RESOLVING THE BURIED STARBURST IN ARP 299

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ABSTRACT

We present new 37.7 μm far-infrared imaging of the infrared luminous (L_{IR} \sim 5.16 \times 10^{11} L_\odot) interacting galaxy Arp 299 (= IC 694 + NGC 3690). We show that the 38 μm flux, like the 60 and 100 μm emission, traces the luminosity of star forming galaxies, but at considerably higher spatial resolution. Our data establish that the major star formation activity of the galaxy originates from a point source in its eastern component, IC 694, which is inconspicuous in the optical, becoming visible only at the near and mid-infrared. We find that IC 694 is two times more luminous than NGC 3690, contributing to more than 46% of the total energy output of the system at this wavelength. The spectral energy distribution of the different components of the system clearly shows that IC 694, has 6 times the infrared luminosity of M82 and it is the primary source responsible for the bolometric luminosity of Arp 299.

Subject headings: dust, extinction — infrared — galaxies — galaxies: individual (Arp 299, VV 118, NGC 3690, IC 694) — galaxies: interactions — galaxies: peculiar — galaxies: starburst

1. INTRODUCTION

One of the major results of the IRAS survey was the discovery of a class of extremely luminous galaxies (L \geq 10^{11} L_\odot) which emit most of their energy in the far-infrared (Houck et al. 1984; Soifer et al. 1989). These ultraluminous infrared galaxies (ULIRGs) have been intensely studied over the past 15 years leading to significant progress in our understanding of their properties (see review of Sanders & Mirabel 1996). For example, it is now clearly established that most, if not all, ULIRGs are interacting systems (i.e. Clements et al. 1996; Duc et al. 1997; Borne et al. 2000), with ample quantities of molecular gas and dust surrounding their active central regions (Solomon et al. 1997; Gao & Solomon 1999). It appears likely that the mergers caused the inordinate far-infrared luminosities, either by compressing the natal ISM and triggering a global starburst, or by triggering accretion onto a central super massive black hole forming an AGN (Genzel et al. 1998; Sanders 1999; Joseph 1999). It is not clear, however, which mechanism dominates. This is because massive star formation is always expected near the central potential well of ULIRGs, but the spatial resolution at mid- to far-infrared wavelengths, where most of the energy of those galaxies appears, is rather poor. For example, for Arp 220, the prototypical ULIRG, its two putative nuclei are separated by \sim 1", and most of the molecular gas is well within the central 10" (Scoville et al. 1991). The peak of the far-infrared spectral energy distribution for Arp 220 though lies near 60 μm where the spatial resolution available from IRAS and ISO is greater than 30" – insufficient to resolve the locations of the heating source(s). Consequently we rely on less direct diagnostics, usually in the near and mid-infrared, to address the questions of the origins of the far-infrared luminosity (Veilleux et al. 1995; Genzel et al. 1998; Murphy et al. 1999; Laurent et al. 2000; Soifer et al. 2000). This approach has proven to be extremely powerful and has produced many surprises. One prime example was the mid-infrared imaging of the Antennae galaxies (NGC 4038/39) with the Infrared Space Observatory which revealed that 15% of its energy at 15 μm originated from a star cluster inconspicuous in the optical and near-infrared (Mirabel et al. 1998). However, while observations in the mid-infrared can much better probe the dusty cores of IR bright galaxies than visible observations, the cores can still be extincted in the mid-infrared. Furthermore, only a small fraction (\sim 3%) of the total luminosity of infrared galaxies emerges in the mid-infrared (Laurent et al. 2000), so that we are still not directly probing the regions where the far-infrared flux originates. Arp 299 (= Mrk 171, VV 118, IC 694+NGC 3690), at a distance of 41 Mpc, (v_Hel = 3080 km s^{-1}, H_0=75 km s^{-1} Mpc^{-1}), is a relatively nearby peculiar galaxy. The system is dynamically young, its components still violently interacting leading to the formation of an 180 kpc (13") long tidal tail (Hibbard & Yun 1999). Diffuse emission around the central regions extends over an area 1.5' in size, while the galaxy itself consists of IC 694 (=Mrk171B = UGC6472 = VV118a) to the east and NGC 3690 (=Mrk171A = UGC6471 = VV118b) nearly 20" to the west (see Figure 1a). Following the nomenclature of Gehrz et al. (1983) and Wynn-Williams et al. (1991), the nucleus of IC 694 is often called source A. NGC 3690 is resolved to sources B1 and B2 to the south, with B2 marking the position of its nucleus, and sources C and C' located \sim 7" to the north of B2. It is believed that Arp 299 results from a prograde-retrograde encounter between a gas rich Sab-Sb galaxy (IC 694) and an Sb-Sc galaxy (NGC 3690) that occurred 750 Myrs ago, and that the system will merge in 20–60 Myrs (Hibbard & Yun 1999). Sources C and C' do not seem to have significant potential wells to be considered individual galaxies given the lack of evidence for an underlying concentration

1 For normal late type galaxies it has been shown that \sim 15% of the luminosity is emitted between 5–20μm (Dale et al. 2001)
of old, red stars (i.e. Alonso-Herrero et al. 2000). Due to its proximity, Arp 299 has been studied extensively ever since it was discovered to have the most luminous emission lines of any non-Seyfert Markarian galaxy (Weedman 1972). It is among the most X-ray luminous galaxies (L_X \sim 10^{42}\text{ergs s}^{-1} \text{Fabbiano et al. 1992; Zezas et al. 1998}) and it is also infrared luminous since, based on its IRAS faint source catalogue fluxes (Moshir et al. 1999), one can calculate^2 that L_{IR} = 5.16 \times 10^{11}L_\odot. Large quantities of molecular gas with strong streaming motions are observed in the system, providing ample fuel for the star formation activity taking place (Sargent & Scoville 1991; Aalto et al. 1997; Casoli et al. 1999). Recent high resolution imaging has revealed that the morphology of NGC 3690, which is brighter than IC 694 in the optical and near infrared, is quite complex (Lai et al. 1999; Alonso-Herrero et al. 2000). Even though there is no compelling evidence for an active galactic nucleus (AGN) anywhere in the system (i.e. Augarde & Lequeux 1985; Armus et al. 1989; Smith et al. 1996) it is clear that the extinction due to dust is high, considerably changing the apparent morphology of the galaxy as one observes it from the UV and optical to near- and mid-infrared wavelengths (Gehrz et al. 1983; Joy et al. 1989; Dudley & Wynn-Williams 1993; Gallais et al. 1999; Dudley 1999; Xu et al. 2000; Soifer et al. 2001).

In the present paper we will focus our attention on IC 694. While this component appears quite diffuse in the UV and optical, its bulge becomes obvious as a point source only at near- and mid-infrared wavelengths (Gehrz et al. 1983; Soifer et al. 1984). The description of our observations is presented in Section 2, the implications of our findings to the current understanding of Arp 299 are discussed in Section 3, and finally our conclusions are summarized in Section 4.

2. OBSERVATIONS

Continuum images of Arp 299 at 37.7 μm were obtained on 28 February, 1994, using the Kuiper Widefield Infrared Camera (KWIC, see Stacey et al. 1993). KWIC is an imaging spectrometer/spectrophotometer designed for use between 18 and 40 μm on the Kuiper Airborne Observatory (KAO). KWIC employs a 128\times128 element Si:Si BIB detector with a 2.73′′ square pixel format, so that it oversamples the diffraction limited beam on the KAO at 38 μm (λ/D \sim 8′′), yielding resulting 5.8′′ \times 5.8′′ field of view. KWIC’s filters are fully tunable cryogenic Fabry-Perots, which we fixed at 37.7 μm, with a 0.5 μm bandwidth for the present observations. The data were obtained using standard chopping and beam switching techniques, and calibrated by comparing with images taken of Orion and M82 at the same wavelength. The system noise equivalent flux density was \sim 20 \text{JyHz}^{-1/2}, and the beam size was 8.5′′. The total integration time was 34 minutes. For all observations, we dithered the array to eliminate bad pixels and flat fielded by dividing by an image of our blackbody calibration source. Absolute pointing on the KAO with KWIC was good to \sim 10′′.

The deep ISOCAM (Cesarsky et al. 1996) broad-band mid-infrared images presented here (see also Gallais et al. 1999, 2002) were created using the spectrophotometric observations of Arp 299 taken on 27 April 1996, after correcting for the transmission of the 7 and 15μm band-passes (of 2.5 and 5μm respectively). The estimated photometric uncertainties of the images are less than 20%. Details on this method as well on the reduction and calibration, of the data are presented by Laurent et al. (2000). The ISO-CAM field of view easily encompasses the whole system with a pixel size of 1.5′′ and a FWHM of the point-spread-function (PSF) of \sim 4.5′′ at 15μm.

3. DISCUSSION

3.1. The 38 μm morphology of Arp 299

Our new high spatial resolution two dimensional image of Arp 299 is presented in Figure 1c. The system is clearly resolved into its two primary components: source A, the nucleus of IC 694, and source B, the nuclear region of NGC 3690. Source C, the overlap region to the north of source B, is not apparent as an independent source, but lies along a ridge of emission extending from source B. Since the identification of the different components of Arp 299 has often been challenging and our 8.5″ beam is rather large, extra care was taken in registering the astrometry of our map and it is therefore useful to describe our method here. Knowing the pixel scale and rotation angle of our 38 μm image we first compared our results with the 10 μm observations of Gehrz et al. (1983) and Keto et al. (1997) which are tied to the highly accurate VLA radio continuum images. Based on the spectrum of IC 694, which is discussed in more detail in the following section, we do not expect the centroid of source A to change between 10 and 38 μm and consequently we set the PSF fit of our identified source A at the same position as their measured coordinates for A. Furthermore, we compared our image to the 7 and 15 μm ISOCAM maps of Gallais et al. (1999), revised versions of which are shown in Figure 1a and 1b and discussed in more detail later. We concluded again that our positions for the centroid of source A were in agreement, which also enabled us to tie our 38 μm astrometry to the HST/NICMOS J-band image of Alonso-Herrero et al. (2000) since the latter had been used to bootstrap the astrometry of the ISOCAM images. Finally, measuring the angular separation (23″) and position angle (-103deg) between our source A and the second brightest peak in our map, we believe that this second peak actually coincides with the location of source B1. This will become more apparent when we discuss the mid-infrared spectral shape of sources B1 and B2 in the next section. However, given the fact that the separation between B1 and B2 is just \sim 2″ (see Fig. 4c of Soifer et al. 2001), which is well within our 38 μm beam, we feel that it is more reasonable to consider that our measurement in that location refers to the flux density of the whole nucleus B (=B1+B2) of NGC 3690. Similarly, C and C’, which are separated by \sim 6″ and are located \sim 9″ to the north of B1, are not resolved as point sources. Hence, the value we quote for source C is the one engulfed in our 38 μm beam at that position.

Given the above considerations we find that source A accounts for 46% of the total flux density of the galaxy at 38 μm. Source B accounts for 22% and source C for 8%. The remaining 24% is in “diffuse” emission over a 45′′ \times 45′′ area covering the galaxy. Details of our photometry measurements are presented in Table 1.

^2 We use the standard definition of L_{IR}(8-1000 \mu m)=5.62 \times 10^5\text{D(Mpc)^2} (13.48f_{12}+5.16f_{25}+2.58f_{60}+f_{100})L_\odot \text{ (see Sanders & Mirabel 1996).}
3.2. The origin of the 38 μm emission

Much of the luminosity in infrared bright galaxies emerges at wavelengths longer than 30 μm. This far-infrared radiation is “down converted” optical or UV radiation: dust in the interstellar medium absorbs optical and UV radiation, heats up, and reradiates the energy in the far-infrared. For most galaxies, the source of the optical or UV radiation is starlight, although active galaxies may have a significant contribution from their active nuclei. Our 38 μm image of the Orion A star formation region (Stacey et al. 1995) demonstrated that the 38 μm flux arises from the warm dense photodissociation region at the interface between the Orion A H II region and the parent molecular cloud. For Orion, the 38 μm flux traces the same dust at the 60 and 100 μm studies: the observed flux matches the longer wavelength color temperature and optical depth maps very well. We expect for this to hold in general for starburst galaxies as well. For example, it is easy to show that for a gray body index of 1.5 (Fν ∝ νβ Bν) the 38 μm flux is proportional to the far-infrared luminosity to within 50% for an assumed dust temperature between 40 and 150 K. To first order, then, our 38 μm images traces luminosity.

3.3. The mid- to far-infrared spectrum of Arp 299

Imaging and spectroscopy at UV, optical, and near-infrared has revealed that obscuration due to dust throughout Arp 299 is high. B1, the nucleus of its eastern component NGC3690 (=Sources B+C), is visible from the UV to near-infrared, even though differential extinction of the various regions of the galaxy (B1, B2, C, and C’) make one or the other source more dominating at a given wavelength range. It is beyond the scope of this paper to discuss NGC3690 in detail. The latest high resolution analysis of the system by Alonso-Herrero et al. (2000) using the HST and NICMOS, has demonstrated that it is IC 694 the most enshrouded source in the galaxy, in agreement with earlier work (i.e. Nakagawa et al. 1989). Given the high 38 μm flux density of this component in our KAO images, as well as the findings of Joy et al. (1989), we will focus our attention to its properties as it appears that IC 694 is responsible for the largest fraction of the far-infrared luminosity of Arp 299.

There are several independent clues which lead us to believe that the dominant starburst of Arp 299 is buried at the nucleus of IC 694. Its UV image (see HST/FOC archive) shows only diffuse emission with no apparent bright core (Vacca 1995). High resolution HST optical imaging (Malkan et al. 1998) displays only patchy emission from several areas of IC 694, with a dust lane running along the southeast-northwest direction. Clearly the UV and optical imaging traces only the surface. The nucleus is not associated with any of the bright optical features and only becomes visible at near-infrared or longer wavelengths (see Wynn-Williams et al. 1991; Lai et al. 1999; Alonso-Herrero et al. 2000). The radio continuum and CO line emission (Gehrz et al. 1983; Aalto et al. 1997; Soifer et al. 2001) coincide with the near infrared peak, confirming that this is the dynamical centre of IC 694. It also contains 3.9 × 109 M⊙ of H2, nearly half of the total observed in Arp 299, over an area less than 500 pc in diameter (Sargent & Scoville 1991). The high a surface density of molecular gas, 2.4 × 104 M⊙ pc−2 of H2, indicates that massive star formation can be sustained over ~107 yr (Nakagawa et al. 1989).

Source A has a flat radio spectrum and it was first thought that an AGN was contributing to a considerable fraction of the IR flux originating from it. However, as we note from Table 1, A does not exhibit an excess of emission in the 3–7 μm range relative to regions B and C. Such a “hot bump” would be expected in an AGN spectrum due to the presence of dust grains associated with the torus surrounding the active nucleus and heated to near sublimation temperatures (see the spectrum of NGC1068 in Le Floc’h et al. 2001). Recent work though indicates that the flat radio spectrum of A can be attributed to free-free absorption and a high supernovae rate of 0.65 yr−1 in it. This rate is almost 5 times that from sources B and C combined (Alonso-Herrero et al. 2000). The extinction of A is somewhat uncertain. As it often happens in deeply obscured objects short wavelength observations merely skim the surface of the star forming regions and do not probe deep enough to account for the total dust content. Consequently its quoted value increases as a function of the wavelength used to measure it: from AV ~ 5 mag at ~ 0.6 μm, to ~ 25 mag at ~ 2 μm, and ~ 25 μm using the CO (Sargent et al. 1987; Nakagawa et al. 1989; Alonso-Herrero et al. 2000). The latter value, however, depends critically on the CO to H2 conversion, as well as the exact CO column density in front of the buried source, both rather poorly known in this case. Large quantities of dust in A are also inferred by the deep 9.6 μm silicate absorption feature in this location – much more pronounced than in any other component of the Arp 299 system (Dudley 1999). This result is confirmed by ISO/ICAM 5–16 μm spectra which show that the 9.6 μm silicate band of A is indeed nearly saturated with no observable continuum emission (Gallais et al. 2002).

The overall morphology of the system in the mid-infrared, presented in Figure 1, is rather intriguing. It is apparent that as we move from shorter to longer wavelengths, NGC 3690, which hosts numerous sites of massive stars and is the major source of the energy output of the system in the optical and near-infrared, progressively diminishes in its overall strength presenting a single isolated unresolved source of emission near the region B1 (see also Gallais et al. 1999; Soifer et al. 2001). IC 694 though, displays a steep rise in its spectrum and at 38 μm is more than two times brighter than NGC 3690. The ratio of the f38μm/f12.5μm is 13.8, ~4 times higher of those regions B and C+C’. Unfortunately, we lack the spatial resolution to examine in detail the behavior of region C’, which according to Soifer et al. (2001) displays the highest f12.5μm/f2.2μm ratio among the resolved components in Arp 299. Consequently, it remains unclear whether this trend continues in our KWIC data since we can only measure the emission within one beam at the location of C+C’. Even though the difference in beam sizes and the extent of the old stellar population may conspire against us we do find that the f38μm/f2.2μm ratio of IC 694 is 890, which is again ~4 times higher than the same ratio for regions B and C+C’. Interestingly at 7 and 15 μm the deep ISO-CAM images reveal that 48% and 40% of their respective emission originates from areas outside regions A, B, and
C contrary to just 24% we find at 38 µm. This was suggested by the 3.2 µm images of Soifer et al. (2001) and can be attributed to emission from warm dust and polycyclic aromatic hydrocarbons (PAH) due to star formation activity in the extended disks and the overlap region between the two galaxies.

Based on the above information and the data of Table 1 we plot the spectral energy distribution (SED) for regions A, B, and C of Arp 299. We find a good fit to the 10 to 100 µm fluxes for the three sources with a two component dust model3, each with a gray body spectral index of 1.5. The fit is presented in Figure 2 and is valid only for wavelengths longer than 10 µm. It is well known that at shorter mid-infrared wavelengths not only feature emission from PAHs dominates the spectrum, but also the grains are clearly out of thermal equilibrium. Hence a more detailed treatment of the underlined physics is necessary (see Dale et al. 2001). The results of our model are presented in Table 2. Our model suggests that for component A $T_{\text{warm}} \sim 44 \text{ K}$, $\tau_{\text{warm}} \sim 6.8 \times 10^{-2}$, and $T_{\text{hot}} \sim 140 \text{ K}$, $\tau_{\text{hot}} \sim 2.2 \times 10^{-5}$. For components B and C, the model is similar except with smaller optical depth. Based on our model, we predict that the flux density of A at 100 µm is 47 Jy which suggests4 that its dust mass is $9.6 \times 10^{7} M_{\odot}$. For a Galactic dust to gas ratio this would imply $\sim 10^{9} M_{\odot}$ of gas at the center of IC 694. Furthermore, if we assume “outer cloud” dust, then these optical depths correspond to a visual extinction, $A_V \sim 250 \times 738_{\mu m}$, or $A_V \sim 17$ through the warm dust at region A. With a gas column to visual extinction ratio of $2 \times 10^{22}$, we also estimate that the gas and dust mass traced by the 38 µm emission at A is $\sim 10^{9} M_{\odot}$. If our assumptions are correct then based on the dust properties the concomitant gas mass is $\sim 7\%$ of the gas observed (Hibbard & Yun 1999). Clearly there is an additional component of cold dust not traced through its 38 µm emission. However, since the far-infrared luminosity is nearly entirely in the warm dust component, and $\sim 75\%$ of the observed 38 µm flux comes from this component, our analysis confirms that the 38 µm flux traces the far-infrared luminosity. Integrating the modeled SEDs, we derive infrared luminosities ($L_{IR}$) of $1.8 \times 10^{11}$, $9.4 \times 10^{10}$, and $4.4 \times 10^{10} L_{\odot}$ for A (IC 694), B(NGC 3690), and C+C’(overlap) components respectively. Our model fit estimates the total infrared luminosity of Arp 299 to be $4.6 \times 10^{11} L_{\odot}$, which is 90% of the amount observed based only on the IRAS fluxes. One should also note that according to our model $\sim 30\%$ of the infrared luminosity of the system is outside the above defined regions.

4. CONCLUSIONS

We have obtained high resolution 38 µm mid-infrared images of the peculiar galaxy Arp 299. Our data clearly shows that despite its diffuse and quiescent appearance in the UV and optical, IC 694 harbors a strong point-like source in the mid and far-infrared and is the dominant source of far-infrared radiation in the system. Together with shorter wavelength images, we construct the spectral energy distribution of the various components of the galaxy. We find that IC 694 is by far the strongest source, with an infrared luminosity of $1.8 \times 10^{11} L_{\odot}$, or $\sim 40\%$ of the whole Arp 299 system. The infrared luminosity of IC 694 is 6 times the luminosity of M 82, while the one inferred for component C is about 1.5 times that of M 82, making it one of the most luminous non-nuclear starbursts known.

Our analysis suggests that in order to accurately determine the starburst activity and infrared luminosity of different regions in interacting/merging luminous infrared galaxies it is imperative to obtain good spatial resolution maps covering the 15-40 µm range to better trace the colder dust component. Future instruments such as IRS and MIPS on SIRTF and FORCAST on SOFIA will provide valuable information in addressing these problems.

We are greatly indebted to the efforts of T. L. Hayward and H. M. Lattvakoski in the design and construction of KWIC and during the observations. We thank the staff and crew of the Kuiper Airborne Observatory for their excellent support, especially during the observatory’s challenging final year of operations. This work was supported in part by NASA grants NAG2-800 and NAG2-1072. VC would also like to thank O. Laurent (Saclay) for help and suggestions on the optimum analysis of ISOCAM data as well as G. Neugebauer (Caltech) and E. Le Floc’h (Saclay) for useful discussions. This research has made extensive use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

REFERENCES


3 Since multiple data exist for the same or nearby wavelengths, in our fitting method we weighted all measurements according to their quoted uncertainties. For the far-infrared one-dimensional scans of Joyce et al. (1989) we conservatively assumed that the flux distribution in the different components follows our KWIC 38 µm image.

4 We use the definition of $M_{\text{dust}}=4.81 \times 10^{-12} f_{100} D[pc]^{1/2} (e^{143.88/T -1}) M_{\odot}$ from Allen’s Astrophysical Quantities.
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<table>
<thead>
<tr>
<th>Region</th>
<th>2.2 μm* (mJy)</th>
<th>3.2 μm* (mJy)</th>
<th>7 μm* (mJy)</th>
<th>12.5 μm* (mJy)</th>
<th>15 μm* (mJy)</th>
<th>17.9 μm* (mJy)</th>
<th>19.5 μm* (Jy)</th>
<th>20 μm* (Jy)</th>
<th>23 μm* (Jy)</th>
<th>25 μm* (Jy)</th>
<th>32μm* (Jy)</th>
<th>37μm* (Jy)</th>
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<tr>
<td>A (=IC 694)</td>
<td>19.4</td>
<td>18.9</td>
<td>325</td>
<td>1230</td>
<td>1860</td>
<td>1950</td>
<td>2.29±0.13</td>
<td>5.00</td>
<td>5.82±0.44</td>
<td>12.40</td>
<td>27.00±8.00</td>
<td>17.00</td>
</tr>
<tr>
<td>B=B1+B2f</td>
<td>22.0+11.7</td>
<td>11.7+8.7</td>
<td>505</td>
<td>2010</td>
<td>1951</td>
<td>6520</td>
<td>2.27±0.15</td>
<td>4.80</td>
<td>4.03±0.30</td>
<td>6.9</td>
<td>13.00±4.00</td>
<td>8.00</td>
</tr>
<tr>
<td>C′</td>
<td>1.12</td>
<td>1.99</td>
<td>76</td>
<td>188</td>
<td>232</td>
<td>1100</td>
<td>1.41±0.31</td>
<td>2.20</td>
<td>2.60±2.30</td>
<td>2.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arp 299g (total)</td>
<td>78.1</td>
<td>144.2</td>
<td>1846</td>
<td>4030</td>
<td>7037</td>
<td>12650</td>
<td>5.26±0.23</td>
<td>11.90</td>
<td>11.66±0.62</td>
<td>21.50</td>
<td>43.00</td>
<td>36.96</td>
</tr>
</tbody>
</table>

*Based on Table 2 and Figure 4e of Soifer et al. (2001). The quoted photometric accuracy is ~5%.

From Laurent et al. (2000) using a 4.5′′ beam. The photometry is accurate to a 20% level.

Fluxes densities are for a 5′′ beam from Gehrz et al. (1983).

From Wynn-Williams et al. (1991). Errors are 20% unless otherwise specified.

This work.

We provide the integrated values for source B=B1+B2 at 2.2 and 3.2 μm. At longer wavelengths the apertures are centered on B1, which dominates the emission of B, and any direct contribution due to B2 is well within the measurement uncertainties.

The integrated IRAS flux densities for the whole galaxy at 12, 25, 60 and 100 μm, as presented in the IRAS faint source catalogue, are 3.81, 23.19, 103.7, and 107.4 Jy respectively (Moshir et al. 1990).
# Table 2

Gray body model for Arp 299

<table>
<thead>
<tr>
<th>Region</th>
<th>$T_{\text{warm}}$ (K)</th>
<th>$\tau_{\text{warm}}$</th>
<th>$T_{\text{hot}}$ (K)</th>
<th>$\tau_{\text{hot}}$</th>
<th>$L_{\text{IR ; warm}}$ L$_{\odot}$ %</th>
<th>$L_{\text{IR ; hot}}$ L$_{\odot}$ %</th>
<th>$L_{\text{IR}}$ L$_{\odot}$</th>
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<tbody>
<tr>
<td>A</td>
<td>44</td>
<td>$6.8 \times 10^{-2}$</td>
<td>140</td>
<td>$2.2 \times 10^{-5}$</td>
<td>88</td>
<td>12</td>
<td>1.8×10^{11}</td>
</tr>
<tr>
<td>B=(B1+B2)</td>
<td>44</td>
<td>$2.6 \times 10^{-2}$</td>
<td>135</td>
<td>$3.5 \times 10^{-5}$</td>
<td>67</td>
<td>33</td>
<td>9.4×10^{10}</td>
</tr>
<tr>
<td>C+C’</td>
<td>40</td>
<td>$2.2 \times 10^{-2}$</td>
<td>120</td>
<td>$2.8 \times 10^{-5}$</td>
<td>67</td>
<td>33</td>
<td>4.4×10^{10}</td>
</tr>
<tr>
<td>Arp 299 (total)</td>
<td>44</td>
<td>0.15</td>
<td>130</td>
<td>$1.5 \times 10^{-4}$</td>
<td>75</td>
<td>25</td>
<td>4.6×10^{11}</td>
</tr>
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</table>
Fig. 1.—a) An ISOCAM 7 μm image of Arp 299 (adapted from Gallais et al. 1999) overlayed on an HST/NICMOS 2.2 μm image from (Alonso-Herrero et al. 2000), were the different components of the galaxy are marked. The 9 contour levels are set with logarithmic spacing between 1 and 33 mJy arcsec$^{-1}$. b) Same as in a) but using the ISOCAM 15 μm image as an overlay having set the contour limits to 6 and 60 mJy arcsec$^{-1}$. c) Our 37 μm over the same HST image. The contour levels are 1.5 Jy beam$^{-1}$ beginning at 3 Jy beam$^{-1}$ (6σ).
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Fig. 2.— The mid- and far-infrared spectral energy distribution of Arp 299. The fluxes from region A (IC 694) are marked with the red symbols, the ones from region B (NGC 3690) are shown in blue. Global measurements for the whole system are given in black. The gray body fits (see section 3.3) are also included in the respective colors. Our fit to the emission from the region C+C’ is also displayed in green. It is evident from the figure that even though NGC 3690 has a warmer mid-infrared component, past 20 μm the emission from IC 694 dominates the observed spectrum of the galaxy.