Mon. Not. R. astr. Soc. (1991) **250**, 138–143

Detection of an [O III] $_{\lambda 5007}$ radiation cone in the nuclei of NGC 1365 and 7582

Thaisa Storchi-Bergmann* and Charles J. Bonatto*

Instituto de Física, Universidade Federal do Rio Grande do Sul, Campus do Vale, CP 15051, CEP 91500, Porto Alegre, RS, Brasil

Accepted 1990 December 10. Received 1990 November 23; in original form 1990 August 29

SUMMARY

Using narrow-band imagery, we have detected a cone of radiation in the [O III]$_{\lambda 5007}$ line in the nuclei of NGC 1365 and 7582 with emission directed, respectively, towards the south-east and south-west. Adopting a distance of 20 Mpc to NGC 1365 and 21 Mpc to NGC 7582, with $H_0 = 75$ km s^{-1} Mpc^{-1} the projected dimensions of the cones are about 1.0×1.5 and 1.9×1.6 kpc, respectively. The presence of these cones had been previously suggested on the basis of images obtained with the TAURUS Fabry–Perot interferometer and spectroscopic observations, and can be clearly seen in our images after the subtraction of the continuum emission. These observations are new examples of cone morphologies of high-excitation gas previously found in other Seyfert 2 galaxies. The analysis of the available data on NGC 1365 and 7582 favours the so-called 'unified AGN models'.

1 INTRODUCTION

As part of an ongoing study of the emission gas structure in the nucleus of nearby Seyfert 2 galaxies we have obtained narrow-band images of the galaxies NGC 1365 and 7582. NGC 1365 is a giant barred SBb-c galaxy in the Fornax cluster with a nuclear region containing a Seyfert nucleus (Edmunds & Pagel 1982), dust lanes and bright hotspots, and has been studied by several authors (Sérsic & Pastoriza 1965; Phillips *et al.* 1983, hereafter PTEP, and references therein). The relative intensities of the emission lines of NGC 1365 are typical of a Seyfert 2 galaxy, although Véron *et al.* (1980) have found a broad component in Hα suggesting that this galaxy could have a hidden Seyfert 1 nucleus. NGC 7582 is a highly inclined barred SBab(rs) spiral galaxy with a composite nuclear emission spectrum indicating the presence of both power-law and hot star photoionization; it also presents X-ray emission (Morris *et al.* 1985).

Using long-slit spectroscopy on NGC 1365, PTEP have shown that the [O III]$_{\lambda 5007}$ line presents a strong off-nuclear component, blueshifted by 300 km s^{-1} relative to the nuclear emission in the direction of the minor axis of the galaxy. The presence of a weaker red component has led to a possible interpretation of the data on the basis of a conical ejection model. Using the TAURUS imaging Fabry–Perot interferometer (Taylor 1978; Atherton *et al.* 1982), Edmunds, Taylor & Turtle (1988) have shown that the [O III]$_{\lambda 5007}$ emitting gas in NGC 1365 extends smoothly over the whole nuclear region. Our data show a similar emission structure in the [O III] image before the continuum subtraction. Nevertheless, after the subtraction a very clear cone-shaped structure can readily be seen, in agreement with the model suggested by PTEP.

NGC 7582 was also observed with TAURUS (Morris *et al.* 1985) when it was noted that the [O III] velocity field is different to that of Hα, and that the [O III] profiles present a uniform blueshift of about 100 km s^{-1}. They propose a model comprising an H II region disc responsible for the Hα emission with a conical outflow of a high-excitation gas emitting [O III]. Again our pure [O III] image shows the proposed conical structure.

*Visiting Astronomer at Cerro Tololo Inter-American Observatory.

2 OBSERVATIONS AND REDUCTIONS

The images of NGC 1365 and 7582 were obtained at the CTIO's 91-cm telescope on 1989 August 17–19, using the TI2 CCD with an image-scale of 0.494 arcsec per pixel. Observations of each galaxy were made through narrow-band interference filters centred on the redshifted [O III]$_{\lambda 5007}$ and Hα + [N II]$_{\lambda\lambda 6548,84}$ lines and the corresponding continua. Details regarding the observations, filters, and integration times are given in Table 1. Flat fields were obtained for each filter used.

We would like to point out that Véron *et al.* (1980) have found a broad Hα component in the nuclear spectrum of NGC 1365 whose wing could be present in our continuum filter. Nevertheless the broad Hα component has FWHM ≈ 35 Å and a low peak intensity centred at λ6600. Thus its contribution to our continuum filter centred at

Table 1. Log of observations.

Galaxy	Date	Exp.Time(s)	No.Exp.	Filter/Width(Å)	Seeing(")
NGC1365	17-18	600	1	5032/15	1.7
NGC1365	17-18	900	2	5032/15	1.7
NGC1365	17-18	900	1	5400/100	1.7
NGC1365	18-19	600	2	6520/75	2.1
NGC1365	18-19	600	2	6600/110	2.1
NGC1365	18-19	600	2	5032/15	2.1
NGC1365	18-19	600	1	5400/100	2.1
NGC7582	17-18	900	2	5032/15	1.7
NGC7582	17-18	900	1	5400/100	1.7
NGC7582	17-18	900	1	6520/75	1.7
NGC7582	17-18	900	1	6600/110	1.7

Notes. Column 4 gives the number of exposures. Column 5: width corresponds to the FWHM transmission.

λ6520 with a FWHM transmission of 75 Å should be negligible and does not affect our conclusions.

Data reduction was performed with the IRAF package. All the frames were corrected for DC electrical offset obtained from an overscan region of the chip and were bias subtracted. Each frame was divided by a normalized dome flat field, and had the bad pixels replaced by an average value from the neighbouring pixels. The data were corrected for atmospheric extinction using the CTIO average extinction curve. We then aligned all the frames using field stars as reference points and then individual integrations for each filter were averaged (according to each frame's integration time) to produce the final frames. We then subtracted the sky contribution. Because the point-spread function (PSF) varies for each filter, we measured the PSF for each pair of continuum and continuum + emission frames. Then we convolved the frames with the narrower PSF with a circular Gaussian having a FWHM such that the resulting PSF was equal to the broader one. Before the subtraction the continuum frame was scaled as follows: for each field star we calculated the count ratio in the continuum and the continuum + emission frames; the final scale factor was determined as the average ratio for all stars.

3 RESULTS

3.1 NGC 1365

We show in Fig. 1 the images obtained on the first night, when we could only observe NGC 1365 with the [O III] filters. Fig. 1(a) presents the continuum subtracted [O III] (pure emission) frame and Fig. 1(b) the corresponding continuum frame. On the second night, we again observed with the [O III] filters and also with the Hα filters. The corresponding frames are shown in Figs 2 and 3: Fig. 2(a) presents the pure emission Hα frame, Fig. 2(b) the Hα continuum frame, Fig. 3(a) the pure emission [O III] frame, and Fig. 3(b) the [O III] continuum frame. The most external isophotes plotted correspond to a 2σ level above the residual 'sky' (actually the sky has been already subtracted). It can be seen that the [O III] images obtained on the first night have a better signal-to-noise ratio than those obtained on the second night.

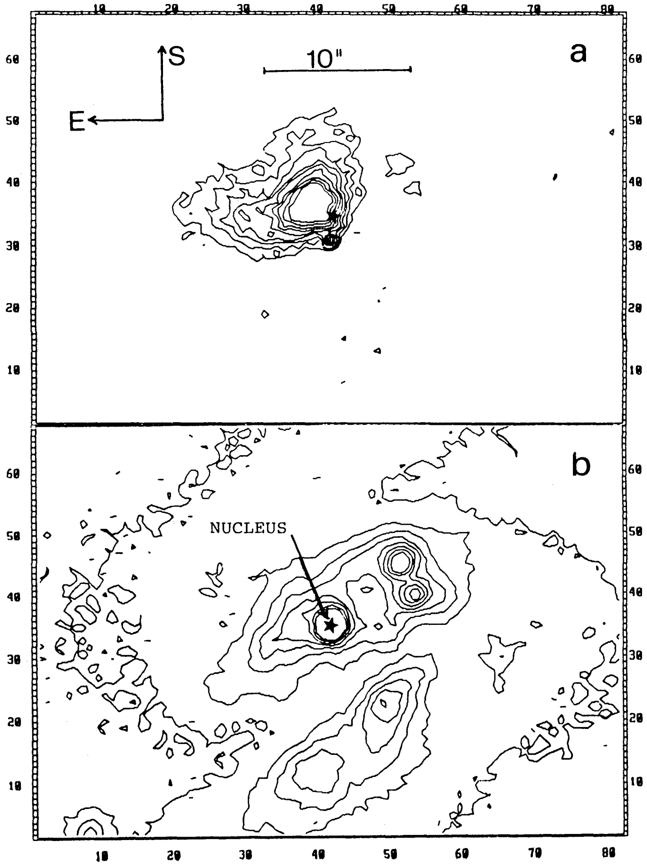

Figure 1. (a) Contour map of the N1365 continuum-subtracted [O III] frame obtained on the first night; contours in counts, from 11 to 78 per cent of maximum value, step 7 per cent. (b) [O III] continuum frame contoured from 9 to 54 per cent of maximum value, step 5 per cent; x and y scale in pixels. The centre of the nuclear emission of the continuum frame is indicated in both frames by a star symbol. The small knot at the 'vertex' of the cone in (a) is due to a cosmic ray hit.

In the Hα pure emission frame (Fig. 2b) as well as in the Hα and [O III] continuum of the first night, several structures can be easily identified: the nucleus, the hotspots, the dust lane, and the northern H II region complex (Edmunds & Pagel 1982). The centre of the nuclear emission (represented by a star symbol in the figures) coincides in these three frames, as well as the position of the other structures mentioned above. On the [O III] frame of the first night, we see traces of the hotspots, whose emission centres coincide with those of the other frames. At the 1σ level it is also possible to see traces of emission from the northern H II complex. Nevertheless, the bulk of the pure [O III] emission presents a different structure: the centre of the emission does not coincide with the previous nucleus, being displaced towards the south-east by 1.5 arcsec (projected distance 150 pc at the galaxy); the isophotes accumulate towards the north-west and present a cone-shaped form, which can be seen in both (first and second nights) pure [O III] frames. This structure is not present in the pure Hα and continuum frames. The dimensions of this structure at the 2σ level, adopting a dis-

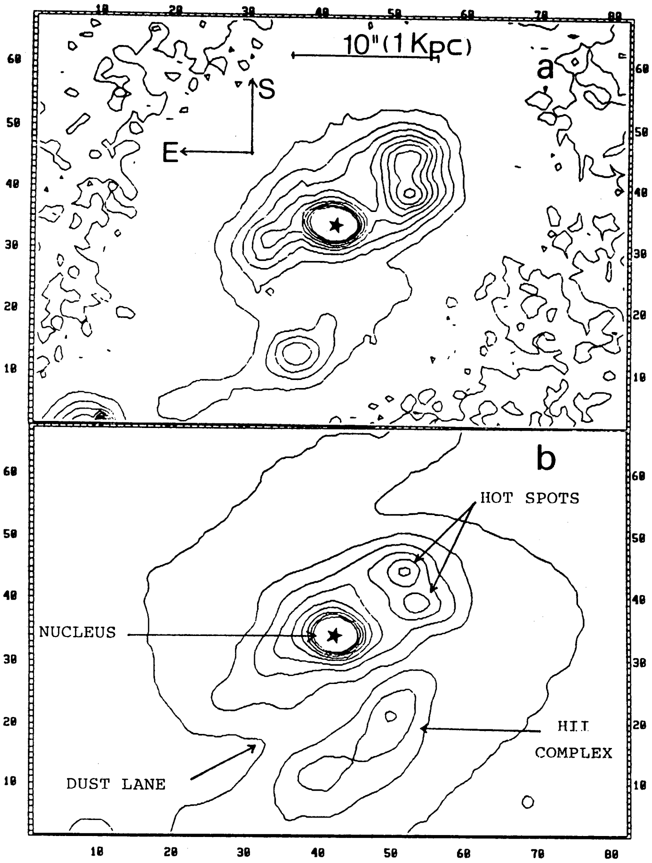

Figure 2. (a) Contour map of the N1365 continuum-subtracted Hα frame, in counts, from 1 to 37 per cent of maximum value, step 4 per cent. (b) Hα continuum frame contoured from 1 to 46 per cent of maximum value, step 5 per cent; x and y scale in pixels. The centre of the pure Hα nuclear emission is indicated in Figs 2 and 3 by a star symbol.

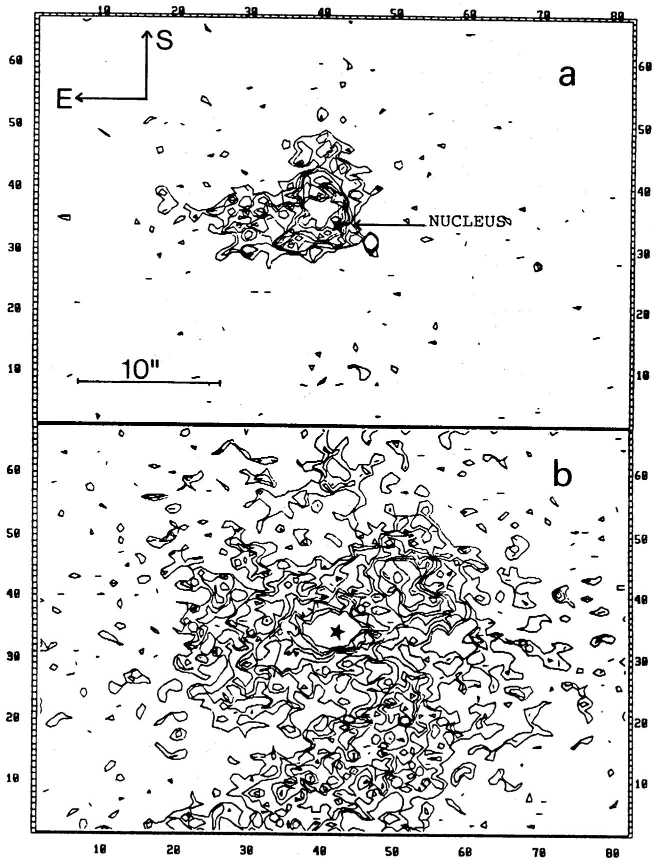

Figure 3. (a) Contour map of the N1365 continuum subtracted [O III] frame obtained on the second night; contours in counts, from 19 to 67 per cent of maximum value, step 8 per cent. (b) [O III] continuum frame contoured from 15 to 57 per cent of maximum value, step 6 per cent; x and y scale in pixels.

tance of 20 Mpc to the galaxy (PTEP), are 1.5 kpc in the east–west direction and 1 kpc in the north–south direction.

In order to better demonstrate the distribution of the [O III] emission we have constructed a three-dimensional plot which is shown in Fig. 4 with the counts on the vertical axis.

One way to interpret our data together with the results of PTEP is using their model. Thus NGC 1365 presents a high-excitation gas outflow emitting mostly in [O III]. The geometry of the emission is that of a hollow cone which we are seeing partially from the top.

3.2 NGC 7582

The images of NGC 7582 are shown in Figs 5 and 6: Fig. 5(a) shows the pure [O III] emission frame, Fig. 5(b) the [O III] continuum, Fig. 6(a) the pure Hα emission frame and Fig. 6(b) the corresponding continuum. Again, the outermost isophotes correspond to 2σ level.

As in the case of NGC 1365, the centre of the emission coincides in all frames except in the [O III] pure emission one. In this frame, all the emission is displaced towards the south-west, the emission centre being displaced by 0.7 arcsec (projected distance 71 pc at the galaxy) with respect to the other frames. The isophotes accumulate towards the north-east

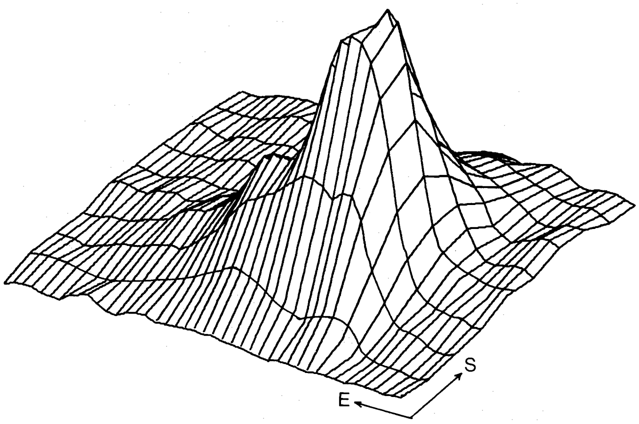

Figure 4. Smoothed three-dimensional representation of the NGC 1365 isophotal map of Fig. 1(a). Vertical scale in counts with bottom at zero and top at 234.

and a very similar conical structure to that found in NGC 1365 can be readily seen, with dimensions at the 2σ level of 1.6 kpc in the east–west direction and 1.9 kpc in the north–south direction. A comparison between the shapes of the internal isophotes in the pure Hα and the corresponding

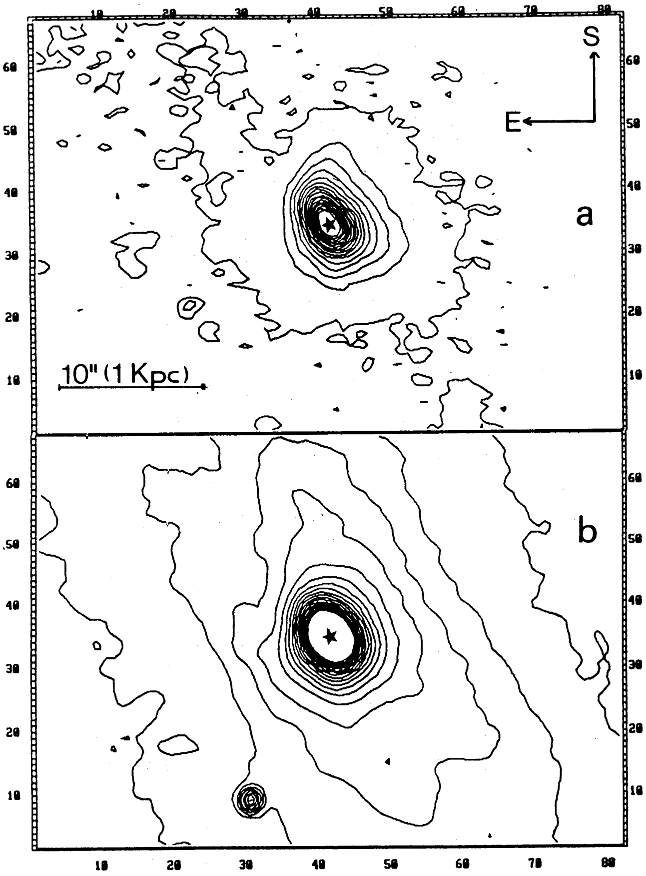

Figure 5. (a) Contour map of the N7582 continuum subtracted Hα frame in counts, from 1 to 81 per cent of maximum value, step 5 per cent. (b) Hα continuum frame contoured from 1 to 45 per cent, step 2 per cent; x and y scale in pixels.

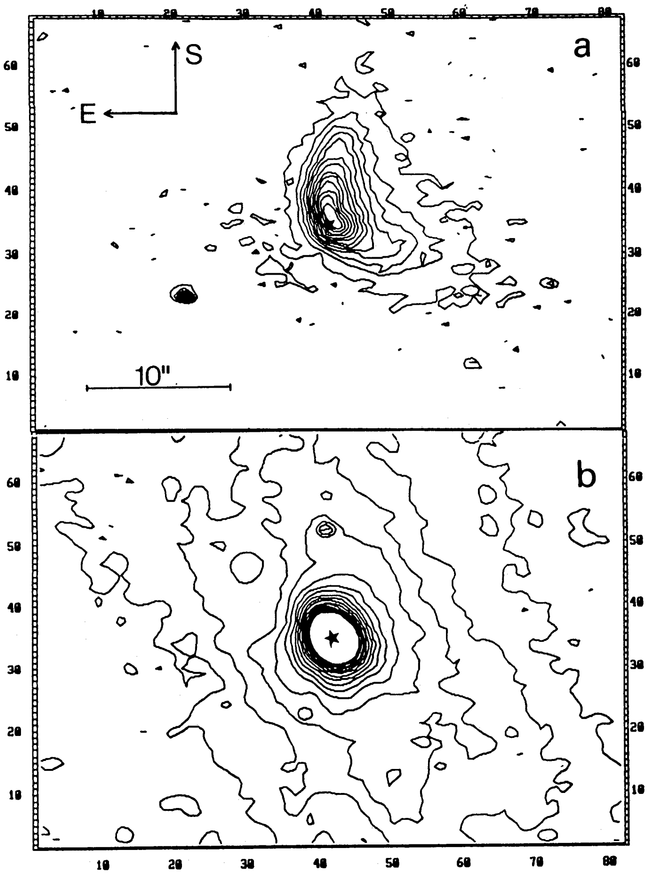

Figure 6. (a) Contour map of the N7582 continuum subtracted [O III] frame in counts, from 4 to 88 per cent of maximum value, step 7 per cent. (b) [O III] continuum frame contoured from 1 to 37 per cent of maximum value, step 2 per cent; x and y scale in pixels.

continuum shows that the first are more elongated and present a slight accumulation towards the north-east, giving a hint of the conical structure present in the pure [O III] frame. This indicates that the cone also emits in Hα, although the conical structure is less evident because the nucleus and surroundings also emit strongly in this line.

We have also constructed a three-dimensional plot of the pure [O III] emission with counts on the vertical axis, which is shown in Fig. 7.

Our data together with kinematic and spectroscopic information showing that the [O III] gas is blueshifted indicate that NGC 7582 presents an outflow of high-excitation gas. This gas outflow has a cone-shaped structure which we are viewing at a grazing angle to its external wall in agreement with the model by Morris *et al.* (1985).

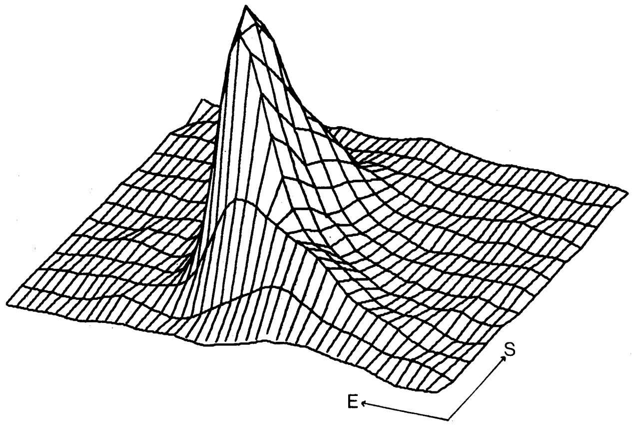

Figure 7. Smoothed three-dimensional representation of the NGC 7582 isophotal map of Fig. 6(a). Vertical scale in counts with bottom at zero and top at 438.

4 DISCUSSION

Previous works involving narrow-band imaging of Seyfert galaxies have found elongated emission structures in the nuclear region. In particular Haniff, Wilson & Ward (1988) have found an alignment between the direction of the radio and emission-line axes for a sample of 10 Seyfert galaxies. Conical structures have been found through the construction of excitation maps obtained by dividing the [O III] frame by the Hα frame (Pogge 1988a) for a number of galaxies: NGC 1068 (Pogge 1988a), NGC 4388 (Corbin, Baldwin & Wilson 1988; Pogge 1988b), NGC 5252 (Tadhunter & Tsvetanov 1989; Haniff, Ward & Wilson 1991), NGC 5728 (Schommer *et al.* 1988; Pogge 1989), Mkn 573 and possibly NGC 2110 (Haniff *et al.* 1991).

These findings support the so-called 'unified models' of

AGN in which a Seyfert 1 nucleus and a broad-line region would also be present in Seyfert 2 galaxies but hidden by a thick accretion torus (Antonucci & Miller 1985). Biconical radiation fields would be produced either through collimation by the torus walls or if the central source is intrinsically anisotropic. As an alternative they suggest that a plasma jet forms a channel through which the radiation from the central engine escapes along a cone, possibly reaching great distances (e.g. NGC 5252 and 4388).

Our observations of NGC 1365 and 7582 give further support for the above models. The conical structure for both galaxies is clearly seen in the continuum-subtracted images without having to construct excitation maps. This means that in these galaxies the bulk of the [O III] emission comes from the high-excitation gas which is confined to the conical structures.

The kinematics of the central region studied in previous works and described in the introduction shows that the gas is outflowing along the cones thus indicating that not only radiation but also matter is being collimated. The presence of gas motions could lead to shock ionization, but the optical spectrum of both galaxies (Ward *et al.* 1980; Diaz, Pagel & Wilson 1985; Edmunds & Pagel 1982) do not show any clear evidence of this process. Instead the line ratios favour photoionization by a power law. This seems to be the case in other Seyfert galaxies with anisotropic [O III] morphologies (Wilson, Ward & Haniff 1988, hereafter WWH).

The presence of beaming in NGC 1365 and 7582 is obvious through our pure [O III] images and previous kinematic studies. In more distant, less spatially resolved galaxies, one way to check the beaming hypothesis is through comparison between the power in optical–ultraviolet continua available to heat dust ($L_{\rm H}$), and the thermal luminosity of the nuclear infrared source ($L_{\rm IR}$). In general it is found that $L_{\rm IR} \geq L_{\rm H}$ suggesting that part of the radiation heating the dust is not observed (WWH).

We have followed the procedures outlined in WWH to estimate $L_{\rm H}$ and $L_{\rm IR}$ in order to check if this indeed occurs in NGC 1365 and 7582. Flux densities at 60 and 100 μm were taken from the IRAS *Point Source Catalogue* (1985) and used to calculate $L_{\rm IR}$; $L_{\rm H}$ was calculated integrating a power-law spectrum ($F_\nu \propto \nu^{-\alpha}$) beween 0.01–1 μm. For NGC 1365 we have used the results from a spectroscopic study by Edmunds & Pagel (1982) in which it is concluded that in order to reproduce the ratio He II$_{\lambda 4686}$/Hβ and the equivalent width of Hβ the slope α of the ionizing continuum should be ≈ 1.5, and with a value of the reddening corrected continuum at λ4681 of 3.2×10^{-14} erg cm^{-2} s^{-1} Å^{-1}. For NGC 7582 we have taken $\alpha = 1.5$ and the Hβ continuum as 1.2×10^{-14} erg cm^{-2} s^{-1} Å^{-1} from the spectroscopic study of Ward *et al.* (1980). We found for NGC 1365 $L_{\rm IR}/L_{\rm H} = 11$, and for NGC 7582 $L_{\rm IR}/L_{\rm H} = 13$, showing that the above hypothesis is confirmed in these galaxies. However, part of the 60 and 100 μm emission may come from extra-nuclear regions, but even assuming a 50 per cent extra-nuclear contribution to $L_{\rm IR}$ the ratios would still be $\geqslant 5$, not changing the conclusion.

5 CONCLUSIONS

In this paper we have analysed narrow-band [O III] and Hα + [N II] images of the galaxies NGC 1365 and 7582. The subtraction of continuum emission from the [O III] frames revealed the presence of a cone-shaped structure in the pure [O III]$_{\lambda 5007}$ frames in both galaxies. In NGC 7582 there is also a hint of the cone structure in Hα. This emission seems to have a vertex centred at the nucleus of the host galaxy but which is hidden due to its orientation. Our observations together with previous kinematic and spectroscopic ones, clearly show that high-ionization gas is being ejected from the nuclei of NGC 1365 and 7582 with a cone-shaped geometry.

We have used the far-infrared luminosity of both galaxies to show that the dust in the nuclear region is exposed to more continuum radiation than that directly observed, thus favouring beaming and/or partial obscuration of the radiation field.

Our work gives further support to the 'unified AGN models' proposed in previous studies in which elongated emission structures of high-excitation gas were found in the nuclear region of some Seyfert galaxies. In particular, our observations of NGC 1365 and 7582 add new data on objects with anisotropic radiation fields and are clear examples of a cone-shaped geometry, favouring models with radiation beaming and gas outflow that could be accelerated by plasma jets. It would be interesting to check the presence of these jets through high-resolution radio observations of these galaxies.

ACKNOWLEDGMENTS

We would like to acknowledge the hospitality of the CTIO Observatory and CTIO's Director Dr R. Williams. We also acknowledge the support of the CTIO's staff during the observations and data reduction, and the valuable help of H. Schmitt in the frame manipulation. We also thank an anonymous referee for valuable suggestions that helped to improve the paper. This work was supported by the Brazilian institutions FAPERGS and CNPq.

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