Direct imaging search for planetary companions next to young nearby stars

Ralph Neuhäuser
MPI Extraterrestrische Physik, D-85740 Garching, Germany

E. Guenther
Thüringer Landessternwarte Tautenburg, D-07778 Tautenburg, Germany

W. Brandner
University of Hawaii, Institute for Astronomy, Honolulu, USA

N. Huéamo, T. Ott
MPI Extraterrestrische Physik, D-85740 Garching, Germany

J. Alves, F. Comerón
European Southern Observatory, D-85748 Garching, Germany

A. Eckart
Universität Köln, Germany

J.-G. Cuby
European Southern Observatory, Chile

Abstract. We report first results from our ground-based infrared imaging search for sub-stellar companions (brown dwarfs and giant planets) of young (up to 100 Myrs) nearby (up to 75 pc) stars, where companions should be well separated from the central stars and still relatively bright due to ongoing accretion and/or contraction. Among our targets are all members of the TW Hya association, as well as other binary and single young stars either discovered recently among ROSAT sources (some of which as yet unpublished) or known before. Our observations are performed mainly with SOFI and SHARP at the ESO 3.5m NTT on La Silla and with ISAAC at the ESO 8.2m Antu (VLT-UT1) on Cerro Paranal, all in the H- and K-bands. We present direct imaging data and H-band spectroscopy of a faint object detected next to TWA-7 which, if at the same age and distance as the central star, could be an object with only a few Jupiter masses. Our spectrum shows, though, that it is a background K-dwarf.
1. Introduction

Despite extensive imaging surveys, only a few sub-stellar companions to normal stars were detected already by direct imaging: Gl 229 B (Nakajima et al. 1995, Oppenheimer et al. 1995), G196-3 B (Rebolo et al. 1998), and Gl 570 D (Burgasser et al. 2000), brown dwarf companions confirmed by spectroscopy and proper motion. Three more candidates were presented: GG Tau Bb (White et al. 1999), HR 7329 B (Lowrance et al. 2000), and CoD−33°7795 B (Lowrance et al. 1999), but spectroscopy and/or proper motion were not available so far. Most recently, Neuhäuser et al. (2000b) have shown that CoD−33°7795 B has spectral type M8.5 to M9 with an optical and an infrared spectrum, both taken with the VLT, and that it is co-moving with star A, after two years epoch difference with 5σ significance. The extra-solar planet candidate directly detected by the HST near a T Tauri star in Taurus (Terebey et al. 1998) has not yet been confirmed by spectroscopy (Terebey et al. 2000).

Several extra-solar planet candidates have been detected indirectly by radial velocity variations of stars (Latham et al. 1989, Mayor & Queloz 1995, etc, see review by Marcy & Butler 1998), one such candidate is confirmed by a transit event (Charbonneau et al. 2000). There is no direct imaging detection of an extra-solar planet, yet. Direct imaging detection of planets like those in our solar system but orbiting other stars is difficult due to the limited dynamical range: Extra-solar planets are simply too faint and too close to their bright host stars. One can try to avoid the problem of spatial resolution by searching for planetary companions around nearby stars, where the orbit of the outermost solar system planet corresponds to several arcsec, sufficient to resolve a faint object next to a bright star. However, very nearby stars usually are too old, so that their hypothetical planets (like e.g. our Jupiter) are correspondly too faint for direct detection with current technology.

Young planets, on the other hand, are still self-luminous due to on-going accretion and/or contraction (Burrows et al. 1997, Brandner et al. 1997, Malkov, Piskunov & Zinnecker 1998) and, if also nearby, they would be sufficiently bright and resolved for direct detection. Direct imaging of these young planets is optimal at the near-infrared bands H and K, where the brightness difference between young stars and young planets is expected to be the lowest (Burrows et al. 1997) and where also the seeing is better than in the optical. In addition, nearby stars usually have large proper motion, so that one can decide after only a few years whether a companion candidate is co-moving. Finally, there is a crucial advantage in studying companion planets candidates instead of free-floating planet candidates: The mass can be better constrained for companions than for free-floating planets, because age and distance of the primary is usually well-known.

2. Our sample: Young nearby stars

We selected young (≤ 100 Myr) nearby (≤ 75 pc) stars, some of them from the literature, others discovered recently among ROSAT sources by ourselves (some of these as yet unpublished). We are confident on the young age of our sample of stars because of Lithium 6708Å absorption lines (and/or Hα emission, IR excess and/or kinematic membership to a young cluster). We know the distances
of most target stars from Hipparcos (and for some of them, from kinematic membership to a cluster with known distance). Our target list includes all members of the TW Hya association (TWA), the T Tauri stars in the nearby and even younger MBM 12 cloud (Hearty et al. 2000a,b), the members of the more recently discovered Tucanae (Zuckerman & Webb 2000) and HorA moving groups (Torres et al. 2000), as well as isolated young stars like GJ 182.

Because we know the distances and ages of the stars in our sample, we can predict the H- and K-band magnitudes of possible substellar companions for different masses, e.g. from 1 to 80 $M_{\text{jup}}$, using the non-gray theory by Burrows et al. (1997). In Figure 1, we present the H-band magnitudes of the program stars (either known from infrared photometry, or estimated from their known spectral types and optical magnitudes), their distance distribution, the corresponding angular separation between those stars and possible companions at assumed 50 AU physical separations, and the K-band magnitude distribution of assumed $\sim 10 M_{\text{jup}}$ mass companions (estimated from Burrows et al. (1997) for the known ages and distances of the stars). These distributions clearly show that such companions can be detectable and resolvable with current technology.

Hence, we have started an observational program using mainly the SOFI and SHARP infrared cameras at the ESO-3.5m-NTT on La Silla, and the ISAAC imaging camera at the ESO-8.2m-Antu (VLT-UT1), but also other state of the art instruments.
3. First results: Case study TWA-7

Using the MPE-build SHARP speckle camera, we have detected a very faint object 2.5 arcsec south-east of the young nearby star T Tauri TWA-7, a member of the TW Hya association (called TWA, see Webb et al. 1999). Four stars of the TWA association have been observed by Hipparcos, their mean distance being 55 pc. By comparison with isochrones, we obtain an age of 1 to 6 Myr (Neuhäuser et al. 2000a).

The faint object TWA-7B detected by SHARP, 2.5 arc sec south-east of TWA-7A has $H = 16.4$ and $K = 16.3$ mag, which is more than 9 mag fainter than the primary star at these wavelengths. If TWA-7B were to be a companion to TWA-7A, i.e. if it were to be at the same distance and age, then its apparent H- and K-band magnitudes would correspond to absolute magnitudes (at 55 pc) consistent with an effective temperature $T_{\text{eff}} \simeq 1050$ K and a surface gravity $\simeq 3000$ g/s$^2$ (see table 5 in Burrows et al. 1997). These values are then consistent with an object with a mass of $\sim 3M_{\text{jup}}$ and an age of $\sim 10^{6.5}$ yr (see Figure 9 in Burrows et al. 1997). This derived age is in agreement with the ages of TWA-7A and the other TWA members. The angular separation of 2.5 arc sec (at a distance of 55 pc) corresponds to a physical separation of 138 AU, well within typical T Tauri disk sizes.

TWA-7B has previously been detected by HST Nicmos observations in the F160W, F090M, F165M, and F180M filters. The HST F160W image has been shown in Neuhäuser et al. (2000a), where a coronograph has been used as in the F165M and F180M images. Only in the F090M image with NIC1, no coronograph was used. See Neuhäuser et al. (2000a) for the HST magnitudes, the position angles between TWA-7A and B, and more details on data reduction.

Confirmation of the possibly substellar nature of TWA-7B by spectroscopy is required. To check for a possible spectral signature of a very cool object we took an H-band spectrum of TWA-7B using ISAAC at the ESO-8.2m-Antu (VLT-UT1). In fact, the derived temperature of $\sim 1050$ K for TWA-7B (if indeed a companion) is similar to those of known old T-dwarfs, so that one might, under some conditions, expect to see methane absorption features in the spectrum of TWA-7B. The technical problem with taking and analysing a spectrum of such a faint object so very close ($\sim 2.5$ arcsec) to a much brighter star (contrast $\sim 10^4$) is again dynamical range. To maximize both the separation between TWA-7B and A and also the fraction of the light coming from TWA-7B, we placed the slit neither along both stars (i.e. along their Position Angle (PA)), nor perpendicular to this PA (with only B in the slit). In the latter case, the signal from B would be on top of the dominant signal from TWA-7A scattered light in the collapsed spectrum (zero separation). In the former case (maximum separation), the light from TWA-7A would have “swamped” the signal from TWA-7B. We used, instead, a slit orientation in between those two extremes.

We modelled the flux of TWA-7A at each wavelength and then subtracted it from TWA-7B. The spectrum of TWA-7B is shown in Figure 2. TWA-7B turned out to be of spectral type K. This means that, given its brightness, TWA-7B cannot be at the same small distance as TWA-7A (55 pc) and it is most likely a background K-type main sequence star. Given that it is a faint source ($H = 16.4$ mag), this K dwarf should be at a distance between $\sim 2$ and 4 kpc, in the halo.
Figure 2. Our ISAAC H-band spectrum of TWA-7B showing that it has spectral type K, i.e. that it is a background object.

of our galaxy ($b = 21^\circ$). Curiously, the probability of finding a background object as faint as TWA-7B within a 2.5 arcsec radius circle in the sky, towards this direction of the Galaxy, is about 1%. This shows how important it is to take spectra of companion candidates.

4. Summary

We show that ground-based direct imaging detection of extra-solar planets is in principle possible. As an example, we present the detection of a very faint object ($H = 16.4$, $K = 16.3$ mag, i.e. $\sim 9.5$ mag fainter than a nearby young star), which could have been a few Jupiter-mass giant extra-solar planet, given its brightness and color, and given the fact that it is located very close to a young star. At the age and distance for this star, this faint object could have been the first direct imaging detection of an extra-solar planet. However, our H-band spectrum shows that it is likely to be a background K-dwarf. We demonstrate, nevertheless, that spectroscopic observation of such a faint object that close to a brighter star (contrast $\sim 10^4$) is possible with current technology from ground-based telescopes.

We are now living in very special times, where we are starting to be able to directly image extra-solar planets and obtain their spectra. We believe that the first direct imaging detection of an extra-solar planet is imminent. For achieving this goal, a large-scale survey is essential.

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