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A Precise Radial Velocity Search for Giant Planets orbiting polluted White Dwarfs

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Abstract

We present a feasibility study for extending the well-known radial velocity technique to search for planetary companions around white dwarfs. Typically, the spectra of white dwarfs contain only a few pressure-broadened hydrogen and/or helium lines, which do not permit to meausre the radial velocity with sufficient precision to detect planets. A small subset of white dwarfs do also show sharp metal lines, presumably from infalling circumstellar material. We suggest to search these "polluted" white dwarfs for possible giant planets using the Doppler reflex moton technique. We show here first results to estmate the Doppler informaton content from simulated spectra of the metal-polluted WD GD 362.

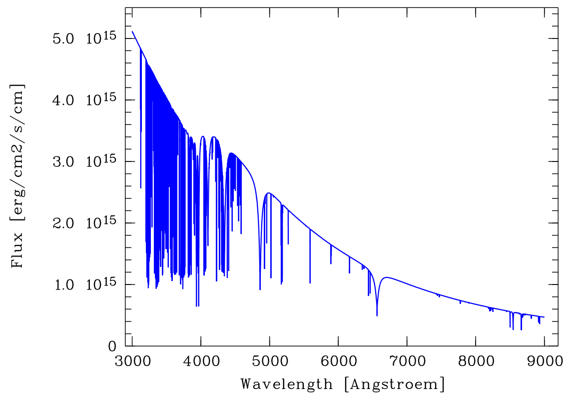

Figure 1: Model spectrum of a metal-polluted WD (GD 362). The large number of metal lines in the blue part contain Dopper information for the precise RV method. (model provided by D. Koester)

1 Astrophysical Context

The precise radial velocity (RV) method has been extraordinarily successful to detect planetary companions to a wide range of different stellar types. While intial focus was primarily on Sun-like stars (e.g. Latham et al. 1989; Mayor & Queloz 1995), it has also been used to detect planets around other spectral types, including M-dwarfs (e.g. Anglada-Escudé et al. 2016) and evolved stars (e.g. Hatzes et al. 2003). But not all stars are suitable for this technique. Early type and hot stars usually have not enough spectral lines and rotate too fast. Other limitations are variable stars that produce intrinsic RV signals either by magnetic activity and/or pulsation. These intrinsic RV signals can either mimick or mascerade RV signals of planets. White dwarf (WD) stars have also not been regarded as suitable targets for RV planet searches.

It is still under debate what the ultmate fate is of planets in the post-planetary nebula phase (e.g. Nordhaus & Spiegel 2013). There is compelling photospheric evidence for planetary material in the proximity of some white dwarfs (e.g. Kilic et al. 2005).

In order to employ the RV method on WDs we face two major challenges: (1) they are typically too faint for current precise RV instruments and (2) they lack the sufficient line densites for precise Doppler measurements. The former can be overcome with the use of a large aperture telescope (e.g. the 10 m Hobby Eberly Telescope) and the latter can be mitigated by focusing on WDs with an abundance of metal lines.

In this paper we present an analysis of the Doppler information content of the polluted WD GD 362.

2 The Method

In Fig. 1 we show a model of the optical spectrum of the metal polluted WD GD 362 (see Kilic et al. 2003). We calculate the Doppler Information Content (DIC) at a certain wavelength λ the following way:

$$DIC(\lambda) = (f(\lambda_1) - f(\lambda_2))^2 \tag{1}$$

with $\lambda = (\lambda_1 + \lambda_2)/2$ and f being the flux values at the corresponding wavelengths. We then form the sum of the DVICs over 50 Å-wide wavelength bins.

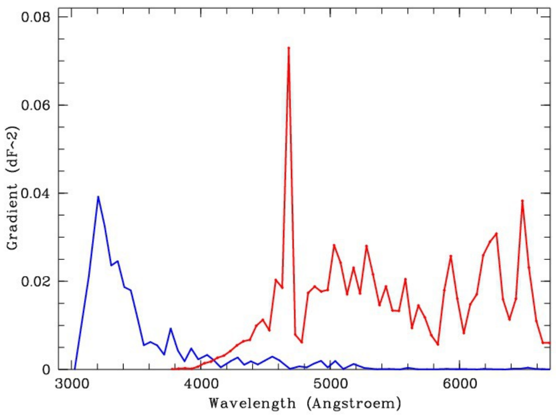

Figure 2: Dopper information content of GD 362 (blue) as a function of wavelength, compared to a main sequence star (τ Ceti, red) which is known to be constant at the 1 m s$^-1$ level. The average Doppler content at wavelengths shorter than 4,000 Åis comparable to the main sequence star.

3 Results

We show the DIC computed from the model spectrum of GD 362 in Figure 2 (blue line). This demonstrates that the largest amount of Doppler information is in the blue part of the spectrum ($\lambda <$4,000 Å), which was expected from the density of metal lines in this part of the spectrum.

We compare the DIC of the WD to a known RV-stable main sequence star. We used the star τ Ceti (G8V), which is observed to be stable at the 1 m s^{-1} level using the HARPS spectrograph (Pepe et al. 2011). We compute the DIC in the same manner as for the WD. We display the Doppler content of a spectrum of τ Ceti as red line in Figure 2.

We find that the DIC of this metal-polluted WD is comparable to the Doppler content of this excellent main sequence RV target, but only in the bluest part of the optical spectrum. There is bascially no overlap between the wavelength regions where GD 362 and τ Ceti provide sufficient Doppler information for the RV technique.

4 Conclusions

Our results indicate that the optimal wavelength window for precise RV measurements of polluted WDs is far in the blue, between 3,000 and 4,000 Å. This eliminates the use of RV spectrographs equipped with an iodine (I2) absorption cell, as the I2-cell provides reference lines only between 5,000 and 6,300 Å. The only viable instrument is a stabilizied optical spectrograph with high efficiency in the blue and using only the bluest orders going all the way to the atmospheric cut-off.

For example, the blue arm of the extremely stabilized RV-spectrograph ESPRESSO (Pepe et al. 2010) at the ESO VLT starts at 3,800 Å. This would provide about 200 Å coverage of the optimal wavelength of a metal-polluted WD. While this small bandpass will not be sufficient to reach the nominal RV precision of ESPRESSO of less than 1 m s^{-1}, it might allow us to obtain measurements with a precision of ≈ 10 m s^{-1} or even less. Endl, Kürster & Els (2000) demonstrated an RV precision of ≈ 15 m s^{-1} for solar-type stars using a bandpass of only 48 Å. This level of RV precision is sufficient to detect giant planetary companions. As next step, we suggest to carry out a pilot study to determine empirically the feasibility of using ESPRESSO (or similar instruments with a blue arm) to search for planets around this type of WDs.

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