Ionized Gas Kinematics in Active and Related Galaxies

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ABSTRACT

The kinematics of ionized gas in active (and normal) galaxies is reviewed. For clarity, discussion is divided first by emission region size, and then by galaxy type. Although a wide range of velocity fields are encountered on all scales, a number of recent developments are stressed : large scale outflows in Seyfert and Starburst galaxies (1 – 20 kpc); gravitationally dominated motion on intermediate scales in all galaxies (few $\times 10^2$ pc); radial flows of uncertain direction on small scales in Seyferts (3 – 100 pc); and possible continuity of velocity field in Seyferts down to very small scales ($\lesssim 0.1$ pc, BLR).

1 INTRODUCTION

Ionized gas can be found on many scales in both active and normal galaxies — on large scales $\sim 1-20$ kpc in the body and near environment of the host galaxy; on intermediate scales $\sim 0.1-1$ kpc in the bulge dominated regions; on small scales $\sim 3-100$ pc in the inner bulge cores; and on very small scales $\sim 0.01-1$ pc within the Broad Line Region (BLR). My intention is to review observations which shed light on the kinematics of this ionized gas, recognizing that the velocity fields on one scale may be quite unrelated to those on another.

Studies of ionized gas kinematics focus, of course, on emission lines and their Doppler profiles. First order information comes from the profile center and width, while higher order information comes from profile asymmetry, kurtosis, and substructure, as well as the comparison of these for different emission lines. Additional useful information comes from the host galaxy reference frame and/or gravitational field, which can be obtained from absorption line studies. Observational data is usually obtained in one of a few basic forms. Zero dimensional, single aperture spectra of the nuclear region ($\sim 2'' - 4'' \sim$ few $\times 10^2$ pc) yield a single set of emission line profiles. One dimensional, long-slit, spectra give velocity information along a line — usually the galaxy major or minor axis, or the radio axis. Two dimensional velocity information comes from multiple long-slit, multi-pupil, or Fabry-Perot observations. Not surprisingly, the number of objects studied in these various ways drops dramatically from zero- to one- to two- dimensional studies.

For clarity, our discussion will focus separately on the various different classes of (active) galaxy — Radio galaxies, Seyfert galaxies, LINERs, Starbursts, as well as brief comparisons with normal galaxies and our own galaxy. One aim, of course, is to look for systematic differences between the velocity fields in these different classes of galaxy. Such differences may highlight, for example, the role played by the active nucleus, the radio jet, or star formation.

Before describing the observational results, it is helpful to outline the basic velocity patterns — inflow, outflow, or some other form — and the physical contexts in which they might arise. Due to the extent of the subject, references are far from complete and I apologize in advance for the many omissions.

Inflows : The past decade has seen a large number of studies which aim to identify ways in which angular momentum can be drained from gas, allowing it to fall in towards the nucleus. These include studies of gas motion in spheroidal potentials (*e.g.,* Gunn 1977; Steiman-Cameron and Durisen 1984, 1988; Christodoulou *et al.* 1992; Habe and Ikeuchi 1988), bars (*e.g.,* Sanders and Huntley 1976; Shlosman *et al.* 1989, Athanassoula 1992), satellite passage (*e.g.,* Noguchi 1988), mergers (*e.g.,* Negroponte and White 1983; Barnes and Hernquist 1991; Noguchi 1991), self-gravitating disks (*e.g.,* Bailey 1980; Lin, Pringle, and Rees 1988; Shlosman and Begelman 1989), and magnetized disks (*e.g.,* Balbus and Hawley 1991; Christodoulou 1993). In a spheroidal potential, differential precession can lead to settling and infall on a timescale which depends on the orbital inclination and the form of the potential. While *net* inflow in bar simulations are undetectably low, streaming motions can include radial components which attain a significant fraction of circular velocity. In the case of satellite passage and mergers gravitational torques between the induced gas and stellar bars are sufficiently powerful to allow infall on dynamical timescales. A necessary condition for rapid infall in all these cases is that the gas cool efficiently. The infalling gas can settle into rings or disks which need not share the angular momentum of the host galaxy, leading to the possibility of a kinematically distinct gaseous subsystem or, if the gas forms stars, stellar subsystem. It is also worth noting that over a Hubble time, continued gas dissipation, settling, and subsequent star formation may be the principle factor which governs the shape and depth of the near nuclear potential, generating significantly deeper potentials than would otherwise result from the evolution of purely collisionless systems. Part of this dissipative evolution may, of course, include formation of a massive object.

Outflows : The most commonly considered form of outflow is a wind, driven either by stellar processes or an active nucleus. In the case of stellar input, the kinetic energy from supernova ejecta or winds from OB or Wolf Rayet stars is rapidly thermalized in shocks to produce a very hot bubble which expands, sweeping up and driving shocks into the ISM (*e.g.,* Chevalier and Clegg 1984; Norman and Ikeuchi 1989; MacLow *et al.* 1989). If the hot bubble attains a size comparable to the scale height of the disk gas, it expands rapidly along the minor axis in a "blowout" phase, entraining and carrying ISM well above the galactic plane. In the case of an AGN as the energy source, radiation pressure or radiative heating may drive an outflow (*e.g.,* Begelman *et al.* 1983, 1989), or a particle wind may flow directly from the AGN, perhaps as an MHD wind from an accretion disk (*e.g.,* Blandford and Payne 1982; Heyvaerts and Norman 1989). The final geometry of the wind depends in large part on the geometry of the confining medium and to a lesser extent on the geometry of the energy input, and can range from spherical, through conical, to bipolar. The most extreme bipolar flows are, of course, jets. Although classical radio jets do not themselves contain line emitting gas, they can interact with and accelerate ionized gas leaving emission line signatures. The form of the interaction is not yet clear, though possibilities include acceleration at the jet head through the bow shock (*e.g.,* Taylor *et al.* 1992), entrainment along the jet (*e.g.,* Blandford and Konigl 1979; Coleman and Bicknell 1985) or lateral acceleration around the jet driven by an expanding cocoon (*e.g.,* De Young 1986; Begelman and Cioffi 1989).

Other Forms : The majority of gas in galaxies is, of course, rotationally supported and the inflow/outflow velocity fields described above can be viewed as deviations from this overall graviational motion. Dispersion support may be dominant in contexts where gas has a low filling factor, perhaps as mass loss from bulge stars. Finally, there may be situations in which more general chaotic or turbulent motion is prevelant, either locally or globally, for example in cooling flows.

2 RESOLVED SCALES ($\sim 1 - 20$ KPC)

2.1 Radio Galaxies

The two most recent systematic studies of emission line gas in and around radio galaxies are those of Tadhunter *et al.* (1989) and Baum *et al.* (1992). They measured or compiled long-slit data on the extended emission line regions (EELRs) of ~ 40 low redshift radio galaxies, measuring both global velocity patterns and local velocity dispersions. Adopting the terminology of Baum *et al.*, the radio galaxies can be roughly divided into three kinematic groups. Calm Rotators show global rotation and low local linewidth. They tend to be found surrounding FR-II radio sources whose host galaxies show signs of distortion but are nevertheless isolated or in low density environments. The gas kinematic axis is aligned with the radio axis and the gas is of high ionization, probably photoionized by a hard nuclear spectrum. The interpretation of these sources is that they are recent post merger systems in which the EELR gas has been aquired externally, and is rapidly settling to fuel the nucleus. The overall lifetime is therefore quite short ($\sim 10^8$ yr). Calm Non-rotators have locally narrow lines but show no global rotation. They tend to be found surrounding FR-I radio sources whose hosts are giant elliptical or cD galaxies in a rich environment. A number are found in cooling flow clusters and the gas is generally of low ionization, possibly ionized and heated by shocks and/or the hot gaseous environment. The interpretation of these sources is that their EELRs originate either as cooling flows or as recycled ISM. The processes are therefore quasi-continuous leading to a long lifetime ($\sim 10^9$ yr). Violent Non-rotators share many of the characteristics of the

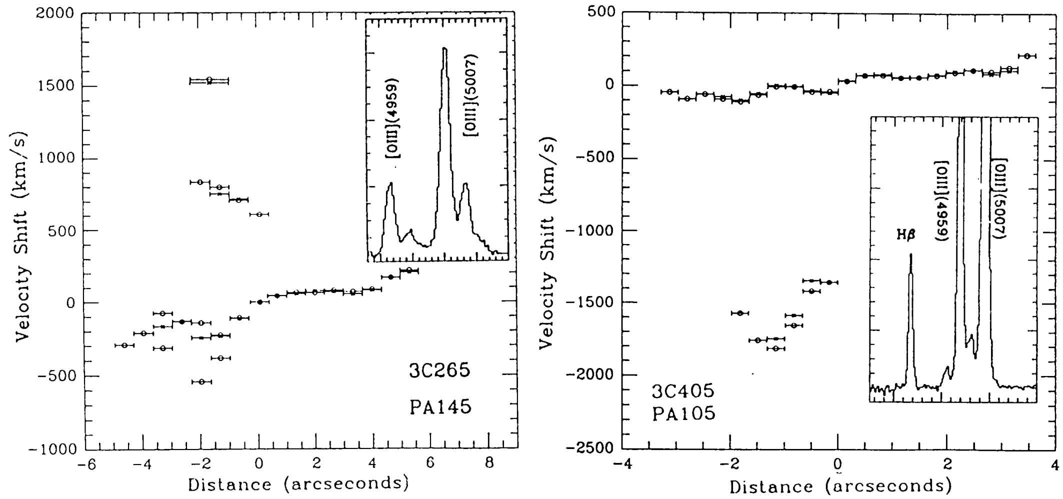


Fig. 1—Emission line velocities for 3C 265 (PA=145, left) and 3C 405 (PA=105, right). [O III]λ4959, 5007 profiles are inset. (From Tadhunter 1991).

calm rotators, while having higher local velocities, possibly related to radio source interactions.

Overall, the global and local velocity amplitudes are consistent with gravitational motion in the potential of the host galaxies. In a few cases ($\lesssim 20\%$) there is also evidence for interactions with the radio source. Two extreme examples of this are shown in Figure 1, taken from Tadhunter (1991). Along the radio axes of 3C 405 and 3C 265, a few arcseconds off nucleus, there are high velocity components red and blueshifted by $\sim 1,000 - 1,500$ km s^{-1}. In these cases it is interesting that the interactions with the ionized gas does not seem to have influenced the stability and propagation of the jets.

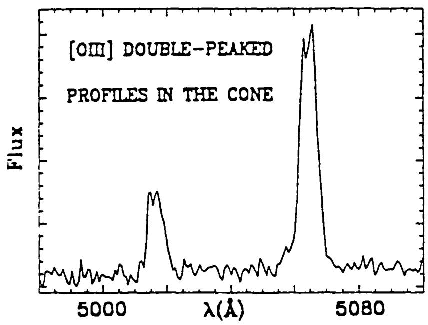
2.2 Seyfert Galaxies

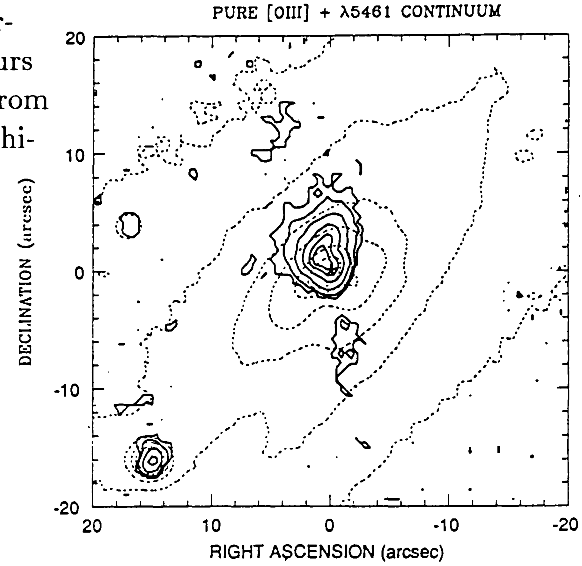
Although the classical narrow line regions (NLR) of Seyferts are highly compact, most are slightly resolved in ground based spectra and there are a number of examples where emission is found extending over a few kpc. In some Seyferts there is a low surface brightness extended component (ENLR) thought to arise from normal disk ISM photoionized by the (possibly anisotropic) nuclear UV source (Unger *et al.* 1987).

Rotation. When resolved, the NLR of most Seyferts show at least some rotation, usually following the overall rotation curve of the host galaxy, as does the low surface brightness ENLR emission. There is evidence that the rotation curves of some Seyferts have large regions of solid body form (Keel 1993) and a local maximum near turnover (Afanasiev and Shapovalova 1993), though there are also cases of very steep, possibly unresolved, rotation (Whittle 1992*b*).

Biconical Outflows. Some Seyferts have well resolved NLR emission with clear signatures of minor axis outflow, probably in a biconical form (*e.g.,* NGC 7582,

Fig. 2—[O III] emission cone superimposed on continuum (dotted) contours in NGC 3281. Double [O III] profiles from cone center shown below. (From Storchi-Bergmann *et al.* 1992).





Morris *et al.* 1985; NGC 1365, Jorsater *et al.* 1984; Edmunds *et al.* 1988; NGC 7469, Wilson *et al.* 1986; NGC 3281, Storchi-Bergmann *et al.* 1992). Figure 2 shows, for NGC 3281, a classic [O III] cone of high excitation gas, with possible counter-cone partially obscured behind the galaxy disk. Spectra show double peaks in the cone center, becoming single peaks at the cone edge, suggesting conical outflow of a few hundred km s^{-1}. It is not yet clear what drives the outflows in these cases. For the Seyfert/Starburst hybrid systems NGC 7582 and NGC 1365, strong circumnuclear star formation may drive the outflows. In NGC 3281, however, there are no obvious signs of circumnuclear star formation and so its outflow may be driven by the AGN.

Jet Driven Outflows. Long slit studies of Seyferts with linear radio sources frequently show red and/or blue shifted components located close to the radio lobes and superimposed on a more general rotation pattern (Whittle *et al.* 1988; Cecil and Rose 1984). In the most clearcut cases the component velocities lie well outside the rotation curve and can switch sign across the nucleus, strongly suggesting a bipolar outflow. In more detailed Fabry-Perot studies of NGC 1068 and M51, high velocities are found in the vicinity of the radio 'jet' although in these cases it is not clear whether the flow is best described by radial acceleration, lateral cocoon driven expansion, or even a fast wind (*e.g.,* Cecil *et al.* 1990; Cecil 1988).

Bar Driven Inflows. NGC 1068 is particularly suitable for studies of extended kinematics because emission is found across the entire galaxy. Extensive Fabry-Perot data in several emission lines has been discussed by Cecil *et al.* (1990). More recent work considers the large scale velocity field (Bland-Hawthorn and Cecil 1993). The iso-velocity map shows an approximately flat rotation curve with spiral (density wave) perturbations beyond $\sim$ 1.5 kpc. At intermediate radii, the contours twist in a manner consistent with elliptic streaming in a barred potential with an orientation consistant with the nuclear bar seen in the near IR. If a model of these components is subtracted from the data, the residuals show 'bi-symmetric spiral streamers' spanning $\sim 20'' - 5''$. This residual pattern seems to fit the classic pattern of gas slowing at a bar shock, losing angular momentum, and flowing inwards with projected streaming velocities ~ 50 km s^{-1}.

Using multiple long slits and a multi-pupil fiber spectrograph, Afanasiev and Sil'chenko (1990) have mapped the velocity fields in several Seyferts, particularly those with linear radio sources. They find unusual velocity components spatially associated with the radio lobes, in overall agreement with the long-slit data from Whittle *et al.* (1988). Afanasiev and Sil'chenko, however, chose to interpret the velocity field not in terms of a jet driven outflow but in terms of inflow along a bar, where shocks at the leading edge of the bar give rise to the emission line components and linear radio structure. In order to explain the high infall velocities in some of the objects, they consider a counter-circulating vortex at the end of an inner bar. Possible objections to such an explanation center on the unusual nature of the Seyfert radio sources and velocity components compared to those of normal barred spirals, suggesting at least some link to the active nucleus. Their work nevertheless points to the need for more detailed two-dimensional studies and the possible roles played by nuclear bars and jets.

2.3 Starbursts

Rotation. To some extent, the kinematic properties of starbursts may depend on the way in which the sample has been selected. For a number of modest luminosity starbursts selected from the Markarian lists, DeRobertis and Shaw (1988) find approximately normal rotation.

Biconical Outflows. However, in samples of more luminous starbursts selected to have high far-infrared luminosities, clear evidence of minor axis outflows are found (*e.g.,* Heckman *et al.* 1990, 1992). In these objects a number of features suggest that an intense nuclear starburst has driven a wind out of the galaxy disk. Images in Hα show cones or bubbles along the minor axis. Recent *ROSAT* images show X-ray emission extended along the minor axis (*e.g.,* Petre 1993). Spectra show double emission lines and generally larger linewidths along the minor axis than along the major axis. Nuclear spectra show extended blue wings suggesting an outflow in which a dusty disk obscures the far side. In NGC 1808, spectra around NaD show blueshifted absorption and redshifted emission, confirming the outward direction of flow (Phillips 1993). In this object the NaD column suggests a neutral component of $\sim 10^8$ M$_\odot$ dominating the mass and at an outflow velocity ~ 400 km s^{-1} providing a kinetic energy $\sim 10^{56}$ ergs, comparable to the energy released in the observed nuclear starburst integrated over the lifetime of the superwind. The existance of these starburst driven superwinds has important implications for the chemical evolution of galaxies since evolved gas can be recycled back onto the disk via this nuclear 'fountain'. At higher redshifts, such enriched halo gas may provide the sites of metal line absorption systems seen in the spectra of background quasars.

Inflows. Inflow of gas to galactic nuclei is thought to predate the episode of rapid star formation which drives the outflowing winds described above. Evidence for such inflows is somewhat indirect, relying on morphological rather than kinematic arguments. For example, a number of studies show that interacting galaxies have enhanced *nuclear* emission relative to normal galaxies — including Hα, FIR, molecular, or radio (*e.g.,* Condon *et al.* 1982; Joseph *et al.* 1984; Keel *et al.* 1985). Presumably, as found in numerical simulations, gas moves down to the nuclear regions as the galaxy responds to tidal interactions. A nice demonstration of this effect comes from our recent Hα objective prism survey of $\sim$ 200 sprial galaxies in 8 nearby Abell clusters (Moss and Whittle 1993). We classify the Hα emission seen on the *prism* plates as compact (nuclear; median size $\sim 7'' \sim 4$ kpc) or diffuse (disk-wide; median size $\sim 18'' \sim 10$ kpc), while we independently classify the galaxy morphology on *direct* plates as disturbed or non-disturbed. Figure 3 shows not only that disturbed galaxies have a much greater likelyhood of being detected in Hα emission ($P_{\rm null} \sim 10^{-4}$) but also that there is a strong association between galaxy disturbance and compact nuclear emission ($P_{\rm null} \sim 10^{-10}$).

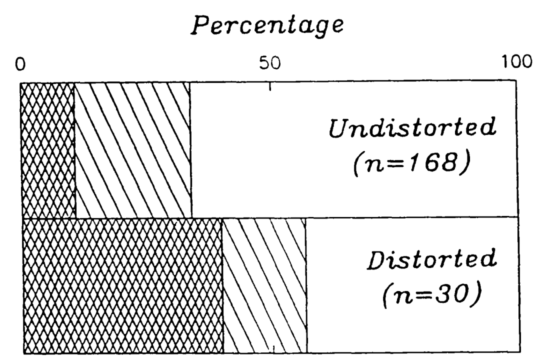


Fig. 3—Fraction of distorted and undistorted spiral galaxies detected with diffuse disk-wide emission (open shade) and compact nuclear emission (dense shade). Galaxy distortion leads not only to enhanced Hα emission, but specifically enhanced nuclear emission. (From objective prism survey of 8 Abell clusters by Moss and Whittle 1993).

3 INTERMEDIATE SCALES ($\lesssim$ FEW $\times\ 10^2$ PC)

Data on ionized gas velocities on intermediate scales ($\sim$ few $\times\ 10^2$ pc) comes from the core of emission line profiles obtained with nuclear apertures. The basic parameter, FWHM, provides a rough estimate of the overall velocity amplitude. While inadequate for providing detailed velocity information it does allow us to identify the dominant acceleration mechanisms acting on the gas on these length scales.

3.1 Seyferts

The fact that early samples of Seyferts clearly had broader lines than starbursts, despite both samples drawing heavily on the Markarian lists, helped fuel the notion that Seyfert lines are broad because of the presence of an active nucleus. Before one can conclude this, however, it is important to test whether the line widths can be explained in terms of simple gravitational velocities in the host galaxy potential. Whittle (1992*a*, *b*, *c*) presents such an analysis for a sample of 140 Seyferts. The principle studies which provide line width information include Feldman *et al.* (1982), Heckman *et al.* (1984), DeRobertis and Osterbrock (1984), Whittle (1985*a*), Vrtilek and Carleton (1985), Busko and Steiner (1988), and the recent high resolution study by Veilleux (1991). Parameters which characterize the nuclear gravitational velocities are host galaxy rotation amplitude, $\Delta V_{\rm rot}$, and the absolute blue magnitude of the host galaxy bulge $M_{\rm bul}$. A more direct gravitational parameter is the stellar velocity dispersion, σ_*, which has only recently been measured for a significant number of Seyferts (Terlevich *et al.* 1990; Nelson and Whittle 1993). Figure 4*a* is taken from Whittle 1992*c* and illustrates the basic result — for most Seyferts the dominant velocity field in the NLR is of gravitational origin and is not driven by the active nucleus. The linewidths correlate well with bulge luminosity, following closely the classic Faber-Jackson (1976) law for elliptical and spiral bulges (dashed line).

There are nevertheless secondary influences which contribue to the scatter on this correlation.

Jets: Seyferts with luminous linear radio sources (plotted as + symbols) have systematically broader lines at a given bulge luminosity, suggesting additional line broadening due to jet interactions. This is the same phenomenon identified in long slit data discussed previously in section 2.2. Digressing for a moment, if we want to identify examples of more powerful jet interactions we should look at objects similar to Seyferts in radio morphology and size but with much higher radio luminosity. Such a class of objects does exist — the Compact Steep Spectrum (CSS) radio galaxies and quasars. A high dispersion study of the CSS class indeed reveals broader forbidden lines than essentially all other classes of active galaxy, confirming the importance of jet interactions in at least some of these objects (Gelderman and Whittle 1993).

Disturbance: Seyferts which appear disturbed or have a nearby companion (plotted as Δ symbols in Figure 4*a*) also have systematically broader lines at a given bulge luminosity. Although such perturbations are identified on large scales, they evidently influence the velocity field in the inner regions.

Bars: The sample of Seyferts with sufficiently clear morphology to assign a reliable bar designation is significantly smaller than the sample plotted in Figure 4*a*. There is some indication, however, that unbarred Seyferts show a tighter correlation on the FWHM *vs* $M_{\rm bul}$ plot than the barred Seyferts, suggesting that bars may also influence the NLR velocity field.

Inclination: By analysing the inclination dependence of the scatter on the correlations between FWHM and both $\Delta V_{\rm rot}$ and $M_{\rm bul}$ it is possible to identify to what extent the NLR velocity field is coplanar with the galaxy disk and therefore to what extent projection effects influence the observed linewidths. It seems that the observed FWHM contain both a projected and non-projected component (in approximately

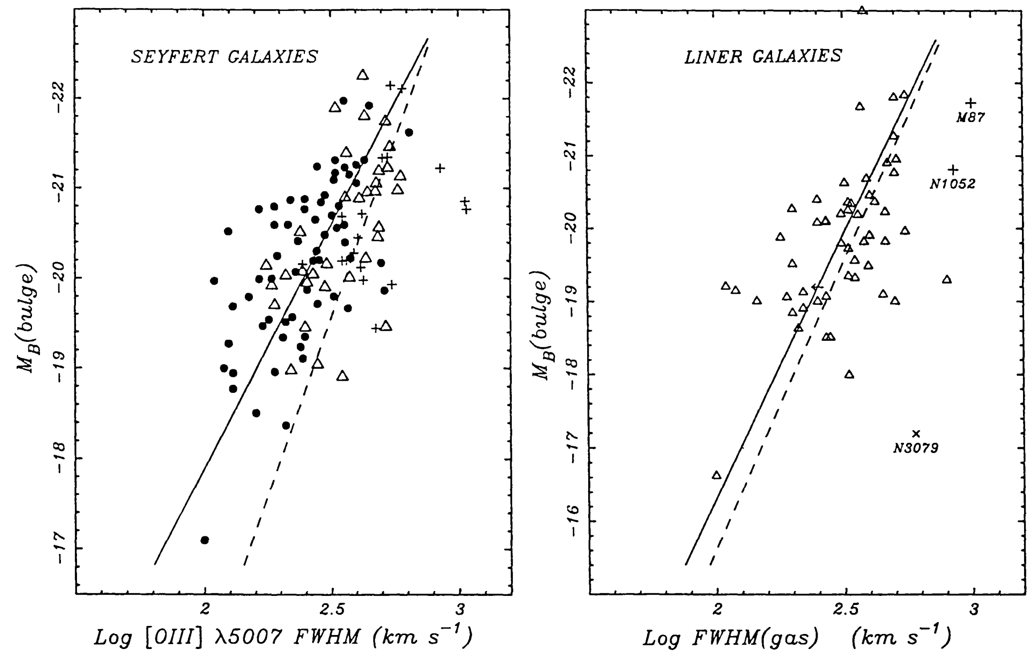
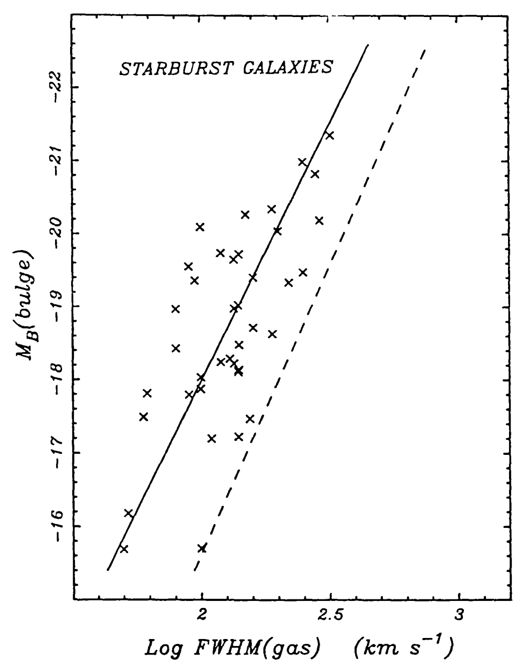


Fig. 4*a*, *b*, *c*—Correlations between emission line FWHM and galaxy bulge luminosity for Seyferts (top left), LINERs (top right), and Markarian Starbursts (right). Best fits given by solid line. Dashed line is Faber-Jackson relation for normal spiral bulges and ellipticals. Correlations suggest gravitational linewidths dominant in each sample. Additional line broadening seen for linear (jet-like) radio sources (+ symbols). For Seyferts, disturbances also cause broader lines (triangles). (From Whittle 1992*c*, 1993).



equal degree). While some of this is likely to result from including normal galaxy rotation inside the nuclear apertures, particularly for the more distant Seyferts, there nevertheless seems to be a genuine non-planar component to the NLR velocity field. Whether this reflects inner disk motion inclined to the galactic plane, or a true turbulent or dispersion supported component is not yet clear.

3.2 LINERs and Starbursts

Repeating much of the above analysis for LINERs and Markarian Starbursts yields very similar results (Whittle 1993). Figures 4*b* and 4*c* show FWHM ([O III], or Hα, or [N II]) *vs* $M_{\rm bul}$ for samples of LINER and Starburst galaxies. Statistically strong correlations again support nuclear gravity as the primary factor determining linewidth. Scatter to the high velocity side can be traced to strong winds (*e.g.* NGC 3079, see Veilleux *et al.* 1993) or probable jet interactions (*e.g.* NGC 1052, M87). Furthermore, overall offsets from the Faber-Jackson relation can be interpreted in terms of mass to light ratio. LINERs fit the F–J relation because their hosts are essentially normal spirals, the Seyferts are somewhat offset suggesting statistically lower M/L (which is also supported by offsets from the Tully-Fisher relation, see Whittle 1992*c*), while the Starbursts are significantly offset suggesting an even lower M/L ratio, as one expects from ongoing star formation.

We can now account for the difference in mean linewidth between Seyferts, LINERs, and (Markarian) Starbursts: Seyferts and LINERs have broad lines because they inhabit luminous early type spirals with high nuclear virial speeds, while (Markarian) Starbursts have narrow lines because they inhabit low luminosity late type galaxies with low nuclear virial speeds.

3.3 Normal Galaxy Nuclei

Since line emission is quite weak in normal galaxy nuclei, especially those of early Hubble type, obtaining reliable kinematic information is quite difficult. Phillips *et al.* (1986) give nuclear Hα or [N II] FWHM for a sample of E/SO galaxies while Bertola *et al.* (1984) and Fillmore *et al.* (1986) present long-slit gas (Hα, [O II]) and stellar kinematics. Roughly speaking, the gas velocities have approximately gravitational amplitude. Inside the bulge, gas usually rotates faster than the stars, but slower than the circular velocity, and often has significant local linewidth. Fillmore *et al.* (1986) suggest the Hα comes from mass loss from bulge stars, reflecting rotation/dispersion dynamics for a time until it settles inwards or expands to become invisible.

3.4 Our Galaxy Nucleus

Despite superficial complexity arising from our proximity, the *overall* gas velocities in the inner few hundred parsecs have gravitational amplitude, in the sense that our galaxy would fit on the relations shown in Figure 4 (*e.g.* at $\lesssim 300$ pc gas has $\Delta V \sim 200$ km s^{-1} and $M_{\rm bul} \sim -18.0$). If we speculate that a Seyfert NLR would be somewhat smaller in a galaxy with $M_{\rm bul}$ of only -18, then it is appropriate to look at gas velocities on scales $\sim$ few pc in the galactic center for the purposes of comparison with Seyferts. The molecular and ionized gas on these scales, while having some non-circular and random components, still follows the rotation curve expected from the

2 μ stellar light distribution. At ~ 1.7 pc the circumnuclear disk is slightly inclined ($\lesssim 20°$) with moderate turbulent velocities. These characteristics are consistent with those found for Seyfert NLRs.

Given the similar origin for the near nuclear (few $\times 10^2$ pc) velocity field of ionized gas in Seyferts, LINERs, Starbursts, Normal galaxies, and even our own Galaxy, one is tempted to speculate that if a strong hard ionizing source were placed at the center of all the non-Seyfert galaxies, we would find kinematically normal NLRs. Thus, the ionization criteria used to define the separate galaxy classes distracts us from their kinematic similarities. It is interesting to further speculate that, apart from ionization degree, the *physical* properties (*e.g.* densities, pressures) of the near nuclear gas in all these classes also has a similar origin.

4 SMALL SCALES ($\sim 3 - 100$ PC)

Information on gas velocities in even more nuclear regions comes from profile bases and wings. Most of the information pertains to Seyfert galaxies. Typical Seyfert [O III]λ5007 profiles have significantly broader wings relative to their cores than do Gaussians, suggesting velocities increase towards the nucleus. A more convincing demonstration of increasing velocities comes from the fact that the FWHM for lines of high critical density are frequently broader than those of low critical density. Because gas density almost certainly increases towards the nucleus, then so too must gas velocity.

In addition to being broader, the [O III] wings are frequently asymmetric, with the blue wing extending to higher velocities than the red wing. For Seyferts the statistical excess of blue asymmetries is very strong, with typical asymmetry parameters A20 $\sim 0.1 - 0.3$ (A20 characterizes the ratio of the difference between the blue and red extents in the base to the total base width). Since the lines are forbidden, the profile asymmetries indicate a significant radial velocity component with dust opacity suppressing the red side. Despite knowing about profile asymmetries for over a decade, the embarrassing fact is that the *direction* of the flow — in or out — is still not known, because the location of the dust is not known. If the dust is distributed throughout the NLR or in a nuclear disk then emission from the far side is suppressed, implying outflow. If the dust is inside the NLR clouds then we see less emission from clouds on the nearside (because they radiate preferentially on the side facing the central UV source), implying inflow.

Thus, we have two clear alternatives, (a) energy input by the AGN drives a fast outflow giving broad asymmetric wings, and (b) the nuclear gravitational potential is steep giving higher nuclear velocities and infall. Although there are a few observational results which have been interpreted to favour inflow (DeRobertis and Shaw 1990; Whittle 1985*c*) these are not conclusive and the question of flow direction is still unsettled. We can briefly weigh the relative merits of each. Outflow certainly seems plausible, even probable — given the proximity to the AGN and its possible energy input to the most nuclear regions. The fact that FIR luminous starburst galaxies also have nuclear blue asymmetries argues strongly, by analogy, for outflow since superwinds are unambiguously identified on larger scales in these galaxies. In this case one suspects a nuclear disk (perhaps the same disk which collimates the ionizing radiation in AGN) blocks radiation from the far side. In addition, there is a moderately good correlation between radio luminosity and wing width suggesting radio source expansion may be driving the outflow. The difficulty with AGN driven outflows is that the wing widths are largely oblivious of the overall level of activity, with similar velocities in modest luminosity Seyferts and luminous quasars.

Although gravity and infall may at first sight seem less appealing, it is still important to test this possibility (*e.g.* Whittle 1992*d*). The strongest general argument for the importance of gravity in the base and wing velocities is that the [O III] profiles have approximately similar shapes — a line with a broad core also has a broad base and wings, and a line with a narrow core also has a narrow base and wings. Thus, if the *core* velocities are gravitational then so are the base and wings. This is supported to some extent by correlations between bulge gravitational parameters and base and wing widths, although the strength of these correlations is less than for the core width.

If wing widths are gravitational, what constraints does this place on the form of the nuclear potential? We need to estimate the relative velocities and radii of the gas emitting the core and wings. Considering the core and wings as a two component Gaussian requires FWHM(core)/FWHM(wings) $\sim 0.4 - 0.6$ to give realistic values of profile kurtosis. To estimate radii, we assume the core gas has density $n_e \sim 10^2$ cm^{-3} (from [S II] line ratios), the wing gas has $n_e \sim 10^7$ (critical density), and the region as a whole has approximately constant radiation parameter, *i.e.* $n_e \propto r^{-2}$. Thus, $r(\text{core})/r(\text{wings}) \sim 10 - 100$. Combining these and characterizing the velocity field as a power law we obtain $V(r) \propto r^{-0.1} - r^{-0.3}$ which, for circular velocity, gives a mass density $\rho(r) \propto r^{-2.2} - r^{-2.7}$ and, for constant M/L, gives a surface brightness $I(r) \propto r^{-1.2} - r^{-1.7}$. Comparing these with data on Seyferts is thoroughly undermined by their nuclear light contribution. Even checking with normal galaxies is difficult since the length scales of interest are comparable to the seeing disk even for nearby galaxies. It does seem, however, that these relatively steep nuclear potentials are not excluded by the limits found from ground and space based imaging. Finally, we ask whether such potentials can readily explain the profile asymmetries in terms of infall. If we associate the difference between red and blue velocities as the radial component and the total velocity as the circular velocity, then observed asymmetry parameters imply $V(\text{radial})/V(\text{circular}) \sim 0.2 - 0.9$. Assuming rapid loss of angular momentum and infall on a dynamical time within the potentials defined above, we require free-fall through $\sim 10\% - 50\%$ of the initial radius to achieve the necessary radial velocity. Whether or not one regards this as reasonable depends on how efficiently angular momentum can be lost, and on whether simple elliptical streaming constitutes a viable velocity field incorporating a strong radial component.

6 VERY SMALL SCALES ($\lesssim$ 0.1 PC, BLR)

Velocities of ionized gas in the broad line region (BLR) are still comparatively poorly understood, despite being easier to observe than velocities in the NLR. Line width *vs* luminosity relations have often been interpreted in terms of gravitational motion in the Keplerian potential of a central massive object, accreting at a significant fraction of the Eddington rate (*e.g.,* Padovani 1989; Wandel 1991). Comparison of line shapes (*e.g.,* Hα/Hβ, Hβ/He II, Hβ/He I, C IV/Lyα) generally indicate higher velocities at smaller radii (*e.g.,* Shuder 1982). This result is supported by the recent extensive variability studies which find shorter lag times for higher ionization lines (*e.g.,* Peterson 1993). Although line asymmetries are common, there are no clear systematic effects and the majority of the variability studies show little evidence for systematic radial flow.

Two interesting results point to a global link between NLR and BLR velocity fields. First, there is a loose but statistically significant correlation between FWHM of Hβ(broad) and [O III]λ5007 (Cohen 1983; Whittle 1985*b*). Second, in at least one object (PG 2251+113, Espey 1993), there is a continuous correlation between line width and critical density, ranging from the forbidden lines through the BLR semi-forbidden lines to the BLR permitted lines, where densities are estimated assuming the lines are emitting at thermal rates. A complete picture of the nuclear regions must account for these kinematic correlations which span 5 decades in radius. If the BLR velocities are indeed tied to a central object, then we require a globally coherent nuclear potential spanning the bulge, the inner nucleus, and the central object itself.

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