

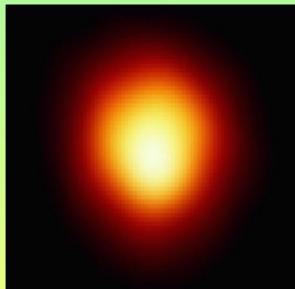
Silicon BURNING NEUTRINOS

Andrzej Odrzywolek

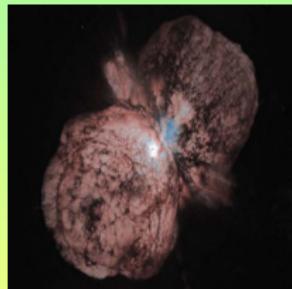
Jagiellonian University Cracov

24 Feb 2007, 16:30

Betelgeuse

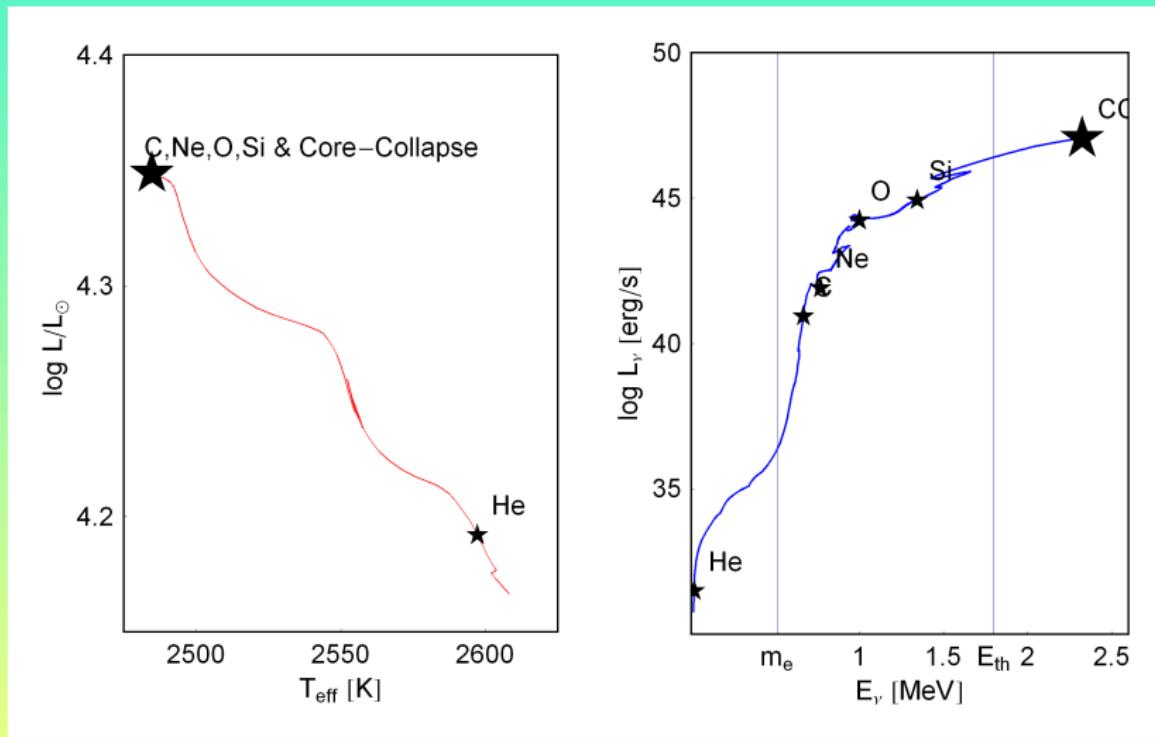


WR 104



Eta Carina

Evolution on the H-R & " $\bar{\nu}_e$ H-R" diagrams



Failure of the "electromagnetic" astronomy

- After ignition of the C burning star¹ do not move on H-R
- Traditional astronomy unable to detect last stages
- Rapid central evolution
- Neutrinos dominate emission
- Neutrinos leave center of a star immediately

¹All numeric values refer to s15 ($15 M_{\odot}$) pre-supernova model provided generously by **Alexander Heger** (LANL).

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What about prospects to detect these neutrinos?

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Can we detect these neutrinos?

- 2 days BC total L_ν is 1.3×10^{45} erg/s = $1.7 \times 10^{12} L_\odot^{(\nu)}$.
- Observable ν flux on Earth is dominated by the pre-supernova up to the distance of $\sqrt{L_\nu/L_\odot^{(\nu)}}$ AU=20 pc.
- Betelgeuse (β Orionis) is at distance 130 ± 30 parsecs.
- No way to see pre-supernova?

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Caution!

Comparison of the solar and pre-supernova neutrinos is illustrative but dangerous: they are *completely* different!

Some vital information

- Most of these neutrinos come from $e^+ + e^- \rightarrow \nu_x + \bar{\nu}_x$
- Mixture of $\nu_e, \bar{\nu}_e, \nu_\mu, \bar{\nu}_\mu, \nu_\tau, \bar{\nu}_\tau$ is produced.
- Central zone at Si ignition: $kT = 0.32$ MeV, $\mu = 1.33$ MeV

Electron antineutrino ($\bar{\nu}_e$) fraction

Average neutrino energy from $e^+ e^-$ annihilation

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Electron antineutrino ($\bar{\nu}_e$) fraction

$$\frac{F_{\bar{\nu}_e}}{F_{total}} \simeq \left[2 + 4 \left(C_V^{e2} + C_A^{e2} \right) / \left(C_V^{\mu,\tau 2} + C_A^{\mu,\tau 2} \right) \right]^{-1} = 0.35$$

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Average neutrino energy from e^+e^- annihilation

$$\frac{2}{5}\mu + 2kT + m_e/2 = 1.43 \text{ MeV (degenerate electrons)}$$

$$4.106 kT = 1.3 \text{ MeV (relativistic electrons)}$$

$$m_e + \frac{3}{2} kT = 0.99 \text{ MeV (non-rel., non-deg. electrons)}$$

Some vital information

- ① Strong source of the $\bar{\nu}_e$'s with $\langle \mathcal{E}_{\bar{\nu}_e} \rangle \sim 1.5$ MeV !
- ② Reines-Cowan detection technique should work
- ③ Pre-supernova overlap reactor and geoneutrinos

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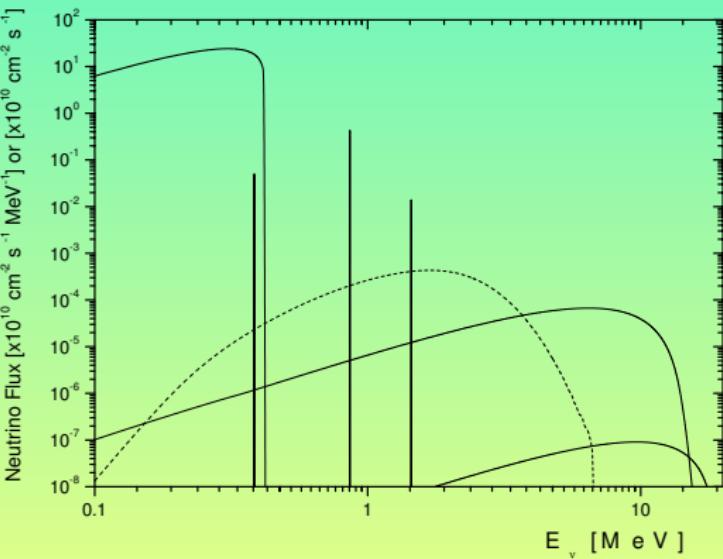
Old "one-zone" model

Si burning star $\bar{\nu}_e$ @ 1 kpc *versus* solar neutrinos @ 1 AU

For inv. β reaction:



~ 1 event/1 kt H₂O/day.



Main flaws in "one-zone" model

- ➊ Internal structure of a star neglected
- ➋ $L_{\bar{\nu}_e}$ assumed to be constant during Si burning
- ➌ Monte Carlo inefficient, produces wrong tail with large errors
- ➍ Remaining thermal (plasmon decay, photoproduction) neutrinos not included
- ➎ Weak nuclear neutrinos (β decays/captures) neglected

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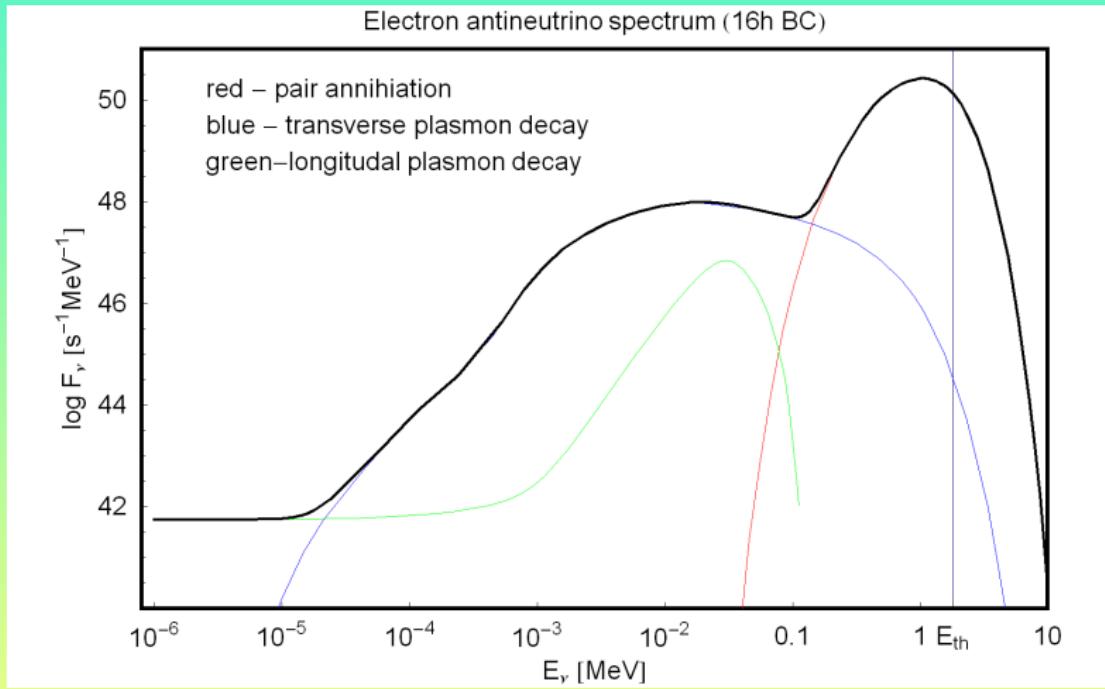
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Four of these issues are now fully resolved.

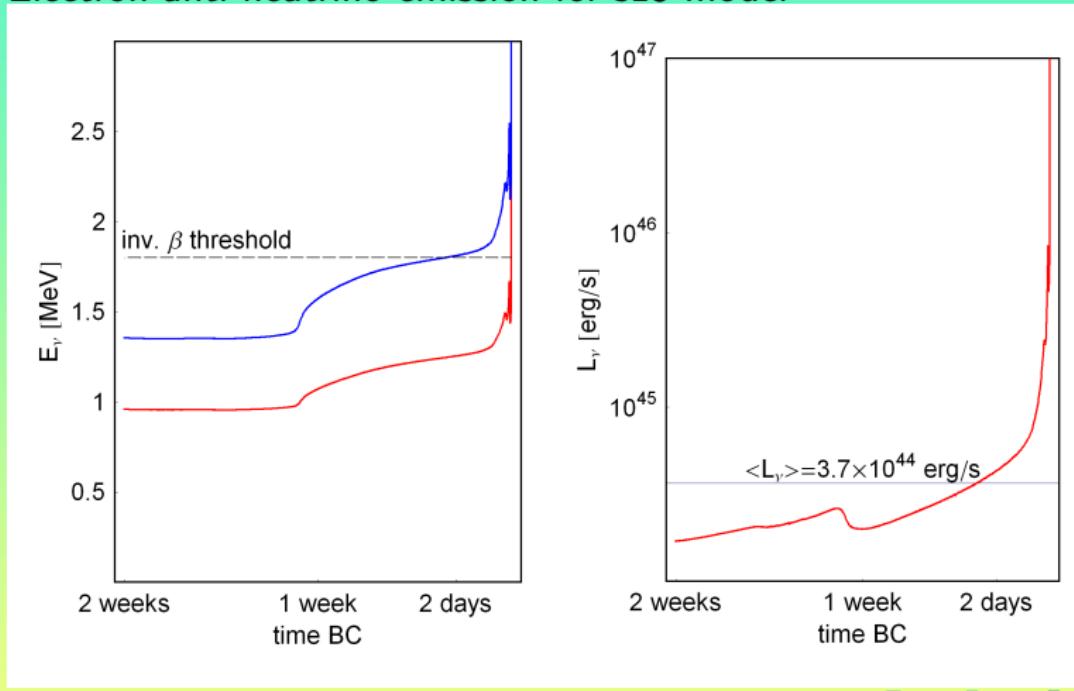
Combined thermal neutrino spectrum from center



Mean $\bar{\nu}_e$ energy and $Q_{\bar{\nu}_e}$ profiles

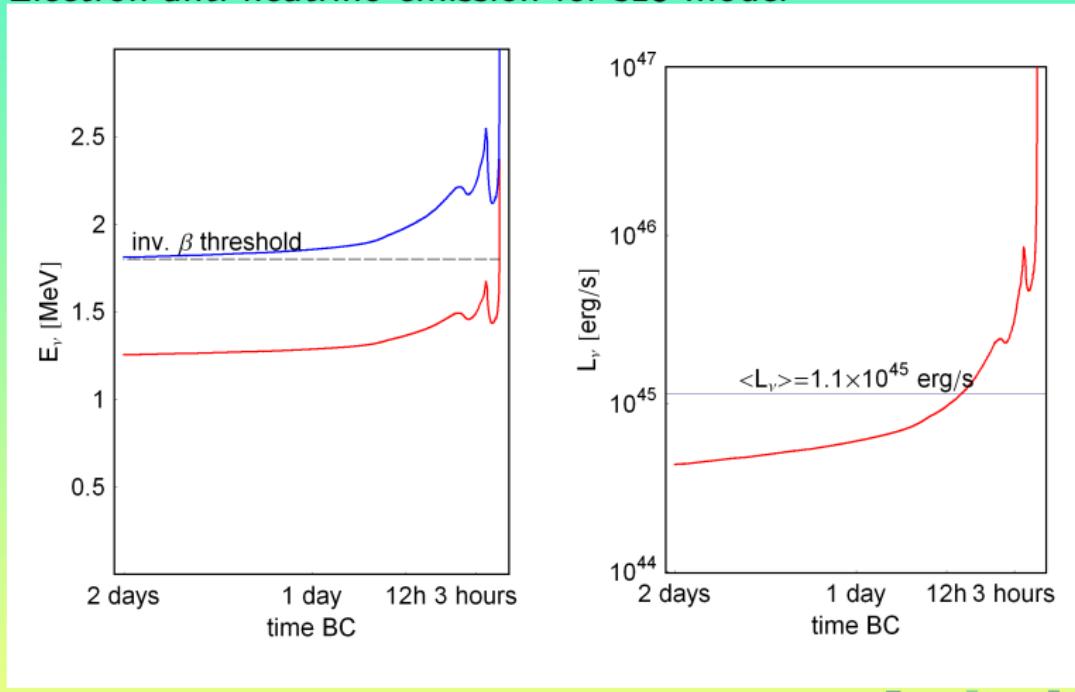
Neutrino emission *versus* time

Electron anti-neutrino emission for s15 model



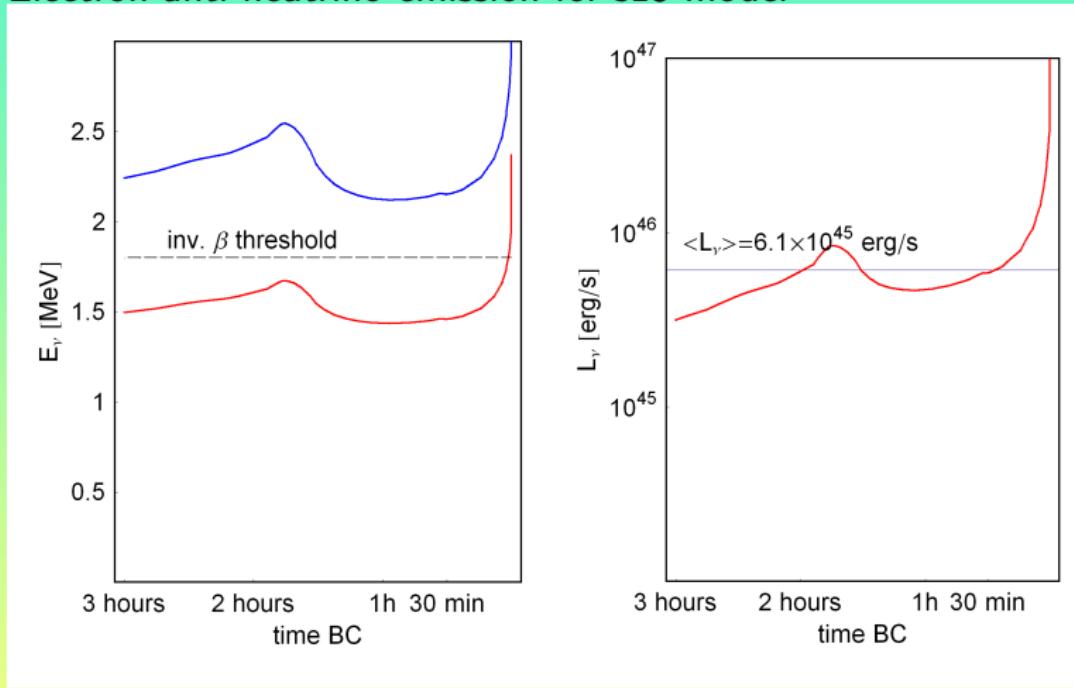
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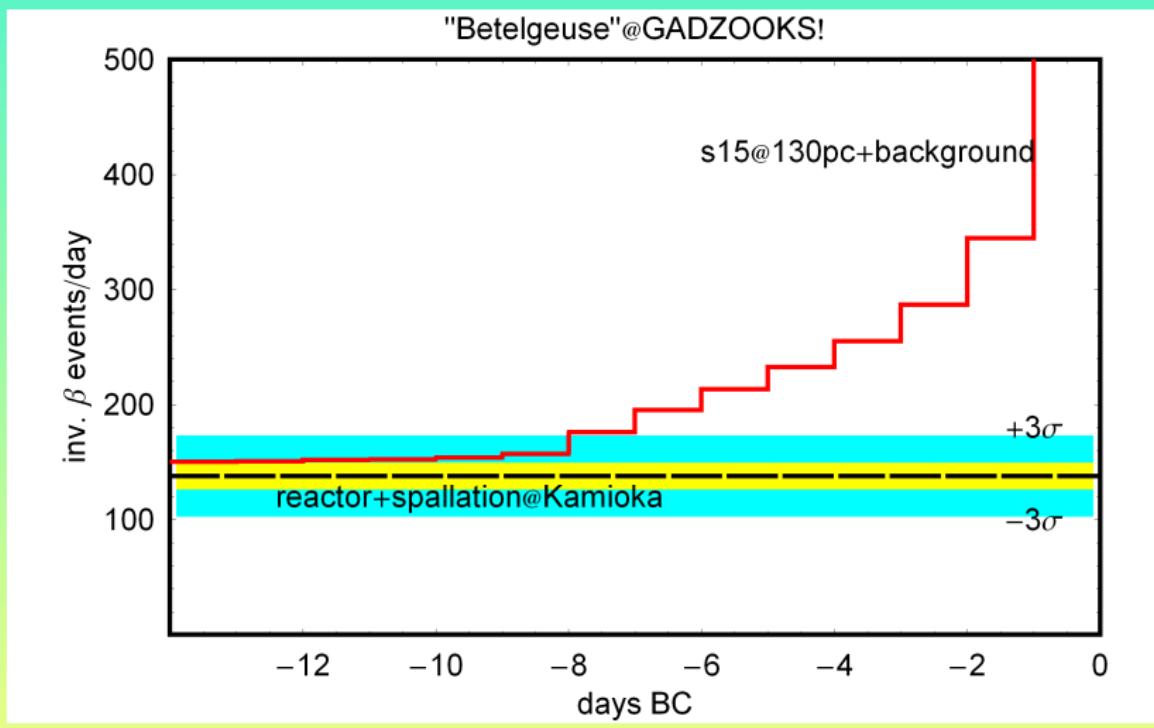


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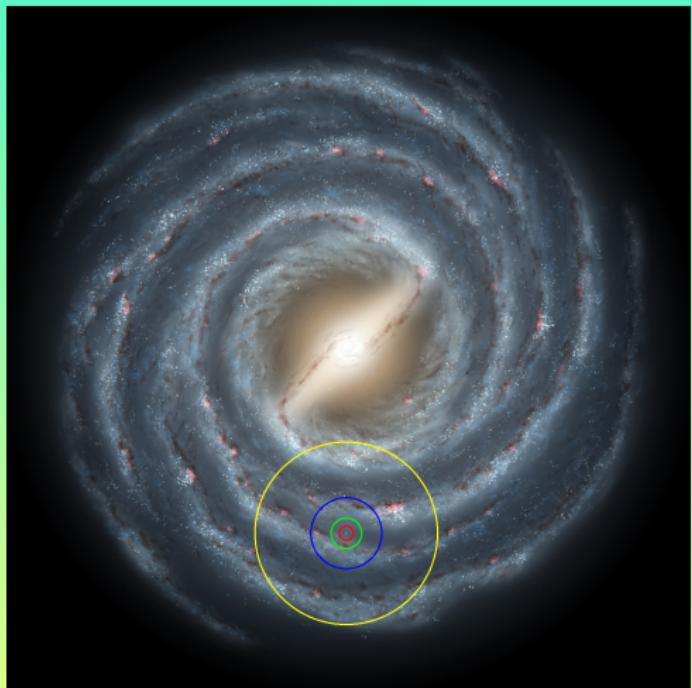
Betelgeuse in GADZOOKS!



Expected signal from Betelgeuse (inv. β events)

Detector	Target mass (H ₂ O+GdCl ₃ or LS)	2 week avg. [day ⁻¹]	2 day avg. [day ⁻¹]
Gadzooks!(SK)	22.5 kt H ₂ O+GdCl ₃	200	1000
Borexino	0.3 kt LS	3	13
Kamland	1 kt LS	9	45
SNO+	0.7 kt LS	6	30
Hanohano	10 kt LS	90	450
HyperK/UNO/ Memphys	0.5 Mt H ₂ O+GdCl ₃	5×10^3	3×10^4
LENA	45 kt LS	400	2×10^3
Deep underwa- ter balloon	10 Mt H ₂ O+KCl	10^5	5×10^5

Range for pre-supernova warning ($15 M_\odot$ model)



Data taken during:

- 48-24 hours BC
- 6-3 hours BC

Red - GADZOOKS!

300 pc

Green - HK/UNO/Memphys

650 pc

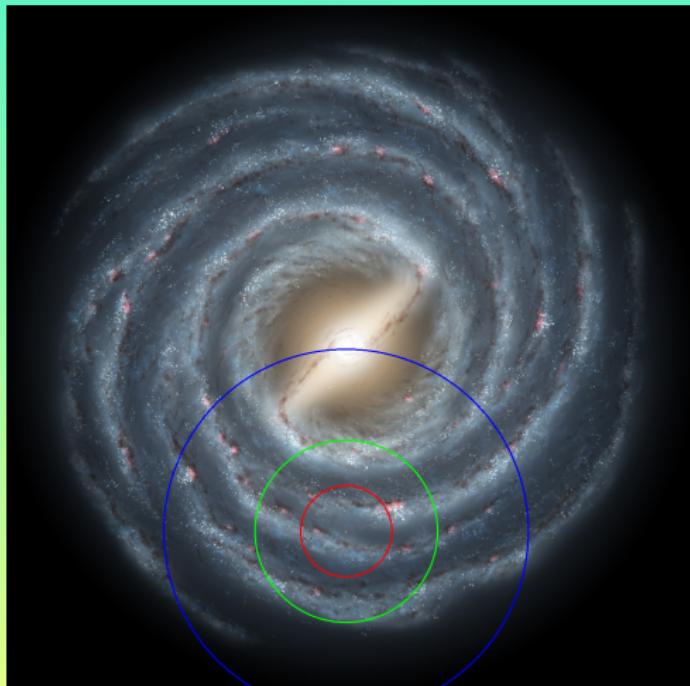
Blue - 10Mt balloon

1.5 kpc

Yellow - Gigaton Array

4 kpc

Range for pre-supernova warning ($15 M_\odot$ model)



Data taken during:

- 48-24 hours BC
- 6-3 hours BC

Red - GADZOOKS!

2 kpc

Green - HK/UNO/Memphys

4 kpc

Blue - 10Mt balloon

8 kpc

Yellow - Gigaton Array

25 kpc

Future directions

PSNS code

- **DONE:** batch processing of stellar models using PC Linux clusters with state-of-art pair and Braaten/Segel plasma neutrino spectra saved to CERN ROOT trees.
- **TODO:** weak nuclear neutrino spectra !
- Coming soon: <http://th-www.if.uj.edu.pl/psns/>

Pre-supernova study

- Processing various $10\text{-}100 M_{\odot}$ stellar models
- Integrating neutrino signal with Galaxy model & IMF

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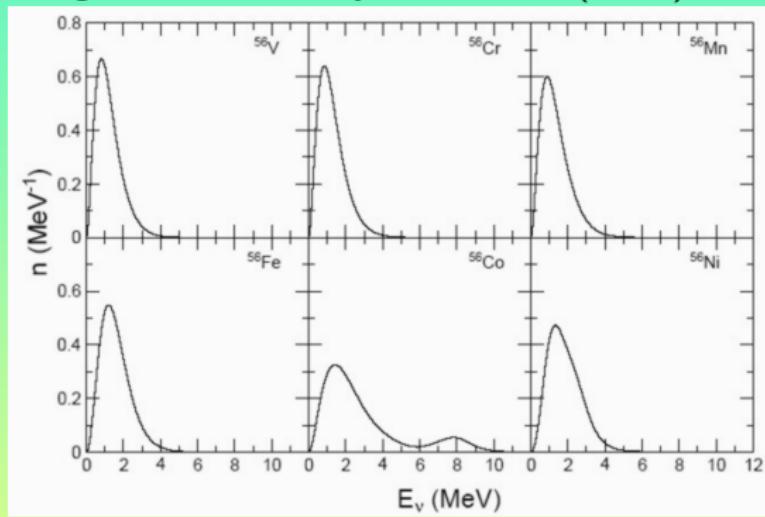
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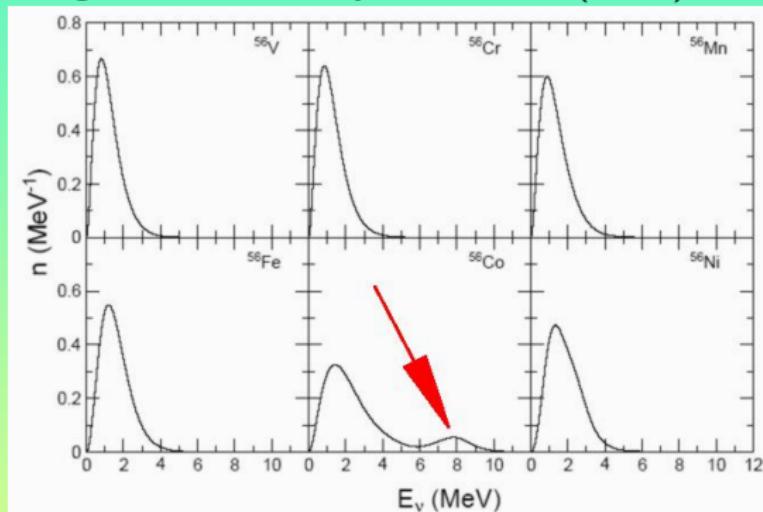
Weak nuclear neutrino spectrum

Langanke et. al. Phys.Rev. C64 (2001) 055801



Weak nuclear neutrino spectrum

Langanke et. al. Phys.Rev. C64 (2001) 055801



High energy β^\pm neutrinos from presupernova?

Acknowledgements

Work done with **M. Misiaszek & M. Kutschera**

- **A. Heger** provided us with $15 M_\odot$ pre-supernova model
- LOC: **J. G. Learned, M. Vagins, M. Nakahata**
- **Y. Totsuka** referee of our first article on subject
- **M. Wojcik, K. Grotowski**

Some notable references

Antineutrino detection:

- J. F. Beacom and M. R. Vagins, Phys. Rev. Lett. 93, 171101 (2004)
J. G. Learned, White paper on Gigaton Array

Thermal neutrinos:

- E. Braaten and D. Segel, Phys. Rev. D 48, 1478 - 1491 (1993)
S. Ratkovic, S. Dutta & M. Prakash, Phys. Rev. D 67, 123002 (2003)
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Itoh et. al. series
M. Misiaszek et. al., Phys. Rev. D74, 043006 (2006)

Pre-supernova stars:

- S. E. Woosley, A. Heger, T. A. Weaver, RMP 74, 1015 - 1071 (2002)
R. Hirschi, G. Meynet, A&A 425, 649-670 (2004)

Other information

- ffdshow is required for movie playback inside Adobe Reader under Windows XP