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Citation: *AIP Conf. Proc.* **1331**, 170 (2011); doi: 10.1063/1.3556197

View online: <http://dx.doi.org/10.1063/1.3556197>

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Radial Velocity Search for Substellar Companions to sdB Stars

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Abstract. After the discovery of a substellar companion to the hot subdwarf HD 149382, we have started a radial velocity search for similar objects around other bright sdB stars using the Anglo-Australian Telescope. Our aim is to test the hypothesis that close substellar companions can significantly affect the post-main sequence evolution of solar-type stars. It has previously been proposed that binary interactions in this scenario could lead to the formation of hot subdwarfs. The detection of such objects will provide strong evidence that Jupiter-mass planets can survive the interaction with a solar-type star as it evolves up the Red Giant Branch. We present the first results of our search here.

Keywords: stars: binaries – stars: brown dwarfs

PACS: 97.20.Rp, 97.10.Wn, 97.82.Fs

INTRODUCTION AND MOTIVATION

Most investigations into the so-called “Hot Jupiters” and other exoplanets close to their parent stars have focused on the formation and migration of these objects to their present-day location. The planets’ subsequent evolution – and especially their effect on the evolution of the stars they orbit – has received less attention. For the former, the proximity of the exoplanet to its star leads to measurable mass loss through evaporation (e.g. Vidal-Madjar et al. 2003). By considering the energy of the system, Lecavelier des Etangs (2007) found that despite this mass loss, all of the known exoplanets will survive at least 5 billion years. On these time-scales the evolution of the host stars begins to become important.

In a study examining the influence of planets on post-main sequence evolution, Soker (1998) found that substellar companions in orbits of up to 5 AU interact with the evolving star as it expands during the red giant phase. Mass loss on the red giant branch is enhanced as the companion(s) deposit angular momentum and energy in to the stellar envelope and this leads to a bluer horizontal branch (HB) star than might otherwise be expected. Soker used this model to explain the observed morphologies of the HB in galactic globular clusters, and predicted that massive planets or brown dwarfs should orbit stars at the extreme blue end of the HB with orbital periods of ~ 10 days. In a later study, Livio & Soker (2002) found that at least 3.5% of evolved solar-type stars will be “significantly affected by the presence of planetary companions”. This number increases

to more than 9% for stars with metallicities above the solar value. It is now well established that metal-rich stars are more likely to harbour planetary companions (e.g. Fischer & Valenti 2005). An analysis of the group properties of exoplanets of Marcy et al. (2008) found that $\sim 4\%$ of solar-type stars have planets with orbits of < 2.5 AU. Most recently, Bowler et al. (2010) found that $26^{+9}_{-8}\%$ of evolved A-type stars ($1.5 \leq M_*/M_\odot \leq 2.0$) host Jupiter-mass planets within 3 AU. It is clear then, that *there should be a population of very blue HB stars with substellar companions.*

THE HOT SUBDWARFS

The very blue, or extreme, HB stars are the hot subdwarf B (sdB) stars. These objects, like their more normal HB counterparts, are core helium-burning stars, except with hydrogen envelopes too thin to sustain nuclear burning. Their masses are typically $\sim 0.5 M_\odot$. After the consumption of helium in their cores, they evolve directly into white dwarfs, avoiding a second red-giant phase. Most formation scenarios for sdB stars have focused on close binary interaction with a main sequence – not substellar – companion or the merger of two He-core white dwarfs (e.g. Han et al. 2003). A large fraction of sdB stars are predicted to be in close binaries with a main sequence star or white dwarf companion.

Several radial velocity studies have found that this is the case: many sdB stars reside in close binaries with periods as short as 0.07 days, and with either an M-type main sequence star or an invisible white dwarf companion (e.g. Maxted et al. 2001; Heber et al. 2004; O’Toole et al. 2004; Edelmann et al. 2005). Other studies have used 2MASS photometry to estimate the fraction of sdBs with main sequence stars (Stark & Wade 2004; Reed & Stiening 2004), although they are limited by the flux of the sdB to stars earlier than $\sim M_2$. Binary fraction estimates are in the 40–70% range, with selection effects difficult to determine. This still leaves at least 30% of all sdBs as apparently single stars. The Han et al. (2003) formation models suggest that these stars are the product of a merger between two helium-core white dwarfs. It is not clear, however, whether there are enough of these double-degenerate systems that are close enough to merge within a Hubble time. Perhaps instead of mergers, the majority of single sdB stars are the product of common envelope evolution with a *substellar* companion.

THE SEARCH FOR SUBSTELLAR COMPANIONS TO SDB STARS

The discovery of HD 149382b with mass $6\text{--}23 M_{\text{Jup}}$ by Geier et al. (2009) has clarified the situation somewhat, and forced a re-examination of the Soker (1998) and Livio & Soker (2002) models. The detected Doppler velocity variations of the sdB star are sufficiently low ($K = 2.3 \text{ km s}^{-1}$, see Figure 1) that previous surveys for RV variability – whose limits are typically $2\text{--}3 \text{ km s}^{-1}$ – would not have seen them. Furthermore, HD 149382 is the brightest known sdB, where very high quality data is easily accessible. We note however, that this results is the subject of debate; see Jacobs et al. (these proceedings). The detection of more substellar companions in short-period orbits around other sdB stars will strengthen the case that these objects *can* cause common envelope ejection.

Using UCLES + CYCLOPS on the AAT

We have been granted 10 nights in total with the Anglo-Australian Telescope (AAT) to carry out time-resolved high-resolution spectroscopy with UCLES/CYCLOPS of a sample of bright sdBs. The CYCLOPS fibre-feed to UCLES provides higher resolution ($R=70000$) with no loss in signal when compared to the standard mode ($R\approx 45000$). One of the key features of the new system is the ~ 2.1 arcsecond lenslet array feeding the fibres; this makes the spectrograph more immune to the sometimes poor seeing at Siding Spring Observatory. Overall a gain in throughput is expected once the system is fully implemented. Our goal is to search for Doppler velocity variations with semi-amplitudes of $1\text{--}2\text{ km s}^{-1}$ on timescales of days. This will allow us to detect companions with masses as low as $\sim 4M_{\text{Jup}}$.

Target Selection

Previous observations of the bright sdB HD 205805 with ESO-2.2m/FEROS found a shift of $2.5\pm 0.5\text{ km s}^{-1}$, larger than the measurement uncertainties. This object, along with HD 149382, was one of our highest priority targets with UCLES/CYCLOPS. No intensity variations have been detected for this star (Chris Koen, priv. comm.) as might be expected for stellar pulsation, suggesting that the Doppler velocity variability is more likely due to a companion. We have taken high cadence observations of the star, which will allow us to accurately measure its orbital period. The other stars in our sample are well studied bright subdwarfs where no companion has been detected up to now, either with Doppler velocities or infrared colours. Should the ejection of the common envelope be caused by close substellar companions for apparently single sdBs, most of these stars are predicted to show Doppler velocity variations with low semi-amplitudes. The fact that the brightest known sdB shows variability is a strong hint in this direction.

EARLY RESULTS... OR WHAT YOU WILL

Our first four night allocation was very successful, despite a few small teething problems with the newly commissioned instrument (note that CYCLOPS was offered in shared risk mode for the first few semesters). We obtained over 50 spectra of HD 149382, and over 30 of HD 205805. An example of an extracted (but not yet wavelength calibrated) spectrum of the latter star is shown in Figure 1. We also have time-series spectra of another 3–4 objects. Once we have determined a wavelength solution for the spectra we will be in an excellent position to address some of the questions raised here.

ACKNOWLEDGMENTS

We would like to thank Chris Tinney for his help using CYCLOPS, Paul Butler for reducing the raw CYCLOPS data, and the staff at the AAT for help debugging the system.

FIGURE 1. An extracted non-wavelength calibrated CYCLOPS spectrum of HD 205805, showing pixels and counts on the x- and y-axes, respectively.

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