Planets of young stars: the TLS radial velocity survey

M. Esposito\textsuperscript{1,2}, E. Guenther\textsuperscript{1}, A.P. Hatzes\textsuperscript{1}, M. Hartmann\textsuperscript{1}

\textsuperscript{1}Th"uringer Landessternwarte Tautenburg, Sternwarte 5, 07778 Tautenburg, Germany

\textsuperscript{2}Dipartimento di Fisica “E.R. Caianiello”, Universit`a di Salerno, via S. Allende, 84081 Baronissi (Salerno), Italy

Abstract. We report on the search for planets orbiting 46 nearby young stars performed at the State Observatory of Turingia (TLS) by means of a radial velocity survey. The aim of this program is to test the theories of formation/evolution of planetary systems. For 19(8) stars we can exclude planets with $M \sin i \geq 1 \, M_J$ (5 $M_J$) and $P \leq 10$ days; we find 1 short period binary and 5 stars with long period RV-trend. One good young exo-planet candidate is presented.

1. Introduction

In the last ten years, thanks to high precision radial velocity (RV) measurements, more than 100 extrasolar planets have been found. The most important observational campaigns up to now have focused on old solar type stars because such stars present all the characteristics (small $v \sin i$, high number of spectral lines, low activity) to exploit the best potentialities of the RV technique.

The orbits of the extra-solar planets are strikingly different from those of our solar system: some of them have massive planets of extremely short orbital periods (so called “hot Jupiters” or “Pegasides”), while others exhibit very high eccentricities. These results have given a new strong impulse to the theoretical efforts to explain the formation and evolution of planetary systems. However, even the most fundamental questions are still open. How common are planetary systems? How do planets form? By core accretion or by gravitational instability in the disk. Where do they form? Close-in Jupiter mass planets can form
in situ, or do they have to form at a certain distance and then migrate inward? New insights should come from the determination of the orbital parameters for planets in early evolutionary phases. According to some scenarios the frequency of planets was initially much higher than is observed in old stars, as a substantial fraction of the planets might have been either ejected from the system, or have been engulfed in the host stars. Since capture of planets is highly unlikely, the frequency of planets of young stars ought to be higher than that of old stars. The aim of this survey is to find out by how much. Another issue we could address concerns the evolution of the orbital parameters. In particular it would be important to know whether close-in planets have round orbits when they form or eccentric orbits, which then get circularised by tidal interaction with the host star.

There is an additional reason for searching for planets of young stars. As pointed out by Sudarsky, Burrows, & Hubeny (2003) even old exo-planets orbiting a solar-like star at 0.1 AU would have a temperature of up to 900 K, because they are heated by the star. A massive, isolated planet with an age between $10^7$ to $10^8$ yrs would also have a temperature of more than 800 K but this time because it is still contracting. For close-in young planets both effects would add up resulting in objects of spectral type early L or even late M, which would be only 5 to 7 mag fainter than the host star. The direct detection of these objects, especially in the infrared light, would be possible by means of interferometric observations as well as tracking down spectral signatures, giving access to fundamental parameters like temperature, radius and true masses.

The presence of spots and/or plages in the photosphere of active stars changes the profile of spectral lines causing fictitious variations in the RV measurements (the so-called jitter). Not only this source of noise can mask the periodical variations which are the characteristic signature of the presence of a planet, but what makes it even worse is the fact that the presence of spots combined with the stellar rotation can itself introduce spurious periodicities in the radial velocity signal. This explains why young stars, which are supposed to be active, have so far been excluded from the major RV surveys for planets detection. However Paulson et al. (2002) monitored 82 stars in the Hyades (age $\sim$ 700 Myr) finding a significant correlation between simultaneous RV and $R_{HK}$ for only 5 stars. Indeed exactly to what extent the stellar activity can hinder the detection of exoplanets in RV measurement has not yet clearly assessed.

Weighing pros and cons we finally decided to undertake a RV survey of young stars.
2. The TLS radial velocity survey

Observations began in 2001. We monitored a sample of 46 young, nearby dwarf stars of late spectral type and took 1500 spectra of these up to now.

2.1 The instrumental setup

The observations have been carried out at the State Observatory of Turingia (TLS) using the 2m “Alfred Jensch” telescope which is equipped with a Coudé echelle spectrograph. We used the visual grism which cover the spectral region from 4660 to 7410 Å in 44 orders. With a slit width of 1.2 arcsec a resolution of $R = 67000$ is achieved. An iodine cell placed in front of the slit generates a very dense system of absorption lines superimposed onto the stellar spectrum, which provides a highly precise wavelength scale and at same time allows to measure the PSF in situ over the spectrum. Radial velocities (RV’s) are measured by means of a software package called RADIAL developed at the University of Texas and McDonald Observatory, based on the methods described in Marcy & Butler(1992) and Valenti, Butler & Marcy(1995).

2.2 Characterisation of the sample

The identification of bona-fide young post-T-Tauri stars near the Sun still is an open astrophysical issue (Jensen 2001). Recently many nearby associations of young stars have been recognised: TWA, β Pic, Tucana-Horologium, η Cha, AB Dor (Zuckermann & Song 2004). For such coeval stellar groups statistics considerations help to achieve reliable estimations of the common age. Unfortunately all those associations are located in the Southern hemisphere. Thus in selecting the sample of stars to survey we did the Hobson’s choice and looked out for young ‘field’ stars.

One of the best indicators of young age, especially for G and K stars, is the presence of the lithium Liλ6708 absorption line. The convective envelope of these stars brings the lithium in contact with the stellar core where the temperature is high enough to cause its burning. As a consequence the lithium in the stellar atmospheres is progressively depleted. The lithium abundances can thus be used as an age estimator. Fig.1 shows the Liλ6708 equivalent width (EW) as a function of the $T_{\text{eff}}$ for the stars in our sample and, as a comparison, for the Pleiades (age $\sim$ 100 Myr). As can be seen for the stars of Pleiades, the Liλ6708 EW scatters significantly for the same $T_{\text{eff}}$. Thus it is not possible determine the age for every single star in our sample precisely. Rather, in a schematic way, we can subdivide our sample in two groups, one having ages comparable to the Pleiades and the other consisting of older
Figure 1: Plot of the LiI$\lambda$6708 vs log$T_{\text{eff}}$ for the TLS sample and, as a comparison, for the Pleiades. Most of the star surveyed have ages comparable to the Pleiades ($\sim 100$ Myr); the clump with $3.65 < \log T_{\text{eff}} < 3.75$ and EW $< 50$ mÅ is probably made of $300 \div 500$ Myr old stars (see text).

stars. In fact, many stars in the latter group have been recognised as members of the Ursa Major association which is 300 Myr old (Soderblom & Major 1993) (500 Myr according to King & Schuler 2005).

Based on the Hipparcos parallaxes all our stars are at a distance of less than 50 pc from the Sun, and 36 of them are closer than 30 pc. Accordingly, they are relatively bright, ranging from the fifth to the ninth visual magnitude.

3. Analysis of the data
3.1 Internal errors

Fig. 2 (left panel) shows the average internal errors $\sigma_{\text{int}}$ in the RV's as a function of the projected stellar rotational velocity $v \sin i$. As expected for rapidly rotating stars, the spectral lines broadening makes it difficult to achieve high precision RV values. However, up to a $v \sin i \leq 10$ km/s, we routinely get internal errors of 10 to 15 m/s.

![Figure 2: (left) Plot of the average internal errors $\sigma_{\text{int}}$ as a function of the stellar rotational velocity $v \sin i$. (right) $\sigma_{\text{RV}}$ vs $v \sin i$; see the text for the definition of $\sigma_{\text{RV}}$. In this analysis only 34 stars have been considered excluding stars with less than 20 data points and stars which show clear RV-trend.](image)

3.2 RV-jitter

Apart from the fact that the RV’s for rapidly rotating stars are more difficult to determine, these stars are also more active. In order to demonstrate this, we consider the $\sigma_{\text{RV}}$ which is defined as the square-root of the difference between the standard deviation of the observed RV’s ($\sigma_{\text{obs}}$) and the $\sigma_{\text{int}}$ squared. $\sigma_{\text{RV}}$ thus is a measure of the RV-variations presumably due to stellar activity. Fig. 2 (right) shows $\sigma_{\text{RV}}$ against $v \sin i$. It can clearly be seen that stars of larger $v \sin i$ also show larger $\sigma_{\text{RV}}$-values. On the other hand the majority of stars in our sample which have $v \sin i \leq 10$ km/s show a $\sigma_{\text{RV}}$ lower than 35 m/s. Such a level of ‘noise’ in the RV-measurements, even if larger than typical values for old dwarf stars of the same spectral type (Santos et al. 2000), still allows the detection of a RV-signal of most of the known exo-planets. For instance, a planet with $M \sin i = 1$ $M_J$ in a circular
orbit around a 1 $M_\odot$ star with a period $P = 10(100)$ days induces a stellar wobble with a RV semi-amplitude of $K = 94(44)$ m/s which is larger than the scatter caused by activity for a star with a $v \sin i \leq 10$ km/s.

![Figure 3](image_url)

**Figure 3.**: (lower panels) RV vs HJD (heliocentric Julian date) for two stars showing a low (c) and high (d) level of jitter respectively. (upper panels) The detection limits in the mass-period diagram. Iso-probability curve for the 100%, 50% and 10% levels are plotted. In the green zone we are virtually sure that a planet would have been detected.

### 3.3 Detection limits

In order to derive upper limits for the detection of planets in our sample, we carried out simulations. For each point on a grid of values of the orbital period $P$ and the planetary mass $M \sin i$, assuming for the star a mass on the basis of its spectral type, we generate a sinusoidal RV curve.
The curve is then sampled in the same way as the real data for that star, obtaining a set of simulated RV values. In the next step, we add noise of normal distribution to the data. The noise is scaled so that the $\sigma$ of the simulated data is equal to the observed $\sigma_{\text{obs}}$. The whole procedure is repeated 5000 times, varying the phases randomly. For each of the 5000 simulated data-sets we then derive the value of the periodogram $(S)$ for that period $P$ (Scargle 1982) and thus obtain for a given $P$ and $M \sin i$ a distribution of $S$, which is compared to a similar distribution for $M \sin i = 0$. If the two distributions do not overlap, we conclude that a planet of that $P$ and $M \sin i$ can be excluded. Similarly, from the overlap of the two distributions, we can calculate the probability for excluding such planet.

The results of our simulations for two opposite cases are shown in Fig. 3. Quite remarkably in the best conditions (panel a) we easily would have been able to detect a planet with $M \sin i = 1 M_J$ for a period as large as 300 days. Besides, even in the worst case (panel b) thanks to the high number of data points ($N_{\text{meas}} = 68$) we are still sensible to very hot Jupiter-mass planets.

3.4 A young exo-planet candidate

![Figure 4: The RV measurements for a G0 star in our sample phase-folded with a $P=1.3381$ days period. The best-fit RV curve and corresponding orbital parameters are reported.](image)
In the whole sample we have found only three objects which show a long period RV trend compatible with the presence of a stellar companion and one young planet candidate. The RV data set for all these stars has been analysed in the same way: we calculated the Scargle periodogram and in correspondence to the periods with higher peaks we estimate the weighted least squares best-fit orbital solution. The phase-folded RV curve for our candidate planet is shown in Fig.4 together with the best-fit orbital parameters. As we know that RV variations can also be induced by stellar activity, we analysed the Hipparcos photometry and found a $P=1.6477$ days periodicity. It is hence possible that the RV as well as the photometric variations originate from a $\sim 1.5$ days stellar rotational period. However the star does not present enhanced X-ray luminosity and strong emission in the cores of the CaII H and K lines, which are typical of fast rotators, and the $v \sin i = 4$ km/s would imply that we are observing the star almost pole-on. Further simultaneous spectroscopic and photometric observations will possibly confirm or discard the planet hypothesis.

Acknowledgements. M. Esposito’s work was performed under the auspices of the EU, which has provided financial support to the “Dottorato di Ricerca Internazionale in Fisica della Gravitazione ed Astrofisica” of the Salerno University, through the “Fondo Sociale Europeo, Misura III.4”.

References

Jensen E.L.N. 2001, in ASP Conf. Ser. 244, Young Stars Near Earth: Progress and Prospects, ed. R. Jayawardhana & T.P. Greene (San Francisco: ASP), 3

King J.R. & Schuler S.C. 2005, PASP, 117 , 911

Marcy G.W. & Butler R.P. 1992, PASP, 104 , 270

Paulson D.B., Saar S.H., Cochran W.D. & Hatzes A.P. 2002 AJ124, 572

Santos N.C., Mayor M., Naef D., Pepe F., Queloz D., Udry S. & Blecha A. 2000, A&A361, 265

Scargle, J.D. 1982, ApJ, 263, 835

Soderblom D.R. & Major M. 1993, ApJ, 402 , 5

Sudarsky D., Burrows A., & Hubeny I. 2003, ApJ, 588, 1121

Valenti J.A., Butler R.P. & Marcy G.W. 1995, PASP, 107 , 966

Zuckermann B. & Song I. 2004, ARA&A, 42, 685