Mem. S.A.It. Vol. 84, 1047

Memorie della

Stellar activity, difference spectra, and the dynamical masses of M dwarf companions

N. M. Kostogryz[1,3], M. Kürster[2], and Y. Lyubchik[3]

[1] Kiepenheuer-Institut für Sonnenphysik, Schöneckstr.6, 79104, Freiburg, Germany
e-mail: kostogryz@kis.uni-freiburg.de
[2] Max-Planck-Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany
[3] Main Astronomical Observatory of NASU, Zabolotnoho str., 27, 03680 Kyiv, Ukraine

Abstract. We provide a differential technique that aims at discovering companions to late-type stars by removing the stellar spectrum through subtraction of spectra obtained at different orbital phases and identifying the companion spectrum in the difference spectrum. As we need to observe at different observational epochs our approach may be susceptible to changes in the stellar surface temperature distribution arising from appearing and disappearing star spots. For very active stars the temperature difference between the spots and the photosphere remains a rather unknown parameter. In our simulations we assume a single spot that can have different values of surface filling factor, spot-to-photosphere temperature ratio, and instantaneous radial velocity on the rotating star. For our test case, the M dwarf/brown dwarf binary GJ 1046, we show that the companion difference flux has a larger amplitude than the residual signal from the active star unless extreme spot filling factors and spot-to-photosphere temperature differences are assumed.

1. Introduction

The difference spectrum technique was developed for the dynamical mass determination of low-mass companions to M dwarfs by Kostogryz et al. (2013). The idea of this technique is to observe the combined spectrum at different orbital phases, where suitable spectral line shifts are observed, and shift and subtract them in such a way that the host star spectrum cancels. As a result we obtain the difference spectrum of the companion in which its spectral lines appear twice, as positive and negative signals. The wavelength shift between these signals yields the star-to-companion mass ratio, and knowing the stellar mass we can obtain the dynamical mass of the companion. The technique was developed around the example of the M dwarf/brown dwarf binary GJ 1046 found by Kürster et al. (2008). The secondary has a minimum mass of 27 $M_{\rm Jup}$ that was derived from RV measurements. From a combination of the radial velocity measurements with Hipparcos astrometry these authors determined a confidence of 97% that the companion is a brown dwarf (and not a star). With a separation of 0.4 AU the companion is close to its M2.5V host star ($M = 0.39\,M_{\odot}$) and consequently it is located in the so-called brown dwarf desert.

It is known that M dwarfs can be very active, and if we want to observe them at different orbital phases, we need to consider that

Send offprint requests to: N. Kostogryz

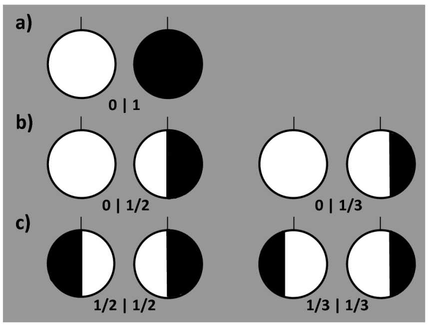

Fig. 1. Spot distributions on the host star considered in our simulations. In case a) the spectra observed at different two epochs differ maximally from each other. In cases b) and c) there are also radial velocity (RV) shifts between the pairs of spectra.

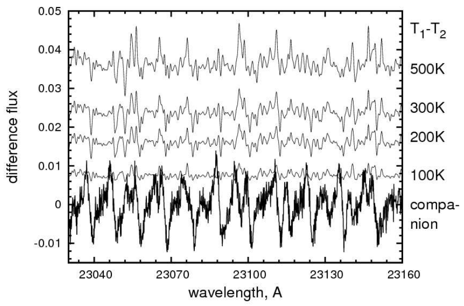

Fig. 2. Simulation of the residual signal of the star with $v \sin i = 5\,\mathrm{km\,s^{-1}}$ and strong activity (the geometry of the spot corresponds to case "a)" in Fig. 1; thin lines) compared to the difference flux of the companion with the maximum mass (i.e. minimum RV amplitude) and $v \sin i = 20\,\mathrm{km\,s^{-1}}$ (thick line). The labels point at the temperature differences of the host star between the two observational epochs.

the stellar signal can change from one epoch to the other. Then, the subtraction of two spectra will not remove completely the stellar signal from the companion difference one. In this paper we simulate the residual spectrum of the active host star that can be immersed in the difference spectrum.

2. Results and conclusion

In our simulations based on AMES-cond and AMES-dusty models (Allard et al. 2001) we assume a single dark spot that is a function of spot surface filling factor, spot-to-photosphere temperature ratio, and the instantaneous radial velocity of the spot on the rotating star. As little information is available about spot distributions on M dwarfs, we choose extreme spot geometries (Fig. 1).

As it is not known what the temperature of the spot on the M dwarf is, we choose an extreme value of 1000 K lower than the photospheric value of 3500 K (see, however, Terndrup et al. 1999; Scholz et al. 2005). The combined stellar spectrum is then composed of the spectrum of the unspotted photosphere and the spectrum of the spot considering the areas covered and the RV shifts (details in Kostogryz et al. 2013). Taking the difference between the spectra from two epochs, we get the residual signal of the active star. We can infer from Fig. 3 that we can neglect the activity of the star except in the most extreme case when we have a slowly rotating and spotless star during the first epoch and a completely spotted star during the next (Fig. 3, top left panel, curve labelled "a)"), and fast rotation and maximum mass (i.e. minimum RV amplitude) for the companion (Fig. 3, bottom right panel).

For our technique the K-band spectral region was chosen (see Kostogryz et al. 2013), so we need to consider the spot-to-photosphere temperature ratio in K-band where this ratio is particularly small. Reducing the temperature difference to values ranging from 100 K to 500 K, we simulate the residuals from the extremely active host star (Fig.1a). As is seen from Fig.2, for a temperature difference of 500 K the activity could still be a problem for our technique, but we notice here that this case is quite unrealistic. Moreover, even for such an extreme case, the activity of the host star is not an issue anymore when the temperature difference is smaller than 500 K. As was shown by Terndrup et al. (1999), for a star with a mass similar to that of our test object the temperature contrast in the NIR is about 6%, i.e. 200 K, but the spot-filling factor is only 13%, much

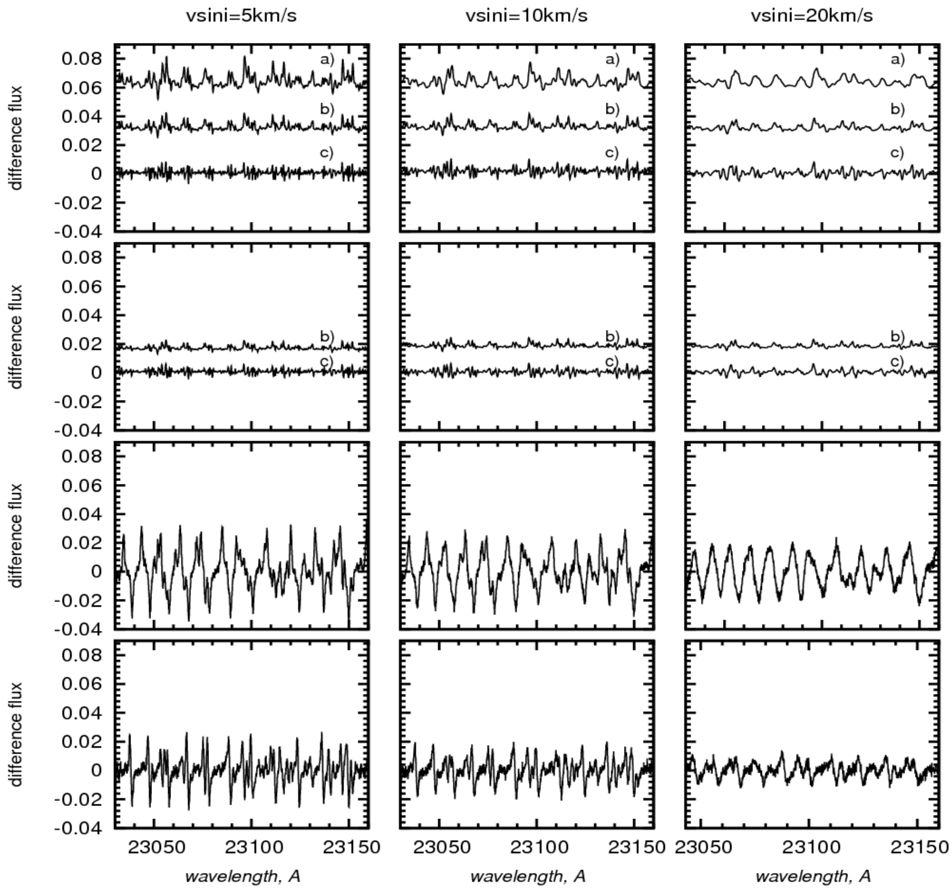

Fig. 3. Simulations of the residual signal from the active host star (upper two panel rows) and the difference flux of its companion (lower two panel rows) with an effective temperature of 1500 K for different rotational velocities. The first row corresponds to the first column of Fig. 1. The second row presents the results of the simulation when the filling factor is equal to 1/3 (second column of Fig. 1). The labels “a)”, “b)”, “c)” refer to the geometry shown in Fig. 1. The last two rows show the difference spectra of the companion with the minimum and maximum masses (i.e. the maximum and minimum RV amplitude), respectively. The signal in the companion difference spectrum exceeds that produced by the activity effects in the host star in almost all cases, and will therefore be detectable in spite of the activity.

smaller than in our simulation. So, stellar activity is not an issue when applying our technique to early M dwarfs.

References

Allard, F., et al. 2001, ApJ, 556, 357
Kostogryz, N. M., et al. 2013, AN, 334, 648
Kürster, M., Endl, M., & Reffert, S. 2008, A&A, 483, 869
Scholz, A., Eislffel, J., & Froebrich, D. 2005, A&A, 438, 675
Terndrup, D. M., Krishnamurthi, A., Pinsonneault, M. H., & Stauffer, J. R., 1999, AJ, 118, 1814