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# 2MASS J10274572+0629104: The very short period young M6 Dwarf Binary System identified in K2 data

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## ABSTRACT

We report the identification of a very low mass new binary system 2MASS J10274572+0629104, based on *Kepler* K2 photometry and *Gaia* DR2 astrometry. The K2 light curve is consistent with a beat pattern of two periodic signals, and using Lomb-Scargle periodogram, we find two rotation periods of  $0.2114 \pm 0.0002$  day and  $0.2199 \pm 0.0003$  day. We conclude that these rotation periods arise from two stars with similar spectral types of M6, and have near equal luminosity. It is the first ultracool binary system to be identified based on beat patterns in the light curve. Near-infrared spectroscopy yields  $RV = -9.8 \pm 0.6$  km s<sup>-1</sup>,  $v \sin i = 21.5 \pm 1.1$  km s<sup>-1</sup>,  $T_{\text{eff}} = 3110 \pm 40$  K, and  $\log g = 5.2 \pm 0.2$ . The motions are consistent with a young age, as are the rotation periods, but the source does not appear to be part of any known moving group. Furthermore, we detected three strong white light flares in the K2 light curve, with estimated total bolometric (UV/optical/IR) energies to be  $2.8 \times 10^{33}$ ,  $5.2 \times 10^{33}$  and  $3.8 \times 10^{33}$  erg respectively.

**Key words:** stars: individual: 2MASS J10274572+0629104 - stars: rotation - stars: low-mass - stars: binaries

## 1 INTRODUCTION

M dwarfs, commonly known as red dwarfs, are the most populous stellar objects in the solar neighborhood and our Galaxy, comprising ~75% of all main sequence stars (Clements et al. 2017). In addition, ~25% of these red dwarfs are found to be in binary or higher order multiple systems (Duchêne & Kraus 2013), and ultracool dwarfs (with spectral type  $\geq M6$ ) have a binary fraction of  $20 \pm 4\%$  (Allen 2007). The discovery of TRAPPIST-1 planetary system (Gillon et al. 2016, 2017; Luger et al. 2017) demonstrates that M dwarfs have a high potential of hosting planets, making the study of various fundamental parameters such as rotational period, multiplicity, age, etc, important for characterizing these planets. The rotational period, in particular, measures the angular momentum evolution of M dwarfs, and can be used for gyrochronology - when combined with other properties like activity and color. Rotation also plays a role in powering the magnetic dynamo of fully convective stars with masses  $M < 0.35 M_{\odot}$  (Newton et al. 2016 and references therein).

There are different methods of identifying binary systems, including direct imaging, radial velocity (RV) variability, spectral blend inversion, astrometric variability and overluminosity on color magnitude diagrams (Bardalez Gagliuffi et al. 2014 and references therein). These methods are biased toward different types of binary

systems based on separations, mass ratios and/or luminosity ratios. The high precision photometry of the *Kepler* and K2 missions (Koch et al. 2010; Howell et al. 2014) have provided another binary detection method: beat patterns in the combined light curves of variable stars with different rotation periods. Such patterns were seen in *Kepler* light curves of rapidly rotating M dwarfs studied by Rappaport et al. (2014). Here we report the discovery of a very low-mass binary by this method: 2MASS J10274572+0629104 (hereafter 2M1027+0629) which most likely consists of two mid-M dwarfs with very similar rotation periods.

2M1027+0629 (aka SDSS J102745.73+062910.1) was previously reported as a single M6 red dwarf by West et al. (2011). It has a high quality SDSS spectrum which shows H $\alpha$  emission with an equivalent width of  $9.6 \pm 1.4$  Å. In Section 2, we describe K2 photometry, *Gaia* DR2 astrometry and photometry, NIRSPEC spectroscopy of 2M1027+0629, and white light flares observed on it. In Section 3 we discuss the results of observations obtained by K2, *Gaia* and NIRSPEC.

## 2 OBSERVATIONS

### 2.1 K2 photometry

2M1027+0629 was monitored continuously by *Kepler* K2 mission (Howell et al. 2014) in long cadence (~30 minutes, Jenkins et al. 2010) mode in Campaign 14 (31 May, 2017 - 19 August, 2017). Its

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**Table 1.** Properties of 2M1027+0629

	Value	Units	Ref.
PHOTOMETRIC PROPERTIES			
Sp. Type	M6		1
<i>J</i>	14.11±0.03	mag	1
<i>H</i>	13.51±0.04	mag	1
<i>K<sub>s</sub></i>	13.22±0.04	mag	1
<i>i</i>	17.034±0.004	mag	2
<i>G</i>	17.782±0.003	mag	3
<i>K<sub>p</sub></i>	18.17	mag	4
H $\alpha$ EW	9.6±1.4	Å	1
PHYSICAL PARAMETERS			
distance (phot)	67.6	pc	1
$\alpha$	156.940573 <sup>a</sup> (±0.2 mas)	deg	3
$\delta$	6.486120 <sup>a</sup> (±0.3 mas)	deg	3
parallax	10.1 ± 0.3	mas	3
$\mu_{\alpha}$	-1.2 ± 0.5	mas yr <sup>-1</sup>	3
$\mu_{\delta}$	-15.1 ± 0.5	mas yr <sup>-1</sup>	3
SPECTRAL PROPERTIES			
RV	-9.8±0.6	km s <sup>-1</sup>	
$v \sin i$	21.5±1.1	km s <sup>-1</sup>	
$T_{eff}$	3110±40	K	
log <i>g</i>	5.2±0.2	cgs	
CALCULATED KINEMATICS			
<i>X</i>	-34.1±1.1	pc	
<i>Y</i>	-53.5±1.8	pc	
<i>Z</i>	75.9±2.5	pc	
<i>U</i>	6.1±0.3	km s <sup>-1</sup>	
<i>V</i>	-0.57±0.43	km s <sup>-1</sup>	
<i>W</i>	-10.4±0.5	km s <sup>-1</sup>	

**Note:** RV is heliocentric.

<sup>a</sup> epoch J2015.5

**References:**

- (1) West et al. (2011); (2) Chambers et al. (2016);  
(3) Gaia Collaboration et al. (2018); (4) Huber et al. (2017)

Ecliptic Plane Input Catalog (EPIC) ID number is 248624299. The total observation time is 79.64 days, and the total number of good quality ( $Q = 0$ ) data points is 3560. Each data point represents the average flux measured during a 29.4 minute interval. The median count rate through 2-pixel radius aperture is 889 counts s<sup>-1</sup>. A part of *K2* light curve is shown in Figure 1 in which we can see the beat patterns resulting from two closely separated periods. The Lomb-Scargle (LSP) periodogram of the *K2* light curve is shown in Figure 2 with the power in *Y*-axis expressed in some arbitrary units. The LSP is constructed by taking a sample of 10,000 periods in the range (0.1-0.32)day, after getting an initial estimation that the periods lie in this range. The two closely spaced peaks in this LSP correspond to 0.2114±0.0002 days and 0.2199±0.0003 days, which are most likely due to spot modulations of two rapidly rotating stars in a binary system. The uncertainties in the periods are based on half width at half maximum (HWHM) of the periodogram peaks as suggested by Mighell & Plavchan (2013).

## 2.2 Gaia Astrometry and photometry

2M1027+0629 is one of the ~1.7 billion sources, which has five-parameter astrometric solution measured by the *Gaia* mission (Gaia Collaboration et al. 2016). The *Gaia* DR2 (Gaia Collaboration et al. 2018) released on 25 April, 2018 lists its parallax to be 10.1 ± 0.3 mas. This corresponds to a distance of 99.0±2.9 pc, and is farther than the previously reported photometric distance of 67.6 pc (West et al. 2011) assuming it to be a single star. In addition, the *Gaia* proper motions are  $\mu_{\alpha} = -1.2 \pm 0.5$  mas yr<sup>-1</sup> and  $\mu_{\delta} = -15.1 \pm 0.5$  mas yr<sup>-1</sup>.

## 2.3 Spectroscopy

High resolution near-infrared spectra of 2M1027+0629 were obtained with the Near InfraRed SPECTrometer (NIRSPEC; McLean et al. 2000) on the Keck II Telescope on 2018 April 26 (UT) in partly cloudy conditions. The N7 order-sorting filter and 0.''432-wide slit were used to measure 2.00-2.39  $\mu$ m spectra over orders 32-38 with  $\lambda/\Delta\lambda \approx 20,000$  ( $\Delta v \approx 15$  km s<sup>-1</sup>) and dispersion of 0.315 Å pixel<sup>-1</sup>. Two exposures of 1500 s each were obtained at an airmass of 1.04, nodding 7'' along the slit for sky subtraction. This was followed by observations of the A0 V star 69 Leo ( $V = 5.404$ ) at similar airmass. Flat field and dark frames were obtained at the start of each night for detector calibration. Data were reduced and the raw extracted spectrum forward modeled following the methodology described in Burgasser et al. (2016), with BT-Settl Solar-metallicity spectral models drawn from Allard et al. (2012). The best fit-model (shown in Figure 3) has  $T_{eff} = 3110 \pm 40$  K,  $\log g = 5.2 \pm 0.2$  (cgs),  $RV = -9.8 \pm 0.6$  km s<sup>-1</sup> and  $v \sin i = 21.5 \pm 1.1$  km s<sup>-1</sup>. Using radial velocity and *Gaia* astrometry ( $\alpha = 156.940573^\circ$  and  $\delta = 6.486120^\circ$ ), *UVW* components of space velocities of 2M1027+0629 are  $U = 6.1 \pm 0.3$  km s<sup>-1</sup>,  $V = -0.57 \pm 0.43$  km s<sup>-1</sup>, and  $W = -10.4 \pm 0.5$  km s<sup>-1</sup>.

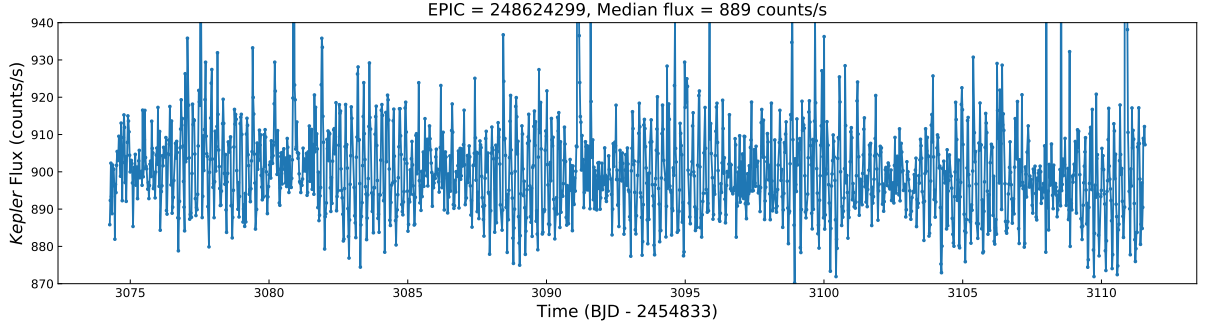
In Table 1, we list all the photometric and physical properties of 2M1027+0629, which are available in literature, measured by *Gaia* mission, and spectral properties from best-fit model to NIRSPEC spectrum.

## 2.4 Flares

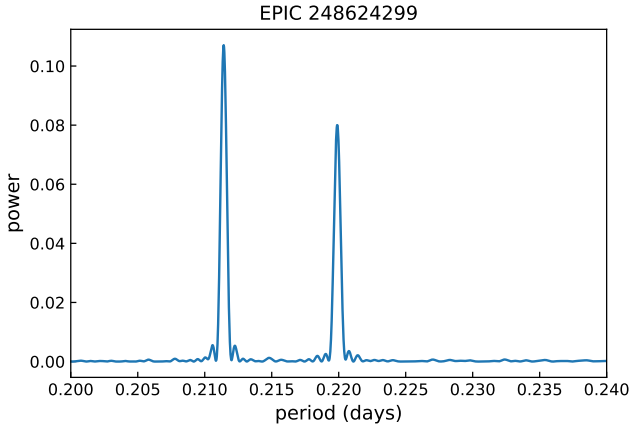
We detected three strong white light flares in the *K2* light curve, as shown in Figure 4. The three flares (left to right) in Figure 4 have equivalent durations (time during which the flare emits the same amount of energy as the star does in its quiescent state) of 15.0 minutes, 29.1 minutes, and 20.3 minutes respectively. To estimate the flare energy, we first calculated the bolometric energy of flare for an equivalent duration of 1 second by approximating the flare to be a 10,000 K hot blackbody and has same count rate through *Kepler* filter as 2M1027+0629. Assuming that both stars have equal luminosity, same spectral type of M6, and are at same distance of 99.0±2.9 pc measured by *Gaia*, we first estimated bolometric (UV/optical/IR) energy of 10,000 K flare having equivalent duration of 1 second to be  $2.9 \times 10^{30}$  erg. We then multiplied this energy by the equivalent duration to estimate the bolometric (UV/optical/IR) energies of the flares to be  $2.6 \times 10^{33}$ ,  $5.0 \times 10^{33}$  and  $3.5 \times 10^{33}$  erg respectively. More details about flare energy estimation can be found in Paudel et al. (2018).

## 3 DISCUSSION AND CONCLUSION

Using Lomb-Scargle periodogram, we find two closely separated periods 0.2114±0.0002 days and 0.2199±0.0003 days, in the *K2* light curve of 2M1027+0629, and correspond to the rotation period of two stars in a binary system. They form beat patterns in the light curve. The *Gaia* parallax supports the evidence for 2M1027+0629 as a near-equal luminosity binary system. Previously, West et al. (2011) reported its photometric distance to be 67.6 pc, assuming it as a single star. The *Gaia* DR2 parallax of (10.1 ± 0.3) mas corresponds to (99.0±2.9) pc, and hence this binary system appears to be twice as luminous as a single M6 star. The values of *UVW* components of space velocities are consistent with a young age, as are the rotation periods. Furthermore, the membership probabilities calculated by using the BANYAN  $\Sigma$  tool (Gagné et al. 2018)



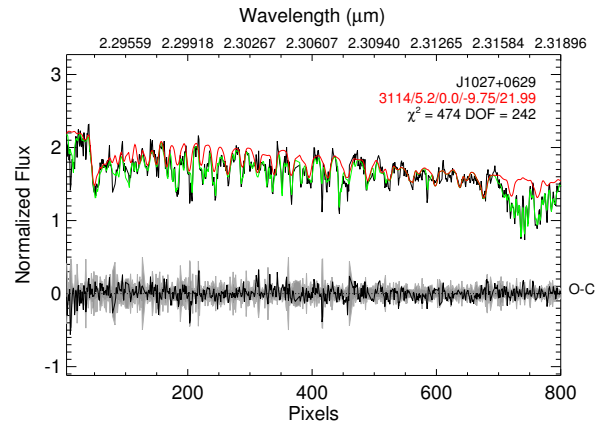
**Figure 1.** K2 light curve of 2M1027+0629, in Campaign 14. Only a portion of the light curve is shown to focus on the beat patterns which are produced as a result of two closely separated periods 0.2114 day and 0.2199 day.



**Figure 2.** Lomb-Scargle periodogram of 2M1027+0629. The two peaks correspond to periods 0.2114 days and 0.2199 days.

suggest that it does not belong to any known moving group. We also detected three strong white light flares in the K2 light curve, which have equivalent durations of 15.0 minutes, 29.1 minutes and 20.3 minutes respectively. We estimated bolometric (UV/optical/IR) energies of those flares to be  $2.8 \times 10^{33}$  erg,  $5.2 \times 10^{33}$  erg, and  $3.8 \times 10^{33}$  erg respectively. If we consider the flares to occur on one of the stars, these flares have amplitudes  $\sim 2$  relative to the quiescent photospheric level.

The beat patterns in the light curves of stars can also arise due to two more phenomena. One is the result of differential rotation of the star, such that spots in different latitudes would have close periods. The horizontal shear differential rotation parameter ( $\Delta\Omega$ ) of M dwarfs are however very small ( $< 0.1$  rad day $^{-1}$ ; Reinhold et al. 2013). For the two observed periods here,  $\Delta\Omega = 1.2$  rad day $^{-1}$ . The next is the result of stellar pulsations. There is not any observational evidence of pulsating M dwarfs and the theoretical calculations predict pulsations due to convectionally excited oscillations or due to  $\epsilon$  mechanism in M dwarfs, have very short periods ranging from a few minutes to about half an hour. In addition, the convectionally excited oscillations in M dwarfs would have amplitudes no more than a few ppm (Rodríguez-López et al. 2012; Corsaro et al. 2013; Rappaport et al. 2014). We rule out both possibilities in the case of 2M1027+0629.

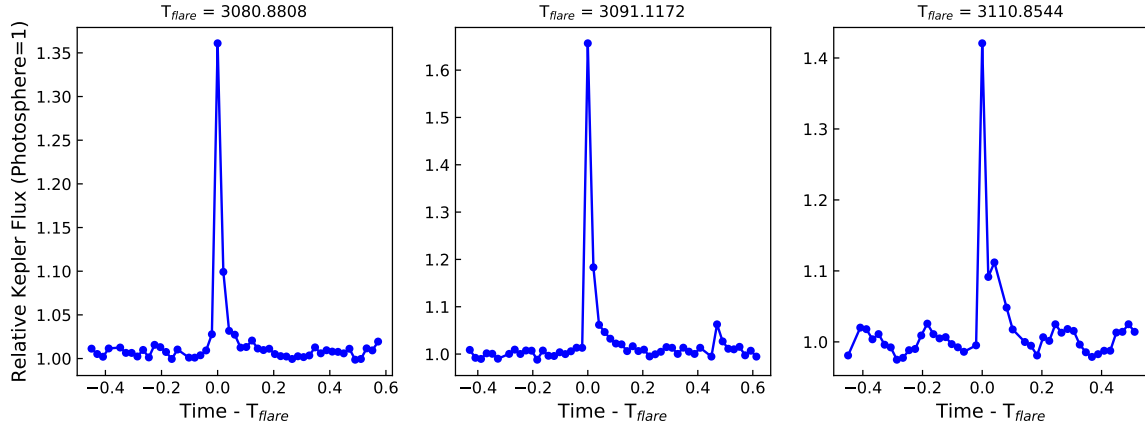


**Figure 3.** NIRSPEC spectrum of 2M1027+0629 obtained on UT 2018 April 26 (black line). The red line represents BT-Settl Solar-metallicity spectral model from (Allard et al. 2012). The best fit parameters are  $T_{\text{eff}} = 3110 \pm 40$  K,  $\log g = 5.2 \pm 0.2$ ,  $RV = -9.8 \pm 0.6$  km s $^{-1}$  and  $v \sin i = 21.5 \pm 1.1$  km s $^{-1}$ . The difference between data and model (O-C) is shown in black at the bottom of the plot; the  $\pm 1\sigma$  uncertainty spectrum is indicated in gray.

The two similar rapid rotation periods indicate that both stars are likely to have similar spectral types of M6 (Stauffer et al. 2016). Additional follow-up observation of this system using high resolution AO imaging and spectroscopy is necessary to constrain the separation and the masses of the two stars, and orbital period of the system, which will be valuable to understand the various aspects like rotation-activity-age relationships, evolution of angular momentum in rapidly rotating stars in binary system, and gyrochronology.

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**Figure 4.** The three strong flares observed on 2M1027+0629. The blue dots represent the observed data. The time in X-axis of each panel is centered at peak flare time mentioned above each panel.

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