Supernova Neutrino Light Curves from Proto-Neutron Star Cooling with Various Nuclear Equation of State

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We present a series of numerical data for the supernova neutrinos obtained by simulations of proto-neutron star (PNS) cooling with use of various nuclear equation of state (EOS) models. For this purpose, quasi-static evolution of PNS cooling are computed and time variability of the neutrino spectra is provided. Eight PNS cooling models with different initial conditions are involved for each EOS. The details of these models are described in our paper [1]. These data are open for use in any scientific research, provided that our paper is referenced in your publication.

The data files are named `spectobXXXYZZ.data` with

- `XXX` corresponds to the baryon mass of PNS, M_b
- `Y` represents the EOS: `Y` = `S` (Shen), `L` (LS220), `T` (Togashi), and `U` (T+S)
- `ZZ` is a zero-age main sequence mass of the progenitor, $M_{\rm ZAMS}$

For instance, `spectob140S15.data` is a data for the model with $M_b = 1.40 M_\odot$, $M_{\rm ZAMS} = 15 M_\odot$, and the Shen EOS. The available models are listed in Table 1.

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† `nuLC` stands for *neutrino-light curve*, which is neutrino analogue of the light curves of supernovae. The `nuLC` collaboration began in 2017 aiming to build a methodology to derive supernova and neutron star physics out of supernova neutrinos. Through the combined efforts of theoretical and experimental researchers, the collaboration is constructing a real data analysis framework for supernova neutrinos that will be observed in the near future.

The format of the spectral data is the same with that of Supernova Neutrino Database [2] and spectral data for high/low-mass PNS models in our previous study [3]. Note that the number of energy bin is 25 in the present data although it was 20 in the Supernova Neutrino Database [2]. The data are arranged as follows:

$$t_0$$

$$E_0 \quad E_1 \quad \frac{\Delta N_{1,\nu_e}(t_0)}{\Delta E_1} \quad \frac{\Delta N_{1,\bar{\nu}_e}(t_0)}{\Delta E_1} \quad \frac{\Delta N_{1,\nu_x}(t_0)}{\Delta E_1} \quad \frac{\Delta L_{1,\nu_e}(t_0)}{\Delta E_1} \quad \frac{\Delta L_{1,\bar{\nu}_e}(t_0)}{\Delta E_1} \quad \frac{\Delta L_{1,\nu_x}(t_0)}{\Delta E_1}$$

$$E_1 \quad E_2 \quad \frac{\Delta N_{2,\nu_e}(t_0)}{\Delta E_2} \quad \frac{\Delta N_{2,\bar{\nu}_e}(t_0)}{\Delta E_2} \quad \frac{\Delta N_{2,\nu_x}(t_0)}{\Delta E_2} \quad \frac{\Delta L_{2,\nu_e}(t_0)}{\Delta E_2} \quad \frac{\Delta L_{2,\bar{\nu}_e}(t_0)}{\Delta E_2} \quad \frac{\Delta L_{2,\nu_x}(t_0)}{\Delta E_2}$$

$$\cdots$$

$$E_{24} \quad E_{25} \quad \frac{\Delta N_{25,\nu_e}(t_0)}{\Delta E_{25}} \quad \frac{\Delta N_{25,\bar{\nu}_e}(t_0)}{\Delta E_{25}} \quad \frac{\Delta N_{25,\nu_x}(t_0)}{\Delta E_{25}} \quad \frac{\Delta L_{25,\nu_e}(t_0)}{\Delta E_{25}} \quad \frac{\Delta L_{25,\bar{\nu}_e}(t_0)}{\Delta E_{25}} \quad \frac{\Delta L_{25,\nu_x}(t_0)}{\Delta E_{25}}$$

$$t_1$$

$$E_0 \quad E_1 \quad \frac{\Delta N_{1,\nu_e}(t_1)}{\Delta E_1} \quad \frac{\Delta N_{1,\bar{\nu}_e}(t_1)}{\Delta E_1} \quad \frac{\Delta N_{1,\nu_x}(t_1)}{\Delta E_1} \quad \frac{\Delta L_{1,\nu_e}(t_1)}{\Delta E_1} \quad \frac{\Delta L_{1,\bar{\nu}_e}(t_1)}{\Delta E_1} \quad \frac{\Delta L_{1,\nu_x}(t_1)}{\Delta E_1}$$

$$\cdots$$

where t_n [s] is a time measured from the bounce. Incidentally, the definition of the time origin in the present data set is different from that in Ref. [3], where the time is measured from the onset of the computation. E_k [MeV] is a neutrino energy, which is defined on the interface between k-th and $(k+1)$-th energy bins while $E_0 = 0$ MeV. For k-th energy bin, $\frac{\Delta N_{k,\nu_i}(t_n)}{\Delta E_k}$ [/s/MeV] and $\frac{\Delta L_{k,\nu_i}(t_n)}{\Delta E_k}$ [erg/s/MeV] are differential neutrino number flux and differential neutrino luminosity, respectively, where $\nu_x = (\nu_\mu + \bar{\nu}_\mu + \nu_\tau + \bar{\nu}_\tau)/4$. Thus, the luminosity of $\bar{\nu}_e$ [erg/s] is given by

$$L_{\bar{\nu}_e}(t_n) = \sum_{k=1}^{25} (E_k - E_{k-1}) \times \frac{\Delta L_{k,\bar{\nu}_e}(t_n)}{\Delta E_k}, \tag{1}$$

and the number luminosity of $\bar{\nu}_e$ [/s] is given by

$$N_{\bar{\nu}_e}(t_n) = \sum_{k=1}^{25} (E_k - E_{k-1}) \times \frac{\Delta N_{k,\bar{\nu}_e}(t_n)}{\Delta E_k}. \tag{2}$$

Therefore the mean energy of emitted $\bar{\nu}_e$ at the time t_n is given by

$$\langle E_{\bar{\nu}_e}(t_n) \rangle = \frac{L_{\bar{\nu}_e}(t_n)}{N_{\bar{\nu}_e}(t_n)} \times \frac{\mathrm{MeV}}{1.6022 \times 10^{-6}\ \mathrm{erg}}. \tag{3}$$

If you find some strange problem, please contact us. We would appreciate it very much if you could give us comments or suggestions on our data. The correspondence address is

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Table 1: List of neutrino-light curve models.

File name	M_b ($M_\odot$)	EOS	$M_{\rm ZAMS}$ ($M_\odot$)	$t_{\rm init}$ (s)	$M_{\rm NS,g}$ ($M_\odot$)	$R_{\rm NS}$ (km)
`spectob140S15.data`	1.40	Shen	15	0.110	1.289	14.33
`spectob147S15.data`	1.47	Shen	15	0.300	1.348	14.31
`spectob154S15.data`	1.54	Shen	15	0.602	1.407	14.28
`spectob162S15.data`	1.62	Shen	15	1.012	1.473	14.24
`spectob162S40.data`	1.62	Shen	40	0.092	1.473	14.24
`spectob170S40.data`	1.70	Shen	40	0.145	1.539	14.20
`spectob178S40.data`	1.78	Shen	40	0.206	1.604	14.14
`spectob186S40.data`	1.86	Shen	40	0.274	1.668	14.08
`spectob140L15.data`	1.40	LS220	15	0.133	1.277	12.73
`spectob147L15.data`	1.47	LS220	15	0.325	1.335	12.70
`spectob154L15.data`	1.54	LS220	15	0.642	1.392	12.66
`spectob162L15.data`	1.62	LS220	15	1.061	1.457	12.62
`spectob162L40.data`	1.62	LS220	40	0.110	1.457	12.62
`spectob170L40.data`	1.70	LS220	40	0.166	1.521	12.56
`spectob178L40.data`	1.78	LS220	40	0.230	1.584	12.49
`spectob186L40.data`	1.86	LS220	40	0.299	1.647	12.40
`spectob140T15.data`	1.40	Togashi	15	0.105	1.266	11.54
`spectob147T15.data`	1.47	Togashi	15	0.300	1.323	11.55
`spectob154T15.data`	1.54	Togashi	15	0.605	1.379	11.55
`spectob162T15.data`	1.62	Togashi	15	0.974	1.443	11.55
`spectob162T40.data`	1.62	Togashi	40	0.061	1.443	11.55
`spectob170T40.data`	1.70	Togashi	40	0.103	1.505	11.54
`spectob178T40.data`	1.78	Togashi	40	0.146	1.567	11.53
`spectob186T40.data`	1.86	Togashi	40	0.214	1.628	11.51
`spectob140U15.data`	1.40	T+S	15	0.105	1.266	11.45
`spectob147U15.data`	1.47	T+S	15	0.300	1.323	11.46
`spectob154U15.data`	1.54	T+S	15	0.605	1.379	11.47
`spectob162U15.data`	1.62	T+S	15	0.974	1.442	11.47
`spectob162U40.data`	1.62	T+S	40	0.061	1.442	11.47
`spectob170U40.data`	1.70	T+S	40	0.103	1.505	11.47
`spectob178U40.data`	1.78	T+S	40	0.146	1.567	11.46
`spectob186U40.data`	1.86	T+S	40	0.214	1.628	11.44

$t_{\rm init}$ is the initial time of the PNS cooling simulation, which is measured from the core bounce. $M_{\rm NS,g}$ and $R_{\rm NS}$ are the gravitational mass and radius of the neutron star born in the supernova explosion, respectively.