Astron. Astrophys. 315, L85–L88 (1996)

ASTRONOMY AND ASTROPHYSICS

NGC 5195 - a look into the hot dusty ISM of an interacting SB0 galaxy with ISOCAM*

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Received 16 July 1996 / Accepted 31 July 1996

Abstract. We present broad-band images and a CVF spectrum of NGC 5195, the companion of M 51. NGC 5195 appears as a very strong point source while its spectrum is dominated by the so-called PAH features at 6.2, 7.7, 8.6, and 11.3μm. No hot continuum is detected longward of 14μm, and infrared ionic lines are absent from the spectrum. We examine in turn possibilities for the generation of this infrared emission: (1) photospheres or circumstellar envelopes, (2) an embedded current starburst, (3) a LINER, and (4) the evolved starburst population. We find that only 3 and 4 are compatible with the data and tend to prefer 4 since ionic lines expected in LINERs are absent. We also show that, to produce the detected flux, the dust has to take a substantial fraction of its heating energy from optical photons, eventhough PAH features dominate the emission.

Key words: galaxies: individual: NGC 5195 – galaxies: ISM – galaxies: spiral – infrared: ISM: continuum – stars: formation

1. Introduction

NGC 5195, the interacting companion of M 51, is cataloged as an SB0 psc in the RSA catalog and as an SB0/a(r) by Thronson et al. (1991). It is clearly distorted by its interaction with M 51. Current views of the interaction between NGC 5195 and M 51 have the companion passing perigalacticon $\simeq 7 \times 10^7$ yrs ago (Howard & Byrd, 1990) with NGC 5195 currently on the far side of M 51 with respect to us. Its optical aspect is that of a diffuse disk galaxy with stellar plumes characteristic of gravitational interaction. Confirmation that it is indeed behind the disk of M 51 comes from the fact that one arm of the spiral galaxy is seen protruding all the way to the east of NGC 5195's nucleus and from the numerous dust lanes that are evident in optical images (e.g. Sage, 1990).

NGC 5195 has long been known for being an intriguing source: being part of an interacting system, it is expected to be a starburst galaxy. This is confirmed by the warm infrared colors as deduced from IRAS measures (Sage, 1990), as well as by the detection of extended CO emission clearly associated with the galaxy, at a distinct velocity from the neighboring arm of M 51 (Sage, 1990).

However star-formation, though actively searched for, does not seem to occur presently in NGC 5195. Thronson et al. (1991) do not detect any Hα emission at the location of the galaxy's nucleus or in its disk. The Hα data presented in Sauvage et al. (1996) confirm this, as Hα is detected in absorption on an extent of $\simeq$10". Brα detection was also attempted by Beck et al. (1986) with no success. UV emission is also seriously lacking if one is to think of NGC 5195 as of a star forming galaxy: the UIT-ASTRO-2 observations reveal no emission in the FUV filter (1520Å, Hill et al., 1996) and only weak diffuse emission appears at longer wavelength (Hill et al., 1996, Maoz et al., 1996).

These measures give strong limits on the number of high mass stars, raising questions concerning the heating sources for the infrared fluxes. Indeed, Beck et al. (1986) already noted that these are a factor 6-7 in excess of what can be expected if they were to come from classical HII region dust. We therefore embarked on a multi-mode ISOCAM observation of this peculiar galaxy. In section 2 we present the observations used in this work and sketch out the data reduction steps. Section 3 interprets the result we derive on NGC 5195 in the context of interacting early-type galaxies. Our conclusions are presented in section 4.

2. Observations and data reduction

The data presented here have two origins. First we extracted from the raster images of M 51 (Sauvage et al., 1996) the observation centered on NGC 5195 (the infrared emitting region is smaller than one ISOCAM array). This eliminates the tran-

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

sient effects while using the very good calibration obtained from the whole raster. We therefore obtain deep LW2 (6-8.5μm) and LW3 (12-18μm) images of NGC 5195. Given that overlap between adjacent fields in the raster was kept to a minimum, the sensitivities derived in Sauvage et al. (1996) apply here also and are 4.3 μJy$''^{-2}$ at LW2 and 5.7 μJy$''^{-2}$ at LW3.

The ISOCAM raster (Sauvage et al., 1996, their figure 1) shows NGC 5195 as a very strong point-like source. In fact the peak brightness of NGC 5195 is about 6 times higher than any other location in M 51. The position of this source extracted from the ISO LW2 pointing is $13^h\,27^m\,53\overset{s}{.}9$ $+47°\,31'\,28\overset{''}{.}2$ (1950.0). This is, to the pointing accuracy of ISO (Kessler et al., 1996), the position of the nucleus of the galaxy, inferred from NIR or radio observations (Smith et al., 1990). We have examined the profiles of this source and find that it is marginally resolved in both filters with an observed FWHM of $6\overset{''}{.}7$ and $7\overset{''}{.}9$ in LW2 and LW3 respectively. Taking into account the PSFs of the two filters, this gives an intrinsic source size of $1\overset{''}{.}7$ in both filters. At a distance of 9.6 Mpc, this converts into $\simeq$80 pc. However, this size is close to ISO's intrinsic jitter, so the quoted size is probably more an upper limit. Fluxes, both integrated to the sky level and in the central 5$\times$5 pixels are listed in table 1. Since the source is barely resolved we applied the 0.85 correcting factor for point sources in broad bands mentioned in Césarsky et al. (1996).

Second, using the spectro-imaging capabilities of ISOCAM (CVF) we obtained an R$\sim$40 scan of the companion of M 51, from 5.9 to 16μm. The increment per scan step was 1 CVF step, with 12 exposures of 2.1 s per step, at a pixel field of view of $3''$.

Dark correction and removal of cosmic ray hits are done in the standard way as described in Siebenmorgen et al. (1996). CVF scans are affected mostly by stray-light from the zodiacal light or from the source itself, and transients due to the high contrast of some interstellar features. Given the relatively small number of exposures taken at each wavelength, no transient correction was attempted. As a result, and the scan being performed along decreasing wavelength, high level features (such as the 11.3 μm one) are probably higher than indicated by our scan, while low-level ones (such as the 9-10 μm region or that between the 6.2 and 7.7 μm features) are probably lower than what we measure.

In the CVF, stray-light materializes itself as two bright areas on the right and left side of the detector. A possible way to correct for it is to use a scan of a flat region of the sky. However, since NGC 5195 is rather point-like, and sits in a region relatively less affected by the problem, we decided to measure the background level (intrinsic and reflected) close to the source, and substract it. Then, we converted from detector units into astrophysical ones using the prescription of Césarsky et al. (1996). We then summed the signal measured in the central 5$\times$5 pixels to produce figure 1. We also integrated that spectrum in the various filters of ISOCAM to produce table 1. As mentioned in Césarsky et al. (1996), CVF sensitivity for point sources is a factor 0.67 lower than what it is for extended source. From table 1, we can see that there is quite a good agreement between the two methods (broad band imaging or CVF spectrum integrated over the filters bandpasses): the LW2/LW3 ratio is the same at 0.7 .

Table 1. NGC 5195 fluxes in ISOCAM filters derived from the CVF scan in the central $15'' \times 15''$, as well as those derived from the raster map in LW2 and LW3 both in the same area and integrated down to the sky level.

Filter	λ (μm)	$\Delta\lambda$	Flux (mJy)
central 5×5 pixels - CVF			
LW2	6.75	1.65	331
LW3	15.0	2.75	452
LW4	6.00	0.59	237
LW5	6.75	0.285	238
LW6	7.75	0.76	404
LW7	9.63	1.26	280
LW8	11.4	0.60	635
LW9	15.0	0.85	352
LW10	11.5	3.45	419
central 5×5 pixels - Raster			
LW2	6.75	1.65	307
LW3	15.0	2.75	434
total flux - Raster			
LW2	6.75	1.65	381
LW3	15.0	2.75	580

Table 1 can be used to check our consistency with the IRAS 12μm measures as the LW10 filter is identical to it. The Faint Source Catalog lists a flux of 0.72 Jy. If we assume that the ratio of the LW10 total flux to what is measured in the central 5$\times$5 pixels is the same as for LW3 we measure a flux of 0.56 Jy. This cannot be said to be in good agreement; however, given the numerous sources of error in both measurements (IRAS contamination by M 51, uncertain calibration of ISOCAM), the obtained values are encouraging concerning the possibility to connect IRAS measurements to ISOCAM ones.

3. NGC 5195, an extremely bright old starburst nucleus

It is quite interesting to see that the infrared emission is extremely symmetric, and therefore shows no sign of the bar detected in the NIR by Smith et al. (1990). In fact the source we detect is even smaller than the already small bulge of NGC 5195. Given the good coordinates match, we are thus confident that the source we detect is indeed located at the very nucleus of NGC 5195.

The spectrum of NGC 5195 (figure 1) shows very clearly the so-called PAH features at 6.2, 7.7, 8.6 and most evidently 11.3μm. All together, these features make up for 20% of the flux detected between 6 and 17μm. Also evident is a yet unidentified broad feature located at 12.7μm. It should be noted that at 12.8μm we expect the NeII line. However it is not very clear whether it contributes some flux here, especially considering the low ionization environment of NGC 5195. Continuum is detected in the range 14-16μm and seems to connect nicely with the flux level at 9-10μm, the expected location of the silicate absorption band.

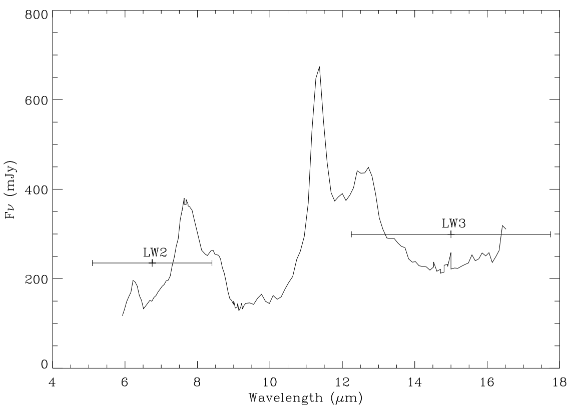

Fig. 1. CVF spectrum of the central 15″ of NGC 5195. The horizontal bars show the widthes of the LW2 and LW3 filters.

Given the information already known on NGC 5195, there are 4 possible explanations for the infrared properties of the galaxy: (1) what we see with ISOCAM is associated with the stellar populations, either dust in circumstellar envelopes or cool photospheres, or (2) NGC 5195 harbors an obscured compact starburst, showing only in the mid and far infrared, or (3) dust belonging to the dense surroundings of an active nucleus, or (4) we are seeing diffuse dust heated by the numerous stars present in the nucleus such as hypothesized to explain IRAS colors of early-type galaxies by Sauvage & Thuan (1994).

Circumstellar dust or cool photospheres. There are many reasons to think that NGC 5195 may harbor such a type of population. First, being an SB0/a galaxy, it has a large population of evolved stars, and stars with photospheric temperatures of the order of 5000-3000 K should be abundant. The tail of their emission can indeed reach the mid-infrared range, when no other emission is present. Second, having crossed the M 51 disc $\sim 10^8$ yrs ago, one should expect to see stars with circumstellar envelopes which can also contribute significantly to the MIR band (Jura et al., 1987). This, however, is not very consistent with either the fluxes or the spectrum. Indeed, given that our source is point-like, we can compare its fluxes with the NIR aperture photometry of Smith et al. (1990) in their 8″ aperture. From their measurements in the H and K bands, we would expect fluxes of the order of 30 mJy in LW2 and 10 mJy in LW3, well below our measurements.

NGC 5195 being an early type spiral, it should harbor a population of evolved stars, the same that is invoked in elliptical galaxies to explain their 12μm emission. However once again, the spectrum of NGC 5195 is not consistent with this explanation. PAH bands could be present in the envelopes of mass-losing stars (these are in fact a site of dust formation) but one would expect these bands to sit on a much hotter continuum as the one we observe. Moreover, the drop of the spectrum at the shortest wavelength is similar to that observed in other regions of the ISM of galaxies where stellar emission is not likely to happen.

An obscured starburst. This explanation is unlikely for two reasons. First the presence of Hα in absorption only in the direction of the nucleus makes it unlikely that we are not directly seeing the nuclear regions. Second, the spectrum shown in figure 1 is not what can be expected from a starburst (see e.g. Vigroux et al., 1996): the spectrum is dominated by the so-called PAH bands and the level of the continuum in the LW3 bandpass is quite low, while for a starburst region, one sees a strongly rising emission from 12 to 16μm. Furthermore the ionic lines of [NeII] 12.8μm and [NeIII] 15μm are absent from the spectrum. This imposes strong constraints on the hardness of the heating spectrum. Since the [NeII] line is present over the whole face of starburst galaxies observed with ISOCAM, its non-detection in NGC 5195 is a strong indication that this object is not undergoing current star-formation.

One could argue that the “hole" observed in the spectrum at 9.7μm is in fact the sign of very strong silicate absorption occuring on the line of sight, an absorption that could be high enough to hide a starburst. From the spectral data obtained with ISOCAM on various regions of the ISM, this is far from being clear. In the coal model for example (Papoular et al., 1991), there is no band emission from 8.6 to 11.3 and therefore one should expect to drop down to the continuum emission of the grain. This drop is comparable in amplitude to that seen in figure 1. In the PAH model, similarly, no emission is expected in this wavelength range. It is therefore quite difficult to estimate where the continuum level should be in this region and what the silicate extinction is, if any. Furthermore, in galactic regions where little extinction is expected on the line of sight (at least not several magnitudes as would be required here to hide the starburst), the amplitude of the drop around 10μm is similar (see Césarsky et al., 1996). There is thus little evidence for a high extinction hiding a nuclear starburst in NGC 5195.

Dust enshrouding an active nucleus. Detection of a compact, very bright source immediately leads to the Active Nucleus hypothesis. This is reinforced by the occasional classification of NGC 5195 as a LINER, and by the existence of a rather compact radio source at the nucleus (van der Hulst et al., 1988), although Keel et al. (1985) concluded that, if anything, it has an HII region type nucleus. Indeed a LINER (low ionization) should not produce much ionizing photons and thus could be the heating source for the spectrum we detect since (1) the continuum at 15μm is very low and argues against the presence of hot small grains, and (2) the 6.2/11.3 feature ratio is very high as expected for instance in the coal model of Papoular et al. (1991) for grains in a relatively soft radiation environment.

However, there are some indications that lead us to think that such an explanation may be unlikely. None of the infrared neon lines are detected in figure 1. Yet these, and particularly the [NeIII] 15.6μm are expected to be bright in LINERS (Voit, 1992). Furthermore, in a LINER the [OIII] 5007Å and the [NII] 6584Å should have equivalent intensities (Spinoglio & Malkan, 1992). Ho, et al., (1995) have obtained optical spectroscopy of NGC 5195 where the [NII] line is very strong and the [OIII] line absent. Therefore there is quite a lack of conclusive signs for the present of a LINER heating the dust we detect.

Dust heated by the evolved starburst population. It is clear that NGC 5195 has undergone a starburst, that this starburst has ceased and that very few stars younger than B5 exist in NGC 5195. This evolved stellar population can provide the energy to the dust phase observed with ISOCAM. As in a LINER, this population would provide a relatively soft heating spectrum, compatible with figure 1.

Assuming that this population alone heats the dust, from the spectral energy distribution of Smith et al. (1990) in the central 8″ and the 2300Å point of Maoz et al. (1996) we can estimate (1) how much reprocessing is required and (2) up to which wavelength the MIR emitting dust has to absorb light to obtain enough energy to produce the detected emission.

The MIR luminosity, integrated from 6 to 17μm is $\sim 2\,10^8\,L_\odot$. Depending on the cut-off for the integration of the spectral energy distribution, the available energy ranges between $2\,10^8$ and $1\,10^9$. If we assume that only 20% of the available energy is reprocessed in the MIR band (a rather optically thin case), then the MIR emitting dust has to absorb efficiently up to 7500Å. If we tolerate 40% reconversion, the cut-off wavelength can be brought down to 4500Å. We should mention however that since we see no sign of strong extinction, we tend to favor a rather low reprocessing ratio, and therefore a long-wavelength cut-off. This is even more true when one considers the fact that this stellar population also has to power the far-infrared emitting dust. Thus the data argue for NGC 5195 as being an example of a site where PAH features are present, though excited primarily by optical photons.

4. Conclusions

The observations we have presented on NGC 5195 reveal a very strong nuclear source, which size is $\lesssim$80 pc. A spectrum was taken on this source and is dominated by the so-called PAH features. No hot continuum is detected longward of 14μm and the ratio of 6.2 to 11.3μm feature intensity also argues for dust in a relatively soft radiation environment. We have envisioned the possible explanations for the dust spectrum and intensity detected and favor a heating by the evolved starburst population (stars older than B5) present in the nucleus of the galaxy. Heating by a LINER would probably produce a similar dust spectrum however the neon infrared lines are completely lacking, as well as the [OIII] line in the optical. Computation of the energy available for dust heating indicates that the dust we detect has to take a substantial fraction of its energy from optical photons, eventhough PAH features dominate the spectrum.

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