Astrophysical Applications of Stellar Pulsation
ASP Conference Series, Vol. 83, 1995
R. S. Stobie and P. A. Whitelock, eds.

Oblique Pulsator Model for the Blazhko Effect of RR Lyrae Stars

Hiromoto Shibahashi and Masao Takata

Department of Astronomy, University of Tokyo, Tokyo, Japan

Abstract. By assuming that the RR Lyrae stars have fairly strong dipole magnetic fields with the symmetry axis oblique to the rotation axis of the star, we show that the oscillation mode which would be a pure radial oscillation in absence of the magnetic field has a quadrupole component, which is axisymmetric with respect to the magnetic axis. The aspect angle of the quadrupole component changes due to the stellar rotation, and this apparent variation is interpreted as the Blazhko effect in RR Lyrae stars.

About one third of RR Lyrae stars show long-term amplitude modulation, which was first noticed by Blazhko (1907), and this phenomenon is called the Blazhko effect after his name. This phenomenon has been a puzzle for a long time (see, e.g., Teays 1993), and it still remains to be solved. The period of amplitude modulation is typically in the range of 30 days to 100 days. Some possible explanations have been proposed for the Blazhko effect: (i) the modulation in terms of beats among multiple modes; (ii) the internal resonances between the radial fundamental mode and the third harmonic (e.g., Moskalik 1986); (iii) the effect of a magnetic field (e.g., Cousens 1983). The existence of strong magnetic fields in the RR Lyrae stars is still controversial. In the following, we assume that RR Lyrae stars have substantial magnetic fields and that the magnetic symmetry axis is inclined to the rotation axis of the star, and we propose the oblique pulsator model for the Blazhko effect (see Shibahashi 1994).

We assume the Lorentz force is stronger than the Coriolis force and ignore the effect of the centrifugal force. We treat these forces as perturbations. We assume the magnetic field is a poloidal field and expand it in terms of Legendre harmonics, and assume that the magnetic axis is inclined to the rotation axis of the star. The effects of the Lorentz force and the Coriolis force appear both in the eigenfrequency shift and in deformation of the eigenfunction. Our interpretation of the Blazhko effect is as follows: The radial eigenfunction excited by the kappa mechanism is deformed mainly by the Lorentz force to have additional non-radial components, whose symmetry axis coincides with the magnetic axis which is assumed to be inclined to the rotation axis of the star. As the star rotates, the aspect angle of the non-radial components varies and then these components manifest themselves as the long-term modulation of the luminosity variation of RR Lyrae stars. This model is essentially the same as the oblique pulsator model for the rapid oscillations of the Ap stars (Kurtz 1982), but a little bit different from Cousens' (1983) model since we adopt the regular perturbation method.

Takata and Shibahashi (1994) derived the selection rules concerning the perturbation to the eigenfunctions. According to their result, in the case of a

https://doi.org/10.1017/S0252921100036757 Published online by Cambridge University Press

pure dipole magnetic field, the selection rules say the allowed perturbations to eigenfunctions of the degree $l = 0$ are only the spheroidal components with the $l = 2$ and $m = 0$ and the toroidal components with the $l = 1$ and $m = 0$. Since the dominant component of the oscillations of RR Lyrae stars is the radial mode, the amplitude is almost constant over the rotational phase of the star. However, the aspect angle of the quadrupole oscillation component caused by the magnetic field varies with the rotation of the star, and hence the contribution to the apparent luminosity variation from this component synchronously varies with the rotation of the star. We interpret the Blazhko effect as being a manifestation of this periodic variation. According to this model, if one performs a frequency spectrum analysis with a long time span, one will get a quintuplet fine structure in the frequency spectrum. The relative height of each peak of the quintuplet is dependent on the magnetic field strength and the geometrical configuration among the rotation axis of the star, the magnetic axis, and the line-of-sight. The separation between the adjacent peaks is equal to the rotation frequency of the star. At certain geometrical configurations, a pair of peaks in the quintuplet fine structure have so small amplitudes that they cannot be detected. In such a case, the fine structure should appear practically as a triplet [see observations by Smith et al. (1994) and Kovacs (1994)], and the separation between the adjacent peaks may be either the rotation frequency of the star or twice the rotation frequency. In the case that the magnetic axis passes through the stellar center, the fine structure is symmetric with respect to the central component. The off-axis components of the magnetic fields lead to asymmetry. According to this model, the Blazhko period must be equal to the rotational period of the star or twice that. Though the rotation periods of RR Lyrae stars have not been observationally determined, they are thought to be several ten days and seem consistent with the observed range of Blazhko periods. We performed numerical simulations, in which the magnetic field strength and the geometrical configurations were treated as free parameters, and we found that a magnetic field of order one kilogauss is needed to explain the observed Blazhko effect of RR Lyrae stars.

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