Strong Neutrino-Majoron Interactions in Supernovae?

Tina Lund

UniverseNet, Oxford

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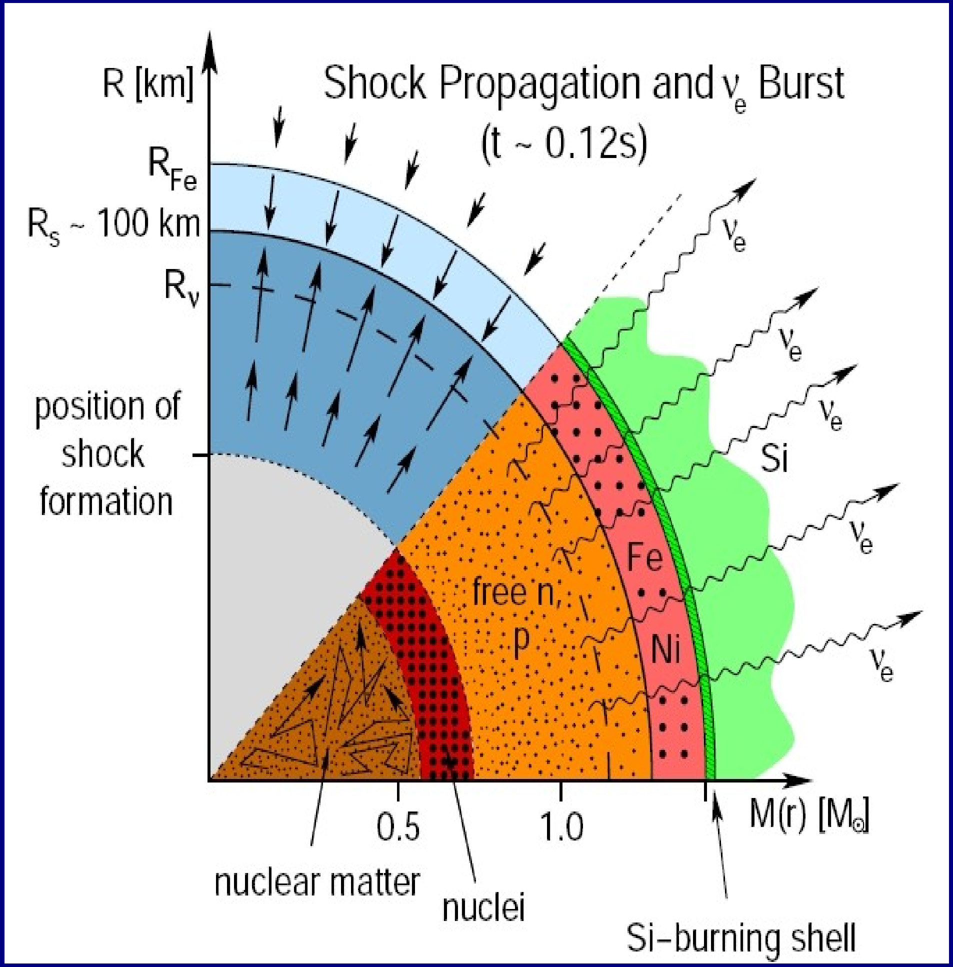
Bounce to burst

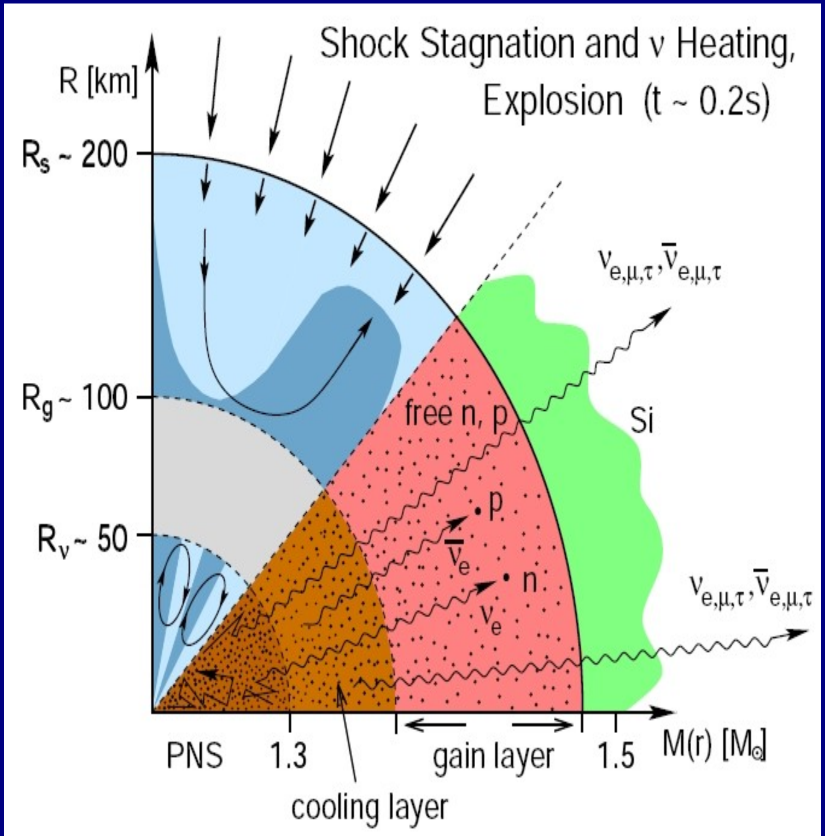
- ν's are trapped when $\rho > 10^{12}$ g/cm^3 – neutrino sphere.
- The strong interaction becomes repulsive when $\rho > \rho_{nucl} = 10^{14}$ g/cm^3. Infalling material bounces ⇒ shock wave moving to the outer parts of the core.
- Energy in the shock wave is spent dissociating nuclei to nucleons ⇒ electron capture ⇒ plenty of ν_e.
- ν_e's leave the star taking energy with them ⇒ neutrino burst.
- Energy loss halts shock wave turning it into an accretion shock.
- Inside the original shock formation radius we have the beginning of a NS.



[H.-Th. Janka et al.]

Neutrino sphere

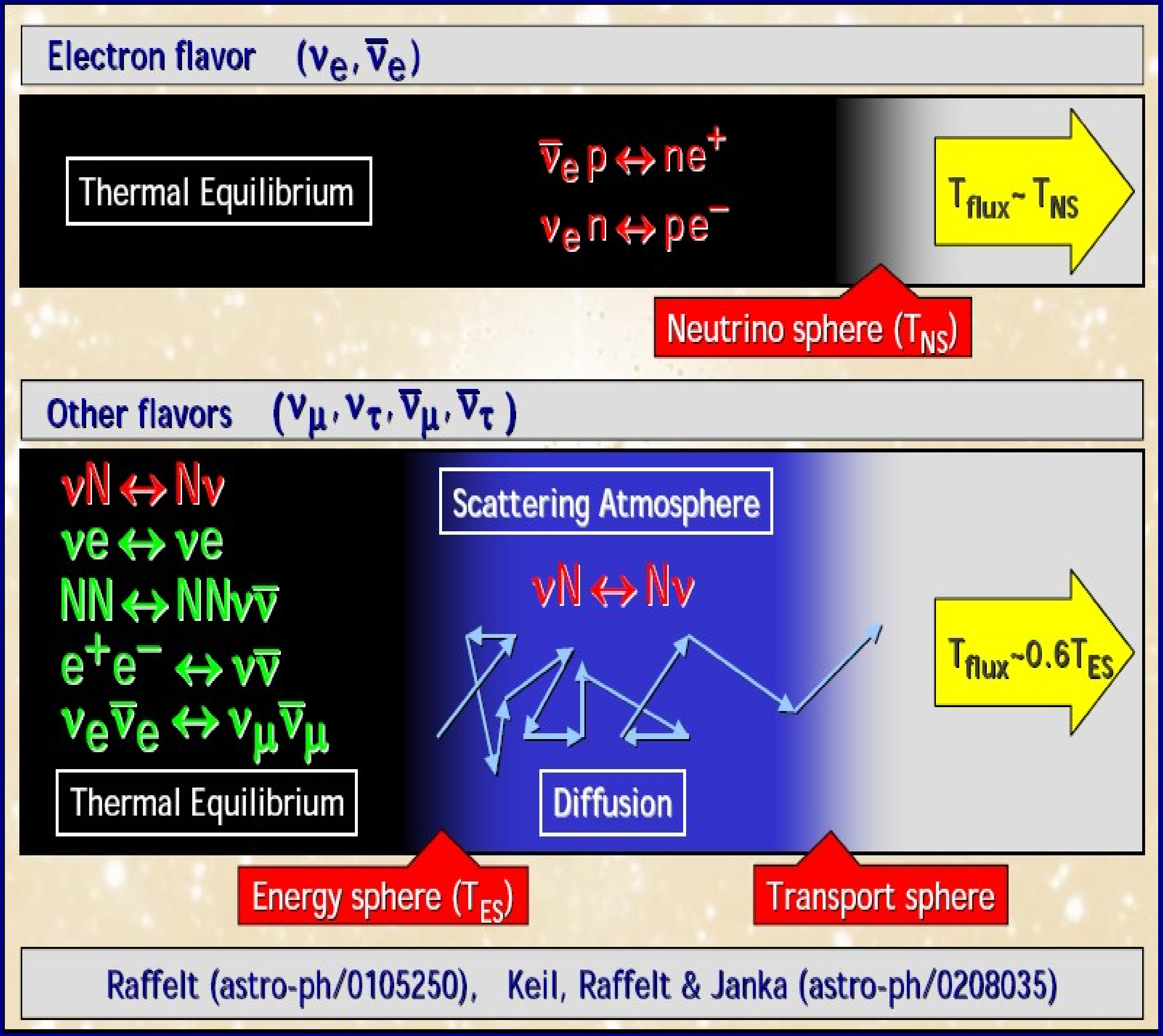
- In PNS ν's are still trapped, due to $\lambda_{mfp} < R_{ns}$, but they diffuse to the ν-sphere in seconds.
- Some of the ν_e's streaming from the ν-sphere can deposit energy in the region between the ν-sphere and the shock front via CC interactions, thereby reviving the stalled shock. ν_x only have NC interactions. Not enough energy is transfered.
- Energy needed to revive shock propagation.
- ”Hot bubble”: ρ~10^6-10^8 g/cm^3 , T~1 MeV.



[H.-Th. Janka et al.]

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

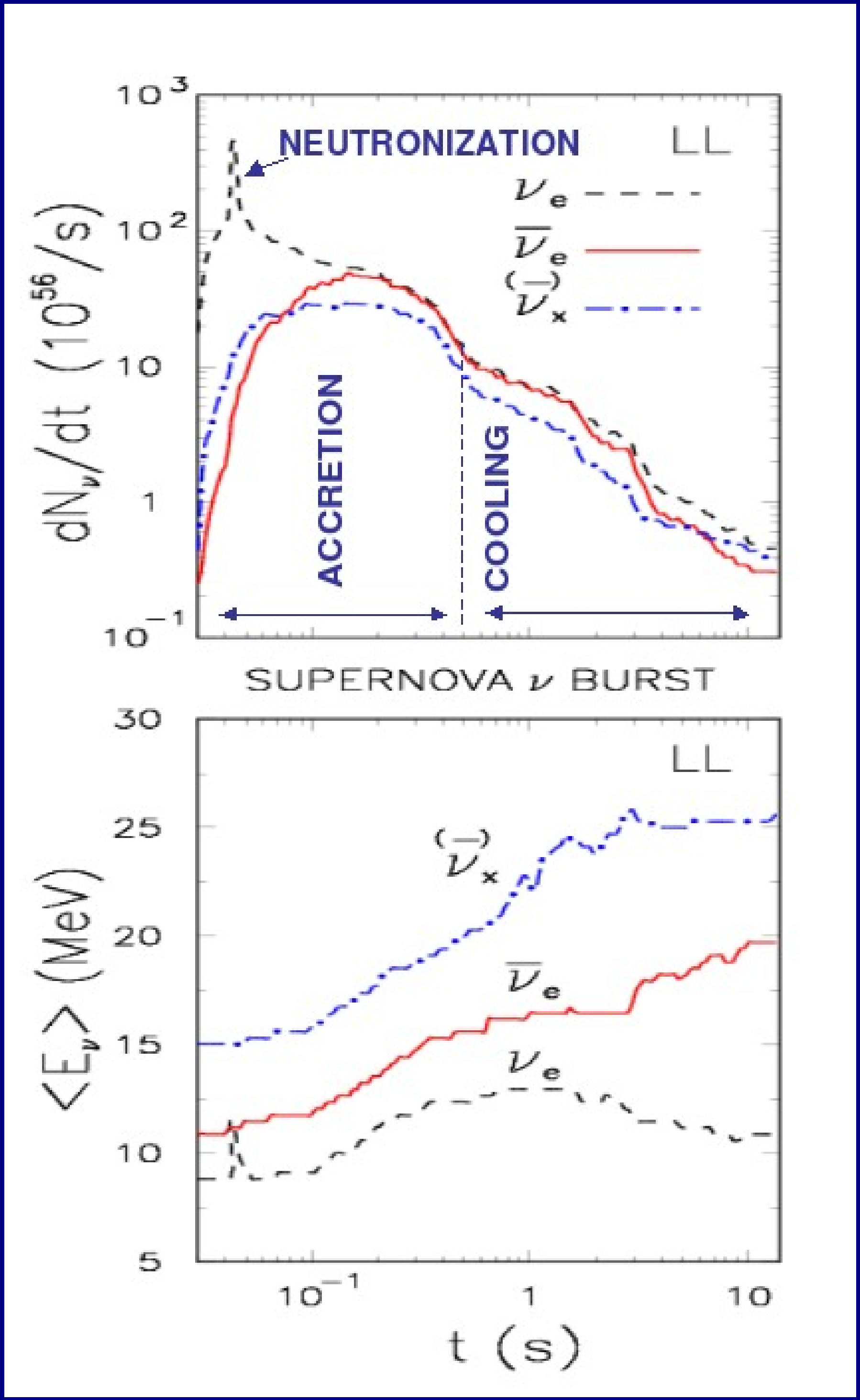
Neutrino spheres



[G. Raffelt.]

- Different spheres for different flavors due to interactions.
- Spheres are extended because $\sigma \propto E^2$.
- By changing which interactions to include and their assigned strength, you change the shape of the resulting ν_x-spektra.

$$\langle E_{\nu_e} \rangle < \langle E_{\bar{\nu}_e} \rangle < \langle E_{\nu_\mu} \rangle$$



Fluxes and Energies

$$\langle E_{\nu_e} \rangle \sim 10 - 12 MeV$$

$$\langle E_{\nu_{\bar{e}}} \rangle \sim 12 - 18 MeV$$

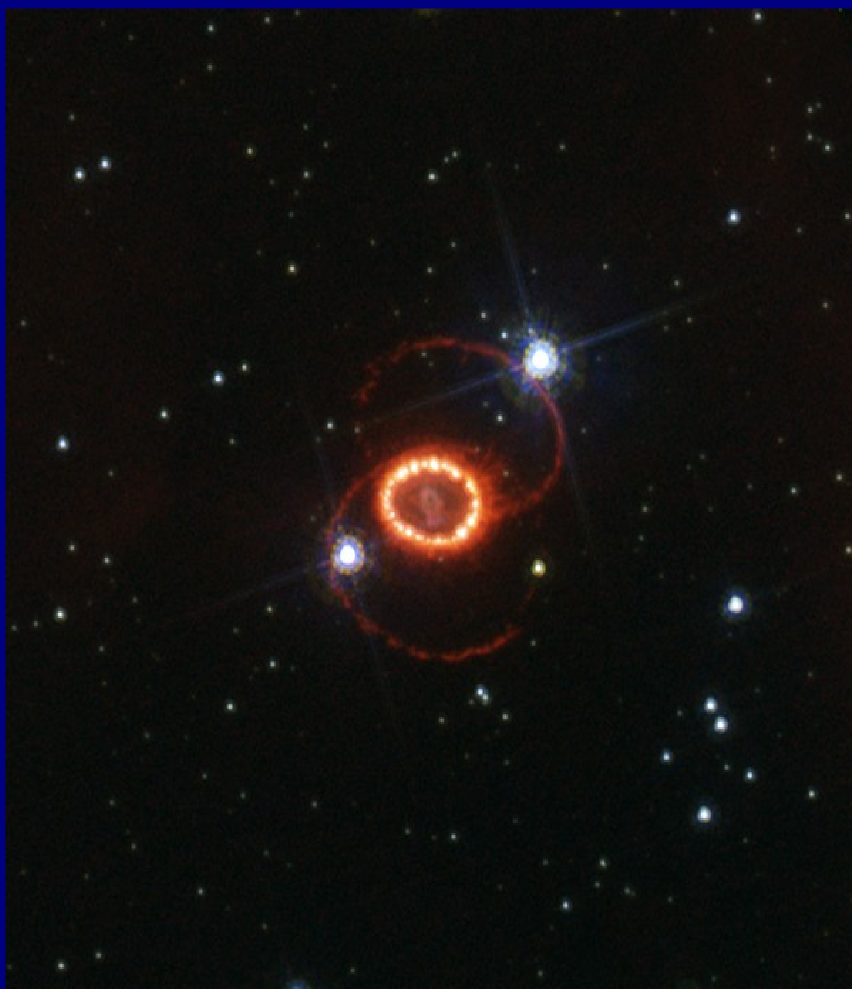
$$\langle E_{\nu_x} \rangle \sim 15 - 25 MeV$$

- In principle observed spectra apart from neutrino oscillations between the different flavors on their way to Earth.

$$\vec{\nu}_{weak} = \mathcal{M} \circ \vec{\nu}_{mass}$$

[A. Mirizzi; T.Totani et al.]

SN1987A



- Confirmed overall understanding.
- Low statistics ⇒ time integrated spectrum ⇒ constrained alternative energy loss mechanisms.

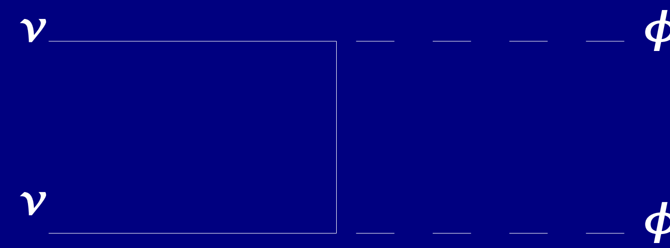
$$\varepsilon_X < 10^{19}\ \mathrm{erg\ g^{-1}\ s^{-1}}$$

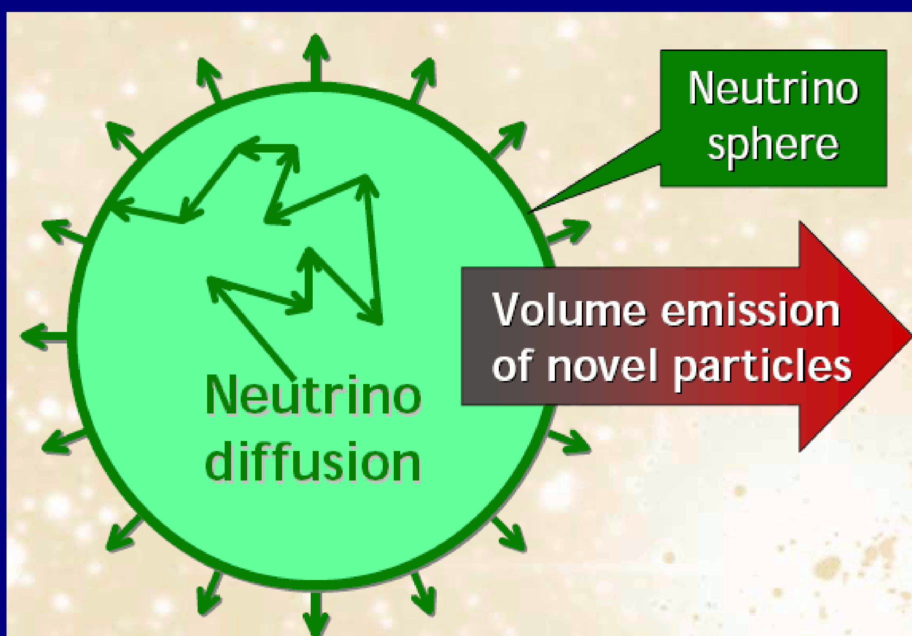
[G. Raffelt.]

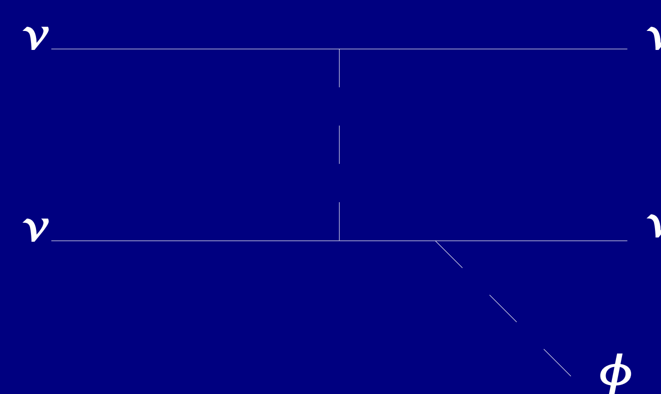
- Comparable to energy released in neutrinos.

New particles

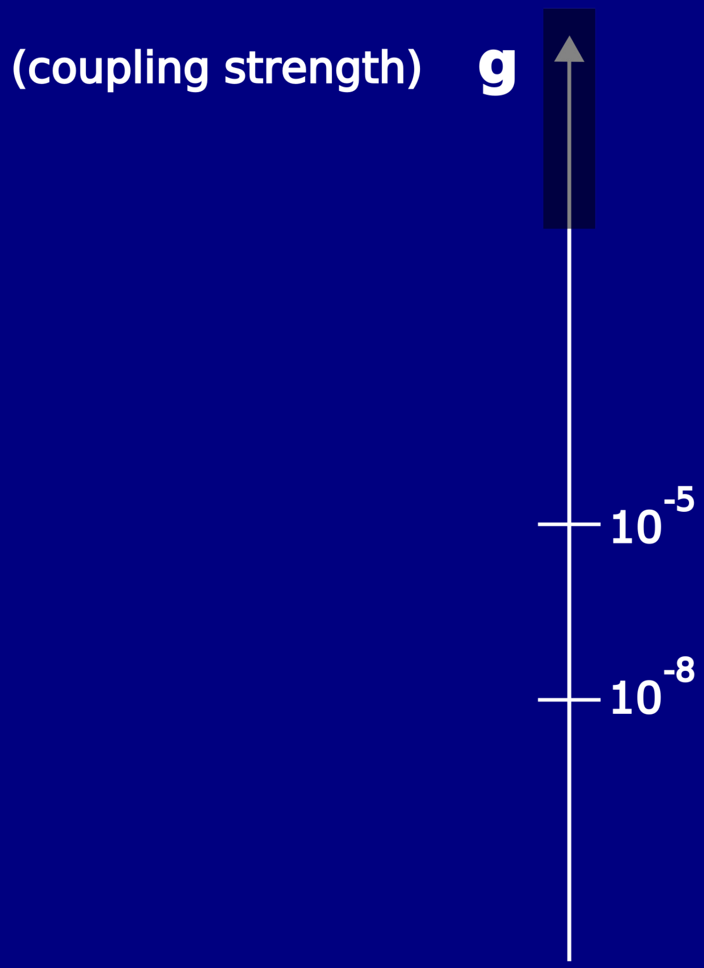
- Strong interactions with a massless pseudoscalar particle. ”Majoron models.”
- Annihilation and bremsstrahlung as representative interactions.







Coupling strengths

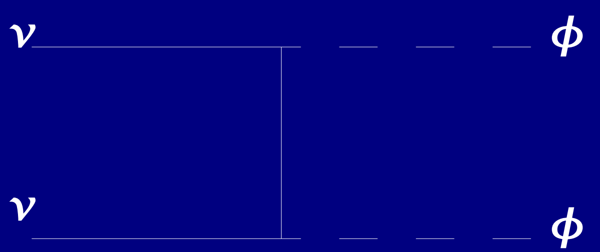


No direct constrains from cosmology; $g \geq 10^{-5}$

Excluded from SN1987A based on neutrino pulse duration.

Neutrino-Majoron interactions

$$\sigma_J(\eta) = \frac{g^4}{128\pi}\frac{1-\eta}{m_{\nu_\tau}^2\eta}\left[\ln\left(\frac{1+\sqrt{\eta}}{1-\sqrt{\eta}}\right) - 2\sqrt{\eta}\right]$$

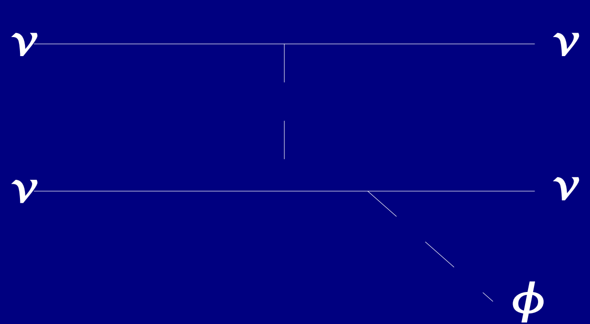


$\eta \equiv 1 - 4m_{\nu_\tau}^2/s$ A. D. Dolgov et al (1997).

g = 10^{-3} leads to r_{dec} = 22.9 km comparable to the CC value of 23.2 km and the NC value of 21.0 km.

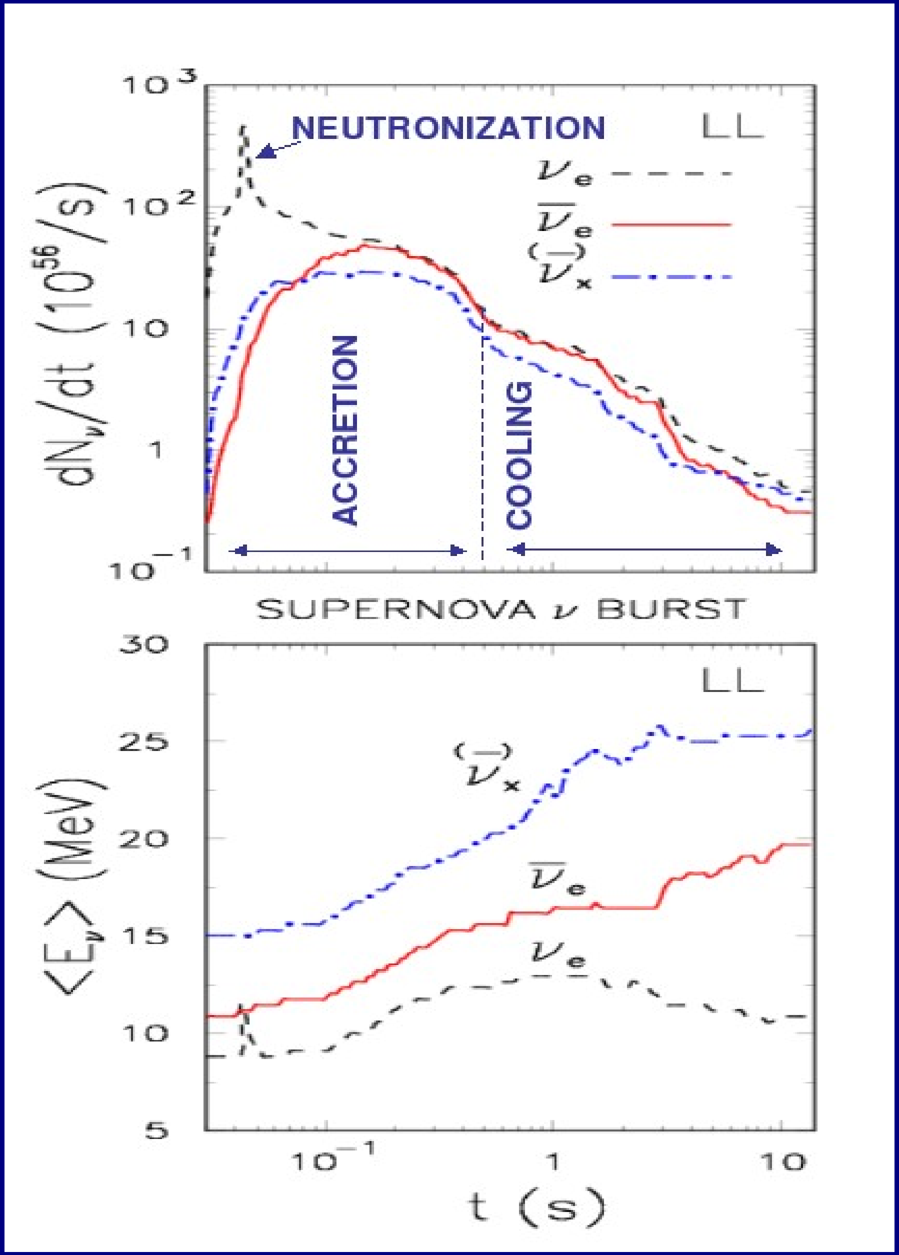
$$\langle\lambda\rangle = \frac{\int \frac{c}{n_\nu\langle\sigma v\rangle} f_\nu\,\omega^2\;d\omega}{\int f_\nu\,\omega^2\;d\omega}$$

$$r^2 = \frac{g^4\,\hbar^2\,R_{NS}}{m_\nu^2/c^2} 5.416\cdot 10^{26} cm^{-1}$$

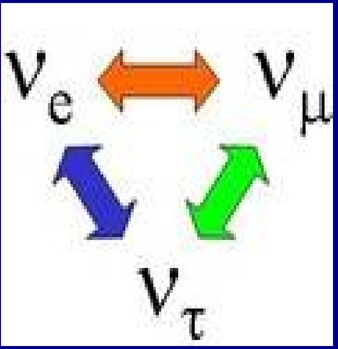


The Bremsstrahlung process has $\sigma \propto g^6$ and with g = 10^{-3} this process can be ignored.

New spectra



- Effectively ”back door” leading to similar spectra for all flavors.
- Transfer of energy to ν_e and thus to the shock.



Conclusion

- Possible to transfer more energy to the shock.
- Next step; is it enough?
- MW SN may give answers.