Report B01:
EOS constraints from neutron stars and mergers

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TECHNISCHE UNIVERSITÄT DARMSTADT

3rd Workshop of the SFB 1245
Schloß Waldthausen, Mainz-Budenheim
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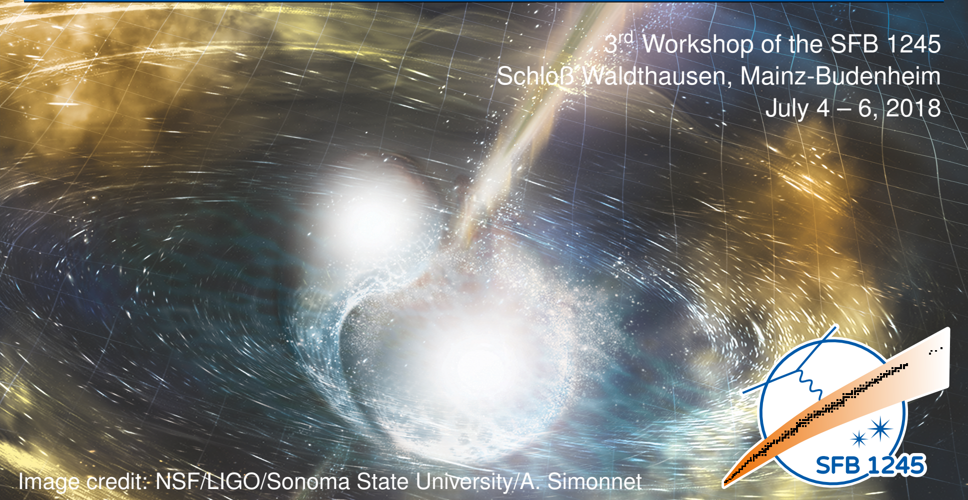

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Image credit: NSF/LIGO/Sonoma State University/A. Simonnet

Motivation

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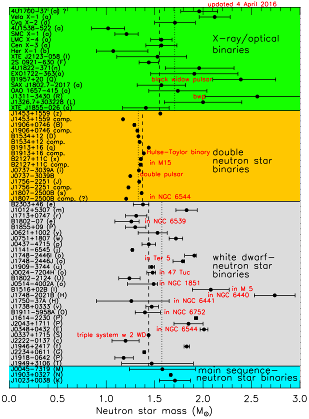
- unique relation between EOS and mass/radius of neutron stars
- precise mass measurements
- direct radius determination is challenging
  - X-ray observations (in future: NICER, eXTP, . . .)
  - moment of inertia
  - tidal deformability
- moment of inertia measurement seems feasible in the future: PSR J0737-3039A

  Burgay et al., Nature 426 (2003); Lyne et al., Science 303 (2004)
- first gravitational wave detection of a binary neutron star merger last year! GW170817

  LIGO Scientific and Virgo Collaborations, PRL 161101 (2017)



Lattimer & Prakash, Phys. Rev. Lett. 94 (2005); https://stellarcollapse.org/nsmasses (last checked: 12-15-2017)

- early inspiral phase ($f \leq 400$ Hz) gives constraints on tidal deformability λ

Equation of State and Neutron Star Structure: Nuclear Physics and Observational Constraints

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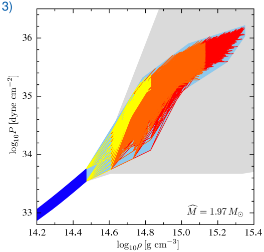
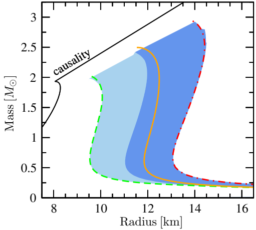
Hebeler, Lattimer, Pethick, Schwenk, Phys. Rev. Lett. 105 (2010); Hebeler, Lattimer, Pethick, Schwenk, APJ 773 (2013)

- low density regime: knowledge of nuclear physics
  - BPS crust up to $\sim \rho_{\mathrm{sat}}/2$
  - Chiral EFT interactions up to $\sim \rho_{\mathrm{sat}}$
- high density regime: requirement of causality and constraints from 2 $M_\odot$ neutron stars
  - polytropic expansion for high-density extension: $P = K\rho^\Gamma$

    Read, Lackey, Owen, Friedman, Phys. Rev. D 79 (2009)
- radius prediction for PSR J0737-3039A (M = 1.338 $M_\odot$): R = (9.9 – 13.6) km

extend this to the moment of inertia and tidal deformability





Hebeler, Lattimer, Pethick, Schwenk, APJ 773 (2013)

Results for Moment of Inertia
Universal Relations

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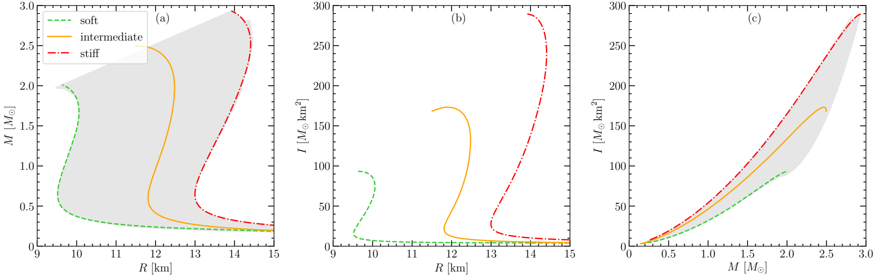

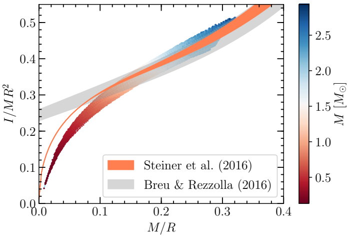

- EOS insensitive relations between neutron star observables exist
  Lattimer & Schutz, APJ 629 (2005); Yagi & Yunes, Science 341 (2013); Steiner et al., Eur. Phys. J. A 52 (2016); Breu & Rezzolla, Mon. Not. Roy. Astron. Soc. 459 (2016)

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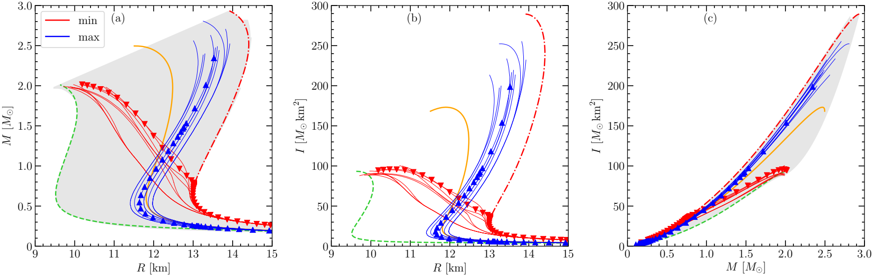

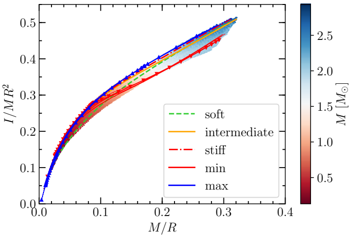

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- extreme EOS yield *MR* relations with strong and no back-bending

Results for Moment of Inertia
Radius constraints

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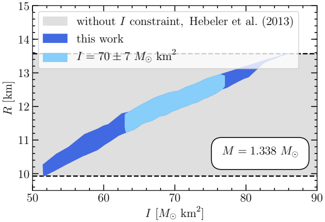

- prospect of moment of inertia measurement of PSR J0737–3039A

  Burgay et al., Nature (2003); Lyne et al., Science (2004)

- assume $I = (70 \pm 7)\ M_\odot\ \mathrm{km}^2$ – 10% uncertainty seems feasible

$$R_{1.338\ M_\odot} = (9.9 - 13.6)\ \mathrm{km}$$
$$\Downarrow$$
$$R_{1.338\ M_\odot} = (11.2 - 12.9)\ \mathrm{km}$$

- a 10% measurement of I can yield a reduction in radius uncertainty of about 50%!

Results for Moment of Inertia
Radius constraints

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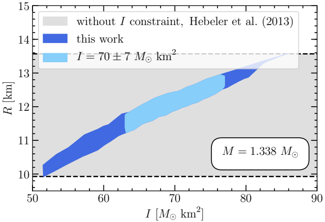

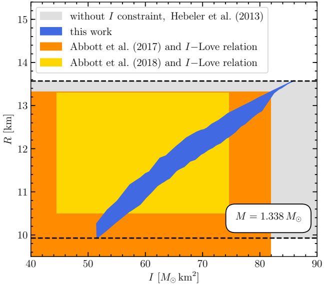

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- a 10% measurement of I can yield a reduction in radius uncertainty of about 50%!
- GW170817 with universal relation gives constraints for moment of inertia and radius

Results for Tidal Deformability
Hypothetical Λ Observation

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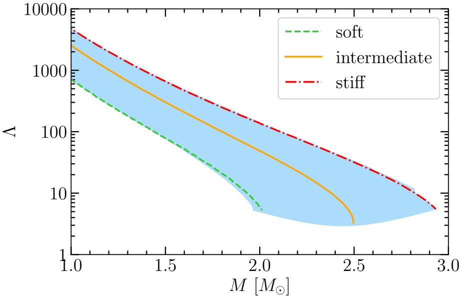

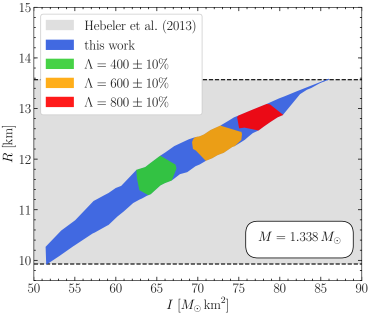

- polytropic EOS predict for $M = 1.338\ M_\odot$ a range for the tidal deformability: $\Lambda = 154 - 1164$
- measurements of Λ will give strong constraints on the radius of neutron stars

Results for Tidal Deformability
Radius constraints from GW170817

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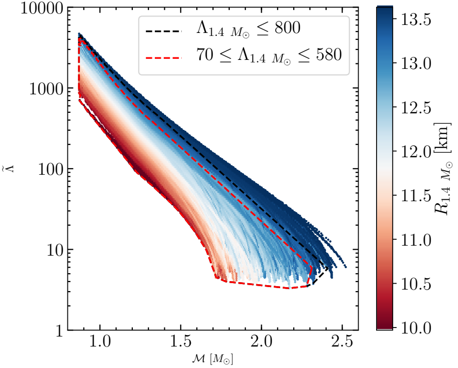
- chirp mass $\mathcal{M}$ and binary tidal deformability $\widetilde{\Lambda}$ were measured, range for $\Lambda_{1.4\ M_\odot}$ was inferred
  LIGO Scientific and Virgo Collaborations, PRL 161101 (2017) (Updates: arXiv:1805.11579; arXiv:1805.11581)

- the upper bound of $\widetilde{\Lambda}$ from GW170817 yields no substantial new constraints for the radius of $M = 1.4\ M_\odot$ neutron stars
- information from gravitational wave observations have the potential to give constraints on neutron star radii and the equation of state



Summary and Outlook

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- future moment of inertia measurement has the potential to provide strong constraints on neutron star radii and the EOS
- gravitational wave observations open new possibilities
  - observations could result in stronger constraints for neutron star radii and the equation of state
  - synergies between different observations (i.e. radii, moments of inertia, tidal deformabilities) will yield more input and further constraints for our approach
- investigate the impact of the upcoming results from the NICER mission

In collaboration with K. Hebeler, J. Lattimer, C. Pethick, and A. Schwenk.

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Thanks for your attention!

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