Two-Stage Supernova Collapse and Double Neutrino Signal from SN1987A

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Neutrino signal from SN1987A

Detector	Working mass	Number of events	
		2:52 UT	7:35 UT
LSD	C_nH_{2n} 90 t Fe 200 t	5	2
KII	H_2O 2140 t	3	12
IMB	H_2O 5000 t	0	8
Baksan	C_nH_{2n} 200 t	1	6

LSD signal:

fluctuation?

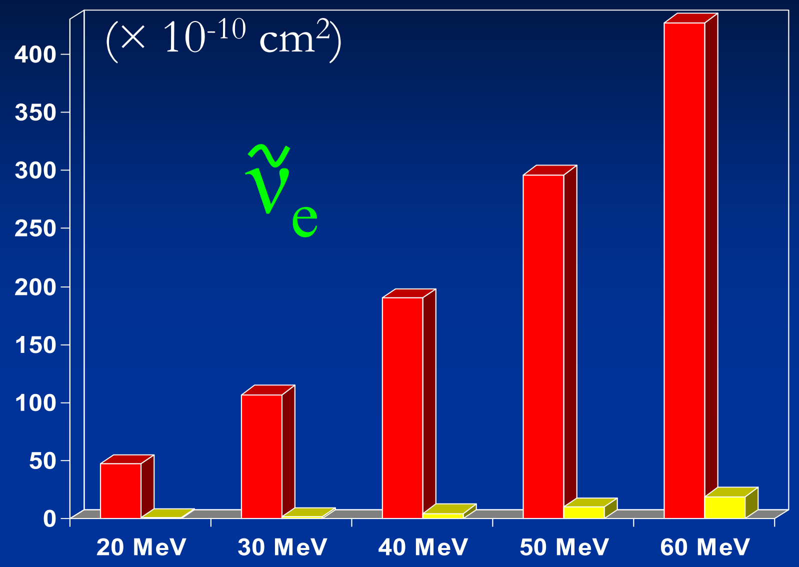
reported probability < 10^{-3}

- ν **from the first stage of 2-stage collapse?**

De Rujula,1987; Dokuchaev et al., 1987; Imshennik & Ryazhskaya, 2004

why other detectors have not seen them?

Kamiokande and LSD sensitivities

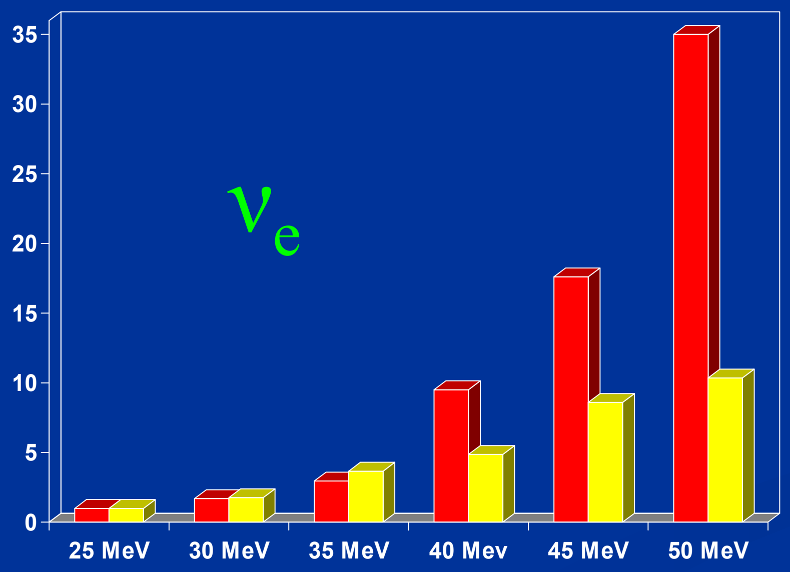


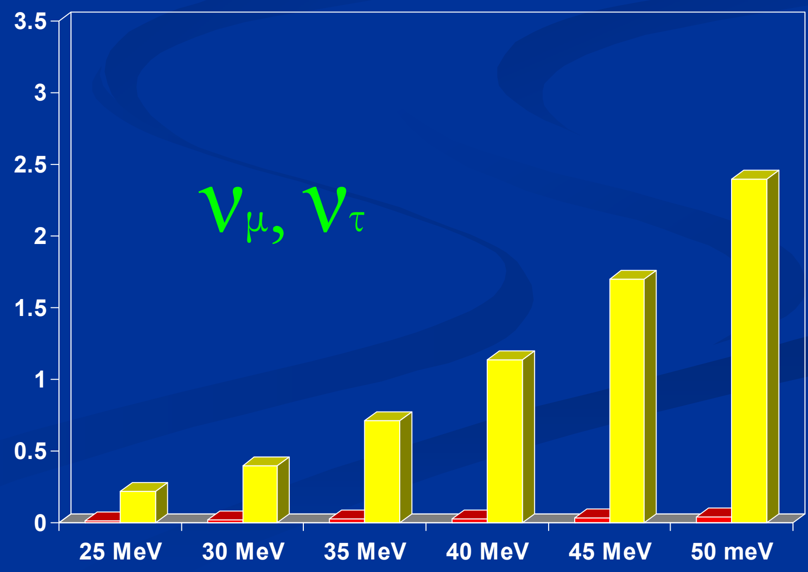
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

$$\nu_e + O \rightarrow e + N^*$$

$$\nu_e + Fe \rightarrow e + Co^*$$

$$\nu_l + Fe \rightarrow \nu_l + Fe^*$$





Question:

what properties should have a two-stage collapse model to explain the double SN1987A neutrino signal?

Constraints to be considered:

$M_{core} < 2.2\, M_{Sun}$ → Total neutrino energy < $\mathbf{10^{54}}$ erg

Flavour conservation in production processes:

$$N(\nu_e) - N(\tilde{\nu}_e) = N(e),\quad N(\nu_\mu) = N(\tilde{\nu}_\mu),\quad N(\nu_\tau) = N(\tilde{\nu}_\tau)$$

Flavour transformation in the matter of the star (MSW)

Results

- Production of non-electron neutrinos in the core should be **suppressed** → **no thermal equilibrium!**
- $\theta_{13}<0.003$ → $\tilde{\nu}_e$ production **suppressed**, **45 MeV < E_ν < 50 MeV**
- $\theta_{13}>0.03$, normal neutrino mass hierarchy

  ↓

  $\tilde{\nu}_e$ production **suppressed**, **E_ν > 60 MeV**
- $\theta_{13}>0.03$, inverted neutrino mass hierarchy

  ↓

  $\tilde{\nu}_e$ production **allowed**, **30 MeV < E_ν < 45 MeV**

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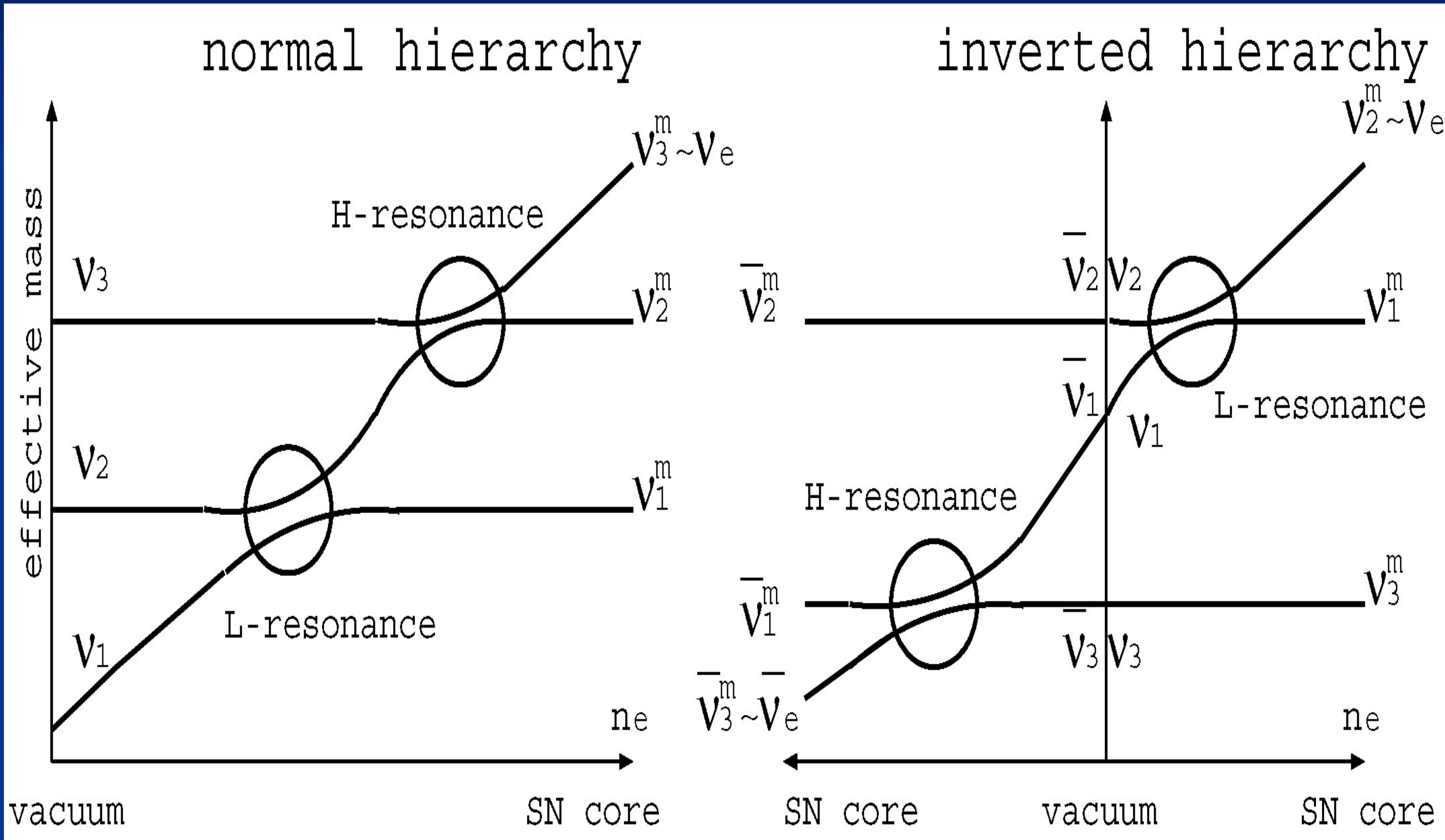
Appendix



normal hierarchy
inverted hierarchy
effective mass
H-resonance
L-resonance
$\nu_3^m \sim \nu_e$
ν_3
ν_2^m
ν_2
ν_1^m
ν_1
ne
vacuum
SN core
$\nu_2^m \sim \nu_e$
$\bar{\nu}_2$ ν_2
$\bar{\nu}_2^m$
ν_1^m
$\bar{\nu}_1$
ν_1
L-resonance
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$\bar{\nu}_3$ ν_3
$\bar{\nu}_3^m \sim \bar{\nu}_e$
ne
SN core
vacuum
SN core

Appendix

$$F_e = pF_e^0 + (1-p)F_x^0$$

$$F_{\bar{e}} = \bar{p}F_{\bar{e}}^0 + (1-\bar{p})F_x^0$$

$$4F_x = (1-p)F_e^0 + (1-\bar{p})F_{\bar{e}}^0 + (2+p+\bar{p})F_x^0$$

$$p \equiv |U_{e2}|^2 P_H + |U_{e3}|^2 (1-P_H) \approx |U_{e2}|^2 P_H$$

$$\bar{p} \equiv |U_{e1}|^2 \overline{P}_H + |U_{e3}|^2 (1-\overline{P}_H) \approx |U_{e1}|^2 \overline{P}_H$$