General Search for Stars with Rapid Optical Variations: Test Fields

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Abstract:

We present a search for stars exhibiting short time-scale optical light variations. Our search employs archival data taken by the ROTSE1 telephoto array in two eight degree fields-of-view. This is a test study considering two fields which overlaps fields previously mined for variables, but with different data and search techniques. Each field was observed for approximately six continuous hours. We employ a general search strategy based on statistical properties of the observed lightcurves for each object. The analysis is sensitive to sources with variations < 0.25 day and > 0.1 mag and with mean magnitudes between 9.5 mag to 14 mag. We selected 42 variable star candidates, of which 17 are new detections. Attempts at classification yield four new W UMa systems and two new δ Scu stars. The remaining eleven transient detections exhibit incomplete lightcurves and require further study for classification.

I. Introduction

Stars with varying brightness or `magnitude', known as variable stars, have interested astronomers for hundreds of years. In Western Europe, this began with the sudden awareness to "new stars" (L. 'novae stellae') which had previously been unrecorded. Since then, thousands of variable stars have been discovered and classified based on their peculiarities in variation. The observation of these celestial phenomena have allowed astronomers, both amateur and professional, to learn more about the night sky, particularly objects too dim to see with the unaided eye.

Variable stars are grouped into two major categories: intrinsic, those whose luminosity varies due to pulsating or other alterations in physical characteristics, and extrinsic, those who appear to vary in magnitude due to an eclipsing companion. Long period variable stars have been studied for many years because of their apparent brightness changes that can be easily observed using a telescope, depending on the magnitudes of variation. Their periods can last from weeks up to several years.

Short period variation has also been studied, but such stars can require more frequent observations to be well-measured. Such objects have periods that can last from less than an hour to a few days. These types of variables are more commonly the subject of professional research today because of their high energy outputs and unusual patterns of light variation, termed a "lightcurve". Two examples of these types of variables are the RR Lyraes (period: $0.2\ \text{d} \leq \mathbf{T} \leq 1.0$ day) and δ Scuti stars (period: $\mathbf{T} \leq 0.3$ d, amplitude: $0.01\ \text{mag} \leq \mathbf{\Delta m} \leq 0.5$ mag), which are pulsators. Such stars do not exhibit a static equilibrium between the outward pressure from radiation and the inward pull of gravity. Instead, they exhibit complex alternations of contraction and heating with expansion and cooling.

Eclipsing binary systems containing stars relatively close or touching each other also exhibit short period behavior. Some have lightcurves generally characterized by a span of brighter magnitude with one or two dips to dimmer magnitude. Binary systems of the W UMa type contain stars that are so close that the surfaces are in contact and the stars share their atmospheres[1]. The second law of thermodynamics states that "the entropy of an isolated system which is not in equilibrium will increase until equilibrium is attained." In a binary star system, heat transfers from the body of higher temperature to the body of lower temperature, therefore the heat, and thus luminosity, is transferred from the more massive star to the less massive one until equal temperatures are acquired. This theory is best modeled by a lightcurve that resembles that of a typical binary system, with the dips in magnitude becoming less different from each other.

There are many other types of variable source that exhibit rapid optical light variation. Flare stars exhibit substantial changes in brightness in a few minutes before relaxing to quiescence. Cataclysmic variables can have erratic lightcurves. Other objects, not stars but active galaxies, can also exhibit rapidly varying lightcurves.

Many telescopes including the Robotic Optical Transient Search Experiment[2] (ROTSE) telescopes observe sources with short time-scale variation. The ROTSE1 telescope provided the data used in this paper. We have pursued a study to identify in an unbiased way the catalog of variable stars with gross characteristics of variation which do not assume a particular kind of physical system. We have employed a basic statistical analysis looking for lightcurves showing variation during much of a given night of observation.

II. Detector and Data

The ROTSE telescopes were originally created to study the optical light emitted by gamma ray bursts (GRBs), but they are also used to study optical light from numerous types of sources, including variable stars. These small but powerful telescopes are distributed around the world and used internationally. We utilize a subset of data taken between 1999 and 2000 with the ROTSE1 telescope for the purpose of looking for isolated optical bursts associated with GRBs[3].

The ROTSE1 telescope was an array of four Canon telephoto lenses with 8 degree field-of-view each. These lenses were attached to Apogee AP-10 charge-coupled device (CCD) cameras. A CCD is an array of cells which send an electric signal based on the intensity of the light striking them. The AP-10 was designed initially for ROTSE1 and had a relatively high number of pixels (4 megapixels) and low electronics noise.

The ROTSE telescopes take measurements when photons emanating from a light source are focused to an image onto the CCD array of cells. The ROTSE optics do not include filters in order to allow the maximum light to strike the CCD. The resulting ROTSE1 measured magnitude corresponded approximately to a V or R band magnitude.

The optics typically focus the signals from a point source such as a star to a region approximately 14 arc seconds wide. This is the size of an AP-10 CCD cell. For the brightest stars, signals can spill over to many neighboring cells. This is termed 'saturation' and it creates an undesirably bright and distorted image. As a result, it is difficult to obtain accurate photometry for stars brighter than 10^{th} mag in one minute exposures. In addition, the electronics associated with the CCD generates an electronic noise which makes it difficult to find or accurately measure the brightness of dim stars.

Therefore, ROTSE1 is not sensitive to stars below approximately 15th magnitude.

Sixty second exposures were obtained repeatedly for several consecutive hours for several days using different fields in April, 2000 and July, 2000 (and other periods) as part of a study for lone optical bursts[3]. We use the data for camera 'b' from the April 14 data, and camera 'a' for the July 6 data as test cases for a future analysis of the entire untriggered sample. These fields are termed '000414b' and '000706a', respectively. Approximately 6 consecutive hours of data were taken in each night. The July data was taken by alternating with another field every few minutes, so half the observations are absent. The images were processed through a chain which corrects for lens vignetting and noise effects, finds stars from the cell readouts in the CCD[4], and provides a precision calibration of positions and magnitudes by comparing to the Hipparcos astrometry catalog[5]. Typically, a position resolution of 1.5 arc seconds is achieved. For bright sources, a magnitude uncertainty of 0.02 magnitudes is achieved.

For each object, many observations can be obtained over the span of one night. With the use of programs written at the U. of Michigan using the Interactive Data Language (IDL), these collected data inputs are placed together based on magnitude of light intensity versus time, creating a lightcurve.

III. Lightcurve Selection

Typically, the fields used for this analysis yield approximately 20,000 observed sources per image. The vast majority of these are non-variable objects, so a search must be made for varying lightcurves. The data stored in the University of Michigan's archive can be extracted through a special lightcurve search called "find_burst." Data is selected by quantifying search "cuts" input by the user based on three basic statistical criteria calculated in the ways described below. Two of the parameters account for the level of error present in each measurement in the lightcurve.

Amplitude of magnitude variation (Δm): We calculate the difference between the brightest observed magnitude and the dimmest for the lightcurve:

$$\Delta m = m_{max} - m_{min} \qquad (1)$$

We require Δm to be greater than some value.

Significance of maximum variation (σ_{max}): We calculate this as the difference in magnitude divided by the estimated errors on the magnitude measurement, added in quadrature:

$$\sigma_{max} = (m_{max} - m_{min}) / (\varepsilon_{max}^2 + \varepsilon_{min}^2)^{1/2} \qquad (2)$$

This parameter attempts to determine if an observed variation is significant by seeing if it is large compared to the errors on the measurements. We require σ_{max} to be greater than some value to select variable stars which have large, significant variations.

Chi-squared (χ^2): This is calculated as

$$\chi^2 = \Sigma \left((m_i - m_{avg}) / \sigma_i \right)^2 \qquad (3)$$

where the sum is performed over all measurements, **i**, and m_i and σ_i are the magnitude and estimated error for each measurement, respectively. We calculate m_{avg} to be the average magnitude for the whole lightcurve. We exclude the single measurement furthest from m_{avg} from the calculation to reject lightcurves where one measurement is bad. This parameter tests the consistency of the whole lightcurve with a constant brightness. We require the lightcurve to be inconsistent with constant brightness, so χ^2 should be large.

To perform a general search, we tried several combinations of cuts on the 000414b data using the above three parameters and counted the number of objects which fell into four general categories. The brightest sources exhibit lightcurves where most or all of their measurements are saturated, which results in a highly discontinuous lightcurve which is not a sign of a variable star. We omit the candidates from our list that are brighter than the magnitude in which this phenomena is no longer observed. The dimmest sources are strongly affected by noise in the camera and often may not even be identified, resulting in a sparse and erratic lightcurve with poorly assessed errors on the measurements. We omit stars dimmer than the brightest stars in which we begin observing this phenomena.

Of the remaining candidates, there are two types of lightcurve overall. The first type exhibits at least two abrupt, consecutive and opposite changes in brightness, producing one observation substantially different than immediately preceding and following measurements. Usually there must be two such occurrences because the χ^2 requirement rejections candidates with just one isolated bad observation. The other type exhibits a lightcurve in which most observations are continuous with their immediate neighbors in time. This is not to say they have regular variation: such lightcurves can be very variable on the timescale of several minutes.

Δm	σ_{max}	χ^2	bright	bad obs.	dim	candidates
0.5	2.0	3.0	0	84	117	2
0.1	0.0	3.0 (‘B’)	24	63	171	15
0.1	0.0	5.0	18	7	15	11
0.1	5.0	1.0 (‘A’)	54	410	195	16
1.0	2.0	5.0	18	0	0	0
1.0	5.0	0.0	0	30	27	0

Table 1: Cuts used in initial lightcurve search in a test on field 000414b. The four columns at right give the number of backgrounds of different types, and the number of good candidates. Cuts ‘A’ and ‘B’ were chosen for variable star selections in this paper.

Although it is very difficult, based on general physics principles, to have objects fluctuate by > 0.1 mag in brightness in 1 minute, extreme examples such as gamma-ray bursts have been observed. We keep our search general, while also yielding a purer sample of clear variables, by taking the following approach. We visually inspect the lightcurves and omit all observations that are discontinuous from their predecessors and successors simultaneously. In other words, we permit an object to change by several times its error in 1 minute, or we allow it to dim similarly, but we do not permit it to brighten and return back to its original state in three consecutive observations. Such variations can happen rarely due to improperly corrected or noisy pixels, but can produce a large number of false candidates because we are analyzing over 330 observations for 20,000 stars in each field. In making this requirement, we remove isolated bad observations while remaining sensitive to variation on the timescale of a few minutes without bias.

The results of our scan of selections, with the number of rejected bright or dim candidates, and those from bad observations, are shown in Table 1. The rightmost column indicates the number of good variable candidates we observe. The results support the following conclusions. Cuts using $\Delta \mathbf{m} > 0.1$ yielded the most good variable candidates: i.e. $\Delta \mathbf{m} = 0.1$, $\sigma_{max} = 5.0$, $\chi^2 = 1.0$ yielded 16 variables out of over 670 light curves. The use of the χ^2 cut significantly reduces the background due to bad observations, with a value of 3.0 (selection 'B') showing the next largest number of good candidate light curves. A selection emphasizing the χ^2 parameter yields a lower background with a similar number of good objects. Selections 'A' and 'B' find a common set of 11 variables candidates, plus five with 'A' only and four with 'B' only.

IV. List of Objects

A total of 42 candidates are identified in the two fields. For the 000706a field, the 22 identified candidates were varying in at least one other night. All candidates are listed in Table 2 and Table 3, along with their positions and measured lightcurve characteristics. The designations at left follow the form 'ROTSE1 JHHMMSS.SS±ddmmss.s' where 'HH', 'MM' and 'SS.SS' give the RA position in hours, minutes and seconds, and the 'dd', 'mm' and 'ss.s' give the declination analogously. The ROTSE1 magnitude, $\mathbf{m}_{R1}$, is calculated as the average of $\mathbf{m}_{max}$ and $\mathbf{m}_{min}$. The time interval $\Delta \mathbf{T}$ is calculated as the apparent time from maximum to maximum, or minimum to minimum, if a pair of either are apparent. In the case of δ Scu and other pulsating stars, this will be the period. For symmetric W UMa stars and other eclipsing binaries where both dips are deep, it will be half the period. For longer period variables, the quoted value is merely a lower limit as only 6 hours of data were used. Because of the length of time ROTSE1 was observing in the night, there is a natural insensitivity to medium or long time-scale variables.

Also shown in Table 2 and Table 3 are the rise time and fall time of the lightcurve, labeled $\mathbf{T}_1$ and $\mathbf{T}_2$, respectively. $\mathbf{T}_1$ is defined as the shortest time it takes to rise from the end of a period of minimum brightness to the beginning of a period of maximum brightness. $\mathbf{T}_2$ is defined conversely. These parameters may not correspond to the full time to transition from minimum to maximum brightness for the star. But if $\mathbf{m}_{min}$ and $\mathbf{m}_{max}$ correspond to the actual minima and maxima, these parameters assist in classification efforts, which will be described later.

Source	m_{R1}	Δm	ΔT (days)	T_1(days)	T_2(days)
ROTSE1 J110448.11+353626.6	10.96	0.21	0.20	0.09	0.09
ROTSE1 J113721.25+425544.6	11.49	0.36	0.21	0.10	0.09
ROTSE1 J111345.07+423951.7	11.77	0.15	>0.25	0.16	0.15
ROTSE1 J113334.68+425829.2	11.81	0.28	>0.25	0.11	0.19
ROTSE1 J113536.72+384557.5	12.01	0.47	0.25	0.09	0.20
ROTSE1 J112141.02+433653.1	11.70	0.28	0.25	0.12	0.13
ROTSE1 J111719.74+394303.0	11.98	0.31	0.10	0.08	0.07
ROTSE1 J112541.63+423448.8	12.11	0.35	0.18	0.08	0.09
ROTSE1 J111305.98+402137.7	11.89	0.36	>0.25	0.12	0.17
ROTSE1 J112037.62+392100.3	12.15	0.12	0.07	0.03	0.04
ROTSE1 J111615.06+355027.2	12.66	0.39	0.20	0.09	0.11
ROTSE1 J113928.29+403632.8	12.85	0.50	0.25	0.13	0.12
ROTSE1 J111340.03+424413.8	12.68	0.26	0.21	0.09	0.13
ROTSE1 J111415.57+371825.6	13.02	0.10	0.05	0.02	0.02
ROTSE1 J111105.45+381123.5	13.22	0.21	0.08	0.03	0.03
ROTSE1 J111716.02+385716.9	13.24	0.27	0.20	0.08	0.10
ROTSE1 J112148.80+405938.4	13.25	0.26	0.21	0.07	0.04
ROTSE1 J112009.02+435349.0	11.52	0.17	0.25	0.14	0.12
ROTSE1 J111734.08+410649.0	13.45	0.50	0.10	0.06	0.05
ROTSE1 J110340.78+402617.1	13.80	0.60	0.11	0.07	0.03

Table 2: Candidate variable stars identified by lightcurve selection in field 000414b. Lightcurve properties are tabulated.

Source	m_{R1}	Δm	ΔT (days)	T_1(days)	T_2(days)
ROTSE1 J154029.81+453200.6	13.25	0.39	0.15	0.07	0.05
ROTSE1 J154136.92+515926.5	13.42	0.42	0.075	0.02	0.055
ROTSE1 J154436.45+461922.0	12.54	0.32	0.12	0.04	0.08
ROTSE1 J155028.43+455751.0	12.83	0.29	0.065	0.015	0.05
ROTSE1 J155600.54+494757.0	13.05	0.36	>0.24	0.07	0.11
ROTSE1 J155705.19+500527.6	12.48	0.45	0.16	0.08	0.06
ROTSE1 J155809.25+485742.7	12.58	0.55	>0.24	0.12	--
ROTSE1 J155825.31+492652.1	11.88	0.15	0.16	0.08	0.045
ROTSE1 J155853.75+463548.7	13.34	0.44	0.12	--	0.075
ROTSE1 J160032.12+465526.8	11.70	0.36	>0.17	0.06	0.11
ROTSE1 J160048.24+511648.0	13.32	0.30	0.13	0.06	0.06
ROTSE1 J160121.91+482938.3	12.70	0.55	0.15	0.06	0.06
ROTSE1 J160434.17+504514.5	12.56	0.23	0.18	0.09	0.08
ROTSE1 J160602.27+501111.4	10.23	0.51	0.21	0.08	0.08
ROTSE1 J160653.63+513835.7	13.44	0.67	0.13	0.06	0.07
ROTSE1 J161033.65+514401.1	11.20	0.16	0.20	0.09	0.10
ROTSE1 J161134.29+471612.6	13.52	0.62	0.14	0.05	0.06
ROTSE1 J161321.76+515524.2	11.51	0.45	0.16	0.09	0.07
ROTSE1 J161506.00+445822.3	12.11	0.30	>0.17	0.06	0.08
ROTSE1 J161801.01+511153.0	13.83	0.65	>0.22	0.07	--
ROTSE1 J162004.25+451259.4	9.62	0.07	>0.23	0.23	--
ROTSE1 J162410.37+455527.0	10.29	0.42	0.13	0.06	0.06

Table 3: Candidate variable stars identified by lightcurve selection in field 000706a. Lightcurve properties are tabulated.

Source	Nearest Object	Δr (arcsec)	Object type
ROTSE1 J110448.11+353626.6	HH UMa	0.51	Contact binary[5]
ROTSE1 J113721.25+425544.6	[GGM 2006] 4974567	4.86	Contact binary[6]
ROTSE1 J111345.07+423951.7	TYC 3012-1895-1	0.43	Star
ROTSE1 J113334.68+425829.2	MT UMa	0.30	W UMa[7]
ROTSE1 J113536.72+384557.5	MU UMa	0.55	RR Lyr[7]
ROTSE1 J112141.02+433653.1	MQ UMa	0.87	W UMa[7]
ROTSE1 J111719.74+394303.0	FIRST J111722.9+394253	38.28	Radio[8]
ROTSE1 J112541.63+423448.8	BS UMa	0.80	Algol[9]
ROTSE1 J111305.98+402137.7	MO UMa	0.38	RR Lyr[7]
ROTSE1 J112037.62+392100.3	MP UMa	0.15	Pulsating[3]
ROTSE1 J111615.06+355027.2	[GGM 2006] 7575961	0.13	contact binary[6]
ROTSE1 J113928.29+403632.8	FIRST J113922.2+403640	68.63	Radio[10]
ROTSE1 J111340.03+424413.8	---	---	---
ROTSE1 J111415.57+371825.6	---	---	---
ROTSE1 J111105.45+381123.5	SDSS J111055.84+381055.1	116.74	Quasar[11]
ROTSE1 J111716.02+385716.9	---	---	---
ROTSE1 J112148.80+405938.4	FIRST J112148.9+405909	29.15	Radio[10]
ROTSE1 J112009.02+435349.0	GB6 B1117+4411	99.11	Radio[12]
ROTSE1 J111734.08+410649.0	FIRST J111740.0+410628	69.94	Radio[10]
ROTSE1 J110340.78+402617.1	---	---	---

Table 4: Nearest matches in SIMBAD database to observed candidate variables from the 000414b field. Notes on object classification are given in the rightmost column.

Source	Nearest Object	Δr (arcsec)	Object type
ROTSE1 J154029.81+453200.6	---	---	---
ROTSE1 J154136.92+515926.5	---	---	---
ROTSE1 J154436.45+461922.0	TYC 3483-746-1	1.58	δ Scu[13]
ROTSE1 J155028.43+455751.0	TYC 3490-814-1	0.87	δ Scu[13]
ROTSE1 J155600.54+494757.0	BPS BS 16029-0008	3.92	Star[14]
ROTSE1 J155705.19+500527.6	[GGM2006] 5207106	1.29	contact binary[6]
ROTSE1 J155809.25+485742.7	---	---	---
ROTSE1 J155825.31+492652.1	V* V1023 Her	1.10	W UMa
ROTSE1 J155853.75+463548.7	---	---	---
ROTSE1 J160032.12+465526.8	V* AR Her	1.57	RR Lyr
ROTSE1 J160048.24+511648.0	GSC 03497-01775	2.67	W UMa[15]
ROTSE1 J160121.91+482938.3	[GGM2006] 5208621	0.78	contact binary[6]
ROTSE1 J160434.17+504514.5	GSC 03497-00900	6.64	W UMa[15]
ROTSE1 J160602.27+501111.4	V* V842 Her	1.78	W UMa
ROTSE1 J160653.63+513835.7	---	---	---
ROTSE1 J161033.65+514401.1	TYC 3497-1342-1	0.44	Star[16]
ROTSE1 J161134.29+471612.6	GSC 03491-00010	0.91	W UMa[15]
ROTSE1 J161321.76+515524.2	[GGM2006] 5214166	2.94	contact binary[6]
ROTSE1 J161506.00+445822.3	---	---	---
ROTSE1 J161801.01+511153.0	GSC 03498-01093	1.10	RR Lyr[15]
ROTSE1 J162004.25+451259.4	V* V893 Her	1.91	RR Lyr
ROTSE1 J162410.37+455527.0	TYC 3492-1272-1	0.73	Star[17]

Table 5: Nearest matches in SIMBAD database to observed candidate variables for the 000706a field. Notes on variable classification are in the rightmost column.

Catalog Matching

We have compared these lists to existing objects catalogued in the SIMBAD[18] astronomical database according to their right ascension and declination. Close matches to known or suspected variable stars in the catalog were found for 22 candidates. We further check the the AAVSO site[19] for remaining objects and find three more matches. All proved to be either pulsating variables or eclipsing binaries. Most of these were identified using ROTSE1 data in previous publications. Of these, twelve are recent, unconfirmed identifications. We present these lightcurves in this section. The other 17 candidates are newly identified transients. We discuss these cases in the next section.

Recently Identified Eclipsing Binaries

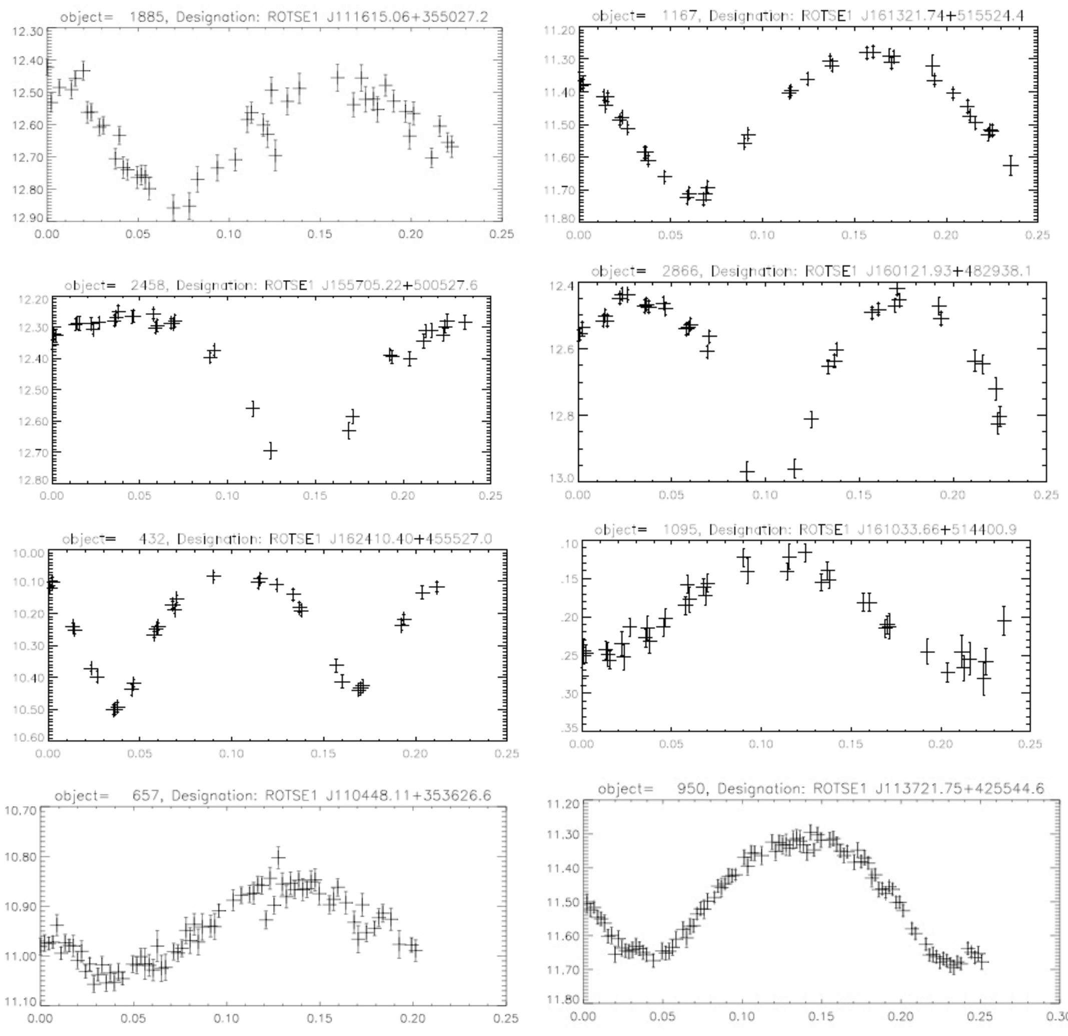

Figure 1: Eight single-night light curves for previously suspected contact binaries. Plotted errors are statistical + systematic. Times are in days.

There are 16 candidates matching previously identified or suspected eclipsing systems. Eight of the 16 candidates are not listed as definite classifications in the SIMBAD catalog, although there are claims these are W UMa systems[5],[6]. The lightcurves for the six suggested variables are shown in Figure 1. We measure $T_1 \sim T_2$ and ΔT to be a little larger than T_1+T_2 for these objects, which suggest W UMa classification. These lightcurve data therefore support the existing claims.

Recently Identified Pulsating Variables

There are nine sources identified as pulsating variables. Four of them are not clearly categorized in SIMBAD. Their lightcurves are shown in Figure 2. One candidate (ROTSE1 J112037.63+392100.3) is listed as a variable of general 'pulsating' classification in the SIMBAD catalog. This is based on a preliminary identification of this as a δ Scu star[3]. Three and a half more periods are evident in the lightcurve in Figure 2. At least two periods are evident for two of the other candidates. Considering that $T_1 \neq T_2$ and $\Delta T = T_1+T_2$, these data support the claims of these being of δ Scu type. The last star is an RR Lyr star for which we observe a partial lightcurve which is consistent with this classificiation.

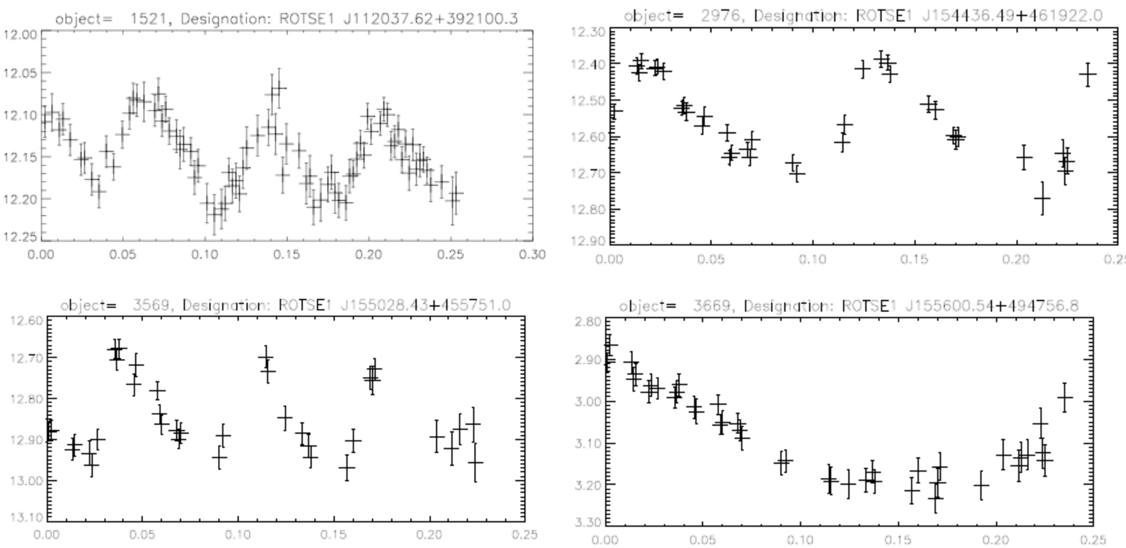

Figure 2: Four single-night light curves for previously suspected pulsating variables. Plotted errors are statistical + systematic. Times are in days.

V. Analysis of Unmatched Sources

Seventeen candidates are previously unknown as variable sources. For field 000414b, one of the candidates matching a radio source, ROTSE1 J112148.80+405938.4, has been suggested to be a variable of potentially pulsating type[3]. The lightcurve presented here does not support the pulsating classification but it does confirm the variable nature of the source. We divide the new variables into four categories: new eclipsing candidates, new pulsating candidates, incomplete smooth lightcurves, and irregular variables. This is based upon the lightcurve characteristics in Table 2 and Table 3. In order to assist identification of the candidates, it is also useful to examine multiband photometry of these objects. For this purpose, we consulted the IPAC[20] online catalog to extract infrared or optical band magnitudes.

New Eclipsing Candidates:

Eclipsing candidates are identified by exhibiting clear minima and maxima which allow a full set of lightcurve parameters to be calculated in Table 2 and Table 3. We select those with parameters satisfying the $T_1 \sim T_2$ and $\Delta T > T_1+T_2$ conditions. Their lightcurves are shown in Figure 3.

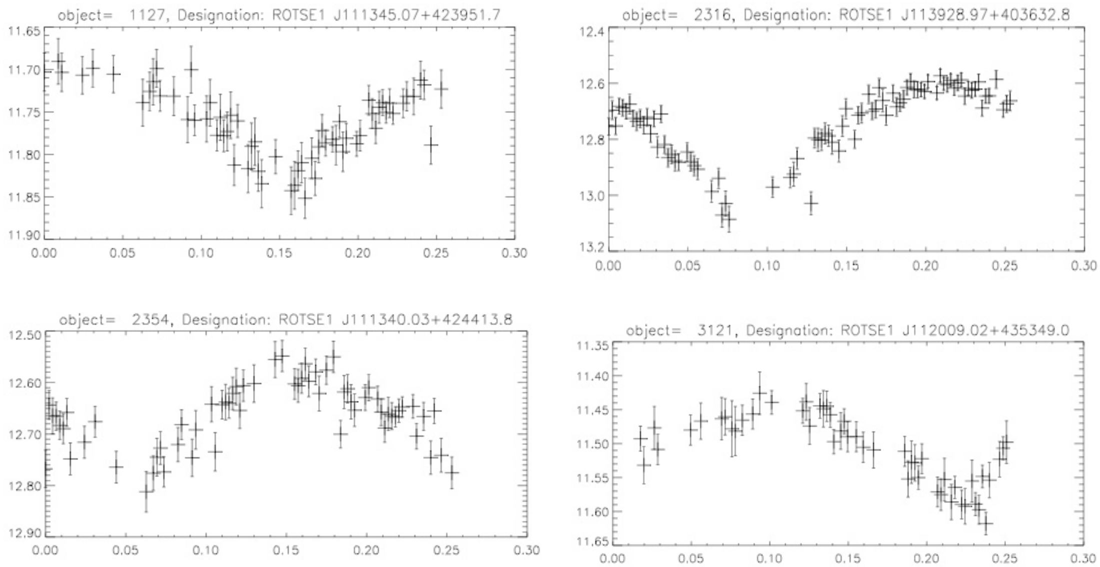

Figure 3: Single-night light curves for eclipsing binary candidates without a known variable match. Plotted errors are statistical + systematic. Times are in days.

The estimated periods and infrared band magnitudes for these candidates are given in Table 6. All four objects satisfy the selections used in Ref. 6 to identify W UMa stars: $0.26 < \mathbf{T} < 0.6$, m_{R1}-J ≤ 3.0, **H-K** ≤ 0.35, and 0.71-1.45**T** < **J-H** < 0.96-1.45**T**. The amplitudes of variation for these stars tend to be lower than was typical in that search.

Source	T (days)	J	H	K	m_{R1}-J	H-K	J-H
ROTSE1 J111345.07+423951.7	0.55	10.925	10.735	10.660	0.84	0.08	0.19
ROTSE1 J113928.29+403632.8	0.50	11.940	11.697	11.625	0.91	0.07	0.24
ROTSE1 J111340.03+424413.8	0.42	11.422	11.165	11.103	1.26	0.07	0.25
ROTSE1 J112009.02+435349.0	0.5	10.427	10.234	10.147	1.09	0.08	0.20

Table 6: Period, infrared band magnitudes and colors for four new W UMa candidates. J through K bands are from 2MASS[21].

New Pulsating Candidates:

The new pulsating candidates are identified by also exhibiting minima and maxima. These candidates satisfy $T_1 \neq T_2$ and $\Delta T \sim T_1+T_2$. Their lightcurves are shown in Figure 4. ROTSE1 J111415.57+371825.6 is not a clear variable detection. The second half of the lightcurve is very erratic, suggesting an instrumental problem, while the earlier 3 hours may indicate a δ Scu with ~0.1 mag amplitude and 0.05 day period at the edge of sensitivity. A firm identification will require examining more data.

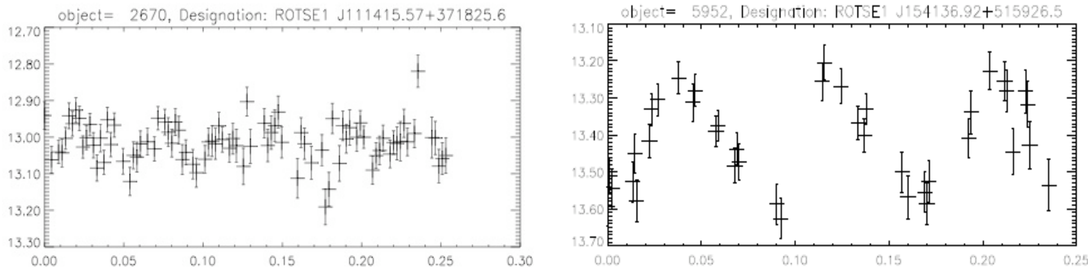

Figure 4: Single-night light curves for objects without a match but which may be pulsating variables. Plotted errors are statistical + systematic. Times are in days.

Color information for ROTSE1 J154136.92+515926.5 and ROTSE1 J111415.57+371825.6 is given in Table 7. Pulsators of δ Scu type are expected to reside in spectral categories A0-F5, which corresponds roughly to -0.1 < B-V < 1.0. We do not have B and V magnitudes for these two objects, but obtain B and R by averaging the two measurements from the USNO-B1 catalog. If we assume that B>V and V>R, then B-R is an upper limit on B-V. These quantities are consistent with both stars being δ Scu stars.

Source	T (days)	B	R	B-R
ROTSE1 J111415.57+371825.6	0.05	13.68	13.00	0.68
ROTSE1 J154136.92+515926.5	0.08	13.39	12.67	0.72

Table 7: Period, optical band magnitudes and color for two new δ Scu candidates. B and R band magnitudes are from USNO-B1.

New Variables with Continuous, Incomplete Lightcurves:

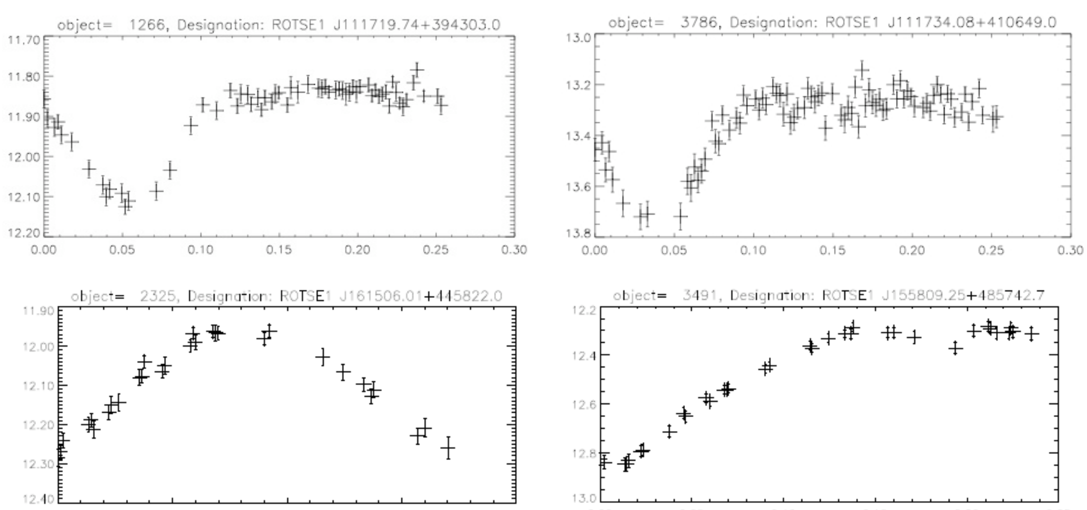

Figure 5: Single-night light curves for objects without a transient match. Lightcurves appear to be incomplete segments from regular variables. Errors are statistical + systematic. Times are in days.

Four new variables with incomplete smooth lightcurves are shown in Figure 5. These lightcurves are missing some information needed for a preliminary classification.

In all cases, we cannot properly estimate $\mathbf{T_2}$ or $\mathbf{\Delta T}$, and either the maxima or minima are missing. Although they appear clearly distinct from the irregular variable category, use of further data will be needed to establish these identifications.

New Irregular Variable Candidates:

Seven of the candidates appear to fall into an irregular variable category. These lightcurves are shown in Figure 6. We will present further results on these objects in a future study.

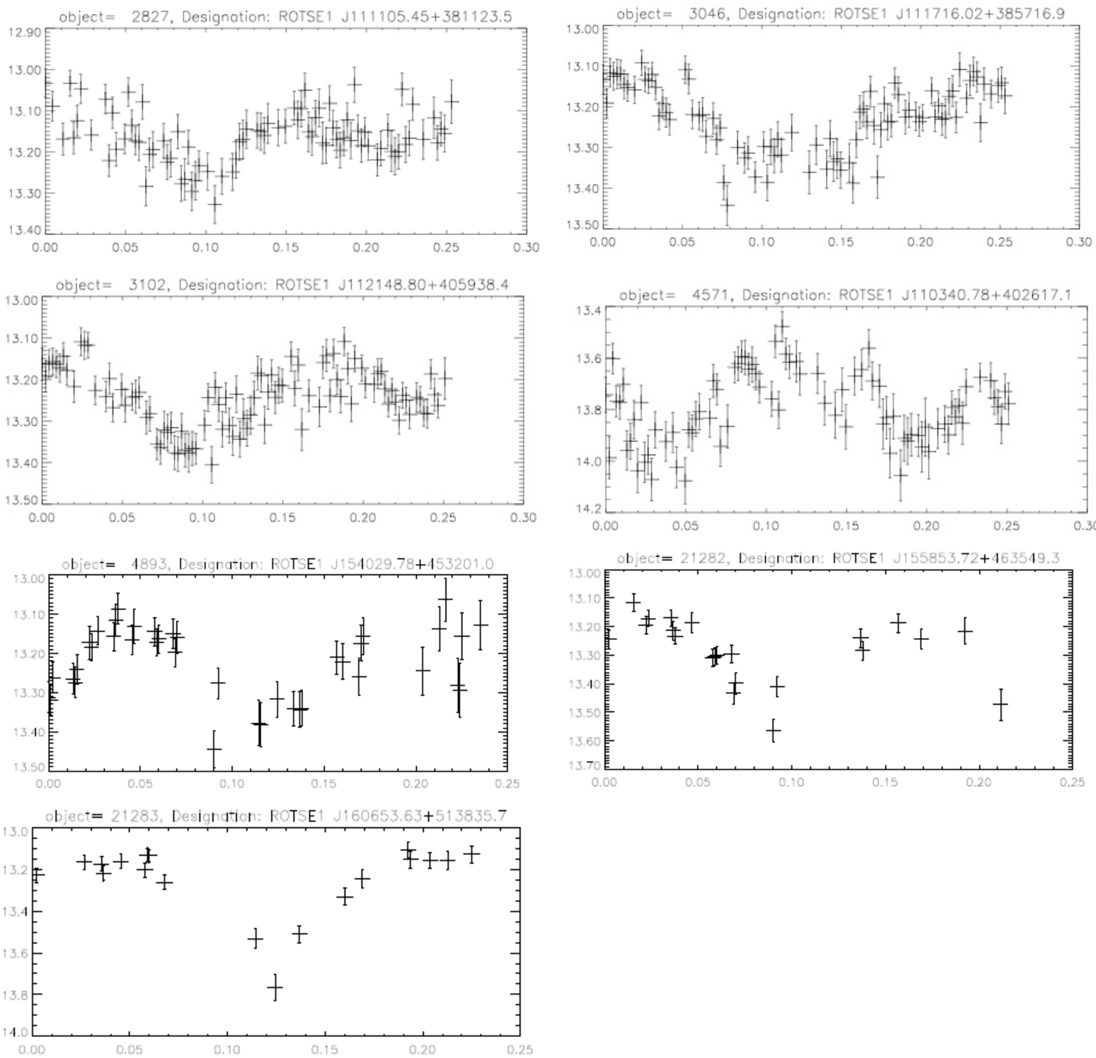

Figure 6: Single-night light curves for objects without a variable match and exhibiting irregular variations. Plotted errors are statistical + systematic. Times are in days.

VI. Results

We have performed a search for optically variable sources in two fields with one night each of ROTSE1 data and identified 42 variable candidates. Of these, 10% were previously discovered with non-ROTSE1 data, and 17 are new detections. We provide lightcurves to support classification for twelve W UMa, δ Scu and RR Lyr variables whose identification may not be settled. We identify four previously unidentified W UMa contact binaries and two new δ Scu stars. We also identify 11 candidates that are clearly variable but require more data to ascertain their physical characteristics.

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