Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Neutrino flavor evolution in supernova: theory and experiment

FRANCESCO CAPOZZI
(Theoretical Astroparticle Group)

SFB 1258 | Neutrinos Dark Matter Messengers

elusives
neutrinos, dark matter & dark energy physics

MPP contribution

~100 papers from our astroparticle group: ~10% of total

HEP 108 record trovati - 25 salta al record: 1 La ricerca ha impiegato 0.17 secondi.

1. **Normal-mode Analysis for Collective Neutrino Oscillations**
Sagar Airen (Indian Inst. Tech., Mumbai & Munich, Max Planck Inst.), Francesco Capozzi (Munich, Max Planck Inst.), Sovan Chakraborty (Munich, Max Planck Inst. & Indian Inst. Tech., Guwahati), Basudeb Dasgupta (Tata Inst.), Georg Raffelt, Tobias Stirner (Munich, Max Planck Inst.). Sep 24, 2018. 26 pp.
MPP-2018-224, TIFR-TH-18-25
e-Print: arXiv:1809.09137 [hep-ph] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
Record dettagliato - Citato da 2 record

2. **Collisional triggering of fast flavor conversions of supernova neutrinos**
Francesco Capozzi (Munich, Max Planck Inst.), Basudeb Dasgupta (Tata Inst.), Alessandro Mirizzi (Bari U. & INFN, Bari), Manibrata Sen (Tata Inst.), Günter Sigl (Hamburg U., Inst. Theor. Phys. II). Aug 20, 2018. 6 pp.
MPP-2018-206, TIFR/TH/18-27
e-Print: arXiv:1808.06618 [hep-ph] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
Record dettagliato - Citato da 1 record

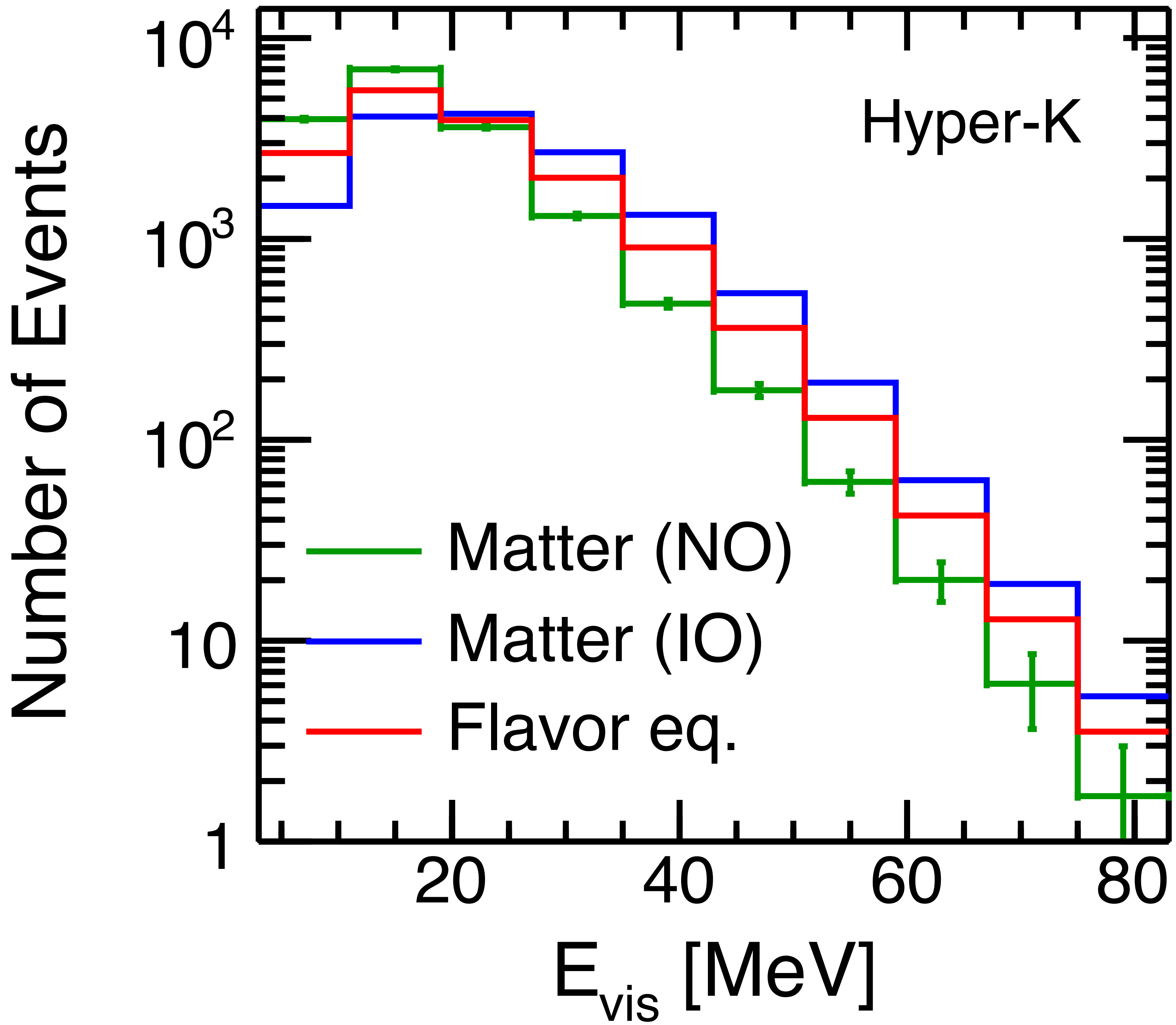
3. **Model-independent diagnostic of self-induced spectral equalization versus ordinary matter effects in supernova neutrinos**
Francesco Capozzi (Munich, Max Planck Inst.), Basudeb Dasgupta (Tata Inst.), Alessandro Mirizzi (Bari U. & INFN, Bari). Jul 2, 2018. 16 pp.
Published in **Phys.Rev. D98 (2018) no.6, 063013**
TIFR/TH/18-15, MPP-2018-147, TIFR-TH-18-15
DOI: 10.1103/PhysRevD.98.063013
e-Print: arXiv:1807.00840 [hep-ph] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service; Link to Article from SCOAP3
Record dettagliato - Citato da 1 record

4. **Flavor-dependent neutrino angular distribution in core-collapse supernovae**
Irene Tamborra (Bohr Inst.), Lorenz Huedepohl (Garching, Max Planck Inst.), Georg Raffelt (Munich, Max Planck Inst.), Hans-Thomas Janka (TUM-IAS, Munich). Jan 31, 2017. 10 pp.
Published in **Astrophys.J. 839 (2017) 132**
DOI: 10.3847/1538-4357/aa6a18
e-Print: arXiv:1702.00060 [astro-ph.HE] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
Record dettagliato - Citato da 17 record

5. **Fast Pairwise Conversion of Supernova Neutrinos: A Dispersion-Relation Approach**
Ignacio Izaguirre, Georg Raffelt (Munich, Max Planck Inst.), Irene Tamborra (Bohr Inst.). Oct 5, 2016. 6 pp.
Published in **Phys.Rev.Lett. 118 (2017) no.2, 021101**

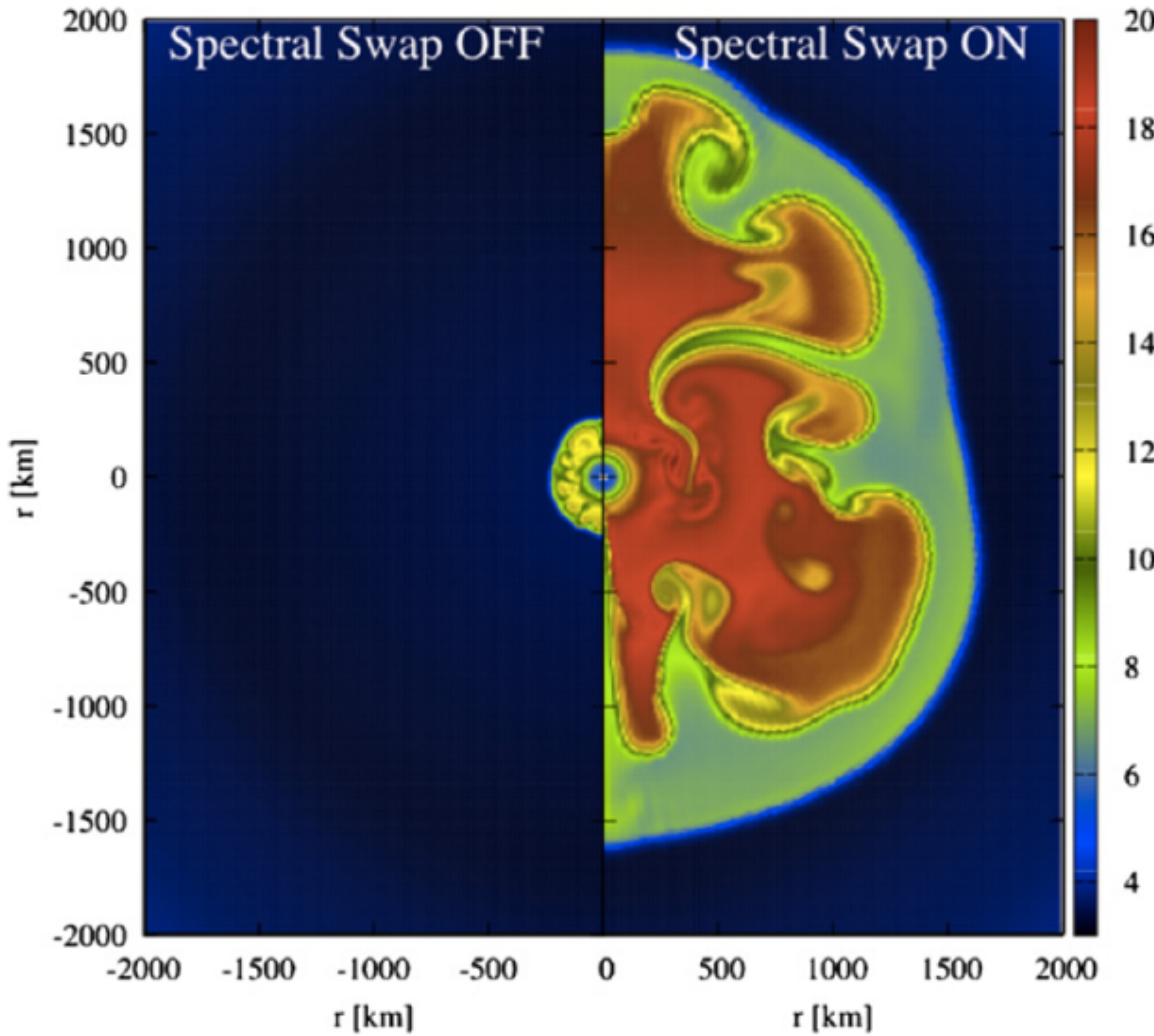
Why do we care?

Understanding conversions ⇔ correct interpretation of SNν signal



Why do we care?

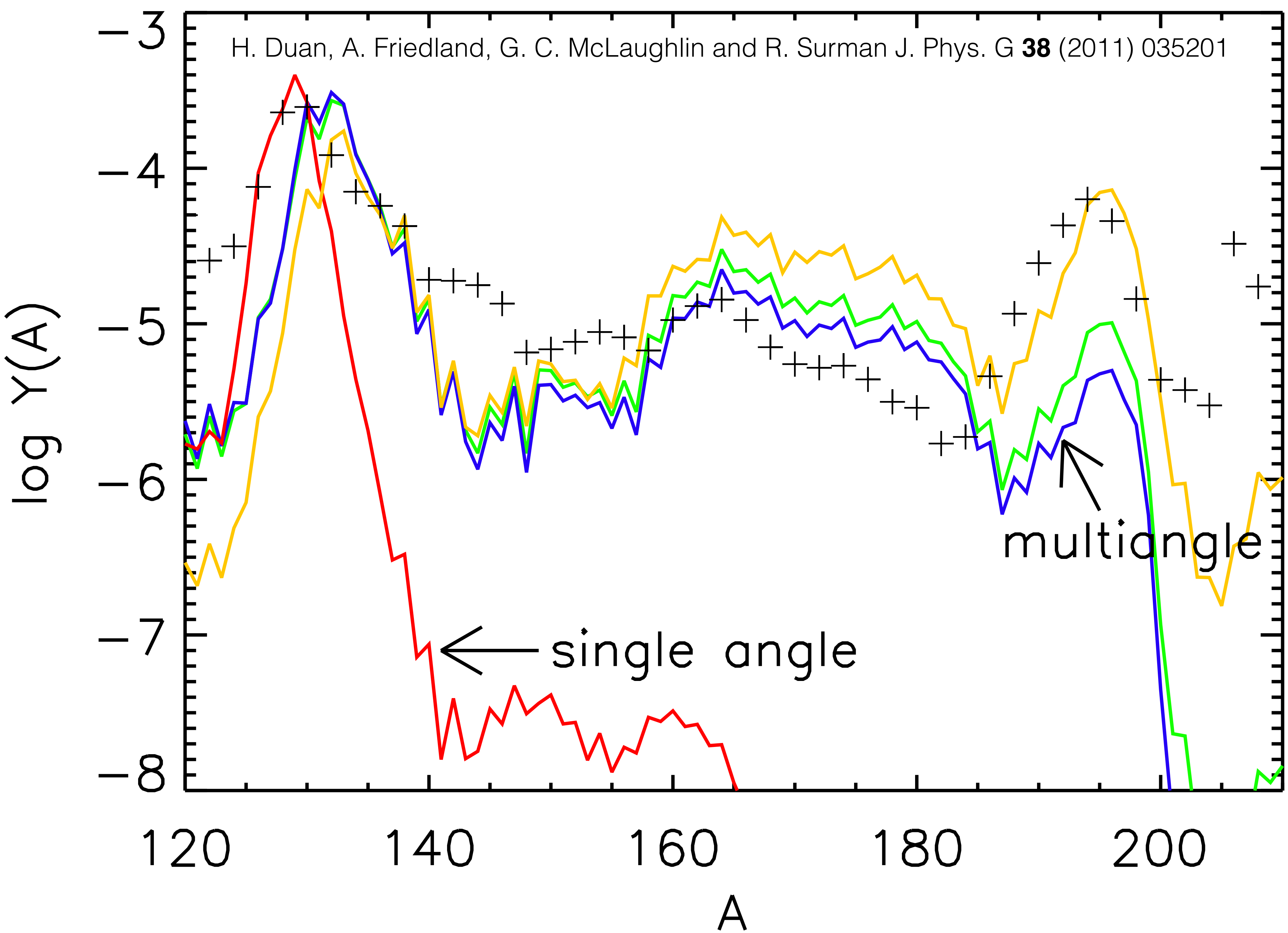
Flavour conversions alter the neutrino heating of the shock

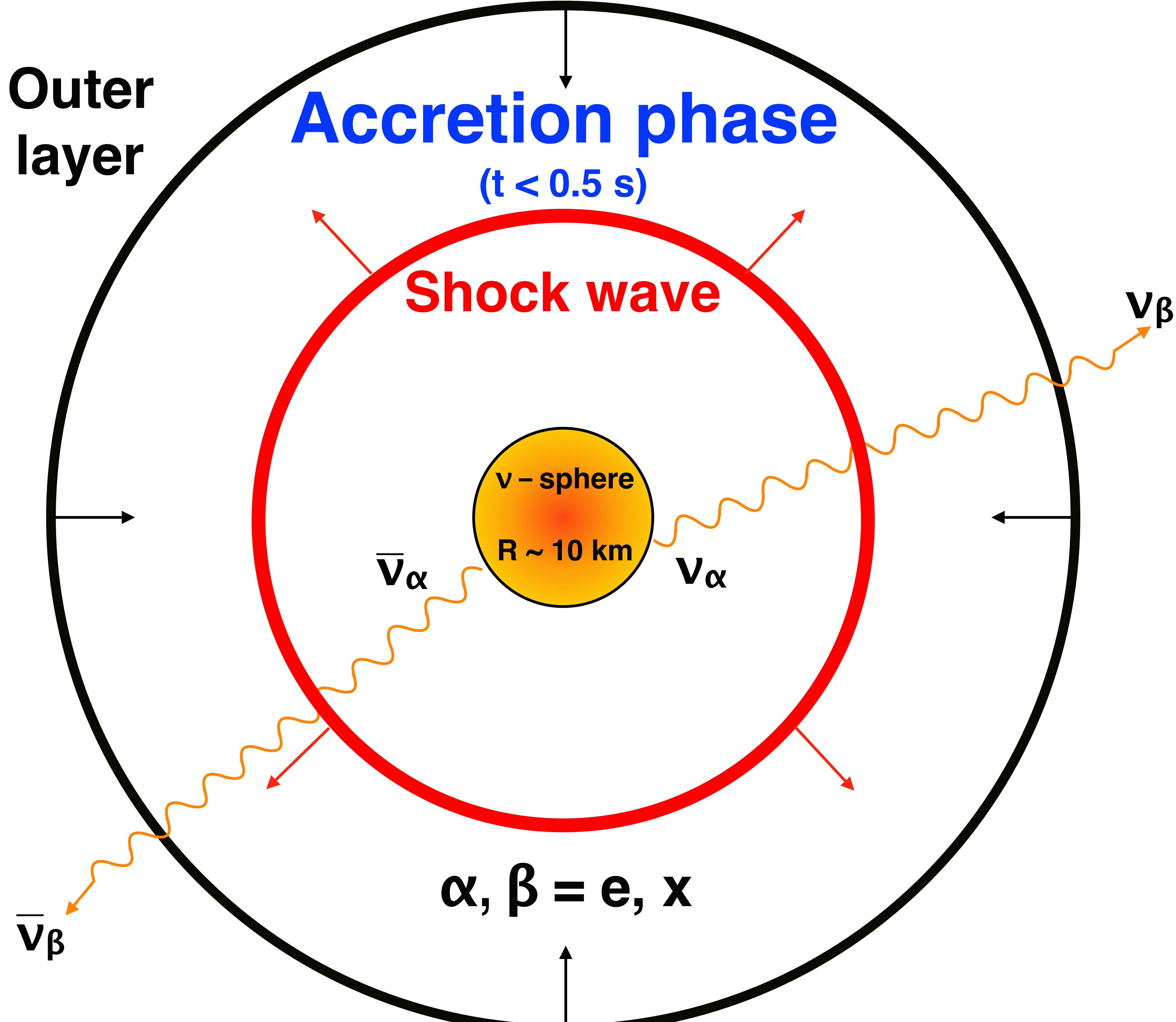


Y. Suwa, et al.,
Astrophys. J. **738** (2011) 165

Why do we care?

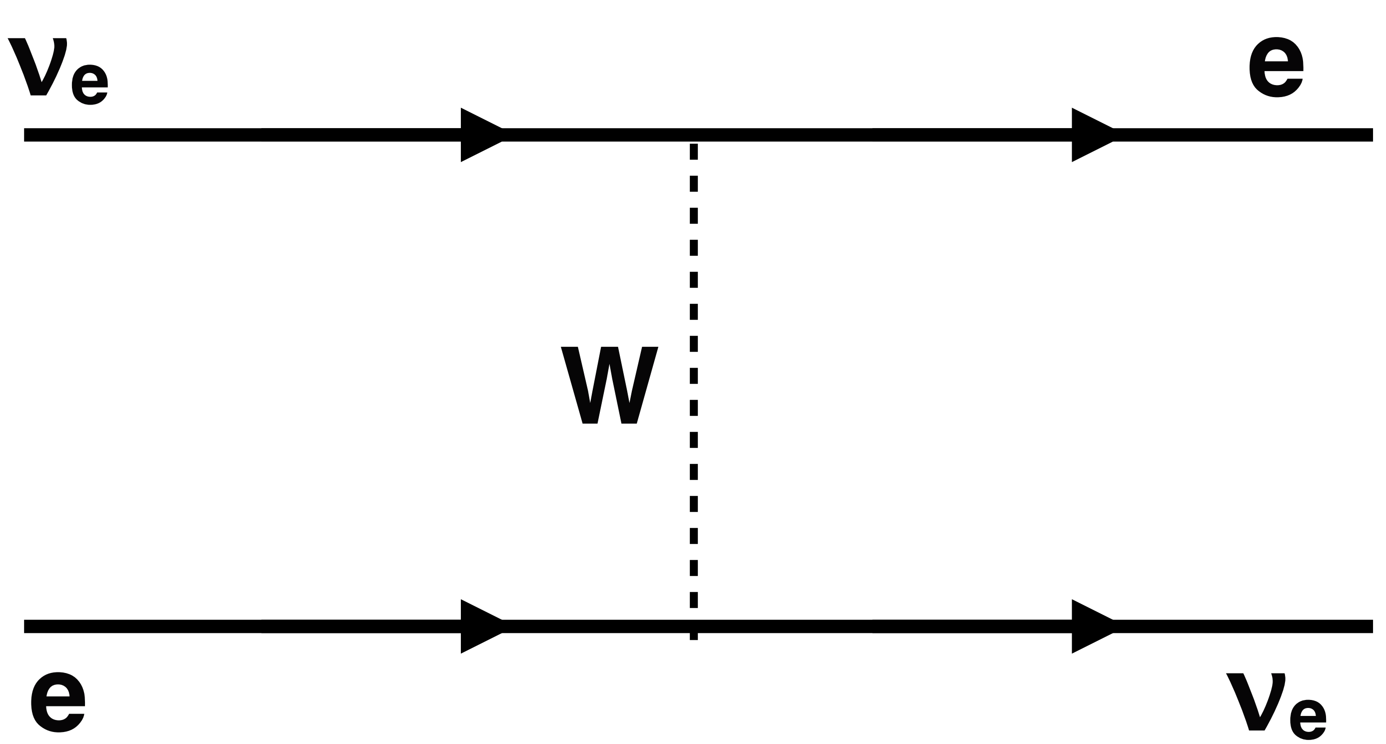
Flavour conversions alter the nucleosynthesis processes



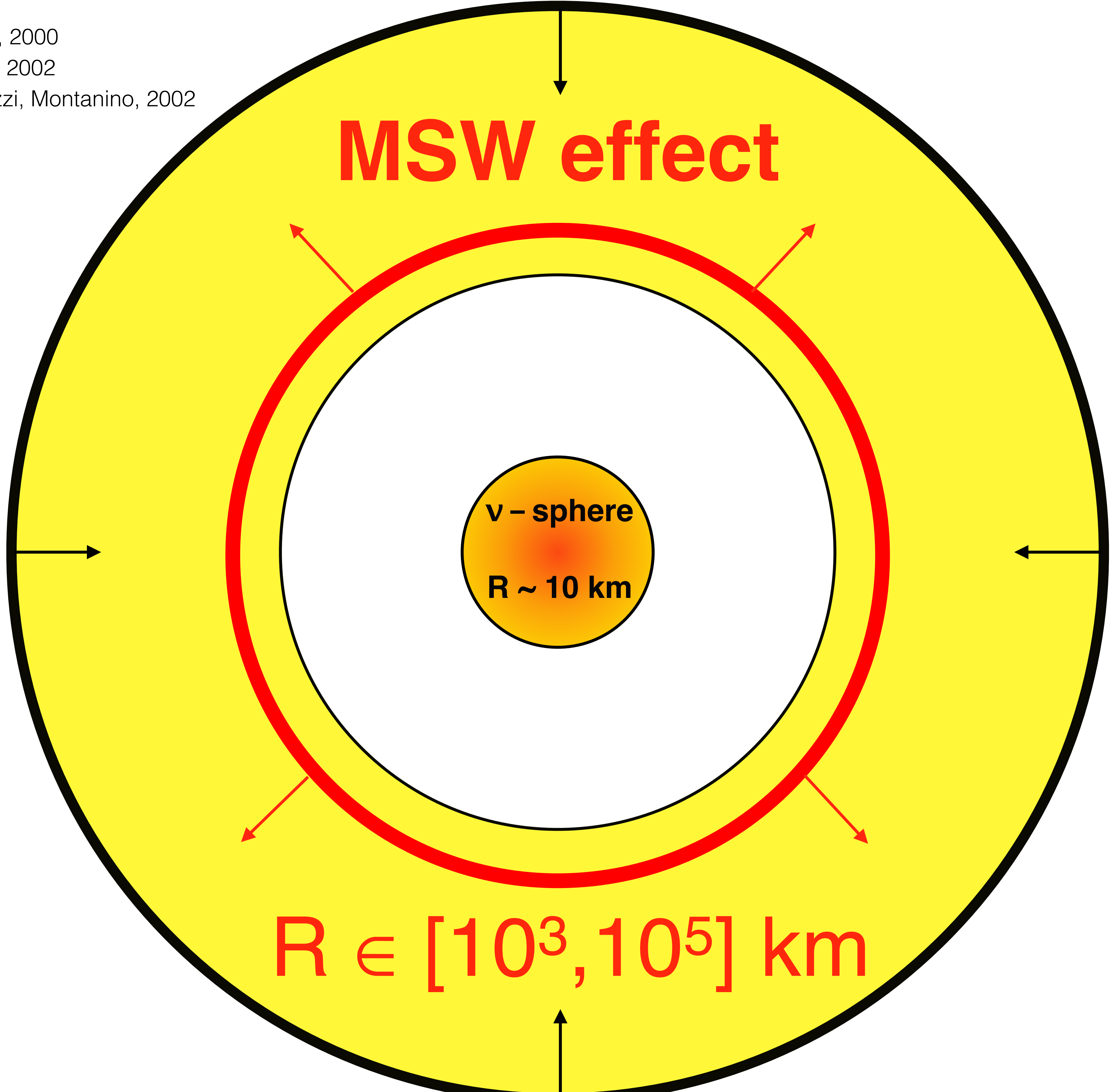

Outer layer
Accretion phase
(t < 0.5 s)
Shock wave
ν_β
ν – sphere
R ~ 10 km
$\bar{\nu}_\alpha$
ν_α
$\alpha, \beta = e, x$
$\bar{\nu}_\beta$

MSW effect

$$\lambda = \sqrt{2} G_F n_e$$



[1] Dighe, Smirnov, 2000
[2] Schirato, Fuller, 2002
[3] Fogli, Lisi, Mirizzi, Montanino, 2002



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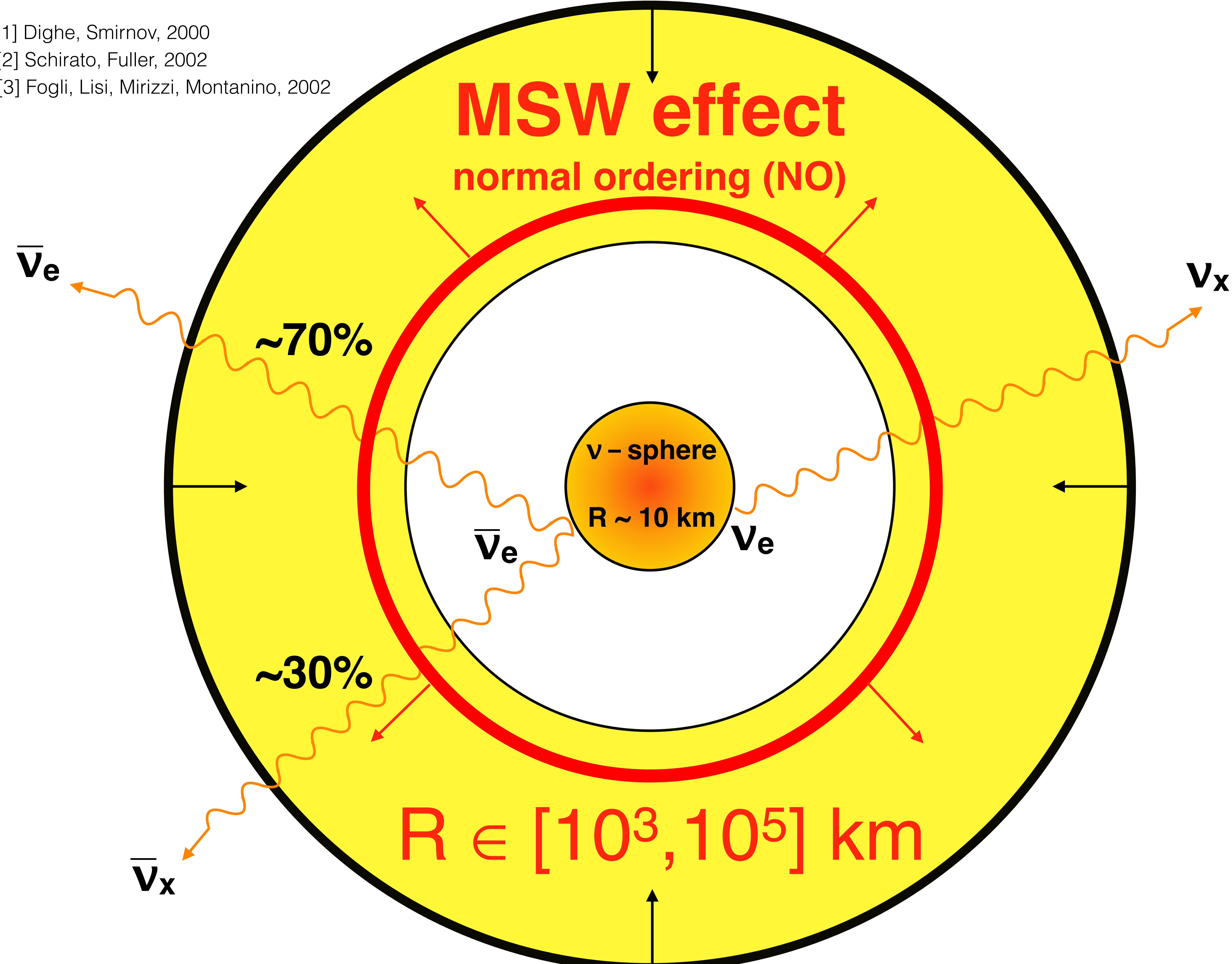

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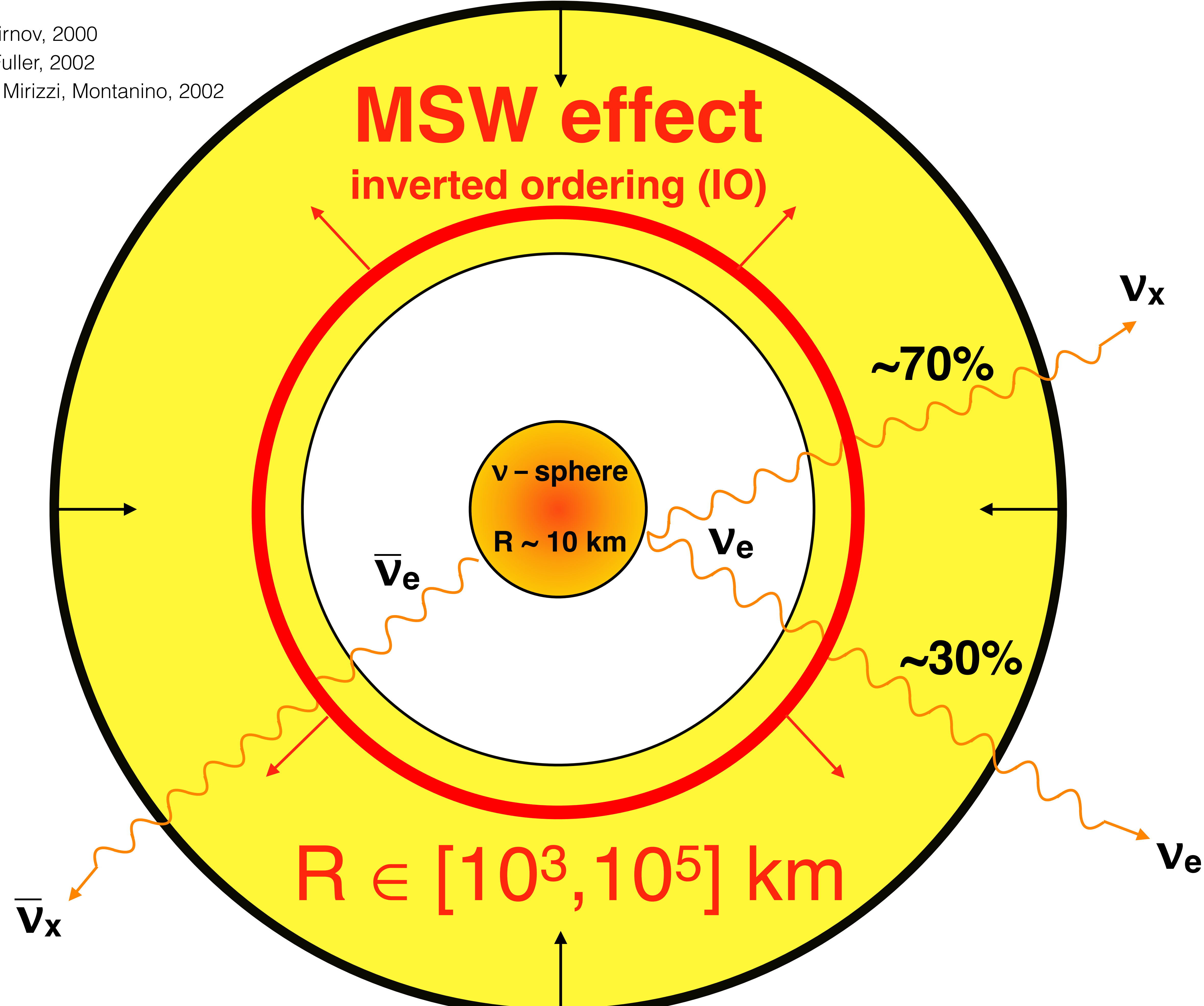
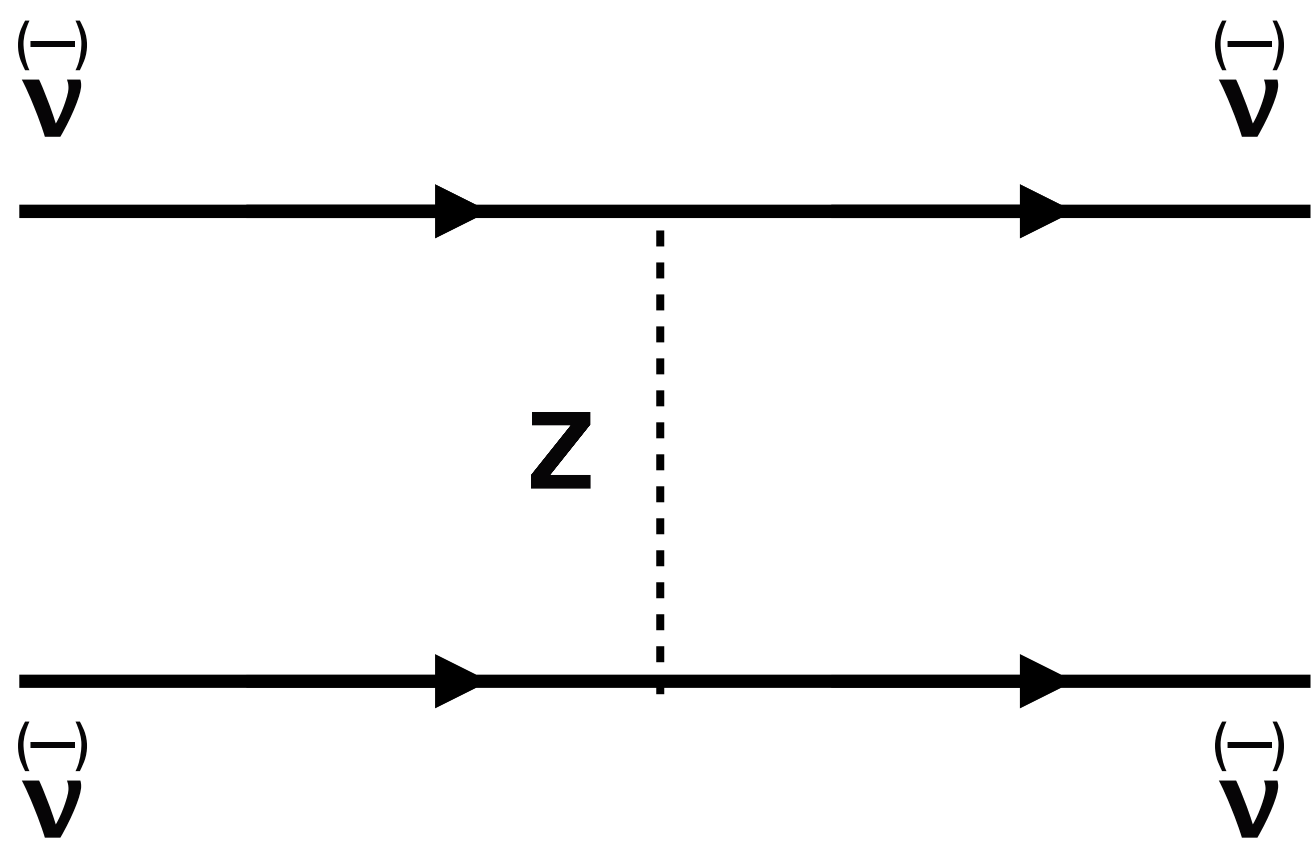


Self induced slow conversions

$$\mu = \sqrt{2} G_F n_\nu$$

$$\text{time} \propto \sqrt{\mu\, \omega_{\text{vac}}}$$



[1] Pantaleone, 1992
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[3] Duan, Fuller, Carlson, Qian, 2006
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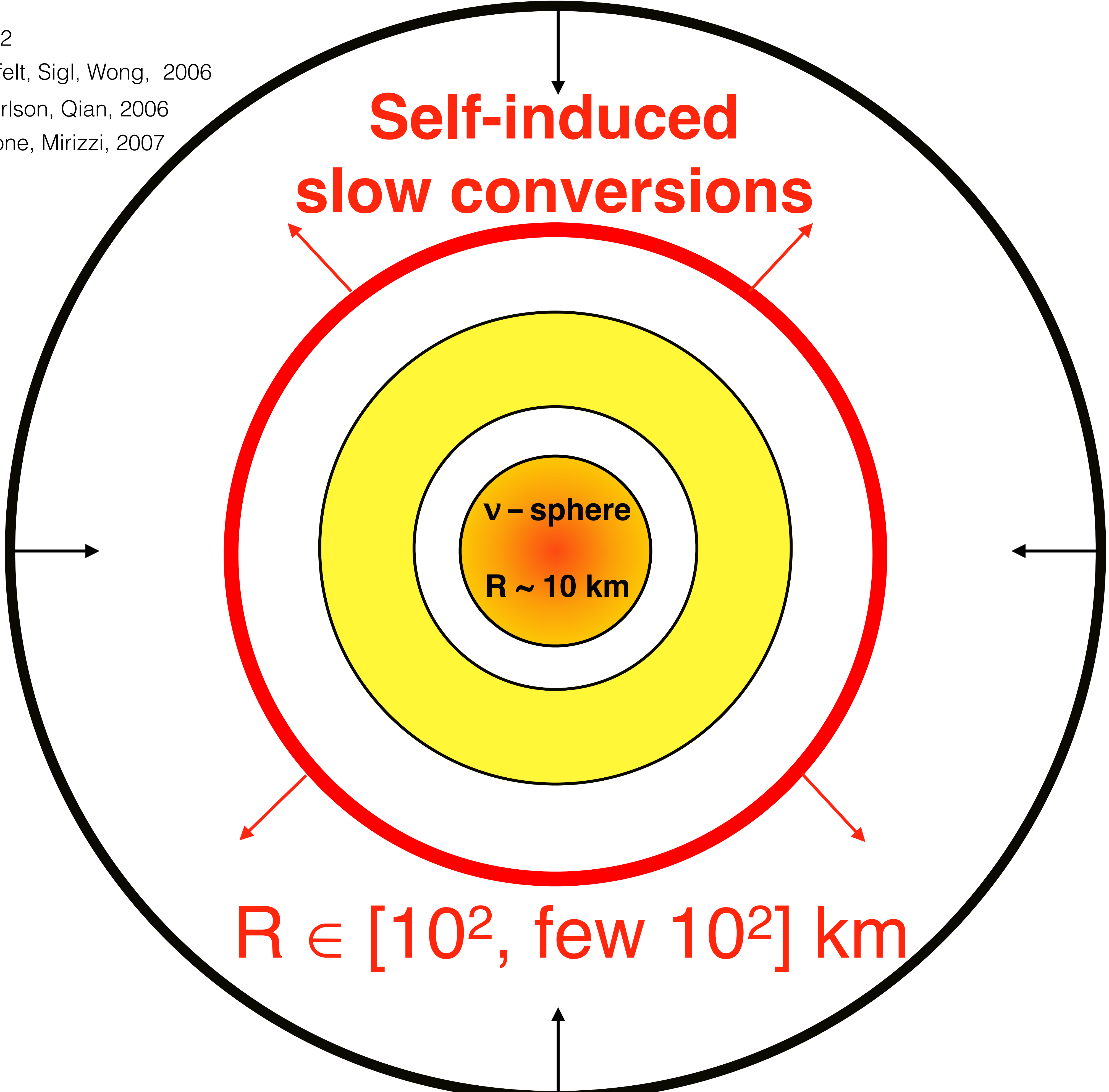

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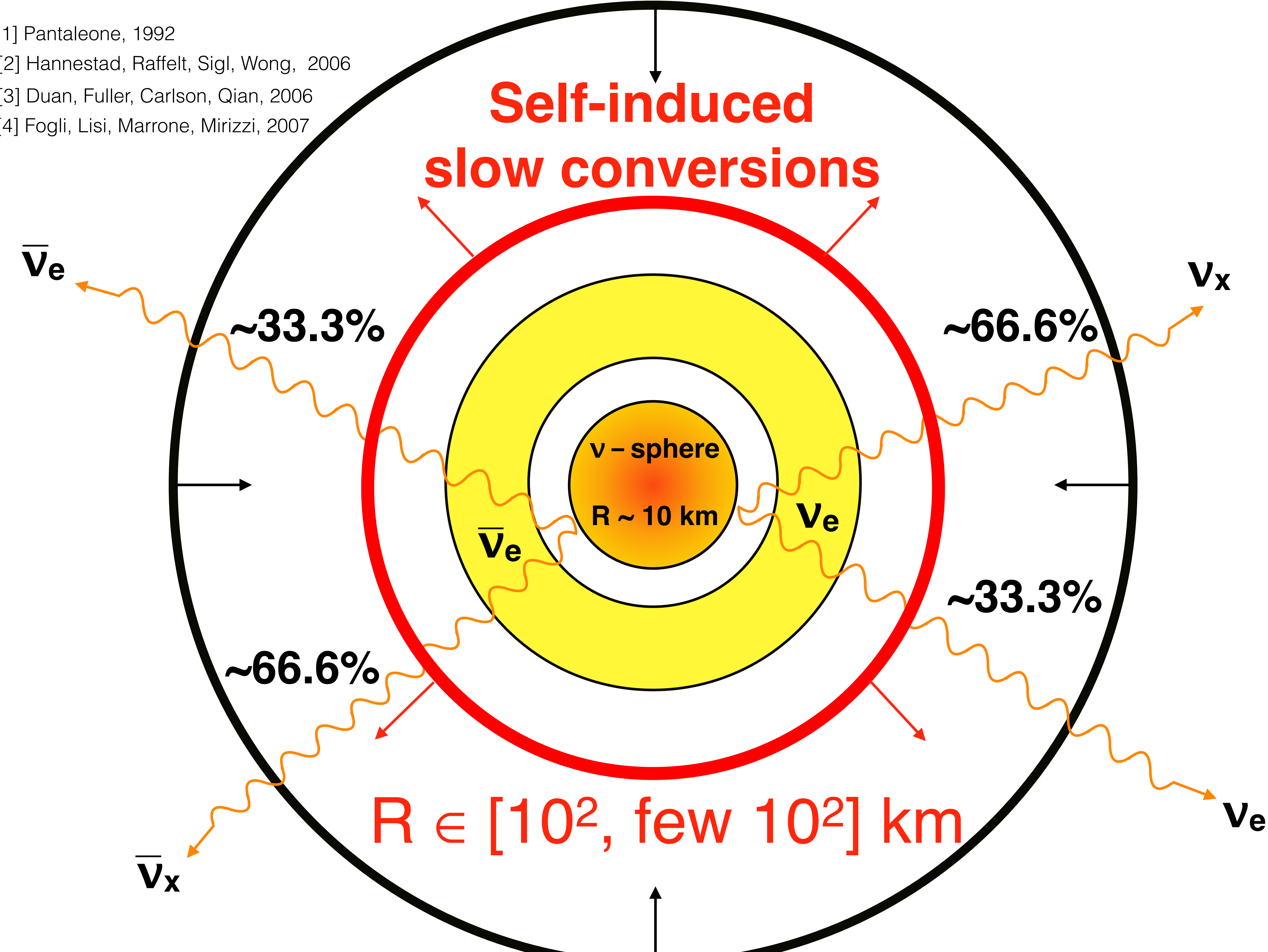

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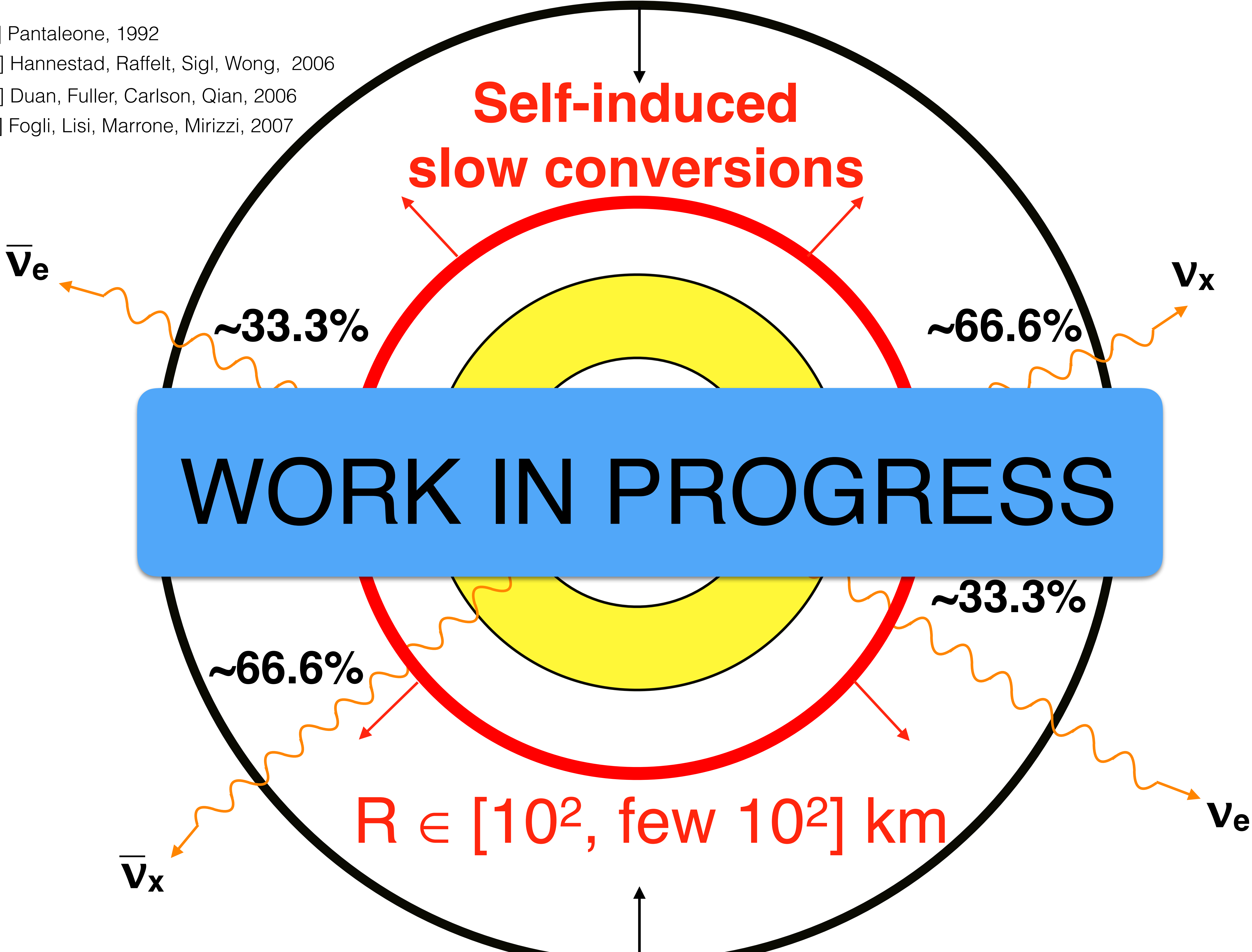
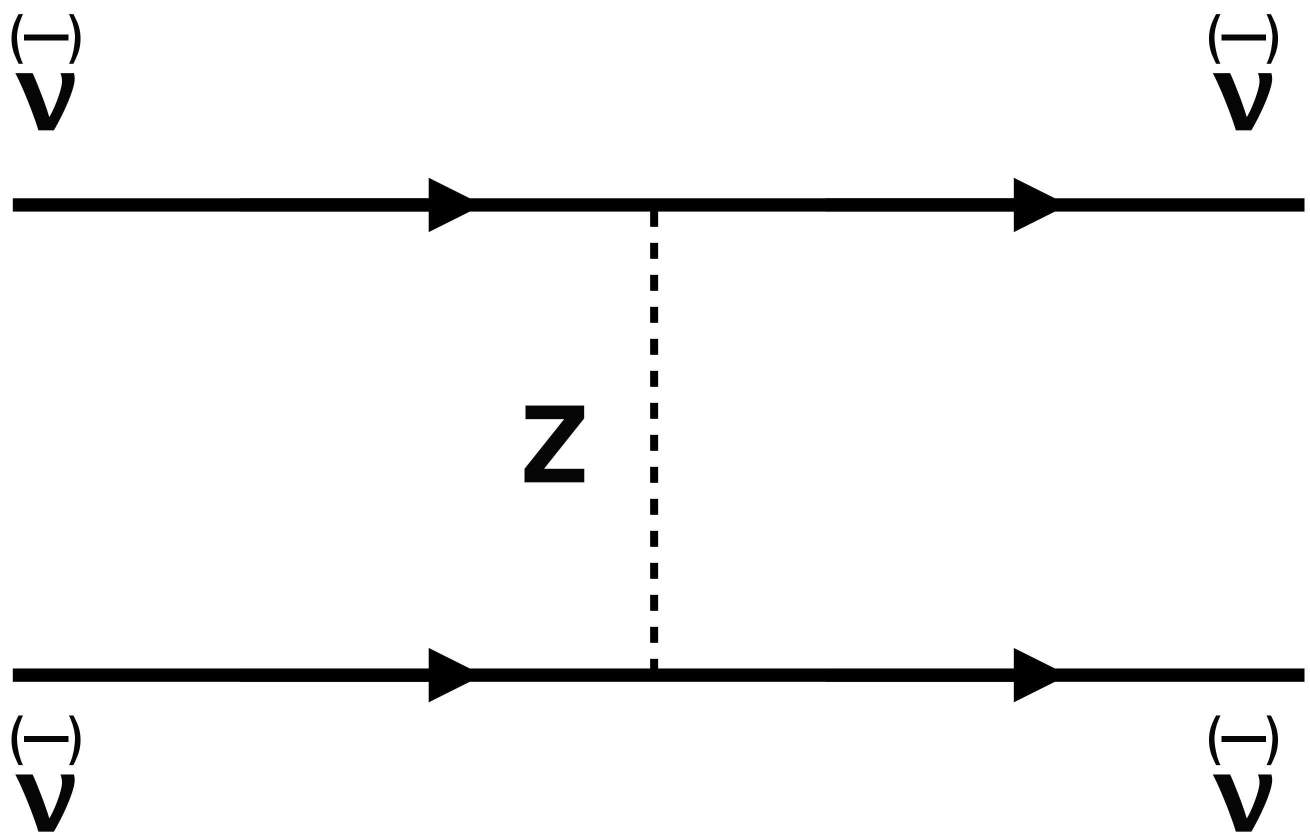


Self induced fast conversions

$$\mu = \sqrt{2} G_F n_\nu$$

$$\text{time} \propto \mu$$



[1] Sawyer, 2005-2009-2016
[2] Chakraborty, Hansen, Izaguirre, Raffelt, 2016
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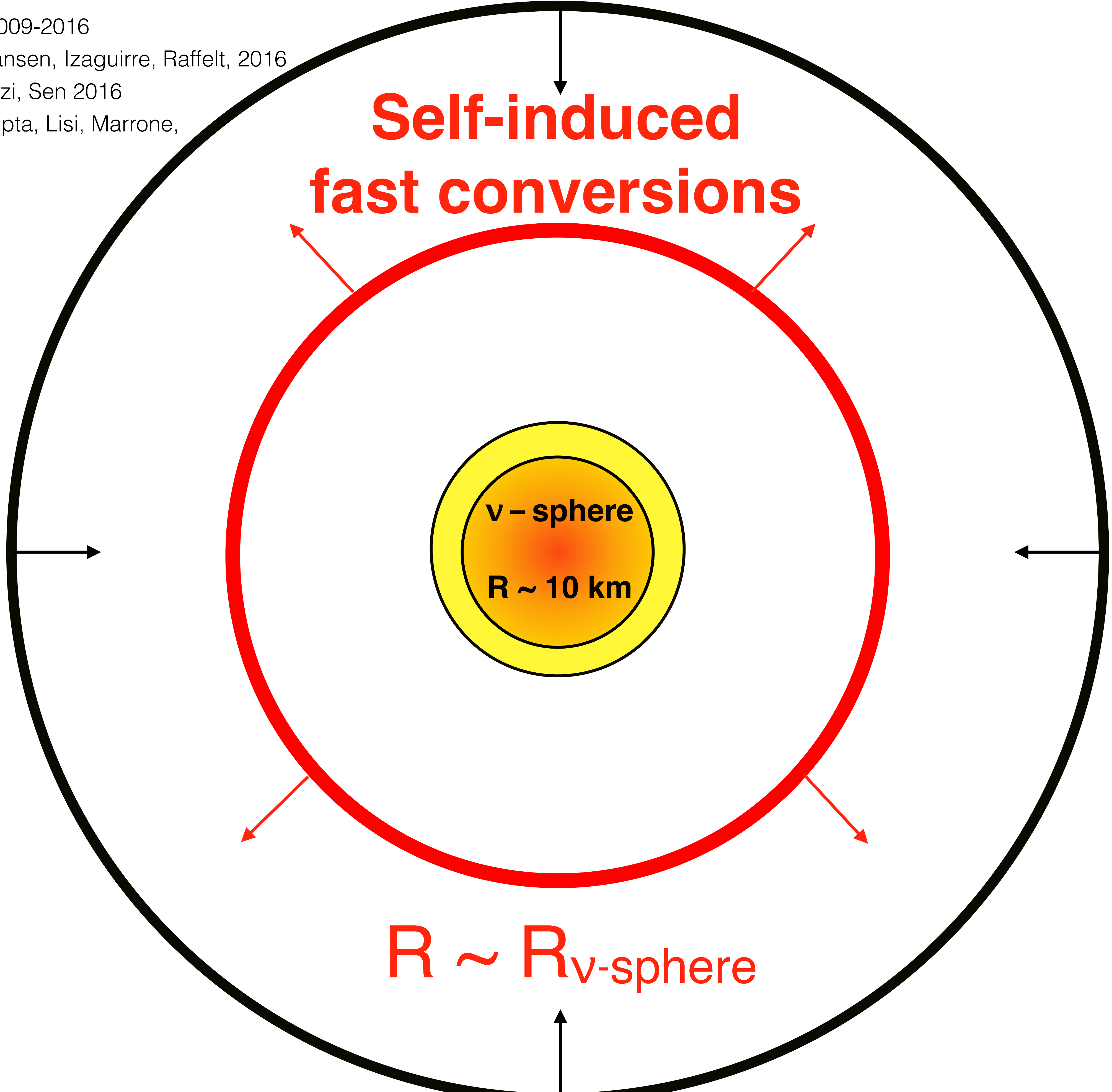

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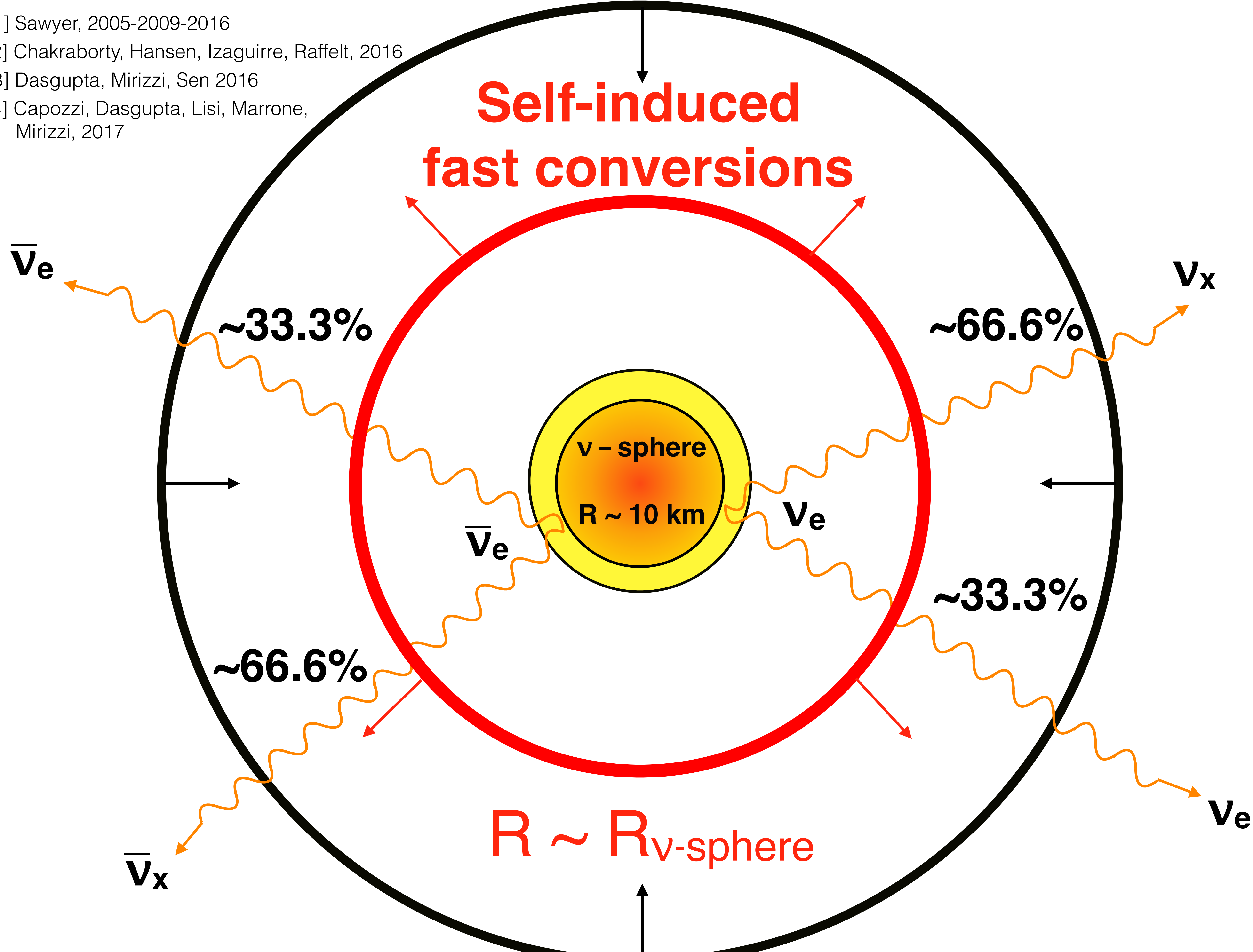

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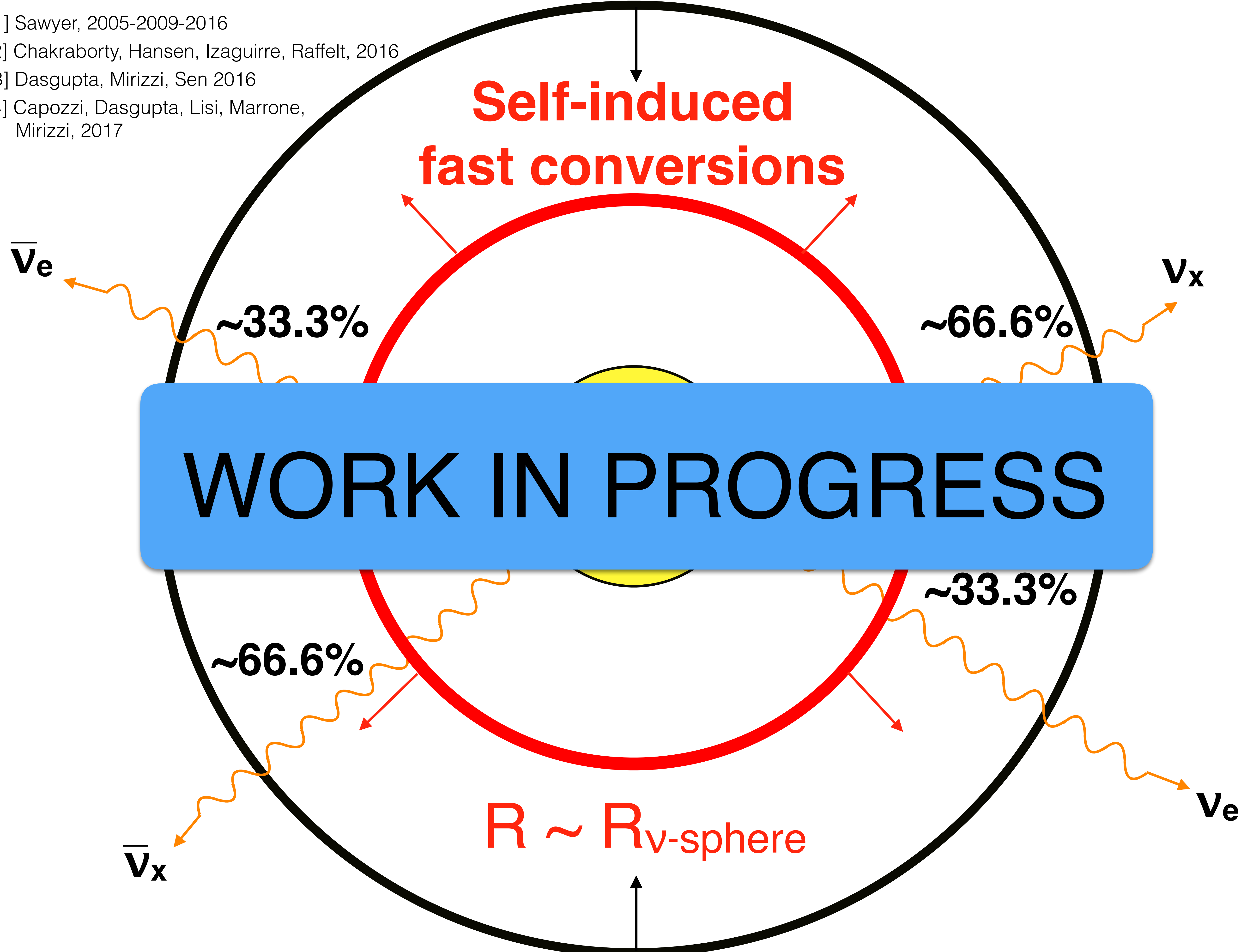

How to study self-induced conversions

- Numerical Simulations

- Normal mode analysis

- Experimentally?

Numerical simulations

We need to solve a Boltzmann kinetic equation

$$(\partial_t + \hat{\mathbf{p}} \cdot \partial_{\mathbf{x}})\varrho_{\mathbf{p}} = -i[\mathsf{H}_{\mathbf{p}}, \varrho_{\mathbf{p}}] + \mathcal{C}[\varrho]$$

Numerical simulations

We need to solve a Boltzmann kinetic equation

Flavor conversions

$$(\partial_t + \hat{\mathbf{p}} \cdot \partial_{\mathbf{x}})\varrho_{\mathbf{p}} = -i[\mathsf{H}_{\mathbf{p}}, \varrho_{\mathbf{p}}] + \mathcal{C}[\varrho]$$

Numerical simulations

We need to solve a Boltzmann kinetic equation

Collisions

$$(\partial_t + \hat{\mathbf{p}} \cdot \partial_{\mathbf{x}})\varrho_{\mathbf{p}} = -i[\mathsf{H}_{\mathbf{p}}, \varrho_{\mathbf{p}}] + \mathcal{C}[\varrho]$$

Numerical simulations

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Only solvable with some approximations

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Only solvable with some approximations

No conversions: study supernova explosion

Numerical simulations

We need to solve a Boltzmann kinetic equation

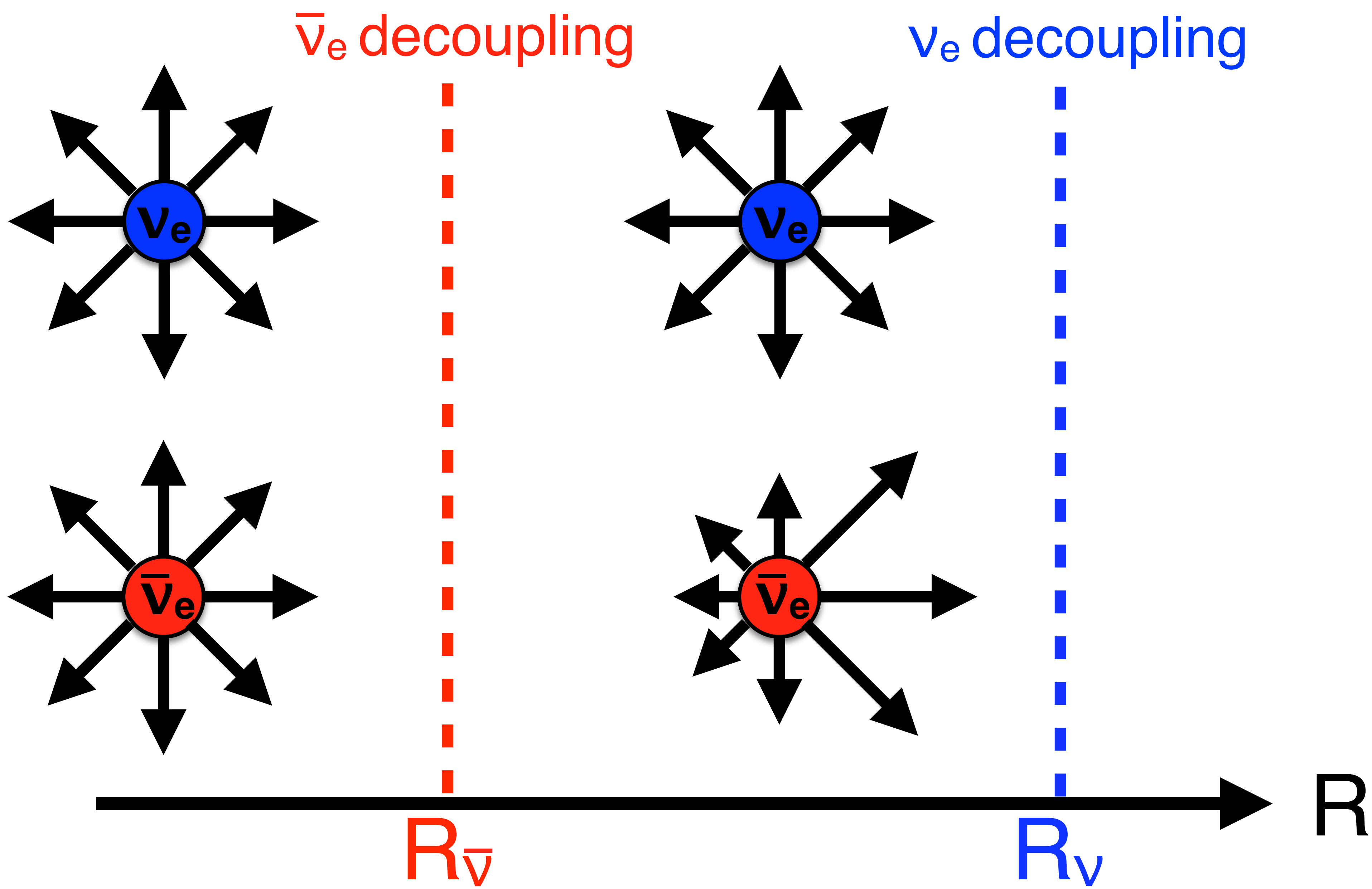
$$(\partial_t + \hat{\mathbf{p}} \cdot \partial_{\mathbf{x}})\varrho_{\mathbf{p}} = -i[\mathsf{H}_{\mathbf{p}}, \varrho_{\mathbf{p}}] + \mathcal{C}[\varrho]$$

Only solvable with some approximations

No collisions: study flavor conversions

Numerical simulations: fast conversions

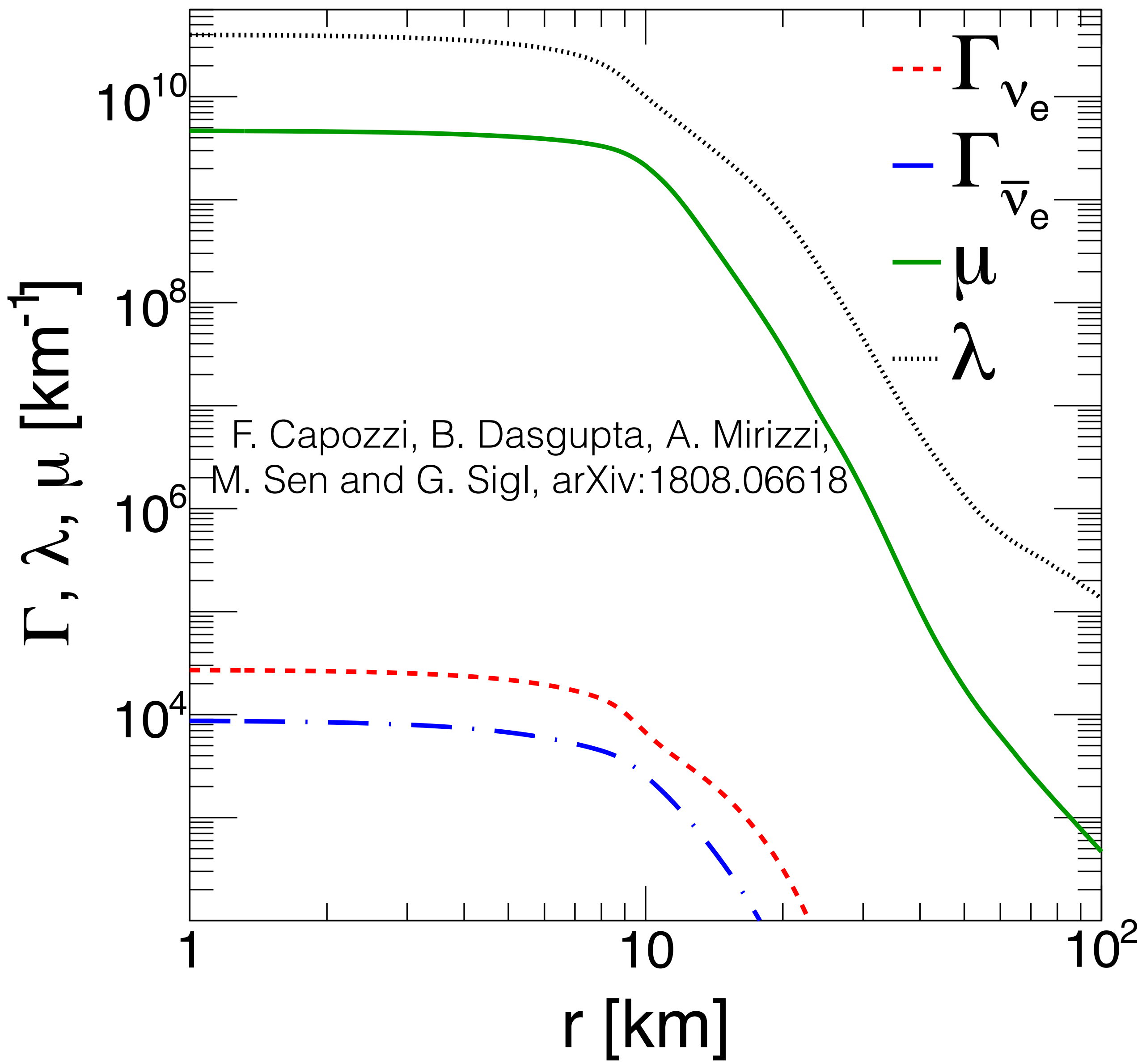
Fast conversions ⇔ different angular distributions of ν_e and $\bar{\nu}_e$



Favorable conditions are expected before ν_e decoupling

Numerical simulations: fast conversions

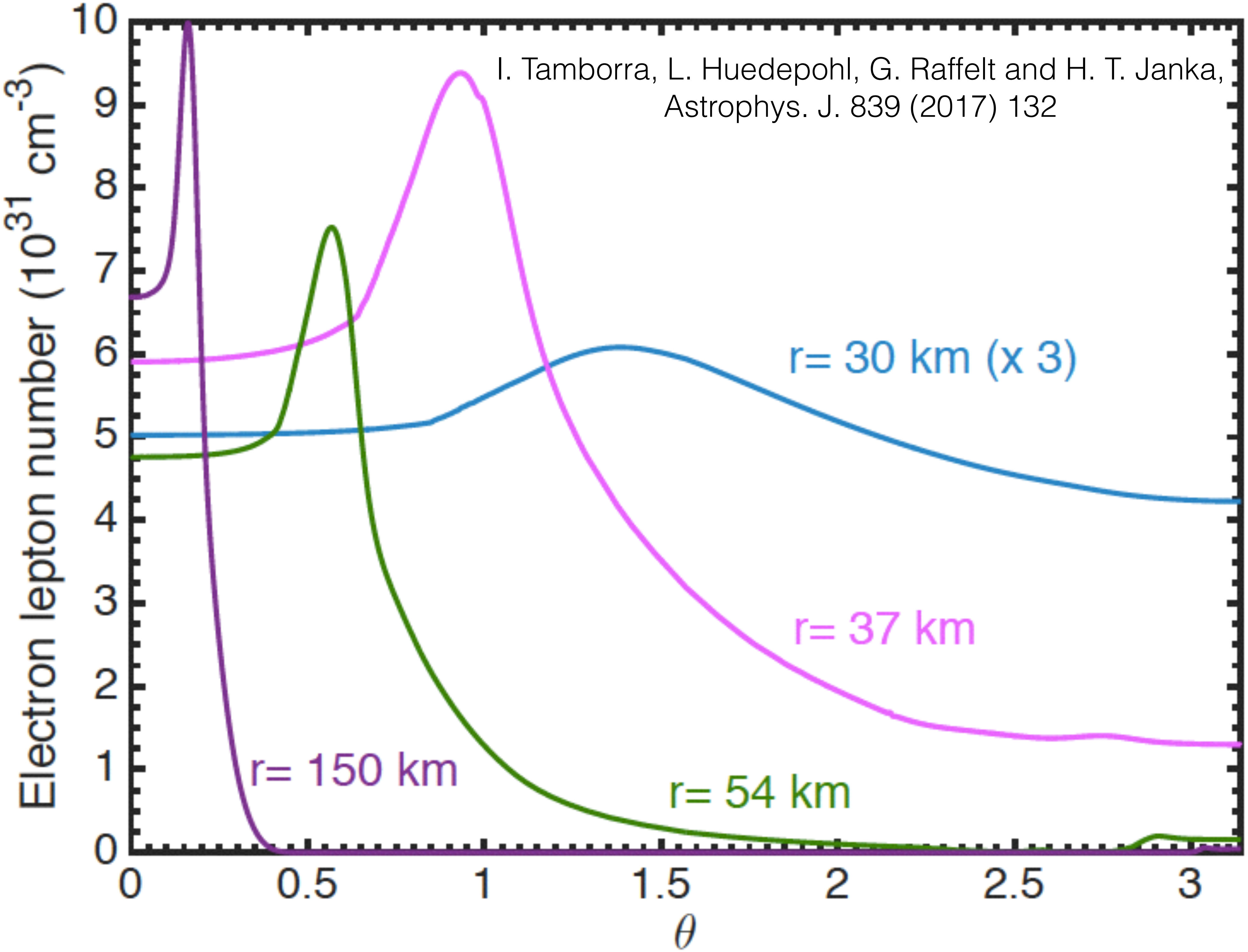
Fast conversions must be simulated with collisions



Collision rate is much smaller than conversion rate **($\Gamma \ll \mu$).**
Collisions generate fast conversion, but do not suppress them

Numerical simulations: fast conversions

No conditions for fast conversion in 1D simulations



How to study self-induced conversions

- Numerical Simulations

- Normal mode analysis

- Experimentally?

Normal mode analysis

$$\varrho_{\mathbf{v}} \propto \begin{pmatrix} s_{\mathbf{v}}(t,x) & S_{\mathbf{v}}(t,x) \\ S^*_{\mathbf{v}}(t,x) & -s_{\mathbf{v}}(t,x) \end{pmatrix}$$

Normal mode analysis

occupation numbers

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occupation numbers

Normal mode analysis

occupation numbers — flavour coherence

$$\varrho_{\mathbf{v}} \propto \begin{pmatrix} s_{\mathbf{v}}(t,x) & S_{\mathbf{v}}(t,x) \\ S^*_{\mathbf{v}}(t,x) & -s_{\mathbf{v}}(t,x) \end{pmatrix}$$

flavour coherence — occupation numbers

Normal mode analysis

$$\varrho_{\mathbf{v}} \propto \begin{pmatrix} s_{\mathbf{v}}(t,x) & S_{\mathbf{v}}(t,x) \\ S^*_{\mathbf{v}}(t,x) & -s_{\mathbf{v}}(t,x) \end{pmatrix}$$

Neutrinos are produced in flavour eigenstates

$$s_{\mathbf{v}}(t,x) \simeq 1$$

Standard oscillations suppressed by strong matter effects

$$S_{\mathbf{v}}(t,x) \ll 1$$

Normal mode analysis

Self induced conversions can introduce a rapid growth of S

$$S_{\mathbf{v}}(t,\mathbf{x}) = Q_{\mathbf{v}} e^{i(\mathbf{k}\cdot\mathbf{x}-\omega t)}$$

Normal mode analysis

Self induced conversions can introduce a rapid growth of S

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DISPERSION RELATION

$$D(\omega, k) = 0$$

I. Izaguirre, G. Raffelt and I. Tamborra, Phys. Rev. Lett. 118 (2017) no.2, 021101

F. Capozzi, B. Dasgupta, E. Lisi, A. Marrone and A. Mirizzi, Phys. Rev. D 96 (2017) no.4, 043016

S. Airen, F. Capozzi, S. Chakraborty, B. Dasgupta, G. Raffelt and T. Stirner, arXiv:1809.09137

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$$\omega, k \in \mathbb{C} \;\Rightarrow\; \text{FLAVOUR INSTABILITY}$$

Normal mode analysis: future work

Extend analysis to more complicated (multi-D) models

F. Capozzi, G. Raffelt, T. Stirner [MPP astro-partilce group]

Normal mode analysis: future work

Extend analysis to more complicated (multi-D) models

F. Capozzi, G. Raffelt, T. Stirner [MPP astro-partilce group]

Apply analysis to real supernova simulation and look for instabilities

F. Capozzi, B. Dasgupta, H.-T. Janka, R. Glas, A. Mirizzi, M. Sen

How to study self-induced conversions

- Numerical Simulations

- Normal mode analysis

- Experimentally?

Information from experiments

Experiments can distinguish flavour conversion scenarios?

Scenario	Mass Ordering	P_{ee}	$\bar{P}_{ee}$
ME	NO	0	$\cos^2\theta_{12} \simeq 0.7$
ME	IO	$\sin^2\theta_{12} \simeq 0.3$	0
FE	either	$1/3 \simeq 0.33$	$1/3 \simeq 0.33$

ME = Matter effects (MSW)

FE = flavour equalisation

Information from experiments

We use three detection channels

ν-proton elastic scattering (pES)

$\overset{(-)}{\nu}_{e,\mu,\tau} + p \longrightarrow \overset{(-)}{\nu}_{e,\mu,\tau} + p$

$$F_{\rm pES}(E_\nu) = F_{\nu_e}(E_\nu) + F_{\bar{\nu}_e}(E_\nu) + 4F_{\nu_x}(E_\nu)$$

Information from experiments

We use three detection channels

inverse β decay (IBD)

$\bar{\nu}_e + p \longrightarrow e^+ + n$

$$F_{\rm IBD}(E_\nu) = F_{\bar{\nu}_e}(E_\nu)\bar{P}_{ee} + F_{\nu_x}(E_\nu)(1 - \bar{P}_{ee})$$

Information from experiments

We use three detection channels

DEEP UNDERGROUND NEUTRINO EXPERIMENT

ν charged-current on ^{40}Ar (ArCC)

$\nu_e + {}^{40}Ar \longrightarrow e^- + {}^{40}K^*$

$$F_{\mathrm{ArCC}}(E_\nu) = F_{\nu_e}(E_\nu)P_{ee} + F_{\nu_x}(E_\nu)(1 - P_{ee})$$

Information from experiments: ratios

Assume we are in normal mass ordering. We define:

$$R = \frac{F_{\mathrm{pES}}}{F_{\mathrm{ArCC}}} \qquad x = \frac{F^0_{\nu_e}}{F^0_{\nu_x}} \leq 1 \qquad \bar{x} = \frac{F^0_{\bar{\nu}_e}}{F^0_{\nu_x}} \leq 1$$

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$$R_{\mathrm{ME}} = \begin{cases} 4 & x, \bar{x} \ll 1 \\ 5 & x \ll 1, \text{ and } \bar{x} \lesssim 1 \\ 6 & x \lesssim \bar{x} \lesssim 1 \end{cases} , \qquad R_{\mathrm{FE}} = \begin{cases} 6 & x, \bar{x} \ll 1 \\ 7.5 & x \ll 1, \text{ and } \bar{x} \lesssim 1 \\ 6 & x \lesssim \bar{x} \lesssim 1 \end{cases}$$

Information from experiments: ratios

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R > 6 disfavours "matter effects only" scenario

Information from experiments: ratios

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R > 6 disfavours “matter effects only” scenario

R < 6 disfavours “flavour equalisation” scenario

Information from experiments: ratios

Assume we are in normal mass ordering. We define:

$$\bar{R} = \frac{F_{\mathrm{pES}}}{F_{\mathrm{IBD}}} \qquad x = \frac{F^0_{\nu_e}}{F^0_{\nu_x}} \leq 1 \qquad \bar{x} = \frac{F^0_{\bar{\nu}_e}}{F^0_{\nu_x}} \leq 1$$

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$$\bar{R}_{\text{ME}} = \begin{cases} 13.3 & x, \bar{x} \ll 1 \\ 5 & x \ll 1, \ \text{and}\ \bar{x} \lesssim 1 \\ 6 & x \lesssim \bar{x} \lesssim 1 \end{cases}, \qquad \bar{R}_{\text{FE}} = \begin{cases} 6 & x, \bar{x} \ll 1 \\ 5 & x \ll 1, \ \text{and}\ \bar{x} \lesssim 1 \\ 6 & x \lesssim \bar{x} \lesssim 1 \end{cases}$$

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$\bar{R}$ > 6 disfavours “flavour equalization” scenario

Information from experiments: ratios

Assume we are in normal mass ordering. We define:

$$\bar{R} = \frac{F_{\rm pES}}{F_{\rm IBD}} \qquad x = \frac{F^0_{\nu_e}}{F^0_{\nu_x}} \leq 1 \qquad \bar{x} = \frac{F^0_{\bar{\nu}_e}}{F^0_{\nu_x}} \leq 1$$

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$\bar{\text{R}} > 6$ disfavours “flavour equalization” scenario

$\bar{\text{R}} \sim 5$ - 6 leads to degeneracy between scenarios

Conclusions

Three complimentary ways of studying flavour conversions:

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1) we can use "brute force" numerical simulations

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Conclusions

Three complimentary ways of studying flavour conversions:

1) we can use “brute force” numerical simulations

2) we can use normal mode analysis

3) real data can in principle exclude some scenario

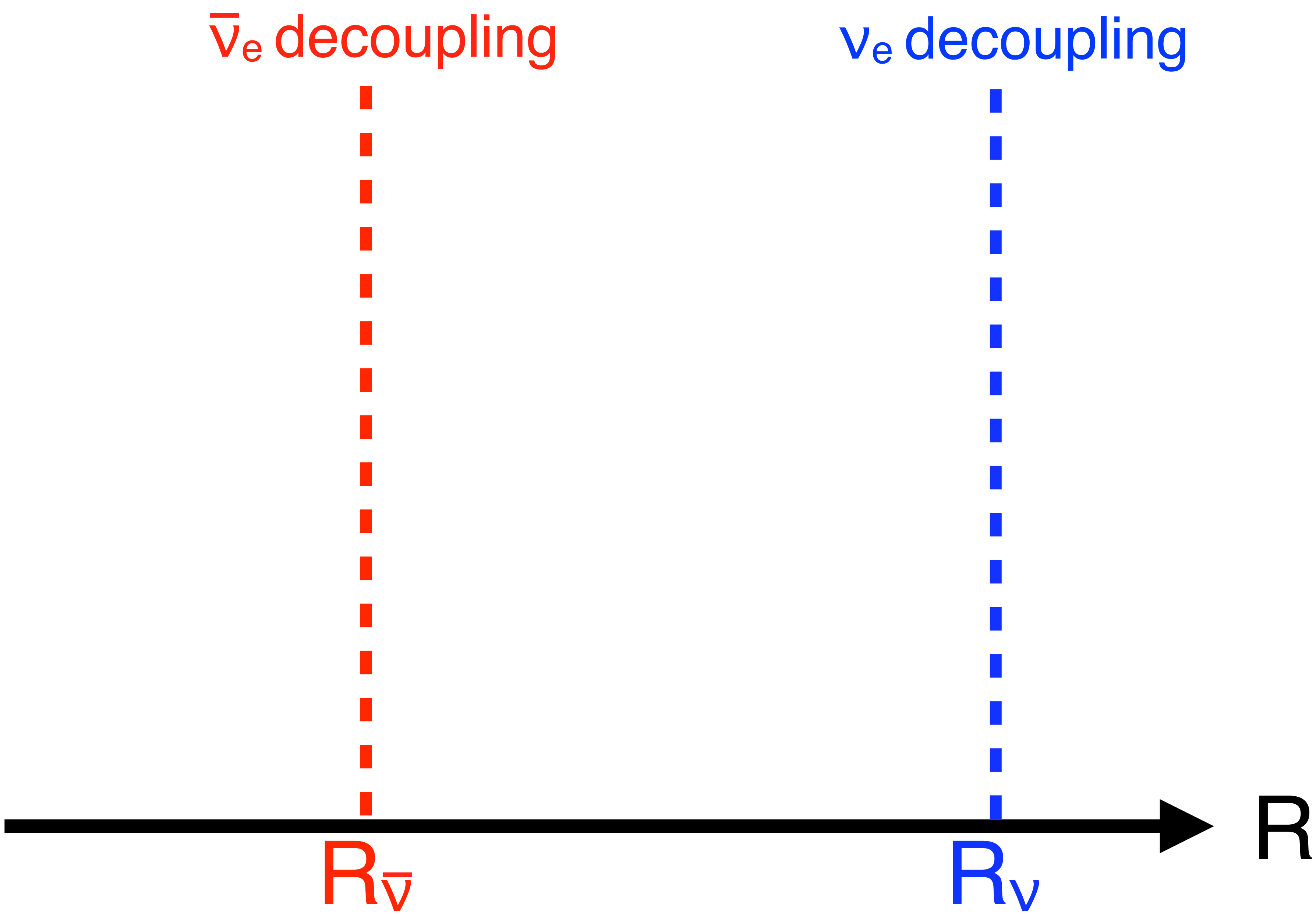
Synergy with SN explosion simulators is required

Thank you

Backup

Numerical simulations: fast conversions

Fast conversions ⇔ different angular distributions of ν_e and $\bar{\nu}_e$



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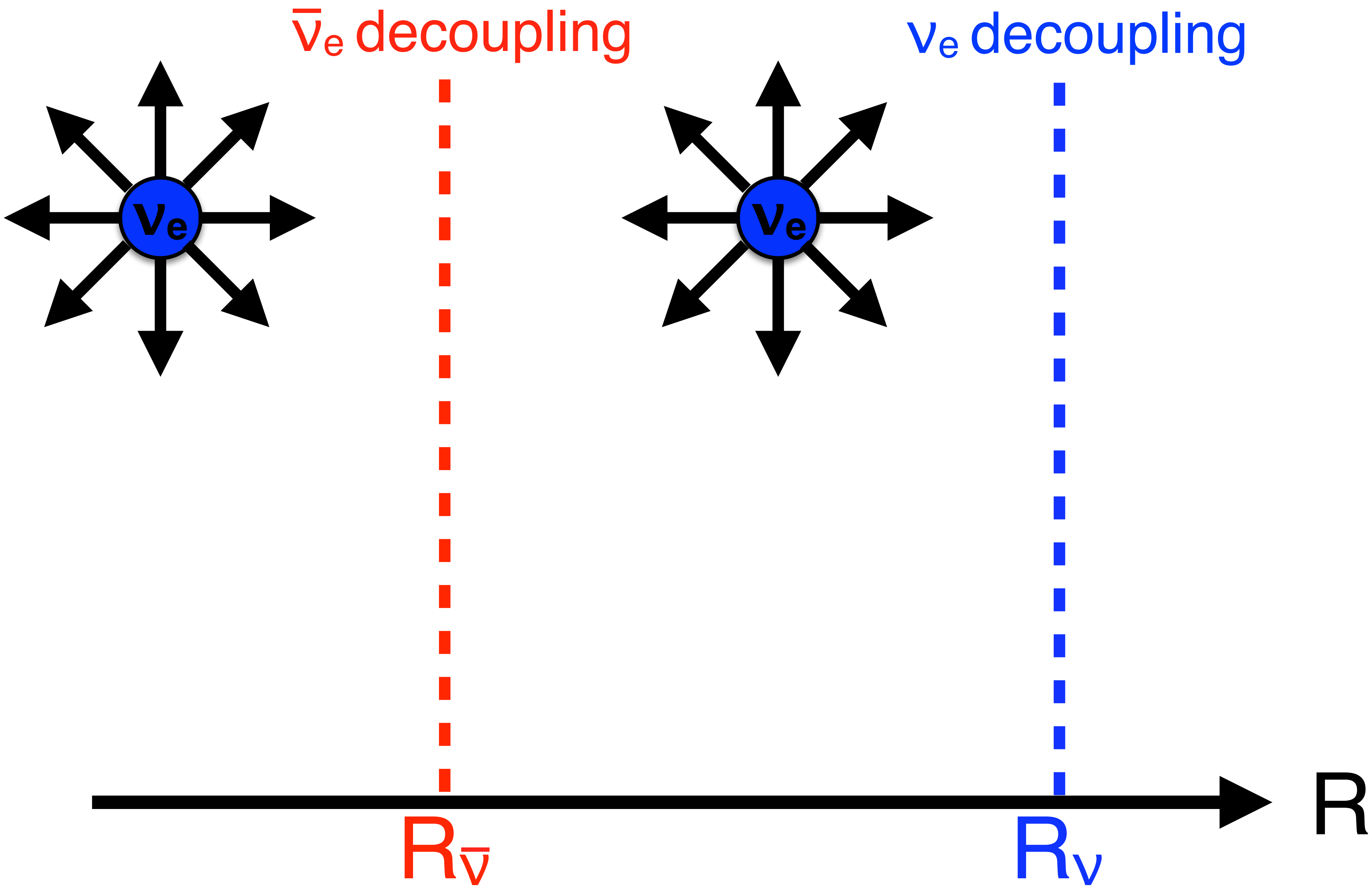
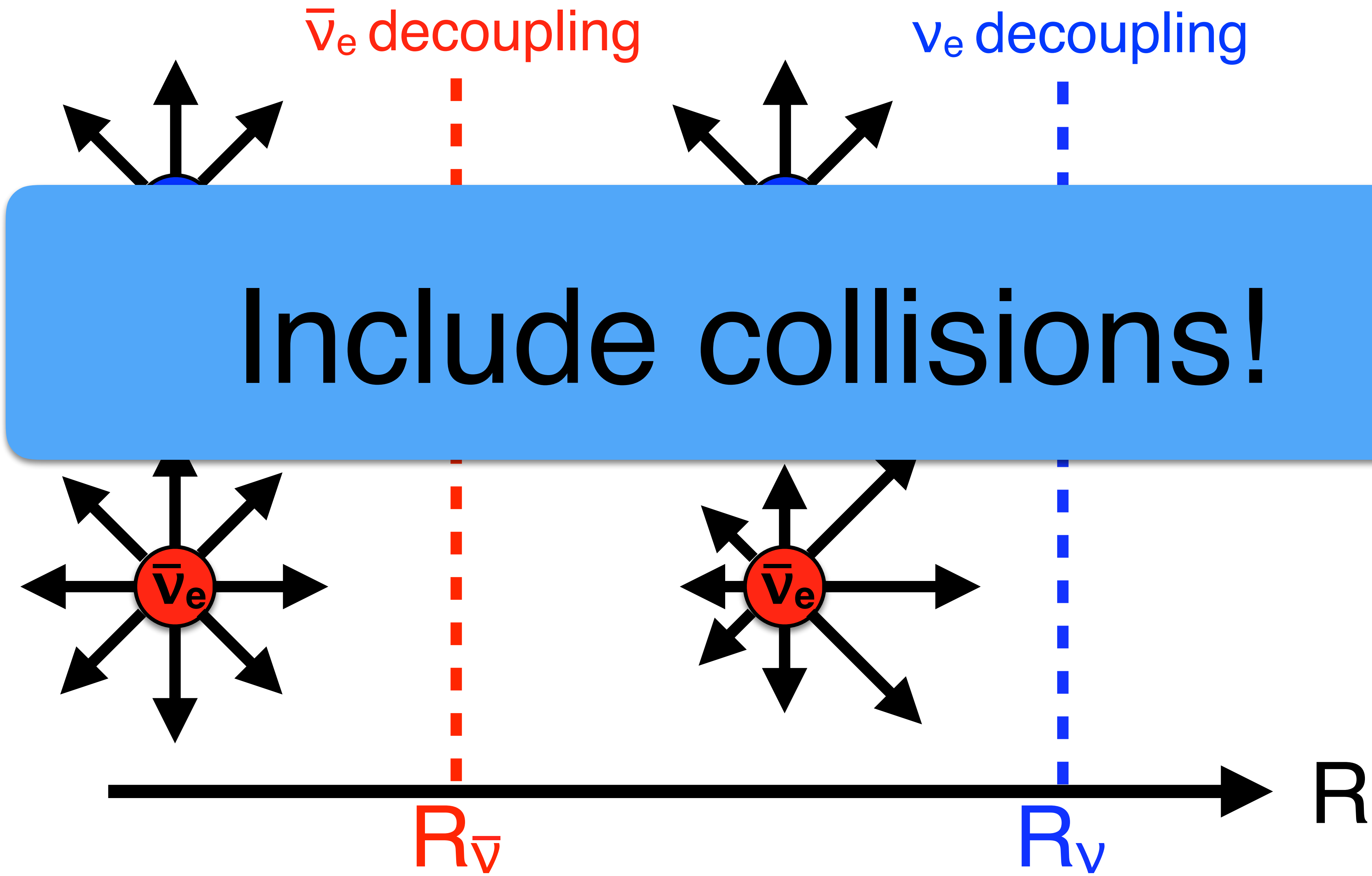


Numerical simulations: fast conversions

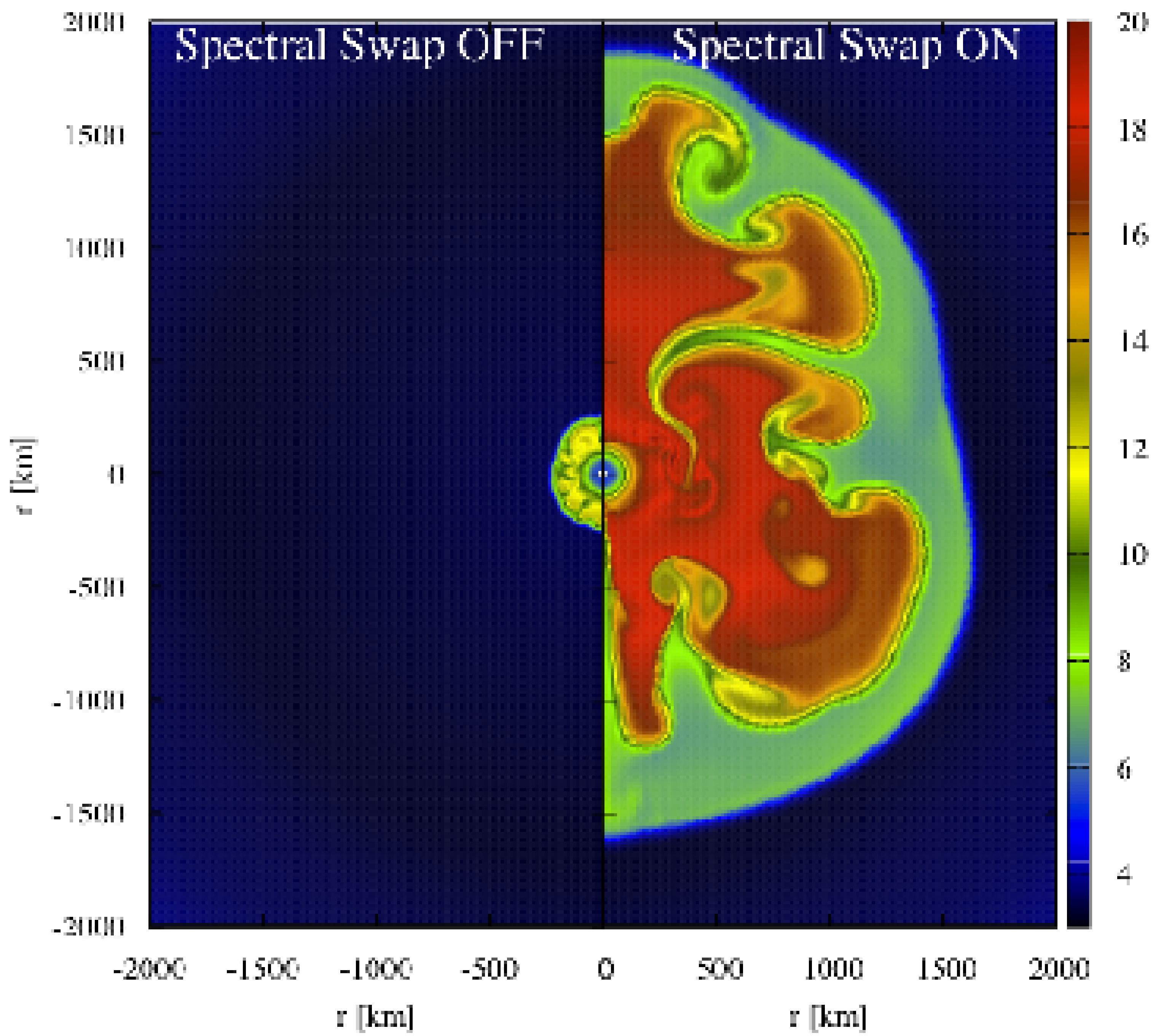
Fast conversions ⇔ different angular distributions of ν_e and $\bar{\nu}_e$



Favorable conditions are expected before ν_e decoupling

Flavour conversions: why study them?

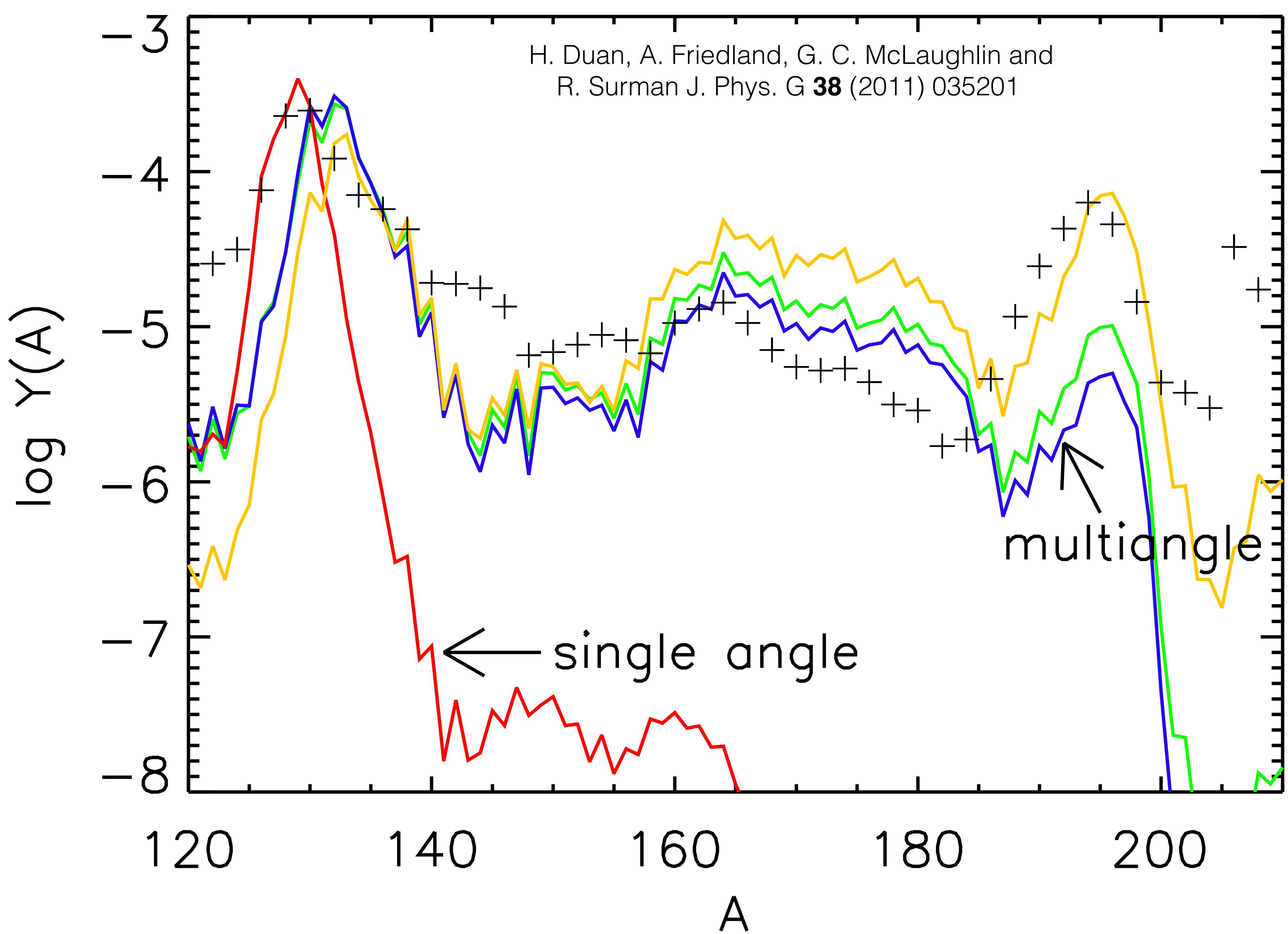
Impact on neutrino heating of the shock



Y. Suwa, et al.,
Astrophys. J. **738** (2011) 165

Flavour conversions: why study them?

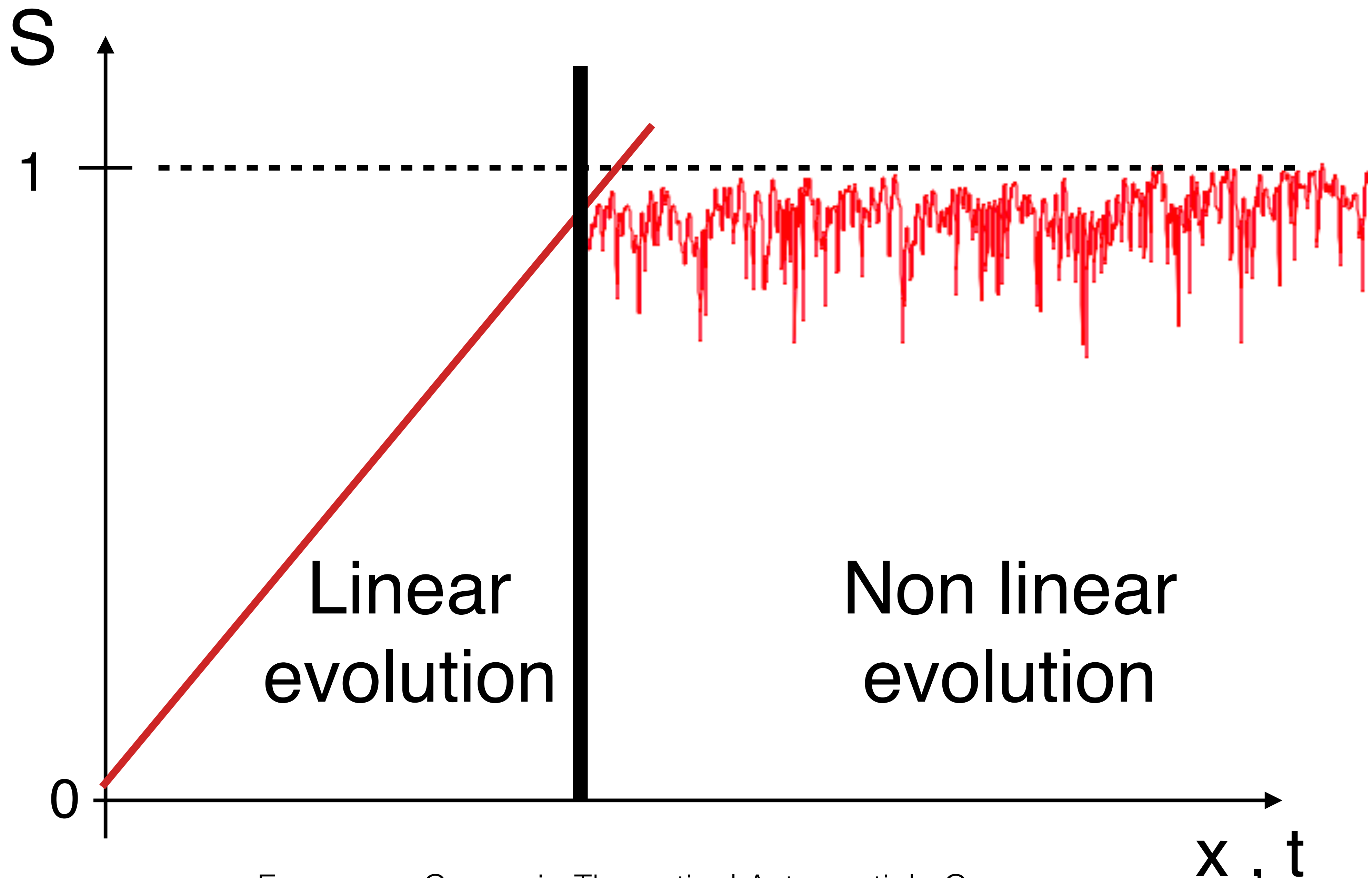
Impact on nucleosynthesis (r-process)



Normal mode analysis

Self induced conversions can introduce a rapid growth of S

$$S_{\mathbf{v}}(t,\mathbf{x}) = Q_{\mathbf{v}} e^{i(\mathbf{k}\cdot\mathbf{x}-\omega t)}$$



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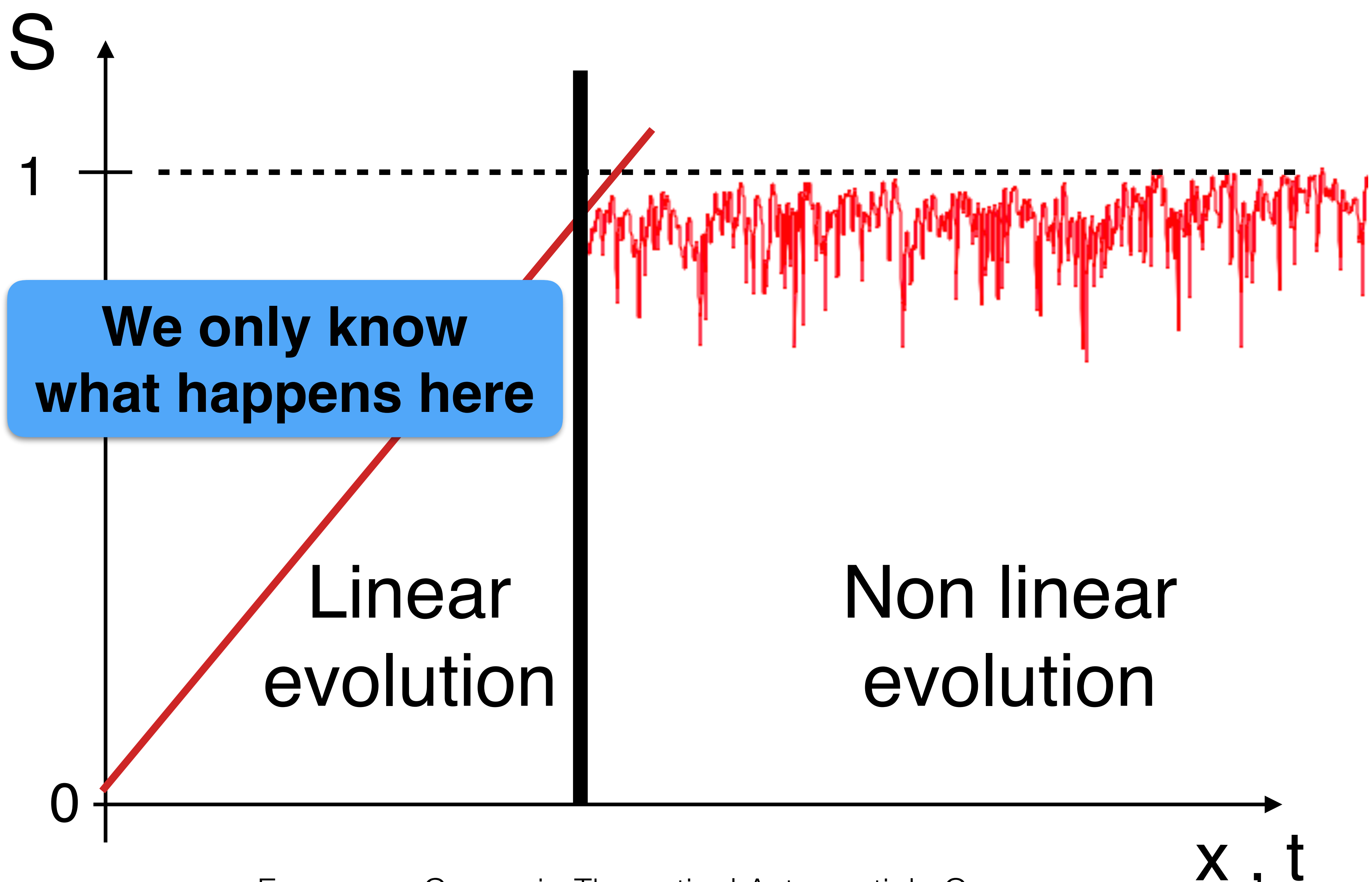
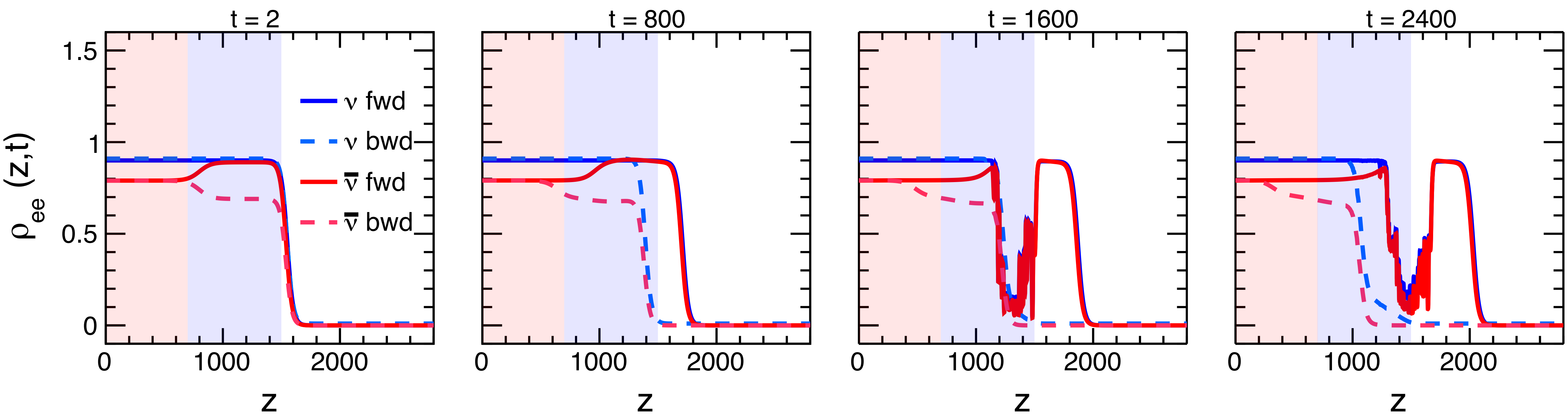


Numerical simulations: fast conversions

Simulation with toy model in 1 spatial + 1 temporal dimensions

F. Capozzi, B. Dasgupta, A. Mirizzi, M. Sen and G. Sigl, arXiv:1808.06618



After generating fast conversions, collisions are unimportant

SN fluxes: parametrization

We adopt the following parametrisation:

$$F_\nu^0(E) = \Phi_\nu^0 \, f_\nu^0(E)$$

$$f_\nu^0(E) = \frac{1}{\langle E_\nu \rangle} \frac{(1+\alpha_\nu)^{1+\alpha_\nu}}{\Gamma(1+\alpha_\nu)} \left(\frac{E}{\langle E_\nu \rangle} \right)^{\alpha_\nu} \exp\left[-(1+\alpha_\nu) \frac{E}{\langle E_\nu \rangle} \right]$$

$$\alpha_\nu = \frac{2\langle E_\nu \rangle^2 - \langle E_\nu^2 \rangle}{\langle E_\nu^2 \rangle - \langle E_\nu \rangle^2}$$

[1] M. Keil, G. G. Raffelt, and H.-T. Janka, Astrophys. J. **590**, 971–991 (2003)

SN fluxes: parametrization

List of fit parameters for W and G models

Model	$\langle E_{\nu_e}\rangle$ (MeV)	$\langle E_{\nu_x}\rangle$ (MeV)	$\Phi_{\nu_e}(\times 10^{56})$	$\Phi_{\nu_x}(\times 10^{56})$	α_{ν_e}	α_{ν_x}
W	9.5	15.6	8.53	3.13	3.4	2.0
G	10.9	14.0	5.68	2.67	3.1	2.5

Model	$\langle E_{\bar{\nu}_e}\rangle$ (MeV)	$\langle E_{\bar{\nu}_x}\rangle$ (MeV)	$\Phi_{\bar{\nu}_e}(\times 10^{56})$	$\Phi_{\bar{\nu}_x}(\times 10^{56})$	$\alpha_{\bar{\nu}_e}$	$\alpha_{\bar{\nu}_x}$
W	11.6	15.6	7.51	3.13	4.0	2.0
G	13.2	14.0	4.11	2.67	3.3	2.5

JUNO: ν-proton elastic scattering (pES)

$$\overset{(-)}{\nu}_{e,\mu,\tau} + p \longrightarrow \overset{(-)}{\nu}_{e,\mu,\tau} + p$$

$$\frac{dN_{\mathrm{pES}}}{dE_{\mathrm{vis}}} = N_p \int_0^{+\infty} dT'_p \frac{dT_p}{dT'_p} W(T'_p, E_{\mathrm{vis}}) \int_{E_\nu^0}^{\infty} dE_\nu F_{\mathrm{pES}}(E_\nu) \frac{d\sigma_{\mathrm{pES}}(E_\nu, T_p)}{dT_p}$$

$$F_{\mathrm{pES}} \equiv 4F^0_{\nu_x} + F^0_{\bar{\nu}_e} + F^0_{\nu_e}$$

$$W(T'_p, E_{\mathrm{vis}}) = \frac{\exp\left(-\frac{(T'_p - E_{\mathrm{vis}})^2}{2\sigma_E^2}\right)}{\sqrt{2\pi}\sigma_E}$$

$$\frac{\sigma_E}{E_{\mathrm{vis}}} = 0.03\sqrt{E_{\mathrm{vis}}/\mathrm{MeV}}$$

Hyper-Kamiokande: inverse β decay

$\bar{\nu}_e + p \longrightarrow e^+ + n$

$$\frac{dN_{\rm IBD}}{dE_{\rm vis}} = N_p \int_{E_T}^{\infty} dE_\nu F_{\rm IBD}(E_\nu)\sigma_{\rm IBD}(E_\nu)\, W(E_\nu - 0.782\ \ {\rm MeV},\ E_{\rm vis})$$

$$F_{\rm IBD} \equiv \begin{cases} 0.7F^0_{\bar{\nu}_e} + 0.3F^0_{\nu_x} & \text{matter effects only, with NO} \\ F^0_{\nu_x} & \text{matter effects only, with IO} \\ 0.33F^0_{\bar{\nu}_e} + 0.66F^0_{\nu_x} & \text{flavor eq.} \end{cases}$$

$$\frac{\sigma_E}{E_{\rm vis}} = 0.6\sqrt{E_{\rm vis}/{\rm MeV}}$$

DUNE: ν-CC scattering on ^{40}Ar (ArCC)

$\nu_e + {}^{40}\mathrm{Ar} \longrightarrow e^- + {}^{40}\mathrm{K}^*$

$$\frac{dN_{\mathrm{ArCC}}}{dE_{\mathrm{vis}}} = N_{\mathrm{Ar}} \sum_{i=1}^{N_{\mathrm{ex}}} \int_0^\infty dE_\nu F_{\mathrm{ArCC}}(E_\nu) \sigma^i_{\mathrm{ArCC}}(E_\nu)\, W(E_{\mathrm{vis}}, T_e)$$

$$F_{\mathrm{ArCC}} \equiv \begin{cases} F^0_{\nu_x} & \text{matter effects only, with NO} \\ 0.3F^0_{\nu_e} + 0.7F^0_{\nu_x} & \text{matter effects only, with IO} \\ 0.33F^0_{\nu_e} + 0.66F^0_{\nu_x} & \text{flavor equalization} \end{cases}$$

$$\sigma_E = 0.11\sqrt{E_{\mathrm{vis}}/\mathrm{MeV}} + 0.02\, E_{\mathrm{vis}}/\mathrm{MeV}$$

Reconstructing ν flux from pES

We define the extrema and midpoint for the neutrino energy bins as $[E^i_\nu, E^{i+1}_\nu]$ and $\bar{E}^i_\nu$, respectively, where $E^i_\nu = \sqrt{T^i_p m_p/2}$

$$\left.\frac{d\tilde{F}_{\rm pES}}{dE_\nu}\right|_{\bar{E}^N_\nu} = \frac{N^N_{\rm pES}}{K_{NN}}$$

$$\left.\frac{d\tilde{F}_{\rm pES}}{dE_\nu}\right|_{\bar{E}^i_\nu} = \left(N^i_{\rm pES} + \sum_{j>i} \left.\frac{d\tilde{F}_{\rm pES}}{dE_\nu}\right|_{\bar{E}^j_\nu} K_{ij} \right) / K_{i,i} \, ,$$

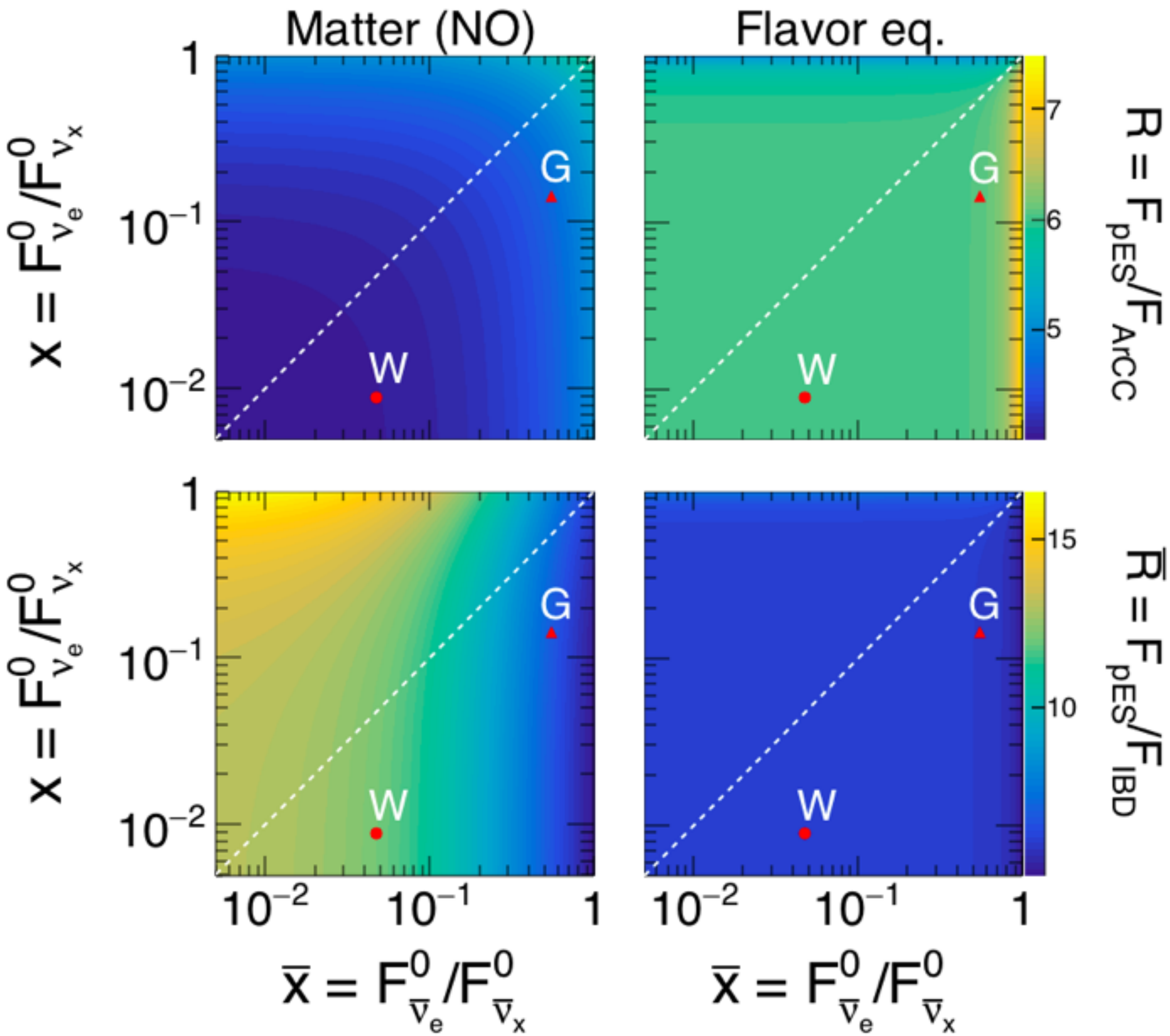
$$K_{i,j} = N_p \Delta T'^i_p \left.\frac{dT_p}{dT'_p}\right|_{\bar{T}'^i_p} \left.\frac{d\sigma_{\rm pES}(E_\nu, T_p)}{dT_p}\right|_{(\bar{T}'^i_p, \bar{E}^j_\nu)}$$

Reconstructing ν flux from IBD and ArCC

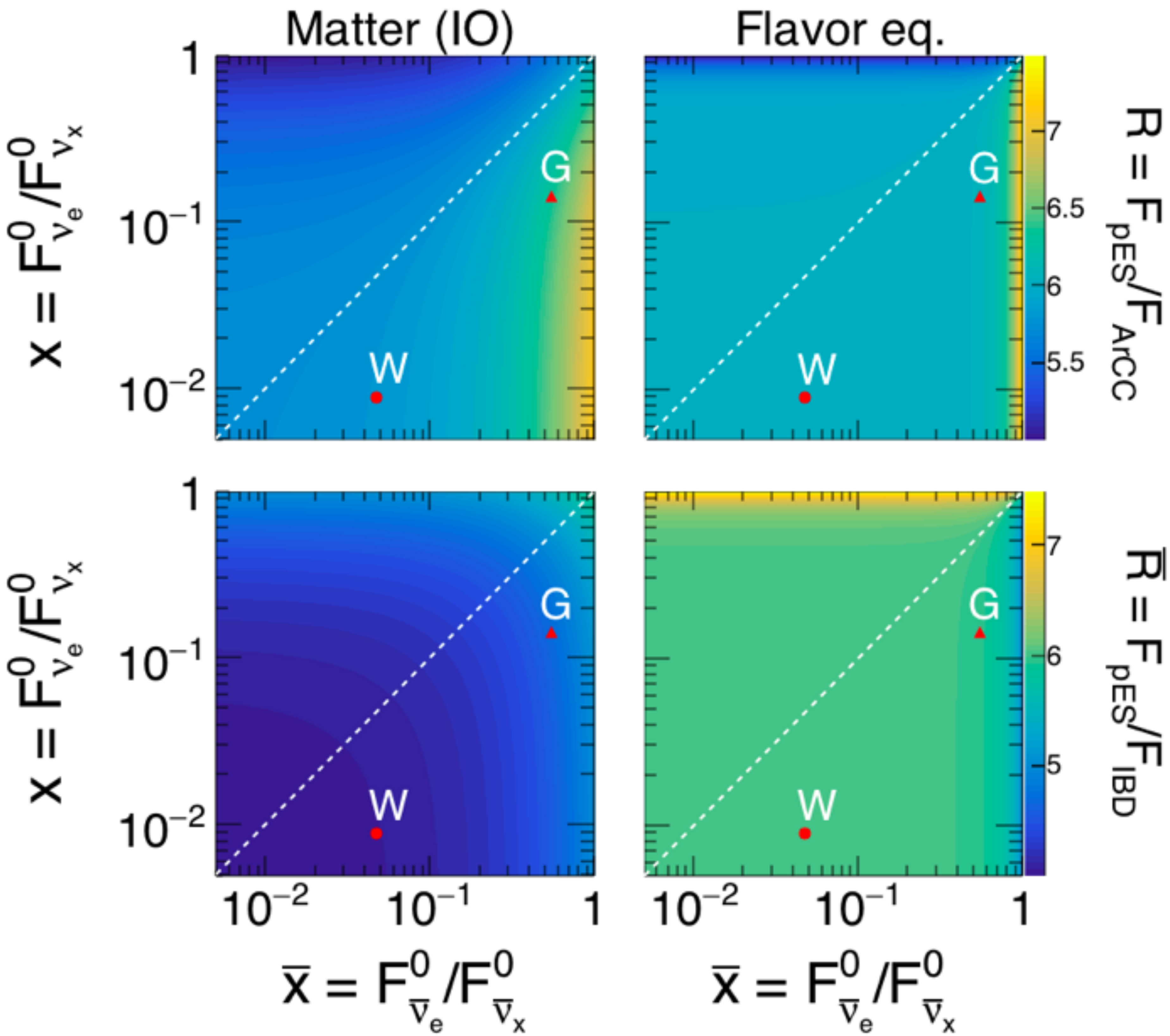
$$\left.\frac{d\tilde{F}_{\mathrm{IBD}}}{dE_\nu}\right|_{\bar{E}_i} = \frac{1}{N_p \sigma^{\mathrm{tot}}_{\mathrm{IBD}}(\bar{E}_i)} \frac{N^i_{\mathrm{IBD}}}{\Delta E^i_{\mathrm{vis}}}$$

$$\left.\frac{d\tilde{F}_{\mathrm{ArCC}}}{dE_\nu}\right|_{\bar{E}_i} = \frac{1}{N_{\mathrm{Ar}} \sigma^{\mathrm{tot}}_{\mathrm{ArCC}}(\bar{E}_i)} \frac{N^i_{\mathrm{ArCC}}}{E^i_{\mathrm{vis}}}$$

Flux ratios: R and $\bar{R}$, normal ordering

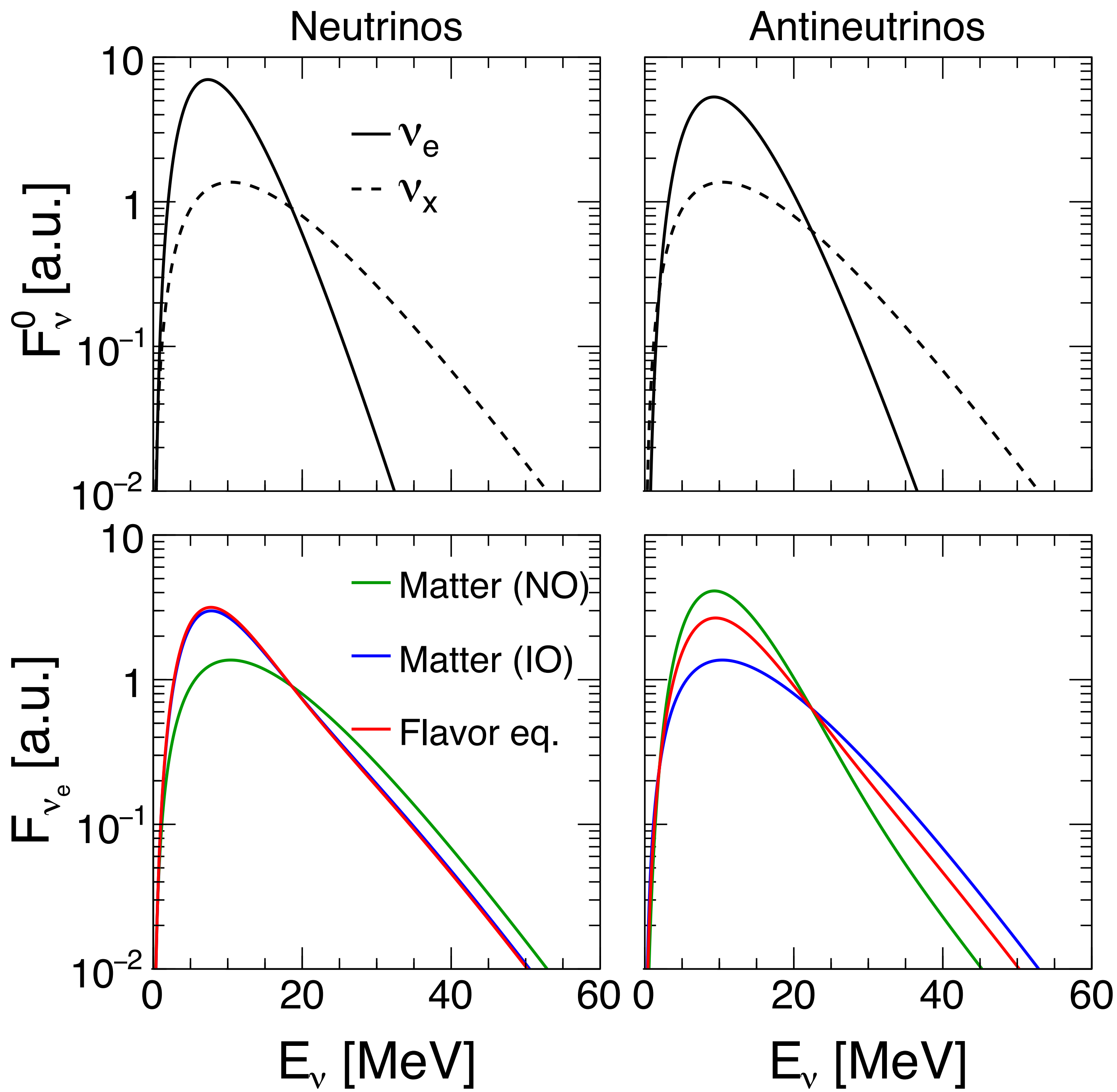


Flux ratios: R and $\bar{R}$, inverted ordering



SN fluxes: Wroclaw/Basel 1D model (W)

(Un)Oscillated (Anti)Neutrino energy fluxes

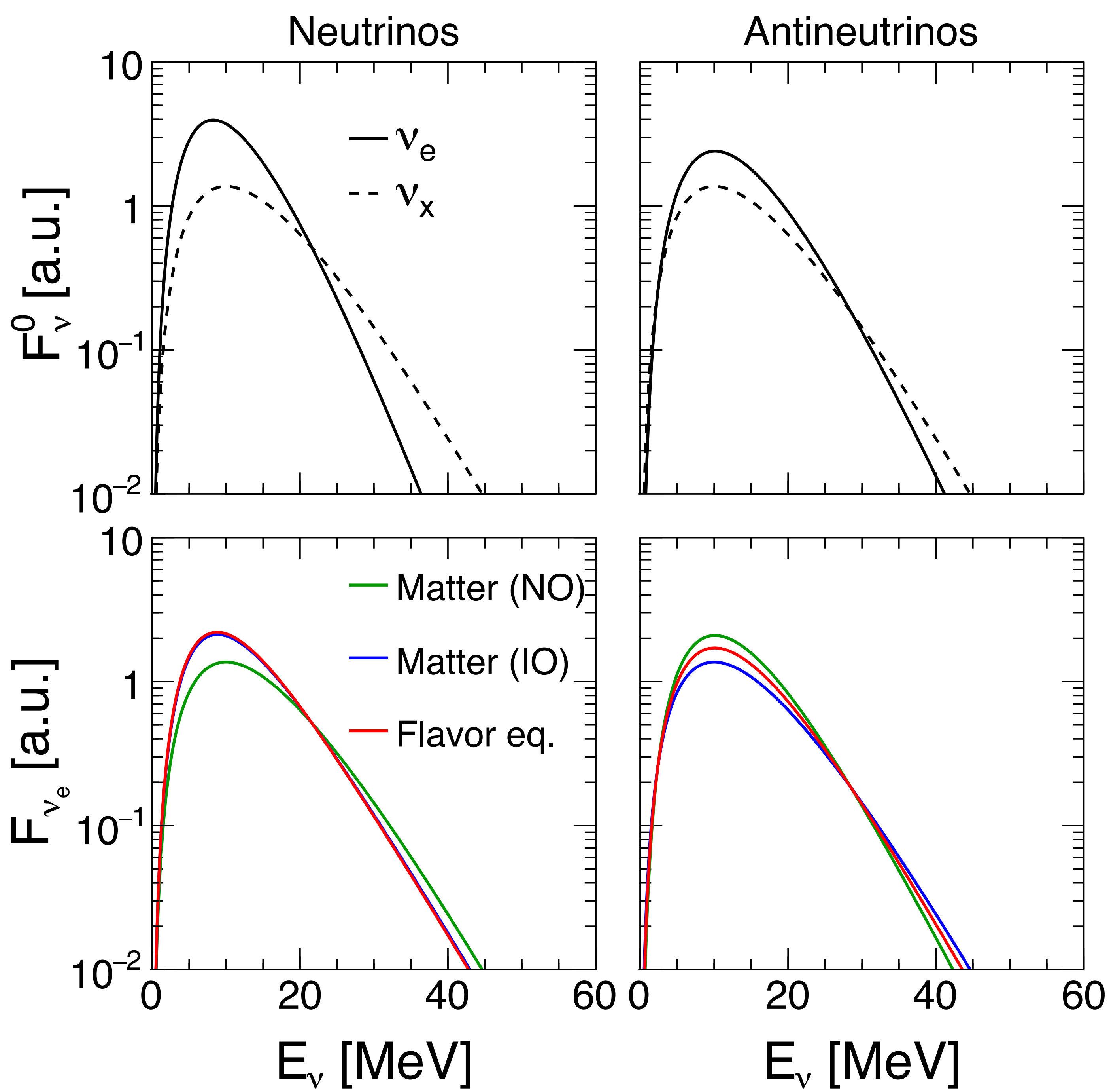


Fit parameters from:
Fischer, *et al.*,
Astron. Astrophys. **517**, A80 (2010)

In NO differences in P_{ee} for both ν and $\bar{\nu}$

SN fluxes: Garching 1D model (G)

(Un)Oscillated (Anti)Neutrino energy fluxes



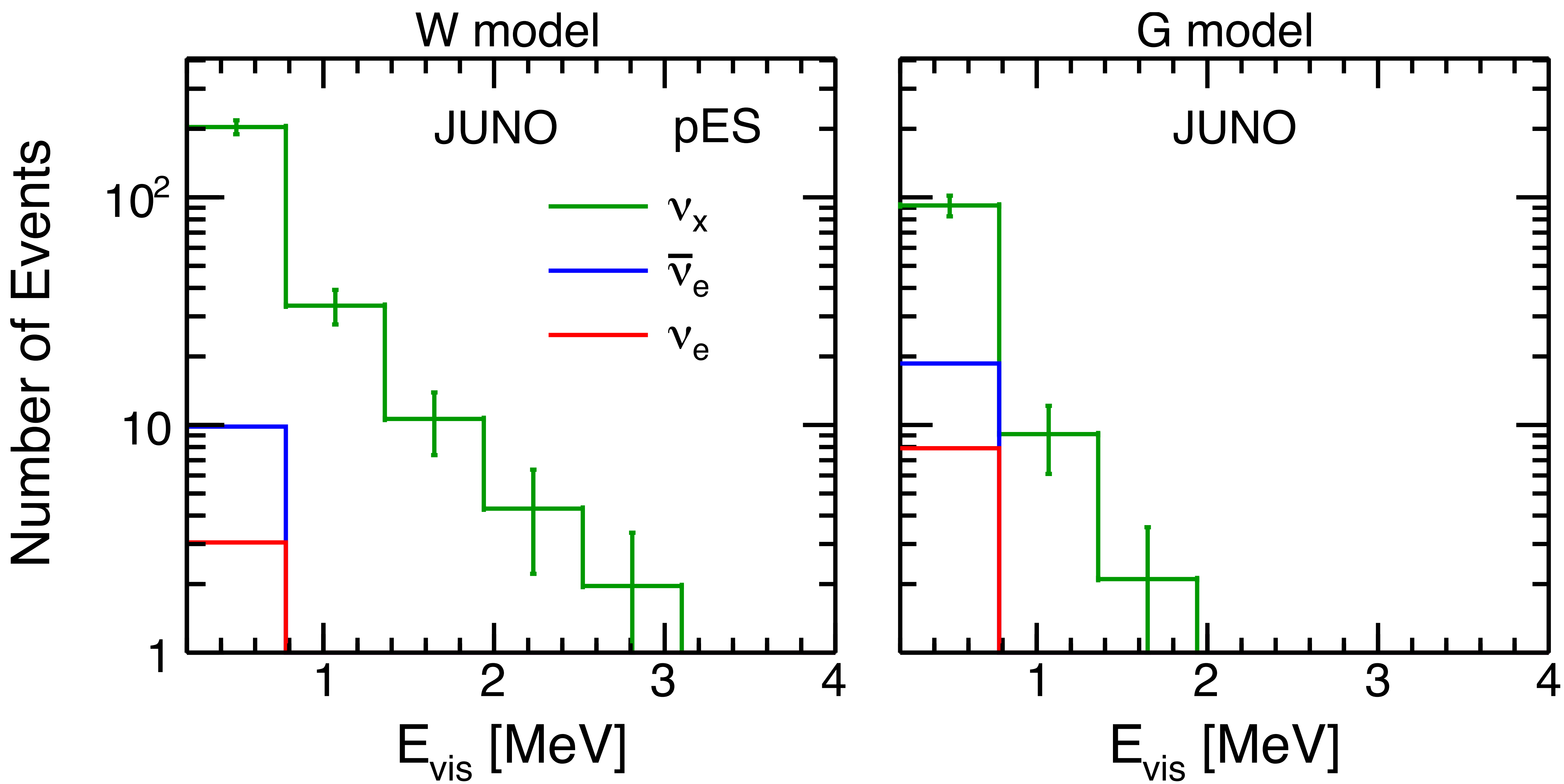
Fit parameters from:
Serpico, *et al.*,
Phys. Rev. D**85**, 085031 (2012)

Smaller differences compared to W model

1) Three SNν detection channels

JUNO: ν-proton elastic scattering (pES)

$$\overset{(-)}{\nu}_{e,\mu,\tau} + p \longrightarrow \overset{(-)}{\nu}_{e,\mu,\tau} + p$$

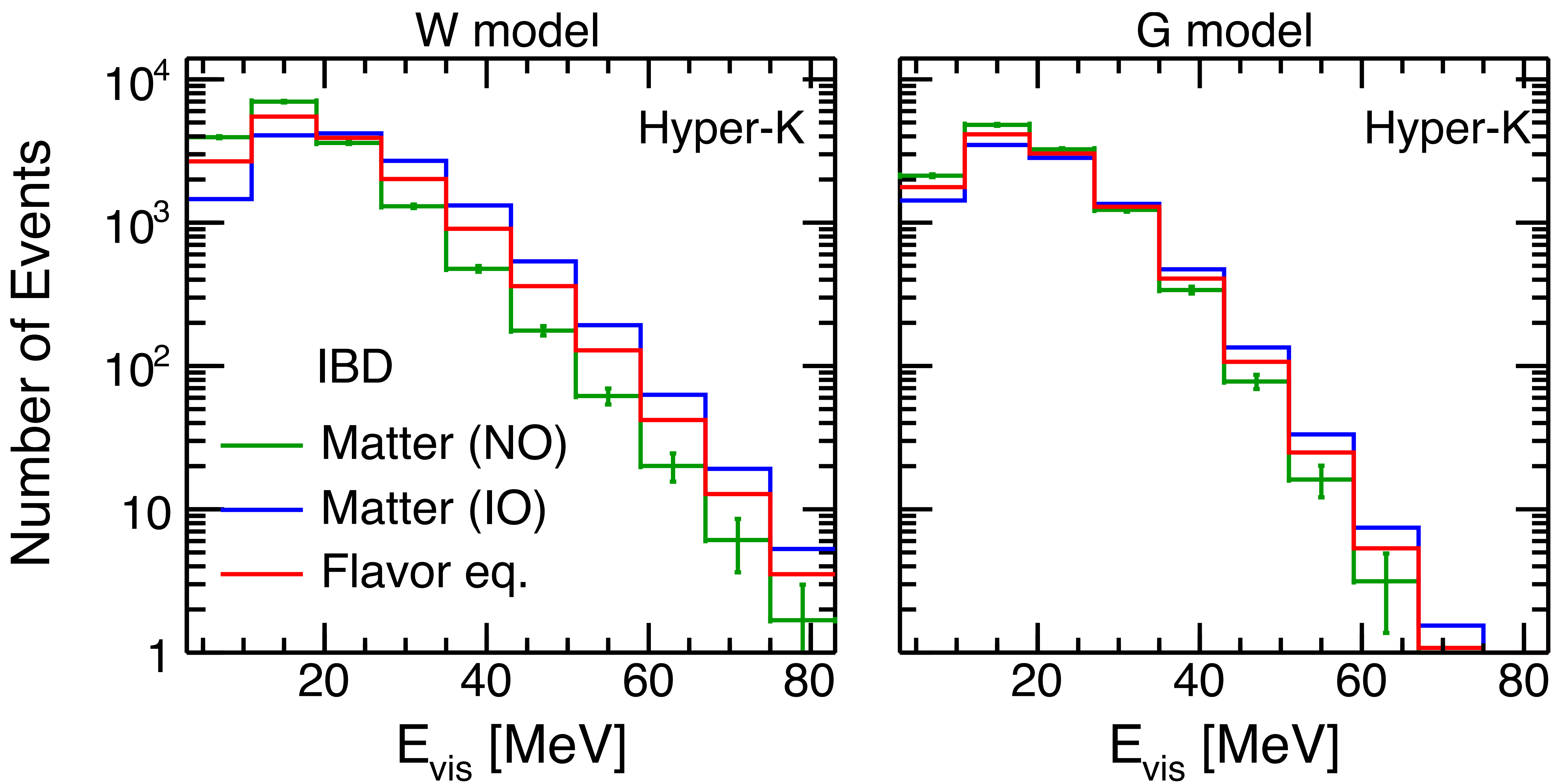


JUNO is sensitive mainly to ν_x and to $E_\nu > 25$ MeV.

No dependence on flavour conversions

Hyper-Kamiokande: inverse β decay

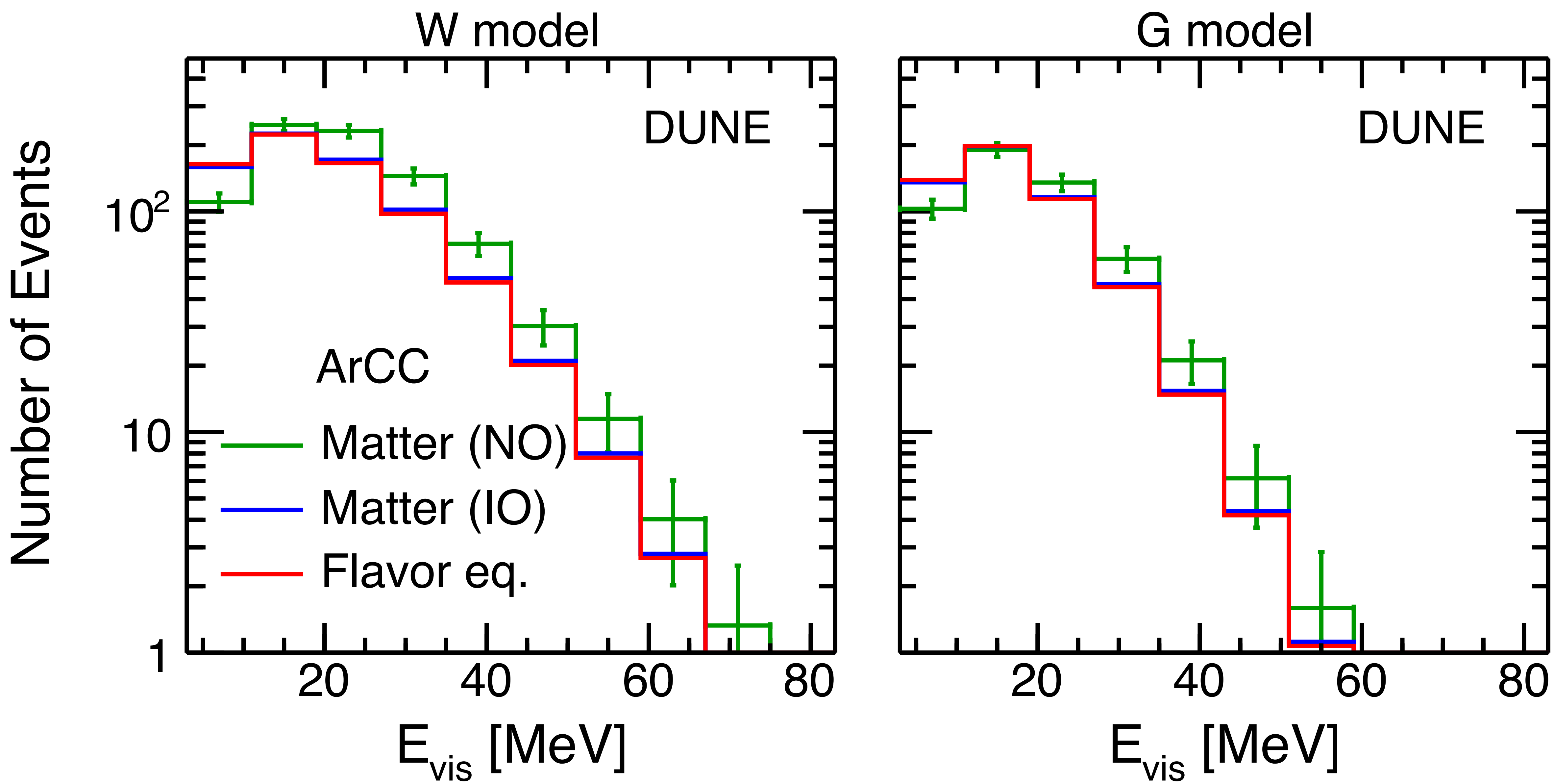
$\bar{\nu}_e + p \longrightarrow e^+ + n$



Hyper-K is sensitive to $\bar{\nu}_e$

DUNE: ν-CC scattering on ^{40}Ar (ArCC)

$$\nu_e + {}^{40}Ar \longrightarrow e^- + {}^{40}K^*$$



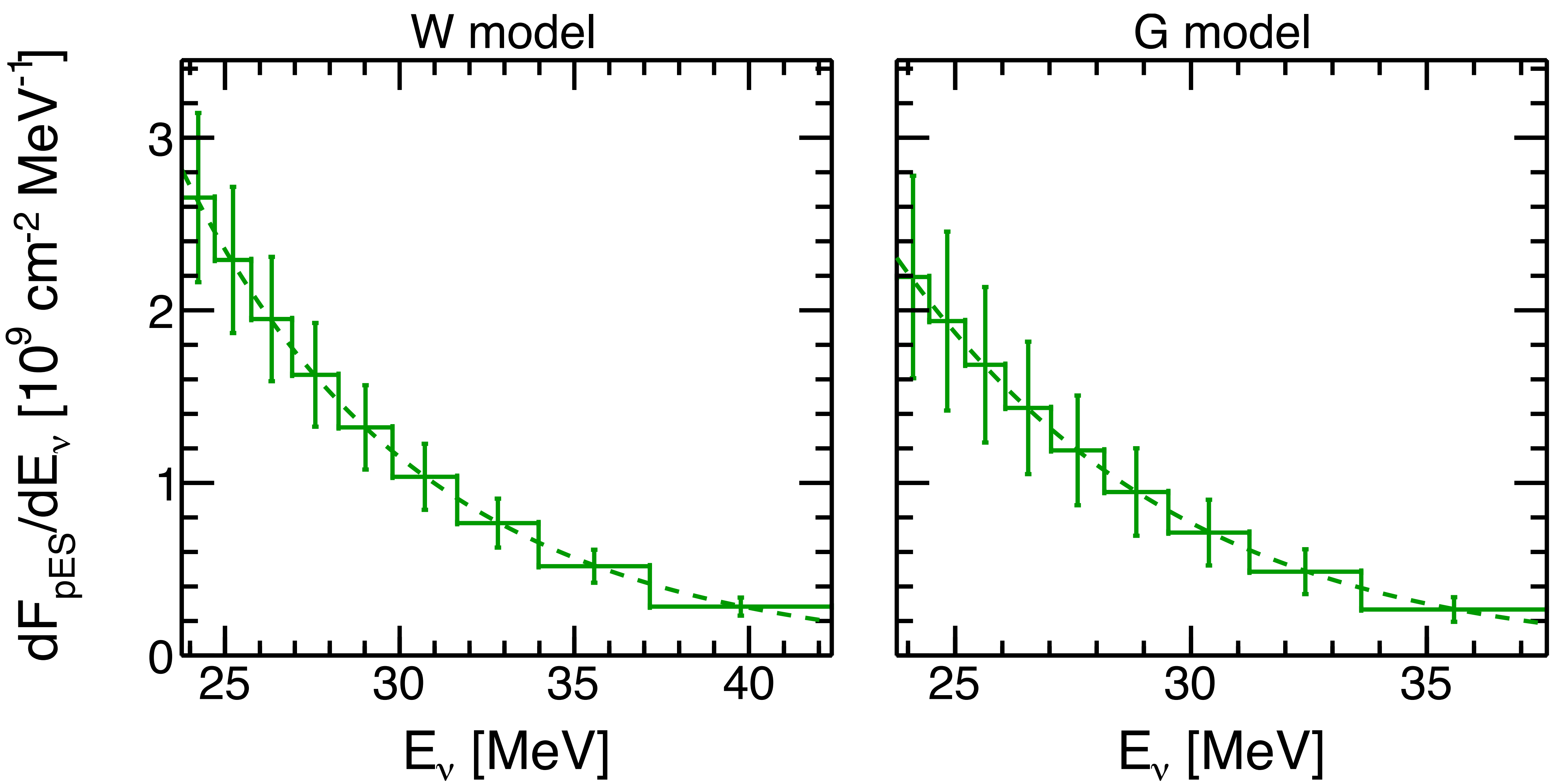
DUNE is sensitive to ν_e

2) Reconstructing oscillated ν-fluxes

Reconstructing ν flux from pES

$$\frac{N_i}{\Delta E^i_{\rm vis}} \rightarrow \frac{dF_{\rm pES}}{dE_\nu} \simeq \frac{dF_{\nu_x}}{dE_\nu}$$

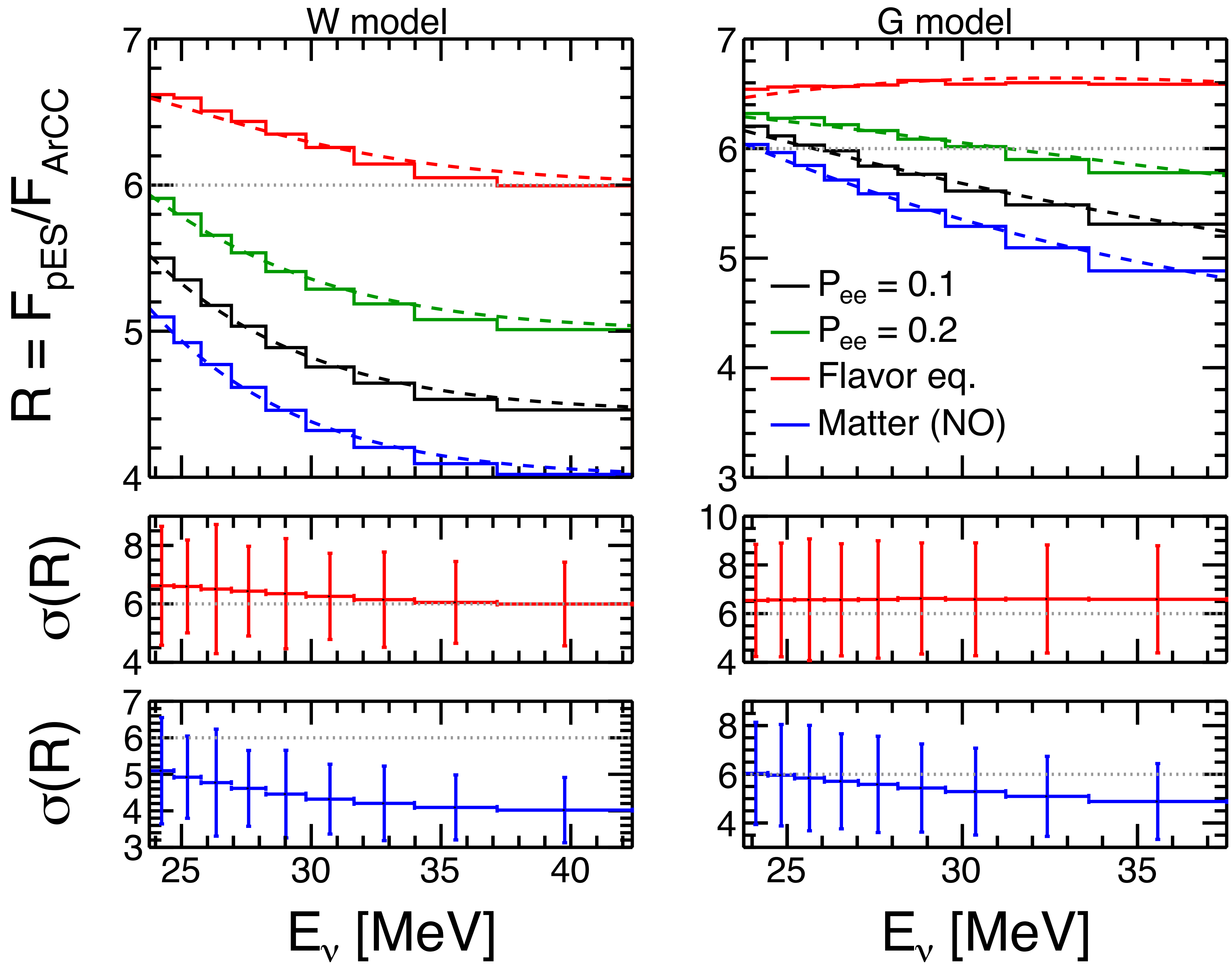
[1] H. L. Li, Y. F. Li, M. Wang, L. J. Wen and S. Zhou, Phys. Rev. D **97** (2018) no.6, 063014
[2] B. Dasgupta and J. F. Beacom, Phys. Rev. D **83** (2011) 113006



Similar reconstruction method applies to IBD and ArCC

3) Flux ratios:

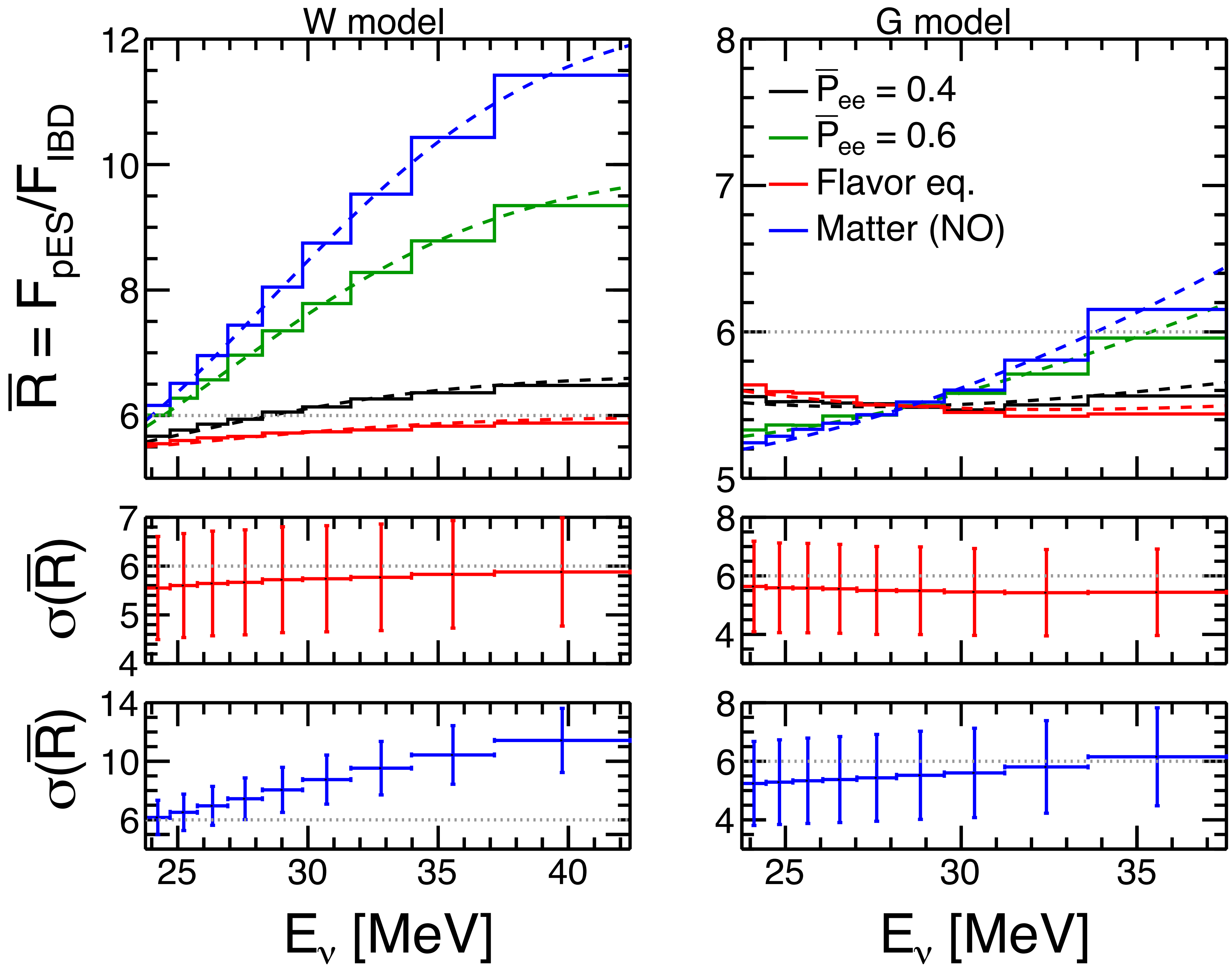
Statistical significance: R at 10 kpc



F. Capozzi, B. Dasgupta and A. Mirizzi, Phys. Rev. D 98 (2018) no.6, 063013

In the case of pure "matter effects" we can disfavour flavour equalisation at ~2σ (only for W model)

Statistical significance: $\bar{R}$ at 10 kpc



F. Capozzi, B. Dasgupta and A. Mirizzi, Phys. Rev. D 98 (2018) no.6, 063013

In the case of pure "matter effects" we can disfavour flavour equalization at >~2σ (only for W model)