EXTRANUCLEAR CLUES TO THE ORIGIN AND EVOLUTION OF ACTIVITY IN GALAXIES

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1 INTRODUCTION

Fifty-eight years ago Hubble expanded the vistas of astronomy from the Milky Way into what appeared to be a serene Universe. Forty years later the recognition of quasars (QSOs) permanently upset this notion of extragalactic serenity. With time has come the realization that every large galaxy may have erupted in QSO-like activity, perhaps repeatedly. The rich history of the field of active galaxies can be found in Weedman's (1976) fascinating review.

Active galactic nuclei (AGN) and their more spectacular counterparts, the QSOs, have received a tremendous amount of attention from both the observational and theoretical front. This attention has centered on the phenomenology of AGNs and QSOs (e.g. studies of the nonthermal radio emission, the bright, broad emission lines) leaving largely unexplored the question of how and why certain galaxies become "active." While there has been a wealth of clever speculation about the nature of the "machine" that powers the activity, no single idea has gained universal acceptance. To discriminate among such plethoric ideas as massive black holes and their accompanying accretion disks or spheres, spinars, magnetoids, dense star clusters, giant stars, and star-antistar collisions (Rees 1977, 1978a,b, McCray 1979, Alven 1979, Carter 1979, Fabian 1979, Lu et al. 1977, Ozernoy & Reinhardt 1978, Vil'koviskij 1978, Hills 1978, McMillan et al. 1981, Shields & Wheeler 1978, Edwards 1980, Pacini & Salvati 1978, 1981, Jones & Racine 1980, and many earlier papers referenced therein) may require knowledge about how nuclear activity is triggered. Accordingly, in this article we concentrate on clues to the origin and evolution of nuclear activity and leave aside questions of nuclear phenomenology and taxonomy.

Even though our approach emphasizes observations, active galaxies are inherently complex in nature, and ours is an interpretive rather than purely descriptive problem. Consequently, theoretical concepts are crucial to our discussion. This paper, then, is a collection of interpretive ideas by extragalactic archeologists searching through the habitats of the most unruly residents of the Universe. Such a search is particularly challenging because AGNs have the power to obliterate, alter, and obscure the clues that we seek, especially in their immediate surroundings.

The number of relevant papers published in the past five years alone exceeds three hundred. In the interest of conciseness and timeliness we emphasize only the recent work; earlier references can be located from those cited here. For obvious reasons of spatial scale, our search emphasizes the closest active galaxies, primarily Seyfert, radio, and X-ray galaxies and, as a control sample, "normal" or undisturbed galaxies.

1.1 What is an Active Galaxy?

For our purposes we operationally define an active galaxy to be one in which signs of qualitatively unusual and quantitatively energetic activity (i.e. activity not associated with the evolution of normal stars) are clearly visible and can be connected directly or indirectly to the nucleus. Excluded are simple interacting pairs in which no other signs of abnormalities appear and many emission-line or infrared galaxies, which can be entirely explained as multiple H II regions and/or supernova remnants (French 1980, French & Miller 1981, Weedman 1977a, Weedman et al. 1981). M82 and many other Irr II galaxies may be examples of this last class of interesting but, by our criteria, "inactive" galaxies.

A quantitative definition of what constitutes an active galaxy is perhaps not very useful, since galaxies showing low-level nuclear activity (e.g. Heckman 1980b, Stauffer 1981, Hawley & Phillips 1980) may be in a pre- or post- eruptive stage, and so may yield valuable clues into the origin and evolution of nuclear activity. Such AGNs may be difficult to identify because of extinction (e.g. Abell et al. 1978, Keel 1980, Lawrence & Elvis 1982) or confusion with an HII region (e.g. Wron et al. 1981). The number of weak AGNs increases every time deep searches are made. Heckman (1980b) has shown that fully one third of a complete sample of "normal" galaxies exhibit signs of nuclear activity. It remains to be seen whether all galaxies harbor active nuclei of low luminosity, much like the Milky Way (Balick & Brown 1974, Brown et al. 1981).

Radio and X-ray emission are generally regarded as telltale signs of activity in galaxies, and so we include all classical radio galaxies (e.g. Miley 1980) and X-ray galaxies (e.g. Giacconi 1978, Wilson 1979) in the class of active galaxies. Yet here too ambiguities arise. For example, recent VLA studies of the nuclear regions of "normal" galaxies show a variety of morphologies for the nuclear radio sources, some of which can be interpreted in the context of star formation/supernova remnants, and others that are much more suggestive of nuclear activity (e.g. Condon et al. 1982, van der Hulst et al. 1981). Whether the core radio or X-ray luminosity of a spiral galaxy is an accurate barometer of activity can be problematic.

1.2 The Scope of the Review

Our search for clues to the origin and evolution of activity in galaxies leads in a variety of directions. First we consider the environment of presently active galaxies in order to understand the possible effects of cluster or group membership on the one hand, and nearby interacting companions on the other.

Then we consider the relationships between galactic activity and the internal properties of galaxies, such as stellar content, mass, dynamics, structure, and optical luminosity. We also briefly examine the distributions, motions, and physical and chemical properties of the gas and dust in active galaxies for historical clues.

Several problems must be borne in mind. One is that distinctions between active and normal galaxies often turn out to involve subtleties or questions of degree. Another is the Malmquist bias; the most active galaxies are also frequently the brightest and rarest. A third problem is that many components of a galaxy, and especially the gas and dust, are susceptible to distortion by both the causes and the effects of activity, so interpretive ambiguity or controversy concerning causal relationships is frequent. Finally, as mentioned before, the problem at hand is interpretive rather than descriptive, and therefore the discussion is constrained by the limits of present theoretical knowledge and the availability of models.

2 THE INFLUENCE OF THE EXTRAGALACTIC ENVIRONMENT

2.1 Cluster Environment

Clusters have long been suspected as sites favorable in some ways to the formation and development of galactic activity. Certainly the high frequency of activity in cluster-centered cD galaxies is well known, as is the likelihood of an intracluster medium (ICM) with a substantial pressure (see Miley 1980 for summary). Generally, and perhaps surprisingly, cluster galaxies other than cDs (which are extremely massive and probably unique to the cluster environment) show little if any preferential propensity for activity over their more Isolated counterparts.

RADIO LUMINOSITY Bright radio emission is a sure and conveniently observed sign of galactic activity. The probability that a galaxy in a given range of absolute magnitude has a radio luminosity within specified limits is known as the bivariate radio-luminosity function. Auriemma et al. (1977) and Perola et al. (1980) have shown that the bivariate luminosity function of field and rich-cluster galaxies does not differ by more than a factor of two. Adams et al. (1980) reanalyzed the data of Auriemma et al. and reached a slightly different conclusion; Luminous cluster galaxies are stronger radio sources than luminous field galaxies, but for faint galaxies the opposite is true. This may partly reflect the unusual nature of the very luminous dominant-cluster galaxies (the cDs).

Longair & Seldner (1979) have found that the strongest radio galaxies tend to be found in regions intermediate in galaxy richness between Abell clusters and randomly selected fields, whereas the distribution of less luminous radio sources is statistically similar to the distribution of randomly selected galaxies. Longair & Seldner included spiral as well as elliptical galaxies in their "control sample" whereas radio galaxies are generally found in ellipticals and ellipticals are preferentially located in clusters, so their results may be misleading. Stocke (1979) and Longair & Seldner both find that radio sources in dense galactic environments tend to have a more complex morphology than relatively isolated radio sources.

EMISSlON LINE LUMINOSITY Gisler (1978) conducted a comprehensive survey of a heterogeneous sample of 1316 galaxies for line emission. He concluded that emission-line galaxies (ELGs) are much less common in dense than in groups, associations, and the field. The statistics for the very active ELGs (i.e Seyfert galaxies) are less compelling in Gisler's sample, although a tendency for such galaxies to avoid the rich-cluster environment is apparent. The same conclusion, though not statistically firm, has been drawn by Adams (1977) and van den Bergh (1975). Furthermore Hine & Longair (1979) find that 3CR radio galaxies with strong emission lines behave similarly, and Roberts et al. (1977) have shown that QSOs are less frequently associated with rich Abell clusters than are radio galaxies (which have much weaker emission lines).

The literature is rich in exceptions, however, Seyfert galaxies detected in clusters include NGC 4388 (Phillips & Malin 1981) and perhaps NGC 4235 (Abell et al. 1978) in Virgo, NGC 1365 (Veron et al. 1980) and NGC 1386 (Phillips & Frogel 1980) in Fornax, IC 4329A (Wilson & Penston 1979, Pastoriza 1979) in Klemola 27, IC 1182 = Mrk 298 (Bothun et al. 1981b) in Hercules, and of course, some cD galaxies such as NGC 1275 in Perseus. Hawley & Phillips (1978) find two extremely luminous Seyferts in loose clusters. Stauffer (1981) suggests that the frequency of Seyfert-like ELGs in Virgo is not significantly different than the field. Finally, low-redshift quasars sometimes turn up in clusters (e.g. Wehinger & Wyckoff 1978, Phillips 1980, Stockton 1980, Wyckoff et al. 1980, and Steiner et al. 1981).

These counterexamples notwithstanding, the apparent avoidance of ELGs in rich clusters may be interpreted in several ways. There may be an intrinsically low incidence of activity. Or, active galaxies may not be able to generate observable radiation even if they are active. Gisler (1978) suggested that the sweeping of gas by a dense, hot ICM in rich clusters may explain the low frequency of detectable EGNs in this environment. This conclusion, however, is not fully supported by several lines of evidence. First, an extensive survey of H I in cluster galaxies by Bothun (1981) failed to find any statistically significant sweeping of gas in cluster spirals except at the center of Coma. Second, studies of radio-source morphology and calculations of stripping efficiency by the ICM both indicate only the loosely bound gaseous "halo" of a galaxy can be stripped (e.g. Jones & Owen 1979, Wilkinson et al. 1981). X-ray observations suggest that some cD galaxies are accreting the ICM, rather than losing it (see below). Other nondominant cluster galaxies can also have X-ray halos (Jones et al. 1979, Forman et al. 1979), showing that efficient sweeping is not ubiquitous in clusters.

BL LAC OBJECTS Butcher et al. (1976) suggested that 3C 66A might be located near the center of a rich cluster at $z \sim 0.37$. Moreover, NGC 1275, which displays many of the defining characteristics of a BL Lac (Angel & Stockman 1980), is near the center of the Perseus cluster.

However, most BL Lacs are evidently not located in the central regions of rich clusters. Visvanathan & Griersmith (1977) find that AP Lib may be in a poor group of galaxies at $z = 0.0487$, while Baldwin et al. (1977) reach similar conclusions regarding 1400+162 at $z = 0.244$. We have examined the locations of six Northern Hemisphere BL Lacs at $z < 0.10$ with respect to Zwicky and Abell clusters and find that Mrk 421, Mrk 501, 3C 371, and BL Lac lie near the edges of mostly open clusters. On the other hand, Mrk 180 ($z = 0.044$) and IZw 1757+50 are apparently not in any cluster.

DOMINANT-CLUSTER GALAXIES The brightest and most massive galaxies known - the cD or dominant-cluster galaxies - are situated at the geometrical and probably gravitational centers of clusters. It has been frequently suggested that cD galaxies are growing by occasionally cannibalizing a smaller cluster member (e.g. Hoessel 1981, McGlynn & Ostriker 1980) and by accreting the nearby hot ICM (Fabian & Nulsen 1977, Cowie et al. 1980, Binney & Cowie 1981, Mushotsky et al. 1981). This infalling matter, particularly the ICM, might be available to provide $\gtrsim 10^2\ M_\odot\ \mathrm{yr}^{-1}$ of fuel to the nucleus. As discussed later, there is fairly strong evidence for these "cooling accretion flows."

As Burns et al. (1981c) have emphasized, cD and related galaxies are unusually active in the radio compared to other cluster ellipticals, whether located in poor groups or rich clusters. However, given the well-established, strong, and positive correlation between the likelihood of radio emission and galaxy absolute magnitude (see below), it is not clear that these galaxies are unusually active for their absolute magnitude. While the luminous X-ray sources and emission-line nebulosities (Burns et al. 1981a, Jones et al. 1979, Ford

& Butcher 1979, Heckman 1981) frequently associated with these superluminous galaxies might be taken as signs of activity, the emission is spatially extended and presumably arises as the hot gas is being steadily accreted onto the galaxy, a process believed to be unique to these objects. Thus these X-ray galaxies should not be considered genuinely active unless their nuclei exhibit the usual symptoms of activity. Nonetheless their central location in the cluster and their large masses contribute to their ability to accrete material for the nucleus.

2.2 Near-Neighbors and Interacting Systems

Stocke (1979), Dressler (1980a), and others have argued convincingly that the immediate environment of a galaxy has a far more important influence on its properties than membership or nonmembership in a cluster. Such a suggestion and the relevant observations are explored in this section.

A pair of galaxies with a small ($\lesssim$ 100 kpc) projected separation is almost certain to be a physical rather than optical pair. Interacting galaxies are those for which one or more companions are nearby, and evidence suggestive of tidal "debris" (Toomre & Toomre 1972) can be identified. Probably closely related are disturbed galaxies that show the usual signs of tidal stress, yet no companion is readily identifiable. We further consider galaxies with double nuclei since such galaxies may be in an advanced stage of an interaction leading to a merger. All such types of galaxies often show signs of activity.

Galaxy-galaxy interactions or mergers may be a very important mechanism in triggering and sustaining galactic activity, and there are a large number of radio galaxies whose *optical* morphology supports this (see below). Begelman et al. (1980) argue that the observed structure of some radio sources can be explained in terms of a merger which produces two orbiting, precessing, supermassive black holes in the merged galaxy's center. Whitmire & Matese (1981) have extended this suggestion; by analogy with SS 433 they argue that supermassive binary systems can explain many phenomena in radio galaxies. Roos (1981b) has detailed how a merger can lead to stars being scattered into the "loss cone" of a central black hole and, through subsequent stellar disruption and accretion, can power the nuclear activity.

RADIO SOURCES A number of recent surveys of radio emission have convincingly shown that the presence of nearby or interacting galaxies enhances the probability of finding a radio source associated with at least one of the galaxies (Sulentic 1976, Stocke 1978, Condon & Dressel 1978, Dressel 1981, Condon et al. 1982, Hummel 1980, 1981b, Adams et al. 1980). This result holds for both spiral and elliptical galaxies, and is of unquestionable significance as a clue to the origin of galactic activity.

Some debate attends specifics of the radio morphology and its implications concerning the onset of activity. Hummel (1981b) has shown that the enhanced radio emission associated with close pairs of galaxies comes from the nucleus of a galaxy rather than its disk. However, Condon (1980) and Condon et al. (1982) find that the radio emission is not strictly nuclear, and that it preferentially arises within 1 kpc of the nucleus in areas of the greatest stellar projected density. They argue that the radio emission comes from supernovae and that the nucleus plays only a minor role, if any (see also Feldman et al. 1981).

The situation is somewhat less complicated for interacting elliptical and SO galaxies where, in general, the radio sources are clearly not associated with starbursts inside the galaxy. In most such cases these sources qualitatively resemble the much more powerful radio sources in quasars. Surveys of radio emission from relatively bright, nearby early-type galaxies have been made by Condon & Dressel (1978), Dressel (1981), Hummel (1980), and Kotanyi (1981). For the low-luminosity radio sources it is fairly clear that the luminosity of radio emission is enhanced by the presence of close companions.

At the high levels of radio luminosity typical of sources selected from radio flux-limited samples (e.g. 3C, 4C, Parkes), there is little information concerning the effects of neighboring galaxies on the production of radio emission. The occurrence of strong radio emission associated with double-nucleus galaxies has long been recognized (e.g. the "db" classification of Mathews et al. 1964). Stocke (1979) pointed out that most classical radio galaxies have a companion galaxy of comparable brightness within $\sim$ 50 kpc, but no correlations were found between the attributes of the companions and the radio source according to Kingman (1981).

There is growing evidence, though not as yet of a statistical nature, to suggest that galaxy mergers may be important in triggering the production of a radio source. The two nearest radio galaxies, NGC 1316 = Fornax A (Schweizer 1980) and Cen A (Tubbs 1980), have both been interpreted as cases of a recent galaxy merger. Other noteworthy radio galaxies in which a recent merger has been proposed include NGC 1052 and NGC 4278 (Gunn 1979), 3C 305 (Heckman et al. 1981a), 4C 29.30 (van Breugel et al., in preparation), and NGC 6240 (Fosbury & Wall 1979). The latter authors have drawn attention to the fact that Toomre's (1977) merger candidates from the NGC catalog may have higher-than-normal radio luminosities.

The properties of these systems that are suggestive of a merger include the following: unusually large amounts of gas and/or dust for their early Hubble type, misaligned stellar and dust/gas dynamical axes, morphological or kinematic peculiarities in the ionized gas, morphological peculiarities in the stellar body of the galaxy, and shock-heated extranuclear emission-line gas.

SEYFERT GALAXIES Considering the avalanche of literature published on Seyfert galaxies, it is astonishing that no methodical statistical study of the effect of interactions, mergers, or even nearby galaxy density exists for these objects. Stauffer (1981) has found that galaxies with emission lines indicative of low-level nuclear activity (most of which are not classical Seyferts) occur more frequently in groups than in more isolated environments.

Studies of the morphologies of classical Seyfert galaxies have been conducted by Simkin et al. (1980), Adams (1977), and Wehinger & Wyckoff (1977). The Iwo earlier surveys give the impression (not rigorously statistically substantiated) that an anomalously large fraction of Seyfert galaxies are interacting and disturbed.

To the list of active interacting galaxies can probably be added two "ring galaxies" with Seyfert nuclei: NGC 985 (de Vaucouleurs & de Vaucouleurs 1975) and "The Carafe" (Hawarden et al. 1979a). Such objects may be produced as a consequence of a violent collision (Theys & Spiegel 1976).

Often both members of an interacting pair of galaxies are active, or at least have strong emission-line nuclei (ELNs) (Ward et al. 1978, Ward & Wilson 1978, Burbidge et al. 1963). Petrosyan et al. (1979, 1980a,b) have identified several double-nucleus Seyfert or Seyfert-like galaxies, all of which may be interactions in an advanced stage of evolution. Further studies of these types of active galaxies, including neutral hydrogen and deep optical imaging, would be of considerable importance in establishing mergers as a cause of activity in Seyfert galaxies.

Tifft (unpublished) has discovered a strong correlation between the spectroscopic properties in pairs of galaxies, in that both members tend to have a comparable degree of line emission. Furthermore, he finds that the strength of the emission lines correlates with the relative radial velocities of the nuclei; strongest emission is found in low-velocity interactions ($\Delta v \sim 10^2$ km s^{-1}). Both the emission-line strength and the relative velocity of galaxy pairs could easily depend on the total masses of the galaxies, and so the correlation between them could be secondary. Little correlation between nuclear activity and pair separation has been found. This last result is perhaps surprising and in need of further examination. Further work on this sample would be most valuable.

QUASARS There is little information on the local extragalactic environment of quasars. Weymann et al. (1978) showed that the positions of galaxies are more strongly correlated with quasars than with other galaxies. Stockton (1980) similarly concluded that (radio-loud) QSOs occur in regions where the density of galaxies is significantly higher than average. Stockton emphasized that quasars are found in galaxy groups rather than rich clusters — a conclusion consistent with Seyfert galaxies and low-luminosity radio galaxies. However, Seidner & Peebles (1979) find a statistically significant excess of galaxies around quasars at all redshifts, which, if not accidental, may argue that quasars are local and their redshifts are noncosmological.

Hutchings et al. (1981) and Wyckoff et al. (1981) have shown that the fuzz — presumably starlight — surrounding low-redshift QSOs is sometimes asymmetric. This might suggest that a substantial number of QSOs originate in closely interacting systems. Stockton (1982) reports the discovery of three cases of nearly stellar objects located within a few kpc (in projection) and ~ 200 km s^{-1} of a low-redshift quasar. He suggests that these objects are close companions whose interaction with the quasar host galaxy has triggered the quasar activity.

In concluding this section, we must note that available observations of active interacting galaxies are consistent with the theoretical notions of interactions as one of the many causes of galactic activity. As yet the observational tests are not critical; many details remain to be explored and a more secure statistical foundation for the models is still needed.

3 ACTIVITY AND THE STELLAR PROPERTIES OF GALAXIES

The structure and mass of an active galaxy are often correlated with the degree of its activity. Since galactic properties such as these are generally believed to be nearly permanent features of a galaxy, we now investigate what role they may play in causing, or at least facilitating, activity. We must note, however, the comments recently made by Simkin et al. (1980): Active galaxies may be undergoing major and perhaps repeated morphological changes, some of which are transitory activity. The discussion here (for obvious reasons) emphasizes active galaxies that are not interacting strongly with other galaxies.

3.1 Morphological Types

RADIO SOURCES Conventional astronomical folklore is replete with stories about the relationship between morphology and activity in galaxies. For example, it is widely accepted that powerful extragalactic radio sources are associated exclusively with elliptical galaxies. However, the earliest comprehensive optical morphological survey of extragalactic radio sources (Mathews et al. 1964 — thereafter MMS) reached different conclusions. They found that there was a good correlation between the radio luminosity of a source and its optical identification; in order of increasing radio luminosity, the typical identification was spiral, E, D (or related cD or db classes), N galaxies, and QSOs. Quantitative studies, e.g. surface photometry, strongly confirm that global differences between ellipticals and cDs exist (Hoessel 1981, Hoessel et al. 1981). However, it has never been confirmed that the radio galaxies classified as D by MMS are significantly different photometrically from normal E galaxies, although Simkin (1979) has presented kinematic evidence, as we discuss in Section 3.2.

In any event there are several examples of extended, luminous radio sources associated with galaxies that are clearly not simple ellipticals. Some of these galaxies are classified peculiar ellipticals (e.g. Cen A, Cyg A, and Fornax A; see MMS). and others have been classified as disk systems, e.g. NGC 612 (Ekers et al. 1978), 3C 293 (Sandage 1966), NGC 6240 (Fosbury & Wall 1979), 3C 305 (Sandage 1966, Heckman et al. 1981a). To these could perhaps be added 3C 120 (Arp 1975, 1981, Heckman & Balick 1979) and PKS 0400-181 (Shaver 1981).

The radio properties of Seyfert galaxies (typically early-type spirals; see the next section) are germane. Seyferts have radio luminosities intermediate between radio sources in similar non-Seyfert spirals and classical radio galaxies (e.g. de Bruyn & Wilson 1976, 1978). Many of them exhibit a strong morphological resemblance to radio galaxies but in miniature (size scales are smaller by $\sim 10^2$; Wilson & Willis 1980, Wilson et al. 1980, Wilson & Ulvestad 1981, Ulvestad et al. 1981). The frequent appearance of colinear double- or triple-radio structures suggests that the nuclei of disk galaxies sometimes have collimated ejecta just like the brighter radio galaxies (although perhaps at a lower power level) and/or that the relatively dense extranuclear gas in the disk inhibits the full development of the radio source. The radio axis is uncorrelated with any isophotal axis of the stars (see summary by Ulvestad et al. 1981). On the other hand, many other radio Seyferts bear less resemblance to radio galaxies than to "normal" spirals (e.g. Condon et al. 1981) in terms of radio properties, and the radio emission in these objects could be due to "starbursts" rather than nuclear activity. The morphology and power of the radio sources in Seyferts do not appear to be correlated.

The radio properties of nearby "normal" galaxies clearly depend on Hubble type. Proceeding from late-type to early-type disk galaxies, the nuclear radio source becomes stronger, morphologically simpler, and more compact (e.g. Hummel 1980, van der Hulst et al. 1981, Condon et al. 1982). Ultracompact flat-radio-spectrum sources are seen almost exclusively in early-type galaxies (Ekers 1978a,b,c, Condon & Dressel 1978, Heckman 1980b). Hummel (1980) and Kotanyi (1981) find elliptical galaxies (especially round ones) to be more radio-loud than SOs. However, Dressel (1981) could not confirm these last results.

In summary, radio power appears to increase with the prominence of the bulge component in galaxies, and radio sources of greater-than-galaxy size seldom appear in galaxies with prominent stellar disks. Apparently some features of systems with disks thwart the development of a large, powerful radio source, independent of the power of the nuclear machine.

SEYFERT GALAXIES The propensity of Seyfert galaxies for early-type spirals has long been known (e.g. Adams 1977), a result which was quantified by Heckman (1978) and from a homogeneous data sample, by Simkin et al. (1980). Here, of course, we ignore the Seyferts with highly disturbed or peculiar morphology.

The absence of Seyfert activity in Sc or later-type galaxies is in accord with conclusions regarding the incidence of radio emission discussed in the previous section. The apparent rarity of Seyfert activity in ellipticals is perhaps more surprising. However, emission-line nuclei (ELNs), as a rule of thumb, are known to be deficient in rich clusters where elliptical galaxies are the most abundant (Section 2.1). Thus the absence of Seyferts in ellipticals may be in part an indirect effect of the cluster environment. Also, there are many classical radio galaxies (ellipticals or related N and D galaxies) whose emission-line spectra are essentially the same as Seyfert nuclei (Grandi & Osterbrock 1978). Finally, 10% of the known Seyfert nuclei lie in galaxies that could perhaps be classed as ellipticals — Mrk 6, Mrk 50, Mrk 78, Mrk 290, Mrk 298, and Mrk 509 (Adams 1977), NGC 2110 (Bradt et al. 1978), and IC 5063 (Caldwell & Phillips 1981, but see also Danziger et al. 1981). Nonetheless it is clear that the typical Seyfert galaxy has a more developed disk than a typical radio galaxy.

Simkin et al. (1980) and Su & Simkin (198O) have suggested that Seyfert galaxies, when examined carefully, possess disks that differ morphologically from non-Seyferts, and hence lie off the usual Hubble sequence (see Section 3.5).

NUCLEAR EMISSION-LINE GALAXIES We now consider "normal" galaxies with weak ELNs. As discussed by Heckman (1980b) and Stauffer (1981), ELNs in late-type galaxies are generally explainable as nebulae photoionized by hot stars and thus not truly active by our criteria. However, the ELNs in early-type galaxies are characterized by low-level, low-ionization, and probably shock-related activity. (Heckman designated such nuclei as LINERs, for Low-Ionization Nuclear Emission-Line Regions.) That LINERs occur preferentially in the same types of galaxies as Seyferts was cited by Heckman to argue that LINERs are true activity at a low level. A close study of LINERs may reveal whether they represent pre-eruptive active galaxies.

BL LAC OBJECTS The fuzz around a small number of BL Lac objects has been studied in order to determine the nature of the underlying galaxy. In all such cases the galaxy strongly resembles an E galaxy (Miller et al. 1978, Weistrop 1981, Ulrich 1978, Miller 1981), both in terms of its morphology and its stellar content.

3.2 Stellar Kinematics

RADIO GALAXIES An enormous number of papers have appeared recently on the stellar dynamics of active galaxies, and the following tentative conclusions emerge:

1. Radio galaxies associated with powerful radio sources apparently rotate more rapidly than normal elliptical galaxies. Illingworth (1977), Schechter & Gunn (1979), and others find that the rotation amplitude of a typical elliptical galaxy is $\lesssim 50$ km s^{-1}. Simkin (1979) first drew attention to the differences between normal elliptical and radio galaxies in their rotation amplitudes. A survey of the recent literature (Simkin 1977, 1979, Appenzeller & Mollenhoff 1980, Efstathiou et al. 1980, Carter et al. 1981, Goss et al. 1980, Graham 1979, Heckman et al. 1981a, Jenkins 1981, Jenkins & Scheuer 1980, Schweizer 1980, and others) shows that for radio galaxies with a power $\gtrsim 10^{24.5}$ W Hz^{-1} at 1420 MHz, the average rotation amplitude is ~ 150 km s^{-1}. We hasten to add that luminous radio galaxies are often associated with D and cD galaxies, and not ellipticals, and Simkin (1979) suggested that the large rotation amplitudes of strong radio galaxies are strongly related to their morphological classification as D galaxies by MMS (Section 3.1). The rotation amplitudes of these radio-loud D galaxies are apparently similar to the bulges of SO galaxies (Kormendy & Illingworth 1981).

Theoretically, however, the relatively large rotation amplitudes of radio galaxies run counter to the proposal of Sparke & Shu (1980) and Sparke(1981) in which a narrow channel in the galaxy's halo (through which the radio-emitting plasma is collimated) is produced by the very small rotation speed of the system. Rapid rotation is also in conflict with the expectation that the gas within the galaxy can freely fall into the nucleus of a galaxy as fuel.

2. Powerful radio sources ($> 10^{25}$ W Hz^{-1} at 1420 MHz) have a projected axis of ejection aligned to within $\sim 10^{o}$ of the galaxy's rotation axis. Less powerful sources show little alignment (misalignments are typically 50^{o}), and the radio, rotation, and isophotal minor axes are often all misaligned with each other (Jenkins 1981). Of course there are specific examples with a high degree of alignment in the low-luminosity radio sources.

Even though the rotation and radio axes are highly aligned in powerful radio sources, the alignment of these axes with the isophotal minor axis is variable in the few cases in which all three axes have been measured. ln NGC 612 (a disk galaxy) all three axes are aligned (Goss et al. 1980); in 3C 33 the rotation and minor axes are misaligned by 20^{o}; and in 3C 98 the misalignment is 58^{o} (Simkin 1979, Palimaka et al. 1979).

NUCLEAR VELOCITY DISPERSION Based on observations of an anomalous increase in the stellar velocity dispersion and departures from a King model at the nucleus of M87, Sargent et al. (1978) and Young et al. (1978) proposed that a compact dark mass, probably a black hole, with a mass exceeding $10^9 M_{\odot}$, lies at the nucleus of M87. Such a black hole might orchestrate the galactic activity in M87 and other active galaxies. This suggestion was supported by further observations of M87 (de Vaucouleurs & Nieto 1979, Jenkins 1980). However, this interpretation of the observations has not met universal acceptance.

Faber (1980) has questioned whether the observations in M87 are unusual and whether their interpretation in terms of a compact mass are required. Duncan & Wheeler (1980) also challenge the interpretive model; they suggest that an anisotropic velocity dispersion can explain the data equally as well. Moreover, Dressler (1980b) finds that the velocity dispersion in the inner $0\farcs5$ of M87 is lower than the compact mass model would predict. Finally Young et al. (1979) observed three other ellipticals for similar signs of a compact mass. The only other galaxy to show photometric peculiarities in its nucleus is NGC 6251, the only radio galaxy in the sample (no kinematic data were obtained). NGC 6251 is six times more distant than M87, and a detailed study of its nuclear region is difficult.

There are only two other classical radio galaxies at distances comparable to M87: M84 (Illingworth et al., in preparation) and NGC 1316 = Fornax A (Jenkins & Scheuer 1980). Neither show a similar rise in velocity dispersion near the nucleus. The kinematic anomalies in the nuclei of M87 and NGC 6251, whatever their origin, are not ubiquitous in radio galaxies.

Heckman (in preparation) has found that radio-loud elliptical galaxies have significantly larger nuclear velocity dispersions and global mass-to-light ratios than radio-quiet ellipticals of the same luminosity. It is clear from this that unless large velocity dispersions are transitory, the ability of an elliptical galaxy to produce radio emission depends more strongly on galaxy mass than luminosity.

SEYFERT DISKS There are several suggestions that a nonaxisymmetric gravitational potential can result in gas flows that might deliver gas to the nucleus of an active galaxy, and virtually all Seyferts show signs of such a potential (Section 3.4). However, the near-nuclear dynamics of Seyfert disks have only been traced extensively in the gas (Section 4.3), which is susceptible to kinematic distortion by the active nucleus.

3.3 Absolute Magnitude

RADIO EMISSION The dependence of radio luminosity on the optical luminosity of radio galaxies was discussed in detail in Section 3.1. To summarize, for radio power $\gtrsim 10^{25}$ W Hz^{-1} at 1.4 GHz, luminous galaxies are far more likely to produce a radio source (probability $\propto L_{\rm opt}^{1.5}$) as discussed by Auriemma et al. (1977), Meier et al. (1979), and Dressel (1981). Below this radio power, more optically luminous galaxies are still more likely to be radio sources, but the dependence is weaker and/or more complex.

Similar patterns are found in other morphological types of galaxies. Dressel (1981) concludes that SO galaxies show a strong correlation between probability of radio emission and absolute magnitude. Unlike E galaxies, the radio emission of SOs tends to be dominated by a compact core. For spiral galaxies, the most comprehensive work is that of Hummel (1981a) who shows that nuclear radio power is directly proportional to the luminosity of the parent galaxy. The same trend holds for total radio emission, but disk emission, which is probably unrelated to galactic activity, frequently dominates the observed radio flux in this case (Hummel 1981a, Gioia et al. 1981). Finally, Heckman (1980b) detected nuclear radio emission in 13 of 20 galaxies with $M_{\rm B} < -20$, and in only 2 of 12 with $M_{\rm B} > -20$.

EMISSlON LINE GALAXIES The luminosity function of Seyfert galaxies has been investigated by Huchra & Sargent (1973) and Terebizh (1980). Both studies conclude that the probability of finding a Seyfert nucleus increases strongly with absolute magnitude, and that almost all galaxies with $M_{\rm B} < -23$ are Seyferts. However, this result is partly circular; in luminous Seyfert galaxies nuclear light dominates the total luminosity (de Bruyn & Sargent 1978, Heckman et al. 1978, Yee 1981), especially in type 1 Seyferts (Weedman 1977b) for which the nuclear luminosity consists largely of nonstellar continuum. This is supported by Terebizh's data. Type 2 Seyferts (narrow permitted lines), for which the nonstellar continuum is very weak (Koski 1978, de Bruyn & Sargent 1978), show little, if any, correlation between absolute magnitude and the probability of becoming a Seyfert galaxy. In any case, no Seyferts have been identified in a galaxy fainter than $M_{\rm B} \sim -18$. Were such objects common they would have turned up in existing surveys as very low-z quasars.

Heckman (1980b) concluded that LINERs, which are found almost exclusively in early-type galaxies, do not preferentially occur in luminous galaxies. Indeed, some examples occur in faint ($M_{\rm B} \sim -18.5$) galaxies. Stauffer (1981) investigated both LINERs and their high-excitation counterparts (HINERs). LINERs are found to occur in galaxies that are typically ~ 1 mag brighter than galaxies with HINERs. ($M_{\rm B} \sim -20.5$ vs. $M_{\rm B} \sim -19.5$.)

QUASARS Studies of galaxies surrounding QSOs are made difficult if QSO distances, as we shall now assume, are cosmological. In fact, only recently is there any evidence whatsoever that the fuzz around QSOs consists of a galactic disk or bulge (Morton et al. 1978, Hutchings et al. 1981) or even starlight (Cowie et al. 1981). Absolute magnitudes of the fuzz in several QSOs average $M_{\rm R} \sim -21.8 \pm 0.8$ ($H_0 = 60$ km s^{-1} Mpc^{-1}), consistent with galaxies of typical luminosities (Wyckoff et al. 1981). Interestingly, the magnitudes range from those like cD galaxies in 3C 273 ($M_{\rm R} \sim -23.2$) to a possible unresolved dwarf in PKS 1510-089 ($M_{\rm R} > -17.4$). Aside from the last faint example and perhaps a few other unresolved QSOs discussed by Hutchings et al., these results are consistent with what is known about Seyfert galaxies. Furthermore, looking at the data of Wyckoff et al., there appears to be no correlation between galaxy magnitude and nuclear luminosity, spectrum of the nucleus, or the shape and size of the radio source associated with the QSO.

BL LACS The spectroscopic studies of Miller et al. (1978) suggest that the host galaxies of BL Lacs are quite luminous. More recent data (Miller 1981) show that the average magnitude of the host is $M_{\rm R} \sim -22.7 \pm 0.6$ ($H_0 = 60$ km s^{-1} Mpc^{-1}), or intermediate between the hosts of QSOs and Seyferts on the one hand and first-ranked cD galaxies in rich clusters on the other. Thus it would seem that BL Lac host galaxies are a relatively luminous population.

In summary, it seems that the probability of activity in galaxies and its degree depend in some way on the luminosity — and, by implication, the mass — of the associated galaxy. This statement is valid for almost every type of galactic activity and morphological class of galaxy. However, with the possible exception of the most luminous galaxies ($M_{\rm R} < -23.5$), most galaxies are not active. Luminosity (mass?), then, is a statistical indication of propensity for activity.

3.4 Bars, Rings, and Disk Anomalies

The significance of morphological anomalies in active galaxies is another subject riddled with vague impression and controversy. Among active ellipticals in noninteracting systems there are few reports of structural peculiarities in the stellar distribution. For this reason, our attention turns to disk galaxies with activity, and of these the population studied most intensively for morphological anomalies is the Seyferts. Adams (1977) studied the morphologies of some eighty Seyferts and reviewed the earlier results and conclusions. More recently Heckman (1978), Su & Simkin et al. (1980 — hereafter SS), and, using extensive new observations, Simkin et al. (1980 - hereafter SSS) have reconsidered differences in disk morphologies between Seyfert and comparable normal galaxies.

It now appears as if there is no statistically significant excess of bars in galaxies having LINERs, flat-spectrum compact radio sources, or Seyfert nuclei (Heckman 1980c, SSS). Heckman further finds that star formation is enhanced in the near-nuclear regions of barred spirals, and this may explain Hummel's (1980) result that the total nuclear (steep-spectrum) radio emission of barred spirals exceeds that of unbarred systems by a factor of two (see Condon et al. 1982). The absence of enhanced nuclear activity in barred systems comes as a surprise; models (e.g. Sanders & Huntley 1976, Sancisi et al. 1979, Huntley 1980, Huntley et al. 1978) and observations (e.g. Huntley 1978, Peterson & Huntley 1980, Peterson et al. 1978) indicate that gas can flow into or near the nuclei of such galaxies. Perhaps the explanation is that the ready availability of food for nuclear activity is no particular problem for spiral galaxies. Alternatively, the flow rate of gas through the nucleus in a barred spiral may be much less than predicted (as recent work by van Albada & Roberts (1981) suggests), or the food may be in an "indigestible" form.

SSS have shown that stellar rings or ring-like structure, unlike bars, are much more common in Seyferts than in normal disk galaxies. However, Seyferts are typically early-type (SO-Sb) disk galaxies (Heckman 1978, SSS), as are ringed galaxies (e.g. Heckman 1978). Thus, SSS should have compared Seyferts to normal early-type (rather than both early and late-type) disk galaxies. We have done this comparison and find only 15% of the normal galaxies have external rings, while SSS find such rings in 43% of their sample of Seyferts. There is no significant excess of inner rings in Seyferts.

Ring-like structure may frequently be a result of a global nonaxisymmetric gravitational potential (e.g. an oval distortion or a nearby companion galaxy). If we take either a bar or ring to indicate a nonaxisymmetric disk potential, we find that all but two of the 28 Seyferts studied by SSS are nonaxisymmetric. The exceptions are Mrk 348, which is known to have a large, ovally distorted H I ring (Heckman et al. 1981c), and IC 5063, which may have no disk at all (Caldwell & Phillips 1981, but see also Danziger et al. 1981).

Model studies by SSS of the structure and evolution of galaxies with nonaxisymmetric potentials show an intriguing result. Under the proper — and fairly restrictive — conditions, galaxies will develop both ring-like structures and a flow rate of $\sim 0.5 M_{\odot}$ yr^{-1} of gas into the nucleus. The disks of Seyfert galaxies will go through phases in which multiple ring-like features change in their relative prominences. Specifically, SSS propose that Seyfert disks have a three-step distribution in radial surface brightness: "(1) an inner disk or ring, (2) an intermediate envelope, bar, or lens, and (3) a faint outer envelope, ring, or pseudoring." (Kachikian & Weedman 1971 suggested a similar description of type 2 Seyfert galaxies based on less uniform data.) Spiral arms appear transiently in the earlier phases of the system's evolution. Later the disk becomes amorphous while the second and third ring components grow in prominence.

For type 1 Seyfert galaxies, SS have carried these ideas further and present evidence that the nucleus evolves along with the disk; As the disk becomes increasingly amorphous, the width of the broad Balmer emission lines in the nucleus increases. This process ends with the production of a powerful double-radio source. While fascinating, this scenario is supported by a very heterogeneous data base in which the objects having the most amorphous disks (and the broadest Balmer lines) are also the most distant objects. The purported correlations are not very clear if only galaxies of comparable redshifts are examined, and thus seeing-related and Malmquist bias problems are likely. Nonetheless the concepts proposed by SS and SSS are of sufficient interest to pursue observationally and theoretically.

3.5 Stellar Populations and Birthrates

Biermann et al. (1979), De Young (1981), and others have suggested that star formation might result from nuclear activity or that star formation and nuclear activity are different manifestations of a common cause (in which case either process may occur independently). M82 is an example of an inactive galaxy undergoing a rapid burst of star formation, Mrk 335 is a luminous active galaxy with no signs of extranuclear stellar anomalies, and NGC 1068 has both an active nucleus and many young stars. In this section we explore whether nuclear activity and the presence of young stars are related and if so, how.

EMISSION LINE GALAXIES Spectroscopy of the nuclei of Seyfert, BL Lac, and radio galaxies (e.g. Costero & Osterbrock 1977, Koski 1978, Miller et al. 1978, Yee & Oke 1978, Wilkinson et al. 1981) have shown that the underlying continuum energy distribution is usually an admixture of featureless power-law and old stellar components; in such systems young stars are inconspicuous. Furthermore, although both young stars and low-level activity are not infrequent at the centers of early-type galaxies, the presence of the two phenomena is not correlated (Heckman 1980a,b). There are some important individual exceptions. In addition to those pointed out by the authors above, there are NGC 1275 (Rubin et al. 1977), 3C 305 (Heckman et al. 1981a), NGC 7582 (Clavel et al. 1980), Mrk 231 (Boksenberg et al. 1977, Kodaira et al. 1979), and Mrk 11 (Ulrich 1978).

Data on the stellar populations in extranuclear regions of active galaxies are sparse. Yee (1981) confirmed and extended the earlier results of de Vaucouleurs & de Vaucouleurs (1972), Smith et al. (1972), Weedman (1973), Penston et al. (1974), and Huchra (1980): The disks of Seyfert galaxies have colors that are normal for their morphological types. Thus far, the only Seyfert with abnormally blue colors outside the nucleus is NGC 1068 (Smith et al. 1972). NGC 1068 exhibits many other signs of recent star formation, such as an extended 20μ emission region (Telesco et al. 1980), bright Hα emission in a ring surrounding the nucleus, presumably from numerous H II regions (Alloin et al. 1981), and an anomalously large abundance of molecular gas (cf. Bieging et al. 1981).

Balick & Heckman (unpublished) have constructed Hα images of some 35 nearby active galaxies (mostly

Seyferts) with the starlight removed. Of these, only 4 galaxies show evidence of abnormal numbers of H II regions for their morphological types. and it is not always obvious that nuclear activity bears any direct, let alone causal, relationship.

Sanders & Bania (1976) show how a nuclear explosion can cause transient rings in which star formation should be active. Large-amplitude resonances in density waves can achieve the same sort of result without help from the nucleus (van der Kruit 1976a). It is worth noting that galaxies with interior rings do not generally show enhanced levels of nuclear activity.

RADIO GALAXIES There is now evidence (Windhorst et al. 1981, Katgert et al. 1979, Spinrad et al. 1981) that star formation in the giant elliptical parent galaxies of radio sources has continued to relatively recent times. Models in which star formation has declined exponentially since galaxy formation (Bruzual 1981, Bruzual & Kron 1980) are successful at reproducing the available photometric (Windhorst et al. 1981) and spectroscopic (Spinrad et al. 1981) data. It is not yet known whether this continuing star formation in giant ellipticals is peculiar to radio galaxies (cf. Butcher & Oemler 1978, Turner 1980a). Heckman (in preparation) has examined the question of the stellar metallicity of active and inactive elliptical galaxies. He finds that active ellipticals tend to have stronger stellar metallic absorption lines than inactive ellipticals of the same galaxy luminosity. It is not yet possible to interpret this unambiguously in terms of a direct causal link between high metallicity and nuclear activity (e.g. it may be that both stellar metal abundance and activity are tied more directly to the galaxy mass than to luminosity).

4 GAS AND DUST IN ACTIVE GALAXIES

The gaseous and dusty components of galaxies are generally believed to be the reservoir of fuel for nuclear activity. Clearly it is important to understand not only the sources of such material, but also how the material can find its way into the nucleus. Since gas and dust can behave as a hydrodynamic fluid, they can dissipate energy and redistribute angular momentum, and thus can fall more easily into an active nucleus than can stars. For similar reasons, a fluid can easily be disrupted by energy released from the nucleus, especially if the nucleus ejects a fluid itself. Consequently, studies of gas and dust distributions and dynamics are of great interest, but interpretation must be made cautiously.

4.1 Dust

Dust lanes and patches are common in many active and inactive ealaxies. In systems later than Sa, the normal content of dust is sufficiently large that only gross anomalies in dust content and structure are useful as potential clues to causes of galactic activity. While many of the best known elliptical radio galaxies show conspicuous dust lanes (e.g. Ceo A, Fornax A, Cygnus A), there are inactive early-type galaxies having dust lanes (e.g. Hawarden et al. 1981), as well as radio galaxies without conspicuous dust lanes.

A striking correlation between dust lane orientation and the alignment of lobes in eight radio galaxies has been noted by Kotanyi & Ekers (1979). A brief literature search shows that for active ellipticals, dust lanes are strongly preferentially oriented along the minor axis (NGC 1316, 2685, 4374, 5128, 5363, Cygnus A, PKS 1934-63, and 3C 293). In one case (NGC 3665) the dust lane lies along the major axis, in another (NGC 3801) dust lanes are found along both the major and minor axis, and in 3C 305 the dust lanes do not lie along any structural or dynamical axis (Kotanyi & Ekers 1979, Sandage 1961, Goss et al. 1980, Bertola & Galleta 1978, Kormendy & Bachall 1974, van Breugel, in preparation). Hawarden et al. (1981) have studied dust lane orientations in 40 active and inactive early-type galaxies and find roughly equal numbers of dust lanes oriented along either the major or minor galaxy axis. It is clear that dust lanes in active ellipticals are not generally counterparts of the relaxed disks of spiral galaxies. As Hawarden et al. (1981), Schechter & Gunn (1978) and others have suggested, dust lanes are probably recent ($10^8 - 10^9$ yr), unrelaxed additions to the active galaxies, perhaps the results of a merger with a gas-rich system, and probably a by-product of the processes that activate the nucleus.

Because of its proximity (~ 5 Mpc), Cen A provides an important opportunity to study the relationships between the dust, the stellar component, the nuclear activity, and the extragalactic environment. The dust and associated gas has been studied by Appenzeller & Mollenhoff (1980), Dufour & van den Bergh (1978), Dufour et al. (1979), Graham (1979), Mollenhoff (1979, 1981), Phillips (1981), Rodgers (1978), Rodgers & Harding (1980), and Telesco (1978). There is general, but not unanimous, agreement that the thick (~ 2 kpc), patchy dust lane is the nonstellar remnant of a spiral galaxy that was tidally disrupted within the past few rotational time scales ($< 10^9$ yr) by Cen A (e.g. Dufour et al. 1979, Tubbs 1980). The "normal" disk heavy element abundances and the distribution of the dust, including the thickness and apparent warps, are taken as evidence of incomplete relaxation of the spiral's remnants as they settle into stable circular orbits. Several tests of this idea have been suggested. (*a*) Unless the original spiral was a very late type, its former nucleus may still be identifiable. (However, no such nucleus has yet been located.) (*b*) During relaxation the disk rotation axis may precess. The S-shaped morphology of the radio lobes in Cen A provides indirect corroboration that this process might occur. (*c*) Parts of the disrupted spiral may have been ejected from the system during relaxation, including some of the gas and dust, and may be observable in the halo of Cen A. (*d*) As described by Gunn (1979), some gas of the spiral can fall into the nucleus to fuel its activity; evidence of such infall may exist in the H I and molecular line spectra of Cen A (Section 4.2). The biggest problem for this merger scenario is that Cen A has no near-neighbors; thus the present chances of a spiral interacting with Cen A are negligible.

4.2 Neutral and Molecular Gas

Gas, like dust, is a common constituent of all spiral galaxies, active and inactive. Unlike dust, gas can be studied through emission lines, making it possible to determine column densities, excitation temperatures, and kinematics.

We first consider early-type galaxies whose gaseous content is normally (but not uniformly) below $\sim 10^{8.5} M_\odot$, i.e. under present detection limits, Nonetheless some ellipticals do, in fact, show substantial amounts of HI. Sanders (1980) has shown that the distance-independent ratio of HI mass to blue optical luminosity ($M_{\rm HI}/L_{\rm B}$ in elliptical galaxies has a bimodal distribution: 70% of ellipticals are gas-poor ($M_{\rm HI}/L_{\rm B} < 0.003$ in solar units) and the remainder are gas-rich galaxies ($M_{\rm HI}/L_{\rm B} \sim 0.03$). As noted by Sanders (1981a) and Raimond et al. (1981), gas-rich elliptical galaxies are generally active. O'Connell & Dressel (1978) find a significant link between the presence of [O II] λ 3727 emission (generally a sign of nuclear activity according to Heckman 1980a) and detectable H I in ellipticals. The analogous link between HI and a compact nuclear radio source is less well established, however.

Spatial-kinematic maps of NGC 4278 and NGC 1052 are now available (Raimond et al. 1981, Knapp et al.

1978a,b, Reif et al. 1978, Bottinelli & Gougenheim 1980, and references within). In the case of the relatively simple system NGC 4278, the HI appears to lie in a spinning disk whose rotation axis does not lie along the minor axis of the galaxy. The observations require a radial component of motion, which may be related to oval orbits in a bar-like gravitational potential, or "sloshing" motions as a recently captured cloud settles into a stable configuration.

Although gas-rich ellipticals are generally active, it is not clear whether active ellipticals, as a class, are gas-rich. Strong radio emission, characteristic of active ellipticals, makes the detection of HI emission difficult in practice. By the same token, such ellipticals are ideally suited for searches of HI in absorption. However, a surprisingly small fraction of radio galaxies, whether ellipticals or spirals, exhibit HI absorption (see reviews by Roberts & Steigerwald 1977, Burke 1978; see also Heckman et al. 1978, Bieging & Bierman 1981, and Burns et al. 1981b). Even so, several radio galaxies exhibit HI absorption: NGC 1275 (Crane et al. 1981, van Gorkom & Ekers 1981 and references therein), Cen A (see below), 3C 293 (Baan & Haschick 1981), 3C 305 (Heckman et al. 1981a), and NGC 315 and NGC 1052 (van Gorkom, private communication) are some recently detected examples. However, HI absorption is as yet undetected even in some bright radio ellipticals with dust lanes crossing near their nuclei (e.g. Cyg A). Presumably the paucity of HI absorption detections reflects the geometry of the HI distribution relative to the radio source (searches for HI absorption in systems in which the radio source is mostly within the galaxy would be interesting in this regard), or it may be that hydrogen is not atomic in most ellipticals (see the recent discussion by Burns et al. 1981b).

Cen A is of particular interest since it shows both HI emission and absorption (Gardner & Whiteoak 1976). Aside from velocities affected by absorption, the HI emission line has a shape typical of late-type systems which, for such galaxies, could suggest that HI extends through the inner regions of the galaxy. An H I mass of $\sim 10^9 M_\odot$ and a total virial mass $10^{11.5} M_\odot$ are suggested. Assuming that no H I has been ejected or converted into nonatomic form, the original spiral may have been a small late-type galaxy.

Gardner & Whiteoak (1976) observed a series of HI and molecular absorption lines against the central parts of Cen A. All of these lines are seen in absorption between 541 and 551 km s^{-1}, close to the HI systemic emission-line velocity of 535 km s^{-1}. Additional weaker HI absorption lines extend redward some 200 km s^{-1} in velocity. High spatial resolution observations at the VLA (van der Hulst & Haschick, private communication) show that the clouds producing these highly redshifted absorption lines are seen only against the radio nucleus, even though there are several other nearby radio sources lying behind the dust lane. Similar redshifted HI absorption lines are seen in the radio galaxies NGC 315, NGC 1052 (van Gorkom, private communication), NGC 1275 (Crane et al. 1981), and in several other kinds of galaxies (e.g. Haynes & Giovanelli 1980, Thuan & Wadiak 1982), but the spatial distribution of the redshifted absorbing material is not known. Gordon & Gottesman (1981) suggest that infalling HI may be common, at least in very-late-type galaxies.

The peculiar motions of gas in the dust lane (Mollenhoff 1981) cannot account for the high-z HI features in Cen A. Thus it is tempting to associate these HI absorption features with clouds falling into the active nucleus, as the observations of van der Hulst & Hasehick strongly suggest. However, several caveats must be stated. First, Mollenhoff (1981) and H. Harris (private communication) present evidence that the systemic velocities of the disk emission-line gas and the system of globular clusters are significantly higher than that of the HI emission. Second. several cases of HI absorption blueshifted by 100 km s^{-1} or more are also known among Seyfert (Heckman et al. 1978, 1981b) and normal (Gottesman et al. 1976) galaxies. In 3C 293 (Baan & Haschick 1981), HI absorption occurs to the blue and red side of the systemic velocity. Detailed maps of HI absorption, together with the collection of a sample of cases that is large enough for statistical investigation, is required in order to understand the significance of these HI absorption features.

The gas-rich disks of spiral galaxies can be a handy reservoir of fuel for galactic activity. HI surveys have been conducted by Heckman et al. (1978 — hereafter HBS), Biermann et al. (1979 — hereafter BCF), and Bieging & Biermann (1981 - hereafter BB), and observations of individual galaxies abound in the literature. The common properties of HI in active spirals, and some notable exceptions, include the following.

1. The HI masses and $M_{\rm HI}/L_{\rm B}$ ratios of active galaxies are generally normal for galaxies of their morphological classes. Yet Mrk 348 remains one of the most extreme examples of large $M_{\rm HI}/L_{\rm B}$ and HI-to-Holmberg radius ratios (HBS, Morris & Wannier 1980, Heckman et al. 1981c). Because of its normal colors (Huchra 1980), Mrk 348 has not recently formed, but star formation may have been delayed or suppressed (Hawarden et al. 1979b). Heckman et al. (1981c) propose that much of the HI in Mrk 348 was stripped from the presently gas-poor spiral NGC 266 about 3×10^9 yr ago; however, the gas has not yet relaxed. Other active galaxies with grossly anomalous surplusses of HI are PKS 1718+649 (Fosbury et al. 1977), Mrk 298 = IC1182 (Bothun et al. 1981b), the "quasar" 0351+026 (Bothun et al. 1981a), and the type I Seyfert galaxy NGC 931 (G. Bothun, private communication). Another important oddball is NGC 1068, which is surprisingly depleted of HI for its luminosity (HBS). In this case, $L_{\rm B}$ may be enhanced by the disk of young stars lying near the nucleus (see Section 3.5).

2. HI profiles of several active galaxies show evidence of missing horns and high-velocity wings, consistent with tidal disruption of their disks (see Section 2.2).

3. HBS noted a propensity for the galaxies with the most luminous nuclear activity to exhibit the most unusual HI properties. It is possible to interpret this in terms of either the causes or results of galactic activity. BB find no correlation between the HI properties of active galaxies and the characteristics of their nuclear spectra or their IR luminosities at 10 μm. However, they did notice a relationship between HI mass, nuclear X-ray luminosity, and optical stellar luminosity, which suggests that the galaxies with the largest bulge luminosities (i.e. masses) are the most active (Section 3.3).

Recent HI studies of other individual active disk and peculiar galaxies include NGC 4151 (Bosma et al. 1977), IC 5063 (Danziger et al. 1981), and NGC 4258 (van Albada & Shane 1975, van Albada 1980). These galaxies have notable characteristics (e.g. 0351 + 026 has a HI line width exceeding 1000 km s^{-1}). NGC 2685, a peculiar SO with a mildly active nucleus, appears to have disks of HI perpendicular to its major and minor stellar axes (Shane 1980).

Finally we mention observations of molecules in active galaxies. Three of the five initial detections of CO (Rickard et al. 1977) were made in highly peculiar galaxies, and galactic activity was first suspected to be related to the production of CO. More recent surveys suggest that active galaxies are probably similar to normal galaxies in their CO properties. NGC 1068 is an outstanding exception; in addition to its abundant CO, H_2 is also plentiful (Thompson et al. 1978), perhaps collisionally excited (Carlson & Foltz 1979). The H_2 is concentrated in a zone comparable in extent to the ring of young stars and HII regions about one kpc from the nucleus (Section 3.5). However, the relevance of this region to the question of the evolution of activity is dubious.

4.3 Extranuclear Ionized Gas

A wealth of extranuclear emission-line regions (ELR) have been studied in the past five years. The relevance of much or all of this information to the causes of galactic activity is uncertain, however. Recombination and cooling times in these nebulae are short (typically $\lesssim 10^7$ yr) compared to dynamical time-scales; this suggests that the agents that ionize and heat the gas must be continuously supplied, presumably directly or indirectly by the active nucleus. Energy estimates ($10^{52} - -10^{55}$ erg in the ionized nebulae, $\gtrsim 10^{58}$ ergs in the nucleus or associated lobes of radio galaxies) add credence to this suggestion. Thus we must view the ionized nebulae with caution because clues to the origin of galactic activity implanted in the gas may be obliterated by the energy sources that power the ionized component.

ACTIVE GALAXIES At the risk of adding credence to speculation, we have chosen to organize the following discussion by the mechanisms proposed to explain the ELRs and the origin of nuclear activity.

Accretion flows in dominant cluster galaxies Such flows are unique, at least in a quantitative sense, to giant cluster-centered ellipticals (or cDs), as discussed in Sections 2.1, 3.1, and 3.3. Ionized gas is observed in nearby cDs, including M87 and NGC 1275, and more than half of thirteen cDs surveyed by Heckman (1981) (see also Fabian et al. 1981). Heckman's limits on the nondetected galaxies do not exclude emission at the intrinsic level of M87. Ford & Butcher (1979), Kent & Sargent (1979), Stauffer & Spinrad (1979), and others find that the filaments in M87 and NGC 1275 are probably collisionally ionized. The galaxies detected by Heckman (1981) have spectra similar to these two closer cDs; moreover, their luminosity correlates with X-ray luminosity and cluster richness, as might be expected for an accretion flow (e.g. Binney & Cowie 1981, Mushotsky et al. 1981; see also Section 2.1). The ELRs probably arise in cool (10^4 K) thermal instabilities, perhaps triggered by the radio source pushing outward through the accretion flow (Ford & Butcher 1979).

In any event, the ELRs are associated with material involved in the flow to the nucleus, and useful abundance and kinematic information can be obtained. In M87 and NGC 1275, abundances are comparable to the respective nuclear (and solar) abundances, and point-to-point velocity differences and line widths are on the order of the sound speed in the adjacent X-ray-emitting gas ($\sim 10^{2.5}$ km s^{-1}; Rubin et al. 1977, 1978, De Young et al. 1980, and other references above). Thus the ELRs and X-ray gas seem to be in close contact.

NGC 1275 is unique in its morphology, multiple redshift systems, and large emission-line luminosity among nearby cD systems. Only the lower of the two redshift systems appears to arise from an accretion flow (e.g. Kent & Sargent 1979).

Encounters and mergers Explanations of the ELRs seen in some active early-type galaxies in terms of a recent encounter or merger have recently become very popular. Fosbury (1981) has suggested that the ELRs in the active ellipticals 2158-380 and 0349-27 are the partially relaxed remnants of disrupted galaxies. The same type of scenario can be (and often has been) applied to active galaxies such as 3C 120 (Baldwin et al. 1980), Cen A (Dufour et al. 1979, Tubbs 1980; in addition see Graham & Price 1981, Phillips 1981), Fornax A (Schweizer 1980), 3C 305 (Heckman et al. 1981a), IC 5063 (Caldwell & Phillips 1981, Danziger et al. 1981), IC 1182 = Mrk 298 (Bothun et al. 1981b), NGC 3310 (Balick & Heckman 1981), NGC 6240 (Fosbury & Wall 1979), NGC 1275 (Rubin et al. 1977, 1978, Kent & Sargent 1979), and the class of NGC 1052/NGC 4278-type emission-line ellipticals (e.g. Fosbury et al. 1978, Raimond et al. 1981, Ulrich et al. 1980).

The higher velocity ELR in the multiple redshift system in NGC 1275 is of particular interest. It has been identified by Rubin et al. (1977, 1978) and Kent & Sargent (1979) as a rotating spiral galaxy, probably a nearly edge-on late-type system, seen projected onto the elliptical. The peculiar properties of the putative spiral (disturbed appearance, blue colors, abundance of giant H II regions) have been cited (e.g. van den Bergh 1977) as evidence against this hypothesis. These peculiar properties cannot be attributed to a dynamical interaction between the spiral and elliptical because the velocity difference between the two galaxies ($\sim$ 3000 km s^{-1}) is so large relative to characteristic galaxian dynamical velocities (e.g. Toomre & Toomre 1972). However, a hydrodynamical interaction between the spiral and the dense X-ray gas centered on NGC 1275 could severely alter the appearance of a gas-rich interloper (e.g. ram-pressure-driven star formation and ablation of the interstellar medium) and might perturb gas near the nucleus of the elliptical so as to facilitate its infall into the nucleus.

Noninteracting active spiral galaxies The mechanism proposed to explain activity in such systems is related to global asymmetries in the gravitational potential, which can deliver gas into the nuclear vicinity (Section 3.4). Observations of gas motions in barred systems by Meaburn et al. (1981) and by Peterson, Huntley, and their collaborators confirm the existence of radial flows near the nucleus. It is thus surprising that barred systems do not show enhanced incidence or luminosity of nuclear activity.

Observations neither confirm nor reject the notion that radial streams induced by nonaxisymmetric potentials fuel nuclear activity. However, few detailed studies of near-nuclear gas motions have been made. Limited kinematical data are available for NGC 3516, an SBO galaxy (Ulrich & Pequignot 1980). Hydrodynamical models by Sanders & Tubbs (1980) of gas flows in ordinary barred galaxies with "slow" bars qualitatively explain the kinematics and the morphology of extranuclear gas in this galaxy. The motions of gas near the nucleus of NGC 1068 (an Sc galaxy with an ovally distorted disk and bright outer ring — e.g. Hodge 1968) are very chaotic (Walker 1968). Some speeds are well in excess of the galaxy's escape velocity (see also Pelat & Alloin 1980). Neither galaxy offers much insight into the origins of nuclear activity.

5 COSMOLOGICAL EVOLUTION OF ACTIVE NUCLEI

Galaxies and their environments have evolved significantly since $z \sim 3$ to 4. The question of this evolution has recently been discussed by Longair (1978), Schmidt (1978), Schmidt & Green (1980), Schmidt (1981), and Wall (1981) on the basis of quasars and radio sources. Turner (1980b), Avni (1981), and Tyson (1981) have raised the caveat of gravitational lensing. To summarize: High-luminosity active nuclei were much more common in the early Universe. Less luminous sources evolve more slowly with look-back time or not at all. The evolution, however, must cease at times before $z \sim 3.5$. Optically selected QSOs evolve more rapidly with z than do radio-selected quasars. Steep-radio-spectrum QSOs may evolve more rapidly than flat-spectrum sources, although this point is disputed (Wall 1981).

Models of the origin and evolution of activity in galaxies must be able to account for the evolution of the strength and number density of galactic activity in the past. Clearly galaxy-galaxy interaction models, ICM accretion models, and other models sensitive to the density of the extragalactic environment will predict evolution of activity at earlier cosmological eras. Stocke & Perrenod (1981) have been able to set some constraints on such processes related to the evolution of QSOs. Cosmological implications of internally generated galactic activity in an evolving Universe have been addressed by McMillan et al. (1981), who show that quasar evolution can be reproduced by a model involving the dynamical evolution of a nuclear star cluster and a massive black hole. Roos (1981a) has investigated the cosmological evolution of the galaxy merger rate and its implications for nuclear activity.

6 PERSPECTIVES

6.1 Summary

We have now reviewed the galactic and extragalactic environment of galaxies with emphasis on how active and normal galaxies may differ in their intrinsic properties.

CLUSTER ENVIRONMENT Location in a cluster appears to be far less important for galactic activity than previously thought. Large, cluster-dominant ellipticals are often active. However, in general, the radio luminosity as a function of absolute magnitude does not differ strongly for cluster and field galaxies, Seyferts, quasars, and emission-line galaxies are less frequently found in the centers of rich clusters than in other relatively sparser environments.

LOCAL GALAXY DENSITY Radio and optical-line emission is enhanced in galaxy groups or pairs compared to isolated galaxies. However, for very luminous activity the situation is less clear. Mergers and interactions appear to be very important for fostering activity.

MORPHOLOGICAL TYPE Extended radio emission and the occurrence of BL Lac-type nuclear activity is most pronounced in elliptical galaxies. Luminous radio sources are frequently identified with D galaxies, which may differ from ellipticals. Radio morphology is relatively compact - and perhaps related to bursts of near-nuclear star formation in many spirals, particularly late-type. Flat-spectrum nuclear sources are seen in early-type spirals and predominately ultracompact SOs. Seyfert and low-level emission lines indicative of activity are seen almost exclusively in early-type galaxies, but may be deficient in ellipticals.

STELLAR DYNAMICS Extended radio sources seem to occur preferentially in elliptical (D?) galaxies, which rotate relatively rapidly. The most luminous radio galaxies exhibit the highest degree of rotation axis-radio axis alignment. Radio-loud ellipticals exhibit higher core velocity dispersions (and hence higher masses) at a fixed galaxy luminosity than radio-quiet ellipticals. Many (or perhaps all) Seyfert nuclei are found in galaxies showing some sign of a global nonaxisymmetric potential (implying noncircular motions); however, classical stellar bars do not appear preferentially in active disk galaxies.

ABSOLUTE MAGNITUDE The propensity for radio emission correlates well with galaxy absolute magnitude (especially for radio galaxies and BL Lacs). The hosts of Seyfert nuclei (and probably quasars) are galaxies of "normal" stellar luminosity. Nuclear activity of any kind avoids dwarf galaxies. More generally, it seems that bulge luminosity, rather than total stellar luminosity, is the critical parameter regarding activity.

STELLAR POPULATIONS Anomalously large star-formation rates are observed in some active galaxies, but cannot be linked statistically to nuclear activity. Radio-loud ellipticals have a higher metal-abundance stellar population at a fixed galaxy luminosity than radio-quiet ellipticals.

DUST Some radio galaxies exhibit conspicuous dust lanes oriented along their minor axes and perpendicular to the radio-lobe axis. Some Seyferts are exceptionally dusty galaxies. Statistical data on the frequency of anomalous dust in active galaxies compared to normal galaxies are not available. Dust is probably ubiquitous in the emission-line regions in active nuclei.

NEUTRAL AND MOLECULAR GAS Gas-rich ellipticals are more likely to be active than gas-poor systems. In spirals there is no clear correlation of nuclear activity and gas content. Some exceptionally gas-rich galaxies are active. HI absorption is seen in several active galaxies, often at a greater velocity than the galactic systemic velocity by about 10^2 km s^{-1}. However, cases of blue-shifted H I absorption are also known, so interpretation is not vet completely clear.

IONIZED GAS Active galaxies often exhibit extranuclear ionized gas, but this is probably more a result of activity than a cause. Study of the properties of extranuclear emission line gas lends support to the idea of galaxy mergers and of cooling accretion flow onto cluster-centered giant ellipticals (two hypothetical causes of nuclear activity). In some cases, highly unusual emission-line regions can be seen outside of active galaxies that pose challenging interpretive problems.

6.2 The Importance of Fluids: Radial Motions

The observations strongly suggest that the nucleus of an active galaxy is in communication with its exterior. The galactic environment can both control the rates of energy and fuel delivery to the nucleus and confine and organize the by-products (radiation and energetic particles) of nuclear activity. Some sort of fluid, presumably aboriginal gas or the debris from disrupted stars, is the most efficient agent for delivering kinetic energy, fuel, and angular momentum to the nucleus.

However, a fluid is likely to be ejected as a by-product of nuclear activity, and outward-directed fluid can limit or arrest the delivery process into the nucleus. Consequently, we consider the question and origin of radial motions in both active and nonactive galaxies. Are radial motions dominated by infall or outflow? Can such motions be directly related to the causes or effects of nuclear activity?

OUTFLOW Oort (1977) summarized the importance of explosive phenomena in a very "normal" galaxy; the Milky Way. Two papers in 1978 (Burton & Liszt 1978, Liszt & Burton 1978) emphasized the need for an expanding, tilted disk to explain gas motions near the Galactic plane. More recently, however, Liszt & Burton (1980) concluded that the data were also compatible with expected radial-streaming motions associated with a bar. Therefore the case for outflow is ambiguous. However, there is much to be understood about motions in the Galaxy. For example, why does ionized gas in the immediate vicinity of the Galactic center have an average radial velocity of more than 50 km s^{-1} (e.g. Wollman et al. 1977) with respect to the Sun?

Radial motions in nearby galaxies have been reviewed by van der Kruit & Allen (1978), and Burbidge's (1970) review is also relevant. The data are extensive and cannot be fully discussed here. Although radial motions near the nuclei of galaxies are not uncommon, an interpretation of motions as infall or outflow is impossible without knowledge of the effects of sky projection. The same holds for active galaxies, even where velocities consistently exceed the escape velocity of the system (see e.g. Heckman et al. 1981b). Balick & Heckman (unpublished) find that the ionized gas in several edge-on active galaxies is confined to the plane (e.g. IC 4329A, in which nuclear outflowing gas has been proposed by Pastoriza 1979, but not supported fully by Wilson & Penston 1979). There are some important counterexamples generally associated with unrelaxed systems (e.g. NGC 2992, which is in an interacting system with NGC 2993, exhibits outflow not confined to a disk; see Heckman et al. 1981b). The uncertainty of the gas geometry is a particularly poignant issue in the case of the complicated active galaxy NGC 1068 (Walker 1968, Pelat & Alloin 1980, Alloin et al. 1981) in which very strong and complex radial motions are observed near the nucleus. Yet in one nearby normal galaxy, M31, outflow from the nucleus appears to be incontestable (Rubin & Ford 1971, Morton & Anderdeck 1976), and a strong case has been made for outflow in M81 (Goad 1974, 1976).

Whether outflow is related to nuclear activity is an independent question. In elliptical galaxies, winds driven by supernovae can sweep the ISM outward in a "galactic wind"(Bregman 1978). Global radial motions can and do occur in galaxies with nonaxisymmetric potentials and without an active nucleus (Section 3.4), in interacting systems (Section 2.2), or near Lindblad resonances and streams in spiral arms associated with density waves (.e.g. van der Kruit & Allen 1978). Schommer & Sullivan (1976) have, for example, interpreted radial motions in NGC 4736 without need of the explosive activity proposed by van der Kruit (1974a, 1976b).

Radial motions are particularly easy to detect in active galaxies owing to their bright emission lines, However, the caveat of "normal" radial motions has been sometimes ignored in the interpretation of the kinematics of Seyferts, most all of which show evidence for oval distortions. For example, the kinematics of the ionized gas in NGC 4151 (Anderson 1974, Fricke & Reinhardt 1974, Simkin 1975) was first thought to indicate violent outflow (or infall) owing to the incorrect identification of the galaxy's rotation axis. Such motions are now believed to indicate rotation plus some noncircular motions associated with the galaxy's fat bar (Bosma et al. 1977, Heckman et al. 1981b). The disturbed galaxy NGC 3310 has very strong noncircular motions, which might have been misinterpreted as outflow were it not for the detailed Hα kinematic studies of van der Kruit (1976a), who showed that density-wave motions also explain the data. Global noncircular motions in the luminous disturbed spiral NGC 253 (Ulrich 1978, Beck et al. 1979, Pence 1981) can be qualitatively understood by models of gas flow in a barrel potential (Pence 1981). However, the motions in the core of the galaxy are apparently dominated by outflow (Gottesman et al. 1976, Ulrich 1978), which may be unrelated to the global oval distortion. Further, at least some active galaxies show little evidence for radial gas motions (e.g. Ulrich et al. 1980, Rubin & Ford 1968). Some inactive galaxies (by our criteria) such as M82 (Gottesman & Weliachew 1977, Cottrell 1978, O'Connell & Mangano 1978, Axon & Taylor 1978, Solinger et al. 1977, Watson & Griffiths 1980), NGC 1569, (Hodge 1974, de Vaucouleurs et al. 1974), and NGC 5253 (Sersic et al. 1972, Graham 1981) have strong radial flows.

Motions exceeding $\sim 10^3$ km s^{-1} are far in excess of the escape velocity of a galaxy of any reasonable mass. It is difficult to envisage such motions as the result of free-fall or rotation. Examples of active nuclei near which such motions are seen include DA 240 (Burbidge et al. 1975, 1978), AO 0235+164 (Smith et al. 1977), and NGC1275 (Section 4.3). NGC1275 is apparently an example of a high-velocity encounter of a spiral and elliptical (i.e. infall) which, if seen at much larger distances, could go unrecognized. Explanations for the other objects are needed.

Despite our warnings concerning the existence and interpretation of radial motions, there are some fairly clear examples of nuclear ejecta in active galaxies. The anomalous Hα/radio arms of NGC 4258 appear to result from collimated outflow from the nucleus (van der Kruit et al. 1972, van der Kruit 1974b, van Albada & Shane 1975, Icke 1976, 1979, van Albada 1980, Sanders 1981b). Heckman et al. (1981a) similarly interpret the bright radio/Hα lobes in 3C 305. Graham & Price (1981) and De Young (1981) propose that nebulae along the NE jet in Cen A are a result of outflow. And, of course, the geometry of radio lobes, jets, etc. strongly supports the idea of collimated outflow in all extended radio galaxies (e.g. Miley 1980). Direct evidence of outflow is seen in expanding nuclear radio sources (cf. Kellermann & Pauliny-Toth 1981). Heckman et al. (1981b), Capriotti et al. (1979, 1980, 1981) and others have argued that the line shapes of Seyfert galaxies are best explained as nuclear outflow, although this interpretation is model-dependent (e.g. Whittle 1981). Blueshifted H I absorption lines observed in three Seyferts (Heckman et al. 1978, 1981b) and a blueshifted radio recombination line in the Seyfert OQ 208 = Mrk 668 (e.g. Bell & Seaquist 1980) further suggest that outflow occurs in at least some Seyferts. The broad blueshifted optical absorption lines in front of a few bright, distant QSOs (Turnshek et al. 1980, Turnshek 1981, Weymann et al. 1981) and their narrower counterparts in the Seyfert galaxies Mrk 231 (Boksenberg et al. 1977) and NGC 4151 (Anderson & Kraft 1969, Cromwell & Weymann 1970, Anderson 1974, Penston et al. 1979) also provide direct evidence for outflow in active systems.

INFALL The evidence for infall is sketchy and infrequent. Of course, the caveats concerning projection effects and the naive interpretation of radial motions being related to galactic activity apply to infall as well as outflow. There is strong indirect evidence for infall in massive cluster-centered ellipticals, in which accretion flows are alleged to exist (Sections 2.1, 4.2, and 4.3). Direct evidence is sometimes found in redshifted H I lines, most notably in Cen A where such lines are unique to the nuclear radio source (Section 4.2). Redshifted optical absorption lines exist, but are very rare in QSOs (see references in the previous paragraph), and the link between such features and galactic activity is speculative.

Of course, there may be selection effects that hide infalling gas from detection. For example, a free-falling fluid will have characteristic speeds approaching the escape velocity, and will heat up until the sound speed and escape velocities are comparable. Such a medium will be characterized by temperatures near 10^6 K (e.g. Silk & Norman 1979, Bregman 1980). A fluid of this type is too hot to detect optically, yet too cool or underluminous to be observed as an X-ray halo. Potentially observable cooling instabilities in the fluid can lead to infall under some conditions (Bailey 1980, Loose & Fricke 1981). Of course, infall will be common if not ubiquitous in interacting systems, because gas in one galaxy is likely to have small angular momentum with respect to the nucleus of the second galaxy for wide ranges of impact conditions. VLA H I studies of radio nuclei in interacting systems will be important in this regard.

It is also possible that both infall and outflow are germane. Three appropriate mechanisms have been suggested.

1. Sanders (1981a) has argued that infall and outflow can occur in alternate cycles. Outflow dominates until the reservoir of fluid is exhausted, then infall takes over until the mechanism that sustains outflow is reactivated. This is the "hot gust" model. Bailey (1980) has a similar model in which intermittent thermal instabilities allow gas to fall periodically onto the nucleus.

2. The outflow may be collimated; this is nearly always the ease in radio galaxies (Miley 1980) and is common in radio Seyferts (Wilson et al. 1980, Ulvestad et al. 1981, Wilson & Ulvestad 1981, and references therein). As suggested by the radio observations, the degree of collimation can be so high that infall to the nucleus in most directions can occur without resistance.

The infalling material may arrive near the nucleus as numerous small dense clouds with a high ratio of mass to surface area. Such clouds, perhaps produced initially in thermal instabilities in an accretion region (Ford & Butcher 1979) or behind shocks (Marscher & Weaver 1979), might move freely through a low-density outbound wind. Taken to an an extreme, the infalling clouds might actually be stars that are disrupted on close approach to the nucleus (Hills 1978, Shields & Wheeler 1978, McMillan et al. 1981, Norman & Silk 1981, Roos 1981b). This last mechanism might be very important in BL Lac objects, which prefer luminous gas-free galaxies as their hosts.

6.3 Causes of Activity

There are several proposed models that offer appealing but incomplete scenarios for the origin and evolution of galactic activity. Examples include accretion flows, interactions and mergers, gas motions in nonaxisymmetric potentials, and periodic ejection followed by infall (hot gusts). Taking the observations and models as a whole and exercising the prerogative of authors of *Annual Review* articles to end their papers in unmitigated speculation, we now attempt to develop a coherent view of the origin of galactic activity and, hence, to point out additional areas for future research.

In the conventional picture two necessary (and perhaps sufficient) conditions for the onset of nuclear activity are the presence of a nuclear "monster" and a supply of "food" (Gunn 1979). The monsters are presumed to be long-lived, compact, and presumably massive objects in galactic nuclei.

Do all galaxies harbor monsters? We would argue that the lack of activity in the nuclei of late-type galaxies, despite the apparent abundance of food (as evidenced by the on-going star formation), means that monsters do not live in such galaxies. Instead, the striking incidence of activity in bulge-dominated systems strongly indicates that the core of a bulge is the monster's favored lair and that monsters are fairly common in systems with massive bulges. Moreover, monsters need not all be alike. Some galaxies may have multiple monsters in orbit about one another whose orbital axis can be an important preferred direction.

Activity is more common in luminous (massive) galaxies, although the dependence is stronger for radio sources than for emission-line nuclei (i.e. Seyfert galaxies and quasars). The form of this dependence suggests that monsters are fed more continuously in the more massive galaxies. Dominant-cluster galaxies would be expected to receive an almost continual supply of food from accretion flows or cannibalization of cluster galaxies. Less massive galaxies may erupt intermittently (Bailey & Clube 1978), perhaps suggesting that food for the monster is only occasionally plentiful. Yet, low-level activity is present even between outbursts in at least a third of all early-type galaxies, so the monsters must get frequent snacks.

The role of galaxy rotation in feeding or fostering a monster needs clarification; despite the naive expectation that food can be more easily supplied to the nucleus in a low angular momentum system, the most menacing monsters are seemingly found in galaxies in which rotation is dynamically important. Perhaps a disk component, even though weak, is required to supply food at a large rate. Better statistical data on radio luminosity and galaxy rotation are needed.

The evidence seems to lend support to a number of currently popular schemes to feed the monster. Mergers and interactions may be generally relevant to nuclear activity, since they can obviously supply the monster with fresh food in the form of gas (Gunn 1979) or, if digestible, stars sent inward on plunging orbits. Interactions may also trigger the growth of oval distortions in the galaxy's gravitational potential leading, eventually, to the deposition of gas at the nucleus (Simkin et al. 1980). Finally ellipticals may periodically accrete their own ejecta from previous hot gusts, a process which conceivably could be aided by the "back-pressure" supplied by the gaseous medium found in compact groups of galaxies.

This description of the care and feeding of galactic activity carries with it the usual obligatory statement "More and better observations are needed." Few of the observational underpinnings of this scenario are based on proper, statistically secure results. Many facets of the problem are complicated by its multivariate nature, and the truly important independent variables are yet to be identified.

6.4 Concluding Remarks

Historically, most observational research has been concentrated on the bright, unusual nuclei of active galaxies or their extranuclear manifestations (e.g. radio lobes, jets). Of course, the nature of the nucleus and the associated bizarre phenomena are important scientific problems. Nonetheless observations that treat active galaxies as galaxies can point the way to understanding the origin and evolution of nuclear activity. This last generally overlooked direction of research may ultimately be more fruitful in understanding the fundamental nature of nuclear activity than the currently popular phenomenological studies.

Future studies will require statistically oriented approaches in order to understand the crucial issue: How do the extranuclear properties of active and quiescent galaxies compare with one another? Such studies need to be conducted for every galaxian attribute listed in the subsections of Sections 2, 3, and 4. Top priority goes to studies of local galaxy density, especially the identification and observational exploration of merging systems. The *Space Telescope* affords important opportunities to study the monsters, asleep or otherwise. Dominant cluster galaxies may prove an immediate and perhaps crucial proving ground for the "monster-feeding" scenario.

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