The Young Exoplanet Transit Initiative (YETI)

R. Neuhäuser
R. Errmann
A. Berndt
G. Maciejewski
H. Takahashi

See next page for additional authors

Let us know how access to these works benefits you

Follow this and additional works at: http://works.swarthmore.edu/fac-physics

Recommended Citation
R. Neuhäuser; R. Errmann; A. Berndt; G. Maciejewski; H. Takahashi; W. P. Chen; D. P. Dimitrov; T. Pribulla; E. H. Nikogossian; Eric L. N. Jensen; L. Marschall; Z.-Y. Wu; A. Kellerer; F. M. Walter; C. Briceno; R. Chini; M. Fernandez; S. Raetz; G. Torres; D. W. Latham; S. N. Quinn; A. Niedzielski; L. Bukowiecki; G. Nowak; T. Tomov; K. Tachihara; S. C.-L. Hu; L. W. Hung; D. P. Kjurkchieva; V. S. Radeva; B. M. Mihov; L. Slavcheva-Mihova; I. N. Bozhiuova; J. Budaj; M. Vanko; E. Kundra; L. Hambalek; V. Krushevski; T. Movsessian; H. Harutyunyan; J. J. Downes; J. Hernandez; V. H. Hoffmeister; David H. Cohen; Imoleayo Samson Abel , '14; Rebecca Ruby-Ahmad , '14; Seth Walker Chapman , '14; Sierra Clare Eckert , '14; Jackson Goodman , '13; Adrien Charles Guerrard , '14; H. M. Kim; Andrew Evan Koontharana , '11; Joshua Daniel Sokol , '11; Jennifer Trinh , '11; Yuwen Wang , '14; X. Zhou; R. Redmer; U. Kramm; N. Nettelmann; M. Mugrauer; J. Schmidt; M. Moulant; C. Ginski; C. Marka; C. Adam; M. Seeliger; S. Bara; T. Roell; T. O. B. Schmidt; L. Trepl; T. Eisenbeiss; S. Fiedler; N. Tetzlaff; E. Schmidt; M. M. Hohle; M. Kitze; N. Chakrova; C. Grafe; K. Schreyer; V. V. Hambaryan; C. H. Broeg; J. Koppenhoefer; and A. K. Pandey. (2011). "The Young Exoplanet Transit Initiative (YETI)". Astronomische Nachrichten. Volume 332, Issue 6. 547-561.
http://works.swarthmore.edu/fac-physics/41
Authors
R. Neuhäuser; R. Errmann; A. Berndt; G. Maciejewski; H. Takahashi; W. P. Chen; D. P. Dimitrov; T. Pribulla; E. H. Nikogossian; Eric L.N. Jensen; L. Marschall; Z.-Y. Wu; A. Kellerer; F. M. Walter; C. Briceño; R. Chini; M. Fernández; S. Raetz; G. Torres; D. W. Latham; S. N. Quinn; A. Niedzielski; L. Bukowiecki; G. Nowak; T. Tomov; K. Tachihara; S. C.-L. Hu; L. W. Hung; D. P. Kjurkchieva; V. S. Radeva; B. M. Mihov; L. Slavcheva-Mihova; I. N. Bozhinova; J. Budaj; M. Vanko; E. Kundra; L. Hambalek; V. Krushevska; T. Movsessian; H. Harutyunyan; J. J. Downes; J. Hernandez; V. H. Hoffmeister; David H. Cohen; Imoleayo Samson Abel, ’14; Rebecca Ruby Ahmad, ’14; Seth Walker Chapman, ’14; Sierra Clare Eckert, ’14; Jackson Goodman, ’13; Adrien Charles Guerard, ’14; H. M. Kim; Andrew Evan Koontharanana, ’11; Joshua Daniel Sokol, ’11; Jennifer Trinh, ’11; Yuwen Wang, ’14; X. Zhou; R. Redmer; U. Kramm; N. Nettelmann; M. Mugrauer; J. Schmidt; M. Moualla; C. Ginski; C. Marka; C. Adam; M. Seeliger; S. Baar; T. Roell; T. O.B. Schmidt; L. Trepl; T. Eisenbeiss; S. Fiedler; N. Tetzlaff; E. Schmidt; M. M. Hohle; M. Kitze; N. Chakrova; C. Grafe; K. Schreyer; V. V. Hambaryan; C. H. Broeg; J. Koppenhoefer; and A. K. Pandey

This article is available at Works: http://works.swarthmore.edu/fac-physics/41
Young Exoplanet Transit Initiative (YETI)

R. Neuhaus

Atmosphärisches Institut und Universitäts-Sternwarte, FSU Jena, Schillergässchen 2-3, D-07745 Jena, Germany
Toruń Centre for Astronomy, Nicolaus Copernicus University, Gagarina 11, PL87-100 Toruń, Poland
Gunma Astronomical Observatory, 6860-86 Nakayama, Takayama-mura, Agatsuma-gun, Gunma 377-0702 Japan
Graduate Institute of Astronomy, National Central University, Jhongli City, Taoyuan County 32001, Taiwan (R.O.C.)
Institute of Astronomy and NAO, Bulg. Acad. Sc., 72 Tzarigradsko Chaussee Blvd., 1784 Sofia, Bulgaria
Astronomical Institute, Slovak Academy of Sciences, 059 60, Tatranská Lomnica, Slovakia
Byurakan Astrophysical Observatory, 378433 Byurakan, Armenia
Dept. of Physics and Astronomy, Swarthmore College, Swarthmore, PA 19081-1390, USA
Gettysburg College Observatory, Department of Physics, 300 North Washington St., Gettysburg, PA 17325, USA
Key Laboratory of Optical Astronomy, NAO, Chinese Academy of Sciences, 20A Datun Road, Beijing 10012, China
Institute of Astronomy, University of Hawaii, 640 N. A’ohoku Place, Hilo, Hawaii 96720
Big Bear Solar Observatory, 40386 North Shore Lane, Big Bear City, CA 92314-9672, USA
Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY 11794-3800, USA
Centro de Investigaciones de Astronomía, Apartado Postal 264, Merida 5101, Venezuela
Astronomisches Institut, Ruhr-Universität Bochum, Universitätsstr. 150, D-44801 Bochum, Germany
Facultad de Ciencias, Universidad Católica del Norte, Antofagasta, Chile
Instituto de Astrofísica de Andalucía, CSIC, Apdo. 3004, 18080 Granada, Spain
Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Mail Stop 20, Cambridge MA 02138, USA
Joint ALMA Observatory, Alonso de Córdova 3107, Vitacura, Santiago, Chile
National Astronomical Observatory of Japan, ALMA project office, 2-21-1 Osawa Mitaka Tokyo 181-8588 Japan
Shumen University, 115 Universitetska str., 9700 Shumen, Bulgaria
Main Astronomical Observatory of NAS of Ukraine, 27 Akademika Zabolotnoho St., 03680 Kyiv, Ukraine
Institut für Physik, Universität Rostock, D-18051 Rostock, Germany
MPI für extraterrestrische Physik, Giessenbachstraße 1, D-85740 Garching, Germany
Institute for Applied Physics, FSU Jena, Max-Wien Platz 1, D-07743 Jena, Germany
Christian-Albrechts-Universität Kiel, Leibnizstraße 15, D-24098 Kiel, Germany
Physikalisches Institut, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland
Universitäts-Sternwarte München, Scheinerstraße 1, D-81679 München, Germany
Aryabhatta Research Institute of Observational Science, Manora Peak, Naini Tal, 263 129, Uttararakhand, India

Received 2011 April 20, accepted 2011 June 15

Key words star formation, planet formation, extra-solar planets

We present the Young Exoplanet Transit Initiative (YETI), in which we use several 0.2 to 2.6m telescopes around the world to monitor continuously young (≤ 100 Myr), nearby (≤ 1 kpc) stellar clusters mainly to detect young transiting planets (and to study other variability phenomena on time-scales from minutes to years). The telescope network enables us to observe the targets continuously for several days in order not to miss any transit. The runs are typically one to two weeks long, about three runs per year per cluster in two or three subsequent years for about ten clusters. There are thousands of stars detectable in each field with several hundred known cluster members, e.g., in the first cluster observed, Tr-37, a typical cluster for the YETI survey, there are at least 469 known young stars detected in YETI data down to R=16.5 mag with sufficient precision of 50 milli-mag rms (5 mmag rms down to R=14.5 mag) to detect transits, so that we can expect at least about one young transit object in this cluster. If we observe ~ 10 similar clusters, we can expect to detect ~ 10 young transiting planets with radius determinations. The precision given above is for a typical telescope of the YETI network, namely the 60/90-cm Jena telescope (similar brightness limit, namely with ±1 mag, for the others) so that planetary transits can be detected. For targets with a periodic transit-like light curve, we obtain spectroscopy to ensure that the star is young and that the transiting object can be sub-stellar; then, we obtain Adaptive Optics infrared images and spectra, to exclude other bright eclipsing stars in the (larger) optical PSF: we find dark spots in our Prelopnik at host star to rule out other false positive scenarios; finally, we also perform spectroscopy to determine the mass of the transiting
1 Introduction: Extrasolar planets

Beginning with the discovery of planets around a neutron star (Wolszczan & Frail 1992; Wolszczan 1994) and around normal stars (Latham et al. 1989; Mayor & Queloz 1995; Marcy & Butler 1996), it has become possible to study planetary systems and their formation outside the Solar System.

The most successful of the detection methods (the spectroscopic or radial velocity (RV) technique) yields only a lower limit \( m \cdot \sin i \) on the mass \( m \) of the companions, because the orbital inclination \( i \) is unknown. RV companions could be planets, brown dwarfs, or even low-mass stars. Combined with other observational techniques (e.g. astrometry, Benedict et al. 2002), one can determine the orbital inclination \( i \) and the true mass \( m \).

The very existence of a transit requires that \( \sin i \) is close to 1, hence it confirms an RV planet candidate to be really below some upper mass limit of planets (see below for the definition of planets). The transit technique can then even give the planetary radius and, together with the mass (from RV and transit data), also the mean density (e.g. Torres, Winn, Holman 2008). Modeling can then constrain the chemical composition and the mass of a solid core (e.g. Guillot et al. 2006; Burrows et al. 2007; Nettelmann et al. 2010). The first transiting extrasolar planet identified was the planet candidate HD 209458b found by RV by Mazeh et al. (2000) and confirmed to be a planet with 0.7 Jup masses (Charbonneau et al. 2000; Henry et al. 2000); it is also the first RV planet candidate confirmed by another technique. For transiting planets, one can also obtain spectral information by transmission spectroscopy (e.g. Charbonneau et al. 2002). One can also indirectly determine the brightness of the planet by detecting the secondary eclipse (e.g. Deming et al. 2005). The Rossiter McLaughlin effect can provide information about spin axis-orbital plane alignment and, hence, dynamics in the system (e.g. Queloz et al. 2000; Triaud et al. 2010; Winn et al. 2010).

The direct imaging technique can detect planets or candidates at wide separations from the star, for which one can then often also take spectra, e.g. GQ Lup b (Neuhäuser et al. 2005) or CT Cha b (Schmidt et al. 2008). The mass is difficult to determine and model-dependent, so that all or most directly imaged planets (or planet candidates) can be either planets or brown dwarfs. The upper mass limit of planets is also not yet defined and can be either the Deuterium burning mass limit (~ 13 M\(_{\text{Jup}}\), Burrows et al. 1997) or the mass range of the brown dwarf desert (~ 35 M\(_{\text{Jup}}\), Grether & Lineweaver 2006).

Some additional planets or planet candidates detected by microlensing or timing have not yet been confirmed (see, e.g., exoplanet.eu for references).

The detectability of a planet depends on its mass, radius, or luminosity (depending on the technique) relative to the host star. Since all detection techniques are biased towards more massive (or larger) planets, it is not surprising that Earth-mass planets have not yet been discovered. Low-mass planets in the so-called habitable zone can possibly be detected by the RV technique around low-mass stars like M dwarfs (e.g. GJ 1214 by Charbonneau et al. 2009). The RV and transit techniques are also biased towards close-in planets, while direct imaging is biased towards wide separations. The RV technique has led to the discovery of ~ 500 planet candidates, of which some 20% are confirmed by either the astrometry or transit technique (see e.g. exoplanet.eu for updates). The latter method has detected ~ 100 planets, all of which have been confirmed by RV data (or transit timing, see Lissauer et al. 2011). Many more transit candidates are reported by Borucki et al. (2011) with the Kepler satellite.

Almost 50 planet host stars are already known to be surrounded by more than one planet (e.g. Fischer et al. 2002; Lovis et al. 2011), e.g. most recently Kepler-11 with six transiting planets, where the transit timing variations (TTV) could be used to determine the masses of the planets (Lissauer et al. 2011) instead of radial velocity follow-up; several planet host stars are multiple stars themselves (Cochrane et al. 1997; Mugrauer, Neuhäuser, Mazeh 2007). Planetary systems can also be discovered (indirectly) by TTV (Maciejewski et al. 2010, 2011a; Holman et al. 2010). One can also observe in several cases dust debris disks around planet host stars, which are produced by colliding planetesimals (e.g. Krivov 2010), e.g. the probably planetary mass companions around the A0-type star HR 8799 discovered by Marois et al. (2008, 2010) and studied in detail by Reidemeister et al. (2009) with a debris disk resolved by Su et al. (2010).

Stellar activity can be a problem for the RV, transit, TTV, and astrometric techniques, but not for direct imaging. Most of the planet host stars are main-sequence G-type stars, few planets are also discovered around more or less massive stars including giants (Frink et al. 2002; Niedzielski et al. 2007) and M-type dwarfs (Marcy et al. 1998; Charbonneau et al. 2009), respectively. The MEarth project is searching for transiting planets around M-type dwarfs (see, e.g., Charbonneau et al. 2009). Almost all the planets (and host stars) are, however, Gyr old, so that it might be difficult to study planet formation from this sample. Among the important overall statistical results is the fact that many planets orbit their stars on much shorter orbits than in the Solar System; hence, planets may migrate inwards after formation further outwards (Goldreich & Tremaine 1980; Lin et al. 1996), e.g. beyond the ice line, if they did not form in-situ. In addition, many more planets have been detected around metal-rich stars than around metal-poor stars (e.g. Marcy et al. 2005; Butler et al. 2006), which may suggest that planets are more likely to form when there is a more abundant supply of dust.

Planes (or planet candidates) around pre-main sequence (PMS) stars or stars significantly younger than 100 Myr (the maximal PMS time-scale for very low-mass stars) have been discovered so far only with the direct imaging tech-
nique, so that the mass and, hence, the planetary status of those objects are model-dependent and still uncertain. The youngest known planetary system - except maybe HR 8799 (Marois et al. 2008, 2010, four planets by direct imaging) - may be WASP-10bc, where WASP-10b was discovered by the transit technique and confirmed by RV (Christian et al. 2009) and WASP-10c by transit timing (Maciejewski et al. 2011a), still to be confirmed independently; the age of WASP-10 was inferred from the 12 day rotation period using gyro-chronology to be only 200 to 350 Myr (Maciejewski et al. 2009). In addition, there were also RV surveys for planets among young, PMS stars, e.g. Guenther & Esposito (2007) have monitored 85 young pre- and zero-age main sequence stars with ESO 3.6m HARPS without planet discoveries; Joergens (2006) observed 12 very low-mass PMS stars and brown dwarfs in Cha I and found one companion with $25 \pm 7$ to $31 \pm 8$ Jup mass lower mass limit around Cha Hr 8 (Joergens & Müller 2007; Joergens, Müller, Refvert 2010); and Setiawan et al. (2008) monitored young stars including PMS stars and published an RV planet candidate around TW Hya, which was not confirmed by Huelamo et al. (2008).

To study planet formation (planets younger than 100 Myr, partly even younger than $\sim 10$ Myr), measuring their ages, masses, radii, and orbital elements, studying their internal structure) and possible secular effects (by comparing the architecture, i.e. the number and properties of planets including their semi-major axes, of young planetary systems with the Solar System and other old systems), we started a project to monitor young stellar clusters (age $\leq 100$ Myr) in order to find young transiting planets (called YETI for Young Exoplanet Transit Initiative) and also to study other variability in general in the young stars. A first brief presentation of the project was given in Maciejewski et al. (2011b).

In this paper, we first summarize previous and/or ongoing searches for young planets in clusters (Sect. 2) and then describe the YETI target selection criteria and list the first few clusters being observed (Sect. 3). In Sect. 4 we present the telescope network put together for continuous monitoring and follow-up observations. We mention other science projects to be studied with the same data sets in Sect. 5. Finally, we present in Sect. 6 the YETI data reduction technique and then also a few preliminary YETI results from the Trumpler 37 (Tr-37) cluster observed in 2009 and 2010.

2 Previous searches for young transit planets

We know of two other previous and/or ongoing searches for planetary transits in young clusters: CoRoT’s survey of NGC 2264 and the MONITOR project.

The French-European satellite CoRoT with its 30 cm mirror continuously monitored the young cluster NGC 2264 for 24 days in March 2008, the PI being F. Favata. NGC 2264 is $\sim 3$ Myr old at $\sim 760$ pc (Dahm 2008). Some first preliminary results (rotation periods of member stars, but no transit candidates) were presented by Favata et al. (2010). Because of the unprecedented precision of a space telescope like CoRoT, we will not observe NGC 2264 in the YETI survey.

The MONITOR project aims at observing ten young clusters (1-200 Myr) also mainly to detect transiting planets (Hodgkin et al. 2006, Aigrain et al. 2007), including h and χ Per, also potential target clusters for the YETI survey. So far, rotation periods of hundreds of member stars have been reported for the clusters M34 (Irwin et al. 2006), NGC 2516 (Irwin et al. 2007), NGC 2362 (Irwin et al. 2008a), NGC 2547 (Irwin et al. 2008b), and M50 (Irwin et al. 2009). Results for the planet transit search have been published so far only for NGC 2362, where no planet was found among 475 member stars observed for a total of 100 hours spread over 18 nights within 362 days (Miller et al. 2008); the non-detection of transiting planets was not surprising given the expectation value for this cluster: Aigrain et al. (2007) expected that there are in total 11.3 transiting planets in NGC 2362 – however, only 0.0 of them were expected to be detectable by their survey. This non-detection is for planets with 1.5 Jupiter radii and periods between 1 and 10 days (Miller et al. 2008). With the $\sim 50$ mmag rms precision down to R=16.5 mag (5 mmag rms down to R=14.5 mag, both for Jena), we can detect (young large) planets down to $\sim 1$ Jupiter radius, given the typical radii and brightness of the YETI targets stars. Given the YETI approach to observe a certain field continuously for several days (24h per day), e.g. continuously for up to $\sim 2$ weeks (e.g. the Tr-37 run 2010 Aug 26 to Sept 13), we would be able to detect all planets down to $\sim 1$ Jupiter radius with periods up to $\sim 14$ days. Hence, even if we would not detect any planets, we would be able to place limits (for the frequency of young planets) lower than the current limits for either the solar neighbourhood or the NGC 2362 cluster (Miller et al. 2008).

To justify the YETI project, it is important that we understand why no transiting planets have been reported by the MONITOR survey so far. It is possible that this is due to the fact that the telescopes used in the MONITOR project do not cover all longitudes on Earth (being located in Europe and America only), so that continuous coverage is not possible. Hence, transits can be missed; the light curves of stars from the MONITOR project as published in the papers listed above also show that the phase coverage is not complete.

3 YETI target selection criteria and transit planet detection expectations

For successful detection of a planetary transit it is very important to choose regions on the sky where there is a high probability to observe this event.

An interesting environment is represented by stars in a cluster. Open cluster surveys should help to clarify the fac-
tors that control the formation and survival of planets by characterizing hot Jupiter populations as a function of age, metallicity and crowding. A significant fraction of stars in the solar vicinity form in clusters (Lada & Lada 2003). Stars in clusters also have the advantage that their age and distance is known, which is otherwise often difficult to obtain precisely for isolated stars.

Wide-field CCD cameras on 1-2 m telescopes with ~ 1° Field-of-View (FoV) are suitable for surveying stars in open clusters fields.

An estimate of the number of expected transiting planets, \( N_p \), can be parameterized as

\[
N_p = N_s \cdot f_p \cdot \rho_t \cdot \rho_{\text{eff}}. \tag{1}
\]

Here \( N_s \) is the number of stars included in the transit search, \( f_p \) is the fraction of stars with close-in planets within 0.1 AU (\(~0.012, Butler et al. 2006\)), \( \rho_t \) is the probability to view the orbit nearly edge-on (\(~0.1\) for close-in planets), and \( \rho_{\text{eff}} \) is a measure of the efficiency of the observation.

The number of stars \( N_s \) depends on the FoV of the telescope, the magnitude limits (excluding the brightest earliest stars and the faintest latest stars), and the photometric precision. In wide-field transit searches or deep searches with large telescopes, usually thousands of stars are covered in the FoV. However, only the number of stars with sufficiently high S/N for detecting transits are relevant in Eq. 1. For typical giant planets around solar-type stars, this means the S/N must provide a detection limit of ~ 0.5% dimming of the stellar light, or ~ 5 milli-mag (mmag) rms for a significant detection. For young 10 Jup mass planets that are still contracting (hence, large), the transit depth can be as large as ~ 80 mmag (Burrows et al. 1997; Baraffe et al. 1998, 2000, 2001, 2002, 2003, 2008), see below for details. Target stars must not be too faint, so that high-resolution spectroscopic follow-up for determining the mass of the transiting companion from radial velocities is possible with current-generation telescopes (8 to 10 meter mirrors), i.e. down to about 16.5 mag (see e.g. the OGLE-TR-56 transit planet, Konacki et al. 2003). The first observations with the Jena 90/60-cm telescope (90-cm mirror reduced to 60-cm effective mirror diameter in Schmidt mode) in 2009 show that we can reach sufficient photometric precision down to R=16.5 mag and 5 mmag rms down to R=14.5 mag (Fig. 5). The limiting sensitivity of other telescopes for the Tr-37 cluster campaigns, from 0.4 to 2.6m, are similar within ±1 mag. Hence, the number of stars \( N_s \) in Eq. 1 in the FoV should be the number of stars brighter than R=16.5 mag (the number of stars being too bright so that they saturate the CCD are negligible).

The parameter \( \rho_{\text{eff}} \) in Eq. 1 depends on many observational factors, e.g. weather, coordinates of targets and observatories; in Rauer et al. (2004), who have observed with only one telescope (the Berlin Exoplanet Search telescope, BEST) at Tautenburg near Jena for 3 years, this factor was 0.7 - limited by weather and the fact that only one telescope was used; this factor is a period-dependent variable only calculable after the fact as done for the BEST survey at Tautenburg by Rauer et al. (2004). We can assume a larger number for the YETI survey, because we will use several telescopes at many different longitudes on Earth to observe continuously. Hence, we can use \( \rho_{\text{eff}} \approx 1 \) for our calculations (the factor should definitely lie between 0.7 and 1.0; if it would be 0.7 only, the number of expected observable transits listed in Table 1 would decrease by only 30 %, ~ 1.0 is a good approximation for planet periods up to ~ 14 days, detectable by us completely down to ~ 1 Jupiter radius given the continuous observations.

See Table 1 for the clusters being observed so far and the expected number of transiting planets in the whole FoV (including old field stars and among young members in the YETI clusters). For young planets around young stars, we may assume a larger fraction of transiting planets than for old planets around old stars: If planets form partly by contraction, they are larger than old planets (Burrows et al. 1997; Baraffe et al. 1998, 2000, 2001, 2002, 2003, 2008). E.g., ~ 3 Myr young planets with 1 to 10 Jup masses are expected to have radii of 1.4 times the radius of Jupiter, hence are a factor of 2 larger than old Gyr old 1 to 10 Jup mass planets (Burrows et al. 1997). For planets with 1 to 12 Jup masses (radii from Baraffe et al. 2003, COND models) transiting stars with 1 or 0.5 M_⊙ (radii from Baraffe et al. 1998, 2002), the transit depth will have a maximum of ~ 15 to 80 mmag at ~ 50 to ~ 100 Myr, respectively; for 40 Jup mass brown dwarfs (radii from Baraffe et al. 2003) eclipsing such stars, the transit depth will have a maximum of ~ 60 to 100 mmag at ~ 5 Myr, respectively; see Fig. 2. For planets with 10 to 13 Jup masses (radii from Baraffe et al. 2000, 2001, DUSTY models) transiting stars with 1 or 0.5 M_⊙ (radii from Baraffe et al. 1998, 2002), the transit depth will have a maximum of ~ 20 to 80 mmag at ~ 50 to ~ 200 Myr, respectively; for 40 Jup mass brown dwarfs (radii from Baraffe et al. 2000, 2001) eclipsing such stars, the transit depth will have a maximum of ~ 70 to 100 mmag at ~ 10 to 20 Myr, respectively. For planets with 1 to 10 Jup masses (radii from Baraffe et al. 2008, both radiated and non-irradiated models) transiting stars with 1 or 0.5 M_⊙ (radii from Baraffe et al. 1998, 2002), the transit depth will have a maximum of ~ 20 to 70 mmag at ~ 50 to 200 Myr, respectively. Even though these models may still be uncertain, in particular for young ages and low masses, they tend to show that the transit depth reaches a maximum at ~ 10 to 200 Myr (for 40 to 1 Jup mass companions and 1 to 0.5 M_⊙ stars), see Fig. 2. After that maximum, the transit depth decreases only slowly with age. If the models are correct, we can use for young planets a factor of roughly 2 larger than for old planets (for number of expected detectable planets).

Through its first four months of operation, NASA’s Kepler mission (Koch et al. 2010) detected 83 transit candidates with transit depths of at least 5 mmag and periods shorter than 10 days (Borucki et al. 2011). Given the Kepler target list of ~ 160,000 stars (Koch et al. 2010), this is an occurrence rate of 0.00052 short period transiting plan-

R. Neuhäuser: Young exoplanet transit initiative

© 2011 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim www.an-journal.org
ets of this size per star. If we can assume that the rate of planet occurrence is the same for the Kepler target list and the YETI Tr-37 sample, then we can estimate the rate of planets detectable in Tr-37: The Kepler target list has been carefully selected using the Kepler Input Catalog, and the Kepler targets are nearly all on or near the MS; the Kepler target list is dominated by F and G dwarfs, similar to the sample of Tr-37 members; the Tr-37 members are of course younger (pre-MS) and, hence, larger than the Kepler MS targets; the Kepler target list is, however, probably not a good match to a magnitude-limited sample in the Tr-37 FoV (field stars), which will have heavy contamination by giants; however, we can apply the Kepler planet rate to the Tr-37 members. Nevertheless, if we apply this estimate to Tr-37 (6762 stars in the Jena FoV, including 469 young members), and also correct for the size of young stars with young planets compared to old systems in the Kepler field, we expect ~ 0.5 short-period planets among the known cluster members (and ~ 3.8 short-period planets total for the Tr-37 FoV). If we include periods out to 30 days, the number of candidates with transits deeper than 5 mmag detected by Kepler is 131, corresponding to ~ 3 expected planets among the known Tr-37 cluster members (and 5.9 total in the Tr-37 FoV).

This estimate (~ 0.8 transiting planets) is consistent with our other estimate (derived differently) given in Table 1. The estimates of expected detectable planets in Table 1 are upper limits in the sense, that we may still miss some planets, if we always would have problems with weather and/or technical issues, i.e. would never reach a truly continuous monitoring, or due to the activity and, hence, intrinsic variability of the young targets (however, ~ 10 to 100 Myr old stars like weak-line T Tauri stars and zero-age main sequence stars already show much lower variability amplitudes compared to ~ 1 Myr young classical T Tauri stars). The estimates for planets in Table 1 are also lower limits, because the number of young members in the clusters known (and given in Table 1) are also lower limits; in the YETI survey, we will find new members by photometric variability and follow-up spectroscopy. Using the monitoring campaigns with three one- to two-week runs in three consecutive months, repeated in two or three consecutive years, it will be possible to detect most of the transiting planets with periods up to ~ 30 days.

We show in Fig. 6 below that we are indeed able to combine the photometric data points from different telescopes (with different mirror sizes, different detectors, and different weather conditions) with sufficient precision to detect transits: Fig. 6 shows a preliminary light curve for an eclipsing double-lined spectroscopic binary in the Tr-37 field; this is probably not a young member of Tr-37, but still to be confirmed.

Even though transiting planets have not yet been found in clusters (most of the clusters surveyed for transits are several Gyr old), it is not yet known, whether the occurrence rate of (transiting) planets is lower in clusters compared to non-cluster field stars. If hot (transiting) Jupiters do not survive as long as the cluster age, then young clusters may still have more planets than old clusters. On the other hand, stars in young clusters are more active than in old clusters, which makes it more difficult to detect and confirm young transiting planets. It is also not yet known how long planet formation (and migration) lasts, i.e. whether planet formation is possible during the (small) age of the YETI clusters. In this project, we aim to clarify those questions.

We argue that the fraction of transiting planets expected and found in the MONITOR survey is lower than expected in the YETI survey, because we obtain continuous monitoring with telescopes covering all longitudes on Earth, i.e. 24h per day for several consecutive days. With such continuous observations, we will be able to detect any transit with a depth of at least about 5 mmag down to 14.5 mag, the mean YETI sensitivity, for every planet with an orbital period lower than the survey - or, in order to detect the periodicity of the candidate, lower than about half the survey duration (somewhere between a few days and a few months).

The YETI cluster target selection criteria to study planet formation by transit observations are therefore as follows:

- Young age: At least one Myr, so that planets may already exist, and younger than ~ 100 Myr, the PMS time-scale of the lowest mass stars.
- Intermediate distance: Neither too close (otherwise the field with enough stars would be too large on the sky) nor too distant (otherwise the stars would be too faint), roughly 50 to 1000 pc.
- Size of the cluster on sky: Roughly 1° x 1°, i.e. well suited to the typical field sizes set be the YETI telescope optics and CCD sizes; in case of smaller FoVs and mosaicing, the cadence should still be high enough to obtain sufficient data points during the typical transit duration.
- Clusters not studied before with similar or better observations, e.g. like NGC 2264 with CoRoT.
- As many young stars as possible in a useful magnitude range in VRI: Not too bright (fainter than ~ 10 mag) to avoid saturation and not too faint (brighter than 16.5 mag) not to lose sensitivity (even if different exposure times are used for stars of different brightness) and to be able to do RV follow-up spectroscopy of transit candidates (the faintest host star where this was successfully done is OGLE-TR-56 with V=16.6 mag, Konacki et al. 2003).
- Location on sky, so that many telescopes can observe and monitor it continuously.

The number of confirmed transiting planet detections is 134 (e.g. exoplanet.eu), relatively small when compared with early predictions (Horne 2003).

The origin of this discrepancy may have several causes:

(i) simplifying assumptions in the noise properties that govern the detection limits in previous predictions - in many cases red instead of white noise may be dominating (Pont et
and... or partly in future years are Pleiades, NGC 2244, α Per evolution of planets. Additional clusters to be observed fully to cover the full age range to study formation and early clusters to be observed, several more will follow later in or-

clected the clusters Tr-37 and 25 Ori (Table 1) as the first two dering binaries blended with the target. We obtain follow-up continuous monitoring of the companion. Except when TTV signals are observed,

detections as well as ages and masses of individual stars. We al. 2006),

(ii) unaccounted errors in aperture photometry on non-auto-
guided telescopes,

(iii) overestimates of the fraction of stars that are suitable as targets for transit surveys, and

(iv) underestimates of the need for continuous observations.

Another topic whose consequences have only been rec-
ognized during the course of the first transit searches is the problem of false alarms caused by other stellar combinations that may produce transit-like light curves. Of these, the most notorious case may be that of an eclipsing binary star located within the point spread function (PSF) of a brighter star (Brown 2003). An increasing number of tools are now available to recognize false alarms: (i) precise analysis of transit shapes or durations, (ii) color signatures, (iii) variations in the positioning of the stellar PSF. The effectiveness of several of these tools depends strongly on the information (e.g., temperature, radius) that is available for the host star, and underlines the need for auxiliary observations in transit detection experiments.

In practice, it is not always possible from the light curve alone to exclude false positives, such as background eclipsing binaries blended with the target. We obtain follow-up spectroscopy to aid in examining these possibilities, as well as to measure the stellar properties temperature, rotational velocity, gravity, and metallicity, and to measure the mass of the companion. Except when TTV signals are observed, one always needs follow-up spectroscopy to determine the mass of the companion.

4 The YETI telescope network for continuous monitoring

Given the target selection criteria listed above, we have se-
lected the clusters Tr-37 and 25 Ori (Table 1) as the first two clusters to be observed, several more will follow later in or-
der to cover the full age range to study formation and early evolution of planets. Additional clusters to be observed fully or partly in future years are Pleiades, NGC 2244, α Per, h and χ Per, Collinder 69, σ Ori, IC 2602, etc. If we will ob-
serve approximately ten clusters in the project, each cluster for 2 or 3 years, and not more than two different clusters per year, then the whole YETI project will last for more than ten years. Most of the observatories participating can allocate their telescopes for all nights in all runs for the whole dura-
tion of the YETI project (mostly already guaranteed, partly by internal proposals), while for some of the participating telescopes, we have to apply for time (e.g. Sierra Nevada, Calar Alto, Mauna Kea).

The clusters Tr-37 (Fig. 1) and 25 Ori have been ob-

served since 2009. The cluster Tr-37 was observed by most of the participating telescopes in 2010 during the three runs August 3/4 to 12/13, August 26/27 to September 12/13, and September 24/25 to Sept 30/Oct 1, i.e. 35 nights in total. The cluster 25 Ori was observed simultaneously and con-

sequently observing seasons are expected to be allocated on all the YETI telescopes, 34 nights for Tr-37 in 2011 and 29 nights for 25 Ori in the (northern) winter 2011/12. We also observed a field at the edge of the Pleiades cluster (Eisen-
beiss et al. 2009, Moualla 2011). First results from Tr-37 are reported below.

Given the problems listed in the previous section and in order not to miss a transit and to determine the periodic-
ity in the transit-like variability, it is important to monitor the targets (almost) continuously, i.e. 24 hours per day for the whole run of at least several days. Therefore, we established a network of several observatories around the world covering many longitudes, to that we can observe the YETI targets continuously.

The participating observatories are listed in Table 2 with their telescopes and instruments.

5 Additional science projects

Although the main thrust of this project is the search for young transiting planets, the observations we are collecting also lend themselves to studies of variability phenomena on different time-scales, and can be co-added as well to pro-

vide very deep imaging of the YETI target clusters. An ad-
ditional component of the project is a theoretical study of the interiors of young transiting planets to provide a frame-
work for interpreting the YETI discoveries. We describe these topics below.

5.1 Other variability phenomena

The precise and nearly continuous time series photometry gathered for this project enables us to investigate rotational periods for cluster members and field stars (see e.g. Fig. 3; first results on Tr-37 data from Jena from 2009 can be found in Berndt et al. 2011), longer-term cycles (Fig. 4), and irreg-
ular variability like flares. We can also detect eclipsing bina-

ries comprised of two stars, or two brown dwarfs, or a brown dwarf orbiting a star. From eclipsing binaries among young cluster members, we can derive mass-luminosity relations, which are one of the main uncertainties in obtaining lumi-

nosity and mass functions and of pre-main sequence popu-
lations as well as ages and masses of individual stars. We plan to use multi-color photometry to refine age, distance, and extinction measurements for the clusters, e.g. from the color-magnitude or color-color diagrams.

5.2 Deep imaging

We can add up many images obtained per cluster to get much deeper photometry. We have already tested this using a field at the edge of the Pleiades, where we could find se-

eral brown dwarf candidates by RIJKH colors (Eisenbeiss...
Table 1. First two target clusters

<table>
<thead>
<tr>
<th>Cluster name</th>
<th>central coordinates</th>
<th>age [Myr]</th>
<th>distance [pc]</th>
<th>number of stars with ( R \leq 16.50 ) mag expected no. of transit planets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RA J2000.0</td>
<td>Dec J2000.0</td>
<td></td>
<td>in total</td>
</tr>
<tr>
<td></td>
<td>[hh:mm:ss]</td>
<td>[dd:mm:ss]</td>
<td></td>
<td>members</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>members</td>
</tr>
<tr>
<td>Trumpler 37</td>
<td>21:38:09</td>
<td>+57:26:48</td>
<td>7</td>
<td>870</td>
</tr>
<tr>
<td>25 Ori</td>
<td>05:24:45</td>
<td>+01:50:47</td>
<td>7-10</td>
<td>323</td>
</tr>
</tbody>
</table>

Remarks: (a) According to Eq. 1 and Sect. 3. (b) Jena FoV is \( 53' \times 53' \) for STK, see Table 2.

References for coordinates, age, distance, and members: 25 Ori: Kharchenko et al. (2005), Briceño et al. (2005, 2007); Trumpler 37: See Sect. 6.

Table 2. Telescope network (1) (sorted by longitude)

<table>
<thead>
<tr>
<th>Observatory</th>
<th>Long. [deg]</th>
<th>Lat. [deg]</th>
<th>Mirror diameter [m]</th>
<th>CCD type (camera)</th>
<th>no. of pixels</th>
<th>size of field [min x min]</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gunma/Japan</td>
<td>139.0</td>
<td>36.6</td>
<td>1.50</td>
<td>Andor DW432</td>
<td>1250 x 1152</td>
<td>12.5 x 12.5</td>
<td>(2)</td>
</tr>
<tr>
<td>Lulin/Taiwan</td>
<td>120.5</td>
<td>23.3</td>
<td>1.00</td>
<td>Marconi CCD36-40 PI1300B</td>
<td>1340 x 1300</td>
<td>22 x 22</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.41</td>
<td>E2V 42-40 (U42)</td>
<td>2048 x 2048</td>
<td>28 x 28</td>
<td></td>
</tr>
<tr>
<td>Xinglong/China</td>
<td>117.6</td>
<td>40.4</td>
<td>0.90 (3)</td>
<td>E2V CCD203-82</td>
<td>4096 x 4096</td>
<td>94 x 94</td>
<td></td>
</tr>
<tr>
<td>Nainital/India</td>
<td>79.5</td>
<td>29.4</td>
<td>1.04</td>
<td>TK2048E</td>
<td>2000 x 2000</td>
<td>13 x 13</td>
<td></td>
</tr>
<tr>
<td>Byurakan/Armenia</td>
<td>44.3</td>
<td>40.3</td>
<td>2.60</td>
<td>SCORPIO Loral</td>
<td>2058 x 2063</td>
<td>14 x 14</td>
<td></td>
</tr>
<tr>
<td>Rozhen/Bulgaria</td>
<td>24.7</td>
<td>41.7</td>
<td>0.60</td>
<td>FLI ProLine 09000</td>
<td>3056 x 3056</td>
<td>17 x 17</td>
<td>(4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.60 (5)</td>
<td>FLI ProLine 09000</td>
<td>3056 x 3056</td>
<td>27 x 27</td>
<td>(4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.70 (6)</td>
<td>FLI ProLine 16803</td>
<td>4096 x 4096</td>
<td>73 x 73</td>
<td>(4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.00</td>
<td>Princ. Instr. VersArray:1300B</td>
<td>1340 x 1300</td>
<td>6 x 6</td>
<td>(4)</td>
</tr>
<tr>
<td>Stará Lesná (Slovak Rep.)</td>
<td>20.3</td>
<td>49.2</td>
<td>0.50</td>
<td>SBIG ST10 MXE</td>
<td>2184 x 1472</td>
<td>20 x 14</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.60</td>
<td>STTe TK1024</td>
<td>1024 x 1024</td>
<td>11 x 11</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.25</td>
<td>SBIG ST10 MXE</td>
<td>2184 x 1472</td>
<td>43 x 29</td>
<td></td>
</tr>
<tr>
<td>Toruń/Poland</td>
<td>18.6</td>
<td>53.1</td>
<td>0.90 (3)</td>
<td>SBIG STL-11000</td>
<td>4008 x 2672</td>
<td>48 x 72</td>
<td></td>
</tr>
<tr>
<td>Jena/Germany</td>
<td>11.5</td>
<td>50.9</td>
<td>0.90 (3)</td>
<td>E2V CCD42-10 (STK)</td>
<td>2048 x 2048</td>
<td>53 x 53</td>
<td>Mug10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.25 (7)</td>
<td>STTe TK1024 (CTK)</td>
<td>1024 x 1024</td>
<td>38 x 38</td>
<td>Mug09</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.25 (8)</td>
<td>E2V CCD47-10 (CTK-II)</td>
<td>1056 x 1027</td>
<td>21 x 20</td>
<td>Mug11a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.20</td>
<td>Kodak KAF-0402ME (RTK)</td>
<td>765 x 510</td>
<td>8 x 5</td>
<td>Mug11b</td>
</tr>
<tr>
<td>S. Nevada/Spain</td>
<td>3.4</td>
<td>37.1</td>
<td>1.50</td>
<td>EEV VersArray:2048B</td>
<td>2048 x 2048</td>
<td>8 x 8</td>
<td></td>
</tr>
<tr>
<td>Calar Alto/Spain</td>
<td>2.5</td>
<td>37.2</td>
<td>2.20 (9)</td>
<td>STTe1d (CAFOS)</td>
<td>2048 x 2048</td>
<td>16 x 16</td>
<td>(10)</td>
</tr>
<tr>
<td>Armazones/Chile</td>
<td>70.2</td>
<td>24.6</td>
<td>0.15</td>
<td>Apogee U16M KAF-16803</td>
<td>4096 x 4096</td>
<td>162 x 162</td>
<td>(11)</td>
</tr>
<tr>
<td>CIDA/Venezuela</td>
<td>70.9</td>
<td>8.8</td>
<td>1.00</td>
<td>Quest-I CCD Mosaic</td>
<td>8000 x 8000</td>
<td>138 x 138</td>
<td>Ba02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.00 (5)</td>
<td>FLI ProLine E2V42-40</td>
<td>2048 x 2048</td>
<td>19 x 19</td>
<td></td>
</tr>
<tr>
<td>Stony Brook/USA</td>
<td>73.1</td>
<td>40.9</td>
<td>0.37</td>
<td>SBIG ST1001E KAF-1001E</td>
<td>1024 x 1024</td>
<td>17 x 17</td>
<td></td>
</tr>
<tr>
<td>Swarthmore/USA</td>
<td>75.4</td>
<td>39.9</td>
<td>0.62</td>
<td>Apogee U16M KAF-16803</td>
<td>4096 x 4096</td>
<td>26 x 26</td>
<td></td>
</tr>
<tr>
<td>Gettysburg/USA</td>
<td>77.2</td>
<td>39.8</td>
<td>0.40</td>
<td>STTe 003B</td>
<td>1024 x 1024</td>
<td>18 x 18</td>
<td>(12)</td>
</tr>
<tr>
<td>Tenagra II/USA</td>
<td>110.5</td>
<td>31.3</td>
<td>0.81</td>
<td>STTe SI003 AP8p</td>
<td>1024 x 1024</td>
<td>15 x 15</td>
<td></td>
</tr>
<tr>
<td>Mauna Kea/Hawaii</td>
<td>155.5</td>
<td>19.8</td>
<td>2.20</td>
<td>8 CCD chips for mosaic</td>
<td>8 x 2048 x 4096</td>
<td>33 x 33</td>
<td></td>
</tr>
</tbody>
</table>

Remarks: (1) Listed are only those, from which we have obtained (or proposed) photometric monitoring data so far; (2) www.astron.pref.gunma.jp/e/inst_ldsi.html; (3) 0.60m in Schmidt mode; (4) www.nao-rozhen.org/telescopes.fr_en.htm; (5) with focal reducer; (6) 0.50m in Schmidt mode; (7) until July 2010; (8) since August 2010; (9) by open time observing proposals; (10) www3.caha.es/CAHA/Instruments/CAFOS/overview.html; (11) www.astro.ruhr-uni-bochum.de/astro/oca/vysos6.html; (12) www3.gettysburg.edu/~marschal/clea/obshome.html.

Ref.: Mug09 - Mugrauer 2009; Mug10 - Mugrauer & Berthold 2010; Mug11a,b - Mugrauer 2011a,b (in prep); Wu07 - Wu et al. 2007; Ba02 - Baltay et al. 2002.

et al. 2009), for which we have recently obtained follow-up optical and infrared spectra with the ESO VLT (Seeliger 2011). We also applied this technique very successfully by combining co-added optical I-band data of \( \sim 180 \) square degrees across the Orion OB1 region, with 2MASS JHK data (Downes et al. 2008; Downes et al., in preparation), to identify several thousand young very low-mass stars and brown dwarfs, for many of which we have confirmed membership through follow-up spectroscopy (Downes et al., in preparation).

Co-added individual frames from the larger telescopes will also provide a more sparsely sampled, but much deeper time series, which will allow us to carry out systematic variability studies amongst the young brown dwarfs of the YETI target clusters.

Similar studies can be done for all clusters observed by YETI. Such a study can reveal the very low-mass population including massive brown dwarfs, i.e. the low-mass end of the mass function. We can re-determine cluster distance, age, and mass function based on a larger set of photometric and spectroscopic data obtained for a larger sample of...
the high-pressure phase diagram, nonmetal-to-metal transitions, and demixing phenomena which are important for interior models.

Based on these results, we have determined the structure of giant planets and calculated their cooling history: Jupiter (Nettelmann et al. 2008), the hot Neptune GJ436b (Nettelmann et al. 2010; Kramm et al. 2011), and for Uranus and Neptune (Fortney & Nettelmann 2010; Redmer et al. 2011).

Within the YETI project we plan to develop interior models especially for young planets that are detected within the observational campaigns. Then, we can study the formation and early evolution of giant planets.

6 First results for Trumpler 37

The open cluster Trumpler 37 (Tr-37), first studied by Trumpler (1930) and Markarian (1952), is embedded in the HII region IC 1396, and is the nucleus of the Cep OB2 association (Simonson 1968). The V = 4 mag M2Ia super-giant μ Cep is a probable member of the cluster, but outside of the Jena FoV (and outside the mosaic in Fig. 1). Comparison of the Tr-37 main sequence to that of Upper Scorpius yielded a distance modulus of 9.9 to 10 mag, i.e. ~ 1000 pc (Garrison & Kormendy 1976); from the MS life-time of the earliest member, the O6e type star HD 206267 (V = 5.6 mag), they conclude an age of 2 to 4 Myr. Marschall & van Altena (1987) studied the proper motions of ~ 1400 stars within 1.5° of HD 206267 down to V = 15 mag and found ~ 500 kinematic members. Marschall et al. (1990) then determined the age of the cluster by the MS contraction time of those members which just have reached the zero-age main-sequence (ZAMS), to be ~ 6.7 Myr; later, an age range from 3 to 10 Myr was considered (Contreras et al. 2002; Sicilia-Aguilar et al. 2004a, 2005). The current best age estimate is ~ 4 Myr (Kun, Kiss, Balog 2008), and the latest distance estimate is 870 ± 70 pc (Contreras et al. 2002).

A three-color BVR composite image of the Tr-37 cluster obtained with the STK CCD camera at the Jena 60-cm Schmidt telescope is shown in Fig. 1.

A total of 732 members or member candidates of the cluster were found by Hα emission, ZAMS or pre-MS location, Lithium absorption, X-ray emission, infrared excess emission, proper motion or radial velocity (Marschall & van Altena 1987; Marschall et al. 1990; Contreras et al. 2002; Sicilia-Aguilar et al. 2004a,b; Sicilia-Aguilar et al. 2005; Sicilia-Aguilar et al. 2006a,b; Mercer et al. 2009). Some of the candidates may not be members, e.g. stars with either radial velocity or proper motion consistent with membership, but no or very weak Lithium absorption, while true members may still be missing, e.g. faint very low-mass members. We are taking low- and high-resolution spectra of hundreds of stars in YETI ~ 1° × 1° FoV with MMT/Hectochelle, in particular of suggested but uncertain member candidates, in order to confirm or reject them as members based on radial velocity and Lithium absorption (Errmann et al., in prep.).
A BVR three-color composite image of the Tr-37 cluster as observed with STK at University Observatory Jena in July 2009. The image is a mosaic of nine STK images, each the composite of three 60s integrations taken in the B-, V-, and R-band. The total FoV shown is $2.1\degree \times 2.1\degree$ (north is up, and east to the left). The central dashed box indicates the STK $53' \times 53'$ FoV monitored in Jena only in 2009 and with the YETI consortium in 2010.

We present here preliminary results including a few exemplary light curves from the 2009 data, obtained in Jena only with the 90/60-cm telescope. In 2009, we observed only from Jena. The observations log from 2009 (Jena only) is given in Table 3. Only in Fig. 6, we also show a preliminary light curve from the 2010 campaign. In addition, in Fig. 7, we show a spectrum obtained with the Jena 90-cm telescope and a fiber-fed spectrograph; we can take spectra of bright stars (90-cm mirror) also simultaneously with optical CCD photometry with the small 25-cm telescope, which can be quite interesting for variable young active stars. The Tr-37 was observed for three runs in 2010 and will also be observed for three runs in 2011 and 2012 by most telescopes of the network. Final results including follow-up observations will be presented later.

Basic data reduction of the Jena data from 2009 shown in the figures here includes bias, dark, flat-field, illumination, and bad pixel corrections. Relative photometry follows the procedure described in Broeg et al. (2005): We compare each star in the FoV with all other stars to investigate its variability, then we construct an artificial comparison star, then iterate by giving variable stars less weight; the final artificial comparison star is then very constant. We do this not only for one particular program star, as in Broeg et al.
Fig. 7 An optical spectra of HD 206267A+B (together), C, and D all obtained with the FIASCO spectrograph at the Jena 90-cm telescope on 2010 June 7, shown together with template spectra (O5 star HD 93250 and B0V star HD 36512 from Le Borgne et al. 2003). The spectrum of HD 206267A+B is consistent with a spectral type of O6 (as in Simbad and Sota et al. 2011), and the spectra of both HD 206267 C and D are consistent with a spectral type of B0V (as in Simbad and Sota et al. 2011); HD 206267A+B as well as C and D show Hα and He absorption as well as diffuse interstellar absorption bands and telluric oxygen.

(2005), but for all stars in the field. For details, see Broeg et al. (2005). Finally, we also test de-trending (Tamuz, Mazeh, Zucker 2005).

Periodic variability can then be detected by typical period search procedures like Stringlength, Lomb-Scargle, or Fourier analysis (see e.g. Berndt et al. 2011 for rotation periods of members of Tr-37). We are currently implementing a Bayesian transit detection routine (Hambaryan et al., in prep.) to search for the exact type of the signal (planetary transit), even if not strictly periodic, as in the case of TTV signals or very long periods (so that only one transit is observed).

The first few planetary transit observations with a 25-cm telescope of the University of Jena Observatory near the village of Großschwabhausen near Jena of the objects TrES-1, TrES-2, and XO-1 (Raetz et al. 2008; Vaño et al. 2008; Raetz et al. 2009a, 2009b) show that transits can be detected from the Jena observatory, but they do not prove that we can find new transiting planets. Since early 2009, we also use the 90-cm mirror of the Jena observatory in its 60-cm Schmidt mode (53′ × 53′ FoV) with the CCD called Schmidt-Teleskop-Kamera (STK), see Mugrauer & Bertold (2009) for details. With that telescope and camera, we could also re-detect known planetary transits with a precision of ~ 1 mmag rms scatter and ±27s transit timing precision (Maciejewski et al. 2010, 2011a).

We reached 5 mmag rms precision for all un-saturated stars down to R=14.5 mag with the Jena 90-cm telescope in the 60-cm Schmidt mode (see Fig. 5). For the other telescopes of the network with similar mirror size and similar CCD detectors, we can reach a similar precision: 50 mmag rms down to R=17.7 mag for Byurakan 2.6m, as well as down to R=17.8 mag for Lulin 1m, down to R=15.4 mag for Swarthmore 0.6m, and to R=16.9 mag for Xinglong 0.9m; also 5 mmag rms down to R=14.9 mag for Byurakan 2.6m, as well as down to R=15.4 mag for Lulin 1m, and down to R=13.4 mag for Swarthmore 0.6m: the data for the other telescopes are still being reduced.

We show a few preliminary results in figures 2 to 6: Light curves from the 2009 monitoring only at the Jena telescope, e.g. a 3.5 day rotation period of a classical T Tauri star (Fig. 3) - but also light curves with obvious gaps (e.g. Fig. 4), motivating the collaboration with many other observatories (YETI). We show the sensitivity obtained with
Fig. 3  Phase-folded R-band light curve from Jena STK data from July to Nov 2009 for the star 2MASSJ21353021+5731164. The error bar in the lower left is the typical (mean) photometric error. The star is a classical T Tauri member of Tr-37 with spectral type K6 according to optical spectra (Sicilia-Aguilar et al. 2005, 2006b). We find R=15.8 mag and V=16.9 mag, consistent with K6, and a rotation period of $\sim 3.5$ days, it has a relatively large peak-to-peak amplitude of $\Delta R \simeq 0.5$ mag, which has been observed also in a few other classical T Tauri stars before.

Fig. 4  R-band light curve from Jena STK data from July to Oct 2009 for the star MVA 1312, spectral type B4 (Contreras et al. 2002, Sicilia-Aguilar et al. 2005), it has a proper motion membership probability of 0.84 (Marschall & van Altena 1987). The observing date is given in JD since 2009 June 17. The error bar in lower left is the typical (mean) photometric error. We find R=10.6 mag and V=10.3 mag, consistent with early B. The star shows variability on short (nightly) and longer time-scales (days to weeks), but we also have strong gaps in the light curve from one observatory (Jena). This shows the need for continuous monitoring.

Fig. 5  Photometric precision achieved (in mag) versus apparent photometric brightness (in mag in R-band with Jena 90/60-cm telescope in the night 2009 Sept 9/10) with 6762 stars in the Tr-37 field. A precision of better than 50 milli-mag rms (sufficient to detect transits) is achieved for all stars brighter than 16.5 mag, and a precision of 5 milli-mag rms for all stars brighter than R=14.5 mag.

the Jena 90/60-cm in Fig. 5. In Fig. 6, we show a preliminary light-curve with data combined from several telescopes from the 2010 Tr-37 campaign. We also show a spectrum obtained with the 90-cm telescope in Jena (Fig. 7), namely for the brightest member of Tr-37 (HD 206267), together with a light curve for this star with high time resolution with 5s exposures (Fig. 8). In Fig. 9, we show the light curve for an apparently non-variable member star ($\pm 2.7$ mmag). We also found a few new eclipsing binaries, both member candidates and field stars. For the member candidates, low-resolution spectra have been obtained at Calar Alto with CAFOS, see below, to confirm membership; high-resolution spectra were obtained at Keck with HIRES to measure the masses of the companions (Errmann et al., in prep.). Since the FIASCO spectrograph at the 90-cm Jena telescope is useful only down to about 11th mag, we also use the Calar Alto 2.2m/CAFOS for low-resolution and the 1.5m Tillinghast Reflector for high-resolution spectra.

The optical spectra of HD 206267A+B (V=5.6 mag), C (V=8.1 mag), and D (V=7.9 mag) were obtained with the fiber-fed spectrograph FIASCO (Mugrauer & Avila 2009) operated at the Nasmyth port of the 90cm telescope of the University Observatory Jena. The data were taken on 2010 June 7, using three exposures with 600s exposure time each for HD 206267 A+B and four such 600s exposures for HD 206267 C and D. Standard calibration was done (dark and flat-field correction, removal of bad pixels). Flux correction was performed by using a Vega spectrum from the same night and airmass, standard spectra are from Le Borgne et al. (2003). The de-reddened spectrum of HD 206267A+B is consistent with a spectral type of O6 (as in Simbad and Sota et al. 2011) and the spectra of HD 206267 C and D show spectral type B0V (as in Simbad and Sota et al. 2011),
A preliminary light curve of an eclipsing star in the Tr-37 field phased to a 6.005 day orbital period. Data from Jena are shown as red and green diamonds (for 10s and 60s exposures, respectively). From Jena alone, we could not fully cover the secondary (shallower) eclipse (phase 0.5). The bars on the figure top show the phases covered from Jena. The other (colored) symbols show the data from four other telescopes: Brown plusses from Byurakan/Armenia (60s), pink crosses from Xinglong/China (10s), grey stars from Swarthmore/USA (60s), and pink circles from Lulin/Taiwan (10s). This example shows how important it is to cover all longitudes on Earth, hence the YETI telescope network. Follow-up spectroscopy has shown that this star is a double-lined spectroscopic binary. This particular star is probably not a young member of the Tr-37 cluster, but follow-up observations are still ongoing. Final results will be reported later in Ermann et al. This figure shows that we can successfully combine data from different telescopes with different CCDs and different ambient conditions.

all spectra show Hα and He absorption as well as telluric oxygen, all as expected.

For transit candidates, i.e. stars showing a light curve with periodic, small, transit-like, flat-bottom dips, we will do the usual follow-up observations: First, a high-precision photometric light curve is obtained with a larger telescope to confirm that the dip is consistent with a planet transit, i.e. shows a flat-bottom light curve. Then, low- to high resolution spectroscopic reconnaissance spectra are taken, e.g. with the 2.2 Calar Alto CAFOs spectrograph or the 1.5m Tillinghast Reflector at the Whipple Observatory, the latter giving a resolution of 6.5 km/s down to V=14 mag. If the object is still not found to be a binary star, then we obtain high-angular resolution follow-up imaging with Adaptive Optics (AO, large telescope mirror, small PSF, e.g. Subaru) to check whether there are background eclipsing binaries in the larger optical PSF (from imaging photometry with a smaller telescope mirror), which could mimic a transit-like periodic event. Then, we can also consider to obtain high-resolution infrared spectra, to check for background eclips-
ing binaries even closer to the target star, i.e. within the AO PSF (not yet done). If the transit-like event can still only be explained by a sub-stellar object transiting the star, then the last follow-up observation is time-critical high-resolution spectroscopy, to measure the mass of the transiting companion. With the RV data, we can then also use the Rossiter McLaughlin effect to show that a body of small radius orbits the observed star, excluding a faint eclipsing binary hidden in the system PSF.

We have done most of those follow-up observations so far for one transit candidate (Errmann et al., in prep.). This first candidate was detected in the 2009 data of the Jena 90/60-cm telescope only. Hence, after combining the data from all telescopes from the 2010 campaign, we can expect to detect several more candidates.

We will report results of the photometric monitoring campaigns and the follow-up observations in the near future.

### 7 Summary

We presented the motivation, observing strategy, target cluster selection, and first results of the new international multi-site project YETI with its main goal being the discovery and study of young exoplanets. The photometric precision is 50 mmag rms down to R=16.5 mag (5 mmag rms down to R=14.5 mag, both values for Jena 90/60-cm, similar brightness limit within about ±1 mag also for the other telescopes of the network), i.e. sufficient to detect planetary transits. We use several telescopes around the world to observe continuously for 24h per day for several days in order not to miss a transit.

For young transiting exoplanets, we can determine mass and radius, hence also the density and possibly the internal structure and composition. With young exoplanets, one can constrain planet formation models, e.g. whether they form by gravitational contraction (disk instability) or by core accretion (nucleated instability), during which time-scale and at which separations from the star planets can form. By comparing different planets found within one cluster, one can determine the role of stellar parameters like mass on planet formation; by comparing the planetary population between the different clusters, we can study the impact of environmental conditions on planet formation like metallicity and density of the cluster.

**Acknowledgements.** All the participating observatories appreciate the logistic and financial support of their institutions and in particular their technical workshops. We would like to thank DFG for support in the Priority Programme SPP 1385 on the First ten Million years of the Solar System in projects NE 515 / 34-1, NE 515 / 33-1, and NE 515 / 35-1. RN, GM, TP, and MV would like to thank the European Union in the Framework Programme FP6 Marie Curie Transfer of Knowledge project MTKD-CT-2006-042514 for support. SF thanks the State Framework Programme FP6 Marie Curie Transfer of Knowledge project MTKD-CT-2006-042514 for support. SF thanks the State Framework Programme FP6 Marie Curie Transfer of Knowledge project MTKD-CT-2006-042514 for support. SF thanks the State Framework Programme FP6 Marie Curie Transfer of Knowledge project MTKD-CT-2006-042514 for support. SF thanks the State Framework Programme FP6 Marie Curie Transfer of Knowledge project MTKD-CT-2006-042514 for support. SF thanks the State Framework Programme FP6 Marie Curie Transfer of Knowledge project MTKD-CT-2006-042514 for support. SF thanks the State Framework Programme FP6 Marie Curie Transfer of Knowledge project MTKD-CT-2006-042514 for support.
DFG for financial support for a Keck run in project NE 515 / 42-1. ELNJ and his colleagues from Swarthmore acknowledge support from the US National Science Foundation grant, AST-0721386. Osservatorio Cerro Armazones (OCA) is supported as a project of the Nordrhein-Westfälische Akademie der Wissenschaften und der Künste in the framework of the academy program by the Federal Republic of Germany and the state Nordrhein-Westfalen. ZYW is supported by the National Natural Science Foundation of China, No. 10803007. JB, TP, and MV thank VEGA grants 2/0094/11, 2/0078/10, 2/0074/09. DPD, DPK, and VSR would like to acknowledge financial support to the National Science Foundation of the Bulgarian Ministry of Education and Science (project DO 02-362). We used Simbad, ViziR, 2MASS, and WEBDA. We would like to thank an anonymous referee for good suggestions.

References

Broeg, C., Fernandez, M., Neuhauser, R., 2005: AN 326, 134
Eisenbeiss, T., Moualla, M., Mugrauer, M., et al., 2009: AN 330, 439
Sicilia-Aguilar, A., Hartmann, L.W., Hernandes, J., Briceño, C., Calvet, N., 2005: AJ 130, 188
Sicilia-Aguilar, A., Hartmann, L.W., Füresz, G., Henning, T., Dullemond, C., Brandner, W., 2006b: AJ 132, 2135
Trumpler, R.J., 1930: Lick Obs. Bull. 14, 420
Výško, M., Raetz, St., Mugrauer, M., et al., 2008: ASP Conf. Series. IAU Symp. 253, 440
Wolszczan, A., 1994: Science 264, 538