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Research Note

On the planetary companions of solar-type stars

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Abstract. The problem of planets around solar type stars is reinvestigated using model stellar atmospheres and synthetic spectra. It is shown that a possible stellar companion may be spectroscopically well hidden. The changes in the corresponding line profile shapes are too small to be seen. Consequently, an erroneous classification of such secondary as a planet is possible.

Key words: stars: binaries: spectroscopic – stars: late-type – stars: low-mass, brown dwarfs – stars: planetary systems

1. Introduction

Recently, very accurate measurements of stellar radial velocities became available (Baranne et al. 1990, Butler et al. 1996). It turned out that several stars showed radial velocity changes with an amplitude of tens to hundreds of m s^{-1}, namely 51 Peg (Mayor & Queloz 1995, Marcy et al. 1997), 70 Vir (Marcy & Butler 1996), 47 UMa (Butler & Marcy 1996), 55 Cnc, υ And, τ Boo (Butler et al. 1997), HD 114782 (Latham et al. 1989), 16 Cyg B (Cochran et al. 1997), and ρ CrB (Noyes et al. 1997). The most attractive interpretation is that the stars have low-mass companions (brown dwarfs or planets) and the possibility of an almost pole-on-viewed binary star is rejected by simple probabilistic arguments (Marcy & Butler 1996, Butler & Marcy 1996). Using model atmospheres and synthetic spectra, we would like to discuss some aspects of the possibility that the "planetary companions" of the above mentioned stars may not be planets of a Jupiter mass, but main sequence stars of similar stellar type as the primaries.

For binaries with different spectral types it may easily happen that the brighter star simply overshines the fainter one by an order of magnitude (or even two). In a case of a non-interacting system, there is only a marginal chance to detect the secondary and the star will be a single lined spectroscopic binary.

If the angle of the orbital plane is nearly perpendicular and the components of the binary have different spectral types, such configuration may lead to a one-component spectroscopic binary with low radial velocity amplitudes, as is the case of planetary candidates. To be more specific let us consider an example based on the parameters of one star from the list above that supposedly has a planetary candidate companion, namely 70 Vir. We shall use the physical parameters of this star to calculate emergent spectra from corresponding model atmospheres.

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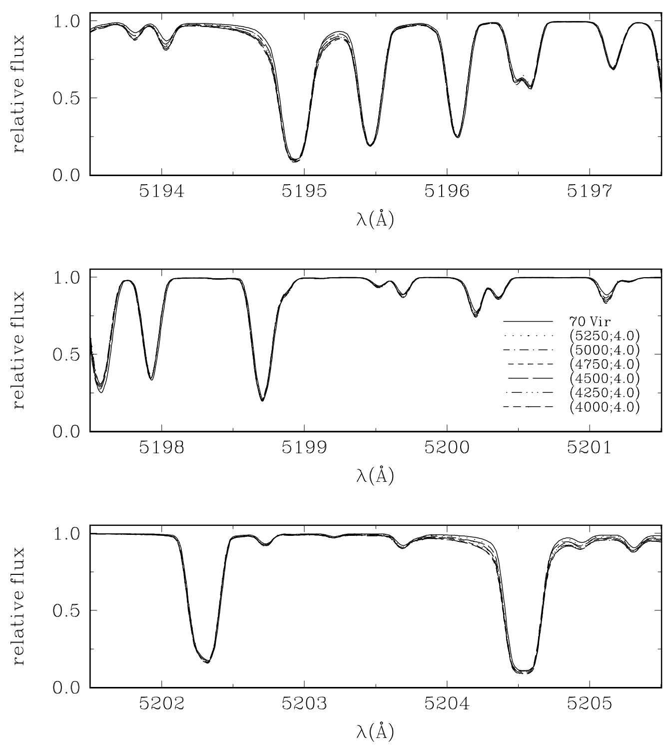

Fig. 1. The spectra of a single star corresponding to the parameters of 70 Vir (full line) together with theoretical composite spectra of binaries consisting of model 70 Vir and a cooler companion. The effective temperature and gravity of the companion are denoted in parentheses.

2. Model atmospheres and synthetic spectra

Blackwell & Lynas-Gray (1994) found for 70 Vir (HD 117176, HR 5072) $T_{\rm eff} = 5488\,{\rm K}$ and $\log g = 3.80$. Since our test is not critically sensitive to the accurate values of $T_{\rm eff}$, we adopted the values $T_{\rm eff} = 5500\,{\rm K}$ and $\log g = 3.80$. Different estimates

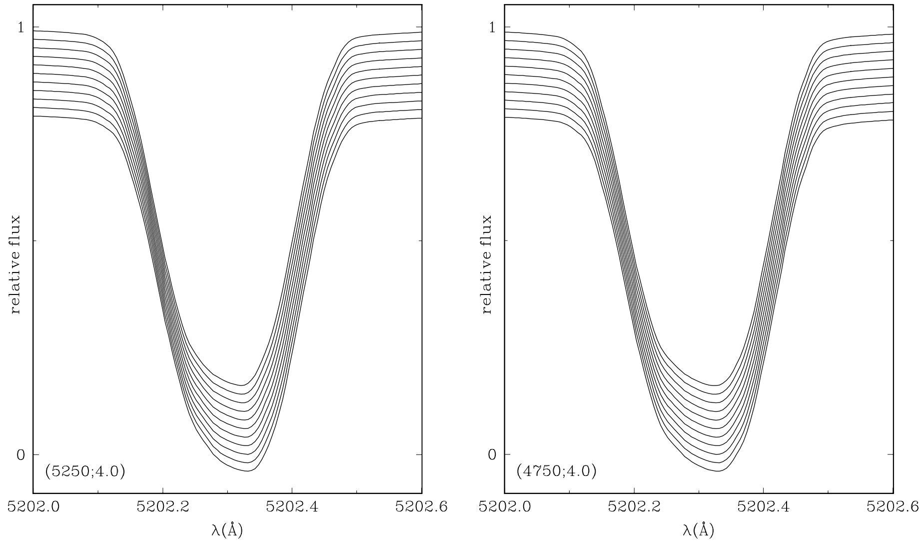

Fig. 2. Summed spectra of the Fe I 5202 Å line for various differences of radial velocities. The spectrum of the model $T_{\rm eff} = 5500\,{\rm K}$, $\log g = 3.8$ (70 Vir) is kept on the fixed position, the spectra of the secondary are shifted by velocity ranging from $-500\,{\rm m\,s}^{-1}$ (the uppermost spectrum) to $+500\,{\rm m\,s}^{-1}$. The effective temperature and gravity of the companion are denoted in parentheses.

Table 1. The parameters of the theoretical secondary. All models have $\log g = 4.0$. Radii are according to Harmanec (1988). The primary has $T_{\rm eff} = 5500\,{\rm K}$, $\log g = 3.8$, and $R = 1.11 R_{\odot}$ (Harmanec 1988). The flux at 5200 Å is $6.559 \cdot 10^5$ in cgs units.

$T_{\rm eff}$(K)	R ($R_{\odot}$)	F_{ν} at 5200 Å in cgs units	secondary light (%)
5250	1.03	5.200 +5	41
5000	0.94	4.023 +5	31
4750	0.85	2.995 +5	21
4500	0.75	2.131 +5	13
4250	0.66	1.431 +5	7
4000	0.56	8.933 +4	3

of the metallicity ($[{\rm Fe/H}] = -0.11$ (Blackwell & Lynas-Gray 1994), $[{\rm Fe/H}] = -0.035$ (Henry et al. 1997)) reveal the underlying uncertainty; hence we decided to adopt the solar value. Using Kurucz's program ATLAS9 we calculated a solar composition LTE line blanketed model atmosphere for $T_{\rm eff} = 5500\,{\rm K}$ and $\log g = 3.80$. The model was calculated in analogy to the solar model atmosphere described by Kurucz (1992), i.e. the microturbulent velocity was set to $1.5\,{\rm km\,s}^{-1}$, and the mixing-length parameter to 1.25. The emergent spectrum from this model atmosphere was calculated using Hubeny's code SYNSPEC (Hubeny et al. 1994) and the Kurucz (1993a) line list.

Another important parameter is the stellar radius. For its determination we used the empirical relation between radius and effective temperature of Harmanec (1988). For $T_{\rm eff} = 5500\,{\rm K}$ it yields the value of $1.11 R_{\odot}$.

In order to check how the presence of a stellar secondary influences the emergent radiation, we calculated a small grid of "summed" spectra. The model atmospheres of the secondary were taken from the Kurucz (1993b) grid. They are summarized in Table 1. We calculated emergent spectra from these models and summed them individually with a theoretical spectrum of 70 Vir using the appropriate light ratio. The composite spectra in a representative region 5193.5 – 5205.5 Å are plotted in Fig. 1. It is clearly seen that there is no direct evidence of lines of the secondary and one can guess at the duplicity only from the slightly different shapes of the spectral lines (e.g. the blend of Cr I and Fe I lines at 5204.5 Å).

In order to mimic the behavior of a system with low radial velocity changes we plotted a sequence of summed spectra near the Fe I 5202 Å line with various radial velocity differences between primary and secondary for two of the secondaries mentioned in Table 1. Although the radial velocity shift may be seen in Fig. 2, any significance of the secondary is missing. One might expect changes in the line profile shapes, but they are too small to be seen.

3. Cross-correlation technique

In order to examine the possibility of detecting a secondary, the synthetic binary spectra were analyzed using the cross-correlation technique, similar to the technique used by Latham et al (1989). A segment of a synthetic binary spectrum covering the wavelength range 5165–5215 Å was cross–correlated with a similar synthetic template spectrum of a single star. We note that this wavelength interval contains many weak metal lines, as well as two strong calcium lines. Cross–correlation functions (ccfs) were computed both with and without the calcium lines present, but differences in the resulting ccfs are small. The secondary star was not detected, even though it was used in the construction of the synthetic spectra. In fact, the cross-correlation function of a synthetic binary is indistinguishable from the autocorrelation function of the single template spectrum. Thus, the secondary is spectroscopically well hidden.

4. Discussion

Although we did our calculations for the specific parameters corresponding to the star 70 Vir, similar conclusions can be drawn for all stars from the list of planetary companion candidates. In other words, it is impossible to exclude the presence of a stellar secondary purely by radial velocity measurements.

The probabilistic arguments do not exclude the possibility of a stellar secondary. Consequently, they *do not prove* the existence of a planet. Thus conclusions based on such arguments should be viewed with caution. In addition, the observational technique (Butler et al. 1996) used by Marcy & Butler (1996) for the case of 70 Vir introduces additional complication, because the stellar spectrum is superimposed with the iodine cell spectrum. The lines of stellar secondary in our case of an almost pole-one-viewed binary cause much smaller changes in the emergent spectrum than do the iodine lines originating in the cell. The original binary spectrum as well as the particular stellar spectra can be easily recovered using the spectrum disentangling technique of Hadrava (1995). Another way of checking the possibility of the stellar secondary is using the two-dimensional cross-correlation technique of Zucker and Mazeh (1994). To our knowledge, such analysis was not done by the discoverers of "planetary companions" to solar type stars.

5. Conclusion

In this note we do not aim at disproving the existence of a planetary companion to 70 Vir. Rather we aim at pointing out a possible source of blunders. Of course, *the possibility* of the existence of the stellar secondary does not mean that the existence of a planet is impossible. We would like to point out that every possibility (however unpleasant it may be) must be seriously taken into consideration if one aims at *proving* the existence of extrasolar planets.

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