ISOCAM OBSERVATIONS OF THE INTERACTING GALAXY SYSTEM MRK 171*

P. Gallais[1], O. Laurent[1], V. Charmandaris[2,1], D. Rouan[3], I.F. Mirabel[1], M. Sauvage[1], D. Tran[4], L. Vigroux[1]

[1]CEA/DSM/DAPNIA Service d'Astrophysique, 91 191 Gif-sur-Yvette, France
[2]Observatoire de Paris, DEMIRM, 61 av. de l'Observatoire, 75 014 Paris, France
[3]DESPA, Observatoire de Paris-Meudon, 92 195 Meudon Cedex, France
[4]MPI für Extraterrestrische Physick, Postfach 1603, 85740 Garching, Germany

ABSTRACT

We present mid-infrared observations of Mrk 171, a system of at least two interacting galaxies, which has been observed with the ISOCAM camera in the spectral range 5–16 μm. The comparison of the mid-infrared morphology with that at shorter wavelengths, as well as the overall variation of the spectral energy distribution of the different components leads us to conclude that i) the system is the result of the interaction of ONLY two galaxies, ii) there is no evidence of an active galactic nucleus in the system and iii) intense star formation occurs outside the nucleus of NGC 3690. Mid-infrared observations appear then to be a powerful tool to probe deeply obscured regions harboring either star forming regions or AGNs.

Key words: ISO; infrared astronomy; galaxies: individual: Mrk 171, Arp 299; galaxies: interactions; star: formation

1. INTRODUCTION

At a distance of 42 Mpc, Mrk 171 (Arp 299 = IC 694 + NGC 3690) is one of the nearest interacting galaxies. Because of its proximity, and its intrinsic size (8 kpc), it provides good conditions to explore the effects of star formation activity triggered by an interaction. This system is in a stage of interaction where the main components are close enough to suggest that the outer part of their galactic disks are overlapping/merging (see Angonin et al. 1996) even though the individualities of the galaxies are still conserved.

Mrk 171 has been studied extensively in optical (Augarde and Lequeux 1985), infrared (Gallais 1991; Wynn-Williams et al. 1991; Shudong Zhou et al. 1993; Gehrz et al. 1983; Keto et al. 1997), and radio wavelengths (Gehrz et al. 1983; Zhao et al. 1997; Aalto et al. 1997; Casoli et al. 1998). Based on those observations the overall morphology (see Fig. 1 for details) is characterized by: i) the nuclear region of IC 694 (source A) at the east, ii) the nuclear region of NGC 3690 (source B = B1 + B2) at the south-west and iii) two regions of emission (sources C and C') at the north-west. The nuclear region of NGC 3690 has been resolved in two components, B1 and B2, which have distinct spectral behaviours. At short near infrared wavelengths (I, J, H bands), the emission from B2 is dominant. On the other hand, the flux of B1 becomes increasingly stronger at longer wavelengths (K, L bands) as well as in the radio while B2 is hardly or not detected (see Fig. 2). It has been suggested that source C could be the nucleus of a third galaxy in the interacting system but this hypothesis is questioned by the location of this source on the [J-H]/[H-K] color-color diagram (Gallais 1991), far from the nuclei locus, and by recent CO observations (Aalto et al. 1997; Casoli et al. 1998) which suggest that this source, associated to the source C', could be attributed to star forming complexes in the overlap region of the two galactic disks.

High resolution HST observations in the visible revealed a clumpy distribution in NGC 3690 at a very small spatial scale, showing emission from at least 4 components in the B region. Adaptive optics near-infrared imaging reveals even more (a dozen) unresolved ($\theta < 0.3$ arcsec) knots at K (Lai et al. 1998). Source C is also resolved in several sources of emission. Moreover, while component A is characterized by a flat spectrum at radio wavelengths, its optical spectrum does not show evidence of the presence of an active galactic nucleus (AGN) (Gehrz et al. 1983).

Several questions regarding Mrk 171 are still open to debate:

- how many galaxies are really involved in the interaction ?
- what is the exact position of the nucleus of NGC 3690 ?
- what is the nature of sources C and C' ?
- does the system host any deeply embedded active nuclei ?

Using its capabilities to probe dusty regions, new sensitive mid-infrared (mid-IR) observations of Mrk 171 have been performed with the ISOCAM instrument

*ISO is an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with the participation of ISAS and NASA.

on-board the ISO spacecraft (Kessler et al. 1996). The preliminary results of these observations are presented in the following sections.

2. OBSERVATIONS AND DATA REDUCTION

Mrk 171 has been observed with ISOCAM (Cesarsky et al. 1996) with the Continuously Variable Filter (CVF), resulting in a full coverage of the spectral range from 5 to 16 μm with a spectral resolution of 40. The pixel size was 1.5 arcsec giving a total field of view of 48 arcsec $\times$ 48 arcsec. The system is then fully mapped with an angular resolution ranging from 3 to 4.5 arcsec. The data reduction and analysis were performed using the CAM Interactive Software (CIA)[1].

Even though the pointing of ISO in the CVF mode has proven to be fairly reliable, we verified the relative astrometry after identification and detailed comparison of all main features of our mid-IR images with those found in a series of existing near-IR and optical images. The shape of their spectral energy distribution as well as possible effects of absorption were taken into account. Absolute astrometry uses the HST WFPC2 archive images as reference.

In order to make a first order estimate for the principal characteristics of the different components of Mrk 171 and compare it with other extragalactic sources of our sample, we use the CVF data set to construct the equivalent images at LW2 and LW3, two of the most commonly used ISOCAM broad band filters. The LW2 [5–8.5 μm] filter is dominated by the PAH-like emission features while the LW3 [12–18 μm] filter mainly samples the thermal signature of hot dust as well as emission from high excitation forbidden lines (i.e. [NeII], [NeIII]). The resulting contours in these filters are presented in Fig. 1, overlaid on HST red images.

3. DISCUSSION

In Fig. 1, we indicate the naming convention adopted by previous authors. Region A corresponds to the central region of IC 694, (the eastern part of Mrk 171), B corresponds to the central region of NGC 3690 at the south-western part, and the 2 northern components of NGC 3690 are addressed as C and C'. The mid-IR fluxes have been measured and are reported in Table 1.

All main components in the system exhibit both high fluxes in both filters and extremely red colors. The flux ratios LW3/LW2, ranging from 2.5 to 6.6, are quite high in regards to the ones measured in other objects such as normal galaxies in which it takes values from 0.7 to 1.2 (Roussel et al. 1999) or in the Antennae galaxies in which the brighest spot has a ratio of 2.6 (Mirabel et al. 1998). In Mrk 171, all the components present a very large excess of emission at 15 μm which can be interpreted as an important concentration of hot dust heated by young massive stars and/or as due to a still important extinction at 6 μm, also pointing to a high concentration of dust.

If we derive an equivalent IRAS 12 μm flux assuming a power-law SED in the 5–18 μm range, we find that 86% of the overall IRAS 12 μm flux is accounted for by the 4 sources, with A and B1 contributing dominantly (respectively 28 and 44%). If we assume that for each region, the ratio of the 12 μm flux to the bolometric luminosity is the same as for the whole system, then we derive luminosities ranging from 0.3 to $2.\,10^{11}\,L_\odot$, implying that those sources are extraordinary brighter (up to 3 orders of magnitude) than any star forming region in the local universe (for instance, the brightest complexes in M82 exhibit luminosities of "only" $1.5\,10^8\,L_\odot$). The star formation mechanism in Mrk 171 is obviously of a remarkably high efficiency; Rouan et al. (1998) reach a same conclusion, based on near-IR adaptive optics observations.

Table 1. Integrated fluxes in the LW2 and LW3 broad band filters. Fluxes are corrected for dilution due to the size of the point spread function.

Source	LW2 (Jy)	LW3 (Jy)	LW3/LW2
A	0.25	1.66	6.6
B	0.57	2.17	3.8
C	0.13	0.52	4.0
C′	0.11	0.28	2.5

3.1. The nuclear region of IC 694

The central region of IC 694 (region A) is clearly recognized in our images. It appears as an unresolved bright source, corresponding to the radio peak observed at 6 and 20 cm by Gehrz et al. (1983). However, in the optical image, there is no such source at this position, indicating a high absorption in the visible, and indeed, an important dust lane crosses A. The observed emission in the optical HST images shows a "patchy" pattern suggesting that what we actually sample is the star forming complexes in the outskirts of an obscured central source. High resolution near-IR imaging confirms this interpretation (Lai et al. 1998).

3.2. The nature of sources C and C'

The nature of source C is not clear. Casoli et al. (1989) had proposed that this source could be associated with the nucleus of a third galaxy while other authors (Keto et al. 1997, Casoli et al. 1998, for instance) support the hypothesis of an extraordinary extra-nuclear starburst. The mid-IR diagnostic flux ratio LW3/LW2 (see Table 1) for region C agrees with the latter interpretation, since it is similar to values found in regions dominated by young massive stars rather than in a post-starburst population. This is also supported by the shape of the full mid-IR spectrum of this region (Gallais et al. 1999).

[1]The ISOCAM data presented in this paper were analysed using "CIA", a joint development by the ESA Astrophysics Division and the ISOCAM Consortium led by the ISOCAM PI, C. Cesarsky, Direction des Sciences de la Matière, C.E.A., France.

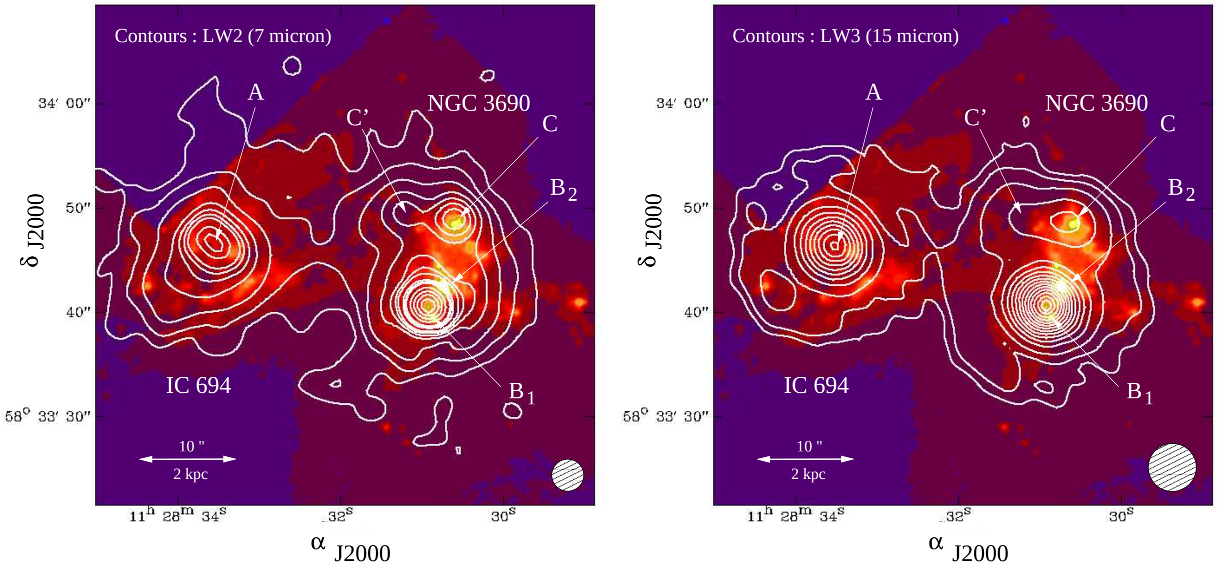

Figure 1. Mid-IR emission in the LW2 and LW3 bands in contours superimposed to the HST WFPC2 red image (593.5 nm). The different regions in the two galaxies are clearly marked.

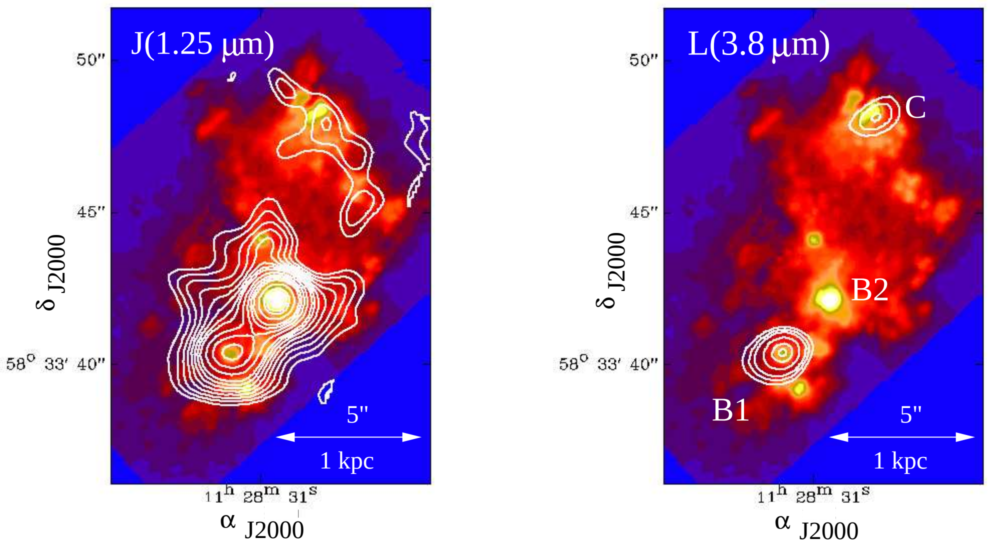

Figure 2. Near-IR J and L band contours (Gallais 1991) of NGC 3690 superimposed on the same HST image. One can clearly see that the flux of region B1 dominates at longer wavelengths, while B2 having a spectral signature of an old stellar population practically disappears.

3.3. The nature of source B

The southern part of NGC 3690 is quite complex:

- HST observations, as well as Adaptive Optics imaging have revealed that the southern part of NGC 3690 is very clumpy and hosts many sources (see Figure 1).
- in the near-infrared, ground-based observations (see Fig. 2), have shown that the bulk of the emission is coming from 2 main sources: B1 and B2 (Gallais 1991, Wynn-Williams et al. 1991). The northern source B2 coincides with an extended source in the HST image, and its near-infrared colour indices indicate an emission typical of an old stellar component while the southern one is very reddened.
- the brightest mid-IR emission coincides very well with near-infrared source B1 which is rather faint and unresolved at optical wavelengths and is not detected in the UV band (see Fig. 3).

These points support the hypothesis that the nucleus of NGC 3690 is located at the position B2 (Gallais 1991, Wynn-Williams et al. 1991), while B1 is an extremely powerful highly obscured star forming region, located at a projected distance of 500 pc from the nucleus. Such a region has already been observed with ISOCAM in the Antennae (NGC 4038/39), where the brightest mid-IR knot is located at about 2 kpc from the nucleus of the galaxy, in a very clumpy region (see Fig. 1 of Mirabel et al. 1998).

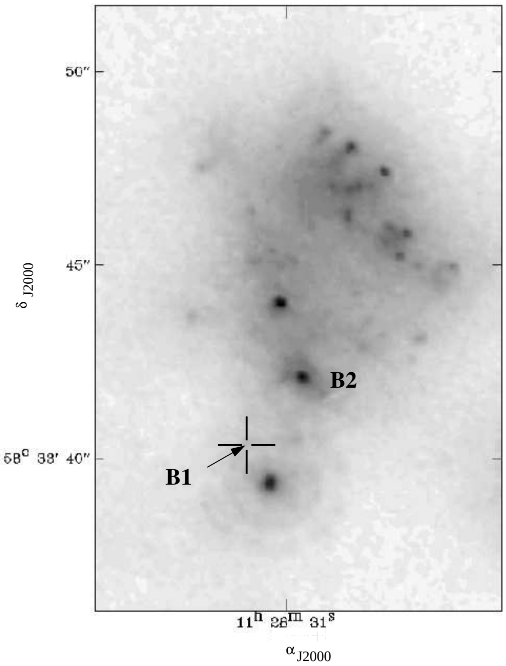

Figure 3. We present a UV image (200 nm) of NGC 3690 taken with the FOC on-board the HST. The position of B1 and B2 are marked. One can see that no emission is associated with B1 confirming its highly obscured nature.

4. CONCLUSIONS

Based on these morphological and qualitative considerations, we can conclude that:

- the intrinsic luminosities of any of the identified source is extremely high, compared to star forming regions in classical nearby starburst galaxy;
- the nucleus of NGC 3690 is located at the position of source B2;
- the emission from region B originates from several sources, of which B1 appears to be an extraordinary active region of star formation ($L_{bol} > 10^{11}\,L_{\odot}$);
- the emission from sources C and C' can be explained by star formation occurring in tidally distorted regions of the galactic disks;
- there is no evidence of an active nucleus, based on the individual spectra of sources that does not correspond to typical AGN spectra: for instance, all SED exhibit the whole set of PAH-like features.

ACKNOWLEDGMENTS

We thank HST team and PIs of the proposals which provided the WFPC2 and FOC images made with the NASA/ESA Hubble Space Telescope and obtained from data archive at the Space Telescope Science Institute. STScI is operated by the Association of Universities for Research in Astronomy, Inc. under the NASA contract NAS 5-26555.

REFERENCES

Aalto, S., Radford, S.J.E., Scoville, N.Z., Sargent, A.I. 1997, ApJ 475, L107

Angonin-Willaime, M.-C., Casoli, F., Gerin, M., Rouan, D. 1996, CFHT bull 34, 8

Augarde R., Lequeux J., 1985, A&A 147, 273

Casoli, F., Combes, F., Augarde, R., Fignon, P., Martin, J.-M. 1989, A&A 224, 31

Casoli, F., Willaime, M.-C., Viallefond, F., Gerin, M. 1998, submitted to A&A

Cesarsky, C.J., Abergel, A., Agnese P. et al. 1996, A&A 315, L32

Gallais, P., 1991, Thèse de Doctorat de l'Université Paris VII

Gallais, P., Laurent, O., Charmandaris, V., et al. 1999, (in preparation)

Gehrz R.D., Sramek R.A., Weedman D.W., 1983, ApJ 267, 551

Kessler, M.F., Steinz, J.A., Anderegg M.E. et al. 1996, A&A 315, L27

Keto E., Hora J.L., Deutsch L. et al., 1997, ApJ 485, 598

Lai, O., Rouan, D., Alloin, D. 1998, in proceedings of the conference *Astronomy with Adaptive Optics*, Sonthofen, Sep. 1998

Mirabel, I.F., Vigroux, L., Charmandaris, V., Sauvage, M., Gallais, P., Tran, D.Q., Cesarsky, C.J., Madden, S.C., Duc, P.-A. 1998, A&A 333, L1

Rouan, D., Clenet, Y., Lai, O. 1998, in proceedings of the conference *Astronomy with Adaptive Optics*, Sonthofen, Sep. 1998

Roussel, H., Vigroux, L., Sauvage, M., Bonoli, C., Bosma, A., Gallais, P., Hawarden, T., Madden, S., Mazzei, P., 1999, *these proceedings*

Vigroux, L. Mirabel, I.F., Altiéri, B. et al. 1996, A&A 315, L93

Wynn-Williams, C.G., Eales, S.A., Beklin, E.E., Hodapp, K.-W., Joseph, R.D., McLean, I.S., Simons, D.A., Wright, G.S. 1991, ApJ 377, 426

Zhao J.-H., Anantharamaiah K.R., Goss W.M., Viallefond F., 1997, ApJ 482, 186

Zhou S., Wynn-Williams C.G., Sanders D.B., 1993, ApJ 409, 149