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LONG PERIOD VARIABLES IN STELLAR CLUSTERS: IC4651

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Introduction

The research on long period variables (LPVs) experienced a significant upturn in the past two decades when large photometric surveys led to a huge number of high quality LPV light curves. Major steps forward in our understanding were possible by the observation of stellar samples with known distance, in particular those from the Magellanic Clouds (e.g. Wood 2000, Lebzelter et al. 2002, Fraser et al. 2005, Soszyński et al. 2007). It was found that the pulsation of any LPV follows one of several parallel period-luminosity (PL) relations. To better understand this variability behavior, two of us (TL, PW) initiated a monitoring program to detect and characterize LPVs in stellar clusters. For a detailed description of this program we refer to Lebzelter & Wood (2011) and references therein. Observations and data reduction are briefly summarized below.

Within this program we monitored the open cluster IC4651. Several photometric and spectroscopic studies exist for this cluster in the literature, among the most recent ones being Anthony-Twarog et al. (2000), Meibom et al. (2002), Pasquini et al. (2004), and Mikolaitis et al. (2011). IC4651 is an intermediate age open cluster (1.7 Gyr) at a distance of about 1.01±0.05 kpc and a reddening value of E($B-V$)=0.1 mag (Meibom et al. 2002; Pasquini et al. 2004). Various spectroscopic studies on cluster dwarfs suggest a slightly super-solar metallicity (e.g. Carretta et al. 2004, Pace et al. 2008). A depletion of carbon and an overabundance of nitrogen relative to the sun have been reported by Mikolaitis et al. (2011).

Observation and data reduction

Monitoring of IC4651 started in May 2002 at the 50 inch telescope at Mount Stromlo. The telescope was equipped with a two channel camera used earlier for the MACHO experiment (Alcock et al. 1992) and it obtained red and blue images simultaneously. The wavelength centre of the blue channel was similar to that of Johnson V, while the centre of the red channel was close to that of Johnson R. Observations were obtained once to twice a week. Our monitoring came to an abrupt stop after a few months when Mount Stromlo observatory was destroyed by a bush fire. Altogether we collected 23 frames over 130 days, but only 17 frames were usable for our analysis. All observations were done in queue observing mode.

Since in the blue band the light amplitude of long period variables is typically larger than in the red (e.g. Fox & Wood 1982), the blue range received a higher weight for detecting and characterizing variables. The presence of bad pixels did not allow to search for variability in all the stars in our field of view.

The image subtraction code ISIS 2.1 (Alard 2000) was used for the detection of variable stars and extraction of light curve data. Stellar fluxes of the candidate stars on the reference frame were measured using standard IRAF routines. To determine the photometric zero point, the known V mag of several standard stars from the Guide Star Catalogue (Lasker et al. 2008) were compared with our calculated values. No correction has been made for the difference between Johnson V and MACHO Blue.

Among the 150 variable star candidates detected in the observed field, the long period variables were selected based on the brightness (on the upper giant branch), timescale of the variation (more than 30 days), and a total light amplitude in V of at least 0.05 mag. The period search was done using Period98 (Sperl 1998), a code which computes a discrete Fourier transformation in combination with a least-squares fitting of multiple frequencies on the data. We considered a maximum of two periods for each star. We note that for the typical periods of tens of days found for the variables, the light curves are well sampled so that aliasing should not be a significant problem. Due to the semi-regular nature of LPVs, any periodicity found represents only a snapshot of a possibly more complex light curve, and some non-detected variability of much longer time scales (more than 250 days) may exist as well.

Results

One likely LPV had been detected in IC4651 in the course of the ASAS survey (Pojmanski & Maciejewski 2004). We could confirm that detection and found three new long period variables in the cluster. All four stars are listed in Table 1 with their coordinates, V and DENIS I magnitudes, periods, amplitudes, and 2MASS magnitudes. We used V1 as identifier for the known variable while other variables were named using the prefix 'SLW'.

In Figure 1, the light variations of the four LPVs are plotted against time starting with the first date of our time series. Also shown are synthetic light curves using the periods given in Table 1. From previous work on similar data sets we estimate a typical photometric error around 0.02 mag. The weakest point in the light curve of SLW3 may have a higher photometric uncertainty. As one can see, all the variables have a period exceeding 60-70 days. At least one complete variability cycle has been covered for each star. We cannot say anything about possible long secondary periods in these stars since they are expected to exceed the time span of our monitoring by a factor of about six. The period we find for V1 is in good agreement with the literature value of 93.8 d.

Along with the variable stars for which we can estimate a period, we have listed 3 stars in Table 2 that showed variability but without a clear periodicity. This may be due to a truly irregular nature of their light change, but the length of our time series is not sufficient to clearly classify them as long period variables.

Concerning the membership in IC4651 of the stars in Tables 1 and 2, we can rely on a few studies found in the literature and the stars' locations in the cluster's colour-magnitude diagram (CMD, Fig. 2). Unfortunately, there is very little information available for V1. Based on the CMD, its membership is rather unlikely, since the star is clearly offset to the red from the cluster's giant branch. Much better data exist for the newly discovered variables. SLW1, SLW2, SLW3, SLW5, and SLW6 all show radial velocities very close to the mean cluster velocity (Meibom et al. 2002, Kordopatis et al. 2013). Including also

Table 1: Long period variables in the field of IC4651

Name	RA(2000)	Dec(2000)	$V_{\rm mean}$ [mag]	I^a [mag]	J [mag]	H [mag]	K [mag]	Period [d]	ΔV [mag]
V1	17 25 09.35	−49 52 03.6	12.89	9.413	7.007	6.051	5.646	97	0.75
SLW1	17 25 08.95	−49 53 57.1	9.28	8.641	5.747	4.948	4.660	114	0.06
SLW2	17 24 49.48	−49 57 26.7	11.01	9.809	8.901	8.350	8.209	73	0.4
SLW3	17 24 33.40	−49 54 56.0	10.54	9.109	8.137	7.528	7.341	85	0.27

[a] I-band data taken from DENIS database.

Table 2: Long period variable candidates of IC4651 with unknown periods

Name	RA(2000)	Dec(2000)	$V_{\rm mean}$ [mag]	I^a [mag]	J [mag]	H [mag]	K [mag]
SLW4	17 25 14.50	−50 02 49.2	11.51	10.203	9.408	8.881	8.740
SLW5	17 24 54.16	−49 53 07.5	10.53	9.182	8.081	7.469	7.264
SLW6	17 24 46.71	−49 54 07	11.04	9.728	8.912	8.391	8.247

[a] I-band data taken from DENIS database.

proper motion information, Kharchenko et al. (2004) give a high membership probability to these five stars. However, membership probabilities from proper motion data do not give a homogeneous result (e.g. Dias et al. 2006). SLW4 is probably a field star according to its radial velocity.

While the radial velocity data suggest a membership of most of the newly detected variables, the situation is not as clear when combining variability information and location in the cluster's CMD. Using an age of 1.7 Gyr, a star on the upper giant branch would have had a main sequence mass of about 1.7 $M_\odot$ (Bertelli et al. 2008). The tip of the RGB of IC4651 would then be near K=4.0. SLW1 is therefore located about half a magnitude below the RGB tip, SLW2-6 are 3-4 magnitudes below the RGB tip. Thus these variables could be either RGB or early-AGB stars of the cluster. Two stars, SLW2 and 3, have photometric amplitudes of a few tenths of a magnitude and periods of ≈80 days. However, such an amplitude and period, while typical of an AGB star, is not expected for an object that far below the RGB tip according to results from the Magellanic Clouds (cf. Kiss & Bedding 2003). Their variability behaviour suggests that these stars are more likely background objects. However, considering the cluster's location this would place them ≈700 pc above the Galactic plane, which would be quite unlikely. Further studies of these two stars are needed to clarify their nature. SLW1 has a photometric amplitude of less than 0.1 mag, so we think it is an RGB or AGB star belonging to the cluster.

The number of known long period variables with independently defined masses is still very small, in particular for masses above 1 $M_\odot$. A systematic search of LPVs in open clusters is an important source for increasing this number. In this paper we presented several candidates that are possibly members of the intermediate-age cluster IC4651. Further studies are needed to confirm and characterize their nature.

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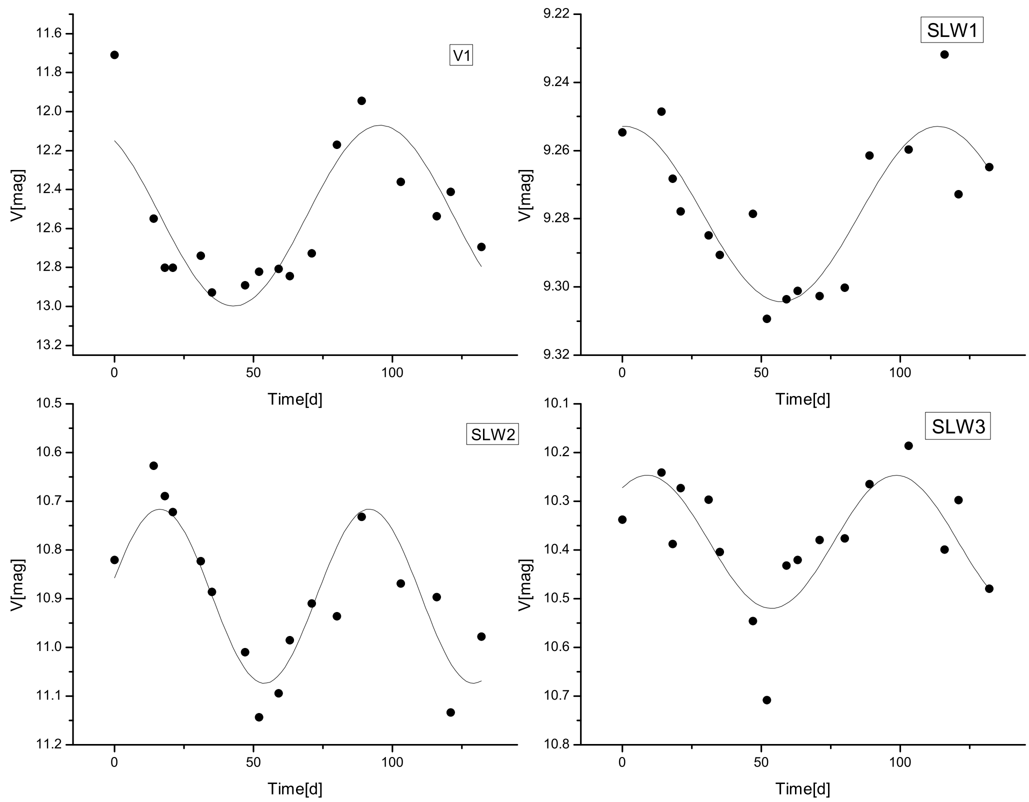

Figure 1. Light curves of the four variables detected in IC4651. Fits to the brightness change are based on the periods given in Table 1. The time axis starts at JD 2452410, the start of our monitoring.

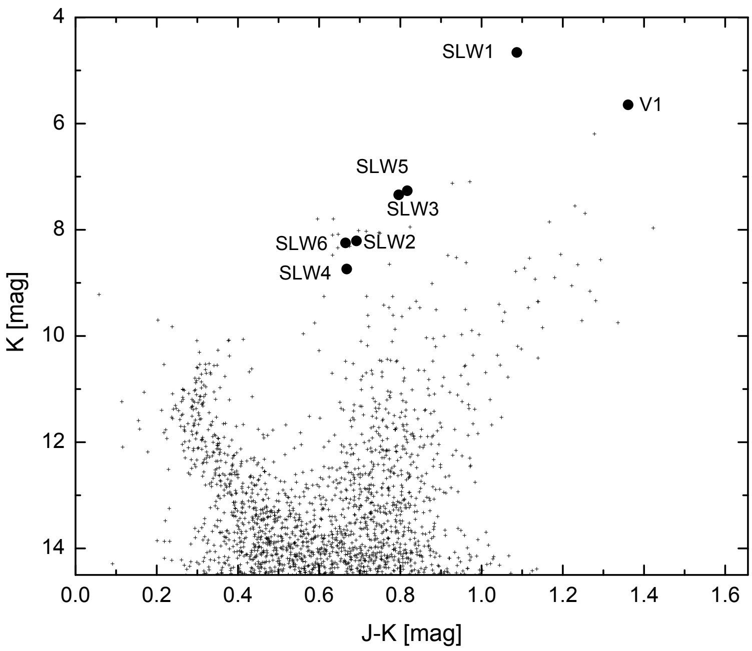

Figure 2. 2MASS colour-magnitude diagram for sources 10 arcminutes around the centre of IC4651. The LPVs from Tables 1 and 2 are marked. The position of the giant branch in this intermediate age cluster is consistent with the positions of variables SLW 1-6 (see the collection of intermediate age giants in Fig. 2 of Bessel et al. (1983), adjusted for a distance modulus of 10.0).

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