Presupernova neutrinos at SNEWS2.0 : theory overview

Cecilia Lunardini

Arizona State University

Disclaimer*:*
partial coverage based on my (limited and possibly outdated) knowledge and experiences.
Apologies for omissions!

Contents

- Status of pre-SN neutrinos theory:
  - flux predictions & detectability
- Directions for future work:
  - flux predictions & detectability
  - interdisciplinary/multimessenger connections

STATUS

Pre-SN neutrinos: *before* the burst

- Neutrinos from advanced stages of nuclear burning
  - Thermal (pair production)
  - Beta processes (capture, decay)

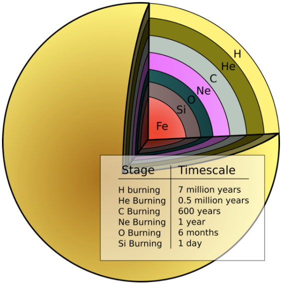


fig: Phillips, The Physics of Stars, (Wiley, 1999)

Odrzywolek, Misiaszek, and Kutschera, Astropart. Phys. 21, 303 (2004)
Itoh, Hayashi, Nishikawa and Kohyama, 1996, ApJS, 102, 411
Kato, Azari, Yamada, et al. 2015, ApJ, 808, 168
Kato, Yamada, Nagakura, et al. 2017, arXiv:1704.05480

- 0.1-5 MeV energy → Need low energy threshold
- Detectable hours (days?) before the neutrino burst
  - For near-earth stars ($D < 1$ kpc)

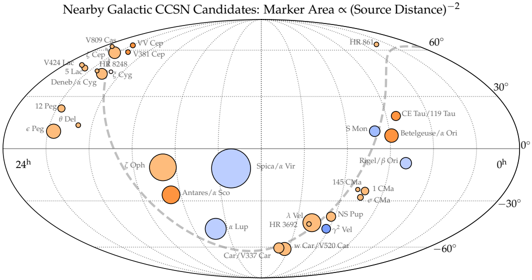


fig: Al Kharusi et al., New J. Phys. 23 031201 (2021); adapted from Mukhopadhyay, CL and Timmes, ApJ 899 (2020) 2, 153)

Numerical flux predictions

- Built on pre-existing stellar evolution codes
- bulk contribution from thermal processes (pair production)
- contribution of β processes (nulear decay, $e^{\pm}$ capture) important at late times and high energy

Odrzywolek and Heger, Acta Phys.Polon.B 41 (2010) 1611-1628 (thermal ν only)
Kato, Yamada, Nagakura, et al. Ap.J. 848 (2017) 1, 48
Patton, Lunardini, Farmer and Timmes, ApJ 851 (2017) no.1, 6; ApJ. 840 (2017) no.1
Yoshida, Takiwaki, Kotake, et al. Ap.J. 881 (2019) 1, 16 (thermal ν only)
Guo, Qian and Heger, Phys. Lett. B 796, 126 (2019)

New (?): Yusof, Kassim, Garba, Ahmad, MNRAS 503, 4, pp.5965, 2021. ($M \gtrsim 100 M_\odot$)

time structure reflects stages of evolution (e.g., start of O burning, Si burning)

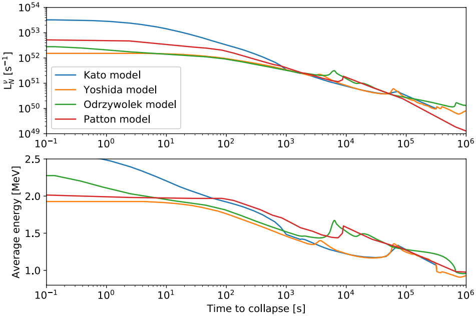
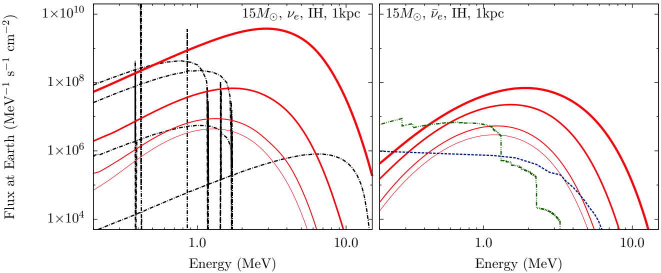


fig: Kato, Ishidoshiro and Yoshida, Ann.Rev.Nucl.Part.Sci. 70 (2020) 121-145

Energy spectra critical for detection



solid: pre-SN fluxes at advancing times; others: competing neutrino fluxes (solar, atmospheric, reactor, etc.);

fig. from Patton, CL, Farmer and Timmes, Astrophys.J. 851 (2017) 1, 6

DIRECTIONS FOR FUTURE WORK

Improving flux predictions: microphysics

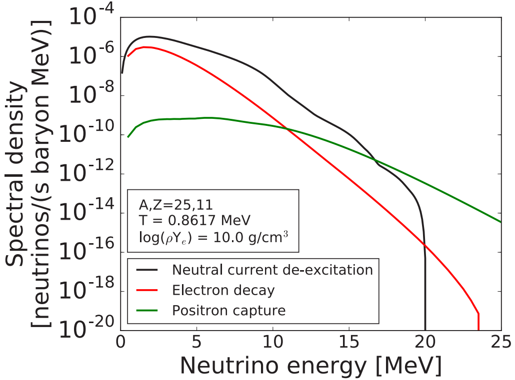
- include subdominant (?) processes
  - neutral current de-excitation?
  - electron-nucleus bremsstrahlung

Misch, Sun, Fuller, EPJ Web of Conf. 178, 04005 (2018); Guo & Qian, PRD 94, 043005 (2016)

- improve rates and cross sections
- urgent for β processes:
  - tabulated nuclear rates need major modernization (replace single Q-value rates with fully accounted excited states)
  - expand nuclear network to include neutrino-relevant nuclei that may be negligible for energy generation

Misch, Sun & Fuller, ApJ 852, 43 2018; https://archive.jinaweb.org/html/mischnuspectra.html

Effect of neutral-current de-excitation, for ^{25}Na

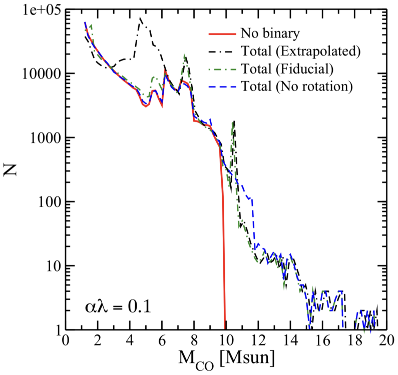


Misch, Sun, Fuller, EPJ Web of Conferences 178, 04005 (2018)

Improving flux predictions: progenitors and their evolution

- simulate for wider range of progenitor parameters (mass, metallicity, etc.)
- run stellar evolution with environmental effects (mass exchange with binary companion, etc.).
- research nearby stars: how are the above relevant to them?

Binary interaction results in larger CO cores



Horiuchi et al., arXiv:2012.08524

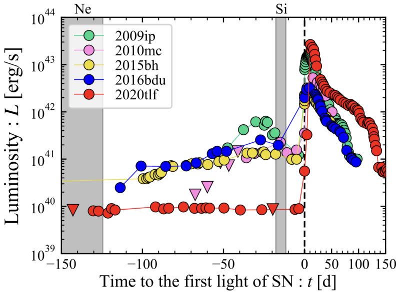
Improving flux predictions: produce dedicated codes

- most codes (e.g., MESA) were designed for stellar evolution, not neutrino flux prediction
- wish list:
  - fully embed neutrino spectra calculations
  - make codes public and user-friendly, make detailed comparisons.

Interdisciplinary connections

Astronomy: EM precursor due to stellar eruptions, winds, common envelope with a companion, etc.

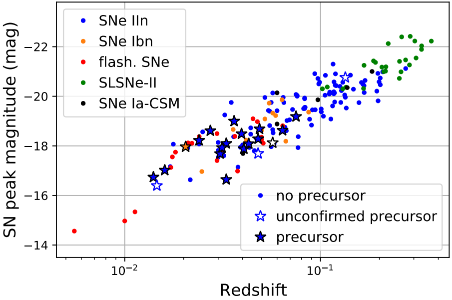
- possible common origin with neutrinos: Si-burning
- ν emission causing mass loss (Moriya, A&A, 564, id.A83, 5 pp. (2014))



Strotjohann et al., ApJ 907 99 (2021)

fig. from Matusumoto and Metzger, arXiv:2206.08377

- rare occurrence?



" [....] 12 precursors per year are bright enough to allow the prediction of an imminent SN explosion. "

Strotjohann et al., ApJ 907 99 (2021)

Conclusions

- pre-SN neutrino predictions have reached a mature stage
- more realistic time profile and energy spectra are desirable
  - will need improve nuclear physics and improved stellar evolution
- Interesting connections with astronomy remain to be explored
- *workforce is needed!*