Załącznik nr 3

Autoreferat w języku angielskim
Summary of professional accomplishments

1. Name and surname: **Gracjan Maciejewski**

2. Degrees with name, place, and year, as well as with a title of a PhD thesis

- Master of Science degree awarded by the Faculty of Physics, Astronomy, and Informatics of the Nicolaus Copernicus University, Toruń, 2002,
- Doctor of Philosophy in physical sciences in the field of astronomy given by the resolution of the Council of the Faculty of Physics, Astronomy, and Informatics of the Nicolaus Copernicus University, Toruń, 2007 r., thesis title: „Photometric Sky Surveys: Search for Variability and Astrophysics of Open Clusters".

3. Information on employment

- from June 1, 2007 to September 30, 2011: teaching and research assistant in the Department of Astronomy and Astrophysics of the Centre for Astronomy of the Nicolaus Copernicus University,
- from March 1, 2009 to November 30, 2010: postdoctoral Marie Curie Fellow at the Institute of Astrophysics and University Observatory of the Friedrich Schiller University in Jena (Germany),
- since October 1, 2011: assistant professor in the Department of Astronomy and Astrophysics of the Centre for Astronomy of the Nicolaus Copernicus University.

4. The scientific achievement, in accordance with art.16 paragraph 2 of the Act of March 14th, 2003, concerning the scientific degrees and titles (Dz. U. item no. 882, 2016, with amendments in Dz. U. item no. 1311, 2016)

a) Title of the scientific achievement

Transit timing for hot Jupiters: from a search for additional planets to the discovery of the shortening of the orbital period for the exoplanet WASP-12 b

b) List of publications constituting the scientific achievement (author/authors, title, date, journal/publisher name)

H1.
G.Maciejewski, D.Dimitrov, R.Neuhaeuser, A.Niedzielski, St.Raetz, Ch.Ginski, Ch.Adam, C.Marka, M.Moualla, M.Mugrauer, „Transit timing variation in exoplanet WASP-3b", 2010, Monthly Notices of Royal Astronomical Society, 407, 2625

H2.
G.Maciejewski, A.Niedzielski, A.Wolszczan, G.Nowak, R.Neuhaeuser, J.N.Winn, B.Deka, M.Adamów, M.Górecka, M.Fernandez, F.J.Aceituno, J.Ohlert, R.Errmann, M.Seeliger, D.Dimitrov, D.W.Latham, G.A.Esquerdo, L.McKnight, M.J.Holman, E.L.N.Jensen, U.Kramm, T.Pribulla, St.Raetz, T.O.B.Schmidt, Ch.Ginski, S.Mottola, S.Hellmich, Ch.Adam, H.Gilbert, M.Mugrauer, G.Saral, V.Popov, M.Raetz, „Constraints on a second planet in the WASP-3 system", 2013, Astronomical Journal, 146, 147

H3.
G.Maciejewski, St.Raetz, N.Nettelmann, M.Seeliger, Ch.Adam, G.Nowak, R.Neuhaeuser, „Analysis of new high-precision transit light curves of WASP-10 b: starspot occultations, small planetary radius, and high metallicity”, 2011, Astronomy & Astrophysics, 535, A7

H4.
G.Maciejewski, M.Fernández, F.J.Aceituno, J.Ohlert, D.Puchalski, D.Dimitrov, M.Seeliger, M.Kitze, St.Raetz, R.Errman, H.Gilbert, A.Pannicke, J.-G.Schmidt, R.Neuhäuser, „No variations in transit times for Qatar-1 b”, 2015, Astronomy & Astrophysics, 577, A109

H5.
G.Maciejewski, D.Dimitrov, M.Fernández, A.Sota, G.Nowak, J.Ohlert, G.Nikolov, Ł.Bukowiecki, T.C.Hinse, E.Palle, B.Tingley, D.Kjurkchieva, J.W.Lee, C.-U.Lee, „Departure from the constant-period ephemeris for the transiting exoplanet WASP-12 b”, 2016, Astronomy & Astrophysics, 588, L6

c) Description of the scientific objectives and the research results presented in the scientific achievement, together with the discussion of their possible applications

Introduction

Since the discovery of planets around a neutron star (Wolszczan & Frail 1992, Wolszczan 1994) and around main-sequence stars (Latham et al. 1989, Mayor & Queloz 1995, Marcy & Butler 1996), it is possible to study the architecture of planetary systems and their formation outside the Solar System. Orbital planes of some planets are aligned in such a way that the planets pass across the disk of its host star, temporarily blocking a fraction of stellar light. The first discovered transiting exoplanet (TEP) was the planet candidate HD 209458 b found by the radial velocity (RV) method by Mazeh et al. (2000) and confirmed to be a planet by transit observations (Charbonneau et al. 2000, Henry et al. 2000). Many of known TEPs have been found by ground-based surveys such as TrES (Trans-Atlantic Exoplanet Survey, Alonso et al. 2004), HATNet (Hungarian-made Automated Telescope Network, Bakos et al. 2004), or SuperWASP (Wide Angle Search for Planets, Pollacco et al. 2006). As the probability of the transit detection decreases with the increase of the orbital semi-major axis, most of known TEPs occupy orbits with periods of a few days. A typical transit lasts up to 2 – 3 hours. However, there are rare cases, like the HD 80606 planetary system, in which one planet orbits in 110 days and its transits last 12 hours (e.g. Hebrard et al. 2010). Such long transits are difficult to detect by the ground-based surveys, so wide-orbit TEPs are discovered by dedicated space-borne telescopes CoRoT (Baglin et al. 2007) and Kepler (Koch et al. 2010, Borucki et al. 2010).

Exoplanets with masses greater than 0.3 Jupiter mass ($M_{\rm Jup}$) and orbital periods shorter than 10 d (e.g. Hatzes & Rauer 2015, Mancini & Southworth 2016) constitute a group of so called hot Jupiters. Statistical studies show that hot Jupiters are a very small minority of the overall planet population (Howard et al. 2012b, Wright et al. 2012). They appear to be usually alone (see e.g. Steffen et al. 2012) or accompanied by other planetary bodies on wide, eccentric orbits (e.g. HAT-P-13 b – Bakos et al. 2009). The WASP-47 system is an interesting and so far the only exception from this picture. The hot Jupiter-like planet WASP-47 b (Hellier et al. 2012) is accompanied by two nearby low-mass planets on inner and outer orbits (Becker et al. 2015). Both planets were detected with the transit technique in high precision photometric time series acquired with the Kepler telescope. The outer planet perturbs the orbital motion of WASP-47 b rising deviations from the strictly Keplerian case. The orbital period is no longer strictly periodic and its variations are observed as sinusoidal signal in transit times. For WASP-47 b, the amplitude of this signal was found to be 30 s, so potentially detectable from the ground with 2 m telescopes. This finding demonstrates that the transit timing variation (TTV) method (Miralda-Escude 2002, Holman & Murray 2005, Agol et al. 2005) may be used for discovering additional planets in hot Jupiter systems.

In contrast to hot Jupiters, warm Neptunes or Saturns from the Kepler sample are known to have close planetary companions. In many cases, such planetary pairs are close but not in mean-motion resonances (Fabrycky et al. 2014). Theoretical studies show that system architecture depends on many factors, including the ratio of both planets relative to the central star, the mass of the protoplanetary disk, and the mechanism of the planetary migration (e.g. Goldreich & Schlichting 2013). It is postulated that differences between hot Jupiters and other planetary systems may be caused by distinctly different formation conditions and dynamical evolution of their planetary systems (see e.g. Kley & Nelson 2012, Ogihara et al. 2013).

The formation of hot Jupiters is not yet fully understood (Steffen et al. 2012, Lloyd et al. 2013). Conventional planet formation theory (Pollack et al. 1996) indicates that in situ formation of hot Jupiters is unlikely. If it is true, these planets must have formed beyond the ice-lines of protoplanetary disks (at the distance of a few AU), and then migrated to the tight orbits observed today. The postulated loneliness of hot Jupiters and highly inclined or even retrograde orbits for some of them speak in favour of inward migration theories of massive outer planets through planet-planet scattering caused by mutual dynamical perturbations in unstable planetary systems (Rasio & Ford 1996; Weidenschilling & Marzari 1996) or the Lidow-Kozai mechanism due to the presence of an outer perturber (e.g. Fabrycky & Tremaine 2007). In both scenarios, the planet goes into orbit with a significant eccentricity, and then it loses the angular momentum of the orbital motion via tidal interactions with the star and finally ends up as a hot planet on a circularised tight orbit. On the other hand, Schlaufman & Winn (2016) have recently shown that the occurrence rate of additional giant planets inside the water-ice line in systems with hot Jupiters argues against the high-eccentricity migration. Numerical simulations show that compact planetary systems similar to WASP-47 are highly unlikely to be formed via high-eccentricity migration, and disc migration scenarios are favoured (Mustill et al. 2016).

Alternatively, if *in-situ* formation of hot Jupiters is possible – as it has been demonstrated recently by Batygin et al. (2016) – the giant planets could be accompanied by additional low-mass planets with periods shorter than 100 days. Calculations demonstrate that dynamical interactions would increase the inclinations of such companions. Those additional planets would be unlikely to transit, so they could be detected by TTV and RV methods.

The architecture of the WASP-47 system has overthrown the paradigm that hot Jupiters do not exist in compact systems, but the question about the occurrence rate of such systems remains opened. That discovery also demonstrates that the population of known hot Jupiters still remains unexplored and high-precision follow-up photometric, Doppler, and transit timing observations are required to identify more such systems. Their properties will place constraints on planet formation and migration theories.

There are reported hot Jupiters on non-circular orbits. In many such cases, the circularisation time scale might be shorter than the system age. On the one hand, the efficiency of the circularisation process depends on the tidal dissipation constant, which is poorly constrained for exoplanets. On the second hand, the non-zero orbital eccentricity could be pumped up by gravitational interactions with unseen planetary companions (Peale et al. 1979, Bodenheimer et al. 2001, Adams & Laughlin 2006). It has been shown that even very small (Earth-mass or less) companions in certain orbits can provide significant eccentricity excitation (Mardling 2007).

Massive planets on extremely short-period orbits are expected to be unstable to tidal dissipation and finally spiral in toward the host star because they transfer the angular momentum of the orbital motion through tidal dissipation inside the star (e.g., Levrard et al. 2009, Essick & Weinberg 2016). The rate of this orbital decay can help determine the efficiency of the tide dissipation. The decaying orbital period can be observed through transit timing. For some planets, the cumulative shift in transit times may be about 100 s after ten years (Birkby et al. 2014). Tentative detections of the orbital decay were reported for the systems OGLE-TR-113 and WASP-43 (Adams et al. 2010, Blecic et al. 2014), but so far they have not been confirmed by further observations (Hoyer et al. 2016, Jiang et al. 2016).

In the case of hot Jupiters on tightest orbits, the shapes of a planet and a star depart noticeable from spherical symmetry, because both bodies raise mutual tides. The non-spherical mass component of the gravitational field results in precession of the orbit (e.g., Ragozzine & Wolf 2009). This apsidal rotation might be observed through precise timing of transits for non-zero orbital eccentricities. The total apsidal precession is the sum of components induced by tidal and rotation bulges and relativistic effects. Calculations show that a precession period of 10 – 50 yr might be expected for the most promising planets. Even a small departure from a circular orbit would results in transit timing variations with amplitude of minutes, so easily detectable from the ground. Long-time precise transit timing observations are required to detect that TTV signal.

Being motivated by a number of phenomena that can be addressed via studies of hot Jupiters, I initiated a long-term research project that is focused on precise transit timing for hot Jupiters (Maciejewski et al. 2011a). Its scientific goal is detection of changes in orbital periods that could be caused ether by perturbations from undetected planetary companions or by star-planet tidal interactions. The project is run in a cooperation with astronomers mainly from Germany, Spain, and Bulgaria, but also from Great Britain, Italy, Japan, Slovakia, South Korea, and United States of America. As the scientific achievement, I present a set of 5 papers, which demonstrate various aspects of the project (papers **H1**-**H4**), leading the original discovery of the shortening of the orbital period for the exoplanet WASP-12 b (paper **H5**, highlighted by the A&A editor).

A search for additional planets in the WASP-3 system (H1 and H2)

The observing campaign organised for WASP-3 b is used here to illustrate the strategy and methodology of the project. The planet is a strongly irradiated gas giant (Pollacco et al. 2008). Its mass and radius were found to be ~1.8 M_{Jup} and ~1.3 Jupier radii (R_{Jup}), respectively. It orbits its host star in ~44 h in a circular orbit with the semi-major axis of ~0.032 AU. The host star is a dwarf and has a spectral type of F7–8 and photospheric temperature of 6400 K. Spectroscopic observations of the Rossiter-McLaughlin effect showed that the sky-projected angle between the stellar rotation axis and planetary orbital axis is equal to 3.3 ± 2.5 degrees, i.e. is consistent with zero within 2σ (Tripathi et al. 2010). This result indicates that WASP-3 b underwent relatively non-violent migration process which did not perturb it from the primordial alignment of the protoplanetary disc. Follow-up observations showed some deviations from a linear ephemeris for transit times, and were explained as a result of possible genuine period variations (Tripathi et al. 2010).

Being motivated by this finding, we acquired additional photometric observations for 6 transits between July 2009 and April 2010 (Maciejewski et al. 2010, **H1**). The data were obtained with 60 cm telescopes located at the Rozhen National Astronomical Observatory (Bulgaria) and the University Observatory Jena (Germany). Those reconnaissance observations seemed to confirm previous claims and showed that transit timing of WASP-3 b cannot be explained by a constant value of the orbital period. We put

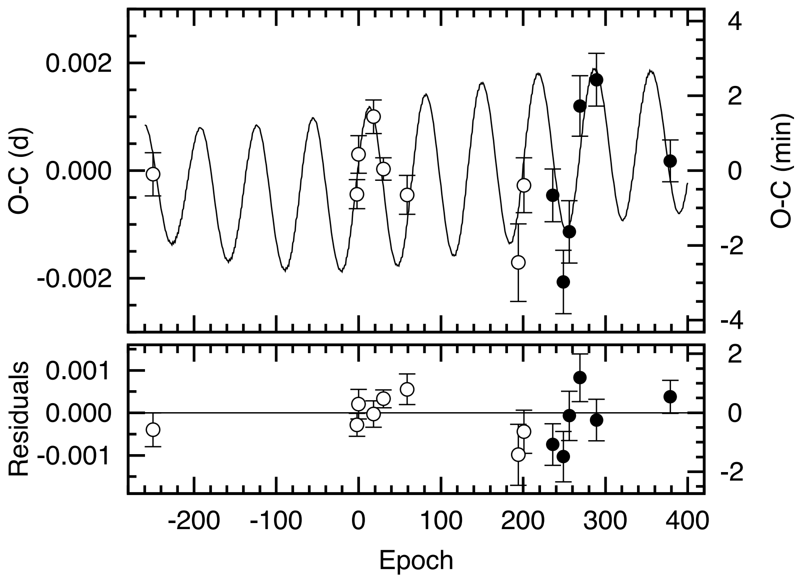

Fig. 1. *Upper panel:* the transit timing residuals from a linear ephemeris in a so called *O* – *C* diagram. The best-fit model which reproduces the observed variations is sketched with a continuous line. The open symbols denote literature data while the filled ones denote mid-transit times reported in Maciejewski et al. (2010, **H1**). *Bottom panel:* the final residuals from the dynamical model. Taken from Maciejewski et al. (2010, **H1**).

forward a provisional hypothesis which assumed the existence of a perturber in that system. As a result of three-body simulations, two groups of configurations which reproduce the observed TTV were identified close to the outer 2:1 mean motion resonance (MMR) and one group close to the 5:3 MMR. A model with the hypothetical second planet of the mass of ~15 $M_{\oplus}$ and orbital semi-major axis of ~0.051 AU was found to be most likely. In that scenario, both planets stayed in the stable orbital resonance with a period ratio of 2.02, i.e. very close to the 2:1 MMR. A plot of the timing residuals from a linear ephemeris, together with the best-fit model is shown in Fig. 1.

The expected radial velocity semi-amplitude of the proposed second planet was found to be much smaller than the precision of RV measurements available then. Further precise RV follow-ups could be used to detect the perturber's signal. We also discussed possibility that the hypothetical second planet transits the host star, causing periodic flux drops. The depth of these transits would be in the range of 0.03 – 0.35 per cent (or 0.3 – 3.8 mmag) depending on the adopted mean planetary density – for a rocky planet such as CoRoT-7 b or an ultra-low-density hot Neptune such as WASP-17 b.

Our finding was based on few data points. As the TTV method requires many high-quality light curves, more observations were gathered for WASP-3 b to verify the claimed variations in transit timing. We performed high precision photometric and spectroscopic follow-up observations (Maciejewski et al. 2013b, **H2**). We acquired 32 new transit light curves with 0.6 – 2.2 m telescopes located in Turkey, Bulgaria, Germany, Spain, and USA. In addition, 17 Doppler measurements were obtained with the Hobby-Eberly Telescope at the McDonald Observatory (USA). Our new data covered a timespan of 2 years from 2009 to 2011. Despite all of this observational effort, no evidence for the presence of the additional planet in the WASP-3 system was found. As it is displayed in Fig. 2, our newly measured mid-transit times were found to be consistent with a refined linear ephemeris. The RV data showed no sign of additional bodies, and in particular no long-term trend over a few years. Our spectroscopic and photometric data sets were used to refine stellar, orbital, and planetary parameters with improved precision. We placed tighter constraints

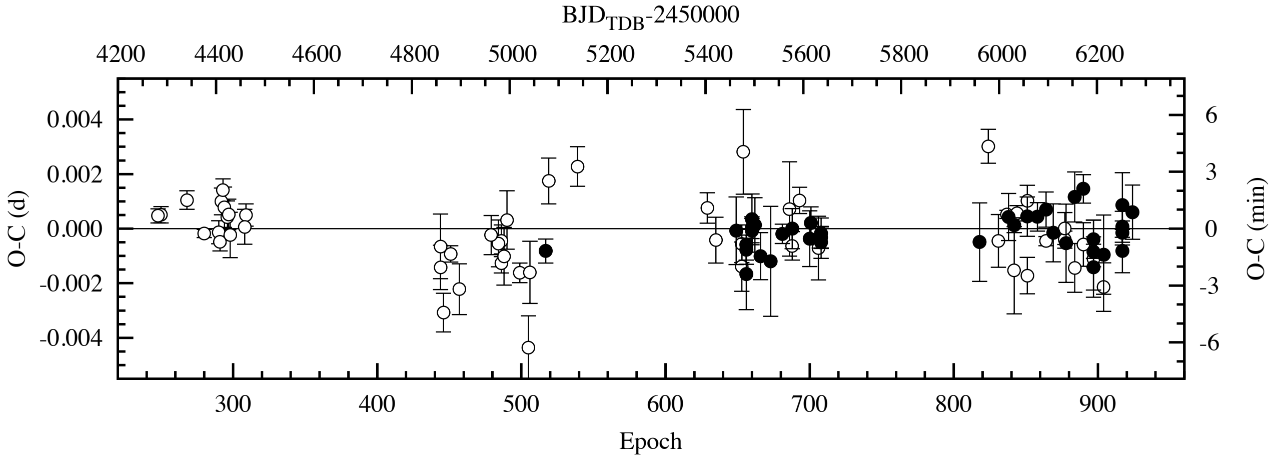

Fig. 2. Final O – C diagram for transit timing of WASP-3 b. Open and filled symbols mark times from the literature and our new results, respectively. The cycle numbering starts from the ephemeris given in the discovery paper by Pollacco et al. (2008). Taken from Maciejewski et al. (2013b, **H2**).

on the orbital eccentricity of WASP-3 b that was found to be circular within 2σ. This finding was in line of expectations because the circularisation timescale is 1 – 14 Myr for the tidal dissipation parameter Q_p between 10^5 and 10^6 is much shorter than the system's age of ~4 Gyr.

The absence of any detectable periodic TTV signal and the absence of any RV evidence for a departure from a single Keplerian orbit allowed us to place constraints on the properties of any hypothetical second planet in the system. The timing data set was combined with RV measurements to determine mass limit for a fictitious second planet in the WASP-3 system as a function of its orbital period. As it is illustrated in Fig. 3, the RV method gives tighter constraints for most configurations, and the TTV technique is sensitive to low-mass perturbers close to low-order MMRs. The RV data set limits masses of inner perturbers to ~40 $M_⊕$ for tightest orbits and to ~70 $M_⊕$ for orbits close to WASP-3 b. The transit timing constrained masses of fictitious planets down to 1.7, 0.9, and 1.9 $M_⊕$ in inner 3:1, 2:1, and 5:3 orbital resonances, respectively. For the outer perturbers, the RV method limited their masses down to ~100 $M_⊕$ for the most close-in orbits. The TTV

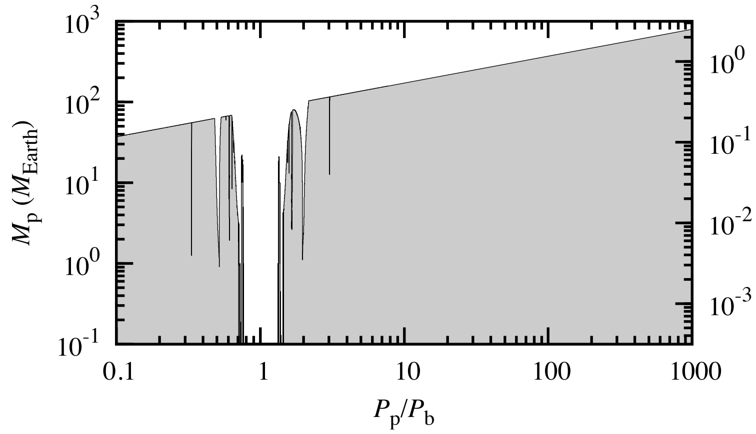

Fig. 3. Upper mass limit for a fictitious second planet in the WASP-3 system, based on timing and RV data sets, as a function of an orbital period of that planet, P_p. P_b is the orbital period for WASP-3 b. Most of orbits located within ~3.5 Hill radii of WASP-3 b (i.e., close to 1:1 orbital period commensurability) were found to be highly unstable and planetary close encounters or planet ejections occurred during the relatively short time of integration. The greyed area marks configurations that were below our detection threshold. Taken from Maciejewski et al. (2013b, **H2**).

method allowed us to probe masses down to 2.6, 0.8, and 13 $M_{\oplus}$ in outer 5:3, 2:1, and 3:1 orbital resonances, respectively. We note, however, that the portion of parameter space for additional bodies that remains unexplored is still significant.

The originally postulated periodic TTV signal was also excluded by other research teams (Nascimbeni et al. 2013, Montalto et al. 2012). However, Nascimbeni et al. (2013) showed that the measured mid-transit times were still not statistically consistent with a linear ephemeris, and pointed out that such apparently chaotic timing variations could be produced by some specific orbital configurations. Montalto et al. (2012) suggested that chromospheric activity of the parent star could be a potential source of the transit timing noise.

Our studies of the stellar activity of WASP-3 confirmed its long timescale variation reported by Montalto et al. (2012) and also revealed a night-to-night variability when the star was in a more active state. These short timescale variations were likely to be caused by active regions that were carried around by stellar rotation. However, our high-precision photometry showed no evidence for starspot-crossing anomalies or other effects that stellar activity might have on transit light curves.

Starspot occultations by WASP-10 b (H3)

Signature of dark starspot occultations by a planetary disc were detected in the WASP-10 system (Maciejewski et al. 2011c, **H3**). The host star is a K5 dwarf with an effective temperature of ~4700 K. It was found to be orbited by a ~3 $M_{\rm Jup}$ transiting planet on a ~3.1 d orbit (Christian et al. 2009). The light curve of WASP-10 exhibits a photometric variability caused by stellar rotation and differential distribution of starspots (Smith et al. 2009). Our preliminary observations revealed that transit timing cannot be explained by a constant period (Maciejewski et al. 2011b).

High-precision transit light curves of a planet moving across a spotted stellar disc offer an outstanding opportunity to map the starspot distribution. When a planet occults a starspot area on a star's surface, the flux increases and a characteristic feature in a light curve – a bump – is observed. Unocculted dark spots outside the planetary path across the stellar disc may still be present on the stars's surface and affect the transit light curve. Compared to a spot-free case, spots reduce the effective stellar-disc area, so a stellar radius is underestimated. The observed transits are deeper than a spot-free scenario predicts. This, in turn, results in the overestimate of the planet-to-star radius ratio. The opposite effect may be observed if faculae are considered. These active regions should introduce rather random variations not only in the transit depth, but also in the transit timing and duration.

In 2010, we acquired 4 high-precision light curves for transits of WASP-10 b with the 2.2 m telescope at the Calar Alto Observatory (Spain). As it is shown in Fig. 4, a visual inspection of three transit light curves reveals features that affect the shape of transits and could be attributable to starspot features. The height of the bumps was found to be between 2 and 3 mmag. The durations of the events are slightly shorter than a sum of transit ingress and egress durations. No flat top phase was visible. These findings are most consistent with a grazing scenario and non-central occultations of single spots whose sizes are comparable to or larger than the planetary disc projected onto the stellar surface. The occulted starspots were found to be located near the centre of the stellar disc at longitudes within 20 degrees of the line of sight. The flux bumps can be translated into the area of a spot occulted by the planetary disc. Assuming that the spot contrast is equal to 0.7, a value typical of the Sun, the occulted spot area was found to be in a range between 0.6% and 0.9% of the stellar surface (or 25% and 37% of the planetary disc). These inhomogeneities alone cannot produce the observed rotational modulation in

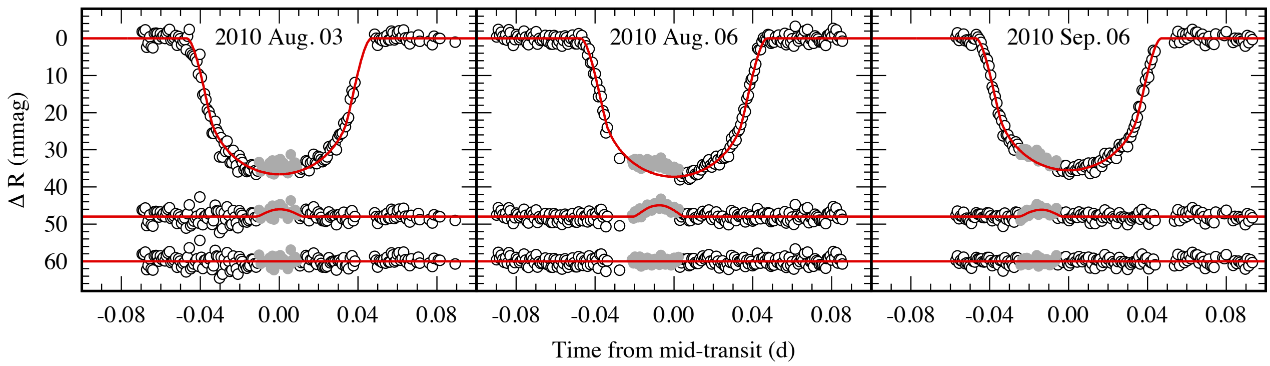

Fig. 4. Light curves for three transits of WASP-10 b with individually fitted model light curves after rejecting data points affected by stellar spots (grey points). The residuals that were used to model starspot features are plotted in the middle graphs. In the bottom graphs, the final residuals are plotted. Adopted from Maciejewski et al. (2011c, **H3**).

photometry. To reproduce the observed amplitude, a distinct spot of a size of ~9% of the stellar disc would be needed for a solar contrast dark spot.

New precise mid-transit times in conjunction with the literature data allowed us to refine the transit ephemeris. They were found to follow the linear ephemeris. To estimate the influence of starspot occultations on transit timing, a bump-free light curve was artificially deformed by injecting flux bumps randomly located in the time of the transit. The duration of these artificial occultations was assumed to be ~40 min and its height 3 mmag, i.e. values of the most prominent feature observed. Two separate scenarios were considered: an affected first half of a flat bottom and ingress/egress. In the first case, 2000 deformed light curves were produced and then fitting procedure was performed. The mean difference in mid-transit times was found to be negligible with a value of 0.09 ± 0.06 min. This finding was also confirmed by our analysis of 3 light curves with flux bumps: the mid-transit times derived from original and starspot-feature-cut light curves were found to be similar well within 1σ error bars. The planet-to-star radius ratio was found to be significantly smaller by about 5σ. This result meets expectations because injected bumps increase the averaged brightness during the flat bottom phase, hence decrease the averaged transit depth. In the second scenario, the procedure was repeated for ingress/egress phase based on 1000 deformed light curves and yielded the mean difference in mid-transit times of ~0.9 min. This result indicates that the apparent mid-transit times happened noticeably later (earlier) for ingress (egress) deformed light curves than the spotless ephemeris predicted. Transits appeared to be shorter on average by ~1.5 min. This phenomenological approach gives the upper limits to any possible deviations in timing because the influence of occulted starspots located close to the stellar limb is smaller by a factor of 3 – 5 due to the effects of limb darkening and geometrical foreshortening.

If the spins of both the stellar rotation and planetary orbital motion are roughly parallel to each other, this configuration may allow one to either determine or refine a period of stellar rotation by analysing the starspot distribution probed by a transiting planet (e.g. Silva-Valio 2008). In a some fraction of extrasolar systems, both axes were found to be misaligned (see e.g., Hébrard et al. 2011) and this could also apply to the WASP-10 system. The ratio of periods of WASP-10 b's orbital motion to stellar rotation is close to 1:3.8, hence the occultations of the same spot near the centre of the stellar disk are impossible to observe during two consecutive transits. However, assuming that the active regions exist longer than a few stellar rotation periods and the system is not significantly tilted, we found that features observed during 2 runs, which were separated by the time span of about three rotation periods, could be attributable to the same spot complex. In this case, mid-occultation times would refine the rotation period of WASP-10 to 11.85 d. This value agrees with the period known from photometric observations.

Furthermore, our reanalysis of system parameters, which took stellar activity into account, indicated that the radius of WASP-10 b is smaller than most previous studies reported. The planet is three times more massive than Jupiter but has a similar radius. We calculated interior structure models of WASP-10 b assuming a two-layer structure with one homogeneous envelope atop a rock core. The total mass of metals equal to 270 – 450 $M_{\oplus}$ was found to be needed to reproduce the radius value reported in our work. This large amount is challenged by the core-accretion formation where the maximum mass of available heavy elements is 80 $M_{\oplus}$ for the parameters of WASP-10 b (Leconte et al. 2010).

No variations in transit timing for Qatar-1 b (H4)

With a mass of mass of ~1.3 $M_{\rm Jup}$, radius of ~1.2 $R_{\rm Jup}$, and orbital period of 1.42 d, the transiting planet Qatar-1 b is a typical hot Jupiter on a circular orbit (Alsubai et al. 2011). It orbits a metal-rich dwarf of spectral type K3 which exhibits a moderate chromospheric activity. Signs of long-term variations in transit timing residuals from a linear ephemeris were reported in the literature (von Essen et al. 2013). The periodicity of this signal was postulated to be close to 190 or 390 d with an amplitude of about 1 min. These variations were interpreted as the result of the exchange of energy and angular momentum via gravitational interaction with an unseen, close-in planetary companion. This finding motivated us to organise an observing campaign to confirm or refute postulated perturbations in the orbital motion of Qatar-1 b by the method of transit timing (Maciejewski et al. 2015, **H4**).

Employing six 0.6 – 2.0 m telescopes located in Bulgaria, Poland, Germany, and Spain, we acquired 18 new light curves for 16 transits between 2011 and 2014. Our new data set was analysed in a homogeneous way together with observations available in the literature. Our light curve modeling provided planetary and stellar parameters with the smallest uncertainties published so far. Despite the host star exhibits a moderate chromospheric activity, we identified no features in the transit light curves that could be attributed to starspot occultations by the planetary disc.

New transit timing observations clearly show that the orbital motion of Qatar-1 b is not perturbed by any body that could produce periodic deviations with an amplitude greater than 30s. We find no evidence to confirm the TTV signal with the periodicity and amplitude reported by von Essen et al. (2013). A plot of the transit timing residuals from the refined linear ephemeris is shown in Fig. 5. Combining the transit timing and RV datasets, we can rule out three proposed scenarios with perturbers in 2:1, 5:2, and 3:1 resonances even for circular orbits. The lack of the TTV signal also makes a proposed massive perturber on a wide orbit unlikely.

We conclude that Qatar-1 b has no detectable planetary companions on nearby orbits. The loneliness of Qatar-1 b speaks in favour of inward migration theories of massive outer planets through the planet-planet scattering caused by mutual dynamical perturbations.

Detection of the departure from the linear ephemeris for WASP-12 b (H5)

The transiting extrasolar planet WASP-12 b was found to be one of the most intensely irradiated planets (Hebb et al. 2009). It orbits an F/G-type star on a tight orbit with a semi-major axis of ~0.023 AU and an orbital period as short as ~1.09 d. The planet's proximity to the star results in a high equilibrium temperature of 2500 K, thus inducing numerous studies on the properties of the planetary atmosphere. With a mass of 1.4 $M_{\rm Jup}$ and a

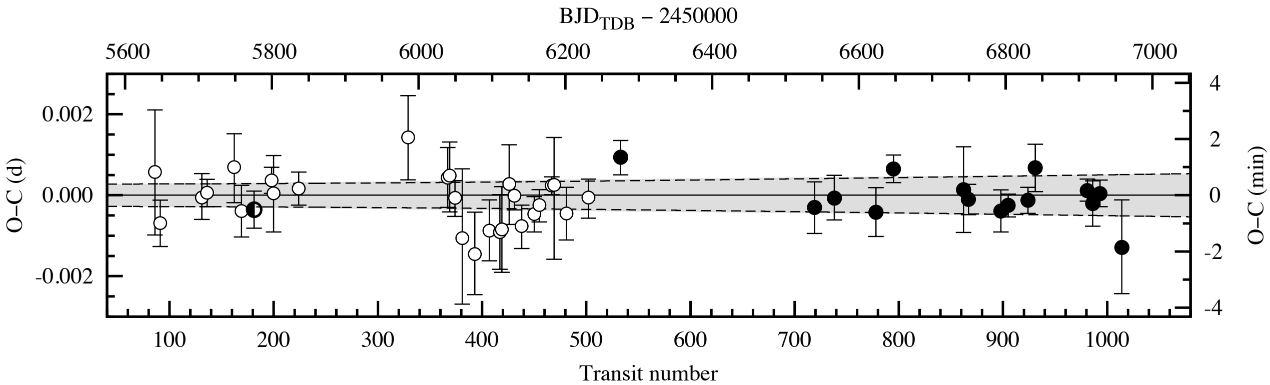

Fig. 5. Residuals of transit times from the refined linear ephemeris. Open symbols indicate the literature data. Filled dots denote our new transits. The mid-transit time at epoch 181 (BJD 2455775.4), marked with a half-filled symbol, is determined using a light curve from von Essen et al. (2013) and a light curve acquired by us. The greyed area between dashed lines shows the propagation of uncertainties of the ephemeris at a 95.5% confidence level. Taken from Maciejewski et al. (2015, **H4**).

relatively large radius of 1.8 $R_{\rm Jup}$, the planet is one of the most bloated planetary bodies. The initial studies showed that the orbital eccentricity of WASP-12 b is equal to 0.049 ± 0.015, so noticeable non-zero. Such a non-circular orbit might drive the dissipation of tidal energy. This mechanism, in turn, might be responsible for heating up the planet's interior and bloating its radius in consequence (Miller et al. 2009). The orbit of WASP-12 b is expected to be circularised on short timescales if the tidal dissipation constant is not significantly larger than a value typical of giant planets. Its eccentricity, if real, could be sustained by gravitational perturbations from an additional planet in the system, and such a perturbing body could affect the orbital motion of WASP-12 b, causing its transits to exhibit a departure from a linear ephemeris. This scenario motivated us to organise the follow-up campaign for this system.

Our initial studies revealed that WASP-12 b might show variations in transit timing. (Maciejewski et al. 2011d, 2013a). While the question of the periodic signal, which could be induced by a nearby planetary companion, remains opened, we have detected that the transit times of WASP-12 b do not follow the linear ephemeris, and they may be approximated with a quadratic model (Maciejewski et al. 2016, **H5**).

Having in hand a set of more than 60 precise and reliable mid-transit times, determined from the literature and our observations, we have found that the linear ephemeris is unsatisfying, and the null hypothesis can be rejected with a 5σ (99.9999%) confidence level. A quadratic ephemeris in a form

$$T_{\rm mid} = T_0 + P_{\rm b}E + \frac{1}{2}\delta P_{\rm b}E^2,$$

where *E* is the transit number from the cycle-zero epoch T_0 and δP_b is the change in the orbital period P_b between succeeding transits, yields a much better fit with reduced chi-squared close to 1. We obtained $\delta P_{\rm b} = (-8.9 \pm 1.4) \times 10^{-10}$ days epoch^{-2}. This quantity translates into the short-term change rate in the orbital period $\dot{P}_{\rm b} = \delta P_{\rm b}/P_{\rm b} = (-2.56 \pm 0.40) \times 10^{-2}$ s yr^{-1}. The timing residuals from the linear ephemeris are plotted in Fig. 6.

The negative value of $\delta P_{\rm b}$ may be interpreted as evidence of an orbital decay that is driven by tidal dissipation in the host star. For a star-planet system in which the total angular momentum $L_{\rm tot}$ is conserved, but energy is dissipated by tides, no equilibrium state exists if $L_{\rm tot}$ is smaller than the critical angular momentum $L_{\rm crit}$ (Levrard et al. 2009),

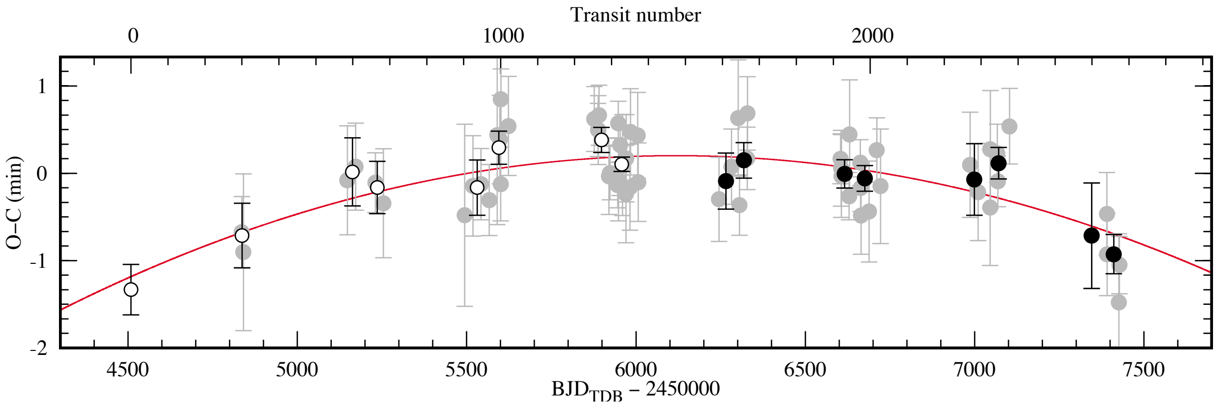

Fig. 6. Transit timing residuals from the linear ephemeris for WASP-12 b. The black open and filled circles denote literature and new data, respectively. Each point represents a half-season average of individual observations, which are marked with grey dots. The continuous lines sketch the quadratic ephemeris. Adopted from Maciejewski et al. (2016, **H5**).

which is required for the star-planet system to reach a state of dual synchronisation. The spin of the star may be a significant, if not dominant, component of $L_{\rm tot}$. It depends on the rotational velocity of the star, which remains roughly constrained for the WASP-12 star by spectral observations (Albrecht et al. 2012). For the WASP-12 system, we obtained $L_{\rm tot}/L_{\rm crit} = 0.4 - 0.7$, depending on the rotation period of the star. Since this ratio is obviously lower than 1, the planet will unavoidable spiral inward. We find a relatively short in-spiral time of about 10^6 yr, which is very short compared to the age of the system of ~2 Gyr (Hebb et al. 2009).

The observed rate of the orbital decay may be used to determine the stellar tidal quality parameter Q'_*. We adopted Eq. (3) of Levrard et al. (2009) for synchronous planetary rotation and negligible eccentricity and obliquity

$$Q'_* = 9 P_{\rm b} \dot{P}_{\rm b}^{-1} \frac{M_{\rm b}}{M_*} \left(\frac{R_*}{a_{\rm b}} \right)^5 \left(\omega_* - \frac{2\pi}{P_{\rm b}} \right),$$

where M_b is the mass of the planet, M_* is the mass of the host star, R_* is the stellar radius, a_b is the semi-major axis, and ω_* is the rotational velocity of the star. We obtained Q'_* of about 2.5×10^5, which is noticeable smaller than the theoretical expectations for the F-type stars that have thinner convective envelopes (thus greater Q'_*), turning to the completely radiative ones for the early F types. Models of Essick & Weinberg (2016) give Q'_* of 4.3×10^5 for solar-type host stars. WASP-12 is 300–500 K hotter than the Sun, so one would expect to find values of Q'_* rather greater than smaller.

Alternatively, the observed departure from the linear ephemeris may be a part of a long-period signal induced by star-planet tidal interactions. We found the timescale of the rotation of the pericentre caused by tides that have risen in the planet as a response to stellar gravity to be of about 10 yr. This value might correspond to the observed signal. We also found that other contributions to the rotation of the pericentre can be neglected. The timescales of the rotation caused by rotational deformation of the star and the planet are of about 10^4 yr. The timescales for the tidal deformation of the star and relativistic effects are of about 10^3 yr.

Using the transit and occultation timing data together with Doppler time series, we derived the precession rate $\dot{\omega} = 0.095 \pm 0.020$ deg per day, which corresponds to a period of the periastron precession $\tau_\omega = 10.4 \pm 2.2$ yr with the orbital eccentricity

$e_\mathrm{b} = 0.00110 \pm 0.00036$. The periastron precession with the very low value of e_b would have a marginal effect on transit parameters that are directly determined from light curves. In particular, the range of variations in transit duration is expected to be 2.7 s, that is much smaller than typical transit duration uncertainties of 1 – 3 min.

To distinguish between both scenarios (i.e. the orbital decay and orbital precession), the Bayesian information criterion (BIC) was used. It favours the quadratic model with BIC = 21.8 over the periodic model with BIC = 28.6 with a probability ratio of $e^{\Delta \mathrm{BIC}/2}$ = 29.

Our discovery was confirmed by Patra et al. (2017). They also discuss other possible explanations of the departure of transit times from a linear ephemeris, including radial acceleration of the system, the Shklovskii effect, and the Applegate effect. All of them were found to be ruled out by Doppler data or occultation timing.

Summary

The set of articles, focused on the investigations of hot Jupiters and presented here as my scientific achievement, illustrates my main scientific activities after doctorate. Papers **H1** and **H2** demonstrate the ability to carry out both preliminary studies of planetary systems, which are selected according to specific criteria, and large-scale observation campaigns employing photometric and spectroscopic observational methods. Paper **H3** is an example of a report on in-depth investigations of additional astrophysical issues, such as stellar activity or the internal structure of a planet. Paper **H4** is an example of a reaction to literature reports whose results require immediate verification. The culmination of this set is paper **H5** that presents the original scientific result – the detection of the orbital decay of a planet into a star driven by tidal interactions between the both bodies.

References

Adams, F. C., Laughlin, G., 2006, ApJ, 649, 1004
Adams, E. R., López-Morales, M., Elliot, J. L., et al., 2010, ApJ, 721, 1829
Agol, E., Steffen, J., Sari, R., Clarkson, W., 2005, MNRAS, 359, 567
Albrecht, S., Winn, J. N., Johnson, J. A., et al. 2012, ApJ, 757, 18
Alonso, R., Brown, T. M., Torres, G., et al., 2004, ApJ, 613, L153
Alsubai, K. A., Parley, N. R., Bramich, D. M., et al. 2011, MNRAS, 417, 709
Baglin, A., Auvergne, M., Barge, P., et al., 2007, AIP Conf. Proc., vol. 895, 201
Bakos, G., Noyes, R. W., Kovács, G., et al., 2004, PASP, 116, 266
Bakos, G., Howard, A. W., Noyes, R. W., et al., 2009, ApJ, 707, 446
Batygin, K., Bodenheimer, P. H., Laughlin, G. P., 2016, ApJ, 829, 114
Beckers, J. C., Vanderburg, A., Adams, F. C., et al., 2015, ApJL, 812, L18
Birkby, J. L., Cappetta, M., Cruz, P., et al., 2014, MNRAS, 440, 1470
Blecic, J., Harrington, J., Madhusudhan, N., et al., 2014, ApJ, 781, 116
Bodenheimer, P., Lin, D. N. C., Mardling, R. A., 2001, ApJ, 548, 466
Borucki, W. J., Koch, D., Basri, G., et al., 2010, Science, 327, 977
Charbonneau, D., Brown, T. M., Latham, D. W., Mayor, M., 2000, ApJ, 529, 45
Christian D. J. et al., 2009, MNRAS, 392, 1585
Essick, R., Weinberg, N. N., 2016, ApJ, 816, 18
Fabrycky, D. C., Tremaine, S., 2007, ApJ, 669, 1298
Fabrycky, D. C., Lissauer, J. J., Ragozzine, D., et al., 2014, ApJ, 790, 146
Goldreich, P., Schlichting, H. E., 2014, AJ, 147, 32
Hatzes, A. P., Rauer, H., ApJ, 810, L25
Hebb, L., Collier-Cameron, A., Loeillet, B., et al. 2009, ApJ, 693, 1920
Hebrard, G., Désert, J.-M., Díaz, R. F., et al., 2010, A&A, 516, 95
Hébrard, G., Ehrenreich, D., Bouchy, F., et al. 2011, A&A, 527, L11
Hellier, C., Anderson, D. R., Collier Cameron, A., et al., 2012, MNRAS, 426, 739
Henry, G. W., Marcy, G. W., Butler, R. P., Vogt, S. S., 2000, ApJ, 529, 41
Holman, M., Murray, N. W., 2005, Science, 307, 1288

Howard, A. W., Marcy, G. W., Bryson, S. T., et al. 2012b, ApJS, 201, 15
Hoyer, S., López-Morales, M., Rojo, P., et al., 2016, MNRAS, 455, 1334
Jiang, I.-G., Lai, C.-Y., Savushkin, A., et al., 2016, AJ, 151, 17
Kley, W., Nelson, R. P., 2012, Annual Review of Astronomy & Astrophysics, 50, 211
Koch, D. G., Borucki, W. J., Basri, G., et al., 2010, ApJ, 713, L79
Latham, D., Stefanik, R. P., Mazeh, T., et al., 1989, Nature, 339, L38
Leconte, J., Barafee, I., Chabrier, G., Barman, T., & Levrard, B. 2010, A&A, 506, A385
Levrard, B., Winisdoerffer, C., Chabrier, G., 2009, ApJ, 692, L9
Lloyd, J. P., Lunine, J. I., Mamajek, E., et al., 2013, preprint (arXiv:1309.1520)
Maciejewski, G., Dimitrov, D., Neuhäuser, R., et al., 2010, MNRAS, 407, 2625
Maciejewski, G., Neuhäuser, R., Raetz, S., et al., 2011a, EPJ Web of Conferences, 11, 05009
Maciejewski, G., Dimitrov, D., Neuhäuser, R., et al., 2011b, MNRAS, 411, 1204
Maciejewski, G., Raetz, S., Nettelmann, N., et al., 2011c, A&A, 535, A7
Maciejewski, G., Errmann, R., Raetz, S., et al., 2011d, A&A, 528, A65
Maciejewski, G., Dimitrov, D., Seeliger, M., et al., 2013a, A&A, 551, A108
Maciejewski, G., Niedzielski, A., Wolszczan, A., et al., 2013b, AJ, 146, 147
Maciejewski, G., Fernández, M., Aceituno, F. J., et al., 2015, A&A, 577, A109
Maciejewski, G., Dimitrov, D., Fernández, M., et al., 2016, A&A, 588, L6
Mancini, L., Southworth, J., 2016, in Proceedings of the Haute Provence Observatory Colloquium, 5-9 October 2015, edited by I. Boisse, O. Demangeon, F. Bouchy & L. Arnold
Marcy, G. W., Butler, R. P., 1996, ApJ, 464, L147
Mardling, R. A., 2007, MNRAS, 382, 1768
Mayor, M., Queloz, D., 1995, Nature, 378, 355
Mazeh, T., Naef, D., Torres, G., et al. 2000, ApJ, 532, L55
Miller, N., Fortney, J. J., & Jackson, B. 2009, ApJ, 702, 1413
Miralda-Escude, J., 2002, ApJ, 564, 1019
Montalto, M., Gregorio, J., Boue´, A., et al. 2012, MNRAS, 427, 2757
Mustill, A. J., Davies, M. B., Johansen, A., et al., 2016, preprint (arXiv:1603.09506)
Nascimbeni, V., Cunial, A., Murabito, S., et al. 2013, A&A, 549, A30
Ogihara, M., Inutsuka, S., Kobayashi, H., 2013, ApJL, 778, L9
Patra, K. C, Winn, J. N., Holman, M. J., et al., 2017, AJ, 154, 4
Peale, S. J., Cassen, P., Reynolds, R. T., 1979, Science, 203, 892
Pollack, J. B., Hubickyj, O., Bodenheimer, P., et al., 1996, Icarus, 124, 62
Pollacco, D. L., Skillen, I., Collier Cameron, A., et al., 2006, PASP, 118, 1407
Pollacco D. et al., 2008, MNRAS, 385, 1576
Ragozzine, D., Wolf, A. S., 2009, ApJ, 698, 1778
Rasio & Ford 1996
Schlaufman, K. C., Winn, J. N., 2016, astro-ph/1604.03107
Silva-Valio, A. 2008, ApJ, 683, 179
Smith A. M. S. et al., 2009, MNRAS, 398, 1827
Steffen, J. H., Ragozzine, D., Fabrycky, D. C., 2012, PNAS, 109, 7982
Tripathi A. et al., 2010, ApJ, 715, 421
von Essen, C., Schröter, S., Agol, E., & Schmitt, J. H. M. M. 2013, A&A, 555, A92
Weidenschilling & Marzari 1996
Wolszczan, A., Frail, D., 1992, Nature, 355, 145
Wolszczan, A., 1994, Science, 264, 538
Wright, J. T., Marcy, G. W., Howard, A. W., et al., 2012, ApJ, 753, 16

5. Discussion of other scientific achievements.

My scientific activities after receiving the Ph.D. degree (i.e. other scientific achievements) can be split into two parts, which are marked by my post-doc position held in the Institute of Astrophysics and University Observatory of the Friedrich Schiller University in Jena (Germany). In this discussion I skip my minor contributions (i.e., with a percentage share below 10%) to research activities which I was not a leading author of.

Studies of neglected open clusters

In 2008 – 2009, my research work was focused on studies of neglected open clusters. That was a natural extension of the research topic of my Ph.D. thesis. A dedicated research project „Open Cluster Survey" was established (http://www.home.umk.pl/~gmac/OCS).

Multi-band photometric observations were acquired with the 90/60 cm Schmidt-Cassegrain Telescope at the Centre for Astronomy of the Nicolaus Copernicus University in Piwnice, near Toruń (Poland), as well as with the 70/50 cm Schmidt telescope and the 2 m Ritchey-Chretien-Coude telescope at the National Astronomical Observatory Rozhen (Bulgaria). Those data were combined with near-infrared photometry from the 2-Micron All Sky Survey, and two-colour and colour-brightness (Fig. 1) diagrams were used to determine basic parameters, such as the age, distance, reddening, number of members, total cluster mass, and dynamical-evolution parameters. For the majority of investigated cluster, such as Berkeley 95, Czernik 21, Czernik 38, Juchert 11, King 17, King 18 (Maciejewski 2008), and Berkeley 53 (Maciejewski et al. 2009), these were the first results based on deep (down to ~21 mag in *V*) and wide-field CCD photometry.

Furthermore, the population of cluster member stars was search for variable stars of various types – from pulsating ones to eclipsing binaries. Properties of such stars could help constrain cluster parameters tighter (e.g., Maciejewski et al. 2008a, 2008b).

For the young open cluster Trumpler 3, low-dispersion prism spectra were acquired to determine spectroscopic parallax for the brightest member stars (Maciejewski & Bukowiecki 2010). The cluster was found to be a young low-massive stellar ensemble with a typical mass function slope. As a result of a wide-field search for short period variable stars, 24 variables were discovered in the cluster's area (Fig. 2). Only one of them – a pulsating variable of the γ-Doradus type – was identified as a likely cluster member.

During my active work as part of the project, a total of 23 neglected open clusters were studied.

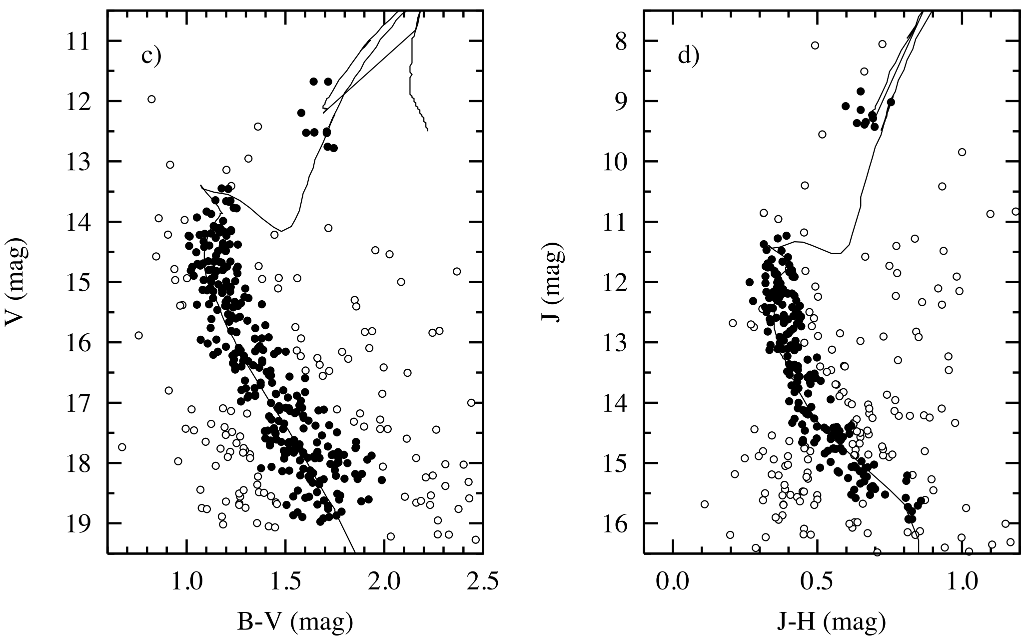

Fig. 1. Optical (left) and near-IR (right) color-magnitude diagrams for NGC 7762. The dots and open circles are probable cluster members and field stars, respectively. The best-fit isochrone is sketched with a continuous line. Adopted from Maciejewski et al. (2008a).

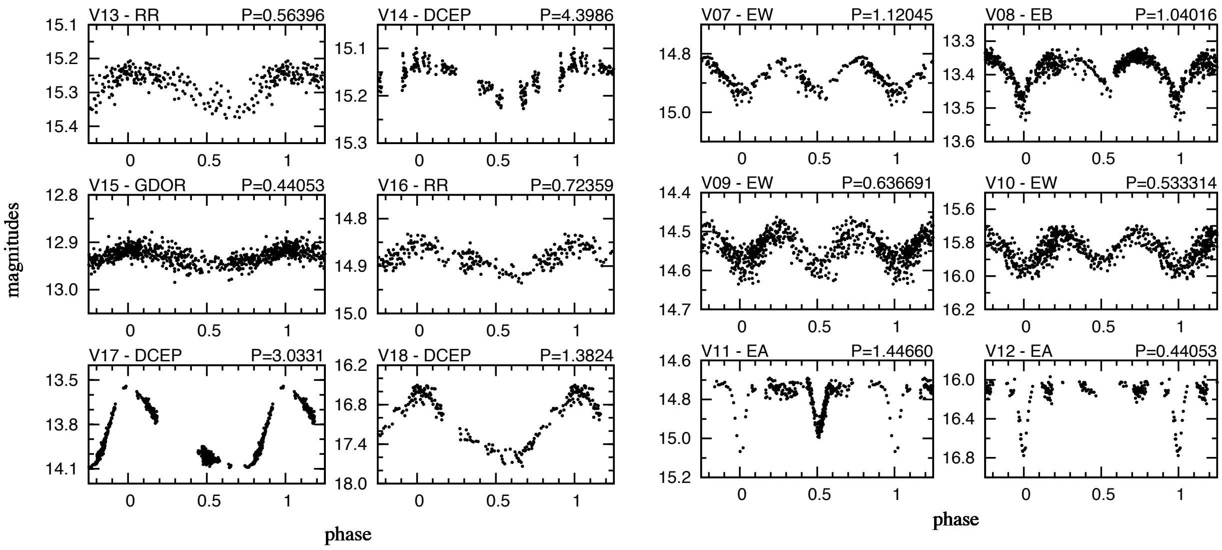

Fig. 2. A sample of light curves of pulsating and eclipsing variable stars discovered in the field of the Trumpler 3 cluster. Adopted from Maciejewski & Bukowiecki (2010).

Transit timing of hot exoplanets

Since 2010 my scientific interests have been focused on transiting planets. While being on my postdoc position, I initiated a scientific project, the aim of which is a detection of deviations from the Keplerian motion of hot transiting exoplanets (Maciejewski et al. 2011a, see also http://www.home.umk.pl/~gmac/TTV). In addition to studies of planetary systems, which are presented as the scientific achievement, more than 20 hot planets have been investigated and almost 20 papers have been published.

We gathered high-precision light curves for two transits of XO-5 b (Maciejewski et al. 2011b). The planet was found to have an anomalously high Safronov number and surface gravity. Our aim was to refine parameters of this intriguing system and search for signs of transit timing variations. Although system's parameters obtained by us were found to agree with previous studies within one sigma, the planet was found to be notable smaller with the radius of $1{,}03^{+0{,}06}_{-0{,}05}$ $R_{\rm Jup}$. Our results confirmed the high Safronov number of $0{,}113^{+0{,}013}_{-0{,}011}$. Such a high value suggests that the planet has not undergone a phase of the significant mass evaporation driven by the radiation of the host star (e.g., Hansen & Barman 2007). This finding is not surprising if one considers the spectral type of the star (G8) and a relatively small amount of the extreme ultraviolet radiation that it emits. The surface gravity of the planet was found to be $24{,}6^{+2{,}8}_{-2{,}3}$ m s^{-2} that is comparable to that of Jupiter. New mid-transit times allowed us to refine a transit ephemeris. No significant transit timing variation was detected.

In Vaňko et al. (2013), we used 14 new transit light curves acquired for TrES-3 b to redetermine system parameters and to calculate a new transit ephemeris. Since the timing residuals showed no significant deviation from the linear ephemeris, we concluded that a periodic TTV signal with an amplitude greater than 1 min over a 4 year time span seemed to be unlikely. Our analysis of an upper mass limit allowed us to exclude an additional Earth-mass planet close to inner 3:1, 2:1, and 5:3 and outer 3:5, 1:2, and 1:3 MMRs.

The planet WASP-1 b was a next target of our TTV campaign (Maciejewski et al. 2014a). Early studies suggested that a small but non-zero value of the orbital eccentricity of this planet, excited by an undetected planetary companion, could bloat the planet through tidal heating and explain its anomalous size. This finding motivated us to study the WASP-1 system with the TTV method. Our homogeneous analysis, which was based on

13 new transit light curves acquired between 2007 and 2013 and the literature data, resulted in determining precise system parameters. New values were found to be in agreement with those reported in previous studies. Transit times were found to follow a linear ephemeris with no sign of any transit time variations. Similar conclusions were reached for systems: HAT-P-30, HAT-P-37, TrES-5, WASP-28, WASP-36, and WASP-39 (Maciejewski et al. 2016).

The GJ 436 system contains a transiting hot analogue of Neptune on an eccentric orbit. Two additional transiting sub-Earth planets have been postulated in the literature (Stevenson et al. 2012). We observed three transits of GJ 436 b over the course of three years using two-meter class telescopes, each with a photometric precision better than 1 mmag. We studied system dynamics based on the existence of the additional planets (Maciejewski et al. 2014b). We redetermined system parameters, which were in agreement with those found in the literature. We refined the orbital period of GJ 436 b and found no evidence for transit timing variations. The orbital motion of the GJ 436 c planet candidate was found to be significantly affected by the planet b with variations in transit times at a level of 20 minutes. As the orbital period of the GJ 436 d planet candidate was unknown, our numerical experiments ruled out orbits in low-order resonances with GJ 436 b.

Other contributions

The star TYC 1422-614-1 is a K2 red giant that harbours a multiple planetary system (Niedzielski et al. 2015). Precise RV observations, which were acquired with the Hobby-Eberly Telescope and the 3.6 m Telescopio Nazionale Galileo, revealed the existence of two massive planets on wide orbits (~200 and ~570 d). Their minimal masses are ~2.5 and ~10 $M_{\rm Jup}$. The ratio between their orbital periods was found to be close to a 7:20 commensurability, which suggests that the system might be in a MMR. A dynamical model of the system was elaborated to refine orbital parameters, which were initially obtained with a Keplerian approach, and to track the system evolution. We found that the eccentricity-type resonant angles, defined as a linear combination of mean longitudes and arguments of periastron, showed no libration. The difference between arguments of periastron demonstrated a lack of apsidal alignment and oscillations. Thus, the system was found not to be in a dynamical resonance. Variations in eccentricities in the first thousand years are shown in Fig. 3.

The red giant star TYC 3667-1280-1 was found to be orbited by a planet candidate with a minimal mass of ~5.4 $M_{\rm Jup}$ (Niedzielski et al. 2016). The orbital period is as short as 26.5 d and the semi-major axis is equal to ~7 stellar radii. The equilibrium temperature of the planet was found to be ~1350 K, so the planet can be classified as warm or even hot Jupiter. The geometrical probability that the body transits its evolved host star was found to be 13.9 ± 2.0%. Since the host star is expanding because of its evolution toward the giant branch, the planet could be bloated. Assuming that the planetary radius is in a range of between 1 and 2 $R_{\rm Jup}$, the transits are expected to be 0.3–1.1 mmag deep. The predicted transit duration is between 5.2 h for grazing transits and 29 h for central transits. These transit parameters together with possible photometric variability of the host star make transit observations challenging from the ground with telescopes smaller than 2 m. The system could be followed with space-borne instruments. If the planet was found to be transiting, it would be a very interesting object for studies of star-planet interactions in late stages of stellar evolution.

References

Hansen, B.M.S., Barman, T., 2007, ApJ, 671, 861
Maciejewski, G., 2008, Acta Astronomica 58, 389

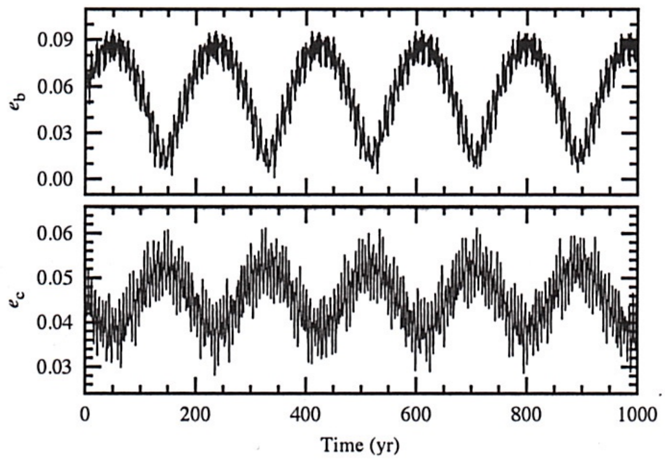

Fig. 3. Evolution of orbital eccentricities in the first thousand years for massive planets in the TYC 1422-614-1 planetary system. Adopted from Niedzielski et al. (2015).

Maciejewski, G., Boeva, S., Georgiev, Ts., et al., 2008a, Baltic Astronomy, 17, 51

Maciejewski, G., Georgiev, Ts., Niedzielski, A., 2008b, Astronomische Nachrichten, 329, 387

Maciejewski, G., Mihov, B., Georgiev, Ts., 2009, Astronomische Nachrichten, 330, 847

Maciejewski, G., Bukowiecki, Ł., 2010, AN, 331, 312

Maciejewski, G., Neuhäuser, R., Raetz, S., et al., 2011a, EPJ Web of Conferences, 11, 05009

Maciejewski, G., Seeliger, M., Adam, Ch., et al., 2011b, AcA, 61, 25

Maciejewski, G., Ohlert, J., Dimitrov, D., et al., 2014a, AcA, 64, 27

Maciejewski, G., Niedzielski, A., Nowak, G., et al., 2014b, AcA, 64, 323

Maciejewski, G., Dimitrov, D., Mancini, L., et al. 2016, AcA, 66, 55

Niedzielski, A., Villaver, E., Wolszczan, A., et al., 2015, A&A, 573, 36

Niedzielski, A., Villaver, E., Nowak, G., et al., 2016, A&A, 589, 1

Stevenson, K.B., et al., 2012, ApJ, 755, 9

Vaňko, V., Maciejewski, G., M.Jakubík, M., et al., 2013, MNRAS, 432, 944

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