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Precision Galactic Structure

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For the SDSS Collaboration

Abstract. Optical and IR surveys in progress or in the planning stages will lead to substantial improvements in our picture of the Milky Way as a consequence of their providing large volumes of data with much improved photometric and positional measurements compared with existing datasets.

1. Introduction

The structure of the Milky Way can be described to first order by a canonical model that is the sum of a circularly symmetric disk (or two disks, one thick, one thin), a bulge (either an oblate spheroid or a triaxial bar), and an oblate spheroidal halo; each component has characteristic shape parameters, stellar populations, and kinematic properties. While the major features of each component are reasonably well known, gaps remain (e.g. the mass function for low mass stars); further, in detail the Milky Way has a more complex structure than that of the canonical model. Existing and future optical and near IR surveys such as SDSS and 2MASS will provide a wealth of new data on the Milky Way, and it would seem that it should be possible to improve our models of the Milky Way immensely. However, interpretation of the data is not necessarily straightforward, and this paper will discuss how precision Galactic Structure requires data of high quality, not just large quantity.

The data sets provided by the photometric surveys typically consist of star counts as a function of position, apparent magnitude, and mulitple colors. The first problem one encounters is that interpretation of these data requires that one model the galaxy in equal detail; a study of Galactic structure ends up being as much an exercise in modeling stellar populations as it is in modeling the structure itself. If one wishes to probe the structure of the disk at large distances from the sun, one must additionally deal with problems of confusion due to high star densities and extinction by dust. Fortunately the dust seems to follow the total gas content of the Galaxy, so maps can be contructed based on HI and CO surveys (Kent, Dame and Fazio 1991). Finally, to probe the kinematic properties of the Galaxy, one would like to combine radial velocity and proper motion surveys to obtain 3-dimensional velocities of large samples of stars.

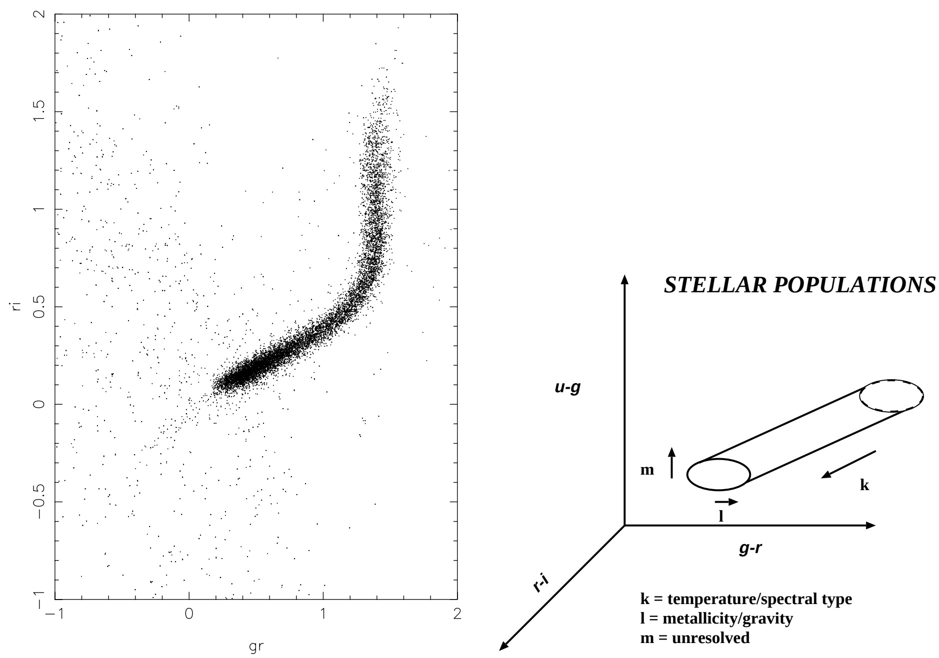

Figure 1. Stellar locus in two SDSS colors (left) and three colors (right)

2. Stellar Populations

The observable properties of a population of stars can be expressed as a multidimensional function of luminosity and color. Stars do not uniformly fill this space, but are concentrated in a narrow locus.

Figure 1 shows a typical projection of the stellar locus in two SDSS colors On the right is a schematic representation of a section of the locus in a 3 dimensional color space. Newberg et al (1997, APJS, 113, 89) have shown that the locus is remarkably well behaved. If one defines principal axes k, l, m as shown, then the k axis primarily measures temperature, l measures a mix of metallicity and gravity, while the m dimension is essentially unresolved. The widths in the l and m direction are .07 mag and .03 mag respectively (FWHM). Newberg et al. have shown that it is possible to measure metallicities of F and G main sequence stars with an accuracy of 0.13 dex.

In a typical magnitude-limited sample of stars, stars with the same apparent magnitude but different colors can a wide range of intrinsic luminosity, making it difficult analyze such samples as a single set. Often it is possible to select a subset of stars based on color alone that have a narrow range in luminosity compared with the ensemble of all stars, esaing the task of making detailed structure maps Two features that will be used in the next section include the main sequence turnoff, which is readily identified in any histogram of stars vs. color, and the blue horizontal branch, which can be picked out using u, g, r colors or their equivalent. Color alone cannot distinguish blue horizontal branch stars from blue stragglers, however.

3. Halo

Properties of the halo that are not yet well known include:

1. Radial density profile: $\rho(r)$.
2. Metallicity vs. radius.
3. Triaxiality: $a : b : c$, which may be a signature of the underlying dark matter distribution.
4. Substructure.

Figure 2 is a plot from Yanny et al. (2000) of the distribution of BHB stars along the equator in early SDSS data. The most notable feature is the presence of bands of stars between 19th and 21st mag (g) in both the Northern and Southern Galactic hemispheres. The double band seen in the North (lower right part of the figure) is thought to be a single structure seen in BHB's at 19th mag and blue stragglers at 21st mag. The bands are thought to be the tidally disrupted remnants of companion galaxies of the Milky Way captured at some previous time. The masses are a few million solar masses.

4. Disk/Halo Transition

Figure 3 is a color/apparent-magnitude diagram for stars from the SDSS commissioning data covering approximately 8 square degrees of sky in the South Galactic Hemisphere. This line-of-sight is close to perpendicular to the Galactic disk and thus samples primarly the old disk and the nearby halo. The near-vertical band on the left side of the figure arises from stars at the main sequence turnoff; the band fainter than $g = 18$ on the right side of the diagram arises from K and M dwarfs in the Galactic disk. The turnoff stars show an abrupt change in color from $g - r = 0.4$ to $g - r = 0.25$ at around $g = 18$. This change reflects the transition from the metal-deficient thick disk to the even more metal-poor halo (Chen et al. 2000). The vertical extent of the thick disk has been notoriously tricky to measure; with accurate photometry, its separation from the halo is straightforward.

5. Precision Dynamics

Measurement of dynamical quantities such as the local mass density in the solar neighborhood proves to be perniciously difficult when one attempts to attains accuracies of better than a factor 2. In principle the problem is well defined: one only needs to measure the density and velocity dispersions, including their gradients, for a homogeneous subpopulation of stars. In practice, the amount of data required to do a complete job is prohibitive, and virtually all analyses introduce simplifying assumptions, at the cost of possibly introducing biases in the results (e.g., Kuijken and Gilmore 1989). Limiting factors include the lack of combined radial velocity/proper motion data for large samples of stars that are needed to construct 3-dimensional velocity ellipsoids. Future proper motion

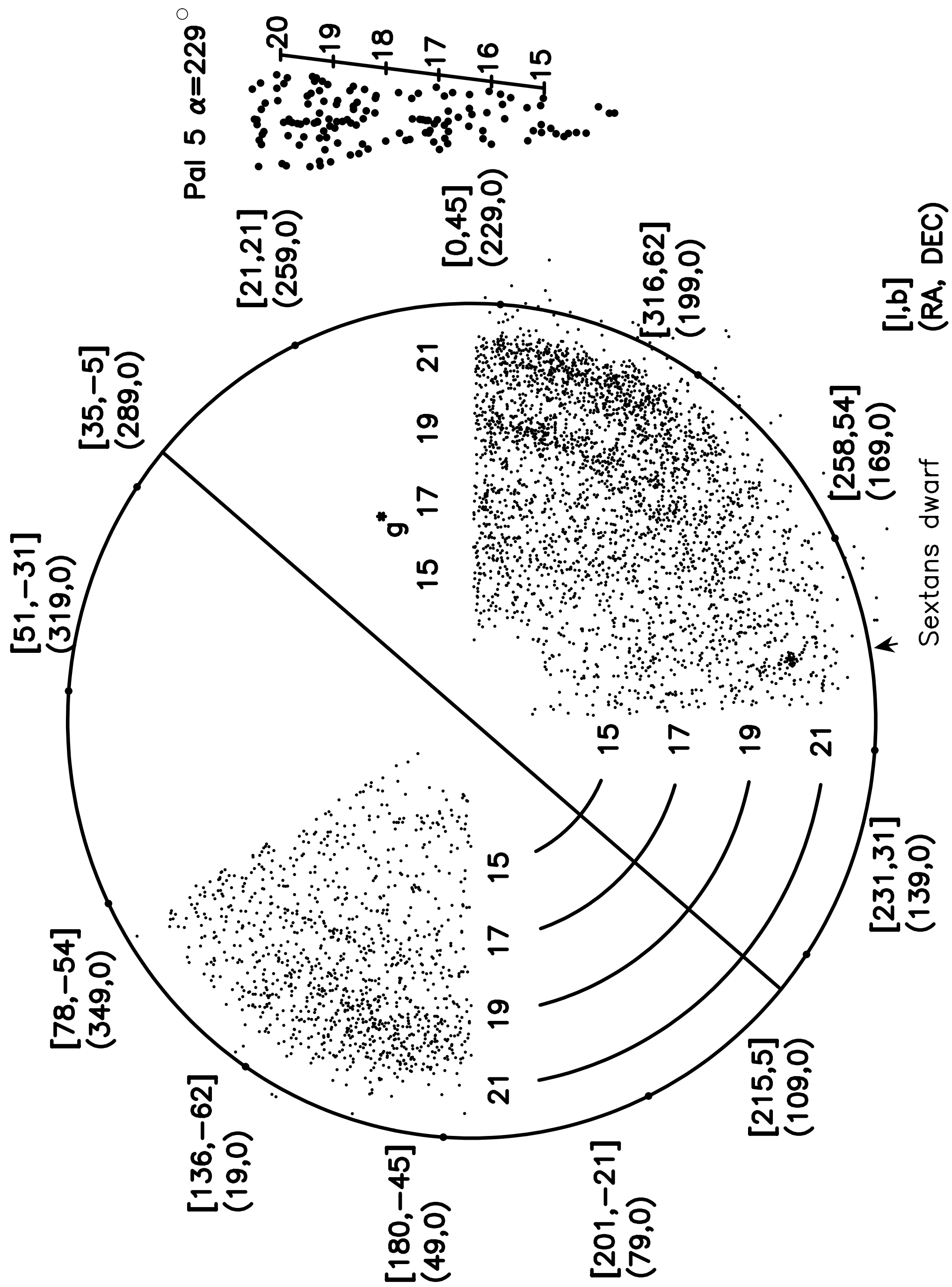

Figure 2. Distribution of horizontal branch stars on the celestial equator.

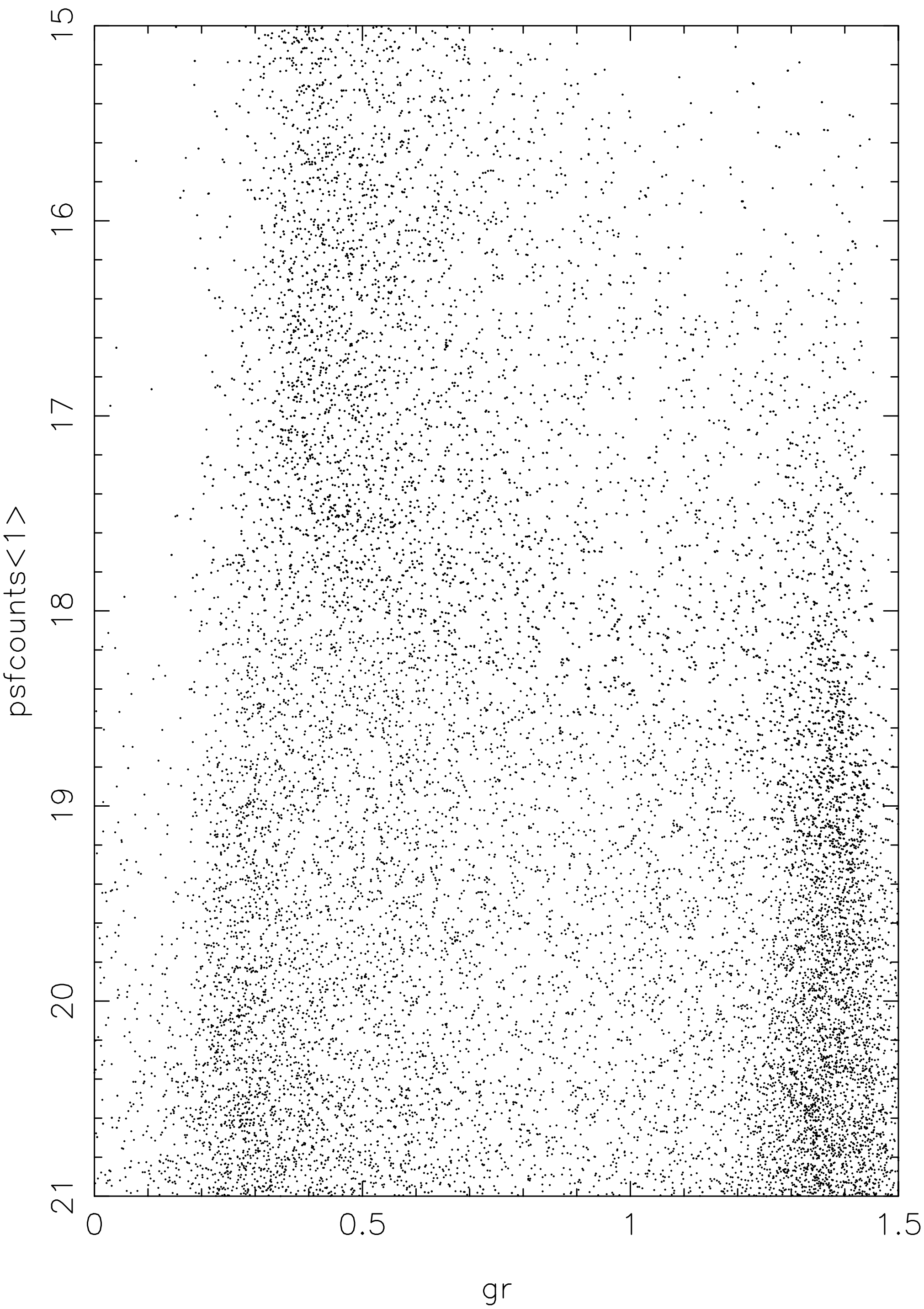

Figure 3. g-r color vs. apparent g magnitude for a sample of stars near the SGP

surveys (e.g., as might be constructed by combining scans of plates from the two Palomar Sky Surveys) could have a major impact.

A classic problem is measurement of the tilt of the velocity ellipsoid for a population of stars as one moves out of the Galactic plane (Kent and De Zeeuw 1991). For stars in the plane of the disk, the velocity dispersion in the radial direction is about twice that perpendicular to the disk. If the mass of the Galaxy is spherically symmetric, then as one moves out of the plane, the major axis of the velocity distribution function rotates so as to continue pointing to the Galactic center, but if the mass is primarily in the disk, the major axis will remain parallel to the disk. A measurement of this direction gives information on the ratio of disk to (dark) halo mass. Halo stars, for example, have a characteristic velocity dispersion of 150 km s^{-1}, so measurement of the tilt term at a height of 10 kpc above the plane requires accurate radial velocities combined with proper motions that have errors of order 3 milliarcseconds per year.

6. Conclusions

The field of Galactic Structure will benefit greatly from the new generation of surveys, both because of their completeness and their accuracy. The problems and possibilities discussed above are just a fraction of the total that one can imagine. Full utilization of these surveys will require joint analyses of combined data sets.

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