Recent news on hybrid stars & mass twins

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1. **Introduction: "alternative facts" = fake news vs. reality check**

2. **Third family, twins, ABCD, HMT, triples, fifth family & all that:**
   - Constant Speed of Sound (CSS) model
   - Multi-Polytrope (MP) model
   - Relativistic Density Functional (RDF) approach

3. **Outlook: Full thermal hybrid EoS for Supernovae & Mergers**

Astro-Coffee, FIAS, Goethe-University Frankfurt, 19.12.2017

DUBNA

NARODOWE CENTRUM NAUKI

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Uniwersytet Wrocławski

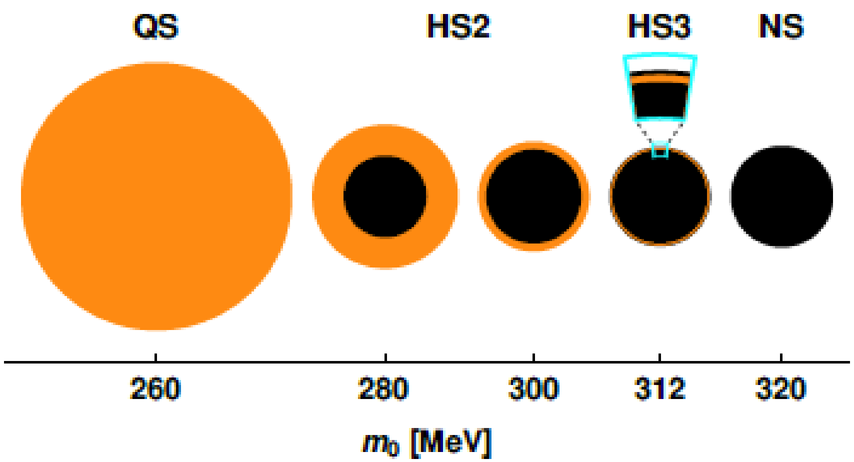
Russian Science Foundation

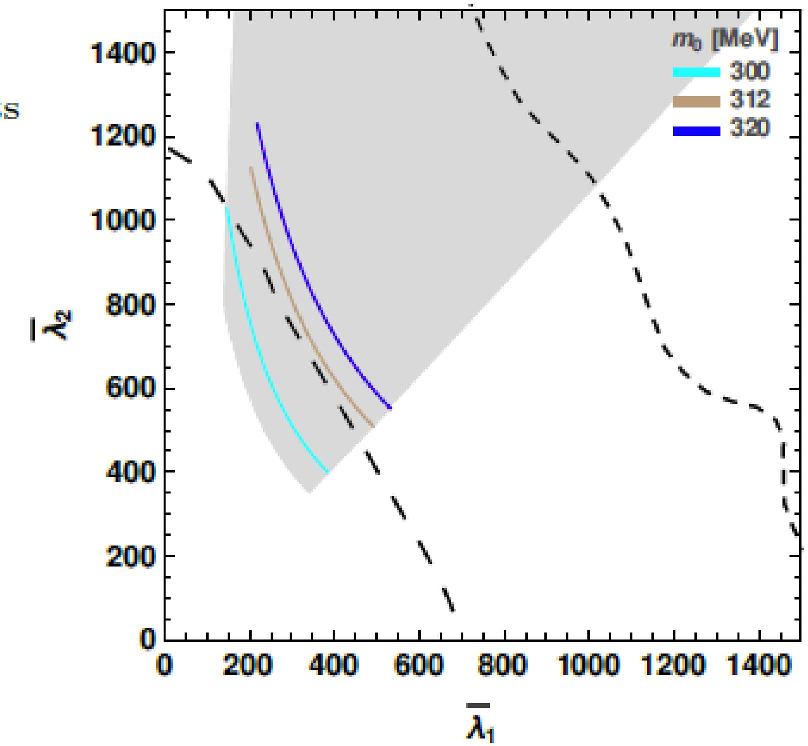
Alternative facts of the day: New hybrid star solutions!

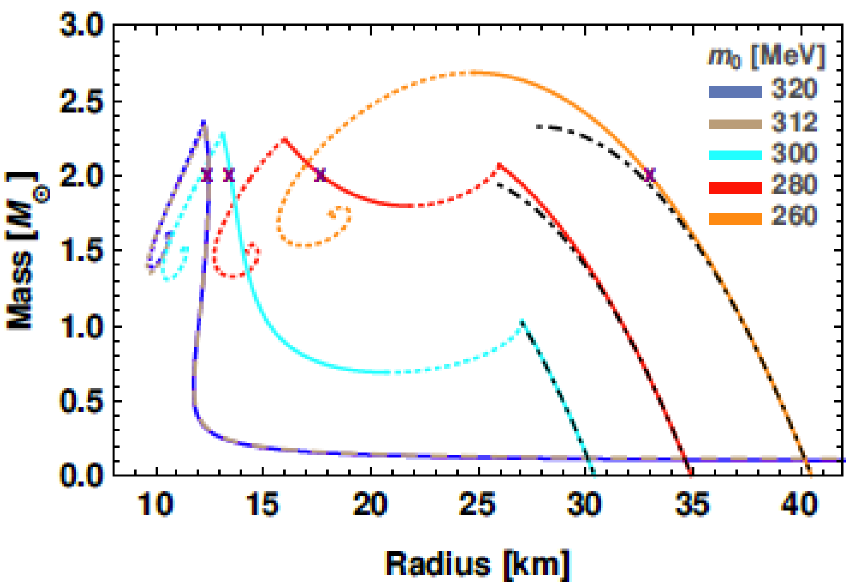
arxiv:1711.06244v1, 1611.2017

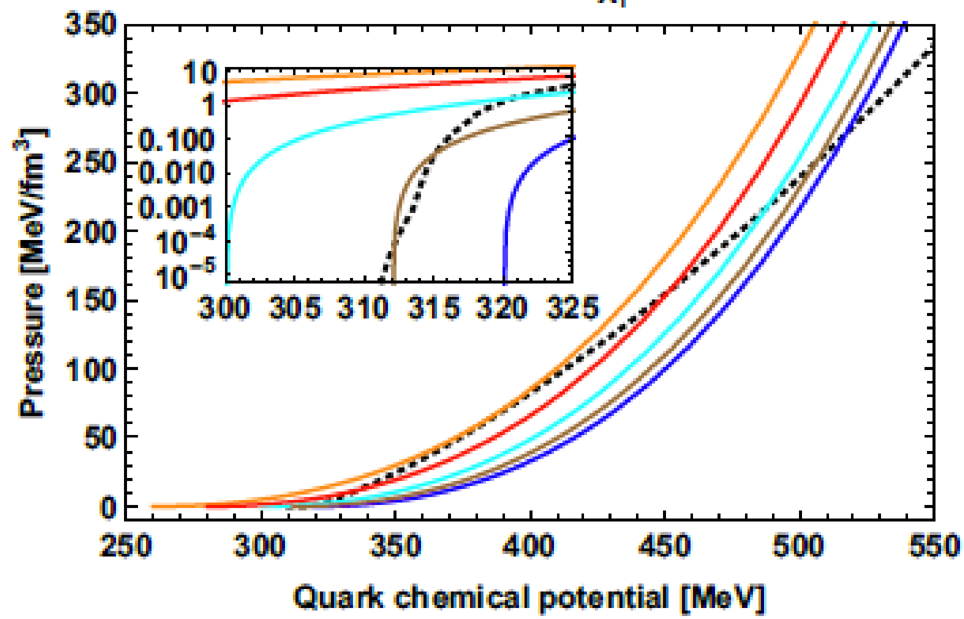
Holographic compact stars meet gravitational wave constraints

Eemeli Annala,[1,*] Christian Ecker,[2,†] Carlos Hoyos,[3,‡] Niko Jokela,[1,§]
David Rodríguez Fernández,[3,4,¶] and Aleksi Vuorinen[1,**]









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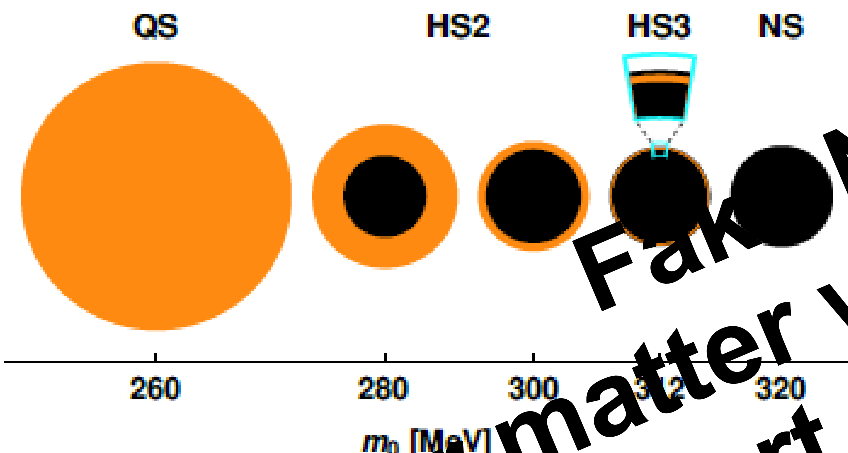
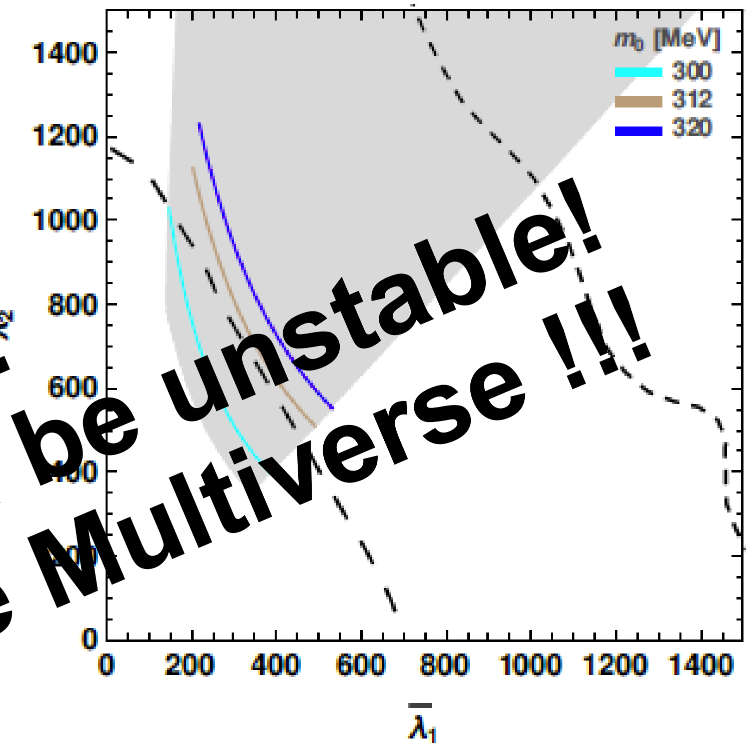
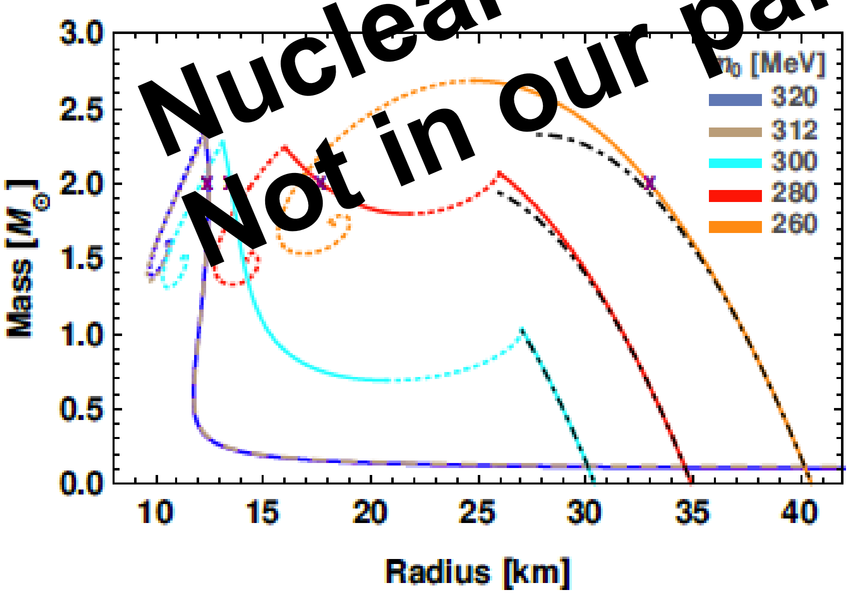
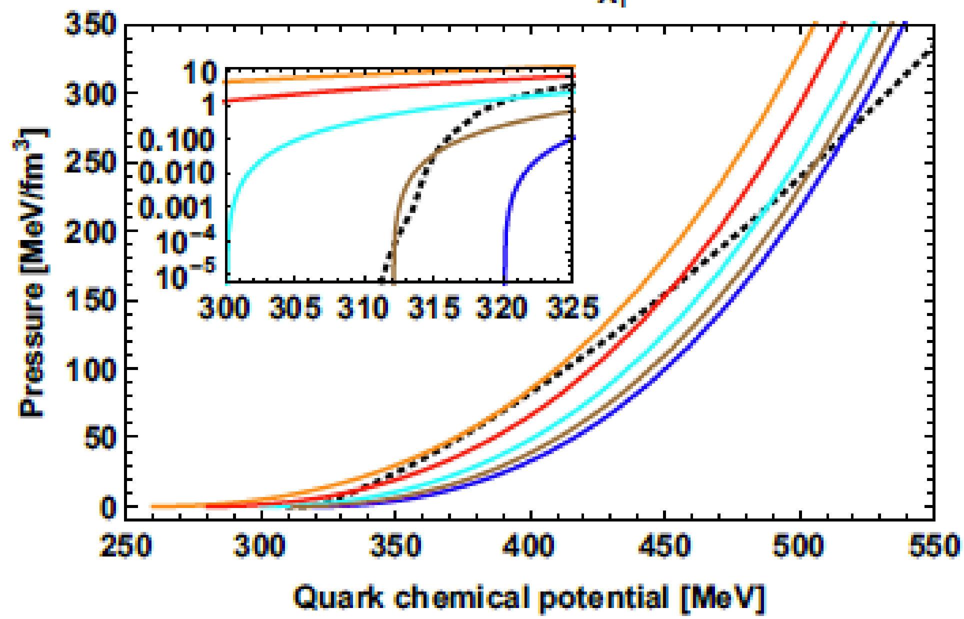




Fake News:
Nuclear matter would be unstable!
Not in our part of the Multiverse !!!





History: Third family & Nonidentical Twins

PHYSICAL REVIEW VOLUME 172, NUMBER 5 25 AUGUST 1968

Equation of State at Supranuclear Densities and the Existence of a Third Family of Superdense Stars*†

ULRICH H. GERLACH‡§
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey

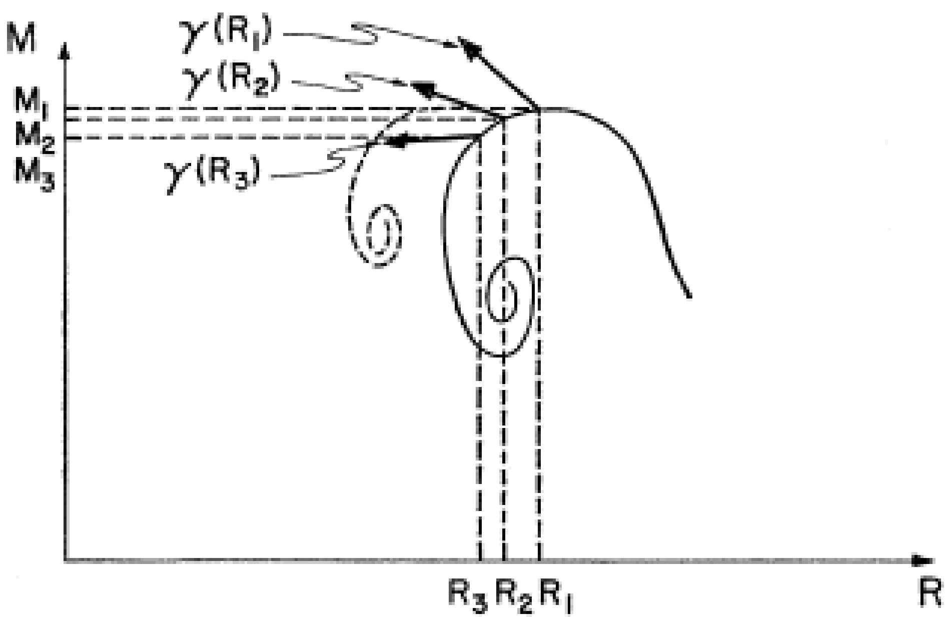
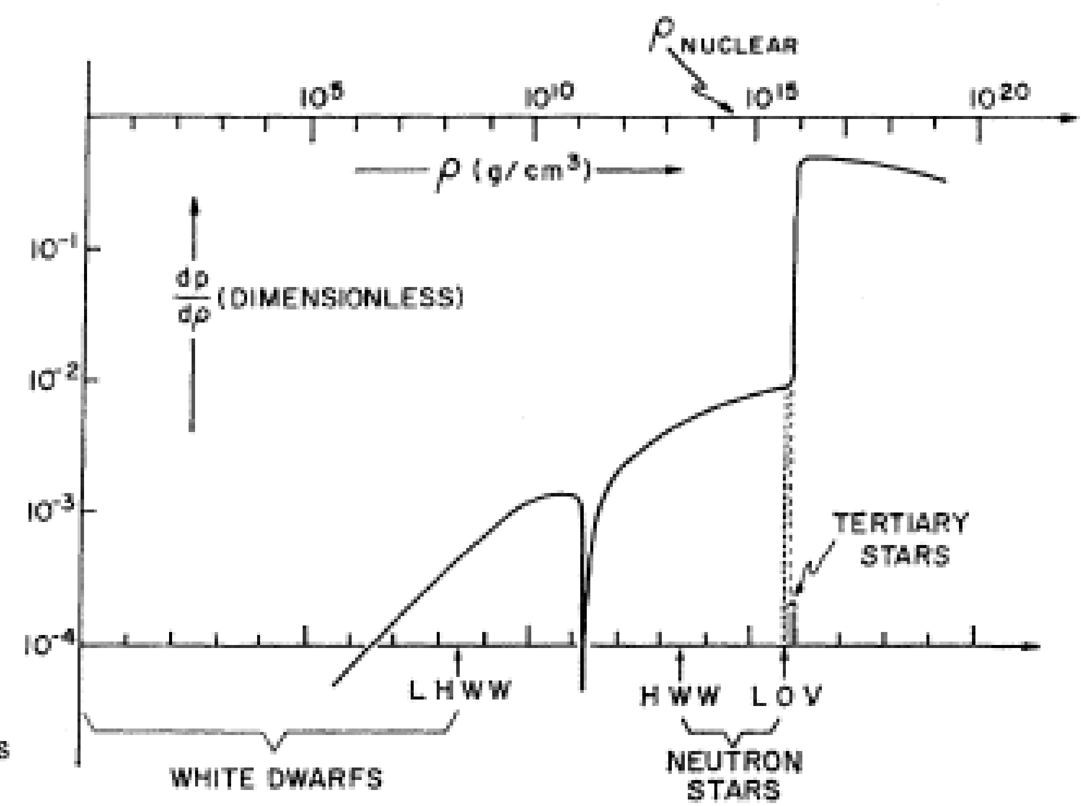


FIG. 3. A blow-up of the LOV maximum. The central densities



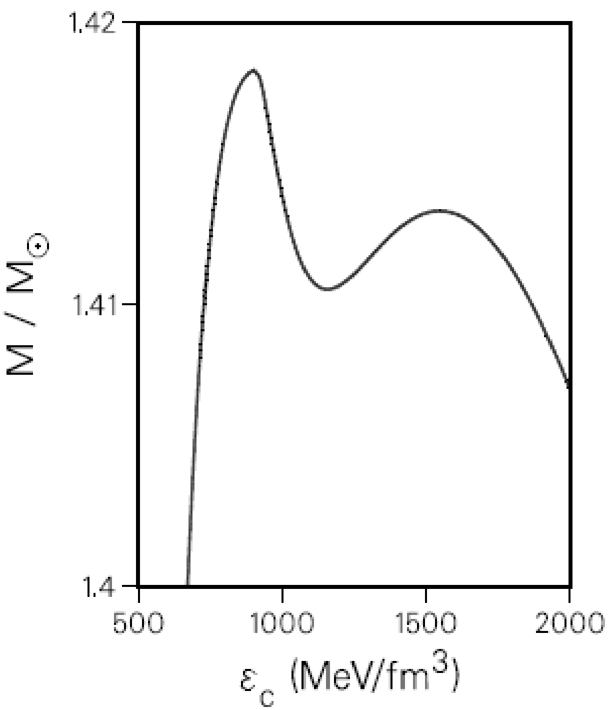
History: Third family & Nonidentical Twins

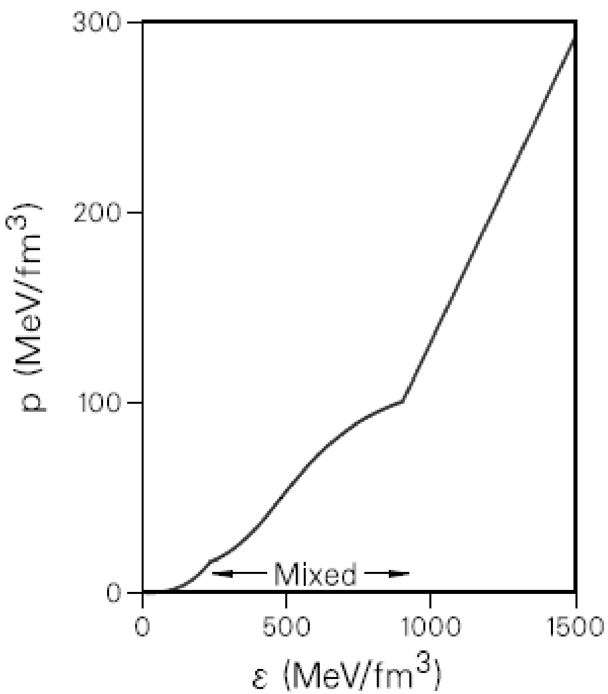
Non-Identical Neutron Star Twins

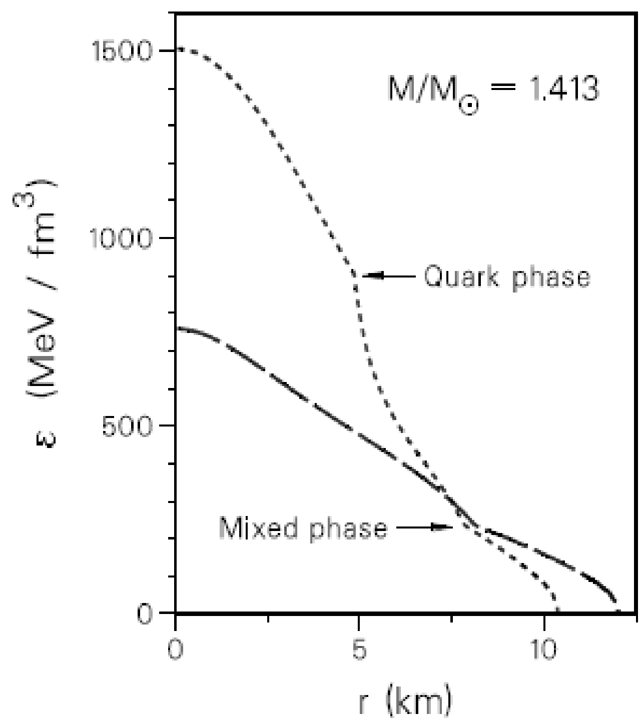
Norman K. Glendenning
Nuclear Science Division, Lawrence Berkeley National Laboratory,
University of California, Berkeley, CA 94720, USA

Christiane Kettner
Institut fuer theoretische Physik I, Universitaet Augsburg
Memmingerstr. 6, 86135 Augsburg
(June 17, 1998)

astro-ph/9807155; A&A (2000) L9

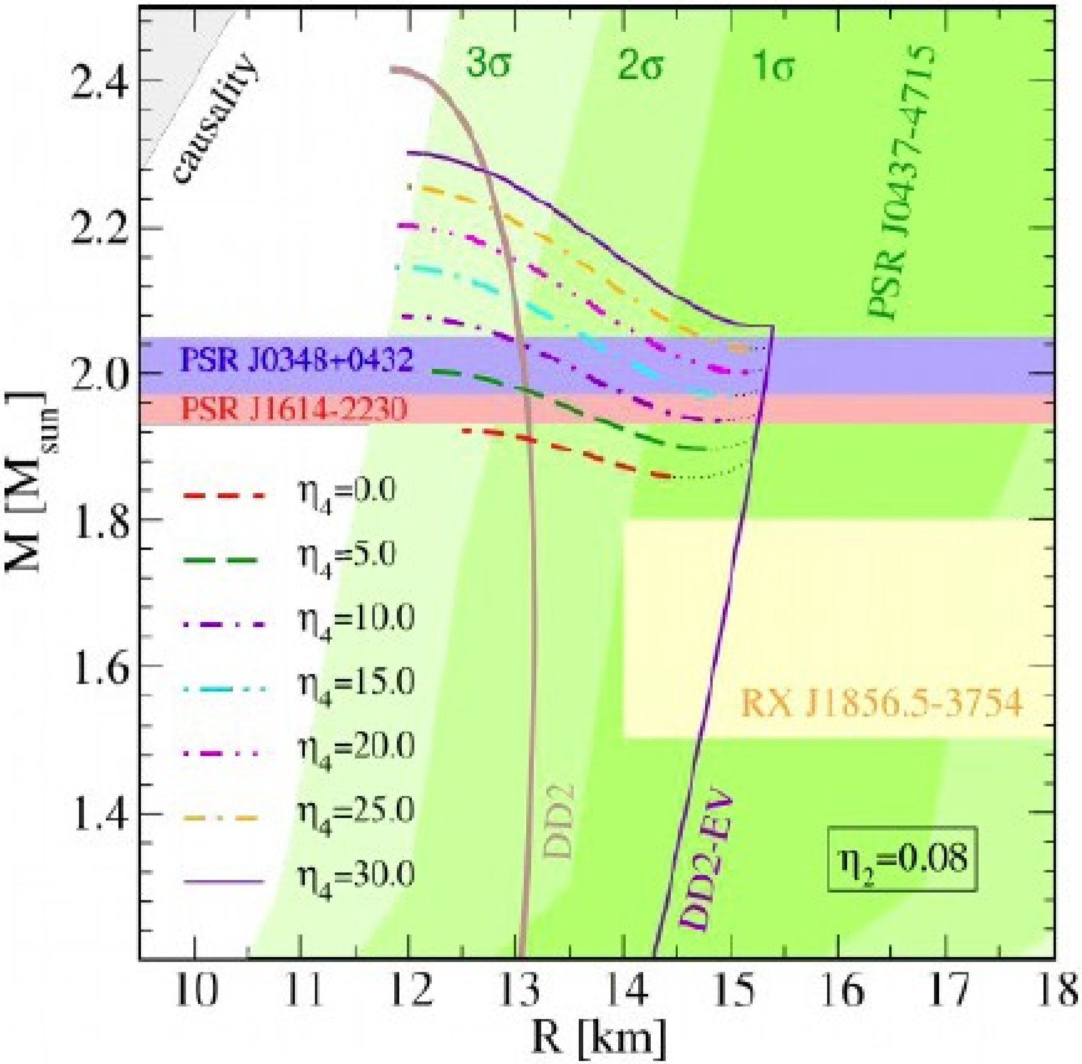




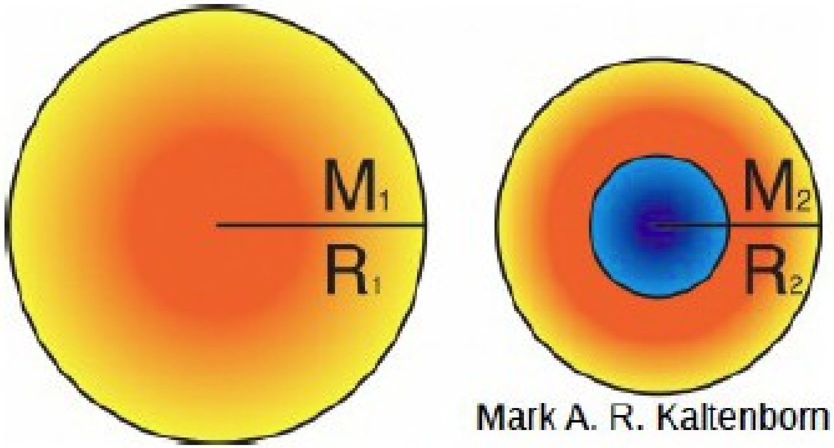


The original Twin paper uses Glendenning construction, not Maxwell one -
Surface tension zero vs. infty!
Pasta phases in-between ...

Neutron Star Interiors: Strong Phase Transition?



- Star configurations with same masses, but different radii

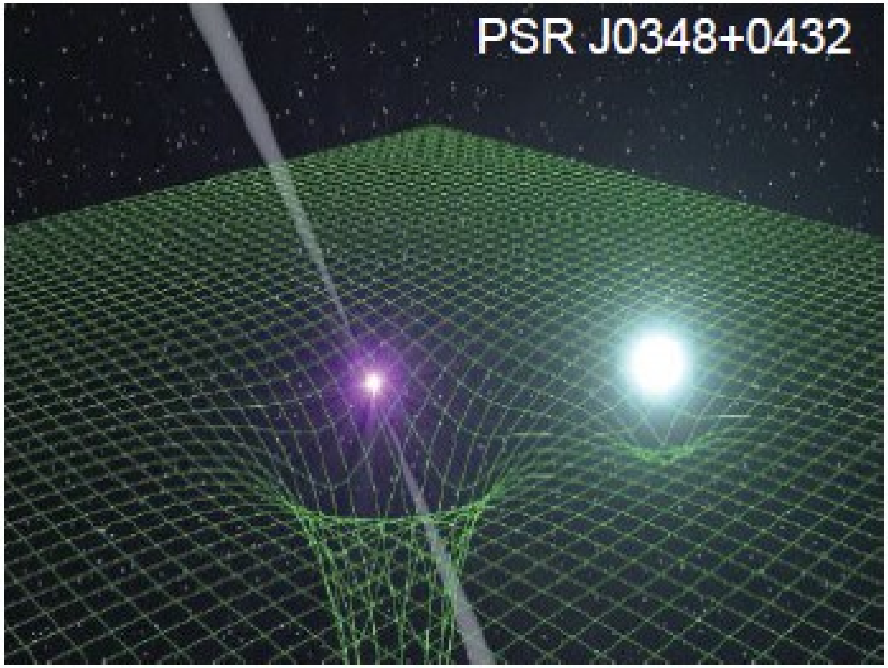


- **New class of EOS, that features high mass twins**
- NASA NICER mission: radii measurements ~ 0.5 km
- Existence of twins implies 1st order phase-transition and hence a critical point

Benic, Blaschke, Alvarez-Castillo, Fischer, Typel, A&A 577, A40 (2015)

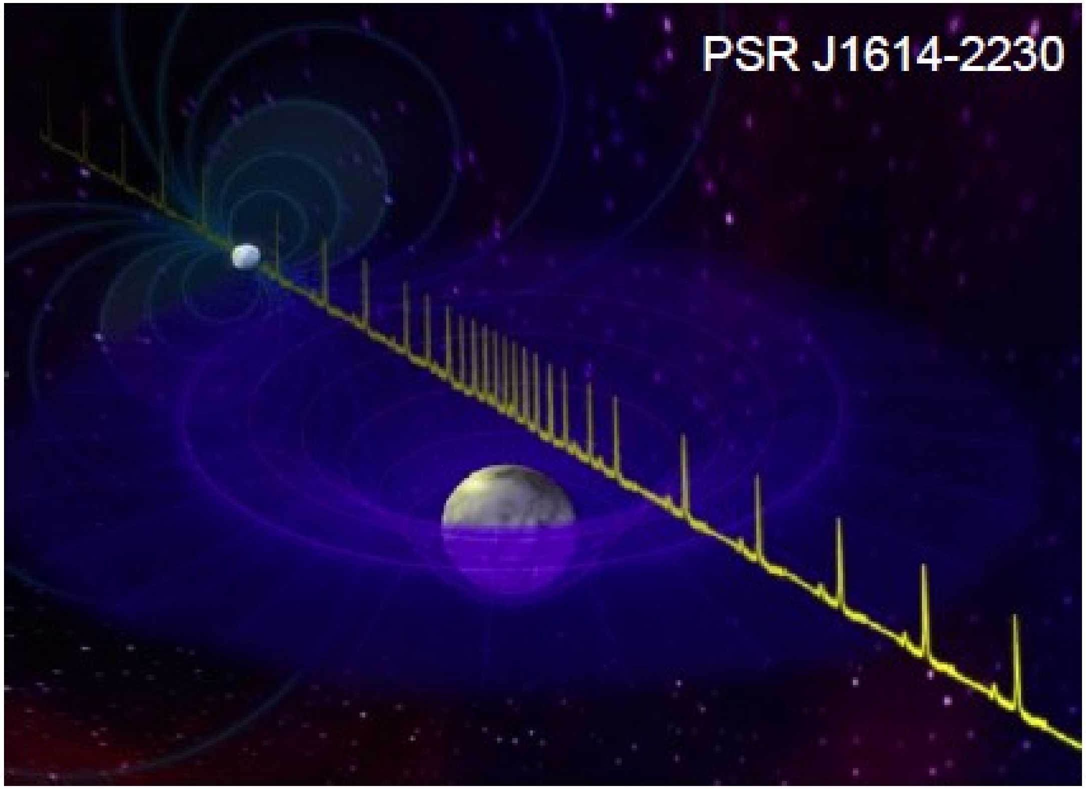
Neutron Star Interiors: Strong Phase Transition?

M=2.01 +/- 0.04 Msun



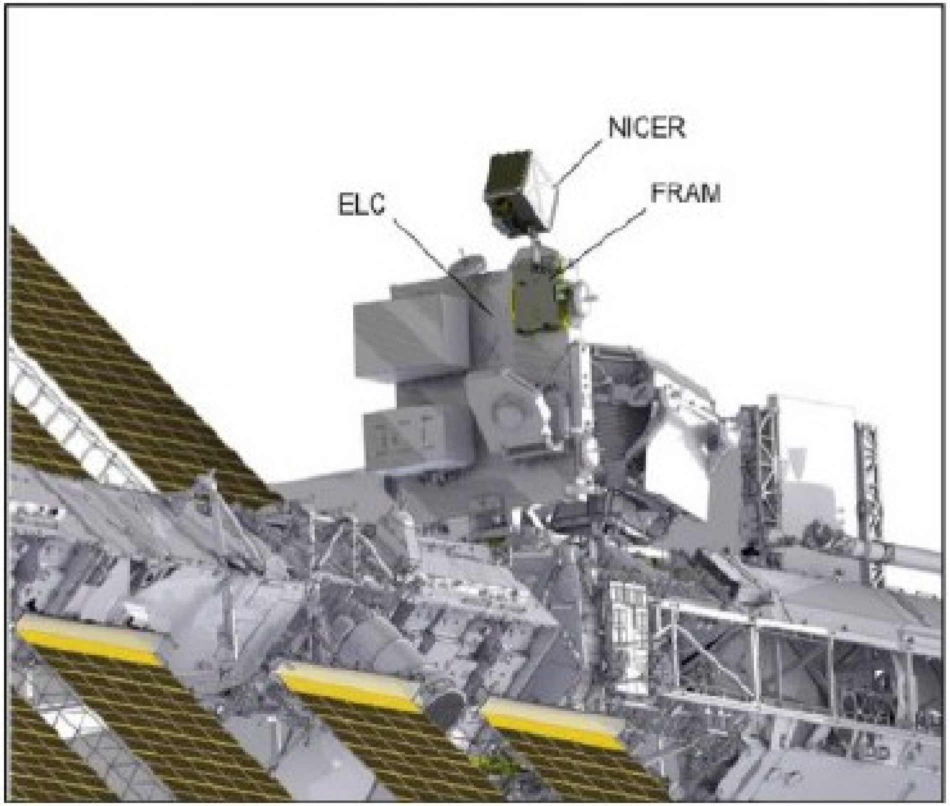
Antoniadis et al., Science 340 (2013) 448
Demorest et al., Nature 467 (2010) 1081
Fonseca et al., arxiv:1603.00545

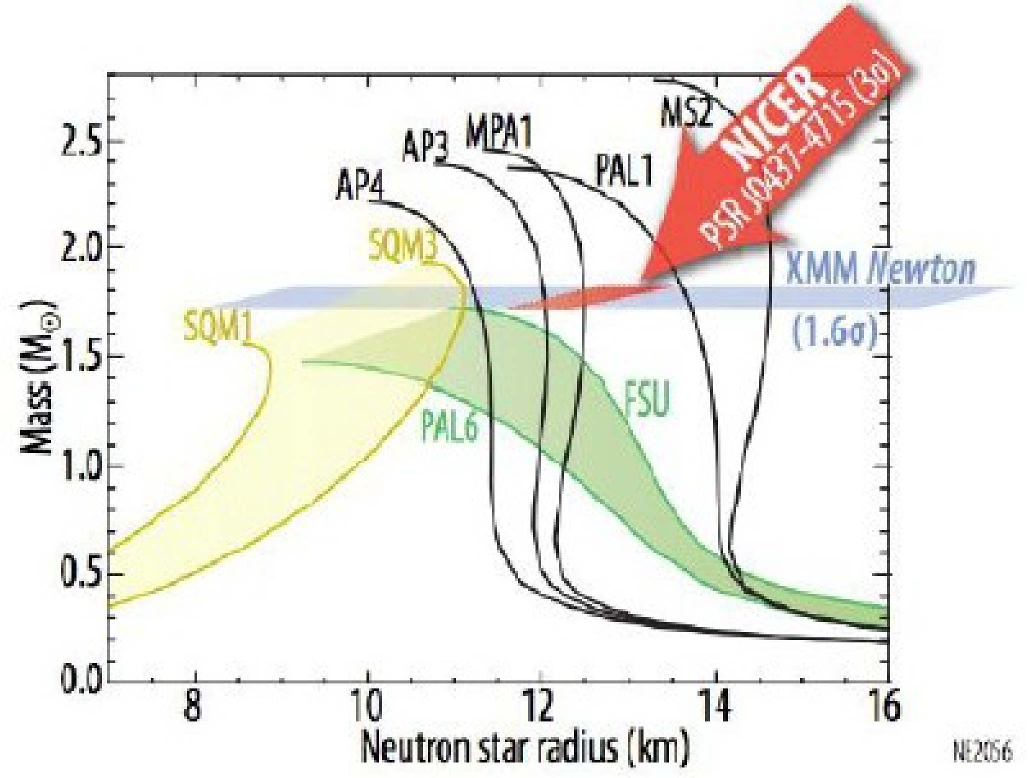
M=1.928 +/- 0.017 Msun



What if they were high-mass twin stars?

→ radius measurement required ! → NICER (2017)

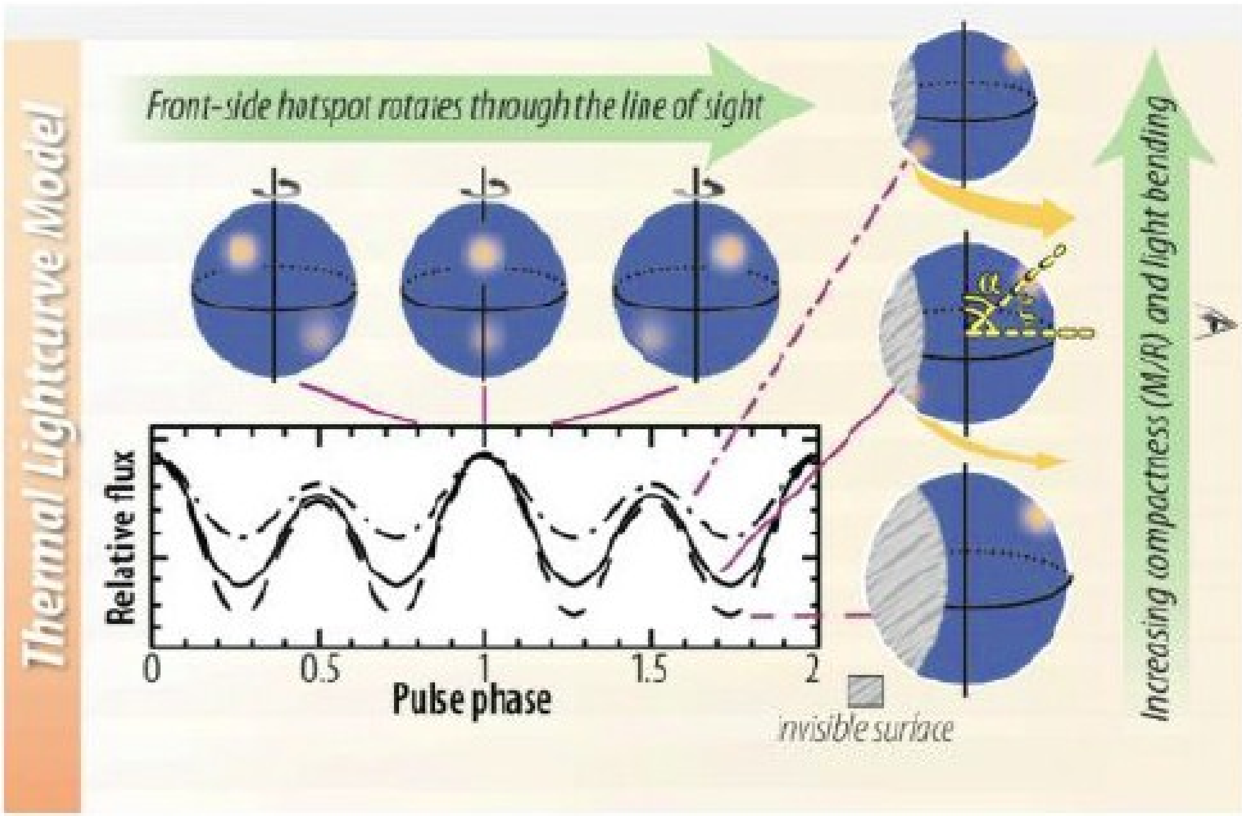


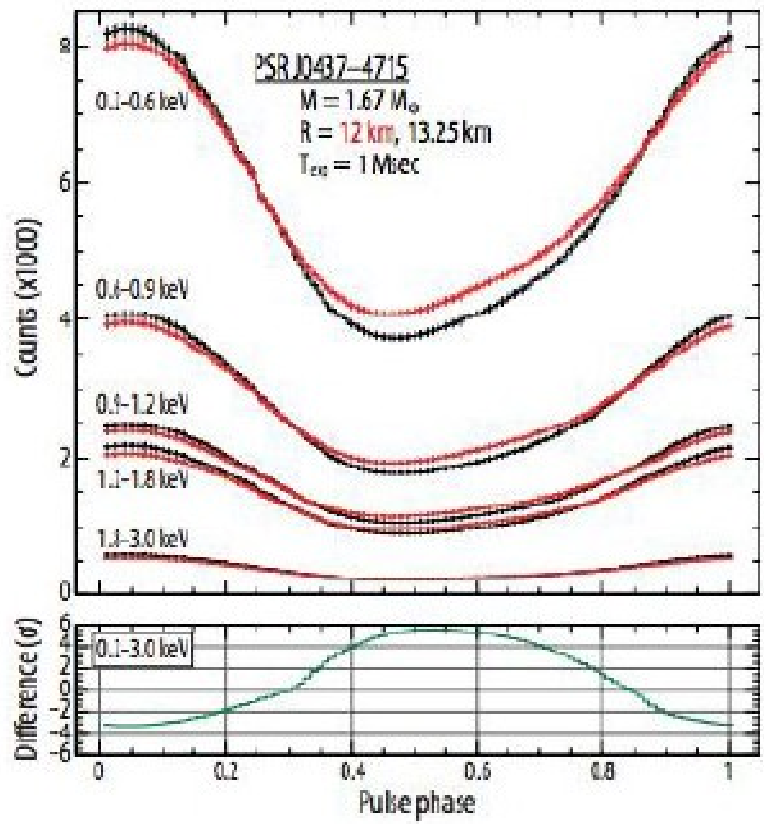


NICER 2017

Gendreau, K. C., Arzoumanian, Z., & Okajima, T. 2012, Proc. SPIE, 8443, 844313

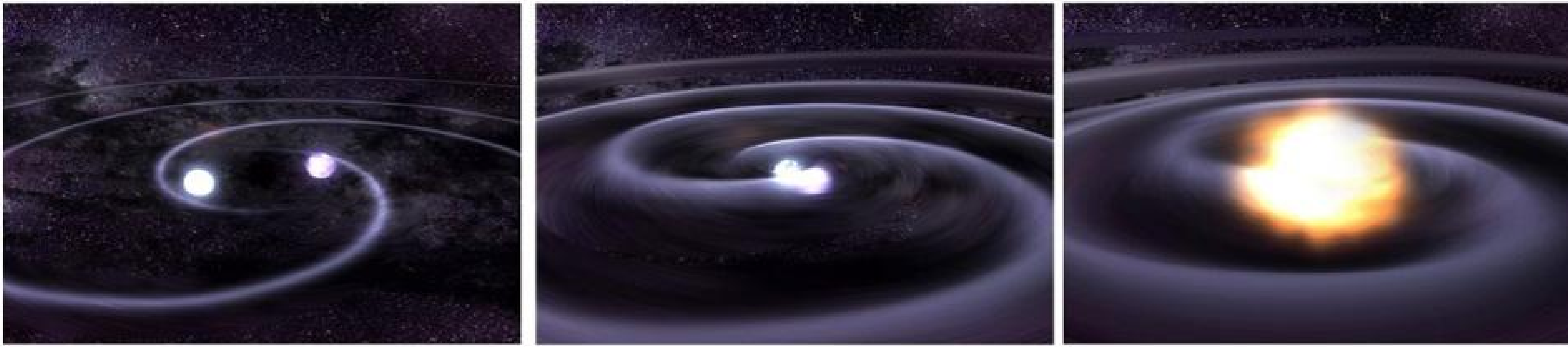

NICER
Neutron star Interior Composition ExploreR

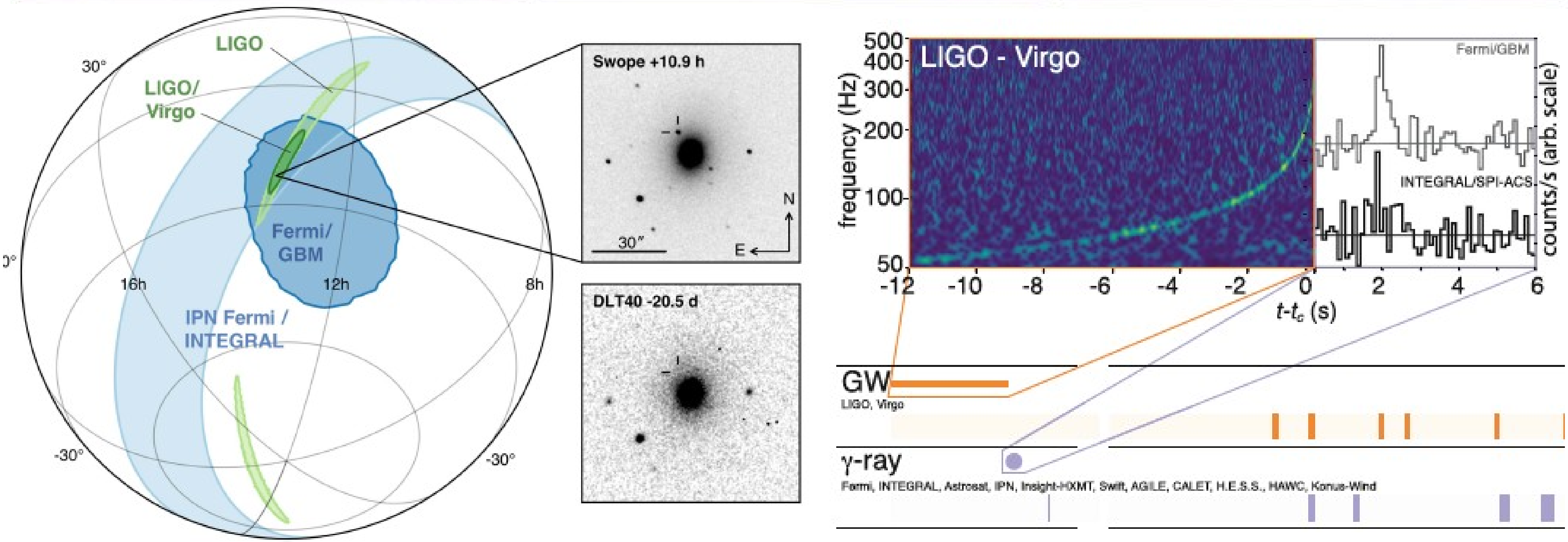

Thermal Lightcurve Model
Front-side hotspot rotates through the line of sight
Increasing compactness (M/R) and light bending
Relative flux
Pulse phase
0
0.5
1
1.5
2
invisible surface


PSR J0437−4715
M = 1.67 M⊙
R = 12 km, 13.25 km
0.1–0.6 keV
0.6–0.9 keV
0.9–1.2 keV
1.2–1.8 keV
1.8–3.0 keV
Counts (x1000)
Difference (σ)
0.1–3.0 keV
Pulse phase

Hot Spots

Mass-Radius Constraints: GW170817 & NICER





GW170817, announced on 16.10.2017

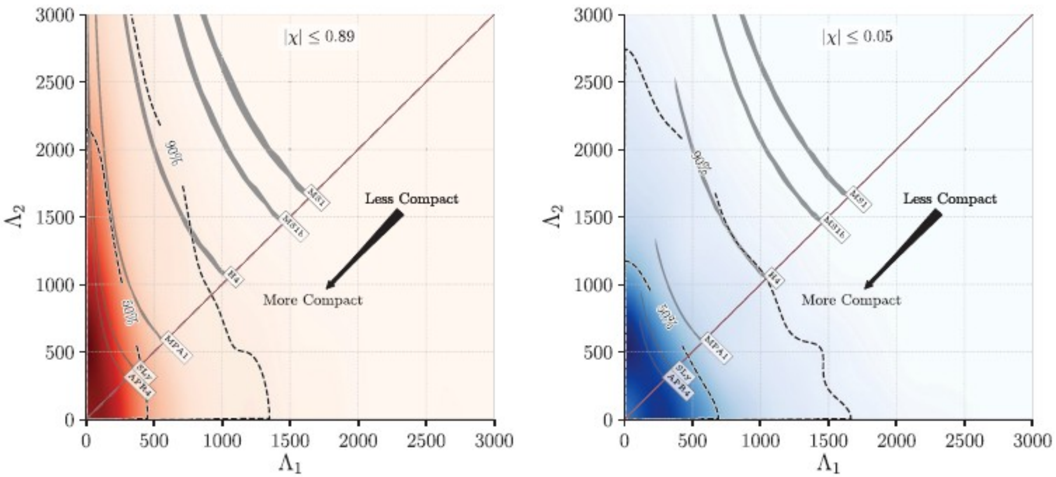
B.P. Abbott et al. [LIGO/Virgo Collab.], PRL 119, 161101 (2017); ApJLett 848, L12 (2017)

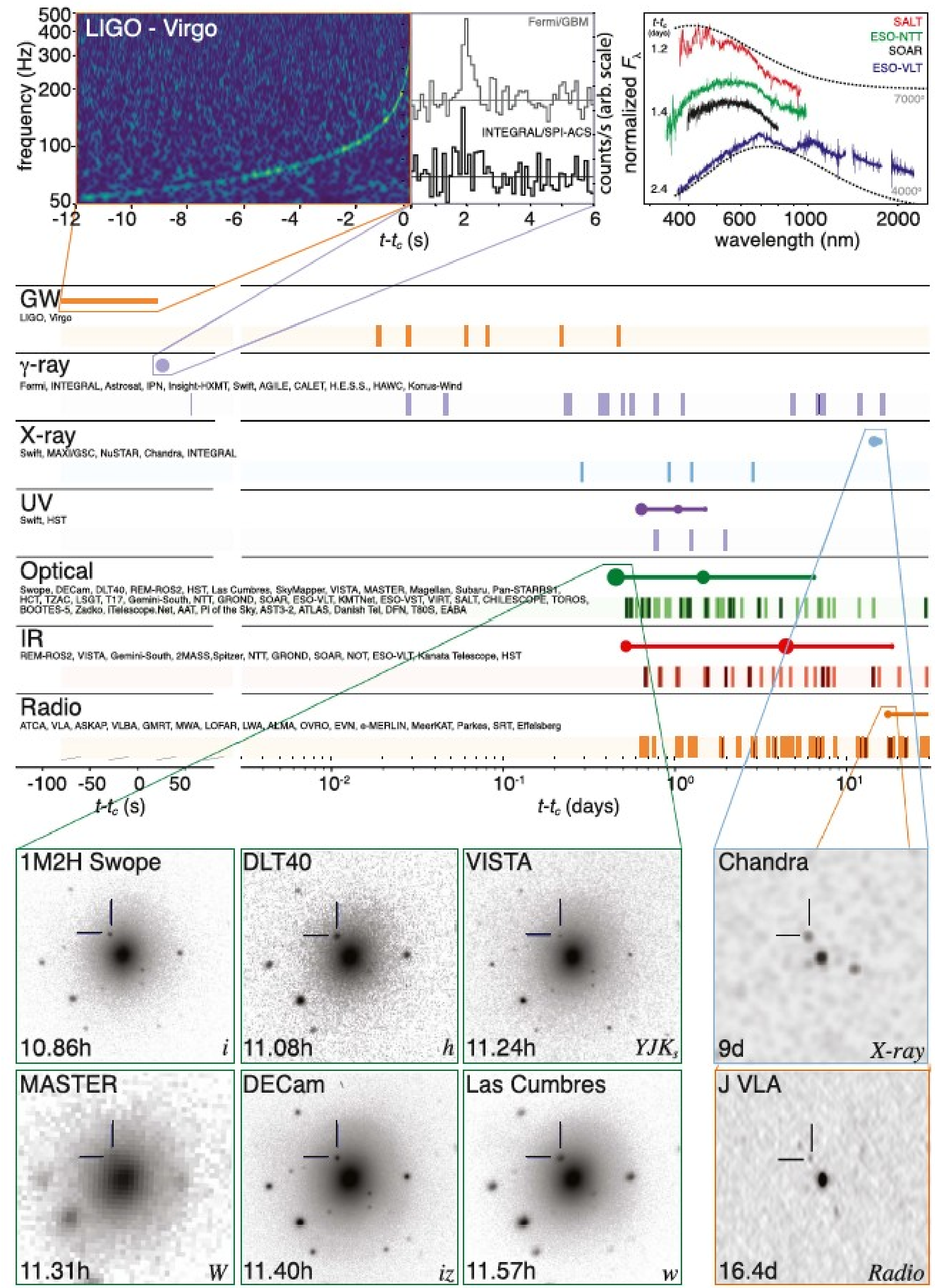
GW170817: NS-NS Merger

Multi-Messenger Astrophysics !!

M < 2.17 M_sun (arxiv:1710.05938)

	Low-spin priors ($|\chi| \leq 0.05$)
Primary mass m_1	$1.36–1.60\ M_\odot$
Secondary mass m_2	$1.17–1.36\ M_\odot$
Chirp mass $\mathcal{M}$	$1.188^{+0.004}_{-0.002} M_\odot$
Mass ratio m_2/m_1	0.7–1.0
Total mass $m_{\rm tot}$	$2.74^{+0.04}_{-0.01} M_\odot$
Radiated energy $E_{\rm rad}$	$> 0.025 M_\odot c^2$
Luminosity distance $D_{\rm L}$	40^{+8}_{-14} Mpc





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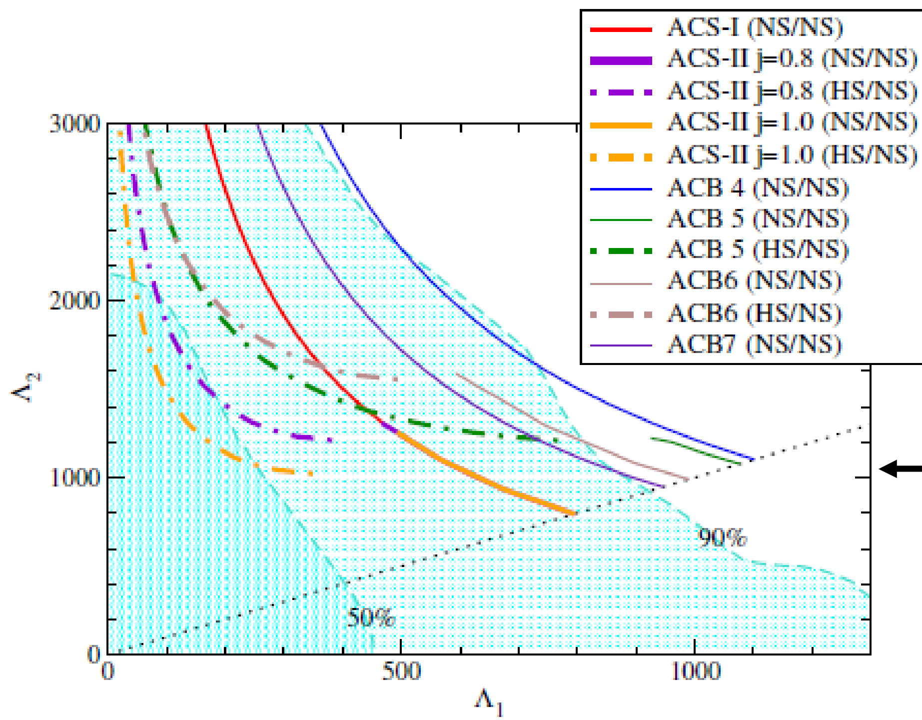
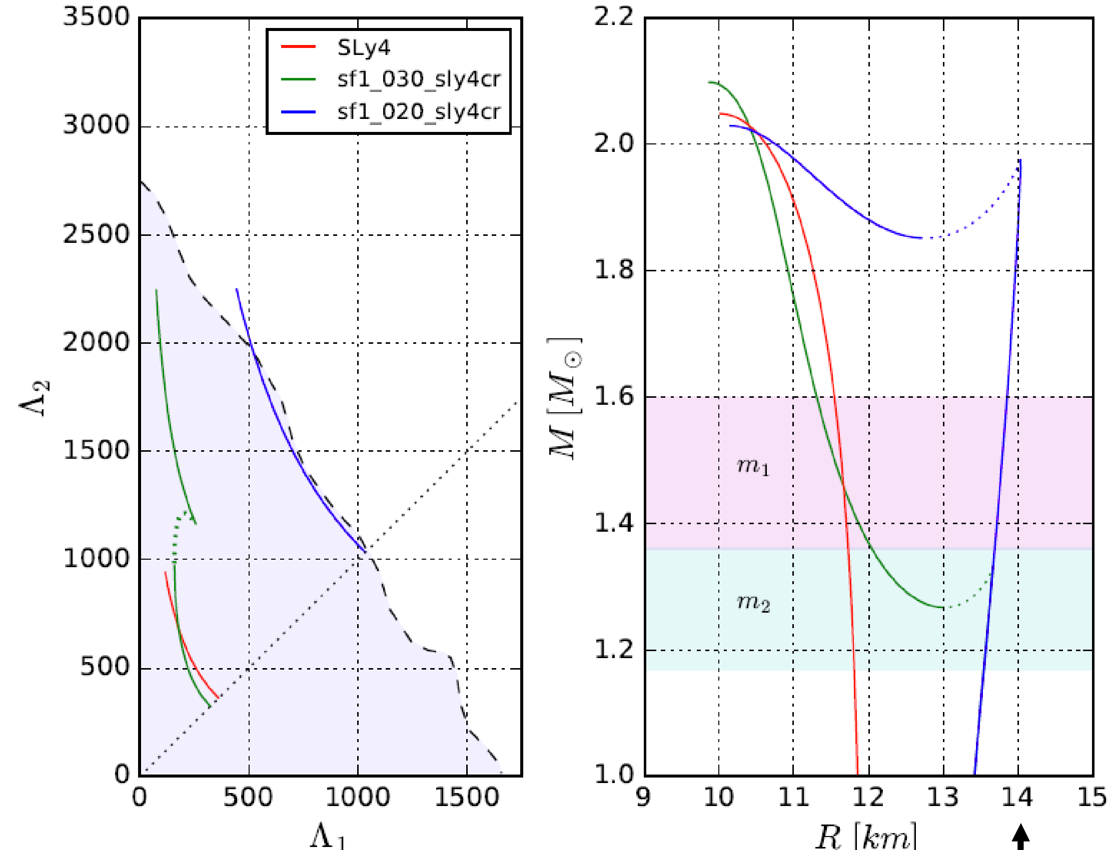




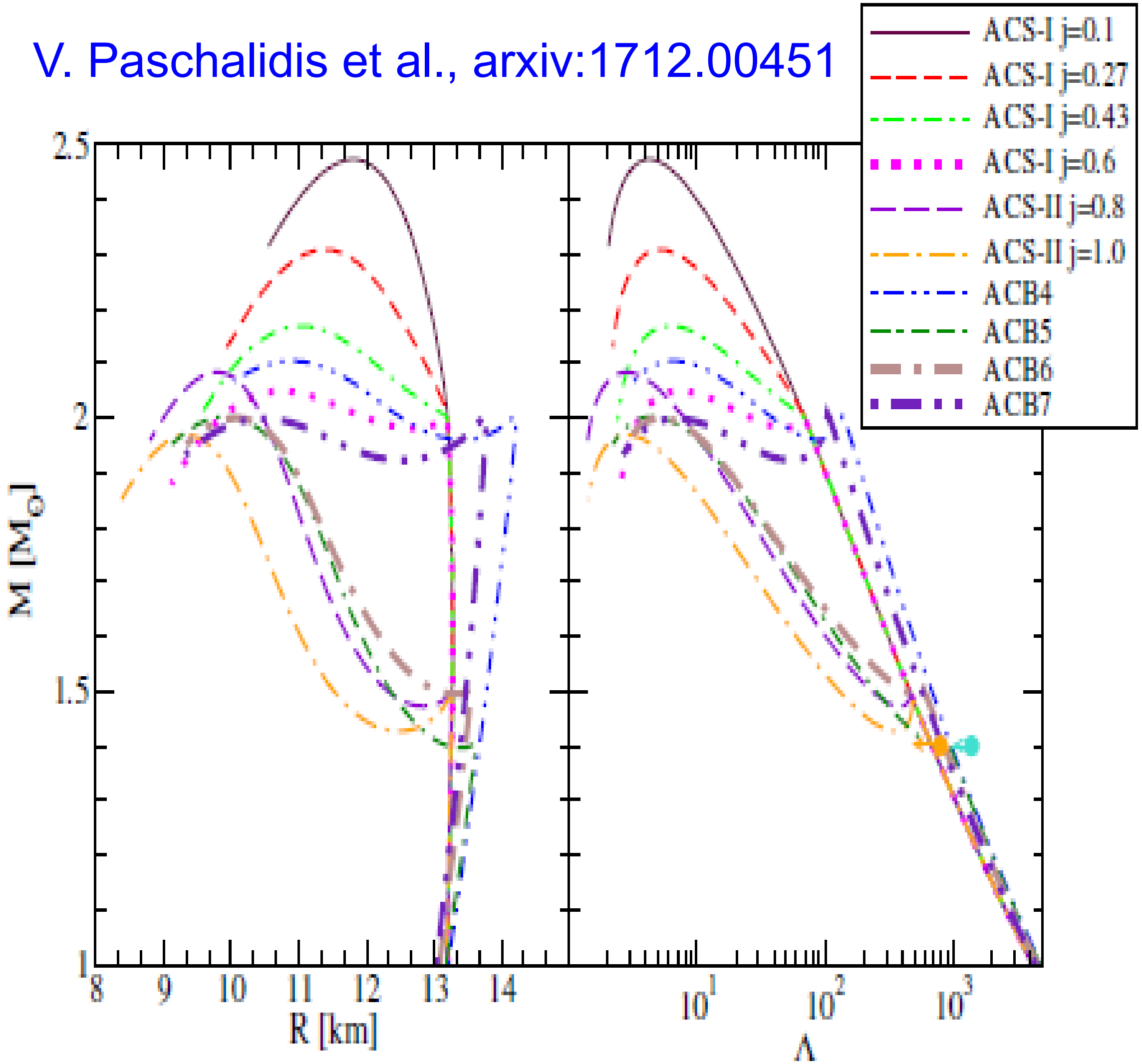
M. Bejger, D.B., et al., in preparation (2017)

V. Paschalidis, K. Yagi, D. Alvarez-Castillo, D.B., A. Sedrakian, arxiv:1712.00451 (2017)

Suggestion: The heavier NS be a hybrid star (HS) with a quark core, evtl. member of a “third family”!

Neutron Star Interiors: Strong Phase Transition? M-R Relation!

V. Paschalidis et al., arxiv:1712.00451



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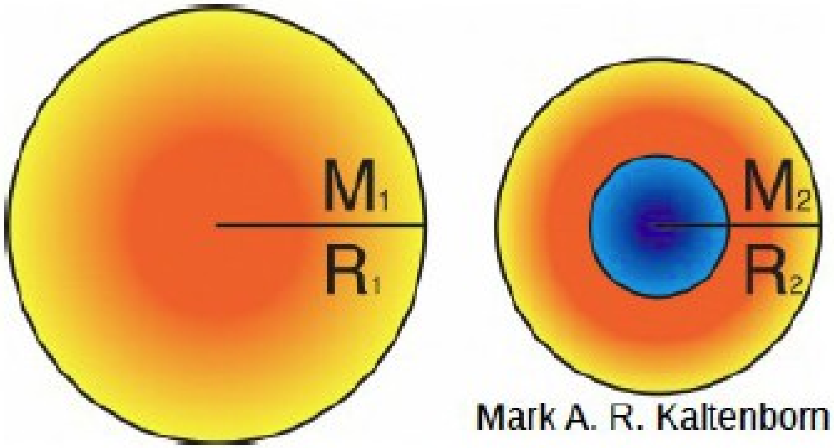


- **New class of EOS, that features high mass twins**
- NASA NICER mission: radii measurements ~ 0.5 km
- Existence of twins implies 1st order phase-transition and hence a critical point

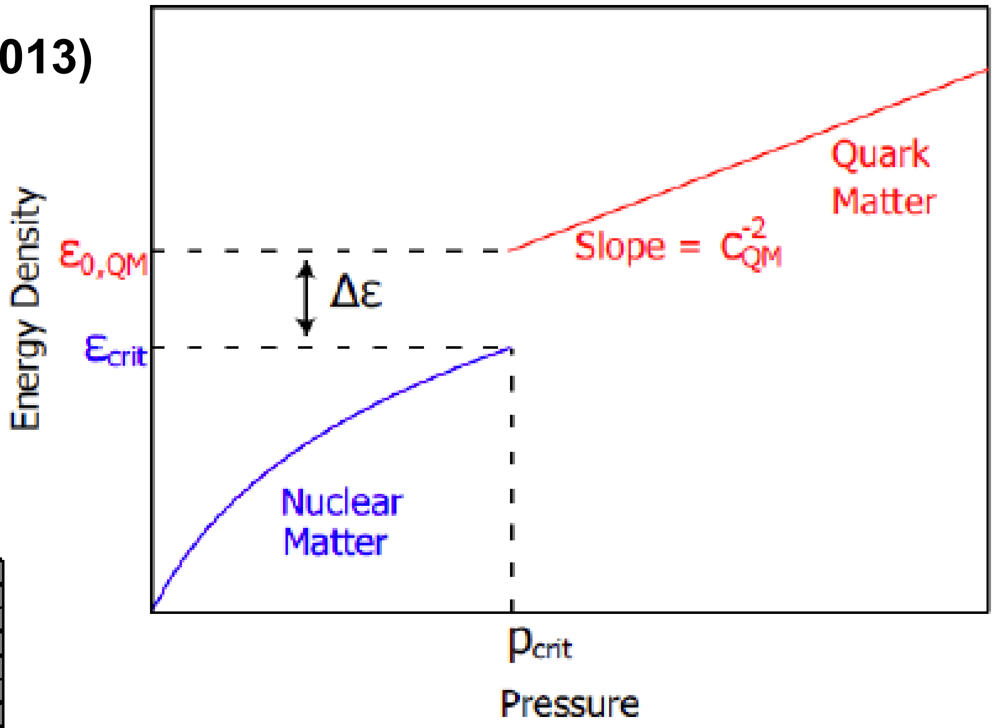
High-mass twins (HMT) or typical-mass twins (TMT) ?

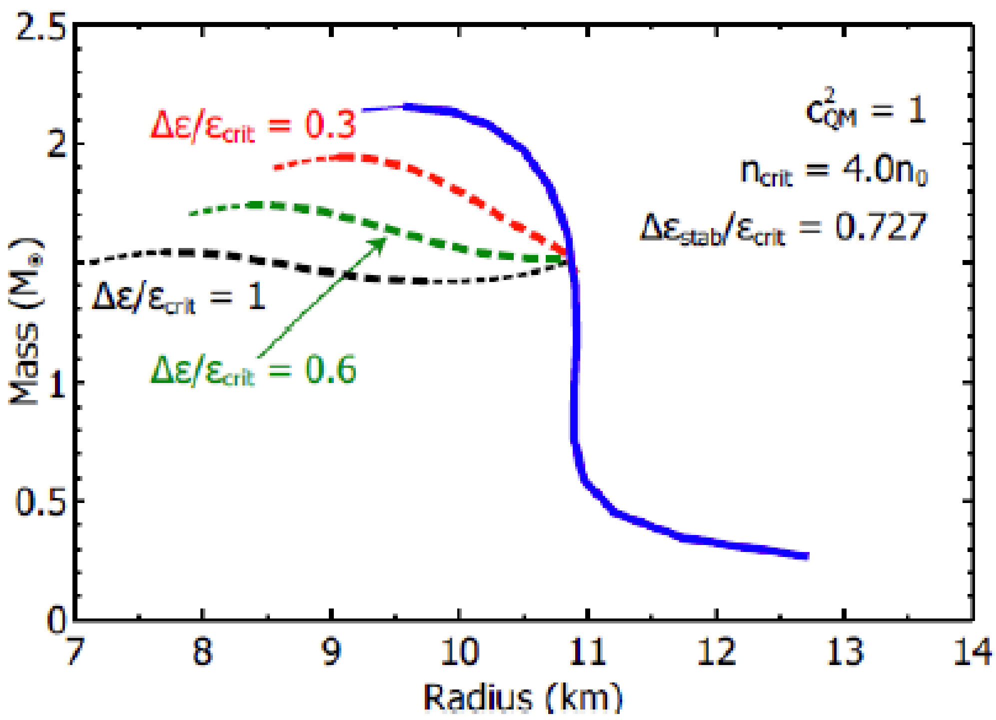
For a classification see: J.-E. Christian, A. Zacchi, J. Schaffner-Bielich, arxiv:1707.07524

2.1 Constant Speed of Sound (CSS) Model

Alford, Han, Prakash, PRD88, 013083 (2013)

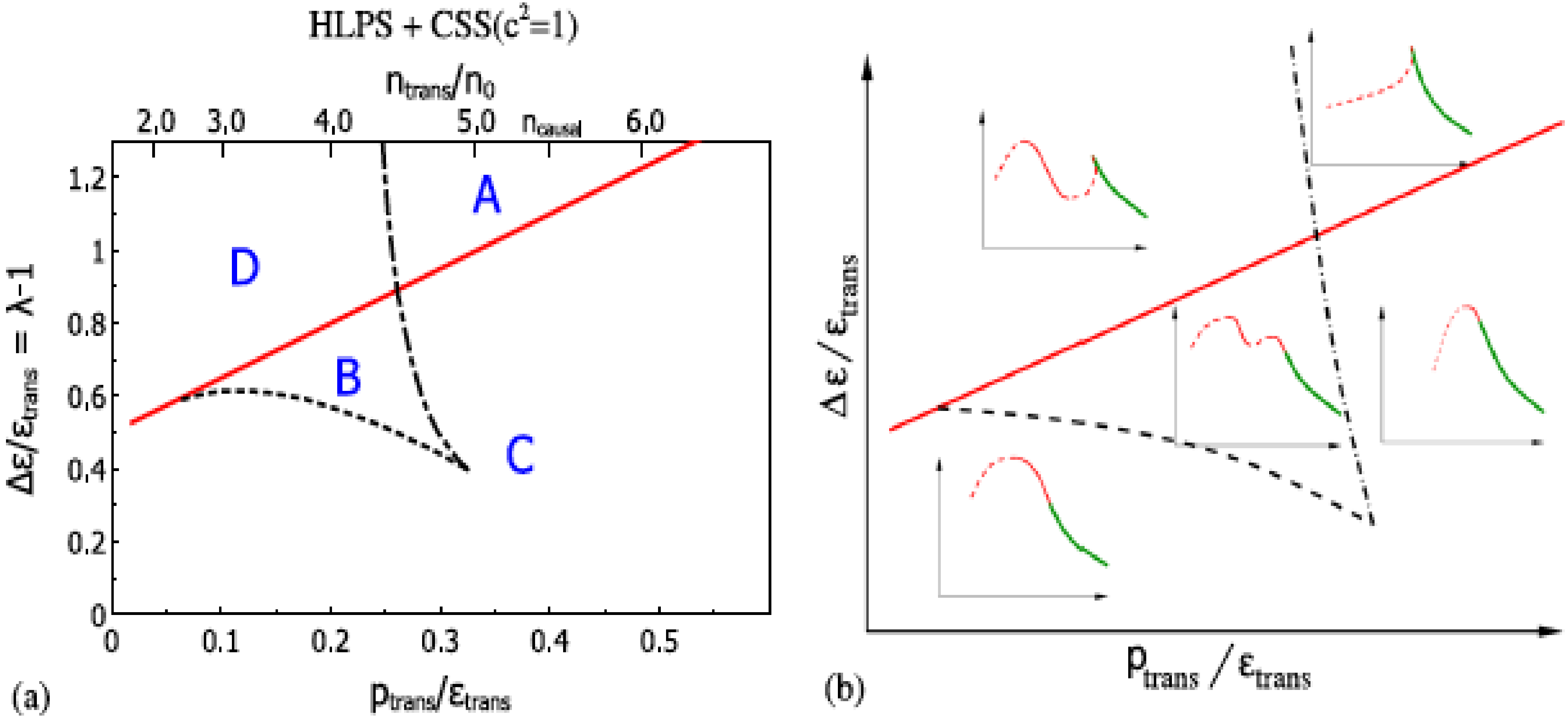
First order PT can lead to a stable branch of hybrid stars with quark matter cores which, depending on the size of the "latent heat" (jump in energy density), can even be disconnected from the hadronic one by an unstable branch → **"third family of CS"**.





Measuring two **disconnected populations** of compact stars in the M-R diagram would be the **detection of a first order phase transition** in compact star matter and thus the indirect proof for the existence of a **critical endpoint (CEP) in the QCD phase diagram**!

Key fact: Mass “twins” ↔ 1st order PT



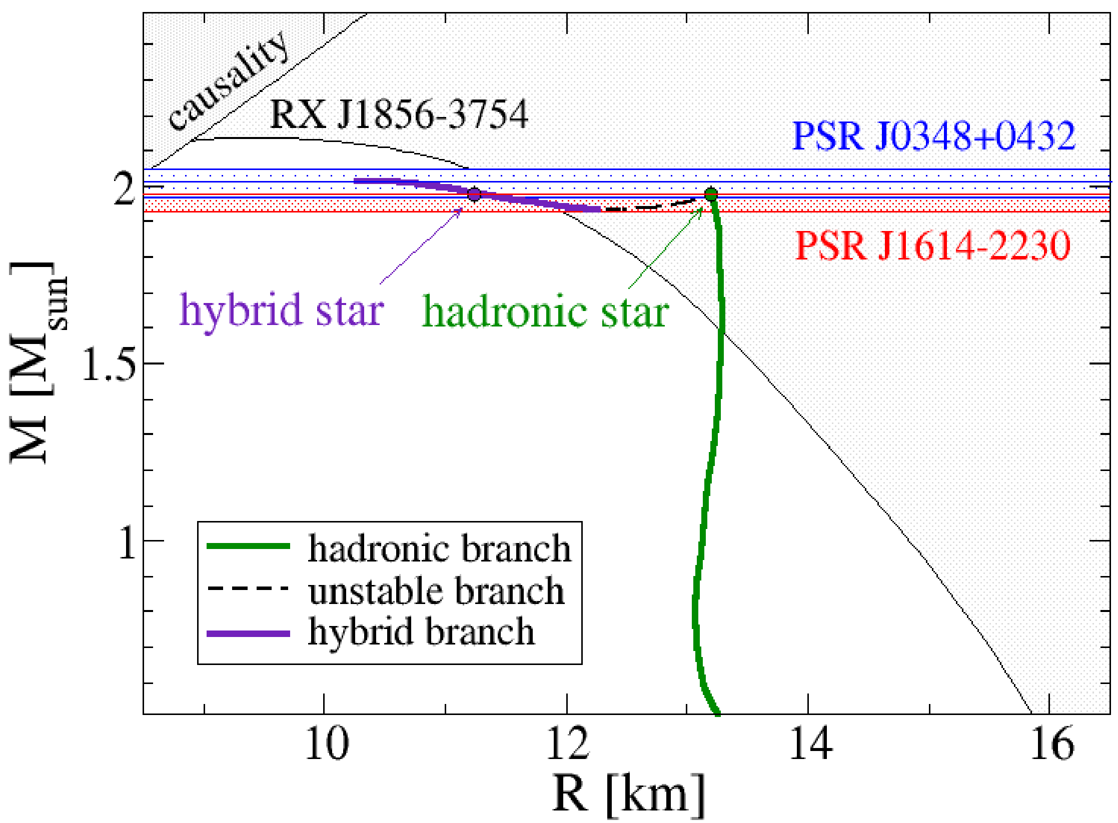
Systematic Classification [Alford, Han, Prakash: PRD88, 083013 (2013)]

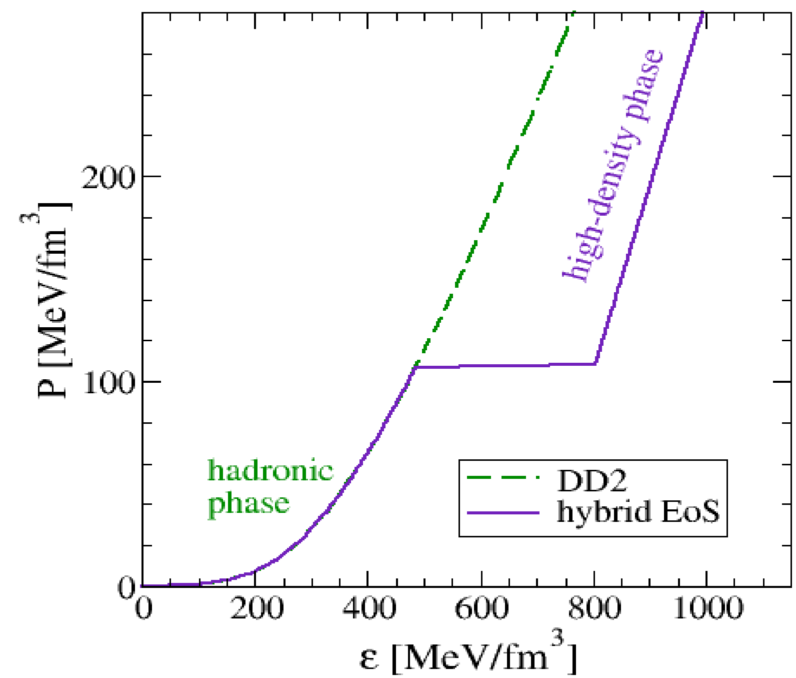
EoS P(ε) <--> Compact star phenomenology M(R)

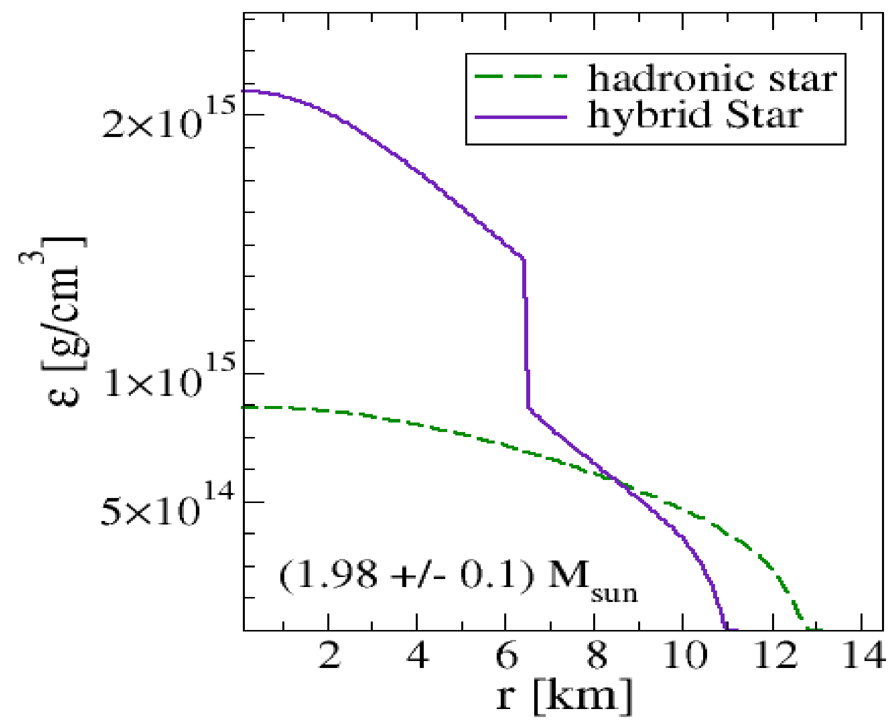
Most interesting and clear-cut cases: (D)isconnected and (B)oth – high-mass twins!

"Holy Grail" - High-Mass Twin Stars

Twins prove exitence of **disconnected populations** (third family) in the M-R diagram
Consequence of a **first order phase transition**
Question: Do twins prove the 1st order phase trans.?







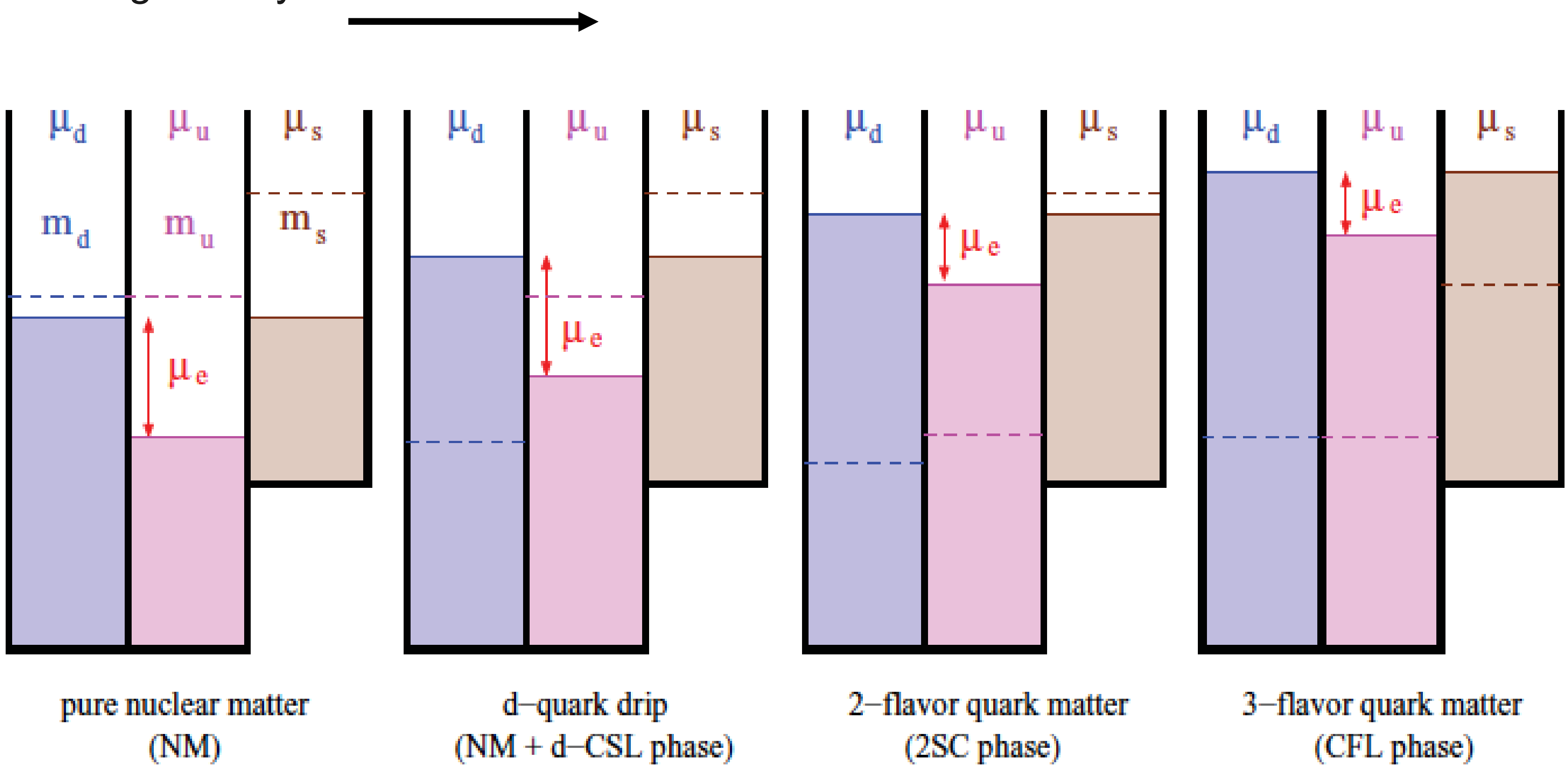
Alvarez & Blaschke, arxiv:1304.7758

Neutron Star Interiors: Sequential Phase Transitions?

How likely is it that s-quarks (and no s-bar) exist and survive in neutron stars in a QGP or in hyperons. How large is then the ratio s/(u+d) in neutron stars and in the Universe?

There could also be single flavor quark matter, mixed with nuclear matter (d-quark dripline)

Increasing density



D.B., F. Sandin, T. Klaehn, J. Berdermann, PRC 80 (2009) 065807

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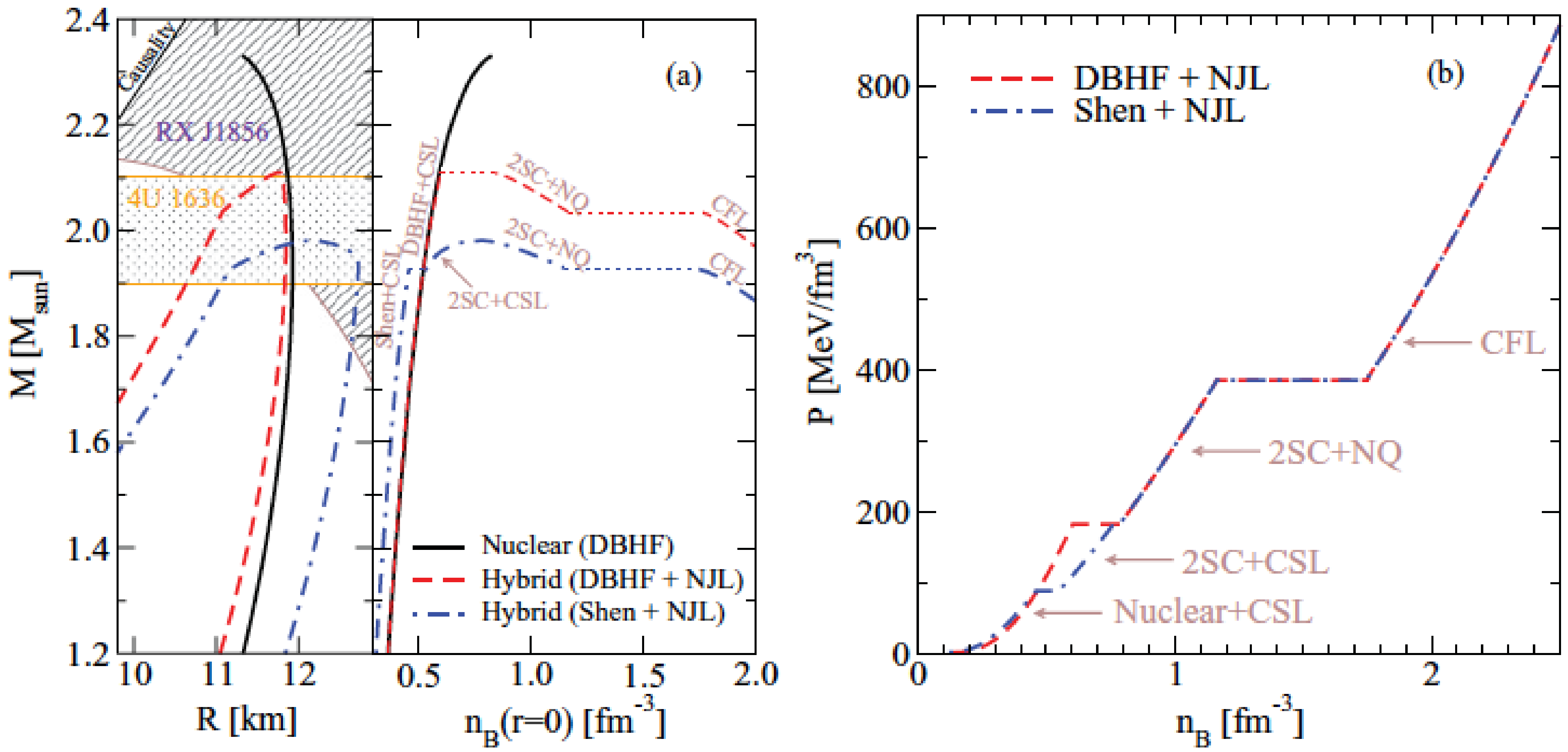
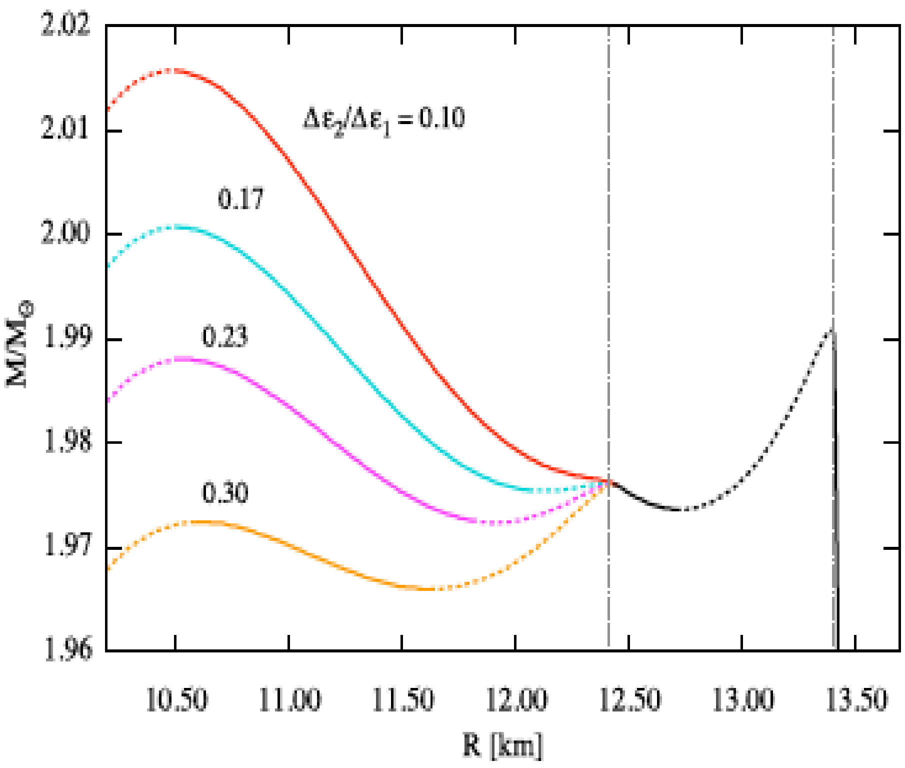
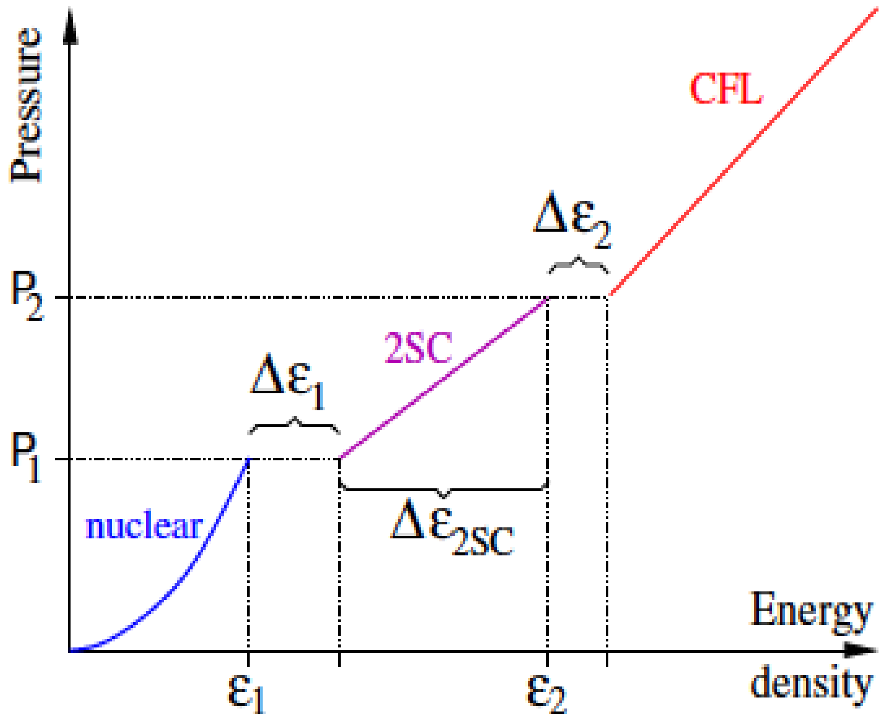


D.B., F. Sandin, T. Klaehn, J. Berdermann, PRC 80 (2009) 065807

Neutron Star Interiors: Sequential Phase Transitions?

Measuring Mass vs. Radius ⟷ Equation of state



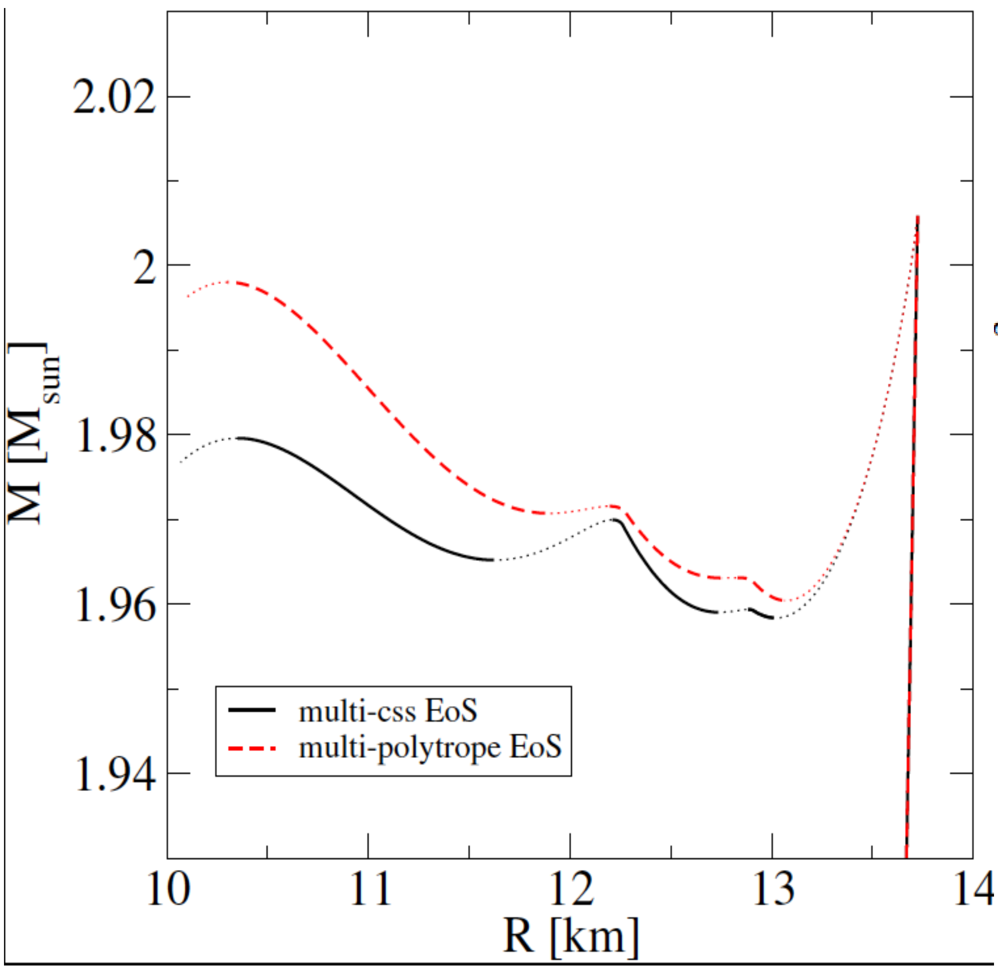


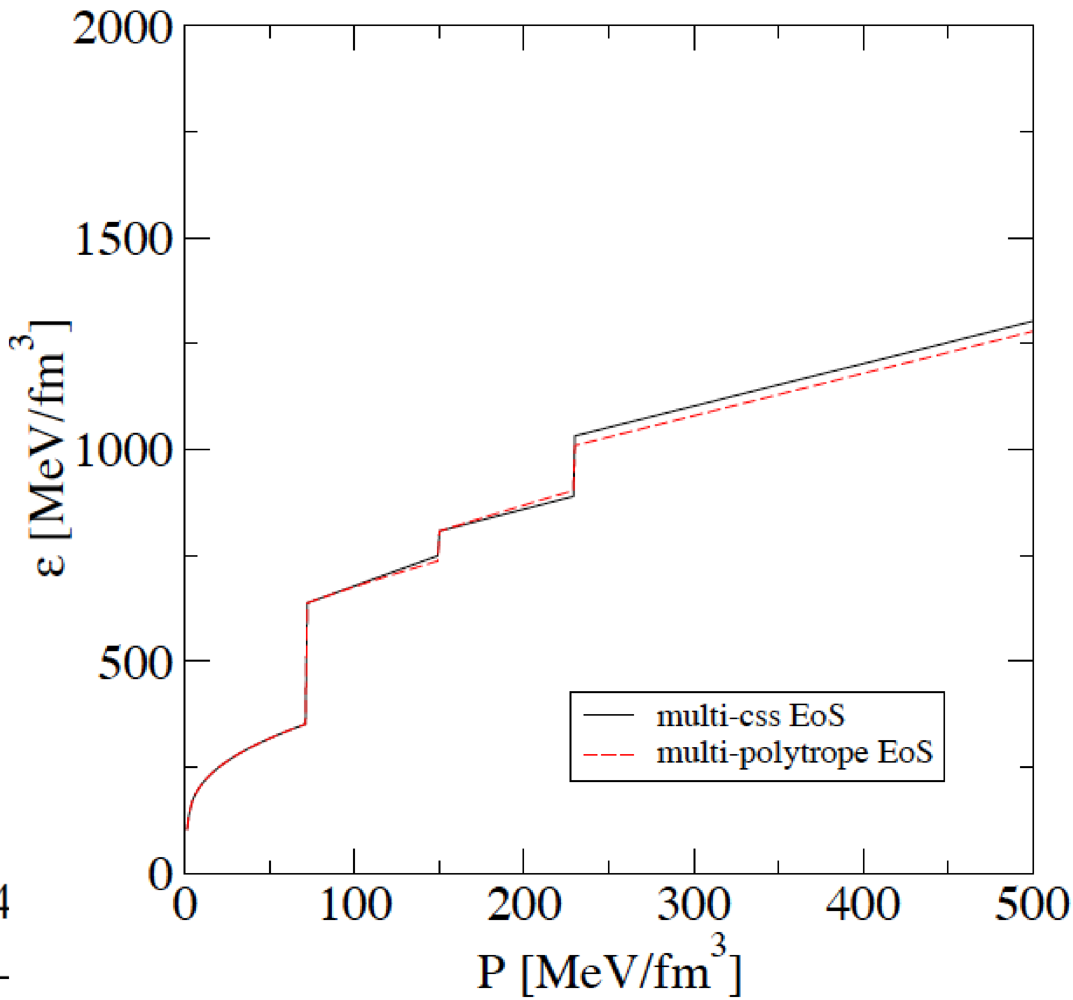
High-mass twins:
D. Blaschke et al., PoS CPOD 2013
S. Benic et al., A&A 577 (2015) A50

High-mass triples and fourth family:
M. Alford and A. Sedrakian, arxiv:1706.01592
PRL 119 (2017)

Neutron Star Interiors: Sequential Phase Transitions?

Measuring Mass vs. Radius ⟷ Equation of state





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S. Benic et al., A&A 577 (2015) A50

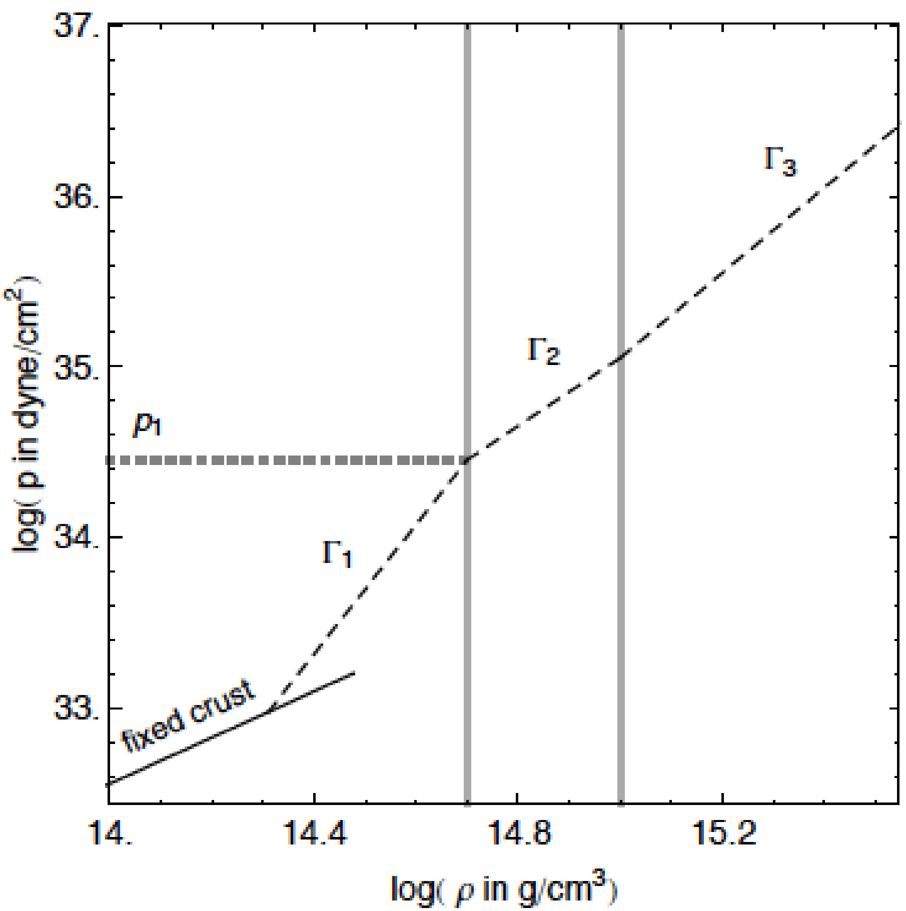
High-mass triples and fifth family:
A. Ayriyan, D.B., H. Grigorian, in preparation (2017)

3. Piecewise polytrope EoS – high mass twins (HMT)?

J. Read et al., PRD 79, 124032 (2009)

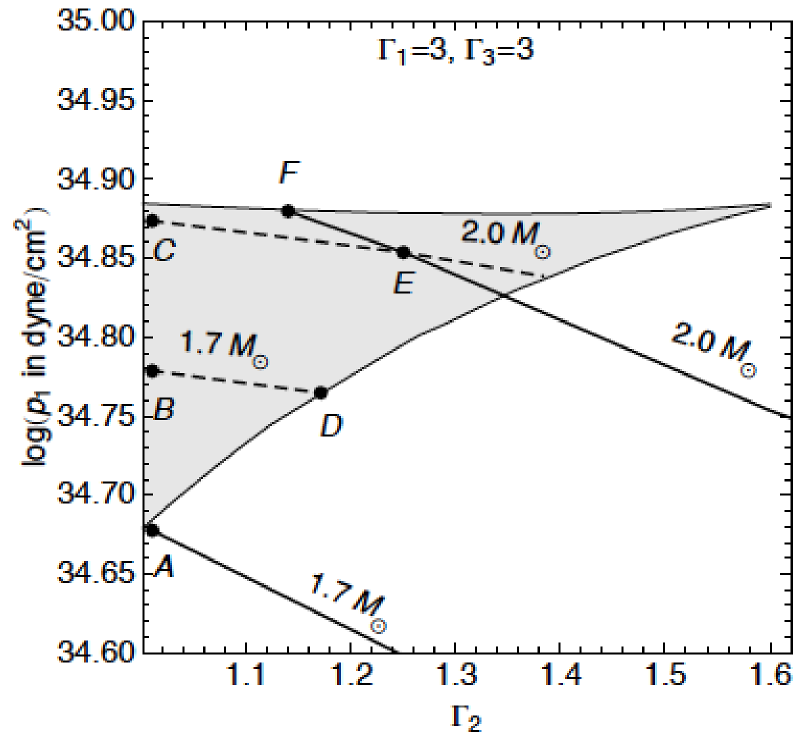
$$P_i(n) = \kappa_i n^{\Gamma_i}$$

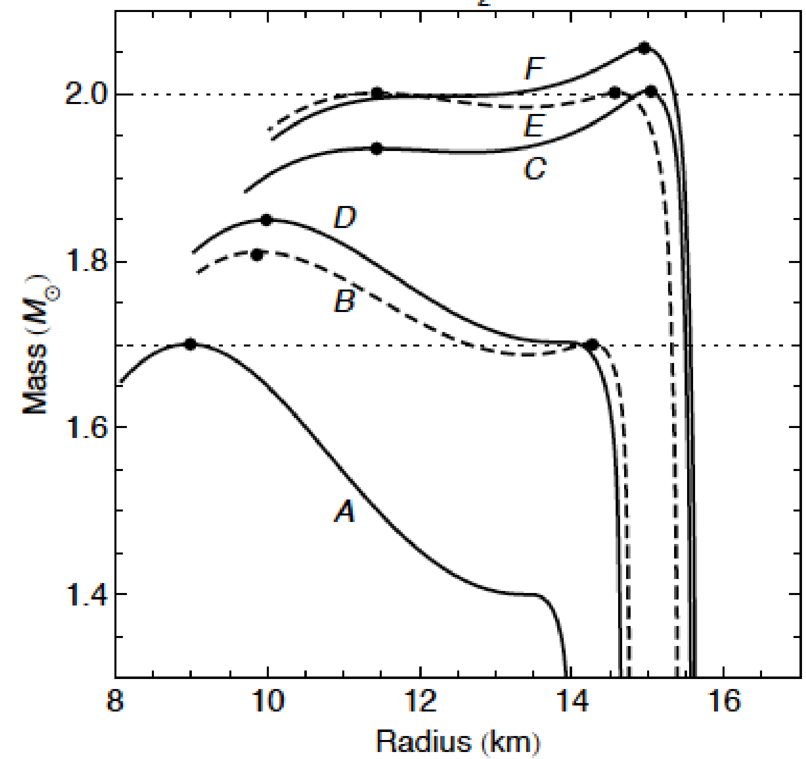
$$\begin{aligned} i = 1 &: n_1 \le n \le n_{12} \\ i = 2 &: n_{12} \le n \le n_{23} \\ i = 3 &: n \ge n_{23} \,, \end{aligned}$$



Case E:

HMT @ 2 M_{sun}





3. Piecewise polytrope EoS – high mass twins?

Hebeler et al., ApJ 773, 11 (2013)

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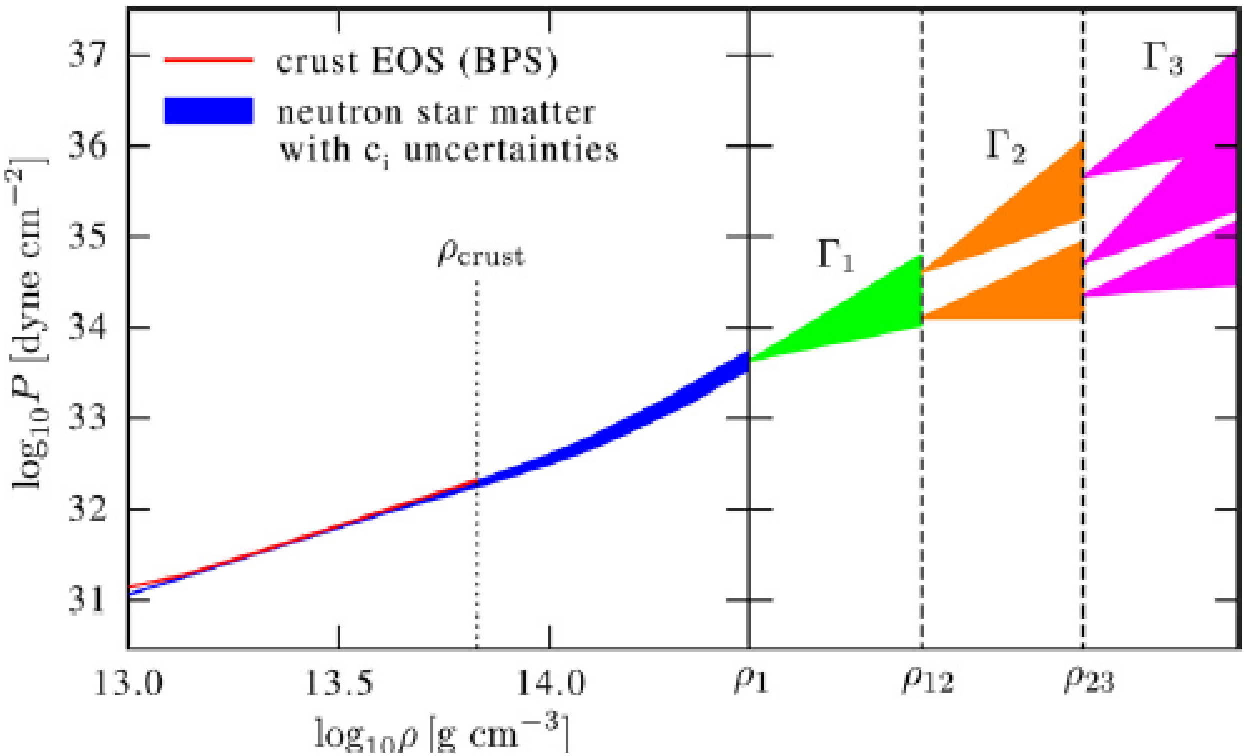

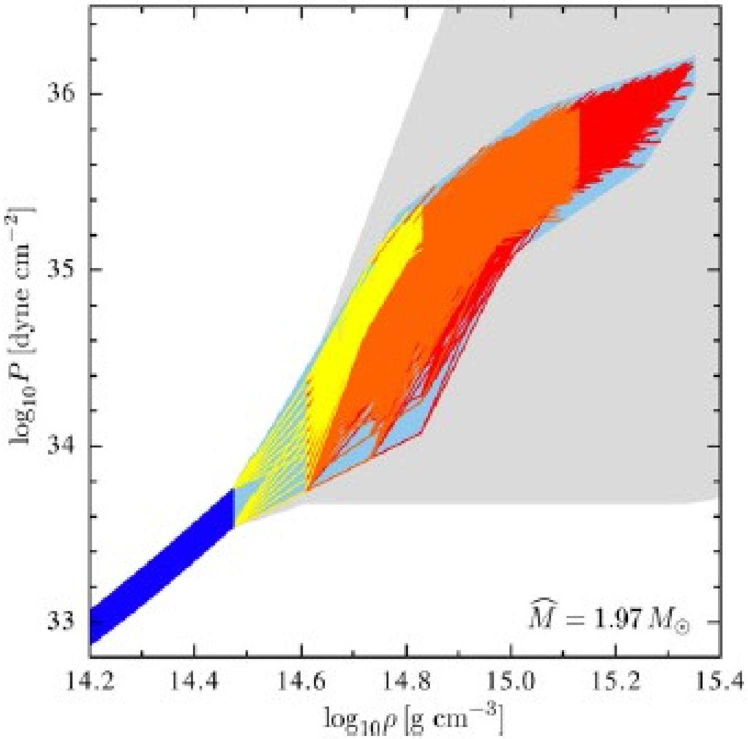

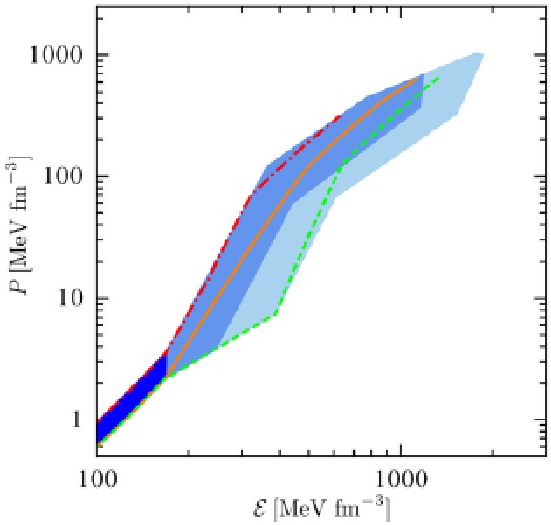

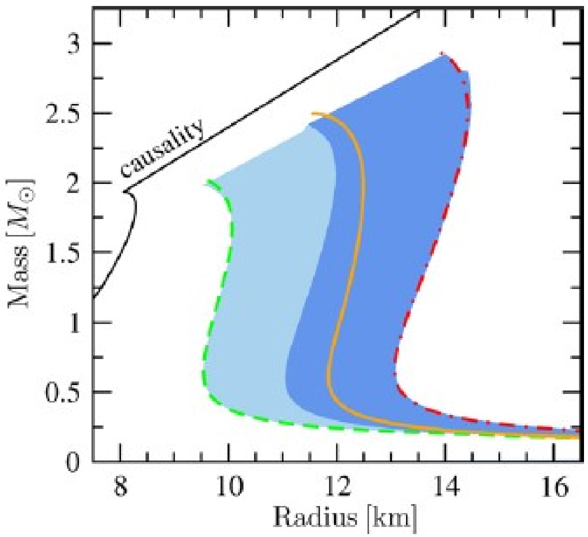

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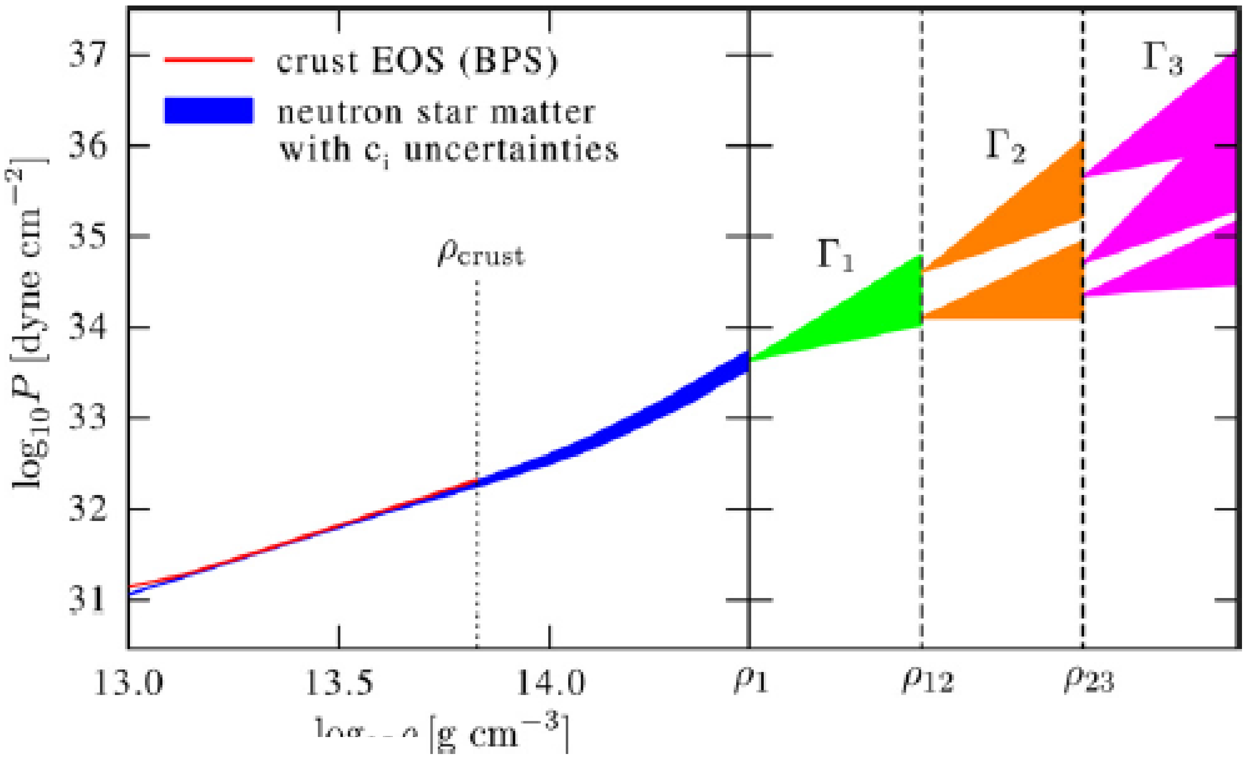


$$P_i(n) = \kappa_i n^{\Gamma_i}$$

$$i = 1 \ : \ n_1 \le n \le n_{12}$$
$$i = 2 \ : \ n_{12} \le n \le n_{23}$$
$$i = 3 \ : \ n \ge n_{23} \ ,$$

Here, 1st order PT in region 2:

$$\Gamma_2 = 0 \text{ and } P_2 = \kappa_2 = P_{\rm crit}$$

$$P(n) = n^2 \frac{d(\varepsilon(n)/n)}{dn},$$

$$\varepsilon(n)/n = \int dn \, \frac{P(n)}{n^2} = \int dn \, \kappa n^{\Gamma-2} = \frac{\kappa \, n^{\Gamma-1}}{\Gamma-1} + C,$$

$$\mu(n) = \frac{P(n)+\varepsilon(n)}{n} = \frac{\kappa\Gamma}{\Gamma-1} n^{\Gamma-1} + m_0,$$

$$n(\mu) = \left[(\mu - m_0)\frac{\Gamma-1}{\kappa\Gamma}\right]^{1/(\Gamma-1)}$$

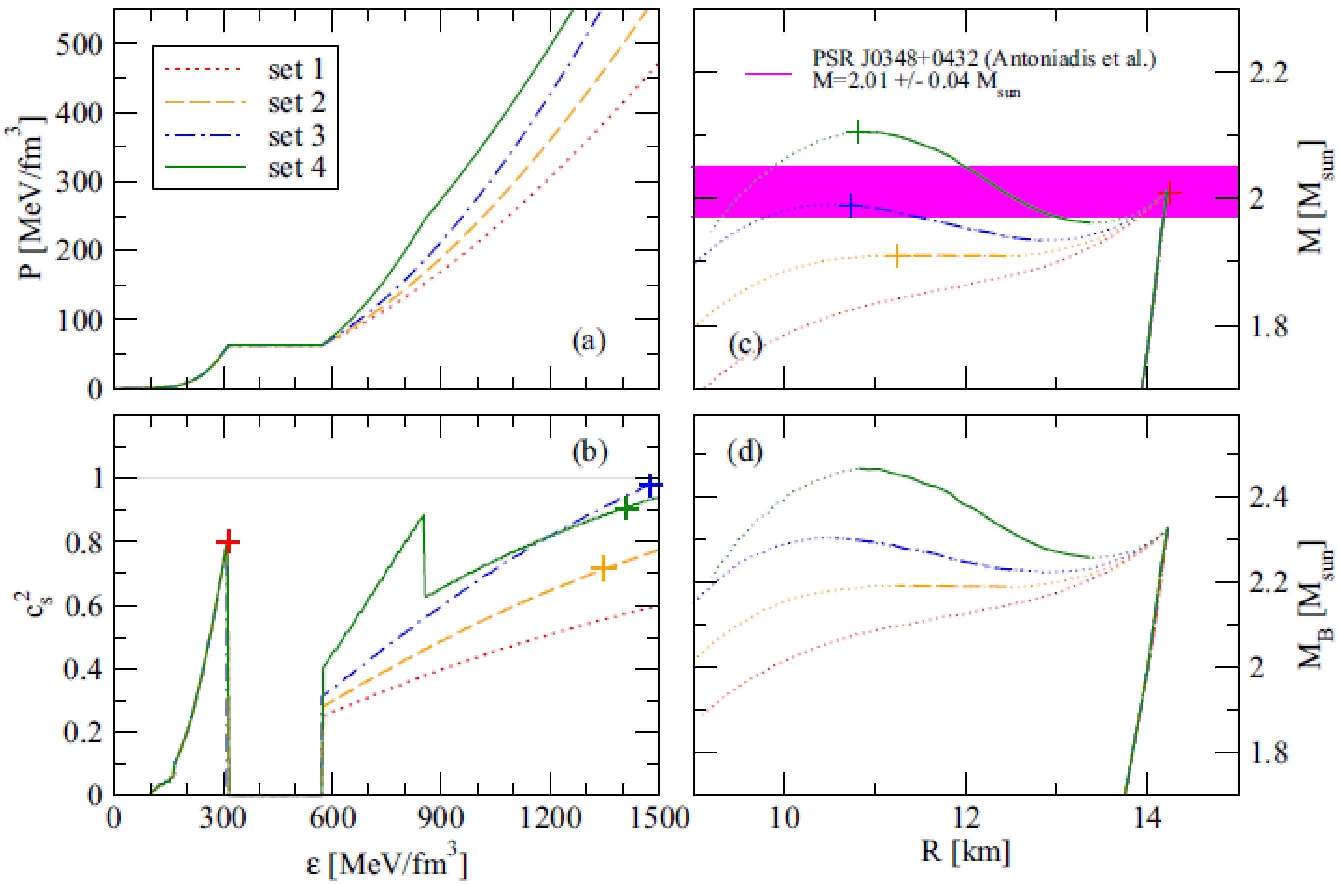
$$P(\mu) = \kappa\left[(\mu - m_0)\frac{\Gamma-1}{\kappa\Gamma}\right]^{\Gamma/(\Gamma-1)}$$

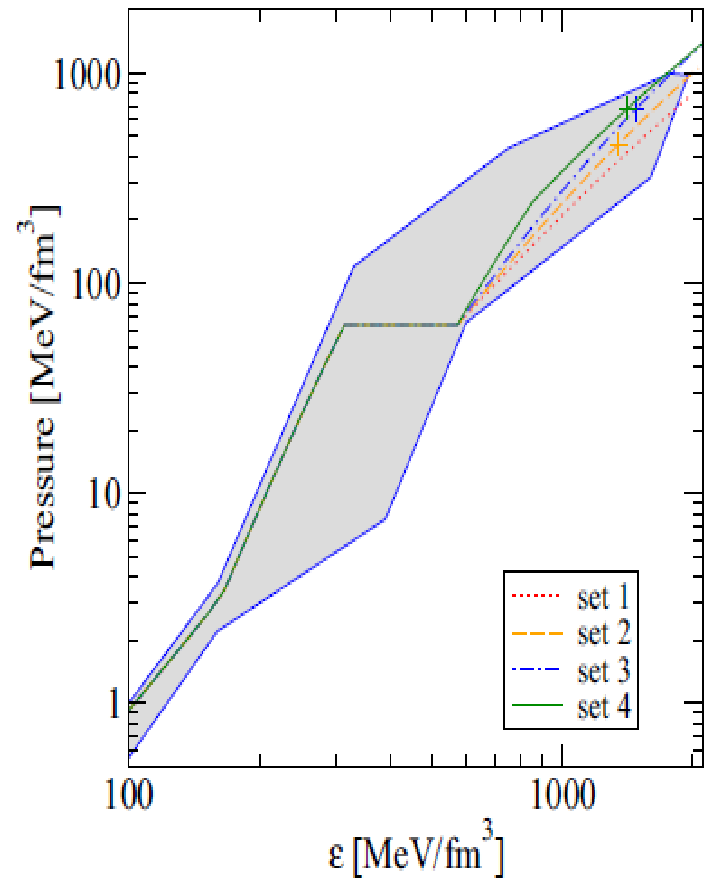
Maxwell construction:

$$P_1(\mu_{\rm crit}) = P_3(\mu_{\rm crit}) = P_{\rm crit}$$
$$\mu_{\rm crit} = \mu_1(n_{12}) = \mu_3(n_{23})$$

Seidov criterion for instability: $\dfrac{\Delta\varepsilon}{\varepsilon_{\rm crit}} \ge \dfrac{1}{2} + \dfrac{3}{3}\dfrac{P_{\rm crit}}{\varepsilon_{\rm crit}}$

3. Piecewise polytrope EoS – high mass twins?





	Γ_3	κ_3 [MeV fm$^{3(\Gamma_3-1)}$]	$m_{0,3}$ [MeV]	M^{NS}_{max} [$M_\odot$]	M^{HS}_{max} [$M_\odot$]	M^{HS}_{min} [$M_\odot$]
set 1	2.50	302.56	991.75	2.01	–	–
set 2	2.80	365.12	1004.88	2.01	1.910	1.909
set 3	3.12	447.16	1014.87	2.01	1.991	1.934
set 4a	4.00	774.375	1031.815			
set 4b	2.80	548.309	958.553	2.01	2.106	1.961

All sets with same onset of phase transition; P_{crit} = 63.2 MeV/fm^3, ε_{crit} = 318.3 MeV/fm^3 and same jump in energy density $\Delta\varepsilon$ = 253.9 MeV/fm^3; varying Γ_3

Third family solutions found at 2 Msol (HMT), 4-tropes favored; match with Hebeler et al.!

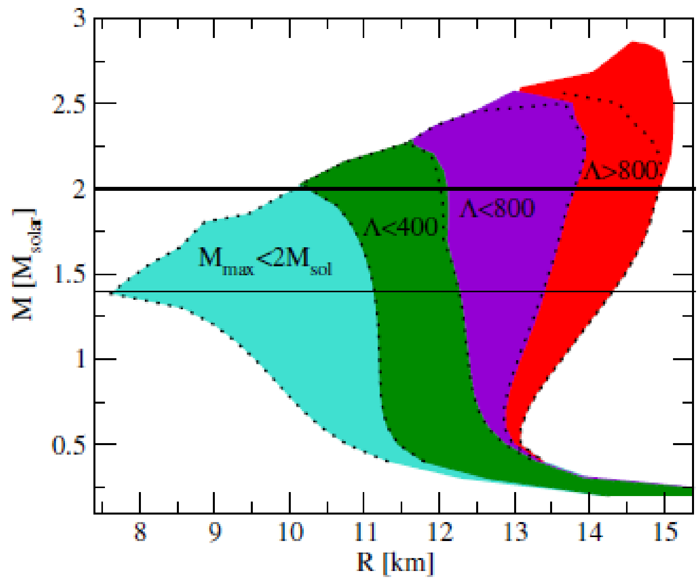
[D. Alvarez & D.B. PRC 96 (2017) 045809]

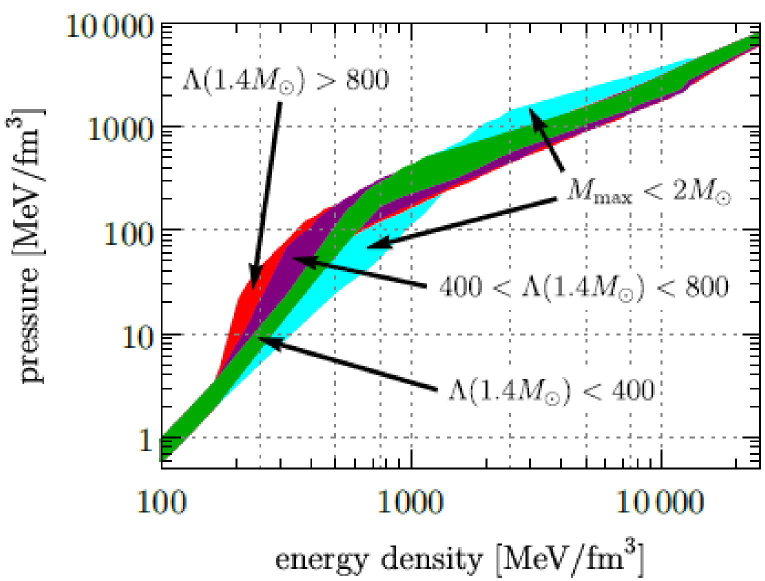
Arxiv:1711.02644 [astro-ph.HE]

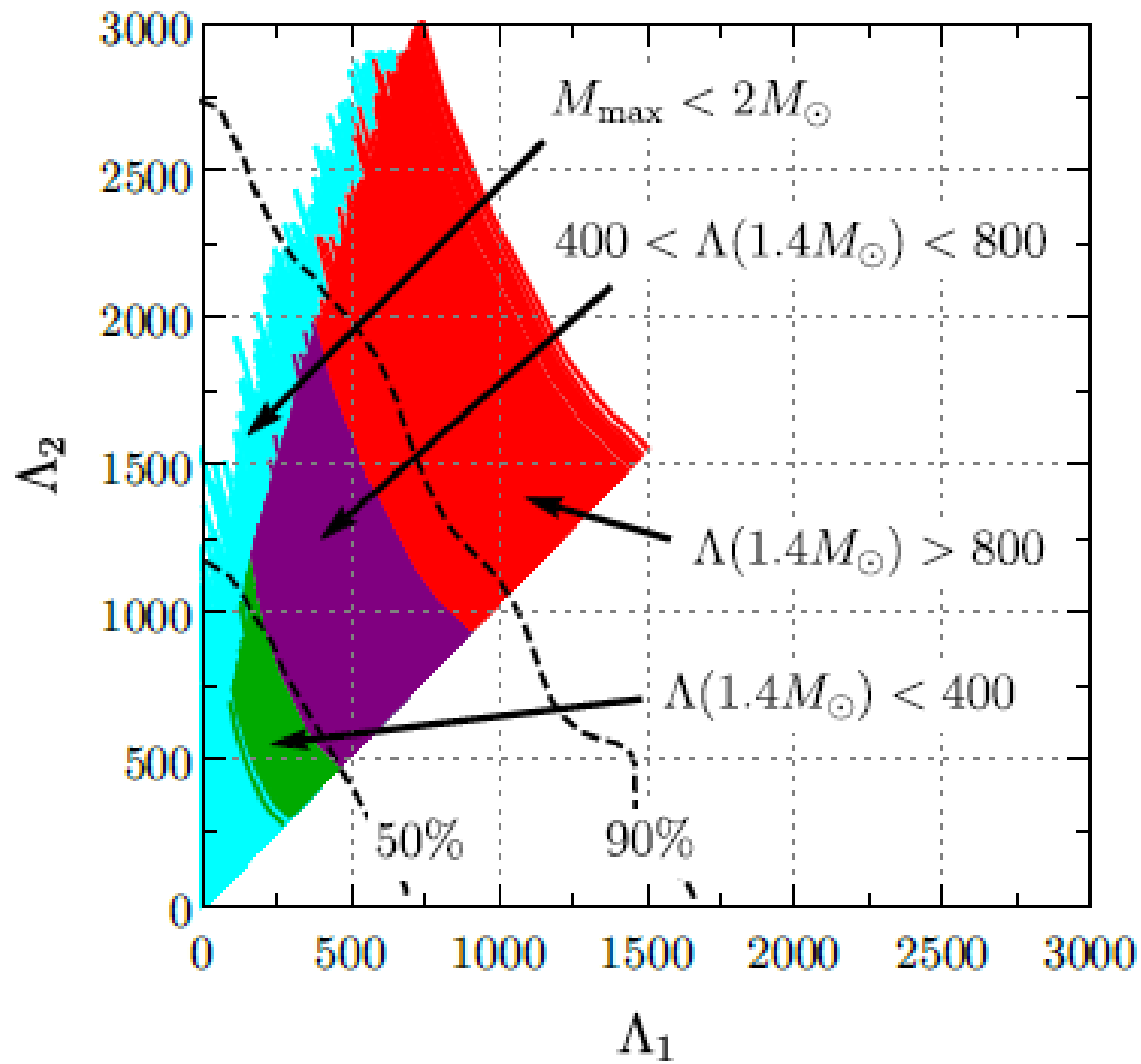
CERN-TH-2017-236, HIP-2017-30/TH

Gravitational-wave constraints on the neutron-star-matter Equation of State

Eemeli Annala,[1] Tyler Gorda,[1] Aleksi Kurkela,[2] and Aleksi Vuorinen[1]







Unfortunately, twins and third family forgotten !!!
For this aim, 2- and 3-tropes not sufficient, 4-tropes!

Arxiv:1712.00451 [astro-ph.HE]

Implications from GW170817 and I-Love-Q relations for relativistic hybrid stars

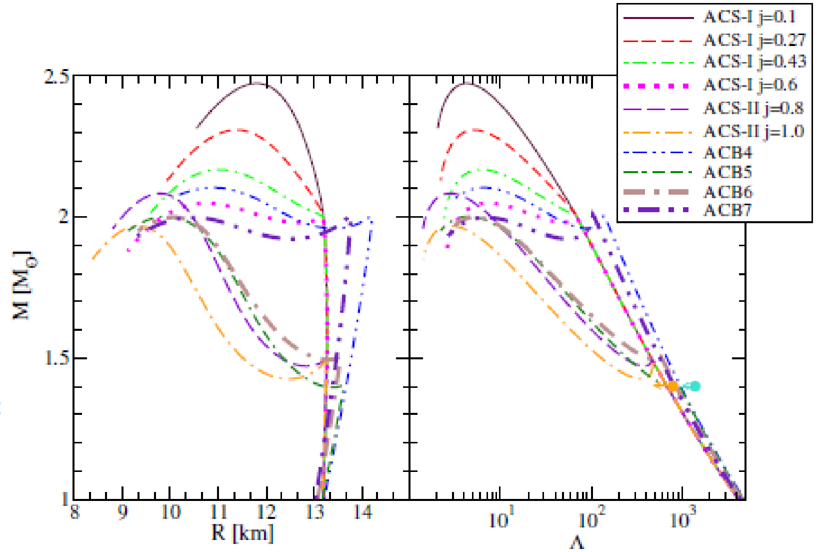
Vasileios Paschalidis,[1] Kent Yagi,[2] David Alvarez-Castillo,[3,4] David B. Blaschke,[3,5,6] and Armen Sedrakian[7]

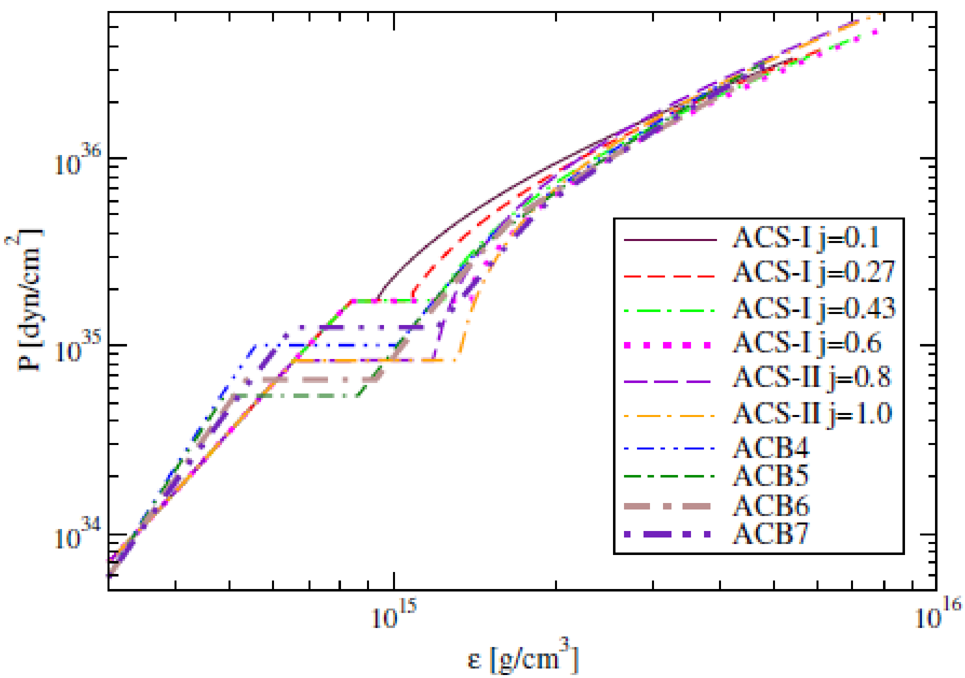
CSS model (ACSX)

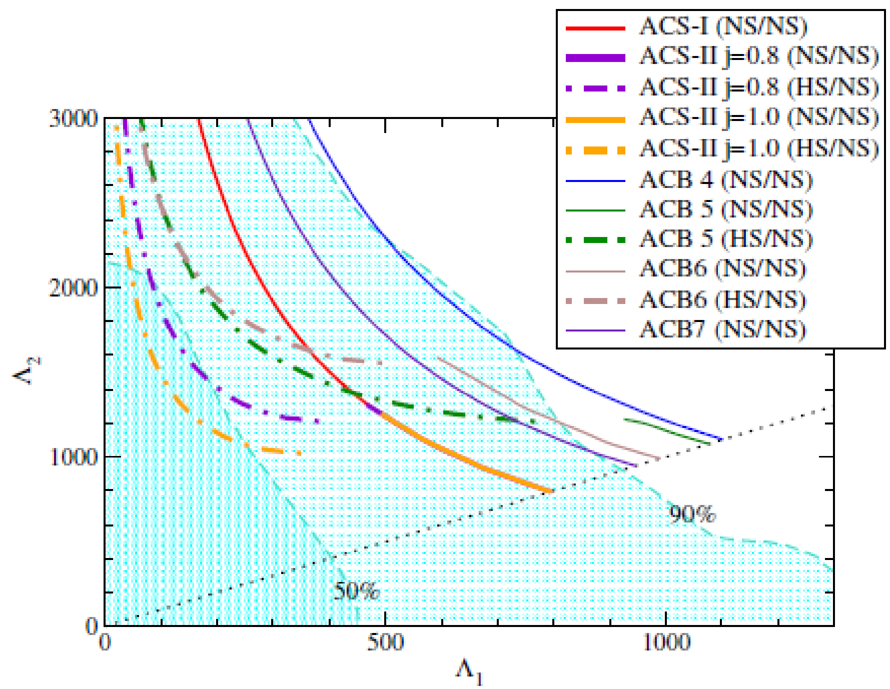
$$P(\varepsilon) = \begin{cases} P_{\rm tr}, & \varepsilon_1 \le \varepsilon \le \varepsilon_2, \\ P_{\rm tr} + c_s^2(\varepsilon - \varepsilon_2), & \varepsilon > \varepsilon_2, \end{cases}$$

MP model (ACBx)

$$P(n) = \kappa_i (n/n_0)^{\Gamma_i}, \; n_i < n < n_{i+1}, \; i = 1 \dots 4$$







Relativistic density functional approach to quark matter - string-flip model (SFM)

M.A.R. Kaltenborn, N.-U.F. Bastian, D.B. Blaschke, PRD 96 (2017) ; arxiv:1701.04400 v3

PHYSICAL REVIEW D VOLUME 34, NUMBER 11 1 DECEMBER 1986

Pauli quenching effects in a simple string model of quark/nuclear matter

G. Röpke and D. Blaschke
Department of Physics, Wilhelm-Pieck-Universtiy, 2500 Rostock, German Democratic Republic

H. Schulz
Central Institute for Nuclear Research, Rossendorf, 8051 Dresden, German Democratic Republic and The Niels Bohr Institute, 2100 Copenhagen, Denmark

(Received 16 December 1985)

Relativistic density functional approach* (I)

$$\mathcal{Z} = \int \mathcal{D}\bar{q}\mathcal{D}q \exp\left\{\int_0^\beta d\tau \int_V d^3x \left[\mathcal{L}_{\rm eff} + \bar{q}\gamma_0\hat{\mu}q\right]\right\}, \quad q = \begin{pmatrix} q_u \\ q_d \end{pmatrix}, \quad \hat{\mu} = {\rm diag}(\mu_u, \mu_d)$$

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm free} - \boxed{U(\bar{q}q, \bar{q}\gamma_0 q)}, \quad \mathcal{L}_{\rm free} = \bar{q}\left(-\gamma_0\frac{\partial}{\partial\tau} + i\vec{\gamma}\cdot\vec{\nabla} - \hat{m}\right)q\,, \ \hat{m} = {\rm diag}(m_u, m_d)$$

General nonlinear functional of quark density bilinears: scalar, vector, isovector, diquark ...
Expansion around the expectation values:

$$U(\bar{q}q,\, \bar{q}\gamma_0 q) = U(n_{\rm s}, n_{\rm v}) + (\bar{q}q - n_{\rm s})\Sigma_{\rm s} + (\bar{q}\gamma_0 q - n_{\rm v})\Sigma_{\rm v} + \ldots\,,$$

$$\langle\bar{q}q\rangle = n_{\rm s} = \sum_{f=u,d} n_{{\rm s},f} = -\sum_{f=u,d}\frac{T}{V}\frac{\partial}{\partial m_f}\ln\mathcal{Z}\,, \quad \Sigma_{\rm s} = \left.\frac{\partial U(\bar{q}q, \bar{q}\gamma_0 q)}{\partial(\bar{q}q)}\right|_{\bar{q}q=n_{\rm s}} = \frac{\partial U(n_{\rm s}, n_{\rm v})}{\partial n_{\rm s}}\,,$$

$$\langle\bar{q}\gamma_0 q\rangle = n_{\rm v} = \sum_{f=u,d} n_{{\rm v},f} = \sum_{f=u,d}\frac{T}{V}\frac{\partial}{\partial \mu_f}\ln\mathcal{Z}\,, \quad \Sigma_{\rm v} = \left.\frac{\partial U(\bar{q}q, \bar{q}\gamma_0 q)}{\partial(\bar{q}\gamma_0 q)}\right|_{\bar{q}\gamma_0 q=n_{\rm v}} = \frac{\partial U(n_{\rm s}, n_{\rm v})}{\partial n_{\rm v}}$$

$$\boxed{\mathcal{Z} = \int \mathcal{D}\bar{q}\mathcal{D}q \exp\left\{\mathcal{S}_{\rm quasi}[\bar{q}, q] - \beta V\Theta[n_{\rm s}, n_{\rm v}]\right\}\,, \quad \Theta[n_{\rm s}, n_{\rm v}] = U(n_{\rm s}, n_{\rm v}) - \Sigma_{\rm s}n_{\rm s} - \Sigma_{\rm v}n_{\rm v}}$$

$$\mathcal{S}_{\rm quasi}[\bar{q}, q] = \beta\sum_n\sum_{\vec{p}}\bar{q}\,G^{-1}(\omega_n, \vec{p})\,q\,, \quad G^{-1}(\omega_n, \vec{p}) = \gamma_0(-i\omega_n + \hat{\mu}^*) - \vec{\gamma}\cdot\vec{p} - \hat{m}^*$$

*This work was inspired by the textbook on “Thermodynamics and statistical mechanics” of the “red” series on Theoretical Physics by Walter Greiner and Coworkers.

Relativistic density functional approach (II)

$$\mathcal{Z} = \int \mathcal{D}\bar{q}\mathcal{D}q \exp\left\{\mathcal{S}_{\rm quasi}[\bar{q},q] - \beta V \Theta[n_{\rm s},n_{\rm v}]\right\}\ , \quad \Theta[n_{\rm s},n_{\rm v}] = U(n_{\rm s},n_{\rm v}) - \Sigma_{\rm s} n_{\rm s} - \Sigma_{\rm v} n_{\rm v}$$

$$\mathcal{Z}_{\rm quasi} = \int \mathcal{D}\bar{q}\mathcal{D}q \exp\left\{\mathcal{S}_{\rm quasi}[\bar{q},q]\right\} = \det[\beta G^{-1}]\,, \qquad \ln\det A = {\rm Tr}\ln A$$

$$P_{\rm quasi} = \frac{T}{V}\ln \mathcal{Z}_{\rm quasi} = \frac{T}{V}{\rm Tr}\ln[\beta G^{-1}]$$

"no sea" approximation ...

$$= 2N_c \sum_{f=u,d}\int \frac{d^3p}{(2\pi)^3}\left\{T\ln\left[1+{\rm e}^{-\beta(E_f^*-\mu_f^*)}\right] + T\ln\left[1+{\rm e}^{-\beta(E_f^*+\mu_f^*)}\right]\right\}$$

$$P_{\rm quasi} = \sum_{f=u,d}\int \frac{dp}{\pi^2}\frac{p^4}{E_f^*}\left[f(E_f^*-\mu_f^*) + f(E_f^*+\mu_f^*)\right]$$

$$E_f^* = \sqrt{p^2 + {m_f^*}^2}$$

$$f(E) = 1/[1+\exp(\beta E)]$$

$$P = \sum_{f=u,d}\int_0^{p_{{\rm F},f}} \frac{dp}{\pi^2}\frac{p^4}{E_f^*} - \Theta[n_{\rm s},n_{\rm v}]\,, \quad p_{{\rm F},f} = \sqrt{{\mu_f^*}^2 - {m_f^*}^2}$$

$$\hat{m}^* = \hat{m} + \Sigma_{\rm s}$$
$$\hat{\mu}^* = \hat{\mu} - \Sigma_{\rm v}$$

Selfconsistent densities

$$n_{\rm s} = -\sum_{f=u,d}\frac{\partial P}{\partial m_f} = \frac{3}{\pi^2}\sum_{f=u,d}\int_0^{p_{{\rm F},f}} dp\, p^2 \frac{m_f^*}{E_f^*}\,, \quad n_{\rm v} = \sum_{f=u,d}\frac{\partial P}{\partial \mu_f} = \frac{3}{\pi^2}\sum_{f=u,d}\int_0^{p_{{\rm F},f}} dp\, p^2 = \frac{p_{{\rm F},u}^3 + p_{{\rm F},d}^3}{\pi^2}\,.$$

Relativistic density functional approach (III)

Density functional for the SFM

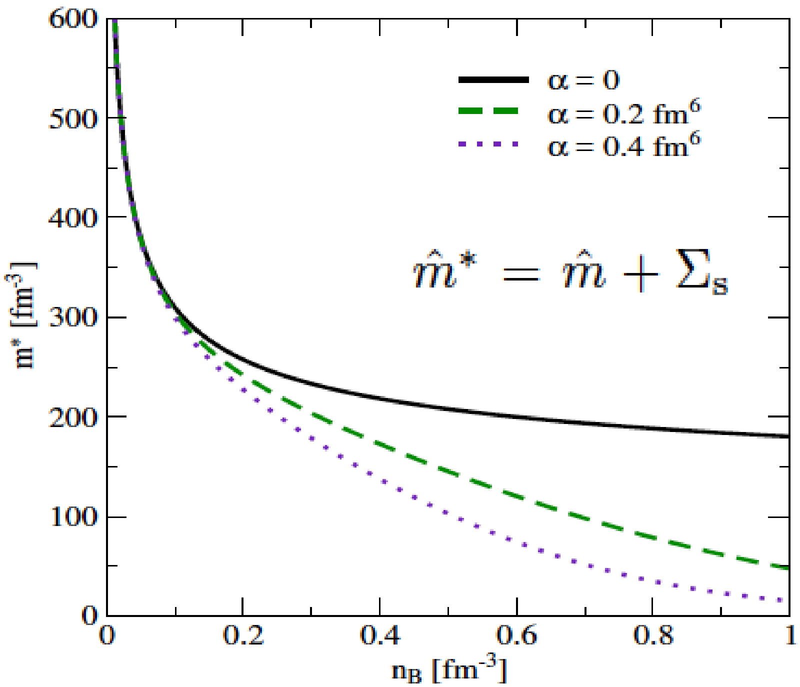
$$U(n_s, n_v) = D(n_v) n_s^{2/3} + a n_v^2 + \frac{b n_v^4}{1 + c n_v^2} \,,$$

Quark selfenergies

$$\Sigma_s \;=\; \frac{2}{3} D(n_v) n_s^{-1/3} \,,$$

Quark “confinement”

$$\Sigma_v = 2 a n_v + \frac{4 b n_v^3}{1 + c n_v^2} - \frac{2 b c n_v^5}{(1 + c n_v^2)^2} + \frac{\partial D(n_v)}{\partial n_v} n_s^{2/3}$$

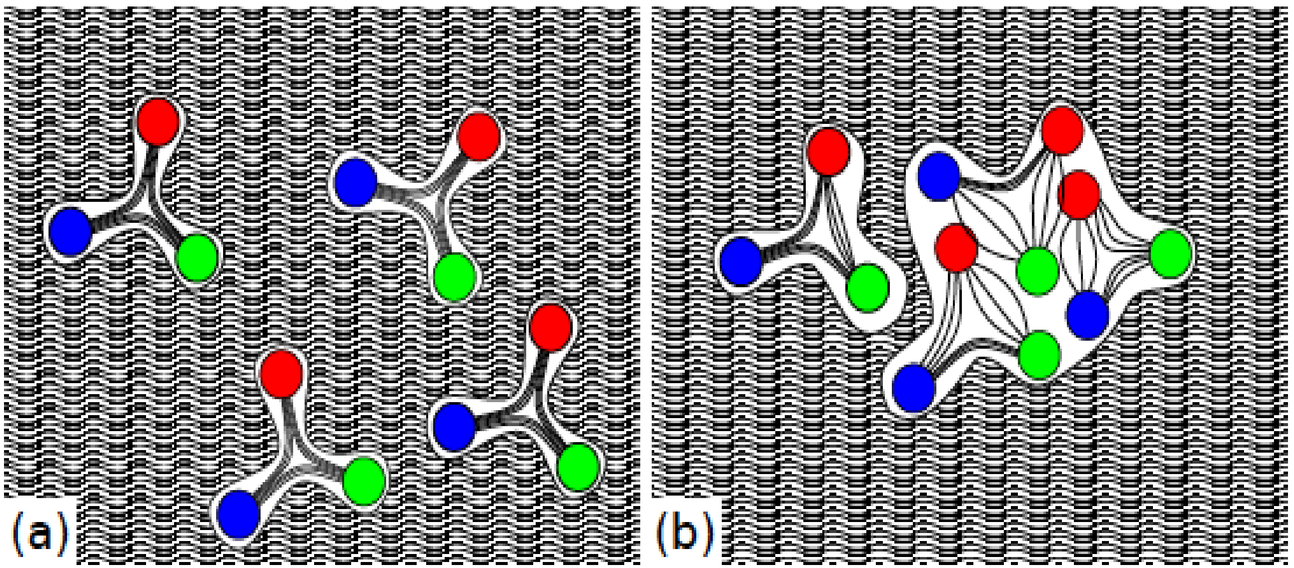


String tension & confinement due to dual Meissner effect (dual superconductor model)

$$D(n_v) \;=\; D_0 \Phi(n_v)$$

Effective screening of the string tension in dense matter by a reduction of the available volume $\alpha \;=\; v|v|/2$

$$\Phi(n_B) = \begin{cases} 1, & \text{if } n_B < n_0 \\ e^{-\alpha(n_B - n_0)^2}, & \text{if } n_B > n_0 \end{cases}$$

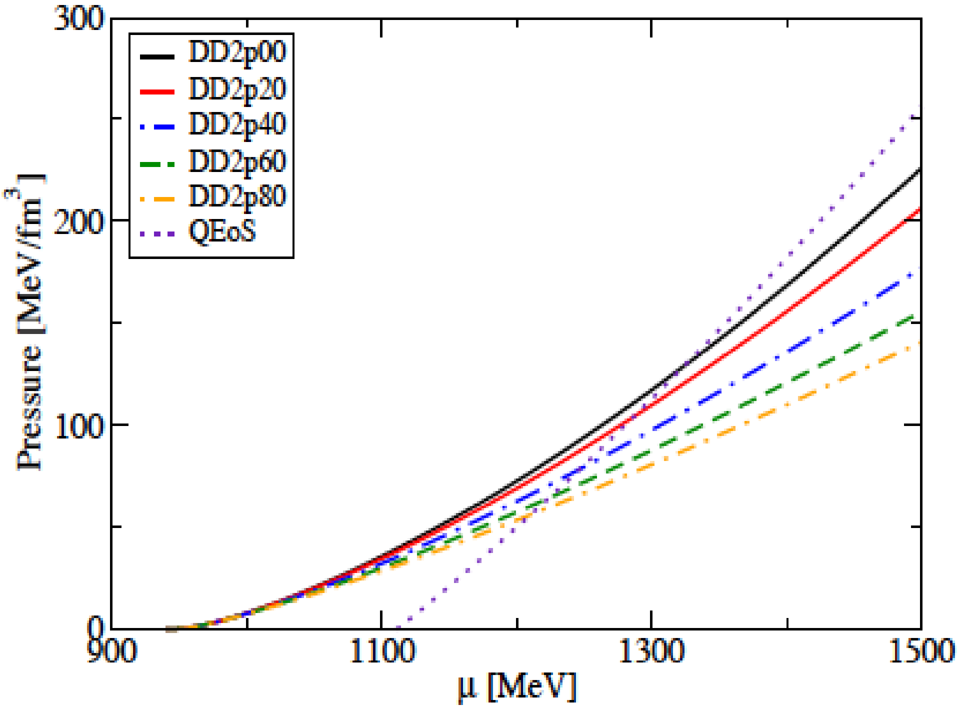


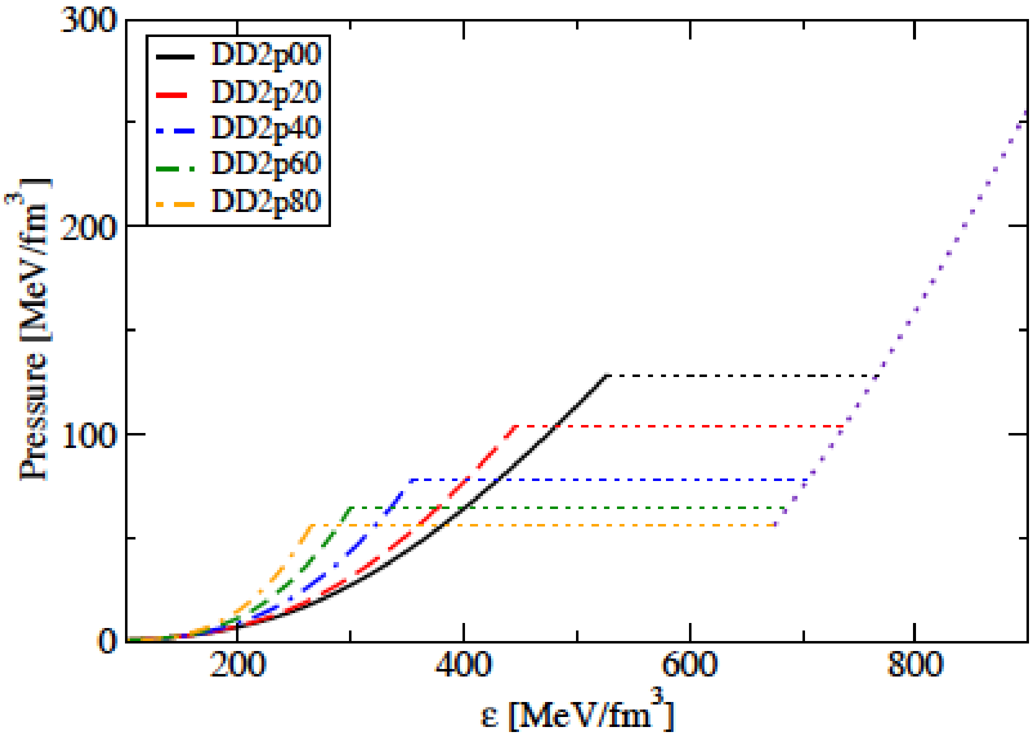
3. Phase transition to SFM quark matter

Hadronic matter: DD2 with excluded volume **[S. Typel, EPJA 52 (3) (2016)]**

$$\Phi_n = \Phi_p = \begin{cases} 1, & \text{if } n_B < n_0 \\ e^{-\frac{v|v|}{2}(n_B - n_0)^2}, & \text{if } n_B > n_0 \end{cases}$$

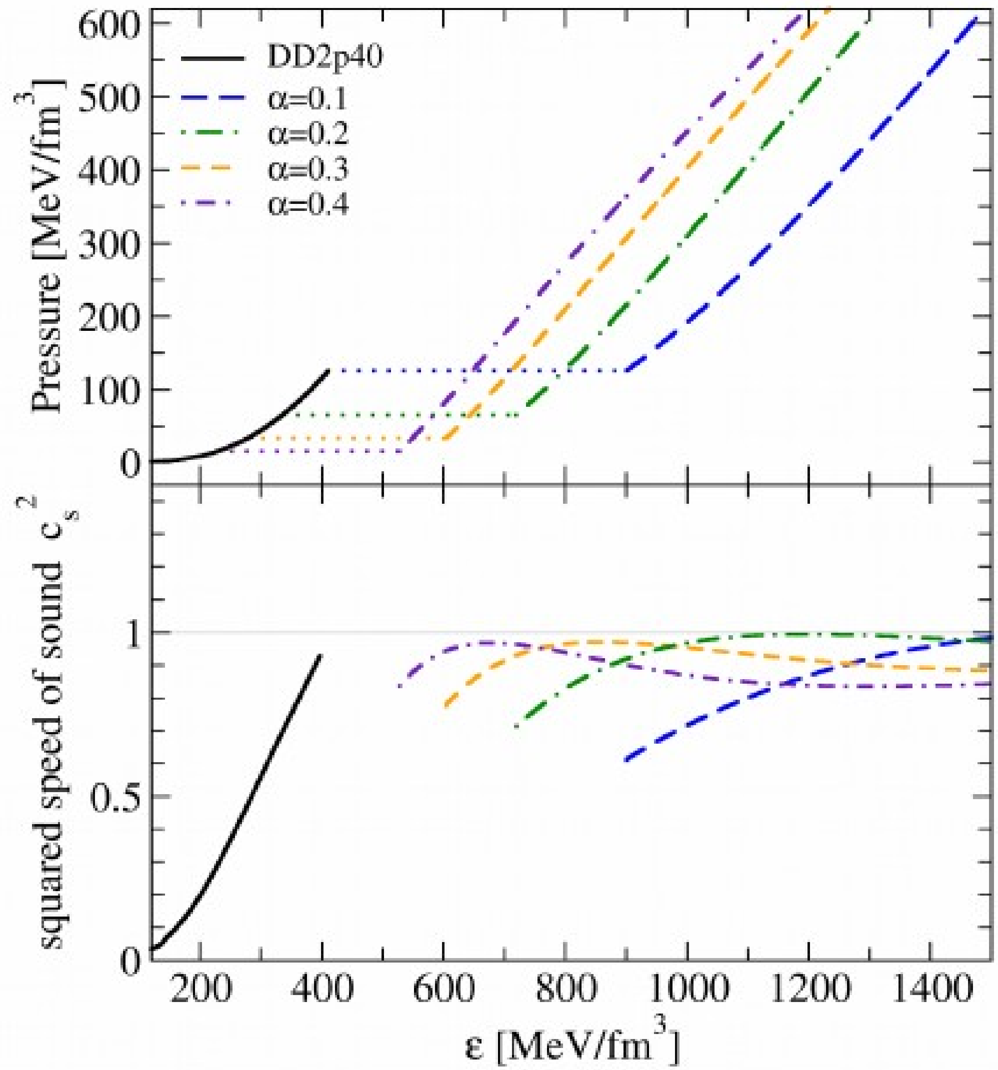
Varying the hadronic excluded volume parameter, p00 → v=0, … , p80 → v=8 fm^3

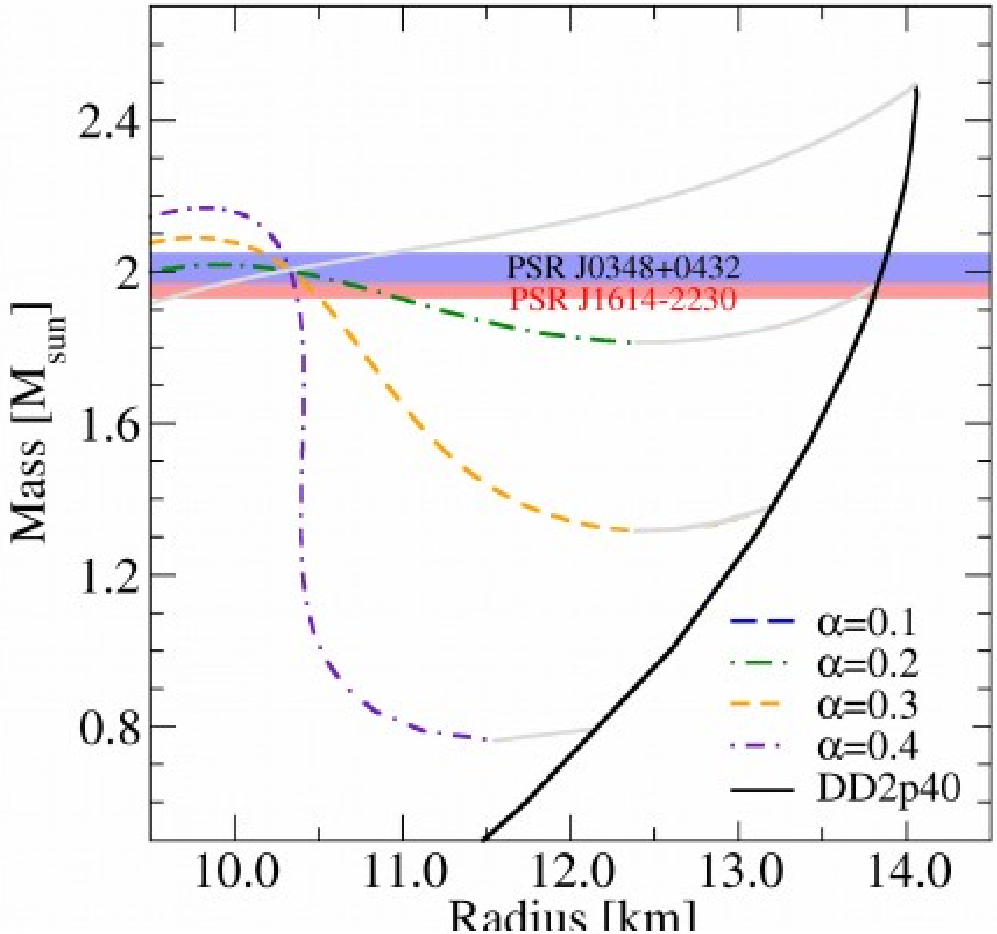




Hybrid EOS - parameters

$\underline{\alpha}, a, b$





Kaltenborn, Bastian, Blaschke, arXiv:1701.04400 → Phys. Rev. D 96 (2017) to appear 22.09.

KVOR_cut2 vs. string-flip model (SFM)

A. Ayriyan, N.-U.Bastian, D.B., H. Grigorian, K. Maslov, D. Voskresensky; arxiv:1711.03926

Robustness of Twins against Pasta Phase Effects

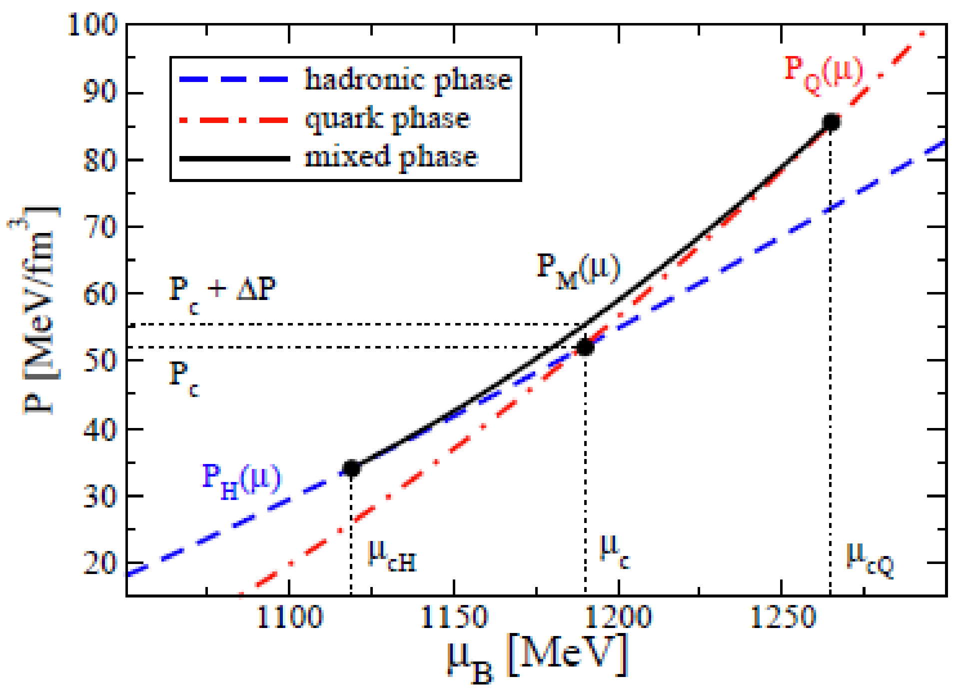
arxiv:1711.03926v1, 10.11.2017

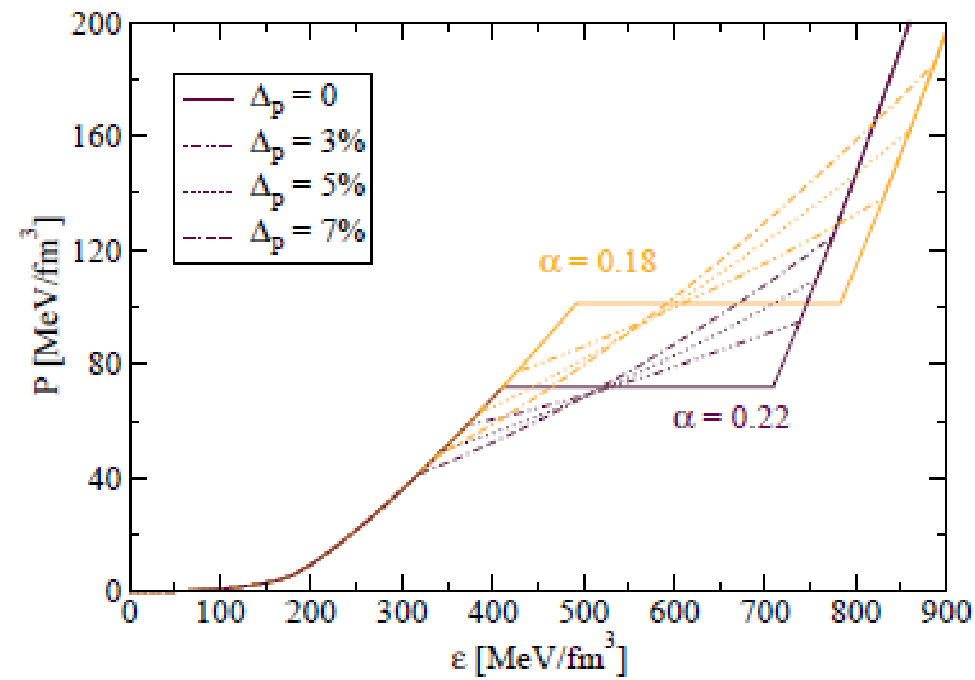
How robust is a third family of compact stars against pasta phase effects?

A. Ayriyan,[1,*] N.-U. Bastian,[2,†] D. Blaschke,[2,3,4,‡] H. Grigorian,[1,§] K. Maslov,[3,4,¶] and D. N. Voskresensky[3,4,**]

[1] *Laboratory for Information Technologies, Joint Institute for Nuclear Research, Joliot-Curie street 6, 141980 Dubna, Russia*
[2] *Institute of Theoretical Physics, University of Wroclaw, Max Born place 9, 50-204 Wroclaw, Poland*
[3] *Bogoliubov Laboratory for Theoretical Physics, Joint Institute for Nuclear Research, Joliot-Curie street 6, 141980 Dubna, Russia*
[4] *National Research Nuclear University (MEPhI), Kashirskoe Shosse 31, 115409 Moscow, Russia*

(Dated: November 13, 2017)





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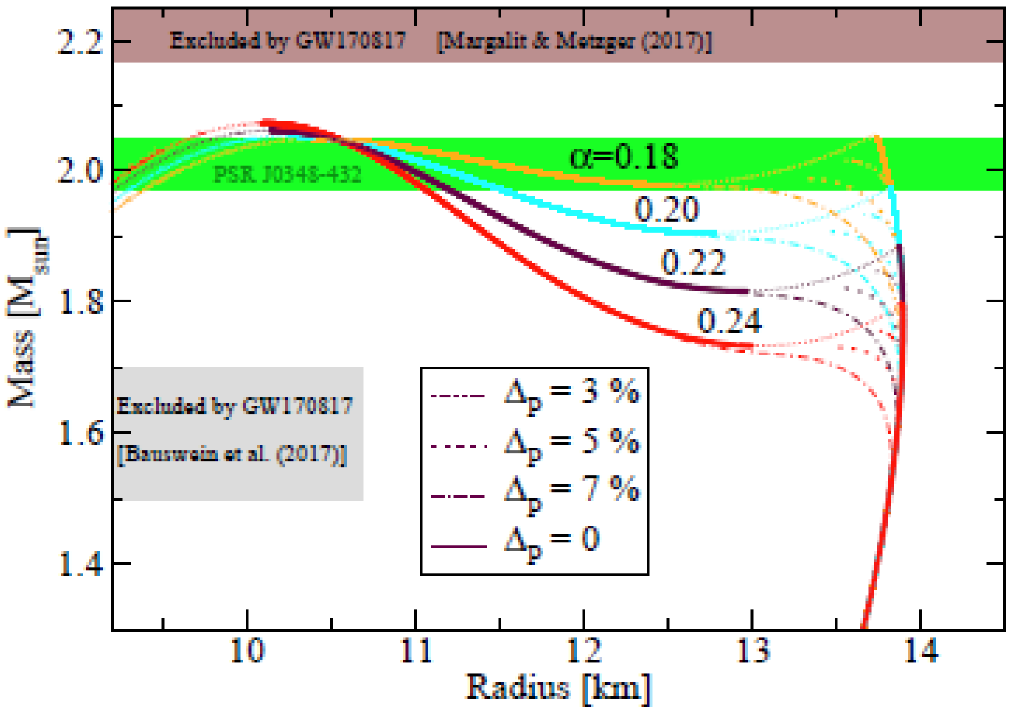
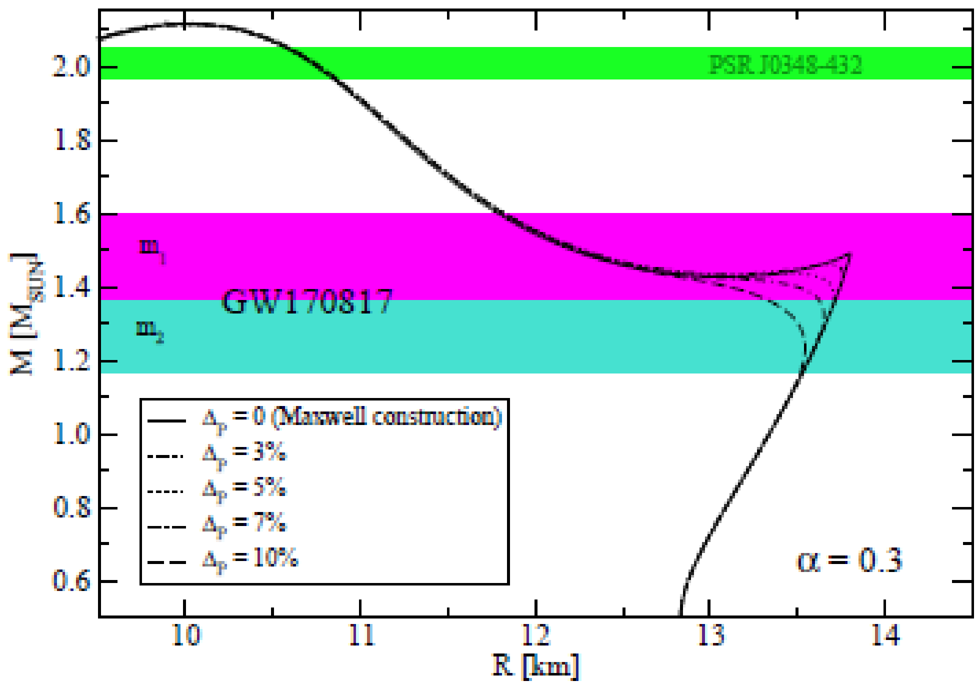
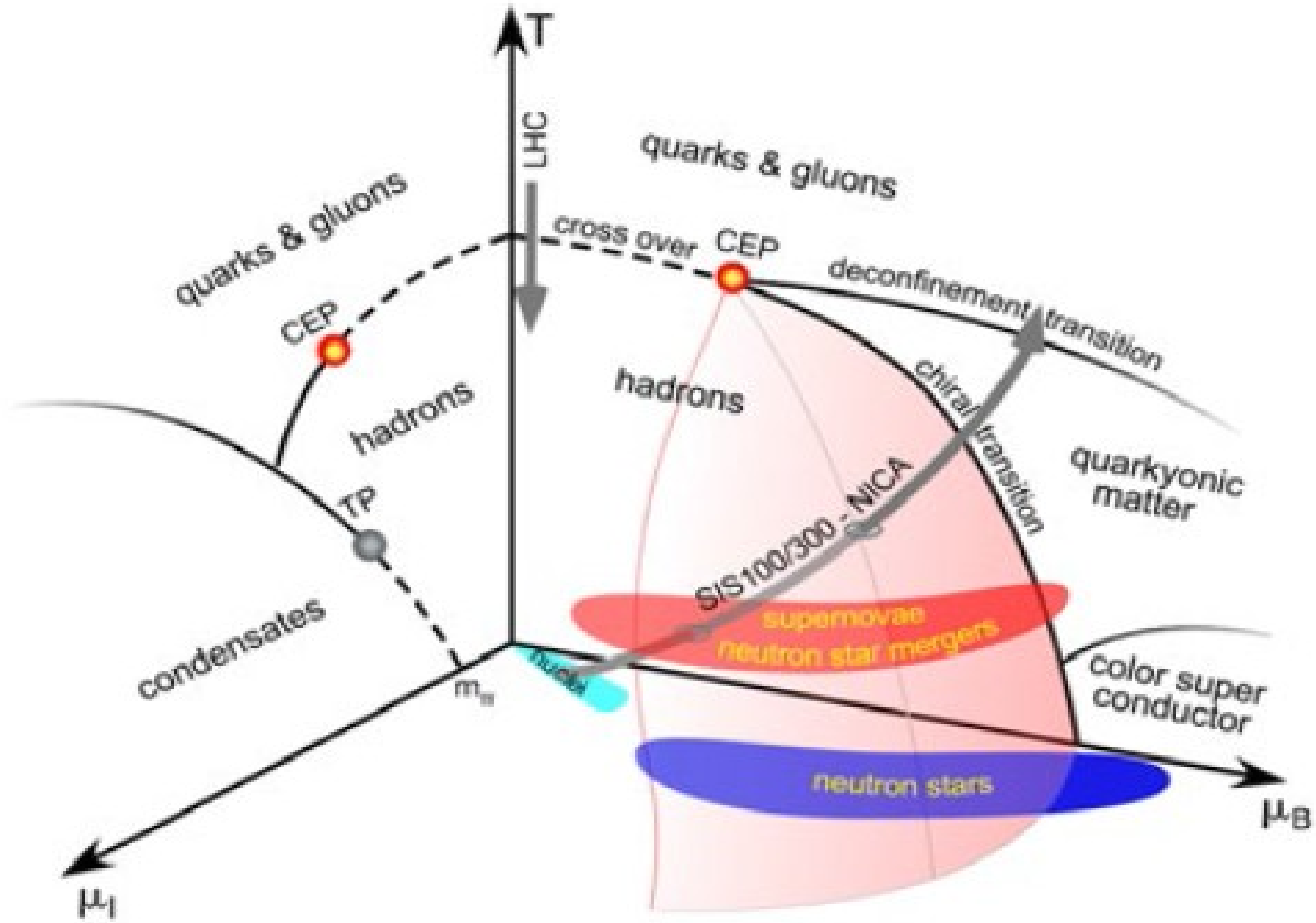




CEP in the QCD phase diagram: HIC vs. Astrophysics

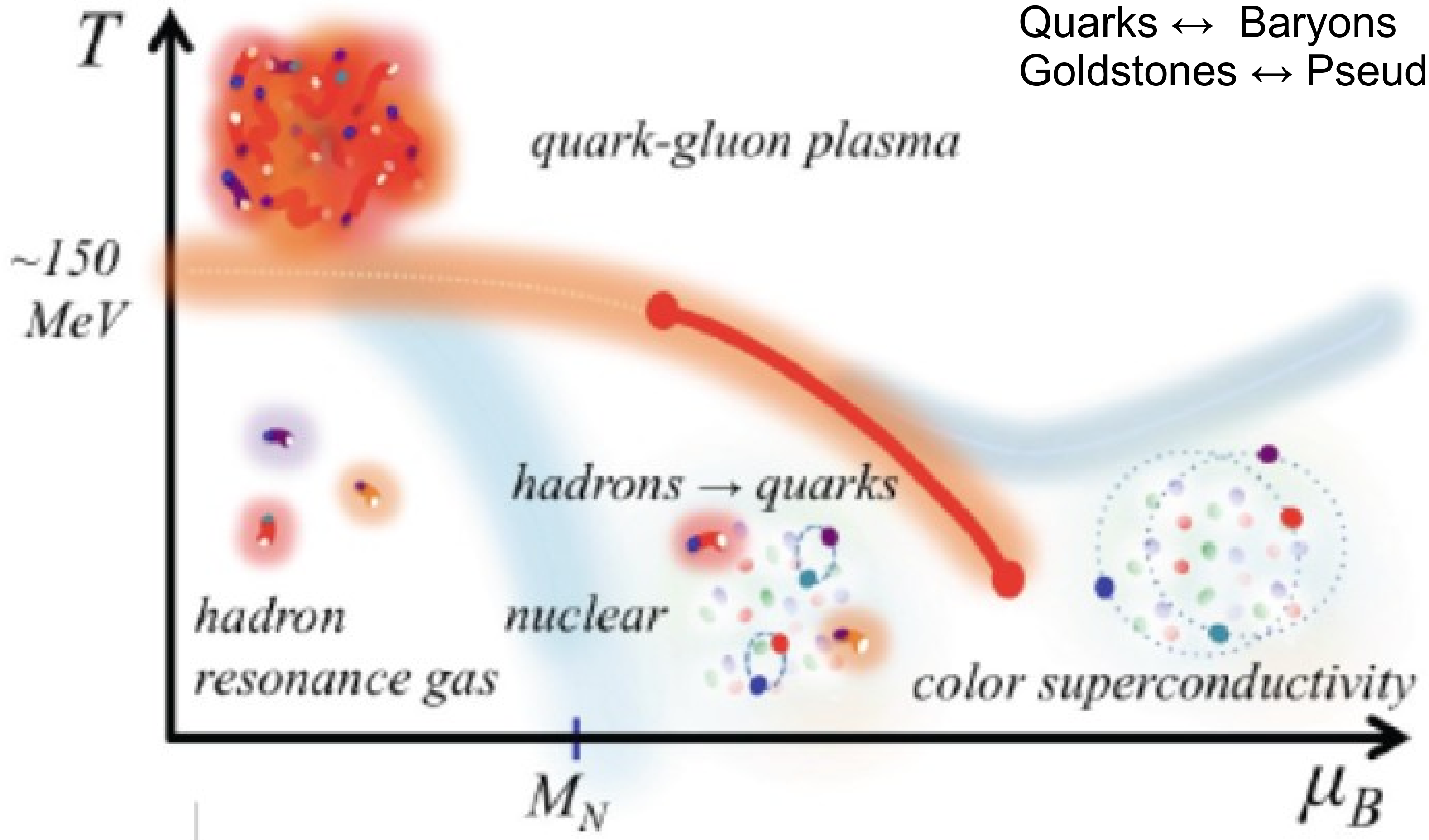


NuPECC Long Range Plan 2017; http://www.nupecc.org

A. Andronic, D. Blaschke, et al., "Hadron production ...", Nucl. Phys. A 837 (2010) 65 - 86

2^{nd} CEP in QCD phase diagram: Quark-Hadron Continuity?

Gluons ↔ Vector mesons
Quarks ↔ Baryons
Goldstones ↔ Pseudoscalar mesons

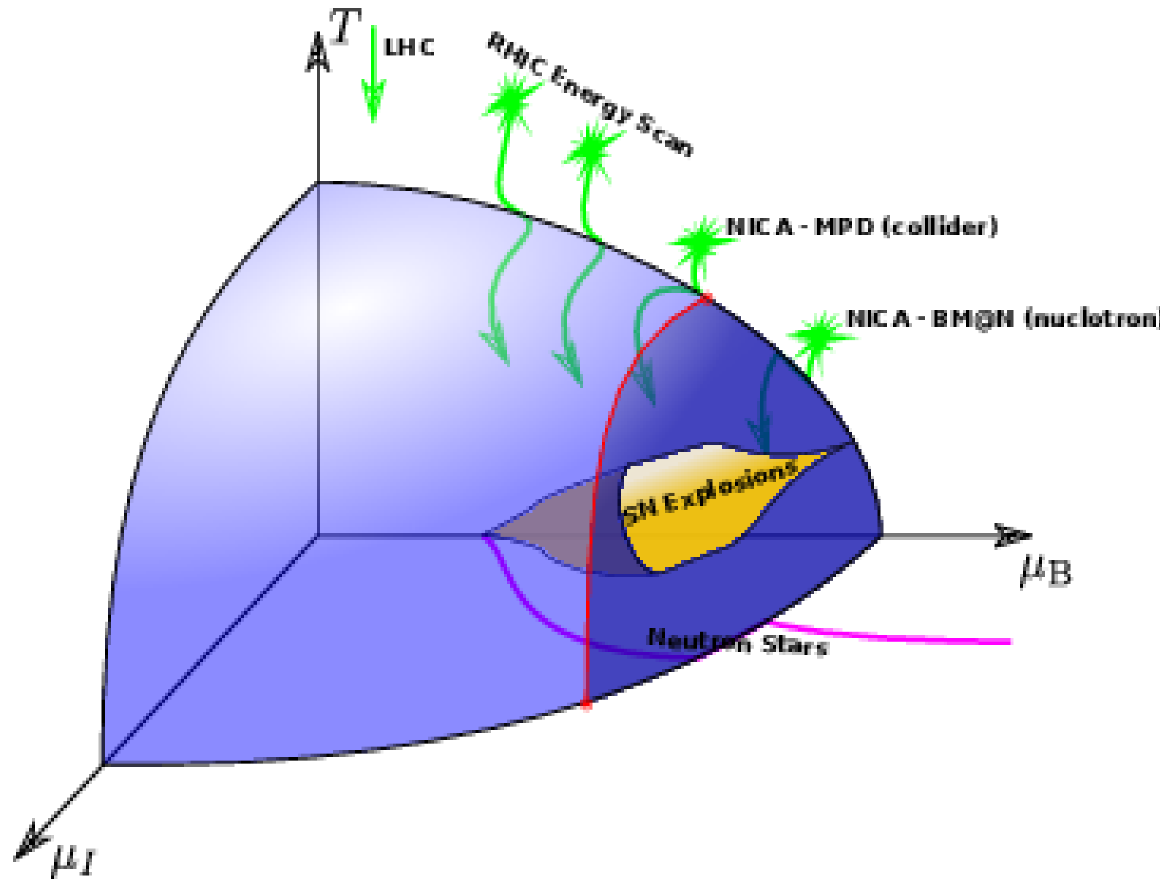


T. Schaefer & F. Wilczek, Phys. Rev. Lett. 82 (1999) 3956
C. Wetterich, Phys. Lett. B 462 (1999) 164
T. Hatsuda, M. Tachibana, T. Yamamoto & G. Baym, Phys. Rev. Lett. 97 (2006) 122001

Conclusions:

High-mass twin (HMT) and Typical-mass twin (TMT) solutions obtained within different hybrid star EoS, e.g.,
- constant speed of sound
- higher order NJL
- piecewise polytrope
- density functional

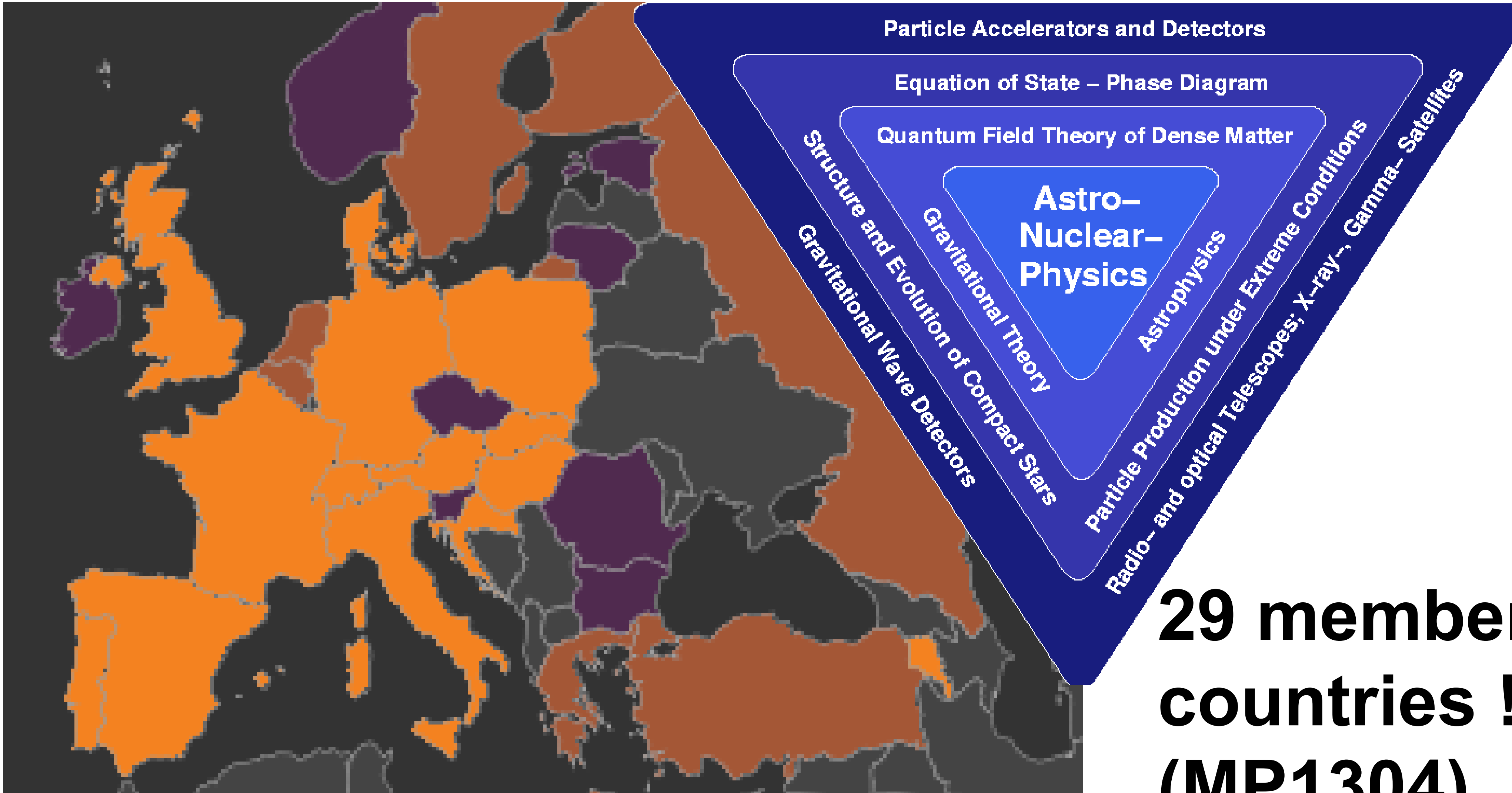
Main condition: stiff hadronic & stiff quark matter EoS with strong phase transition (PT)



Existence of HMTs & TMTs can be verified, e.g., by precise pulsar mass and radius measurements (and good luck) → Indicator for strong PT !!

Extremely interesting scenarios possible for dynamical evolution of isolated (spin-down and accretion) and binary (NS-NS merger) compact stars; GW170817 could be the inspiral of a neutron star – hybrid star binary !

Critical endpoint search in the QCD phase diagram with Heavy-Ion Collisions goes well together with Compact Star Astrophysics

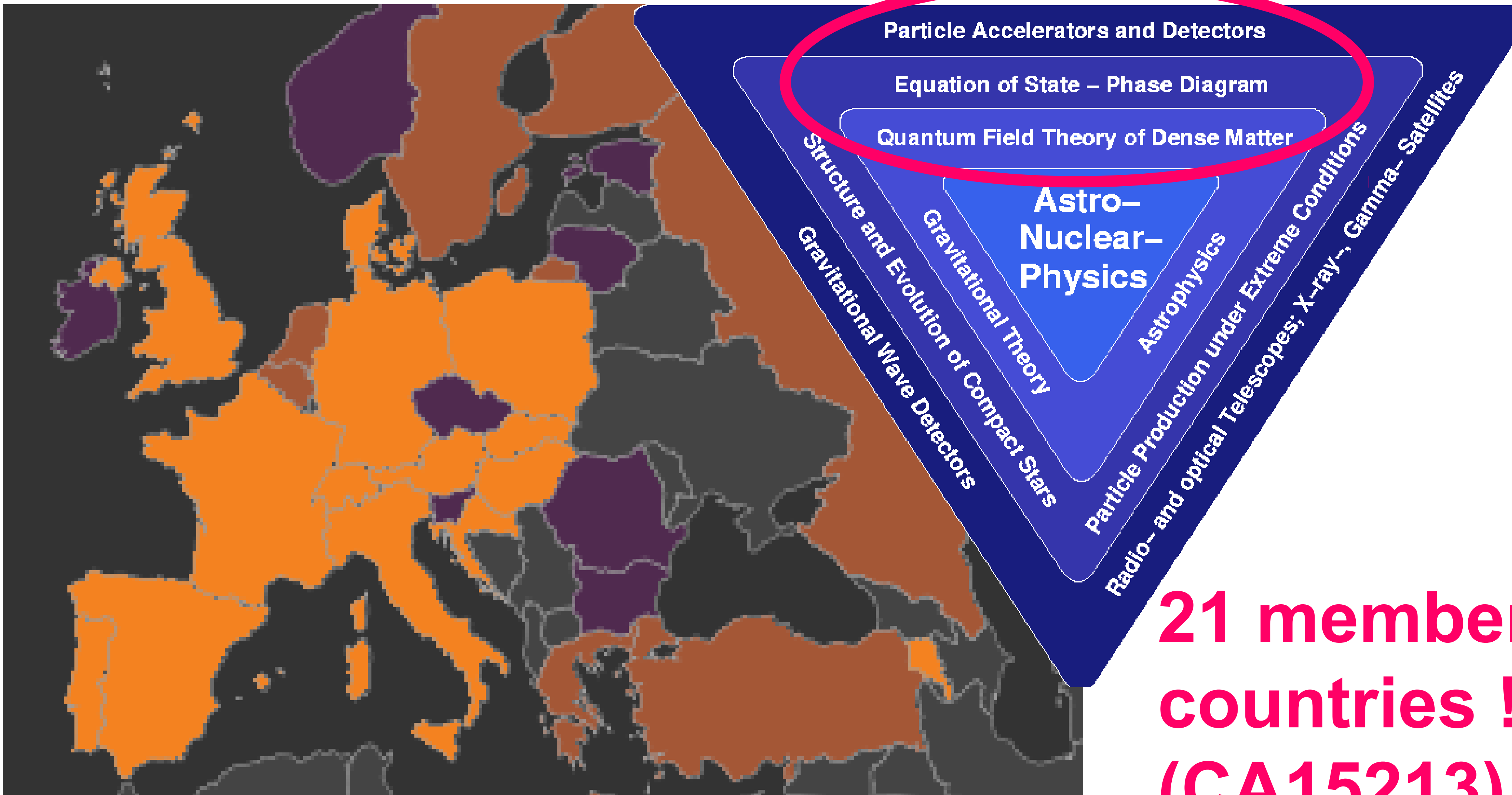


29 member countries !! (MP1304)

New comp star **!**

cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

Kick-off: Brussels, November 25, 2013



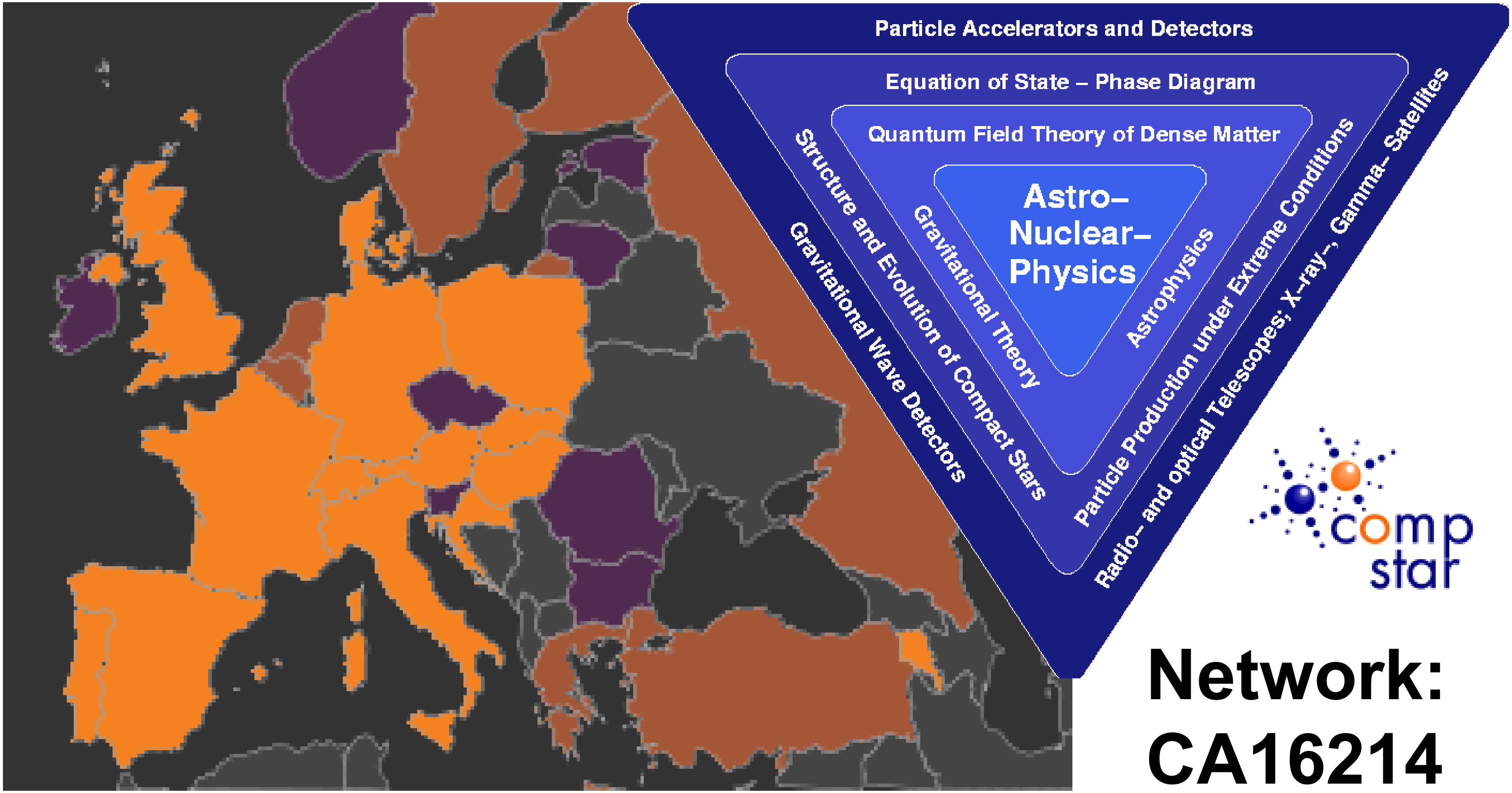
21 member countries !
(CA15213)

"Theory of HOt Matter in Relativistic Heavy-Ion Collisions"

New: THOR!

cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

Kick-off: Brussels, October 17, 2016



compstar

Network: CA16214

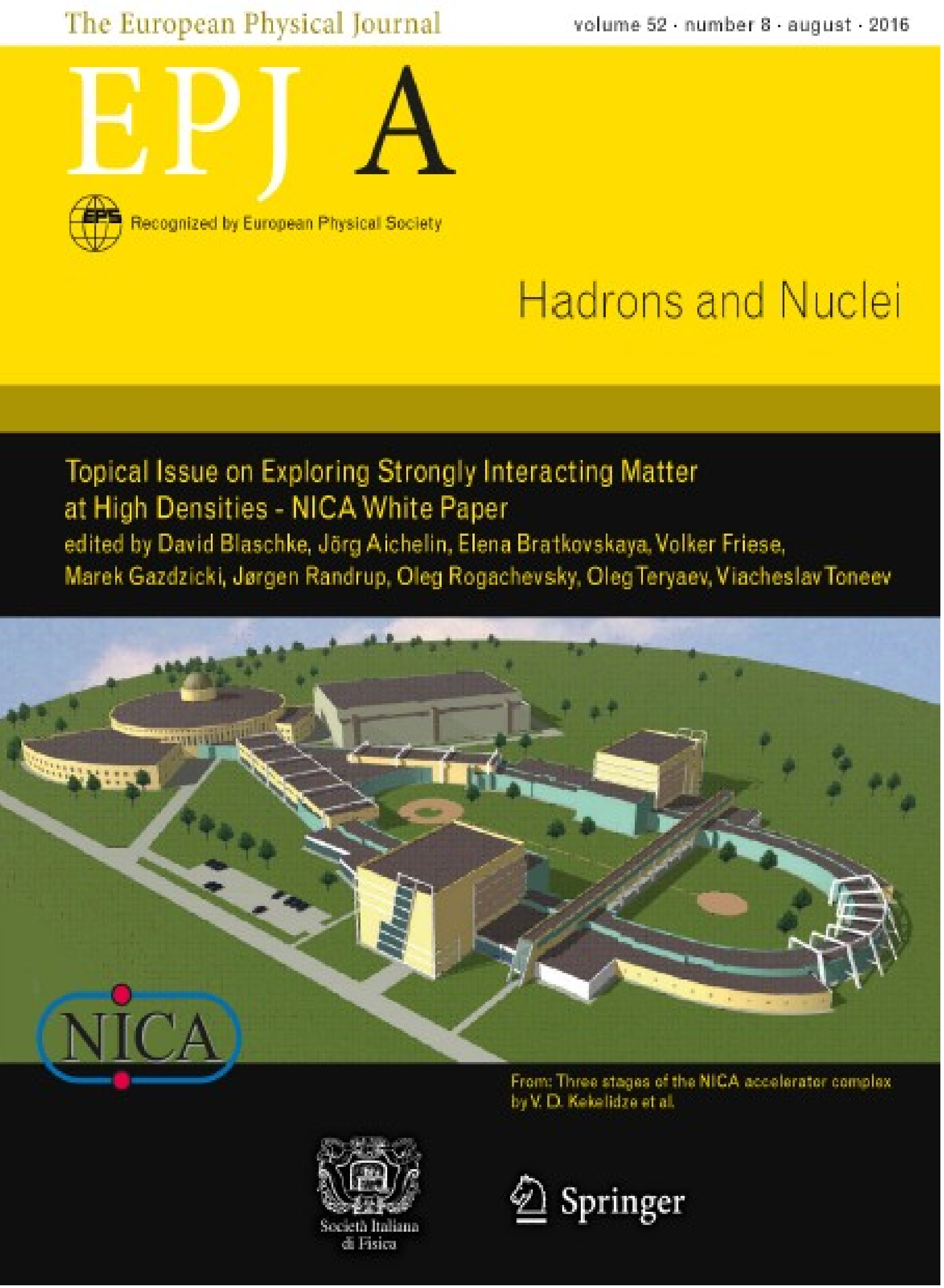
Newest: PHAROS

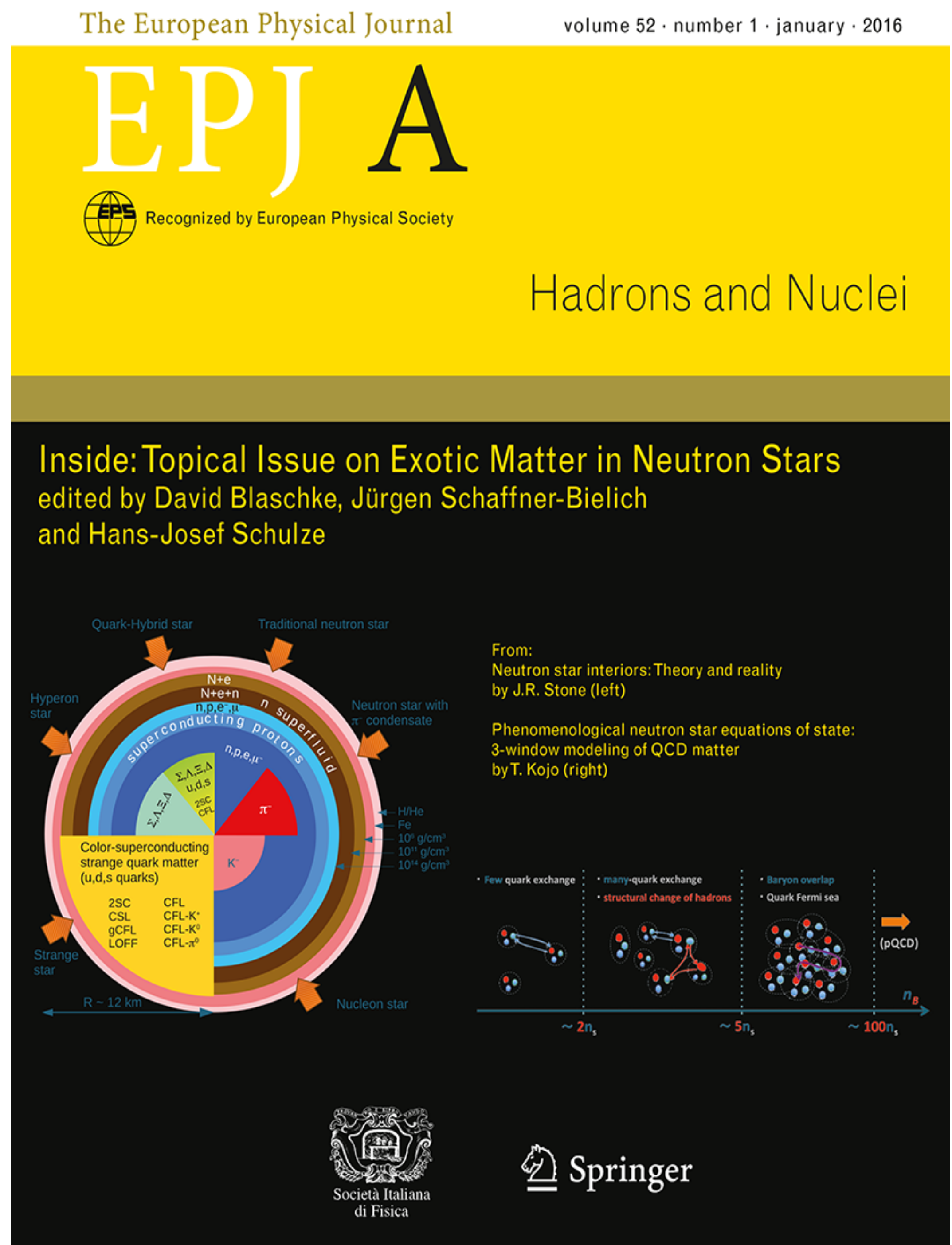
COST
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

http://www.cost.eu/COST_Actions/ca/CA16214

Kick-off: Brussels, 22.11. 2017

International Conference “Critical Point and Onset of Deconfinement”
University of Wroclaw, May 29 – June 4, 2016





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