Kappa-Mechanism Excitation of Retrograde Mixed Modes in B-Type Stars

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Abstract. The stability of retrograde mixed modes in rotating B-type stars is investigated. It is found that these modes are susceptible to $\kappa$-mechanism excitation, due to the iron opacity bump at $\log T \approx 5.3$. The findings are discussed in the context of the pulsation of SPB and Be stars.

1. Introduction

In a uniformly-rotating star, the low-frequency oscillation spectrum comprises four classes of pulsation mode — Poincaré, Kelvin, Rossby and mixed Rossby-Poincaré. The Poincaré modes rely on a combination of buoyancy and the Coriolis force to restore displaced fluid elements to their equilibrium positions; they reduce to ordinary gravity (g) modes in the non-rotating limit. The Kelvin modes are a prograde-propagating subset of the Poincaré modes that exhibit geostrophic balance between polar pressure gradients and the polar component of the Coriolis force. The Rossby modes, which take the form of large-scale, retrograde-propagating horizontal circulations, arise due to conservation of vorticity; they exist independent of buoyancy, but reduce to trivial zero-frequency toroidal modes in the non-rotating limit.

Finally, the mixed Rossby-Poincaré modes — or ‘mixed modes’ for brevity — are a curious hybrid between Poincaré and Rossby modes. In the limit of slow rotation, the prograde mixed modes (azimuthal orders $m < 0$) behave like Poincaré modes, while the retrograde mixed modes ($m > 0$) behave like Rossby modes. However, toward rapid rotation both prograde and retrograde mixed modes approach one another in character, exhibiting properties that lie somewhere between pure Rossby and Poincaré modes.

Like Rossby modes, non-trivial retrograde mixed modes do not exist in the absence of stellar rotation. However, in contrast to the Rossby modes (which are essentially solenoidal), these modes are able to generate significant fluid compressions and rarefactions, due to the Poincaré-mode character they acquire in the rapid-rotation limit. This property renders them in principle susceptible to the classical instability mechanisms ($\gamma$, $\delta$, $\epsilon$ and $\kappa$) that rely on a thermodynamic Carnot cycle. The present paper investigates whether such mixed-mode instability could be present in B-type stars.
2. Stability Analysis

I use an updated version of the boojum pulsation code (Townsend 2005a) to investigate the stability of retrograde $m = 1\ldots4$ mixed modes in a set of stellar models representative of main sequence B-type stars. This non-adiabatic code treats the effects of the Coriolis force using the traditional approximation (see, e.g., Lee & Saio 1987), but departures from sphericity due to the centrifugal force are neglected. Two rotation rates are considered: $\Omega/\Omega_c = 0.5$ (where $\Omega$ is the star’s angular velocity, and $\Omega_c$ the corresponding critical angular veloci-
ity) is chosen to approximate the observed upper limit on the rotation of the slowly pulsating B-type (SPB) stars (Mathias et al. 2001), while $\Omega/\Omega_c = 0.25$ is representative of more-moderately rotating stars.

The general finding is that the retrograde mixed modes are unstable due to an opacity peak situated at a temperature $\log T \approx 5.3$. This peak is the same ‘iron bump’ responsible for the pulsation of $\beta$ Cep and SPB stars (e.g., Dziembowski & Pamiatnykh 1993, Dziembowski et al. 1993). As shown in Fig. 1, the mixed-mode instability extends over an effective temperature range $\log T_{\text{eff}} \approx 4.0–4.2$, corresponding loosely to spectral types B4 to A0.

3. Discussion

Figure 1 indicates that the mixed-mode instability is unlikely to furnish a better explanation for SPB-star variability than the canonical picture of $\kappa$-mechanism excitation of gravity/Poincaré modes. A similar conclusion could be reached for the Be stars, were it not for the fact that these stars are rapid, perhaps near-critical rotators (Townsend et al. 2004). Although there are difficulties in performing stability analyses at such extreme rotation rates, the trends shown in Fig. 1 suggest that the mixed-mode instability may shift to encompass the earlier spectral types — where the preponderance of Be stars are situated — as $\Omega$ approaches $\Omega_c$. Therefore, it seems plausible that the retrograde-propagating pulsation observed in variable Be stars (Rivinius et al. 2003) may actually be due to unstable mixed modes rather than the usually-supposed g modes.

If confirmed, the latter hypothesis may help establish what role pulsation plays in the Be phenomenon. Although they propagate with a retrograde phase velocity, the unstable mixed modes show a prograde group velocity, and therefore can assist in ejecting material into orbit from the equator of a near-critical star (see Owocki 2005). This issue is discussed further in a forthcoming paper (Townsend 2005b), which also presents a more in-depth analysis of the newly-discovered mixed-mode instability. Those interested in this topic should also refer to the investigation by Saio (these proceedings), who examines retrograde mixed modes (in his terminology, ‘buoyant r modes’) using an approach that does not rely on the traditional approximation.

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