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THE ASTRO-F ALL SKY SURVEY

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ABSTRACT

ASTRO-F is the next generation Japanese infrared space mission of the Institute of Space and Astronautical Science. ASTRO-F will be dedicated to an All Sky Survey in the far-infrared in 4 bands from 50-200microns with 2 additional mid-infrared bands at 9microns and 20microns. This will be the first all sky survey in the infrared since the ground breaking IRAS mission almost 20 years ago and the first ever survey at 170microns. The All Sky Survey should detect 10's of millions of sources in the far-infrared bands most of which will be dusty luminous and ultra-luminous star forming galaxies, with as many as half lying at redshifts greater than unity. In this contribution, the ASTRO-F mission and its objectives are reviewed and many of the mission expectations are discussed.

Key words : cosmology, infrared: source counts — infrared: galaxy evolution — galaxies: starburst

I. INTRODUCTION

Ground based studies of the infrared universe are essentially blind at wavelengths longer than ≈20μm (Low & Reike 1974). The launch of the InfraRed Astronomical Satellite (IRAS) in 1983 transformed our understanding of the infrared universe, revealing a quarter of a million point sources (2 orders of magnitudes above the previous number known) and a sky dominated by dust emission and prolific in star formation (Soifer et al. 1987). IRAS surveyed the entire sky (>96%) at 4 wavelengths from 12, 25, 60μm and 100μm to completeness limits of 0.5Jy and 1.5Jy resepctively. In the most sensitive 60μm band, more than 25,000 galaxies were discovered providing a huge legacy and data archive that is still very much active today. Although similar advances in galaxy evolution have also been made in other wavebands, notably the Lyman break galaxies at optical wavelengths (Steidel et al. 1996, Madau et al. 1996), it has become apparent that the infrared-sub-mm regime may in fact hold the key to galaxy evolution. Optical surveys are plagued by the effects of extinction due to dust that conceals much of the star formation history of the Universe from optical eyes. At infrared wavelengths the Universe becomes relatively transparent to these extinction and absorption effects, thus providing a unique opportunity to study the star formation history of the Universe relatively unhindered.

Following the IRAS mission, the ESA Infrared Space Observatory (ISO) launched in 1995 (Kessler et al. 1996), although strictly speaking an observatory not a surveyor, carried out deep extragalactic surveys over ≈10sq.deg. of sky at 6.7, 15, 60, 90, 175μm Puget et al. 1996, Serjeant et al. 997, Taniguchi et al. 1997, Kawara et al. 1997, Flores et al. 1999b, Oliver et al. 2000, Linden-Vørne et al. 2000). At 15μm in particular, ISO covered a wide range in both spatial area and sensitivity from 500μJy down to 50μJy for the lensed surveys (Elbaz et al. 1999, Altieri et al. 1999). The Space Infra-Red Telescope Facility (SIRTF) due for launch in early 2003 (Rieke 2000), covering the wavelength range from 3.6-160μm and spectroscopy from 5-37μm is the next major space infrared telescope although again like ISO before it, SIRTF is an observatory and will cover areas of the order of 10's sq.deg..

Although, undoubtably, enormous leaps forward have been made and are expected with both the ISO and SIRTF missions, studies of galaxy evolution, number densities (luminosity functions) and large scale structure require large area surveys, the larger - the better. Aptly, around the 20th anniversary of the launch of IRAS, the Japanese infrared space telescope ASTRO-F is set to take such IR surveys to the next generation. For a more detailed analysis of the ASTRO-F All Sky Survey, on which this contribution is based, the reader is referred to Pearson et al. (2002). Previous predictions and simulations for the ASTRO-F All Sky Survey have been made by Jeong et al. (2002), Takeuchi et al. (1999). Pearson et al. (2001) gives a detailed analysis of the IRC pointing surveys.

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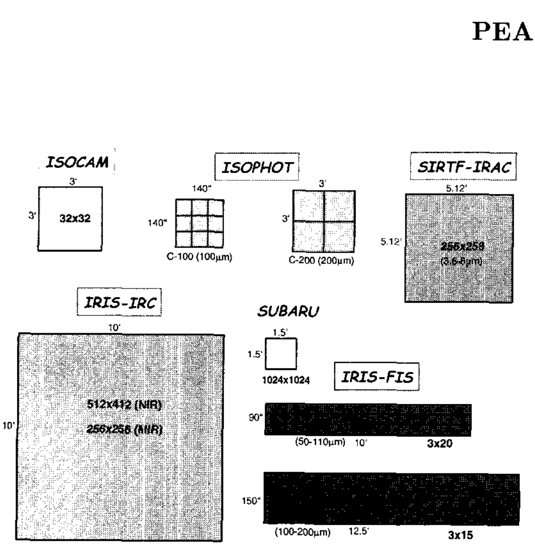

Fig. 1.— Relative detector sizes with number of detector pixels for ASTRO-F-FIS and ASTRO-F-IRC instruments compared with those of ISO-ISOCAM, ISO-ISOPHOT and SIRTF-IRAC, SIRTF-MIPS. Also shown for comparison is the detector for the Japanese Subaru ground based telescope.

II. THE ASTRO-F MISSION

(a) Mission Objectives

ASTRO-F, also known as the Infra-Red Imaging Surveyor (IRIS, Murakami 1998) will be the second infrared astronomy mission of the Japanese Institute of Space and Astronautical Science (ISAS). The ASTRO-F infrared space telescope incorporates a 67cm diameter silicon carbide Ritchey-Chretien design telescope (11kg primary mirror) cooled to 5.8K (the detectors to 1.8∼2.5K) by ≈170l of liquid Helium contained within a light weight cryostat (Kaneda et al. 2002). The temperature of the outer wall of the cryostat is expected to be maintained below 200K via radiation cooling and a pair of 2-stage Stirling-cycle coolers ensure minimum heat flow from the outer wall of the cryostat, thus almost doubling the lifetime of the Helium providing a mission lifetime of more than 550 days. Furthermore, the use of mechanical coolers means that the near-infrared detectors will still be usable even after Helium exhaustion. ASTRO-F is scheduled to be launched in mid 2004 into a sun-synchronous polar orbit at an altitude of 750 km with ISAS's M-V launch vehicle.

The mission lifetime can be divided into 4 discrete phases as follows; *PHASE 0 - Performance Verification* - ∼60 days - Initial check out and calibration of telescope and instruments. A mini-survey may also be attempted. *PHASE 1 - All Sky Survey* - ∼180 days - ASTRO-F will scan the entire ecliptic longitude in survey mode performing a continuous scan of the sky. ASTRO-F spins around the Sun pointed axis once every orbit of 100 minutes, keeping the telescope away from the Earth. The result is to trace out a great circle with a solar elongation of 90deg scanning the sky at a rate of 3.6arcmin/sec.. In this phase, the All Sky Survey will have first priority although there may be as many as 1500 independent IRC pointings and ∼300 FIS pointings planned. *PHASE 2 - Pointing Observations* - ∼300 days - Any supplemental survey observations will be performed. The rest of this phase will be dedicated to pointing observations with the IRC and FIS instruments. This phase will last until Helium exhaustion during which ∼6000 pointings are expected. *PHASE 3 - Helium Boil Off* - >365 days - Even after the liquid Helium has been exhausted the mechanical coolers will keep the temperature low enough to enable the continuation of observations using the IRC-NIR detector. In this phase there is hoped to be as many as 10500 pointings.

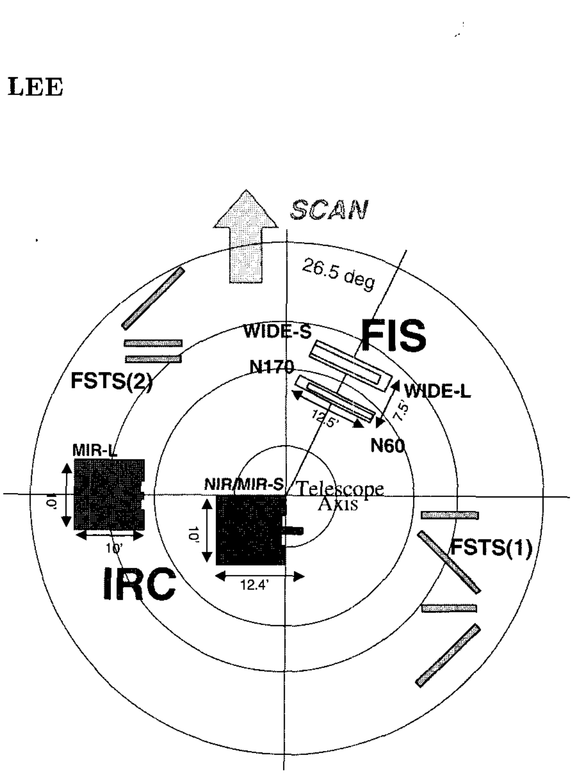

Fig. 2.— Focal plane configuration of ASTRO-F showing the two main instruments, the Far Infrared Surveyor (FIS) and the Infra-Red Camera (IRC). The relative location of the entrance field of views are shown. The scan direction is the direction along the FIS all-sky survey trajectory on the celestial sphere. The three cameras of the IRC are operated simultaneously and observe different areas about 20'apart from each other. The small protruding areas at the right hand edges of the IRC-MIR-S, L and IRC-NIR are for slit spectroscopy with the unfilled areas (slit mask) allowing spectroscopy of extended sources without contamination from surrounding background light. The field of view of the FIS is tilted from the scan direction to achieve the diffraction-limited resolution as defined by the Nyquist's sampling. In addition, the FIS also has a Fourier-Transform spectrometer. FSTS1 & FSTS2 are the focal plane star sensors.

(b) Focal Plane Instruments

ASTRO-F will cover a wide wavelength range from the 2μm to 200μm. Two focal-plane instruments are installed.

Table 1. ASTRO-F FIS filter specifications. Numbers are for FIS in survey mode. Source confusion is the limiting sensitivity due to the superposition of unresolved point sources from the models of Pearson et al. (2002)

Filter	Wavelength Band	Array Size	Pixel size (Diffraction Beam)	Sensitivity (5σ, mJy)	Source confusion (μJy)
N60	$50 - 75\mu$m	20x2	$26.79''(21.6'')$	44	9
N170	$150 - 200\mu$m	15x2	$44.20''(60'')$	55	83
Wide-S	$50 - 110\mu$m	20x3	$26.79''(30'')$	20	20
Wide-L	$110 - 200\mu$m	15x3	$44.20''(50'')$	31	82

Table 2. ASTRO-F IRC Filter Specifications. Numbers are for IRC in pointing mode for a single pointed observation. Source confusion is the limiting sensitivity due to the superposition of unresolved point sources from the models of Pearson et al. (2001)

Channel	Wavelength (μm)	FOV (pixel size)	Sensitivity (5σ,μJy)	Source confusion (μJy)
N2	K	$10'$x$10'$ ($1.4''/pixel$)	1.3	0.2
N3	L	$10'$x$10'$ ($1.4''/pixel$)	1.2	0.2
N4	M	$10'$x$10'$ ($1.4''/pixel$)	1.9	1.4
S7	7μm	$10'x10'$ ($2.34''/pixel$)	19	3.3
S9W	9μm	$10'$x$10'$ ($2.34''/pixel$)	19	17.2
S11	11μm	$10'$x$10'$ ($2.34''/pixel$)	51	14.5
L15	15μm	$10'$x$10'$ ($2.34''/pixel$)	101	76
L20W	20μm	$10'$x$10'$ ($2.34''/pixel$)	92	277
L24	24μm	$10'$x$10'$ ($2.34''/pixel$)	170	363

The Far-Infrared Surveyor (Kawada 1998, Takahashi et al. 2000) will survey the entire sky in the wavelength range from 50 to 200μm with angular resolutions of 30 - 50 arcsec using two high sensitivity detector arrays; a short wavelength array (50-110μm) comprised of unstressed Ge:Ga detectors and a long wavelength array (110-200μm)comprised of stressed Ge:Ga detectors. These 2 arrays are divided into 2 further narrow and wide bands known as N60, WIDE-S, N170, WIDE-L respectively (see Table 1). The arrays are tilted against the scan direction by 26.5deg. to obtain diffraction limited resolution by Nyquist spatial sampling, such that the interval between the scan paths traced by the detector pixels is half of the physical pitch of the pixels. The long and short wavelength arrays essentially observe identical areas of sky, the only discrepancy being due to the difference in the size of the arrays. As well as the all sky survey mode the FIS will also be used for pointing observations and includes a Fourier-transform spectrometer mode that can be operated via the wideband arrays with a resolution of $\approx 0.2cm^{-1}(\lambda/\Delta\lambda = 250 - 1000, \lambda = 50 - 200\mu m$ *allowing imaging spectroscopy of selected sources.*

The other focal-plane instrument is the Infrared Camera (IRC, see Table 2 (Watarai et al. 2000, Wada et al. 2002). The IRC employs large-format detector arrays which will take deep images of selected sky regions at near-infrared and mid-infrared wavelengths. The IRC has 3 cameras each with 3 filters. The IRC-NIR has bands in K, L, M plus a grism and prism from 2.5-5μm & 2.0-5μm respectively. The IRC-MIR-S has narrow bands at 7μm & 11μm and a wide band at 9μm, plus 2 grisms at 5-8μm & 7-12μm. The IRC-MIR-L has narrow bands at 15μm & 24μm, a wide band at 20μm, plus 2 grisms covering the range 11-19μm & 18-26μm. Pearson et al. (2001) made detailed predictions for small, deep and large, shallow area survey strategies using the IRC instrument in pointing mode. Furthermore the two wide band channels of the IRC-MIR (S9W, S20W) may be operated in scan mode during the All Sky Survey phase of the mission at the lower estimated sensitivities of 50mJy and 100mJy respectively (Ishihara et al. 2002). In the All Sky Survey mode, the IRC would utilize just one line (perpendicular to the scan direction of the telescope beam) of the mid-IR detector arrays of the MIR-S and MIR-L channels. Data from these channels would be sampled and downloaded to the ground simultaneously with the FIS all-sky survey data. Typical angular resolutions of $\sim 10''$are expected (since integrated signal will be read

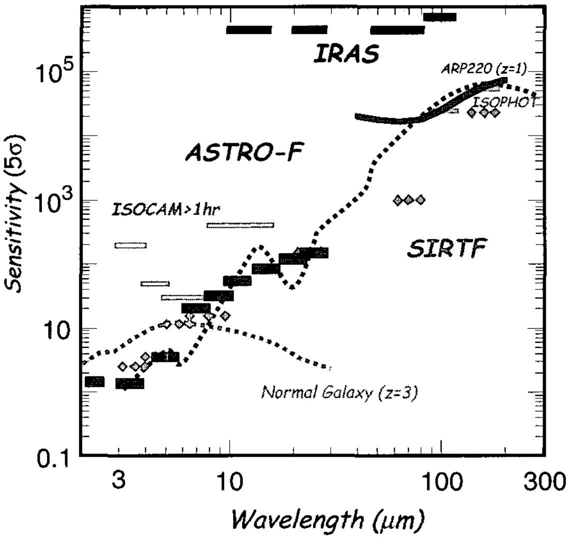

Fig. 3.— ASTRO-F survey sensitivities (5σ) in μJy compared with other IR detection limits. ASTRO-F FIS (survey) and IRC (pointing mode assuming a 500s integration) (*broken black line and filled boxes*), IRAS (*black bars*), ISOPHOT , ISOCAM Hubble Deep Field survey limits (*unfilled boxes* from Goldschmidt 1997) SIRTF-SWIRE (*diamonds* Also shown is the SED of a normal galaxy redshifted to z=3 and an ARP220 ULIG SED at z=1 (*dot-dash & dotted lines*

out every 10″) .

ASTRO-F will have a much higher sensitivity and resolution than that of the IRAS survey, with 50-100 times higher sensitivity at 100μm and more than 1000 times that at mid-infrared wavelengths. The detection limits for the FIS All Sky Survey and the IRC in pointing mode are given in table 1 and table 2 respectively. In Figure 3 the sensitivity of ASTRO-F is compared to IRAS, ISO & SIRTF. Also plotted is the SED of an ARP220 type ULIG redshifted to z=1 and the SED of a normal galaxy at z=3. ASTRO-F will be able to detect such ULIGs out to these redshifts in all almost all bands and even the faint normal galaxy would be detected with the IRC-NIR. Figure 1 shows a comparison of the relative detector sizes and pixel resolutions of the ISO, ASTRO-F & SIRTIF instruments in the infrared. ASTRO-F will also offer 4 times the resolution over 10 times the detector area compared to ISOCAM on ISO. Although similar sensitivities are also capable with SIRTIF (Fazio et al. 1999), ASTRO-F will be able to reach such limits over a wider area (10-20sq. deg. due to the larger FOV) in the mid-infrared and the entire sky at far-infrared wavelengths. Furthermore, ASTRO-F has the added capability of spectroscopy at near-infrared wavelengths (<5μm) beyond the point of liquid Helium exhaustion.

III. THE COSMOLOGICAL GALAXY EVOLUTION MODEL

In order to investigate the expectations of the All Sky Survey, such as predominantly, *how many sources will ASTRO-F detect?* , a reliable cosmological galaxy evolution model is required. More specifically, we would like to predict and simulate various observables such as the source counts as a function of flux, the number-redshift distributions and expected colours of the sources in the ASTRO-F All Sky Survey. This galaxy evolution model is also important as it can provide input to the simulations of the ASTRO-F satellite and future data reduction routines (Jeong et al. 2002).

In general, for an observation at frequency $\nu = c/\lambda$, the total number of sources per steradian observable down to a flux sensitivity S is given by;

$$N(S_\nu) = \int_0^\infty \int_0^{z(L,S)} \phi(L/f(z)) \frac{dV(z)}{dz} g(z) dlgL dz, \quad (1)$$

$$\frac{dV(z)}{dz} = \frac{4\pi D^2}{H_o(1+z)^2(1+\Omega_o z)^{1/2}}, \quad (2)$$

where $\phi = d\Phi/dlgL =$ the zero redshift differential luminosity function per decade in luminosity L, parameterizing the number density of extragalactic sources as a function of luminosity at a frequency ν. dV/dz is the general form of the differential volume element with redshift, z, and is dependent on the luminosity distance, D, and assumed cosmological world model. $f(z)$ & $g(z)$ are luminosity and density evolutionary parameters respectively. The limiting redshift $z(L,S)$, is determined by the flux, S, below which a source of luminosity, L, becomes too weak to be included in the sample of galaxies observed, where;

$$S(\nu_o) = \frac{L_{\nu_o}}{4\pi D^2} \frac{\nu_e L_{\nu_e}}{\nu_o L_{\nu_o}} f(z), \quad (3)$$

$$D(z) = \frac{2c}{H_o \Omega_o^2}(\Omega_o z + (\Omega_o - 2)[(1+\Omega_o z)^{1/2} - 1]), \quad (4)$$

where $\frac{\nu_e L_{\nu_e}}{\nu_o L_{\nu_o}}$ is effectively the ratio of the emission luminosity (luminosity at ν_e) to the observed luminosity (i.e. the K-correction).

The currently most fashionable values for the cosmological parameters as constrained by theory and experiment are assumed where $H_o = 72kms^{-1}Mpc^{-1}, \Omega = 0.3, \Lambda = 0.7$ unless otherwise explicitly stated. (e.g. Balbi et al. 2000, Freedman et al. 2001, Kravtsov et al. 1998).

The galaxy evolution models of Pearson (2001) are used to predict the observables for the ASTRO-F All Sky Survey. The model is an significant extension of the original model of Pearson & Rowan-Robinson (1996)

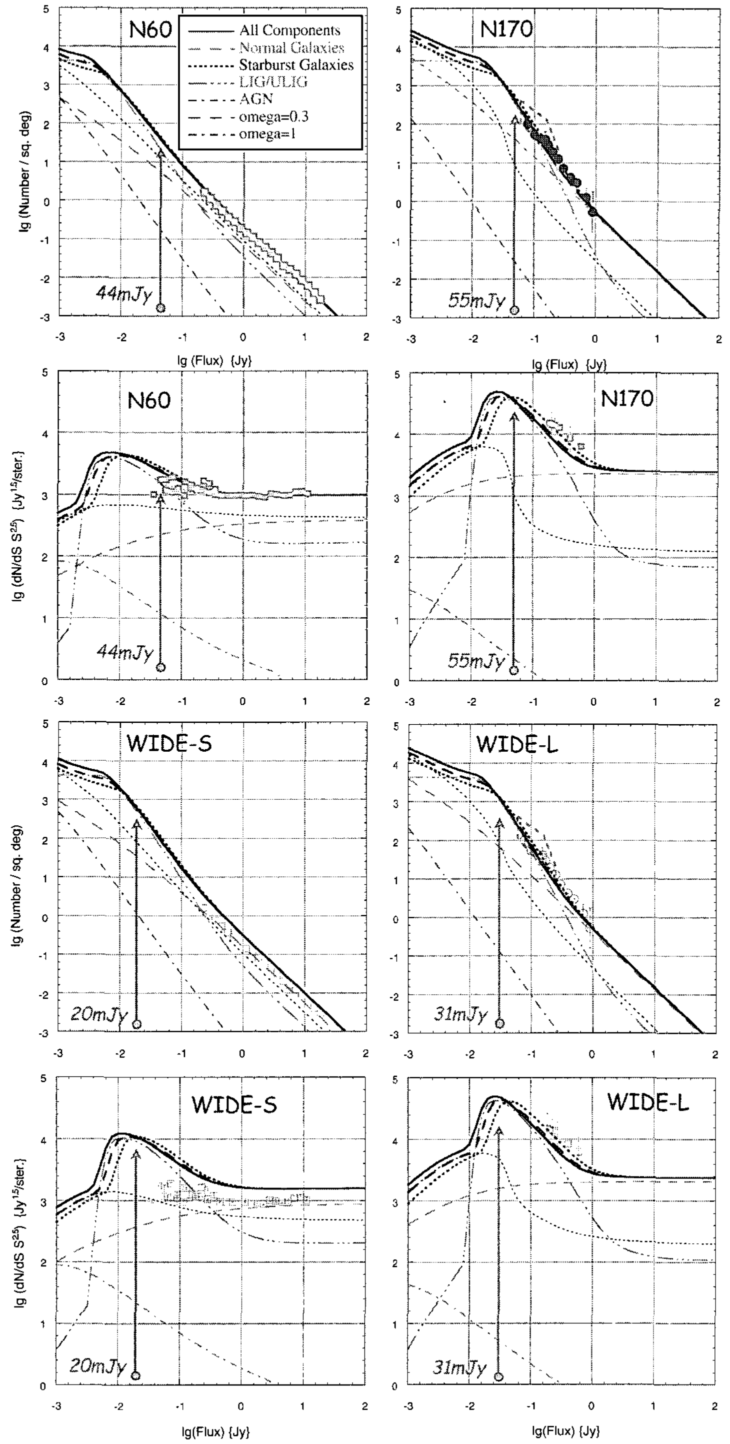

Fig. 4.— Predicted integral (rows 1 & 3) and normalized differential (rows 2 & 4) source counts for the ASTRO-F All Sky Survey N60, N170, WIDE-S, WIDE-L bands with expected sensitivities in mJy (*arrows*). Observed counts shown for N60 band are from IRAS data - Lonsdale et al. (1990), Hacking & Houck (1987), Rowan-Robinson et al. (1990), Saunders (1990), Gregorich et al. (1995). Observed counts shown for N170 band are from ISO data at 175μm - Kawara et al. (1998), Puget et al. (1999), Matsuhara et al. (2000) (fluctuation analysis - *dotted box*), Dole et al. (2001). The observed data at 60μm and 170μm are also overplotted as unfilled symbols for comparison, on the WIDE-S & WIDE-L counts.

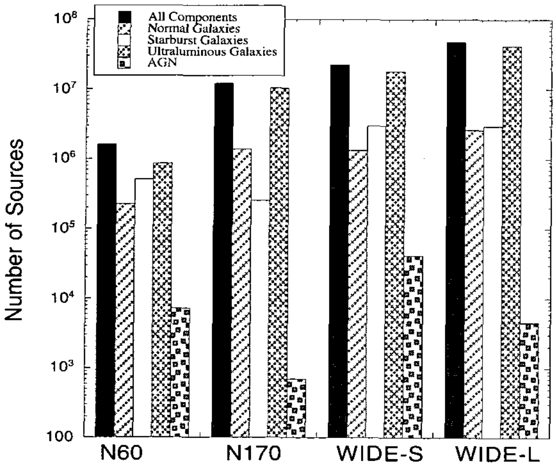

Fig. 5.— Predicted numbers of sources in the 4 FIS bands in the ASTRO-F All Sky Survey. The total number of sources detected are shown, then the number by source component type is also plotted

model and provides a good fit to the source counts, number-redshift distributions and the integrated background radiation from sub-mm to NIR wavelengths. The model incorporates a 4 component parameterization of galaxies segregated by IRAS colours (Rowan-Robinson & Crawford 1989).

This consists of normal, starburst, ultraluminous galaxies (Sanders & Mirabel 1996), defined at 60μm. The cool (high S(100μm)/S(60μm) colours) and warm component (low S(100μm)/S(60μm) colours) 60μm luminosity functions of Saunders et al. (1990) are used to represent the normal, starburst & ULIG galaxies respectively, the ULIGs comprising the high luminosity tail of the warm luminosity function ($L_{60\mu m} >\sim 10^{12} L\odot$). The fourth component is an AGN dust torus (or hot component). The AGN population utilizes the 12μm luminosity function of Lawrence et al. (1986) modelled on the sample of Rush et al.(1993). Spectral energy distributions are required both to obtain K-corrections of sources and to transform the luminosity functions from their rest wavelength to the observation wavelength i.e. by a factor $L(\lambda_{obs})/L(\lambda_{LF})$ where λ_{LF} is the wavelength at which the luminosity function is defined and λ_{obs} is the wavelength of observation. The model spectral templates for the normal, starburst & ULIG components are taken from the new radiative transfer models of Efstathiou et al. (2000a) which also model the unidentified infrared bands in the galaxy SEDs (UIBs probably due to PAH features, e.g. Puget & Leger (1989), Xu et al. (1998). The AGN spectral template is represented by the dust torus model of Rowan-Robinson (1995).

The strong evolution observed from sub-mm to mid-infrared wavelengths necessitates the r equirement of extreme evolution in the models of infrared galaxies, e.g. with ISO; Oliver et al. (1997), Flores et al. (1999a), Altieri et al. (1999), Efstathiou et al (2000b), Serjeant et al.(2000), Dole et al (2001), Serjeant et al. (2001), Elbaz et al. (2002), and in the sub-mm with SCUBA on the JCMT; Smail et al. (1997), Hughes et al. (1998), Barger et al. (1998), Scott et al. (2002). The model of Pearson (2001) assumes that the starburst, ULIG and AGN components evolve with cosmic time. The normal galaxy population does not evolve. The starburst and AGN components undergo positive luminosity evolution of the form $L(z) = L(0)(1+z)^{3.2}$ to a redshift of $z = 2.5$ and then decline to higher redshift. The ULIG population is assumed to undergo extreme evolution in both density and luminosity (see Pearson (2001) for details of these evolutionary models). The density evolution is of the form $D(z) = 1 + g\exp[-\frac{(z-z_p)^2}{2\sigma^2}]$ with $g = 250$, $\sigma = 0.2$ to $z_p = 0.8$ where both the ISO 15μm differential source counts (Elbaz et al. 1999) and the dust enshrouded star formation rate (Chary & Elbaz 2001), (Elbaz et al. 2002) appear to exhibit a peak. This evolution then decays quickly towards higher redshifts. The luminosity evolution is of the form $L(z) = 1 + k\exp[-\frac{(z-z_p)^2}{2\sigma^2}]$ with $k = 40$, $z_p = 2.5$, $\sigma = 0.58$ to z_p and decaying quickly to higher redshifts. This scenario can be envisaged as the accretion of matter onto a core initiating star-formation at high redshifts (luminosity evolution) while the density evolution corresponds to major mergers at a later epoch. Note that locally, ULIGs have a space density comparable to optically selected QSOs ($\sim 0.001 persq.deg.$), although analysis of the IRAS Faint Source Catalogue leads to the conclusion that they should be much more numerous at higher redshift (Kim & Sanders 1998).

IV. SURVEY PREDICTIONS

(a) Source Counts from the All Sky Survey

The ASTRO-F All Sky Survey will provide a huge database for the statistical study of galaxies, extending the IRAS surveys out to between 1-2 orders of magnitude in redshift. Indeed the median redshifts in the ASTRO-F All Sky Survey are predicted to be ≈ 0.3, 1.0, 0.6, 1.0 for the N60, N170, WIDE-S & WIDE-L bands respectively, c.f. IRAS-QDOT=0.03 (Rowan-Robinson et al. 1991). In Figure 4 the predicted counts using the models of Pearson (2001) are plotted for each of the 4 FIS bands by galaxy component, for cosmologies assuming a Hubble constant of $72 kms^{-1} Mpc^{-1}$, a flat $\Omega = 0.3, \Lambda = 0.7$ universe, an open $\Omega = 0.3, \Lambda = 0$ universe and a flat $\Omega = 1, \Lambda = 0$ universe (note, changing the value of the Hubble constant will have no effect on the source counts). The source counts in the N60 and N170 narrow bands can be compared directly with observations by IRAS and ISO respectively whilst counts in the wide far-IR bands will probe down to

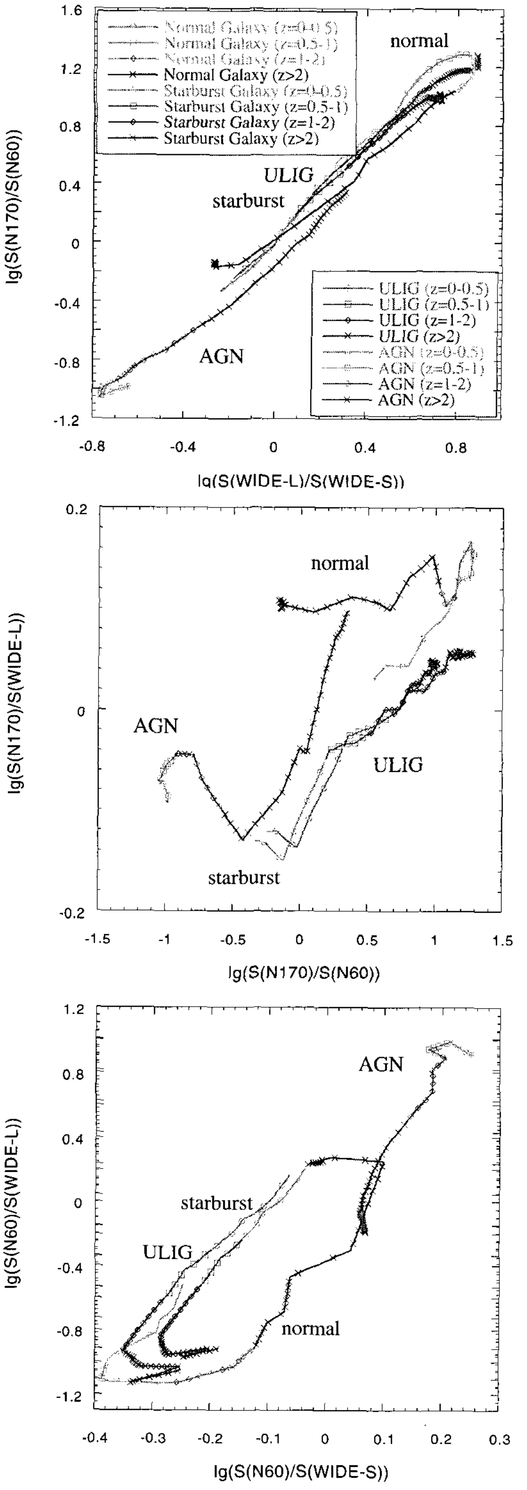

Fig. 6.— Colour-Colour Diagrams plotted for ASTRO-F FIS bands. The colour tracks for normal, starburst, ULIG and AGN components are shown. Markers correspond to redshift steps of δz=0.1.

and below the confusion limit due to point sources. The counts are very steep down to fluxes of 10-20mJy where they begin to flatten off. Approximately, 1.6 million sources are predicted in the N60 band compared to more than 10 million in the N170 band (see Figure 5). The N170 band samples higher up the source count slope (closer to the turn over) and is more sensitive to higher redshift galaxies due to the negative K-corrections. In the wide bands, approximately 22 million and 47 million galaxies may be detected in the WIDE-S and WIDE-L bands respectively. For comparison, the ISO-ELAIS (Serjeant et al. 2000), IRAS (Moshir et al. 1991), SIRTF-SWIRE (Lonsdale 2001) surveys have/will have detected of the order of 10^4, 10^3, 10^5 sources respectively. The vast majority of sources detected in all 4 ASTRO-F bands will be luminous and ultraluminous galaxies. Expected numbers range from 1-40 million from N60 - WIDE-L respectively although the exact numbers will be dependent on the assumed evolutionary scenario. Approximately 7000 AGN will be detected in the N60 band, with as many as 40,000 in the superior WIDE-S band. The N170 band will detect between 700-1000 while the WIDE-L band should see as many as 4500 (these numbers being dependent on the assumed cosmology).

In the N60/WIDE-S bands at 60μm ASTRO-F will probe 3 times deeper than the very deepest IRAS surveys (120mJy for the VFSS, (Bertin et al. 1997)). Comparison with the IRAS 60μm differential source counts shows that ASTRO-F will be reaching very interesting flux levels. At the limit of the IRAS-VFSS (~200-300mJy) an upturn in the Euclidean differential source counts is observed, similar to that found in the differential counts at radio wavelengths due to the emergence of a radio sub-mJy population of starburst galaxies (Condon 1984). The nature of this evolution in the far-infrared cannot be constrained by the IRAS source counts at 60μm with both luminosity evolution or density evolution being equally acceptable (Pearson 2001, Oliver et al. 1992). ASTRO-F will be able to detect and quantify the upturn in the differential counts at fluxes <200mJy.

The ultimate sensitivity for the survey (indeed any survey) is a competing factor between the noise due to the instrumentation & telescope emission etc and the noise due to the superposition of unresolved point sources below the resolution of the telescope (the source confusion noise [Condon 1974, Hogg 2001]), and will be determined by the most dominant of the two. To estimate the source confusion noise, the classical confusion criteria of a source density of 1 source per ~40 beams of the observing instrument is assumed, where the beam diameter is given by $d = 1.2\lambda/D$ (equivalent to the FWHM of the Airy disc), where D is the telescope diameter. From table 1 we see that for the shorter FIS bands the confusion limit due to point sources is below the expected sensitivity capabilities of the instruments. For the longer wavelength bands (N170, WIDE-L) we would expect that the galaxy counts and associations

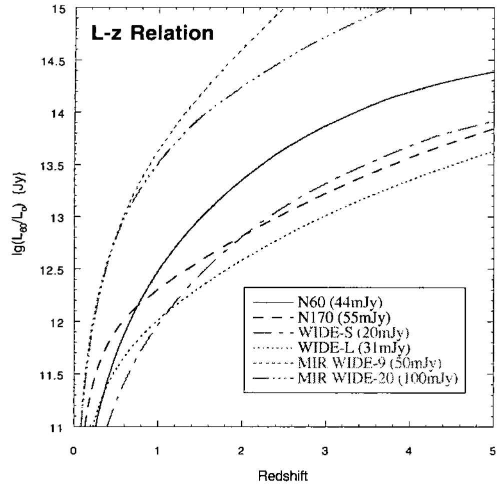

Fig. 7.— The detectability of hyperluminous sources in the ASTRO-F All SKy Survey. The 60μm luminosity a source must have to be detected at redshift, z in a given ASTRO-F band is plotted for the 4 FIS bands and the 2 MIR bands assuming sensitivities for the all sky survey

will be quite severely restricted by the source confusion due to the extremely steep slope of the source counts expected (~3.3 compared to 2.5 expected for a non-evolving population in a Euclidean universe).

(b) Colour segregation of the extragalactic populations

Monochromatic galaxy surveys provide insight into source densities, background contributions and serendipitous discoveries. ASTRO-F will survey in 4 FIR (+2 MIR) bands allowing multi-band correlations and FIR (+MIR) colours producing as many as 6 new points on the IR SEDs of galaxies. In the same way as the IRAS galaxies were segregated into cirrus, starburst and AGN populations on the basis of their IR colours (Rowan-Robinson & Crawford 1989), it should be possible to define a number of sub-classes of ASTRO-F galaxies using similar colour schemes and perform source counts as a function of galaxy type. In figures 6 the colour-colour diagrams for FIS bands are plotted for a normal galaxy of $L_{60\mu m} = 10^{10}L\odot$, a starburst galaxy of $L_{60\mu m} = 10^{11}L\odot$, an ultraluminous galaxy of $L_{60\mu m} = 10^{12}L\odot$ and an AGN of $L_{12\mu m} = 10^{12}L\odot$. In general the different galaxy types occupy distinct regions of the colour-colour plane and by combining one or more of these plots we should be able to obtain some degree of segregation in the galaxy populations both in type and in redshift. To illustrate this, for starburst, LIG & ULIG sources there is a trend towards redder N170/WIDE-L - N170/N60 colours with redshift with galaxies at z>2 having colours an order of magnitude redder than those at z<1. The N60/WIDE-L - N60/WIDE-S colour-colour distribution of normal galaxies are similarly elongated with increasing redshift. However, there is some degeneracy between the low redshift colours of normal galaxies and the high redshift colours of starburst/LIG/ULIG sources. None of the FIS colour-colour plots are capable of confidently separating these source populations from each other. Note that combining the FIS-FIR colours with the IRC-MIR colours would provide a set of more powerful discriminators, although the relatively low sensitivity of the MIR bands would limit such discriminations to z<<1.

The AGN, however, are very well segregated in both redshift and from the other galaxy populations by their colours. The low redshift AGN occupy very distinct areas in both the N60/WIDE-L- N60/WIDE-S and N170/N60 - WIDE-L/WIDE-S colour-colour diagrams. IRAS/ISO data has suggested that it may be difficult to distinguish Seyfert galaxies from normal galaxies in 100-60μm colours or 200-100μm colours (Spinoglio et al. 2002). However the ASTRO-F N170 band may provide additional discriminators that will allow us to unravel the 2 populations somewhat. In fact, although the colours of high redshift AGN are similar to those of high redshift normal (cool) galaxies it is dubious that any any such cool sources could be detected in the ASTRO-F All Sky Survey so it seems reasonable to assume that any sources with lg(S(N60)/S(WIDE-L))>~0 in the N60/WIDE-L - N60/WIDE-S plane would indeed be high redshift AGN, since a normal galaxy at redshift ~1 would have to have an IR luminosity > $10^{12}L_\odot$ to be detected in the all sky survey.

(c) Serendipitous Discovery of Rare Objects

One of the most spectacular objects discovered in the IRAS all sky survey was the hyperluminous galaxy IRAS F10214+4724 discovered at the limit of the IRAS-FSS with S_{60}=0.2Jy, at z=2.286 with far-IR luminosity ~ $10^{14}L_\odot$ (Rowan-Robinson et al. 1991b). The discovery of rare objects such as hyperluminous and primeval galaxies ($L_{60\mu m}$ >~ $10^{13}L_\odot$, (Rowan-Robinson 2000)) requires;

1. Wide area shallow as opposed to narrow, deep surveys, since these objects are rare but bright with source densities of between 0.001-0.01per sq.deg.
2. Far-IR wavelengths since the bulk of any emission (90-99%) should emerge at these wavelengths due to the copious amounts of dust expected due to star formation.
3. Multi-wavelength survey for IR colours for photometric redshifts, SED fitting and discrimination from other less luminous sources.

In Figure 7 we plot the 60μm luminosity that a source must have to be detected at redshift z, in the ASTRO-F All Sky Survey assuming the spectral template of the hyperluminous galaxy IRAS F10214+4724. A F10214 type hyperluminous galaxy with an infrared luminosity of order a few $10^{14}L\odot$ would be detectable out to redshifts ~4 in the FIS bands and at z>1 in the

IRC-MIR bands. Depending on the cosmology, models predict that we could expect of the order of 300 such sources over the entire sky detected in the WIDE-S and WIDE-L bands and between 40-100 in the WIDE-9 and WIDE-20 MIR bands respectively.

Corresponding follow up and cross correlations will answer many of the questions surrounding the hyperluminous population (of which to date only a handful $\sim$50, have been discovered). Of particular importance is the question of their origin and fuelling mechanisms; Are they a completely new population of sources or simply the fireworks at the end on the far-infrared luminosity function? Are their huge luminosities predominantly driven by a galaxy wide starburst or a central AGN? Furthermore future mm wave instruments (e.g. the LMTwww.lmtgtm.org,with a large area survey of a few 1000sq.deg.) would be particularly sensitive and will further constrain the detections of such objects since a detection at mm wavelengths with no corresponding ASTRO-F counterpart will automatically imply a high redshift (and therefore high luminosity) for any given source.

(d) Large Scale Structure

Wide sky coverage is a necessity for large scale structure studies, as studies on smaller scales can be effected by localized fluctuations. Theoretical simulations measure the variation in the galaxy density field $\delta = \frac{n-<n>}{<n>}$ while large scale K-band studies such as 2MASS (Cross et al. 2001) can measure the variation in the stellar mass density field $\delta_* = \frac{L_k n-<L_k n>}{<L_k n>}$. However, a more important quantity is the rate of change of the stellar mass field since it is a differential quantity, i.e. the star formation rate density field $\delta_*' = \frac{L_{FIR} n-<L_{FIR} n>}{<L_{FIR} n>}$ hence why the so-called *Madau Plot* was so popular (Madau et al. 1996). IRAS mapped the local density field of the Universe out to redshifts $\approx$0.01-0.1 covering 35000sq.deg.down to 600mJy at 60μm and 20000sq.deg. down to 200-250mJy at 12,25,60μm (e.g. Lonsdale et al. (1990), Rush et al. (1993), Oliver et al. (1996), Saunders et al. (2000)). ASTRO-F will probe to 10-100 times deeper than IRAS over 500x the area of the SIRTF-SWIRE survey.

As a first approximation, the Visibility Function can be used to assess the capability of the ASTRO-F All Sky Survey ((Von Hoerner 1973), (Condon 1984)). In general, the total number of sources observable down to some limit S is given by equation 1. Discarding the volume-redshift integral gives$\int_0^\infty \phi(L) dlgL$, the number density of galaxies in a given redshift bin at redshift z. This is effectively the galaxy luminosity function in a bin of width dz centred on a redshift z, and is sometimes known as the Density Function $\rho(z)$ and is essentially a measure of the survey sensitivity. Taking logarithmic steps in the density, a threshold redshift $z_o(\rho_o)$ can be calculated from the density function from which a corresponding cosmological volume is calculated which will be the sampled volume above a given galaxy density for the proposed survey, where $V(\rho_o) = V(z_o)$. Convolving this volume with the total coverage of the survey gives us the quantity referred to as the Visibility Function of sources in the all sky survey and is a function of both the depth (sensitivity) and the coverage of any given survey. The Visibility Function is plotted in Figure 8 and clearly shows the power and potential of the ASTRO-F All Sky Survey for large scale structure studies with 2-3 orders of magnitude in the volume being sampled at densities of $lg(\rho) = -7 \sim -4 Mpc^{-3}$ compared to the equivalent SIRTF-SWIRE bands. In truth, the ASTRO-F and SIRTF-SWIRE surveys supplement rather than supplant one another and are extremely complementary, as can be seen from figure 8 with ASTRO-F covering scales from $\sim$10-1000h^{-1}Mpc from z$\sim$0.01-1 and the SIRTF-SWIRE survey covering the range from scales

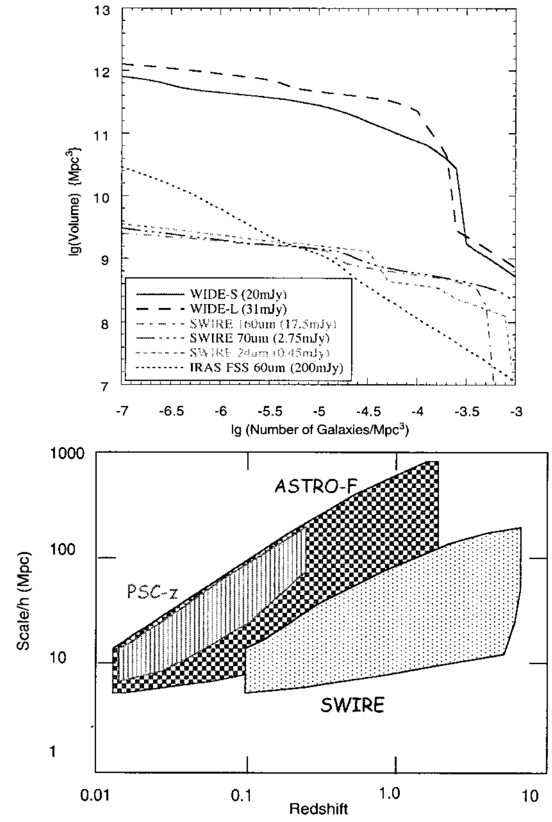

Fig. 8.— (*top panel*) the Visibility Function of the ASTRO-F All Sky Survey. Results are plotted for the WIDE-S (S=20mJy) & WIDE-L(S=31mJy) FIS bands. Also shown for comparison are the predictions for the SIRTF-SWIRE survey covering 70sq.deg. at wavelengths of 160μm (S=17.5mJy), 70μm (S=2.75mJy), 24μm (S=0.45mJy) and the IRAS FSS all sky survey at 60μm (S=200mJy).(*bottom panel*) the scale probed by the ASTRO-F All Sky Survey at a given redshift. Also shown for comparison are the IRAS-PSCz sample (Saunders et al. 2000) and the predictions for SIRTF-SWIRE.

of ~10-100h^{-1}Mpc from redshifts >0.1-5.

V. SUMMARY

ASTRO-F will carry out the first all sky survey at infrared wavelengths for 20 years and will probe down to sensitivities between 10-1000 times deeper than the IRAS mission to more than 5 times the angular resolution in 4 far-IR bands from 50-200μm and 2 mid-IR bands at 9 & 20μm, detecting 10's millions of sources in the longest wavelength bands and > 10,000 at mid-IR wavelengths. Most of the sources detected by the FIS will be dusty LIGs & ULIGs of which, in the longest wavelengths bands, >50% will be at redshifts greater than unity.

Ultimately ASTRO-F should provide an unbiased survey with ~95% sky coverage to a reliability of >99% for bright sources. Absolute flux uncertainties of 10% and 20% are expected for point and diffuse sources respectively. Pointing accuracy is expected to be $< 5''$. The ASTRO-F All Sky Survey will produce several catalogue products which would be released in a timely fashion after the completion of the survey phase;

1. *ASTRO-F Flux of known sources* - Measurement of sources used for the Input Source Catalogue and fluxes of IRAS point sources.
2. *Bright Source Catalogue* - A catalogue of sources that can be extracted easily such as bright sources or those at high ecliptic latitude.
3. *Faint Source Catalogue* - The all sky point source catalogue to the optimum sensitivity.
4. *Image maps* - Crude maps, square degree imagelets and 10's sq.deg. image atlases.

These catalogues may then serve as input catalogues and cross correlation databases for later missions such as Herschel (Pilbrat 2000) & Planck (including the all sky survey with HFI (Coburn & Murphy 1999)) due for launch in 2007. Planck will be an ideal companion to ASTRO-F surveying the whole sky at sub-mm wavelengths down to 200μm thus providing an important longer wavelength channel to join FIR survey of ASTRO-F.

In closing, it should be stressed that the ASTRO-F surveyor mission should be seen as supplementing not supplanting the SIRTF observatory mission. The two are complementary. SIRTF will cover relatively small areas (1-70sq.deg.) to high sensitivity while ASTRO-F will cover the entire sky to more moderate sensitivities.

VI. INTERNET ACCESS TO SIMULATED DATA

The simulations for the ASTRO-F All Sky Survey discussed in this contribution can be accessed through the world wide web at *http : //astro.ic.ac.uk/ ~ cpp/astrof/*. Other information on the ASTRO-F mission can be found at *http : //www.ir.isas.ac.jp/*.

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