Supernova Neutrino in a Strangeon Star Model

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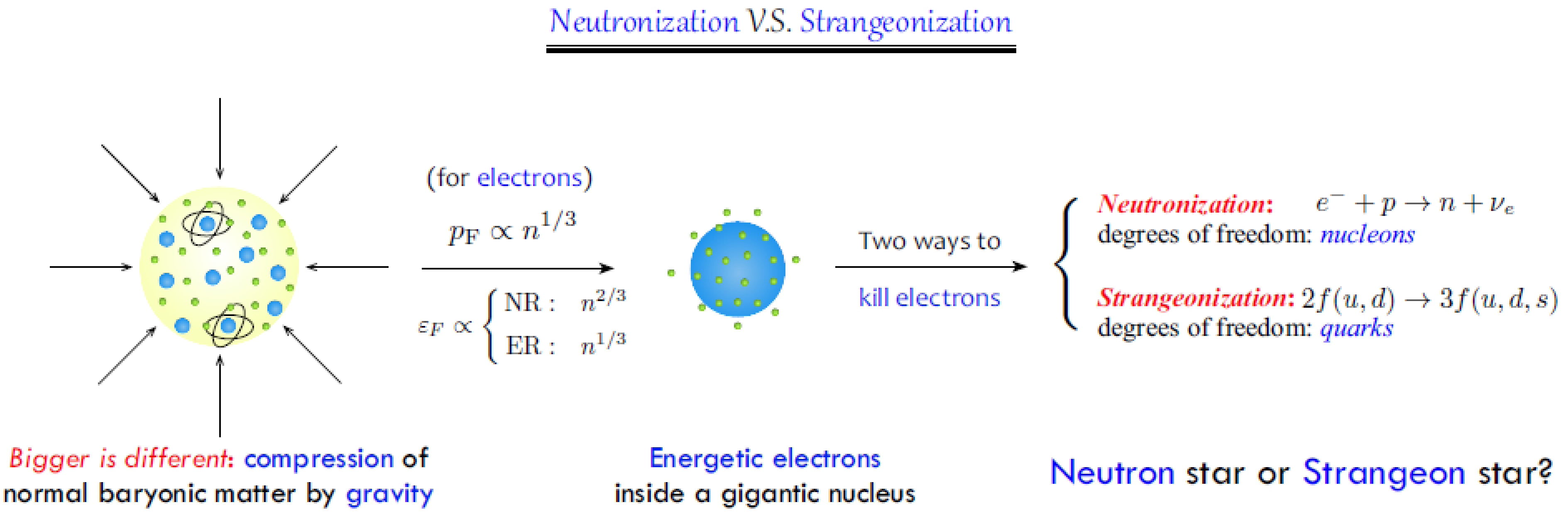
Outline

1 Strangeon star



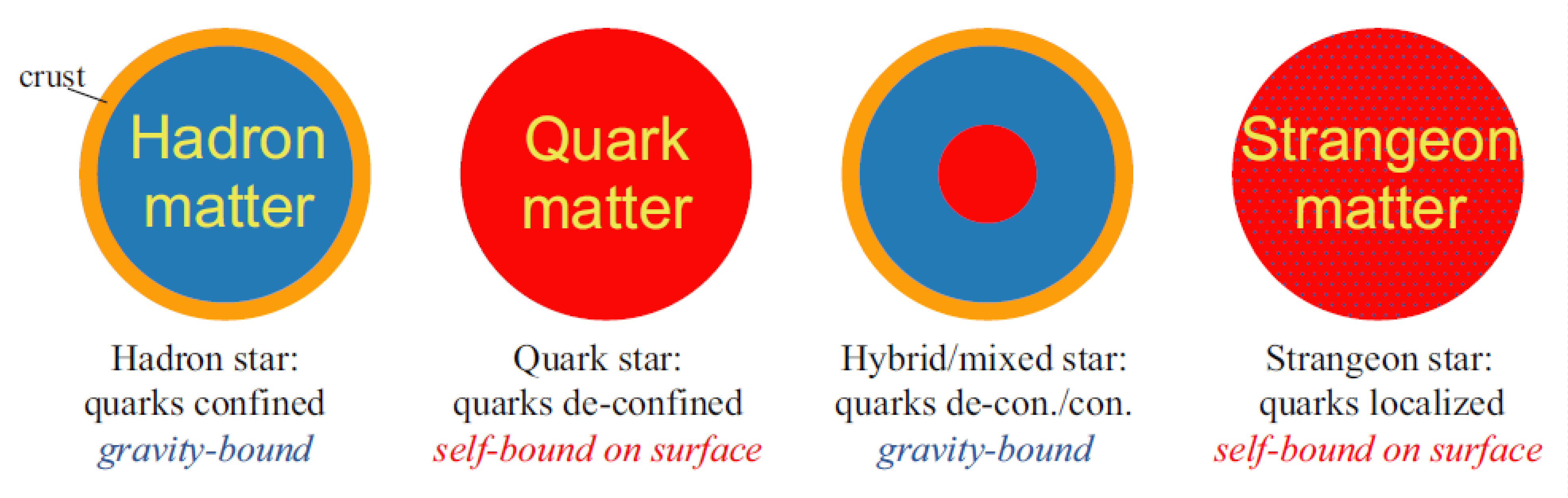
（R. X. Xu et al. ,2017）

strange nucleon

↓

strangeon

1 Strangeon star



传统意义上
的中子星

三味轻夸克对称
的奇异星

- Three-light-flavor symmetry
- Self-bound
- Solid

2.1 Internal energy

$$\boldsymbol{U} = (\boldsymbol{U}_{\boldsymbol{\pi}} + \boldsymbol{U}_{\boldsymbol{s}} + U_e + U_{\gamma+v})$$

- gravitational binding energy of a collapsed core： $E_G \sim 1.5 \times 10^{53} (\frac{M}{M_\odot})$ erg $= U$
- $n_e \sim 10^{-5} n_s$， $U_e \ll U_s$；
- $U_{\gamma+v} \sim 10^{49}erg\ll 10^{53}$erg.

$$\boldsymbol{U} = \boldsymbol{U}_{\boldsymbol{\pi}} + \boldsymbol{U}_{\boldsymbol{s}}$$

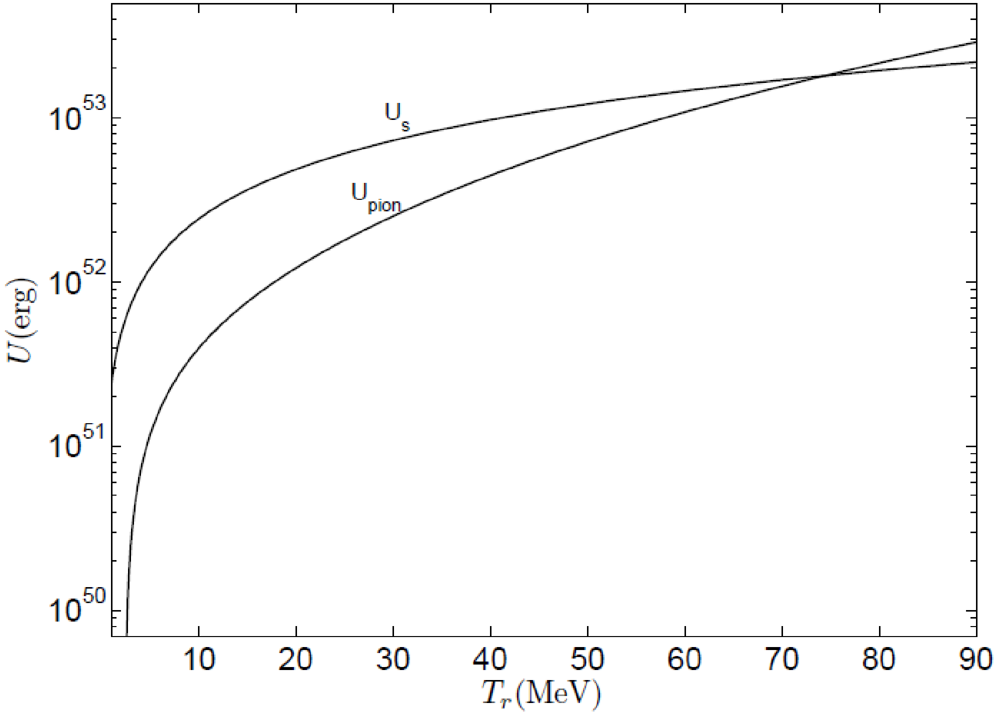
Two cases:
Isothermal： constant temperature T_r；
Non-isothermal： temperature gradient T_s.

2.1 Internal energy

isothermal

$$U_s = \frac{3}{2} N k T_r$$

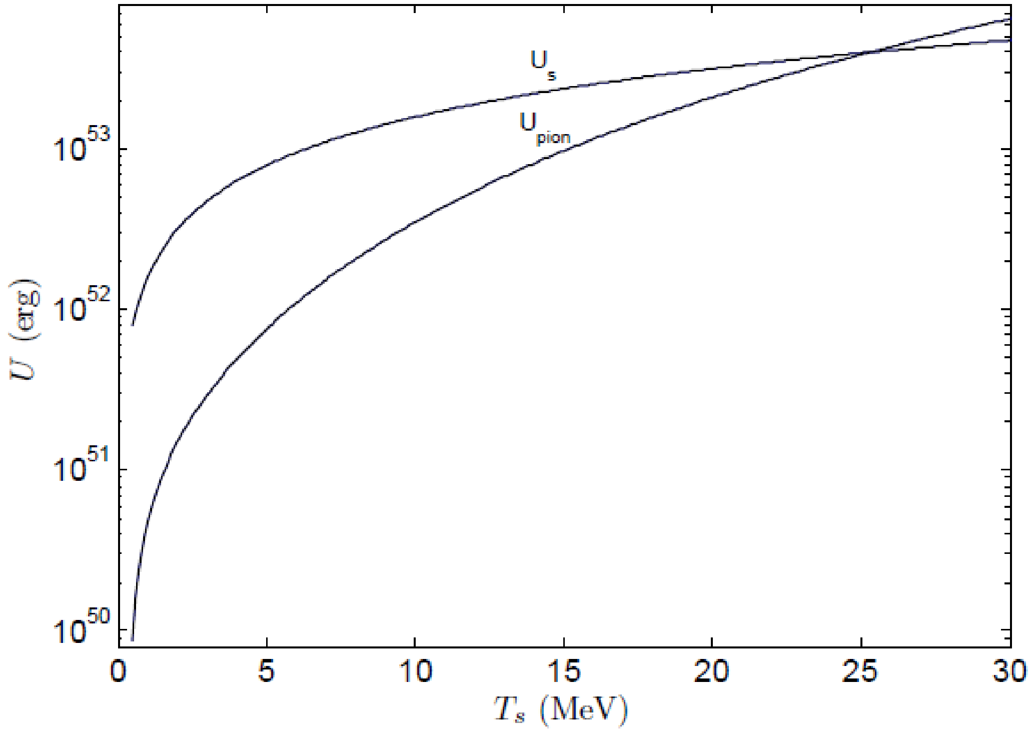
$$U_\pi = 3\frac{4\pi V}{h^3}\int_0^\infty p^2 \frac{\varepsilon}{e^{\frac{\varepsilon-\mu}{kT_r}}-1} dp$$



Non-isothermal

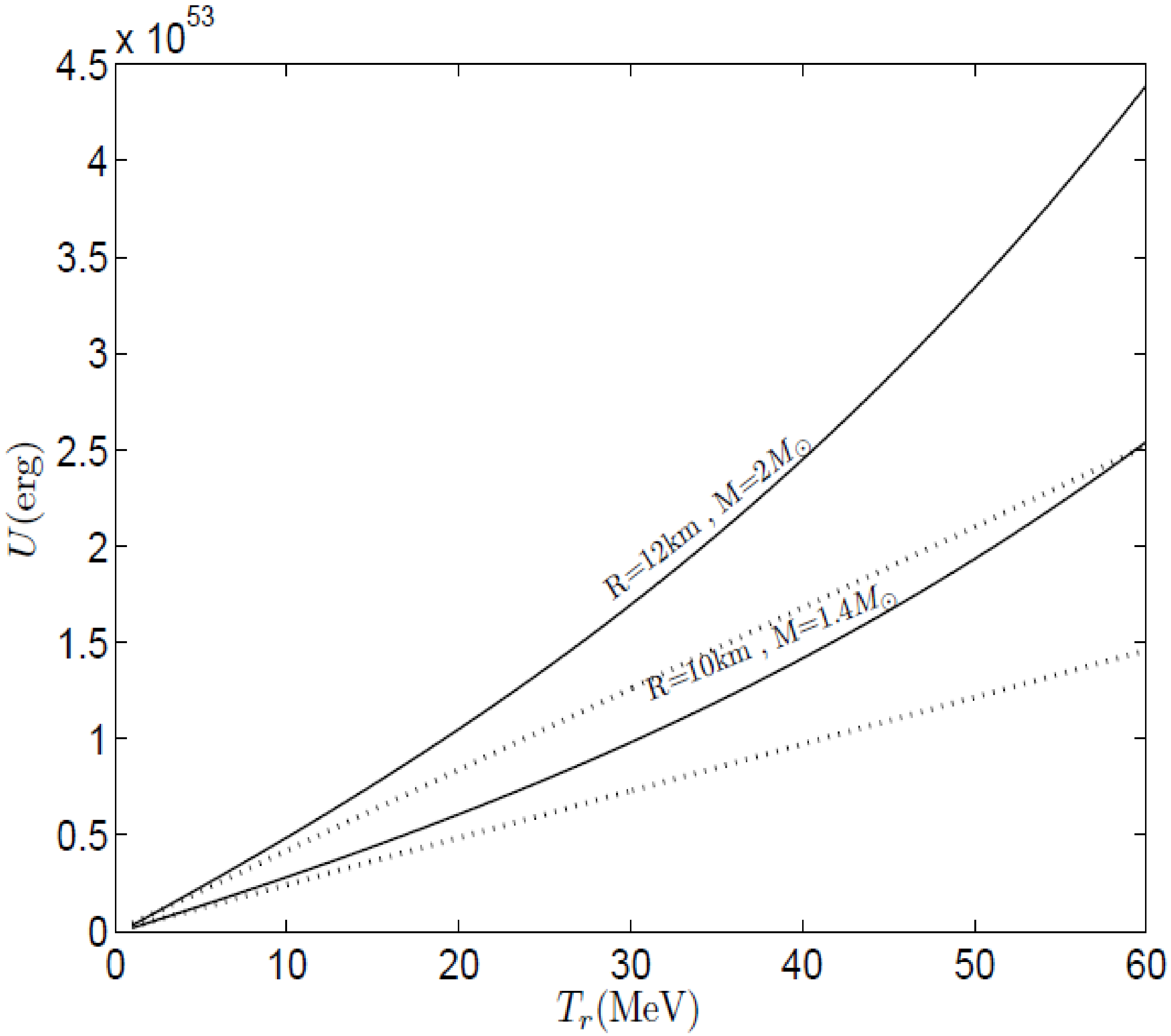
$$U_s = \frac{3}{2} nk \cdot 4\pi \int_0^{R_0} r^2\, T_s dr$$

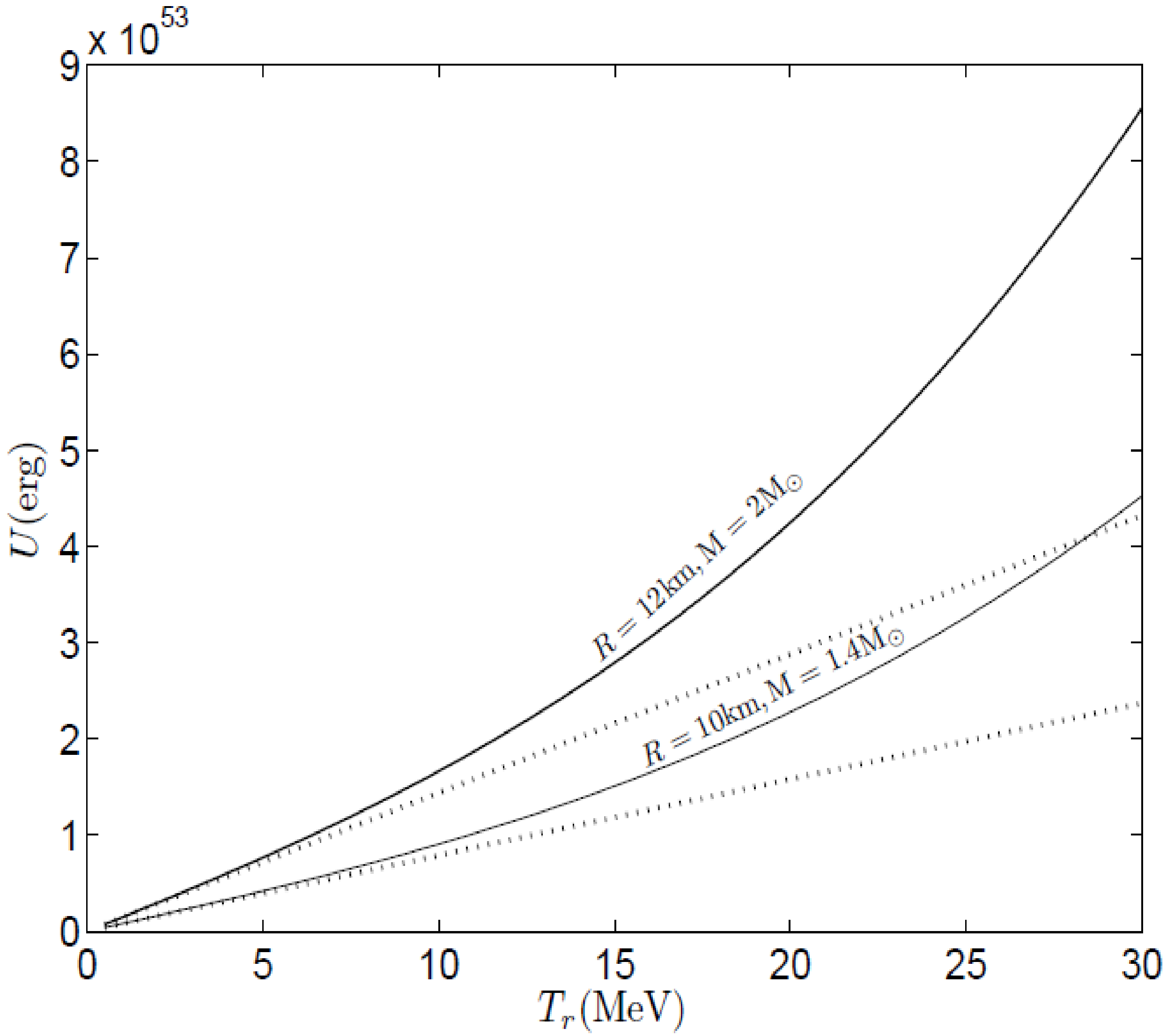
$$U_\pi = 3\int_0^R \int_{140}^\infty \frac{4\pi}{h^3} p^2 \frac{\varepsilon}{e^{\frac{\varepsilon-\mu}{kT_s}}-1} dpdr$$



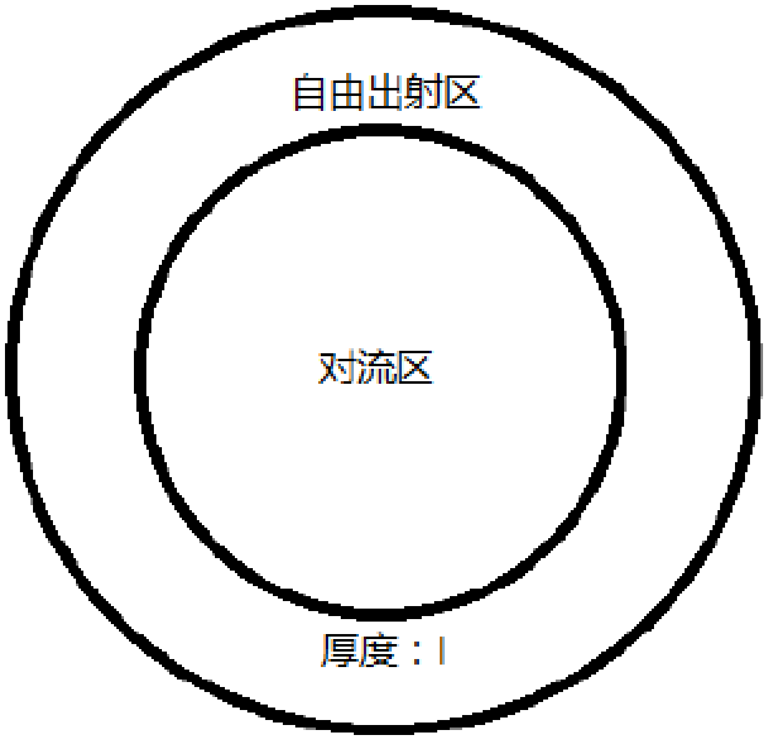
2.1 Internal energy

$$U = U_\pi + U_s$$



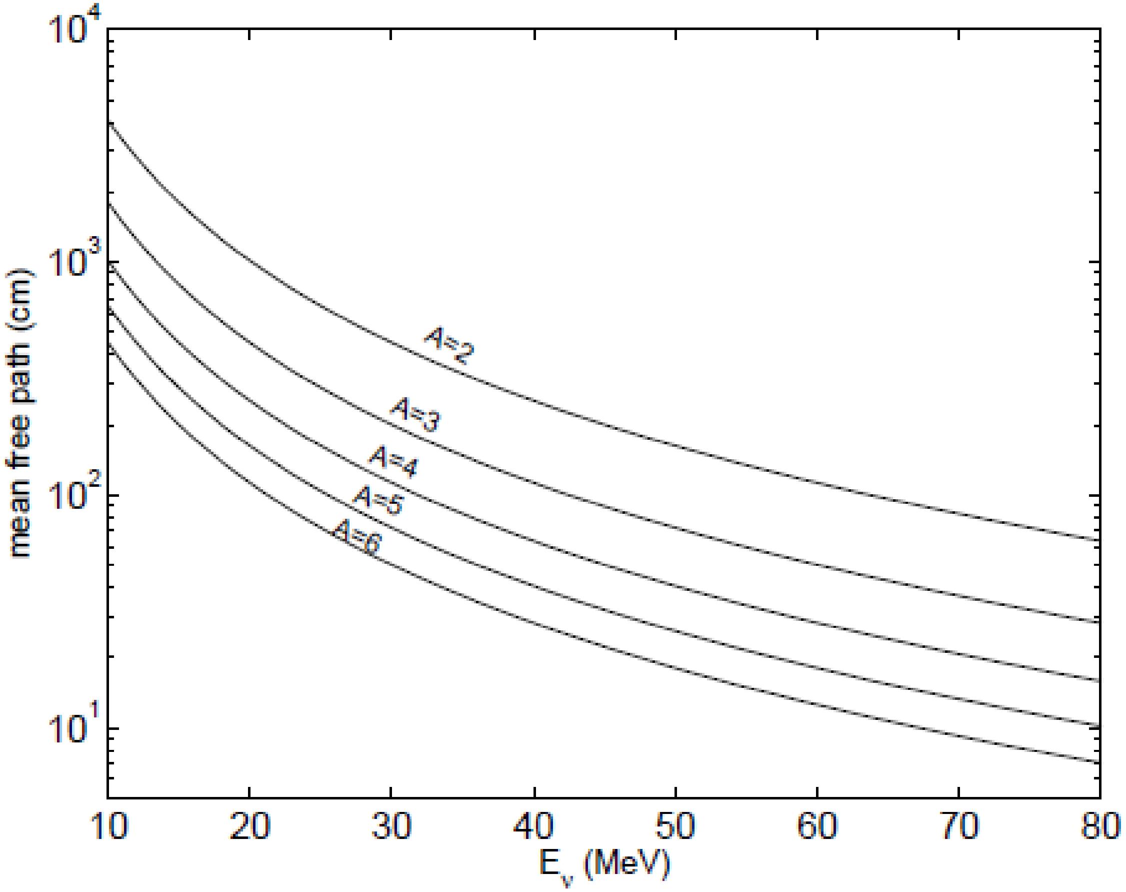


2.2 Thermal radiation



Neutrino radiation

中微子平均自由程



$l \sim 10^3\text{cm}$

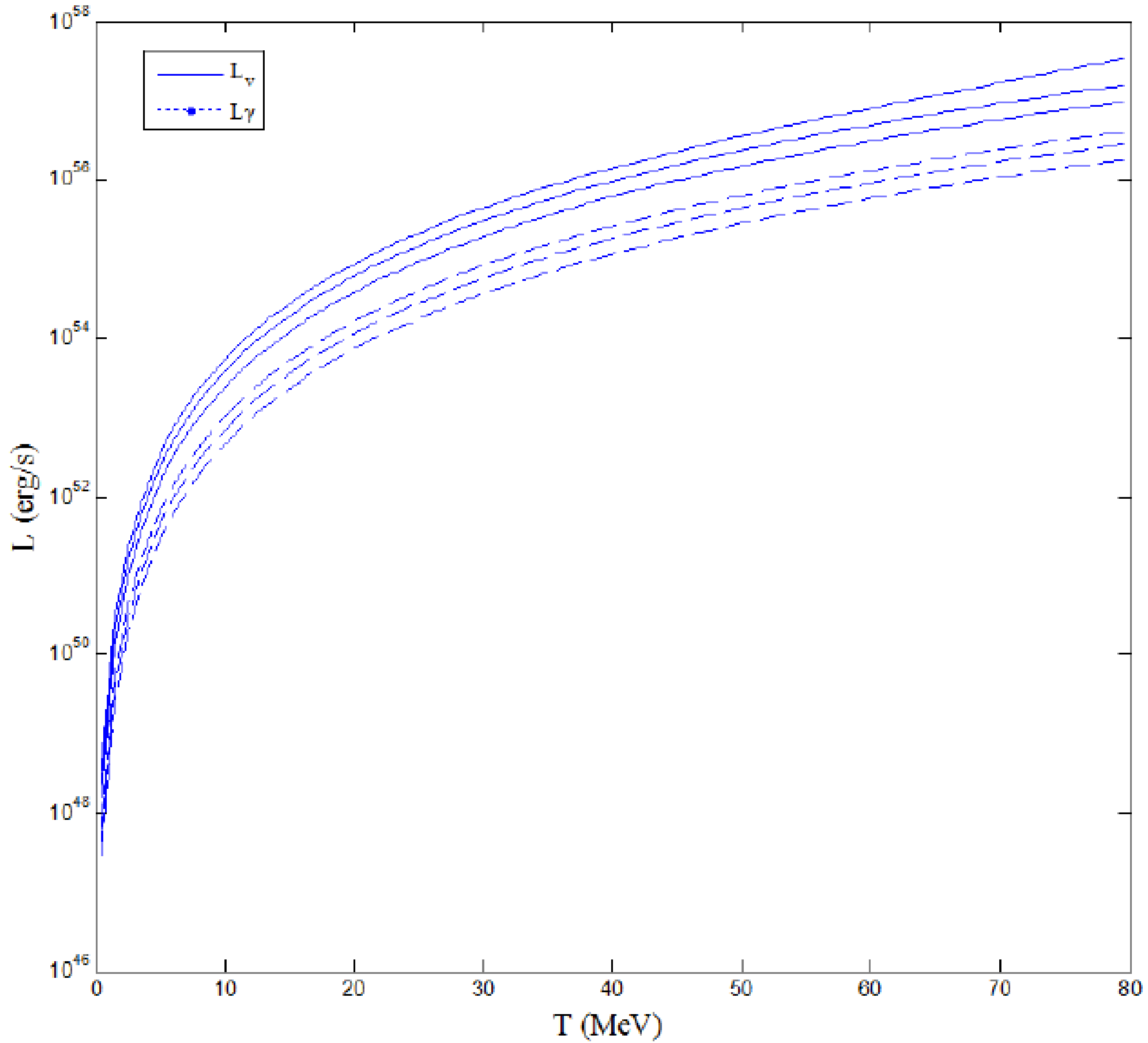
2.2 Thermal radiation

$$L_{bol} = L_{v.s} + L_{v.b} + L_{\gamma}$$

$$L_{v.b} = \frac{4}{3}\pi\left[R^3 - (R-l)^3\right]\varepsilon_{pair}$$

$$L_{v.s} = 4\pi R^2 \sigma_\nu T^4,$$
$$\sigma_\nu = 14.88 \times 10^{-8}\mathrm{W}\cdot m^{-2}\cdot k^{-4}$$

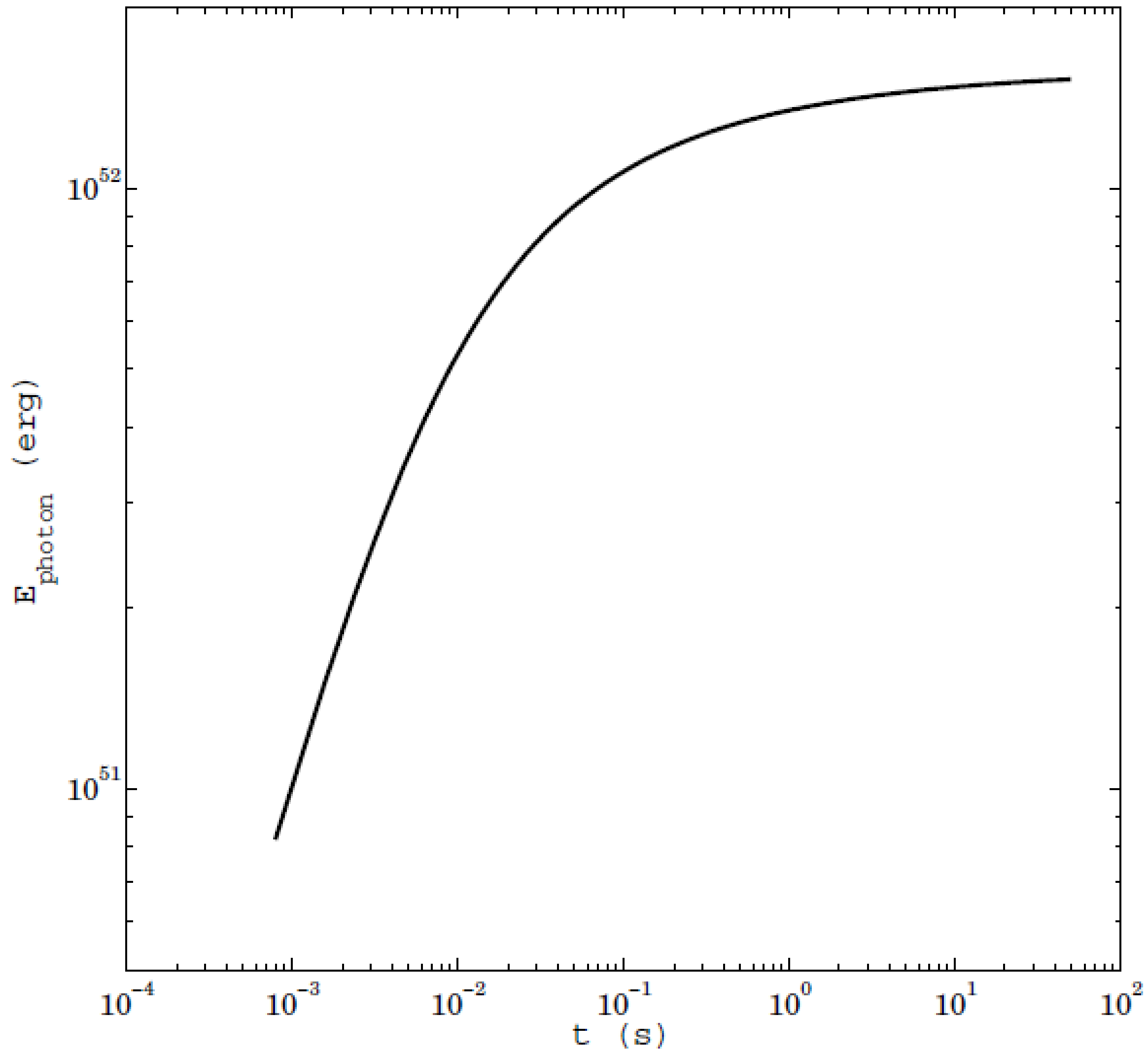
$$L_{\gamma} = 6\cdot 4\pi R^2 \sigma_\gamma T^4,$$
$$\sigma_\gamma = 5.67 \times 10^{-8}\mathrm{W}\cdot m^{-2}\cdot k^{-4}$$



（Parameters：R=13km、12km、10km，and with corresponding M=3 $M_\odot$，$2M_\odot$，1.4 $M_\odot$）

2.2 Thermal radiation

Supernova explosion mechanism: Photon-driven （Chen et al. , 2007）。



Supernova neutrinos in strangeon star model: reflecting the information of the proto-strangeon star immediately.

2.3 Phase transition

- **Solidification：** melting temperature $T_m \sim 1-6\ MeV$ (Lai et al. , 2013).

Time scale of the constant-temperature stage of phase transition process t，

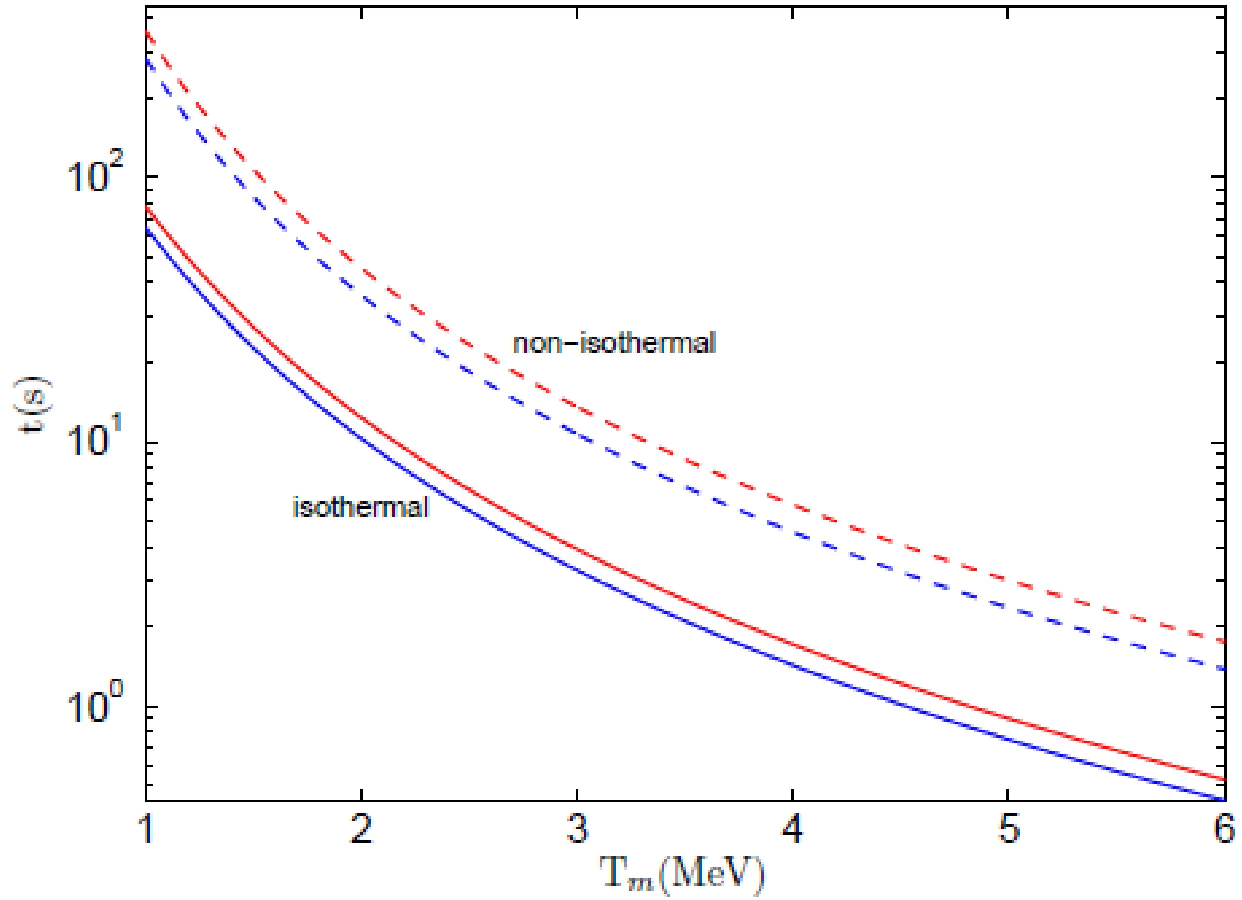
$$\boldsymbol{L_{bol} \cdot t = U(T_m)}$$

- **Thermal quantities：**

$$U_{re} = \int C_V dT$$

$$C_V = C_V^l + C_V^e$$

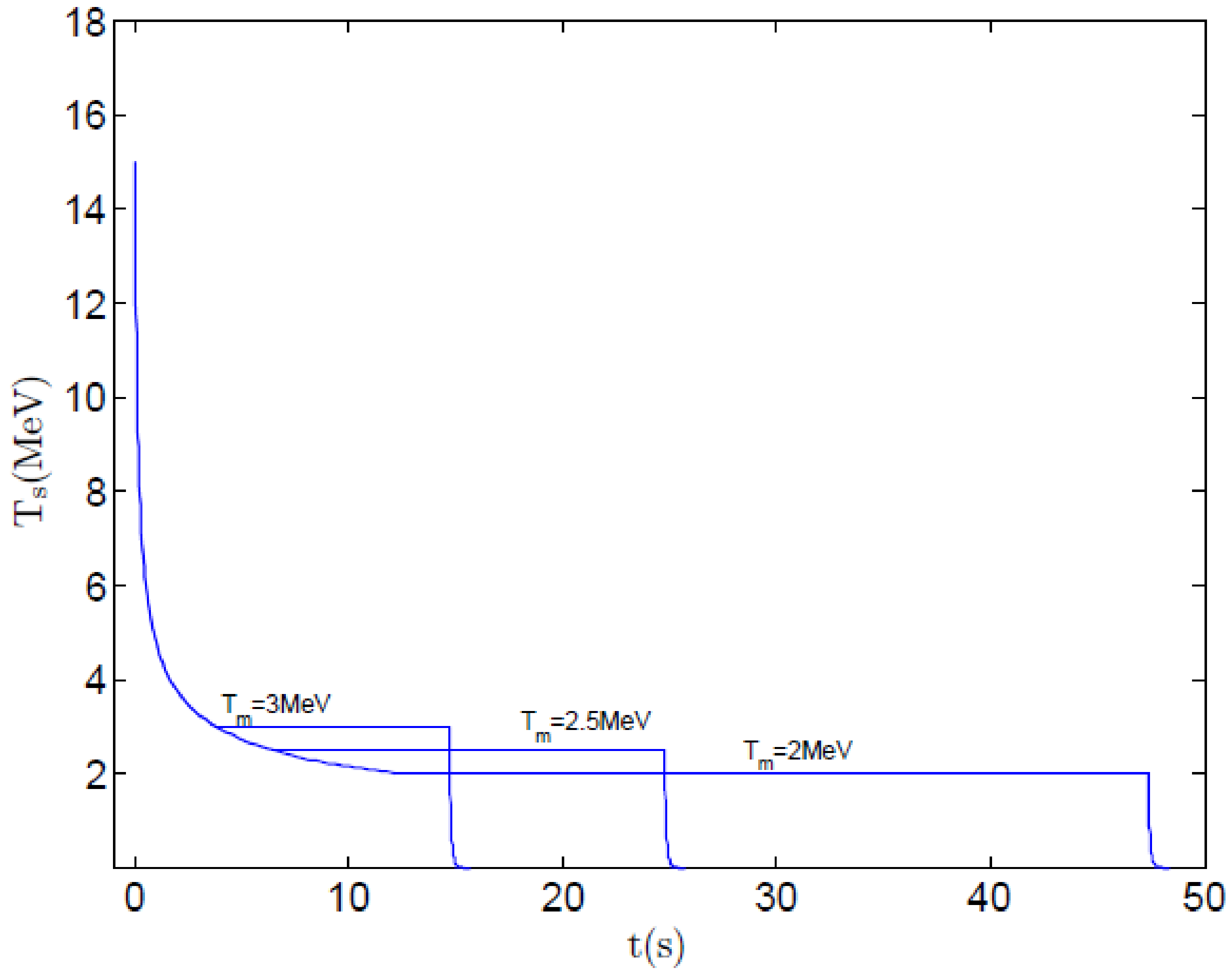
$$C_V^l = N \cdot \frac{12\pi^4}{5} k \left(\frac{T}{\theta_D}\right)^3$$ （M.Yu et al. , 2011）



2.4 T−t evolution

- Before solidification: $-\frac{dU}{dt} = L_{bol}$
- Solidification： $L_{bol} \cdot t = U(T_m)$
- After solidification： $-C_v \frac{dT}{dt} = L_{bol}$

Non-isothermal proto-strangeon star



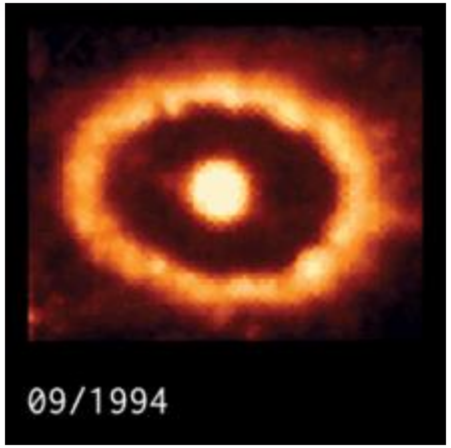
（R=10km， M=1.4 $M_{\odot}$）

3 SN 1987A neutrino burst

探测器	相对时间 (s)	能量 (MeV)	探测器	相对时间 (s)	能量 (MeV)
K1	0	20.0±2.9	I1	0	38±7
K2	0.107	13.5±3.2	I2	0.412	37±7
K3	0.303	7.5±2.0	I3	0.650	28±6
K4	0.324	9.2±2.7	I4	1.141	39±7
K5	0.507	12.8±2.9	I5	1.562	36±9
K6	0.686	6.3±1.7	I6	2.684	36±6
K7	1.541	35.4±8.0	I7	5.010	19±5
K8	1.728	21.0±4.2	I8	5.582	22±5
K9	1.915	19.8±3.2			
K10	9.219	8.6±2.7			
K11	10.433	13.0±2.6			
K12	12.439	8.9±2.9	B1	0	12.0±2.4
K13	17.641	6.5±1.6	B2	0.435	17.9±3.6
K14	20.257	5.4±1.4	B3	1.710	23.5±4.7
K15	21.355	4.6±1.3	B4	7.687	17.5±3.5
K16	23.814	6.5±1.6	B5	9.099	20.3±4.1

- energy thresholds：

Kamiokande Ⅱ：4.5 MeV;
IMB：17 MeV;
Baksan：10 MeV.



- UT of the first case：

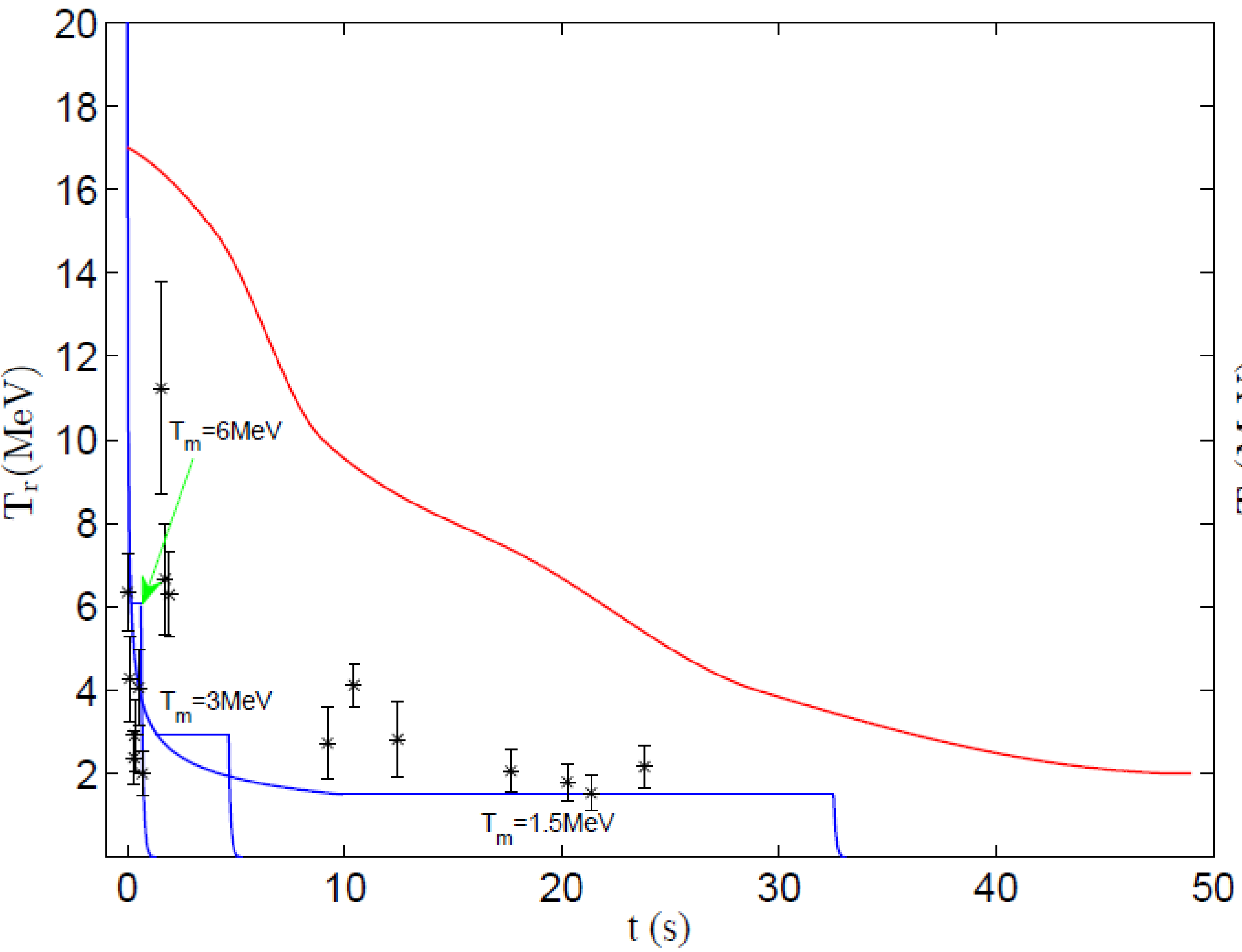
Kamiokande Ⅱ ： 7：35：35UT±1 min;
IMB：7：35：41UT ± 50 ms;
Baksan：7：35：46UT ± 28s.

- Relation of neutrino energy and temperature：

$$\langle E_\nu \rangle \approx 3.15T$$

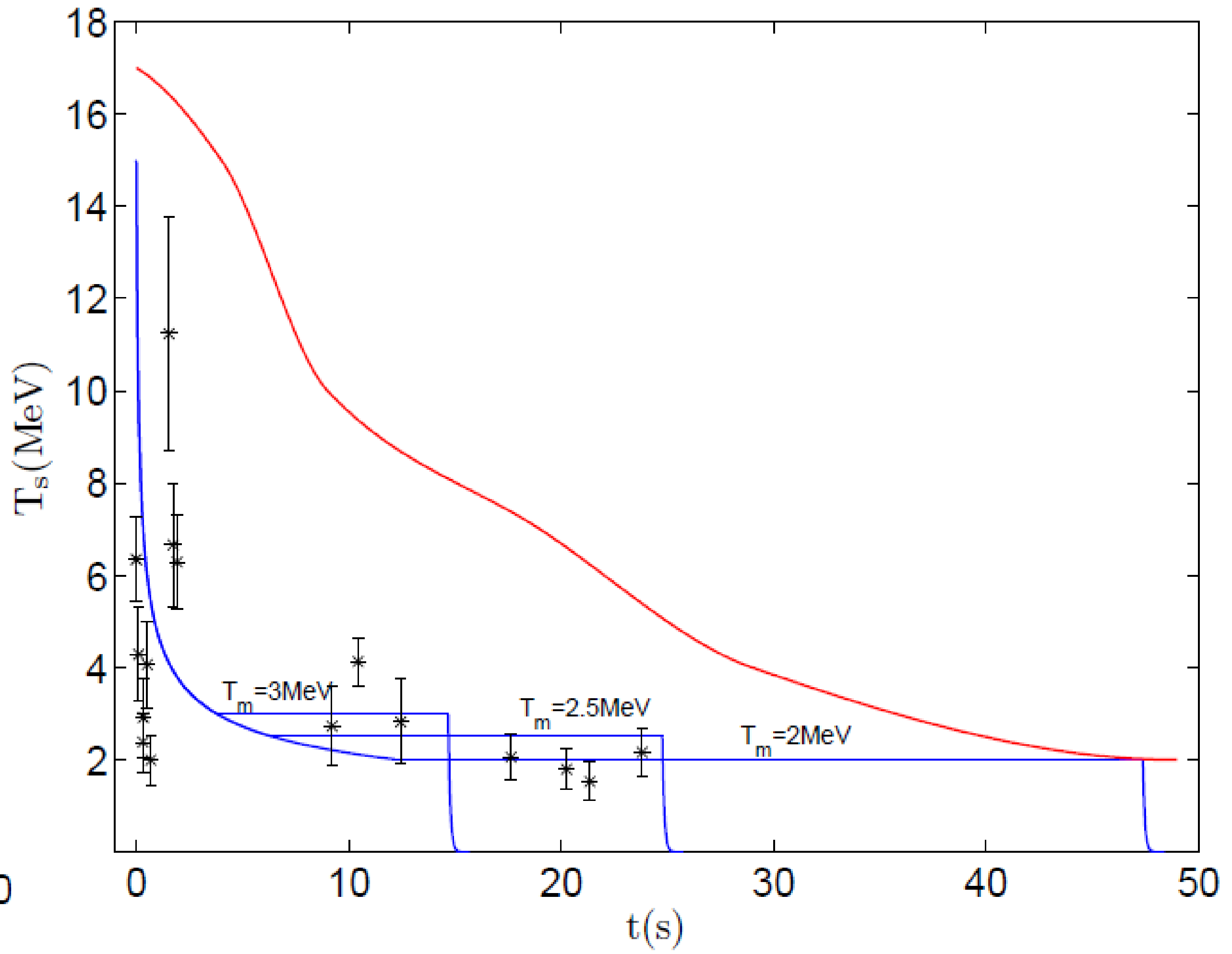
SN 1987A neutrino burst

M=1.4$M_\odot$， R=10km



Isothermal proto-strangeon star :

T_0 =52.9MeV

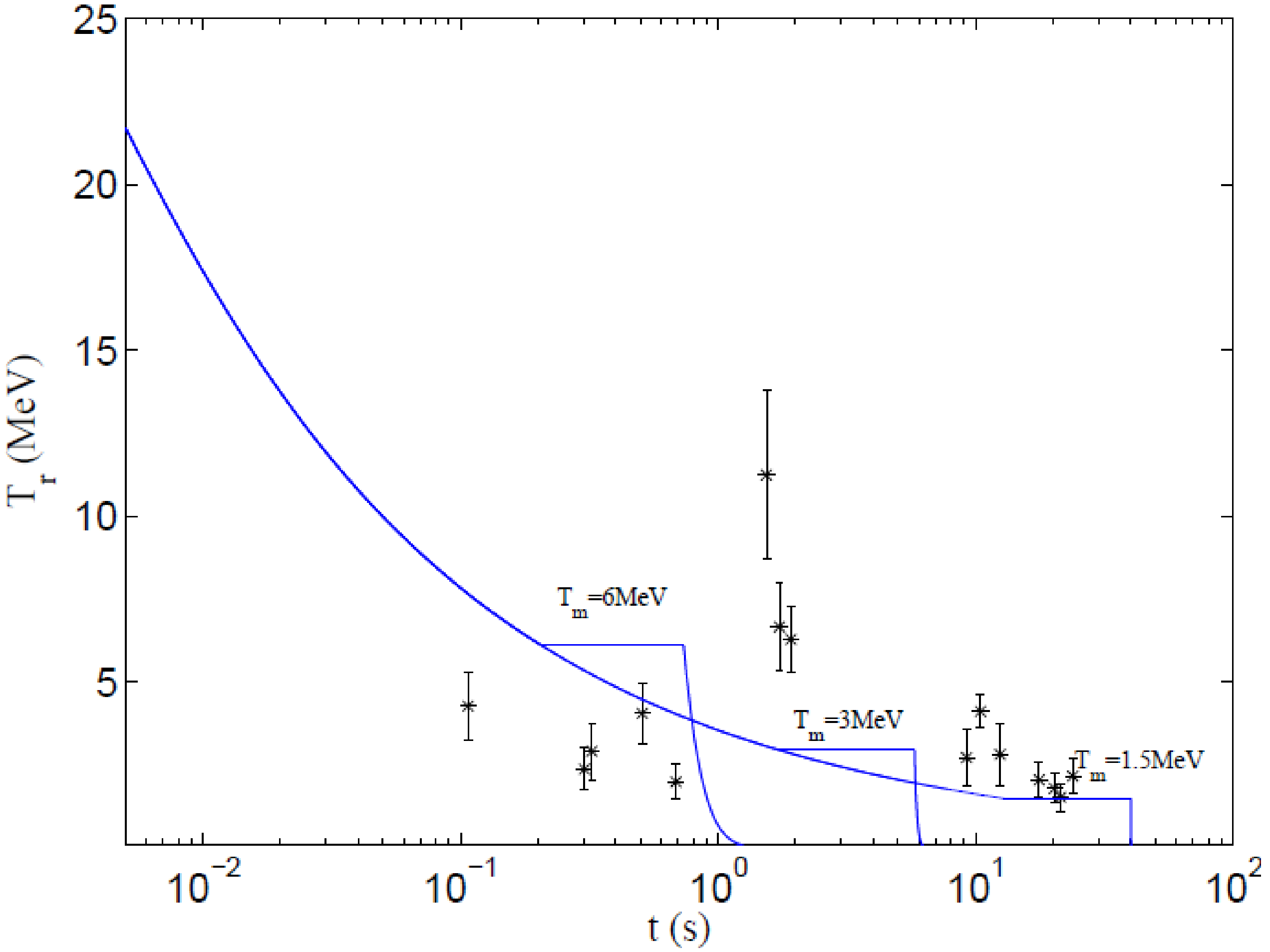


Non-isothermal proto-strangeon star :

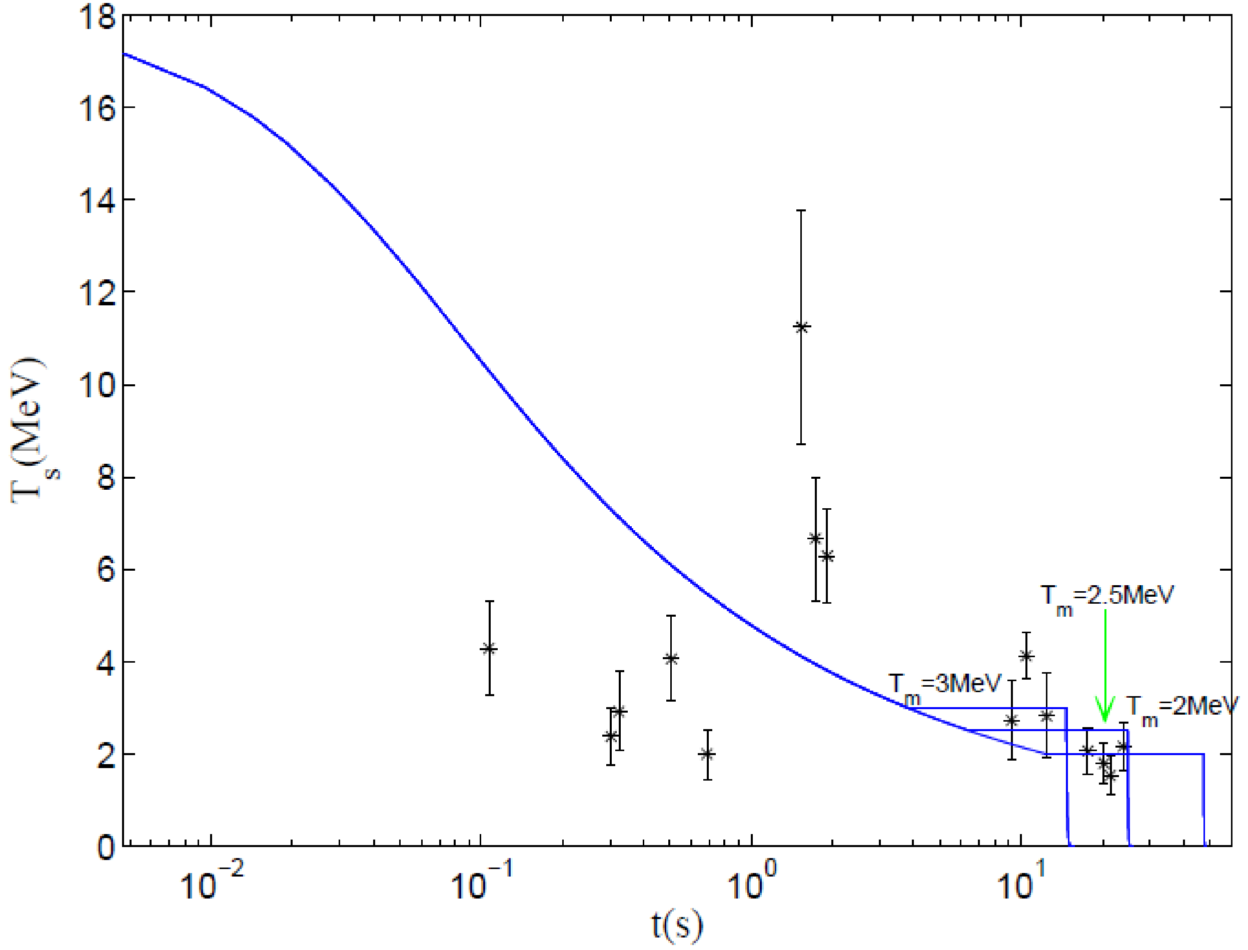
T_0 =18MeV

SN 1987A neutrino burst

M=2$M_{\odot}$， R=12km



Isothermal proto-strangeon star :
T_0 =50.7 MeV



Isothermal proto-strangeon star :
T_0 =17.8MeV

4 Conclusion and discussion

- The neutrino burst observed from SN 1987A could be re-produced in such a cooling model.

- The number of observed neutrinos is small.
- JUNO can detect at least 5000 supernova neutrinos in future.

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Thank you all for listening

请各位老师批评指正！