WHAT GAIA WILL SEE: ALL-SKY SOURCE COUNTS FROM THE GSC2

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ABSTRACT

The Guide Star Catalogue II (GSC2) is an all-sky catalogue based on several photographic Schmidt plate surveys completed over the last century. The GSC2 has a magnitude limit of 20.5 in the photographic red passband (R_F) and nearly a billion classified objects ('stars' and 'nonstars'), making it a valuable data set for Gaia mission studies.

Using the known passbands of the GSC2 and Gaia, synthetic photometry is used to determine the colour transformation from the GSC2 (B_J, R_F) photometry to the Gaia G band: we find that within the GSC2 photometric errors, $R_F \approx G$. We therefore adopt the GSC2 counts in R_F to estimate the number of sources that Gaia will detect, after correcting for blending in the GSC2, an important effect in regions of high object field density.

Key words: Gaia: photometry; Galaxy: stellar content; Catalogs; Methods: data analysis.

1. INTRODUCTION

The astrometric instrument of Gaia is expected to detect sources as faint as $G = 20$, G being the effective transmission curve (passband) of the unfiltered CCD's on the astrometric focal plane (Astro). To prepare for the Gaia mission, i.e., to properly evaluate onboard hardware/software requirements it is necessary to have some expectation of the magnitude distribution over the whole sky of sources that Astro will detect. That is, a need has been identified for an all-sky map of source densities in the Gaia bands for mission development activities, and in particular to properly evaluate onboard hardware/software requirements:

- telemetry rate simulations
- data compression algorithms
- on-board object detection and data handling
- sampling and window strategy
- on-board processing requirements
- on-board solid-state memory requirements.

Thus the GSC2 (McLean et al. 2000) represents a potentially valuable resource for Gaia mission studies, given its similar magnitude limit and its all-sky coverage. Moreover, a comparison of the transmission curves of the Gaia G band and the GSC2 R_F band show that they have nearly the same central wavelength, suggesting that a $G - R_F$ colour transformation is small. Already the GSC2 source counts to $R_F = 20$ has been made available to the Gaia community in the form of an all-sky source density map. In addition the GSC2 counts have been corrected for object blending, an important bias effect in crowded fields.

Here we use the known GSC2 and Gaia G passbands, together with a stellar spectral library, to determine the $G - R_F$ colour transformation. With such a transformation we can in principle determine the G magnitude of each star in the GSC2, and thus produce a source density map for the G band. However, we find that R_F is already close to G, making GSC2 a viable, observationally-based analogue of what Gaia will see. We summarize the method used to correct for blending, and present all-sky source density statistics. We also compare the corrected GSC2 R_F counts to the G band counts produced by the Besançon Galaxy model.

2. GSC2 – GAIA PHOTOMETRY

Using the known Gaia and GSC2 passbands and the Gunn-Stryker library of stellar spectra (Gunn & Stryker 1983), synthetic photometry has been calculated for 175 stars covering a full range of stellar spectral types. The synthetic photometry then allows the $G - R_F$ colour transformation to be determined.

As shown in Figure 1, the colour transformation $G - R_F$, as traced by the fitted polynomial, is found to be smaller than the typical photometric error (random) of the GSC2, indicated by the error bar in the upper-left corner of the plot. However, a reliable colour transformation can only

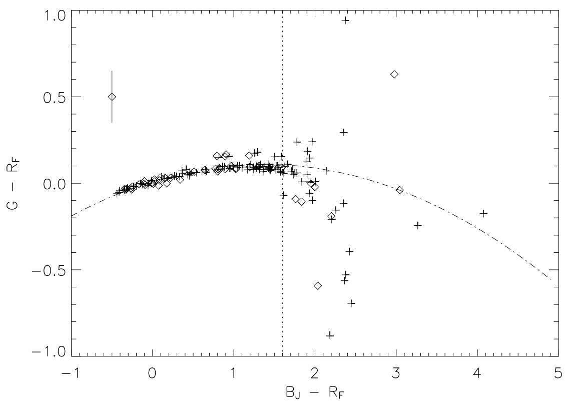

Figure 1. Colour transformation based on the synthetic photometry of 175 stellar spectra. Diamonds corresponds to main sequence (MS) stars, pluses (+) giants. A second order polynomial (dash-dot line) is fit to the MS data with $B_J - R_F < 1.6$.

be defined for stars bluer than about $B_J - R_F < 1.8$ due to the large scatter for the reddest stars. This large scatter is partly due to the presence of different luminosity classes, but errors in the synthetic photometry cannot yet be excluded. Work is currently underway to clarify the colour transformation for the red stars.

Given the small difference between G and R_F for stars bluer than $B_J - R_F < 1.8$, and given that we cannot yet reliably define a colour transformation for the reddest stars, we adopt as a working assumption $G = R_F$. We believe this is a prudent choice also because applying a colour transformation can introduce systematic errors in as much as actual observed stars will not always correspond to those selected from the adopted spectral library to construct the colour transformation (unreddened main-sequence stars). Indeed, as most of the stars in the Galaxy suffer interstellar extinction, a deeper study with the inclusion of synthetic reddening to define suitable transformations is planned.

We note here that the assumed G passband is consistent with the QE specified in Short & de Bruijne (2003), predating the recent update of the CCD quantum efficiency and optical transmission of the Gaia Astro instrument. Work has been initiated to update our synthetic G band photometry, though the resulting difference is expected to be small.

3. CORRECTED GSC2 COUNTS

Before using the raw object counts from GSC2 it is important to correct for the effect of object blending in crowded fields. Blending occurs when multiple objects lie nearly on the same line-of-sight, making them appear as a single object (a blend) on the Schmidt plates which have a typical resolution of 2–3 arcsec. Such a blend will appear brighter than the objects blended and will typically be classified as a 'nonstar' (i.e., extended object) in the GSC2. Hence blending leads to object loss (undercounting), magnitude biases and misclassification, as most objects in a crowded field will in fact be stars.

A simple but effective method to correct for blending has been applied to the GSC2 data. The method makes the following assumptions:

1. The intrinsic galaxy magnitude distribution is isotropic, consistent with the assumption of a homogenous universe.
2. Objects classified as nonstars are blends and galaxies.
3. Each blend is composed of two stars of equal magnitude.

Once a galaxy magnitude distribution is adopted, either from the literature or from the GSC2 itself (i.e., the nonstar magnitude distribution at the NGP, where blending is negligible), the adoption of a Galactic extinction map allows the expected observed galaxy magnitude distribution to be calculated. At galactic latitudes $|b| > 30°$ we adopt the extinction map of Schlegel et al. (1998), while at lower latitudes the total extinction resulting from the extinction model of Drimmel et al. (2003c) is used. From the second assumption and the expected magnitude distribution of the galaxies, the number of blends is deduced from the nonstar magnitude distribution. The last assumption allows the magnitude distribution of blends to be transformed to a magnitude distribution of de-blended stars which are then added to the magnitude distribution of the GSC2 objects classified as stars.

It should be noted that at low galactic latitudes, where blending is important, galaxies make a very small relative contribution to the total object counts. Thus uncertainties in the galactic extinction model have little consequence to the corrected counts. See Drimmel et al. (2003b) and Drimmel et al. (2003a) for further details.

As an example we here show the result of the correction as compared to high-resolution CCD data from the Guide Star Catalogue *Photometric* Survey (Bucciarelli et al. 2001) for a relatively crowded field at low galactic latitude toward the Galactic centre (Figure 2). The effect of crowding on the raw star counts is dramatic, while even the total object count begins to show evidence of incompleteness at about $R_F = 19$. Meanwhile the blending correction effectively corrects the star counts to $R_F = 20$.

4. ALL-SKY STELLAR DENSITY MAP

An all-sky map of the object and stellar field density is constructed from the GSC2 by compiling source counts, as a function R_F magnitude, for individual Hierarchical Triangular Mesh (HTM) regions[1]. There are 32768 HTM regions covering the sky, each region approximately covering 1.2 square degrees. It is to these region counts that the blending correction is applied.

[1] see http://www.sdss.jhu.edu/htm/ for details on the HTM

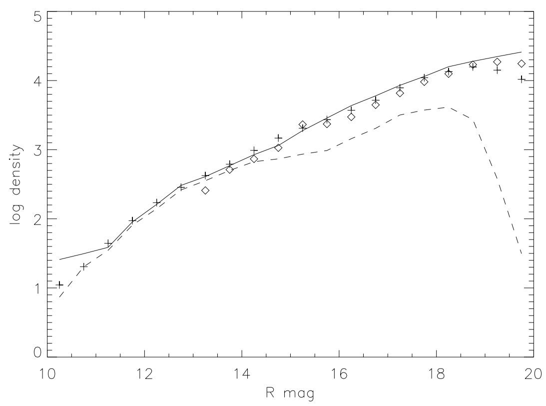

Figure 2. Stellar field density distribution according to the GSC2 for a field at galactic coordinates $(l, b) =$ (8.1,−17.5), before (dashed line) and after (solid line) correcting for blending. Diamonds show the stellar field density from the GSPC, while pluses (+) show the GSC2 total object field density (no correction).

After correction for blending we have an all-sky map of the stellar field density (Figure 3). The resulting total number of stars to 20th magnitude is 0.9 billion; accounting for possible incompleteness in GSC2, we estimate there are approximately 1 billion stars to 20th magnitude.

From the corrected GSC2 counts we can perform all-sky statistics. Figure 4 shows the fraction of sky with cumulative stellar field densities greater than the indicated limits. The plot shows, for example, that approximately 4% of the sky has a stellar field density greater than 10^5 stars per square degree at a magnitude limit of $G = 20$.

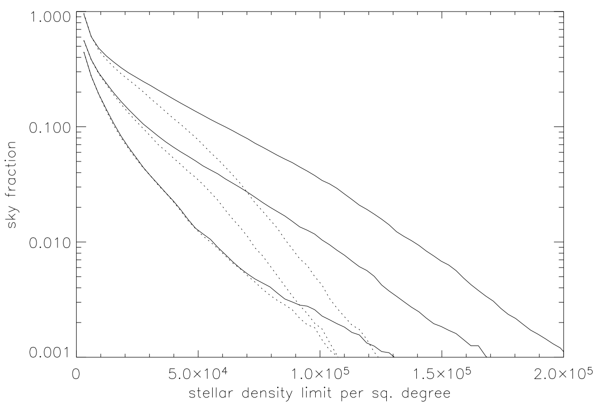

Figure 4. The two sets of curves (dashed and solid) are before and after the blending correction is performed, with the three curves corresponding to the magnitude limits of 17, 18.5, and 20 magnitude (left to right).

5. MAP VERSUS MODEL

The GSC2 catalogue fulfills the requirements for a static source density map appropriate for many Gaia mission studies. However, other studies require a galaxy model, such as testing data reduction methods, where the time dependence in the astrometric parameters must be included in the simulated data. One such model that has been recently employed is the Besançon model (Robin et al. 2003; Robin 2005). A data set such as GSC2 can be used to 'normalize' such a model to insure that it corresponds as closely as possible with the real sky.

Here we show a preliminary first comparison between the GSC2 and the Besançon model counts in the form of a relative difference map (Figure 5). Most of the discrepancy between the model and the observations are within 10° of the Galactic plane, probably due to inadequate extinction. The extinction model employed here by the Besançon model is that of Arenou et al. (1992), which only describes local extinction. A version of the Besançon model implementing the Galactic extinction model of Drimmel et al. (2003c) will be used for future comparisons. Meanwhile at mid to high latitudes ($|b| > 20°$) the systematic difference between GSC2 and the Besançon model is less than 15%.

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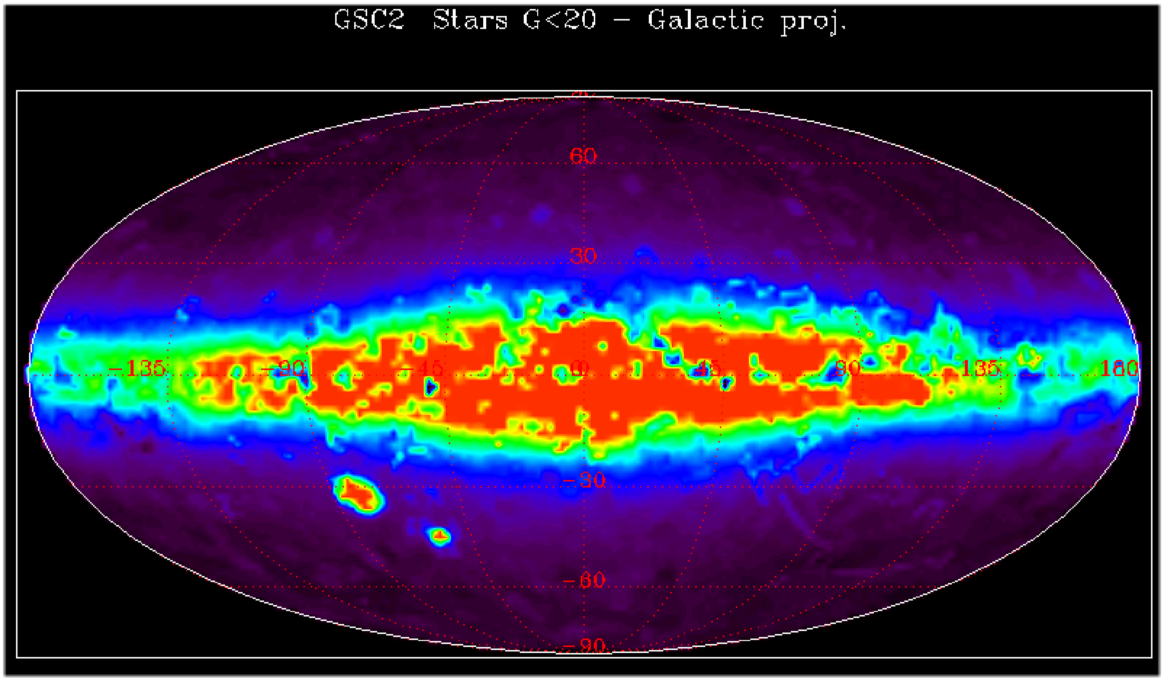

Figure 3. *Corrected GSC2 stellar field densities to $R_F = G = 20$. Red corresponds to a stellar field density of 70 000 stars per square degree.*

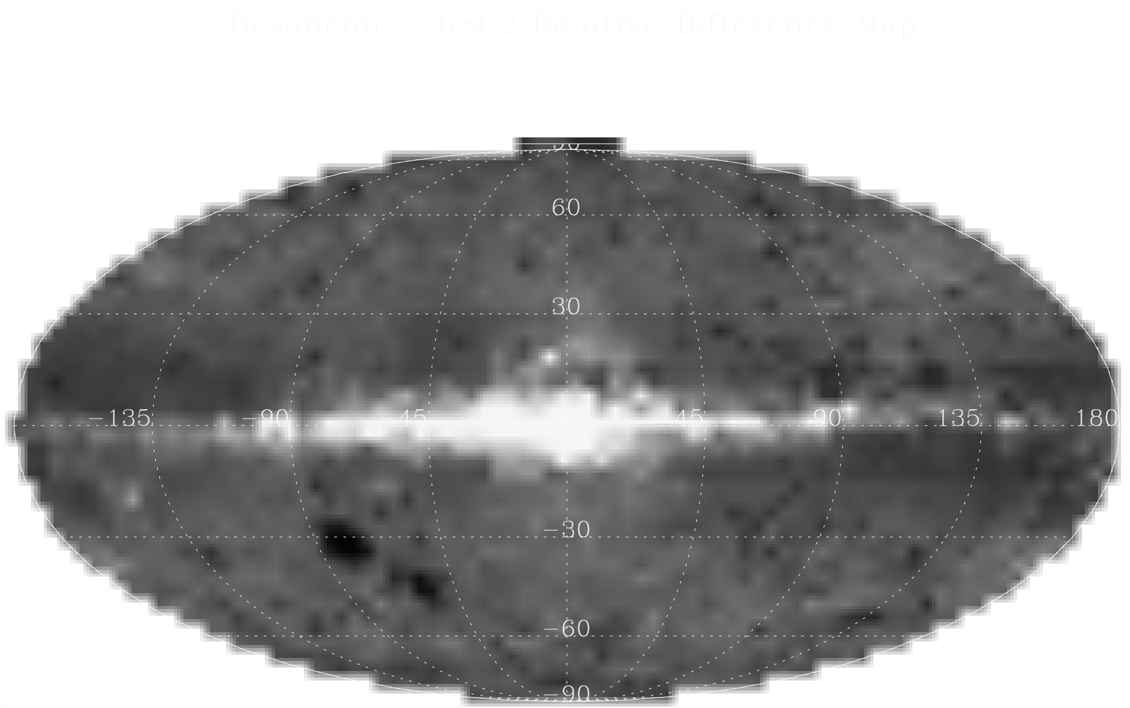

Figure 5. *The relative difference D=(Besançon - GSC2)/GSC2 to $R_F = G = 20$, shown on a logarithmic scale. White corresponds to $D = 5$, black to $D = -1$. The two dark regions below the Galactic plane correspond to the Magellanic Clouds.*