Crowding in the GAIA spectrograph focal plane

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Abstract. Superpositions of stellar tracings are present in every slitless spectrograph. The probability for such overlaps in the GAIA RVS spectrograph focal plane is estimated using photometric observations of 66 stellar fields, mostly close to the Galactic plane. It is shown that overlaps of bright stars ($V < 17$) are common near the Galactic plane, and no spectrum is free from superpositions of faint star tracings. Most overlappers are of spectral type K.

1. Introduction

GAIA RVS is a slitless spectrograph, so some degree of crowding due to spectral tracing overlaps in the focal plane is to be expected. Overlapping spectra increase the effective background signal and make it highly uniform. In an accompanying paper (Zwitter 2002) we show that superpositions of spectral lines of background stars can be removed by careful modelling. Here we use photometry of actual stellar fields in 66 directions in the Galaxy to assess the probability for an overlap, as well as the typical spectral type of overlappers.

2. Observations

We use B, V, and I$_C$ photometry of 66 fields around a sample of symbiotic stars (Henden & Munari 2000, 2001). These fields were observed with the USNO Flagstaff Station, 1.0m telescope and two CCD detectors. The exposures were designed to permit accurate photometry of the symbiotic star, and so were of varying depth depending on the brightness of the target star. However, all fields are relatively complete to $V \sim 17$ with stellar detections reaching $V = 20.5$. Only photometric, good seeing nights were used, with extinction and transformation coefficients determined from nightly measures of Landolt standard stars. Aperture photometry was used, with a minimum of three observations on separate photometric nights per field. Typical zeropoint errors are around 0.01mag. More complete description of the observations and techniques can be found in the referenced papers. These fields can be used to assess stellar density and dis-
Figure 1. Luminosity function from 66 stellar fields with 76000 stars. Histogram represents magnitude distribution of V-magnitude measurements, solid line is the assumed true distribution (eq. 1), while dashed line is a potential fit \( dN/dV \propto 2.3^V \) to the bright stars \( V < 16 \).

Distribution of spectral types down to the GAIA faintness limit. A total of 75959 stars were analyzed.

The luminosity function for \( V > 15 \) is frequently described by a potential law. Here we adopt a heuristic law

\[
dN/dV \propto 2.3^V - 0.05(V-15)^2
\]

which gives a better fit to the data (see Fig. 1). The relation is compatible with star counts predictions by the Galaxy model (ESA-SCI(2000)4, Torra et al. 1999) using Hakkila et al. (1997) extinction law.

Average star density of \( V < 17 \) stars equals 15100 stars/degree\(^2\) close to the Galactic plane \((|b| < 20^\circ)\) and 1900 stars/degree\(^2\) away from it \((|b| > 20^\circ)\). This is somewhat larger than the corresponding values (6100 and 1200 stars/degree\(^2\)) from the Galaxy model (ESA-SCI (2000)4). This is probably a statistical anomaly; symbiotic stars tend to lie close to the galactic plane and selection effects may emphasize regions of higher star density. Even so only 10% of directions close to the Galactic plane \((|b| < 20^\circ)\) reach the density of 40000 \((V < 17)\) stars per degree\(^2\). Spectral types of field stars cluster around an early K type at the bright end, reaching a mid-K for the faintest targets (Figure 2).
Figure 2. (a) Observed star density as a function of Galactic coordinates. (b) Distribution of observed colours for different magnitude classes: $14 < V < 16$ (dotted line), $16 < V < 18$ (dashed line), and $18 < V < 20$ (solid line). The latter is corrected for incompleteness. Labels on top mark colours of unreddened main sequence stars.

3. Crowding and the sampling law

The sampling law of the GAIA satellite guarantees that the arrangement of stars in the focal plane will be different for each of the $\sim 100$ transits of a given star, providing that the spin and precession periods of the satellite are kept incommensurate. Two stars that badly overlap in one passage have non-overlapping tracings on the next pass. This is a simple consequence of the fact that the length of the spectral tracing in the dispersion direction is much larger than its width. There will be unfortunate cases, for example close optical doubles, with tracings overlapping in a significant fraction of observations. But such stars are rare and so of no interest to us here. Below we discuss the results on spectral overlaps for typical randomly positioned stars in the focal plane.

Two spectra overlap with a probability $p$ if the length of the spectrum is larger than the free length

$$L = (ns)^{-1} \ln[(1-p)^{-1}]$$

where the star density equals $n$ stars per degree$^2$ and the width of the stellar tracing is $s$ arc-sec ($s \sim 4.5$ arc-sec for the Astrium design of the GAIA spectrograph). The results are presented in Table 1.

4. Conclusions

We shall comment on the result for a resolution of 10,000 assuming a spectral width of 4.5 arcsec. Results for other resolutions and spectral widths can be easily judged from Table 1.

The wavelength interval of GAIA spectra covers 250 Å around $\lambda_c = 8615$ Å. The spectral length for $R = 10,000$ is 580 pixels, assuming 2 pixels per resolution
Table 1. Severity of crowding following Eq. 2.

| star density \( n \) (stars/deg\(^2\)) | average free length (arcsec) | probability \( p \) that the distance between spectral heads is smaller than \( L \) (arcsec) |
|----------------------------------------|-------------------------------|-----------------------------------|
|                                        | \( L = 1 \)            | \( L = 10 \)       | \( L = 100 \)      | \( L = 500 \)     | \( L = 1000 \)    |
| 600                                    | 4800                         | 0.000                           | 0.002                           | 0.021                           | 0.099                           | 0.188                           |
| 1200                                   | 2400                         | 0.000                           | 0.004                           | 0.041                           | 0.188                           | 0.341                           |
| 3000                                   | 960                          | 0.001                           | 0.010                           | 0.099                           | 0.406                           | 0.647                           |
| 6000                                   | 480                          | 0.002                           | 0.021                           | 0.188                           | 0.647                           | 0.875                           |
| 20000                                  | 144                          | 0.007                           | 0.067                           | 0.501                           | 0.969                           | 0.999                           |
| 50000                                  | 57                           | 0.017                           | 0.159                           | 0.824                           | 1.000                           | 1.000                           |
| 100000                                 | 28                           | 0.034                           | 0.293                           | 0.969                           | 1.000                           | 1.000                           |

Since each pixel covers 1 arcsec on the sky in the dispersion direction the spectral overlap with another \( (V < 17) \) star will occur if the distance between spectral heads is smaller than 580 arcsec. One can see from Table 1 that this happens in some 21 out of 100 spectra if the star density is 1200 stars/deg\(^2\), a typical value for field stars with \( V < 17 \) at high Galactic latitudes. Density of fainter stars at the same position is much higher (see Eq. 1), so overlaps with \( V \sim 18 \) stars are common even at high latitudes. If one considers overlapping stars down to \( V = 20 \) the probability for an overlap increases to 97%. If the resolution were smaller than \( R = 10.000 \) the length of the spectral tracing covering the GAIA spectral wavelength interval would be shorter. Still it is clear that lower spectral resolutions cannot make spectra free from spectral overlaps of faint stars even at high Galactic latitudes. Fraction of spectra overlapped with \( V < 17 \) background stars increases to 70% at the star density of 6000 \( (V < 17) \) stars/deg\(^2\) (i.e. a value typical close to the Galactic plane).

Spectral overlap is never complete. Even at extreme star densities of 50.000 stars/deg\(^2\) only 16% of the spectra would have an overlapping \( (V < 17) \) spectrum starting within 10 arcsec (= 10 pixels) behind its head.

Spectral tracings in the focal planes of the GAIA spectrograph will overlap at all star densities and at all resolutions. The policy cannot and should not be to keep only the spectra that are free from overlaps. Should this be the case one would throw away most of the collected GAIA spectra.

References

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