Problematic systematics in neutron-star merger simulations

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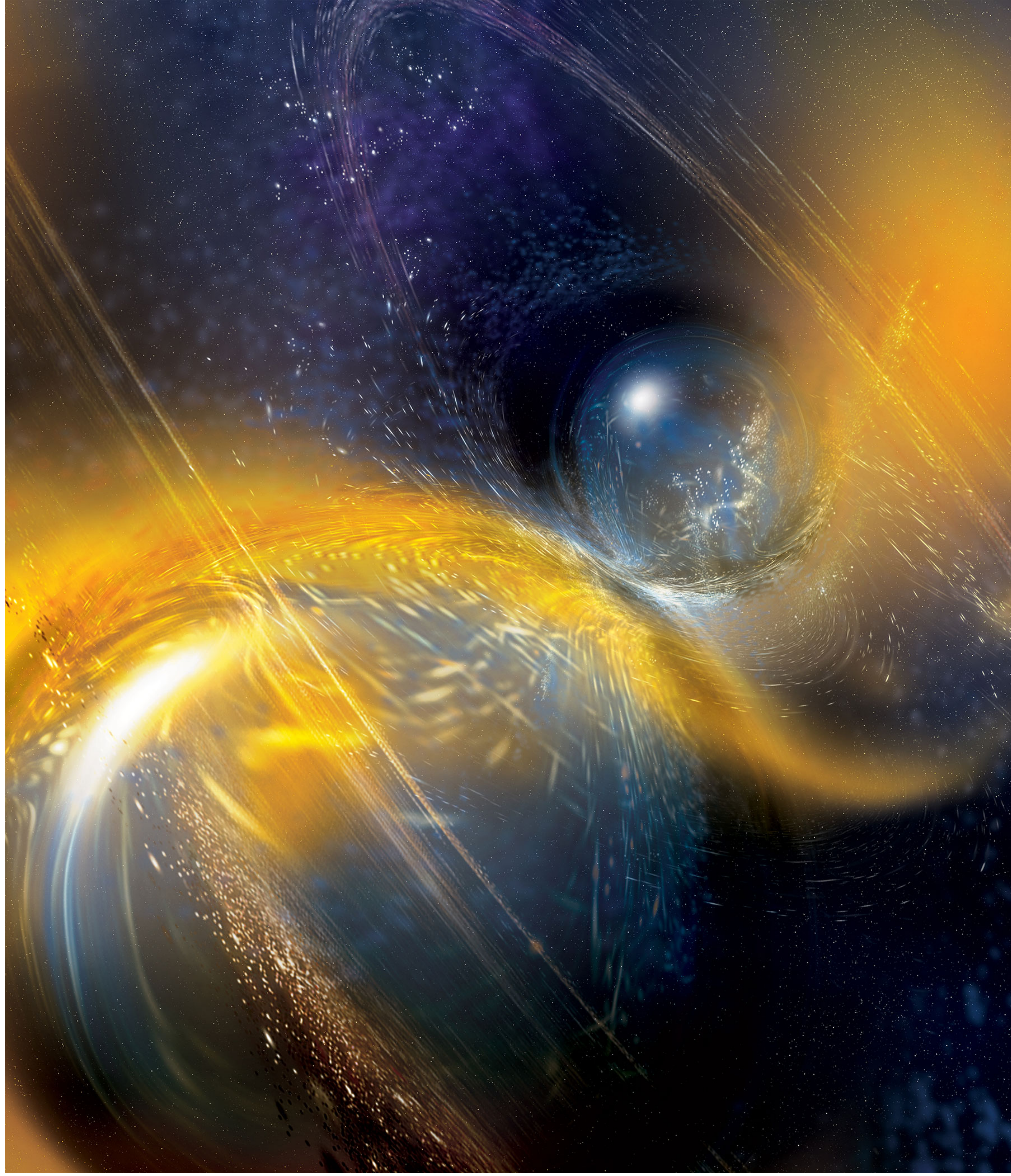

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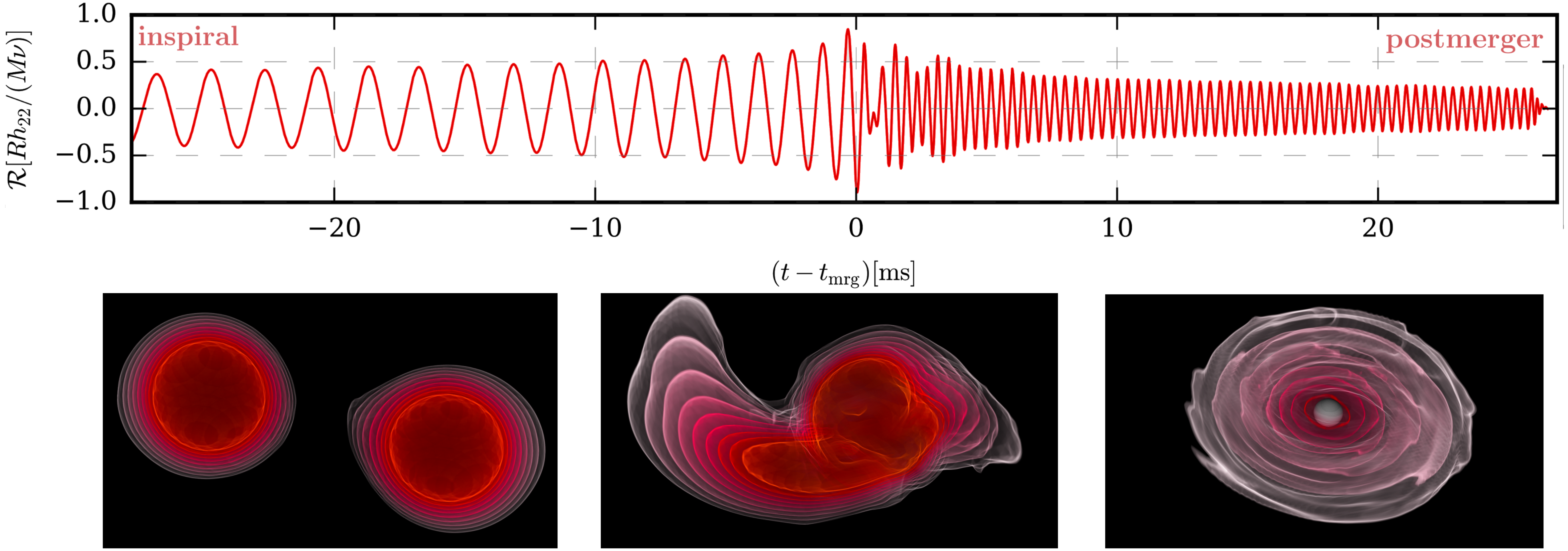
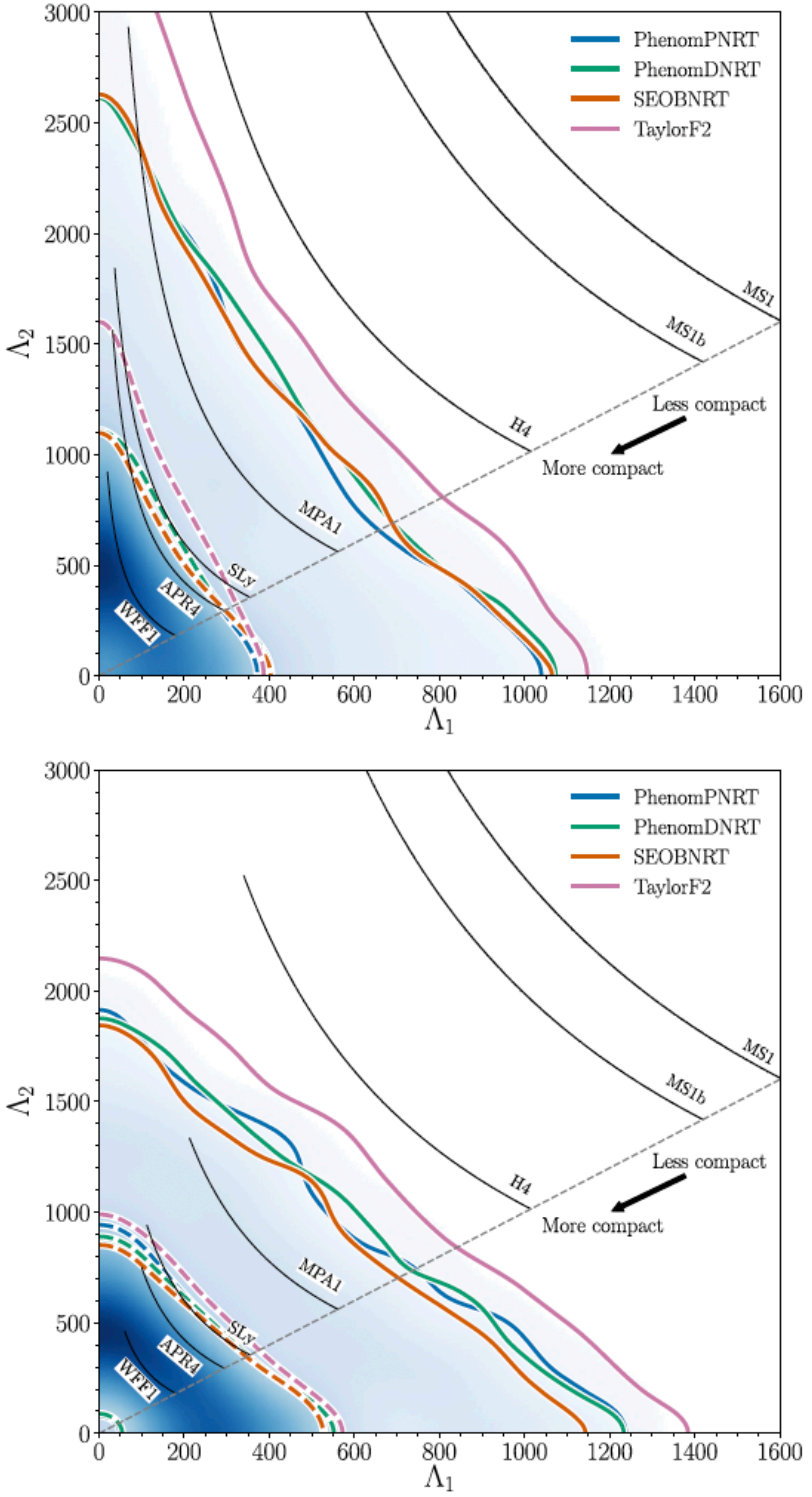
gravitational waves from neutron-star binaries



[Dietrich+, Gen. Relativ. Gravit. **53**, 27 (2021)]

- The gravitational waveform encodes fundamental properties about the binary.
- Taking measurements involve cross-correlating the strain data with theoretical waveform models.
- These models rely on matching post-Newtonian, inspiral waveforms to those generated from computationally expensive, numerical-relativity simulations.

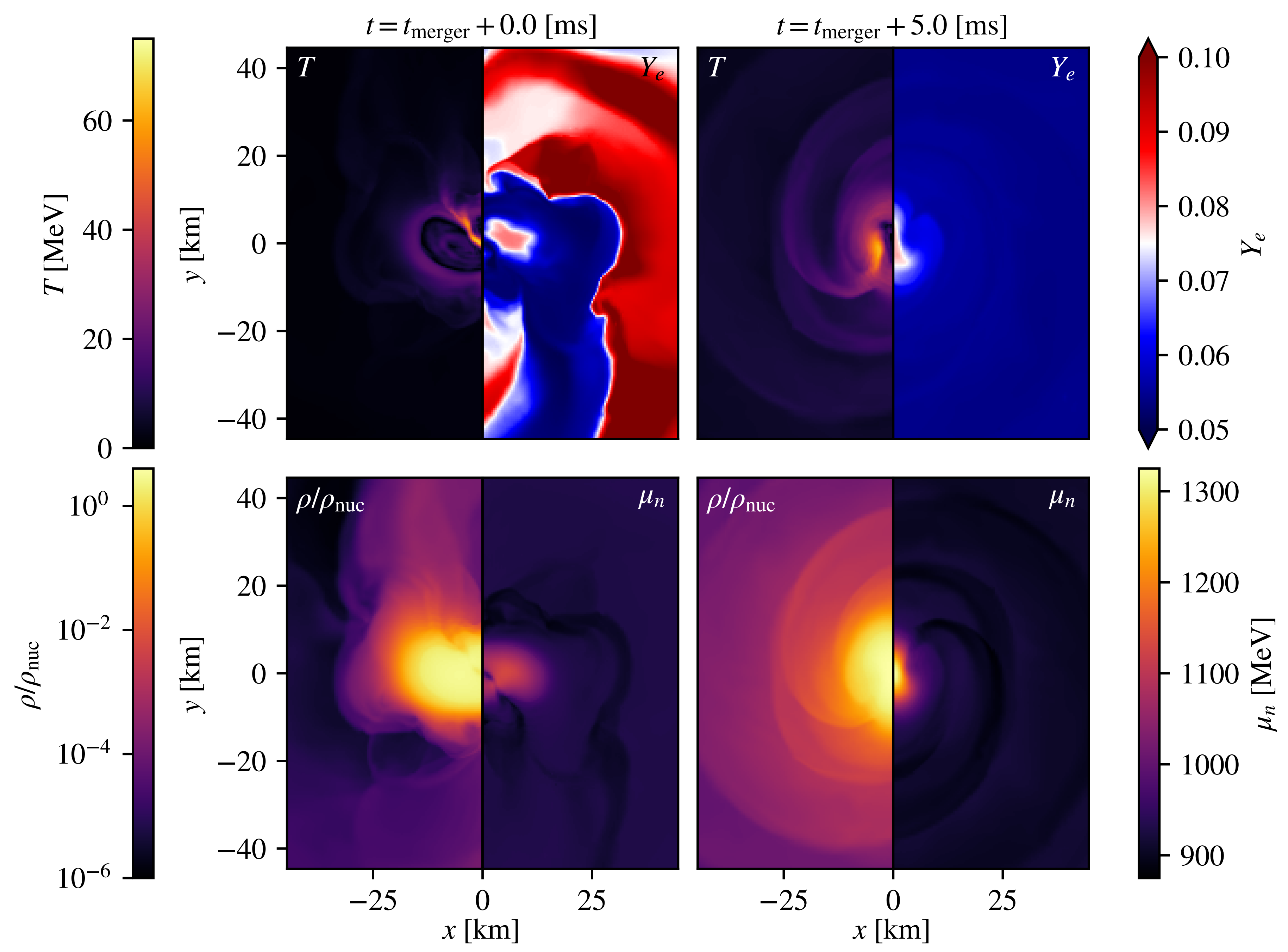


[Abbott+, Phys. Rev. X **9**, 011001 (2019)]

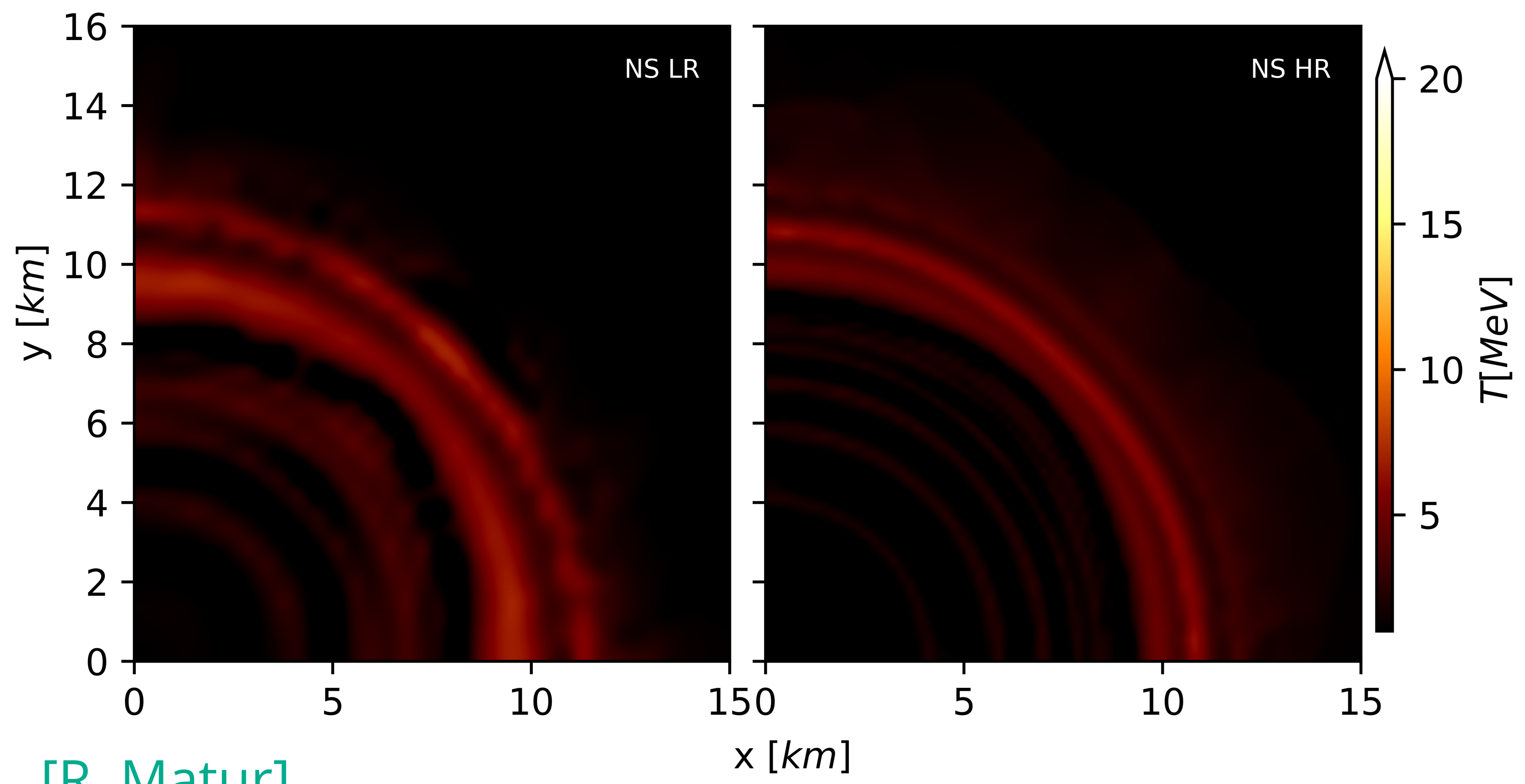
gravitational-wave observations

- Neutron-star matter effects are small, but cumulative—the phase gradually changes with many orbits.
- The leading-order contribution (the *static tide*) is accessible with current interferometers and was constrained with GW170817.
- Third-generation observatories—the Einstein Telescope and Cosmic Explorer—will possess even greater sensitivity to the *dynamical tide* than previously anticipated [Ho+Andersson, Phys. Rev. D **108**, 061104 (2023)].
- Neglecting these effects could introduce severe biases in equation-of-state inference [Pratten+, Phys. Rev. Lett. **129**, 081102 (2022)].

hot simulations



[Hammond+ (2021)]



[R. Matur]

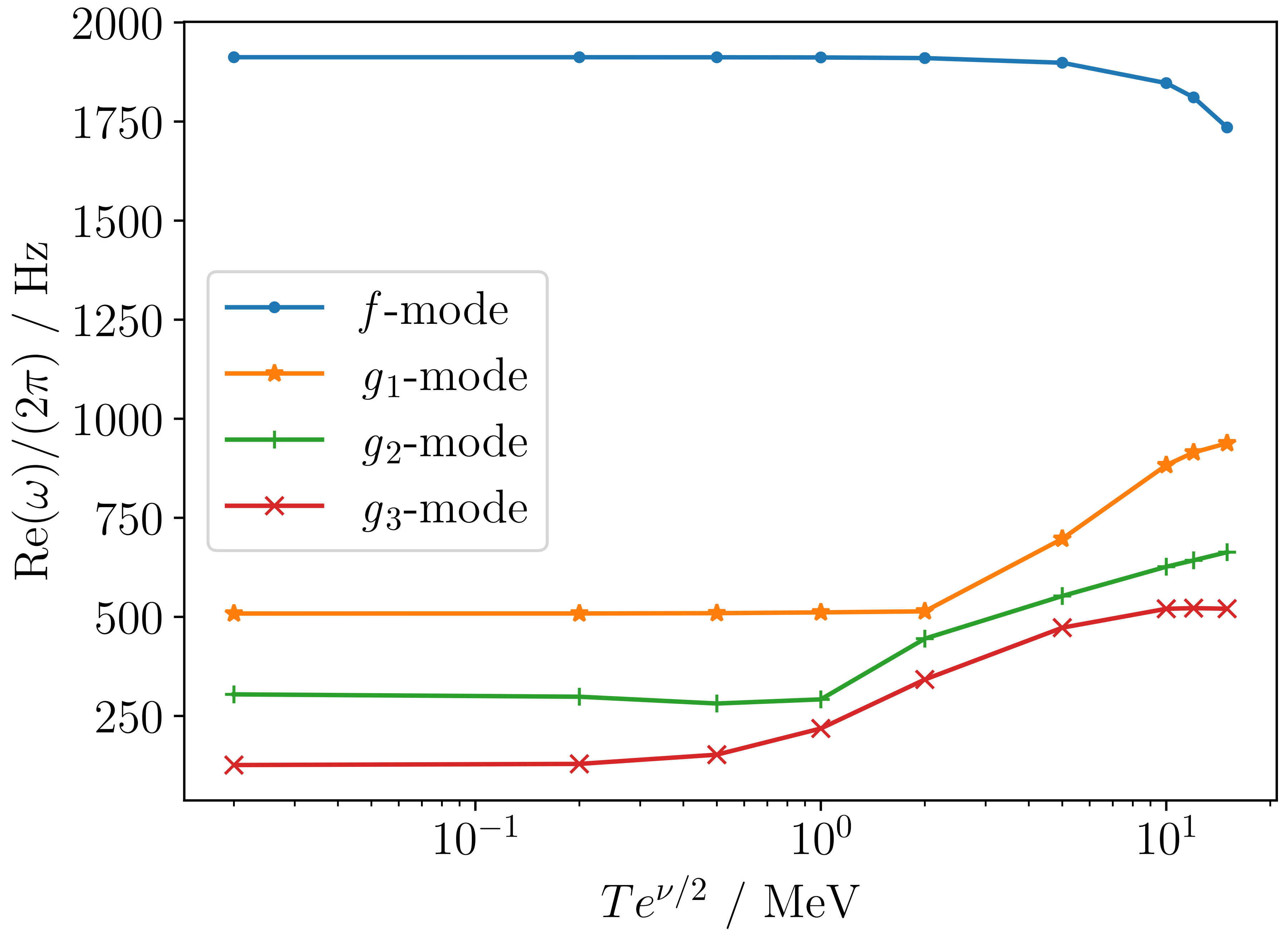
- Simulations of neutron-star mergers get very hot [Perego+, Eur. Phys. J. A **55**, 124 (2021); Endrizzi+, Eur. Phys. J. A **56**, 15 (2020); Prakash+, Phys. Rev. D **104**, 083029 (2021); Hammond+, Phys. Rev. D **104**, 103006 (2021)].
- Shock heating associated with the merger heats the matter up to extreme temperatures.
- During the inspiral, the stellar surface reaches order $10\,\mathrm{MeV} \approx 1.16 \times 10^{11}\ \mathrm{K}$. This leads to systematics already at the beginning of the simulations.*

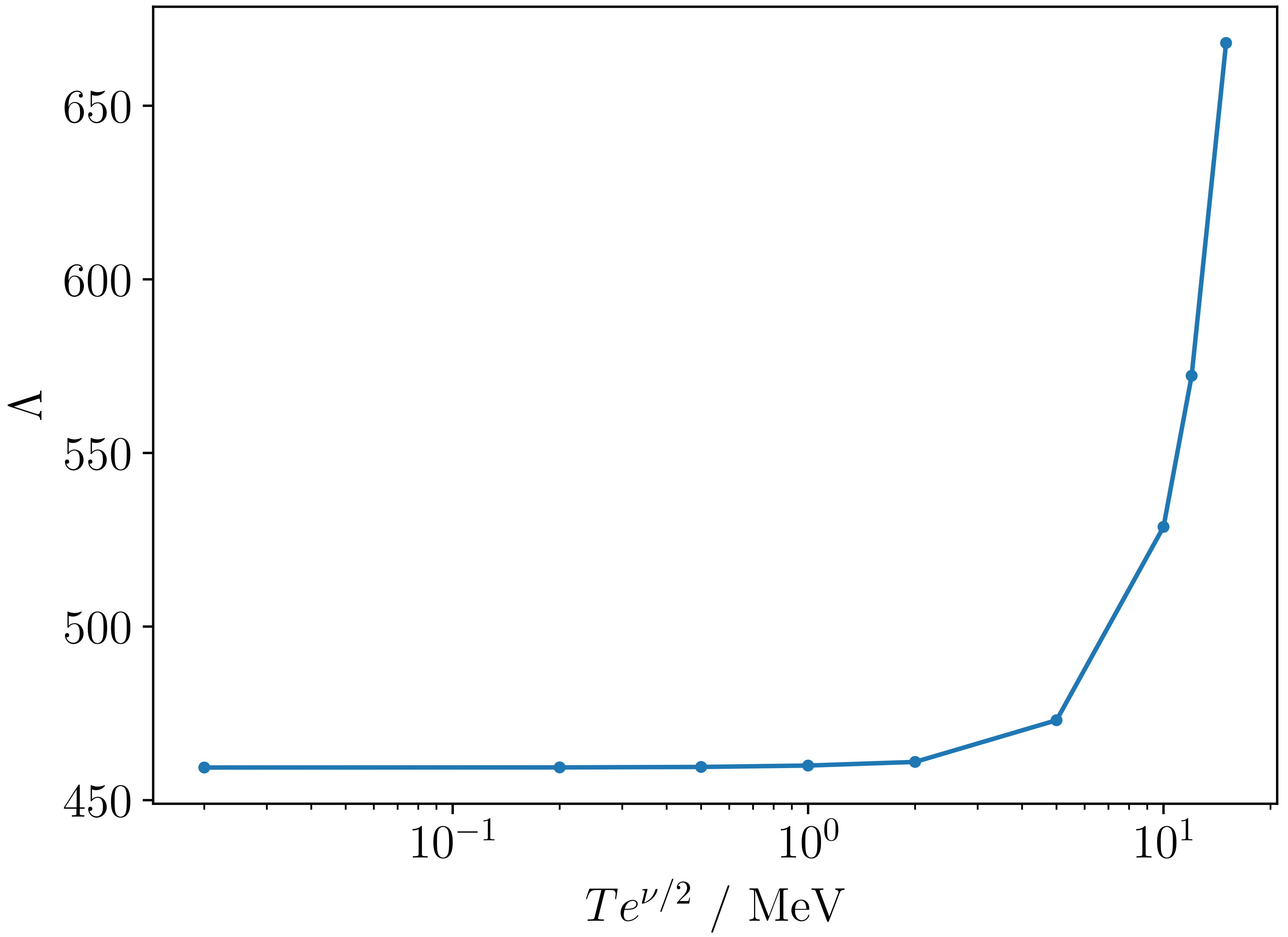
*Cf., mature neutron stars are $\sim 10^6\ \mathrm{K}$.

impact on the tidal dynamics

- To illustrate this effect, we compute the linear perturbations of a neutron star described by a three-parameter, nuclear-matter equation of state $f = f(T, n_b, Y_e)$.

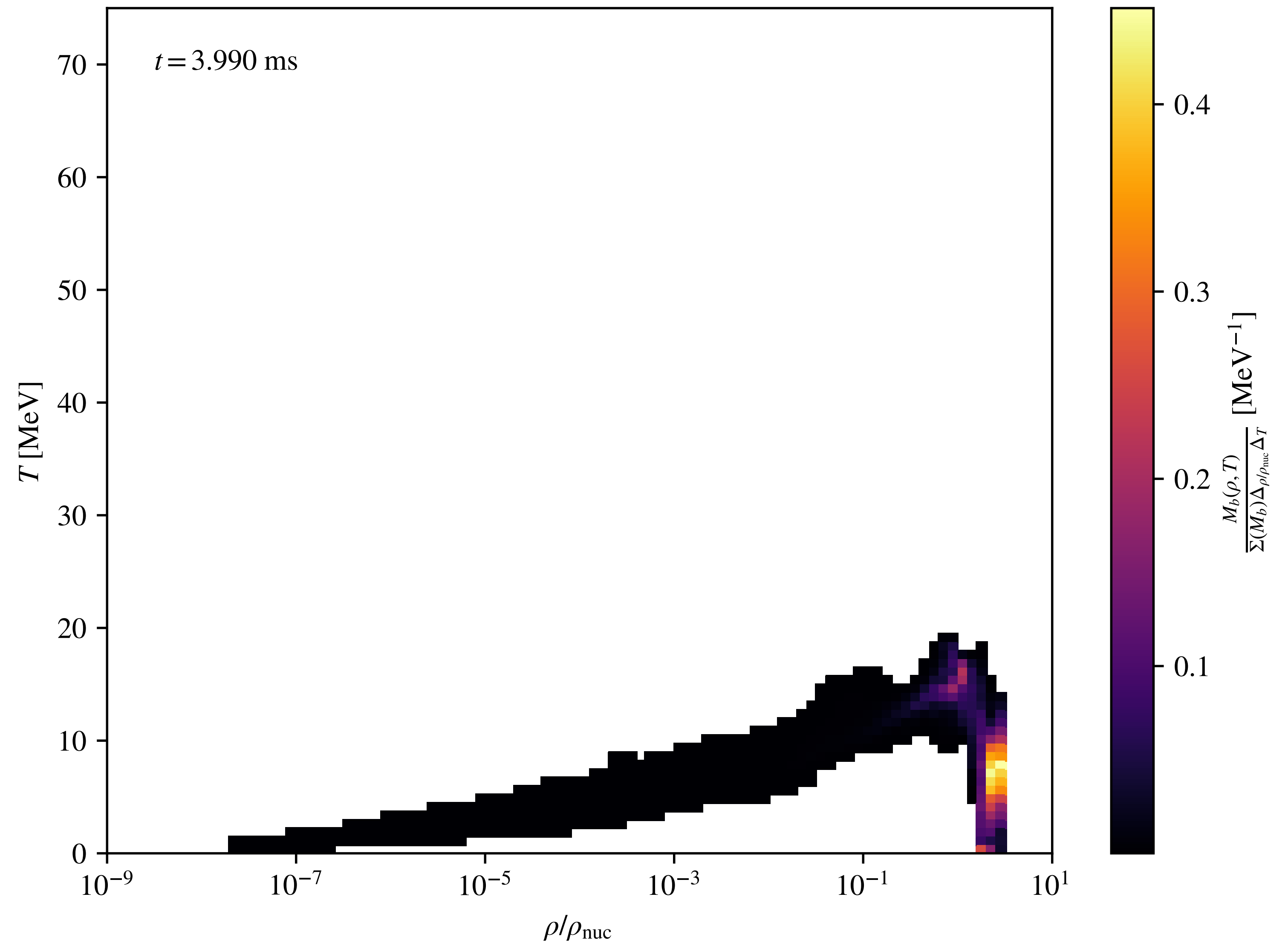
- We determine the oscillation modes of the star and its (static) quadrupolar tidal deformability. We assume that the neutron star has uniform redshifted temperature.





simulation temperatures

- We implement a temperature profile extracted from a numerical simulation of merging neutron stars [Hammond+ (2021)].
- In addition to distorting the oscillation spectrum, the tidal deformability ($\Lambda = 534.4$) changes by $16\,\%$ with respect to the colder star ($\Lambda = 459.4$).
- Therefore, we need to be very careful with systematic errors from simulations with this effect.



summary

- The Einstein Telescope and Cosmic Explorer will have enhanced sensitivities to neutron-star coalescences and may provide the first measurement of the dynamical tide.
- We have demonstrated how the artificial temperatures encountered in numerical-relativity simulations severely distort the oscillation spectrum and tidal deformability of the neutron star.
- We need to understand the systematics in order to conduct reliable parameter inference with future gravitational-wave detections.
- Look out for this work coming to the arXiv soon!