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RADIAL AND NONRADIAL MODE INSTABILITY IN B-TYPE STARS

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Recently, three independent groups(Cox *et al.* 1992; Kiriakidis *et al.* 1992; Moskalik and Dziembowski, 1992), using opacity tables published by Iglesias and Rogers (1991), demonstrated that β Cep star models are pulsationally unstable. The instability is driven by the classical κ- mechanism acting in the layer with temperatures near 2×10^5K where there is a bump in metal opacity. The groups reported results of calculations made for rather narrow ranges of stellar parameters and oscillation modes. We conducted an extensive search for unstable modes in complete evolutionary models of B-type stars of luminosity classes III – V. Our aim was to determine the domain of instability and examine its role not only in β Cep stars but also in variable stars located in the nearby areas of the H-R diagram.

An unexpected new aspect of our calculations is the use of the improved opacity data. In a very recent work Iglesias, Rogers and Wilson (1992) showed that effects of spin-orbit interactions significantly enhance opacity in the critical region for driving the pulsations in β Cep stars. These effects and improved information about the solar metal mixture have been included in the updated opacity tables kindly provided to us via electronic mail by Dr. Rogers. The consequences of this change in opacity for stability of B-type star models are indeed quite important. Contrary to previously announced results, that only the fundamental mode is unstable, we now find the first two radial overtones to be unstable, as well. Thus, the discrepancy between the theoretical prediction and the mode identification suggested by observers has been removed. Furthermore, no longer is a high metal abundance ($Z > 0.03$) required to explain the occurrence of pulsation in most of the objects. In fact, the theoretical instability domain in the H-R diagram, based on the models calculated with $Z = 0.02$, agrees better with the observational β Cep domain than that based on the models $Z = 0.03$.

The pattern of appearance of unstable modes in a selected sequence of stellar models is shown in Figure I. Frequencies plotted there are expressed in the $\sqrt{4\pi G\bar{\rho}}$ units. Only the expansion phase of the Main Sequence evolution is covered. Models in the contracting phase have similar pulsation properties except that the nonradial mode spectrum is somewhat denser. This effect becomes much more pronounced in models with hydrogen exhausted cores. However, since the crossing of the instability strip in this evolutionary phase is very fast, these models cannot be regarded as realistic for most β Cep stars.

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The behavior of radial modes ($l = 0$) is reminiscent of that in the Cepheid instability strip. With decrease of effective temperature, we first encounter an overtone instability. However, the effect of luminosity changes is exactly the opposite. In the β Cep instability strip, the overtones are unstable only in the more luminous objects. One may notice in Figure I that the onset of the instability in nonradial modes of low degree does not depend on l in a visible way. In models calculated with $Z = 0.02$, the instability domain is naturally smaller. In particular, the second overtone (p_3) is always stable.

In Figure I one can see the familiar behavior of the low-order g-modes whose frequencies grow during Main Sequence evolution to enter the low-order p-mode frequency range at some time. Such modes become unstable remaining largely trapped in deep interior. Their frequencies are sensitive to the evolution of the convective core boundary, which is still not well understood. Thus, detection of such modes in β Cep stars would be great importance for asteroseismology.

In the plots for $l = 6$ and 8 modes, a separate instability domain appears at low frequencies. The unstable modes are high-order g-modes which are propagating rather than evanescent waves in the driving zone. Nevertheless the physical mechanism of the instability remains the same. Occurrence of two separate instability domains is consequence of the fact that the modes in the intermediate period range have relatively low amplitudes in the driving zone. Instability of these long-period modes of rather high l may be relevant to the line-profile variability discovered in several Be stars (see e.g. Baade 1984). However, they are not likely to be detectable by means of photometry.

For stars with lower effective temperatures and luminosities the instability shifts toward lower l's. We found lots of unstable modes with $l = 1$ and 2 and periods ranging up to 3 days, in sequences of $5M_\odot$ star models calculated with $Z = 0.02$ and 0.03. It seems virtually certain that this high-order g-mode instability explains the origin of long-period variability discovered by Waelkens and Rufener(1985) in certain mid-B stars.

The possibility that the same mechanism may drive oscillations in Luminous Blue Variables has been already suggested by Moskalik and Dziembowski (1992) who noted that the instability strip widens in the supergiant domain of the H-R diagram. Thus, it is not unlikely that the κ-mechanism acting in the layer of the metal opacity bump is the ultimate cause of all of the intrinsic variabilities discovered in B-type stars.

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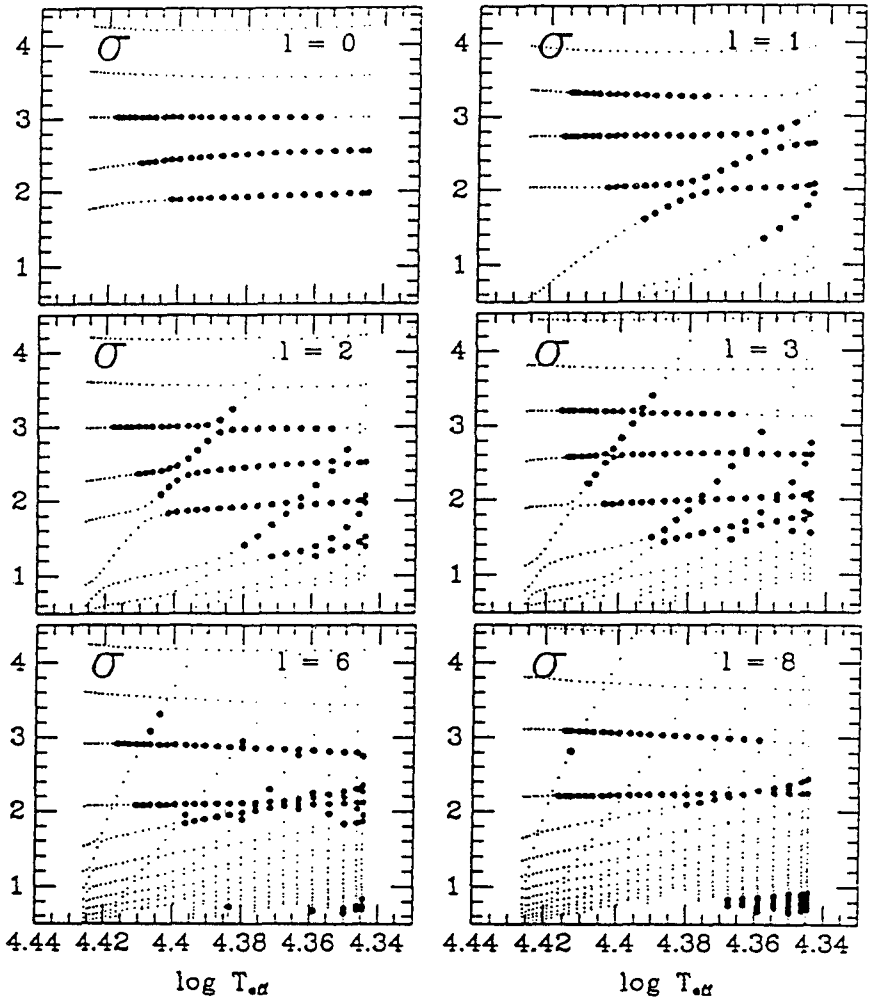

FIGURE I Dimensionless frequencies, σ, of low order and low degree, l, modes in models of a $12M_{\odot}, Z = 0.03$ star in their Main Sequence evolutionary phase. The small and the big dots correspond to stable and unstable modes, respectively.

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