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# THE BIMA PROJECT: O–C DIAGRAMS OF ECLIPSING BINARY SYSTEMS

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## ABSTRACT

The Eclipsing **Bi**naries Mini**ma** (BIMA) Monitoring Project is a CCD-based photometric observational program initiated by Bosscha Observatory - Lembang, Indonesia in June 2012. Since December 2012 the National Astronomical Research Institute of Thailand (NARIT) has joined the BIMA Project as the main partner. This project aims to build an open-database of eclipsing binary minima and to establish the orbital period of each system and its variations. The project is conducted on the basis of multisite monitoring observations of eclipsing binaries with magnitudes less than 19 mag. Differential photometry methods have been applied throughout the observations. Data reduction was performed using IRAF. The observations were carried out in *BVRI* bands using three different small telescopes situated in Indonesia, Thailand, and Chile. Computer programs have been developed for calculating the time of minima. To date, more than 140 eclipsing binaries have been observed. From them 71 minima have been determined. We present and discuss the *O-C* diagrams for some eclipsing binary systems.

*Key words:* methods: observational, stars: binaries: eclipsing, techniques: photometric

## 1. INTRODUCTION

An eclipsing binary star (EB) is a type of variable star caused by an eclipse. EB studies often involve the combination of photometric (light curve) and spectroscopic (radial velocity curve) data. These data provide a direct way to determine the fundamental stellar and orbital elements of the systems. Determination of the time of minimum (ToM) from photometric observation will reveal if there is a change in the orbital period of the system. In many systems, period changes are frequently detected, indicated by eclipses that occur earlier or later than the predicted time. These variations may be due to the influence of a third body in the system or mass exchange between the components. The *O-C* diagram will enable us to see the modulation of the orbital period and whether it comes from the intrinsic or extrinsic cause.

In this paper we introduce the Eclipsing Binaries Minima Monitoring (BIMA) project, aiming to build an open database containing information for mid-eclipse timings, periods, ephemerides, and the light curve data for those binaries. The BIMA Project was initiated in June 2012 at Bosscha Observatory - Lembang, Indonesia, and has been open for collaboration since. Observations at Bosscha Observatory are mainly served by a small-aperture (20 cm) telescope. The National Astronomical Research Institute of Thailand (NARIT) contributes to the project as the main partner through a joint observation collaboration starting on December 2012. NARIT has a major role in obtaining the photometric data for eclipsing binaries using the Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes (PROMPT) at Cerro Tololo Inter-American Observatory (CTIO) in Chile and another two telescopes at Mt. Inthanon, Thailand.

## 2. TARGET LIST

The General Catalogue of Variable Stars (GCVS) (Kukarkin et al., 1969) and the All-Sky Automated Survey (ASAS) database[1] have largely been used to compile the target list. Some selection criteria had been applied by taking into account the limitation of the instruments employed in this project. These criteria are: (1) Apparent brightness less than 19 magnitude at maximum light, and (2) Orbital periods less than two days. As the result, more than 1000 eclipsing binary systems have been selected.

The calculation of predicted ToM has an im-

[1]http://www.astrouw.edu.pl/asas/

portant role in order to facilitate efficient observation. Using the ephemerides given in Kreiner (2004) for all the systems, the observer can calculate predicted ToM. The ephemerides are provided at http://www.as.up.krakow.pl.

## 3. OBSERVATIONS AND DATA ANALYSIS

The differential photometry method has been applied to all the BIMA project observations. Here, at least a comparison star and a check star are required. A non-variable star which has nearly same colors and brightness as the target star was selected as comparison star. In addition, it should be in the same frame as target star. A check star that shares similar criteria with the comparison star should be selected to check the constant brightness of the comparison star. A typical photometric observation should cover an average of 0.2 to 0.3 times the period of each system, with a symmetric amount of time before and after the predicted ToM.

The project is conducted on the basis of multisite monitoring observations. There are three observing sites for this project: Bosscha Observatory in Indonesia, Thai National Observatory in Thailand, and the Cerro Tololo Inter-American Observatory in Chile. A 0.2 m ($f/10$) Schmidt-Cassegrain telescope installed installed at Gunma Astronomical Observatory-Institut Teknologi Bandung Remote Telescope System (GAO-ITB RTS) house is used for this project. This telescope is equipped with an SBIG ST Series CCDs and Bessell $BVRI$ filters. The 0.5 m Schmidt-Cassegrain telescope equipped with an Apogee CCD and the 2.4 m Ritchey-Chretien telescope equipped with ULTRASPEC CCD have been used since late December 2013 in Thailand. NARIT has use of the Panchromatic Robotic Optical Monitoring and Polarimetry Telescope (PROMPT) which was built by the University of North Carolina. We have been using this telescope since late December 2012.

A standard reduction of CCD images (bias and dark subtraction, flat-fielding) has been performed using the Image Reduction and Analysis Facility (IRAF). The instrumental magnitudes from each observation are obtained by applying aperture photometry. A computer program has been developed to run this process automatically to generate the light curves. The light curve is buildt with HJD (Heliocentric Julian Day) as the x-axis and delta instrumental magnitude in various filters as the y-axis (see Figure 1). The observed ToM is calculated using the Kwee-van Woerden method (Kwee & van Woerden, 1956).

## 4. RESULTS

Up to June 2014 we have observed 142 eclipsing binaries in total. From them 71 minima have been determined. In this paper, we present the light curves and the $O$-$C$ diagrams for two eclipsing binaries (see Table 1). We collect all reliable times of minimum light available in the literature and current database for each system and use the ephemerides to build the $O$-$C$ diagrams.

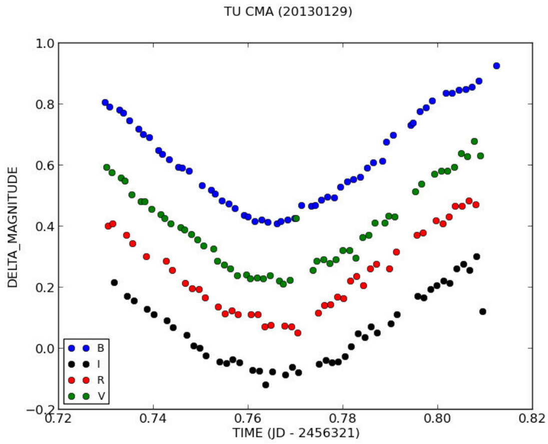


**Figure 1.** Sample of the light curves of TU CMa in $BVRI$ filters on January 29$^{th}$ 2013 using PROMPT-CTIO.

### 4.1. *TU CMa*

$BVRI$ light curves at minimum times ahve been acquired for this system. As a result, we observed two times of minimum light for this system, on January 29$^{th}$ 2013 and January 8$^{th}$ 2014. A total of 42 times of minimum light were used in our analysis, with 3 secondary eclipses among them. The times of minimum have been collected from 1968 and obtained from Kukarkin et al. (1969); BBSAG Bull.; Mallama (1980); Wolf et al. (1982); Wolf & Kern (1983); Ogloza, Niewiadomski, & Barnacka (2008); Samolyk (2008, 2009, 2010, 2011, 2013); and this paper. These data were used to build an $O$-$C$ diagram using the linear ephemerids of Mallama (1980):

$$Min.I = 2441316.34383 + 1.1278012 \times E \qquad (1)$$

where E represents the cycle number of periods elapsed since the designated epoch.

It can be seen from Figure 2 that the $O$-$C$ diagram shows a positive slope. This indicates that this system has a constant period and the real period is longer than the period used to construct the diagram (Equation 1). The linear ephemerids were calculated and shown below:

$$[O - C] = a_1 E + a_0 \qquad (2)$$

$$[O - C] = 2.6542 \times 10^{-6} E - 0.0048 \qquad (3)$$

where $a_0 = T - T_1$, $T$ is the new zero epoch and $T_1$ is old zero epoch used in the linear ephemeris (Equation 1) and $a_1 = P - P_1$, $P$ is the new period and $P_1$ is the old period used in the linear ephemeris. From Equation 3, we propose a new linear ephemerids for TU CMa:

$$Min.I = 2441316.33898 + 1.127803854 \times E \qquad (4)$$

### 4.2. *GO Cyg*

This system was observed on June 7$^{th}$ 2014 using the 0.2 m GAO-ITB RTS at Bosscha Observatory. Times

Table 1
LIST OF ECLIPSING BINARY STARS

| System | RA(2000) Dec(2000) | Mag | Period (days) | Type |
|---|---|---|---|---|
| TU CMa | $06^h31^m36.72^s$ $-24^o09'50.5''$ | 9.7–10.7 | 1.1278012* | EA |
| GO Cyg | $20^h37^m20.13^s$ $+35^o26'10.3''$ | 8.47–9.09 | 0.71776382** | EB |

Notes:
* Mallama (1980)
** Purgathofer & Prochazka (1967)

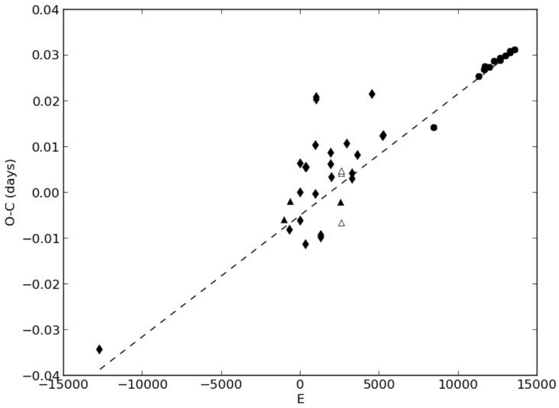


Figure 2. *O-C* diagram of TU CMa from the data given in Table 2. Filled marks refer to primary minima while open marks refer to secondary minima. The diamond, triangle, and circle symbols represent the observational techniques: visual, photoelectric, and CCD, respectively.

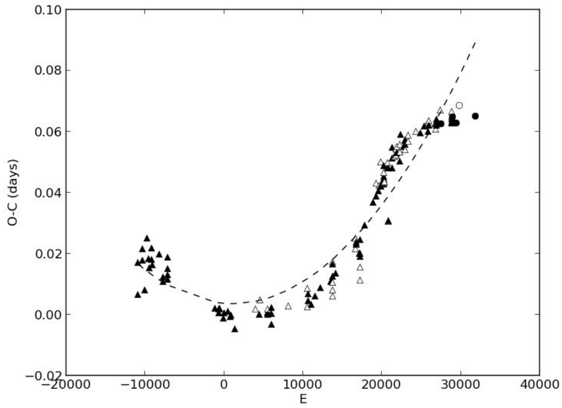


Figure 3. Period behavior of GO Cyg. Filled marks refer to primary minima while open marks refer to secondary minima. The photoelectric and CCD data are shown by triangle and circle symbols, respectively.

of mid-eclipse for 95 primary and 40 secondary minima have been determined from all available observations collected between 1936 and 2014 [Beyer (1936), Iwanowska & Dziewulski (1932), Szczyrbak (1932), Kukarkin (1932), Kordylewski (1933), Warmbier (1938), Dziewulski (1936), Micaika (1939), Pierce (1939), Piotrowski & Strzalkowski (1951), Szafraniec (1962), Popper (1957), Kaho (1952), Ovenden (1954), Kwee (1958), Fitch (1964), Koch et al. (1962), Mannino (1963), Purgathofer & Widorn (1964), Hall & Louth (1990), Cester et al. (1979), Sezer et al. (1985), Rovithis & Rovithis (1985), Isles (1988, 1991, 1992), Rovithis et al. (1993), Quester (1991), Hubscher et al. (1991, 1992, 1993, 1994), Goss et al. (1993), Wolf & Diethelm (1992), Jones et al. (1994), BBSAG Bull., Jassur & Puladi (1993), Agerer & Hubscher (1995, 1996, 1998, 2001, 2002), Edalati & Atichi (1997), Martignoni (1996), Vukasovic (1997), Oh et al. (2000), Ogloza (1997), Dariush et al. (2003), Senavci et al. (2007), and this paper]. In the *O-C* diagram, the time of minimum were calculated using Purgathofer & Prochazka (1967):

$$Min.I = 2433930.40561 + 0.71776382 \times E \quad (5)$$

Using the least-square method, we obtained quadratic equation:

$$[O-C] = 9.052 \times 10^{-11}E^2 - 1.912 \times 10^{-7}E + 0.0038 \quad (6)$$

with $\frac{dP}{dt} = 2.5221\times10^{-10}$ days per cycle or $1.2834\times10^{-7}$ day per year, the equivalent of 1.109 seconds per century. The period of the system has constantly increased since the first monitoring observation of this system. Although we fit the *O-C* diagram of GO Cyg using a parabolic term in this paper (see Figure 3), we suggest that the rate of period change began to decrease from cycle 26921. We can see from Figure 4 that there is a periodic term in the residual *O-C* diagram of GO Cyg.

Further CCD photometric and spectroscopic observations are needed to gain more information about the cause of the period change, whether from mass transfer or a multiple system.

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## REFERENCES

Agerer, F. & Hubscher, J., 1995, Photoelectric Maxima/minima of Selected Variables, IBVS, 4222
Agerer, F. & Hubscher, J., 1996, Photoelectric Minima of Selected Eclipsing Binaries, IBVS, 4383
Agerer, F. & Hubscher, J., 1998, Photoelectric Minima of Selected Eclipsing Binaries and Maxima of Pulsating Stars, IBVS, 4606
Agerer, F. & Hubscher, J., 2001, Photoelectric Minima of Selected Eclipsing Binaries and New Elements for Several Stars, IBVS, 5016

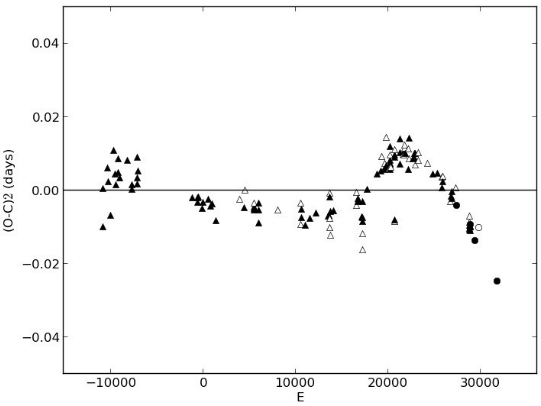


Figure 4. Residual *O-C* diagram of GO Cyg.


Agerer, F. & Hubscher, J., 2002, Photoelectric Minima of Selected Eclipsing Binaries and Maxima of Pulsating Stars, IBVS, 5296

Beyer, M., 1936, Beobachtungen von kurzperiodischen Veranderlichen, Astron. Nachrichten, 258, 273

Cester, B., Giuricin, G., Mardirossian, F., & Mezzeti, M., 1979, On the Period of the Eclipsing Binary GO Cygni, Acta Astron, 29, 433

Dariush, A., et al., 2003, Times of Minima of Eclipsing Binary Systems DO Cas, V1143 Cyg, GO Cyg, and VW Cep, IBVS, 5456, 1

Dziewulski, W. 1936, Wilno Bull. Tome, II, 6

Edalati, M., & Atichi, M., 1997, Photometric Observations and Light Curves Analysis of GO Cygni, Ap&SS, 253, 107

Elkhateeb, M. M., 2005, Variation In The Period of The System GO Cyg, JKAS, 38, 13

Fitch, W., 1964, Minima of Eclipsing Stars, AJ, 69, 316

Goss, A., Fried, R., Robb, S., & Hall, D. S., 1993, Useful Photometry of Eight Variables, Seven of them Eclipsing and Three of Them Triple, IAPPP, 53, 26

Hall, D. & Louth, H., 1990, New Times of Minimum and a Period Study for GO Cygni, JApA, 11, 271

Hubscher, J., Agerer, F., & Wunder, E., 1991, Beobachtungsergebnisse der Berliner Arbeitsgemeinschaft fr Vernderliche Sterne e.V., BAVSM, 59

Hubscher, J., Agerer, F., & Wunder, E., 1992, Beobachtungsergebnisse der Berliner Arbeitsgemeinschaft fr Vernderliche Sterne e.V., BAVSM, 60

Hubscher, J., Agerer, F., & Wunder, E. 1993, Bundesdeutsche Arbeitsgemeinschaft fr Vernderliche Sterne e.V. (BAV): Beobachtungsergebnisse, BAVSM., 62

Hubscher, J., Agerer, F., & Wunder, E., 1994, Bundesdeutsche Arbeitsgemeinschaft fr Vernderliche Sterne e.V. (BAV): Beobachtungsergebnisse., BAVSM, 68

Isles, J., 1988, JBAA, Variable Star Sect. Circular, 67, 8

Isles, J., 1991, British Ast. Assoc., Variable Star Sect. Circular, 72, 25

Isles, J., 1992, British Ast. Assoc., Variable Star Sect. Circular, 173, 20

Iwanowska, W., & Dziewulski, W., 1932, Wilno Bull., 13, 30

Jassur, D., & Puladi, R., 1993, UBV Photometry of GO Cyg, IBVS, 3897, 1

Jones, R., et al,. 1994, Sinusoidal Variation in the Period of the Eclipsing Binary GO Cygni, IAPPP Comm., 54, 34

Kaho, S., 1952, TokAB, Ser. II, No. 49

Koch, J. C. & Koch, R. N., 1962, Light Elements of Some Eclipsing Binaries, AJ, 67, 462

Kordylewski, K., 1933, AAc, 2, 48

Kreiner, J. M., 2004, Up-to-Date Linear Elements of Eclipsing Binaries, AcA, 54, 207

Kukarkin, B. W., 1932, Uber eine Gesetzmabetaigkeit in den sakularen Anderungen der Perioden fur langperiodische Cepheiden. Mit 3 Abbildungen, Zeitschrift fur Astrophysik, 4, 247

Kukarkin, B. V., et al., 1969, General Catalogue of Variable Stars. Volume 1. Constellations Andromeda - Grus., Sternberg State Astronomical Institute of the Moscow State University

Kwee, K., 1958, Investigation of Variations in the Period of Sixteen Bright Short-period Eclipsing Binary Stars, BAN, 14, 131

Kwee, K. K. & van Woerden, H., 1956, A Method for Computing Accurately The Epoch of Minimum of An Eclipsing Variable, BAN, 12, 327

Mallama, A. D., 1980, New Ephemerides For 120 Eclipsing Binary Stars, ApJS, 44, 241

Mannino, G., 1963, Pubbl. Univ. Bologna, 8, 15

Martignoni, M., 1996, Improved Elements for the Eclipsing Binary EH Cnc., BBSAG, 113, 11

Micaika, G., 1939, BZ, 21, 78

Ogloza, W., 1997, Photoelectric Minima of Eclipsing Binaries, IBVS, 4534

Ogloza, W., Niewiadomski, W., & Barnacka, A., et al., 2008, Times of Minima Observed by Pi of The Sky, IBVS, 5843, 1

Oh, K.-D., Kang, Y. W., Ra, S., & Park, S., 2000, A Photometric study of EB-type eclipsing binary GO Cyg, Ap&SS, 271, 303

Pierce, N., 1939, The Eclipsing Variable GO Cygni, AJ, 48, 113

Piotrowski, S. & Strzalkowski, A., 1951, Acta Astr., 4, 129

Popper, D., 1957, Photoelectric Observations of Eclipsing Binaries, ApJS, 3, 107

Purgathofer, A. & Widorn, Th., 1964, Mitt. Univ. Sternwarte Wien, 12, 31

Purgathofer, A. & Prochazka, F., 1967, Mitt. Univ. Sternwarte Wien, 13, 151

Quester, W., 1991, BAV Rundbrief-Mitteilungsblatt der Berliner Arbeits gemeinschaft fuer Veraende, 40, 68

Rovithis-Livaniou, H., & Rovithis, P., 1985, Minima Times of GO Cygni, IBVS, 2842, 1

Rovithis, P., et al., 1993, Photometric Minima Times of the Eclipsing Variables AB Andromedae, 44i Bootis and GO Cygni, IBVS, 3950, 1

Samolyk, G., 2008, Recent Minima of 155 Eclipsing Binary Stars, JAVSO, 36, 171

Samolyk, G., 2009, Recent Minima of 154 Eclipsing Binary Stars, JAVSO, 37, 44

Samolyk, G., 2010, Recent CCD Minima of 185 Eclipsing Binary Stars, JAVSO, 38, 183

Samolyk, G., 2011, Recent Minima of 146 Eclipsing Binary Stars, JAVSO, 39, 177

Samolyk, G., 2013, Recent Minima of 273 Eclipsing Binary Stars, JAVSO, 41, 122

Samolyk, G., 2013, Recent Minima of 199 Eclipsing Binary Stars, JAVSO, 41, 328

Senavci, H. V., et al., 2007, Photoelectric Minima of Some Eclipsing Binary Stars, IBVS, 5754, 1

Sezer, C., Gulmen, O., & Gudur, N. 1985, BV Photometry and Period Variation of GO Cygni, IBVS, 2743, 1

Sterken, C., 2005, The O-C Diagram: Basic Procedures, AS-

PCS, 335, 3
Szafraniec, R., 1962, The Nordmann-Tikhov Effect in the Light of Photoelectric Observations, Acta Astron., 12, 181
Szczyrbak, S., 1932, SAC 10, 44
Vukasovic, M., 1997, Differential Photoelectric Photometry of the Eclipsing Binary GO Cygni, IAPPP Comm., 67, 11
Warmbier, E., 1938, AAc, 3, 95
Wolf, G. W., Kern, J. T., Hayes, T. L. & Chaffin, C. R., 1982, Times of Minima For Southern Hemisphere Eclipsing Binaries, IBVS, 2185, 1
Wolf, G. W. & Kern, J. T., 1983, A uvby Beta Photometric Survey of Southern Hemisphere Eclipsing Binary Stars, ApJS, 52, 429
Wolf, M. & Diethelm, R., 1992, Period Changes of Early-type Eclipsing Binaries, AcA, 42, 363