Nearby Large-Scale Structures and the Zone of Avoidance
*ASP Conference Series, Vol. ASP Conference Series, Vol. ***, 2004*
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The 2MASS Redshift Survey and Low Galactic Latitude Large-Scale Structure

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** Guest Observer, Cerro Tololo Interamerican Observatory, operated by AURA for the National Science Foundation.*

Abstract. We have used the 2 Micron All-Sky Survey to produce an extremely uniform galaxy catalog down to low galactic latitude. Spectroscopy is nearly complete for a sample of galaxies brighter than K=11.25. Due to its completeness, uniformity and high object density, this survey elucidates nearby low-latitude structures better than any previous work.

1. Introduction

A major revolution in observational cosmology started three decades ago with several technological advances and astronomical insights. The first was the development of sensitive, inexpensive electronic detectors that enabled the first of the large galaxy redshift surveys so important today (cf. Davis, Huchra, Latham & Tonry 1982). The second was the discovery of the motion of the Milky Way w.r.t. the general field of galaxies by the discoveries of both the dipole in the Cosmic Microwave Background (CMB, cf. Cheng et al 1979; Fabbri et al. 1980) and our infall into the Virgo Cluster, the core of the local supercluster (cf. Aaronson et al 1982; de Vaucouleurs 1956). The redshift surveys not only enabled large statistical studies of virial motions of galaxies but also the comparison of the galaxy distribution to simulations of the growth of structure in different cosmological models. All of these, in turn, drove the favored cosmological model to one where the majority of gravitating matter is cold, probably non-baryonic and dark. Further work , such as the discovery of our motion w.r.t. the Great Attractor (Tully & Shaya 1984; Lynden-Bell et al. 1988) and the large-scale motion surveys based on IRAS (c.f. Strauss et al. 1992; Saunders et al. 2000) confirmed this picture but left several major problems unanswered. There still are serious inconsistencies between flow versus density field studies based on IRAS and optical surveys, we still have not convincingly found the gravitational sources of the CMB dipole (Schmoldt et al 1999; Santiago et al. 1995; Willick et al. 1997). Last but not least, we still don't know exactly what and exactly where Dark Matter is.

One key observational question concerned the difference between those optical and far-IR surveys. Was it real or were there problems with the data or the theory? Most of the community realized that **all** extant maps were tremendously biased, either by wavelength (read young Star Formation, which dominates blue and far-IR=IRAS light) or by extinction. This was the explanation pushed by the theorists — the galaxies we were measuring were not really tracing the mass.

2. 2MASS

What is the ideal survey of the nearby universe? Could we design a survey that would not be biased and would trace, at least, the baryonic mass in stars. The best and simplest solution was clear — go to the near IR! Figure 1 shows why. A survey done at 2μ would beat extinction, the bane of optical surveys, and would select for the stars that trace the baryonic mass in normal, old stellar populations. The light from old populations peaks, at z=0, at $\sim 1.6\mu$. The Galactic Center is dimmed by a factor of 10^{12} at the B-band but less than a factor of 10 at K. However the only all-sky survey at the time, the TMSS (Neugebauer & Leighton 1969), could barely see 8th magnitude stars, never mind distant galaxies.

The first opportunity to do such a survey came in 1988, when NASA announed an opportunity for the first Small Explorer (SMEX) missions. A group of us headed by Giovanni Fazio and driven by the desire to produce all sky maps of both galaxies and stars, proposed NIRAS, the Near IR Astronomy Satellite, to map the sky in K and L with the detectors that had been selected for SIRTF (nee Spitzer). This proposal failed because many people on the NASA review panel for the SMEX program felt that it would be cheaper to do this survey from the ground. Based on the strongly positive response to the science, we(Susan Klienmann and I and others) submitted a groundbased ground-based version of the proposal, 2MASS, to NSF and NASA in 1991. Our basic idea was to use two matched small telescopes to do a simultaneous (with dichroics) JHK all-sky survey. Our goal, for the extragalactic science, was to produce an all sky galaxy catalog complete to K$\sim$ 13.5 with extremely good photometric uniformity. Studies of clustering and flows require photometric uniformity at a level better than $\Delta v\ v$, so 100 km/s at 10,000 km/s demands 1% uniformity.

The survey was funded in the mid 1990's, first light on our first telescope at Mt. Hopkins was in Feb 1997, and the survey was completed in early 2001. The final data release of 2MASS is available now (see Skrutskie et al 2005, Cutri et al. 2003 and Jarrett et al. 2000 for descriptions of the data products and the Extended Source Catalog = XSC). Figure 2 shows our all-sky map (e.g. Jarrett 2004) of the galaxy distribution, with well known, nearby, large-scale structures labeled (c.f. Fairall, 1998).

The XSC is extremely uniform; the photometric zeropoint varys by less than 0.01 magnitude over the sky. Our tests show that is complete for galaxies above $|b| \sim 10°$ to $K_S \sim 13.5$ (see the on-line Explanatory Supplement and related links, Cutri et al 2003). At low galactic latitudes, our preliminary indications are that we are essentially complete for galaxies, even to b$\sim$ 2° at K_S

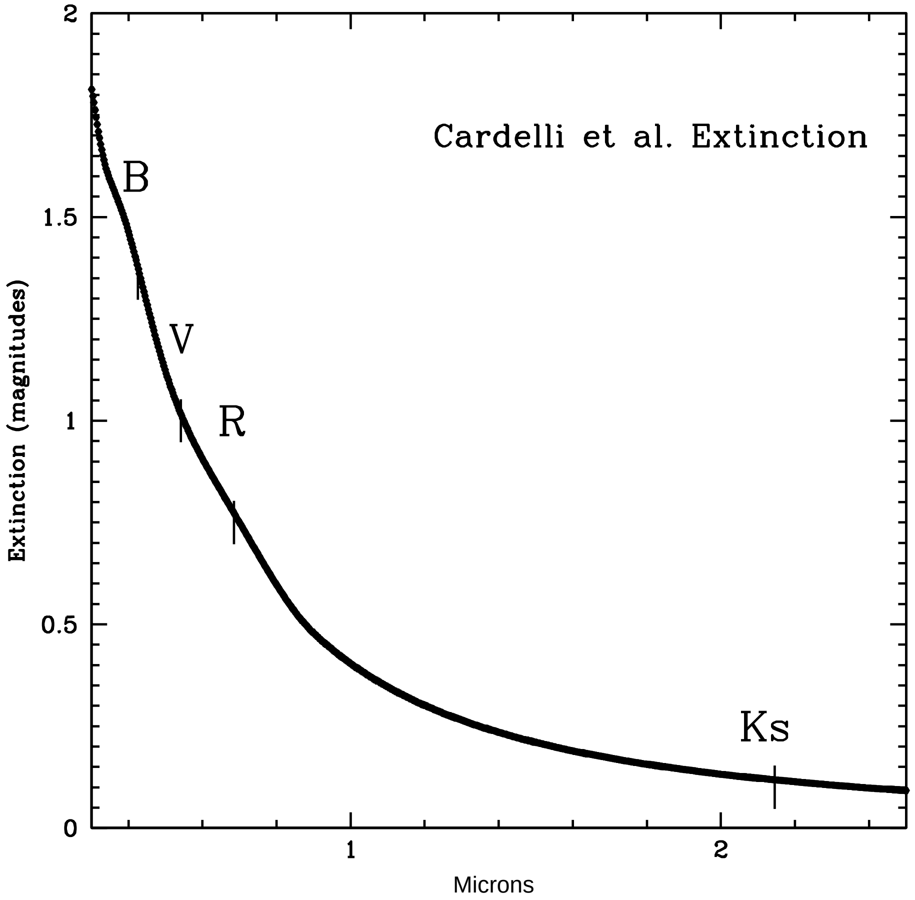

Figure 1. Extinction as a function of wavelength normalized to 1 magnitude at V, from Cardelli, Clayton and Mathis (1989). Remember that the B band extinction to the Galactic Center is approximately 30 magnitudes or a factor of 10^{12}. Even to the GC, the extinction in the K_S band is only about 2 magnitudes, a rather significant advantage for IR surveys over optical.

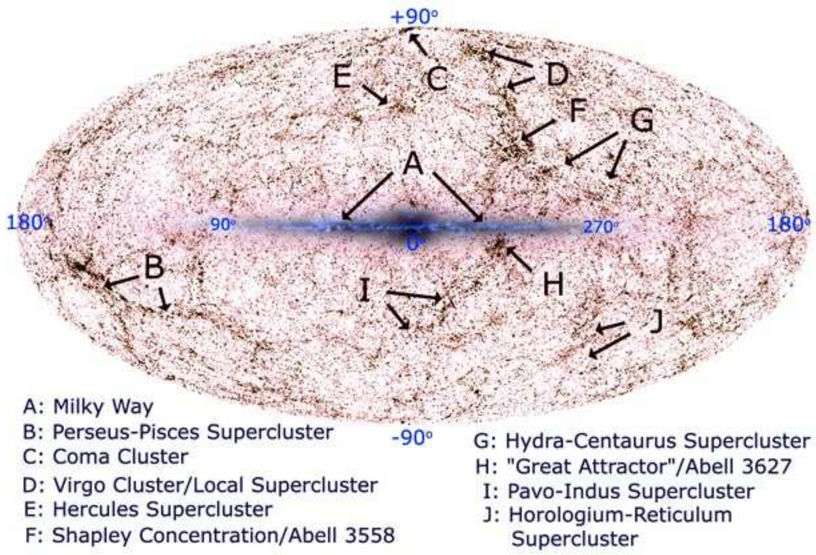

Figure 2. An all sky Aitoff view of the 2MASS Extended Source Catslog (XSC). The coordinate system is galactic and the 2MASS point source catalog is used to display the Milky Way itself. The plane of the Local Supercluser stands out to the right of center. Major known structures labeled.

magnitudes brighter than 12th, because these objects are sufficiently bright and extended to be distinguishable from stars and star clusters except at extremely low latitudes and near the Galactic Center. The major problem we face identifying the galaxies at low latitude and bright magnitudes is not extinction but rather confusion (Jarrett et al 2000).

3. The 2MASS Redshift Survey

The primary extragalactic goal of 2MASS, however, was to feed the next generation of all-sky redshift survey to fully map the nearby universe. To that end, we have been obtaining redshifts for 2MASS identified galaxies with the goal of completing a survey of all objects brighter than 13.0 over the next decade. This work is being done in phases. The first phase of the project is to complete the redshifts to all galactic latitudes for galaxies brighter than K=11.25. The second stage of the project will be to extend that to 12.25, but limiting ourselves to galactic latitudes above 5-10 degrees. The final stage is based on the 6dF survey in the southern hemisphere (Heath Jones et al 2004; which uses 2MASS as its parent catalog to observe to $K_{Total}=12.8 = K_{iso}=13.0$) and an as yet to be determined survey in the north. (I keep hoping to get the rock pounders and Richard Ellis to give up the Palomar Schmidt!)

We have nearly completed the redshifts for 22,750 of the 23,016 galaxies brighter than K=11.25 and above $|b|=5°$ (98.8%), and are now pushing as deeply into the galactic plane as the coverage map and available spectrographs

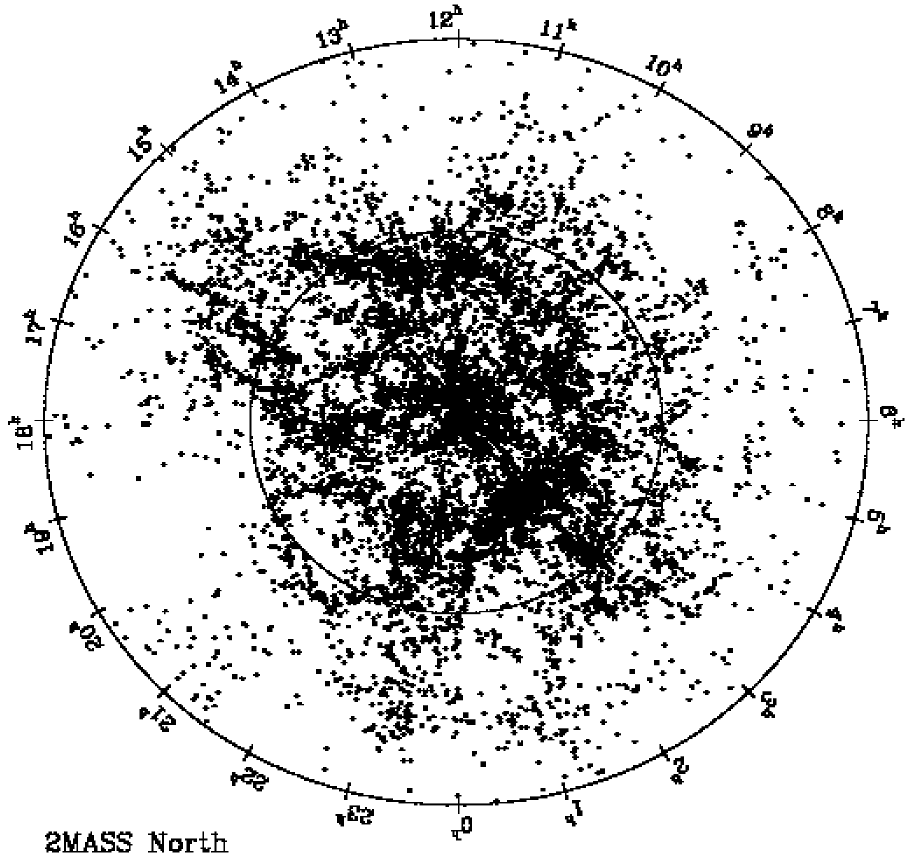

Figure 3. Hockey Puck plot — a full cylinder section — of the 2mass Redshift Survey (2MRS) in the north celestial cap. The view is looking downwards from the NCP, the thickness of the "puck" is 8000 km/s and its radius is 15,000 km/s.

allow. Some initial qualitative results from this survey are shown below via two visualization techniques: Hockey Pucks and Onion Skins.

3.1. Hockey Pucks

An all-sky survey allows us to make plots of the nearby galaxy distribution that are more representative than simple strip surveys (deLapparent, Geller and Huchra, 1986). The angular nature of strips around the sky, when projected onto a plane, are somewhat deceptive of real structure. They are thin at the center and thick at the edge. While this partially makes up for the normal decrease in the selection efficiency as a function of redshift in a flux limited sample, it provides a representation of structure that varies quite strongly from the center to edge. With full sky coverage, it is possible to project actual cylinders of redshift space. Coming from Boston, I naturally call these Hockey Puck plots. One such plot, for the northern celestial hemisphere, is given in Figure 3.

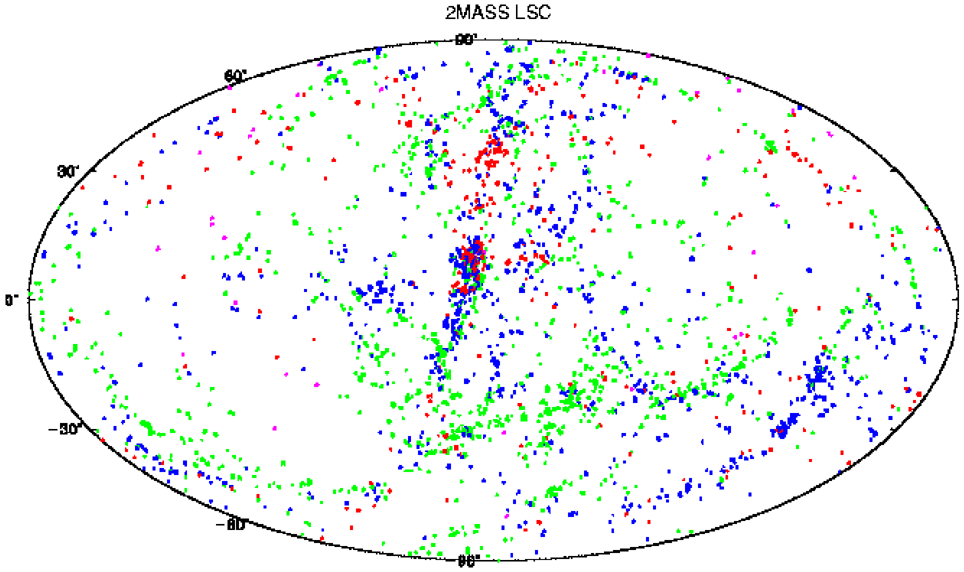

Figure 4. 2MASS galaxies inside 3000 km/s. Objects with velocities less than 1000 km/s are shown in magenta, blue for 1000-2000 km/s, and green for 2000-3000 km/s. The LSC dominates.

Many of our favorite structures are easily seen in this plot. Our northern puck has an aspect ratio of about 3.5 to 1 (30000 km/s diameter / 8000 km/s thickness). It is dominated by the Local Supercluster at the center, the Great Wall at 10-14.5 hours and Pisces-Perseus at 0-5 hours. In addition, there are several new but smaller structures such as the one at 19 hours and 4000 km/s, probably best associated with the Cygnus Cluster (Huchra, Hoessel & Elias 1977).

The southern celestial hemisphere is more amorphous. There is the well known Cetus Wall (Fairall 1998) between 0 and 4 hours, the southern part of the Local Supercluster at the center, and the Hydra-Centaurus region, but also a large and diffuse overdensity between 19 and 22 hours, a region hitherto not mapped because of its proximity to the galactic plane. This structure appears to be both large and rich and should have a large effect on the local velocity field.

3.2. Onion Skins

Another projection that can highlight the properties of nearby structures are surface maps of the galaxy distribution as a function of redshift. Since these are conceptually like peeling an onion, they are best called “onion skins.” Figures 4, 5, & 6 show three sets of these skins, moving progressively outward in redshift.

The first plots the distribution on the sky of all galaxies in the survey inside 3000 km/s color coded by redshift in 1000 km/s skins. The plane of the Local Supercluster dominates the map, but there is also a diffuse component between 2000 and 3000 km/s and 6 to 13 hours in the south.

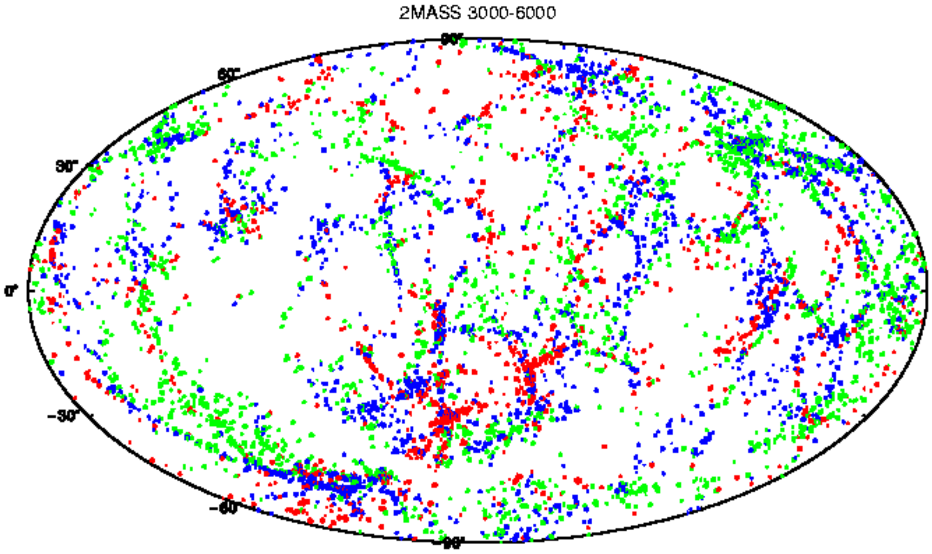

Figure 5. 2MASS galaxies between 3000 and 6000 km/s. Red shows the lowest redshift "skin," blue the middle range and green the high 1000 km/s range.

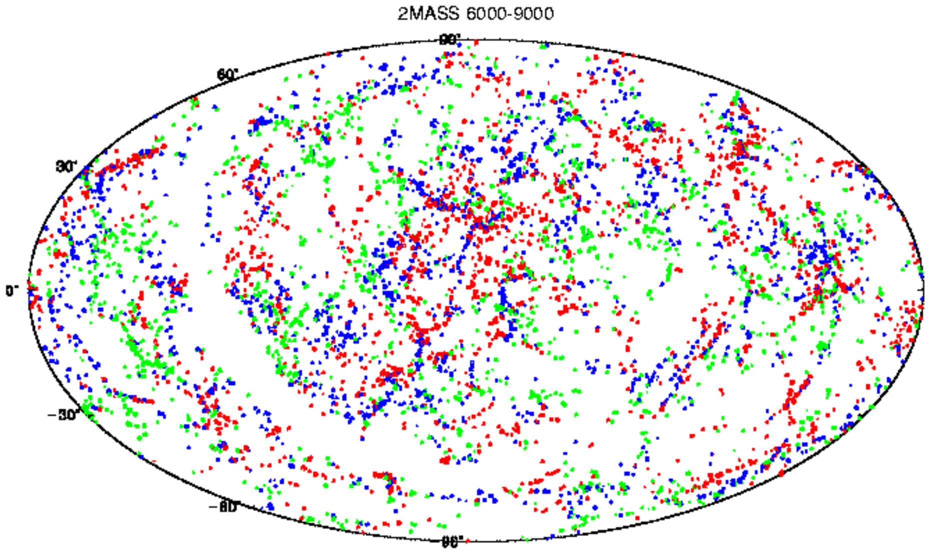

Figure 6. Ditto but now for 6000-9000 km/s.

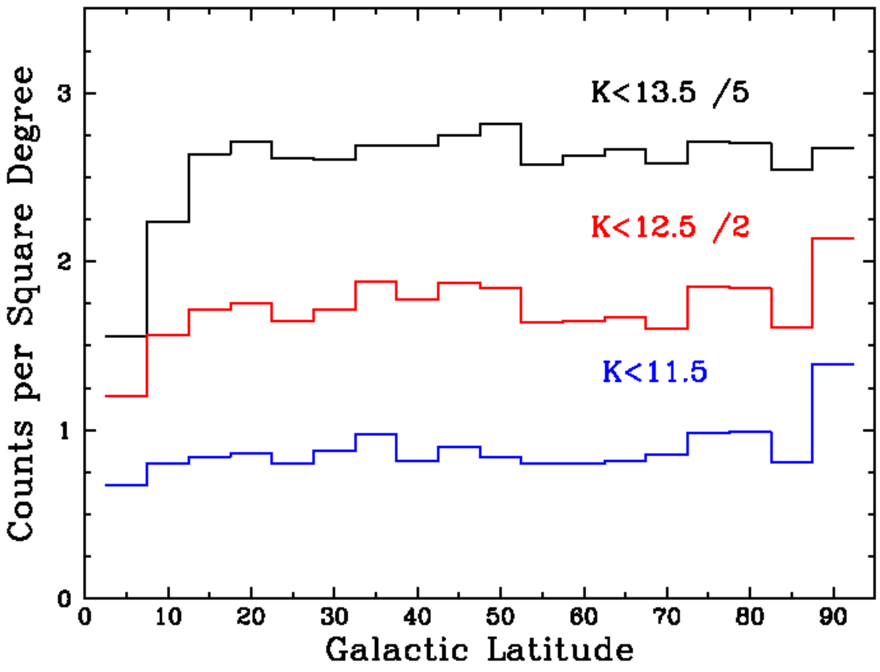

Figure 7. Surface number density vs galactic latitude for three cuts in the 2MASS catalog, limiting magnitudes of 11.5, 12.5 and 13.5. While the number counts drop sharply (x2) for $|b| \leq 10°$ for the 13.5 mag catalog, the drop (or incompleteness) for the 12.5 limit is only 30% and is essentially zero for $K_s \leq 11.5$. The upturn in all samples at 90° is due to the Coma supercluster.

The next two images again show some familiar structures but with a few surprises. The Great Wall Pisces-Perseus and Great Attractor dominate the mid ranges. The overdensity of galaxies in the direction of A3627 is high, and the comparison of the 3-6k map with the 6-9k map clearly shows why we are moving w.r.t. the CMB towards a point around 12 hours RA and in the southern hemisphere.

4. The Zone of Avoidance

2MASS is an excellent probe of the zone-of-avoidance for bright galaxies. Figure 7 shows the galaxy surface density versus galactic latitude for several cuts. At the bright magnitudes we are currently surveying with the 2mass redshift survey, the catalog is essentially complete to very low latitudes.

Figure 8 shows our planned coverage at $K_S = 11.25$, limited only by confusion near the galactic center. We now have 23,153 redshifts for the 24,820 galaxies brighter than 11.25, or about 93% of the sample. We will attempt to

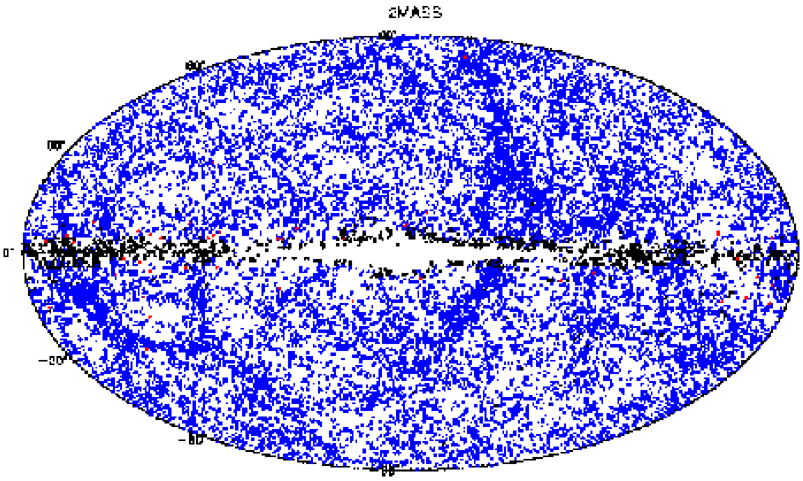

Figure 8. The sky distribution of the galaxies in the 2MASS redshift survey including those at very low galactic latitude. Note that we cannot cover, even just to K_S=11.25, the very central region of the galaxy but we do cover ~95% of the sky.

observe the remaining objects with the CTIO 4-m and other telescopes. Not bad, eh!

Figures 9 and 10 show our maps, as hockey pucks of thickness 2000 and 4000 km/s respectively, projected on the galactic plane.

There are several very large and dense structures in the plane. The LSC dominates the center (near the Milky Way). In the north, at r$\sim$ 4000 km/s and 10^h=l=150°, we see the Perseus cluster and at l=$310^c irc$ and the same distance we see a large structure probably associated with A3627 and the Great Attractor. There is also a closer structure at l $\sim$ 270 and 2000 km/s in Puppis. The small cluster at l=45° and 4000 km/s is the Cygnus cluster again (Huchra, Hoessel & Elias 1977).

5. Conclusions

The first phase of the 2MASS redshift survey is nearing completion and will be released this year. It provides a spectacular 3-D view of the Local Universe unbiased by the extinction in our own galaxy.

2MASS has fulfilled its goal of providing and extremely uniform, deep and unbiased survey of the nearby Universe. The characteristics of the structures are similar to what have been seen before, however we now have an essentially complete local map. We are measuring both additional redshifts, to complete the redshift coverage to very low galactic latitudes and to push the high latitude survey deeper, and real distances vis Tully-Fisher and, with the 6dF Survey, $D_n - \sigma$, to extract the full measure of cosmological information from density versus flow field comparison. When the full redshift survey is complete in a

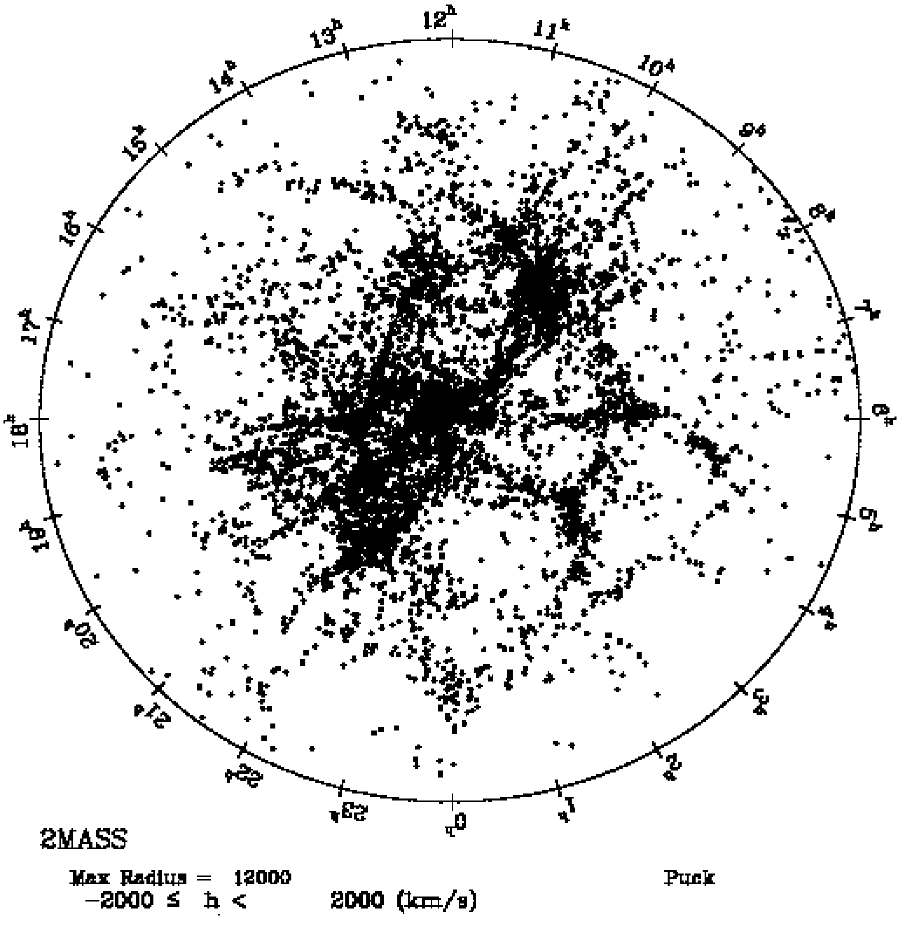

Figure 9. Hockey Puck plot — a full cylinder section — of the 2mass Redshift Survey (2MRS) ± 2000 km/s from the Galactic Plane/ The view is looking downwards from the NG Pole, the thickness of the "puck" is 4000 km/s and its radius is 12,000 km/s.

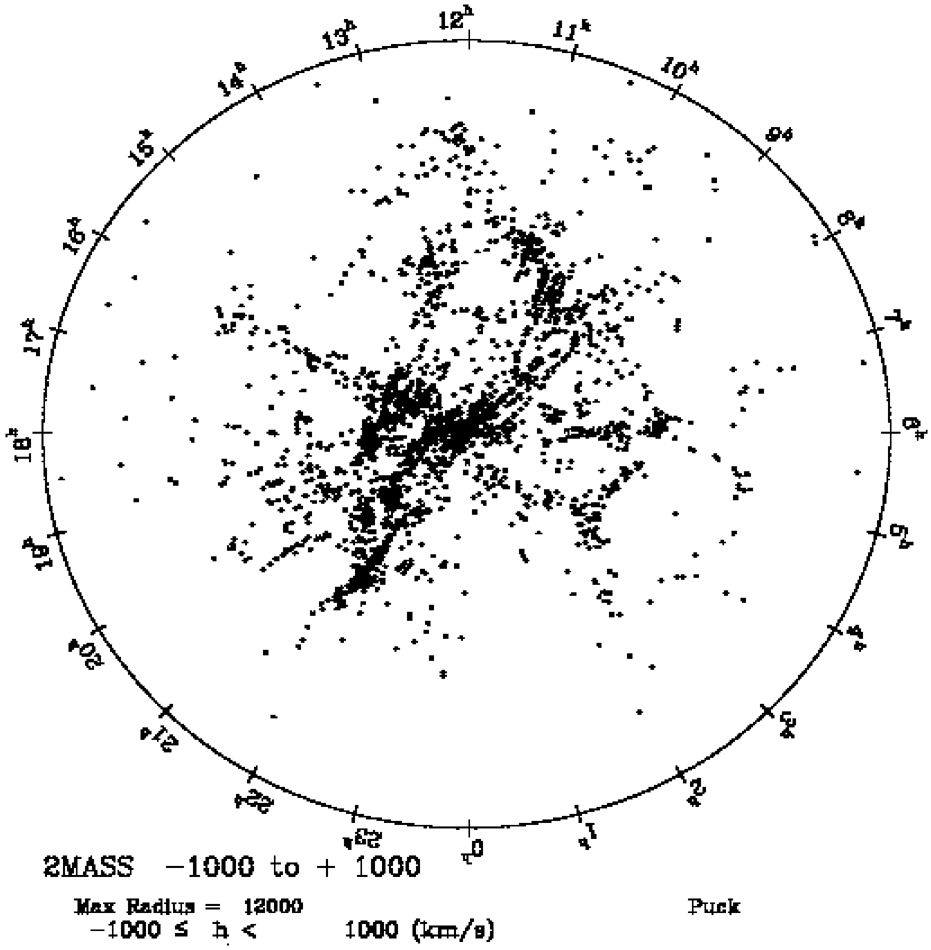

Figure 10. The +/−1000 km/s Hockey Puck plot. Again, the view is looking downwards from the NG Pole, the thickness of the "puck" is 2000 km/s (the plane +/- 1000 km/s), and its radius is 12,000 km/s.

decade, we will have a map of the Local Universe out to a tenth the speed of light.

Acknowledgments. 2MASS and the 2MRS was supported by NASA, the NSF, the State of Massachusetts, the Air Force, the Navy and the Smithsonian Institution. Thanks are also due to the stalwart observers at the FL Whipple Observatory, Mc Donald Observatory, the support staff at CTIO and the entire 2MASS team, including Susan Kleinmann, the prime mover behind 2MASS, who left the teamin 1995. This paper was written in part while JPH was a Sackler visitor at the Institute of Astronomy, Cambridge, UK. Additional information on the 2MASS Redshift Survey can be found at http://cfa-www.harvard.edu/∼huchra/2mass.

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