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Rapidly Rotating Neutron Stars

Instabilities and Gravitational Wave Asteroseismology

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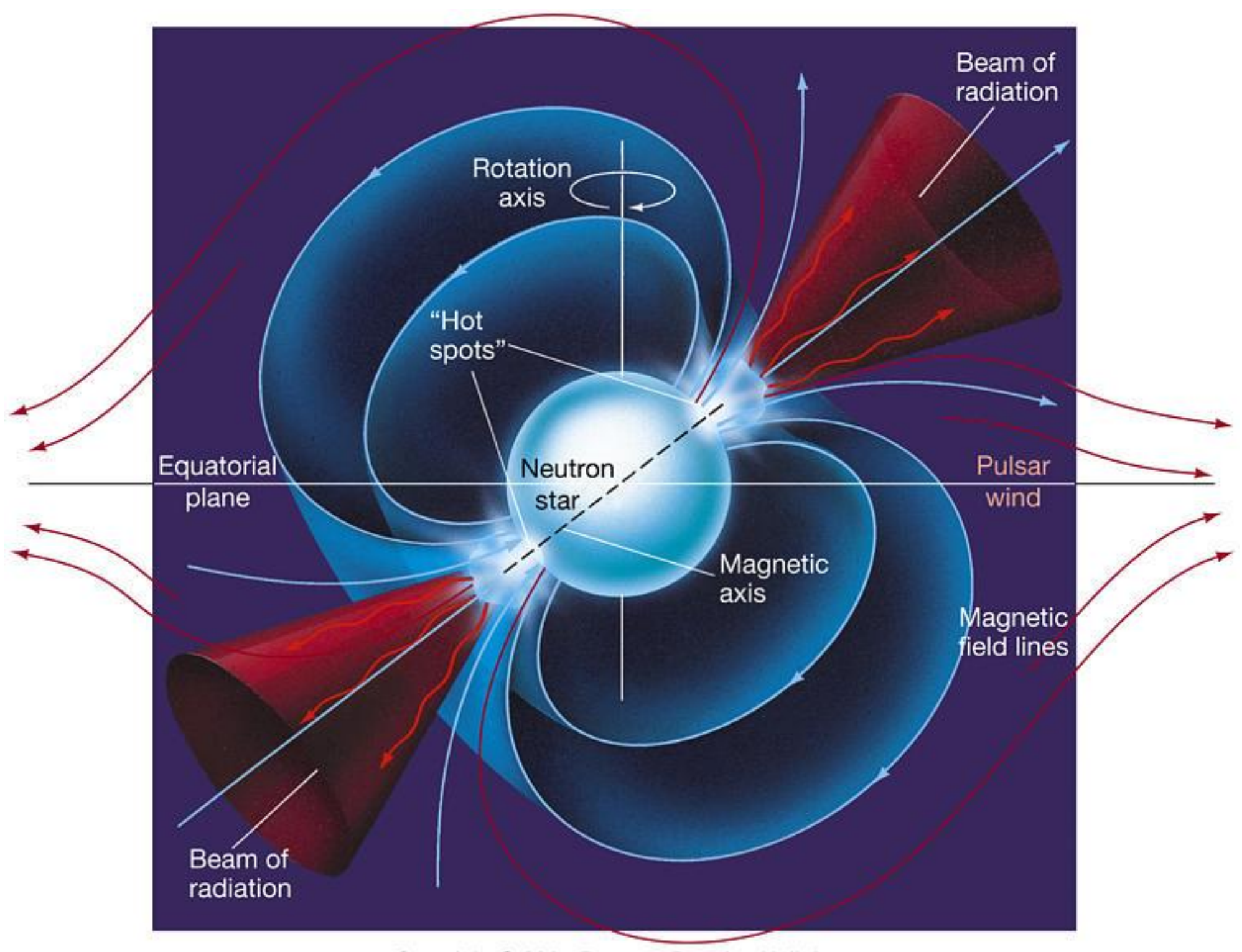
Oscillations of rapidly rotating neutron stars and CFS instability



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During their evolution, relativistic stars may undergo oscillations which can become unstable under certain conditions. For example newly born neutron stars are expected to oscillate wildly during their creation shortly after the supernovae collapse. Other mechanisms, such as accretion and glitches, can also lead to oscillations with high amplitude. The rotation strongly affects these oscillations. For example the perturbed stars can develop the Chandrasekhar-Friedman-Schutz (CFS) instability if they rotate faster than some critical velocities. This could potentially lead to a detectable amount of gravitational radiation.

Mode splitting, unstable modes and gravitational wave asteroseismology

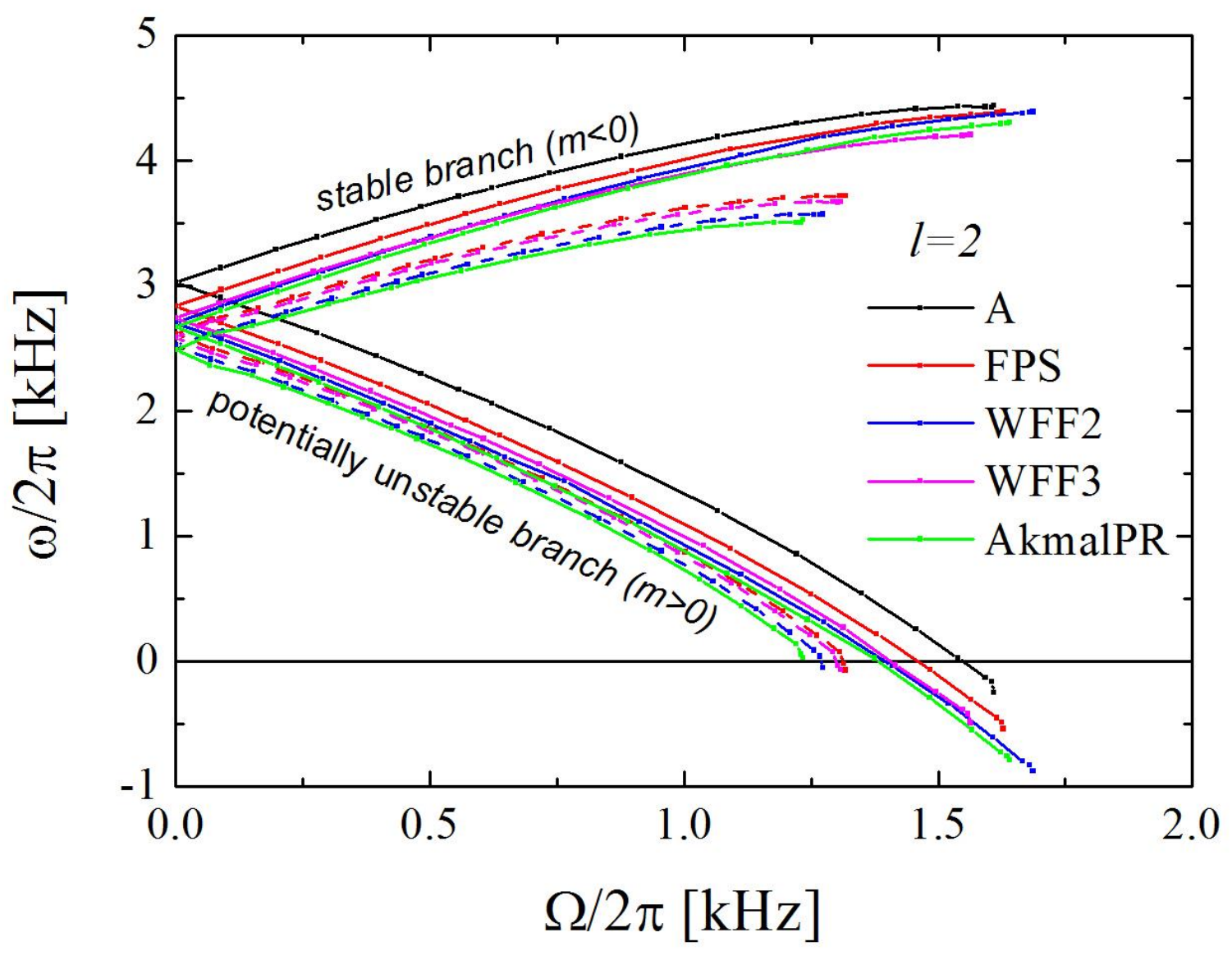

Fig. 1: Splitting of the mode frequencies of rotating stars in the inertial frame of reference.

The fundamental *f*-modes are degenerate in the nonrotating case – the frequencies for fixed spherical mode number l and different azimuthal mode number m are the same. This degeneracy is broken when we add rotation and modes with different values of m have different frequencies. Negative frequencies in the inertial frame of reference correspond to CFS unstable modes.

The observed gravitational wave signal from oscillating neutron stars can serve as a tool to determine the neutron star parameters, which is the essence of the gravitational wave asteroseismology. In order to do that we derived a set of relations connecting the oscillation frequencies and damping times of a neutron star to its mass, radius and rotational frequency. These relations lead in practice to a good estimation of the neutron star parameters. Even though our calculation are made in Cowling approximation, we give strong evidences that most of the relations will remain very similar also in the full general relativistic case.

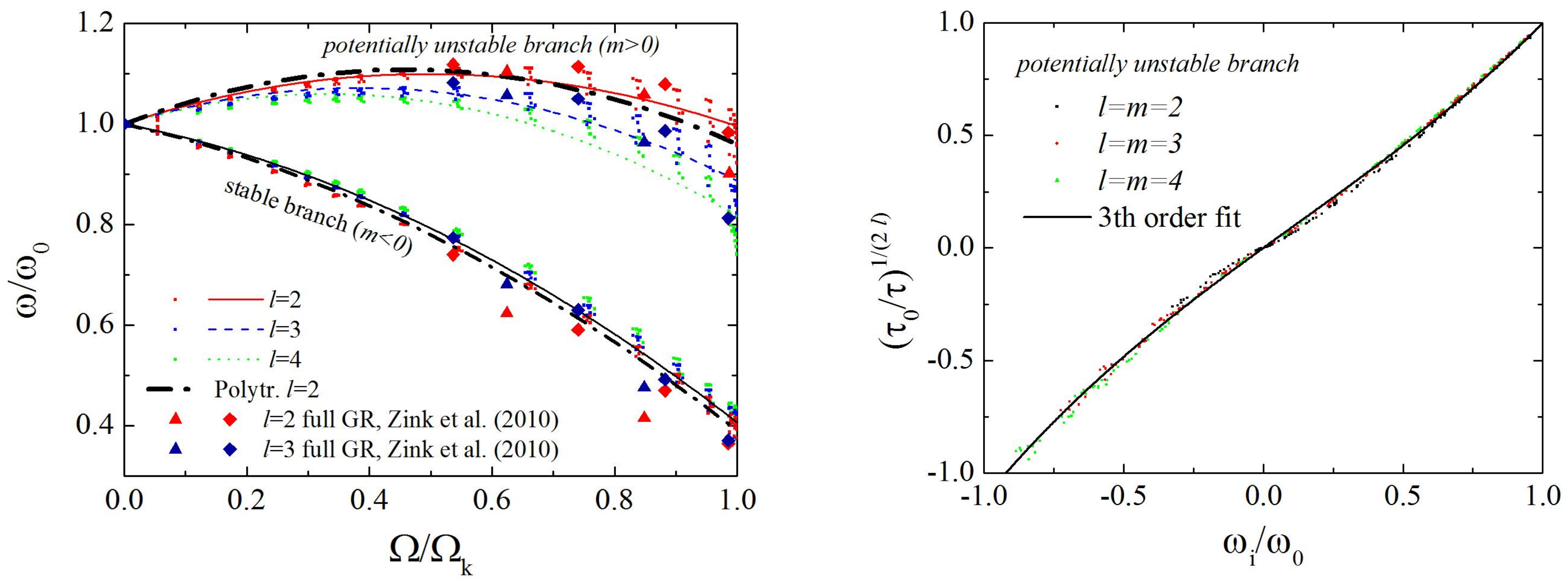

Fig. 2: Examples for asteroseismology relations – normalized frequencies in the corotating frame as a function of the rotational frequency and normalized damping times as a function of the normalized frequencies in the inertial frame.

Instability window

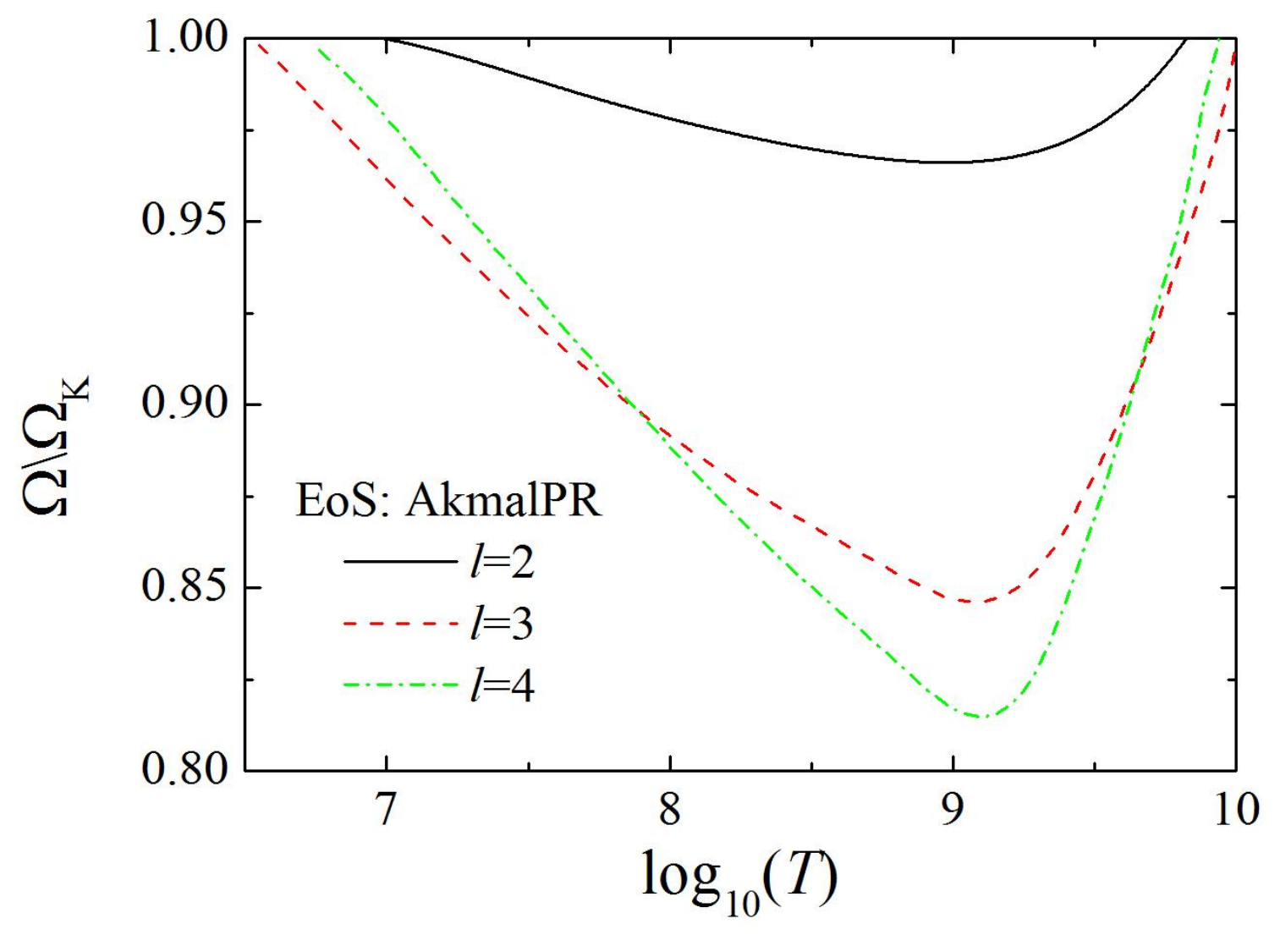

Fig. 3: The *f*-mode instability window of a two solar mass neutron star with realistic EoS.

The instability window is a limiting curve in a $T-\Omega$ (temperature–spin frequency) plane where the CFS instability overcomes the dissipative effects such as bulk and shear viscosity. We study the window for a range of masses, equations of state (EoS) and different values of l. It turns out that the instability window for the $l=m=3$ and $l=m=4$ modes is much larger than for the $l=m=2$ modes. Therefore they can develop CFS instability easier and it is important to consider them in the gravitational wave asteroseismology.

Our results also show that the realistic equations of state can have much bigger instability window than the standard polytropic ones. The window can reach down to almost 80% of the Kepler (mass shedding) limit.

Evolution though the instability window and detectability

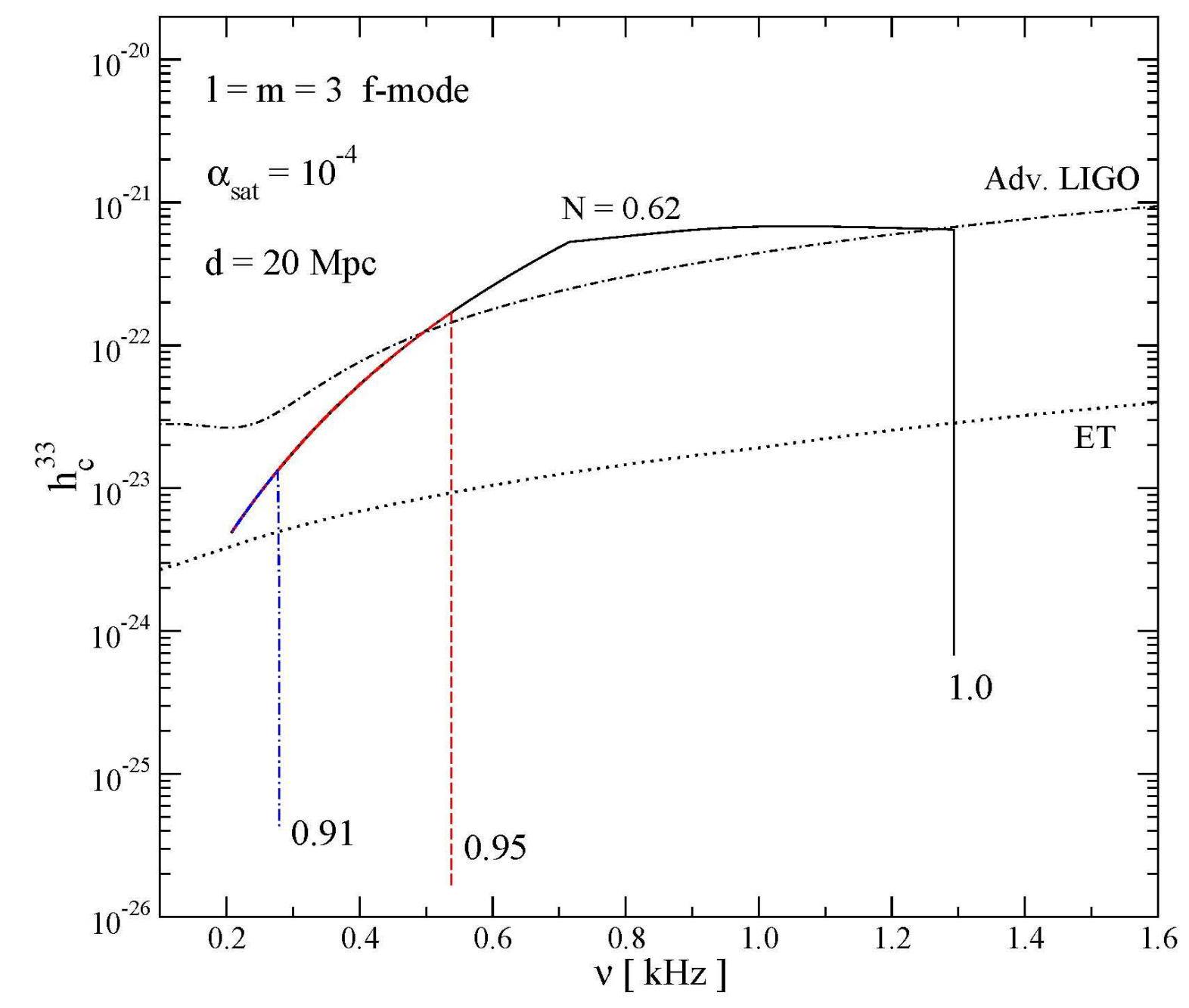

Fig. 4: Characteristic strain generated by the $l=m=3$ f-mode instability for a polytropic star with index $N=0.62$ and magnetic field $B_p=10^{11}G$.

With an approach based on linear perturbation theory we describe the evolution of the f-mode amplitude and follow the trajectory of a newborn rapidly rotating neutron star through its CFS instability window. The models we consider are relativistic. We incorporate the effects of viscosity, magnetic fields and unstable r-modes. These are the dominant effects which may have a significant impact on the f-mode evolution.

We find that the gravitational-wave signal emitted during the instability may be detected by a third generation gravitational wave detectors, such as the Einstein Telescope, from sources located in the Virgo cluster, and even by the Advanced LIGO/Virgo in some of the cases.

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