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Low $T/|W|$ dynamical instability in differentially rotating stars: Diagnosis with canonical angular momentum

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ABSTRACT
We study the nature of non-axisymmetric dynamical instabilities in differentially rotating stars with both linear eigenmode analysis and hydrodynamic simulations in Newtonian gravity. We especially investigate the following three types of instability; the one-armed spiral instability, the low $T/|W|$ bar instability, and the high $T/|W|$ bar instability, where T is the rotational kinetic energy and W is the gravitational potential energy. The nature of the dynamical instabilities is clarified by using a canonical angular momentum as a diagnostic. We find that the one-armed spiral and the low $T/|W|$ bar instabilities occur around the corotation radius, and they grow through the inflow of canonical angular momentum around the corotation radius. The result is a clear contrast to that of a classical dynamical bar instability in high $T/|W|$. We also discuss the feature of gravitational waves generated from these three types of instability.

Key words: gravitational waves – hydrodynamics – instabilities – stars: evolution – stars: oscillation – stars: rotation

We study the nature of three different types of dynamical instability in differentially rotating stars both in linear eigenmode analysis and in hydrodynamic simulation using canonical angular momentum distribution.

We find that the low $T/|W|$ dynamical instability occurs around the corotation radius of the star by investigating the distribution of the canonical angular momentum. We also find by investigating the canonical angular momentum that the instability grows through the inflow of the angular momentum inside the corotation radius. The feature also holds for the dynamical bar instability in low $T/|W|$, which is in clear contrast to that of classical dynamical bar instability in high $T/|W|$. Therefore the existence of corotation point inside the star plays a significant role of exciting low $T/|W|$ dynamical instabilities.

Quasi-periodic gravitational waves emitted by stars with $m = 1$ instabilities have smaller amplitudes than those emitted by stars unstable to the $m = 2$ bar mode. For $m = 1$ modes, the gravitational radiation is emitted not directly by the primary mode itself, but by the $m = 2$ secondary harmonic which is simultaneously excited. Possibly this $m = 2$ oscillation is generated through a quadratic nonlinear selfcoupling of $m = 1$ eigenmode, supported by the numerical simulations that the pattern speed of $m = 2$ mode is almost the same as that of $m = 1$ mode. Unlike the case for bar-unstable stars, the gravitational wave signal does not persist for many periods, but instead is damped fairly rapidly. One possibility may be that the unstable $m = 1$ eigenmode tends to couple to higher and higher m modes and pump its energy to them in a cascade way. Another possibility is that the spiral pattern formed in $m = 1$ instability redistributes the angular momentum of the original unstable flow, so that the flow is quickly stabilized.

A more detailed discussion is presented in Saijo & Yoshida (2006). ⋆

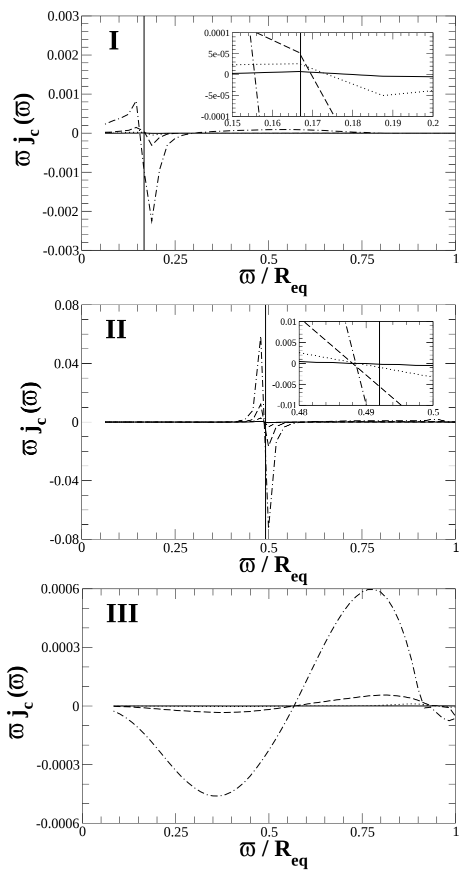

Figure 1. Snapshots of the canonical angular momentum distribution $\varpi j_c(\varpi)$ in the equatorial plane for three differentially rotating stars. Solid, dotted, dashed, and dash-dotted line represents the time t/P_c =(3.47, 6.93, 10.40, 13.86) for model I, t/P_c =(45.68, 56.43, 67.18, 77.97) for model II, and t/P_c =(1.10, 2.19, 3.29, 4.39) for model III, respectively.

⋆ Saijo M., Yoshida S'i., 2006, MNRAS, in press, preprint (astro-ph/0505543)