EoS for dense matter with a QCD phase transition

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Compact stars in the QCD phase diagram VI, Dubna, Russia

September 26-29, 2017

1st order QCD phase transition?

- finite T: crossover
- **how about finite μ?**

1st order QCD phase transition?

- HICs: small, short lived, and not very dense
- stars: large, long lived and very dense

1st order QCD phase transition?

- lattice QCD's sign problem $\rightarrow$ no first principle results yet
- assume a 1st order QCD transition

  how to verify it?

  $\rightarrow$ **imprint on mass-radii relations**

3rd family and twin stars

1st: white dwarfs

2nd: neutron stars

3rd: hybrid stars

(not absolutely stable strange matter!)

- twin stars: neutron and hybrid stars of same mass and different radii

Twin stars

- twin stars $\leftrightarrow$ strong 1st order

- not new

  Glendenning, Kettner, A&A **353** (2000) L9
  Schertler, Greiner, Schaffner-Bielich, Thoma, NPA **677** (2000) 463

- this work: **twin stars at** $2M_{\odot}$

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

Twin stars - recent developments

- Bayesian analysis

  (talk by Sasha Ayriyan)

- CEP and Compact Stars

  (talk by David Alvarez)

- twins in proto-neutron stars

  (softening of EoS with increase of entropy)

  Hempel, Heinimann, Yudin, Iosilevskiy, Liebendörfer, Thielemann, PRD **94** (2016) no.10, 103001

- 4th family - triplets

  (strong 2SC to CFL transition in quark matter)

  Alford, Sedrakian, 1706.01592

Engineer a strong 1st order transition?

- calculate hadron and quark EoS, join by Maxwell construction

  $\rightarrow$ 1st order by construction

- strong 1st order: two EoS should have different slopes at the transition on the $p - \mu$ plot

Hadrons

- DD2: density dependent couplings RMF

  Typel, Wolter, NPA **656** (1999) 331

- excluded volume

$$\Phi \equiv \frac{V_{\text{av}}}{V} = 1 - v \sum_{i=n,p} n_i$$

$$E_i = \mu_i - V_i - \frac{v}{\Phi} \sum_{j=p,n} p_j$$

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- two flavors

  no hyperon problem $\rightarrow$ phase transition to quark matter

Quarks

- NJL8: multiquark interactions model

$$\mathcal{L}_{\text{scal}} = \frac{g_{20}}{\Lambda^2}(\bar{q}q)^2 + \frac{g_{40}}{\Lambda^8}(\bar{q}q)^4$$

- g_{40} corrections to μ_{chiral} small

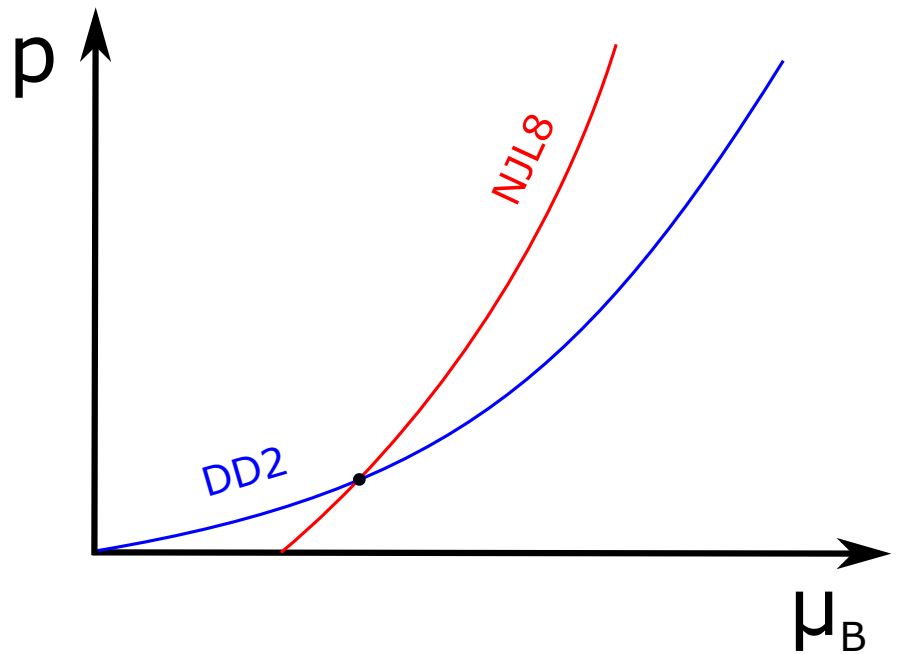
$$\mathcal{L}_{\text{vec}} = \frac{g_{02}}{\Lambda^2}(\bar{q}\gamma^\mu q)^2 + \frac{g_{04}}{\Lambda^8}(\bar{q}\gamma^\mu q)^4$$

- $\omega \sim \bar{q}\gamma^0 q$ increases with density

SB, EPJA **50** (2014) 111
SB, Blaschke, Alvarez-Castillo, Fischer, Typel, A&A **577** (2015) A40

EoS + M-R systematics

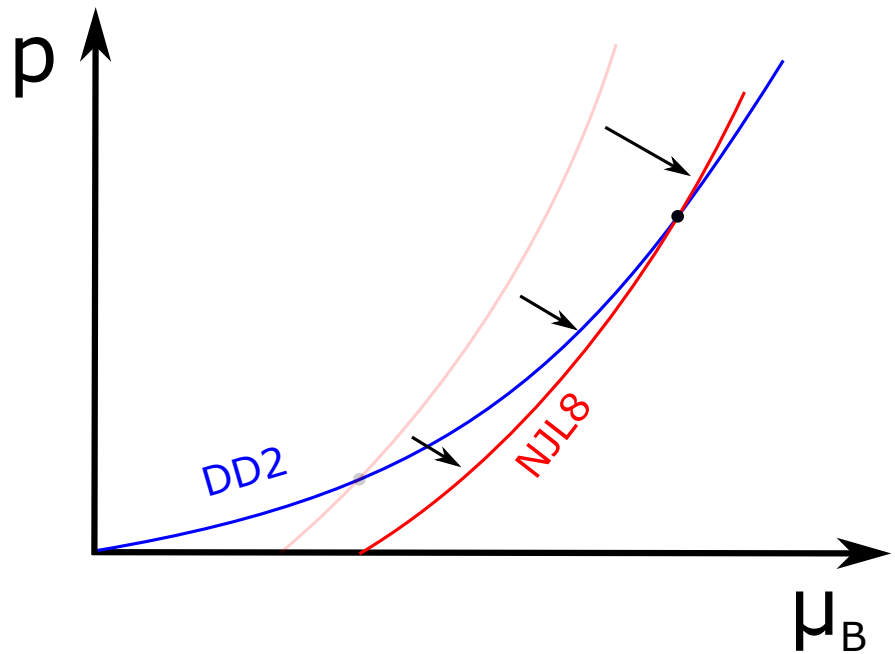
- no repulsion hadrons + no repulsion quarks



- no repulsion $\rightarrow$ no $2M_\odot$

EoS + M-R systematics

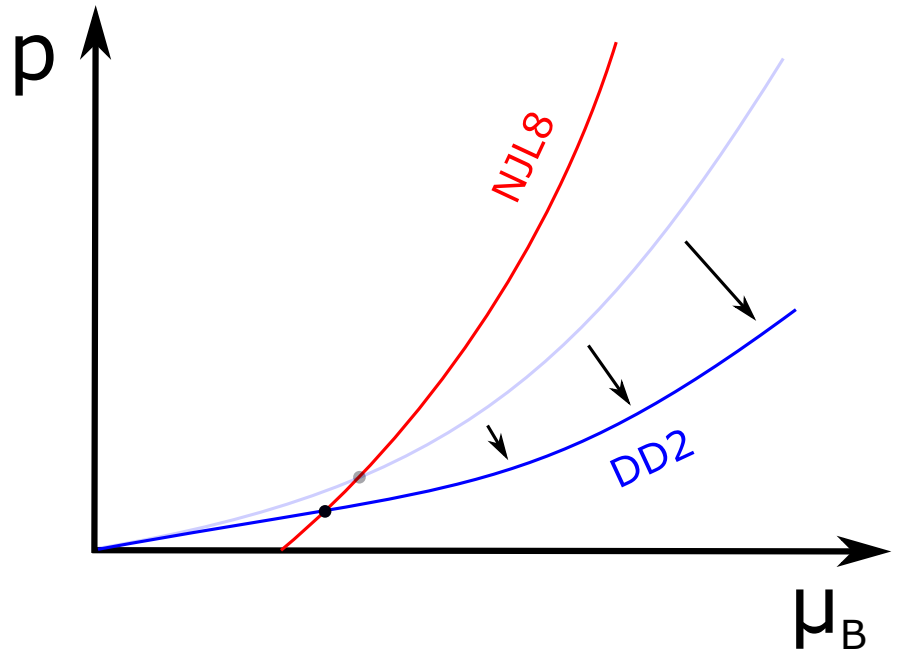
- no repulsion hadrons + repulsion quarks



- onset of quarks delayed
- latent heat reduced
- $2M_\odot$ OK - typically hybrid stars

EoS + M-R systematics

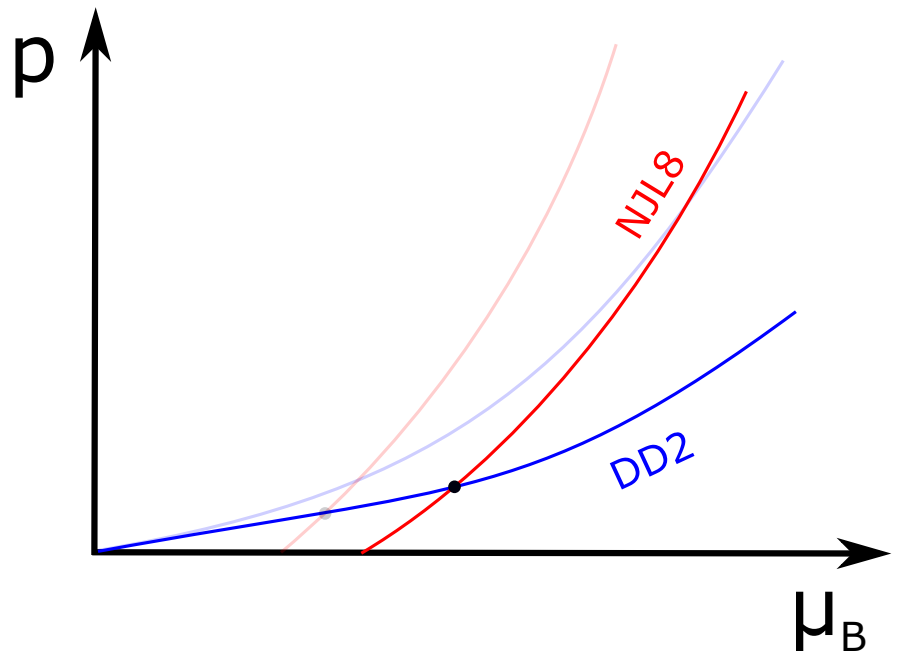
- repulsion hadrons + no repulsion quarks



- onset of quarks lowered
- latent heat increased
- $2M_\odot$ OK - typically neutron stars

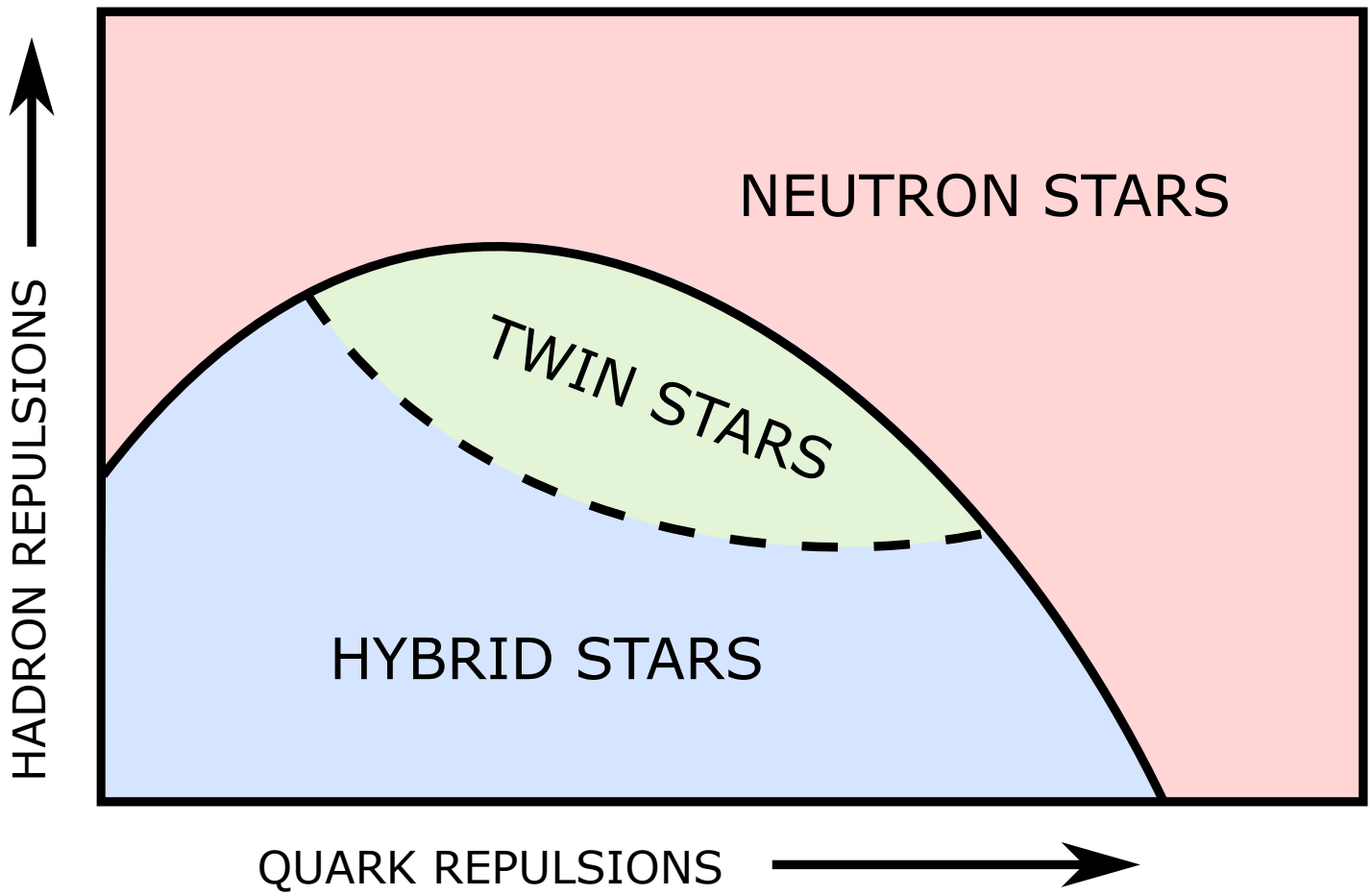
EoS + M-R systematics

- repulsion hadrons + repulsion quarks

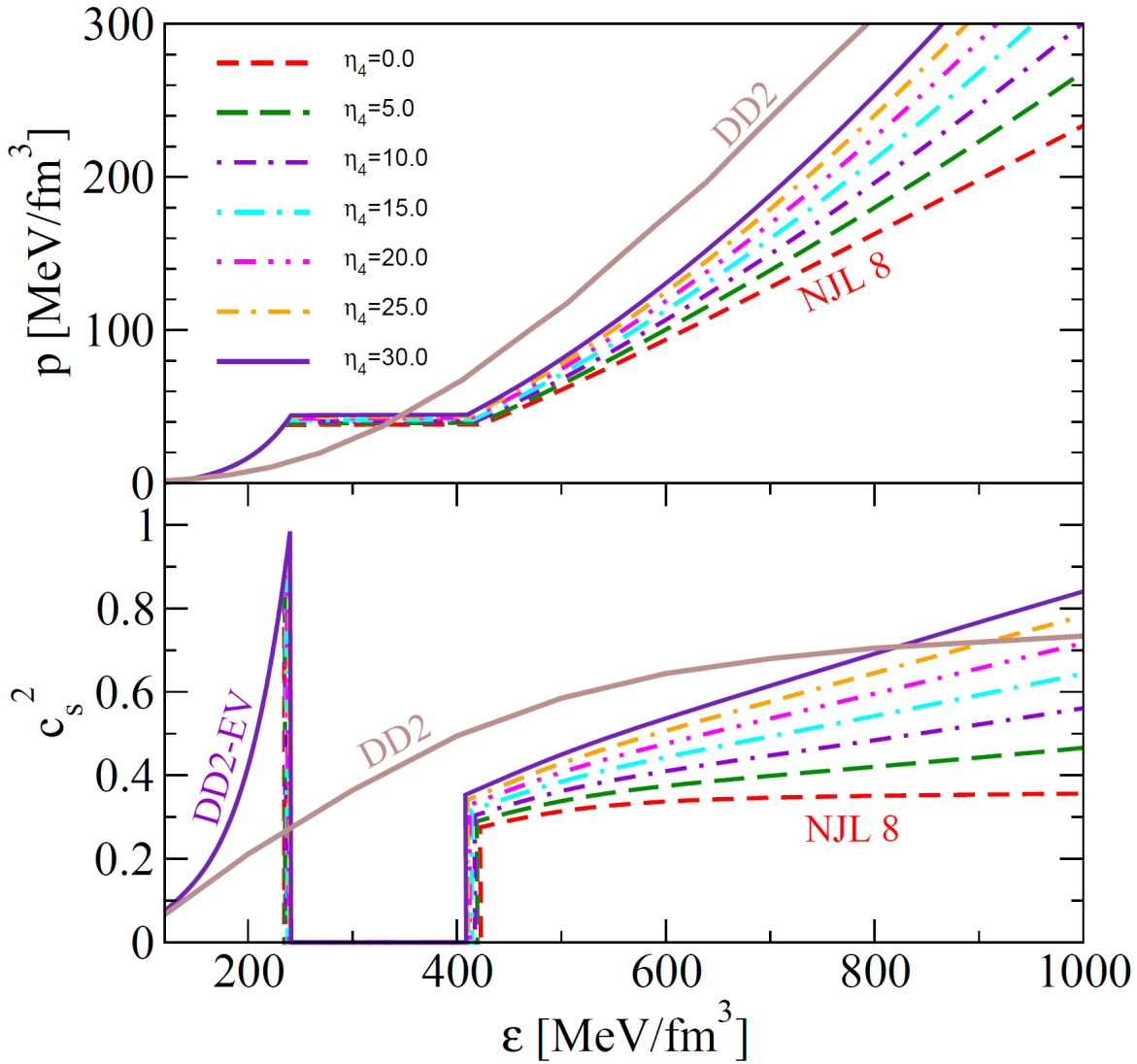


- $2M_\odot$ OK - twin stars window

EoS + M-R systematics



Numerical calculations



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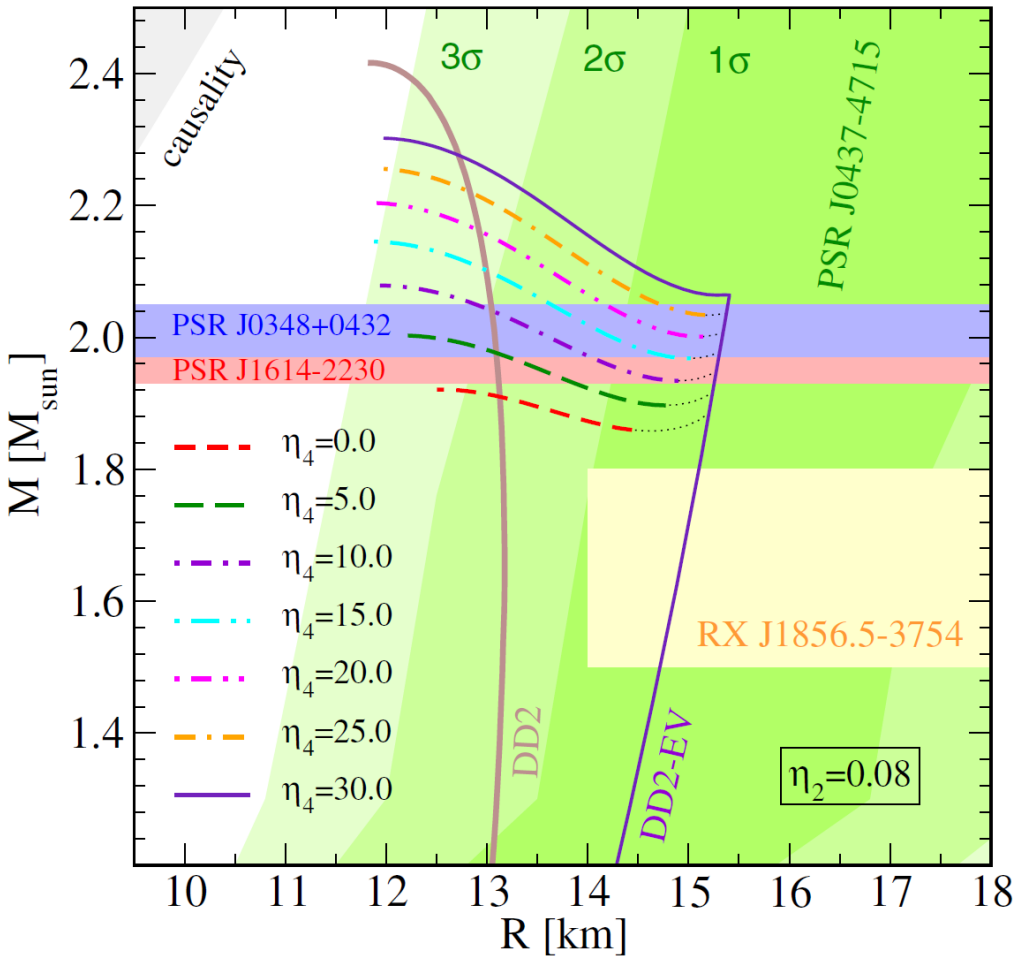

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Conclusions

- twin stars @ $2M_{\odot}$: quite strong repulsion in nuclear and in quark matter

- twin stars exclude models with stiffening in the transition region
- two EoS scenario cannot be excluded (strange stars + neutron stars)

- EoS stiff $\rightarrow$ big, dilute stars
  $\rightarrow$ measurement of a very small radii would disfavor our scenario

Conclusions

- strong 1st order in β-eq. QCD matter

  $\longrightarrow$ strong 1st order transition in symmetric QCD matter?

- pasta effects

  (talks by Sasha Ayriyan and David Alvarez)