Recent advances in neutrino (astro)physics

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Cristina VOLPE

(Institut de Physique Nucléaire Orsay, France)

OUTLINE

- Introduction : neutrino physics and neutrino propagation in matter

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- Ongoing progress for neutrino propagation in massive stars (supernovae)

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- CP violation effects in astrophysics and cosmology (BBN)

Neutrino Oscillations

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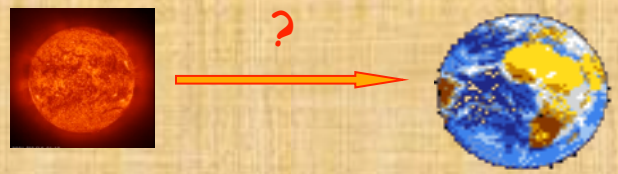

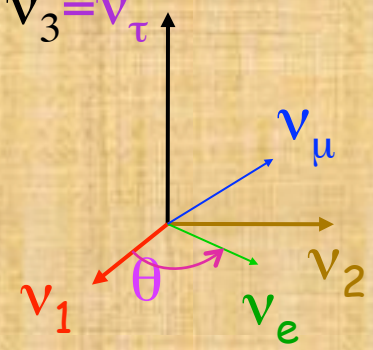

mixing angle

$$\begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$$

flavour basis — mass basis

$\Delta m^2 = m_2^2 - m_1^2$

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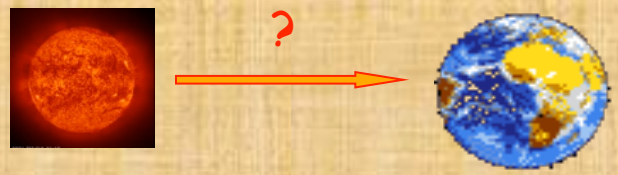

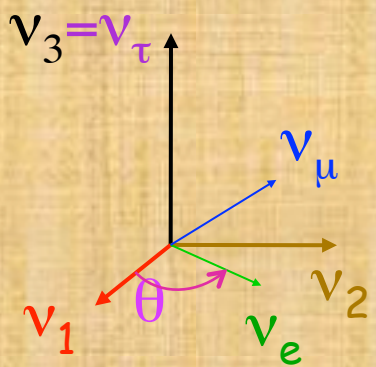

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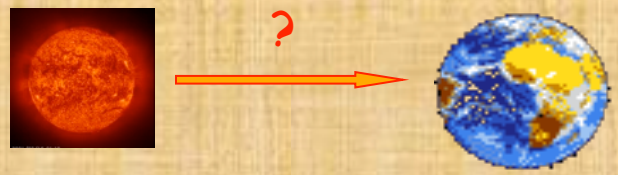

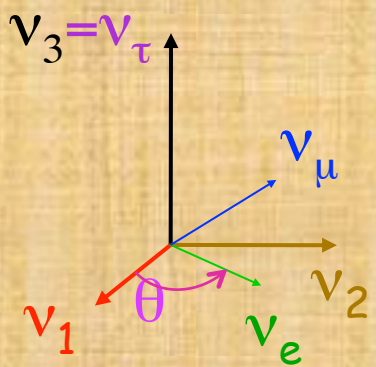

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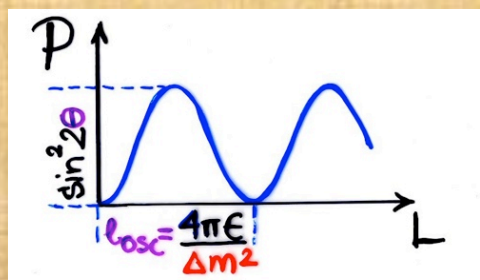

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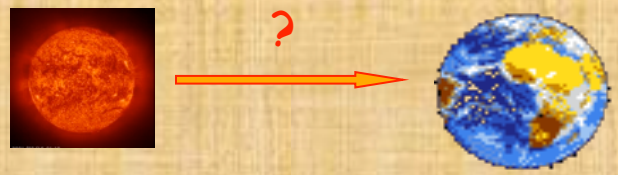

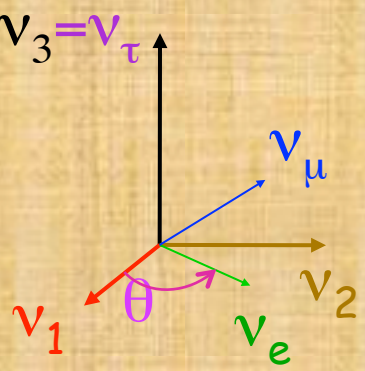

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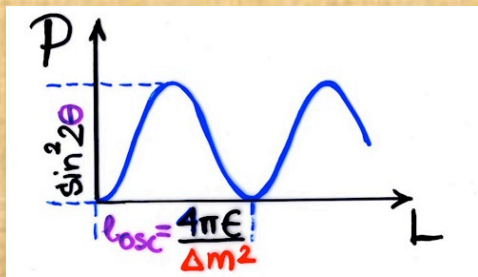

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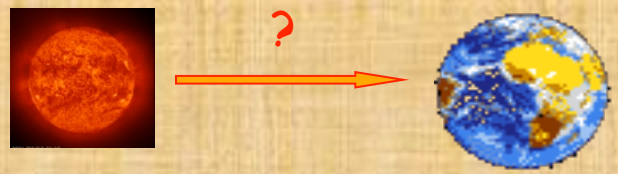

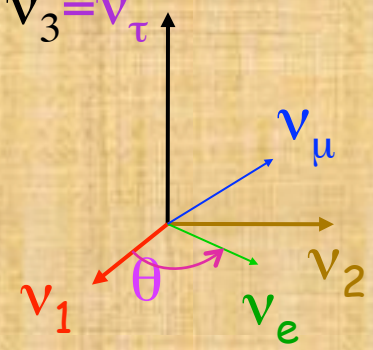

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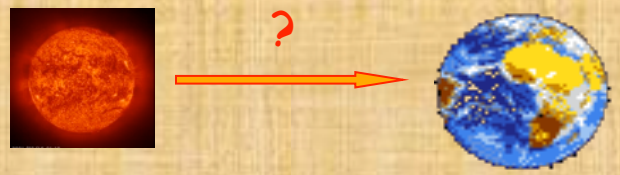

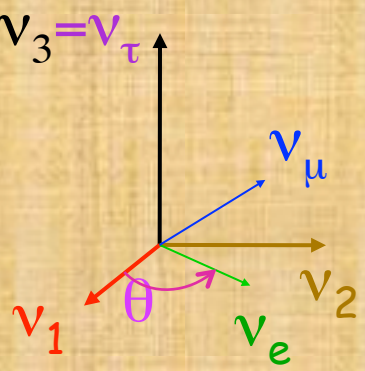

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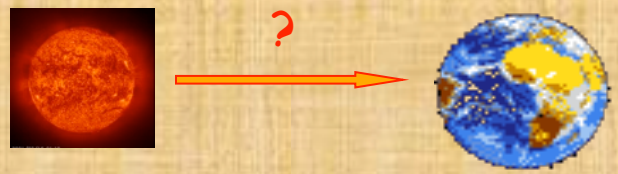

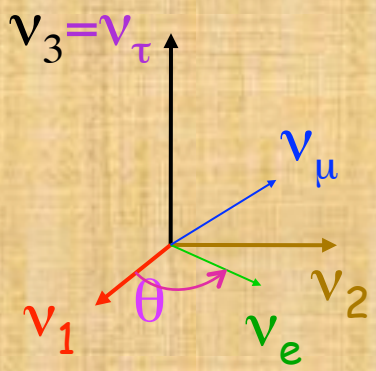

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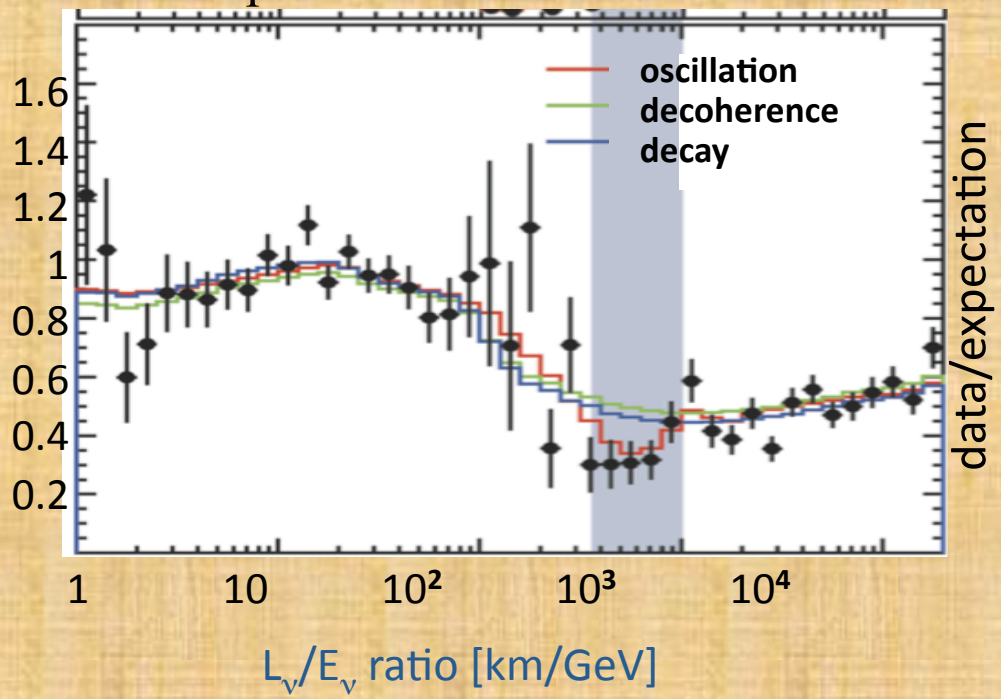
Super-Kamiokande results .



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θ_{12}		$sin^2 2\theta_{12} = 0.86^{+0.03}_{-0.04}$	(SNO, Kamland)
θ_{23}		$sin^2 2\theta_{23} > 0.92$	(Super-Kamiokande, K2K, MINOS, …OPERA)
θ_{13}	?	$sin^2 2\theta_{13} < 0.19$	(CHOOZ,..., soon Double-CHOOZ, RENO, Daya-Bay, T2K, NOνA…)

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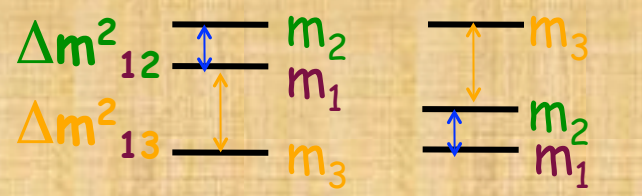
Mass scale? →



Inverted (Δm^2_{13} <0) Normal (Δm^2_{13} >0)

$$\Delta m^2_{32} = m^2_3 - m^2_2 = 1.9 \text{ to } 3.0 \times 10^{-3} eV^2$$

$$\Delta m^2_{21} = m^2_2 - m^2_1 = 8.0^{+0.4}_{-0.3} \times 10^{-5} eV^2$$

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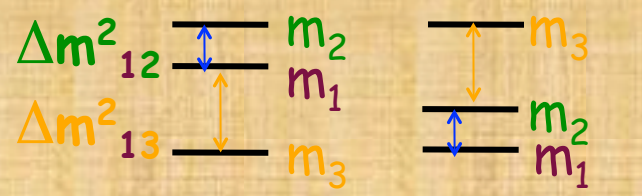

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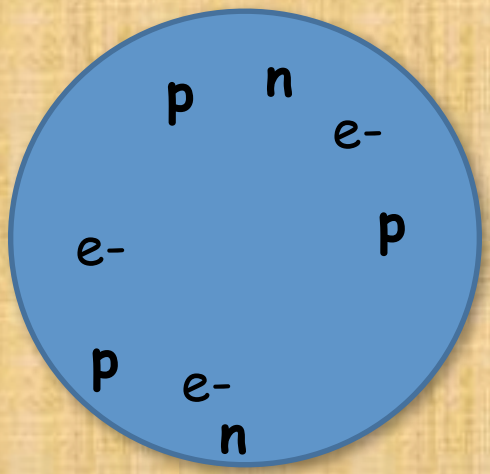
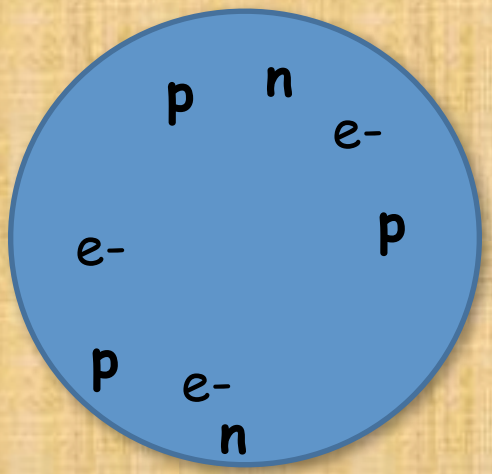
Important experimental results in the near future.



Neutrino propagation in media

THE PHYSICAL CONTEXT :

- Neutrinos are produced in a medium



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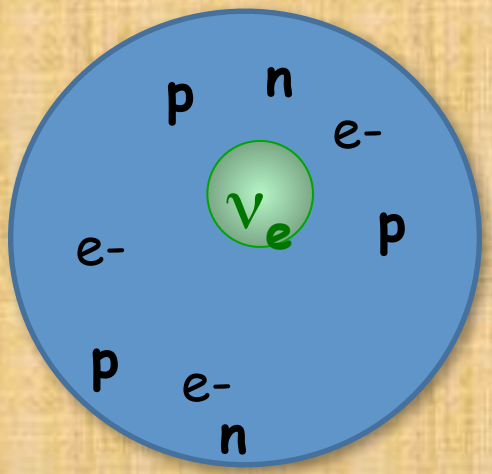

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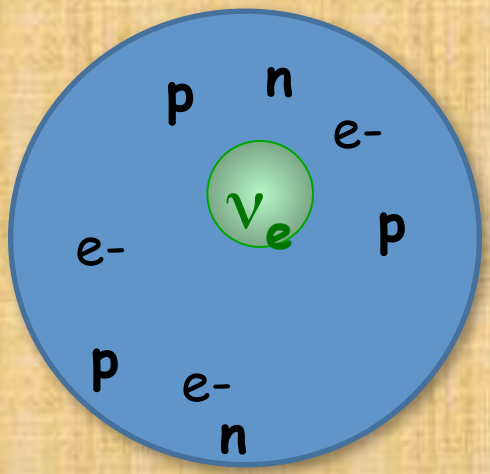

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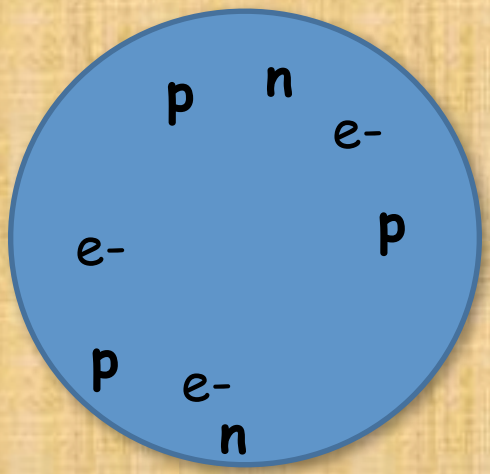

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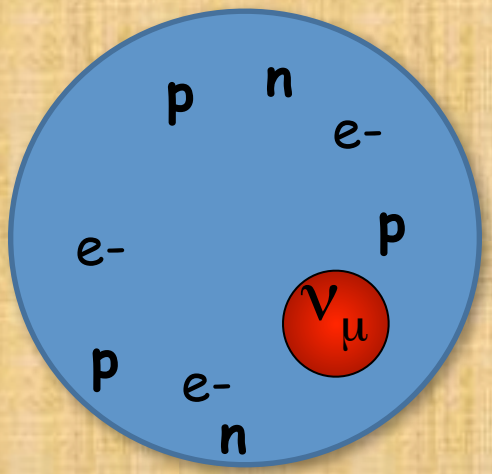

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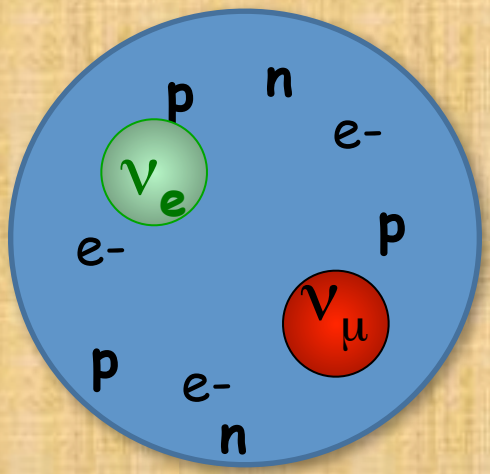

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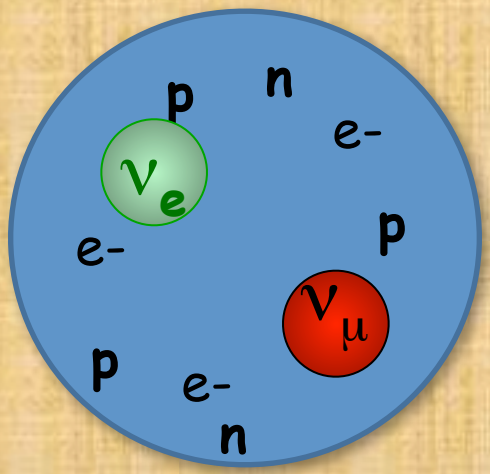
  - Neutrinos interact with the background medium (e,p,n) or plasma



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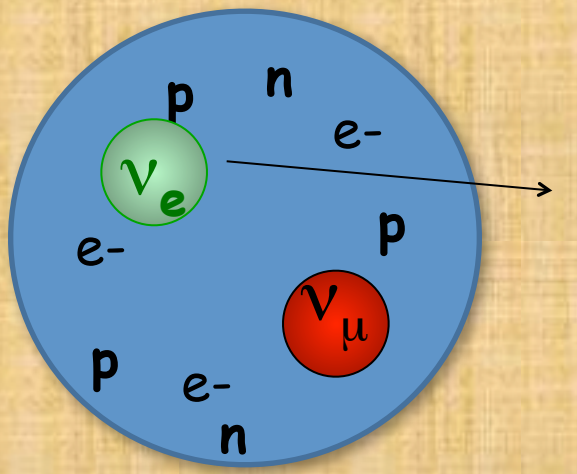

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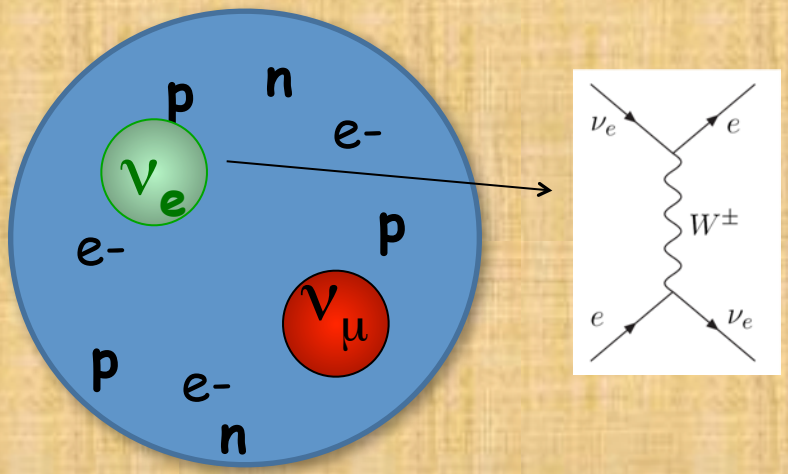

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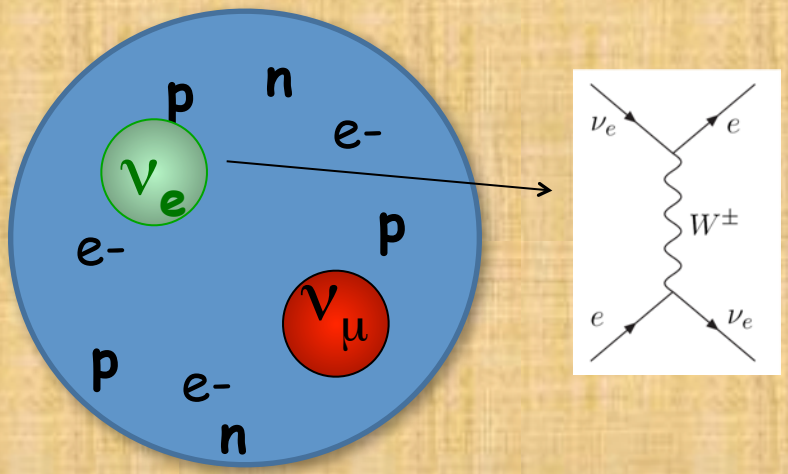

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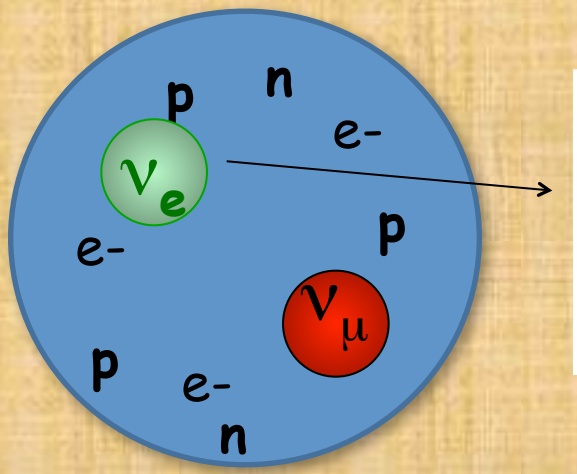

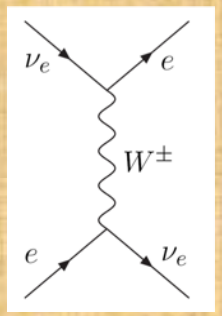

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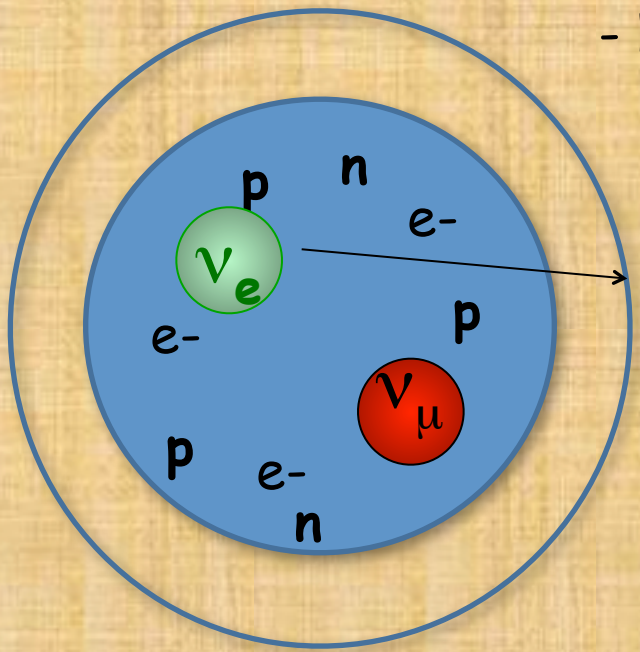

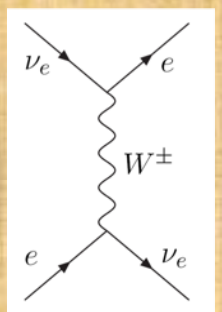

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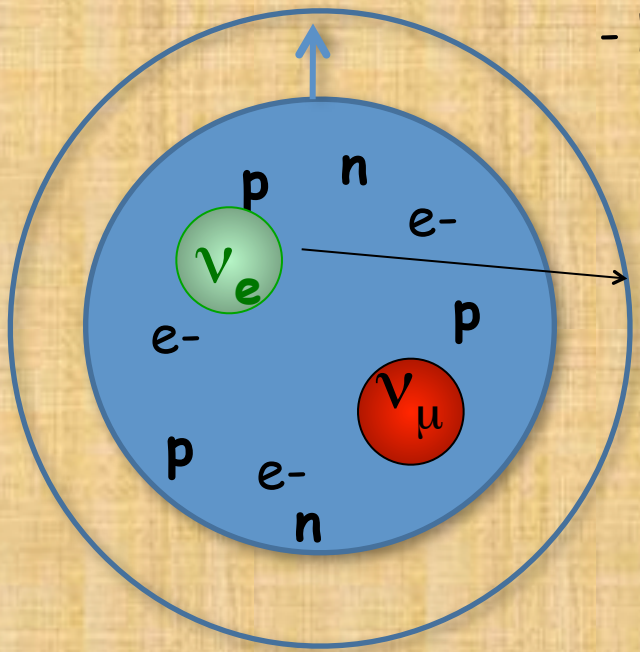

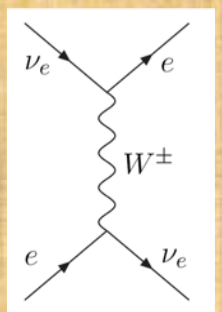

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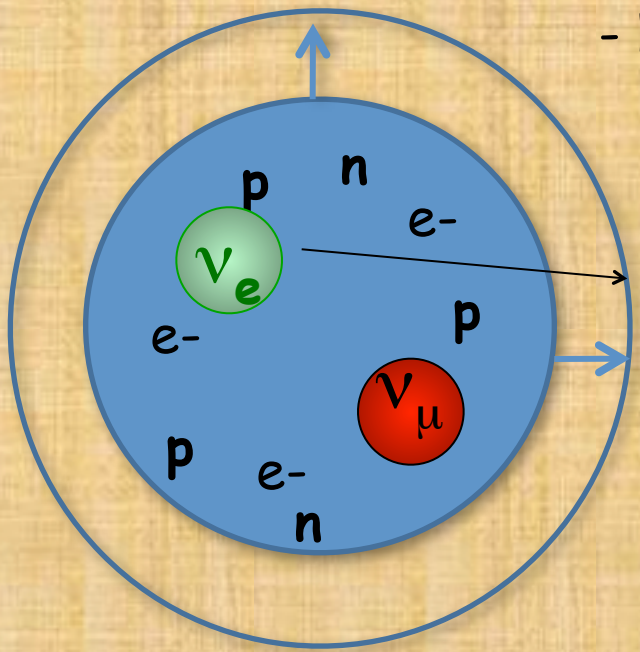

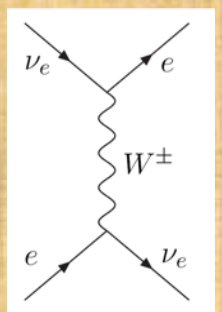

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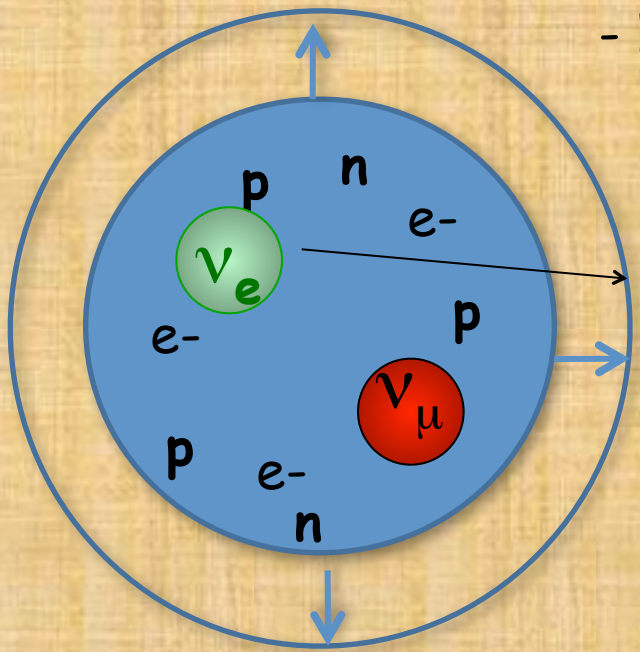

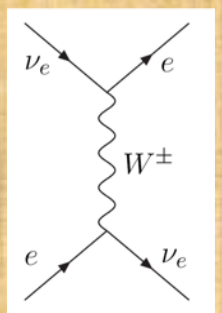

Neutrino propagation in media

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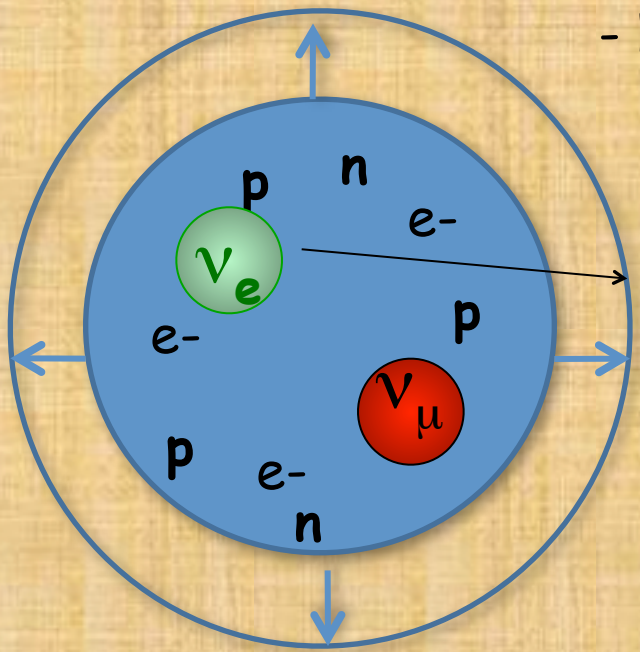

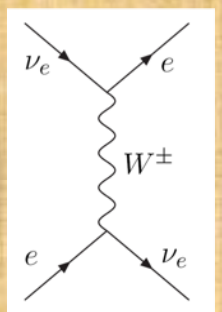

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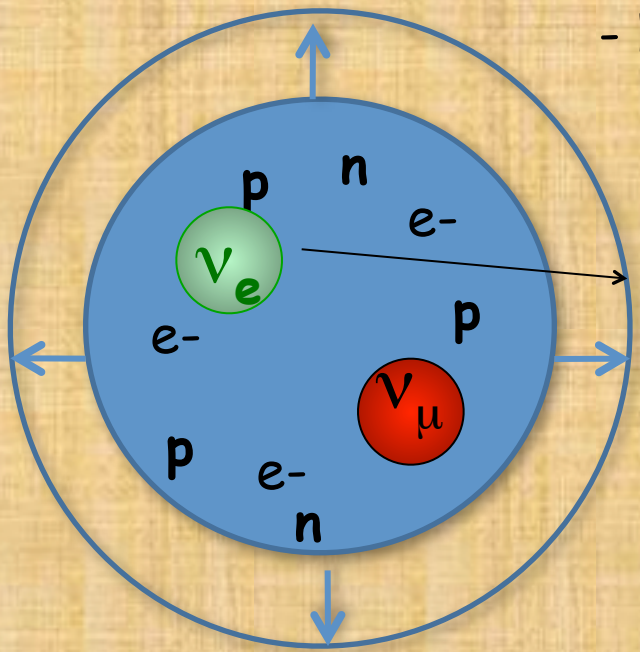

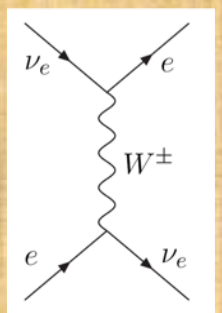

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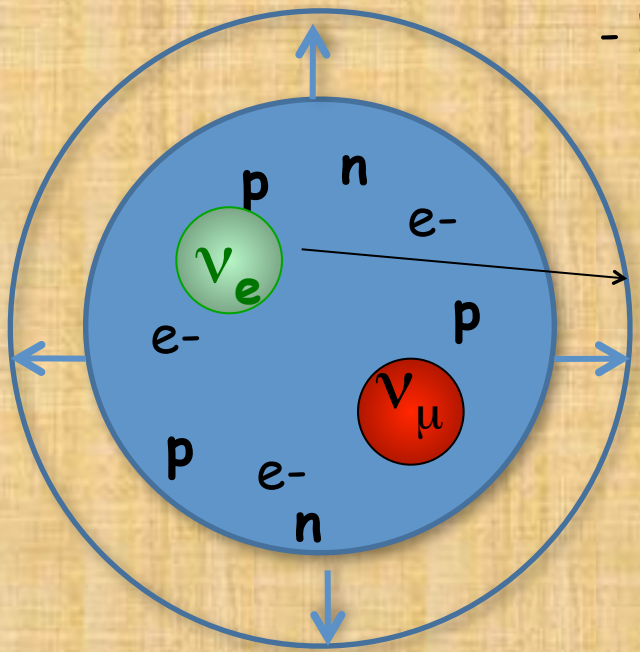

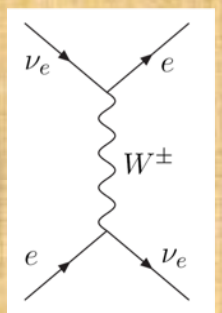

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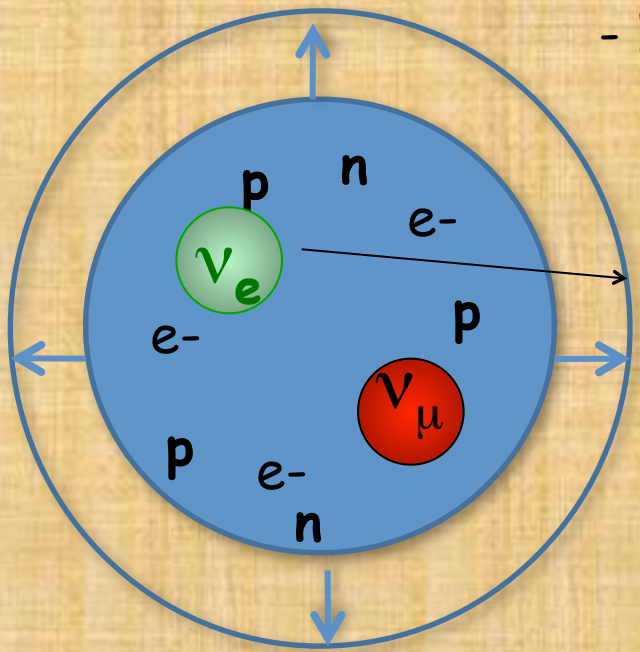
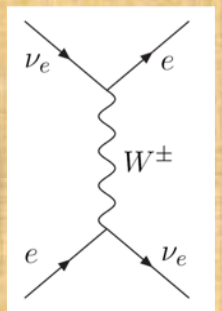




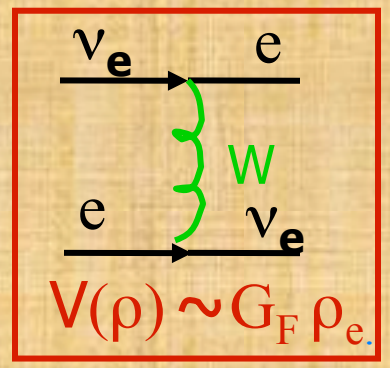
Neutrino propagation in media

➡ Neutrinos emitted from the Sun

➡ Core-collapse supernovae and accretion disk-black holes

➡ Neutrino evolution in the Early Universe (Big-Bang Nucleosynthesis)

The Mikheev-Smirnov-Wolfenstein effect



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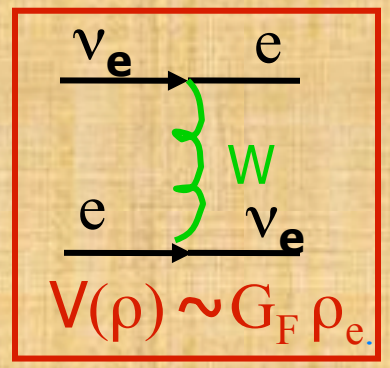

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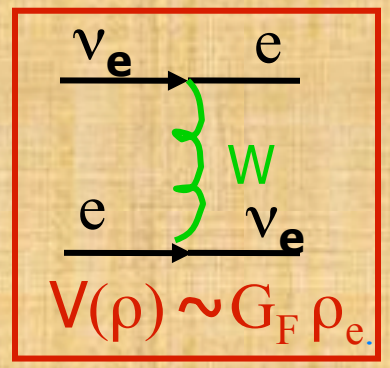

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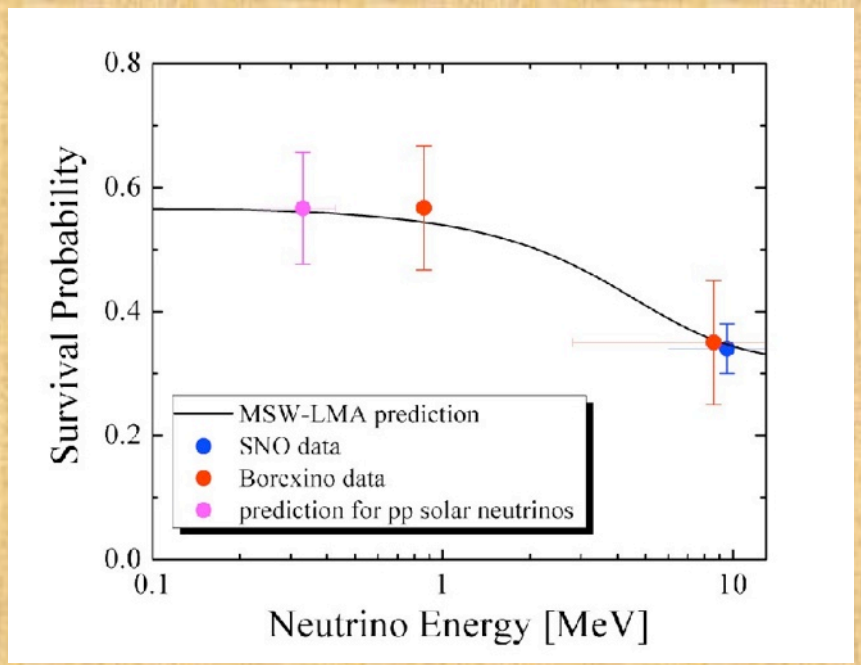
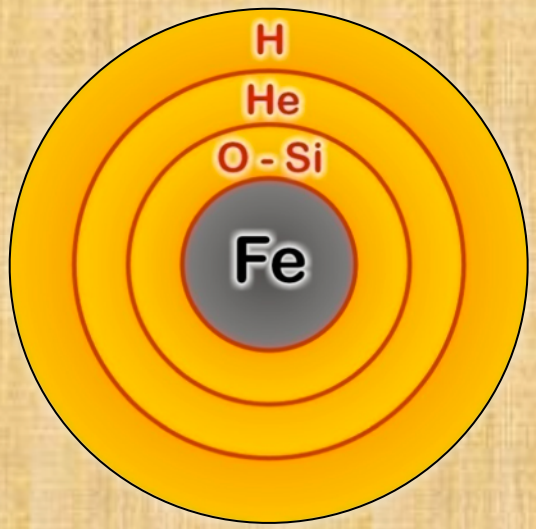


the beautiful explanation of the « solar neutrino deficit » problem !

Borexino Collaboration, J. Conf. Ser. 202, 012028 (2010)

Core-collapse supernovae (SN)



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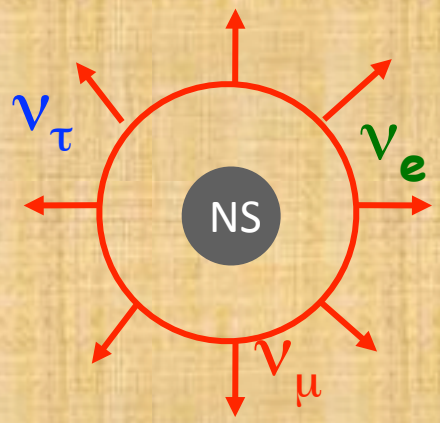

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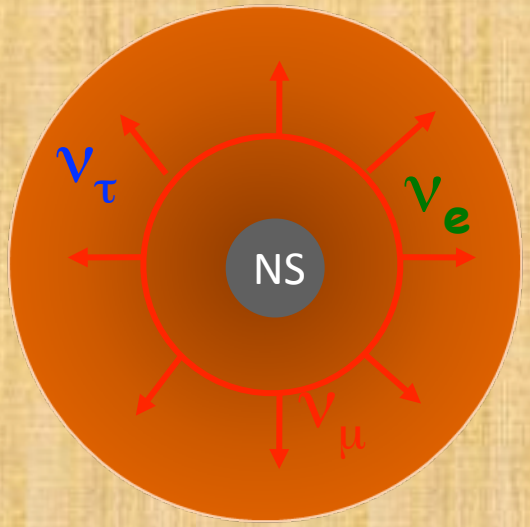

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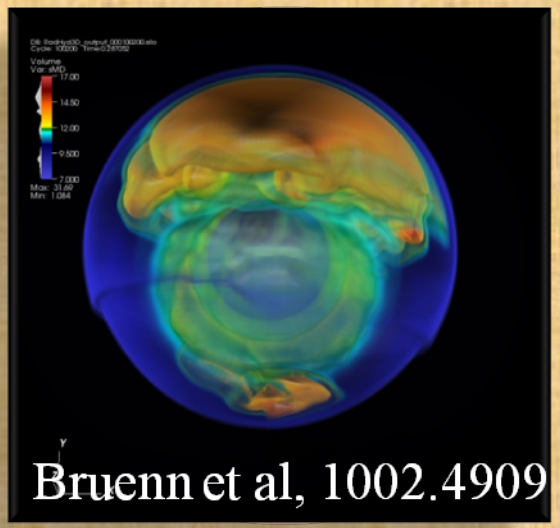

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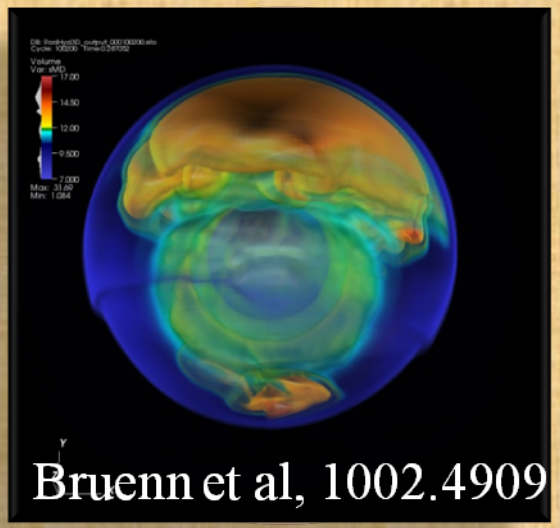

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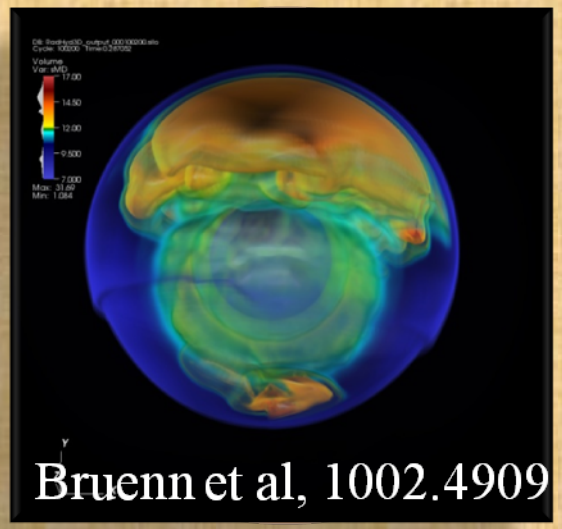

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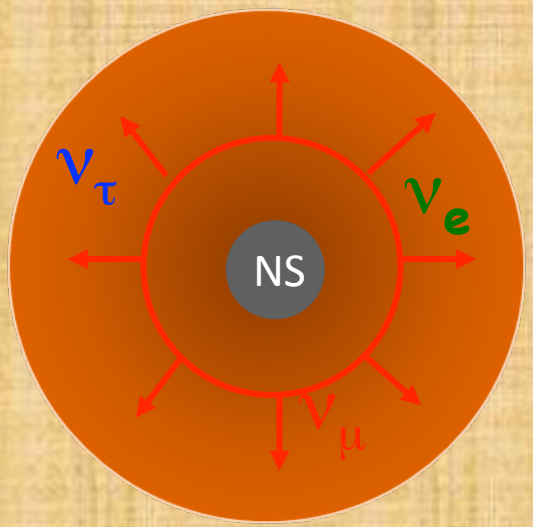

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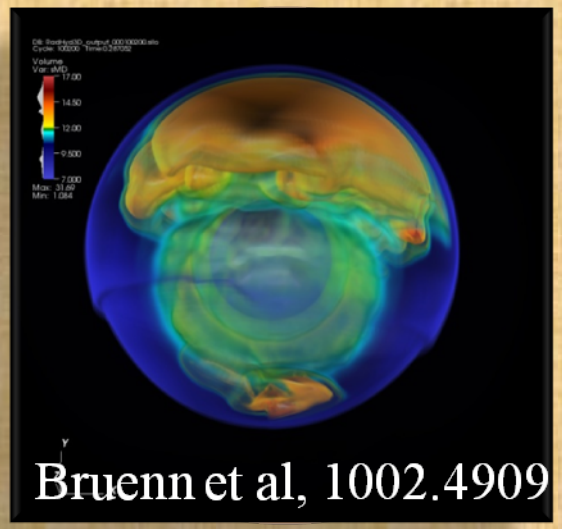

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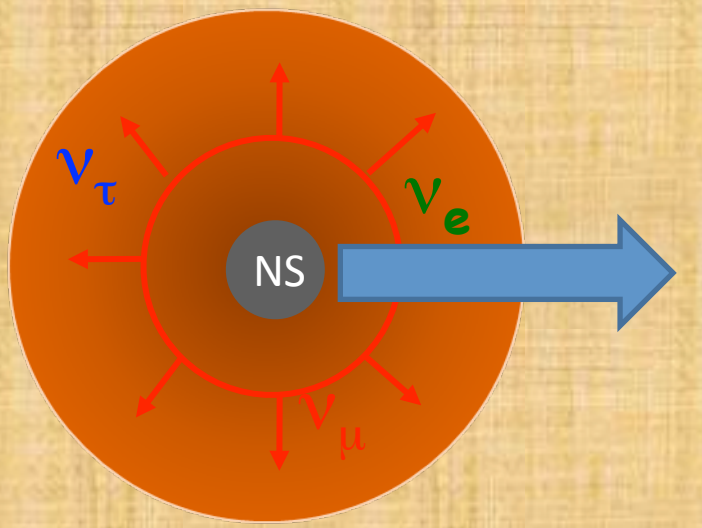

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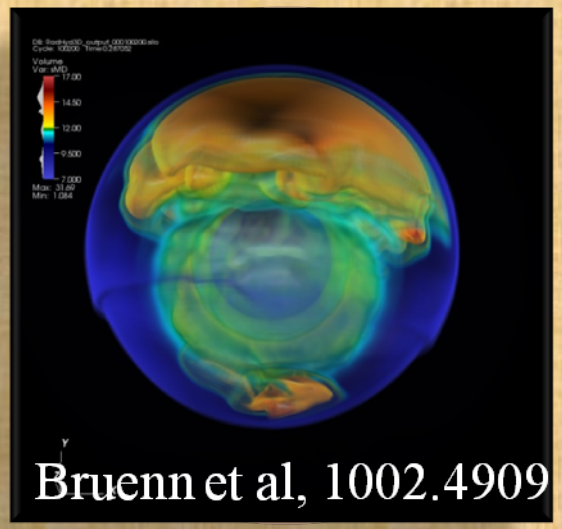

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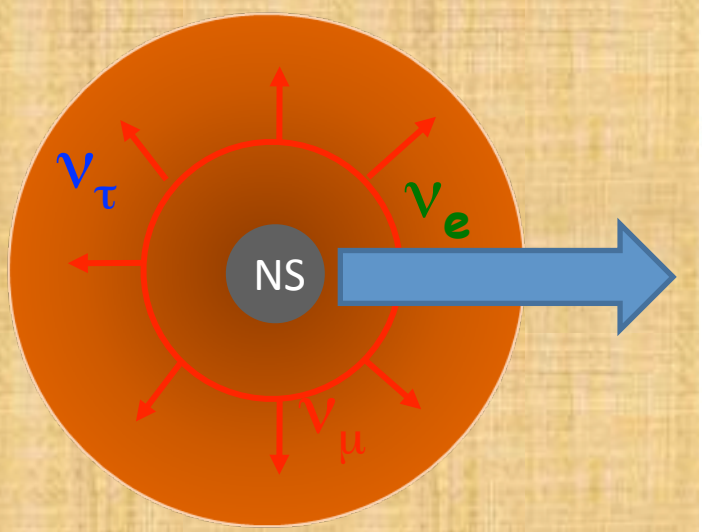

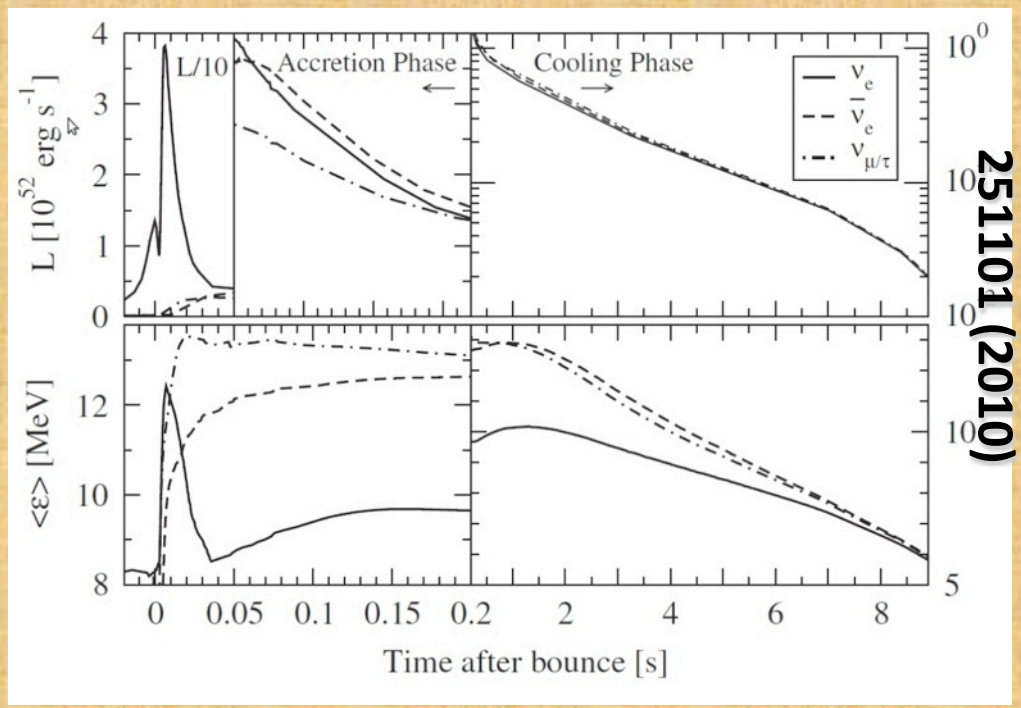

Hüdepohl *et al.* PRL 104, 251101 (2010)

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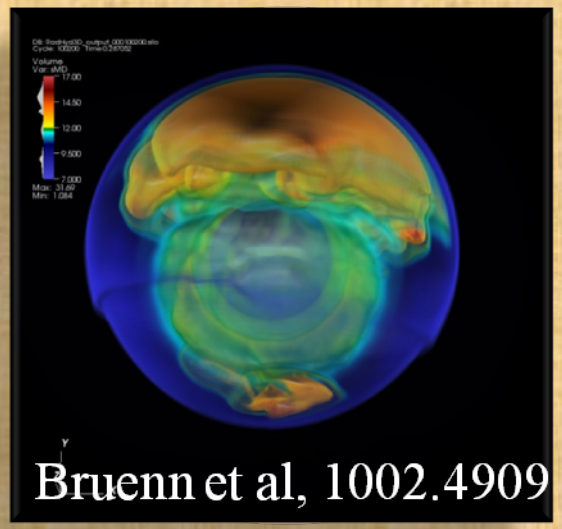

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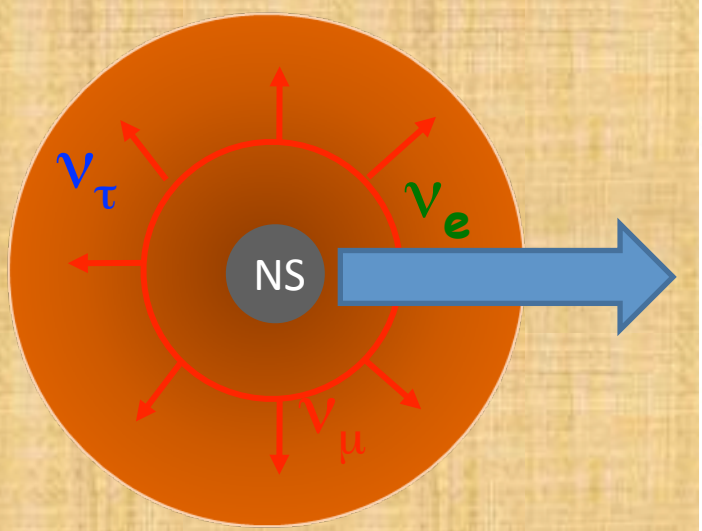
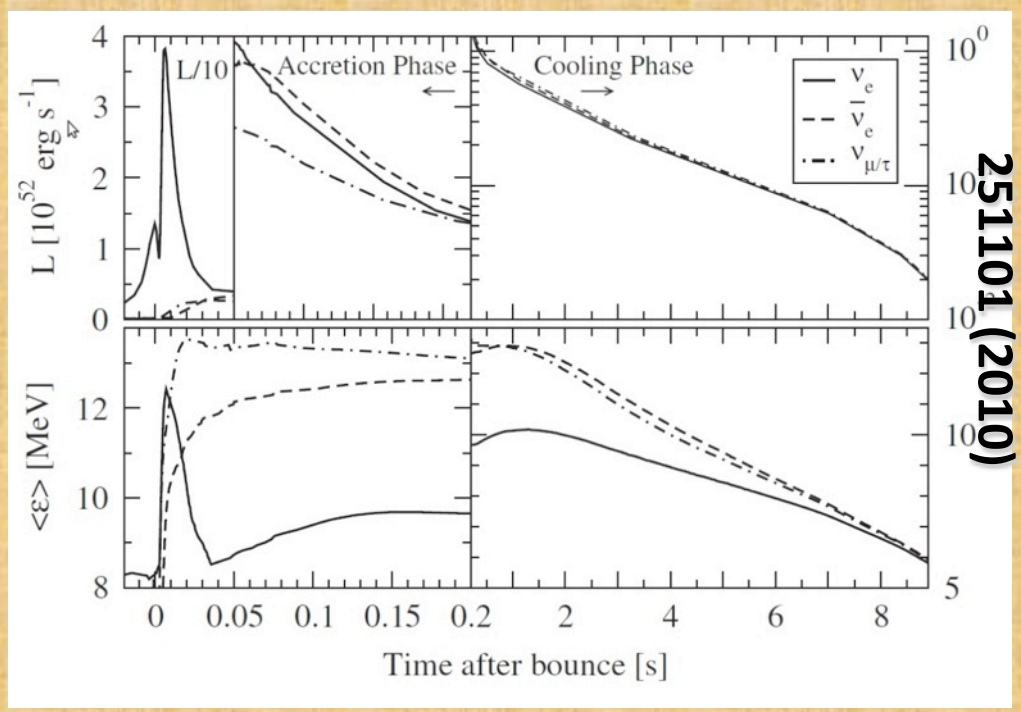


FUTURE OBSERVATIONS IMPORTANT !



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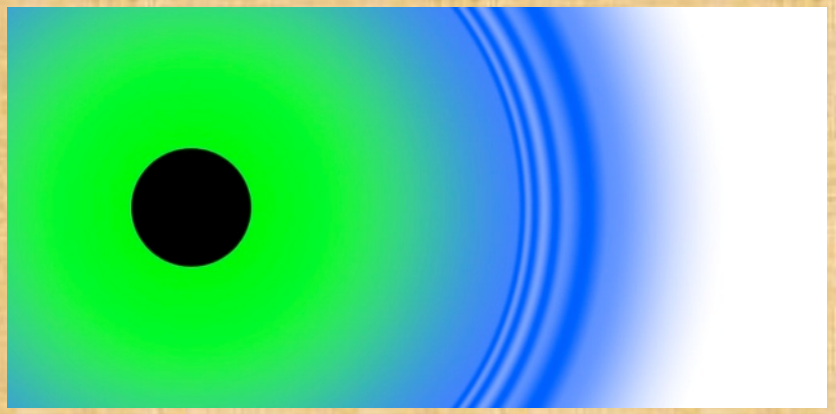

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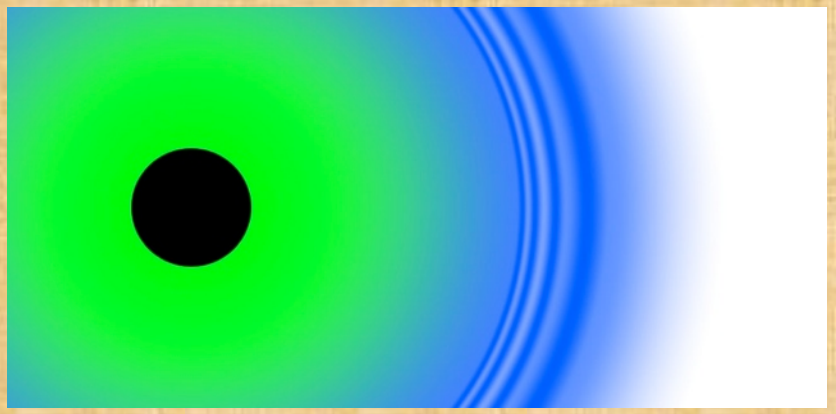

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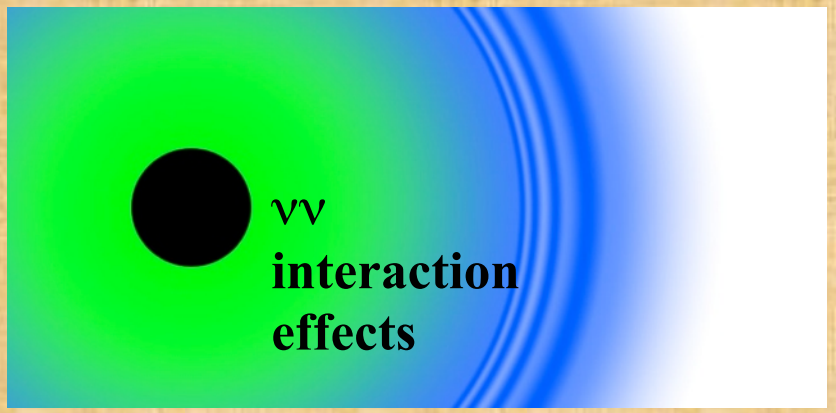

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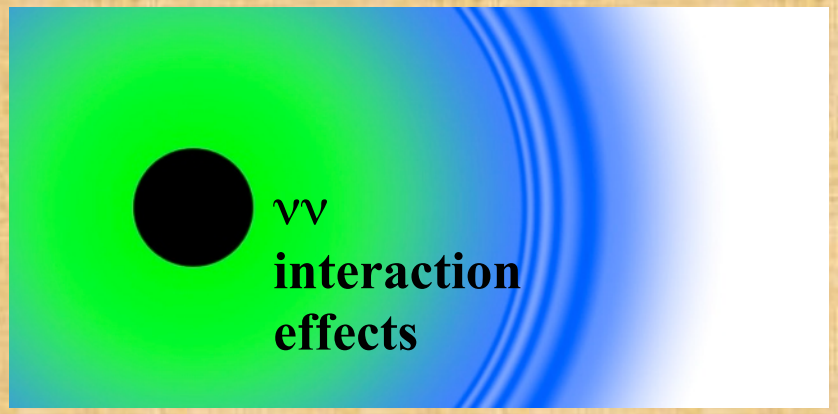

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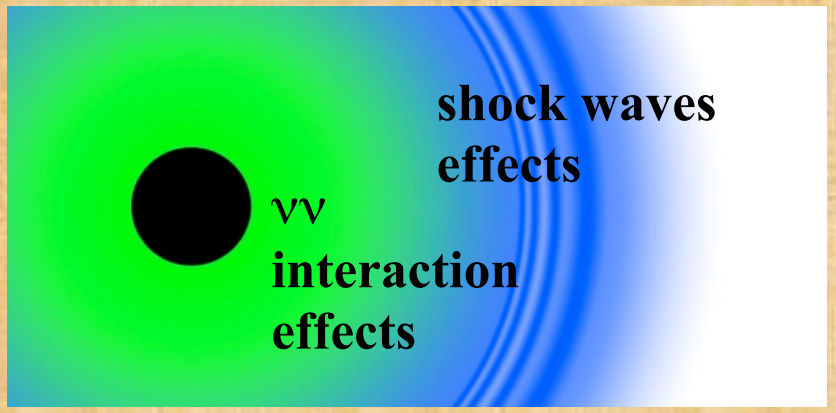

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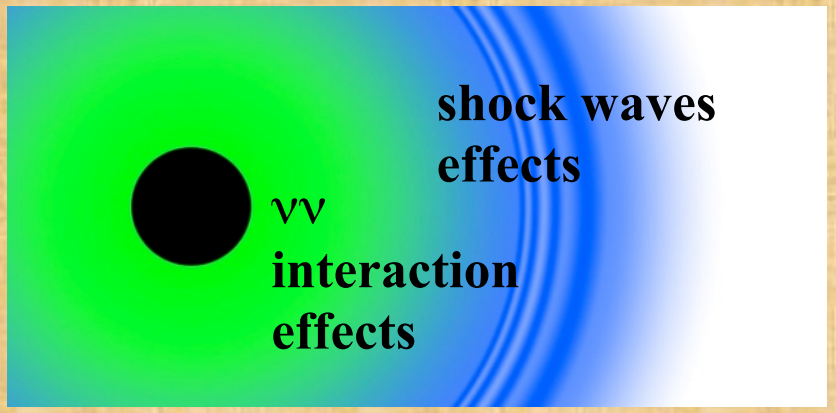

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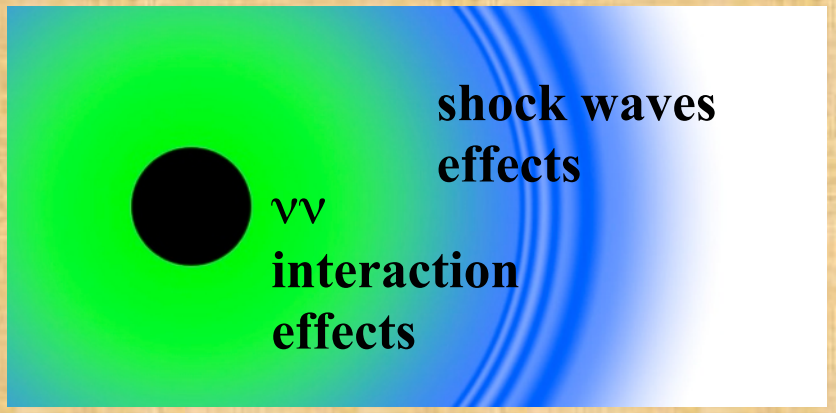

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- Important progress since 2006 : Duan,Fuller,Qian PRD74 (2006

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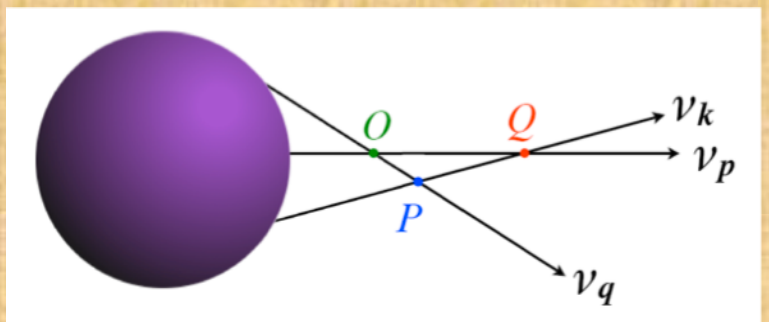

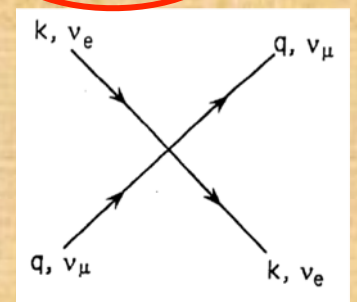

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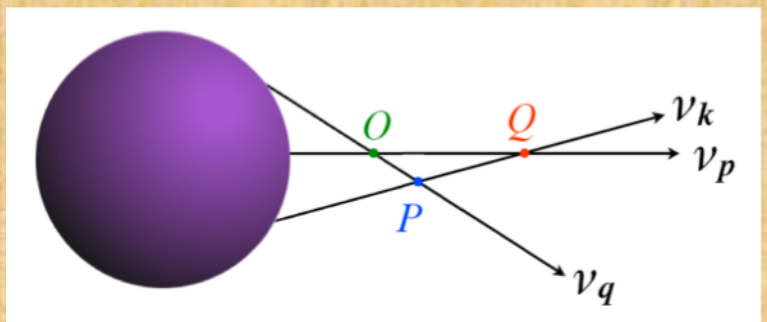

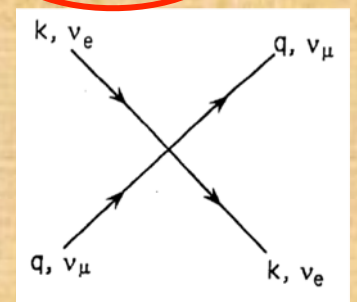

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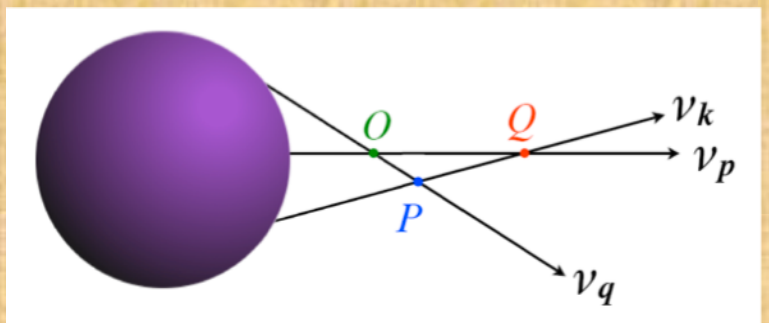

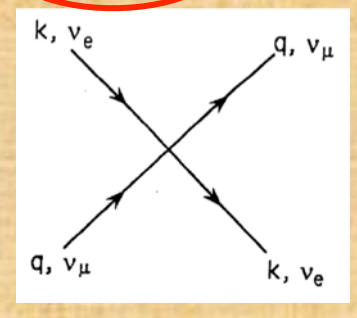

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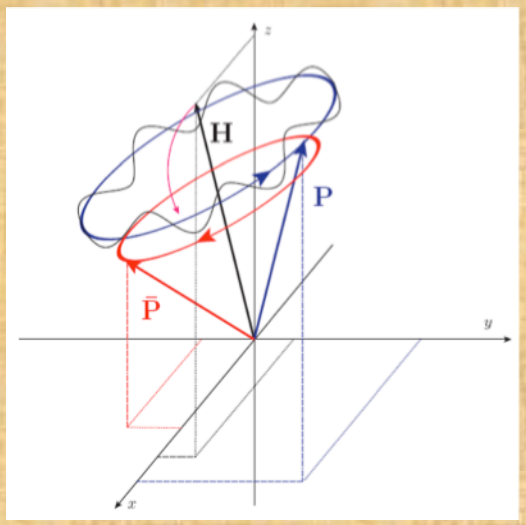

- Three regimes are identified :
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  - -The bipolar oscillations
  - - The spectral split

  Duan,Fuller,Qian PRD74 (2006), PRL 97 (2006), Hannestad, Raffelt, Sigl, Wong, PRD 74 (2006), Raffelt,Smirnov, PRD 76 (2007)

Important modifications of ν-fluxes

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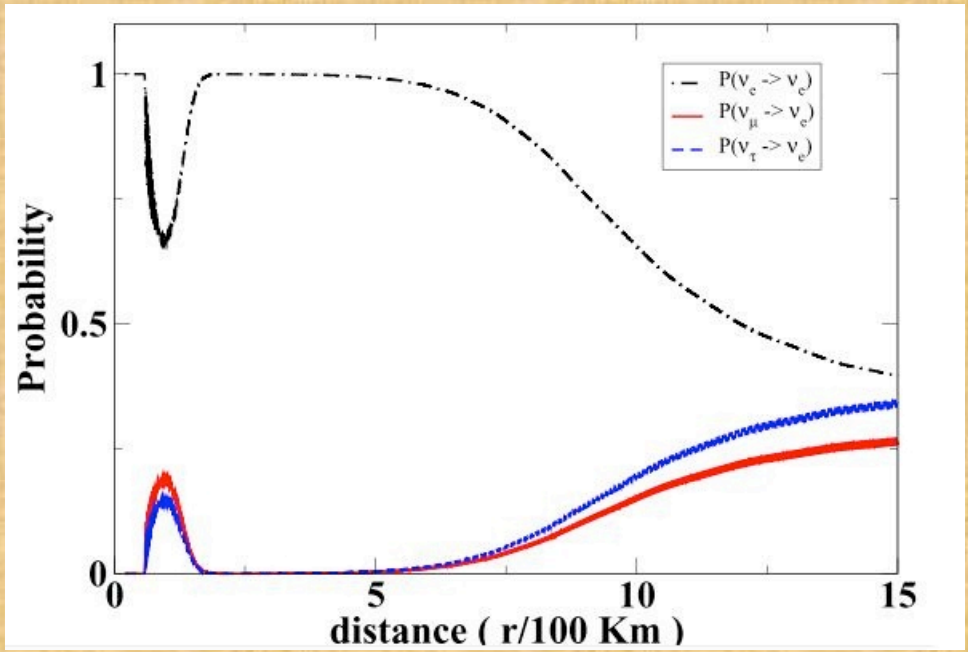

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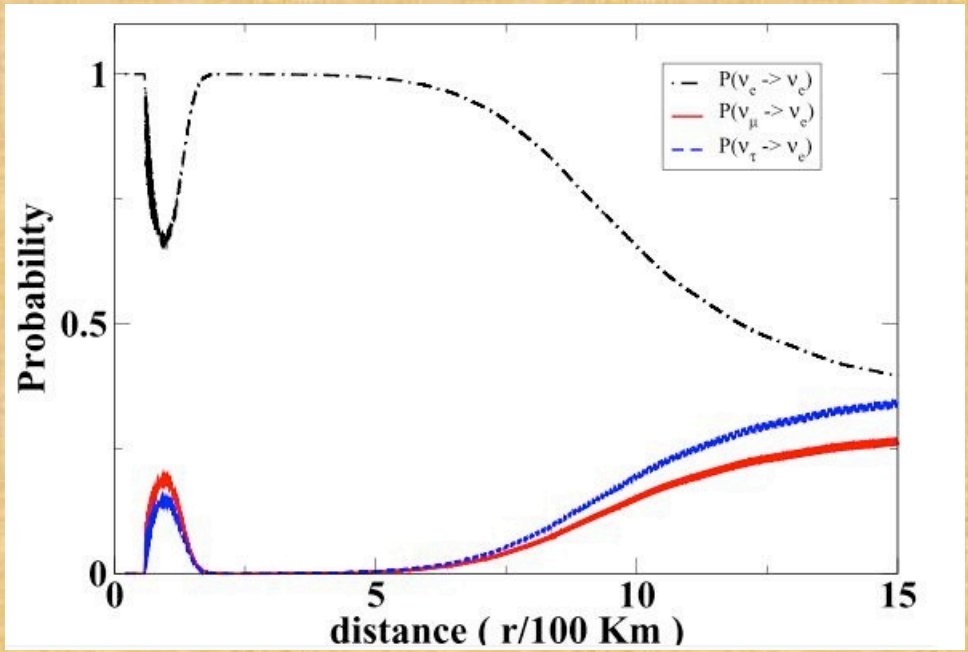

J. Gava and C.Volpe. PRD 78, 083007 (2008)

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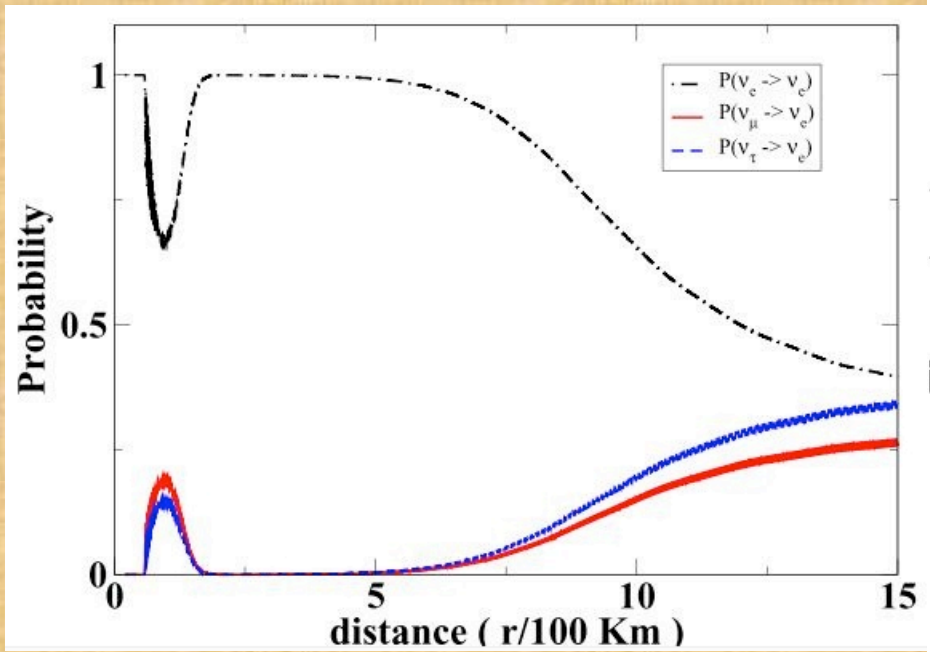

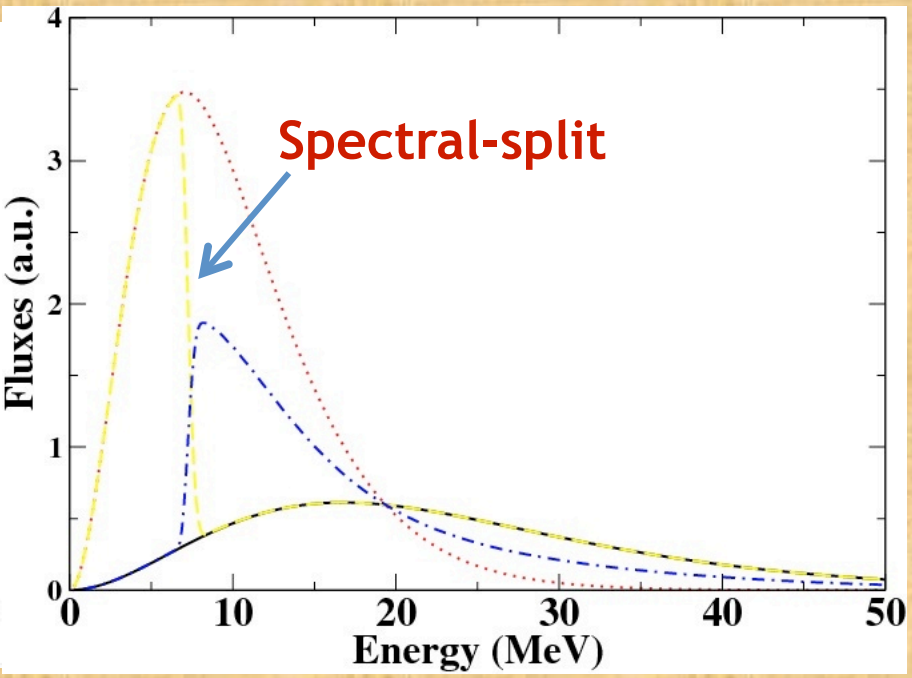

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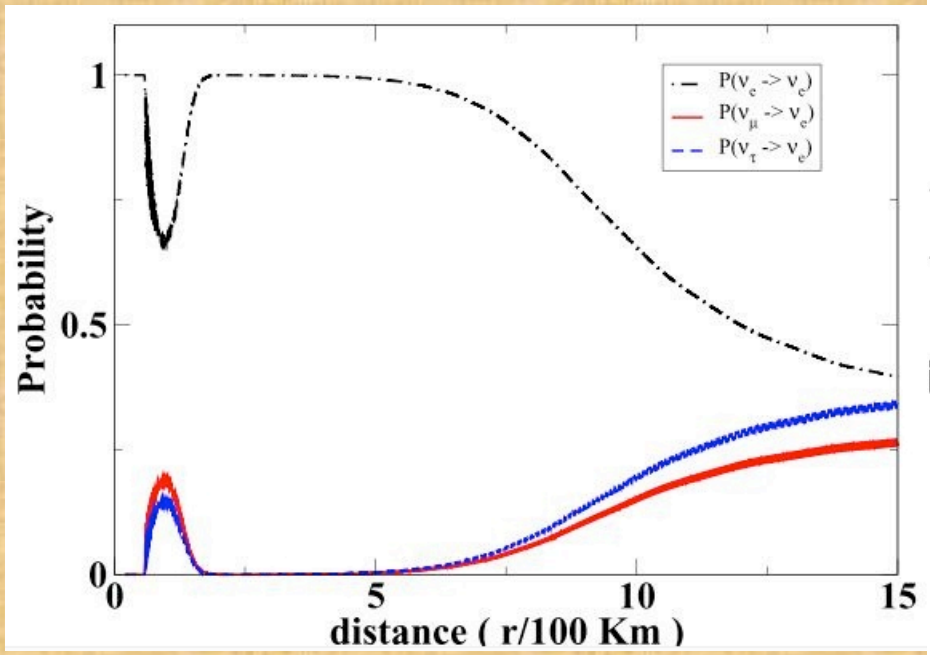

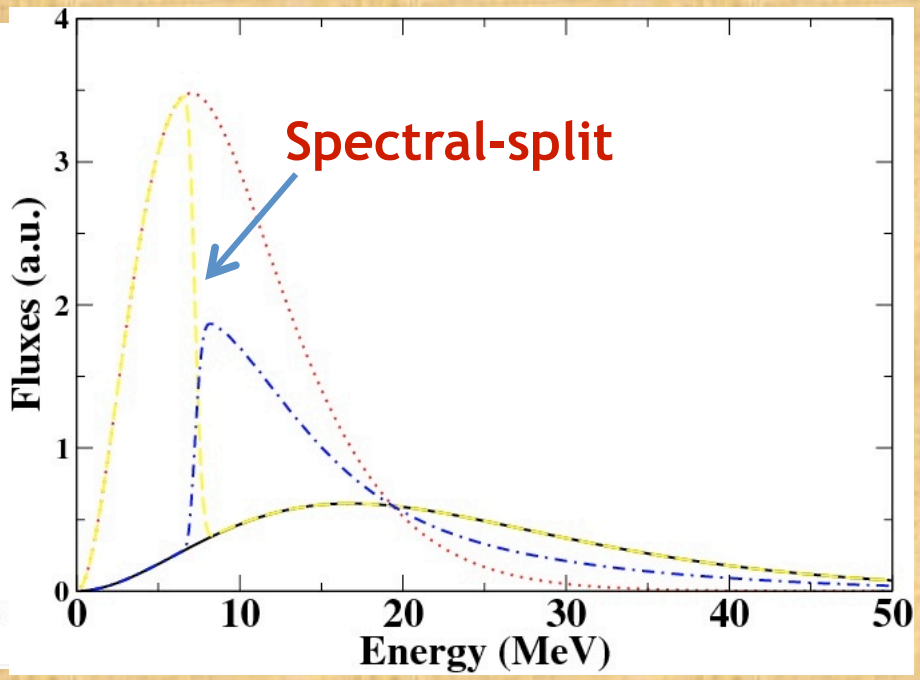

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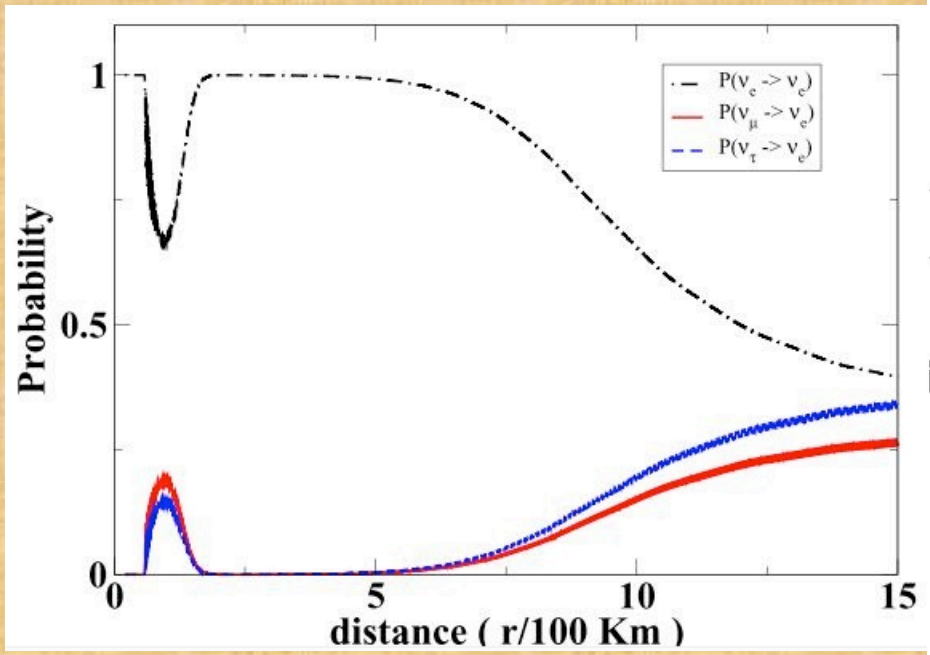

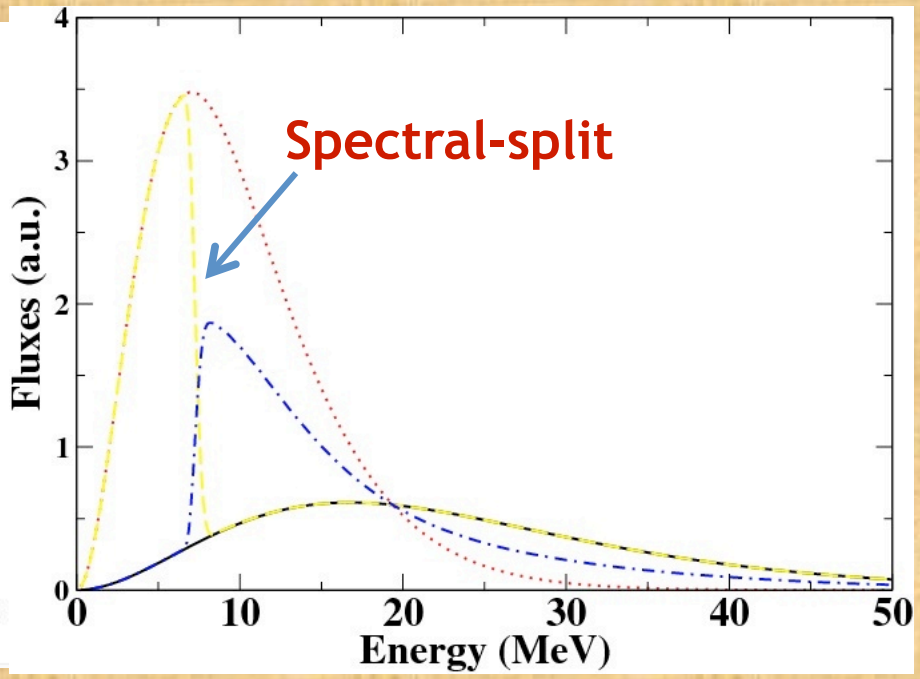

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We have discovered that the spectral split is similar to a magnetic resonance phenomenon! ***See S. Galais' talk.***

S. Galais and C.Volpe. in preparation.

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Schirato and Fuller (2002), arXiv : 0205390.

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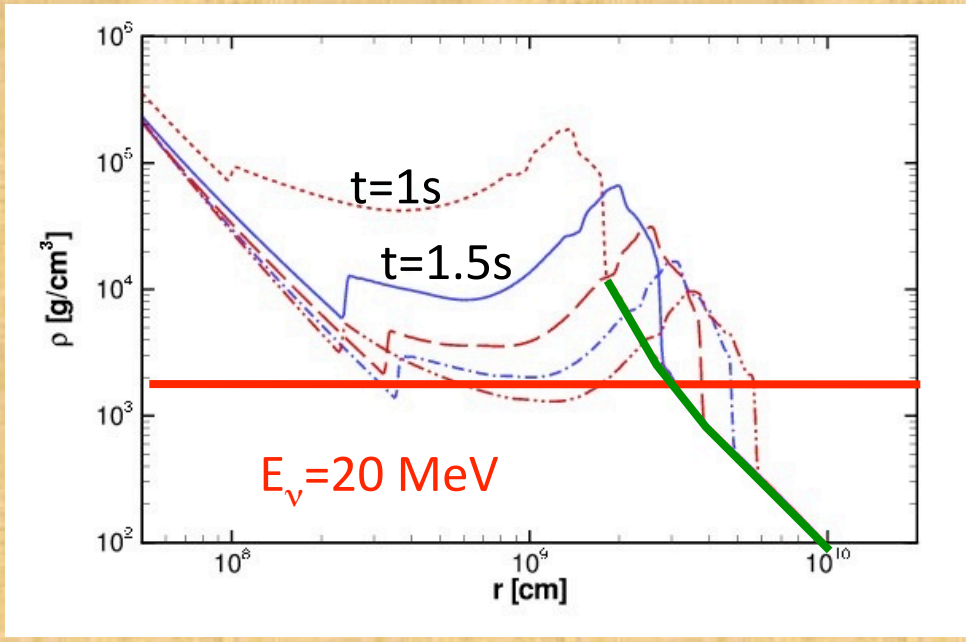

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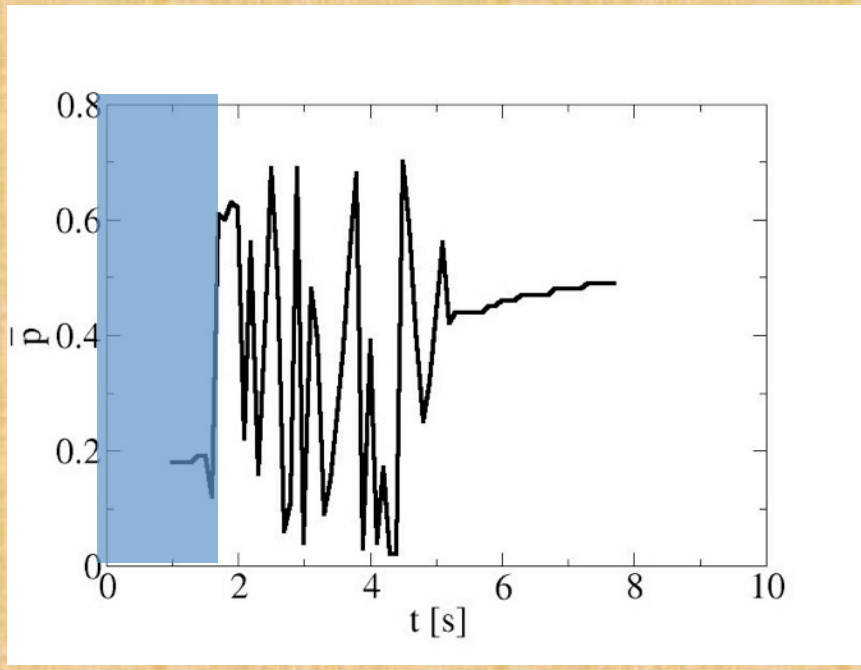

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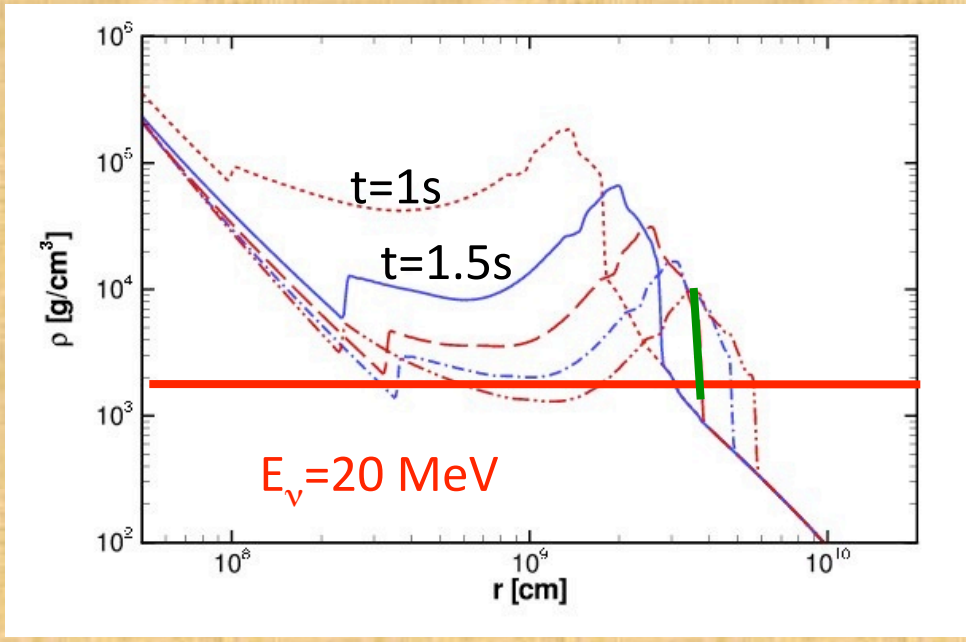

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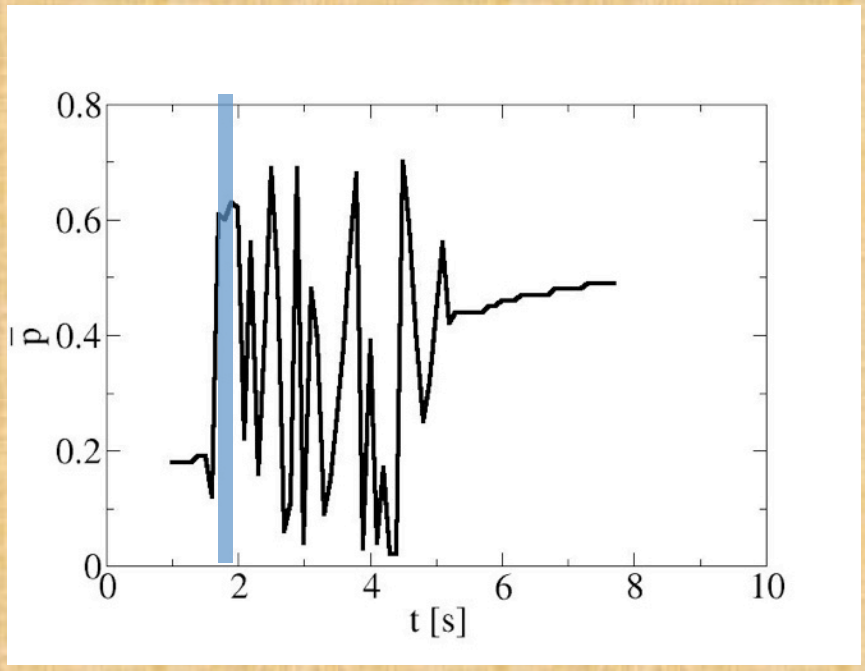

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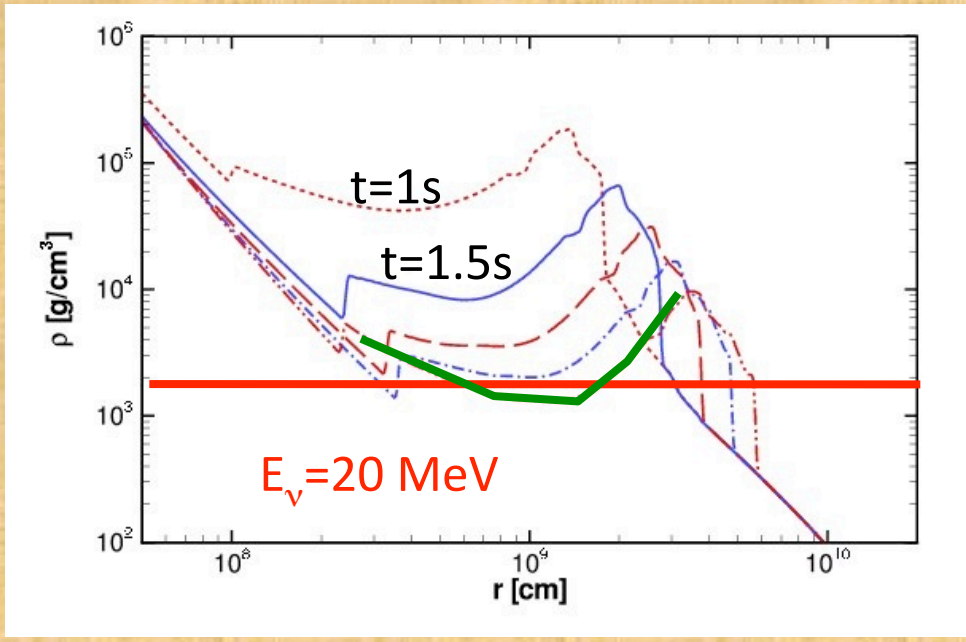

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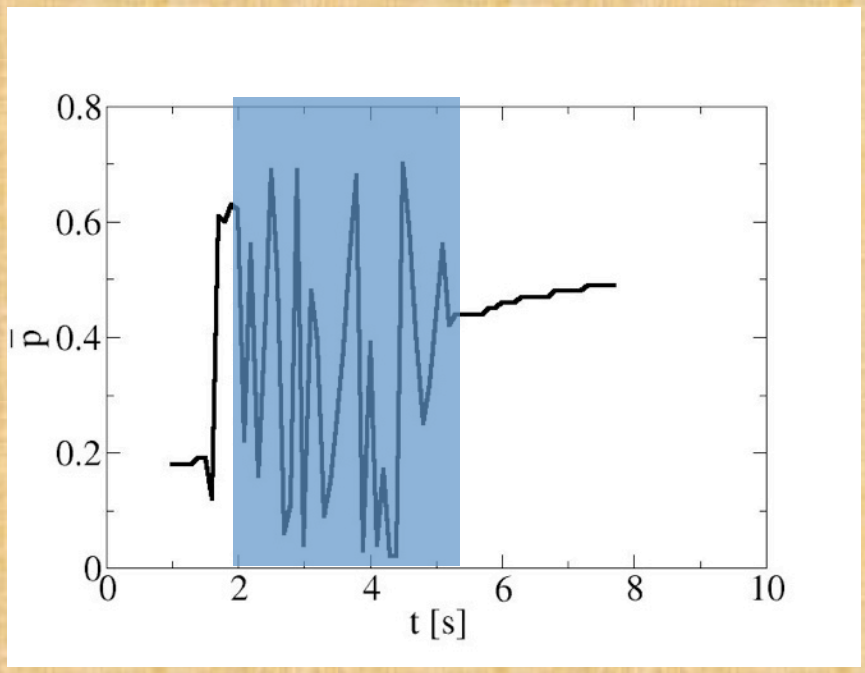

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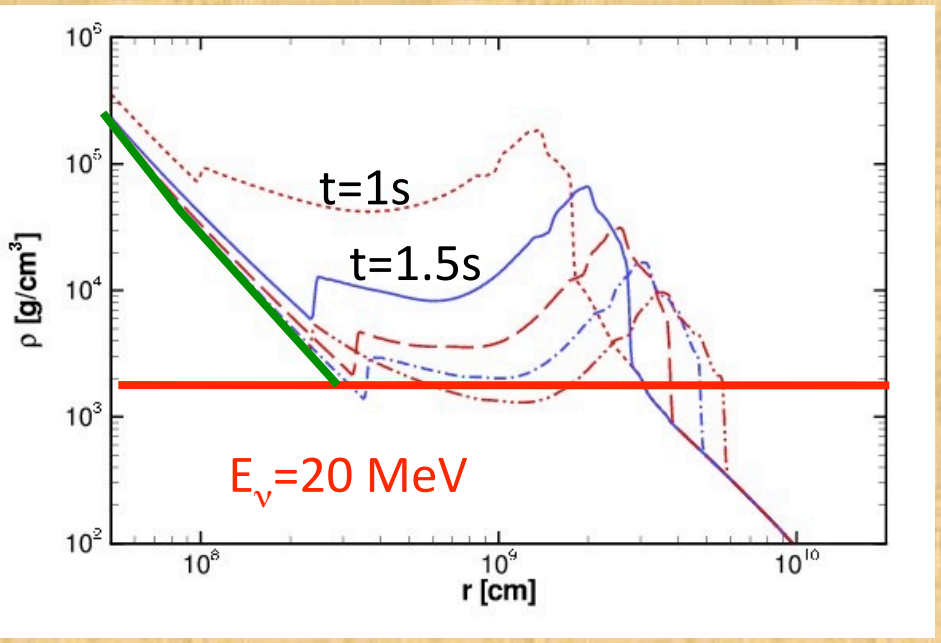

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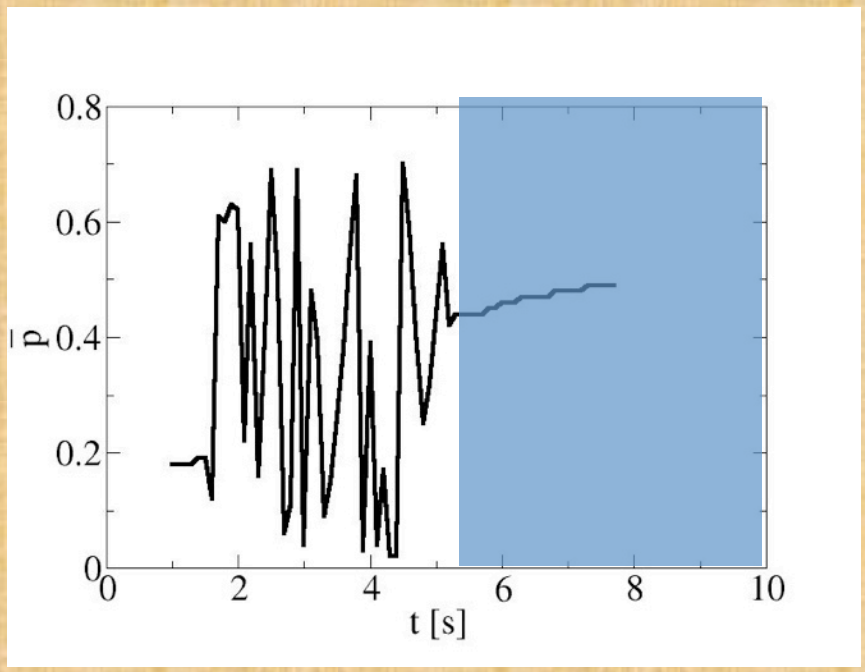

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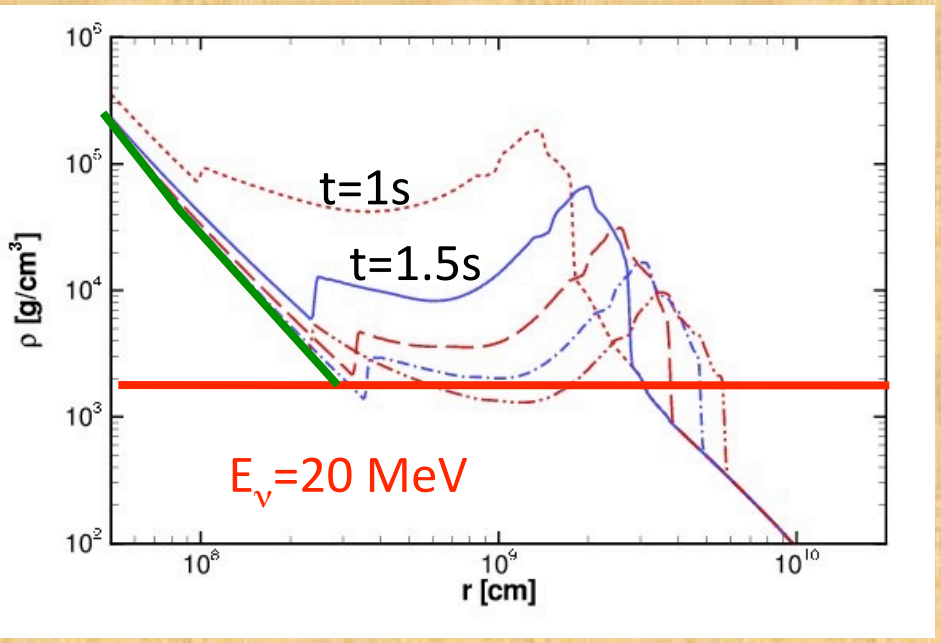

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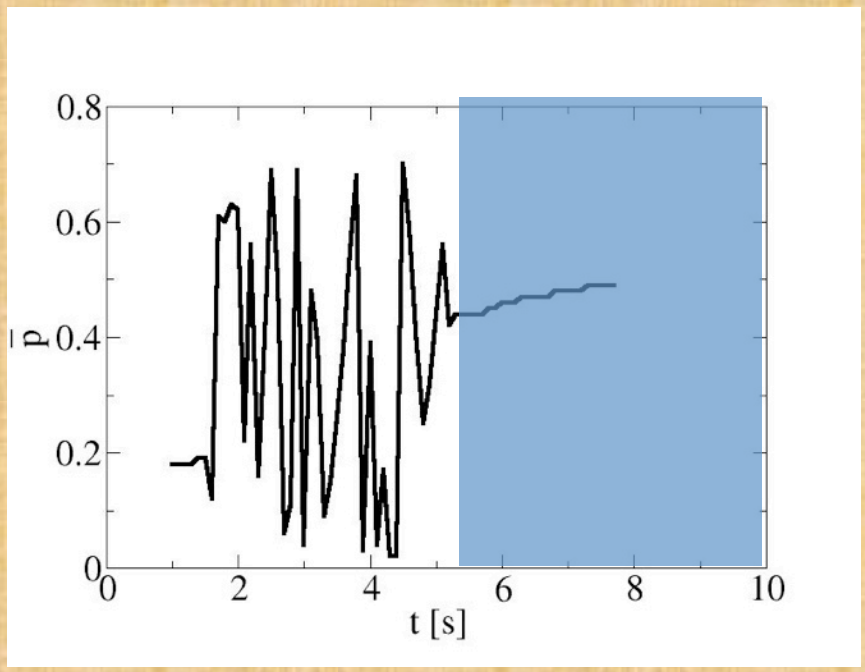

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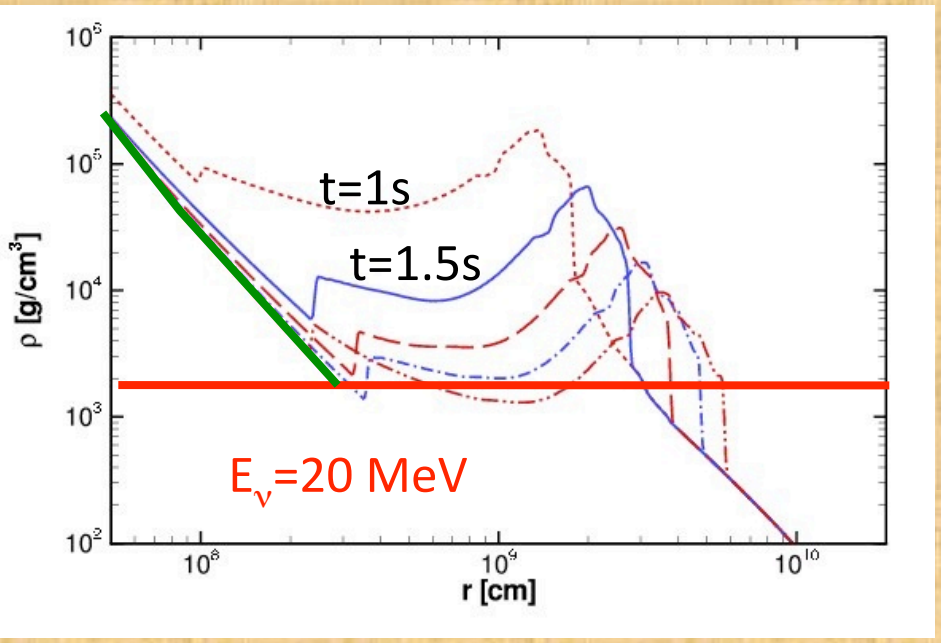

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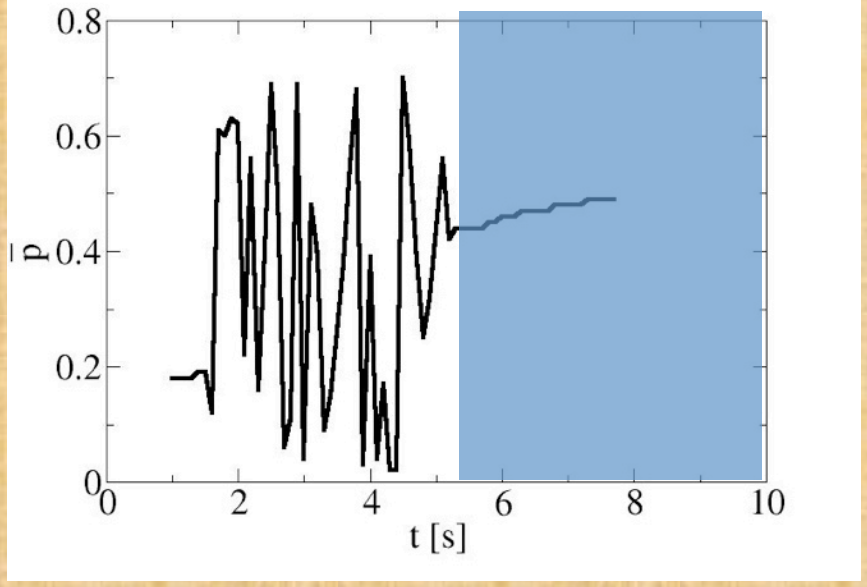
inverted hierarchy, large θ_{13}



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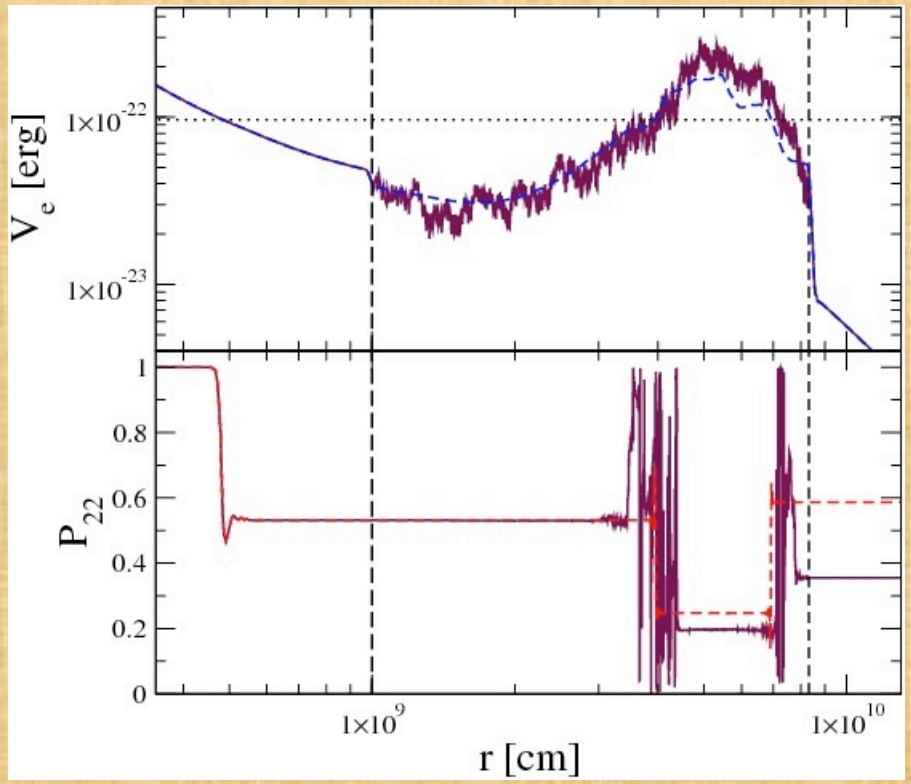

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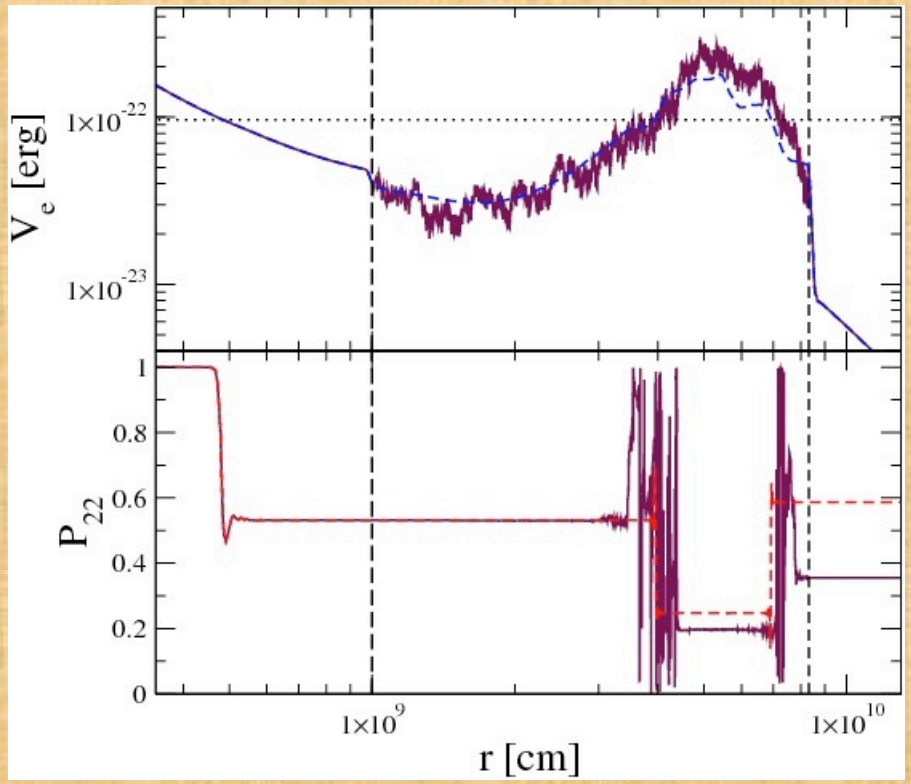

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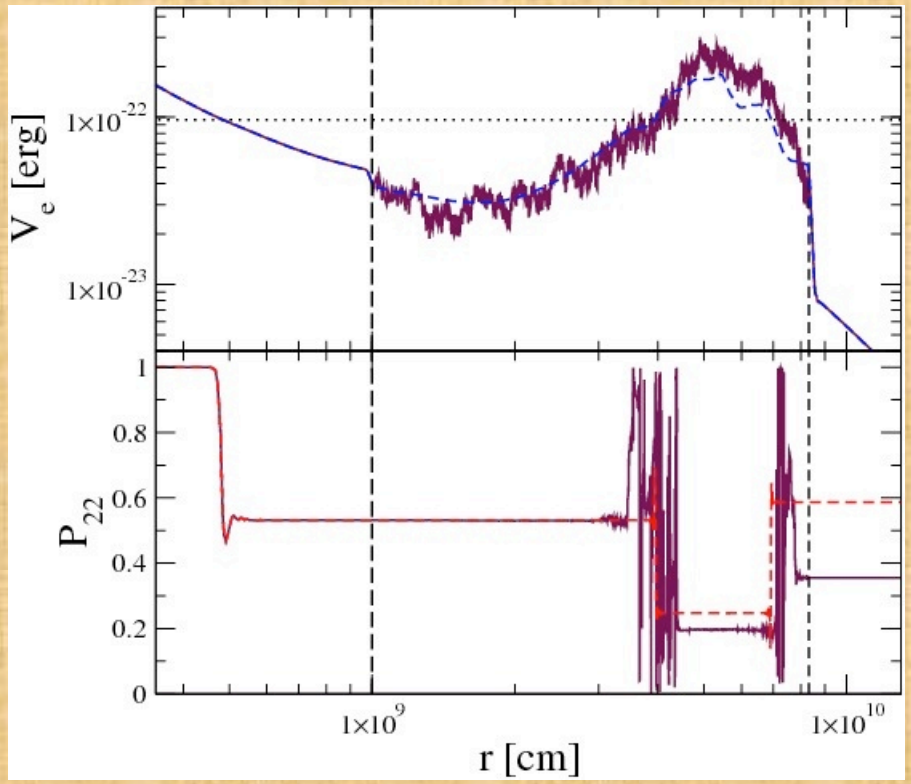

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TRANSITION FROM shock-wave to turbulence dominated regime, as the fluctuation amplitude increases.

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80 tonnes of Pb, HALO-2: 1kt

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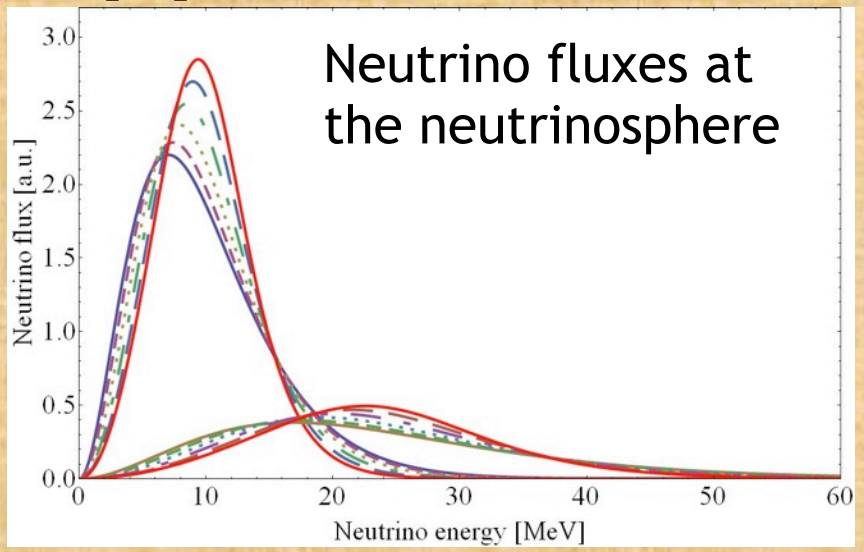

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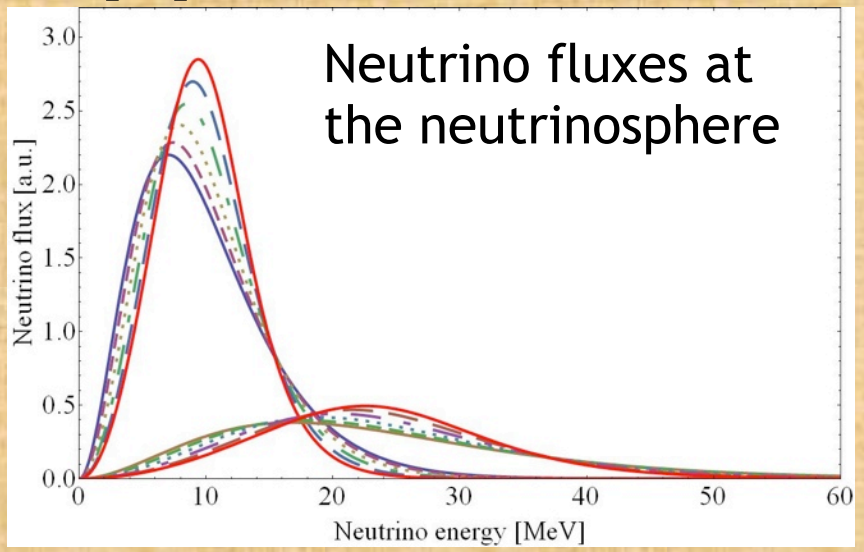

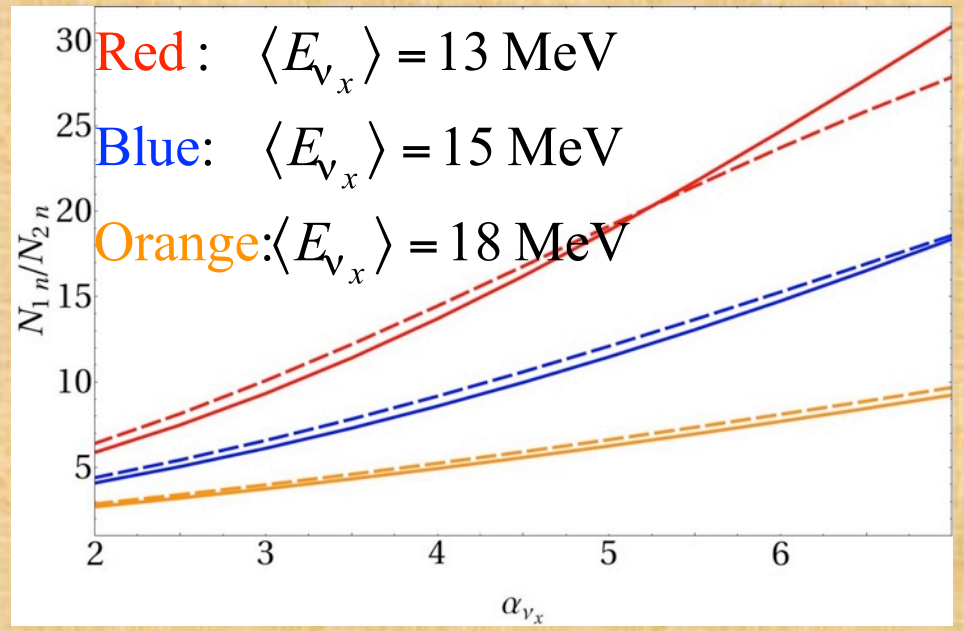

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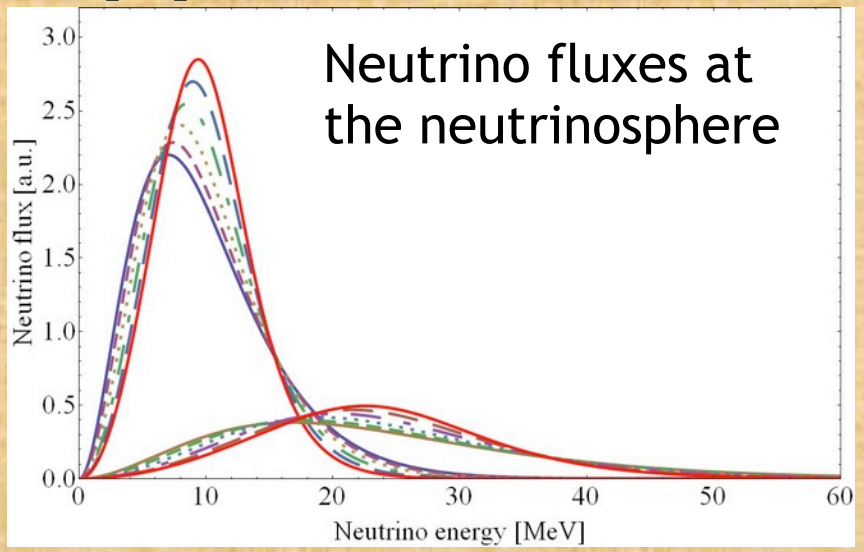

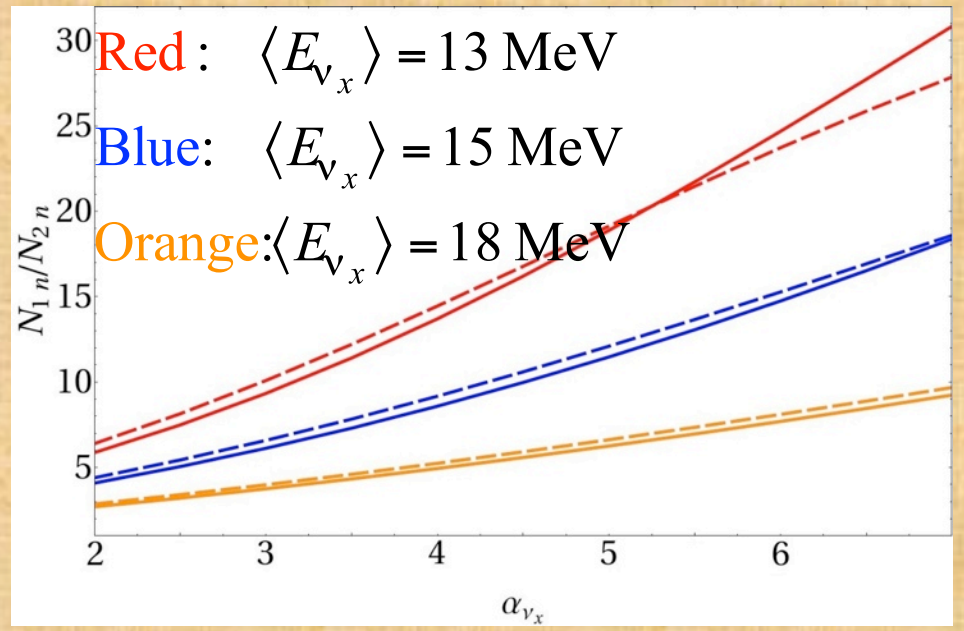

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vacuum term

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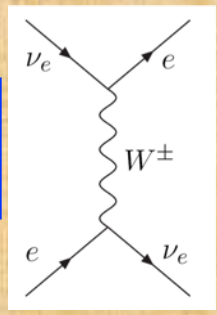

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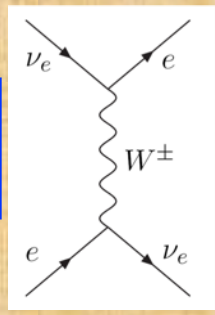

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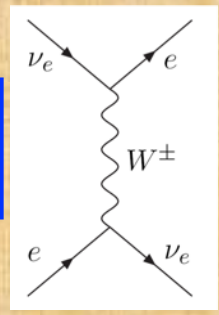
matterterm



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factorizes out easily and gives:

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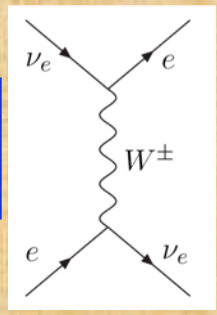

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the T23 basis

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CP violation effect in SN

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$$\tilde{H}(\delta) = S^{\dagger}\tilde{H}(\delta = 0)S$$

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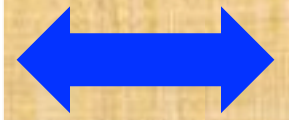

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Evolution operator in the T_{23} basis

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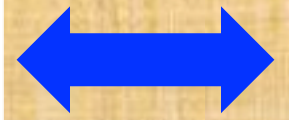

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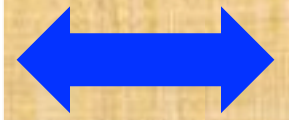

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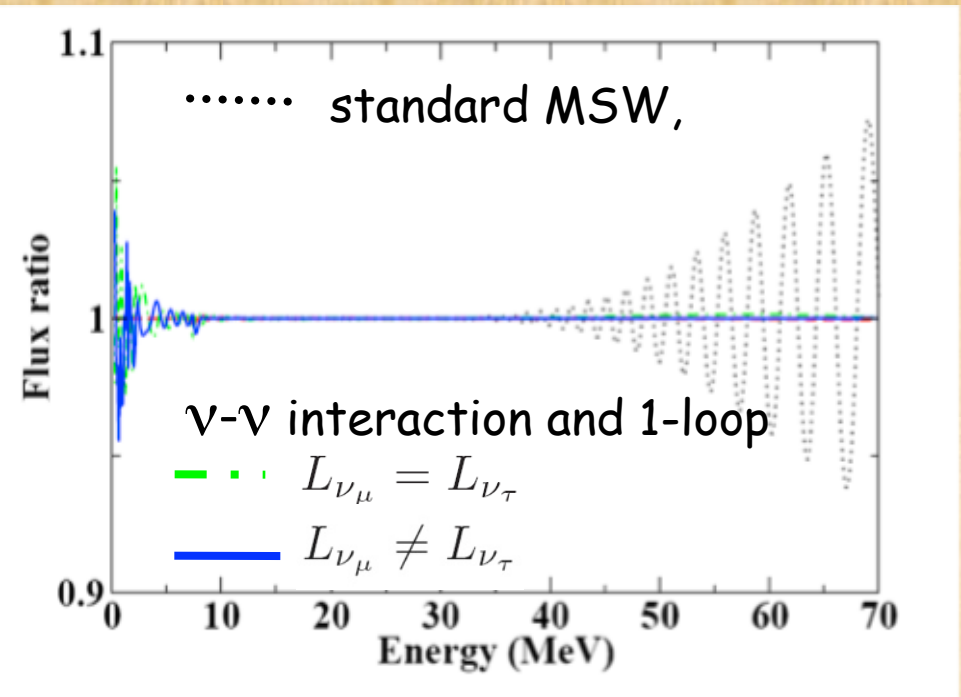
THERE CAN BE CP-VIOLATION EFFECTS IN SUPERNOVAE.

Numerical results



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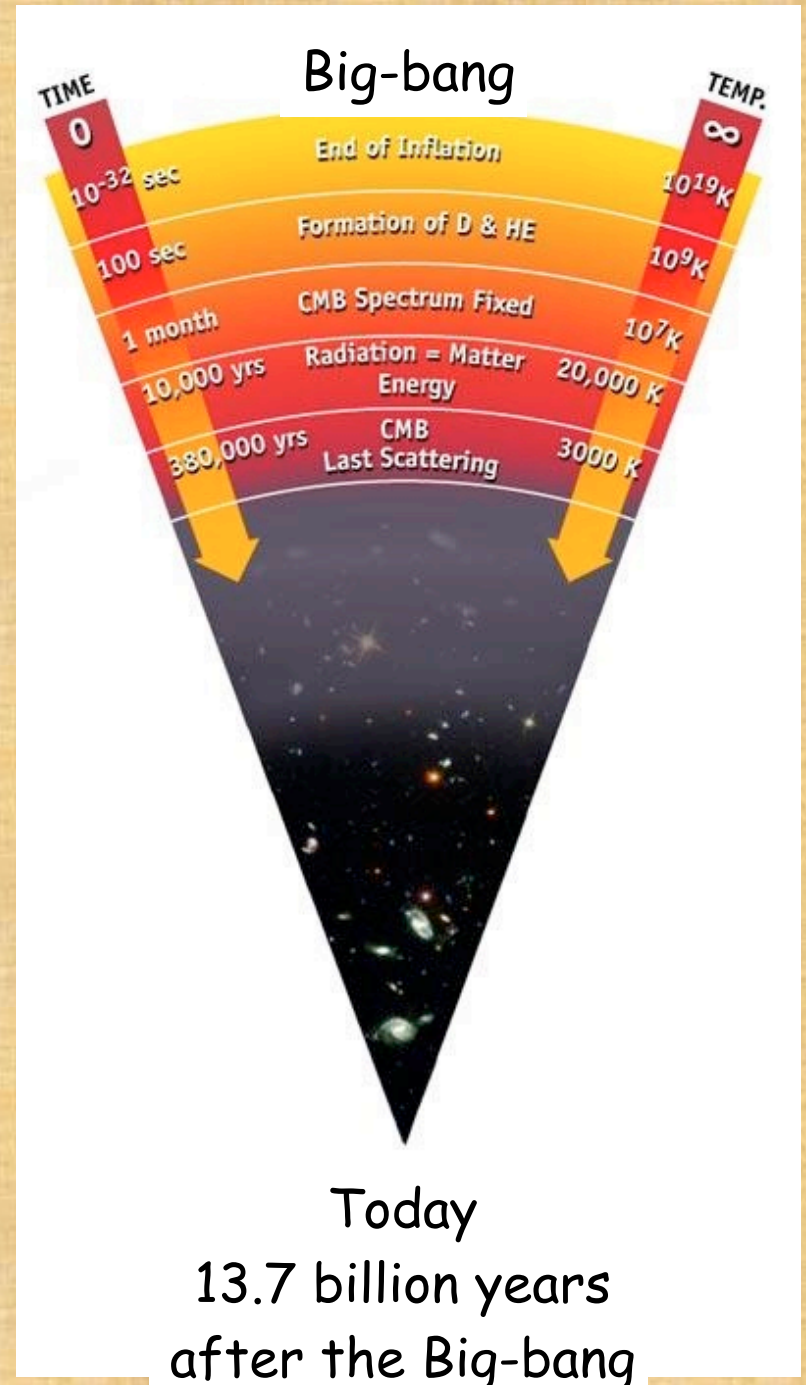
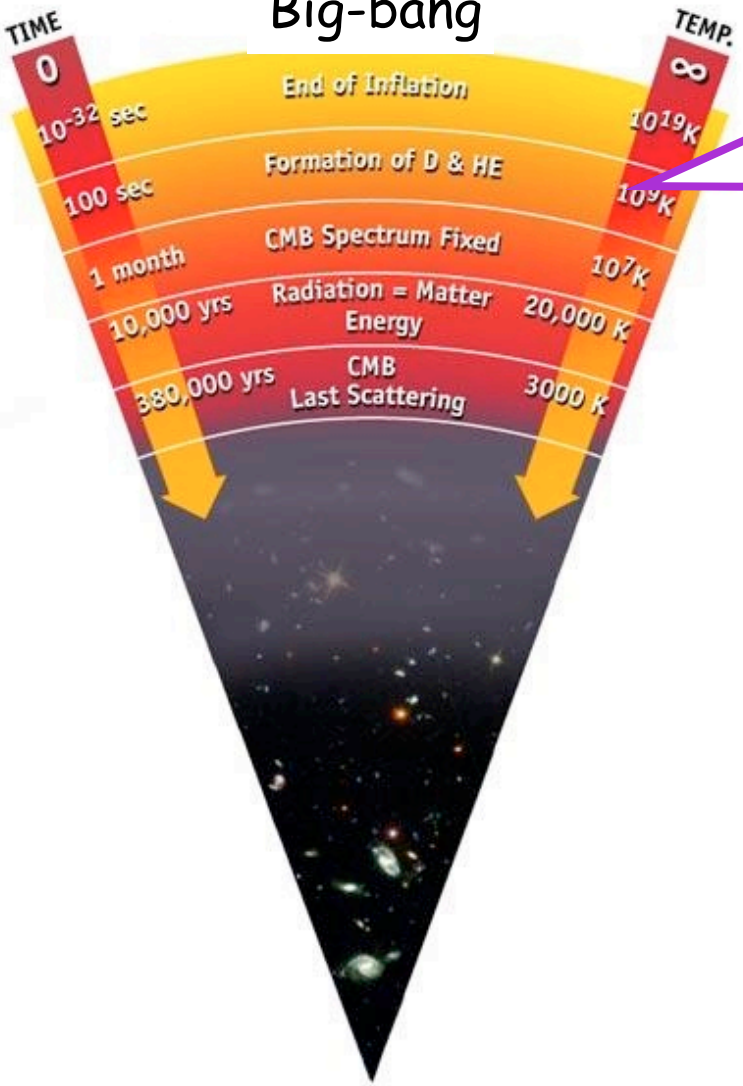
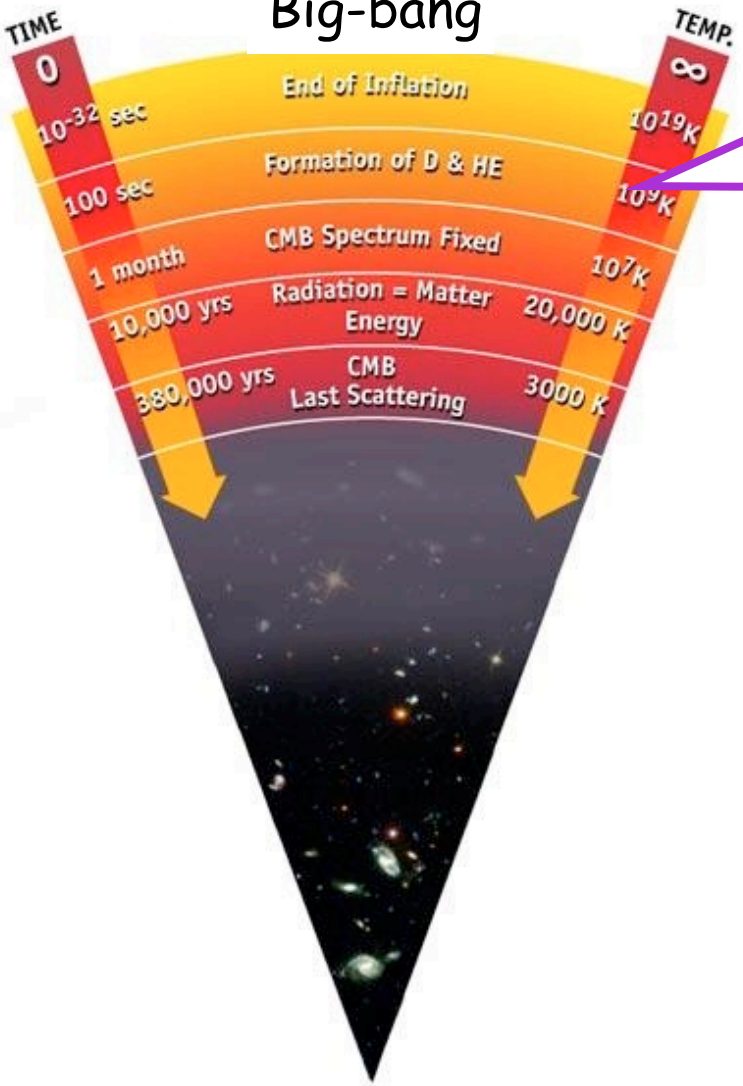
EFFECTS OF 5% ON THE ELECTRON NEUTRINO FLUXES.


Big-bang
TIME
0
TEMP.
∞
End of Inflation
10-32 sec
10^19 K
Formation of D & HE
100 sec
10^9 K
CMB Spectrum Fixed
1 month
10^7 K
Radiation = Matter
Energy
10,000 yrs
20,000 K
CMB
Last Scattering
380,000 yrs
3000 K
Today
13.7 billion years
after the Big-bang



Today
13.7 billion years
after the Big-bang

neutrinos from early Universe
a picture of the Universe
1 second after the Big-Bang



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1 second after the Big-Bang

Neutrino properties leave an imprint on the neutron/proton ratio that sets the abundance of light elements.
Several properties have been studied in the past (ex. sterile neutrinos, non-standard interactions, …)

A.D. Dolgov, Phys. Rept 370, 333 (2002), hep-pth/0202122.

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Calculations including mixing, e.g.

Abazajian, Beacom, Bell, PRD 66 (2002) 013008,
Mangano et al, Nucl. Phys. B 729 (2005) 221,
Pastor, Pinto and Raffelt, PRL 102 (2009) 241302

Dolgov et al, Nucl. Phys. B 632 (2002) 363,

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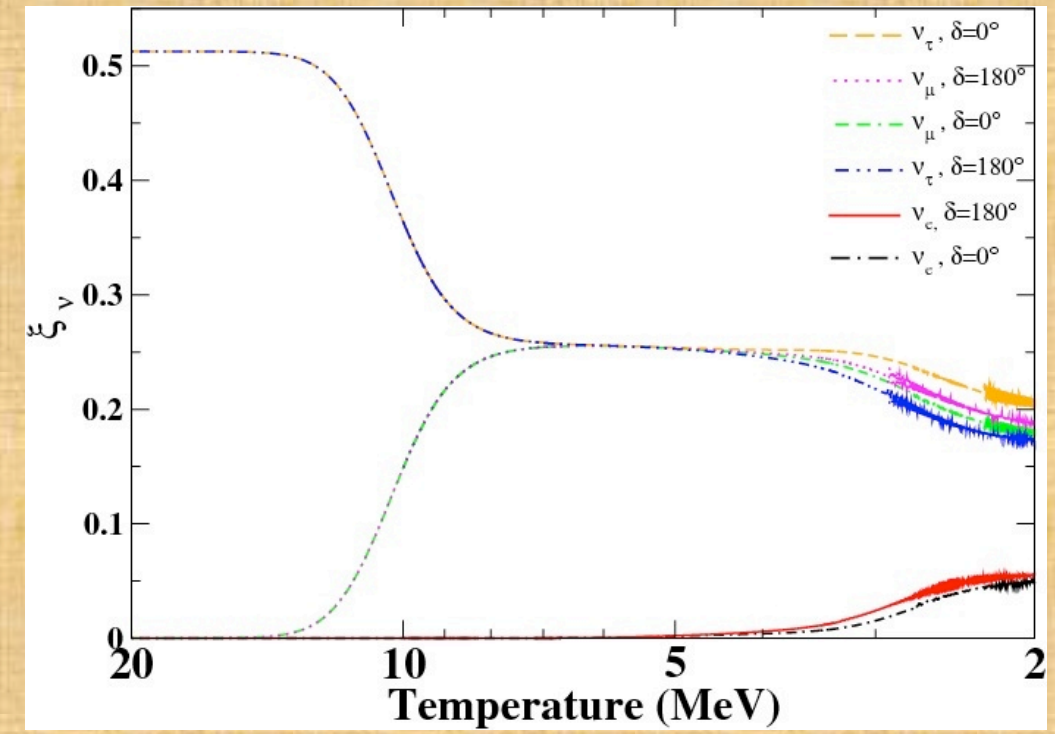

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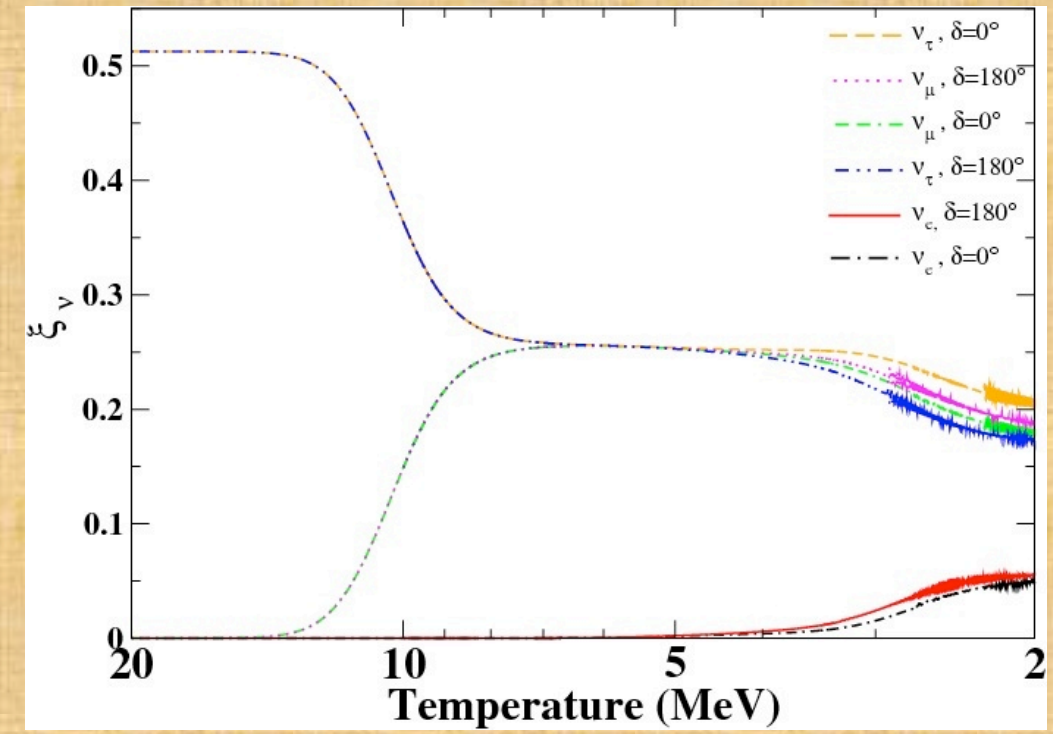

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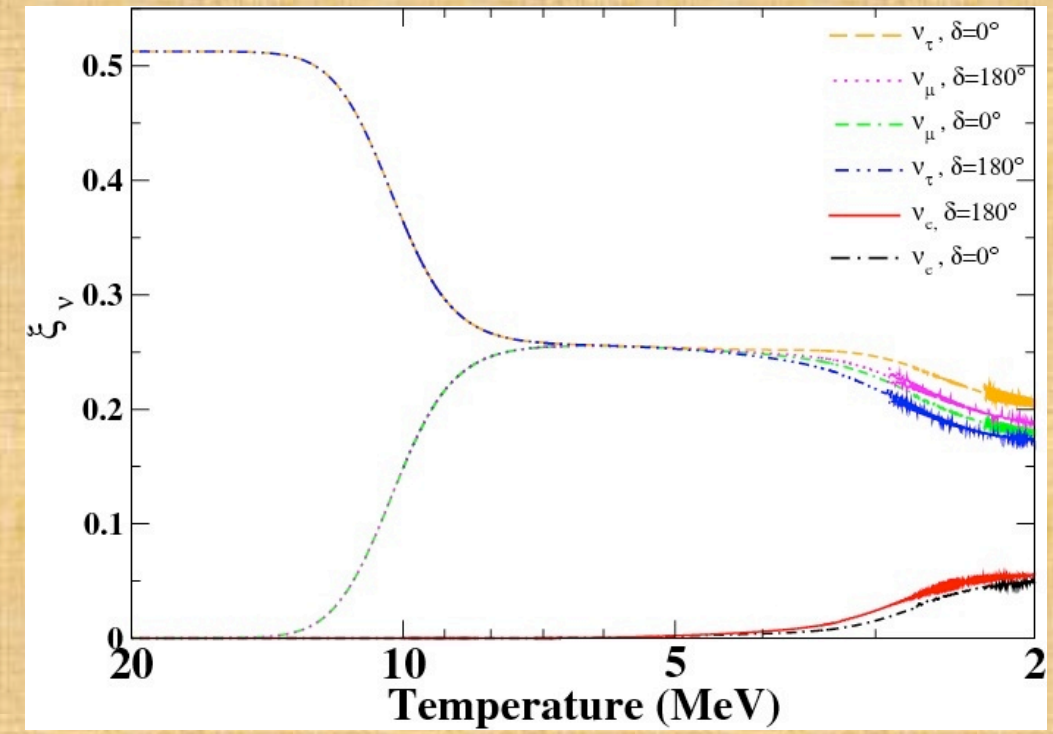

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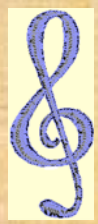
In D. Horn's Master Thesis we are now implementing the full collision intergral.

Conclusions and Perspectives



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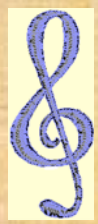

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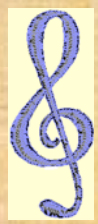

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Theoretical and phenomenological work still needed to come to an established framework.

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We have set the basis for the exploration of CP violating effects in media.
In particular, radiative corrections and beyond the Standard Model physics can engender CP effects on the neutrino fluxes.

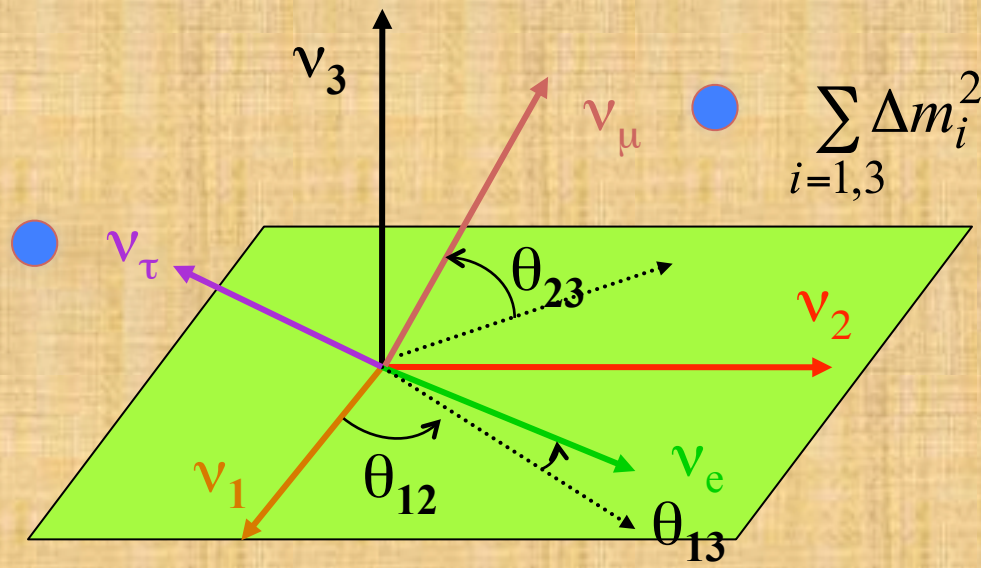
Further work is needed to study the possible impact e.g. on the r-process and in other Environments, such as the Early Universe.


Danke.
Thank you!
Gracias.
Grazie.
Merci.
Andromeda (M31)

« Doctoral Training Program (DTP) »
at the European Center for Theoretical Physics in Trento
« Neutrinos in Nuclear-, Particle and Astrophysics »
April-June 2010 See http://www.ect.it/

THE 3-flavours OSCILLATION PARAMETERS

- In the case of three families, there are three mass eigenstates (ν_1, ν_2, ν_3) and three flavour eigenstates (ν_e, ν_μ, ν_τ).



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Only two Δm^2 are independent.

The two basis are related by a unitary matrix, called the Maki-Nakagawa-Sakata-Pontecorvo (MNSP) matrix.

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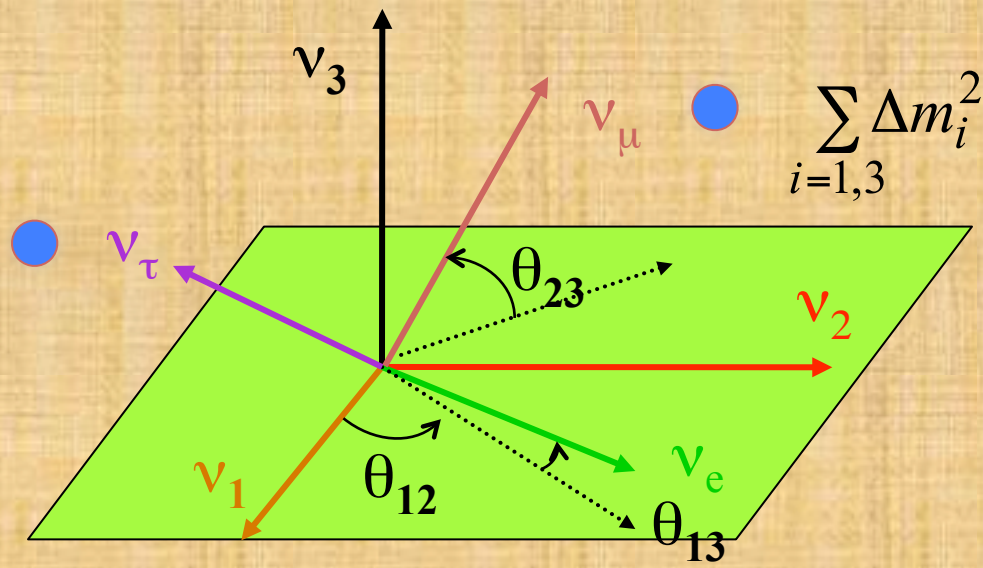

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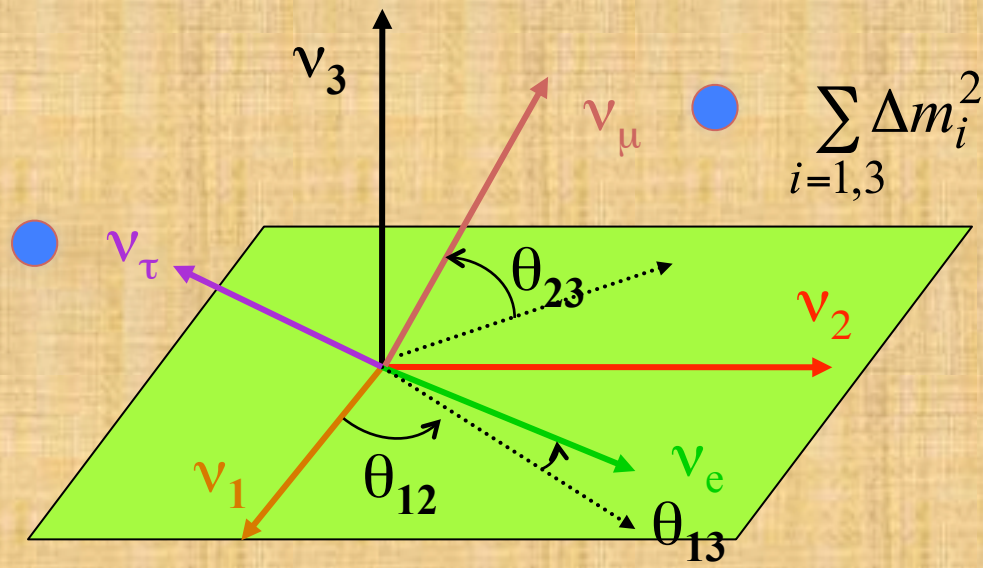

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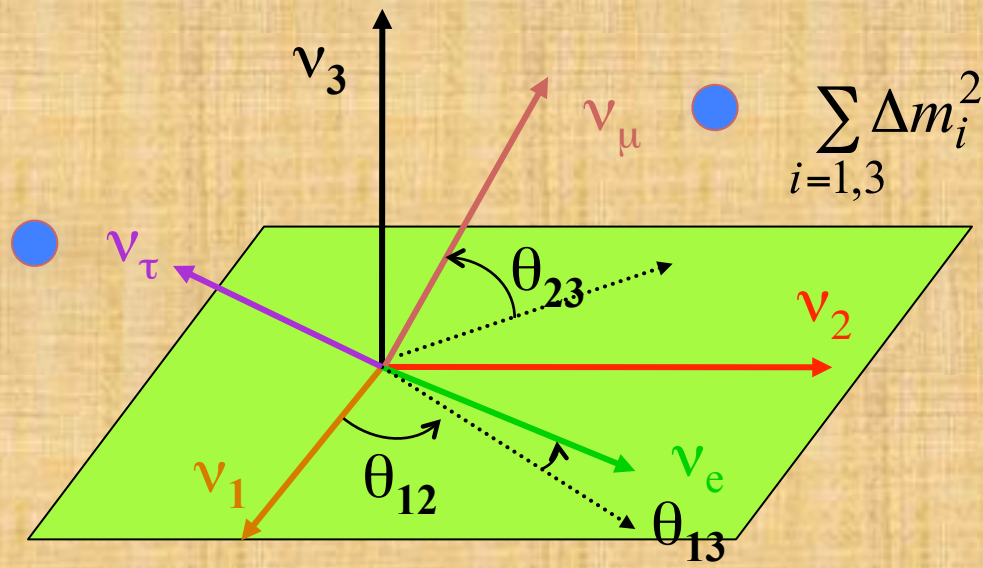

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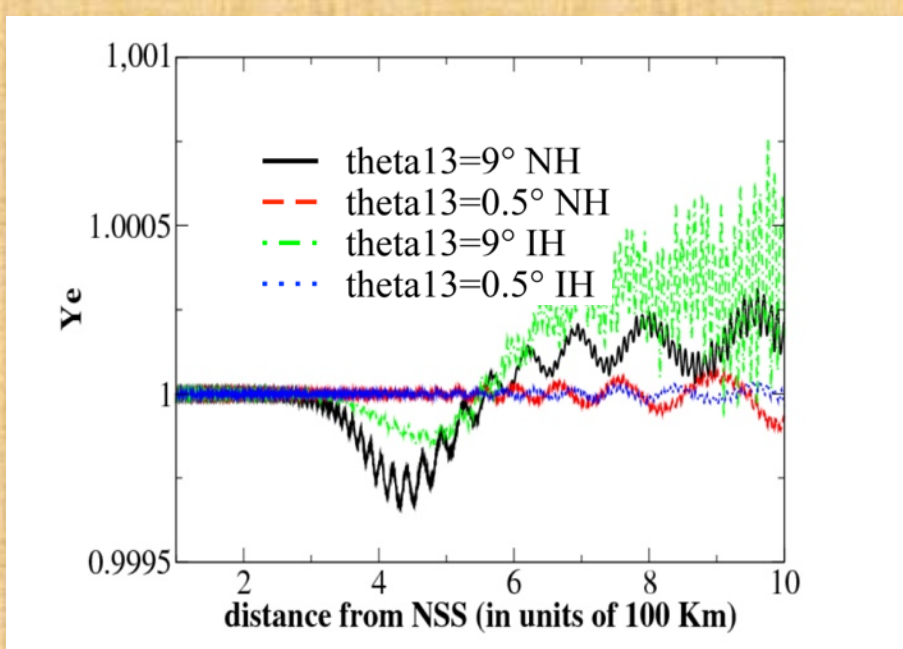

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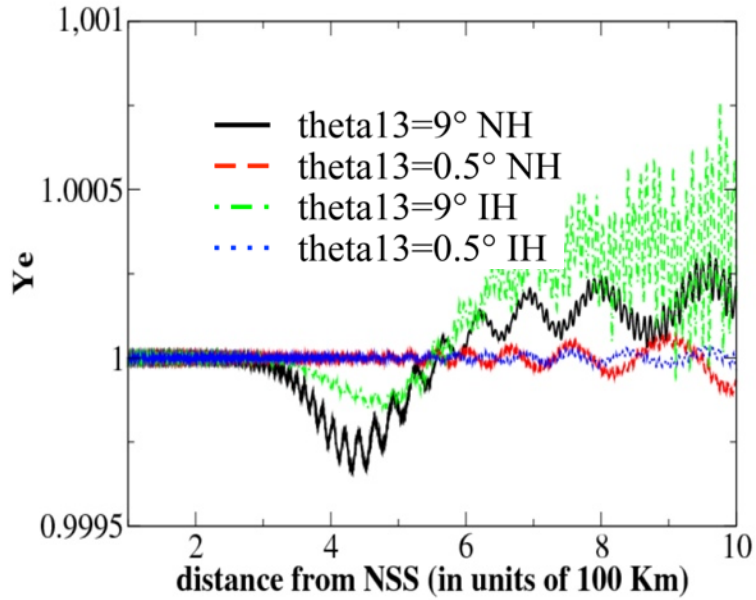

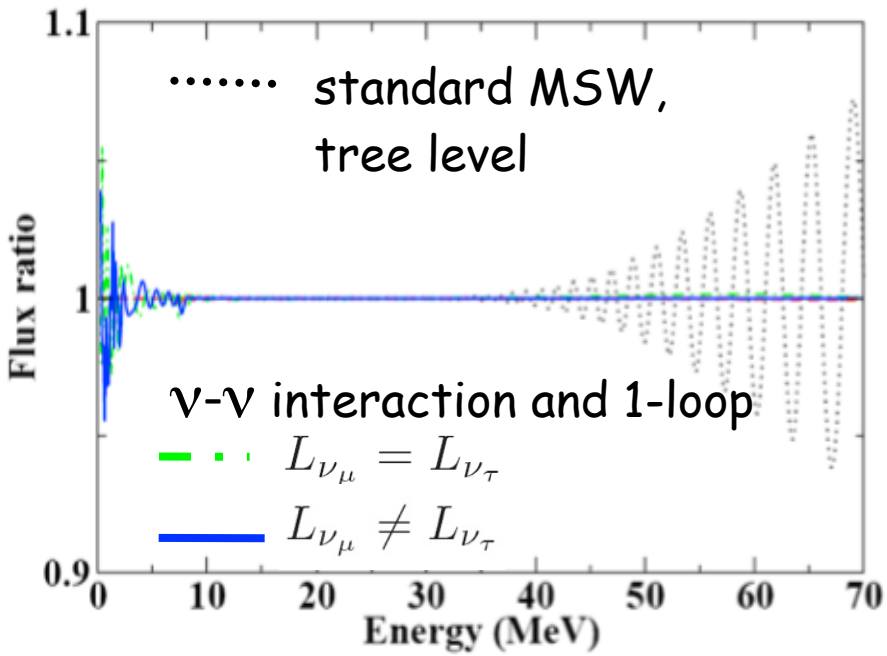

Gava, Volpe, Phys. Rev. D78 (2008), arXiv:0807.3418

EFFECTS OF 5% ON THE ELECTRON NEUTRINO FLUXES.