RAFT I: Discovery of New Planetary Candidates and Updated Orbits from Archival FEROS Spectra

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The first results of the Reanalysis of Archival FEROS specTra (RAFT) project are presented. We have analysed FEROS data for five stars with proposed planetary companions in order to test the reliability of the solutions with our new methodology. For HD 11977, HD 47536 and HD 110014 we confirm the presence of one orbiting companion. We reject the presence of a second companion around HD 47536, as well as the planets detected around HD 70573 and HD 122430. Finally, we propose the existence of a new second planetary companion around the giant star HD 110014.

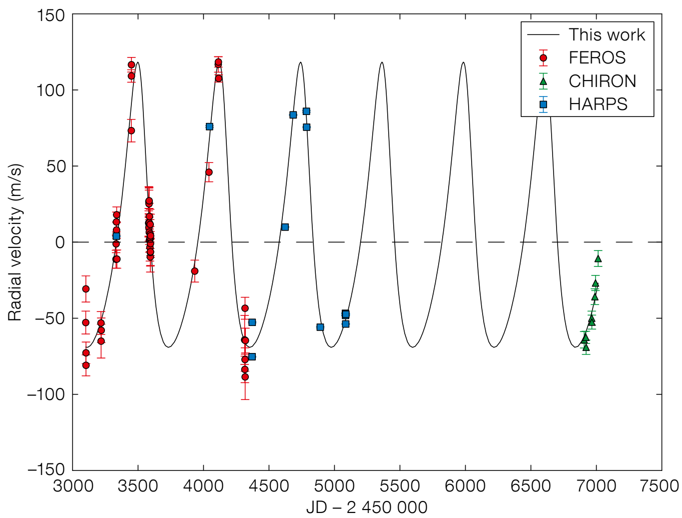

Figure 1. RV measurements for HD 11977.

Exoplanetary science is a burgeoning field in astronomy, focusing on the detection and study of planets outside the Solar System. Indirect techniques are mostly used to study exoplanets, one of them being the radial velocity (RV) method, which can be described as follows: when a star has an orbiting companion, it will move in a small orbit due to the gravitational pull produced by the companion. It is possible to measure the radial velocity of the star at different epochs through the Doppler effect and that way derive characteristics of the companion, such as its minimum mass and orbital period, through the application of simple Keplerian models.

The RV method uses spectrographs to measure the spectrum of a star and retrieve the flux from the source as a function of wavelength. After identifying the spectral lines, we measure the velocity of the star as a function of the time of observation. For this study, we used archival spectra from the Fibre-fed Extended Range Optical Spectrograph (FEROS; Kaufer et al., 1999), which has an operating spectral resolution of R = 48 000 and a large wavelength range (~ 350–920 nm). Several exoplanet systems have been detected with FEROS, but some of these have been thrown into doubt after reanalysis of the spectra. These differing results were obtained because of improvements in the calibration technique, and by the discovery that the FEROS pipeline barycentre correction did not include a correction for the precession of the coordinates (Müller et al., 2013). In this work the reanalysis of five stars using FEROS is presented: HD 11977, HD 47536, HD 70573, HD 110014 and HD 122430, all of which have a reported planet orbiting them. A more detailed version of this work can be found in Soto et al. (2015).

All the data we analysed were obtained from the ESO archive[1]. We reduced and calibrated the spectra using the FEROS pipeline, but disabled the barycentric correction. To obtain the shift of the spectral lines, we cross-correlated the spectra with a template (spectrum for the star with a high signal-to-noise). We then computed our own barycentric correction and applied it to the velocities. Finally, we measured the internal drift, which can be due to changes in pressure and temperature within the instrument enclosure, by measuring the velocity shift of the thorium–argon lines that are observed simultaneously with the stellar spectra, and we then removed this velocity from the radial velocity measured for each epoch.

For this work, we have also used data from three other instruments: HARPS (High Accuracy Radial velocity Planet Searcher; Mayor et al., 2003), a spectrograph with which it is possible to reach an accuracy on the order of 1 m s^{-1}; CORALIE (Queloz et al., 2000), for which it is possible to obtain an accuracy of ~ 6 m s^{-1}, or better, for most of the observations; and CHIRON (Tokovinin et al., 2013), with which it is possible to reach a precision in velocity of ~ 6 m s^{-1} (Jones et al., 2014).

In the following sections, the RAFT I results for the five stars are presented and discussed.

HD 11977

This is a giant star, with a mass of 2.31 $M_{\odot}$), and a metallicity of −0.16 dex, with respect to Solar. A planet was discovered by Setiawan et al. (2005), with a minimum mass of 6.5 Jupiter masses (M_{Jup}) and an orbital period of 711 days. We reanalysed 48 spectra for this star from FEROS, and also included 13 spectra from HARPS and eight spectra taken with CHIRON. We were able to detect a period of 625 days in the data. Starting from that period, we minimised the orbital parameters of the system and found a signal produced by a planet orbiting this star with a period of 621 days, a minimum mass of 6.5 M_{Jup} and eccentricity of 0.3. The data, along with the fit, are shown in Figure 1. The precision of this

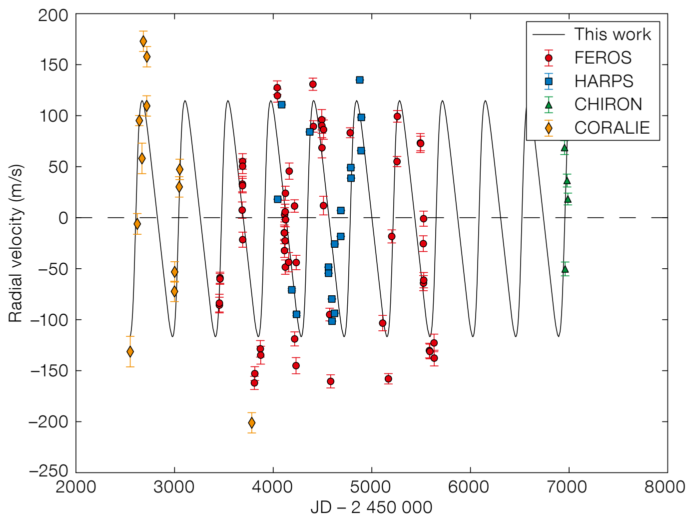

Figure 2. RV measurements for HD 47536.

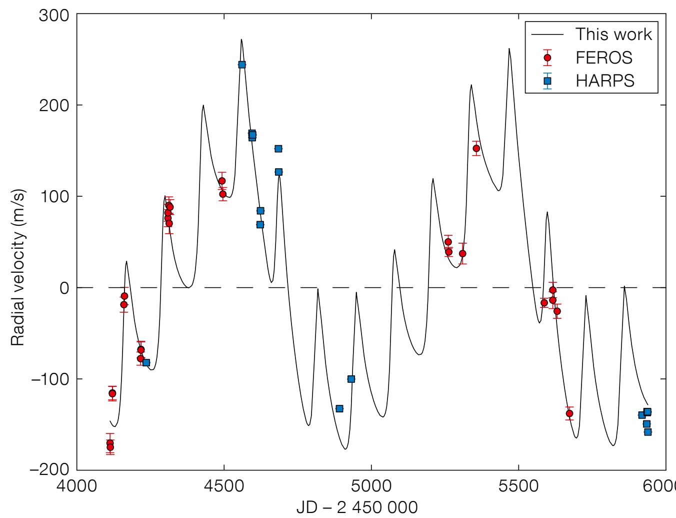

Figure 3. RV measurements for HD 110014.

solution is 11.2 m s^{-1}, significantly better than the one found previously, leading us to believe these parameters for the system are more accurate.

HD 47536

This giant star has a mass of 0.98 $M_{\odot}$ and a metallicity of –0.65 dex, making it the most metal-poor star in our sample. It was studied in two different publications. In the first (Setiawan et al., 2003), a planet with a period of 619 days was found, and later (Setiawan et al., 2008), after adding more radial velocities, a two-planet solution was reported: one signal with a period of 430 days, and the other with a period of 2500 days.

We reanalysed 56 spectra from FEROS, 18 from HARPS, 12 from CORALIE, and six from CHIRON. We found a period of 434 days in the data, and starting from that we found a solution for a planet with a period of 434 days, a minimum mass of 4 M_{Jup} and an eccentricity of 0.3. The precision of this solution is 51.7 m s^{-1} and is shown in Figure 2. We tried to find another planet in this system, but were not able to find any period that could provide a first solution. We did fit a planet with a period of 2500 days, obtaining a solution with two planets and a precision of 48.9 m s^{-1}. Although the two-planet solution has a better precision than the one-planet solution, it is not a great improvement. We found that the probability that the two-planet configuration is similar to the one-planet one is ~ 70 %. This shows that the two-planet solution is not a genuine configuration for the system given the current data, (the data is being overfitted), and therefore it only supports the existence of one planetary companion.

HD 110014

This giant star has a mass of 2.09 $M_{\odot}$ and a metallicity of 0.14 dex, making it the star with the highest metallicity in our sample. In de Medeiros et al. (2009) it was claimed that there is a planet orbiting the star with a mass of 9.5–11.1 M_{Jup} and a period of 835 days. We reanalysed 25 FEROS spectra for this target, and also included 17 data points from HARPS. Our periodogram search located a period of 833 days, and starting from this period we obtained a solution agreeing with a planet of minimum mass 13.7 M_{Jup} and period of 936 days. This solution has a scatter of 44.6 m s^{-1}.

The residuals from this fit hinted at the presence of a second signal with a period of 133 days. When we tried to add a new planet to the system with this starting period, we obtained a new configuration, consisting of two planets orbiting the star: one with a period of 882 days and a minimum mass of 10.7 M_{Jup}, and the second with a period of 130 days and a minimum mass of 3.1 M_{Jup}. This fit is plotted in Figure 3. The scatter around this solution is 19.4 m s^{-1}, significantly better than the one-planet solution. We also found that the probability that the two solutions are similar is essentially 0 %, meaning that this is the statistically preferred configuration.

HD 122430

This is a giant star with a mass of 1.68 $M_{\odot}$ and metallicity of –0.09 dex, making it another metal-poor star. Setiawan (2003) reported the discovery of a planet with a period of 344 days and minimum mass of 3.71–6.04 M_{Jup}. We reanalysed the FEROS data for this star, consisting of 42 radial velocities and also included six observations taken with HARPS. We were not able to find any significant period in the data, so we tried to fit a solution for a planet with a starting period equal to the one published before, and then minimised the orbital parameters. We finally obtained a solution for the orbit of a planet with a period of 455 days, minimum mass of 2.1 M_{Jup}, and eccentricity of 0.6. The root mean square (RMS) scatter on the solution was 29.3 m s^{-1} and the fit is shown in Figure 4. Even though the scatter is smaller than we obtained for other fits, we are still not certain about the existence of this companion because of the lack of a significant period in the data. We conclude that there is not enough data to confirm the presence of a companion around this star.

HD 70573

This is a very young star, with an estimated age of 78–125 Myrs, about 5 % of the Solar age, and a mass of 1.0 $M_{\odot}$. Its rotational period was found to be 3.296 days from photometry. A planet was announced in Setiawan et al. (2007), with a mass of 6.1 M_{Jup} and an orbital period of 852 days. We reanalysed 55 spectra taken with FEROS for this star and could find only one significant period in the data. That period was 3.296 days, remarkably similar to the star's rotational period. We fit a curve with this period and obtained a scatter of 36.4 m s^{-1}. The curve is shown in Figure 5. When we tried to fit the solution published before, we obtained a scatter of 78.78 m s^{-1}, much worse than our previous fit. We also found a period of 833 days, close to the orbital period of the planet candidate, produced by the window function of the data. This means that the planet found before could correspond to a signal produced by the sampling of the data, and therefore would not be a signal produced by the presence of a planet orbiting this star.

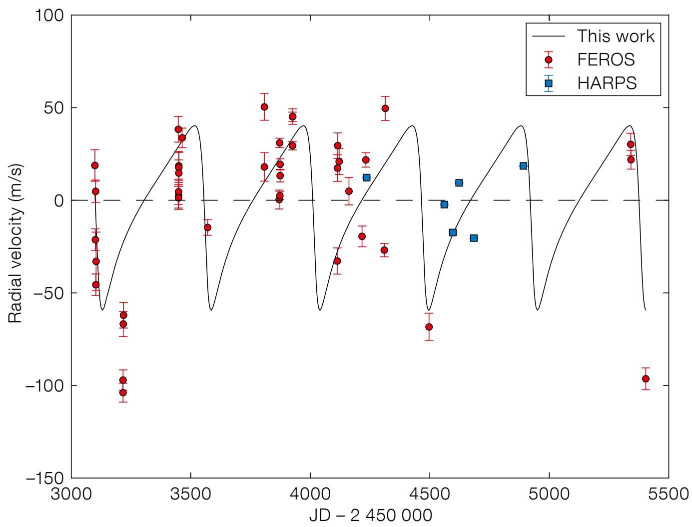

Figure 4. RV measurements for HD 122430.

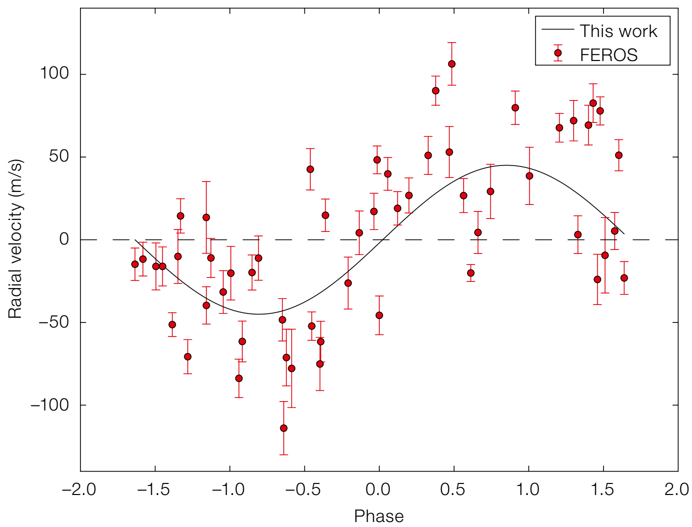

Figure 5. Phased RV measurements for HD 70573.

Activity indices and photometric analysis

The shift produced by the spectral lines in a star can be produced not only by the movement of said star, but also by phenomena in its photosphere, like dark spots on the stellar surface, or velocity fields produced by stellar convection zones. We computed three tests to verify if our velocities were a product of these phenomena. First, we calculated the S-index, which measures the change in the flux from the Calcium II HK lines. These are chromospheric lines that are affected by the magnetic activity within the star. Then we performed a bisector analysis, which detects asymmetries in the line profiles caused by intrinsic phenomena, by computing the bisector velocity span (BVS). This measures the velocity difference between the bottom and top parts of the cross-correlation function (CCF) used to measure the radial velocities. Finally, we analysed the CCF full width at half maximum. More details about the use of these indices can be found in numerous works, e.g., Dumusque et al. (2014), Jenkins et al. (2014), etc. For all the stars we found no significant correlation between the radial velocities and the activity indices for each epoch, which led us to conclude that activity within the stars is not the cause of the claimed Doppler signals.

We also studied the photometry of the stars for which we confirm a companion, *viz*. HD 11977, HD 47536, and HD 110014. We obtained the photometric data from the All Sky Automated Survey (Pojmanski, 1997). We found no periods in the data that could match the period of any detected companions. For example, if the signal from the proposed second companion orbiting HD 110014 was produced by a dark spot on the surface of the star, then it should cover 13.8 % of the surface. If that was the case, then a period of 130 days should be seen in the photometry of HD 110014, but we do not find any. That led us to discard the possibility that the 130-day signal is produced by a rotating spot group on the stellar surface.

The planets found in this work follow the trend that the higher the metallicity of a star, the higher the probability of detecting an orbiting planet. This trend can be seen in the case of HD 110014, which was the star with the highest metallicity in our sample and is the one with the highest number of planets. One special case however is HD 47536. According to Reffert et al. (2015), there is almost 0 % probability of finding a planet orbiting a giant star with metallicity of –0.65 dex. The existence of a planet around HD 47536 shows that it is possible to form planets with masses on the order of the mass of Jupiter around even very metal-poor stars.

We plan to continue with the RAFT project by reanalysing FEROS data for other giant stars. Most of these stars belong to programmes aimed at detecting giant planets in this poorly studied parameter space, leaving us with a sample of around 80 stars that we plan to study in the future.

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Links

[1] ESO Archive: http://archive.eso.org

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Night view over the La Silla Observatory from the north featuring the Galactic Plane. In the foreground is the Swedish ESO Submillimetre Telescope (SEST), which was decommissioned in 2003. The experience gained on the SEST paved the way towards the Atacama Pathfinder Explorer (APEX) and the Atacama Large Millimeter/submillimeter Array (ALMA). In the background is the dome of the-3.6-metre telescope.