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PULSATIONS OF B STAR MODELS BY AN OPACITY MECHANISM

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ABSTRACT The pulsation mechanism for B stars has been sought for 30 years. No proposed radial or nonradial mechanism, either deeply seated or in the surface layers, has been successful in explaining all the observational details. Perhaps the missing piece in the puzzle is the opacity of the stellar material. Many times the first author has tried to make unconventional surface compositions give instability, but none were ever found. We now propose that the sudden appearance of a tremendous number of iron lines, as the temperature rises above about 150,000K, gives a high sensitivity of the opacity to temperature at the very low densities found in these blue giants. Opacities need to increase quickly to a factor of three or more above the Cox-Tabor (1976) values in the range around 200,000K. These increases are the same needed to decrease theoretical period ratios of double-mode Cepheids and δ Scuti variables to agree better with observations for conventional yellow giant masses (Andreasen, 1988). They are also those now proposed by Rozsnayi (1989) and by Rogers and Iglesias (1989) with improved accounting for all the iron lines and their widths. The reason why not all B stars pulsate is that a slight primordial deficit in the iron abundance in the surface layer (2×10^{-5} of the mass) can reduce the opacity and its sensitivity to temperature. A slight amount of iron concentration by radiative levitation could make a star pulsate even if it did not originally have enough primordial iron to cause this opacity mechanism to operate. Then any slow slight mixing caused by the unstable nonradial pulsations could restabilize the pulsations as actually observed in α Vir and β CMa. Rapid levitation and mixing for the very luminous B stars with their very low density envelopes could even explain the puzzling luminous blue variables with this standard κ mechanism. Large amplitude pulsations like those seen in BW Vul would indicate a somewhat larger iron abundance compared to all other B stars. Modes found unstable for a typical 12 $M_\odot$, 21,000 $L_\odot$, 22,750K, 360 zone stellar model with X=0.70 and Z=0.02 in linear nonadiabatic calculations are the radial fundamental and one or two overtones as well as nonradial p-modes of low degree with periods (near 0.3 days) in the same range as the radial modes. Thus multimode behavior is theoretically expected for this pulsation mechanism, and only a few nonradial modes (possibly selected by rotation) may survive to observable amplitudes.

BACKGROUND

Since the beginning of this century (Frost, 1902) intrinsic variations in light and radial velocities have been observed for B stars. Perhaps the major problem in explaining them has been that no pulsation destabilizing mechanism was known. Another key observation is that not all B stars pulsate, and those that do, are not always varying. Two very important recent cases are α Vir (Lomb 1978) and β CMa (Myron Smith, private communication), whose light variations have now essentially ceased. The contrast with the situation for the Cepheids is striking. All Cepheids, RR Lyrae variables, and Type II Cepheids are always pulsating, and probably there is no star in the upper Cepheid instability strip that does not pulsate. How can some of the B stars pulsate, while many others seem quite stable?

A clue to this puzzle is the fact that many stars in the lower Cepheid instability strip, where the δ Scuti variables are found, are not pulsating. The standard explanation is that the helium, with its high opacity and low γ, drains away from the pulsation driving layers so that no longer is there enough driving to overcome the ever present damping. Thus for B stars, perhaps enough driving thermodynamics is not always present.

It is now proposed that the B star pulsation mechanism is the well-known κ effect. It is not due to hydrogen and helium ionization, but to the sudden opacity increase at temperatures above 10^5K from iron lines. These iron lines can more than triple the opacity over the current best values from the Los Alamos Astrophysical Opacity Library. The driving mechanism is not accompanied by the γ mechanism, however, because this opacity increase with temperature is not accompanied by an increase of ionization as for the hydrogen and helium Cepheid instability strip.

We wish to find a mechanism that can destabilize any star from spectral class A0 to the late O stars. Also the pulsations should be found at luminosities in this temperature range from the to even the Hubble-Sandage variables. The idea then is to see if a small change in the iron abundance can push the destabilization over a threshold to cause pulsations. Low metallicity objects in the Magellanic Clouds or even far out from our galactic center then would never display these B star pulsations.

OPACITY DATA

The new B star model discussed in this paper was generated in an unconventional way, because a complete opacity table including the newly discovered same shell transition iron lines is not available. Fortunately, the opacity enhancement in a very thin shell has no effect on the overall evolution of a 12 $M_\odot$ star. A guess for the opacity increase was made in the form of ramps that multiplied the opacity by varying factors for temperatures between 10^5 and 10^6 K. Then temperature density pairs in the model were given to Rogers and Iglesias at Livermore for detailed opacity calculations. Then a new set of ramps were coded in the model building program.

Table I gives the opacity factors relative to the Iben fit that we now use for our B star models. For the low density giant B stars, large opacity increases and large logarithmic derivatives with respect to temperature are found.

TABLE I   Opacity Factors

ρ (10^{-7} g cm^{-3})	T (10^{5} K)	$\kappa_{FULL}/\kappa_{Fe=0}$	$\kappa_{Fe=0}/\kappa_{LANL}$	$\kappa_{FULL}/\kappa_{LANL}$	$\kappa_{LAOL}/\kappa_{Fe=0}$
0.533	1.00	1.01	1.28	1.39	1.00
0.996	1.21	1.27	1.32	1.68	1.03
1.54	1.39	1.65	1.29	2.13	1.63
2.14	1.59	2.22	1.23	2.73	2.30
2.26	1.77	2.67	1.20	3.20	2.90
2.60	1.99	2.94	1.20	3.53	3.00
4.63	2.19	2.25	1.20	2.70	2.80
9.24	3.03	1.97	1.26	2.48	2.59
16.4	3.54	1.69	1.20	2.03	2.38
25.5	3.97	1.52	1.10	1.67	2.21
62.2	5.01	1.23	1.05	1.29	1.80
123.	5.96	1.18	1.02	1.20	1.42
435.	8.05	1.16	1.02	1.18	1.00
1158.	10.03	1.13	1.01	1.14	1.00

TWELVE SOLAR MASS MODEL

The evolution run includes both element diffusion effects that float some hydrogen to the surface, as well as a stellar wind that blows away most of the hydrogen abundance enhancement. Material properties for the evolution and pulsation calculations are obtained from the Iben (1963, 1965, 1975) procedures. Models from the main sequence homogeneous composition state to after the central convection zone has converted all the hydrogen to helium are available.

The particular model for this paper has a luminosity of 21,600 L, an effective temperature of 22,750 K, and primordial hydrogen and helium mass fractions of X=0.70 and Z=0.02. It has almost all the central hydrogen exhausted, and is at the red "kink" in its Hertzsprung-Russell diagram evolution track. Figure 1 shows the opacity versus mass into the model. The important logarithmic derivative of the opacity with respect to temperature reaches between 1 and 2 at the proper mass depth into the model, producing enough κ mechanism to overcome the strong damping in deeper levels.

The pulsation driving is mostly in a very weak convection zone between 2×10^{-7} and 7×10^{-7} of the mass into the model at temperatures between 130,000K and 200,000K, just a few percent of the radius into the model.

DISCUSSION AND CONCLUSIONS

It is proposed that the iron abundance in nearly pulsating B stars is almost enough to produce κ effect driving to overcome the normal strong damping. In most of these high luminosity stars, the photon flux absorbed by these iron lines might be large enough to levitate iron so that there is a slight abundance increase. When that occurs, the star would pulsate. However, since low order radial and low order and degree p-modes are excited (and observed), these might cause enough mixing of the small iron overabundance, that the driving drops again below the threshold. Then pulsations stop for maybe 10^5 years while the levitation cycle operates again.

For the very strongly pulsating variable BW Vul, perhaps the iron is abundant enough so that no concentration is needed even though it may occur. For other B stars the possible few percent abundance increase attainable from levitation is never enough to produce pulsations.

For the very high luminosity Hubble-Sandage variables, levitation of the iron atoms in the extremely low density envelope might have a short time scale. Further, the mixing due to nonradial pulsations might occur in only a few pulsation cycles. Thus OB supergiants might be destabilized by the same iron lines κ effect, but the pulsations would not always be present.

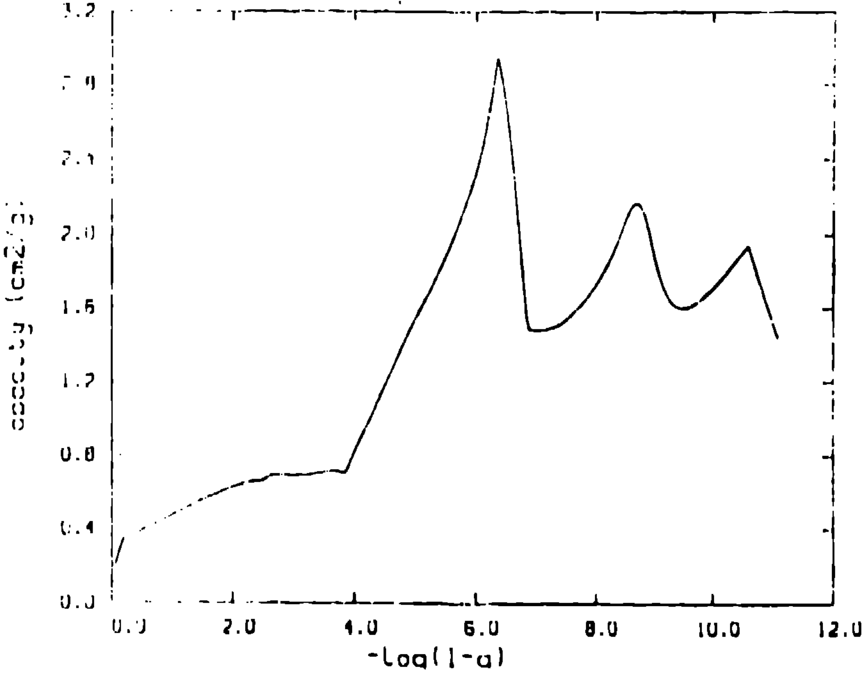

Fig. 1. Model opacity versus the external mass fraction.

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