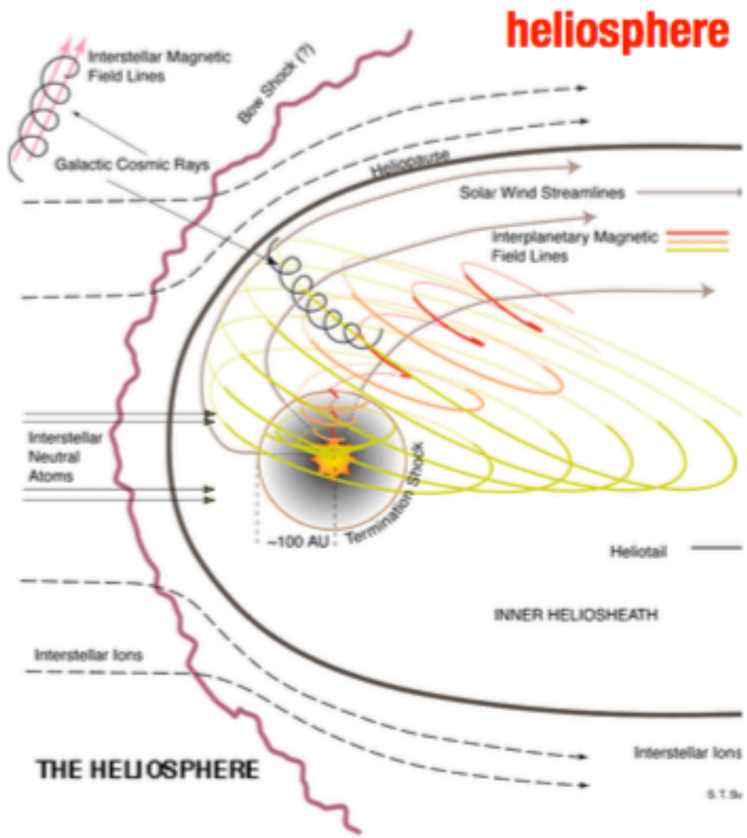
$$t_{\rm psr} \ll \tau_{\rm loss} = \frac{E}{b(E)}; \text{ for } E = 100 \text{ GeV}, \tau_{\rm loss} \sim \frac{100}{10^{-16} \cdot 100^2} \text{ s} \sim 10^{14} \text{ s} \sim 3 \text{ Myr}.$$

$$r_{\rm diff} \simeq \sqrt{D(E) \cdot t}.$$

$$\sqrt{D(E) \cdot t_{\rm psr}} \gg \text{ distance} \rightarrow \text{distance} \ll (3 \times 10^{28} \cdot 100^{0.7} \cdot 10^{14})^{1/2} \text{ cm} \sim 10^{22} \text{ cm} \sim 3 \text{ kpc}.$$

One possible way to **disentangle** PSR from DM: **anisotropy**

Complication: Larmor radius for **heliospheric** magnetic fields ***B~ nT***, is of the order of the **solar system size** (exercise)



**Not-so-indirect** DM detection: **neutrinos**!

Only **two** observed astrophysical sources of neutrinos!

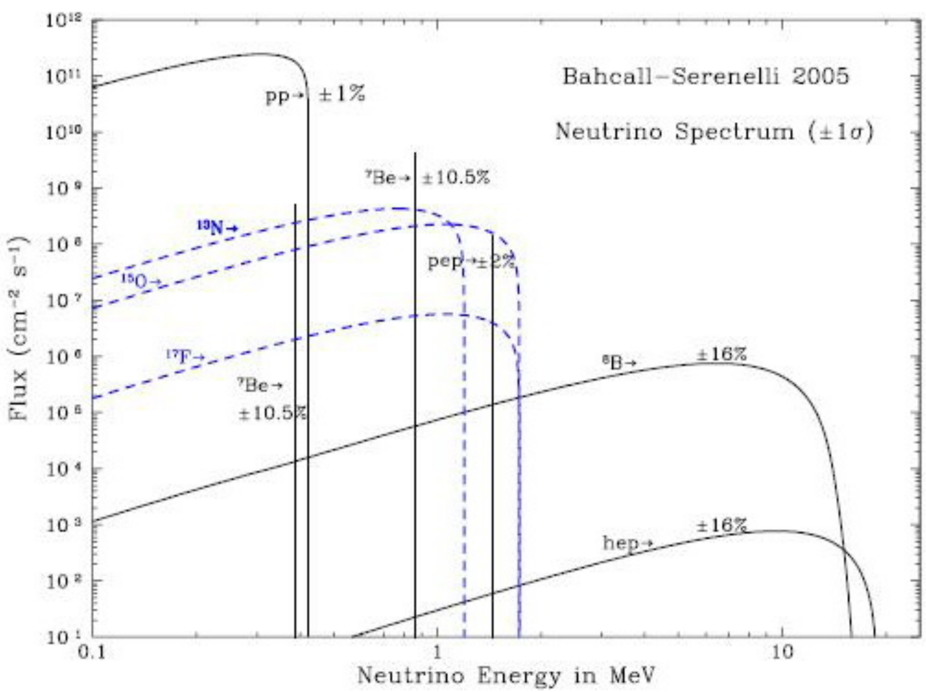
**Hard** (but not impossible) to detect particles

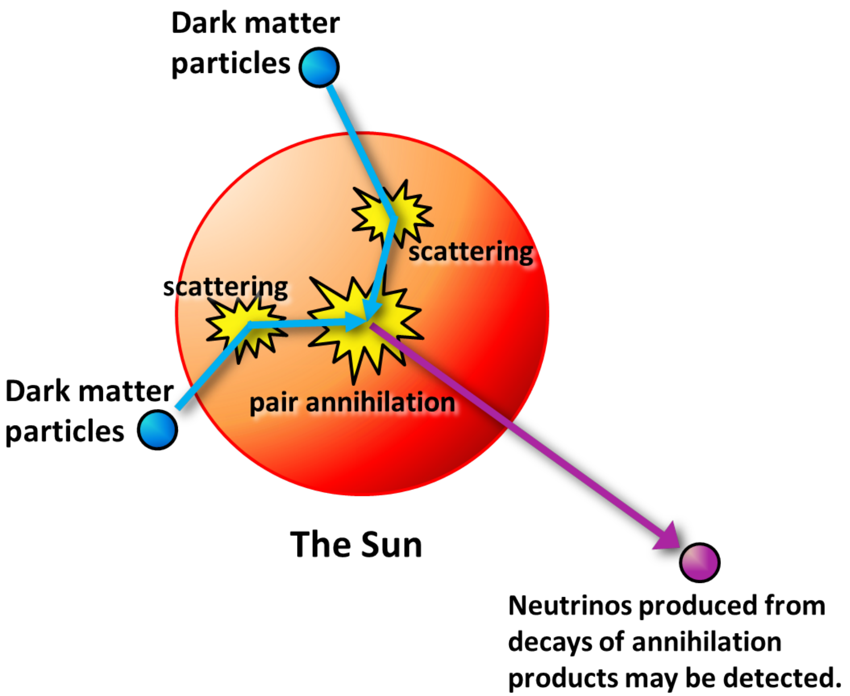
flip side: neutrinos have very **long mean free paths** in matter!

idea: DM can be **captured** in celestial bodies, **accrete** in sizable densities, start pair-annihilating

if the process of capture and annihilation is in **equilibrium**, large **fluxes** of neutrino can escape

# best target: **Sun**! Large, **nearby**, **low-E** neutrino emission



**Estimate** the process **quantitatively**!

First: **capture rate**

$$C^{\odot} \sim \phi_\chi \cdot \left(\frac{M_\odot}{m_p}\right) \cdot \sigma_{\chi-p}, \qquad \phi_\chi \sim n_\chi \cdot v_{\rm DM} = \frac{\rho_{\rm DM}}{m_\chi} \cdot v_{\rm DM}$$

$$\begin{aligned} \sigma_{\chi-p}^{\text{spin dependent}} &\lesssim 10^{-39}\ \text{cm}^2, \\ \sigma_{\chi-p}^{\text{spin independent}} &\lesssim 10^{-44}\ \text{cm}^2. \end{aligned}$$

$$C^{\odot} \sim \frac{10^{23}}{\text{s}} \left(\frac{\rho_{\rm DM}}{0.3\ \text{GeV}/\text{cm}^3}\right) \cdot \left(\frac{v_{\rm DM}}{300\ \text{km/s}}\right) \cdot \left(\frac{100\ \text{GeV}}{m_\chi}\right) \cdot \left(\frac{\sigma_{\chi-p}}{10^{-39}\ \text{cm}^2}\right)$$

# Number of **accreted** DM **particles** *N*

$$\frac{\mathrm{d}N}{\mathrm{d}t} = C^{\odot} - A^{\odot}[N(t)]^2 - E^{\odot}N(t)$$

$$A^{\odot} \simeq \frac{\langle \sigma v \rangle}{V_{\mathrm{eff}}} \qquad\qquad \frac{m_\chi\, \phi_{\mathrm{grav}}(R_{\mathrm{eff}})}{T^{\odot}} \simeq 1$$

$$V_{\mathrm{eff}} \sim 10^{28}\ \mathrm{cm}^3 \left(\frac{m_\chi}{100\ \mathrm{GeV}}\right)^{3/2}$$

$$\Gamma_A = \frac{1}{2} A^{\odot}[N(t^{\odot})]^2 = \frac{C^{\odot}}{2}\left[\tanh\left(\sqrt{C^{\odot}A^{\odot}}\, t^{\odot}\right)\right]^2$$

$$t^{\odot} \sim 4.5\ \mathrm{Byr} \sim 10^{17}\ \mathrm{s}$$

$$t^{\rm eq} \equiv \frac{1}{\sqrt{C^{\odot} A^{\odot}}} \ll t^{\odot} \qquad\qquad C^{\odot} \sim 10^{23}\ {\rm s}^{-1}\ \left(\frac{\sigma_{\chi-p}}{10^{-39}\ {\rm cm}^2}\right)$$

$$A^{\odot}_{\rm eq} \gg \frac{1}{(t^{\odot})^2\ C^{\odot}} = \frac{1}{10^{34}\cdot 10^{23}\ {\rm s}} \sim 10^{-57}\ {\rm s}^{-1}$$

$$A^{\odot} = 3\times 10^{-54}\ {\rm s}^{-1}\ \left(\frac{\langle\sigma v\rangle}{3\times 10^{-26}\ {\rm cm}^3/{\rm s}}\right)$$

So yes thermal DM is in **equilibration** as long as WIMP-nucleon cross section is **larger** than $10^{-41}\ {\rm cm}^2$

With **equilibration**, flux of neutrinos only depends on **capture rate**!

$$\Gamma_A = \frac{1}{2} A^{\odot} [N(t^{\odot})]^2 = \frac{C^{\odot}}{2} \left[ \tanh(\sqrt{C^{\odot} A^{\odot}}\, t^{\odot}) \right]^2$$

$$\Gamma_A \simeq \frac{C^{\odot}}{2}$$

flux of **neutrinos** is then

$$\frac{\mathrm{d}N_{\nu_f}}{\mathrm{d}E_{\nu_f}} = \frac{C^{\odot}}{8\pi (D^{\odot})^2} \left( \frac{\mathrm{d}N_{\nu_f}}{\mathrm{d}E_{\nu_f}} \right)_{\mathrm{inj}}$$

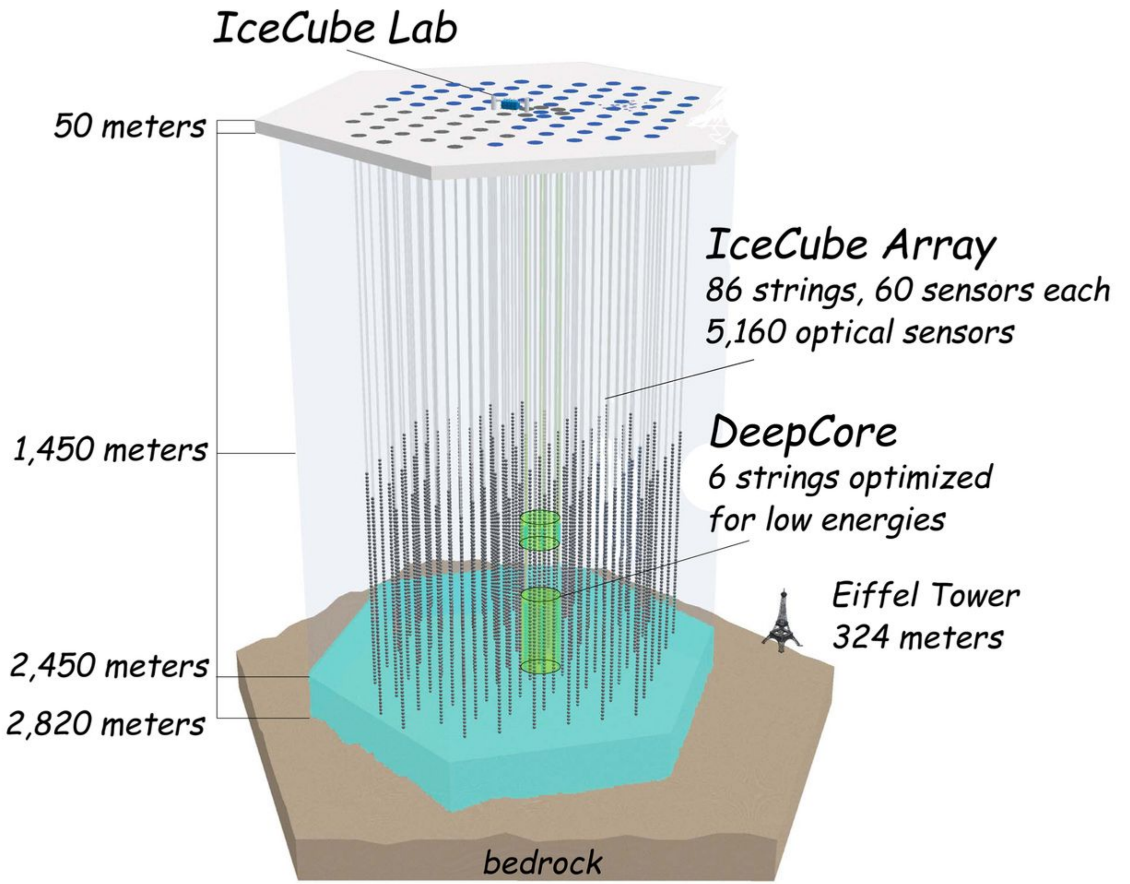
...and the number of **events** at **IceCube**

$$N_{\mathrm{events}} = \int \mathrm{d}E_{\nu_\mu} \int \mathrm{d}y \left( A_{\mathrm{eff}} \cdot \frac{\mathrm{d}N_{\nu_\mu}}{\mathrm{d}E_{\nu_\mu}} \cdot \frac{\mathrm{d}\sigma}{\mathrm{d}y}(E_{\nu_\mu}, y) \cdot (R_\mu(E_{\nu_\mu})) \right)$$

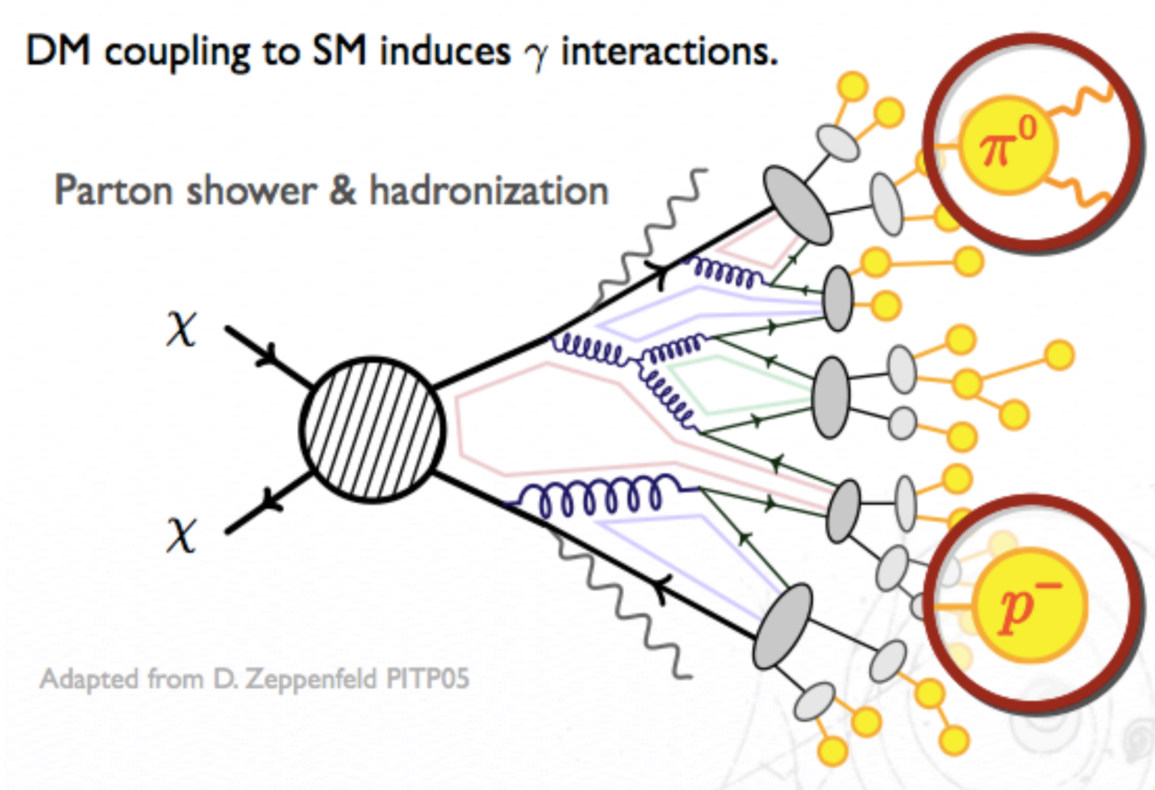
Best **final states**: *WW*, *ZZ*, or leptophilic

So far **no anomalous events** from Sun observed; **Earth** less promising

Opportunities with
**lower-energy**
threshold sub-detectors
**DeepCore**, **PINGU**

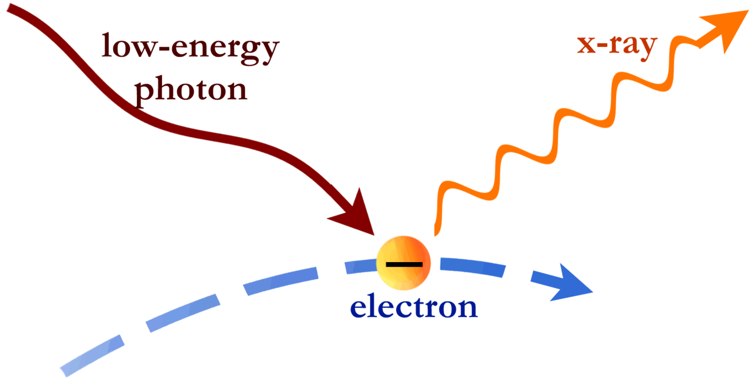


# Light from dark matter!




**Primary** photons: prompt, or internal brems; just run Pythia (if you can!)

**Secondary** photons: IC, synchrotron

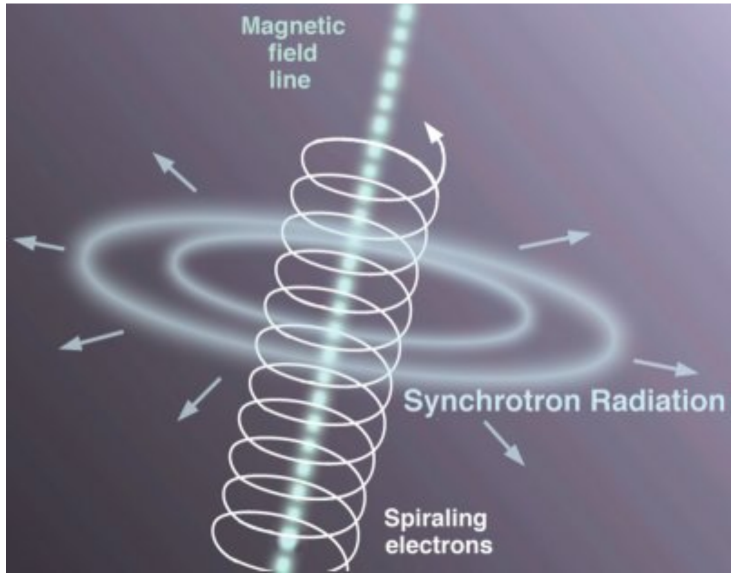



$$\langle E_0' \rangle \sim \frac{4}{3}\gamma_e^2 \, E_0.$$

$$\textbf{CMB} : E_0 \sim 2 \times 10^{-4} \text{ eV}$$
$$\textbf{starlight} : E_0 \sim 1 \text{ eV}$$
$$\textbf{dust} : E_0 \sim 0.01 \text{ eV}$$

$$E_e \sim \frac{m_\chi}{10} \rightarrow \gamma_e \sim 2 \times 10^4 \left( \frac{m_\chi}{100 \text{ GeV}} \right)$$

$$E'_{\text{CMB}} \sim 10^5 \text{ eV} \left( \frac{m_\chi}{100 \text{ GeV}} \right)^2$$




$$\frac{\nu_{\rm sync}}{\rm MHz} \simeq 10 \cdot \left(\frac{E_e}{\rm GeV}\right)^2 \left(\frac{B}{\mu{\rm G}}\right) \simeq 2.8 \cdot \left(\frac{\gamma_e}{1000}\right)^2 \left(\frac{B}{\mu{\rm G}}\right)$$

Prompt emission simply depends on
**annihilation** final state, and **target** of choice

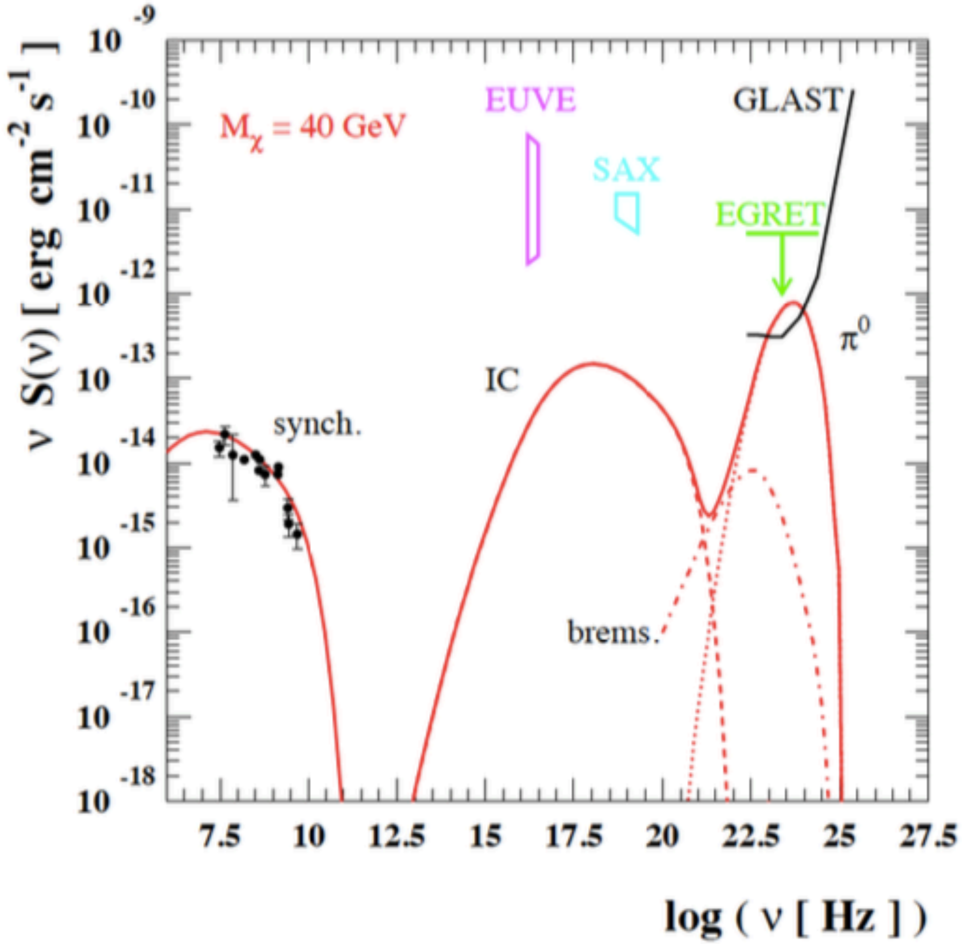
$$\phi_\gamma = \frac{\Delta\Omega}{4\pi}\left\{\frac{1}{\Delta\Omega}\int \mathrm{d}\Omega \int \mathrm{d}l(\psi)\ (\rho_{\mathrm{DM}})^2\right\}\frac{\langle\sigma v\rangle}{2m_\chi^2}\frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma}$$

$$\frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma} = \sum_f \frac{\mathrm{d}N_\gamma^f}{\mathrm{d}E_\gamma}$$

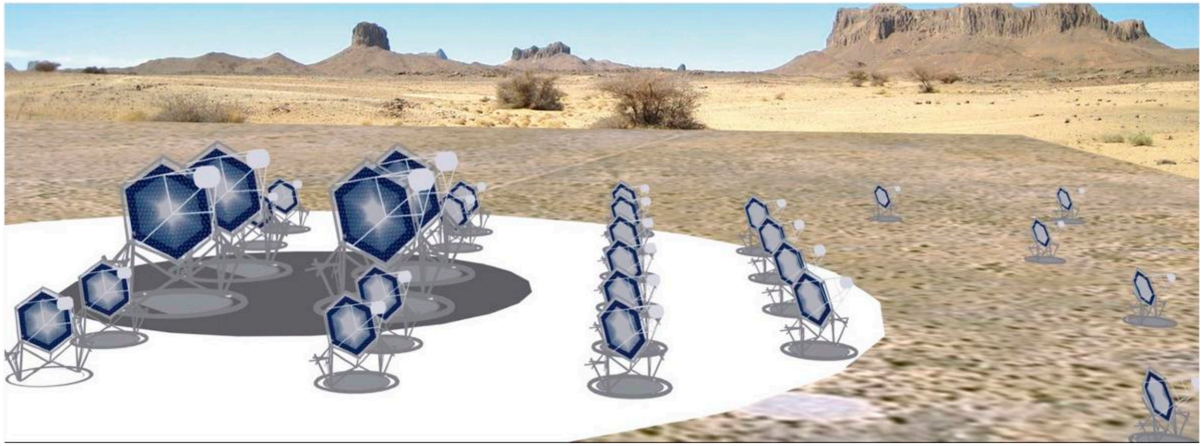
**Angular region** varies from 1 degree, to 0.1 degrees ($10^{-3}$, $10^{-5}$ sr, resp)

1. Dwarf Spheroidal Galaxies
   - Draco, $J \sim 10^{19}$ GeV$^2$/cm$^5$, $\pm$ a factor 1.5;
   - Ursa Minor, $J \sim 10^{19}$ GeV$^2$/cm$^5$, $\pm$ a factor 1.5;
   - Segue, $J \sim 10^{20}$ GeV$^2$/cm$^5$, $\pm$ a factor 3
2. Local Milky-Way-like galaxies
   - M31, $J \sim 10^{20}$ GeV$^2$/cm$^5$
3. Local clusters of galaxies
   - Fornax, $J \sim 10^{18}$ GeV$^2$/cm$^5$
   - Coma, $J \sim 10^{17}$ GeV$^2$/cm$^5$
   - Bullet, $J \sim 10^{14}$ GeV$^2$/cm$^5$
4. Galactic center
   - $0.1^\circ$: $J \sim 10^{22} \ldots 10^{25}$ GeV$^2$/cm$^5$
   - $1^\circ$: $J \sim 10^{22} \ldots 10^{24}$ GeV$^2$/cm$^5$

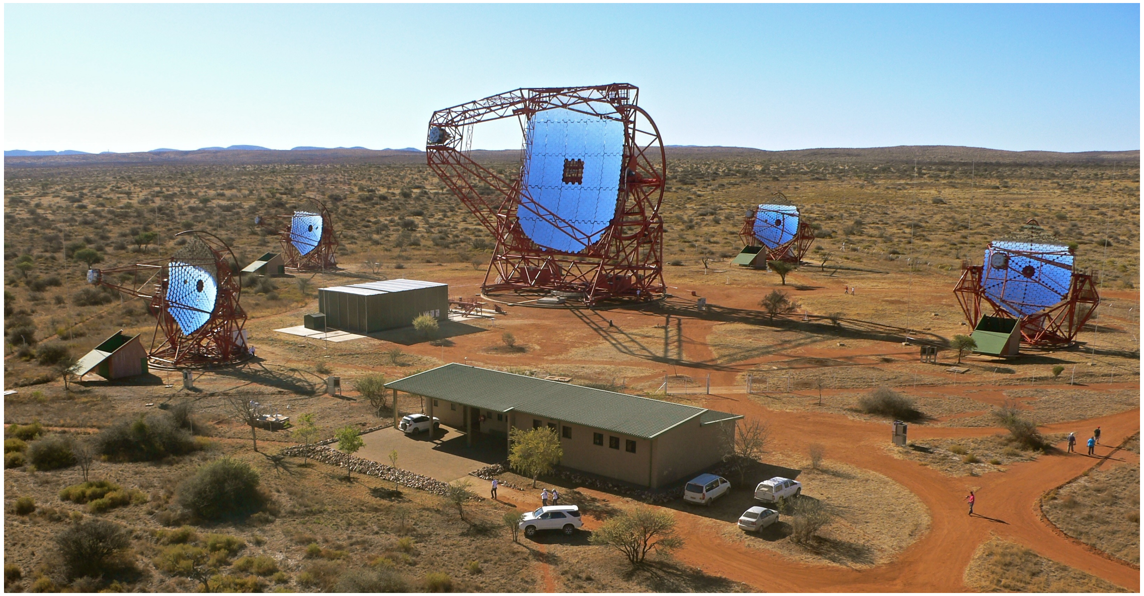
Overall **emission** looks like this, e.g. in a **cluster** of galaxies




here, **normalization** chosen to fit radio emission



| | Fermi-LAT | H.E.S.S. | CTA |
| --- | --- | --- | --- |
| $E_\gamma$ range | 0.1 to 300 GeV | 0.1 to 10 TeV | 10 GeV to 10 TeV |
| $A_{\rm eff}$ | $\sim 1$ m$^2$ | $\sim 10^5$ m$^2$ | $\sim 10^6$ m$^2$ |
| $T_{\rm obs}$ | $\sim 10^8$ s | $\sim 10^6$ s | $\sim 10^6$ s |



to have a **detection**: collect **some photons**, beat **background** (S/N>>1)

$$\int \mathrm{d}E_\gamma \frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma} \sim \frac{m_\chi}{\mathrm{GeV}}$$

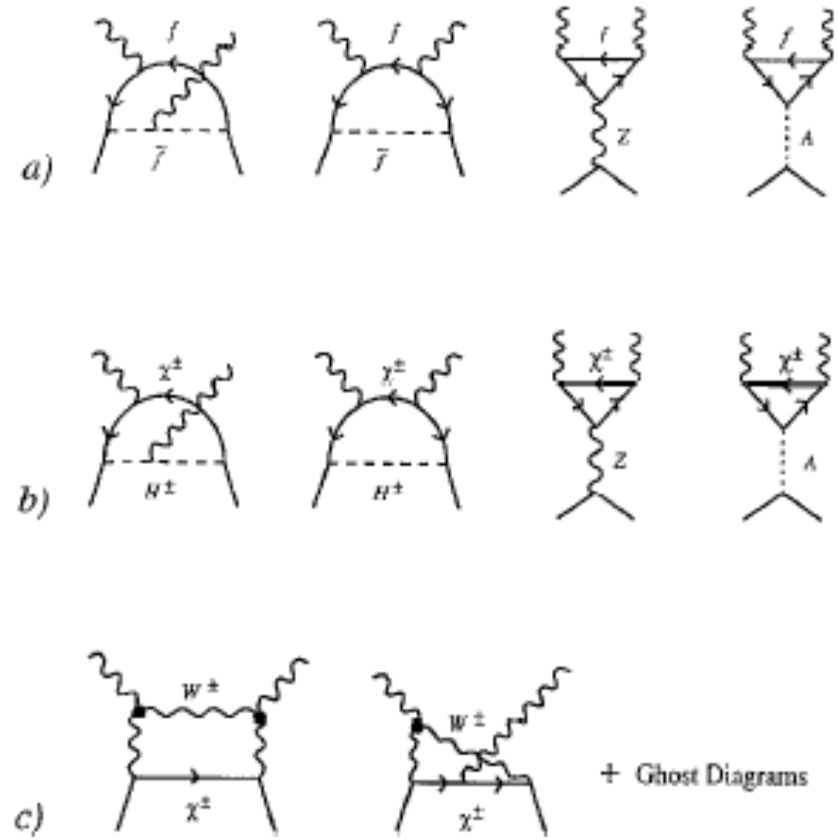
$$\phi_\gamma = (\Delta\Omega \cdot J) \frac{1}{8\pi} \frac{\langle \sigma v \rangle}{m_\chi^2} \cdot m_\chi \sim 10^{-32} \frac{1}{\mathrm{cm}^2\,\mathrm{s}} \left( \frac{J}{\mathrm{GeV}^2/\mathrm{cm}^5} \right)$$

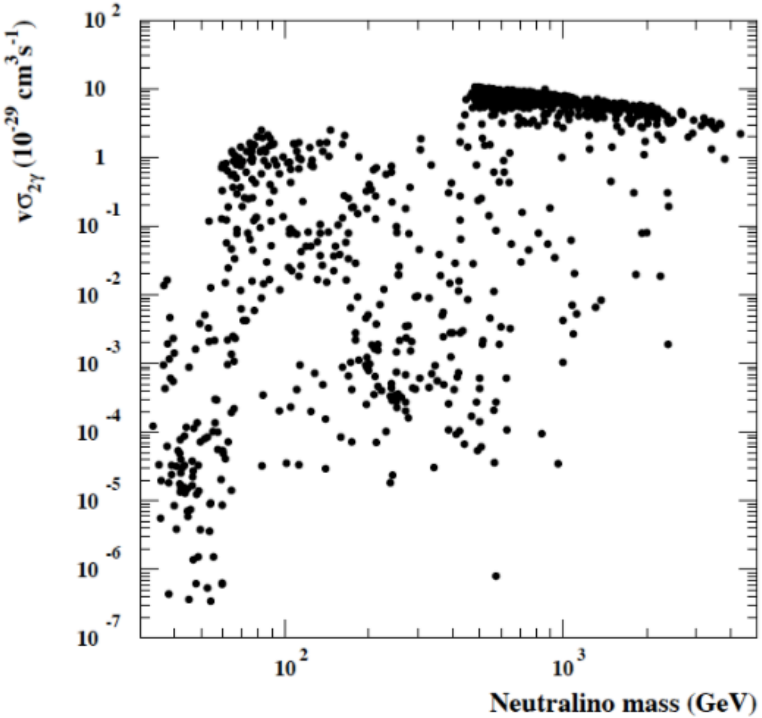
$$N_\gamma \sim A_{\mathrm{eff}} \cdot T_{\mathrm{obs}} \cdot \phi_\gamma \sim 10^{-20} \frac{J}{\mathrm{GeV}^2/\mathrm{cm}^5}$$

$$J^{\mathrm{tot}} \sim \mathrm{few} \times 10^{20}\ \mathrm{GeV}^2/\mathrm{cm}^5; \qquad \langle \sigma v \rangle_{\mathrm{lim}} \sim 3 \times 10^{-26} \frac{\mathrm{cm}^3}{\mathrm{s}} \left( \frac{30\ \mathrm{GeV}}{m_\chi} \right)$$

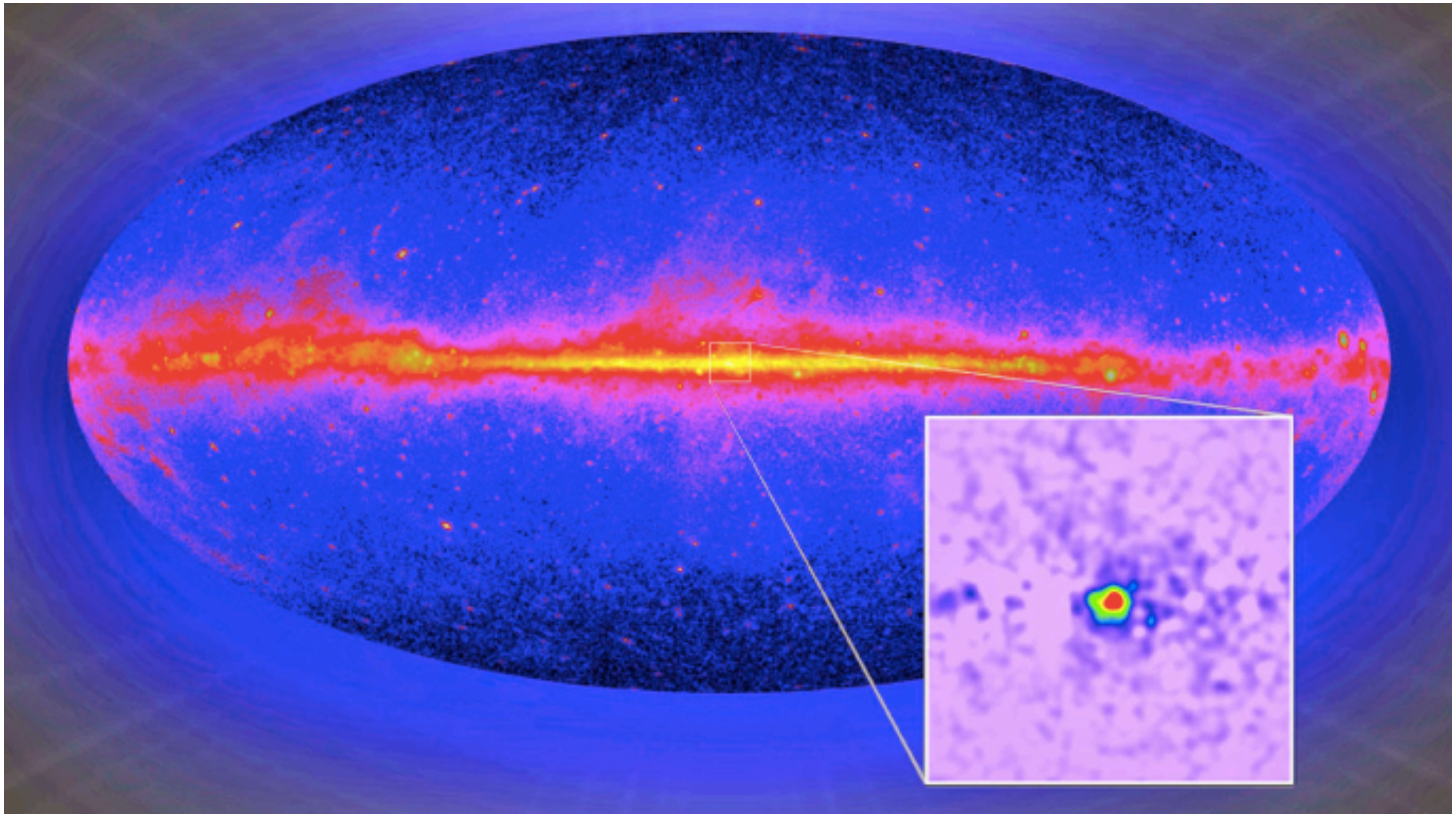
In addition, **monochromatic** photons $\chi\chi \to \gamma\gamma$

$$\frac{\langle \sigma v \rangle_{\gamma\gamma}}{\langle \sigma v \rangle_{\rm tot}} \sim \frac{\alpha^2}{16\pi^2}$$



After early reports (primarily by Hooper et al) **Galactic Center Excess** reported independently, and with a variety of different assumptions for background etc, by Daylan et al (Harvard+MIT+Fermilab); Abazijian et al (UCI); Macias and Gordon (NZ)



# What produces the Galactic Center excess?

## Fitting the excess with
## Dark Matter Annihilation not problematic

- ✓ Morphology ~OK
- ✓ Spectrum ~OK
- ✓ Constraints from dSph, radio, CMB
  ~sort of OK

# What produces the Galactic Center excess?

## Most obvious astrophysical counterpart (unresolved pulsars) does not work

- ✓ Morphology NOT OK
- ✓ Spectrum NOT OK
- ✓ Not enough!

What **produces** the Galactic Center **excess**?

**WRONG QUESTION**!

Rather: **is the excess** indeed **there**?

Are models of **diffuse** emission
**adequate** to current **data**?