

# Neutrino oscillations in the galactic DM halo

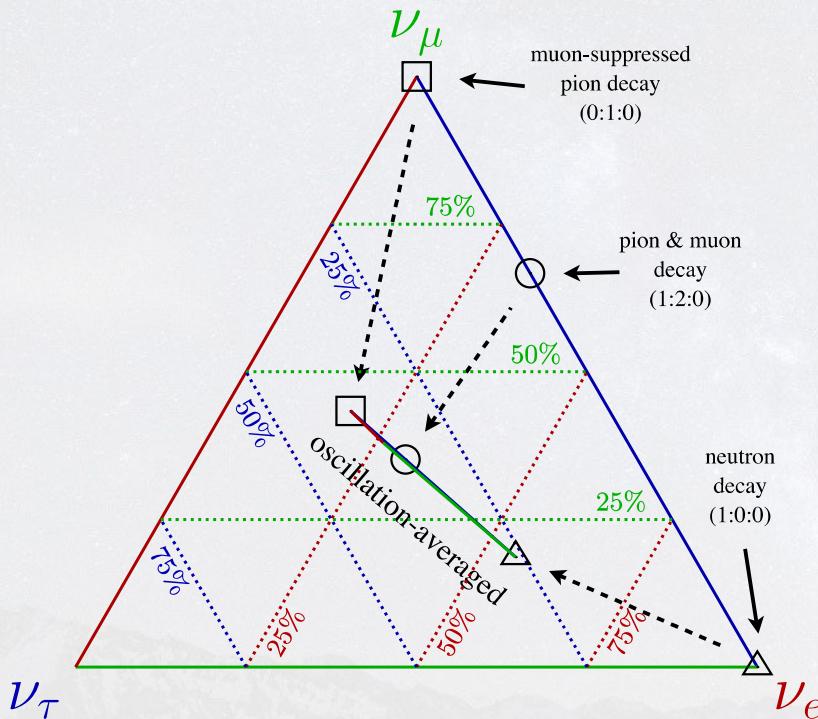
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In collaboration with P. F. de Salas and M. A. Tórtola  
arXiv: 1601.057980

RICAP 2016. 21-24 June 2016



# Motivation



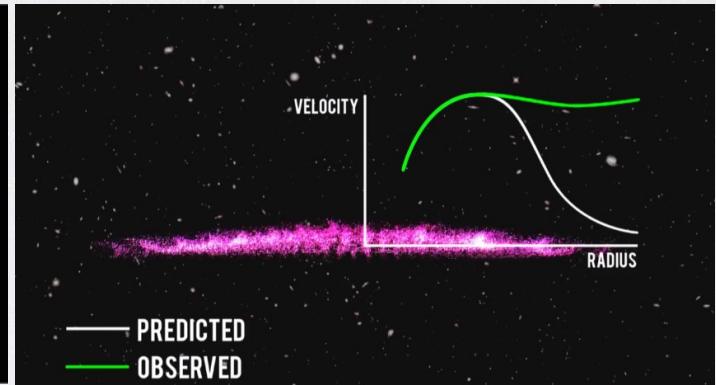
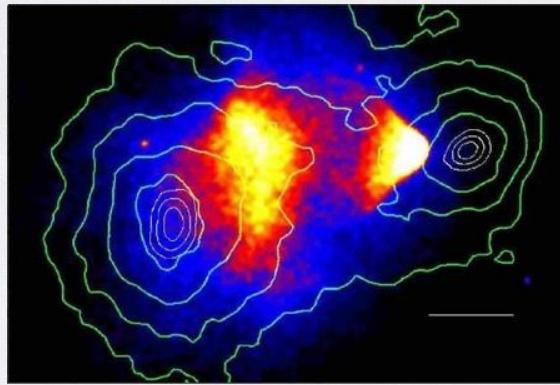
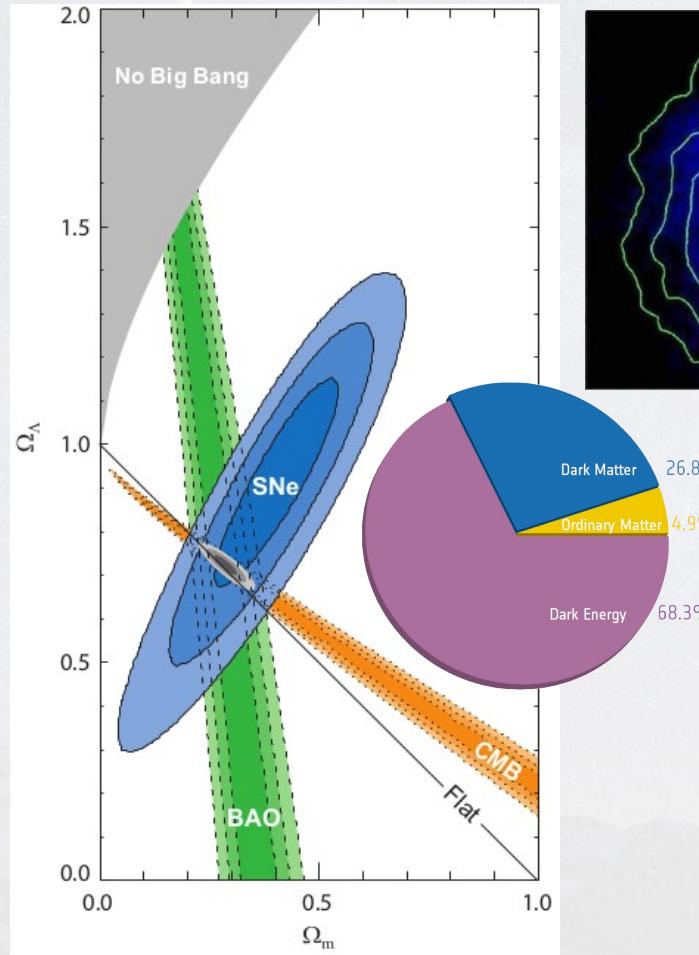
## Outline

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

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

# Neutrino oscillations



Flavor and mass eigenstates **do not coincide**

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

Mass eigenstates **evolve** differently.

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

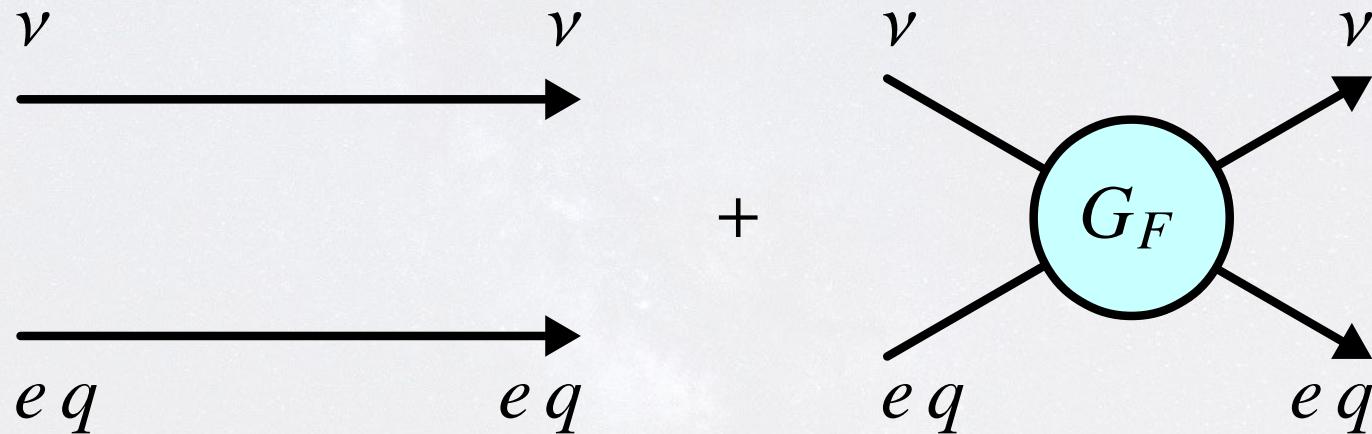
The final neutrino flavor depends on:

- Initial state
- Source distance
- Neutrino energy

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

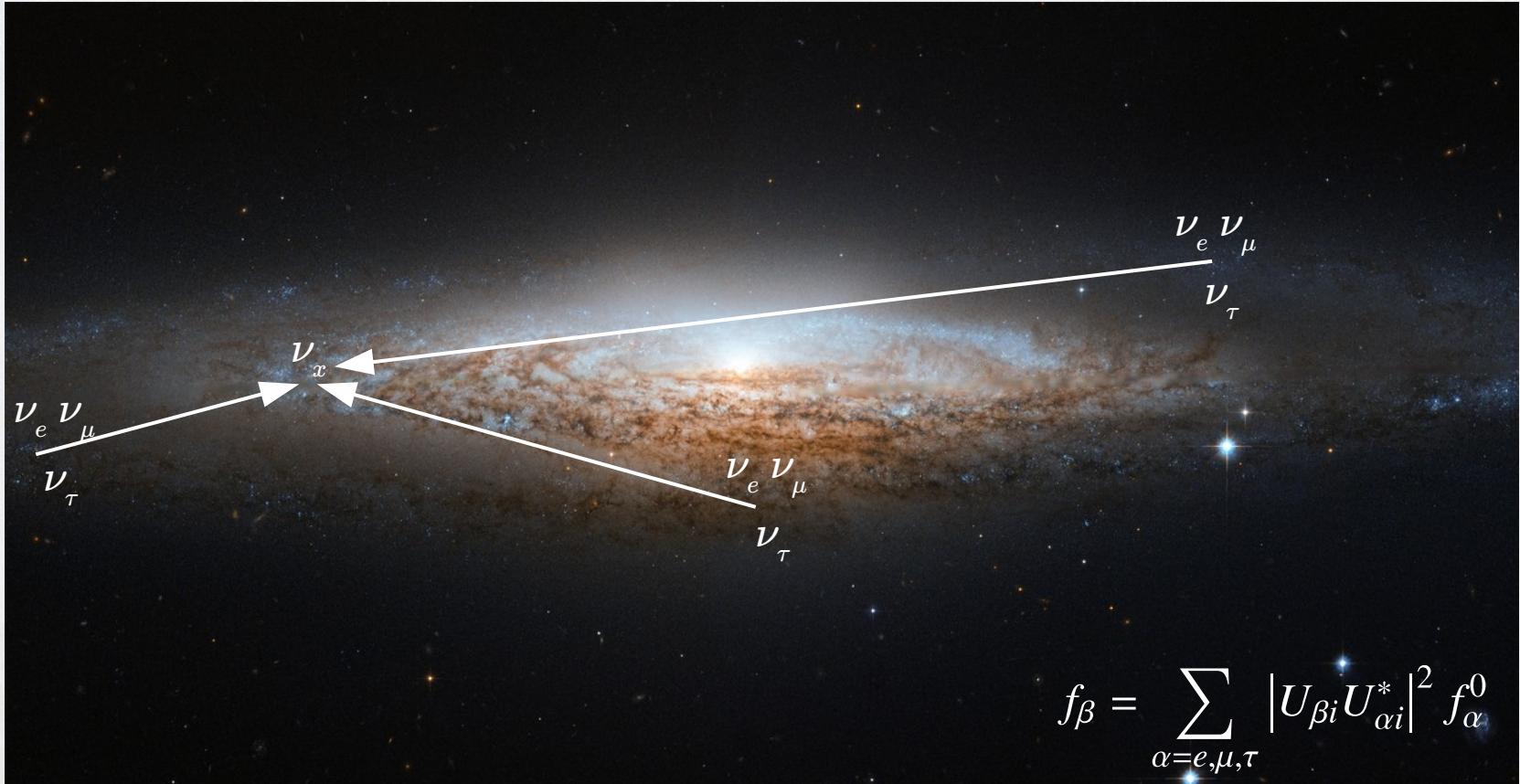


The interaction with a medium modifies the oscillation patterns w.r.t. vacuum



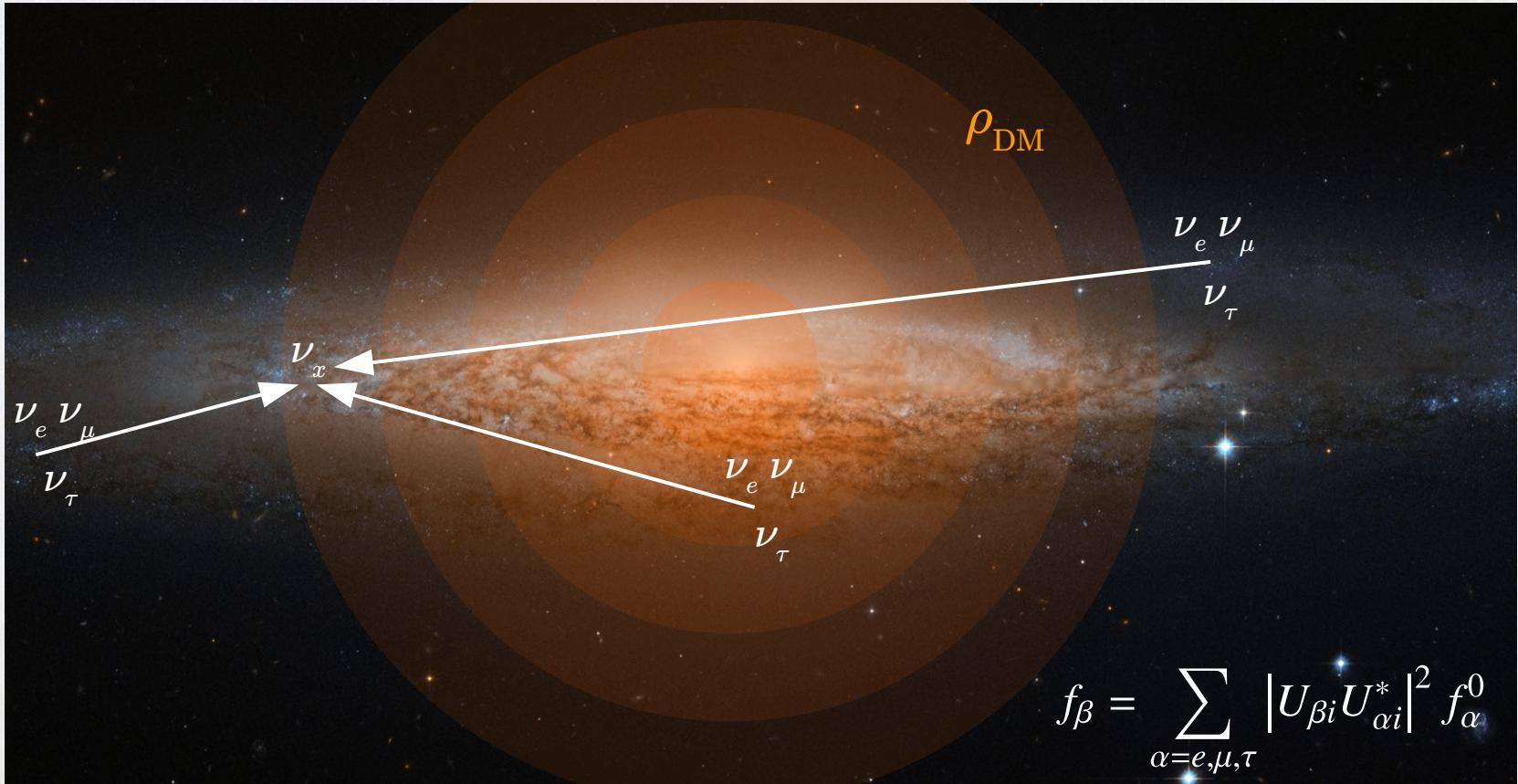
$$\mathcal{H}_{\text{tot}} = \mathcal{H}_{\text{vac}} + \mathcal{V}$$

# Dark Matter effects

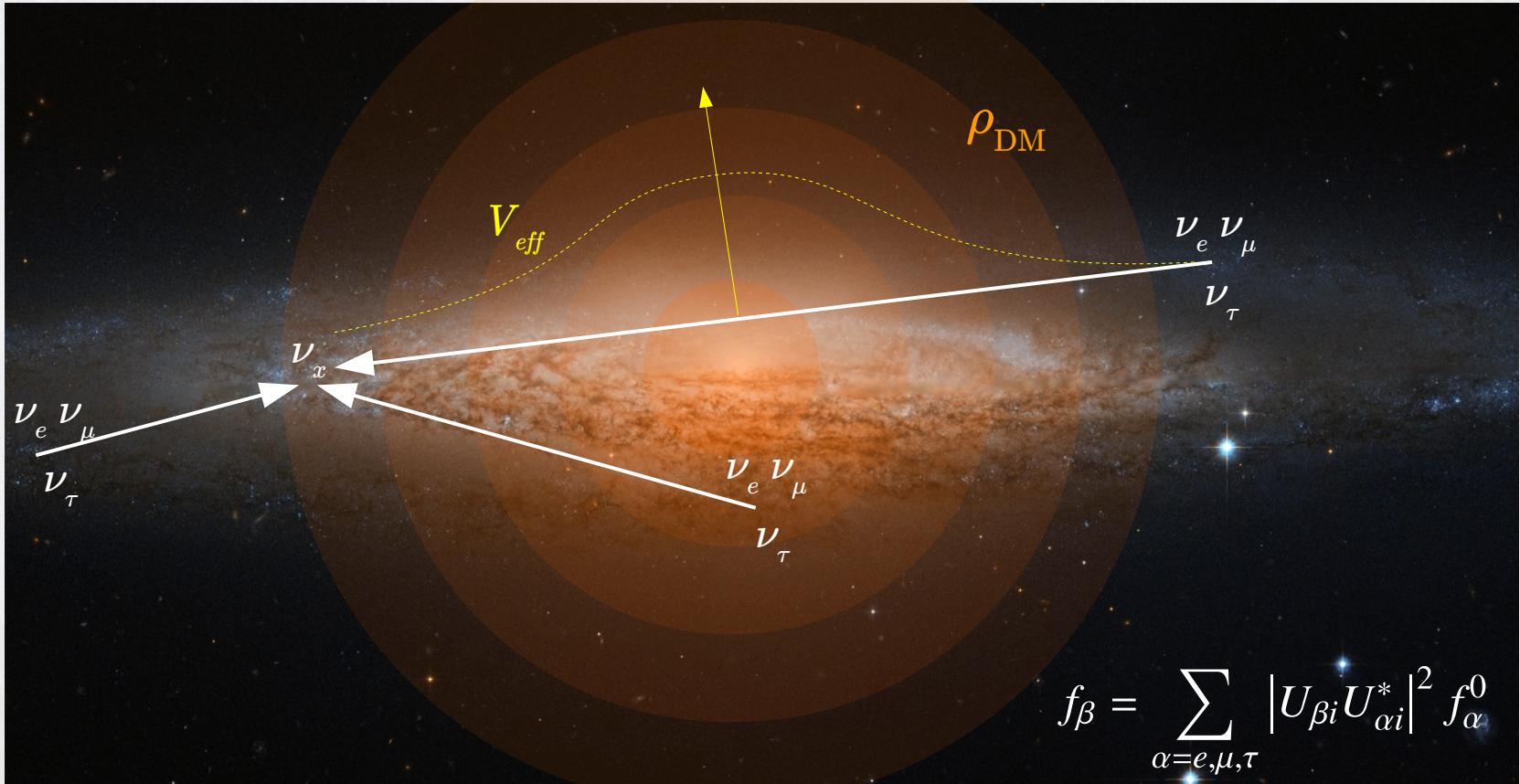


$$f_\beta = \sum_{\alpha=e,\mu,\tau} |U_{\beta i} U_{\alpha i}^*|^2 f_\alpha^0$$

# Dark Matter effects

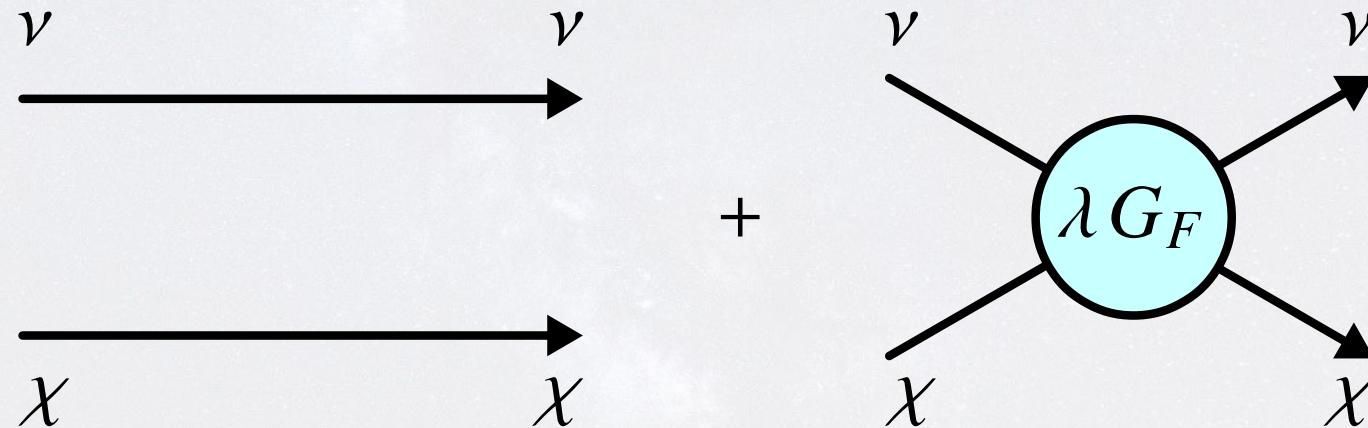


# Dark Matter effects



# 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:

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

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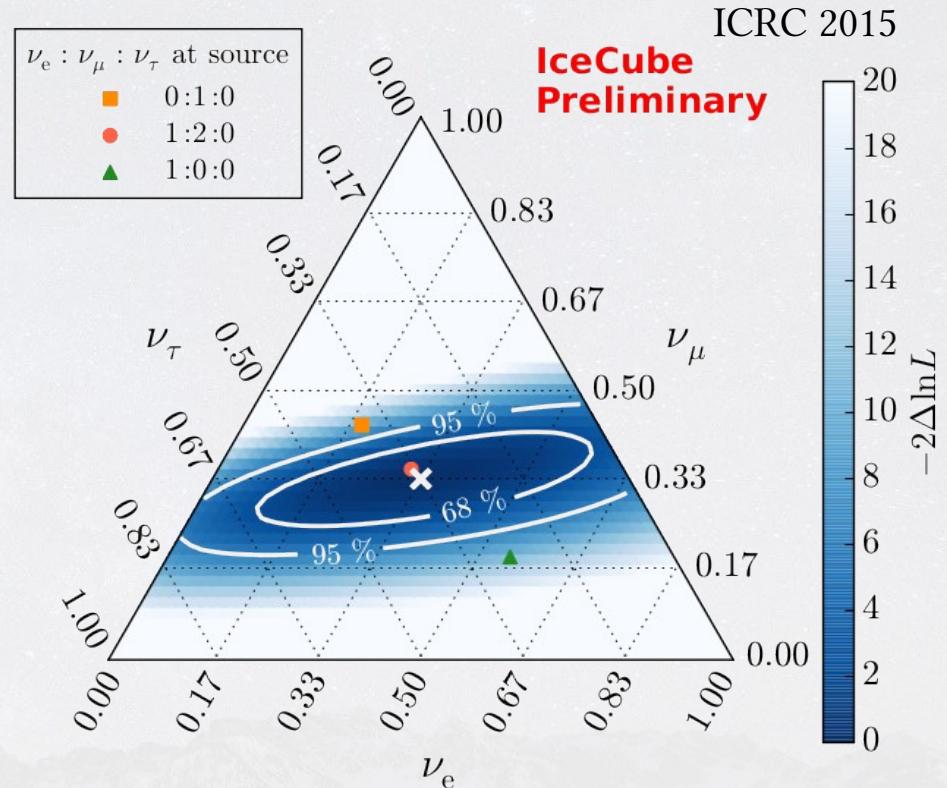
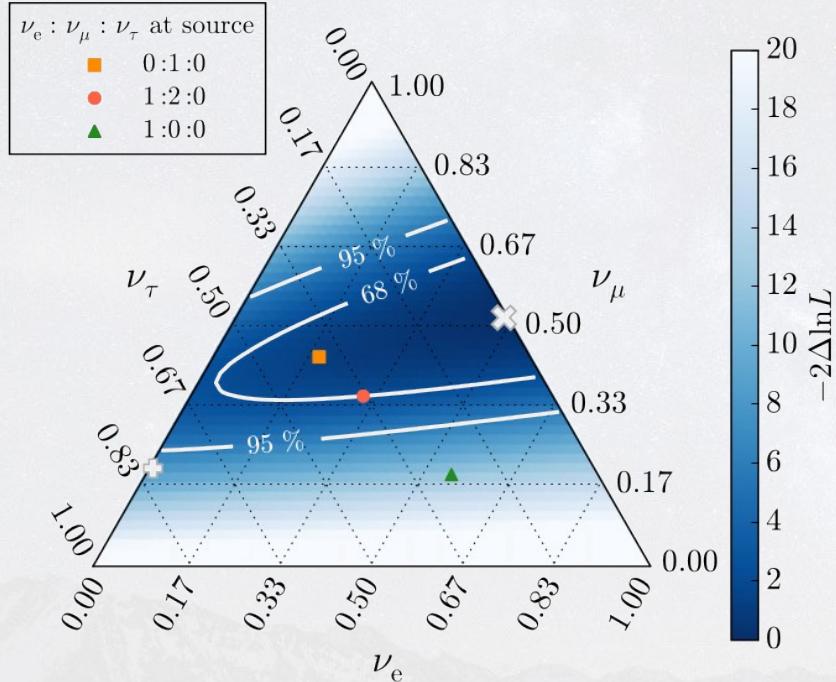
What is the motivation to add neutrino-DM interactions?

But also spatial dependency:

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

# Flavor composition in IceCube

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

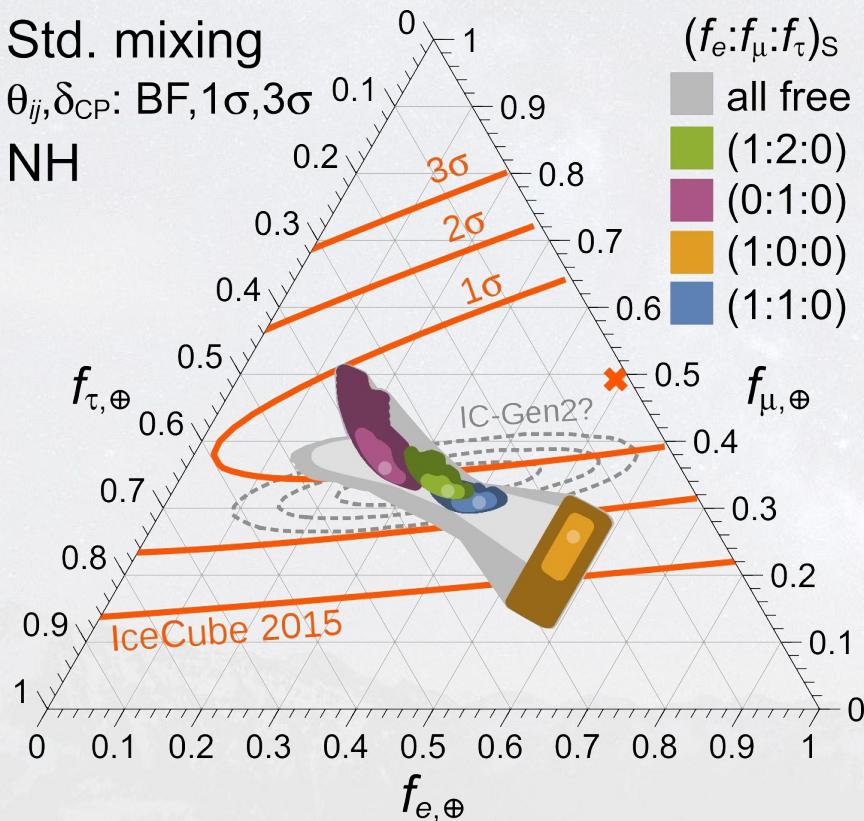


# What we expect?

Std. mixing

$\theta_{ij}, \delta_{CP}$ : BF,  $1\sigma, 3\sigma$

NH

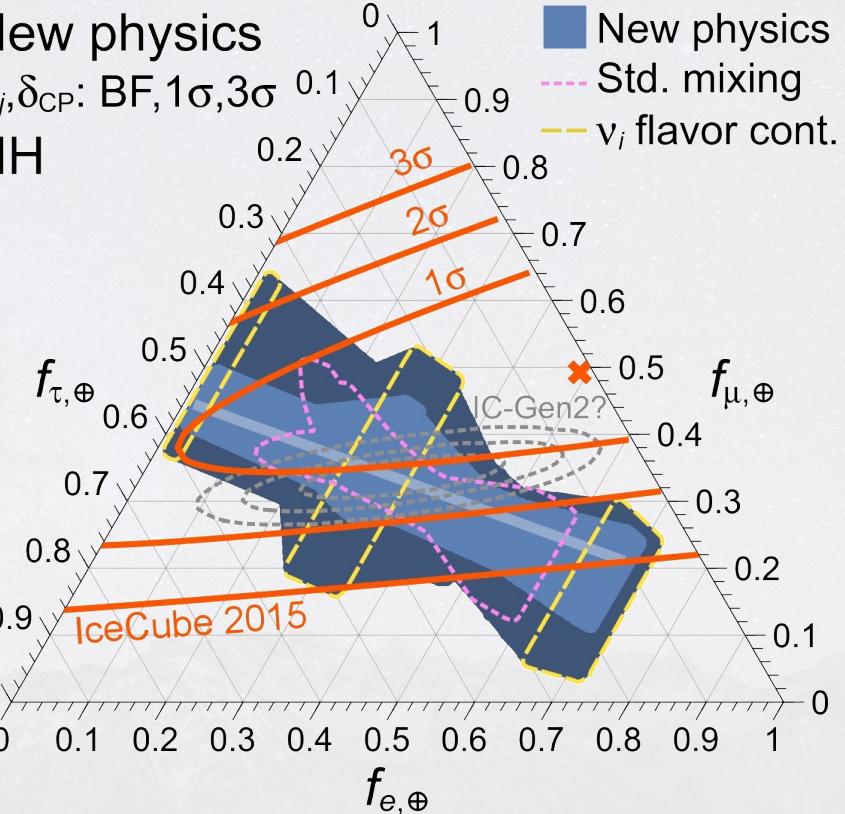


New physics

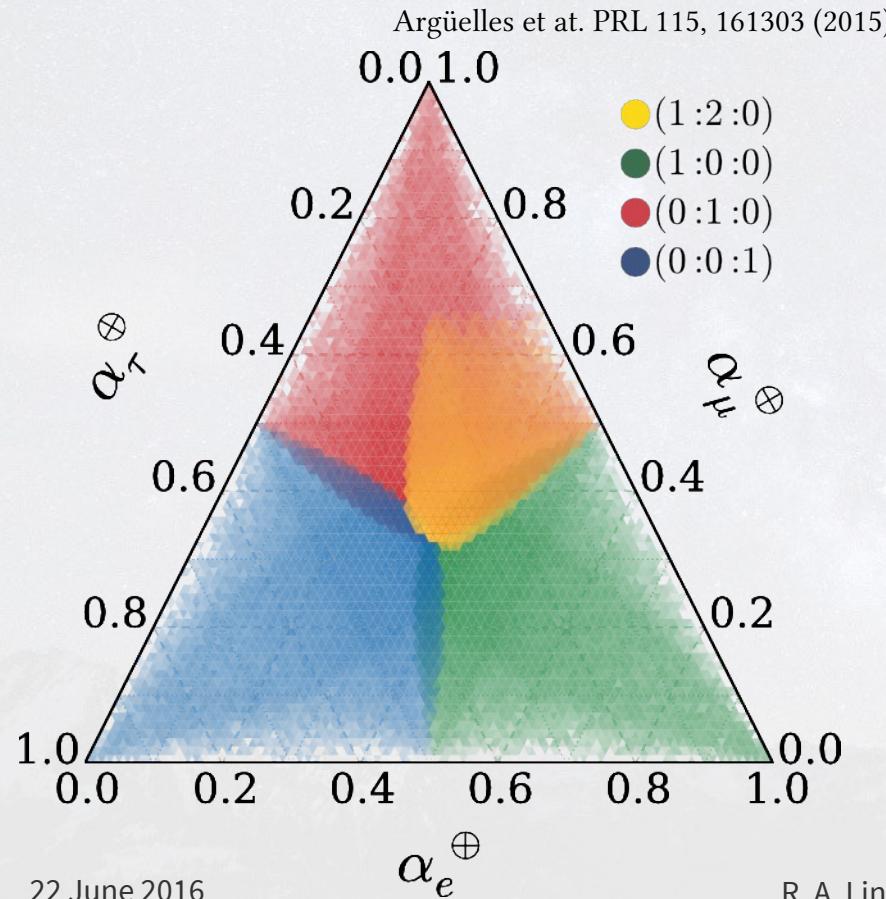
$\theta_{ij}, \delta_{CP}$ : BF,  $1\sigma, 3\sigma$

NH

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



# Effects from New Physics

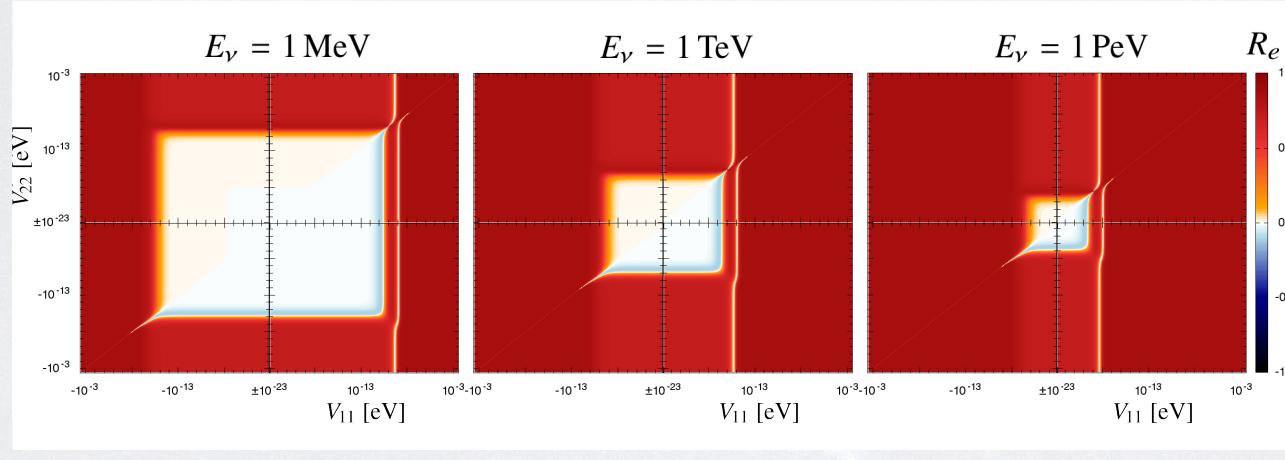


Sources of New Physics:

- Space torsion
- CPT - Lorentz violation

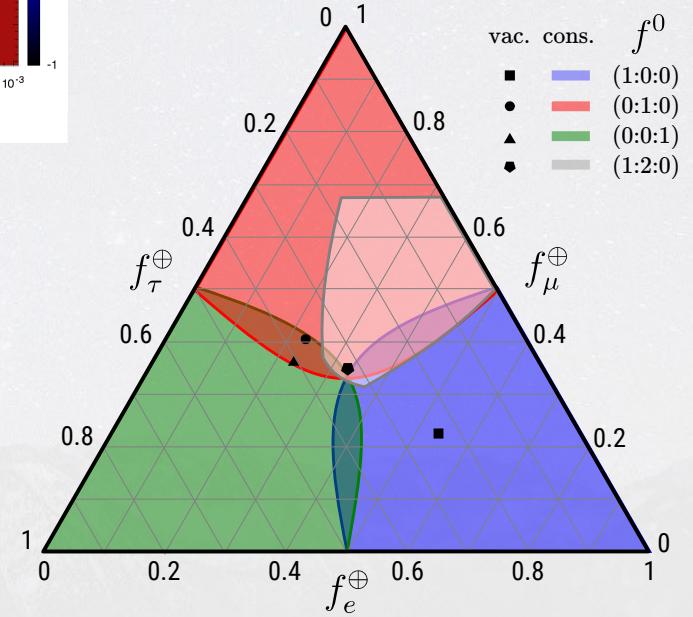
All NP effects are **homogeneous** in space

# Composition in a homogeneous halo



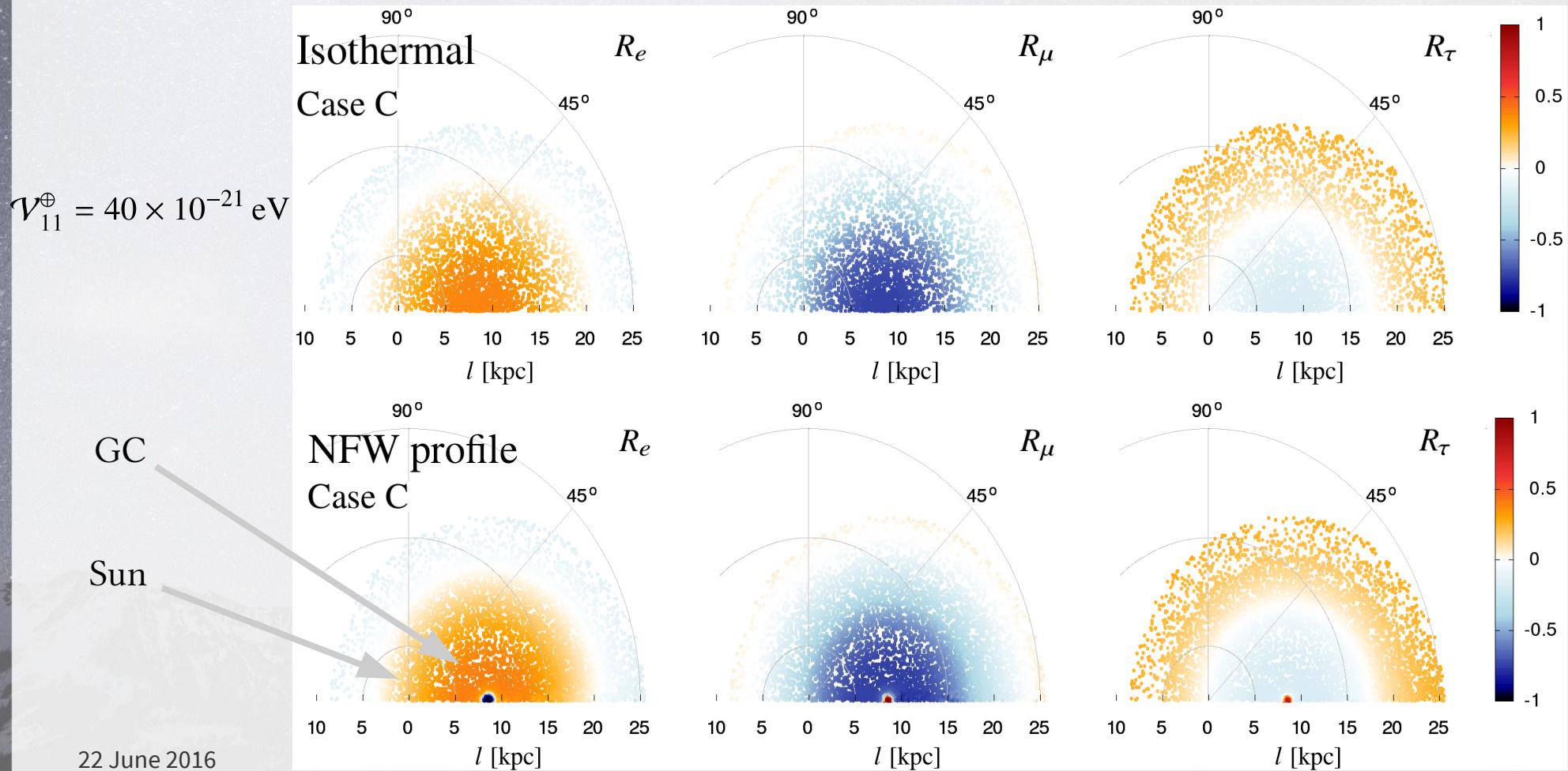
Homogeneous DM distribution can mimic  
New Physics effects

Higher  $\nu$ -energy, smaller potential are  
accessible

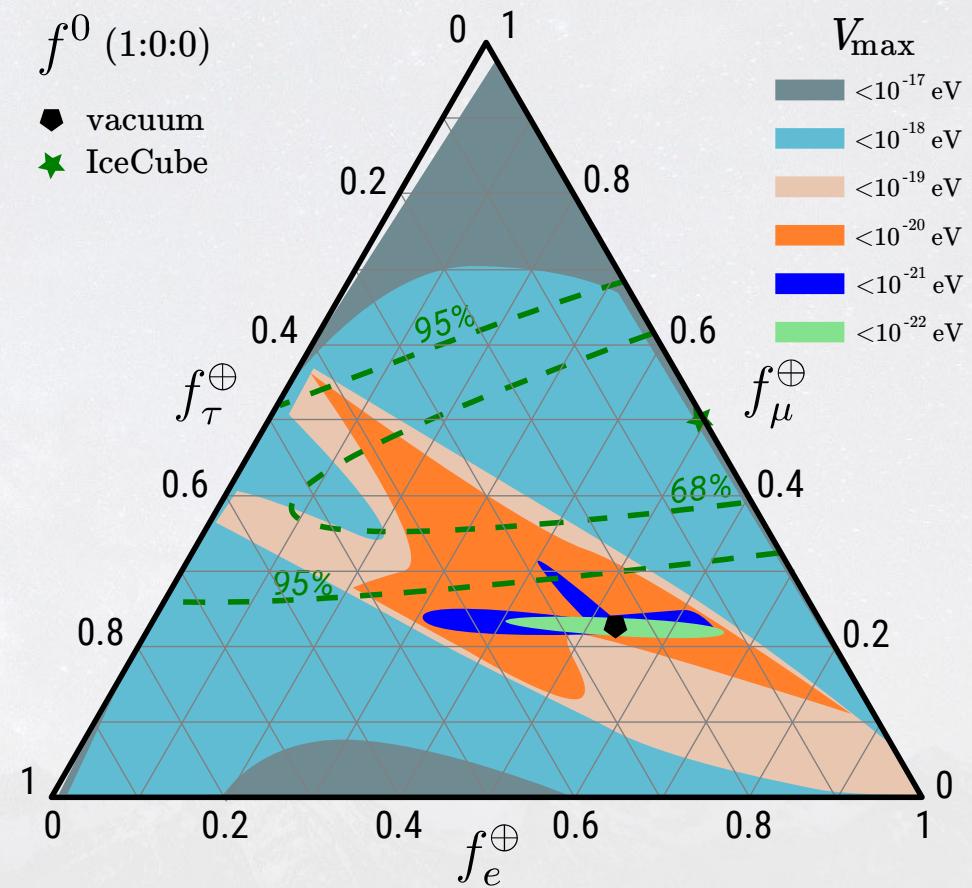
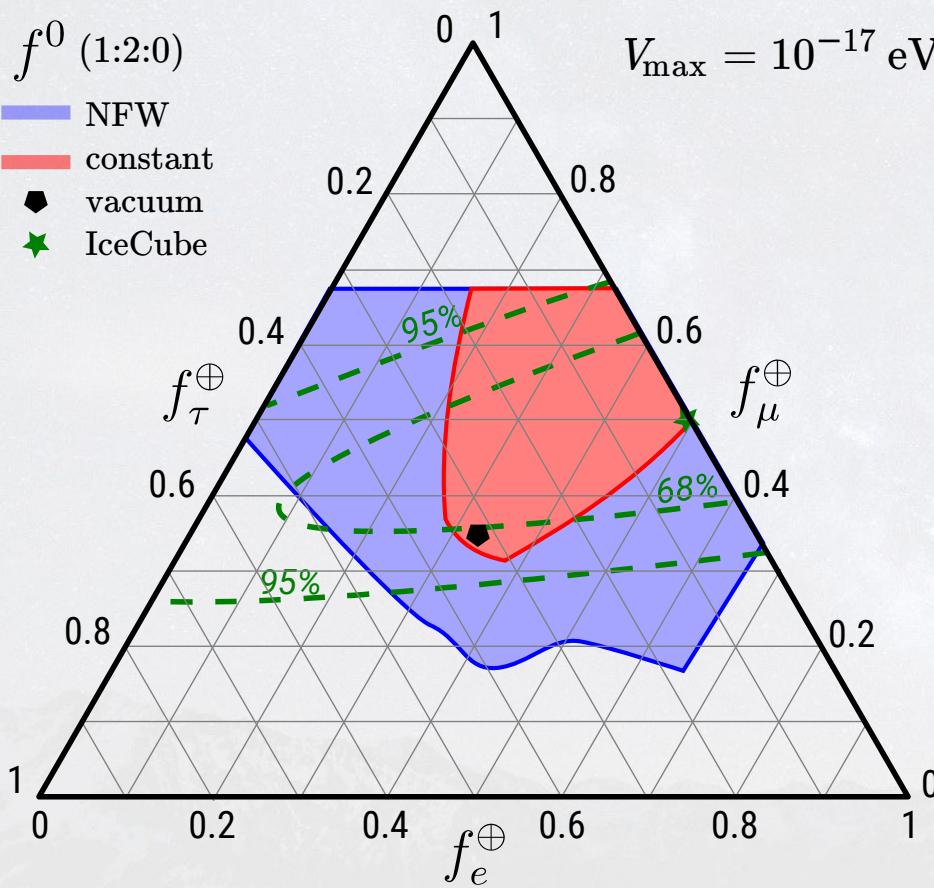


# Spatial dependence

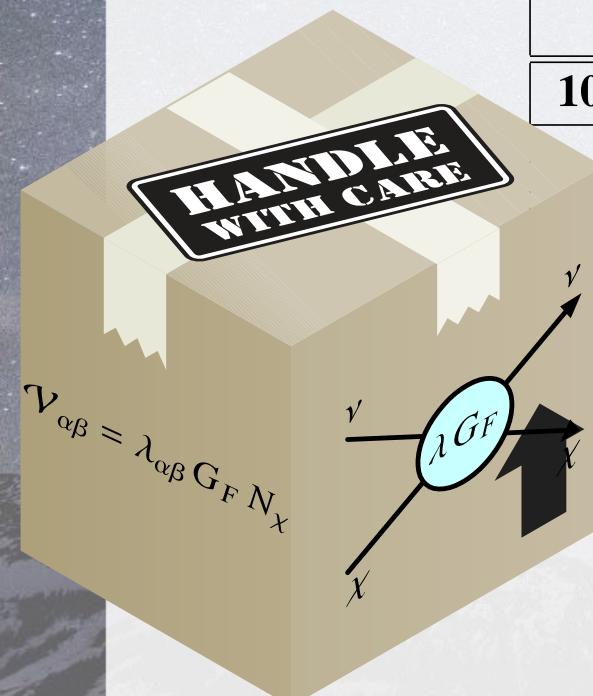
$$\mathcal{V}_{\alpha\beta} = \mathcal{V}_{\alpha\beta}^\oplus \times f_{\text{DM}}(r)$$



# Composition in a NFW halo



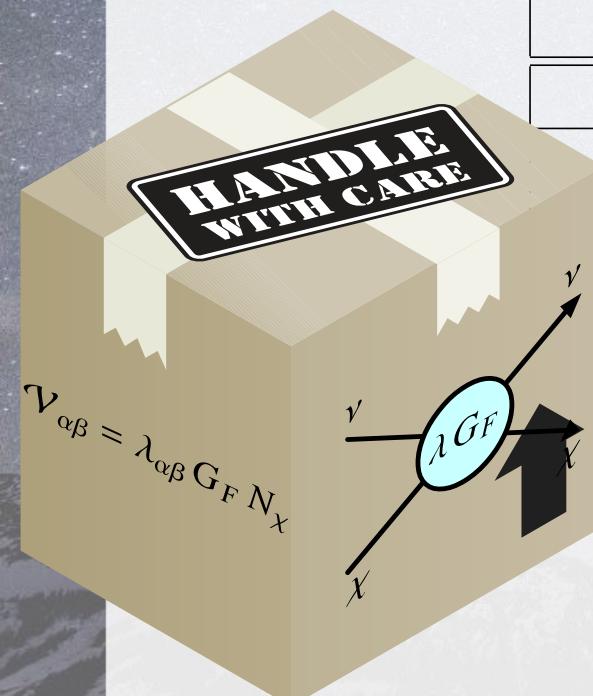
# Particle physics interpretation



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

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

# Particle physics interpretation



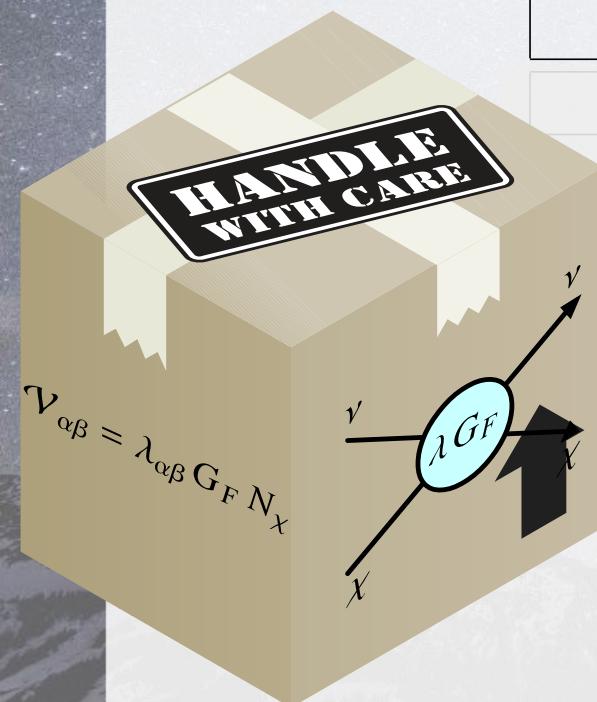
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<b>Weak scale (b) assumptions:</b> $G'_F = G_F, l_\nu = 50$ kpc			
$\lambda_{11}$	$10^{-7}$	$10^{-9}$	$10^{-11}$
$m_{\text{DM}}$ [eV]	$10^{-15}$	$10^{-19}$	$10^{-23}$

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

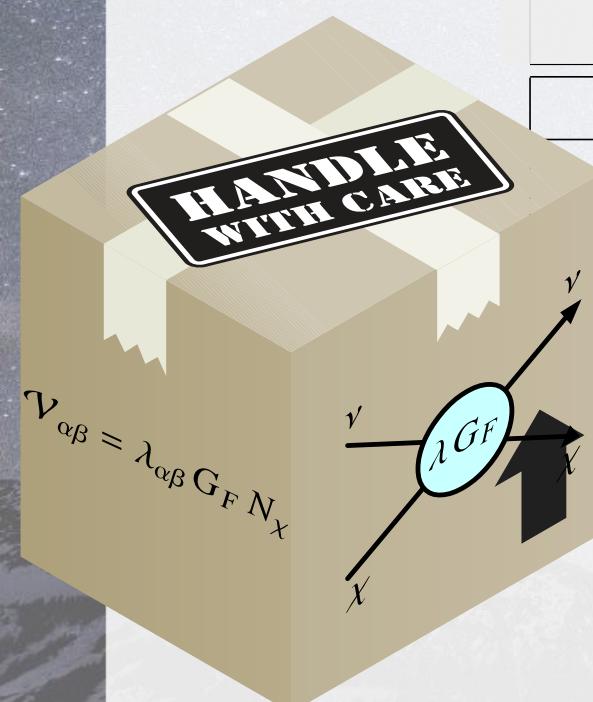
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**100 GeV DM**  
sub-eV mediators,  $g \sim \lambda^{1/2} = 10^{-3} - 10^{-6}$

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

# Particle physics interpretation

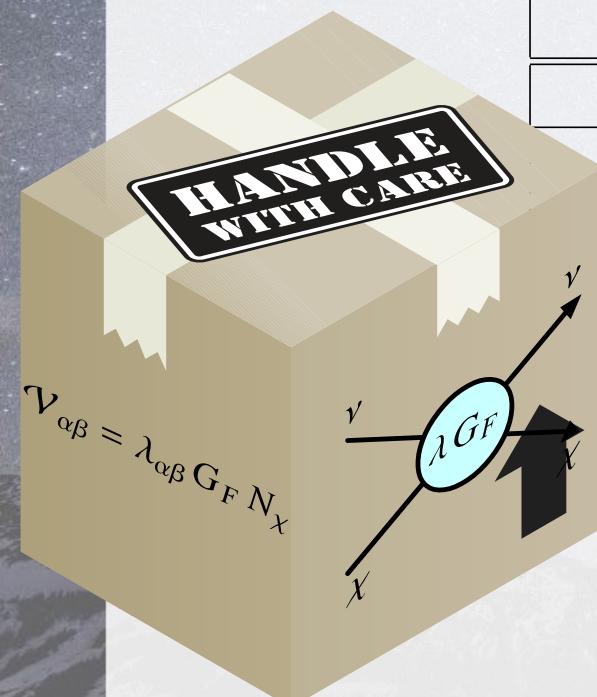


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$\lambda_{11}$	$10^{-17}$	$10^{-19}$	$10^{-21}$
$m_{Z'} \text{ [eV]}$	$10^{-3}$	$10^{-5}$	$10^{-7}$



Assuming mean free path larger than the **Observable Universe**

Wilkinson et al. JCAP 1405 (2014) 011

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

# Conclusions

Flavor composition of astro- $\nu$  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

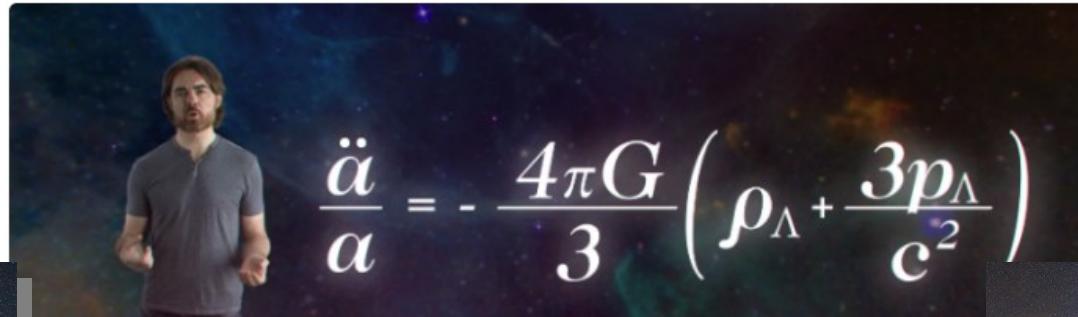
[www.dmhunters.org](http://www.dmhunters.org)

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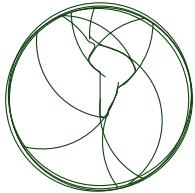
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in Galactic Subhalos.  
A Look into the Smith Cloud**

Martin Vollmann, Technische Universität München  
Host: Roberto A. Lineros, IFIC-UVEG/CSIC

Wednesday 29 June 2016 15:00 UTC

10:00 Mexico City - 10:00 Lima and Bogotá - 11:00 Santiago - 12:00 São Paulo - 17:00 Central European Time



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# Thanks