RELATIONSHIPS OF THE ACTIVE NUCLEUS, GALAXY, AND ENVIRONMENT

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INTRODUCTION

35 years ago Baade and Minkowski (1954) suggested that a galaxy collision - diagnosed from the peculiar appearance of the parent object and its strong emission lines - is responsible for the strong radio-source CygA. This was the first time that gravitational interactions between galaxies were suggested to trigger nuclear activity. Over the following decades after the detection of the quasars and the gradual realization that quasars, comparable to the Seyfert phenomenon, are events at the nuclei of seemingly isolated galaxies, the collision hypothesis was abandoned. Efforts concentrated on the understanding of the activity as internal processes in the host galaxies, possibly aided by infall of gas from the intergalactic medium (cf. Rees, 1978; Gunn, 1979).

It was only during the last decade after Adams (1977) had noticed from his image-tube survey a "surplus of Seyfert nuclei in disturbed and interacting systems", and later-on when more resolved and deeper quasar imaging became possible that the concepts of triggering interactions gained ground. Presently, the "interaction model" seems to be the dominating paradigm for explaining the origin of nuclear activity in galaxies. In this connection also the wider environment of AGN's and its evolution on cosmical time scales received much attention recently.

In this review we concentrate on clues to the origin of AGN's within the interaction picture which we have adopted as working hypothesis. Thus, we shall not much consider here the influence of an already established active nucleus on its galaxy and environment. Consequently, radio jets,galactic winds,and other outflow phenomena, as well as the impact of the active nucleus on the stellar populations of its host galaxy etc. will not be in the main focus of this review talk.

Much of the earlier work on the topics covered here is contained in a review article by Balick and Heckman (1982).

In the first part we shall consider the environment of QSO's as distant AGN's. Here main aspects and problems of the interaction picture will emerge. In the major second part we concentrate on clues

D. E. Osterbrock and J. S. Miller (eds.), Active Galactic Nuclei, 425–444.

https://doi.org/10.1017/S0074180900141580 Published online by Cambridge University Press

regarding this picture from observations of nearby AGN's like the Seyfert galaxies.

A. QSO's

1. Host galaxies

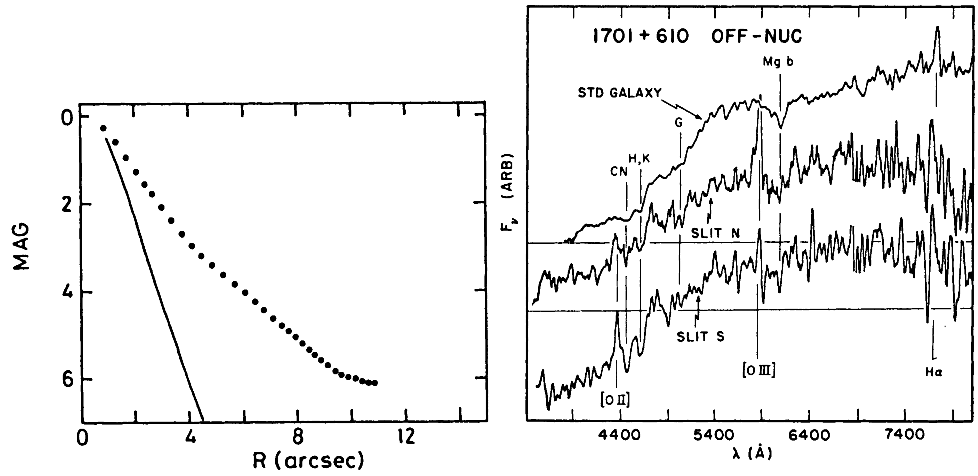
During the last 5 years first by using photographic and later-on CCD imaging convincing evidence has been collected that QSO's are the high-luminous nuclei of distant galaxies. The host galaxies of QSO's have been spatially resolved up to redshifts $z \lesssim 0.5$, and the continuity of the QSO properties to the lower-level nearby AGN's seems now to be established. Besides being a very difficult task observationally and methodologically the morphological classification of the host galaxies of quasars has been influenced by prejudices and ambiguities.

The most comprehensive recent studies on QSO imaging are by Hutchings et al. (1984a, b), Gehren et al. (1984), Malkan et al. (1984), and Smith et al. (1986). From the results of these papers the simple correspondence of radio-loud QSO's with elliptical host galaxies and of optically or X-ray selected QSO's with spiral host galaxies is not clear-cut. From model fitting Hutchings et al. (l.c.) found for a well-mixed sample (78 objects) of radio-, optical- and X-ray-selected quasars over 40% of the host galaxies to be consistent with spirals, the remainder having undetermined or perturbed morphologies. Smith et al. (1986) confirmed the high incidence of disturbed morphologies (~ 75% of the radio-loud and ~ 30-40% of the radio-quiet QSO's) and found the general tendency that radio-quiet QSO's are better fitted by disk galaxies and radio-loud QSO's by elliptical galaxy models.

A trend of QSO's residing in luminous galaxies and a direct relationship between the luminosity of the nucleus and that of the host galaxy are indicated (Smith et al. 1986; Hutchings, 1987; De Robertis, 1985). This could mean that more luminous host galaxies are more likely to develop effectively fuelled central engines.

In extension of earlier work (Boroson et al. 1985) on the fuzz around quasars, Hickson and Hutchings obtained spectra of some host galaxies. An example showing absorption lines is reproduced in Fig. 1a,b (Hickson and Hutchings, 1987). The spectra of the host galaxies of selected QSO's show both late-type and early-type stellar populations (starbursts). (B-V) color changes over the face of the host galaxies have been detected by Hickson and Hutchings (l.c.) and are also reported for the quasar Mkn 876 by Yee and Green (1987a). The strong narrow-emission lines found in the spectra appear to be spatially more extended than the continuum light of the host galaxies in all cases. Thus, also from the spectroscopic evidence the host galaxies seem to be highly disturbed. From the [OII]/[OIII] line ratio the density in the extended emission region has been estimated. Hutchings and Hickson (1988) find an electron density too low to be adequate for the interpretation of this emission by a cooling flow from the hot intergalactic medium.

The phenomenon that a high fraction of the host galaxies of active nuclei is disturbed or shows peculiarities has recently been verified



(a) (b)

Fig. 1a, b: The host galaxy of the radio-quiet QSO 1701+610 a) brightness profile (dotted line) together with point source (full line); b) off-nuclear spectra

also for the population of the very powerful radio galaxies (Heckman et al. 1986; Hutchings, 1987). This possibly underlines the crucial role of galaxy interactions for nuclear activity in general and adds to the evidence for the continuity of active phenomena out to cosmological distances.

2. Extended emission and tidal tails

The hypothesis that the perturbations of the host galaxies seen in the morphological surveys and deduced from colors and spectroscopy are indeed connected with ongoing merging or close unbound encounters has received independent support by the work of various authors,notably by Stockton and MacKenty (1983, 1987). Narrow-band imaging of a larger sample (47 objects) of luminous low-redshift quasars in the [OIII] 5007 line revealed in 25% of the objects luminous and highly structured extended emission on the 10kpc scale. A prominent example is the radio quasar 3CR 249.1. Its extended [OIII] - emission does not show any resemblance of the continuum light distribution. Whenever such extended emission is present the nuclear narrow-line emission is found to be strong. The authors argue that the extended gas is ionized by the nuclear UV-source and the ionization is density bounded. Other possibilities, however, like in situ shock ionisation by the action of radio jets should be discussed carefully in view of the fact that 70% of Stockton and MacKenty's objects are radio-loud.

The authors point out that an image like that of 3CR 249.1 is reminiscent of the numerical simulations of interacting galaxies by Toomre and Toomre (1972) and suggest that the extended gas is debris from tidal interactions or mergers and traces the tidal arms produced

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by the interacting precursor galaxies of the perturbed host galaxy visible now. According to recent N-body models (Barnes, 1988) encounters between disk galaxies embedded in massive dark halos can produce pronounced tidal tails while the formation of peculiar systems does not play a major role over long timescales. De Robertis (1985) suggests that interactions of a large galaxy which are "useful" for the effective fuelling of its nonthermal central source occur mainly with the more frequently available companion galaxies of small mass, a scenario also proposed by Gaskell (1985). Observational evidence for double-lined quasars led Gaskell (1983, 1985) to propose merging and the formation of binary massive compact nuclei as a possible mechanism for the activation of quasars.

3. Companions, groups and clusters

The imaging surveys of quasars revealed early-on the frequent presence of close companion galaxies currently interacting with the quasar galaxy, and the location of quasars in groups of galaxies. Hutchings and Campbell (1983) and Hutchings et al. (1984a, b) report 30-40% of their objects to be interacting and another third to reside in clusters or small groups. An example of a quasar interacting with a nearby galaxy is PKS 2349-01 (Fig. 2).

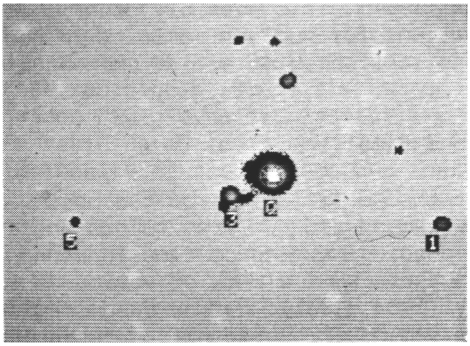


Fig. 2: Direct V-image of the quasar PKS2349-01 (z=.178) with intensive tidal tail to a companion ~ 50kpc away (proj. dist.)

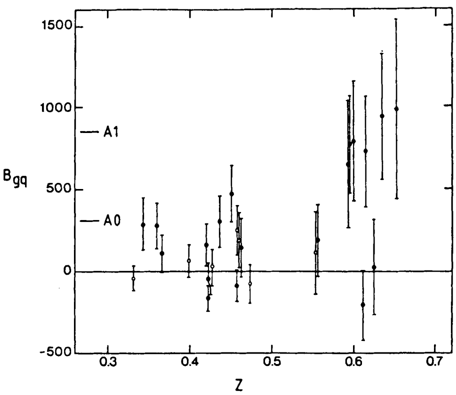
From an imaging sample of low-redshift QSO's Yee (1987a) attempts to estimate statistically the frequency of finding companion galaxies to quasars as a function of distance to the quasar and of the magnitude of the companion. He argues that quasars have at least one close companion within projected distance ~ 100kpc, and all quasars can be expected to have companions brighter than - 16.5mag. According to him, quasars have close companions 6 times more frequently than expected for field galaxies. Since the properties of the companions do not seem to be correlated with the level of quasar activity it may be concluded that companions are acting mainly as triggers of activity while the level of activity must be determined by properties of the host galaxy. Details of this mechanism have recently been discussed by Byrd et al. (1987), as is described below.

Published work on spectroscopy of QSO companions is extremely scarce. Stockton (1982) has observed 2 companion galaxies and found them to be active. Heckman et al. (1984) report spectroscopy of 18 close companions of low-z quasars. 14 of their spectra show emission lines while the remaining 4 galaxies are so distant that Hα was outside of the observed spectral range. Preliminary results of multi-object spectroscopy of quasar fields provide further evidence for emission-line activity within companions around QSO's (Kollatschny and Fricke, 1988a).

Yee (1987a) finds on average no indication that the companions of quasars are affected photometrically by the quasar. This is consistent with the result of Tyson (1986) that companions to low-z quasars are not abnormally bright. Evidence on colors of companion galaxies is insufficient to draw definite conclusions at the present time (Yee, 1987b,1988).

Yee and Green (1987b) in their analysis of quasar fields relative to control fields do not find significant differences between the covariance amplitudes of fields around radio-loud and radio-quiet quasars at low z. Deriving the quasar-galaxy covariance amplitude Bgq as function of z for fields around radio-loud quasars they report significant evolution between z=0.4 and z=0.6 (Fig. 3a). At higher z the quasars are found in Abell class 1 clusters while at lower z the quasars tend to prefer less dense clusters or groups. The authors conclude that physical environmental conditions play a significant role in the evolution of quasars besides luminosity evolution, in the sense that the availability of sites for quasar activity increases with look-back time in this narrow redshift range. This is in agreement with the prediction by De Robertis (1985) who has calculated QSO evolution on the basis of the interaction model and accounts for substantial density evolution around z=0.5.

(a)



(b)

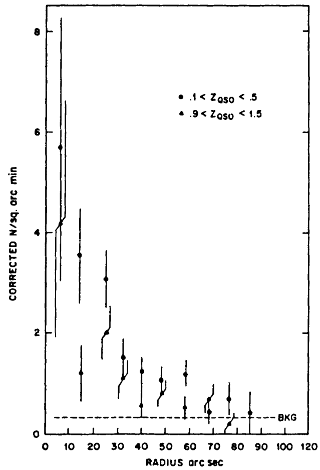


Fig. 3a: Quasar-galaxy spatial covariance amplitude vs. z

Fig. 3b: Galaxy counts for two QSO samples showing significant excess near QSO's over background to R = 21 mag

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The issue of density evolution, however, is controversial at present. Tyson (1986) investigated two samples of quasars in the redshift ranges 0.13 - 0.48 and 0.96 - 1.47. He finds a significant excess of detected galaxies within 30 arcsec of the QSO's in the high redshift sample (Fig.3b). He explains this in terms of luminosity evolution. In this redshift range the galaxies associated with quasars are more than 2 mag brighter than predicted by passive evolution models. Tyson does not find an indication for significant density evolution over epochs up to z~1.5.

B. SEYFERT GALAXIES

From the convincing evidence for the continuity between quasars and Seyferts it is generally assumed that we observe the same phenomenon in both types of objects and that the activity mechanisms and causes are also basically the same.

The Seyfert galaxies and their environment can be studied in much greater detail than that of the quasars as regards spatial resolution of the host galaxy (~ 15kpc), detection of companions (~ 50kpc), and the description of the surrounding groups or clusters (~ 1Mpc).

The interaction picture emerging from quasar imaging studies can be put to the test here, by probing the environment in detail at all such scales.

4. Host Galaxies of Seyferts

Commonly Seyfert nuclei are regarded to be hosted by spiral galaxies (Adams, 1977) as are their prototypes NGC 1068 and NGC 4151. Véron (1986) finds the largest fraction of galaxies with Seyfert-like spectra for the Hubble types Sa - Sab. Yee (1983) finds from the colors of 20 Seyfert galaxies the wide range Sa - Sbc.

We have looked up the morphological types of all galaxies listed in the VCV catalogue (Véron-Cetty and Véron, 1987) as Seyfert 1, Seyfert 2, and HII. To insure the homogeneity of the classification we restricted ourselves to the RC2 (de Vaucouleurs et al., 1976) and to the SGC (Corwin et al., 1985) catalogues. The resulting distribution of revised Hubble types for Seyfert 1 and Seyfert 2 and HII galaxies is given in Fig. 4a-c and is compared to the distribution of all SGC galaxies in Fig. 4d. The total distribution is best resembled by the Seyfert 2 galaxies, while there might be a trend of Seyfert 1 galaxies towards earlier types. The HII (starburst) galaxies are most frequent among the later Hubble types as has been noted before (Véron 1986, Terlevich et al.1987).Not untypical is the large fraction (2/3) of Hubble types with listed perturbations (shadowed in Fig. 4a-c) whereby the fraction is higher for the early types (~ 90%) than for the later Hubble types ($\lesssim$ 30%). Adams (1977)has emphasized that Seyfert galaxies are often mildly disturbed. From the VCV, RC2, and SGC,galaxies with central bars are found to be marginally overrepresented in the Seyfert population (Fig. 5). Such a trend has been reported earlier by Adams (1977), and Simkin et al. (1980). We have conducted a spectrophotometric survey at ESO/La Silla of 100 normal and 230 barred spiral galaxies searching for

(a-c)

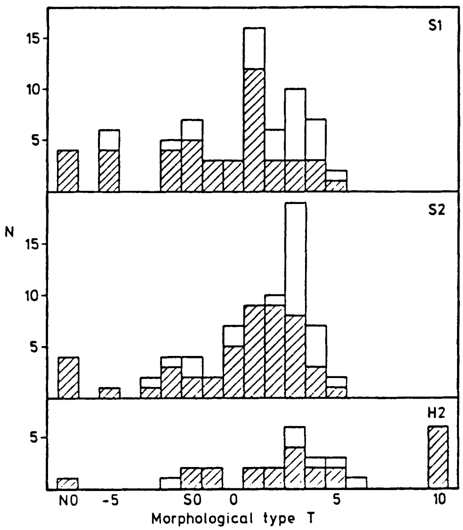

Fig. 4a-c: Distribution of revised Hubble types for a) Sey 1, b) Sey 2, and c) HII galaxies. The shadowed columns yield the distribution of perturbed systems.

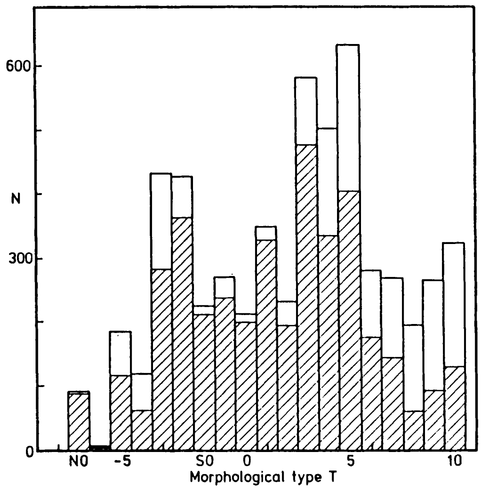

Fig. 4d: Total distribution

nuclear emission-line activity. In comparison to Seyfert galaxies and low-level active galaxies only the starburst galaxies showed a significant (4 to 1) excess of barred relative to non-barred spirals (Fricke and Kollatschny, 1988a). Thus, continuous feeding by departures from symmetry such as bar instabilities (Simkin et al., 1980; Schwarz, 1981; Norman and Silk, 1983) seems not to be efficient in generating Seyfert activity but favours central starburst activity.

Published work on host galaxy luminosities of Seyferts is very limited. From surface photometry of a small sample Yee (1983) finds a tendency of Seyferts to occur in luminous galaxies. Circumnuclear spectroscopy of the central regions of Seyferts is important to study the theoretically predicted impact of nuclear activity on the gas and stellar population of the host galaxy (Begelman, 1985).

Substantial work has been done on the influence of the nuclear activity on the gas of the host galaxy and the surrounding medium regarding ionization and dynamics. Extended narrow-line regions (ENLR), both contigous (Fricke and Reinhardt, 1974, Baldwin et al. 1987) and detached (Tadhunter et al. 1987) are present in many Seyfert galaxies.

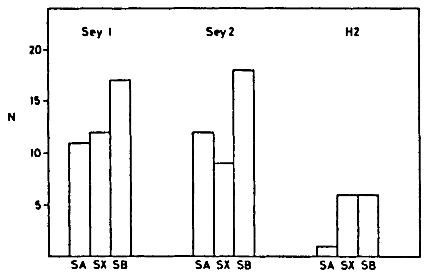

Fig. 5: Fraction of barred galaxies and pure spirals for Sey 1, Sey 2, and HII galaxies

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The [OIII]-structure is generally correlated to the radio structure seen with the VLA and may be induced by it (Whittle et al. 1988, Wilson et al. 1988). Various aspects of the nucleus - host galaxy relation have recently been reviewed by Fosbury (1987) and Wilson and Heckman (1985), and will not further be considered here.

5. Multiple nuclei systems

From the point of view of the interaction model for quasar activity it is important to look for Seyferts which show characteristics of on-going close collisions or merging as the most extreme forms of interaction. Some prominent examples of this type have first been listed by Petrosian et al. (1979). The definite double nucleus nature of such objects must be demonstrated for each individual candidate. This can be attempted by looking for the presence of tidal arms and/or highly disturbed velocity fields. The mere presence of morphological irregularities seems not sufficient to diagnose ongoing merging. A representative list of Seyfert nuclei and starburst nuclei found in double-nucleus systems is given in Table 1.

Table 1: Multiple Nucleus Galaxies

Name	Types	Comments
Mkn 110	Sey 1	spatially not resolved
Mkn 231	Sey 1	(< 2 arcsec),
Mkn 273	Sey 2	strong tidal arms
Mkn 78	Sey 2+Sey 2	spatially not resolved, spectr.
NGC 5956	Sey 2+Sey 2	separated, weak tidal arms
Mkn 739	Sey 1+Starburst	spatially separated,
Mkn 266	Sey 2+Sey 2/Liner	tidal arms,
Mkn 463	Sey 2+Starburst/Sey 2	Seyfert
Mkn 673	Sey 2+Starburst (?)	characteristics
Mkn 1027	Starburst+Starburst	spatially separated
Mkn 788	Starburst+Starburst	tidal arms
Arp 220	Starburst+Starburst	starbursts

For the first three objects of this list the multiple nuclear structure implied by the strong tidal tails in these cases is not spatially resolved (separation of the nuclei < 2 arcsec). For Mkn 110 Hutchings and Craven (1988) find a single Seyfert 1 nucleus and a tidal tail (a distinct second point source in Mkn 110, previously supposed to be a second nucleus, turned out to be a foreground star). A strong case for Mkn 231 being a recently merged system has been put forward by Hutchings and Neff (1987) and Hamilton and Keel (1987) where detailed interpretations of this violently disturbed objects are given.

The direct narrow-band image in the light of the [OIII] 5007 line of Mkn 273 shows an extended nuclear region. On the high-resolution VLA map at 6cm two radio nuclei separated by ~ 1 arcsec are seen; the 20cm map only shows extended structure. A main strong tidal arm of ~ 20kpc extent is visible in the [OIII]image together with several features to the NE viewed at as the debris from recent tidal interactions.

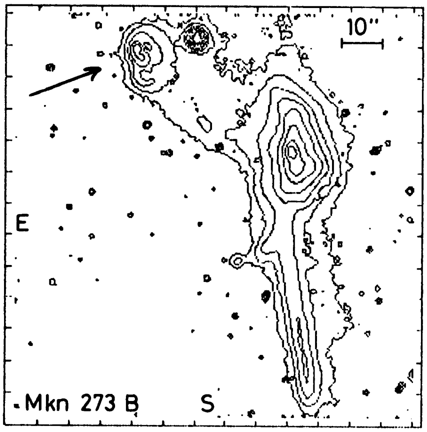

Fig. 6: B-band image of Mkn 273

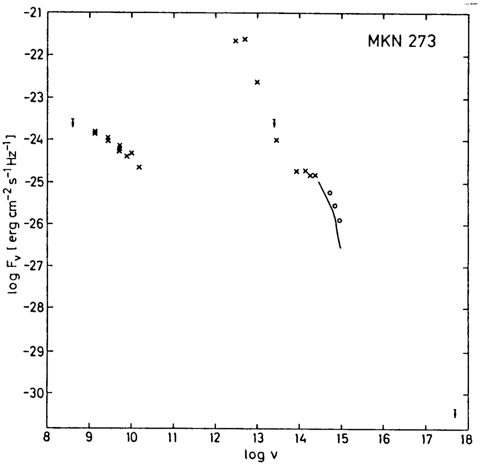

Fig. 7: Overall spectrum of Mkn 273

The tidal arms are as strong in the continuous light. In addition an extremely blue emission region (arrow) is visible in the B-band (Fig. 6). The extended emission of Mkn 273 is of different nature than the ENLRs described by Fosbury (1987). The ENLRs are an effect of the active nucleus while the tidal features discussed here are connected with its formation.

The optical spectrum of the nucleus of Mkn 273 has a steep Balmer decrement. This is consistent with its strong far-infrared excess due to thermal dust reemission (Fricke and Kollatschny 1986) and with a UV spectrum being unusually weak for a Seyfert galaxy (Kollatschny and Fricke, 1988b). The overall spectrum with its high peak at 60μm (Fig.7) puts Mkn 273 among the most extreme infrared sources in the sky.

The nuclei of the next two objects listed in Table 1 are only separated spectroscopically. Mkn 78 and NGC 5929 both have double Seyfert 2 spectra (De Robertis, 1987; Keel, 1985). The spectral region around Hβ is reproduced in Fig. 8 for Mkn 78 (De Robertis, l.c.). Tidal arms are weak in these cases. These two objects may be compared to the quasar 0945 + 076 with its displaced narrow-emission lines which Gaskell (1983) inspired to propose a scenario for quasar activity involving supermassive binaries.

The double nucleus galaxies Mkn 266, 739, 463, and 673 contain at

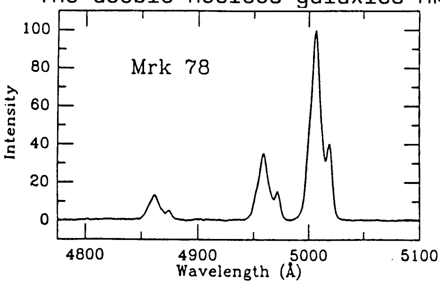

Fig. 8: The double-lined nuclear spectrum of Mkn 78

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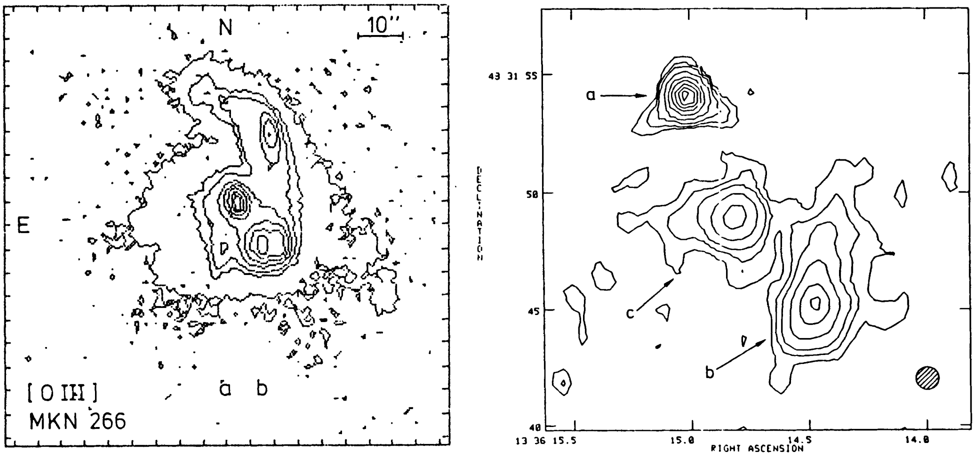
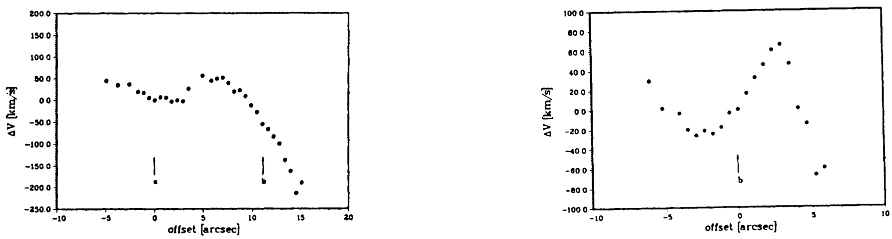
least one Seyfert nucleus each. The nuclei are well separated and strong tidal arms are present. These objects are considered to be in the process of merging or close unbound encounters. The tidal tail seen in the [OIII]image of Mkn 266 (Fig.9a) resembles the extended [OIII] emission observed by Stockton and MacKenty (1983) of e.g. the quasar 3CR 249.1



(a) (b)

Fig. 9: direct images of the double Seyfert nucleus galaxy Mkn 266 a) in the [OIII]λ5007 line, b) at 20cm with the VLA (A-configuration)

The gas in these features is supposed to be remnant gas of the colliding disk galaxies. The 20cm VLA radio map of Mkn 266 has between the two radio sources corresponding to the optical nuclei a strong third source whose origin is unclear (Fig. 9b). In the IUE spectrum taken through the optical nuclei (Kollatschny and Fricke, 1984) both nuclei are seen separated in the UV proving their nonthermal origin. Mkn 266 is one of the few multiple nucleus sources where it is possible to obtain a not heavily reddened strong UV spectrum owing to its small dust content which is consistent with the observed small Balmer decrement in the nuclear spectrum and its small infrared excess. The velocity field determined from long-slit spectroscopy in position angles 33° through nuclei a and b (Fig. 10a) and 123° through nucleus b (Fig. 10b) has a very disturbed appearance.



(a) (b)

Fig. 10a: Rotation curves of Mkn 266 a) through nuclei a and b (P.A.33°), and b) through nucleus b (P.A.123°)

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Mkn 739 has a Seyfert 1 and a starburst nucleus separated by 6 arcsec (~ 3.5kpc) (Netzer et al. 1987). On the VLA map the starburst nucleus appears extended; the Seyfert 1 nucleus is compact. The velocity field is similarly disturbed as for the previously discussed object; nucleus B is stationary with respect to its surroundings in the parent galaxy while nucleus A approaches the observer with a velocity of ~ 100 km/s.

The double nucleus galaxy Mkn 673 has an unusual host galaxy with colors like an elliptical galaxy. The spectra of the nuclei are a mixture of an elliptical galaxy spectrum and an A-type absorption line spectrum originating from a past starburst as well as a heavily reddened emission line spectrum with strong Hα and [NII] lines. This object with its composite spectrum is reminiscent of the recently defined "E + A"-galaxies (Dressler and Gunn, 1985) as observed in the central regions of distant clusters (Butcher-Oemler-effect , cf. Koo, 1987).

An example of a double nucleus system with two starbursts is Mkn 1027. This object shows all the signatures of a merging system: strong tidal arms, strong far-infrared emission, and a highly disturbed rotation field.

Early-on we have noticed that all multiple nucleus galaxies are among the strongest far-infrared sources detected by IRAS (Fricke and Kollatschny, 1986, 1987a). Recently, it has been proposed by Sanders et al. (1988) that such dust-enshrouded ultra-luminous mergers or interacting galaxies with far-infrared luminosities exceeding 10^{12} $L_{\odot}$ will take on the appearance of quasars once the dust is swept out. In support of this idea the comparable space densities of the infrared objects and the quasars are invoked. Such an evolutionary link, however, is not entirely compelling. First, it seems to be difficult to account for the composite nature of these objects within this picture. Some of these objects are just double starburst galaxies, others have a Seyfert nucleus and a concomitant starburst showing that not always in such close encounters Seyfert nuclei are generated in the collision partners. Obviously, the nuclei of the colliding galaxies must already be endowed with central machines (e.g. supermassive black holes) which then can be fed as a result of the encounter or merging by gas and molecular clouds if a Seyfert nucleus or quasar is to be formed. Secondly, the different lifetimes of the starburst and the Seyfert phenomena (see below) make an evolutionary link between the two objects difficult to accept even if the space densities of the two object classes are found to be comparable. For a critical discussion of an evolutionary link between starburst galaxies and Seyfert galaxies as suggested by Weedman (1983) and Balzano (1983) see De Robertis and Shaw (1988).

6. Seyfert galaxies in tidally interacting systems

Next we turn to Arp type interacting systems (Arp, 1966, Vorontsov-Veljaminov, 1977) in which two or more individual galaxies are mutually distorted. The incidence of nonthermal nuclei and starbursts among such systems seems to be generally enhanced (Keel et al., 1985). In fact, very luminous and extended starbursts have been observed in interacting and merging galaxies (Joseph et al., 1985; Schweizer, 1982; Bergvall and Johansson, 1985). A deficiency of active nuclei in violently inter-

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active systems has been noticed (Keel et al., 1985; Bushouse, 1986). We suspect that this may be effected by heavy dust obscuration of already present active regions and/or by a delayed turn-on of Seyfert activity after tidal perturbations. Recent investigations by Sanders et al. (1988) and Lin et al. (1988) are lending some support to these possibilities.

Typical examples for Seyferts in tidally distorted galaxies are the Seyfert 1 galaxy Arp 102B and the Seyfert 2 galaxy NGC 2992. NGC 2992 has a companion (NGC 2993) 25kpc away with a starburst spectrum. An ENLR contiguous with the NLR of the active nucleus is present in NGC 2992 and has been analysed spectroscopically in various slit positions around the axis of its radio source by Colina et al. (1987). This ENLR reaches far out (~ 2kpc) into the host galaxy and is dynamically decoupled from the nuclear NLR.

Bushouse (1986) has studied spectrophotometrically a sample of ~ 70 violently interacting systems and Keel et al. (1985) a sample of ~ 50 of such systems. Among interacting systems Keel does not find evidence for a dependence of the emisison-line activity on galaxy separation over the range 15-50kpc and likewise Bushouse for the range 25-125kpc.

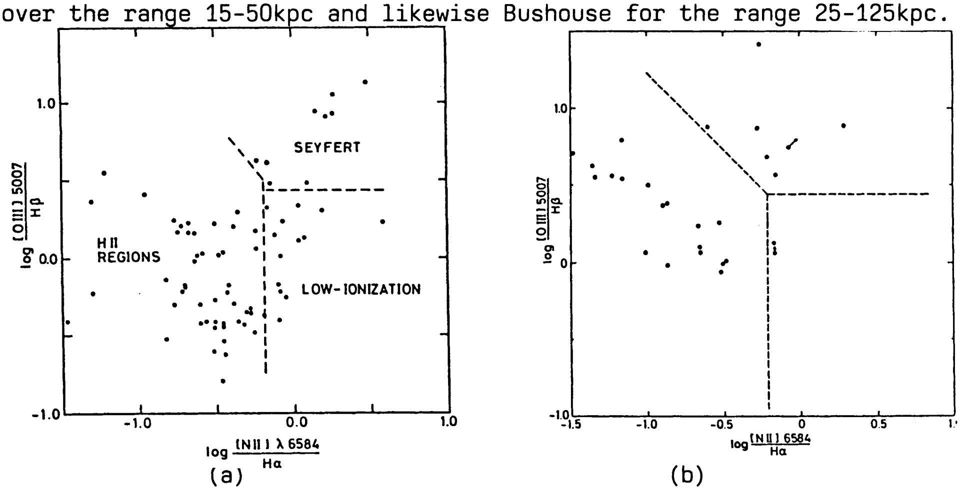

Fig. 11a,b: The "Baldwin" diagrams a) for Keel's sample (15-50kpc galaxy distance), b) for a sample of multiple nuclei (< 15kpc gal. dist.)

The distribution of the starburst nuclei found in interacting systems covers a wide range in the line-ratio diagram [OIII]λ5007/Hβ vs. [NII]λ 6584/Hα (Baldwin diagram). For Keel's sample this diagram is reproduced in Fig. 11a. The same diagram for a sample of double nucleus galaxies (Fig. 11b) shows much higher excitation (higher [OIII]/Hβ ratio) of the individual nuclei (Kollatschny et al., 1986). Thus, the nuclear activity gets strongly enhanced if the interaction reaches the extreme of merging or penetrating collision below the 15kpc scale.

7. Companions and groups around Seyfert galaxies

The environment of Seyfert galaxies out to ~ 50kpc has been explored by Dahari (1984, 85) by searching on POSS plates for companions which are closer than 3 times the major axis to the Seyfert galaxy and greater than a certain angular size. From a sample of 93 Seyferts he finds that Seyfert galaxies have by a factor of ~ 4 more frequently (15 per cent) such companions than the field galaxies in his control sample. Byrd et al. (1987) rediscussed this analysis by taking into account small angular size companions and distant companions that may trigger or may have triggered Seyfert activity. These authors estimate that at least 75% of the Seyfert galaxies have companions within distances of several 100kpc. They conclude that tidal interactions could be the predominant cause of Seyfert activity. Fuentes-Williams and Stocke (1988) using different selection criteria than Dahari in defining the environment of Seyfert galaxies reach the conclusion that Seyferts do not possess a clear excess of luminous ($M_V \lesssim -18$) companions relative to a control sample of normal spirals.

One of the major difficulties in this program seems to be the proper choice of control fields.

Recently, evidence has been collected from inspection of POSS and ESO/SRC plates as well as subsequent spectroscopy that the environment of Seyfert galaxies has to be searched at least out to ~ 1Mpc for companions which may have interacted earlier with the Seyfert galaxy (Kollatschny and Fricke, 1985, 1987b; Fricke et al. 1986; Fricke and Kollatschny, 1987b). Thereby, it has been found that Seyfert galaxies occur in galaxy groups which possibly contain one or more of the collision partners responsible for the Seyfert activity. 15 groups around Seyfert galaxies have been analysed together with 9 control groups around non-Seyfert galaxies of the same morphological type. Examples of a Seyfert and a control group are shown in Fig. 12a, b. Membership of those groups has been confirmed spectroscopically. The spatial distribution, kinematics and the high percentage of spirals are typical for loose groups. Spectroscopy of the member galaxies reveals that on average in the vicinity of the Seyfert galaxies the companions are more active than further out. This is interpreted in terms of previous interactions of those closer companions with their Seyfert galaxy. Instead of loosing their gas content, starbursts were initiated within the companions during the hyperbolic encounters. After sufficiently large travel times such starbursts - due to their limited lifetimes - will be extinct in the companions receding at large distances from their Seyfert galaxy.

For all galaxies we have measured the emission-line intensities and have determined the dereddened Hα-luminosity which we adopted as measure of the activity level in these galaxies. The distributions with distance from the Seyfert galaxy of a) the total number of galaxies, b) of the galaxies with high emission-line activity (L(Hα) $>10^{39}$erg/s), and c) of the galaxies having low activity are given in Figs. 13a-c, respectively. The more active companions concentrate around the Seyfert galaxies, while at larger distances mainly lower level activity is found. The distributions with respect to non-Seyfert reference galaxies do not show this characteristic behaviour. The control groups contain mainly galaxies with low-level activity and do not show any spatial concentration of the more active members (Fig. 14a-c). A detailed discussion

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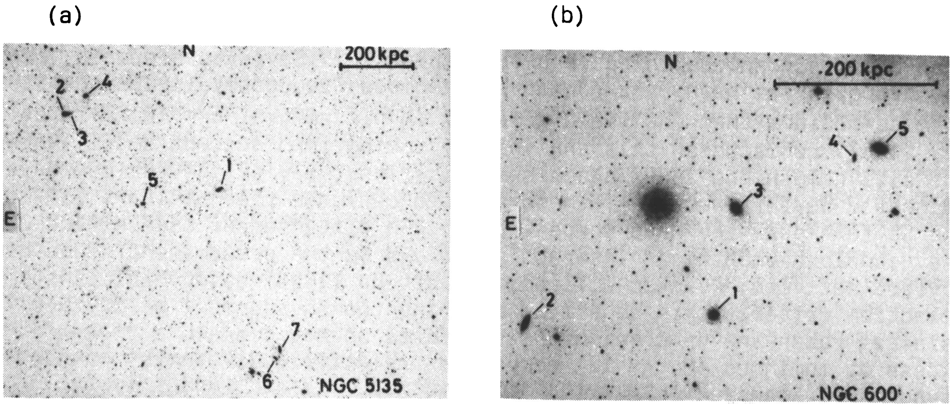

Fig. 12: Loose groups around a) the Seyfert galaxy NGC5135, and b) the non Seyfert galaxy NGC600.

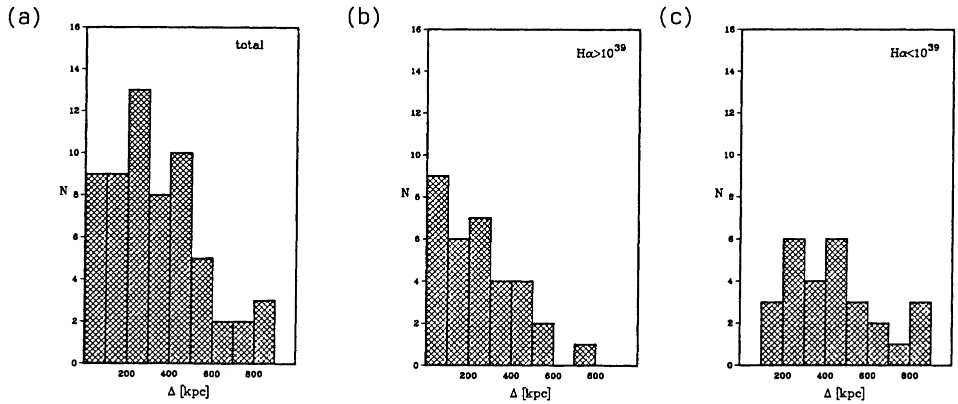

Fig. 13: Spatial distributions of galaxy counts around Seyfert galaxies a) all, b) more active, c) less active galaxies

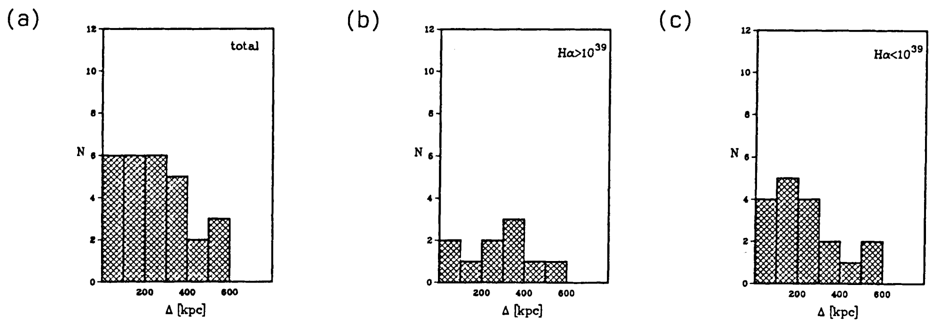

Fig. 14: Spatial distributions of galaxy counts around non-Seyfert reference galaxies, a) all, b) more active, c) less active galaxies

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is given by Kollatschny and Fricke (1988c) and Fricke and Kollatschny (1988b).

The starburst activity in the companions can be taken as strong evidence that these objects were previously engaged in hyperbolic encounters with a Seyfert galaxy. Recently, Byrd et al. (1987) have demonstrated in numerical experiments that hyperbolic encounters can trigger disk instabilities in the outer regions of a spiral galaxy at a very low threshold of the interaction parameter (Dahari, 1984) or at minimum distances as large as several disk radii. They show in their experiments that by virtue of the Toomre (1981) "swing-amplification" process gaseous inflow rates appropriate for starburst activity or the feeding of a non-thermal source are generated in a region 1-2kpc from the nucleus (cf. also Noguchi, 1987). Lin et al. (1988) demonstrate the feasibility of a mechanism (nonaxisymmetric gravitational instability of marginally self-gravitating disks) for communicating the tidal disturbance down to the compact nucleus of the galaxy with a sufficient accretion rate to power Seyfert activity. The resulting lifetime of a Seyfert nucleus after a tidal encounter according to this model may be as long as $\sim 10^{10}$ yrs. This is consistent with the distances and velocities measured for the active group members. The maximum observed distance of an active companion to the Seyfert galaxy is $\sim$ 600kpc. With a velocity dispersion of $\sim$ 400km/s follows a minimum lifetime for the Seyfert activity of $\sim 10^9$ yrs.

The critical triggering level of a selfgravitating disk found by Byrd et al. (1987) is very sensitive to the presence of a stabilising massive halo which can suppress the instability and quench the fuelling flow. The inflow rate vs. time from simulations of close encounters of a disk galaxy without a massive halo is shown in Fig. 15. The phenomenon of a latency period of $2\ 10^8$ yrs after the encounter and a triggering period of $\gtrsim 5 \cdot 10^8$ yrs, is seen. The flow rates are reduced by two orders of magnitude compared to those shown here if a massive halo of three times the disk mass is present.

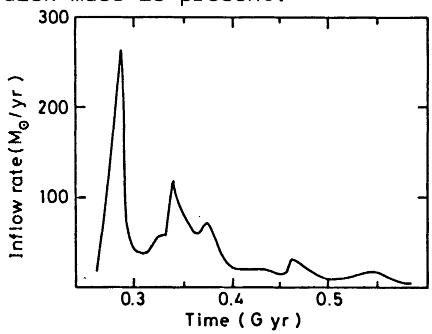

Fig. 15: Inflow rates vs. time triggered by a close encounter in the outer galactic disk

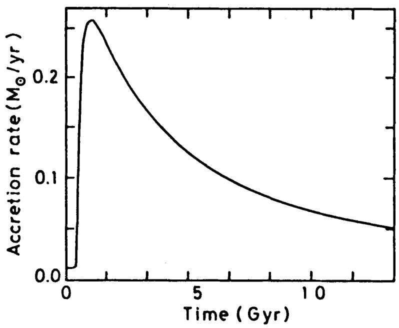

Fig. 16: Black-hole-feeding accretion flow vs. time triggered by a disturbance at the inner disk

The close encounter causes a strong disturbance inside the 2kpc region which will strongly enhance the accretion flow around any dormant black hole at the center. According to the calculations by Lin et al.

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(1988) the accretion rate reaches a maximum after 1Gyr and declines slowly afterwards (Fig. 16).

The strongly stabilising effect of massive halos may be the reason why in the non-Seyfert groups only low-level activity is found, namely if in such groups the galaxies have systematically more massive halos. In this respect observations of rotation curves by Burstein and Rubin (1985) may be relevant which indicate that galaxies not in the field have systematically lower halo/disk ratios, independent of morphological type and luminosity.

Since disk galaxies without halos are very easily perturbed, they will have survived to the present epoch preferentially in less dense environments. There is some evidence that Seyfert galaxies and nearby QSO's occur less frequently in rich clusters than in the field (cf. Osterbrock, 1986, 1987).

CONCLUSIONS

The interaction picture as a framework for discussing nuclear activity (QSO's, Seyfert-, radio- and strong far-infrared galaxies) has developed from various different directions. We explicitly mentioned in this review the perturbed host galaxies - sometimes with strong tidal arms - the high frequency of companions both interacting or cruising close-by, and the preference of QSO's to reside in regions with enhanced galaxy density relative to the field. For the quasars most of the existing work consists of CCD imaging. Many important questions, however, may only be answered by detailed deep spectroscopy both of the host galaxies and of the companions.

Work on the nearby active objects tells us that merging events actually occur and are associated with nuclear activity (non-thermal and starburst activity; strong far-infrared emission). The study of the group environment of Seyfert galaxies shows that ongoing interactions are not required to produce nuclear activity in an object. The triggering event of activity is probably not always connected with merging, this being only the most extreme form of interaction. The triggering may have happened long ago during a hyperbolic encounter, and the fromer collision partners are now being observed at large separations from each other when the AGN is still strong. There is now much evidence that a close interaction is merely necessary for triggering of an instability in the self-gravitating disk of the host galaxy while the level of activity is to be linked to the properties of the host galaxy itself (gas content, gravitational field at the center, velocity dispersion of the stars, halo mass, etc.). Then, it presumably depends mostly of the properties of the host galaxy and its nucleus whether the activity resulting from the action of the environment will become manifest as a starburst, a Seyfert galaxy, a radio-loud or radio-quiet AGN.

Besides further high-precision observations, more theoretical investigations which could enlighten our understanding of the complex processes following a tidal encounter in the host galaxies are needed and are a great challenge.

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DISCUSSION

SIMKIN You mentioned the difference between objects with massive haloes and those without. This is a difference in the radial mass distribution of the host galaxy. Only with certain compact mass distributions will interactions (or bars) result in nuclear inflow. Do you see any evidence of this concentration discrimination between interacting objects with AGNs and those without?

FRICKE Not at this moment. It may be possible to get this information from the rotation curves in both kinds of interacting systems. This is indeed an important next step in this process.

SHLOSMAN Your conclusions about normal abundance of large-scale stellar bars in AGNs seem to be in contradiction with the surveys of Seyfert and starburst galaxies, e.g., Adams (1977), Simkin *et al.* (1980), Balzano (1983), Verter (1987), MacKenty (1988). How do you explain this difference?

FRICKE We took the morphological classifications for all active galaxies listed in the Véron-Cetty and Véron (1987) catalogue from the RC2 and SGC. This combination provides the largest homogeneously classified sample of AGNs. The derived incidence of barred spirals among the various AGN types is fully confirmed by our spectrophotometric survey at ESO. Adams and Simkin considered much smaller samples and merely stated a marginal preponderance of bars in Seyfert galaxies. For starburst galaxies as investigated by Balsano there is no disagreement. I am not aware that Verter addresses the frequency of bars and I did not see the preprint by McKenty which you mention.

ROOS I have two comments regarding mergers. First, estimates of the present merging rate among galaxies indicate that it is sufficient to account for the present number of AGNs. Second, it is possible, and in my view even likely, that a galactic nucleus becomes active only in the relatively late stage of the merger event, when the nuclei are separated by less than 1 kpc. The outer parts of the galaxy would probably still look distorted but you would not see a double nucleus.

FRICKE Regarding your first point, I don't think that the environment of Seyfert galaxies is sufficiently explored to estimate the merger rate accurately. As to your second statement, from the existence of merging double-nucleus Seyfert galaxies, I am not convinced that the nuclear activity turned on only in such late stages as you have in mind.

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