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Dark Matter effects on oscillations of galactic high-energy neutrinos

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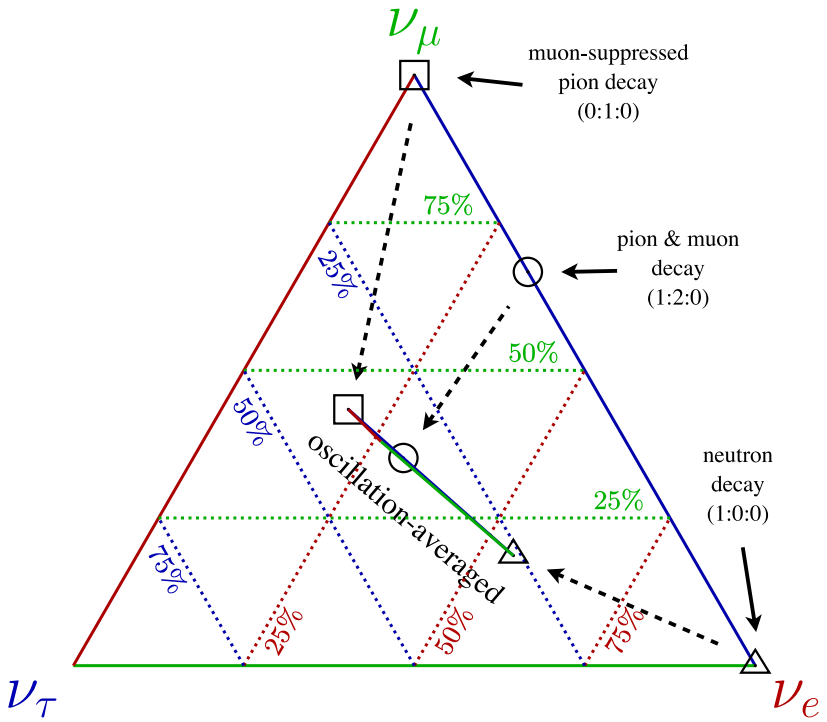
Neutrino propagation in the galactic dark matter halo. P.F. de Salas, R.A. Lineros, M. Tórtola. [arxiv:1601.05798] - PRD

XXI Simposio Chileno de Fisica – 15 Noviembre 2018

Motivation


ν_μ
muon-suppressed
pion decay
(0:1:0)
75%
25%
pion & muon
decay
(1:2:0)
50%
50%
oscillation-averaged
neutron
decay
(1:0:0)
25%
75%
25%
50%
75%
ν_τ
ν_e

Winter is coming
in Antarica
?

Outline

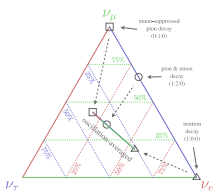
You are here

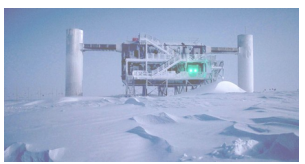
Introduction

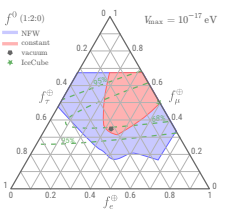
DM effects in neutrino oscillations

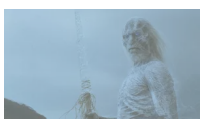
Results

Conclusions

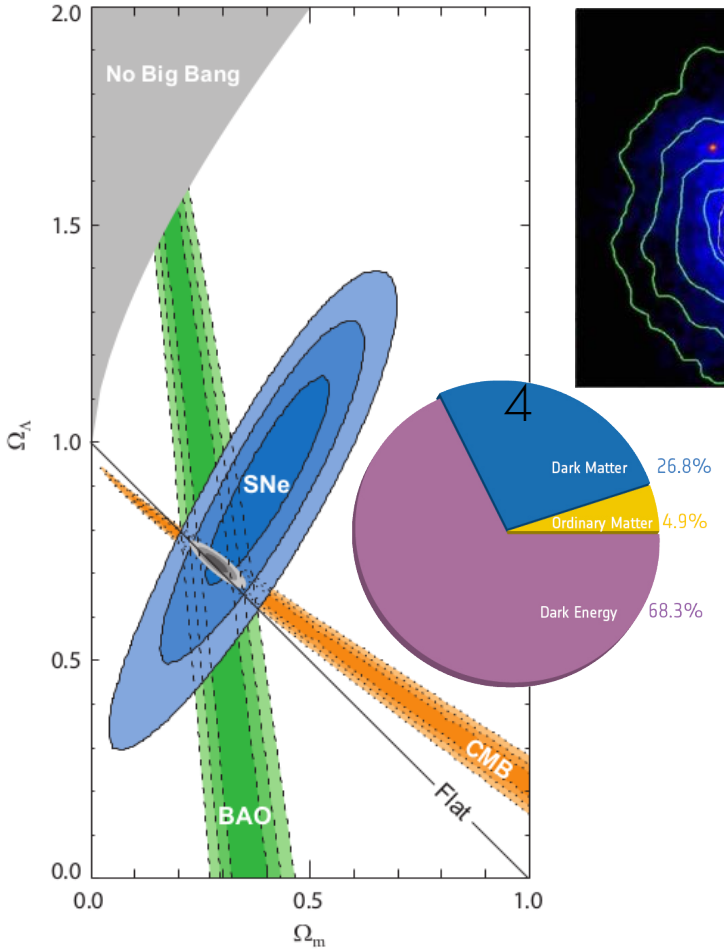


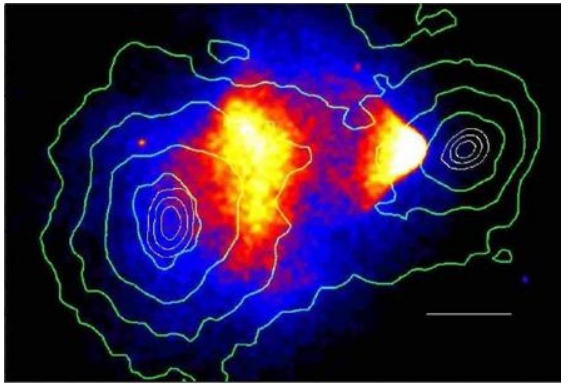


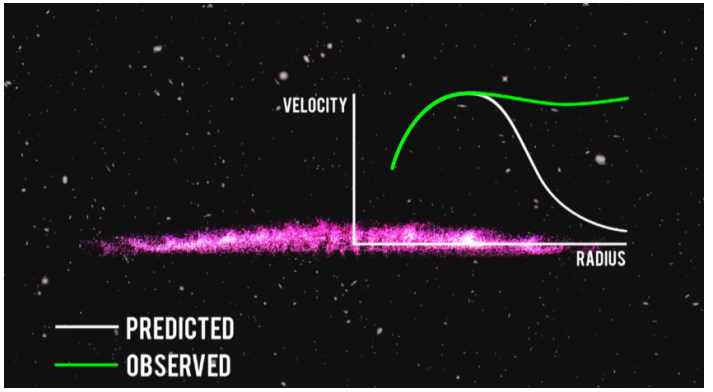




Dark Matter





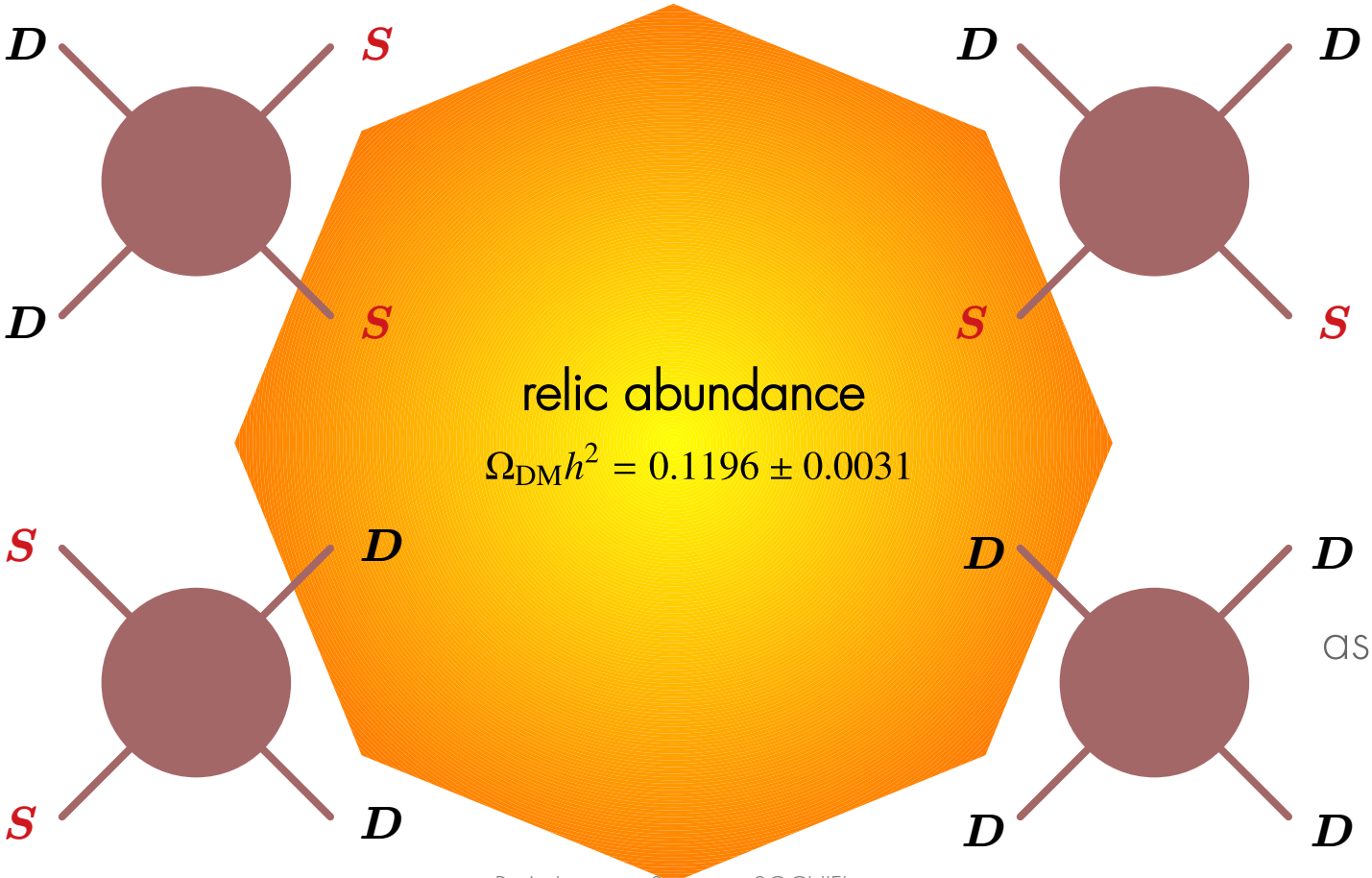


Observations support Dark Matter

- Dynamics of clusters and galaxies
- Structure formation
- CMB anisotropies
- Baryon Acoustic Oscillation

$$\Omega_{\mathrm{DM}} h^2 = 0.1196 \pm 0.0031$$

Dark Matter Searches



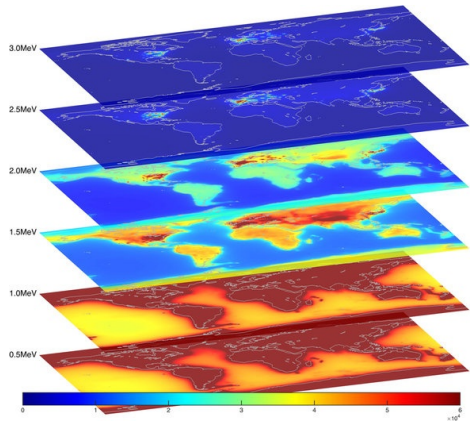
indirect detection

direct detection

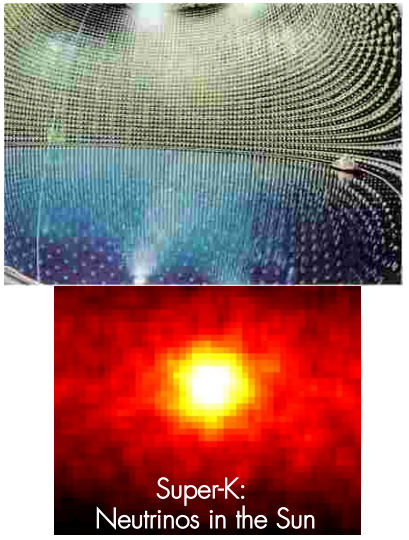
particle collider

astrophysical probes

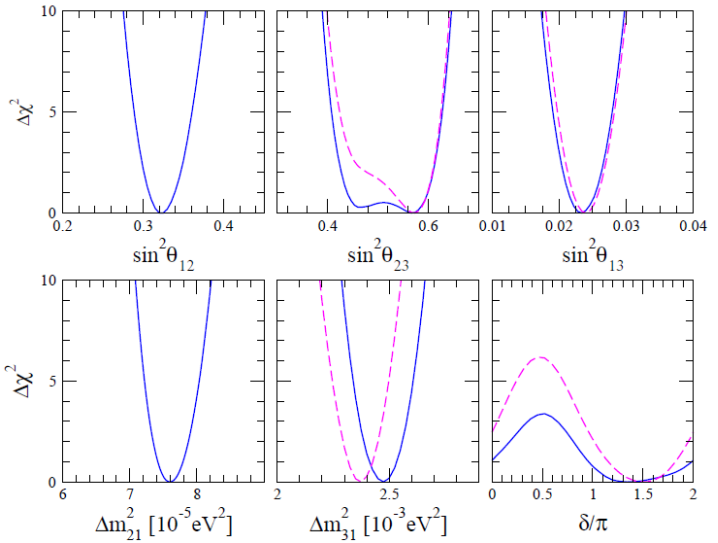
Neutrinos



AGM2015: Antineutrino Global Map 2015



Forero, Tortola and Valle PRD 90 (2014) 093006



The SM predicts zero neutrino mass

Beyond SM physics is required to explain mass spectrum and mixing angles

Neutrino oscillations

Flavor and mass eigenstates do not coincide $|\nu_\alpha\rangle = \sum_k U^*_{\alpha k}|\nu_k\rangle$

Mass eigenstates evolve according to:

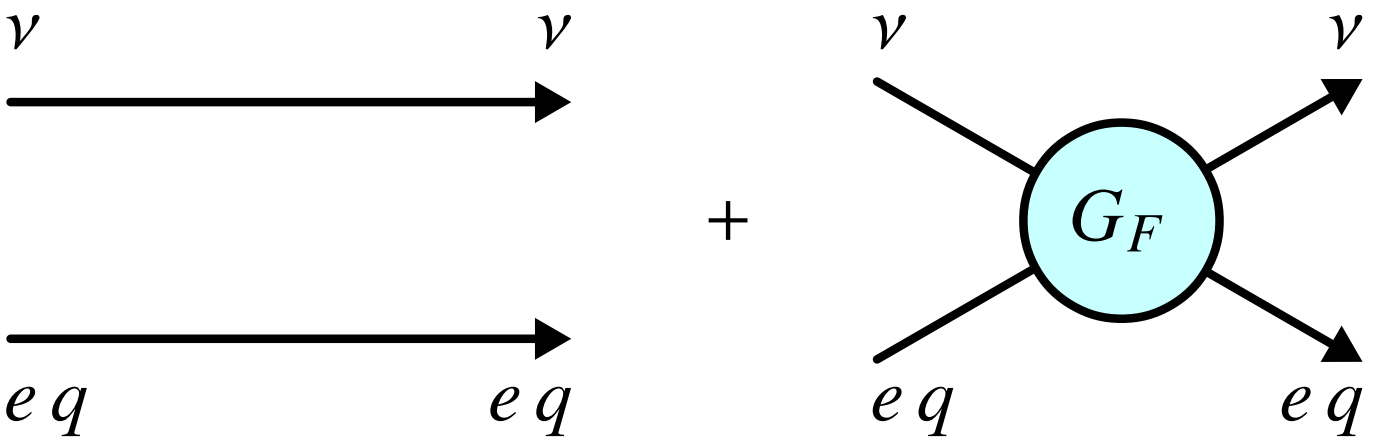
$$i\frac{\partial \Psi}{\partial t} = \mathcal{H}\,\Psi$$

$$\mathcal{H}_{\rm vac} = \frac{1}{2E}\,U \begin{pmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{pmatrix} U^\dagger$$

The final ν flavor depends on: Initial state, Source distance, Neutrino energy

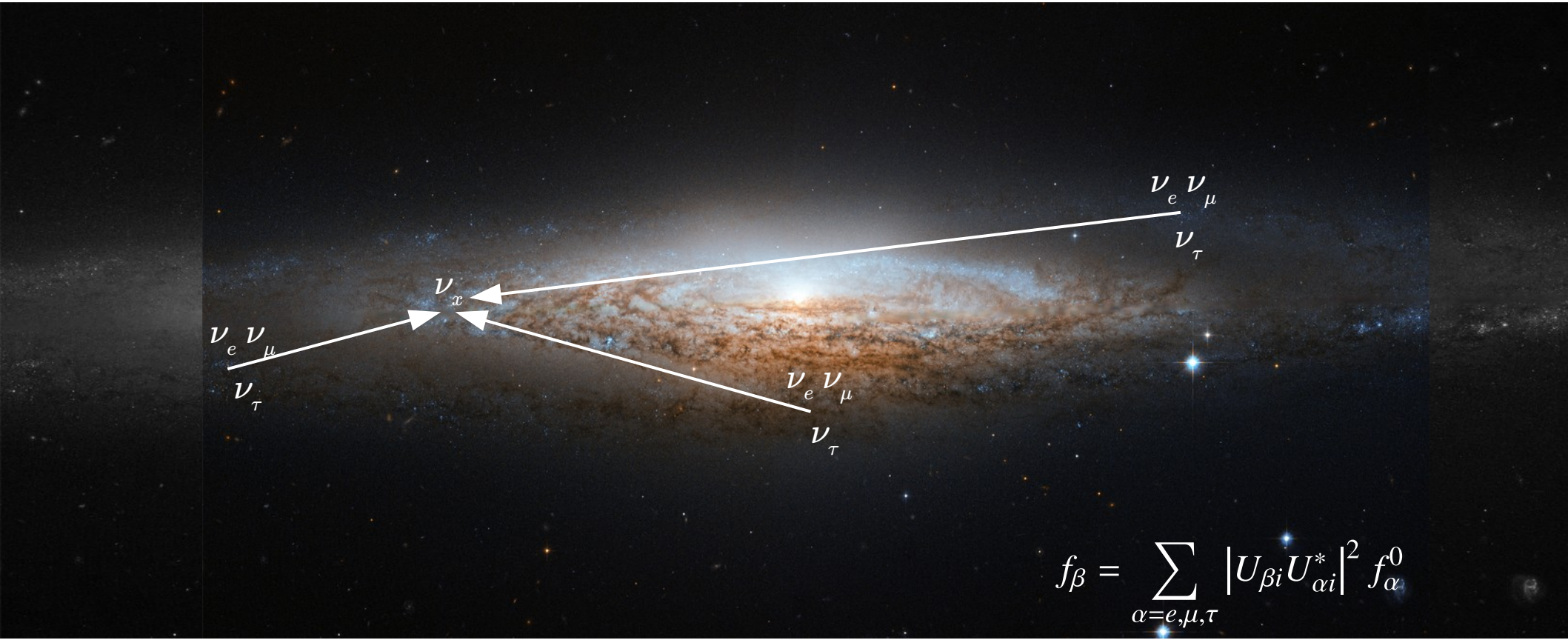
Matter effects (a.k.a. MSW effect)

The interaction with a medium modifies the oscillation patterns w.r.t. vacuum

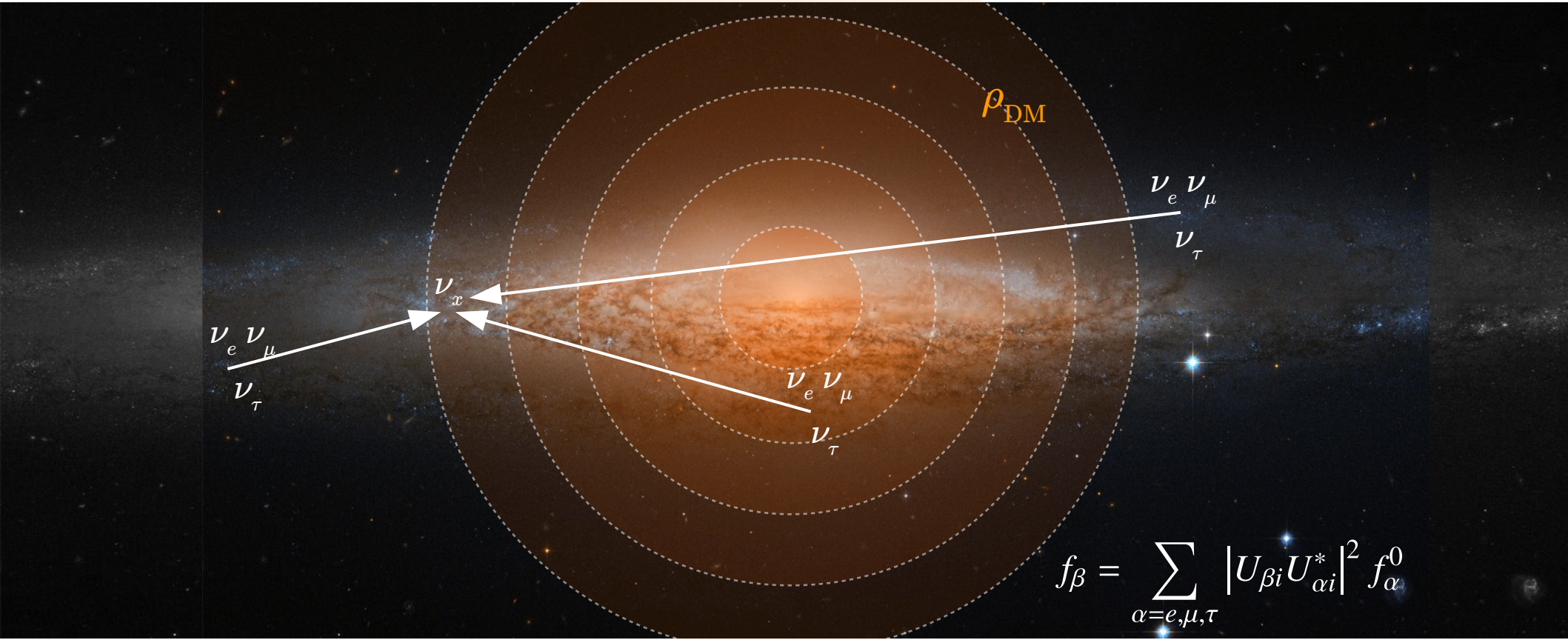


$$\mathcal{H}_{\text{tot}} = \mathcal{H}_{\text{vac}} + \mathcal{V}$$

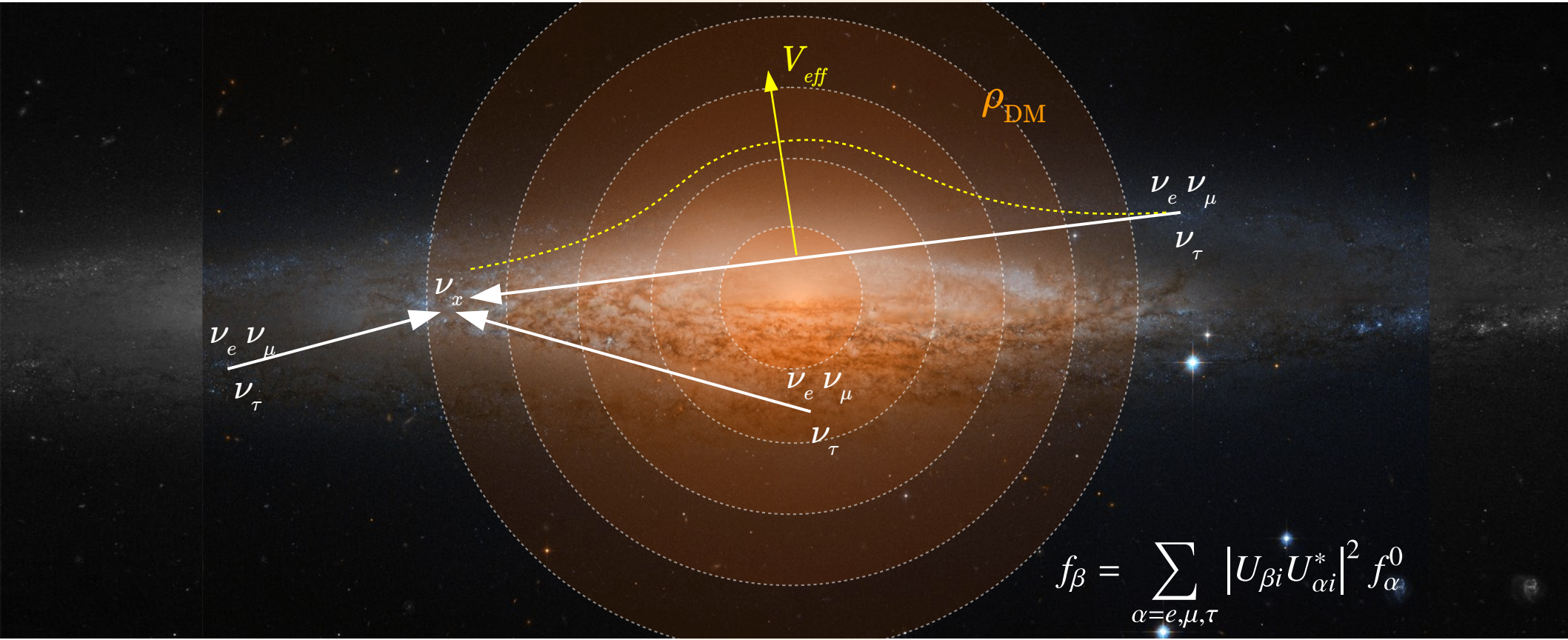
Dark Matter effects



Dark Matter effects

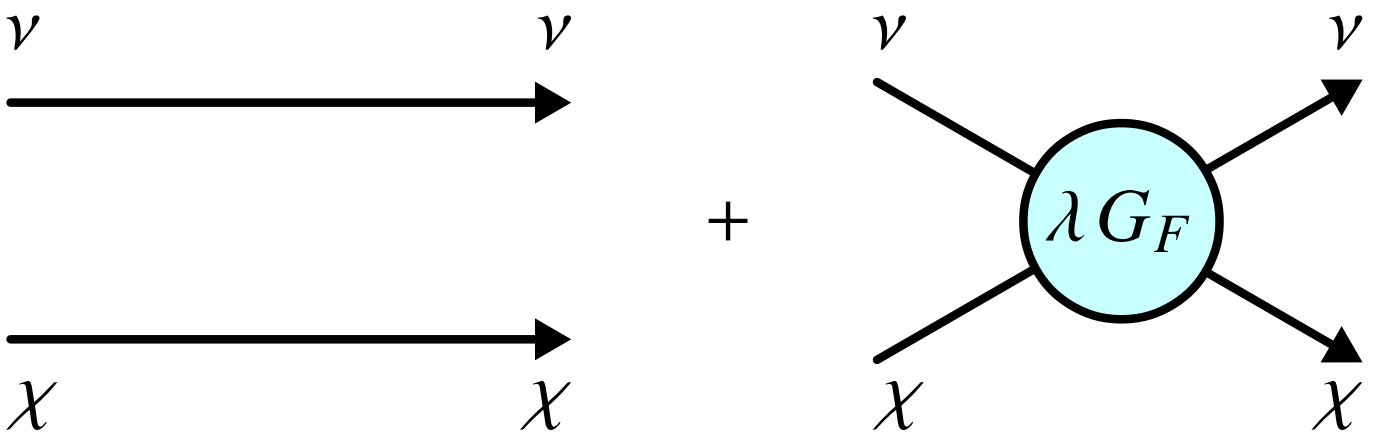


Dark Matter effects



Dark Matter effects

The interaction with DM might modify the oscillation patterns w.r.t. vacuum



$$\mathcal{H}_{\rm tot} = \mathcal{H}_{\rm vac} + \mathcal{V}$$

Dark Matter effects

We parameterized the effective potential using a "weak interaction" form:

$$\mathcal{V}_{\alpha\beta} = \lambda_{\alpha\beta}\, G_F\, N_\chi(\vec{x})$$

But also spatial dependency:

$$\mathcal{V}_{\alpha\beta} = \mathcal{V}^{\oplus}_{\alpha\beta} \times f(\vec{x})$$

$$N_\chi(\vec{x}) = \frac{\rho_\chi(\vec{x})}{m_\chi}$$

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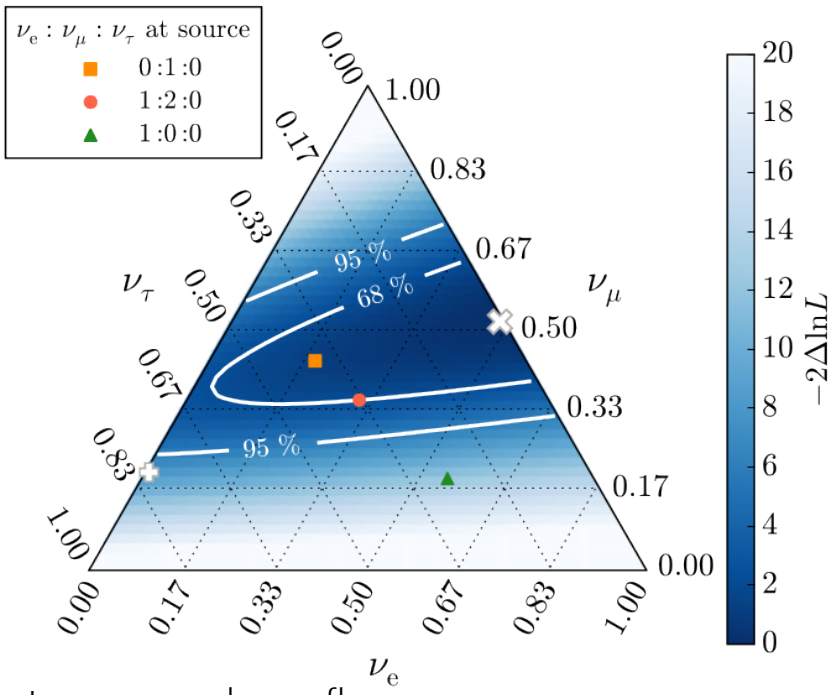
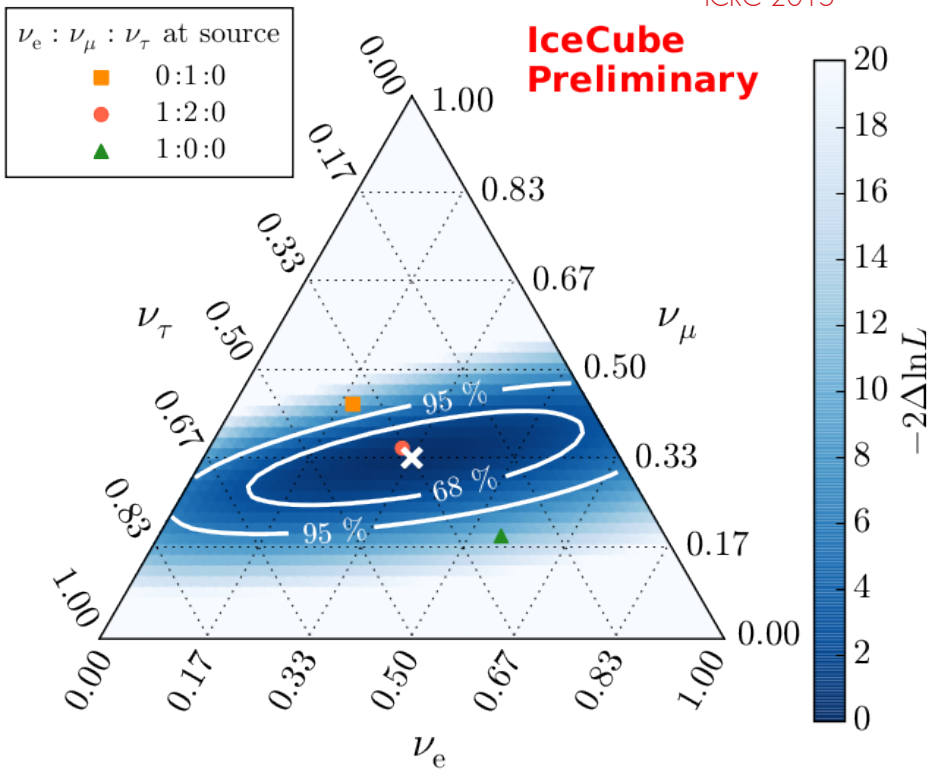
Flavor composition in IceCube

THE ASTROPHYSICAL JOURNAL, 809:98 (15pp), 2015 August 10



Latest result on flavor composition

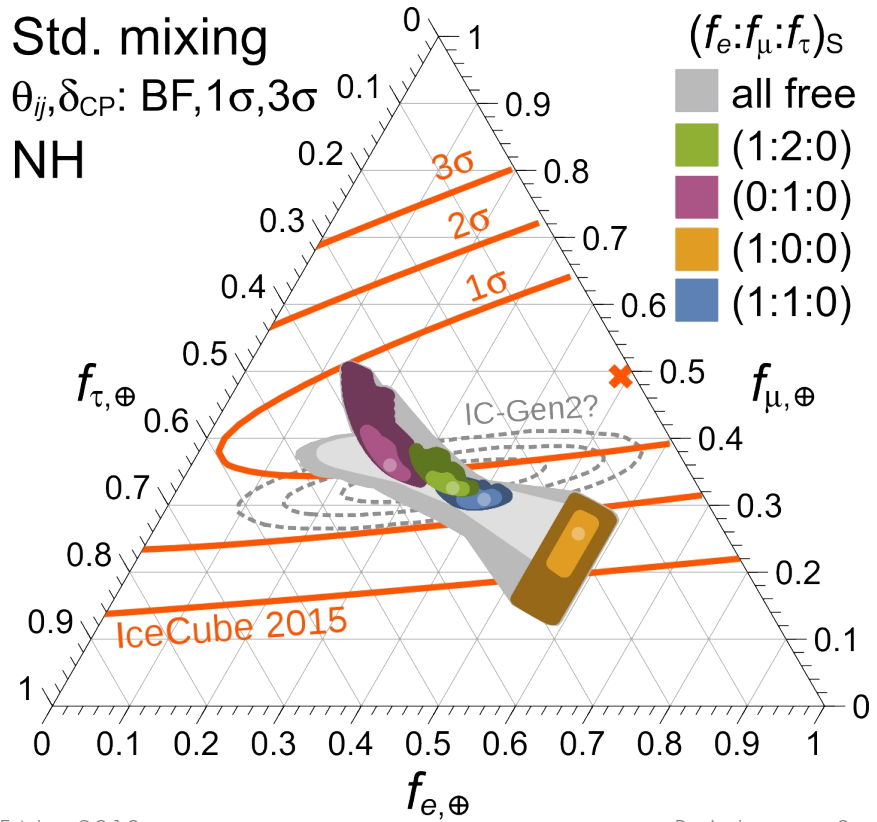
ICRC 2015

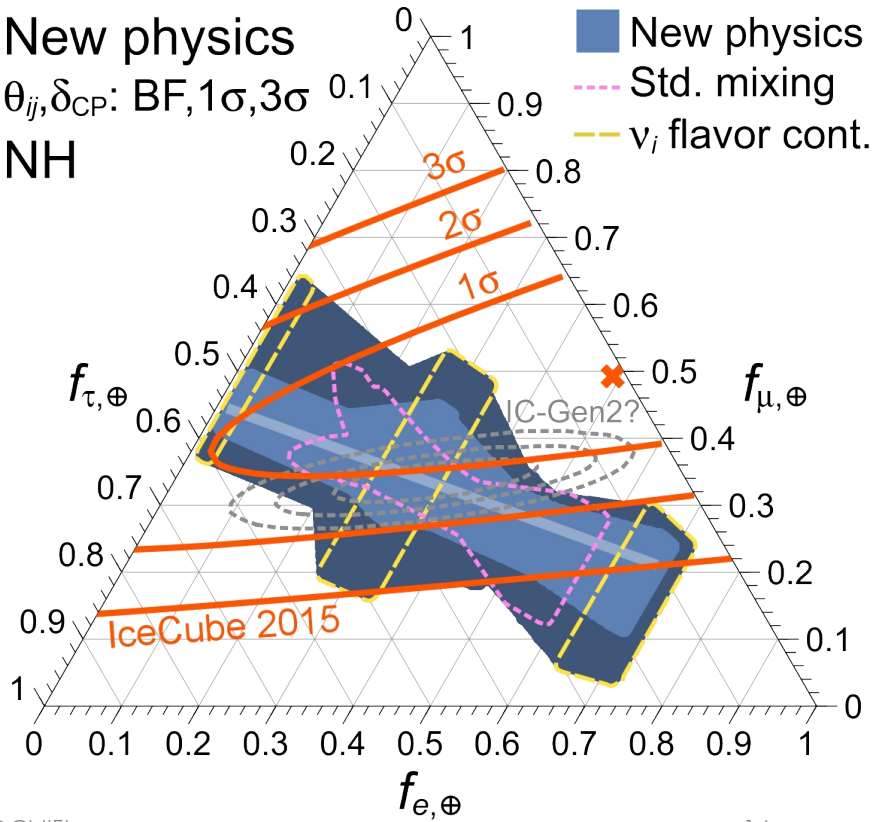


Sensitivity after 10 years

What we expect?

M. Bustamante et al. PRL 115, 161302 (2015)

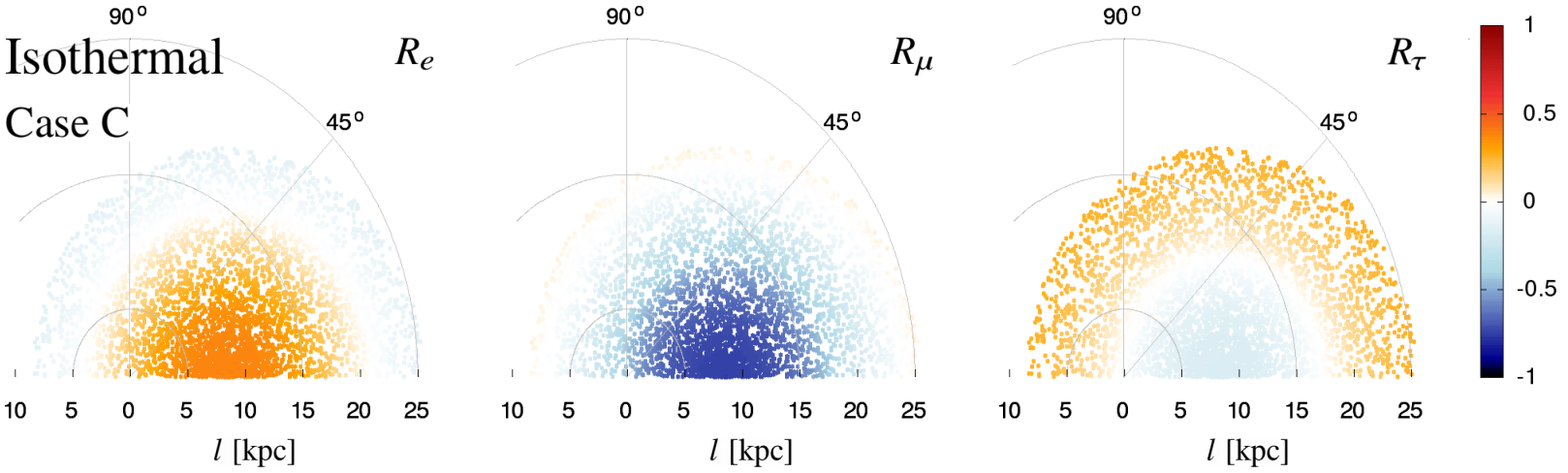


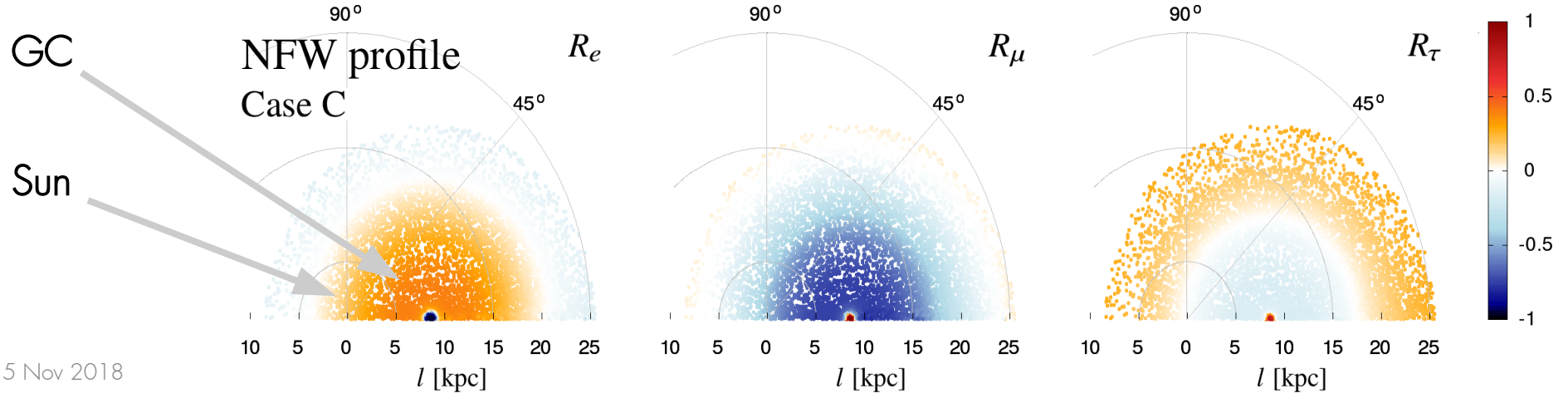


Spatial dependence

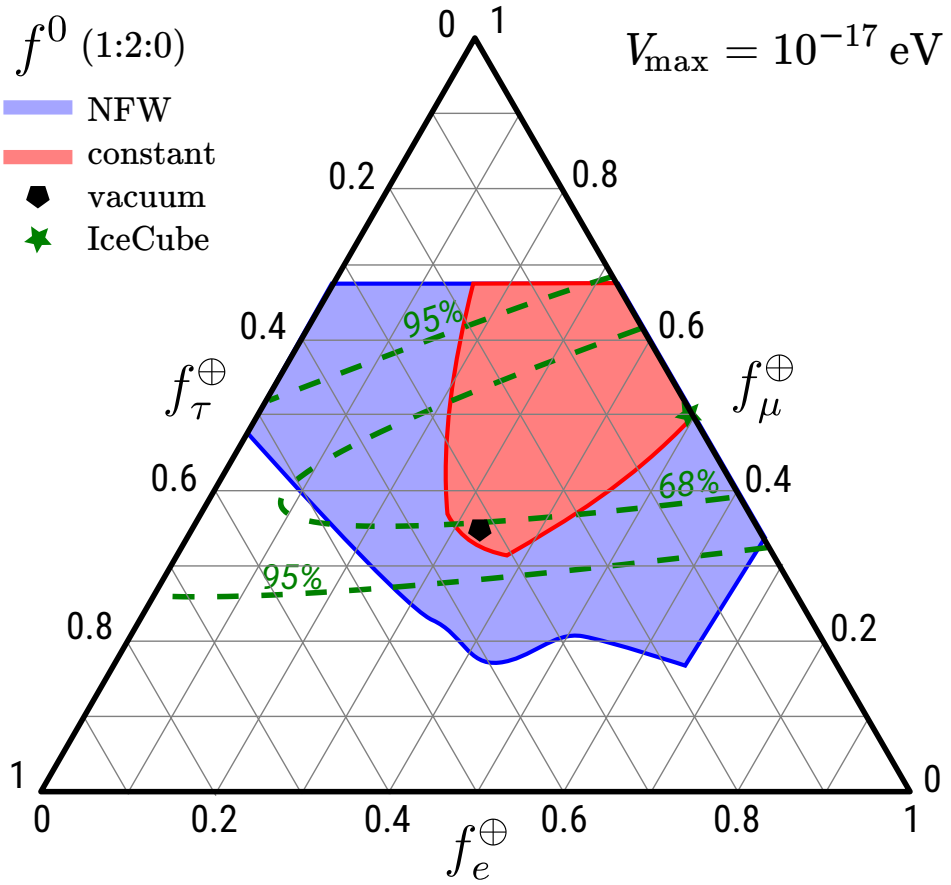
$$\mathcal{V}_{\alpha\beta} = \mathcal{V}^{\oplus}_{\alpha\beta} \times f_{\rm DM}(r)$$

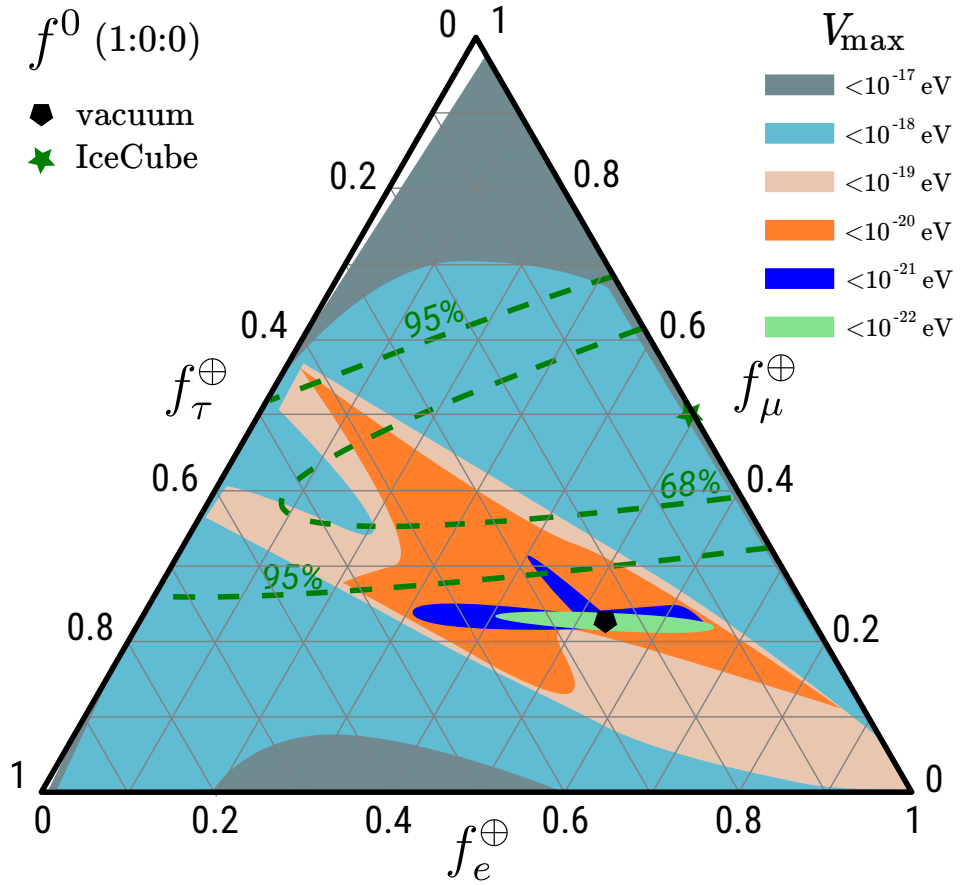
$\mathcal{V}^{\oplus}_{11} = 40 \times 10^{-21}\,\text{eV}$





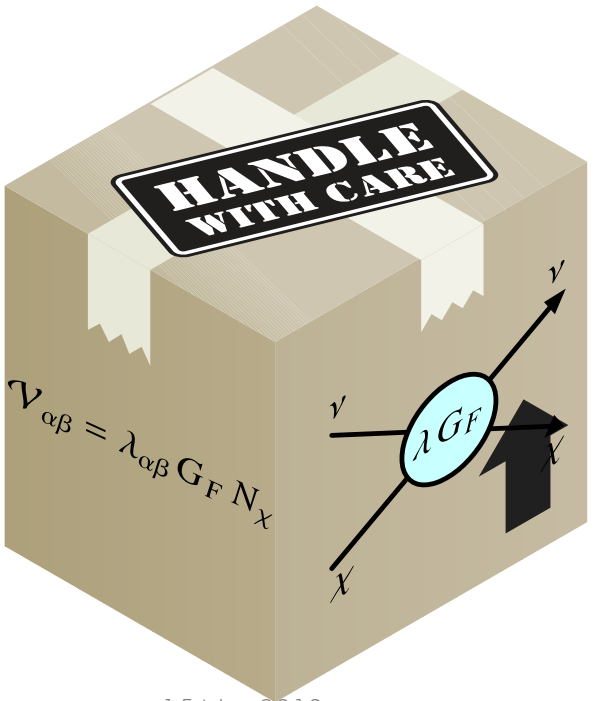
Composition in a NFW halo

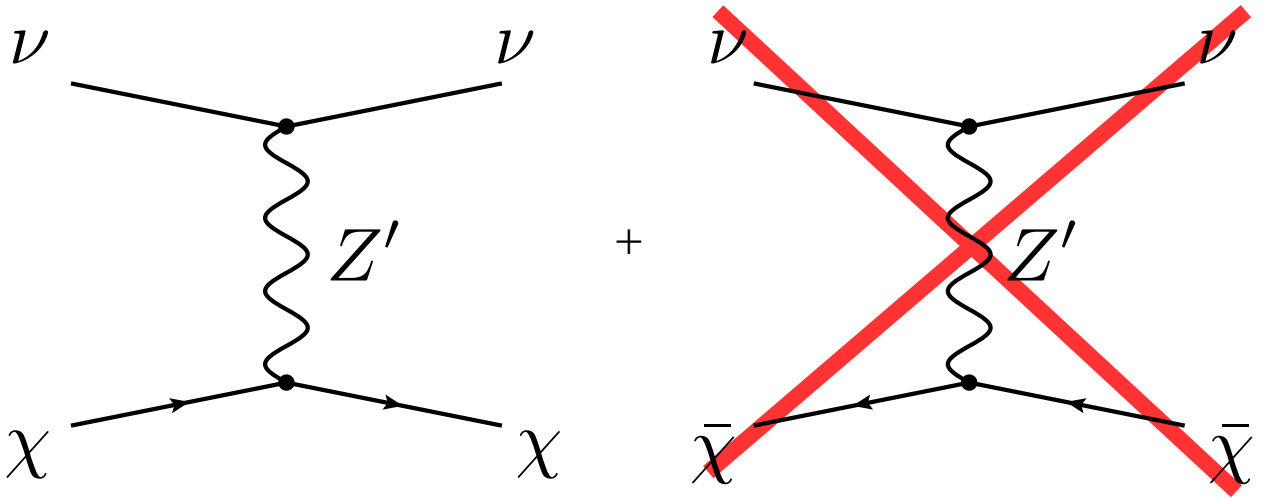




Particle physics interpretation

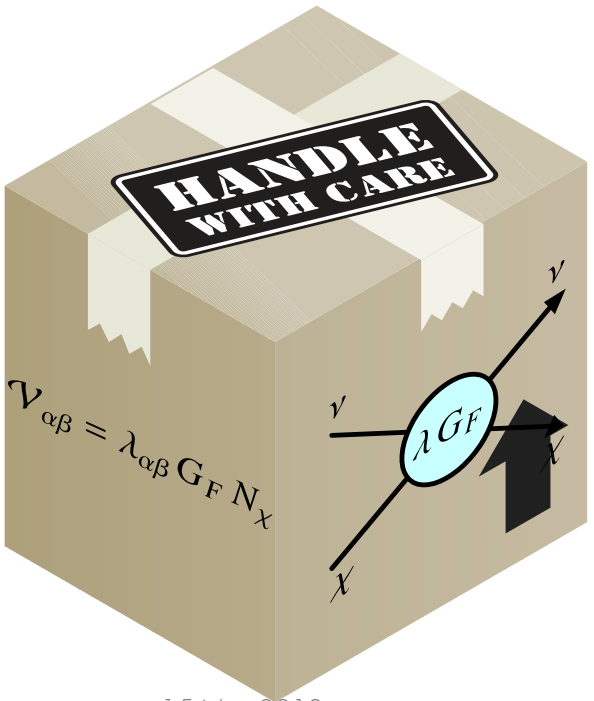
The simplest scenarios are models with asymmetric DM



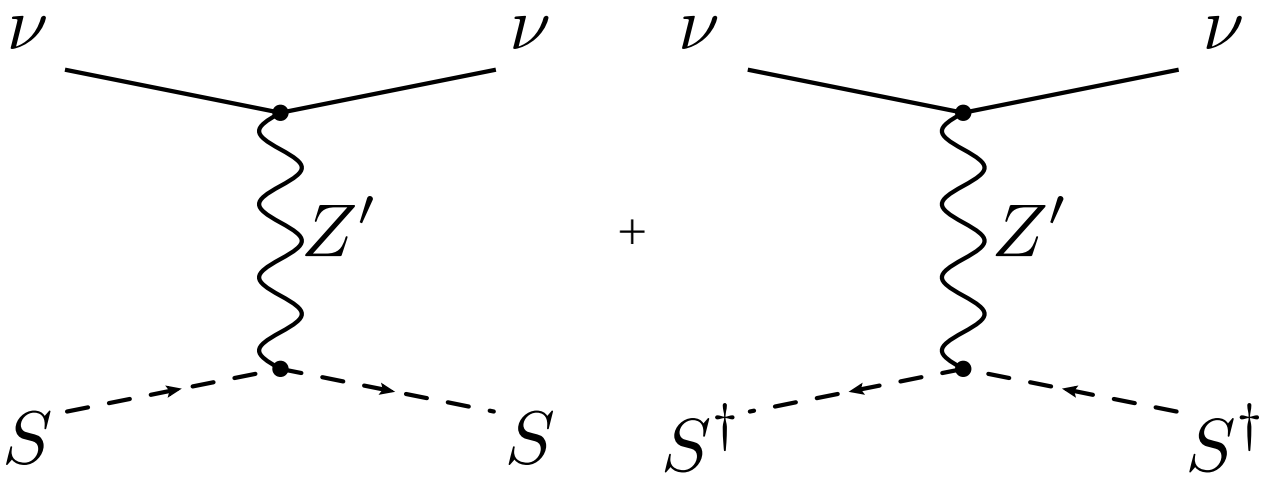


$$\mathcal{V}_{\alpha\beta} = \lambda_{\alpha\beta} G_F N_\chi$$

Particle physics interpretation



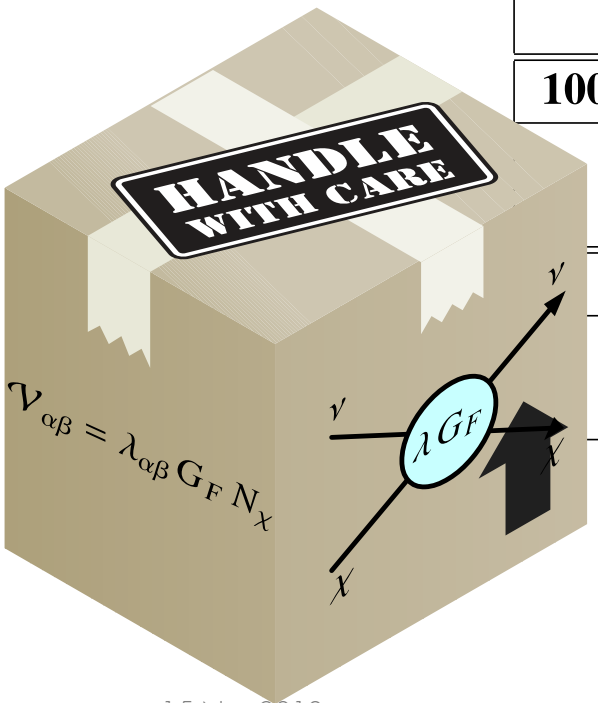
Or with scalar DM



$$\mathcal{V}_{\alpha\beta} = \lambda_{\alpha\beta} G_F N_\chi$$

Particle physics interpretation

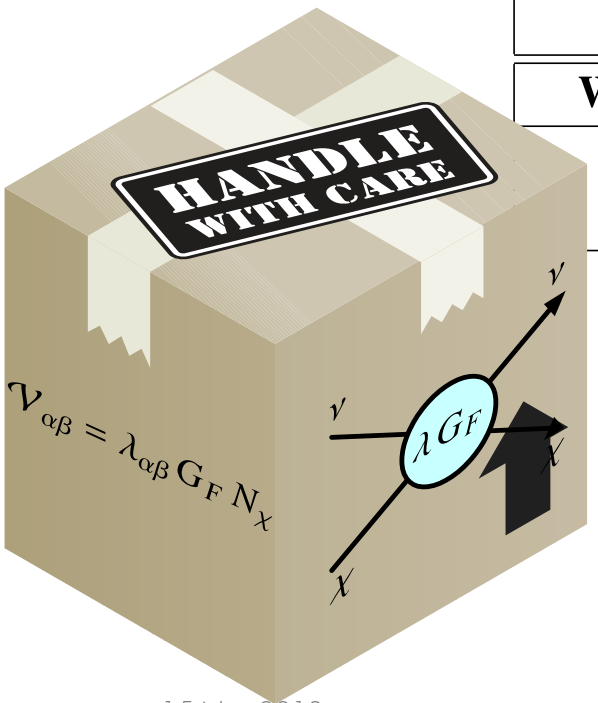
$V_{11}^{\oplus}$ [eV]	10^{-21}	10^{-19}	10^{-17}
Weak scale (a) assumptions:	$G'_F = G_F$, $\lambda_{11} = 1$		
$m_{\rm DM}$ [eV]	10^{-8}	10^{-10}	10^{-12}
l_ν [pc]	10^{-2}	10^{-4}	10^{-6}
100 GeV DM (a) assumptions:	$m_{\rm DM} = 100$ GeV, $l_\nu = 50$ kpc		
λ_{11}	10^{-7}	10^{-9}	10^{-11}
$m_{Z'}$ [eV]	10^{-2}	10^{-4}	10^{-6}
1 keV DM (a) assumptions:	$m_{\rm DM} = 1$ keV, $l_\nu = 50$ kpc		
λ_{11}	10^{-7}	10^{-9}	10^{-11}
$m_{Z'}$ [eV]	10^2	1	10^{-2}



One can try to explain the effective potential in terms of particle physics scales

Particle physics interpretation

$V_{11}^{\oplus}$ [eV]	10^{-21}	10^{-19}	10^{-17}
Weak scale (a) assumptions:	$G'_F = G_F$, $\lambda_{11} = 1$		
$m_{\rm DM}$ [eV]	10^{-8}	10^{-10}	10^{-12}
l_ν [pc]	10^{-2}	10^{-4}	10^{-6}
Weak scale (b) assumptions:	$G'_F = G_F$, $l_\nu = 50$ kpc		
λ_{11}	10^{-7}	10^{-9}	10^{-11}
$m_{\rm DM}$ [eV]	10^{-15}	10^{-19}	10^{-23}



Assuming weak scale couplings and mediators DM has to be extremely light. Fuzzy DM, Bose-Einstein DM?

For $\lambda=1$, the mean free path is sub-pc :-(

Particle physics interpretation

$V_{11}^{\oplus}$ [eV]	10^{-21}	10^{-19}	10^{-17}
100 GeV DM (a) assumptions:	$m_{\rm DM} = 100$ GeV, $l_\nu = 50$ kpc		
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1 keV DM (a) assumptions:	$m_{\rm DM} = 1$ keV, $l_\nu = 50$ kpc		
λ_{11}	10^{-7}	10^{-9}	10^{-11}
$m_{Z'}$ [eV]	10^{2}	1	10^{-2}

100 GeV DM

sub-eV mediators, $g \sim \lambda^{1/2} = 10^{-3} - 10^{-6}$

$$\sigma_{\nu\chi} = 1.62 \times 10^{-23}\ (m_{\rm DM}/{\rm GeV})\,{\rm cm}^2$$

Particle physics interpretation

$V_{11}^{\oplus}$ [eV]	10^{-21}	10^{-19}	10^{-17}
100 GeV DM (a) assumptions:	$m_{\rm DM} = 100$ GeV, $l_\nu = 50$ kpc		
λ_{11}	10^{-7}	10^{-9}	10^{-11}
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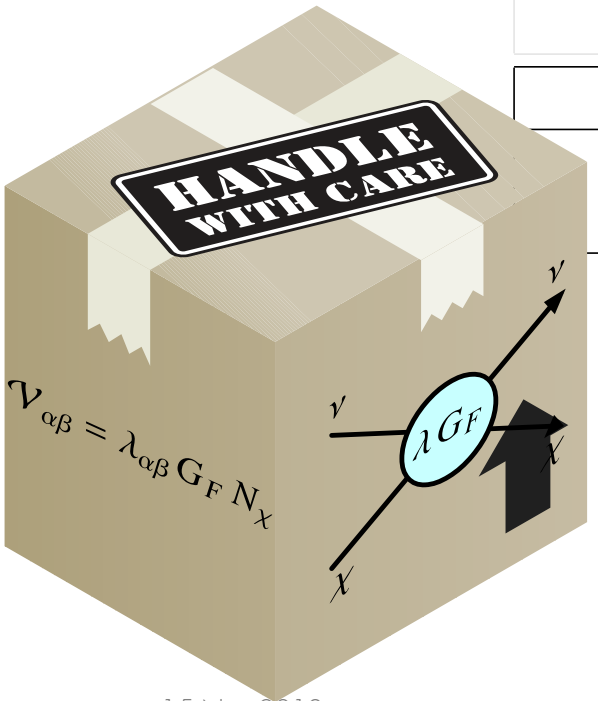
λ_{11}	10^{-7}	10^{-9}	10^{-11}
$m_{Z'}$ [eV]	10^{2}	1	10^{-2}



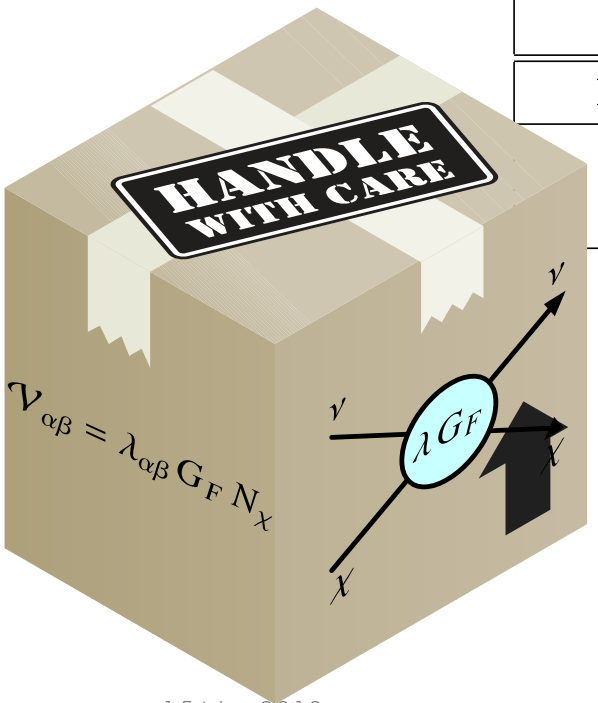
1 keV DM

eV mediators, $g \sim \lambda^{1/2} = 10^{-3} - 10^{-6}$

$$\sigma_{\nu\chi} = 1.62 \times 10^{-23}\ (m_{\rm DM}/{\rm GeV})\,{\rm cm}^2$$

Particle physics interpretation

$V_{11}^{\oplus}$ [eV]	10^{-21}	10^{-19}	10^{-17}
100 GeV DM (b) assumptions:	$m_{\rm DM} = 100$ GeV, $l_\nu = 10^6$ Gpc		
λ_{11}	10^{-17}	10^{-19}	10^{-21}
$m_{Z'}$ [eV]	10^{-7}	10^{-9}	10^{-11}
1 keV DM (b) assumptions:	$m_{\rm DM} = 1$ keV, $l_\nu = 10^6$ Gpc		
λ_{11}	10^{-17}	10^{-19}	10^{-21}
$m_{Z'}$ [eV]	10^{-3}	10^{-5}	10^{-7}



Assuming mean free path larger than the Observable Universe

Wilkinson et al. JCAP 1405 (2014) 011

$$\sigma_{\nu\chi} = 10^{-33}\ (m_{\rm DM}/{\rm GeV})\,{\rm cm}^2$$

@MeV!

Conclusions

- Flavor composition might open a door to New-Physics effects
- Effects from the DM halo modify the oscillation pattern differently than in the homogeneous scenario
- (Hopefully) Correlation between flavor and arrival direction might serve as test of this hypothesis
- A particle physics explanation requires mediators lighter than eV

Final words

- Neutrinos observables and DM are keys to unveil New Physics
- DM candidates lighter than WIMPs can affect neutrino observables
- We propose a novel way to test «unobservable» DM candidates

Dark Matter Hunters

Digital resources for hunting the dark sector

@dmhunters

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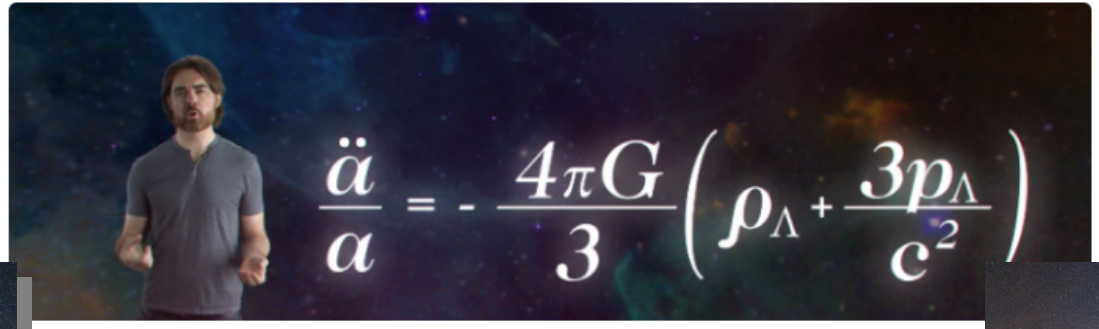
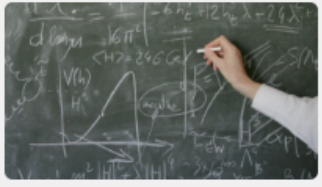
BLOG

MORE

130Line AMS02_Observatory analysis astro axion axion_like_particles BICEP2_experiment black_holes cmb constraints cosmic_rays cosmology dark_energy dark_radiation direct_detection dm_distribution dynamics experimental FERMI_LAT galactic_center gamma_lines



NEWS



Daily digest of papers about

Dark Matter and related topics

lawphysics

Latin American Webinars on Physics

Recent detections of gravitational waves

Isabel Cordero-Carrión
University of Valencia, Spain

Host: Joel Jones-Perez
Wednesday 13 December 2017 15:00 GMT

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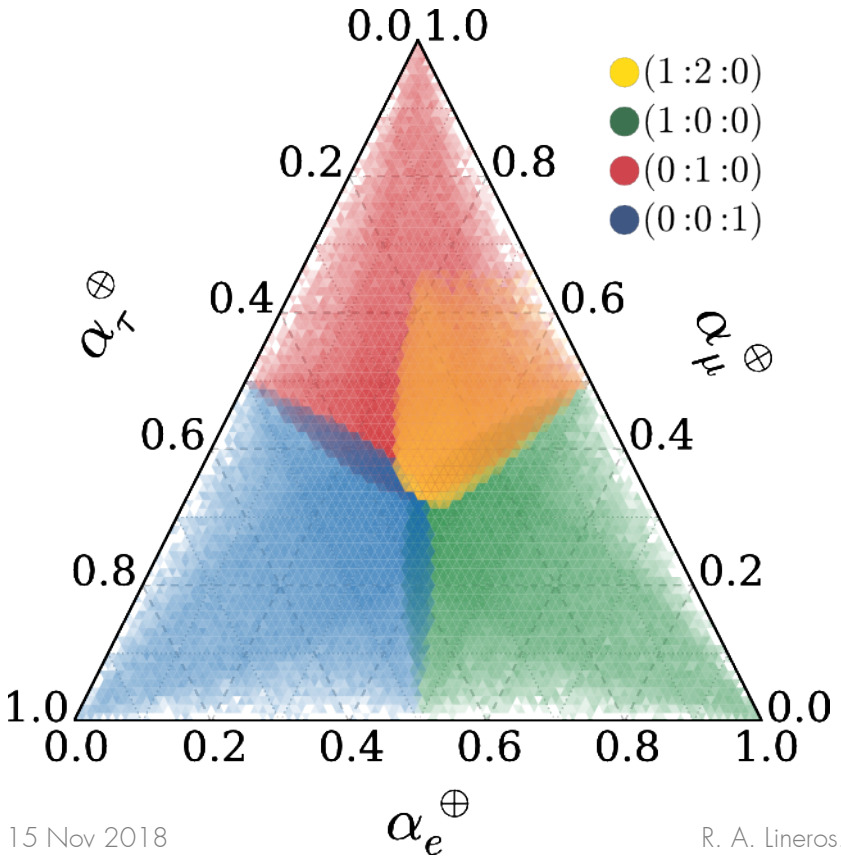
lawphysics.wordpress.com

Thanks

Backup

Effects from New Physics

Argüelles et at. PRL 115, 161303 (2015)



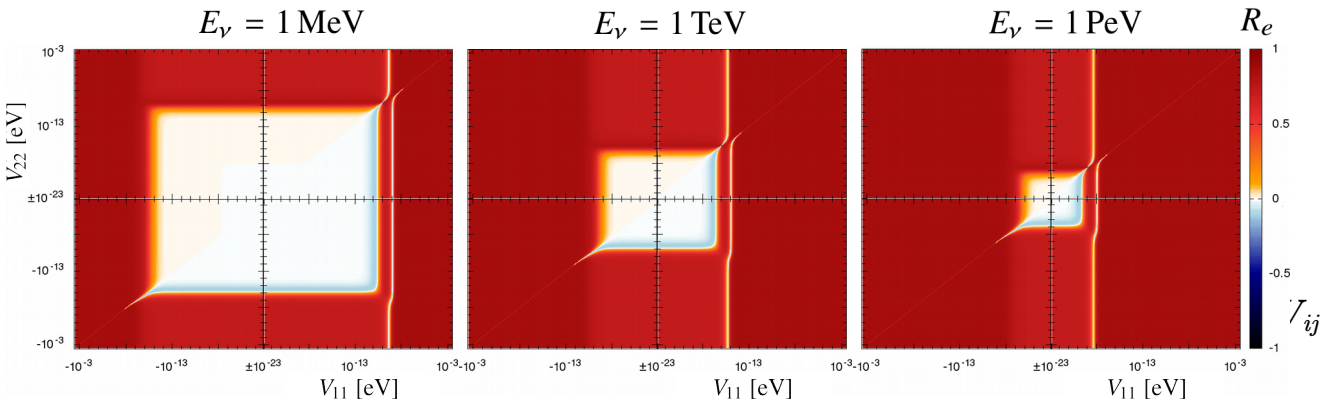
Sources of New Physics:

- Space torsion

- CPT - Lorentz violation

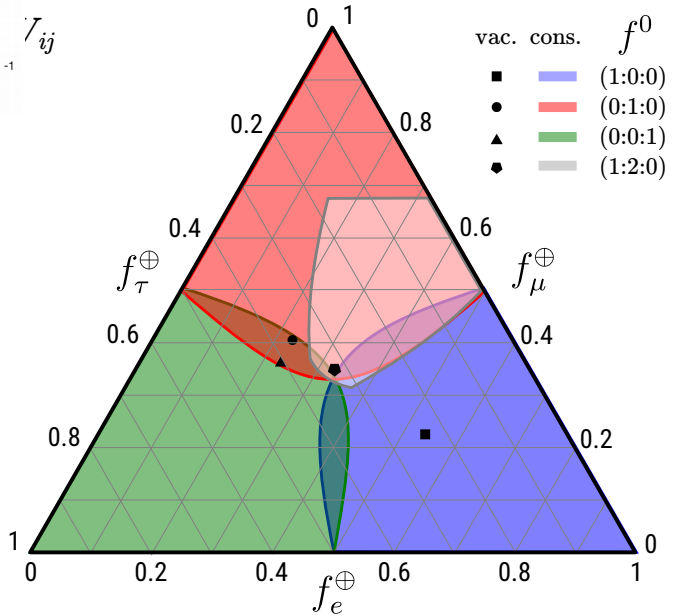
All NP effects are homogeneous in space

Composition in a homogeneous halo



Homogeneous DM distribution can mimic New Physics effects

Higher ν-energy, smaller potential are accessible



Charge assignments

5 possible models

	L	N_1	N_2	S	X
$n=1$	1	-1	$1/7$	$6/7$	$2/7$
$n=2$	1	-1	$1/3$	$2/3$	$2/3$
$n=3$	1	-1	$3/5$	$2/5$	$6/5$

m+n = 4

$$V_{\rm I} = \lambda_{\rm cp} e^{i\delta} X^m S^{\dagger n}$$

m+n = 3

	L	N_1	N_2	S	X
$n=1$	1	-1	$1/5$	$4/5$	$2/5$
$n=2$	1	-1	$1/2$	$1/2$	1

The rest of the scalar potential

$$V_{SX} = -\mu_S^2 |S|^2 + \frac{\lambda_S}{4} |S|^4 - \mu_X^2 |X|^2 + \frac{\lambda_X}{4} |X|^4 + \lambda_5 |S|^2 |X|^2 + V_{\rm I}$$

$$V_{\rm HSX} = -\mu_H^2 H^\dagger H + \frac{\lambda_H}{4} (H^\dagger H)^2 + \lambda_{HS} |S|^2 H^\dagger H + \lambda_{HX} |X|^2 H^\dagger H$$

Mass spectrum

$$m_h^2 \simeq \frac{v_h^2}{2}\left\{\frac{\lambda_H}{2} + 2\left(\frac{\lambda_{HX}^2\lambda_S + \lambda_{HS}^2\lambda_X - 4\lambda_5\lambda_{HS}\lambda_{HX}}{4\lambda_5^2 - \lambda_S\lambda_X}\right)\right\}$$

$$M_{\zeta_3}^2 \simeq \frac{v_S^2}{2}\left(\frac{-A + A\psi + 2\lambda_X\omega\psi}{2\psi}\right)$$

$$M_{\zeta_4}^2 \simeq \frac{v_S^2}{2}\left(\frac{A + A\psi + 2\lambda_X\omega\psi}{2\psi}\right)$$

$$\lambda_S = A + \lambda_X\omega^2$$

$$\lambda_5 = -A\left(\frac{\sqrt{1-\psi^2}}{4\,\omega\,\psi}\right)$$

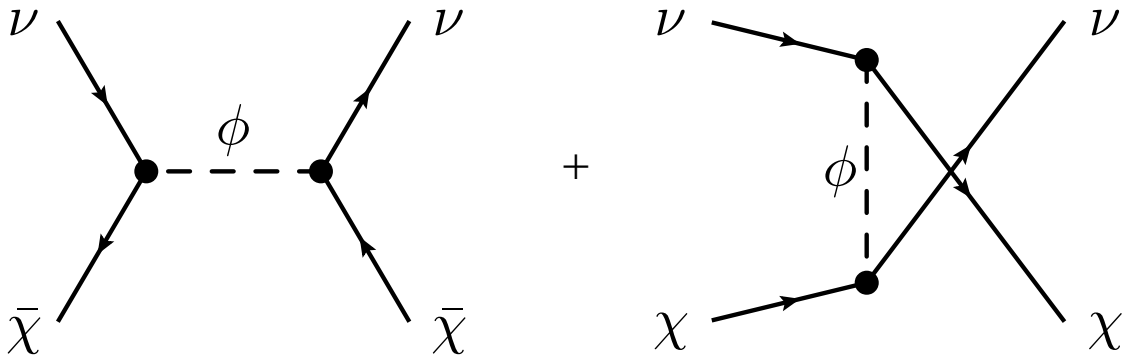
Numerology

Parameter	Value
M	100 TeV
μ	10 MeV
m_D	10 GeV
v_S	10^8 – 10^{12} GeV
ω	0.4 – 1.6

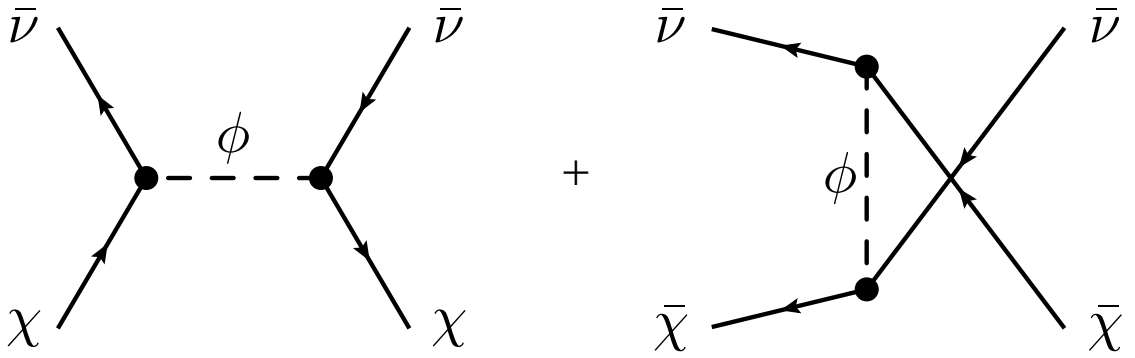
$$\lambda_{\rm cp} \simeq \frac{M_J^2}{v_S^2} < 10^{-22}$$

Dirac DM model

Neutrinos



Antineutrinos



No cancellation at first order due to diagrams are different