NONLINEAR OSCILLATIONS IN MERGERS OF COMPACT OBJECT BINARIES

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Plan of Talk

- Motivation
- Simulations of binary neutron star mergers
- Linear and nonlinear oscillations of compact objects
- GW Asteroseismology
- Identification of oscillation modes in post-merger objects
- Prospects

Collaborators:

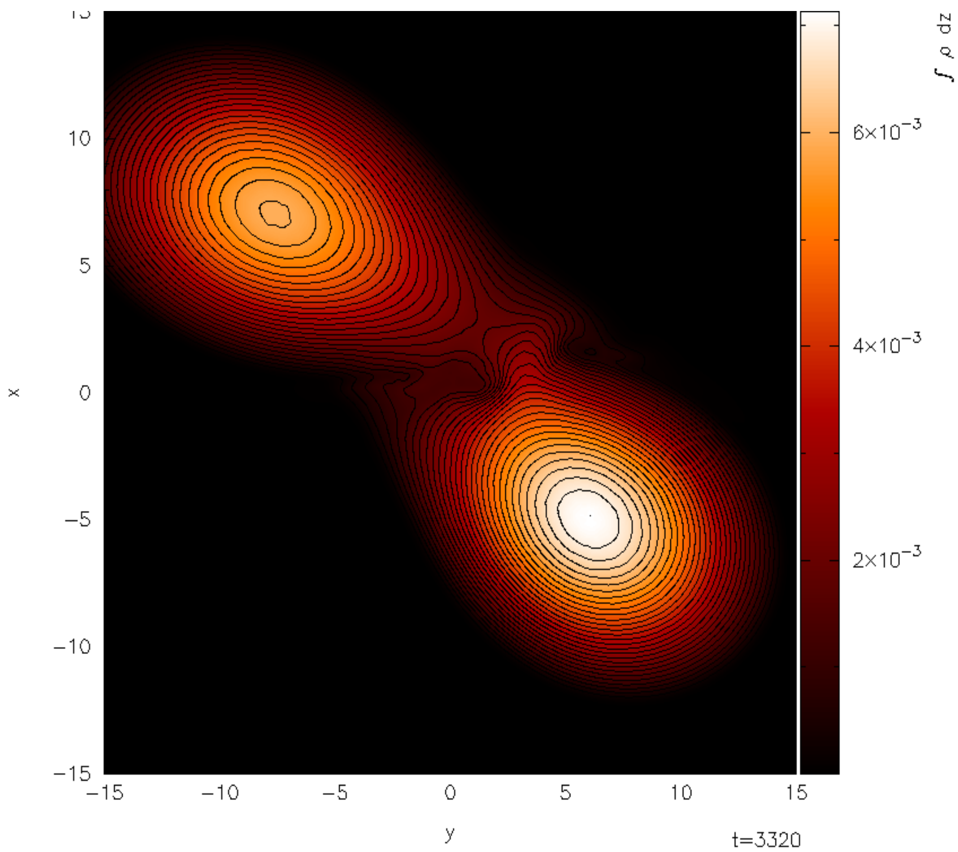
A. Bauswein, H.-T. Janka (MPA), K. Zagkouris (Oxford)

Publication:

Stergioulas, N., Bauswein, A., Zagkouris, K., Janka, H.-T., MNRAS (2011)

Motivation

Binary neutron star mergers are a *prime target* for the upcoming 2nd-generation gravitational-wave detectors (aLIGO, aVIRGO).



The outcome of the merger depends mainly on the two (unequal) *masses* and on the (largely unknown) *EOS* of hot, high-density matter.

Outcome of Binary NS Mergers

(Hotokezaka et al., 2011)
(Bauswein & Janka, 2012)

Most likely range of masses for binary system:

$$2.6 M_{sun} < M_{tot} < 2.9 M_{sun}$$

For EOSs that satisfy the observational constraint of

$$M_{max} > 2 M_{sun}$$

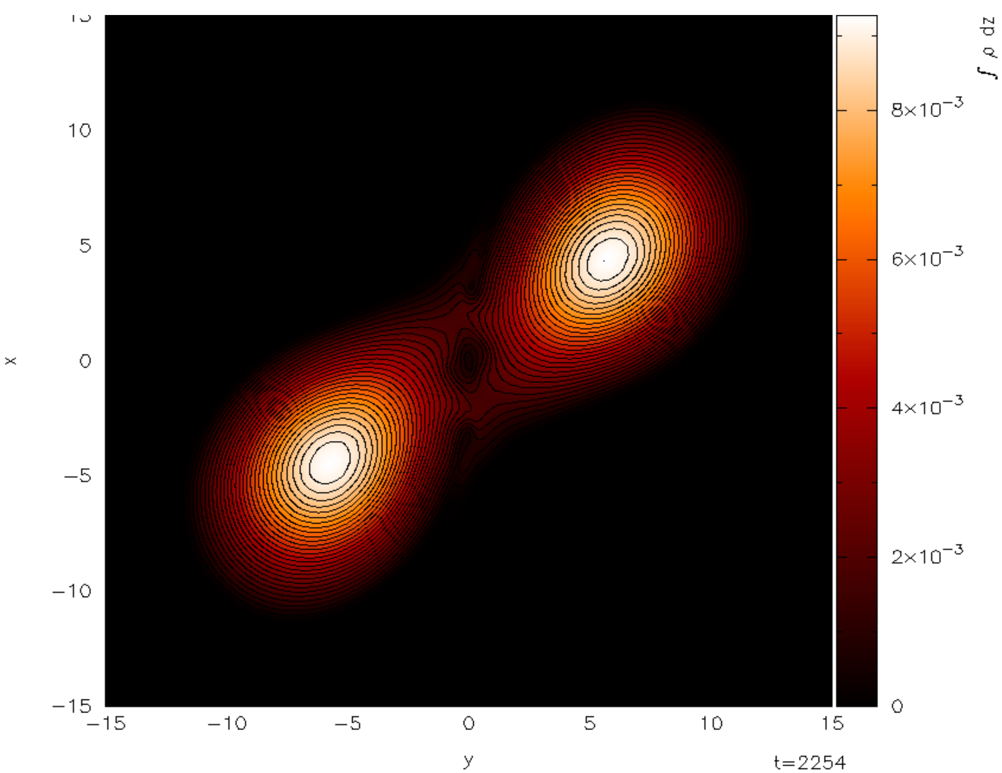
a long-lived ($\tau > 10$ms) remnant is formed.

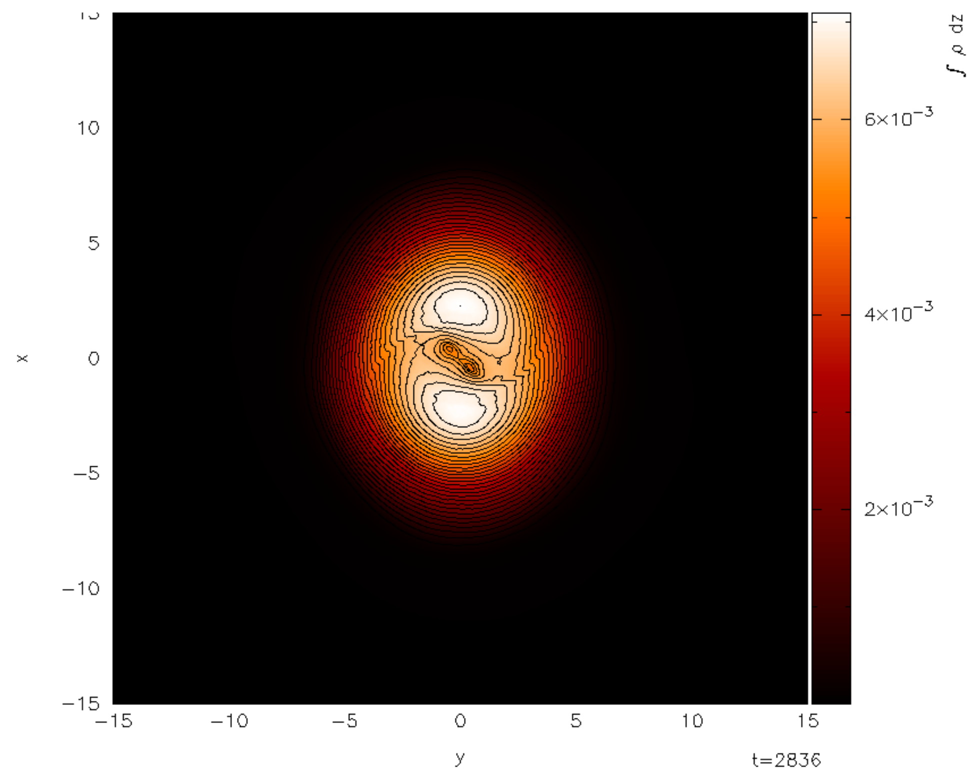
The remnant is a *hypermassive neutron star (HMNS)*, supported by *differential rotation*, with a mass larger than the maximum mass allowed for uniform rotation.

Mergers of Compact Object Binaries

NS, Bauswein, Zagkouris, Janka (2011)

Merger of equal/unequal mass binaries with *LS*, *Shen*, *MIT60* EOS. (3-D GR CFC/SPH code) Example: Shen EOS: $1.35M_{sun} + 1.35M_{sun}$

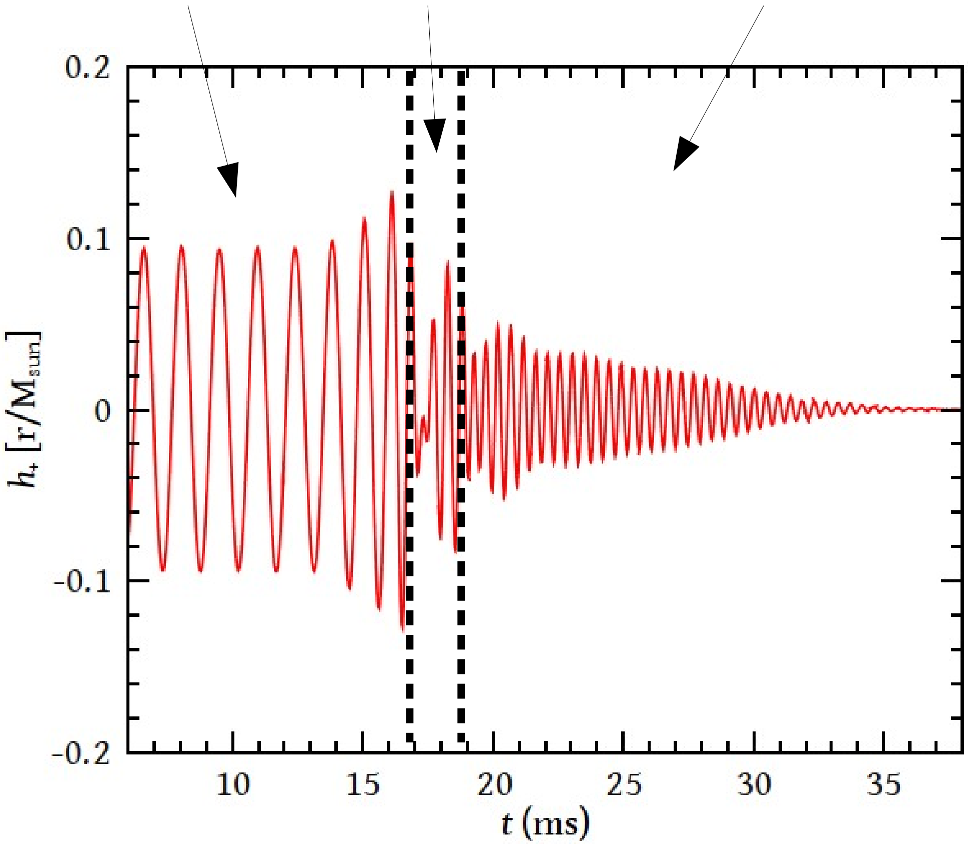


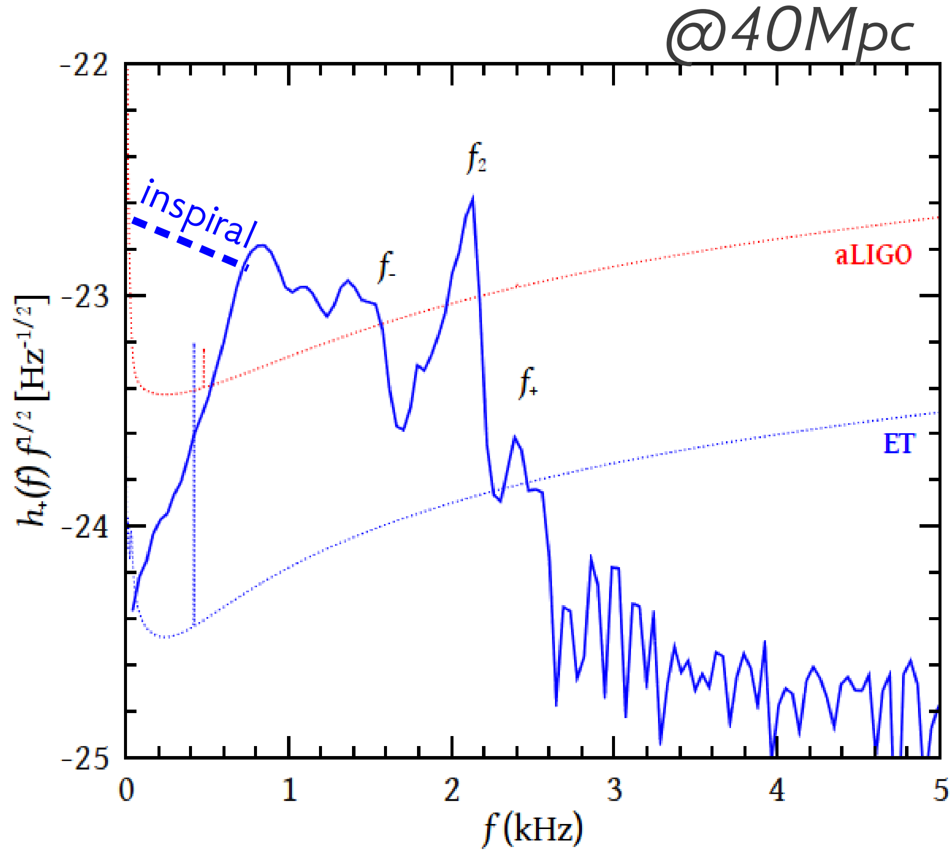


Rotating bar shape + radial oscillation → *transient double core*

Gravitational Waves

The GW signal can be divided into three distinct phases: *inspiral*, *merger* and *post-merger ringdown*.





Several peaks stand above the aLIGO/VIRGO or ET sensitivity curves and are potentially detectable. Are these *oscillations* of the HMNS?

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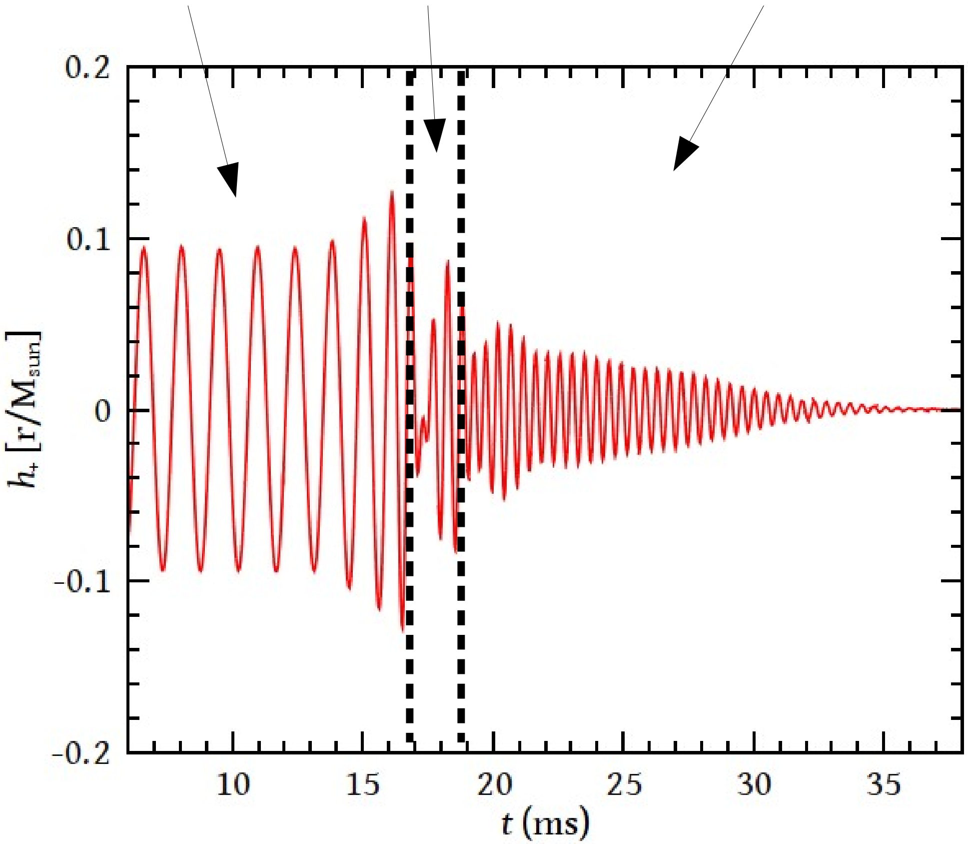

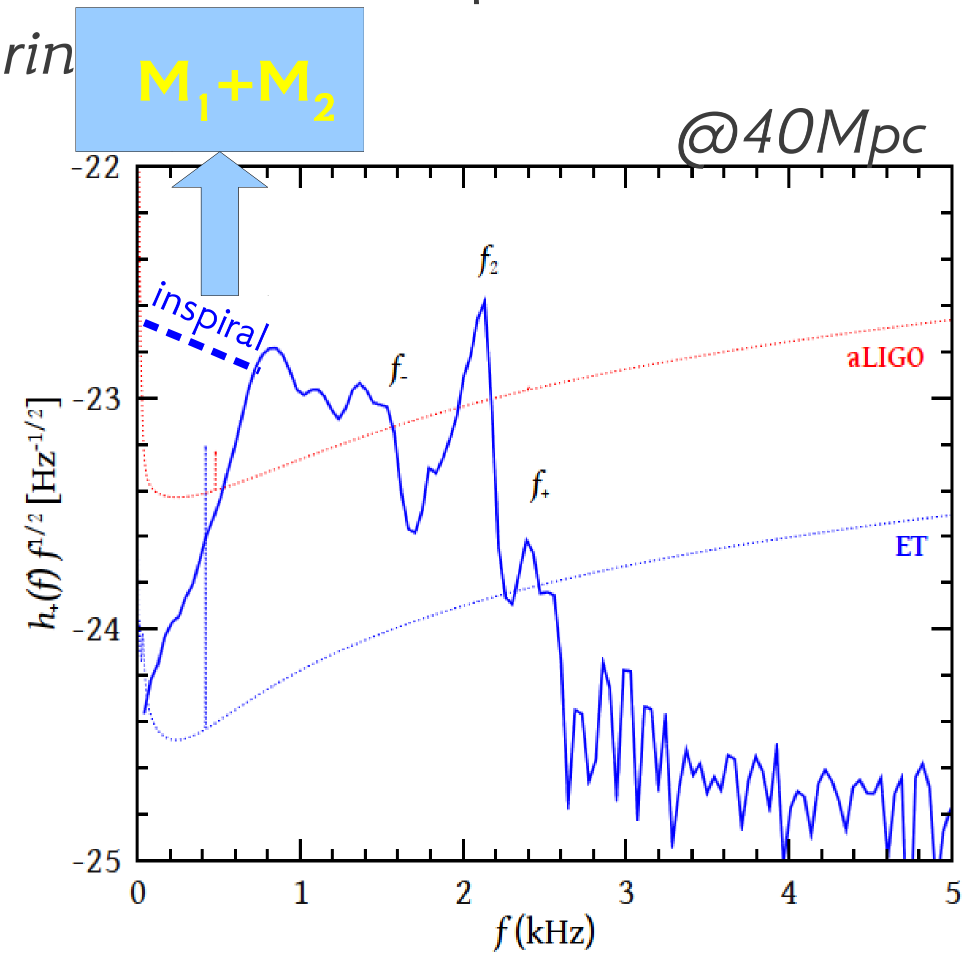

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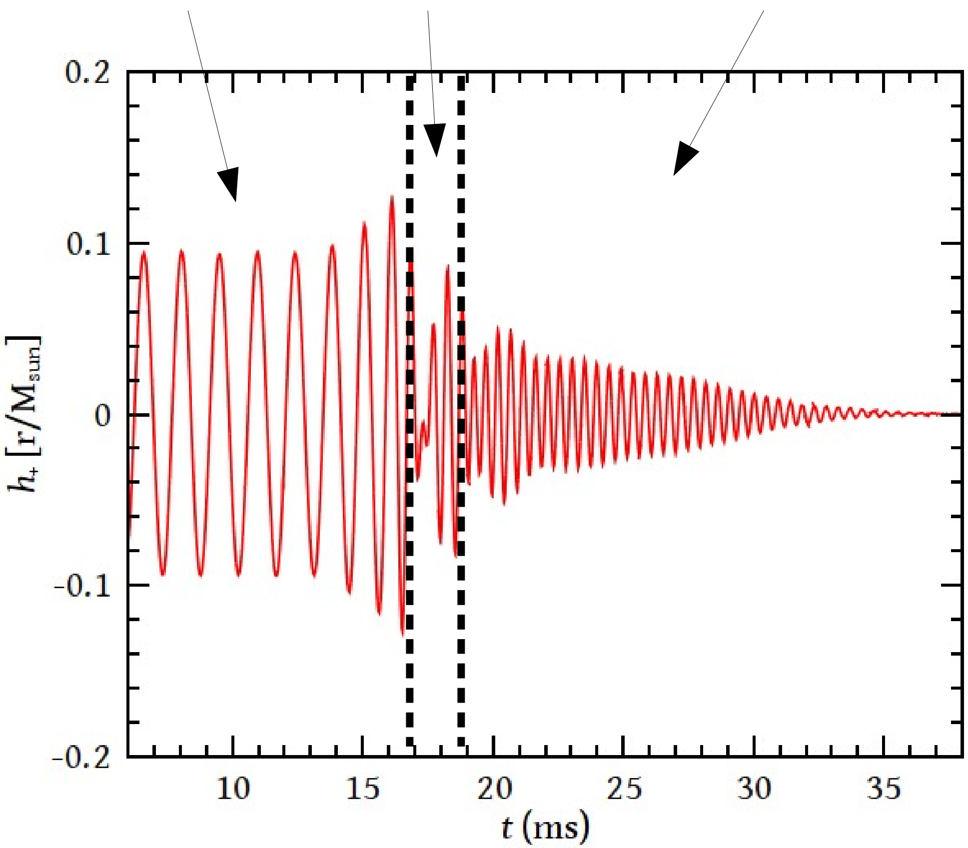

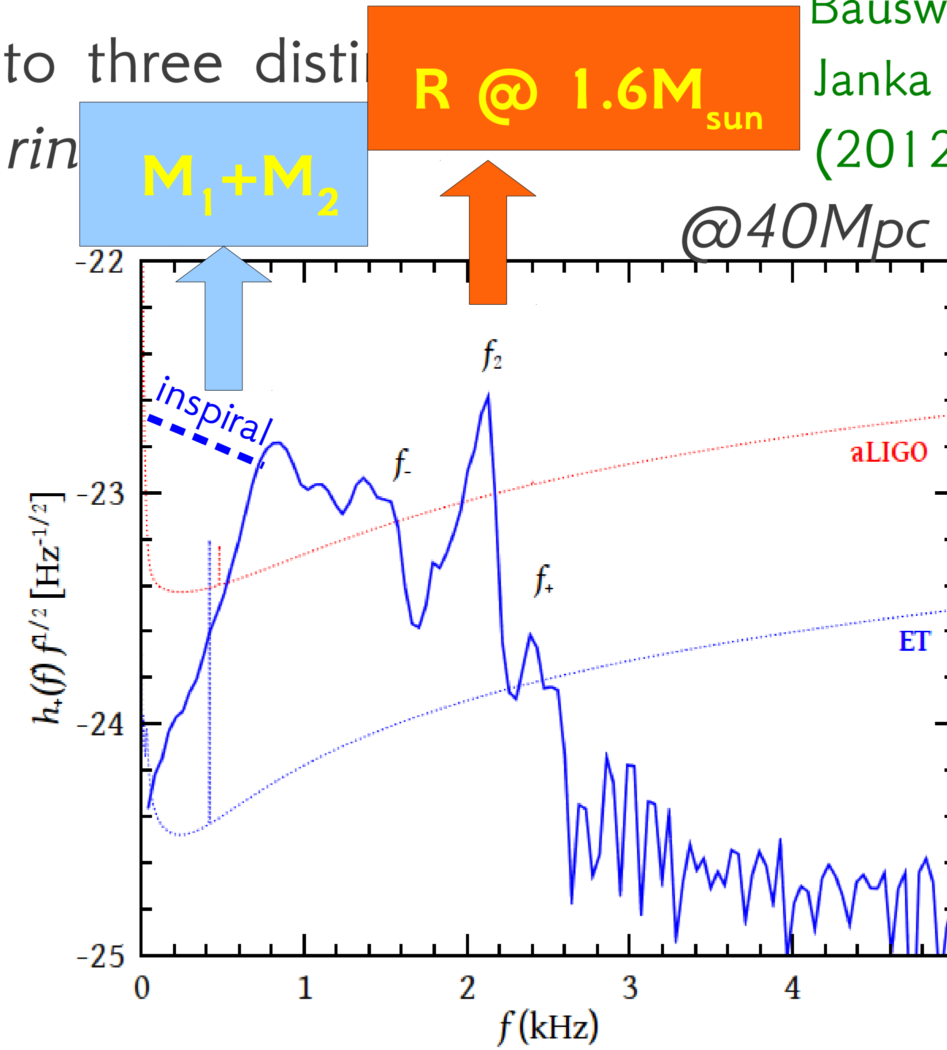

Bauswein Janka (2012)

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What is the parameter space?

For an isolated star, the mode-frequencies would depend on a large number of parameters:

1. Mass
2. EOS
3. Angular momentum
4. Rotational profile
5. Entropy profile

For a binary NS system, if one assumes that a) each NS is initially *slowly-rotating* and b) the binary system is *irrotational*, then the choice of Mass and EOS determines all other properties of the remnant!

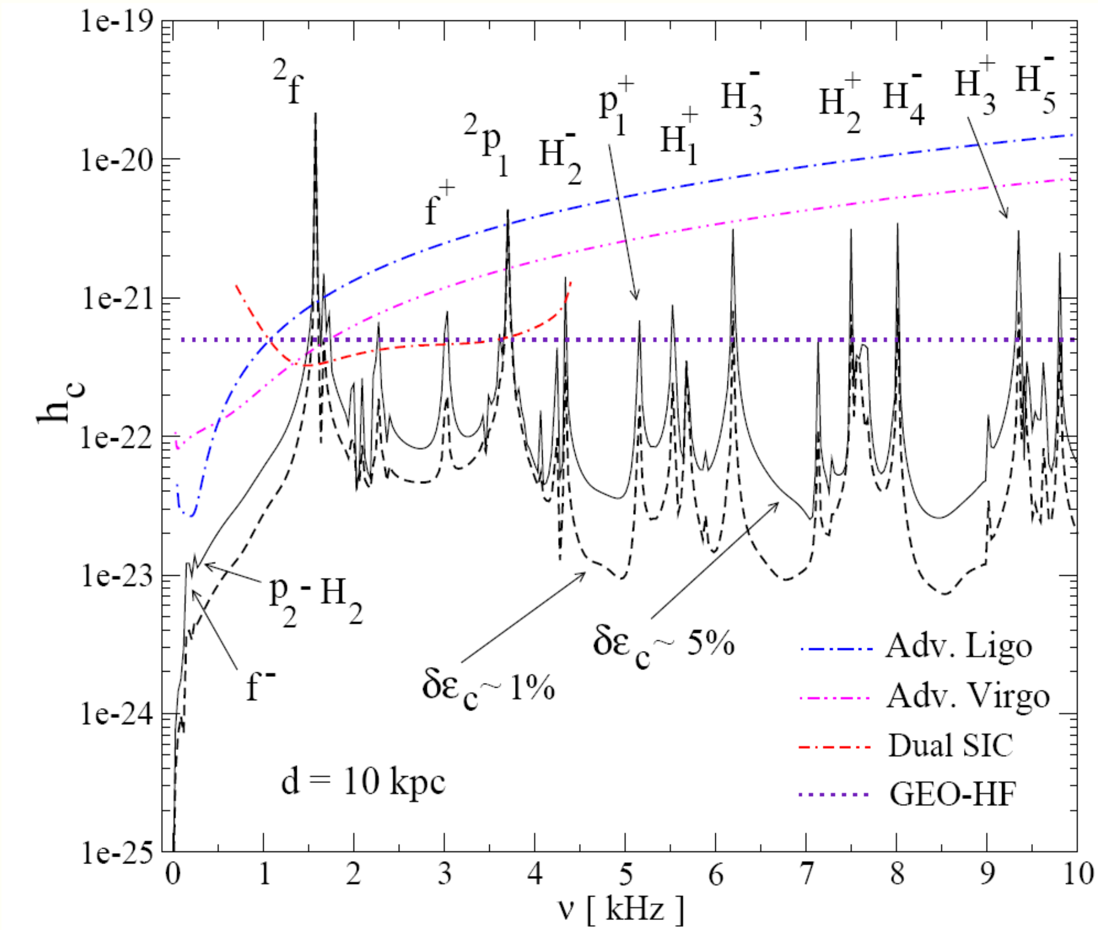
Therefore: Inspiral + f_2 frequency in merger phase → EOS (dependence on mass ratio is weak)

Nonlinear Combination Frequencies

Passamonti, NS & Nagar (007)

Linear sums and differences of linear mode frequencies

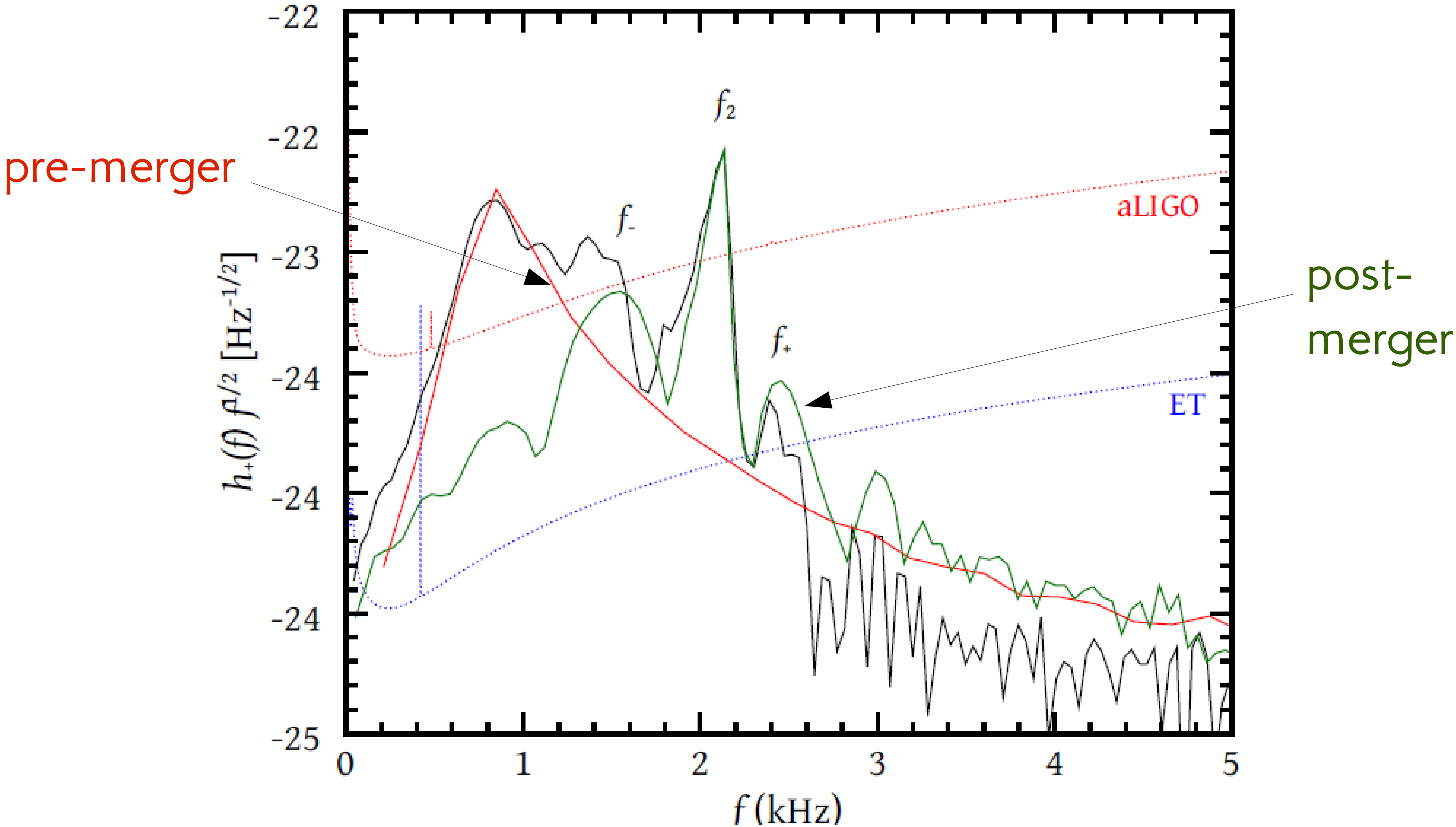
$$f^{\pm} = {}^2f \pm F \qquad p_n^{\pm} = {}^2p_n \pm F \qquad H_n^{\pm} = H_n \pm {}^2f$$



The amplitude of combination frequencies can become large, when the linear modes have amplitude of $O(1)$.

GW Scaled Power Spectral Density

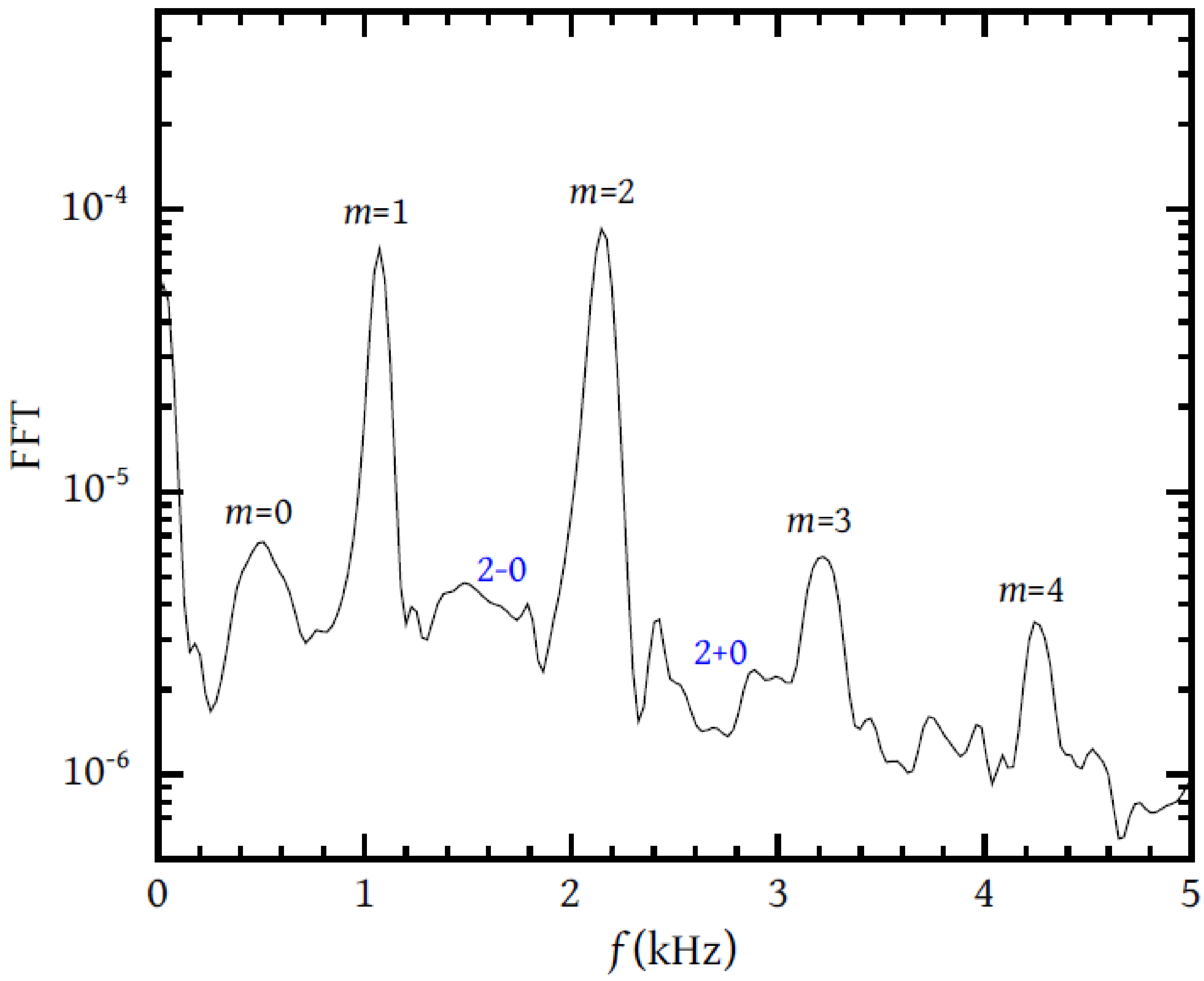
Split the time-series into *pre-merger* and *post-merger* parts:



Triplet of frequencies: f_-, f_2, f_+ *originates in post-merger part.*

FFT of Fluid Variables

For the same simulation, extract FFT of various fluid variables:

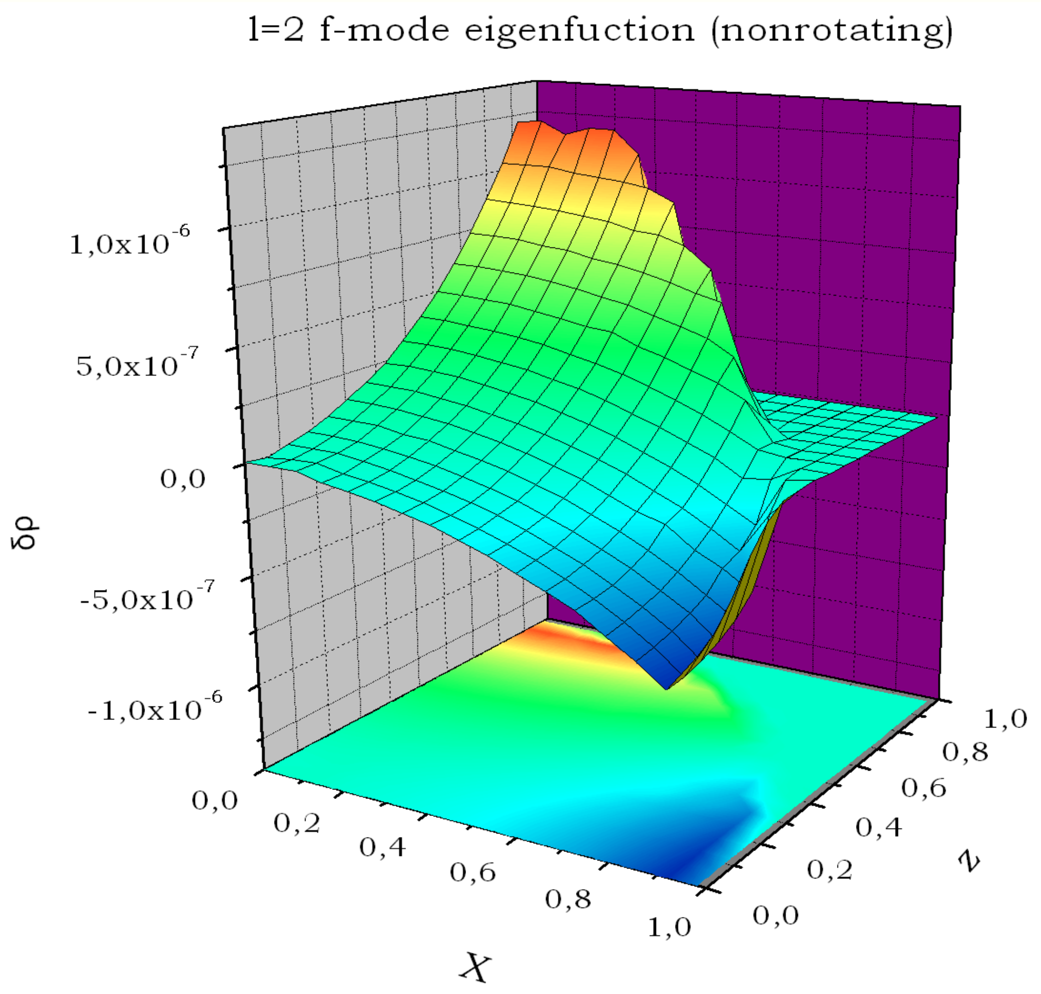


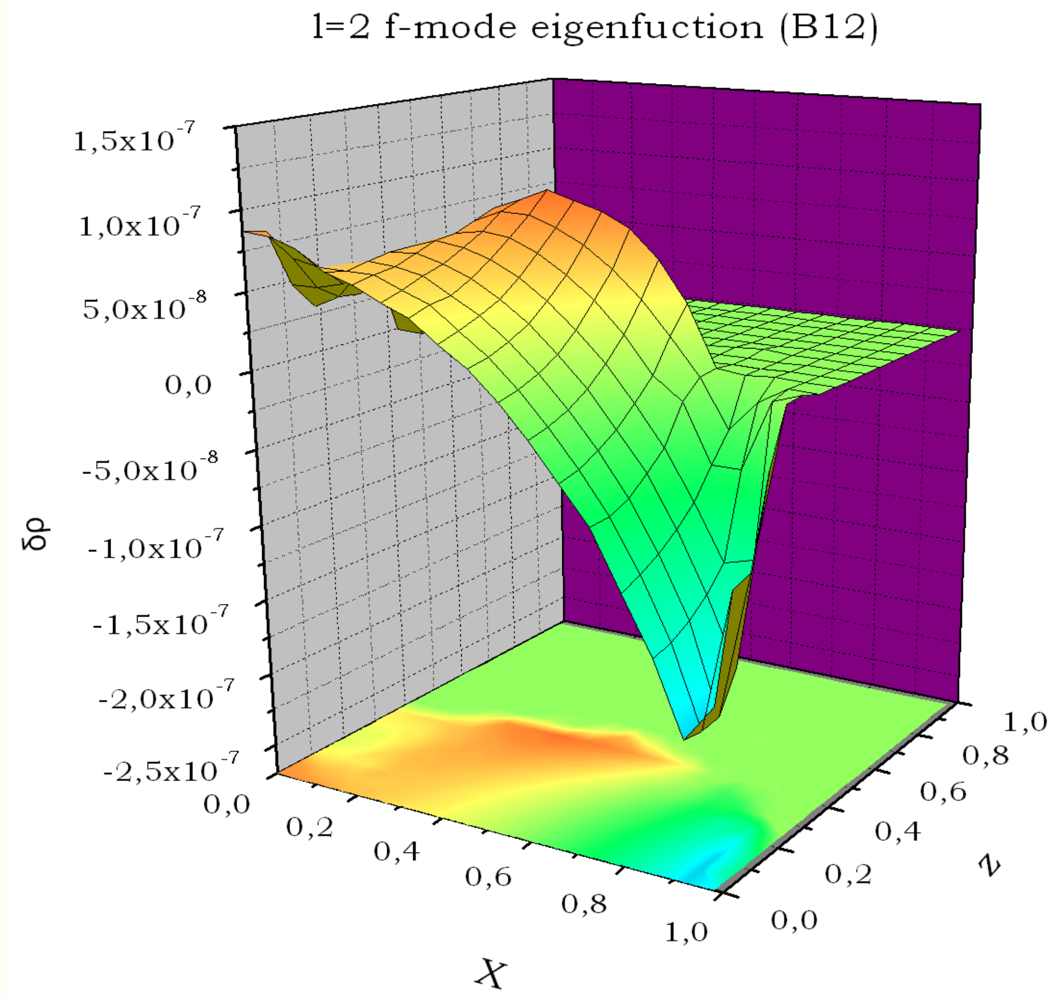
Several *linear mode frequencies* + *nonlinear combination frequencies*!

Eigenfunction Extraction

(NS, Apostolatos, Font, 2004)

Fourier extraction of axisymmetric mode eigenfunctions:

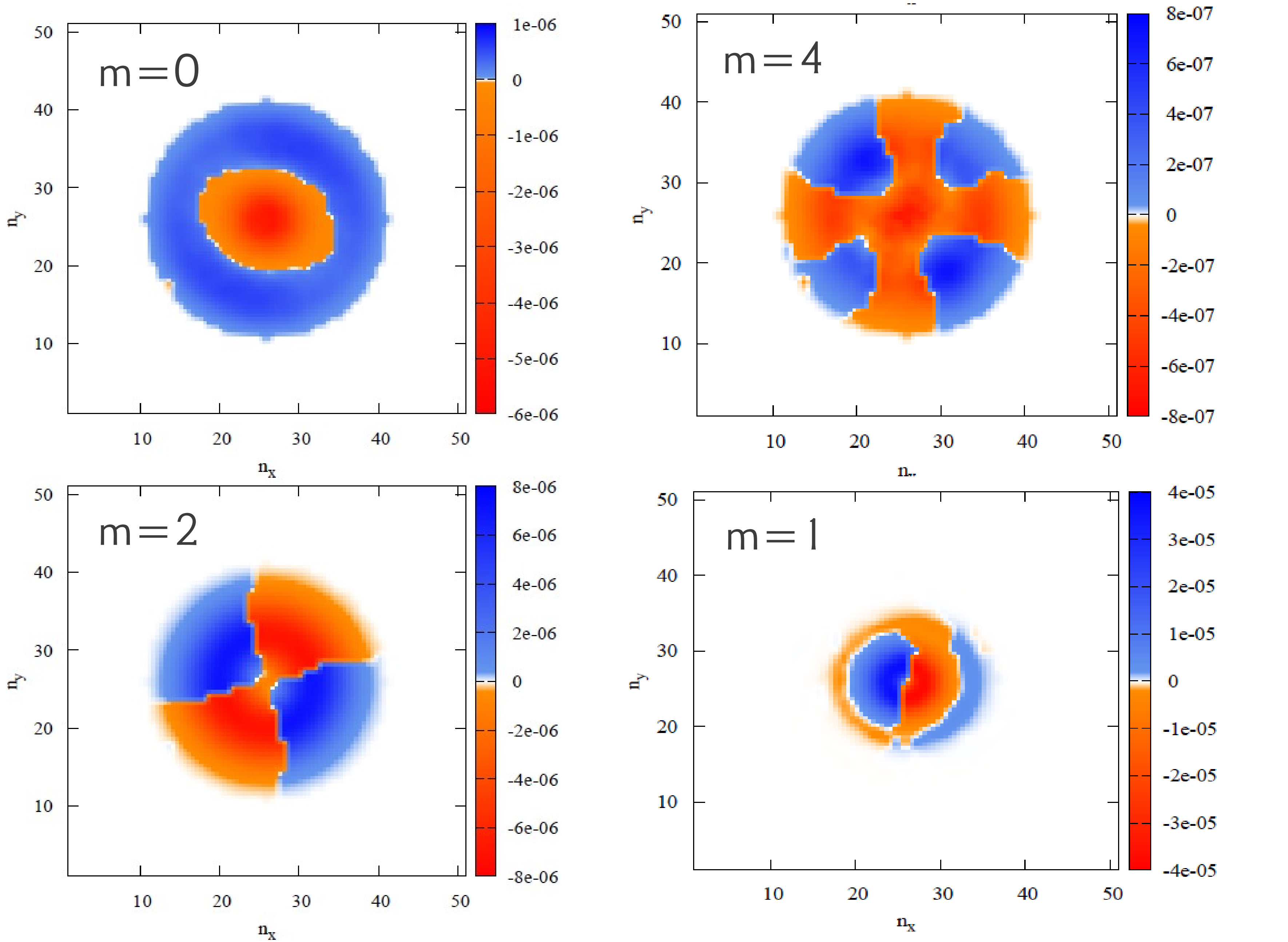




Spatial distribution of FFT *magnitude* at mode-frequency determines shape of *eigenfunction* (but change sign at nodal lines).

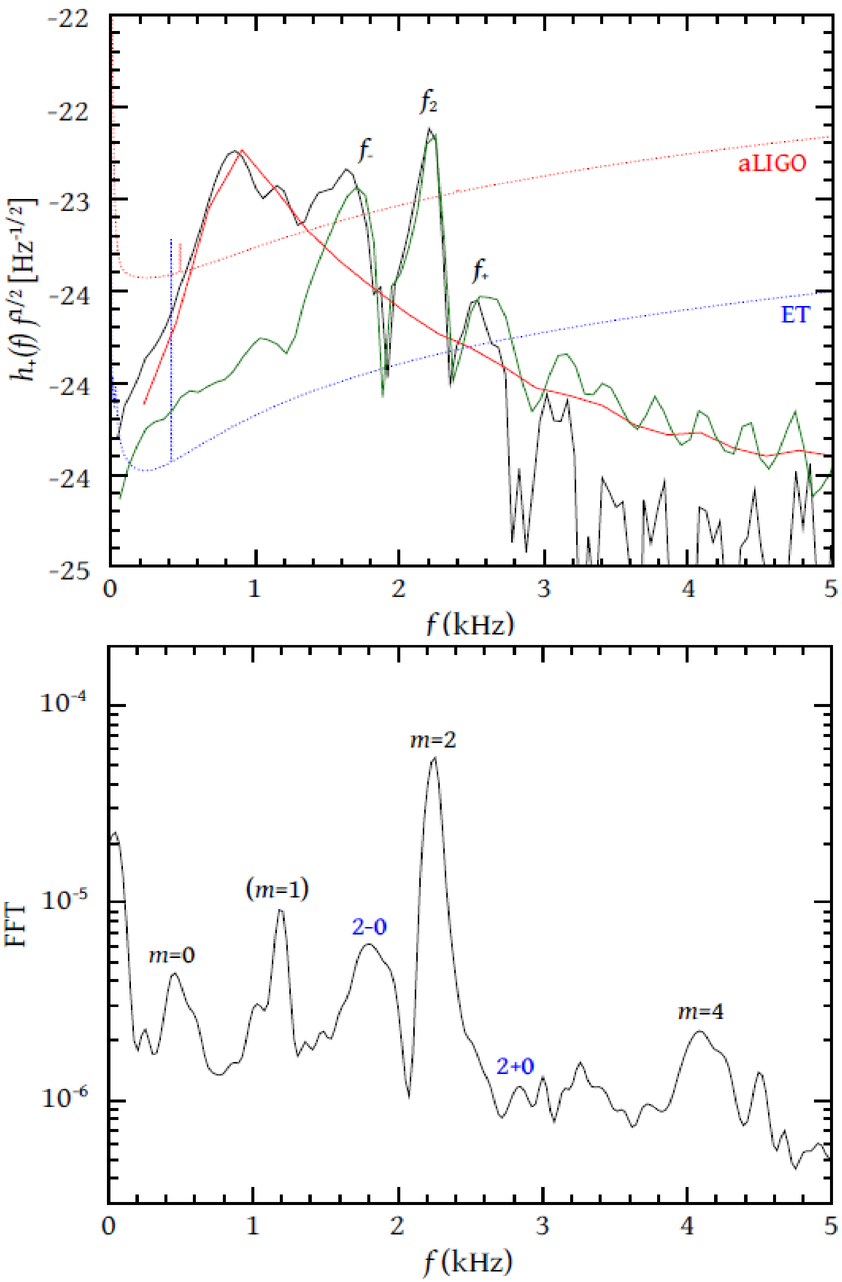
Eigenfunctions in Equatorial Plane

m=0, 2, 4 (Shen $1.35M_{sun}+1.35M_{sun}$) m=1 (MIT60 $1.2M_{sun}+1.35M_{sun}$)

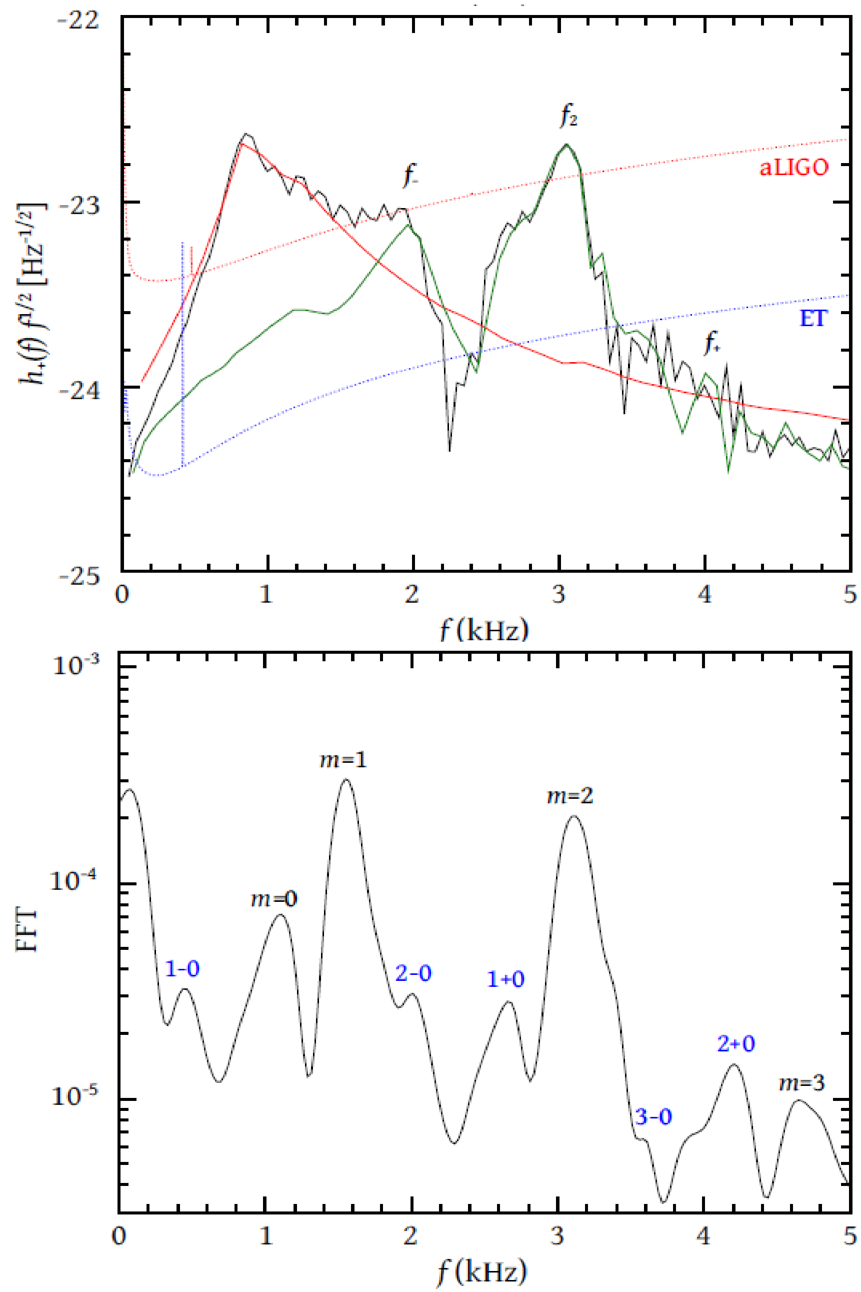


Other Models

Shen 1.35M$_{sun}$ +1.35M$_{sun}$



LS 1.2M$_{sun}$ +1.35M$_{sun}$



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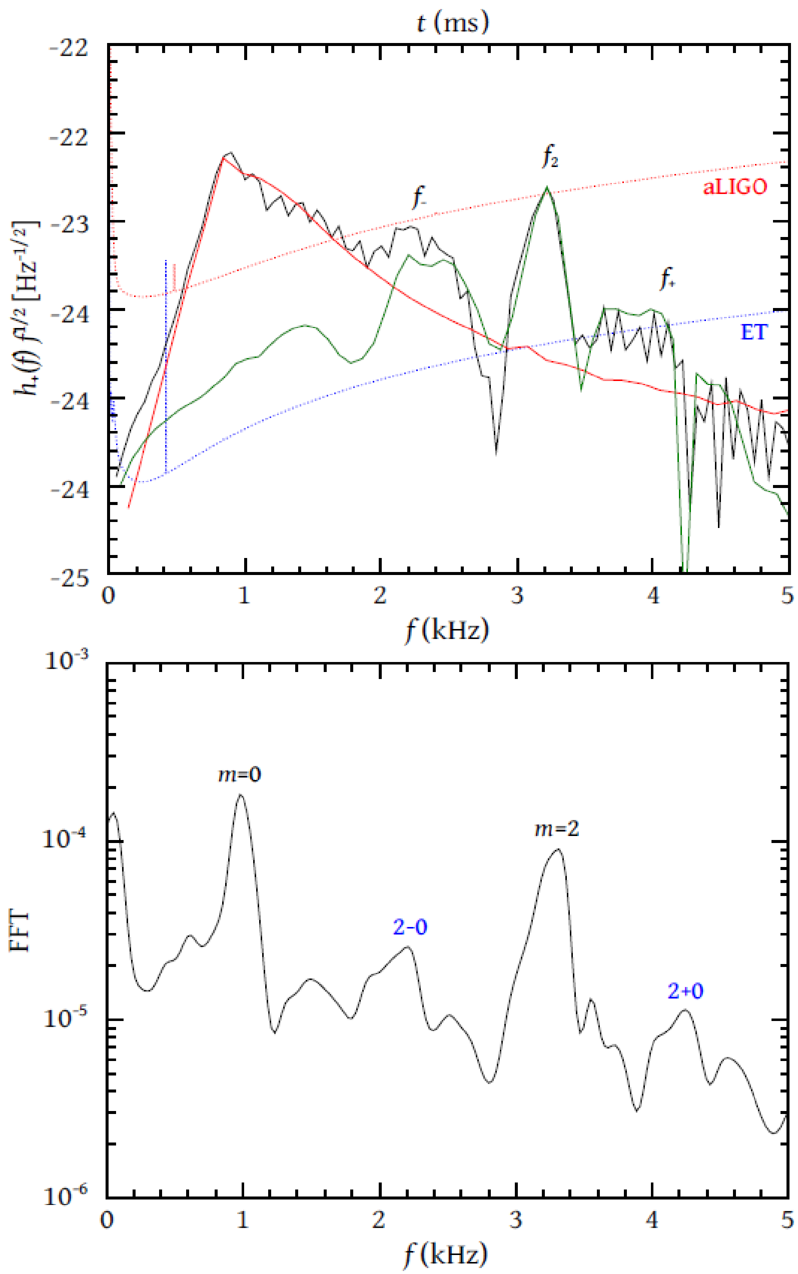
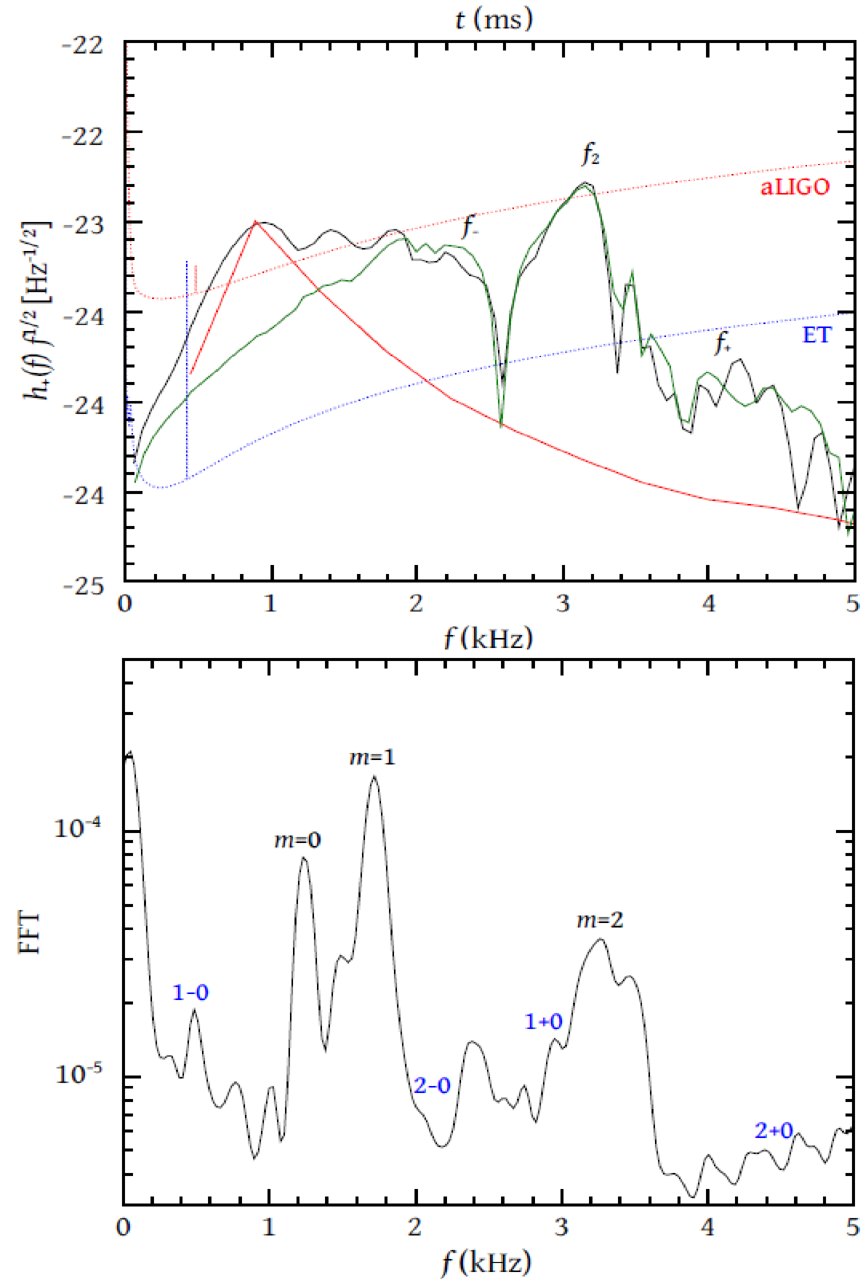


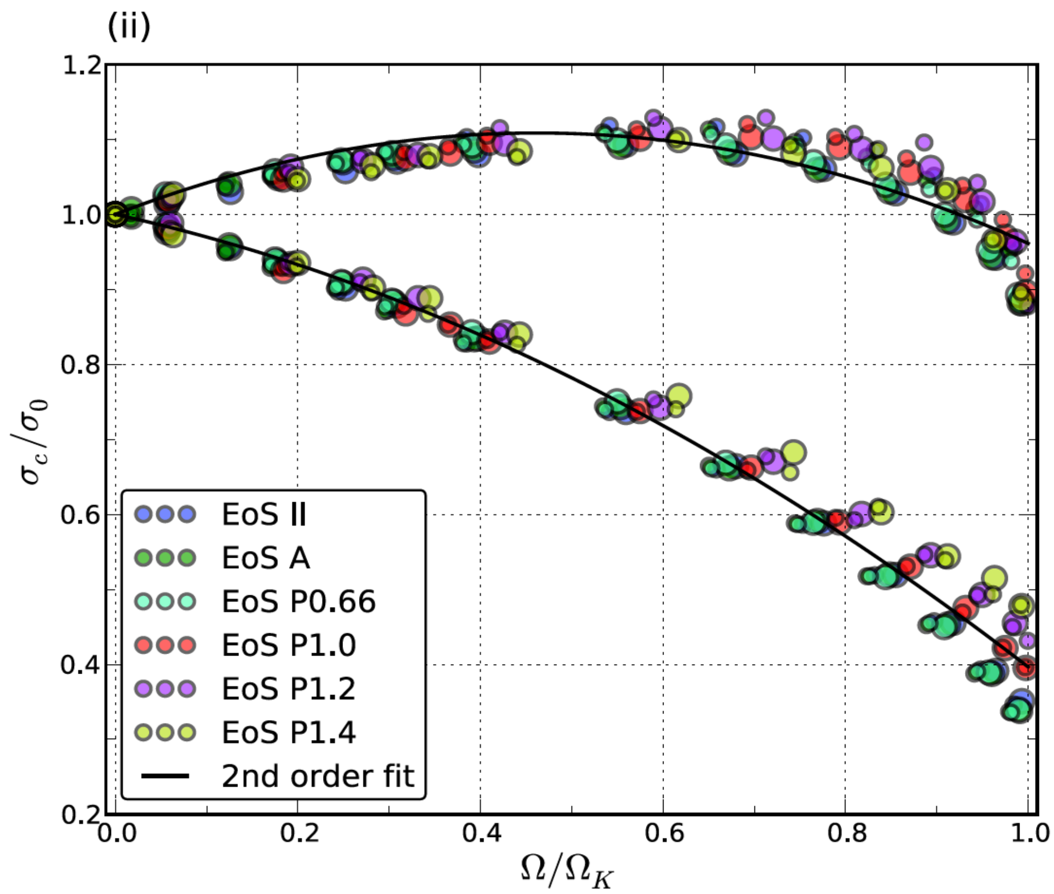
MIT60 $1.2M_{sun} + 1.35M_{sun}$



Asteroseismology of Rotating Neutron Stars?

Gaertig, Kokkotas (2011)

Rapid rotation, Cowling approximation, $l = \pm m = 2$ f-mode frequency (linear time-evolution code)



Corotating frame: same rotational effect, independent of EOS!

→ Empirical relations for GW asteroseismology.

Summary and Prospects

A HMNS created in a binary neutron star merger oscillates in several frequencies with initially high amplitude.

A triplet of frequencies f_-, f_2, f_+ is prominent and potentially detectable.

Identification:

f_2 : $m=2$ mode
f_- : $(m=2)$ - $(m=0)$ nonlinear combination frequency

In case of detection: determine both m=0 and m=2 frequencies

In progress: construct axisymmetric equilibrium model of HMNS remnant and obtain linear oscillation modes.

THANK YOU