Quark Matter and the Cooling of Compact Stars

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- Collaborators
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  - Stefan Schramm (FIAS - Frankfurt)
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  - Veronica Dexheimer (Kent, OH)

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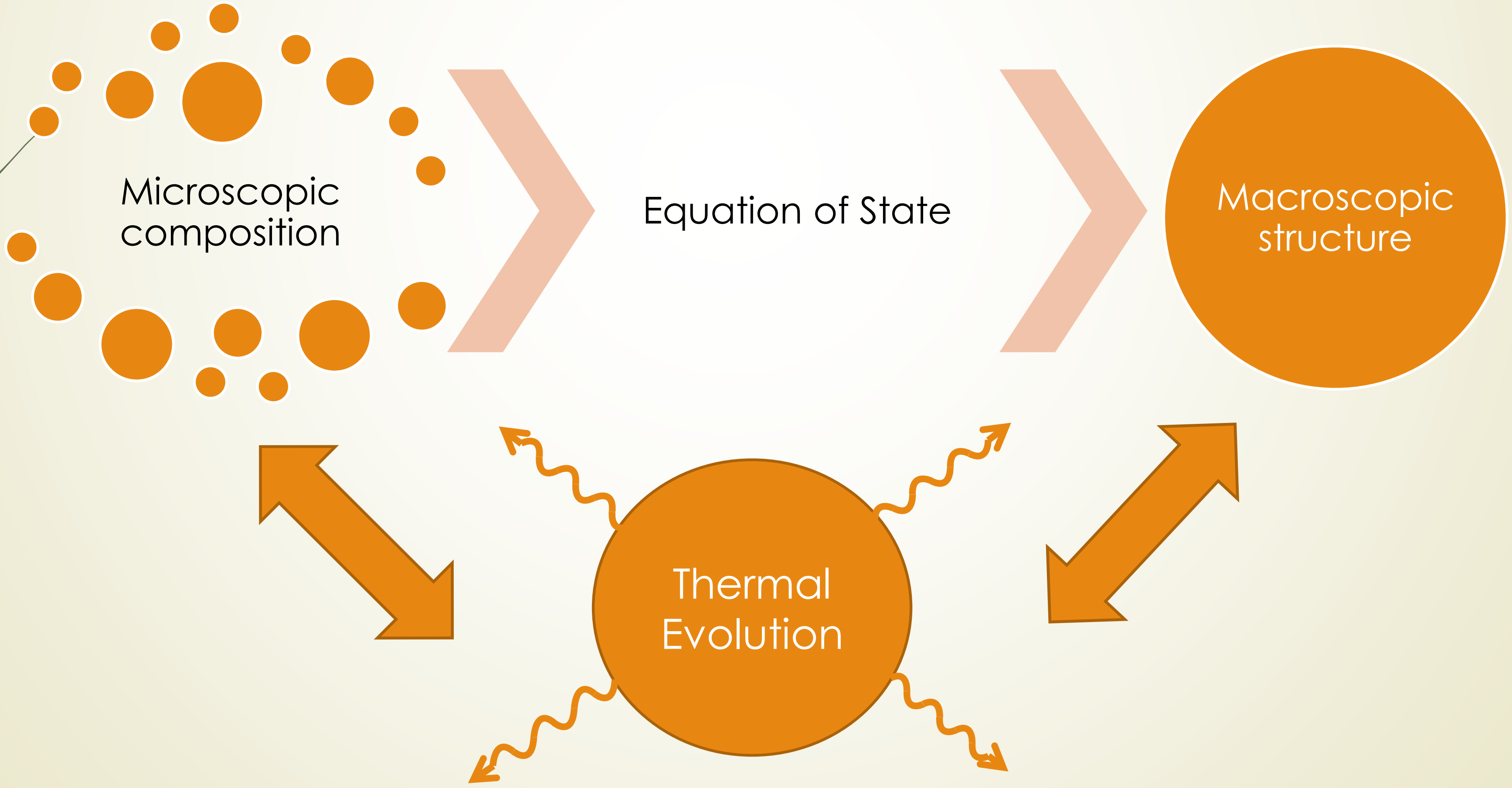
Thermal Evolution - Introduction

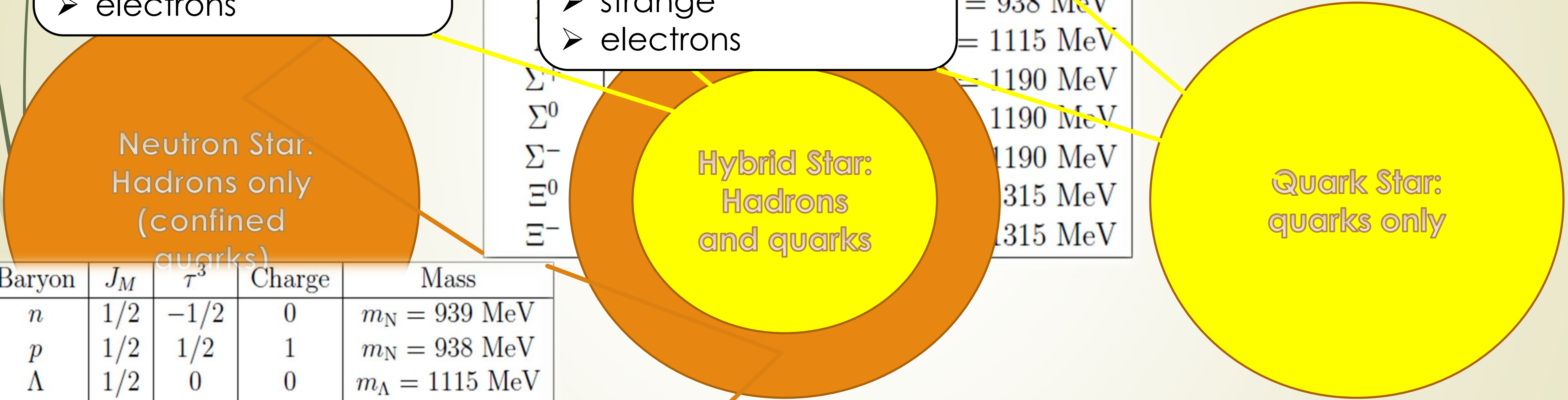
- We need to further constrain the inner composition of compact stars.
- Must make use of all observational data available.
- There is a wealth of data on the thermal properties of compact stars that we can make use of.



Different possible compositions

- up
- down
- strange
- electrons

- up
- down
- strange
- electrons



Baryon	J_M	τ^3	Charge	Mass
n	1/2	−1/2	0	$m_N = 939$ MeV
p	1/2	1/2	1	$m_N = 938$ MeV
Λ	1/2	0	0	$m_\Lambda = 1115$ MeV
Σ^+	1/2	1	1	$m_\Sigma = 1190$ MeV
Σ^0	1/2	0	0	$m_\Sigma = 1190$ MeV
Σ^-	1/2	−1	−1	$m_\Sigma = 1190$ MeV
Ξ^0	1/2	1/2	0	$m_\Xi = 1315$ MeV
Ξ^-	1/2	−1/2	−1	$m_\Xi = 1315$ MeV

Hybrid Star Cooling

- Non-linear sigma SU(3) model

$$L = L_{Kin} + L_{Int} + L_{Self} + L_{SB} - U$$

$$L_{Int} = -\sum_i \bar{\psi}_i[\gamma_0(g_{i\omega}\omega + g_{i\phi}\phi + g_{i\rho}\tau_3\rho) + M_i^*]\psi_i$$

$$L_{Self} = -\frac{1}{2}(m_\omega^2\omega^2 + m_\rho^2\rho^2 + m_\phi^2\phi^2)$$

$$+g_4\left(\omega^4 + \frac{\phi^4}{4} + 3\omega^2\phi^2 + \frac{4\omega^3\phi}{\sqrt{2}} + \frac{2\omega\phi^3}{\sqrt{2}}\right)$$

$$+k_0(\sigma^2 + \zeta^2 + \delta^2) + k_1(\sigma^2 + \zeta^2 + \delta^2)^2$$

$$+k_2\left(\frac{\sigma^4}{2} + \frac{\delta^4}{2} + 3\sigma^2\delta^2 + \zeta^4\right) + k_3(\sigma^2 - \delta^2)\zeta$$

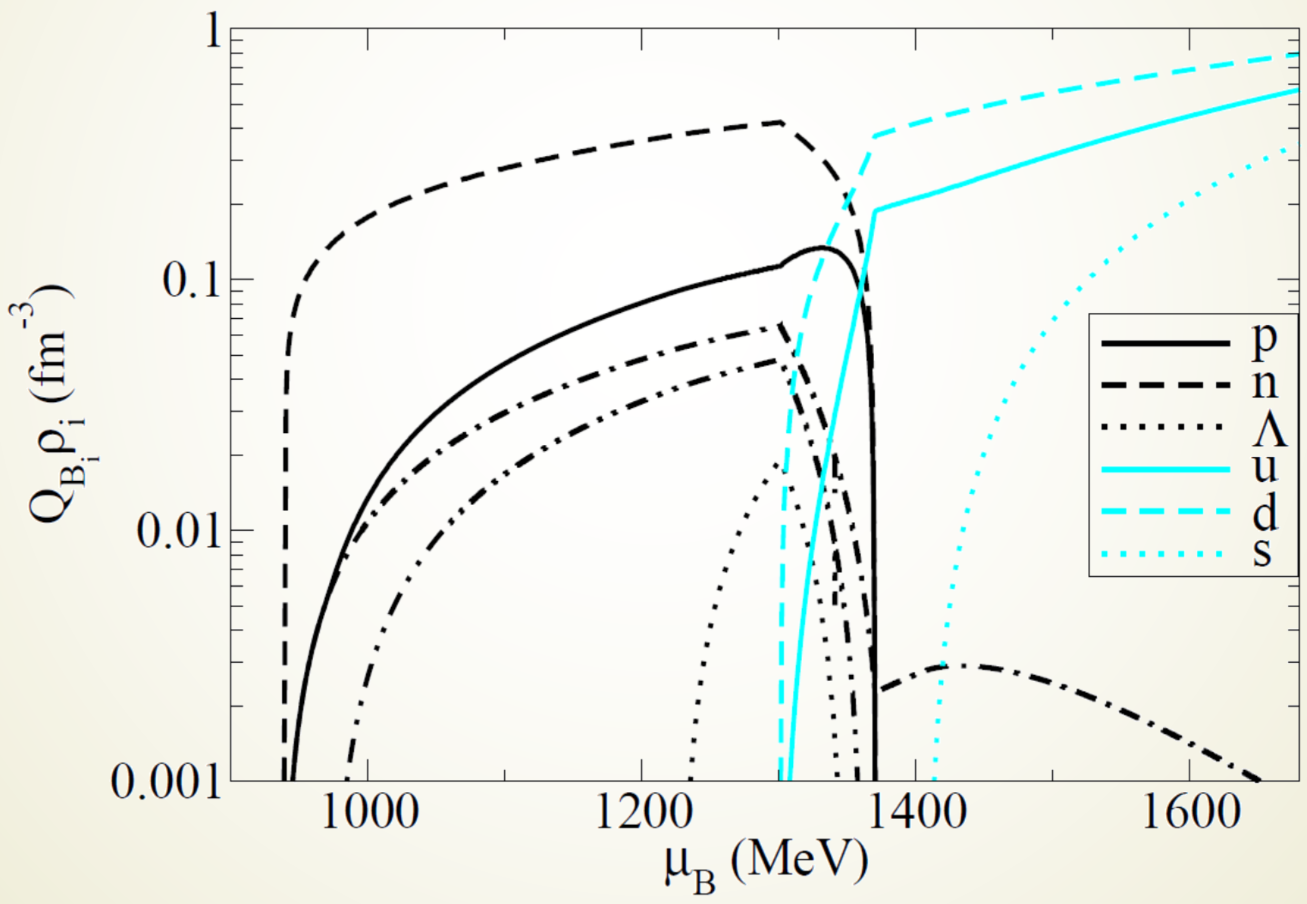
$$+k_4 \quad \ln\frac{(\sigma^2 - \delta^2)\zeta}{\sigma_0^2\zeta_0},$$

$$L_{SB} = m_\pi^2 f_\pi\sigma + \left(\sqrt{2}m_k^2 f_k - \frac{1}{\sqrt{2}}m_\pi^2 f_\pi\right)\zeta$$

R. Negreiros, V.A. Dexheimer, S. Schramm, Phys.Rev.C 82, 035803 (2010)

Hybrid Star Cooling

- Non-linear sigma SU(3) model



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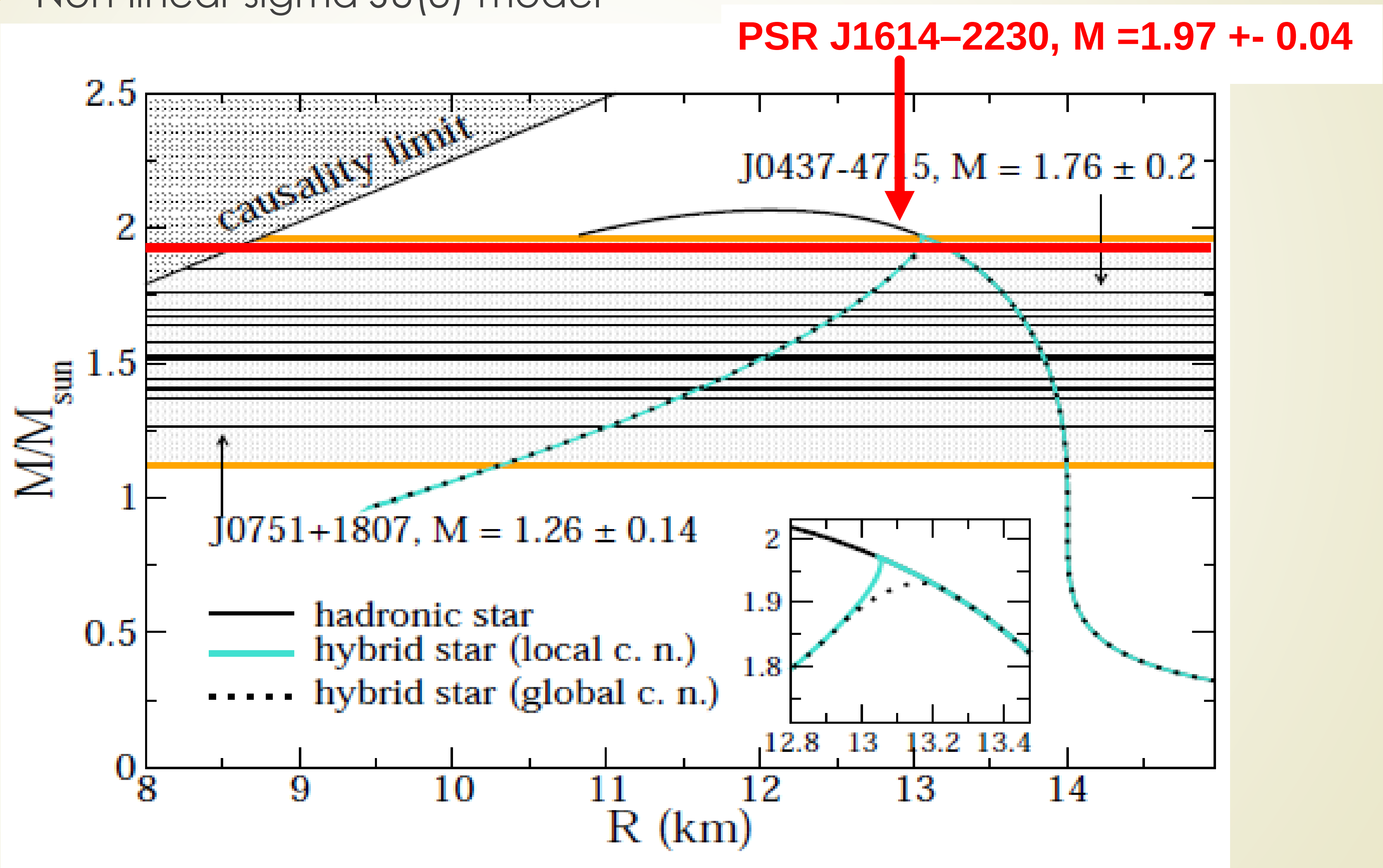

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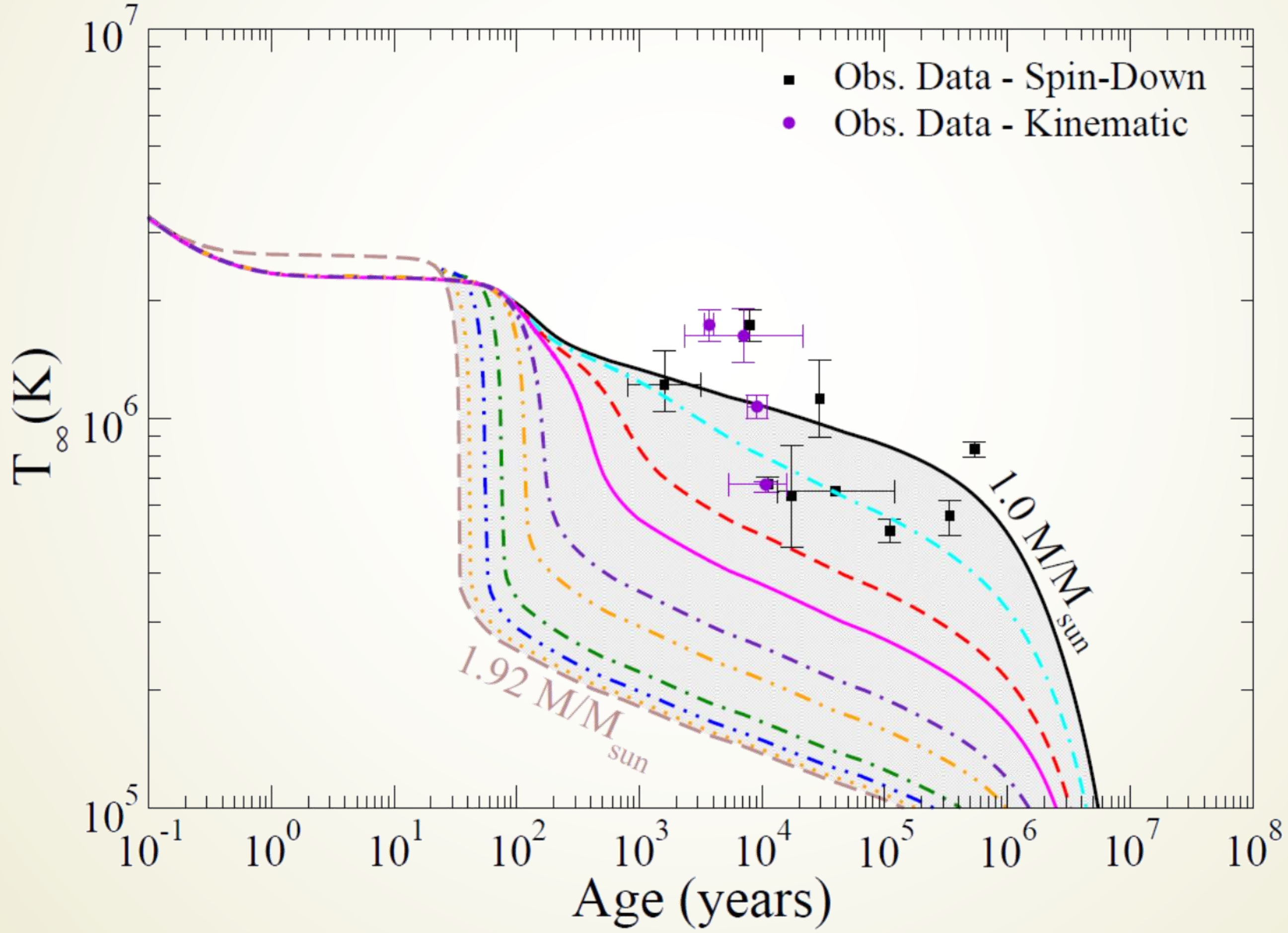
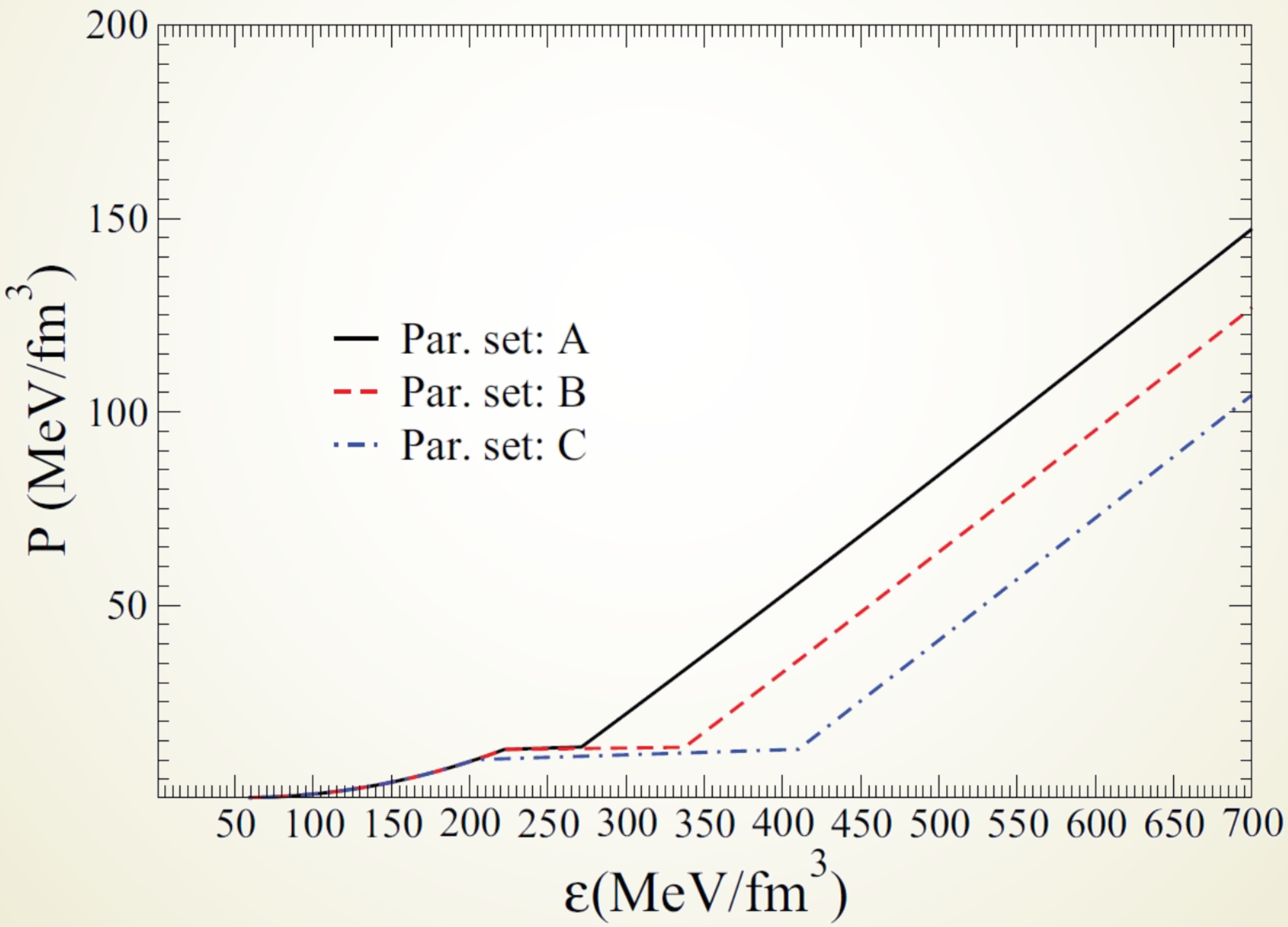


R. Negreiros, V.A. Dexheimer, S. Schramm, Phys.Rev.C 82, 035803 (2010)

Hybrid Star Cooling

- Dependence on the quark-core size

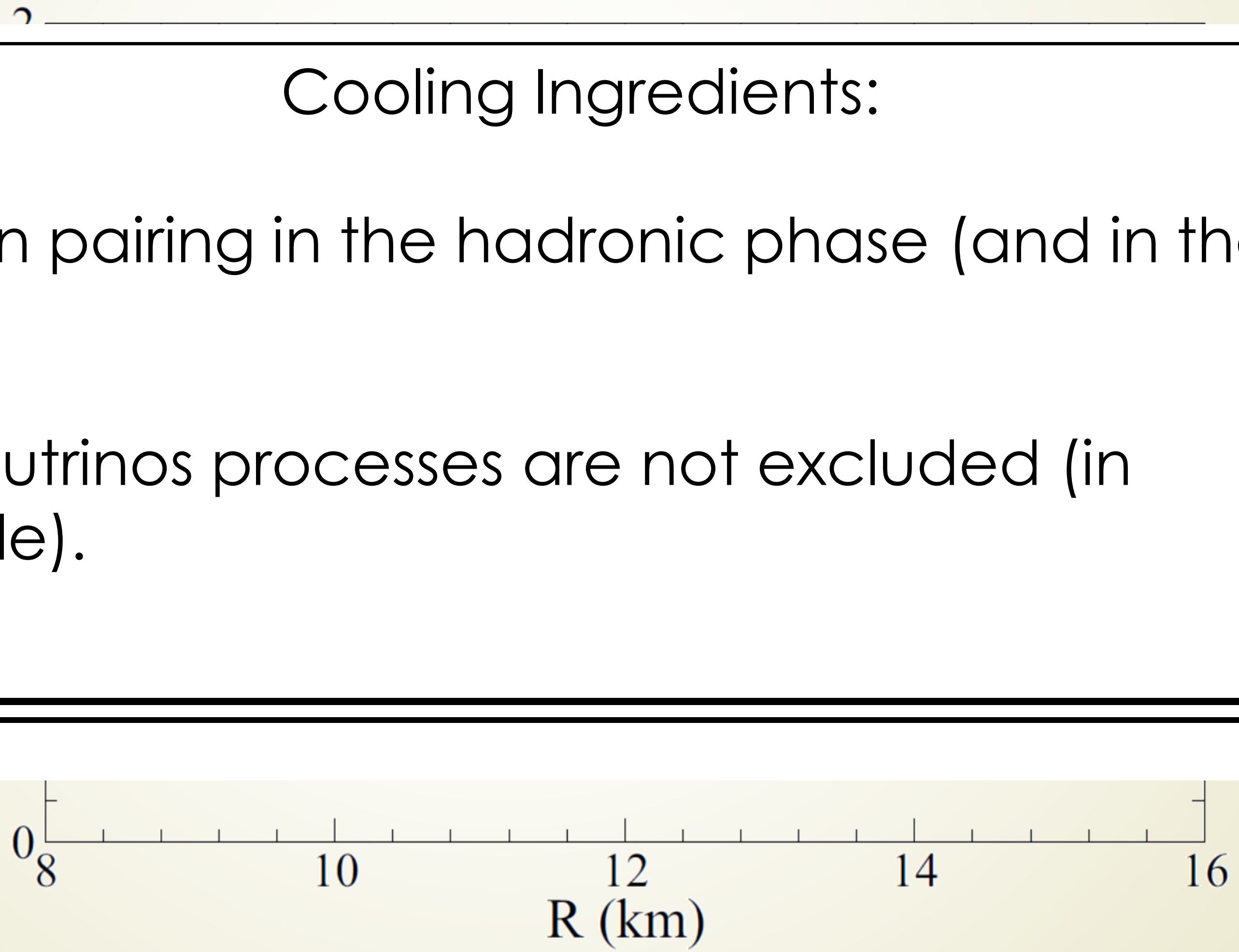
Parameter set	$B^{1/4}$ (MeV)	m_s (MeV)	α_s
A	139	200	0.7
B	150	175	0.4
C	160	150	0.1



R. Negreiros, V.A. Dexheimer, S. Schramm, Phys.Rev.C 85, 035805 (2012)

Hybrid Star Cooling

- Dependence on the quark-core size - Structure



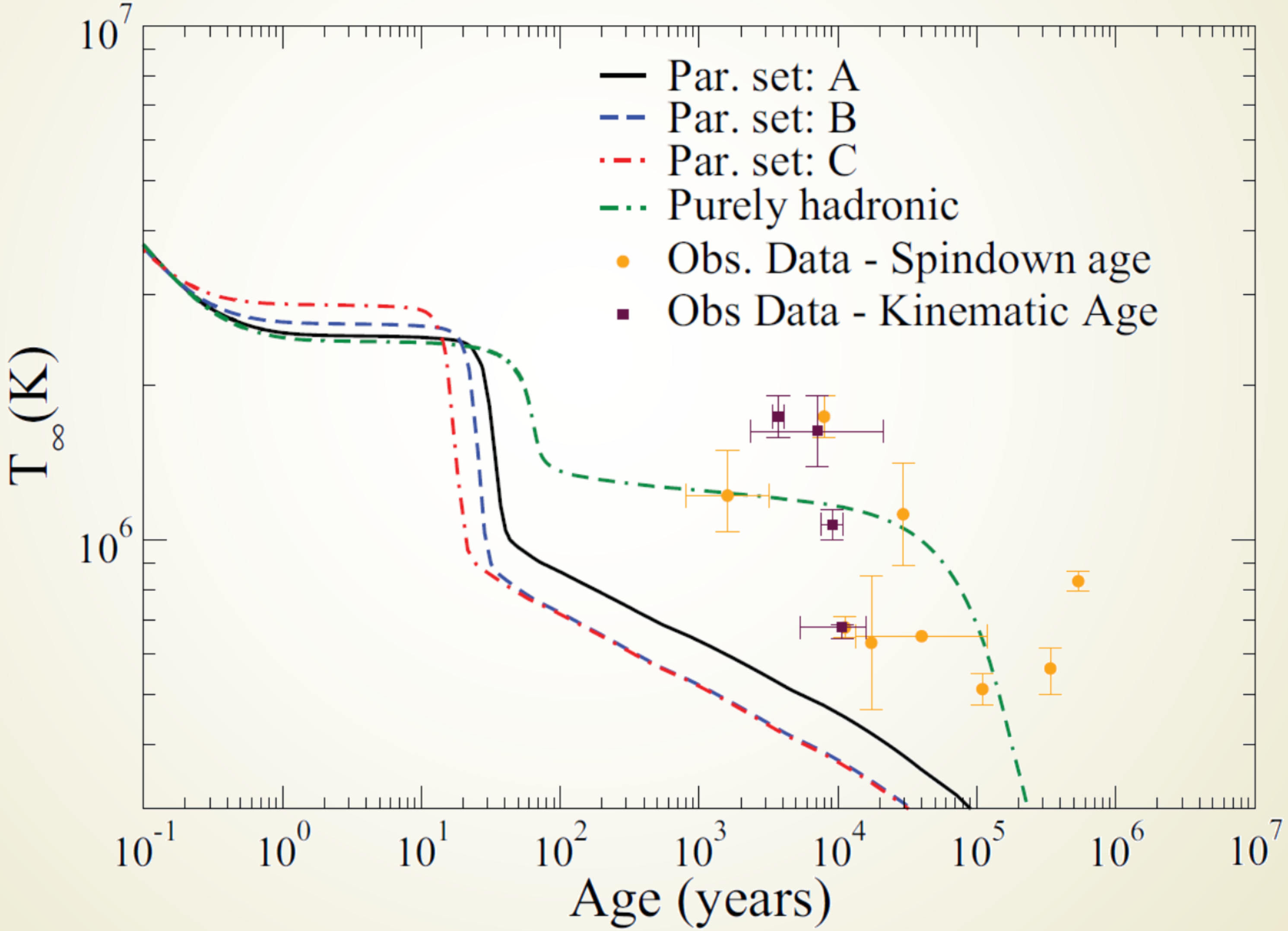
Cooling Ingredients:

- Neutron pairing in the hadronic phase (and in the crust).
- Fast neutrinos processes are not excluded (in principle).

R. Negreiros, V.A. Dexheimer, S. Schramm, Phys.Rev.C 85, 035805 (2012)

Hybrid Star Cooling

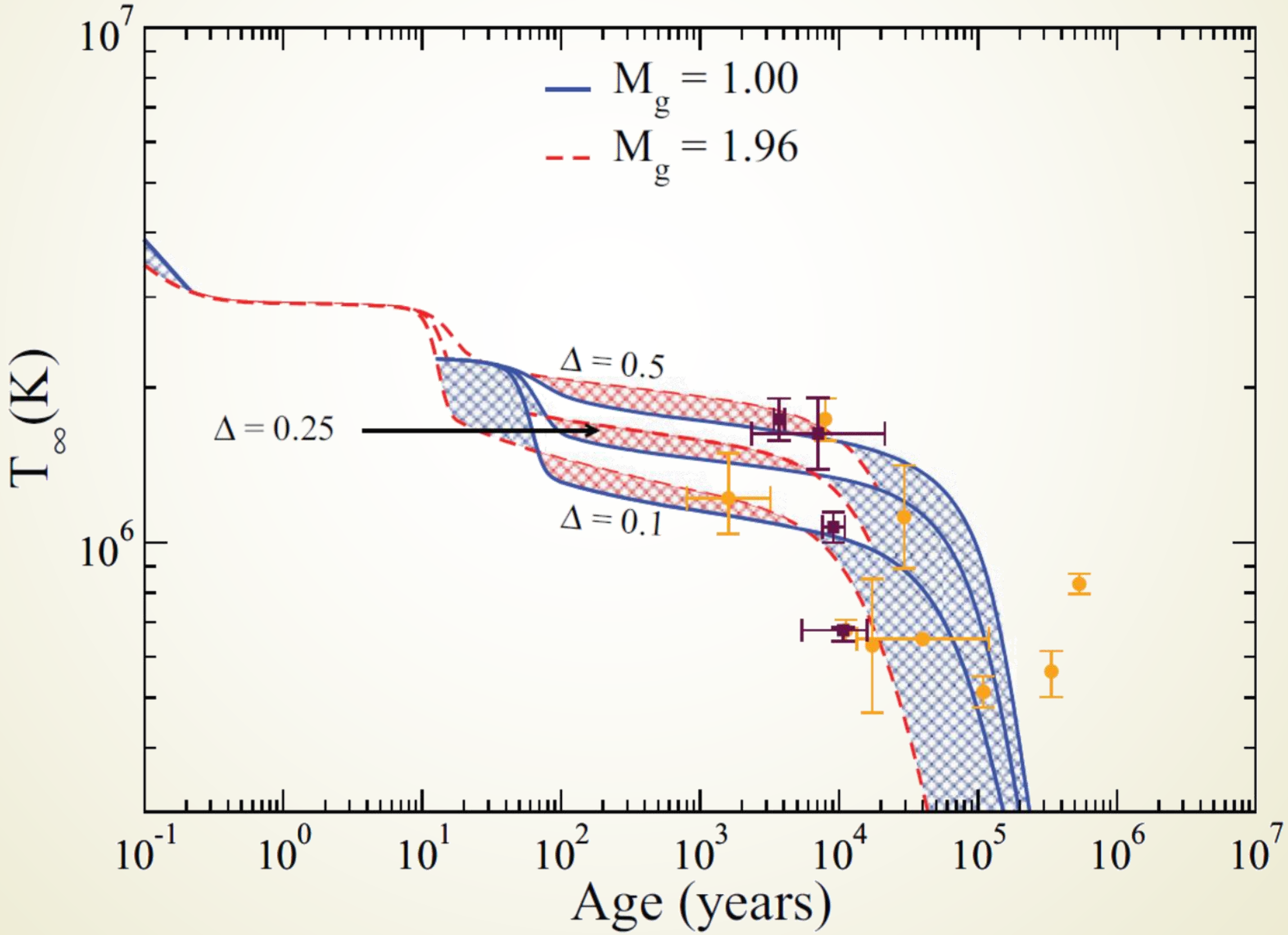
- Dependence on the quark-core size – Cooling – No Quark Pairing (M = 1.4 Msun)



R. Negreiros, V.A. Dexheimer, S. Schramm, Phys.Rev.C 85, 035805 (2012)

Hybrid Star Cooling

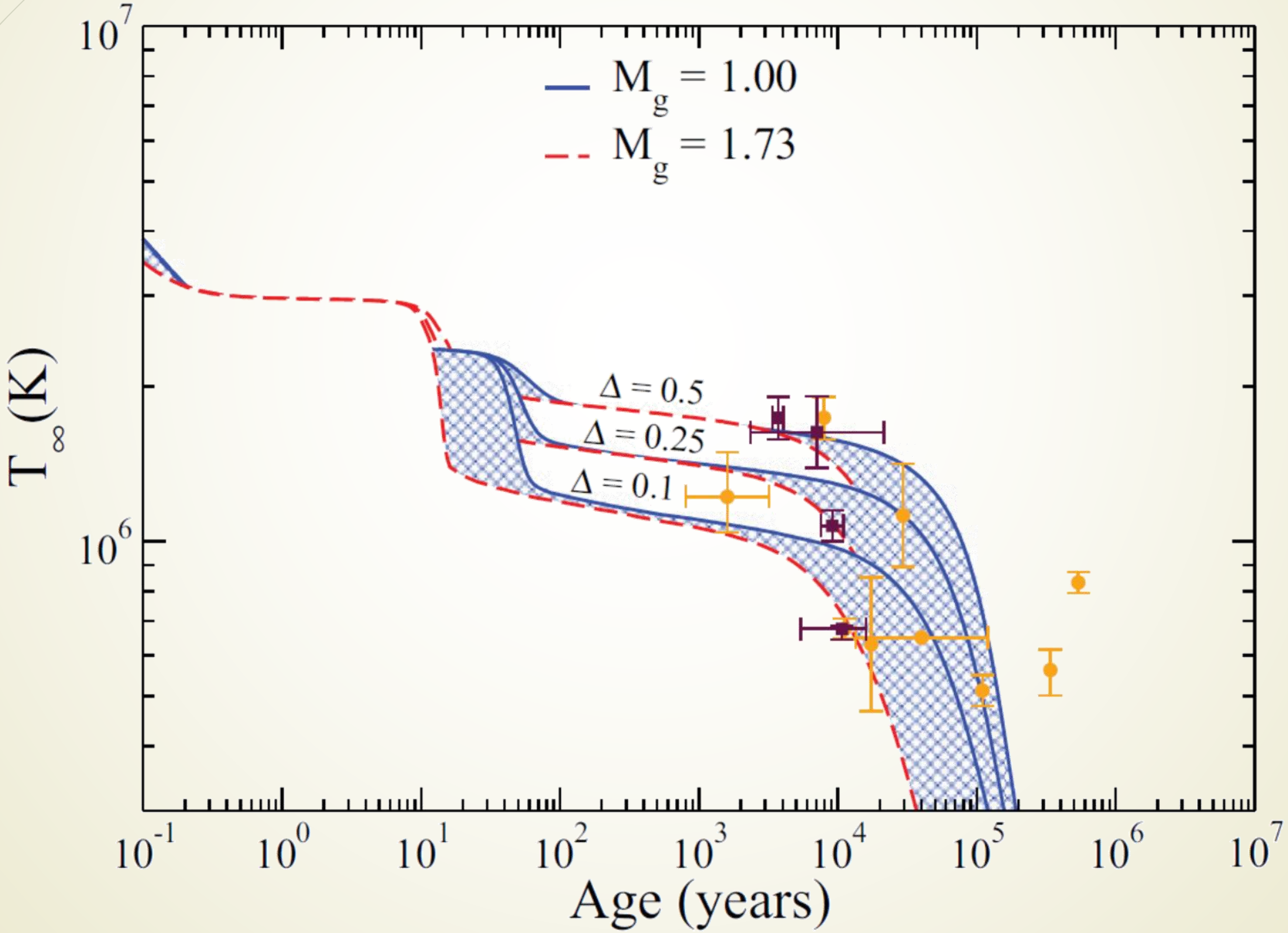
- Dependence on the quark-core size – Cooling – Quark Pairing (Par. Set A)



R. Negreiros, V.A. Dexheimer, S. Schramm, Phys.Rev.C 85, 035805 (2012)

Hybrid Star Cooling

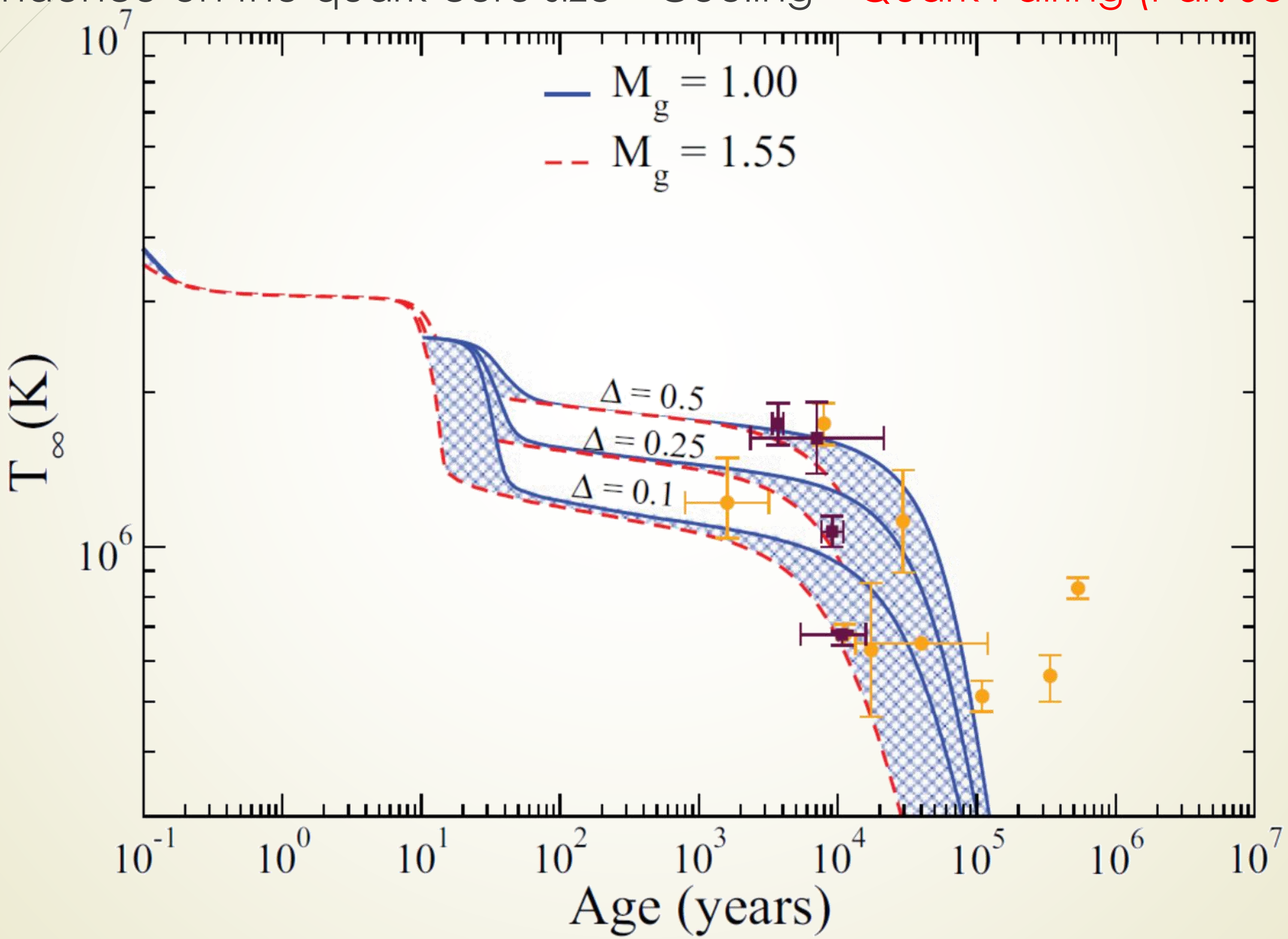
- Dependence on the quark-core size – Cooling – Quark Pairing (Par. Set B)



R. Negreiros, V.A. Dexheimer, S. Schramm, Phys.Rev.C 85, 035805 (2012)

Hybrid Star Cooling

- Dependence on the quark-core size – Cooling – Quark Pairing (Par. Set C)



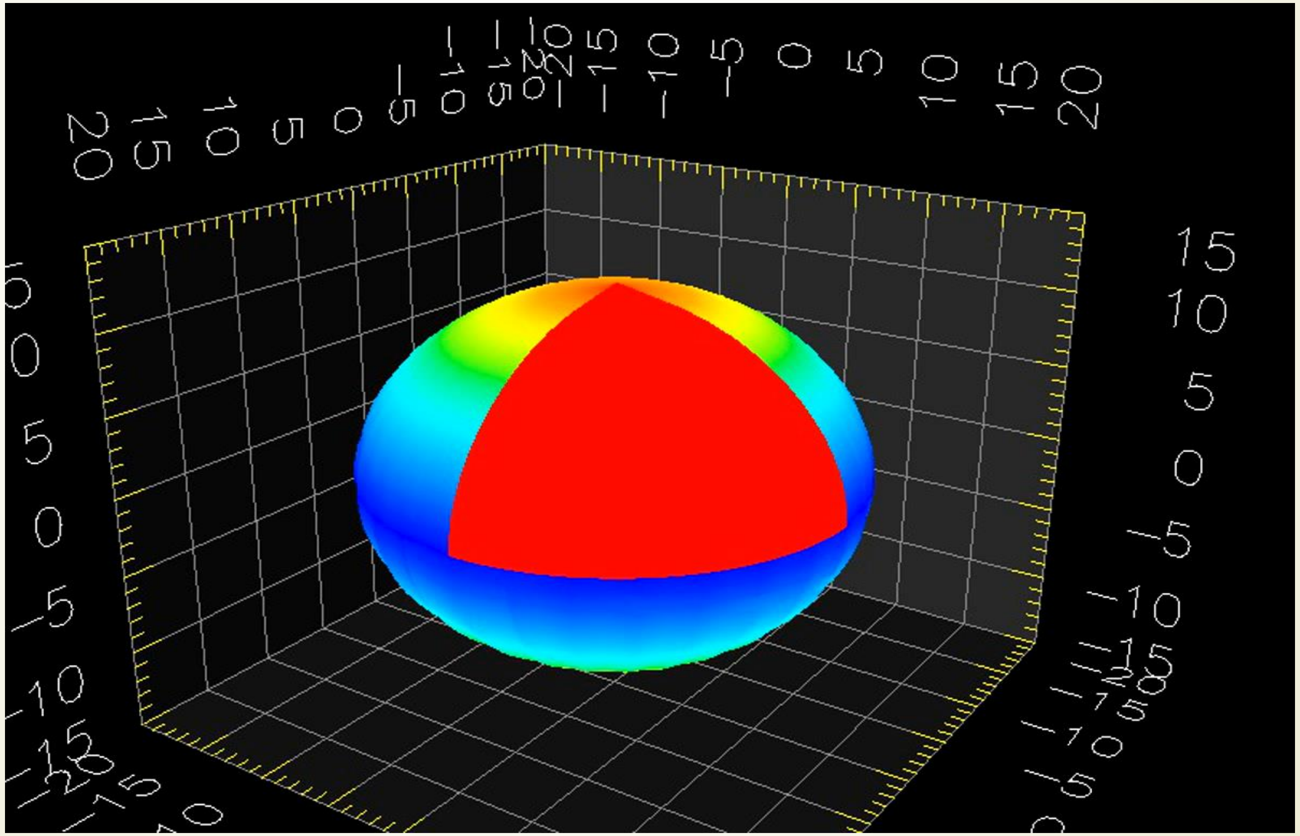
R. Negreiros, V.A. Dexheimer, S. Schramm, Phys.Rev.C 85, 035805 (2012)

Conclusions...

- Parameter set A has the best overall agreement with observed data (high mass)
- Par. Set A has $\alpha = 0.7$, thus its results need to be considered carefully.
- Results indicate that better agreement is obtained for models that yield less massive quark cores and lower electron population in the quark phase.
- Results are independent of the hadronic phase, as long as there is suppression of fast processes in the hadronic phase.
- Results do not depend strongly on the microscopic model used for the quark phase, as long as the models yields similar relative populations.

Next Steps...

- Perform calculations of the cooling of rotating hybrid stars with our 2D cooling code...



Negreiros, Schramm and Weber, Phys.Rev. D85 (2012) 104019