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THE BUSOT OBSERVATORY: TOWARDS A ROBOTIC AUTONOMOUS TELESCOPE

R. García-Lozano[1,2,3], J. J. Rodes[1,2], J. M. Torrejón[1,2], G. Bernabéu[1,2], and J. Á. Berná[1,2]

RESUMEN

Presentamos el observatorio de Busot, nuestro proyecto de telescopio robótico con capacidad para trabajar autónomamente. Este observatorio astronómico, que consiguió la categoría de *Minor Planet Center* MPC-J02 en 2009, incluye un telescopio MEADE LX200GPS de 36 cm de diámetro, una cúpula de 2 m de altura, una cámara CCD ST8-XME de SBIG, con un sistema de óptica adaptativa AO-8 y una rueda de filtros equipada con un sistema UBVRI. Estamos trabajando en la instalación de un espectrógrafo SGS ST-8 al telescopio mediante un haz de fibra óptica. Actualmente, estamos involucrados en el estudio a largo plazo de fuentes variables como sistemas binarios de rayos X y estrellas variables. En este trabajo también presentamos el descubrimiento de sistemas W UMa así como la deducción de los períodos orbitales a partir de la curva de luz fotométrica obtenida en el observatorio de Busot.

ABSTRACT

We describe the Busot observatory, our project of a fully robotic autonomous telescope. This astronomical observatory, which obtained the Minor Planet Centre code MPC-J02 in 2009, includes a 14 inch MEADE LX200GPS telescope, a 2 m dome, a ST8-XME CCD camera from SBIG, with an AO-8 adaptive optics system, and a filter wheel equipped with UBVRI system. We are also implementing a spectrograph SGS ST-8 for the telescope. Currently, we are involved in long term studies of variable sources such as X-ray binaries systems, and variable stars. In this work we also present the discovery of W UMa systems and its orbital periods derived from the photometry light curve obtained at Busot Observatory.

Key Words: stars: W UMa — techniques: photometry — telescopes

1. THE BUSOT OBSERVATORY

The aim of this paper is to show the capabilities of the Busot Observatory to obtain accurate photometric measurements and images of astronomical sources such as variable stars, comets, asteroids, near-Earth objects (NEOs), exoplanets and long-term variability. It is located at the *Urbanización Llano de los Pastores*, latitude 38°28′31″ North, longitude 0°26′42″ West, 185 m above sea level (Busot, Alicante, Spain). The telescope can observe above 30° nearly all the horizon except the North. The benefits of this reduced view of the sky are double (1) minimise the light pollution, and (2) allow protection against the wind.

Thanks to the agreement collaboration between the X-ray Astronomy Group at University of Alicante (XRAGUA) and *Obras e infraestructuras del Mediterráneo* (Obrimed), the observatory is routinely observing scientific targets in an almost autonomous way. This imply that both telescope and dome are computer controlled and all indispensable actions of observation can be done automatically, including processing weather conditions, dome driving, selecting targets to observe, exposing by cameras and filter wheel, taking calibration images and so forth. The only human activities we need to do are just to keep and maintain the observatory. A general block diagram of the system is shown in Figure 2, which is described in detail in the next section. Main parameters of the telescope and the implemented instrumentation are described in Table 1.

2. TELESCOPE SETUP

The Busot Observatory consists in a Schmidt-Cassegrain telescope with an aperture of 35.6 cm (Meade LX200GPS ACF 14″). The telescope is equipped with an ST-8XME CCD camera from SBIG, a Kodak KAF-1603ME+TI TC-237 detector (1530×1020 pixels, pixel size of 9×9 μm) and an AO-8 adaptive optics system. The camera is refrigerated with water achieving temperatures up to −40° in the winter months, and up to −25° in the summer

[1]Departamento de Física, Ingeniería de Sistemas y Teoría de la Señal, Universidad de Alicante, Apartado Postal 99, 03080 Alicante, España (jjrodes@ua.es).

[2]Instituto de Física Aplicada a las Ciencias y las Tecnologías, Universidad de Alicante, 03080 Alicante, España.

[3]OBRIMED, C/ Migjorn 11, 03111 Busot, Alicante, España (ruben@obrimed.es).

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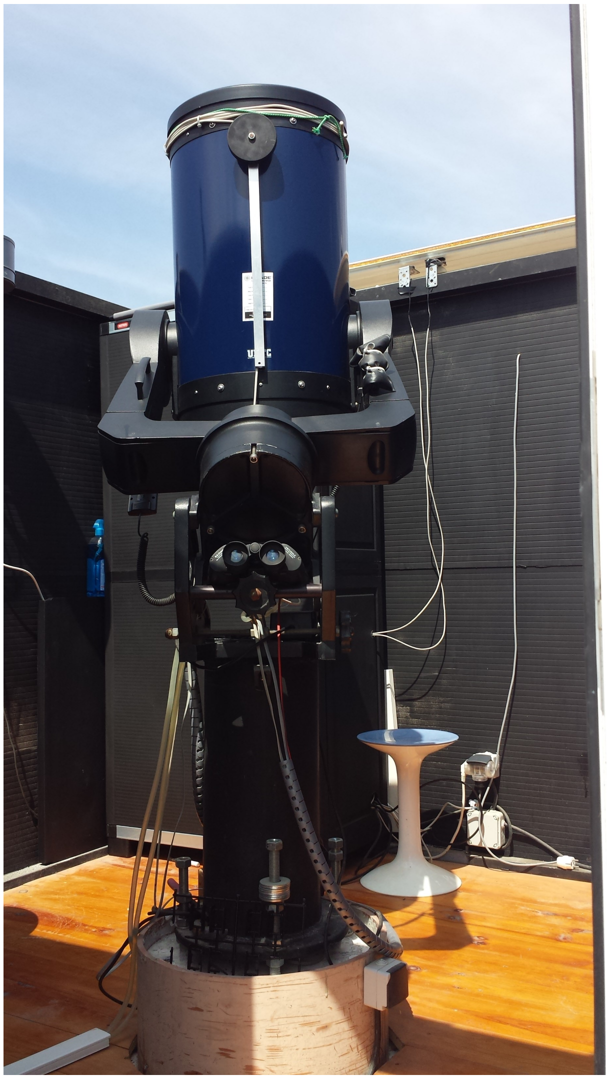

Fig. 1. The telescope and CCD camera.

months. The field of view is $0.39° \times 0.56°$ with a resolution of $1''$ per pixel. The camera has a dual CCD self-guiding camera and a filter wheel with standard UVBRI system. Currently we are ending the implementation of our spectrograph SGS ST-8 in the telescope.

The telescope can operate in remote mode from a computer with Internet connection or a phone mobile as well. The observations can be taken autonomously using commercial software which is implemented in the telescope control system. In order to work properly, the watch of the computer is synchronised with the UTC hour, either via radio or by Internet. Wherever the telescope is pointing we can close the dome automatically avoiding of collision with the roof.

As can be seen in Figure 2, both telescope and

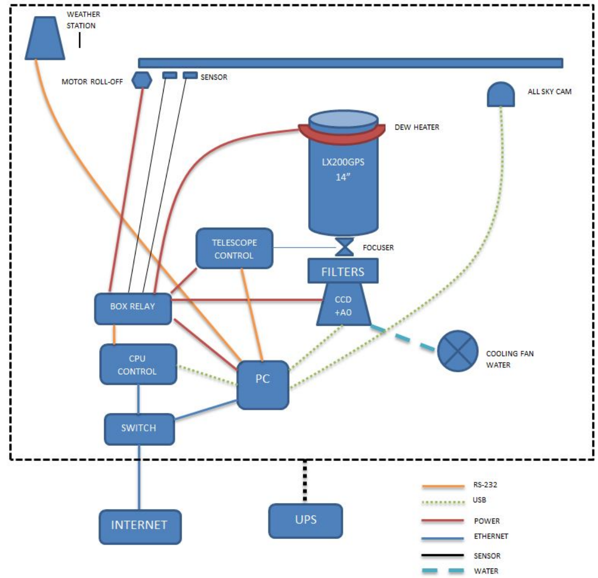

Fig. 2. A schematic view of the telescope control system.

dome can be controlled locally from a personal computer either inside the dome or from another room under the observatory using a controller Seletek. The user interface and main control is also connected to Internet in order to allow the system to be controlled remotely.

3. OBSERVATIONS FROM THE BUSOT OBSERVATORY

In this section we describe the process we follow in a typical observing session. First of all, we check all the weather conditions to assure we can make the observation we have prepared previously. Then we run the telescope control system and start to send the control commands to complete the observation plan. After that, at least 40 bias frames for the habitual temperatures of work are taken. Following this, at least 40 dark frames are exposed, each with 60 s exposure. During the twilight at least 20 flat frames are taken for each filter and for the temperatures of work. Exposure time is tuned to keep the central intensity at $\sim$50% of the maximum value of counts where the camera is linear, i.e., around 25 000 counts.

All the images are reduced using the MaxIm DL software obtaining every average frame, called masters images. This process is not necessary to make it every day because both dark and bias pattern does not seem to change in time. Nevertheless, frames are updated every 15 days. Calibration of frames is done in a standard way and consists of bias and dark subtraction and flat-field correction.

TABLE 1

THE BUSOT OBSERVATORY PARAMETERS

Telescope	
Optical design	Schmidt-Cassegrain
Clear aperture	356 mm
Focal length	3556 mm
Focal ratio	f/10
Angular film coverage	$0.39° \times 0.56°$
Limiting visual magnitude	15.4
Limiting photographic magnitude	18.5
Slew speeds	(1°–8°)/s
CCD camera	
Pixel array	1530×1020 pixels, 13.8×9.2 mm
Pixel size	9×9 μm
Exposure	(0.11–3600) s, 10 ms resolution
A/D converter	16 bits
A/D gain	2.5 e^-/ADU
Read noise	15 e^- RMS
Pixel digitization rate	Up to 420,000 pixels/s
Full frame acquisition	3.7 s
Adaptive optics system	A0-8
Photometric filters	U, B, V, R, I
Other instrumentation	
Spectrograph	SBIG SGS ST-8
All-sky camera	Luna-QHY 5-II + HQDN 1.78 mm 165° Super Wide Lens
Weather station	Davis Vantage VUE AAG CloudWatcher

And finally, we obtain the photometric light curves using the software FotoDif which makes long photometric series in order to obtain the orbital period. These values are derived differentially with respect to some reference stars with similar colours in the same field of view.

4. FIRST SCIENCE AND DISCOVERIES

Eclipsing binary systems are very important in astrophysics because of the effects eclipsing binaries have on light-curves allowing us to estimate the most relevant astrophysical parameters such as masses and radii. Moreover, we are able to apply it to other interesting astrophysical events such as X-ray binary systems, asteroids and exoplanet transits. We present our first results in the next subsections (see also our poster contribution in the proceedings).

Hoňková et al. (2013) presented observations of eclipsing binaries acquired by members and cooperating observers of the Variable Star and Exoplanet Section of Czech Astronomical Society (Brno Regional Network of Observers, BRNO observing project). This paper contained only new, previously observations where each of them is visually validated by the database administrators. Only observations with well defined minimum were accepted to the online database and we contributed with our observation of the source VSX J072306.5+291628 (see § 4.2).

4.1. *Asteroids discovered at the Busot observatory*

This result comes as a part of the sky survey project we are developing at the observatory to try and discover new asteroids. The discovery images of asteroid 2013 AO29 were taken on 2013 January 7 at 00:31, 00:58 and 01:19 UTC. The exposure time for each pass was 20 minutes and we used the filter Clear. The magnitude of the asteroid we obtained was $m_V = 20.7$ mag, near the limit of detection of such exposures. Using the same configuration, the discovery images of asteroid 2013 AP68

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were taken on 2013 January 11 at 21:00, 21:32 and 22:04 UTC. The magnitude of the asteroid we obtained was $m_V = 20.4$ mag.

In Figure 3 we show the orbit we derived from our observations. The blue line implies that the orbit is above the ecliptic plane and the magenta indicates that the orbit is below the ecliptic plane. The 2013 AO29 is moving along an orbit close to the Jupiter's orbit, meanwhile the 2013 AP68 is moving along an orbit close to the Mars' orbit. From the Minor Planet Database we obtain the inclination, i =2.8° (i =17.9°), a measure of the eccentricity, e =0.1823 (e =0.0543) and the semi-major axis, a =2.30 AU (a =5.26 AU). Other data of the AP68 (AO29) asteroid are shown in Table 2. *Radius* indicates the distance of the asteroid from the Sun in units of AU and *Delta* indicates the distance of the asteroid from the Earth.

4.2. *W UMa systems discovered at the Busot observatory*

From the standpoint of stellar structure and evolutionary modeling, overcontact binary stars (Wilson 2001) are the best astrophysical laboratories for studying structural processes that have implications far beyond understanding this binaries themselves. Although there is a common interacting envelope, these systems coexist with remarkable stability. Moreover, they cover nearly all the range of stellar spectral types. W Ursae Majoris (W UMa) sources are the most common type of overcontact binary systems where the dominant energy transport mechanism within the common envelope is convection (Genet et al. 2005). In these binaries, significant energy is transferred from the higher mass star to the lower mass star. As a result, their surface temperatures are almost the same. As a consequence, in eclipsing W UMa systems, the two eclipse depths are barely any different between the two stars. Most of the W UMa binaries have mass ratios between 0.1 and 0.5, but a handful of them have mass ratios close to one (e.g., V753 Mon with 0.97) and the lowest one is SX Crv with a mass ratio of 0.066 (Genet et al. 2005). Moreover, orbital periods are usually between 0.22 and slightly more than one day.

We have chosen to focus our observations on the discovery of the W UMa systems with periods with periods smaller than one night of observation. We present in Table 3 the data of our three W UMa binaries we discovered following the reduction process indicated in § 3 (all of them have been collected by the American Association of Variable Star Observers in the International Variable Star Index database). One of the binaries we discovered is close to the end of the line in the W UMa Period-Colour diagram (Rucinski 1993), although more recent data have shown that this limit may be a bit smaller ∼0.20 days (Dimitrov & Kjurkchieva 2010; Davenport et al. 2013). Nevertheless, the existence of a well-defined boundary is not disputed. This short-period limit is due to the primary components having reached the full convection. At this stage, constrained by their Roche-lobe geometry, the Hayashi limit does not permit dynamically stable contact binaries with effective temperatures lower or orbital periods longer than a certain limit (Rucinski 1992, 1994). A list for the shortest-period W UMa systems (periods less than 0.30 days) can be seen in Pribulla et al. (2003). Therefore, we can add to this list two of our sources we discovered.

TABLE 3

W UMA SYSTEMS DISCOVERED AT THE BUSOT OBSERVATORY[a]

Name VSX J	Period (Days)	Δm_V
021222.2+515559	0.5189	0.40
063116.4+400301	0.25897	0.30
072306.5+291628	0.2908	0.15

[a]See also our poster contribution in the proceedings.

Palaversa et al. (2013) established a period-colour correlation for contact eclipsing binaries fitting the $\log P$ (d) versus $g - i$ colour. The range of observed $g - i$ colours corresponds to spectral types from F5 ($g - i = 0.29$) to K4 ($g - i = 1.38$). The sources they selected satisfied the following criteria: (1) $0.1 < g - i < 1.8$, and (2) $-0.67 < \log P < 0.40$ (period in days). From the VizieR Online Data Catalog URAT1 (Zacharias et al. 2015), we obtained the colour $g - i = 14.688 - 13.656 = 1.032$ value for the shortest-period of our W UMa sample. Based on this $g - i$ colour, we have classified the spectral type between K3 and K2 and luminosity class V. However, when we used the correlation derived by Zacharias et al. (2015), the orbital period was slightly larger than our value P ∼0.2726 days. A schematic drawing of VSX J063116.4+400301 is displayed in Figure 4, showing a simulation of both components close to the eclipse. We note that this is not the solution of the binary system because we have not solved neither the mass ratio nor the radii of the stars yet.

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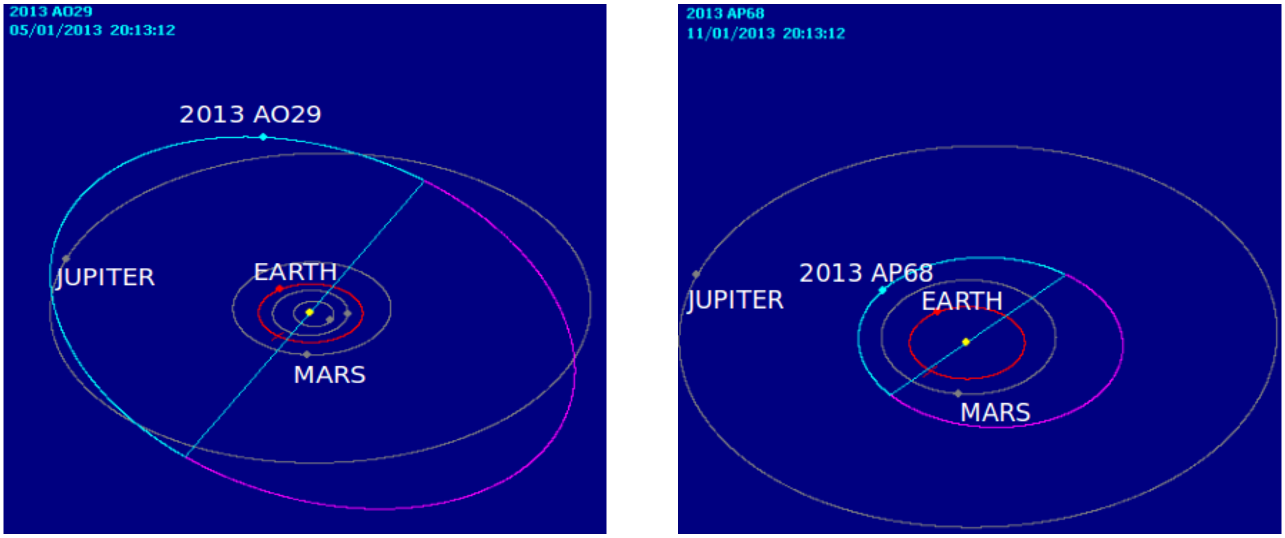

Fig. 3. Two-dimensional orbit of the asteroids (blue and magenta semicircles, red circle show the Earth's orbit).

TABLE 2

2013 AP68 AND AO29 DATA

AP68	2013 Jan 11, UTC hour		
Parameter[a]	21:00:00	21:32:00	22:04:00
RA (J2000)	$05^h\ 05^m\ 22.0^s$	$05^h\ 05^m\ 21.5^s$	$05^h\ 05^m\ 20.9^s$
Dec (J2000)	$+28°03'36''$	$+28°03'33''$	$+28°03'30''$
Radius (AU)	1.96929	1.96932	1.96936
Delta (AU)	1.07566	1.07583	1.07599
AO29	2013 Jan 07, UTC hour		
Parameter[a]	00:31:00	00:58:00	01:19:00
RA (J2000)	$09^h\ 37^m\ 35.7^s$	$09^h\ 37^m\ 35.2^s$	$09^h\ 37^m\ 34.8^s$
Dec (J2000)	$+28°05'40''$	$+28°05'43''$	$+28°05'44''$
Radius (AU)	4.96973	4.96973	4.96973
Delta (AU)	4.11797	4.11782	4.11771

[a]From Minor Planet Database.

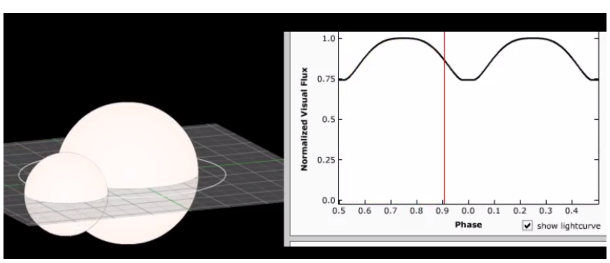

Fig. 4. Representative drawing of VSX J063116.4+400301 showing the eclipse-egress of the less massive star.

4.3. *Transiting exoplanets*

Using the indirect technique of the transit method, we also obtained the photometric light-curve of some exoplanets such as HAT-P-22 b, HAT-P-20 b, HAT-P-16 b, CoRot-12 b and WASP-12 b. In Figure 5 we display the transit light-curve with the best data quality indicator for the exoplanet HAT-P-20 b where we used the filter Clear. Differential magnitude is plotted versus time (Julian date). HAT-P-20 b was discovered in 2010 by Bakos et al. (2011). It orbits the moderately bright $V = 11.339$ mag K3 dwarf star GSC 1910-00239 on a circular orbit, with a period $P = 2.875317 \pm 0.000004$ d and a transit duration $D = 0.0770 \pm 0.0008$ d. The parameters we derived were the central time of the transit, MJD $= 55{,}575.47956 \pm 0.00023$ d, the transit duration, $D = 0.0744 \pm 0.0006$ d, and the depth in

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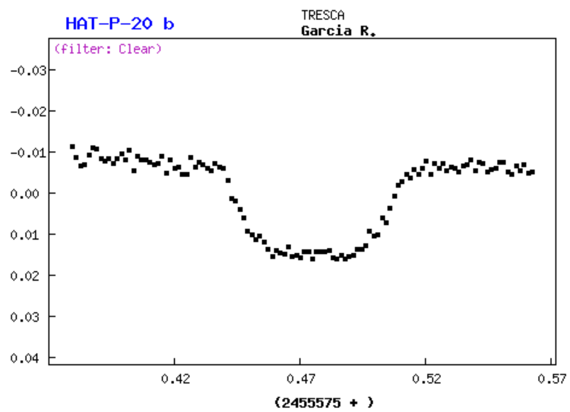

Fig. 5. Transit light-curve of the exoplanet HAT-P-20 b observed on the night of 2011 January 17.

magnitude, i.e. 20.3±0.4 mmag.

5. CONCLUSIONS

The Busot observatory is a good telescope for the monitoring of variable sources in general. The accessibility to the observatory is extremely easy by road, around 14 km from Alicante. The Obrimed-UA agreement allow us to work with the only time restriction being the weather conditions. We can summarize the capabilities of the telescope as follows: (1) to program the observations by scripts and do it automatically (locally or remotely), (2) to achieve a spatial resolution up to $\sim 0\farcs82$ per pixel, (3) to achieve a limiting magnitude up to $m_V \sim 21$ mag, (4) to perform long-term photometric analysis, (5) to carry out survey campaigns and long-term variability studies.

In the near future we will be able to install the spectrograph at the telescope and explore the capabilities to obtain stellar spectra at the Busot observatory. Now we are working on the research projects listed below:

- Simultaneous photometry and spectroscopy observations of high-mass X-ray binary systems.
- Characterization of W UMa binary systems.
- Discovery of new sources based on the photometric variability and combining it with Virtual Observatory tool analysis.

Moreover, we plan to upgrade the telescope with more filters and a new spectrograph with increased capabilities with respect to our current one. The Obrimed-UA agreement is renewable every year.

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