Neutrino oscillations in the galactic DM halo

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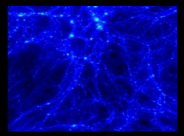
arXiv:1601.05798 [Accepted in PRD]

MultiDark
Multimessenger Approach for Dark Matter Detection



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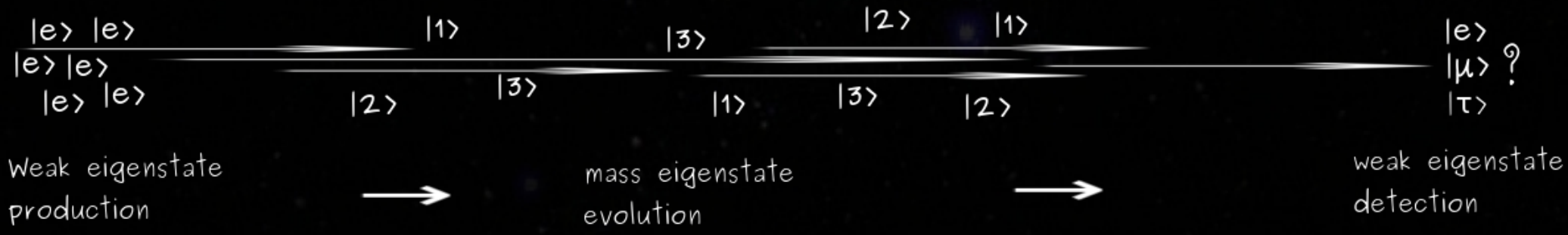
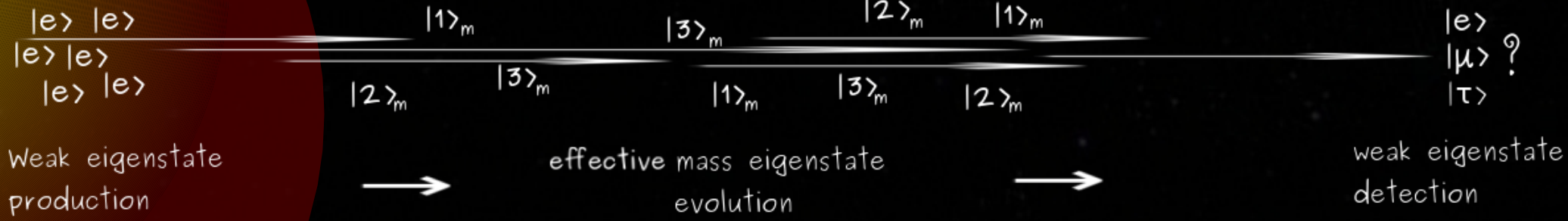
Neutrino oscillations and matter effects

Neutrinos oscillate in flavour



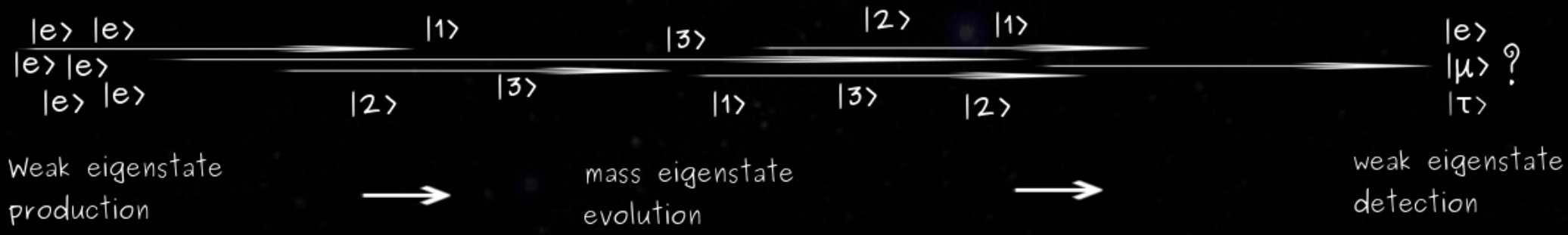
The presence of matter modifies oscillation patterns w.r.t. vacuum

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



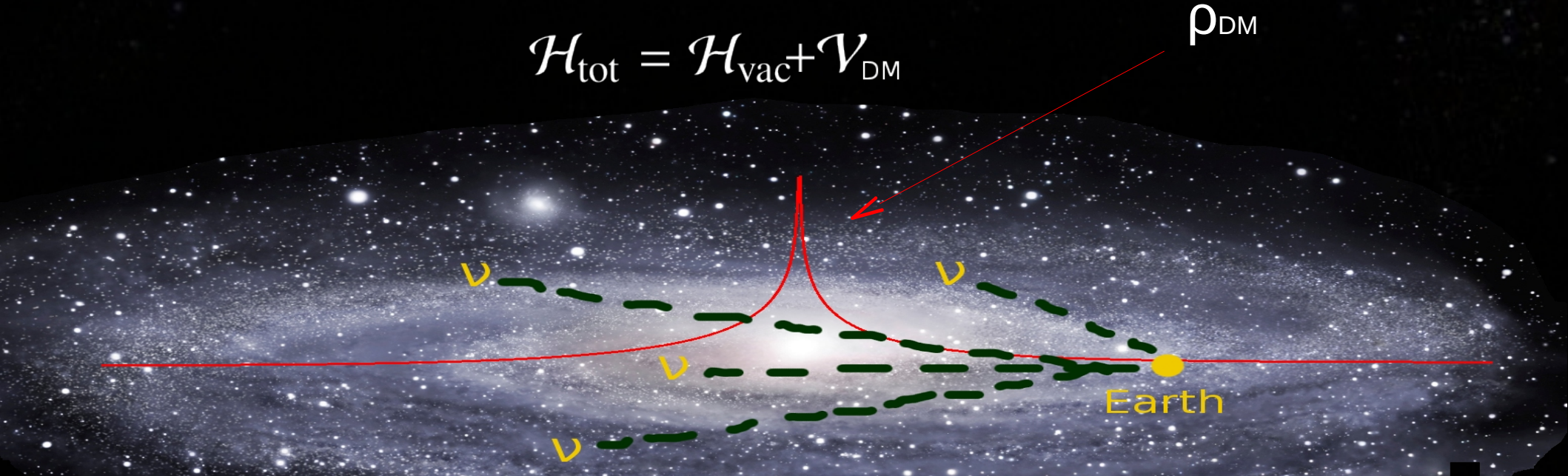
Neutrino oscillations and dark matter effects

Neutrinos oscillate in flavour



Dark Matter might modify oscillation patterns as well

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



Considerations and assumptions

Dark Matter

- Generic DM potential

$$\mathcal{V}_{\text{DM}} = G_F N_\chi \underline{\underline{\lambda}}$$

such that the effect is measurable on VHE-ν only

- Candidate mass included in V_{DM}

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

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

DM profile

- Homogeneous DM profile
- Non-homogeneous NFW profile

Considerations and assumptions

Dark Matter

- Generic DM potential

$$\mathcal{V}_{\mathrm{DM}} = G_F N_\chi \mathcal{A}$$

such that the effect is measurable on VHE-ν only

- Candidate mass included in V_{DM}

DM profile

- Homogeneous DM profile
- Non-homogeneous NFW profile

Neutrinos

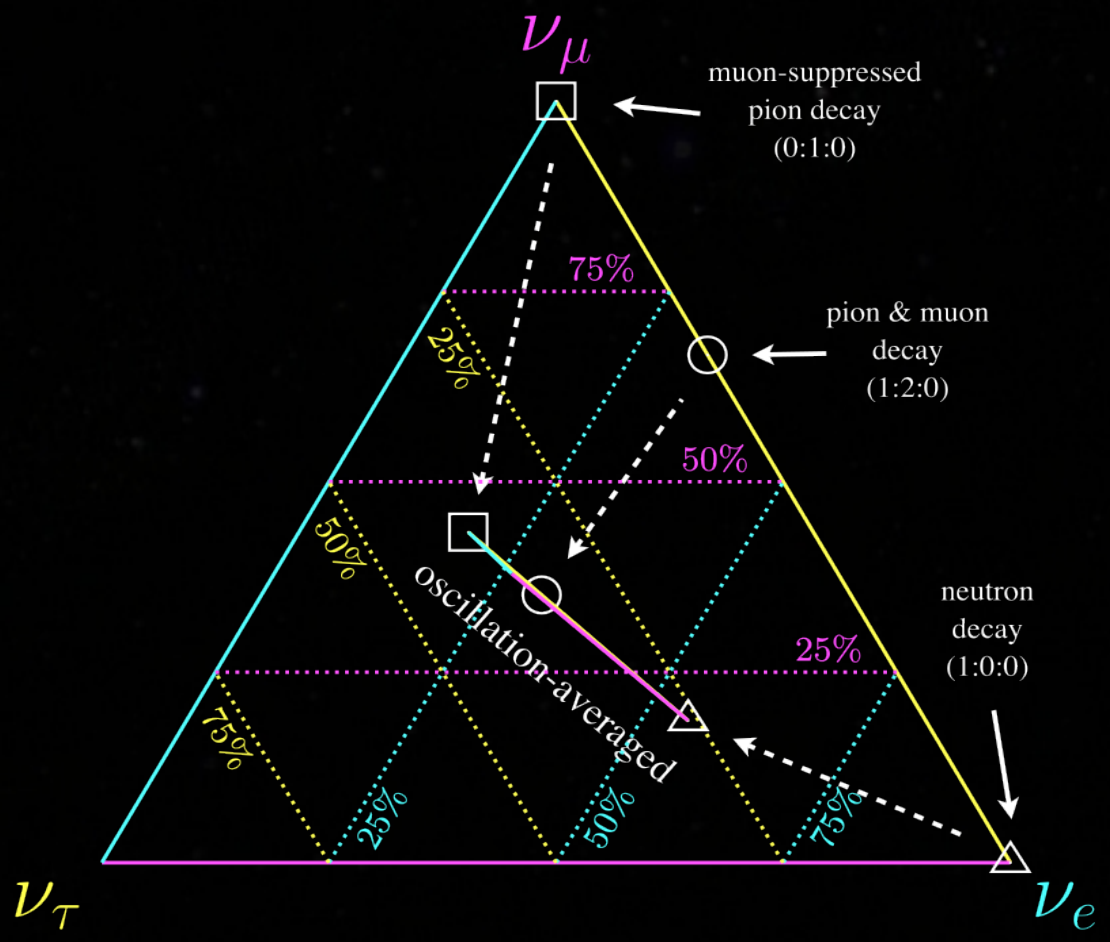
- Averaged neutrino oscillations

$$f_\beta = \sum_{\alpha=e,\mu,\tau} \left(\sum_{i=1}^{3} |U_{\beta i} U_{\alpha i}^*|^2 \, f_\alpha^0 \right)$$

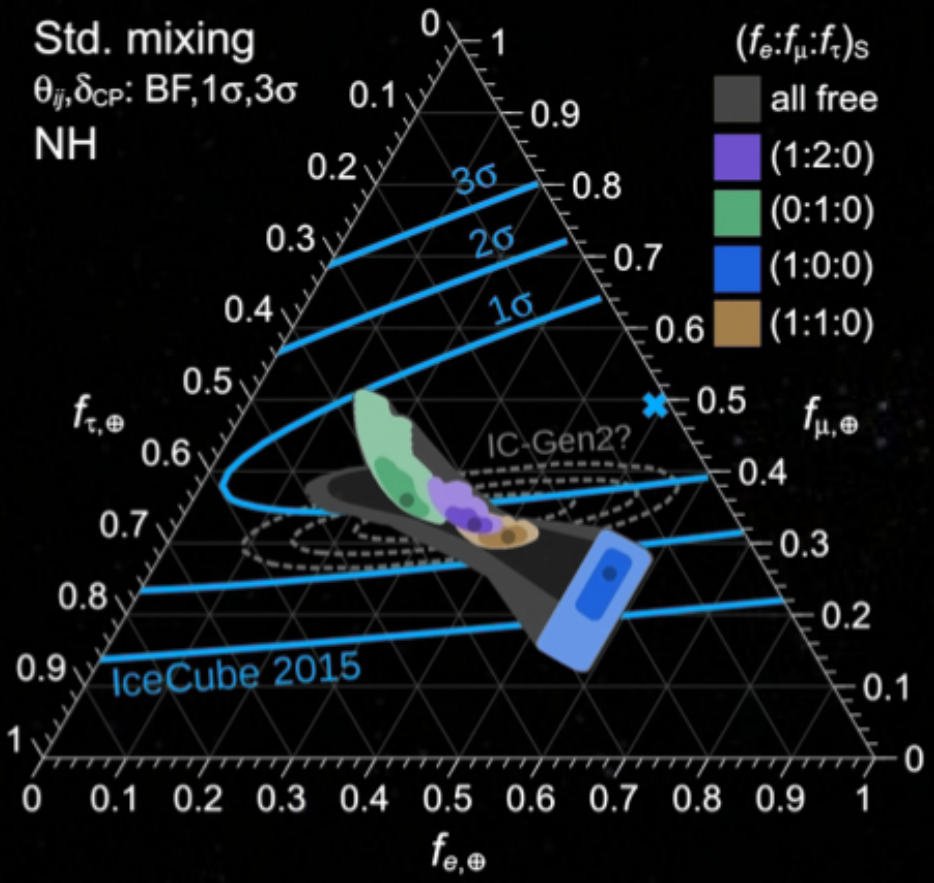
- Neutrino production at any point in the galaxy
- Monoenergetic neutrinos with E = 1 PeV
- Oscillation parameters fixed - best fit in [D.V. Forero *et al*., PRD**90**-093006 (2014)]

What we can expect without New Physics (NP)

Best fit ν mixing parameters

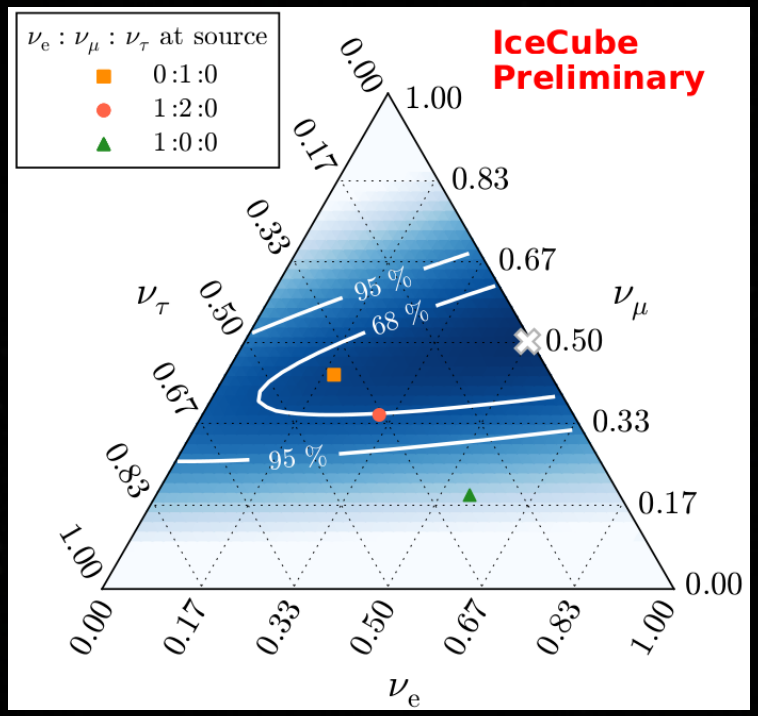


Including uncertainties in source flavor composition and ν mixing parameters

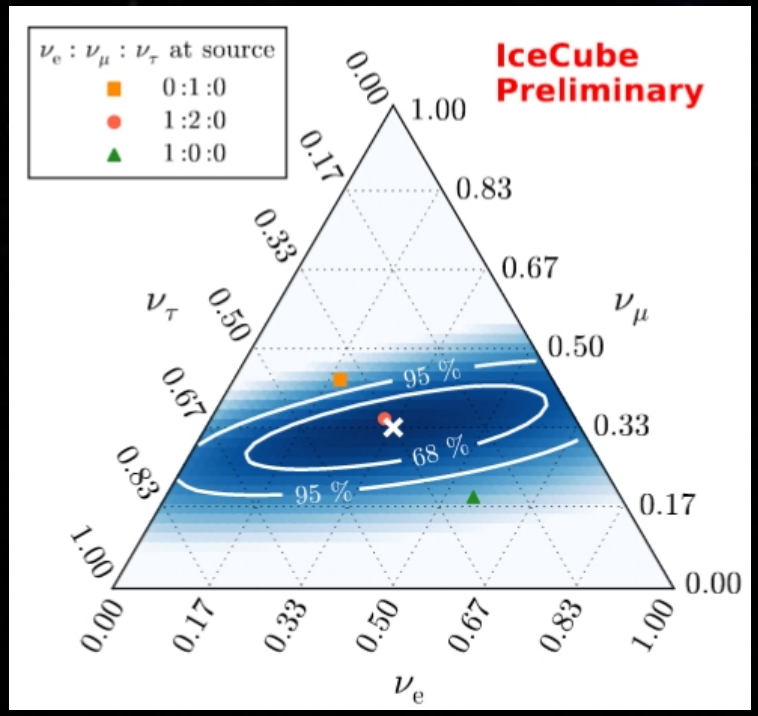


[M. Bustamante *et al*. - PRL **115**, 161302 (2015)]

IceCube VHE neutrinos. Flavour composition



Latest results on flavor composition



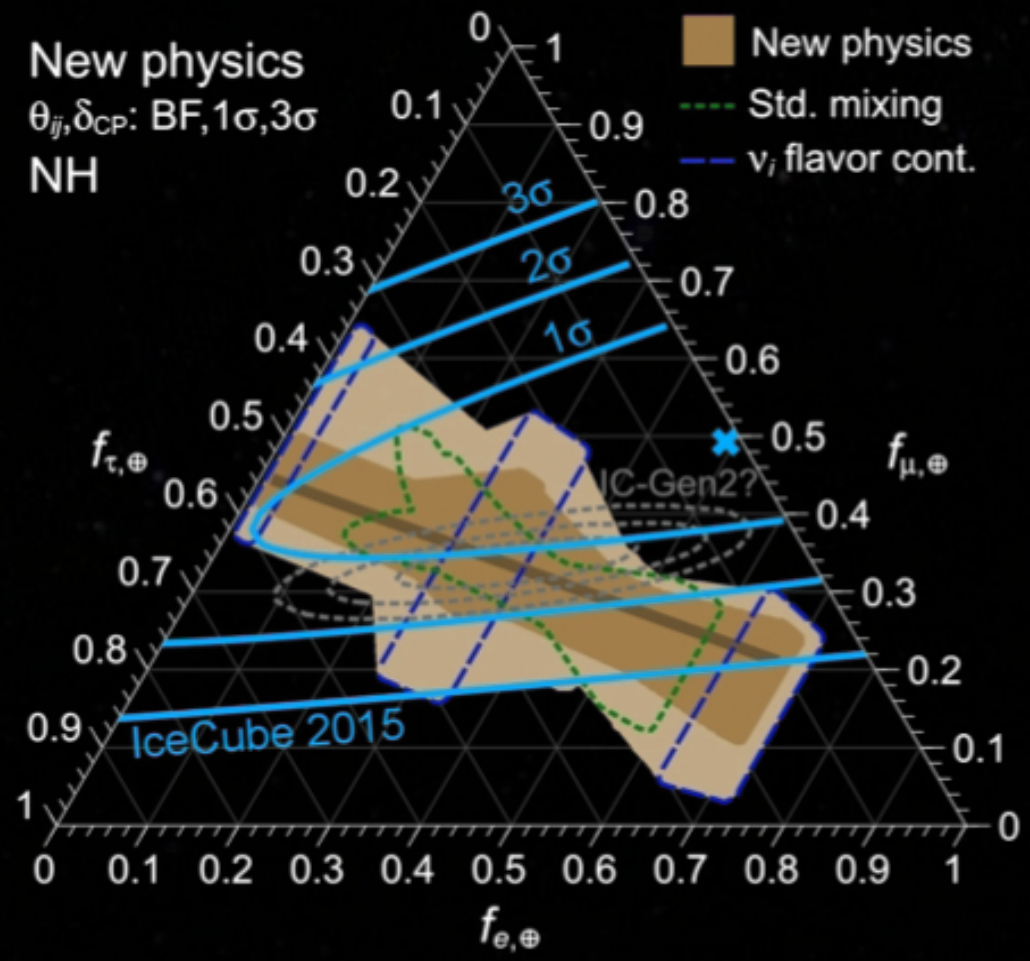
Sensitivity after 10 years

Events in TeV – PeV range

[IceCube Collaboration – ICRC 2015 - *arXiv:1510.05223*]

What we can expect with New Physics

NP does not affect mixing parameters



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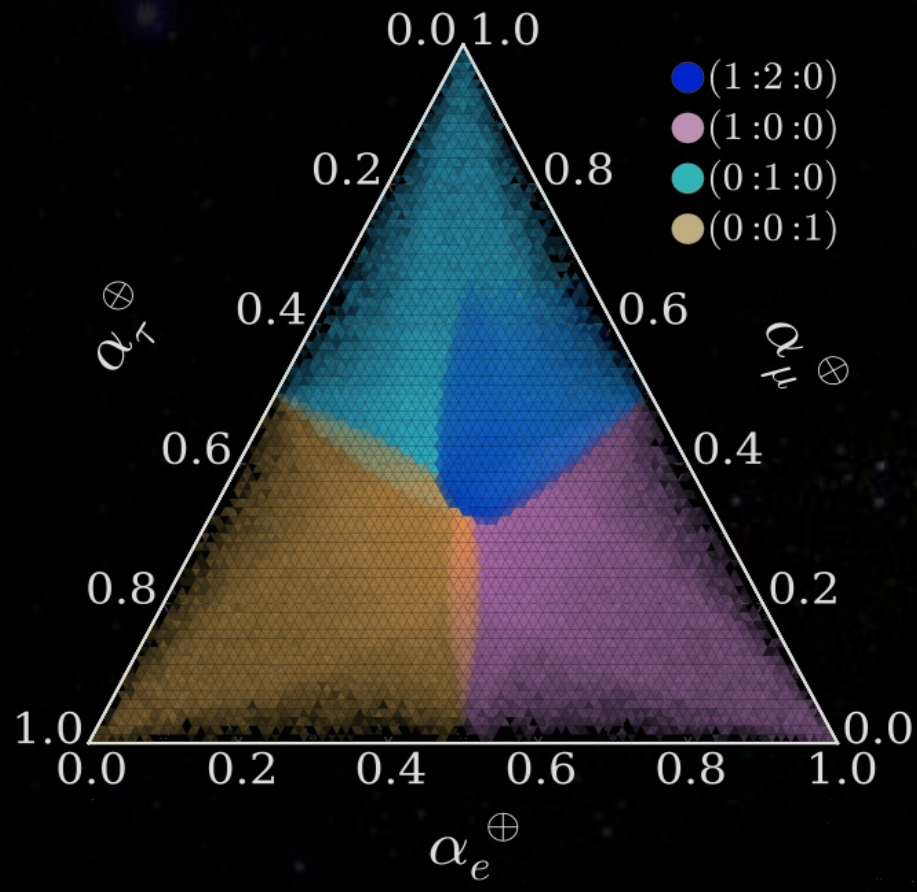
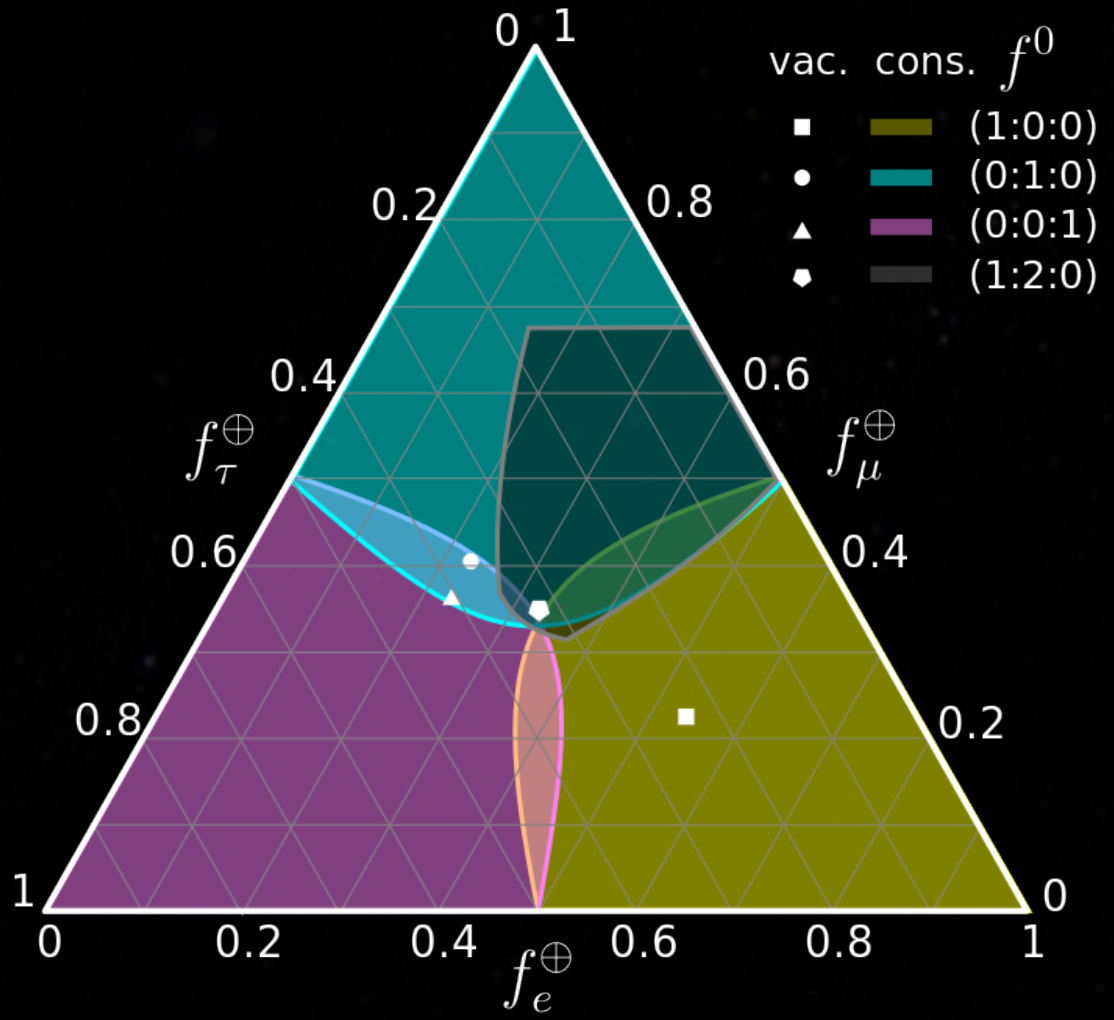
NP affects mixing parameters



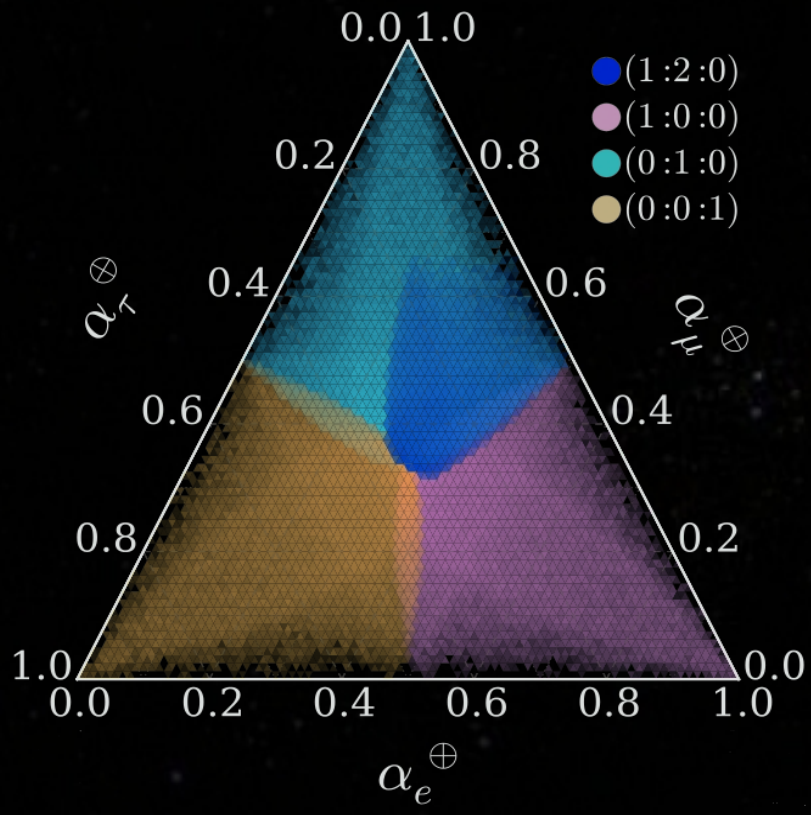
[C. A. Argüelles *et al*. - PRL **115**, 161303 (2015)]

Homogeneous DM profile



Random potential entries

$|V_{ij}| < 10^{-13}$ eV

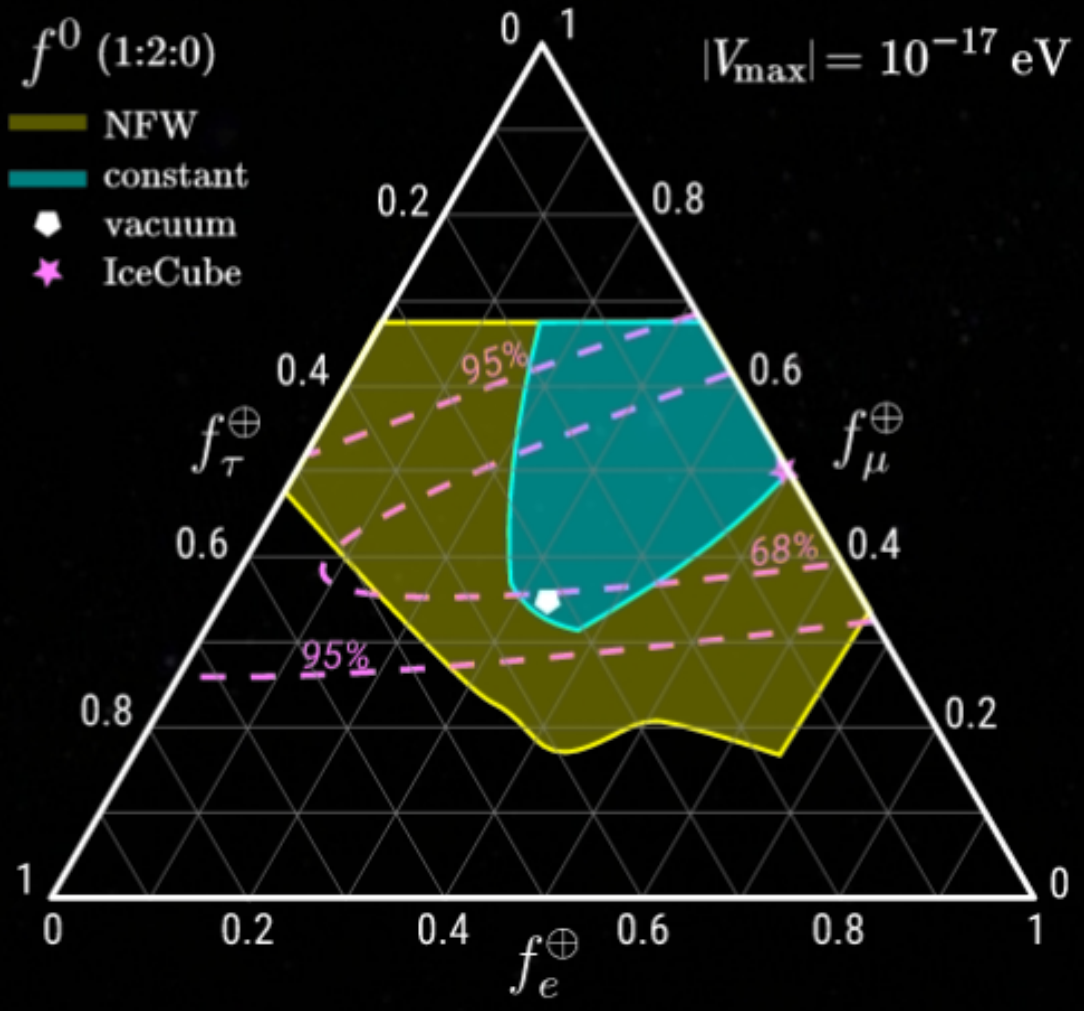


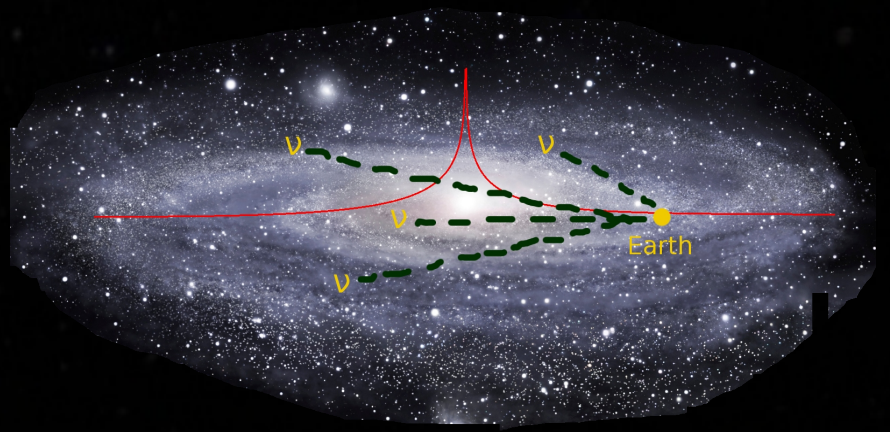
Flavour composition at Earth

Homogeneous DM distribution can mimic NP

[C. A. Argüelles *et al*. - PRL **115**, 161303 (2015)]

NFW DM profile





DM distribution broadens neutrino flavour composition at Earth

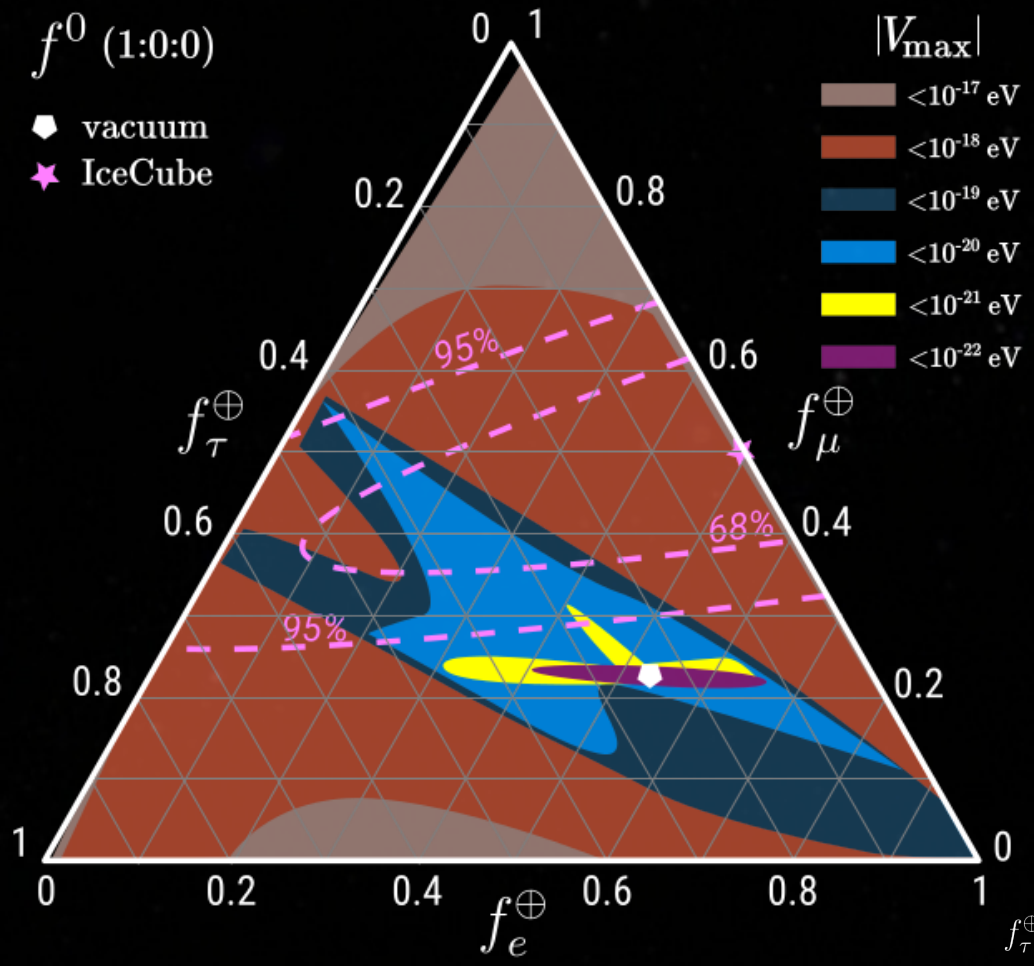
- - - VHE neutrino IceCube data

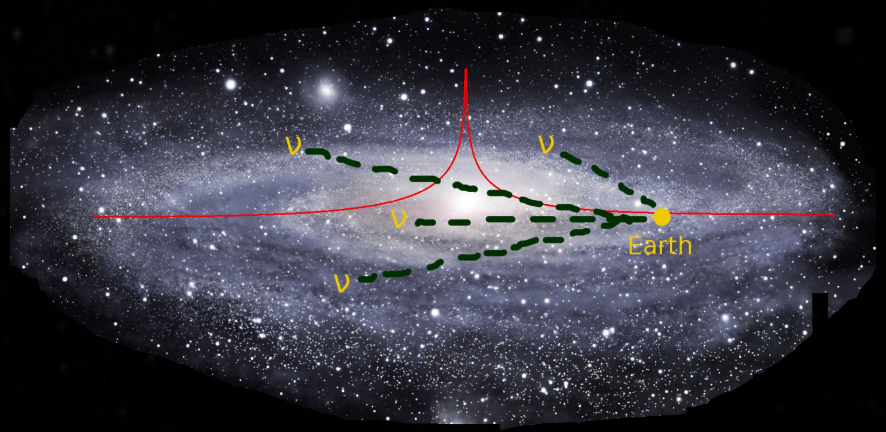
Flavour composition at Earth

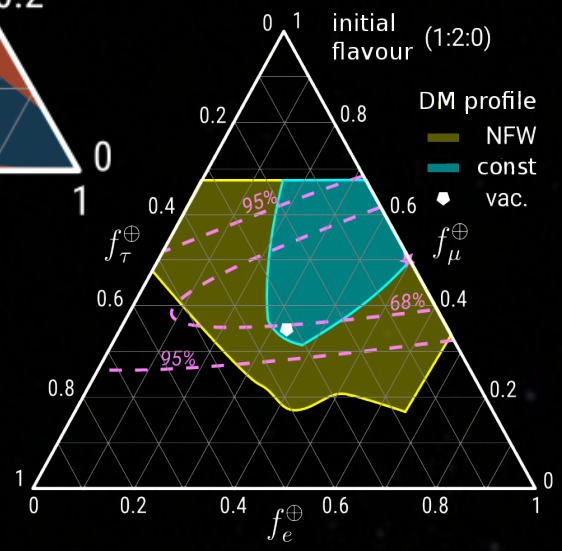
Assuming:

- any production point
- random V_{DM}

NFW DM profile







- - - VHE neutrino

IceCube data

Flavour composition at Earth

Assuming:

- any production point
- random V_{DM}

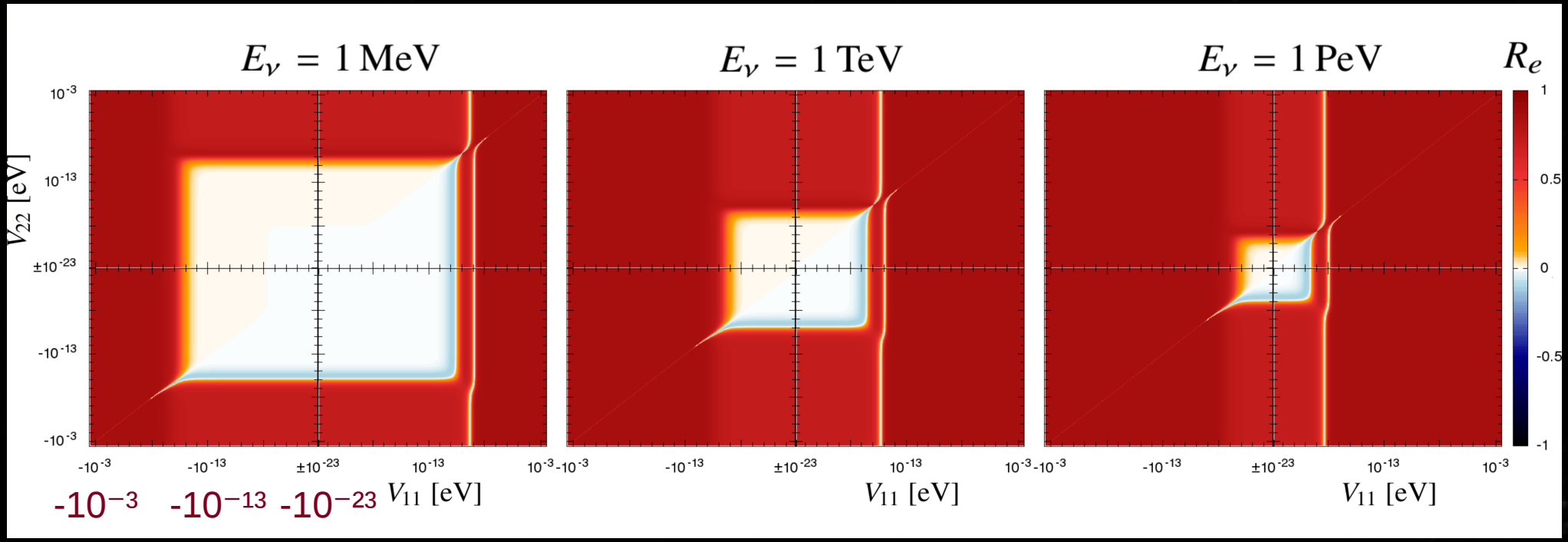
Intermediate (?) Conclusions

- **VHE neutrino oscillations** might be **affected by** the presence of **DM** in the Milky Way

- This could explain a non-standard VHE neutrino flavour composition observed at Earth

- The flavour composition at Earth could give **information** about the **interaction** of **DM** with **neutrinos**

Particle physics interpretation



$$V_{ij} = \lambda'_{ij}\, G'_F\, \frac{\rho_{\mathrm{DM}}}{m_{\mathrm{DM}}} \qquad G'_F = \frac{m_Z^2}{m_{Z'}^2}\, G_F \qquad R_\beta(V,E) = \frac{f_\beta^{\mathrm{DM}} - f_\beta^{\mathrm{vac}}}{f_\beta^{\mathrm{vac}}}$$

$$l_\nu = \left(\sigma_{\nu\chi}\frac{\rho_{\mathrm{DM}}}{m_{\mathrm{DM}}}\right)^{-1} = \left(\frac{\sigma_{\nu\chi}}{8.1\times 10^{-22}\mathrm{cm}^2}\right)^{-1}\left(\frac{m_{\mathrm{DM}}}{\mathrm{GeV}}\right)\mathrm{kpc}$$

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}

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}
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}

$$\sigma_{\nu\chi} = 1.62\times10^{-23}\ (m_{\rm DM}/{\rm GeV})\,{\rm cm}^2 \qquad \sigma_{\nu\chi} < 10^{-33}\ (m_{\rm DM}/{\rm GeV})\,{\rm cm}^2$$

$$l_\nu = 50\ {\rm kpc} \qquad l_\nu = 10^6\ {\rm Gpc}$$

[R. J. Wilkinson *et al*. - JCAP **1405**, (2014) - arXiv:1401.7597]

Particle physics interpretation

$V_{11}^{\oplus}$ [eV]	10^{-21}	10^{-19}	10^{-17}
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 (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}

$$\sigma_{\nu\chi} = 1.62\times10^{-23}\ (m_{\rm DM}/{\rm GeV})\,{\rm cm}^2 \qquad \sigma_{\nu\chi} < 10^{-33}\ (m_{\rm DM}/{\rm GeV})\,{\rm cm}^2$$

$$l_\nu = 50\ {\rm kpc} \qquad l_\nu = 10^6\ {\rm Gpc}$$

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Conclusions

- **VHE neutrino oscillations** might be **affected by** the presence of **DM** in the Milky Way

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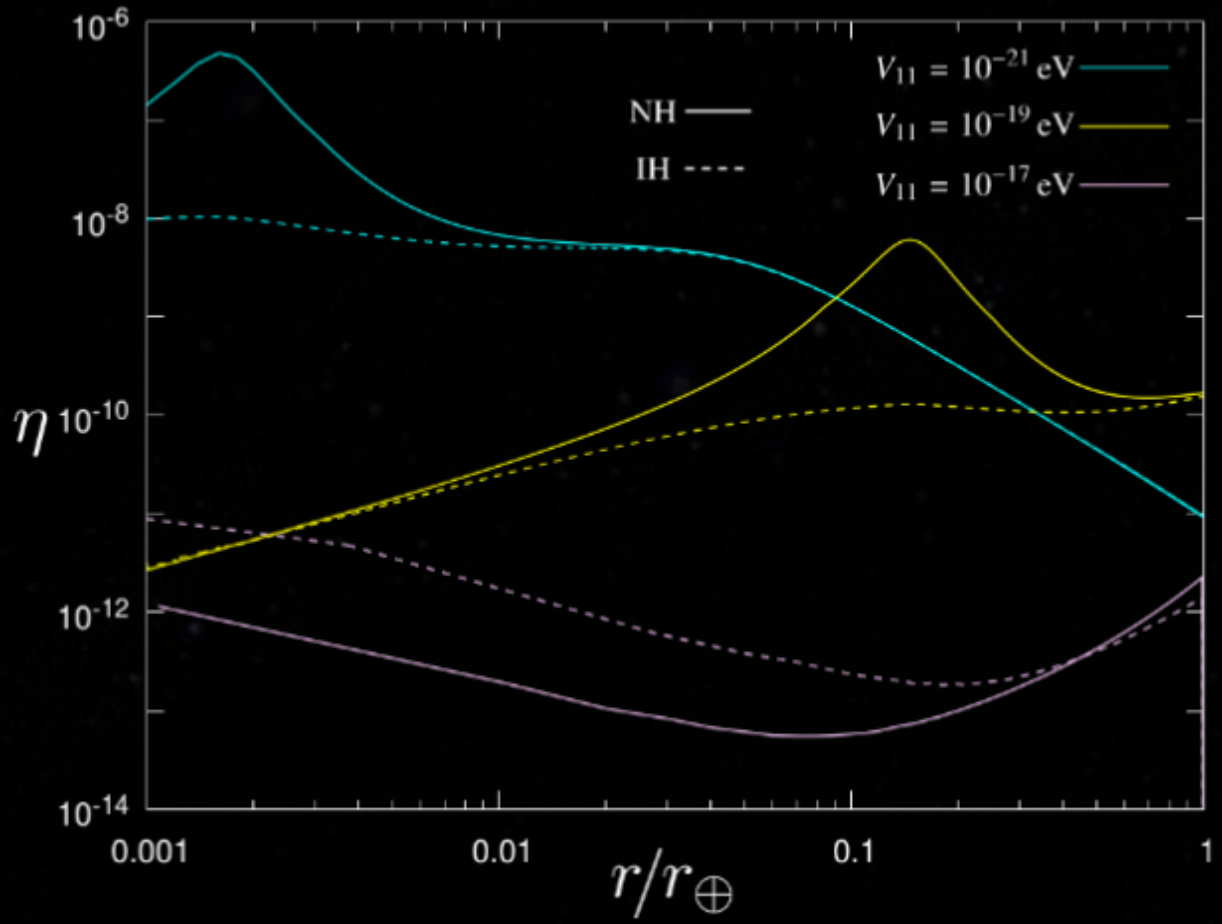
Adiabaticity



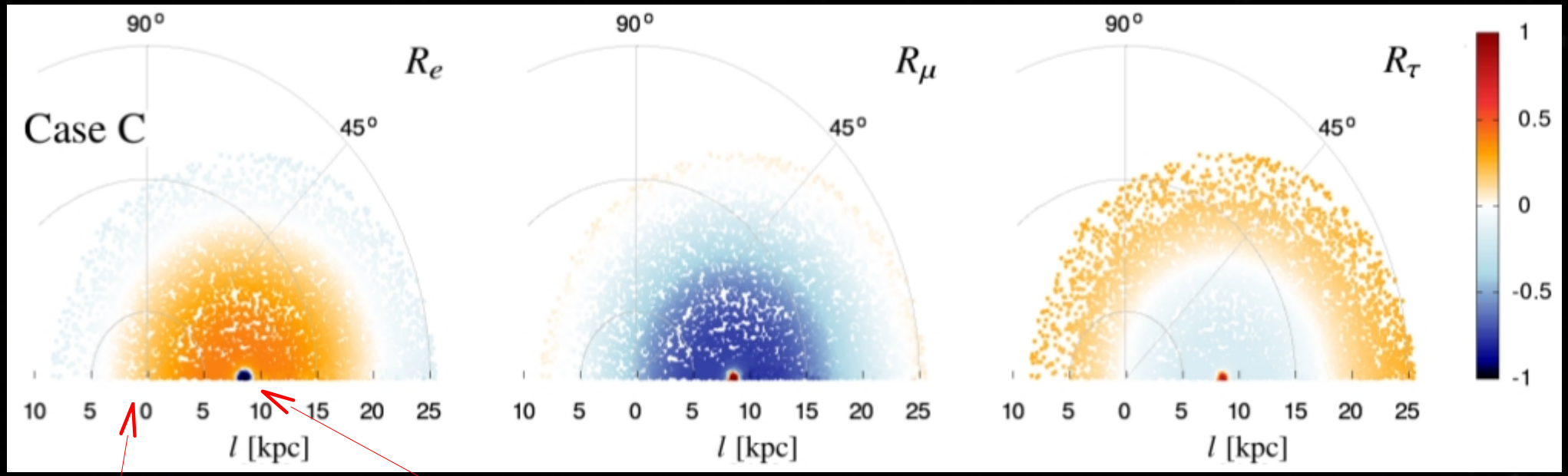
$$\eta = \frac{\left\langle \left| U^\dagger \dot{U} \right| \right\rangle}{\left\langle \left| \mathcal{D} - \mathrm{Tr}\left(\mathcal{D}\right)/3\, \mathbb{I} \right| \right\rangle}$$

$$\mathcal{D} = U^\dagger \mathcal{H}_{\mathrm{tot}} U$$

$$i\,\dot{\nu}_m = \left(\mathcal{D} - i U^\dagger \dot{U} \right) \nu_m$$

1 PeV neutrino crossing the GC

Spatial dependence (symmetric)



Sun

Galactic Center

$$R_\beta(V,E) = \frac{f_\beta^{\mathrm{DM}} - f_\beta^{\mathrm{vac}}}{f_\beta^{\mathrm{vac}}}$$

1 PeV initially electronic neutrino

V_{11} = 40.e-21 eV (at Earth)

What is next?

- For E > 60TeV **40%** of the total **neutrino flux** has a **galactic** origin, but **60%** is **extragalactic**
- Get bounds on Vij from IceCube and KM3NeT data
- Embed this effect in a specific **particle model**, rather than an interpretation