Planetary Systems in the Universe - Observation, Formation and Evolution
Proceedings IAU Symposium No. 202, ©2004 IAU
Alan Penny, Pawel Artymowicz, Anne-Marie Lagrange, & Sara Russell, eds.

Towards 1 ms^{-1} RV Accuracy

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Abstract. Since the discovery of 51 Peg by Mayor & Queloz (1995) about 50 extra-solar planets have been discovered by means of the Doppler technique, and much more will follow. In future the goal will be to detect even lighter planets and/or planets with longer orbital periods, which may induce changes of only few m/s on the radial velocity of their parent star. Therefore very high performance instruments will be required. In view of the realization of HARPS (Pepe et al. 2000), the high-accuracy RV spectrograph for the ESO 3.6-m telescope dedicated to extra-solar planet search, we are investigating the accuracy limits and possible error sources. First results are presented in this paper.

1. Introduction

Different error sources can affect the final radial velocity (RV) accuracy. Photon noise is the limiting factor in high-accuracy large-survey programs or on faint objects. Therefore it will be most important to maximize instrument efficiency. On the other hand many other causes may affect the RV accuracy at the level of 1 m/s. We have investigated two of them: First, the error induced by "bad" telescope guiding and second, the anomalous RV dispersion found on visual binaries having small angular separation, for which the object spectrum is "contaminated" by the light of its stellar companion. Tests have been carried out using the CORALIE instrument on the Swiss-Euler telescope at the ESO-La Silla Observatory, which is a copy of the ELODIE instrument (Baranne et al. 1996) used for the discovery of 51 Peg.

2. RV errors due to bad guiding

For a spectrograph of spectral resolution R = 50'000 a Doppler shift of the spectral lines by 1 m/s corresponds to about 1/6000 of the entrance slit width. Small variations of the object position on the slit (varying slit illumination) produce a change of the photometric barycenter of the slit image on the CCD and are therefore measured as a Doppler shift of the spectral lines of the observed object. It is evident that for a slit-illuminated spectrograph these Line-Spread Function (LSF) variations must be monitored and corrected for. In the case of a fiber-fed spectrograph, however, the image of the star at the fiber entrance is "scrambled" by the fiber, providing a stable spectrograph illumination. In the case of the CORALIE instrument the stability is even increased by means of an additional image scrambler. Nevertheless, at the m/s level some residual

https://doi.org/10.1017/S0074180900217609 Published online by Cambridge University Press

error due to guiding errors which are not completely eliminated by the fiber scrambling might subsist.

In order to estimate this effect we have carried out a series of test measurements on CORALIE. We have measured the radial velocity of a stable and bright object for two different guiding positions alternately, i.e. for a) the object centered on the fiber, and b) the object decentered by 1 arcsec with regard to the fiber center. We have carried out a series of 16 centered and 16 de-centered measurements. For each pair of measurement we have then computed the RV error $RV_{off} - RV_{on}$. The results are shown in the histogram in Figure 1.

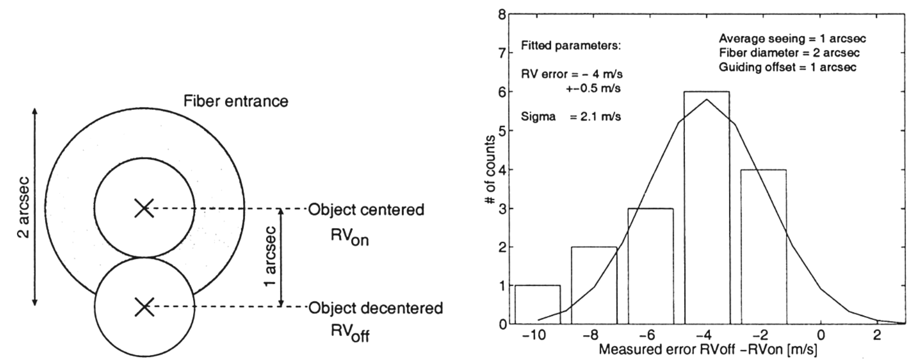

Figure 1. Guiding tests on CORALIE

The mean error produced by a guiding offset of 1 arcsec is 4 ± 0.5 m/s. A guiding offset of 1 arcsec corresponds to an equivalent RV error of 2000 m/s at the fiber entrance. Thus, the scrambling has reduced the effect by a factor 500. Using the measured scrambling factor and assuming a guiding stability of 0.15 arcsec rms we can estimate the errors produced by "bad guiding" to about 0.77 m/s for CORALIE and 0.32 m/s for HARPS.

3. RV errors in binary stars

When observing visual binary stars with CORALIE we found that the RV measurements were relatively noisy (Figure 2 left) and that no orbital solution could be fitted in their periodograms. One way to explain this noise is that the companion of the observed object (if close enough) may contaminate the measured spectrum (light of the companion enters the fiber of the spectrograph) and produce an apparent RV shift of the cross-correlation function. The light contamination by the companion depends on the seeing and thus the produced RV shift will not be constant but also varying with seeing. A simulation of this effect for the CORALIE instrument is shown for comparison on the right hand of Figure 2.

Figure 3 shows the calculated RV error produced by the presence of a stellar companion situated at angular separations ranging from 0 to 5 arcsec. The calculations have been carried out for HARPS, i.e. assuming La Silla seeing conditions and a fiber diameter of 1 arcsec projected on the sky. The left-hand figure shows the results for various magnitude difference dm between the two stars. The difference dRV between the RV of the object and its stellar companion

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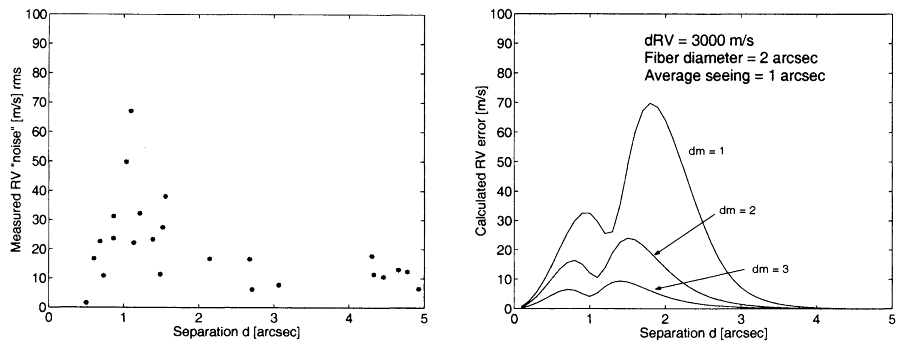

Figure 2. Left: RV dispersion measured on objects known or suspected to have a stellar companion. Right: Simulation (CORALIE)

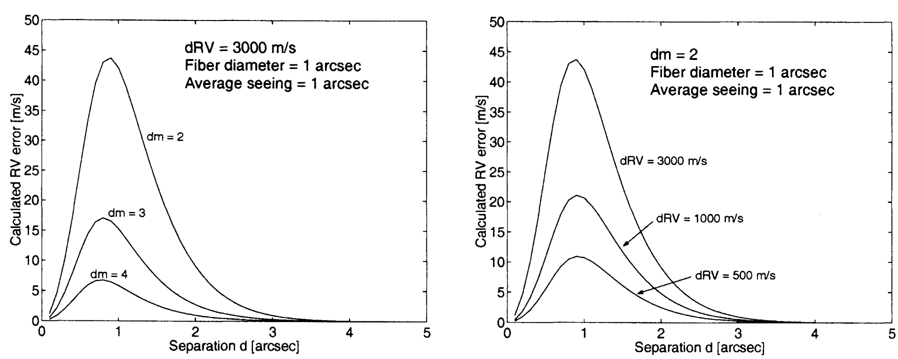

Figure 3. Calculated errors induced by a binary companion

was assumed 3000 m/s. Such high RV differences are not very frequent, but we have chosen this value because it produces the strongest errors. On the right hand of Figure 3 the results for varying dRVs and constant dm are shown.

It should be noted that even for dm = 3 the errors might be as high as 10 m/s. This emphasizes the fact that the sample of objects destined to a high-accuracy RV measurement program (e.g. search for low-mass and/or long-period exoplanets) must be "cleaned" from visual binaries with small angular separation. An accurate analysis of the sample by means of the Hipparcos data base or an adaptive-optics survey must be considered.

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https://doi.org/10.1017/S0074180900217609 Published online by Cambridge University Press