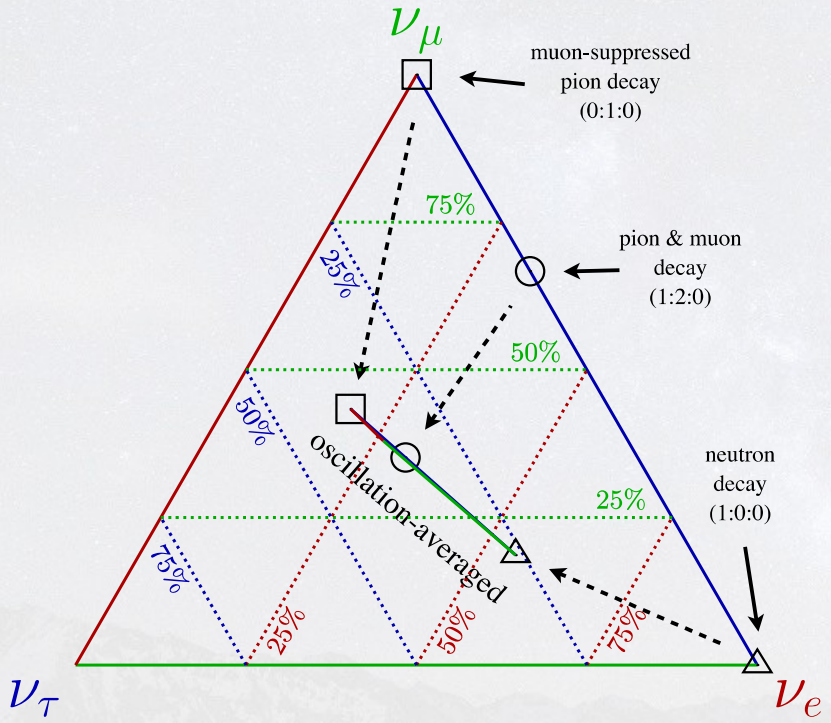
Neutrino oscillations in the galactic DM halo

Roberto A. Lineros
Instituto de Física Corpuscular UVEG/CSIC

In collaboration with P. F. de Salas and M. A. Tórtola
arXiv: 1601.057980

RICAP 2016. 21-24 June 2016

Motivation



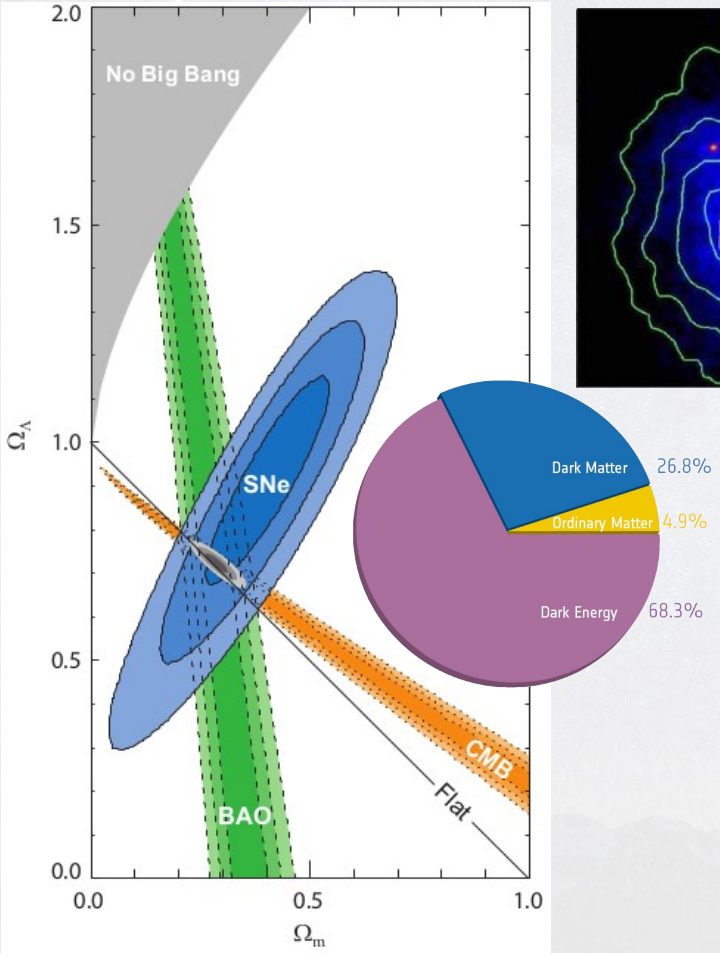
Outline

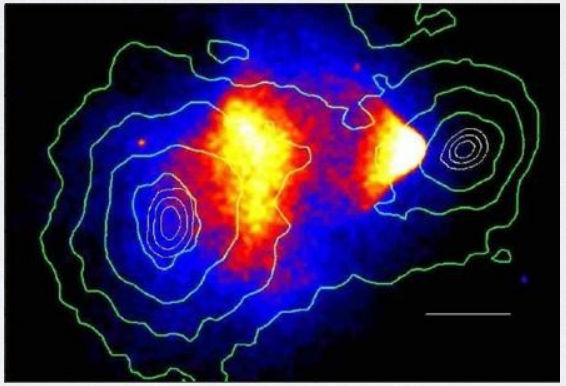
Introduction

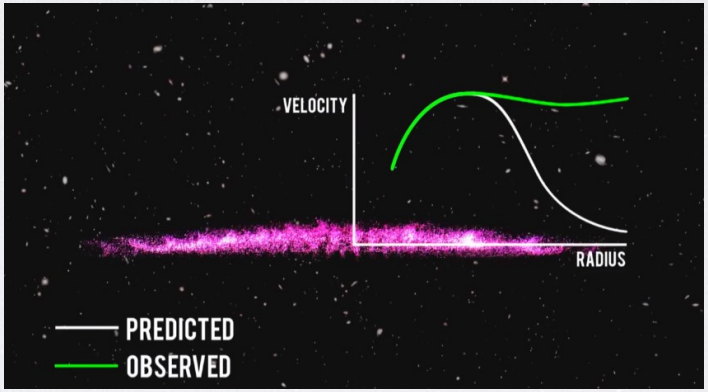
DM effects in neutrino oscillation

Conclusions

Dark Matter







Observations support Dark Matter

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

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

Neutrino oscillations

Flavor and mass eigenstates do not coincide

$$|\nu_\alpha\rangle = \sum_k U^*_{\alpha k} |\nu_k\rangle$$

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

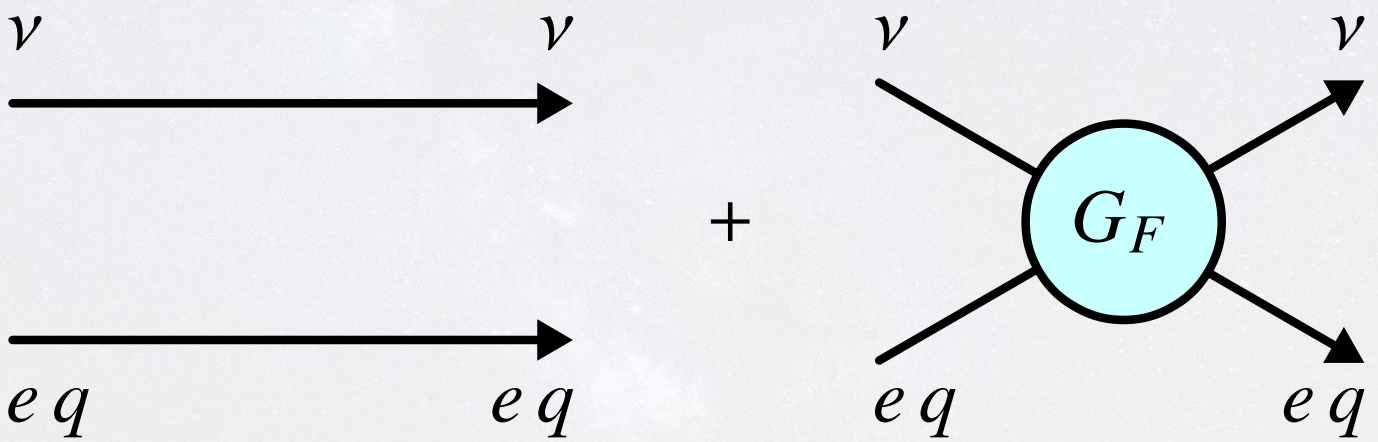
Mass eigenstates evolve differently.

The final neutrino flavor depends on:

- Initial state
- Source distance
- Neutrino energy

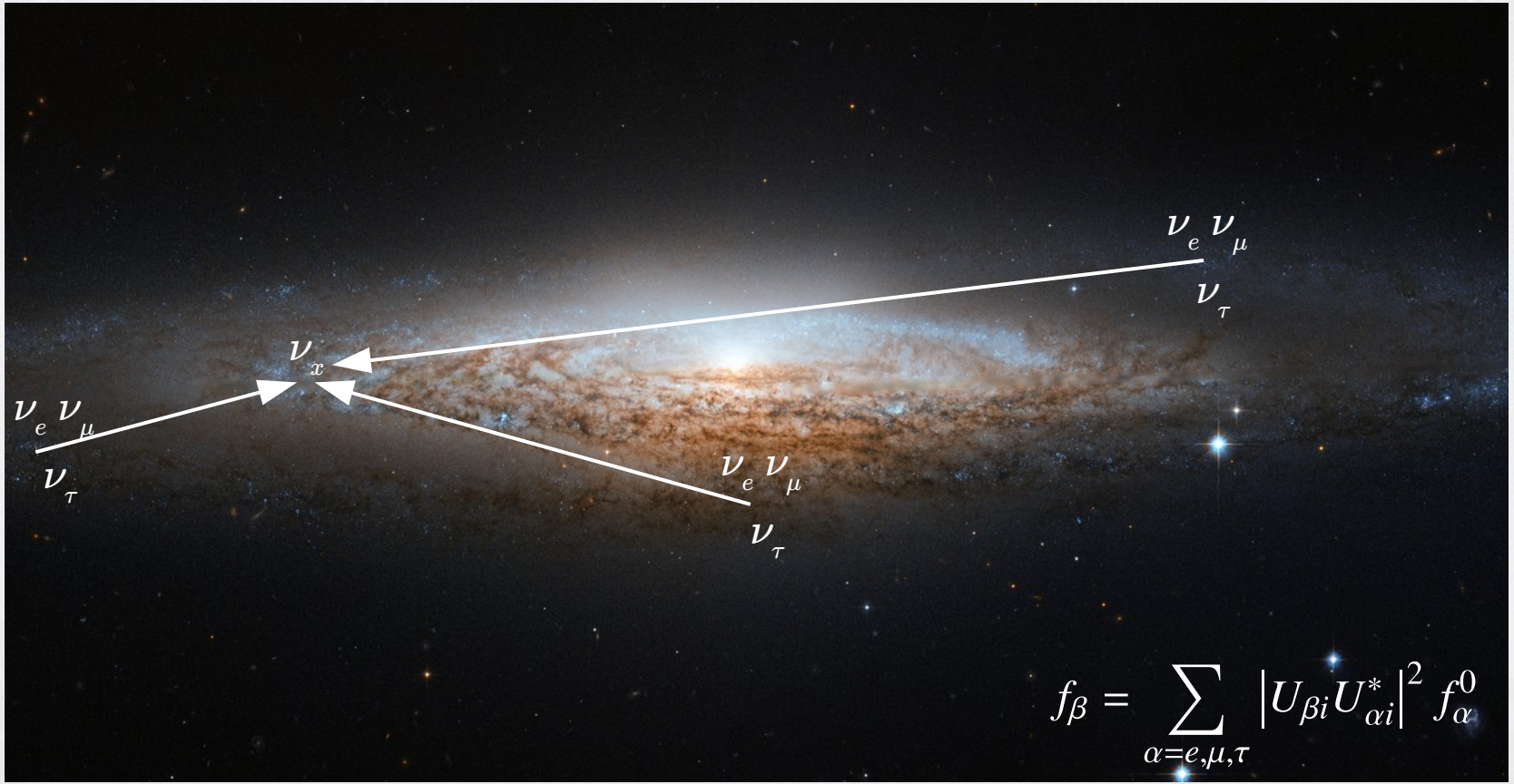
Matter effects (a.k.a. MSW effect)

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

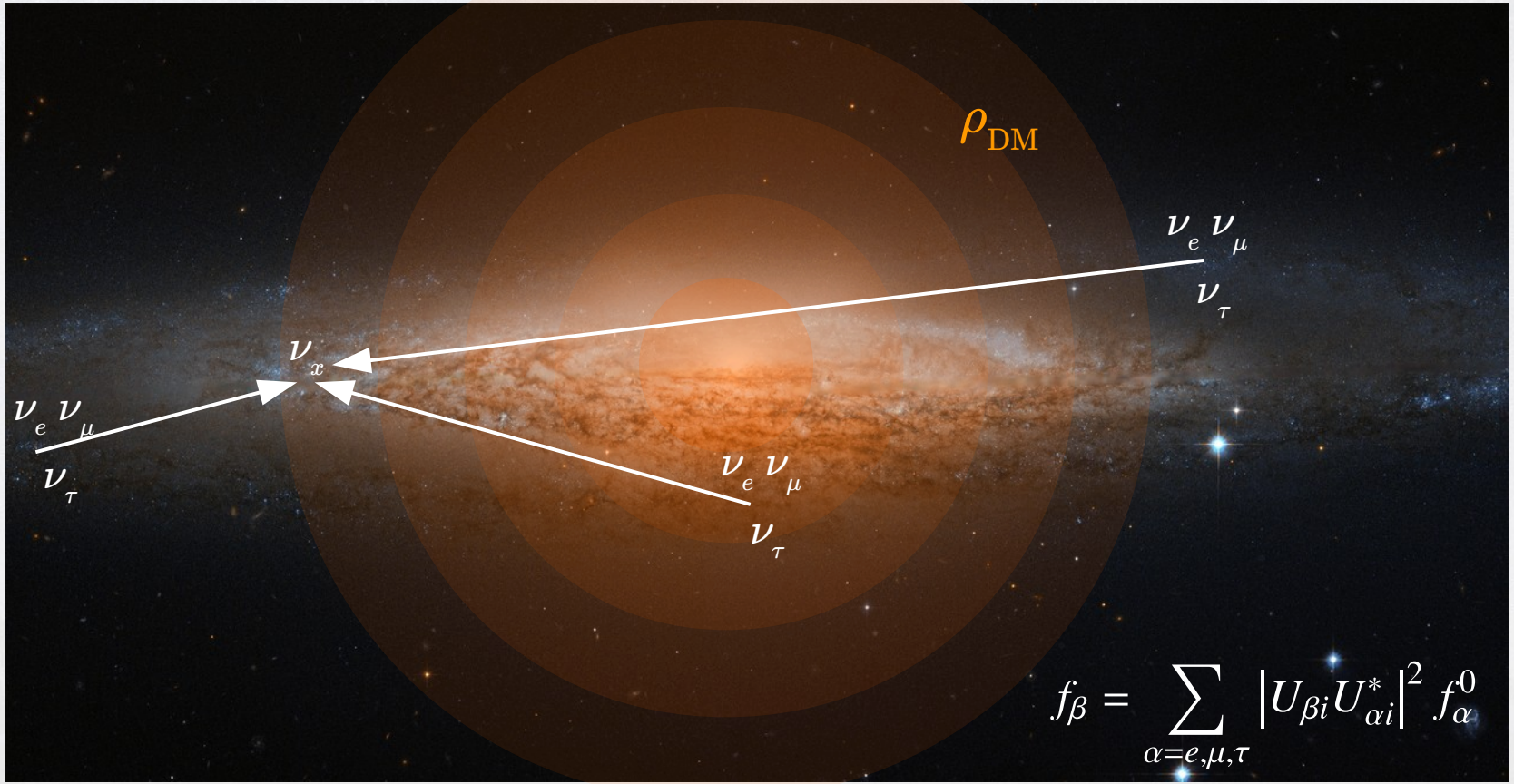


$$\mathcal{H}_{\text{tot}} = \mathcal{H}_{\text{vac}} + \mathcal{V}$$

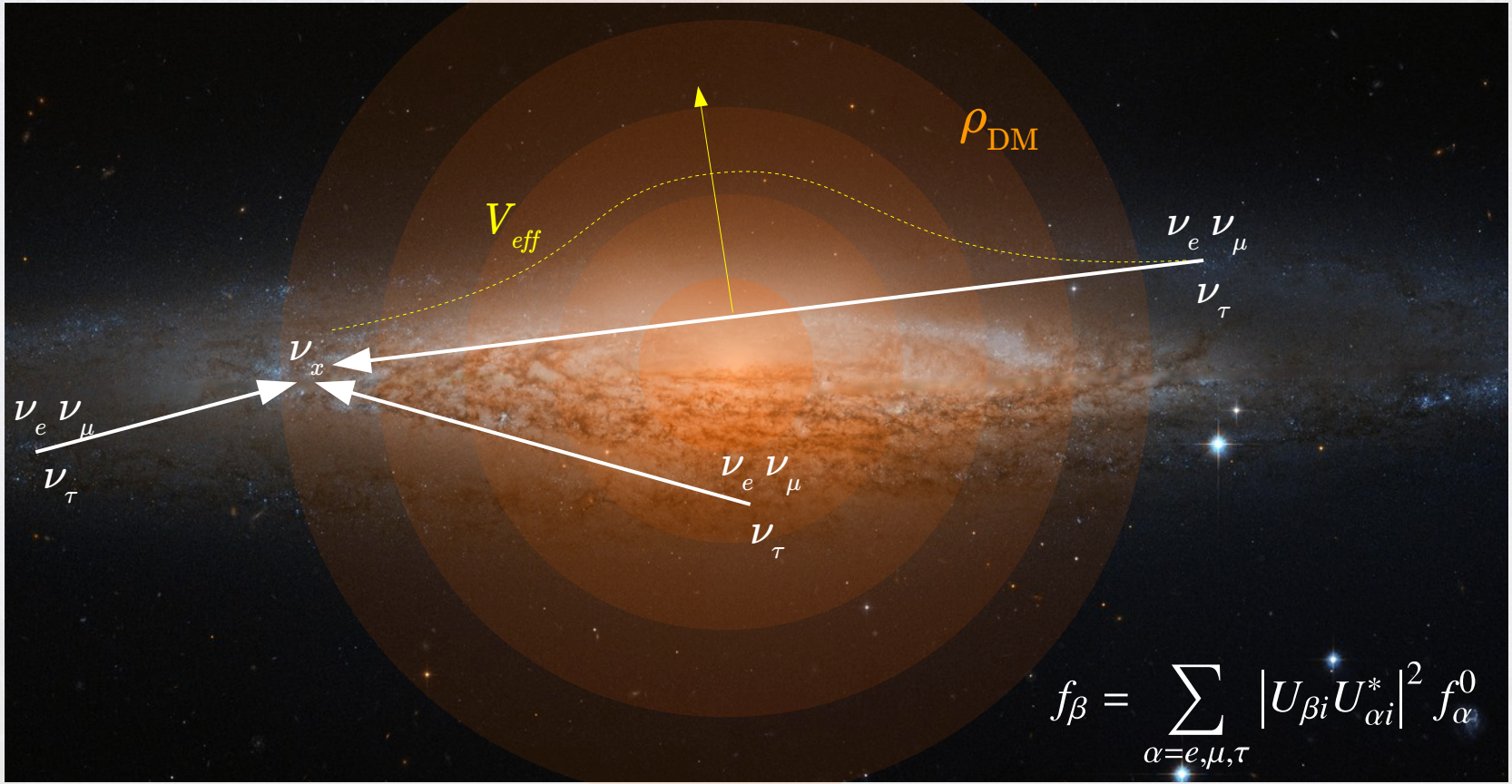
Dark Matter effects



Dark Matter effects

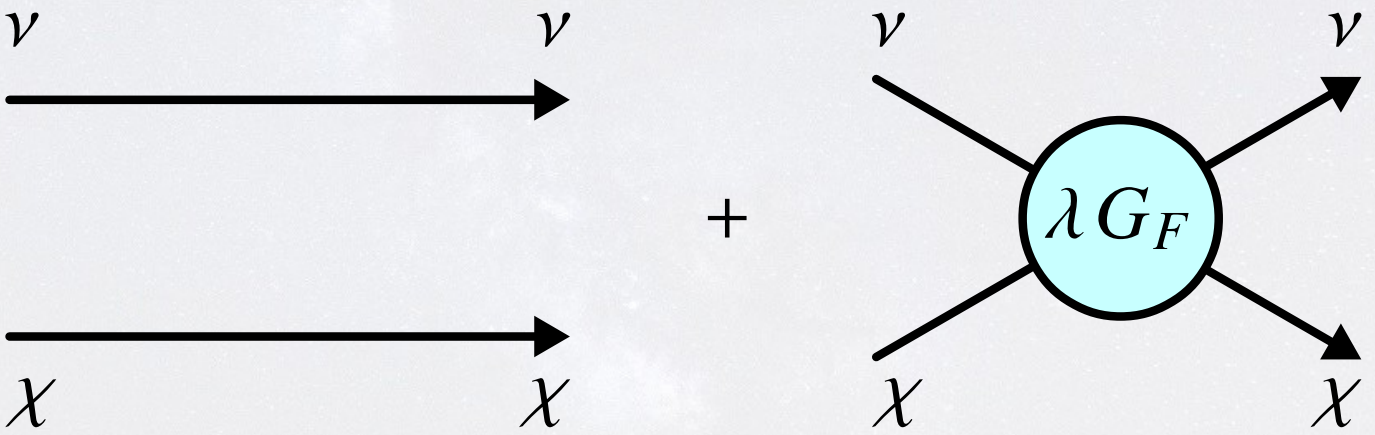


Dark Matter effects



Dark Matter effects

The interaction with a dark matter might modify the oscillation patterns w.r.t. vacuum



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

Dark Matter effects

We parameterized the effective potential using a “weak interaction” form:

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

But also spatial dependency:

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

Dark Matter effects

We parameterized the effective potential using a “weak interaction” form:

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

But also spatial dependency:

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

Dark Matter effects

We parameterized the effective potential using a “weak interaction” form:

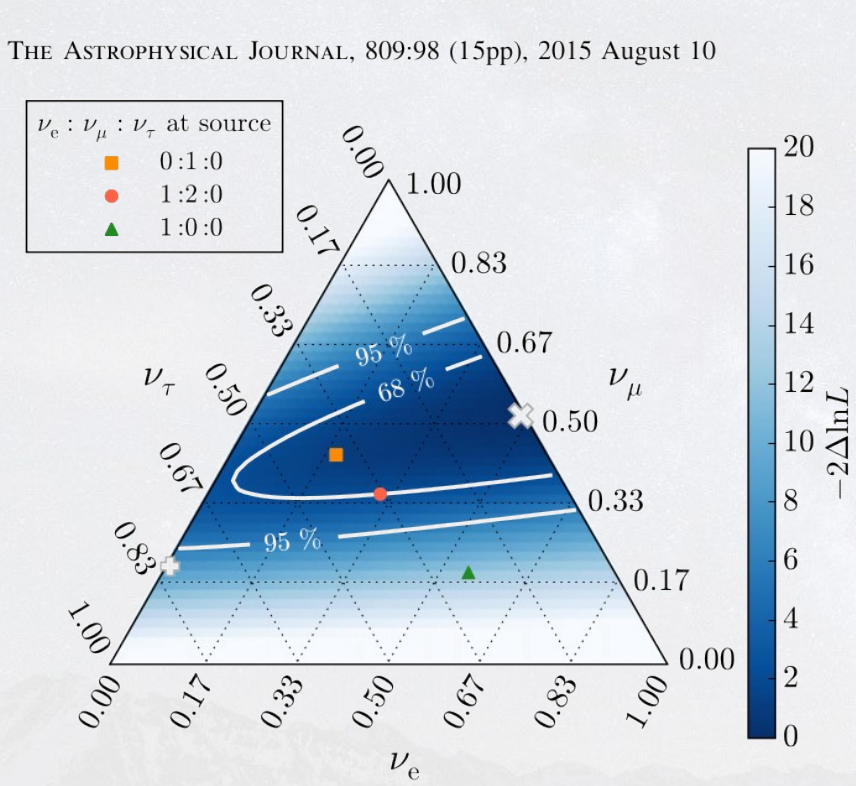
$$\mathcal{V}_{\alpha\beta} = \lambda_{\alpha\beta} G_F N_X$$

What is the motivation to add neutrino-DM interactions?

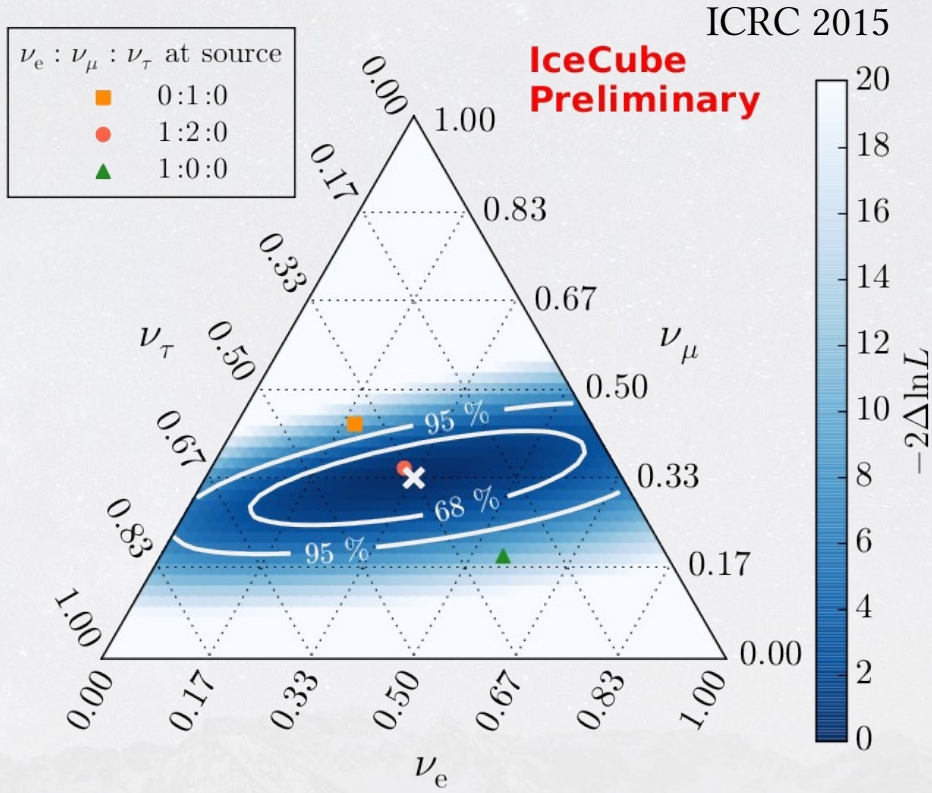
But also spatial dependency:

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

Flavor composition in IceCube

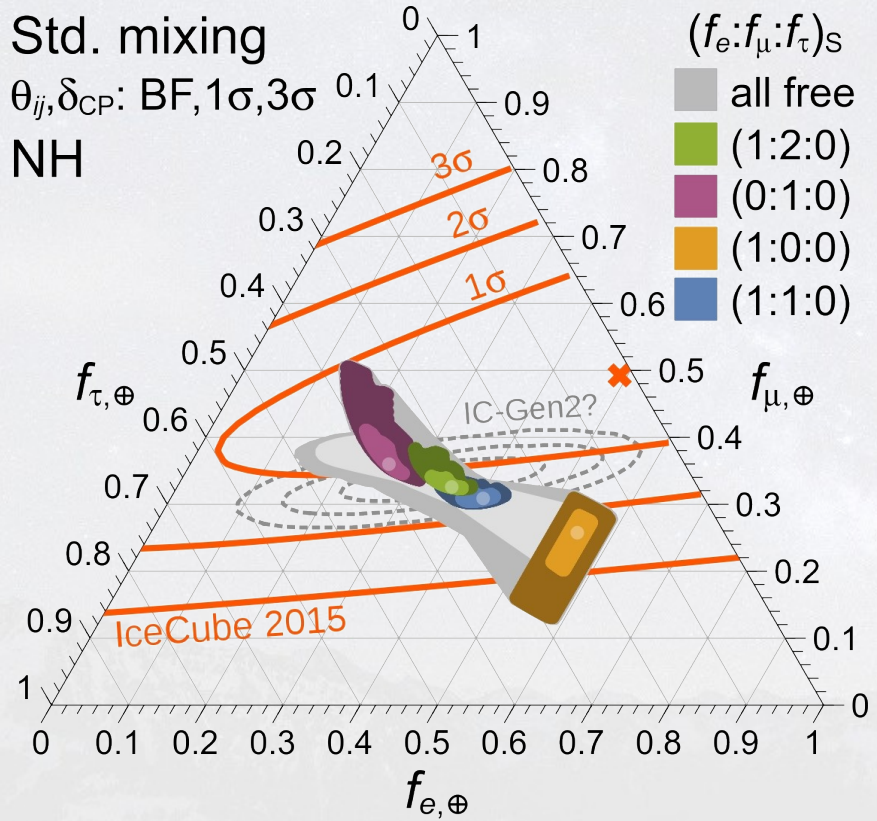


Latest result on flavor composition

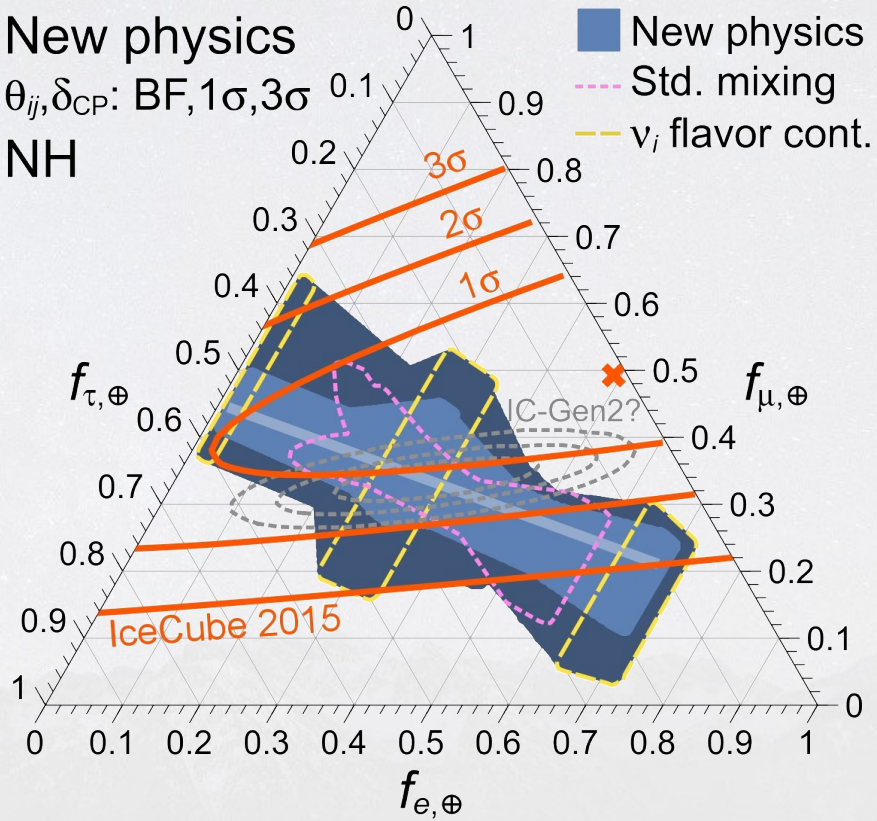


Sensitivity after 10 years

What we expect?

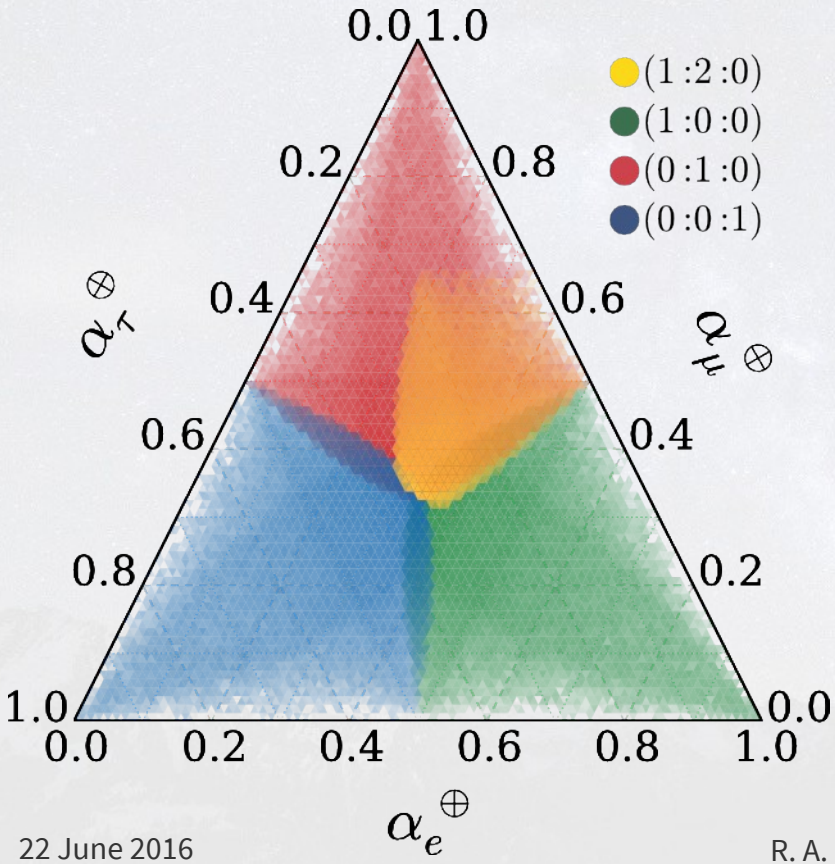


M. Bustamante et al. PRL 115, 161302 (2015)



Effects from New Physics

Argüelles et at. PRL 115, 161303 (2015)



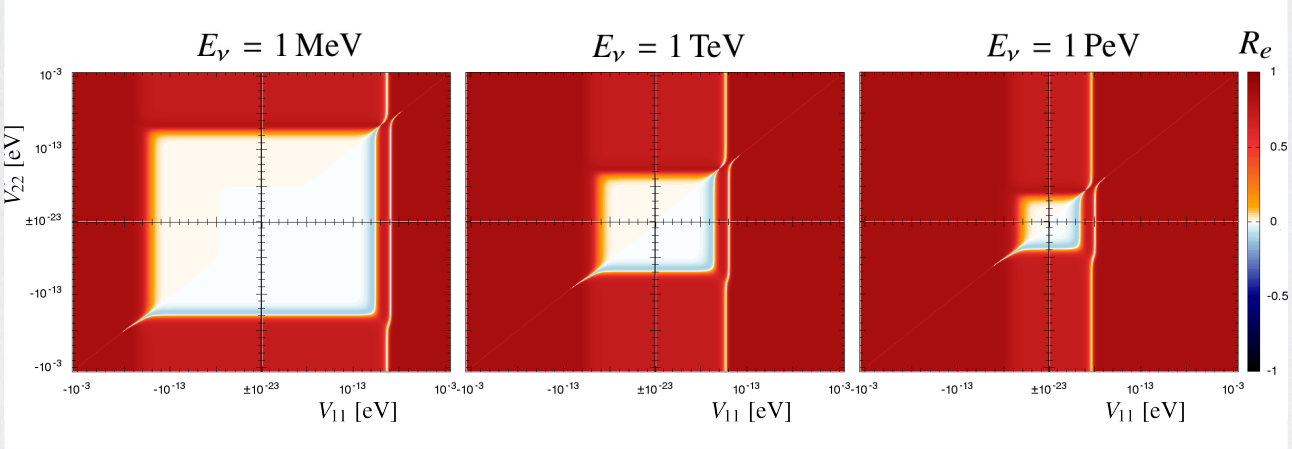
Sources of New Physics:

- Space torsion

- CPT - Lorentz violation

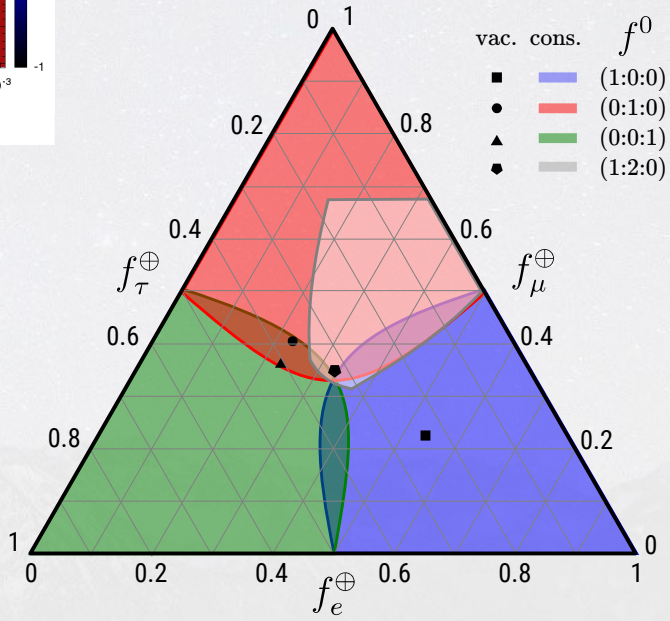
All NP effects are homogeneous in space

Composition in a homogeneous halo



Homogeneous DM distribution can mimic New Physics effects

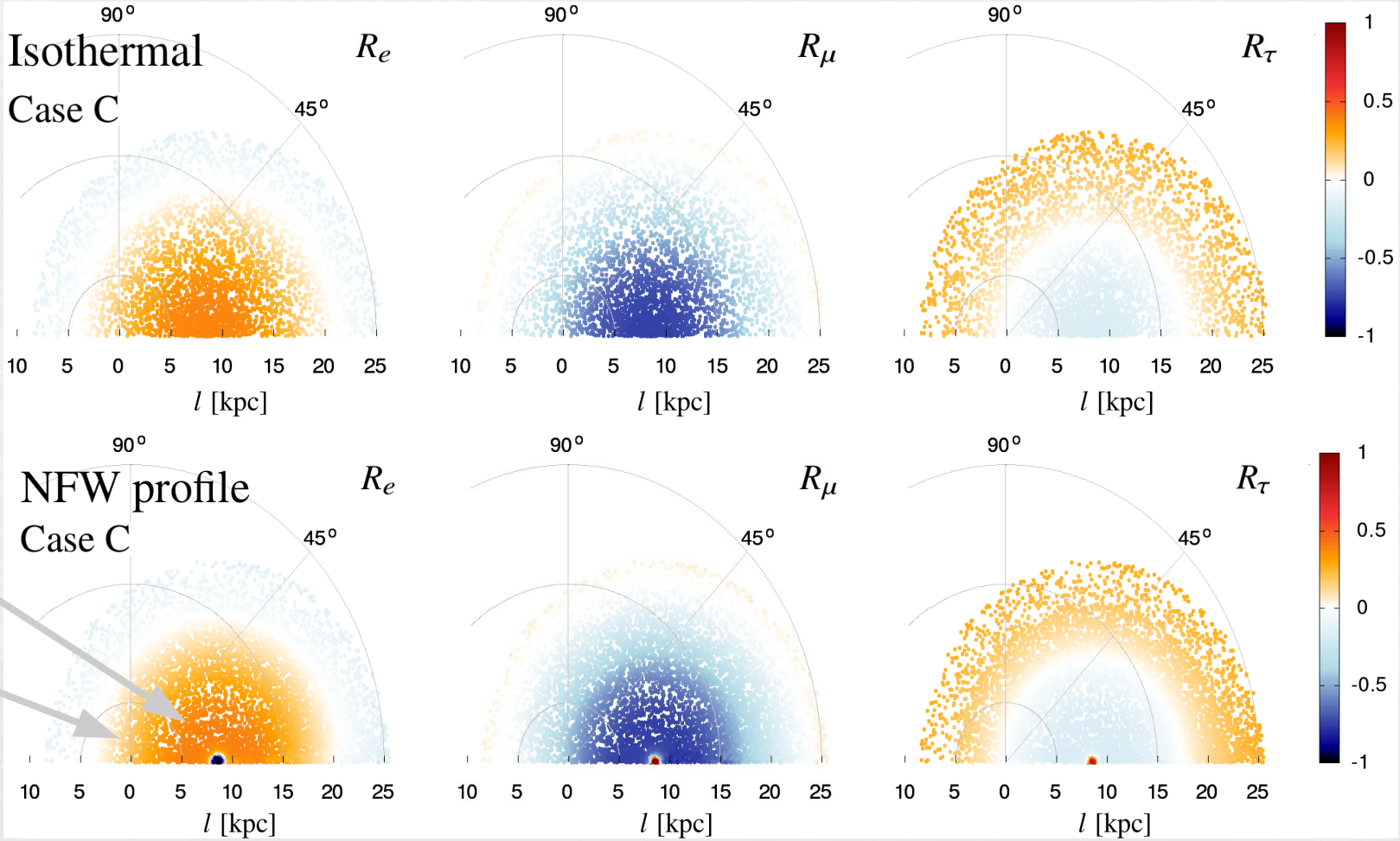
Higher ν-energy, smaller potential are accessible



Spatial dependence

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

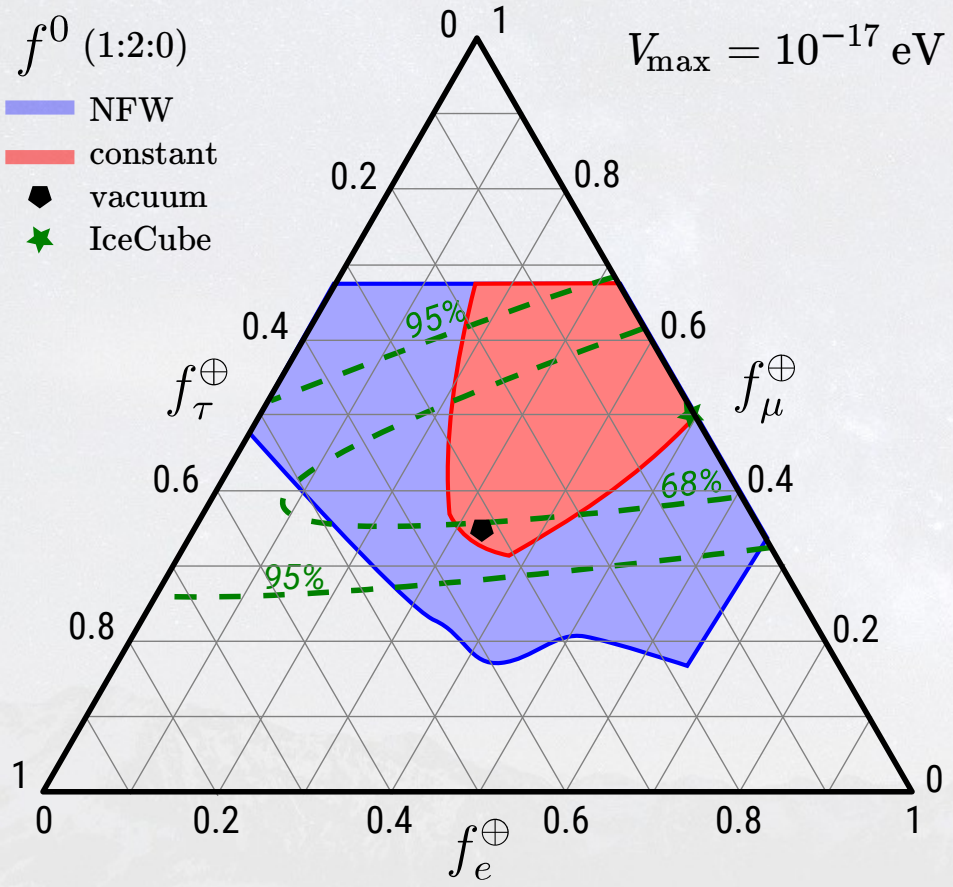
$\mathcal{V}^{\oplus}_{11} = 40 \times 10^{-21}\,\text{eV}$

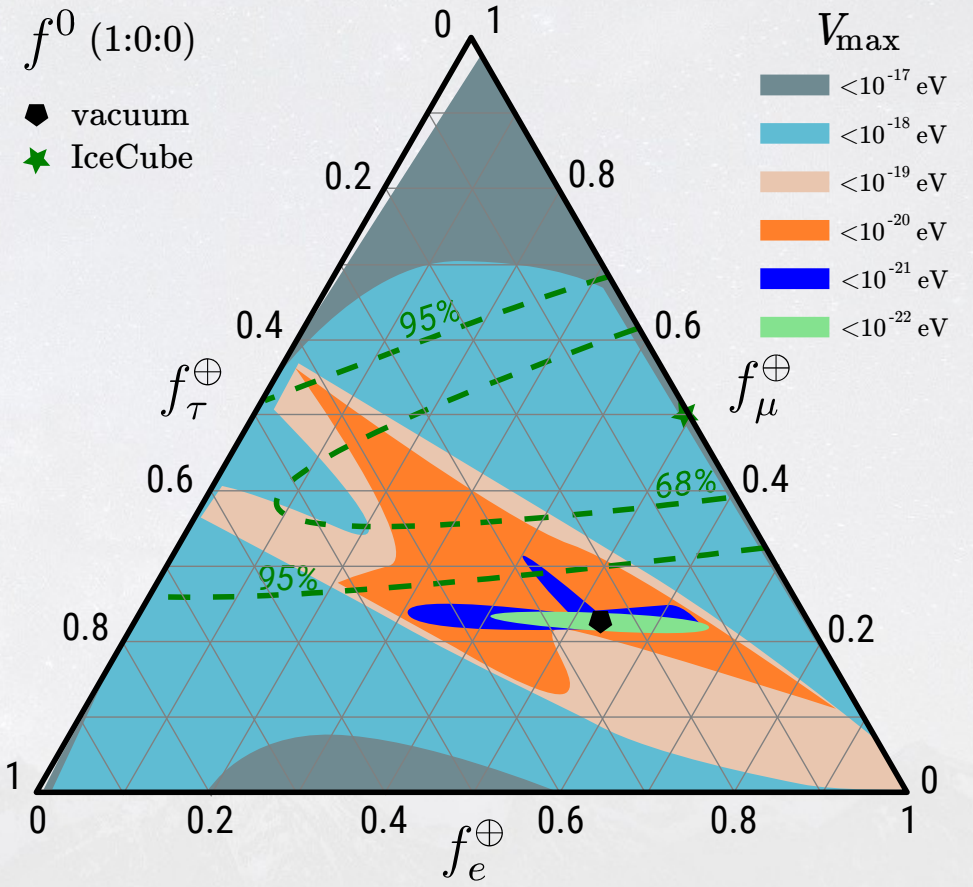


GC

Sun

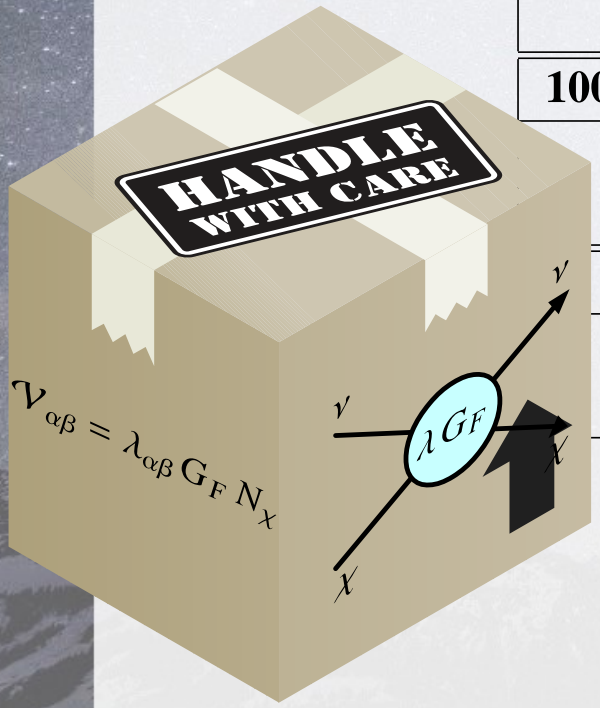
Composition in a NFW halo





Particle physics interpretation

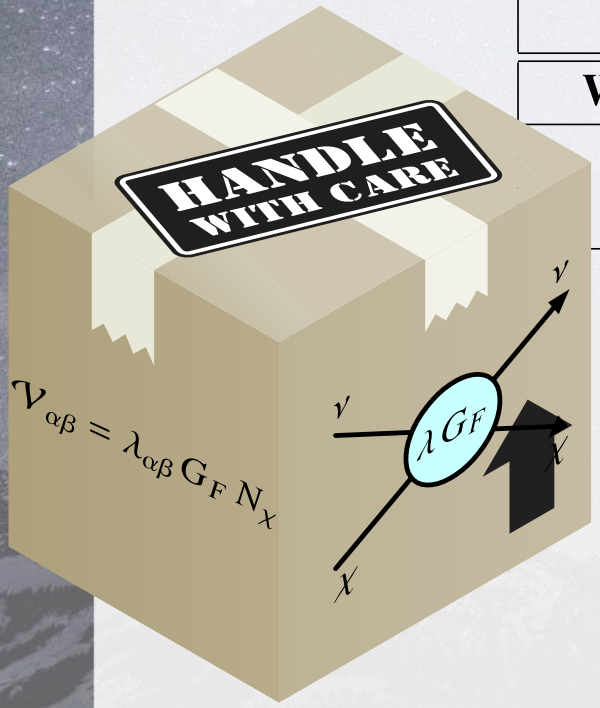
$V_{11}^{\oplus}$ [eV]	10^{-21}	10^{-19}	10^{-17}
Weak scale (a) assumptions:	$G'_F = G_F$, $\lambda_{11} = 1$		
$m_{\rm DM}$ [eV]	10^{-8}	10^{-10}	10^{-12}
l_ν [pc]	10^{-2}	10^{-4}	10^{-6}
100 GeV DM (a) assumptions:	$m_{\rm DM} = 100$ GeV, $l_\nu = 50$ kpc		
λ_{11}	10^{-7}	10^{-9}	10^{-11}
$m_{Z'}$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

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}
$m_{Z'}$ [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}

1 keV DM

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

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

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

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

Conclusions

Flavor composition of astro-ν might open a door to New-Physics effects

Effects from the DM halo modify the oscillation pattern differently than in the homogeneous scenario

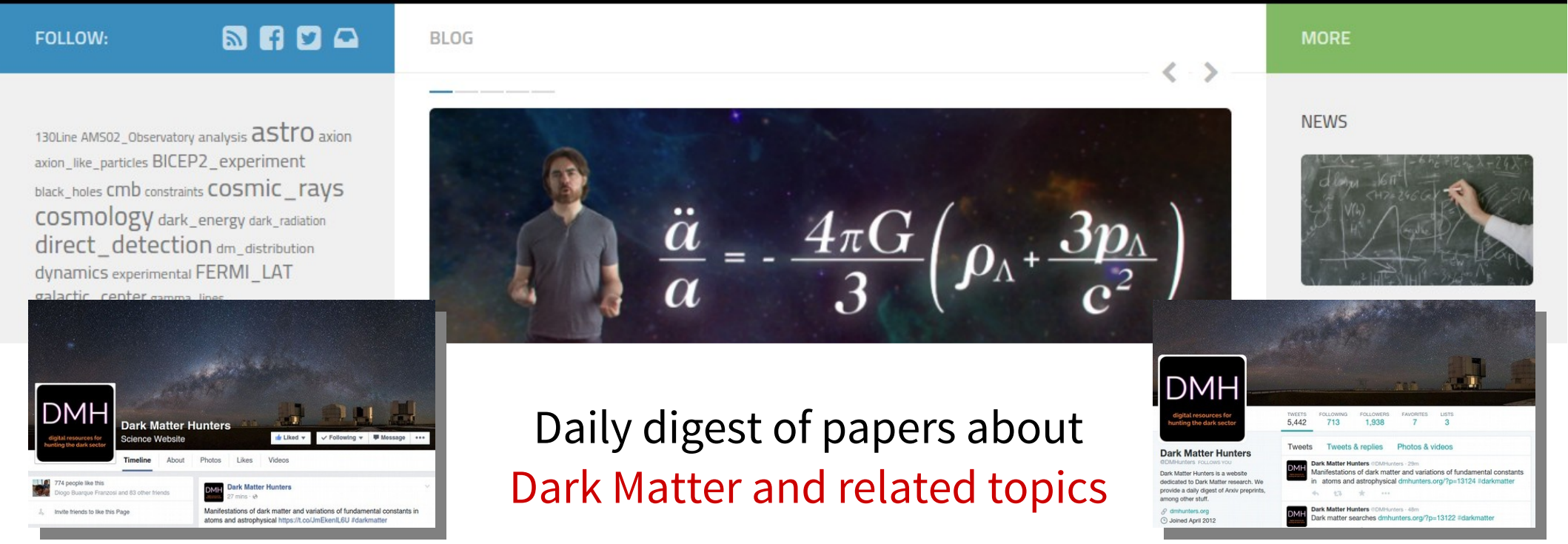
(Hopefully) Correlation between flavor and arrival direction might serve as test of this hypothesis

A particle physics explanation requires mediators lighter than eV

Dark Matter Hunters

Digital resources for hunting the dark sector

www.dmhunters.org



Daily digest of papers about

Dark Matter and related topics

988

2131

LAWPHYSICS

Latin American Webinars on Physics

/LAWebinarsPhysics/

Latin American Webinars on Physics

@lawphysics

lawphysics.wordpress.com

Conclusions

Flavor composition of astro-ν 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

Thanks