DISTRIBUTION OF IRAS GALAXIES

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ABSTRACT Infrared wavelengths are free of several of the problems that plague optical galaxy surveys. At high galactic latitude >99% of 60μ sources in the IRAS Point Source Catalog, after deletion of obvious stars, are galaxies. At lower latitudes care has to be taken to avoid confusion with emission from interstellar dust (the 'cirrus'). IRAS galaxies have been used to determined the direction of the gravitational acceleration acting on the Local Group due to galaxies and clusters within about 200 Mpc. This agrees well with the direction of the microwave background dipole. The density of matter in the universe, distributed like IRAS galaxies, needed to account for the observed velocity of the Local Group, corresponds to $\Omega_0 = 1.0 \pm 0.2$. In the standard hot Big Bang model, 90-95% of this matter would have to be non-baryonic.

IRAS galaxies are significantly less clustered than optically selected galaxy samples.

1. INTRODUCTION.

Galaxy surveys at optical wavelengths have so far failed to derive a convincing value for the velocity of the Local Group of galaxies with respect to the cosmological reference frame. While some determinations are in reasonable agreement with the value derived from the dipole component of the microwave background anisotropy (Hart and Davis 1982, Aaronson et al 1986), which we take here to be

$$v = 600 \text{ km sec}^{-1} \text{ towards } (l,b) = (277, 29) \quad (1)$$

(Lubin et al 1983, Fixsen et al 1983, Yahil et al 1986),

others are wildly discrepant from this value (Rubin et al 1976, de Vaucouleurs 1978, Sandage et al 1979, de Vaucouleurs and Peters 1981, de Vaucouleurs et al 1981, Aaronson et al 1982). Attempts to explain these discrepancies in terms of large-scale streaming motions seem premature. A more likely explanation of the discordant optical results is a combination of the known problems of current galaxy surveys:

(i) there is no all-sky galaxy survey with a well-calibrated homogeneous magnitude scale deeper than the Revised Shapley Ames Catalogue (Sandage & Tammann 1981), which has a completeness limit of about $m_B = 12$ mag. For a typical galaxy with absolute magnitude $M_B = -21$, this corresponds to a survey depth of only 40 Mpc, a volume clearly dominated by the Virgo Supercluster.

(ii) the strength of extinction by interstellar dust is a matter of lively controversy. Estimates of polar extinction range from 0 to 0.3

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magnitudes of visual extinction (Sandage 1973, de Vaucouleurs et al 1976, Burstein & Heiles 1978) and at lower galactic latitudes the uncertainty can be 1 magnitude or more. The neutral hydrogen column-density (Burstein & Heiles 1978, 1982) and the IRAS 100μ background intensity (Rowan-Robinson 1986a) offer useful indicators of the column-density of interstellar dust associated with diffuse neutral gas, but there is little prospect of an effective indicator of the column-density of dust in lines of sight with significant concentrations of molecular gas.

(iii) for studies of late-type galaxies, the strength of extinction by internal dust and its dependence on the orientation of the galaxy is even less well known than that by interstellar dust in our Galaxy.

The IRAS Point Source Catalog provides us with a database for cosmological studies free of the above problems. Interstellar and internal extinction are neglible at far infrared wavelengths, the calibration is carried out in a homogeneous way over the whole sky (Neugebauer et al 1984) and outside the Galactic plane, regions of strong 'cirrus' emission and the 4% of the sky which lies in coverage gaps, the survey is 98% complete and 99.9% reliable (Rowan-Robinson et al 1984). Lawrence et al (1986) have shown that at high galactic latitudes, $>$99% of 60μ sources (after exclusion of sources which are obviously stellar) can be identified with galaxies and that the median depth of the IRAS 60μ survey is 200 $(50/H_0)$ Mpc, where H_0 is the Hubble constant in km s^{-1} Mpc^{-1}. Known systematic errors can be shown to be small (see section 4 below). There remains the problem of emission from interstellar dust (the infrared 'cirrus'), which has to be carefully controlled to achieve reliable results (see section 3 below).

In this paper I review the work carried out by my group at Queen Mary College, London, in collaboration with Amos Yahil of Stony Brook University, N.Y., and colleagues at the Royal Greenwich Observatory. We have used the unique qualities of the IRAS 60μ survey to derive the direction of the gravitational acceleration acting on the Local Group due to galaxies and clusters within about 200 Mpc. This direction agrees well with that of the microwave background dipole. From the 60μ luminosity function for galaxies derived from a redshift survey of IRAS sources we estimate the density of matter in the universe, distributed like the IRAS galaxies, required to accelerate our Galaxy to its observed velocity today (eqn (1)). I shall also comment on the parallel work of Meiksin and Davis (1986) and Lahav (1986).

2. USING IRAS GALAXIES TO MAP THE LOCAL GRAVITATIONAL FIELD

We assume that IRAS 60μ galaxies trace the matter in the universe and that there exists a universal luminosity function $\Phi(L)$, so the number of galaxies in luminosity range dL, volume element d^3r, can be written

$$dN = D(\underline{r})\ d^3r\ \Phi(L)\ dL \qquad (2)$$

where $D(\underline{r})$ is the local relative density function (D=1 corresponds to the mean density of the universe).

Then the smoothed surface brightness due to sources is (Yahil et al 1986)

$$4\pi\sigma(S,\omega) = 4\pi S \frac{dN}{dS d\omega} = \int D(\underline{r})dr \int L\Phi(L)\ \delta\left[S - \frac{L}{4\pi r^2}\right] dL. \quad (3)$$

The peculiar gravitational acceleration $\underline{g}$ acting on the Local Group is proportional to the density moment

$$\underline{G} = \frac{3}{4\pi} \int D(\underline{r}) \left[\frac{\underline{r}}{r^3}\right] d^3r = 3\underline{g}/4\pi G\rho_0 \quad . \quad (4)$$

Now the QMC-RGO redshift survey (Lawrence et al 1986) yields a 60μ luminosity function which can be well represented by (Fig 1)

$$\Phi(L) = CL^{-2}\ (1 + L/\beta L_*)^{-\beta} \quad (5)$$

with $C = (5.75 \pm 0.2) \times 10^6\ (H_0/50)\ L_\odot\ Mpc^{-3}$

$$\beta = 2.4 \pm {}^{1.5}_{0.8}.$$

Substitution into eqn (3) gives

$$4\pi S\sigma(S,\omega) = C \int D(\underline{r})(1 + r^2/\beta r_*^2)^{-\beta}\ dr \quad (6)$$

where $r_* = (L_*/4\pi S)^{1/2}$.

The dipole moment of this

$$4\pi S\underline{\sigma}(S) = \int 3\ S\ \sigma(S,\omega)\ \hat{\underline{r}}\ dw$$

$$= \frac{3C}{4\pi} \int D(\underline{r}) \left[\frac{\underline{r}}{r^3}\right] (1 + r^2/\beta r_*^2)^{-\beta}\ d^3r \quad (7)$$

is now of the same form as $\underline{G}$ except for the cutoff factor $(1+r^2/\beta r_*^2)^{-\beta}$, which has only a small effect.

3. THE IRAS DIPOLE

To evaluate eqn (7) we have used IRAS 60μ sources brighter than the completeness limit of 0.6 Jy (Rowan-Robinson et al 1986a). Stars have been excluded by omitting sources with $S(25\mu)>3S(60\mu)$: virtually all such sources are identified with catalogued stars. Lawrence et al (1986) have shown that $\gg 99\%$ of the remaining sources at $b>60^\circ$ are galaxies.

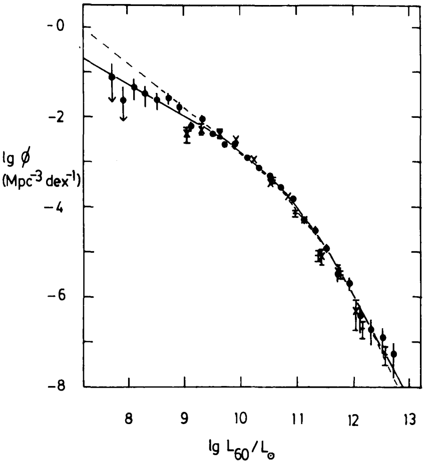

Fig 1: 60μ luminosity function for IRAS galaxies, compared with 2 simple analytical models. The dashed curve is eqn (5). (Filled circles: Lawrence et al 1986, crosses: Soifer et al 1986, x's: Rieke and Lebofsky 1986).

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Table 1: IRAS dipole moment

Mask	%of sky excluded	l	b	θ_{CBR}	$\|4\pi S\underline{\sigma}\|$ (Jy sr^{-1})	Ω_o (linear theory)
n=0 n=1 n=2	66% 53% 46%	237±11 248±9 256±8	33±12 40±8 37±8	34±12 26±10 19±9	1290±190 1550±170 1590±160	1.15 ± 0.29 0.85 ± 0.16 0.81 ± 0.14
n=1 0.5-1Jy 1-2 Jy 2-4 Jy 4-8 Jy 8-16Jy 16-32Jy		 286 232 257 255 240 240	 50 30 20 37 43 33	 22 39 20 20 33 32		
n=1, plus 20°x20° area centred on Virgo	54%	242	36	30		
Meiksin and Davis (1986)	24%	235	43.5	36		
Lahav (merged diameter limited optical galaxy catalogue, |b|>20°	34%	220	44	47		

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To avoid contamination by 'cirrus' and regions of very high source-density like the Milky Way and the Magellanic Clouds, we exclude $|b|<5^{\circ}$ and any one degree square bin which has been flagged in the IRAS Point Source Catalog as a region of exceptionally high source-density at 60μ. We also exclude any one square degree bin in which the cirrus flag CIRR1 (the number of 100μ only sources in a 1 sq deg area centred on a source) has been set > n. After investigating the sensitivity of our results to the value of n, and the values of n found in known clouds of 'cirrus' (eg Rowan-Robinson et al 1986a), we adopt the conservative value n = 1.

The excluded areas, including the 4% of the sky in coverage gaps, define a mask, which is illustrated in Fig 2 a and b. Little of the sky remains unmasked below $|b|=30^{\circ}$. The spherical harmonic components have been calculated over the un-masked area only (this modifies the orthogonality matrix for the harmonics). We are essentially assuming that the un-masked area is representative of the whole sky. Fig 3a,b show the distributions of IRAS 60μ sources in the unmasked area.

Fig 5 of Yahil et al (1986) shows the 3 components of $4\pi S\underline{\sigma}(S)$, eqn (7), as a function of S, together with the average over all S. The amplitude of the dipole component is 20% of the mean surface brightness at 2 Jy and 10% at 0.6 Jy. Table 1 gives the direction of the average dipole and the angular displacement from the microwave background dipole, θ_{CBR}, for 3 values of the cirrus mask parameter n = 0, 1, 2. The direction of the IRAS dipole agrees well with that of the microwave background dipole. This suggests that we have now identified the cause of our motion with respect to the microwave background,

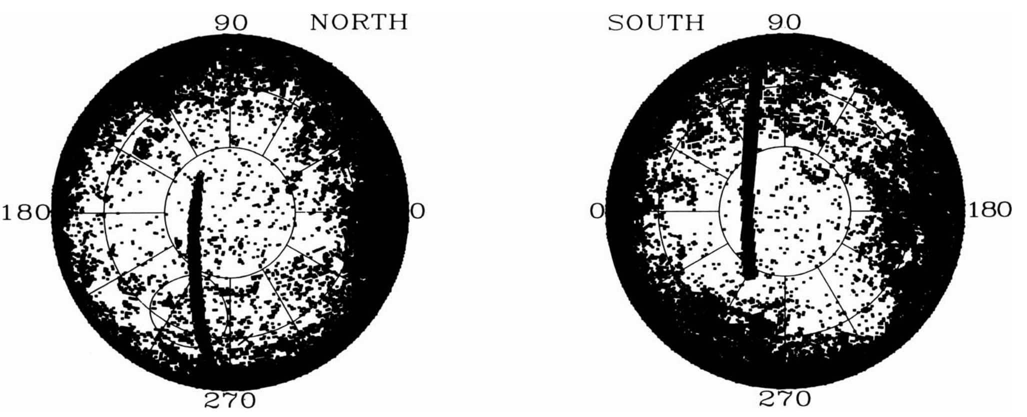

Fig 2: Equal area projections of the north and south Galactic hemispheres showing the mask n=1.

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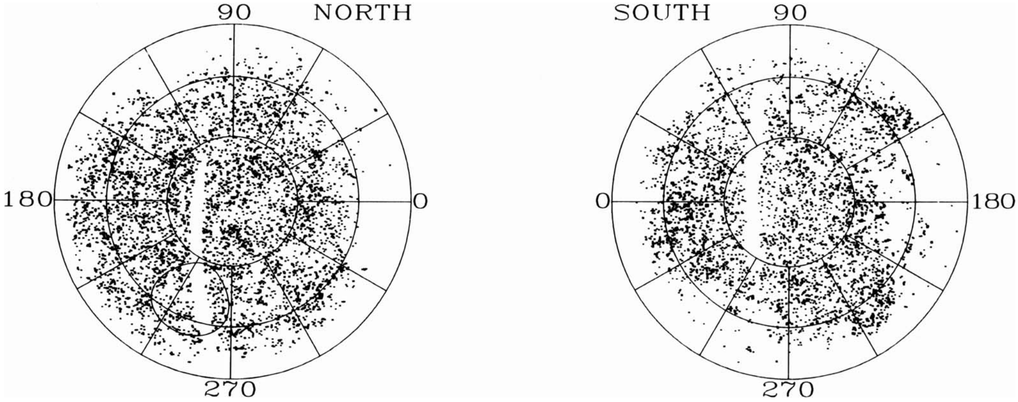

Fig 3: Equal area projections of the north and south Galactic hemispheres showing the IRAS 60μ sources in the unmasked region. Also shown are the 90% confidence limit of the IRAS dipole moment, and the direction of the microwave background dipole moment (large cross).

namely the net gravitational attraction of galaxies and clusters within about 200 Mpc. Table 1 also shows how the direction of the dipole depends on the flux bin: the dependence appears to be slight over the flux range 0.6 - 32 Jy.

4. POSSIBLE SOURCES OF SYSTEMATIC ERROR IN THE IRAS SURVEY

The known systematic errors in the IRAS data have been extensively discussed in the IRAS Explanatory Supplement (1984) and their implications for cosmological studies have been discussed by Rowan-Robinson et al (1986a), Yahil et al (1986) and Rowan-Robinson and Needham (1986). The major effects which could contribute to the IRAS dipole are:

(A) photon-induced responsivity enhancement ('hysteresis') as the detector field of view crosses the Galactic plane and other bright sources. The magnitude of this effect is <1% at 60μ at high Galactic latitudes, but great care would have to be taken when working within 20^o of the Galactic plane.

(B) responsivity changes due to particle hits on orbits passing near the edge of the South Atlantic Anomaly, but where bias boost was not applied to the detectors. This affects about 15% of orbits and the magnitude of the effect is $\lesssim$7% at 60μ, so the net effect on the 60μ fluxes is $\lesssim$1%. Moreover the effect would have opposite signs at 60 and 100μ and the 60 and 100μ source-counts at $|b|>60^o$ are well correlated with each other. The effects of the Polar Horns of the radiation belts on fluxes in the IRAS Point Source Catalog are likely to be even smaller than that of the SAA.

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To explain the observed dipole, a dipole calibration error at 60μ would have to have a 7% amplitude at 0.6 Jy and 13% amplitude at 2 Jy.

5. CALCULATION OF Ω_o

We can now calculate how much matter there needs to be in the universe, distributed like the IRAS galaxies, to accelerate the Local Group to its observed velocity with respect to the microwave background (eqn (1)). In linear perturbation theory, our peculiar velocity would be (Peebles 1980):

$$\underline{u} = \frac{1}{3} \Omega_o^{0.6} H_o \underline{G} \qquad (8)$$

$$= \frac{1}{3} \Omega_o^{0.6} H_o \langle 4\pi S \underline{\sigma} \rangle / C, \text{ using eqns (4) and (7).}$$

Using the value for C of Lawrence et al (1986), eqn (5) above, and correcting for the fact that the area they surveyed has a source-density 18% above the average for the unmasked sky, we find

$$\Omega_o = 0.85 \pm 0.16 \quad . \qquad (9)$$

Applying a small correction for the effects of non-linearity (see Yahil et al 1986) our final result is

$$\Omega_o = 1.0 \pm 0.2 \quad . \qquad (10)$$

In the standard hot Big Bang picture, this would imply that 90-95% of the matter in the universe would be non-baryonic, since consistency with the observed primordial helium and deuterium abundances requires $\Omega_{b,o} \approx 0.05-0.1$.

6. MEIKSIN AND DAVIS STUDY

Meiksin and Davis (1986) have also studied the IRAS dipole and the direction they derive, (l,b) = (235, 43.5), is similar to ours. However there are some key differences of approach and also some puzzling discrepancies between their work and ours (Rowan-Robinson 1986b). Figure 4 shows the mask used by Meiksin and Davis. They have been much less severe than us in excluding regions affected by cirrus and in fact exclude only 24% of the sky, compared with 53% excluded by the n=1 mask. They have used a different colour condition to exclude stars, $S(60\mu) > 3S(12\mu)$, but this should have led to the exclusion of only a further 6% of the sample. However I find (i) Meiksin and Davis appear to have used less than half of the sources in the IRAS catalog satisfying their constraints, (ii) the amplitude of their 2-dimensional covariance function for IRAS galaxies is more than twice that found by Rowan-Robinson and Needham (1986). (i) may be caused by using upper limits to the 12μ flux

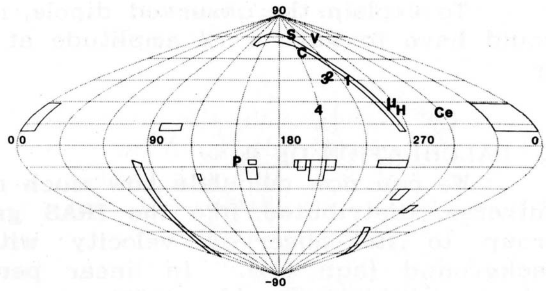

Fig 4: Meiksin and Davis (1986) mask. The excluded area consists of the boxed regions plus $|b|<10^o$.

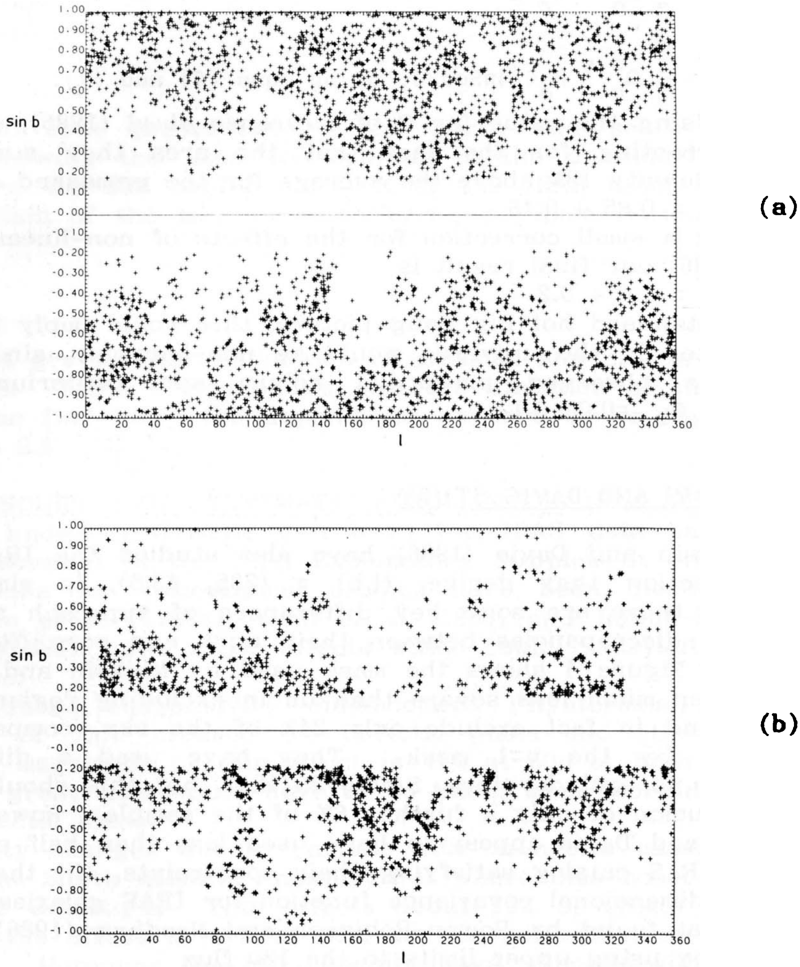

Fig 5: sin b - l distribution for IRAS 0.6 -1Jy 60μ sources outside the Meiksin and Davis mask and satisfying S(60)>3S(12), (a) CIRR1 = 0, (b) CIRR1 > 2.

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in place of the actual 12μ flux, S(12μ), in their colour condition. (ii) is almost certainly due to a substantial contamination of their sample by cirrus.

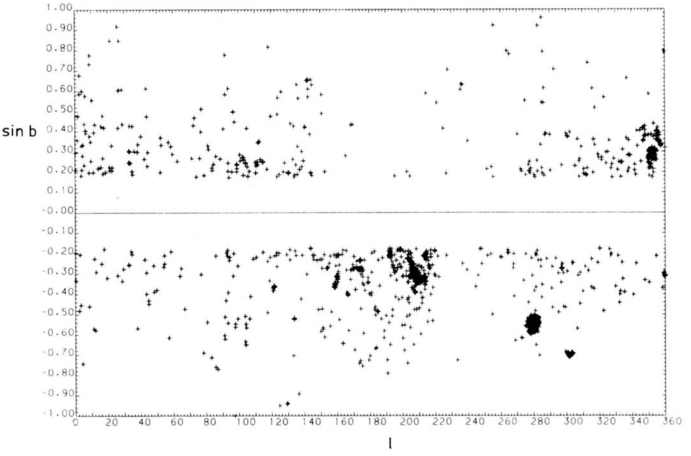
Figure 5 shows the sin b - l distribution of 0.6 - 1.0 Jy IRAS 60μ sources outside the Meiksin and Davis mask, satisfying S(60) > 3S(12), (a) with CIRRI = 0, (b) with CIRRI > 2. The striking difference in the degree of clustering between Fig 5b and Fig 5a is clearly due to strong contamination by cirrus amongst the unidentifed sources with CIRRI > 2. The contamination by cirrus in the flux range 1 < S(60) < 2 Jy is still marked though it is weaker (but not absent) for S(60) > 2Jy. Even in this brighter flux range care has to be exercised. Figure 6 shows the same distribution as Fig 5b for IRAS 60μ sources brighter than 2 Jy, satisfying the Meiksin and Davis colour condition, and with $|b| > 10^o$ (no additional masking). Strong contamination by cirrus and other local sources can still be seen in Fig 6 in the Orion-Taurus and Ophiucus regions (as well as the SMC and LMC). In such regions not only are spurious sources generated but the accuracy of the fluxes of the detected sources can no longer be relied on, nor will the IRAS Point Source Catalog be complete. The very high figures for completeness and reliability on which the present cosmological study relies apply only outside regions affected by cirrus.

7. LAHAV STUDY

Lahav (1986) has attempted to carry out an analysis similar to that of Yahil et al (1986) using optical galaxy catalogues. Merging together the Uppsala, ESO and MCG Catalogues, he has created a diameter - limited ($\theta > 1'.3$) galaxy catalogue covering the whole sky (Figure 7). Replacing the flux in the expression for the surface brightness by (diameter)^2, he calculates the dipole component of the surface brightness, analogously to Yahil et al. The masks he investigates are very simple, of the form $|b| > b_o$ for example, and he calculates the effect of these masks on the dipole components analytically. For $b_o = 20^o$, for example, he finds dipole direction (l,b) = (220,44), similar to that of the IRAS dipole (Table 1). I have also used our software to calculate the dipole for Lahav's galaxy catalogue using the IRAS n = 1 mask, which should delete all area significantly affected by interstellar extinction. The resulting direction is (l,b) = (218,41), not very different from that for the much cruder $|b| > 20^o$ mask.

Lahav's approach is clearly a very interesting one and we plan to carry out further intercomparison of the optical and IRAS samples. Although Lahav's merged galaxy catalogue is not a homogeneous or complete one, the use of diameters rather than magnitudes may have overcome some of the problems of optically selected samples.

Fig 6: sin b - l distribution for IRAS 60μ sources with S(60)> 2 Jy, |b| > 10°, S(60) > 3S(12), and CIRR1 > 2.



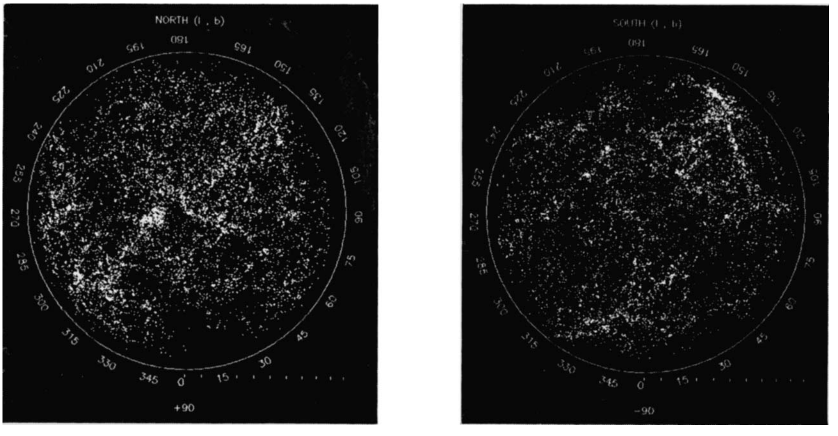


Fig 7: Equal area plot of galaxies in Lahav's (1986) diameter limited merged galaxy catalogue

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8. CLUSTERING OF IRAS SOURCES AND THE DEPTH OF THE IRAS SURVEY

The distribution of IRAS galaxies (Fig 3) shows clear evidence of clustering and many of these concentrations of IRAS sources correspond to known clusters of galaxies at distances ranging from 20 - 200 $(50/H_0)$ Mpc. Rowan-Robinson et al (1986) gave a list of IRAS clusters with $\geqslant 7$ members in a 1° radius circle for $|b| > 60^\circ$. I have now extended this analysis to the whole sky outside the n = 1 mask. Fig 8 shows the sin b - l distribution of these IRAS clusters, with selected identifications with known galaxy clusters (and their distances) indicated. 57 out of a total of 161 IRAS clusters can be identified in this way.

Figure 8 also shows a contour plot of the surface density of IRAS sources in the flux range $0.6 < S < 30$ Jy, made with a resolution of 0.05 in sin b × 10° in l. Here we can see the regions of above average surface density, many identifiable with prominent superclusters like Virgo, Coma, Perseus-Pisces, Hydra-Centaurus, and the regions of below average surface density (voids?), responsible for the IRAS dipole. Virgo itself does not play a major role in our acceleration, since adding the Virgo area to the mask hardly changes the dipole direction (Table 1).

The depth of the IRAS survey has been investigated by Lawrence et al (1986) and Fig 9 shows the redshift distribution found in their survey for sources with $S(60) > 0.85$ Jy. We can also use the survey of Lawrence et al to derive the radial density distribution for IRAS galaxies in this part of the sky ($0^\circ < l < 110^\circ, b > 60^\circ$), using the method of Kirschner et al (1978). The result is shown in Fig 10: the Coma cluster appears as a strong peak at $d \sim 140$ Mpc.

9. DISCUSSION

The calculations of this paper are based on a number of assumptions, which I now discuss in turn.

(i) The 60μ luminosity has to be a measure of the mass of a galaxy. In support of this is the good correlation of 60μ luminosity with optical luminosity (Rowan-Robinson et al (1986b), which in turn is well correlated with galaxy mass. The minority of IRAS galaxies with exceptionally high infrared-to-optical ratios do not invalidate this assumption.

(ii) IRAS galaxies have to be a good tracer for the overall matter distribution, most of which has to be dark and non-baryonic. It is known that ellipticals and lenticulars are biassed towards rich clusters of galaxies, but IRAS galaxies are predominantly spirals and are the best available candidate for an unbiassed tracer of matter. If IRAS galaxies too are biassed tracers of matter then the density estimate (10) would be a lower limit.

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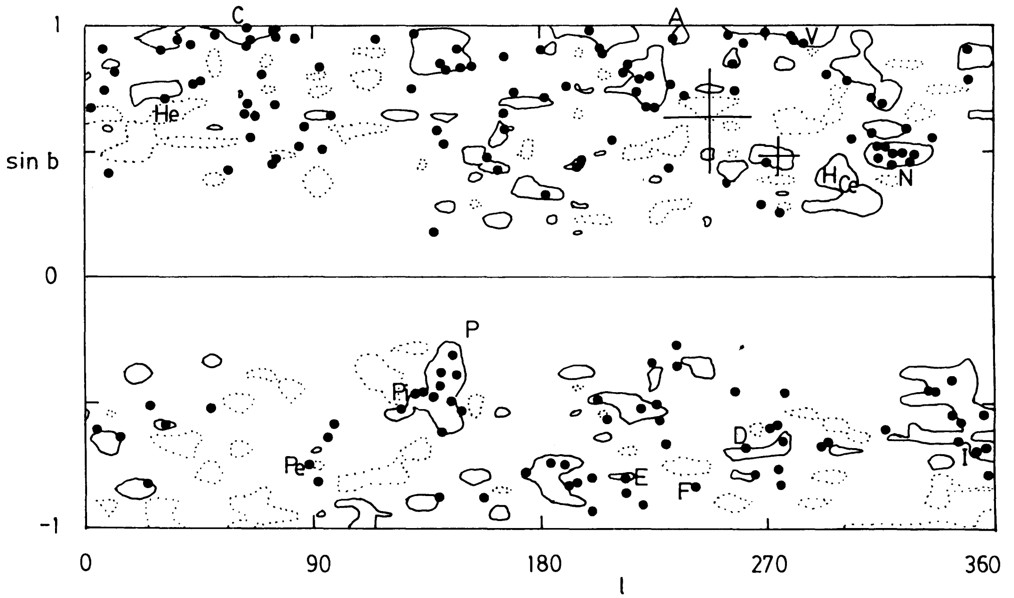

Fig 8: Sin b – l distribution for IRAS clusters (filled circles) superposed on contour plot of surface density of IRAS 60μ sources. Solid curves: source-density 20% higher than average, dotted curves: source-density 20% lower than average. Large cross: direction of IRAS dipole, small cross: microwave background dipole.

Letters denote prominent clusters, with distances in Mpc given in brackets (calculated as $v_0/50$) : C = Coma (133), A = A1367 (122), V = Virgo (20), He = Hercules (220), H = Hydra (60), Ce = Centaurus (60), N = N5419 (83), P = Perseus (108), Pi = Pisces (105), Pe = Pegasus I (77), E = Eridanus (31), F = Fornax I (30), D = Dorado (20), I = Indus II (45).

It is clear that the distribution of IRAS sources (Fig 3) is markedly less clustered than the corresponding distribution of optically selected galaxies (Fig 7). Rowan-Robinson and Needham (1986) have calculated the 2-dimensional covariance function for IRAS 60μ sources outside the n=1 mask (Fig 11). While the power-law form is similar to that found in optical studies, the amplitude is considerably lower. Using the redshift survey of Lawrence et al (1986), Rowan-Robinson and Needham (1986) have calculated the 3-D covariance function corresponding to the model fit in Fig 11 and find

$$\xi(r) = (r/r_0)^{-1.7} \quad (11)$$

where $r_0 = 4.1 \pm 0.7\ (50/H_0)$ Mpc.

which can be compared with a typical value of $10(50/H_0)$ Mpc found in optical studies.

We have also now calculated the 3-D covariance function directly for the Lawrence et al sample (Needham, Lawrence and Rowan-Robinson 1986). The result is shown in Fig 12, compared with the power-law of eqn (11). The agreement is excellent.

(iii) we have to assume that there are no clusters (or voids) behind the mask which are so pronounced as to invalidate the assumption that the unmasked sky is representative of the whole sky. We plan to carry out a careful search for IRAS galaxies at low galactic latitudes to try to check this.

I conclude that the IRAS survey has provided us with an exceptionally rich database for cosmological studies. We have determined the direction of the gravitational acceleration due to galaxies and clusters within about 200 Mpc and find it to agree well with the direction of the microwave background dipole. We have therefore, I believe, found the cause of our motion with respect to the cosmological frame. The density of matter in the universe, distributed like the IRAS galaxies, required to explain our observed velocity with respect to the microwave background corresponds to $\Omega_0 = 1.0 \pm 0.2$. Most of this matter would in the standard model, have to be non-baryonic.

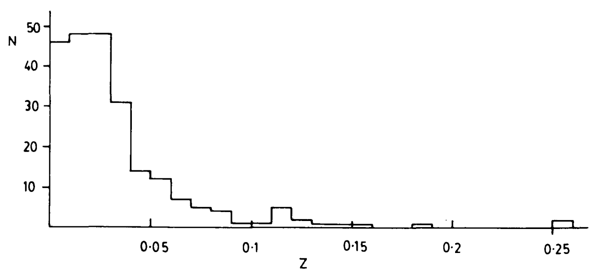

Fig 9: Redshift distribution for IRAS 60μ sources brighter than 0.85 Jy (from Lawrence et al 1986).

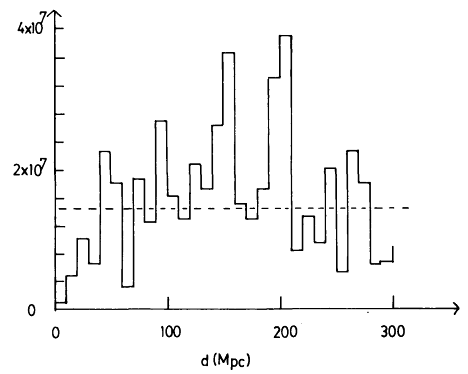

Fig 10: Variation of spatial density of IRAS galaxies with radial distance. The vertical scale is the constant C in eqn (5). (from Rowan-Robinson and Lawrence 1986)

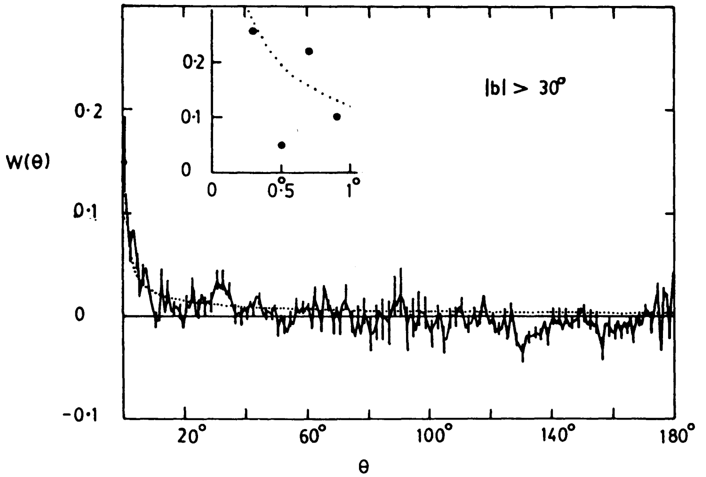

Fig 11: Angular correlation function for IRAS sources at |b|>30°, with 1° bins. Inset is shown data for 12'<θ<1°. The dotted curve is $\omega(\theta)=0.12\ \theta^{-0.7}$. (from Rowan-Robinson & Needham 1986).

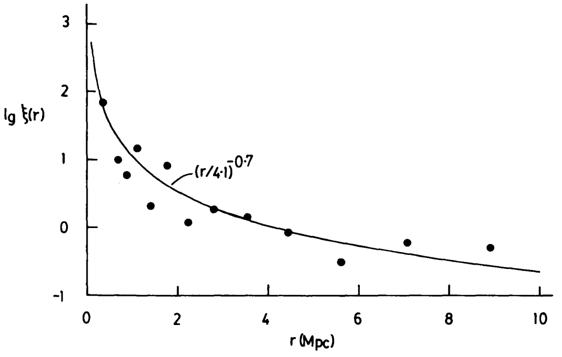

Fig 12: 3-D covariance function for IRAS galaxies (Needham, Lawrence and Rowan-Robinson 1986).

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DISCUSSION

BOLDT: What is the number of sources used for the dipole determination? Is it sufficient to minimize statistical fluctuations?

ROWAN-ROBINSON: There are 9908 IRAS 60 μ sources, after exclusion of stars, with 0.5 Jy $\leq$ S < 30 Jy, outside the N = 1 mask. The uncertainties I have shown are the statistical uncertainties.

DEKEL: I wish to challenge the assumption that we move with a velocity of 600 km/s relative to the IRAS sample, based on the finding discussed by Dr. Davies (Burstein et al.) that we do not move at all relative to the sample of ellipticals which is only twice smaller.

ROWAN-ROBINSON: Although the depth of the IRAS survey may exceed that of the elliptical sample by rather more than a factor of two, I accept that there is probably an inconsistency between the two results. My first comment is that Lahav's study, based on an optically selected galaxy sample covering the whole sky, is consistent with the IRAS result. My second comment is that the Faber-Jackson distance method (and this applies also to the Tully-Fisher method) does not have a real physical basis, so the uncertainty in the distance estimates may be larger than the purely statistical estimates. The fact that you find similarly sloped correlations between observed quantities in different clusters does not prove that the galaxies in two different clusters are identical.

ELLIS: The reduced amplitude of the IRAS galaxy correlation function can largely be explained as due to the dominant spiral mixture. The best estimate of the morphological variation in correlations comes from the Durham/AAT Survey where I find ξ_{spiral} ~ 1.8 times lower than $\xi_{E/S\emptyset}$. Thus your result is not necessarily evidence for biassed galaxy formation.

ROWAN-ROBINSON: Davis and Geller (1976) also found that the clustering amplitude for spirals was lower, by a factor ~ 1.5, than that for galaxies as a whole. However the factor by which the clustering amplitude for IRAS galaxies lies below that found for optical galaxy samples appears to be larger than this. My interpretation of this, and of the higher value of Ω we find compared with that from dynamical studies of optical galaxy samples, is that while the spirals predominantly found by IRAS trace the general matter distribution,

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ellipticals form preferentially in regions of high density contrast, which define the cores of rich clusters.

CHINCARINI: In your detection of clusters using the IRAS survey, how do Coma, A1367 and Virgo compare in number density?

ROWAN-ROBINSON: The numbers of IRAS sources found in clusters associated with Coma, A1367 and Virgo, by the method described in section 8 (1^{o} radius search area) are 10, 7 and 48 respectively. The peak surface-density of sources seen with a pixel size of 0.05 in sin b and 10^{o} in L (section 8, Fig. 8) is 0.89 per sq degree for Coma and Virgo and 0.55 for A1367, compared with a mean surface-density of 0.39 per sq degree.

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