Investigating BNS merger remnants by effective-one-body method

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Outline

1. Background and Purpose
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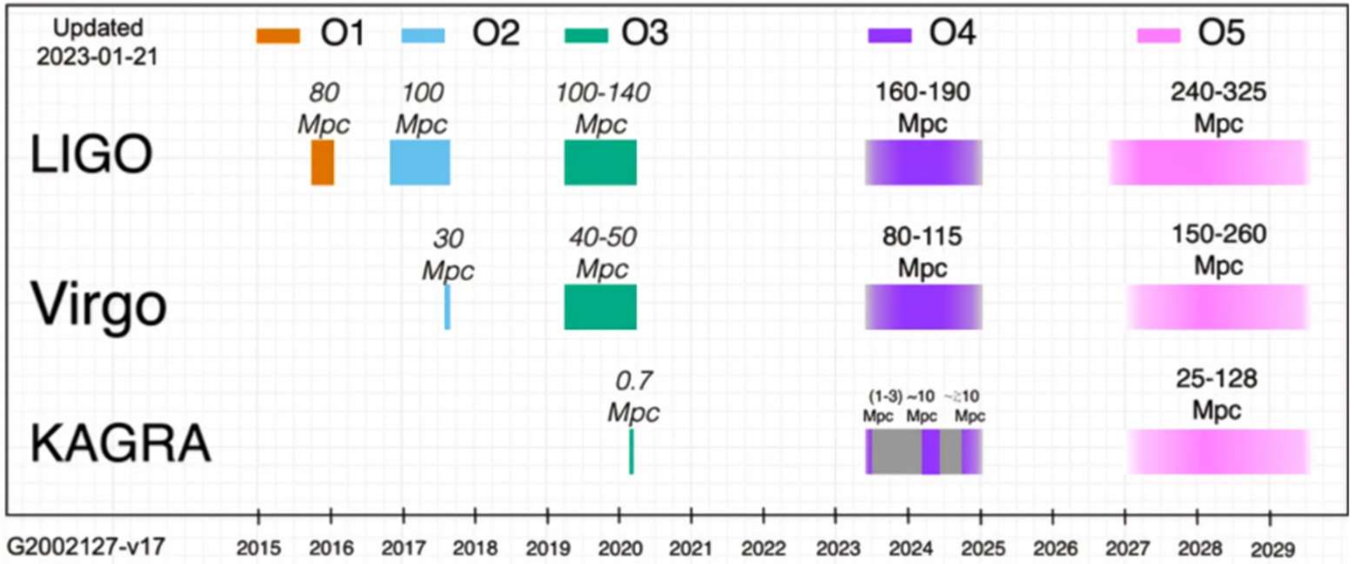
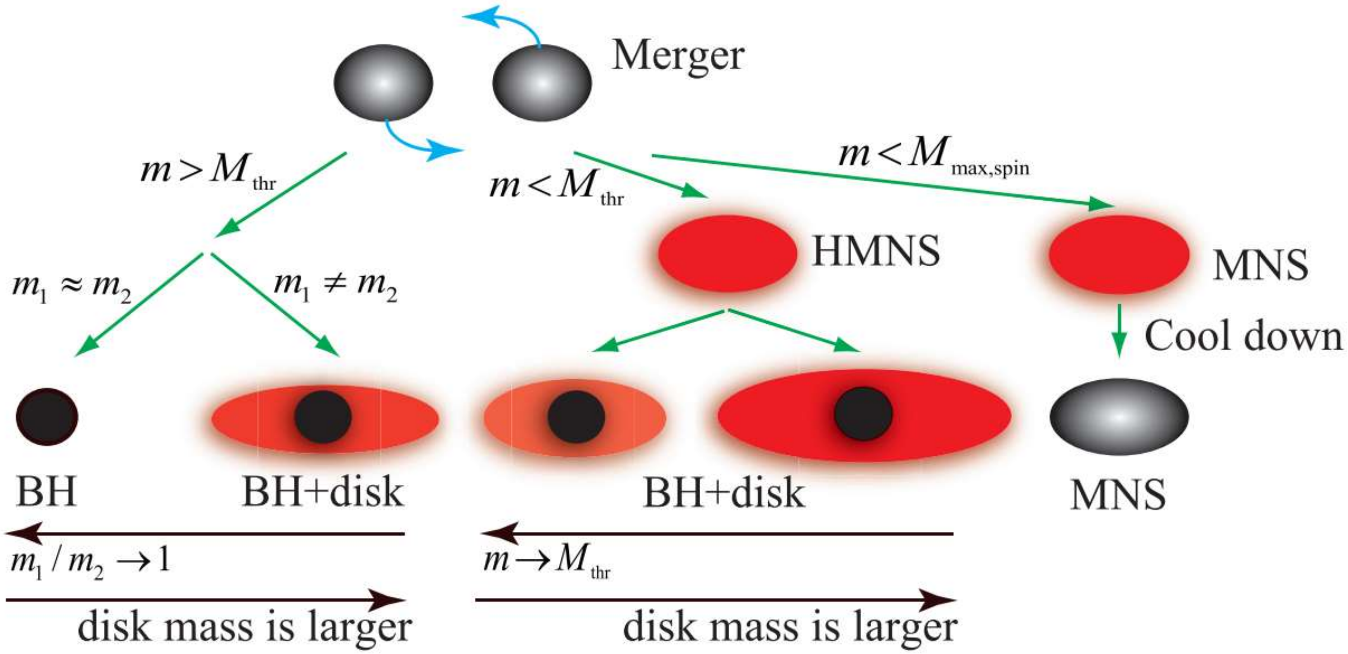
Background and Purpose



Source: https://www.ligo.caltech.edu/news/ligo20220123

With the sensitivity increase of current gravitational-wave detectors, observations of neutron star mergers will become routine in the very near future. This allows us to better constrain the equation of state for neutron stars.

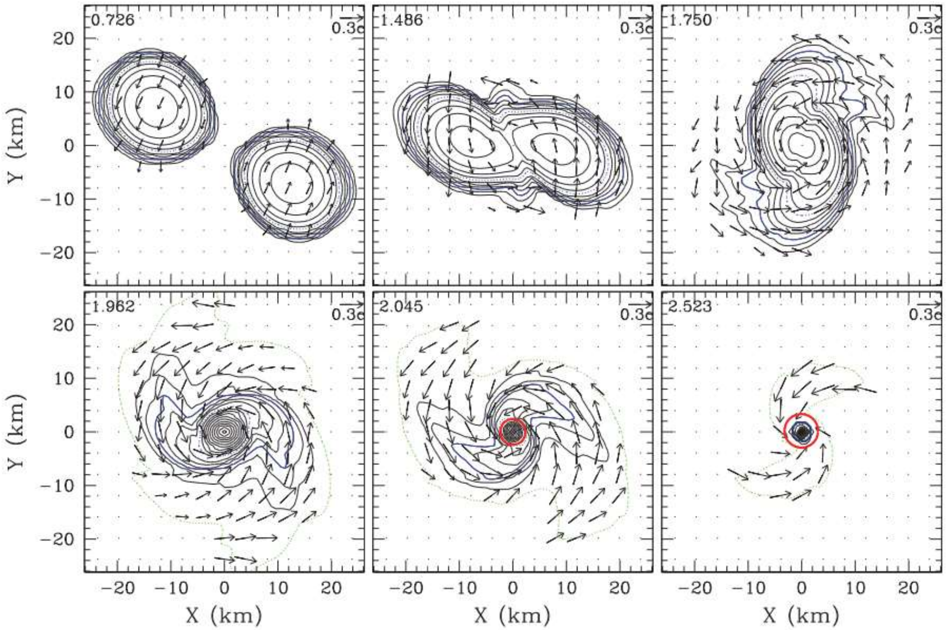
Background and Purpose



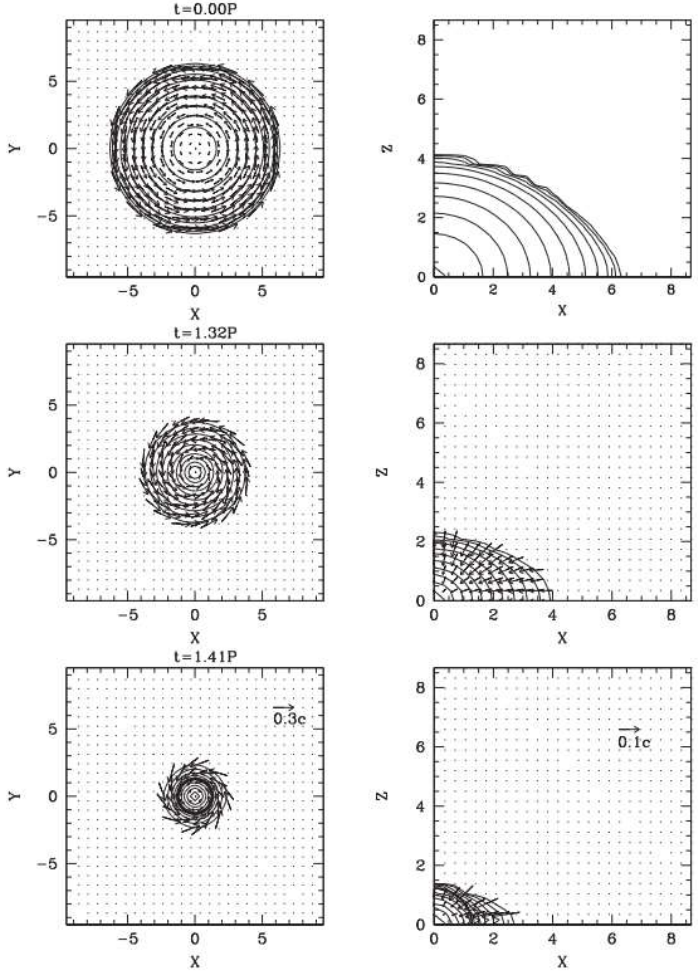
Masaru Shibata 2015

Threshold mass depends in a specific way on the incompletely known equation of state of neutron star matter. Therefore, understanding the equation of state dependence of the collapse behavior is crucial for constraints on unknown properties of neutron stars.

Background and Purpose



Masaru Shibata 2015



There have been a lot of studies on threshold mass. and the most accurate method is numerical simulation, but this method consumes a lot of computing power.

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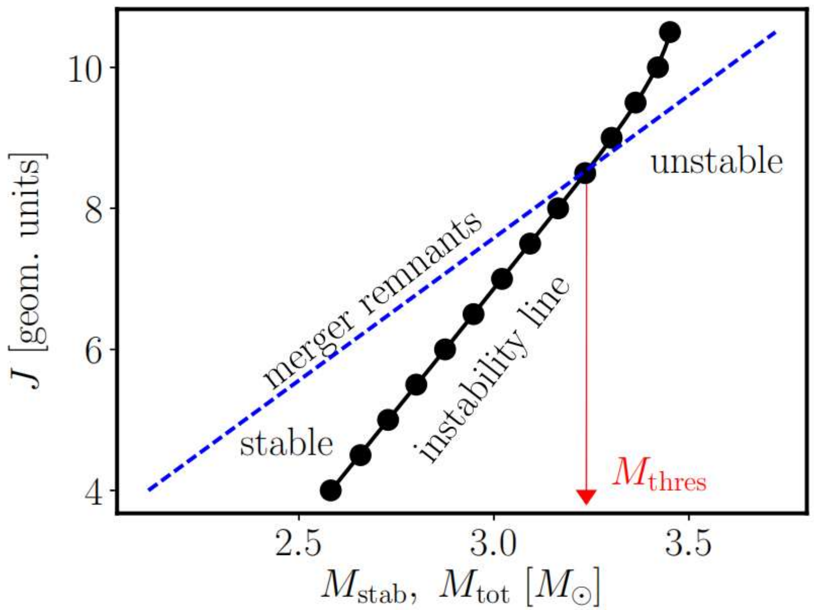

Andreas Bauswein, Nikolaos Stergioulas 2017

It has been shown that the threshold mass can be obtained by comparing the mass-angular momentum relation of the merger remnants with the maximum stable mass-angular momentum relation of the differential rotation models, i.e. the intersection of the solid and dashed lines. However, the mass-angular momentum relation of the merger remnant is described by the empirical relation without considering its dependence on the equation of state. We hope to solve this problem by using the EOB approach.

Effective-one-body approach

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Effective one-body approach to general relativistic two-body dynamics

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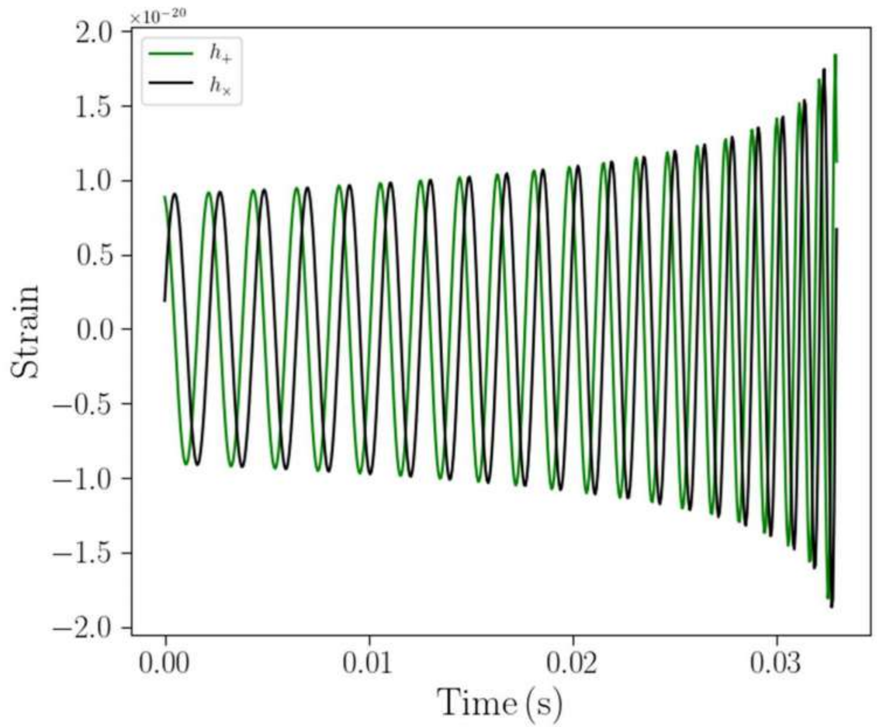
(Received 30 November 1998; published 8 March 1999)

A. Buonanno & T. Damour 1999

The EOB approach is an effective method to calculate the two-body dynamics in general relativity, with high computational efficiency and accuracy, and is the LIGO method to calculate the gravitational wave template.

Generating GW waveforms by EOB



We use TEOBResumS approach to generate the gravitational wave waveform of the merger of two neutron stars.

Energy and angular momentum carried by GW

In the TT gauge, and in a locally inertial frame, the Isaacson stress-energy tensor is given by:

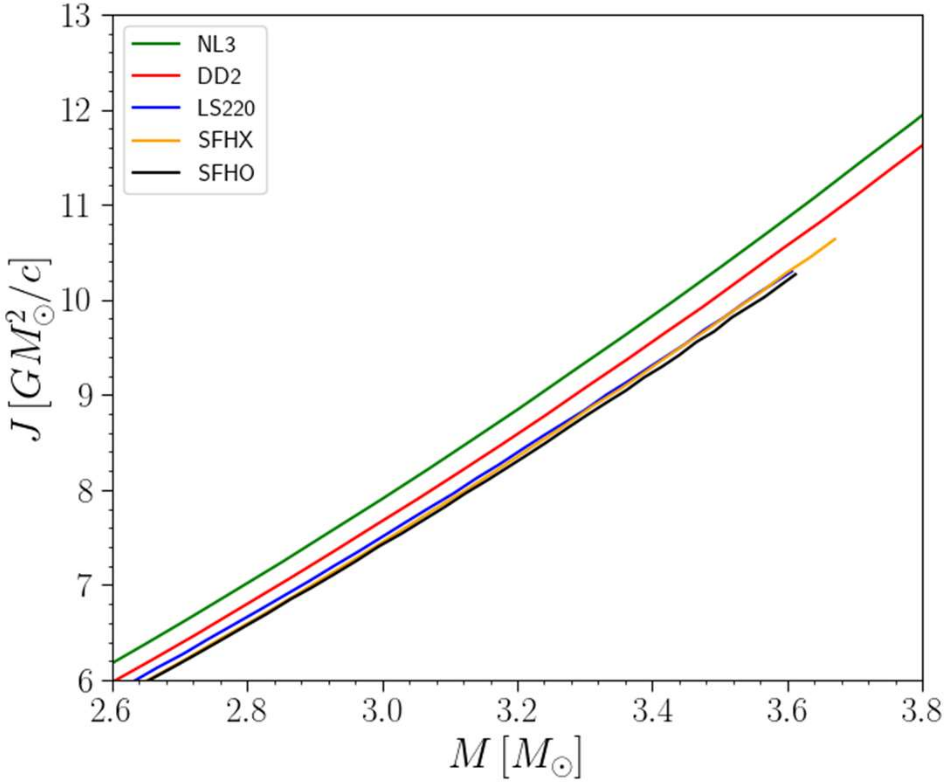
$$T_{\mu\nu} = \frac{1}{32\pi}\left\langle \partial_\mu h_{ij}^{TT}\, \partial_\nu h_{ij}^{TT} \right\rangle,$$

Energy and angular momentum carried by GW is given by:

$$\frac{dE}{dt} = \lim_{r\to\infty} \frac{r^2}{16\pi} \int \left|\dot{H}\right|^2 d\Omega,$$

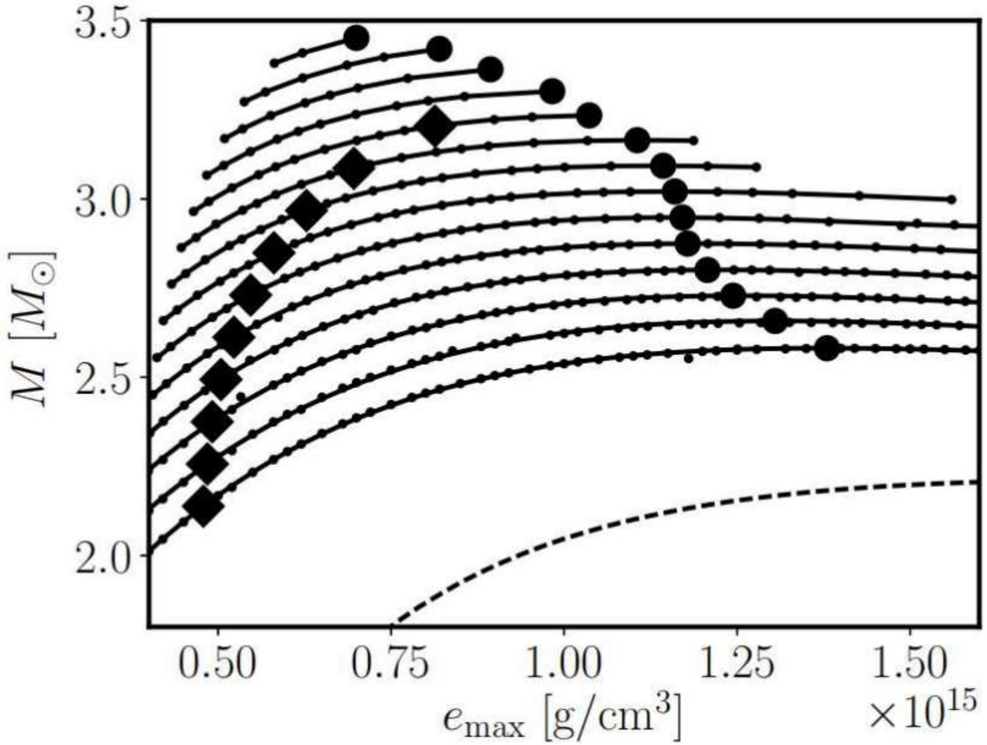
$$\frac{dJ_i}{dt} = -\lim_{r\to\infty} \frac{r^2}{32} \int \left(\mathcal{L}_{\zeta_i} h_{ab} \right) \partial_t h^{ab}\, d\Omega.$$

Mass-angular momentum relation of the merger remnant



The mass-angular momentum relation of the merger remnant can be obtained by subtracting the energy and angular momentum carried by the gravitational wave from initial data.

Differentially rotating equilibrium models



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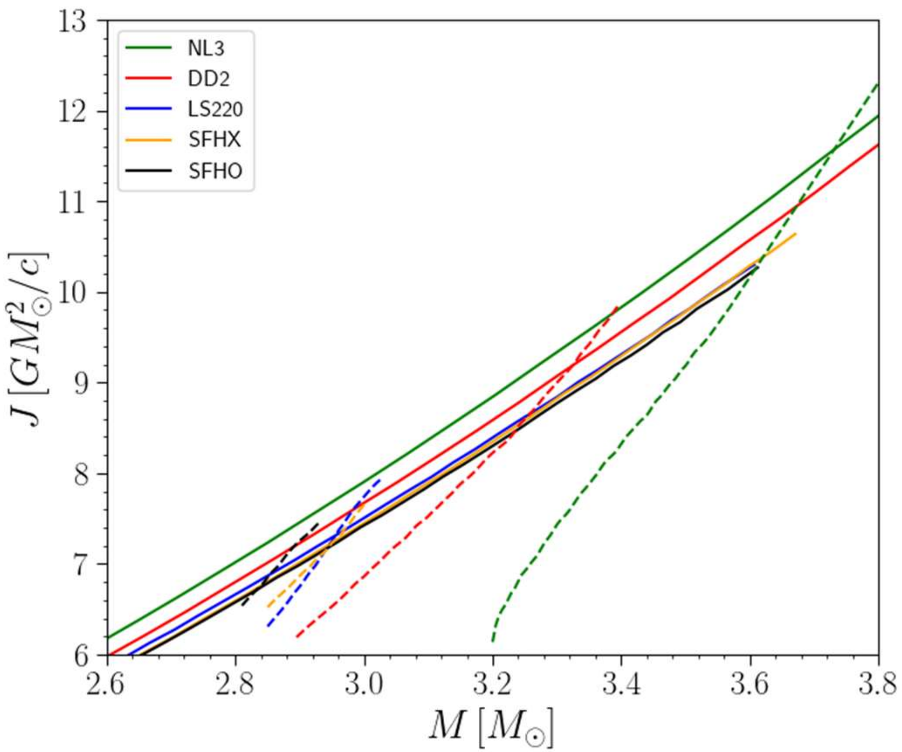
We use the RNS code to construct axisymmetric equilibrium models of differentially rotating NSs, varying systematically the central energy density and polar to equatorial axis ratio, which are the parameters to be specified for obtaining a stellar configuration.

The threshold mass of NSs



The threshold mass can be obtained by comparing the mass-angular momentum relation of the merger remnants with the maximum stable mass-angular momentum relation of the differential rotation models, i.e. the intersection of the solid and dashed lines.

Results

EOS	$M_{thres}^{analytic}(M_\odot)$	$M_{thres}^{sim}(M_\odot)$	$M_{thres}^{EOB}(M_\odot)$
NL3	3.58	3.775	3.731
DD2	3.24	3.325	3.325
LS220	2.94	2.975	2.956
SFHX	2.95	2.975	2.951
SFHO	2.86	2.875	2.834

As can be seen from the above table, the error of our method is about 1%, while the error of the semi-analytic method is about 2%-5%, so our method is more accurate.

Conclusion and Outlook

Advantages: Our method makes an effective way to calculate the threshold mass with rapid calculation and high accuracy, and the influence of spin and mass ratio on threshold mass can also be considered.

Disadvantages: Assuming stationarity and axisymmetry, neglecting thermal effects and assuming a simple rotation law.

Outlook: Because of its fast calculation and high precision, our method can be widely used in threshold mass calculation, and provide reference for numerical simulations.

Thanks!!!