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Letter to the Editor

Accurate determination of the projected rotational velocity of 51 Pegasi*

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Abstract. High resolution spectra of 51 Peg have been obtained in order to determine the projected rotational velocity $v \sin i$ of 51 Peg by using spectrum synthesis methods. Values ranging from 2.3 to 2.5 km s⁻¹ have been found favoring a low inclination of the plane of the orbit of the companion. This suggests that

$$0.45M_J < M_2 < 0.70M_J$$

where M_2 is the mass of the companion of 51 Peg and M_J the mass of Jupiter.

The lithium abundance in 51 Peg is found to be the same as in the Sun, $\log N(\text{Li})=1.16$. This low value is in agreement with Zahn's theory : a star with a planet loses angular momentum which favors a low atmospheric lithium abundance

Key words: Stars:atmospheres – planetary systems – Stars:rotation

1. Introduction.

A recently published paper of Mayor and Queloz (1995) has reported the discovery of a low mass companion orbiting at 0.05 UA around the solar type star 51 Peg (HD 217014). More precisely, the mass of the companion is found to be

$$M_2 \sin i = 0.47 \pm 0.02 M_J$$

where i is the (unknown) inclination angle of the orbital plane, and M_J the mass of Jupiter. Assuming that the normal to the orbital plane is collinear with the rotation axis of the star, an estimation of the inclination can be made by combining the observed projected rotational

velocity ($v \sin i$) with the equatorial velocity v deduced from a relation between chromospheric activity and rotation (Noyes et al. 1984). Three $v \sin i$ determinations of 51 Peg have been found in the literature using different techniques giving values ranging from 1.7 ± 0.8 km s⁻¹ to 2.8 ± 0.5 km s⁻¹. This letter reports an accurate $v \sin i$ determination based on new high resolution spectra performed with two different instrumentations.

2. Observations and data reduction

A spectrum of 51 Peg has been obtained with the spectrograph GECKO combined with the 3.6m CFHT telescope in Hawaii. The resolving power of the spectrograph is $R = 120000$. On the other hand, six spectra of 51 Peg have been obtained with the Aurelie spectrograph at the 1.52m telescope at the OHP (France) with a resolving power of 70000.

For each configuration, a reference spectrum of the reflected solar light by the moon has been also recorded with the same instrumental set-up.

The spectra were centered at 640 nm. All the spectra have been reduced with the same standard procedure using a semi automatic package (Spite, 1990). The 6 spectra from the OHP were co-added after calibration and resampling. A first inspection of the spectra of 51 Peg reveals that the spectral lines have a profile broader than the lines in the moon spectra. 51 Peg has been analyzed by Edvardsson et al. (1993). Its atmospheric parameters are similar to the solar ones, so that a similar line width is expected. Broader lines for 51 Peg suggest a larger value of $v \sin i$. On the other hand 51 Peg has been found slightly metal rich relative to the Sun by Edvardsson et al. (1993) : $[\text{Fe}/\text{H}]=+0.06\text{dex}$.

3. Analysis

For the analysis, models interpolated in the grid of Edvardsson et al.(1993) have been used. The atmo-

* Based on observations collected at the OHP, and CFH observatories.

spheric parameters of 51 Peg ($T_{\text{eff}} = 5755\text{K}$, $\log g = 4.18$, $[\text{Fe}/\text{H}] = +0.06$ and $[\alpha \text{ elements}/\text{H}] = 0.14$) have been taken also in Edvardsson et al. (1993). To minimize the observational errors at each step of the computation, a complete differential analysis with the solar spectrum (Moon) has been performed.

The best candidate to determine the projected rotational velocity is a line with a low Landé factor and with a moderate strength. Among the list of 3 lines proposed by Soderblom (1982), one was severely blended by a telluric line, the second one was rather strong in 51 Peg and thus more sensitive to the collisional broadening in 51 Peg than in the Sun. Finally only one FeI line at 643.086 nm could be used.

To represent the profile of a metallic line in a stellar spectrum beside the thermal broadening we must take into account the broadenings due to

- damping (mainly by collisions with hydrogen atoms)
- macro and the microturbulent velocities
- instrumental profile, and finally
- rotational velocity

The Van der Waals coefficient of collisional broadening of the FeI line at 643.086 nm has been determined by the comparison of the computed synthetic spectrum and the observed solar line at the center of the solar disk (Delbouille et al. 1973). We found that the Van der Waals coefficient C_6 had to be multiplied by 10. Let us note that, at variance with the moon spectrum (integrated flux over all the solar disk), the solar spectrum at the center of the solar disk is not affected by the solar rotation.

From the moon spectra, using this value of the collisional broadening coefficient, a microturbulent velocity of 1km s^{-1} and a solar projected velocity of 1.73km s^{-1} following Soderblom (1982), we determined the width of the gaussian function representing the combined influence of the macroturbulence velocity and the instrumental profile for each set of spectra (CFHT and OHP).

Then we assumed first that the macroturbulence and microturbulence velocities are the same in the Sun and in 51 Peg since the stars are very similar in temperature and gravity. Therefore we used the solar function for computing the instrumental and macroturbulent broadening in 51 Peg and a microturbulent velocity of 1 km s^{-1} . Synthetic spectra of 51 Peg were computed and directly compared with the observed spectra for different values of the projected rotational velocity. Figures 1 and 2 show that the fit between observed and computed spectra for both configurations are excellent. "Best fit" values are obtained for rotational velocities of 2.5km s^{-1} (OHP) and 2.3km s^{-1} (CFHT).

Edvardsson et al. (1993), assuming that the abundance of iron must be independent of the equivalent width of the line used to compute this abundance determine a statistical relation between the microturbulence velocity, the

temperature and the gravity in the atmosphere of the stars. From this relation the microturbulent velocity in the Sun and in 51 Peg differ by 0.25 km s^{-1} . ($v_t(\text{Sun}) = 1.15\text{ km s}^{-1}$ and $v_t(51\text{ Peg}) = 1.40\text{ km s}^{-1}$). We also computed synthetic spectra using this values of the microturbulent velocity. It only modifies the value of the broadening by a few percent. But, at least for this particular line of FeI, a better fit of the observed profile is obtained with a microturbulent velocity of 1km s^{-1} in both cases. Since the shape of the broadening induced by microturbulence and by rotational velocity is not the same, it is not possible to exactly compensate a small change in microturbulence by a small change in rotational velocity, and the deduced value of the rotational velocity is practically the same as it was but with a larger uncertainty.

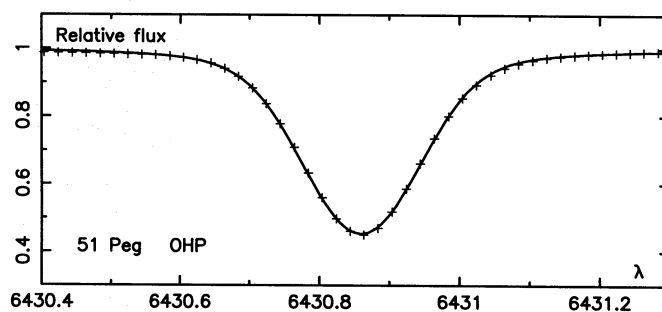


Fig. 1. Comparison of the observed spectrum of 51 Peg with a theoretical spectrum assuming a $v \sin i$ of 2.5 km s^{-1} . The spectrum results from the addition of 6 spectra taken with Aurelie at the OHP .

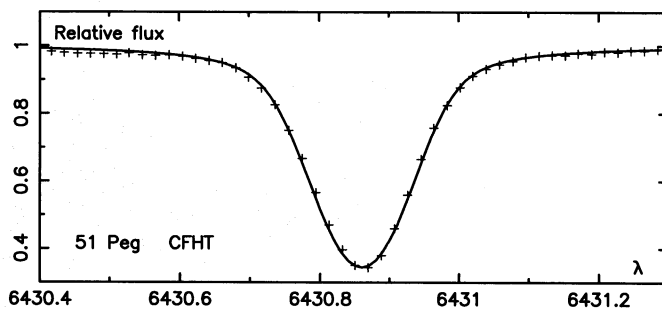


Fig. 2. Comparison of the observed spectrum of 51 Peg with a theoretical spectrum assuming a $v \sin i$ of 2.3 km s^{-1} . The spectrum has been obtained at the 3.6m CFHT telescope with the GECKO spectrograph. .

The comparison of the observed and computed profiles indicates that a reasonable estimation of the error in the determination of the rotational velocity is 0.3 km s^{-1} , thus $v \sin i_{51\text{ Peg}} = 2.4 \pm 0.3\text{ km s}^{-1}$. (Moreover, let us remark that acceptable variations of the atmospherical parameters and of the collisional damping constant,

never provide reasonable fit with a $v \sin i$ value lower than 2 km s^{-1}). Therefore, the value of the projected rotational velocity of 51 Peg is similar to the equatorial velocity $v = 2.2 \pm 0.8 \text{ km s}^{-1}$ estimated by Noyes et al. (1984). As a consequence the inclination of the orbit should be very small.

4. The lithium abundance of 51 Peg

A spectrum of 51 Peg has been taken in the region of the lithium line. The lithium line is very faint. With the model defined hereabove we computed the lithium line with the solar abundance $\log N(\text{Li}) = 1.16 \pm 0.05$ (for $\log N(\text{H})=12$) and found a good fit (Fig. 3).

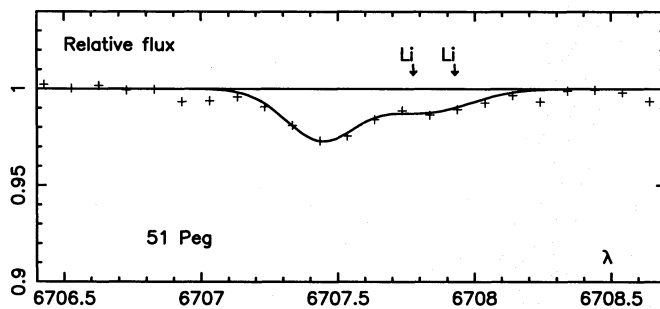


Fig. 3. The lithium doublet in the spectrum of 51 Peg. The synthetic spectrum has been computed with the solar value of the lithium abundance, $\log N_{\text{Li}}=1.16$.

This low abundance of lithium shows that the star is not very young, but does not define an age, since there is no clear correlation between lithium abundance and age in G type stars (cf. Spite & Spite, 1982, and Pasquini et al., 1994). This low value of the lithium abundance is also in agreement (Spite, 1995) with Zahn's theory (1992) : a star with a planet is able, like the Sun, to lose angular momentum in favor of the planet, and this loss of angular momentum favors internal displacements of the matter inside the star, bringing to the surface some processed matter where lithium has been destroyed by proton fusion.

5. Discussion and conclusion

Three $v \sin i$ determinations of 51 Peg have been found in the literature: by line-profile analysis (Soderblom 1983), $v \sin i = 1.7 \text{ km s}^{-1} \pm 0.8 \text{ km s}^{-1}$; by using cross-correlation techniques with CORAVEL and ELODIE giving respectively $v \sin i = 2.1 \pm 0.6 \text{ km s}^{-1}$ and $v \sin i = 2.8 \pm 0.5 \text{ km s}^{-1}$ (Mayor and Queloz 1995). Our determination based on a completely differential analysis between 51 Peg and the Sun gives $v \sin i_{51\text{Peg}} = 2.4 \pm 0.3 \text{ km s}^{-1}$.

This value combined with the estimation of the equatorial velocity by Noyes et al. (1984), $v = 2.2 \pm 0.8 \text{ km s}^{-1}$, favors a large value of $\sin i \simeq 1$ and then a

relatively low value of the mass of the companion: with $2.1 < v \sin i < 2.4 \text{ km s}^{-1}$ and $1.4 < v < 3$ we deduces that $0.7 < \sin i < 1$, and that (cf. section 1) $0.45M_J < M_2 < 0.70M_J$ where M_2 is the mass of the companion of 51 Peg.

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