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Stringent constraints on neutron-star radii from multimessenger observations and nuclear theory

Collin D. Capano[1,2] ✉, Ingo Tews[3], Stephanie M. Brown[1,2], Ben Margalit[4,5], Soumi De[5,6], Sumit Kumar[1,2], Duncan A. Brown[5,6], Badri Krishnan[1,2] and Sanjay Reddy[7,8]

[1]Albert-Einstein-Institut, Max-Planck-Institut für Gravitationsphysik, Hannover, Germany. [2]Leibniz Universität Hannover, Hannover, Germany. [3]Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM, USA. [4]Department of Astronomy and Theoretical Astrophysics Center, University of California, Berkeley, Berkeley, CA, USA. [5]Kavli Institute for Theoretical Physics, University of California, Santa Barbara, Santa Barbara, CA, USA. [6]Department of Physics, Syracuse University, Syracuse, NY, USA. [7]Institute for Nuclear Theory, University of Washington, Seattle, WA, USA. [8]JINA-CEE, Michigan State University, East Lansing, MI, USA. ✉e-mail: collin.capano@aei.mpg.de

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Collin D. Capano[1,2*], Ingo Tews[3], Stephanie M. Brown[1,2], Ben Margalit[4,5,6], Soumi De[6,7], Sumit Kumar[1,2], Duncan A. Brown[6,7], Badri Krishnan[1,2], Sanjay Reddy[8,9]

[1] Albert-Einstein-Institut, Max-Planck-Institut für Gravitationsphysik, Callinstraße 38, 30167 Hannover, Germany,

[2] Leibniz Universität Hannover, 30167 Hannover, Germany,

[3] Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA,

[4] Department of Astronomy and Theoretical Astrophysics Center, University of California, Berkeley, CA 94720, USA,

[5] NASA Einstein Fellow

[6] Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106, USA,

[7] Department of Physics, Syracuse University, Syracuse NY 13244, USA,

[8] Institute for Nuclear Theory, University of Washington, Seattle, WA 98195-1550, USA,

[9] JINA-CEE, Michigan State University, East Lansing, MI, 48823, USA

Comparison to previous multimessenger constraints

Recently, Radice and Dai [1] and Coughlin et al. [2] also performed multimessenger parameter estimation for GW170817. Radice and Dai [1] imposed a lower limit on the tidal polarizability of the merging neutron stars based on arguments that the mass surrounding the remnant after merger (and that can subsequently become unbound and contribute to the kilonova through secular disk winds [3, 4, 5, 6]) is strongly correlated with $\tilde{\Lambda}$ [7]. Combining this lower limit with the GW data and translating their resulting constraints on $\tilde{\Lambda}$ into $R_{1.4\,\mathrm{M}_\odot}$ using an equation-of-state insensitive relation [9], they find $R = 12.2^{+1.0}_{-0.8} \pm 0.2\,\mathrm{km}$. Coughlin et al. [2] performed joint electromagnetic and GW parameter estimation, directly fitting the kilonova photometry using results from radiative transfer calculations [8] and numerical relativity simulations, along with modeling of the associated gamma-ray burst GRB170817A. Sampling in $\tilde{\Lambda}$ space and similarly translating their results into radius constraints using the equation-of-state insensitive relation of De et al. [9], they obtained $R \in (11.1, 13.4) \pm 0.2\,\mathrm{km}$ [2].

These earlier studies differ from our present work in several respects. First and foremost, we combine systematic nuclear theory with the gravitational wave and electromagnetic observations. We use theoretically motivated equations of state that comply with low-density nuclear experimental data and neutron-star mass measurements while allowing for the most general behavior at large densities, and are therefore able to directly constrain the neutron-star radius rather than the tidal polarizability. This alleviates the need of assuming a universal relation between $\tilde{\Lambda}$ and $R_{1.4\,\mathrm{M}_\odot}$, and allows us to explore the parameter space in the most self-consistent way. Furthermore, we have adopted conservative assumptions regarding the electromagnetic constraints, based on purely qualitative features of the electromagnetic counterparts. While quantitatively fitting these counterparts as in Coughlin et al. [2] provides a promising avenue for future investigation, the uncertainties associated with such modeling are still poorly constrained. In this respect, it is unsurprising that the lower limit on $R_{1.4\,\mathrm{M}_\odot}$ we obtain here (and which is governed primarily by the electromagnetic constraint) is lower than in these previous studies as we have made conservative assumptions. As a final note, we point out that our results are also consistent with early suggestions for a small neutron-star radius (≤ 12km) as a possible way to explain the 'blue' kilonova component of GW170817 [10].

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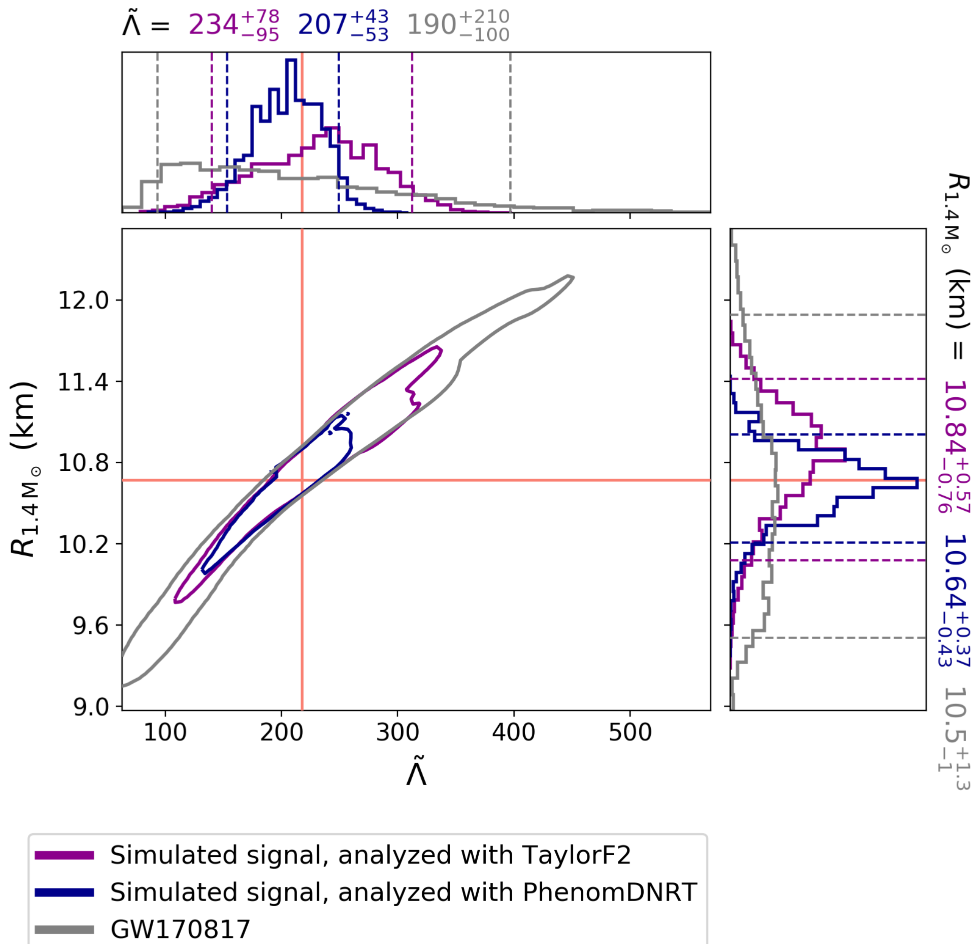

Supplementary Figure 1. Posterior probability distribution of $R_{1.4\,\mathrm{M}_\odot}$ and $\tilde{\Lambda}$ for a simulated GW170817-like signal at a signal-to-noise ratio of ~ 100, compared to our gravitational-wave only analysis of GW170817. Solid red lines show the parameters of the simulated signal. The top and side panels show 1D marginal posterior distributions for the parameters, with the dashed lines showing the 5th and 95th percentiles. The titles quote the median $\pm$ the 95th and 5th percentile for each parameter. The contours show the 90% credible region of the 2D marginalized posterior. All of these analyses used the $2n_{\mathrm{sat}}$ prior for the equations of state.