A SURVEY OF SURVEYS

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Abstract. A new era for the field of Galactic structure is about to be opened with the advent of wide-area digital sky surveys. In this article, I will review the status and prospects for research for 3 new ground-based surveys: the Sloan Digital Sky Survey (SDSS), the Deep Near-Infrared Survey of the Southern Sky (DENIS) and the Two Micron All Sky Survey (2MASS). These surveys will permit detailed studies of Galactic structure and stellar populations in the Galaxy with unprecedented detail. Extracting the information, however, will be challenging.

1. The Surveys

The SDSS is a project to produce a digital photometric map of half the northern sky to about 23 mag in the V band. This map will be used to select about a million galaxies and 100,000 quasars for which high resolution spectra will be obtained with the same wide-field special-purpose telescope. The imaging survey will also be used to produce a catalog in five colors (u' to z') of all detected objects, about 100 million galaxies and a similar number of stars, and a million quasar candidates. The survey will be conducted with a special purpose telescope to be built at Apache Point Observatory in New Mexico. The instrumentation will consist of a mosaic of 30 Site 2048 X 2048

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CCDs and a pair of multi-fiber spectrographs which can obtain spectra of 600 objects simultaneously.

The DENIS project will provide a uniform survey of the southern sky at three near-infrared bands: I, J, and K. The expected data products are a set of elementary images (12' X 12') and specialized catalogs of point and extended sources comprising 10 million stars and 250,000 galaxies. The survey will be used to investigate stellar populations (particularly low temperature stars, brown dwarfs, and red giants and asymptotic giant branch stars, and Galactic bulge stars) and the properties and distribution of external galaxies. The instrumentation will consist of a single Tektronix CCD for the I band and two 256 X 256 HgCdTe array detectors for the J and K bands.

The 2MASS project will provide a uniform survey of the entire sky at three near-infrared bands: J, H, and K' (a modified K). A major goal of the survey is to probe large scale structures in the Milky Way and in the Local Universe, exploiting the relatively high transparency of the interstellar medium in the near-IR and the high near-IR luminosities of evolved low- and intermediate-mass stars. Approximately 100 million stars and 1 million galaxies will be detected. Two special purpose telescopes will be built and sited at Mount Hopkins Arizona in the northern hemisphere and Cerro Tololo in the southern hemisphere. The instrumentation will consist of a camera with a mosaic of 256 X 256 HgCdTe array detectors.

2. Comparison of Surveys

The two near-infrared surveys have rather similar capabilities. The SDSS survey is complementary to the other two. Table 1 compares a number of characterstic parameters among the three surveys.

A comparison of the SDSS with the IR surveys reveals that:

1. Sky Coverage - the SDSS will cover primarily the north Galactic pole region down to b=30 degrees (and a smaller portion of the southern sky). The IR surveys will cover the entire sky, particularly the Galactic plane and bulge. The SDSS will overlap with only the northern half of the 2MASS survey.
2. Detection limits - A comparison of the detection limits for point sources of the 3 surveys is shown in Figure 1. Also plotted are a sample of spectra for "normal" stars. Because the SDSS is a bigger telescope and will have longer integration times, it will be more efficient at detecting stars earlier than spectral type M5. Table 2 gives typically maximum distances out to which stars of various classes will be detected by the surveys. The SDSS actually has a more serious problem in that it will

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TABLE 1. Comparison of Major Optical/IR Surveys

	SDSS	2MASS	DENIS
Coverage	NGP $b > 30$ deg	All Sky	$\delta < 0$ deg
Telescope	2.5 m	1.3 m	1 m
Detector	30×CCDs	3×HcCdTe	1×CCD 2×HgCdTe
Bands	$u'g'r'i'z'$	JHK'	IJK
Pixel size	0.4″	2″	1.5″(I) 3″(JK)
Integration Time (s)	55	8	9
Duration (Yrs)	5	3	3-4
Location	APO	FLWO + CTIO	ESO
Institutions	8	9	20
Phot. Error (rms mag)	0.02	0.05	0.05
Astrometric Error (rms)	< 0.2″	≥ 0.5″	
Limiting Mag	$V = 22$	$K = 14$	$K = 14$
Dynamic Range (mag)	8	10	

saturate for stars brighter than about V=14. This renders it of minimal use for studies of giants at distances of less than a few kpc.

3. Filter Bands - One weakness of the SDSS for Galactic research is that it is being conducted with very non-standard bandpasses. The g' filter, centered at 0.44 microns, is especially wide. Interpreting the SDSS data in the context of existing stellar photometry will be complicated.

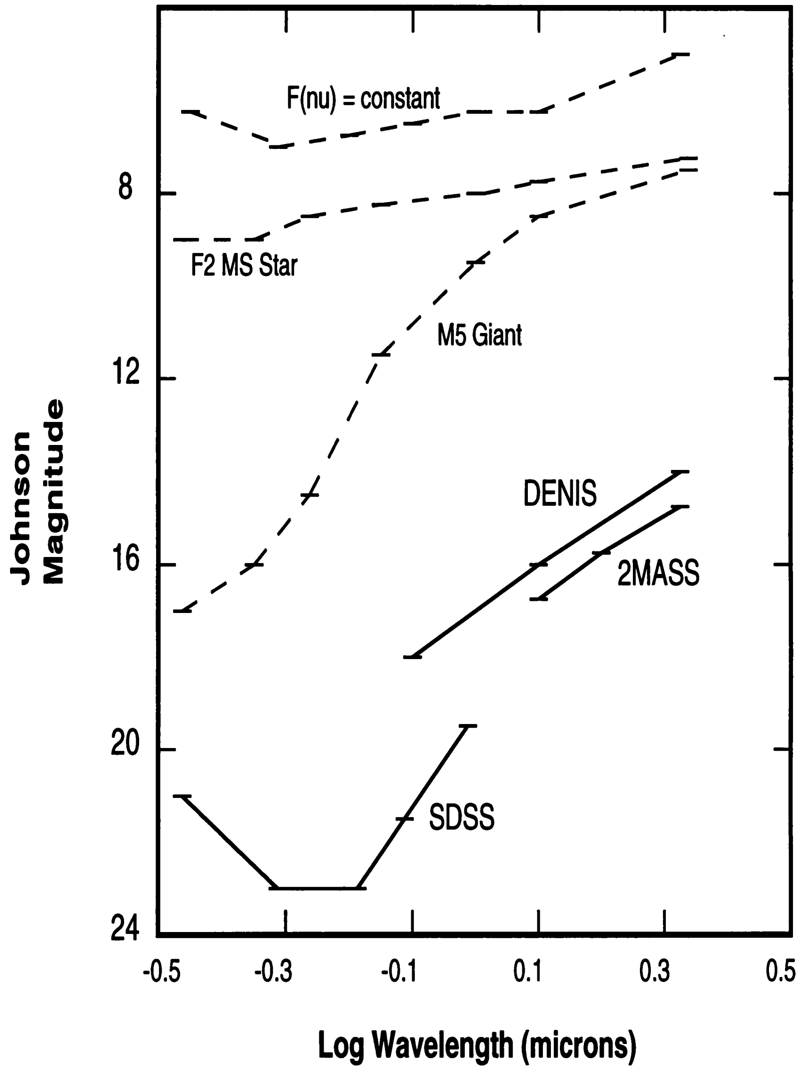

Figure 1. Sensitivity Limits of Optical and IR Sky Surveys

DENIS and 2MASS use standard bands with the exception of K, where each has its own minor variation.

3. Advantages for Galactic Research:

1. Uniformity - The SDSS has a goal of about 2% systematic error over the sky. The IR surveys do not have stated goals but should achieve an error of order 5%. For studies such as number counts of stars, errors

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TABLE 2. Comparison of Survey Depths

Star Type	SDSS (kpc)	2Mass/DENIS (kpc)
OH/IR ojbect	–	100
Mira Giant	1000	300
M5 Giant	126	50
Horizontal Branch Star	275	4.4
F subdwarf	50	1.2
M5 dwarf	0.5	0.1
Brown Dwarf	–	0.01-0.10

in the counts from survey non-uniformity become negligible compared with other uncertainties.

2. Multi-color data - Such data are invaluable for distinguishing stars of different types and metallicities.
3. Coverage - The usefulness of this property is self-evident. The combination of wide angular coverage, depth, and uniformity will permit quantitative probes of Galactic structure that have not been possible up to now.

4. Hazards of Galactic Structure

In principle, star count data, such as will be collected by the three surveys, provide much more information on Galactic structure than integrated light maps from surveys such as the *DIRBE* experiment on *COBE*. The extra information consists of differential counts as a function of both color and magnitude at each position in the sky, One learns about the distribution of stars in the Galaxy from both the distribution of stars along the line of sight and from the variation of the counts with direction in the sky. However, in order make use of this information, one must have some model for the distribution of stars in the H-R diagram. In the absence of *a priori* information about this distribution, the number of additional knowns introduced by having star counts is matched by the additional unknowns, and so, compared with integrated light maps, one actually gains no additional information about Galactic structure at all! In practice we do have a priori knowledge, but interpretation of star count data is as much an exercise in modeling stelllar populations as it is in modeling Galactic structure, and ambiguities are often present in such analyses (e.g., Habing 1988; Wainscoat *et al.* 1992; Ortiz and Lepine 1993). Nevertheless, the new wide angle surveys will provide enough new information that some of the ambi-

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guities will be resolved. particular for populations with with axisymmetric distributions such as the old disk or halo.

In detail, it is convenient to look at halo and disk components separately.

4.1. HALO

The canonical model of the halo is a slightly flattened de Vaucouleurs profile, with parameters given by Bahcall and Soneira (1980). This model works well in reproducing existing star counts at high Galactic latitude for $V < 19$, but predicts too many stars at fainter magnitudes (Reid and Majewski 1993). Some combination of a flatter spheroid and/or a shorter scale length is indicated. The Reid and Majewski paper also illustrates the value to having color information: their "standard model" reproduces the star counts at the NGP reasonably well for $V < 19$, but fails to reproduce the color distribution at a fixed magnitude, indicating that the relative ratios of disk and halo stars is incorrect.

The SDSS should provide the most useful information on the halo. It will detect main sequence turnoff stars to a distance of 50 kpc. For stars fainter than V=17, halo stars are dominant in star counts, and one can further distinguish them on the basis of their blue color (Kron 1980). Some problems that can be addressed are:

1. An improved measure of the density profile with radius.
2. A proper measure of the flattening of the halo, plus a measure of its triaxiality.
3. From multicolor data, an improved measure of the variation of metallicity with radius.

The SDSS u' filter lies shortwards of the Balmer discontinuity at 0.36 microns, and so the SDSS will be able to detect and distinguish blue horizontal branch stars throughout the halo.

4.2. DISK

A number of models for the distribution of stars in the Galaxy incorporate complex models for the disk above and beyond the nominal exponential disk with a sech^2 vertical profile of constant scale height (e.g., Bahcall and Soneira 1980; Hayakawa *et al.* 1981; Gilmore and Reid 1983; Robin & Creze 1986; Habing 1988; Ruelas-Mayorga 1991a,b; Wainscoat *et al.* 1992; Ortiz and Lepine 1993). A composite of such models might incorporate a young thin disk, an old thin disk, a thick disk, and multiple spiral arms. Each component has its own spatial distribution, stellar population, and kinematics. Such complexity seems to be required to explain the cumulative observations of the disk so far, but the number of free parameters required

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to characterize each component is larger than can be constrained by existing observations. To date, global star counts have played little role in contraining these parameters, primarily because the existing data are sporadic, do not go very deep, and are nonuniform. Data for the southern hemisphere are particularly sparse. DENIS and 2MASS will completely reverse this situation. They should detect all AGB stars in the Galaxy and all late type giants to a distance at or beyond the Galactic center. The counts should be dominated by disk giants for all positions in the disk except near the bulge.

Any interpretation of star count data in the Galactic plane must contend with two effects: extinction by dust and confusion due to high star densities in the Galactic plane. Both effects can be minimized by looking just outside of the plane, but the loss of information is high: at a latitude of just 2 degrees, a line of sight to the Galactic center is 280 pc above the Galactic plane and already missing over half the stars in the disk. Even at K band, the extinction to the Galactic center is of order 3 mag. Thus, careful modeling of the dust distribution is necessary. Fortunately, the dust distribution in the Galaxy seems to follow the gas density rather closely, so one can do kinematic modeling of the gas distribution from HI and CO observations and thus construct a 3 dimensional map of extinction over a substantial range of Galactic longitude (roughly 20 to 60 degrees) where extinction problems are most severe (e.g., Kent, Dame and Fazio 1991) A rough estimate of the confusion limit suggest that one will do 10% photometry on $K = 10$ stars at position $b = 0, l = 20$. 2MASS, with its smaller pixels, will be better off than DENIS, and both with be confusion limited well above their sensitivity limits.

A sample of problems that can be attacked by the sky surveys includes:

1. Comparison of starcounts with existing models: Detailed Galaxy models of infrared star counts exist already (e.g., Ortiz and Lepine 1993), but are untested due to a paucity of data. The new surveys will rectify that shortage. It may be possible to probe the dependence of characteristic scale lengths and scale heights on stellar population.
2. Non-axisymmetric Galactic structure: DENIS and 2MASS data will be well suited to probes of nonaxisymmetric structure in the Galaxy. Here, one can use lines of sight outside of the plane itself in order to probe N-S asymmetries and thus overcome the extinction/confusion problems. Of major interest is whether our Galaxy has a classical bar and/or a triaxial bulge. Tantalizing evidence exists (Blitz and Spergel 1991; Weinberg 1992) but at present it is ambiguous as to what the nature of the bulge/bar is, its radial extent, and its thickness. If the Milky Way has a bar of size 1 scale length (3 kpc) which is typical for external barred galaxies, then in projection it will extend to a longitude

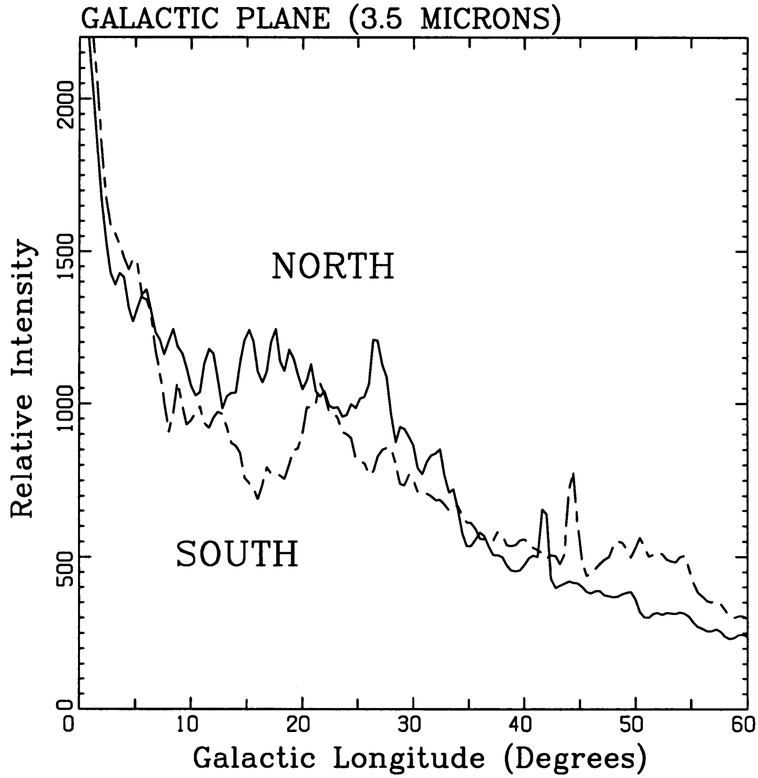

Figure 2. DIRBE 3.5 micron luminosity profiles of Galactic plane. Profiles are integrated over ±1° of latitude.

of between -20 and 20 degrees, depending on the orientation to the line of sight. The difference in distance modulus for stars at opposite ends of the bar will be between 0 and 1.7 mag. Current opinion is that the bar is closer to end on than sideways, so there should be a large asymmetry in the star distribution in the longitude range -10 to 10 degrees.

3. Spiral Structure: In addition to possible asymmetries due to a bar, near-IR integrated light maps (e.g. Hayakawa *et al.* 1981) show that light in the Galactic plane is very asymmetric out to longitudes of $|l| \approx 30°$. Figure 2 shows a plot from the *DIRBE* experiment on *COBE*

(Boggess *et al.* 1992; Hauser 1992) of the 3.5 micron luminosity profile along the Galactic plane for the northern and southern Galactic hemispheres, illustrating the asymmetry. This asymmetry might be due to spiral structure. Such structure should be reflected in star counts. One might be able to use JHK colors and/or extinction modulations (Karawa *et al.* 1982) to identify a young population of stars assocated with spiral arms. Paczinski *et al.* (1994) have already used *visual* color-magnitude diagrams derived from observations of fields in the direction of the Galactic bulge as part of the *OGLE* survey to identify main sequence stars in a nearby spiral arm.

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DISCUSSION

M. Balcells: Could you tell us something about data processing strategy?

Kent: It would take more time than I have here to give a complete answer. Basically, data will be recorded at the mountain on magnetic tape and returned to Fermilab for processing.