24 October 2012
Lioneutrino 2012 - Lyon

DMν: neutrinos from DM

Marco Cirelli
(CNRS IPhT Saclay)

Based on:

Cirelli, Fornengo, Montaruli, Sokalski, Strumia, Vissani,
Nucl.Phys. B727 (2005) 99-138, Erratum-ibid. B790 (2008) 338-344 [hep-ph/0506298]

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Introduction

Basics:

1) neutrinos from galactic center or halo
2) neutrinos from the Sun

Status:

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Conclusions

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DM exists

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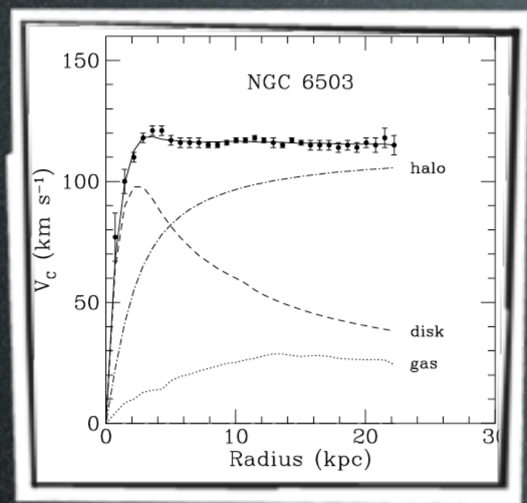
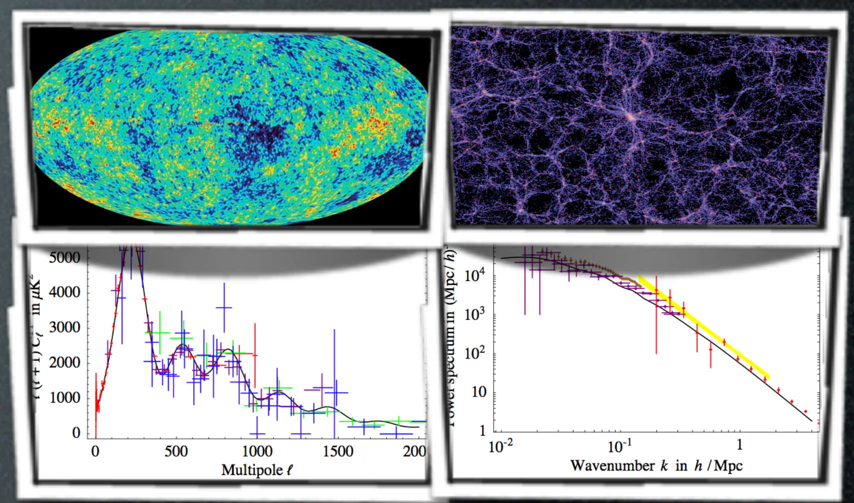


galactic rotation curves

weak lensing (e.g. in clusters)



‘precision cosmology’ (CMB, LSS)

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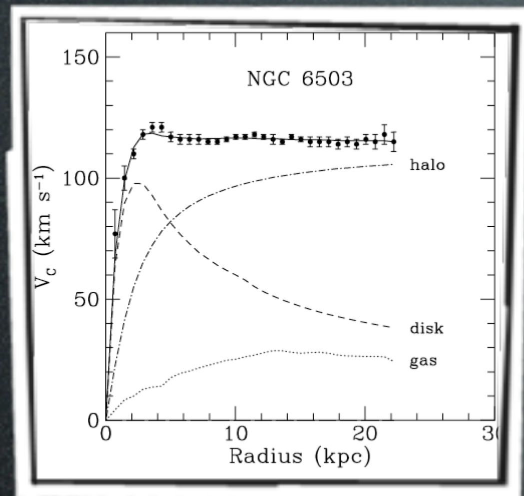

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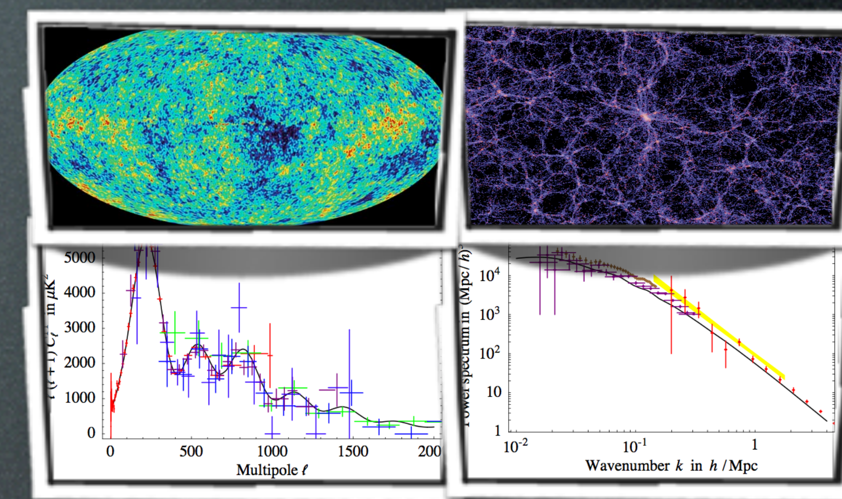

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DM is a neutral, very long lived, feebly interacting particle.

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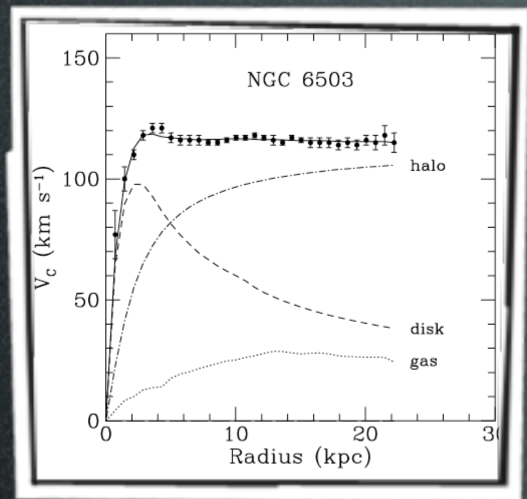

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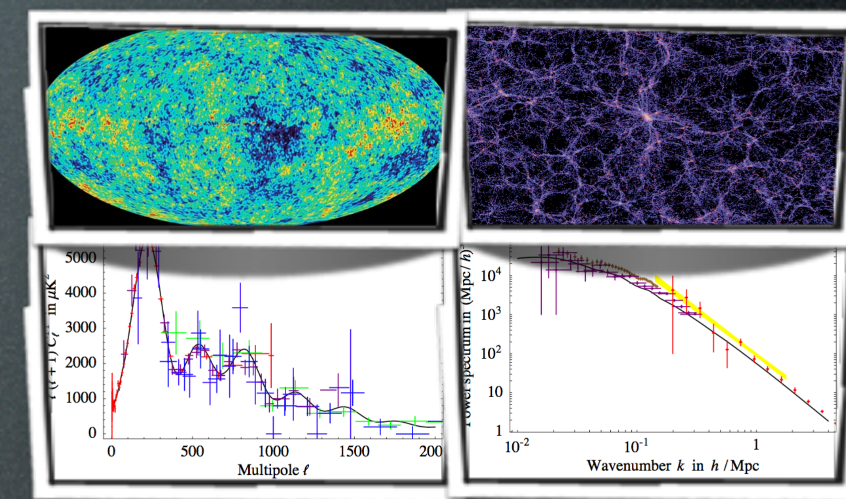
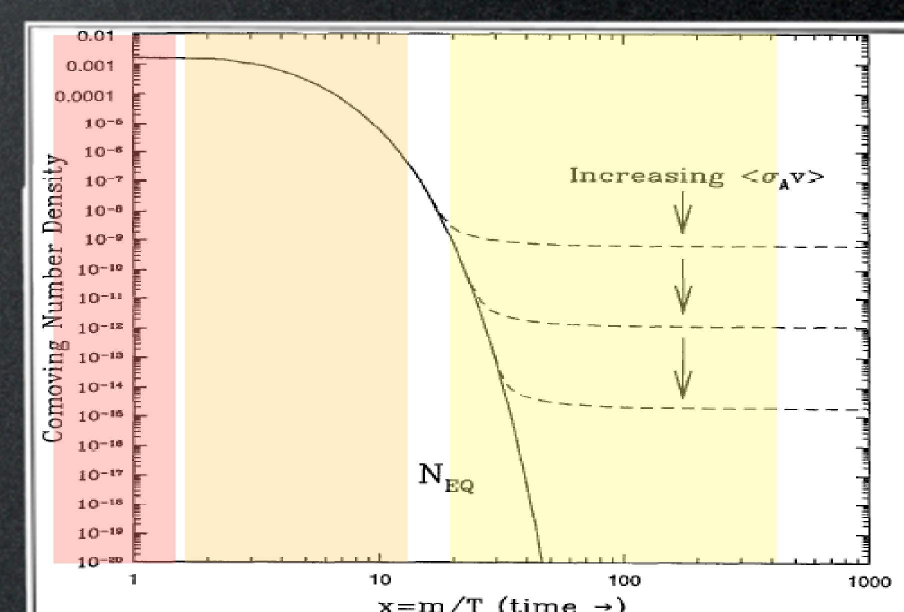


'precision cosmology' (CMB, LSS)

DM is a neutral, very long lived, feebly interacting particle.

Some of us believe in the WIMP miracle.

- *weak*-scale mass (10 GeV - 1 TeV)
- *weak* interactions $\sigma v = 3 \cdot 10^{-26} \mathrm{cm}^3/\mathrm{sec}$
- give automatically correct abundance



DM detection

direct detection

Xenon, CDMS, Edelweiss... (CoGeNT, Dama/Libra...)

production at colliders

LHC

indirect

γ from annihil in galactic center or halo and from synchrotron emission

Fermi, **ICT**, radio telescopes...

e^+ from annihil in galactic halo or center

PAMELA, **Fermi**, **HESS**, AMS, **balloons...**

$\bar{p}$ from annihil in galactic halo or center

$\bar{d}$ from annihil in galactic halo or center

GAPS

$\nu, \bar{\nu}$ from annihil in galactic center or halo or in massive bodies (Earth or Sun)

SK, **Icecube**, Km3Net

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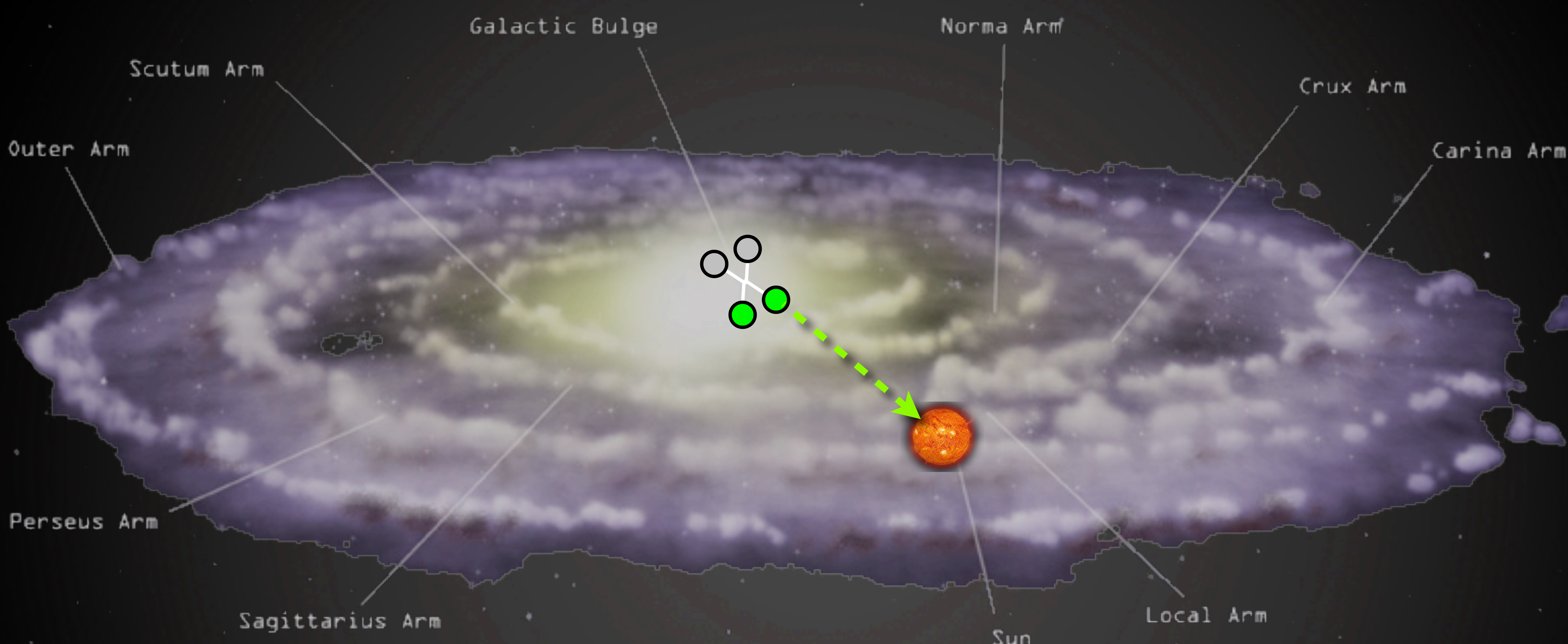
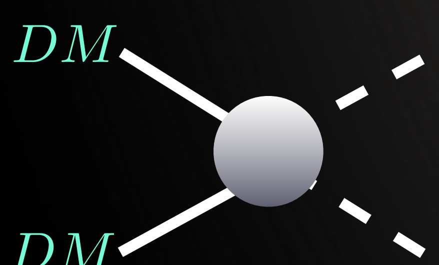
ν from DM annihilations in galactic center





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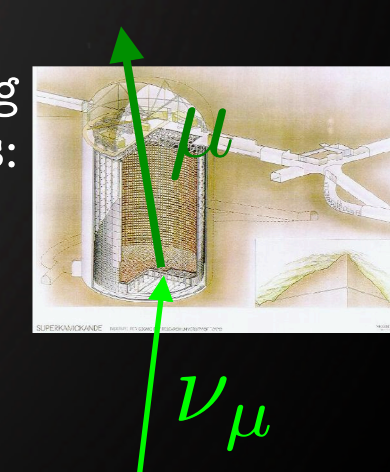

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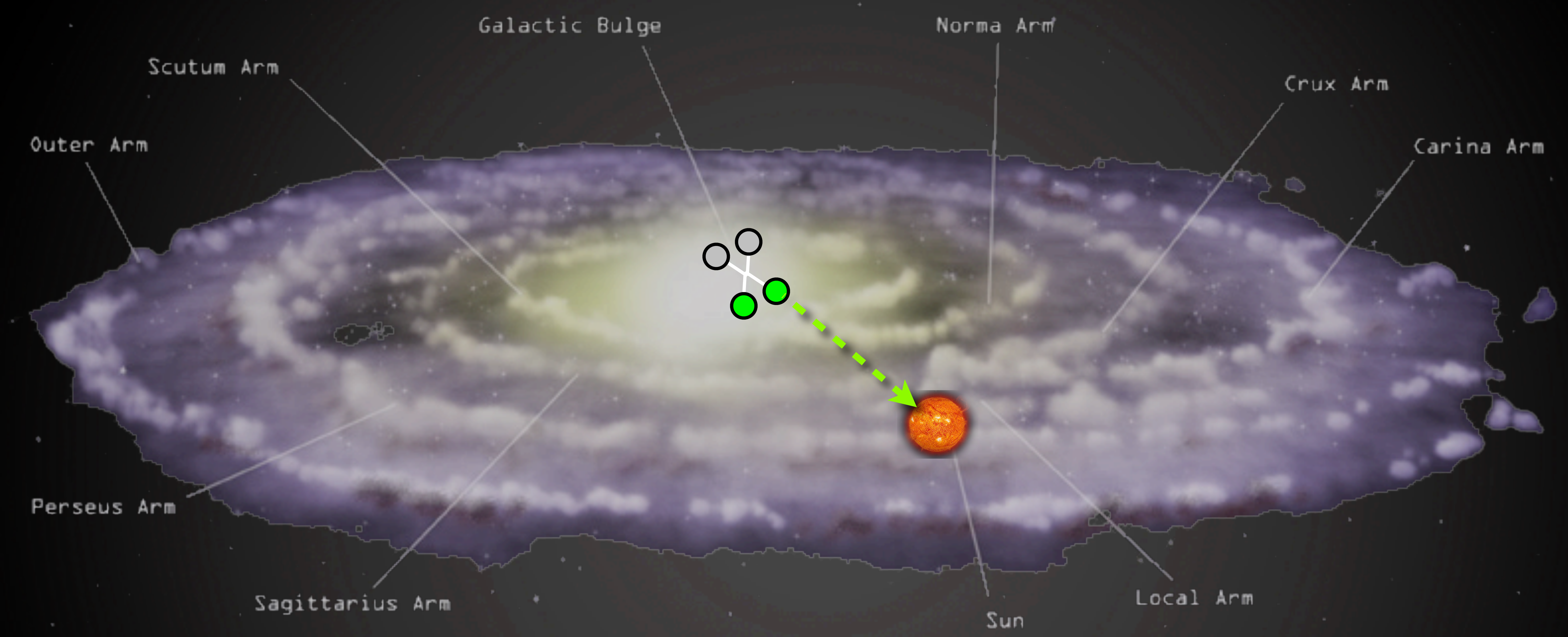

What sets the overall expected flux?

$$\text{flux} \propto n^2 \, \sigma_{\text{annihilation}}$$

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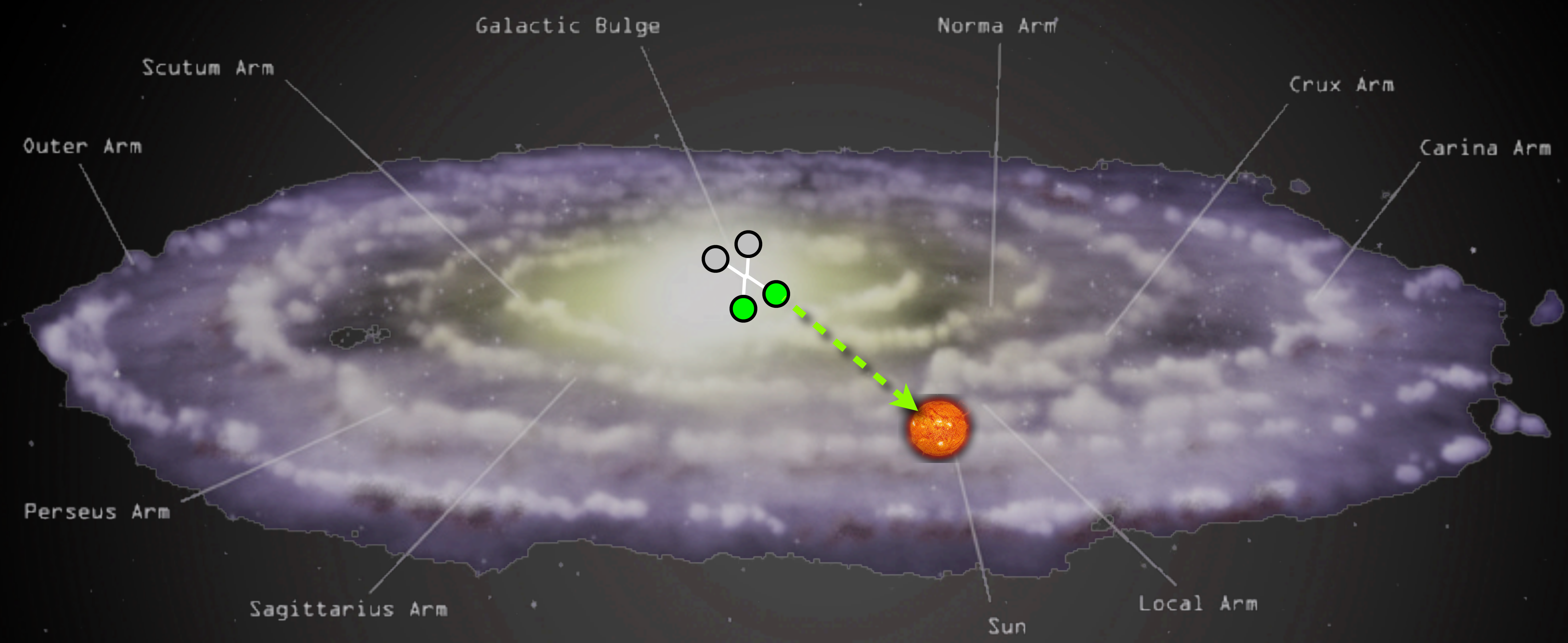

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astro& cosmo

particle

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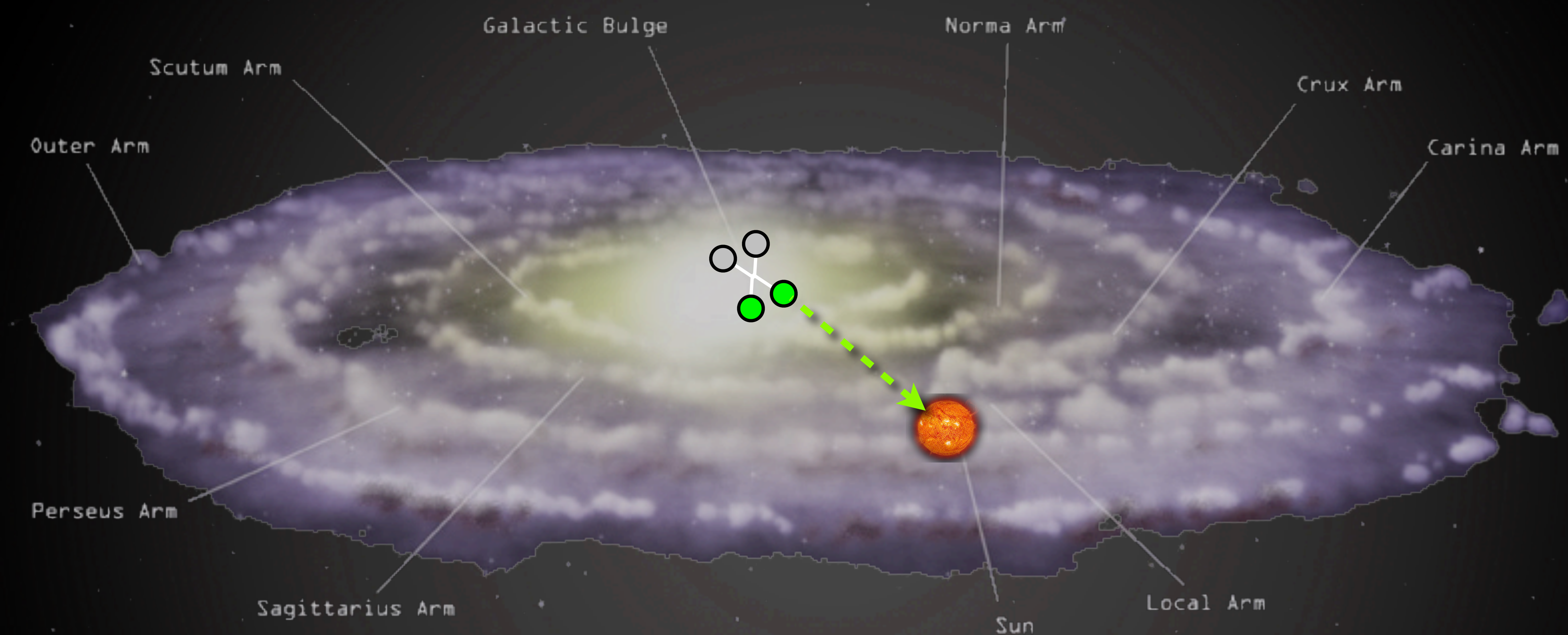

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$$\text{flux} \propto n^2 \, \sigma_{\text{annihilation}}$$

astro& cosmo

particle

reference cross section:

$\sigma v = 3 \cdot 10^{-26} \text{cm}^3/\text{sec}$

DM halo profiles

From N-body numerical simulations:

$$\text{NFW}: \quad \rho_{\text{NFW}}(r) = \rho_s \frac{r_s}{r}\left(1+\frac{r}{r_s}\right)^{-2}$$

$$\text{Einasto}: \quad \rho_{\text{Ein}}(r) = \rho_s \exp\left\{-\frac{2}{\alpha}\left[\left(\frac{r}{r_s}\right)^{\alpha}-1\right]\right\}$$

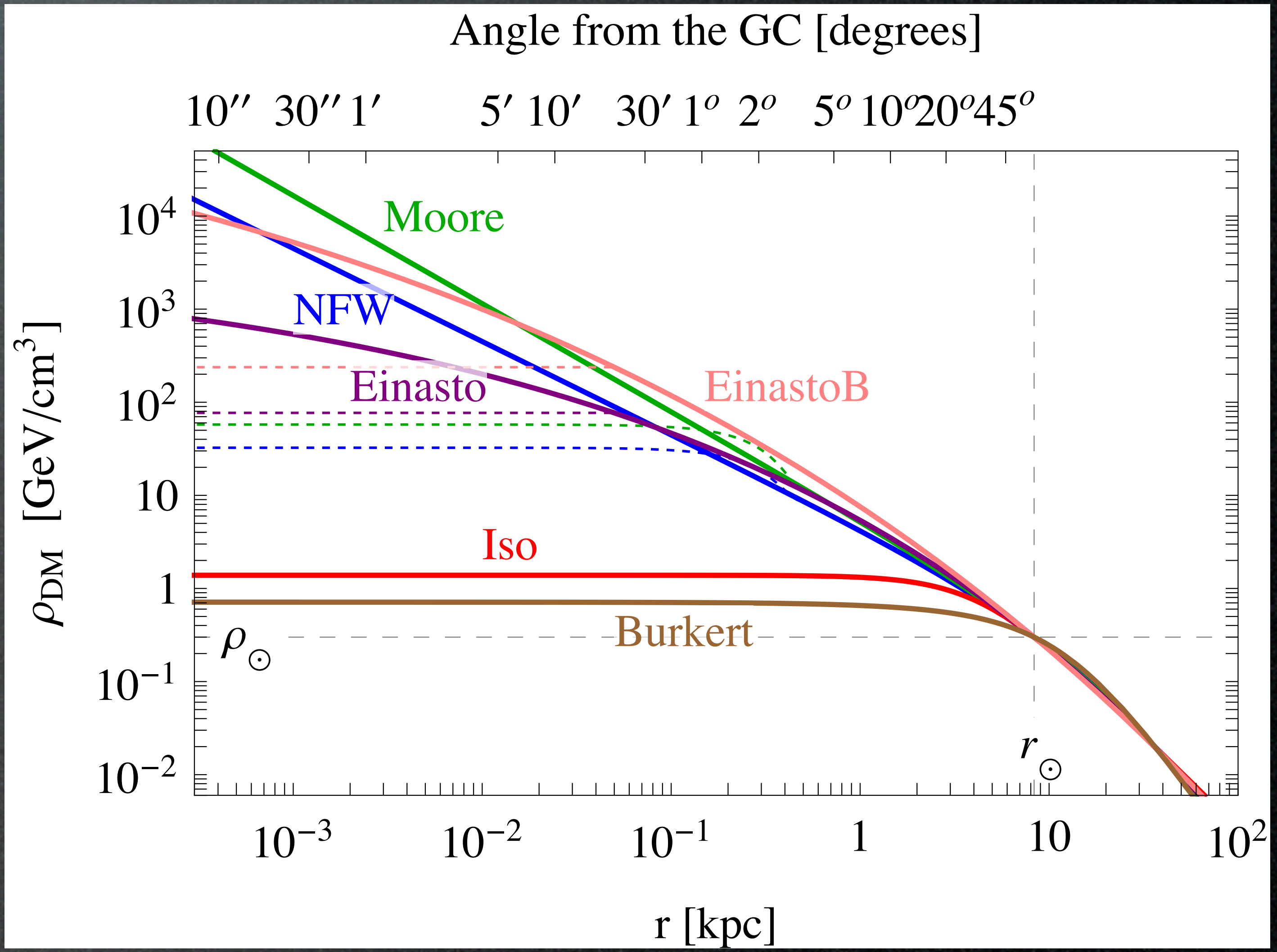
$$\text{Isothermal}: \quad \rho_{\text{Iso}}(r) = \frac{\rho_s}{1+(r/r_s)^2}$$

$$\text{Burkert}: \quad \rho_{\text{Bur}}(r) = \frac{\rho_s}{(1+r/r_s)(1+(r/r_s)^2)}$$

$$\text{Moore}: \quad \rho_{\text{Moo}}(r) = \rho_s \left(\frac{r_s}{r}\right)^{1.16}\left(1+\frac{r}{r_s}\right)^{-1.84}$$

DM halo	α	r_s [kpc]	ρ_s [GeV/cm^3]
NFW	—	24.42	0.184
Einasto	0.17	28.44	0.033
EinastoB	0.11	35.24	0.021
Isothermal	—	4.38	1.387
Burkert	—	12.67	0.712
Moore	—	30.28	0.105

At small r: $\rho(r) \propto 1/r^{\gamma}$

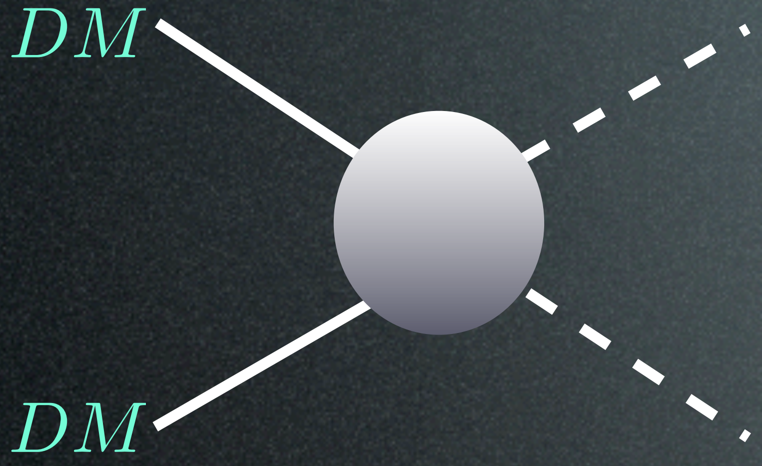


6 profiles:

- cuspy: NFW, Moore
- mild: Einasto
- smooth: isothermal, Burkert

EinastoB = steepened Einasto (effect of baryons?)

Indirect Detection: basics



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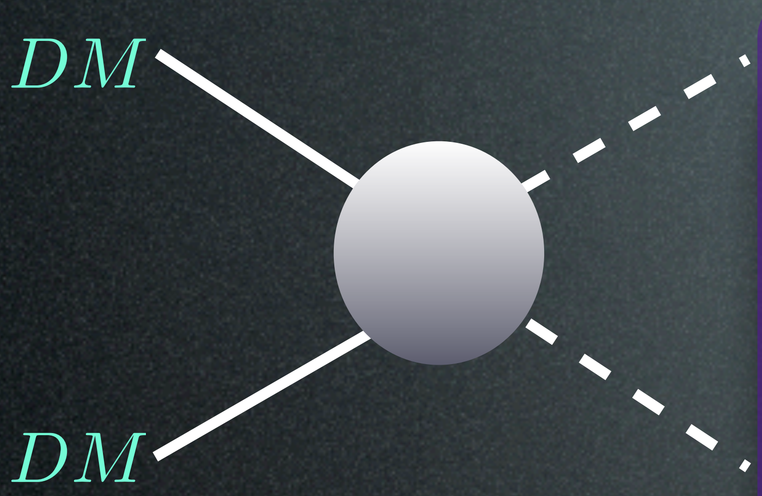
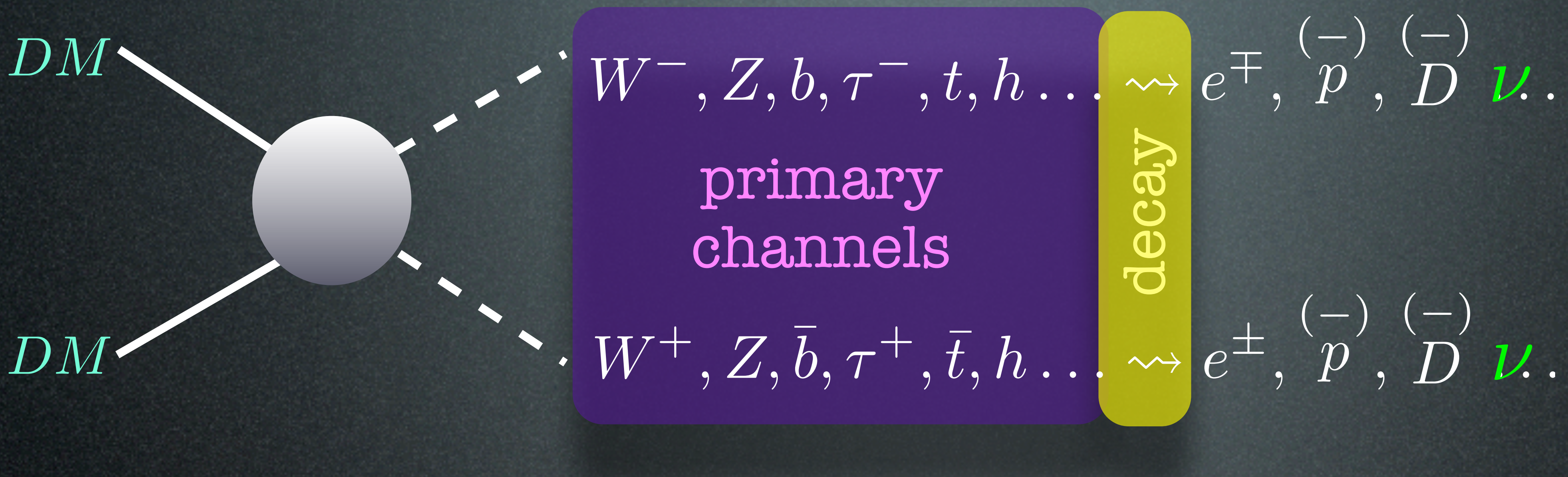


$W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^\mp, \overset{(-)}{p}, \overset{(-)}{D}\ \nu \ldots$

primary channels

$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^\pm, \overset{(-)}{p}, \overset{(-)}{D}\ \nu \ldots$

Indirect Detection: basics



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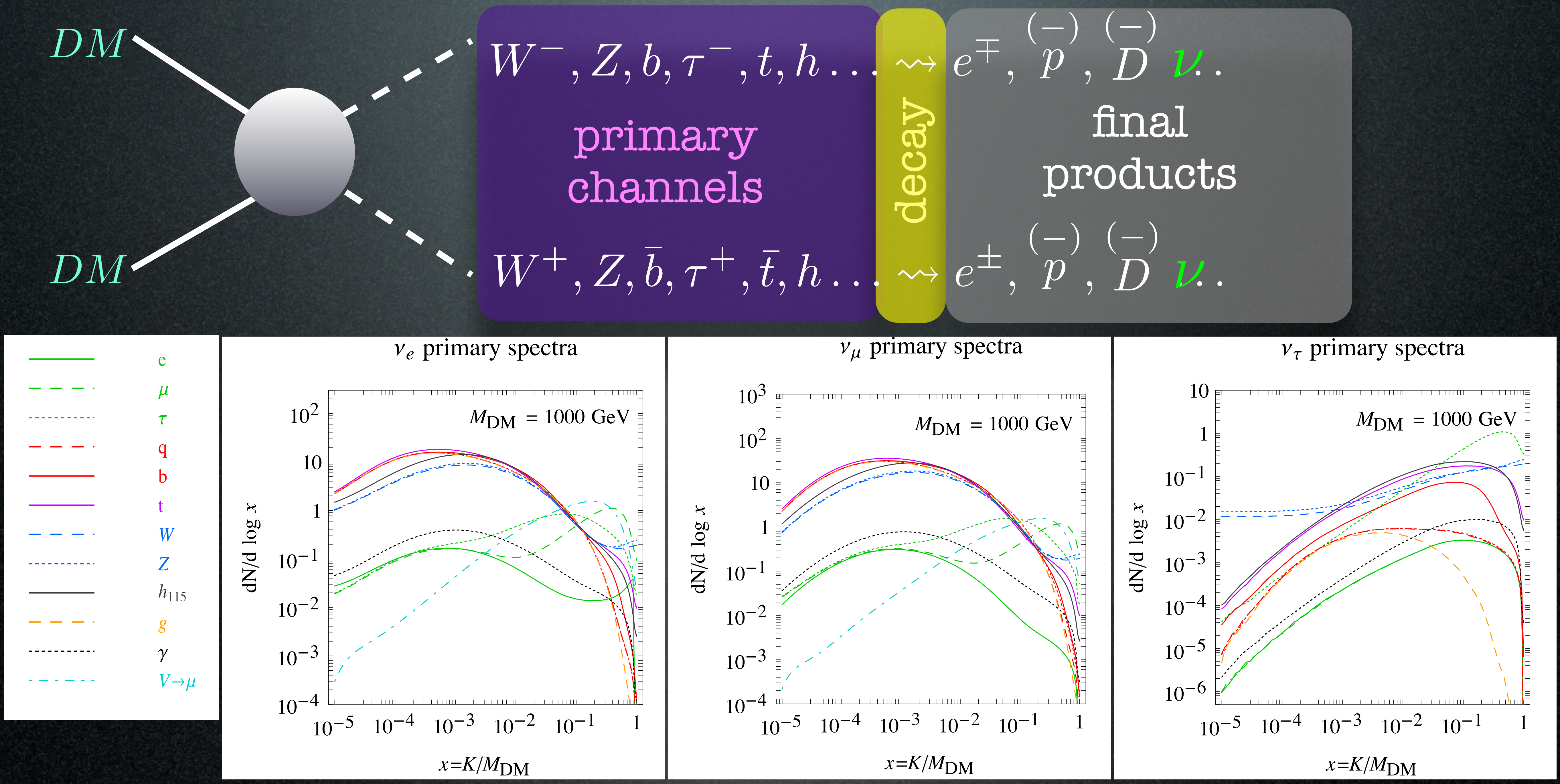

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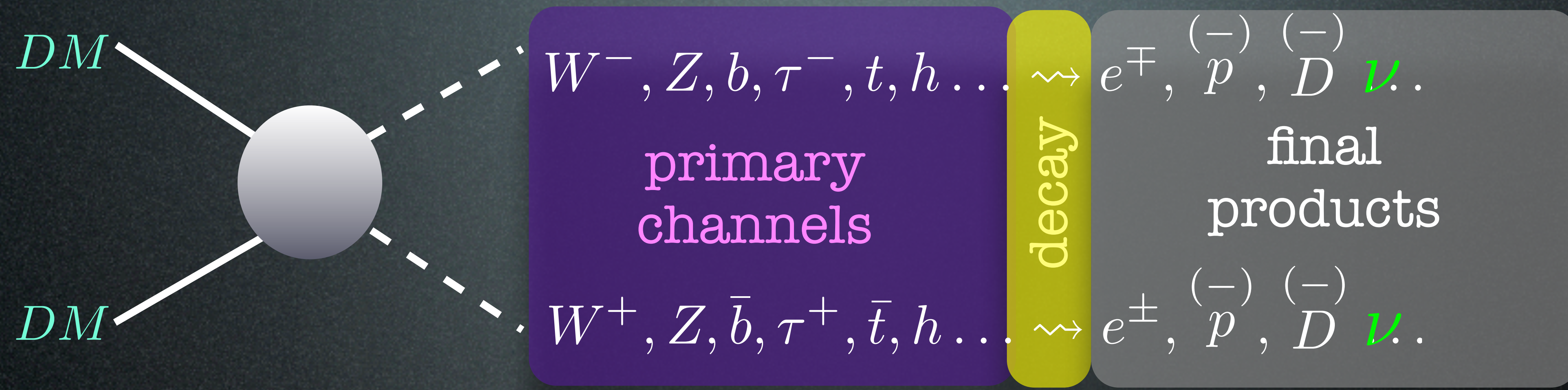

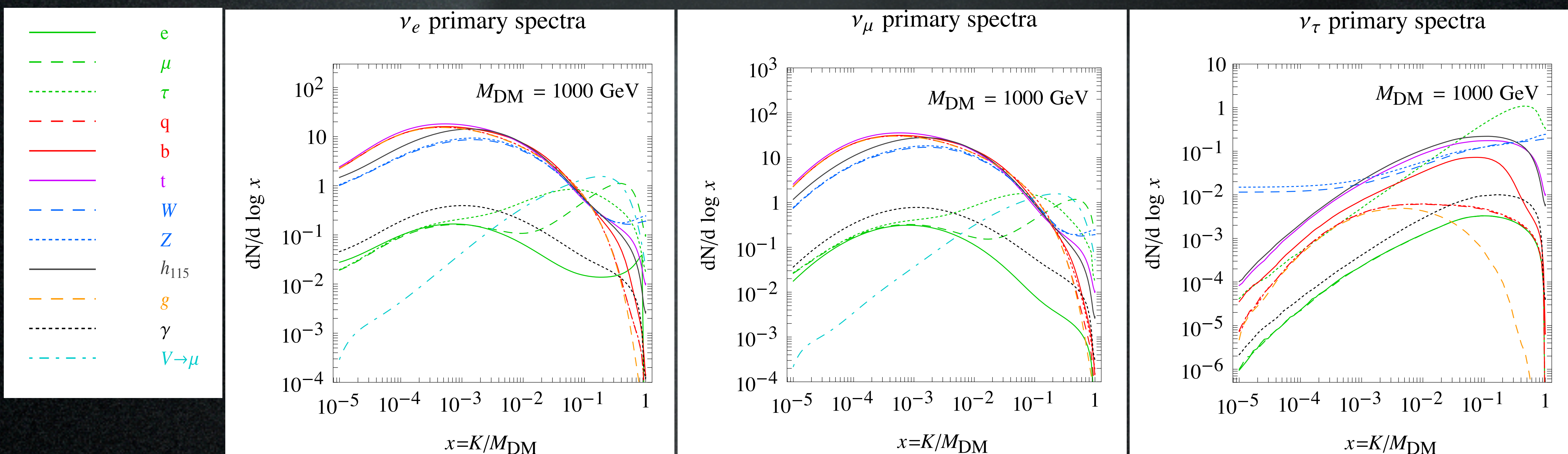

So what are the particle physics parameters?

1. Dark Matter mass
2. primary channel(s)
3. annihilation cross section σ_{ann}

Fluxes at production

ElectroWeak corrections are important!

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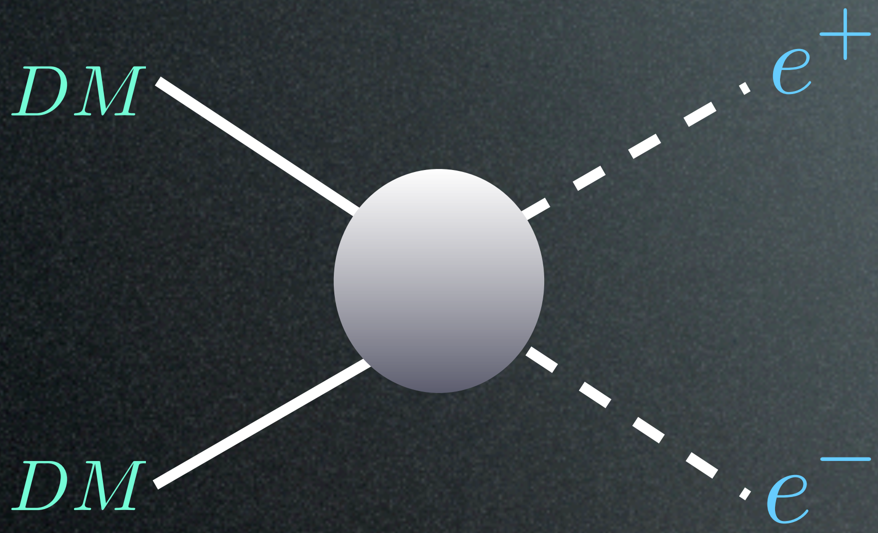

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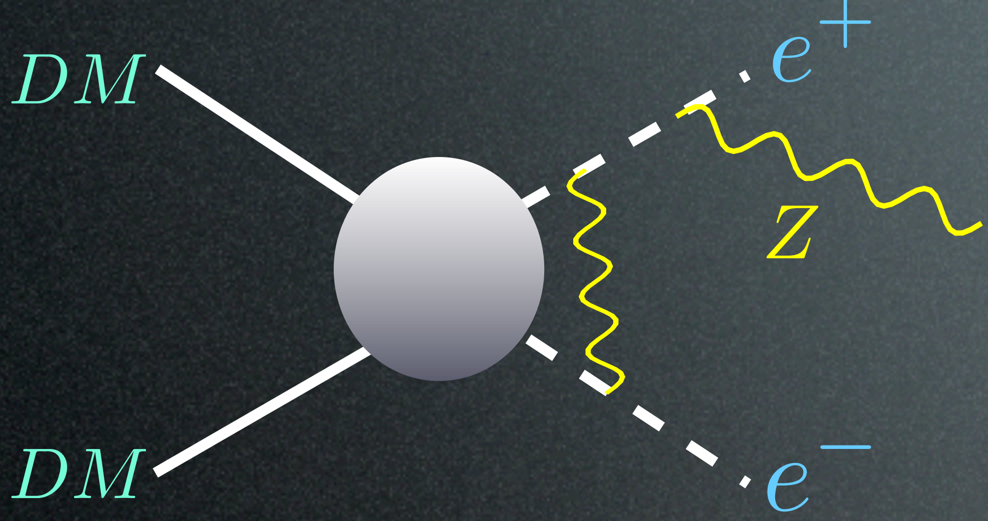

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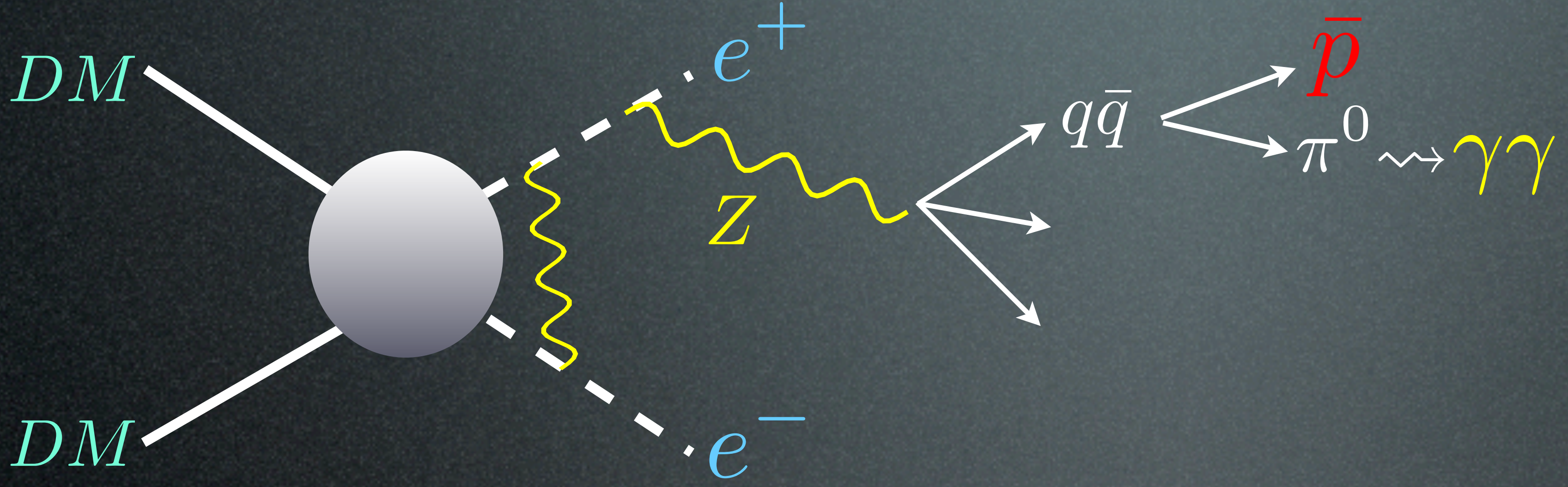

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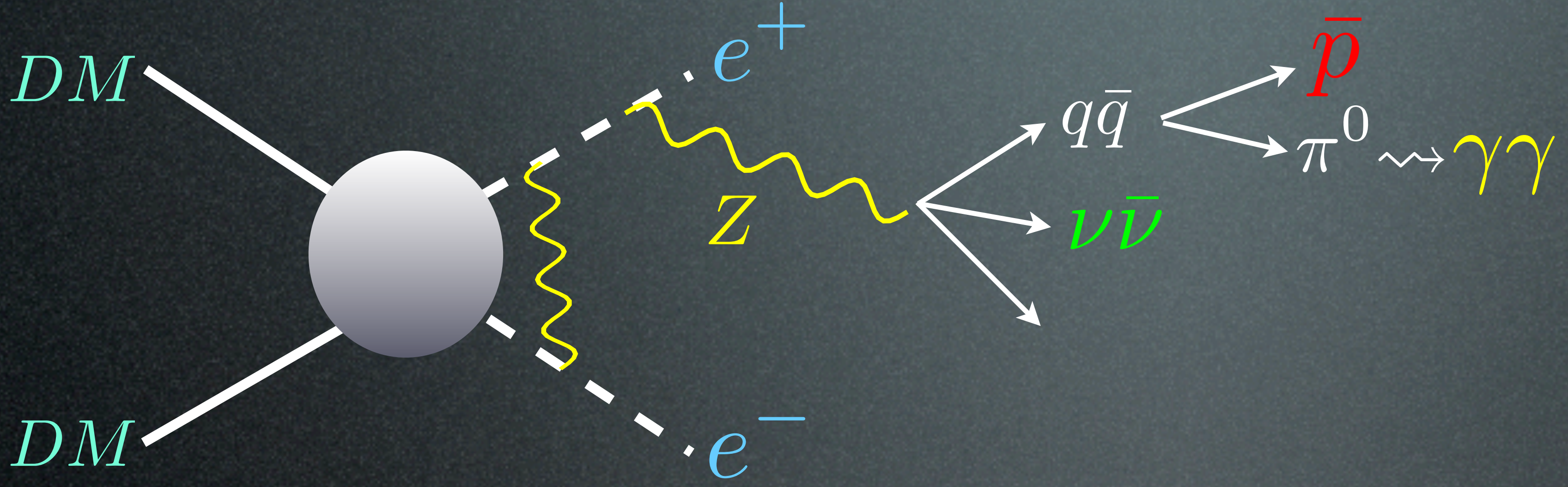

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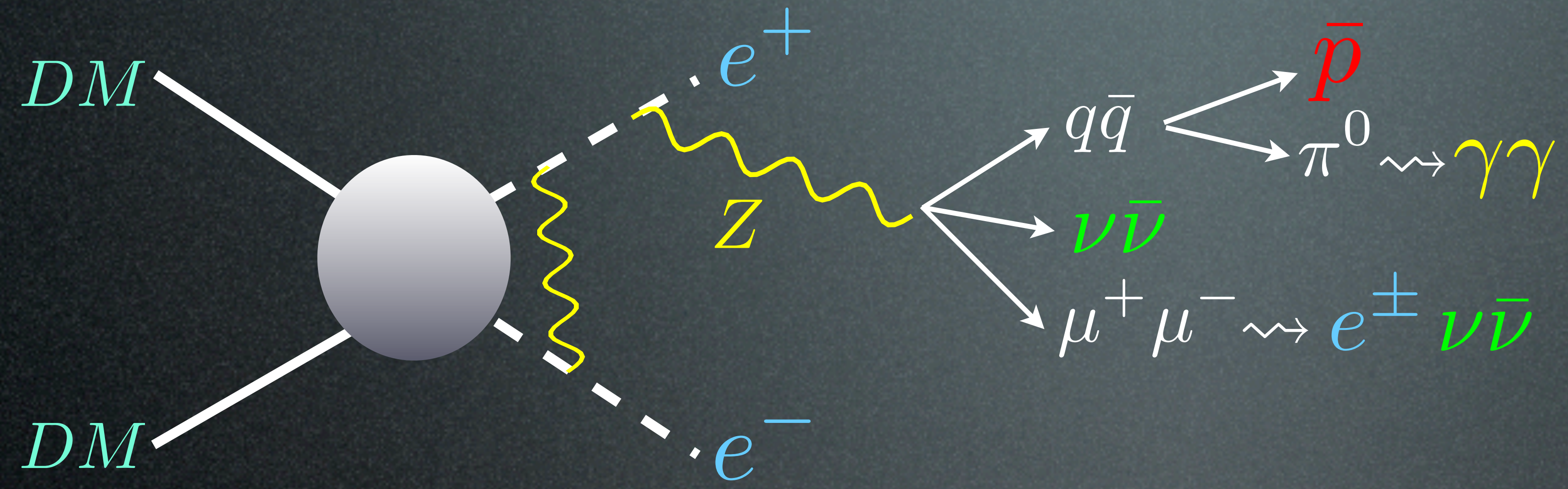

Ciafaloni et al., JCAP 1103 (2011)
See also: Serpico et al., Bell et al.

Fluxes at production

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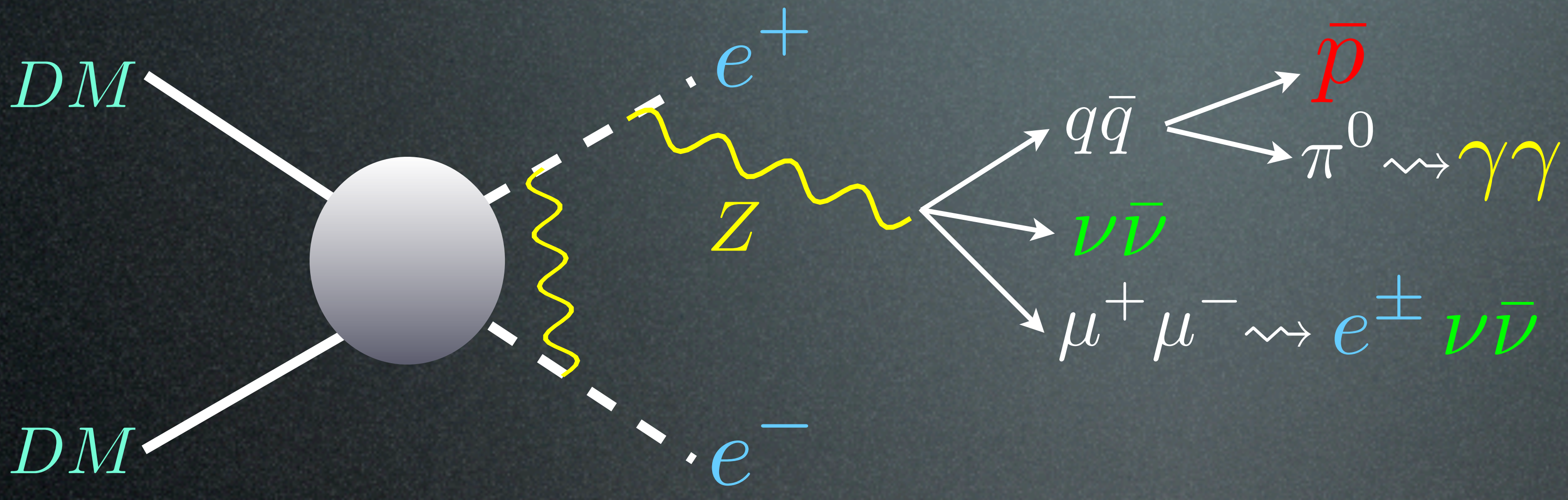

$$\frac{\Delta\sigma}{\sigma} \propto \alpha_{\rm weak} \ln^2\left(\frac{M_{\rm DM}^2}{M_{\rm Z}^2}\right)$$

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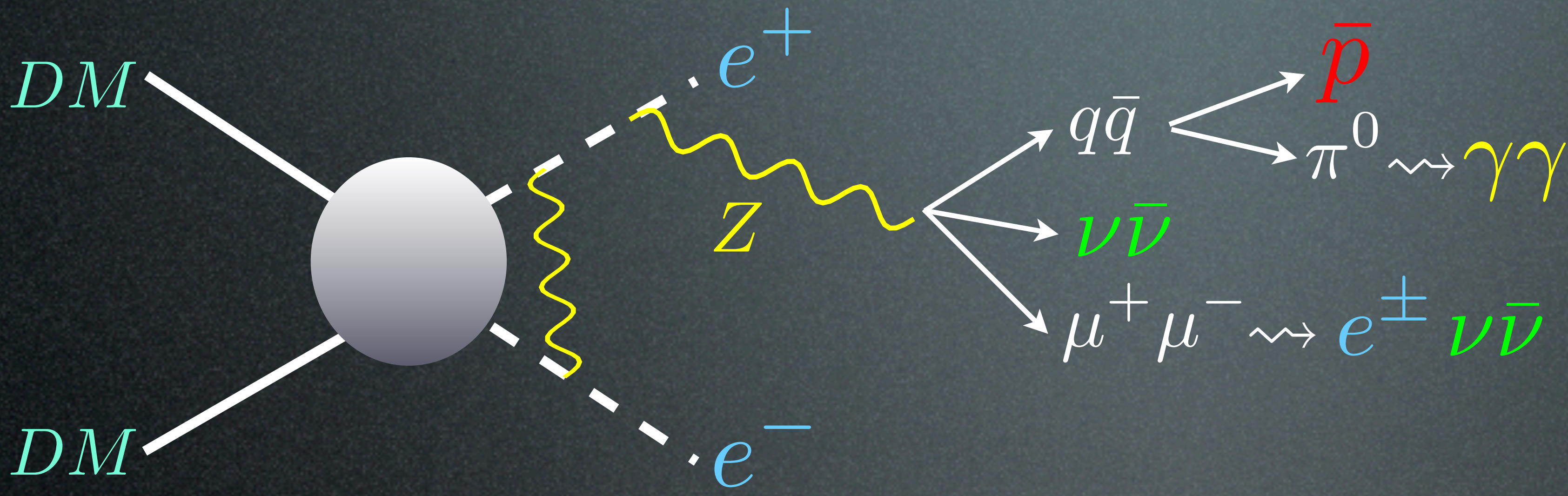

$$\frac{\Delta\sigma}{\sigma} \propto \underbrace{\alpha_{\rm weak}}_{\sim 0.03} \underbrace{\ln^2\left(\frac{M_{\rm DM}^2}{M_{\rm Z}^2}\right)}_{\sim 25}$$

$\sim$ TeV (referring to $M_{\rm DM}$)

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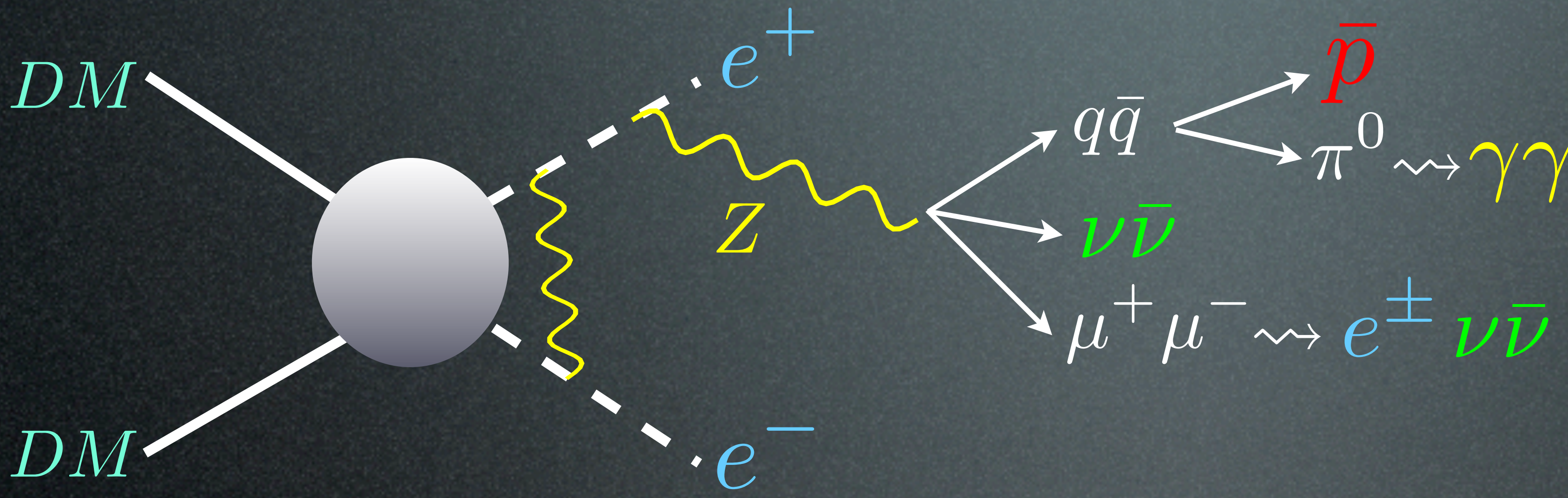
ElectroWeak corrections are important!



$$\frac{\Delta\sigma}{\sigma} \propto \alpha_{\rm weak} \ln^2\left(\frac{M_{\rm DM}^2}{M_Z^2}\right)$$

~ TeV ($M_{\rm DM}$)

$\alpha_{\rm weak}$: ~ 0.03

$\ln^2$ term: ~ 25

Total: ~ 75 %

Ciafaloni et al., JCAP 1103 (2011)

See also: Serpico et al., Bell et al.

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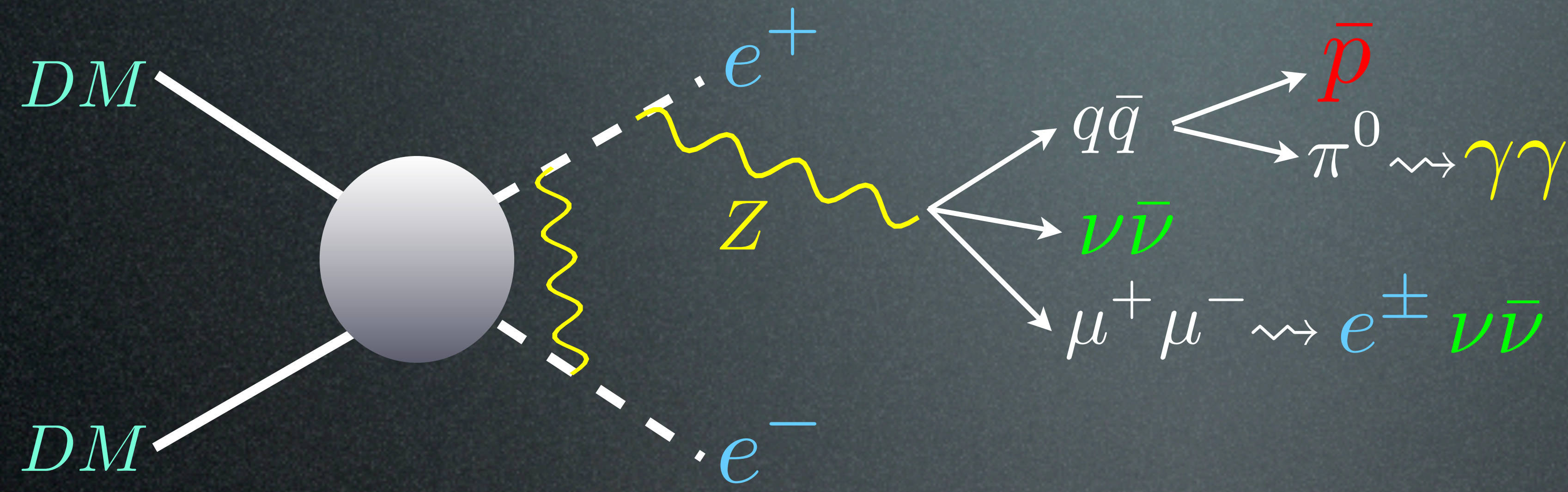

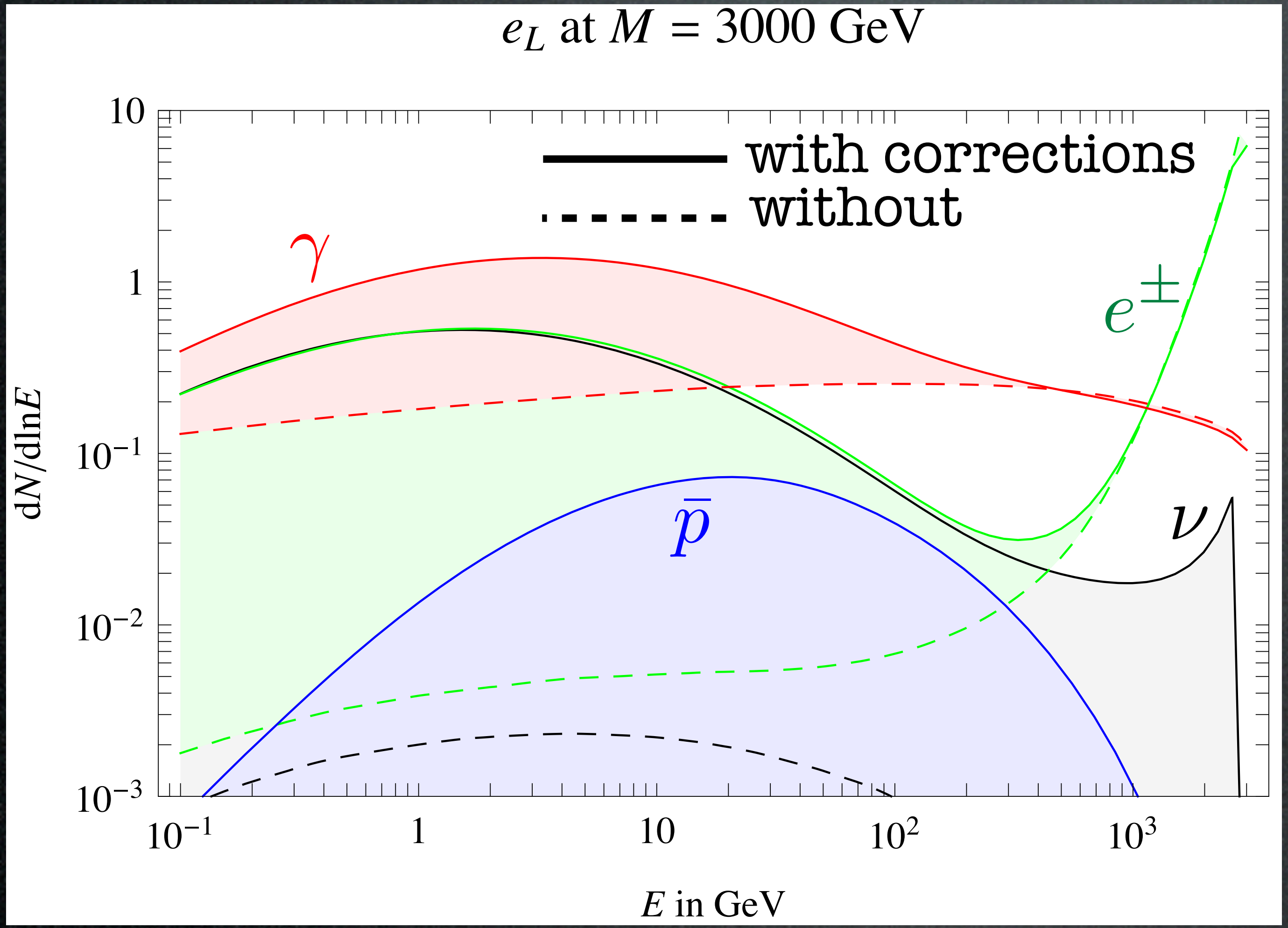

- unexpected species
- different spectra
  (especially at low energy, but not only)

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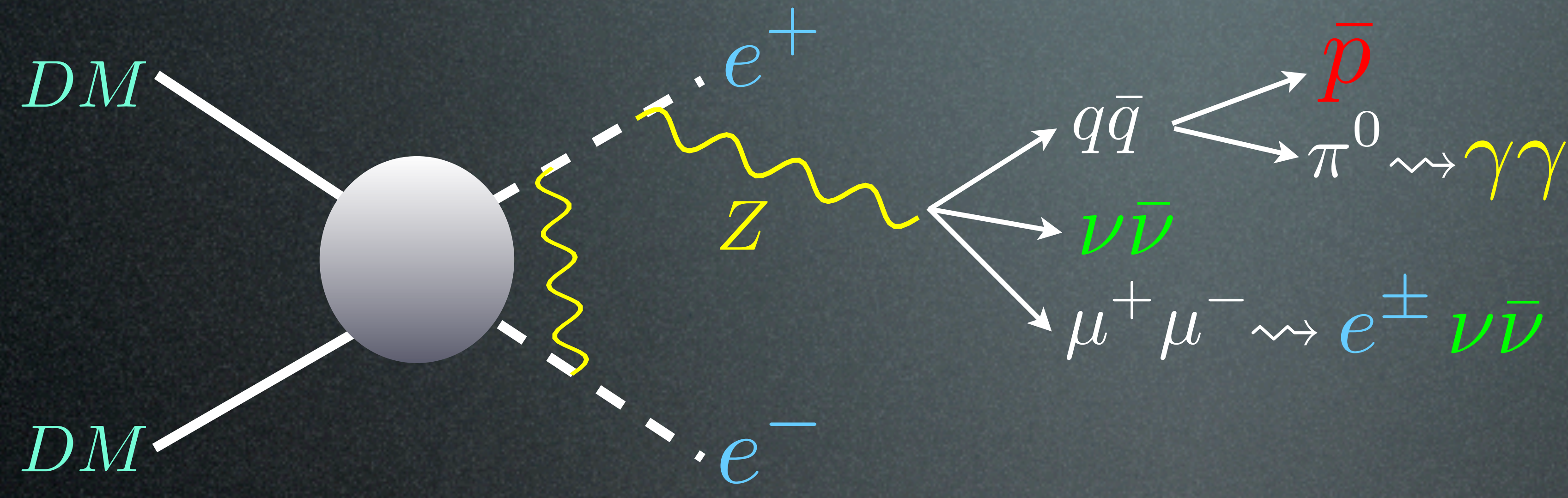

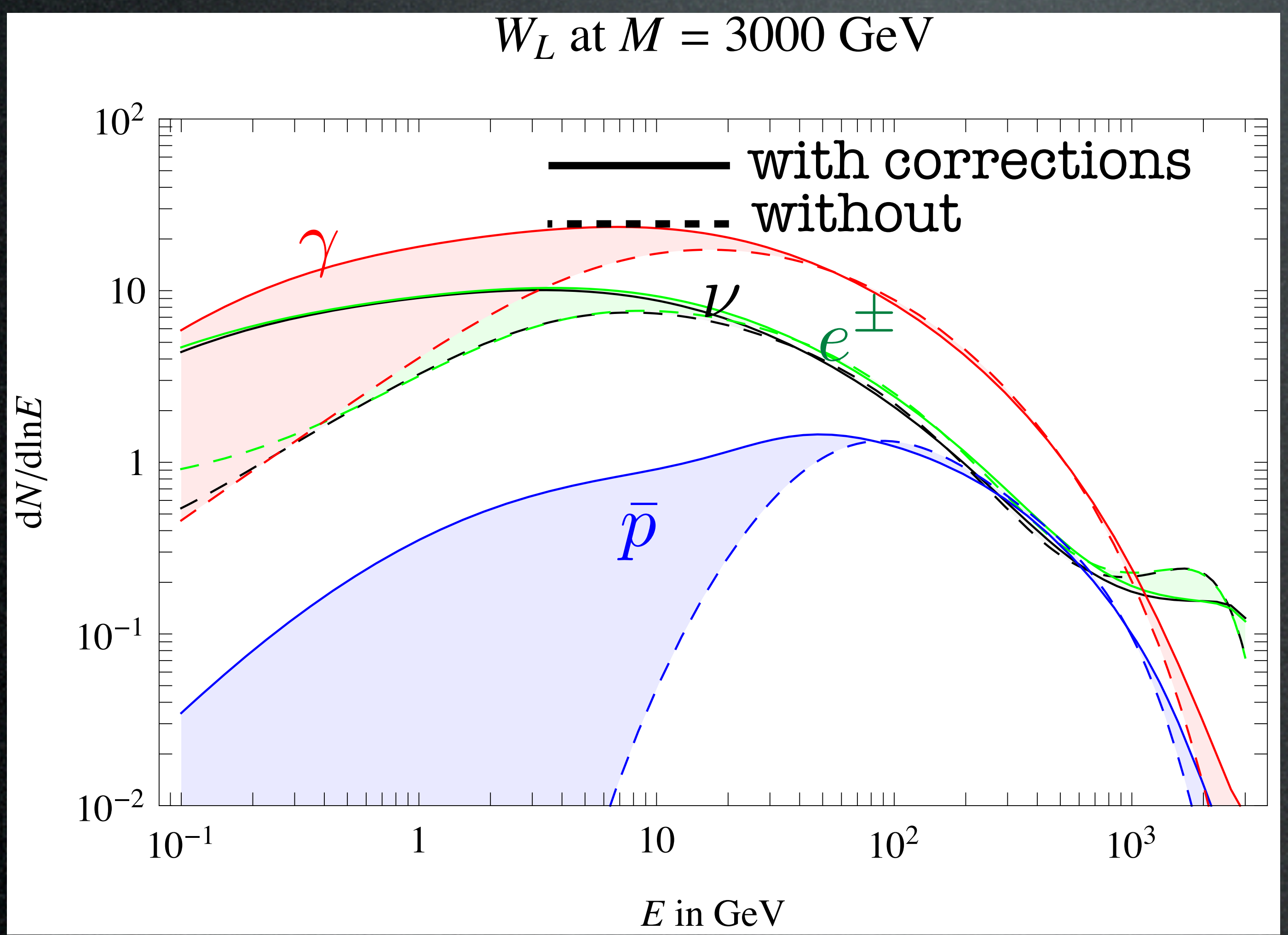

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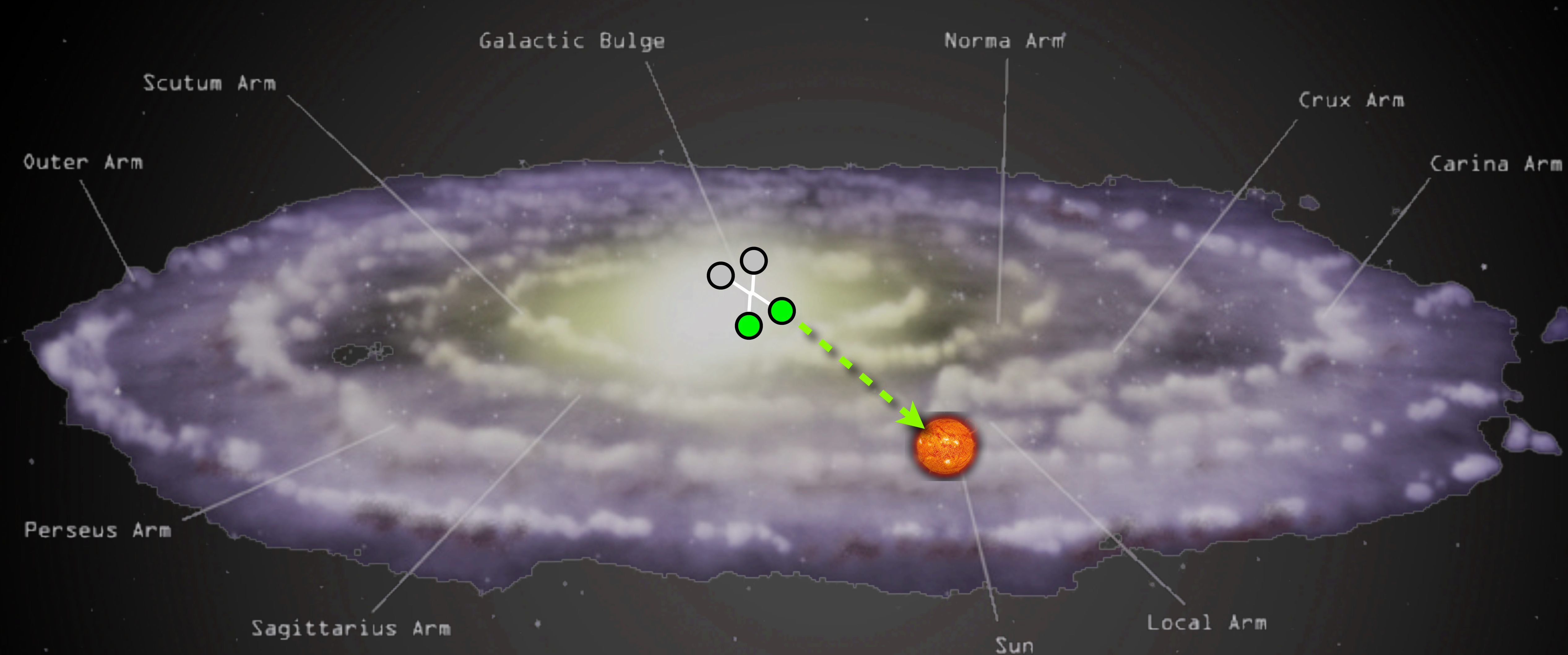
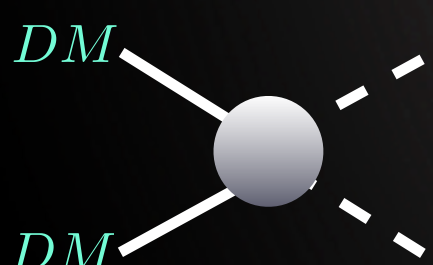
ν from DM annihilations in galactic center





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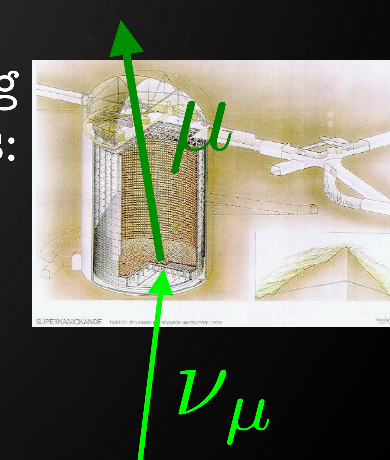
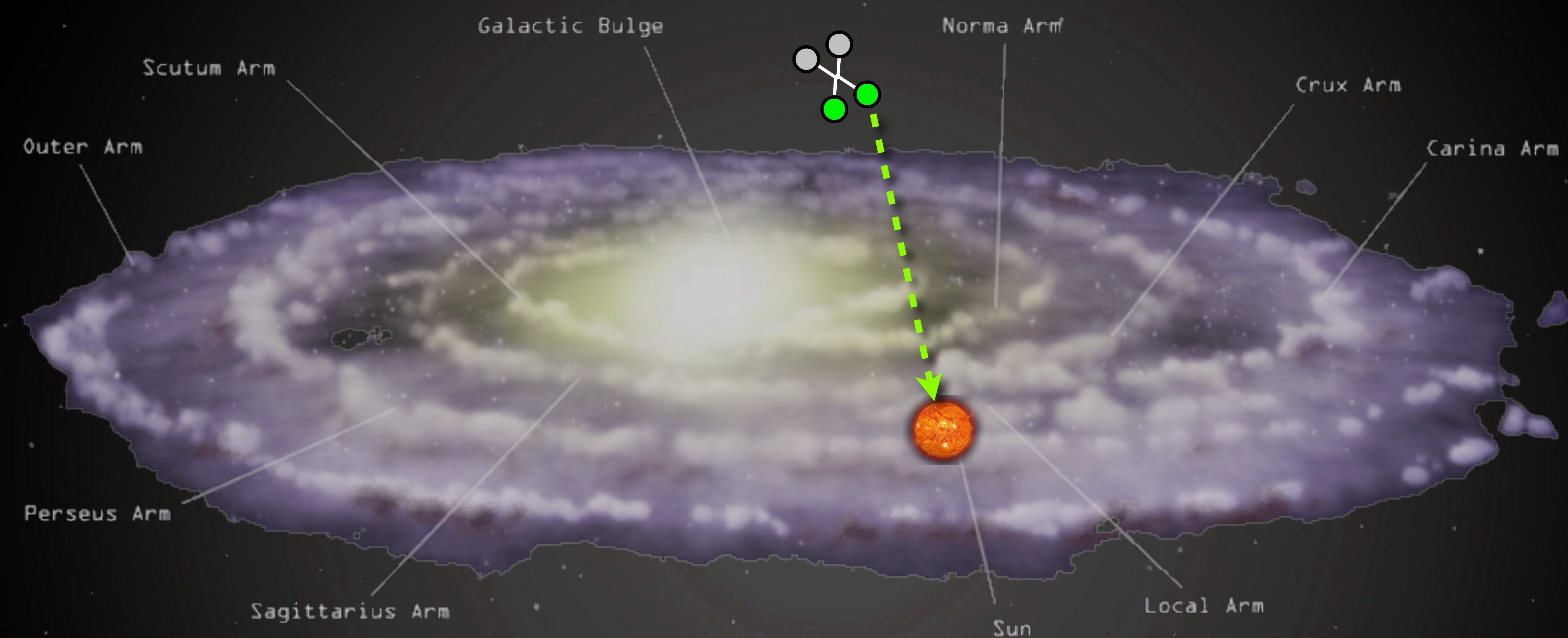
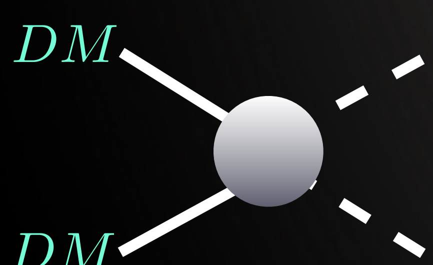
up-going muons:



Indirect Detection

ν from DM annihilations in galactic halo





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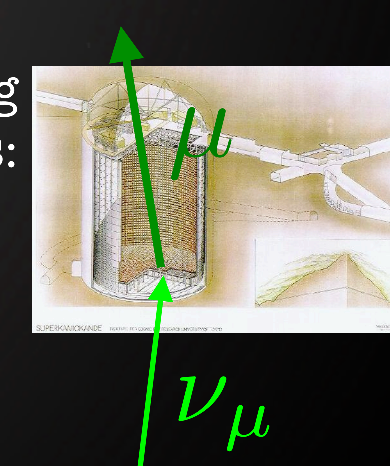

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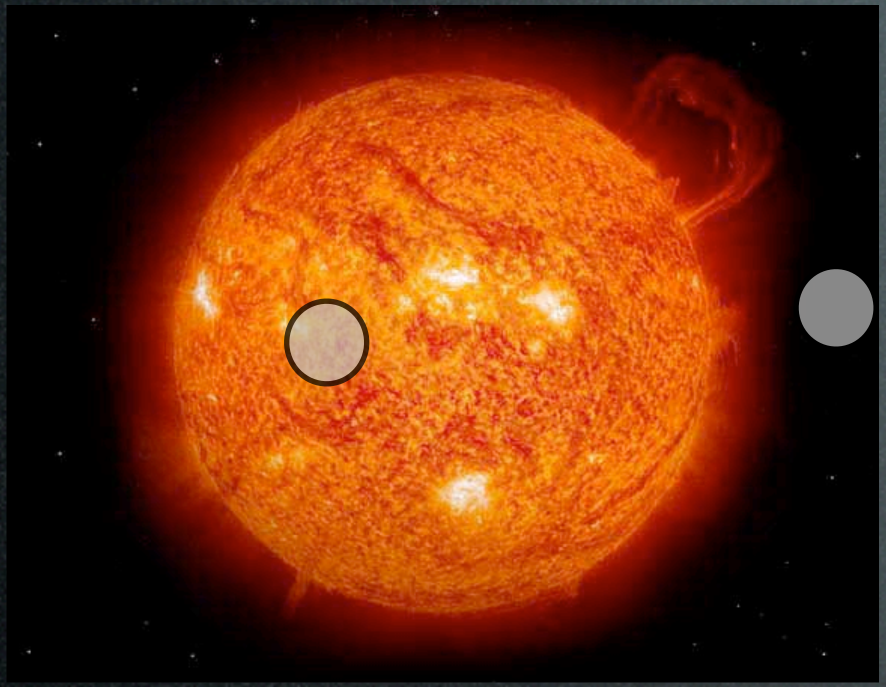

basics: DM particle scatters with nuclei and loses energy
if $v_f < v_{\rm esc}$ particle is gravitationally trapped
it spirals to center of body and accumulates
annihilates

$$v_{\rm halo} \simeq 270 \text{ km/s}$$
$$v_{{\rm esc},\odot} \simeq 620 \text{ km/s}$$
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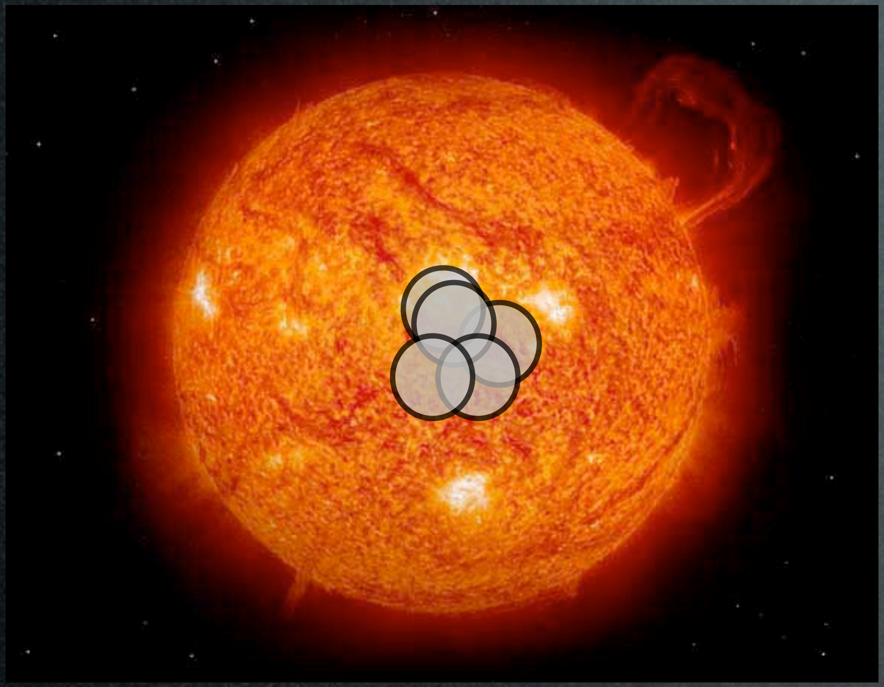

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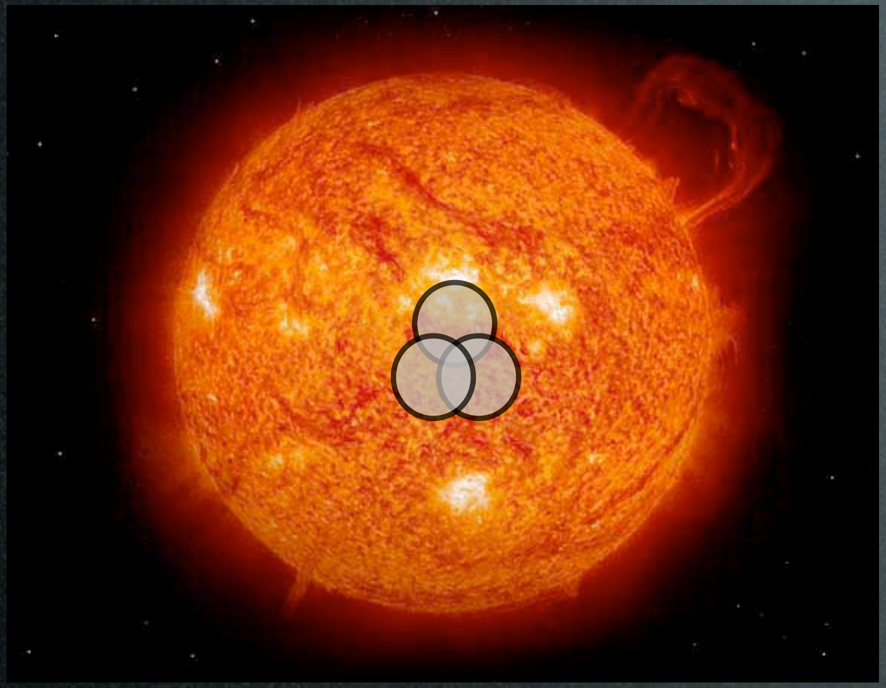

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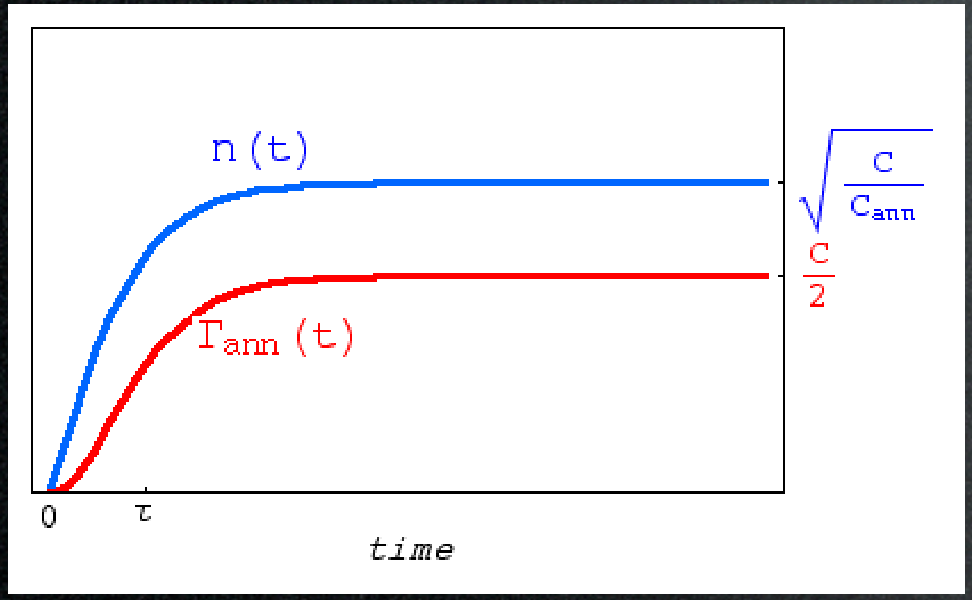
equilibrium attained:



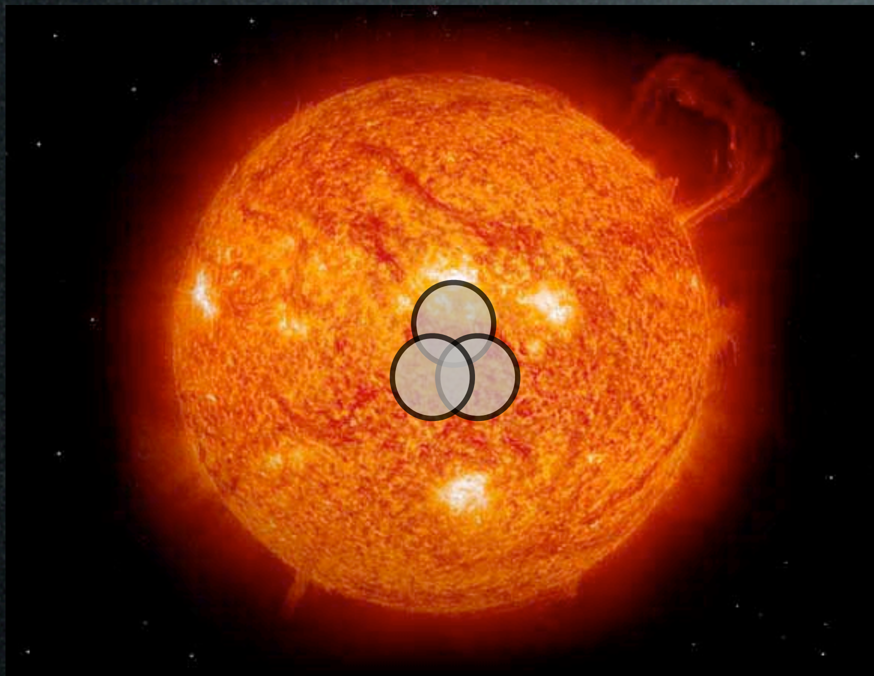
σ_N $\langle \sigma_{\rm ann} v \rangle$

$$\dot{n} = C_{\rm capt} - C_{\rm ann}\, n^2$$

$$n(t) = \sqrt{\frac{C_{\rm capt}}{C_{\rm ann}}} \tanh\left(\frac{t}{\tau}\right) \qquad \left(\tau = \frac{1}{\sqrt{C_{\rm capt} C_{\rm ann}}}\right)$$

$$\Gamma_{\rm ann}(t) = \frac{C_{\rm capt}}{2} \tanh^2\left(\frac{t}{\tau}\right)$$

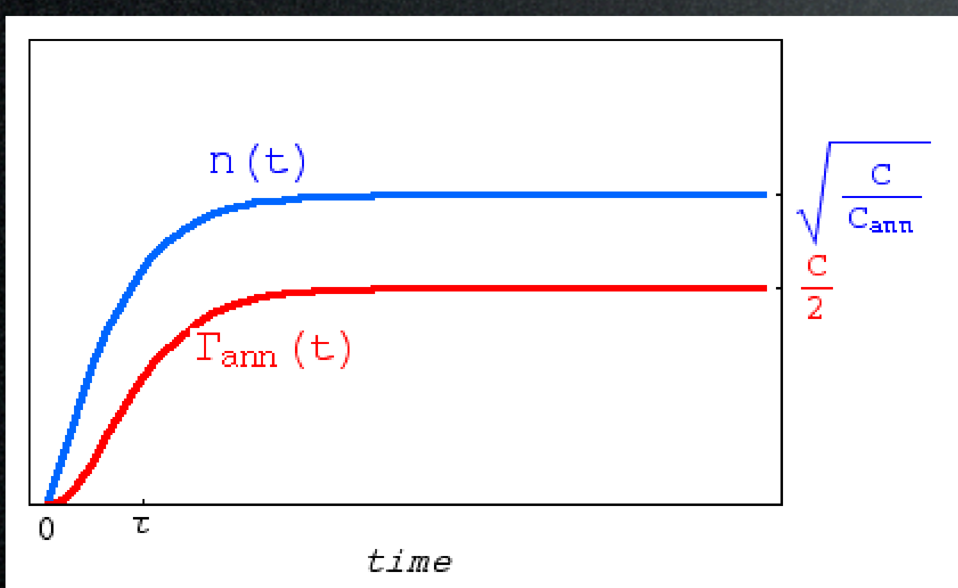
1. Capture & annihilation



basics: DM particle scatters with nuclei and loses energy
if $v_f < v_{\rm esc}$ particle is gravitationally trapped
it spirals to center of body and accumulates
annihilates

$$v_{\rm halo} \simeq 270~{\rm km/s}$$
$$v_{{\rm esc},\odot} \simeq 620~{\rm km/s}$$
$$v_{{\rm esc},\oplus} \simeq 12~{\rm km/s}$$

equilibrium attained:



σ_N $\quad$ $\langle \sigma_{\rm ann} v \rangle$

$$\dot{n} = C_{\rm capt} - C_{\rm ann}\, n^2$$

$$n(t) = \sqrt{\frac{C_{\rm capt}}{C_{\rm ann}}}\tanh\left(\frac{t}{\tau}\right) \qquad \left(\tau = \frac{1}{\sqrt{C_{\rm capt} C_{\rm ann}}}\right)$$

$$\Gamma_{\rm ann}(t) = \frac{C_{\rm capt}}{2}\tanh^2\left(\frac{t}{\tau}\right)$$

The main physical parameter is: σ_N (DM-nucleon scattering cross section)

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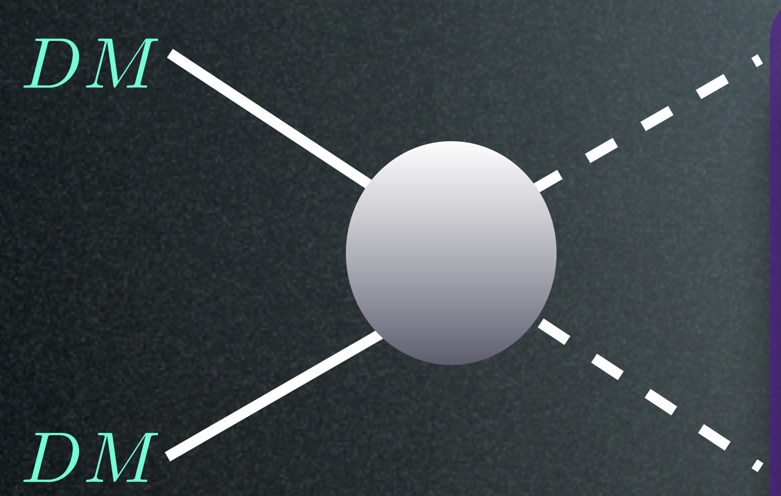


$W^-, Z, b, \tau^-, t, h \ldots$ $\rightsquigarrow$ $e^\mp, \overset{(-)}{p}, \overset{(-)}{D} \ldots$

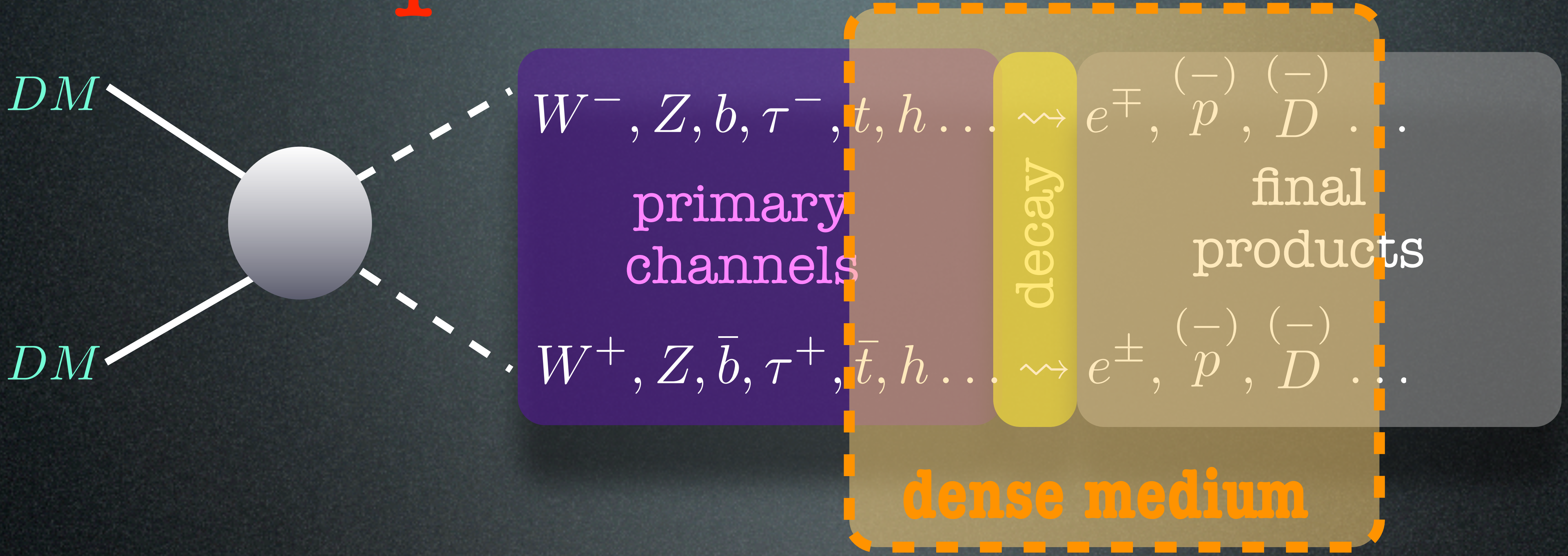
primary channels

decay

final products

$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots$ $\rightsquigarrow$ $e^\pm, \overset{(-)}{p}, \overset{(-)}{D} \ldots$

1. Capture & annihilation



Effects of the medium:

1) light hadrons (π, K...) and leptons (μ) are stopped and absorbed (unless energetic)
2) heavy hadrons/leptons lose some energy before decaying

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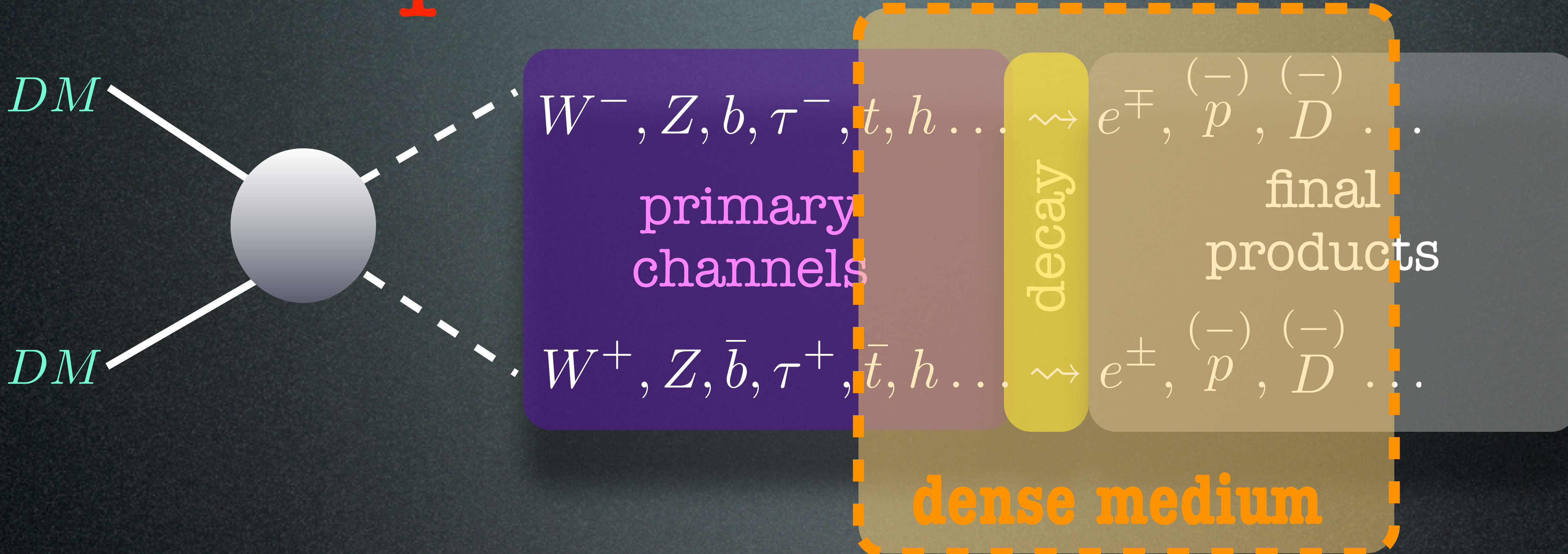

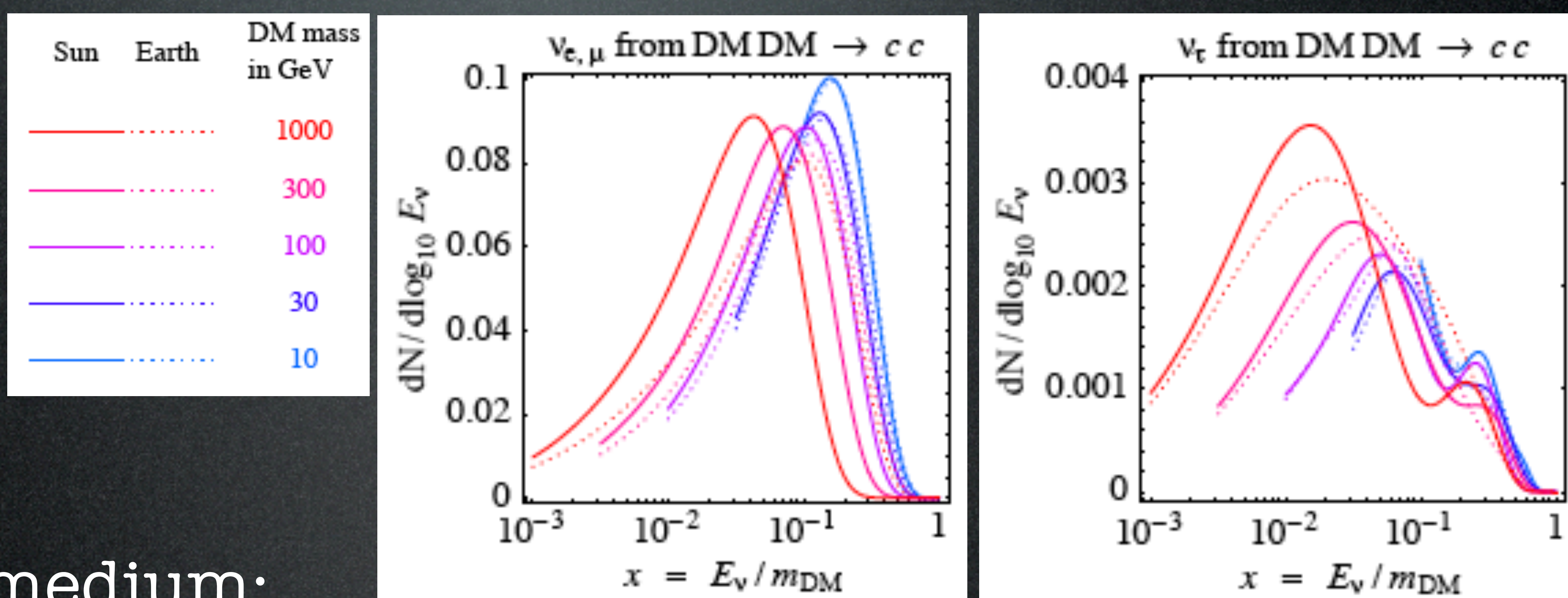

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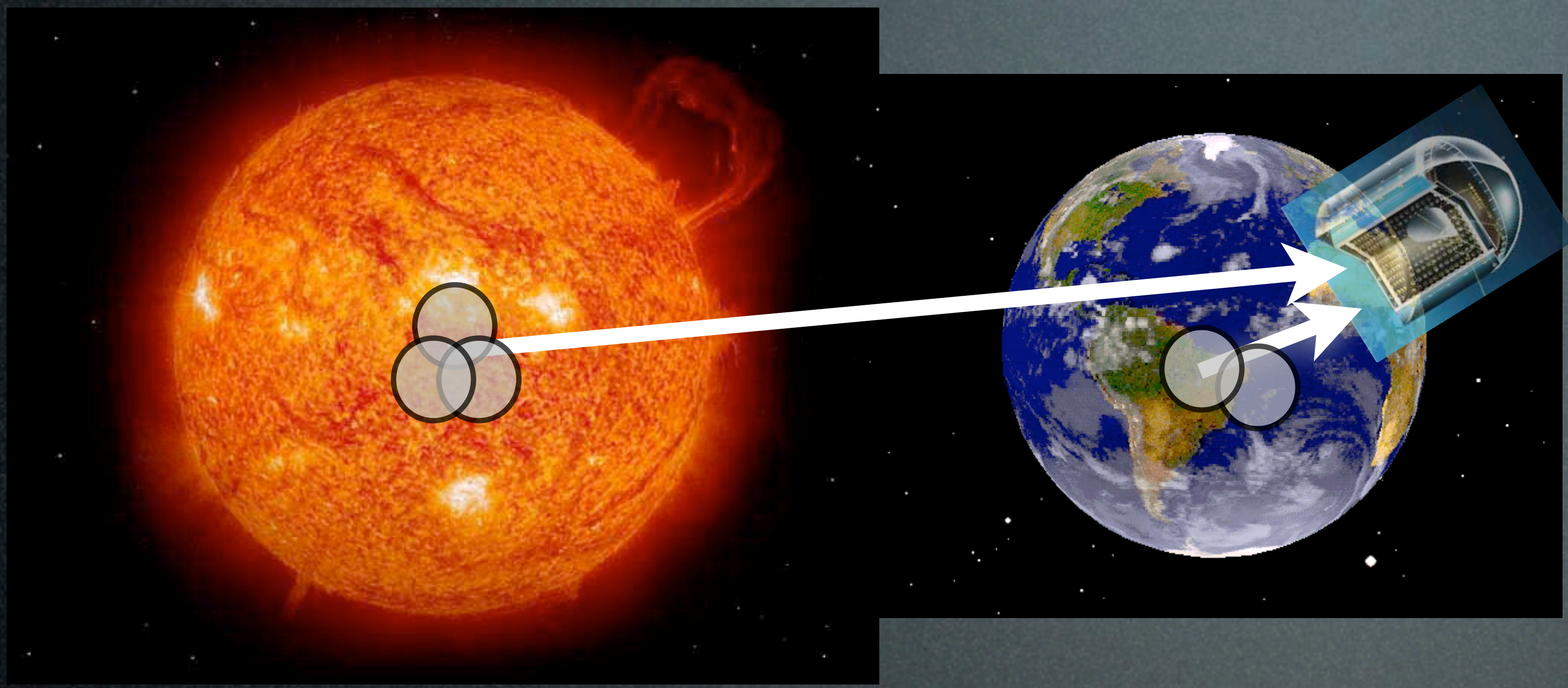
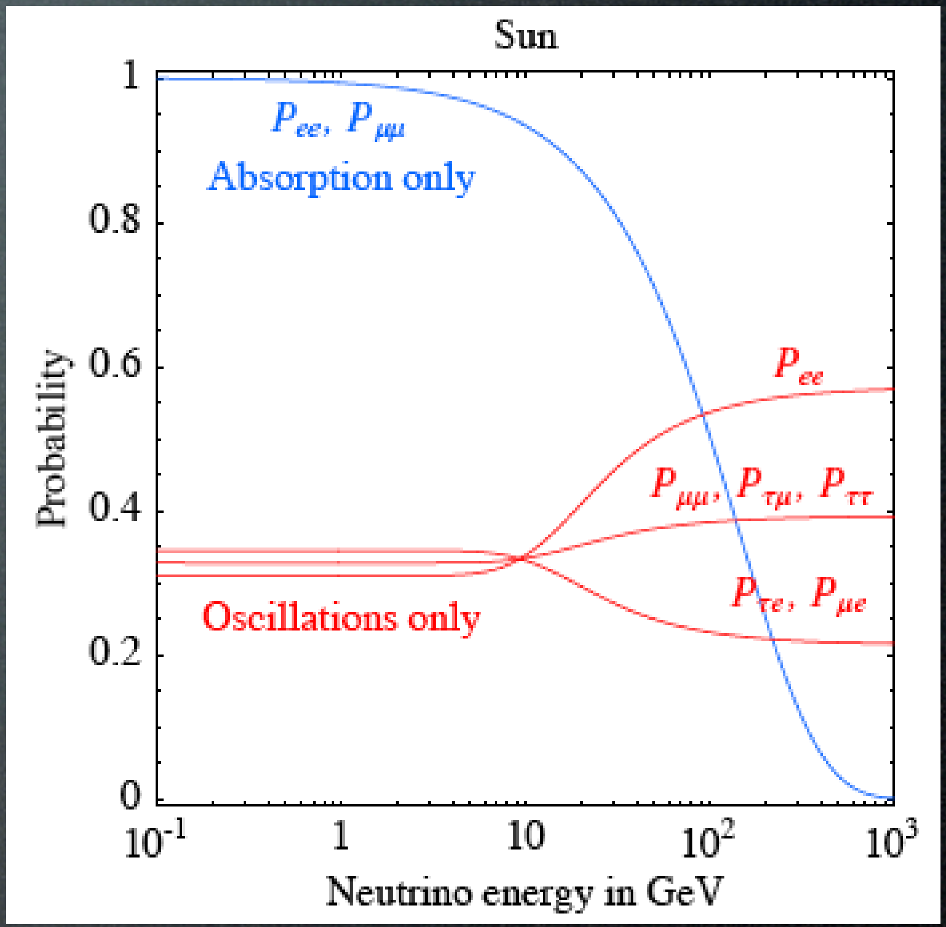
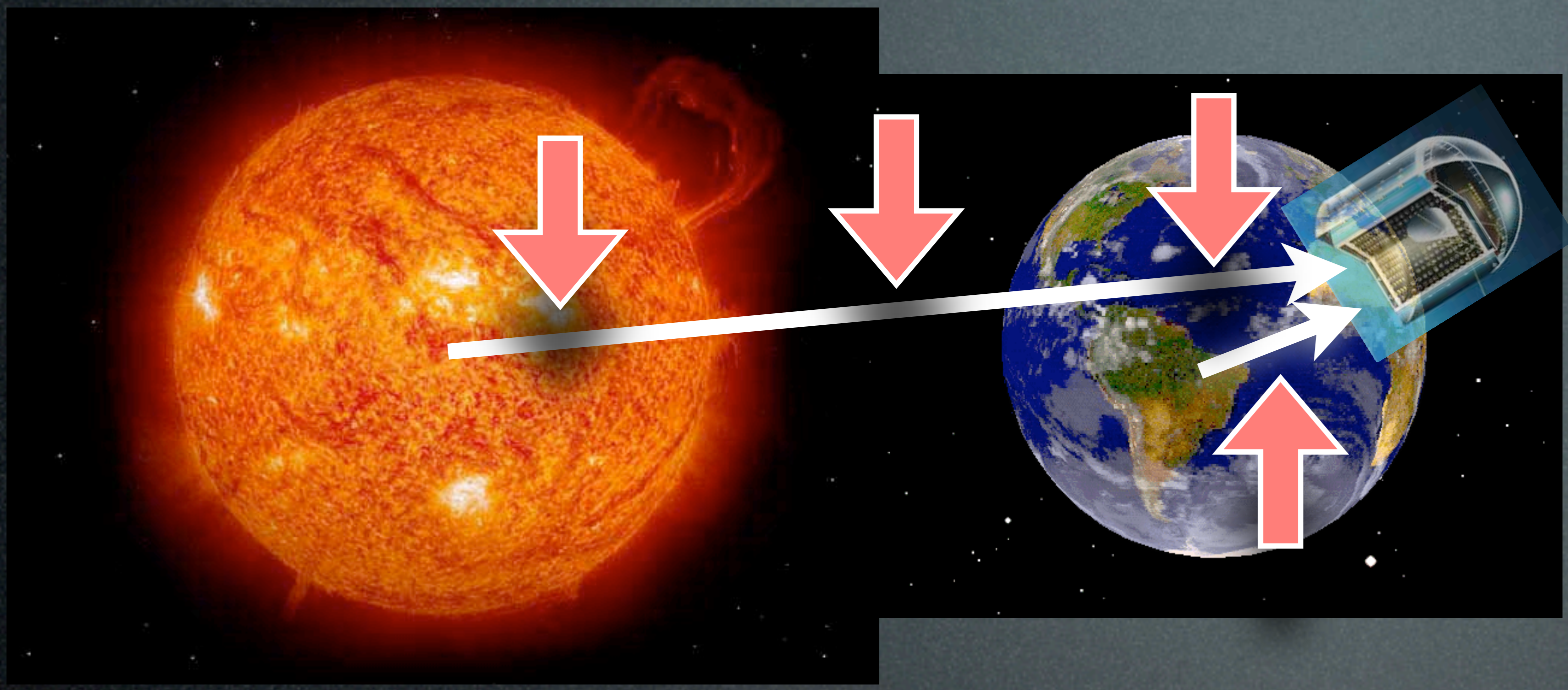
2. Propagation

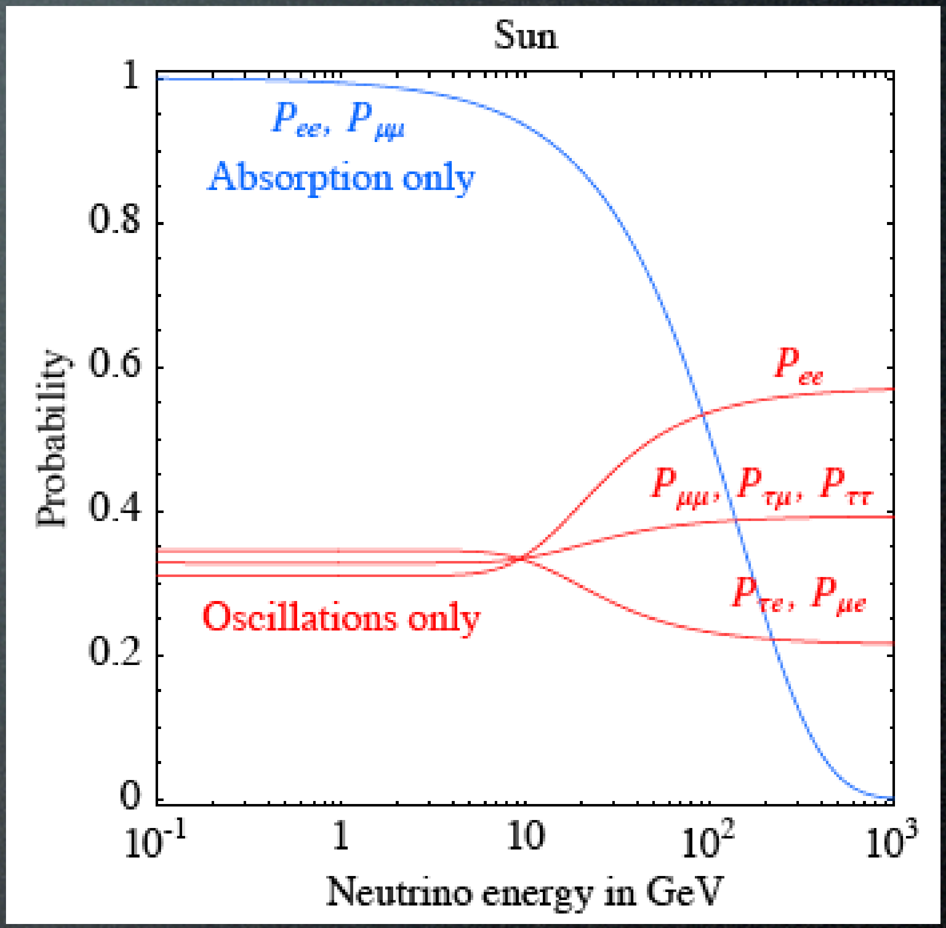




oscillations + interactions

2. Propagation





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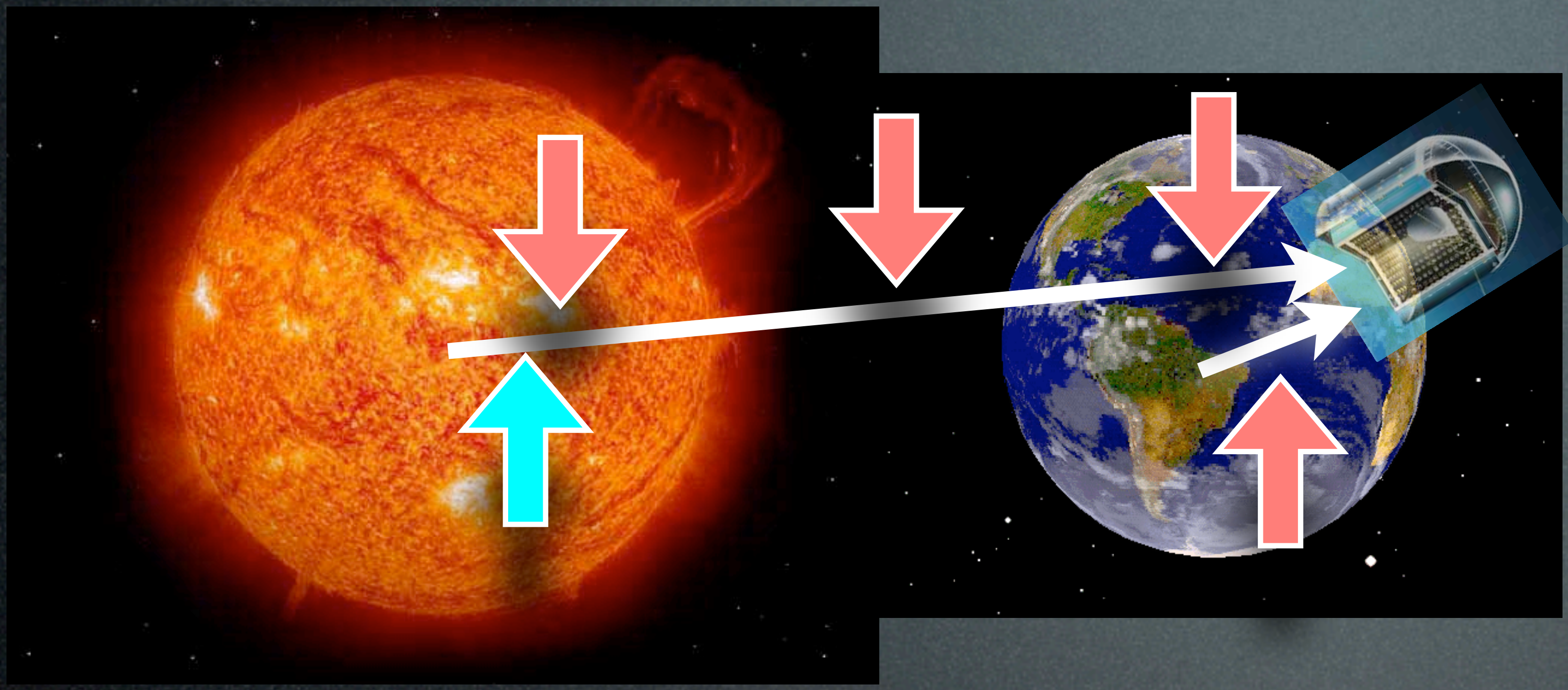

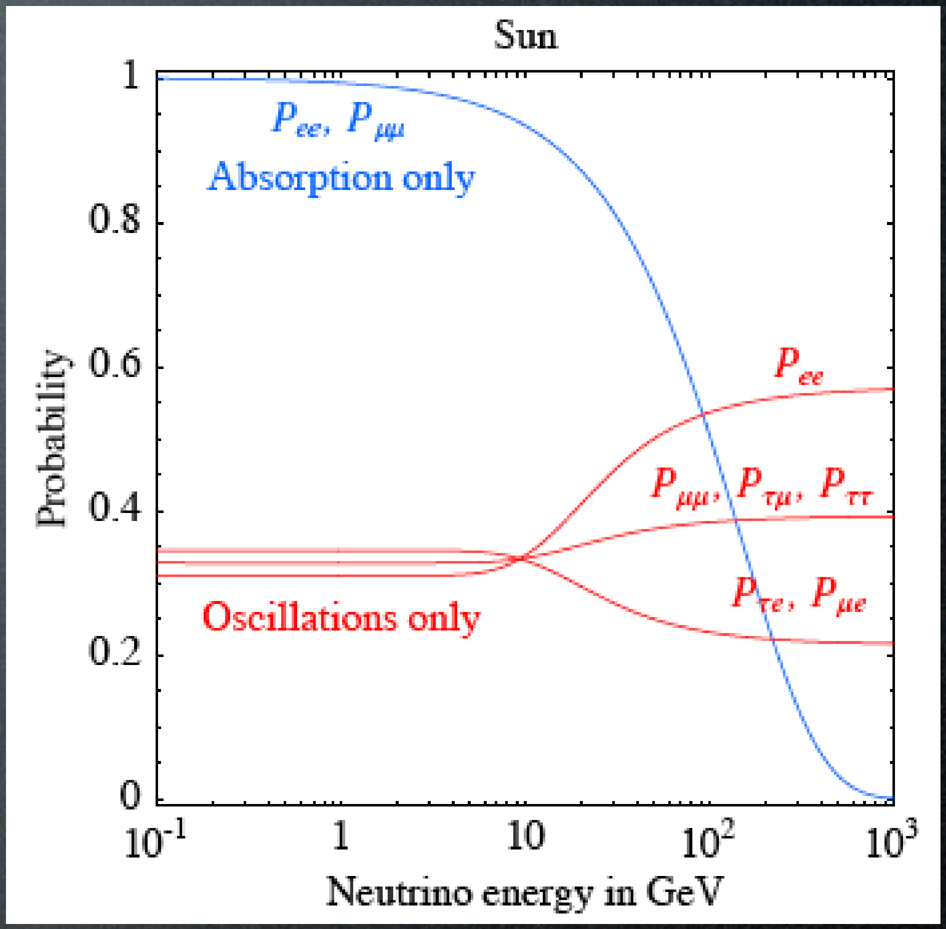

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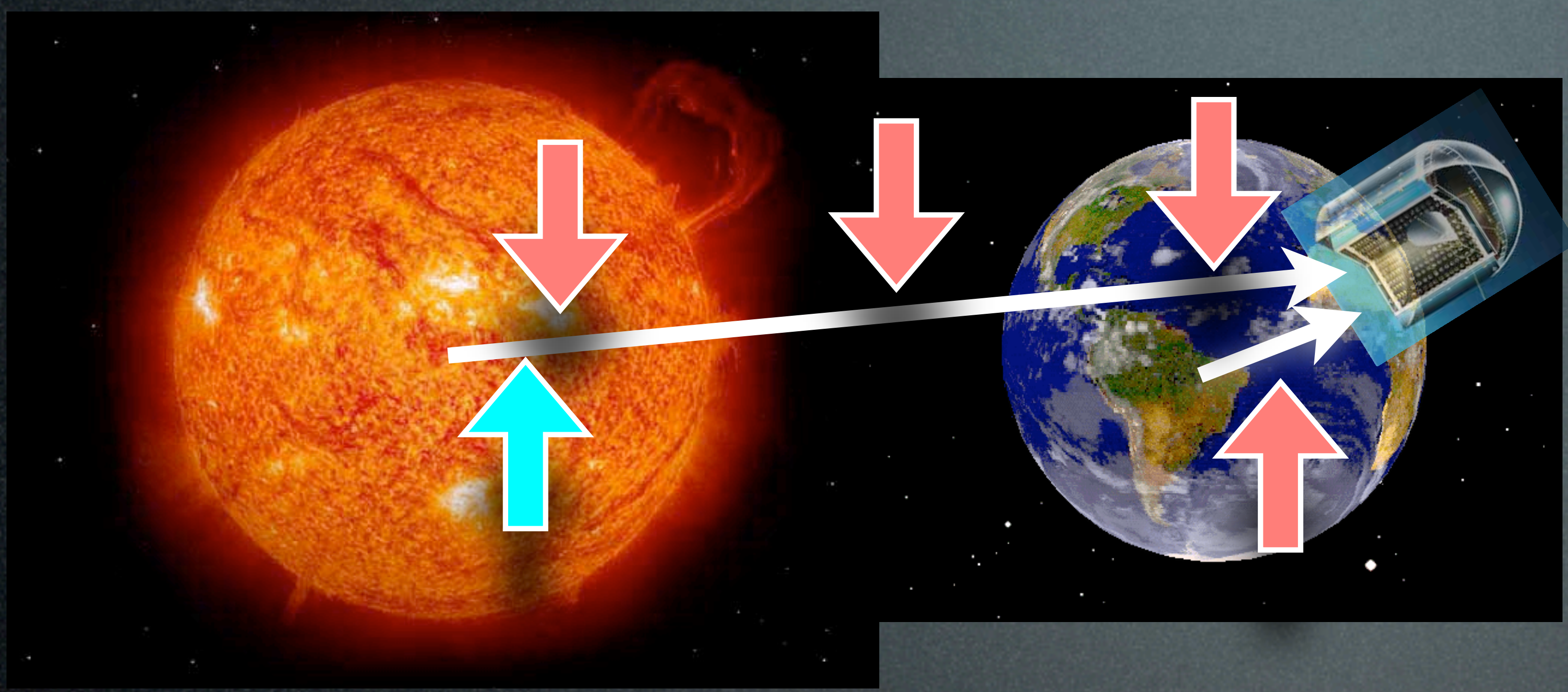
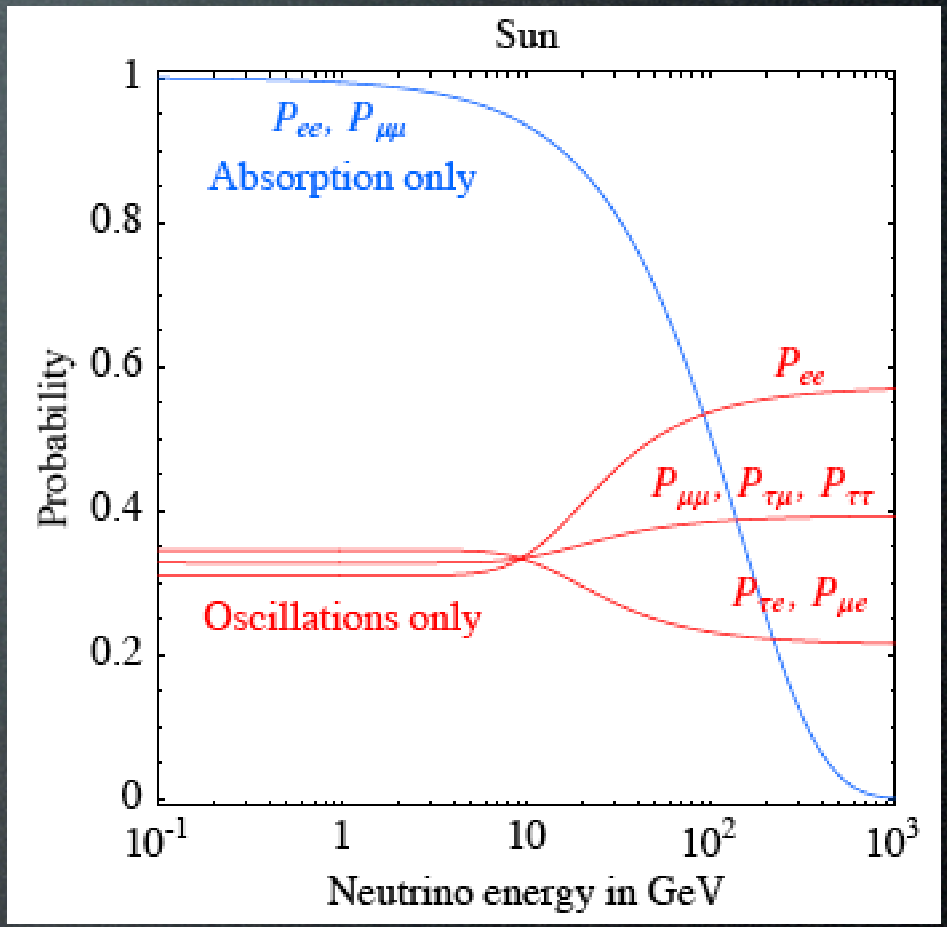
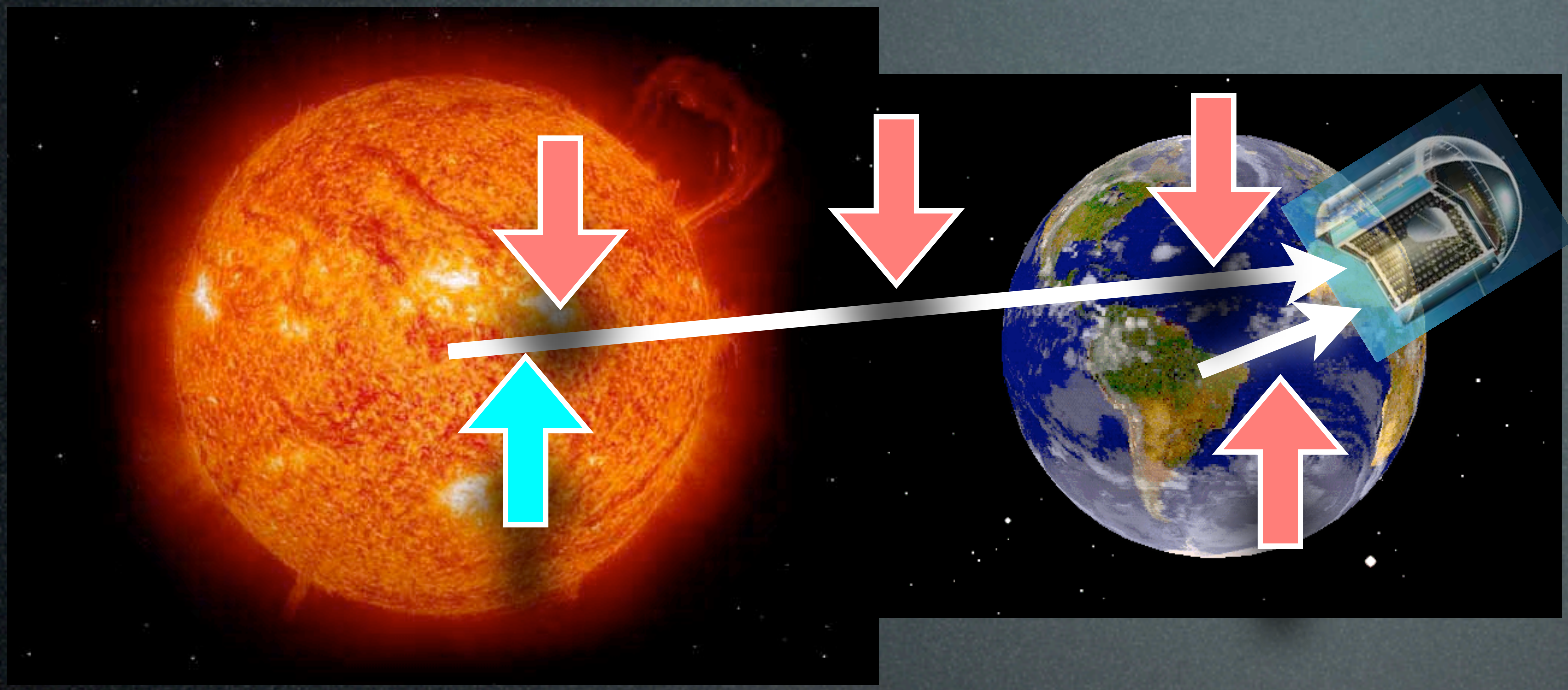


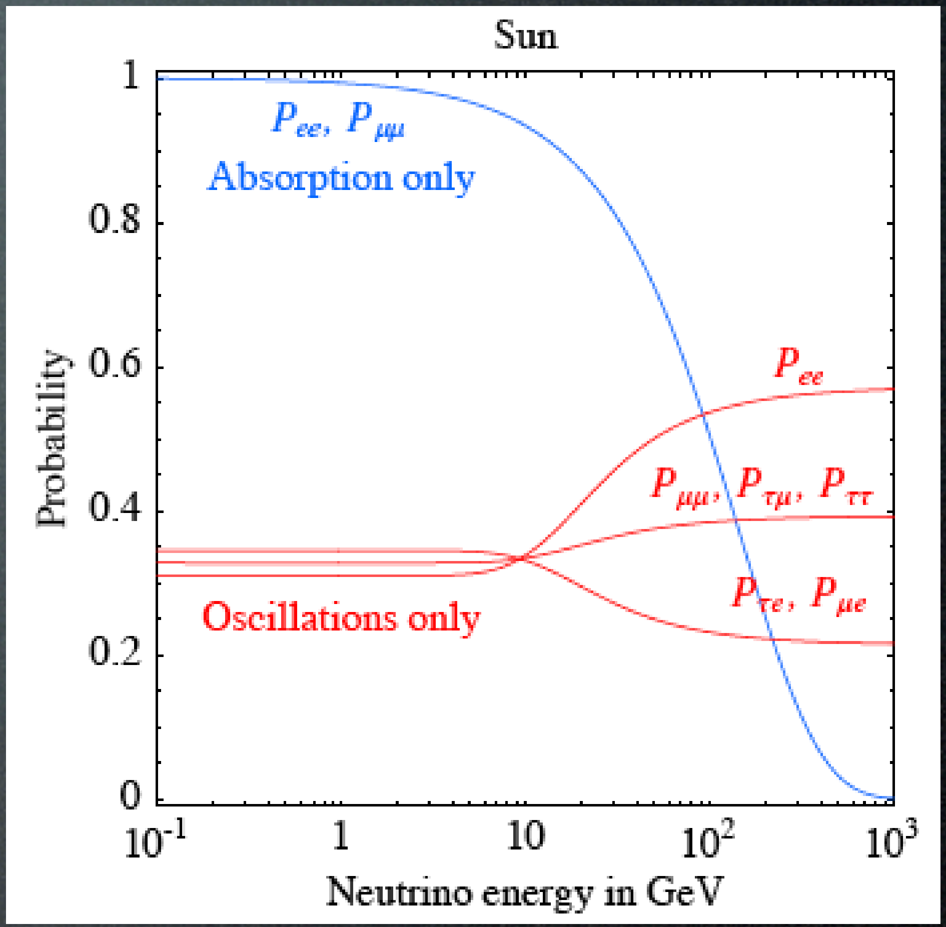


oscillations + interactions

$$\text{production} \longrightarrow \begin{pmatrix} \Phi_{\nu_e} & & \\ & \Phi_{\nu_\mu} & \\ & & \Phi_{\nu_\tau} \end{pmatrix} \longrightarrow \text{detection}$$

2. Propagation





oscillations + interactions

density matrix

$$\boldsymbol{\rho} = \begin{pmatrix} \rho_{ee} & \rho_{e\mu} & \rho_{e\tau} \\ \rho_{\mu e} & \rho_{\mu\mu} & \rho_{\mu\tau} \\ \rho_{\tau e} & \rho_{\tau\mu} & \rho_{\tau\tau} \end{pmatrix}$$

full evolution equation:

$$\frac{d\boldsymbol{\rho}}{dr} = -i[\boldsymbol{H},\ \boldsymbol{\rho}] + \left.\frac{d\boldsymbol{\rho}}{dr}\right|_{\rm CC} + \left.\frac{d\boldsymbol{\rho}}{dr}\right|_{\rm NC} + \left.\frac{d\boldsymbol{\rho}}{dr}\right|_{\rm in}$$

2. Propagation: oscillations

$$\frac{d\boldsymbol{\rho}}{dr} = -i[\boldsymbol{H},\ \boldsymbol{\rho}]$$

$$\boldsymbol{H} = \frac{\boldsymbol{m}^\dagger \boldsymbol{m}}{2E_\nu} + \sqrt{2}G_\mathrm{F}\left[N_e \begin{pmatrix} 1 & & \\ & 0 & \\ & & 0 \end{pmatrix} - \frac{N_n}{2}\begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix}\right]$$

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vacuum mixing:

$$\boldsymbol{m}^\dagger \boldsymbol{m} = \boldsymbol{V} \cdot \begin{pmatrix} m_1^2 & & \\ & m_2^2 & \\ & & m_3^2 \end{pmatrix} \cdot \boldsymbol{V}^\dagger$$

$\theta_\mathrm{sun} = 32°$
$\theta_\mathrm{atm} = 45°$
$\theta_{13} = 0$
$\Delta m^2_\mathrm{sun} = 8.0\ 10^{-5}\mathrm{eV}^2$
$|\Delta m^2_\mathrm{atm}| = 2.5\ 10^{-3}\mathrm{eV}^2$

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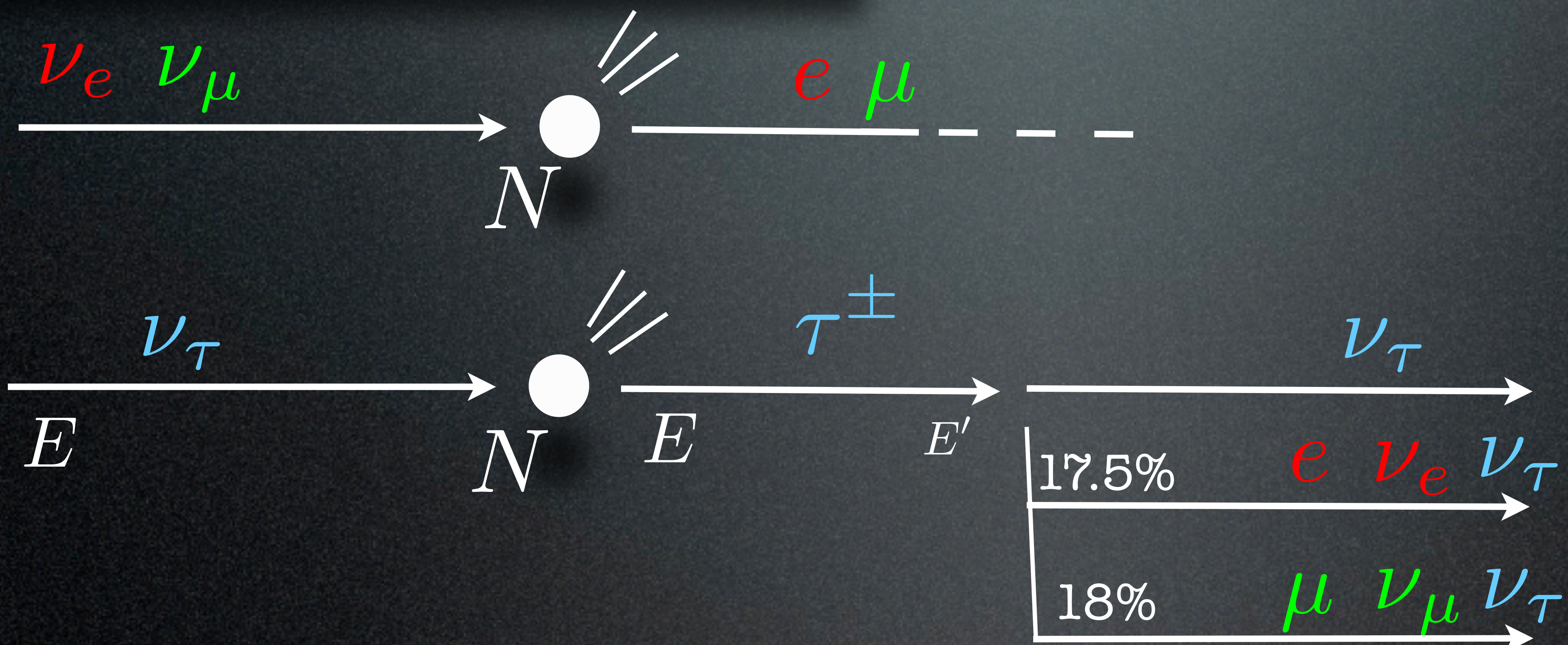
matter effect (MSW):

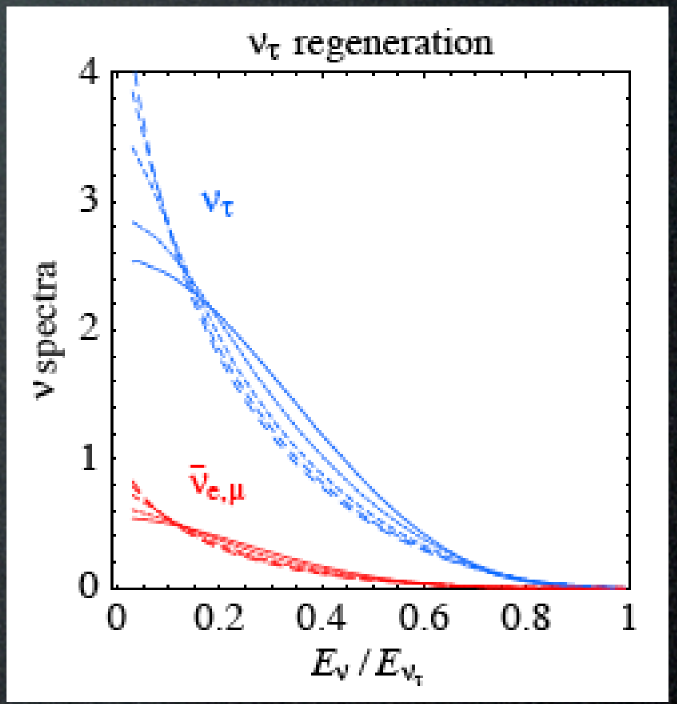
$N_e(r), N_n(r)$ from solar/ Earth models

2. Propagation: CC absorption & tau regeneration

$$\frac{d\boldsymbol{\rho}}{dr} = -i[\boldsymbol{H},\ \boldsymbol{\rho}] + \left.\frac{d\boldsymbol{\rho}}{dr}\right|_{\rm CC}$$



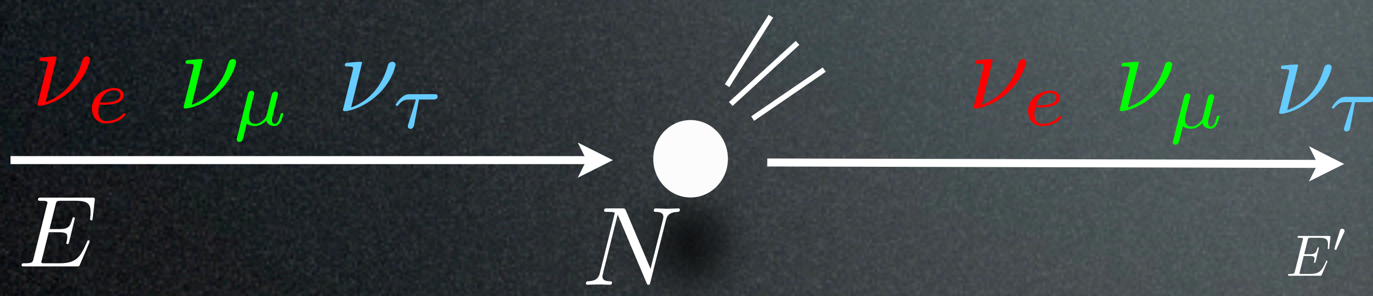
(re)generation

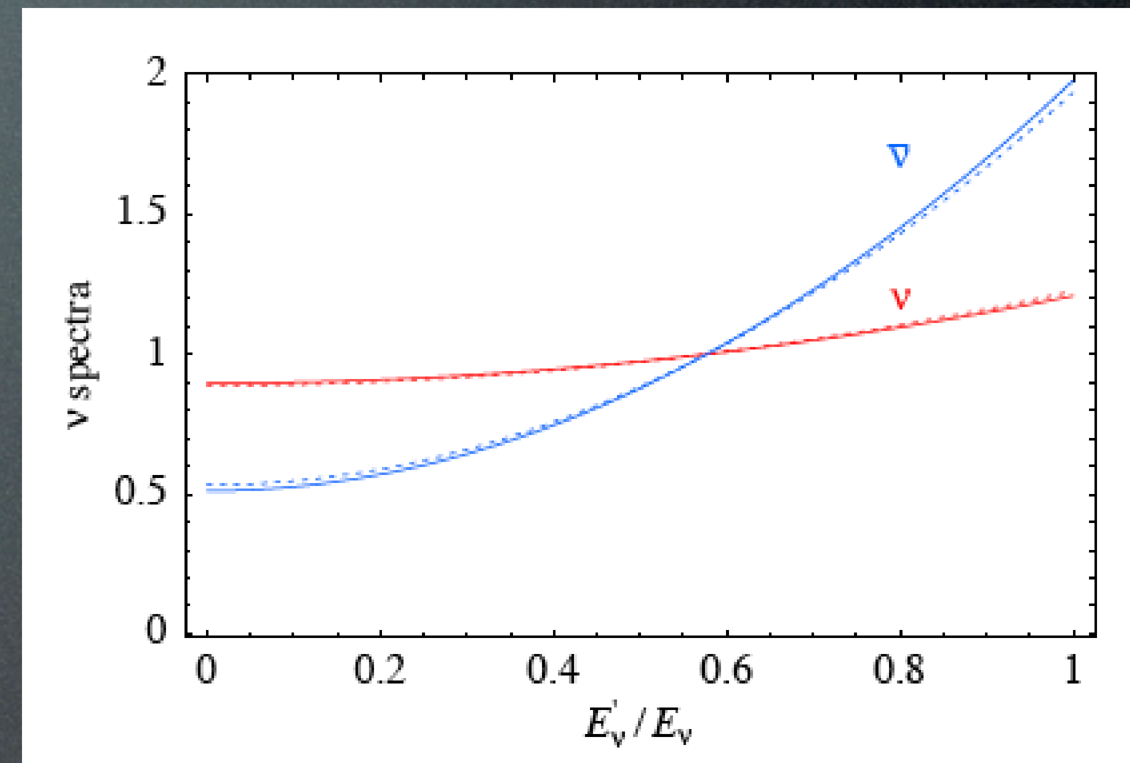


$$\left.\frac{d\boldsymbol{\rho}}{dr}\right|_{\rm CC} = -\frac{\{\boldsymbol{\Gamma}_{\rm CC}, \boldsymbol{\rho}\}}{2} + \int \frac{dE_\nu^{\rm in}}{E_\nu^{\rm in}} \Big[\boldsymbol{\Pi}_\tau \rho_{\tau\tau}(E_\nu^{\rm in}) \Gamma_{\rm CC}^\tau(E_\nu^{\rm in}) f_{\tau\to\tau}(E_\nu^{\rm in}, E_\nu)$$
$$+\boldsymbol{\Pi}_{e,\mu} \bar{\rho}_{\tau\tau}(E_\nu^{\rm in}) \bar{\Gamma}_{\rm CC}^\tau(E_\nu^{\rm in}) f_{\bar{\tau}\to e,\mu}(E_\nu^{\rm in}, E_\nu) \Big]$$

2. Propagation: NC scatterings

$$\frac{d\boldsymbol{\rho}}{dr} = -i[\boldsymbol{H},\ \boldsymbol{\rho}] + \left.\frac{d\boldsymbol{\rho}}{dr}\right|_{\rm CC} + \left.\frac{d\boldsymbol{\rho}}{dr}\right|_{\rm NC}$$





$$\left.\frac{d\boldsymbol{\rho}}{dr}\right|_{\rm NC} = -\int_0^{E_\nu} dE'_\nu \frac{d\Gamma_{\rm NC}}{dE'_\nu}(E_\nu, E'_\nu)\boldsymbol{\rho}(E_\nu) + \int_{E_\nu}^{\infty} dE'_\nu \frac{d\Gamma_{\rm NC}}{dE_\nu}(E'_\nu, E_\nu)\boldsymbol{\rho}(E'_\nu)$$

2. Propagation: summary

Effects of oscillations and interactions:

- reshuffle of the 3 flavors
  (oscillations and regeneration)

- attenuation of the fluxes

- degradation of energy
  (distortion of spectra)

Introduction

Basics:

1) neutrinos from galactic center or halo
2) neutrinos from the Sun

Status:

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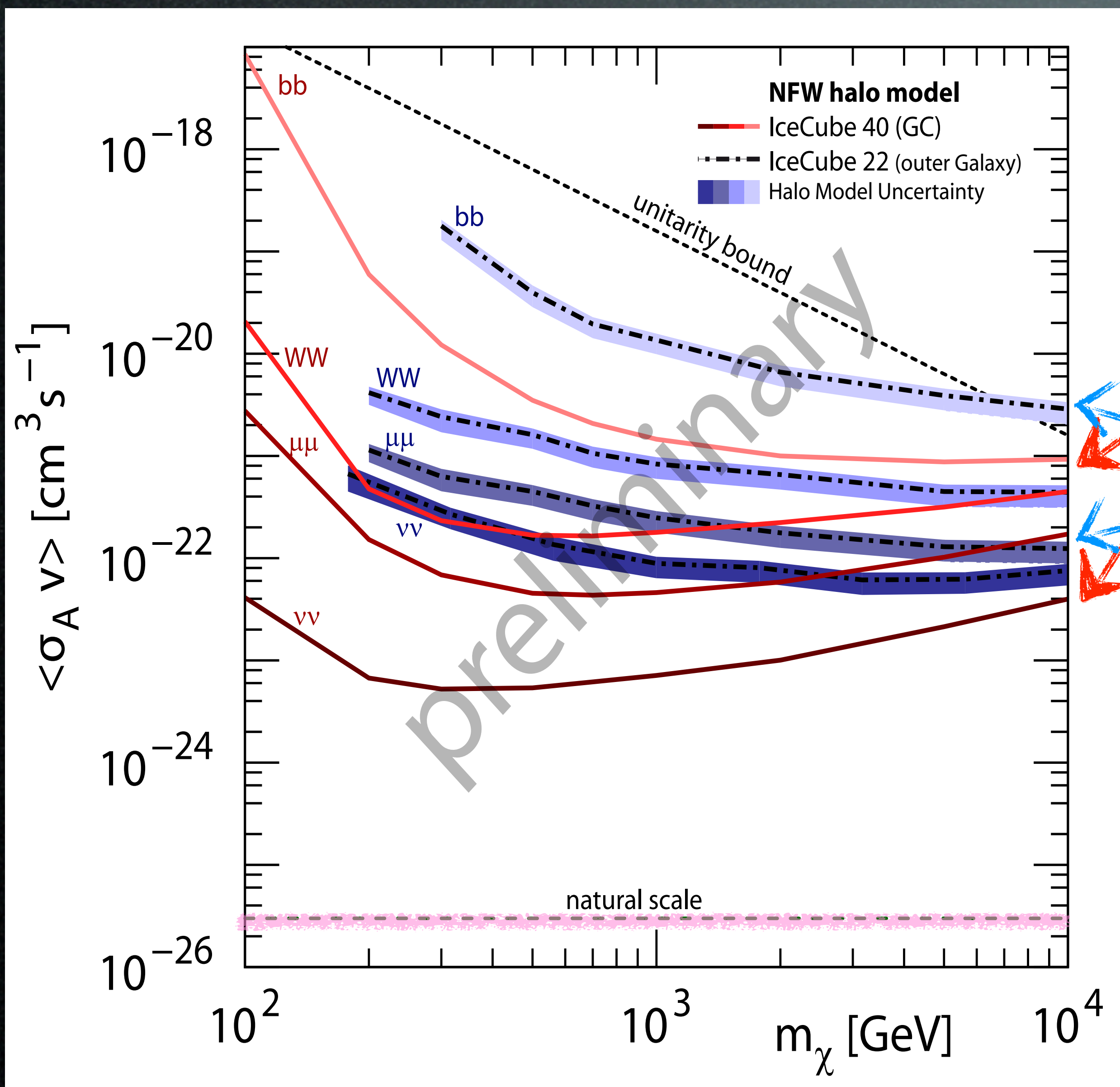
Conclusions

Neutrino constraints

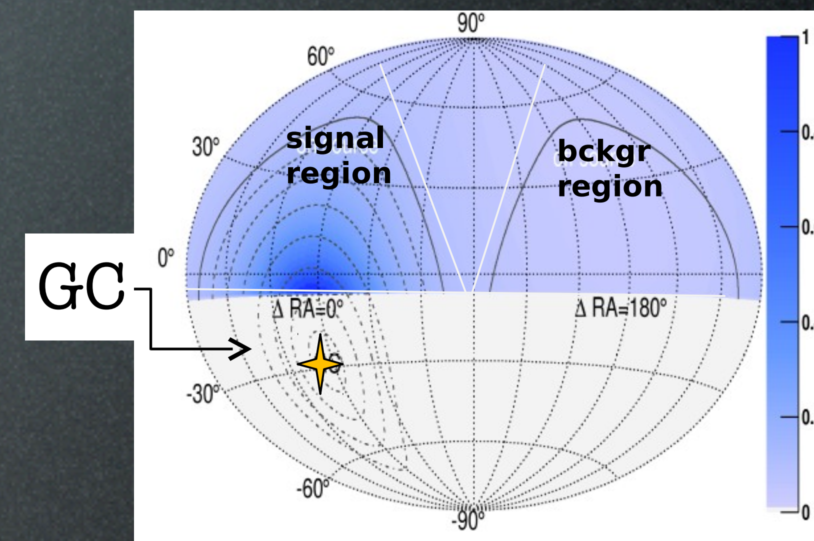
ν from DM annihilations in galactic center/halo

ICECUBE



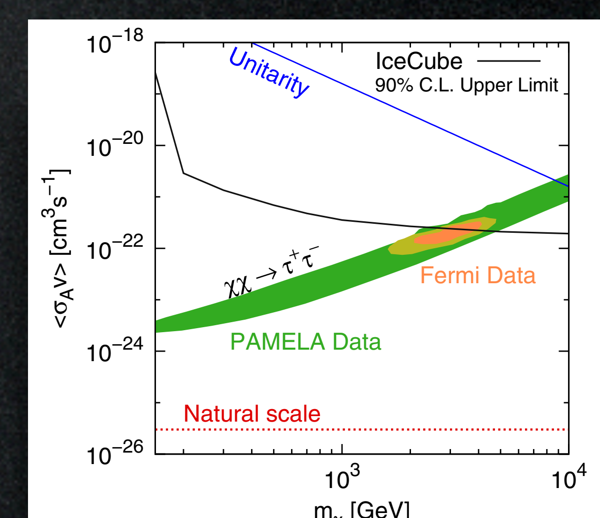
Icecube Coll., 1101.3349 +
Carlos de los Heros, talk at TeVPA 2011, Stockholm +
Icecube Coll., 1111.2738

Gal halo: use on/off technique



Gal center: veto downgoing μ

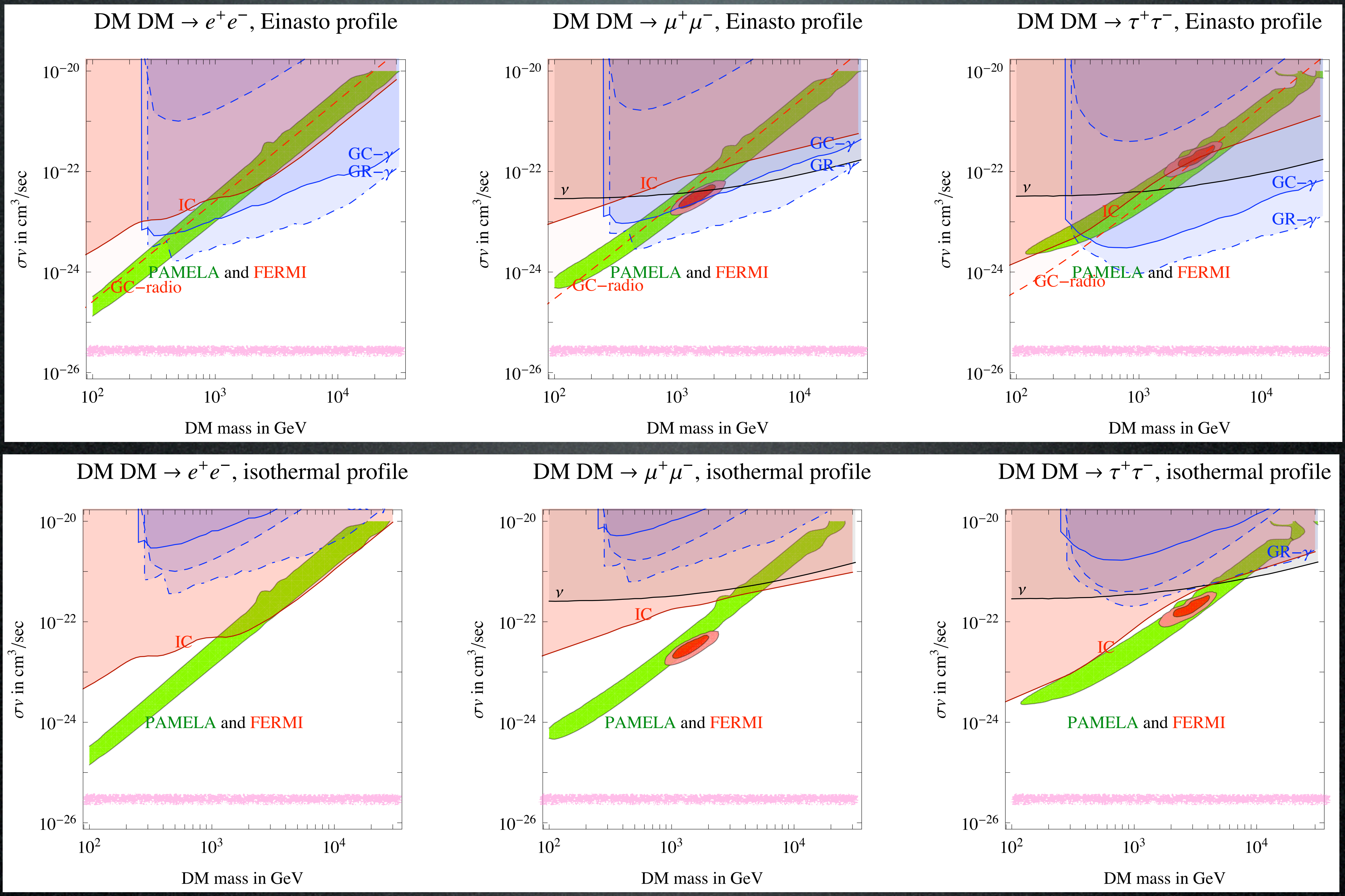
Competitive constraints



Neutrino constraints

Comparing with SuperKamiokande data in 3° to 30°

- dependance on DM profile
- constrains large M_{DM} ($\sigma_{\nu N} \propto E_\nu$)



Strumia, Papucci et al. 0905.0480

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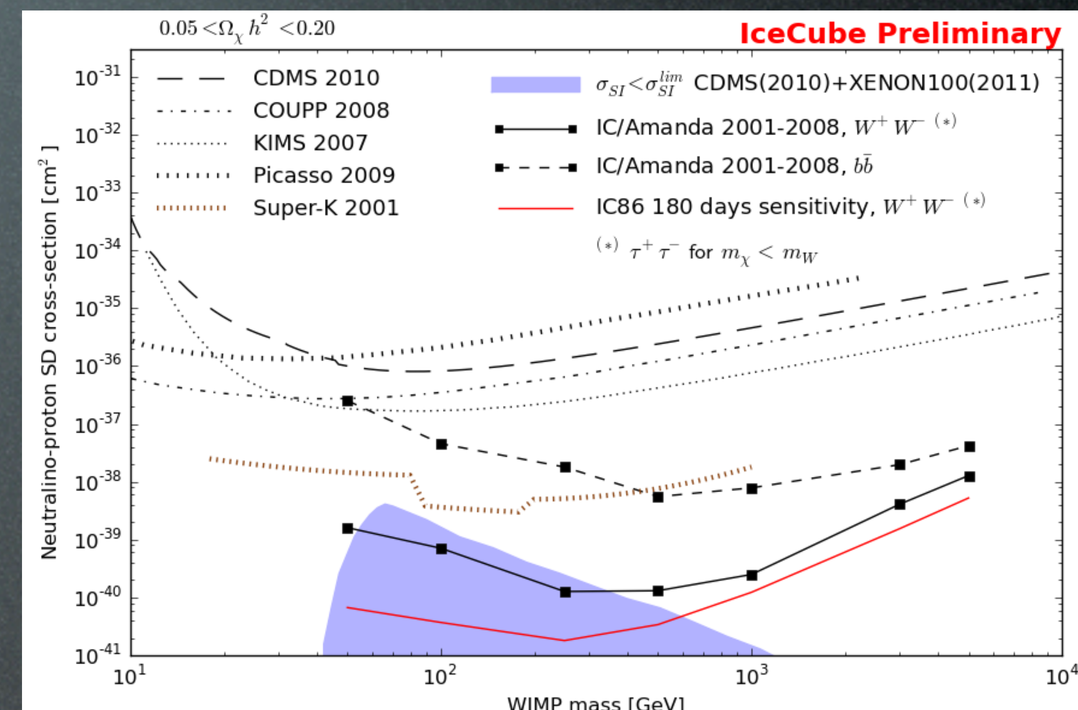
Indirect Detection

ν from DM annihilations in the Sun

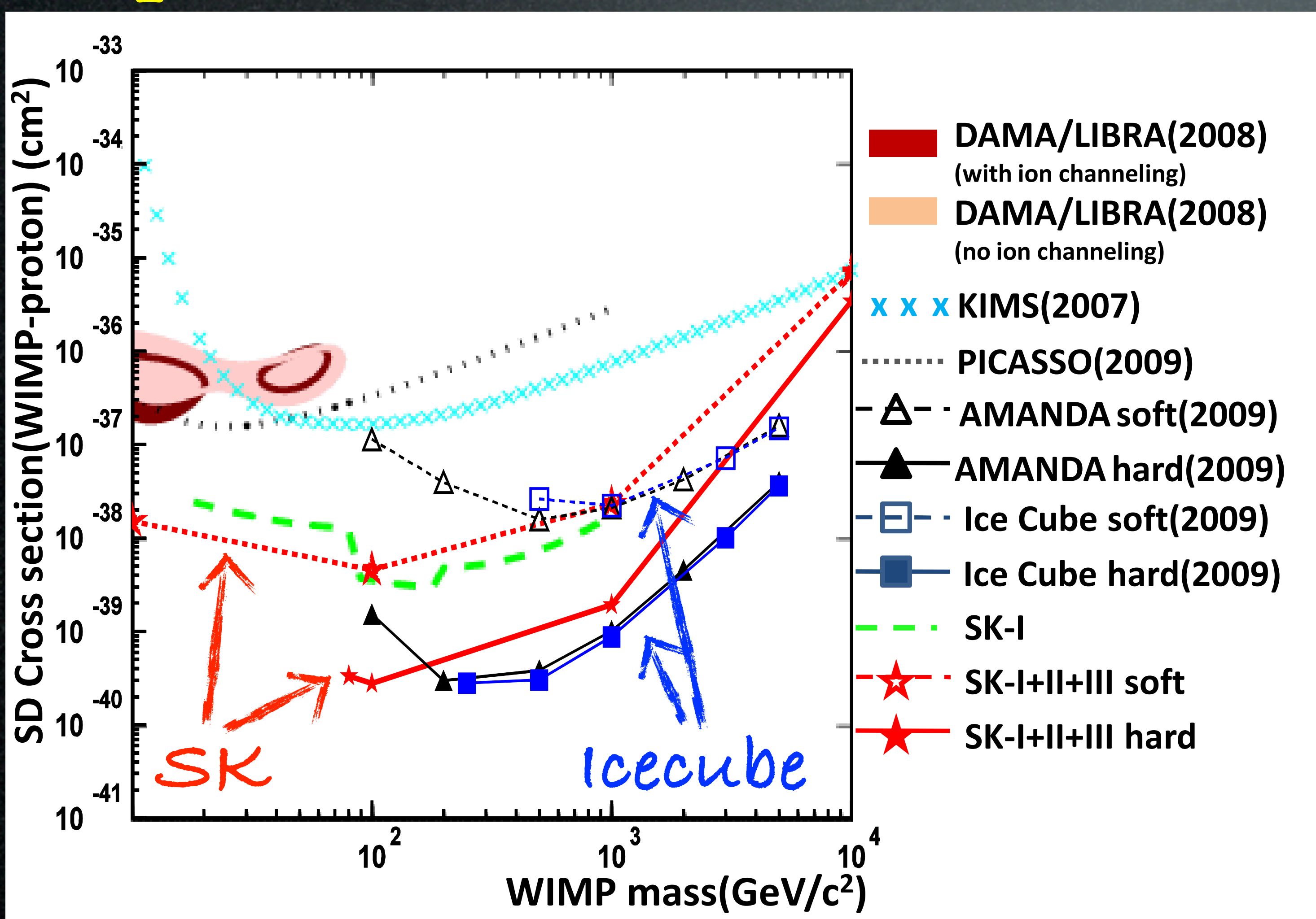
Probe the scattering cross section.

ICECUBE



Icecube Coll., 1111.2738

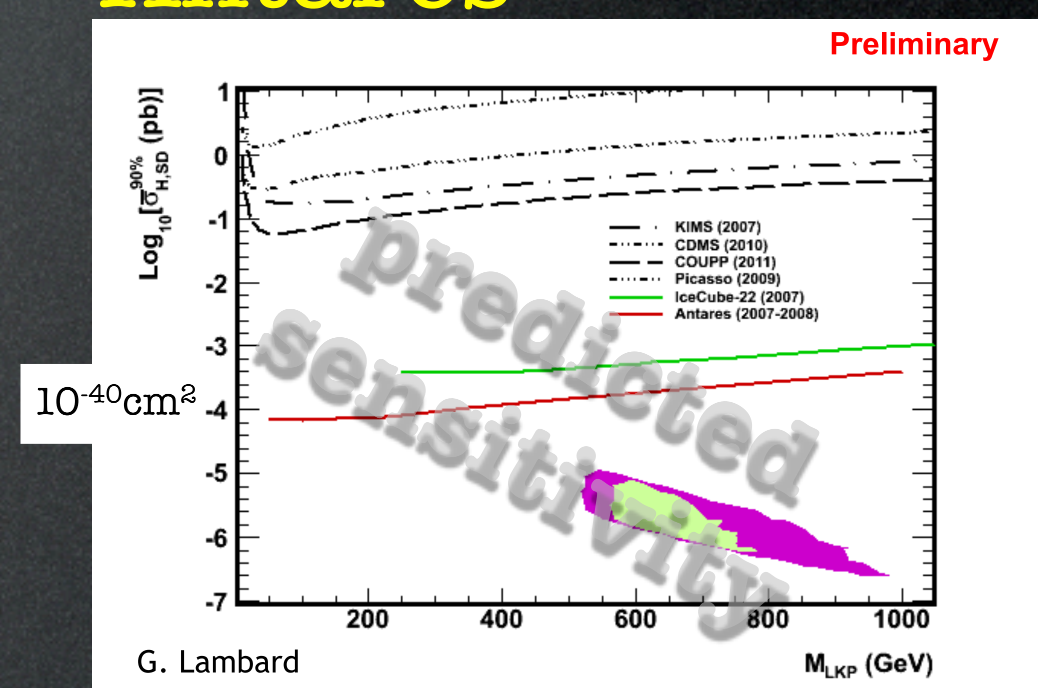
SuperKamiokande



1108.3384

3109.6 days! (now beat that)

Antares



Juande Zornoza, talk at TeVPA 2011, Stockholm

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complementary to other messengers (interesting)

neutrinos travel undisturbed (clean)

rather small astro uncertainty (robust)

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- clean ← neutrinos travel undisturbed
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Two classes: i) from the GC/GH, ii) from massive bodies (Sun)

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Currently only bounds (but experiments get better and better)

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but you don't want to mess around with astrophysics?

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PPPC 4 DM ID

'The Poor Particle Physicist Cookbook for Dark Matter Indirect Direction'

Cirelli, Corcella, Hektor, Hütsi, Kadastik, Panci, Raidal, Sala, Strumia

1012.4515

www.marcocirelli.net/PPPC4DMID.html

DMnu

'Spectra of neutrinos from Dark Matter anihilations'

hep-ph/0506298

Cirelli, Fornengo, Montaruli, Sokalski, Strumia, Vissani

www.marcocirelli.net/DMnu.html