FAR-INFRARED PROPERTIES OF LOCAL STAR-FORMING GALAXIES FROM THE UCM SAMPLE

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Abstract

The Universidad Complutense de Madrid Survey (UCM Survey) has been carried out the last years with the aim of looking for Hα emission-line galaxies. ISO observed some of the UCM galaxies with different instruments but a very high percentage of these star-forming galaxies were observed in ISOPHOT Serendipity Mode. The objective is to get 175μm flux densities for as many objects as possible of the UCM Sample to collect more information about the FIR properties and the star formation processes through the comparison with all the optical data already available.

Key words: Galaxies: formation – Galaxies: surveys

1. Introduction

The Universidad Complutense de Madrid Survey has produced the UCM Sample of Hα emission-line galaxies. They are a fairly complete representation of the star-forming galaxies in the local Universe (z <0.005). During the time ESA's Infrared Space Observatory (ISO) was in space, some of the galaxies from the UCM Sample were observed with several instruments. The imaging camera (CAM) obtained mid-IR images, whereas the long and short wavelength spectrometers (LWS and SWS) produced mid-IR spectroscopy of a few bright objects. ISOPHOT has taken photometric maps in different bands of some of the UCM galaxies, which will allow us to compare this data with all the optical information we already have about them. The ISOPHOT Serendipity Survey at 175μm was carried out with a point source detection limit $\sim$ 1 Jy and surface brightness detection limit $\sim$1 MJy/sr, covering approximately 15% of the sky. The Serendipity Mode was a photometric mode automatically activated when a slew was longer than 30 s in order to utilize the otherwise lost time between pointed observations. Around 60% of the galaxies from the UCM Survey have been more or less covered by ISO in this Serendipity mode, suggesting the possibility of being detected at least in a marginal way. The 175μm integrated fluxes would provide the total IR fluxes and luminosities, flux ratios, dust masses and color temperatures. With this data we expect to make a comparison with previous optical data and all this information will allow us to obtain some clues into the nature and properties of the star-forming processes.

2. The UCM sample

The UCM Survey (Zamorano et al. 1994, 1996) is a low-dispersion objective-prism for low redshift emission line objects (ELGs) and is being carried out with the Schmidt telescope at the German-Spanish Observatory of Calar Alto (Almería, Spain). Galaxies with an important star forming activity (EW(Hα)> 20 Å) and spanning a wide range of luminosities and other physical properties as size, mass and spectral type, belong to the sample. The selection effects of the survey, the spatial and luminosity distributions of the sample galaxies and their nature have been determined after extensive follow-up observations: Spectroscopy, Optical CCD and nIR Photometry. Morphologically, the sample is dominated by late-type spirals with less than 10% presenting typical parameters of earlier types and the remaining 10% being irregulars.

Spectroscopically, all types of star-forming galaxies previously known in the literature are represented; most of the UCM objects are low-excitation, high-metallicity star–burst-like galaxies but there are also high-excitation, low-metallicity HII-like galaxies. Their metallicities range from solar values to 1/40 $Z_\odot$, peaking at 1/4 $Z_\odot$. The most interesting result is the first direct determination of the local H(luminosity function and from it Star Formation Rate function and SFR density of the local Universe. This value has become the local reference for the SFR at intermediate and high redshifts.

3. Serendipity survey data

In order of using the other way waste time between pointed observations (Kessler et al. 1996), the ISOPHOT team proposed to utilize the slewing time and the instrument selected for this aim was ISOPHOT C200 array which was sensitive up to 200μm. The objects observed by this operation mode is known as ISOPHOT Serendipity Survey. For obtaining the Serendipity Survey slew data, the ISOPHOT C200 (Lemke et al. 1996) detector (it is a 2×2 pixel array with a pixel size of 89.″4) and C160 broad band filter (this band is center in 170μm with equivalent width 89μm) were used in conjunction.

Proc. Symposium *'The Promise of the Herschel Space Observatory'* 12–15 December 2000, Toledo, Spain
ESA SP-460, July 2001, eds. G.L. Pilbratt, J. Cernicharo, A.M. Heras, T. Prusti, & R. Harris

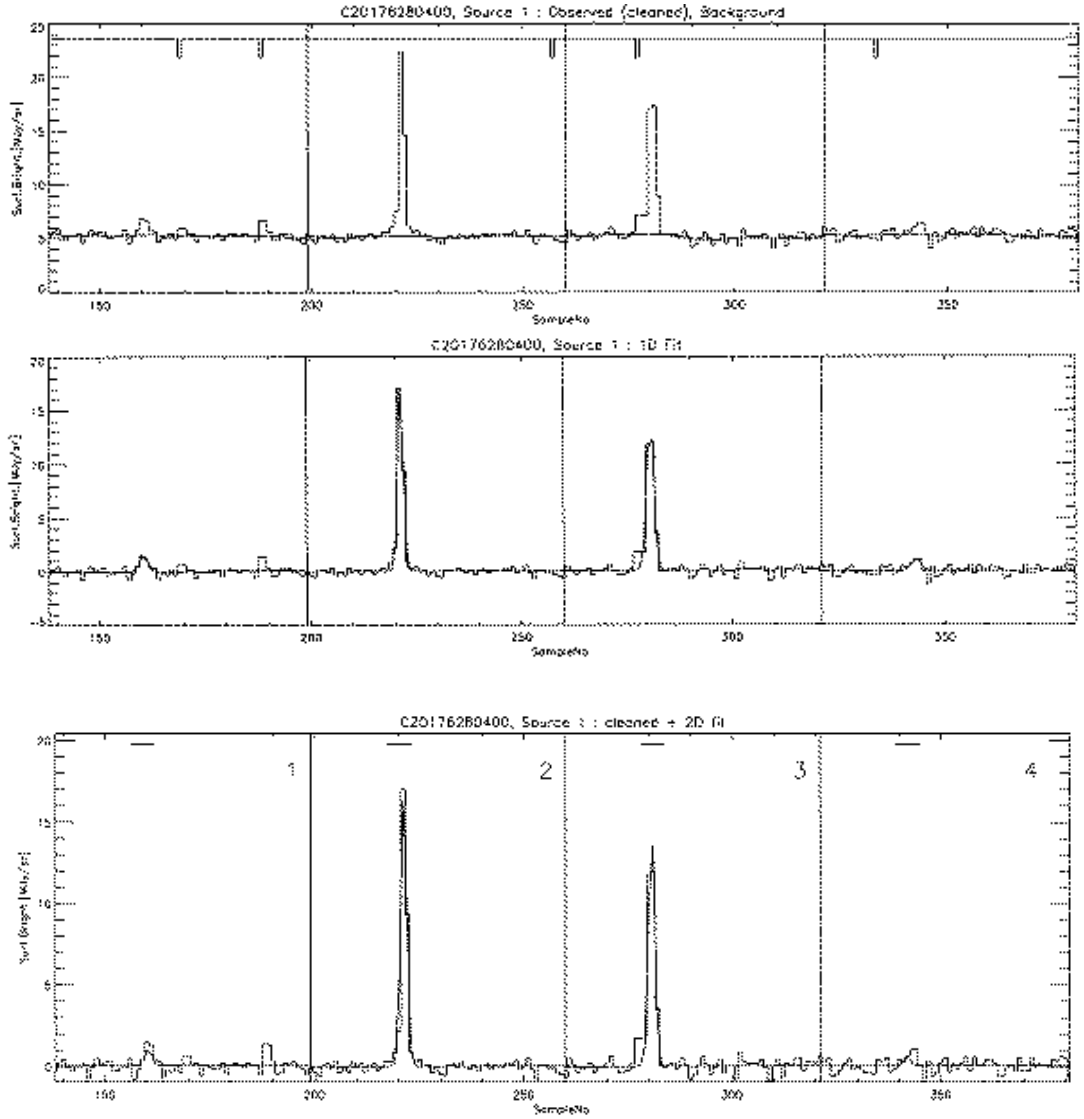

Figure 1. Top to bottom: (1) Data stream of four detector pixels for a serendipity slew crossing UCM0043−0159. (2) Mono-dimensional fit. (3) Bi-dimensional fit.

A still uncertain percentage of the UCM galaxies have been observed by ISO in this ISOPHOT Serendipity Mode and some of them were in ISOs pointed observations. The raw data from the Serendipity observations are available at the ISO Data Archive, and using the ISOPHOT Interactive Analysis (PIA) we can confirm the detection of a faint source that could be the UCM galaxy.

The Max-Planck Institut für Astronomie has implemented a software package for getting the integrated flux densities from the slew raw data of the Serendipity observations. For obtaining information for point sources lying in the slews, first we need to extract the large scale background from diffuse galactic emission. After denoising with a non-linear filter, a morphological rolling ball algorithm was applied to remove all peaks up to width somewhat larger than that point source. Cosmic ray hits (glitches) were removed from the individual background subtracted data stream of the four pixels by using a noise peak elimination filter. The deglitched and background subtracted signals of the four pixels were phase-shifted according to the position angle of the detector and signal-to-noise ratio weighted averaged signal was derived. The resulting mean signal was again slightly filtered (see Stickel et al. 2000 for details).

The early Serendipity source extraction method had shown that fitting the source candidates with a full two-dimensional gaussian to derive both the position and the total source flux simultaneously was not always stable. The position of the gaussian is fixed by the flux determination, the ratio of the four peak fluxes to the highest flux among the four pixels was used in comparison with the expected ratios from a gaussian source model to es-

timate the source position relative to the slew, and then the total source flux is derived from 2D gaussian fitting (Stickel et al., 1998 and 2000). The 170 μm flux densities of some of the UCM galaxies were derived with this Serendipity source extraction method and will allow us to calculate some important parameters for knowing the behavior of the star-forming galaxies.

4. Analysis

We have obtained several 170 μm fluxes and related physical parameters for a pilot sample of nine UCM objects (see Table 1). More details about the technique can be found at Stickel et al. (2000). The expression for obtaining the total FIR flux for the spectral range between 40 and 220 μm is the following:

$$F_{40-220} = 1.47 \times 10^{-14} \times [2.58\, F_{60\mu m} + 1.00\, F_{100\mu m} + 0.63\, F_{170\mu m}] \quad W m^{-2}, \qquad (1)$$

this formula is valid within $\sim \pm 20\%$ for dust temperature between 20 K and 80 K and emissivity indices $0 \leq \beta \leq 2$. Where F_{60}, F_{100} and F_{170} are flux densities in Janskys (Stickel et al. 2000). For the coldest dust components with temperatures of $\sim$20 K, the total integrated IR flux can be expressed:

$$F_{1-1000} = 1.44\, F_{40-220} \quad W\ m^{-2}, \qquad (2)$$

which is accurate to within $\approx \pm 5\%$ for emissivity indices $0 \leq \beta \leq 2$. And then it can be derived the far-infrared luminosity, in units of watts:

$$L_{1-1000} = 4\, \pi\, D^2\, F_{1-1000}. \qquad (3)$$

We adopted $q_0 = 0.5$ and $H_0 = 75$ km s^{-1}Mpc^{-1} to derive the distance d. Even more, we can get the dust mass through the expression:

$$M_{\rm D} = 7.9 \times 10^3 \ \frac{L_{1-1000}}{10^8 {\rm L}_\odot} \left(\frac{T_D}{40{\rm K}}\right)^{-6} \quad {\rm M}_\odot, \qquad (4)$$

assuming standard grain properties, radius 0.1 μm and density 3 g cm^{-3} (Hildebrand, 1983). The flux ratio $F_{170\,\mu{\rm m}}$ / $F_{100\,\mu{\rm m}}$ will indicate a FIR spectra mostly flat between 100 μm and 200 μm when this fraction is between $\sim$1 and $\sim$1.5. Very few galaxies show a down ward trend at this wavelength range, indicating that the coldest dust component is quite warm, with $T_D \geq 20$ K. Some sources can have a ratio over 1.5 up to 3 showing an up-turn in the SED beyond 100 μm (see Stickel et al. 2000 for details). Lets see all the values got from these expressions for some UCM galaxies.

4.1. Individual Comments

– UCM0040+2312 The detection was good but weak. $F_{170}/F_{100} \simeq 0.58$. The FIR luminosity is 310^8 L$_\odot$ and the dust mass is 2.6 10^6 M$_\odot$.

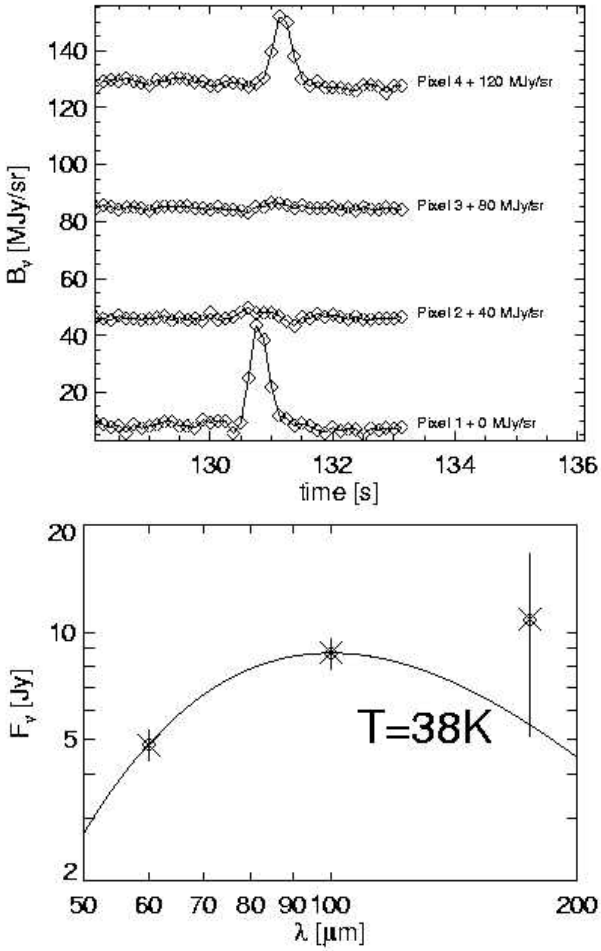

Figure 2. Surface brightness of UCM1422+2450 along the slew path and its derived FIR spectra.

– UCM0043−0159 The detection was good and the flux ratio is 1.1, so this indicates that the FIR spectra is mostly flat between 100 μm and 200 μm, this means that dust component have $T_D \leq 20$ K. The FIR luminosity is 4.910^{10} L$_\odot$ and the dust mass 2.5 10^8 M$_\odot$.
– UCM0157+2413 The detection was weak but right. The flux ratio is once again very low so may be the cold dust component is even warmer than the average. The FIR luminosity is 210^{10} L$_\odot$ and the cold dust mass is 1.6 10^6 M$_\odot$.
– UCM1304+2818 One of the pixels of the detector was noisy but the detection was good. $F_{170}/F_{100} \approx 2.62$ so, there is a up-turn in the SED beyond 100 μm, similar to that seen in the Milky way and M51 (Chini & Krügel, 1993). The FIR luminosity is 1.1610^{10} L$_\odot$ and dust mass 6 10^7 M$_\odot$.
– UCM1308+2950 The detection was good. Total FIR luminosity is $\approx 610^{10}$ L$_\odot$ and dust mass $\approx$5 10^6 M$_\odot$. Given that the flux ratio is $F_{170}/F_{100} \approx 0.7$, the cold dust component could be warmer than 20 K.

Table 1. FIR data and physical parameters for the sample.

UCM Name	z	F_{60} (Jy)	F_{100} (Jy)	F_{170} (Jy)	L_{FIR} (10^{10} $L_\odot$)	M_D (10^8 $M_\odot$)	F_{170} / F_{100}
0040+2312	0.02442	0.75	2.23	1.31	3.07	0.03	0.58
0043−0159	0.01359	4.04	8.85	9.75	4.91	2.47	1.10
0157+2413	0.01643	1.43	2.61	1.27	1.99	0.02	0.48
1304+2818	0.02431	0.08	0.64	1.68	1.16	0.59	2.62
1308+2950	0.02420	2.12	3.64	2.75	6.56	0.05	0.70
1422+2450	0.01688	4.94	7.94	9.33	7.89	3.98	1.17
1426+2322	0.02300	0.31	0.67	4.09	2.21	1.11	6.10
1436+2245	0.04049	1.22	2.19	1.57	10.6	0.08	0.71
1732+2414	0.01900	0.18	1.40	3.02	1.41	0.71	2.16

– UCM1422+2450 The detection has a good quality. A color temperature was derived from the color-corrected IRAS 60 and 100 microns flux densities, assuming a modified blackbody spectrum with an emissivity $\propto \nu$. The result for 175 μm flux density value is larger than the expected one, but it is not excluded the possibility of being due to a systematic calibration offset. In the future a larger statistical sample and improved photometry will decide on the presence of excesses in the very far infrared (Bogun et el, 1996).
– UCM1426+2322 The detection was good, so the 170μm flux is very reliable. Total FIR luminosity is $\approx 210^{10}$ $L_\odot$ and dust mass $\approx$1.1 10^8 $M_\odot$.
– UCM1436+2245 This galaxy is a strong FIR source. It was already identified by IRAS as IRAS14360+2245. The 2D image produced from the IRAS scans shows a very well defined source at 60μm and 100μm bands, but weak at 25μm and almost undetectable at 12μm.
– UCM1732+2414 This observation could be very likely cirrus. This idea is also supported by the IRAS four-bands image were a large structure is visible at the 60μm and 100μm bands.

5. Future Work

A given fraction of UCM Hα emission-line galaxies have been covered by the ISOPHOT Serendipity Survey. After confirming the scientific value of such an analysis with the pilot sample of nine objects presented in this contribution, we will retrieve the integrated ISO 175 μm fluxes for as many UCM galaxies as possible. Comparing these results with the already known optical, near-IR and IRAS data, we expect to obtain more information about the star-forming processes that are taking place in this kind of objects. The 175 μm integrated fluxes will allow us to infer total IR fluxes and luminosities, flux ratios, dust masses, dust temperature, metallicity, color temperatures and a more accurate spectral energy distribution.

An specially interesting fact is that some of the studied galaxies have FIR flux densities larger than expected. We propose to compare the flux densities values obtained from the Serendipity Survey, the flux density got extrapolating color temperatures of a modified blackbody and some others got from ISOPHOT multifilter photometry, and to confirm, if it exists, a FIR excess in the observed 170 μm flux densities respect to predicted ones. All these data will let us get into the star-forming process and its nature through the knowledge of the FIR properties of star-forming galaxies.

Acknowledgements

The ISOPHOT Interactive Analysis (PIA) is a joint development by the ESA Astrophysics Division and the ISOPHOT consortium led by the Max-Planck- Institut für Astronomie, Heidelberg. (Contributing instituts are DIAS, RAL, AIP, MPIK and MPIA). We thank Carlos Gabriel (ESA Villafranca del Castillo, Madrid, SPAIN) for helping us with the PIA software package. We also thank Profesor Emiliano Hernández for all the facilities during the setting up and running the PIA software package.

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