Astro-Solids, Dense Matter, and Gravitational Waves, INT, April 16 - 20, 2018

Could GW170817 tell us something about dense matter composition?

Jérôme Margueron, IPN Lyon & INT Seattle

The masquerade issue

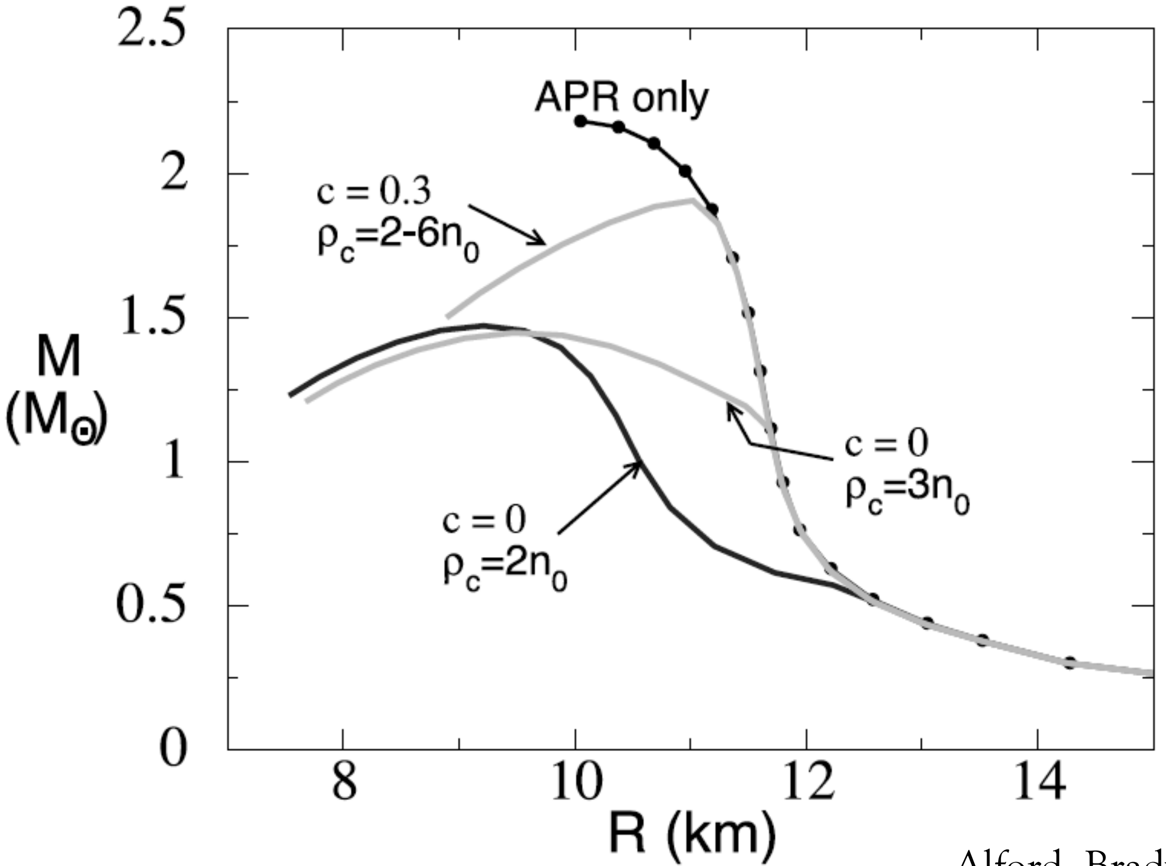
A meta-model for nucleonic EOS (minimal model)

Confronting MM with CSM for GW170817

Tews, JM, Reddy arXiv:1804.0273,
JM, Casali, Gulminelli, PRC 97, 025805 & 025806 (2018)

The masquerade issue

A hybrid star which looks nuclear

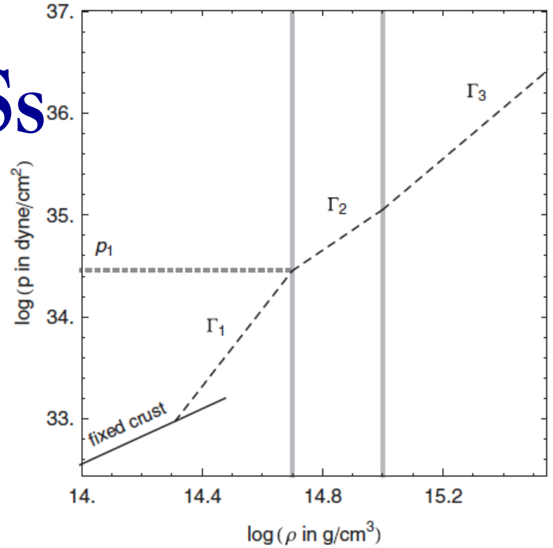


Alford, Brady, Paris, Reddy ApJ 2005

Are we condemned to this duality issue?

Are all nucleonic EOS masqueraded by QM? Are all QM masqueraded by nucleonic EOS?

Parametric forms for general EOSs

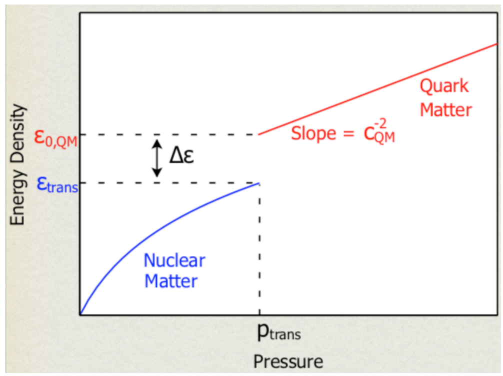


Piecewise polytrope:

3 points: J. Read et al, PRD 2009
5 points: F. Ozel, PRD 2010
Matching pQCD: Kurkela et al., ApJ 2014

Talk by J. Lattimer

Parametric phase transition:

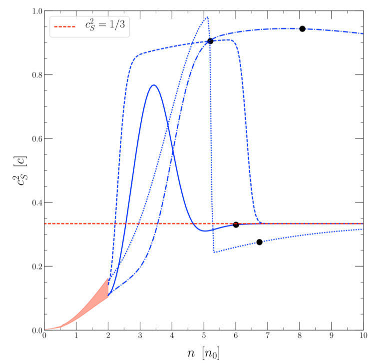


Zdunik & Haensel 2012,
Alford, Han, Prakash 2013

Talk by S. Han

Sound velocity based model (CSM):

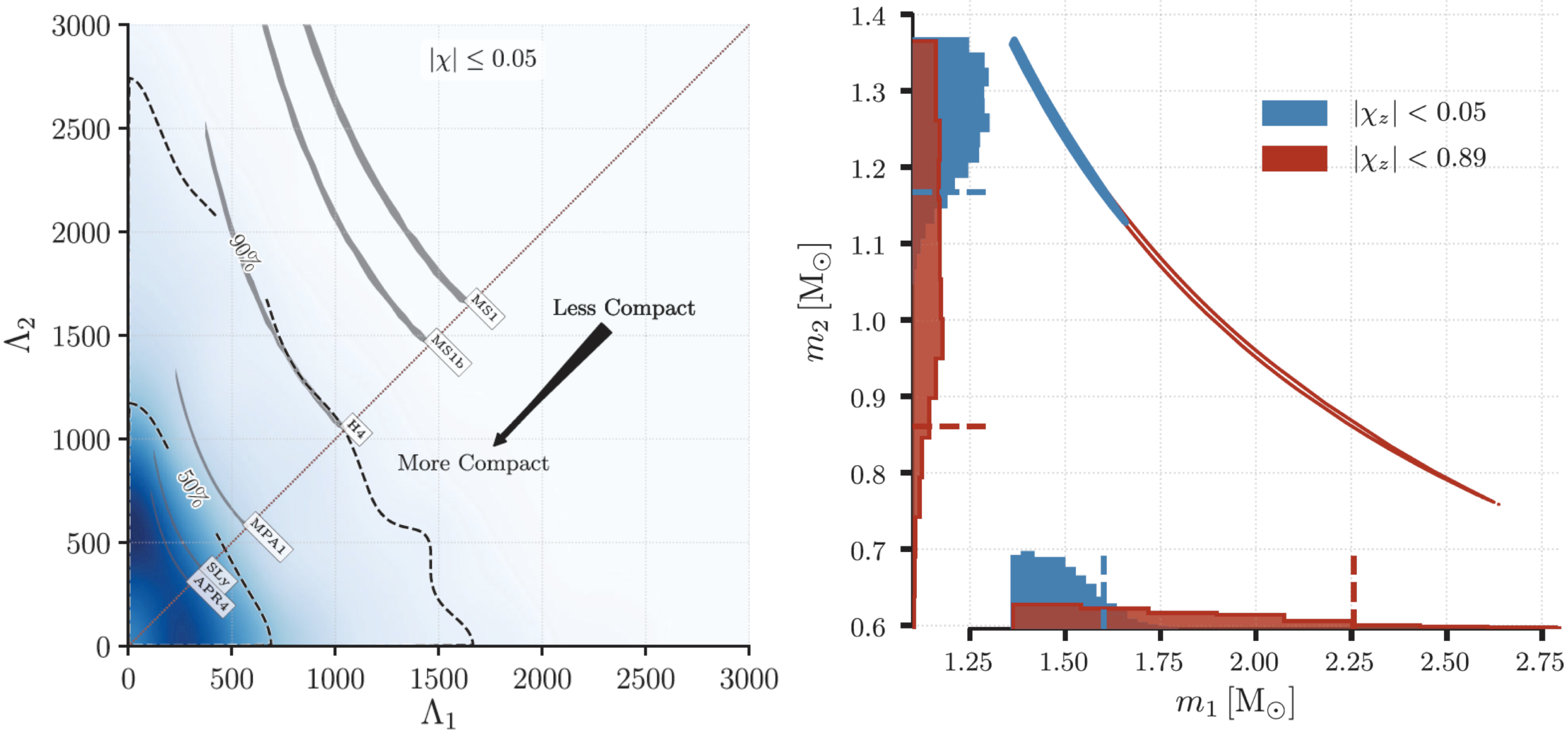
Tews, Carlson, Reddy, Gandolfi 2018



All together they set consistant boundaries of all possible EOS.
But they don't say much about matter composition.

J. M.

Comparison to GW170817 observation



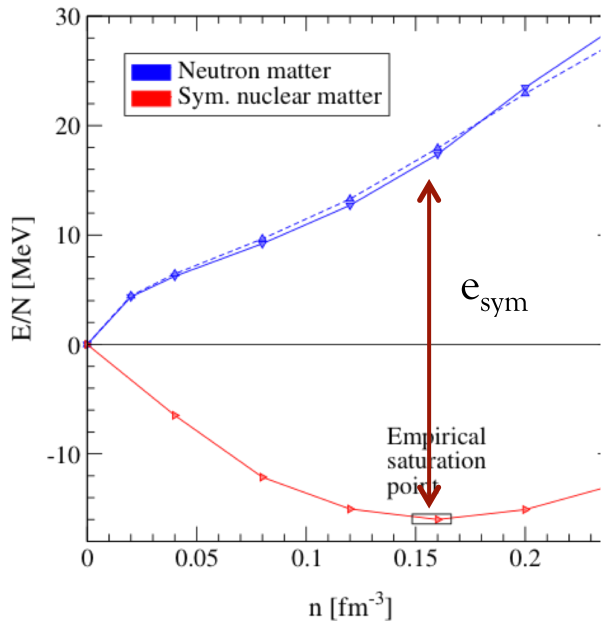
LIGO Virgo collaboration PRL 2017

$\tilde{\Lambda}$=800 → rules out NS with large radii (>13.6km)

Can GW170817 (or future detection) say something about matter composition?

A minimal model is needed → boundaries for nucleonic EOS.

Towards a generic nucleonic EOS (minimal model)



We use a meta-model for nucleonic EOS which assumes:

- Nuclear potential quadratic in δ (isospin asymmetry),
- The EoS is continuous,
- Satisfies causality and stability

Determined by a set of empirical parameters:

$$e_{sat}(n) = E_{sat} + \frac{1}{2}K_{sat}x^2 + \frac{1}{6}Q_{sat}x^3 + \frac{1}{24}Z_{sat}x^4 + \ldots$$

$$e_{sym}(n) = E_{sym} + L_{sym}x + \frac{1}{2}K_{sym}x^2 + \frac{1}{6}Q_{sym}x^3 + \frac{1}{24}Z_{sym}x^4 + \ldots$$

$$x = (n - n_{sat})/(3n_{sat})$$

A large number of nucleonic EOS can be reproduced by this meta-model (maybe all?).

Prediction boundaries are related to empirical parameters boundaries.

From a detailed analysis of experimental predictions, phenomenological and ab-initio models

Around n_{sat}: $\frac{E}{A}(n,\delta) \approx e_{sat}(n) + e_{sym}(n)\delta^2 + e_{sym,4}(n)\delta^4 + \ldots$

with
$$e_{sat}(n) = E_{sat} + \frac{1}{2}K_{sat}x^2 + \frac{1}{6}Q_{sat}x^3 + \frac{1}{24}Z_{sat}x^4 + \ldots$$
$$e_{sym}(n) = E_{sym} + L_{sym}x + \frac{1}{2}K_{sym}x^2 + \frac{1}{6}Q_{sym}x^3 + \frac{1}{24}Z_{sym}x^4 + \ldots$$

In the following, we consider the following central values and uncertainties (1σ):

P_α	E_{sat} MeV	E_{sym} MeV	n_{sat} fm^{-3}	L_{sym} MeV	K_{sat} MeV	K_{sym} MeV	Q_{sat} MeV	Q_{sym} MeV	Z_{sat} MeV	Z_{sym} MeV	m^*_{sat}/m	$\Delta m^*_{sat}/m$
$\langle P_\alpha \rangle$	-15.8	32	0.155	60	230	-100	300	0	-500	-500	0.75	0.1
σ_{P_α}	±0.3	±2	±0.005	±15	±20	±100	±400	±400	±1000	±1000	±0.1	±0.1

Small uncertainties (E_{sat} to K_{sat})

Large uncertainties (K_{sym} to Z_{sym})

Large uncertainties
No effect on the EOS (m^*_{sat}/m, $\Delta m^*_{sat}/m$)

→ Impact on the nuclear EOS

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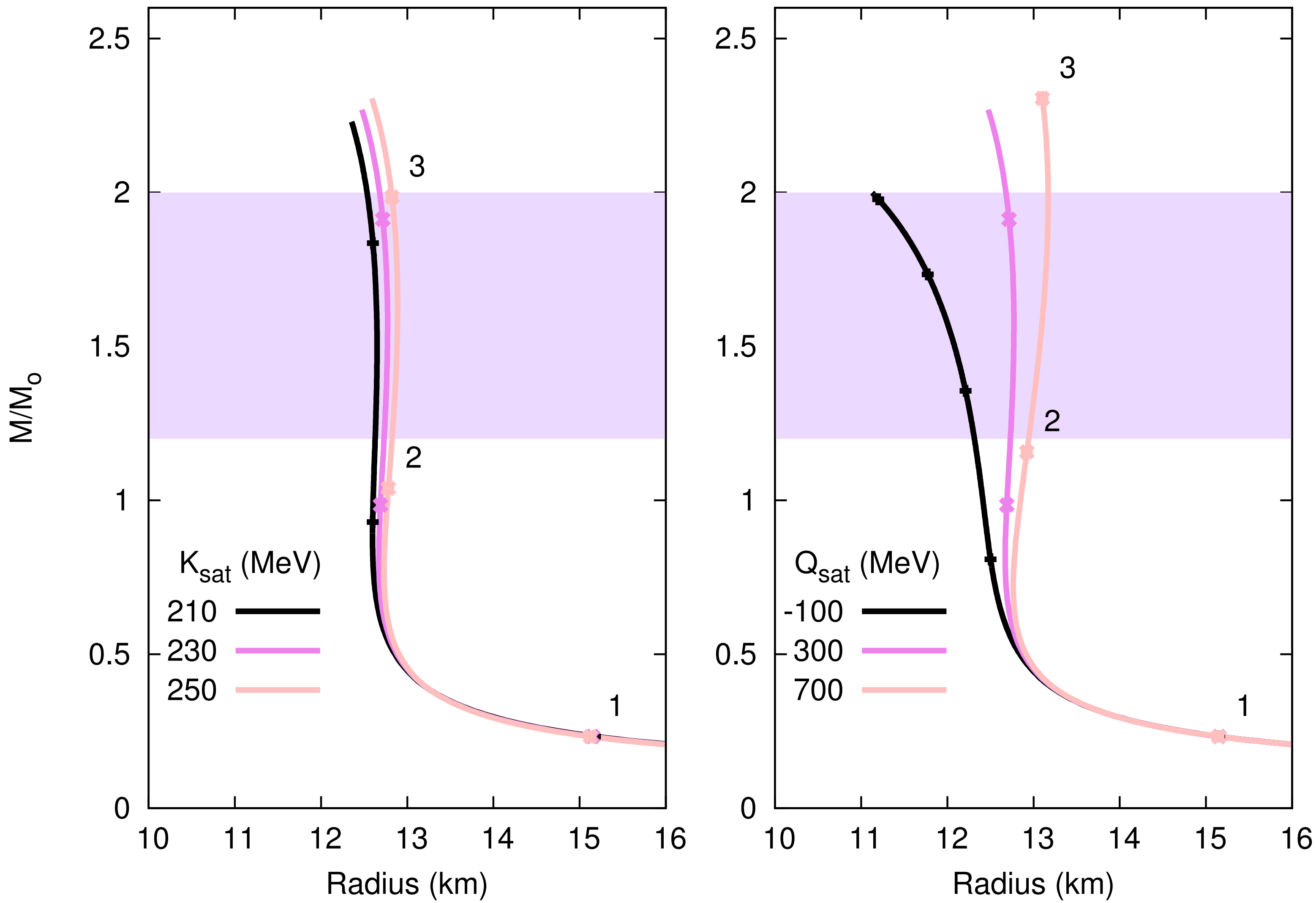
JM, Casali, Gulminelli, PRC 2018

Impact of the isoscalar empirical parameters

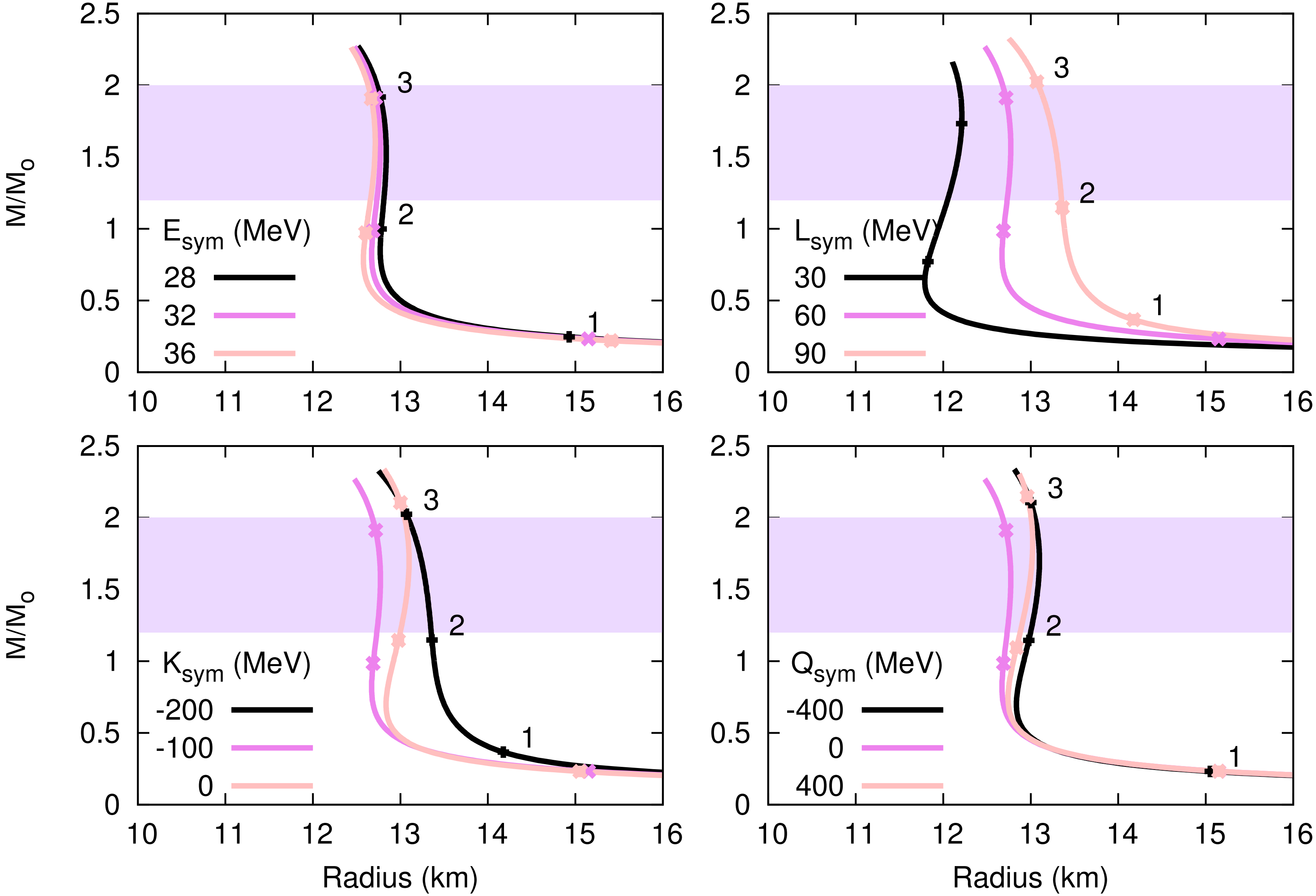
Small impact of these parameters



JM, Casali, Gulminelli, PRC 2018

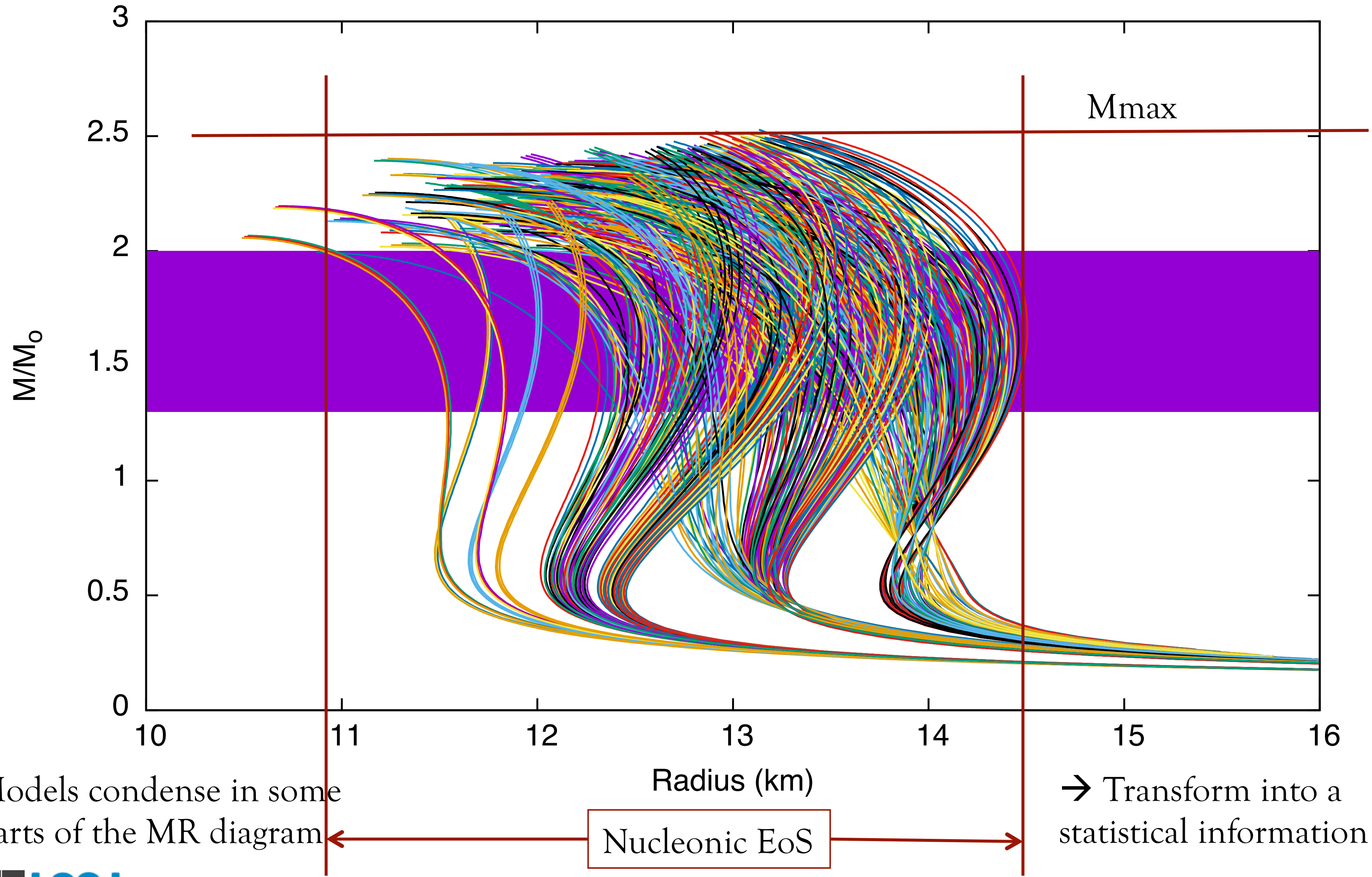
Impact of the isovector empirical parameters

Largest source of uncertainty: Lsym and Ksym



JM, Casali, Gulminelli, PRC 2018

Impact of the "exp" unknown on the Mass/Radius relation



Models condense in some parts of the MR diagram

→ Transform into a statistical information

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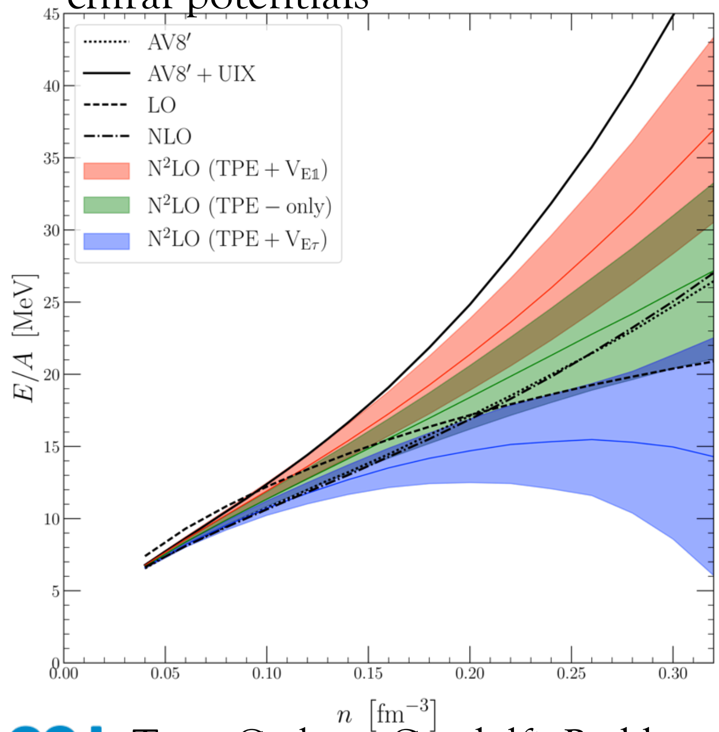
Confronting CSM versus MM

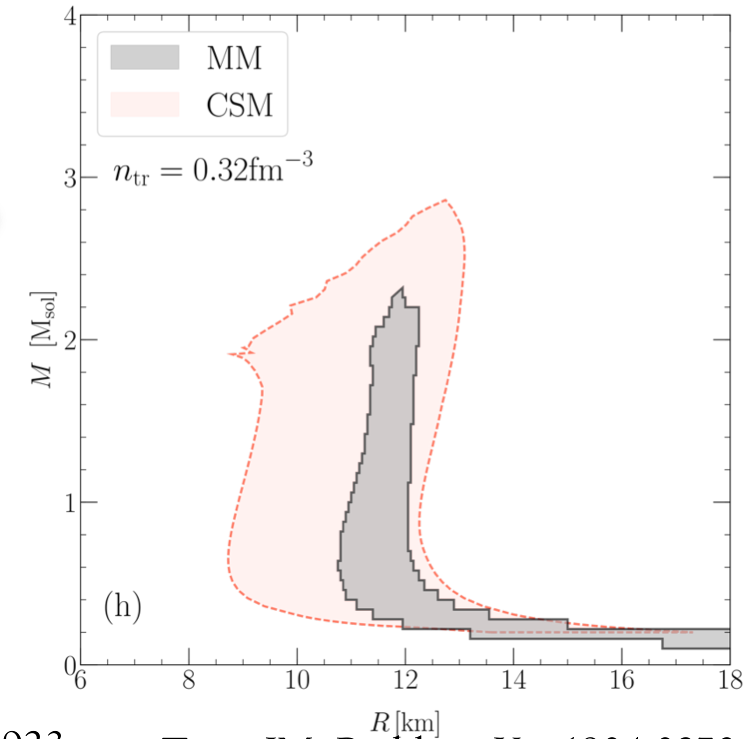
We have a meta-model for the nucleonic EOS (enough general? Maybe).
CSM is more general and contains all sort of « strange » behaviour.

Confronting CSM versus MM informs us where we could expect differences (no masquerade).

QMC calculations with local chiral potentials



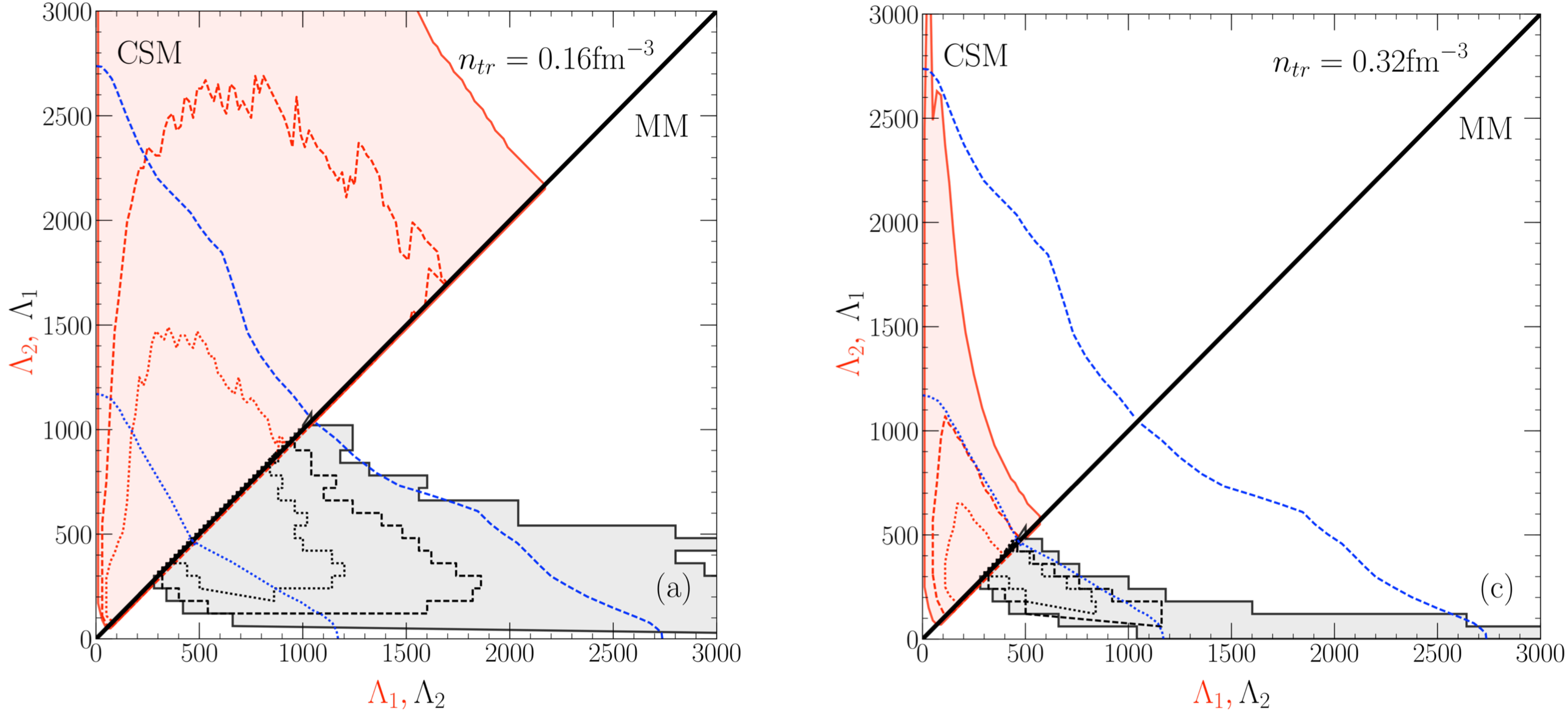
Solution of the non-rotating TOV eqs.



Tews, Carlson, Gandolfi, Reddy, arXiv:1801.01923

Tews, JM, Reddy, arXiv:1804.0273

CSM versus MM (same constraints)



Range of tidal polarizabilities:
CSM: 80 – 570
MM: 260 – 500

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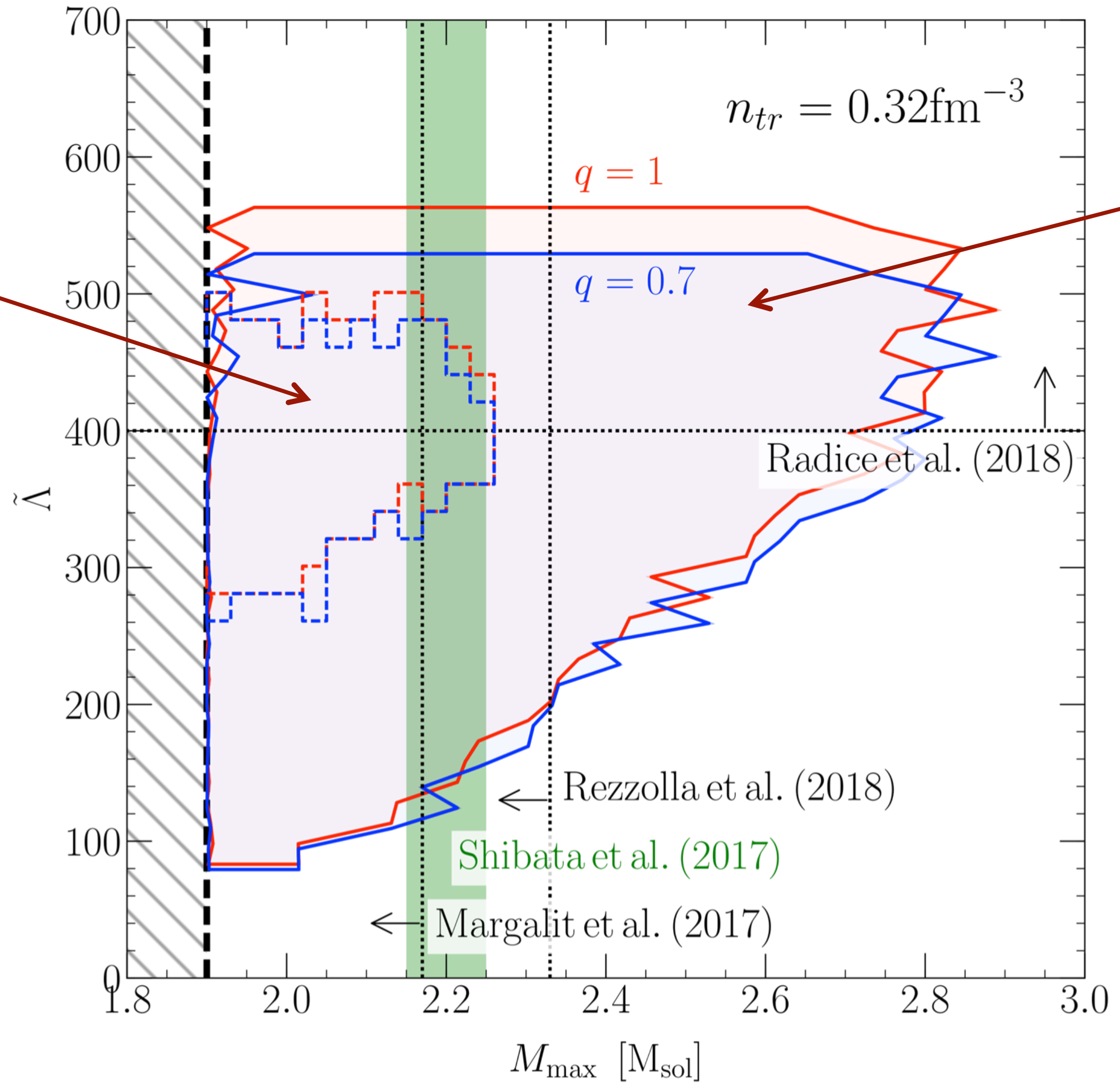
Tews, JM, Reddy, arXiv:1804.0273

CSM versus MM (same constraints)

MM

CSM

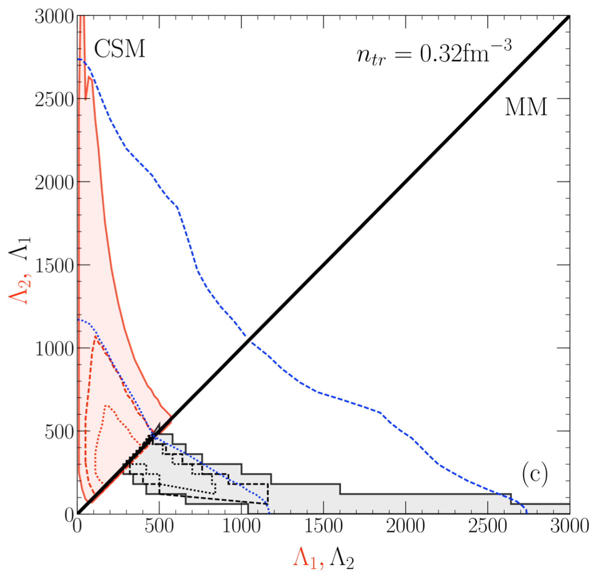


Tews, JM, Reddy, arXiv:1804.0273 J. M.

Conclusions and outlooks

- Both MM and CSM can reproduce existing observations.
- More constraints are needed (NICER soon, more GWs, ...)

  + additional observables: cooling, glitches, ...
- Nuclear physics constraints are still more constraining than GW.
- Required GW accuracy to improve our knowledge:



$\Delta\tilde{\Lambda} \approx$ 300-400 ➡ Probe EOS from 1 to $2n_{sat}$

Confirm or rule out nuclear physics

$\Delta\tilde{\Lambda} \approx$ 100-200 ➡ Probe matter composition above $2n_{sat}$

Will it ever be reached?