And the Oscar Goes to: BD+20 1790 for *The Mystery of the Unseen Companion*

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Abstract BD+20 1790 is a young, rich metal and very active late–type K5Ve star. Our group has been developing a study of stellar activity and kinematics for this star over the past years. Previous results show a high level of stellar activity, with the presence of prominence-like structures, spots on surface and strong flare events. Radial velocity (RV) variations with a semi-amplitude of up to 1 km s^{-1} were detected. When the nature of these variations were investigated it was found that they are not due to stellar activity. Based upon the analysis of bisector velocity span, as well as Ca II H & K emission, we report that the best explanation for RV variations is the presence of a sub–stellar companion. The Keplerian fit of the RV data yields an orbital solution for a close-in massive planet with an orbital period of 7.783 days. Also, the presence of this close–in massive planet could be an interpretation for the high level of stellar activity detected.

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1 BD+20 1790

BD+20 1790 was classified by Jeffries [4] as a K5Ve star. López-Santiago [6] proposed its membership in the AB Dor moving group and derived an estimate age of 35–80Myr by comparing the equivalent width of Li λ 6708 Å with the spectral type. In order to study the stellar activity, our group has been carried out a spectroscopic follow-up and two–band photometry. High-resolution spectral and temporal echelle observations carried out with different spectrographs: SOFIN spectrograph at 2.56m *Nordic Optical Telescope* (NOT) at La Palma (NOT03B), FOCES spectrograph at 2.2m Telescope at Calar Alto Observatory (Almería, FOCES 04A and FOCES 07B) and SARG spectrograph at 3.58m *Telescopio Nazionale Galileo* (TNG) at La Palma (TNG 04B, TNG 06A).
CCD differential aperture photometry was obtained using the 2.0 meters fully robotic Liverpool Telescope (LT 07B) in La Palma. We obtained 22 photometric epochs during November and December 2007. Each epoch consisted in alterning r′ and g′ exposures[1], obtaining quasi–simultaneous two band photometry. Intra night scatter indicates a photometric accuracy of 3 mmag and 4 mmag per exposure (r' and g' bands respectively).

2 Chromospheric activity

Strong chromospheric activity was detected in several observing runs, described by Hernán- Obispo [2], [3]. In spite of the fact that the rotational velocity of BD+20 1790 is not very high ($v\sin i \sim$10 km s^{-1}), all activity indicators are in emission, from Ca II H & K to Ca II IRT lines including all Balmer lines. Through the study of profile line asymmetries of Hα and Hβ, prominence–like structures (Fig. 1) have been detected in the chromosphere of the star ([2, 3]). Two completed transits were detected in different observing runs: NOT03B and TNG04B. The time of the transit was about ∼2h in both cases, smaller than rotational period, and in agreement with typical transit times. So we concluded that the structure we are detecting it is not a superficial feature.

3 Flare activity

In addition, strong flare events were observed. Fig. 2 shows the sequence of consecutive (down to up) line profiles of Hα and He I D_3 and gradual decay of the flare for the SARG 04B run. The flare maximum is marked with bold line. Minimum Hα equivalenth width (EW) is marked with black spotted line and maximum EW is marked with green spotted line. Every observation has a time of integration of 10 minutes. We observed the gradual decay of the flare about ∼4h.

[1] Sloan r’ and g’ filters were used

4 Photospheric activity and light curve

Photometric observations performed produced a light curve with evidence of rotational modulation, the amplitude of which is up to $\Delta V \sim 0.^{m}06$ and indicates the presence of spots on the surface (Fig.3). The period analysis of the entire set of observations reveals a photometric period of 2.801($\pm$0.001) days, in agreement with the period given by SuperWASP photometric survey [8]. The different amplitude in each band (larger in the bluer g' band) is consistent with strong spotty surface features with strong temperature contrasts, and the g' amplitude suggests a surface spot coverage of 7% at least.

5 On the nature of RV variations: activity vs. planetary companion

Heliocentric RV were determined using the cross-correlation technique. Variations of up to 1 km s^{-1} were observed; significantly larger than the individual measurement errors (0.10 to 0.20 km s^{-1}) or the systematic error (0.05 km s^{-1}) The nature of RV variations for BD+20 1790 was investigated. To discriminate if the RV variations are due stellar activity (see [10]) or dynamical motion of a star– planet system, we used the relationship of bisectors of the cross–correlation (CCF) and RV (see [9], [7]). The CCF has been determined by using the same procedure as in the RV case. The lack of a correlation indicates that the RV variations are not due to variations in the asymmetry of the photospheric profile lines, so not due to stellar activity. To support these results we determined the variation of stellar activity indicators, especially those that are ascribed to the presence of plage-like structures on the chromosphere (Ca II H & K). The lack of a correlation confirms that the- RV variations (Fig.4) could be due to a planetary companion (see details in Hernán–Obispo et al. 2008a, submitted). As proposed by Cuntz [1] and Lanza [5], stellar magnetic activity may be influenced and enhanced by the presence of a close-in giant planet, thus this could be an interpretation for the high level of stellar activity detected in BD+20 1790.
We used the Lomb-Scargle periodogram to initially identify the possible periodicities in RV data. The periodogram contains many spurious peaks due to the uneven sampling of the data. However, we identified a group of strong peaks with periods between 6 and 12 days, being the 7.78 days the stronger one, as possible candidates. To compute the False Alarm Probability (FAP), we combined all the observations from each night in a single RV measure. With this we were able to generate much more realistic random periodograms. Using 10000 randomized samples (random switching of the radial velocities) found that the FAP was still smaller than 0.1% as shown in Fig.5.
We computed the orbital solution for the RV data using a standard Keplerian fit.

6 BD+20 1790 b: a massive planetary candidate

A first fit derives a close-in massive planet in a circular orbit with a rotational period of 7.783 days ($a = 0.068$ AU, $M_2 \sin i = 6.87 M_{jup}$, $e = 0.05$, $\chi^2 = 1.09$). Due to the observational strategy (high temporal resolution) the eccentricity is poorly constrained. Also, taking into account that the estimated time for circularization is about of several Gyr, we cannot discard the possibility of an eccentric orbit. A second fit for an eccentric orbit was computed ($a = 0.066$ AU, $M_2 \sin i = 5.44 M_{jup}$, $e = 0.25$, $\chi^2 = 0.83$). Both solutions are shown in Fig.6.

7 Conclusions

This contribution reports the evidence of a planetary candidate orbiting around the young and active K5Ve star BD+20 1790. Based upon the analysis of bisector velocity span, as well as activity indicators, we report that the best explanation for RV variation is the presence of a sub-stellar companion. Since the RV data are not part of a planet search program, we can consider our results as a serendipitous evidence. Indeed, additional RV follow-up can allow us to constraint the orbital solution.

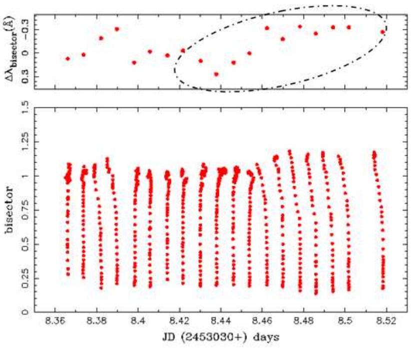

Fig. 1 Bisector of the subracted spectra of Hα line for the 02/02/2004. The dashed ellipse marks the prominence transit. Time of transit$\sim$ 2 h.

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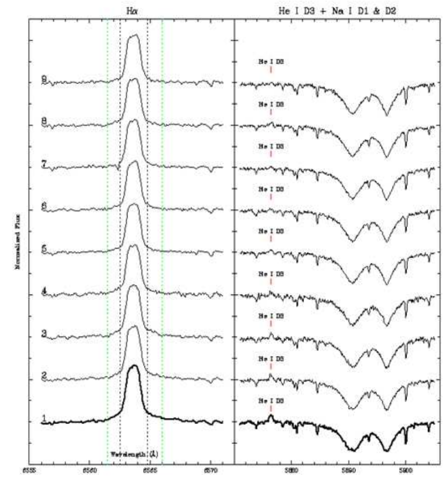

Fig. 2 Sequence of consecutive Hα (left) and He I D_3 (right) line profile for the 22/11/04. We observed the gradual decay of the flare about ∼4h.

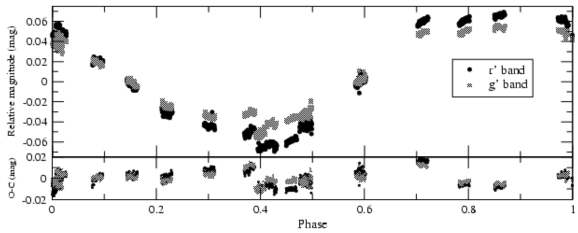

Fig. 3 Photometry phased to the 2.801 days period. A linear trend and a zero point have been subtracted to both bands.

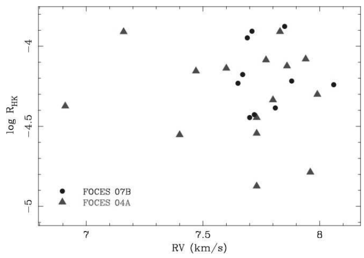

Fig. 4 $logR_{HK}$ vs. RV. Square symbol represents FOCES 04A run and circle symbol represents FOCES 07B run.

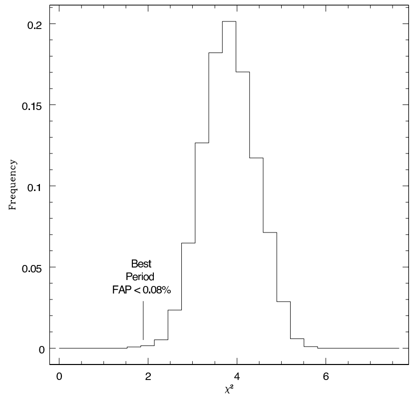

Fig. 5 For each randomized set of data, we compute the strongest peak. An histogram containing the reduced χ^2 of each peak is then constructed. 10000 randomized samples were used to produce this histogram. Only 8 times, the χ^2 of the *spurious* random peak was lower (better) than our best peak, obtaining a FAP of 0.08%.

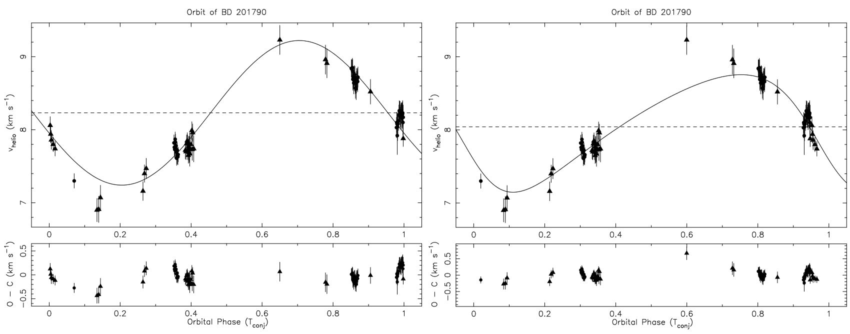

Fig. 6 Radial velocity variability of BD+201790. **Left**: Orbital solution with eccentricity e=0.05. **Right**: Orbital solution with eccentricity e=0.25. Values marked with circle symbol represent SARG runs and triangle symbol FOCES runs.

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