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New CCD photometric investigation of high amplitude δ Scuti star V2455 Cyg

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Abstract New V-band CCD observations of variable star V2455 Cyg were performed during two nights in September 2017. According to all times of maximum light and new maxima, the $O-C$ curve was analyzed. The period changes of V2455 Cyg were investigated and the rate of increasing period was obtained to be $(1/P)\,dP/dt = 1.99 \times 10^{-7}\,\mathrm{yr}^{-1}$. Frequency analysis indicated that V2455 Cyg pulsates with the radial p mode and the fundamental frequency is $10.61574\,\mathrm{d}^{-1}$. Physical parameters of V2455 Cyg at mean temperature were determined (e.g., $R = 2.52\,R_\odot$ and $M = 1.92\,M_\odot$). The position of this star in the H-R diagram confirms that V2455 Cyg is a high amplitude δ Scuti star.

Key words: techniques: photometric — stars: variables: δ Scuti — stars: individual (V2455 Cyg)

1 INTRODUCTION

The pulsating star V2455 Cyg (GSC 03590–01884, TYC 3590–1884–1, HD 204615, SAO 50907, NSV 25610, BD+46 3325, Gaia DR1 1972215241060681728, Gaia DR2 1972215245359762816, 2MASS J21282456+4640308) was observed for the first time by Yoss et al. (1991). They determined the spectral type F2, visual magnitude $V = 8.86\,\mathrm{mag}$, absolute magnitude $M_V = 2.2\,\mathrm{mag}$, index color $B-V = 0.27$, distance of 215 pc and space velocity $S = 32\,\mathrm{km\,s^{-1}}$. Piquard (2001) suggested that V2455 Cyg is an SX Phe variable star with a period of $0.094206\,\mathrm{d}$ (Wils et al. 2003), while Wils et al. reported that V2455 Cyg is a high amplitude δ Scuti star (HADS). They also improved the ephemeris to $Max = 2452885.3992 + 0.0942075 \times E$. In 2011, Wils et al. updated elements of V2455 Cyg to $Max = 2452885.399 + 0.094206008 \times E$. After that, only some times of maximum light for variable star V2455 Cyg were published. Peña et al. (2019), using $uvby-\beta$ photoelectric photometry, determined some physical characteristics of V2455 Cyg such as an effective temperature between $7200\,\mathrm{K}$ and $7900\,\mathrm{K}$ and absolute visual magnitude between $2.066\,\mathrm{mag}$ and $1.075\,\mathrm{mag}$.

In this paper, we present new observations of V2455 Cyg, obtain times of maximum light and investigate changes in the pulsation period. We also analyze the pulsation frequency of V2455 Cyg and determine physical parameters for this δ Scuti star.

2 NEW V-BAND OBSERVATIONS

New photometric observations of V2455 Cyg were carried out at RIAAM[1] observatory ($\phi = 37^\circ\,23'\,58.095''$ N, $\lambda = 46^\circ\,16'\,9.019''$ E) on 2017 September 19 and 23, with a 12-inch Meade LX200 Schmidt-Cassegrain telescope equipped with an SBIG STX-16803 CCD camera. During the observations, a V Johnson-Cousins filter was employed and the exposure time for each image was 20 s. A total of 1146 frames was obtained and 26 bias, dark and flat images were taken each night. Data reduction was performed utilizing MaxIm DL v5 software. BD +46 3328 and TYC 3590–1667–1 were applied as the comparison and check stars, respectively. Table 1 tabulates the coordinates and magnitudes of V2455 Cyg, and those of the comparison and check stars, which were referenced from the SIMBAD astronomical database. New data (i.e., HJD and ΔM) on V2455 Cyg during two nights of observation are listed in Table 2 and new V-band light curves are displayed in Figure 1.

3 TIMES OF MAXIMUM AND $O-C$ CURVE ANALYSIS

During two nights of new observations, five times of maximum light were observed (Fig. 1) and the timings of maxima were obtained by the 5th polynomial function fitting on each maximum light. These maxima and their errors are listed in Table 3.

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Table 1 Coordinates and Magnitudes of Variable, Comparison and Check Stars.

Star	Name	RA	Dec	V (mag)	B (mag)
Variable	V2455 Cyg	$21^{\rm h}28^{\rm m}24.559^{\rm s}$	$+46°\ 40'\ 30.84''$	8.84	9.05
Comparison	BD +46 3328	$21^{\rm h}28^{\rm m}30.007^{\rm s}$	$+46°\ 40'\ 24.99''$	9.54	9.52
Check	TYC 3590-1667-1	$21^{\rm h}28^{\rm m}08.164^{\rm s}$	$+46°\ 37'\ 59.18''$	12.86	12.50

Table 2 New V-Band Observations of V2455 Cyg

HJD	ΔM	HJD	ΔM
2458016.226615	–0.800	2458020.267553	–0.633
2458016.227679	–0.819	2458020.267854	–0.631
2458016.228061	–0.834	2458020.268166	–0.640
2458016.228432	–0.835	2458020.268479	–0.664
2458016.228814	–0.845	2458020.268791	–0.648
2458016.229335	–0.857	2458020.269104	–0.647
2458016.229705	–0.872	2458020.269416	–0.658
2458016.230110	–0.874	2458020.269729	–0.650
2458016.231071	–0.901	2458020.270041	–0.670
2458016.231453	–0.912	2458020.270354	–0.677
2458016.232413	–0.934	2458020.270666	–0.671
2458016.232841	–0.940	2458020.270979	–0.691
2458016.233212	–0.951	2458020.271291	–0.700
2458016.233582	–0.955	2458020.271592	–0.679
2458016.234138	–0.975	2458020.271905	–0.685
...	...	...	...

Table 3 New Light Maximum Times of V2455 Cyg

Date of observation	HJD$_{max}$	Error
2017 September 19	2458016.240334	0.015814
2017 September 19	2458016.334760	0.026290
2017 September 23	2458020.291903	0.027661
2017 September 23	2458020.386033	0.029445
2017 September 23	2458020.480130	0.030144

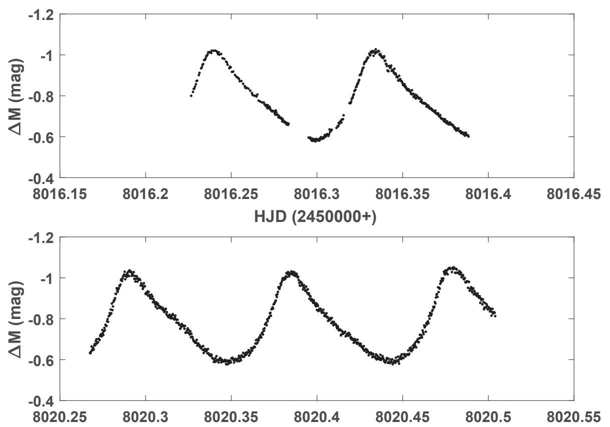

Fig. 1 The V-band observed light curves of V2455 Cyg on two nights.

In order to investigate the period of V2455 Cyg, we compiled 54 times of maximum light from different literatures together with new maxima. All light times of maxima are listed in the first and fifth columns and their associated references are tabulated in the fourth and eighth columns of Table 4. Utilizing all maxima, the new linear ephemeris of V2455 Cyg was determined

$$HJD_{\rm max} = 2458016.237049(509) + 0.094206044^{\rm d}(14) \times E\,, \quad (1)$$

and the ephemeris given by Wils et al. (2011) was improved

$$HJD_{\rm max} = 2452885.399056(429) + 0.094206044^{\rm d}(14) \times E\,. \quad (2)$$

Using the new ephemeris in Equation (1), epochs and the $O - C$ values were calculated and are listed in Table 4. The $O - C$ diagram versus E is plotted in Figure 2. As seen in Figure 2, three maxima (represented as squares) at HJD 2456862.3963, 2456862.4903 and 2456862.5842 (Hubscher & Lehmann 2015) are far removed from other times. So, these times were discarded and the $O-C$ curve was plotted in the upper panel of Figure 3 as dots. The parabolic shape in the $O - C$ curve (Fig. 3) manifests an increasing pulsation period with time. By the least squares method, the best parabolic function was fitted on the $O - C$ curve (solid line in the upper panel of Fig. 3) and the quadratic ephemeris was obtained

$$\begin{aligned} HJD_{\rm max} \; = \; & 2458016.239211(407) \\ & +0.094206204(30) \times E \\ & +2.417(469) \times 10^{-12} \times E^2 \end{aligned} \quad (3)$$

with the standard deviation of $\sigma = 0.00111$ d. The quadratic term in Equation (3) indicates that the period change rate of V2455 Cyg is $dP/dt = 1.87(38) \times 10^{-8}\,{\rm d\,yr^{-1}}$ and $(1/P)\,dP/dt = 1.99(41) \times 10^{-7}\,{\rm yr^{-1}}$. The lower panel of Figure 3 displays the residuals from Equation (3).

4 FREQUENCY ANALYSIS AND PHYSICAL PARAMETERS

Frequency analysis of V2455 Cyg was performed by employing the Period04 (Lenz & Breger 2005) software package, which is based on the Fourier Transform,

$$f(t) = Z + \sum_i A_i \sin(2\pi(\Omega_i t + \Phi_i)) \quad (4)$$

of the observational data, where Ω_i, A_i, t and Φ_i are frequency, amplitude, time and phase, respectively. The results of the fitting (Eq. (4)) on the new data (points in

Table 4 All Times of Light Maxima for Pulsating Star V2455 Cyg

HJD 2450000+	Epoch	$O-C$	Reference	HJD 2450000+	Epoch	$O-C$	Reference
2885.3992	–54464	0.0001	Wils et al. (2003)	4759.3447	–34572	–0.0010	Wils et al. (2009)
2887.3778	–54443	0.0004	Wils et al. (2003)	4759.4389	–34571	–0.0010	Wils et al. (2009)
2887.4720	–54442	0.0004	Wils et al. (2003)	4759.5332	–34570	–0.0009	Wils et al. (2009)
2887.5657	–54441	–0.0001	Wils et al. (2003)	5365.4676	–28138	0.0002	Wils et al. (2011)
2887.6599	–54440	–0.0001	Wils et al. (2003)	5365.5619	–28137	0.0003	Wils et al. (2011)
2928.2634	–54009	0.0006	Wils et al. (2003)	5373.4747	–28053	–0.0002	Wils et al. (2011)
2928.3582	–54008	0.0012	Wils et al. (2003)	5417.5631	–27585	–0.0002	Wils et al. (2011)
2928.4520	–54007	0.0008	Wils et al. (2003)	5820.3880	–23309	–0.0004	Wils et al. (2012)
2928.5465	–54006	0.0011	Wils et al. (2003)	5834.5190	–23159	–0.0003	Hubscher & Lehmann (2012)
2929.2996	–53998	0.0005	Wils et al. (2003)	5855.3390	–22938	0.0002	Wils et al. (2012)
2929.3940	–53997	0.0007	Wils et al. (2003)	6107.3410	–20263	0.0010	Wils et al. (2013)
2929.4885	–53996	0.0010	Wils et al. (2003)	6107.4350	–20262	0.0008	Wils et al. (2013)
2929.5823	–53995	0.0006	Wils et al. (2003)	6107.5290	–20261	0.0006	Wils et al. (2013)
2931.4667	–53975	0.0009	Wils et al. (2003)	6862.3963	–12248	–0.0051	Hubscher & Lehmann (2015)
4357.5561	–38837	–0.0008	Wils et al. (2009)	6862.4903	–12247	–0.0053	Hubscher & Lehmann (2015)
4642.4354	–35813	–0.0006	Wils et al. (2009)	6862.5842	–12246	–0.0056	Hubscher & Lehmann (2015)
4642.5296	–35812	–0.0006	Wils et al. (2009)	6867.4869	–12194	–0.0016	Hubscher (2015)
4646.4860	–35770	–0.0009	Wils et al. (2009)	6867.5832	–12193	0.0004	Hubscher (2015)
4652.5157	–35706	–0.0003	Wils et al. (2009)	6914.5928	–11694	0.0012	Hubscher (2015)
4694.4383	–35261	0.0006	Wils et al. (2009)	7565.9307	–4780	–0.0015	Peña et al. (2019)
4694.5327	–35260	0.0008	Wils et al. (2009)	7574.8801	–4685	–0.0016	Peña et al. (2019)
4730.3298	–34880	–0.0004	Wils et al. (2009)	7575.9157	–4674	–0.0023	Peña et al. (2019)
4730.4239	–34879	–0.0005	Wils et al. (2009)	8016.2403	0	0.0033	This Study
4730.5182	–34878	–0.0004	Wils et al. (2009)	8016.3348	1	0.0035	This Study
4730.6126	–34877	–0.0003	Wils et al. (2009)	8020.2919	43	0.0040	This Study
4758.4031	–34582	–0.0005	Wils et al. (2009)	8020.3860	44	0.0039	This Study
4758.4973	–34581	–0.0005	Wils et al. (2009)	8020.4801	45	0.0038	This Study

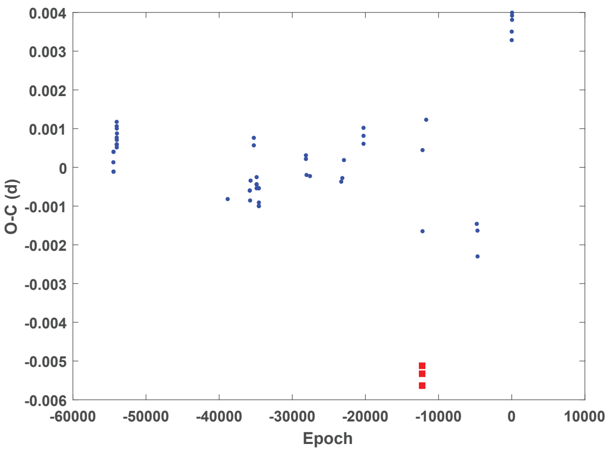

Fig. 2 The $O-C$ diagram of V2455 Cyg obtained from the new ephemeris (Eq. (1)). The *squares* are maxima that are more scattered than other times.

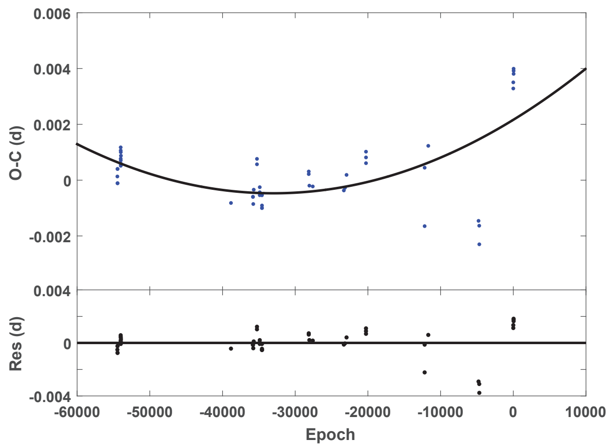

Fig. 3 The $O-C$ curve of V2455 Cyg based on 51 times of maximum light. In the upper panel, the *line* is a parabolic fit (Eq. (3)). The lower panel displays the residuals from a parabolic fit.

Fig. 4) are presented in Table 5 (i.e., frequency, amplitude and phase) and the synthetic light curves of this fitting are signified as solid lines in Figure 4. As listed in the last column of Table 5, the frequencies with signal-to-noise ratio (S/N) greater than four were considered (Breger et al. 1993). The power spectrum of V2455 Cyg is depicted in Figure 5. Given the amplitude values listed in the second column of Table 5 and the power spectrum in Figure 5, it can be concluded that the fundamental frequency of V2455 Cyg is $10.61574\,\mathrm{d}^{-1}$.

Table 5 Results of Frequency Analysis for V2455 Cyg

Ω_i (d^{-1})	A_i (mmag)	Φ_i $(0-1)$	S/N
10.61574(28)	192.440(685)	0.369(1)	66.3
21.22675(564)	52.613(685)	0.067(2)	37.0
32.08961(379)	21.701(685)	0.781(5)	14.4
Zero point $= -0.769355$ mag			
Residuals $= 0.0152$ mag			

In order to calculate the physical parameters, considering the temperature of V2455 Cyg which varies be-

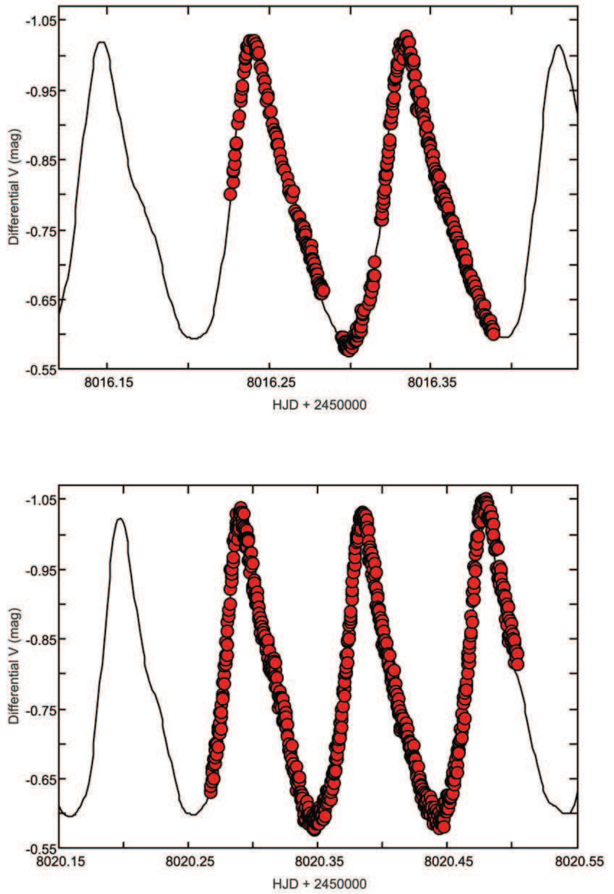

Fig. 4 The V-band observed and synthetic light curves of V2455 Cyg. The *points* represent the observational data on two nights. The *solid lines* indicate the fit of three frequencies listed in Table 5.

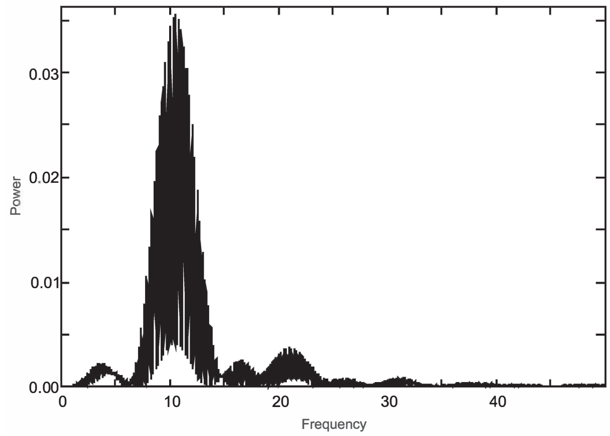

Fig. 5 The power spectrum of V2455 Cyg.

tween $7200\,\mathrm{K}$ and $7900\,\mathrm{K}$ (Peña et al. 2019), mean temperature ($T = 7490\,\mathrm{K}$) and absolute visual magnitude ($M_V = 1.57\,\mathrm{mag}$) values were used. According to table 3 of Flower (1996), in which the bolometric correction was calculated as a function of the effective temperature of the star, the bolometric correction is $BC = 0.035(1)\,\mathrm{mag}$.

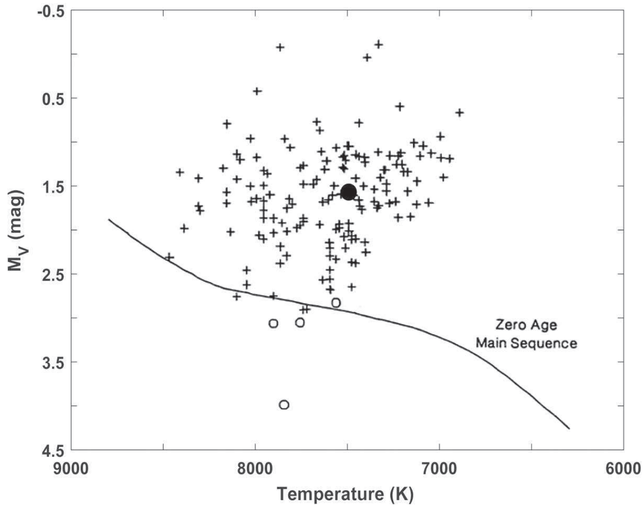

Fig. 6 The position of V2455 Cyg (*filled circle*) in the H-R diagram at mean temperature. The *plus signs* indicate HADS stars and the *open circles* signify SX Phe stars (Breger 1990a).

Applying the relation $M_{\rm bol} = M_V + BC$, the bolometric absolute magnitude was determined to be $M_{\rm bol} = 1.61(24)\,\mathrm{mag}$. The surface gravity g of δ Scuti V2455 Cyg was calculated from the following equation (Claret et al. 1990)

$$\log g = 2.68(\pm 0.10) - 1.21(\pm 0.11)\log P\,, \quad (5)$$

where P is the pulsation period. According to Equation (5), the surface gravity will be $\log g = 3.92(10)$. Applying the following relation (Breger et al. 1990)

$$\log R/R_\odot = -0.2 M_{\rm bol} - 2\log T + 8.472\,, \quad (6)$$

which is derived from the radiation law,

$$\log L/L_\odot = 2\log R/R_\odot + 4\log T/T_\odot\,, \quad (7)$$

the radius R and luminosity L of V2455 Cyg were obtained, where $T_\odot = 5770\,\mathrm{K}$. Since the surface gravity is $g \sim M/R^2$, the mass of V2455 Cyg was determined from the following equation

$$\log M/M_\odot = \log g - 4\log T/T_\odot + \log L/L_\odot - 4.44\,. \quad (8)$$

The values of physical parameters of V2455 Cyg at mean temperature are listed in Table 6.

According to the period-mean density relation for pulsating stars (Petersen & Jørgensen 1972)

$$Q = P\sqrt{\bar{\rho}/\bar{\rho}_\odot}\,, \quad (9)$$

where $\bar{\rho}$ and $\bar{\rho}_\odot$ are the mean density of the star and the Sun respectively, and the pulsation constant Q is obtained from the following equation (Breger 1990b)

$$\begin{aligned}\log Q = &- 6.456 + \log P + 0.5\,\log g \\ &+ 0.1\,M_{\rm bol} + \log T\,.\end{aligned} \quad (10)$$

Using obtained physical parameters and Equation (10), the value of pulsation constant for pulsating star V2455 Cyg will be $Q = 0.0327(21)\,\mathrm{d}$.

Table 6 Physical Parameters of V2455 Cyg at Mean Temperature

Parameters	Value	Unit
Radius (R)	2.52(19)	$R_\odot$
Mass (M)	1.92(49)	$M_\odot$
Luminosity (L)	18.12(3.58)	$L_\odot$

5 DISCUSSION AND CONCLUSIONS

In this paper, we presented new V-band photometric observations of V2455 Cyg during two nights. During observations, five times of maximum were obtained and a new linear ephemeris (Eq. (1)) was determined. By collecting all available maxima, the $O-C$ diagram was plotted which indicates that the period of V2455 Cyg is increasing at the rate of $(1/P)\,dP/dt = 1.99 \times 10^{-7}\,\mathrm{yr}^{-1}$. This slowly increasing period is in agreement with period changes in the majority of δ Scuti stars (Breger 1990a) such as GP And (Zhou & Jiang 2011) and YZ Boo (Yang et al. 2018).

We carried out the analysis of frequencies by employing the Period04 software package. Pulsation frequency analysis demonstrates that the fundamental frequency of V2455 Cyg is $10.61574\,\mathrm{d}^{-1}$. In the following, physical parameters of V2455 Cyg such as the mass and radius were obtained at mean temperature (Table 6) and the pulsation constant was calculated to be $Q = 0.0327\,\mathrm{d}$. Since typical values of pulsation constants for the fundamental radial p modes in δ Scuti stars lie between $0.022 \leq Q \leq 0.033\,\mathrm{d}$ (Breger & Bregman 1975), the value of pulsation constant implies that the variable star V2455 Cyg pulsates with the radial p mode.

Figure 6 depicts the positions of δ Scuti stars in the Hertzsprung-Russell (H-R) diagram (Breger 1990a), in which the population I δ Scuti stars (HADS), population II δ Scuti stars (SX Phe) and δ Scuti V2455 Cyg are indicated as plus symbols, open circles and a filled circle, respectively. As seen in Figure 6, V2455 Cyg is situated above the zero age main sequence line which confirms that V2455 Cyg is an HADS star. For definite results about δ Scuti star V2455 Cyg, more photometric and spectroscopic observations are suggested.

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