Systematic errors in GAIA's radial velocity measurements.
III. Slope-mismatch error.

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1 Results after local rectification.

The present contribution is mainly an addendum to RVS-MD-002, to which we refer for the definition of most of the terminology and for the experimental set-up of the simulations.

In this previous report it was pointed out that the large values for the sampling error and for the boundary error, found at higher $T_{\rm eff}$ could be due to the fact that the flux in those cases sinks well below the continuum level towards the shorter wavelengths. This is mainly due to the Paschen lines whose wings exhibit an increasing overlap towards the shorter wavelengths. The phenomenon is illustrated in Fig. 1. As expected, an increase of $T_{\rm eff}$ or a decrease of $\log g$ do increase the slope of the *pseudo-continuum* (i.e. the flux-level in the regions in-between the spectral lines). Through the CaII triplet, also an increase of the metallicity has some effect on the slope, but naturally this effect weakens with increasing $T_{\rm eff}$ and it disappears

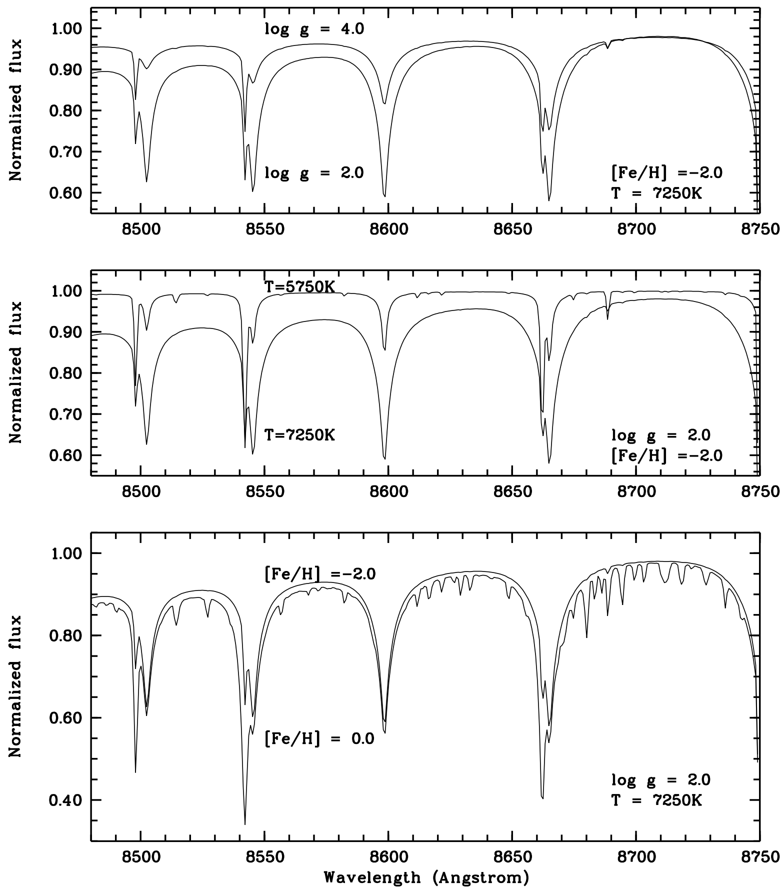

Figure 1: Spectra with a sloping pseudo-continuum: from top to bottom the panels show respectively the effect of a change in surface gravity, in temperature and in metallicity; in all cases $V_{\rm rot} = 0$.

beyond 10^4 °K.

Apart from obviously causing huge end-errors, the mean slope of the flux may also introduce a strong asymmetry in the cross-correlation peak, biasing the position of the latter's maximum.

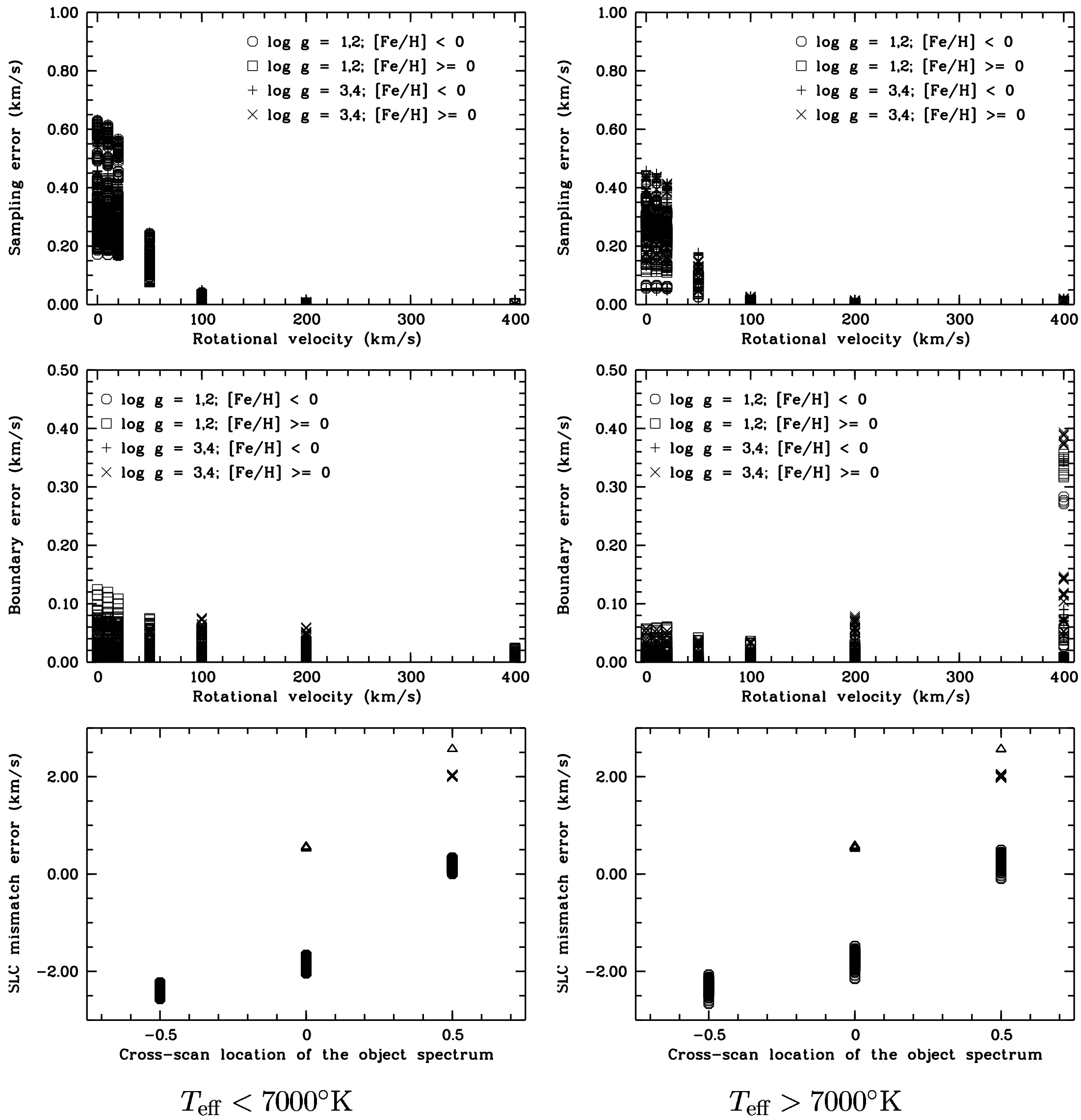

Figure 2: Top panels: the sampling error as a function of rotational broadening. Middle panels: the boundary error as a function of rotational broadening Bottom panels: the error due to a difference in the effect of scan-line curvature on two spectra of the same object, plotted as a function of the position of the object in the FOV; the symbols distinguish different possibilities for the template: circles: template obtained with symmetrical EPSF; triangles: template from position -0.5; Crosses: template from position 0.0.

This level difference can be eliminated by a local rectification, i.e. a division of the flux by a smooth function which represents the downward trend of the pseudo-continuum. We repeated the previous simulations after applying such a rectification, using simply a linear function determined by the flux level at the ends of the spectra. Comparing the results in Fig. 2 to those in Fig. 3-5 of RVS-MD-002, one finds that the anomalous behaviour of the errors at higher $T_{\rm eff}$ has indeed vanished. Actually, also in the lower-$T_{\rm eff}$ group both the sampling error and the boundary error have become significantly smaller. Most importantly, the SLC-mismatch error now behaves in exactly the same way for higher values of $T_{\rm eff}$ as for the lower ones and we may safely say that it is almost independent of the spectral structure. So the derivation of a general correction (i.e. regardless of the spectral type) for the systematic error due to scan-line curvature mismatch is indeed feasible .

2 Is there a slope-mismatch error?

The local rectification mentioned above seems to be a natural thing to do, before any cross-correlation. However, since it inevitably implies a deformation of the spectral lines, one must wonder whether that in its turn might cause another kind of systematic error. It could not do so in the simulations discussed here so far, because object and template were essentially the same so that the rectifying function was the same for both. But in practice inevitably there will be some spectrum mismatch (see e.g. Munari et al. 2001) so there will be a difference between the rectifying functions of object and template which might cause a systematic error in the radial velocity.

A straightforward argument against such a "slope-mismatch error" would be that the original line profiles were deformed already by their being blended with the wings of nearby strong lines outside the cross-correlation interval, and that a local rectification merely reverts that effect. However, it is easily seen that a rectifying function based on the pseudo-continuum level between strong broad lines, inevitably overshoots the cumulative effect of line wings originating outside the cross-correlation interval, because it also compensates for the depth which the internal lines still have at the boundaries (or at any other points where the pseudo-continuum is sampled).

To demonstrate the nature of the effect we first consider a number of fake spectra created by assuming a simple Lorentzian line-opacity at the position of all the Paschen lines (identical for all of them); varying the height and width of the Lorentzian profile then yields "spectra" with a different pseudo-continuum.These were rectified by a linear function of $\ln\lambda$: $C_{\rm o,t}(\ln\lambda) = 1 + S_{\rm o,t}(\ln\lambda - \ln\lambda_e))$ where the subscripts o,t refer to object and template respectively and λ_e is the redward wavelength boundary. The coefficients $S_{\rm o}, S_{\rm t}$ will be termed the "slope" of the respective spectra.

Since corresponding lines in different spectra were at the same position originally, any "shift" found between the spectra represents an error in the RV measurement, due to the fact that the lines of the object spectrum were deformed in a different way than those of the template. More precisely, if a spectrum is divided by a function with positive slope, the redward wing of a line is raised less than the blueward one, so that the position of an absorption line must move slightly redwards. Obviously this displacement will be less for narrower lines. Anyway, if the slope of the object is larger than the slope of the template, after local rectification the object *may* exhibit a positive shift with respect to the template.

Such shifts were in fact found and they turn out to correlate fairly well with the *difference* between the slopes of object and template. This is illustrated in Fig. 3 which moreover compares the results obtained with the complete GAIA wavelength region to those obtained from an interval bracketing only the P_{14} line. Notice that the relation between the error and the slope-difference is practically the same with both regions.

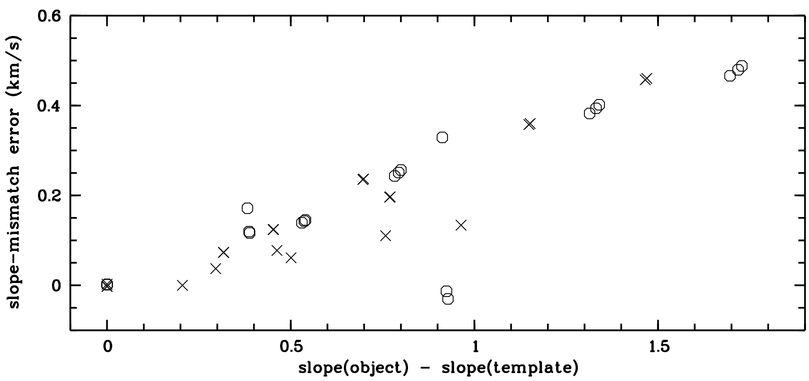

Figure 3: The slope-mismatch error as a function of the difference in slope between object and template, obtained from fake spectra containing only the Paschen lines; circles: CC over the usual wavelength intervals, crosses: CC over the intervals [8572Å,8626Å], [8572Å,8632Å] and [8572Å,8634Å].

Unfortunately the simple case shown in Fig. 3 cannot be used to mimick what happens with real spectra because there the effect will depend not only on the width and the strength of the hydrogen lines but also on the Calcium lines and on the weaker metal lines.

As a matter of fact, almost all attempts to reproduce the effect with the synthetic spectra we used before, failed completely. We first took a subset of synthetic spectra on the grid described in RVS-MD-002, with fixed temperature $T_{\rm eff} = 7250°$K and different metallicities [Fe/H] $= -2, -1, 0, 0.5$, surface gravities $\log g = 1, 2, 3, 4$ and rotational velocities 0, 10, 20, 50, 100, 200, 250, 300, 400km s^{-1}. Among these we considered all couples of spectra which differ *only* in $\log g$, to avoid as far as possible the effect of relative variations in the strength of the metal lines. Couples of identical spectra were also included, to provide a reference point. The couples were cross-correlated over the usual three wavelength intervals with slightly different redward boundaries to provide an estimate of the boundary error.

The shifts (i.e. RV-errors) found between spectra corresponding to different values of $\log g$ were generally much larger than those shown in Fig. 3, and there was no correlation at all between these shifts and the differences in slope. Clearly these RV-errors were dominated by other aspects of spectrum mismatch (mainly through a difference in the shape of blended features, see e.g. Verschueren et al. 1999, Zwitter 2001) which will be studied in a later contribution.

Only if we limit the cross-correlation to intervals bracketing just the P_{14} line, with the strongest rotational broadening and at the lowest metallicity (top left panel in Fig. 4), we find an effect comparable to the one in Fig. 3. Even with $V_{\rm rot} = 200$km s^{-1} the effect is only marginal. With less rotational broadening we found that the errors remained well below

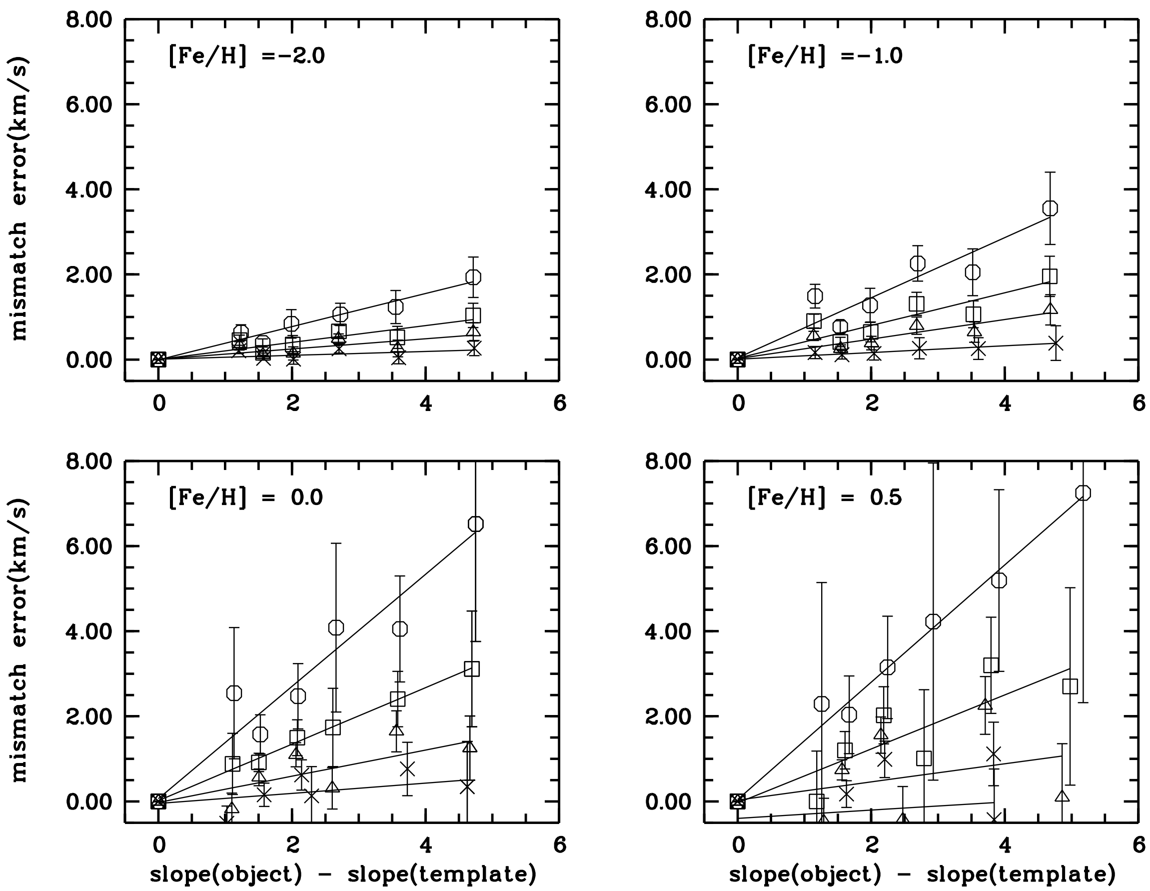

Figure 4: The mismatch error vs. the difference in slope of object and template spectrum at $T_{\rm eff} = 7250°$K, for high values of $V_{\rm rot}$ and for different metallicities as indicated in each panel; circles: $V_{\rm rot} = 400$km s^{-1}, squares: $V_{\rm rot} = 300$km s^{-1}, triangles: $V_{\rm rot} = 250$km s^{-1}, crosses: $V_{\rm rot} = 200$km s^{-1} The error bars represent the boundary error which is the only other systematic error to be reckoned with under the given circumstances; as always in this series the spectra were free of noise. The lines represent a simple linear fit through the results for each value of $V_{\rm rot}$.

$0.1\mathrm{km\,s^{-1}}$ if [Fe/H] =-2 or -1: apparently in these cases the line-profile is still sufficiently steep near its core, to annul any effect of deformation by the rectification.

From the top-right and the bottom panels in Fig. 4 one might get the impression that the "slope-mismatch error" actually becomes more important with increasing metallicity, but this cannot possibly be justified. What we see here must be due to the fact that the P_{14} line is blended with metal lines (strongly smeared-out by rotational broadening, but contributing more as [Fe/H] increases) and that the shape of this blend is different in spectra corresponding to different values of $\log g$; this also causes a mismatch error which in this case, by mere coincidence, has the same sign as the one we associate with the slope-difference. Hence the false impression that the mismatch error becomes more strongly correlated with the slope-difference at higher metallicities.

The same experiments were repeated at $T_{\rm eff} = 9750$°K but these likewise provided only scant evidence of a slope-mismatch error.

3 Conclusion.

The rectification of two spectra whose pseudo-continuum has a different slope is necessary to avoid large errors due to end-effects. Although *in principle* this may cause, in its turn, a "slope-mismatch error", no clear evidence was found that the latter could be important under realistic circumstances. Anyway, the necessity to limit spectrum mismatch because of other errors it may cause, will ensure that the said slope-differences (and hence any slope-mismatch error) will be very small in practice.

References

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