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Optical and Spectroscopic Follow-Up of the Deeper FIR Selected Sample

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Abstract. We present the optical follow up observations of the deepest complete IRAS selected sample (Hacking et al. 1989) so far available, in the North Ecliptic Polar Region (NEPR). This is the first step in the multi-wavelength study of this sample which, thanks to our ISOCAM observations, provides a direct link between IRAS and ISOCAM surveys and the forthcoming deeper Spitzer cosmological surveys. The sample allows a direct investigation of the evolution of the global Spectral Energy Distribution (SED) of dusty galaxies up to a redshift of about 0.3, where the global star formation rate is known to evolve very fast. Here we present an analysis of the optical properties of this sample. These galaxies turn out to be disk like systems and the measured intensity ratios place them among the typical starburst class of objects.

Key words. Galaxies: IR – Galaxies: Photometry – Galaxies: Dynamics

1. Introduction

The IRAS Deep Survey (IDS) sample was defined by Hacking & Houck (1987) by coadding IRAS scans of the north ecliptic polar region, representing more than 20 hours of integration time. It comprises 98 galaxies with S(60μm)> 50mJy over an area of 6.25 sq. deg. and is still the deepest complete far-IR selected sample available; for comparison, the deep ISOPHOT surveys, FIRBACK at 175 μ (Puget et al. 1999) and ELAIS at 90μm (Rowan-Robinson et al. 1999; Rodighiero et al. 2003), are both complete down to about 100mJy. Also, the IDS sample is superior to those in the coverage of the spectral energy distribution of member galaxies. In fact, in addition to 60μm fluxes, most of them have also 100 μm fluxes and several have 25μm fluxes. Moreover we have obtained ISOCAM observations in the LW3 filter (range 12-18μm) of 94 fields including these sources (Aussel et al. 2000). VLA observations for a good fraction of sample sources have been made by Hacking et al. (1989). Optical/near-IR data are essential to get a complete view of the properties of galaxies. Our program is aimed at: investigating the evolution of the spectral energy distribution (SED) of dusty galaxies over several Gyr in look-back time, i.e. over an interval in which the mean star formation rate in the Universe is known to evolve strongly. As al-

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ready mentioned, the IDS sample is currently the best suited for this purpose; of course, a global view of the evolution of the SED, from optical to far-IR, overcomes the difficulties associated with uncertain dust extinction or bolometric corrections appraising current estimates of the 60μm local luminosity function, based on rather shallow samples, and in particular of its quite uncertain faint end. The present sample, 10 times deeper than the IRAS point source catalog, is much less liable to the effect of local density inhomogeneities estimating, through the bivariate 60-14μm function, the poorly known local luminosity function of galaxies in the mid-IR. It can thus provide an important constraint to models interpreting the deep mid-IR ISOCAM counts assessing, by means of an analysis of the 60μm luminosity function in different redshift bins, the cosmological evolution of galaxies, indicated by counts and exploring possible relationships between optical/near-IR morphology, dust temperature, dust extinction, luminosity, etc. The chemical and photometric evolutionary models developed by our group (Mazzei et al. 1992, 1994; Mazzei 2003) , covering the full frequency range from the UV to the far-IR, will be checked against these data and used to interpret them.

Optical spectra of 77 tentative IDS identifications were obtained by Ashby et al. (1996). Although our more precise ISOCAM positions indicate that several of their identifications were not correct, their work has shown that the redshift distribution extends at least to a redshift of 0.3. According to some models (e.g. Franceschini et al. 1994; Guiderdoni et al. 1998) some IDS sources may be at substantially higher redshifts. In this paper we present the results of the optical follow up observations of the galaxies belonging to our sample including 39 new redshift determinations.

2. Observations and Data reduction

A program of optical imaging and spectroscopy was undertaken to observe our sample. For this we acquired B and R images and low-resolution spectra of all the objects (106) identified in Aussel et al. (2000). Both imaging and spectroscopy were done using the 3.5m Telescopio Nazionale Galileo (TNG) with the Low Resolution Spectrograph (DOLORES); for the faintest sources we used the 10m Keck II telescope with the Echellette Spectrograph and Imager (ESI) and for the brightest ones the 1.82m Cima Ekar (Asiago) telescope equipped with AFOSC. We observed spectroscopically 78 sources and 71 in imaging of the 94 fields that compose our initial sample.

All the data (imaging and spectroscopy) were reduced using standard IRAF reduction

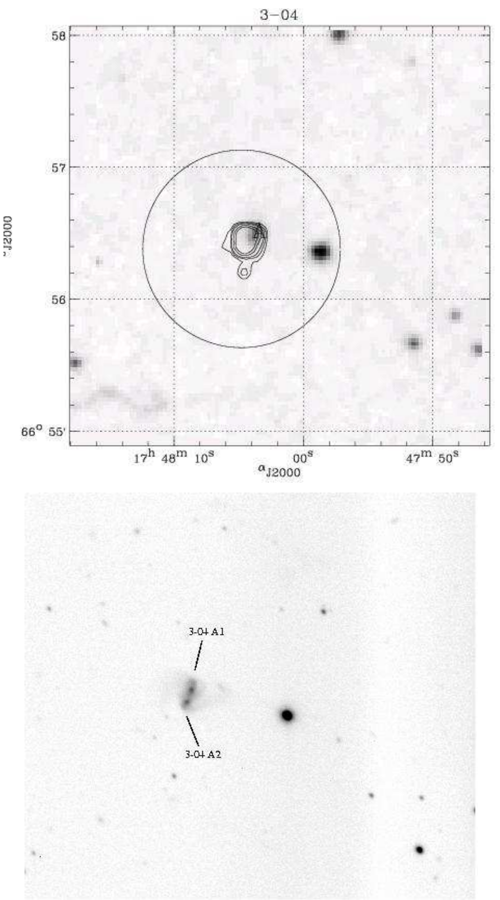

Fig. 1. Upper panel: original finding chart for galaxy 3-04 from Aussel et al. (2000) with the ISO contours superimposed, the circle is the 45" IRAS error box. Lower panel shows R band image obtained at the TNG telescope where two galaxies are clearly visible.

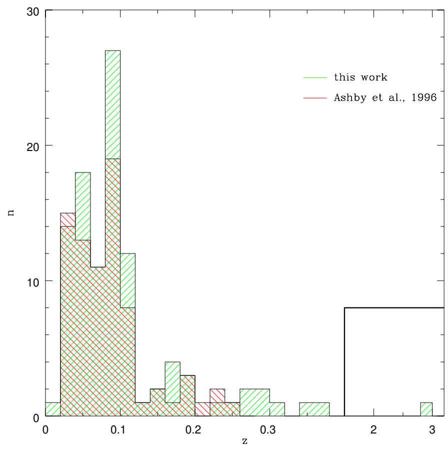

Fig. 2. Redshift distribution of our sample compared to the values from Ashby et al. (1996). Two sub-clusters, at z=0.055 and 0.080, are visible. In the insert at lower right we show the serendipity discovered object at z=2.954

packages. Spectra were classified according to the presence or absence of various emission lines. Once features have been identified, the redshift of a source was measured using standard IRAF tasks that are based on the offset of the features from their rest-frame wavelengths. The good spatial resolution of the ESI spectra allow us to measure the rotation curves for almost all the galaxies observed with Keck (~30 galaxies).

Images were analysed using the GALFIT tool (Peng et al. 2002), a galaxy/point source fitting algorithm that fits 2-D parameterised, axisymmetric, functions directly to images whose output are the geometrical and photometric parameters of the galaxies deconvolved by seeing (see next section).

3. Results

Many sources were found to have a double component, a typical case can be seen in Fig 1. Among the observed targets, 4 turned out to be identified with stars. For all the remaining galaxies but two, the spectra show strong emission lines, i.e. Hα, Hβ, [OIII], [OII], [OI], [NII] and [SII], that were used to measure the redshift.

The redshift distribution of our sample is shown in Fig.2 compared with that of (Ashby et al. 1996). As we can see there is a general agreement with this previous study. Two sub-clusters at z=0.055 and 0.080 are visible together with a higher number of sources at redshift z>0.2. In addition we obtained a Keck spectrum of one object which was indicated as an upper limit both at 60 μm (Mazzei et al. 2001) and at 15 μm (Aussel et al. 2000); the spectrum shows only one emission line that we identified as the Ly-α at z=2.954.

The excellent spectral and spatial resolution of 30 spectra obtained with the Keck+ESI configuration, allow us to obtain, together with the redshift, the rotation curve of many of these objects. Most of these curves are very regular, typical of disk galaxies, some show peculiar motions and in few cases, in general for interacting systems, we can see very disturbed rotation patterns. Some of the observed rotation curves are shown in Fig 3. The observed rotation curves have been modelled with synthetic velocity fields which take into account geometric distortions due to inclination and slit misalignment as well as seeing. Using this maximum velocity, V_{max}, and the photometric parameters we can give an estimate of the mass of these galaxies. We found that the masses are in the range between $1 - 10 \times 10^{10} M_{\odot}$. The derived values are typical of disk galaxies. One of the major goals of our study was to analyse the optical properties of the galaxies. Thus we performed the surface photometry of our objects in order to derive the photometric parameters, i.e. the total B and R magnitudes, and the geometrical ones, i.e. scale radius, position angle, ellipticity and effective surface brightness (μ_e). In general the luminosity profiles of the galaxies in our sample are well represented by an exponential law indicating that it is mainly composed of disk galaxies. In Fig 4 we show the relation between intrinsic disk scale radius, and absolute B magnitude. Our objects follow the typical Freeman (Freeman 1970) line that describes disk galaxies. We have made use of the typical diagnostic diagrams of Veilleux & Osterbrook (1987), based

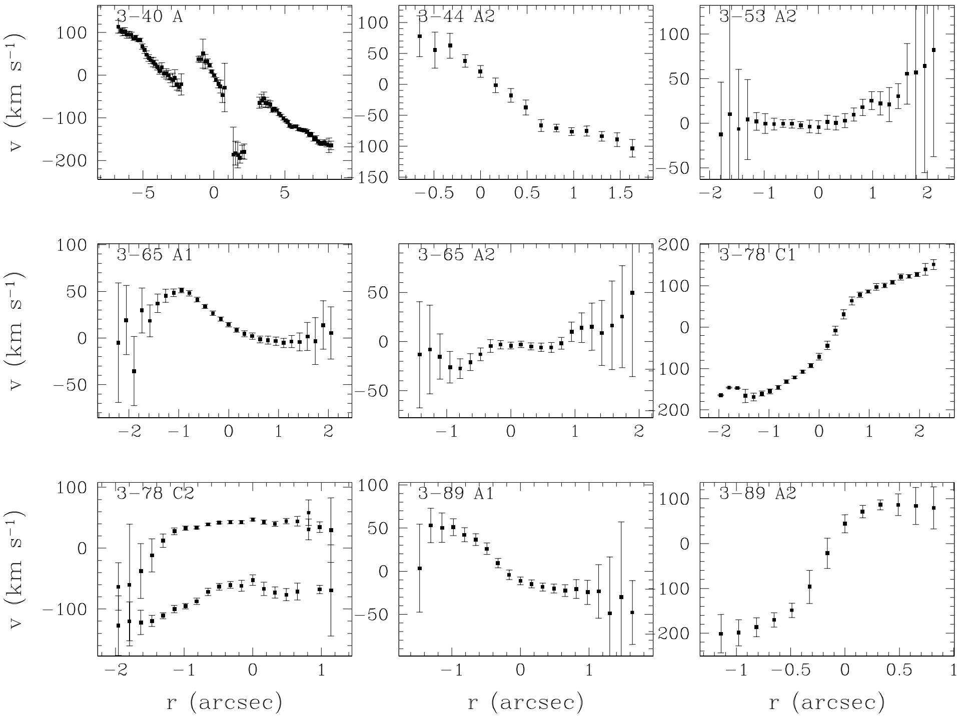

Fig. 3. The observed rotation curves for some galaxies in our sample (at a mean z~0.2). Most have a regular shape, but also cases of peculiar rotation are shown.

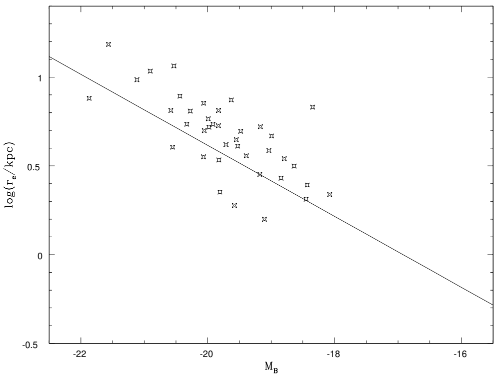

Fig. 4. The size magnitude relation for our sample of galaxies. The solid line represent the Canonical Freeman relation for disk galaxies with central surface brightness μ_{0_B}=21.65 mag arcsec^{-2} (Freeman 1970)

on two-dimensional line-intensity ratios constructed from [OIII]λ5007, Hβ, [OI]λ6300Å, Hα [NII] and [SII]. They are shown in Figure 5, our data are compared with different classes of emission-line objects as defined in Ho et al. (1997) ; i.e. LINERS, Seyfert galaxies, HII regions and a class of objects that can be considered as transition between HII regions and LINERS.

Fig. 5 shows that almost all our objects fall in the region typical of the HII region class. Only one object lies in the region of transition.

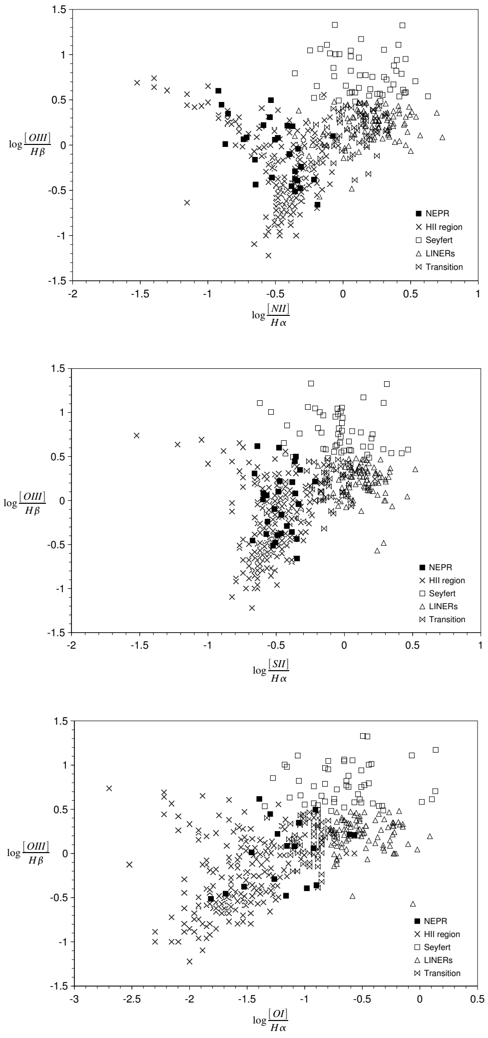

Fig. 5. Diagnostic diagrams: Upper panel: log [OIII] λ5007/Hβ versus log [NII] λ6583/Hα; Middle panel: log [OIII] λ5007/Hβ versus log [SII] λ 6716, 6731/Hα; Lower panel: log [OIII] λ5007/Hβ versus log [OI] λ6300/Hα. The nuclear spectral classes are described in the label, our data are the full squares.

This result seems to indicate that our galaxies can be considered spiral galaxies and confirms our previous finding that their luminosity profiles are well described by an exponential law typical of the disk systems.

4. Conclusions

Using imaging data and spectroscopy we have analysed the optical properties of the deepest complete IRAS selected sample. We obtained data for 78 out of 101 galaxies that compose our original sample. We found that:

– From luminosity profiles ~80% of our galaxies are disk like objects.
– Their spectra can be classified as typical of starburst galaxies mainly HII regions
– For ~30% of our sample we can measure the rotation curve and the derived dynamical masses are typical of disk galaxies with masses in the range between $10^{10} M_{\odot}$ to $10^{11} M_{\odot}$

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