Constraints on the nuclear emission of the Circinus galaxy: the torus

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**ABSTRACT**

In the context of the unified model of Seyfert galaxies, we use observations from the literature and a radiative transfer model to investigate the near–IR to mm emission produced by the presumed torus in the Circinus galaxy, from 2\(\mu m\) to 1.3mm. From the infrared SED modelling, we find that the total luminosity (L\(_{IR}\)) in this wavelength range, consists of similar contributions from the torus and starburst with a ratio of nuclear luminosity to starburst luminosity (L\(_{NUC}/L_{SB}\)) \(\sim 0.8\).

By using a similar torus model to that of NGC1068, *but without the conical dust*, we find an upper limit to the outer torus radius of \(\sim 12\)pc with a best fit of \(\sim 2\)pc. The upper limit torus size estimated from the radiative transfer modelling is consistent with the 16pc torus radius estimated from near–IR imaging polarimetry of Circinus.

**Key words:** galaxies: individual: Circinus - galaxies: nuclei - galaxies: active - infrared: galaxies - radiative transfer

1 INTRODUCTION

Observational evidence for obscuring material in the centres of Active Galactic Nuclei (AGN) is now abundant. Obscuration is observed in the form of molecules and dust, present in the centres of these galaxies on scales that vary from a fraction of a parsec to tens and even hundreds of parsecs (Malkan \etal 1998; Gallimore; Siebenmorgen \etal 1997; Greenhill \etal 1996). It is believed that the obscuring material takes the form of a dusty “torus” which blocks and absorbs part of the radiation from the active nucleus. These dusty tori play an essential role in unified theories of Seyfert galaxies and strongly support the unification models.

The unified model for Seyfert galaxies proposes that all types of Seyfert galaxy are fundamentally the same, but, the presence of the dusty torus obscures the nucleus, including the broad line emission region in many systems. In this picture the classification of Seyfert 1 or 2 depends on the inclination angle of the torus to our line of sight (e.g. Antonucci and Miller 1985; Antonucci 1993). Strong support for this model has come from X–ray observations, showing that Seyfert 2 galaxies are Compton thick, i.e. the nuclear radiation is absorbed by matter with column densities \(>10^{24}\)cm\(^{-2}\) (Lawrence and Elvis 1982; Maiolino \etal 1998a).

Direct imaging of the presumed torus is technically demanding due to its (predicted) small size (e.g. Efstathiou, Hough and Young 1995, hereafter EHY95; Granato, Danese and Franceschini 1997; Alexander \etal 1999). The most convincing direct evidence for a Seyfert torus comes from observations of the HCN molecule (Jackson \etal 1993), which traces dense molecular gas, and near–IR imaging polarimetry (Young \etal 1996), both of NGC1068. These images show a large nuclear structure of \(\sim 200\)pc in extent, approximately perpendicular to the [O\(\text{III}\)]5007 emission cone and radio lobe emission. Indirect support for tori comes from ground–based narrow band imaging (e.g. Wilson and Tsvetanov 1994), high resolution HST imaging (e.g. Capetti \etal 1997; Falcke, Wilson and Simpson 1998) and imaging–polarimetry (e.g. Ruiz \etal 2000; Lumsden \etal 1999; Tadhunter \etal 1999; Packham \etal 1997) which have shown a number of objects with nuclear conelike structures, presumably collimated by the torus.

The origin of the infrared continuum in a number of Seyfert 2 galaxies is clearly thermal as indicated by silicate features such as the broad absorption at 10\(\mu m\) (Roche \etal 1991) and the various emission features from polycyclic aromatic hydrocarbons (PAHs), e.g. 3.3, 6.2 and 11.3\(\mu m\), which are normally associated with the presence of hot stars in a starburst environment. Dust grains, distributed in a toroidal geometry surrounding the central black hole and accretion disc, are believed to be responsible for the absorption of radiation from the central source.

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and re-radiation of energy into longer wavelengths giving rise to the observed “IR bump” longwards of 1μm and peaking at mid-IR wavelengths (Rowan–Robinson and Crawford 1989). The resultant radiation spectrum is dependent on the distribution of dust grain temperatures (≤ 2000K) and optical depth. Two additional components can add to the IR spectra of active galaxies (Rowan–Robinson and Crawford 1989): galactic diffuse emission from large dust grains heated by the interstellar radiation field in the galactic disc (cirrus, \( T_{\text{large-grains}} \leq 40K \)) and a starburst component peaking at about 60μm.

Thus, a radiative transfer model which takes into account dust grain features within a true toroidal configuration and starburst environment is needed to correctly reproduce the near-IR to mm SED of the Circinus galaxy.

Here, we present a model for the IR continuum emission of the Circinus galaxy which successfully fits the observations from 2μm to mm wavelengths. We constrain the size and flux of the dusty AGN torus and estimate the contribution of the starburst emission to total IR emission. Section 2 presents the data compilation and sections 3 and 4 present the model and the fitting procedure. Section 5 discusses the model and its implications and conclusions are summarised in section 6.

2 THE DATA

The continuum and PAHs data points have been compiled from a variety of sources in the literature and are presented in Table 1. The data sources will be described below. There is a large range of sizes in the observational apertures, from arcsec to arcminute beamsizes, equivalent to physical sizes of <5pc and >200pc (for Circinus, 1 arcsec corresponds to 20pc); whenever possible, data from the smallest available aperture were used to minimise the contribution from galactic disk emission.

In the near-IR, below 2μm, the stellar contribution is quite significant, and to study the nuclear emission, the starlight contribution has to be subtracted from the integrated flux. The data point at 2.2μm shown in Table 1 corresponds to the deconvolved non-stellar measurement as presented by Maiolino et al. (1998b) and derived from a 0.15arcsec aperture. This measure will set a limit on the size of the nuclear non–stellar source (see section 2.1).

In the mid-IR, between 3 and 20μm, the continuum data points at 3.8 and 4.8μm, are provided by Siebenmorgen et al. (1997) who carried out speckle interferometry in the L'(3.8μm) and M(4.8μm) bands with a 0.3arcsec aperture. The speckle observations are insensitive to larger scale components, e.g. starlight, and predict more directly the nuclear non–stellar contribution (see section 4). Other continuum data points over this wavelength range are from the ISO–SWS spectrum presented in Sturm et al. (2000).

Line information for the PAH features at 3.28, 6.2, 7.7, 8.6 and 11.3μm were directly measured from the ISO–SWS spectrum in Sturm et al. (2000). The reported values in Table 1 correspond to the peak of these emission lines. ISO apertures are large enough (≈24arcsec\(^2\)) to contain much of the circumnuclear star forming regions as well as the nuclear emission. The ISO spectrum shows that the region between 5 and 12μm is dominated by PAH features, characteristic of star formation activity (see Fig 1), and it is remarkably similar to those of pure starburst galaxies also observed by ISOPHOT (Siebenmorgen, Krügel and Zota 1999).

The spectrum corresponding to the Si absorption feature centered at 9.7μm is shown in more detail in Fig 1. It was provided by P. Roche and published by Roche et al. (1991). This spectrum was taken with the UCL spectrometer and used an aperture of 4.3arcsec. For comparison also shown in Fig 1 is the mid-IR ISO-SWS spectrum of Circinus taken with the much larger aperture of 14×20arcsec\(^2\) (Sturm et al. 2000).

The N(10.3μm) band continuum data point, is also provided by Siebenmorgen et al. (1997) and measured through a 1.3arcsec slit. It is interesting to note that a larger aperture measurement at 10.3μm by Moorwood and Glass (1984) with a 5arcsec aperture is very similar to the smaller aperture data of Siebenmorgen et al. (1997). This is a good indication of the compact nature of the central source at this wavelength. The continuum data points at 20, 30 and 40μm were taken from the ISO-SWS spectrum (Sturm et al. 2000). The ISO SWS spectrum at 25μm agrees within 20% of the IRAS flux.

The far–IR continuum observations were collected from the IRAS large aperture observations (90arcsec) at 12, 25, 60 and 100μm as reported by Moshir et al. (1992). The continuum data point at 150μm was taken from the analysis by Ghosh et al. (1992) which corresponds to an aperture of

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\( a \) Collected from the literature. Data for the 7–13μm range are shown in Fig 1

\( b \) References: (1) Maiolino et al. (1998b); (2) Sturm et al. (2000); (3) Moorwood and Glass (1984); (4) IRAS, Moshir et al. (1992); (5) Ghosh et al. (1992); (6) Siebenmorgen et al. (1997)

\( c \) nuclear measurement

\( d \) PAH feature peak

\( e \) 5σ upper limit

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of 40arcsec. This measurement is only a 5σ upper limit as Circinus was not detected at this wavelength.

At millimeter wavelengths, Circinus has been detected at 1.3mm with an aperture of 23arcsec as reported by Siebenmorgen et al. (1997). Maps of the millimeter continuum emission show Circinus as an unresolved source.

Clearly, the large aperture observations are contaminated with light from various emission sources particularly from the extended galactic disc; thus, special care is needed when fitting the large aperture data points to the individual emission components in the radiative transfer model (see next section).

2.1 Constraints from Observational Data

In the K band (2.2µm), the source is clearly unresolved in a 0.3arcsec aperture (6pc on source). By deconvolving the nuclear K-band surface brightness radial distribution with a stellar profile and a nuclear PSF, Maiolino et al. (1998b) set a constraint on the size of the nuclear non-stellar source of <1.5pc. Similarly, at 3.8 and 4.8µm the source is also observed to be unresolved at 0.7arcsec resolution and is possibly <0.3arcsec in size, putting upper limits of 6pc (Siebenmorgen et al. 1997). Clearly, at wavelengths ≤5µm most of the emission comes from a central source with a size ≤6pc. This size scale almost certainly corresponds to the inner radius of the proposed dusty torus, as the near-IR emission is most likely to result from hot dust grains (T_d <1300K) heated by the intense radiation from the non-stellar central source. Thus, in our model, the near-IR data points at <5µm are assumed to be totally dominated by the emission from the torus component.

Observations at 10µm reveal that the central source size is possibly resolved with a size of 26pc whilst at 20µm it is unresolved and <30pc in size (Siebenmorgen et al. 1997). As mentioned in the previous section, the emission detected with the larger aperture of Moorwood and Glass (1984) at 10µm does not seem very different from that of smaller aperture by Siebenmorgen et al. (1997). At wavelengths larger than 20µm, the IR emission most likely results from a more extended region, and there is possibly a significant contribution from the inner circumnuclear starburst (∼40pc in radius).

The spatial resolution analysis at 60, 100 and 150µm by Ghosh et al. (1992) reveals a deconvolved size of Circinus of 40arcsec at 50µm. However, at these longer wavelengths, the resolution is too poor to put useful constraints on the size of the emitting source.

The spectrum corresponding to the Si feature at 9.7µm (Fig 1) was taken with an on-source equivalent aperture of ∼80pc (Roche et al. 1991). The detection of a number of CO stellar absorption features in a 4.4×6.6arcsec² aperture gives strong evidence for circumnuclear star formation on a region few tens of parsecs from the nucleus (Oliva et al. 1994, Maiolino et al. 1998b), thus, the Si feature cannot be solely modelled by dust self-absorption from the torus component, but a starburst contribution will have to be included when fitting this feature with the SED model.

The long wavelength data points and PAH features (IRAS and ISO data), which correspond to large aperture observations (see Table 1), are hence dominated by the larger scale starburst emission observed in the circumnuclear ring at ∼200pc from the nucleus. Thus, the data points corresponding to IRAS and ISO data are fitted with a starburst component.

3 THE GENERAL INFRARED MODEL

The model used is the radiative transfer model of Efstatthiou et al. as described in detail in Efstatthiou and Rowan–Robinson (1995, hereafter ER95), EHY95, and Efstatthiou, Rowan–Robinson and Siebenmorgen (2000, hereafter ERS). This radiative transfer model has been successful in fitting the IR continuum of NGC1068 (EHY95) and Centaurus A (Alexander et al. 1997). The proposed model for the SED of the Circinus galaxy is a combination of the following two components described below.

3.1 Torus

As concluded in ER95, the most likely geometry for the obscuring material in the center of AGNs, is that of a “tapered disc”. Other proposed geometries for the torus are “flared discs” (Granato and Danese 1994; Efstatthiou and Rowan–Robinson 1990 (hereafter ER90)) or cylinders (Krolik 1992; 1993; Taniguchi and Murayama 1998). However, the shape of the IR continuum spectrum of type 1 and type 2 objects, the appearance of the 10µm silicate features and the statistics of the two types of Seyfert galaxies, give strong support for a tapered disc geometry (see ER95 for detailed discussion). Indeed, there is further confirmation of the validity of the tapered disc geometry to realistically represent the nuclear emission of tori in AGNs. This comes from the fitting of IR data to a sample of Seyfert galaxies with the EHY95 models of Figure 3. They have been successfully used to fit nuclear (non-stellar) near-IR observations for a sample of Sy1s and Sy2s (Alonso–Herrero et al. 2001) showing that the near-IR nuclear emission from Seyfert galaxies can be fitted with the tapered disc geometry tori of EHY95. We therefore assume this geometry for the Circinus torus. As demonstrated in ER90, the orientation of the plane of the system to the line-of-sight is a very important parameter when fitting the observed spectra, since only a small difference in this inclination parameter, θ_V, produces a significant variation in the emergent spectrum. Another important parameter that determines the shape of the IR continuum, is the half-opening angle of the torus, Θ. In general, these parameters are not known for most objects, but fortunately, we have a good idea of their values from spectropolarimetry (Alexander et al. 2000) and IR-imaging polarimetry of Circinus (Ruiz et al. 2000) which gives θ_V ∼40 degrees (measured from the axis of the torus to the line of sight) and Θ ∼45 degrees. Although the emission line cones observed in Circinus and many other AGNs offer a measure of the opening angle of the torus, it is common to find that the conical emission “opens-up” as light travels and scatters in the circumnuclear medium. Thus, we should keep in mind that Θ can be smaller than that derived from emission line cones (see section 4).

Other parameters that will affect the shape of the emergent SED spectrum are: the ratio of the inner and outer radii (r_1/r_2), the ratio of the height to the outer radius (h/r_2), the equatorial optical depth (νA_ν), the dust sublimation
temperature ($T_1$) and the radial dependence of the density distribution $r^{-\beta}$. To take into account the effects of dust in the nuclear regions of Circinus, we assume that there is an additional extinction (i.e. in addition to that produced by the torus). Marconi et al. (1994) found $A_V \geq 20$ mag towards the nucleus. This limit follows from the fact that we can see the nucleus at 1.25 $\mu$m but are unable to do so at 7000 Å, thus, they only set a lower limit for the nuclear extinction. However, we find that $A_V = 25$ mag is required to successfully fit the near–IR data. This value is also close to that found by Moorwood and Glass (1984) from the depth of silicate feature at 9.7 $\mu$m and is also consistent with that estimated by Maiolino et al. (1998b). Based on H and K band observations, they set a minimum extinction $A_V > 12$ mag toward the nucleus of Circinus. From their images, it is clear that this obscuration is caused by the large amounts of dust as seen in their H–K colour map and it is due to the presence of a nuclear gas bar. Their estimated $A_V$ however is only a lower limit and we expect a larger value since the extinction is most likely to be due to an inhomogeneous distribution of dust, gas and stars. The parameters assumed for the torus model are listed in Table 2.

3.2 Starburst

The radiative transfer models of starburst galaxies are described in detail in ERS. The models consider a starburst galaxy as an ensemble of optically thick giant molecular clouds centrally illuminated by recently formed stars. The stellar population is determined according to the Bruzual and Charlot (1993) stellar population synthesis models. The grain model used is that of Siebenmorgen and Krügel (1992) and the emission of transiently heated dust grains is calculated according to their method. In the models, the effects of multiple scattering is taken into account. The models relate the observed properties of a galaxy to its age and star formation history. These models have successfully matched the observational characteristics of M82 and other starburst galaxies (ERS). Various populations of dust particles are considered:

(i) Mathis, Rumpl and Nordsieck (1977). These are large particles with a size distribution of classical grains

(ii) small graphite grains, to account for the extinction bump at around 2175 Å (Draine 1989)

(iii) PAH molecules, to explain the near–IR and mid–IR emission bands

To take into account the effects of dust in the starburst regions of Circinus, we extinct the starburst emission by $A_V = 5$ mag, as measured from narrow emission line ratios (Oliva et al. 1994). This is lower than the additional extinc-
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Table 2. Model parameters

<table>
<thead>
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<th>Parameter</th>
<th>Value</th>
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<td>System inclination</td>
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<td>Cone opening half-angle, $\Theta$ (°)</td>
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<tr>
<td>$e^b A_{UV}$ (mag)</td>
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<td>$e^c A_V$ (mag)</td>
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<tr>
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<tr>
<td>Additional $A_V$ (mag)</td>
<td>25</td>
</tr>
</tbody>
</table>

*a* measured from the plane of the torus to the line of sight
*b* $e^b A_{UV}$ corrected for the inclination of the torus to the line of sight
*c* dust sublimation temperature at torus inner radius
*d* value determined as discussed in EHY95
*e* due to circumnuclear bar

Table 3. Torus characteristics

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<tr>
<td>$h/r_2$</td>
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<td>Inner radius ($r_1$, pc)</td>
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<tr>
<td>Outer radius ($r_2$, pc)</td>
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<tr>
<td>Height ($h$, pc)</td>
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</table>

As described in section 3, the data points will be fitted to the SED model components according to the observational constraints described in section 2.1. The critical wavelength range is likely to be where the torus and starburst components are equally important, that is in the 10–30µm region. Here, the strong absorption feature is indicative of the presence of dust in the form of silicates which are likely to be present in a dusty environment such as the torus, however, the observational beam for this data is large enough to cover a region which also includes star formation. Thus, contributions from both the torus and starburst components are important in this wavelength range. On the other hand, given that the near–IR points are to be modelled by the torus alone (see section 2.1), this sets a strong constraint on the number of possible models to be tested for the torus. Similarly, in the long wavelength range and large aperture data points which include the PAHs features, the starburst component dominates, and only a number of starburst models can be applied. Thus, the overall fitting procedure is much better constrained and the number of free parameters reduced once the short and long wavelength ranges are considered.

The torus input parameters that reproduce the near–IR points are listed in Table 2. The best fits were obtained with a cone half–opening angle of 30 degrees, the same as the best fit obtained for the NGC1068 torus model (EHY95). One important difference with the NGC1068 model is that there is no requirement to include a contribution from hot dust in the torus cone. Indeed, if this is included, then it is very difficult to obtain a fit to the near–IR data points. The starburst parameters which reproduce the PAHs features and large scale emission successfully are also listed in Table 2. Table 3 presents the derived geometrical characteristics for the best fit torus in Circinus. In Figure 2 we show the best model for the SED of the Circinus galaxy which is the addition of the torus and starburst models. Note that the solid line (representing the total emission from the galaxy) exceeds the mid–infrared data of Roche et al. (1991). This is not surprising as the starburst which contributes about half of the emission is more extended than the 4arcsec aperture of Roche et al. (1991). Thus, the final SED for the 10µm absorption feature should not fit the 9.7µm data of Roche et al. 1991 (Fig 1).

Unfortunately, there is a serious lack of small aperture (nuclear) data in the range of 30–60µm. As a consequence, we are unable to rule out tori up to ∼12pc although increasing the torus outer radius further would produce far too much 30–60µm flux. Future observations in this critical wavelength range, will put extra constraints on the torus model, and the torus size would be determined more accurately.

It is interesting to note in Figure 2 the overall larger contribution to the total IR emission of the starburst compared to the torus component. This is indicated by the ratio of the nuclear luminosity –torus component– to starburst luminosity –starburst component– ($L_{NUC}/L_{SB}$) ∼ 0.8 (see next section).

5 DISCUSSION

Our SED model shows that, overall, the starburst contribution to the total IR luminosity, $L_{IR}$ slightly dominates over the torus contribution. A direct result of this, is the relatively small size of the torus in Circinus, with a best fit of ∼2pc for the outer radius, comparable to the torus outer radius of 1.8pc modelled for Cen A (Alexander et al. 1999) but significantly smaller than the ∼90pc torus for NGC1068 (Young et al. 1996 and EHY95). This result is smaller than that calculated from the near–IR imaging polarimetry modelling of Ruiz et al. (2000) which suggests that the torus is approximately 10pc in radius, although consistent with our upper limit of ∼12pc.

So far, by using the radiative transfer models of Efstathiou et al. we have been able to model the size of the torus outer radius for three objects: NGC1068 (EHY95), CenA (Alexander et al. 1999) and Circinus (this work). Although the statistics are small, it is interesting to note that all three AGN can be modelled with tori of very similar parameters. This suggests that whatever the mechanism that
forms these tori in an AGN–SB environment, it is such that the size of the tori scales with the luminosity of the central source but the rest of the torus parameters (Table 2) are scale invariant. For example, the hard X-ray continuum, which is considered to be a good indicator of the central source strength, indicates that the Circinus galaxy is a relatively low luminosity AGN (Matt et al. 1996), while NGC1068 is ~ 100 times more powerful (Turner et al. 1997), with a torus radius ~100pc. The predicted torus radii scales as $L^{1/2}$, reflecting the fact that both objects can be fitted with very similar radiative transfer models.

Of great debate regarding the nature of the Circinus galaxy is the ratio of the AGN to starburst emission ($L_{\text{NUC}}/L_{\text{SB}}$), that is, the relative contribution of the torus and starburst components to the total $L_{\text{IR}}$. Previous predictions from IR modelling differ widely. As already mentioned, Rowan–Robinson and Crawford (1989) found a 20% contribution of the nuclear component to the total $L_{\text{IR}}$ and $L_{\text{NUC}}/L_{\text{SB}} \sim 0.3$ while this work suggests a $L_{\text{NUC}}/L_{\text{SB}}$ of 0.8. On the other hand, from the Br$\alpha$ luminosity, Moorwood et al. (1996) estimate that this ratio is perhaps as high as 9. Our result is in very good agreement with that suggested by Maiolino et al. (1998b) who estimate from K band observations a $L_{\text{NUC}}/L_{\text{SB}}$ ratio of 0.9 for the region <200pc. Similarly, we agree with the ratio derived from the inferred ionising continuum required to produce the highly ionised IR lines suggesting a ratio closer to 1 (Moorwood et al. 1996). We believe that the differences are caused by a number of pitfalls. For example, Rowan–Robinson and Crawford (1989) modelled the far–IR (10-100$\mu$m) IRAS data with a three component model, a starburst, a Seyfert and a disc cirrus–like component. This model assumed a spherically symmetric dust distribution with a power–law density distribution, $n(r) \sim r^{-\beta}$. In this model, radiation from the polar regions of the torus is absorbed by the spherical dust cloud. Thus, this model will naturally under–estimate the nuclear component, as their low $L_{\text{NUC}}/L_{\text{SB}}$ ratio shows. However, there is now ample observational evidence that favours the existence of axially symmetric distributions of dust (Efstathiou and Rowan–Robinson 1990, ER95). On the other hand the large $L_{\text{NUC}}/L_{\text{SB}}$ ratio derived by Moorwood et al. (1996) suggests a strongly dominant AGN over the starburst. This

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**Figure 2.** IR SED for the Circinus galaxy. The SED is fitted with a starburst and a torus model. Dark circles are the data points from Table 1 and Figure 1. Units for $\nu S_{\nu}$ are $10^{-26}$ W/m$^2$. Dotted line corresponds to the torus component, dashed line is the starburst component and the solid line represents the total fit. The model parameters assumed for the torus and starburst are given in Table 2.
was derived from the comparison of near-IR recombination lines in Circinus and M82; from a Brγ map (Moorwood and Oliva 1994), they assume that 50% of the recombination lines are produced in the nucleus of Circinus. However, this is likely to be an over-estimation of the strength of Brγ in the nucleus since, more recently, a more accurate measurement of the Circinus nuclear recombination lines (Maiolino et al. 1998b) has shown that only ~10% of the total recombination lines flux is produced in the nucleus of Circinus. Thus, assuming the standard relation between Brγ and total IR luminosity in starburst galaxies, we can determine the contribution of the starburst to the total IR luminosity in starburst galaxies, we can determine the contribution of the starburst to LIR. We find L_{SB} \sim 8.5 \times 10^9 L_\odot, so L_{NUC}/L_{SB} \sim 1.2 for an AGN luminosity of 10^{10} L_\odot. This is in good agreement with the ratio we find from the SED modelling.

Radio observations suggest that at these wavelengths, the starburst emission is the dominant component (Forbes and Norris, 1998) and Circinus would certainly be classified as a starburst galaxy based purely on radio emission. Indeed, it is interesting to note that the FIR–radio correlation established by Helou, Soifer and Rowan–Robinson (1985) which is followed by normal spiral and starburst galaxies, is closely followed by the Circinus galaxy, confirming Forbes and Norris result. However, it is almost certain that this correlation is the result of large scale star–formation activity unrelated to the Seyfert activity which generates both the synchrotron radio emission and the thermal FIR emission. Given that the Circinus galaxy has strong star–formation activity on small and large scales, it is not surprising that this galaxy follows the FIR–radio correlation. Radio observations on arcsec resolution can not easily distinguish between Seyfert and starburst activity. The radio emission from both starburst regions and Seyfert nuclei have similar spectra and morphology, and the steep spectrum of even the compact cores seen in VLA maps of Seyferts suggests that they might contain a significant nuclear starburst component (Norris et al. 1992). On the other hand, long–baseline radio interferometry is sensitive only to compact, high brightness objects and is an ideal tool to discriminate over the two spatial scales. Unfortunately no radio interferometry is available for the Circinus galaxy and we can not clearly determine the nature of the central source from present radio data.

Nevertheless, there is a clear large variation in the predicted L_{NUC}/L_{SB} ratios for Circinus, from starburst-dominated at FIR wavelengths, to AGN-dominated in the near and mid IR. Indeed, NGC1068, the prototypical Seyfert 2 galaxy shows a similar behaviour. The mid–IR(5-16µm) spectrum of NGC1068 is ~85-95% dominated by the AGN, and L_{NUC}/L_{SB} \sim 3. In the FIR however, where extended emission dominates, the nucleus does not contribute more than 25% to the total IR flux at 450µm (Le Floc’h et al. 2001). Clearly, determination of L_{NUC}/L_{SB} is strongly dependent on the spectral region where it is calculated.

Our SED modelling has the advantages over other predictions of having a more complete model for the SED, including the emission of PAH features and a more realistic torus model. Additionally we have used a large set of recently published data, from NIR to mm wavelengths. More importantly, we pay special attention to the fit of data points from the various aperture sizes which give important constraints to the size of the emitting source. The undoubted composite nature of the Circinus galaxy is shown in our IR SED model which predicts a galaxy dominated by the AGN torus at near and mid–IR wavelengths while at far–IR to mm wavelengths the starburst activity is the dominant one.

6 CONCLUSIONS

We can summarise our results as follows:

- The case of the Circinus galaxy provides strong support for the dusty torus model of active galaxies which further support the unification scheme, that is, thick dusty tori with a tapered disc geometry surrounding the central engine.
- Our best fit for the outer radius of the torus in Circinus is ~2pc, but a radius as large as 12pc can not be ruled out.
- We confirm the composite nature of the Circinus galaxy, which is dominated by the AGN torus emission in the near–IR but largely dominated by starburst phenomena in the far–IR and mm wavelengths. The L_{IR} is slightly dominated by the starburst emission and the ratio L_{NUC}/L_{SB} \sim 0.8.

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