Searching for dark matter with neutrinos

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IFIC, CSIC-U. València

Workshop on New Trends in Dark Matter

International Centre for Theoretical Physics South American Institute for Fundamental Research

December 9, 2020

Neutrino-dark matter connections

Neutrinos

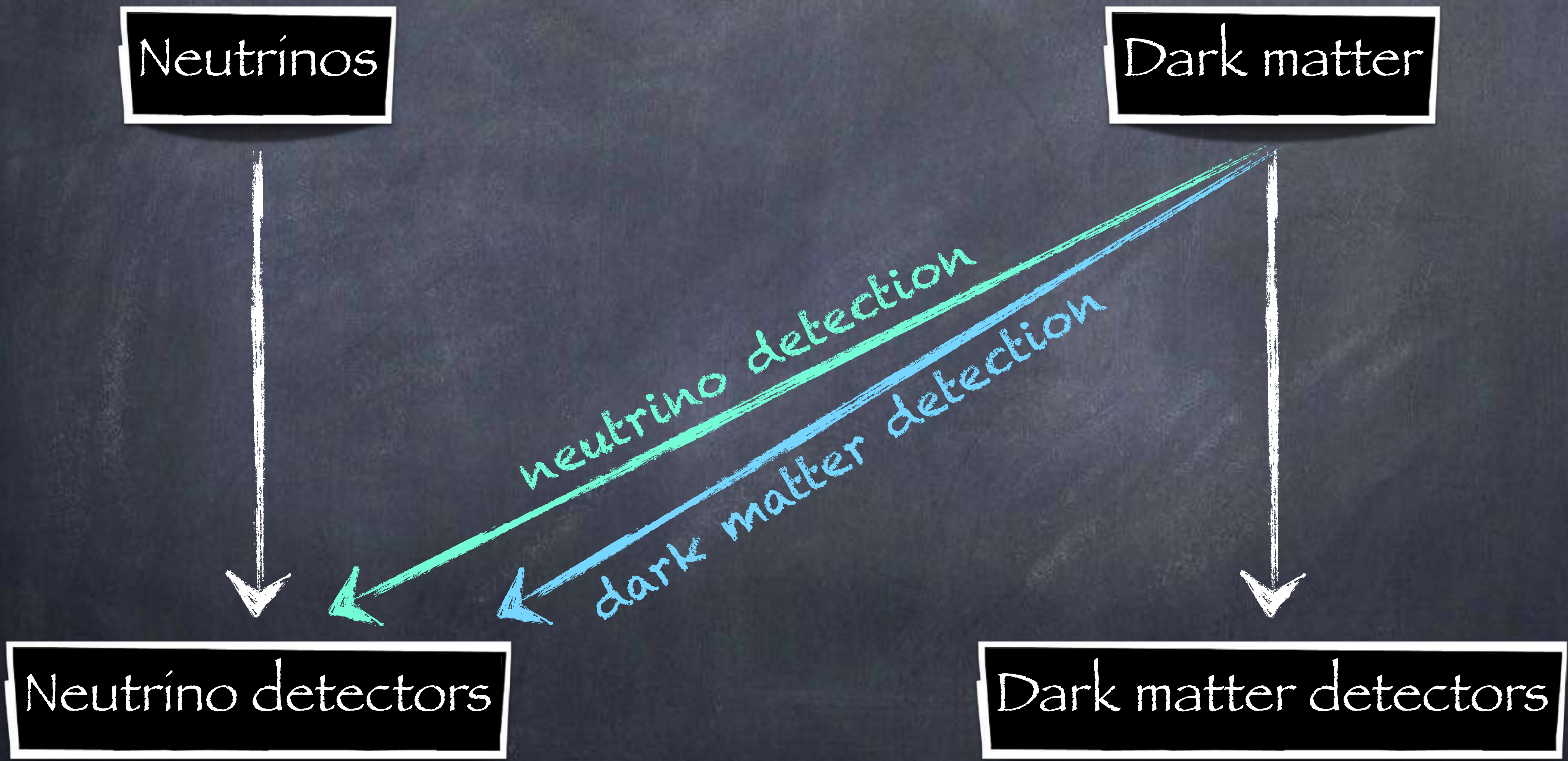
Dark matter

Neutrino-dark matter connections

Neutrinos → Neutrino detectors

Dark matter → Dark matter detectors

Neutrino-dark matter connections



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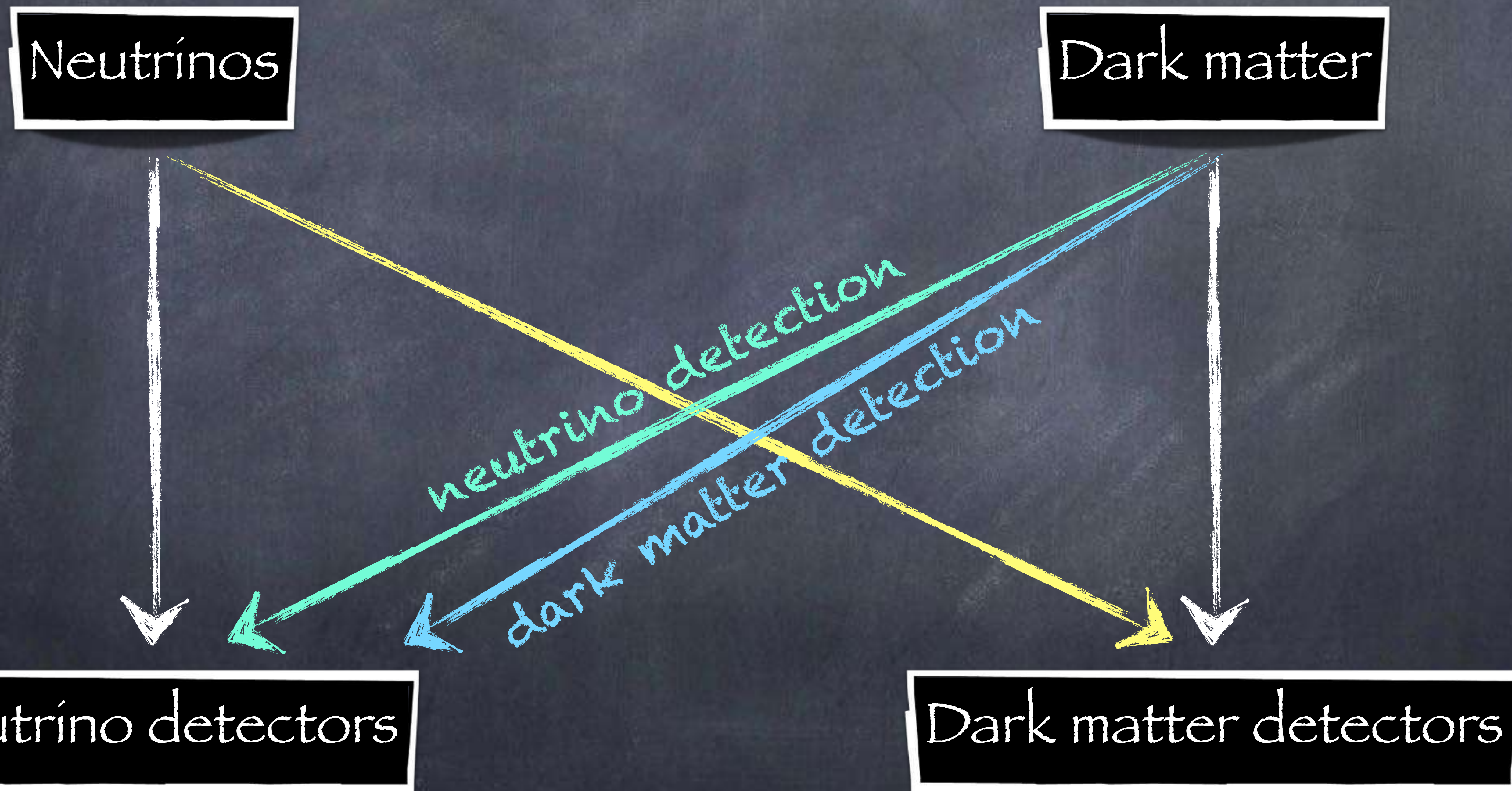

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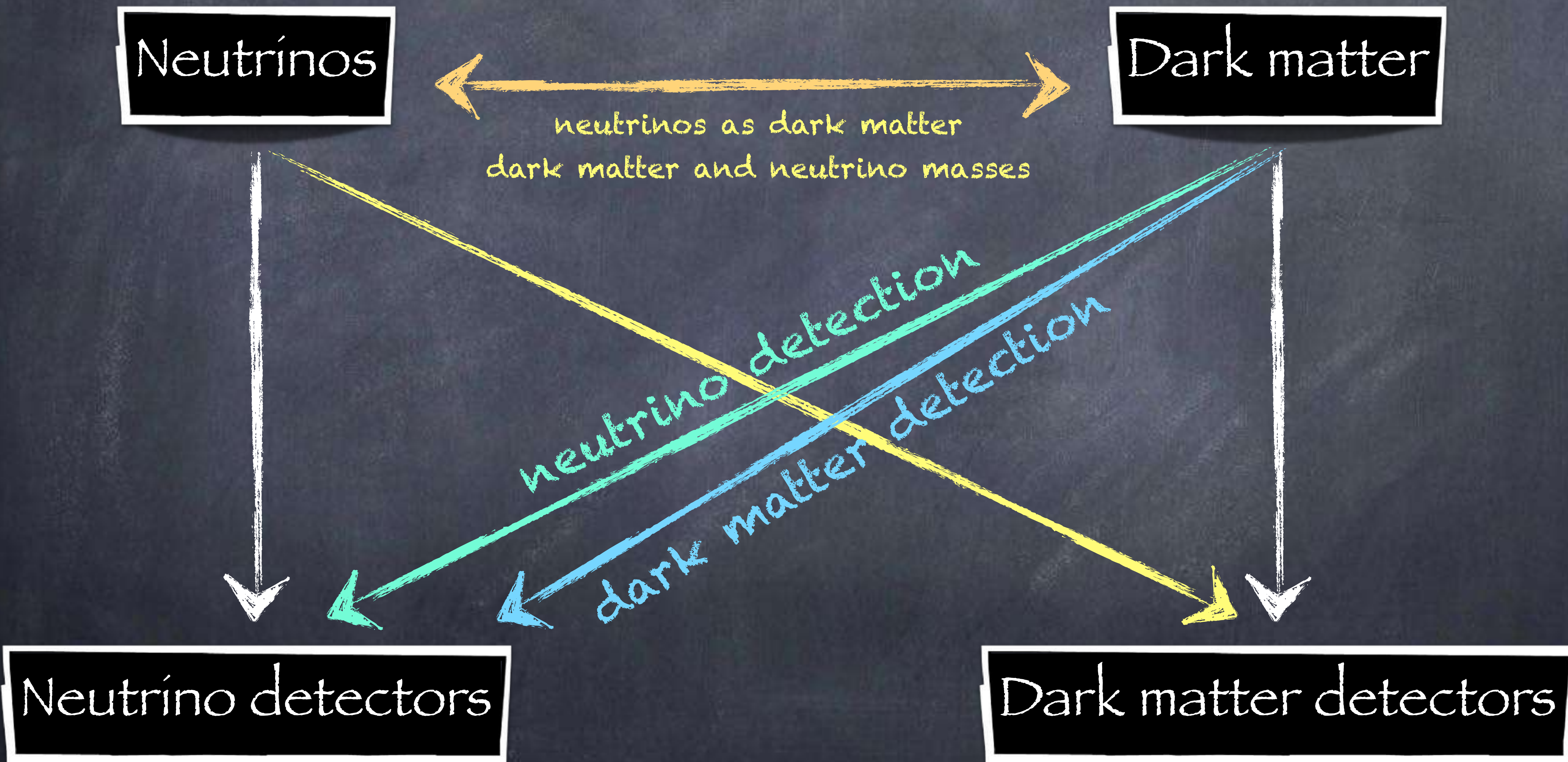

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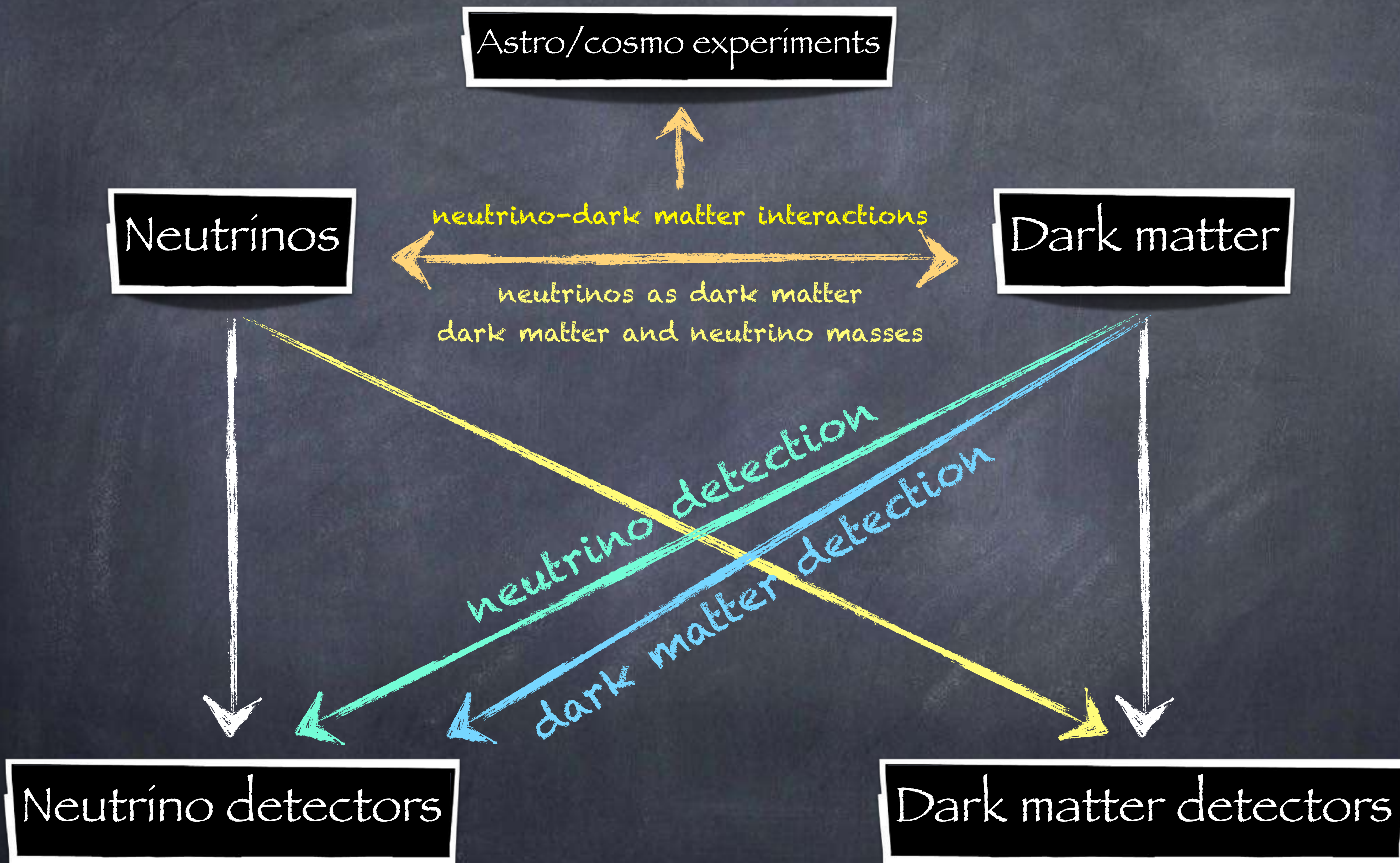
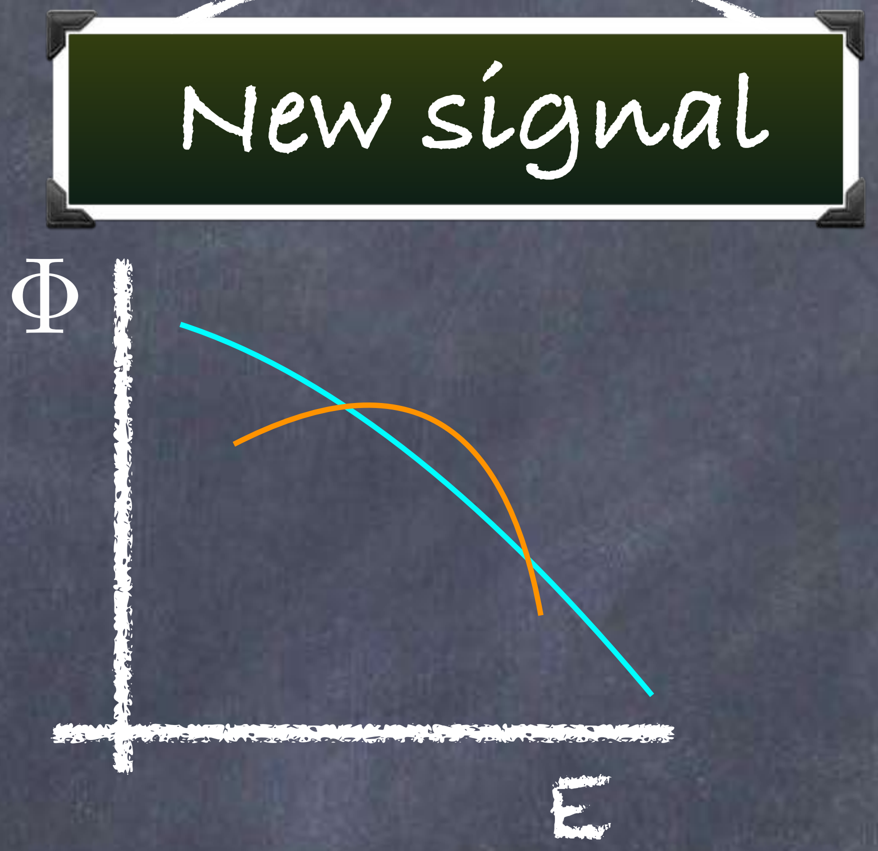


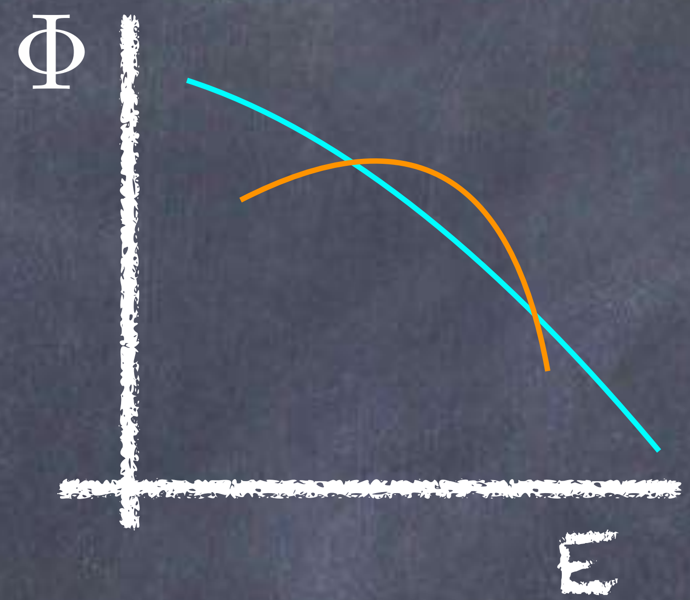
Neutrino-dark matter interactions

Neutrino-dark matter interactions

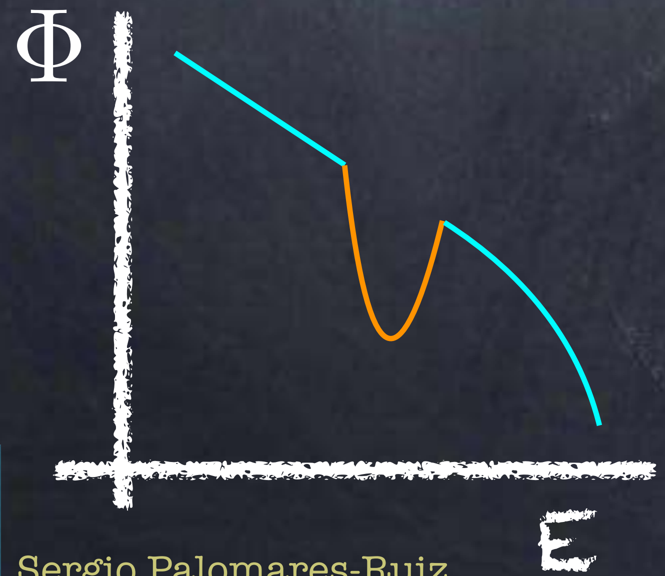


Neutrino-dark matter interactions

New signal



Features on known spectra



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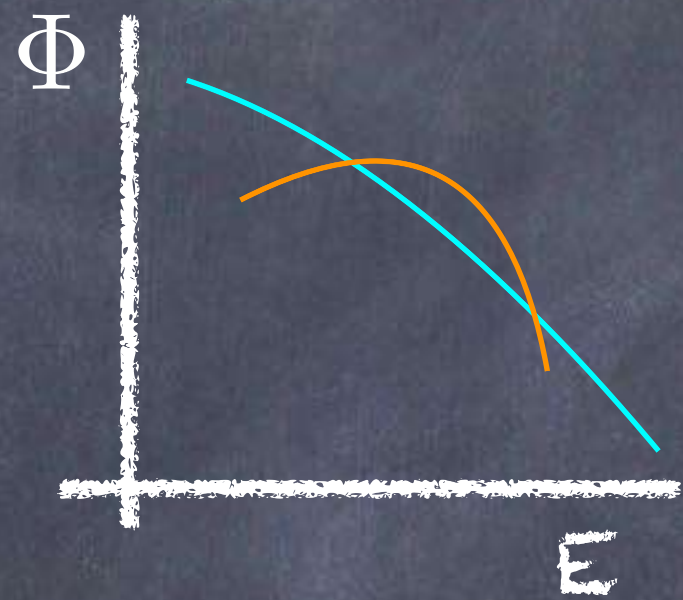

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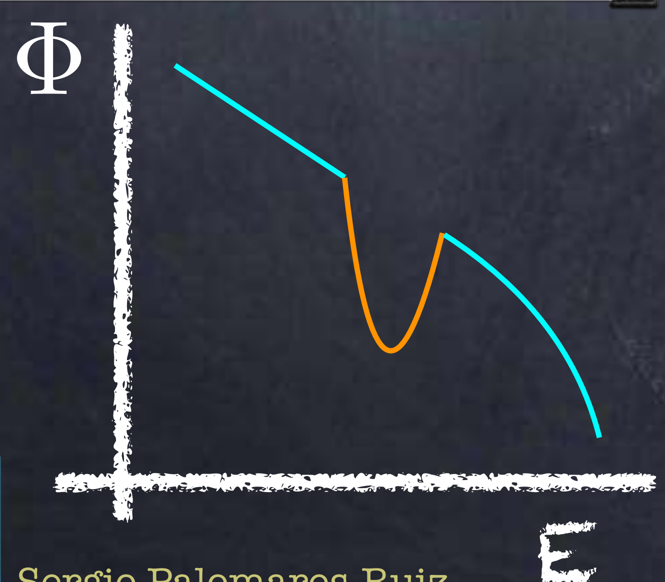
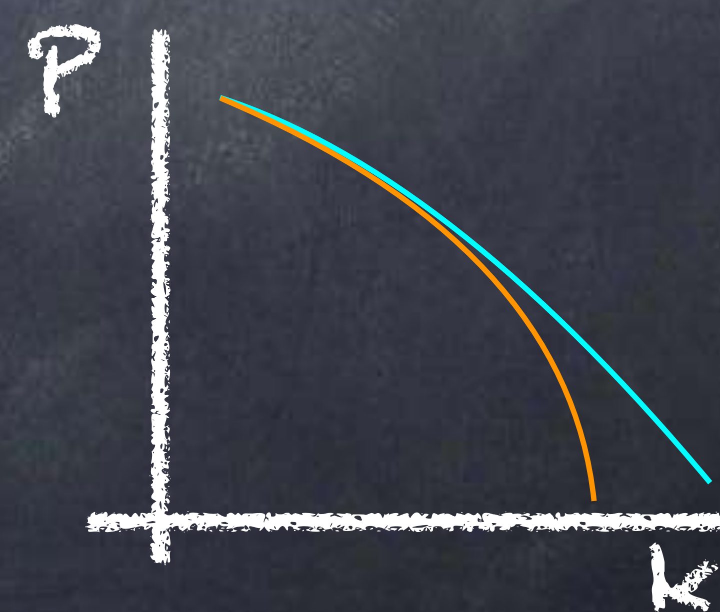


Cosmo/Astro effects



Sources of neutrinos

Natural sources

Atmosphere

Earth

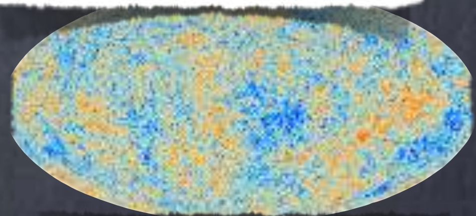
Sun

Farther away

Supernova explosions

Astrophysical sources

Cosmic relics



Man-made sources

Nuclear reactors

Particle accelerators

Sources of neutrinos

Natural sources

Atmosphere

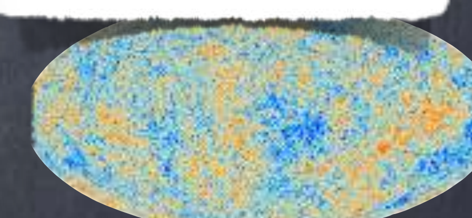
Earth

Sun

Supernova explosions

Astrophysical sources

Cosmic relics



Exotics?

Farther away

Man-made sources

Nuclear reactors

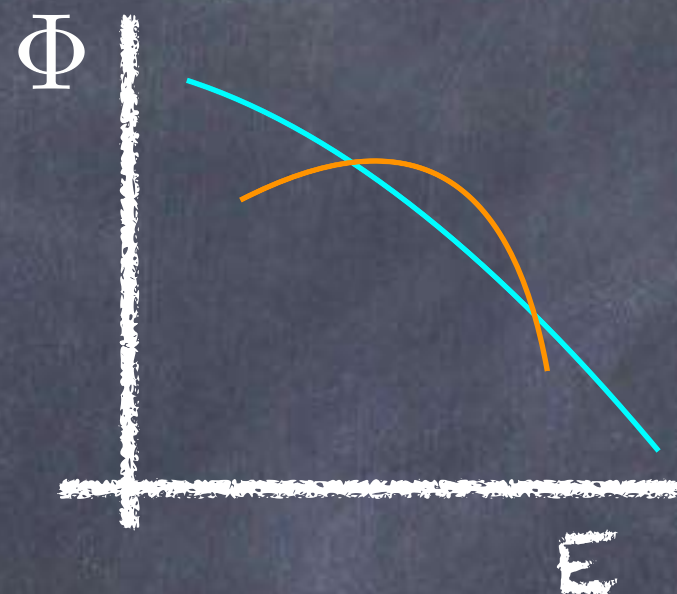
Particle accelerators

New signal

Annihilation of captured DM in the Sun/Earth

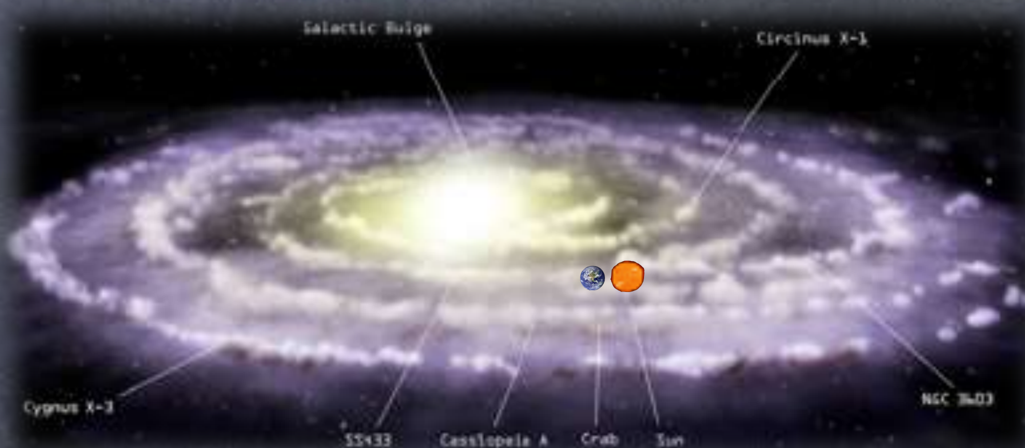
Sensitive to scattering cross section

Only for m > few GeV



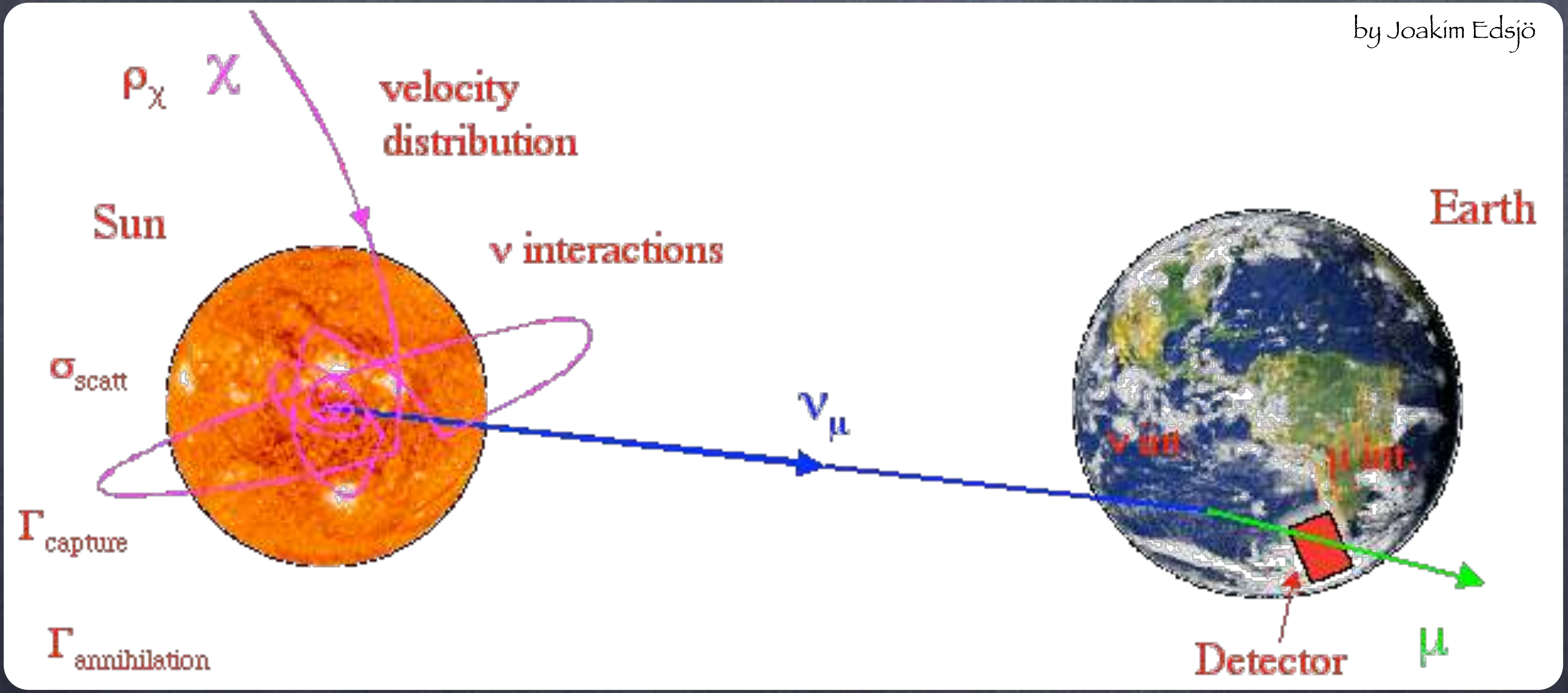
Annihilations/decays in halos

Sensitive to annihilation cross section (link to thermal production in the early Universe?) and lifetime



DM annihilations or decays

Dark Matter capture in the Sun/Earth



J. Silk, K. A. Olive and M. Srednicki, Phys. Rev. Lett. 55:257, 1985
T. K. Gaisser, G. Steigman and S. Tilav, Phys. Rev. D34:2206, 1986
M. Srednicki, K. A. Olive and J. Silk, Phys. B279:804, 1987
K. Griest and D. Seckel, Nucl. Phys. B283:681, 1987

Dark Matter capture in the Sun/Earth

- Local DM particles elastically scatter with the nuclei of the Sun to a velocity smaller than the escape velocity, and they can get gravitationally bound and finally trapped inside

W. H. Press and D. N. Spergel, Astrophys. J. 296:679, 1985

$$C_\odot \simeq 9\times 10^{23}\,s^{-1}\left(\frac{\rho_0}{0.3\ \mathrm{GeV/cm^3}}\right)\left(\frac{270\ \mathrm{km/s}}{\bar{v}_{local}}\right)^3\left(\frac{\sigma_{SD}}{10^{-3}\ \mathrm{pb}}\right)\left(\frac{50\ \mathrm{GeV}}{m_\chi}\right)^2$$

A. Gould, Astrophys. J. 321:560, 1987; K. Griest and D. Seckel, Nucl. Phys. B283:681, 1987; A. Gould, Astrophys. J. 321:571, 1987

Additional scatterings give rise to an isothermal distribution

- Trapped DM particles can annihilate into SM particles

- After some time, annihilation and capture rates typically equilibrate

$$\Gamma(t_\odot) \simeq \frac{1}{2} C_\odot \tanh^2\left(\frac{t_\odot}{\tau_\odot}\right) \simeq \frac{1}{2} C_\odot$$

- Only neutrinos can escape

J. Silk, K. A. Olive and M. Srednicki, Phys. Rev. Lett. 55:257, 1985
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Limits from the Sun

SK: (3902.7 + 4206.7) days

K. Choi et al. [Super-Kamiokande Collaboration], Phys. Rev. Lett. 114:141301, 2015

IceCube: 532 days

M. G. Aartsen et al. [IceCube Collaboration], Eur. Phys. J. C77:146, 2017

Baksan: 24.12 yrs

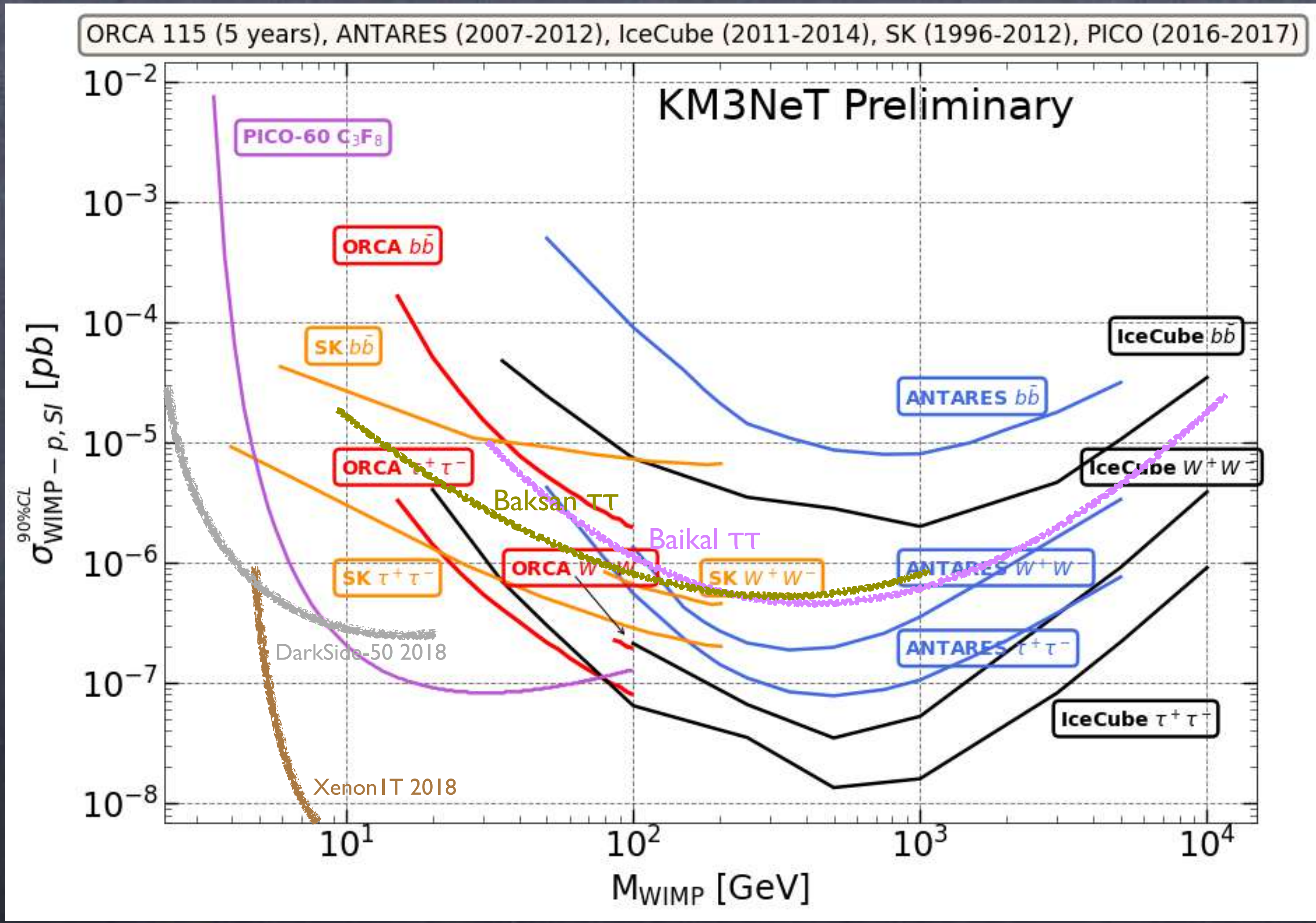
M. M. Boliev et al., JCAP 09:019, 2013

Baikal: 1038 days

A. D. Avrorin et al. [Baikal Collaboration], Astropart. Phys. 62:12, 2015

ANTARES: 5 yrs

S. Adrián-Martínez et al. [ANTARES Collaboration], Phys. Lett. B759:69, 2016



S. Navas, D. López-Coto and J. D. Zornoza [KM3NeT Collaboration], PoS(ICRC2019)536, 2020

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Prospects for INO

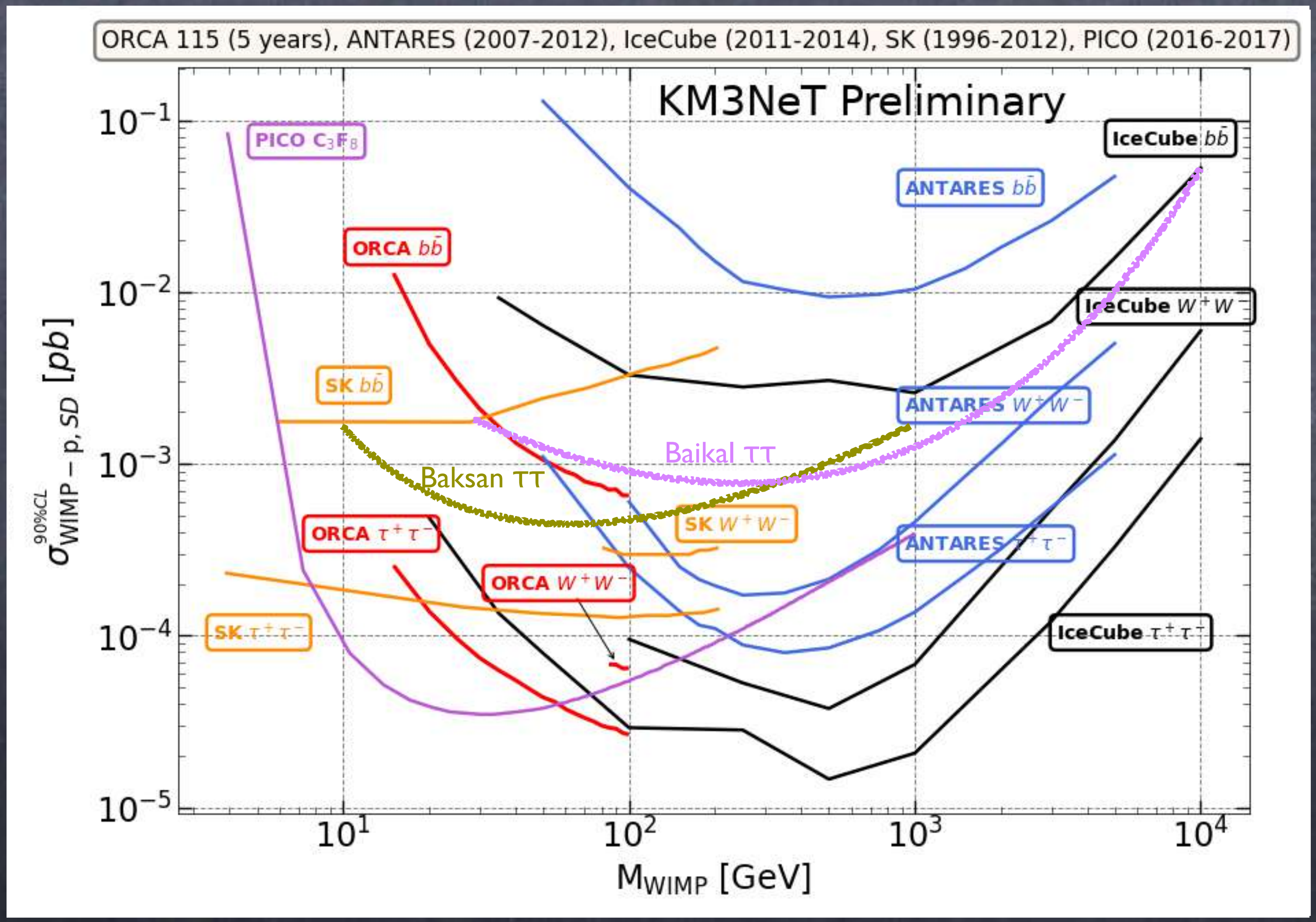
S. Choubey, A. Ghosh and D. Tiwari, JCAP 05:006, 2018

Prospects for DUNE

C. Rott et al., JCAP 07:006, 2019

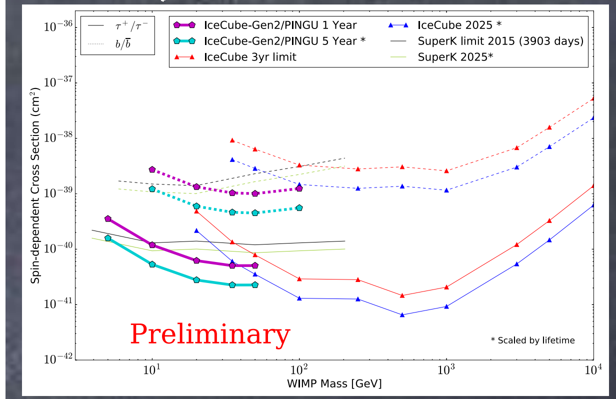
Using KamLAND

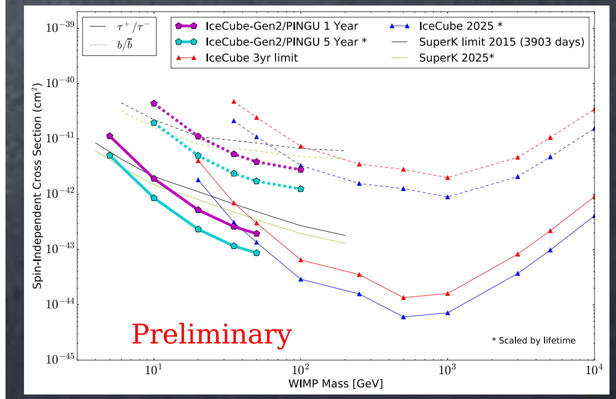
J. Kumar and P. Sandick, JCAP 06:035, 2015



S. Navas, D. López-Coto and J. D. Zornoza [KM3NeT Collaboration], PoS(ICRC2019)536, 2020

Prospects for IceCube





S. In and K. Wiebe [Icecube Coll.], PoS(ICRC2017)912, 2018

Usually only considered annihilations into heavy quarks, gauge bosons or tau leptons...

What about annihilations into light quarks, muons or even electrons?

- Electrons/positrons do not produce neutrinos...
- Muons lose energy electromagnetically very rapidly and decay at rest

$$\tau_{stop} \approx 3 \cdot 10^{-10} \left(\frac{E}{10 \text{ GeV}} \right) s \ll \tau_{decay} \approx 2 \cdot 10^{-4} \left(\frac{E}{10 \text{ GeV}} \right) s$$

- Light-quark hadrons, as pions, are stopped via nuclear interactions and decay at rest

$$\tau_{\text{int}} \approx 10^{-11} s \ll \tau_{decay} \approx 10^{-6} \left(\frac{E}{10 \text{ GeV}} \right) s$$

Usually only considered annihilations into heavy quarks, gauge bosons or tau leptons...

What about annihilations into light quarks, muons or even el...s?

What about the low-energy (tens of MeV) neutrinos from pion and muon decays at rest?

C. Rott, J. Siegal-Gaskins and J. F. Beacom, Phys. Rev. D88:055005, 2013

N. Bernal, J. Martín-Albo and SPR, JCAP 08:011, 2013

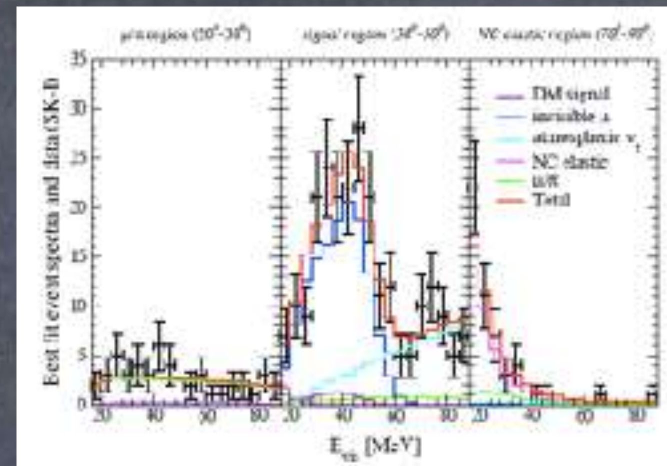
from kaon decays: C. Rott et al., JCAP 11:039, 2015; JCAP 01:016, 2017

... pions, are stopped via nuclear interactions and decay at rest

$$\tau_{\rm int} \approx 10^{-11} s \ll \tau_{decay} \approx 10^{-6} \left(\frac{E}{10 \text{ GeV}} \right) s$$

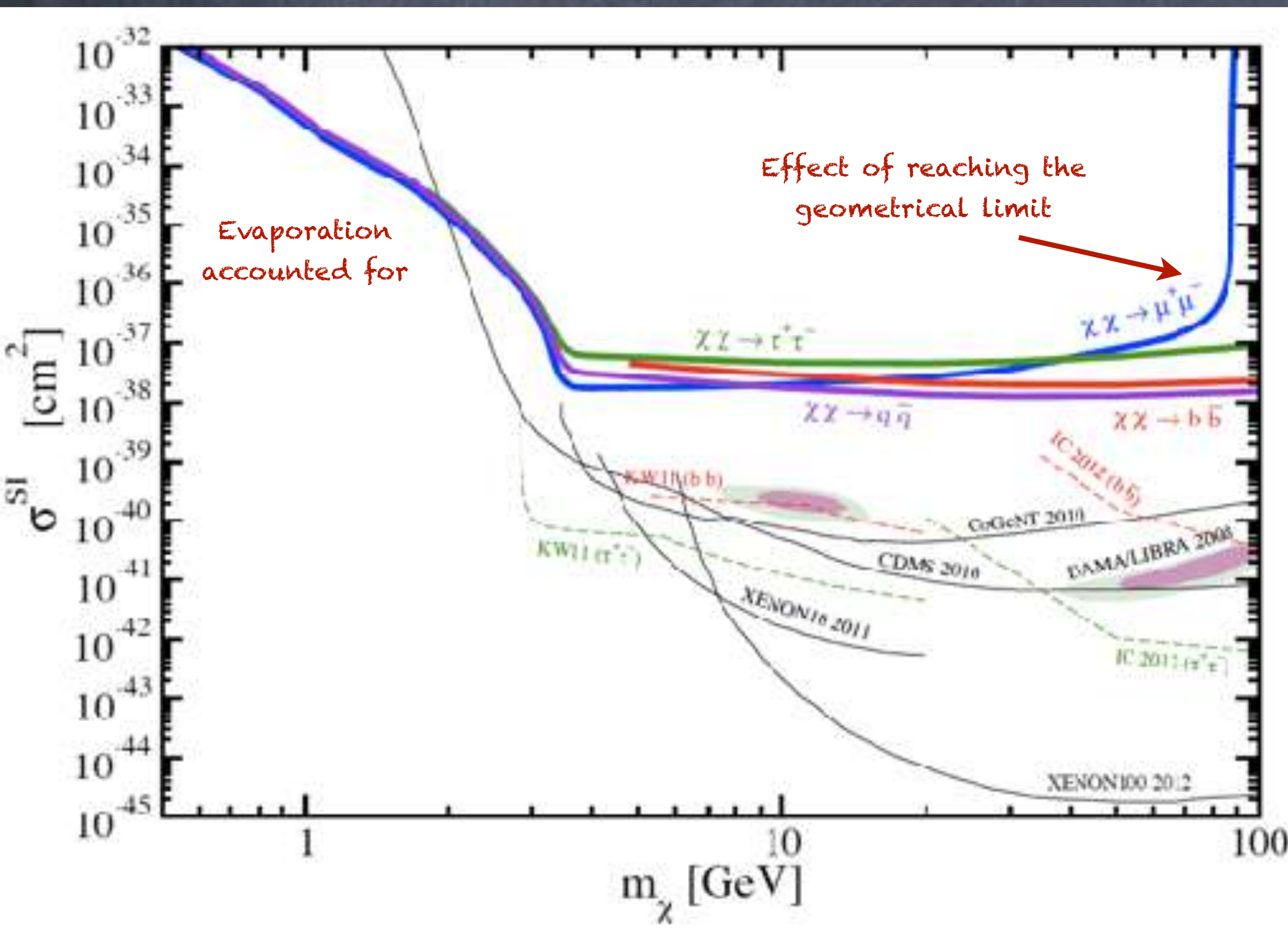
Low-energy neutrinos

Using SK data (DSNB analysis)

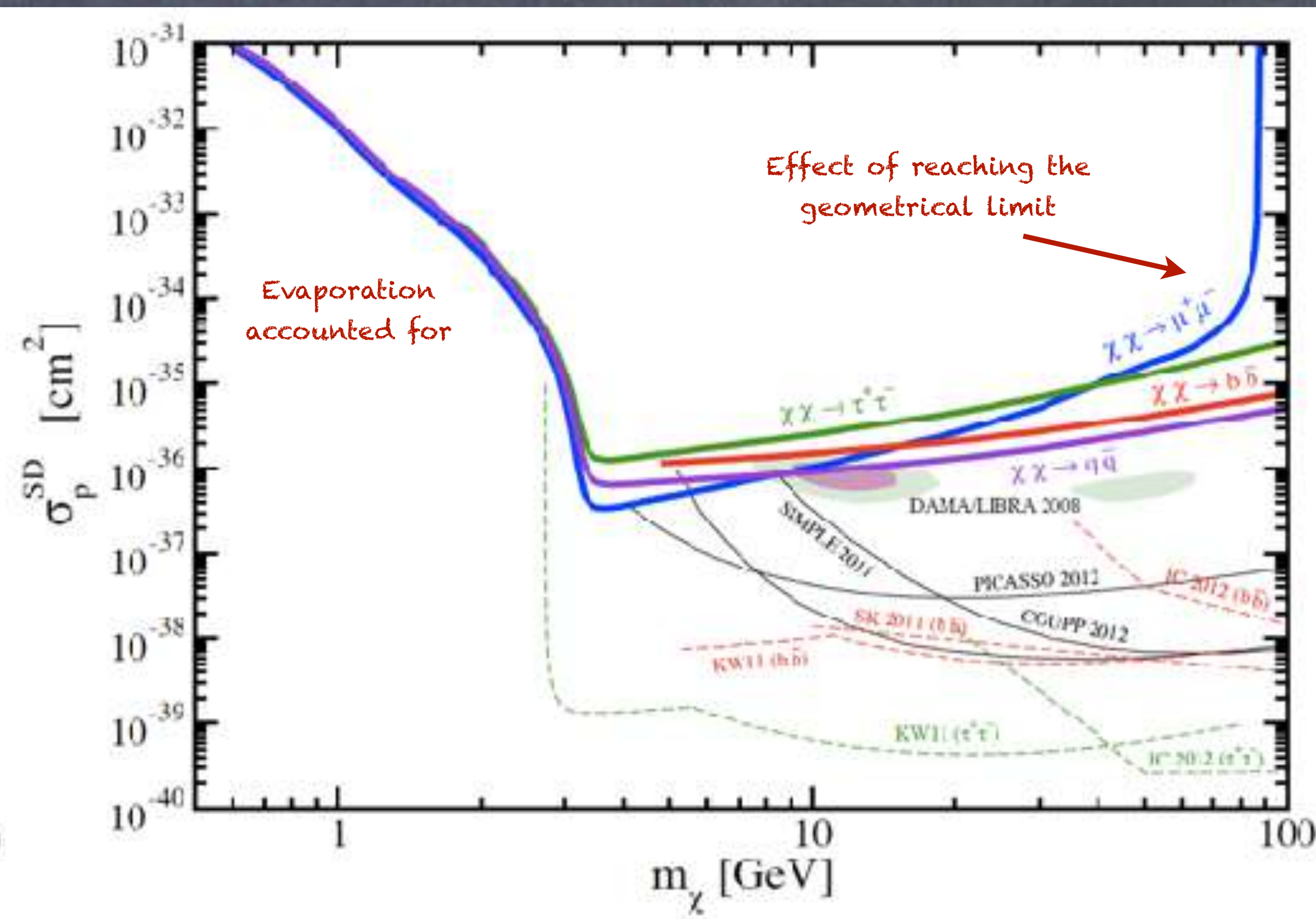


Unique limits (from DM in the Sun) on annihilations into light quarks or muons

spin-independent



spin-dependent



N. Bernal, J. Martín-Albo, SPR, JCAP 08:011, 2013

Low-energy neutrinos

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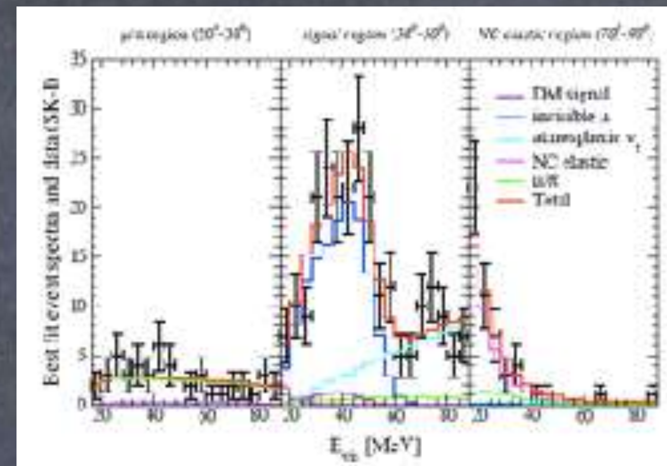

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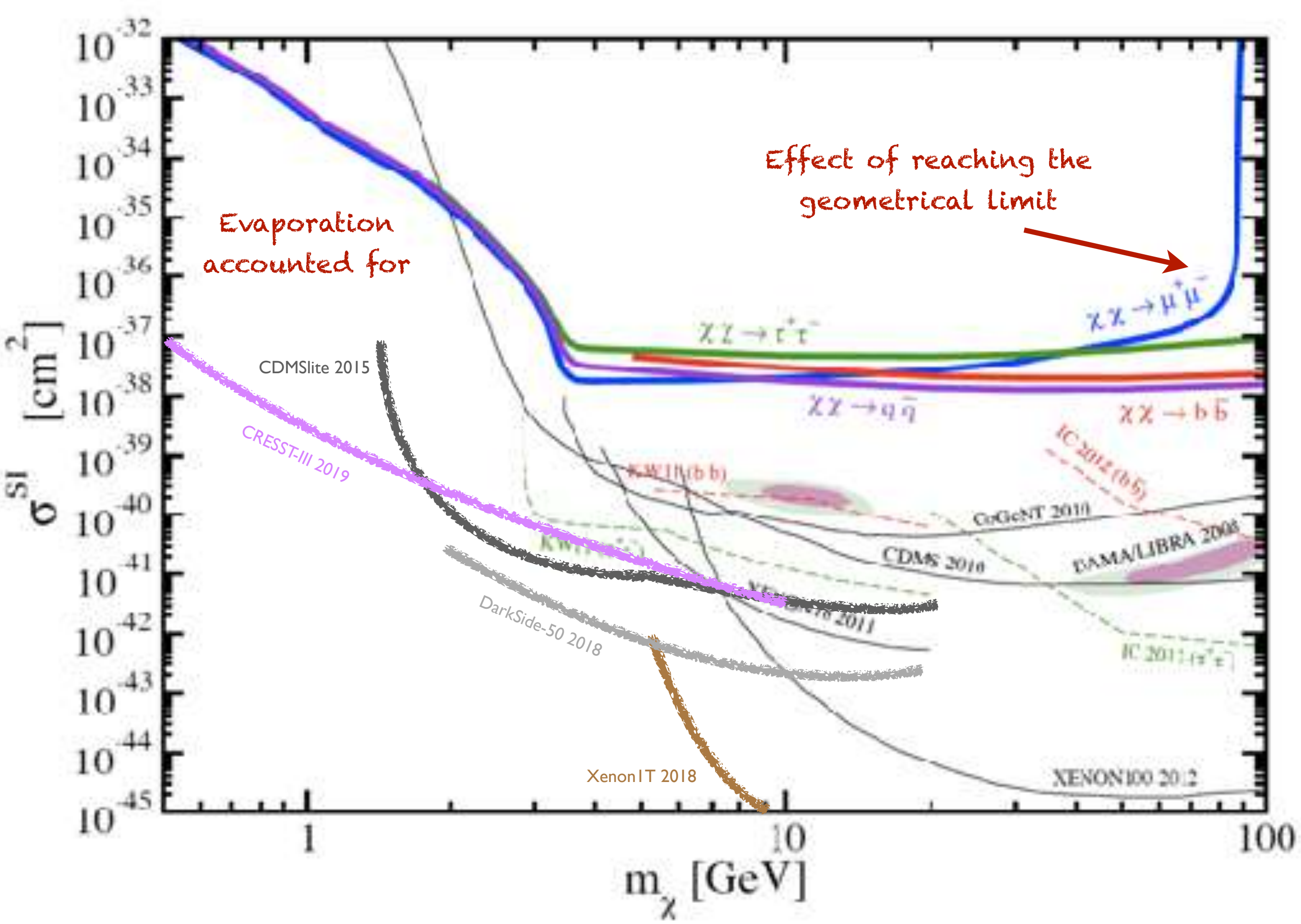

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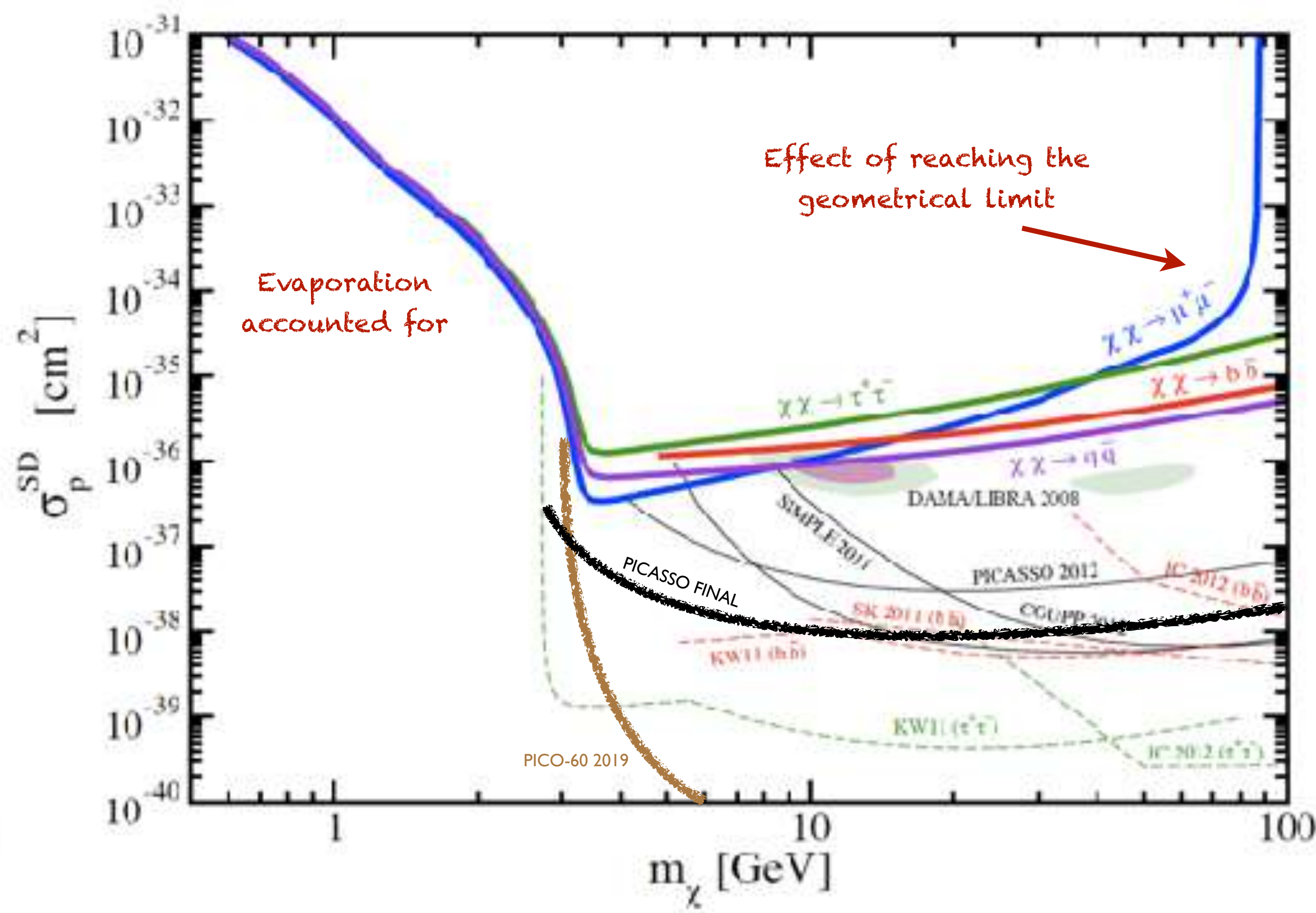


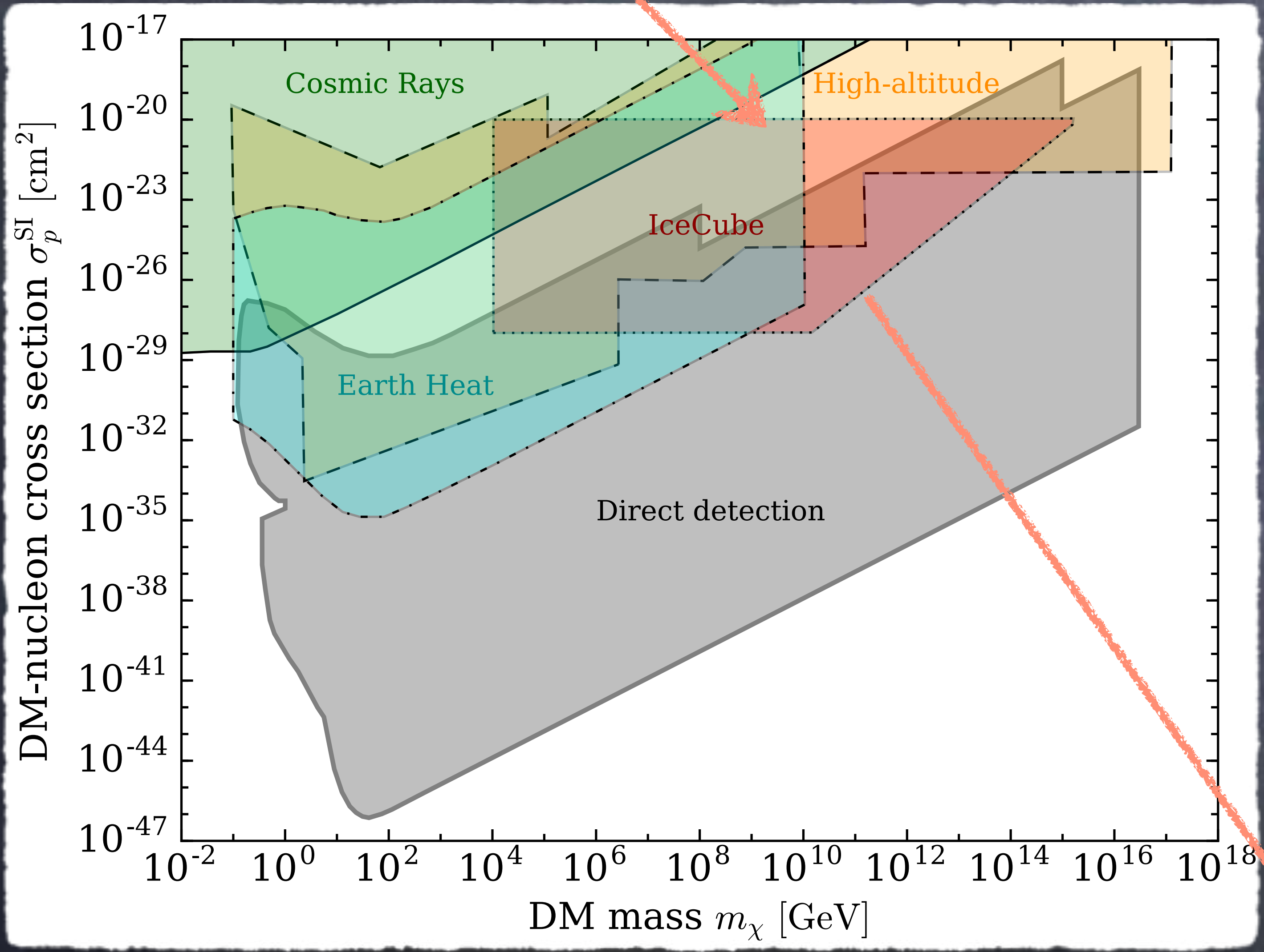
N. Bernal, J. Martín-Albo, SPR, JCAP 08:011, 2013

STRONGLY INTERACTING (HEAVY) DARK MATTER

I. F. M. Albuquerque, L. Hui and E. W. Kolb, Phys. Rev. D64:083504, 2001

104.3 days IC22

I. F. M. Albuquerque and C. Pérez de los Heros, Phys. Rev. D81:063510, 2010



B. J. Kavanagh, Phys. Rev. D97:123013, 2018

R. H. Cyburt et al., Phys. Rev. D65:123503, 2002
G. D. Mack, J. F. Beacom and G. Bertone, Phys. Rev. D76:043523, 2007
G. D. Mack and A. Manohar, J. Phys. G40:115202, 2013

Thick regime:
interaction probability very high

$$n\,\sigma\,R_\odot \gg 1$$

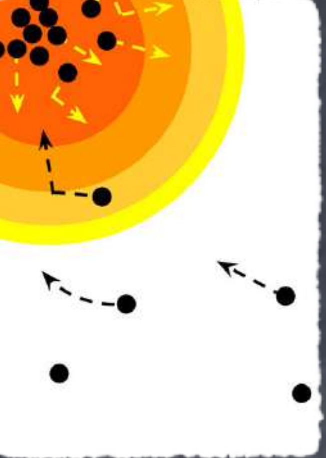
However... the typical momentum transfer (per collision) is ~ m_N/m_{DM}

Key quantity: $$q \equiv \frac{m_{DM}}{m_N\, n\, \sigma\, R_\odot}$$

q > 1: very frequent collisions, but result similar to the thin regime → capture rate scales with inverse of DM mass squared

q < 1: efficient energy transfer → capture rate scales with inverse of DM mass

For applicability of model independence:
M. C. Digman et al., Phys. Rev. D100:063013, 2019



Scattering off electrons

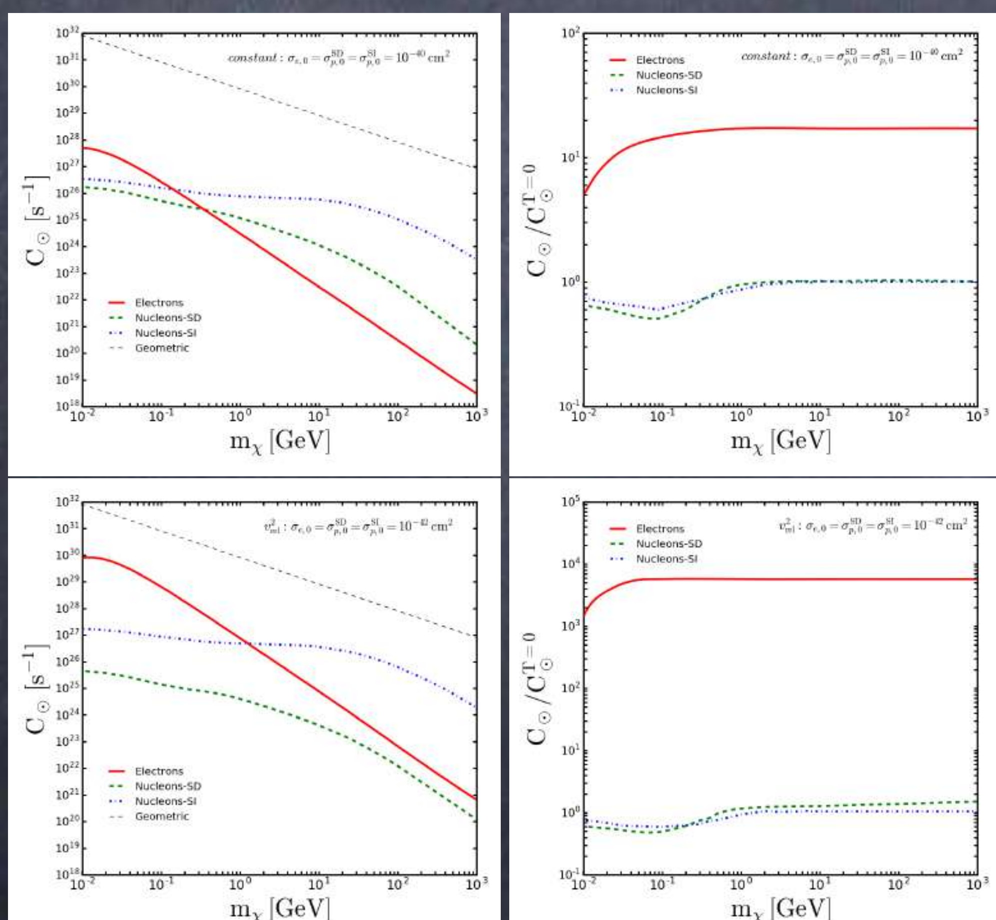
What about interactions with electrons?

J. Kopp et al, Phys. Rev. D80:083502, 2009

smaller mass of targets ⟶ thermal motion is crucial

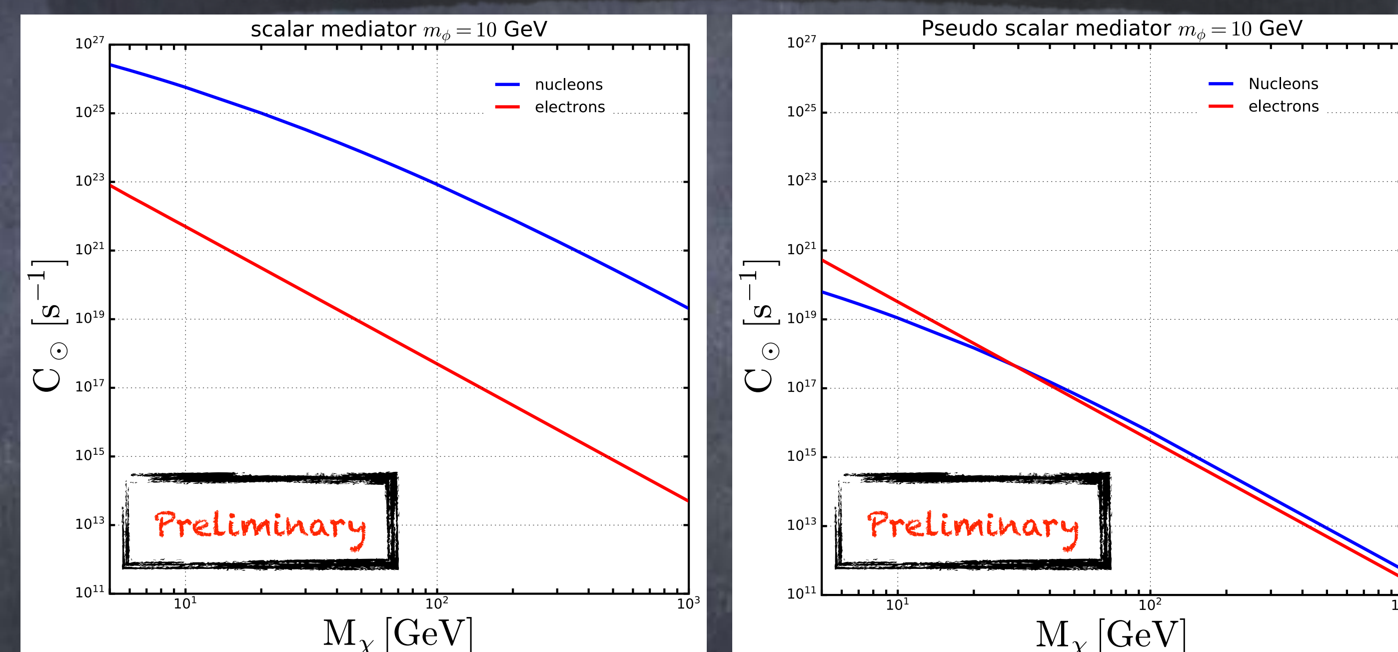
constant scattering cross section

velocity-dependent scattering cross section



R. Garani and SPR, JCAP 05:007, 2017

In leptophilic scenarios, DM-nucleon could occur at loop level. Yet, in some cases DM-electron could be more important than DM-nucleon



R. Garani and SPR, in preparation

using the 2-loop calculation of

R. Garani, P. Mastrolia, SPR and A. Primo, in preparation

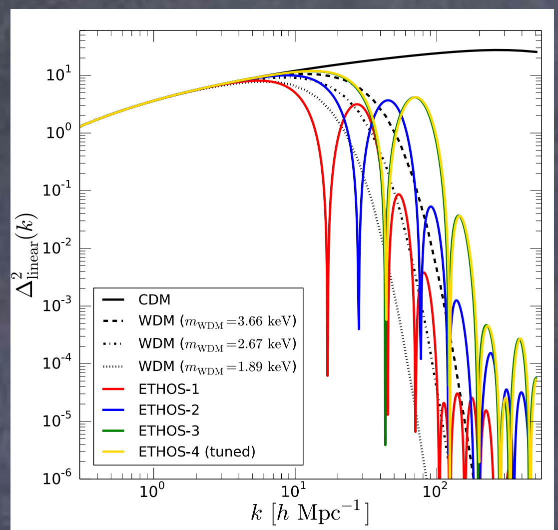
Strong bounds on the DM-electron scattering cross section

Self-interacting Dark Matter

D. N. Spergel and P. J. Steinhardt, Phys. Rev. Lett. 84:3760, 2000

Suppresses small-scale structure

C. Boehm, P. Fayet and R. Schaeffer, Phys. Lett. B518:8, 2001



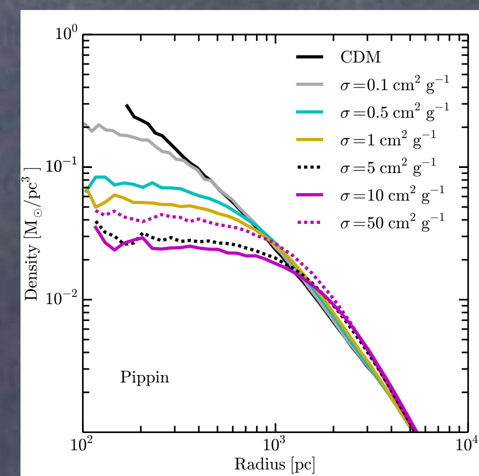
M. Vogelsberger et al., MNRAS 460:1399, 2016

Alleviates cusp-core, too-big-to-fail problems

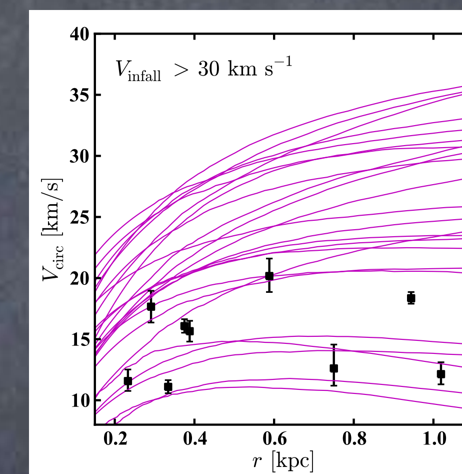
R. A. Flores and J. R. Primack, Astrophys. J. 427:L1, 1994

B. Moore, Nature 370:629, 1994

M. Boylan-Kolchin, J. S. Bullock and M. Kaplinghat, MNRAS 415:L40, 2011; MNRAS 422:1203, 2012



O. D. Elbert et al., MNRAS 453:29, 2015



M. Boylan-Kolchin, J. S. Bullock and M. Kaplinghat, MNRAS 422:1203, 2012

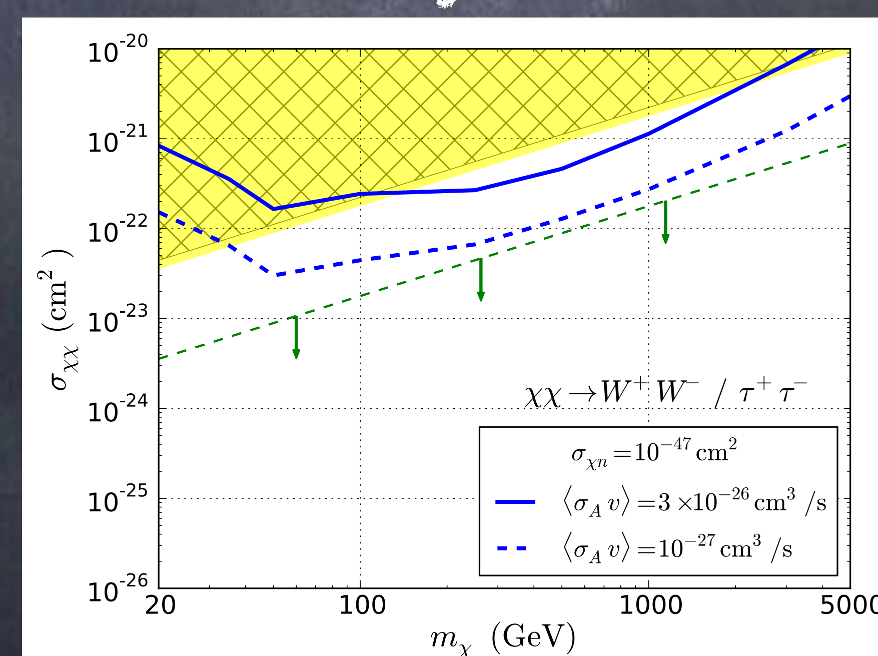
Capture in the Sun

A. R. Zentner, Phys. Rev. D80:063501, 2009

Self interactions enhance the capture rate

DM could reach equilibrium, even if it wouldnt without self-interactions

317 days IC79



I. F. M. Albuquerque, C. Pérez de los Heros and D. S. Robertson, JCAP 02:047, 2014

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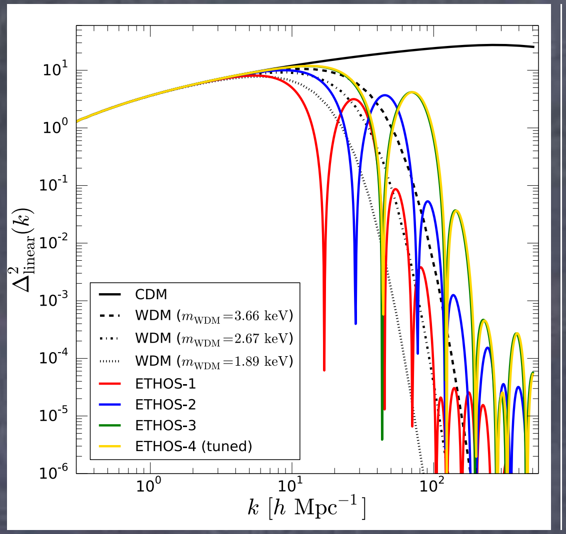

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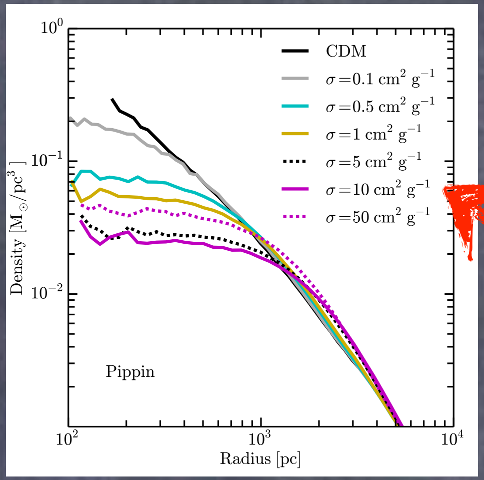

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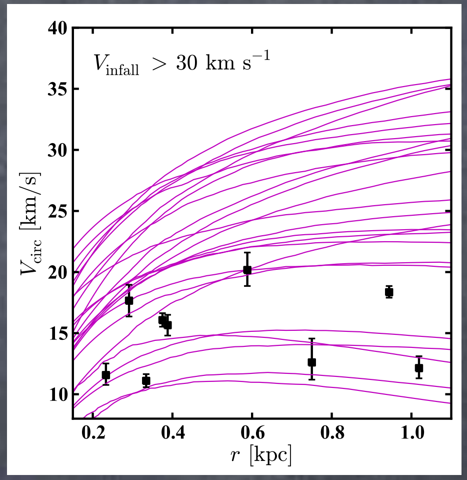

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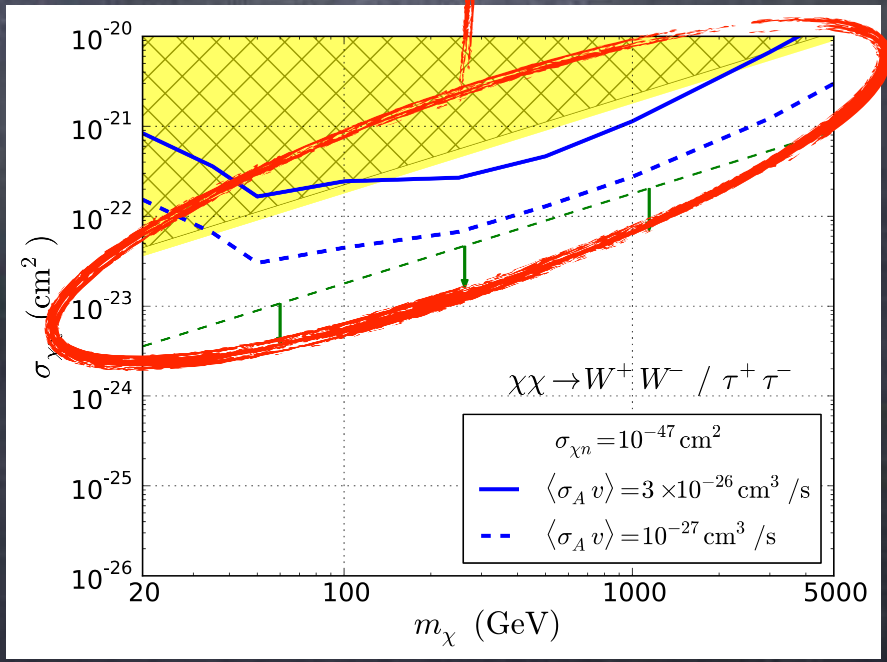
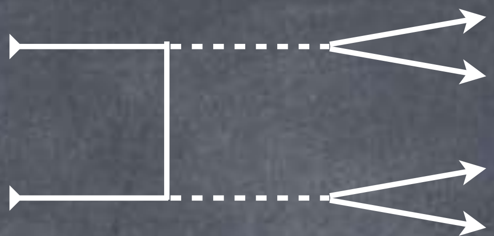


I. F. M. Albuquerque, C. Pérez de los Heros and D. S. Robertson, JCAP 02:047, 2014

Secluded Dark Matter

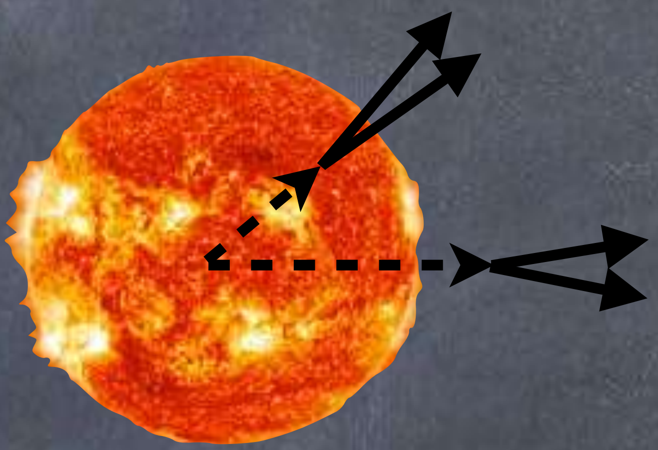
Metastable mediator (dark photon, dark scalar...)
coupled to DM, that subsequently could decay into SM particles



M. Pospelov, A. Ritz and M. B. Voloshin, Phys. Lett. B662:53, 2008

Neutrino signals:

Once captured, DM would annhilate into mediators, which would (partially) escape the Sun and decay into SM before reaching the Earth



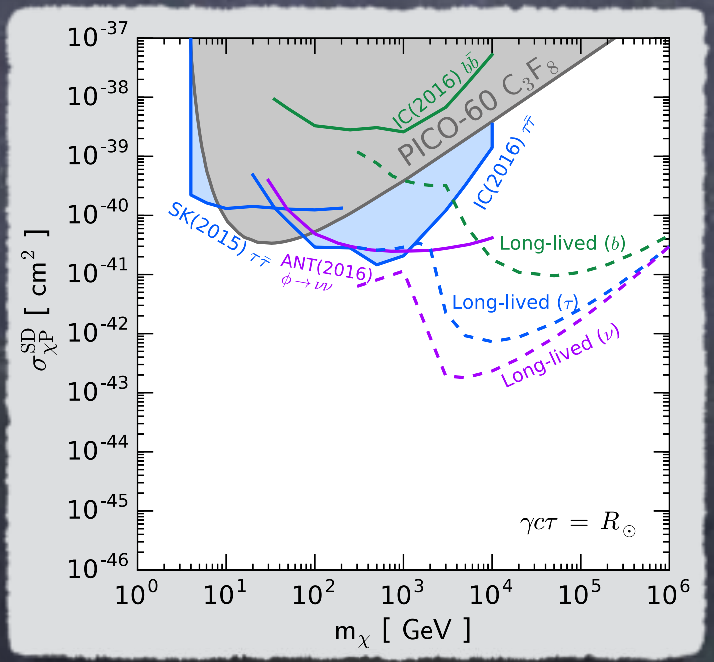
P. Meade et al., JHEP 06:029, 2010

P. Schuster, N. Toro and I. Yavin, Rhys. Rev. D81:016002, 2010

N. F. Bell and K. Petraki, JCAP 04:003, 2011

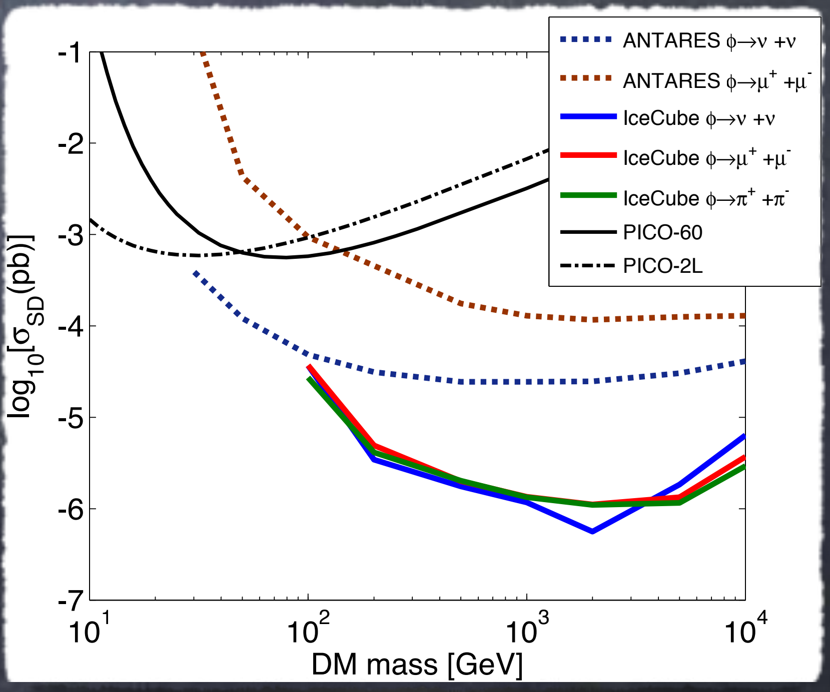
Higher energy neutrinos: mainly from pions/kaons if decays occur outside the Sun

Less absorption: more important for higher energy neutrinos and thus, for larger DM masses



R. K. Leane, K. C. Y. Ng, J. F. Beacom, Phys. Rev. D95:123016, 2017

136 days IC79



M. Ardid et al., JCAP 04:010, 2017

S. Adrián-Martínez et al. [ANTARES Coll.], JCAP 05:016, 2017

C. Tönnis [IceCube Collaboration], PoS(ICRC2019)548, 2019

See also: D. S. Robertson and I. F. M. Albuquerque, JCAP 02:056, 2018

DM Annihilations/Decays in Halos: where to look?

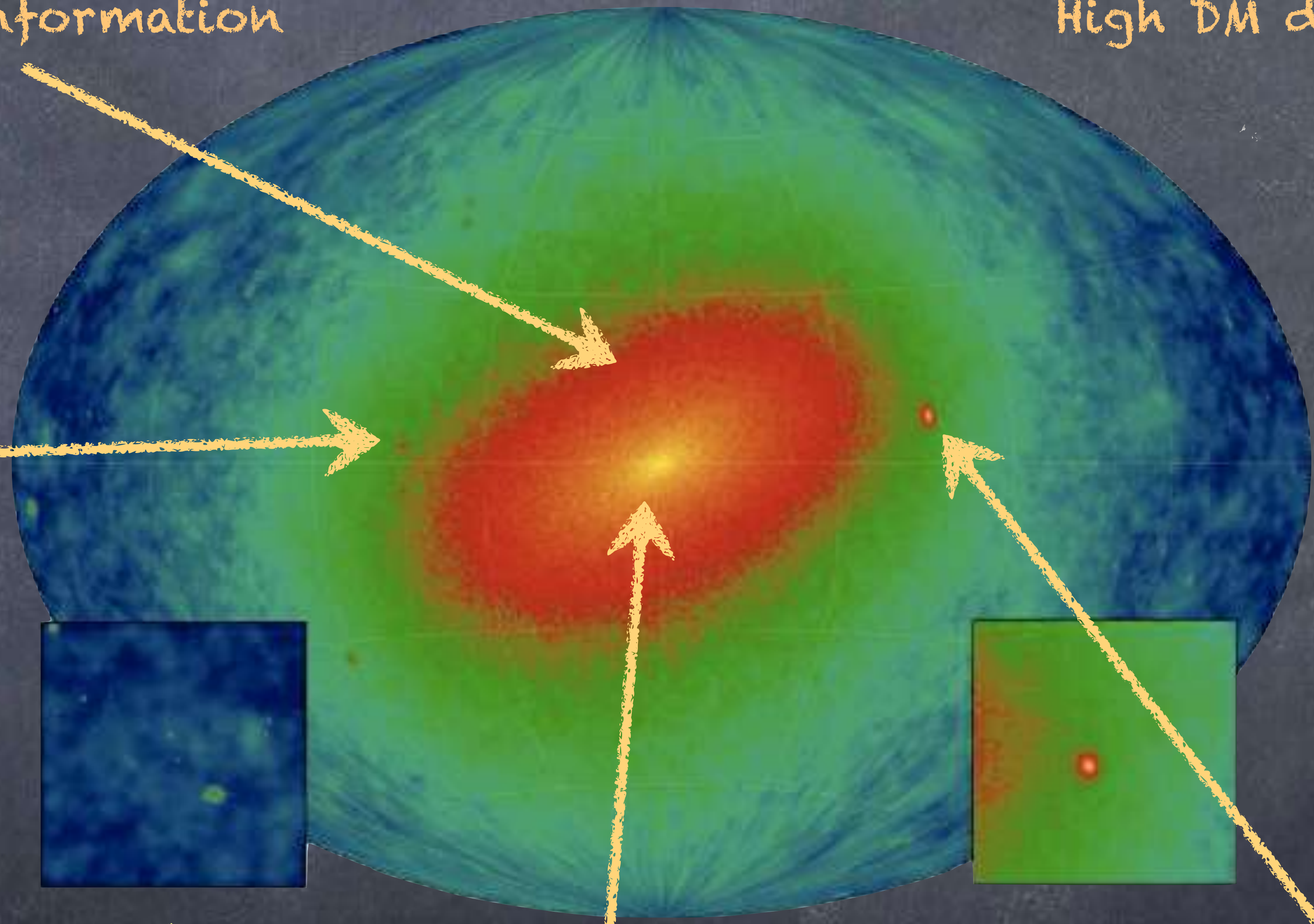


Figure from J. Diemand, M. Kuhlen and P. Madau, Astrophys. J. 657:262, 2007

Two components

Averaged oscillations → $\mathcal{P}$

$$\frac{d\Phi_{\nu_\beta}}{dE_\nu} = \sum_\alpha \mathcal{P}_{\beta\alpha} \left[\frac{d\Phi_{G,\nu_\alpha}}{dE_\nu} + \frac{d\Phi_{EG,\nu_\alpha}}{dE_\nu} \right]$$

(Galactic) (Extra-galactic)

Decays

Particle physics / Astrophysics

$$\frac{d\Phi_{G,\nu_\alpha}}{dE_\nu} = \frac{1}{4\pi\, m_{DM} \tau_{DM}} \frac{dN_{\nu_\alpha}}{dE_\nu} \int_{los} \rho\, ds$$

DM mass; DM lifetime; neutrino flux at production; DM galactic density

$$\frac{d\Phi_{EG,\nu_\alpha}}{dE_\nu} = \frac{\Omega_{DM}\rho_c}{4\pi\, m_{DM}\tau_{DM}} \int \frac{dz}{H(z)} \frac{dN_{\nu_\alpha}[(1+z)E_\nu]}{dE_\nu}$$

DM density; Hubble function; energy redshift

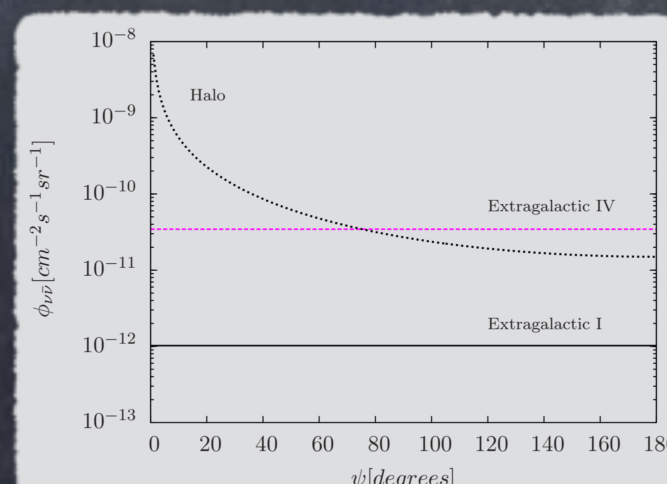
Annihilations

$$\frac{d\Phi_{G,\nu_\alpha}}{dE_\nu} = \frac{1}{4\pi} \frac{\langle \sigma v \rangle}{2\, m_{DM}^2} \frac{dN_{\nu_\alpha}}{dE_\nu} \int_{los} \rho^2\, ds$$

annihilation cross section

$$\frac{d\Phi_{EG,\nu_\alpha}}{dE_\nu} = \frac{(\Omega_{DM}\rho_c)^2}{4\pi} \frac{\langle \sigma v \rangle}{2\, m_{DM}^2} \int \frac{dz}{H(z)} \xi^2(z) \frac{dN_{\nu_\alpha}[(1+z)E_\nu]}{dE_\nu}$$

halo enhancement



Galactic contribution very likely to be larger

A. Moliné, A. Ibarra and SPR, JCAP 06:005, 2015

Annihilations in the Galaxy and others

SK: (5325.8 + 5629.1) days

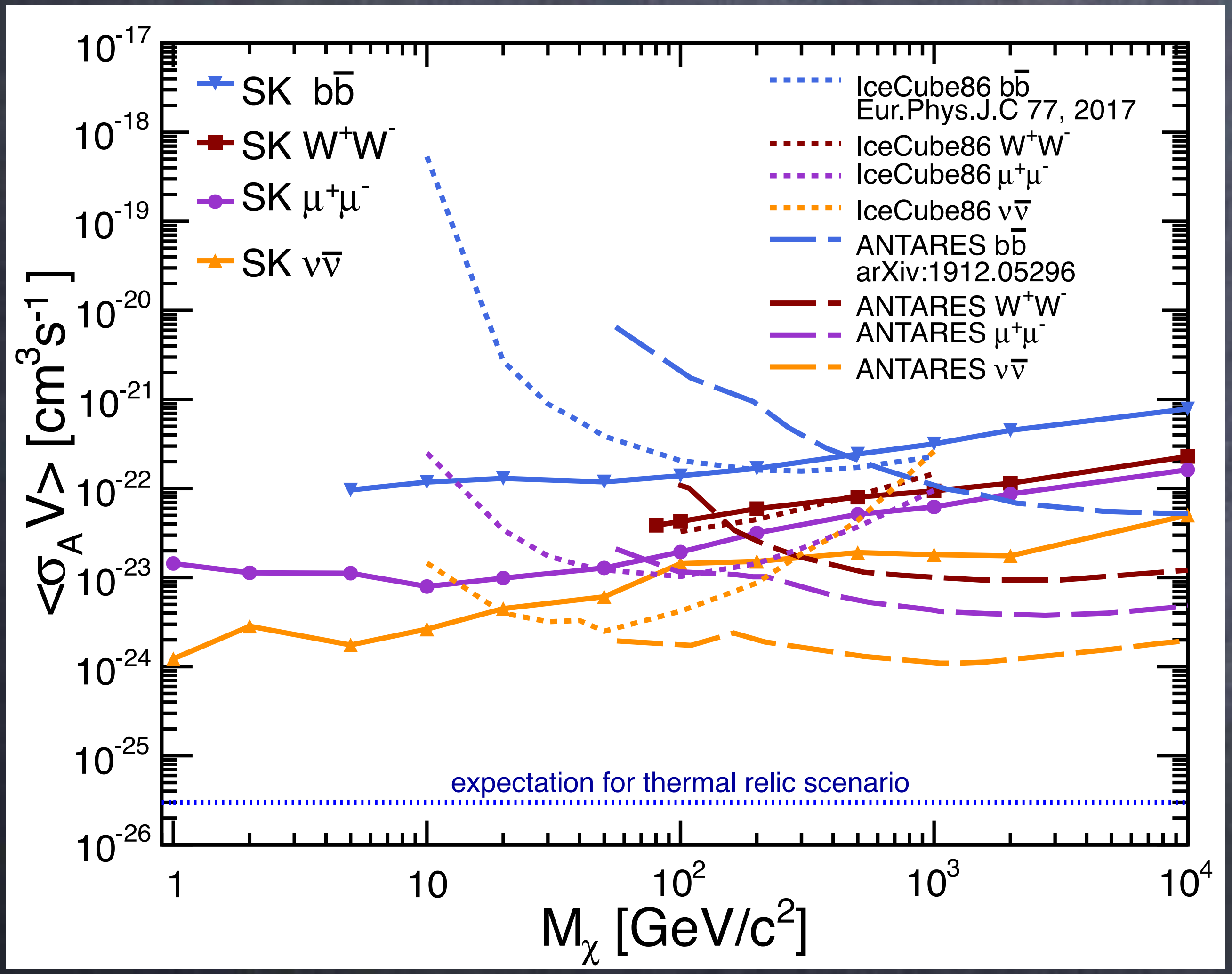
K. Abe et al. [Super-Kamiokande Collaboration], Phys. Rev. D102:072002, 2020

IceCube: 1007 days

M. G. Aartsen et al. [IceCube Collaboration], Eur. Phys. J. C77:627, 2017

ANTARES: 3170 days

A. Albert et al. [ANTARES Collaboration], Phys. Lett. B805:135439, 2020



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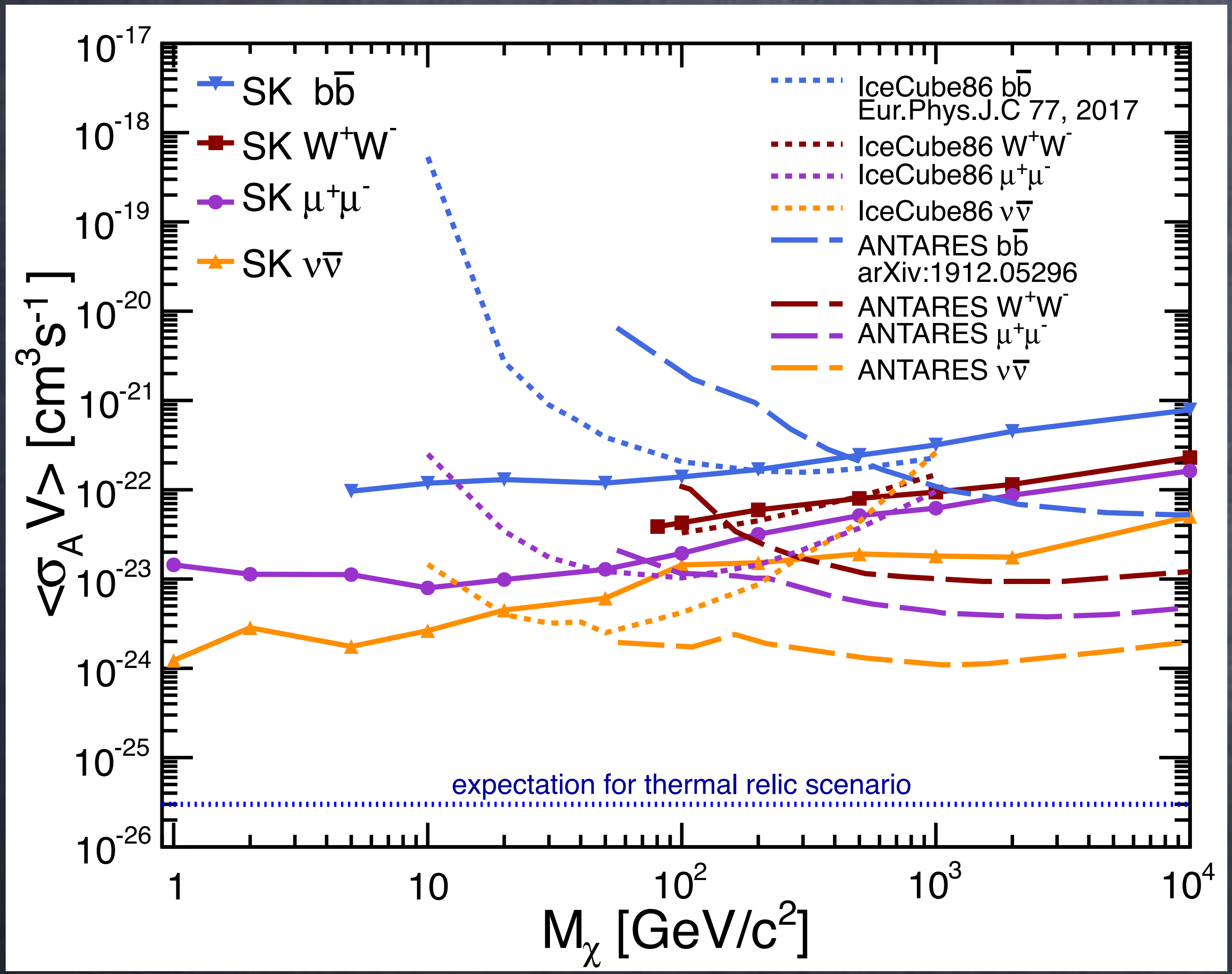
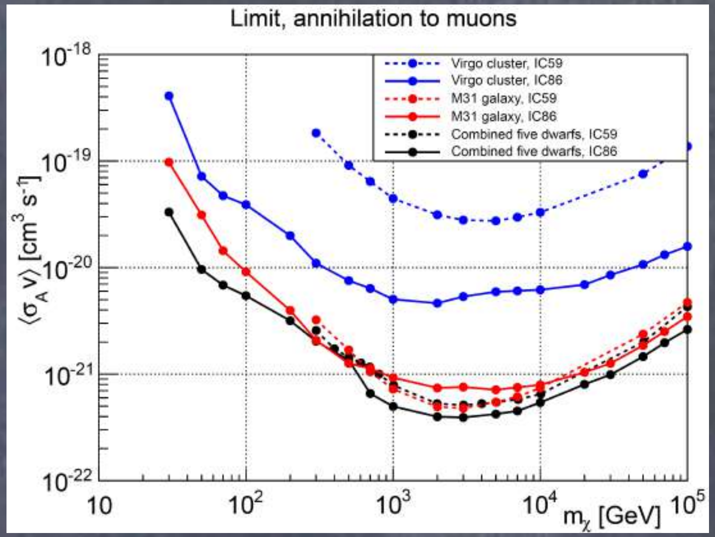


K. Abe et al. [Super-Kamiokande Collaboration], Phys. Rev. D102:072002, 2020

982.7 days IC86: Dwarfs, M31, Virgo



M. M. de With, Ph. D. thesis, 2018

M. G. Aartsen et al. [IceCube Collaboration], Phys. Rev. D88:122001, 2013

Annihilations in the Galaxy and others

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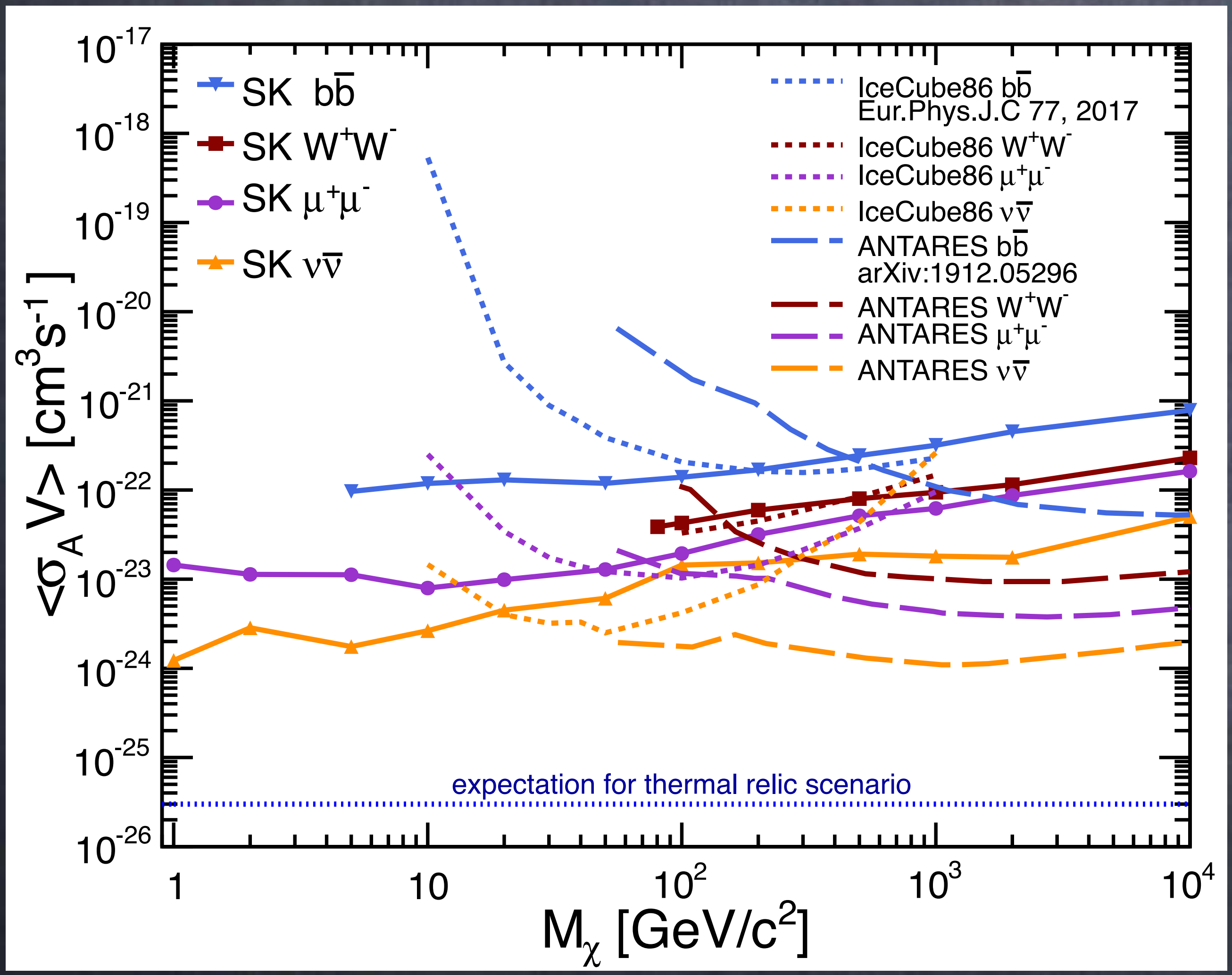
K. Abe et al. [Super-Kamiokande Collaboration], Phys. Rev. D102:072002, 2020

M. G. Aartsen et al. [IceCube Collaboration], Eur. Phys. J. C77:627, 2017

A. Albert et al. [ANTARES Collaboration], Phys. Lett. B805:135439, 2020



K. Abe et al. [Super-Kamiokande Collaboration], Phys. Rev. D102:072002, 2020

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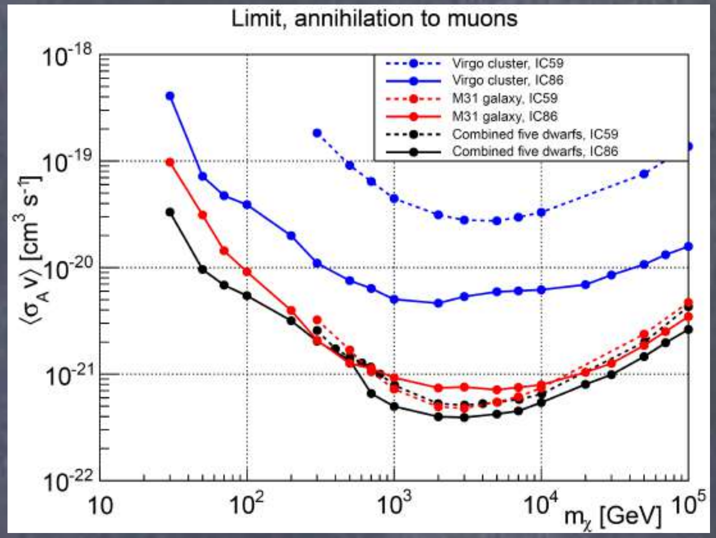
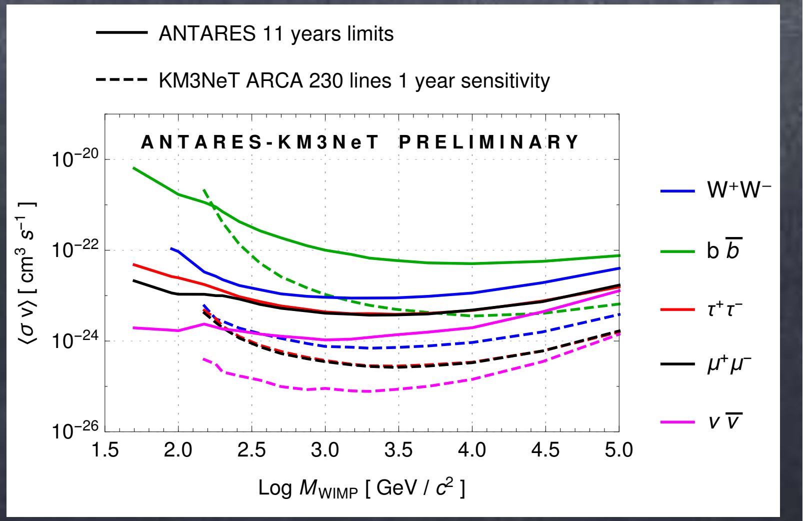


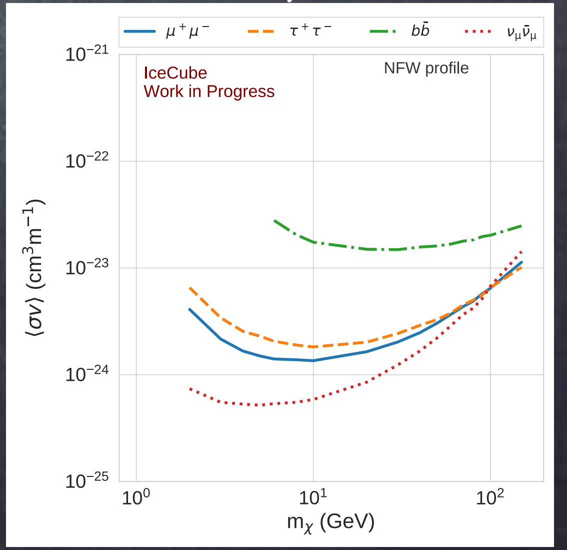
M. M. de With, Ph. D. thesis, 2018

M. G. Aartsen et al. [IceCube Collaboration], Phys. Rev. D88:122001, 2013

Sensitivities for ARCA and IceCube upgrade



S. R. Gozzini and J. D. Zornoza [KM3NeT Collaboration], PoS(ICRC2019)552, 2020



S. Baur [IceCube Collaboration], PoS(ICRC2019)506, 2020

Decays in the Galaxy and others

For E < 10 TeV, there are (almost) no limits on the neutrino flux from DM decays... by the experimental collaborations

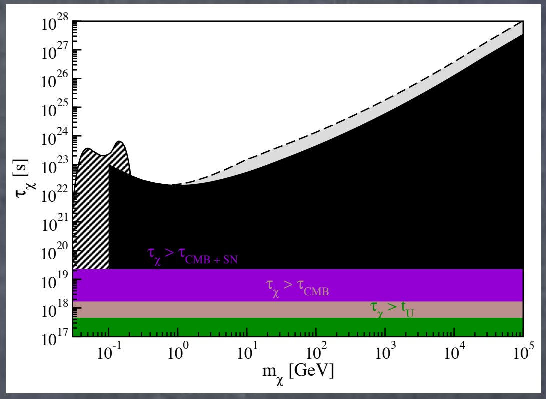
WUMPs

K. S. Babu, D. Eichler and R. N. Mohapatra, Phys. Lett. B226 (1989) 34

First bounds considering the galactic flux

P. Gondolo, Phys. Lett. B295:104, 1992

SPR, Phys. Lett. B665:50, 2008



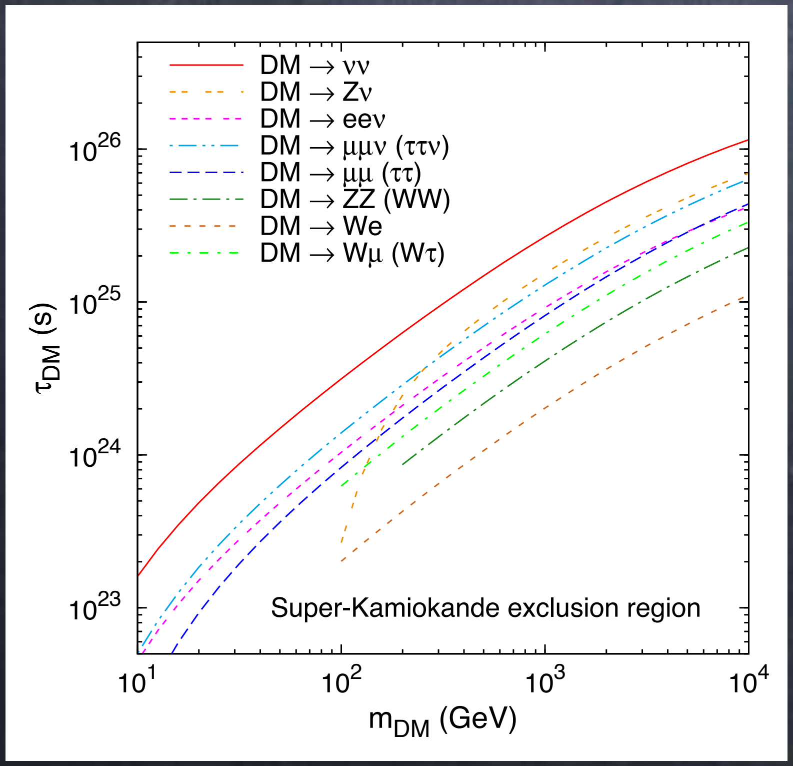
First bounds on the diffuse neutrino flux

V. Berezinsky, LNGS 91/02 preprint, 1991

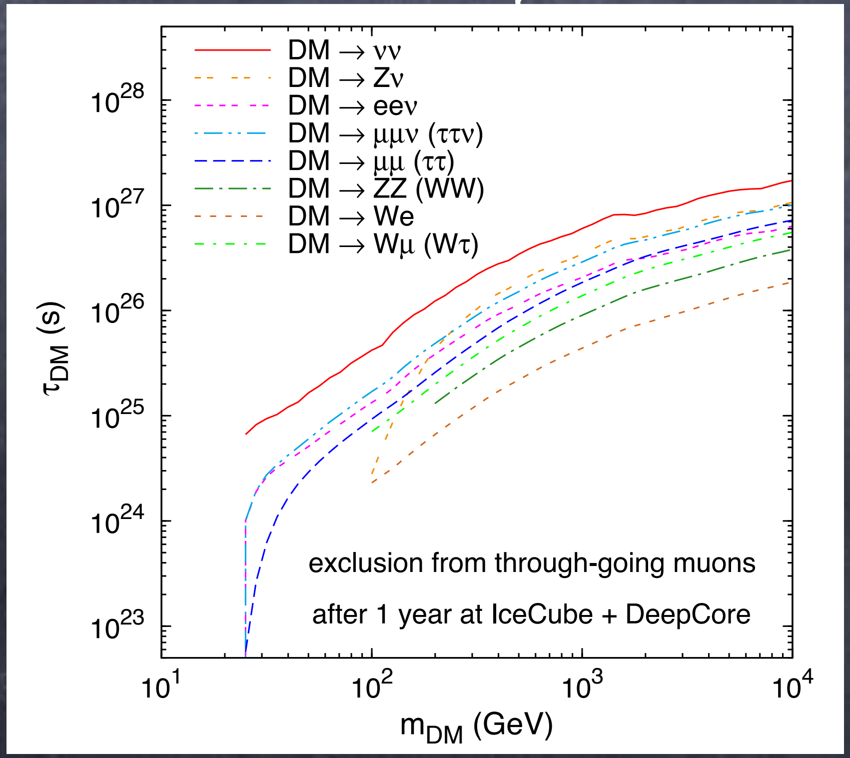
J. Ellis et al., Nucl. Phys. B373:399, 1992

P. Gondolo, G. Gelmini and S. Sarkar, Nucl. Phys. B392:111, 1992

Super-Kamiokande data

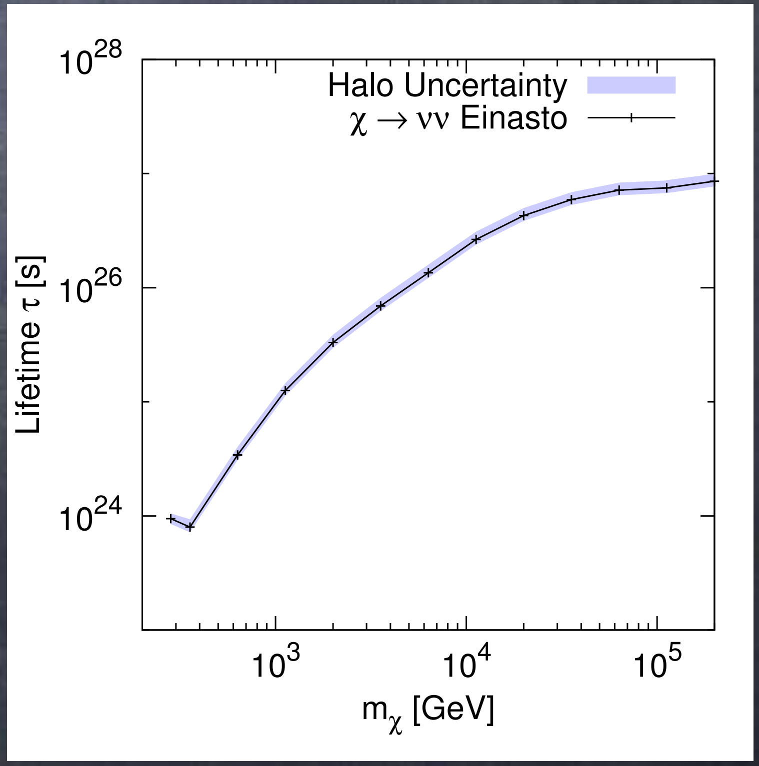


Prospects with 1 year IceCube+DeepCore



L. Covi et al., JCAP 04:017, 2010

276 days IC22



R. Abbasi et al. [IceCube Collaboration], Phys. Rev. D84:022004, 2011

Heavy Dark Matter

Can the highest energy IceCube neutrinos be explained by heavy dark matter annihilations/decays?

B. Feldstein et al., Phys, Rev. D88:015004, 2013

A. Esmaili and P. D. Serpico, JCAP 11:054, 2013

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annihilations A. Esmaili and P. D. Serpico, JCAP 11:054, 2013

$$\text{Rate} \sim V\, N_N\, \sigma_N\, L_{MW} \left(\frac{\rho_{DM}}{m_{DM}}\right)^2 \langle\sigma v\rangle \sim 10/\text{year} \rightarrow \langle\sigma v\rangle \sim 10^{-21}\text{cm}^3/\text{s} \left(\frac{m_{DM}}{\text{PeV}}\right)^2$$

Unitarity limit → non-thermal or composite DM or non-standard Universe evolution

K. Griest and M. Kamionkowski, Phys. Rev. Lett. 64:615, 1990,

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$$\text{Rate} \sim V N_N \sigma_N L_{MW} \frac{\rho_{DM}}{m_{DM}} \frac{1}{\tau_{DM}} \sim 10/\text{year} \rightarrow \left(\frac{\tau_{DM}}{10^{28}\,\text{s}}\right)\left(\frac{m_{DM}}{1\ \text{PeV}}\right) \sim 1$$

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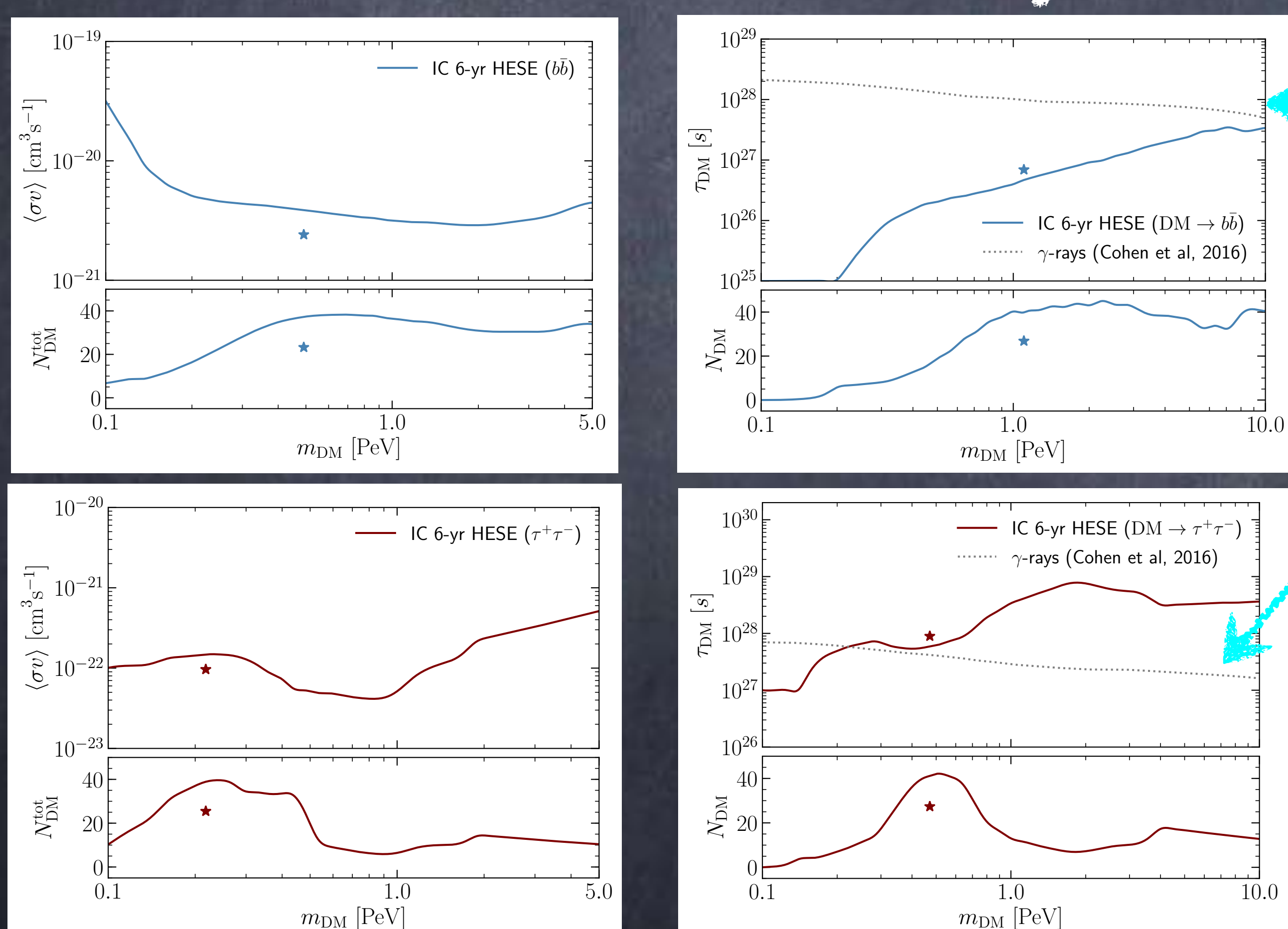
6-yr HESE: Astro + DM

annihilations decays



Neutrino limits are better than gamma-ray ones for relatively hard channels

A. Bhattacharya, A. Esmaili, SPR and I. Sarcevic, JCAP 05:051, 2019

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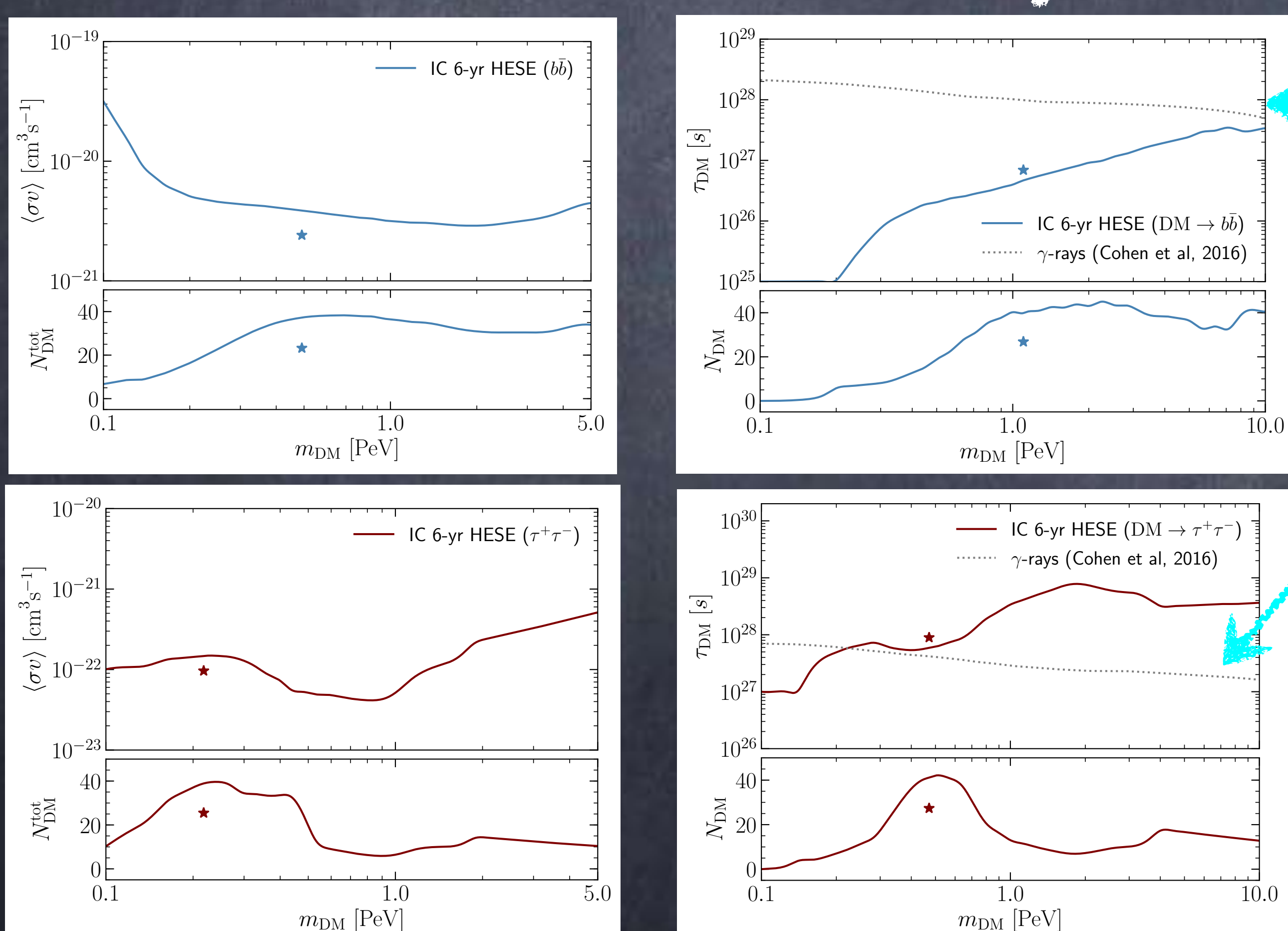

A. Bhattacharya, A. Esmaili, SPR and I. Sarcevic, JCAP 05:051, 2019

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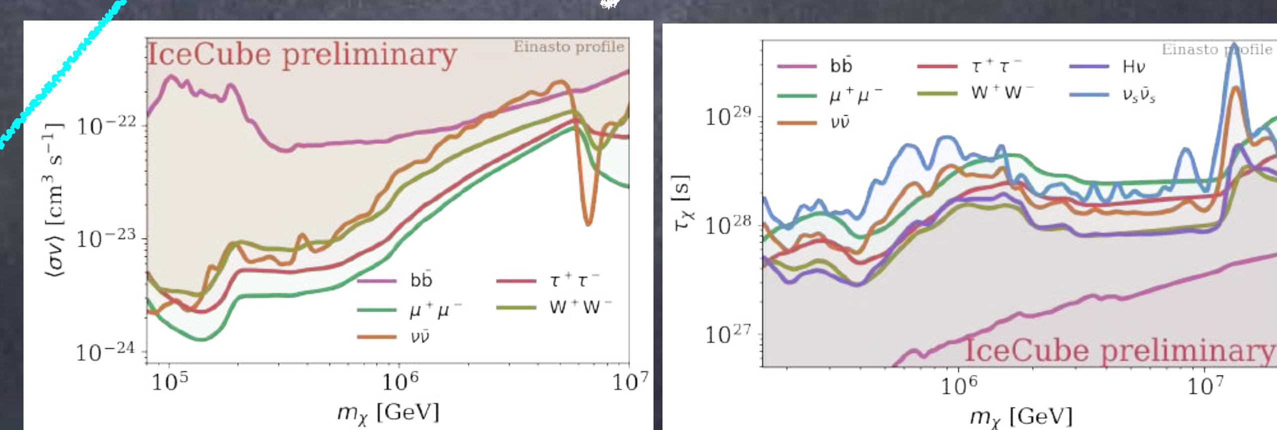
7.5-yr HESE



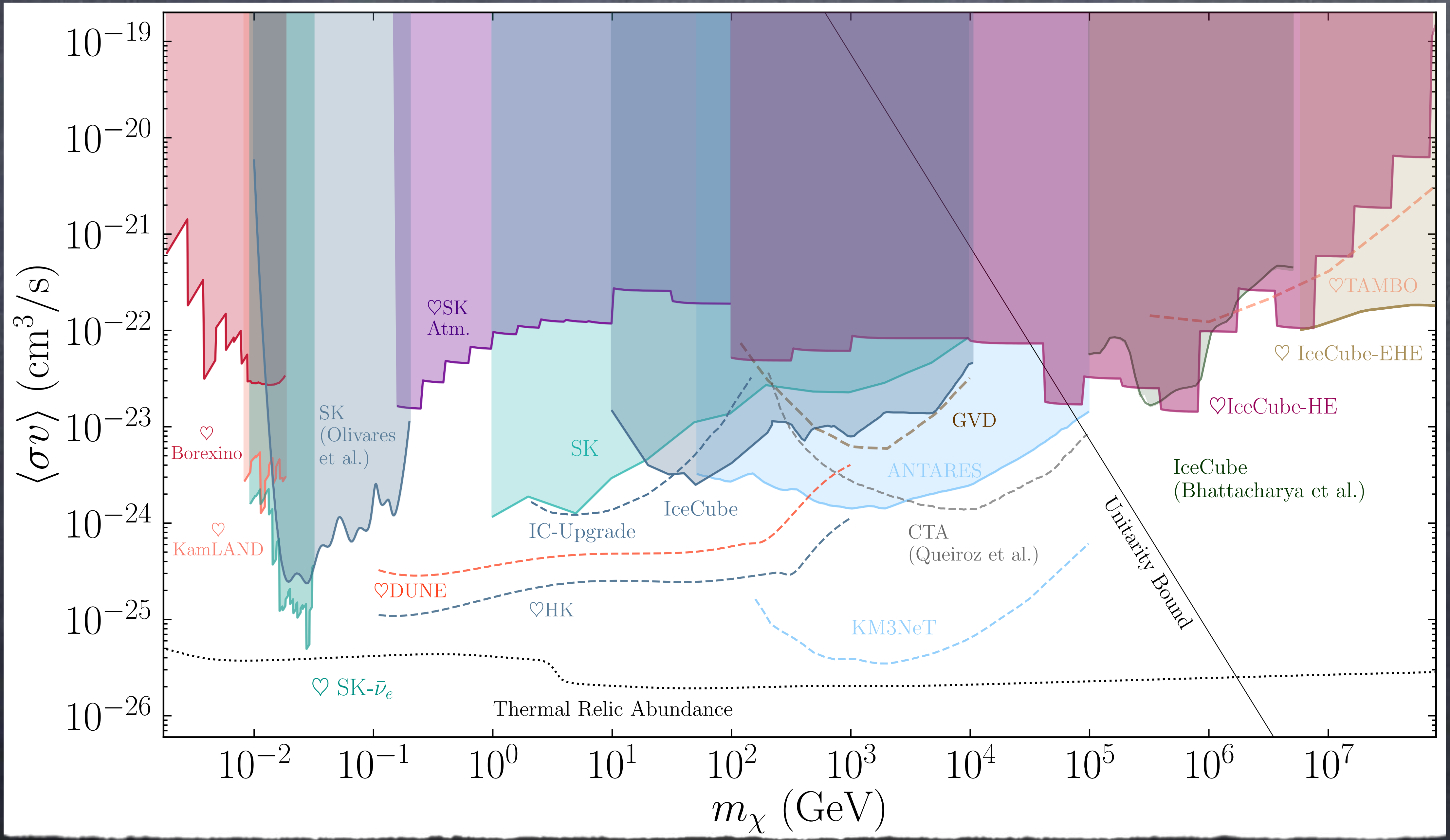
C. A. Argüelles and H. Dujmovic [IceCube Collaboration], PoS(ICRC2019)839, 2020

See also: M. G. Aartsen et al. [IceCube Collaboration], Eur. Phys. J. C78:831, 2018

Annihilations/Decays into monochromatic neutrinos

Given that neutrinos are the least detectable particles in the SM, considering DM annihilations/decays into a pair of neutrinos is the most conservative scenario

J. F. Beacom, N. F. Bell and G. D. Mack, Phys. Rev. Lett. 99:231301, 2007
H. Yüksel et al., Phys. Rev. D.76:123506, 2007
SPR and S. Pascoli, Phys. Rev. D77:025025, 2008
SPR, Phys. Lett. B665:50, 2008



C. A. Argüelles et al., arXiv:1912.09486

Prospects for INO

A. Khatun, R. Laha and S. K. Agarwalla, JHEP 06:057, 2017
D. Tiwari, Ph. D. thesis, 2018

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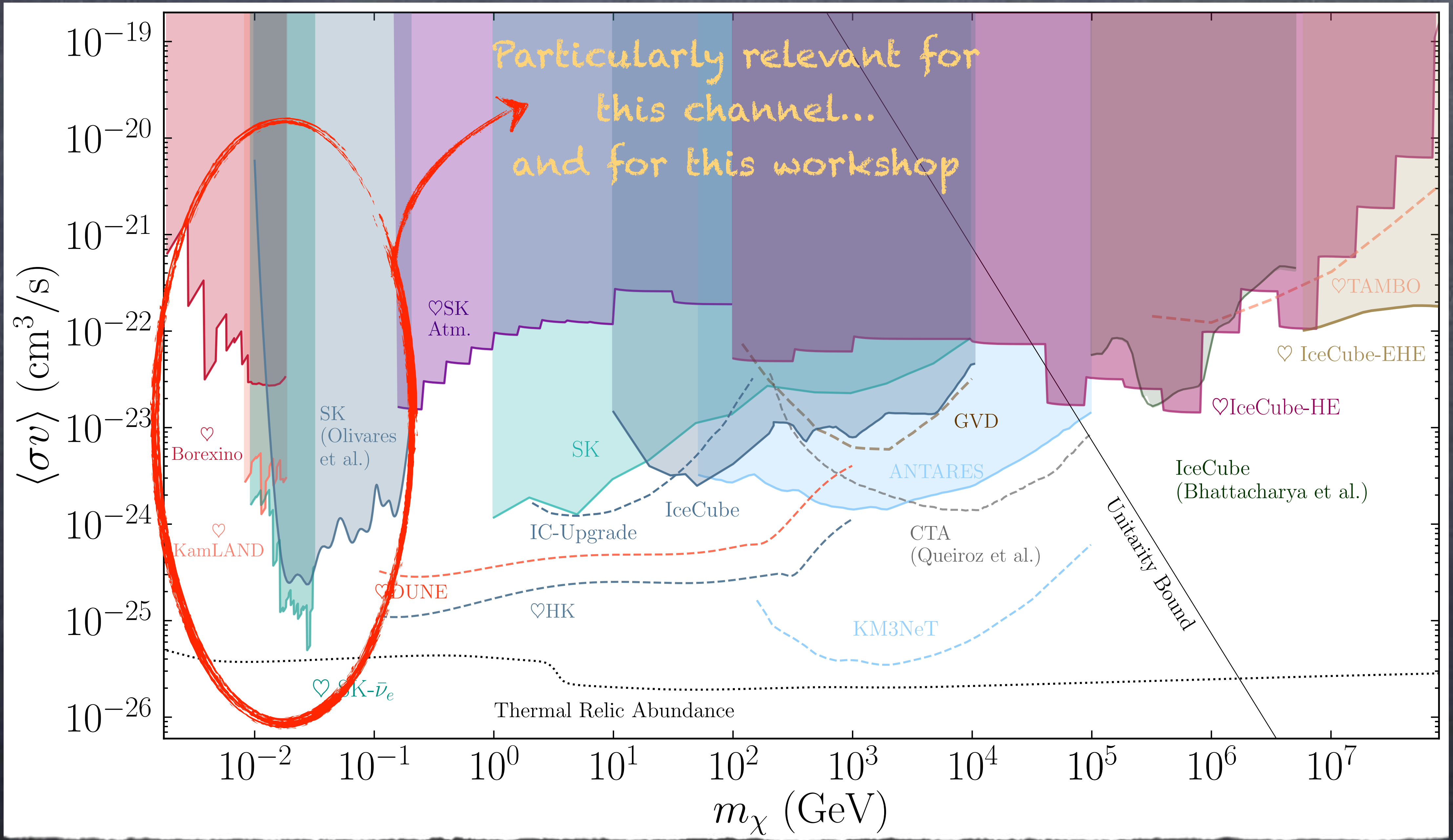

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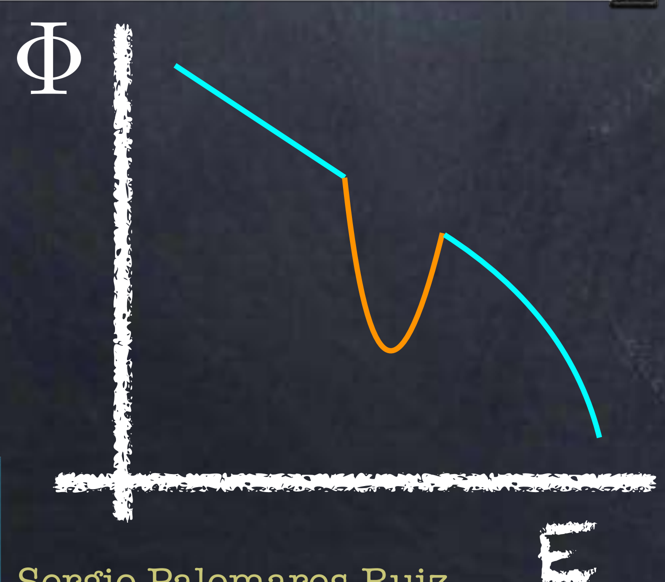
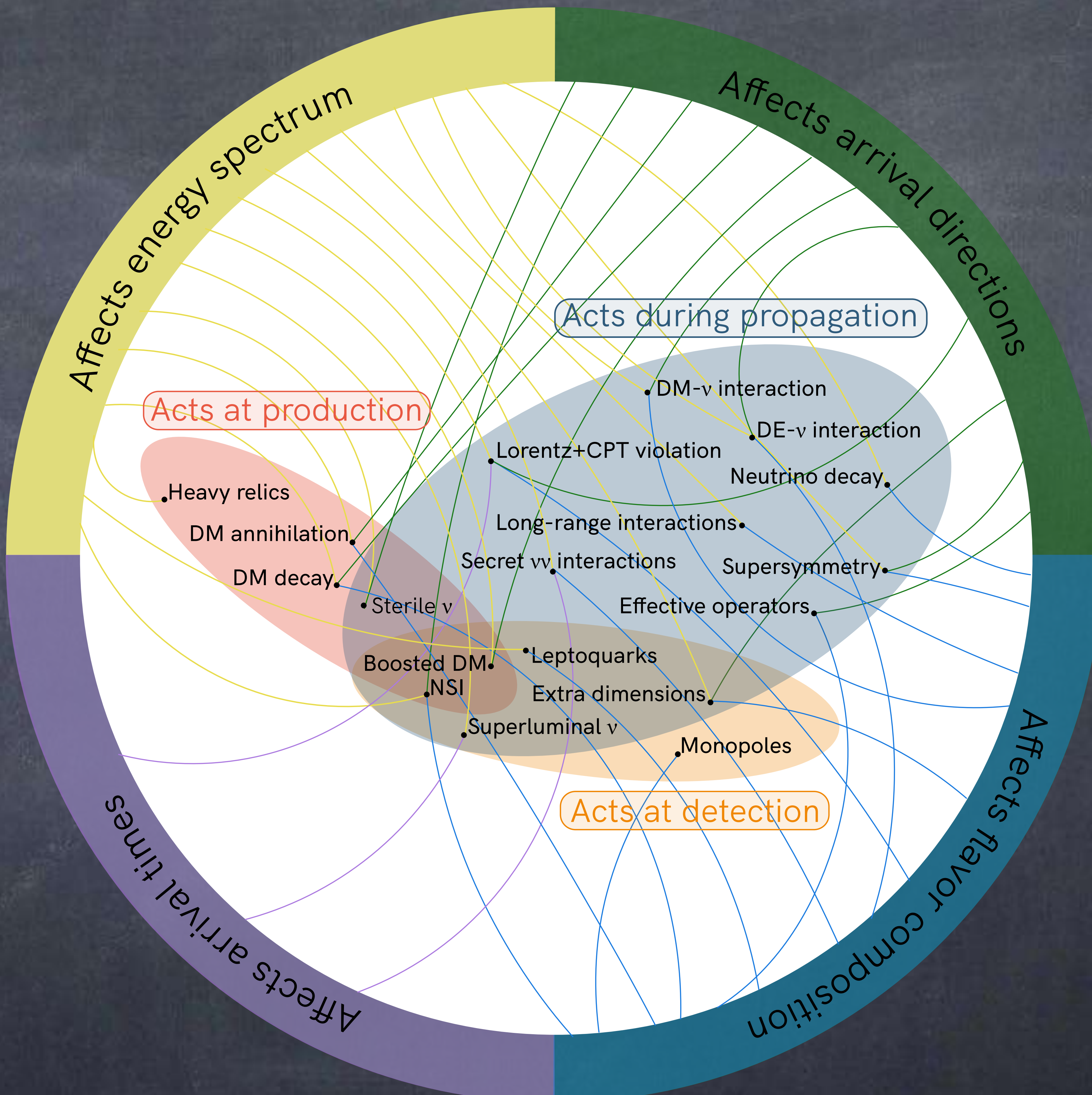
Features on known spectra





C. A. Argüelles et al., PoS(ICRC2019)849, 2020

Neutrino-Dark Matter Interactions

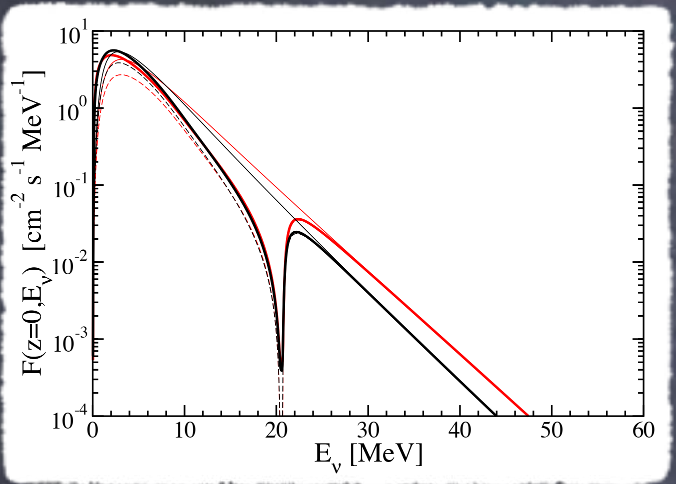
Absorptive effects

$$\frac{d\phi_\nu(E_\nu,x)}{dx} \approx -n(x)\,\sigma(E_\nu)\,\phi_\nu(E_\nu,x)$$

Dips on the SN neutrino spectra

Y. Farzan and SPR, JCAP 06:014, 2014

T. Franarin, M. Fairbairn and J. H. Davis, arXiv:1806.05015

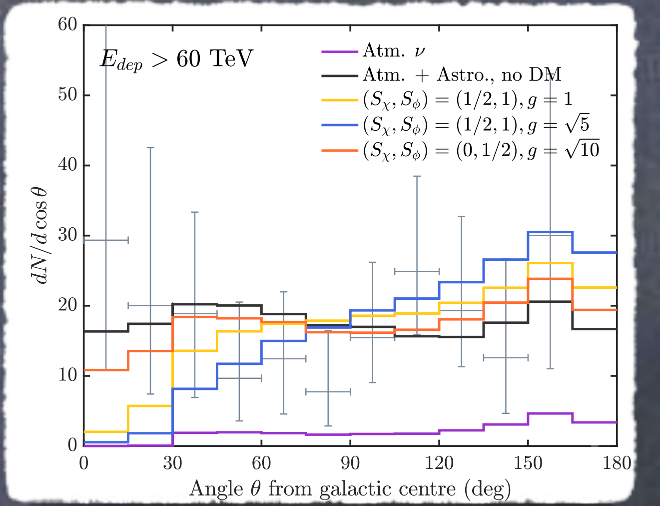


Full absorption of SN neutrinos

G. Mangano et al., Phys. Rev., D74:043517, 2006

Energy-dependent anisotropy of high-energy neutrinos

C. A. Argüelles, A. Kheirandish and A. C. Vincent, Phys. Rev. Lett. 119:201801, 2017



Distortion of high-energy neutrinos

J. Barranco et al., JCAP 10:007, 2011

M. M. Reynoso and O. A. Sampayo, Astropart. Phys. 82:10, 2016

Time delays of high-energy neutrinos

S. Koren, JCAP 09:013, 2019

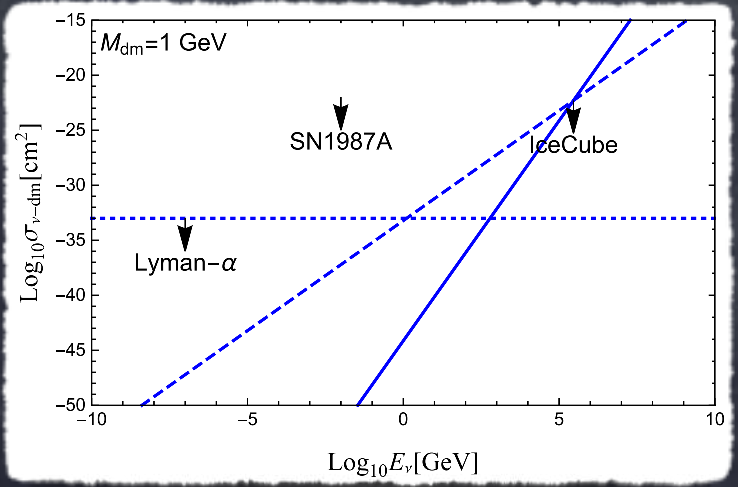
K. Murase and I. M. Shoemaker, Phys. Rev. Lett. 123:24, 2019

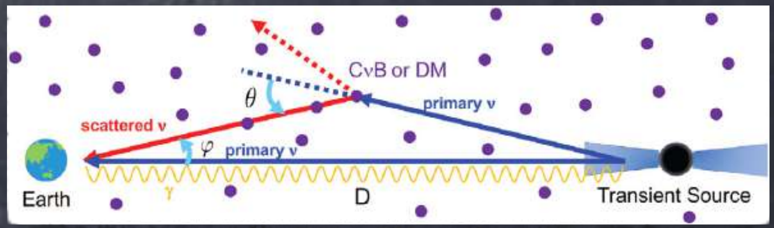
Full absorption of high-energy neutrinos from point sources

K. J. Kelly and P. A. N. Machado, JCAP 10:048, 2018

J. B. G. Alvey and M. Fairbairn, JCAP 07:041, 2019

K. Choi, J. Kim and C. Rott, Phys. Rev. D99:8, 2019

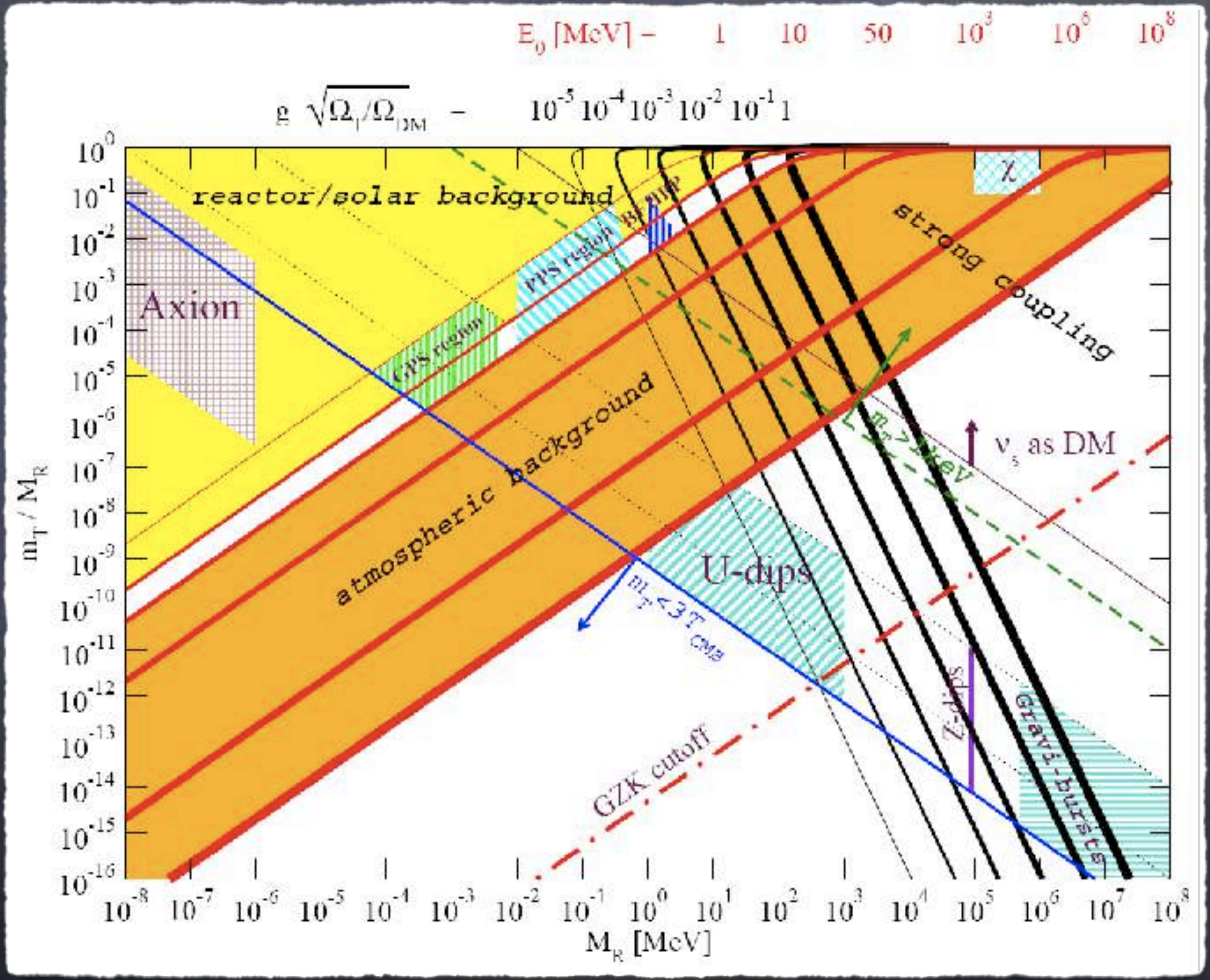




Redshift-Integrated Resonances (zIRs)

Dips in cosmic neutrino spectra

$$E_R \simeq \frac{M_R^2}{2\, m_T}$$



SPR and T. J. Weiler, in preparation... since 2006

Neutrino-Dark Matter Interactions

Coherent effects

$$\frac{d\phi_\nu(E_\nu,x)}{dx} = -i\left(U\,H_{vac}\,U^\dagger + V_m\right)\phi_\nu(E_\nu,x)$$

induce an effective mass or potential

on high-energy neutrinos

O. G. Miranda, C. A. Moura and A. Parada, Phys. Lett. B744:55, 2015

P. F. de Salas, R. A. Lineros and M. Tórtola, Phys. Rev. D94:123001, 2016

on solar neutrinos (DM in the Sun)

F. Capozzi, I. M. Shoemaker and L. Vecchi, JCAP 07:021, 2017

I. Lopes, Astrophys. J. 869:112, 2018

on atmospheric neutrinos

F. Capozzi, I. M. Shoemaker and L. Vecchi, JCAP 07:004, 2018

If neutrinos couple to ultra-light dark matter, these interactions can...

alter flavor ratios of high-energy neutrinos

Y. Farzan and SPR, Phys. Rev. D99:051702(R), 2019

S. Karmakar, S. Pandey and S. Rakshit, arXiv:2010.07336

suppress sterile neutrino production in the early Universe

F. Bezrukov, A. Chudaykin and D. Gorbunov, JCAP 06:051, 2017

Y. Farzan, Phys. Lett. B797:134911, 2019

J. Cline, Phys. Lett. B802:135182, 2020

induce time variations or distortions of masses and mixings

A .Berlin, Phys. Rev. Lett. 117:231801, 2016

G. Krnjaic, P. A. N. Machado and L. Necib, Phys. Rev. D97:075017, 2018

V. Brdar et al., Phys. Rev. D97:043001, 2018

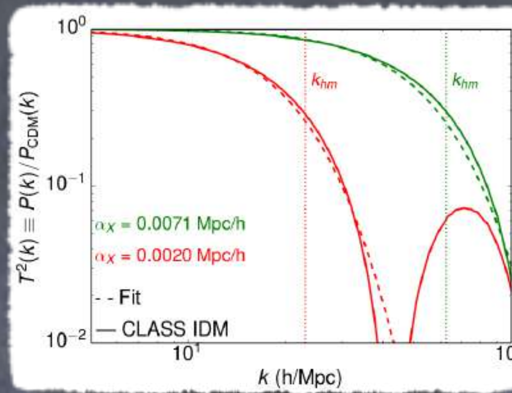
G.-Y. Huang and N. Nath, Eur. Phys. J. C78:922, 2018

A. Dev, P. A. N. Machado and P. Martínez-Miravé, arXiv:2007.03590

Neutrino-Dark Matter Interactions

collisional and mixed damping

C. Boehm, P. Fayet and R. Schaeffer, Phys. Lett. B518:8, 2001
C. Boehm et al., MNRAS 360:282, 2005
C. Boehm and R. Shaeffer, Astron. Astrophys. 438:419, 2005



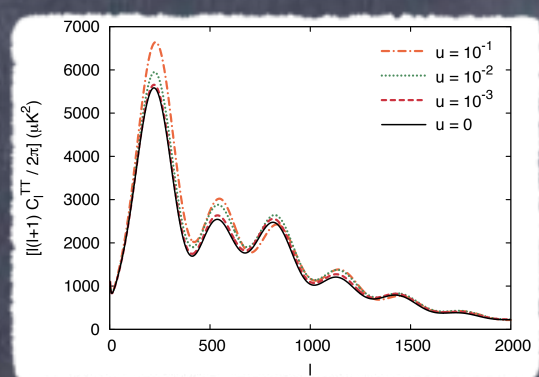
Cosmo/Astro effects

CMB anisotropies

P. Serra et al., Phys.Rev.D 81:043507, 2010
R. J. Wilkinson, C. Boehm and J. Lesgourgues, JCAP 05:011, 2014
M. Escudero et al., JCAP 09:034, 2015
J. A. D. Diacoumis and Y. Y. Y. Wong, JCAP 01:001, 2019
J. A. D. Diacoumis and Y. Y.Y. Wong, JCAP 05:025, 2019

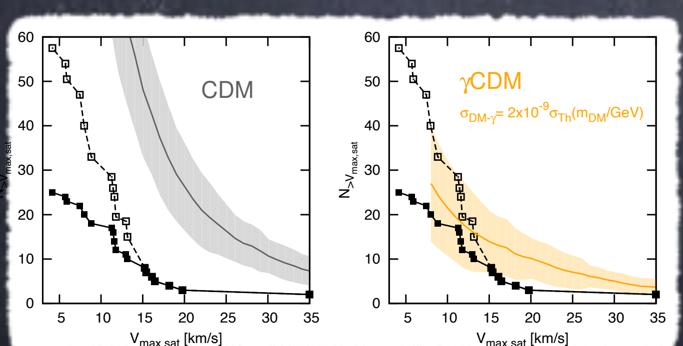
CMB spectral distortions

Y. Ali-Haïmoud, J. Chluba and M. Kamionkowski , Phys. Rev. Lett. 115:071304, 2015
J. A. D. Diacoumis and Y. Y. Y. Wong, JCAP 09:011, 2017



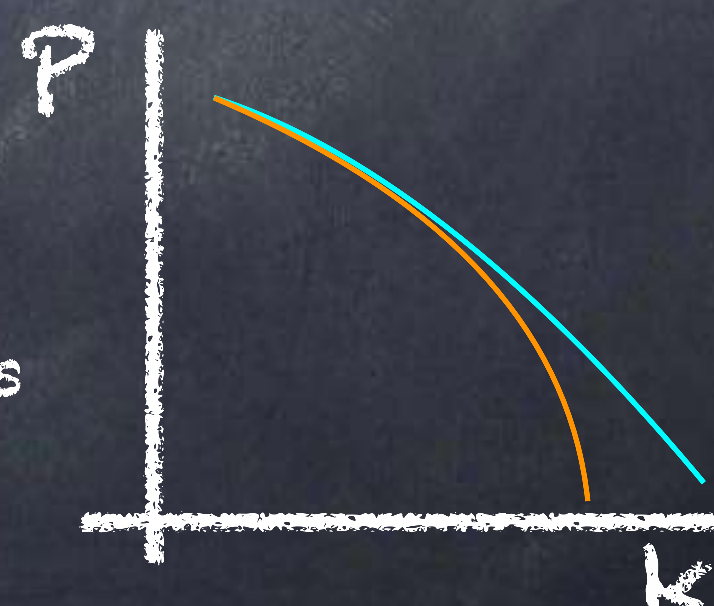
MW satellites

C. Boehm et al., MNRAS 445 :L31, 2014
M. Escudero et al., JCAP 06:007, 2018



Galaxy surveys

G. Mangano et al., Phys. Rev., D74:043517, 2006
P. Serra et al., Phys.Rev.D 81:043507, 2010
M. Escudero et al., JCAP 09:034, 2015



Lyman-alpha

R. J. Wilkinson, C. Boehm and J. Lesgourgues, JCAP 05:011, 2014

Diffuse neutrino flux from DM annihilations

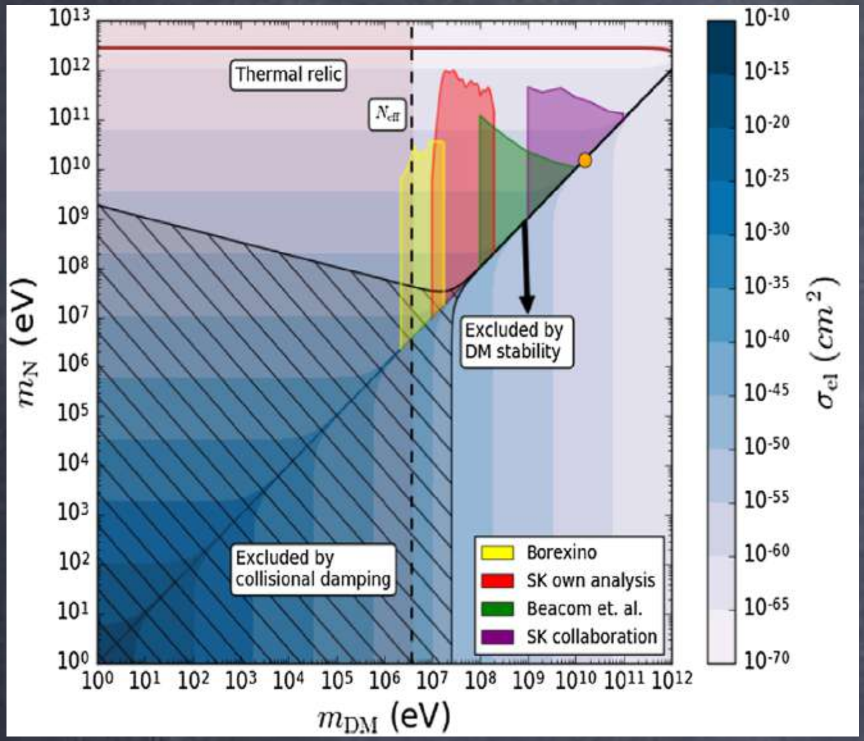
A. Moliné et al., JCAP 08:069, 2016

$$\sigma_{el} < 10^{-33} \left(\frac{m_{DM}}{GeV}\right) cm^2 \qquad \sigma_{el} < 10^{-45} \left(\frac{m_{DM}}{GeV}\right) \left(\frac{T_\nu}{T_0}\right)^2 cm^2$$

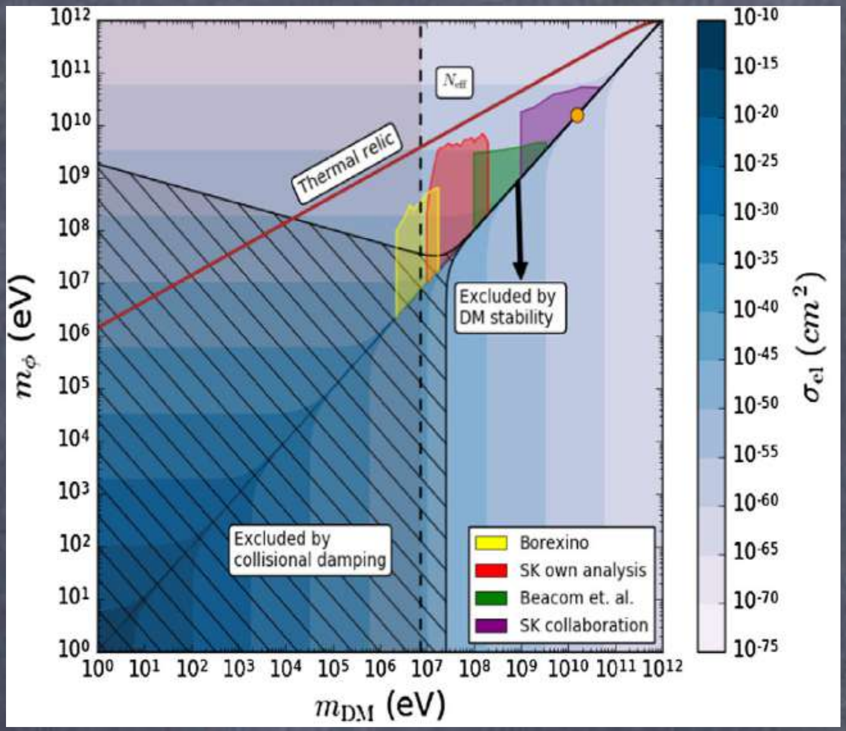
Combining results: interactions/annihilations

Considering all (12) possible dimension-4 operators describing neutrino-dark matter interactions

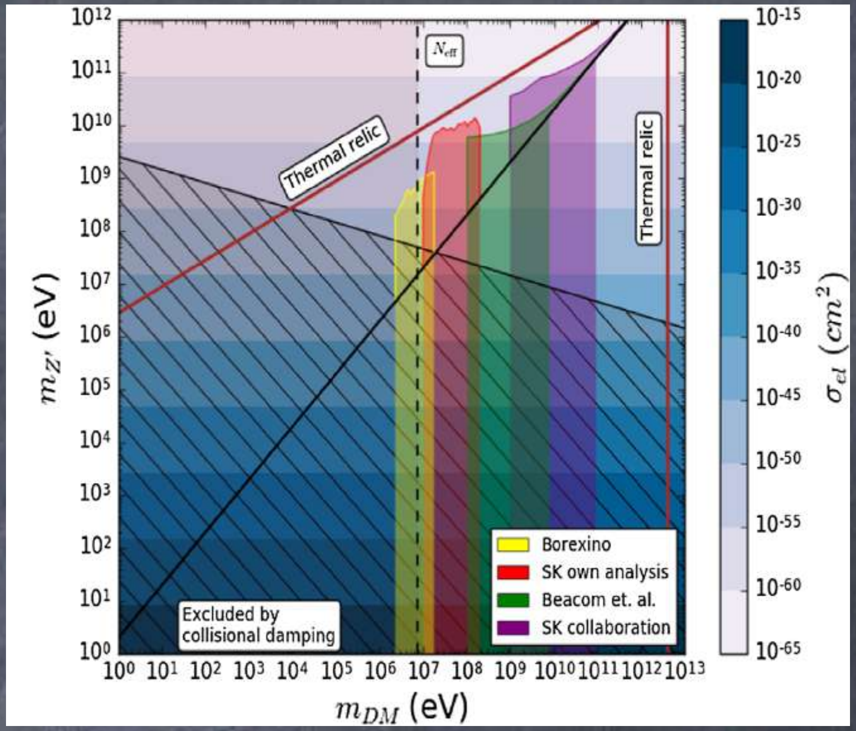
scalar DM - Majorana mediator



Dirac DM - scalar mediator



Dirac DM - vector mediator



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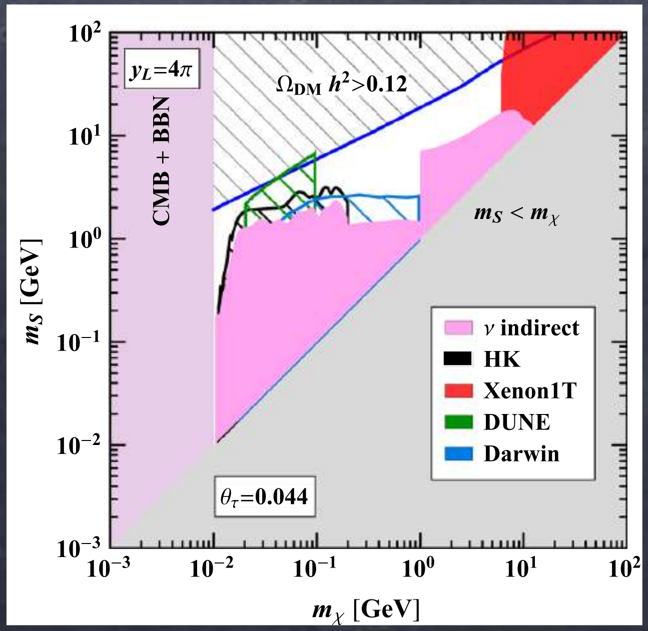

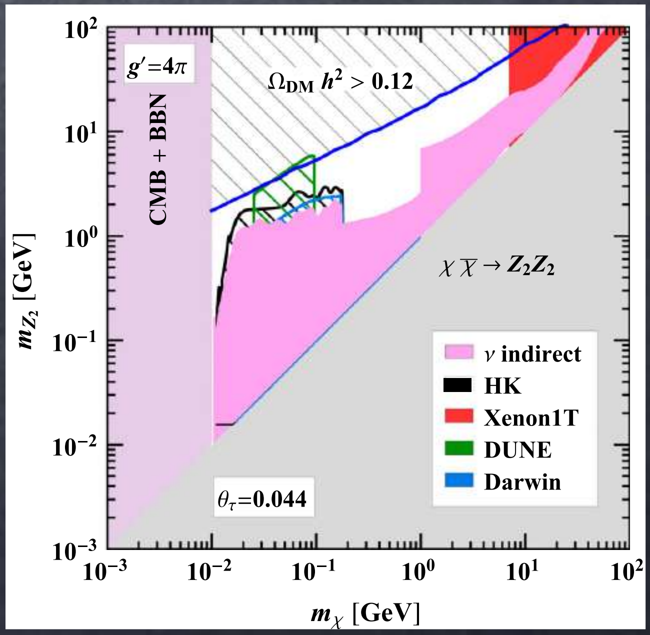

See also:

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Conclusions

Many (potential)
neutrino-dark matter connections

Many indirect dark matter signatures with neutrinos
(not all covered in this talk)... some unique

Neutrino detectors: complementary to direct searches, to indirect searches with other messengers and to astro/cosmo observables