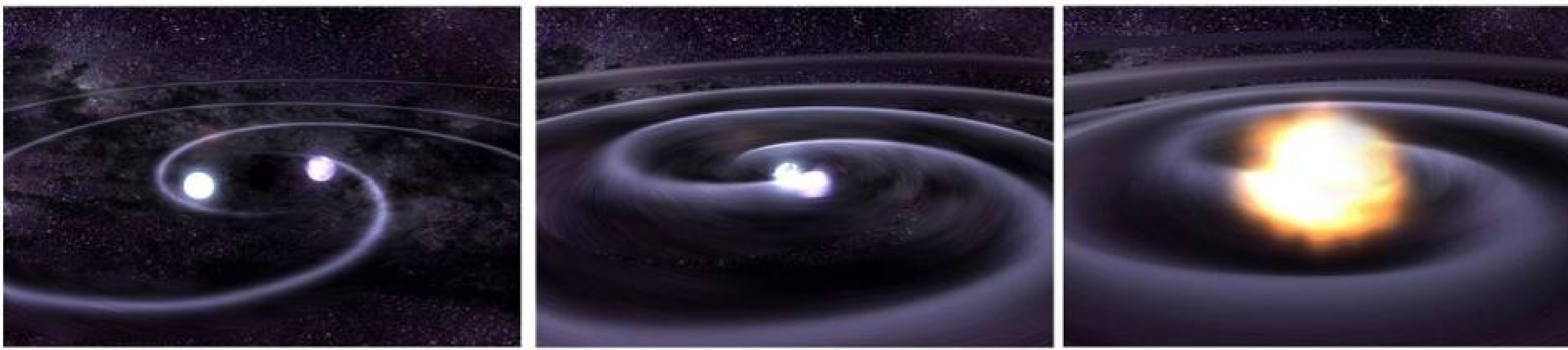
Was GW170817 indeed a merger of two neutron stars ?

David.Blaschke@gmail.com
University of Wroclaw, Poland & JINR Dubna & MEPhI Moscow, Russia



Int. Workshop IWARA-2018, Ollantaytambo, 11.September 2018

JINR DUBNA

MEPhI

NARODOWE CENTRUM NAUKI

cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Uniwersytet Wrocławski

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1. **GW170817 – a binary neutron star merger ?**
2. **Hybrid EoS – 3rd family, twins, triples, fifth family & all that! (Maxwell construction)**
3. **Pasta phases – robustness of the 3rd family solutions?**
4. **Outlook I – discover the 3rd family: NICER vs. GW170817**
5. **Outlook II – discover a strong PT in postmerger GW signal**

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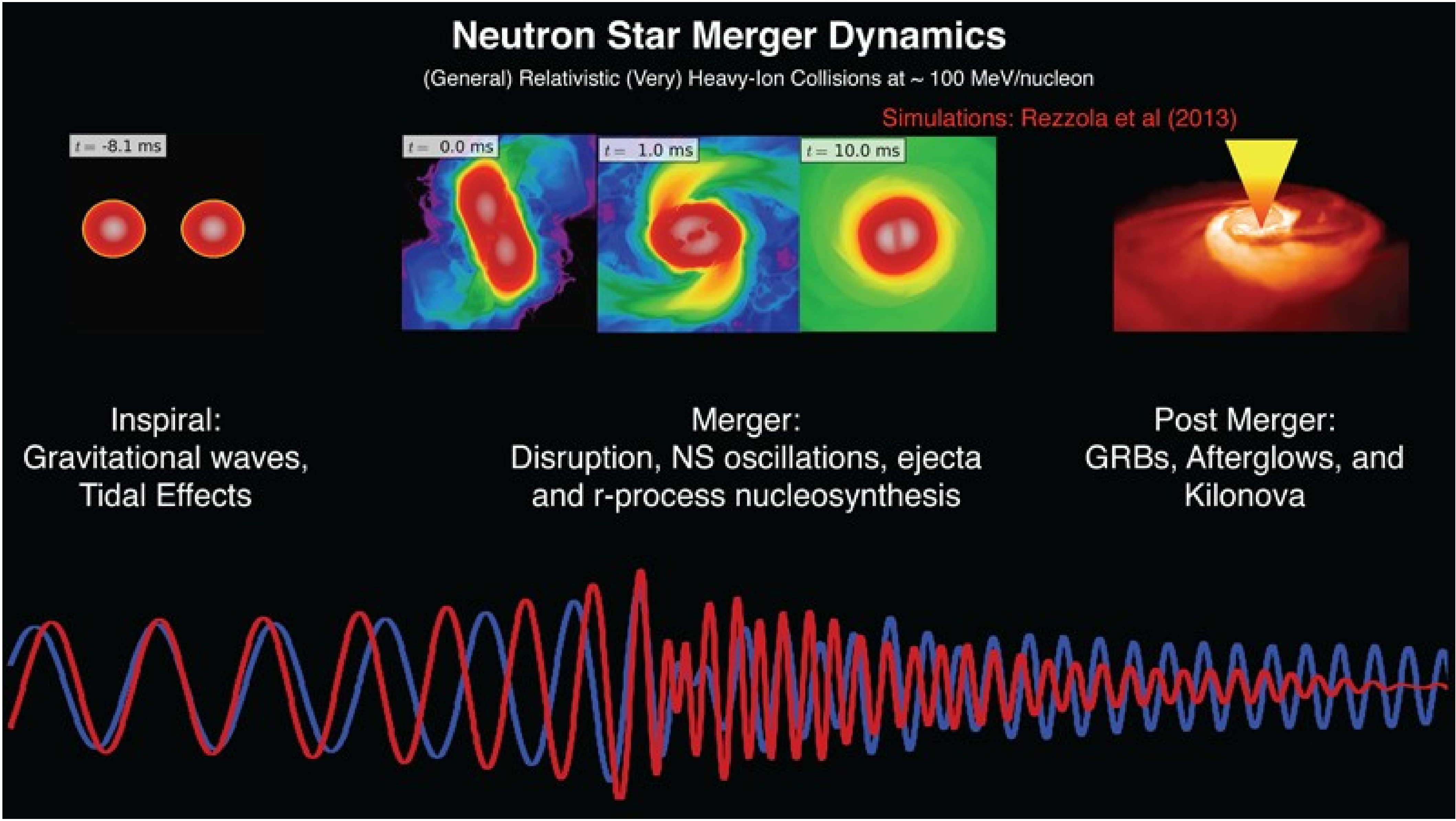
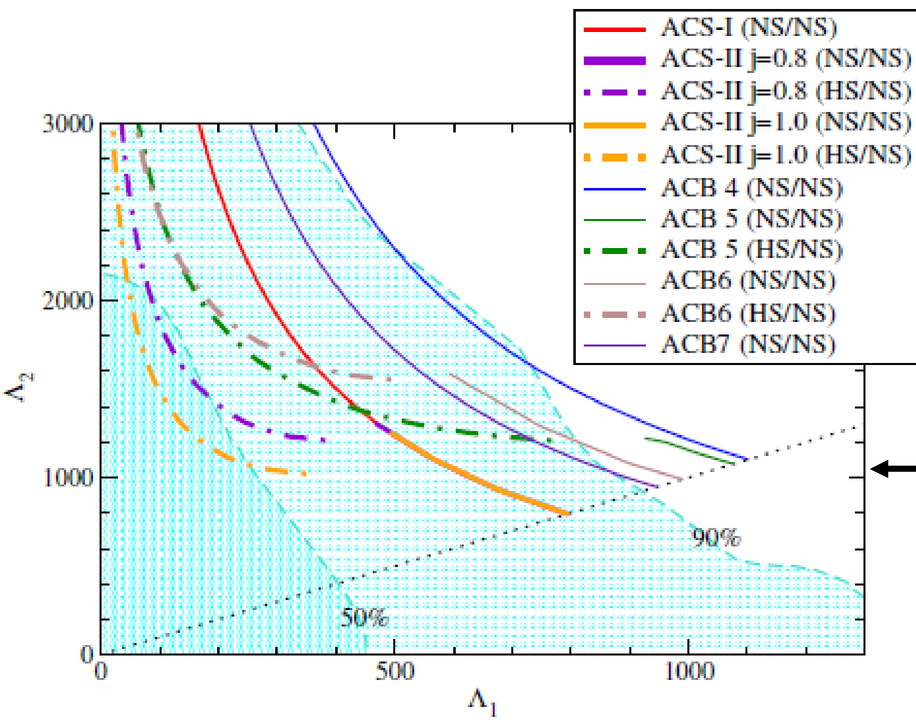
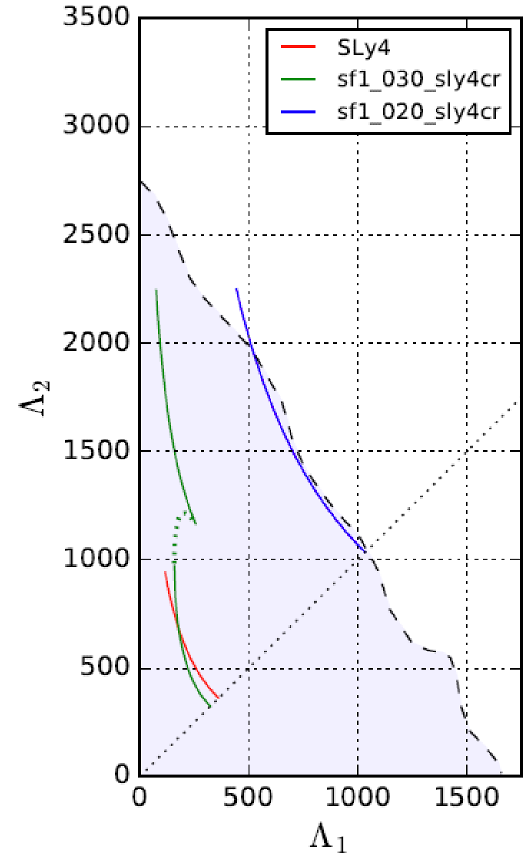
GW170817 – a merger of two neutron stars ?

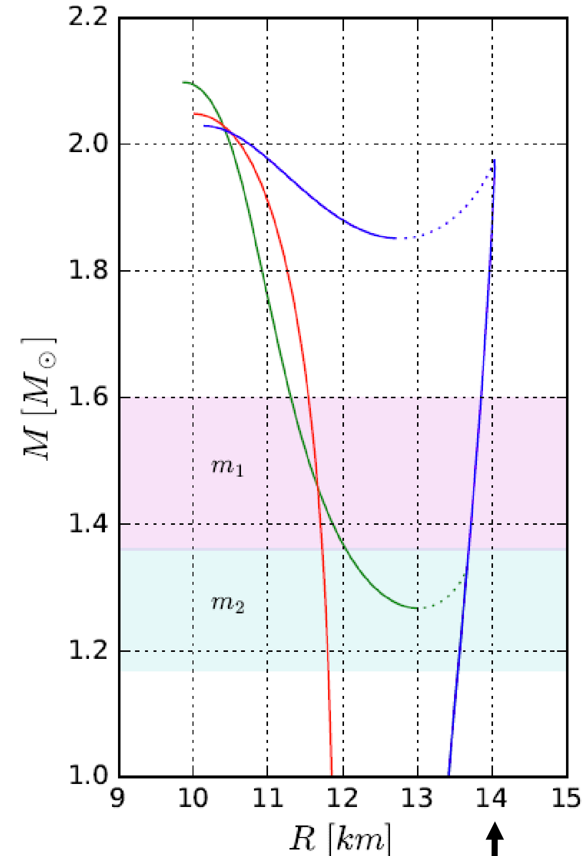


GW170817: NS-NS Merger – Equation of State Constraints

	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







M. Bejger, D.B., et al., in preparation (2018)

V. Paschalidis, K. Yagi, D. Alvarez-Castillo, D.B., A. Sedrakian, arxiv:1712.00451
Phys. Rev. D96 (2018) to appear April 24

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

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

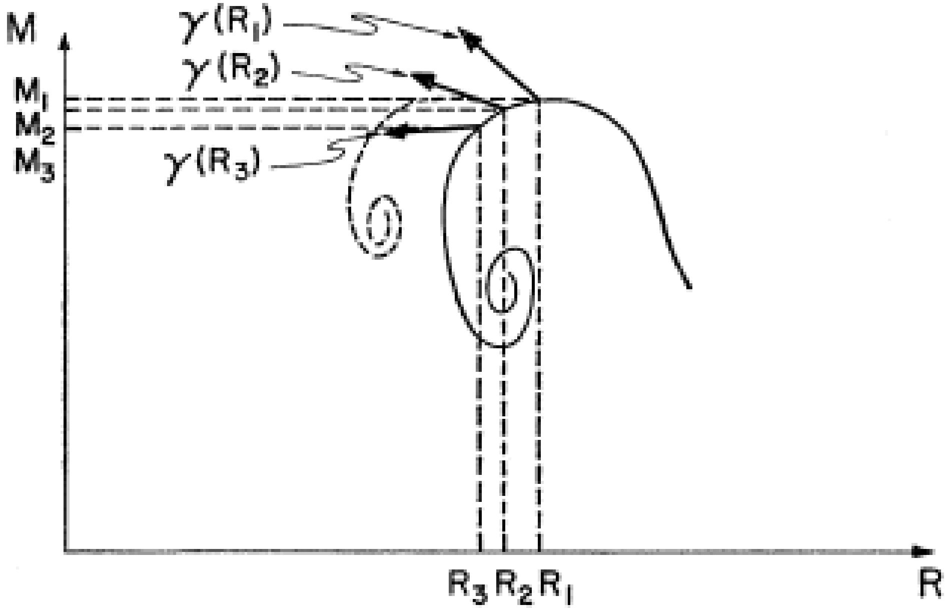
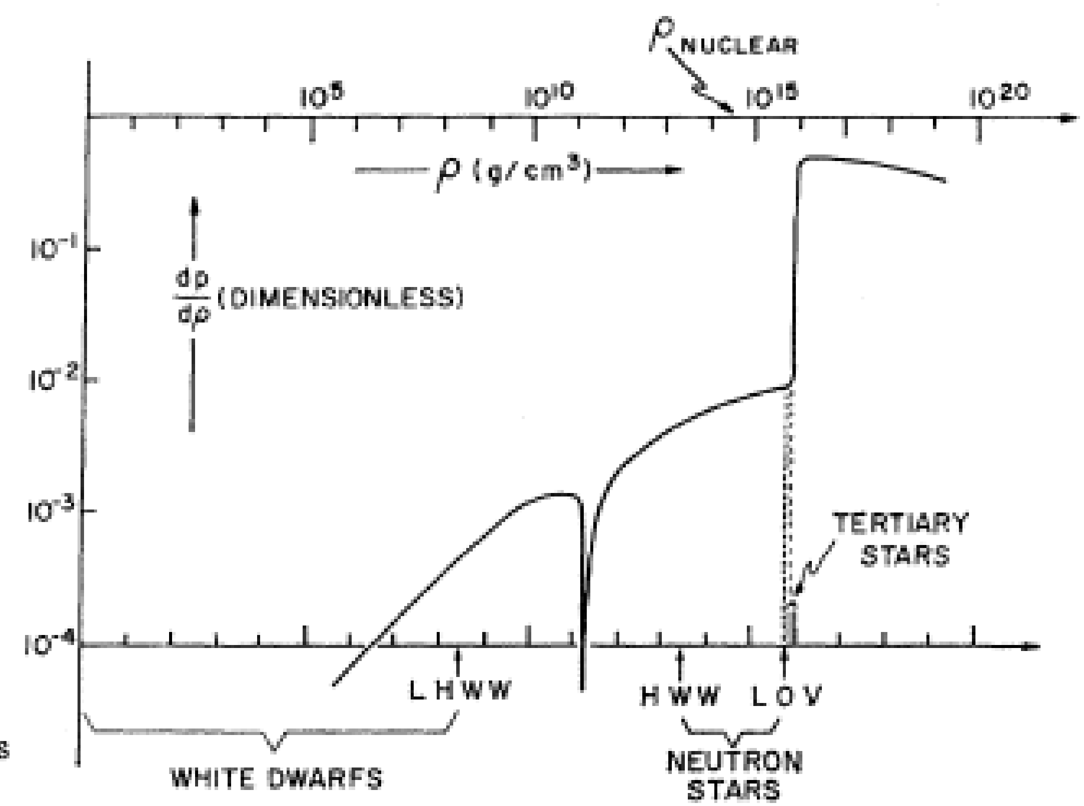


FIG. 3. A blow-up of the LOV maximum. The central densities



History: Third family & Nonidentical Twins

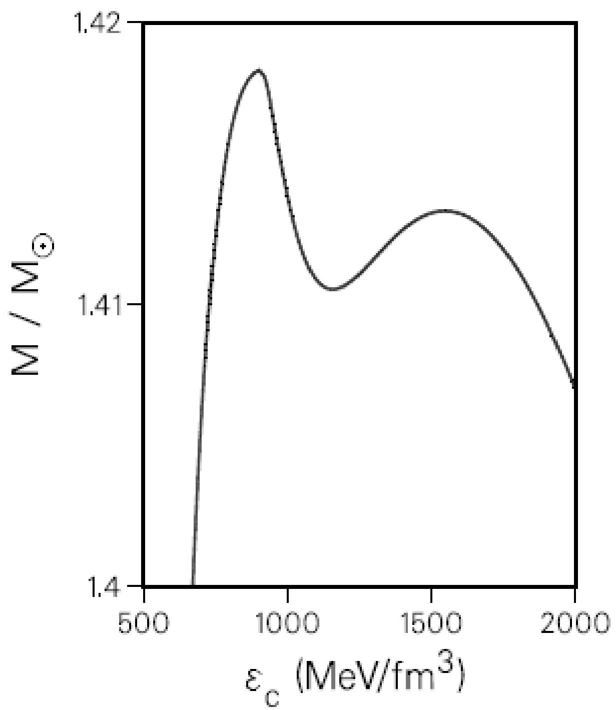
Non-Identical Neutron Star Twins

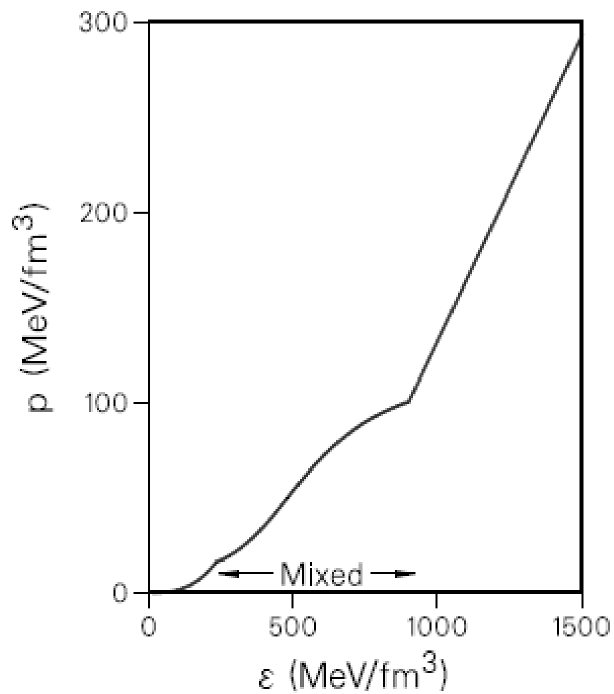
Norman K. Glendenning
Nuclear Science Division, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720, USA

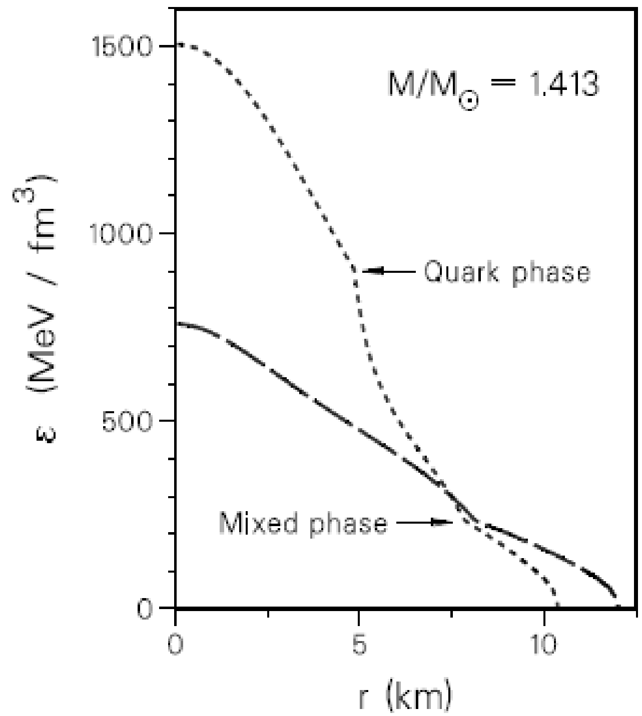
Christiane Kettner
Institut fuer theoretische Physik I, Universitaet Augsburg Memmingerstr. 6, 86135 Augsburg

(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 ...

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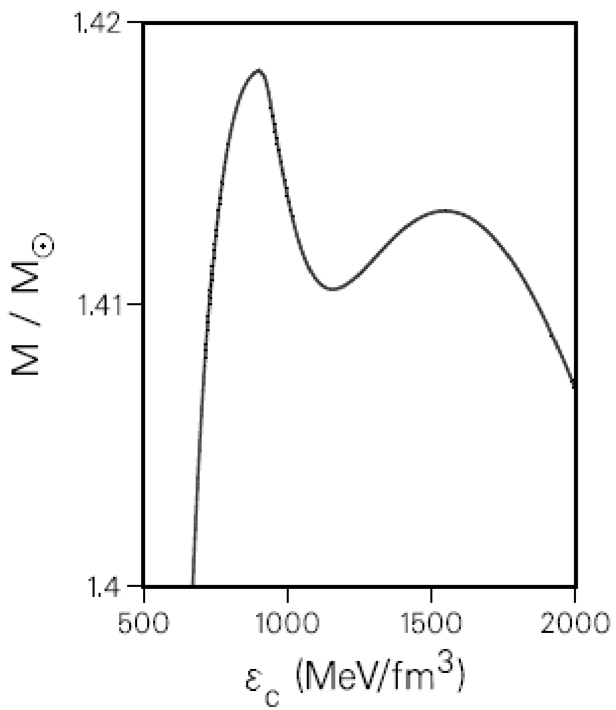
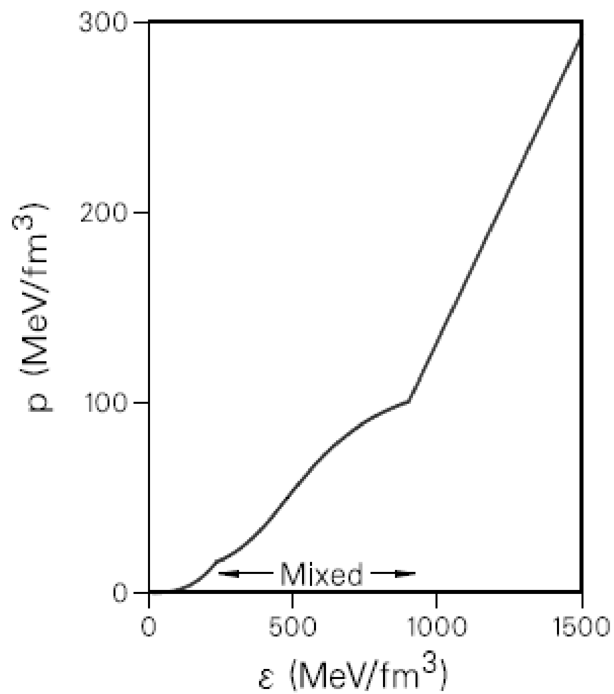
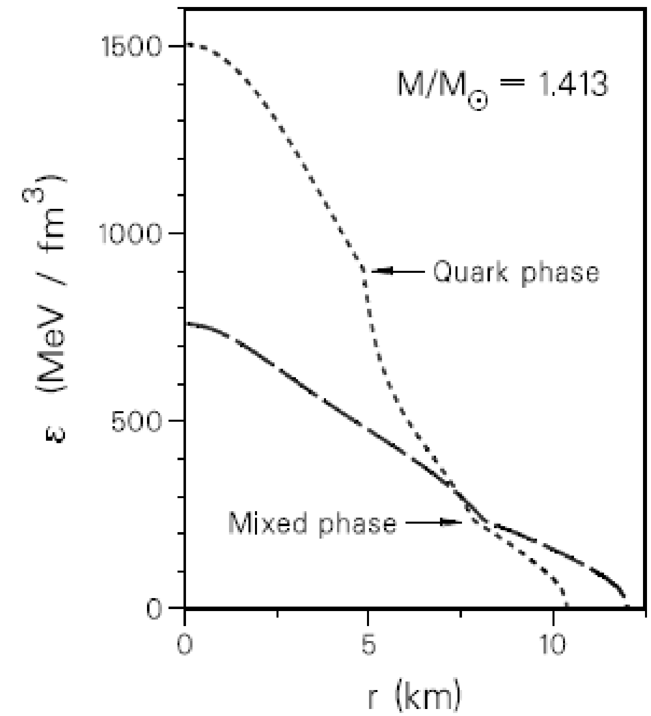


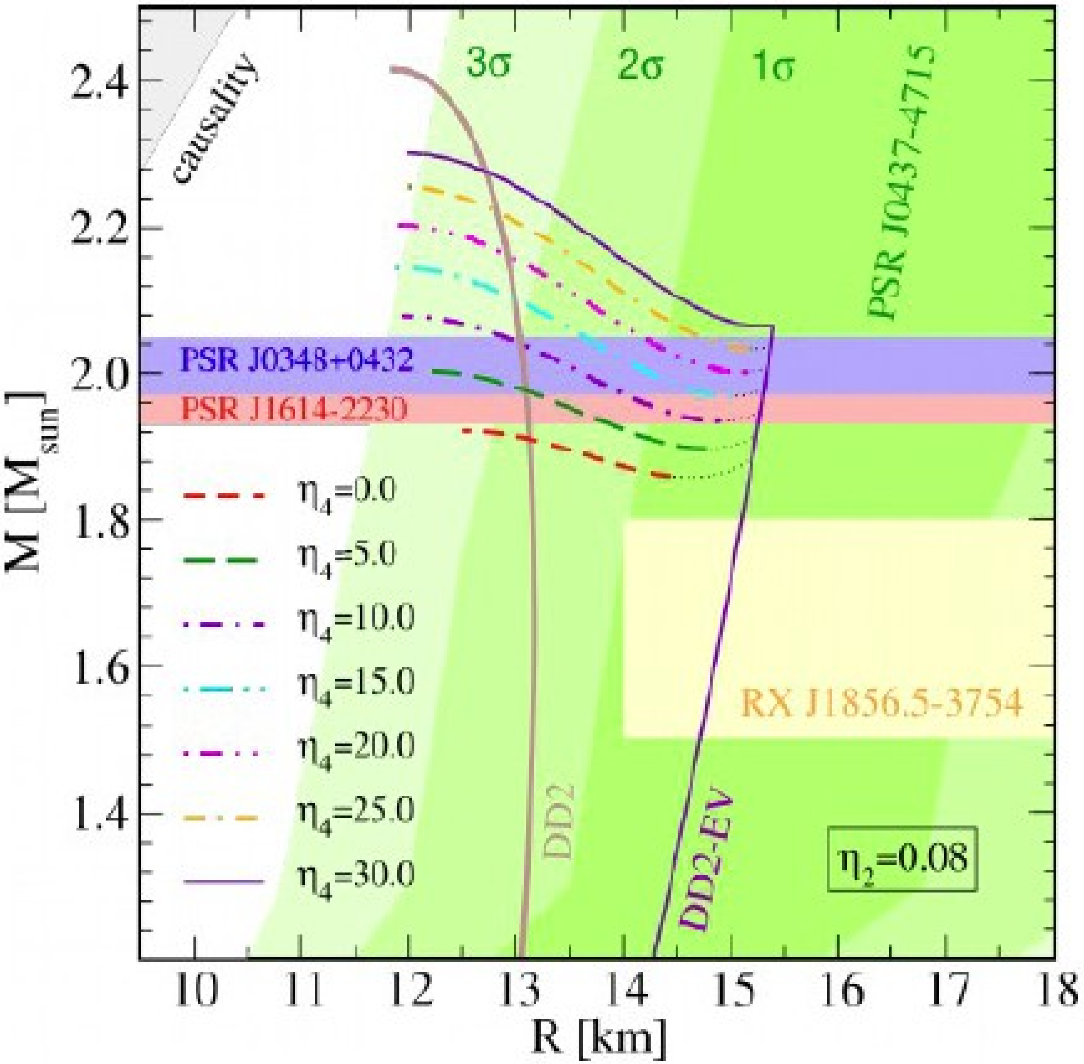




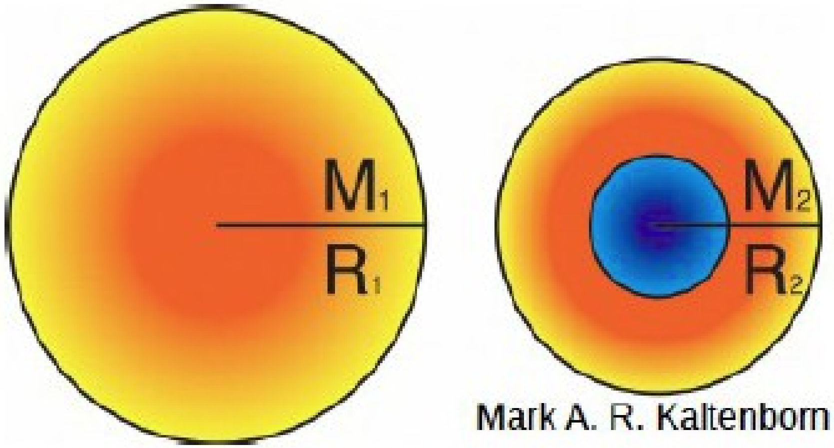
The original Twin paper uses Glendenning construction, not Maxwell one -
Surface tension zero vs. infty!
Pasta phases in-between ...

→ does not fulfill 2Msun constraint ! … Like all follow-up papers until ~2010 (B.K. Agrawal)

Neutron Star Interiors: Strong Phase Transition?



- Star configurations with same masses, but different radii

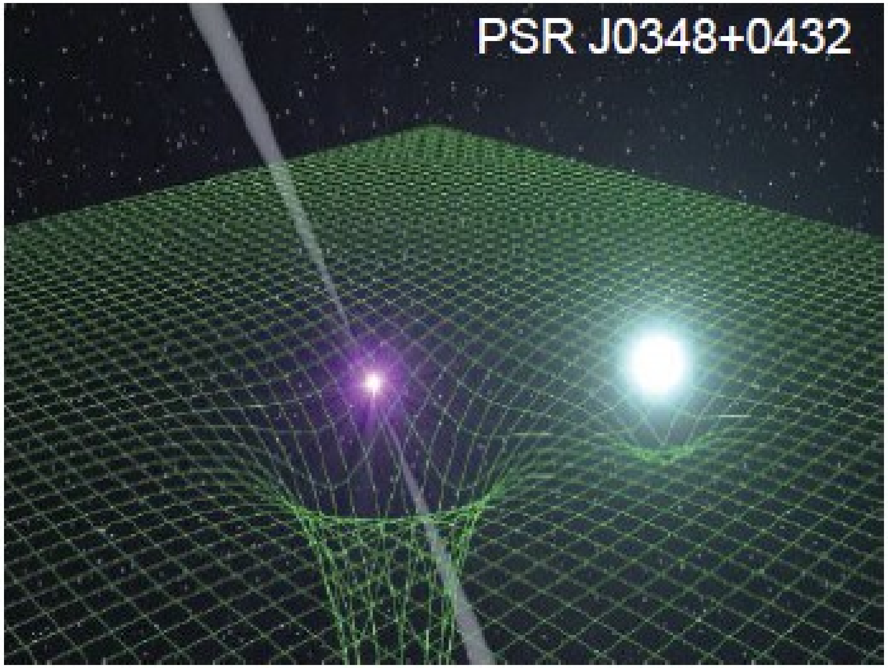


- **New class of EOS, that features high mass twins**
- NASA NICER mission: radii measurements ~ 0.5 km
- Existence of twins implies 1st order phase-transition and hence a critical point

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

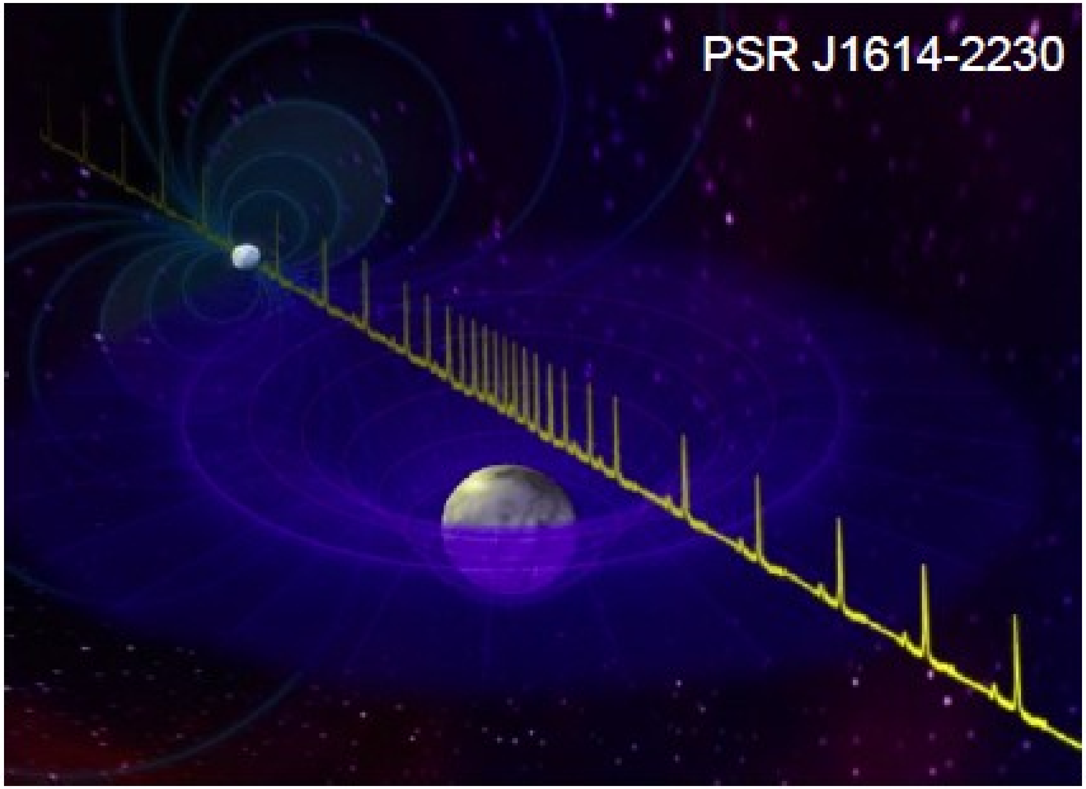
Neutron Star Interiors: Strong Phase Transition?

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

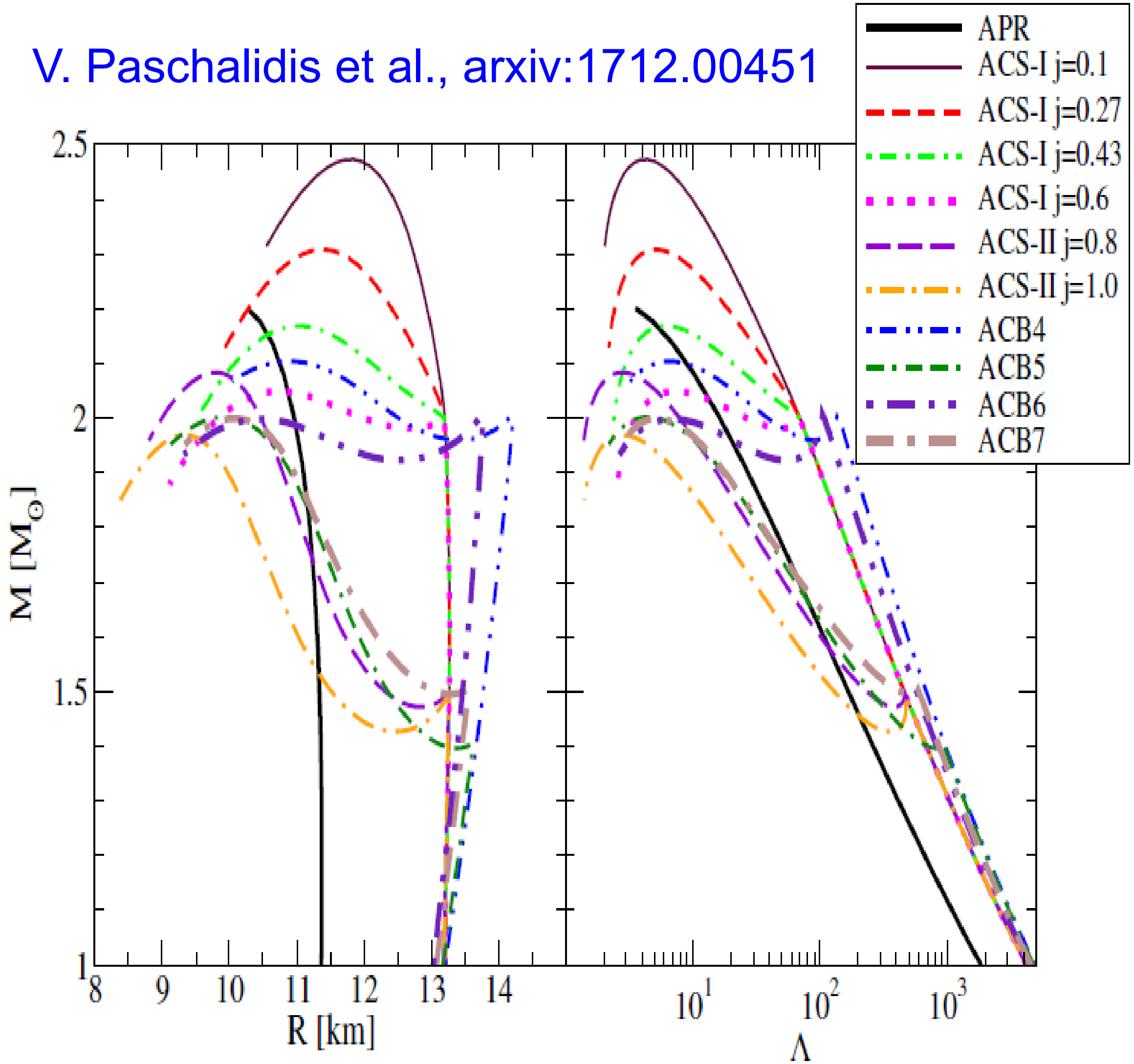


What if they were high-mass twin stars?

→ radius measurement required ! → NICER (2018/19)

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

V. Paschalidis et al., arxiv:1712.00451



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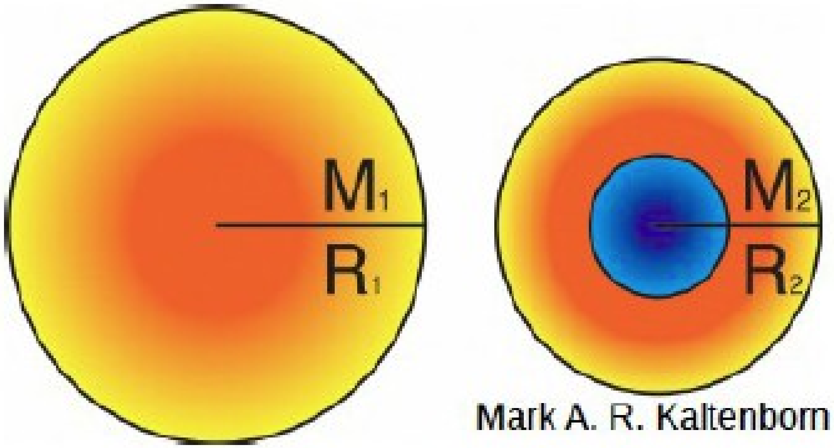

Mark A. R. Kaltenborn

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

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

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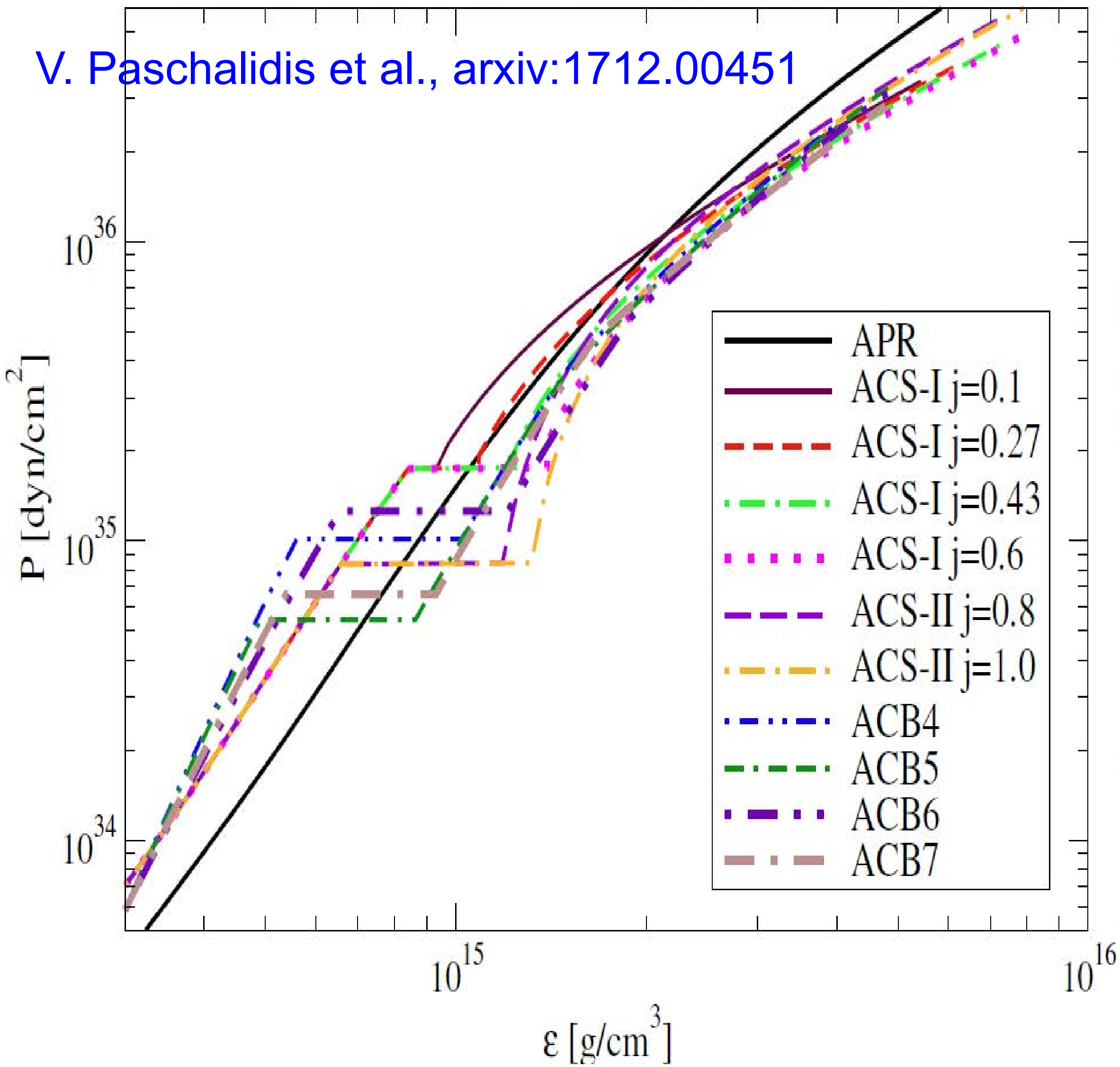

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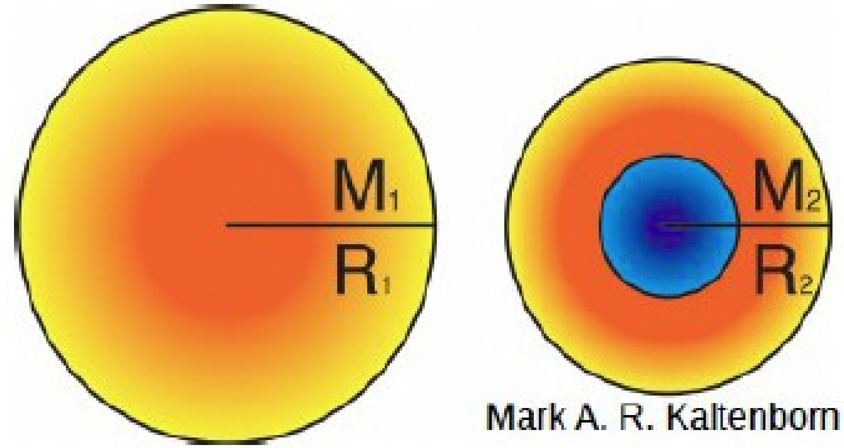

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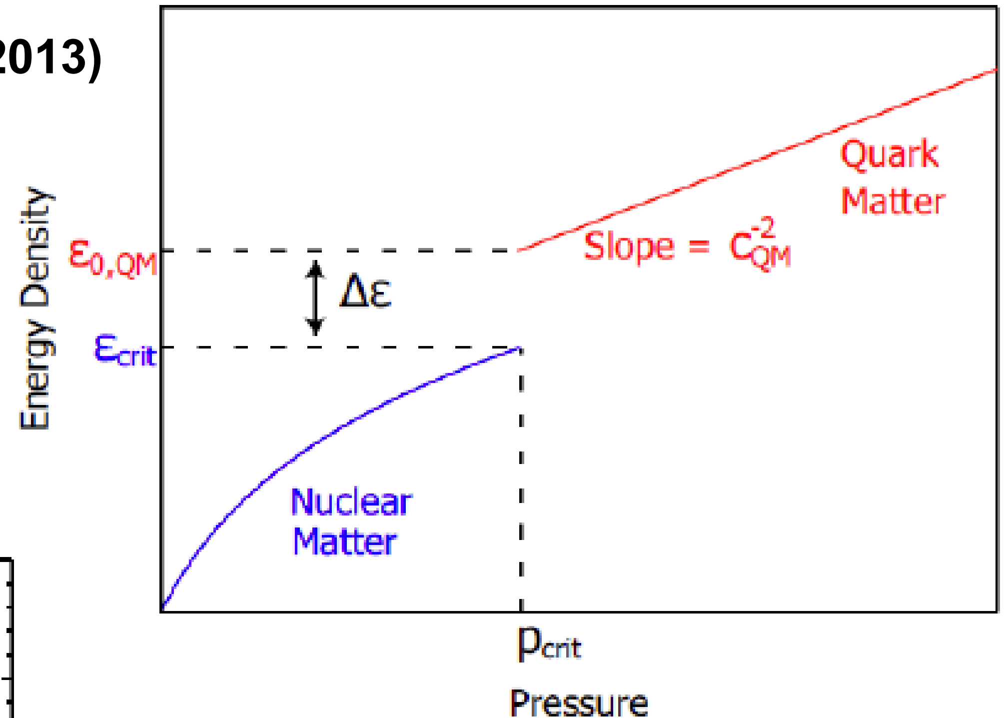
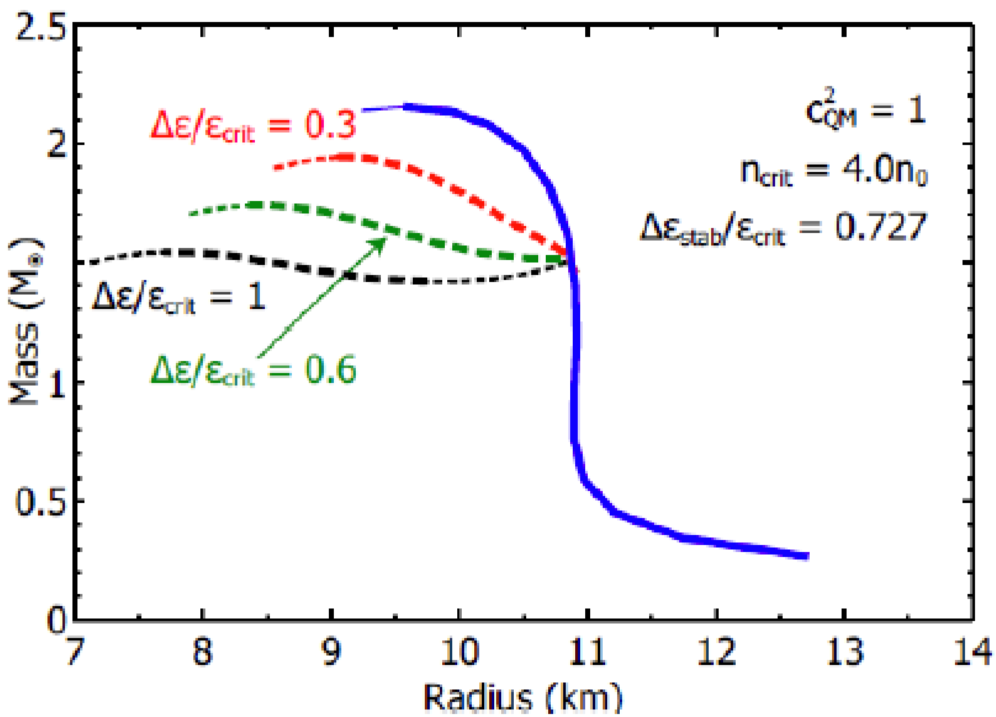
Constant Speed of Sound (CSS) Model

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

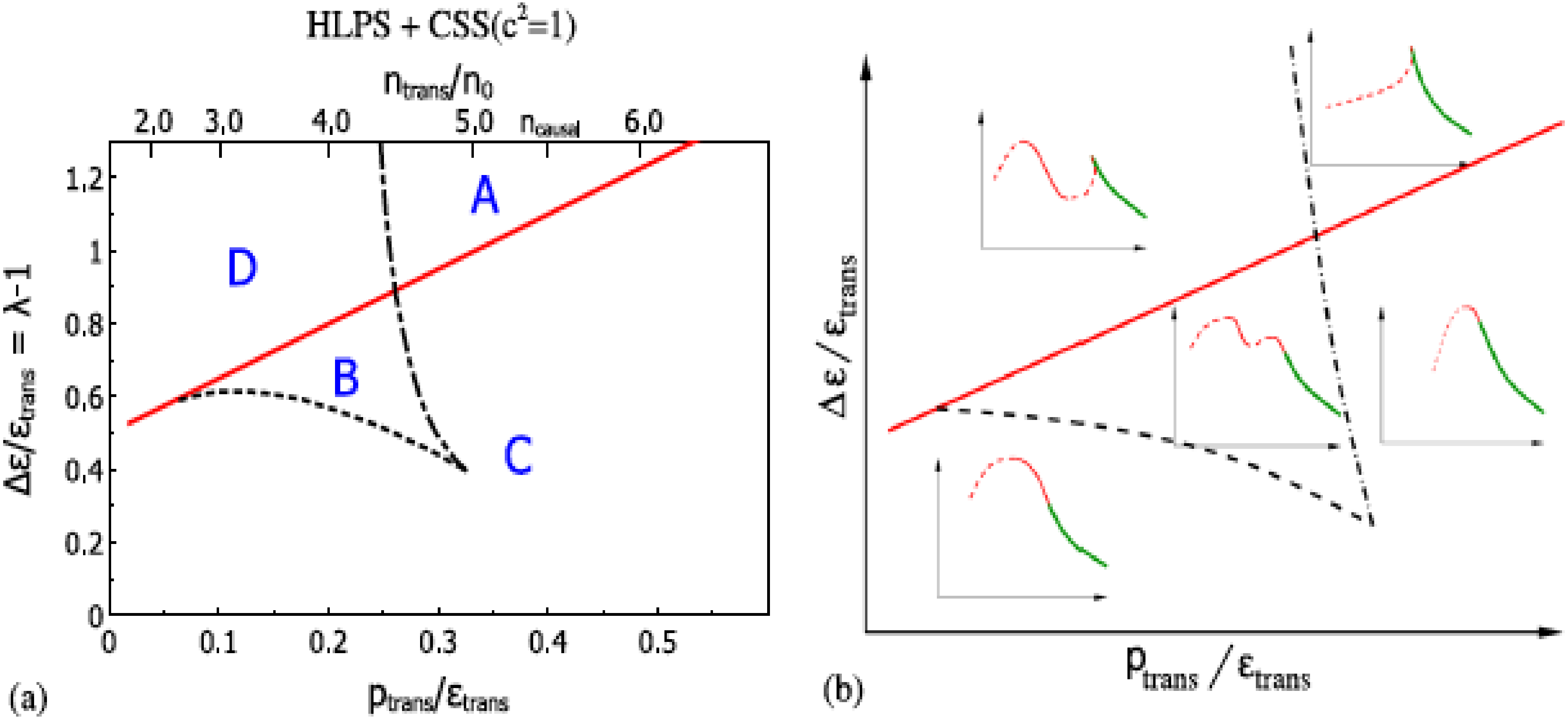
First order PT can lead to a stable branch of hybrid stars with quark matter cores which, depending on the size of the "latent heat" (jump in energy density), can even be disconnected from the hadronic one by an unstable branch → **"third family of CS"**.





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)

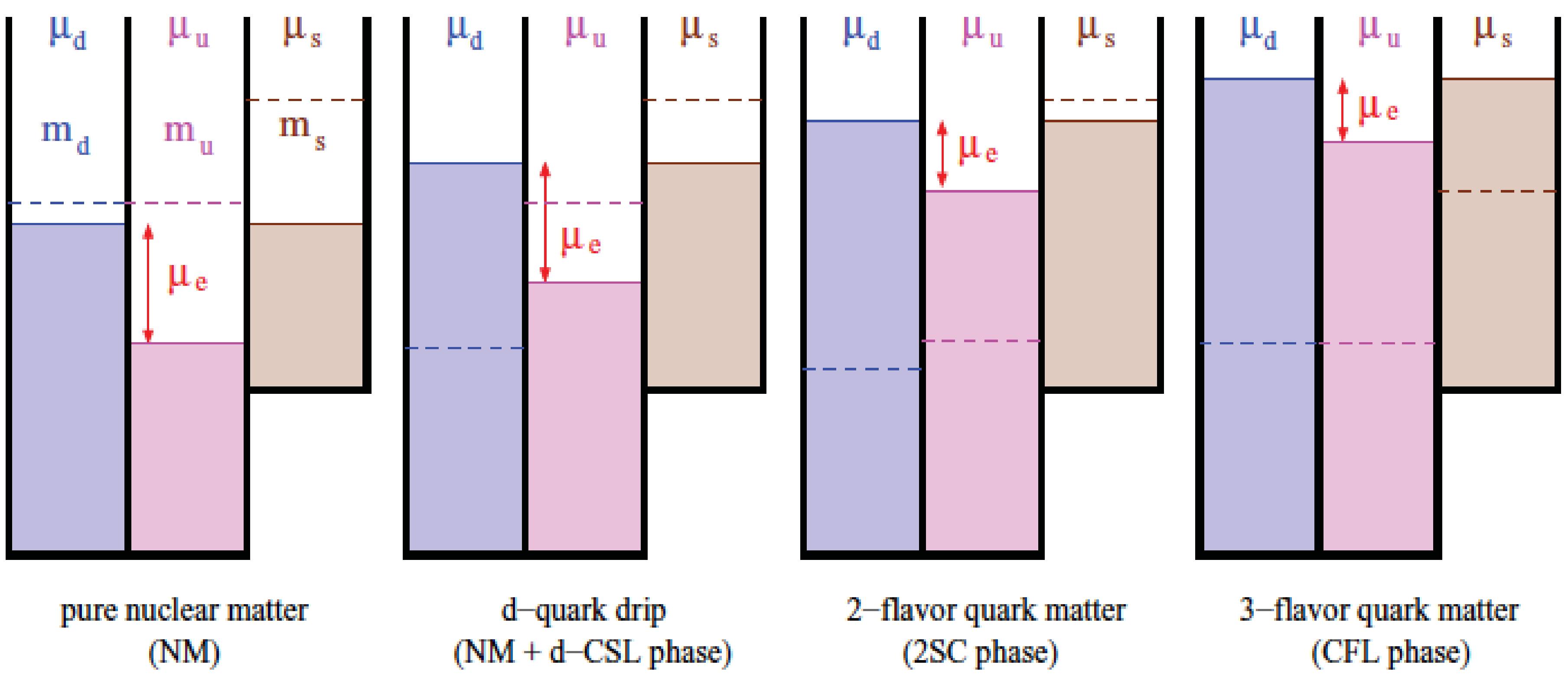
Most interesting and clear-cut cases: (D)isconnected and (B)oth – high-mass twins!

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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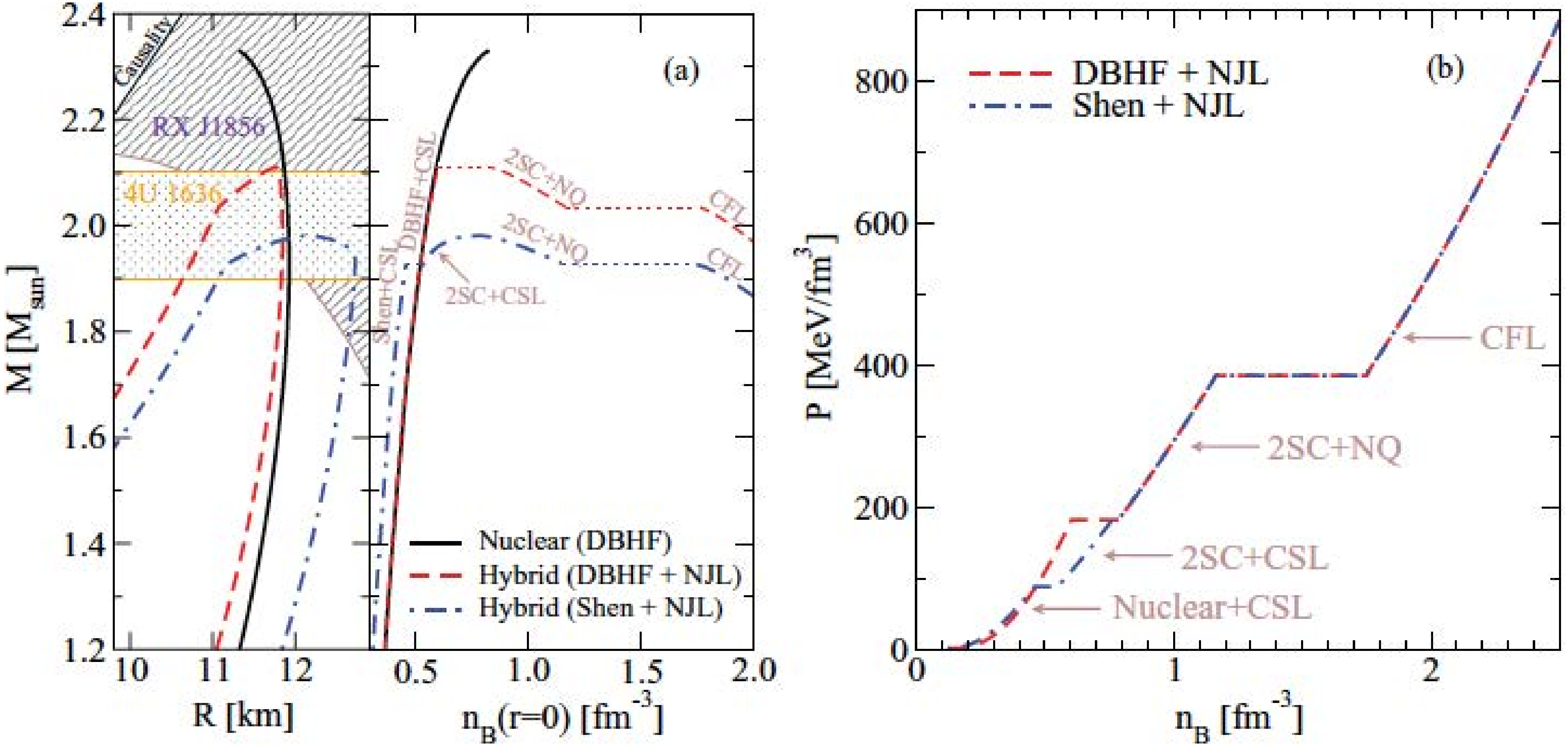
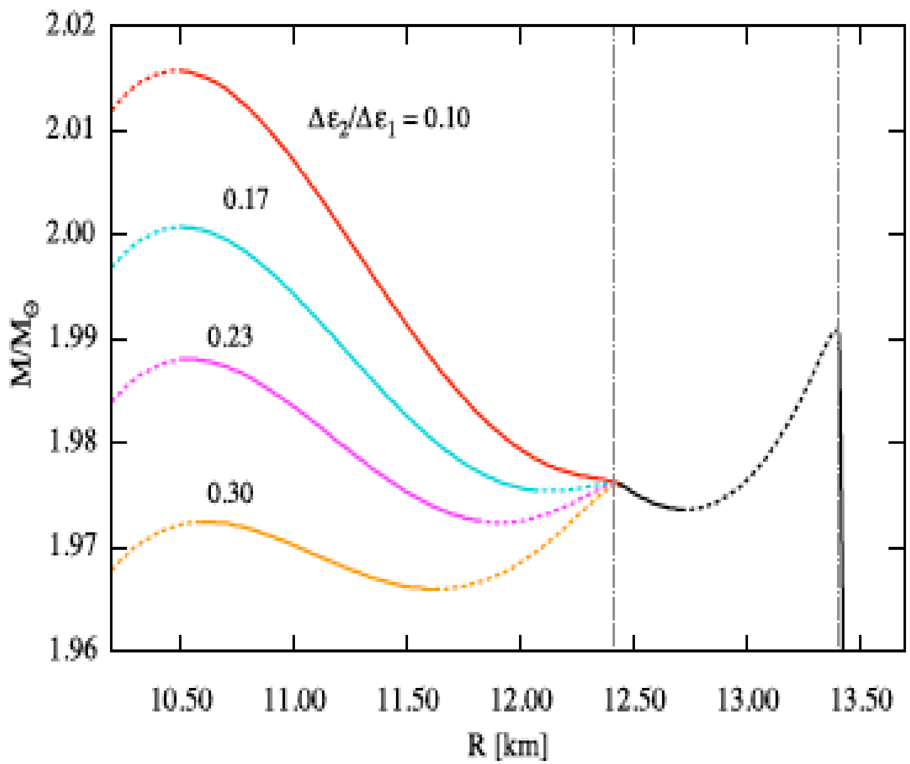
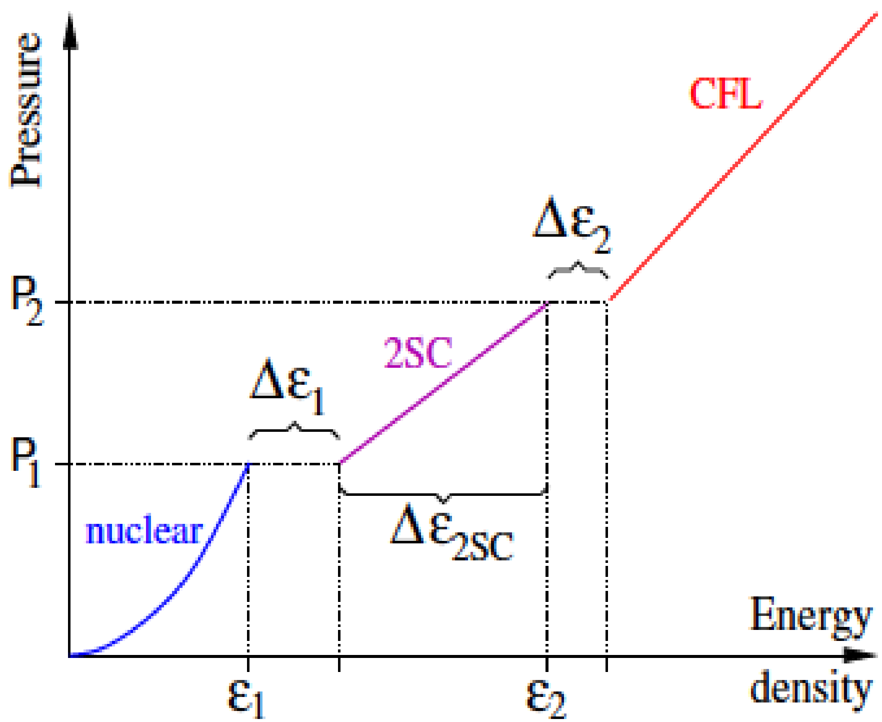


D.B., F. Sandin, T. Klaehn, J. Berdermann, PRC 80 (2009) 065807

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)

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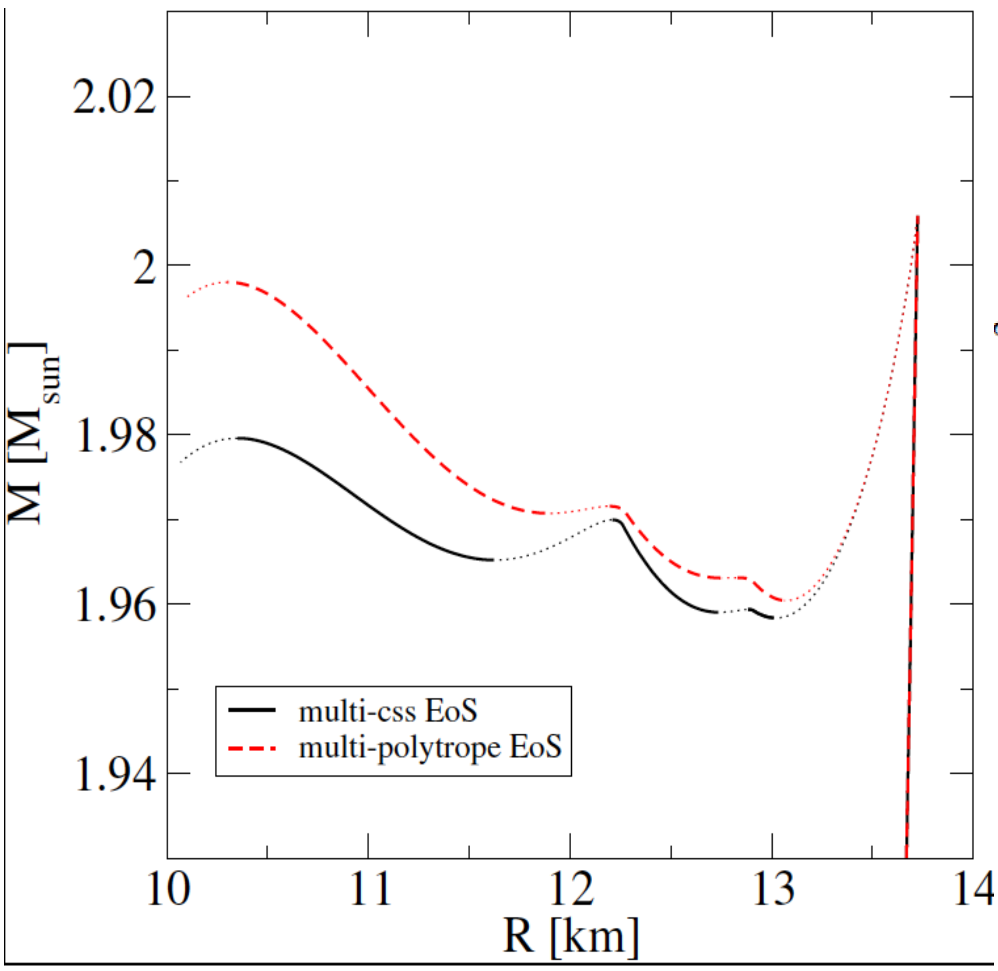

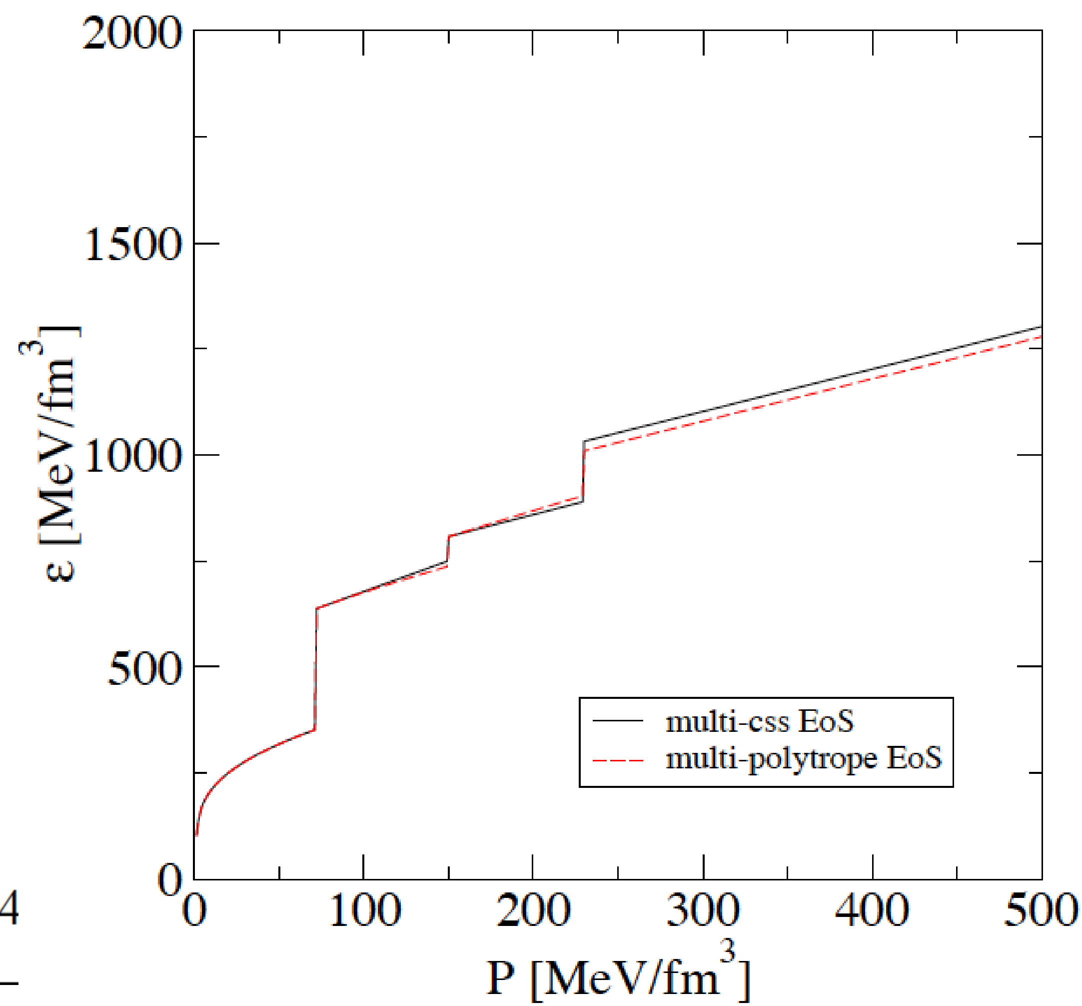

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High-mass triples and fifth family:
A. Ayriyan, D.B., H. Grigorian, in preparation (2018)

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

M.A.R. Kaltenborn, N.-U.F. Bastian, D.B. Blaschke, PRD 96, 056024 (2017) ; [arxiv:1701.04400]

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)

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

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

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

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

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

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

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

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

*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

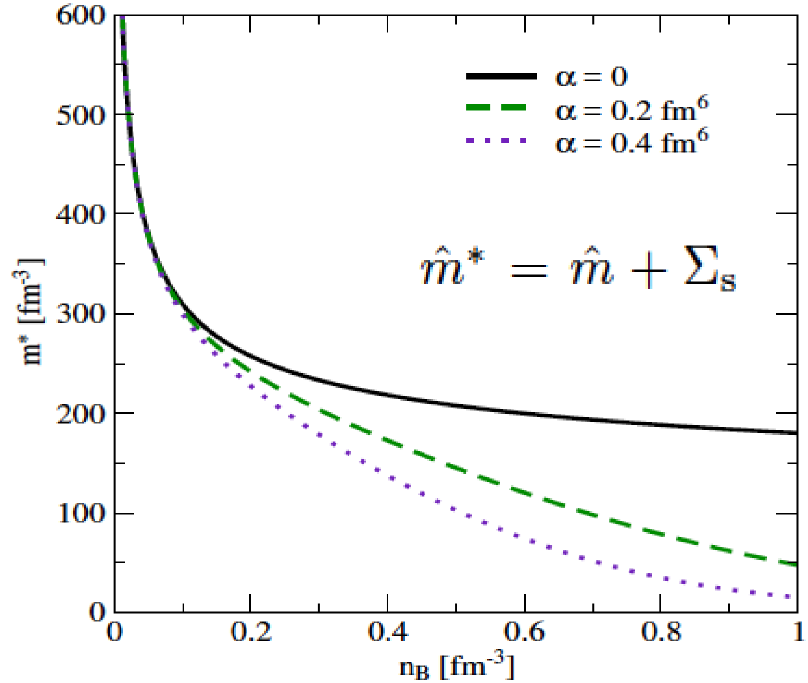
$$U(n_s, n_v) = D(n_v) n_s^{2/3} + a n_v^2 + \frac{b n_v^4}{1 + c n_v^2} ,$$

Quark selfenergies

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

Quark “confinement”

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

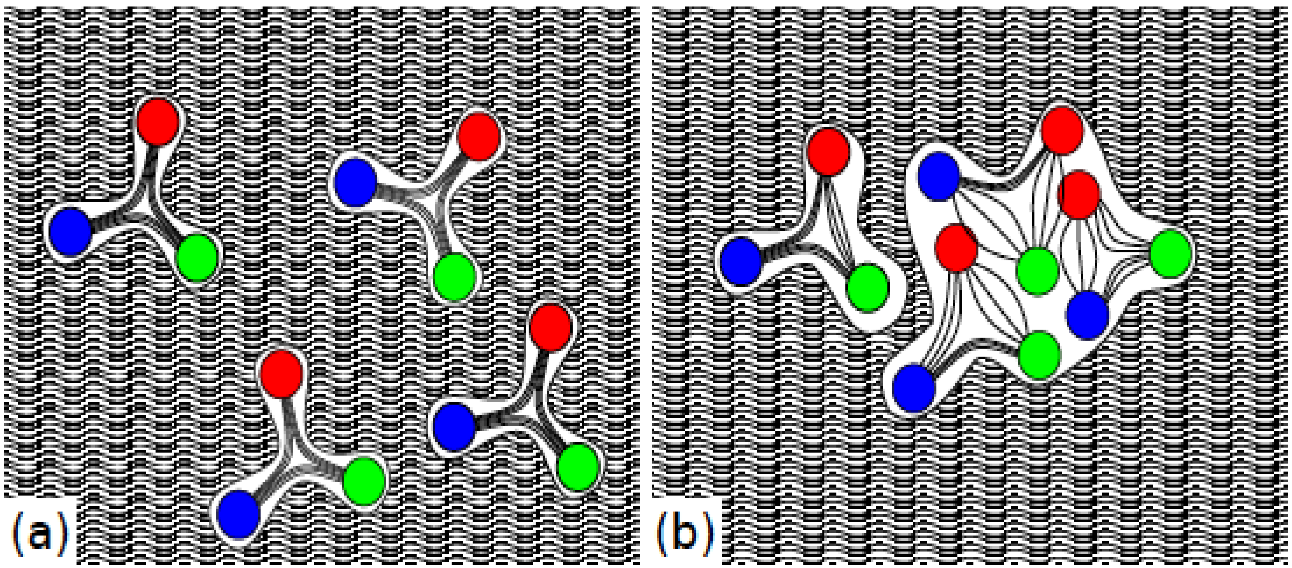


String tension & confinement due to dual Meissner effect (dual superconductor model)

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

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

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

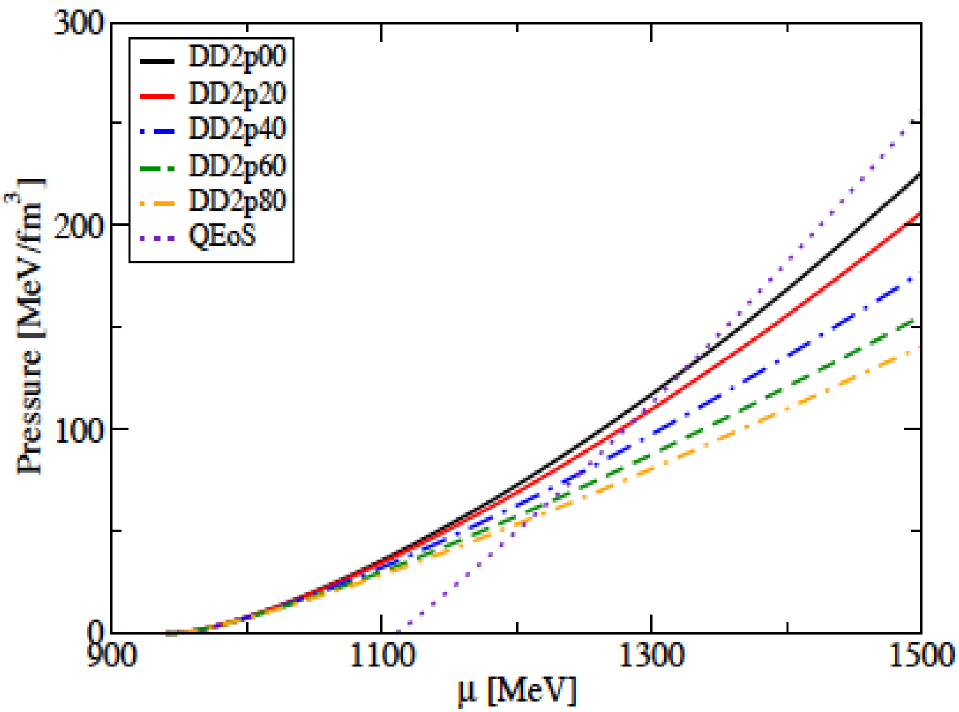


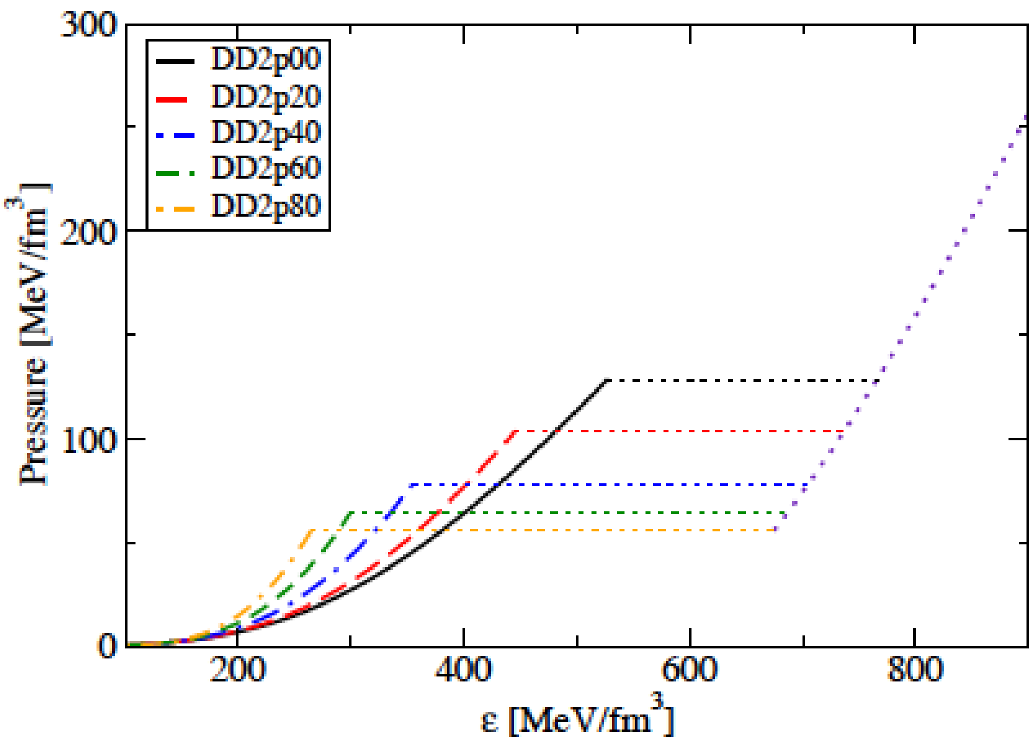
Phase transition from hadronic to SFM quark matter

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

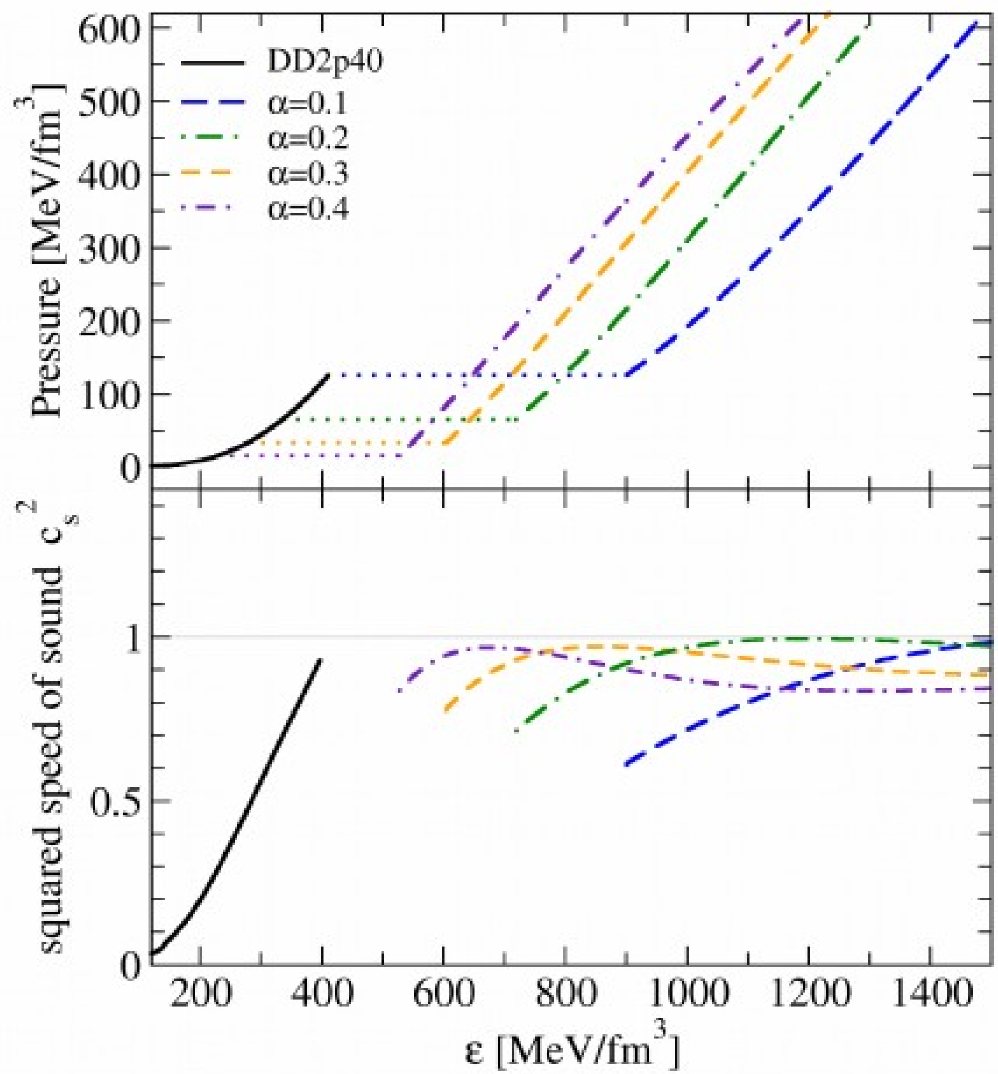
$$\Phi_n = \Phi_p = \begin{cases} 1, & \text{if } n_B < n_0 \\ e^{-\frac{v|v|}{2}(n_B - n_0)^2}, & \text{if } n_B > n_0 \end{cases}$$

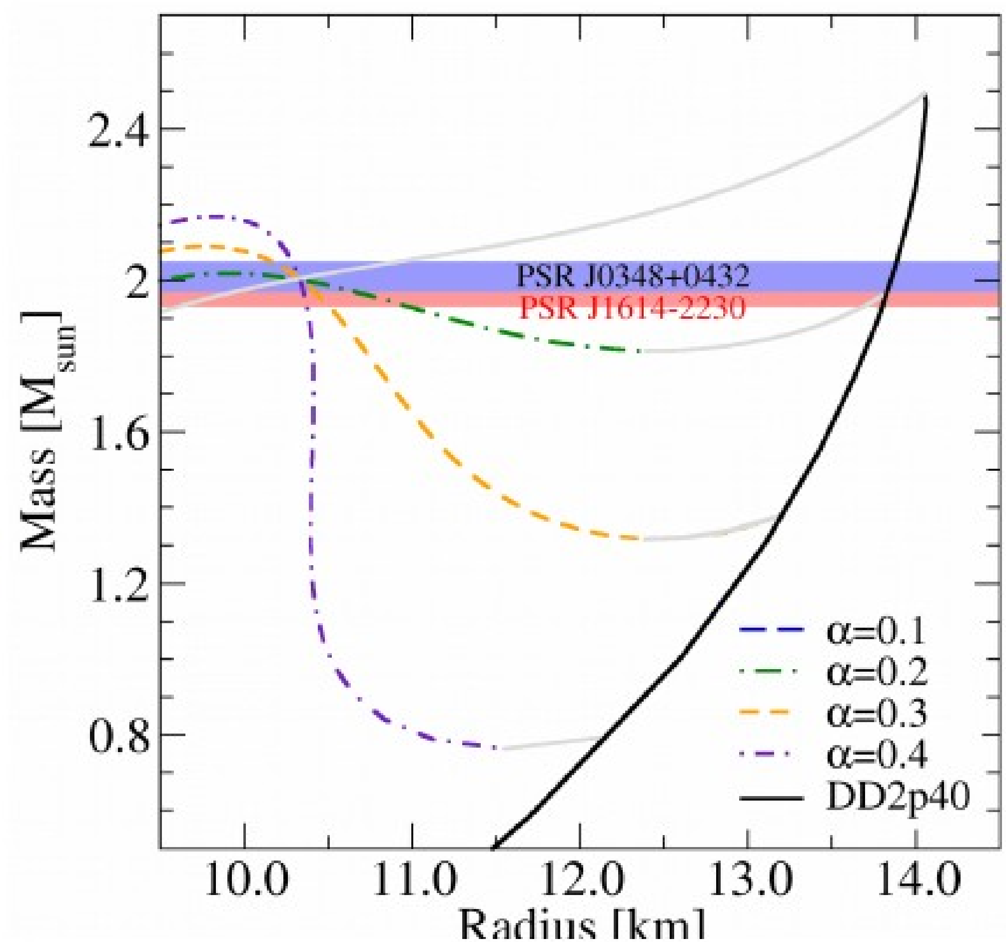
Varying the hadronic excluded volume parameter, p00 → v=0, … , p80 → v=8 fm^3





Hybrid EoS: high-mass and low-mass twins (3rd family) !





Kaltenborn, Bastian, Blaschke, arXiv:1701.04400 → Phys. Rev. D 96, 056024 (2017)

Results of Maxwell construction! Could pasta phases remove the twins (3rd family instability)?

Pasta phases – robustness of 3rd family?

Tatsumi-san,
Voskresensky-san,
Nara (2000)

A. Ayriyan, N.-U.Bastian, D.B., H. Grigorian, K. Maslov, D. Voskresensky;
Phys. Rev. D96, 045802 (2018); [arxiv:1711.03926]

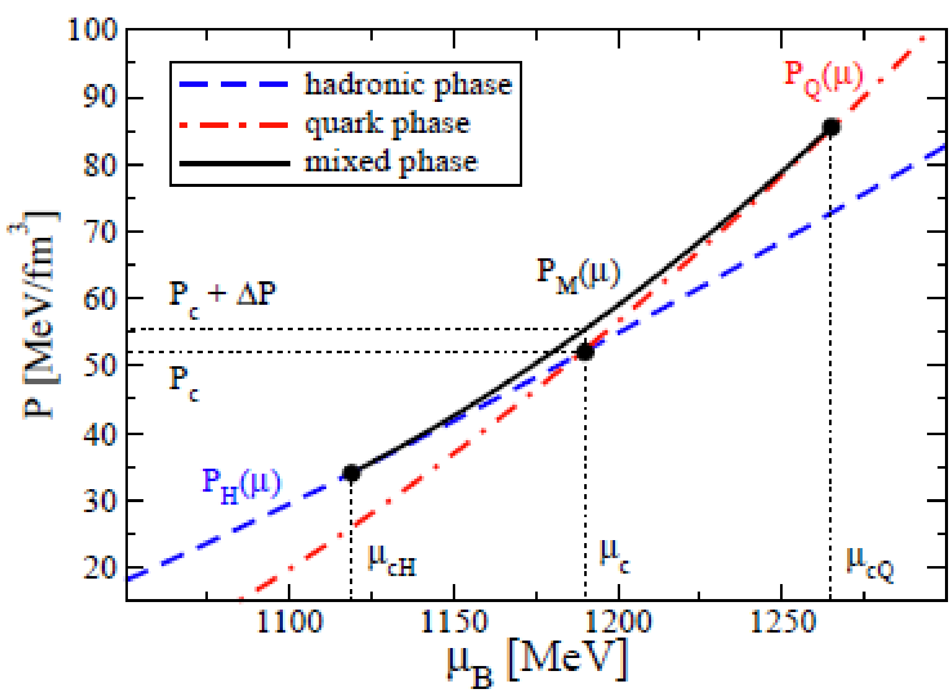
K. Maslov, N. Yasutake, A. Ayriyan, D.B., H. Grigorian, T. Maruyama, T. Tatsumi,
D. Voskresensky; in preparation

Robustness of Twins against Pasta Phase Effects

PHYSICAL REVIEW C 97, 045802 (2018)

Robustness of third family solutions for hybrid stars against mixed 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



Strong 1st order transition (large density jump)
→ surface tension large → structures (pasta phases)

Simple interpolation ansatz (Ayriyan et al.(2017)):

$$P_M(\mu) = a(\mu - \mu_c)^2 + b(\mu - \mu_c) + P_c + \Delta P.$$

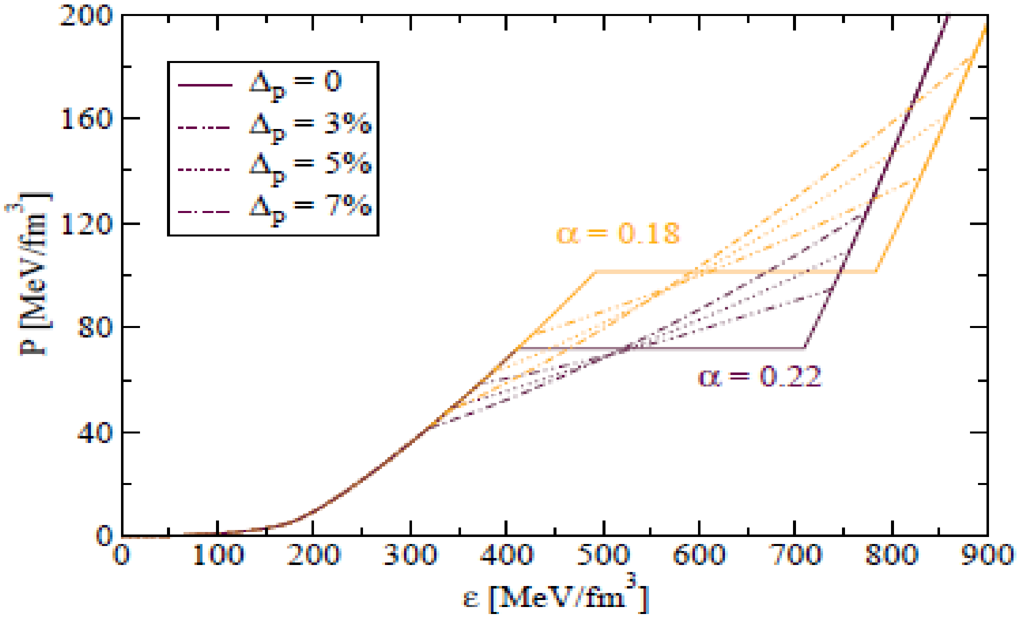
Continuity of pressure: $P_M(\mu_{cH}) = P_H(\mu_{cH}) = P_H$

$$P_M(\mu_{cQ}) = P_Q(\mu_{cQ}) = P_Q,$$

and density: $n_M(\mu_{cH}) = n_H(\mu_{cH})$

$$n_M(\mu_{cQ}) = n_Q(\mu_{cQ})$$

Robustness of Twins against Pasta Phase Effects

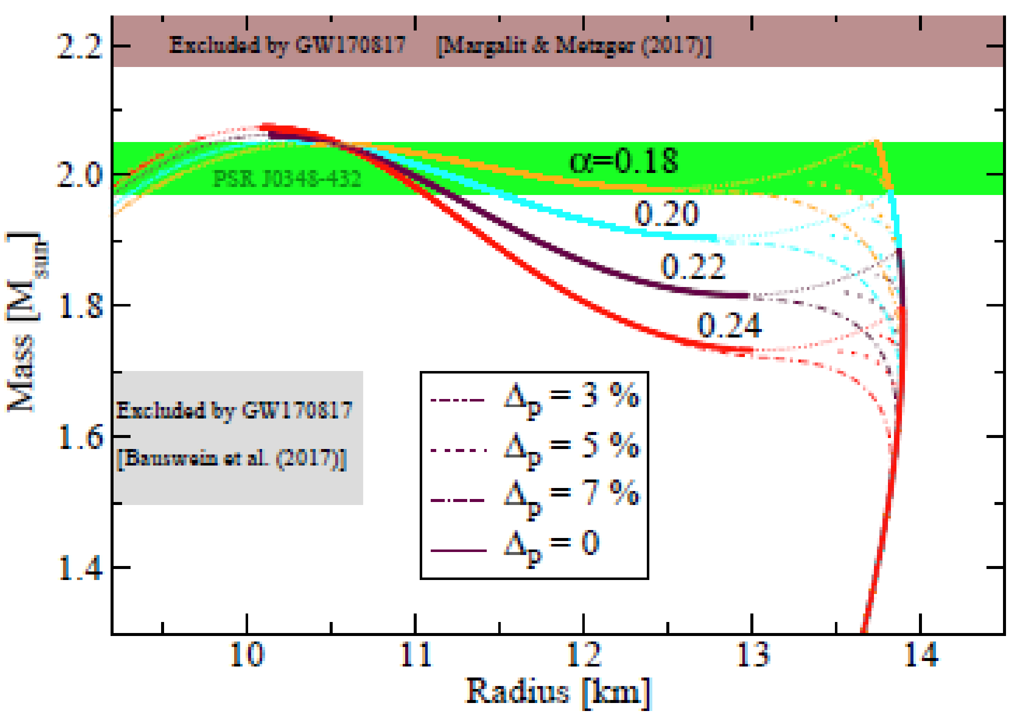


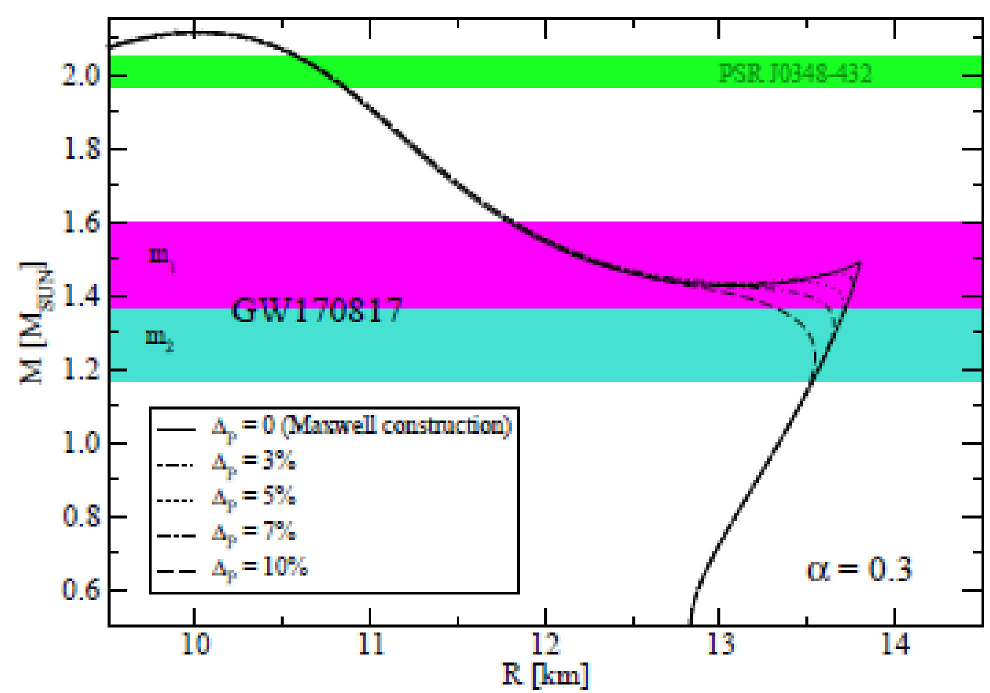
Result:

3rd family solutions (i.e. also the mass twins) are robust against pasta phase effects (mimicked by interpolation) for $\Delta_P < 5\%$

GW170817 could have been a HS-NS or even A HS-HS merger rather than NS-NS merger !!

Ayriyan et al., PRD96, 045802 (2018) [arxiv:1711.03926]





Robustness of Twins against Pasta Phase Effects

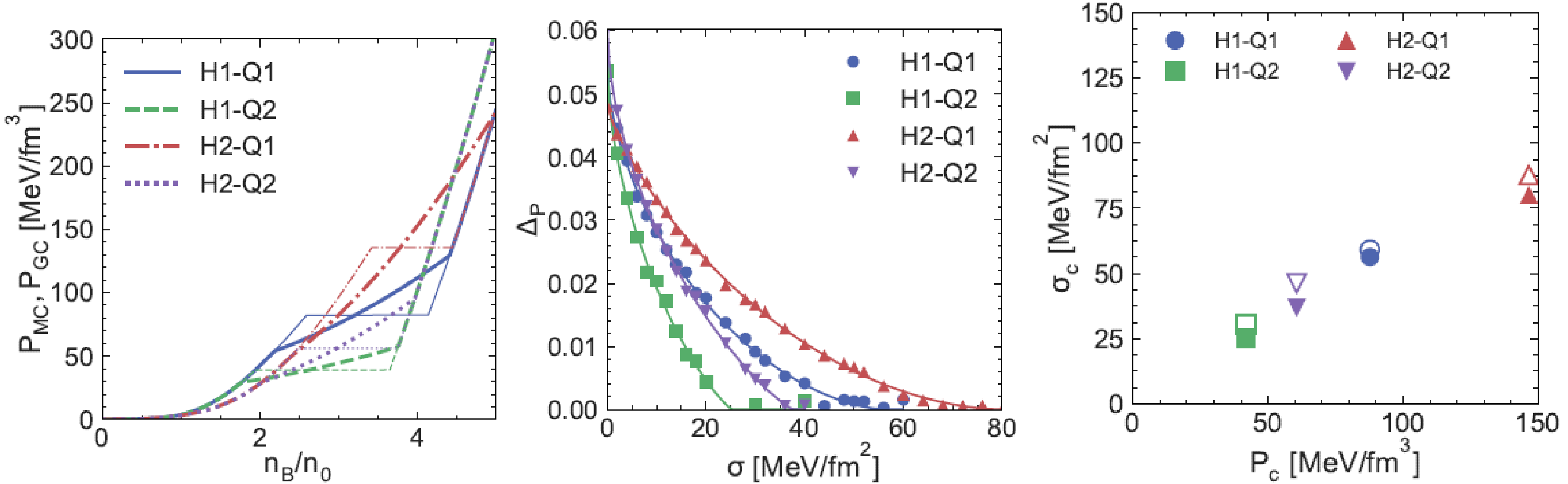
Hybrid equation of state with pasta phases and third family of compact stars
I: Pasta phases and effective mixed phase model

K. Maslov,[1,2,*] N. Yasutake,[3,†] A. Ayriyan,[4,‡] D. Blaschke,[5,2,1,§] H. Grigorian,[4,¶] T. Maruyama,[6] T. Tatsumi,[7] and D. N. Voskresensky[2,1,**]

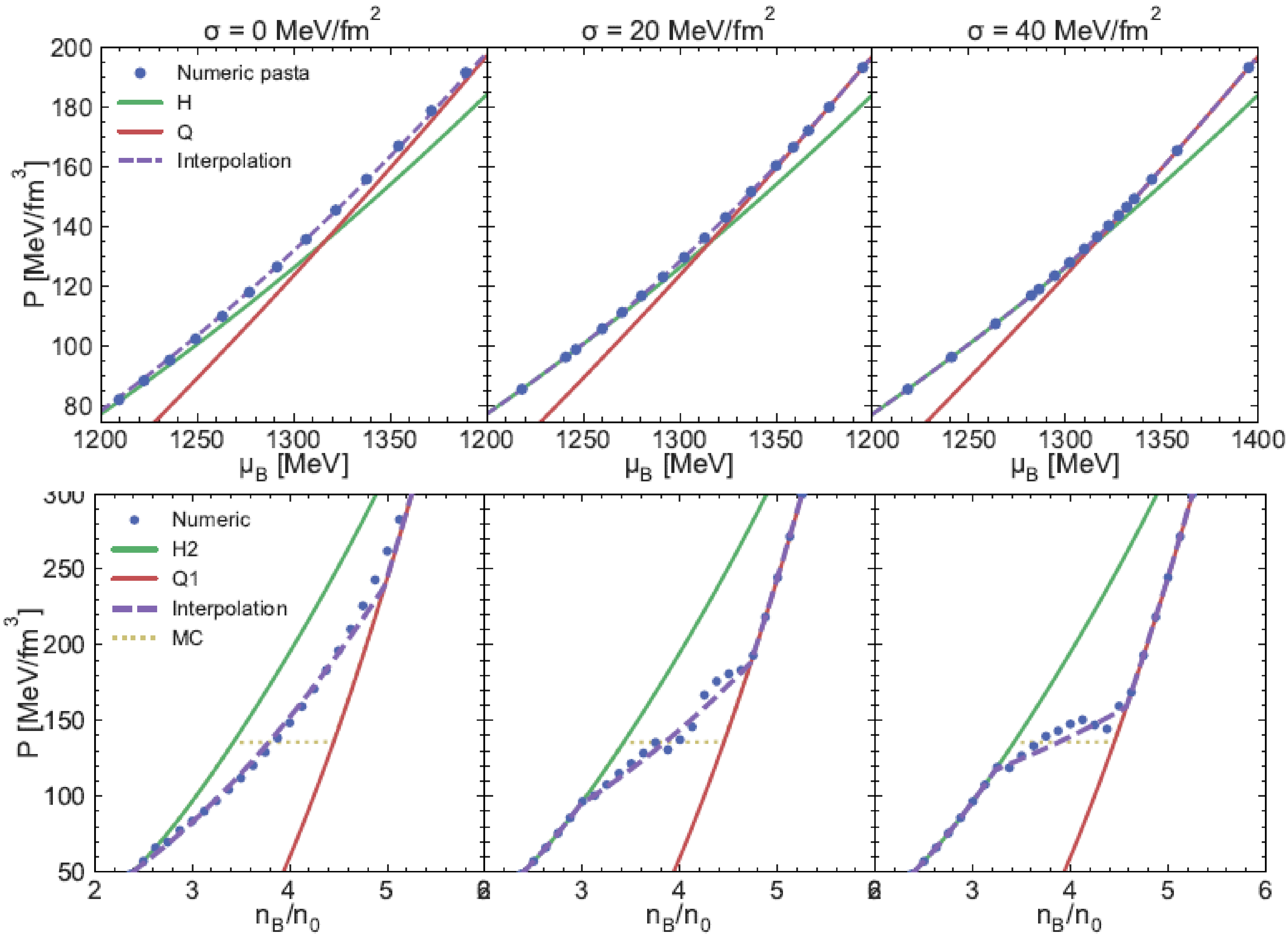
[1] *National Research Nuclear University (MEPhI), Kashirskoe Shosse 31, 115409 Moscow, Russia*
[2] *Bogoliubov Laboratory for Theoretical Physics, Joint Institute for Nuclear Research, Joliot-Curie street 6, 141980 Dubna, Russia*
[3] *Department of Physics, Chiba Institute of Technology (CIT), 2-1-1 Shibazono, Narashino, Chiba, 275-0023, Japan*
[4] *Laboratory for Information Technologies, Joint Institute for Nuclear Research, Joliot-Curie street 6, 141980 Dubna, Russia*
[5] *Institute of Theoretical Physics, University of Wroclaw, Max Born place 9, 50-204 Wroclaw, Poland*
[6] *Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan*
[7] *Department of Physics, Kyoto University, Kyoto 606-8502, Japan*

(Dated: May 26, 2018)

Q: Can real pasta calculations be approximated by the interpolation? **A:** Yes! And $\Delta_P < 5\%$ ...



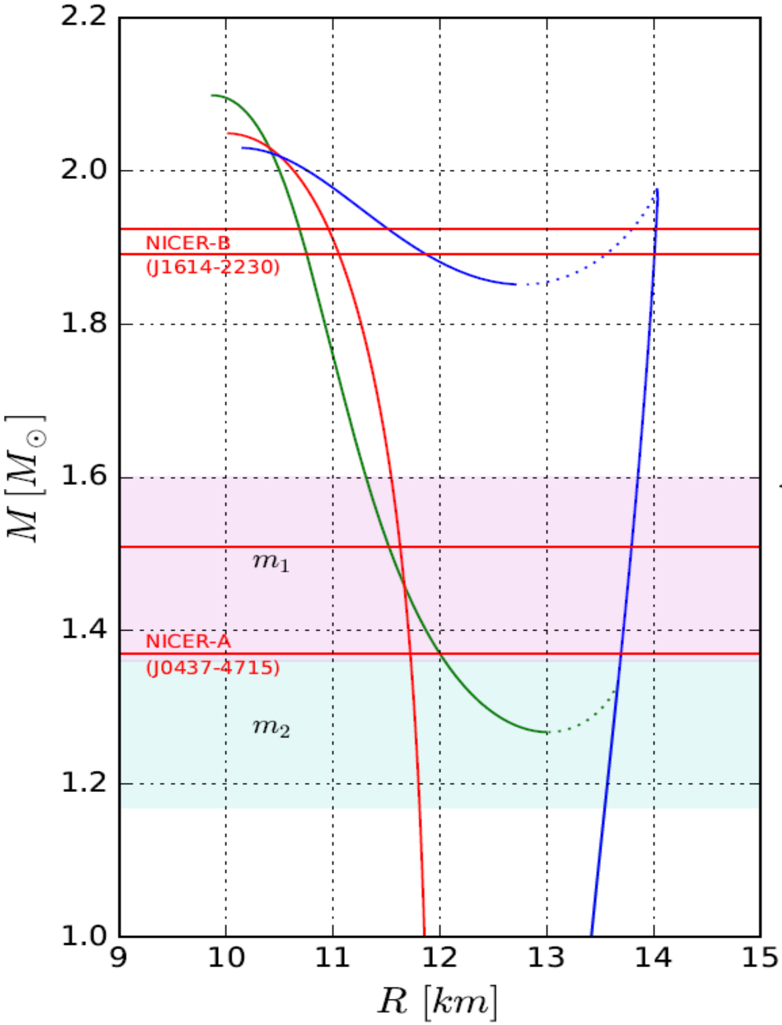
Robustness of Twins against Pasta Phase Effects

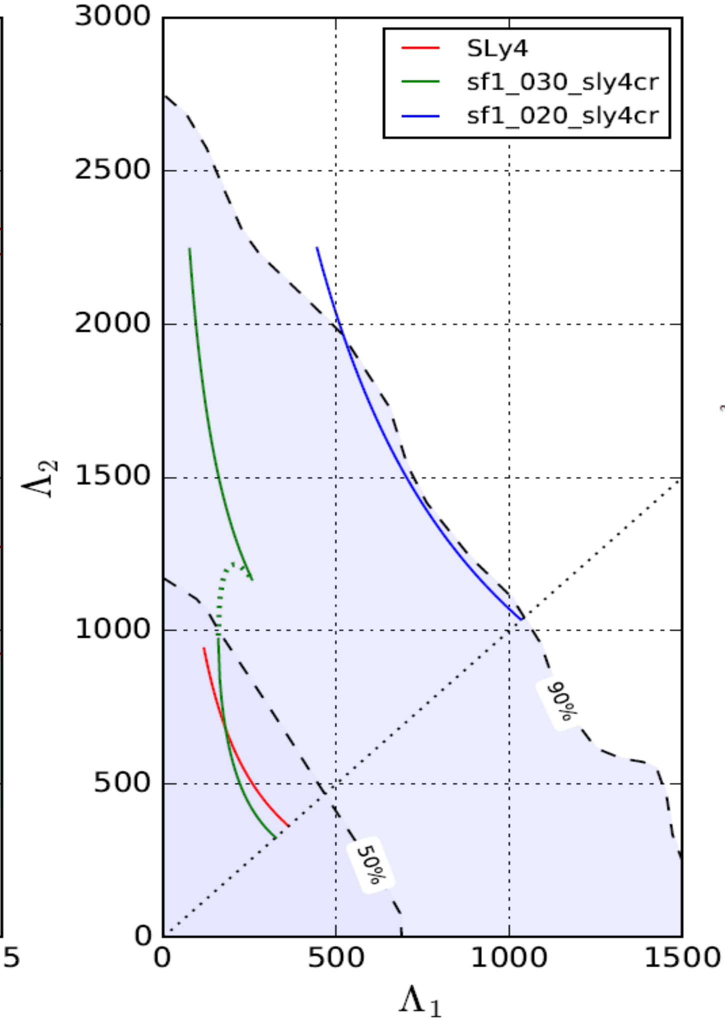


Robustness of Twins against Pasta Phase Effects

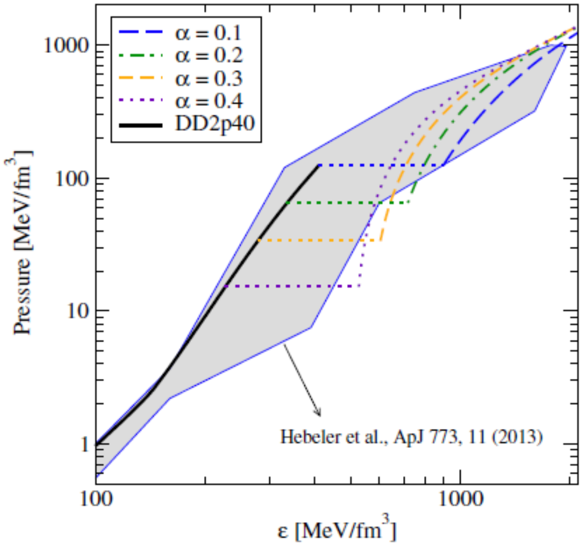
Thanks to the collaborators !

Discover the 3rd family – NICER vs. GW170817





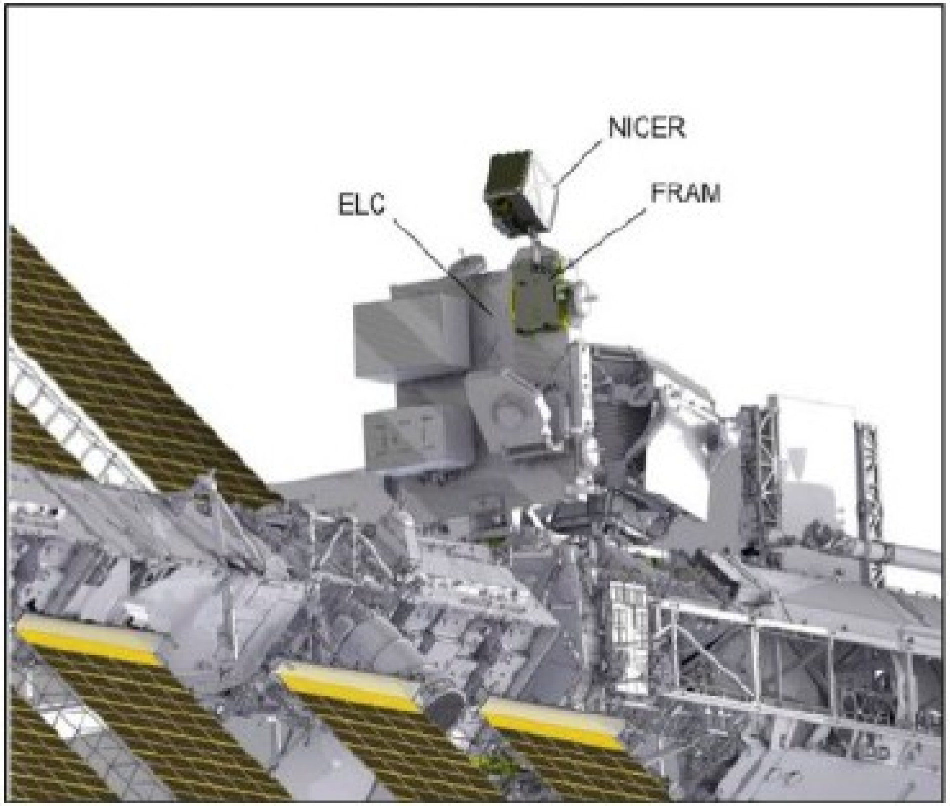
EoS:
DD2_P40 – SFM_α=0.3
M. Kaltenborn et al.
PRD 96 (2017) 056024

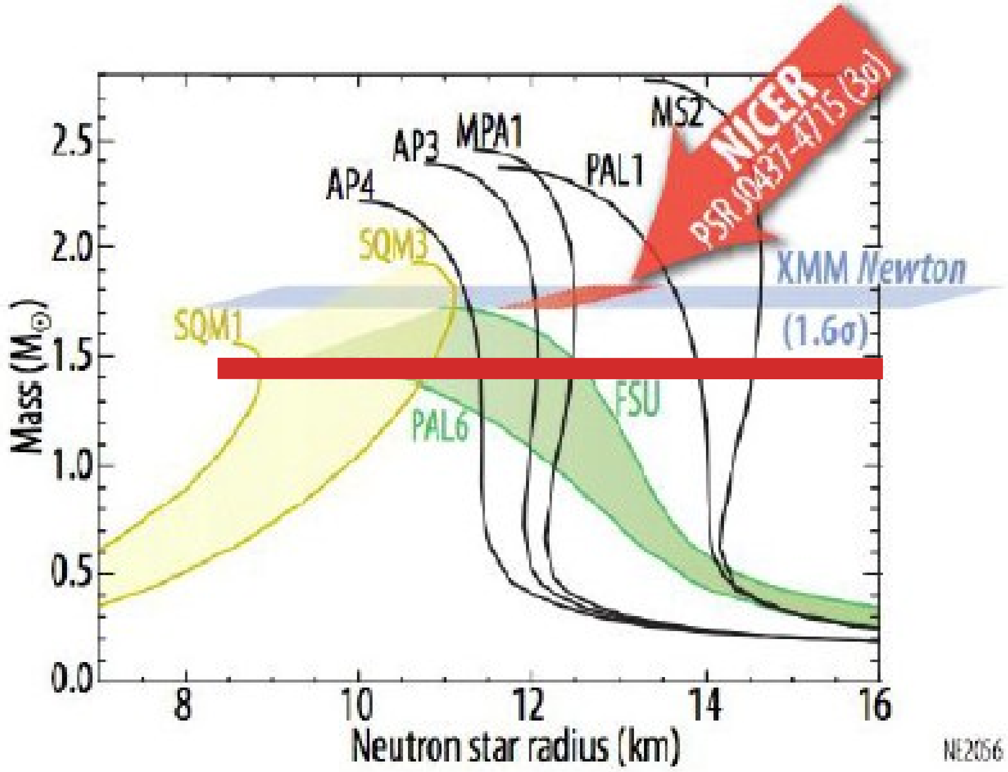


TOV / TD calculation:
M. Bejger et al.

Alternative to NS merger with soft EoS → Hybrid star (HS) – HS / HS-NS merger

If NICER rules out soft EoS (since $R_{0437\text{-}4715}$ >13.5 km) then **Third Family is Discovered !!**

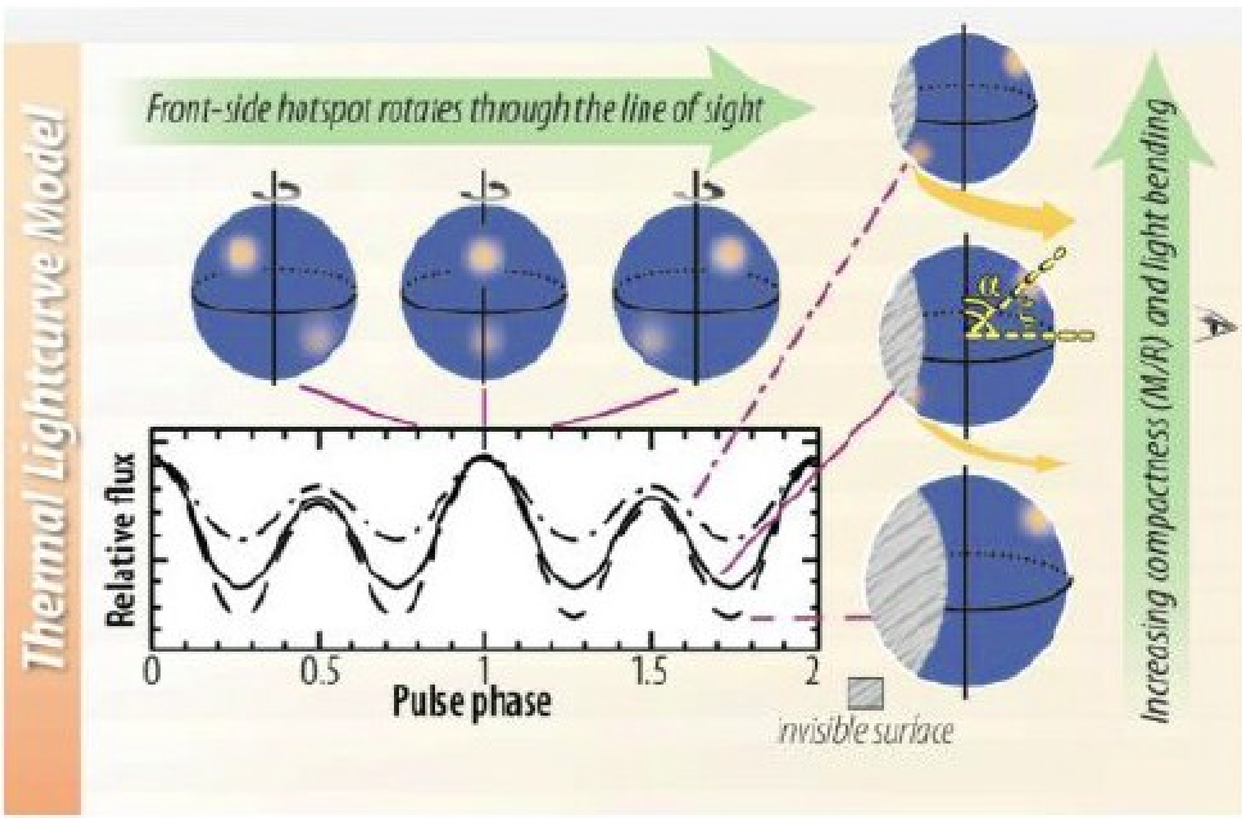


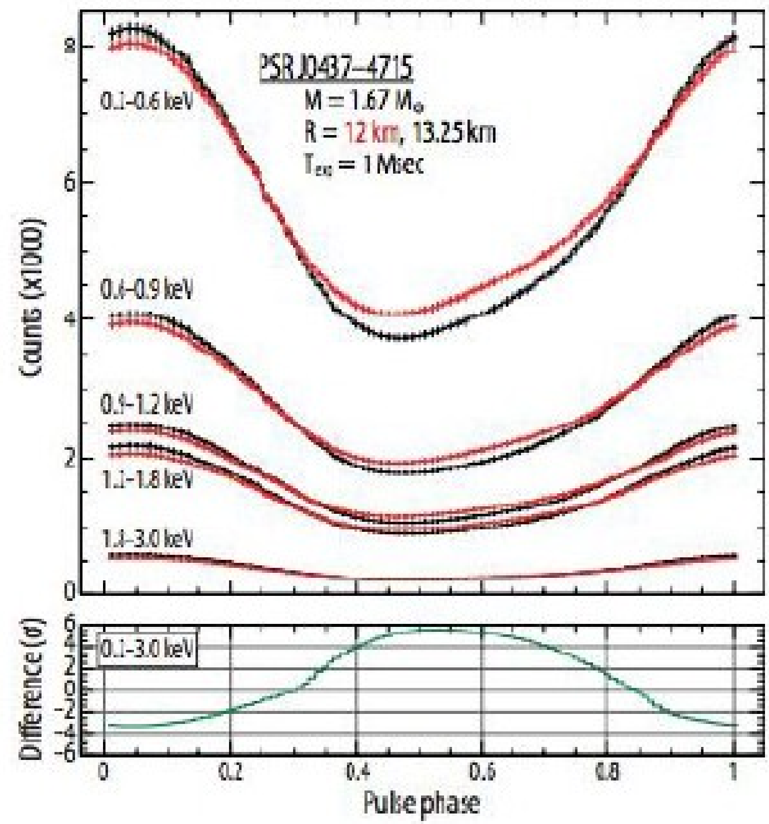


NICER 2017

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


NICER
Neutron star Interior Composition ExploreR

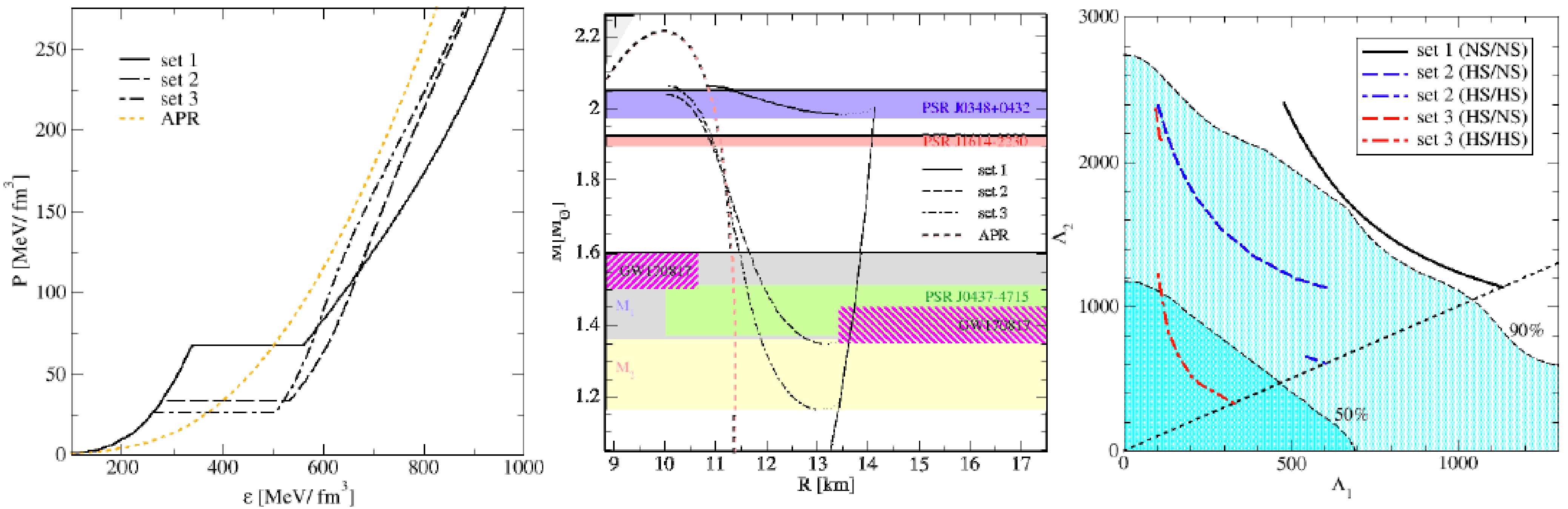

Thermal Lightcurve Model
Front-side hotspot rotates through the line of sight
Increasing compactness (M/R) and light bending
Relative flux
Pulse phase
0
0.5
1
1.5
2
invisible surface


PSR J0437−4715
M = 1.67 M☉
R = 12 km, 13.25 km
T = 1 Msec
0.1–0.6 keV
0.6–0.9 keV
0.9–1.2 keV
1.1–1.8 keV
1.8–3.0 keV
Counts (x1000)
Difference (σ)
0.1–3.0 keV
Pulse phase
0
0.2
0.4
0.6
0.8
1

Hot Spots

Discover the 3rd family – NICER vs. GW170817

Nonlocal NJL model (with interpolation), D. Alvarez-Castillo et al. (arxiv:1805.04105)



EoS based on:
Nonlocal chiral QM with 2SC
Blaschke et al. PRC 75 (2007);
Pasta phase ext. (w/o 2SC):
Yasutake et al. PRC 89 (2014)

TOV / TD calculation:
2 M_sun constraint fulfilled
GW170817: R_1.4 < 13.6 km
[Annala et al., PRL (2018)]
NICER: R_1.44 > ?? (2018)

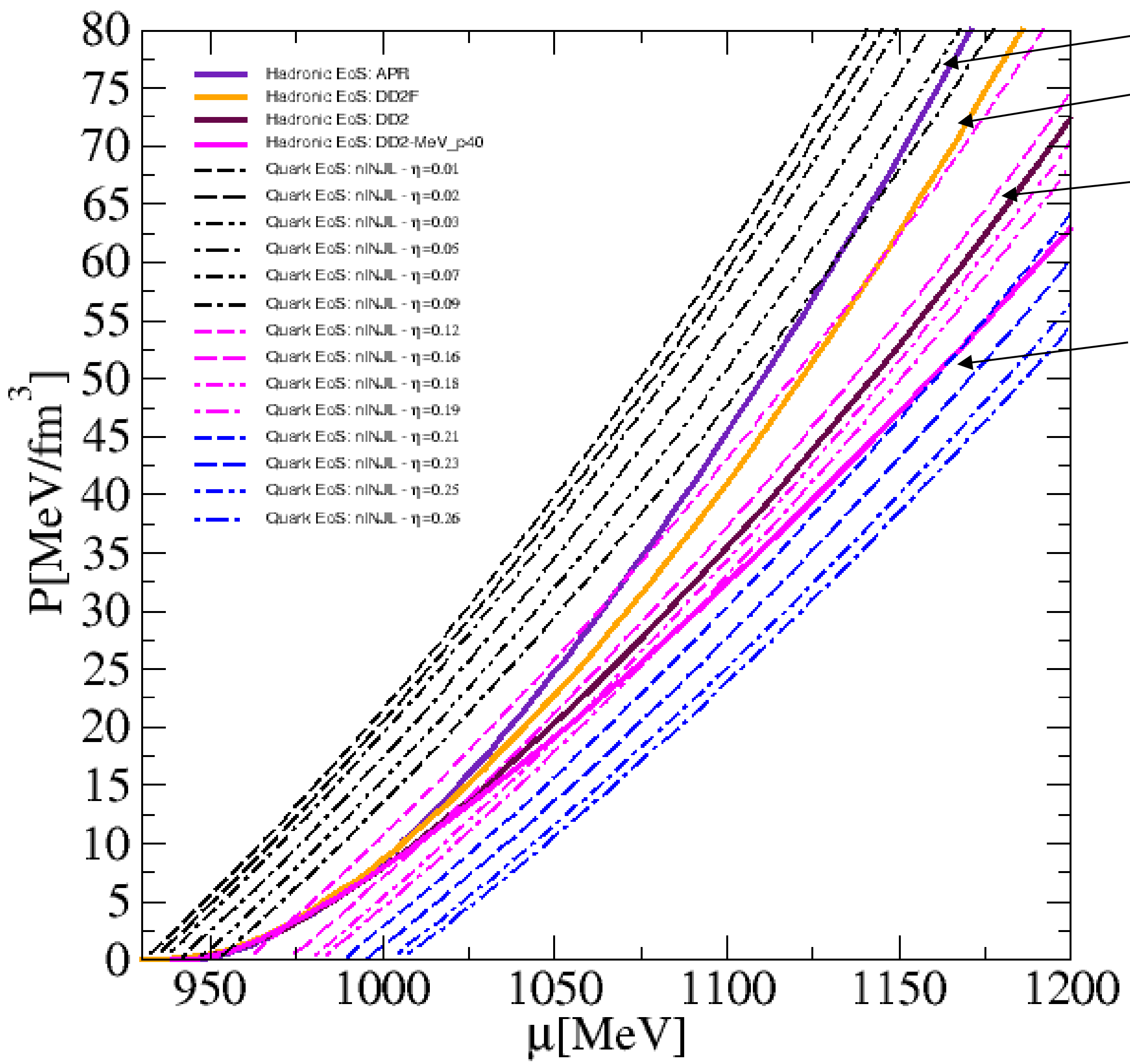
Pasta calculation:
Does not spoil twin scenario of NS-HS or HS-HS merger!
Yasutake et al. (2018)

Alternative to NS merger with soft EoS → Hybrid star (HS) – HS / HS-NS merger

If NICER rules out soft EoS (since $R_{0437-4715}$ >13.6 km) then **Evidence for Third Family !!**

Maxwell Construction between Hadron and Quark Phases

D.E. Alvarez-Castillo, D.B., A.G. Grunfeld, V.P. Pagura, arxiv:1805.04105v2



APR — No Maxwell construction → Kojo interpolation

DD2F

DD2 — Masquerade with nonlocal NJLsc for eta=0.17

DD2_p40 — Normal Maxwell construction

The nonlocal covariant sc quark model:

$$S_E = \int d^4x \left\{ \bar{\psi}(x)\left(-i\partial\!\!\!/ + m_c\right)\psi(x) - \frac{G_S}{2} j_S^f(x) j_S^f(x) - \frac{H}{2}\left[j_D^a(x)\right]^\dagger j_D^a(x) - \frac{G_V}{2} j_V^\mu(x)\, j_V^\mu(x) \right\} .$$

$$j_S^f(x) = \int d^4z\ g(z)\ \bar{\psi}(x+\frac{z}{2})\ \Gamma_f\ \psi(x-\frac{z}{2}) ,$$

$$j_D^a(x) = \int d^4z\ g(z)\ \bar{\psi}_C(x+\frac{z}{2})\ \Gamma_D\ \psi(x-\frac{z}{2})$$

$$j_V^\mu(x) = \int d^4z\ g(z)\ \bar{\psi}(x+\frac{z}{2})\ i\gamma^\mu\ \psi(x-\frac{z}{2}).$$

Nonlocal chiral quark model - generalized

$$S_E = \int d^4x \left\{ \bar\psi(x)\left(-i\not\partial + m_c\right)\psi(x) - \frac{G_S}{2} j_S^f(x) j_S^f(x) - \frac{H}{2}\left[j_D^a(x)\right]^\dagger j_D^a(x) - \frac{G_V}{2} j_V^\mu(x)\, j_V^\mu(x) \right\}$$

$$j_S^f(x) = \int d^4z\; g(z)\; \bar\psi(x+\frac{z}{2})\;\Gamma_f\,\psi(x-\frac{z}{2})\,,$$

$$j_D^a(x) = \int d^4z\; g(z)\; \bar\psi_C(x+\frac{z}{2})\;\Gamma_D\;\psi(x-\frac{z}{2})$$

$$j_V^\mu(x) = \int d^4z\; g(z)\; \bar\psi(x+\frac{z}{2})\; i\gamma^\mu\;\psi(x-\frac{z}{2}).$$

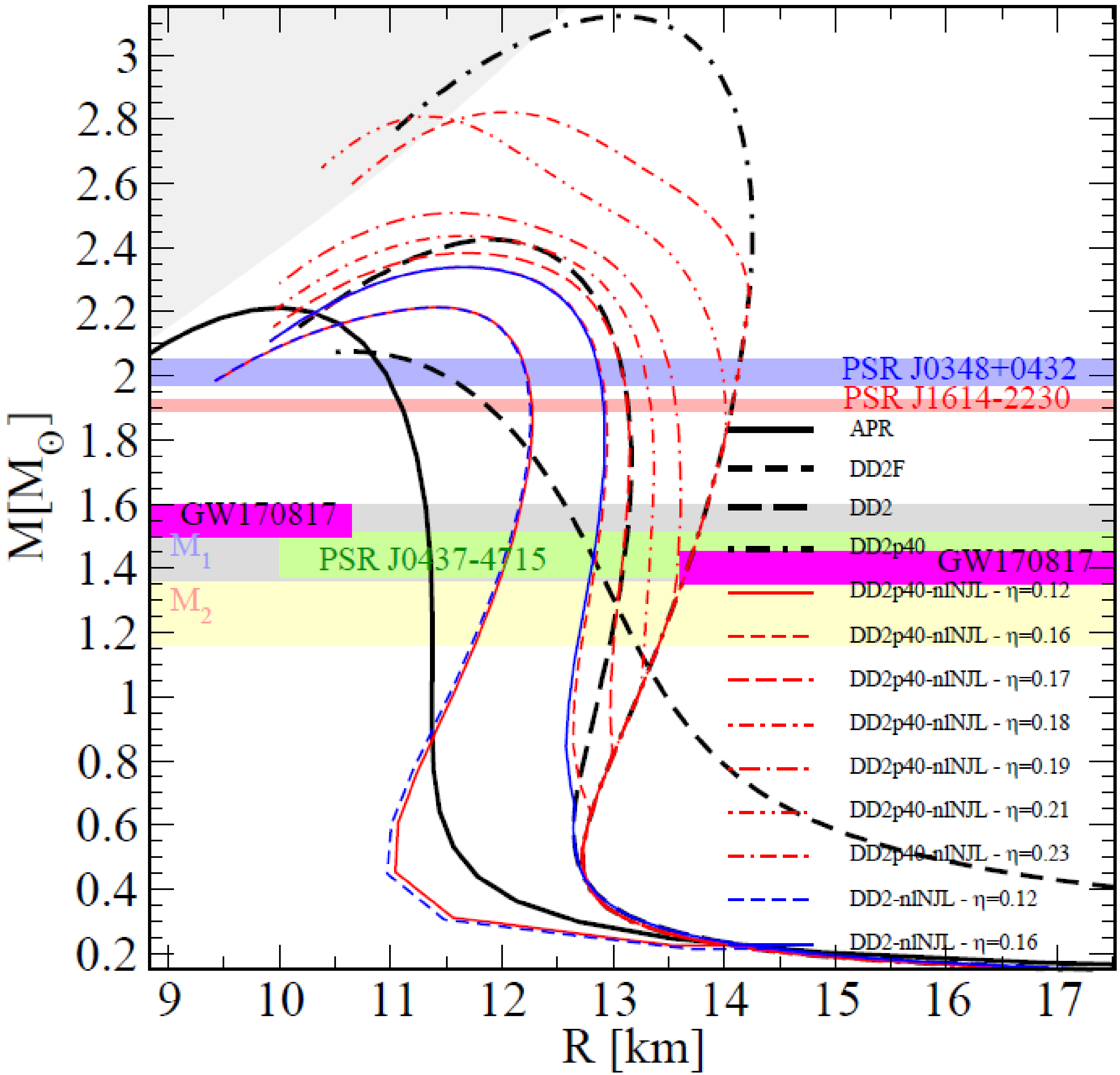
$$\Omega^{MFA} = \frac{\bar\sigma^2}{2G_S} + \frac{\bar\Delta^2}{2H} - \frac{\bar\omega^2}{2G_V} - \frac{1}{2}\int \frac{d^4p}{(2\pi)^4}\;\ln\det\left[\,S^{-1}(\bar\sigma,\bar\Delta,\bar\omega,\mu_{fc})\right]$$

$$\frac{d\Omega^{MFA}}{d\bar\Delta} = 0\,,\quad \frac{d\Omega^{MFA}}{d\bar\sigma} = 0\,,\quad \frac{d\Omega^{MFA}}{d\bar\omega} = 0\,.$$

$$P(\mu;\eta,B) = -\Omega^{MFA} - B$$

D.B., D. Gomez-Dumm, A.G. Grunfeld, T. Klaehn, N.N. Scoccola, "Hybrid stars within a covariant, nonlocal chiral quark model", Phys. Rev. C 75, 065804 (2007)

Maxwell Construction between Hadron and Quark Phases



Here:

Baseline without interpolation

→ no 3rd family, no twins!

Interpolating between Quark Phase Parametrizations

<u>Twofold interpolation method:</u>

1. to model the unknown density dependence of the confining mechanism by interpolating a bag pressure contribution between zero and a finite value B at low densities in the vicinity of the hadron-to-quark matter transition, and
2. to model a density dependent stiffening of the quark matter EoS at high density by interpolating between EoS for two values of the vector coupling strength, $\eta_<$ and $\eta_>$.

$$P(\mu) = [f_<(\mu)(P(\mu;\eta_<) - B) + f_>(\mu)P(\mu;\eta_<)]f_\ll(\mu) + f_\gg(\mu)P(\mu;\eta_>)$$

$$f_<(\mu) = \frac{1}{2}\left[1 - \tanh\left(\frac{\mu - \mu_<}{\Gamma_<}\right)\right], \quad f_\ll(\mu) = \frac{1}{2}\left[1 - \tanh\left(\frac{\mu - \mu_\ll}{\Gamma_\ll}\right)\right],$$

$$f_>(\mu) = 1 - f_<(\mu) \ , \quad f_\gg(\mu) = 1 - f_\ll(\mu).$$

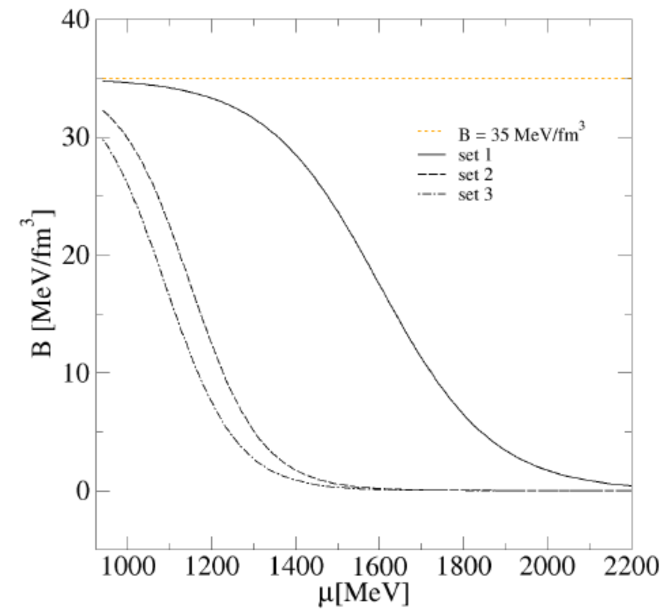
Interpolation vs. medium dependence of coefficients

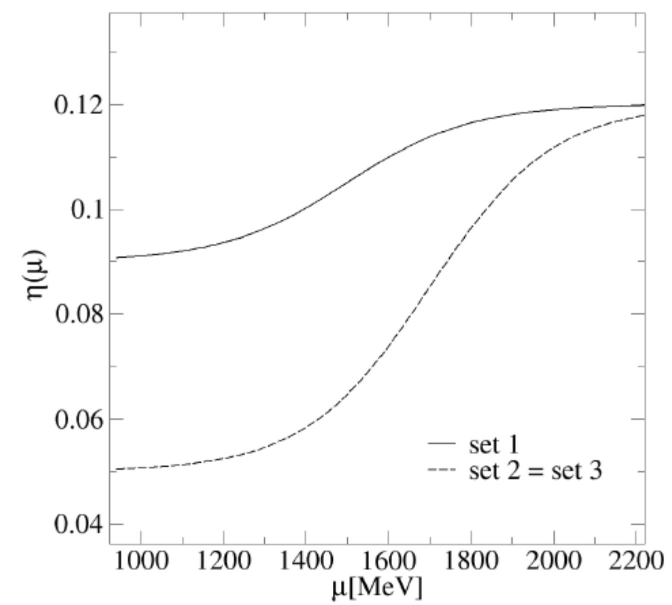
$$
\begin{aligned}
P(\mu) &= P(\mu;\eta,B)f_<(\mu) + P(\mu;\eta,0)f_>(\mu) \\
&= P(\mu;\eta,0)[f_<(\mu)+f_>(\mu)] - Bf_<(\mu) \\
&= P(\mu;\eta,B(\mu)),
\end{aligned}
$$

$B(\mu) = Bf_<(\mu)$ is the $\mu-$dependent bag pressure

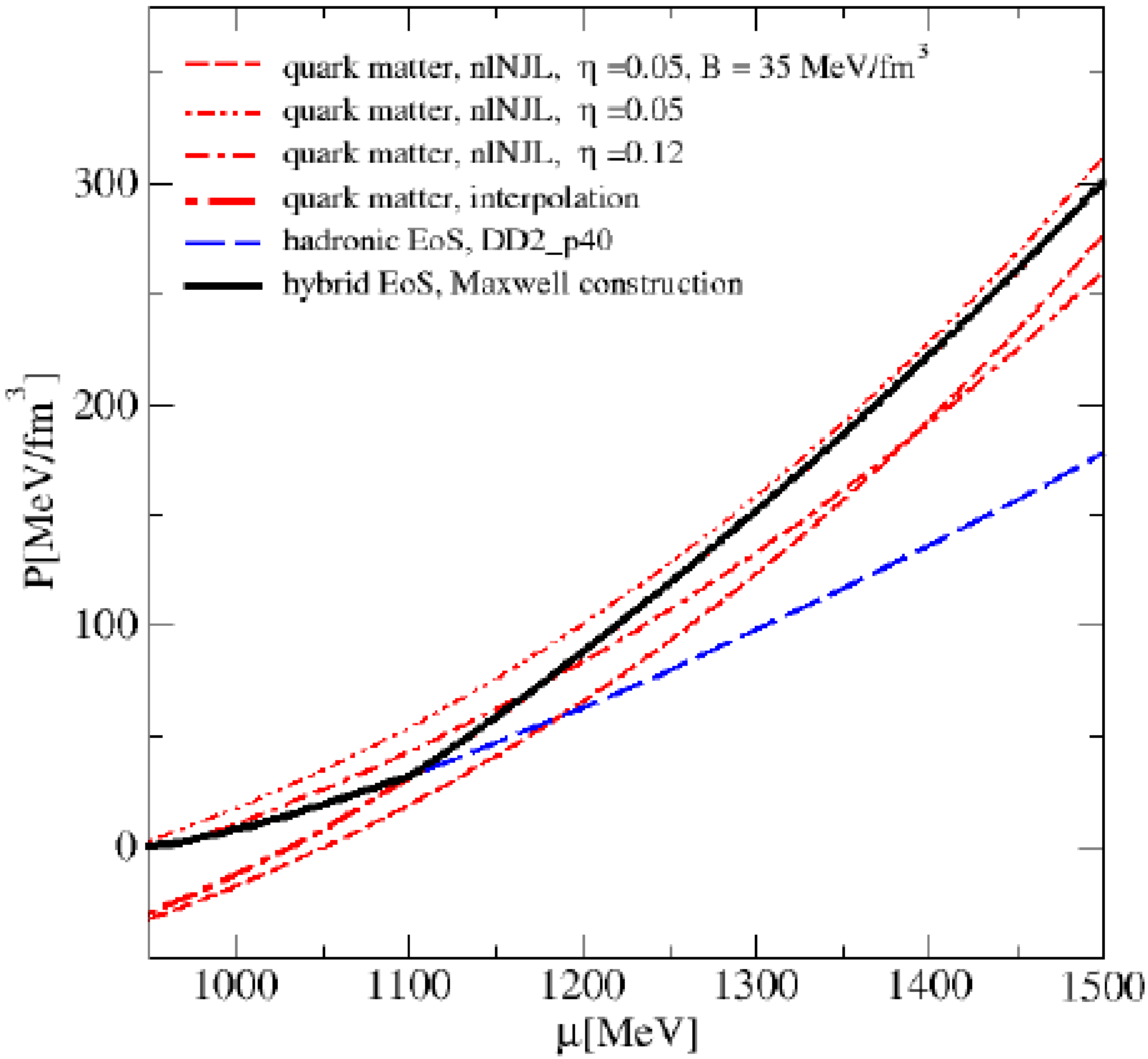
$$
\begin{aligned}
P(\mu) &= P(\mu;\eta_<,B)f_\ll(\mu) + P(\mu;\eta_>,B)f_\gg(\mu) \\
&= P(\mu;\eta_<,B)[f_\ll(\mu)+f_\gg(\mu)] \\
&\quad +(\eta_> - \eta_<)f_\gg(\mu)\frac{dP(\mu;\eta,B)}{d\eta}\bigg|_{\eta=\eta_<} \\
&= P(\mu;\eta_<,B) \\
&\quad +[\eta_> f_\gg(\mu) + \eta_< f_\ll(\mu) - \eta_<]\frac{dP(\mu;\eta,B)}{d\eta}\bigg|_{\eta=} \\
&= P(\mu;\eta(\mu),B)\ ,
\end{aligned}
$$

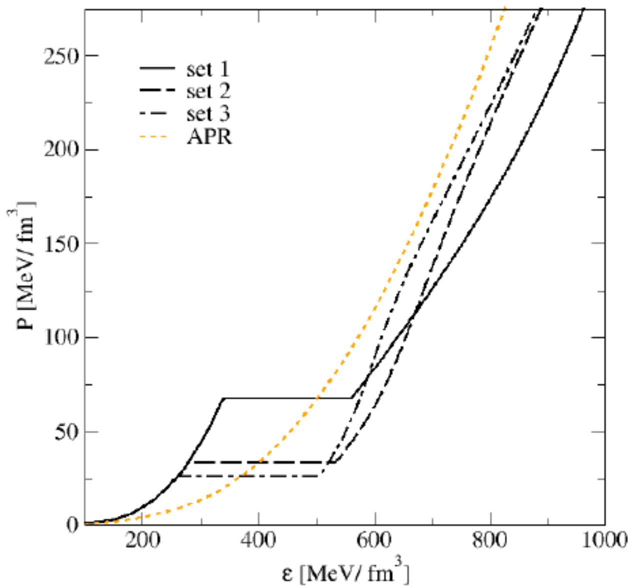
$\eta(\mu) = \eta_> f_\gg(\mu) + \eta_< f_\ll(\mu)$ is the medium-dependent vector meson coupling

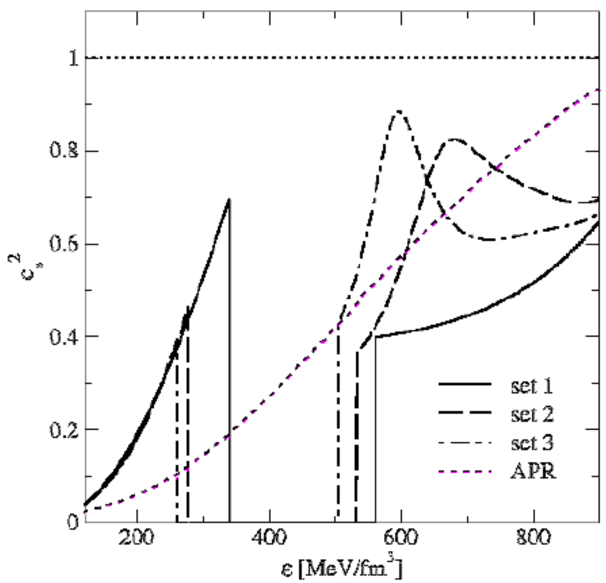




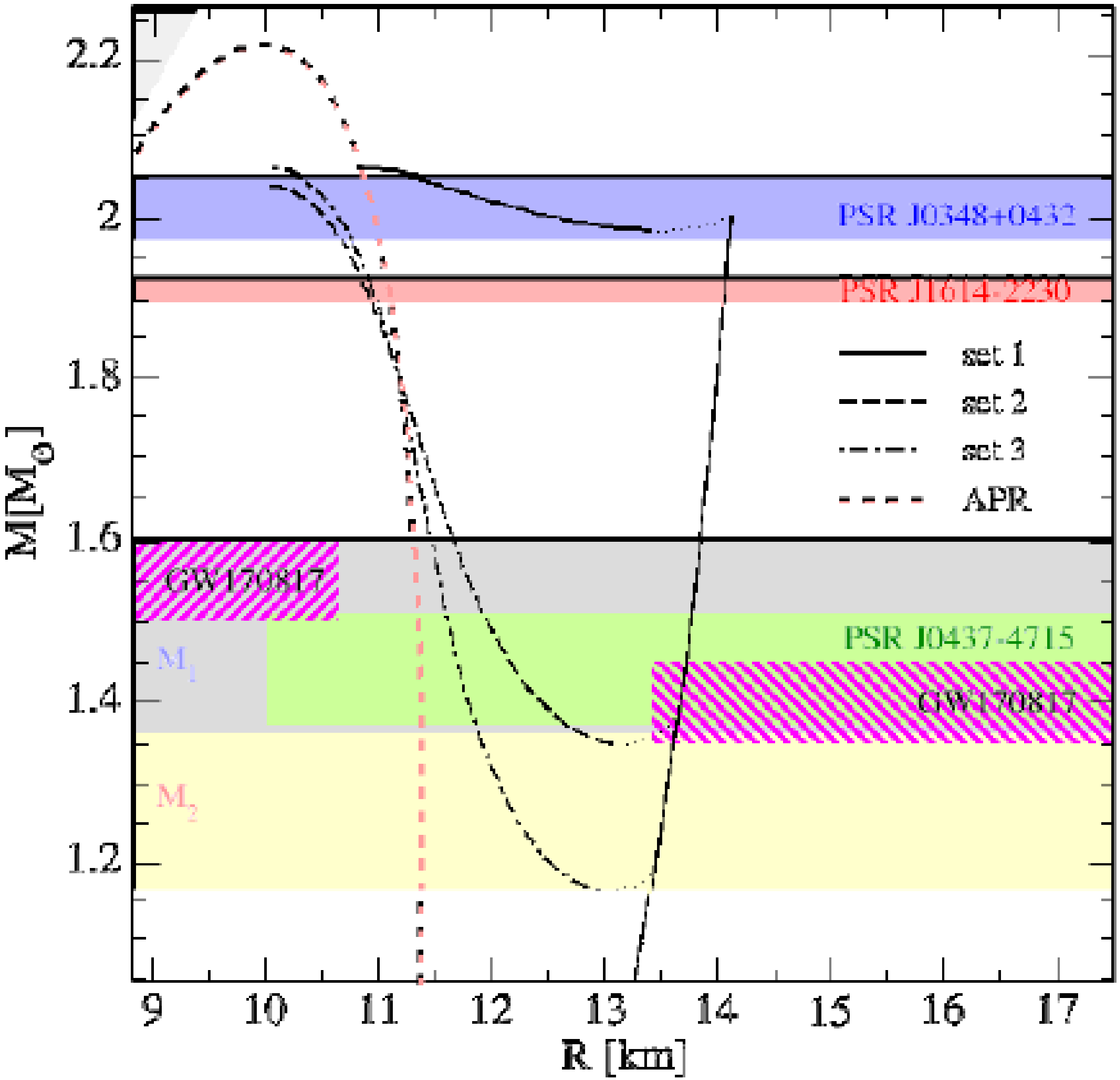
Maxwell Construction between Hadron and Quark Phases

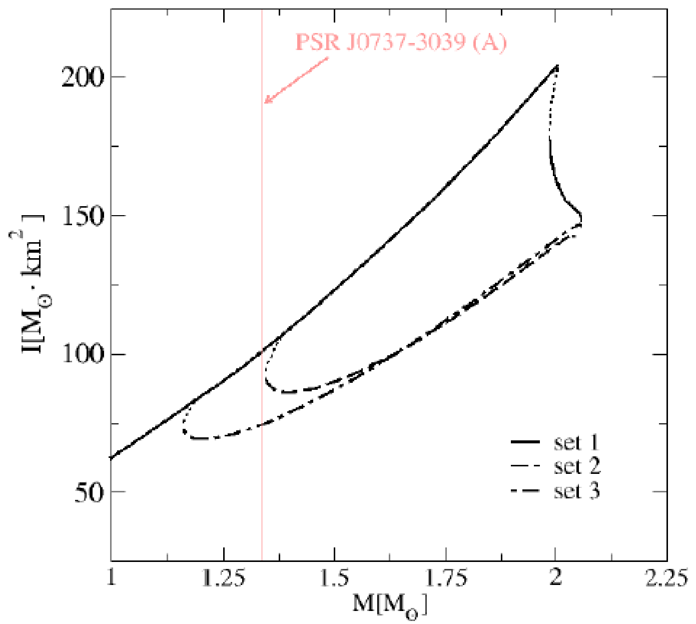


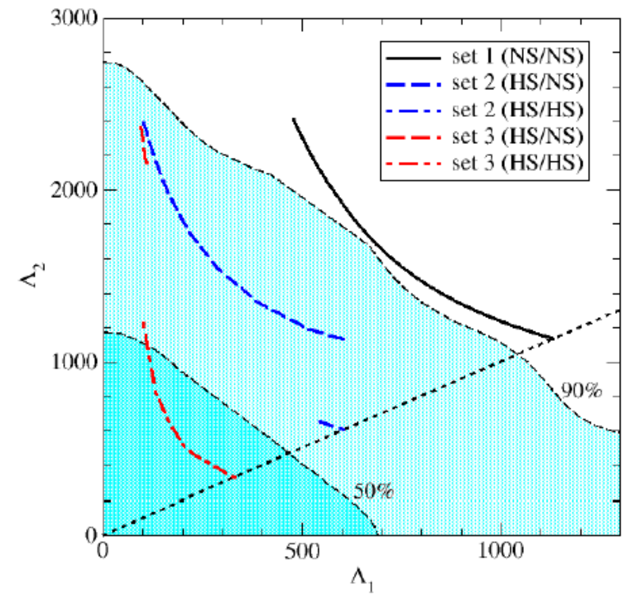




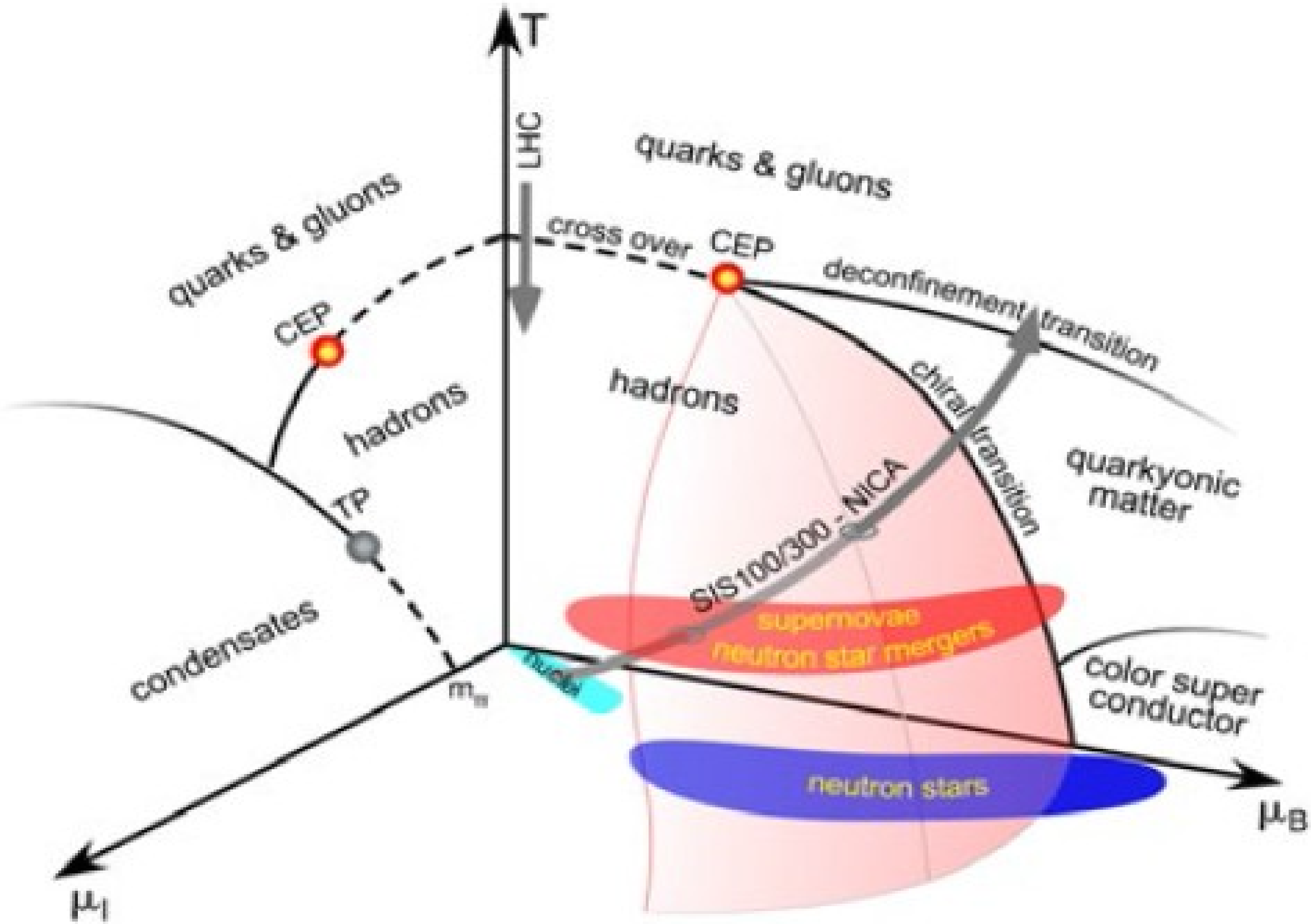
Maxwell Construction between Hadron and Quark Phases







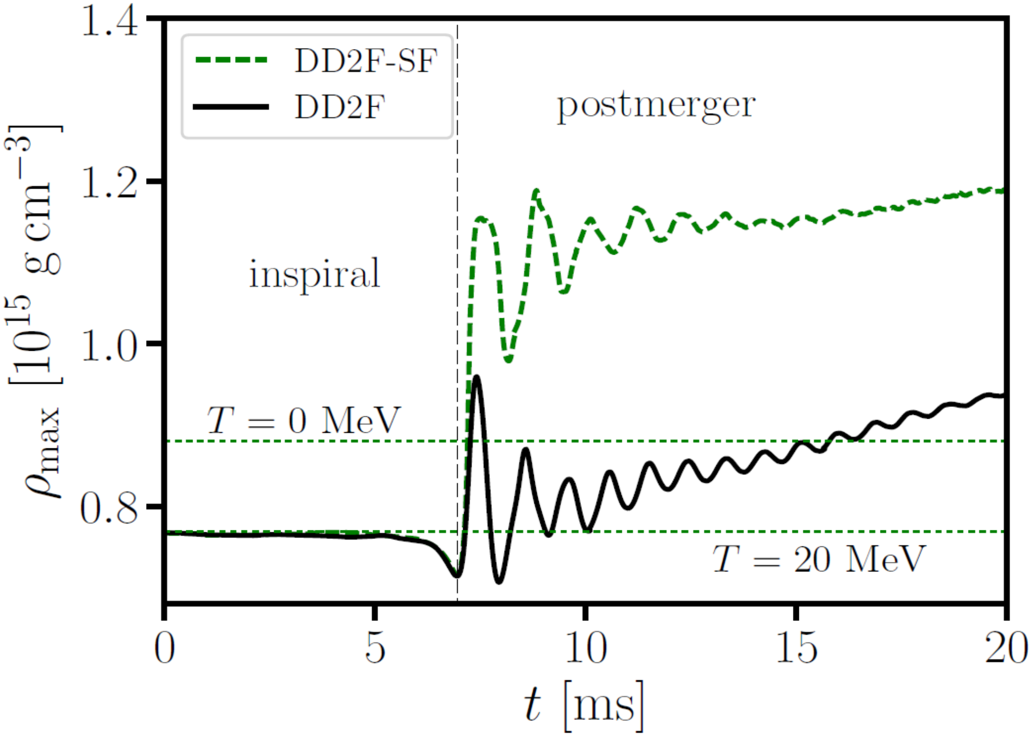
CEP in the QCD phase diagram: HIC vs. Astrophysics



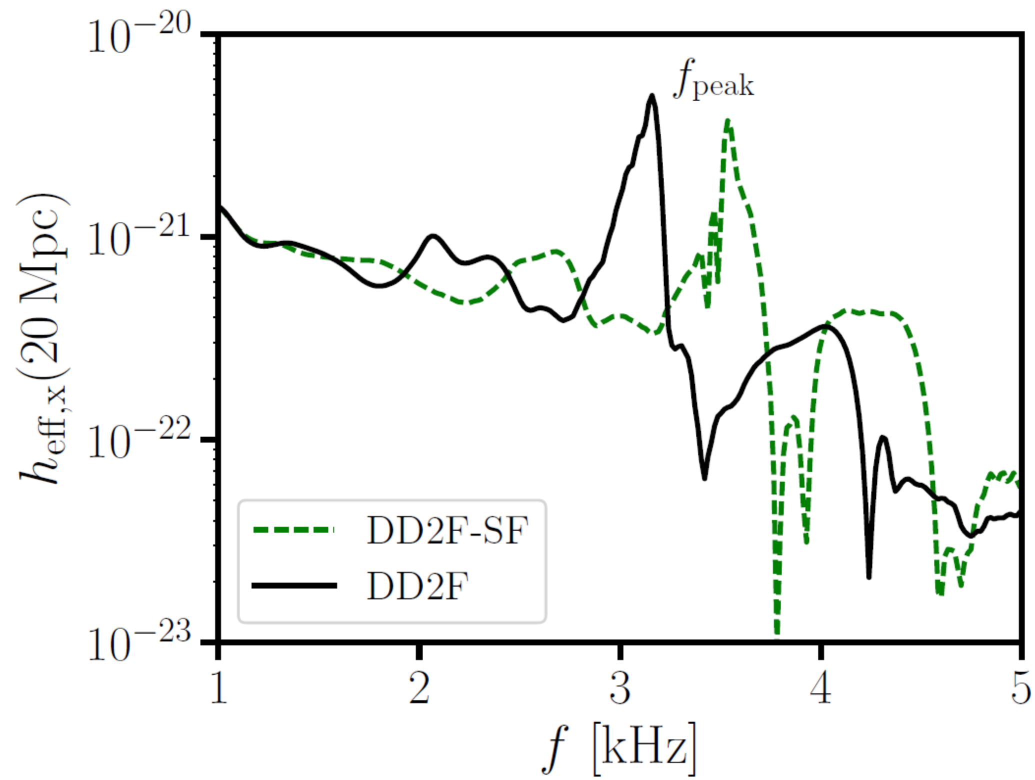
A. Andronic, D. Blaschke, et al., "Hadron production ...", Nucl. Phys. A 837 (2010) 65 - 86

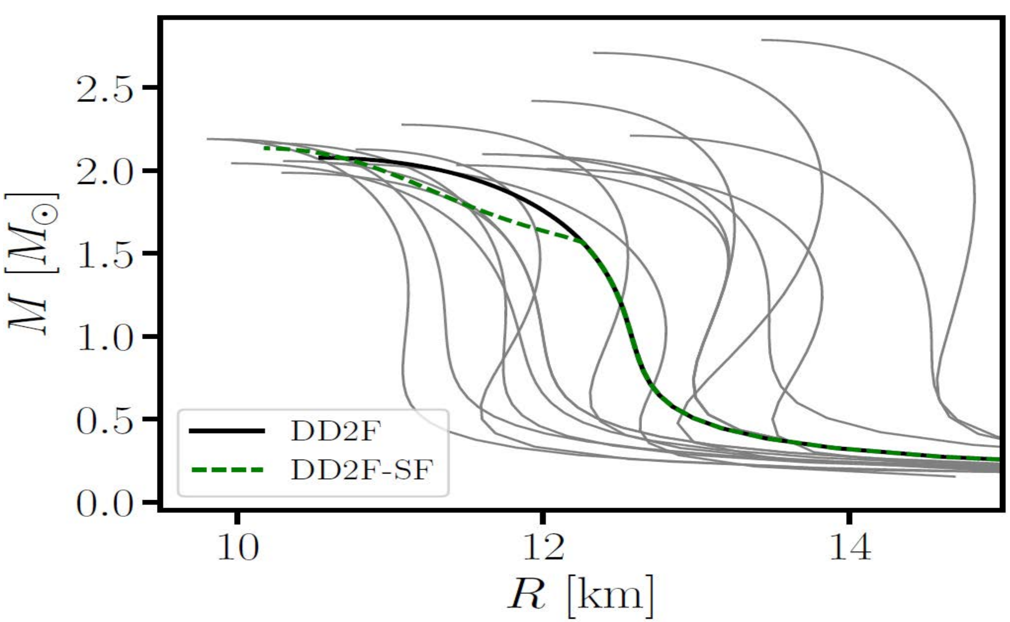
NuPECC Long Range Plan 2017; http://www.nupecc.org

Hybrid star formation in postmerger phase



Strong phase transition in postmerger GW,
A. Bauswein et al. arxiv:1809.01116

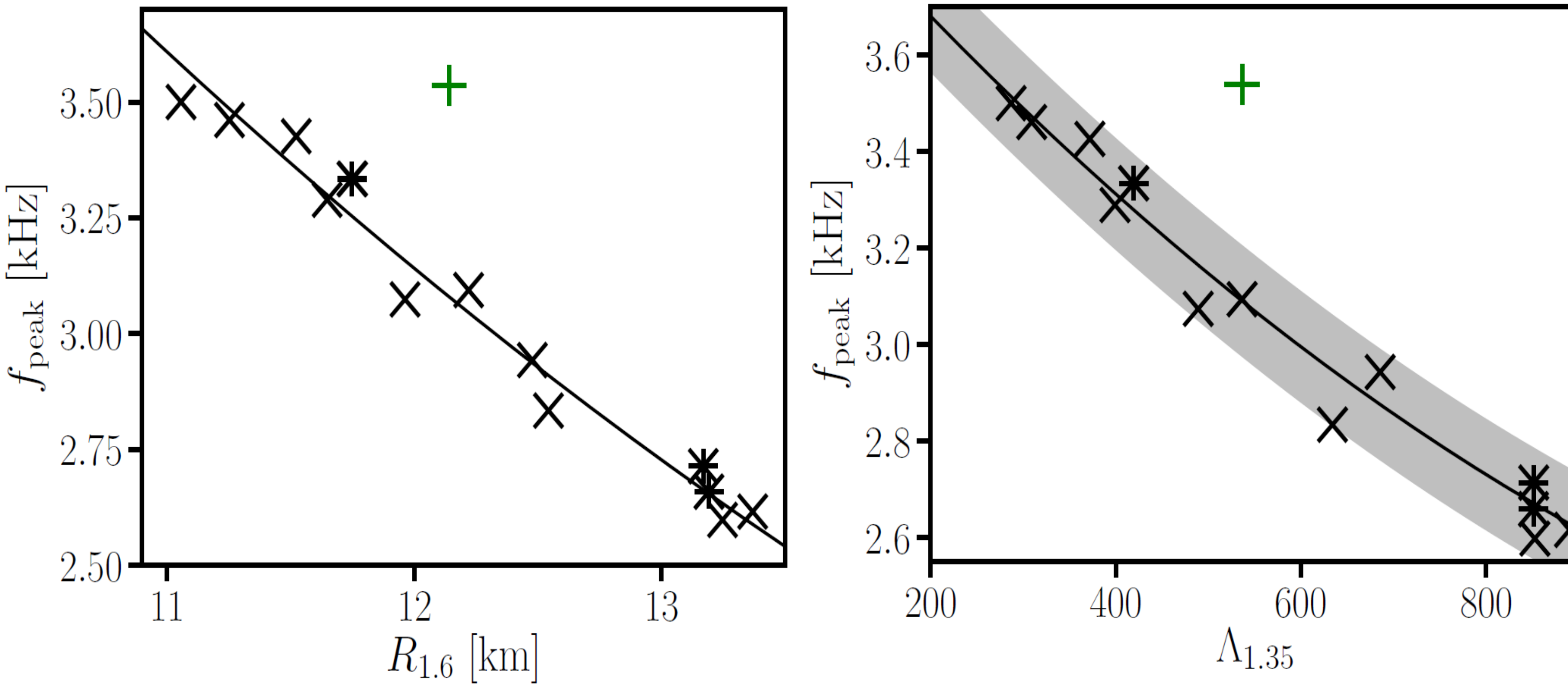




Hybrid star formaton during NS merger
→ higher densities and compacter star
→ higher peak frequency of the GW

Hybrid star formation in postmerger phase

Strong phase transition in postmerger GW signal, A. Bauswein et al. arxiv:1809.01116

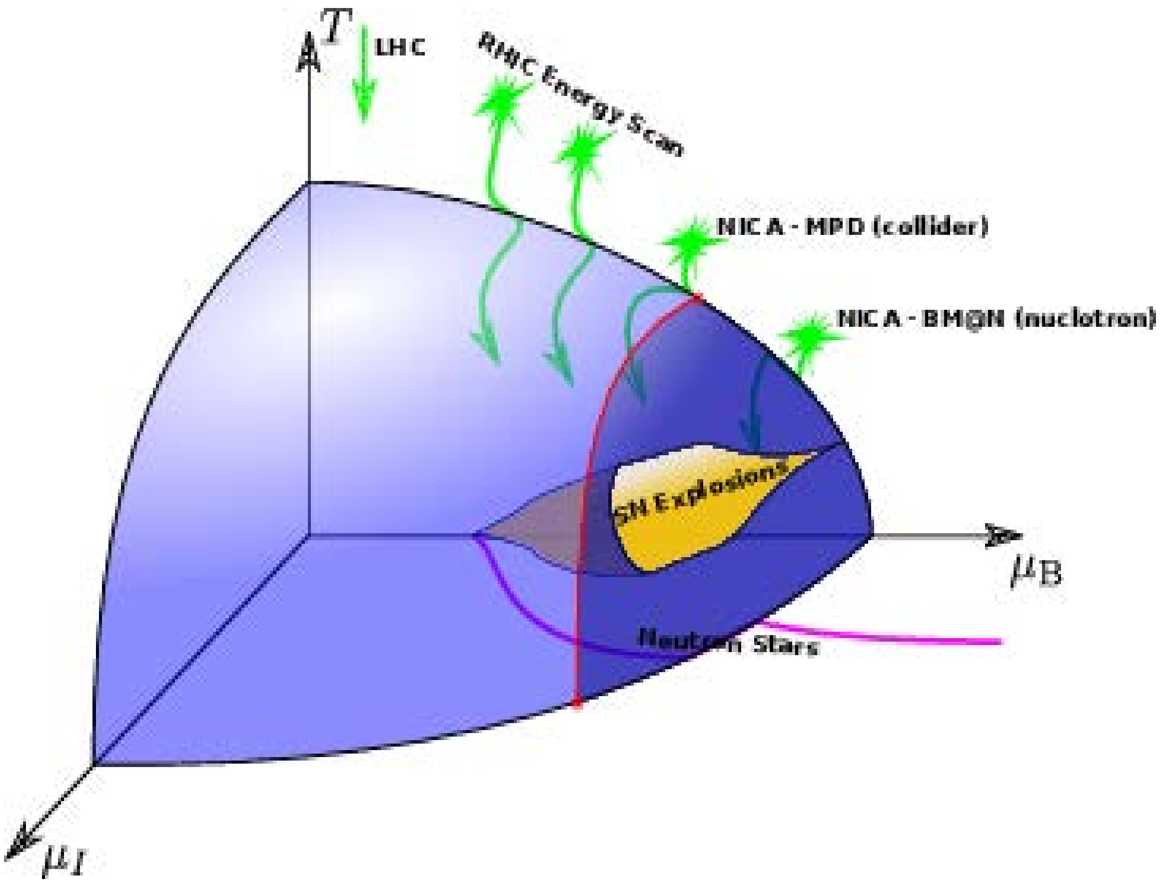


Strong deviation from $\mathbf{f_{peak} - R_{1.6}}$ relation signals **strong phase transition in** NS merger**!**

Complementarity of $\mathbf{f_{peak}}$ from postmerger with tidal deformability $\mathbf{\Lambda_{1.35}}$ from inspiral phase.

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

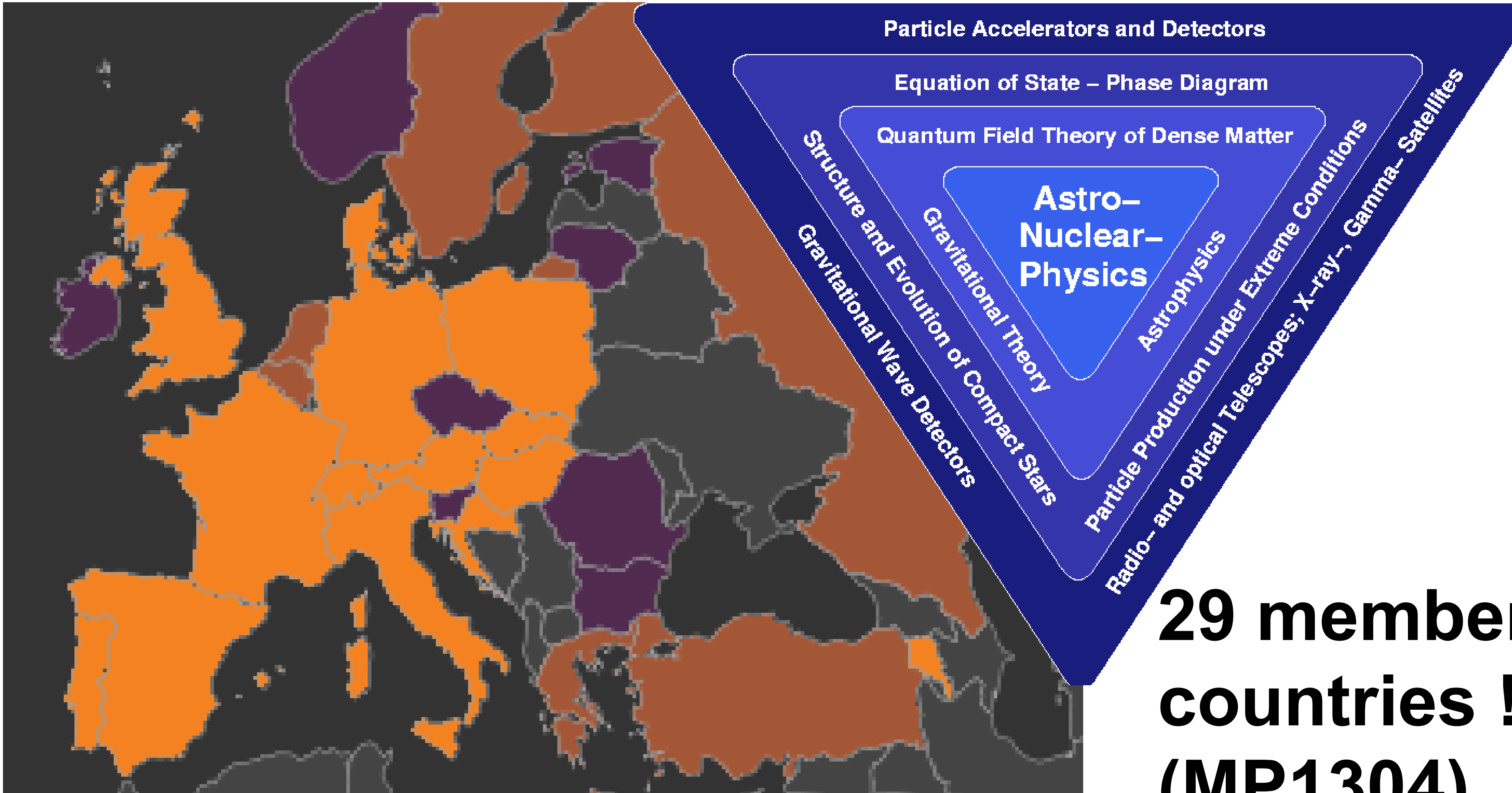


Main condition: stiff hadronic & stiff quark matter EoS with strong phase transition (PT)

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 inspiral of NS – hybrid star (HS) or HS - HS binary !

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



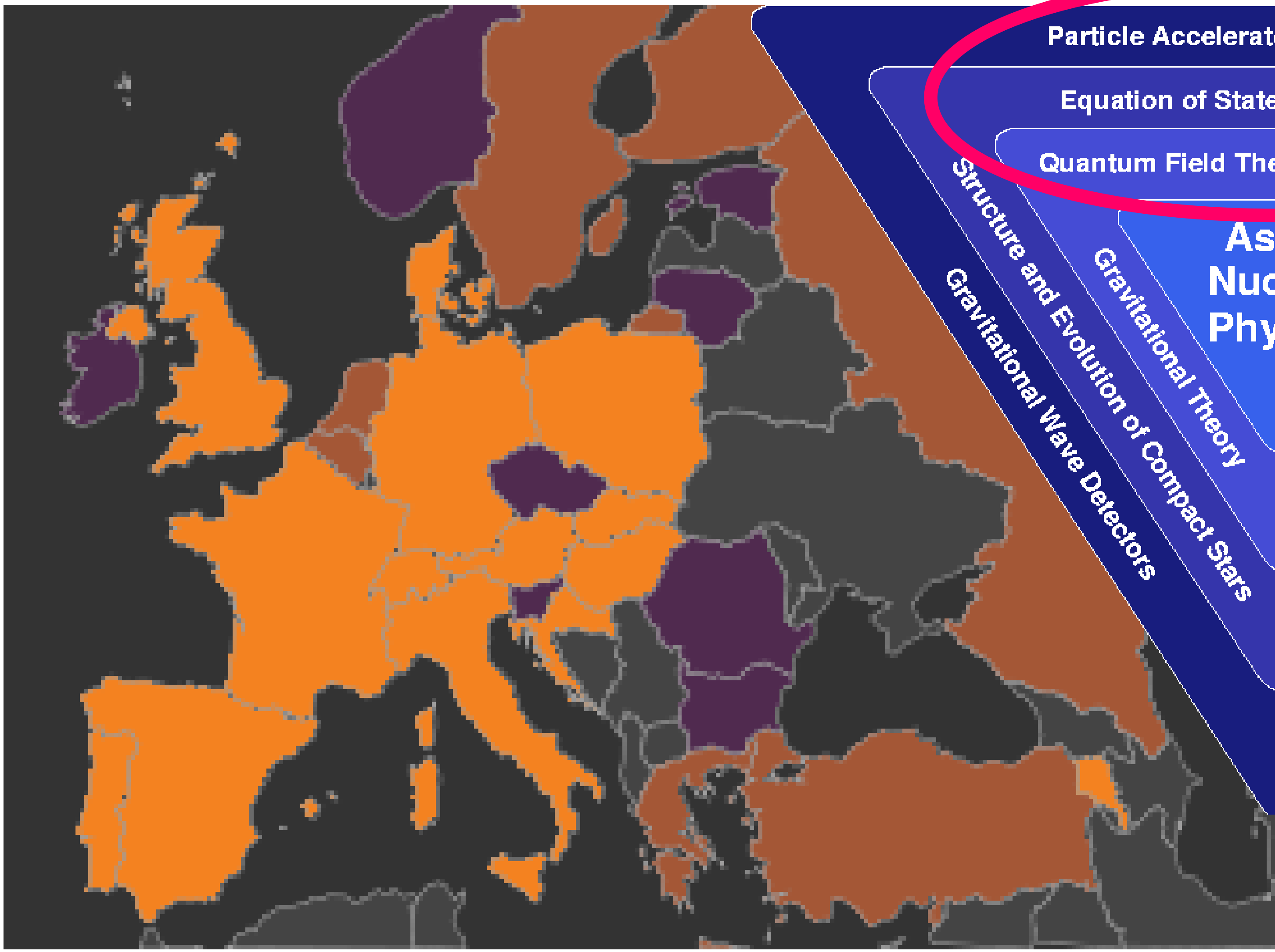
29 member countries !! (MP1304)

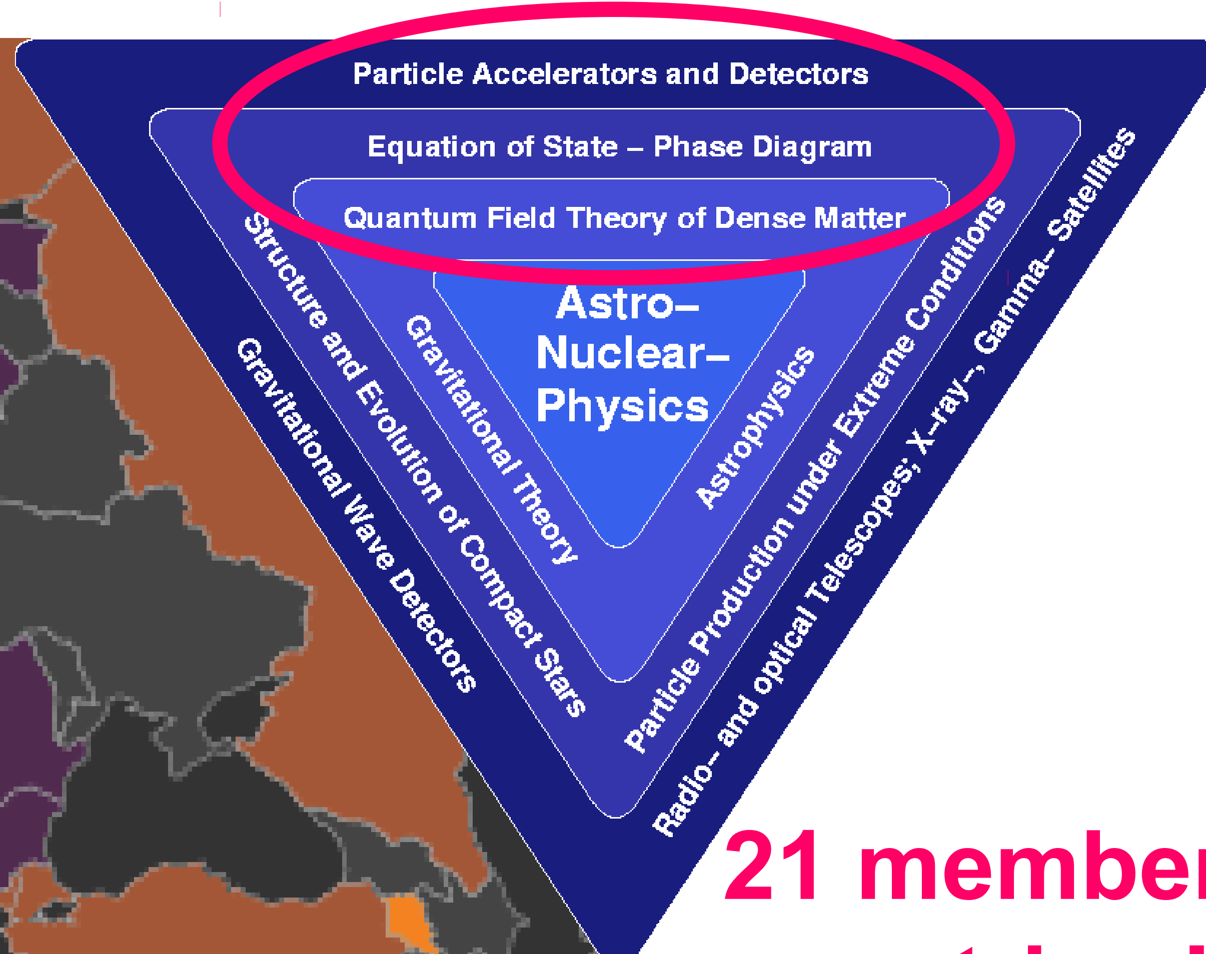
New comp star **!**

cost

EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

Kick-off: Brussels, November 25, 2013





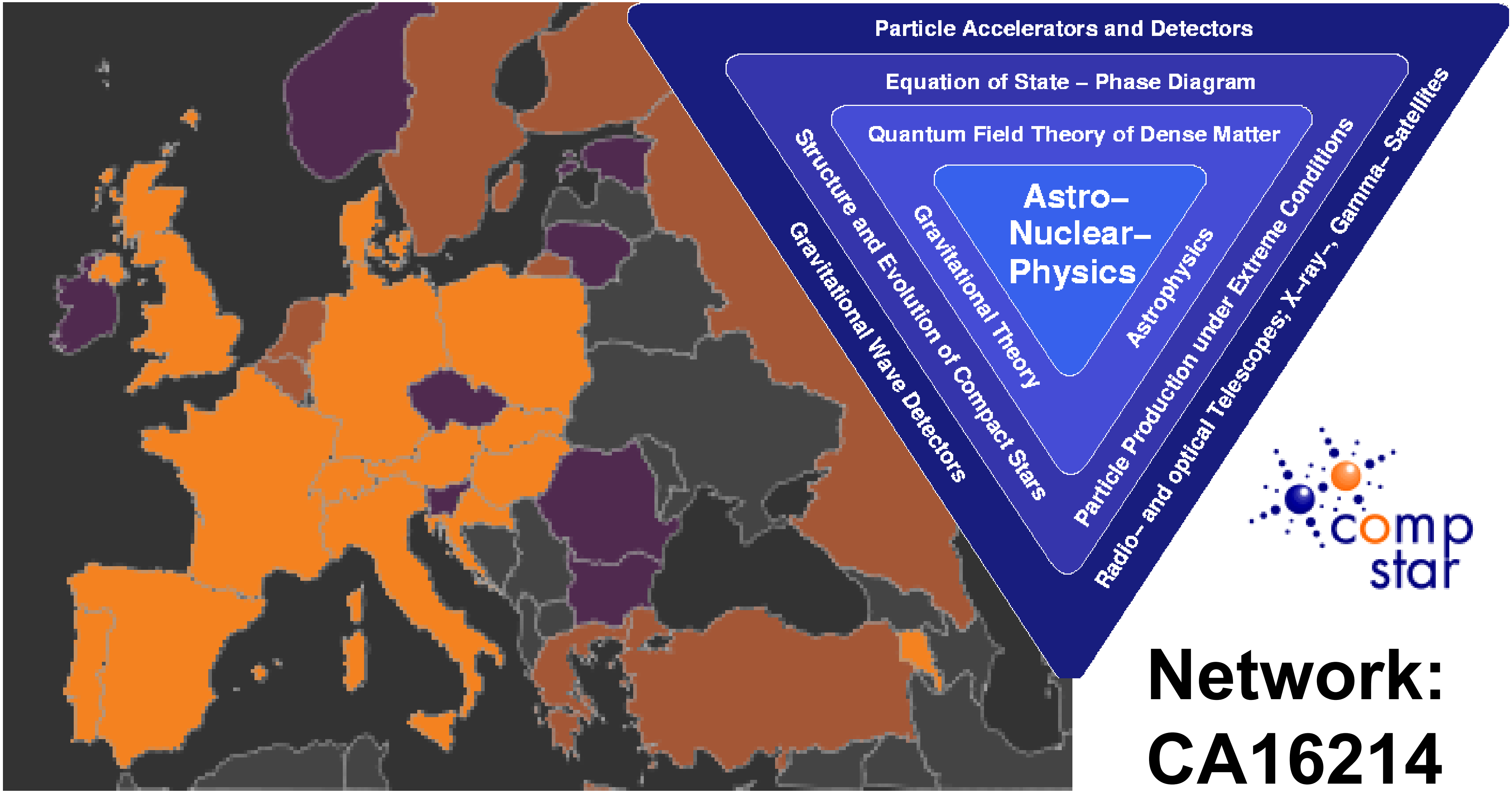
21 member countries ! (CA15213)

“Theory of HOt Matter in Relativistic Heavy-Ion Collisions”

New: THOR!

cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

Kick-off: Brussels, October 17, 2016



comp star

Network: CA16214

Newest:

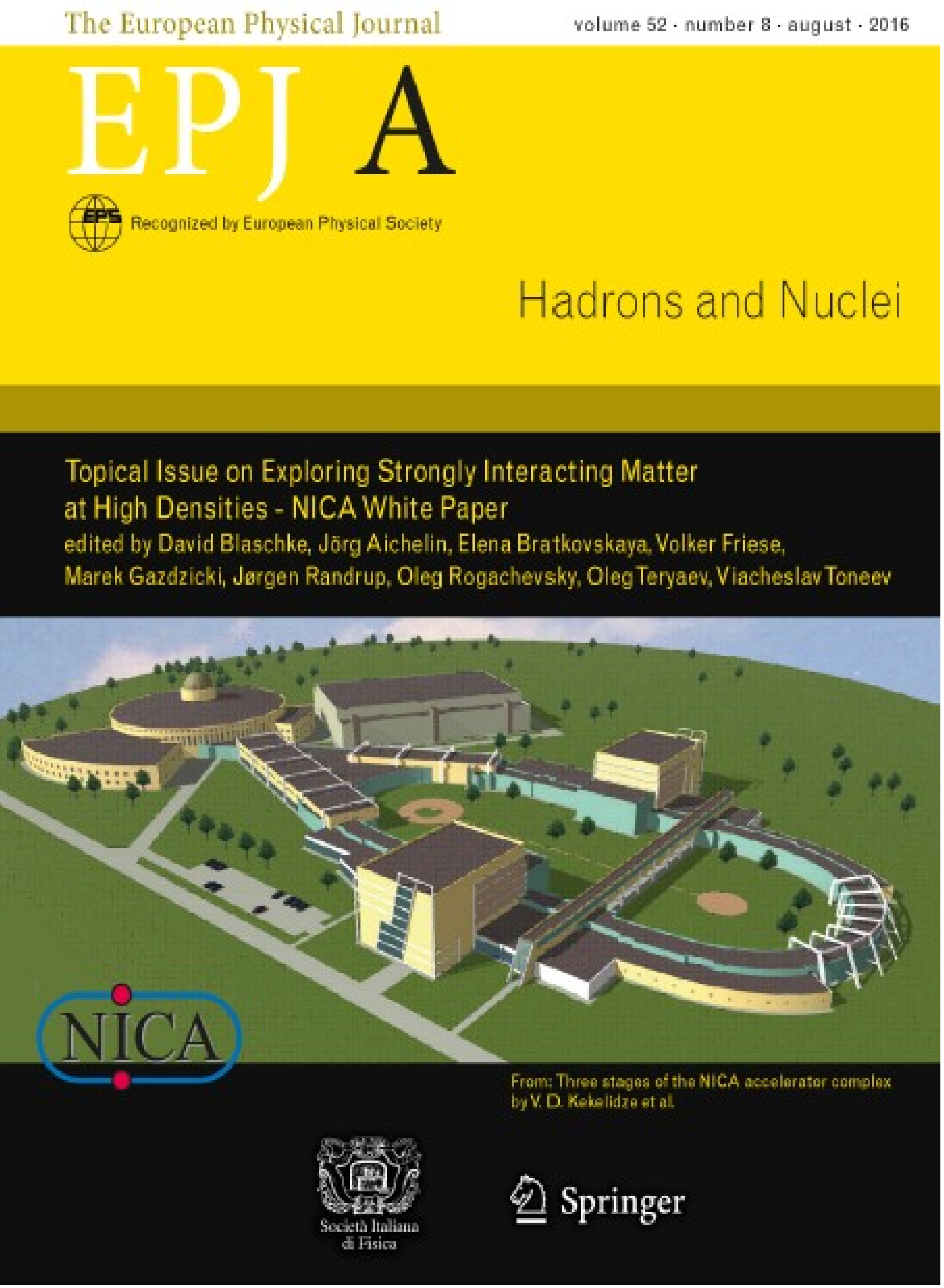
PHAROS
THE MULTI-MESSENGER PHYSICS AND ASTROPHYSICS OF NEUTRON STARS

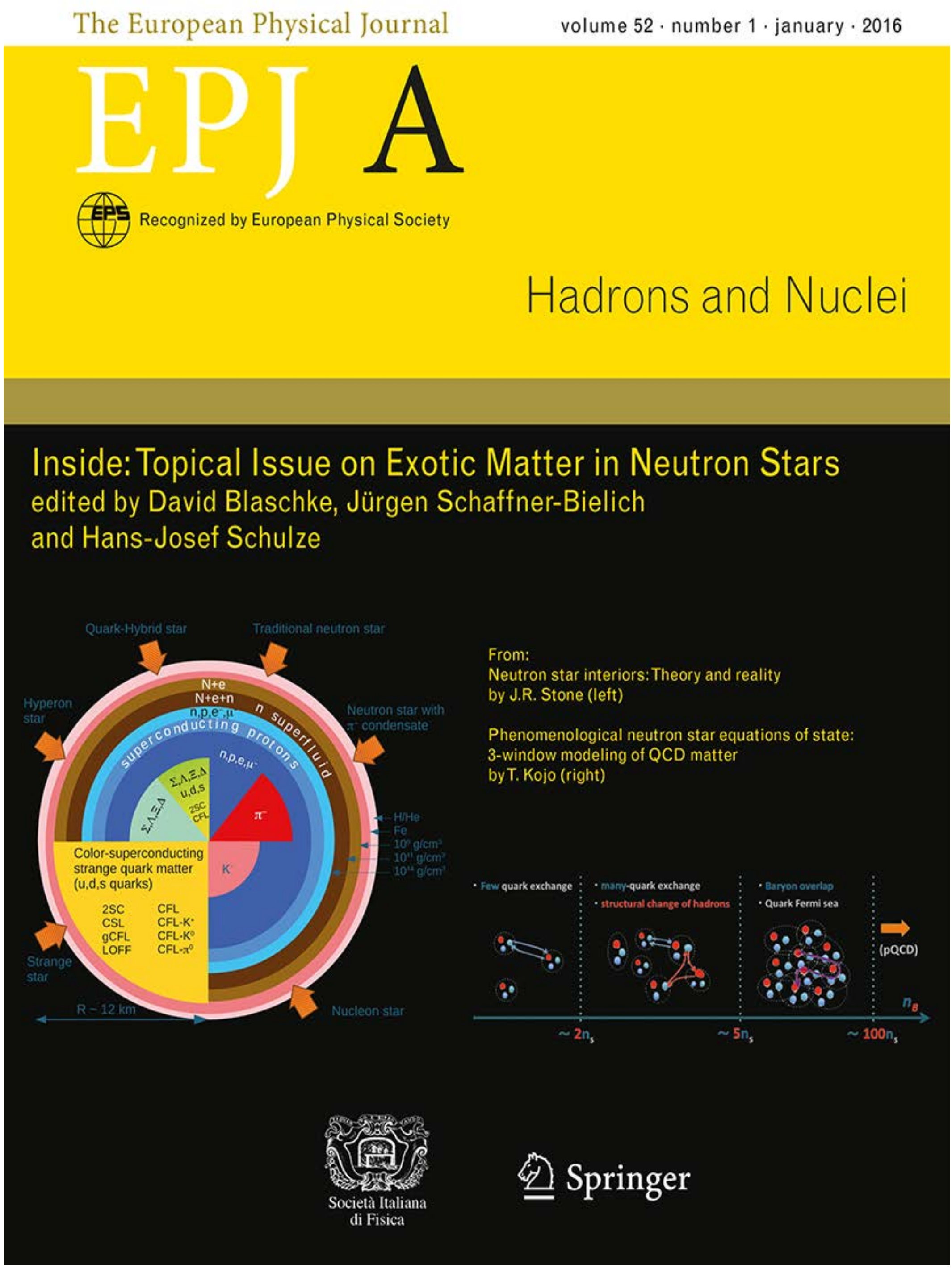
cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

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





EPJA Topical Issues can be found at → http://epja.epj.org/component/list/?task=topic

New Topical Issue:

EPJ A

Recognized by European Physical Society

Hadrons and Nuclei

The first observation of a neutron star merger and its implications for nuclear physics

Editors: D. Blaschke (EPJA), M. Colpi, C. Horowitz, D. Radice

Open call for contributions
Deadline – October 2018

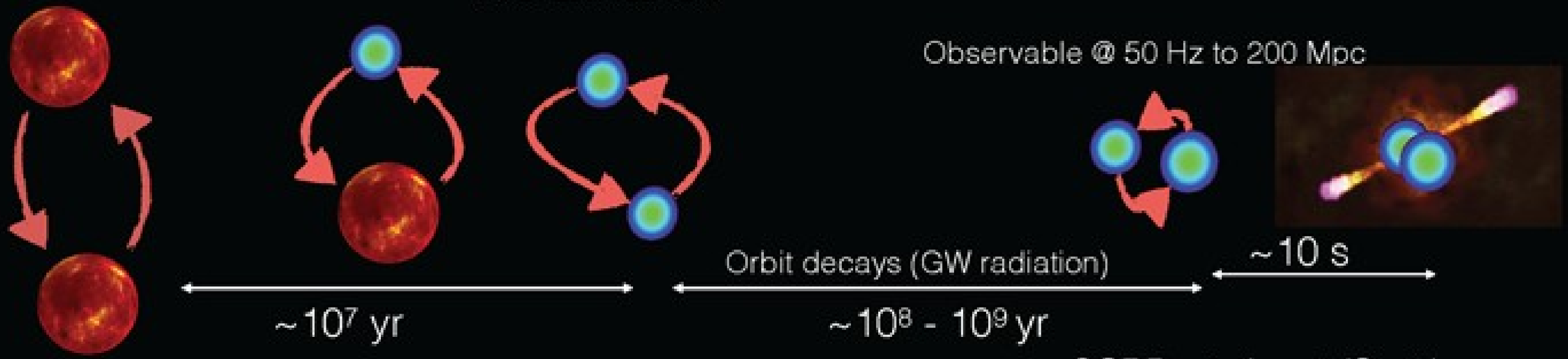
Website: https://www.epj.org/open-calls-for-papers/122-epj-a/

Email: david.blaschke@gmail.com , epja.bologna@sif.it

Backup slides

GW170817 – a merger of two neutron stars ?

NS Binaries



In the Milky Way

	Orbital Period	Masses (solar)	Time to Merger
B1913+16	0.323 days	1.441 + 1.387	3 x 10^8 yrs
B1534+12	0.421 days	1.333 + 1.347	27 x 10^8 yrs
B2127+11C	0.335 days	1.35 + 1.36	2.2 x 10^8 yrs
J0737-3039	0.102 days	1.34 + 1.25	0.86 x 10^8 yrs
J1756-2251	0.32 days	1.34 + 1.23	17 x 10^8 yrs
J1906+746	0.166 days	1.29 + 1.32	3.1 x 10^8 yrs
J1913+1102	0.201 days	1.65 + 1.24	5 x 10^8 yrs

SGRB rate is ~ 6 /Gpc^3/y

If 2/3 of SGRBs are associated with BNS mergers, the rate in Ad. LIGO at design sensitivity would be about

2 per year

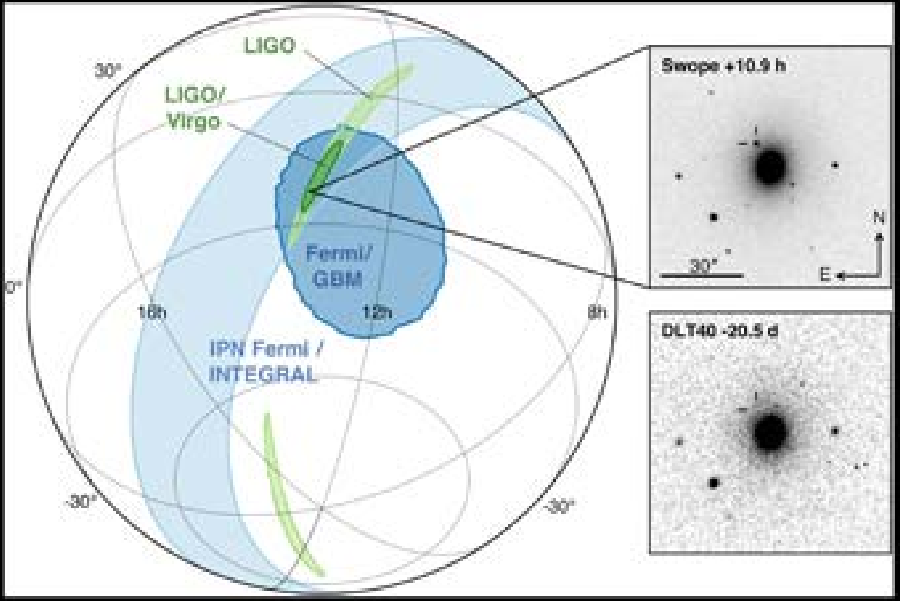
after accounting for beaming.

Initial expectation for BNS mergers in Ad. LIGO at design sensitivity: 0.4 - 400 / year

GW170817 – a merger of two neutron stars ?

August 17, 2017

12:41:06 UTC: Fermi observes the closest SGRB to date !
+14 seconds: Automated alert notice (GCN) sent by Fermi.
+6 minutes: Independently, Ad. LIGO detects inspiral signal with merger time at 12:41:04.
+27 minutes: Alert notice (GCN) sent by Ad. LIGO



Symposium @ INT Seattle, March 2018

GW170817 – a merger of two neutron stars ?

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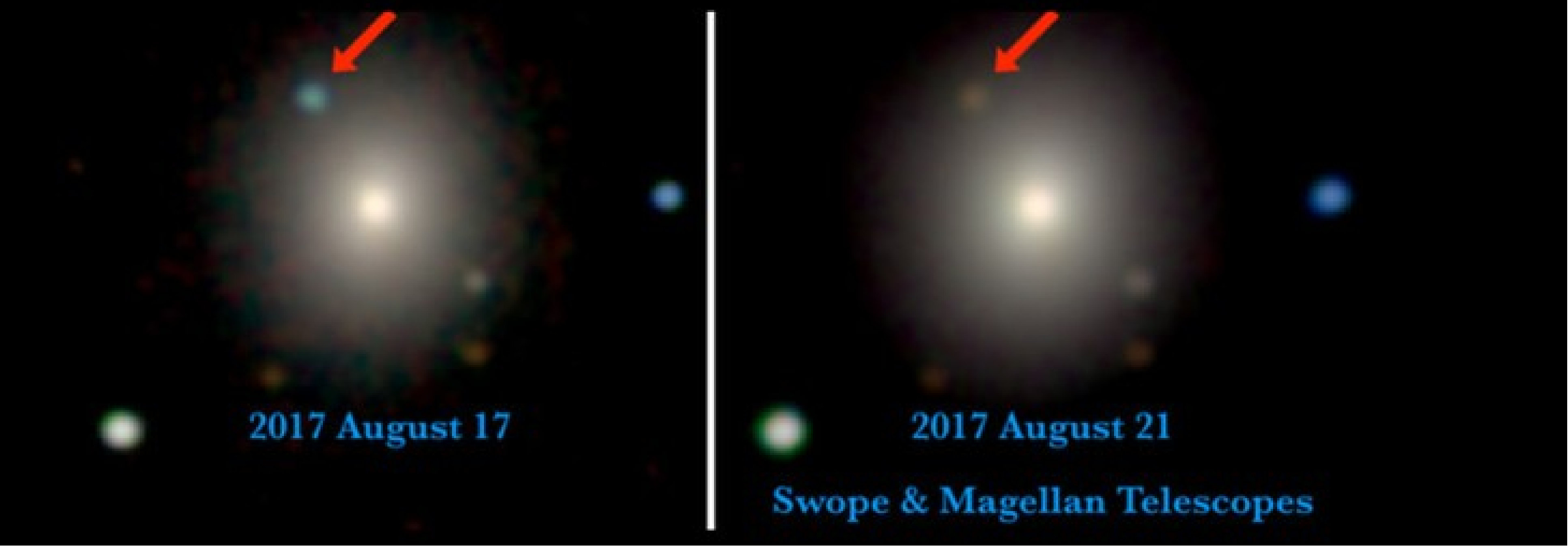
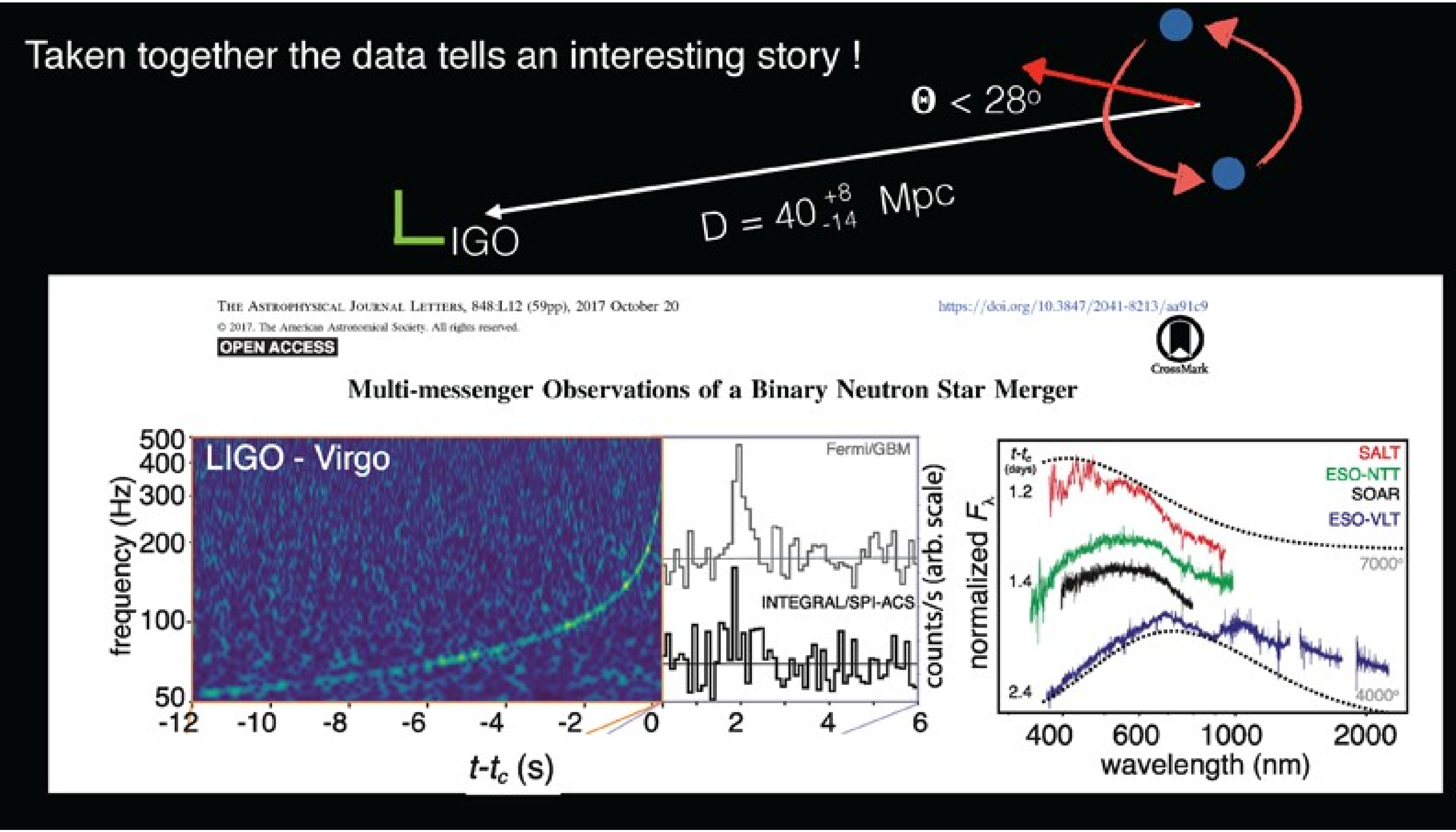
+6 minutes: Independently, Ad. LIGO detects inspiral signal with merger time at 12:41:04.
+27 minutes: Alert notice (GCN) sent by Ad. LIGO
+11 hours: Optical transient detected in a galaxy NGC 4993 at 40 Mpc by the 1M2H team.
Carnegie observatories at Los Campanas, Chile.



GW170817 – a merger of two neutron stars ?



GW170817 – a merger of two neutron stars ?

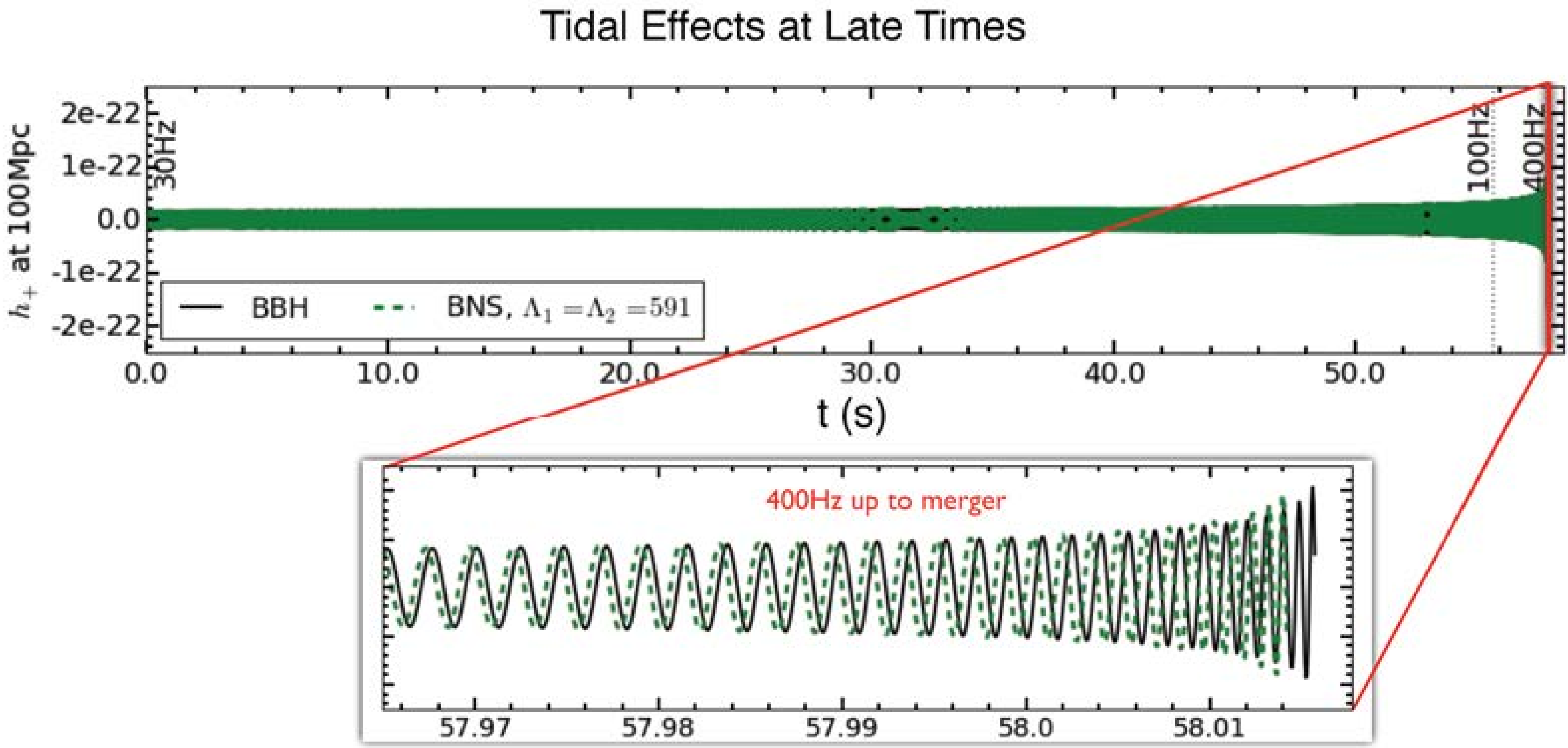
Parameters from GW data analysis

	Low-spin priors ($|\chi| \leq 0.05$)
Primary mass m_1	$1.36\text{–}1.60\ M_\odot$
Secondary mass m_2	$1.17\text{–}1.36\ M_\odot$
Chirp mass $\mathcal{M}$	$1.188^{+0.004}_{-0.002} M_\odot$
Mass ratio m_2/m_1	$0.7\text{–}1.0$
Total mass m_{tot}	$2.74^{+0.04}_{-0.01} M_\odot$
Radiated energy E_{rad}	$> 0.025 M_\odot c^2$
Luminosity distance D_L	40^{+8}_{-14} Mpc
Viewing angle Θ	$\lesssim 55°$
Using NGC 4993 location	$\lesssim 28°$
Combined dimensionless tidal deformability $\tilde{\Lambda}$	$\lesssim 800$
Dimensionless tidal deformability $\Lambda(1.4 M_\odot)$	$\lesssim 800$

$$\mathcal{M} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}} \quad \Longleftarrow \quad \frac{df}{dt} = \frac{96\ \pi^{8/3}}{5} \mathcal{M}^{5/3} f^{11/3}$$

$$\tilde{\Lambda} = \frac{1}{26}\left(\frac{(m_{tot} + m_2) m_1^4}{m_{tot}^5} \Lambda_1 + \frac{(m_{tot} + m_1) m_2^4}{m_{tot}^5} \Lambda_2\right) \quad \text{where} \quad \Lambda_i = \frac{\lambda_i}{m_i^5} = \frac{2}{3} k_2(\beta_i, \mathrm{EOS}) \frac{R_i^5}{m_i^5}$$

GW170817 – a merger of two neutron stars ?



B. Lackey, L. Wade. PRD 91, 043002 (2015)

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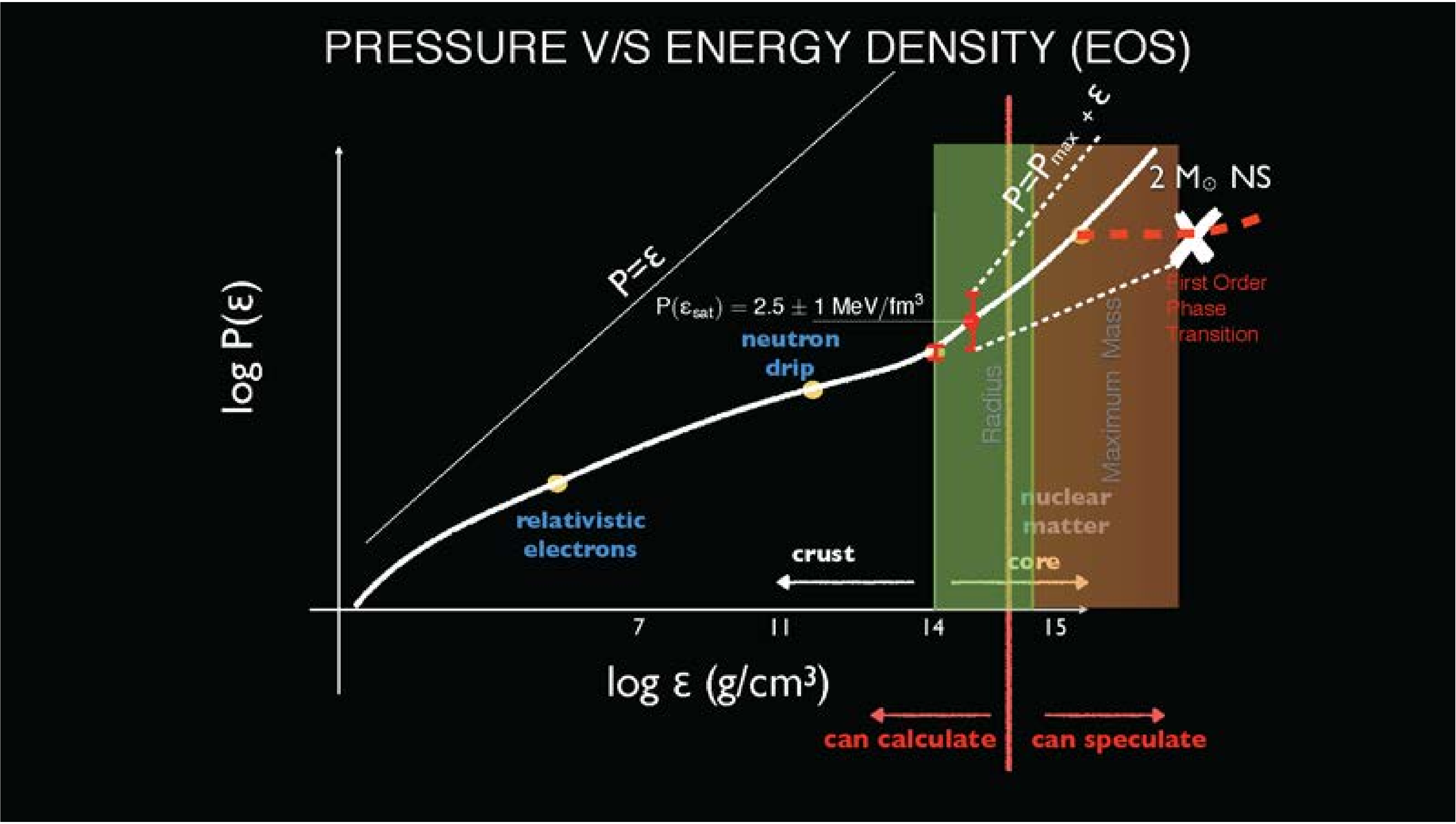
GW170817 – a merger of two neutron stars ?



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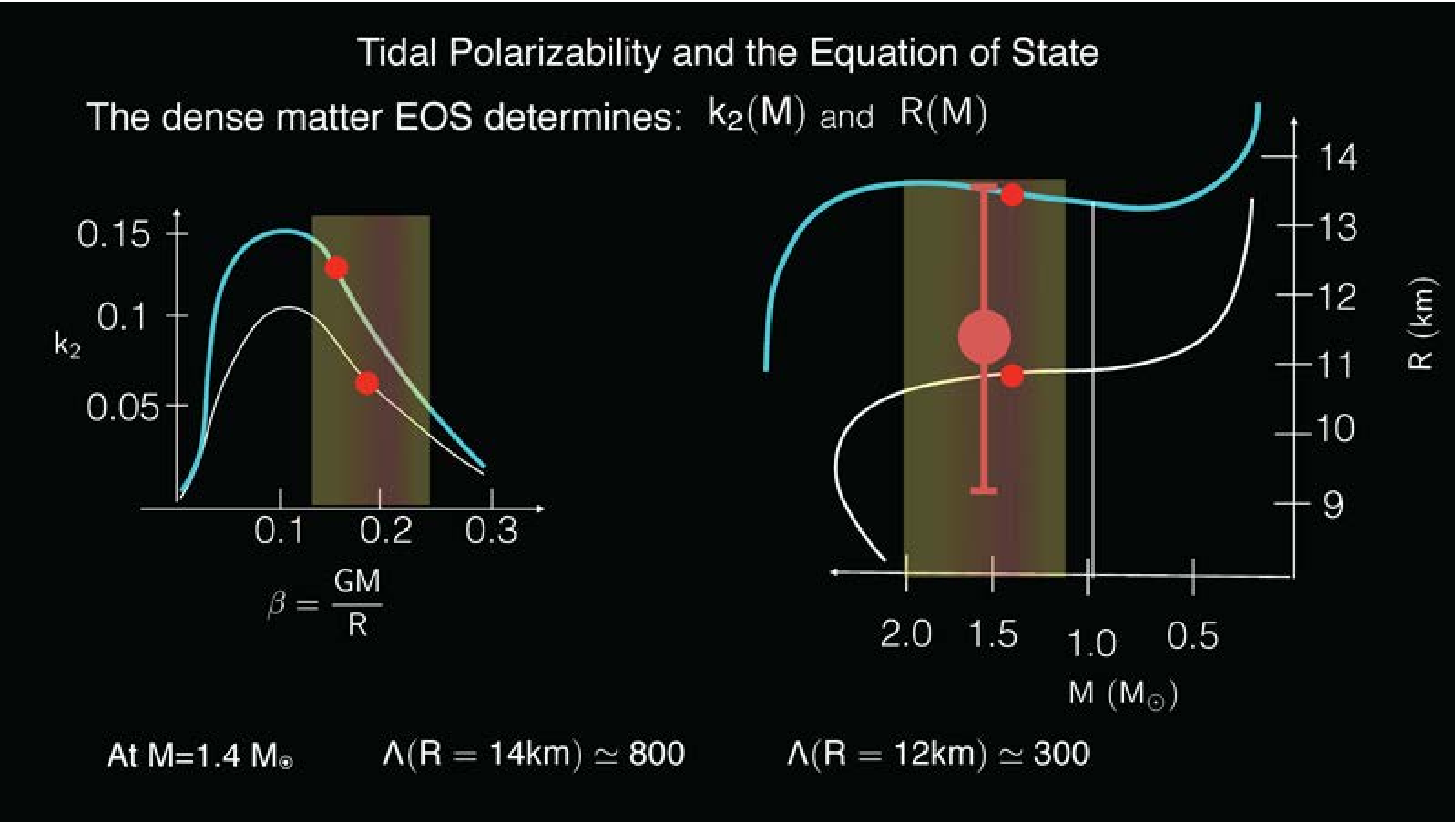

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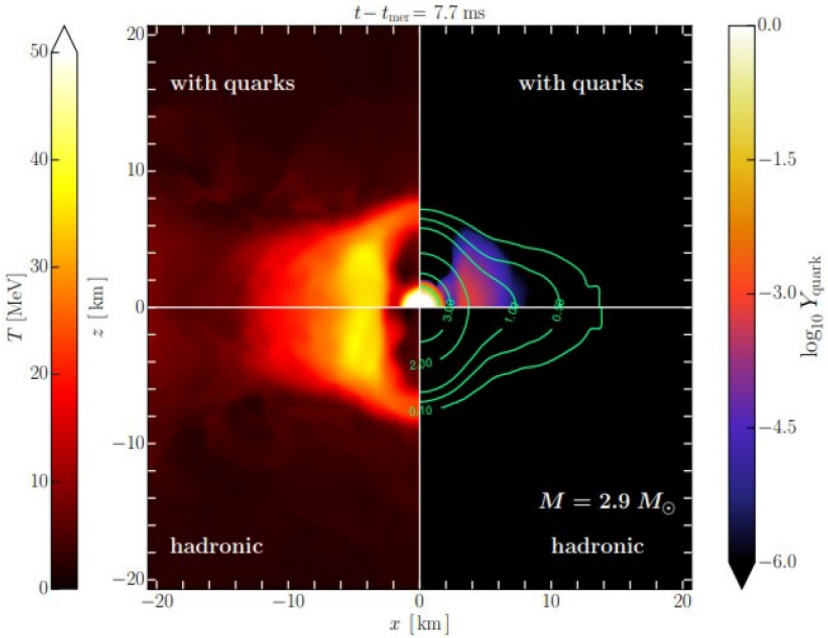
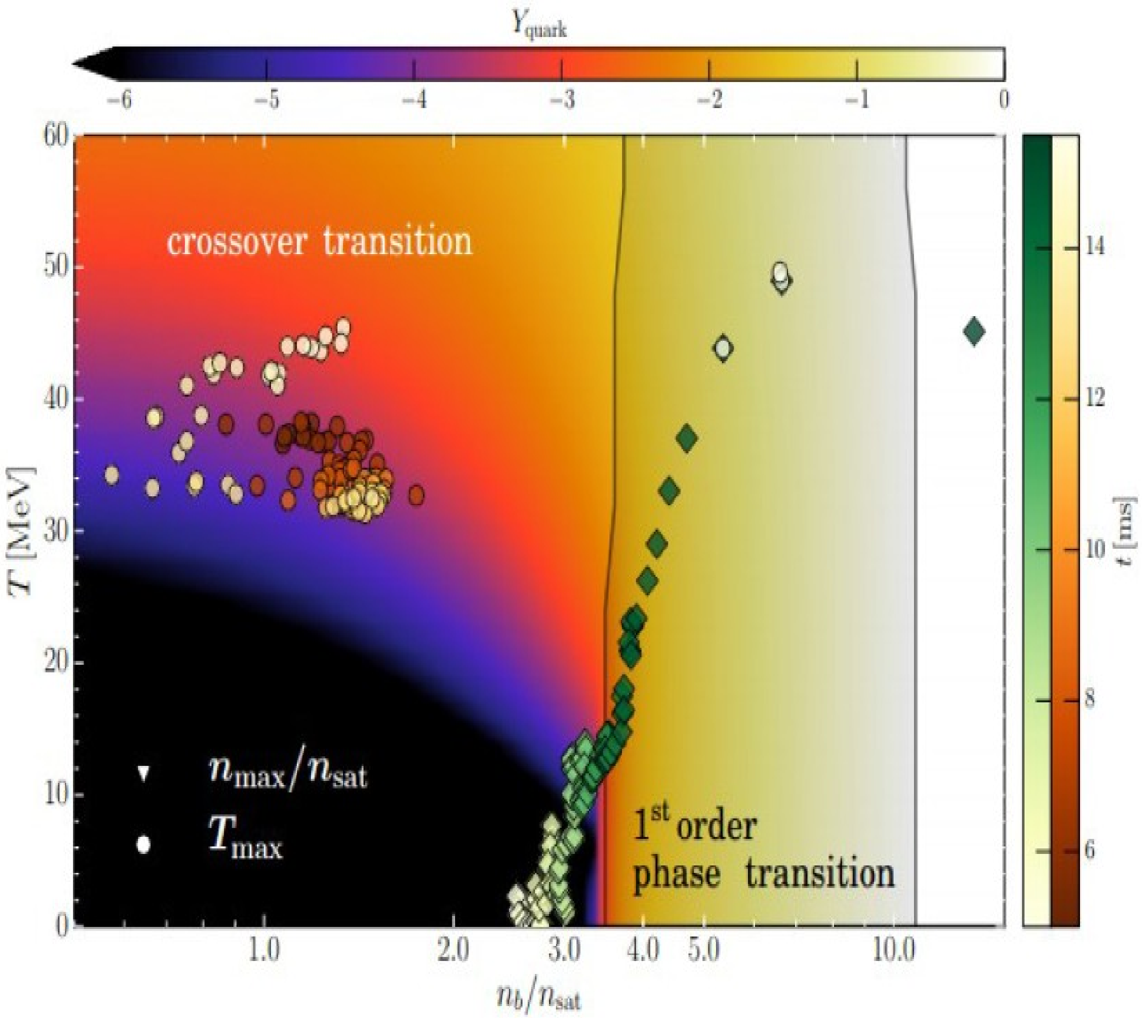


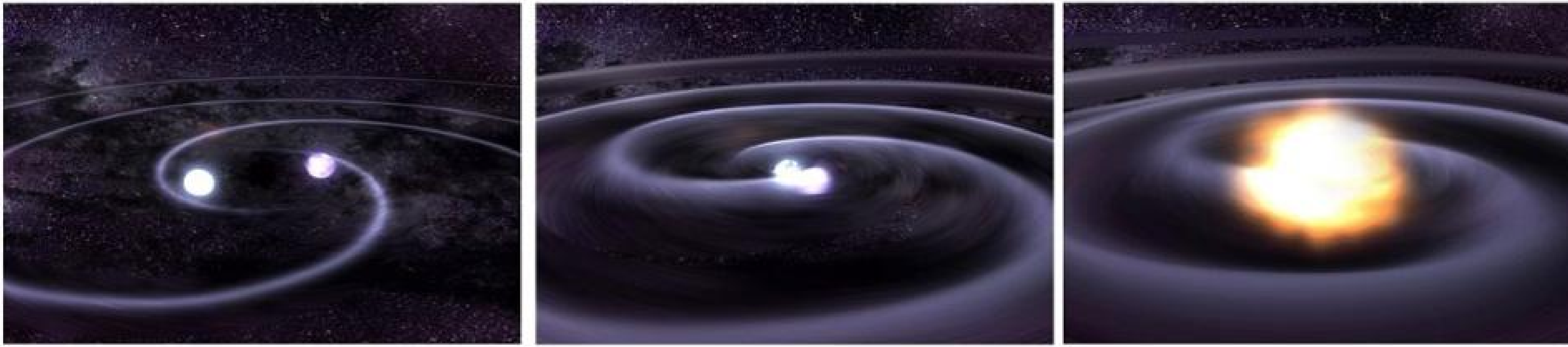
← Meridonal plane of a hot, supermassive binary star during the merger process. quark vs. hadronic chiral meanfield model.

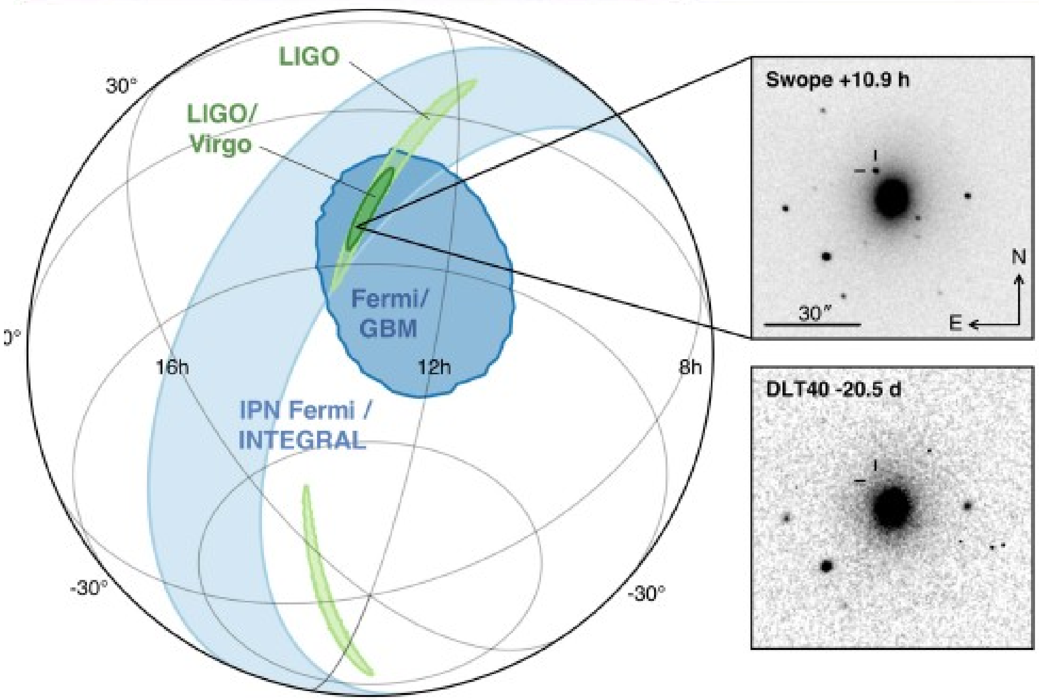


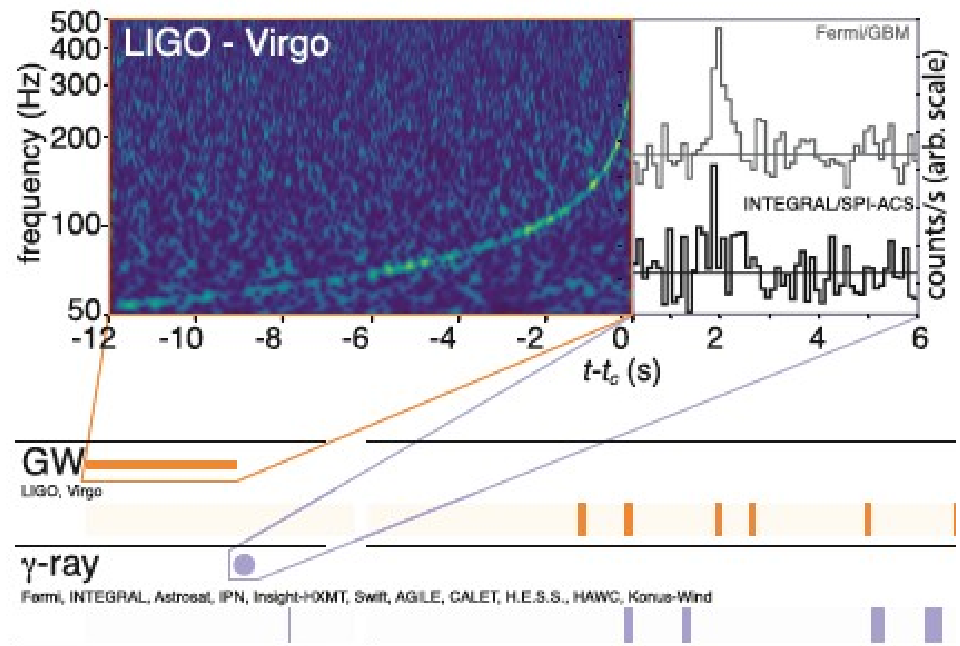
Evolution of the densest and hottest points in the supermassive binary star In the phase diagram during the merger process. The background colors indicate quark fractions.

Most, Papenfort, et al., arxiv:1807.03684

GW170817 – a merger of two neutron stars ?







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	$1.36\text{–}1.60\ M_\odot$
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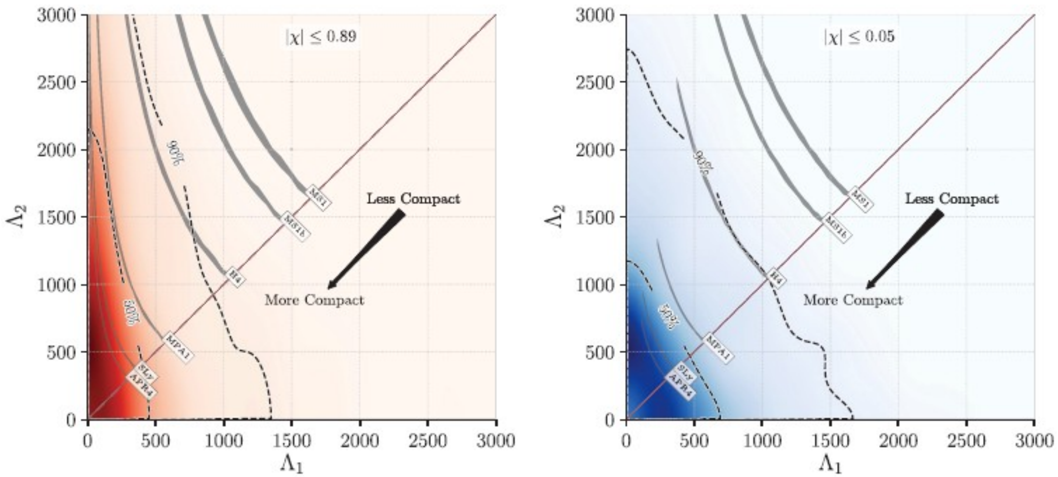

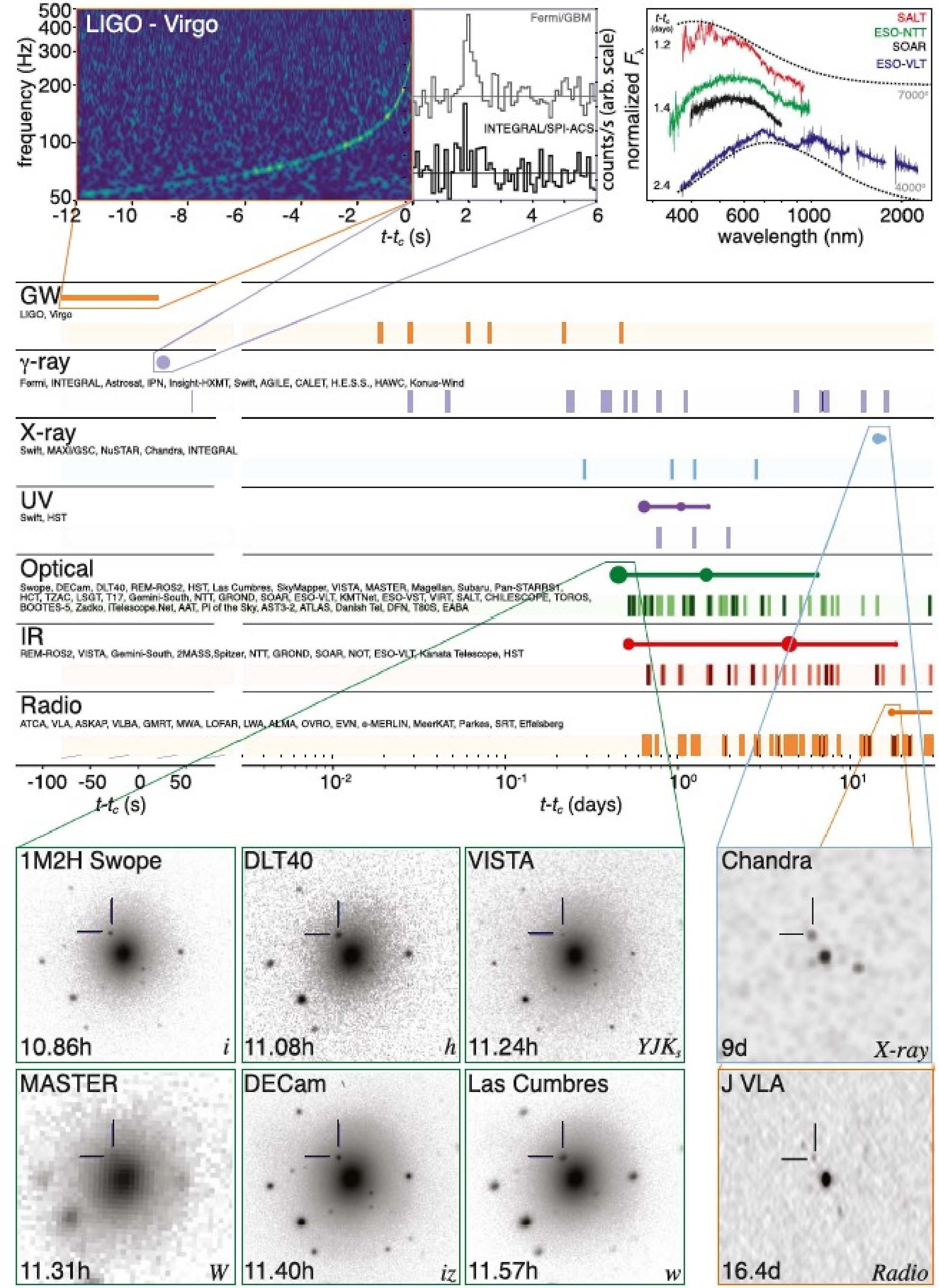

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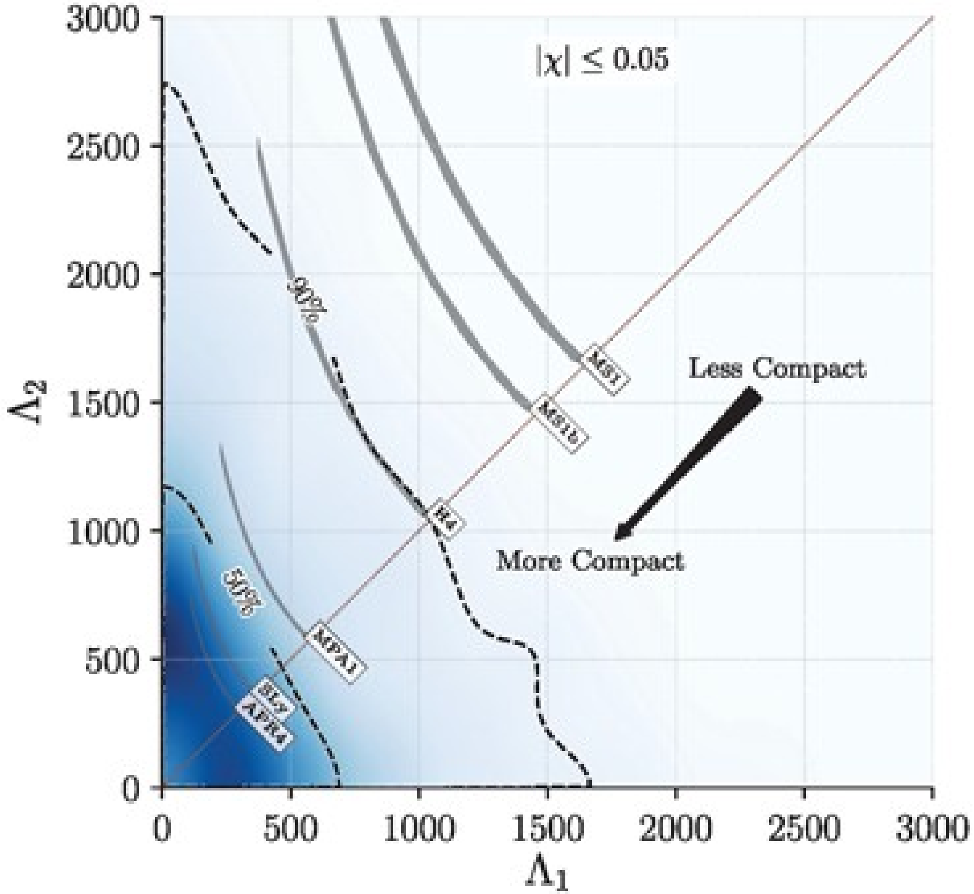
GW170817 – a merger of two neutron stars ?

Selected for a Viewpoint in *Physics*
PRL **119,** 161101 (2017) PHYSICAL REVIEW LETTERS week ending 20 OCTOBER 2017

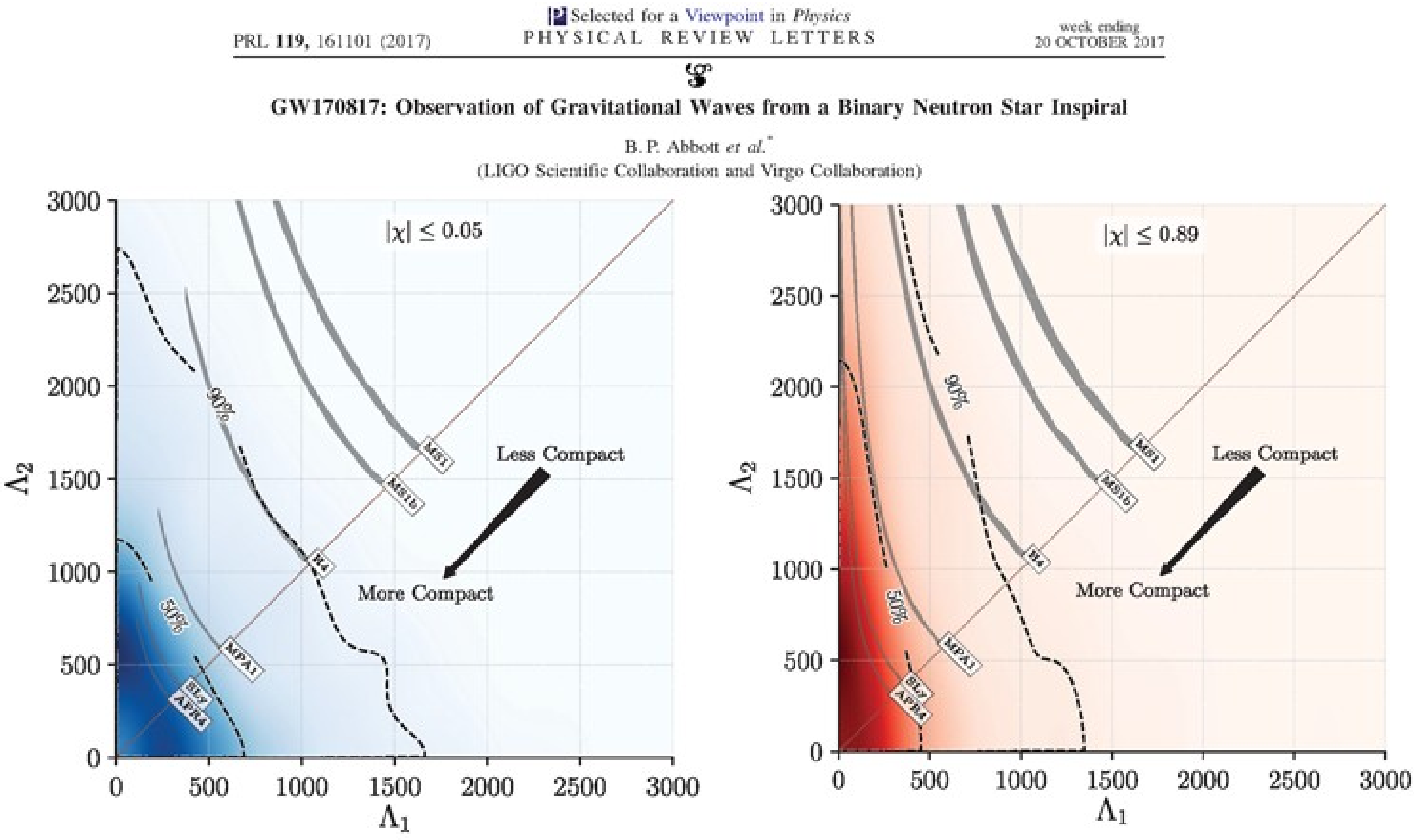
GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

B. P. Abbott *et al.**
(LIGO Scientific Collaboration and Virgo Collaboration)



- Very stiff (unrealistic) EOS which predict R > 14 kms are disfavored.
- Data appears to favor a finite polarizability but cannot distinguish between radii in the range 9-13 kms.
- Systematic errors due to spin-orbit, spin-spin interactions are included in parameter estimation.

GW170817 – a merger of two neutron stars ?



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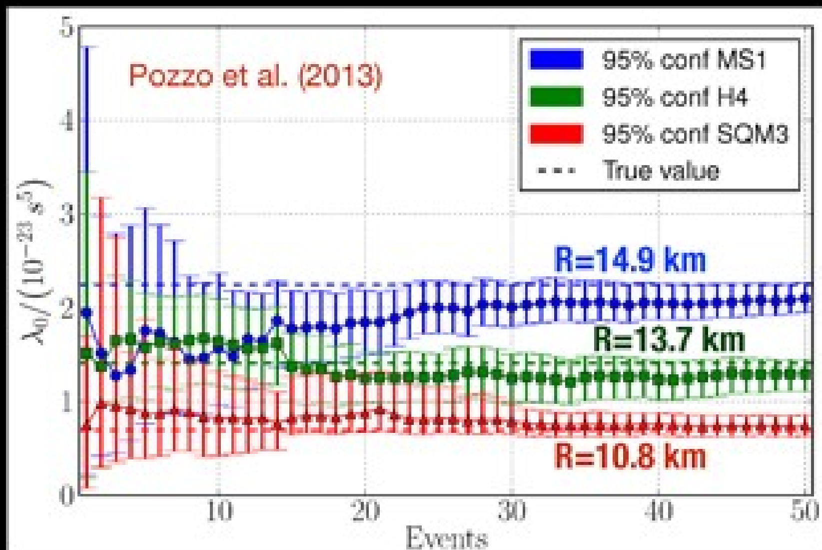
GW170817 – a merger of two neutron stars ?

With Many Detections and Some Luck

Quadrupole Polarizability

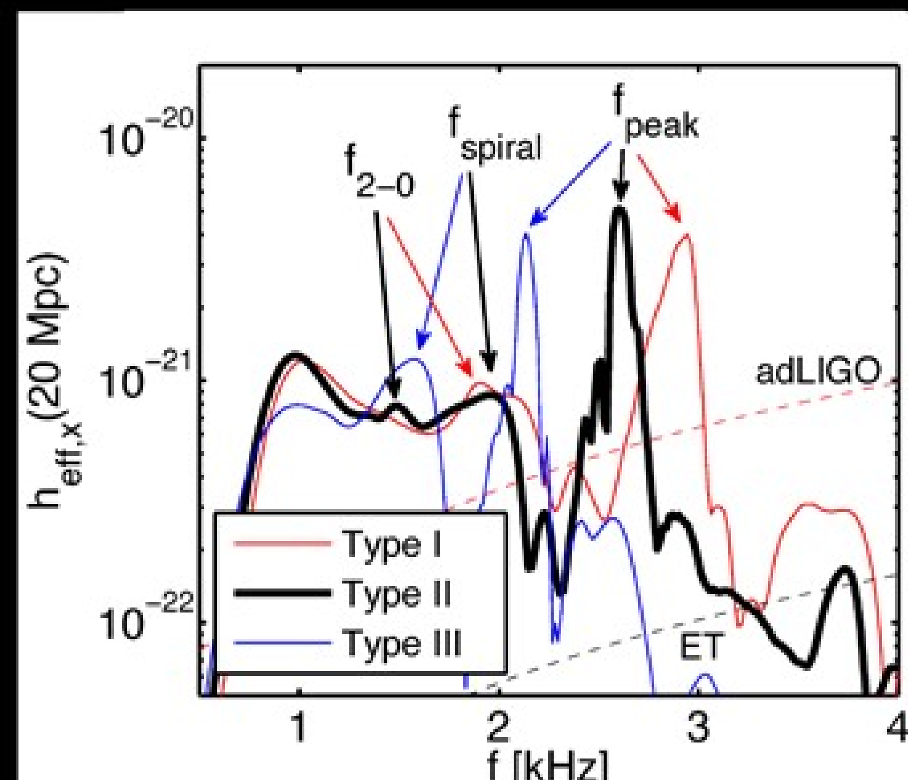


10% measurement of neutron star radius may be possible.

Frequency of quasi-normal modes of NS post merger are sensitive to EOS.

$$
\begin{aligned}
f_{\rm peak}[\mathrm{kHz}] &= 199(M/R)^2 - 28.1(M/R) + 2.33 \\
f_{\rm spiral}[\mathrm{kHz}] &= 358(M/R)^2 - 82.1(M/R) + 6.16 \\
f_{2-0}[\mathrm{kHz}] &= 392(M/R)^2 - 88.3(M/R) + 5.95
\end{aligned}
$$

Bauswein & Stergioulas (2015)



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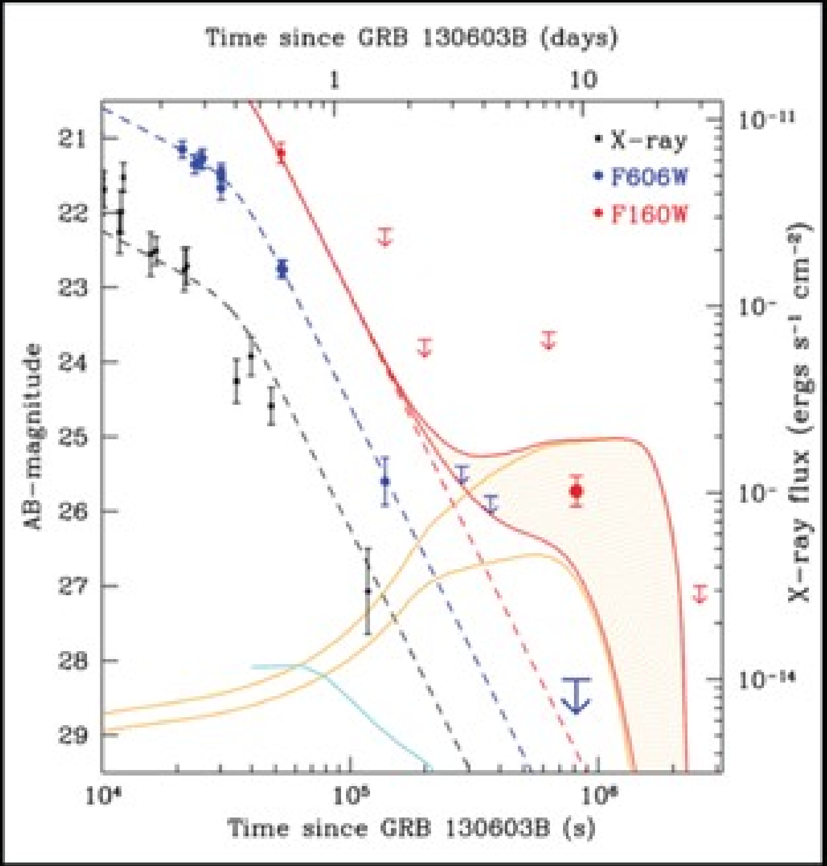
GW170817 – a merger of two neutron stars ?

Ejecta and Kilonova

- Mergers produce and heavy elements.
  Lattimer & Schramm 1974
- Radioactive heavy elements synthesized and ejected can power an EM signal.
  Eichler, Livio, Piran, Schramm 1989, Li & Paczynski 1998, Metzger et al. 2010, Roberts et al. 2011, Goriely et al. 2011
- Magnitude and color of the optical emission is sensitive to the composition of the ejecta.
  Kasen 2013



Detection of a Kilonova ?

Tanvir et al. 2013

GW170817 – a merger of two neutron stars ?

Late time EM emission

Tremendous detail in the observed light curves !

Remarkably, models that fit these light curves suggests:

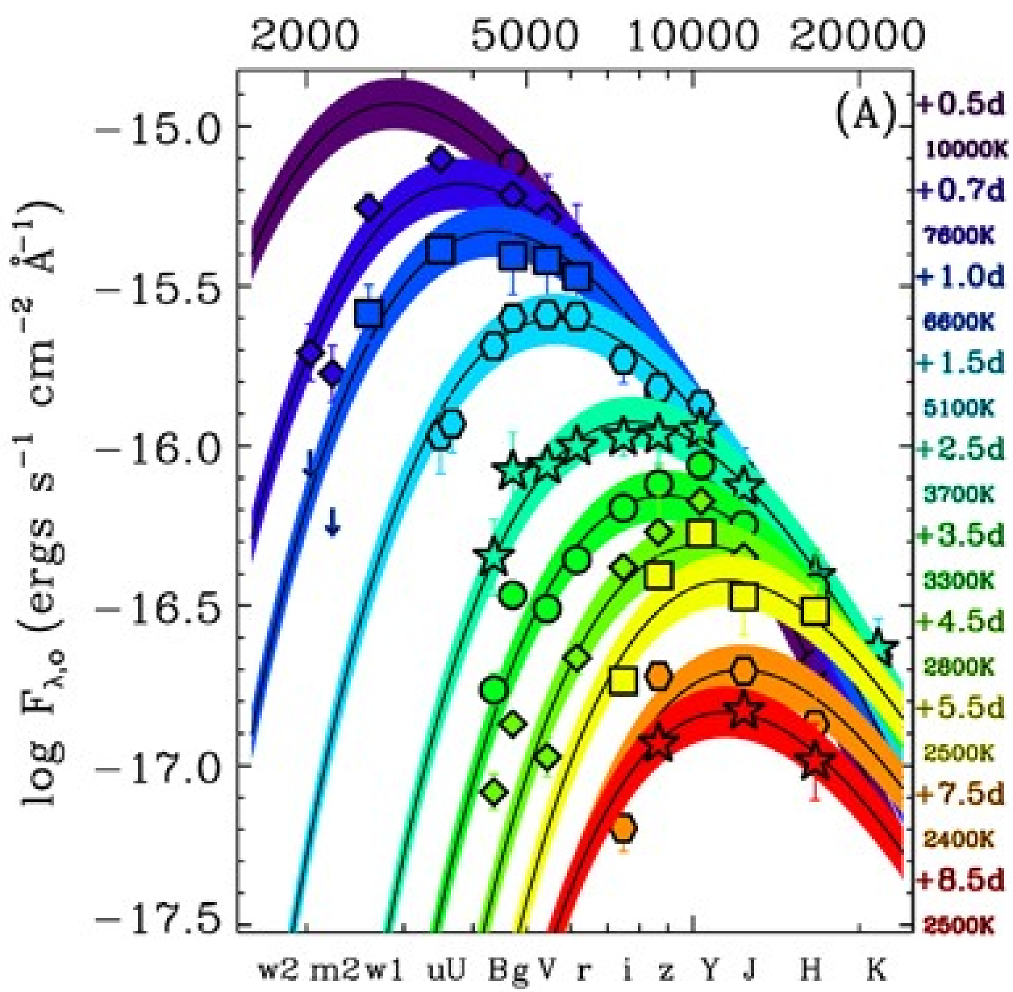
nature Accelerated Article Preview

LETTER

Origin of the heavy elements in binary neutron-star mergers from a gravitational-wave event

Daniel Kasen, Brian Metzger, Jennifer Barnes, Eliot Quataert & Enrico Ramirez-Ruiz

1. Merger ejected ~ 0.06 $M_\odot$ of radioactive nuclei
2. Radioactive ejecta had two components
3. One component with A>140 (heavy r-process)
4. Second component with A<140 (light r-process)
5. Mass of the A>140 component ~ 0.04 $M_\odot$
6. Mass of the A<140 component ~ 0.025 $M_\odot$



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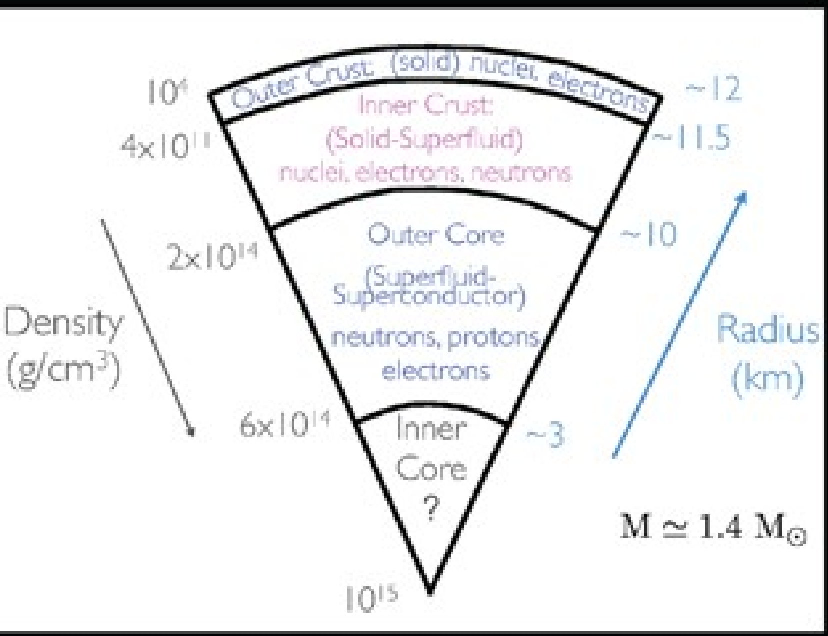
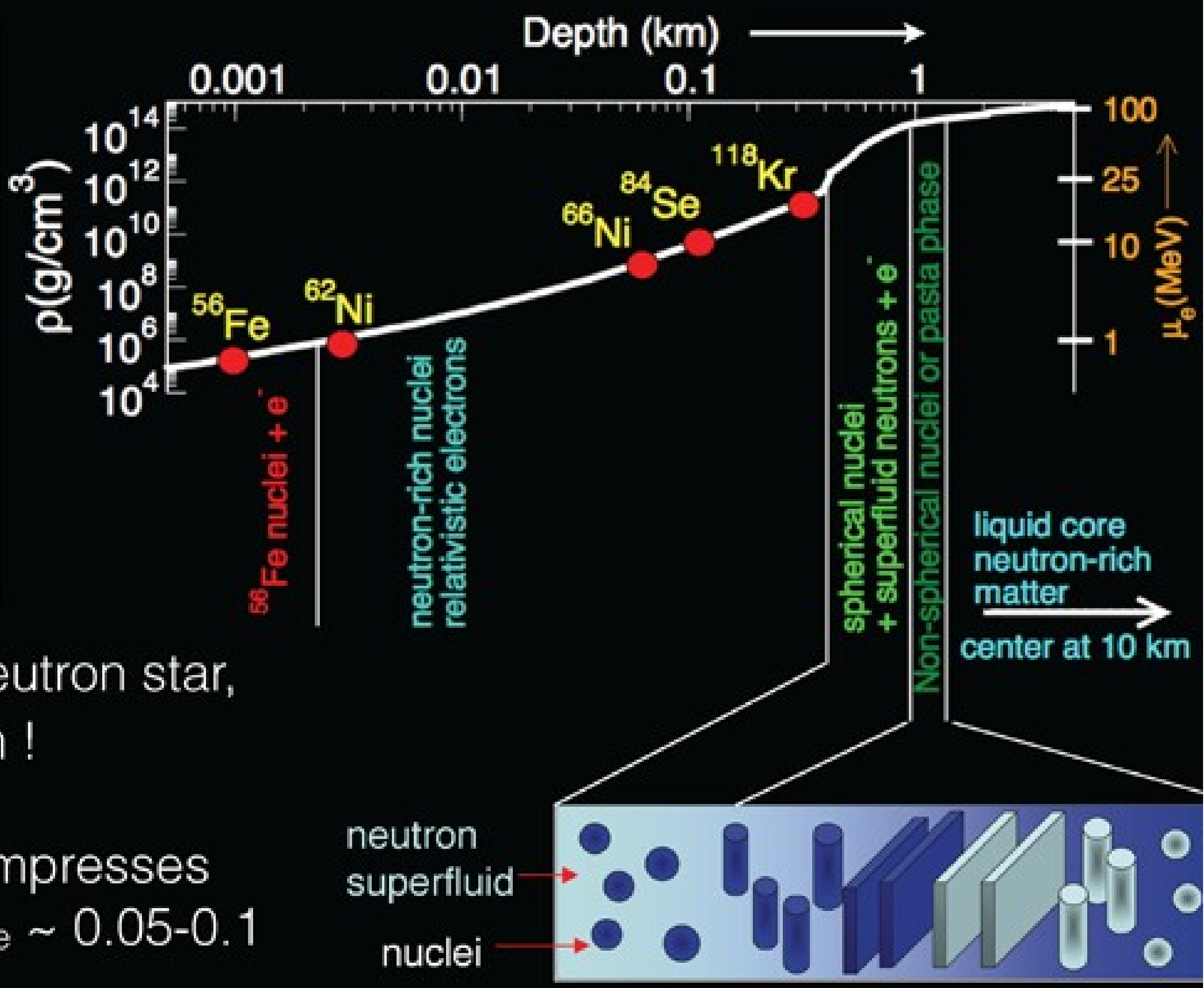
GW170817 – a merger of two neutron stars ?

Blast Mining Neutron Stars

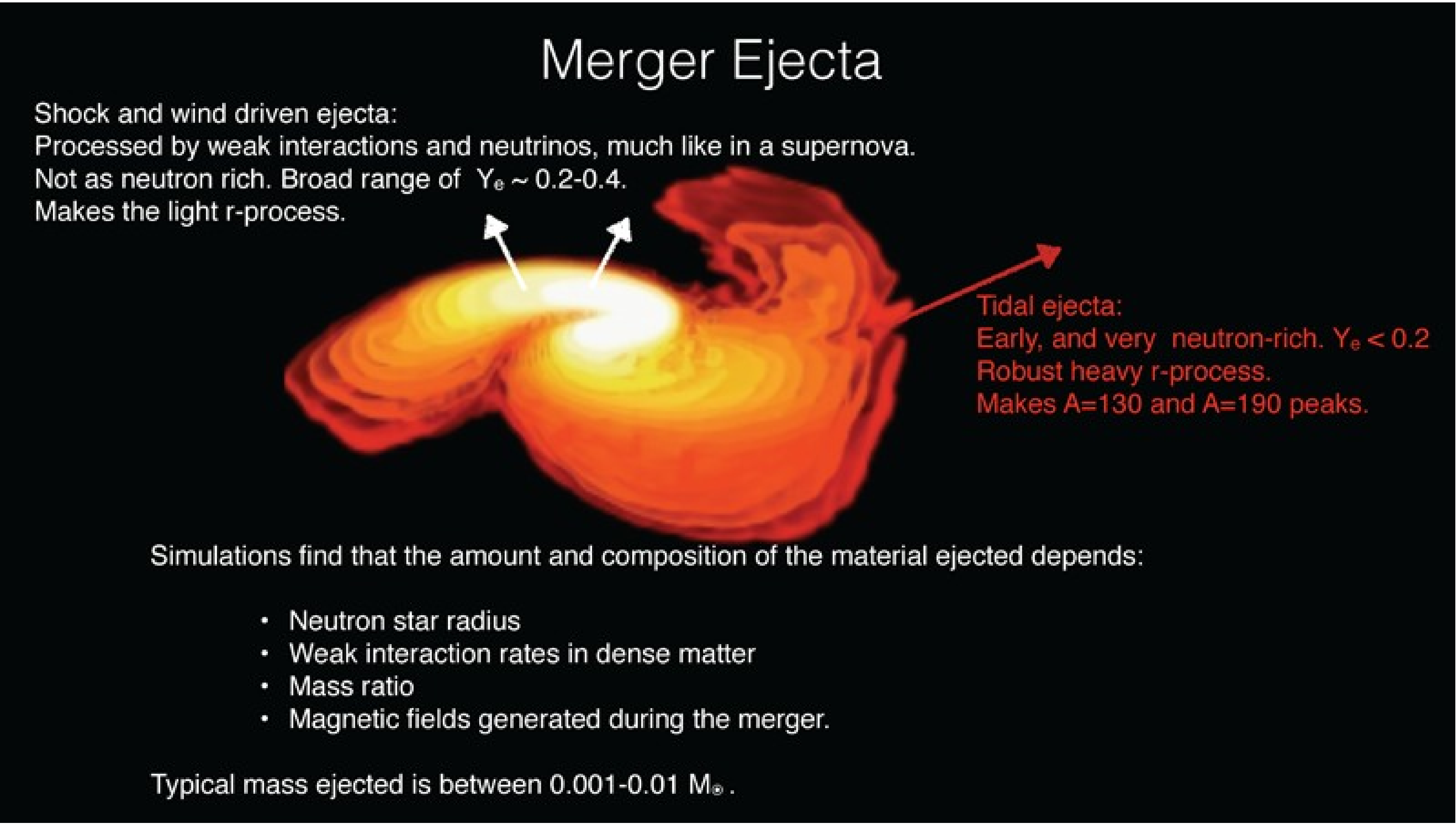




To extract ~0.03 $M_\odot$ from each neutron star, need to dig down >2 km in depth !

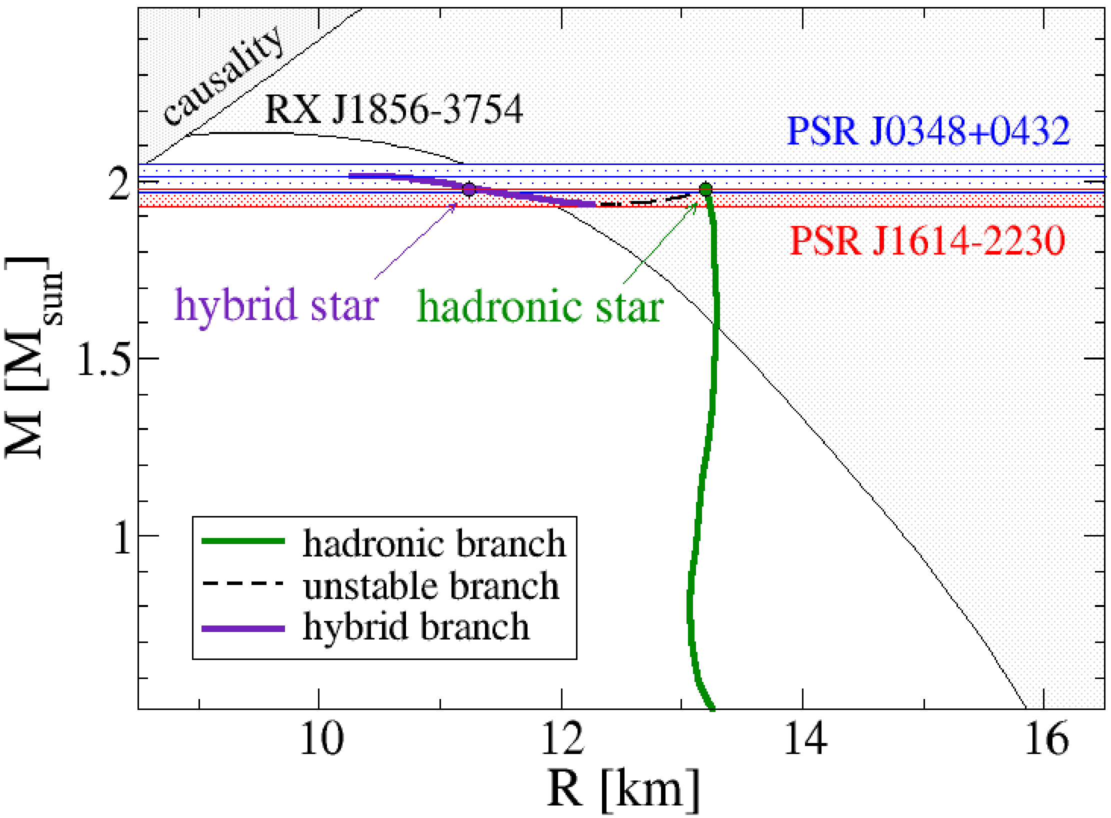
Ejection during the merger decompresses dense neutron-rich matter. $Y_p = Y_e \sim 0.05\text{-}0.1$

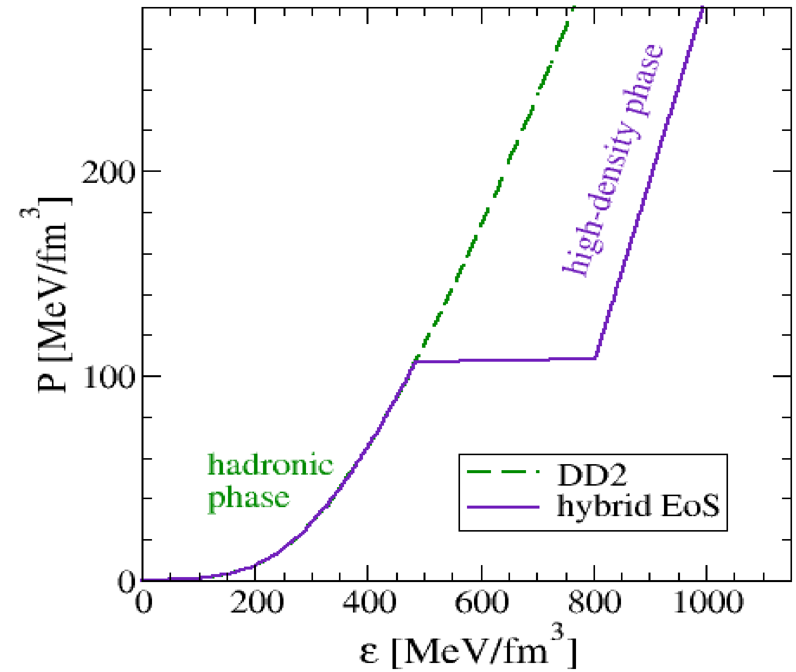
GW170817 – a merger of two neutron stars ?

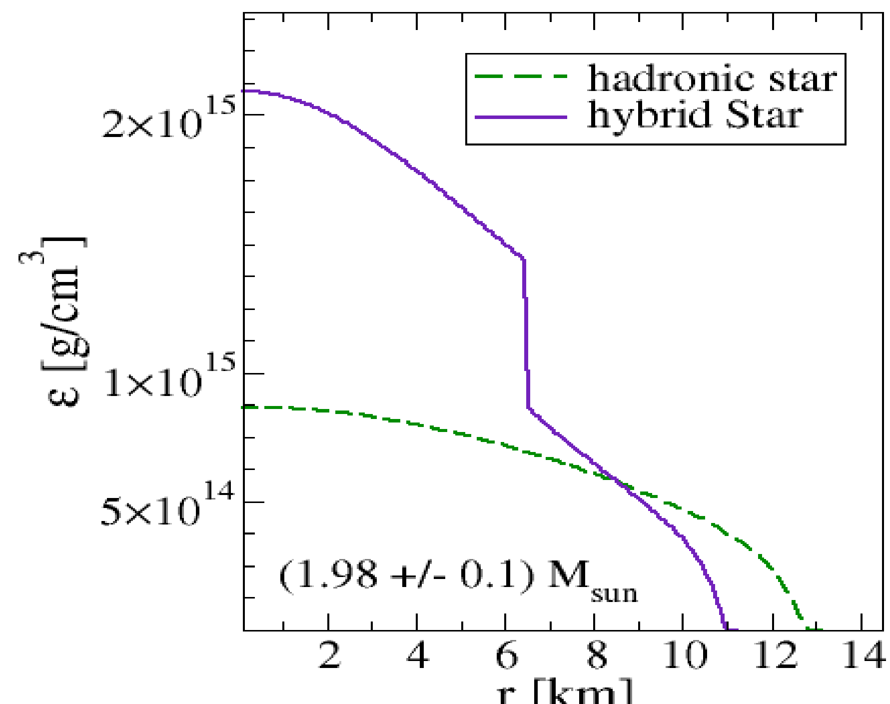


"Holy Grail" - High-Mass Twin Stars

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.?







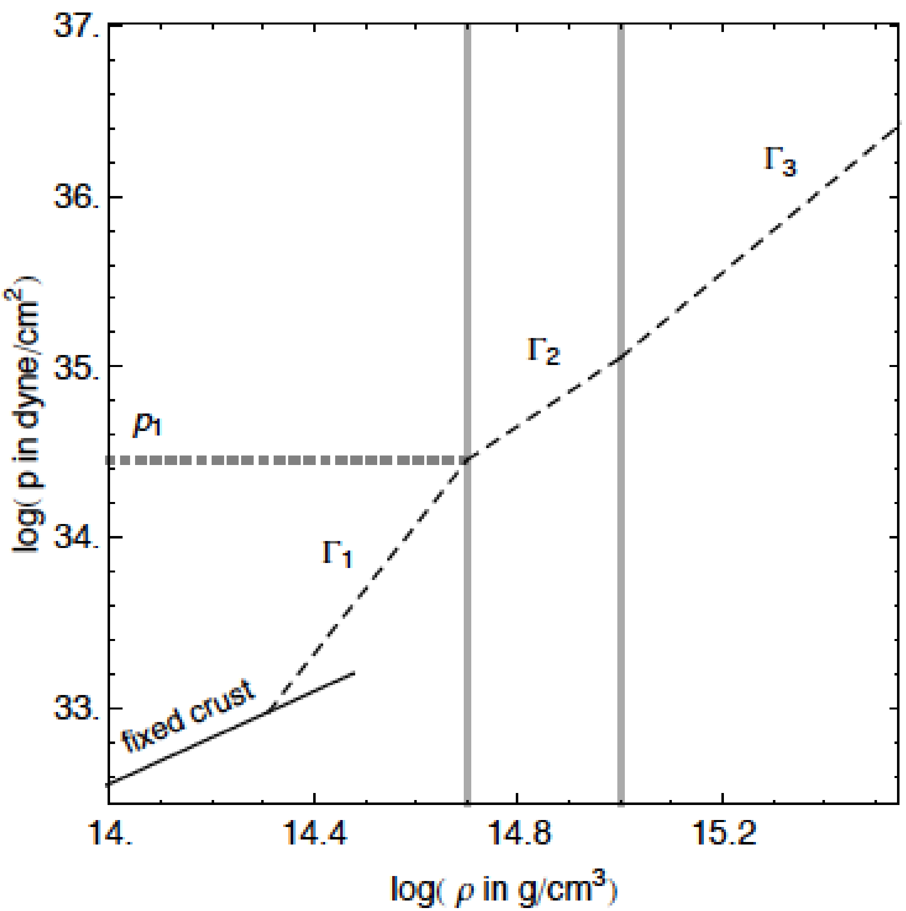
Alvarez & Blaschke, arxiv:1304.7758

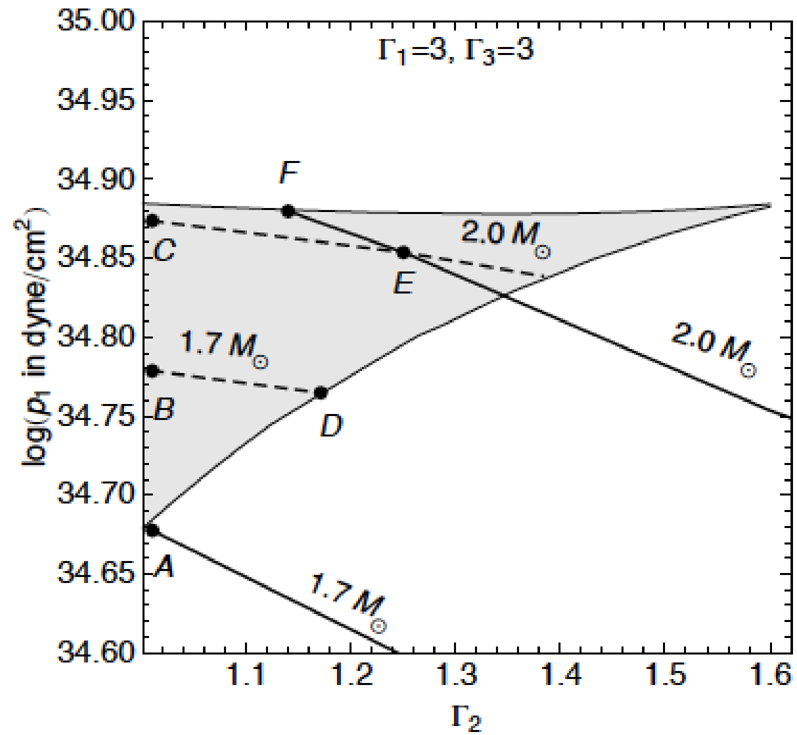
3. Piecewise polytrope EoS – high mass twins (HMT)?

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

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

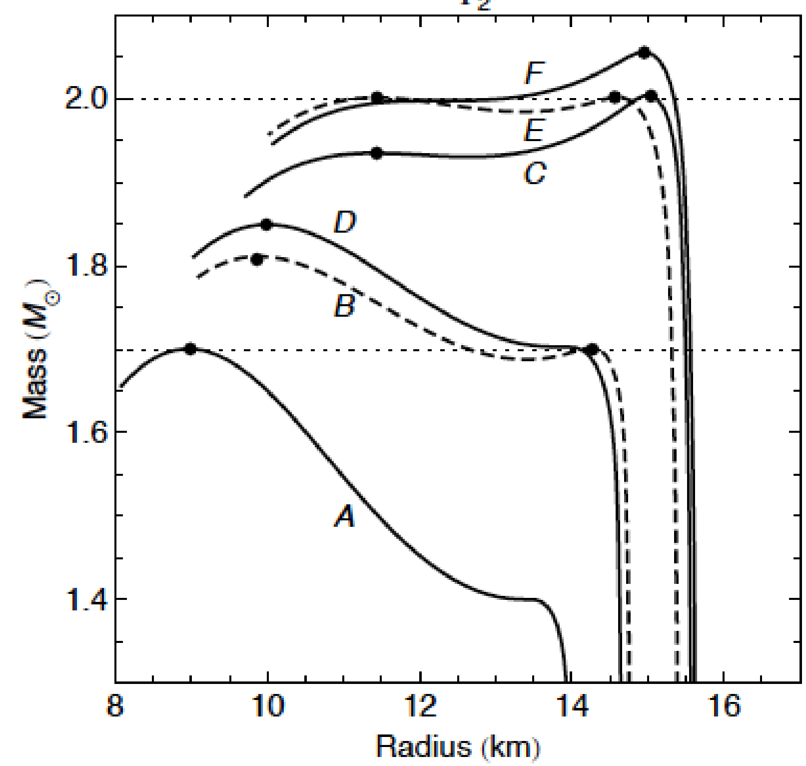
$$i = 1 \;:\; n_1 \le n \le n_{12}$$
$$i = 2 \;:\; n_{12} \le n \le n_{23}$$
$$i = 3 \;:\; n \ge n_{23}\;,$$





Case E:

HMT @ 2 M_{sun}



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

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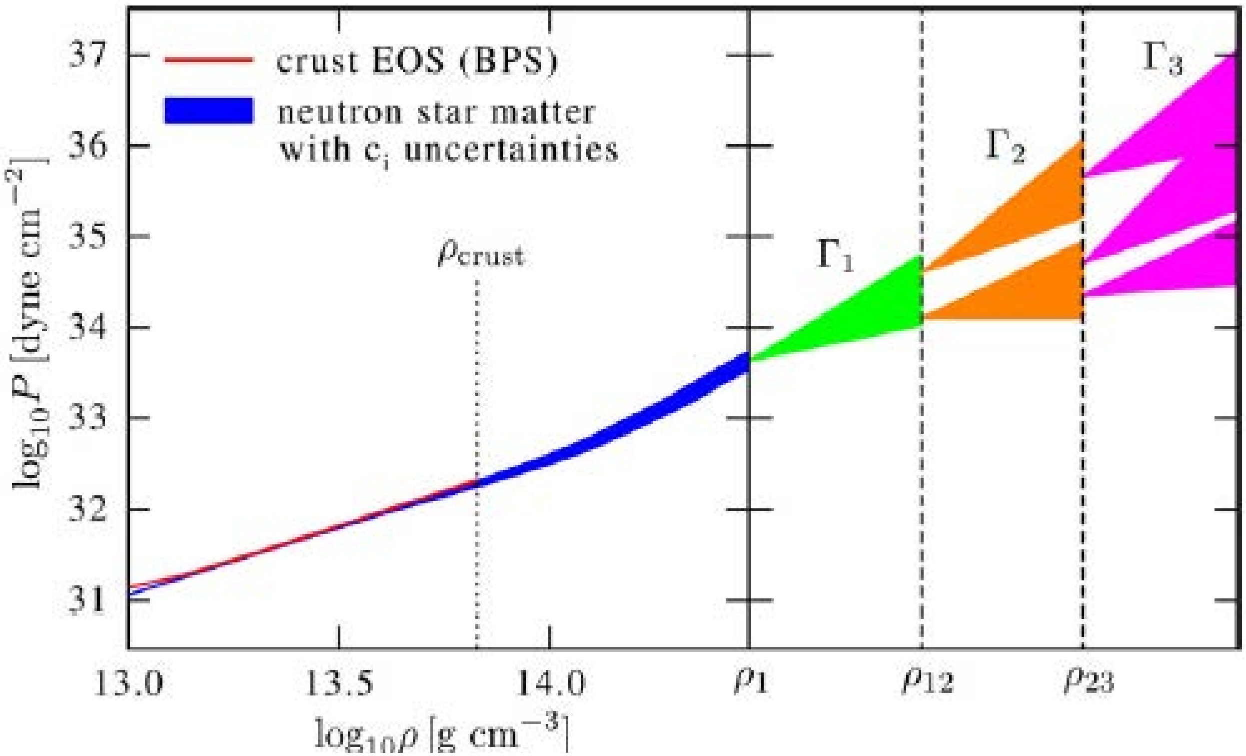

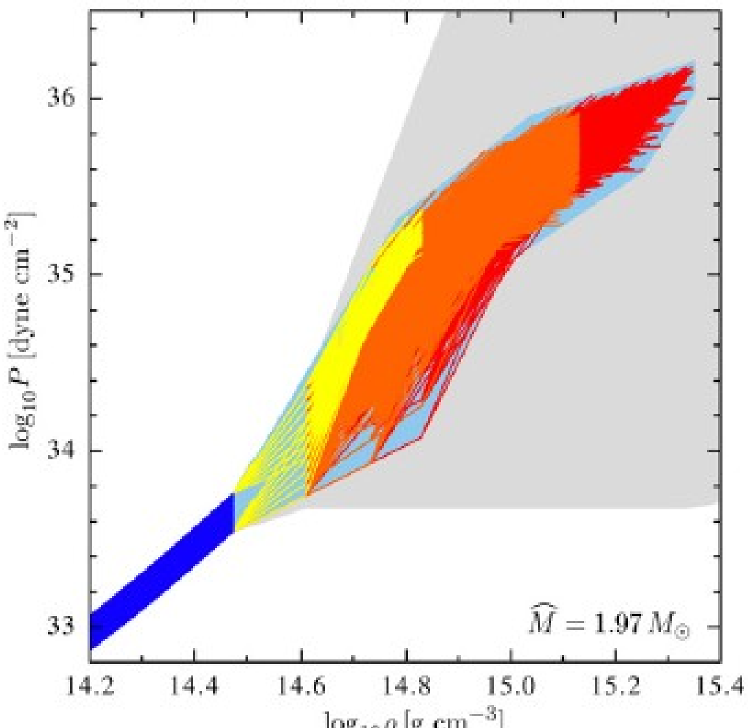

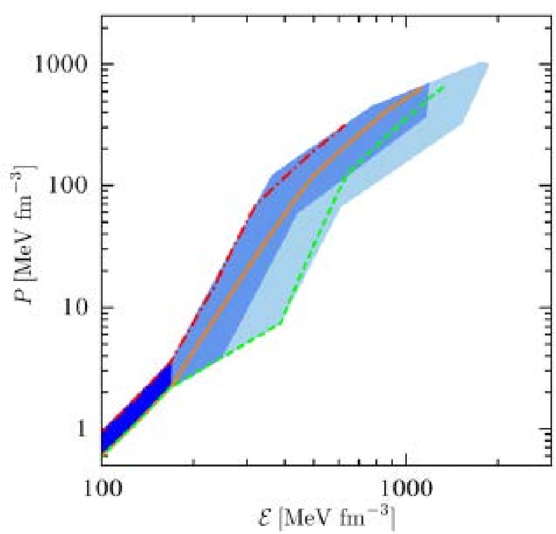

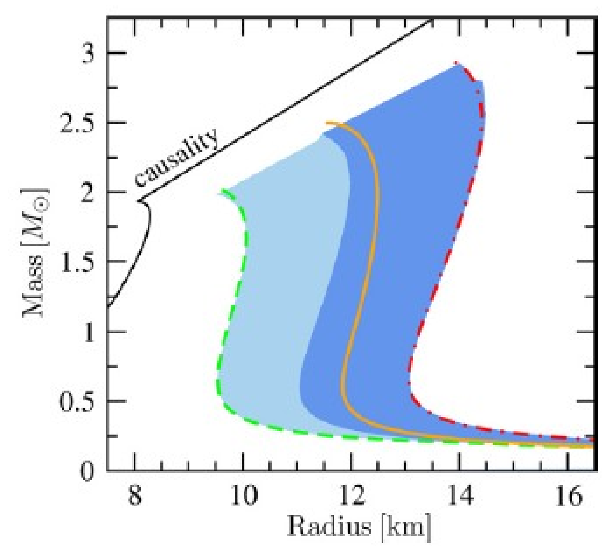

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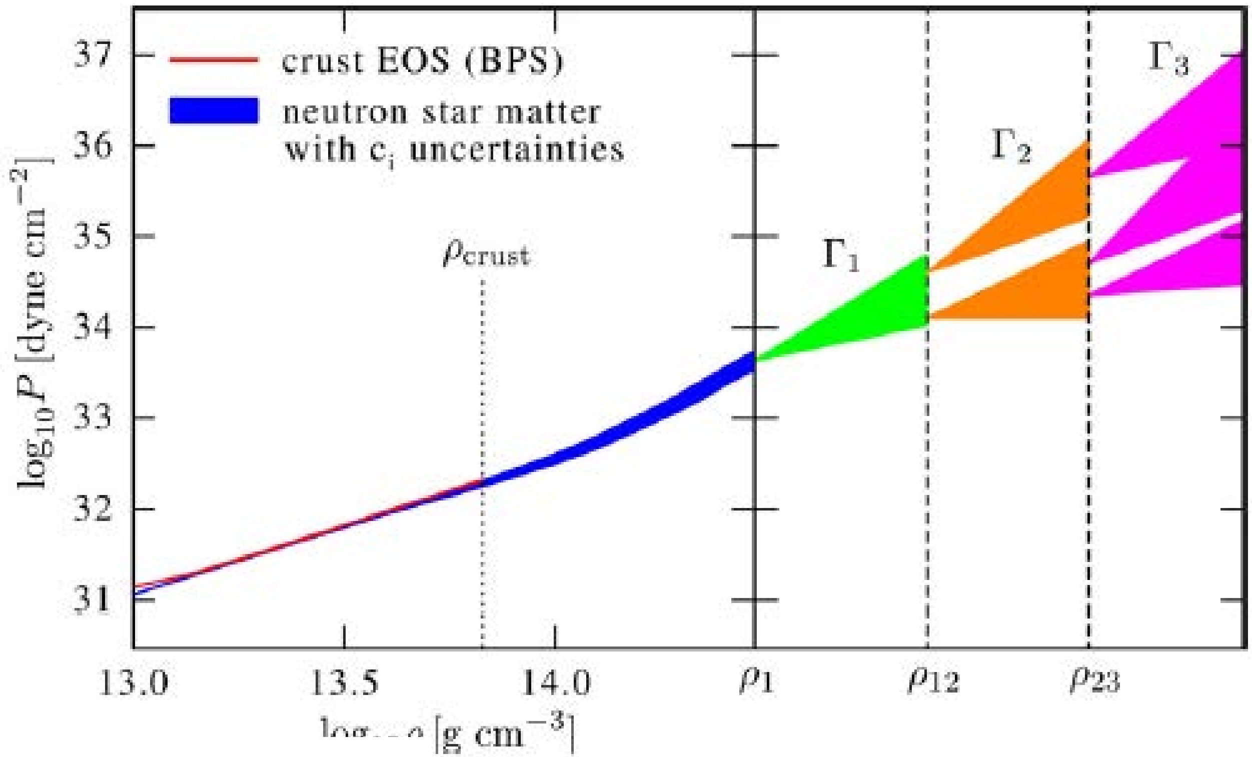


Here, 1st order PT in region 2:

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

$$\begin{aligned} P(n) &= n^2 \frac{d(\varepsilon(n)/n)}{dn}, \\ \varepsilon(n)/n &= \int dn \, \frac{P(n)}{n^2} = \int dn \, \kappa n^{\Gamma-2} = \frac{\kappa \, n^{\Gamma-1}}{\Gamma - 1} + C, \\ \mu(n) &= \frac{P(n) + \varepsilon(n)}{n} = \frac{\kappa \Gamma}{\Gamma - 1} n^{\Gamma-1} + m_0, \end{aligned}$$

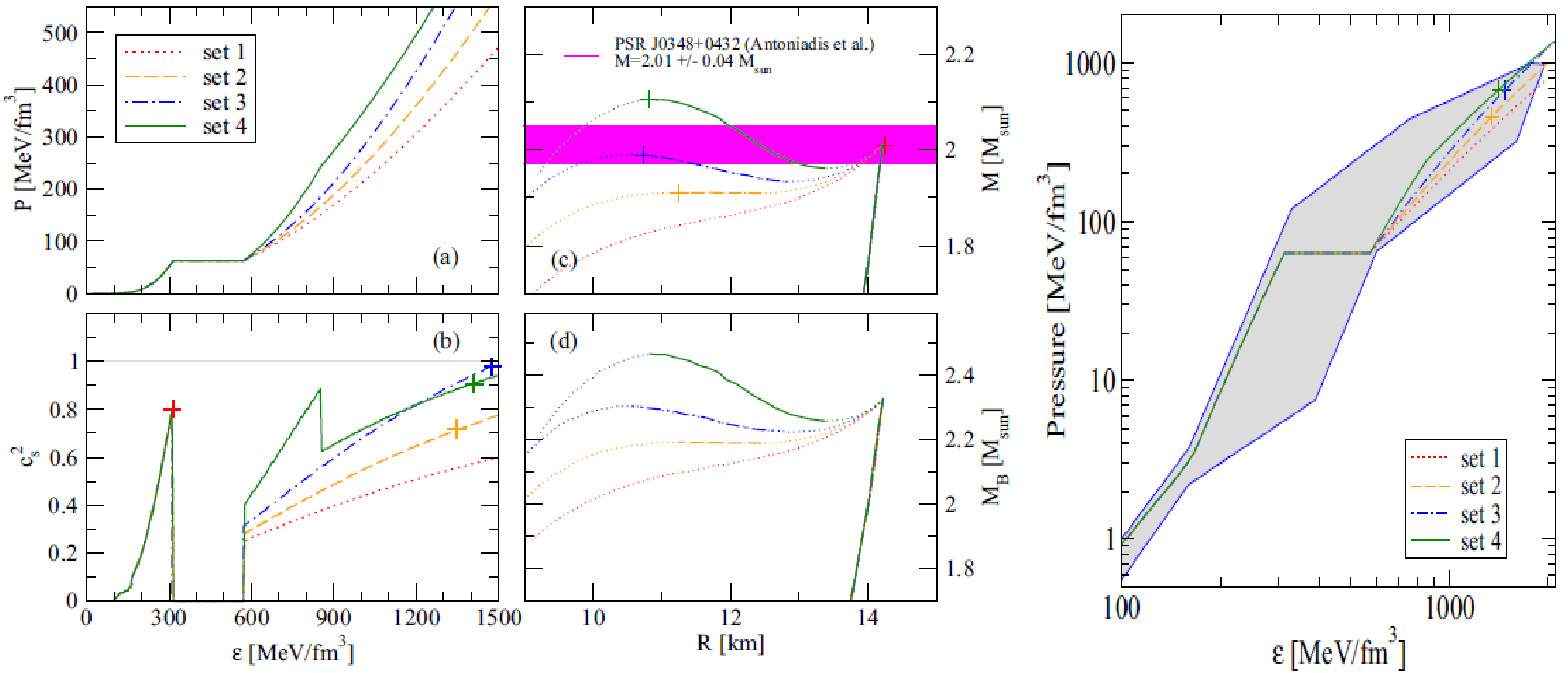
$$\begin{aligned} n(\mu) &= \left[(\mu - m_0) \frac{\Gamma - 1}{\kappa \Gamma} \right]^{1/(\Gamma-1)} \\ P(\mu) &= \kappa \left[(\mu - m_0) \frac{\Gamma - 1}{\kappa \Gamma} \right]^{\Gamma/(\Gamma-1)} \end{aligned}$$

Maxwell construction:

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

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/fm³, ε_{crit} = 318.3 MeV/fm³ and same jump in energy density $\Delta\varepsilon$ = 253.9 MeV/fm³; varying Γ_3

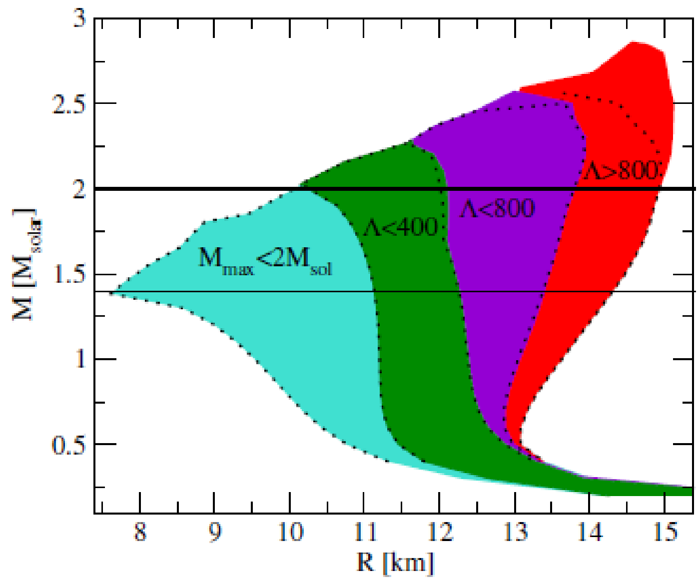
Third family solutions found at 2 Msol (HMT), 4-tropes favored; match with Hebeler et al.!

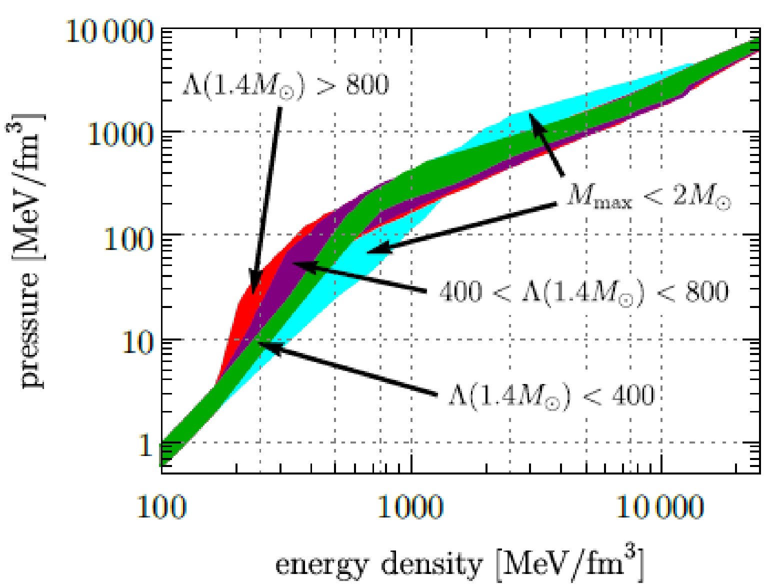
[D. Alvarez & D.B. PRC 96 (2017) 045809] arxiv:1711.02644 [astro-ph.HE]

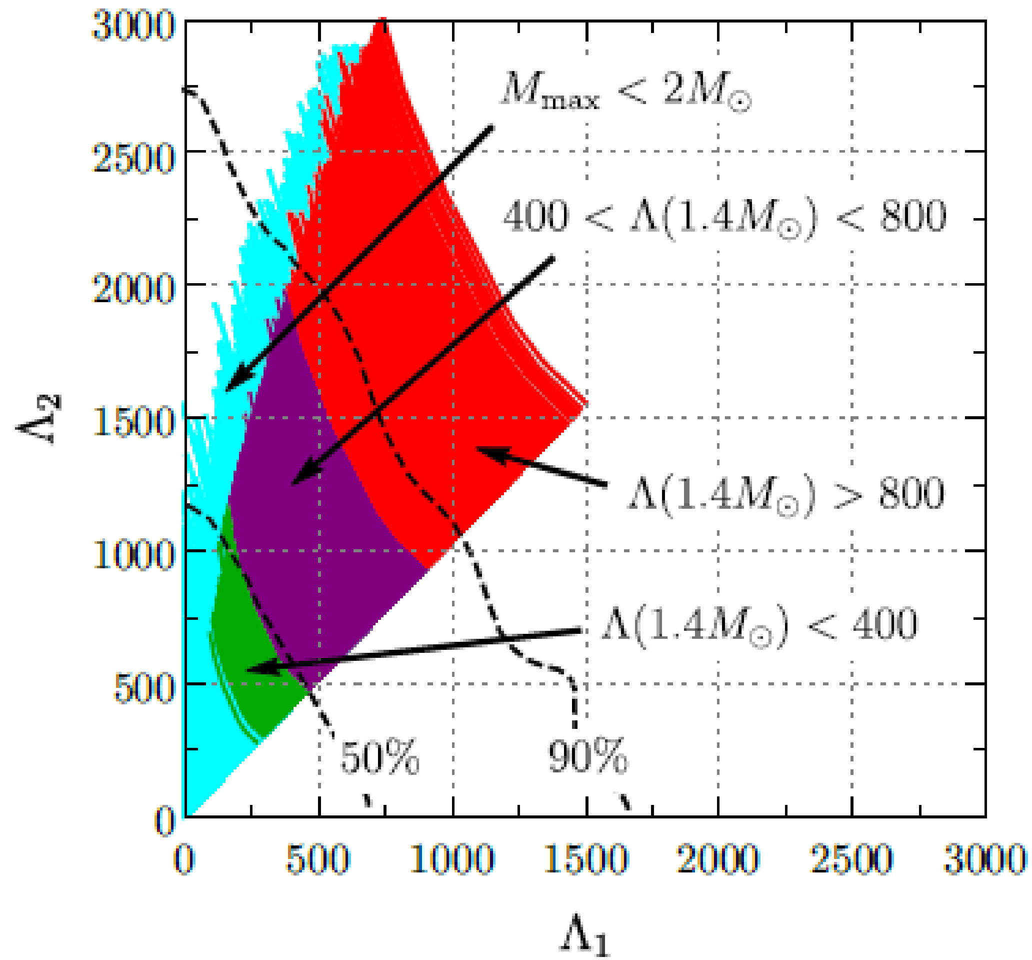
CERN-TH-2017-236, HIP-2017-30/TH

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

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





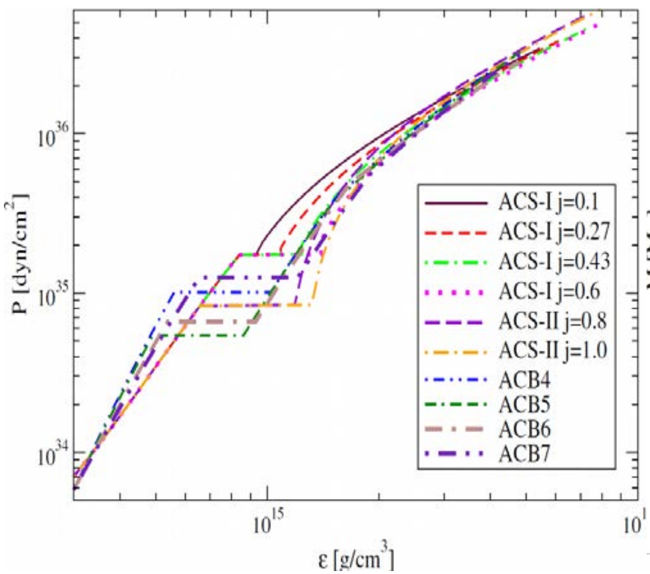


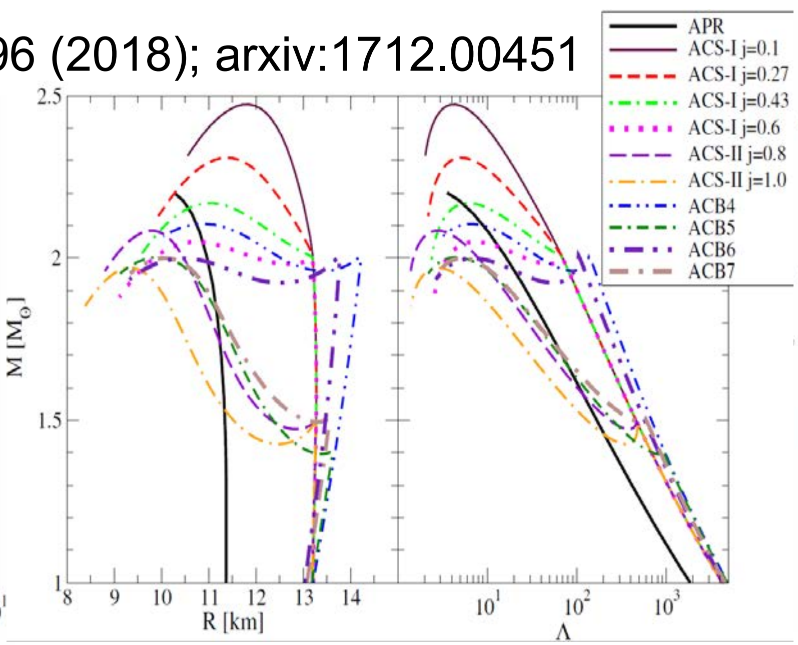
Unfortunately, twins and third family forgotten !!!
For this aim, 2- and 3-tropes not sufficient, 4-tropes!

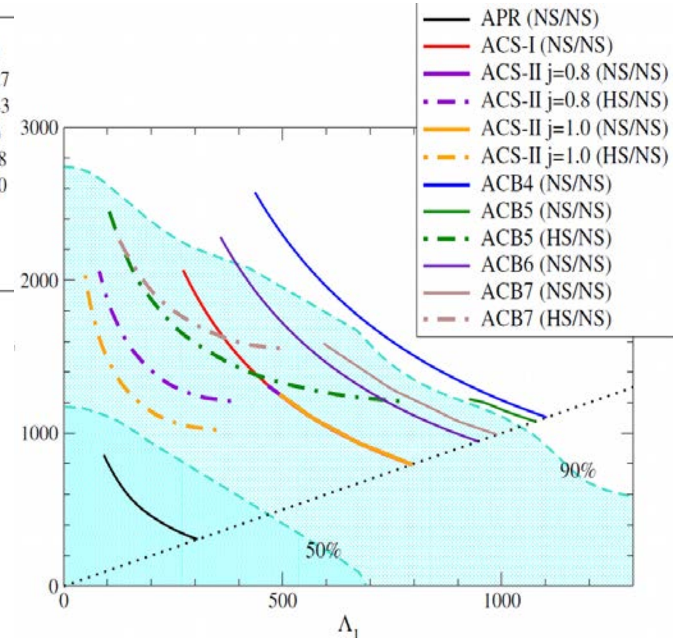
Refined calculation (with twins) is under way (A.V.)

Other examples: Multi-polytrope and multi-CSS model

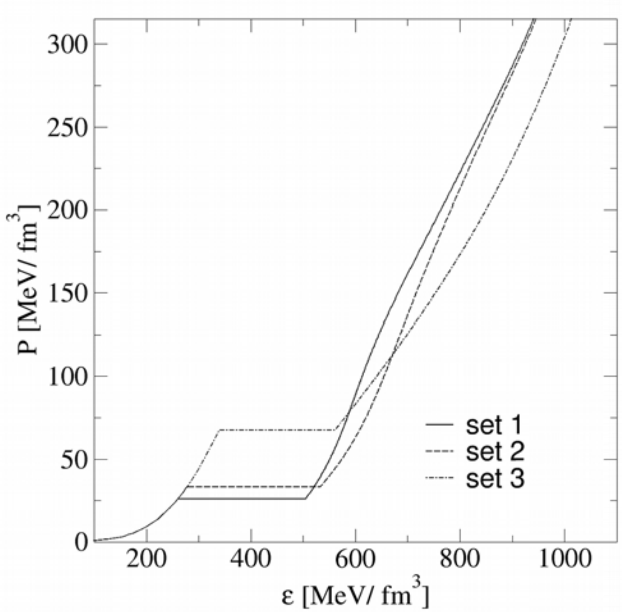
V. Paschalidis et al., PRD 96 (2018); arxiv:1712.00451

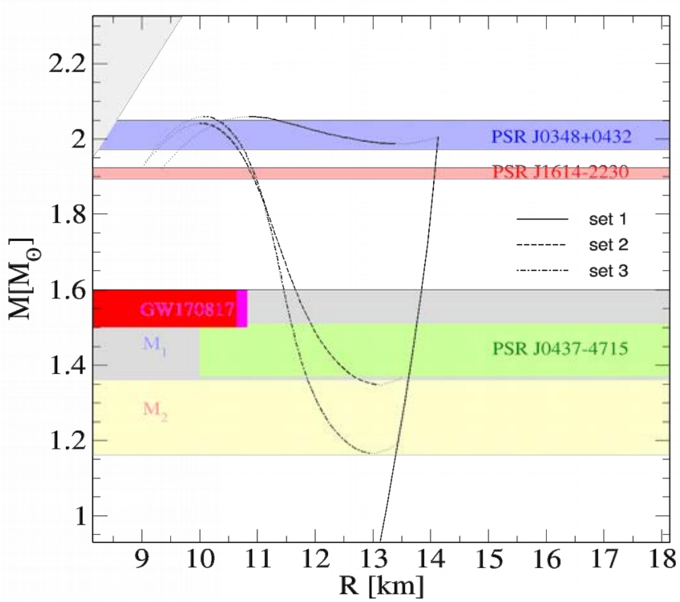


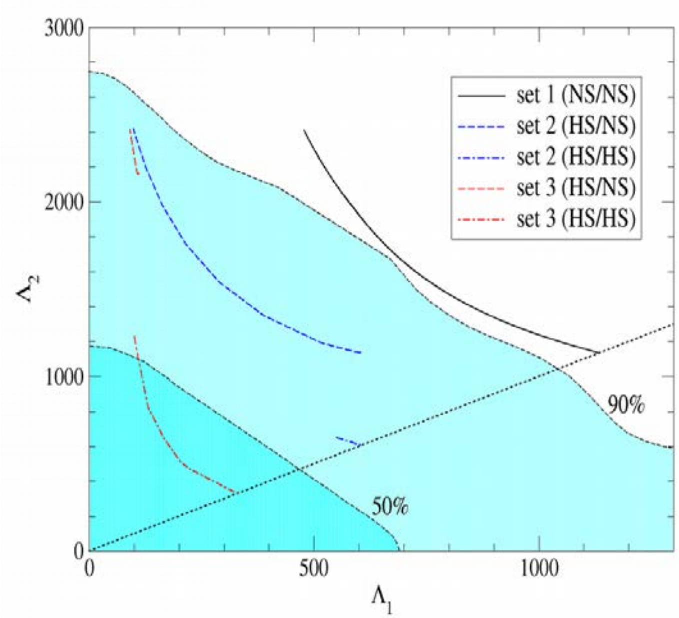




Nonlocal NJL model (with interpolation), D. Alvarez-Castillo et al. (arxiv:1805.04105)

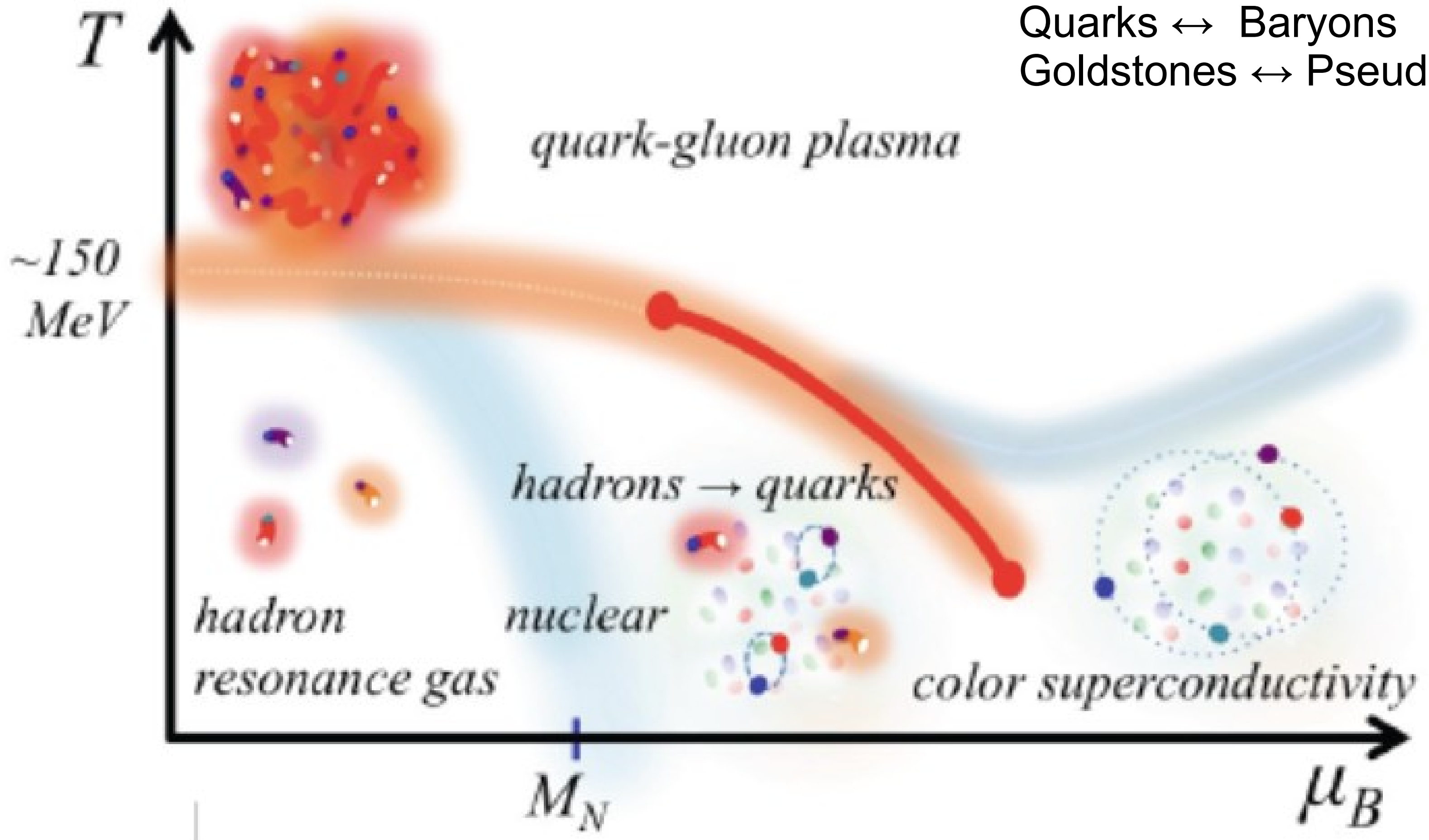






2nd CEP in QCD phase diagram: Quark-Hadron Continuity?

Gluons ↔ Vector mesons
Quarks ↔ Baryons
Goldstones ↔ Pseudoscalar mesons

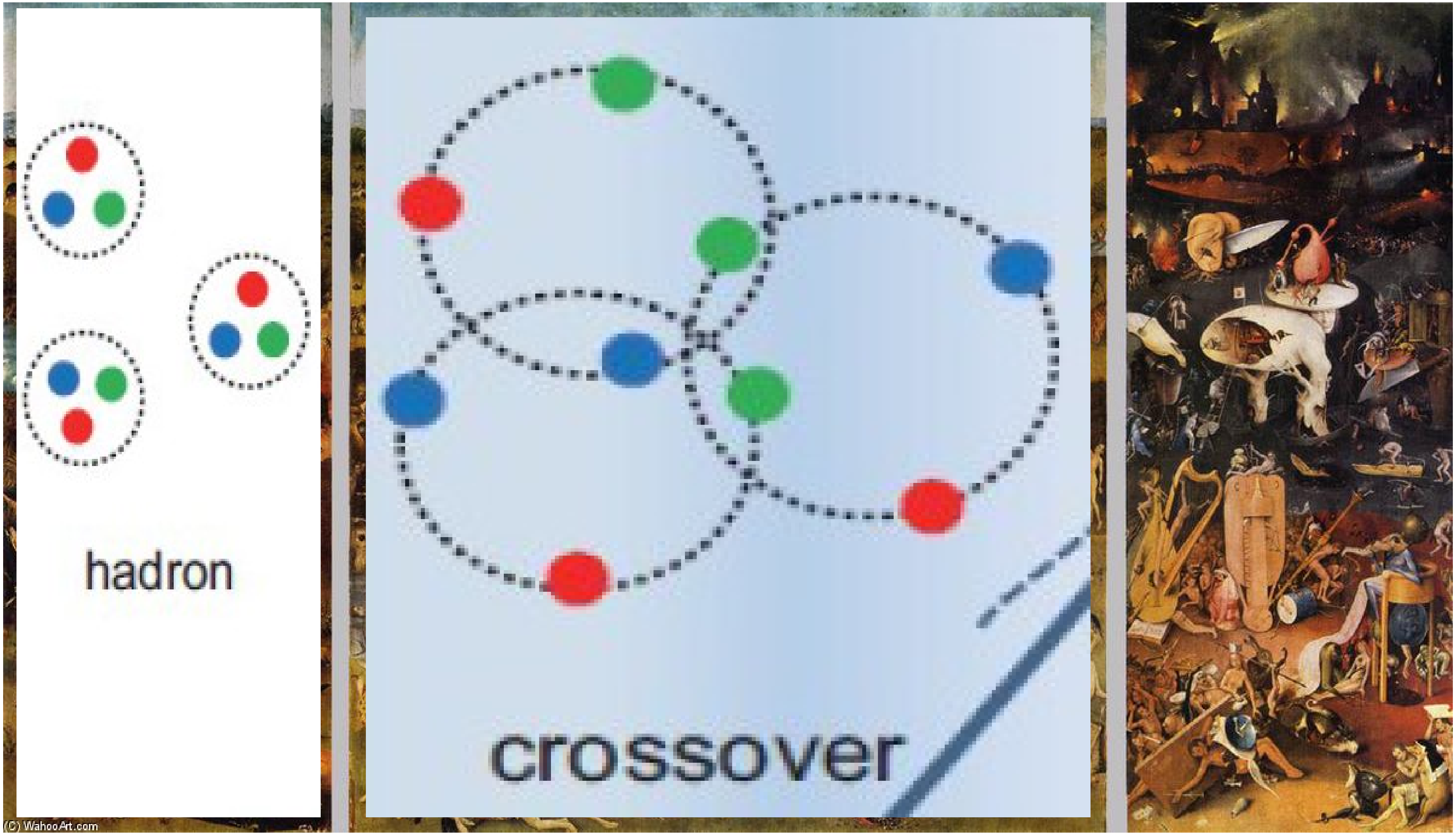


T. Schaefer & F. Wilczek, Phys. Rev. Lett. 82 (1999) 3956
C. Wetterich, Phys. Lett. B 462 (1999) 164
T. Hatsuda, M. Tachibana, T. Yamamoto & G. Baym, Phys. Rev. Lett. 97 (2006) 122001

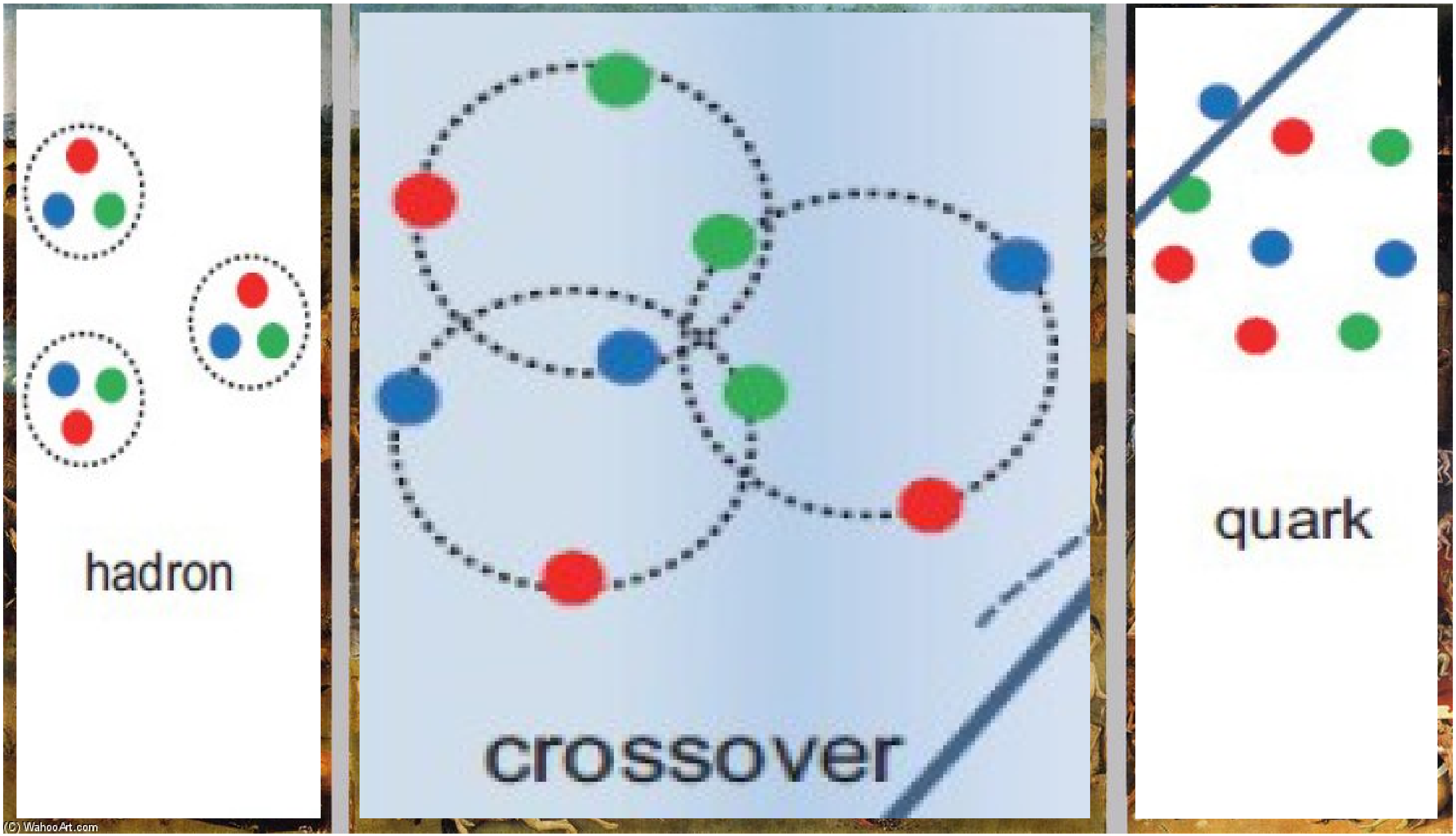
“Three-window picture of dense matter”

“Three-window picture of dense matter”

“Three-window picture of dense matter”



“Three-window picture of dense matter”



PTEP

Prog. Theor. Exp. Phys. **2013**, 073D01 (26 pages)
DOI: 10.1093/ptep/ptt045

Hadron-Quark Crossover and Massive Hybrid Stars

Kota Masuda[1,2,*], Tetsuo Hatsuda[2], and Tatsuyuki Takatsuka[3†]

[1] *Department of Physics, The University of Tokyo, Tokyo 113-0033, Japan*
[2] *Theoretical Research Division, Nishina Center, RIKEN, Wako 351-0198, Japan*
[3] *Iwate University, Morioka 020-8550, Japan*
[*] *E-mail: masuda@nt.phys.s.u-tokyo.ac.jp*

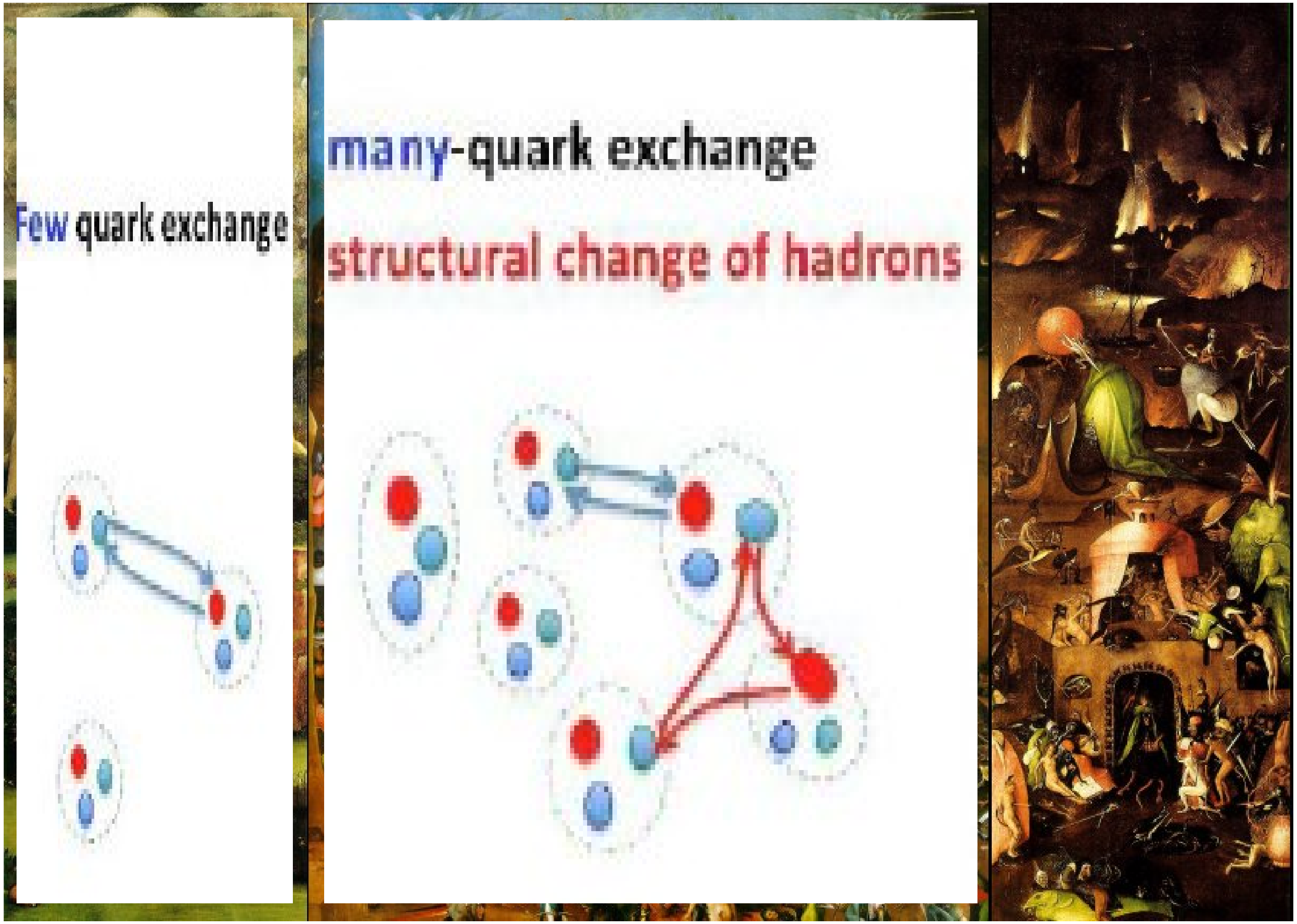
On the basis of the percolation picture from the hadronic phase with hyperons to the quark phase with strangeness, we construct a new equation of state (EOS) with the pressure interpolated as a function of the baryon density. The maximum mass of neutron stars can exceed $2M_{\odot}$ if the following two conditions are satisfied; (i) the crossover from the hadronic matter to the quark matter takes place at around three times the normal nuclear matter density, and (ii) the quark matter is strongly interacting in the crossover region. This is in contrast to the conventional approach assuming the first order phase transition in which the EOS becomes always soft due to the presence of the quark matter at high density. Although the choice of the hadronic EOS does not affect the above conclusion on the maximum mass, the three-body force among nucleons and hyperons plays an essential role for the onset of the hyperon mixing and the cooling of neutron stars.

Subject Index Neutron stars, Nuclear matter aspects in nuclear astrophysics, Hadrons and quarks in nuclear matter, Quark matter

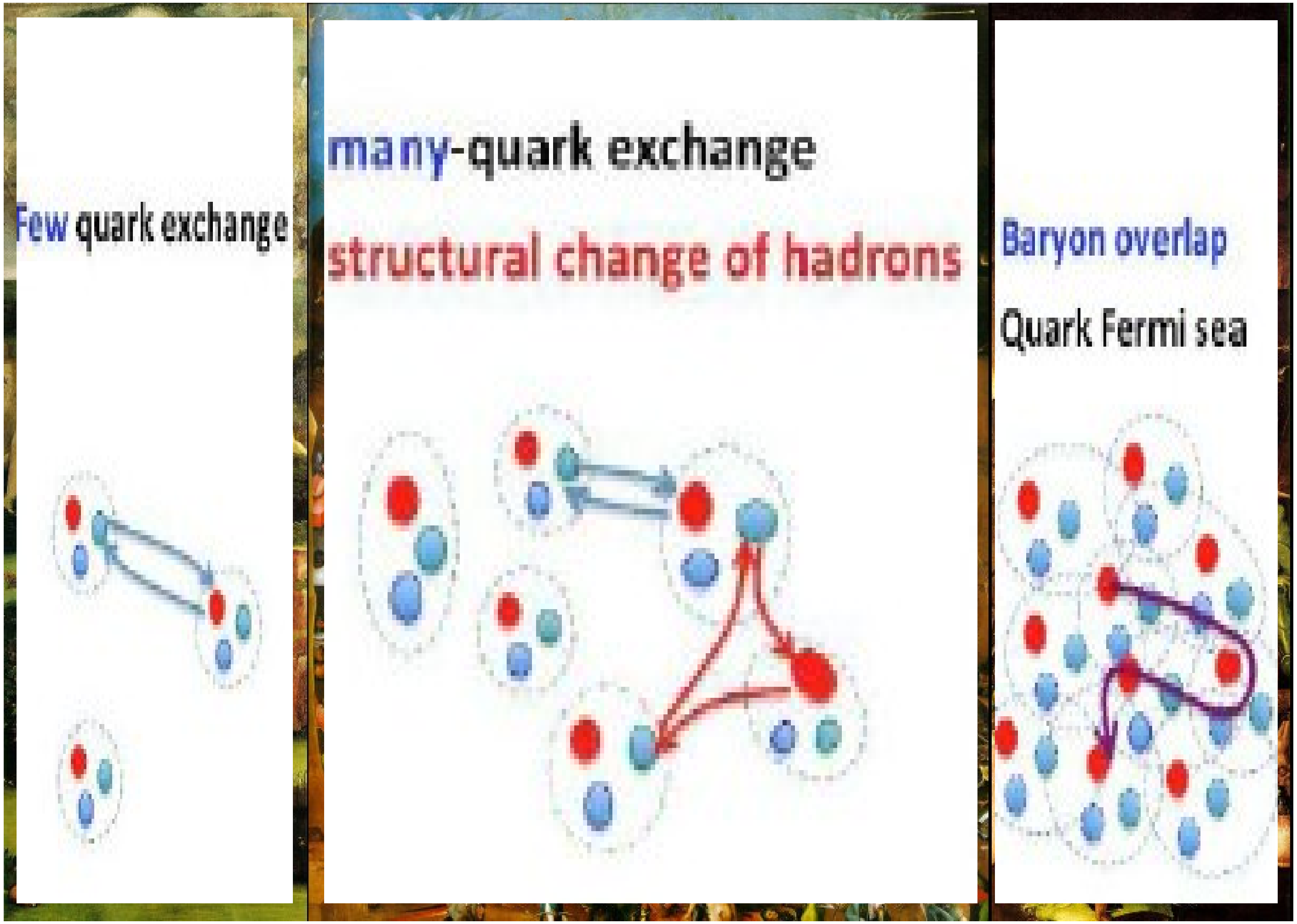
Another "three-window picture of dense matter"

Another "three-window picture of dense matter"

Another "three-window picture of dense matter"

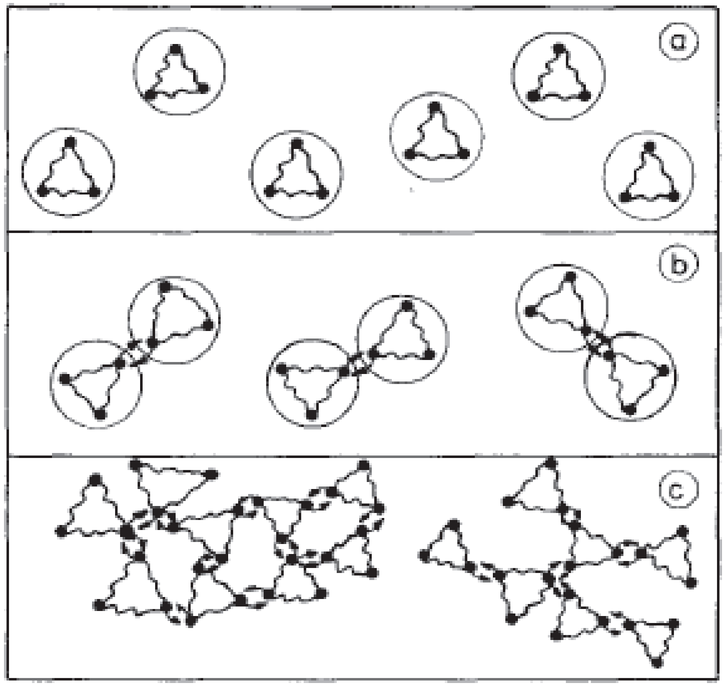


Another "three-window picture of dense matter"



Toru Kojo, EPJA 52, 51 (2016)

Quark Pauli blocking among baryons

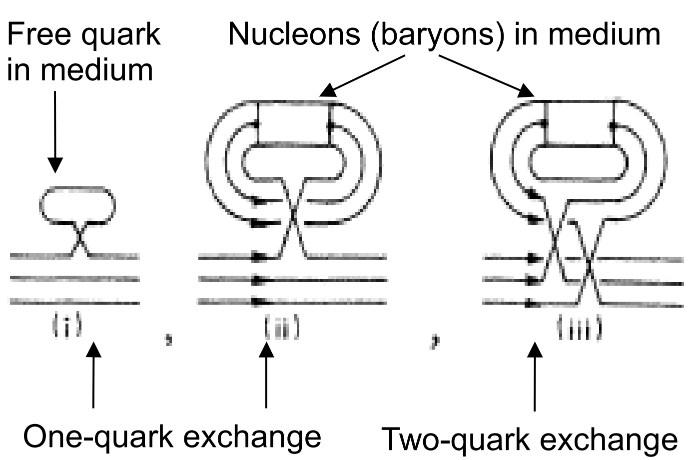


a) Low density: Fermi gas of nucleons (baryons)

b) ~ saturation: Quark exchange interaction and Pauli blocking among nucleons (baryons)

c) high density: Quark cluster matter (string-flip model ...)

Roepke & Schulz, Z. Phys. C 35, 379 (1987); Roepke, DB, Schulz, PRD 34, 3499 (1986)



Nucleon (baryon) self-energy --> Energy shift

$$\Delta E_{\nu P}^{\mathrm{Pauli}} = \sum_{123} |\psi_{\nu P}(123)|^2 [E(1)+E(2)+E(3)-E_{\nu P}^0][f_{\alpha_1}(1)+f_{\alpha_2}(2)+f_{\alpha_3}(3)]$$

$$+\sum_{123}\sum_{456}\sum_{\nu' P'} \psi_{\nu P}^*(123)\psi_{\nu' P'}(456) f_3(E_{\nu' P'}^0)\{\delta_{36}\psi_{\nu P}(123)\psi_{\nu' P'}^*(456)-\psi_{\nu P}(453)\psi_{\nu' P'}^*(126)\}$$

$$\times[E(1)+E(2)+E(3)+E(4)+E(5)+E(6)-E_{\nu P}^0-E_{\nu' P'}^0]$$

$$=\Delta E_{\nu P}^{\mathrm{Pauli,free}}+\Delta E_{\nu P}^{\mathrm{Pauli,bound}} .$$

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

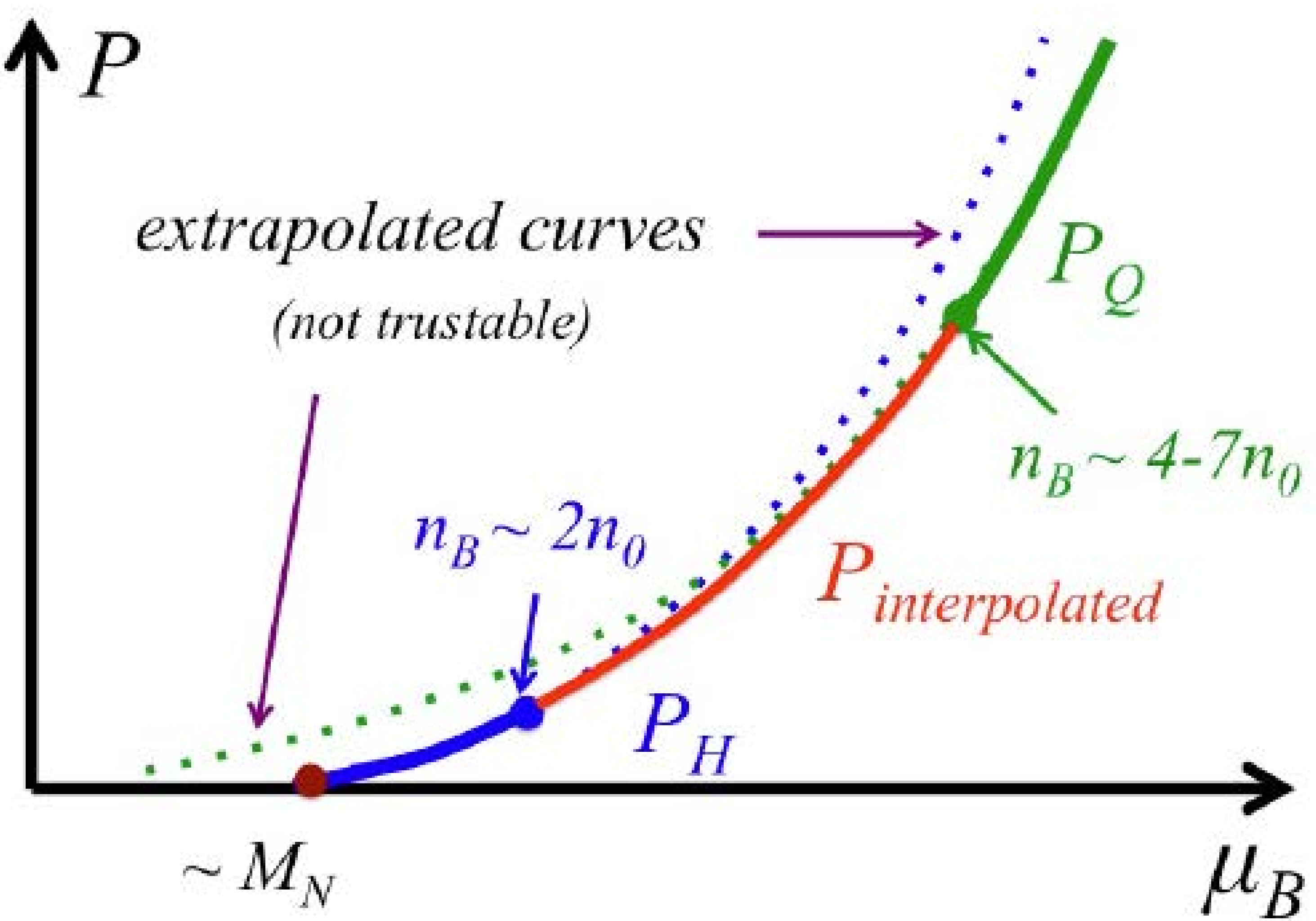
Department of Physics, Wilhelm-Pieck-Universtiy, 2500 Rostock, German Democratic Republic

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)

Interpolating between Hadron and Quark Phases



Note:

Here, a usual Maxwell construction Makes no sense!

Replaced by "Kojo interpolation"

From: T. Kojo, P.D. Powell, Y. Song and G. Baym, PRD 91, 045003 (2015)
See also discussion in: D.B. and N. Chamel, arxiv:1803.01836

COMPACT STARS IN THE QCD PHASE DIAGRAM VI

(COSMIC MATTER IN HEAVY-ION COLLISION LABORATORIES?)

26-29 September 2017 DUBNA

Contacts

csqcd2017@gmail.com

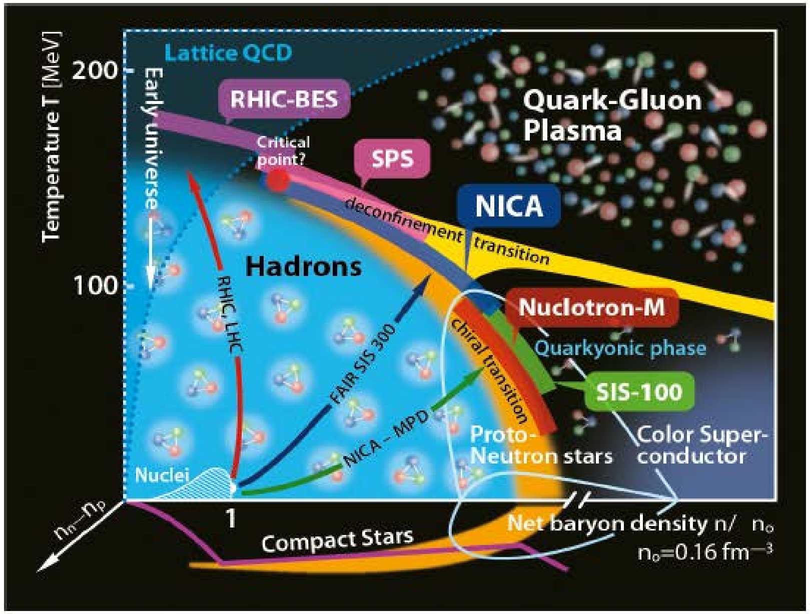
Compact Stars in the QCD Phase Diagram VI
(Cosmic matter in heavy-ion collision laboratories?)

The aim of the conference is to bring together expertise in fields of the heavy-ion collisions, QCD phase diagram, Compact Stars and on related phenomena.

The conference will cover the following main topics:

- QCD phase diagram for HIC vs. astrophysics
- Quark deconfinement in HIC vs. supernovae, neutron stars and their mergers
- Strangeness in HIC and in compact stars
- Equation of state and QCD phase transitions

Previous Meetings could be found on the website http://www.quarknova.ca/CSQCD.html



37 participants
Local support ...

http://theor.jinr.ru/~hmec16/csqcd6/

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Compact Stars in the QCD Phase Diagram

Guest Editors:

Prof. Dr. David Blaschke
david.blaschke@gmail.com

Mr. Alexander Ayriyan
alexander.ayriyan@gmail.com

Dr. Alexandra Friesen
avfriesen@theor.jinr.ru

Dr. Hovik Grigorian
hovikgrigorian@gmail.com

Deadline for manuscript submissions:
closed (6 January 2018)

Message from the Guest Editors

Dear Colleagues,

This special issue is dedicated to the conference: Compact Stars in the QCD Phase Diagram VI http://theor.jinr.ru/~hmec16/csqcd6/.

This special issue will cover the following main topics:

- QCD phase diagram for HIC vs. astrophysics

- Quark deconfinement in HIC vs. supernovae, neutron stars and their mergers

- Strangeness in HIC and in compact stars

- Equation of state and QCD phase transitions

Prof. Dr. David Blaschke
Dr. Hovik Grigorian
Mr. Alexander Ayriyan
Dr. Alexandra Friesen
Guest Editors

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Special Issue

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Editor-in-Chief

Prof. Dr. Lorenzo Iorio
Ministero dell' Istruzione, dell' Università e della Ricerca (M.I.U.R.)-Istruzione. Fellow of the Royal Astronomical Society (F.R.A.S.) Viale Unità di Italia 68, 70125, Bari (BA), Italy

Message from the Editor-in-Chief

The multidisciplinary Universe Journal is aiming to follow and, hopefully, to lead to the largest extent as possible the ever-self renovating threads which weave mathematical theories with our understanding of the magnificent natural world. On behalf of all the distinguished members of the editorial board, I extend my welcome to this new journal and look forward to hearing from the interested contributors and learning about their valuable research.

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Special Issue

20 published papers
58 authors; 228 pages

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Conference Report

Directed Flow in Heavy-Ion Collisions and Its Implications for Astrophysics

Yuri B. Ivanov [1,2,3]

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Conference Report

Charged ρ Meson Condensate in Neutron Stars within RMF Models

Konstantin A. Maslov [1,2,*], Evgeni E. Kolomeitsev [2,3] and Dmitry N. Voskresensky [1,2]

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Conference Report

From Heavy-Ion Collisions to Compact Stars: Equation of State and Relevance of the System Size

Sylvain Mogliacci *, Isobel Kolbé and W. A. Horowitz

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Article

On Cooling of Neutron Stars with a Stiff Equation of State Including Hyperons

Hovik Grigorian [1,2], Evgeni E. Kolomeitsev [3], Konstantin A. Maslov [4,5] and Dmitry N. Voskresensky [4,5,*]

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Article

Vector-Interaction-Enhanced Bag Model

Mateusz Cierniak [1,*], Thomas Klähn [2], Tobias Fischer [1] and Niels-Uwe F. Bastian [1]

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Article

A Phenomenological Equation of State of Strongly Interacting Matter with First-Order Phase Transitions and Critical Points

Stefan Typel [1,2,*] and David Blaschke [3,4,5]

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Article

Prospects of Constraining the Dense Matter Equation of State from Timing Analysis of Pulsars in Double Neutron Star Binaries: The Cases of PSR J0737−3039A and PSR J1757−1854

Manjari Bagchi

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Conference Report

Strangeness Production in Nucleus-Nucleus Collisions at SIS Energies

Vinzent Steinberg [1,2,*], Dmytro Oliinychenko [3], Jan Staudenmaier [1,2] and Hannah Petersen [1,2,4]

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Conference Report

Cracking Strange Stars by Torsional Oscillations

Francesco Tonelli [1,2,†] and Massimo Mannarelli [1,*,†]

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Article

QCD Equations of State in Hadron–Quark Continuity

Toru Kojo

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Article

Many Aspects of Magnetic Fields in Neutron Stars

Rodrigo Negreiros [1,*], Cristian Bernal [2], Veronica Dexheimer [3] and Orlenys Troconis [1]

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Conference Report

Equation of State for Dense Matter with a QCD Phase Transition

Sanjin Benić †

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Article

Rotating Quark Stars in General Relativity

Enping Zhou [1,2,*,†], Antonios Tsokaros [2,4], Luciano Rezzolla [2,3], Renxin Xu [1,5] and Kōji Uryū [6]

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Review

The Merger of Two Compact Stars: A Tool for Dense Matter Nuclear Physics

Alessandro Drago [1], Giuseppe Pagliara [1], Sergei B. Popov [2], Silvia Traversi [1,*] and Grzegorz Wiktorowicz [3,4]

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Communication

Hadron–Quark Combustion as a Nonlinear, Dynamical System

Amir Ouyed [1,*], Rachid Ouyed [1] and Prashanth Jaikumar [2]

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Article

Looking for the Phase Transition—Recent NA61/SHINE Results

Ludwik Turko †

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Article

Non-Radial Oscillation Modes of Superfluid Neutron Stars Modeled with CompOSE

Prashanth Jaikumar *, Thomas Klähn and Raphael Monroy

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Article

Anomalous Electromagnetic Transport in Compact Stars

Efrain J. Ferrer * and Vivian de la Incera

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Article

Neutrino Emissivity in the Quark-Hadron Mixed Phase

William M. Spinella [1], Fridolin Weber [2,3,*], Milva G. Orsaria [4,5] and Gustavo A. Contrera [4,5,6]

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Article

Towards a Unified Quark-Hadron-Matter Equation of State for Applications in Astrophysics and Heavy-Ion Collisions

Niels-Uwe F. Bastian [1,*], David Blaschke [1,2,3], Tobias Fischer [1] and Gerd Röpke [3,4]

Compact Stars in the QCD Phase Diagram in 2019

<u>1. Suggestion:</u> Yerevan, Armenia

Local Organizers: A. Sedrakian, A. Saharian, H. Grigorian

Capsule: The Modern Physics of Compact Stars …
… in the QCD Phase Diagram

Venue: Yerevan State University; Bjurakan Observatory

Background: Pioneering Contr. to Neutron Star Physics
by Ambarzumjan, Sahakian, Sedrakian, Chubaryan

New Group on Compact Stars
at Byurakan Observatory

Compact Stars in the QCD Phase Diagram in 2019

2. Suggestion: Wroclaw, Poland

Local Organizer(s): T. Fischer, D. Blaschke, C. Sasaki

Venue:
Oratorium Marianum
University of Wroclaw

Background:

COST Actions -

MP1304 “NewCompStar”
CA15213 “THOR”
CA16214 “PHAROS”
CA11617 “ChETEC”

Large group of PhD stud.

Gmail

David Blaschke <david.blaschke@gmail.com>

[Universe] Manuscript ID: universe-303232 - Submission Received

---

Fanny Fang <fanny.fang@mdpi.com> Fri, Apr 27, 2018 at 5:05 AM
To: "david.blaschke@gmail.com >> David Blaschke" <david.blaschke@gmail.com>

Hi David,

Weina is now is the new manger editor of Universe. You may feel free to contact with her with any issue or question.

If possible, we hope to work with you further on the new series "Compact Stars in the QCD Phase Diagram".

Thanks for your kind help and effort always!

Kind regards,
Fanny Fang
Senior Assistant Editor

Open Call: EPJA Topical Issue on
The first Neutron Star Merger Observation – Implications for Nuclear Physics

https://www.epj.org/open-calls-for-papers/122-epj-a/

EPJA Topical Issue: The first Neutron Star Merger Observation - Implications for Nuclear Physics

Published on Wednesday, 23 May 2018 09:45

Observation of gravitational waves (GWs), gamma-rays, x-rays, optical, infrared and radio waves from a neutron star (NS) merger event, now called GW170817, has the potential to revolutionize nuclear astrophysics. Data from this event has already provided strong hints that heavy elements are produced in NS mergers, and that these elements directly influence the observed optical and infra-red light curves. Properties of dense matter which was expected to play a key role also appear to be essential in interpreting the GW data.

An unprecedented observing campaign, triggered within hours of the discovery in GWs by Advanced LIGO & VIRGO, and in gamma-rays by Fermi and Integral, resulted in EM and GW data with detailed spectral and temporal features. This wealth of new data has arrived at the most opportune time. Advances in nuclear astrophysics, nuclear theory and computational astrophysics in recent years that led to the development of simulation and analysis tools that have played a critical role in the interpretation of the multi-messenger data from GW170817.

In the coming months, collaborative efforts involving nuclear physicists, computational astrophysicists and the observing (GW and EM) communities will continue to sharpen the interpretation, and likely identify puzzling discrepancies.

In this situation, the Editorial Board of *The European Physical Journal A (Hadrons and Nuclei)* decided that it is absolutely timely to prepare a Topical Issue which provides a forum for contributions from the communities involved in the analysis and early interpretation of data from GW170817 and their implications for nuclear physics.

Deadline for submission: 31 October 2018.

Guest editors of the special issue:

David Blaschke, University of Wroclaw & JINR Dubna & NRNU (MEPhI), Moscow, blaschke@ift.uni.wroc.pl
Monica Colpi, University of Milano Bicocca, Department of Physics G. Occhialini, monica.colpi@mib.infn.it
Charles Horowitz, Indiana University, horowit@indiana.edu
David Radice, Princeton University & Institute for Advanced Study, dradice@astro.princeton.edu

Authors are invited to submit their paper electronically through the website https://mc.manuscriptcentral.com/epja. Submissions should be clearly identified as intended for the Topical Issue "The first Neutron Star Merger Observation - Implications for Nuclear Physics". Papers will be published continuously and will appear (as soon as accepted) on the journal website. The electronic version of the Topical Issue will contain all accepted papers in the order of publication. All submitted papers will be refereed according to the usual high standards of the journal.

Manuscripts should be prepared following the instructions for authors available at: http://www.epj.org/images/stories/instructions/instructions_epja.pdf

The LaTeX template can be downloaded at: http://epj.org/images/stories/latex/epj_a_b_d_e.zip. General information about the journal can be found on http://epja.epj.org/.

For any kind of assistance during the submission procedure or for any technical questions, feel free to contact the editorial office at epja.bologna@sif.it

All is possible with EoS??

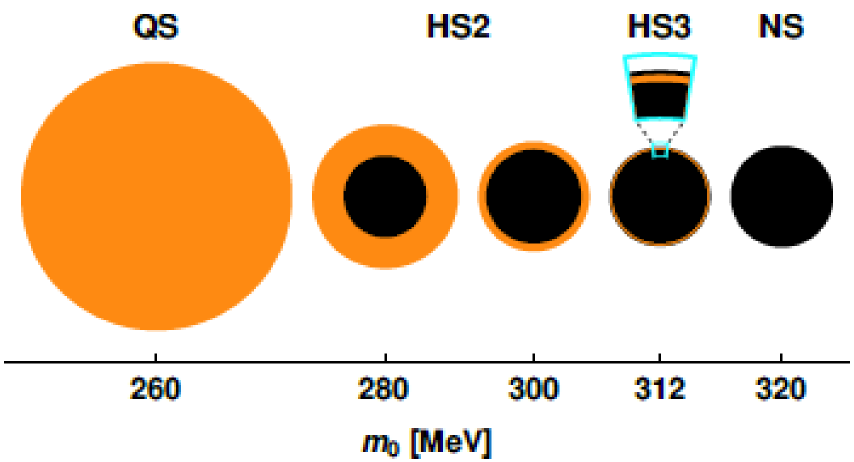
No!!

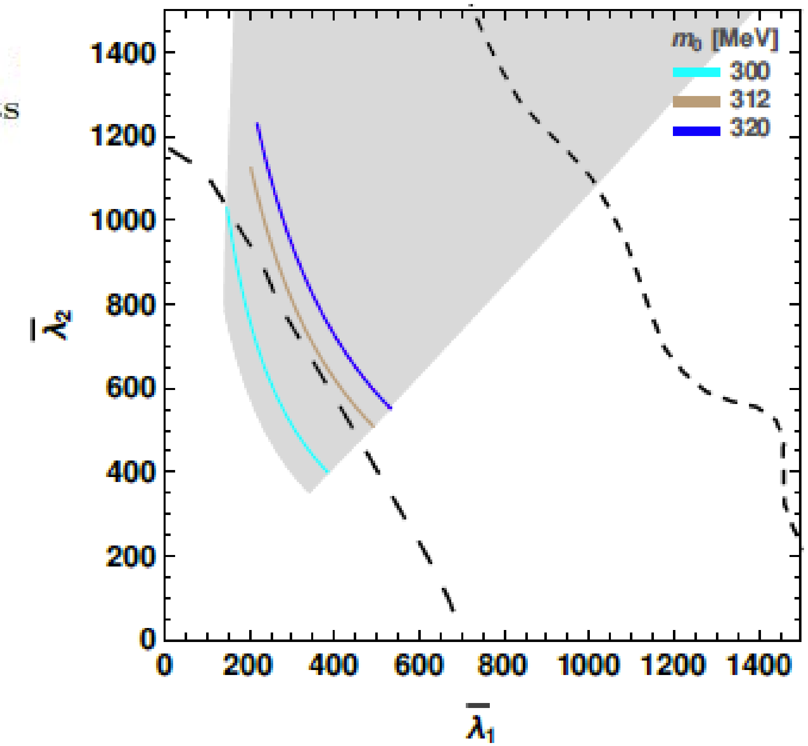
Alternative facts: New hybrid star solutions!

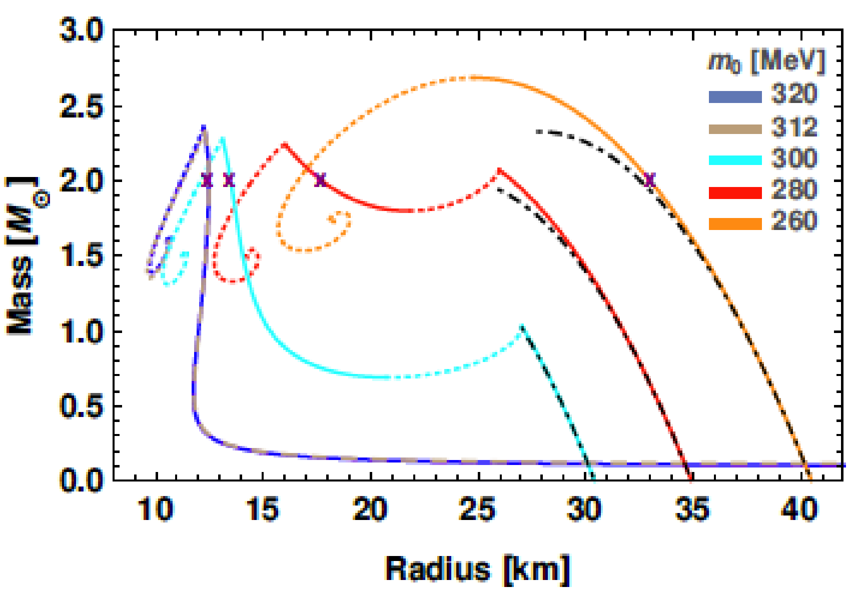
arxiv:1711.06244v1, 1611.2017

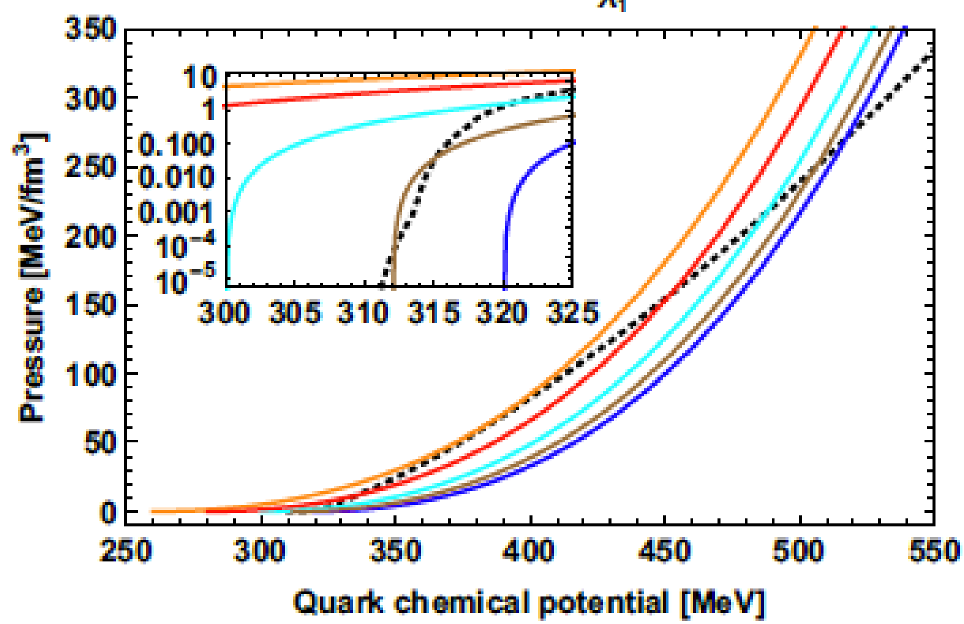
Holographic compact stars meet gravitational wave constraints

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









Alternative facts of the day: New hybrid star solutions!

arxiv:1711.06244v1, 1611.2017

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Eemeli Annala,[1,*] Christian Ecker,[2,†] Carlos Hoyos,[3,‡] Niko Jokela,[1,§]
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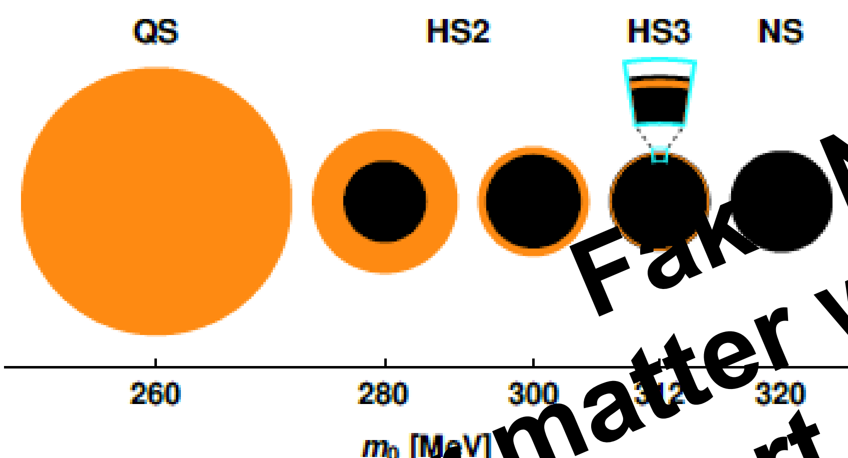

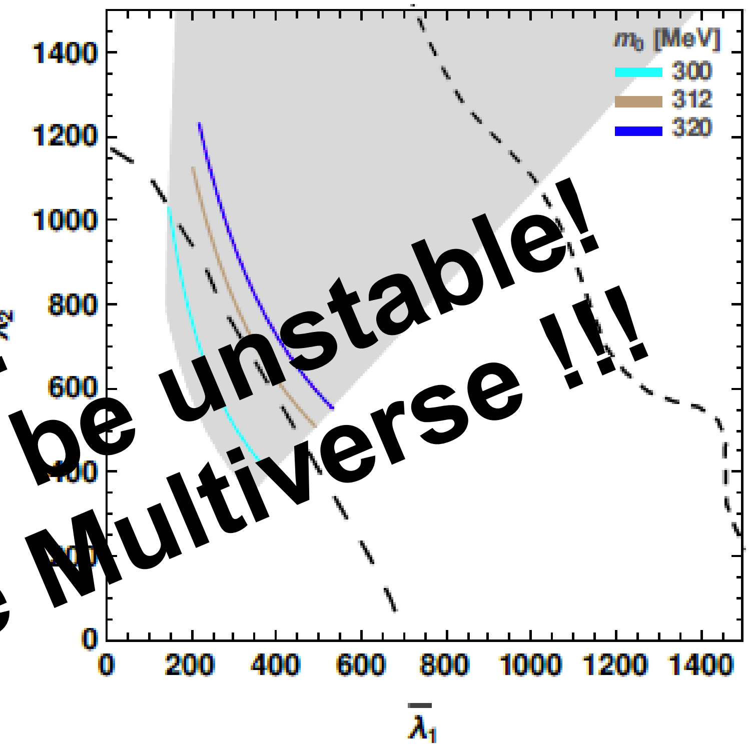

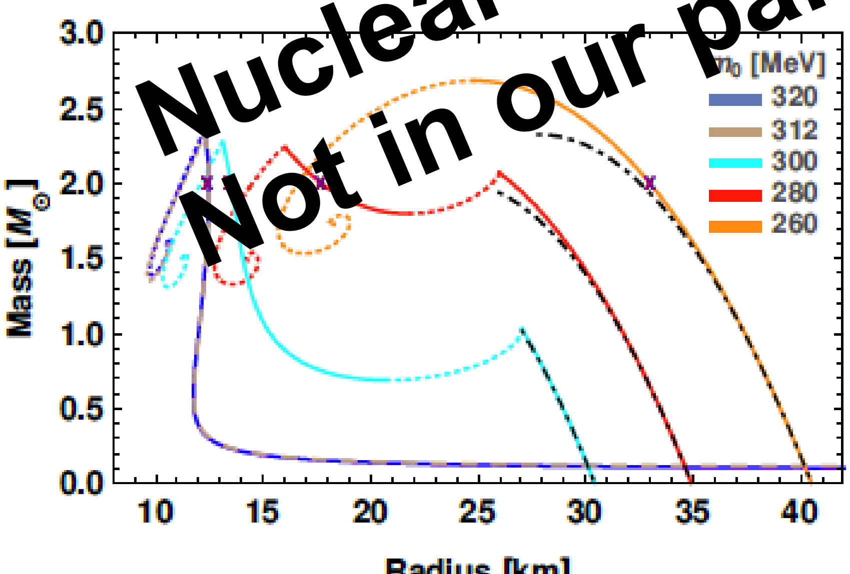

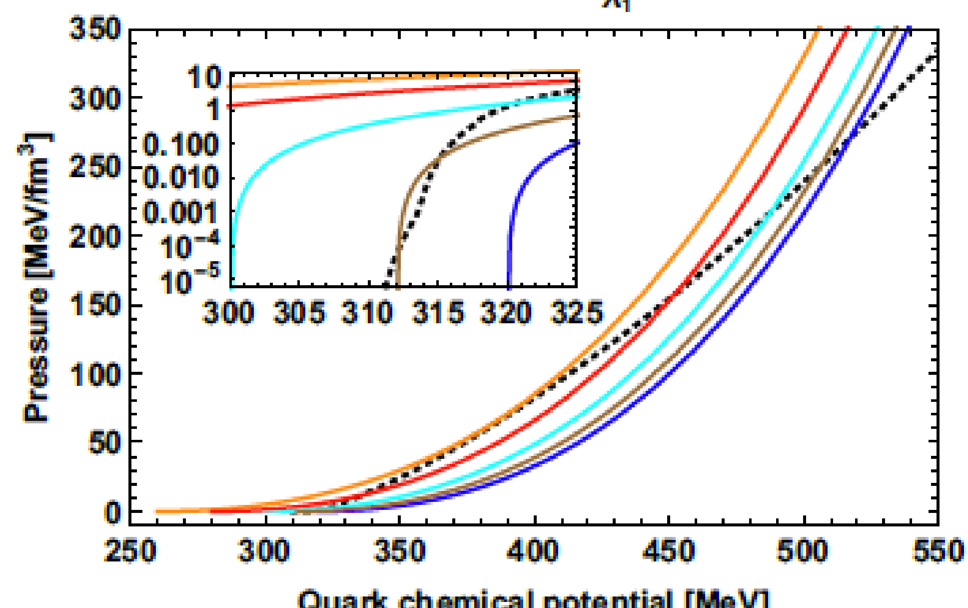

Fake News:
Nuclear matter would be unstable!
Not in our part of the Multiverse !!!