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Long-term variations and periods of Mira stars from ROTSE–IIId

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A B S T R A C T

We have studied the long-term variations of Mira type variables observed with Robotic Optical Transient Search Experiment telescope (ROTSE–IIId) between 2004 and 2009 located at TÜBİTAK National Observatory (TUG) in Antalya, Turkey. The actual pulsation periods, variability amplitudes, epochs of maximums and light curves of selected 70 Mira type variables already defined in the SIMBAD database were investigated. In these variables, 17 periods are identified for the first time.

1. Introduction

Mira type variables are pulsating red giant stars of late spectral type. The visual amplitudes and the periods of Mira stars are greater than $2.^{m}5$ and about 100 d, respectively. They are evolving through the tip of the Asymptotic Giant Branch (AGB) in the H–R diagram and represent a late stage in the evolution of stars with intermediate masses.

Mira variables are affected by two significant processes: (i) in the interior, helium shell flashes, which cause large excursions in their luminosity and period on a timescale of tens of thousands of years, and (ii) in the outer layers, pulsation–enhanced mass loss, which reduces their envelope masses, and drives their evolution to the white dwarf stage. Models of these evolutionary processes can potentially be tested by observing the period changes in Mira variables. Small period fluctuations are usual in Mira variables, although the mean period remains constant in most cases (Isles and Saw, 1987; Percy et al., 1990). The real period changes to be expected in Mira variables are due to their evolution but the evolutionary changes in period tend to be hidden by these fluctuations.

According to most evolutionary models (Wood and Zarro, 1981; Boothroyd and Sackmann, 1988; Vassiliadis and Wood, 1993) the largest period changes caused by thermal pulses should occur over relatively short periods of time, perhaps a few thousand years at most. If Mira pulsations can occur during most of the pulse and interpulse phases, then a few percent of all observed Mira variables will exhibit significant changes to their pulsation behavior over the span of available observations. These changes may define themselves as changes to (i) pulsation period, (ii) mean magnitude, and (iii) amplitude and/or lightcurve shape.

In addition to thermal pulses and mass loss, nonlinear pulsation behavior is unrelated to evolutionary processes for centenary changes in Mira variable pulsations. Mira variables have cycle to cycle variations in period and amplitude because of nonlinear behavior.

Recent observations make it clear that Mira variables are fundamental mode pulsators (Perrin et al., 2004; Weiner, 2004). Both mass loss and luminosity changes will significantly affect pulsation periods of Mira variables on the AGB. Thermal pulses which cause detectable large changes in the period, will change the stellar luminosity and temperature and reform the interior structure of the star on the thermal timescale. Evolutionary models predict that after the pulse onset (less than 1000 yr), for a short period of time, large and observable changes will occur to the star. Such changes will show themselves as changes in pulsation behavior because of changes in both the interior sound speed and stellar radius. Mass loss also occurs on the AGB and it may affect pulsations in Mira variables on observable timescales. It would cause a decrease in envelope mass, which affects the pulsation periods and also cause an increase in dust and molecular opacity, which would affect the absolute magnitude of the star and it would change the spectral energy distribution.

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The magnitude of maximum is constant within the errors of measurements for some of Mira variables while it changes from cycle to cycle for other Mira variables. Sometimes, this might be related to multiperiodicity. The primary period for a typical Mira variable is the first overtone period and the secondary period is another radial mode (Percy and Bagby, 1999). Bedding et al. (1998) have observed mode switching in the Mira-like variable R Dor, and they identify the modes as the first and third overtone. The nature of the long secondary period is not exactly known. Barthes and Tuchman (1994) have presented some evidence for multiple adjacent radial modes in two bright Mira stars, S CMi and X Cyg, but the evidence is not strong. It would be useful, however, to find examples of Mira variables pulsating in multiple radial modes because, from the ratio of the periods, the modes could be identified, and something could be learned about the internal structure of the stars. According to some other studies about the pulsation properties of Mira variables, most of them are pulsating in the first overtone, except for a few long-period stars that pulsate in the fundamental mode (van Leeuwen et al., 1997; Barthes, 1998). Some Mira variables (T UMi, R Aql, R Hya and W Dra) have undergone abrupt period changes associated with evolutionary state (Wood and Zarro, 1981). When the helium flash occurs, the hydrogen-burning shell is rapidly extinguished causing a sudden drop in the star's surface luminosity and a strong decrease in its period (Benitez and Vargas, 2002).

2. Observations and data analysis

2.1. Observations

The observations were predominantly spaced at intervals of 1 d and made with the Robotic Optical Transient Search Experiment telescope (ROTSE–IIId) in long term between June 2004 and December 2009 located at TÜBİTAK National Observatory (TUG) in Antalya, Turkey.

The main goal of the ROTSE–IIId telescope is to observe optical light of Gamma-Ray Bursts (GRBs). The ROTSE–IIId has an aperture of 45 cm and a 2048 × 2048 CCD with the pixel scale 3.3″/pixel for a total field of view 1.85° × 1.85°. Besides, the ROTSE–IIId has no filters but has a wide pass-band which peaks at 550 nm (Akerlof et al., 2003). In the ROTSE–IIId observations between 2004 and 2009 approximately 210 000 CCD frames were collected from 422 different pointings which belong to Turkish Observers. The limiting magnitudes of ROTSE–IIId with three different exposure times of 5, 20 and 60 s are $18.^{m}0$, $18.^{m}7$ and $19.^{m}3$, respectively. The majority of CCD frames analyzed in this study were taken with 5 s exposure time.

Mira variables examined in this study were selected from 422 ROTSE–IIId pointings by matching known Mira stars defined in the SIMBAD database. As a result, 244 known Mira variables were observed in 137 different pointings with ROTSE–IIId telescope. These Mira stars and their sky distributions are shown in Fig. 1.

2.2. Data analysis

ROTSE–IIId telescope uses a well designed data reduction pipeline allowing the near real-time processing of the CCD images taken by the ROTSE–III network telescopes. The steps of the pipeline; dark correction and flat fielding, detection of the sources on the exposed images, measuring the observables of the sources detected, astrometric transformations and photometric calibrations are fully automated without any human supervision (Akerlof et al., 2003). The crucial part of the ROTSE–IIId pipeline, detection and possession of various information (brightness, morphology, etc.) of the sources, is achieved by use of the SExtractor code (Bertin and Arnouts, 1996). The SExtractor does aperture photometry on the observed CCD frames. Measured instrumental magnitudes are then calibrated by comparing all the field stars against the USNO A2.0 R-band catalog to obtain ROTSE–III magnitudes (Monet, 1998).

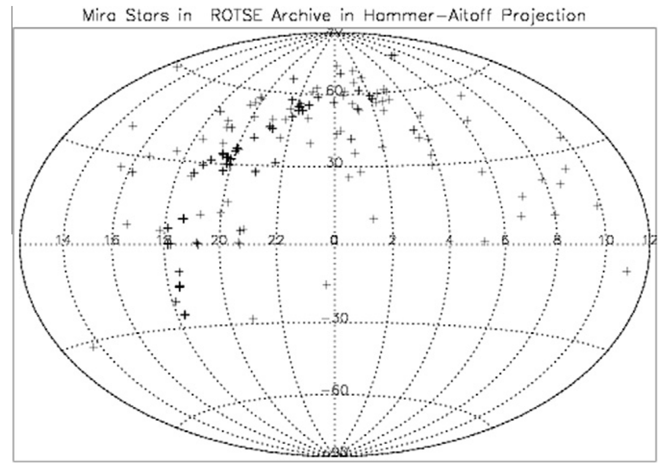

Fig. 1. The sky distribution of 244 known Mira variables observed with ROTSE-IIId telescope between 2004 and 2009.

As the final output of the pipeline, catalog-object (cobj) files are formed in FITS format having the tabulated data in binary tables. In order to obtain the light curves of the Mira variables, these 'cobj' files were used. Concerning the pointing for each Mira star, a source list of the region has been formed in advance with the `cdsclient` tool from the USNO-A2.0 R-band catalog server.

The astrometric transformation made by the ROTSE–IIId pipeline allows the use of source list of the region for identifying the detected sources in the cobj files by a simple cross coordinate checking. When 3.3"/pixel pixel scale has been taken into account, one pixel up-limit matching is well beyond the accuracy of the ROTSE–IIId telescopes as given by Smith et al. (2003a). Although one pixel matching seems to produce fairly good results, false-positive matching must be examined to obtain scientifically correct light curves. Some statistical methods have also been tested, however, manual removal of these possible mismatches currently is the preferred procedure. The outcome of the pipeline was the light curves of 244 well known Mira stars. A detailed period analysis was carried out for 70 Mira variables having sufficient number of data points in their light curves.

We have used the CLEANest method (Foster, 1995, 1996a,b) which is integrated into the Peranso software (Husar, 2006) to determine all periods approximately between 100 and 800 days for Mira variables in our sample. In addition to this, Period04 software (Lenz and Breger, 2005) was used to validate the results that have been examined by the CLEANest. Barycentric corrections were applied to the times of all stars examined in this study.

3. Light curves and periods

Period searches for long period variables (LPV) like semiregular (SR) and Mira type variables are long, time-consuming work and they are also very important for the Period-Luminosity/Color/Radius relations and the pulsation mode detection. LPV require long term continuous photometric observations for the pulsation period detection due to their long period variations and variability natures.

We have examined the long term variations from ROTSE–IIId observations between 2004 and 2009 and looked for the pulsation periods of Mira variables defined in SIMBAD database. All available light curves of Mira variables are used to search the periodicity. We