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Theoretical Pulsations of Luminous Blue Variables

Arthur N. Cox, Joyce A. Guzik, Michael S. Soukup

Los Alamos Astrophysics

Siobahn M. Morgan

University of Northern Iowa

Abstract. Both radial and low degree and order g-mode nonradial pulsations are predicted for luminous blue variables that occur in the blue supergiant region of the Hertzsprung-Russell diagram. It is found that the radial strange modes have very large growth rates due to helium ionization in models at surface effective temperatures between 10,000 and 20,000 K.

1. Introduction

Luminous blue variables (LBVs) are the most massive stars in galaxies with original masses between 30 and over 100 $M_{\odot}$. Luminosities are near 10^6 $L_{\odot}$. They are observed to have microvariations as well as short and long time scale outbursts, and the former seem to be pulsations with periods typically of 30 days. LBVs exist close the the Humphreys-Davidson line in the Hertzsprung-Russell diagram (HRD) that defines the cool limit and maximum luminosity of observed blue supergiants. Mass loss from all these very luminous stars reduces the mass by 30% or more as they evolve into the LBV region. These stars may not survive the LBV stage to produce blue looping evolution tracks.

2. Evolution

Evolution tracks in the HRD have been calculated by the Iben code with an approximate allowance for the opacity changes from the Iben fit to the new OPAL opacities. We discuss here only two models with initial masses of 80 and 50 $M_{\odot}$. Mass loss rates used produce masses of 47.28 and 31.13 $M_{\odot}$ at surface effective temperatures of $logT_{eff}$ = 4.26 and 4.10, and luminosities of $logL_{\odot}$ = 6.10 and 5.77. Both models are in the post-main sequence stage, burning hydrogen in a shell surrounding an almost pure helium core. Mass loss exposes surface helium enhanced to Y= 0.54 and 0.38 for the two models, and the internal composition structures, homogenized in several layers by active or fossil convection zones, are used for models to examine pulsational stability.

3. Theoretical pulsations

As reported before (Cox, Morgan, Soukup, & Guzik 1993, BAAS, 25, 1441 and Soukup, Cox, Guzik, & Morgan 1994, BAAS, 26, 907) nonradial g-modes of radial order between 10 and 20 with periods near 10 days for $\ell=1$, are often found when convection is frozen-in. These earlier papers suggested that convection in the 200,000 K temperature region, caused by the large OPAL iron line opacities, has a time scale very close to the nonradial periods. Thus it is likely that, if convection cannot be suppressed, it will destroy the almost pure kappa effect driving, just as it does at the red edge of the Cepheid instability strip. Suppression was sought by a composition gradient set up by diffusion or merely the result of the helium gradient caused by evolution, but high radiation pressure envelopes do not produce a large enough Ledoux term.

At surface temperatures cooler than 25,000 K, it is discovered that ionization of the enhanced helium gives important pulsation driving by the classical kappa, gamma, and radius effects. In these outer very low density layers, convection occurs but it carries usually less than 1% of the luminosity. Thus any time-dependent convection destruction of driving is minimal, as tests show. Since the LBVs are found in the temperature region all the way down to 10,000 K, independent of the varying Z abundances of our Galaxy and the two Magellanic Clouds, it appears that the iron line kappa effect from the OPAL opacities cannot be the main cause of the LBV microvariations.

When a helium abundance of Y=0.32 or greater exists in the envelopes of these blue supergiants, a density inversion occurs centered around 30,000 K. The high helium opacity requires a high temperature gradient to transport the emergent luminosity. But then only an inverted density gradient can produce the needed pressure gradient for envelope hydrostatic balance. The deeper large iron line opacity also tends to create a density inversion, but there convection is more effective in energy transport, and the inversion is smaller or nonexistent.

This density inversion produces the so-called strange modes found in high luminosity-to-mass ratio envelopes. The temperature gradient variation during a pulsation cycle is another driving mechanism, but it is usually small compared to the classical kappa effect. But for strange modes, the radial perturbation increases with depth in this thin density inversion layer, and the resulting temperature gradient damping overcomes the usual driving. Then, deeper than the density inversion region, the temperature gradient perturbation is much steeper than normal, and now considerable new pulsation driving occurs. The strange mode perturbation structure extends deeper than for normal acoustic modes, and its periods are typically 30 rather than 10 or 20 days for the regular modes. With so much driving, growth rates are often near 100% per period as Kiriakidis, Fricke, & Glatzel (1993, MNRAS, 264, 50) and recently Glatzel (1994, MNRAS, 271, 66) discuss.

We propose that microvariations of LBVs are mostly or all radial pulsations that occur when mass loss exposes enough helium to produce strange modes. The red edge of the pulsation region is caused by the lack of stars that can survive the LBV outbursts when the surface helium is sufficiently enhanced. Whether these radial modes cause outbursts is an unanswered question.