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Exoplanet photometry from backyard observatory

D. Licchelli

Physics Department, University of Lecce, Via Arnesano, 73100 Lecce
e-mail: domenico.licchelli@le.infn.it

Abstract. A typical short-period giant planet occulting a parent star produces a 1% dimming of the star light for an interval of several hours. Time-series photometry easily can show the typical lightcurve of an ongoing transit event. In combination with Doppler radial velocity measurements, photometry can yield unambiguous determination of the orbital and physical parameters of the planet. Nowadays, with a small-aperture telescope, i.e. an 8 inch Dall-Kirkham reflector and an off-the-shelf CCD detector, it is possible to obtain 3-4 millimagnitude photometry. This precision is sufficient to reliably detect the transit of a giant planet like Jupiter. Therefore, a low-cost observational and data-reduction pipeline can provide useful information on the photometric follow-up of candidates identified in the data of professional surveys and on the search of additional transit of known exoplanet.
Here I report the results of photometric measurements of HD209458-b and XO-1b exoplanet transits as examples of this interesting research program from my backyard observatory.

Key words. exoplanet – photometry

1. Introduction

The discovery of the extrasolar planets is certainly a field in which the astrophysics research is making giant steps. In the last years more than 200 planets, orbiting around other stars, are discovered and it is to be expected that much others will find out in a short time.

If surveying through the radial velocity method needs big-aperture telescopes and very high sensitivity spectrometers, for the transit method it is sufficient an equipment not so sophisticated. In Fig. 1 it is reported the minimal instrumentation used in the XO project, consisting of two off-the-shelf photographic lenses, coupled with commercial CCD cameras, that carried out the discovery of a new planet in transit, named XO-1b (McCullough et al., 2006).

In this low resolution survey, the lightcurve analysis of the imaged stars produces transiting-planet candidates that required detailed follow-up. With a 20 cm aperture telescope, it is possible to photometrically study with good resolution the proposed stars, at least within reasonable magnitude values, and to point out the possible transit of Jupiter size planets. In this work are reported the tests done in this subject with this class of instruments.

Send offprint requests to: D. Licchelli

Fig. 1. The XO Mark I system employs twin 200mm Canon EF200 lenses at f/1.8. This yields a plate scale of 1.058”/μm when coupled with the Apogee Ap8p CCD detectors. Each detector covers 7.2 degrees on the sky and at 25.4”/pixel.

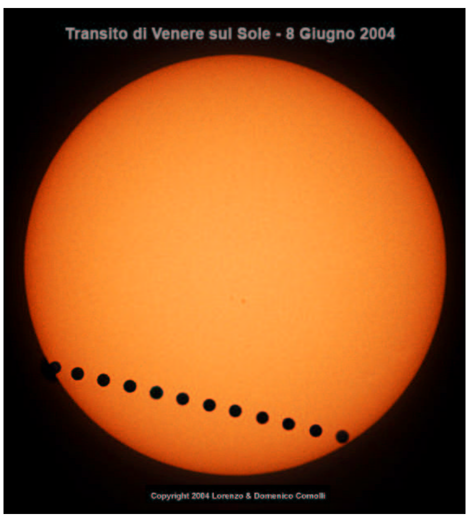

Fig. 2. The transit of Venus over the Sun - June 8, 2004.

2. The transit method

The transit method is based on a little decrease of the star brightness, observed by Earth, that happens when a planet transits over it. The phenomenon is exactly alike the transit of Venus over the Sun - 8th June 2004 (Fig. 2). The amount of the light decrease, typically 0.01-0.1%, depends on the dimension of the star and the planet, whereas the transit duration is function of the star mass and its distance from the planet. Since mass and dimension of the star

Fig. 3. One of the acquired frames with marked comparison stars.

can be deduced by spectroscopic observations, the transit lightcurve analysis allows to determine mass and distance of the planet from it.

3. Observation and data reduction

The selected targets for the photometric measures were HD209458-b and XO1-b, at present the first and the last extrasolar planet in the very restricted list of those in transit over their parent star respectively. The observations were done in my private observatory in the South of Italy at 145m over the sea level. In the first case, I used a 200 mm Newtonian telescope at f/5 on a Gemini G41 Observatory equatorial mount with a FS2 telescope driveout. The CCD Camera is a Starlight-Xpress SXV-H9. Using this configuration, the field of view is about 32x23’, enough to include at least a star of magnitude comparable with the target one.

The first opportunity to measure HD209458-b transit happened during the night of 25th July 2005 whereas, to complete the curve, I had to wait for the 1st August when, based on ephemeris by http://www.transitsearch.org/ web site, it would have been possible to measure all the transit. The only problem was that the entry phase would have been with the star at 30° height and a corresponding value of the air mass equal to 1.8.

The high sensor quantum efficiency and the low magnitude of the star (7.65 in V band) produced the saturation in less that one second.

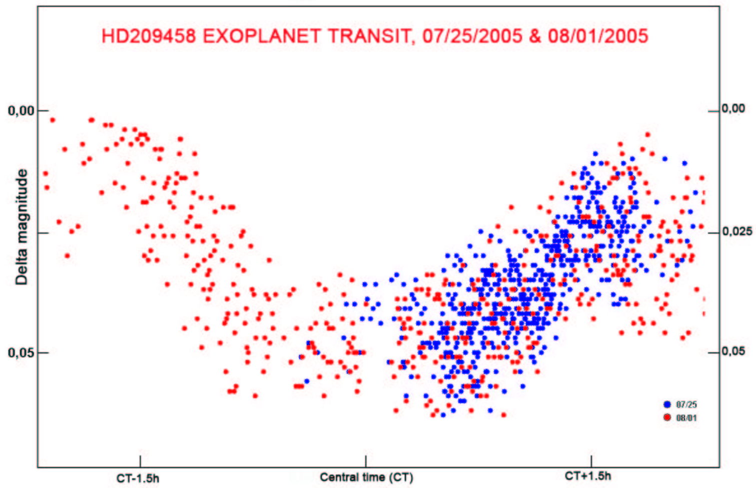

Fig. 4. The transit of HD209458-b during the nights of 25^{th} June and 1^{st} August 2005.

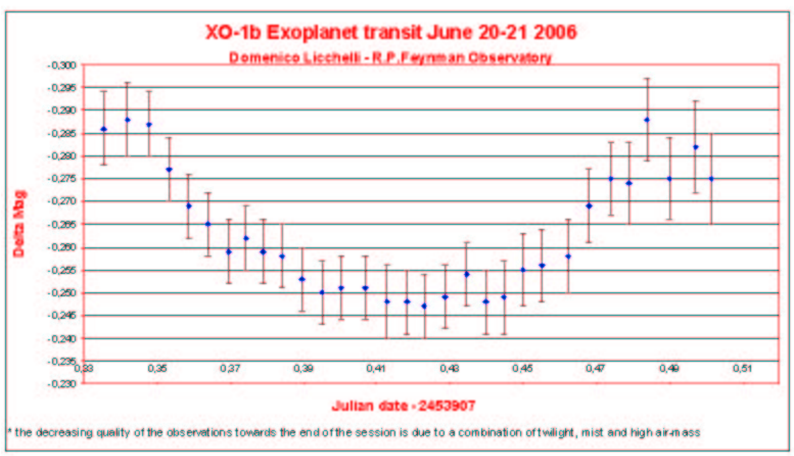

Fig. 5. Lightcurve of the Xo-1b transit during the night of 20^{th}-21^{th} June 2006.

Using a standard Johnson V filter and a large defocus, it was possible to extend the exposure at 7 seconds, certainly a better value to limit the noise due to scintillation. I did not use any autoguide in virtue of a good mount tracking. The frames were acquired continuously, with a planned delay of 30 seconds (about 500 exposures in all). An example it is reported in Fig. 3.

Special care was reserved to the acquisition of calibration frames (21 darks and flats), mediated using a median combination. After the standard calibration (subtraction of the masterdark frame and division of the masterflat frame), I deduced the differential magnitudes using Canopus MPO software that creates a text file. This file contains a table in which are reported the Julian date, the difference between the examined object magnitude and that of the comparison stars, and the associated error.

4. Discussion

In the left zone of the graphic in Fig. 4, that is the phase before the entry, the points seem to arrange themselves more up the equivalent zone after the exit.

This is an effect due to the combination of high air mass and scintillation. The contribute of scintillation to the noise, for views at 30° height, is of 0.01 magnitude. Moreover, we have to add the noise due to the differential extinction both of the first and the second order. As a matter of fact, the distance between HD209458 and the principal comparison star, HD209346 that is at a higher air mass, is about 12'. For air mass about 1.8, this fact implies a 0.003 magnitude extinction, so that the comparison star seems fainter than it really is. A value of about the same size order comes from the different colour index of the two stars, because the target was more red than the reference star and so less liable at extinction with increasing air mass. The magnitude difference between the variable star and comparison stars seems therefore higher than as a matter of fact, and it tends to decrease as the height of the stars increases (Castellano et al., 2004).

The error was calculated treating with respect to the signal-to-noise ratio of the target and the comparison stars used during the photometric reduction in accordance with the formula:

Err = sqrt(sqr(ERR[target]) + sqr(Err[Comps]))
where Err[Target] = 1/SNR[target]
Err[Comps] = sqrt(sqr(1/SNR[Comp1])... + sqr(1/SNR[CompN])) / N

For the XO1-b transit it was used a 21cm aperture Dall-Kirkham reflector + SXVH9 + standard Cousin R filter. Data reduction was done in a standard way and then it was used the binning technique that consists in grouping together more consecutive measures. The magnitude is the average value and the time is the central one between the first and the last averaged measure (Fig. 5).

This method is much effective when we have data characterized by a low signal-to-noise ratio, on condition that the measures are temporally nearly among they.

5. Conclusions

Nowadays, using a modest aperture telescope, of 8” class, and an off-the-shelf CCD camera, it is possible to obtain photometric measures with a precision that can reach 3-4 millimag for sufficiently bright objects. This precision level is enough to see, without ambiguity, the transit of a giant planet of Jupiter size over its star. Therefore, a network of little observatories, preferably located in longitude, equipped with these low-cost instruments, can provide helpful information in the follow-up photometric phase of possible candidates singled out in low resolution surveys or in the search for further transits of well-known exoplanets.

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