Log N – Log S of close-by young NSs: an independent test for cooling curves

Sergei Popov

University of Padua, Italy
Sternberg Astronomical Institute, Russia

Collaborators: H. Grigorian, R. Turolla, D. Blaschke

Plan of the talk

- Introduction.
- $T - t$-test.
  - Overview. *Pro et contra.*
- Log N - Log S. An overview.
- Local population of cooling NSs.
- Ingredients of population synthesis.
  - Stars in the solar proximity. The Gould Belt.
  - Mass spectrum of close-by NSs.
  - Atmospheres and other emission properties.
- Log N – Log S of cooling NSs.
  - A toy model.
  - Effects of different ingredients.
  - Comparison of different cooling curves.
- *Pro et contra* of Log N - Log S.
- Age-distance diagram.
- Conclusions.

TtT – Temperature-age test.

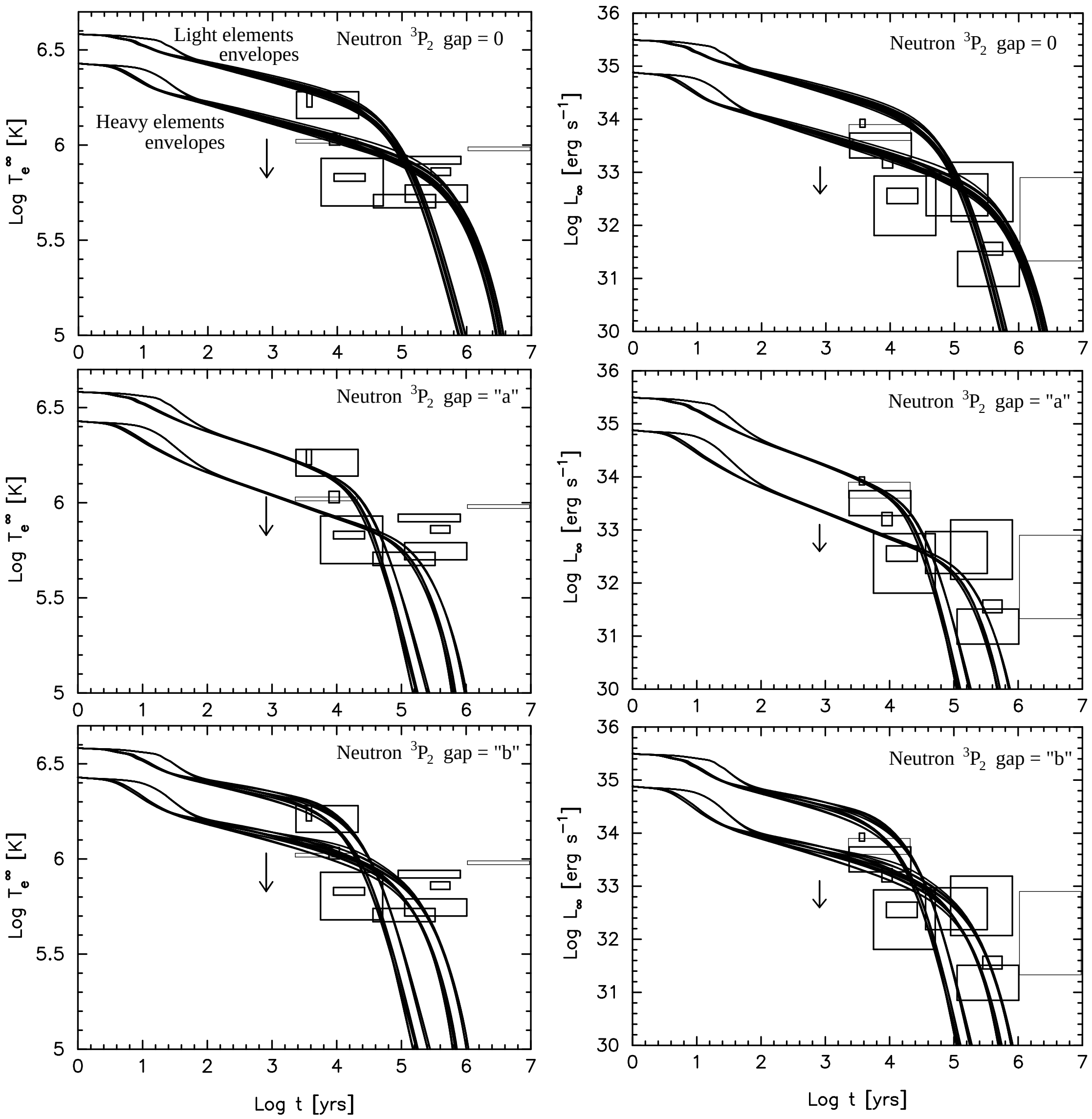


Figure from Page et al. 2004 [astro-ph/0405196].

T-t Test. *Pro et contra.*

Pro

- The most natural plot.
- Perfect illustration.
- Does not care about uncertainties of the "third" parameters. Only internal uncertainties of the model are important.

Contra

- Uncertainties in t.
  Very often an age is determined by $p/\dot{p}$, or as a SNR age.
- Uncertainties in T. Atmospheres etc.
- Comparison of calculations with observations.
  Temperature is not measured directly, it is always obtained as a fit.
- Non-uniform data set.
  Data samples of *coolers* are non-uniform. There are sources of different types. The sample is nor flux, neither volume limited.

Log N - Log S Test. *Pro et contra.*

Pro

- Uses uniform sample of objects.
- Takes into account "populational effects".
- No unsertainties in properties of observed objects!

Contra

- There are many uncertainties of the scenario.
  - Initial distribution of progenitors.
  - Mass spectrum.
  - Emission properties.
- There can be unknown correlations between parameters of synthesis. (For example mass-magnetic field due to fall-back; velocity-internal structure due to deconfinement).
- Finite sample. It is difficult to take into account statistical fluctuations if a data sample is small.
- "Hidden" population (unobserved objects).

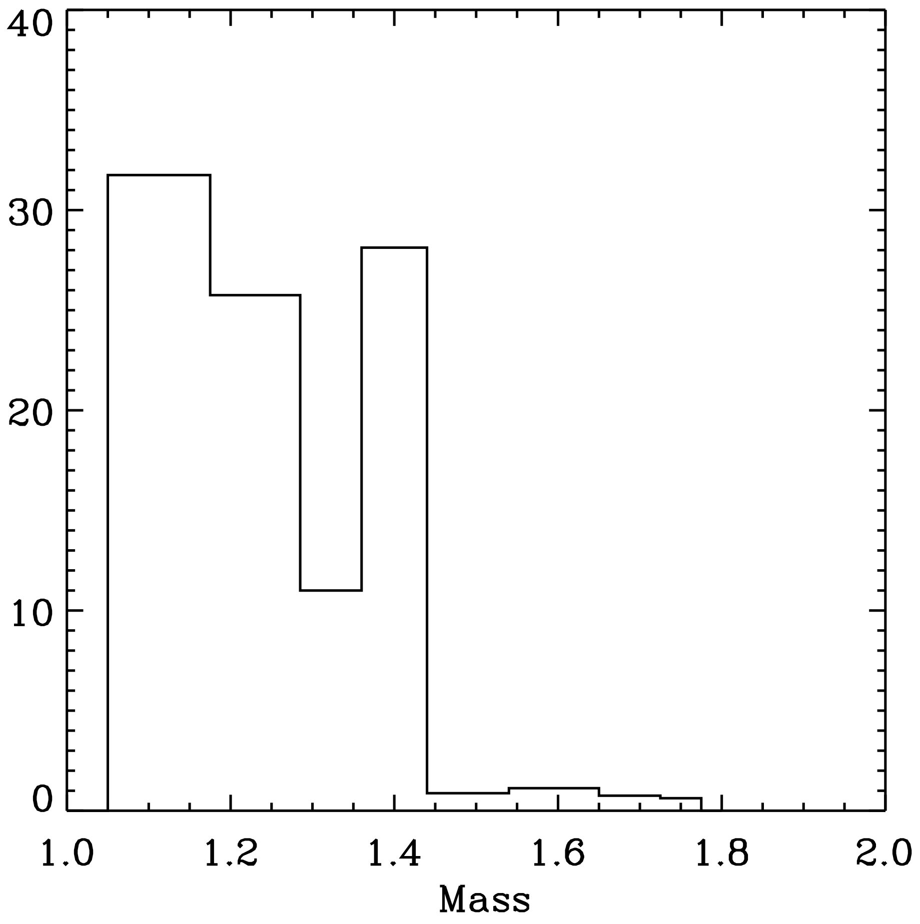
Ingredients of the population synthesis model.

- Initial spatial distribution.
- Velocity distribution.
- Cooling curves.
- Mass spectrum of NSs.
- Emission model (atmospheres etc.).
- Interstellar absorption.

Why population synthesis is important?

Each part by itself can be perfect, but all together do not fit!
It is necessary to analyse how fitting proceedure for some particular objects influences the whole population of sources of that type.
It is necessary to analyse (if possible) uniform data samples.

Mass spectrum.



Here we use bins at low masses since without the low-mass NSs in several model it is impossible to interprete data on the $T-t$ (temperature – age) plot (see Blaschke et al. 2004).

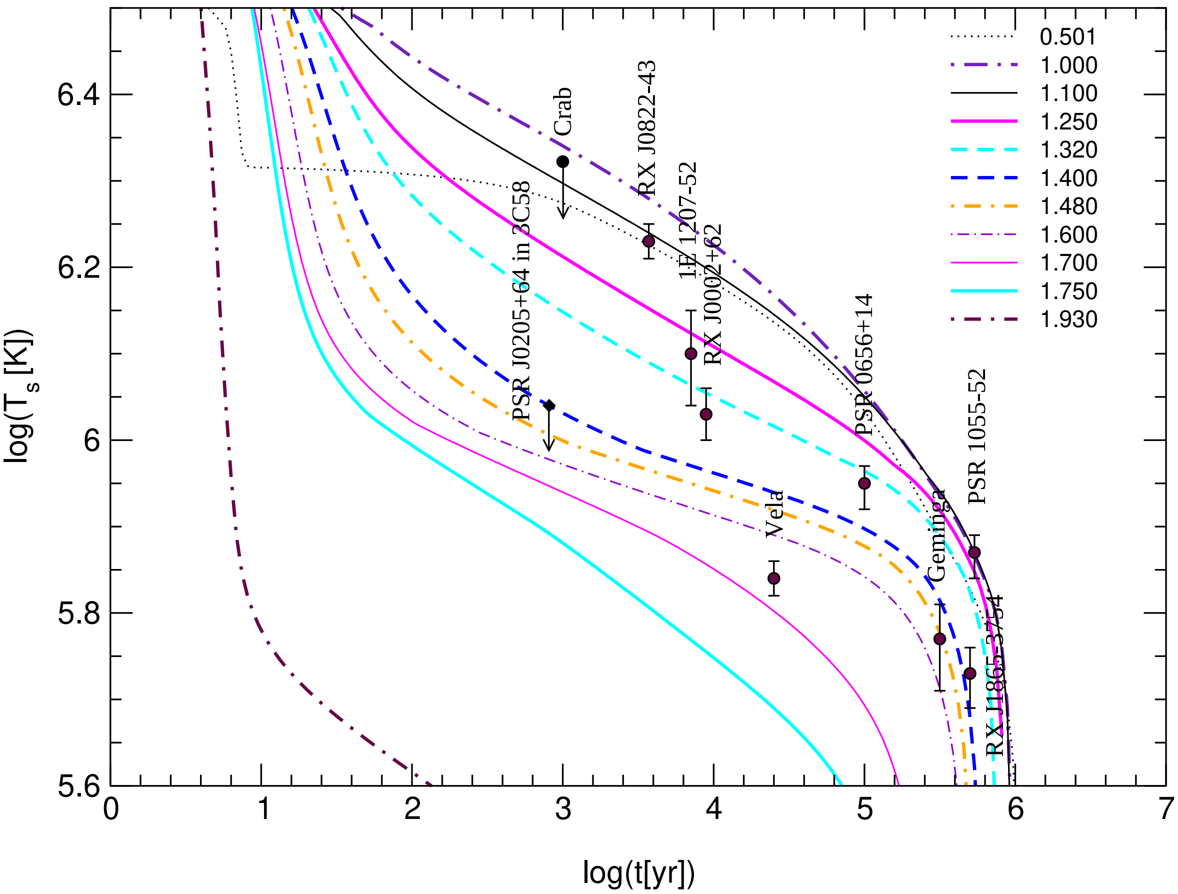
Each bin corresponds to one of the calculated curve. On the vertical axis percentage of stars in each bin (i.e. contribution of each curve) is shown. Masses are not equaly spaced, so widths of bins are different.

We use eight cooling curves for $M = 1.1,\ 1.25,\ 1.32,\ 1.4,\ 1.48,\ 1.6,\ 1.7,\ 1.76\ M_\odot$. Each curve has a statistical weight: 2.54, 2.06, 0.88, 2.25, 0.07, 0.09, 0.06, 0.05 according to the mass spectrum.

Table 1: List of models

Model	Ref. figure	Comments
I	21	Cooling of NS configuration with superfluid nuclear matter with medium effects and with pion condensation. The gaps are taken from Takatsuka & Tamagaki (2004), the neutron gap $3P_2$ is additionally suppressed. The $T_{\rm s}$-$T_{\rm in}$ relation is given by a fit.
II	13	Cooling of NS configuration with superfluid nuclear matter with medium effects but without pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The $T_{\rm s}$-$T_{\rm in}$ relation is given by the Tsuruta law.
III	15	Cooling of NS configuration with superfluid nuclear matter with medium effects and with pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The $T_{\rm s}$-$T_{\rm in}$ relation is given by a fit.
IV	12	Cooling of NS configuration with superfluid nuclear matter with medium effects but without pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The $T_{\rm s}$-$T_{\rm in}$ relation is given by a fit.
V	16	Cooling of NS configuration with superfluid nuclear matter with medium effects and with pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The $T_{\rm s}$-$T_{\rm in}$ relation is given by the Tsuruta law.
VI	14	Cooling of NS configuration with superfluid nuclear matter with medium effects but without pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The $T_{\rm s}$-$T_{\rm in}$ relation is from Yakovlev et al. (2003), $\eta = 4 \cdot 10^{-16}$.
VII	18	Cooling of NS configuration with superfluid nuclear matter with medium effects and with pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The $T_{\rm s}$-$T_{\rm in}$ relation is given by a fit. The proton gap is suppressed by a factor 0.5.
VIII	19	Cooling of NS configuration with superfluid nuclear matter with medium effects and with pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The $T_{\rm s}$-$T_{\rm in}$ relation is given by a fit. The $1S_0$ neutron gap suppressed by a factor 0.5 and $1S_0$ proton gap by a factor 0.2. The neutron $3P_2$ gap is remained to be suppresed by 0.1.

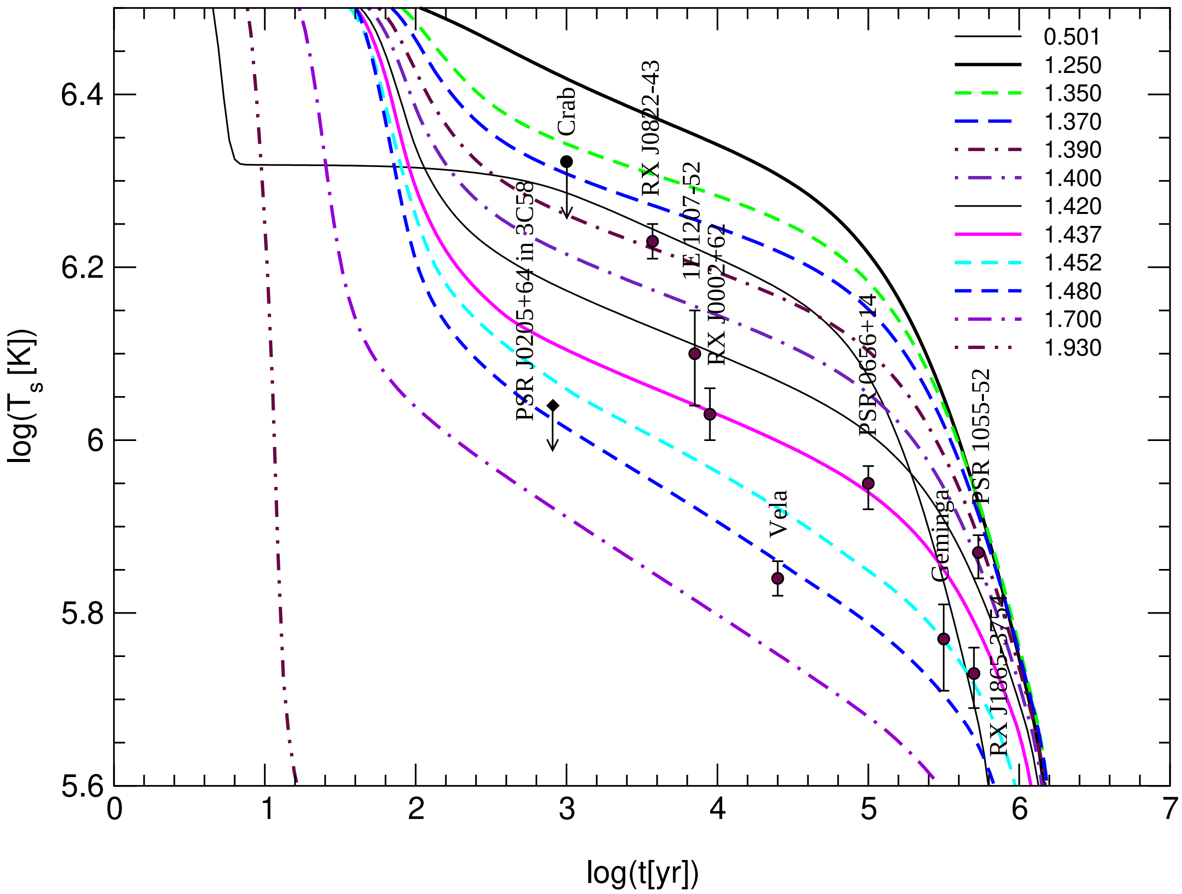
Cooling curves for model I.



From Blaschke et al. (2004); astro-ph/ 0403170.

Cooling of NS configuration with superfluid nuclear matter with medium effects and with pion condensation. The gaps are taken from Takatsuka & Tamagaki (2004), the neutron gap $3P_2$ is additionally suppressed. The T_s-T_{in} relation is given by a fit.

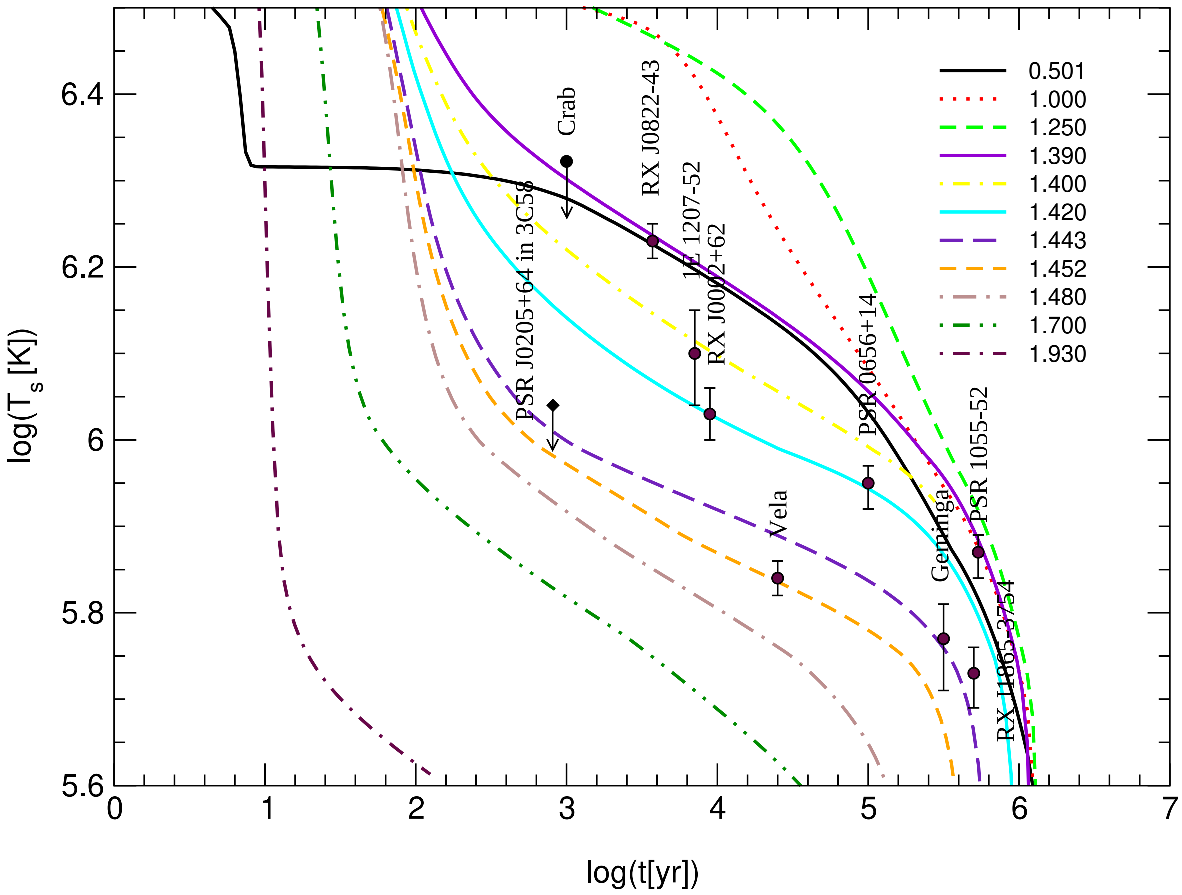
Cooling curves for model II.



From Blaschke et al. (2004); astro-ph/ 0403170.

Cooling of NS configuration with superfluid nuclear matter with medium effects but without pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The $T_{\rm s}$-$T_{\rm in}$ relation is given by the Tsuruta law.

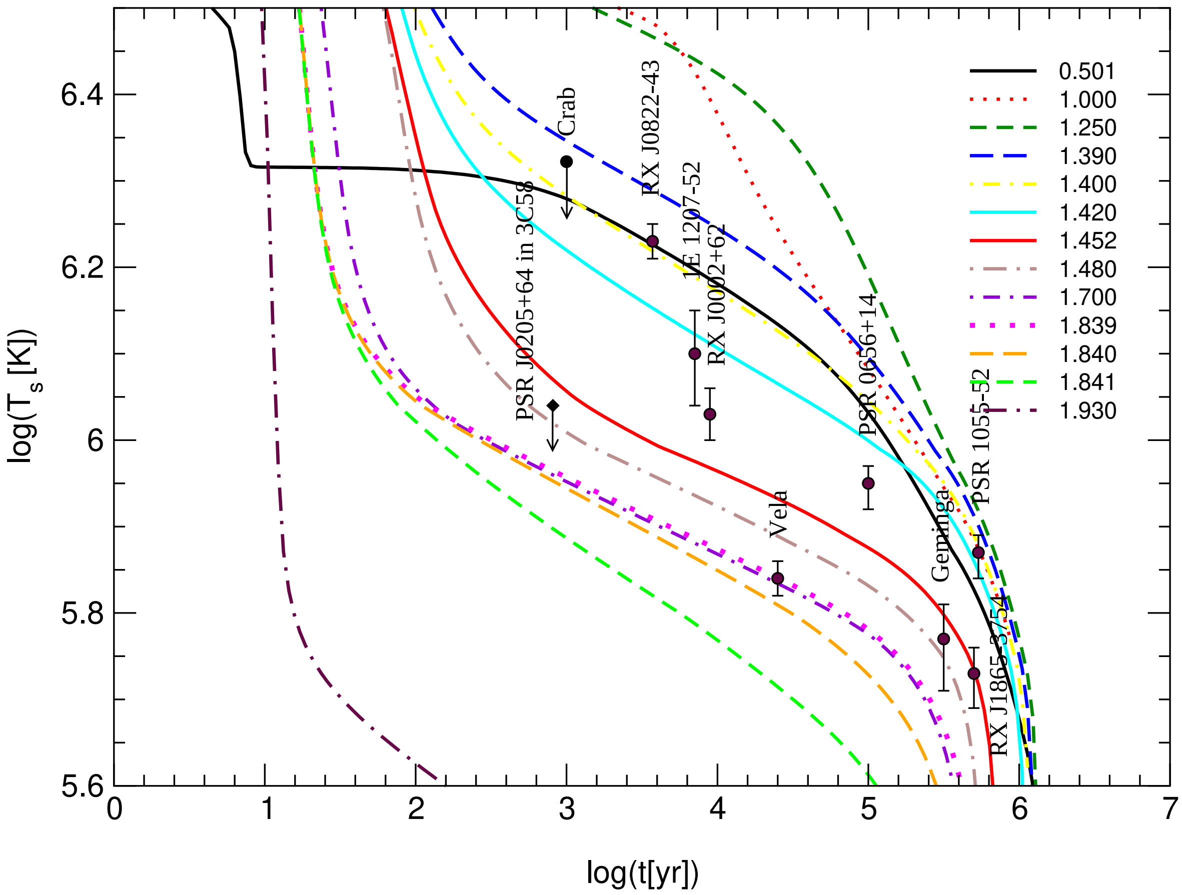
Cooling curves for model III.



From Blaschke et al. (2004); astro-ph/ 0403170.

Cooling of NS configuration with superfluid nuclear matter with medium effects and with pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The T_s-T_{in} relation is given by a fit.

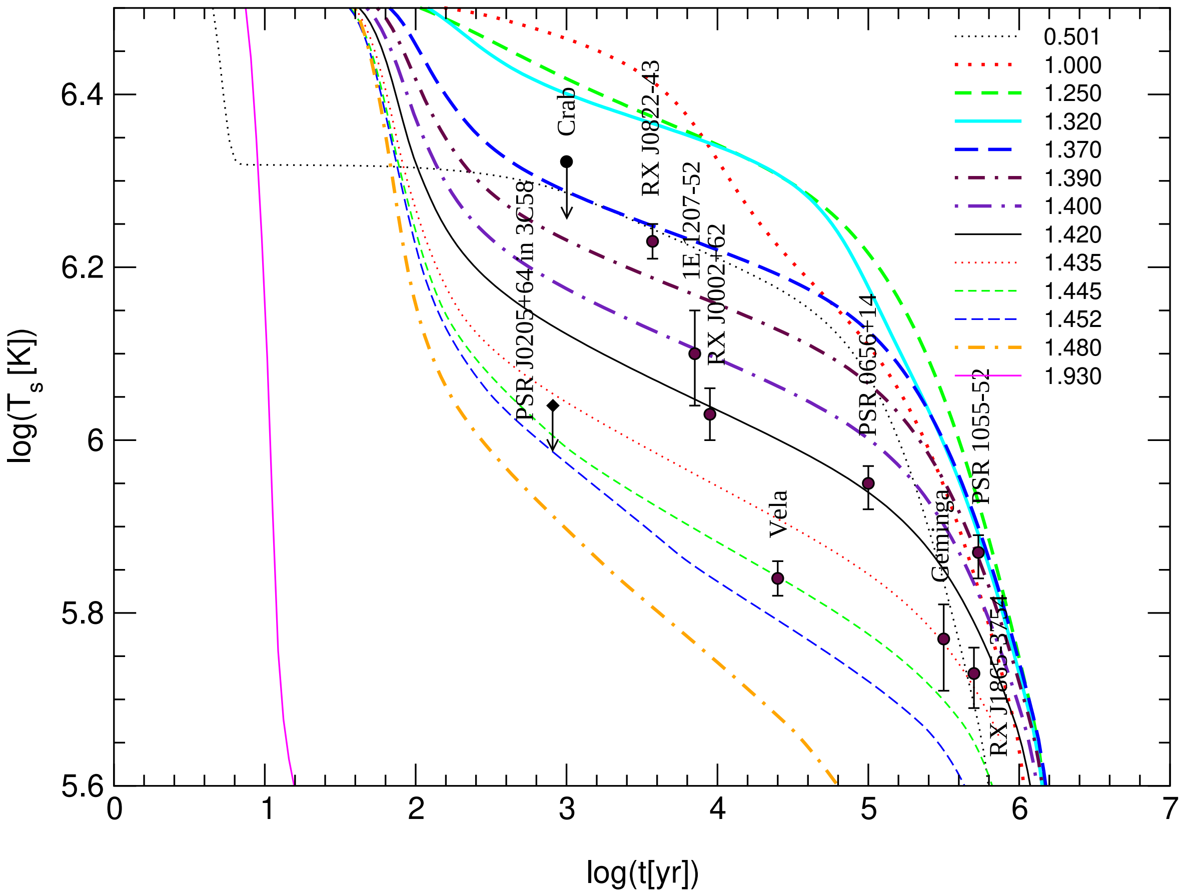
Cooling curves for model IV.



From Blaschke et al. (2004); astro-ph/ 0403170.

Cooling of NS configuration with superfluid nuclear matter with medium effects but without pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The T_s-T_in relation is given by a fit.

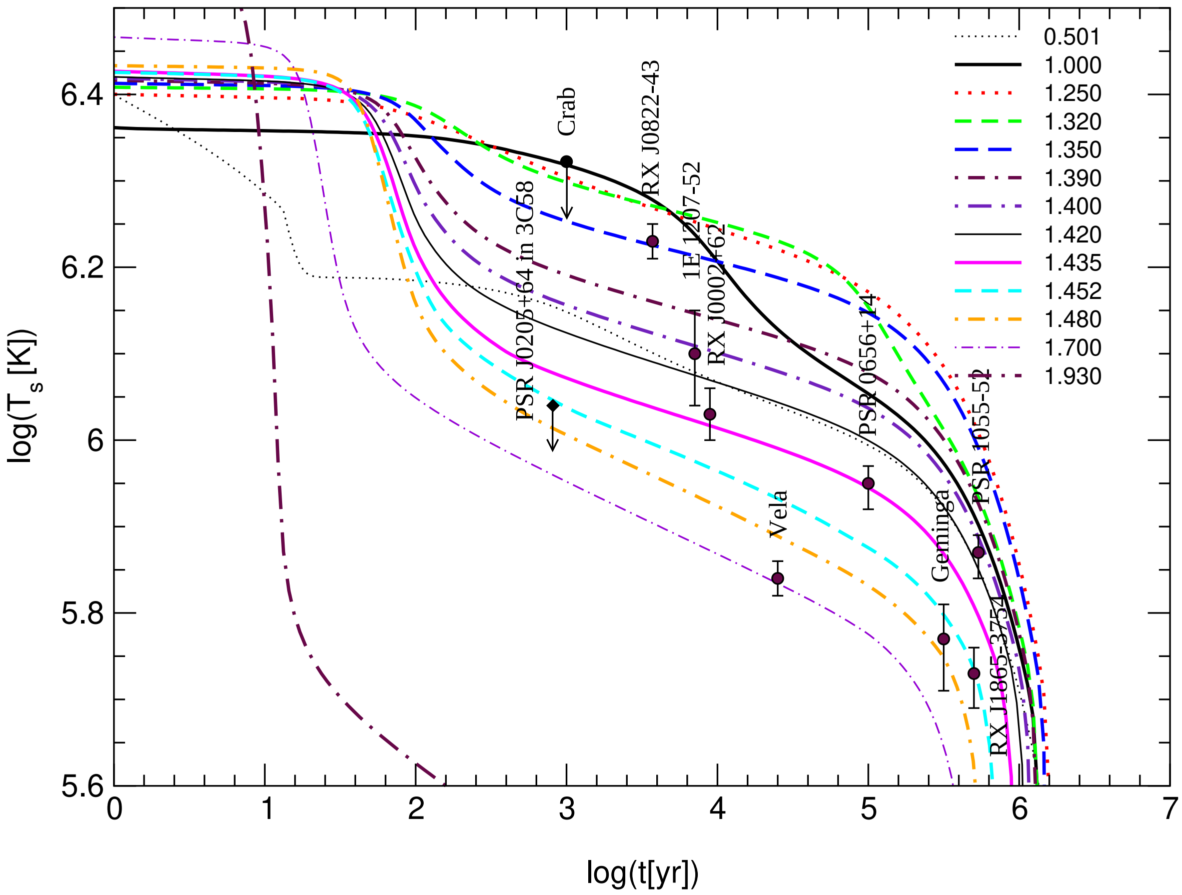
Cooling curves for model V.



From Blaschke et al. (2004); astro-ph/ 0403170.

Cooling of NS configuration with superfluid nuclear matter with medium effects and with pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The $T_{\rm s}$-$T_{\rm in}$ relation is given by the Tsuruta law.

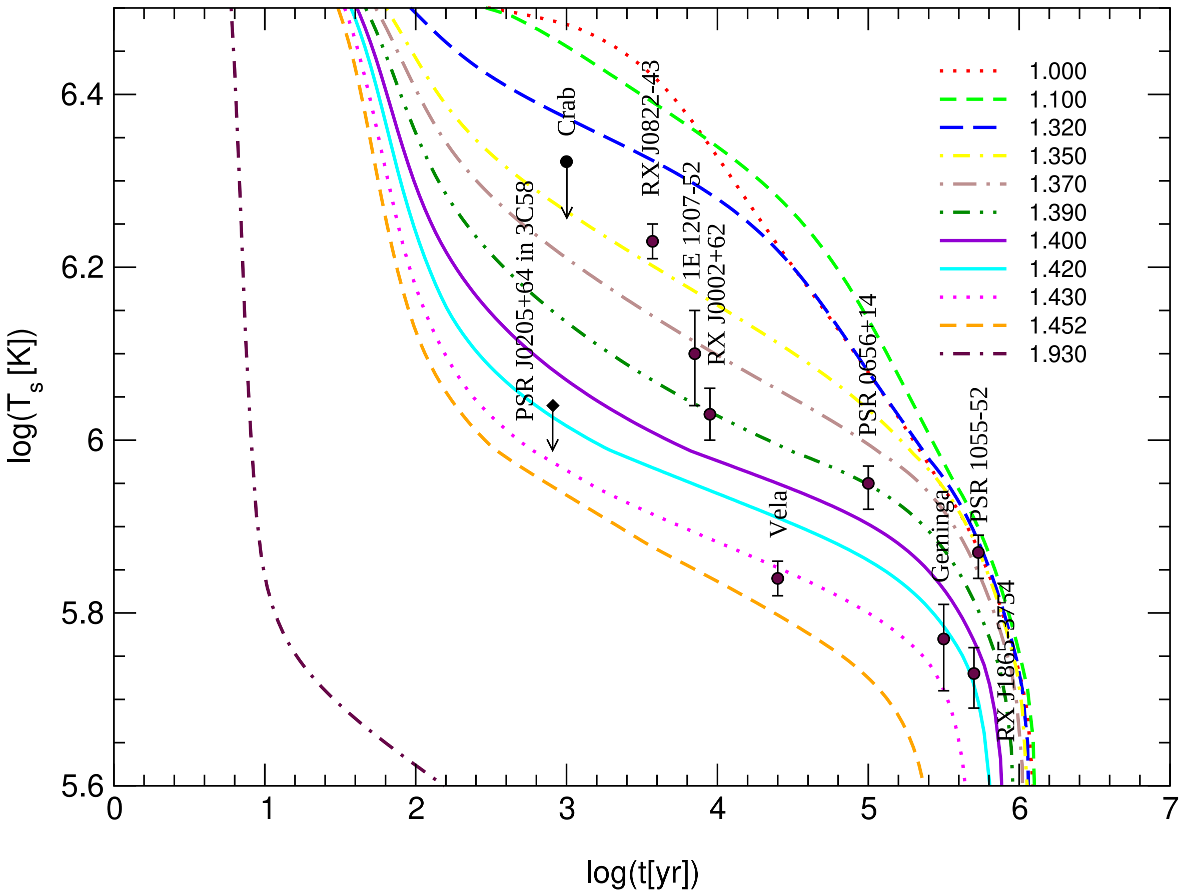
Cooling curves for model VI.



From Blaschke et al. (2004); astro-ph/ 0403170.

Cooling of NS configuration with superfluid nuclear matter with medium effects but without pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The $T_{\rm s}$-$T_{\rm in}$ relation is from Yakovlev et al. (2003), $\eta = 4 \cdot 10^{-16}$.

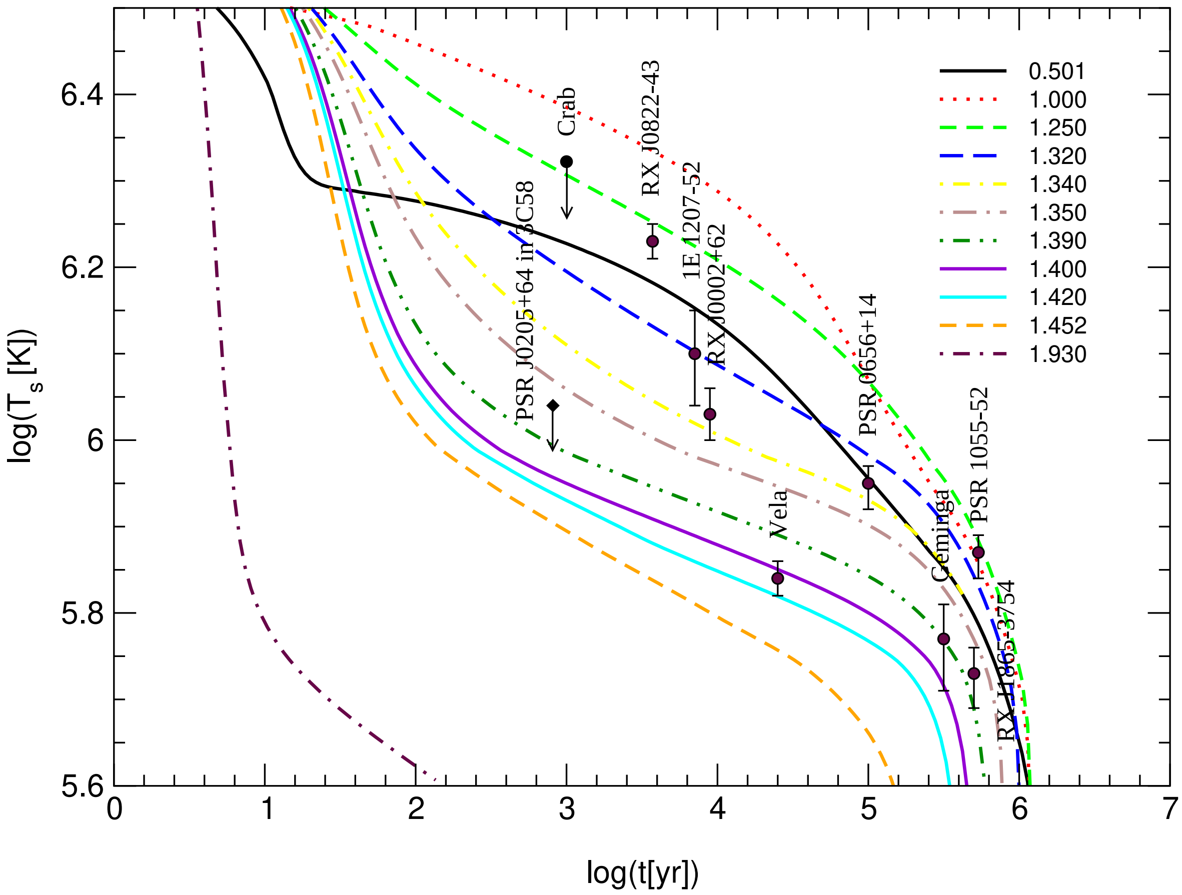
Cooling curves for model VII.



From Blaschke et al. (2004); astro-ph/ 0403170.

Cooling of NS configuration with superfluid nuclear matter with medium effects and with pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The T_s-T_{in} relation is given by a fit. The proton gap is suppressed by a factor 0.5.

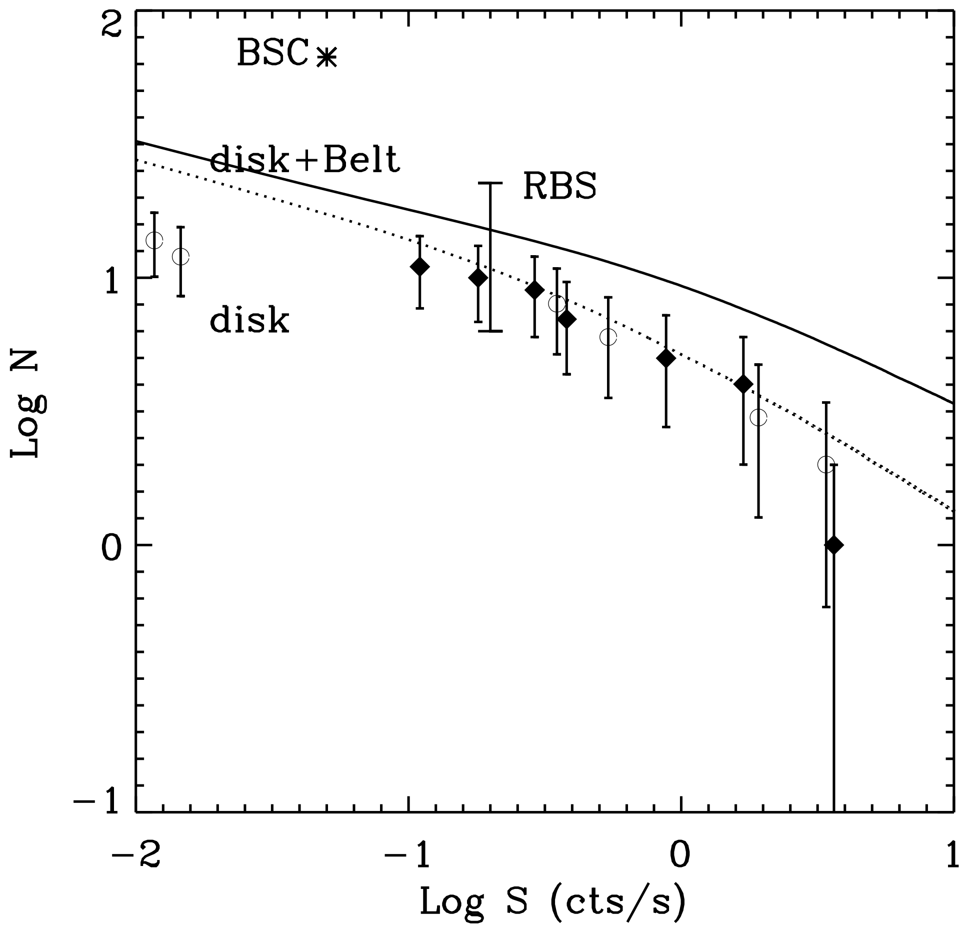
Cooling curves for model VIII.



From Blaschke et al. (2004); astro-ph/ 0403170.

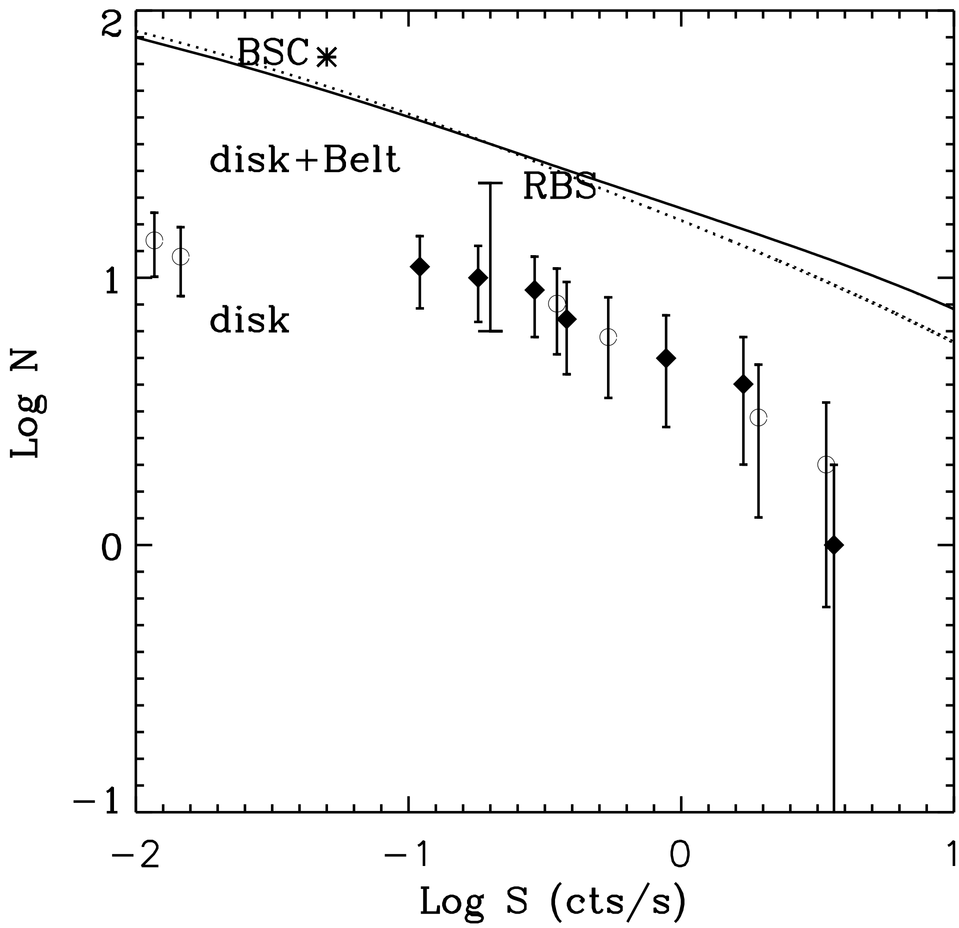
Cooling of NS configuration with superfluid nuclear matter with medium effects and with pion condensation. The gaps are taken from Yakovlev et al. (2003), the neutron gap $3P_2$ is additionally suppressed. The $T_{\rm s}$-$T_{\rm in}$ relation is given by a fit. The $1S_0$ neutron gap suppressed by a factor 0.5 and $1S_0$ proton gap by a factor 0.2. The neutron $3P_2$ gap is remained to be suppresed by 0.1.

Log N - Log S for model I.



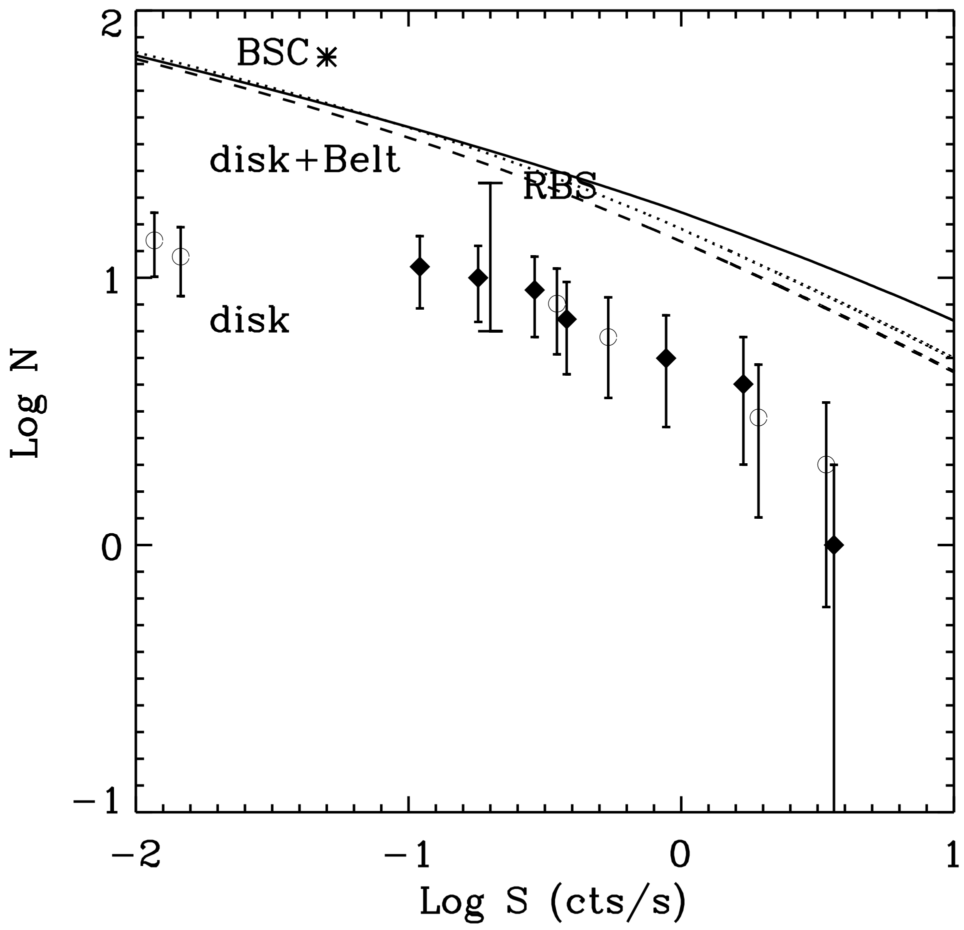
Solid line – $R_{belt} = 300$ pc, mass spectrum is not cutted.
Dotted line – $R_{belt} = 500$ pc, mass spectrum is cutted (no $M = 1.1\,M_{\odot}$).

Log N - Log S for model II.



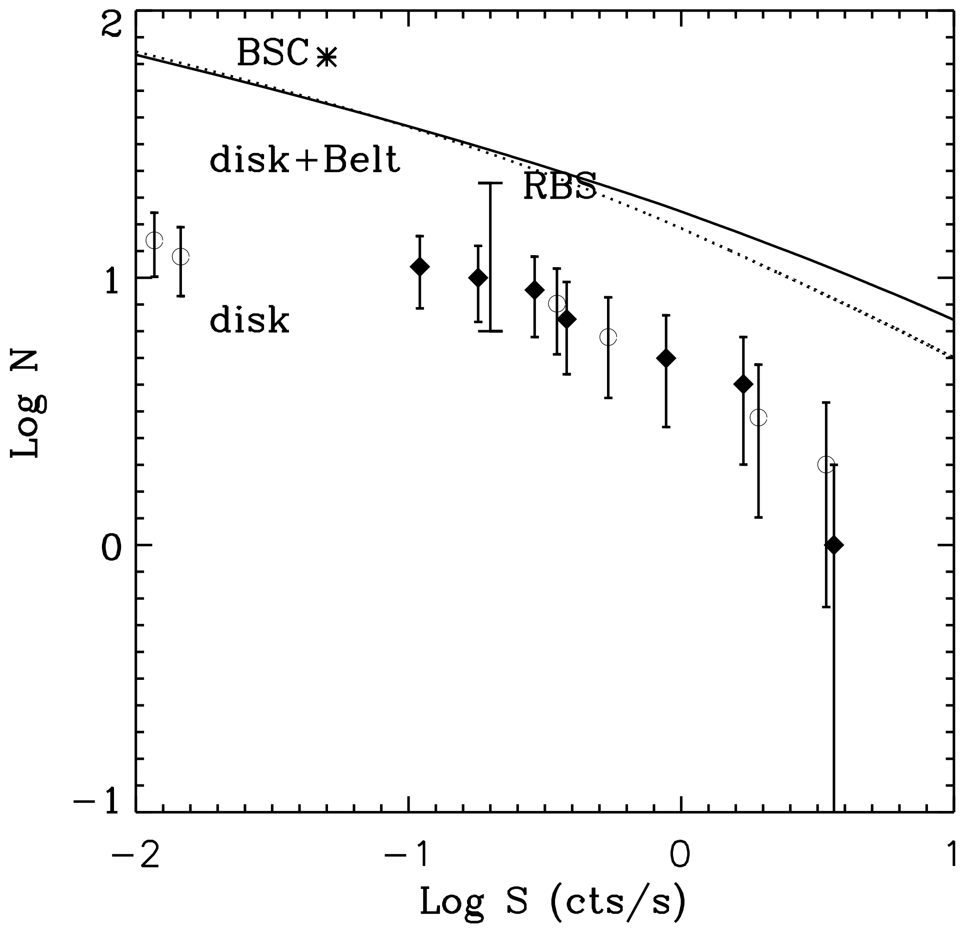
Solid line – $R_{belt} = 300$ pc, mass spectrum is not cutted.
Dotted line – $R_{belt} = 500$ pc, mass spectrum is cutted (no $M = 1.1\,M_{\odot}$).

Log N - Log S for model III.



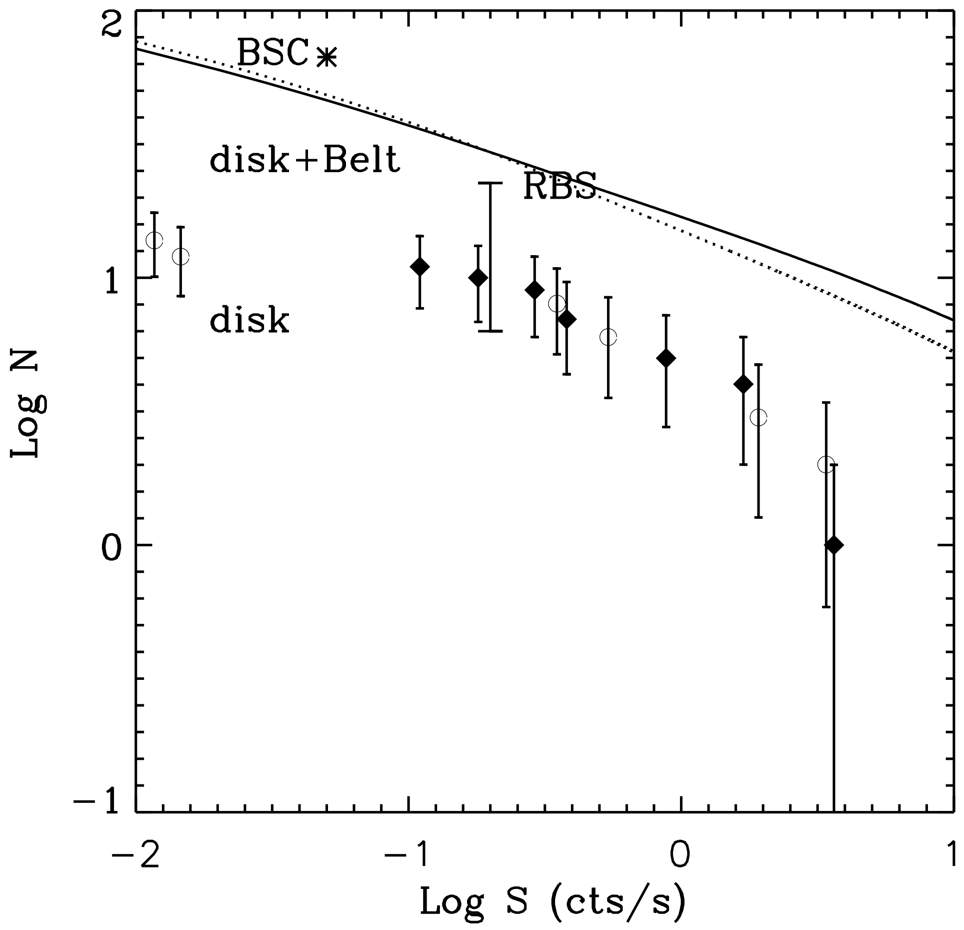
Solid line – $R_{belt} = 300$ pc, mass spectrum is not cutted.
Dotted line – $R_{belt} = 500$ pc, mass spectrum is cutted (no $M = 1.1\,M_{\odot}$).
Dashed line – $R_{belt} = 500$ pc, mass spectrum is not cutted.

Log N - Log S for model IV.



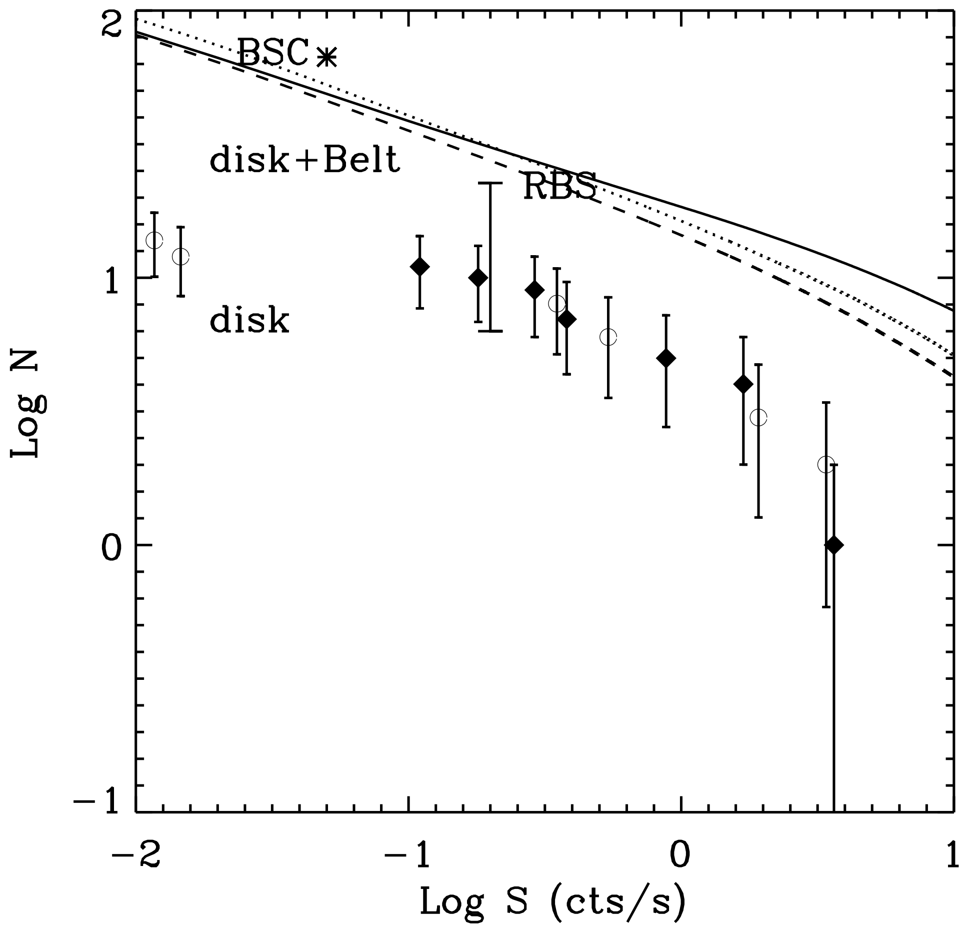
Solid line – $R_{belt} = 300$ pc, mass spectrum is not cutted.
Dotted line – $R_{belt} = 500$ pc, mass spectrum is cutted (no $M = 1.1\,M_{\odot}$).

Log N - Log S for model V.



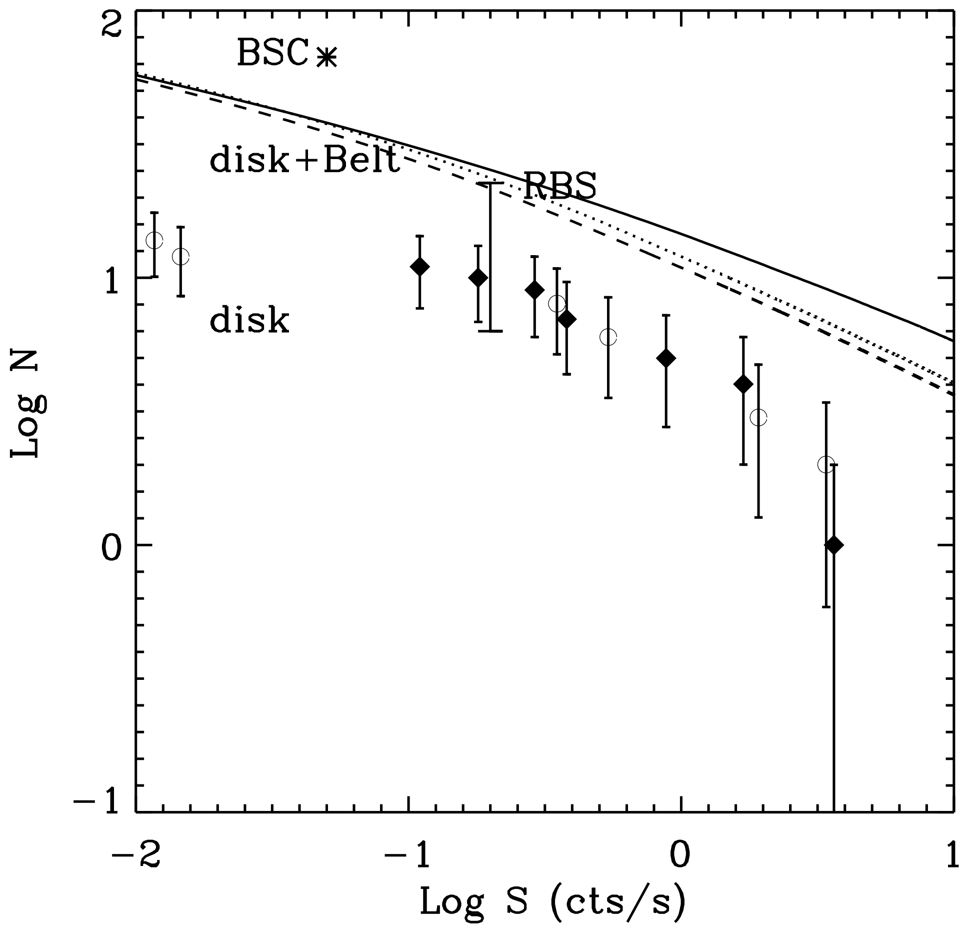
Solid line – $R_{belt} = 300$ pc, mass spectrum is not cutted.
Dotted line – $R_{belt} = 500$ pc, mass spectrum is cutted (no $M = 1.1\, M_{\odot}$).

Log N - Log S for model VI.



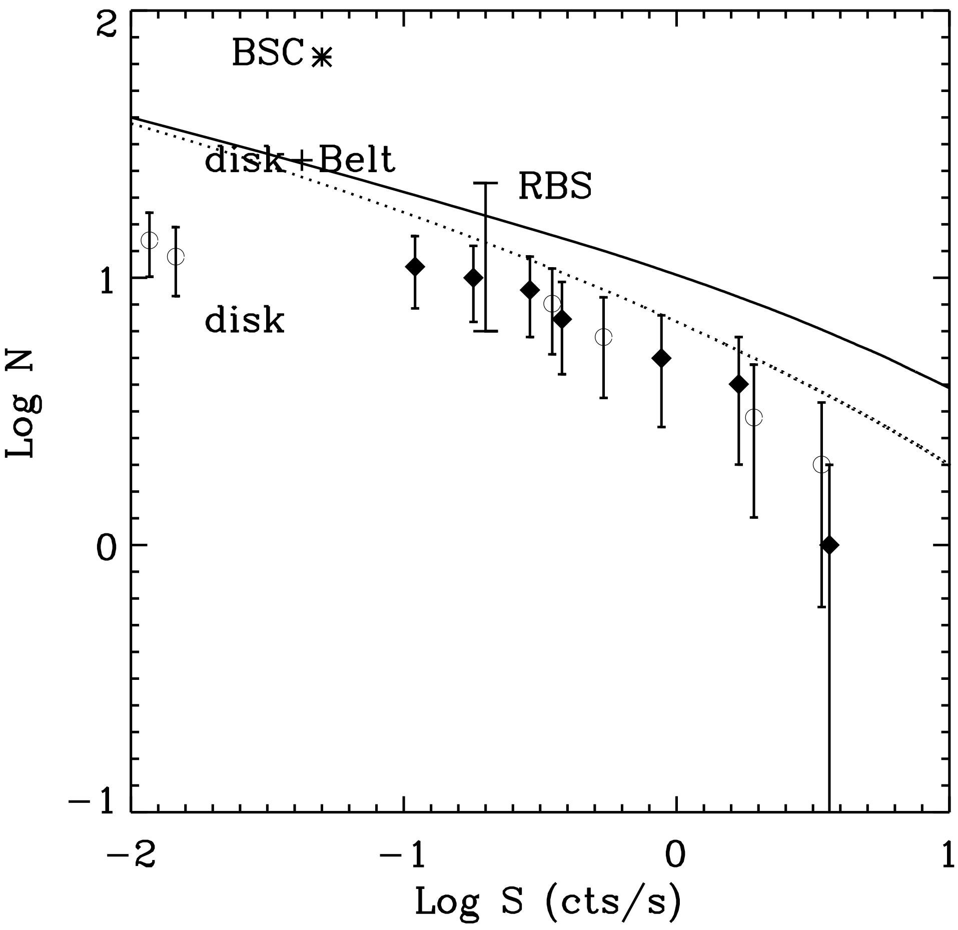
Solid line – $R_{belt} = 300$ pc, mass spectrum is not cutted.
Dotted line – $R_{belt} = 500$ pc, mass spectrum is cutted (no $M = 1.1\,M_{\odot}$).
Dashed line – $R_{belt} = 500$ pc, mass spectrum is not cutted.

Log N - Log S for model VII.



Solid line – $R_{belt} = 300$ pc, mass spectrum is not cutted.
Dotted line – $R_{belt} = 500$ pc, mass spectrum is cutted (no $M = 1.1\,M_{\odot}$).
Dashed line – $R_{belt} = 500$ pc, mass spectrum is not cutted.

Log N - Log S for model VIII.



Solid line – $R_{belt} = 300$ pc, mass spectrum is not cutted.
Dotted line – $R_{belt} = 500$ pc, mass spectrum is cutted (no $M = 1.1\,M_{\odot}$).

Conclusions.

- Log N - Log S distribution of close-by NSs can be a potential test for cooling curves.
- Main difficulties are connected with uncertainties in:
  - Mass spectrum of NSs
  - Emission model (atmospheres etc.)
- Log N - Log S as a test is free from many disadvantages of the $T - t$ test.
- As Log N - Log S has its own problems and uncertainties two test should be used together