Mira Stars with Double Maxima: Humps, Bumps, and Resonances
Matthew Templeton (AAVSO) & Lee Anne Willson (Iowa State University)

Abstract

We investigate the small class of long-period Mira variables that exhibit two distinct maxima during each pulsation cycle, and place them in the context of the general case of Miras with humps or bumps in their light curves. We present a sample of 44 AAVSO and ASAS Miras with known or suspected double maxima. We show example light curves, describe their general characteristics, and consider competing models for explaining the phenomenon. If double maxima are due to resonances between pulsation modes, then they will be useful for studying the internal characteristics of Mira stars. If the cause is atmospheric filtering, where the pulsation period is longer than the acoustic cutoff period, then their utility will be far more intriguing among atmospheric models.

Introduction

Mira variables are stars at the tip of the asymptotic giant branch (AGB) with large amplitude pulsations (1/2-5/2), periodic times ranging from 100 to 2000 days. Historically, the extreme variation of Mira light curves was attributed to the pulsation of the entire star. There is a broad range of behavior within this class, and stars may have regular or irregular light curves. Many Mira stars are known to have "humps" on their light curves, and the phenomena may be attributable to multiple pulsation modes, atmospheric effects such as shocks, nonlinearity, or some combination of these.

A very small group of stars exhibit "double maxima," where the light curve reaches a local maximum twice during each pulsation cycle. The General Catalogue of Variable Stars lists five stars with such behavior: R Cen, R Nor, BH Cru, BN Sco, and UZ Cen, and a sixth, DH Cyg, should also be added to this list.

In this paper, we sum up the observational data for Mira stars with double maxima, and discuss common features found in these stars. We then put this into the context of the current theoretical understanding of Mira star pulsation, and consider possible physical causes of the phenomenon.

Observed Properties

All stars in this sample have periods over 500 days, suggesting they have some common physical characteristics. R Cen, R Nor, and DH Cyg consistently show unambiguous double maxima in their light curves (Figure 1). The light curves for UZ Cen and UZ Cen (Figure 2) do not, but BN Sco (also Figure 2) is not well-behaved enough to determine its light curve shape.

Five of the six stars are classified as oxygen-rich, while BH Cru is a more carbon-rich Mira, so composition variations are unlikely to cause the double maxima. Long period Miras are on average more massive and have higher mass loss rates (Vassiladis & Wood 1993; Willson 2006) but Whitehead, Marang, and Fang (2005) note that the IR colors of BH Cru, R Cen, and R Nor indicate lower mass loss rates, at or below 10^-9 solar masses per year.

Double-mode pulsation

One view of this light curve behavior is that it is a manifestation of double-mode pulsation, where the high-frequency mode is 2.5 times the period of the low-frequency mode, and the amplitude of the high-frequency mode is twice that of the lower one, producing a double-peaked light curve. This is the most-commonly accepted reason for the existence of double-peaked light curves, both for Mira stars and other variable stars. Such a process in Miras would require that both modes are observable and are similar in amplitude. It would also result in other observable effects, such as periodic maxima in radial velocity variations.

Double-mode pulsation: observables

Radial velocity variations

Radial velocity variations in double-mode Mira stars should show two peaks, as each mode generates radial motion at the surface. Leboeuf et al. (2004) measured the radial velocity variations of several AGB stars, including R Cen and R Nor. Interestingly, they found a double-peak radial velocity curve for R Cen but not for R Nor. However, observations of R Nor did not cover the entire pulsation cycle, so this does not define evidence against double-mode pulsations in this star.

Periods and period ratios

All six of our stars have periods at or above 500 days. If these are double-mode pulsators with a period ratio of 2, the modes almost certainly are fundamental and first overtone (Dufour & Cox 1986; Wood et al. 1999). Both fundamental and first overtone modes are possible on theoretical grounds, a fact that led to a long debate about which modes were observed in Mira stars.

R Cen has been identified as going through a thermal pulse because of its large, long-period pulsations. And BH Cru also shows a large dM6. If both stars are indeed going through shell flashes, then these two stars in our sample are in a similar state. During a shell flash the pulsation varies dramatically. It is possible that this is the second mode.

Atmospheric filtering

Another possible explanation for the double maxima is the occurrence of two shocks per cycle, which happens when the pulsation period exceeds the acoustic cutoff period, and becomes especially prominent for pulsations with period ratios of 2 (Bewers 1999). This is what we refer to as atmospheric filtering.

For $P > P_{oc}$, acoustic waves propagate freely from the interior through the atmosphere, and do not establish standing waves in the interior. This greatly increases the driving energy required to sustain large-amplitude pulsations. However, when $P > P_{oc}$, the waves do not propagate outward, but are reflected back into the interior. The standing wave thus produced requires far less driving energy to sustain large-amplitude pulsations, making it more likely such modes will be driven in observable amplitude. Bewers showed that a secondary shock of comparable pressure to the main shock is also produced when $P_{oc} > P$.

The acoustic cutoff period is proportional to the pressure scale height over the sound speed, and goes as $\rho N_0^2$. Because both $P$ and $N_0$ vary, the important region is where the pressure minimum of this quantity occurs in the atmosphere. For $P_{oc}$ proportional to $\rho N_0^2$, $P_{oc}$ should scale with $\sqrt{\rho}$.