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Discovery of a ring Seyfert in a group of galaxies*

E. Davoust[1], **S. Considère**[2], **and P. Poulain**[1]

[1] Observatoire Midi-Pyrénées, UA 285, 14 Avenue E. Belin, F-31400 Toulouse, France
[2] Observatoire de Besançon, BP 1615, F-25010 Besançon Cedex, France

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Abstract. We report the discovery of a Seyfert galaxy with a large ring in a small group of anonymous galaxies. The Seyfert is of type 2, with a heliocentric redshift of 20226 km s^{-1}. We provide a detailed photometric analysis of five galaxies of the group. The brightest companion, which seems perturbed and connected to the ring, has a 4057 km s^{-1} lower redshift. A comparison is made with 4 other ring Seyferts, all IRAS sources. We speculate that the ring was formed by an external event, possibly a high-velocity encounter, which also triggered the Seyfert activity.

Key words: galaxies: Seyfert, structure of

1. Introduction

We are presently studying the effects of gravitational interactions between pairs of early-type galaxies, and we noticed this anonymous group of galaxies while determining the morphological type of catalogued interacting galaxies by inspection of the *Palomar Sky Survey* prints. This system seemed like a case in point, with what looked like prominent tidal arms protruding from the brightest galaxy and one of its companions. It was thus selected for observation.

The coordinates of the group of galaxies are (equinox 1950):

$\alpha = 0^h21^m30^s$, $\delta = 25°08'$.

It turned out to be an interesting system of galaxies, but for reasons other than those expected. The central galaxy has a Seyfert spectrum and the tidal features are in fact a large ring. Adding this piece of evidence to several recently discovered ring Seyferts (Wakamatsu & Nishida 1987; Hippelein 1989; Pérez et al. 1990; Rodriguez Espinoza & Stanga 1990), we might shed some light on what seems to be a new class of galaxies. Finally, the Seyfert's brightest companion has a very different redshift; it would have been dismissed offhand as a foreground galaxy, were it not for the two other peculiarities of the system.

Send offprint requests to: E. Davoust

* Based on observations obtained at the 2-meter telescope of Observatoire du Pic-du-Midi, and the 1.93-meter telescope of Observatoire de Haute-Provence, both operated by INSU (CNRS).

2. Observations and reduction

Three CCD images of the anonymous group of galaxies A 0021 + 25 were obtained at the Cassegrain (F/10) focus of the 2-meter telescope of Observatoire du Pic du Midi. Two 20-min exposures in V and R were obtained on Sept. 27, 1989, in good seeing (FWHM = 1''.10 and 0''.97 in V and R respectively), with a 512 × 323 RCA CCD (pixel size: 0''.324). One 30-min exposure in R was obtained on Sept. 18, 1990 under average seeing conditions (FWHM = 1''.40), with a 576 × 380 Thomson CCD (pixel size: 0''.248). The R band is that of the Kron-Cousins system.

The zero-point of the magnitude scale on our CCD images could not be determined in the usual way, with published aperture photometry. Instead, we determined a mean (instrumental intensity to magnitude) conversion factor per unit exposure time for a given night and filter, using all the CCD frames that could be calibrated by aperture photometry. This zero-point is thus rather uncertain, by at least 0.20 mag.

Two spectra of the galaxy were obtained at the Cassegrain focus of the 1.93-meter telescope of Observatoire de Haute-Provence, using a 512 × 323 RCA CCD and the CARELEC spectrograph (Lemaitre et al. 1990). A 1-hour spectrum was obtained on August 4, 1989, with a dispersion of 130 Å mm^{-1}. The slit width was 2''.5, the spectral range 4770–6720 Å, and the pixel size 4 Å × 1''.31. A second spectrum, also a 1-hour exposure, was obtained on Dec. 1, 1989 at a higher dispersion of 66 Å mm^{-1}, slit width 2''.5, spectral range 4720–5730 Å, and pixel size 2 Å × 1''.31. For both spectra, the slit was placed along a line crossing the nuclei of the two brightest galaxies in the field, the Seyfert and G2, in p.a. 30°.

Spectra of several K0III stars were also obtained, to be used as templates. The reduction of the spectra was done using the ESO-IHAP procedures on an HP computer.

3. Photometric analysis

The Seyfert galaxy is in the center of a small group of galaxies shown on the grey-scale map of Fig. 1 and on the isophote map of Fig. 2. This is a fairly isolated system at high galactic latitude ($b_{II} = -37°$). The closest catalogued galaxy, Z 479.026, is at 15' (= 1.2 Mpc at the assumed distance of the Seyfert galaxy). The Seyfert is the bright galaxy in the center of the image; it is surrounded by seven fainter companions (see Table 1), a bright

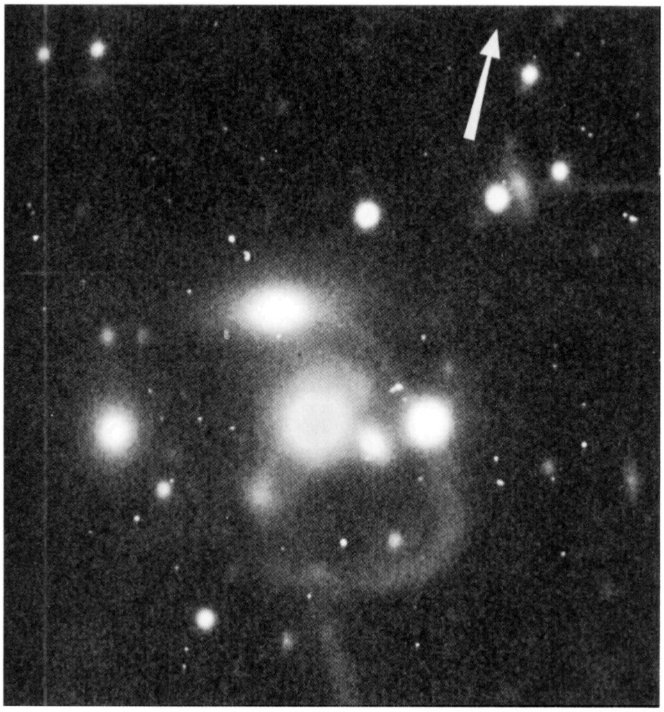

Fig. 1. Grey-scale map of A 0021 + 25 (R band, 30-min exposure). The Seyfert galaxy is in the center, enclosed by the ringlike structure. The seeing (FWHM) is 1''.40. The arrow points north, and east is 90° counterclockwise from north

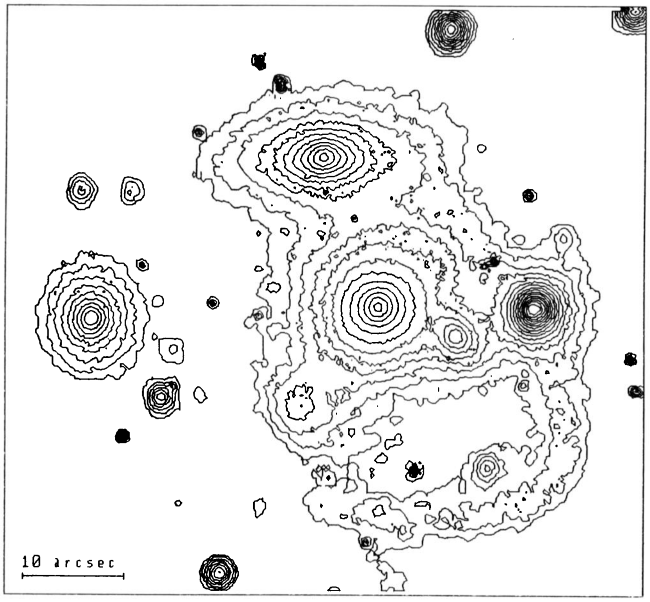

Fig. 2. Isophote map of A 0021 + 25 from the same CCD frame as Fig. 1, showing the detailed structure of the group of galaxies. The isophotes are separated by 0.50 mag and the faintest isophote is at 23.50 mag arcsec^{-2}. A gaussian smoothing has been applied at faint surface brightness levels (3 × 3 below 22 and 5 × 5 below 23)

Table 1. Companions of the Seyfert galaxy

Companions	m_R	Distance (arcsec)	Distance (kpc)	p.a. (°)
G2 lenticular	15.56	16.1	21.2	30
G3 E	16.68	29.1	38.4	102
G4	18.05	11.9	15.7	151
Galaxy [a]	17.:	60.:	79.:	185:
Spiral? (blue)	16.72	89.3	117.8	251
G5 E	17.48	8.3	10.9	259
Star	14.5	15.4	–	280
Spiral? (blue)	19.:	43.8	57.8	327

[a] Not on CCD frames.

foreground star (15'' to the west) and an elongated ring. The diagonal feature at the bottom of Fig. 1 is probably an artifact due to a reflexion in the new adaptator of the telescope, as it is not present in the two images taken earlier. The various companions are identified in Table 1.

We have analyzed the CCD images in an iterative procedure to produce an elliptical model of each object (galaxy or star). The procedure is described in detail in Prugniel et al. (1989). In short, given the image of an isolated approximately elliptical object, the procedure adjusts an ellipse to each isophotal contour, and constructs an elliptical model from the parameters of the whole set of ellipses. The ellipses are not necessarily concentric. In the present case, the procedure is seriously complicated by the presence of not 2 but 6 circular or elliptical objects in the field, as well as a ring feature.

We first modeled and eliminated once and for all the eastern galaxy (G3). We then modeled G2, the Seyfert, the star, G5 and G4 in turn. Three iterations were considered sufficient to disentangle approximately the various objects, as the residuals remaining at the end of an iteration, when all components have been modeled and subtracted, cannot be attributed with certainty to one specific object.

The elliptical model of the Seyfert and of the small companion (G5) have been subtracted from the deepest R frame to reveal the structure of the ring (Fig. 3). This ring is essentially visible on the western side of the Seyfert, although it seems to extend east, tangent to the eastern galaxy (G3). The adjusted ellipse (Fig. 3b) has an axis ratio of 0.65, which corresponds to an inclination of 49° if the ring is circular. Its radius along the major axis (which lies in p.a. 52°) is 24''.4, or 32 kpc (1'' = 1.3 kpc, for $H = 75$ km s^{-1} Mpc^{-1}). The center of the ring and of the Seyfert do not coincide; the latter is about 4'' (= 5 kpc) NW of the former.

We were not able to determine with certainty the color of the ring, because the V frame is not deep enough. The ring is clearly visible on that frame at the brightness level of 23 mag arcsec^{-2}, but not beyond.

We wish to emphasize that the apparent northwestern bridge between the bright star and the lenticular is not an artefact due to an incorrect subtraction of the Seyfert from the image. The model of the Seyfert extends beyond that bridge, which is barely visible in Figs. 1 and 2. Neither is it a shell produced by the Seyfert, as its center of curvature does not match that of the Seyfert. Finally, it cannot be a diffraction spike of the foreground star, as the

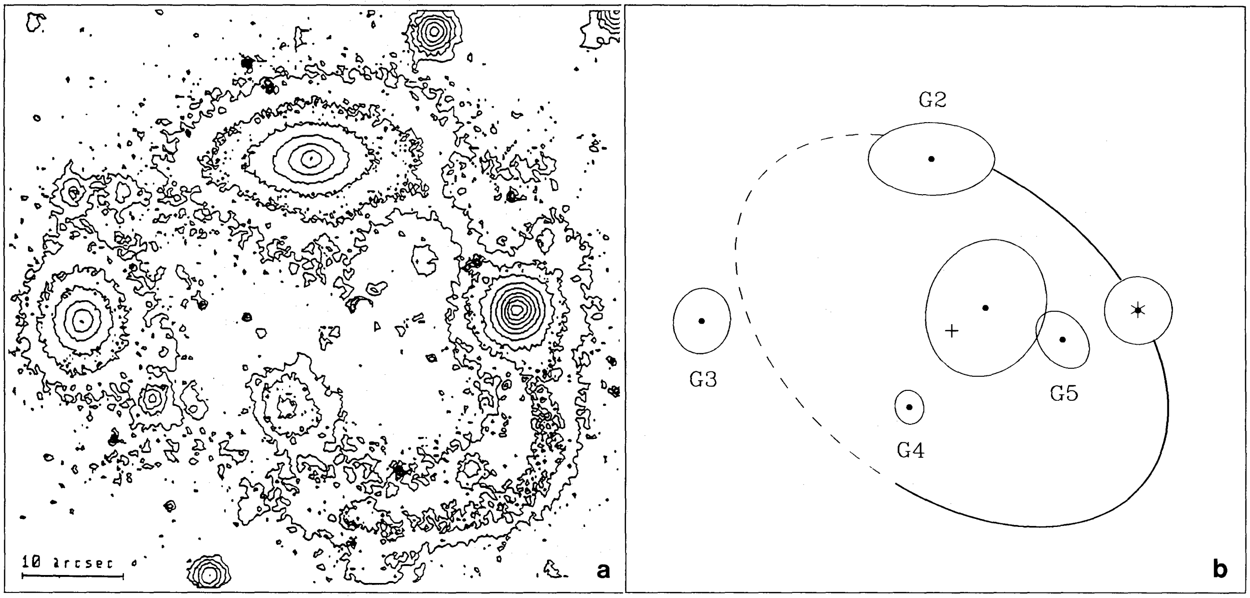

Fig. 3. **a** Same field as in Fig. 2, but after removal of an elliptical model of the Seyfert and of the faint companion G5, in order to show the ring structure. The isophotes are separated by 1 mag and the faintest isophote is at 24.00 mag arcsec^{-2}. A 3 x 3 gaussian smoothing has been applied below 23 mag arcsec^{-2}. **b** Sketch of A0021 + 25, on the same scale as Fig. 3a. The ring is indicated by a solid line when it is clearly visible and by a dashed line when its exact location is uncertain. Because of its uncertain geometry, the northwestern patchy bridge between the star and G2 is not sketched

secondary mirror of the telescope produces a symmetric pattern with 4 spikes.

Besides the ring, there is another peculiar feature to the environment of this Seyfert. The small galaxy G4 is connected to the Seyfert by two faint (presumably tidal) bridges or trails of luminous matter. Opposite G4 with respect to the Seyfert's center is another, fainter condensation. Could these be symmetric ejecta from the Seyfert's nucleus? Incidentally, G4 is also connected to the ring by a bridge.

There seems to be an excess of light on the southern and western edges of the lenticular G2 (see Figs. 1 and 3). Some of this excess could be attributed to the ring and/or the Seyfert, if this luminous excess actually were an arm protruding north from the Seyfert's nucleus and then bending sharply to the west. But there are also some luminous condensations west of G2, joining it to the ring behind the foreground star. All this put together is marginal evidence in favor of an interaction between the lenticular, the Seyfert and its ring. This would not be surprising in such a tight group, if the lenticular were at about the same redshift as the Seyfert. However, as discussed in the next section, this is not the case.

The models for the individual objects obtained after 3 iterations on the various frames were used to derive luminosity profiles (Fig. 4) and mean photometric parameters (Table 2) for the individual galaxies. That table gives the total apparent magnitude in V (m_v), the ($V-R$) color, the effective radius (r_e in arcsec) and the effective surface brightness in V (μ_{ev}) for each object.

The luminosity profiles in R of the galaxies are shown in Fig. 4. These are composite profiles, with the central parts from the high-resolution frame, and the fainter regions from the deeper (but lower-resolution) frame. The Seyfert has the profile of an elliptical galaxy or of a spiral's bulge. The profile of G2 also follows an $r^{1/4}$ law, but the isophote map of the galaxy is that of a lenticular. The slight excess in the profile beyond 5″ might be the beginning of the disk.

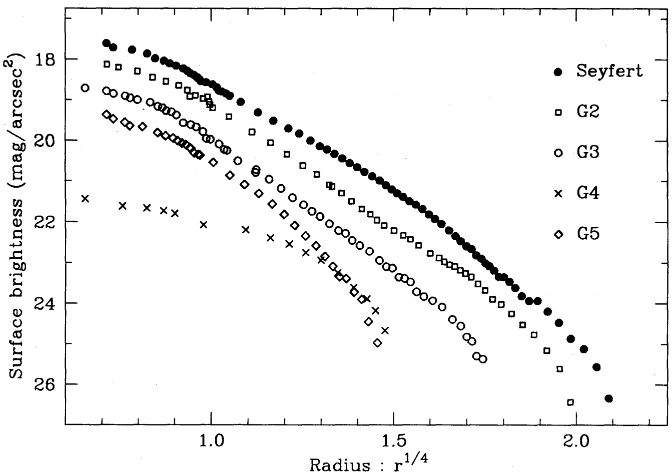

Fig. 4. Luminosity profiles in R of the five closest galaxies in the group against $r^{1/4}$, where r is the equivalent radius in arcsec. Symbols are: filled circles for the Seyfert, open squares for the bright lenticular (G2), open circles for the eastern elliptical (G3), crosses for the low-surface-brightness galaxy (G4), diamonds for the small western galaxy (G5)

Table 2. Photometric parameters of the Seyfert galaxy and its companions

Galaxy	m_v	$V-R$	r_e	μ_{ev}
Seyfert	15.06	0.38	3.9	20.01
G2	15.95	0.39	2.9	20.23
G3	17.03	0.35	2.0	20.56
G4	18.48	0.43	2.6	22.45
G5	17.94	0.46	1.5	20.68

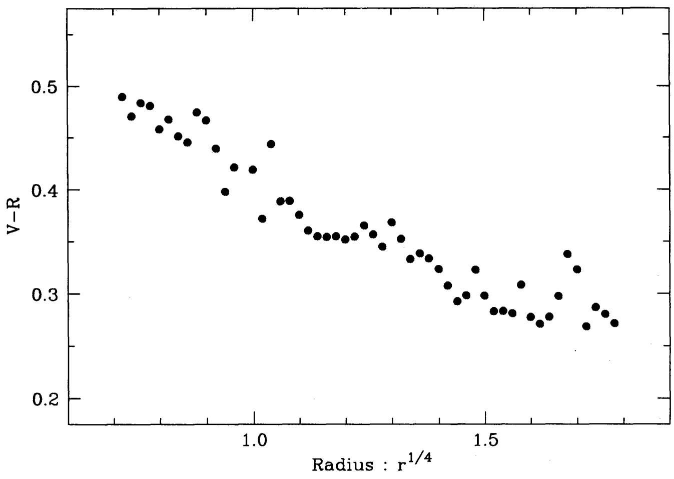

Fig. 5. $V-R$ color gradient of the Seyfert against $r^{1/4}$ (r in arcsec)

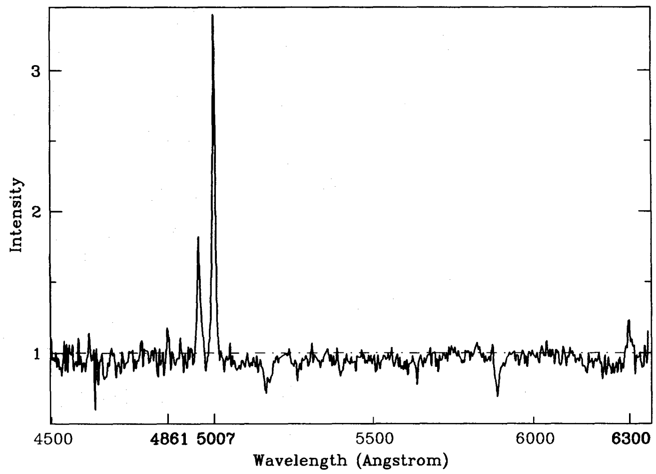

Fig. 6. Spectrum of the Seyfert showing the prominent emission lines; one-hour exposure, dispersion 130 Å mm^{-1}. The intensity of the continuum is unity, and the wavelengths are in the frame of rest of the Seyfert

The profile of G4 has a very shallow luminosity gradient, and is probably not a disk galaxy despite its faint effective surface brightness, but rather a blob of luminous matter ejected from the Seyfert. Its $(V-R)$ is probably overestimated, because the V frame is underexposed and the object has an effective radius of 2.″6 in V, versus 3.″0 in R. The rather steep profile of G5 suggests a tidally truncated elliptical.

There is a color gradient between the V and the R images of the Seyfert, which is not present in any of the 3 other galaxies in the field. As shown in Fig. 5, the galaxy becomes bluer by 0.25 mag between 1″ and 10″. Color gradients of this type occur in normal ellipticals, where they are interpreted as metallicity gradients (Vader et al. 1988).

4. Kinematic analysis

Four emission lines are measurable on the low-dispersion spectrum, Hβ, [O III] at 4959 and 5007 Å, and [O I] at 6300 Å (see Table 3 and Fig. 6). These lines give a mean velocity of 20284 (±53) km s^{-1}. This is a heliocentric velocity, like all the other ones in this paper, except those in Table 4. The relative intensities (I[O III] 5007/I Hβ = 25) and full widths at half maximum (FWHM = 686 km s^{-1} for [O III] 5007) of these lines indicate that this is a Seyfert of type 2.

On the high-dispersion spectrum we only measured the redshift and other parameters of Hβ and the 2 [O III] lines. The other lines, such as Ca V at 5300 Å, are much fainter. The

Table 3. Emission-line velocities of the Seyfert

Dispersion (Å mm^{-1})	Line	Wavelength (Å)	V (km s^{-1})	δV (km s^{-1})	FWZI (km s^{-1})	EW (Å)
130	Hβ	4861	20243	95	741	1
	O III	4959	20311	23	1936	10
	O III	5007	20303	16	2157	29
	O I	6300	20239	37	1524	3
66	Hβ	4861	20263	52	493	1
	O III	4959	20263	14	1210	10
	O III	5007	20291	6	1438	26

Table 4. Physical parameters of the 5 known ring Seyferts

Name	V_0 (km s^{-1})	Seyfert type	M_B	L_{FIR} ($10^{10} L_\odot$)	Ring radius (arcsec)	Ring radius (kpc)	Companion
NGC 1144	8776	2	−21.5	19.1	35	20	NGC 1143
NGC 985	12927	1	−21.7	17.0	44	37	No
IRAS 09595−0755	16500	1	−21.2	7.9	22	23	Yes
IRAS 20210+1121	16905	2	−21.0	58.2	14	15.5	Yes
A0021+25	20443	2	−21.2	–	24	32	Yes

emission-line velocity for this higher-dispersion spectrum is 20281 (±31) km s^{-1}. Table 3 gives, for each emission line in both spectra, the velocity (V) and its rms error (δV), the full width at zero intensity (FWZI) and the equivalent width (EW).

The absorption-line velocity of the Seyfert is 20226 (±11) km s^{-1} from the high-dispersion spectrum, and 20225 (±25) km s^{-1} from the other one, in good agreement with the emission-line velocities.

The surprising fact is that G2, the lenticular 16″ north of the Seyfert, has a much lower absorption-line velocity of 16169 (±3) km s^{-1}. It is 16294 (±31) km s^{-1} from the low-dispersion spectrum taken three months earlier, thus removing any doubt about its correctness. Whether we are dealing with a partly non-cosmological redshift, whether we are witnessing a very high-velocity hyperbolic encounter, or whether the lenticular is a foreground object (or the Seyfert a background object), cannot be decided with certainty on the basis of the material presented here. We nevertheless favor the second scenario.

5. Comparison with other ring Seyfert galaxies

Four other galaxies with a Seyfert nucleus and a large outer ring have been discovered so far; their properties are summarized in Table 4.

NGC 1144 (= Arp 118) is a Seyfert 2 inside an elongated and knotty ring with a very strong velocity gradient (Hippelein 1989), and obviously interacting with an elliptical companion, NGC 1143. NGC 985 (= VV 285) is a Seyfert 1 on the edge of a ring (Rodriguez Espinoza & Stanga 1990), with no obvious companion. The ring galaxy in Sextans, IRAS 0959-0755, is a Seyfert 1 nucleus near the edge of an incomplete knotty ring (Wakamatsu & Nishida 1987). The recently discovered type 2 Seyfert IRAS 20210 + 1121 (Pérez et al. 1990) is somewhat similar to A 0021 + 25, with a bright bulge inside an eccentric ring. The Seyfert is also in contact with a lenticular galaxy in roughly the same orientation as our companion G2. The main difference is that the companion is at the same redshift. It is interesting to note that this system has the brightest far-infrared luminosity, and the smallest ring radius of the 5. This could be an indication that the ring expands as the far-infrared activity decreases.

The ring Seyferts in Table 4 have a very average absolute magnitude, as it is comparable to the mean absolute magnitude ($M_B = -21.7 \pm 1.0$) of the sample of Markarian Seyferts of Meurs & Wilson (1984). The large ring thus does not seem linked to an abnormal luminosity of the galaxy. Nor does it appear to be linked to the presence of companions, as NGC 985 is isolated, and the companion of IRAS 09595-0755 could in fact be a distorted part of the ring, since it has the same radial velocity. This tallies with the conclusion of MacKenty (1989b) that close companion galaxies enhance star formation rather than Seyfert-like activity.

A 0021 + 25 is the only galaxy of Table 4 which is not an IRAS source. This may seem surprising at first, since a large proportion of Seyfert galaxies has been detected by IRAS, 62% in the sample of Miley et al. (1985), 70% in that of MacKenty (1989b). It is admittedly a rather distant object, but other Seyfert 1 and 2 galaxies at similar redshifts have been detected by de Grijp et al. (1985). It may be that this galaxy is not an IRAS source because of internal extinction from the X-ray to the near infrared region of its spectrum. The recent suggestion that Seyfert 2 galaxies are actually obscured Seyfert 1 (see Miller & Goodrich 1990, and references therein) is further indication of the presence of obscuring matter. It is not a Markarian galaxy either, but that catalogue cannot claim completeness at the apparent magnitude of this galaxy.

This sample of Seyfert rings represents about 1.5% of the total number of known Seyferts, but is by no means expected to be complete; faint ringlike structures around other Seyferts (e.g. Mrk 486, Mrk 1095) have been reported by MacKenty (1989a), and a morphological study of nearby Seyferts by Simkin et al. (1980) shows that 85% of them have "a faint outer envelope, ring or pseudoring".

There might in fact be a continuity between the few ring Seyfert galaxies discussed here and spiral galaxies of morphological type (R)S or S(r) with a Seyfert nucleus, where the ring is much smaller (less than 10 kpc in radius) and generally linked to a bar. A survey of all known Seyferts, including deep CCD images, is obviously needed to quantify the presence, size and role of rings in Seyferts.

6. Speculative remarks on the origin of the ring

Nearly all Seyferts have spiral morphology. The ring may thus be a remainder of the disk. The question then is why the disk turned into a ring. The ephemeral study of ring galaxies in the 70's and their interpretation in terms of head-on collisions between a disk and an intruder suggests an external cause for the ring formation, and perhaps for the Seyfert activity as well. The problem is that there is not always an intruder (e.g. in NGC 985).

If, on the other hand, ring Seyferts lost their disk by a mechanism internal to the galaxy, dynamical instabilities in the disk triggered by the nuclear activity may be the key to understanding the structure of these peculiar objects. However, one expects axisymmetric instabilities in a disk to produce oscillations rather than just a ring (e.g. Hunter & Toomre 1969).

Another possibility is that the ring has been formed by radiation pressure from the Seyfert nucleus, pushing away the ionized gas disk before star formation had time to occur. However, the lack of symmetry of the known ring Seyferts suggests that a more violent event is responsible for their appearance. We are thus left with an external cause for the ring.

A very puzzling fact uncovered by this study is the redshift difference of 4057 km s^{-1} between the Seyfert and its brightest companion. As already discussed above, the images suggest a physical association between the two galaxies. Among the three possible explanations for the large velocity difference, we thus privilege the very high-velocity hyperbolic encounter, which might cause the ring, and the Seyfert activity as well. It has not yet been demonstrated that such a high-velocity head-on encounter produces a ring, but Chatterjee (1984) still manages to form rings in encounters with relative velocities of up to 2000 km s^{-1}. Ring-stability arguments (Theys & Spiegel 1977) suggest that the encounter occurred within 10^8 yr. The present separation between the Seyfert and G2 is thus 400 kpc or less, which is not unreasonable if the trajectory of G2 is almost along the line of sight.

While the formation of this large ring in a very high-velocity encounter remains rather speculative, its discovery around a Seyfert galaxy is the main point of the paper.

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Note added in proof. The heliocentric radial velocity of the galaxy G3 is 19628 ± 128 km s^{-1} (one-hour spectrum taken on Sept. 17, 1991 at a dispersion of 260 Å mm^{-1} with Carelec). It is thus the Seyfert, not the lenticular G2, that has the same velocity as the group.