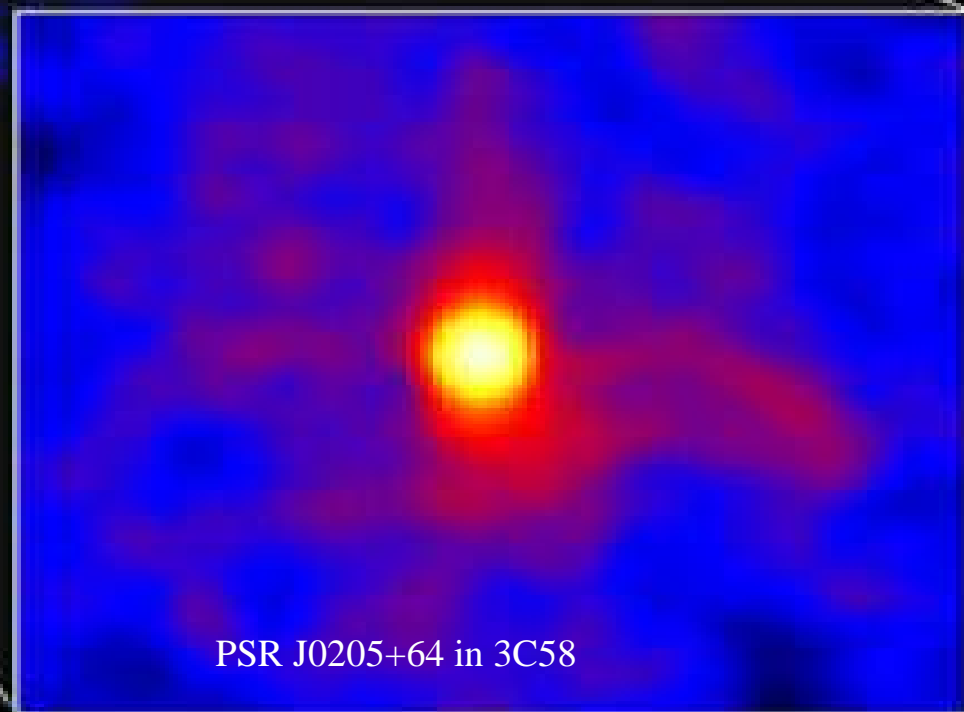
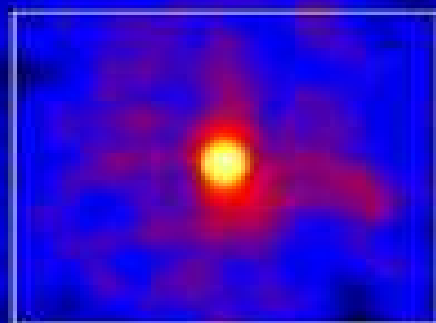


Quark Matter in Neutron Stars



David Blaschke
Univ. Wrocław & JINR Dubna



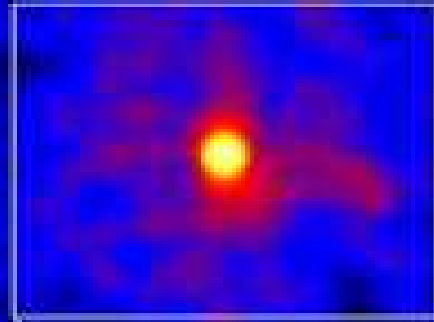
PRex @ ECT*, August 4, 2009

Quark Matter in Neutron Stars



David Blaschke

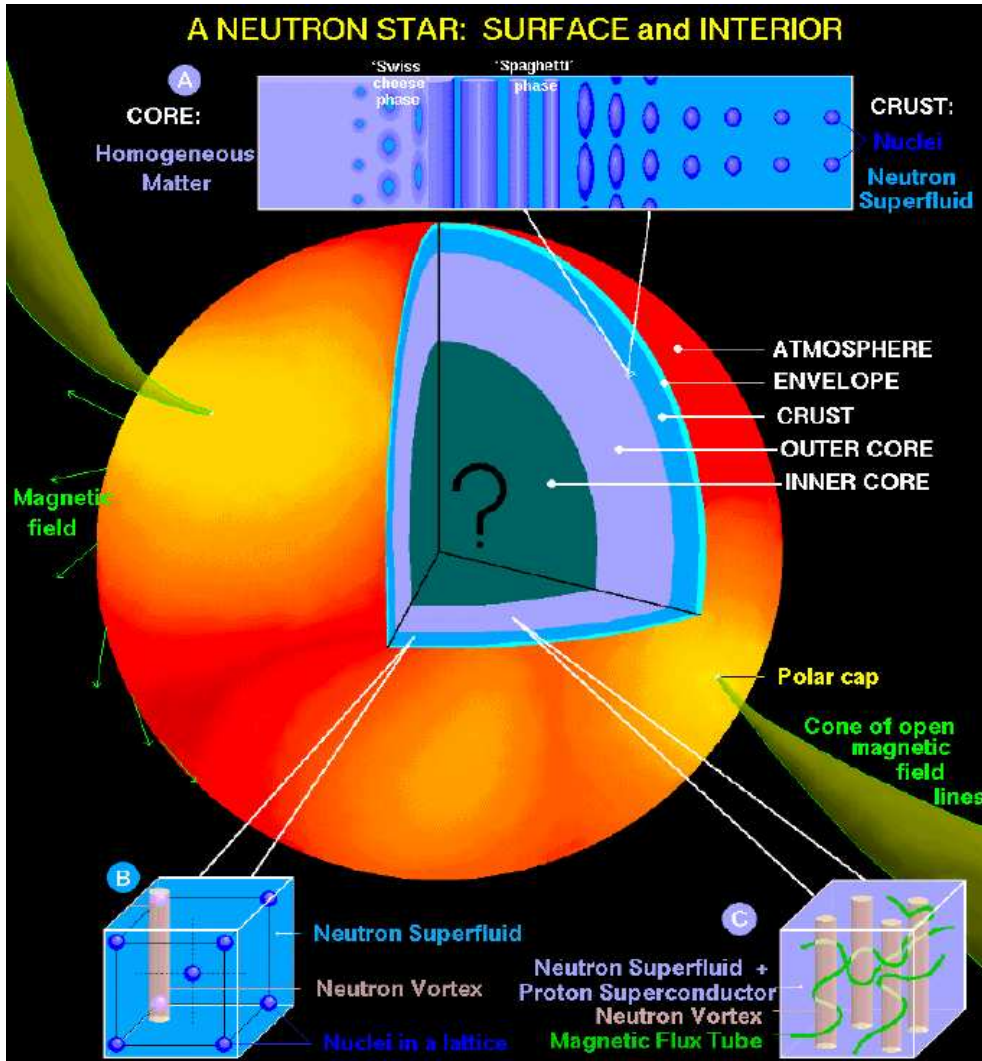
Univ. Wrocław & JINR Dubna



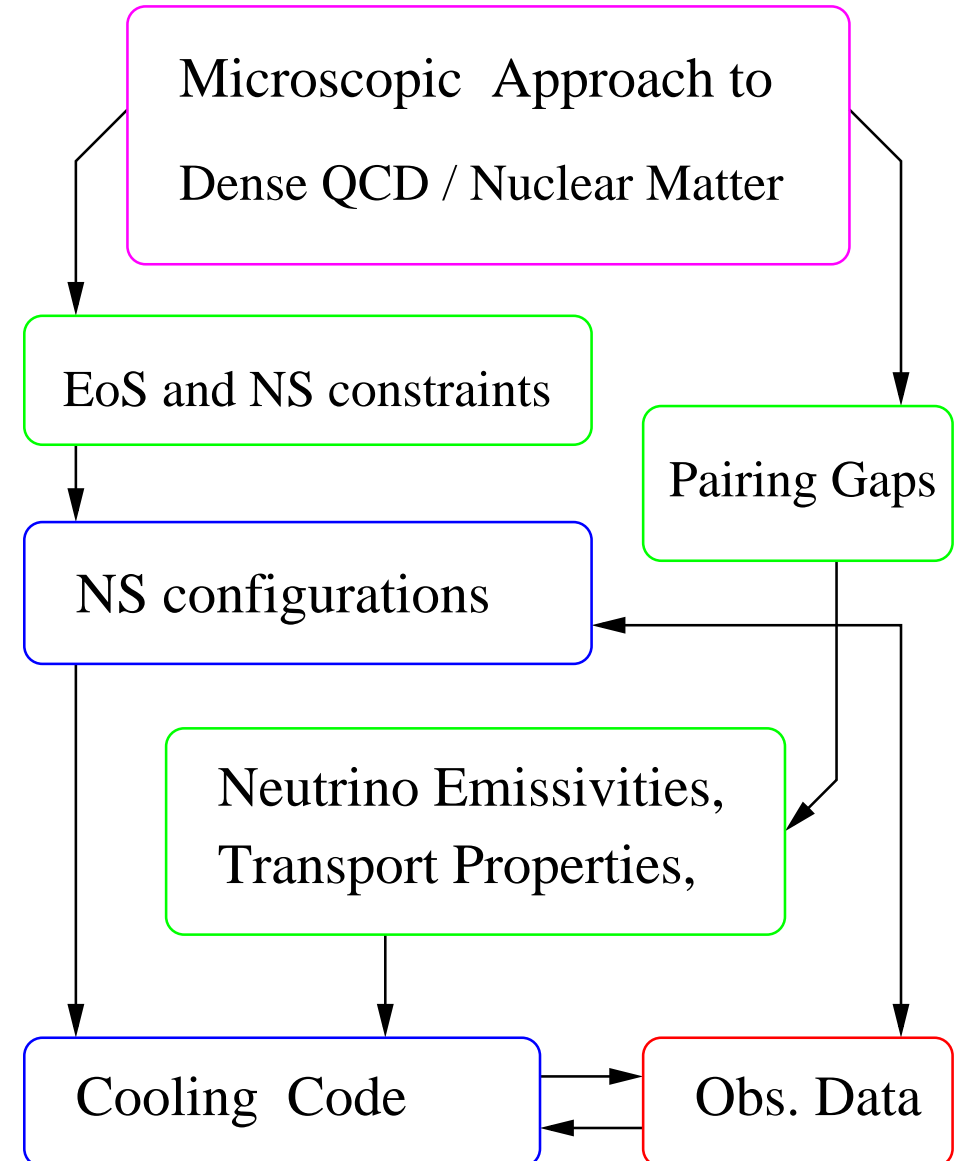
- Introduction:
Hadronic Cooling and EoS Problem
- Quark Substructure and Phases
- Hybrid Star Structure & Cooling
- Quarkyonic Matter ?

Compact Star Constraints - A Complex Problem

1. Introduction
2. Hadronic Cooling
3. Quark Substructure and Phases
4. Hybrid Star Cooling
5. Conclusions

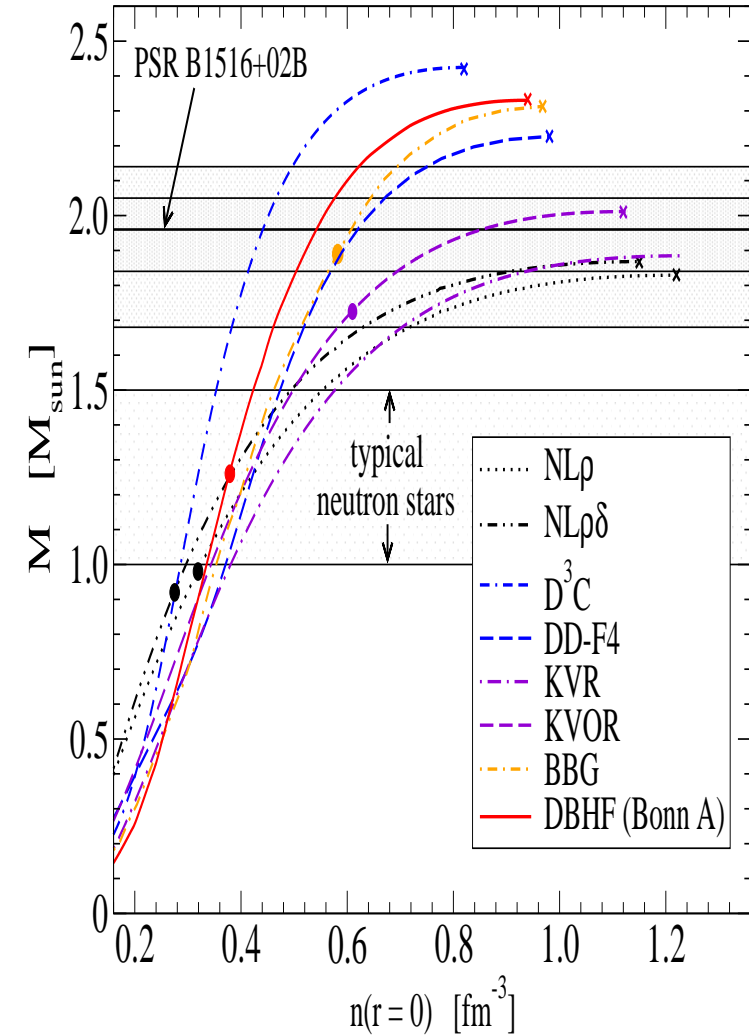
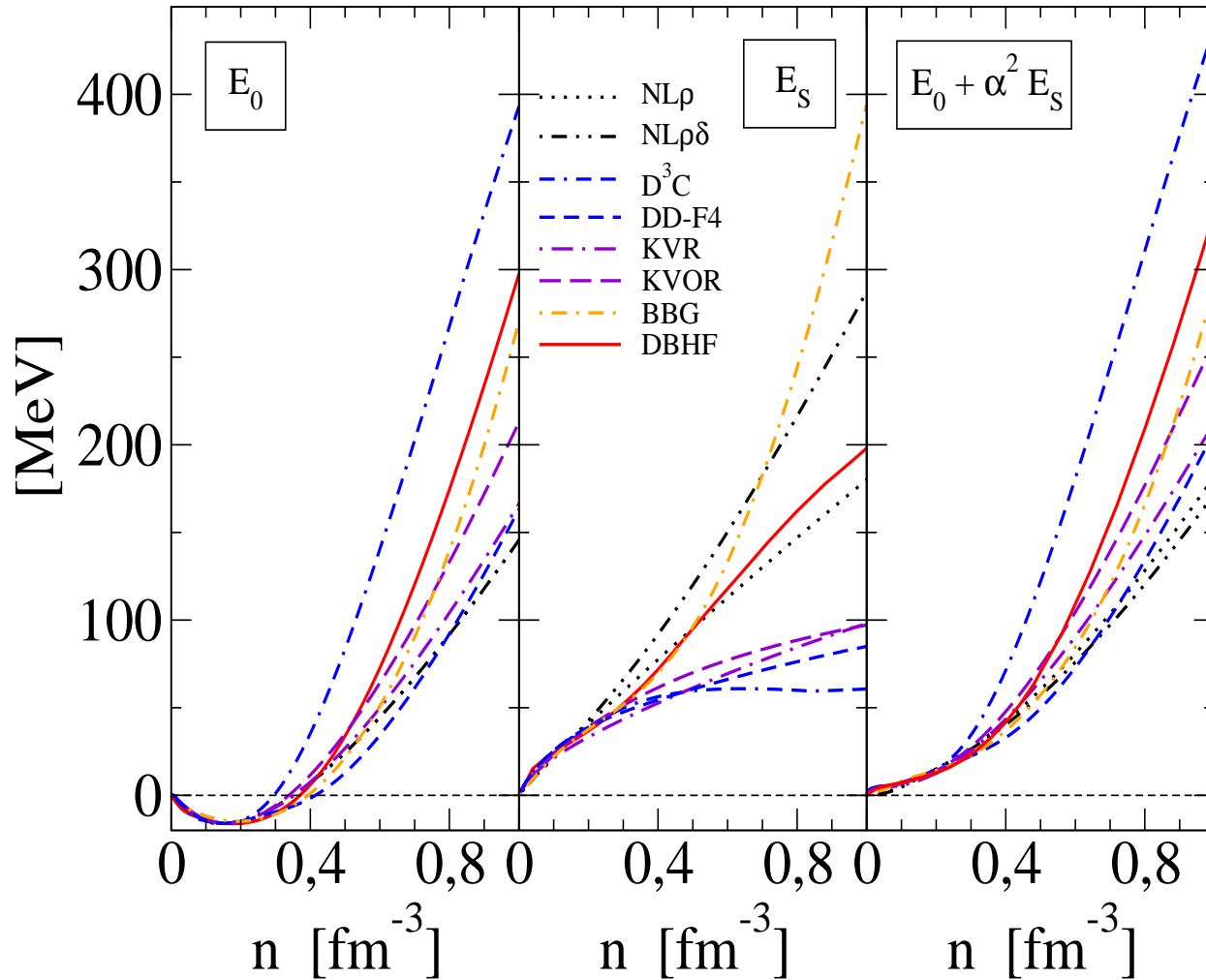


Picture taken from <http://www.astroscu.unam.mx/neutrones/NS-Picture/>



EoS and masses - DU constraint

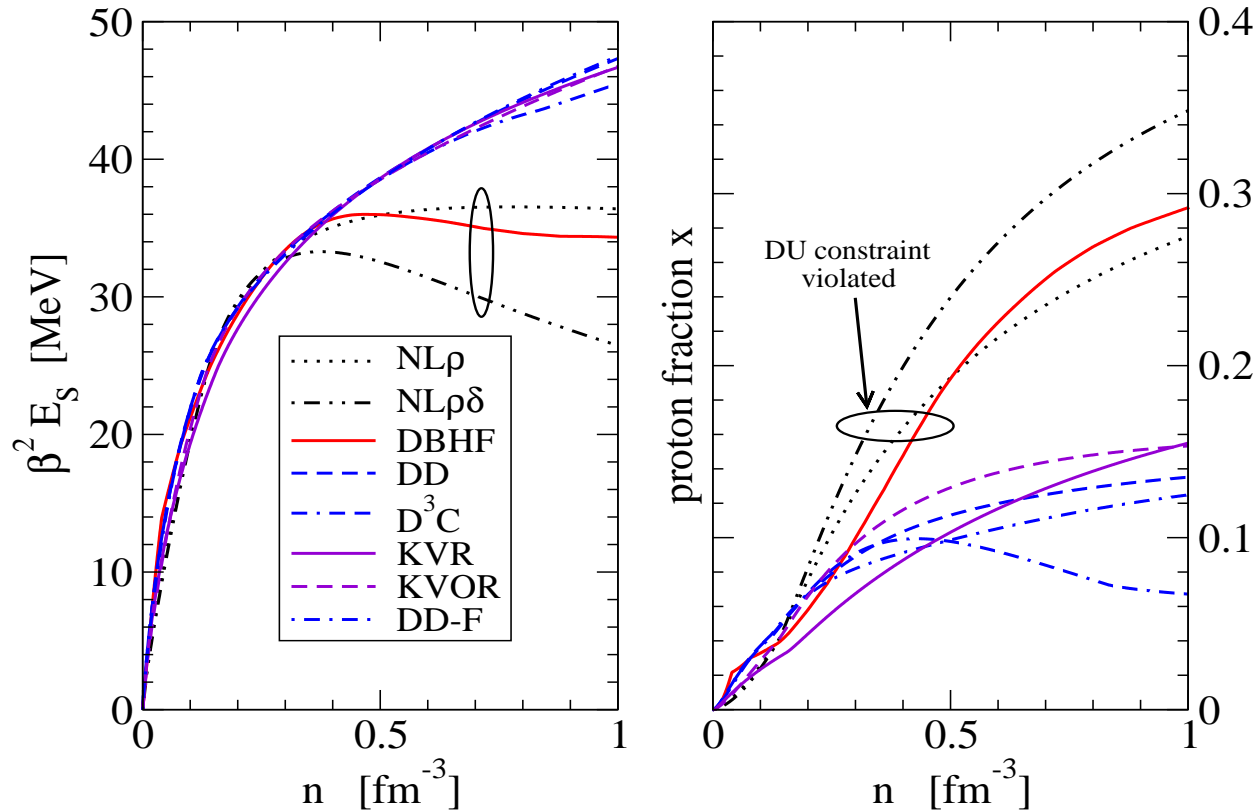
1. Mass and flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL + DBHF hybrid
5. Conclusions



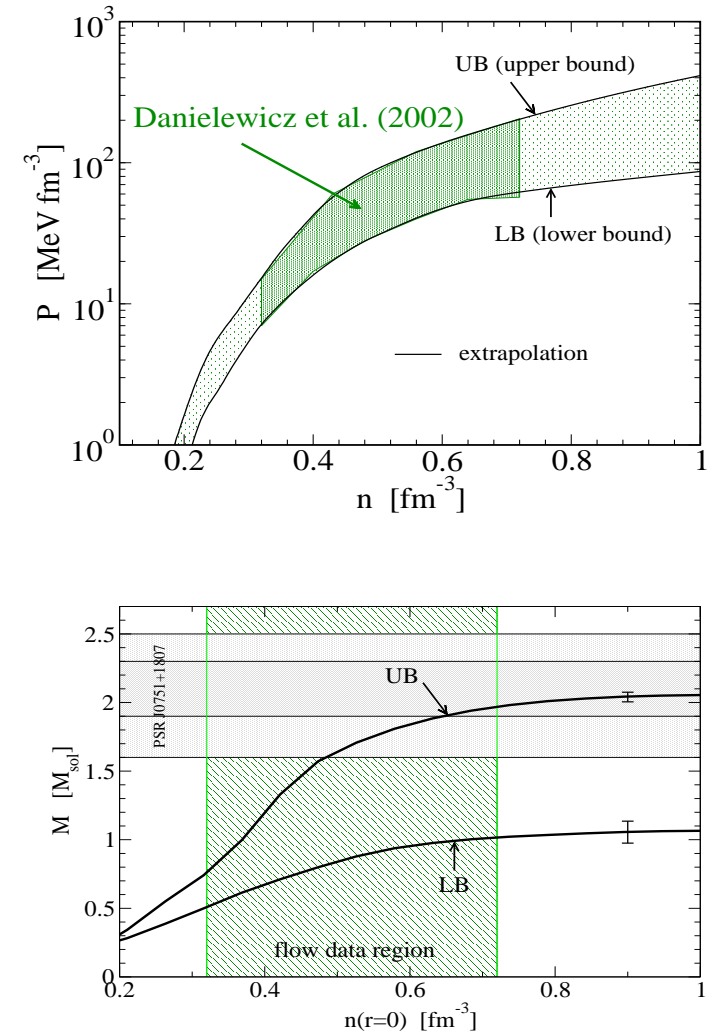
DU threshold for most hadronic EoS active in neutron stars with typical masses !

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

Universal behavior of $(1-2x(n))^2 E_s(n)$?



1. Mass and flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL + DBHF hybrid
5. Conclusions

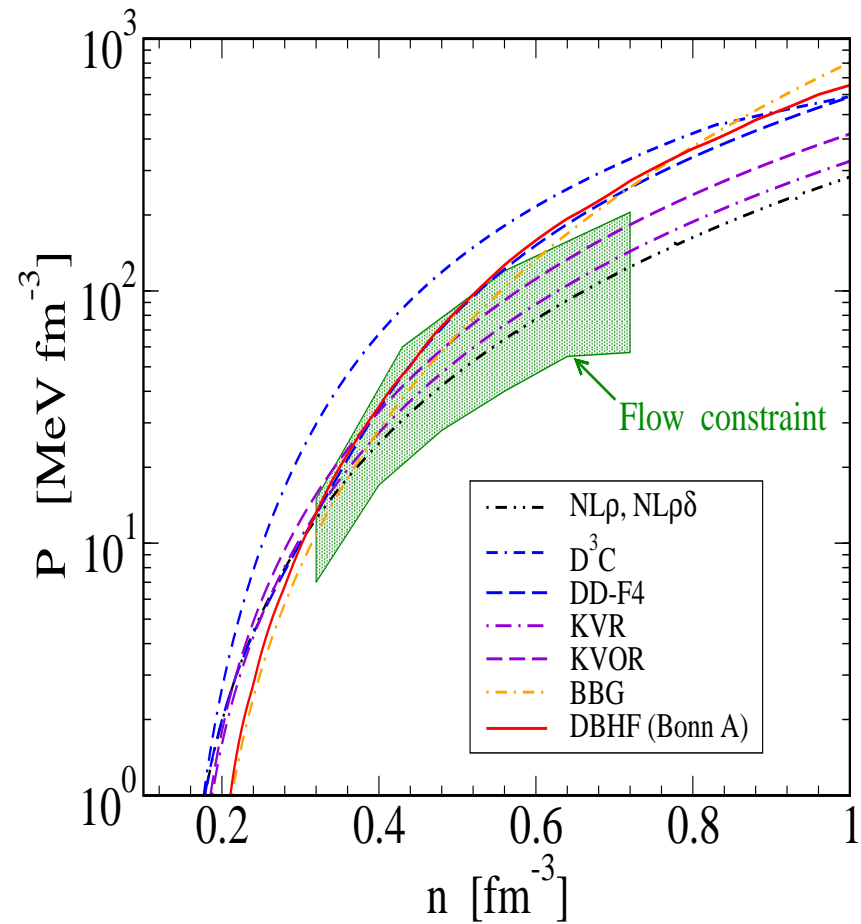
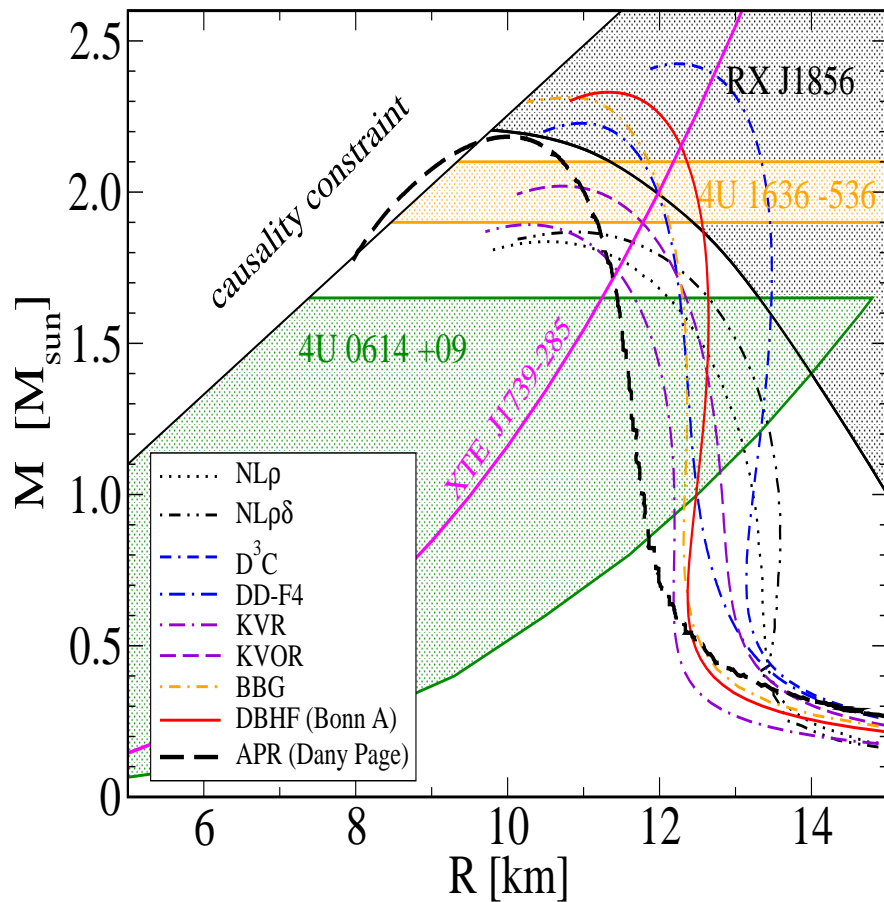


Exclude NL ρ , NL $\rho\delta$, DBHF for violation of DU constraint
 → “universal” high-density behavior of $\beta^2(n) E_s(n)$

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

Mass-Radius constraint and Flow constraint

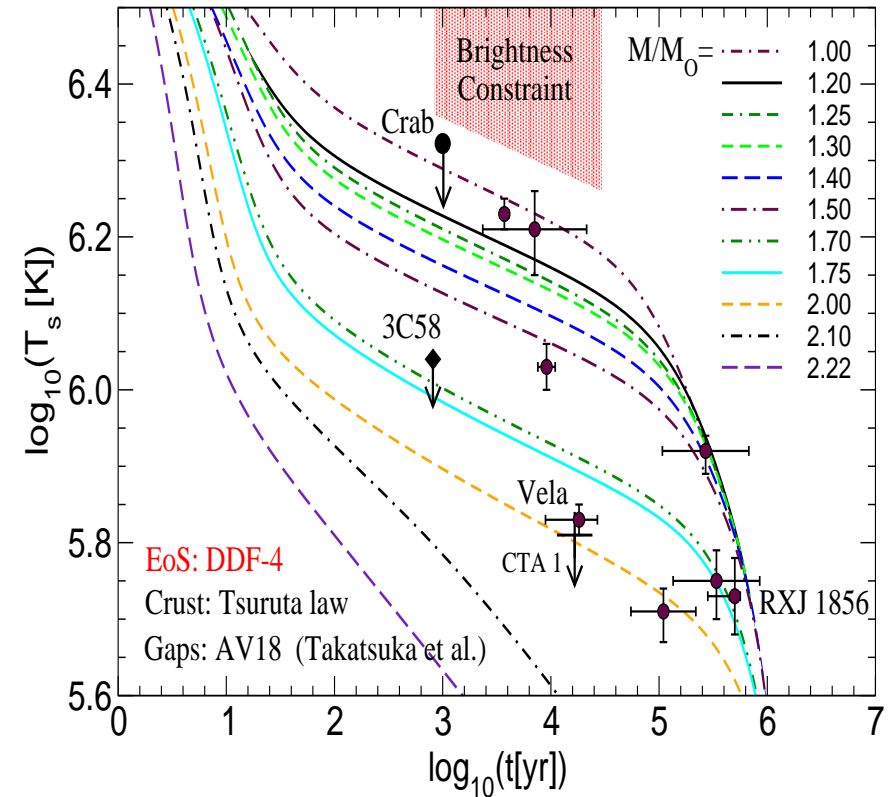
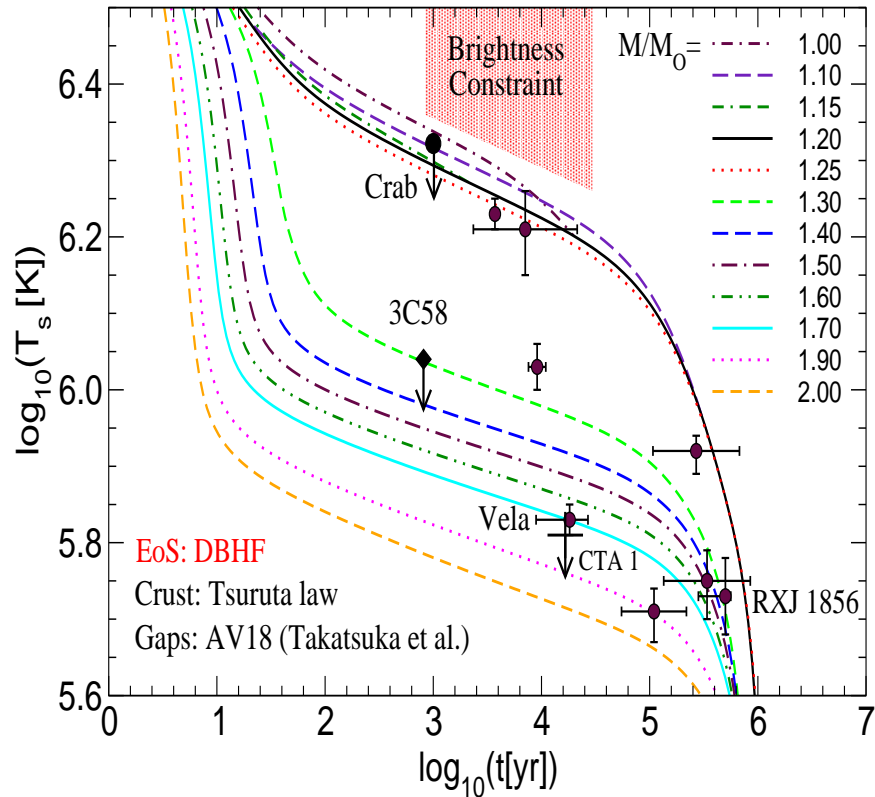
1. Mass and flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL + DBHF hybrid
5. Conclusions



- 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 !

DU threshold and 'hadronic' neutron stars (II)

1. Introduction
2. Hadronic Cooling + Structure
3. Quark Substructure + Phases
4. Hybrid Star Structure + Cooling
5. Conclusions

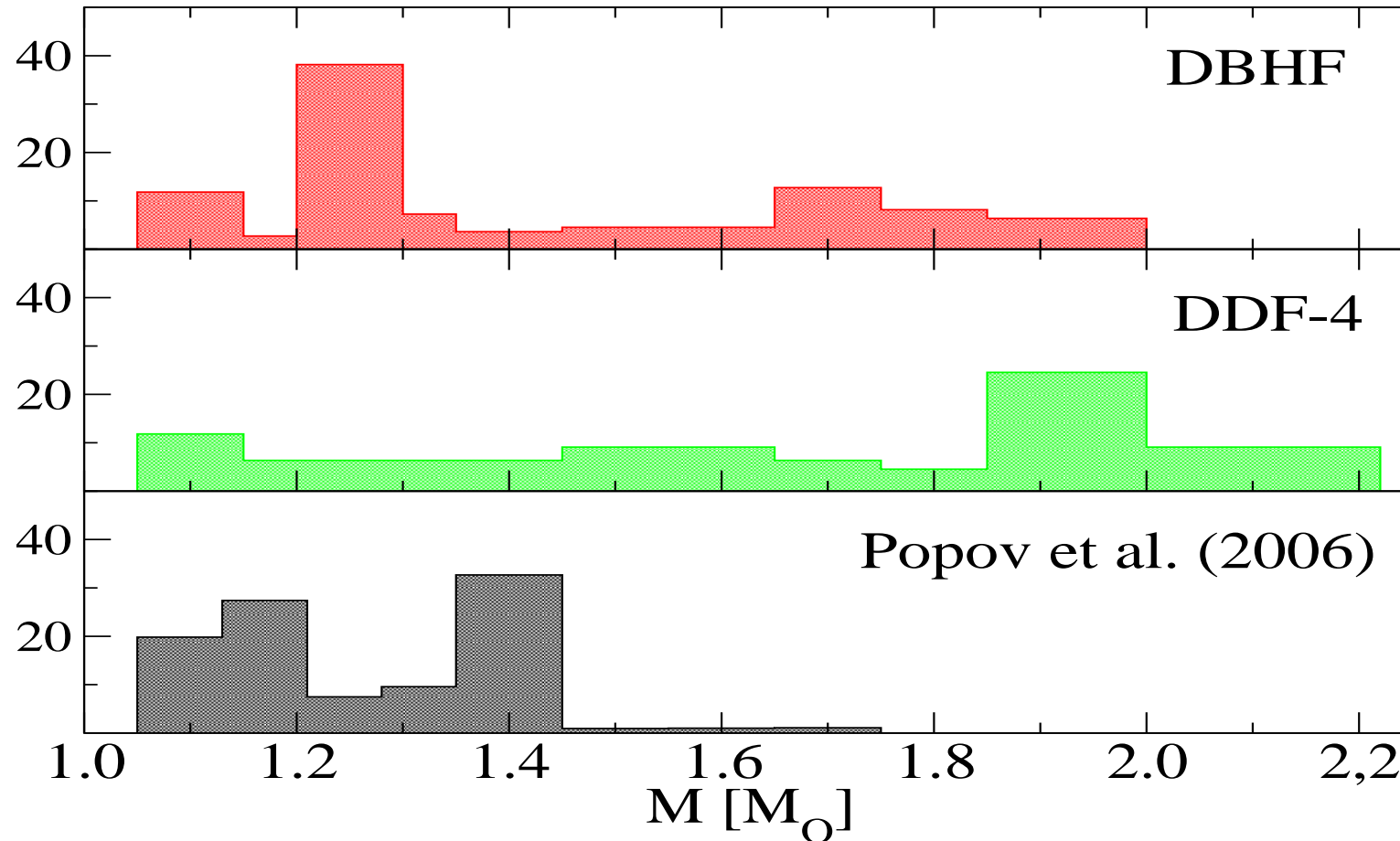


- DU threshold \Rightarrow sensitivity to tiny mass variations;
- Description of Vela not possible with typical masses !

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)

1. Introduction
2. Hadronic Cooling + Structure
3. Quark Substructure + Phases
4. Hybrid Star Structure + Cooling
5. Conclusions

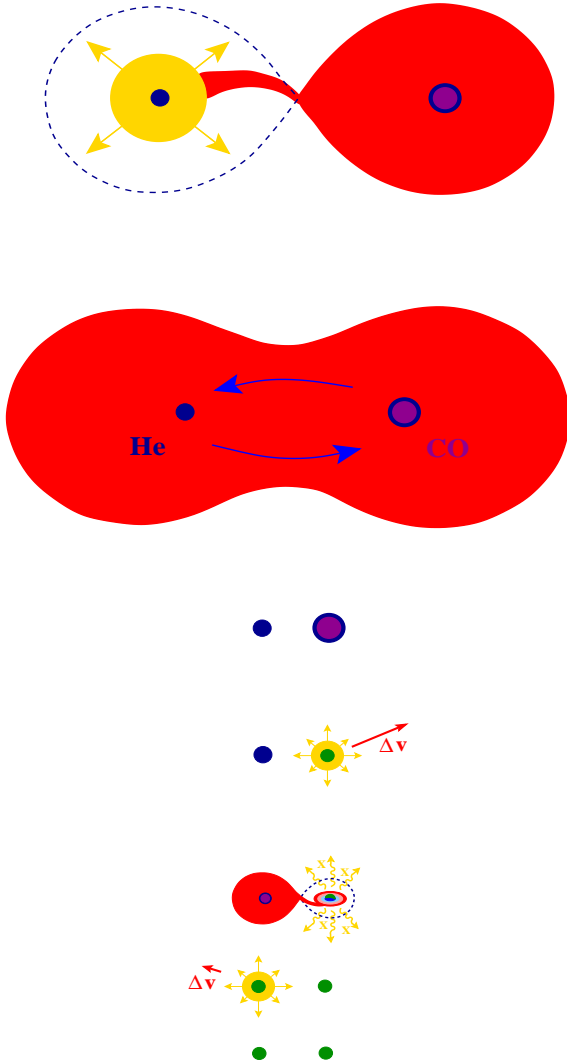


- DU threshold: overpopulation of a small mass window;
- Hadronic cooling not fast enough to describe Vela with $M < 1.5 M_{\odot}$!

EoS constraint from double pulsar J0737-3039?

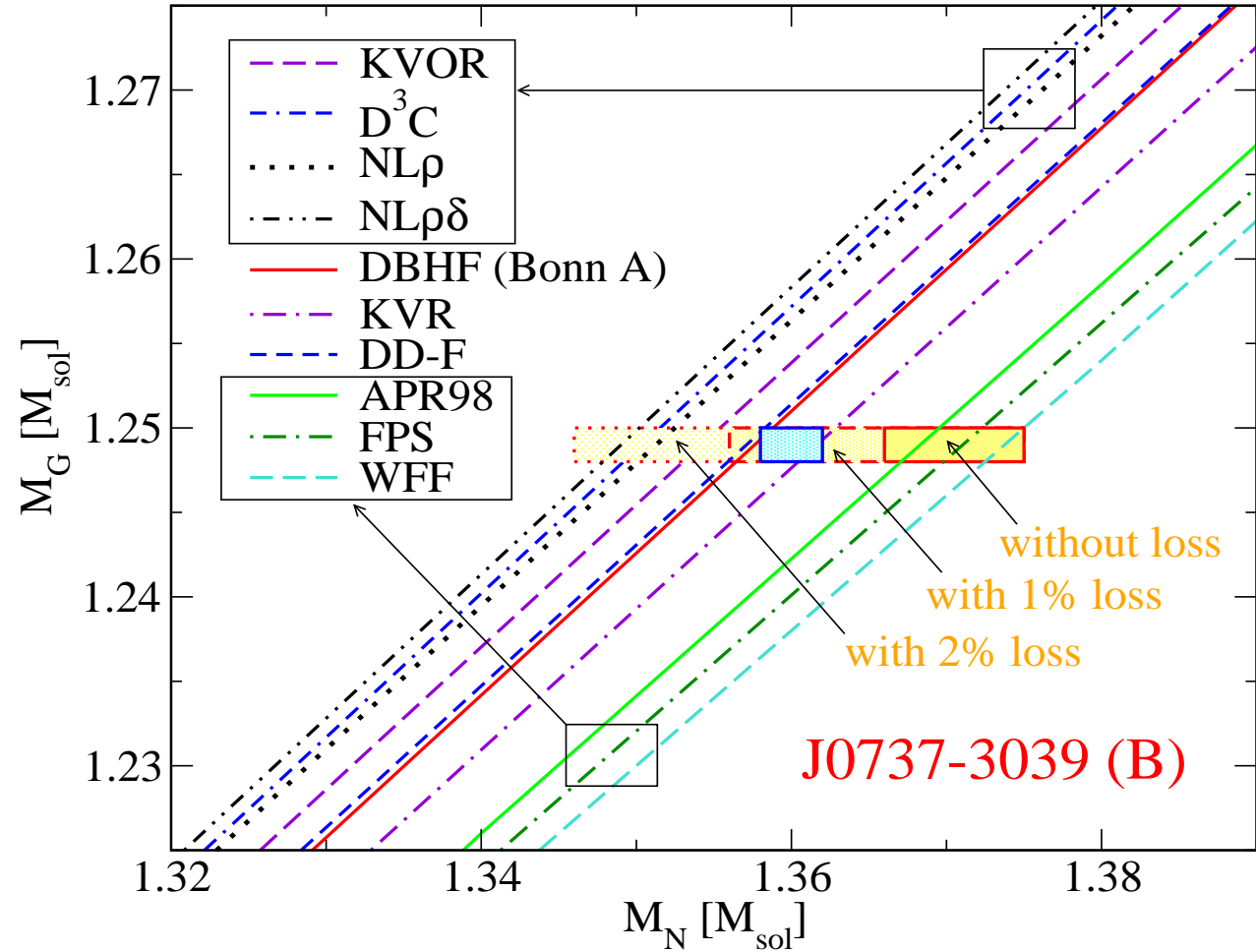
1. Mass and flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL + DBHF hybrid
5. Conclusions

Double core scenario:



Dewi et al., MNRAS (2006)

Baryon mass vs. gravitational mass - constraint or consistency check?



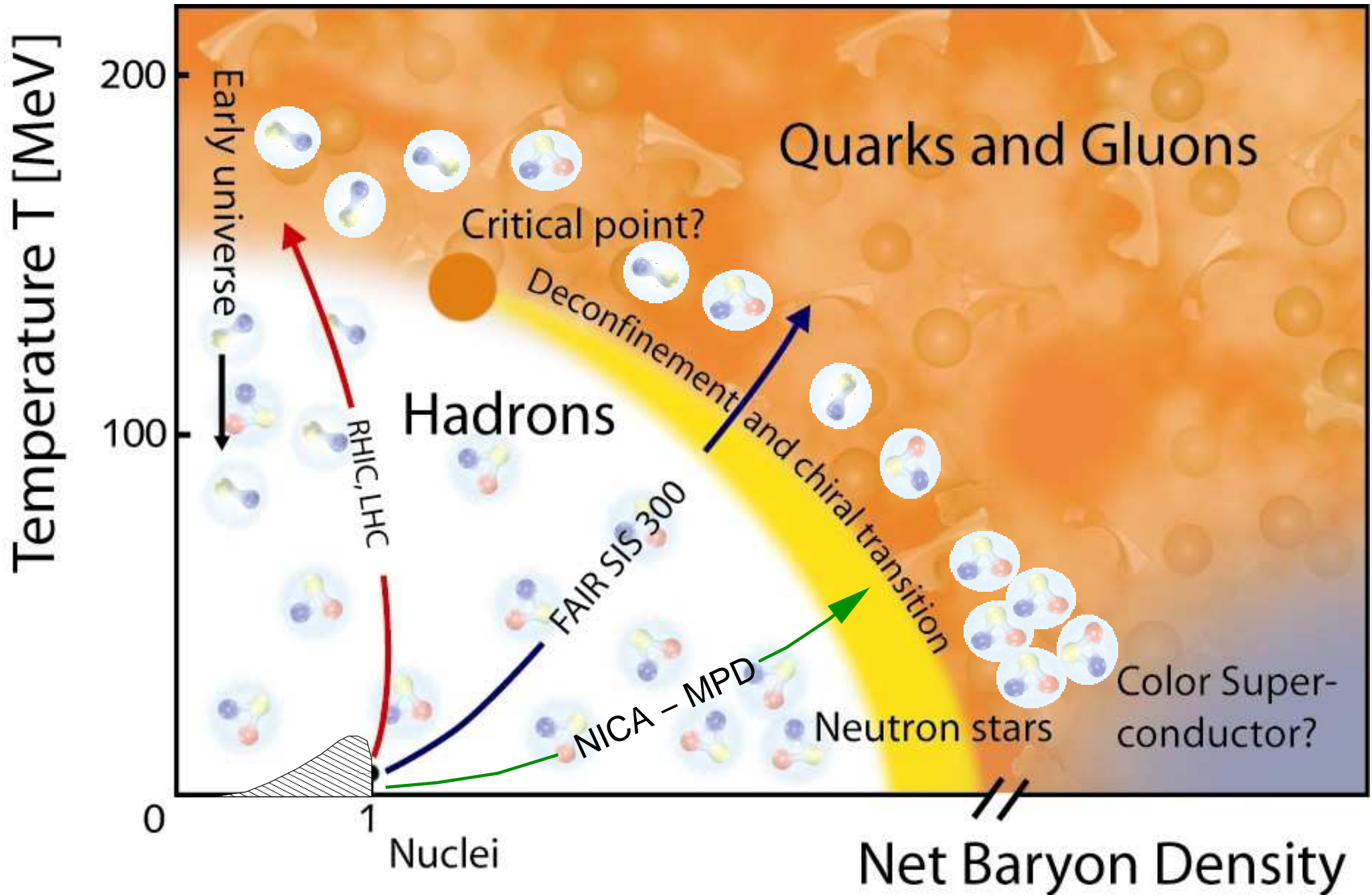
Podsiadlowski et al., MNRAS 361 (2005) 1243

Kitaura, Janka, Hillebrandt, A& A (2006); [astro-ph/0512065]

D.B., T. Klähn, F. Weber, CBM Physics Book (2008)

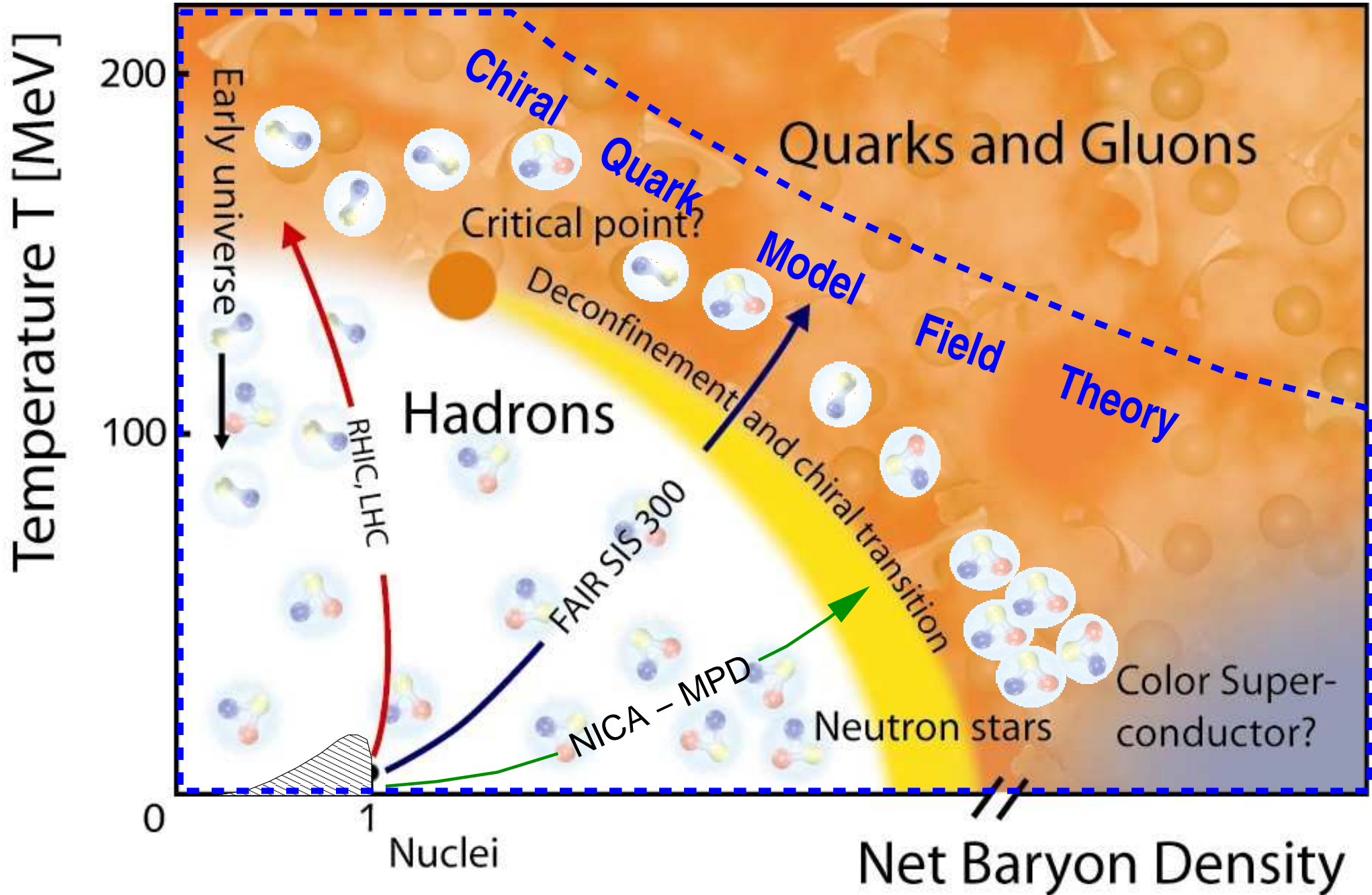
Quark Substructure and Phase Diagram

1. Mass and flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL + DBHF hybrid
5. Conclusion



Phase diagram of QCD: Chiral quark models

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL + DBHF hybrid
5. Conclusion



Quantum Field Theory for chiral Quark Matter

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF Hybrid
4. d-CSL + DBHF hybrid
5. Conclusion

- Partition function for chiral Quark Field theory

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

- Current-current coupling (4-fermion interaction)

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

- Bosonisation (Hubbard-Stratonovich Transformation)

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

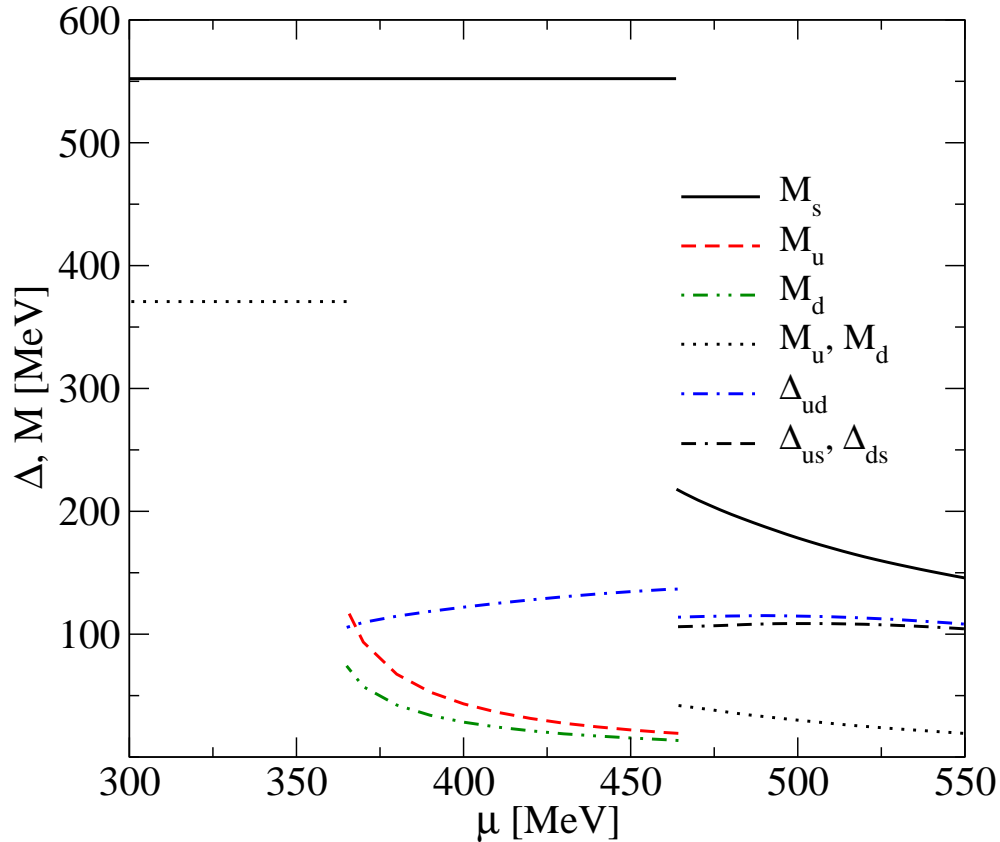
- Collective (stochastic) Fields: Mesons (ϕ_M) and Diquarks (Δ_D)

- Systematic Evaluation: Mean field + Fluctuations

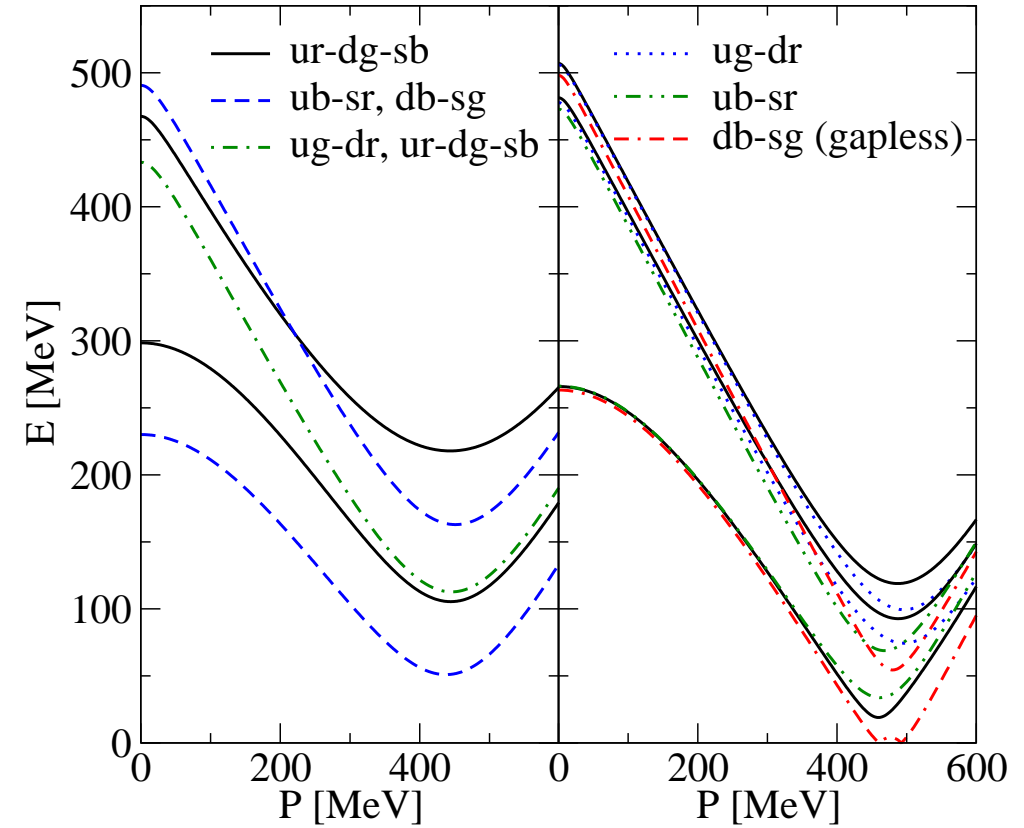
- Mean-field Approximation: Order parameter for Phase transitions (Gap equations)
- Fluctuations (2. Order): Hadronic Correlations (Bound- & Scattering states)
- Fluctuations of higher Order: Hadron-Hadron Interaction

Quark Masses, Diquark Gaps, Gapless Modes

1. Introduction
2. Hadronic Cooling
3. Quark Substructure and Phases
4. Hybrid Star Cooling
5. Conclusions



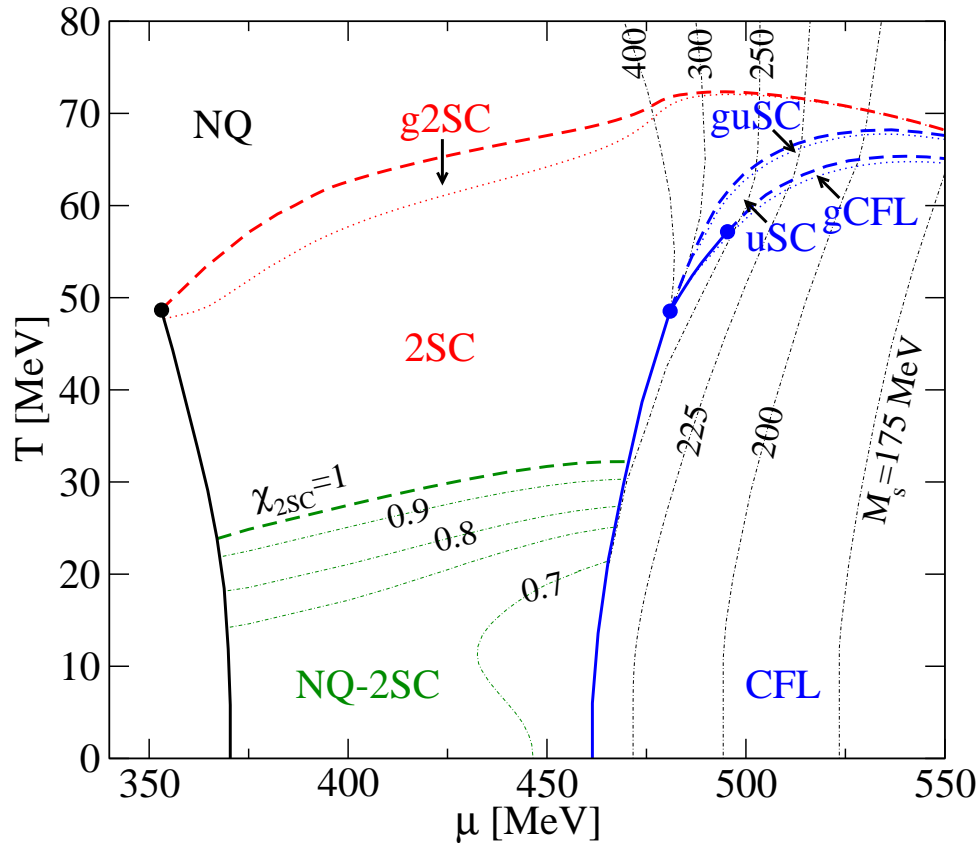
Dynamical quark masses and diquark gaps at $T = 0$ for intermediate diquark coupling $G_D = 0.75 G_S$



Dispersion relations for $G_D = 0.75 G_S$, $T = 0$, $\mu = 465$ MeV (left), $G_D = 1.0 G_S$, $T = 59$ MeV, $\mu = 500$ MeV (right)

Three-flavor Quark Matter Phase Diagram

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL hybrid
5. Conclusion



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

The phases are:

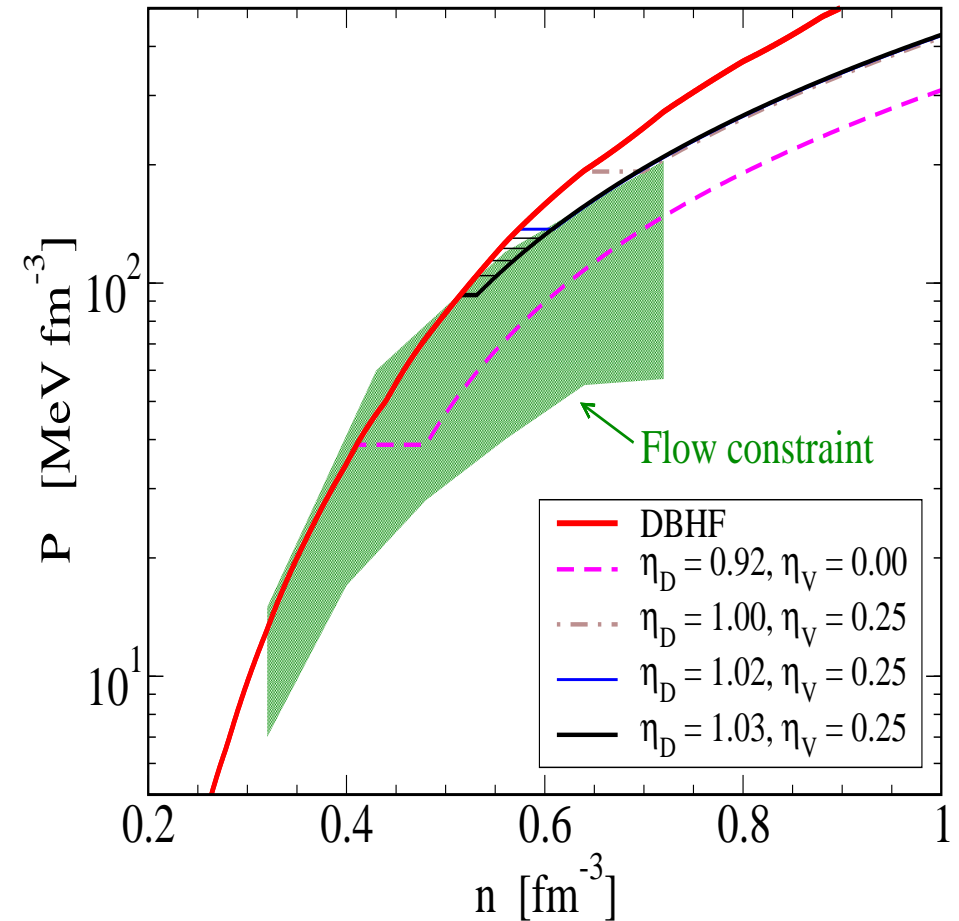
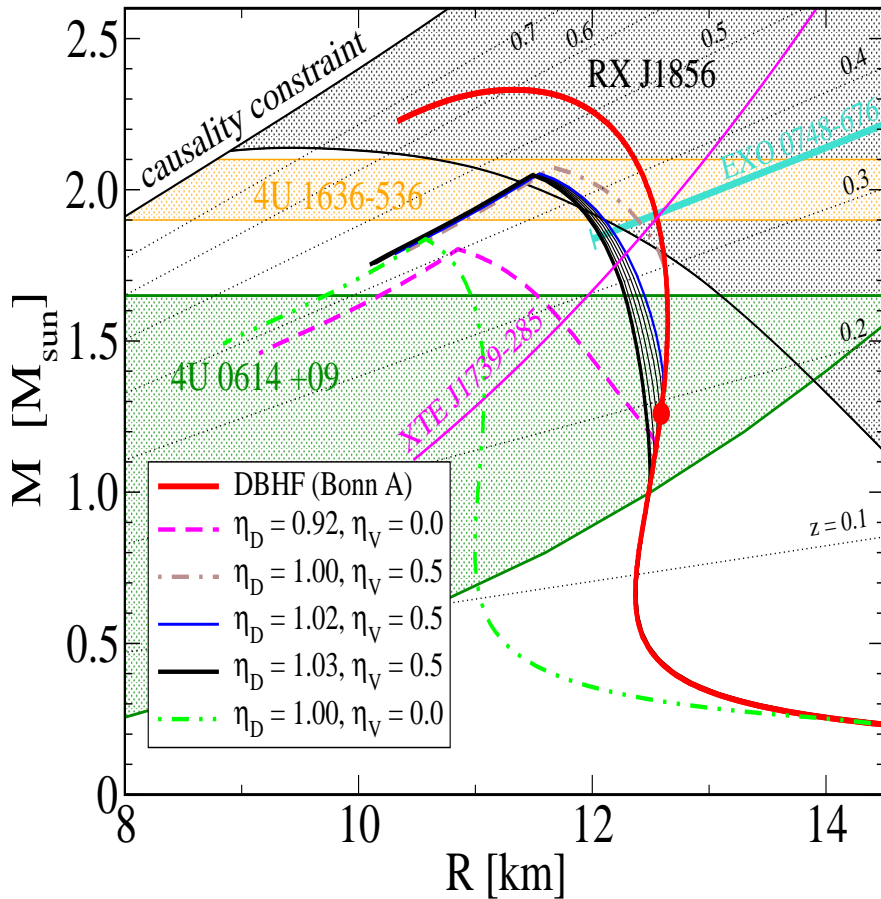
- NQ: $\Delta_{ud} = \Delta_{us} = \Delta_{ds} = 0$;
- NQ-2SC: $\Delta_{ud} \neq 0, \Delta_{us} = \Delta_{ds} = 0, 0 \leq \chi_{2SC} \leq 1$;
- 2SC: $\Delta_{ud} \neq 0, \Delta_{us} = \Delta_{ds} = 0$;
- uSC: $\Delta_{ud} \neq 0, \Delta_{us} \neq 0, \Delta_{ds} = 0$;
- CFL: $\Delta_{ud} \neq 0, \Delta_{ds}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

Result:

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

Mass-Radius constraint and Flow constraint (II)

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL hybrid
5. Conclusion

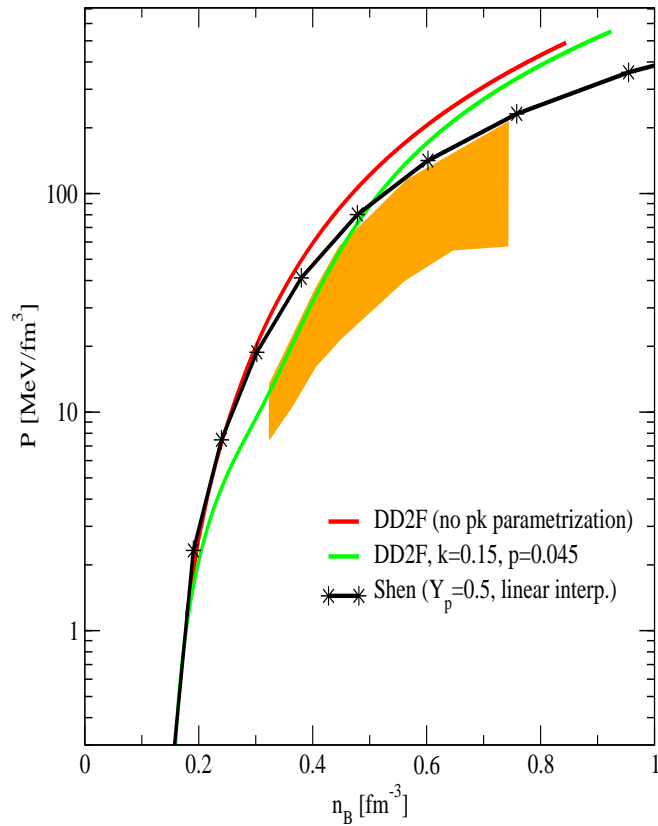


- Large Mass ($\sim 2 M_{\odot}$) and radius ($R \geq 12$ km) \Rightarrow stiff quark matter EoS;
Note: DU problem of DBHF removed by deconfinement! **and:** CFL core Hybrids unstable!
- Flow in Heavy-Ion Collisions \Rightarrow not too stiff EoS !
Note: Quark matter removes violation by DBHF at high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

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

Shen EoS vs. Flow constraint

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL hybrid
5. Conclusion

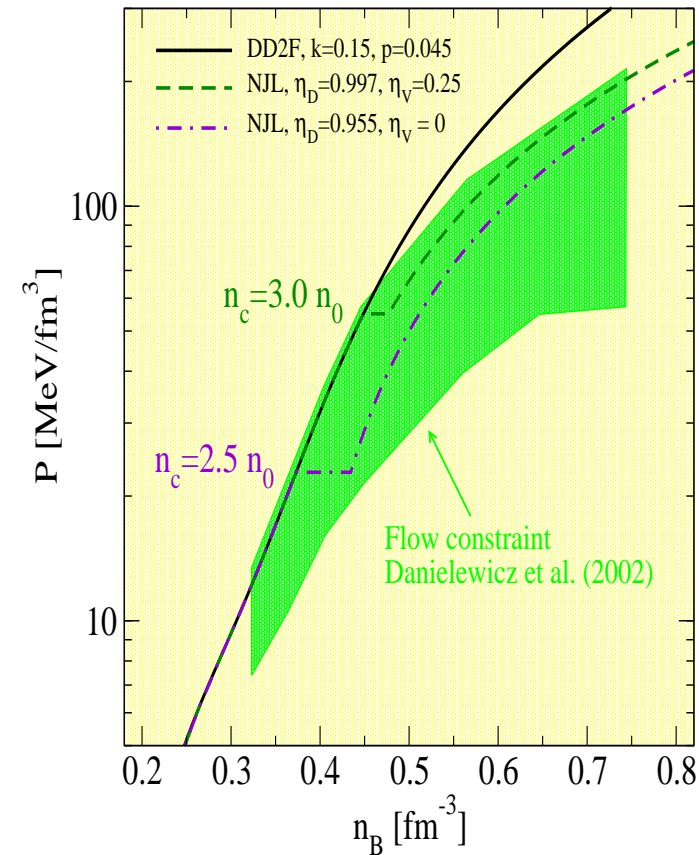
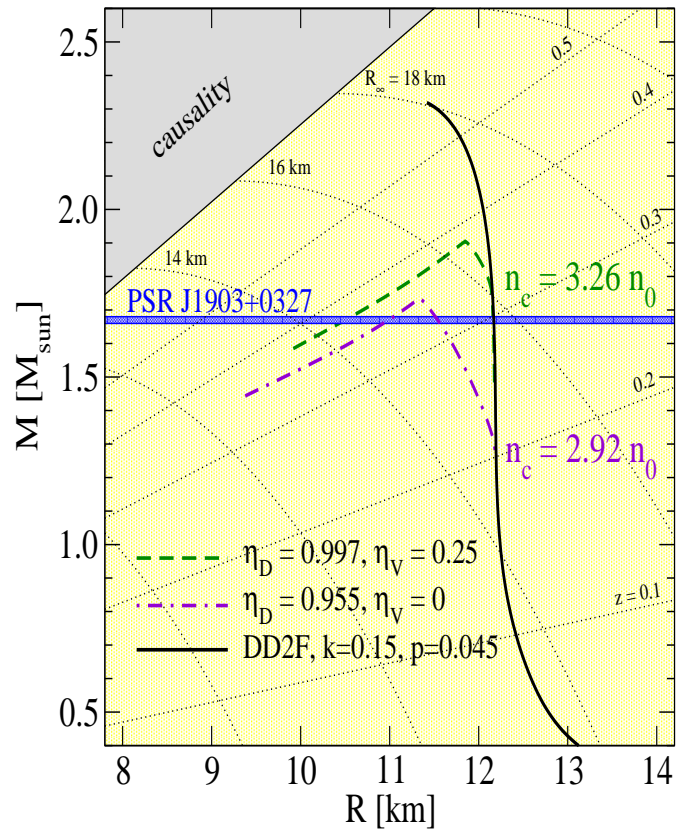


- Shen et al. EoS from supernova studies in contradiction with low-density flow constraint!
- Density-dependent RMF (DD-2F) tuned to fit Shen at very low densities

Typel, Röpke, Klähn, D.B., Wolter, work in progress

Mass-Radius constraint and Flow constraint (III)

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL hybrid
5. Conclusion

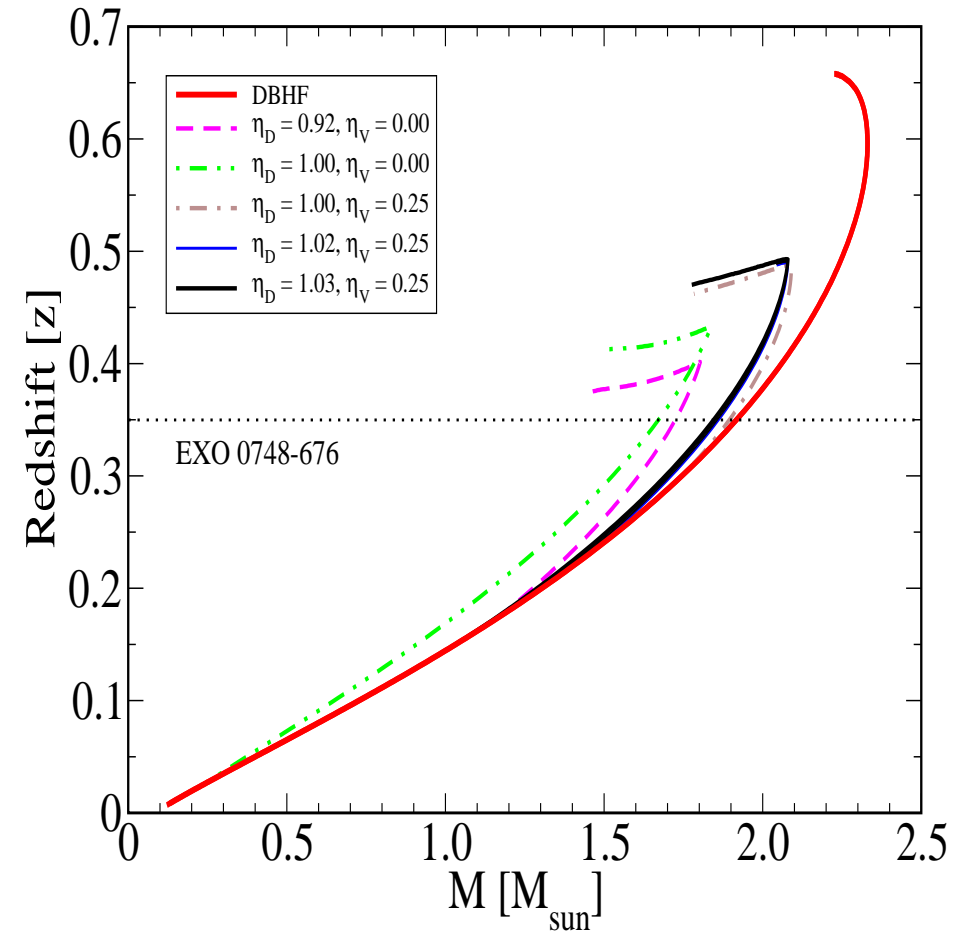
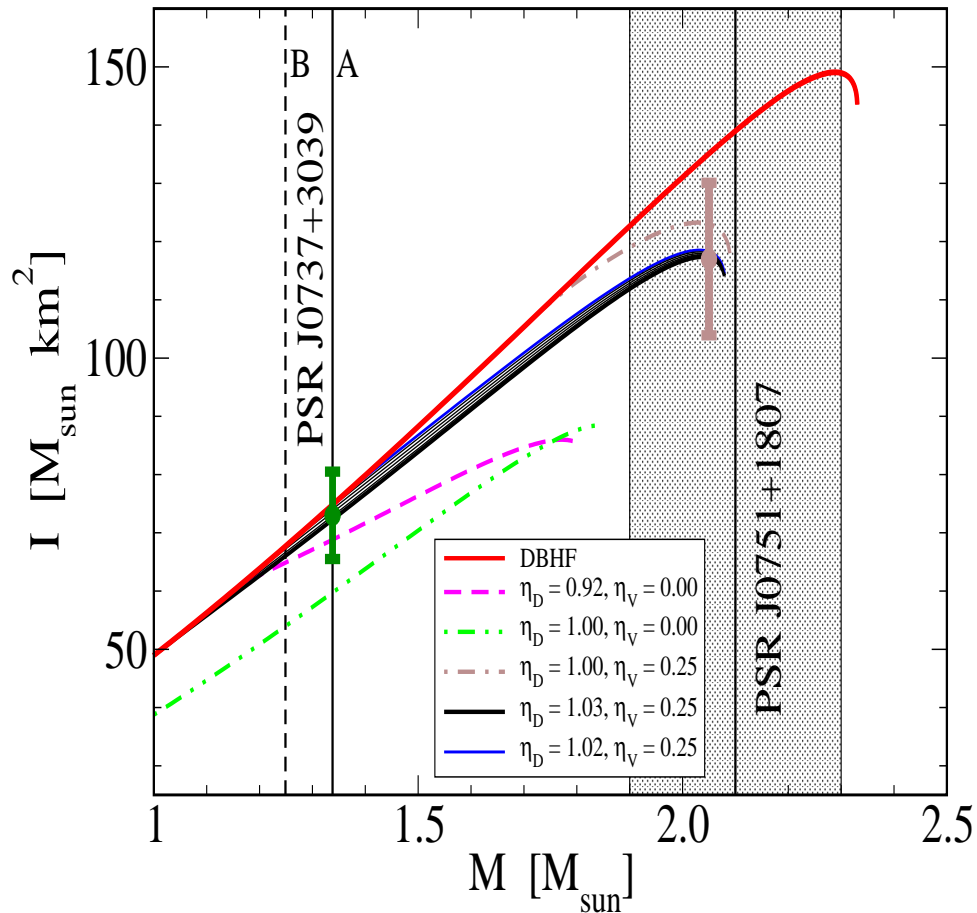


- Large Mass ($\sim 2 M_\odot$) and radius ($R \geq 12$ km) \Rightarrow stiff quark matter EoS;
Note: DU problem of DBHF removed by deconfinement! **and:** CFL core Hybrids unstable!
- Flow in Heavy-Ion Collisions \Rightarrow not too stiff EoS !
Note: Quark matter removes violation by DBHF at high densities

Klähn, D.B., Sandin, Typel: in preparation

Hybrid Stars that masquerade as Neutron Stars*

1. Introduction
2. Hadronic Cooling + Structure
3. Quark Substructure + Phases
4. Hybrid Star Structure + Cooling
5. Conclusions

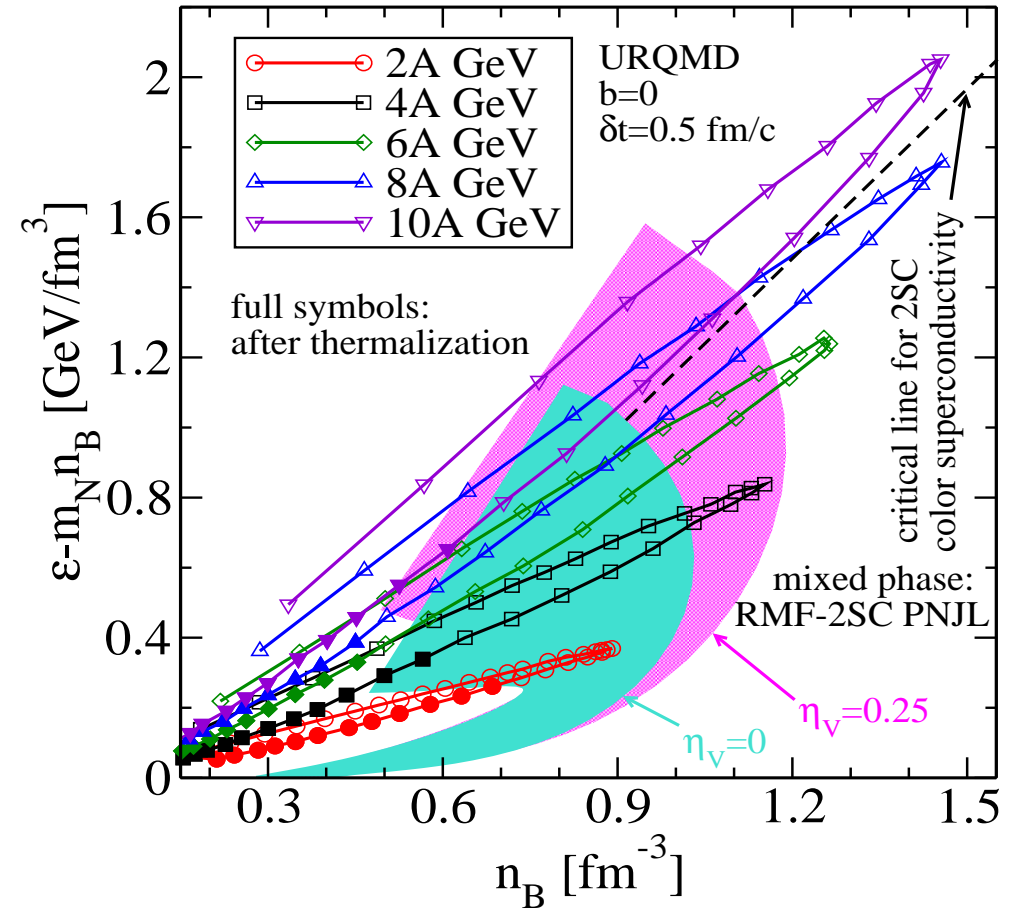
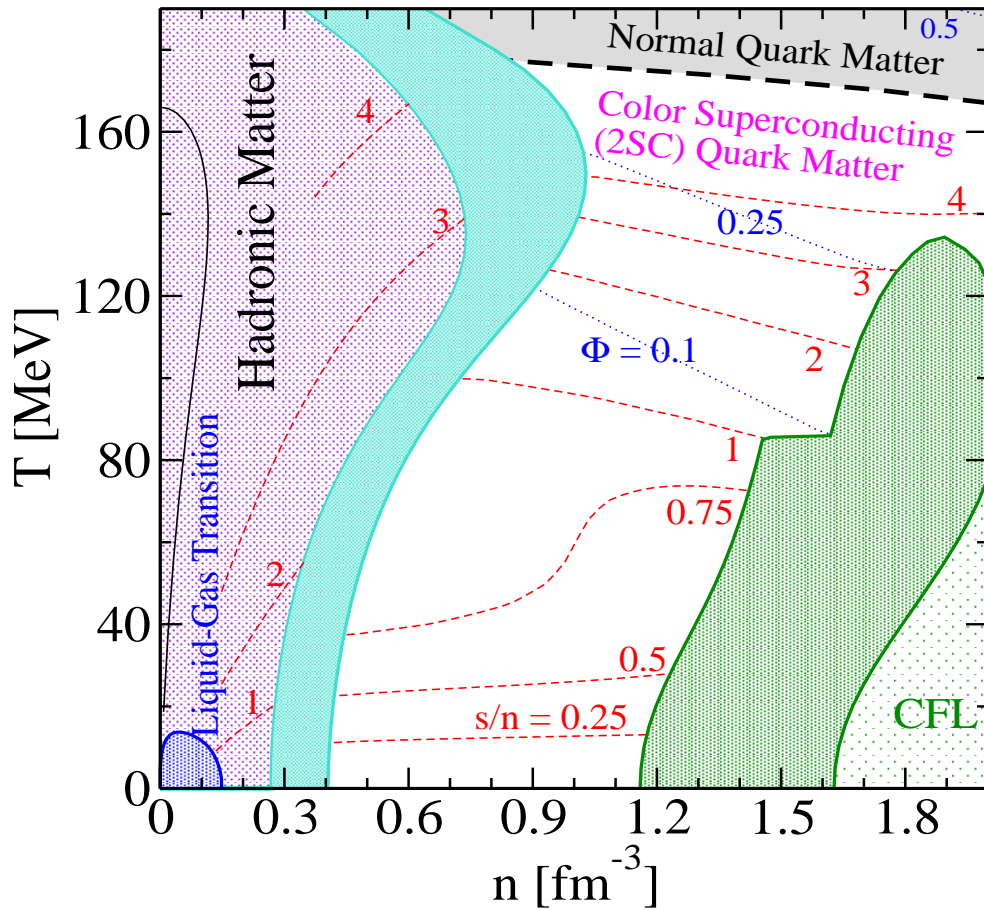


- Moment of Inertia \Rightarrow objects with large masses necessary
- Surface redshift \Rightarrow large values (> 0.5) troublesome for quark matter

* Alford et al., ApJ 629, 969 (2005); Klähn et al., PLB567, 160 (2007), [nucl-th/0609067]

Phase diagram for the CBM NICA experiments

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL hybrid

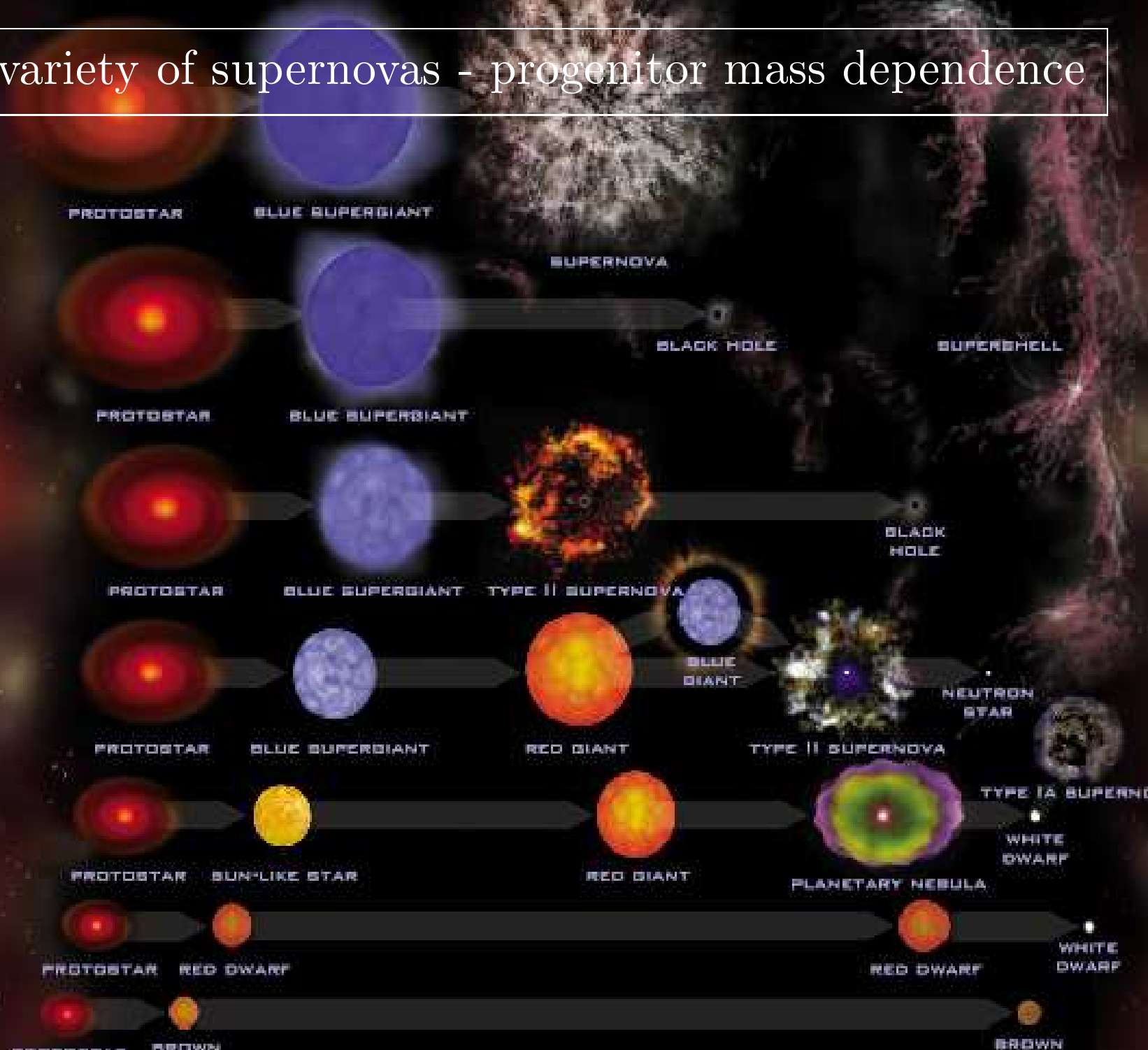


Phase diagram for isospin-symmetric matter, for hybrid star maximum masses $M_{max} = 1.9 M_{\odot}$ ($\eta_V = 0.25$) and $M_{max} = 1.7 M_{\odot}$ ($\eta_V = 0.25$) and accessibility in HIC experiments at different energies.

D. B., F. Sandin, S. Typel, V. Skokov, in preparation.

Wide variety of supernovas - progenitor mass dependence

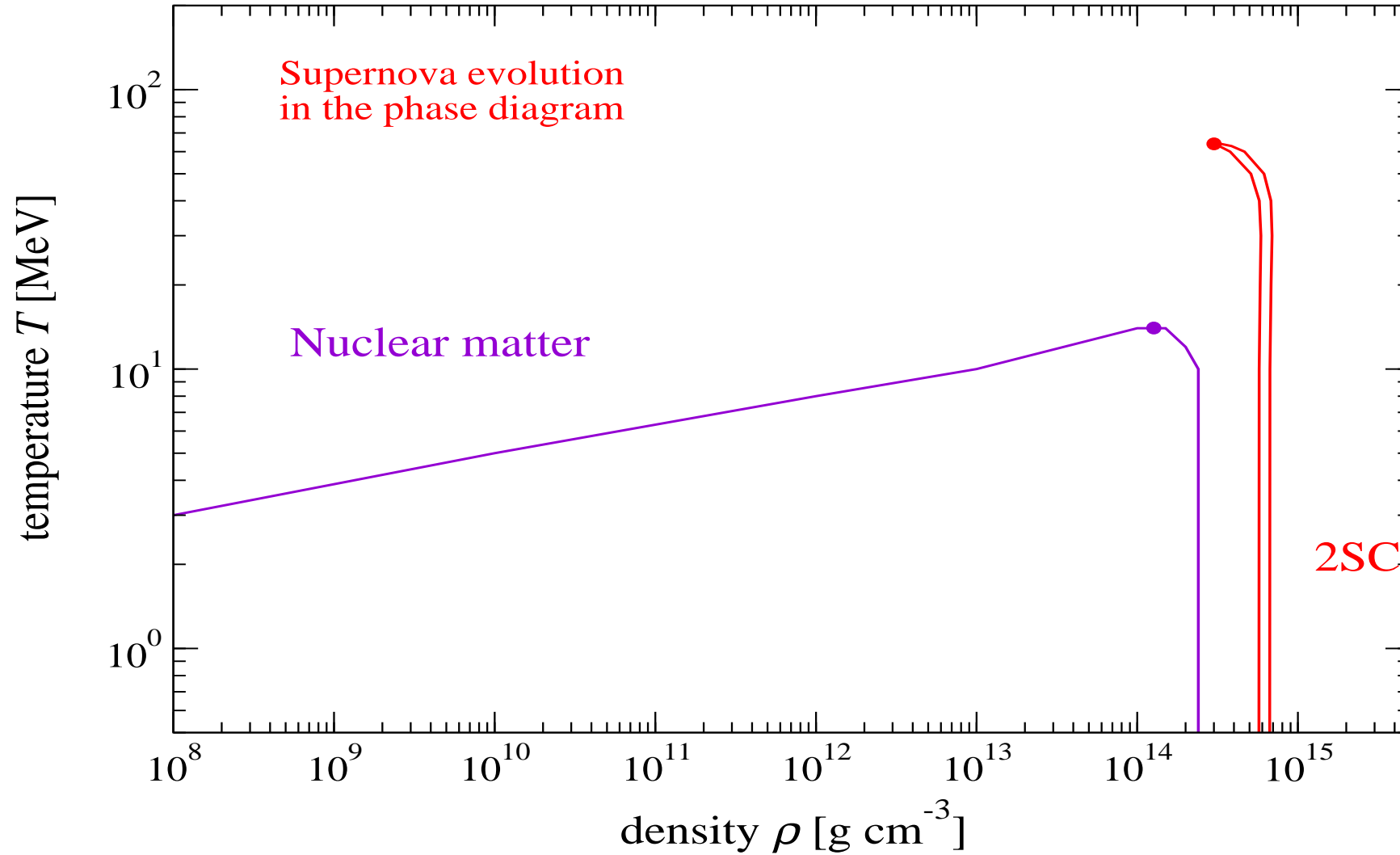
STELLAR NURSERY



STELLAR NURSERY

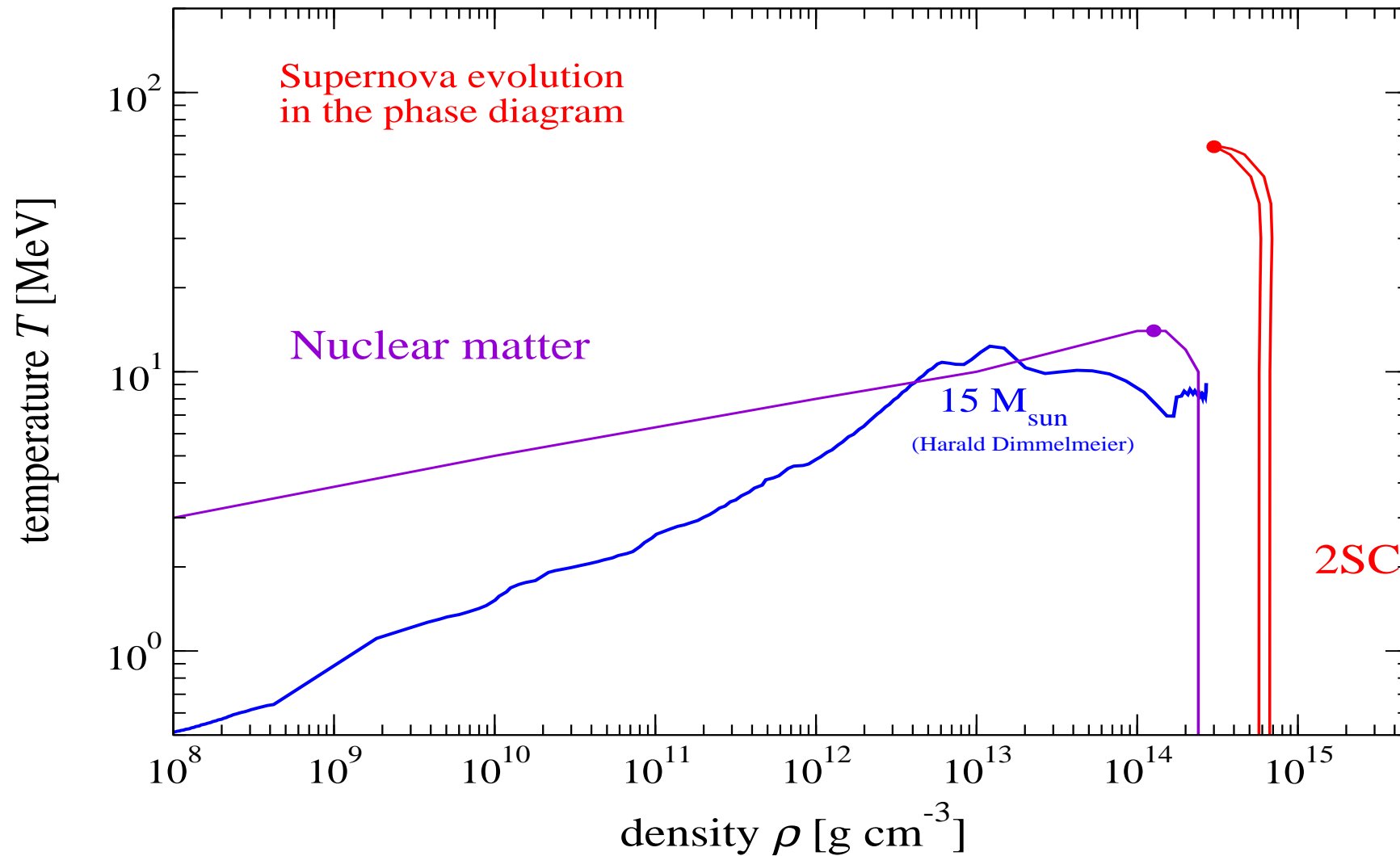
Supernova Collapse in the Phase Diagram

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL hybrid
5. Conclusion



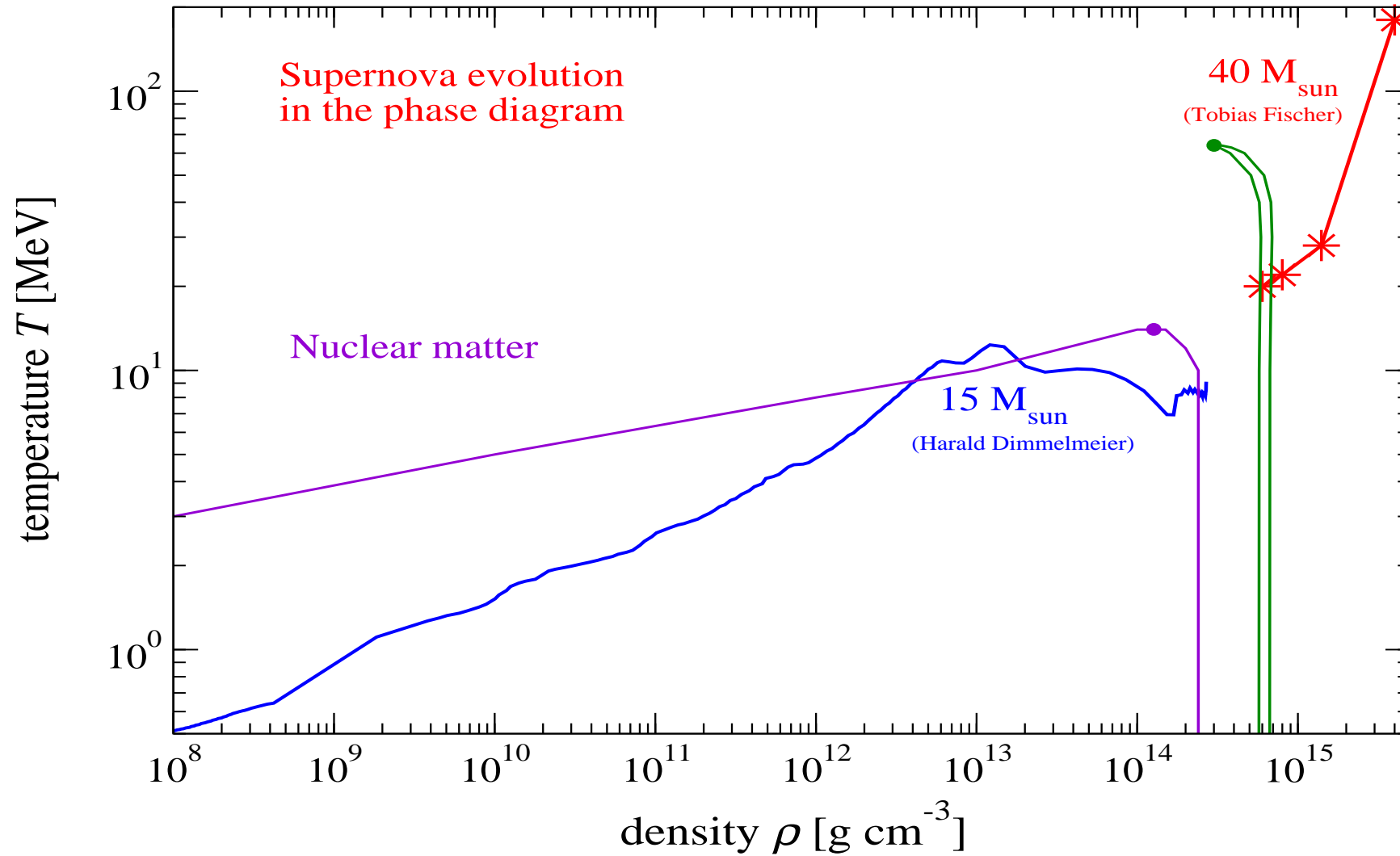
Supernova Collapse in the Phase Diagram (II)

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL hybrid
5. Conclusion



Supernova Collapse in the Phase Diagram

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL hybrid
5. Conclusion



Equation of State for Supernova Applications



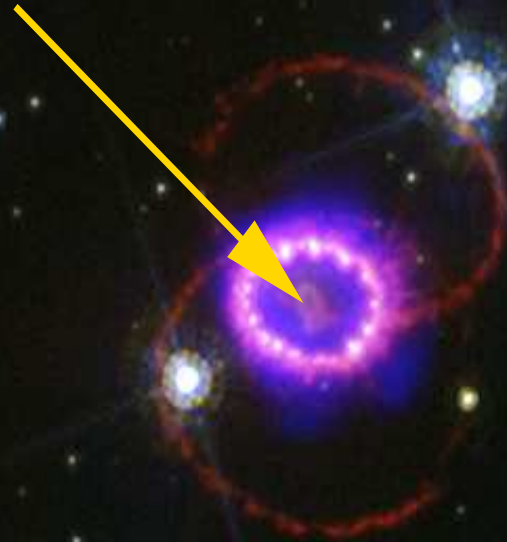
Supernova 1987A - 20 years later:

- Big mystery of rings!
- Double degenerate core in common envelope?
- 2.14 ms periodic signal
- Explanation for 99% of GRB ?

Middleditch, 0705.3846 [astro-ph]

Equation of State for Supernova Applications

What has happened here ??



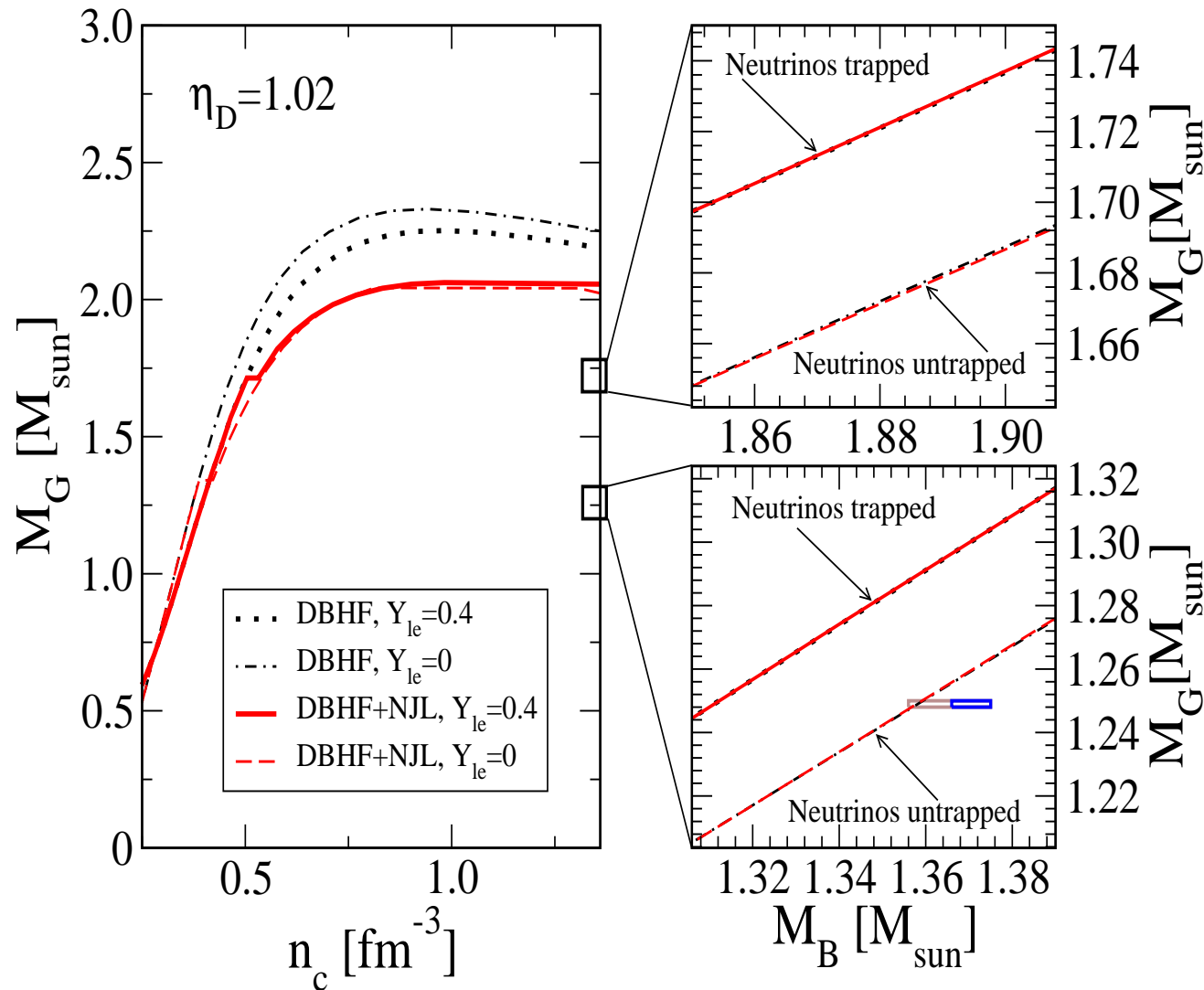
Supernova 1987A - 20 years later:

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

Talk by M. Liebendörfer

Hybrid stars: Effect of neutrino untrapping

1. Introduction
2. Hadronic Cooling + Structure
3. Quark Substructure + Phases
4. Hybrid Star Structure + Cooling
5. Conclusions



The effect of neutrino untrapping ($Y_{\text{le}} = 0.4 \rightarrow 0$) 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. Klöhn, in preparation (2007)

General Relativistic Cooling Equations

1. Introduction
2. Hadronic Cooling
3. Quark Substructure and Phases
4. Hybrid Star Cooling
5. Conclusions

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

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

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:

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

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

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

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

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

$$d \rightarrow u + e + \bar{\nu} \text{ and } u + e \rightarrow d + \nu$$

$$\epsilon_{\nu}^{\text{QDU}} \simeq 9.4 \times 10^{26} \alpha_s u Y_e^{1/3} \zeta_{\text{QDU}} T_9^6 \text{ erg cm}^{-3} \text{ s}^{-1},$$

Compression $u = n/n_0 \simeq 2$, strong coupling $\alpha_s \approx 1$

- **Quark Modified Urca (QMU) and Quark Bremsstrahlung (QB)**

$$d + q \rightarrow u + q + e + \bar{\nu} \text{ and } q_1 + q_2 \rightarrow q_1 + q_2 + \nu + \bar{\nu}$$

$$\epsilon_{\nu}^{\text{QMU}} \sim \epsilon_{\nu}^{\text{QB}} \simeq 9.0 \times 10^{19} \zeta_{\text{QMU}} T_9^8 \text{ erg cm}^{-3} \text{ s}^{-1}.$$

- Suppression due to the pairing

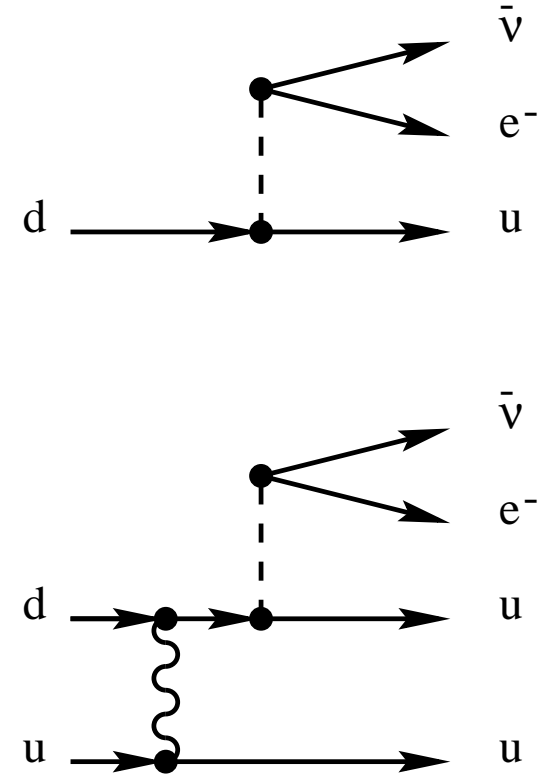
$$\text{QDU} : \zeta_{\text{QDU}} \sim \exp(-\Delta_q/T)$$

$$\text{QMU and QB} : \zeta_{\text{QMU}} \sim \exp(-2\Delta_q/T) \text{ for } T < T_{\text{crit},q} \simeq 0.57 \Delta_q$$

- $e + e \rightarrow e + e + \nu + \bar{\nu}$

$$\epsilon_{\nu}^{ee} = 2.8 \times 10^{12} Y_e^{1/3} u^{1/3} T_9^8 \text{ erg cm}^{-3} \text{ s}^{-1},$$

becomes important for $\Delta_q/T \gg 1$



Quark PBF

Hybrid Star Cooling with 2SC Quark Matter

1. Introduction
2. Hadronic Cooling
3. Quark Matter Phase Diagram
4. Hybrid Star Cooling
5. Conclusions

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

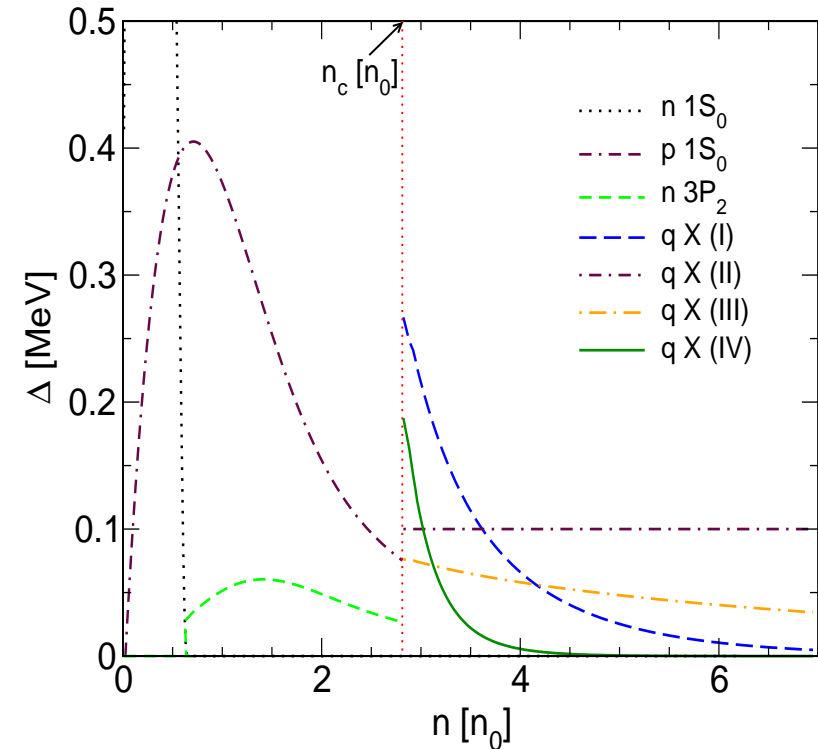
Ansatz 2SC + X phase:

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

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

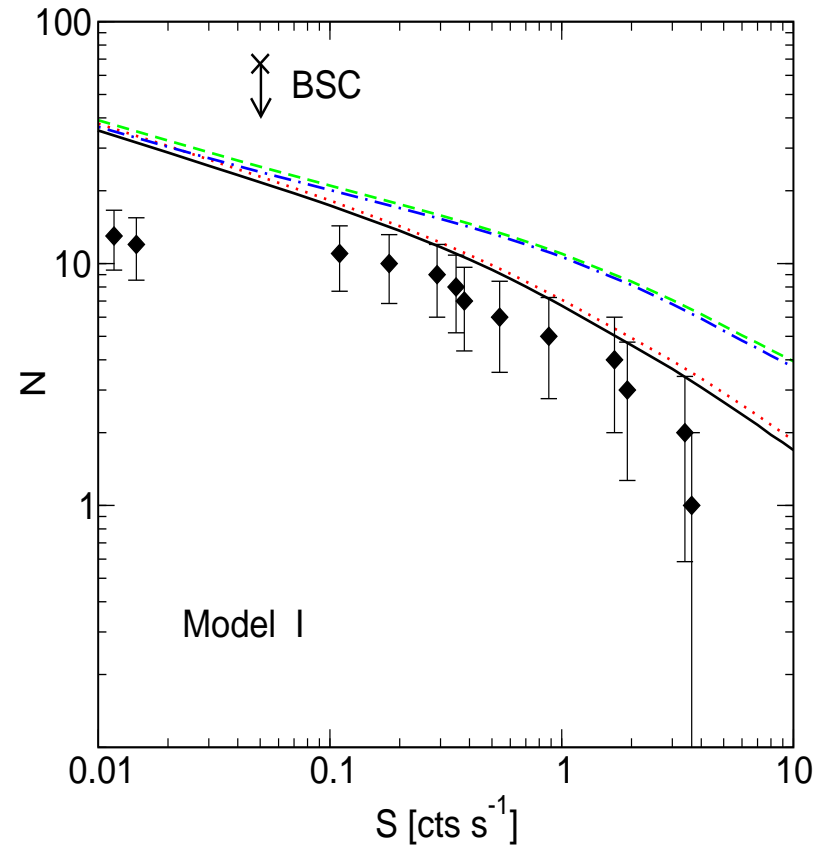
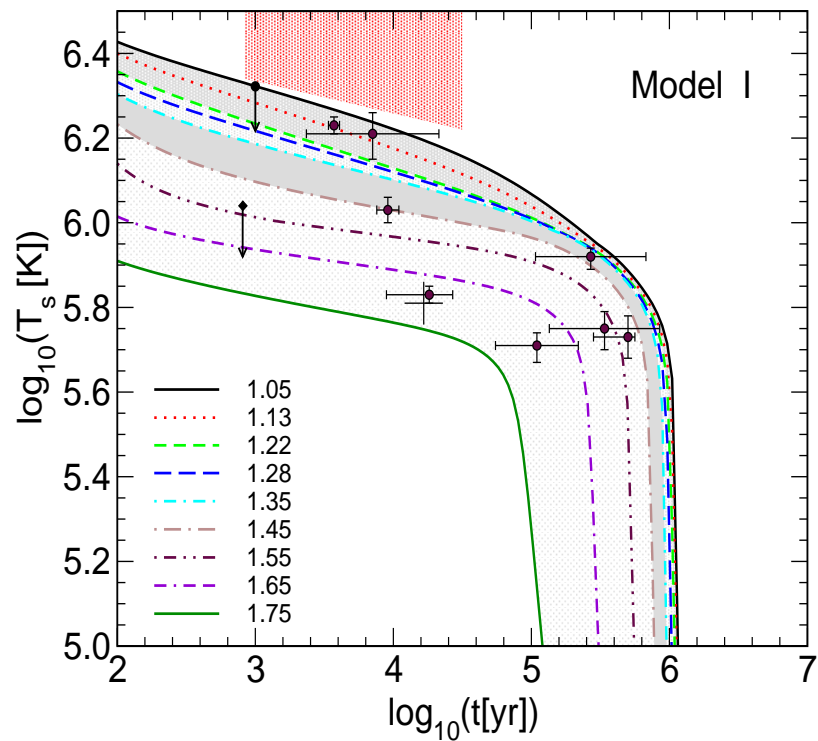
Popov, Grigorian, D.B., PRC 74 (2006)



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

Hybrid Star Cooling with 2SC Quark Matter

1. Introduction
2. Hadronic Cooling
3. Quark Substructure and Phases
4. Hybrid Star Cooling
5. Conclusions



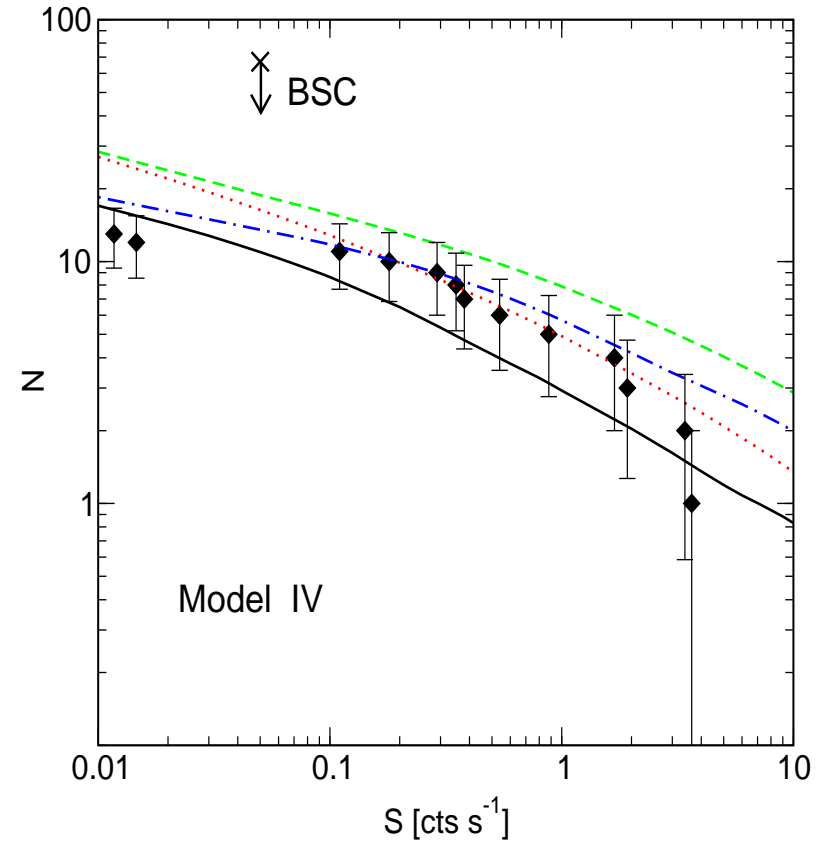
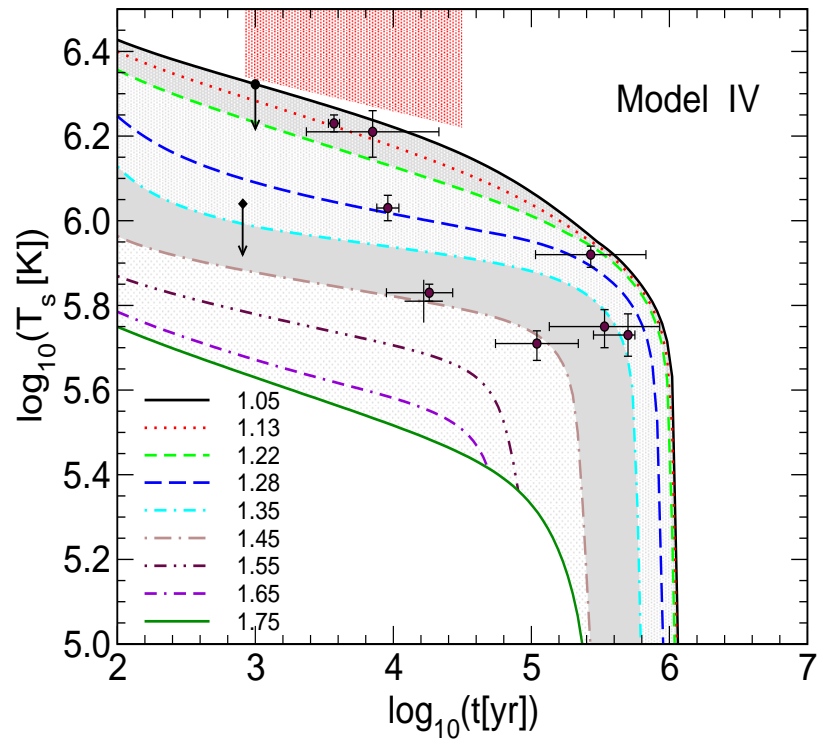
2SC + X phase, $\Delta_0 = 1 \text{ MeV}$, $\alpha = 10$
Too large mass for Vela required

Log N - Log S test fails

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

Hybrid Star Cooling with 2SC Quark Matter

1. Introduction
2. Hadronic Cooling
3. Quark Substructure and Phases
4. Hybrid Star Cooling
5. Conclusions



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

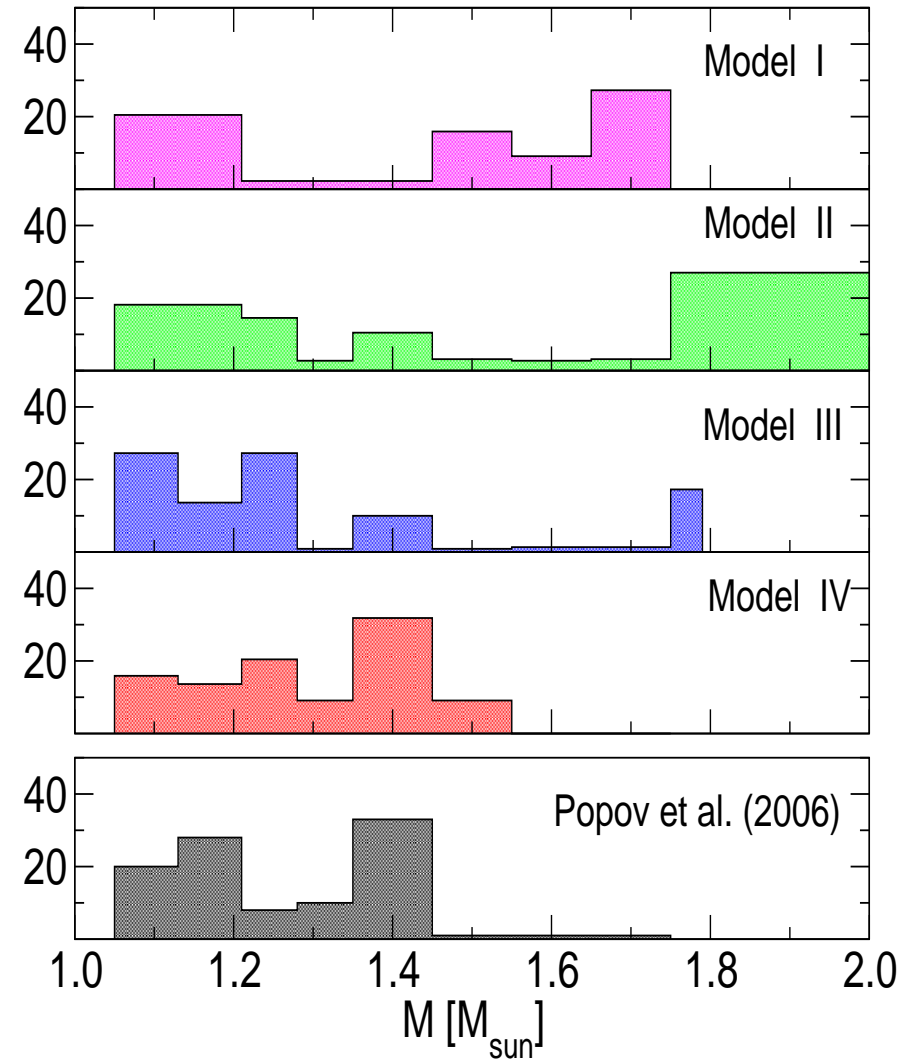
1. Introduction
2. Hadronic Cooling
3. Quark Substructure and Phases
4. Hybrid Star Cooling
5. Conclusions

Hybrid star cooling passes all modern tests:

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

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

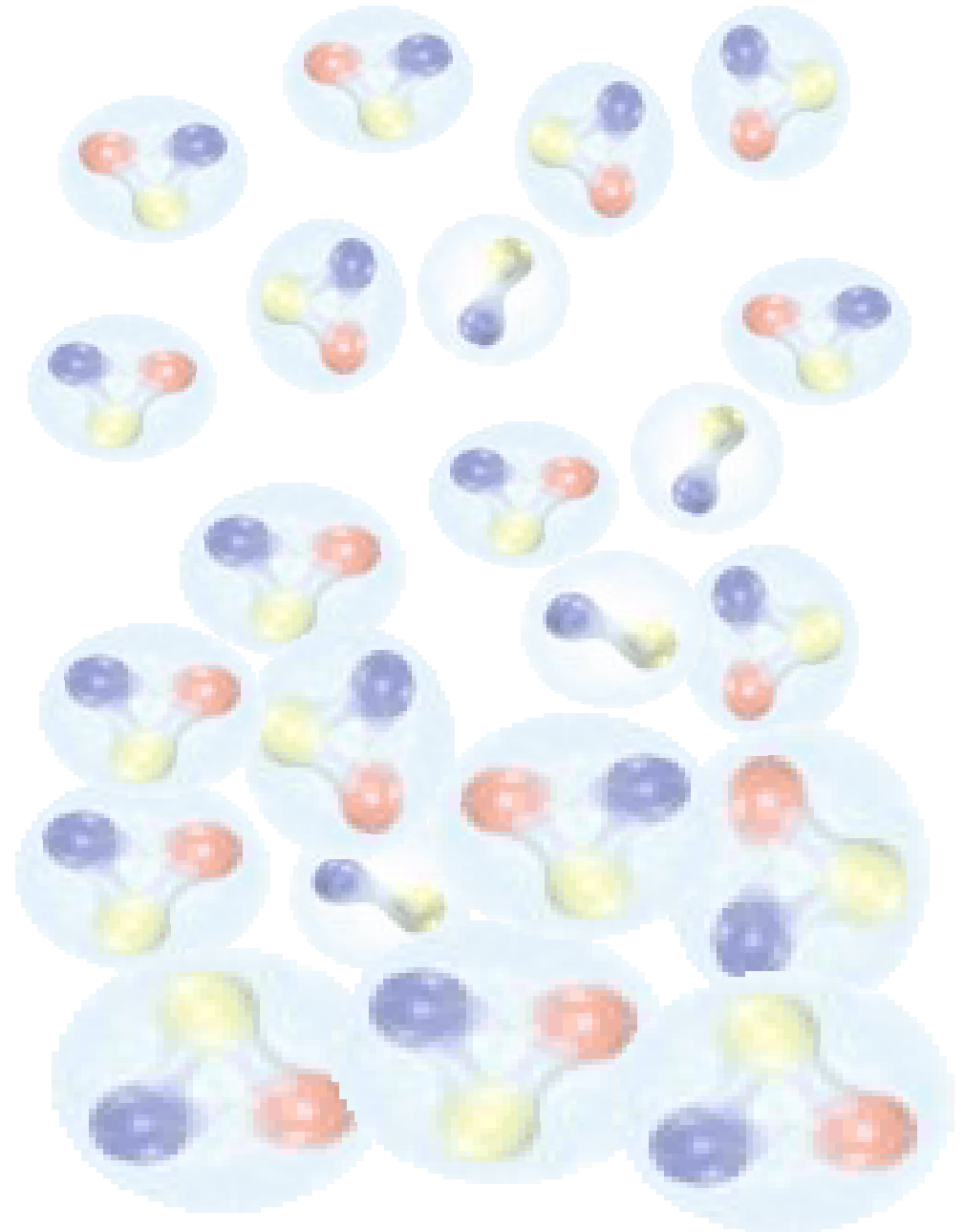
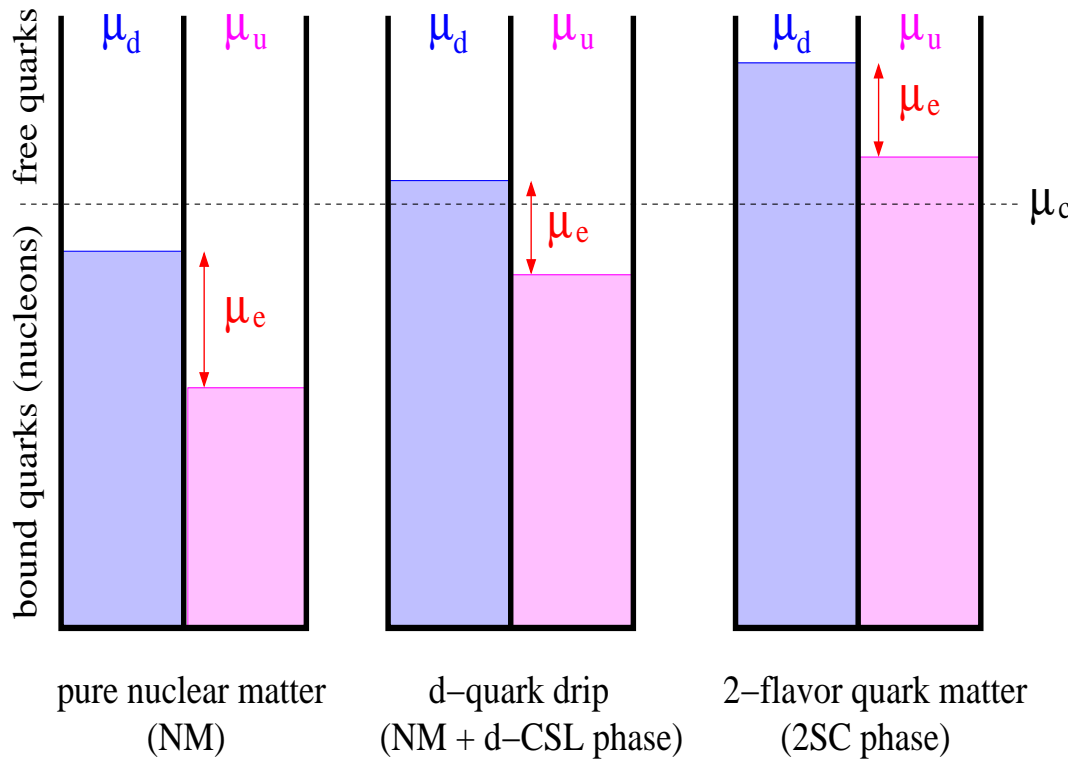
D.B., H. Grigorian, PPNP (2007)



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

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL hybrid
5. Conclusion

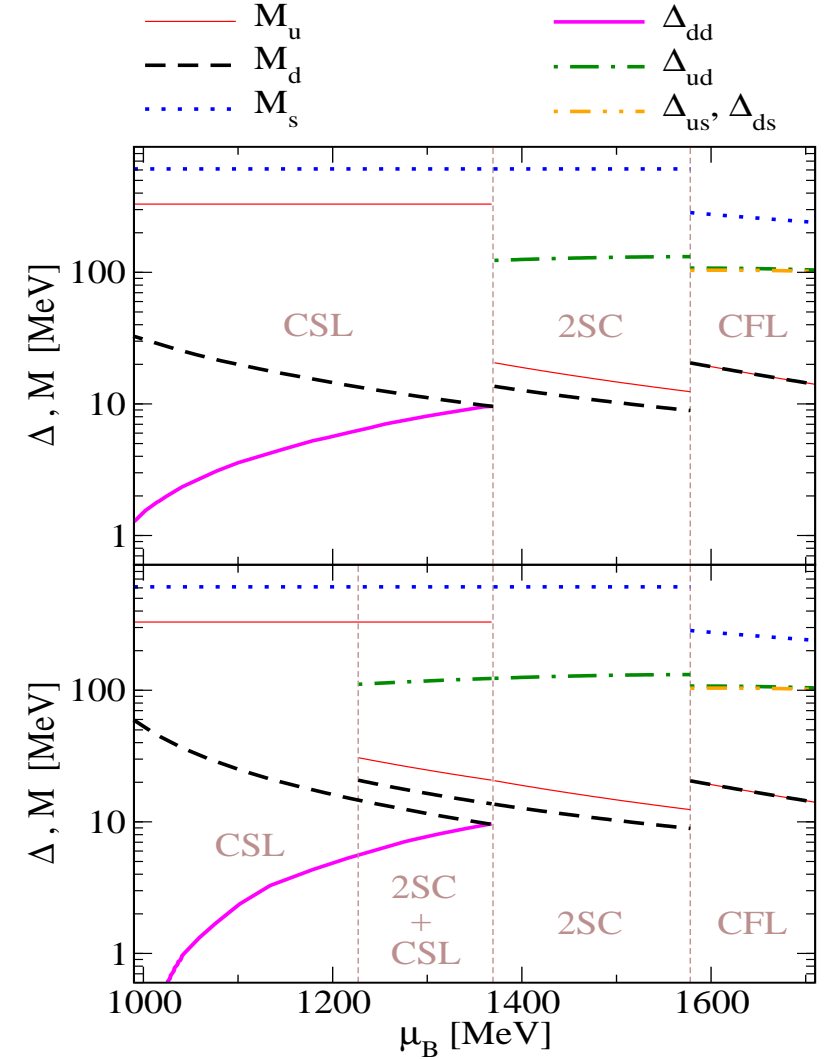
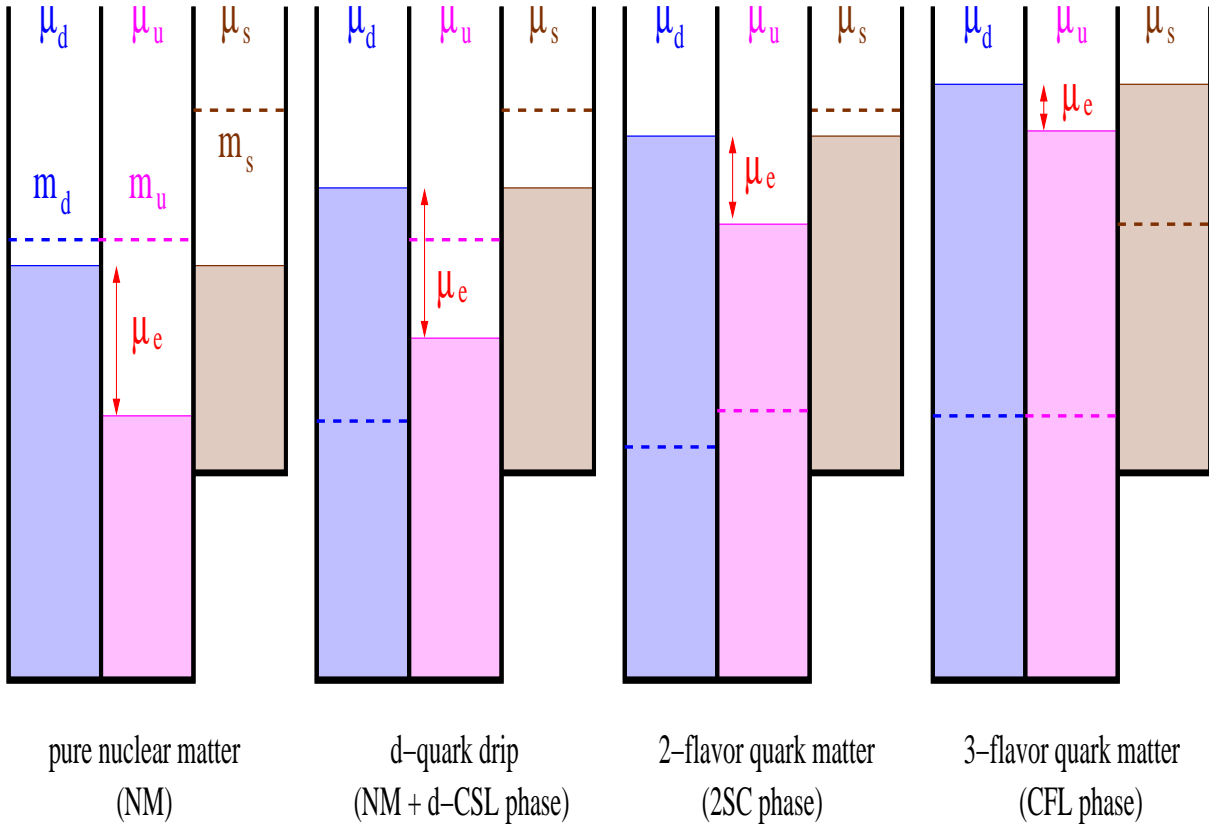
Sequential 'deconfinement' of quark flavors



D.B., F. Sandin, T. Klähn, J. Berdermann,
[arXiv:0807.0414 \[nucl-th\]](https://arxiv.org/abs/0807.0414); [arXiv:0808.1369 \[astro-ph\]](https://arxiv.org/abs/0808.1369)
[arXiv:0808.0181 \[nucl-th\]](https://arxiv.org/abs/0808.0181), *J. Phys. G*, in press

Sequential deconfinement in asymmetric NS matter

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL hybrid
5. Conclusion



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

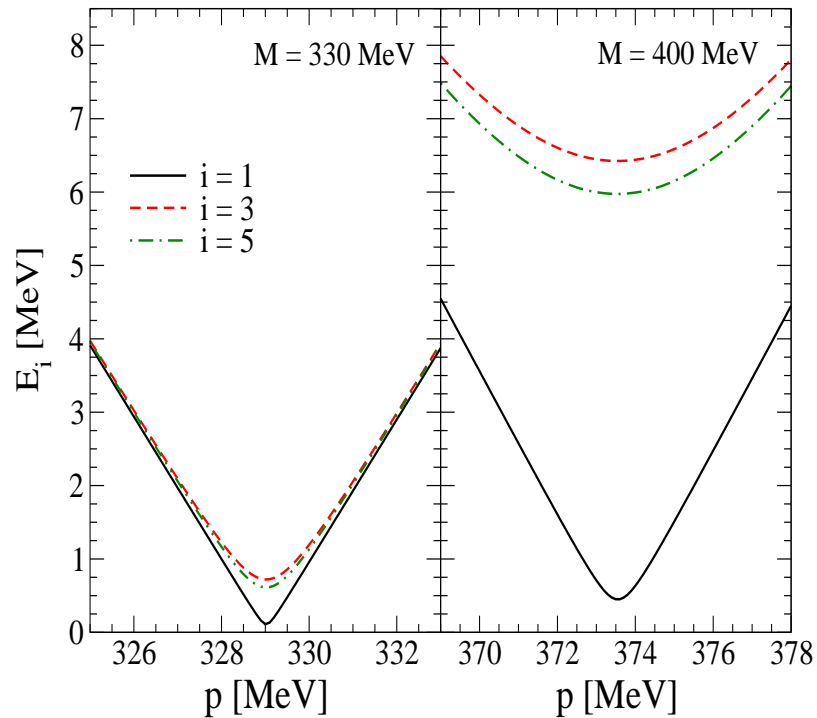
Single-flavor (d-CSL) phase in competition

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;

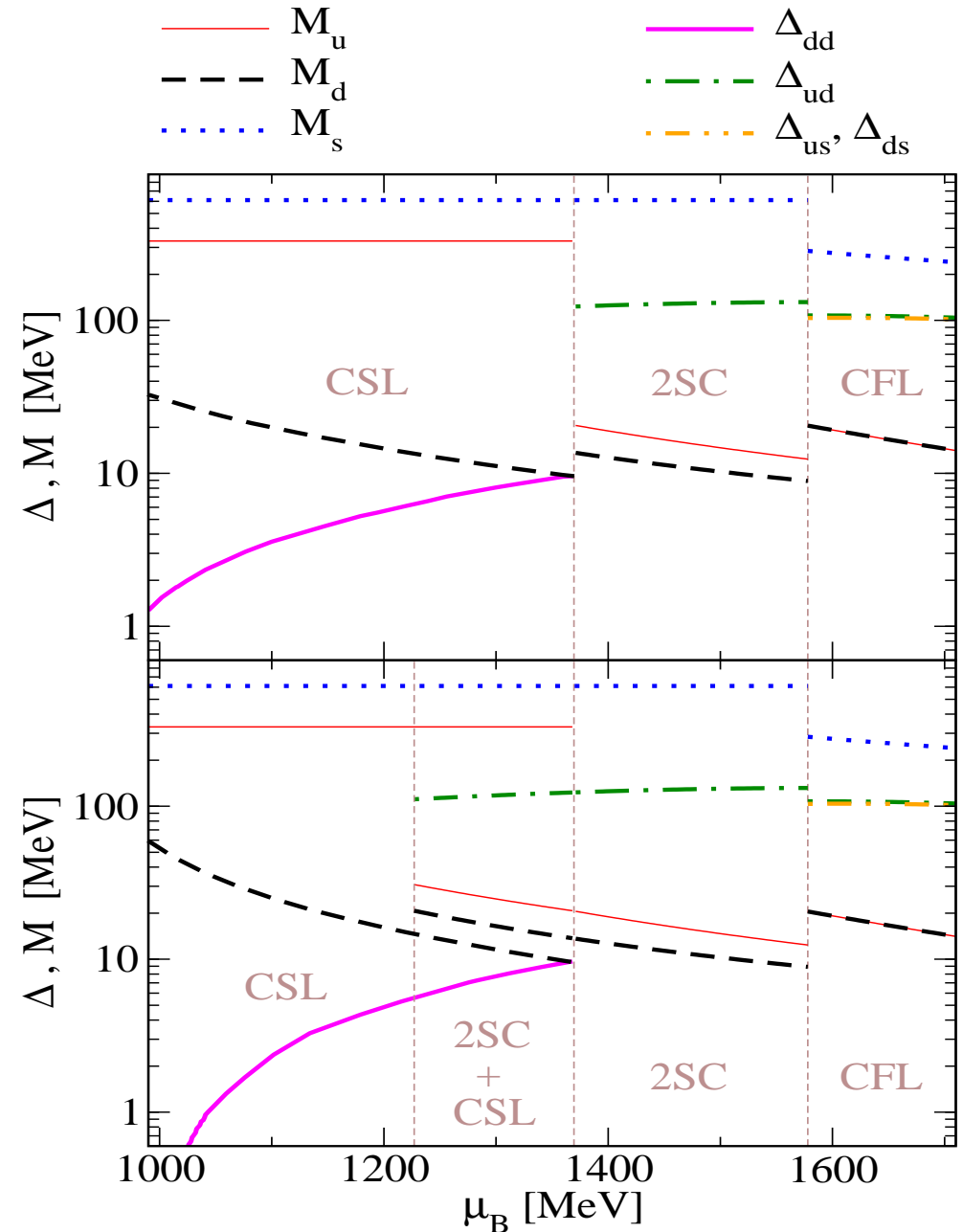
PRD 74 (2006) 114005



See also:

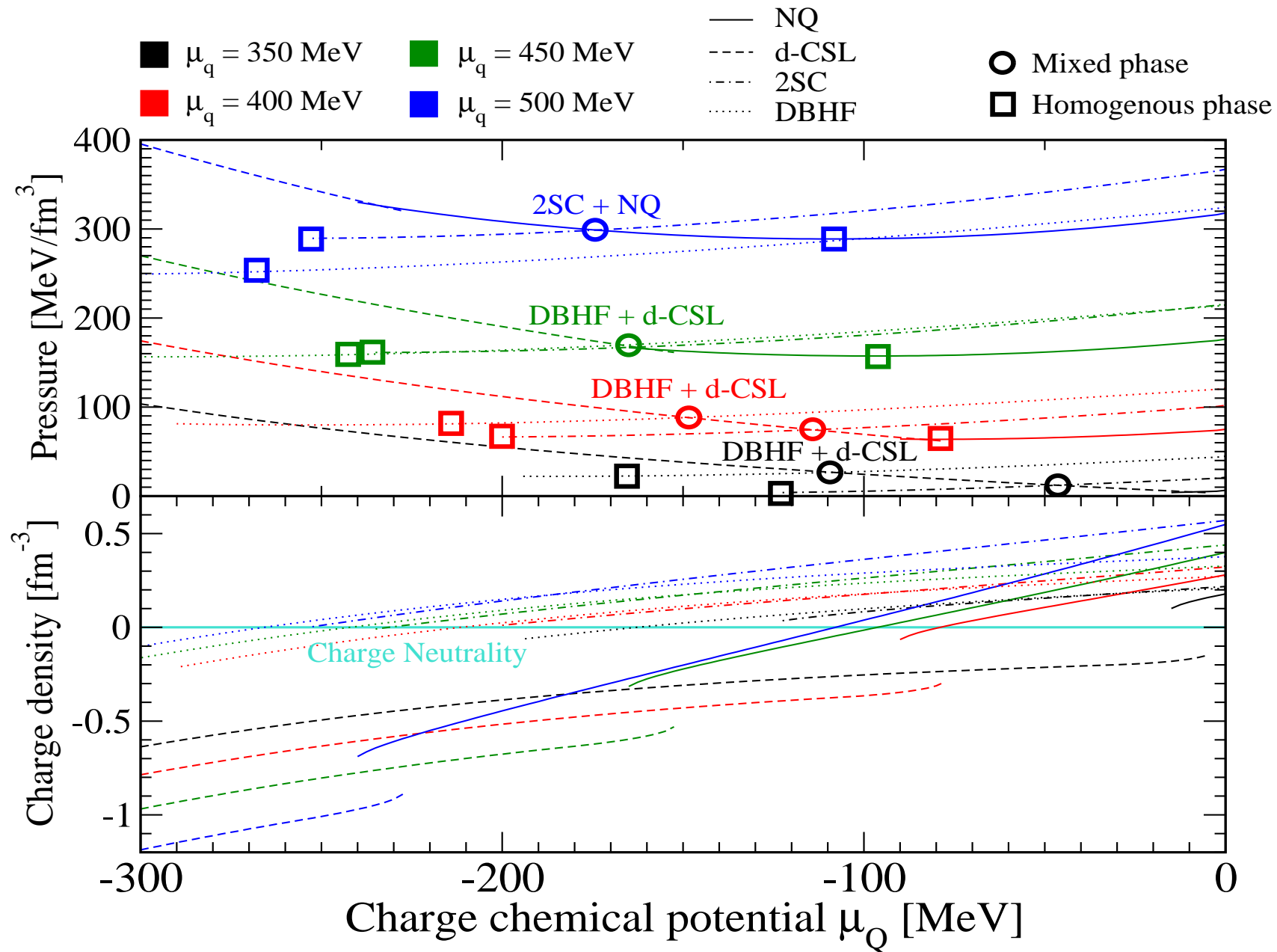
Schmitt, Wang, Rischke, PRD 66, 114010 (2002)

1. Mass and Flow constraint
2. Chiral Quark model
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5. Conclusion



Global charge neutrality: quark-nuclear hybrid

1. Mass and Flow constraint
2. Chiral Quark model
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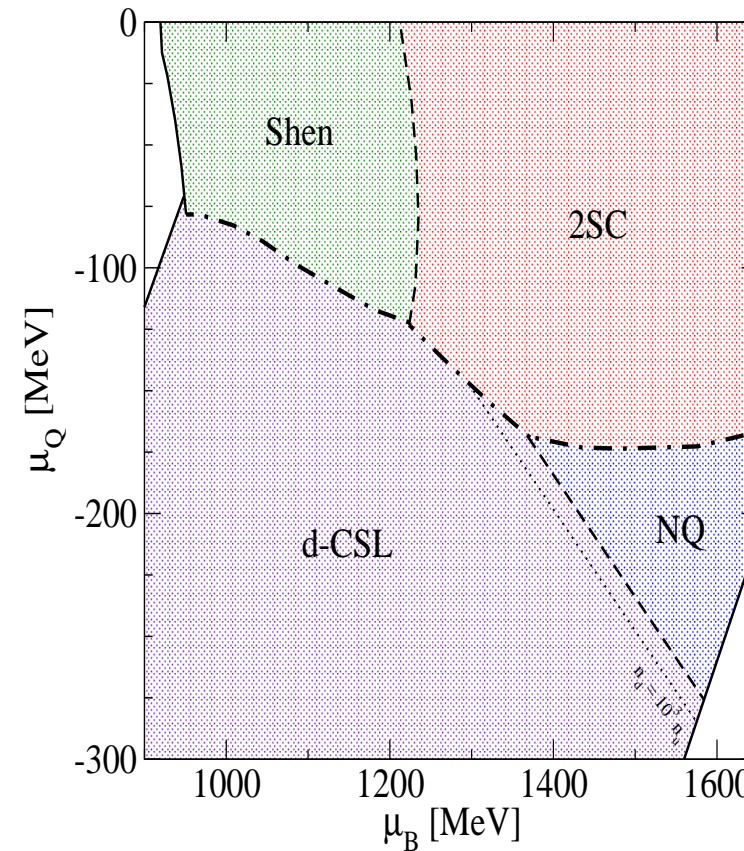
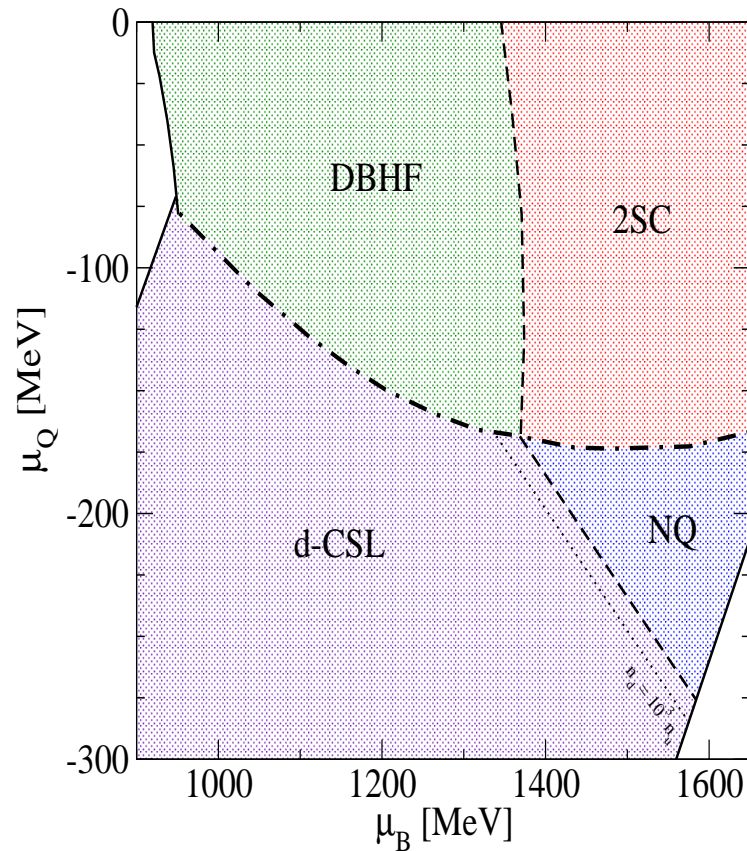


d-CSL: single-flavor phase in competition

1. Mass and Flow constraint
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5. Conclusion

Dash-dotted lines: border between oppositely charged phases

⇒ single-flavor phase only in isospin-asymmetric matter!

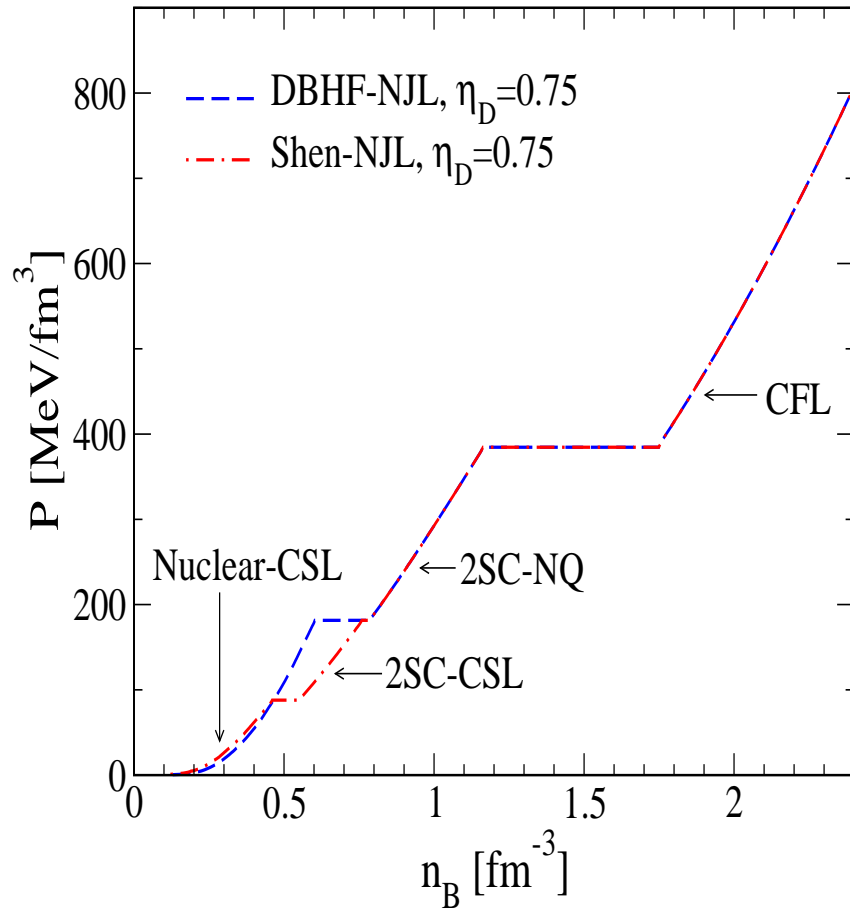


D.B., F. Sandin, T. Klähn, J. Berdermann, arXiv:0807.0414 [nucl-th]; arXiv:0808.1369 [astro-ph]

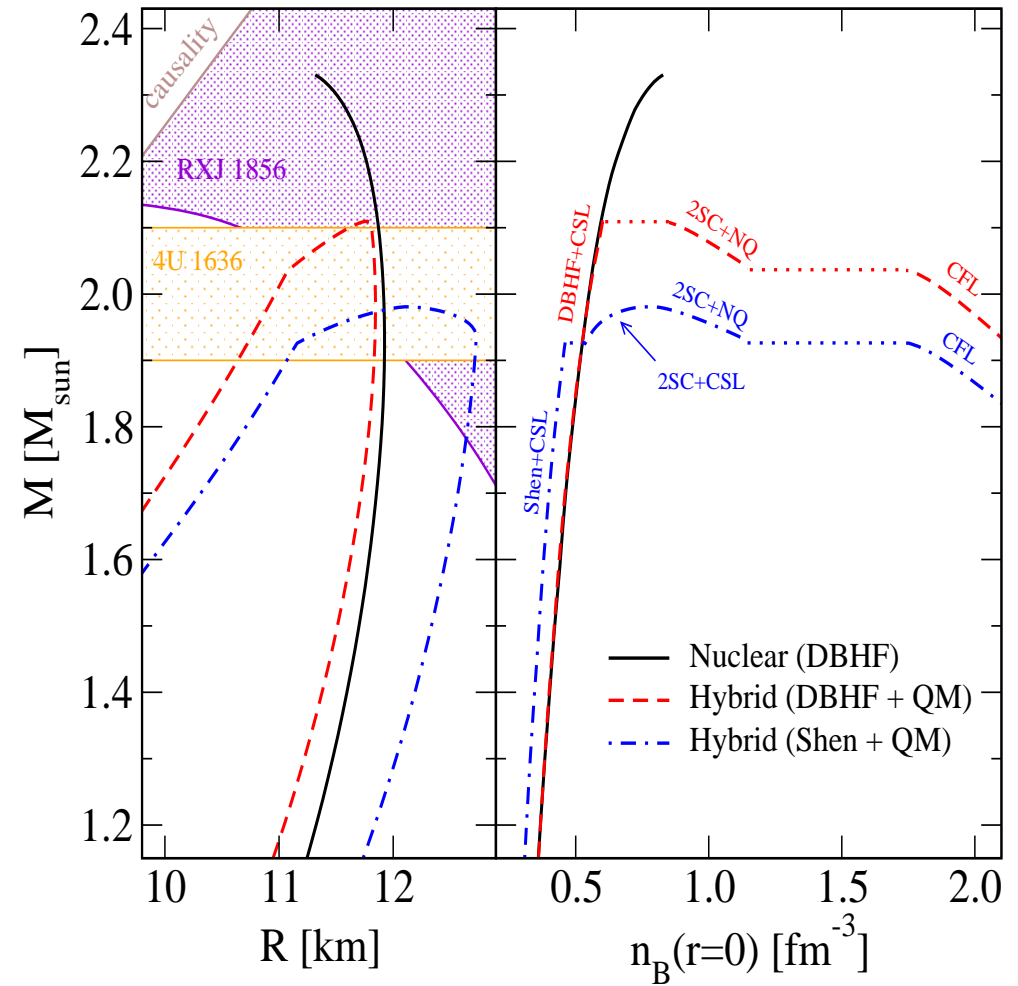
d-CSL: single-flavor phase in neutron stars

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL hybrid
5. Conclusion

Equation of state



Configuration Sequences

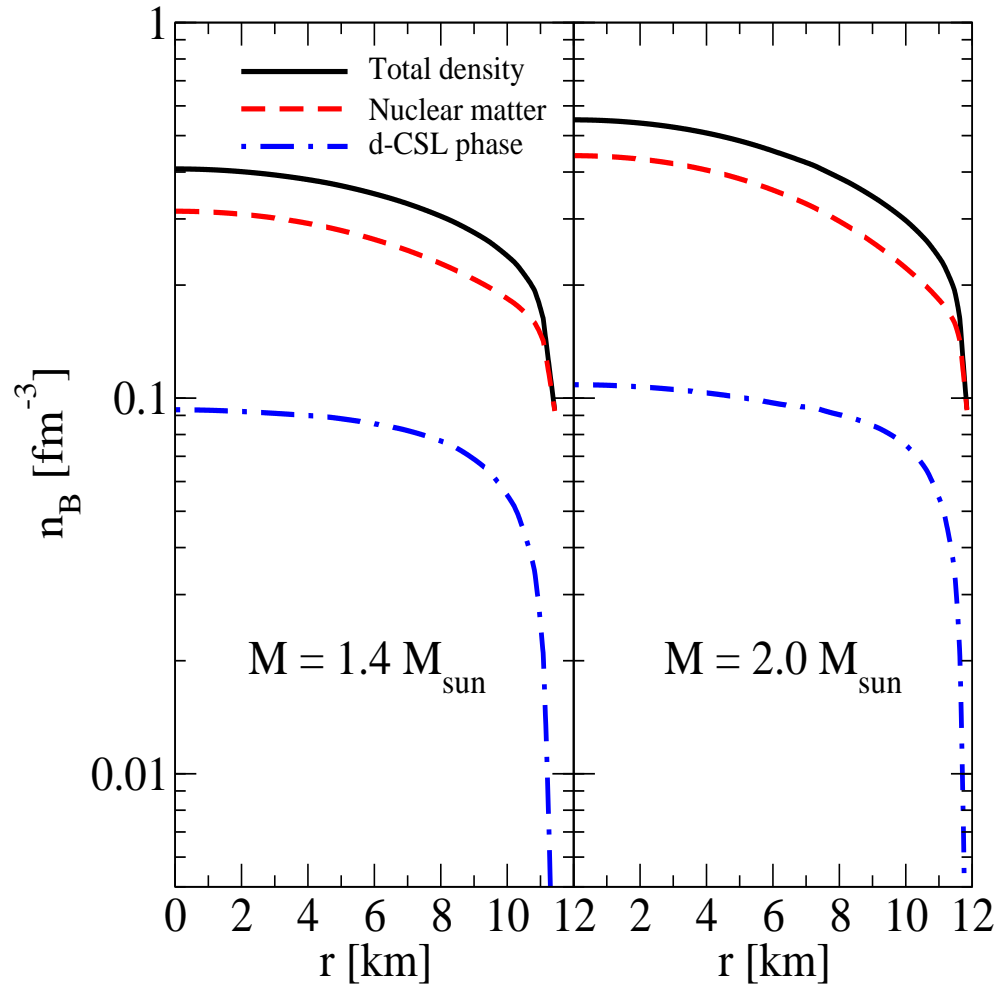


D. B., F. Sandin, T. Klähn, J. Berdermann, arXiv:0807.0414 [nucl-th]; arXiv:0808.1369 [astro-ph]; arXiv:0808.0181 [nucl-th], J. Phys. G, in press (2008).

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

1. Mass and Flow constraint
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4. d-CSL hybrid
5. Conclusion

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



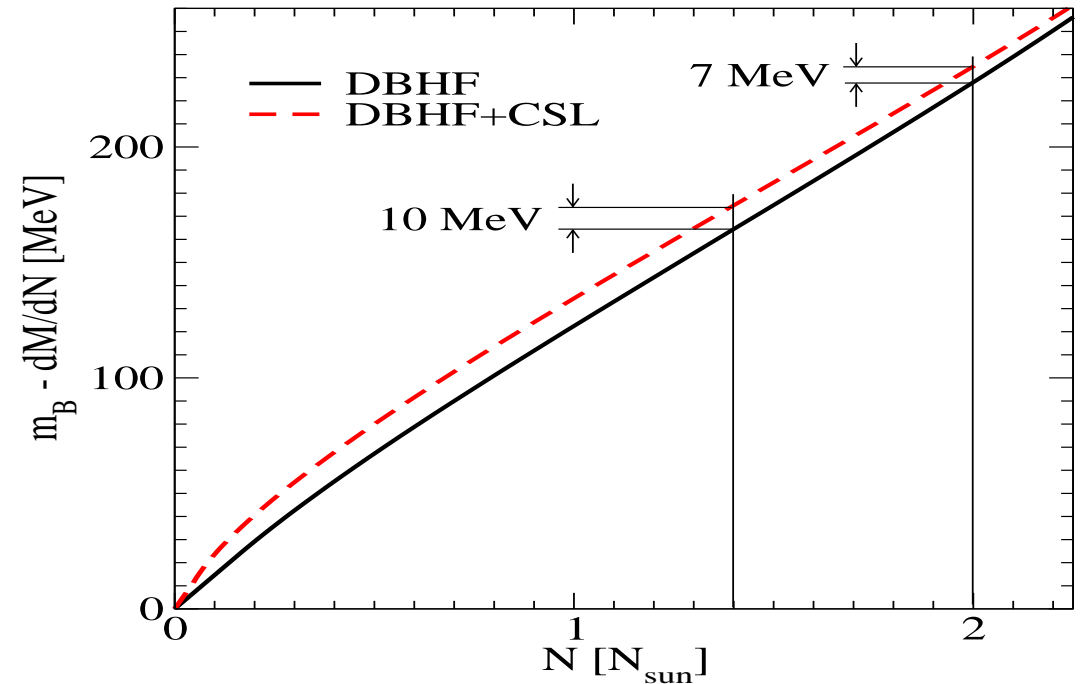
Haensel and Zdunik, *A&A* **227**, 431 (1990)

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

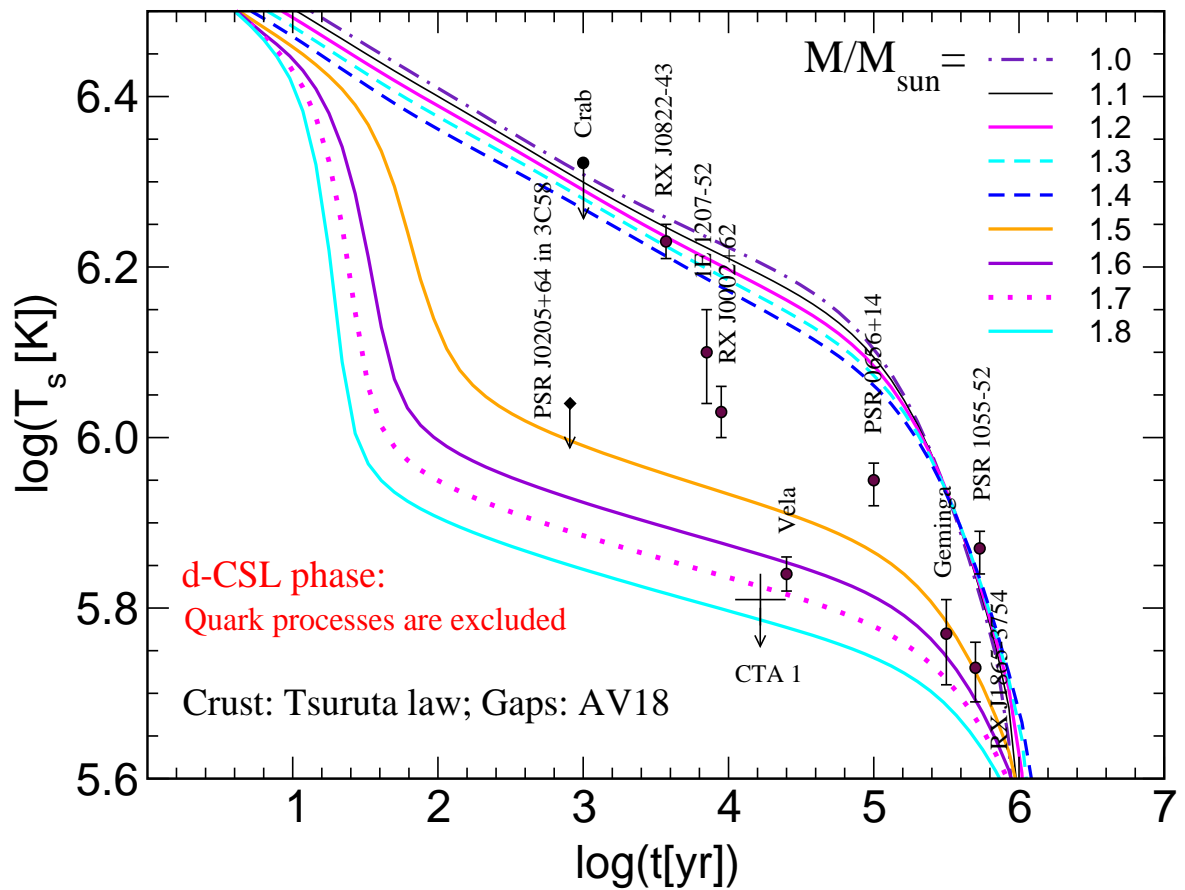


D. B., F. Sandin, T. Klähn, J. Berdermann, arXiv:0807.0414 [nucl-th]

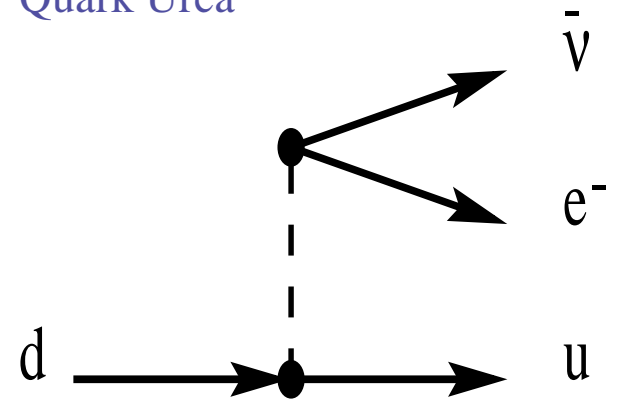
d-CSL: single-flavor phase in neutron stars

- 1. Mass and Flow constraint
- 2. Chiral Quark model
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- 4. d-CSL hybrid
- 5. Conclusion

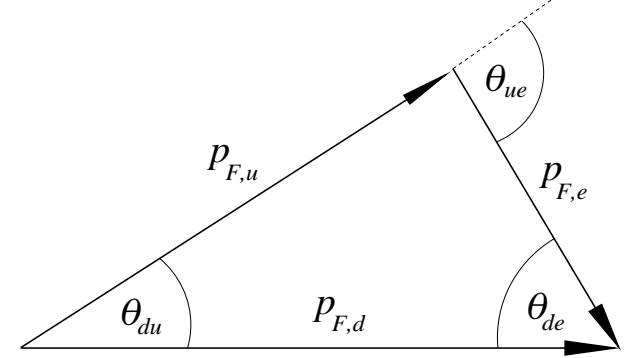
Cooling: processes in single-flavor quark matter are blocked!



Quark Urca



Momentum conservation triangle



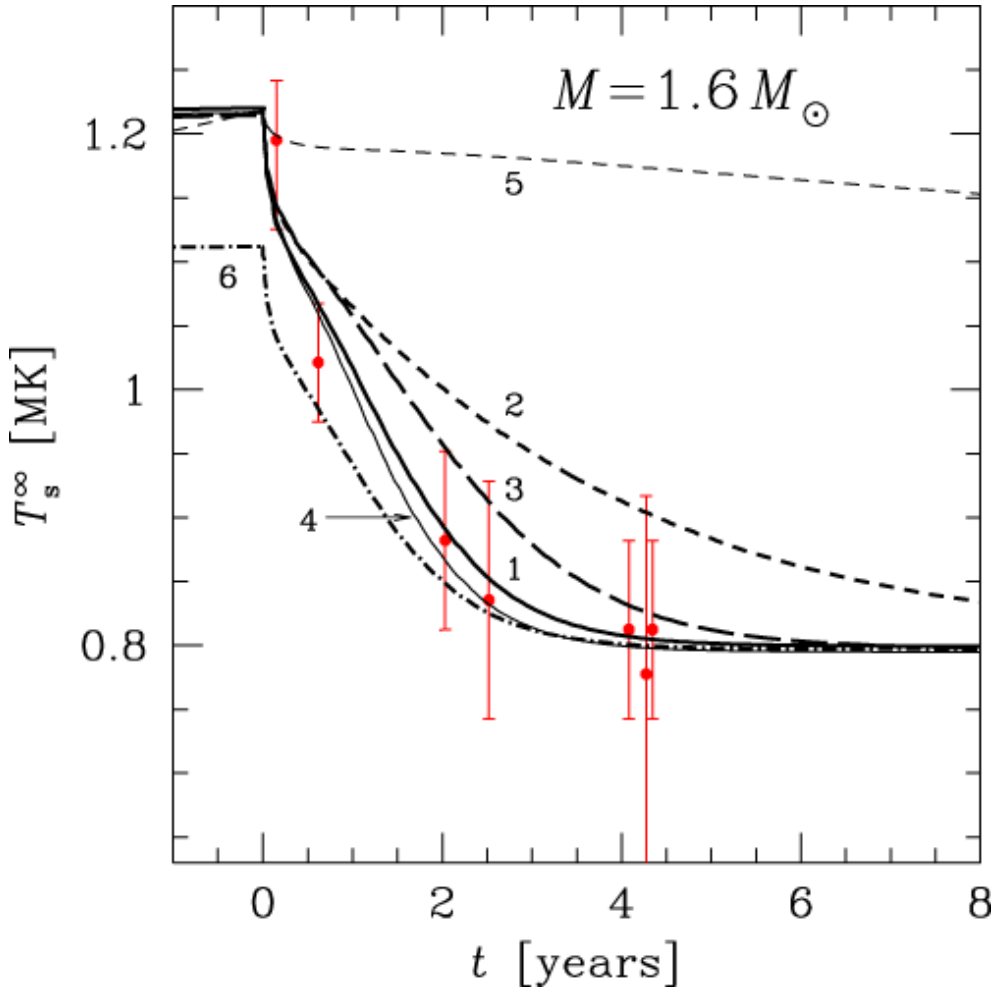
not operative since u-quark Fermi sea not populated ($p_{F,u} = 0$)

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

Cooling of X-ray transients: deep crustal heating!

1. Mass and Flow constraint
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5. Conclusion

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



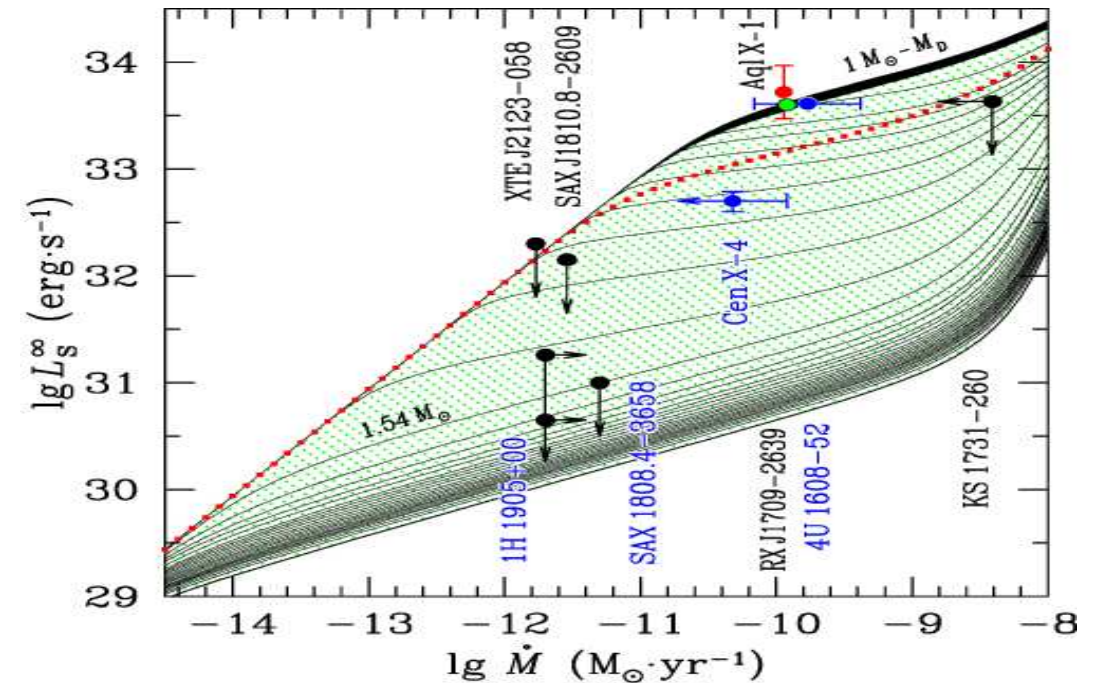
Haensel and Zdunik, *A& A* **227**, 431 (1990)

Ushomirsky and Rutledge, *MNRAS* **325**, 1157 (2001)

Page and Cumming, *ApJ* **635**, L157 (2005): Superbursts & Strange Stars

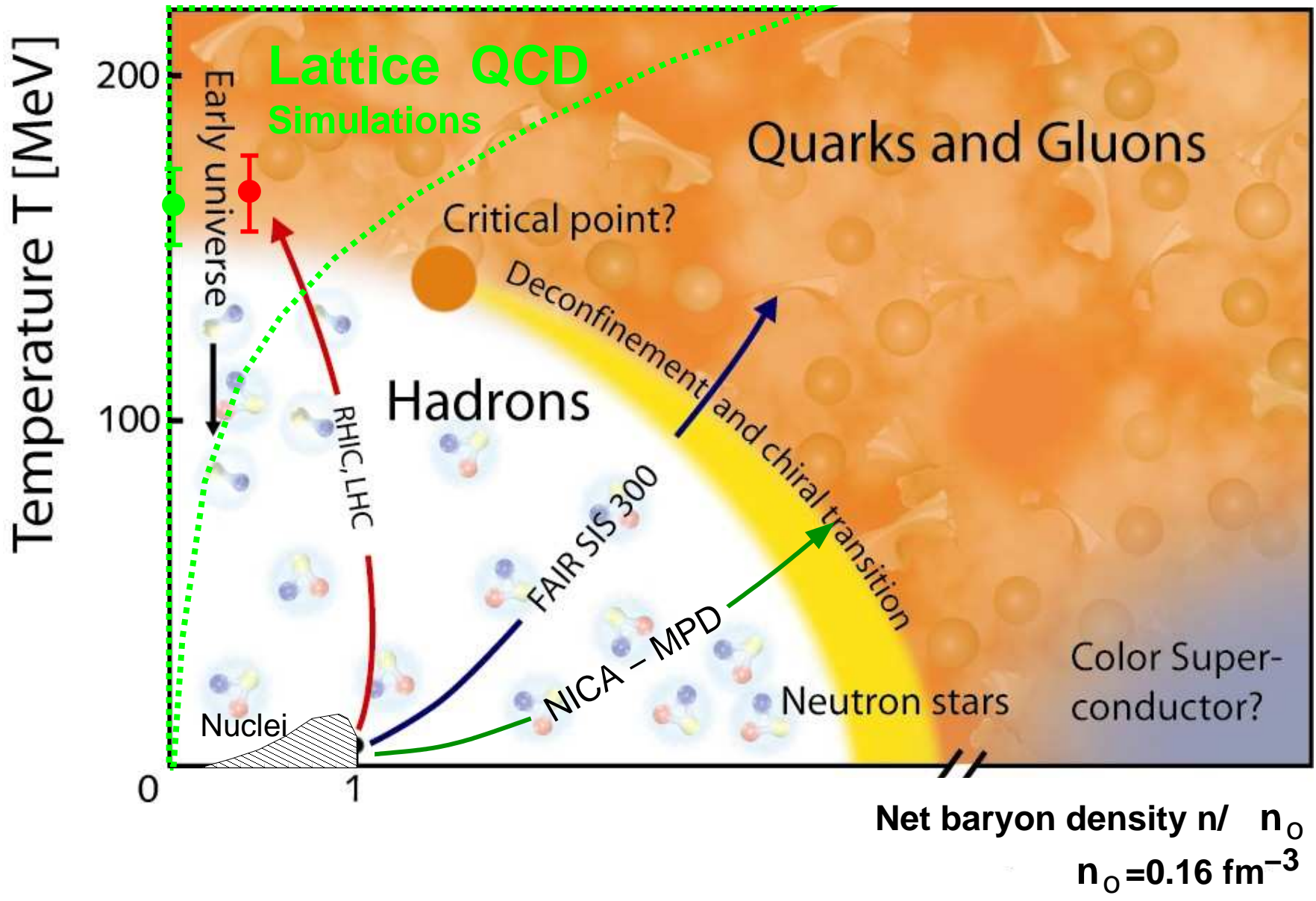
Stejner and Madsen, *A& A* **458**, 523 (2006): SS + Transient Cooling

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

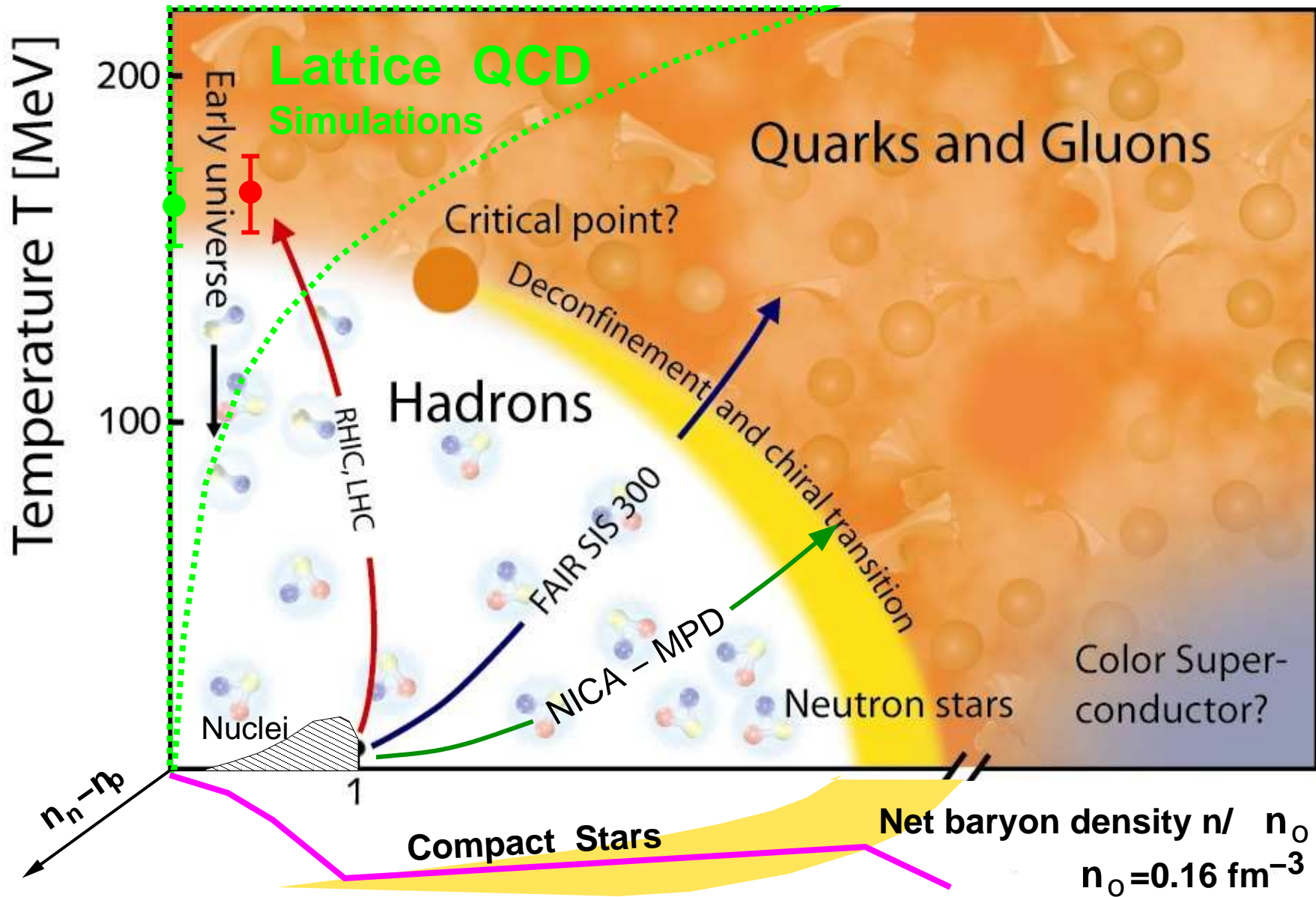


K. Levenfish, P. Haensel (2007)

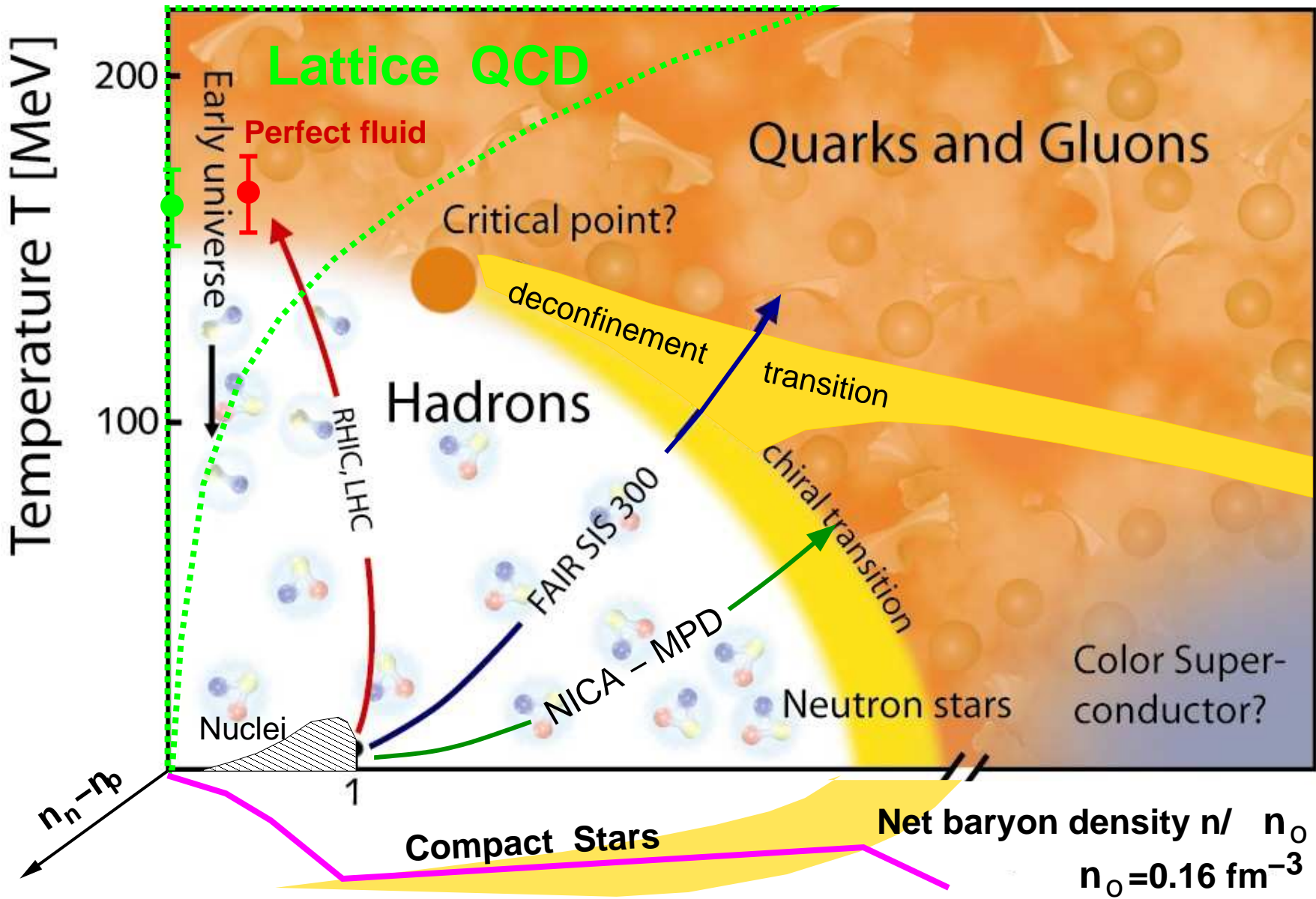
Extreme States of Matter - The Phase Diagram



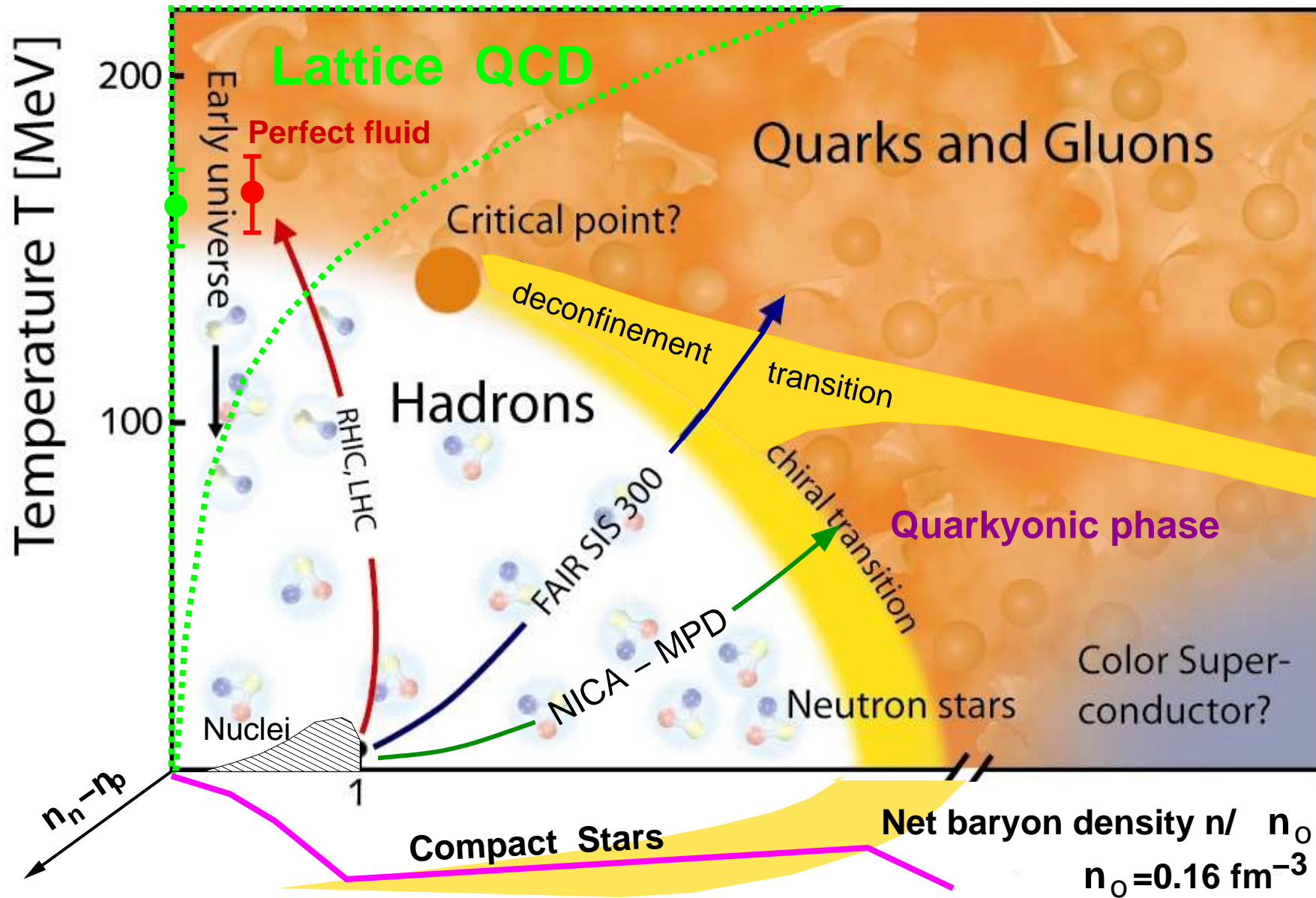
Extreme States of Matter - The Phase Diagram



Extreme States of Matter - The Phase Diagram



Extreme States of Matter - The Phase Diagram



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

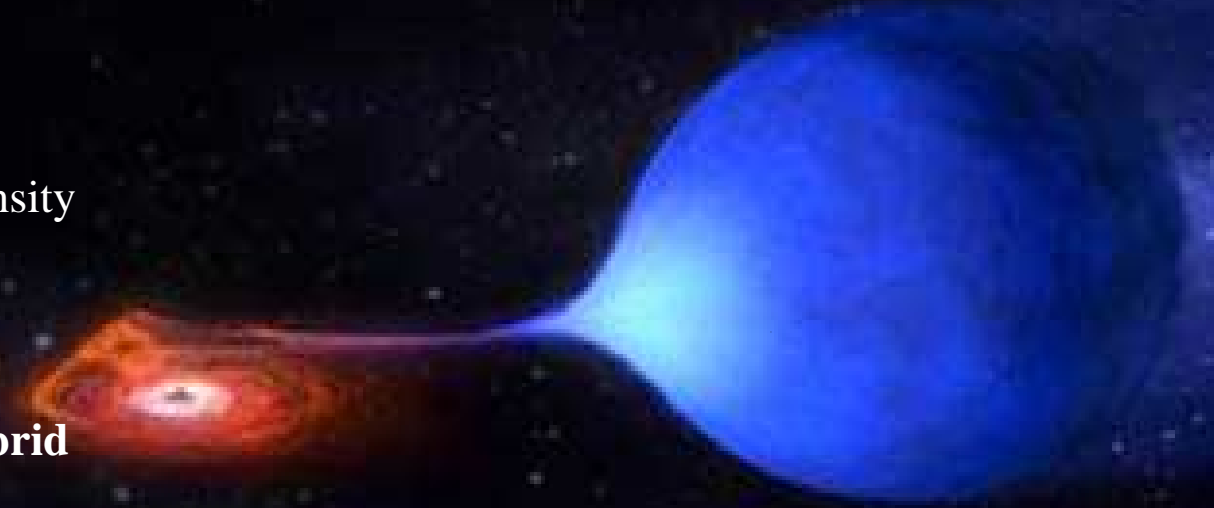


Local charge neutrality: 2SC + DBHF hybrid

- 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 χ SR
- no d-CSL in symmetric matter: $x_{p,crit} < 0.2$
- no Urca cooling processes \rightarrow no neutrino trapping?



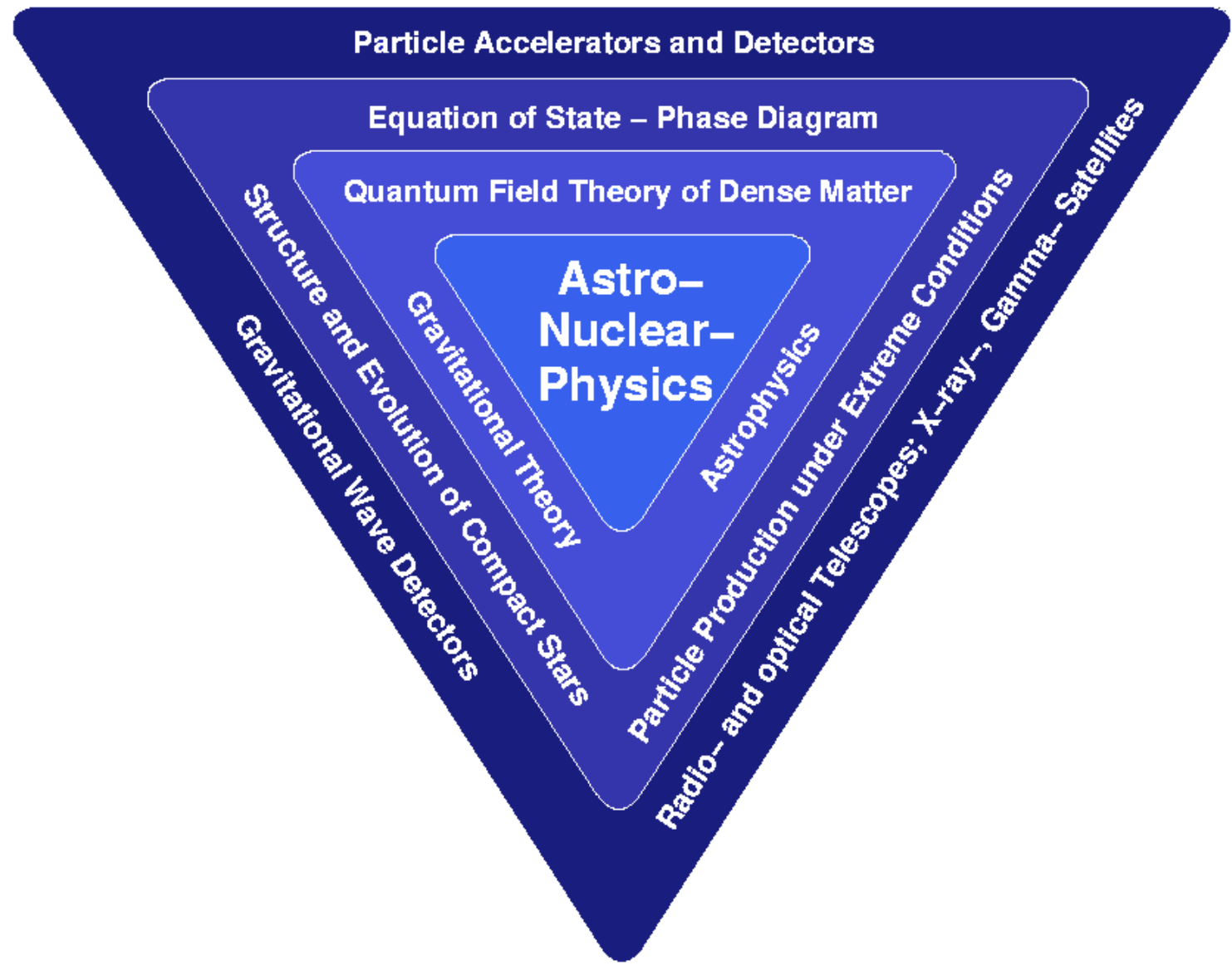
Next steps

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



New ways to understand Dense Matter

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF hybrid
4. d-CSL + DBHF hybrid
5. Conclusion

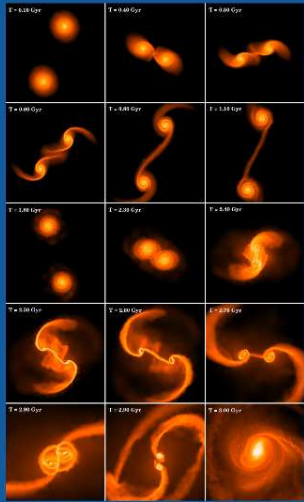


<http://www.esf.org/compstar>

Dense QCD Phases in Heavy Ion Collisions and Supernovae

October 11-13, 2009 Prerow, Germany

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

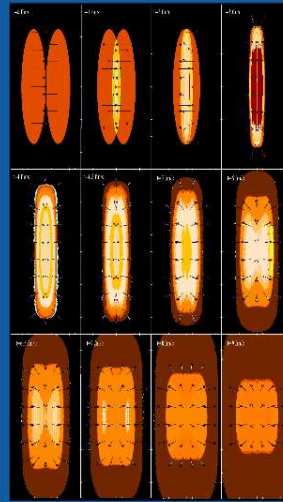


Organizers

C. Greiner
J. Wambach
D. Blaschke

Local Organizers

G. Röpke
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

HIC for **FAIR**
Helmholtz International Center

 **HELMHOLTZ**
ASSOCIATION

Invitations

International Round-Table Workshop
“Physics at NICA”,
Dubna, Russia, September 8-13, 2009
<http://theor.jinr.ru/meetings/2009/~roundtable>

HIC for FAIR Workshop
“Dense Matter in HIC and Supernovae”
Prerow, Germany, October 11-13, 2009
<http://www.mpg.uni-rostock.de/~hic4fair>

ESF Research Networking Programme
“CompStar” (2008-2013)
<http://www.esf.org/compstar>

THANKS FOR YOUR ATTENTION!

1. Mass and Flow constraint
2. Chiral Quark model
3. 2SC + DBHF Hybrid
4. d-CSL + DBHF hybrid
5. **Conclusions**

