Predict and Prejudice: Classification of compact objects and model comparison using EOS knowledge

Hauke Koehn, **Thibeau Wouters**, Henrik Rose, Peter T. H. Pang, Rahul Somasundaram, Ingo Tews, and Tim Dietrich

t.r.i.wouters@uu.nl

Extreme Matter call 17/06/2024

Utrecht University

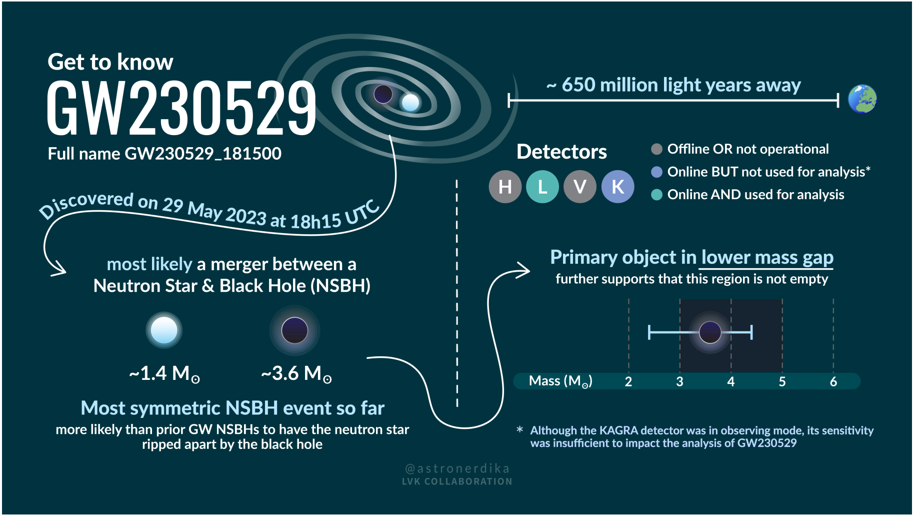
Nikhef

Overview

Our paper has several parts:

- Adding new NICER observation of PSR J0437-4715 (TBA)
- Classification of recent lower mass gap objects:
  - PSR J0514-4002E companion
  - GW230529 primary [1] (**this presentation**)
- Model selection:
  - Comparison of NICER results for PSR J0030+0451
  - Comparison of symmetry energy measurements

Introduction – GW230529



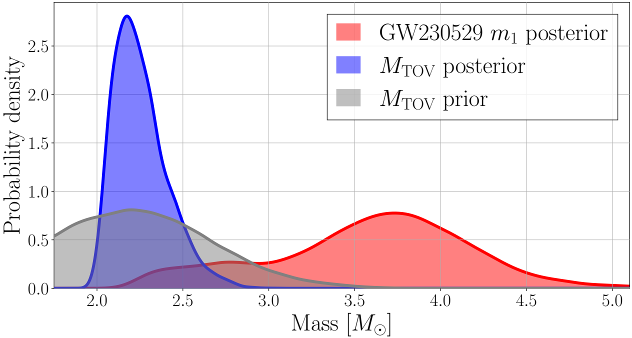
Credit: Shanika Galaudage

Methods – EOS constraints with NMMA

NMMA compiled sets of EOS constraints [2]:

- Nuclear theory and experiments
- Radio observations pulsars, NICER, bursters, X-ray binaries
- GW170817 + EM counterparts & postmerger remnant

NMMA



Methods – EOS constraint sets

Table 1: Overview on the constraints contained within the three different constraint sets.

Set	Label	Description
High confidence	1	Chiral EFT, pQCD, heavy radio pulsars, NICER J0740+6620, NICER J0030+0451, (NICER J0437-4715), GW170817
More vigorous	2	Set 1, Black Widow J0952-0607, heavy ion-collisions, qLMXBs, GW170817+KN+GRB afterglow, CREX, PREX-II, Burster 4U 1702-429, Burster J1808.8-3658, GW170817 postmerger
Aggressive	3	Same as set 2, but for the remnant of GW170817 a hypermassive neutron star above the Kepler limit is assumed

Methods – Classification of compact objects

NMMA sets of constraints $\mathcal{D}$ give posterior on M_{TOV}.
Compare this against GW230529's properties:

- Probability of primary being a neutron star: $P(NS)$:

$$P(\mathsf{NS}) = \int \mathrm{d}M_{\mathsf{TOV}} \int_0^{M_{\mathsf{TOV}}} \mathrm{d}m_1 \; P(M_{\mathsf{TOV}}|\mathcal{D}) P(m_1).$$

- Spinning neutron stars can have higher masses: $M_{\max}(\mathrm{EOS}, \chi_1)$:

$$P(\mathsf{NS}) = \int \mathrm{d}M_{\max} \int_0^{M_{\max}} \mathrm{d}m_1 \int_0^1 \mathrm{d}\chi_1 \; P(M_{\max}|\mathcal{D}, \chi_1) P(m_1, \chi_1) \, .$$

- Use universal relation from Breu and Rezzolla for $M_{\max}$ [3]

Results – Classification of GW230529 primary

- Set 1 and without spin agree well with LVK results [1].
- Spin + PDB raise $P(NS)$ to $\sim 17\%$.
- Set 3 ("aggressive") drastically reduces $P(NS)$.

		Set 1	Set 2	Set 3
default prior	w/o spin	1.6%	1.3%	0.02%
	w/ spin	3.9%	3.9%	0.82%
PDB prior	w/o spin	8.1%	6.9%	0.36%
	w/ spin	17%	17%	1.7%

(PDB: Powerlaw + Dip + Break population model)

Conclusion

- GW230529: primary component in the lower mass gap

- NMMA has compiled current EOS constraints into 3 sets

- Accounting for spin raises $P(NS)$ for GW230529 primary to $\sim 17\%$ with PDB. The "aggressive" constraints gives $P(NS) \lesssim 1.7\%$

- Results are still consistent with black hole interpretation of GW230529 primary

References

[1] "Observation of Gravitational Waves from the Coalescence of a $2.5 - 4.5\ M_\odot$ Compact Object and a Neutron Star". In: (Apr. 2024). arXiv: 2404.04248 [astro-ph.HE].

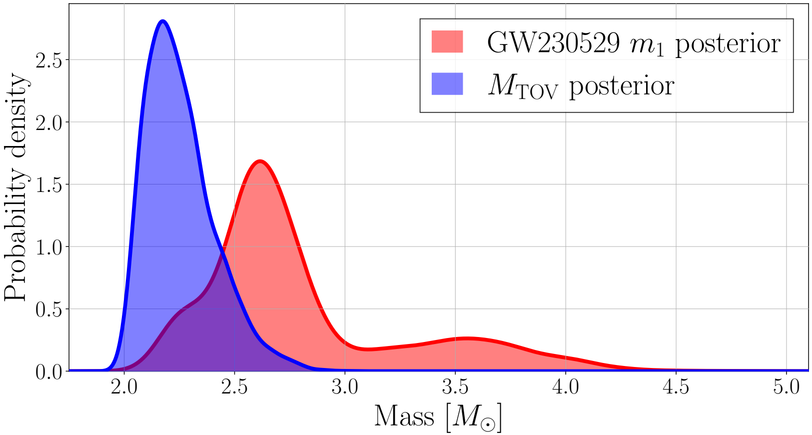
[2] Hauke Koehn et al. "An overview of existing and new nuclear and astrophysical constraints on the equation of state of neutron-rich dense matter". In: (Feb. 2024). arXiv: 2402.04172 [astro-ph.HE].

[3] Cosima Breu and Luciano Rezzolla. "Maximum mass, moment of inertia and compactness of relativistic stars". In: *Mon. Not. Roy. Astron. Soc.* 459.1 (2016), pp. 646–656. DOI: 10.1093/mnras/stw575. arXiv: 1601.06083 [gr-qc].

APPENDIX

Population informed posterior

Posterior obtained with PDB prior:



TOV mass posterior with set 3 ("Aggressive")