Transit timing at Toruń Center for Astronomy

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The transit monitoring is one of well-known methods for discovering and observing new extrasolar planets. Among various advantages, this way of searching other worlds does not require complex and expensive equipment – it can be performed with a relatively small telescope and high-quality CCD camera. At the Center for Astronomy of Nicolaus Copernicus University in Toruń, Poland, we collect observational data using the 60-cm Cassegrain telescope hoping that it would be possible to discover new objects in already known planetary systems using the transit timing variation method. Our observations are a part of a bigger cooperation between observatories from many countries.

Introduction

Our universe is populated by billions of stars, around which, now we are sure, there are amazing new worlds. No exoplanet was known twenty years ago. In 1992 Aleksander Wolszczan, Polish astronomer, discovered the first such objects using timing method [11]. These exoplanet turned out to be strange worlds because their host star is a pulsar – a remnant of stellar evolution. Such a strange discovery gave us a signal that exoworlds do not need to look like our Solar System. In 1995 group of Swiss astronomers led by Michel Mayor and Didier Queloz from Genève University discovered the first planet around a sun-like star using radial velocity method [6]. In 1999 astronomers added a new method – transits. In our century they successfully found new objects using gravitational microlensing, direct imaging and astrometry measurements.

Transits

We may observe a transit when an extrasolar planet moves across the disc of its host star. We can observe the phenomenon in our Solar System in the case of Venus or Mercury. The first transiting exoplanet, HD 209458 b, called also Osiris [2, 5] was observed in 1999. That object was known before. A few years later, astronomers from the OGLE project discovered planet candidates with transit method. Nowadays we know more than 80 transiting exoplanets. Most of them was discovered by dedicated surveys, e.g. SuperWASP or HAT-Net (`http://exoplanet.eu`) and even space missions – French CoRoT (COnvection, ROtation et Transits planétaires, `http://corot.oamp.fr`, `http://smsc.cnes.fr/COROT`) and American Kepler (`http://www.kepler.arc.nasa.gov`).

To observe a transit phenomenon, we need to monitor the brightness of the host star. The shallow dip visible in the light curve is a transit. It is a periodical phenomenon with a period equal to the orbital period of the planet. There are three basic parameters describing a transit: duration, depth and shape [1, 7]. There are four characteristic points of the light curve which are called contacts: first contact – a beginning of eclipse, second contact – the end of ingress, third contact – here the egress begins, and fourth contact – the end of the phenomenon. Other phases are almost flat lines in the light curve graph. The total duration of the transit d is related to the orbital parameters of the planet and star radius. The depth of the transit ϵ is related to radii of the host star (R) and the planet (r): $\epsilon = \frac{R^2}{r^2}$. This formula is simplified bacause the limb darkening phenomenon is neglected. The shape of the transit is correlated with the inclination angle. We can have U-shaped or V-shaped curve. The latter one is the border case between transiting and non-transiting exoplanet, a "grazing occultation".

When we found a candidate, we have to reject false positives or phenomenf mimicking a transit. A periodic phenomenon which looks like V-shaped transit is grazing binary system. It is quite easy to distinguish what case are we dealing with when radial velocities are available. The picture is a little more difficult when we

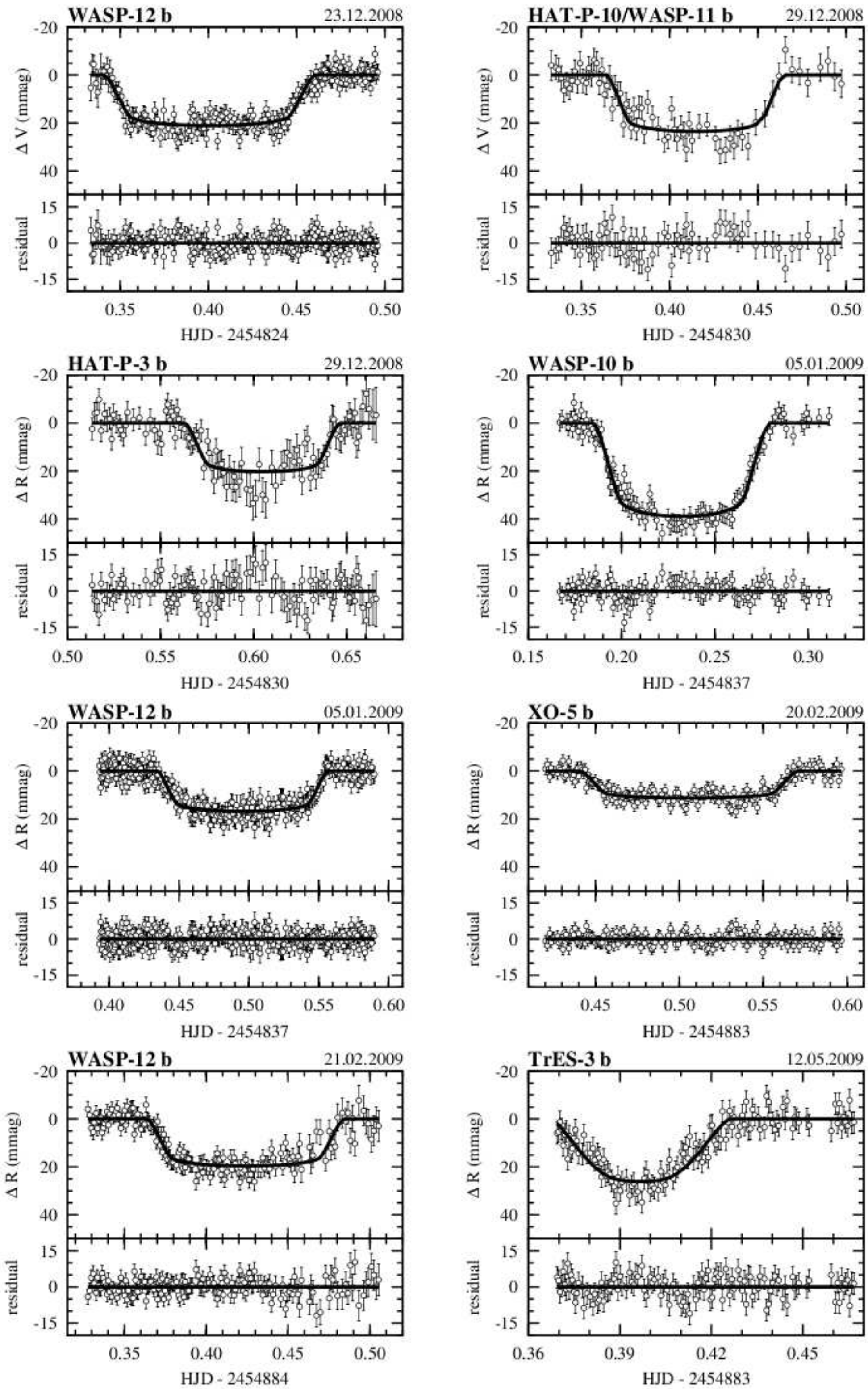

Figure 1: A sample of observed transits at the Astronomical Observatory of the Nicolaus Copernicus University.

have a small stellar companion of a giant star. Only spectrometry with radial velocities or analysis of a secondary eclipse can help us here. The most difficult situation is when we have an eclipsing binary in a triple system or an eclipsing binary with a third star on the background. In some cases, when stars have the same spectral type, only simulations can solve the problem. Of course, we can find any other false positives generated by stellar spots or unidentified instrumental effect (See Fig. 1).

Transits Timing

If we consider an extrasolar planetary system, we may suppose that it has more than one planet. If it is true, we can suspect, that planets interact gravitationally [3, 9]. If we have a transiting planet, its orbital period will vary slightly. Technique which focuses on this phenomenon is called transit timing variation (TTV). Focusing on transits durations we may find exomoons [4], but here we need really good time resolution, so bigger telescopes. We may improve planetary periods with transits monitoring [10]. Moreover, if we monitor transits for long time we should be able to check whether the host star is a close binary [8]. And finally, we expect to find new planets.

To search for any interesting phenomenon using TTV, we create an observations-calculations diagram, or shortly O-C diagram, where we mark differences between predicted mid-transit times and observed ones. If the signal has some regularity, we can suppose that there is an additional planet in the system. But different perturbers can make similar transit timing signatures. For example a hypothetical transiting companion with 0.5 Jupiter mass and period of 4.09 days with a trojan companion of 1 Earth mass would create the same amplitude and periodicity as a companion of 28 Earth mass with a period of 8.7 days. To resolve this degeneracy, we must collect more data points from observations.

Nowadays it is possible to obtain the millimagnitude photometry for $11-13$ magnitude stars with a 60-cm class telescope. This photometric accuracy allows us to determine the mid-transit time with a precision reaching tens of seconds [9]. Our 60-cm class telescope is an appropriate instrument for exotransit timing with the accuracy of mid-transit times better than 1 minute. This is enough for discovering new Neptune-class exoplanets. Observations from Piwnice Observatory are a part of international cooperation of observers from many countries such as Poland, Germany, Bulgaria, Taiwan, USA etc.

Conclusions

Two main targets were selected for our observations. One of them now is one of our candidates for a new discovery. A visible trend which gives us a hope for a planetary TTV signal was found in our data. With more new data we should confirm our predictions. Our experience in data analysis will be useful when numerous data from space observatories such as CoRoT and Kepler are available.

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