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# Mapping the Milky Way with SDSS, Gaia and LSST

**Željko Ivezić (for the LSST Collaboration)**
Department of Astronomy, University of Washington, Seattle, WA 98155, USA
email: ivezic@astro.washington.edu

**Abstract.** We summarize recent work on the Milky Way "tomography" with SDSS and use these results to illustrate what further breakthroughs can be expect from Gaia and the Large Synoptic Survey Telescope (LSST). LSST is the most ambitious ground-based survey currently planned in the visible band. Mapping of the Milky Way is one of the four main science and design drivers. The main $20\,000\,\mathrm{deg}^2$. survey area will be imaged about 1000 times in six bands (*ugrizy*) during the anticipated 10 years of operations, with the first light expected in 2015. Due to Gaia's superb astrometric and photometric accuracy, and LSST's significantly deeper data, the two surveys are highly complementary: Gaia will map the Milky Way's disk with unprecedented detail, and LSST will extend this map all the way to the halo's edge.

**Keywords.** Surveys, atlases, catalogs, astronomical data bases, astrometry, photometry

## 1. The Milky Way Tomography with SDSS

With the SDSS data set, we are offered for the first time an opportunity to examine in situ the thin/thick disk and disk/halo boundaries over a large solid angle, using millions of stars. In a three-paper series, Jurić *et al.* (2008), Ivezić *et al.* (2008a) and Bond *et al.* (2009) have employed a set of photometric parallax relations, enabled by accurate SDSS multi-color measurements, to estimate the distances to tens of millions of main-sequence stars. Photometric metallicity estimates based on the $u-g$ colors are also available for about six million F/G stars, and proper motions based on a comparison of SDSS and the Palomar Observatory Sky Survey positions are available for about 20 million stars.

With these distances, accurate to ∼10%, the stellar distribution in the multi-dimensional phase space can be mapped and analyzed without any additional assumptions. The adopted analytic models and a computer code (*galfast*†) that summarize these results, can be used to generate mock catalogs for arbitrary depths and photometric systems (including kinematic quantities). They also enable searches for substructure by subtracting the smooth background distributions. Indeed, a lot of substructure is seen in the data in all projections of the parameter space (spatial distributions, kinematics, metallicity distribution).

The extension of observations for numerous main-sequence stars to distances up to ∼ 10 kpc represents a significant observational advance, and delivers powerful new constraints on the dynamical structure of the Galaxy. For example, most stars observed by the Hipparcos survey are within ∼100 pc (Dehnen & Binney 1998). In less than two decades, the observational material for such in situ mapping with main-sequence stars has progressed from first pioneering studies based on only a few hundred objects (Majewski 1993), to over a thousand objects (Chiba & Beers 2000), to the massive SDSS data set.

These new quantitative results enable fairly robust predictions for the performance of new surveys, such as Gaia and LSST (Eyer *et al.*, in prep.). Due to Gaia's superb

† See http://hybrid.mwscience.net.

astrometric and photometric measurements, and LSST's significantly deeper data, the two surveys will be highly complementary: Gaia will map the spatial, metallicity and kinematic distributions of stars in the Milky Way's disk with unprecedented detail, and LSST will extend these maps all the way to the halo's edge, and will obtain large local samples of intrinsically faint sources such as L, T and white dwarfs. We briefly describe LSST in the next section.

## 2. Brief Overview of LSST

LSST will be a large, wide-field ground-based system designed to obtain multiple images covering the sky that is visible from Cerro Pachón in Northern Chile. The LSST design is driven by four main science themes: constraining dark energy and dark matter, taking an inventory of the Solar System, exploring the transient optical sky, and mapping the Milky Way. The current baseline design, which envisages an 8.4 m (6.7 m effective) primary mirror, a 9.6 deg$^2$ field of view, and a 3,200 Megapixel camera, will allow about 10,000 square degrees of sky to be covered using pairs of 15-second exposures in two photometric bands every three nights on average. The system is designed to yield high image quality as well as superb astrometric and photometric accuracy. The survey area will include 30,000 deg$^2$ with $\delta < +34.5°$, and will be imaged multiple times in six bands, *ugrizy*, covering the wavelength range 320–1050 nm. About 90% of the observing time will be devoted to a deep-wide-fast survey mode which will observe a 20 000 deg$^2$ region about 1000 times in the six bands during the anticipated 10 years of operations. These data will result in databases including 10 billion galaxies and a similar number of stars, and will serve the majority of science programs. The remaining 10% of the observing time will be allocated to special programs such as Very Deep and Very Fast time domain surveys. More information about LSST can be obtained from www.lsst.org and Ivezić *et al.* (2008b).

Each 30-sec observation will be about 2 mag deeper than SDSS imaging, and the repeated observations will enable proper-motion and trigonometric parallax measurements to $r = 24.5$, about 4-5 mag fainter limit than to be delivered by Gaia, and the coadded LSST map will reach $r = 27.5$. Due to Gaia's superb astrometric and photometric accuracy, and LSST's significantly deeper data, the two surveys will be highly complementary. As shown by Eyer *et al.*, in the range $19 < r < 20$ Gaia's and LSST errors are fairly similar (within a factor of $\sim 2$). Towards brighter magnitudes, Gaia's error significantly decrease (by about a factor of 10 already at $r \sim 14$), and towards fainter magnitudes, LSST will smoothly extend the Gaia's error vs. magnitude curves by over 4 mag.

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