Abstract. G and K giants are a class of radial velocity (RV) variables. One reason for this variability are planetary companions which are indicated in time series of stellar spectra. Since 2004 these spectra in the visual range were obtained with the high resolution coudé échelle spectrograph mounted on the 2m telescope of the Thüringer Landessternwarte Tautenburg (TLS) for a northern sample of 62 very bright K giants. In the South around 300 G and K giants were observed with HARPS mounted on the 3.6m telescope on La Silla. The TLS sample contains at least 11 stars (18 %) which show low-amplitude, long-period RV variations most likely due to planets. This percentage of planet frequency is confirmed by preliminary results of the HARPS study. Moreover the TLS survey seems to indicate that giant planets do not favour metal-rich stars, are more massive, and have longer periods than those found around solar-type host stars.

Keywords: star: general - stars: fundamental parameters - stars: variable - techniques: radial velocities - stars: late-type - planetary systems

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INTRODUCTION

To date there are almost 500 extrasolar planets known orbiting other stars than our Sun, mostly discovered via the RV method. In spite of this large effort, current surveys are giving us a biased view of the process of planet formation because less than 10 % of these planets orbit host stars with masses \( M > 1.3 \, M_\odot \).

Thus our knowledge about planet formation as a function of the most important stellar parameter – the mass of the host star – is poorly understood. To make progress, the search for planets over a wider range of stellar masses is essential. One strategy is to choose massive stars that have evolved off the main sequence (MS). Thus giants have cool temperatures (more lines) and slow rotation rates (narrow lines) resulting in excellent RV measurement precision. G–K giants are a class of variable stars with multi-periodic RV variations with different amplitudes and on two time scales.

The fact that the RV variability in giants has higher amplitudes than that commonly seen in dwarfs suggests that it results from some specific characteristics of these stars.
such as lower surface gravity.

The short-period (2–10 days) variations are likely caused by p-mode oscillations.

In contrast the long-period ones occur on times scales of several hundreds of days and can be due to orbiting stellar and sub-stellar companions as well as rotational modulation due to star spots.

Doppler shifts caused by low-mass companions are expected to be extremely stable with time. In addition they should not induce any variations in the spectral line profile or be accompanied by variations in stellar activity indicators. We thus do not expect any correlation between the radial velocity behaviour and bisector shape or the lines of the chromospheric activity indicators Ca H & K.

By using the projected rotational velocity of the stars and their radius, we can also check that the orbital period differs substantially from the orbital period which will enable us to exclude rotational modulation. If a large surface inhomogeneity passes the line-of-sight of the observer as the star rotates, then this causes distortions in the spectral line profiles that will be detected as RV variations with the rotation period of the star.

Hatzes & Cochran (1993) found first indications of sub-stellar companions around giants. The first extrasolar planet around the K giant HD 137759 (τ Dra) was discovered by Frink et al. (2002). Other exoplanets around HD 13189 and β Gem were detected by Hatzes et al. (2005, 2006). The last planet was independently announced by Reffert at al. (2006). Starting in 1998, Setiawan et al. (2003a) began to search for planets around 83 giants with FEROS. Up to now, this programme has detected two giant exoplanets around HD 47536 (Setiawan et al. 2003b), one around HD 11977 (Setiawan et al. 2005), and more recently one around HD 110014 (de Medeiros et al. 2009). Döllinger (2008) started a similar survey in February 2004 in the northern hemisphere monitoring a sample of 62 K giant stars using higher RV accuracy at TLS. During this survey planets around the K giants 4 UMa (Döllinger et al. 2007), 42 Dra and HD 139357 (Döllinger 2009a), as well as 11 UMi and HD 32518 (Döllinger 2009b), which most likely host extrasolar planets in almost circular orbits, were detected.

Moreover several surveys are actively searching for planets around giant stars. In 2001, Sato started a precise Doppler survey of about 300 G–K giants (Sato et al. 2005) using a 1.88 m telescope at Okayama Astrophysical Observatory (OAO). From this survey, planetary companions around HD 104985 (Sato et al. 2003), the Hyades giant ε Tau (Sato et al. 2007), 18 Del, ξ Aql, and HD 81688 (Sato et al. 2008) were detected. Furthermore, this survey discovered planetary companions around 14 And and 81 Cet (Sato et al. 2008). In the same paper the detection of exoplanets orbiting the subgiants 6 Lyn and HD 167042 were reported. Niedzielski et al. (2007) discovered an exoplanet to the K0 giant HD 17092 using observations taken with the Hobby-Eberly Telescope (HET) between 2004 January and 2007 March. Johnson et al. (2007) published exoplanets around the three intermediate-mass subgiants HD 192699, HD 210702, and HD 175541. Planetary companions around two other subgiants HD 167042 and HD 142091 were discovered monitoring a sample of 159 evolved stars at Lick and Keck Observatories for the past 3.5 years by Johnson et al. (2008). Liu et al. (2009) detected a planetary companion around the intermediate-mass G giant HD 173416. Recently Sato et al. (2010) published a further planetary companion around the K0 giant HD 145457. The detection of other seven exoplanets was recently announced by Johnson et al. (2010).
DATA ANALYSIS

Our spectra in the North have been taken since February 2004 by using the high resolution spectrometer plus an iodine absorption cell mounted at the Alfred-Jensch 2m telescope in Tautenburg. This is a grism crossed-dispersed échelle spectrograph that has a resolution of \( R(\frac{\Delta \lambda}{\lambda}) \sim 67,000 \) and a wavelength coverage of 4630–7370 Å when using the so-called “visual” (VIS) grism.

The high resolution and the large spectral range were required for the determination of RVs and chemical abundances (Döllinger 2008). A high resolving power was essential to guarantee a good wavelength separation, which means that wavelengths with a small wavelength separation of \( \delta \lambda \) can be resolved. A large wavelength coverage was necessary to achieve more accurate Doppler shift measurements by using more spectral lines for radial velocity determinations and to provide enough Fe lines for abundance analysis.

Both criteria are best achieved by cross-dispersed échelle spectrographs which use two separate dispersing elements. The spectral resolution is reached with an échelle grating used in high orders. A second low-dispersion element such as a grism with an orthogonal dispersion axis guarantees that the overlapping orders of the main grating do not fall on the same pixels on the detector. This grating is a cross-disperser which produces a full échellogram on the detector.

The iodine absorption cell used was placed in the optical path in front of the spectrograph slit. The resulting iodine absorption spectrum is superposed on top of the stellar spectrum, providing a stable wavelength reference against which the stellar RV is measured. For the data reduction (bias subtraction, flat-fielding, and extraction) IRAF routines have been used.

RVs have been calculated by modeling the observed spectra with a high signal-to-noise ratio (S/N) template of the star (without iodine) and a scan of our iodine cell taken at a very high resolution of 300,000 with the Fourier-Transform Spectrometer (FTS) of the McMath-Pierce telescope at Kitt Peak National Observatory.

We compute the relative velocity shift between stellar and iodine absorption lines as well as model the temporal and spatial variations of the instrument profile. The spectrum is split up in typically 125 chunks, where the RV values were determined for each chunk. The achieved RV accuracy is 3–5 m s\(^{-1}\).

To complete our global search we started in November 2006 a RV survey with the HARPS spectrograph mounted on the 3.6m telescope at La Silla including the best planet candidates from the previous FEROS study (Setiawan 2004). This spectrograph has a very high resolution of 100,000 resulting in a RV accuracy of 1 m s\(^{-1}\) using the simultaneous ThAr calibration method. The spectral line shape analysis (bisector) is crucial for the confirmation of planet candidates.

STAR SAMPLES

The Tautenburg star sample consists of 62 giants covering the spectral types K0–K5. The TLS target stars are well distributed over the sky in right ascension. Most of the sample stars have declinations greater than + 45° which are circumpolar at the Thüringer Lan-
desernwarte Tautenburg and so visibility over most of the year is guaranteed. In addition the stars are very bright which ensures short integration times. Their *HIPPARCOS* parallaxes have an error of less than 10 % which was essential for the determination of precise stellar parameters such as mass, radius and age for each sample star (Döllinger 2008). Previously known binaries were excluded.

The *HARPS* sample contains 300 G–K giants including the *FEROS* sample. About 80 G and K giant stars, with accurate *HIPPARCOS* parallaxes, have been systematically observed from October 1999 until February 2002 with *FEROS* attached at the 1.5m ESO telescope in La Silla.

The new *HARPS* targets were selected from the Bright Star (BS) catalogue. They are also bright and well distributed over the sky in right ascension. Giants with *HIPPARCOS* parallaxes determined to be better than 10 % and having an intermediate (above 1.5 M⊙) mass have been chosen. The last criteria is quite important to guarantee an enlarged mass range in order to study planet formation as a function of the mass of the host star.

**RESULTS**

The first preliminary results of these northern and southern surveys are now available and will be presented in the next two subsections.

**Statistic of the Tautenburg survey**

- 2 stars (3 %) are constant.
- 15 stars (24 %) exhibit short-period RV variations due to oscillations.
- 12 stars (19 %) belong to binary systems.
- 11 stars (18 %) exhibit long-term RV variations which are most likely caused by planetary companions.

A first result, after approximately 6 years of monitoring the giant TLS sample, is the detection of only 2 stars (3 %) which show RV variations lower than 10 m s⁻¹ at all time scales analyzed. It confirms that K giants are indeed RV variables. However, the term “constant” is relative and very subjective. It depends on the measurement error and the behaviour of the sample. Looking with enough precision and sampling there are probably no “constant” K giant stars.

Moreover the statistics of the programme contain 15 stars (24 %) which show short-period RV variations possibly due to radial and/or non-radial stellar oscillations.

In the case of stellar companions the most important discrimination criteria are the comparatively very large RV amplitudes in the range of km s⁻¹ and the long periods of more than several hundreds of days. This is due to the fact that only the high masses of stellar companions, and not from planets, can cause these high amplitudes. The large period as the second criterion excludes furthermore short-period RV variations due to stellar oscillations. The third criterion, the turnaround points of the orbit, is not visible in all RV curves. This is a consequence of the large periods. It was only possible to obtain a small part of the corresponding long orbits during our time-restricted observations.
Thus the RV curves of a part of the binary candidates show only a snapshot of the whole orbit, expressed by the linear RV changes. The final proof for a binary system is the calculation of an orbit. However, to calculate such an orbit successfully, at least one turnaround point should be visible in the RV curve and enough data points should be available. At the moment for all 12 stars (19 %) of the TLS sample the most likely reason for the RV variations is that the stars belong to binary systems. The percentage of the binaries is in very good agreement with results derived from previous studies (e.g. Setiawan 2003a).

However, the most important result of the TLS survey is the detection of 11 stars (18 %) which show low-amplitude, long-term radial velocity variations on time scales of a few hundreds of days most likely due to planetary companions. Figure 1 shows the $\sigma_{RV}$ versus $M_V$ diagram for the TLS stars. In this plot the different types of RV variability are marked with different symbols. In general the distribution of the stars with planets is quite dispersed over the entire diagram which excludes most likely the presence of possible selection effects.

**Statistic of the FEROS survey**

- 6 stars (8 %) are constant.
- 7 stars (9 %) exhibit short-period RV variations due to oscillations.
- 15 stars (19 %) belong to binary systems.
- 5 stars (7 %) show long-term RV variations which are most likely induced by rotational modulation.
- 7 stars (10 %) exhibit long-term RV variations which are most likely caused by planetary companions.

The southern sample has been monitored from October 1999 until February 2002 with the FEROS spectrograph attached at the 1.5m ESO telescope in La Silla. The first results of this southern survey have been published in Setiawan et al. (2003a,b; 2004; 2005a,b; 2006), da Silva et al. (2006), Pasquini et al. (2007) and de Medeiros et al. (2009). After FEROS has been moved to the 2.2m MPG/ESO telescope, we have continued to follow-up a subsample of several giants showing clear evidence of long-period RV variations. The procedures adopted to compute the RV are explained in detail in Setiawan et al. (2003a).

Figure 2 shows the $\sigma_{RV}$ versus $M_V$ diagram for the FEROS stars. The general behavior is similar to what observed in Fig. 1 for the TLS sample. However, a direct comparison with the corresponding TLS plot (see Fig. 1) clearly shows that the variability observed in the FEROS sample is substantially higher than in the TLS one. We interpret this shift as due to the different levels of precision which were obtained in both surveys: the FEROS survey is less precise than the TLS one. Thanks to these follow-up observations we have detected 15 binary systems (19 %).

For 5 target stars the long-period RV variations can be explained with rotational modulation, because the RV periodical variability is related to the bisector and Ca II variability. The FEROS spectra cover a wavelength region of 360–920 nm with a typical signal-to-
noise ratio (SNR) of $\sim 100–150$. Thus, one can analyze the stellar activity indicators like Ca II H and K, which are located at the $\lambda$ values 393.4 and 396.7 nm, the Ca II IR-triplet with the corresponding $\lambda$ values of 894.8, 854.2 and 866.2 nm, as well as the line profile asymmetry (bisector). It is relevant to note as the majority of the stars showing rotational modulation (see Fig. 2) have quite high luminosity, higher than most stars in the TLS sample. This is the reason why we do not find evidence for these objects in the North.
FIGURE 2. RV variability versus $M_V$ for the FEROS sample. Symbols are as in Fig. 1. Crosses indicate stars for which RV variability is most likely induced by rotational modulation.

Preliminary results from the TLS, FEROS, HARPS and other studies:

Combining the northern and the southern star samples we are able to summarize first results.

- Giant planets around giants are fairly common (about 10–15 %). This percentage is higher than the frequency of $\approx 5$ % for solar-type MS stars.
- Planets around giant stars do not favour metal-rich stars (Pasquini et al. 2007; Hekker & Melendez 2007; Hekker et al. 2008; Takeda et al. 2008). A spectral
analysis of the Tautenburg sample also confirms this behaviour (Döllinger 2008). This is in contrast to planet-hosting solar-type MS stars which tend to be metal-rich (e.g. Santos et al. 2004).

- Planets around giants have periods larger than $\sim 150$ days.
- Inner planets with orbital semi-major axes $a \leq 0.7$ AU are not present (Johnson et al. 2007; Sato et al. 2008).
- Planets around giant stars have large masses, in the range of $3–10 \, M_{\text{Jup}}$. For solar-type MS stars over half of the planets have masses less than $3 \, M_{\text{Jup}}$. For giant stars (intermediate stellar mass) over half of the planets have masses more than $3–5 \, M_{\text{Jup}}$.

**CONCLUSIONS**

Although K giant variability can be complicated and can result from at least three mechanisms, the future aim of our surveys is to distinguish between these mechanisms and to verify the frequency of planets around G and K giants for our samples.

Of course some of the above results are caused by observational or physical biases; the detection of low-mass planets is for instance partially hampered by the high intrinsic variability of giants (Setiawan et al. 2004, Hekker et al. 2008), and the absence of short-period planets is naturally expected because giants have large radii and they thus would have swallowed-up any close-in planets. This region of the planetary orbital parameter space ($P < 20$ days) is thus inaccessible.

In short, the existing results for planets around giant stars show a number of properties which are different from those found around solar-type (and presumably less massive) main-sequence stars.

Combining our northern and southern star sample we were able to put some of these preliminary conclusions on firmer ground.

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