MEMBERSHIP AND PROPER MOTIONS OF THE OPEN CLUSTER STOCK 2 FROM GSC II PLATE MATERIAL

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ABSTRACT.

The second Guide Star Catalog (GSC II) will be an all-sky catalog complete to $V = 18.5$, containing colors from at least two bands and proper motions with errors $\sigma \leq 4\,\mathrm{mas\ yr^{-1}}$. These characteristics make it a very useful tool for membership studies of open clusters. To demonstrate its capabilities, we present the results of a membership study of the open cluster Stock 2 ($d = 320\,\mathrm{pc}$, $\mathrm{l^{II}} = 133$, $\mathrm{b^{II}} = -1.7$). A 3.9×6.2 degree region around Stock 2 was processed, matching more than 240 000 stars on 7 plates from the POSS I (epoch 1952), POSS II (epoch 1987–1993), and Palomar "Quick V" (epoch 1983) surveys. The methods for astrometric calibration and evaluation of proper motion are discussed. We present a vector point diagram of the Stock 2 cluster, finding 1208 probable members that are easily separated from field stars.

1. Introduction

Open clusters are an ideal laboratory for the study of stellar evolution, providing coeval, chemically homogeneous samples of stars across the H-R diagram. In fact, the better studied clusters have provided essential calibration points in the study of the evolution of many important parameters in solar-type stars, including activity, rotation and light element abundances. However, with the exception of a handful of nearby clusters, membership studies are very incomplete, often including only bright stars and/or are limited to the cluster core, excluding most of the solar-type stars. The lack of reliable and complete membership is a serious problem in the study of any open cluster except the few better studied ones. For example, it severely restricts usage of the recent wealth of X-ray observations of open clusters making it difficult to obtain unbiased X-ray luminosity functions.

With all-sky coverage, the GSC II project offers a unique opportunity to derive proper motions for open clusters, allowing to cover extended areas and thus also to study the often neglected cluster halos. For clusters within 500 pc, the GSC II magnitude limit allows memberships to be obtained for K and M dwarfs. Membership studies of open clusters with GSC II will supply a solid foundation to further studies with optical spectroscopy, photometry, and X-ray observations.

2. The GSC II

The first Guide Star Catalog (GSC I) was created to satisfy the pointing requirements of the Hubble Space Telescope, and contains stars to $V = 15$ (Lasker et al. 1990). The GSC II will be complete to $V = 18.5$ with all-sky coverage, with many areas complete to $V \simeq 22$ (Lasker et al. 1995). In addition, it will use plates from at least two epochs and passbands, and will contain positions, magnitudes, colors and proper motions. GSC II uses the same plate surveys as GSC I as first-epoch material, as well as Schmidt plates from the Second Palomar Sky Survey (POSS II) and from the Second Epoch Southern (SES) survey from the UK Schmidt at the Anglo-Australian Observatory for latter epochs. GSC II will contain proper motions for an estimated 5 x 10^8 objects complete to magnitude 18.5, and will not be restricted to processing only selected stars in the fields.

3. Astrometry

It is well known that astrometry from Schmidt plates suffers from many systematic effects due to geometric distortion from the telescope optics, stresses in the photographic plates, atmospheric refraction, and other causes. If not corrected, these effects would overwhelm attempts to extract proper motions. To remove them, a coordinate transformation is made, for each plate, to translate the local plate coordinates to a common reference frame, where the systematic effects are removed. For each field, the Palomar "Quick V" plate is chosen for the common coordinate frame, as it is intermediate in epoch between POSS I and POSS II. The coordinates (x_n, y_n) on plate n are transformed to coordinates (x_1, y_1) on the reference plate with the equations

$$x_1 = \sum_{i=0}^{3} \sum_{j=i}^{3} a_{ij} T_i(x_n) T_j(y_n), \quad y_1 = \sum_{i=0}^{3} \sum_{j=i}^{3} b_{ij} T_i(x_n) T_j(y_n) \tag{1}$$

where T_i and T_j are Chebyshev polynomials of order i and j, and a_{ij} and b_{ij} are coefficients found from a least-squares fitting to astrometric reference objects. For astrometric reference objects, we use faint, low proper motion stars between magnitude 16 and 18. We also use the method of overlapping sub-plates described by Spagna *et al.* (1996), in which each plate is broken into 1×1 degree sub-plates, each sub-plate having its own coordinate transformation from Eq. 1. In calculating the solution to Eq. 1, the sub-plates overlap by 20%, but the overlap is removed when applying the coordinate transformation. Relative proper motions are then calculated from $x(t) = x_0 + \mu_x(t - t_1)$ and $y(t) = y_0 + \mu_y(t - t_1)$ where t_1 is the reference plate epoch, (μ_x, μ_y) are the proper motions in the plate-coordinate frame, and x_0, y_0 are the recomputed positions at the epoch t_1. In this paper we discuss only relative proper motions.

4. The Stock 2 cluster

To demonstrate the performance of the final GSC II processing, we present here our results of a proper motion study of the nearby open cluster Stock 2 (RA = 02:15:30,

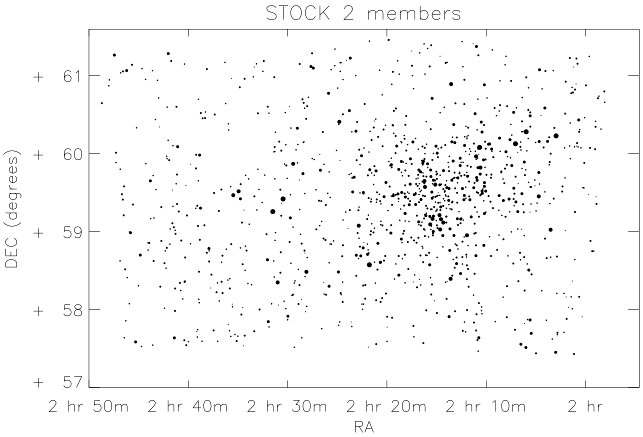

Fig. 1. Map of all 1208 probable members of Stock 2 found in our study. Stock 2 members are chosen from the Vector Point Diagram (Fig. 2) with $\sigma_\mu \leq 6\,\mathrm{mas\,yr^{-1}}$, within a radius of $5\,\mathrm{mas\,yr^{-1}}$ from the center of the Stock 2 group in Fig. 2. The stars are grouped into magnitude bins by dot size as follows: $V \leq 9.5$ (largest dots), $9.5 < V \leq 11$, $11 < V \leq 13$, $13 < V \leq 15$, $15 < V \leq 17$, and $V > 17$ (smallest dots).

Dec = +59:21:37, $l^{II} = 133, b^{II} = -1.7$). We chose Stock 2, among other reasons, because of its large relative proper motion with respect to field stars, which makes it easy to discriminate the member stars. This cluster has not been subjected to any previous membership surveys using proper motions (with the exception of the recent work of Spagna 1996). Krzeminsky & Serkowski (1967) derived membership for about 150 Stock 2 stars down to $V = 13$, based on optical photometry, spectroscopy and polarimetry. They derived a distance of 316 pc and a mean reddening $E_{B-V} = 0.375\,\mathrm{mag}$.

We processed a 3.9×6.2 degree region around the position of Stock 2 (Fig. 1). The region is not centered on the cluster and is oddly shaped due to the particular way the plates from the surveys used overlap. Seven plates were used: two from POSS I (epoch 1952, limiting magnitude 21 in B and V), four from POSS II (epoch 1987–1993, limiting magnitude 21 in R, 22.5 in B), and one from the Palomar "Quick V" (epoch 1983, limiting magnitude 19 in V). In total, 242 881 objects were matched on all the seven plates down to $V = 19$. At $V = 16$ we find that the standard deviation of the error in proper motion is $\sigma_\mu = 4\,\mathrm{mas\,yr^{-1}}$, which is as good as we hope to achieve with the final GSC II catalog.

Fig. 2 shows a vector point diagram (VPD) of all 199 749 objects in the 3.9×6.2 degree region which have formal error in their proper motions $\sigma_\mu \leq 6\,\mathrm{mas\,yr^{-1}}$. The members of the Stock 2 cluster are clearly visible as a separate clump of objects in the VPD at $\mu_{\alpha\cos\delta} \simeq 15\,\mathrm{mas\,yr^{-1}}$, $\mu_\delta \simeq -15\,\mathrm{mas\,yr^{-1}}$, to the lower right of the field star concentration. We find 1208 probable members within a radius of 5 mas from the center of the Stock 2 group in the VPD, of which we estimate about 100 to be false matches due to field stars contamination. Fig. 1 shows the spatial distribution of these probable

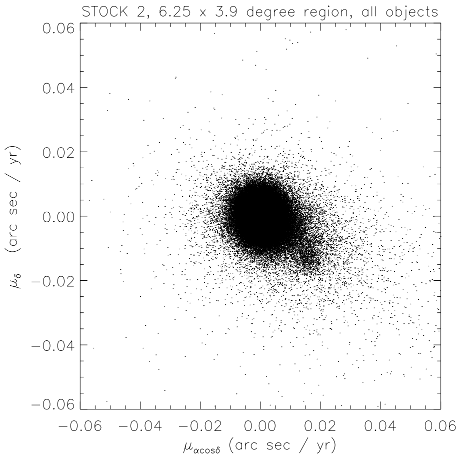

Fig. 2. Vector Point Diagram for all the objects in the Stock 2 region with formal error in the proper motions $\sigma_\mu \leq 6\,\mathrm{mas\,yr^{-1}}$. Only relative proper motions are shown, with the average proper motion of field stars set at (0,0). The Stock 2 cluster members are easily identified as the small clump to the lower right of the larger group of field stars. There are about 200 000 field stars in the main clump, and about 1200 stars in the Stock 2 clump.

members. The ratio between cluster member and field stars in the central 2×2 degree cluster core is 1:70 (541 cluster members and 38 357 field stars).

We are currently determining magnitude and colors for the stars of which here we have presented the proper motions. In the future we will publish a complete list of cluster members, together with an H-R diagram and a luminosity function for the cluster. Further details of the methods used to obtain proper motions with the GSC II and for the Stock 2 field in particular may be found in Spagna (1995).

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References

Krzeminski W., Serkowski K. 1967, *Astrophys. J.* **147**, 988

Lasker B. M. et al. 1990, *Astron. J.* **99**, 2019

Lasker B. M. et al. 1995, in *Future Possibilities for Astrometry in Space*, ESA SP-379, p. 137

Spagna A. 1995, Ph.D. Thesis, Turin, Italy

Spagna, A. et al. 1996, Å311 778