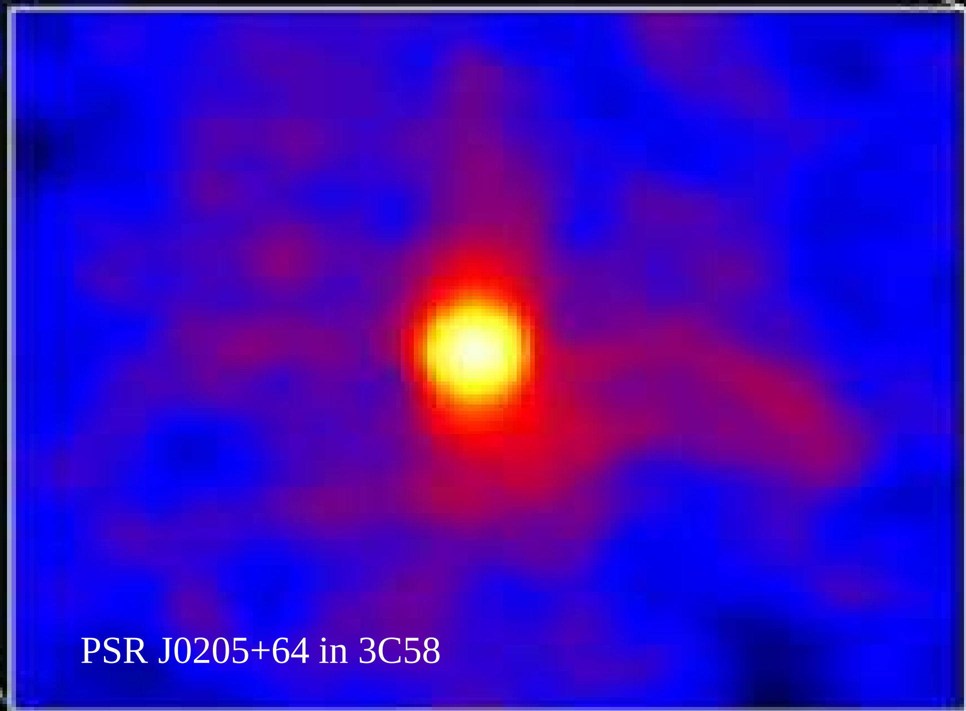
Neutrinos in dense matter & cooling of compact stars

David Blaschke
Univ. Wrocław & JINR Dubna



Erice, September 21, 2009

Neutrinos in dense matter: cooling of compact stars

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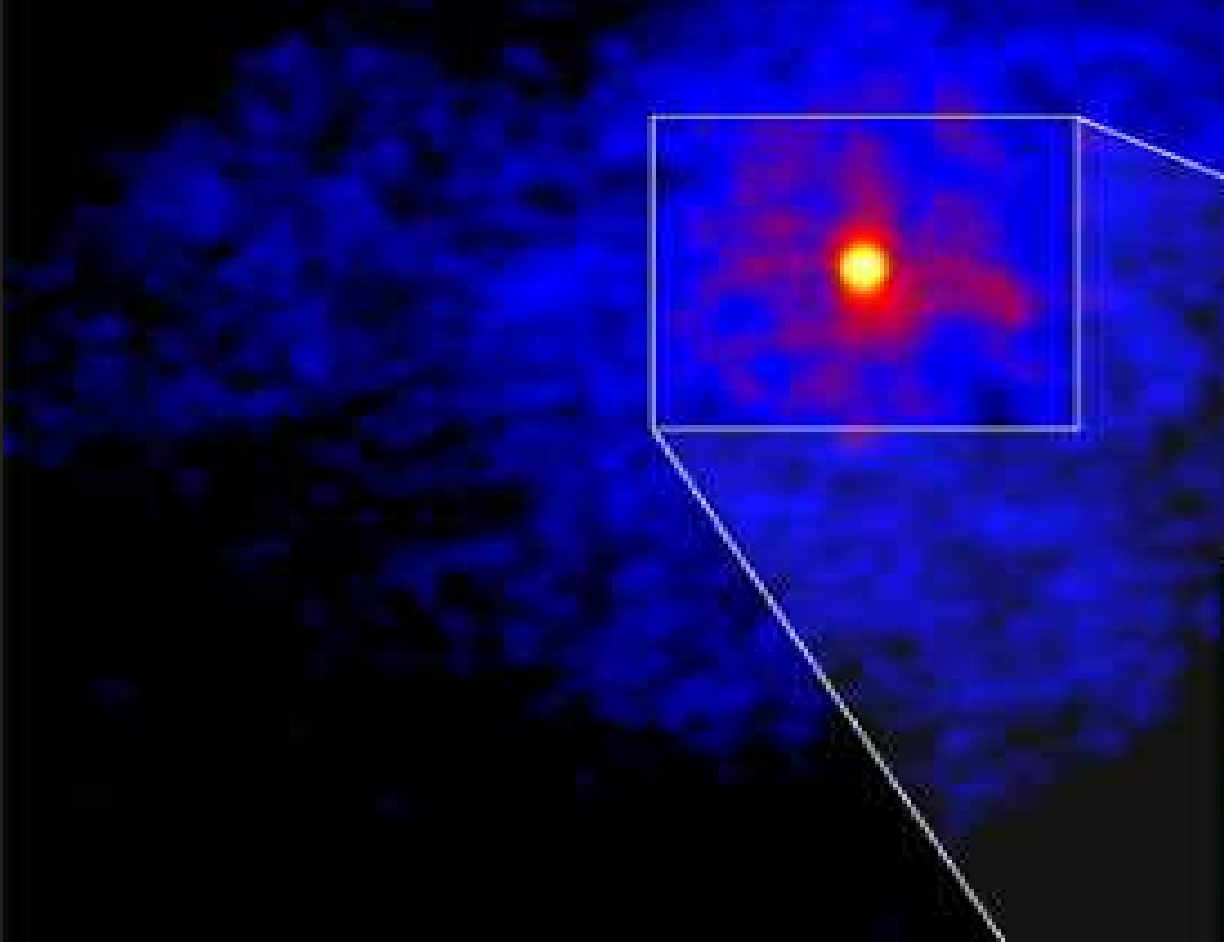
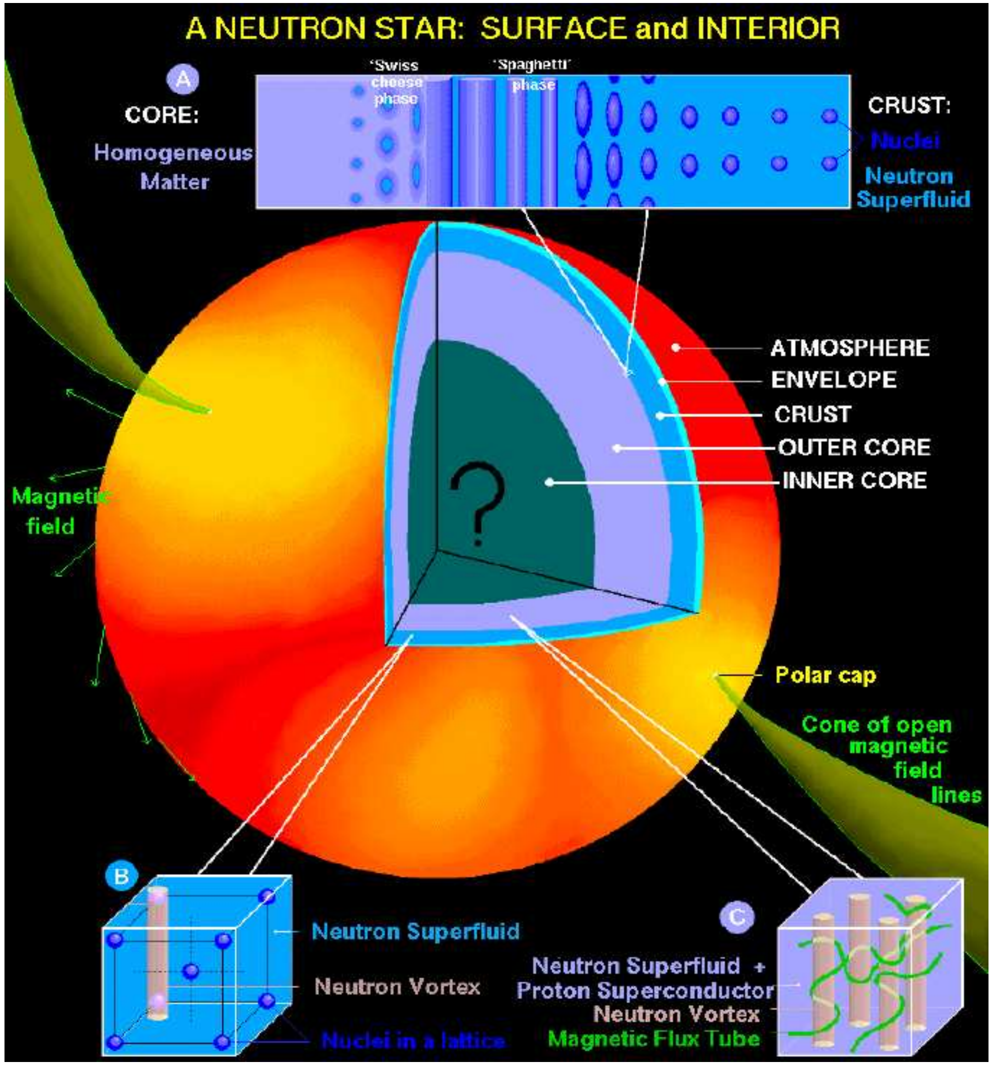
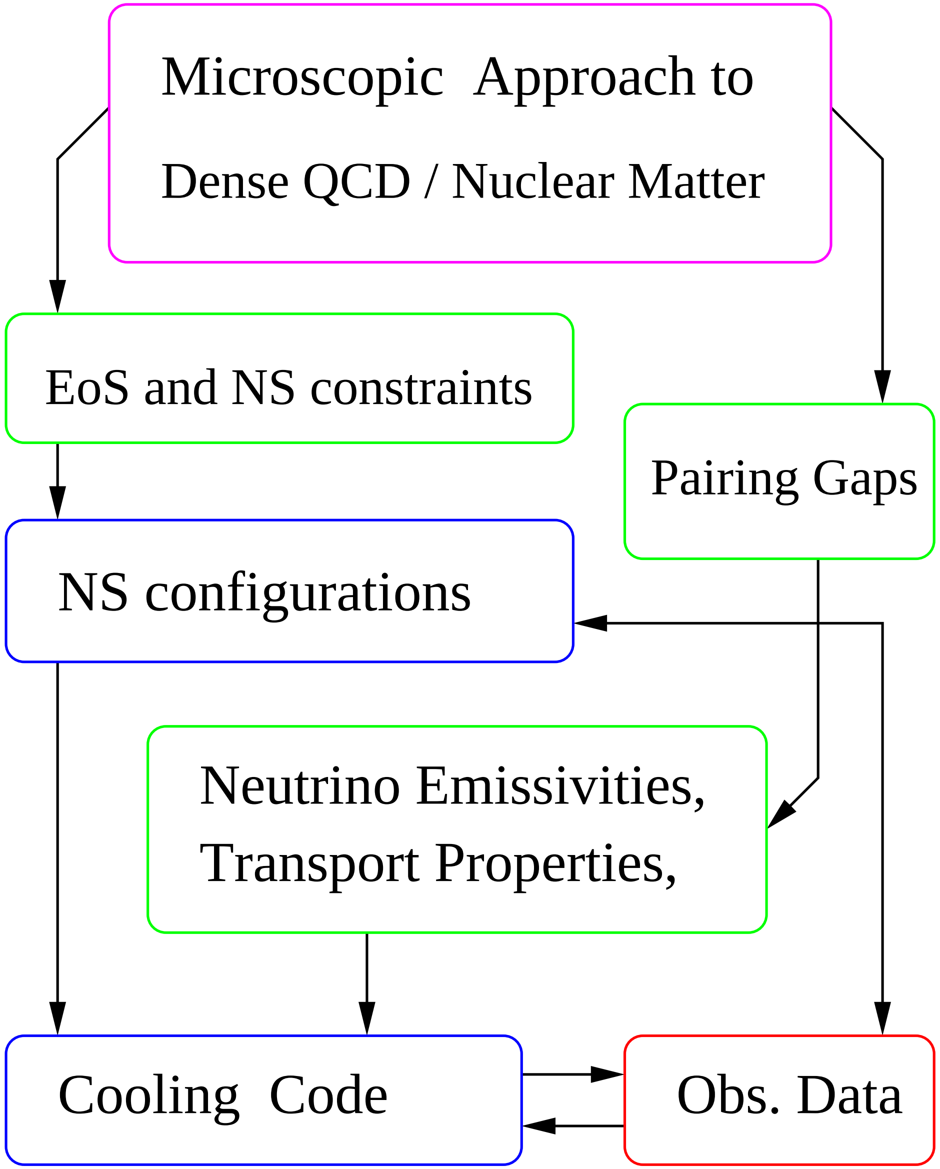


- Introduction:
  Hadronic Cooling and EoS Problem
- Quark Substructure and Phases
- Hybrid Star Structure & Cooling
- Conclusions

Erice, September 21, 2009

Compact Star Cooling - A Complex Problem

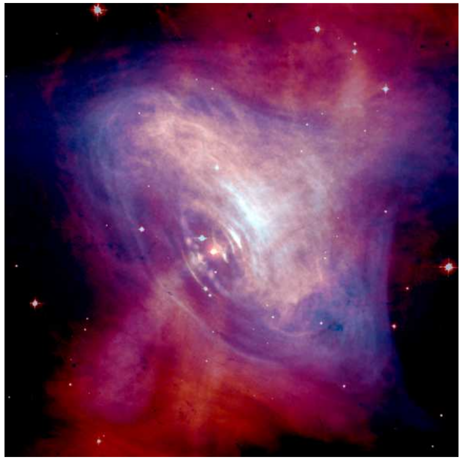




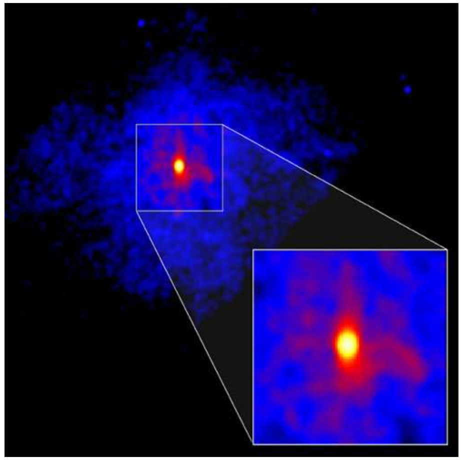
Picture taken from
http://www.astroscu.unam.mx/neutrones/NS-Picture/

Compact Star Cooling - Introduction

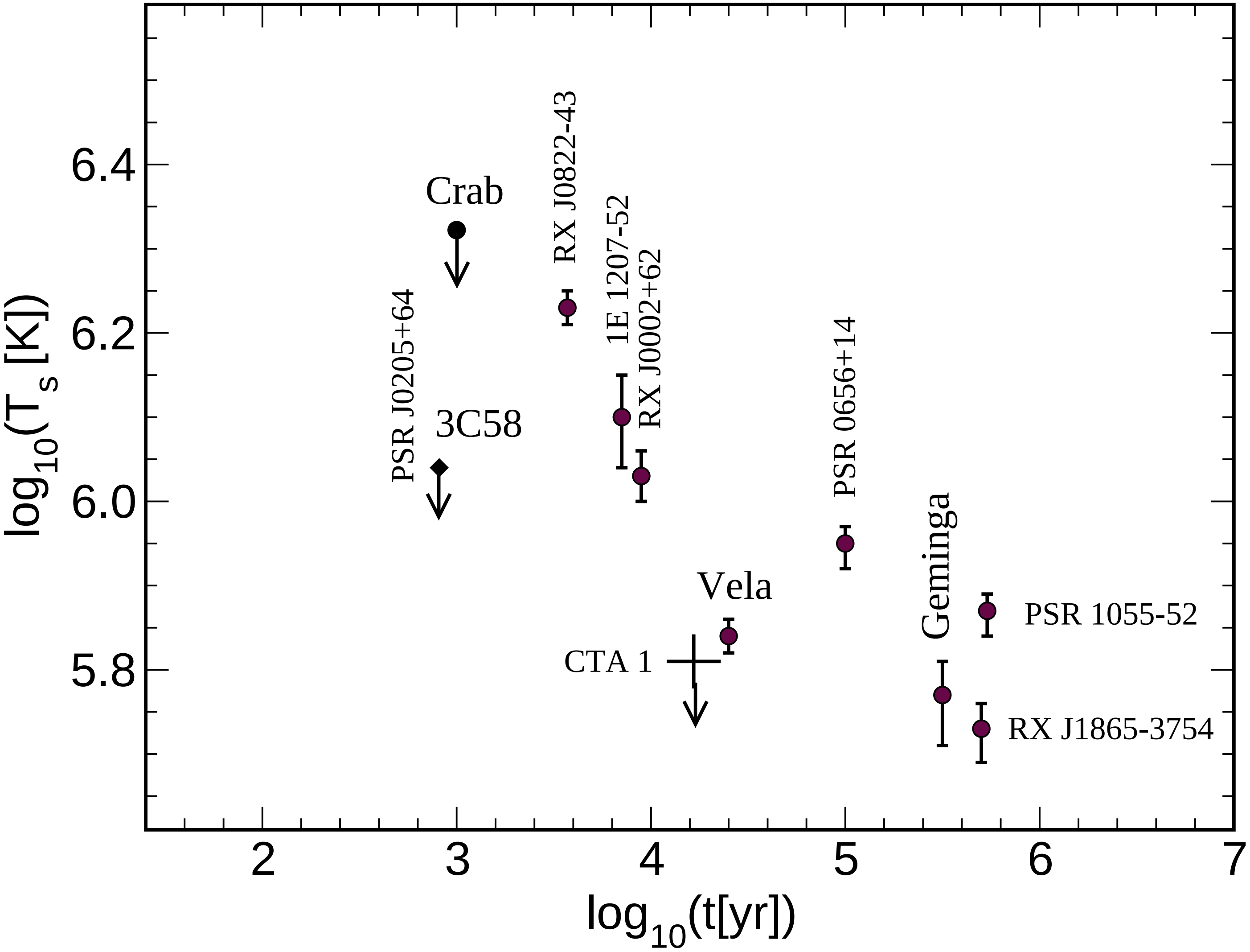
Pulsars in SN remnants:
1054 - Crab



1181 - 3C58



Temperature - age plot: characterizes compact star matter properties



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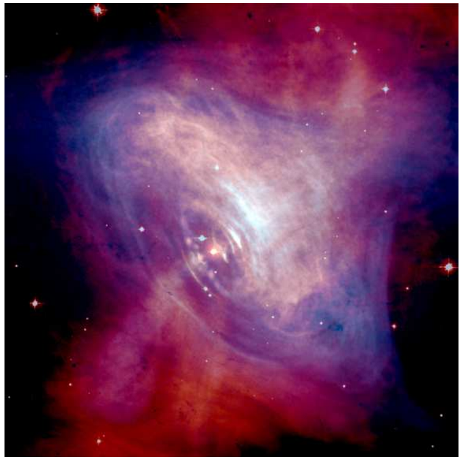

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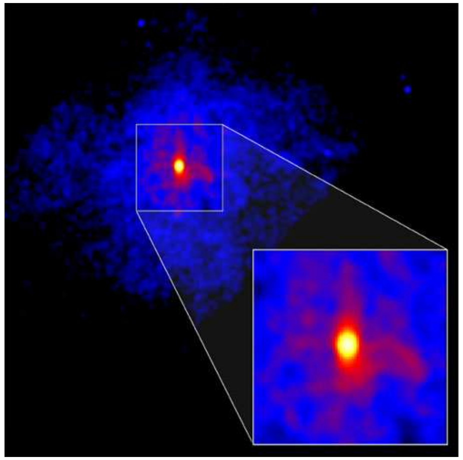
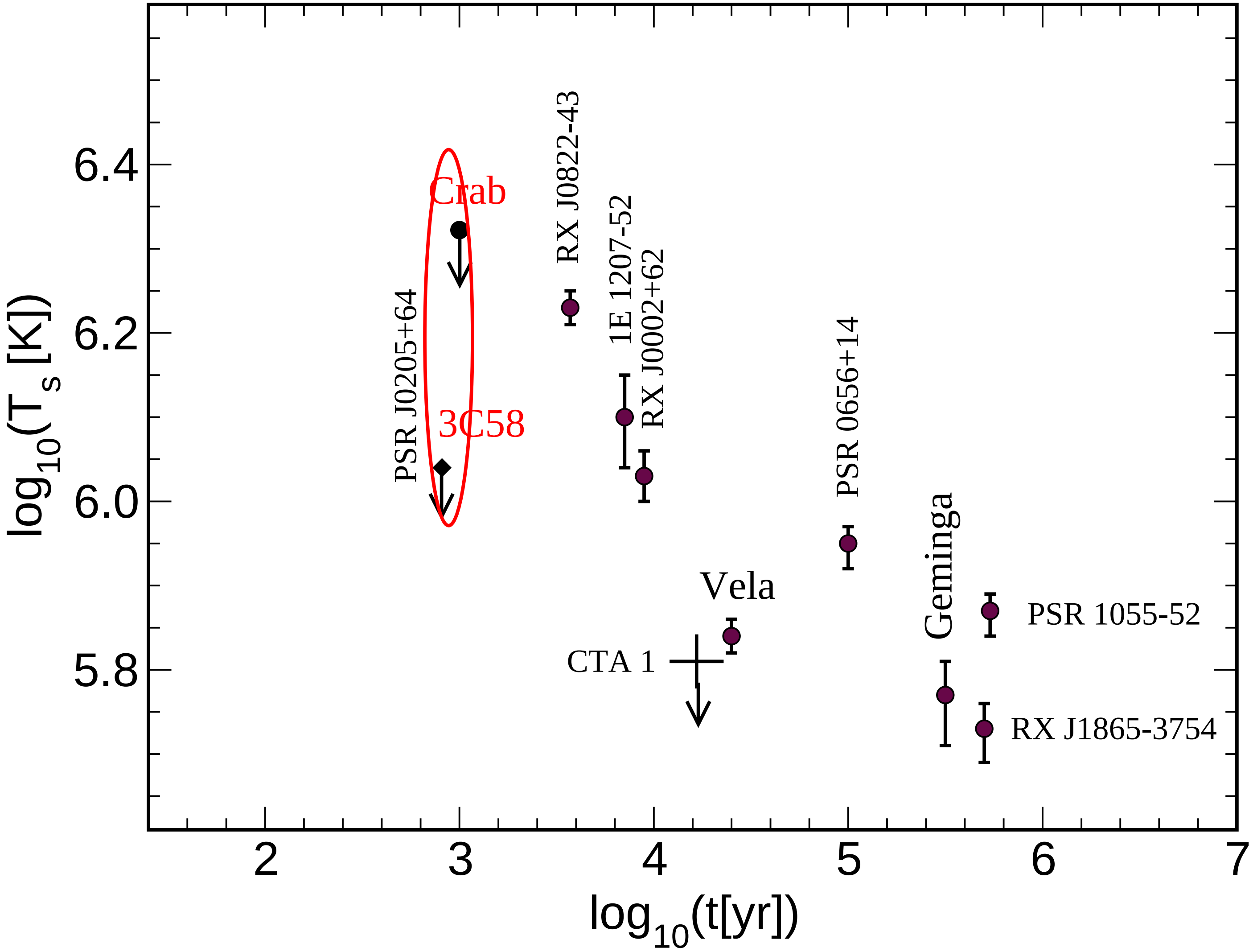
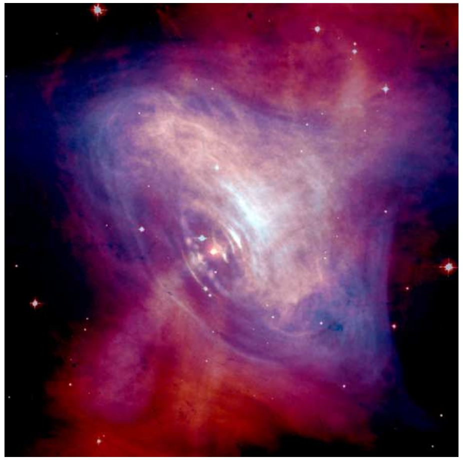


Too cool for its age: Quark matter in PSR J0205+64 ? (NASA 2002)



Compact Star Cooling - Phenomenology

Pulsars in SN remnants:
1054 - Crab



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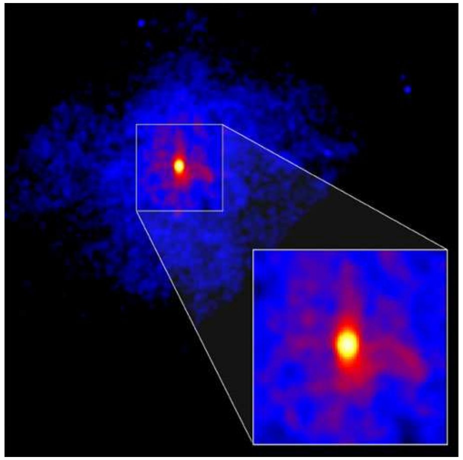

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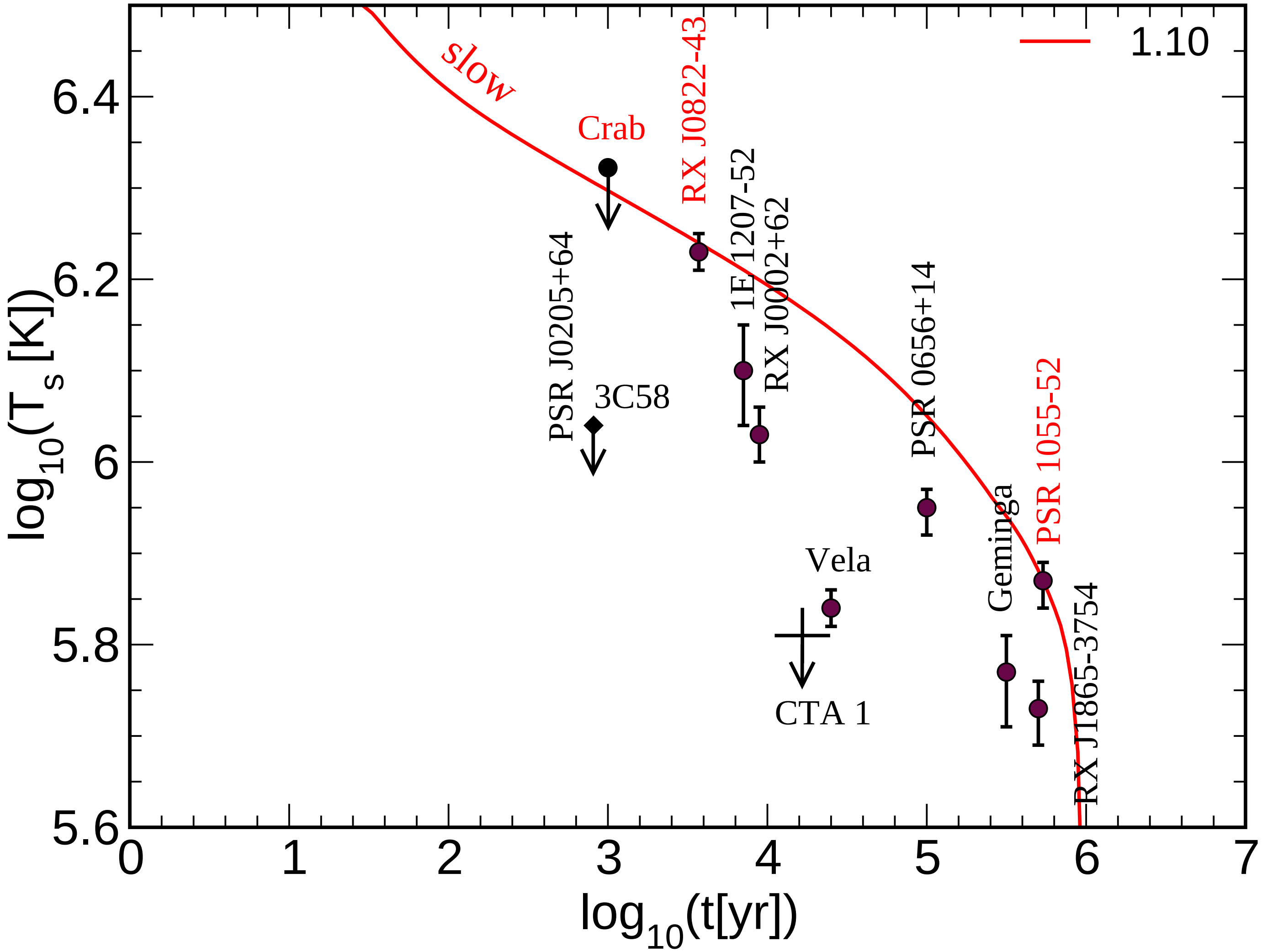

Compact Star Cooling - Introduction

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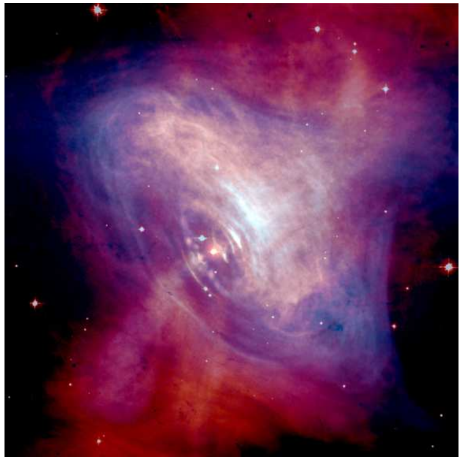

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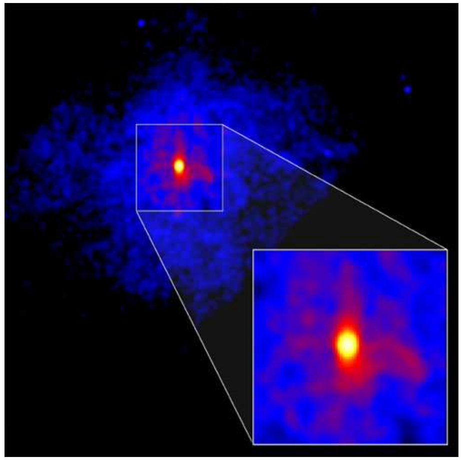

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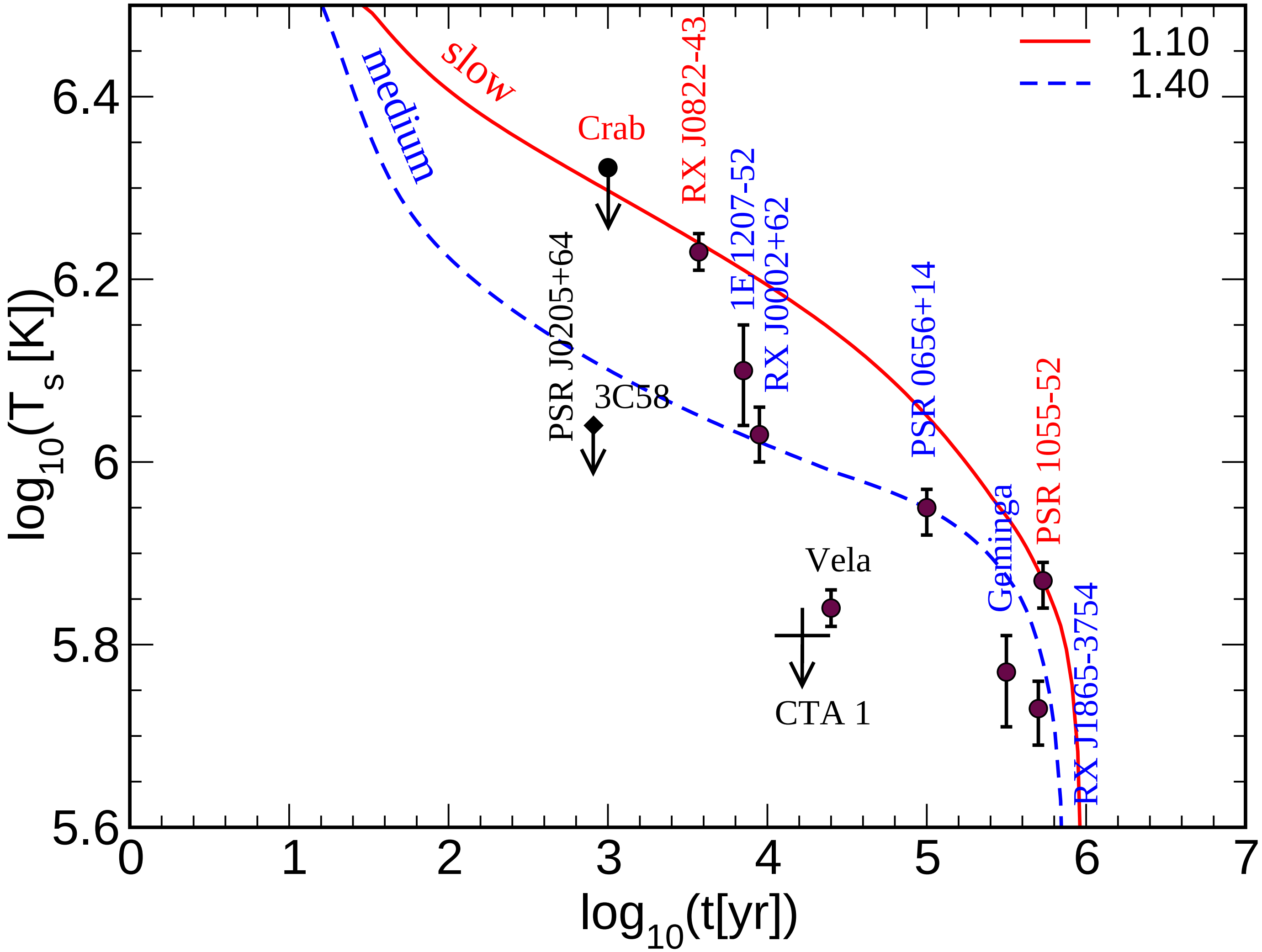

Compact Star Cooling - Introduction

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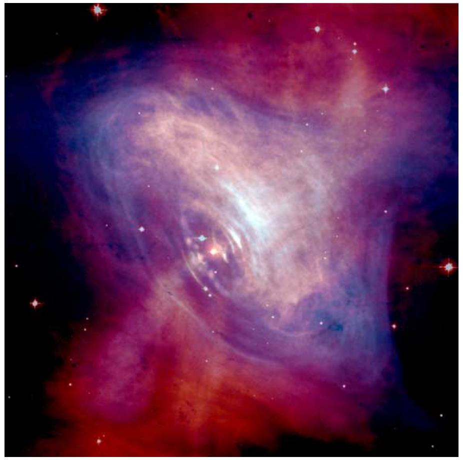
1054 - Crab



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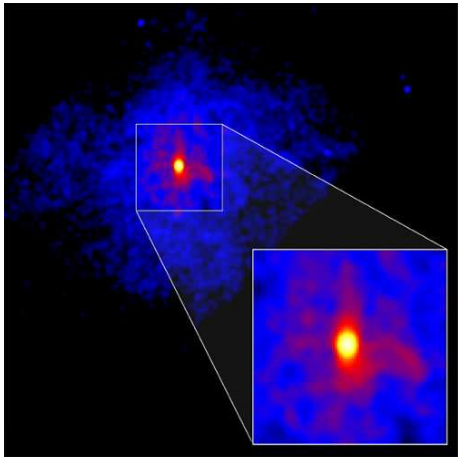
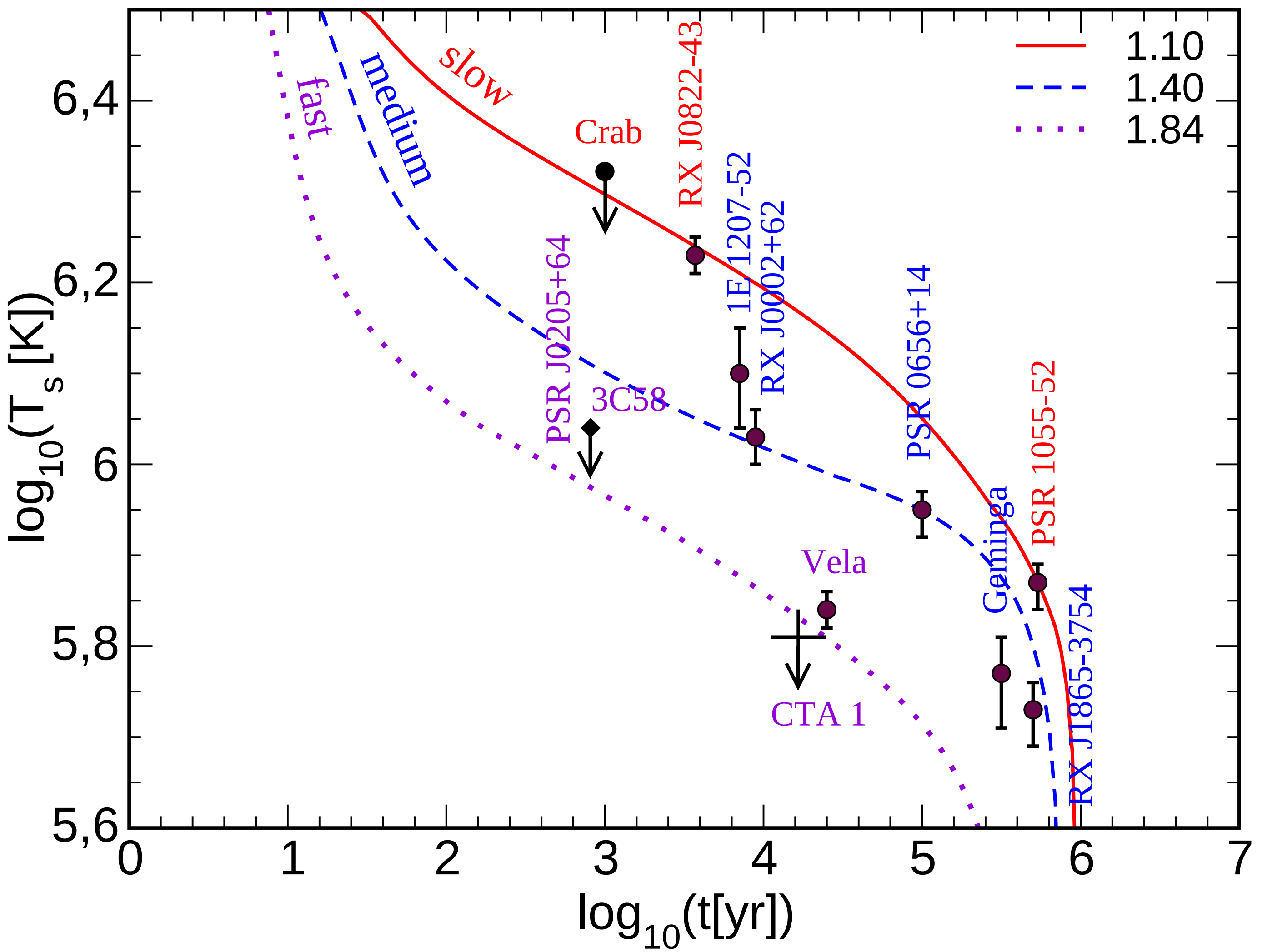
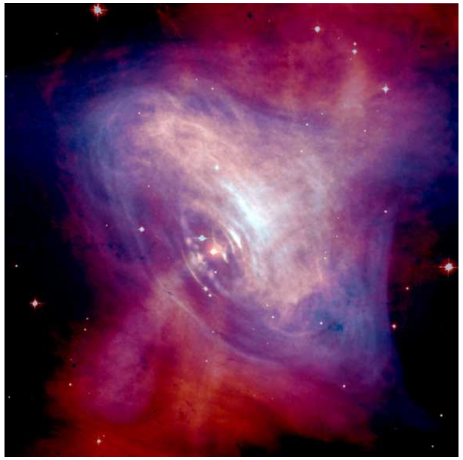


Classification of cooling compact stars



Compact Star Cooling - Hadronic Scenario

Pulsars in SN remnants:
1054 - Crab



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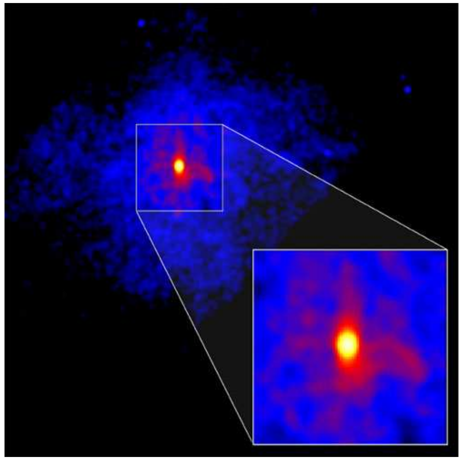
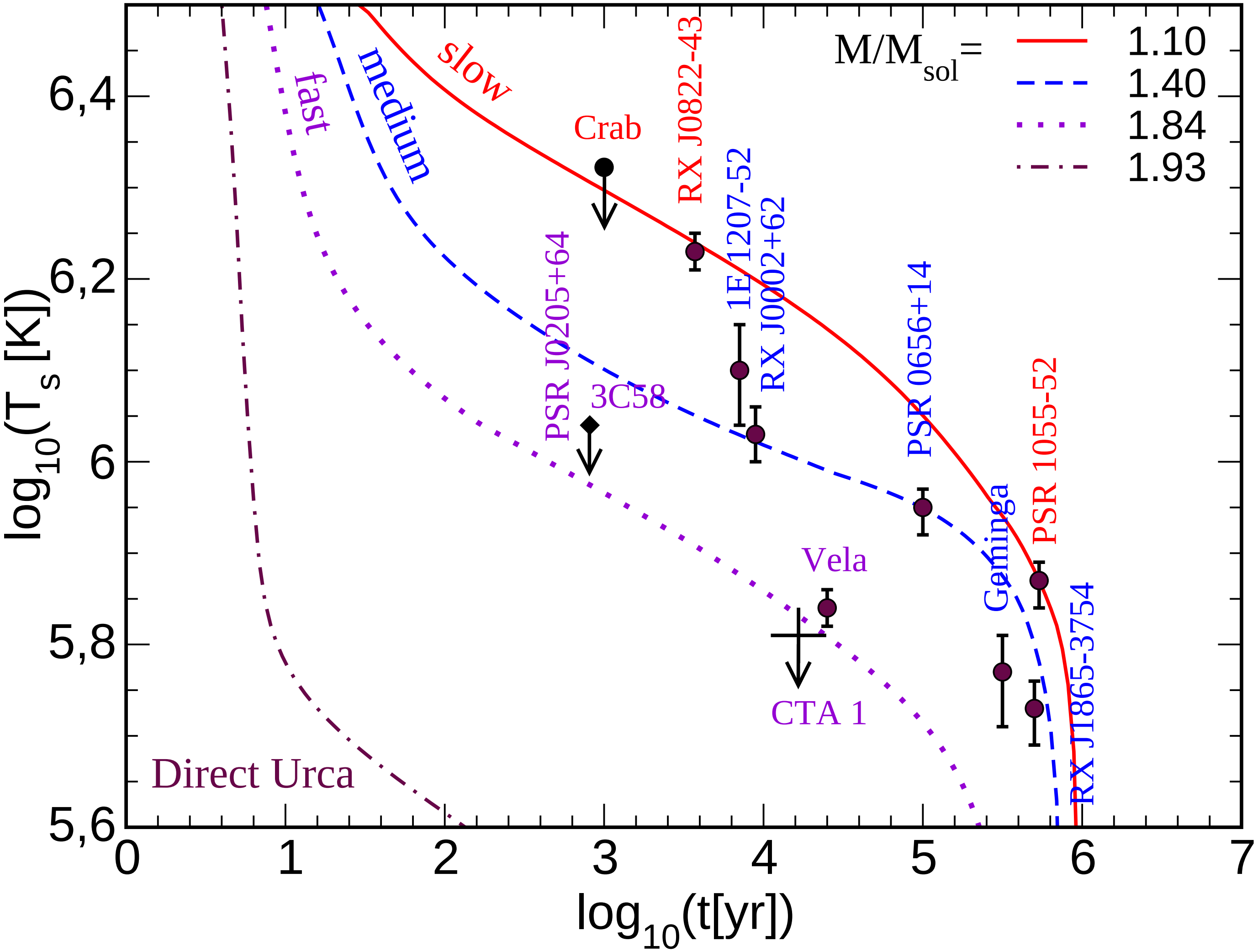


Classification of cooling compact stars: parameter - mass

D.B., Grigorian, Voskresensky, A& A 424, 979 (2004)

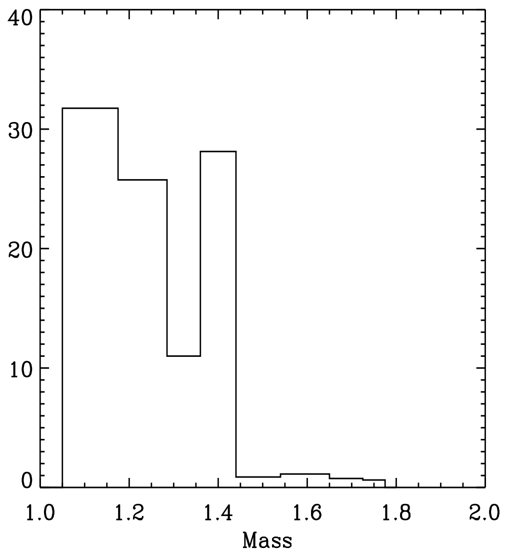


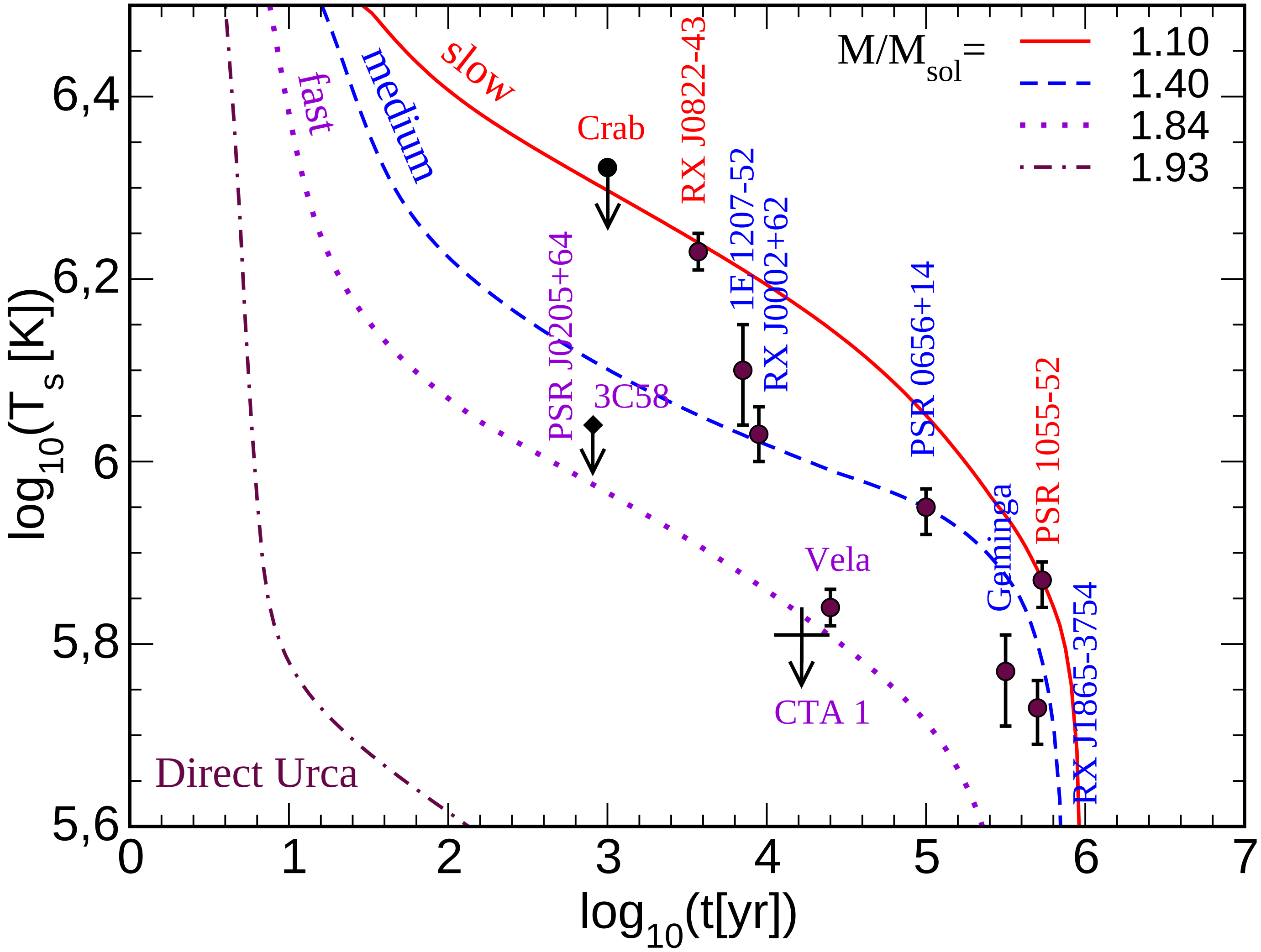
Compact Star Cooling - Hadronic Scenario

Classification of cooling compact stars: parameter - mass

D.B., Voskresensky, Grigorian, A& A 424, 979 (2004)

Mass distribution from population synthesis models for the solar vicinity





Popov et al: A&A 448 (2006)

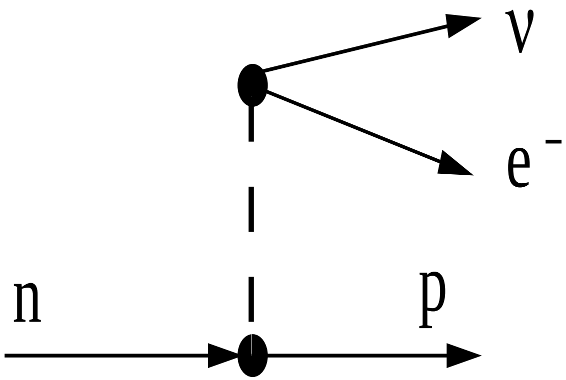
Typical radiopulsar masses ($1.4\ M_\odot$) not sufficient to explain, e.g., Vela cooling

Caution: Beware of the direct Urca process!

Inside Casino DA URCA in 1941 ...

Casino DA URCA today ...

First studied by Gamov and Schönberg, Phys. Rev. 58 (1940)



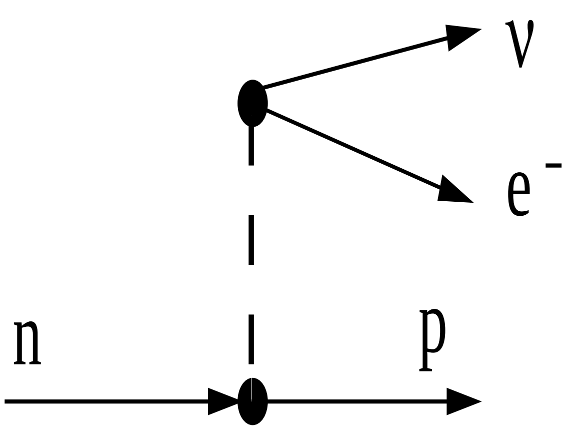
$$\varepsilon_\nu[DU] \sim 10^{27}\, T_9^6 \text{ erg cm}^{-3}\text{s}^{-1}$$

Huge emissivity → cools the star too fastly!!

Schoenberg: “the energy disappears in the nucleus of the supernova as quickly as the money disappeared at that roulette table.”

Direct Urca process threshold

Lattimer, Prakash, Pethick, Haensel; PRL 66, 2701 (1991)



DU process w/o neutrino trapping ($\lambda_\nu \gg R$, $\mu_\nu = 0$):

β-Equilibrium: $\mu_n = \mu_p + \mu_e$

Charge neutrality: $n_p = n_e + n_\mu \Leftrightarrow p_{F,p}^3 = p_{F,e}^3 + p_{F,\mu}^3$

Momentum conservation:

$\vec{p}_{F,n} = \vec{p}_{F,p} + \vec{p}_{F,e} \Leftrightarrow |\vec{p}_{F,n}| \le |\vec{p}_{F,p}| + |\vec{p}_{F,e}|$

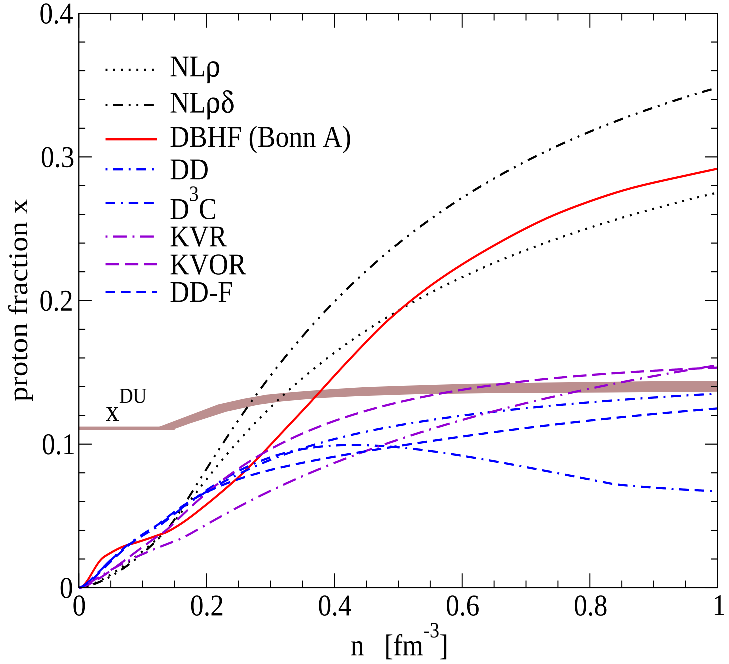
$p_{F,n} \le p_{F,p}[1 + (1 - n_\mu/n_p)^{1/3}] \Rightarrow n_n \le 8\, n_p - 4 n_\mu$

$$\Rightarrow \boxed{\frac{n_p}{n_p + n_n} = x_p \ge \frac{1}{9} + \frac{4}{9} x_\mu}$$

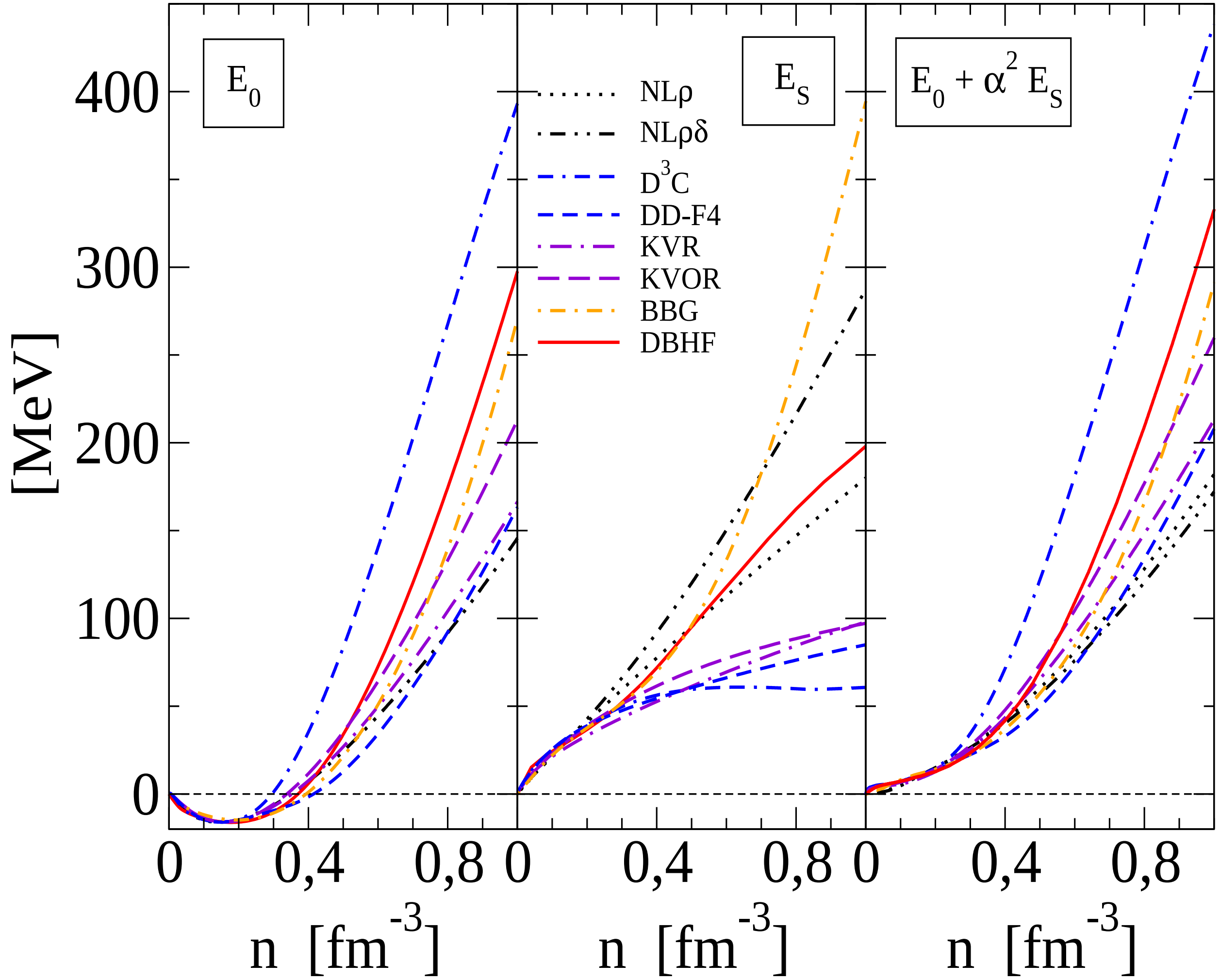
Luminosity:

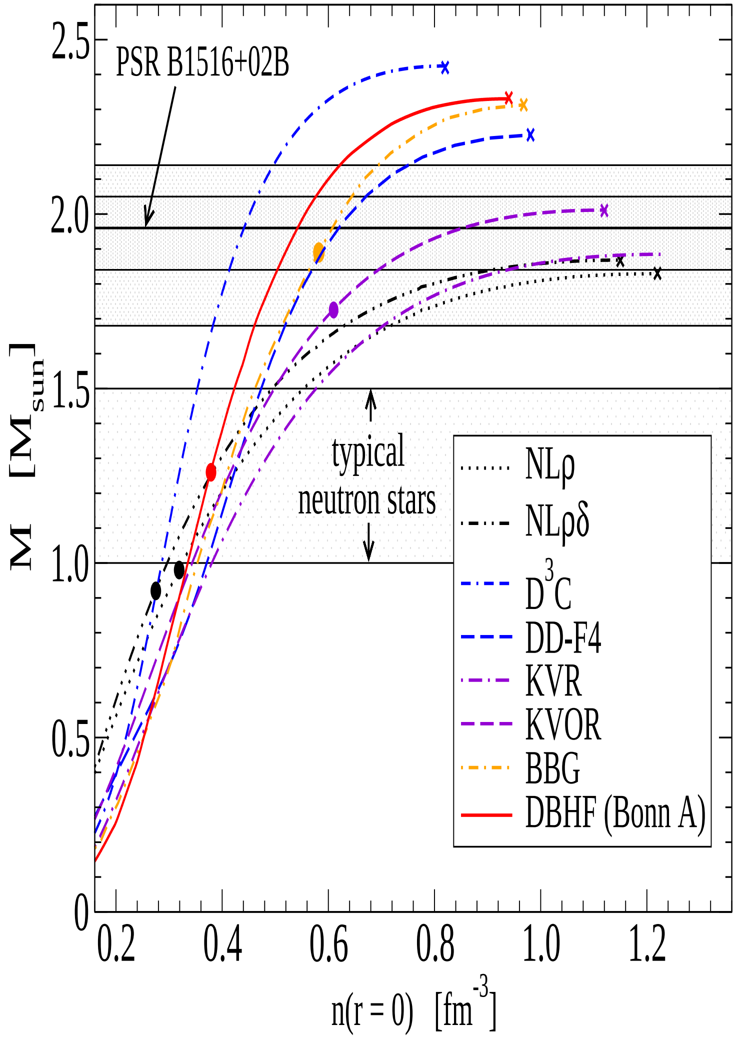
$$L_\nu = (2\pi)^4 \int \frac{d^3 p_n}{(2\pi)^3 2E_n} \dots \int \frac{d^3 p_\nu}{(2\pi)^3 2E_\nu}\, \delta^3(\vec{p}_i)\delta(E_i)\, |M_{fi}|^2\, f_n(1 - f_p)(1 - f_e)$$

Emissivity: $\epsilon_\nu = \frac{L_\nu}{V} \sim 10^{27} \left(\frac{m_n^* m_p^*}{m_N^2}\right) \left(\frac{n_e}{n_0}\right)^{1/3} \left(\frac{T}{10^9 K}\right)^6 \frac{\text{erg}}{\text{cm}^3 s}$



EoS and masses - DU constraint

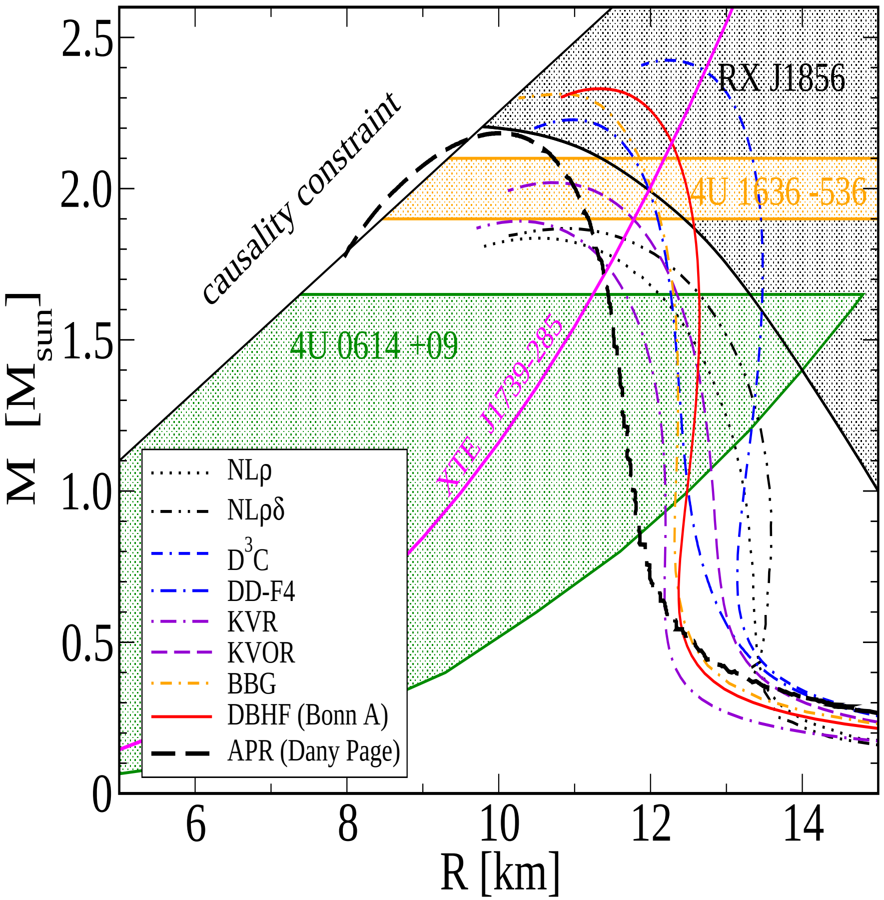


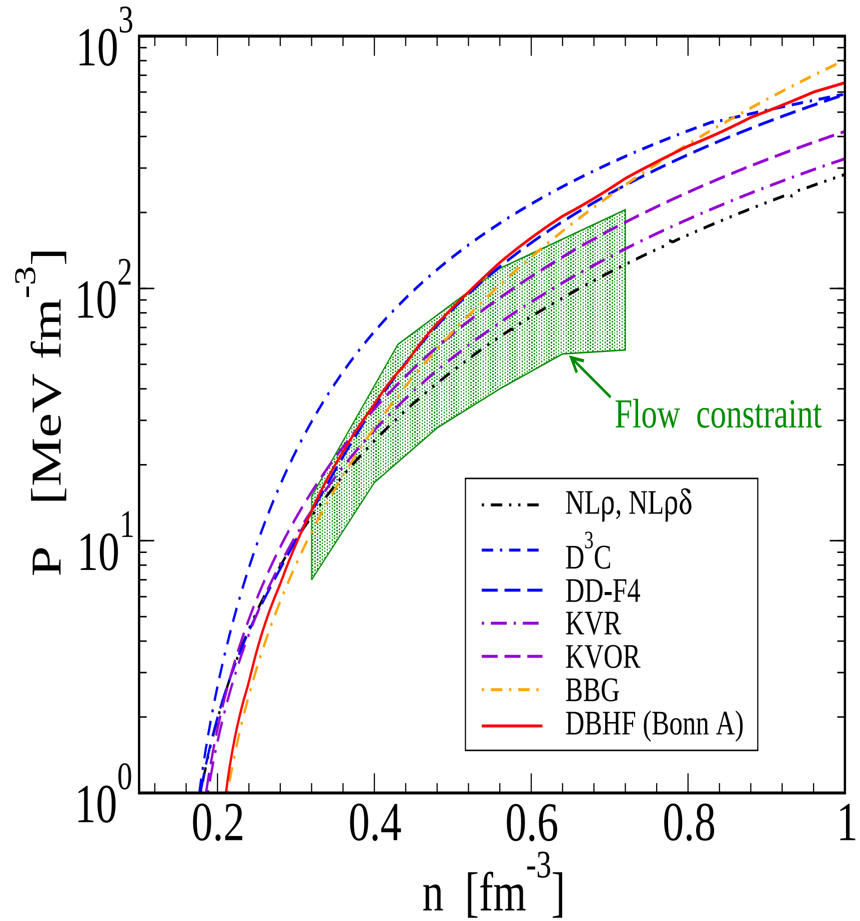


DU threshold for most hadronic EoS active in neutron stars with typical masses !

Klähn, et al., PRC 74, 035802 (2006); [nucl-th/0602038]

Mass-Radius constraint and Flow constraint

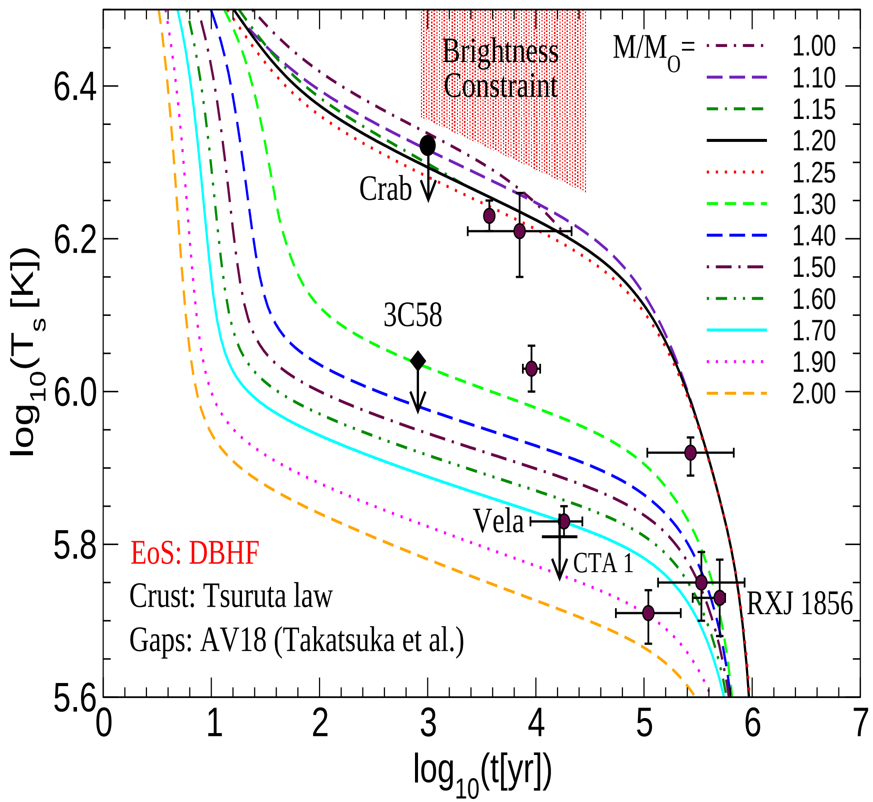


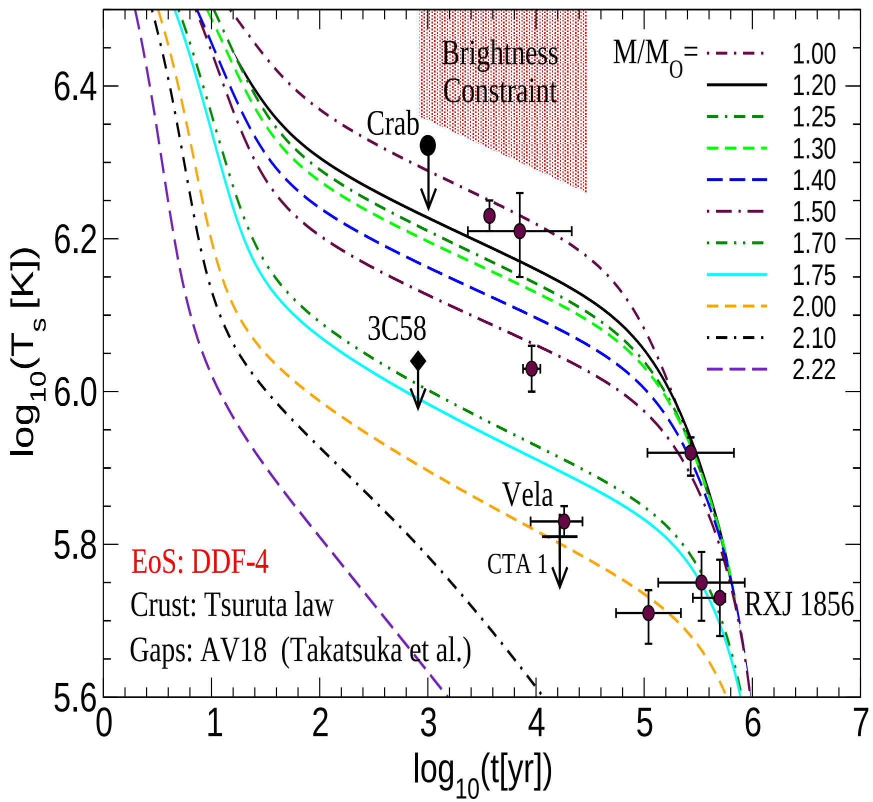


- Large Mass ($\sim 2\ M_\odot$) and radius ($R \geq 12$ km) $\Rightarrow$ stiff EoS;
- Flow in Heavy-Ion Collisions $\Rightarrow$ not too stiff EoS !

Klähn, D.B., Typel, Fuchs, Faessler, Grigorian, Miller, Röpke, Trümper, et al: PRC 74, 035802 (2006)

DU threshold and 'hadronic' neutron stars (II)

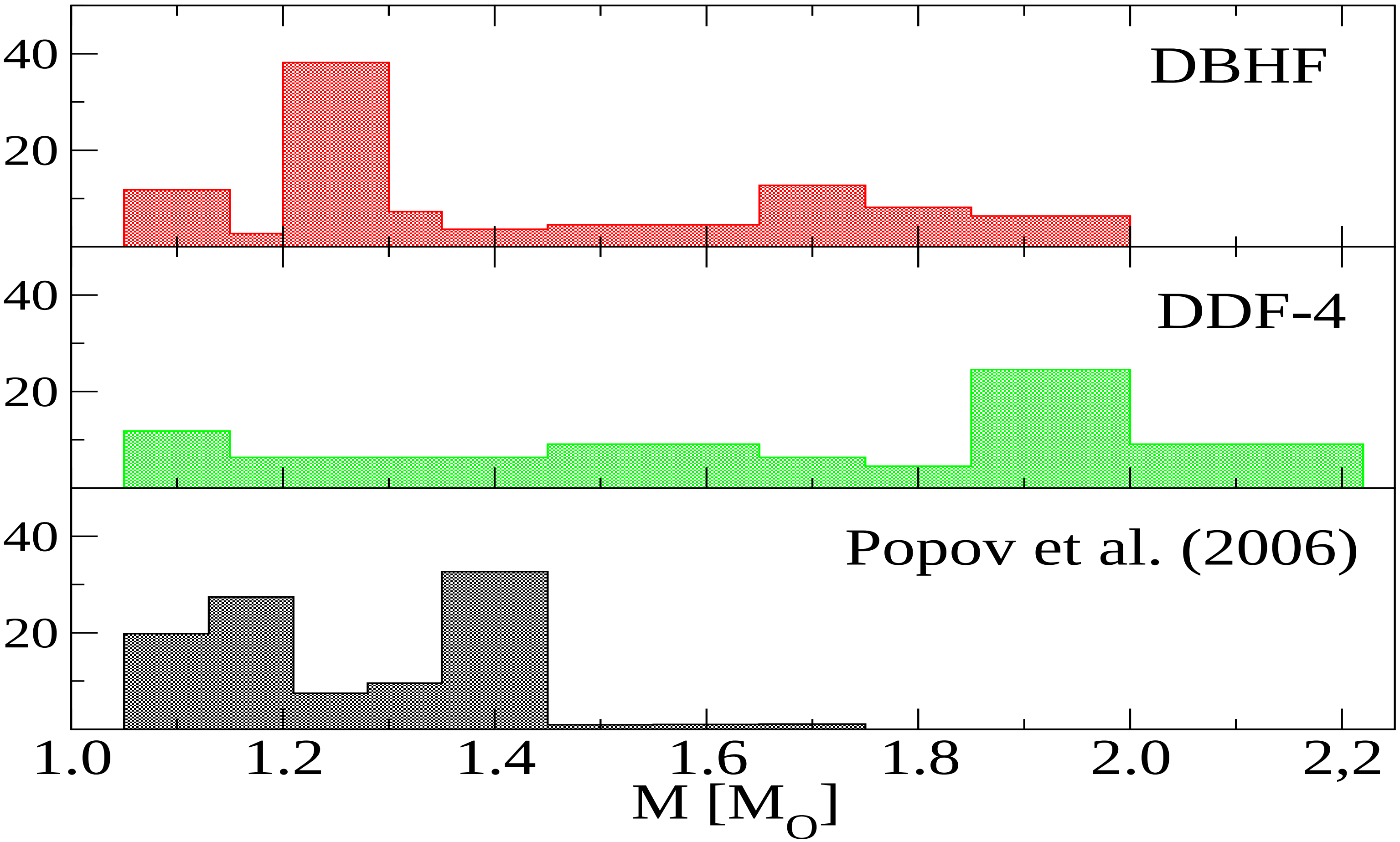




- DU threshold ⇒ sensitivity to tiny mass variations;
- Description of Vela not possible with typical masses !

S. Popov et al., PRC 74 (2006); D.B. and H. Grigorian, Prog. Part. Nucl. Phys. 59 (2007) 139

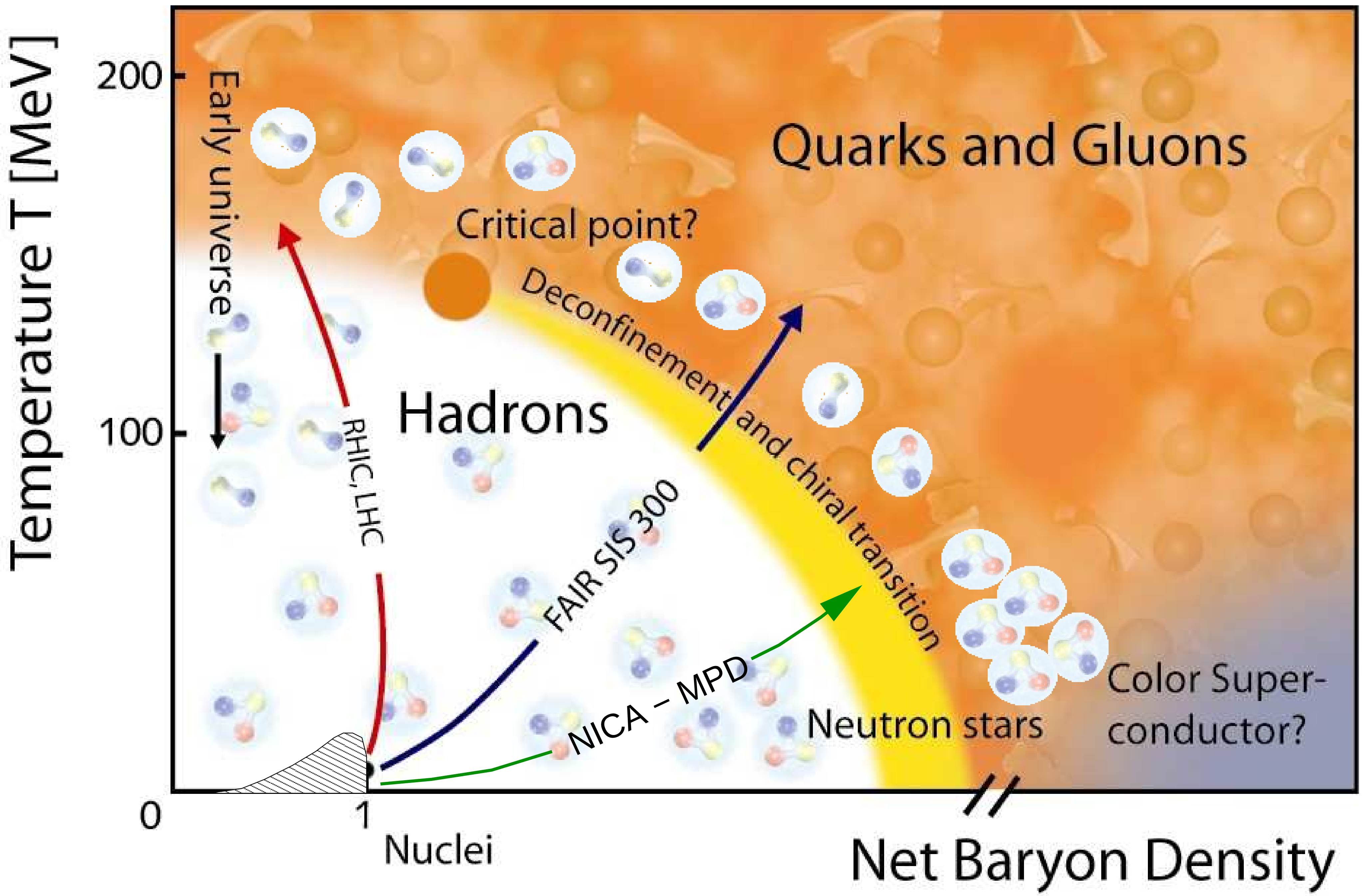
DU threshold and 'hadronic' neutron stars (III)



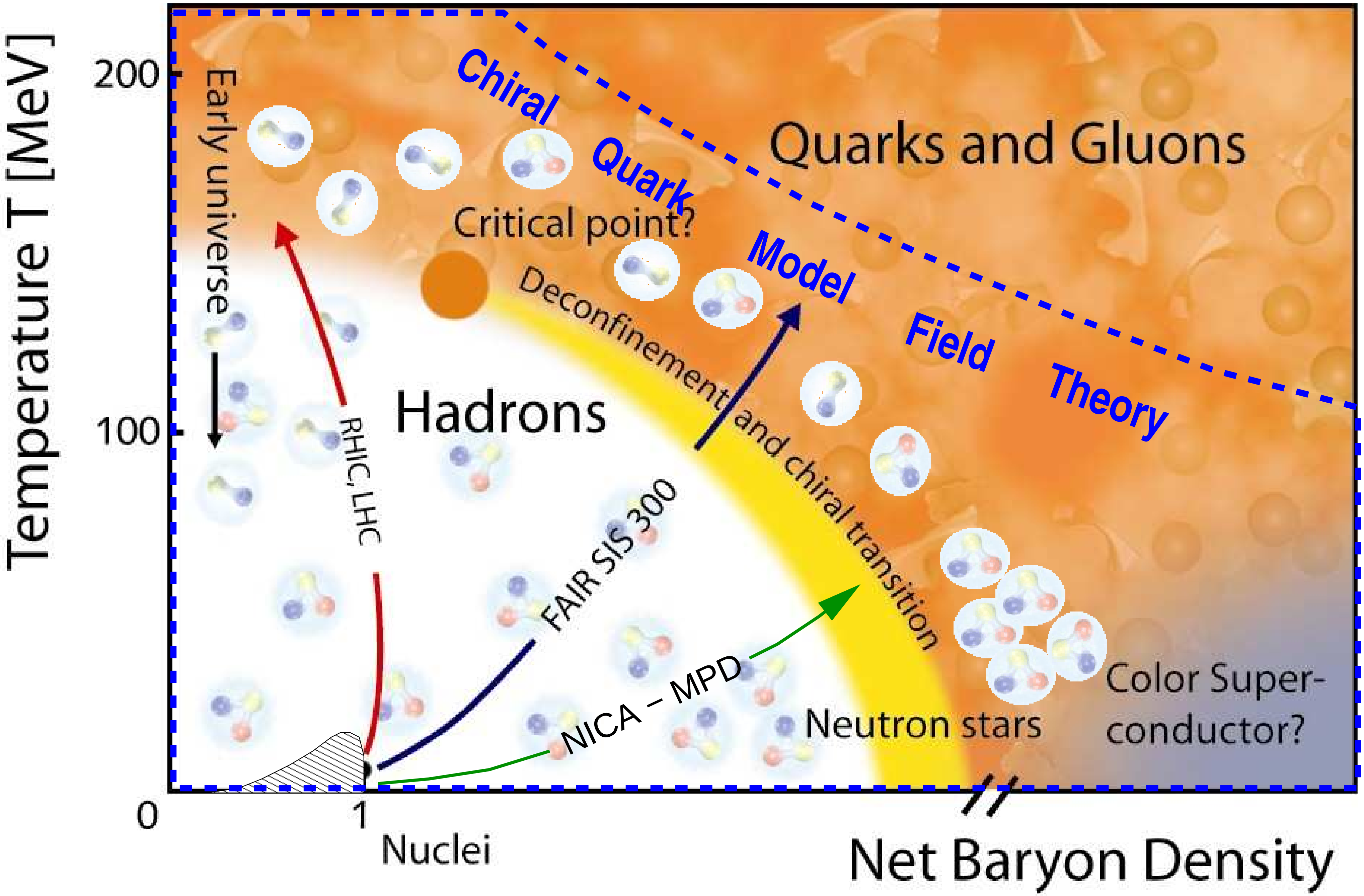
- DU threshold: overpopulation of a small mass window;
- Hadronic cooling not fast enough to describe Vela with $M < 1.5\ M_\odot$!

D.B. and H. Grigorian, Prog. Part. Nucl. Phys. 59 (2007) 139; [astro-ph/0612092]

Quark Substructure and Phase Diagram



Phase diagram of QCD: Chiral quark models



Quantum Field Theory for chiral Quark Matter

- Partition function for chiral Quark Field theory

$$Z[T,V,\mu] = \int \mathcal{D}\bar{\psi}\mathcal{D}\psi \exp\left\{-\int^{\beta} d\tau \int_V d^3x[\bar{\psi}(i\gamma^\mu\partial_\mu - m - \gamma^0\mu + i\lambda_3\phi_3)\psi - \mathcal{L}_{\rm int} + U(\Phi)]\right\}$$

Polyakov loop: $\Phi = N_c^{-1}\mathrm{Tr}_c[\exp(i\beta\lambda_3\phi_3)]$

- Current-current coupling (4-fermion interaction)

$$\mathcal{L}_{\rm int} = \sum_{M=\pi,\sigma,\ldots} G_M(\bar{\psi}\Gamma_M\psi)^2 + \sum_D G_D(\bar{\psi}^C\Gamma_D\psi)^2$$

- Bosonisation (Hubbard-Stratonovich Transformation)

$$Z[T,V,\mu] = \int \mathcal{D}\phi_M\mathcal{D}\Delta_D^\dagger\mathcal{D}\Delta_D \exp\left\{-\sum_M \frac{\phi_M^2}{4G_M} - \sum_D \frac{|\Delta_D|^2}{4G_D} + \frac{1}{2}\mathrm{Tr}\ \ln S^{-1}[\{M_M\},\{\Delta_D\}]\right\}$$

- Collective (stochastic) Fields: Mesons (ϕ_M) and Diquarks (Δ_D)
- Systematic Evaluation: Mean field + Fluctuations
  - Mean-field Approximation: Order parameter for Phase transitions (Gap equations)
  - Fluctuations (2. Order): Hadronic Correlations (Bound- & Scattering states)
  - Fluctuations of higher Order: Hadron-Hadron Interaction

Phase diagram for 3-Flavor Quark Matter

Thermodynamic Potential $\Omega(T,\mu) = -T \ln Z[T,\mu]$

$$\Omega(T,\mu) \;=\; \frac{\phi_u^2+\phi_d^2+\phi_s^2}{8G_S} + \frac{|\Delta_{ud}|^2+|\Delta_{us}|^2+|\Delta_{ds}|^2}{4G_D} - T\sum_n \int \frac{d^3p}{(2\pi)^3}\frac{1}{2}\mathrm{Tr}\ln\left(\frac{1}{T}S^{-1}(i\omega_n,\vec{p})\right) + \Omega_e - \Omega_0.$$

$$\mathrm{InverseNambu-GorkovPropagator} \quad S^{-1}(i\omega_n,\vec{p}) = \begin{bmatrix} \gamma_\mu p^\mu - M(\vec{p}) + \mu\gamma^0 & \widehat{\Delta}(\vec{p}) \\ \widehat{\Delta}^\dagger(\vec{p}) & \gamma_\mu p^\mu - M(\vec{p}) - \mu\gamma^0 \end{bmatrix},$$

$$\Delta_{k\gamma} = 2G_D\langle \bar{q}_{i\alpha} i\gamma_5\epsilon_{\alpha\beta\gamma}\epsilon_{ijk} g(\vec{q}) q^C_{j\beta}\rangle. \quad \widehat{\Delta}(\vec{p}) = i\gamma_5\epsilon_{\alpha\beta\gamma}\epsilon_{ijk}\Delta_{k\gamma} g(\vec{p}).$$

Fermion Determinant (Tr ln D = ln det D)

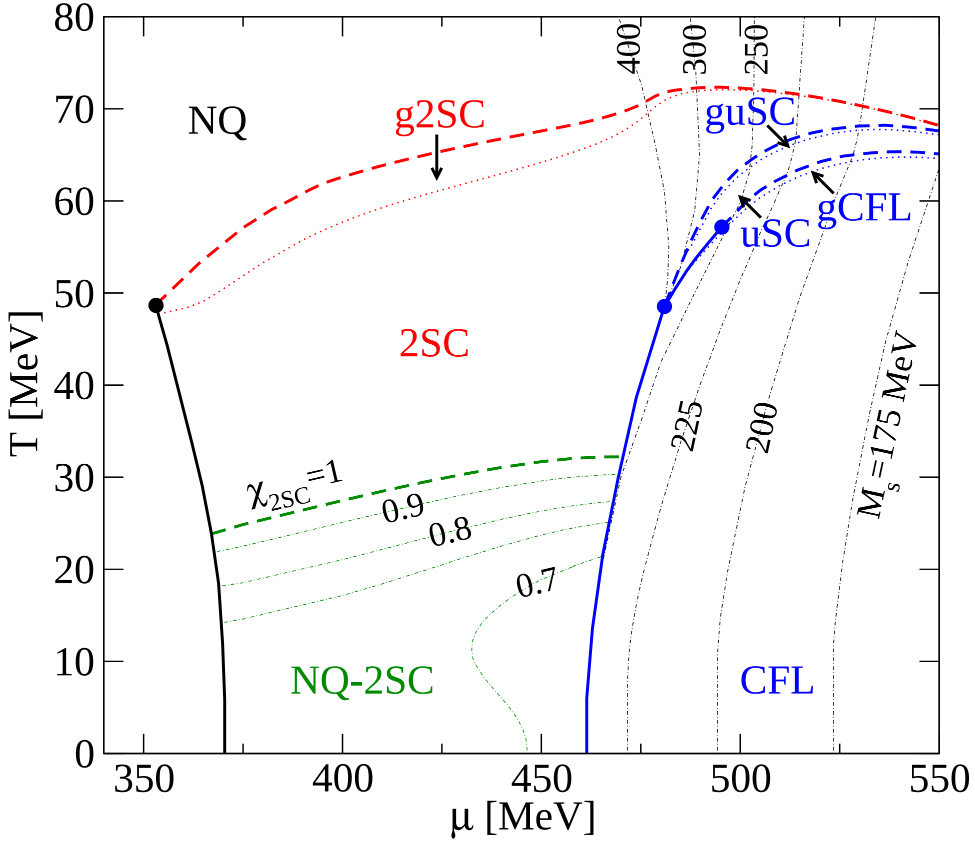
$$\mathrm{lndet}\left(\frac{1}{T}S^{-1}(i\omega_n,\vec{p})\right) = 2\sum_{a=1}^{18}\ln\left(\frac{\omega_n^2+\lambda_a(\vec{p})^2}{T^2}\right).$$

Result for the thermodynamic Potential (Meanfield approximation)

$$\Omega(T,\mu) \;=\; \frac{\phi_u^2+\phi_d^2+\phi_s^2}{8G_S} + \frac{|\Delta_{ud}|^2+|\Delta_{us}|^2+|\Delta_{ds}|^2}{4G_D} - \int \frac{d^3p}{(2\pi)^3}\sum_{a=1}^{18}\left[\lambda_a + 2T\ln\left(1+e^{-\lambda_a/T}\right)\right] + \Omega_e - \Omega_0.$$

Neutrality constraints: $n_Q = n_8 = n_3 = 0$, $n_i = -\partial\Omega/\partial\mu_i = 0$,
Equations of state: $P = -\Omega$, etc.

Three-flavor Quark Matter Phase Diagram



The phases are:

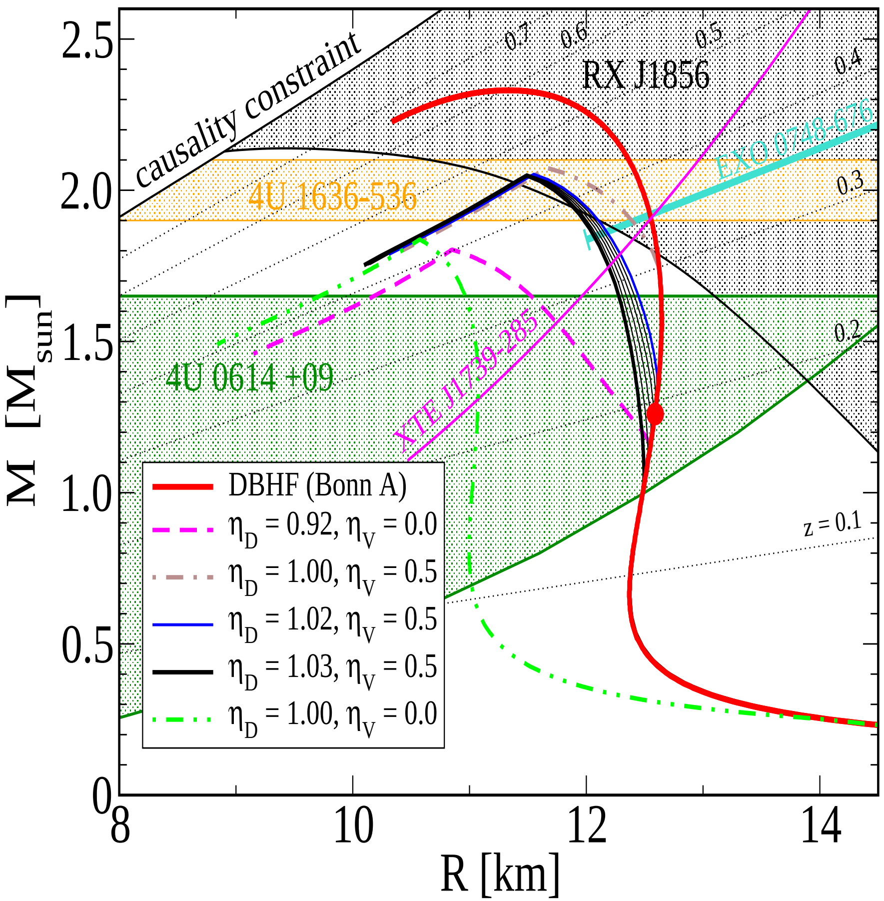
- NQ: $\Delta_{ud} = \Delta_{us} = \Delta_{ds} = 0$;
- NQ-2SC: $\Delta_{ud} \neq 0$, $\Delta_{us} = \Delta_{ds} = 0$, $0 \leq \chi_{2SC} \leq 1$;
- 2SC: $\Delta_{ud} \neq 0$, $\Delta_{us} = \Delta_{ds} = 0$;
- uSC: $\Delta_{ud} \neq 0$, $\Delta_{us} \neq 0$, $\Delta_{ds} = 0$;
- CFL: $\Delta_{ud} \neq 0$, $\Delta_{ds} \neq 0$, $\Delta_{us} \neq 0$;

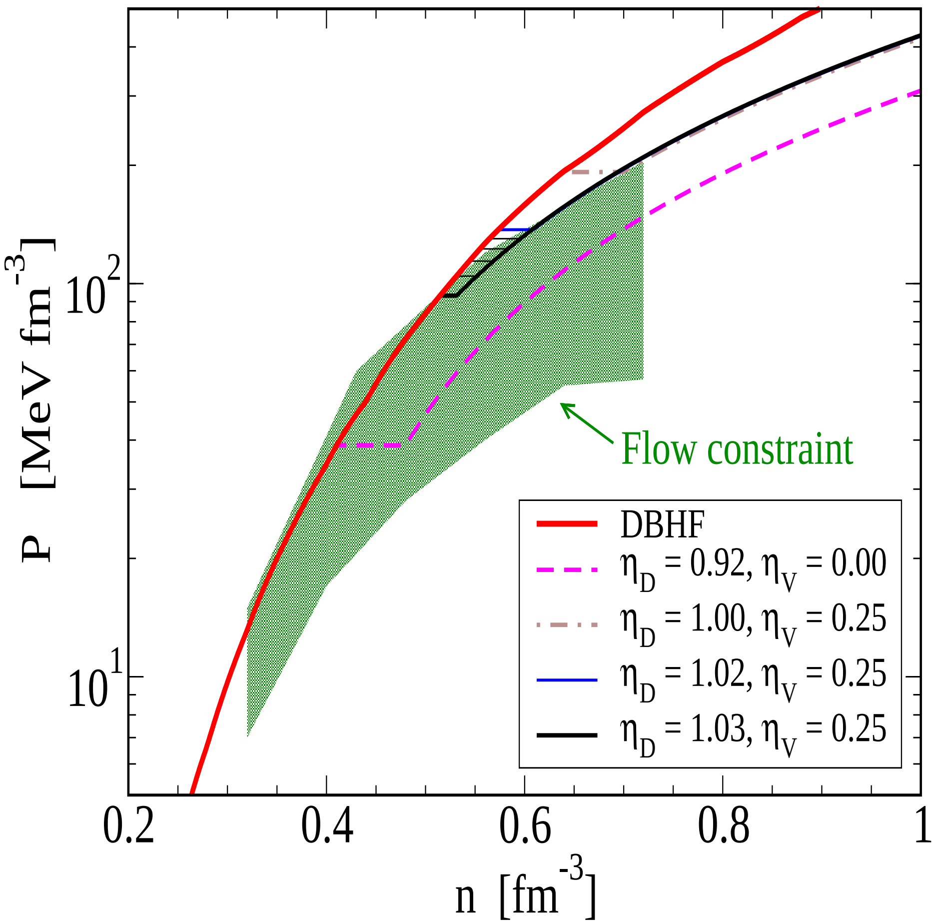
Result:

- Gapless phases only at high T,
- CFL only at high chemical potential,
- At T $\leq$25-30 MeV: mixed NQ-2SC phase,
- Critical point (T_c,μ_c)=(48 MeV, 353 MeV),
- Strong coupling, $G_D = G_S$, similar,
  no NQ-2SC mixed phase.

Rüster et al, PRD 72 (2005) 034004;
Blaschke et al, PRD 72 (2005) 065020;
Abuki, Kunihiro, NPA768 (2006) 118;
Warringa et al, PRD 72 (2005) 014015

Mass-Radius constraint and Flow constraint (II)

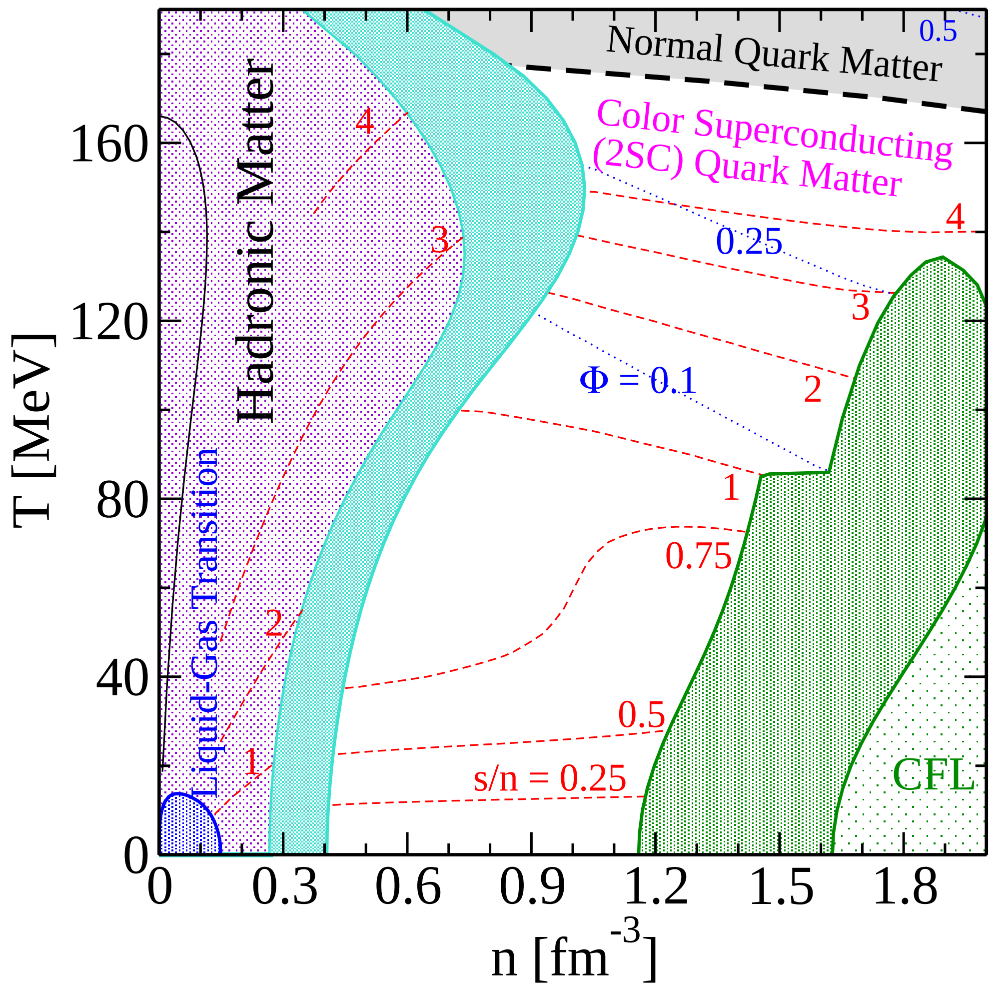




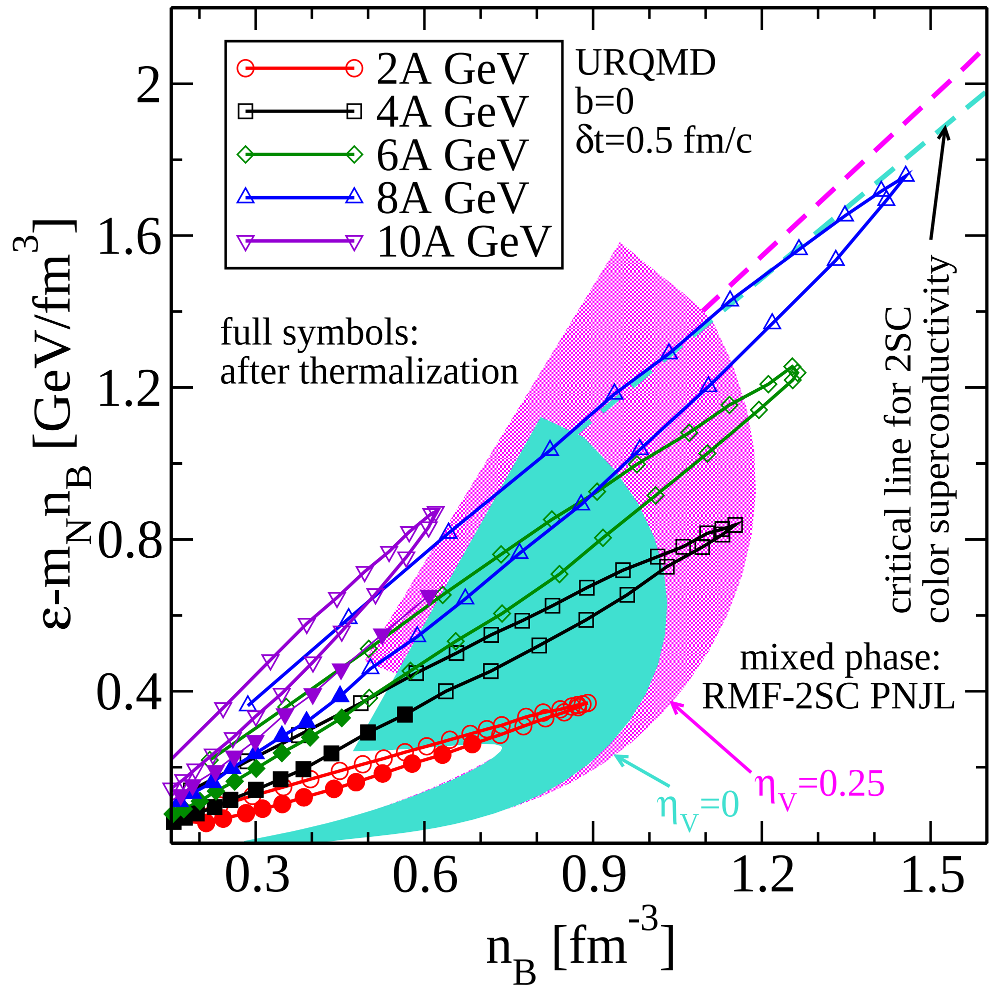
- Large Mass ($\sim 2\ M_\odot$) and radius ($R \geq 12$ km) $\Rightarrow$ stiff quark matter EoS;
  Note: DU problem of DBHF removed by deconfinement! and: CFL core Hybrids unstable!
- Flow in Heavy-Ion Collisions $\Rightarrow$ not too stiff EoS !
  Note: Quark matter removes violation by DBHF at high densities

Klähn, D.B., Sandin, Fuchs, Faessler, Grigorian, Röpke, Trümper: Phys. Lett. B567, 160 (2007)

Phase diagrams for the FAIR & NICA experiments



Phase diagram for isospin-symmetric hybrid matter



Trajectories of heavy-ion collisions for different E_{lab}

D.B., F. Sandin, V. Skokov: "Accessibility of dense QCD phases ...";
`http://theor.jinr.ru/twiki-cgi/view/NICA/NICAWhitePaper`

General Relativistic Cooling Equations

The energy flux per unit time $l(r)$ through a spherical slice at distance r from the center is:

$$l(r) = -4\pi r^2 k(r) \frac{\partial (T e^{\Phi})}{\partial r} e^{-\Phi} \sqrt{1 - \frac{2M}{r}}.$$

The factor $e^{-\Phi}\sqrt{1 - \frac{2M}{r}}$ corresponds to relativistic corrections of time and distance scales.
The equations for energy balance and thermal energy transport are:

$$\frac{\partial}{\partial N_B}(l e^{2\Phi}) = -\frac{1}{n}(\epsilon_\nu e^{2\Phi} + c_V \frac{\partial}{\partial t}(T e^{\Phi}))$$

$$\frac{\partial}{\partial N_B}(T e^{\Phi}) = -\frac{1}{k} \frac{l e^{\Phi}}{16\pi^2 r^4 n}$$

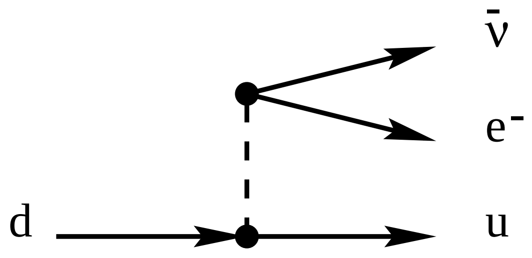
where $n = n(r)$ is the baryon number density, $N_B = N_B(r)$ is the total baryon number in the sphere with radius r and

$$\frac{\partial N_B}{\partial r} = 4\pi r^2 n (1 - \frac{2M}{r})^{-1/2}$$

F. Weber: Pulsars as Astrophys. Labs ... (1999); D.B., Grigorian, Voskresensky, A& A 368 (2001) 561.

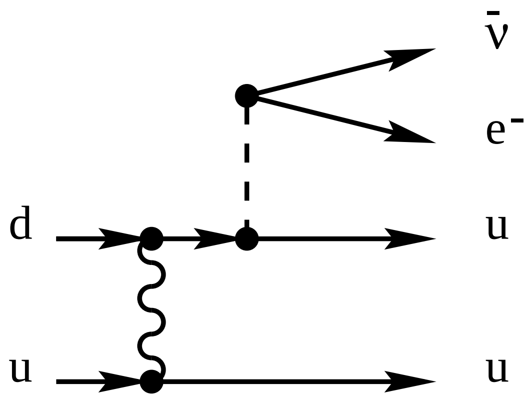
Neutrino processes in quark matter: Emissivities

- Quark direct Urca (QDU) the most efficient processes
  $d \to u + e + \bar{\nu}$ and $u + e \to d + \nu$
  $\epsilon_\nu^{\rm QDU} \simeq 9.4 \times 10^{26} \alpha_s u Y_e^{1/3} \zeta_{\rm QDU}\, T_9^6$ erg cm^{-3} s^{-1},
  Compression $u = n/n_0 \simeq 2$, strong coupling $\alpha_s \approx 1$



- Quark Modified Urca (QMU) and Quark Bremsstrahlung (QB)
  $d + q \to u + q + e + \bar{\nu}$ and $q_1 + q_2 \to q_1 + q_2 + \nu + \bar{\nu}$
  $\epsilon_\nu^{\rm QMU} \sim \epsilon_\nu^{\rm QB} \simeq 9.0 \times 10^{19} \zeta_{\rm QMU}\, T_9^8$ erg cm^{-3} s^{-1}.

- Suppression due to the pairing
  QDU : $\zeta_{\rm QDU} \sim \exp(-\Delta_q/T)$
  QMU and **QB** : $\zeta_{\rm QMU} \sim \exp(-2\Delta_q/T)$ for $T < T_{{\rm crit},q} \simeq 0.57\, \Delta_q$



Quark PBF

- $e + e \to e + e + \nu + \bar{\nu}$
  $\epsilon_\nu^{ee} = 2.8 \times 10^{12}\, Y_e^{1/3} u^{1/3} T_9^8$ erg cm^{-3} s^{-1},
  becomes important for $\Delta_q/T >> 1$

Flowers, Itoh, ApJ 250 (1981) 750; Schaab, Voskresensky, Sedrakian, Weber, Weigel, A & A 321 (1997)591
Yakovlev, Levenfish, Shibanov, Phys. Usp. 169 (1999) 825; Baiko, Haensel, Acta Phys. Polon. B 30 (1999) 1097
Blaschke, Grigorian, Voskresensky , Astron. & Astrophys. 368 (2001) 561; Jaikumar, Prakash, PLB 516 (2001) 345
Jaikumar, Roberts, Sedrakian, PRC 73 (2006) 034012; Wang, Wang, Wu, PRC 74 (2006) 014021

Hybrid Star Cooling with 2SC Quark Matter

2SC phase: 1 color (blue) is unpaired (mixed superconductivity)

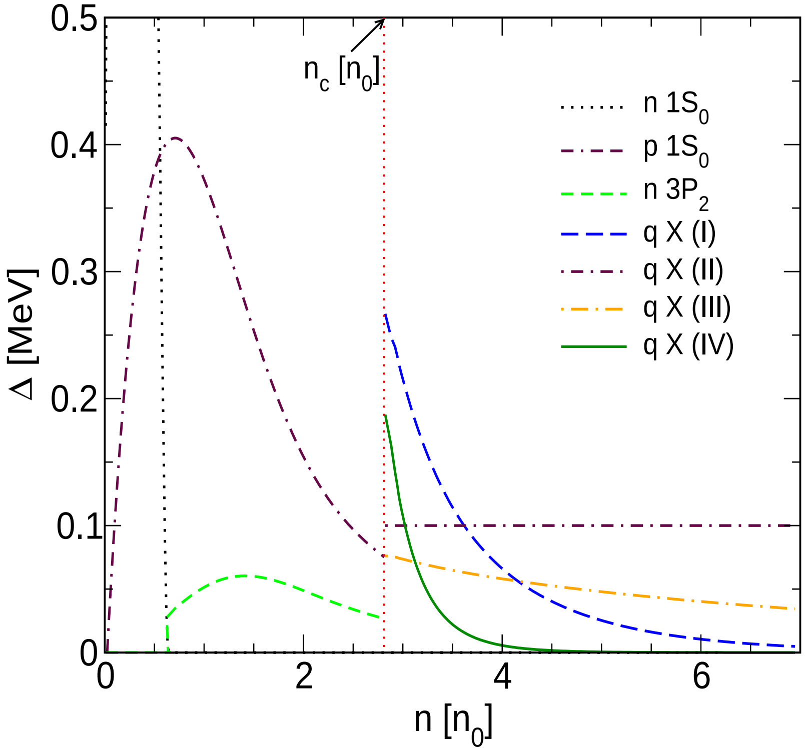
Ansatz 2SC + X phase:

$$\Delta_X(\mu) = \Delta_0 \exp[\alpha(1 - \mu/\mu_c)]$$

Grigorian, D.B., Voskresensky, PRC 71 (2005)

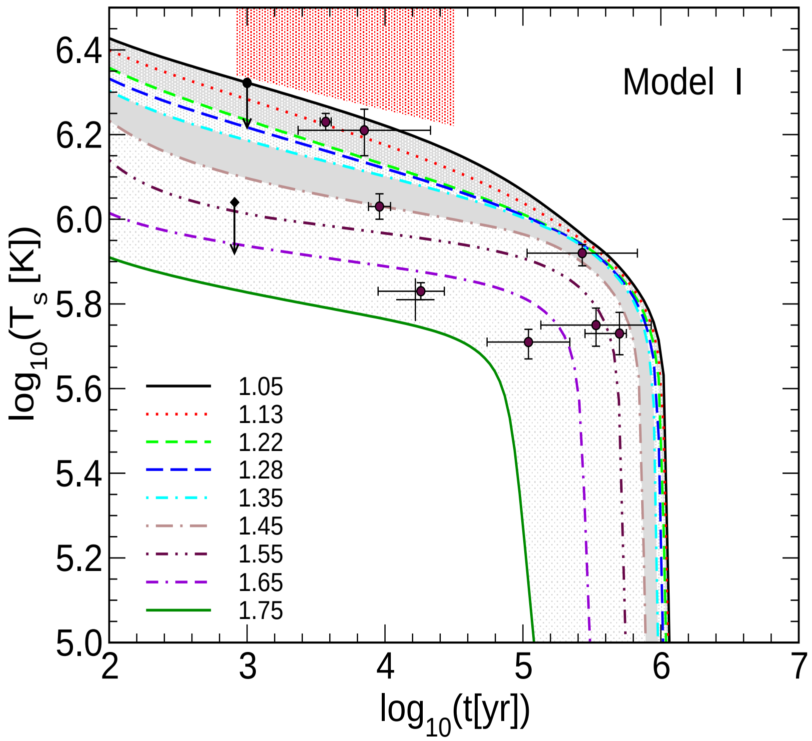
Model	Δ_0 [MeV]	α
I	1	10
II	0.1	0
III	0.1	2
IV	5	25

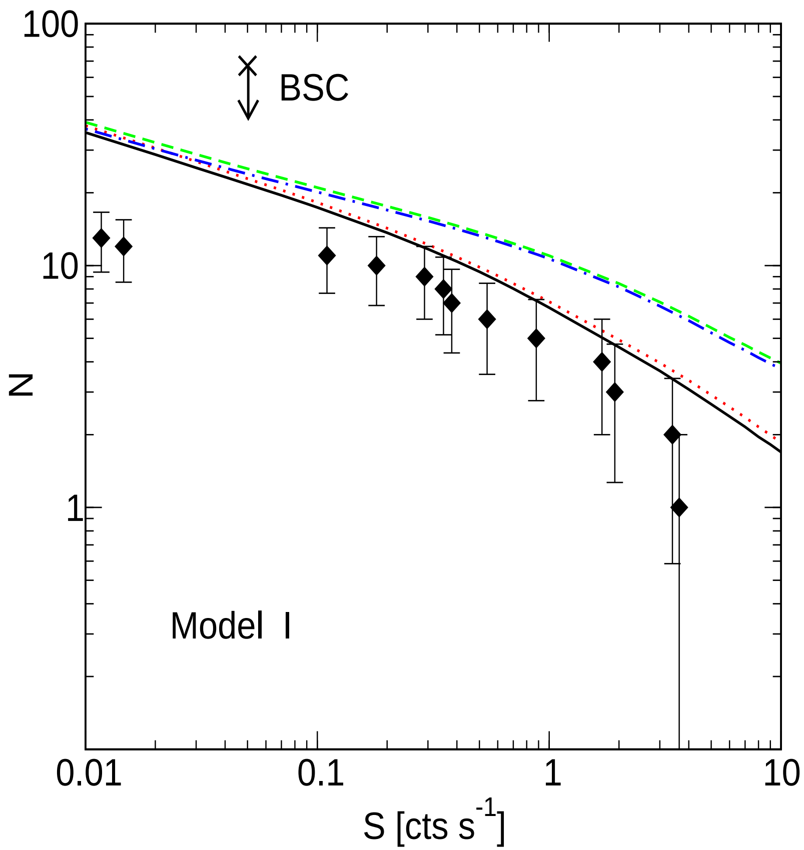
Popov, Grigorian, D.B., PRC 74 (2006)



Pairing gaps for hadronic phase
AV18 - Takatsuka et al. (2004)
and 2SC + X phase

Hybrid Star Cooling with 2SC Quark Matter





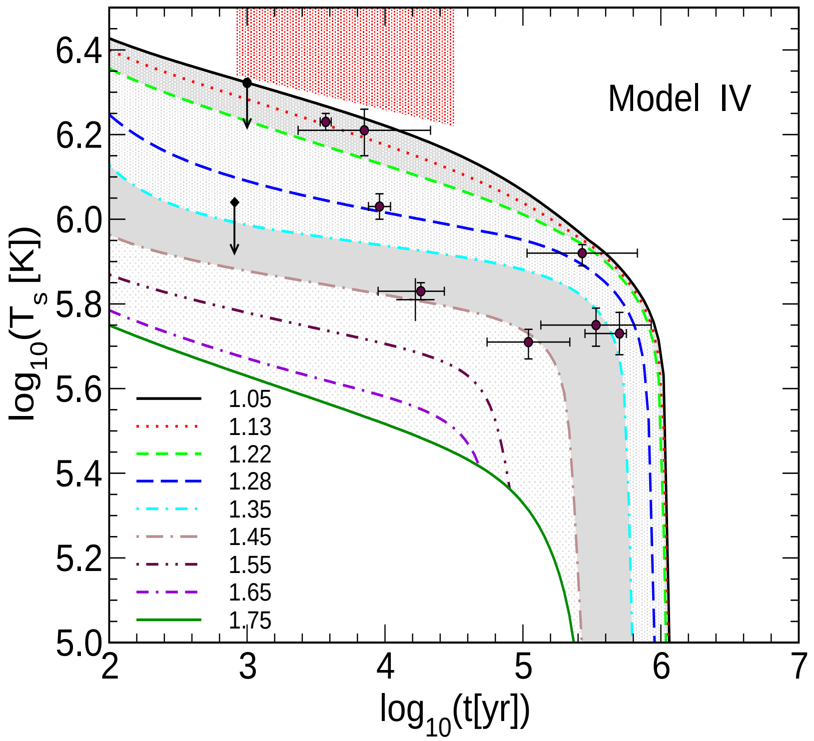
2SC + X phase, $\Delta_0 = 1$ MeV, $\alpha = 10$

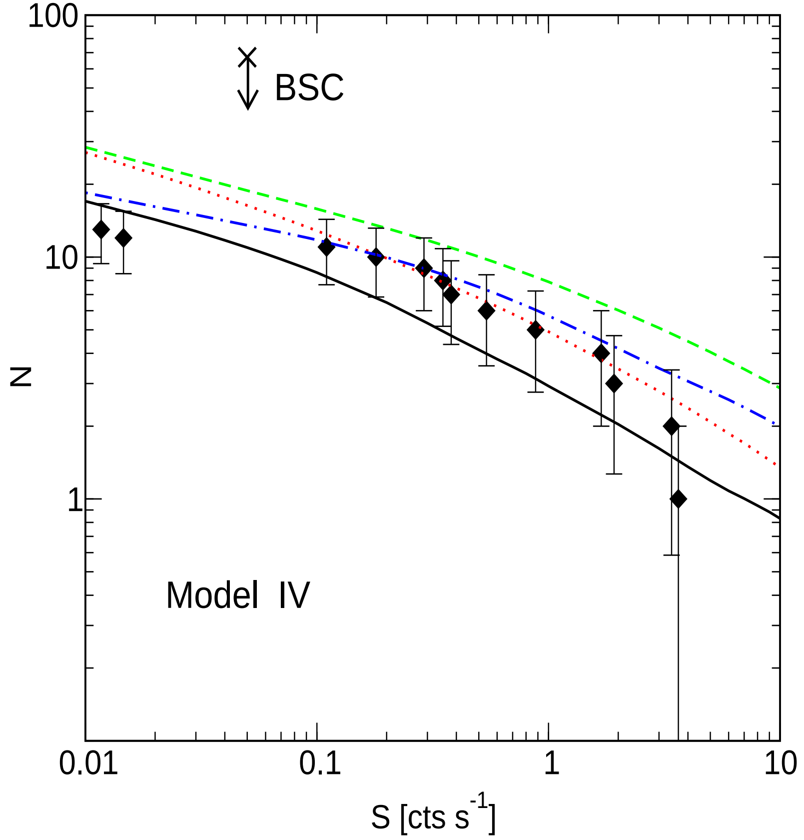
Too large mass for Vela required

Log N - Log S test fails

Popov, Grigorian, D.B., PRC 74 (2006)

Hybrid Star Cooling with 2SC Quark Matter





2SC + X phase, $\Delta_0 = 5$ MeV, $\alpha = 25$

Temperature-age and Vela mass OK

Log N - Log S test passed

Popov, Grigorian, D.B., PRC 74 (2006)

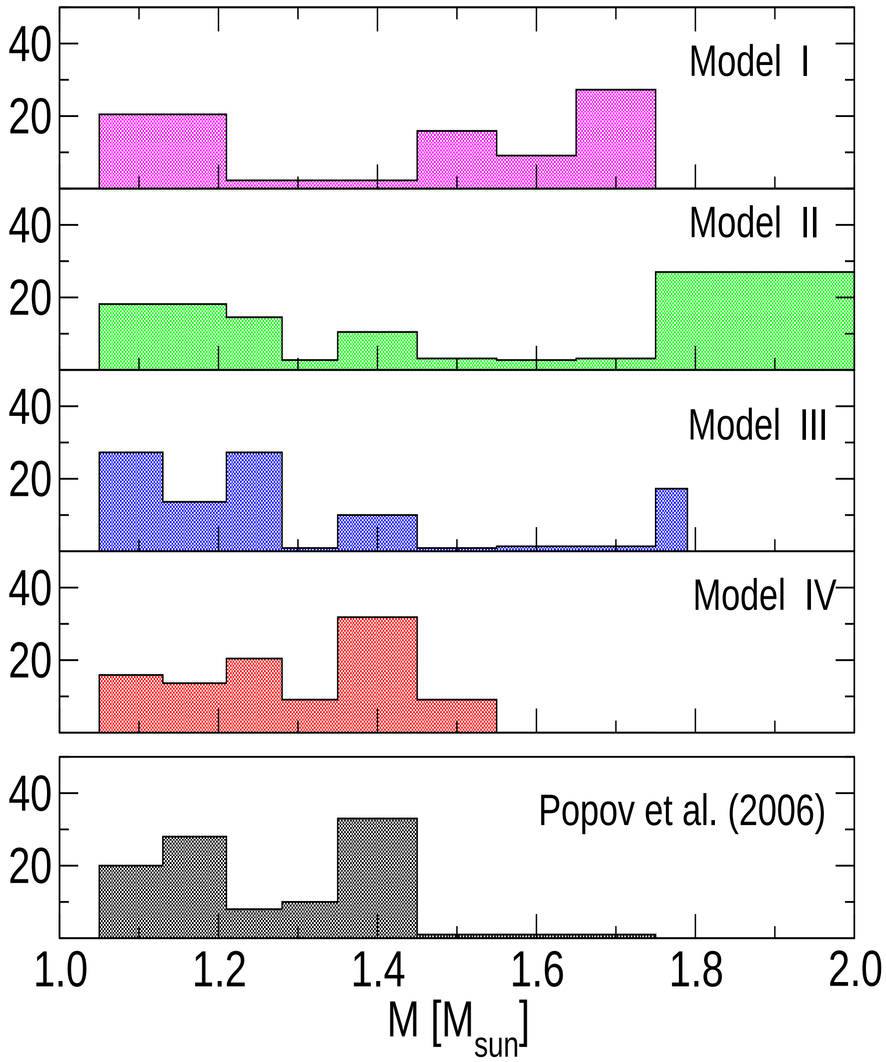
Hybrid Star Cooling with 2SC Quark Matter

Hybrid star cooling passes all modern tests:

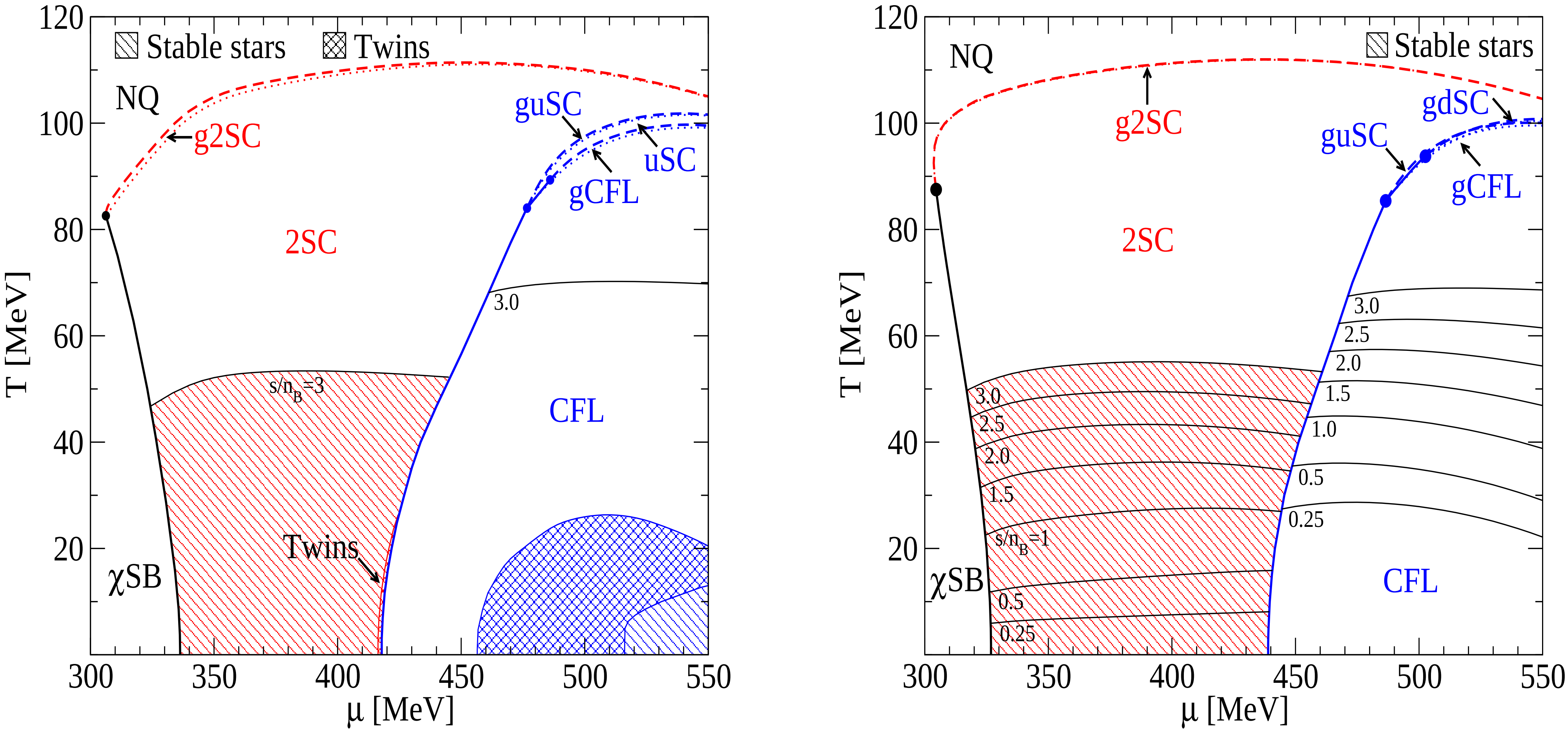
- Temperature - age
- Log N - Log S
- Brightness constraint
- Vela mass (Population sysnthesis)

Popov, Grigorian, D.B., PRC 74 (2006)

D.B., H. Grigorian, PPNP (2007)



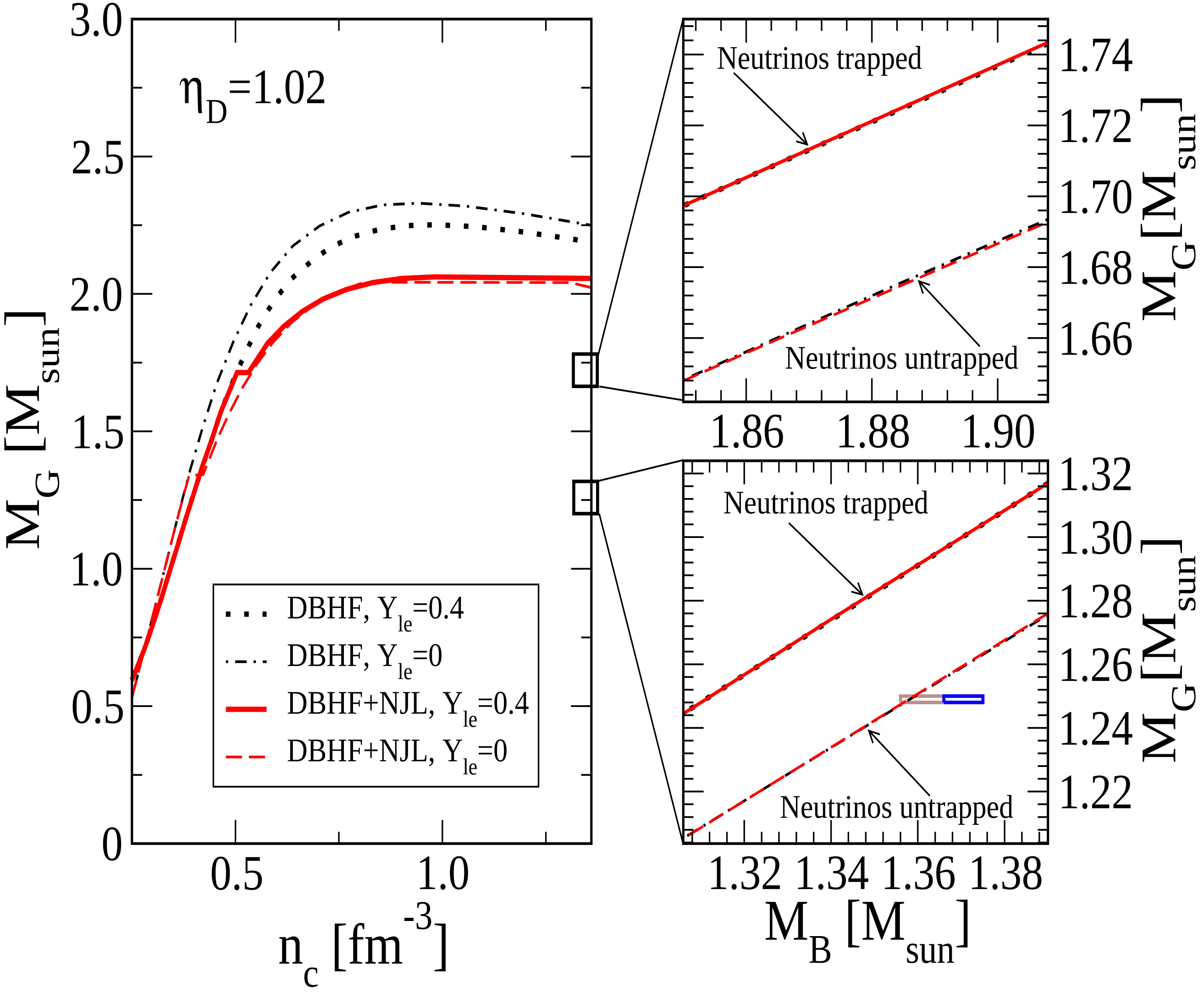
Phase diagram: effect of neutrino trapping



Phase diagrams of charge neutral quark matter in β-equilibrium at strong coupling, $\eta = 1.0$, for fixed values of the electron neutrino chemical potential, $\mu_\nu = 0$ (left-hand side) and $\mu_\nu = 200$ MeV (right-hand side).

F. Sandin, D.B., [arxiv:astro-ph/0701772] PRD (2007)

Hybrid stars: Effect of neutrino untrapping

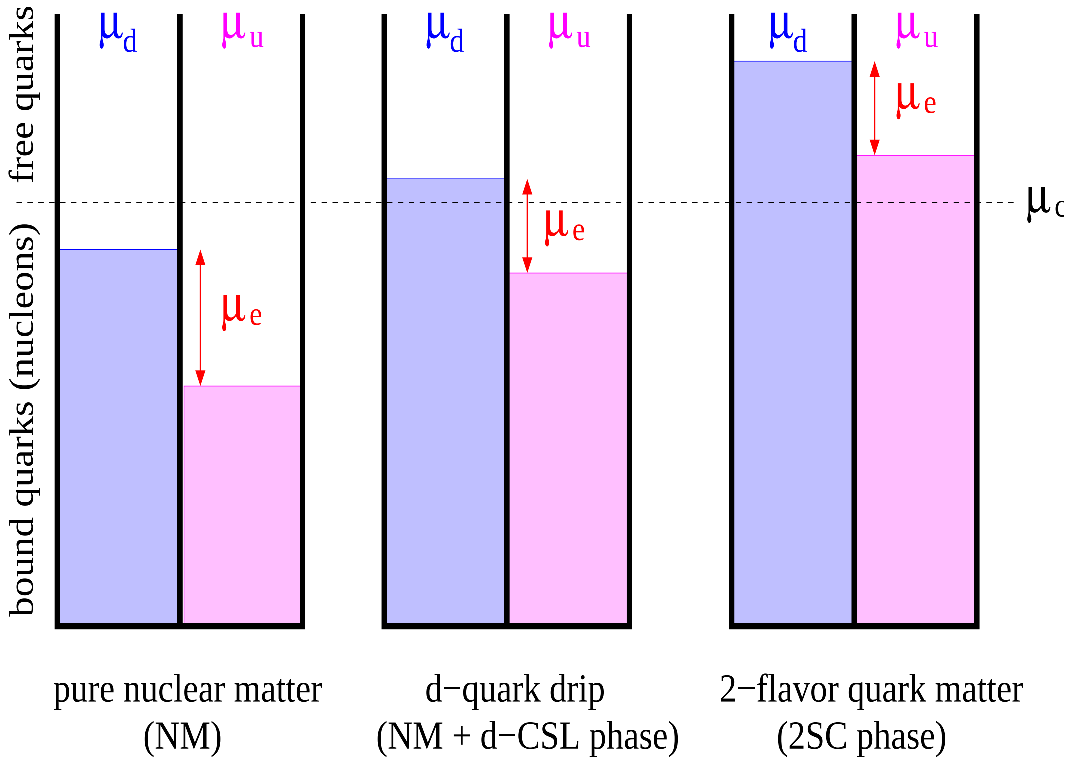


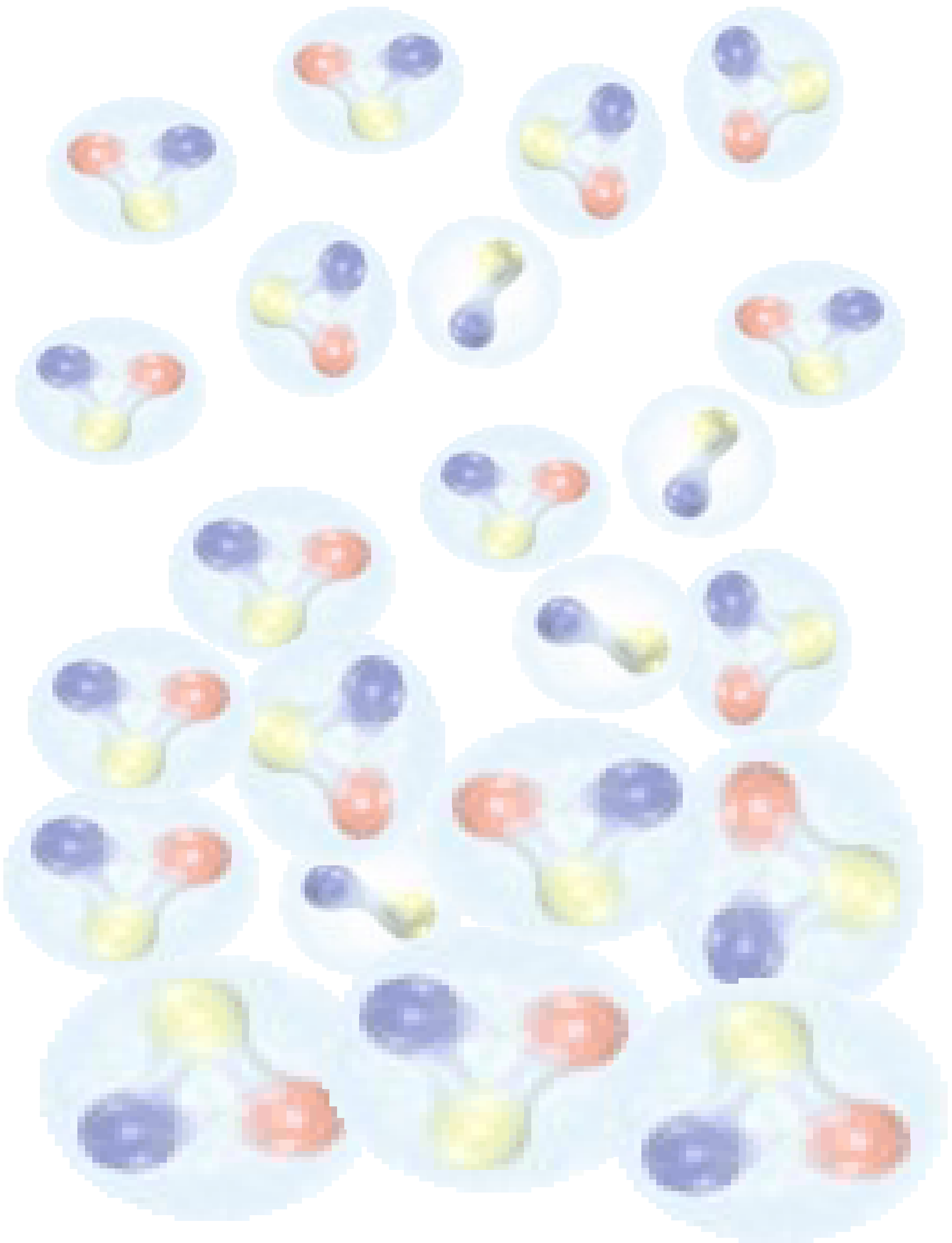
The effect of neutrino untrapping ($Y_{le} = 0.4 \rightarrow 0$) on hybrid star configurations. The release of gravitational binding energy amounts to $\approx 0.04\ M_\odot$. Blue rectangle in lower right is the constraint by Podsiadlowski et al., MNRAS (2005)

F. Sandin, D.B., T. Klähn, in preparation (2007)

d-quark 'dripline' and single-flavor (d-CSL) phase

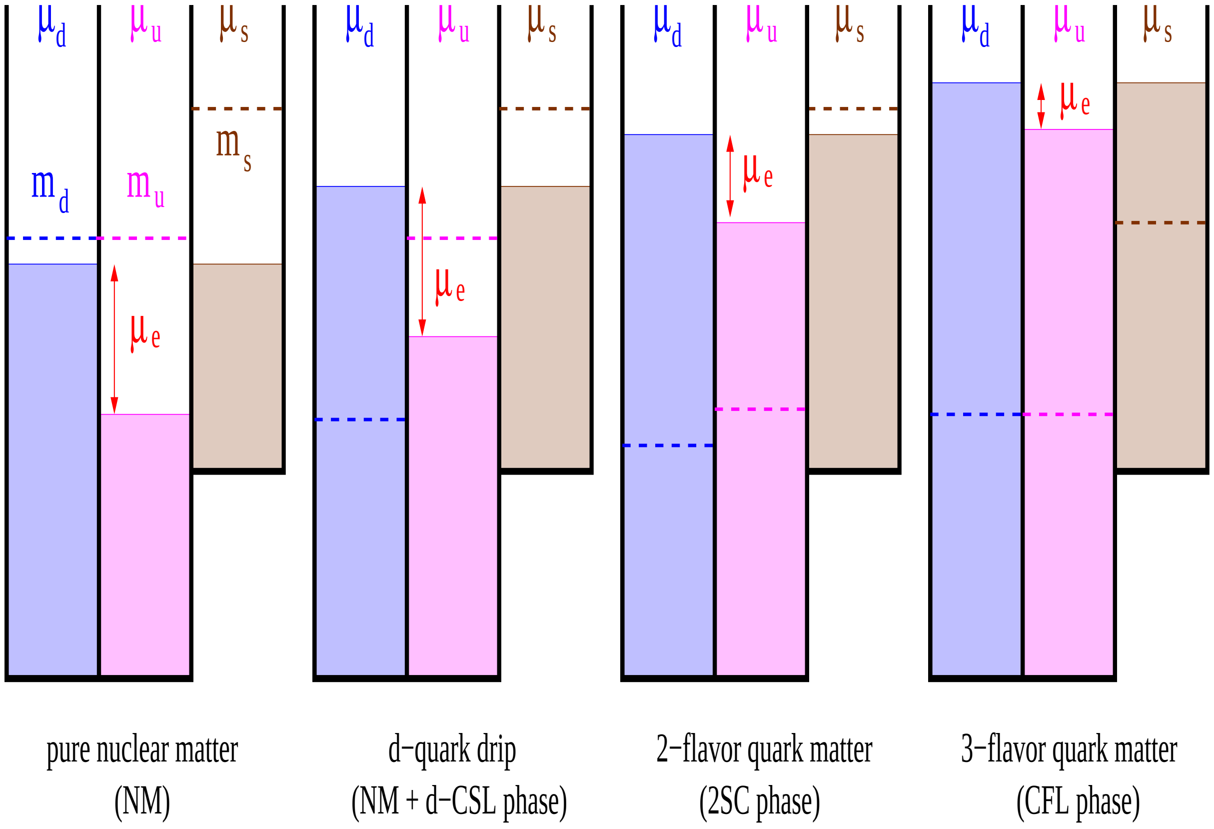
Sequential 'deconfinement' of quark flavors

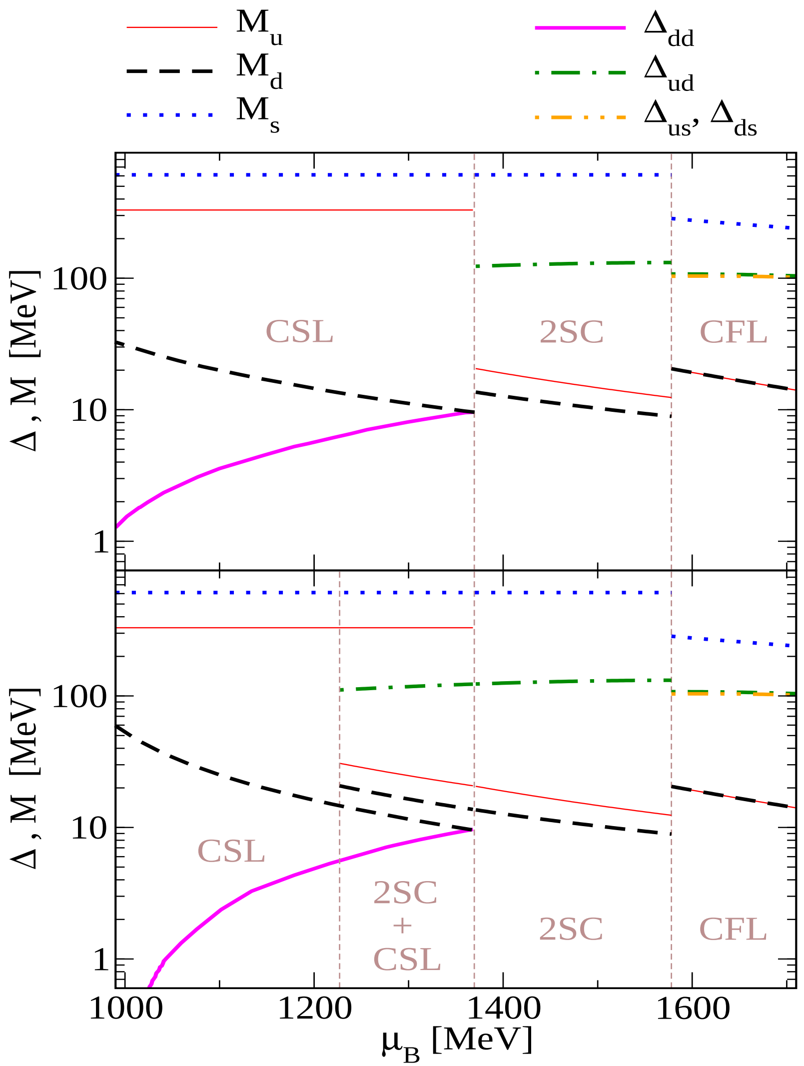




D.B., F. Sandin, T. Klähn, J. Berdermann,
arXiv:0807.0414 [nucl-th]; arXiv:0808.1369 [astro-ph]
arXiv:0808.0181 [nucl-th], J. Phys. G, in press

Sequential deconfinement in asymmetric NS matter





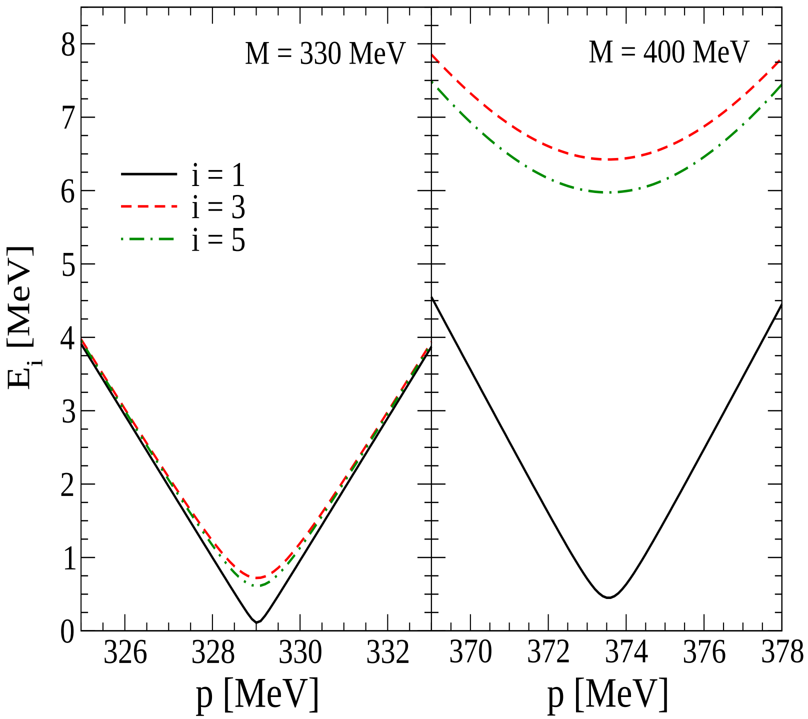
D.B., F. Sandin, T. Klähn, J. Berdermann,
arXiv:0807.0414 [nucl-th]; arXiv:0808.1369 [astro-ph]

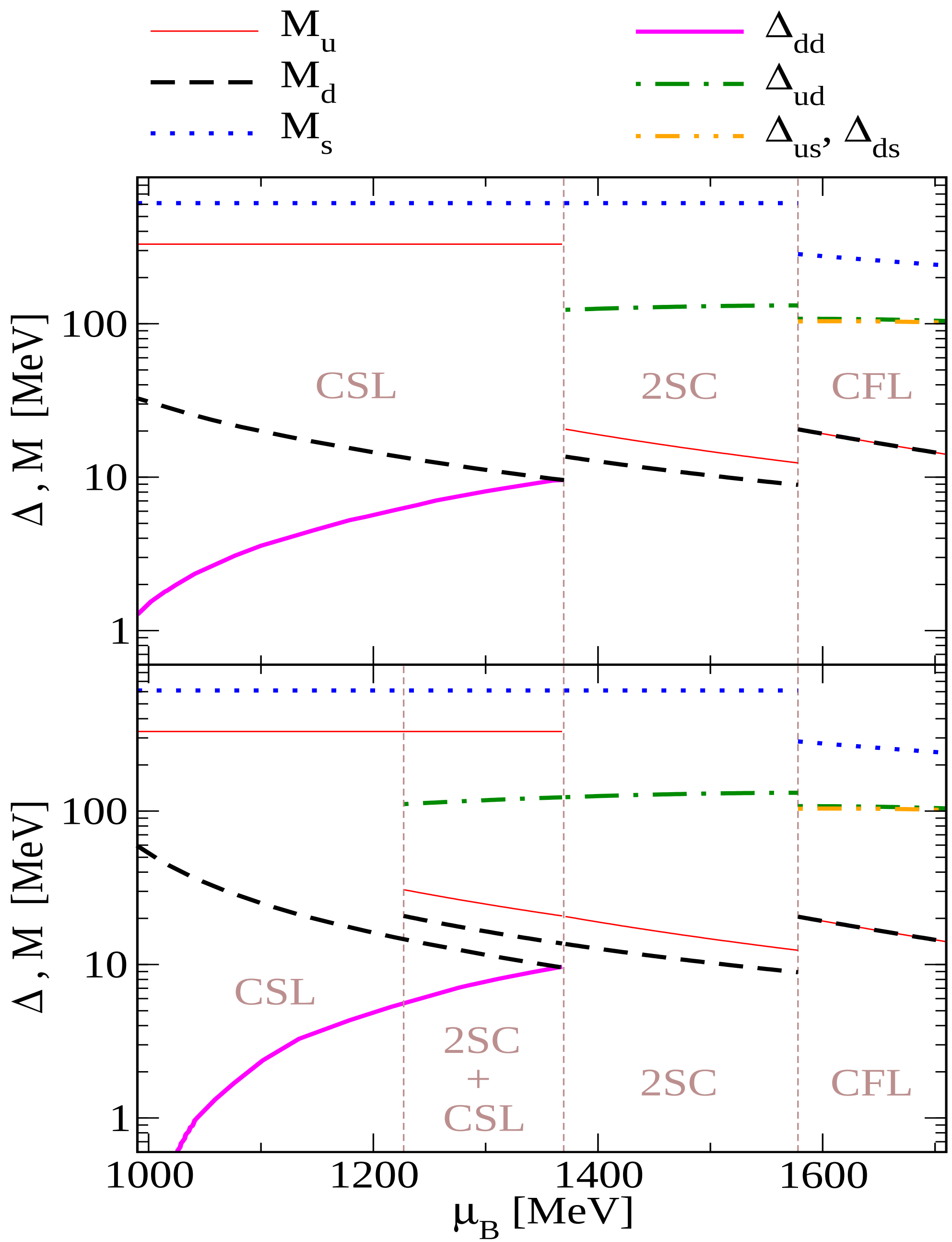
Single-flavor (d-CSL) phase in competition

Ansatz: isotropic Color-spin-locking (CSL)

$$\hat{\Delta} = \Delta(\gamma^3\lambda_2 + \gamma^1\lambda_7 + \gamma^2\lambda_5)$$

Aguilera et al., PRD 72 (2005) 034008;
PRD 74 (2006) 114005





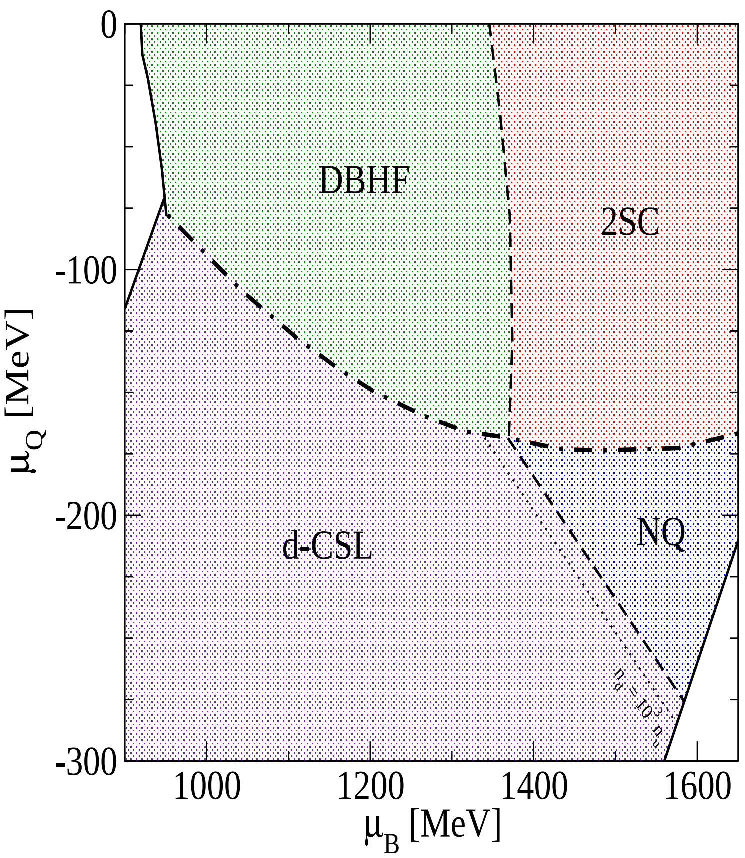
See also:

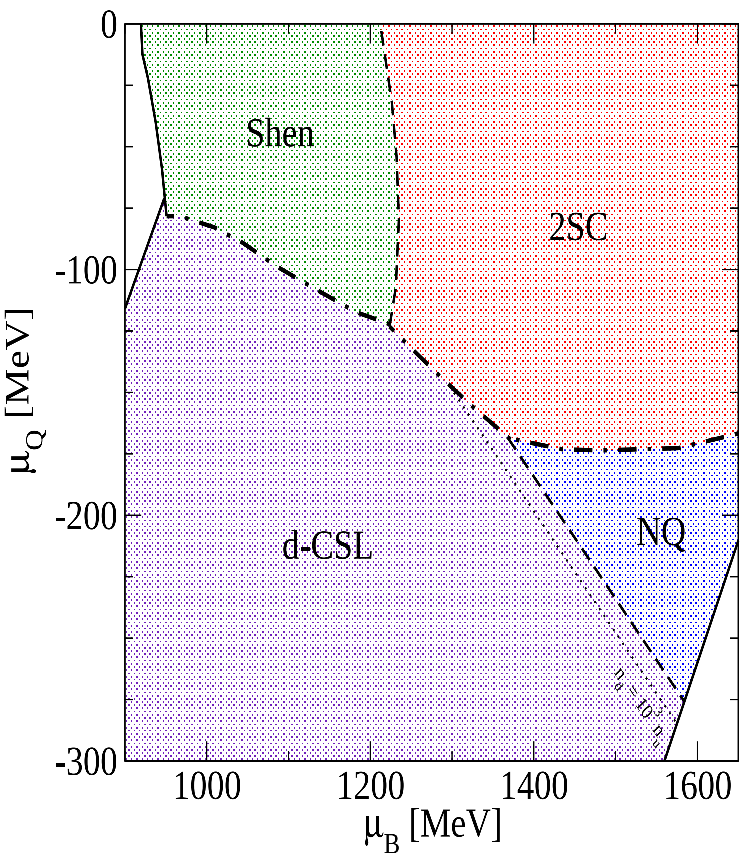
Schmitt, Wang, Rischke, PRD 66, 114010 (2002)

d-CSL: single-flavor phase in competition

Dash-dotted lines: border between oppositely charged phases

$\Longrightarrow$ **single-flavor phase only in isospin-asymmetric matter!**

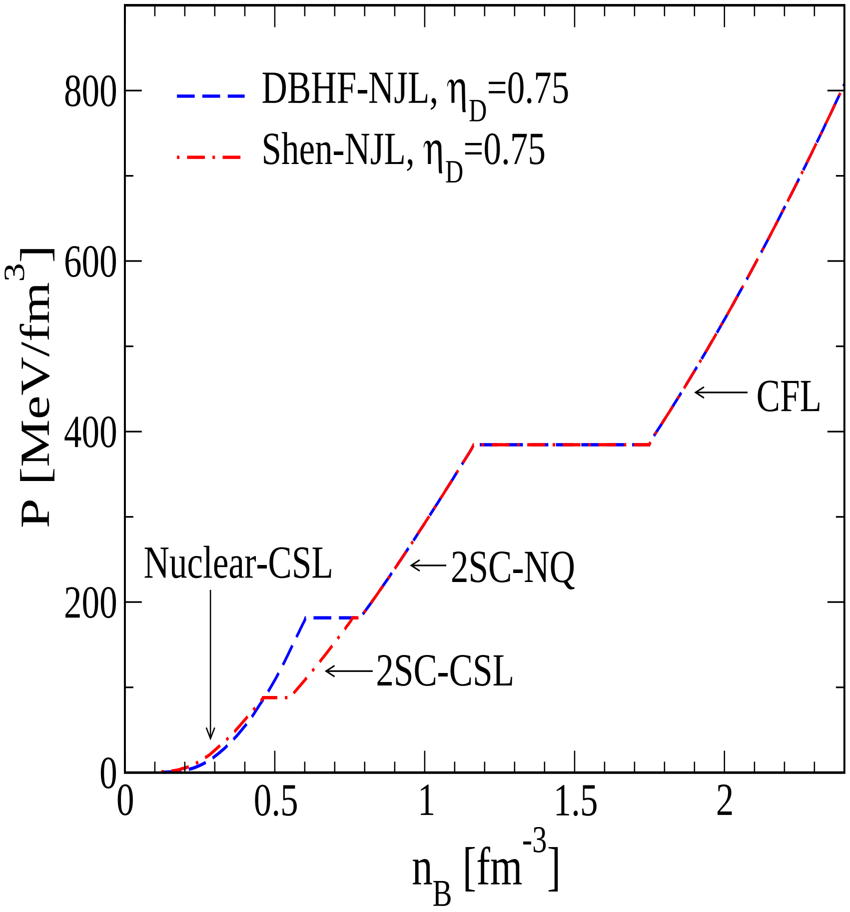




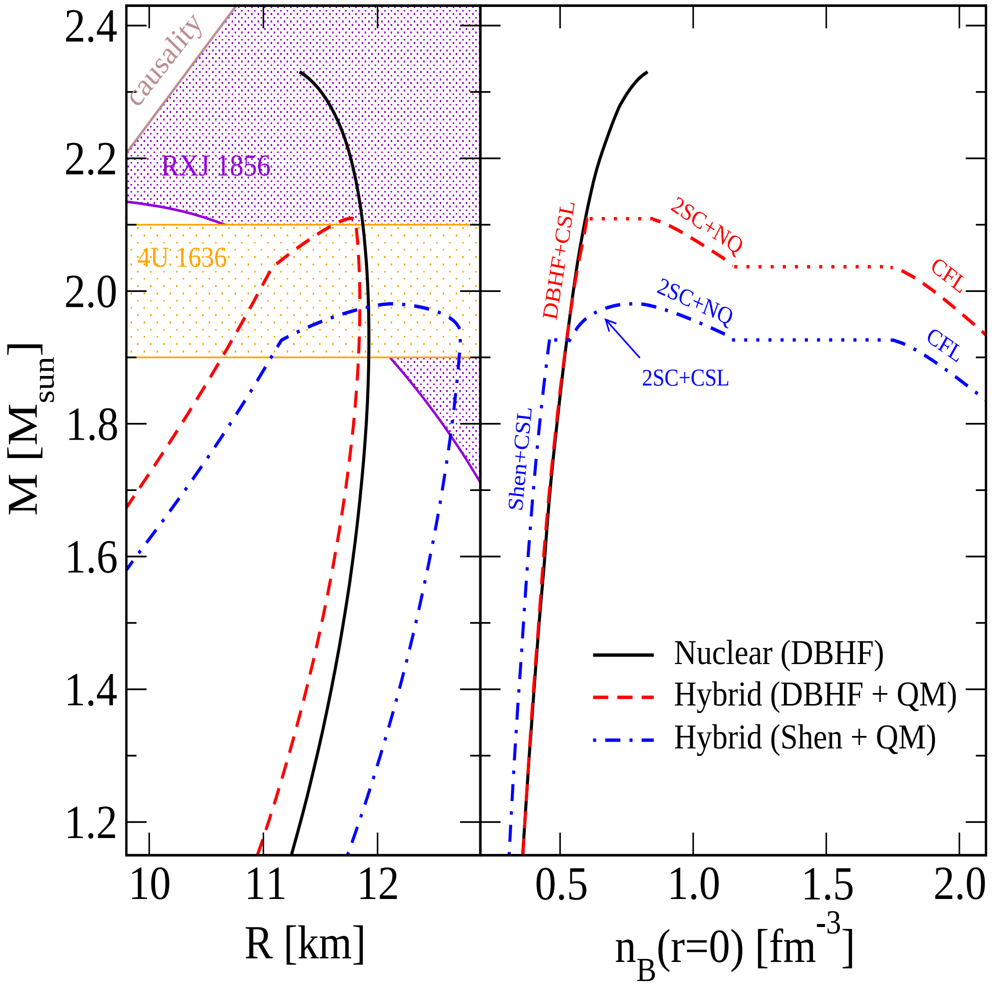
D.B., F. Sandin, T. Klähn, J. Berdermann, arXiv:0807.0414 [nucl-th]; arXiv:0808.1369 [astro-ph]

d-CSL: single-flavor phase in neutron stars

Equation of state



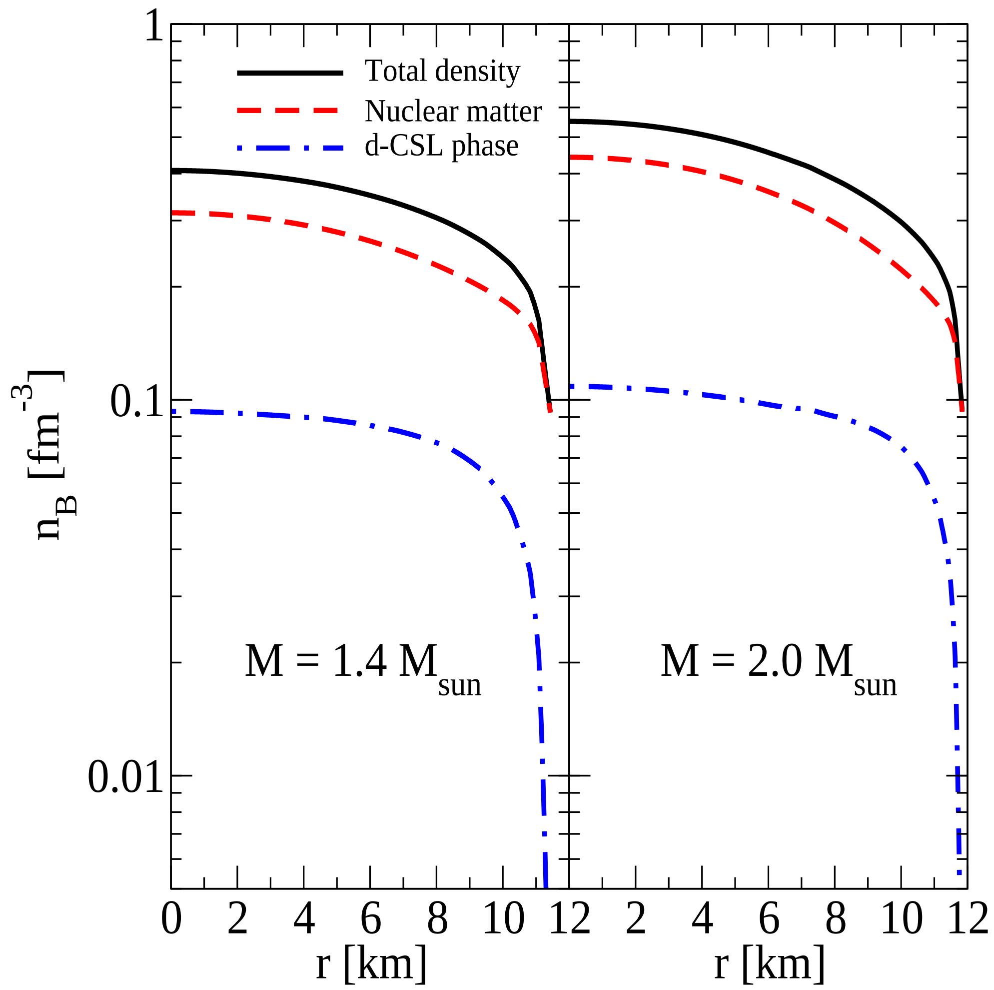
Configuration Sequences



D. B., F. Sandin, T. Klähn, J. Berdermann, arXiv:0807.0414 [nucl-th]; arXiv:0808.1369 [astro-ph]; arXiv:0808.0181 [nucl-th], J. Phys. G, in press (2008).

d-CSL: single-flavor phase in neutron stars (II)

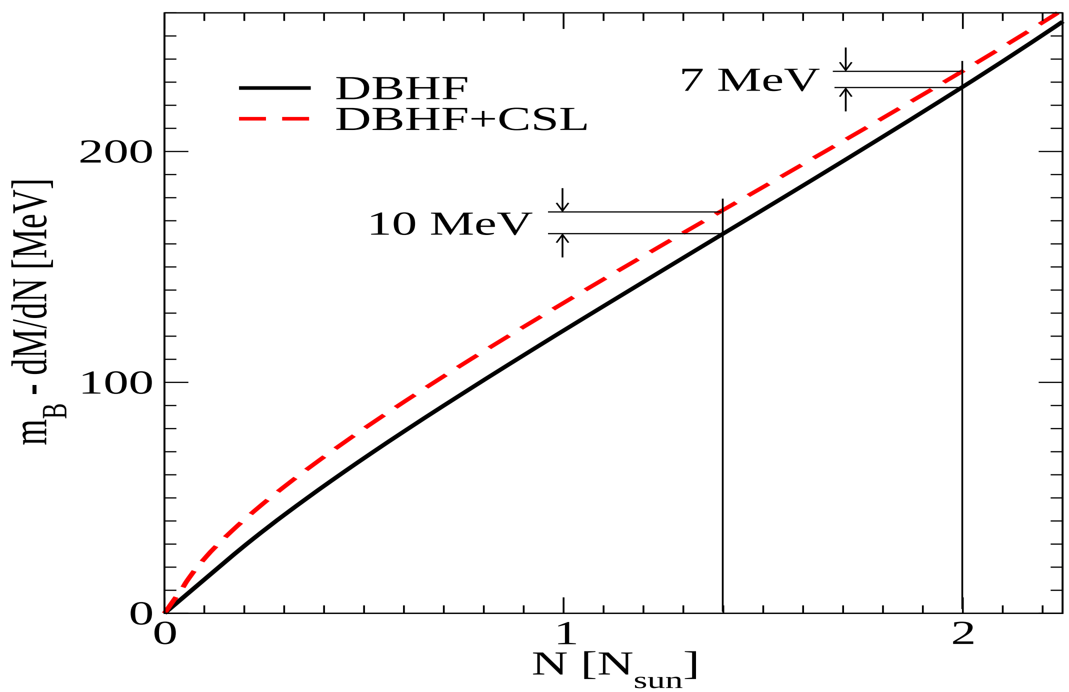
d-quark drip at crust-core boundary: Candidate for “deep crustal heating” (DCH) process?



Haensel and Zdunik, A& A **227**, 431 (1990)
Ushomirsky and Rutledge, MNRAS **325**, 1157 (2001)

Page and Cumming, ApJ **635**, L157 (2005): Superbursts & Strange Stars
Stejner and Madsen, A& A **458**, 523 (2006): SS + Transient Cooling

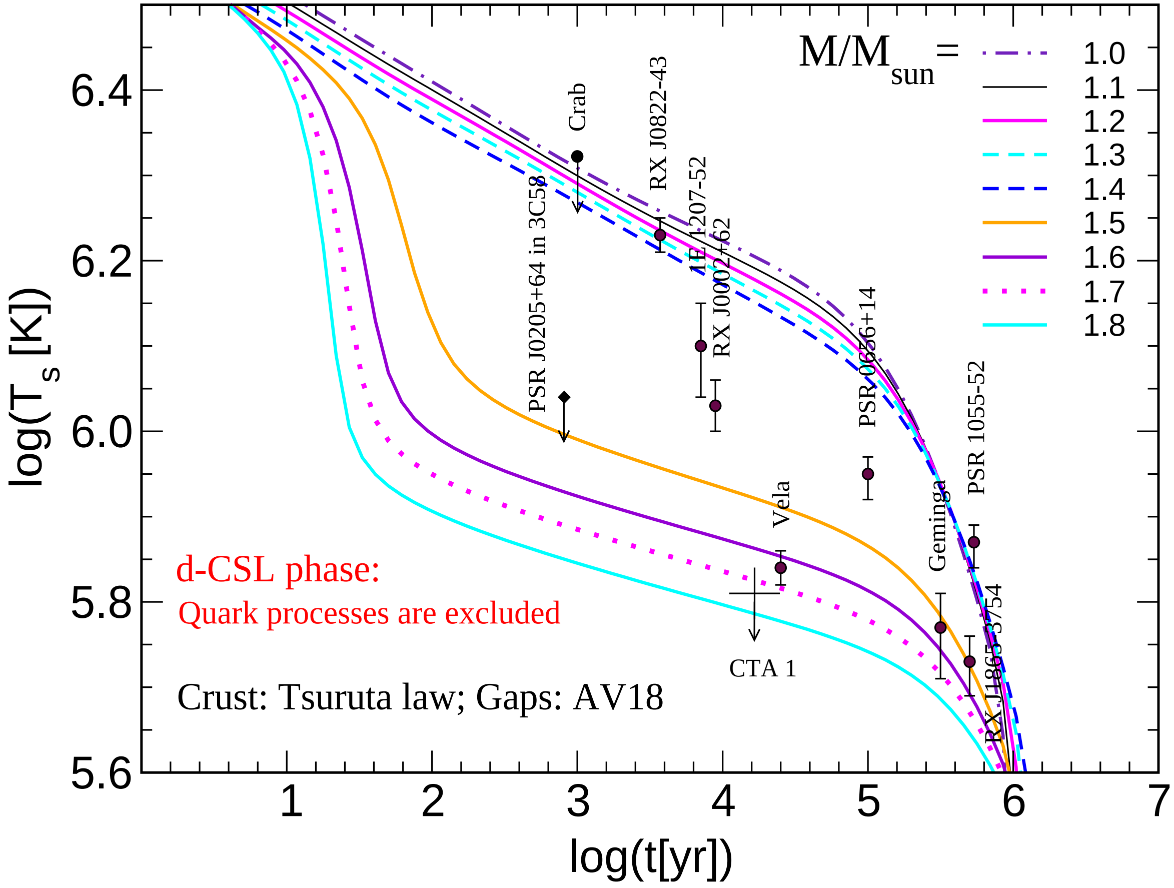
Shternin, Yakovlev, Haensel and Potekhin, MNRAS **382**, L43 (2007): KS1731



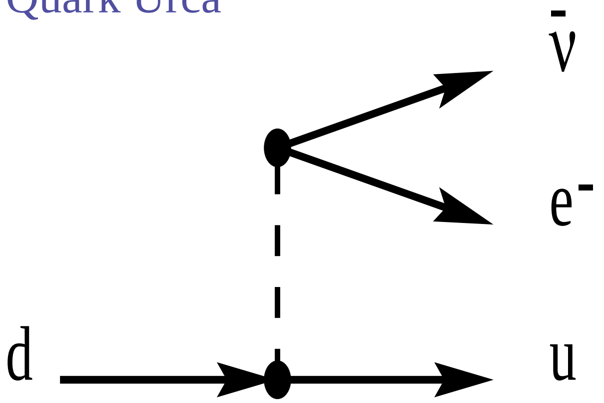
D. B., F. Sandin, T. Klähn, J. Berdermann, arXiv:0807.0414 [nucl-th]

d-CSL: single-flavor phase in neutron stars

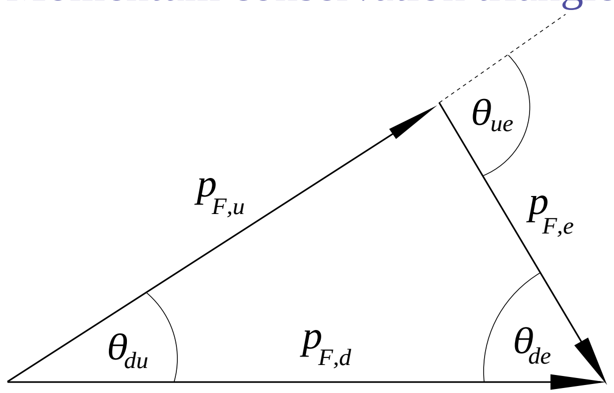
Cooling: processes in single-flavor quark matter are blocked!



Quark Urca



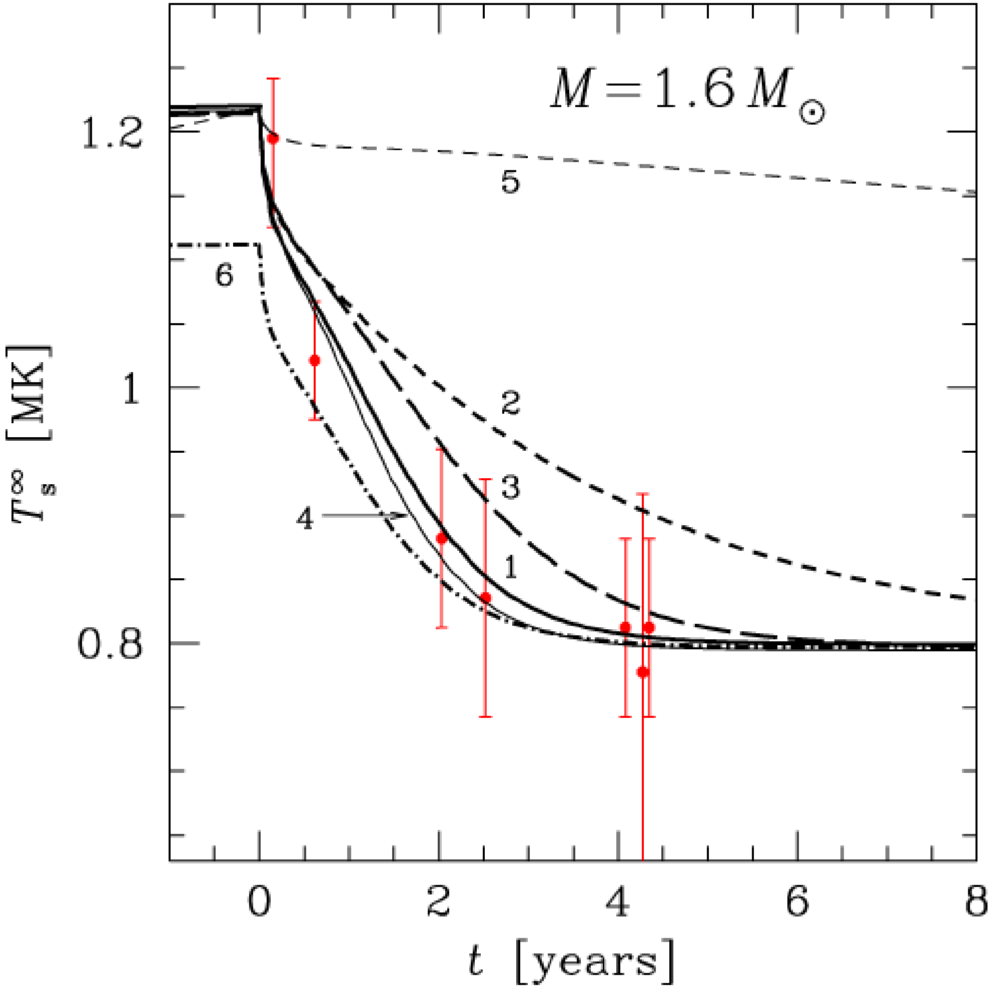
Momentum conservation triangle



not operative since u-quark Fermi sea not populated ($p_{F,u} = 0$)

D. B., F. Sandin, H. Grigorian, in preparation.

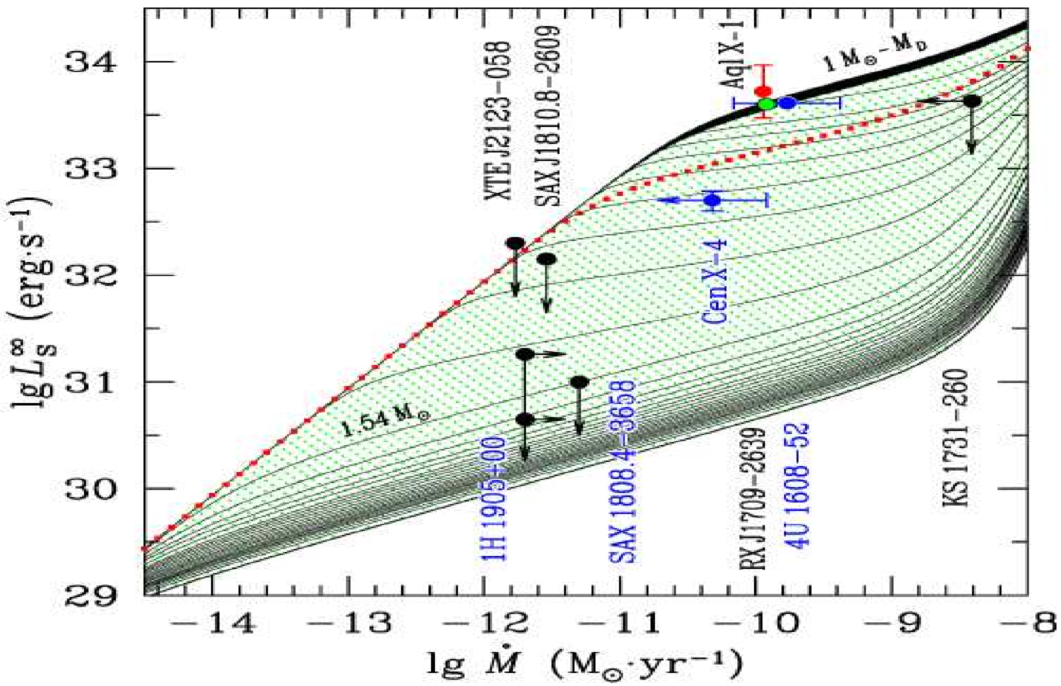
Cooling of X-ray transient KS 1731: too fast without “deep crustal heating” (DCH) process!



Haensel and Zdunik,A& A **227**, 431 (1990)
Ushomirsky and Rutledge, MNRAS **325**, 1157 (2001)

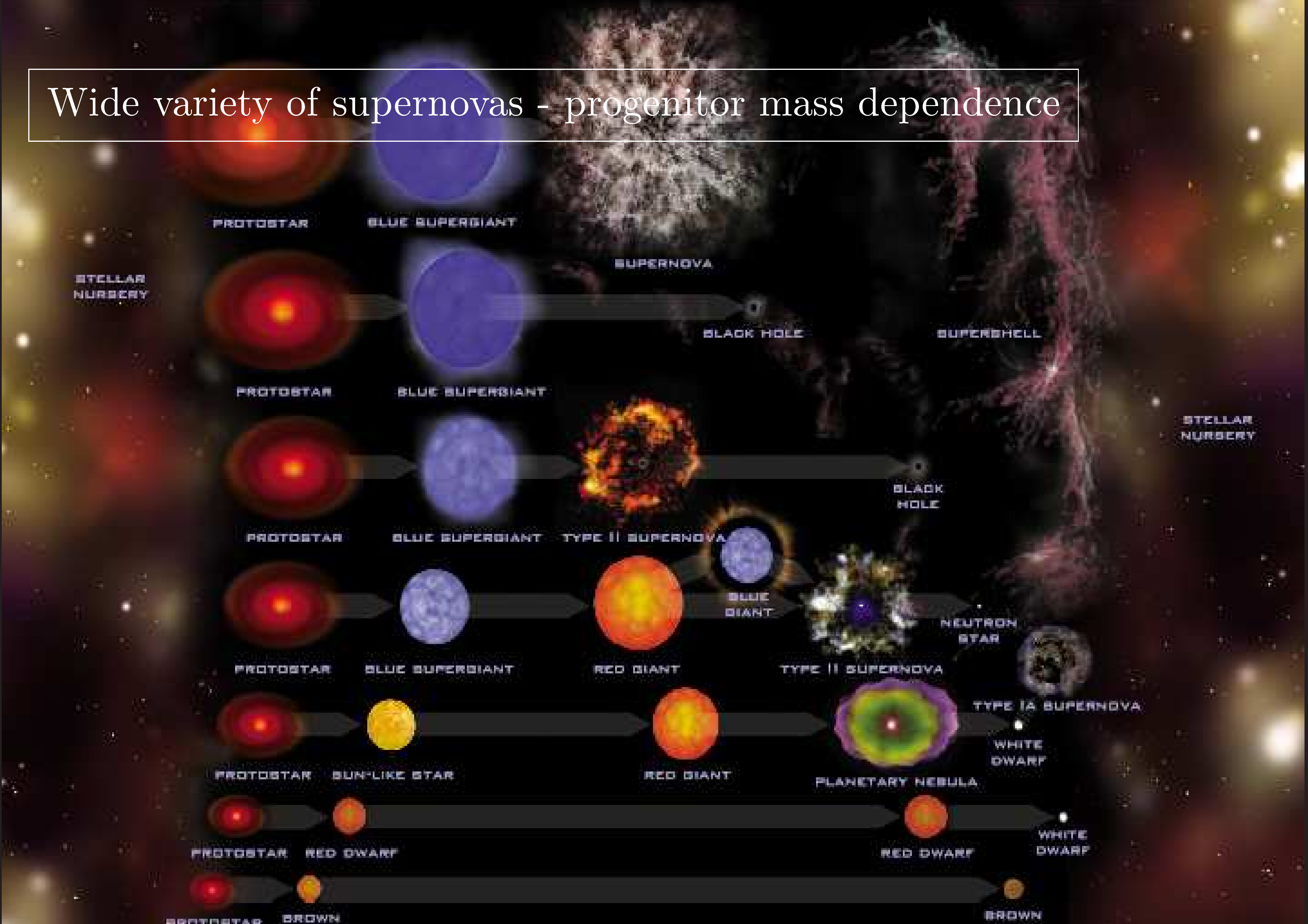
Page and Cumming,ApJ **635**, L157 (2005): Superbursts & Strange Stars
Stejner and Madsen,A& A **458**, 523 (2006): SS + Transient Cooling

Shternin, Yakovlev, Haensel and Potekhin, MNRAS **382**, L43 (2007): KS1731

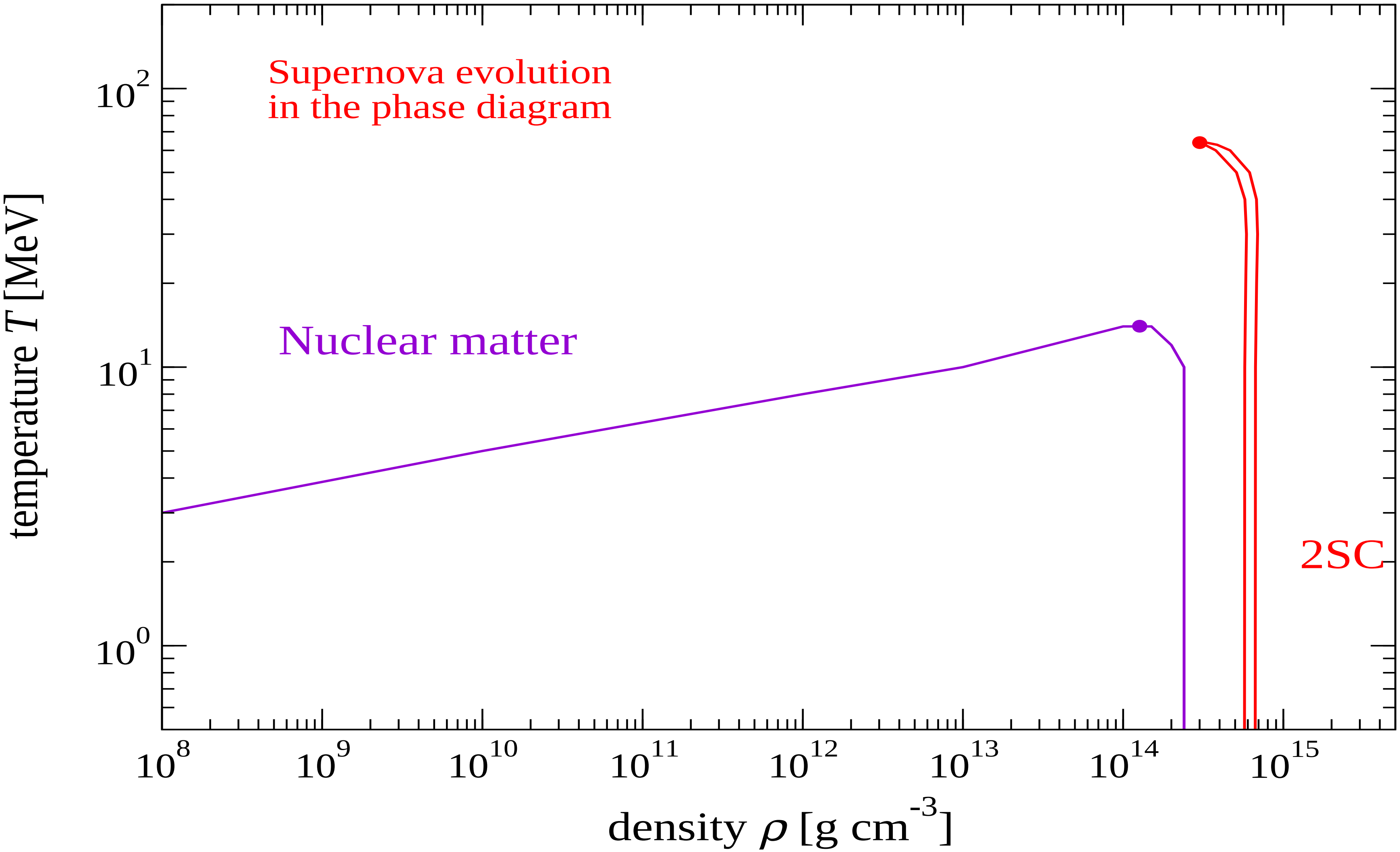


K. Levenfish, P. Haensel (2007)

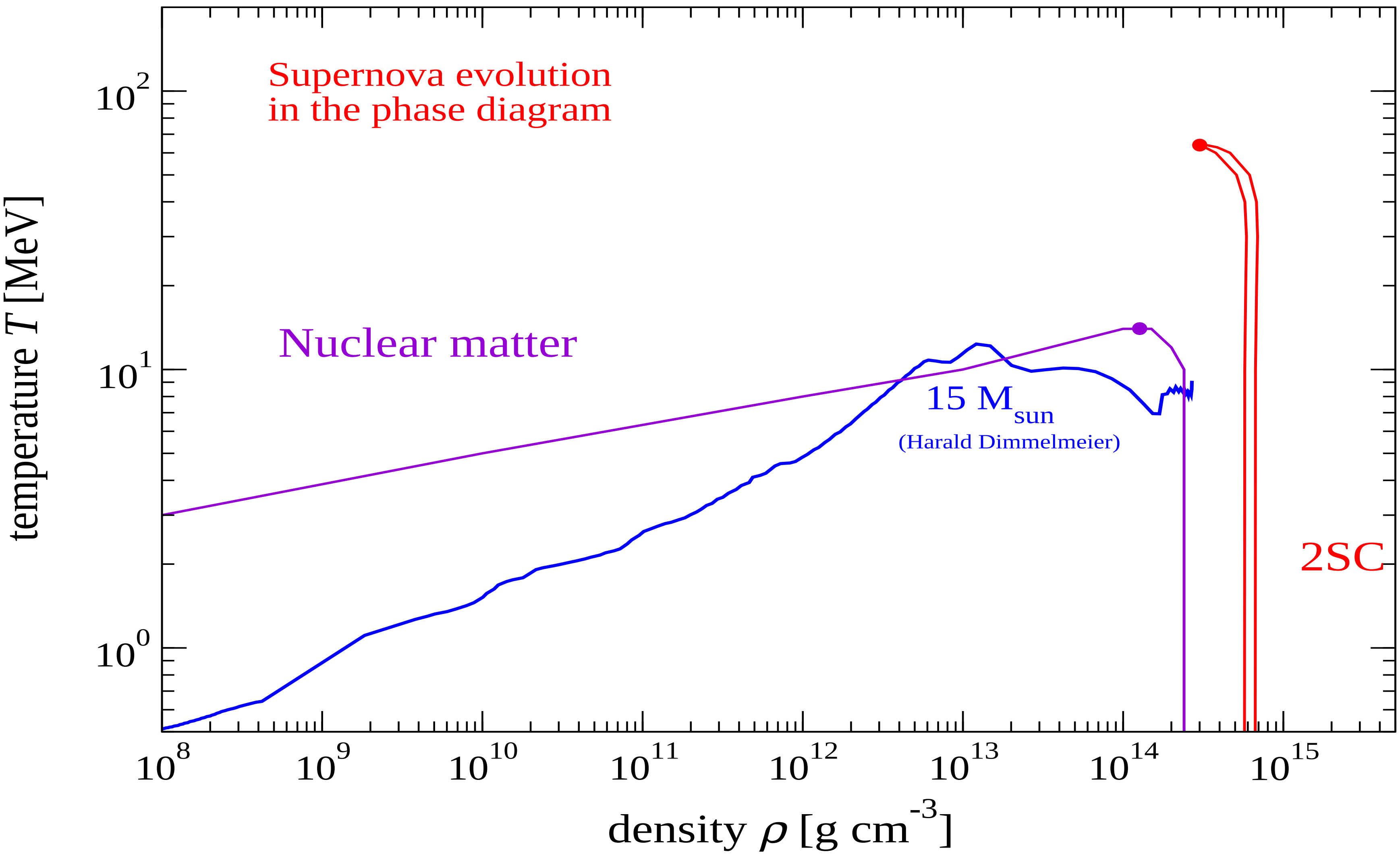
Wide variety of supernovas - progenitor mass dependence



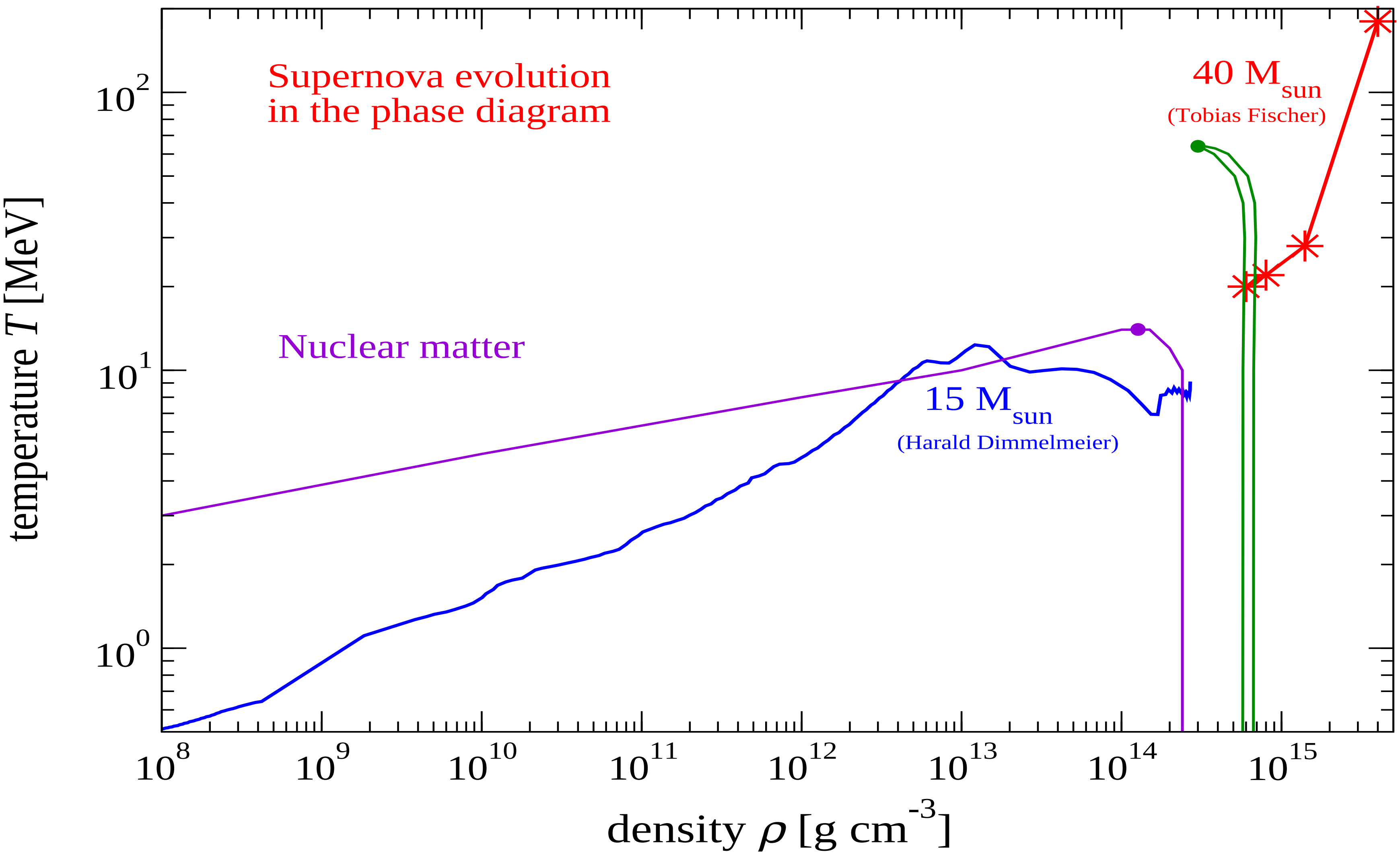
Supernova Collapse in the Phase Diagram



Supernova Collapse in the Phase Diagram (II)



Supernova Collapse in the Phase Diagram



Equation of State for Supernova Applications

Supernova 1987A - 20 years later:

- Explosion powered by QCD transition?
- Antineutrino burst signal?

Work by Sagert et al. arxiv:0809.4225

Conclusions

Constraints on the high-density EoS

- Compact star masses $\sim 2\ M_\odot$ require stiff EoS
- Flow data provide upper limits on the stiffness

Local charge neutrality: 2SC + DBHF hybrid

- diquark coupling lowers phase transition density
- vector meanfield stiffens quark matter EoS

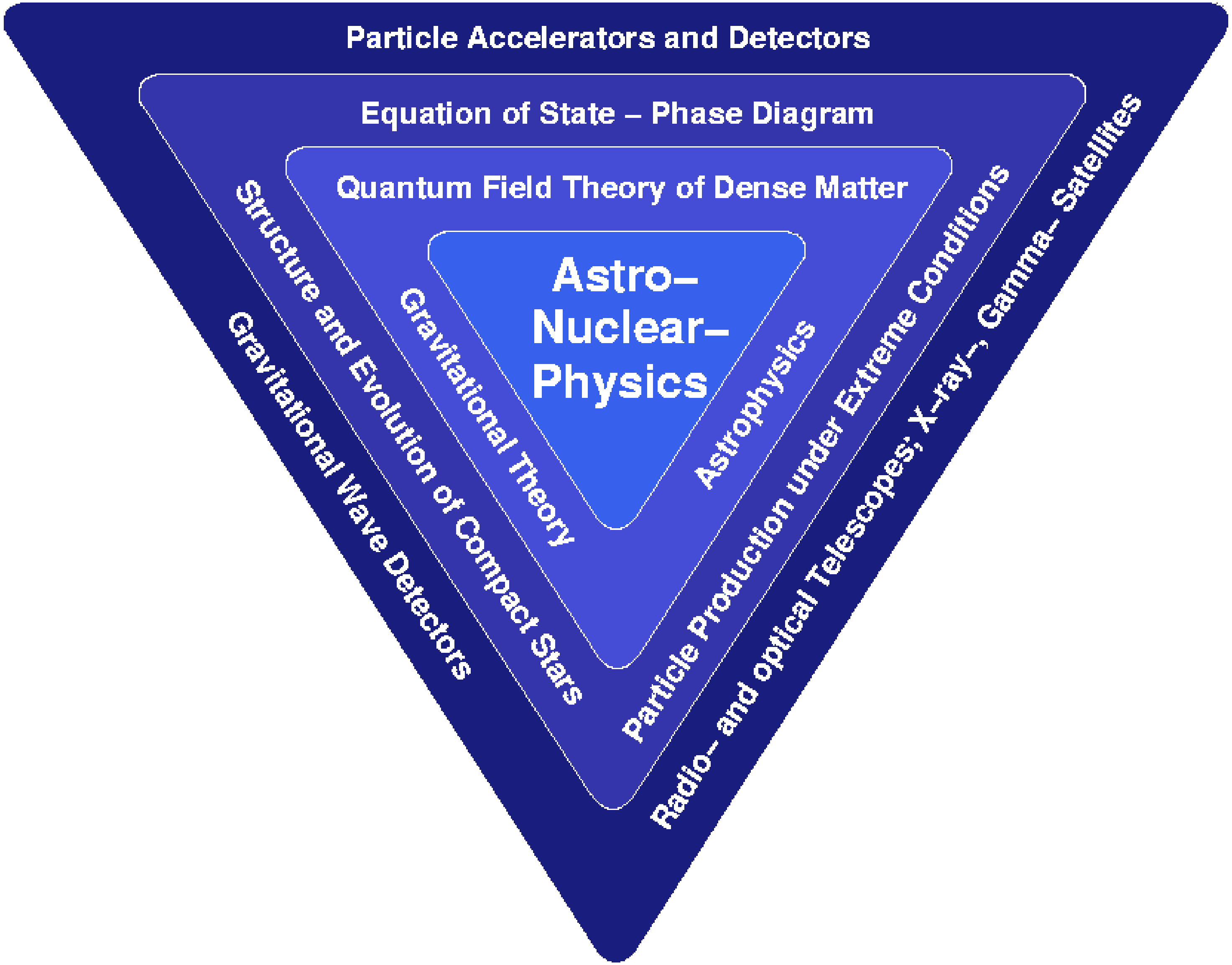
Global charge neutrality: d-CSL + DBHF hybrid

- single flavor phase (d-CSL) as consequence of dynamical χSR
- no d-CSL in symmetric matter: $x_{p,crit} < 0.2$
- no Urca cooling processes $\longrightarrow$ no neutrino trapping?

Next steps

- apply to superbursts, X-ray transients, high-mass supernovae
- extend to inhomogeneous phases: surface tension and Coulomb effects

New ways to understand Dense Matter



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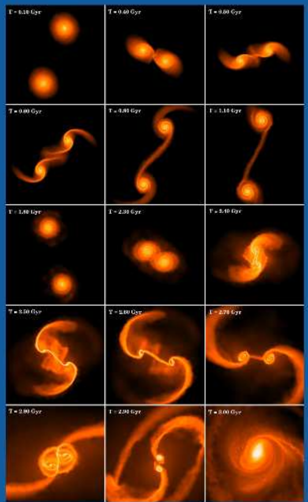
Dense QCD Phases in Heavy Ion Collisions and Supernovae

October 11-13, 2009 Prerow, Germany

www.mpg.uni-rostock.de/~hic4fair



Organizers

C. Greiner
J. Wambach
D. Blaschke

Local Organizers

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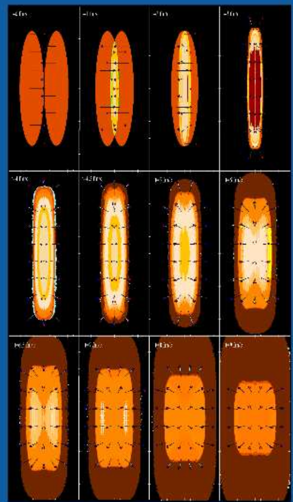
A. Wierling
D. Zablocki



- ✦ Nonequilibrium and Transport Phenomena in Dense Matter
- ✦ Equation of State and QCD Phase Transitions
- ✦ Hadron Production in Heavy Ion Collisions
- ✦ QCD in Compact Stellar Objects, Supernovae and Mergers

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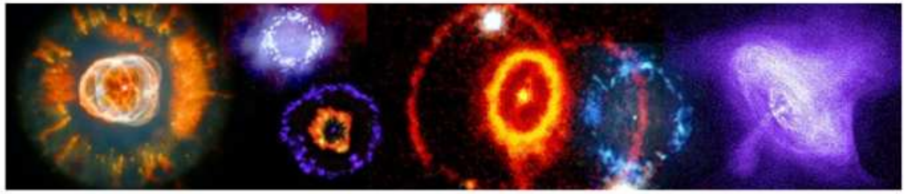

MODE 2009

Modeling and Observation of Neutron Stars

Observatoire de Meudon, France

November, 2009, 16th – 20th

Topics:

- **Radio timing, rotating neutron stars,**
- **General relativity and neutron star modelisation,**
- **Equation of state,**
- **Observation at different wave lengths,**
- **Emission processes and supernovae**
- **Supernovae remnants and pulsar wind nebulae.**

Organizing committee: M. Lemoine-Goumard (Bordeaux), J. Margueron (IPN Orsay), M. Oertel (LUTH, Meudon), M. Renaud (APC, Paris), G. Theureau (GEPI, Observatoire de Paris).

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More informations: snns.in2p3.fr/mode/

GDR PCHE comp star EUROPEAN SCIENCE FOUNDATION

THANKS FOR ... ATTENTION! ... INVITATION!

THANKS FOR ... ATTENTION! ... INVITATION!

From Urca process ... to Erice process ??