MAGNETARS AS COOLING NEUTRON STARS WITH INTERNAL HEATING

A.D. Kaminker, D.G. Yakovlev, A.Y. Potekhin, N. Shibazaki*, P. Sternin, and O.Y. Gnedin**

Ioffe Physical Technical Institute, St.-Petersburg, Russia
**Rikkyo University, Tokyo 171-8501, Japan*
***Ohio State University, 760 1/2 Park Street, Columbus, OH 43215, USA*

- **Introduction**
- **Physics input**
- **Games with cooling code**
- **Conclusions**

Cooling theory with internal heating

Thermal balance:

$$C(T)\frac{dT}{dt} = W - L_\nu - L_\gamma$$

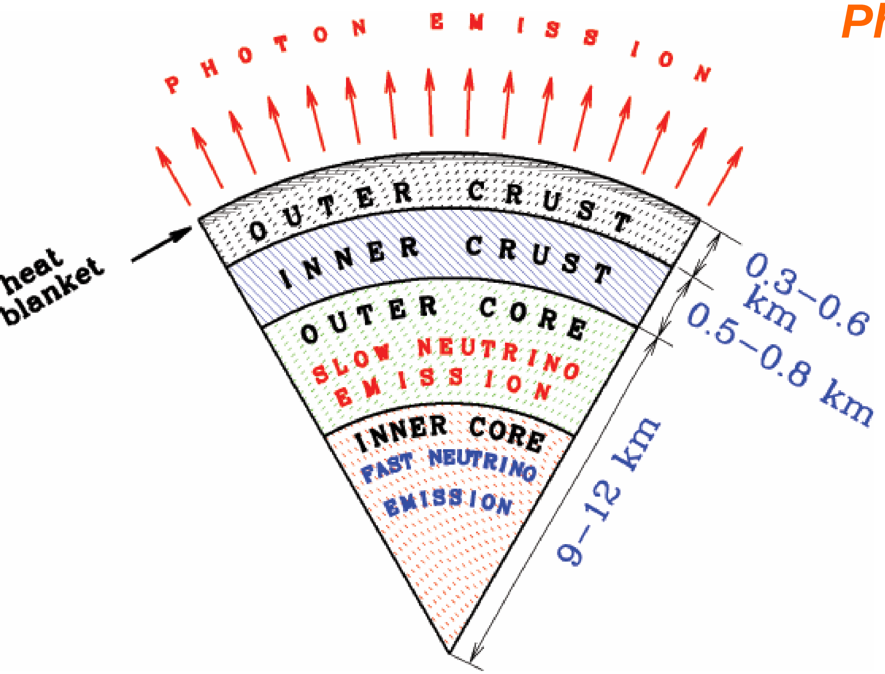
Heat transport:

$$F = -\kappa \frac{dT}{dr}; \quad \kappa$$ - effective thermal conductivity

Photon luminosity: $L_\gamma = 4\pi\sigma R^2 T_s^4$

Heat blanketing envelope: $T_s = T_s(T)$

Heat content: $U_T \sim 10^{48}\ T_9^2\ \ ergs$



Main cooling regulators:

1. EOS
2. Neutrino emission
3. <u>Reheating processes</u>
4. Superfluidity
5. Magnetic fields
6. Light elements on the surface

1. EOS: APR III (n, p, e, μ) Gusakov et al. (2005)

Akmal-Pandharipande-Ravenhall (1998) -- neutron star models

Parametrization: Heiselberg & Hiorth-Jensen (1999)

$$M_{\max} = 1.93 M_{\odot},$$

$$\rho_{\max} = 2.7 \times 10^{15} \mathrm{g\ sm}^{-3},$$

$$R = 10.4\ \mathrm{km},$$

$$M_{\mathrm{D}} = 1.7 M_{\odot},$$

$$\rho_{\mathrm{D}} = 1.3 \times 10^{15} \mathrm{g\ cm}^{-3},$$

$$R = 11.83\ \mathrm{km}$$

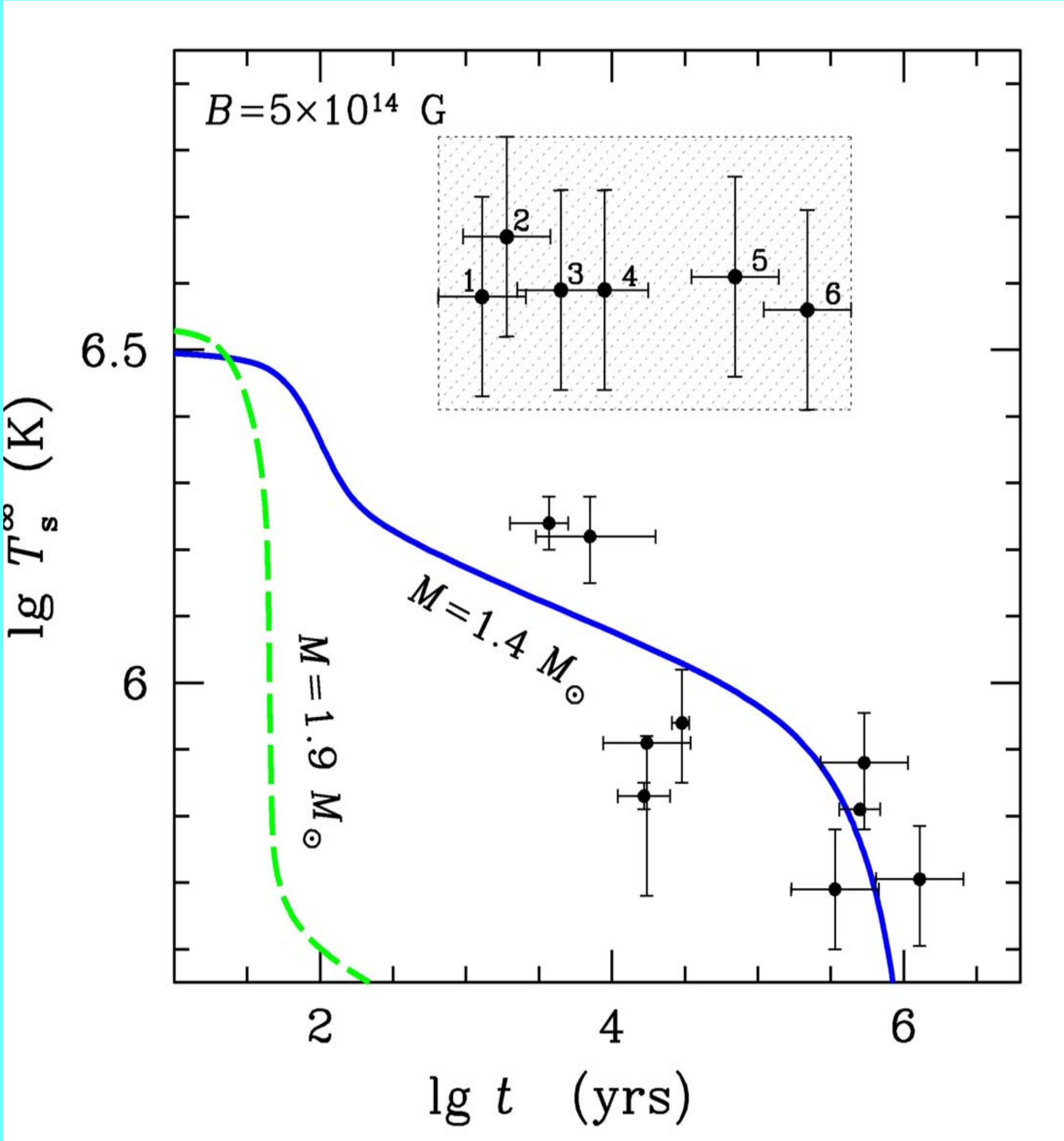
2. Heat blanketing envelope: $\rho \leq \rho_b = 10^{10}\, g / cm^3$

$T_b - T_s$ **-- relation;** $T_b = T(\rho_b)$

T_{eff} **-- effective temperature;** $T_s(\vartheta) -$ **surface temperature,**

$$4\pi\sigma R^2 T_{eff}^4 = L_\gamma = \sigma \int T_s^4 \, d\Sigma;$$

$d\Sigma$ **-- surface element**



1- *SGR* **1900+14**

2- *SGR* **0526-66**

3- AXP ***1E*** **1841-045**

4- AXP ***1RXS J*****170849-400910**

5- AXP ***4U*** **0142+61**

6- AXP ***1E*** **2259+586**

3. **Model of heating:** $H(\rho,t) = H_0 f_1 f_2 \exp(-\frac{t}{\tau})$

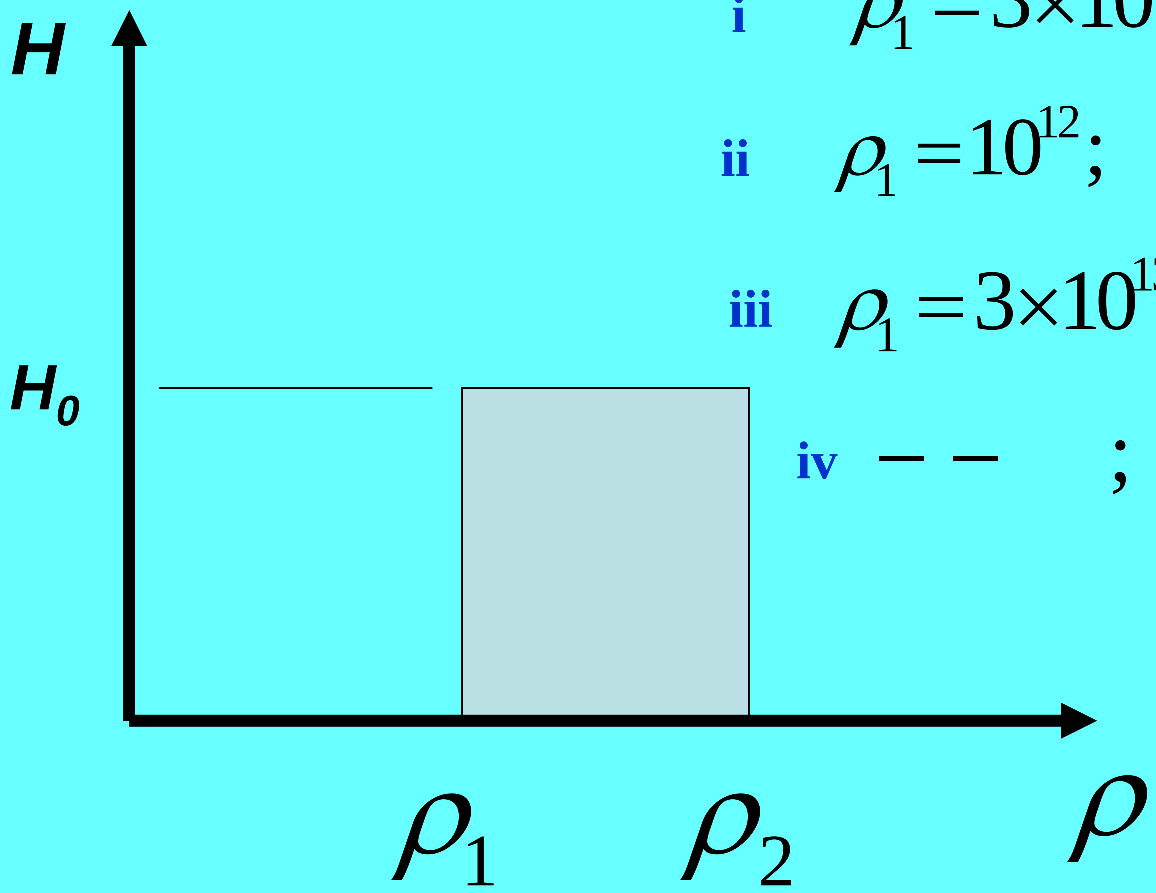
$f_1(\rho) = \dfrac{1}{1+\exp(\frac{\rho-\rho_1}{\Delta\rho_1})}$; $f_2(\rho) = \dfrac{1}{1+\exp(\frac{\rho-\rho_2}{\Delta\rho_2})}$ **at** $\rho_1 \le \rho \le \rho_2$

i $\rho_1 = 3\times10^{10}$; $\rho_2 = 10^{11}\ g\ cm^{-3}$;

ii $\rho_1 = 10^{12}$; $\rho_2 = 3\times10^{12}\ g\ cm^{-3}$;

iii $\rho_1 = 3\times10^{13}$; $\rho_2 = 10^{14}\ g\ cm^{-3}$;

iv $-\ -$; $\rho_2 = 9\times10^{14}\ g\ cm^{-3}$;



$t = 10^3\,yr$

No isothermal stage

Core — crust decoupling

Only outer layers of heating are appropriate for hottest NSs

1- *SGR* 1900+14

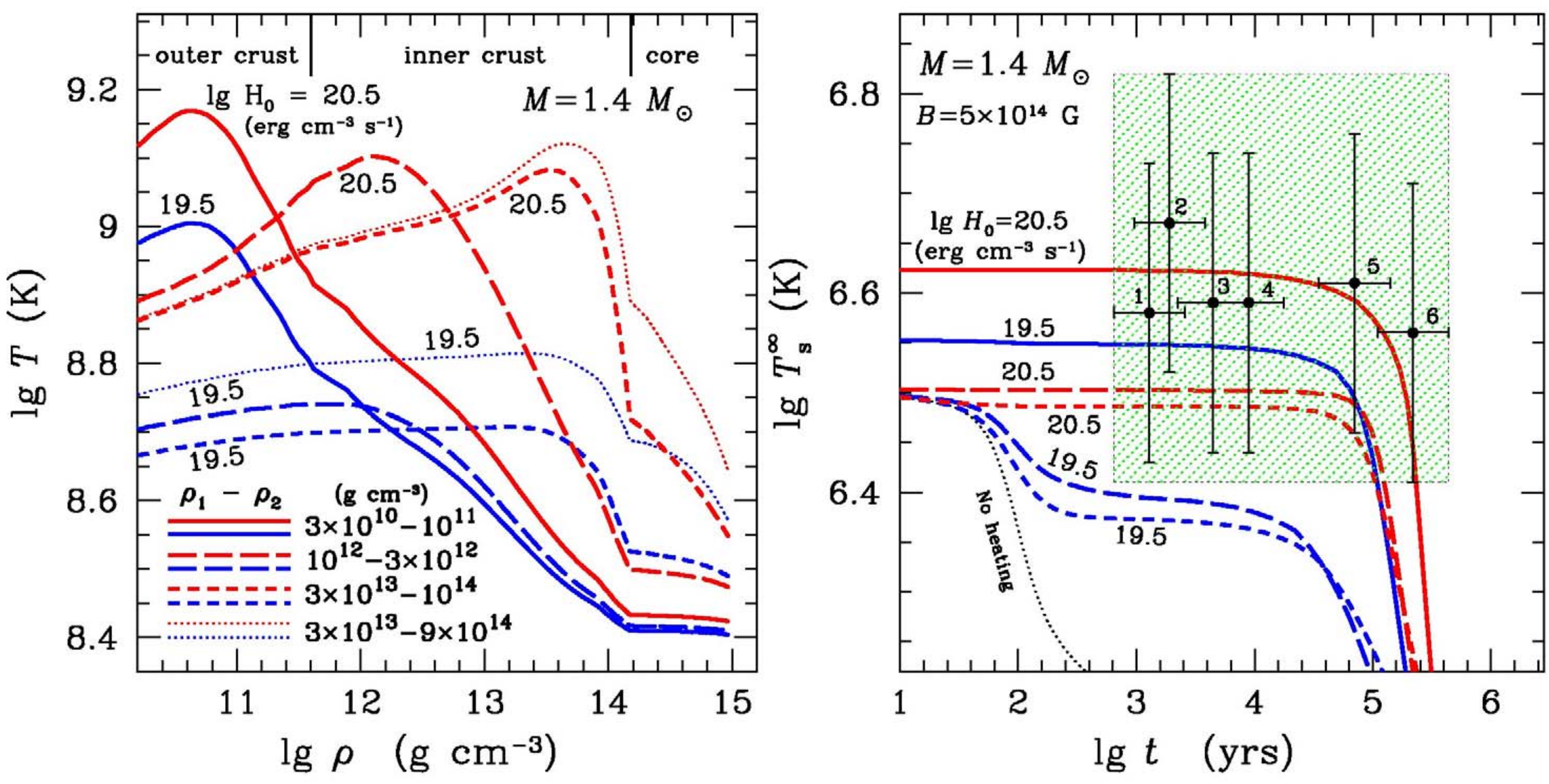
2- *SGR* 0526-66

3- AXP *1E* 1841-045

4- AXP *1RXS J*170849-400910

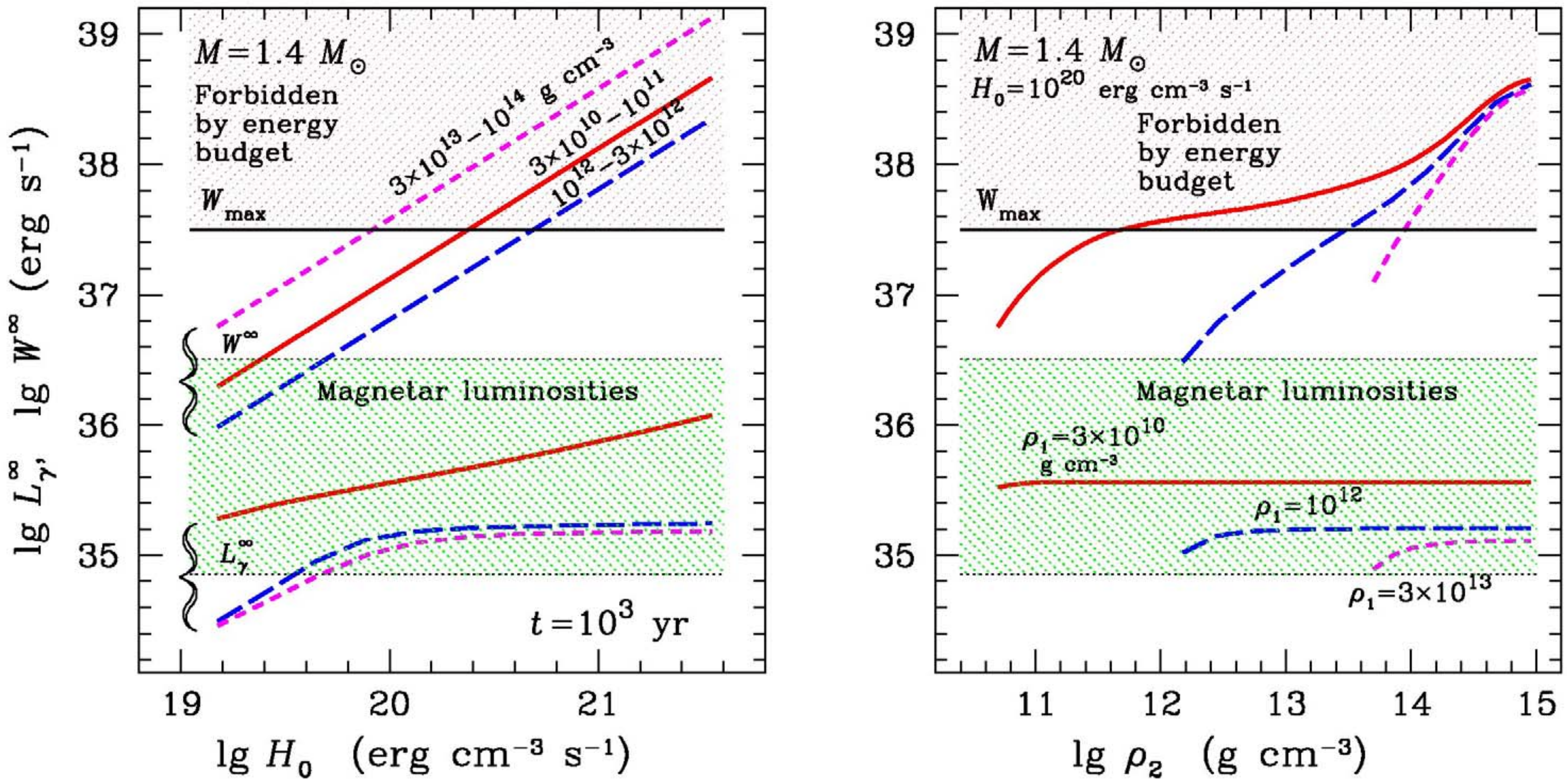
5- AXP *4U* 0142+61

6- AXP *1E* 2259+586



Necessary energy input vrs. photon luminosity

$W^{\infty}(\frac{erg}{s})$ into the layer $\rho_1 \le \rho \le \rho_2$

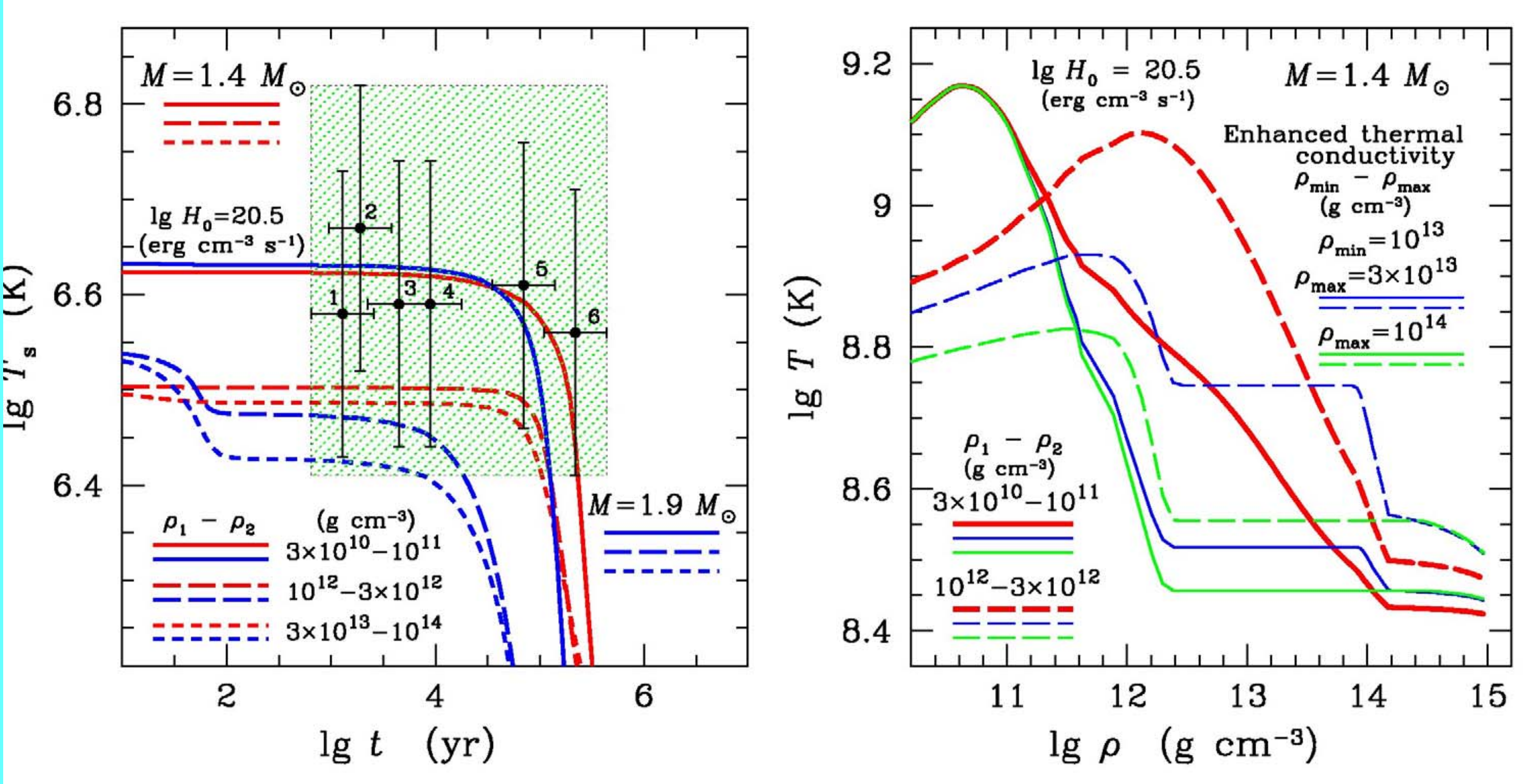


Direct Urca process included

Enchanced thermal conductivity

from $\rho_{\min}$ **to** $\rho_{\max}$

Appearance of isothermal layers



Conclusions

1. High thermal state of magnetars demand a powerful reheating

2. The heating should be located in a thin layer at : $\rho \leq 5\times10^{11}\ g\ cm^{-3}$

   in the outer crust. The heat intensity H_0 should range

   from □ 3×10^{19} to $3\times10^{20}\ erg\ cm^{-3}s^{-1}$.

   Deeper heating would be extremely inefficient due to neutrino radiation

3. Only ~ 1% of the total energy released in the heat layer can be spent to heat the NS surface

4. Pumping huge energy into deeper layers can not increase -- T_{eff}^{∞}

5. Temperature distributions within NS are strongly nonuniform due to thermal decoupling of the outer crust from the inner parts of the star