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FIRST LARGE RADIAL VELOCITY SURVEY FOR EXOPLANETS AND LOW-MASS STARS WITH A MULTIFIBER SPECTROGRAPH

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Abstract. The fascinating discovery of the short-period exoplanet population challenges the conventional view of planet formation and evolution. With only 14 planets among this population well-characterized so far with measured mass and radius, the sample still remains too limited to deeply investigate their nature and origin. We took advantage of the multifiber facility FLAMES (VLT) to perform the first large radial velocity survey aiming at detecting and characterizing a large sample of this population. We observed 774 stars selected within one of the exoplanet CoRoT field. The Doppler measurements allowed us to identify new hot-Jupiter and low-mass star candidates and a sample of binaries. Further higher precision Doppler measurements are now necessary to confirm and better characterize these candidates. Besides this demonstrates the efficiency of such a multifibers approach for large radial velocity surveys. In addition, combined to CoRoT observations these new detections will result in a significant breakthrough in the exoplanets mass function especially toward the low-mass population and in their link with brown dwarfs.

1 Introduction

The discovery of a larger and larger sample of extra-solar planets (more than 200 examples nowadays) has led to point out remarkable objects which orbit very close to their parent star. This exoplanet population, called the hot-Jupiter population, is characterized by giant planets at a short orbital distance. Today, more than 30 have been detected. They are orbiting at less than 0.1 astronomical unity (AU) with a period range from 1.2 to 10 days. By combining radial velocity measurements and transit detection we could obtain the exact mass, radius and further the density. The spatial configuration of these very short period systems induces a high probability to observe photometric transits of their exoplanets. Another approach of the comprehension of these systems could be done through the investigation on the gap which separates the high-mass "planetary" companions from their low-mass "stellar" counterparts.
We perform a large survey of a sample of 774 selected stars with the FLAMES/GIRAFFE multi-fiber spectrograph (ESO VLT) on January 2005. Our goals was to:

- perform a radial velocity survey of a large stellar sample in order to significantly increase the sample of detected hot-Jupiter planets. Doing this survey in one of the exoplanet fields of the CoRoT mission, further transit searches will bring the complementary measures necessary to fully characterize number of them.
- check and further improve the spectral classification as performed in the CoRoT exoplanet fields by photometric observations.
- explore the capacities of a multi-fiber instrument to measure accurate Doppler drifts over more than one hundred of stars simultaneously.

We present here a review of our first results.

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2 Observed Star Sample

Thanks to the multi-fiber facility offers by the FLAMES/GIRAFFE spectrograph (Pasquini et al. 2002) up to 129 stars could be simultaneously observed in a diameter field of 25 arcmin.

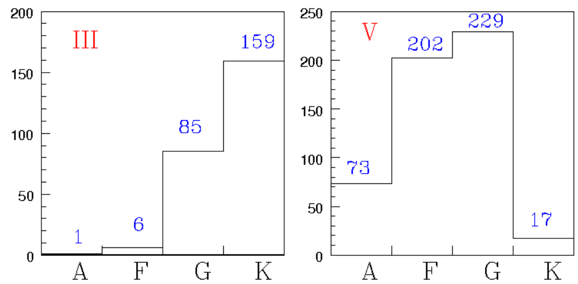


Fig. 1: Distribution of the sample of observed stars with the GIRAFFE spectrograph over the spectral type for dwarfs and giants.

In preparation of the future space mission CoRoT we focus on stars in one of the exoplanet CoRoT field. This field is one of the most attractive for planet search with an homogeneous star density of about 2500 stars per degree square brighter than $V < 16$. With 2.5 night allocated to this program we opted for 6 different FLAMES fields. When selecting our targets in these FLAMES fields, we took advantage of the CoRoT exoplanet entry catalog *EXODAT*. Built from dedicated ground-based observations and existing catalogs to prepare as best the exoplanet program, this catalog provides not only the astrometry of all stars within the potential exoplanet fields of the mission but also an estimate of their spectral type and luminosity class of all the stars in the range 11 to 16 in V-mag. Figure 1 shows the distribution of stars in function of spectral type. We focus on F, G, K dwarfs stars, most favorable for hosting exoplanets, and which represent about 60% of our targets. The remaining targets are mainly giants stars for about 30% and the others A-type dwarfs stars. It's worth noticing this survey covers a larger spectral type range than regular exoplanet surveys, usually focused on F5 to K5 stars.

3 Radial velocity performances of the instrument

We used the spectral range 514-535 nm which offers the best compromise in term of efficiency and number of spectral lines necessary for accurate Doppler measurements. Indeed with this instrument a one hour exposure allow to reach a S/N of 50 on a 14th magnitude star. Combined to the radial-velocity (RV) method, we used the cross-correlation function (CCF) technique (Pepe et al. 2002) to determine the radial velocities.

We calculated the dispersion of the 5 radial velocities values measured for each star. Our study was here restricted to the stars observed 5 times with the GIRAFFE and the UVES spectrographs. It's worth noticing that the spectra generating no peak or a very broad and noisy peak on the CCF were rejected. The CCF gives no correlation peak if 1) the SNR is too small , 2) the $v \sin i$ of the star is too big (greater than 50 km s^{-1}) and 3) the spectrum doesn't have enough spectral lines (for earlier type stars). Thus we studied a final sample composed by the initial sample excluded a rejected group of stars representing about 12% (Loeillet et al. 2006, in prep).

Figure 2 displays the RV dispersion (RMS) as a function of the estimated photon noise uncertainty of each star of the final sample. The highest RV dispersion reaches almost 10^5 m s^{-1}. However the largest part of the points constitutes a significant cloud at small photon-noise uncertainty (less than 100 m s^{-1}). Excepted few targets which describe very small RV dispersion (less than 12 m s^{-1}) the points are distributed around a RV dispersion of 30 m s^{-1} for small photon-noise uncertainty. As described in Bouchy et al. 2001, the fundamental limit of RV variation is photon noise uncertainty. At high values the σ curve on Fig. 2 demonstrates that the RV dispersion is dominated by the photon-noise uncertainty. At small values the distribution shows a flat tendency illustrating a RV dispersion limitation. We assume that this limitation is due to systematic errors.

Simulations allow us to set up the detection threshold to 2.1 σ, distinguishing real RV variations from variations due to statistical effects on 5 measurements.

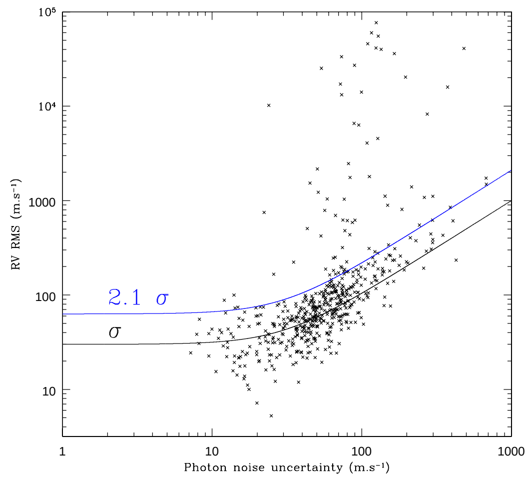


Fig. 2: Distribution of the Radial Velocity Dispersion to the photon-noise uncertainty. Both scales are logarithmic scale. The σ line represent the one-to-one scale line. The $2.1 * \sigma$ stands for the upper limit of the dispersion derived from the different simulation made.

4 Periodic companion candidates

4.1 Spectroscopic binaries

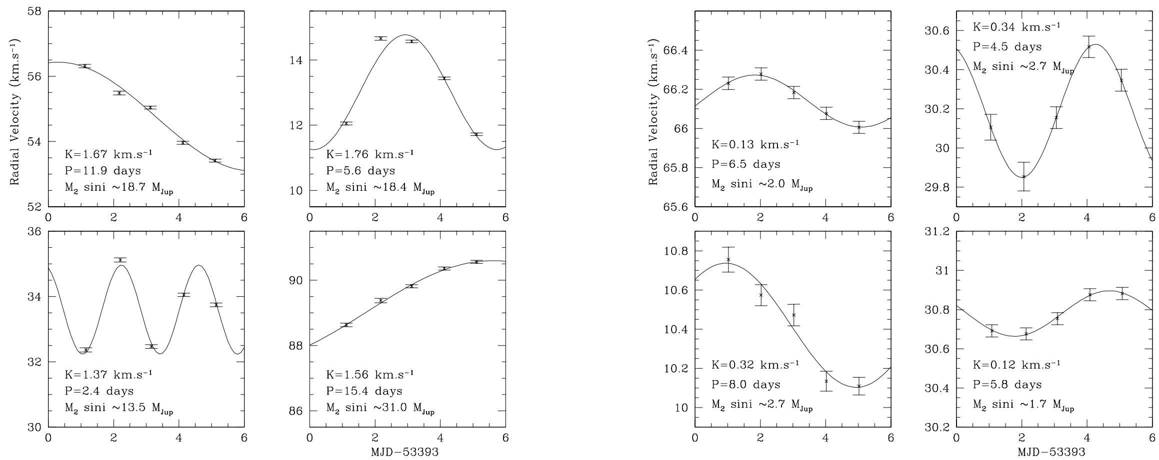
We identified 58 targets with a dispersion greater than the 2.1 σ threshold. We found 16 type 2 spectroscopic binaries which present 2 components in the CCF. From the 58 interesting targets 20 exhibit a RV dispersion greater than 1000 $m.s^{-1}$ with 5 measurements. The amplitude of the radial velocity distribution and the estimated masses allowed us to distinguish the binaries among the sample of 58 interesting stars. We assumed that binaries have a minimum mass greater than 80 M_{Jup}.

Among our whole sample of stars we detected 36 binary stars. Considering that 50 % of stars are binaries and for this population that 13 % have an orbital period less than 100 days (Duquennoy & Mayor 1991), we expected to detect 42 of these systems. This statistics are in good agreement with our results. Some of longer period binary system (limited to 100 days-period) could be hidden in the RV variations of candidates which could present a longer orbital period. We also probably miss some systems with a longer period than 100 days which introduce a slow drift that could not be detected over only 5 consecutive nights and with this precision.

4.2 Possible low mass companion

By fitting sinusoidal orbits to the 5 radial velocity measurements as a function of the time, we estimated the orbital parameters: the semi-amplitude K, the period P, the phase T_0 and the mean value V_0. We set the eccentricity to zero. The zero-eccentricity assumption, necessary with 5 measurements only, is justified in the present case, as the radial velocity precision we achieved could only allow to explore the short-period companion population which is expected to have circular orbits. Besides, we also estimated the stellar masses of these targets from their estimated spectral type and standard tables of stellar masses(Gray 1992). From these elements, orbital parameters and stellar masses, we also computed the approximated minimum mass of the companion of each studied star.

Out of 22 stars with a RV dispersion above the detection threshold (2.1 σ which corresponds to 63 $m.s^{-1}$ at small photon-noise uncertainty) and below 1 km s^{-1}, a sample of 20 good candidates has been identified. These candidates are considered as exoplanet and brown dwarf candidates. For two of the 22 stars the sinusoidal fitted orbital of the RV distribution is not satisfactory. Figure 3 presents the best sinusoidal fits of the 20 exoplanet and brown dwarf candidates. The estimated minimum masses less than 10 $M_{Jup}$are considered as exoplanet candidates and the ones between 10 and 80 $M_{Jup}$are considered as brown dwarf candidates. Some of our 20 candidates present slow drift which prevent us to determine the true period and hence only an approximate minimum mass. These objects could appear to be binaries with a long period. Small radial velocity variations could also be induced by stellar activity (Santos et al. 2002) which may be distinguish thanks to new measurements.



(a) (b)

Fig. 3: Sinusoidal fits of examples of 4 of the brown dwarf candidates on a) and 4 of the exoplanet candidates on b). The points are represented with their error bar and the curve represents the best sinusoidal fit. The amplitude K, the period P and the estimated mass are also mentioned for each candidate.

Considering the "standard" assumption that 5 % of solar-type stars host extra-solar planets (depending of the metalicity of the star) and that about 20 % of discovered planets are hot Jupiters, we expected to detect about 5 hot Jupiter on our sample of 448 solar-type stars. Considering that our large sample is not as biased as standard exoplanet survey (focusing on F5 to K5 stars) we may also expect to have few more exoplanets hosted by more massive stars (in the spectral type range A to F). Promising recent results (Galland et al. 2005, 2006) led us to expect to detect few more exoplanets and few brown dwarves around this kind of stars.

5 Conclusion

Such a survey with such a multifiber instrument allows to perform a very good creaming off by distinguishing binaries and low-mass companions candidates on a large sample of stars. We also show that we have reached a precision of 30 m.s^{-1} with the GIRAFFE spectrograph during few consecutive observational days. Such a precision with such a RV approach appears to be efficient and could contribute in very good agreement in large surveys, as the follow-up of the CoRoT candidates.

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