

MID-FIR PROPERTIES OF ELAIS SOURCES

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ABSTRACT

We present the properties of all the galaxies detected by ISO at 7, 15 and 90 μ m in ELAIS northern fields. The spectral energy distribution (SED) of those 20 galaxies with IRAS detections can generally be well fitted by a predominant cirrus component plus a modest starburst contribution. Follow-up spectroscopy has shown that all the objects are emission-line galaxies but without a very intense star formation event. Most of the galaxies analyzed by means of optical R band photometry result to host an important exponential disk component, in good agreement with the SED IR modelling. We note that galaxies with morphological signs of perturbations seem to show slightly higher $f_{15}/f_{6.7}$ ratios, indicating that star formation could be more important in them. One of the objects is a broad-line, radio-quiet quasar at $z=1.099$; its spectral energy distribution indicates that it is a hyperluminous infrared galaxy (HLIG), the first HLIG detected in the ELAIS areas.

Key words: Galaxies: Infrared: Colors – Galaxies: Surveys – Galaxies: Starbursts, Active

1. INTRODUCTION

The European Large Area ISO Survey (ELAIS) was the largest single Open Time project conducted by ISO. It mapped an area of 12 square degrees at 15 μ m with ISO-CAM (Cesarsky et al. 1996) and at 90 μ m with ISO-PHOT (Lemke et al. 1996), together with a coverage of 6 and 1 square degrees at 6.7 μ m and 175 μ m, respectively. One of the main goals of the project was to be able to obtain greater understanding of the cosmological history of star formation, since ISO allowed to detect galaxies with high rates of star formation at much higher redshifts than IRAS. The complete description of the ELAIS survey is given in Oliver et al. (2000). The production of CAM and PHOT source catalogues are discussed by Serjeant et al. (2000) and Efstathiou et al. (2000), respectively. In

this contribution, we study ELAIS galaxies detected at the three ISO bands. The final sample of 25 galaxies results from the cross-correlation of the PHOT catalogue (285 sources) with the CAM catalogues (with 1322 and 2203 sources at 6.7 and 15 μ m, respectively), by performing a search within a radius of 35", and excluding the only star found. The nature of the sample galaxies is analyzed by means of their infrared colors together with follow-up information on both their optical morphology and their physical properties as derived from optical spectroscopy. The complete version of the analysis will be presented in a forthcoming paper (Morel et al. 2001).

2. COLOR-COLOR DIAGRAM OF ELAIS SOURCES

It has been shown that most emission in the LW2 filter comes from strong emission features at 6.3, 7.7, 8.6, 11.3 and 12.6 μ m, believed to arise from PAH carriers (Tielens et al. 1999). On the other hand, the emission in the LW3 filter mainly comprise continuum emission from very small grains of hot dust (100-200 K) transiently heated by UV photons (Sellgren 1984) with a possible contribution from [NeII] 12.8 μ m or [NeIII] 15.6 μ m. In regions with very strong X-ray/UV radiation field or shocks PAHs may be dissociated leading to a reduced flux in LW2 (Telesco, Decher & Joy 1989; Lutz et al. 1998; Laurent et al. 1999). Under such conditions, the heating of the very small grains also results in an increased level of continuum emission in LW3. Therefore, the combination of these two effects makes $R(15,7) = f_{\nu}(15\mu\text{m})/f_{\nu}(6.7\mu\text{m})$ a good discriminant between galaxies with a low level of star formation and starburst galaxies. On the other hand $R(90,15) = f_{\nu}(90\mu\text{m})/f_{\nu}(15\mu\text{m})$ traces the relative emission from cold to hot dust.

In Fig. 1 the position of the galaxies in the color-color diagram $R(90,15)$ versus $R(15,7)$ is shown for the 20 galaxies for which optical morphology is available¹, but the results are applicable to the sample as a whole (Morel et al. 2001). By comparing the values obtained for these galaxies with those from model predictions for cir-

¹ In Sect. 4 we assign such morphologies.

rus (Efstathiou et al. 2000), starburst (Efstathiou et al. 2000) and active galaxies (see Efstathiou et al. 1995), we find that their colors are well fitted by considering a large cirrus component plus a modest contribution from a starburst. There is only a small tendency for higher $R(15,7)$ ratios in distorted/interacting objects, implying that our sample is in general not made up of systems in the starburst phase (Charmandaris et al. 2000). On the other hand, their $R(90,15)$ ratios as a group are clearly indistinguishable from those of galaxies without any sign of disturbance.

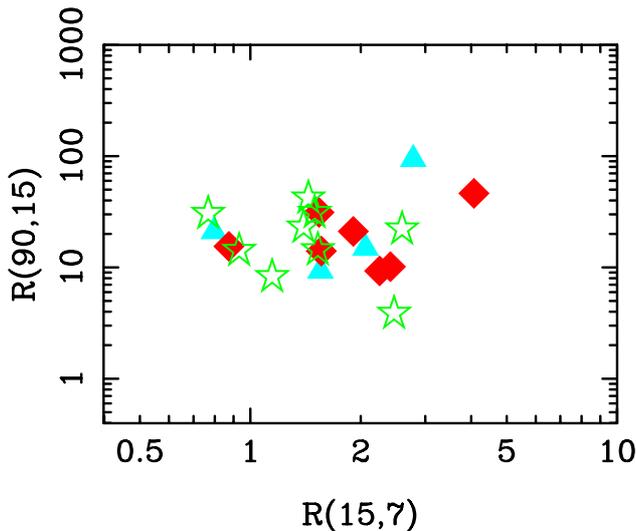


Figure 1. $R(90,15)/R(15,7)$ diagram for the galaxies with optical morphology. Disk galaxies are shown as green stars, distorted/interacting objects as red squares and compact galaxies as blue triangles.

3. OPTICAL SPECTROSCOPY

The data were obtained for nine of the sample galaxies at the NOT² on August 2000 using ALFOSC. We generally posed 1800 seconds for each object. The data were reduced and flux calibrated by using standard IRAF routines. Metallicities have been determined using empirical methods. When $[\text{OII}]\lambda 3727\text{\AA}$ was detected with high enough S/N the calibration by Edmunds & Pagel (1984) has been applied. For the remaining cases the metallicity has been estimated using van Zee et al. (1998).

We note that all the galaxies show $\text{H}\alpha$ emission. The $\text{H}\alpha$ luminosities correspond to moderate star forming processes. The largest star formation rate is around $1 M_{\odot} \text{ yr}^{-1}$, typical of disk galaxies (Kennicutt (1983)).

² The NOT is operated on La Palma jointly by Denmark, Finland, Iceland, Norway and Sweden, in the Spanish Observatorio del Roque de los Muchachos of the IAC. ALFOSC is owned by the Instituto de Astrofísica de Andalucía (IAA) and the NBIfAFG of the Astronomical Observatory of Copenhagen.

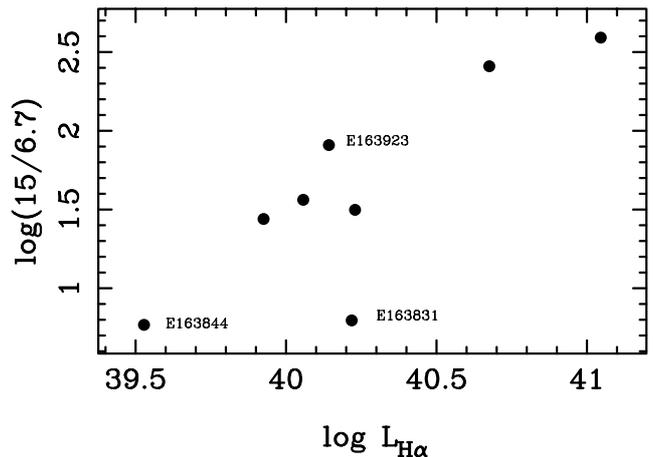


Figure 2. Comparison of the two star forming tracers, $R(15,7)$ and $L_{\text{H}\alpha}$. The position of the three low metallicity blue compact object has been marked.

Both the $R(15,7)$ ratio and $\text{H}\alpha$ luminosity are tracers of star forming activity. In Fig. 2 they are plotted together, showing that higher Star Forming Rates correspond to higher $R(15,7)$ ratios. The galaxy ELAIS P 163831+415339 clearly deviates from this tendency, with a small value for $R(15,7)$. This object is one of the blue compact galaxies found in our sample. The positions of the other two have been also marked in the plot. They have low metallicities ranging from $1/15$ to $1/4 Z_{\odot}$. Madden et al. (1999) suggest that lower $R(15,7)$ ratios are expected in low metallicity galaxies, in agreement with what we have found. The high value for ELAIS P 163923+414413 seems to be the result of a very recent process of star formation, as shown by its bluer continuum, whereas the other two are in a post-starburst phase (see Figs. 3 and 4), with $R(15,7)$ ratios comparable to those of NGC 7714 (O'Halloran et al. 2000).

4. OPTICAL MORPHOLOGY

Optical R-band images of 20 of the 25 galaxies in our sample have been obtained at the INT in La Palma. The sizes of the galaxies are obtained from these images as the extension out to the isophote at 2σ from the noise level. In addition to the three dwarf galaxies and the QSO (with sizes smaller than 10 kpc), four galaxies with sizes between 30 and 40 kpc are found, the rest of the sample having sizes of normal spirals. The biggest sizes correspond to a big edge-on spiral galaxy and three interacting systems (in such systems a larger size can be determined due to the presence of tidal tails extending well beyond the size of the parent galaxy).

The surface brightness profiles have been derived by using the task *ellipse* in IRAF; both exponential and $r^{1/4}$ fits have been tempted. The 2D light distribution together with the result of the best profile fitting have been used to

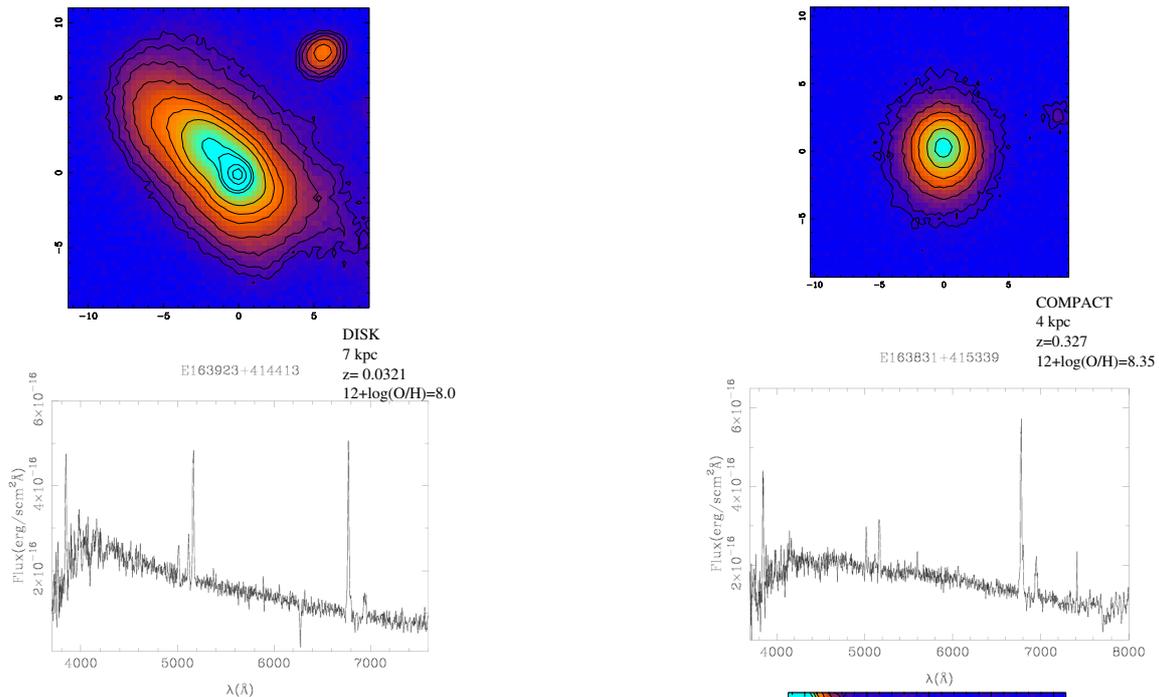


Figure 3. Follow-up data of ELAISP 163923+414413. Top: R-band image. Bottom: optical spectrum.

assign the morphological type to each object. Among the 20 objects, 7 of them are classified as distorted/interacting, 9 are normal disk galaxies and the other 4 are compact objects (the three BCGs and a quasar at $z=1.09^3$, the only AGN in our sample). In Fig 5 an example for each of the subtypes is given.

As anticipated in Sect. 2, distorted/interacting objects show a slightly stronger SF activity as given by $R(15,7)$, but they do not require the contribution of a very strong burst component.

5. CONCLUSIONS

The properties of the ELAIS galaxies detected at 6.7, 15 and $90\mu\text{m}$ have been analyzed by means of their infrared colors and the follow-up data on optical morphology and spectroscopy. They can be summarized as follows:

- they generally show moderate SF process, as it can be derived from either their $R(15,7)$ ratios or their optical emission-line properties.
- half of the galaxies are compatible with being normal spiral galaxies.
- seven of them are distorted/interacting, but they do not harbor a large SF event.
- three low metallicity dwarf galaxies have been found; one of them departs from the expectation of a low

³ This broad-line radio-quiet quasar results to be the first hyperluminous infrared galaxy (HLIG) in the ELAIS areas with $L_{FIR} = 1.2 \times 10^{13} h_{65}^{-2} L_{\odot}$; $q_0 = 0.5$ (Morel et al. 2000).

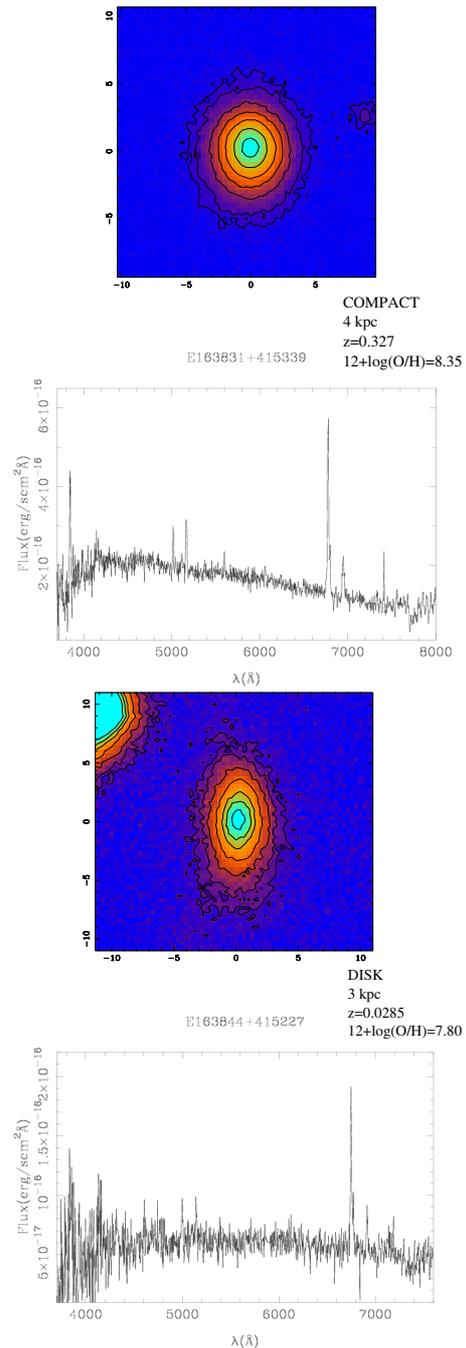


Figure 4. The same as in Fig. 3 for ELAISP 163831+415339 (top) and ELAISP 163844+415227 (bottom)

value for $R(15,7)$, a result that can be explained when taking into account that this galaxy is suffering a recent starburst event.

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REFERENCES

- Cesarsky, C.J. et al. 1996, A&A 315, L32
 Charmandaris, V., Laurent, O., Mirabel, I.F., Gallais, P., Houck, J. 2000,, Proceedings of the conference “ISO beyond the peaks”, p. 15
 Edmunds, M.G., Pagel, B.J. 1984, MNRAS 211, 507
 Efstathiou, A., Hough, J.H., Young, S. 1995, MNRAS 277, 1134
 Efstathiou, A. et al. 2000, MNRAS 319, 1196.
 Efstathiou, A., Rowan-Robinson, M., Siebenmorgen, R. 2000, MNRAS 313, 734
 Kennicutt, R.C. 1983, ApJ 272, 54
 Laurent, O. et al. 1999, Proceedings of the Conference “The Universe seen by ISO”, ESA SP-427, Cox, P. & Kessler, M.F. (eds.) p. 913
 Lemke, D. et al. 1996, A&A 315, L64
 Lutz, D. et al. 1998, ApJ 505, L103
 Madden, S.C., Vigroux, L.; Sauvage, M. 1999, Proceedings of the Conference “The Universe seen by ISO”, ESA SP-427, Cox, P. & Kessler, M.F. (eds.) p. 933
 Morel, T., Efstathiou, A., Serjeant, S. et al. 2000, MNRAS (submitted)
 Morel, T. et al. 2001, in preparation
 O’Halloran et al. 2000, A&A 360, 871
 Oliver, S. et al. 2000, MNRAS 316, 749
 Sellgren, K. 1984, ApJ 277, 623
 Serjeant, S. et al. 2000, MNRAS 316, 768
 Telesco, C.M., Decher, R. & Joy, M. 1989, ApJ 343, L13
 Tielens, E. et al. 1999, Proceedings of the Conference “The Universe seen by ISO”, ESA SP-427, Cox, P. & Kessler, M.F. (eds.) p. 579
 van Zee et al. 1998, AJ 116, 2805

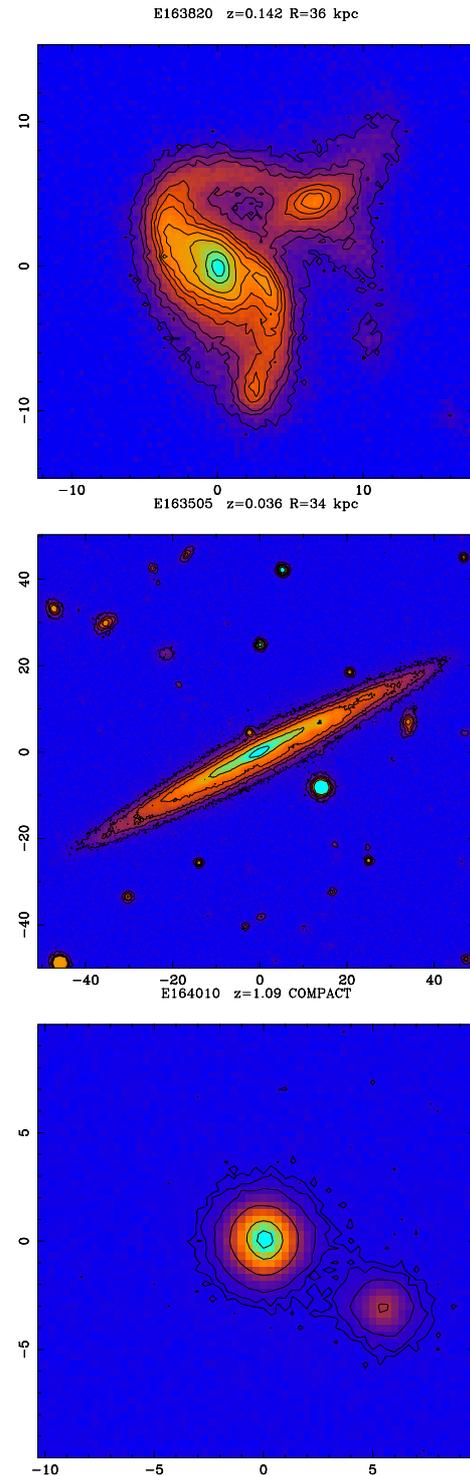


Figure 5. R-band example images for the morphological classification. Top: Interacting galaxy; middle: spiral galaxy; bottom: compact. The compact object is the only quasar (at $z=1.09$) in our sample, that results in being the first hyperluminous infrared galaxy (HLIG) in the ELAIS areas (see Morel et al. 2000). The tips in the images correspond to arcseconds.