

# Consistency between deep crustal heating of strange stars in superbursters and soft X-ray transients



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## Abstract

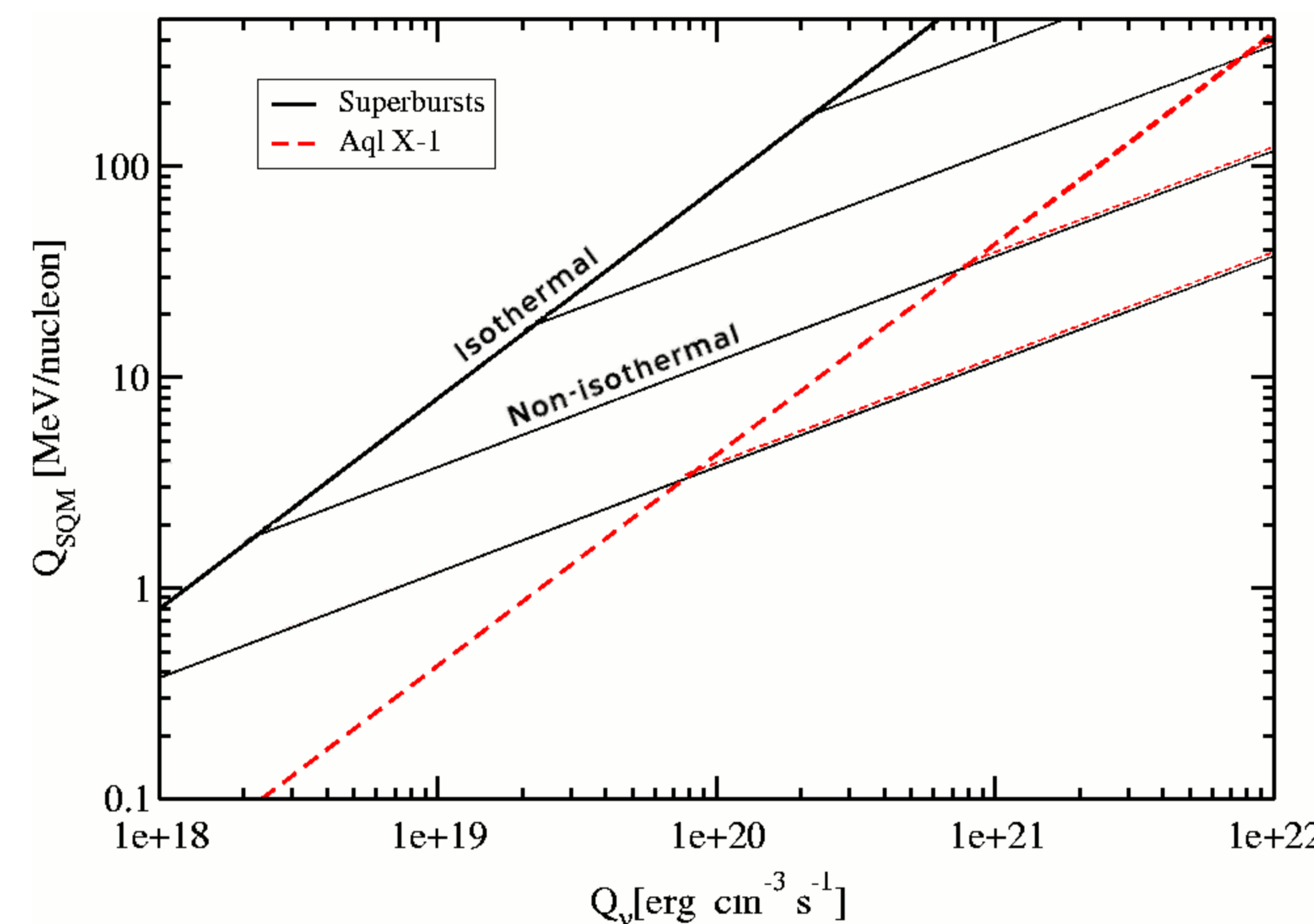
Both superbursters and soft X-ray transients probe the thermal structure of the crust on compact stars and are sensitive to the process of deep crustal heating. It was recently shown that the transfer of matter from crust to core in a strange star can heat the crust and ignite superbursts provided certain constraints on the strange quark matter equation of state are fulfilled [1]. We derive corresponding constraints on the equation of state for soft X-ray transients in a simple parametrized model assuming their quiescent emission is powered in the same way, and further discuss the time dependence of this heating mechanism in transient systems [2].

## Strange Stars, Superbursters and Soft X-Ray Transients

➤ **Superbursters** are LMXBs accreting near the Eddington rate, which display rare but extremely energetic and long lasting type I X-ray bursts. Ignition must happen at densities around  $10^9 \text{ g cm}^{-3}$  and temperatures of  $6 \cdot 10^8 \text{ K}$  to fit observed lightcurves [3].

➤ **Soft X-ray transients** (SXTs) are LMXBs which undergo short accretion outbursts separated by long periods of relative quiescence during which the crust quickly relaxes to a thermal state determined by the cooling core heated during the outburst.

➤ **Strange stars** have no inner crust with free neutrons because their crust is sustained electrostatically above the quark matter core by a huge electric field due to a slight deficit of s-quarks in the core [4]. Hence they cannot be heated by pycnonuclear reactions like neutron stars [5], but deconfinement heating because of transfer of matter from crust to core is potentially just as powerful.



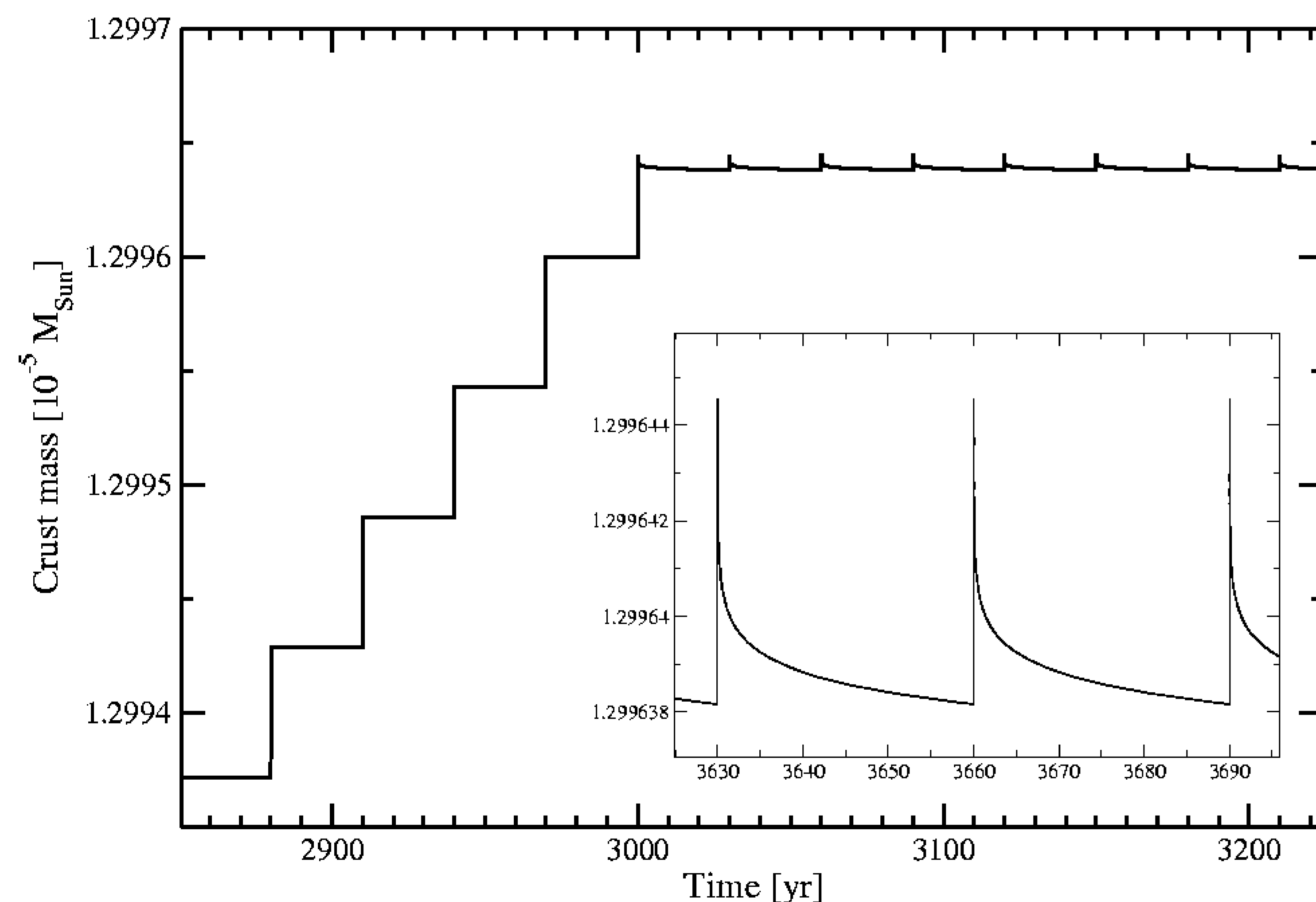
**Fig. 1.** Constraints on the core parameters for strange stars in superbursters and the soft X-ray transient Aql X-1 assuming the core cools only by neutrino emission. From below the thermal conductivity is  $K = 10^{19}, 10^{20}, 10^{21}$  and  $10^{22}$  cgs for the non-isothermal lines.

➤ **Balancing** neutrino cooling with deconfinement heating,  $\dot{Q}_{\text{SQM}} dm_{\text{crust}}/dt - L_{\nu} = 0$ , in a plane-parallel core with thermal conductivity,  $K$ , and slow neutrino emissivity,  $\epsilon_{\nu} = Q_{\nu} T_9^8 \text{ erg cm}^{-3} \text{ s}^{-1}$ , constrains the core parameters as shown in Fig. 1. The core is isothermal for sufficiently high thermal conductivity and we see that the isothermal constraints are not consistent. The non-isothermal constraints look much better.

➤ **Scaling the model** to the superbursters (subscript SB) and taking blackbody cooling from the surface into account we get the surface temperature,  $T_s = [10T_9]^{1/2}$ :

$$\dot{m} Q_{\text{SQM}} = \left(\frac{0.1}{0.7}\right)^{9/2} \dot{m}_{\text{SB}} Q_{\text{SQM}} T_{\text{S},6}^9 + \sigma T_s^4$$

for a non-isothermal core and a similar expression for the isothermal case. This provides a steady state minimum temperature and is compared to the few cases where  $T_s$  is observed in Fig. 2.

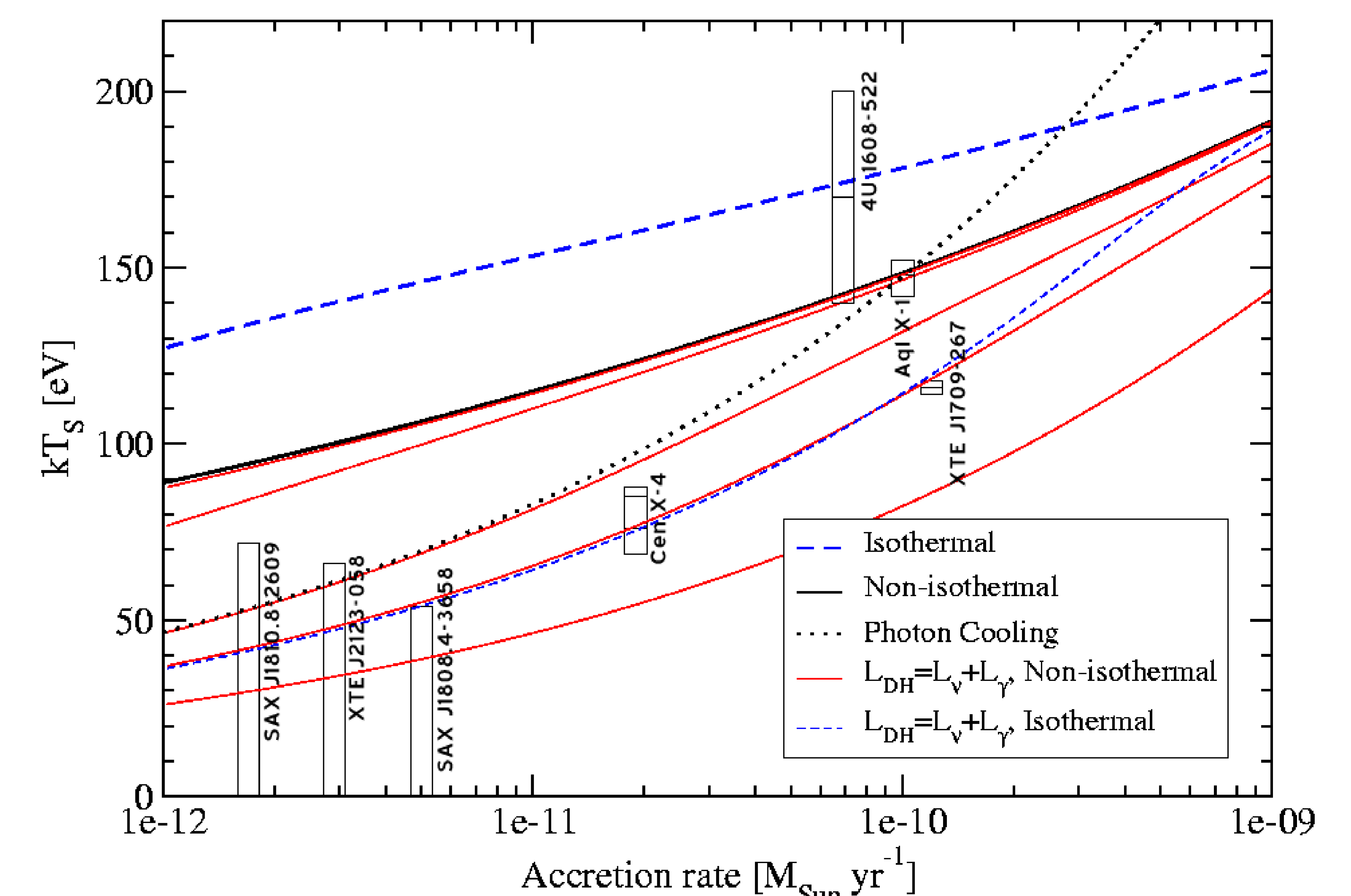


**Fig 3.** Crust mass for a strange star with 10 day long accretion outbursts separated by quiescent intervals of 30 years with an average accretion rate of  $1.9 \cdot 10^{-11} M_{\odot} \text{ yr}^{-1}$  – a crude model for Cen X-4. Eventually the crust reaches a maximum mass and is then in equilibrium transferring most of the accreted mass during or immediately after each outburst.

## Discussion

To explain the coldest soft X-ray transients with the steady state model discussed above we see in Fig. 2 that  $Q_{\text{SQM}}$ , the quark matter binding energy, must be 0.4 MeV or lower. This is conspicuously fine-tuned and would be inconsistent with the mass and radius determined for EXO 0748–676 [6].

Alternatively we note that the transmission coefficient for ions in the crust scattering off the Coulomb barrier which sustains the crust is very density dependent [4]. Thus the heating mechanism is highly time dependent as shown in Fig. 3, and a steady state model may not hold in systems where the outburst recurrence time is longer than a few years such as Cen X-4 – but not SAX J1808.4–3658. This points to the need for a fully time dependent model.



**Fig. 2.** Surface temperature of soft X-ray transients compared to accreting strange stars assuming pure neutrino cooling, pure blackbody cooling and a combination with  $Q_{\text{SQM}} = 0.1, 0.4, 1, 10, 100 \text{ MeV}$  from below. At low accretion rates photon cooling dominates but neutrinos take over near superbursters.