Searching for short-period variable stars in the direction of Coma Berenices and Upgren 1 open clusters: Melotte 111 AV 1224 a new eclipsing binary star

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Abstract

We report the results of CCD photometric observations in the direction of the Coma Berenices and Upgren 1 open clusters with the aim at searching for new short-period variable stars. A total of 35 stars were checked for variability. As a result of this search the star designated in the SIMBAD database as Melotte 111 AV 1224 was found to be a new eclipsing binary star. Follow-up Strömgren photometric and spectroscopic observations allowed us to derive the spectral type, distance, reddening and effective temperature of the star. A preliminary analysis of the binary light curve was performed and the parameters of the orbital system were derived. From the derived physical parameters we conclude that Melotte 111 AV 1224 is most likely a W-Uma eclipsing binary that is not a member of the Coma Berenices open cluster. On other hand, we did not find evidence of brightness variations in the stars NSV 5612 and NSV 5615 previously catalogued as variable stars in Coma Berenices open cluster.

Keywords: techniques: photometric, spectroscopic –open clusters: individual: Melotte 111, Upgren 1, stars: variability – stars:

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1. Introduction

The study of short period variable stars in open clusters is fundamental in stellar evolution. Since all the cluster members are assumed to have the same interstellar reddening, distance, age and chemical abundance, it is possible to put strong constraints on these physical parameters of the cluster variables in asteroseismic model calculations [e.g. Fox Machado et al. (2001, 2006)].

Besides the great success of multichannel photoelectric photometers to study short period variables in open clusters [e.g. Costa et al. 2007; Fox Machado et al. (2002, 2004); Li et al. (2002, 2004)], CCD technique working in the time-series photometry mode has been preferred for open clusters observations (e.g. Kang et al. 2007; Kopacki et al. 2008; Luo et al. 2009, Choo et al. 2003). Indeed a CCD camera allows to obtain high precision photometric data by measuring the program star and reference stars simultaneously in the CCD’s field of view (FOV hereafter) under the same weather and instrumental conditions. The number of stars observed simultaneously with a CCD camera may vary from a couple, in case of a small FOV and sparse fields (e.g. Baran et al. 2011), up to thousands for mosaic CCDs pointing near the plane of the Milky Way.

Taking the advantage of CCD cameras we have carried out a search for new short period variable stars in the direction of the Coma Berenices and Upgren 1 open clusters. Coma Berenices (Melotte 111 hereafter, RA = 12\textdegree 23\textdegree 9, DEC = +26\textdegree 00\textprimeminutes, J2000.0) is the second closest open cluster to the Sun being more distant than the Hyades (∼45 pc) but closer than the Praesepe (∼180 pc). The Hipparcos intermediate astrometry data place it at $d = 86.7 \pm 0.9$ pc (van Leeuwen 2009). An almost solar metallicity has been derived in the cluster (e.g. [Fe/H] = −0.065 ± 0.021 dex, Cavrel de Strobel 1990; [Fe/H] = 0.052 ± 0.047 dex, Friel & Boesgaard 1992). The age of the cluster is estimated at between 400 and 600 Myr (e.g. Bounatrio & Arimoto 1993).

Several investigations which have addressed the stellar population in Melotte 111 support the fact that the cluster has relatively few members and, particularly that it is poor in low-mass stars. (e.g., Artukhina et al. 1955; Argue & Kenworthy 1969; De Luca & Weiss 1981; Bounatrio & Arimoto 1993). Several searches for new low-mass cluster members have been recently performed but without more success than early studies (e.g., Caswell et al. 2006; Mermilliod et al. 2008; Melnikov & Eisloeffel 2012; Terrien et al. 2014). In particular, Terrien et al. (2014) have addressed the membership of the stars in direction of Coma Berenices using SDSS III APOGEE radial velocity measurements, confirming just eight K/M dwarf new candidate members of the cluster. Given that Melotte 111 is relatively sparse and the verification of membership in the cluster has been challenging, the detection of new variable stars that are members of the cluster is very important. Meolotte 111 covers about 100 deg$^2$ on the sky, but its central part occupies only about 25 deg$^2$. The core of the cluster is estimated between 5-6 pc (Odenkirchen et al. 1998). The catalogue of variable stars in open cluster by Zejda et al. (2012) lists 57 variable stars belonging to the Meolotte 111 open cluster.

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Upgren 1 (RA = 12h35m, DEC = +36°22′, J2000.0) is an association of seven F-type stars located at a distance of ~117 pc and considered to be a remnant of an old galactic open cluster \cite{Upgren1965, Upgren1985}. Gatewood, et al. \cite{1988ApJ...327..925G} studied these stars with a multichannel astrometric photometer and proposed that the cluster is composed of two dynamically different groups. We have observed four stars in this association.

The paper is organized as follows. In Sect. 2, the acquisition of the data and the description of the observations are presented. In Sect. 3, the analysis of differential light curves and the fields observed are discussed. Sect. 4 is devoted to the analysis of the light curve and the physical parameters of Melotte 111 AV 1224. In Sect. 5 we summarize our conclusions.

2. Observations and data reduction

The CCD observations have been made with the 0.84-m f/15 Ritchey-Chrétien telescope at Observatorio Astronómico Nacional at Sierra San Pedro Mártir (OAN-SPM), during ten consecutive nights, between April 11 and 20, 2009. The telescope hosted the filter-wheel ‘Mexman’ with the Marconi (E2V) CCD camera, which has a 2048 × 2048 pixels array, with a pixel size of 15 × 15 μm². The gain and readout noise of the CCD camera are 1.8 e⁻/ADU and 7.0 e⁻, respectively. The typical field of view in this configuration is about 8′ × 8′ arcmin² with the scale of 0.28′/pixel. To search for short-period variable stars in direction of Melotte 111 we observed three fields centered at the following coordinates \( \alpha_{J2000.0} = 12^h21^m22^s.0 \), \( \delta_{J2000.0} = +25^\circ08′31.0″ \); \( \alpha_{J2000.0} = 12^h26^m05^s.0 \), \( \delta_{J2000.0} = +26^\circ46′00.0″ \) and \( \alpha_{J2000.0} = 12^h21^m57^s.0 \), \( \delta_{J2000.0} = +25′00″00.0″ \). The images of these FOVs are shown in Figures \ref{fig:fov1} to \ref{fig:fov2} respectively.

Sky flats, dark and bias exposures were taken each night. All CCD images were preprocessed to correct overscan, trim unreliable and useless regions, subtract bias frames, correct flat fielding and reject cosmic rays using the IRAF/CCDRED package. Then, instrumental magnitudes of the stars were computed using the point spread function fitting method of the IRAF/DAOPHOT package \cite{1992AJ....103.1062M}. The photometry is gathered in tables where frame No., HJD, airmass, UT, photometric instrumental magnitudes and photometric errors are included. Typical internal errors of the single frame photometry for stars are of about 0.001 mag in the bands used. The differential light curves were derived on a star-to-star basis computing the difference in magnitude of one star with respect
to the others. In that way each star was checked for variability relative to at least two reference stars.

3. Analysis of differential light curves

We proceeded to search for short-period variable stars in each observed field using the differential CCD time-series photometry obtained in the previous section. Our calculations for a \( V = 15 \) mag star indicated that with 8 hours of data we can achieve a detection threshold around \( 1 \) mmag (millimagnitude) level. Assuming a \( 4\sigma \) definition for the threshold, the noise level should be 0.25 mmag. This detection threshold is very typical for most ground-based observations.

Figure 1: CCD FOV 1. The following targets were observed: 1-NSV 5613 (Galaxy), 2-Melotte 111 AV 1176, 3-USNO B1 1151-0193005, 4-USNO B1 1151-0193006, 5-Melotte 111 AV 1192, 6-Melotte 111 AV 1196, 7-USNO B1 1151-0193137, 8-USNO-B1 1151-0193141, 9-SSDS J122135.75+250714.5, 10-Melotte 111 AV 1204, 11-Melotte 111 AV 1207, 12-SSDS J122135.63+251028.0, 13-SDSS J122135.43+251039.0, 14-SDSS J122133.76+251127.7, 15-SDSS J122133.76+251127.7, 16-SDSS J122121.31+251048.2, 17-SDSS J122123.35+250859.9, 18-SDSS J122123.35+250859.9, 19-SDSS J122108.89+250949.1. North is up and East is left.

Figure 2: CCD FOV 2. The following targets are identified: 1-IC 3194 (Galaxy), 2-Melotte 111 AV 1176, 3-USNO B1 1151-0193085, 4-USNO B1 1151-0193005, 5-Melotte 111 AV 1192, 6-Melotte 111 AV 1196, 7-USNO B1 1151-0193137, 8-USNO-B1 1151-0193141, 9-SSDS J122135.75+250714.5, 10-Melotte 111 AV 1204, 11-Melotte 111 AV 1207, 12-SSDS J122135.63+251028.0, 13-SDSS J122135.43+251039.0, 14-SDSS J122133.76+251127.7, 15-SDSS J122133.76+251127.7, 16-SDSS J122121.31+251048.2, 17-SDSS J122123.35+250859.9, 18-SDSS J122123.35+250859.9, 19-SDSS J122108.89+250949.1. North is up and East is left.
The search for stellar pulsations was done in two steps. First, all differential light curves were visually inspected for the presence of obvious variability. In this way we searched the light curves for features like eclipsing binaries, planetary transits, flares and high amplitude pulsations. Second, all light curves were subject to Fourier analysis. This latter step is very convenient in analysis of periodicities. It may uncover a periodic change with either a very tiny amplitude not easily seen directly in the light curves or a short period like those present in pulsating white dwarfs or sdB type variables. We calculated Fourier transform up to the Nyquist frequency.

Some comments on the observed field can be made. The FOV 1 (Fig. 1) includes six stars. Two stars, NSV 5613 (BD+27 2129) and NSV 5615 (BD+27 2130), have been classified in the literature as variable stars of Melotte 111. NSV 5613 was reported as suspected variable of Melotte 111 by Golay (1973) while NSV 5615 has been classified as a RR Lyrae type variable star by Archer (1959). Since then no new observations...
of these targets has been reported to the best of our knowledge. These stars are also listed in the International Variable Star Index (VSX) database of the American Association of Variable Star Observers (AAVSO). Moreover both stars are included in the catalogue of variable stars in open clusters by Zejda et al. (2012), but no period information is given for them. We have observed both targets and the adjacent field stars through a Strömgren y filter with 30 sec of exposure times which correspond to a Nyquist frequency of 1980 c/d (see Table 1 for details). The light curves and amplitude spectra of these two stars are shown in Fig. 5. As can be seen there is no evidence of periodic variations either in the light curves or in the amplitude spectra. We conclude that these stars have been wrongly classified as variables, as they do not pulsate at all.

The FOV 2 (Fig. 2) is the most crowded field we have observed. The light curves of the 19 targets numbered in the figure has been derived. The following stars are listed as members of Melotte 111 in the SIMBAD database: Melotte 111 AV 1176, Melotte 111 AV 1192, Melotte 111 AV 1196, Melotte 111 AV 1204 and Melotte 111 AV 1207. This FOV was observed through a Johnson V filter with an exposure time per image of 60 sec corresponding to a Nyquist frequency of 635 c/d. After carefully analyzing the light curves and amplitude spectra of all the stars in this FOV we conclude that none of the stars present significant variations attributed to intrinsic pulsations.

As was mentioned before the FOV 3 (Fig. 3) was set in direction of Upgren 1. We have observed four stars of this association namely HD 109509, HD 109530, HD 109542 and BD+37 2295 through a y-Strömgren filter with a exposure time of 20 sec resulting in a Nyquist frequency of 2274 c/d. After checking carefully the light curves and the amplitude spectra we conclude that none of the stars is variable.

Five stars in FOV 4 (Fig. 4) were checked for variability. Three stars are presumable members of Melotte 111, namely Melotte 111 AV 1224, Melotte AV 1236, Melotte 111 AV 1248. We found evident brightness changes on a time scale of few hours in Melotte 111 AV 1224. The adjacent stars in the field were found not to be variable stars. An in depth analysis of the light curve is given in the next section.

4. Melotte 111 AV 1224

4.1. Light curve and period analysis

Due to variable nature of Melotte 111 AV 1224, we decided to monitor this star during all remaining nights. A total number of 818 frames were obtained through a V Johnson filter. The exposure time was set to 120 sec.

The light curve of Melotte 111 AV 1224 in the time space is shown in Fig. 6. As can be seen there is no evidence of periodic variations either in the light curves or in the amplitude spectra. The following ephemeris was derived from the computed period of the binary system:

\[ HJD_{\text{max}} \; I = 2454938.728637 + 0.345895 \times E \]  

where the reference epoch was chosen to be the initial HJD time of the light curve.

Apart from calculating the light elements using the period derived with the Period04 program, we have also explored other means by which to determine the period of Melotte 111 AV 1224. To do so, we determined individual time of maximum from the photometry data via the method of Kwee & van Woerden (1956). A total of 6 timings were obtained (4 primary eclipses and 2 secondary eclipses) which are listed in Table 2. These were then used to establish a period and a reference epoch by solving for a linear ephemeris using standard least-squares techniques. Primary and secondary maxima were adjusted simultaneously and the orbit was assumed to be circular. The resulting period and epoch are given by \( P = 0.3454 \) and \( T_0 = 2454938.7244 \) respectively. The period is in agreement with that derived with the Period04 program. However as the related uncertainties are larger, we adopt the ephemeris (1) for the remainder of the paper.

4.2. Strömgren photometry and spectroscopy

In order to shed more light on the physical nature of Melotte 111 AV 1224 Strömgren photometry and low-resolution spectroscopy was performed.
Strömgren photometric observations were secured in June 2010 by using the 1.5-m telescope with the six-channel Strömgren spectrophotometer. This photometer has been widely used recently for deriving physical parameters of open clusters [e.g. Peña et al. (2007, 2011)]. The observing procedure is the same as explained in Fox Machado et al. (2010). Briefly, the observing routine consisted of five 10 s of integration of the star from which five 10 s of integration of the sky was subtracted. Along with Melotte 111 AV 1224 also observed were some A-F type Kepler targets (Uytterhoeven et al., 2011). A set of standard stars was also observed to transform instrumental observations into the standard system and to correct for atmospheric extinction. The instrumental magnitudes (inst) and colours, once corrected from atmospheric extinction, were transformed to the standard system (std) through the well known transformation relations given by Strömgren (1966):

\[
V_{\text{std}} = A + y_{\text{inst}} + B(b - y)_{\text{inst}}
\]

\[
(b - y)_{\text{std}} = C + D(b - y)_{\text{inst}}
\]

\[
m_{1,\text{std}} = E + Fm_{1,\text{inst}} + G(b - y)_{\text{inst}}
\]

\[
c_{1,\text{std}} = H + Ic_{1,\text{inst}} + J(b - y)_{\text{inst}}
\]

\[
H_{\beta,\text{std}} = K + LH_{\beta,\text{inst}}
\]

where V is the magnitude in the Johnson system, and the \(m_1\) and the \(c_1\) indices are defined in the standard way: \(m_1 \equiv (u - v) - (v - b)\) and \(c_1 \equiv (v - b) - (b - y)\).

The following indices in the Strömgren system for Melotte 111 AV 1224 were derived: \(V = 13.395 \pm 0.018, \ (b - y) = 0.473 \pm 0.001, \ m_1 = 0.271 \pm 0.006, \) and \(c_1 = 0.292 \pm 0.001, \ H\beta = 2.575 \pm 0.083.\)

Spectroscopic observations were conducted at the 2.12-m telescope in June 2011. We used the same equipment as explained by Baran et al. (2011b). In particular, we used Boller & Chivens spectrograph installed in the Cassegrain focus of the telescope. The 400 lines/mm grating with a blaze angle of 4.18\(^\circ\) was used. The grating angle was set to 7\(^\circ\) to cover wavelength range from 4000 Å to 7500 Å. A 2048x2048 E2V CCD camera was used in the observations. The typical resolution of the recorded spectra is 8 Å and the dispersion amounts to 1.8 Å per pixel. The reduction procedure was performed with the standard routines of the IRAF package. The spectral type was derived by comparing the normalized spectrum of Melotte 111 AV 1224 with those of well classified stars taken on the same night. We have assigned a spectral type of K0V to Melotte 111 AV 1224. Fig. 7 shows the reduced spectrum of Melotte 111 AV 1224 and the spectrum of a standard star of spectral type K0V for comparison.

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### Table 1: Log of observations.

| UT Date 2009 | Fields | Start Time (HJD 2454900+) | End Time (HJD 2454900+) | Filter | Exp. time (sec) | No. of Images |
|--------------|--------|--------------------------|-------------------------|--------|----------------|---------------|
| April 12     | FOV 1  | 33.660060                | 33.956975               | y      | 30             | 1069          |
| April 13     | FOV 2  | 34.649227                | 34.974052               | V      | 60             | 350           |
| April 16     | FOV 3  | 37.705917                | 37.989076               | y      | 20             | 1195          |
| April 17     | FOV 4  | 38.631485                | 38.973245               | V      | 120            | 230           |
| April 18     | FOV 4  | 39.683163                | 39.683163               | V      | 120            | 205           |
| April 20     | FOV 4  | 41.661120                | 41.953617               | V      | 120            | 176           |
| April 21     | FOV 4  | 42.669725                | 42.669725               | V      | 120            | 207           |

### Table 2: Times of maxima for Melotte 111 AV 1224.

| HJD       | Type | E    | O-C  |
|-----------|------|------|------|
| 2454938.728637 ± 0.000168 | I    | 0.0  | 0.000000 |
| 2454938.887158 ± 0.000297 | II   | 0.5  | -0.014426 |
| 2454939.761764 ± 0.002490 | I    | 3.0  | -0.004557 |
| 2454939.921642 ± 0.000067 | II   | 3.5  | -0.0017626 |
| 2454941.839738 ± 0.000670 | I    | 9.0  | -0.001950 |
| 2454942.869751 ± 0.000209 | I    | 12.0 | -0.009621 |

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Figure 7: Stellar spectrum of Melotte 111 AV 1224 and HD 185144 a K0V star.
4.3. Physical parameters from Strömgren photometry and spectroscopy

We have used the standard $uvby - \beta$ indices to estimate the unreddened colours of Melotte AV 1224. The UBVYBET[4] IDL code was implemented to derive the following intrinsic colours: $E(b - y) = 0.022, (b - y)_0 = 0.451, m_0 = 0.278, c_0 = 0.288, M_V = 5.35$ which lead to $T_{\text{eff}} = 5450 \pm 300$ K and $R = 0.92 \pm 0.2 R_\odot$. A similar value of $T_{\text{eff}}$ is obtained using the calibrations of Ramirez & Meléndez (2005) for FGK stars. The intrinsic colours are consistent with an early K-type star in agreement with our spectroscopic classification. As a reference, the atmospheric parameters of the standard star HD 185144 are the followings: $T_{\text{eff}} = 5318$ K, $\log g = 4.59$ cm/s$^2$, $T_{\text{c}} = 288, M = 0.92, V = 35$ which lead to a distance of 392 pc implying that Melotte 111 AV 1224 is rather located behind the Melotte 111 open cluster.

4.4. Light curve modeling

Using the light elements derived in Sect. 4.1, we have constructed the phased light curve of Melotte 111 AV 1224 shown in Fig. 8. In an effort to gain a better understanding of the binary system and determine its physical properties, we have analyzed the phased light curve with the software PHOEBE V.0.31a (PHysics Of Eclipsing BinariEs, Prsa & Zwintz 2005). PHOEBE is a software package for modeling eclipsing binary stars based on the Wilson-Devinney code (Wilson & Devinney, 1971). It permits creation of a synthetic light curve that would best fit the observational data by adjusting interactively the orbital and stellar parameters through a user interface friendly. We averaged the phases and magnitudes every three points and use this binned light curve as input in the PHOEBE code.

In the light curve analysis we assume a few fixed parameters during the fitting process: the temperature of the primary star, based on the Strömgren photometry (Sect. 4.3) is set to $T_1 = 5450$ K; the period of the system and zero time $HJD_0$ were obtained from equation (1). The logarithmic limb-darkening coefficients and bolometric limb-darkening coefficients, were determined from tables by van Hamme (1993) for the primary and secondary components, respectively. Standard values of bolometric albedos (Rucinski, 1969), and the gravity-darkening coefficients (Lucy, 1967) for radiative and convective envelopes were used. The adjustable parameters in the light curves fitting were the orbital inclination $i$, the surface potentials $\Omega_1$ and $\Omega_2$, the effective temperature of the secondary $T_2$, the mass ratio $q$ and luminosity of the primary component.

The shape of the light curve of Melotte 111 AV 1224 resembles those of both systems classical Beta Lyrae (EB) and W-UMa, with a difference in amplitude of the primary and secondary eclipses and with no clear beginning and end of the eclipses. The difference in eclipse amplitudes strongly suggests significant deformation of the components and perhaps some degree of contact. Consequently, we performed fits in overcontact mode (Mode-3), in semidetached mode with the primary filling its Roche lobe (Mode-6) and in semidetached mode with the secondary component filling its Roche lobe (Mode-7). As the primary and secondary eclipses occur at almost 0.5 phase interval suggesting a circular orbit, we have set the eccentricity $e = 0.0$. During the fitting process the iterations were carried out automatically until convergence, and a solution was defined as the set of parameters for which the differential corrections were smaller than the probable errors and the smallest $\chi^2$ was obtained. With all configurations two spots on the secondary component have been considered during the fitting process to account for a slight asymmetry in the light curve. Our analysis reveals that astrophysically reasonable solutions are obtained with either configuration overcontact or semidetached with the secondary filling its Roche lobe, even though the smallest $\chi^2$ is achieved in overcontact configuration. Figure 9 depicts our best-fit theoretical light curve (solid line) fitted to the observational data (circles) in overcontact configuration mode. The full list of fitted, absolute and spots parameters is given in Table 3. For comparison in Table 4 the fitted parameters in semidetached configuration are listed. The uncertainties assigned to the adjusted parameters are the internal errors provided directly by the code.

Briefly, our results show that the Melotte 111 AV 1224 system appears to have a mass ratio of $q \approx 0.21$, and low inclination angle of $i \approx 45^\circ$, and a secondary star temperature of $T_2 \approx 4200$ K. A temperature difference of $\sim 1000$ K between the two components is obtained which is consistent with the different eclipse depths observed in the light curves.

5. Results and conclusions

A summary of a search for new short-period pulsating variables in direction of the open clusters Melotte 111 and Upengren 1 has been presented. 35 stars were checked for variability in four observed fields. We did not confirm the variability in the stars NSV 5612 and NSV 5615 considered as variable stars of the Melotte 111 open cluster. On the contrary, the star Melotte 111 AV 1224 was found to be a new eclipsing binary star. Follow-up CCD observations of Melotte 111 AV 1224 allowed us to estimate the orbital period and ephemeris of the system. Based on Strömgren standard photometry and low-resolution spectra we conclude that the primary component is most likely an early K-type dwarf. The analysis of the Strömgren standard photometry place it to 392 pc much more farther that Melotte 111 open cluster ($\sim 87$ pc). Therefore, Melotte 111 AV 1224 is not dynamically associated with the Melotte 111 open cluster. This is consistent with the fact already pointed out in early investigations that the Melotte 111 open cluster has relatively few members and particularly that it is poor in low-mass stars. Although a classical Beta Lyrae (EB) binarity classification cannot be ruled out, our analysis of the light curve of Melotte 111 AV 1224 revealed properties similar in many respects to those of the W UMa systems, which are characterized by having short orbital periods (0.2 - 0.8 d)
and are composed of F-K type stars sharing a common envelope. However the evolutionary history of the system is not clear due to the missing of radial velocity data. We have found that both models, overcontact and semidetached, systems fit the observed light curves equally well. We think that the system is undergoing cyclic variations with alternating phases of true contact and semidetached, but almost contact, phases. During the contact phases the characteristic W-Uma light curve should be observed, while during semidetached phases the surface temperature of the components should be different, thus producing Beta Lyrae (EB) type light curve. Therefore we are probably seeing the semidetached phases of the system.

To date our observations represent the most extensive work on Melotte 111 AV 1224. Overall we believe that our results are the best that we can achieved based solely on photometric observations made in the V filter. For a better understanding of the properties, both spectroscopic observations and photometric data at multiple wavelengths are needed.

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Table 4: Solution parameters for Melotte 111 A V 1224 in semidetached configuration.

| Parameters                                      | Primary component | System               | Secondary Component |
|------------------------------------------------|-------------------|----------------------|---------------------|
| $HJD_0$ [days]                                  | 38.631482         | 4005 ± 100           |
| Orbital period – $P$ [days]                     | 0.345894          |                      |
| Semi-major axis $a$ [$R_\odot$]                 | 2.31 ± 0.49       |                      |
| Mass ratio $q = m_2/m_1$                        | 0.19 ± 0.06       |                      |
| Binary orbit inclination $i$ [°]                | 40 ± 1            |                      |
| Binary orbit eccentricity $e$                   | 0.0               |                      |
| Effective temperature [K]                       | $T_1 = 5450.0$    | $T_2 = 4005 ± 100$   |
| Surface potential                               | $\Omega_1 = 2.349 ± 0.005$ | $\Omega_2 = 3.622 ± 0.06$ |
| Bolometric albedo                               | $A_1 = 0.60$      | $A_2 = 0.60$         |
| Exponent in gravity brightening                 | $g_1 = 0.32$      | $g_2 = 0.32$         |
| Bolometric limb darkening coefficient           | $x_1 = 0.5$       | $x_2 = 0.5$          |
| Linear limb darkening coefficient               | $y_1 = 0.5$       | $y_2 = 0.5$          |
| Absolute parameters                             |                   |                      |
| Potential of Lagrangian point                   | $\Omega(L_1) = 2.379$ | $\Omega(L_2) = 2.211$ |
| Mass [$M_\odot$]                                | $M_1 = 1.064$     | $M_2 = 0.278$        |
| Radius [$R_\odot$]                              | $R_1 = 1.129$     | $R_2 = 0.617$        |
| Bolometric absolute magnitude                   | $M_{bol}^1 = 7.656$ | $M_{bol}^2 = 4.778$  |
| Surface gravity, log $g$                        | $\log(g_1) = 4.359$ | $\log(g_2) = 4.301$ |
| Luminosity [$L_\odot$]                          | 1.622             | 1.659                |
| Spot parameters                                 |                   |                      |
| Colatitude [°]                                   |                   |                      |
| Longitude [°]                                    |                   |                      |
| Radius [°]                                       |                   |                      |
| Temperature factor $T_{spot}/T_{surf}$           |                   |                      |
| Spot 1                                          | 6                 | 100                  | 0.7                 |
| Spot 2                                          | 4                 | 110                  | 35                  | 2.0                 |

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Figure 8: Phased light curve of Melotte 111 AV 1224.

Figure 9: The binned observational light curve in $V$ band (circles) and the best theoretical fit model (solid line) of Melotte 111 AV 1224.
