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Extranuclear [O III] in IR excess Seyfert galaxies [★]

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Summary. Strong extranuclear [O III] emission has been detected in two out of a sample of 10 IRAS-detected Seyferts. One exhibits one-sided emission, the other S-shaped two-sided emission reminiscent of radio galaxies.

Key words: galaxies: active – galaxies: compact – galaxies: Seyfert – infrared radiation

1. Introduction

The Narrow Line Region (NLR) of Seyfert galaxies has a physical extent of typically a few hundred parsecs. In most Seyferts the NLR is therefore unresolved except in a few nearby cases, e.g. NGC 5929 (Keel, 1985; Whittle et al., 1986), NGC 2110 (Wilson and Baldwin, 1985), NGC 1068 (Meaburn and Pedlar, 1986), NGC 1365 (Phillips et al., 1983a).

In a few exceptional cases narrow-line emission has been detected from much larger regions extending over 5 kpc or more, e.g. NGC 7469 (De Robertis and Pogge, 1986), Mkn 509 (Phillips et al., 1983b), Mkn 335 (Heckman and Balick, 1981), indicating ionization of (part of) the gaseous disk of the galaxy. The observed structures of extended emission line regions (EELRs after Fosbury, 1986) are more likely density-limited than radiation-limited. The presence, size and luminosity of EELRs is in most cases not just a function of the nuclear luminosity but several unknown geometrical factors also play a rôle. Most of the galaxies with large extranuclear emission line regions are also strong infrared emitters, probably due to reradiation from heated dust which is in thermal equilibrium with the (ionized) gas.

Turning the argument around, a high infrared luminosity could in some cases indicate such a favourable geometry and possibly by selecting infrared-luminous Seyferts there will be a higher probability of finding a very extended emission line region.

Recently de Grijp et al., 1985 developed a new technique to find active galaxies based on their relatively flat IR spectra. His subsample of “warm” sources was selected from the Infrared Astronomical Satellite (IRAS) Point Source catalog by demanding a flat spectrum between the nominal 25 and 60 μm flux densities ($-1.5 < \alpha < 0.0$ where α is the spectral index using the convention $F_\nu \propto \nu^\alpha$) and excluding sources at low galactic latitude ($|b| < 20^\circ$; to minimize contamination with galactic sources) and

those near the Magellanic Clouds (to minimize confusion). A total of 563 sources was selected of which 75% is expected to be active galaxies as only for a part of the sample spectra have been obtained (de Grijp et al., 1987).

A homogeneous subsample of those IR-excess active galaxies was selected by requiring a compact appearance on POSS plates (in many cases surrounded by very faint fuzz) and strong nuclear narrow-line emission. In this way the large disk-dominated galaxies with significant star formation (relatively frequent in IR-surveys) are eliminated. They are inconspicuous in the optical (i.e. having a high IR/opt ratio) and therefore likely to be missed by other techniques searching for Active Galactic Nuclei (AGN).

One of the aims was to find out whether the surrounding fuzz consists of emission-line gas similar to the gas clouds surrounding some QSOs (Stockton and MacKenty, 1987).

The compact IRAS Seyferts, selected also on observability from the European Southern Observatory (ESO) ($\delta < 20^\circ$), do not form a complete sample (as the list of warm IRAS sources itself is not a complete sample) but, hopefully, a representative one. Out of a total of 70 confirmed compact AGN a subset of 10 galaxies has been observed. For six objects faint fuzz is visible on the POSS plate. All have infrared fluxes at 60 μm between 0.5 and 1.5 Jy and, probably as a result of the selection criteria, all are at a redshift near 0.05 (see Table 1).

2. Observations

The observations were done at ESO, La Silla, Chile in January 1986 using the ESA PCD (Photon Counting Detector, di Serego Alighieri et al., 1985) in direct imaging mode on the 2.2 m telescope. The PCD is troubled by a flux- and position-dependent total efficiency resulting in a large uncertainty in the absolute fluxes (of about 50%). The reduction procedure has been described by van Heerde (1988a). The adopted flux calibration procedure makes use of the field stars present in the observed frame: under the assumption of a flat spectrum over the usually small wavelength range between line and continuum filter the average line-to-continuum flux ratio of the field stars can be used as a correction factor. This factor is indicated in the notes to Table 1.

Also present are small flux dependent variations in the point spread function causing ambiguous results when trying to subtract continuum images: even when there is no extended line emission some spurious emission features might emerge when the continuum image has been subtracted. Vice versa, slightly ex-

[★] Based on observations collected at the European Southern Observatory, La Silla, Chile

Table 1

Designation	Type	z	Filter	T	f_{total}	$f_{[\text{O III}]}$	F	$\log L$	Comments
0135–131	S2	0.040	5200/91 5359/88	1800 1800	10200 4700	5500	58	42.6	$R > 110$
0226–390	H2	0.048	5263/38	1800	23700	—	—	—	—
0412–080 ^a	S1	0.039	5191/39 5284/27	1800 1800	63900 6600 ^b	57300	350	43.4	P.A. = 152°
0444–052	S1	0.044	5232/34 5306/36	1800 900	1880 1400	480	2.0	41.2	$R > 20$
0521–122	S1	0.049	5263/38 5335/39	1800 1800	27100 3900	23200	120	43.1	$R > 640$
0827–027 ^c	S2	0.041	5200/91 5359/88	1800 1800	6100 1700	4400	47	42.5	$R > 180$
1105–115	S2	0.055	5284/27 5448/40	1800 1800	21500 2400 ^d	19100	70	43.0	P.A. = 16°, 213°
1246–111	S2	0.048	5263/38	1800	17500	—	—	—	—
1254–301 ^e	S2	0.055	5284/27 5448/40	3300 1800	2200 900	1300	4.6	41.8	$R > 30$
1351–375 ^f	S1	0.052	5263/38	1800	16900	—	—	—	—

^a Also 1E. ^b Multiplied by 1.13. ^c Also ZG. ^d Multiplied by 0.83. ^e Guiding problems. ^f Also TOL

tended emission line regions might disappear after continuum subtraction. Detailed profile comparisons would therefore not yield any conclusive information. As a result only fairly conspicuous EELRs can be considered real.

All ten objects were observed through a narrow-band filter centred on [O III] λ 5007; of seven objects also an emission-line free continuum exposure was obtained. The total field-of-view is about 3' (512 pixels each 0".293 in size). A summary of the observations can be found in Table 1 which is organized as follows:

- Column 1: object designation, the prefix IRAS has been omitted
- Column 2: object type: S1 (Seyfert 1), S2 (Seyfert 2), H2 (extragalactic H II region)
- Column 3: redshift
- Column 4: filter used: central wavelength/bandwidth, (both in Å). The upper line gives the line filter, the lower, if present, the continuum filter
- Column 5: total integration time in seconds
- Column 6: total observed flux density in mJy (1 mJy = 10^{-26} ergs cm⁻² s⁻¹ Hz⁻¹)
- Column 7: pure flux density of the [O III] emission averaged over the line filter (the difference between line and continuum fluxes) in mJy
- Column 8: integrated [O III] flux in 10^{-14} ergs cm⁻² s⁻¹
- Column 9: logarithm of the [O III] luminosity (for $H_0 = 50$ and $q_0 = 0.5$)
- Column 10: comments listing either the position angle indicating the direction of the strongest extranuclear emission or the ratio R of the nuclear to the very extended extranuclear emission.

3. Results

Most objects appeared unresolved after typical integration times of 30 min. For three objects no continuum image has been obtained. Five objects showed only the strong nuclear [O III] emission that was a condition for inclusion in the sample but no unambiguous sign of extranuclear emission was detected. The only firm statement that can be made is that there is no significant [O III] emission (surface brightness above ~ 21 mag/arcsec) beyond ~ 2 kpc from the nucleus. This holds for 80% of the objects. A lower limit to the ratio of nuclear to very extended extranuclear emission can be estimated and is given in Table 1 for the non-detections. This ratio depends mainly on the pure [O III] flux and the background noise and is obtained by calculating the limiting flux that could be detected in an area with a radius of 10 kpc around the nucleus (excluding the central area with a radius of 2 kpc). Obviously less extended emission in, e. g., an object like IRAS 0412-080 but less luminous could be missed and still the ratio of nuclear to extranuclear flux could be below the lower limit listed in Table 1!

The situation is quite different for the remaining two objects, IRAS 0412-080 and IRAS 1105-115 which will be discussed separately below.

4. IRAS 0412-080

This Seyfert 1 galaxy shows an extension or “jet” toward the SW about 8.5 or 9 kpc long (for $H_0 = 50$ km s⁻¹ Mpc⁻¹ which is used throughout) (Fig. 1). The much weaker continuum image (Fig. 2) is almost unresolved although at the position of the jet very weak emission could be present. The jet is rather similar to the [O III]

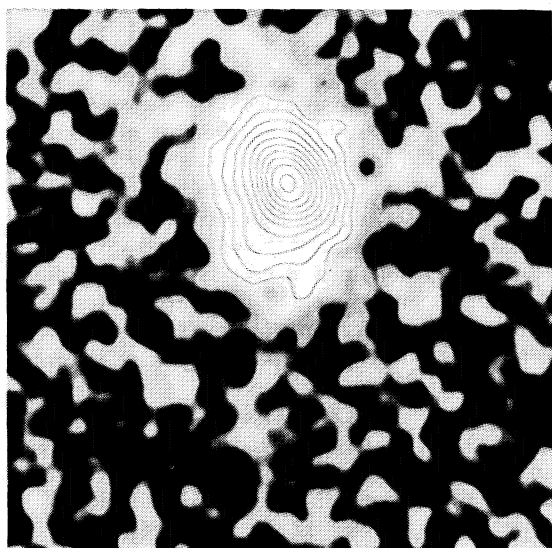


Fig. 1. IRAS 0412–080 pure (continuum subtracted) [O III] image. The field measures $30''$ (or 32.2 kpc) on a side. North is up, east is to the left. Contour levels are at 1, 2, 4, 8, 16, 32, 64, 128, 256, and $512 \mu\text{Jy/pix}$ ($1 \mu\text{Jy/pix}$ corresponds to a surface brightness of $11.6 \cdot 10^{-29} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Hz}^{-1} \text{ arcsec}^{-2}$ or $21.2 \text{ mag arcsec}^{-2}$). Gray scales emphasize the noise (black is zero flux and 8 shades of gray are roughly logarithmically spaced between zero and the lowest contour level)

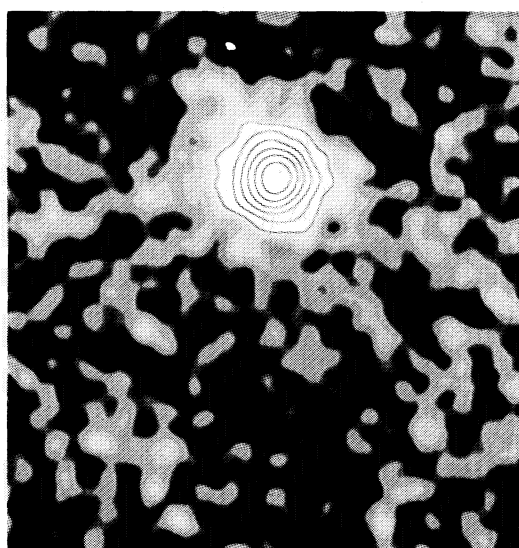


Fig. 2. IRAS 0412–080 continuum image. Highest contour level is at $32 \mu\text{Jy/pix}$. Further as Fig. 1

extension in X 0459 + 034 (van Heerde, 1988 b) although in IRAS 0412–080 no counter feature is present (possibly obscured by the disk of the galaxy).

5. IRAS 1105–115

This is clearly the most interesting object (a Seyfert 2 galaxy) in the present sample. Apart from the strong nuclear emission there are prominent extensions toward the NE and the SW (Fig. 3) the NE extension being the brighter of the two and almost as bright as the nucleus. The estimated extranuclear-to-nuclear flux ratio is ~ 2 .

A closer inspection of the brightness distribution reveals an inner S-shaped structure which does not fall off in brightness away from the nucleus but seems to be almost “edge-brightened” (Fig. 4). A separate blob to the SW is probably an H II-region unrelated to the large-scale structure. The largest diameter of the [O III] emitting region is $9''.2$ or 13 kpc; the size of the inner S-shaped structure is $3''.5$ or 5 kpc.

Continuum emission at the location of the extensions is hardly detectable above the noise (see Fig. 5). Since spontaneous star formation exactly straddling the nucleus is not very likely and the [O III] structure is rather reminiscent of giant radio galaxies, collimated energy emanating from the nucleus is likely to be responsible for the S-shaped structure. A somewhat similar case (NGC 5929), although on a much smaller scale, has been reported by Keel (1985) and by Whittle et al. (1986).

The weak radio emission (2.3 mJy at 6 cm, de Grijp, private communication) is expected to be extended and aligned with the [O III] emission (compare, e. g., Wilson, 1987).

Since the nuclear spectrum (the aperture used includes most of the extensions) shows narrow single-peaked [O III] profiles (de Grijp et al., 1988) the projected velocity difference between nucleus and extensions must be small, i. e. any motion, if present,

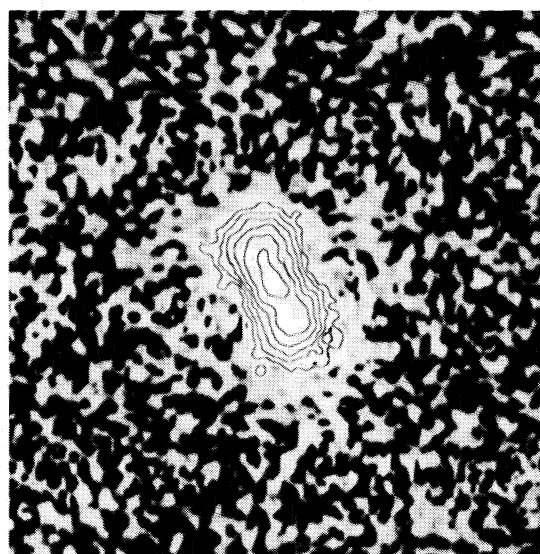


Fig. 3. IRAS 1105–115 pure [O III] image. The image measures $30''$ (or 42.9 kpc) on a side. North is up, east is to the left. Contour levels are at 4, 8, 16, 32, 64, and $128 \mu\text{Jy/pix}$. Further as Fig. 1

must occur in the plane of the sky. A possible explanation for the observed structure is some kind of interaction between “jets” and the rotating disk of the galaxy (seen face-on).

If the model proposed by Pedlar et al., 1985 is valid (interaction of radio plasmons with the ambient medium) high-resolution imaging by HST will provide detailed data on the distribution of the line emitting shells.

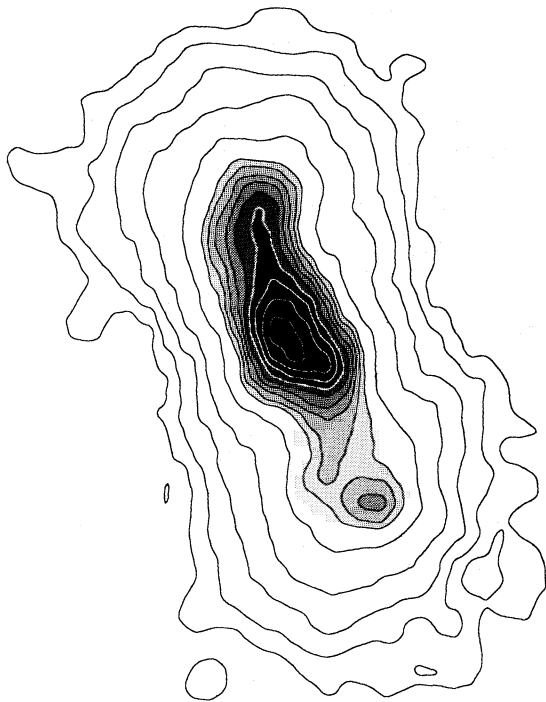


Fig. 4. IRAS 1105–115 pure [O III] image. The image measures $10''$ (or 14.3 kpc) on a side. North is up, east is to the left. The outer contours are as in Fig. 3. The inner two contours from Fig. 3 (above $64 \mu\text{Jy/pix}$) have been filled in with finer contours separated by shades of gray to emphasize the inner structure. The inner levels are at 90, 100, 110, 120, 130, 140, 150, 160, and $170 \mu\text{Jy/pix}$

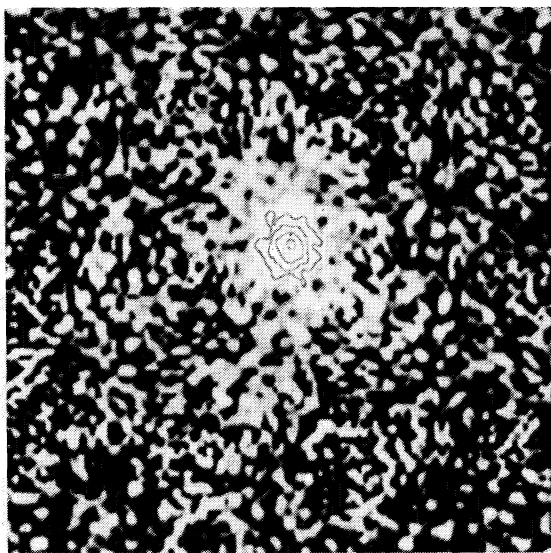


Fig. 5. IRAS 1105–115 continuum image. Highest contour is at $32 \mu\text{Jy/pix}$. Further as Fig. 3

6. Conclusions

In a sample of 10 compact IR-excess Seyfert galaxies detected through their IRAS colours two galaxies showed clear extranuclear line emission which, in spite of the presence of strong IR emission, is not a common feature. One galaxy showed one-sided emission, the other S-shaped two-sided emission. For neither of them the POSS plate showed any sign of surrounding fuzz: drowned in the sky background. For the six objects where some surrounding fuzz was visible it must necessarily be continuum emission as any significant amount of line emission would be prominent in the narrow filters used. Evidently the presence of surrounding fuzz on POSS plates is no good indicator of extranuclear line emission.

The fact that both are compact galaxies could imply that the active nucleus has a relatively large influence on the (small) disk of the galaxy. In particular IRAS 1105–115 might prove to be an excellent studying ground to obtain a better understanding of the way the active nucleus influences the ambient medium on relatively large scales.

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