Towards the Rosetta Stone of planet formation

G.Maciejewski[1,2,*], R.Neuhäuser[1], R.Errmann[1], M.Mugrauer[1], Ch.Adam[1], A.Berndt[1], T.Eisenbeiss[1], S.Fiedler[1], Ch.Ginski[1], M.Hohle[1], U.Kramm[3], C.Marka[1], M.Moualla[1], T.Pribulla[1], St.Raetz[1], T.Roell[1], T.O.B.Schmidt[1], M.Seeliger[1], I.Spaleniak[1], N.Tetzlaff[1] and **L.Trepl[1]**

[1] Astrophysikalisches Institut und Universitäts-Sternwarte, Schillergässchen 2-3, D-07745 Jena, Germany
[2] Toruń Centre for Astronomy, N. Copernicus University, Gagarina 11, PL-87100 Toruń, Poland
[3] Institut für Physik, Universität Rostock, D-18051 Rostock, Germany
* gm@astro.uni-jena.de

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Transiting exoplanets (TEPs) observed just a few Myrs after formation of their host systems may serve as the Rosetta Stone for planet formation theories. They would give strong constraints on several aspects of planet formation, e.g. time-scales (planet formation would then be possible within 10 Myrs), the radius of the planet could indicate whether planets form by gravitational collapse (being larger when young) or accretion growth (being smaller when young). We present a survey which main goal is to find and then characterise TEPs in very young open clusters.

1. Trumpler 37 – the first target of our survey

We are searching for variable stars among young clusters by monitoring them photometrically for several weeks in all clear hours and nights using the 90-cm Schmidt telescope (60-cm effective mirror in Schmidt mode) of the University Observatory Jena with its new large CCD camera. In 2009 we initiated our survey by observing the Trumpler 37 cluster which age is estimated to be 1-5 Myrs.

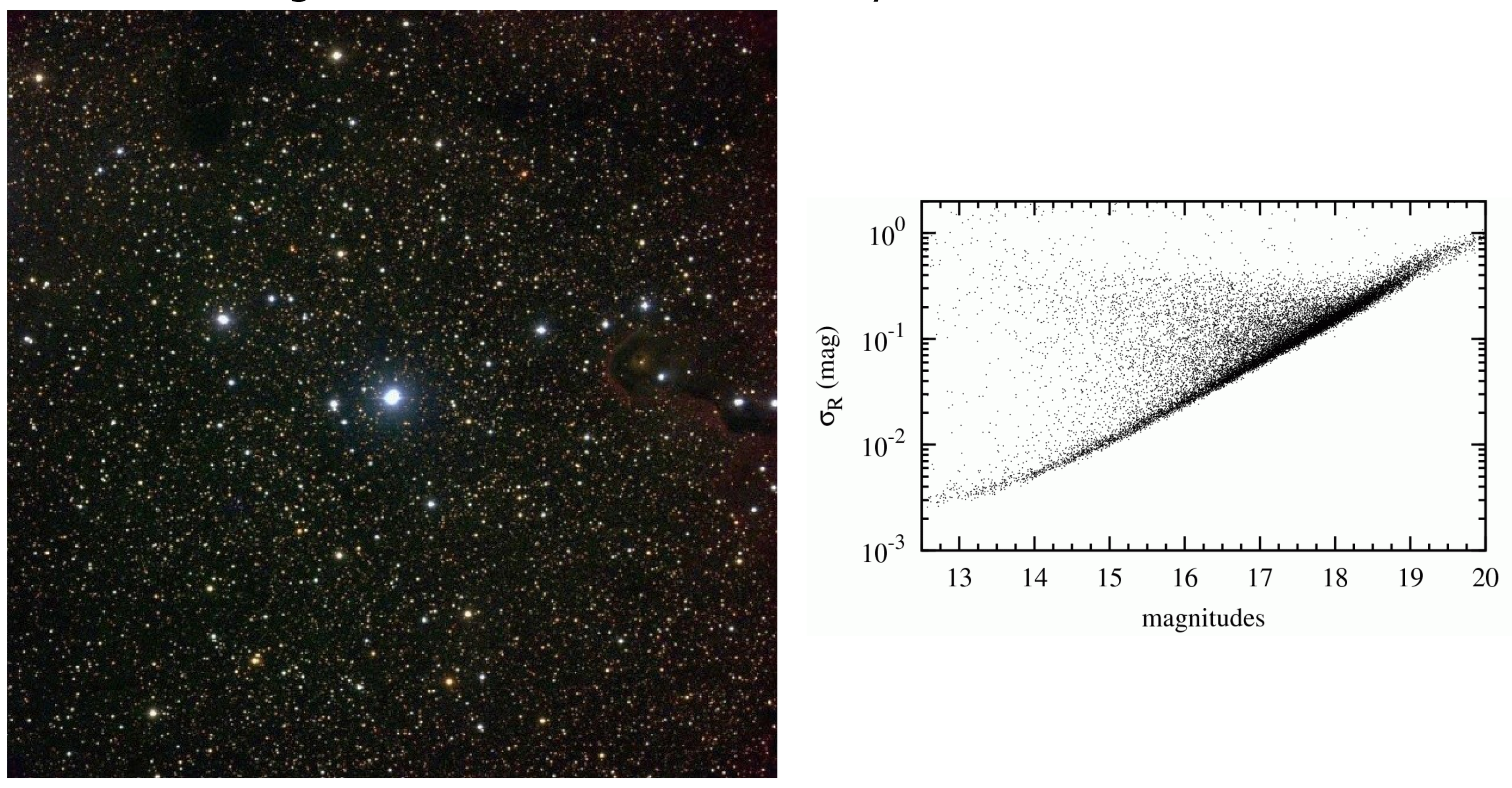

Fig. 1. ***Left:*** **The 53' x 53' field around Trumpler 37, observed with the 90-cm telescope of the University Observatory Jena.** ***Right:*** **The distribution of photometric errors as a function of R-band magnitudes. Millimagnitude precision was achieved for the brightest stars.**

We obtained light curves for 18,000 stars in Trumper-37. For 35 of those stars, we see light curves typical for eclipsing binaries with primary and also secondary eclipses. These objects are almost certainly double-lined SB. They include several known members of the cluster and also several candidate cluster members. As far as low-mass pre-main sequence (PMS) stars, there are only a very few eSB2 stars known. Theoretical models are still uncertain for ages below 10 Myrs because they start with unknown initial conditions and make many assumptions. We can test such models best with eSB2 stars, where the masses are determined dynamically as a result of radial-velocity follow-ups.

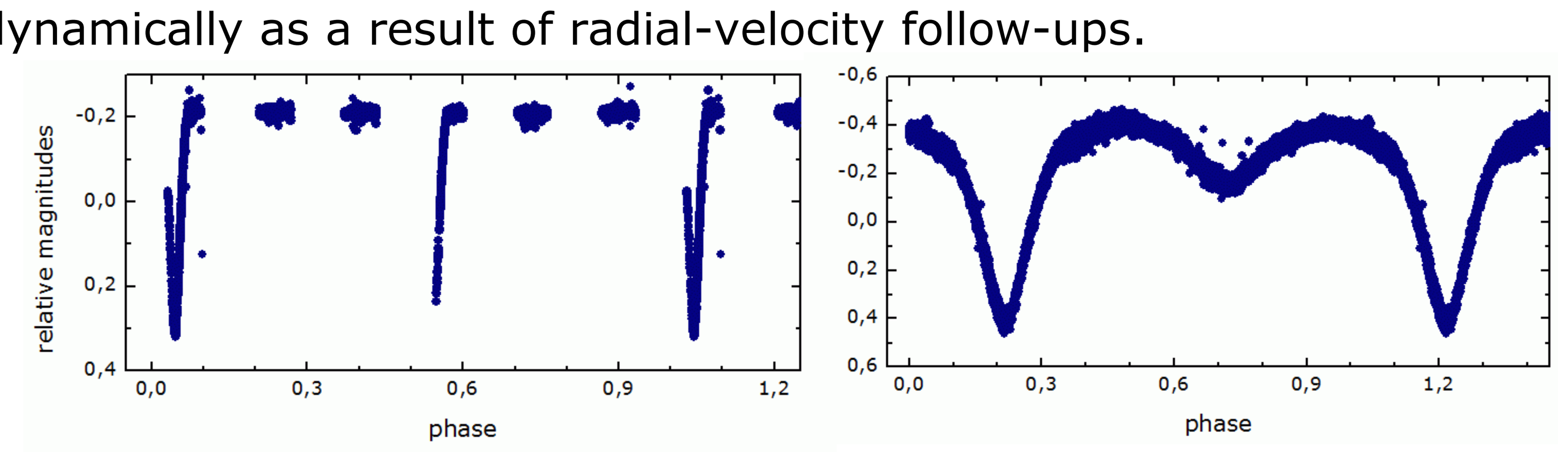

Fig. 2. Phase-folded light curves of some eclipsing variables detected in the field of Trumpler 37.

In addition to eSB2 stars, we also can measure rotation periods for many cluster members and detected several flares among members.

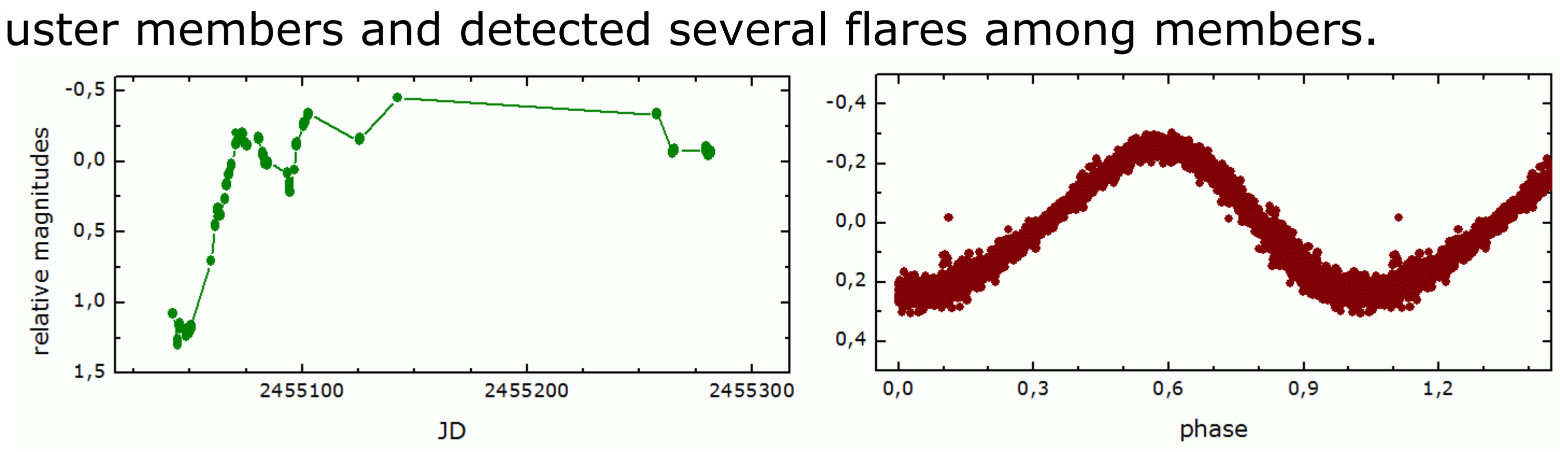

Fig. 3. Light curves of non-eclipsing variables detected in the field of Trumpler 37.

The most interesting object found may be a youngest exo-planet known so far (see Section 2). Given that we found several other interesting objects and given that we do not want to miss any transiting planets due to limited observing time (e.g. last summer just one telescope), we have organised international campaign to observe for 24 hours each day and night for a certain number of days/nights. Telescopes located at different longitudes have been engaged.

2. The exoplanet candidate in Trumpler 37

Detection of flat-bottomed eclipses with the depth of a few tens of millimagnitude in a light curve of a star suggests that there we are dealing with a transiting sub-stellar mass object. The depth of a transit together with the stellar radius give some constraints on the radius of the transiting object. However, no information on the mass of this companion can be extracted from photometric measurements. It may be a planet, a brown dwarf or a low-mass star, because in the low-mass regime the radius is independent on the mass. Doppler follow-up is the only way to determine the mass and, hence, true nature of the transiting object. The radial velocity measurements play the key role in discriminating true central transits from other cases such as grazing eclipsing binaries, blended systems and stellar activity. Radial velocities alone determine $m \sin i$, but due to the transit, the inclination i is known, so that existence of transit and radial velocities together yield the true companion mass m. Moreover, spectroscopic observations of the central star, which are a by-product of the radial velocity measurements, are necessary to better determine, inter alia, the radius of the star and, in turn, that of the companion. Mass and radius lead to a measurement of the transiting object mean density – an essential parameter for the study of the internal structure of extrasolar planets, brown dwarfs and low-mass stars.

In our search for transiting extrasolar planets in young open clusters we found that a light curve of a 15-mag star reveals features typical for a planetary transit. Every 1.36 day its brightness drops by 47.2±1.2 mmag causing a flat-bottom flux dip (Fig. 4). The secondary eclipse is not detectable.

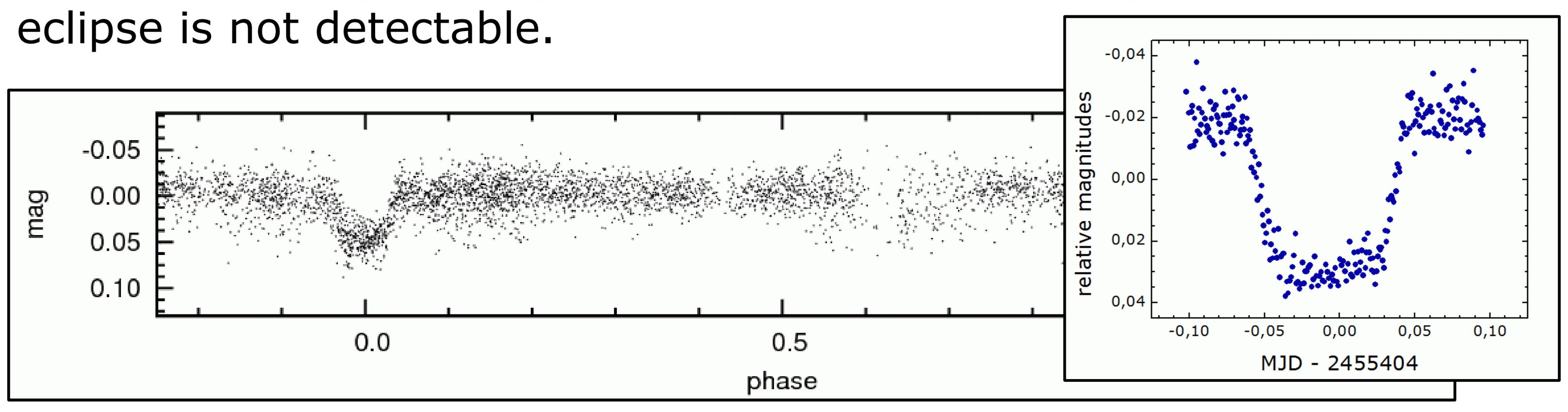

Fig. 4. ***Main panel:*** **The phased light curve of the planetary transit candidate composed of 5548 individual measurements collected in the** ***R*****-band filter with the 90-cm telescope near Jena, Germany.** ***Right:*** **First results of the photometric follow-up: the transit-candidate** ***I*****-band light curve obtained with the 2.2-m telescope at Calar Alto (Spain) in July 2010. The flat bottom is clearly visible.**

Based on *BVJHK* photometry, we determined host star's spectral type to be G8. We noted that the star is located close to the main sequence of the Trumpler 37 cluster (Fig. 5). The proper motion of the star is also consistent with cluster membership, so it may be preliminary treated as a probable member of this very young open cluster.

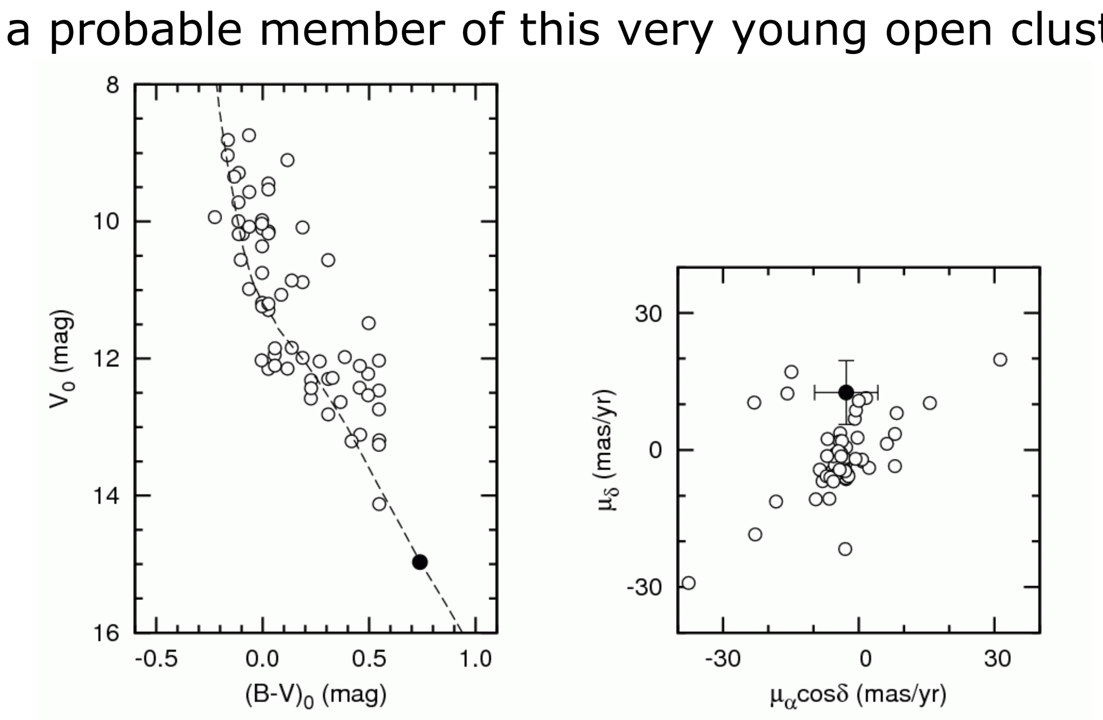

Fig. 5. ***Left:*** **Location of the the planetary transit candidate star (black dot) in the dereddened colour-magnitude diagram of the open cluster Trumpler 37. Open circles denote other probable cluster members.** ***Right:*** **Also its proper motion is consistent with membership.**

The transit depth indicates a radius of a transiting object of about 2 Jupiter radii, and hence about 15 Jupiter masses at 5 Myrs, following evolutionary models of cool brown dwarfs and extrasolar giant planets formation. This object would be by far the youngest transiting planet known and the youngest known exoplanet candidate at all. If confirmed to be a planet, it will give strong constraints on several aspects of planet formation, e.g. time-scales (planet formation would then be possible within 5 Myrs), and the radius of the planet could indicate whether planets form by gravitational collapse (being larger when young) or accretion growth (being smaller when young). It would be the youngest transiting exoplanet with several most important parameters known (such as mass, radius, density, age, and distance), which could serve as the Rosetta stone for planet formation theories.