THE 2MASS REDSHIFT SURVEY

J. HUCHRA & E. TOLLESTRUP
Harvard-Smithsonian Center for Astrophysics, Cambridge, MA USA
S. SCHNEIDER & M. SKRUTSKI
University of Massachusetts, Amherst, MA USA
AND
T. JARRETT, T. CHESTER & R. CUTRI
IPAC, Caltech, Pasadena, CA, USA

1. Introduction

With the current convergence of determinations of the Hubble Constant (e.g. *The Extragalactic Distance Scale,* 1997, Livio, Donahue and Panagia, eds.) to values within ±25% rather than a factor of two, and the clear possibility of determining q_o using high redshift supernovae (Garnavich et al. 1998), the major remaining problem in observational cosmology is the determination of Ω — what is the dark matter, how much is there, and how is it distributed?

The most direct approach to the last two parts of the question has been to study galaxy dynamics, first through the motions of galaxies in binaries, groups and clusters, and in the last decade and a half, driven by the observation of our motion w.r.t. the Cosmic Microwave Background (CMB) and the notion that DM must be clumped on larger scales than galaxy clusters if Ω is to be unity, through the study of large scale galaxy flows.

The ratio of the mass density to the closure mass density, Ω, is thought by most observers to be ~0.1–0.3, primarily based on the results of dynamical measurements of galaxy clusters and, more recently, gravitational lensing studies of clusters. In contrast, most theoretical cosmologists opt for a high density universe, $\Omega = 1.0$, based on the precepts of the inflation scenario, the difficulty of forming galaxies in low density models given the observed smoothness of the microwave background radiation, and the observational evidence from the matching of the available large scale flow measurements (and the absolute microwave background dipole velocity) to the local density field. However this last result is extremely controversial—matching the velocity field to the density field derived from IRAS (60μ) selected galaxy samples yields high Ω values (e.g., Dekel et al. 1993) but matching to optically selected samples yields low values (Hudson 1994; Lahav et al. 1994; Santiago et al. 1995). On small scales, the high Ω camp argues that the true matter distribution is much more extended than the distribution of galaxies, so the dynamical mass estimates are biased low.

A subplot of the Omega problem is conclusively finding the cause of the microwave background dipole. The leading candidate is, of course, the gravitational attraction of nearby density enhancements (or "repulsion" by voids). The current debate centers on two still unresolved issues, the actual motion of the galaxy/local group with respect to reference frames of nearby and moderately distant galaxies and clusters (Rubin et al. 1976; Lauer & Postman 1994, Postman & Lauer 1995; Courteau et al. 1993; Riess, Press & Kirshner 1995), and the cause of those motions (Lynden-Bell et al. 1988; Dressler & Faber 1990; Mathewson & Ford 1994; Huchra 1996; Scaramella et al. 1994; Kraan-Korteweg et al. 1996). The Great Attractor, the Hydra-Centaurus supercluster, Abell 3627, and the Shapley Supercluster all remain candidates, while Virgo is only slowly being understood and the lack of strong motions towards Pisces-Perseus is an unsolved mystery. Because of incompleteness and the very sparse sampling through the galactic plane we still do not have a complete (or even coherent) picture of even the very local universe and galaxy motions nearby (e.g. Shaya, Tully and Pierce 1992).

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2. Existing Surveys

Existing samples are limited. The two major large area/all-sky samples used to study the galaxy density field are relatively small and suffer significant biases. The Optical Redshift Survey (Santiago et al. 1995) consists of about 8000 optically (blue) selected galaxies, diameter limited, from the merge of three catalogs based on visual examination of photographic plates (the UGC, ESO and a merge of the VV and ESGC catalogs in the southern equatorial strip). By definition, the catalog has a very strong bias with galactic latitude due to extinction, moderately large errors in the "by eye" diameter determinations (20-30%), and only poorly determined uniformity across the sky due to the melting of these three catalogs which used differing photographic material (never mind just photographic!). Due to selection in the blue, the catalog underestimates the clustering of early type, generally more massive galaxies.

The IRAS Catalogs (1.936 Jy, Strauss et al. 1992; 1.2-Jy, Fisher et al. 1995; QDOT, Rowan Robinson et al. 1990, Lawrence et al. 1998; PSC-Z, Saunders et al. 1998), while only weakly biased with galactic latitude, select galaxies bright at 60μ — i.e. luminous, dusty spirals, with lots of star formation — and completely miss early type galaxies which dominate rich clusters and the small and intermediate scale clustering seen in most redshift survey maps. Good arguments have been made (e.g. Huchra 1996) that IRAS galaxies are not likely to be the best tracers of mass in the Universe. Both the largest optical and IR *all sky* samples contain only of order 10^4 galaxies, and analyses of these samples are limited to small distances ($\leq$ 10,000-12,000 km/s) and low resolution (1000 km/s or poorer) in the determination of the density field.

Similarly with regard to the flow field, the available datasets are small, crude and limited to small distances. The Mark III catalog (Willick et al. 1997) has ~3500 objects with relative distances measured using several different techniques, but only samples the velocity field out to about 4500 km/s, and again with poor spatial resolution. Deeper catalogs such as the SN catalog of Reiss, Press and Kirsher, while using a high quality distance indicator, have less than 50 objects. Perhaps the deepest survey, the Abell cluster survey of Postman and Lauer, has a few hundred objects and surveys the velocity field only very coarsely.

Both the determinations of the galaxy velocity field and the galaxy density field need to be significantly improved before a conclusive answer is reached.

3. The 2 Micron All-Sky Survey

To attack this problem as well as other problems in galactic structure, unusual objects, etc., a proposal was developed here in 1988 (Fazio, Huchra and others) to do a near infrared all sky survey from an explorer class satellite (NIRAS). While the satellite was not selected, the scientific program developed into today's groundbased 2 Micron All-Sky Survey (2MASS). 2MASS will cover the whole sky and produce large, photometrically accurate catalogs of stars ($\sim 10^8$ to K_S=14.5) and galaxies ($\sim 10^6$ to K_S=13.5). The goal of the survey is to provide catalogs with a uniformity over the sky (variation of photometric zeropoint with position) of $\sim$ 1% or better and with completeness and reliability uniform to 1% or better above $|b| = 30$, and as good as we can make it at low latitudes, including external photometric verification.

Depending on the weather, 2MASS will be completed, in both hemispheres, five years from the start of collecting survey data, or summer of 2002. This is the **only** planned catalog with (1) full sky coverage, including both celestial hemispheres and the galactic plane, (2) precision photometry and astrometry, (3) large numbers of objects, and (4) coverage at wavelengths where galactic extinction is minimal. Survey operations started at the end of April 1997, and currently we are running slightly ahead of schedule with 30% of the northern tiles observed in good to photometric weather.

More information on 2MASS can be obtained at the 2MASS web site:
`http://www.ipac.caltech.edu/2mass/`

4. The 2MASS Redshift Survey

We intend to use the 2MASS galaxy catalog to provide both a significantly improved density field map and an improved velocity field map. The 2MASS Redshift Survey (2MRS) will use the 2MASS catalog as a basis for a whole sky redshift survey of ~250,000 selected galaxies to a limiting K_s magnitude of 13.5 (approximately the combined completeness and reliability limit of the survey), and second to combine the accurate J, H, and K_s band photometry for the edge-on spiral galaxies in our survey with 21-cm line width measurements from Arecibo, Parkes and the GBT and with optically measured rotation curves to measure IR Tully-Fisher distances to a large sample of galaxies ($\geq$ 10,000).

There are several major advantages in the use of the 2MASS galaxy catalog: (1) By definition, we are much less sensitive to extinction both in our galaxy and in others. (2) The near IR is the where the peak of the energy distribution is for low mass stars, the objects that contribute most to the mass of any individual galaxy. (3) The survey processing will provide not only magnitudes but also sizes, inclinations, colors and accurate coordinates.

The 2MRS consists of two phases. The **primary** survey we wish to complete at or near the time of completion of the photometric survey (and the primary survey we are proposing for here) includes all galaxies brighter than $K_s \sim 12.2$ ($\sim$ 150,000 galaxies over the whole sky.) The **secondary** survey, which we will only start on if enough observing time is available, is one-in-ten of the remaining galaxies to $K_S = 13.5$, or about another $\sim$ 100,000 galaxies over the whole sky.

2MRS builds on the narrower CfA (Geller and Huchra 1989; Huchra et al. 1990) and SSRS2 (da Costa et al. 1994) redshift surveys, as well as the ORS and IRAS 1.2-Jy surveys already completed. The 2MASS Redshift Survey (2MRS) will sample the galaxy distribution both to a factor of 3-5 times deeper and over a factor of more than two more of the sky ($\sim$90% of 4π steradians) than the early optical surveys. The median redshift of 2MRS will be $\sim$ 0.08 (compared to about 0.025 for the CfA survey), with dense sampling of the regions inside that redshift and reasonable sampling of the density field out to a redshift of 0.1. This median is computed from the real data — K^* from our preliminary surveys of the A262 and Hercules fields is $\sim$ -24.0$\pm$0.15 (H=100 km/s/Mpc) for K selected galaxies. At our limit of 13.5, the sample depth estimated from K^* is a little over 300 Mpc or a little over z=0.1. We expect about half the galaxies in the survey to be inside z$\sim$0.07.

There are **no** *other comparable surveys underway or planned.* The PSC-Z survey is the only all-sky redshift survey yet to be released, and it (1) only contains 13,000 objects and (2) is still 60μ based, so biased towards dusty galaxies with star formation. Sloan (SDSS), 2DF, LCRS, 15R all cover much smaller areas of the sky — combined, perhaps 4 steradians — so are not very useful for large scale flow studies or the determination of the masscon(s) responsible for our CMB motion. Most of the area we are going to survey, even in the north, is not covered by other surveys, even SDSS. For the first phase of the 2MASS survey, most of the high latitude galaxies to our bright K_s limit have already been observed and the additional redshifts needed are small in number. The goal of the 2MASS redshift survey is to increase, by at least one order of magnitude, the size of the whole-sky sample available for the analysis of the local density field. This is not the goal of SDSS or any other currently planned survey,

5. Northern Primary Survey

The primary program at FLWO will be to provide a large fraction of the redshifts for the 2MRS galaxies brighter than K_S=12.2 and above δ=0°. This sample will be about 60,000 galaxies in total, and $\sim$ 35,000-40,000 of them already have redshifts — the CfA Redshift Catalogue lists redshifts for $\sim$43,200 galaxies above δ=0°, and this does not include the redshifts from the 15R survey and PSC-Z surveys which should be released before 2MRS is completed.

When the 2MRS is completed, we believe we will have taken a very large step toward solving the Omega problem and will have a density map that should determine the source of our motion with respect to the CMB. The data set will be very densely sampled with accurate positions, magnitudes and redshifts. Given the expected number density of objects inside z=0.07, we will be able to measure density enhancements accurate to $\sim$10% of the mean density, on scales of $\sim$ 10 Mpc (h=1). This admittedly crude estimate is based on an effective survey volume, V $\sim 10^6$ Mpc^3, and a mean number density for phase 1 of about 0.1 galaxy /Mpc^3 (for the sample of 150,000 redshifts), which implies that a 10 Mpc cube will contain on average 100 galaxies. This is comparable to the density accuracy in the CfA redshift survey inside z=0.03 (and only over 1/4 the sky), comparable to the ORS survey inside z=0.02, and a factor of 10 better than the IRAS surveys. By definition, even without redshifts, the 2MASS galaxy sample can and will be used to calculate the JHK band dipoles, and will provide a strong and simple test of the relation between the local galaxy density field and the CMB dipole — on the scale probed by 2MASS, in any reasonable cosmological scenario, there should be convergence between the gravity/light vector and the CMB frame.

As part of the program, we will also measure IRTF distances to all the edge on spirals in the sample. Even though classification of the galaxies in the normal Hubble sequence is difficult in the IR, any galaxy with an axial ratio of more than 5-to-1 is almost certainly a spiral. For many galaxies in the northern hemisphere inside about 8,000 km/s, HI velocity widths already exist from the surveys of Giovanelli and Haynes. We will obtain velocity widths for the remaining galaxies from Arecibo, the GBT, or using long-slit spectroscopy. We will observe edge on galaxies which we cannot observe/detect at Arecibo or Green Bank to obtain rotation curves. Again, to provide an order of magnitude improvement over existing compilations (Mark III) we need to obtain ~20,000 distances for galaxies inside z~0.05, more or less uniformly distributed over the sky.

These distance measurements, inside z=0.05, assuming a scatter of 0.30 magnitudes at H, which is slightly pessimistic (Freedman 1990; Pierce and Tully 1992), will measure the flow field at z=0.03 accurate to 200 km/s on a scales of 25 Mpc. This will easily allow a determination our motion inside the Lauer and Postman sample volume, and, via analyses such as POTENT (Dekel et al. 1993; Dekel 1994) a derivation of the inferred density field for comparison to the observed density field. This comparison will provide a strong test of the hypothesis that light traces mass on very large scales.

We also plan to produce intermediate results. 2MASS, like CfA, is being done in strips across the sky. This is a result of the fact that the most efficient tiling algorithms for surveys approximate strips on the sky. This provides moderately large contiguous areas and volumes to study. Several programs we intend to complete include (1) a significantly improved near-IR field galaxy luminosity function, (2) measurement of the standard galaxy clustering statistics ($\xi(r), \xi(r_p, \pi), power spectrum, etc.$, but from an IR selected (and thus early type galaxy weighted) sample, (3) tests of the somewhat discrepant flow field results (e.g. Strauss and Willick, 1995) between Virgo and Pisces-Perseus, (4) maps of large scale structure through the galactic plane (e.g. Marzke, Huchra and Geller 1996), and (5) studies of the colors of galaxies as a function or morphological and spectroscopic type. 2MASS provides both excellent photometry and positions, something in fact found in very few optical surveys — of all the large optical redshift surveys, only LCRS has a photometric sample, and even then in only one filter.

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