The Spheroidal Component of Seyfert Galaxies

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Abstract. We use measurements of the stellar and gaseous kinematics for a large sample of Seyfert galaxies to examine properties of the host galaxy and their relationship to the active nucleus. We find that Seyferts are offset from the Faber-Jackson relation for normal galaxies having brighter bulges at a given velocity dispersion than normal galaxies. This indicates that Seyferts have lower mean mass-to-light ratios than normal galaxies and therefore younger stellar populations. Comparing gas and stars, we find that the kinematics of ionized gas in Seyferts are largely due to gravitational motion in the host galaxy potential. Additional acceleration of emission line gas can occur in objects with kiloparsec-scale linear radio sources and in interacting or morphologically disturbed galaxies. We also find correlations between the emission line and radio luminosity and the stellar velocity dispersion suggesting a link between the host galaxy potential and the strength of the NLR emissions.

We also discuss some results from Hubble Space Telescope snapshots of a sample of 52 Markarian Seyfert galaxies. A number of these show small scale-bars and double nuclei. Also the nuclei of type 1 – 1.5 Seyfert galaxies are dominated by strong point sources, while those of Seyfert 2 galaxies tend to be resolved and resemble normal bulge luminosity profiles. This suggests that the nuclear continuum observed in Seyfert 2 galaxies is extended, covering several tens of parsecs or more, in agreement with unified models of active galactic nuclei.

1 Introduction

Activity in galaxies is a phenomenon of the nucleus — the deepest part of the gravitational potential. It is natural, therefore, to consider the possibility that the host galaxy plays a critical role in the formation and development of the active nucleus. The parameter which perhaps best scales with the depth of the gravitational potential is the nuclear stellar velocity dispersion, σ_*. Until recently relatively few measurements of σ_* have been available for active galaxies. We have therefore obtained stellar kinematic measurements for a large sample of Seyferts to address a number of fundamental questions regarding the host galaxy and its relationship to the active nucleus. Are the dynamics of Seyfert bulges different from those of normal galaxies? What physical processes accelerate emission line gas in the narrow line region? Are these processes related to the host galaxy or to the active nucleus? What links exist between the emission from the active nucleus and the host potential?

2 Background

Several studies of Seyfert galaxies have discussed the possibility of a virial origin for the kinematics of ionized gas in the narrow line region (NLR). For example, Wilson & Heckman (1985) plotted the FWHM of the [OIII] λ5007 emission line against σ_* for a sample of Seyferts and LINERs using data obtained from the literature. They found roughly equal gas and stellar velocity widths with considerable scatter. Whittle (1992a,b) using *indirect* virial parameters $V_{\max}$, the maximum of the rotation amplitude of the galaxy (obtained from rotation curves and HI profiles), and M_{bul}, the bulge magnitude, found that for most Seyferts the kinematics of emission line gas have a gravitational origin. However, Seyferts which harbor nuclear kiloparsec-scale linear radio sources have emission lines considerably broader than expected for normal gravitational motion. In these objects there is an additional acceleration mechanism which is most likely related to the interaction of the line emitting gas with the radio plasma ejected from the nucleus. There have also been indications that the nuclear radio luminosity scales with the optical luminosity of the host galaxy (Meurs & Wilson 1984, Edelson 1987, Whittle 1992b).

3 Sample and Observations

To examine these issues further we have obtained stellar and gaseous kinematic measurements for a sample of 85 objects: 73 Seyferts, 9 LINERs, 3 normal galaxies (Nelson & Whittle 1995). This increases the number of stellar velocity dispersion measurements available for Seyferts by roughly a factor of 3. Where possible we have combined our measurements with previously published values (*e.g.* Whitmore *et al.* 1985; Terlevich *et al.* 1990) to yield a best value for σ_*. We generally find good agreement between these measurements and our own with no systematic trends (see Nelson & Whittle 1995 for a comparison).

The primary difficulty in measuring the stellar kinematics in active galaxies is obtaining high signal-to-noise spectroscopy of the stellar absorption lines. This is most difficult in objects with strong featureless continua (Seyfert 1 galaxies) which dilute the absorption lines. In the near-IR, however, the strength of the nuclear continuum emission relative to the host galaxy starlight is considerably reduced. We have therefore obtained spectroscopy in two wavelength ranges. The first, in the near-infrared, is centered on the Ca II triplet absorption lines. The second, in the visual, is centered on the Mgb absorption lines and includes the [OIII] λ5007 emission line. Systemic velocities and velocity dispersions were obtained using the cross-correlation method (Tonry & Davis 1979) and the widths of emission lines were also measured.

4 The Faber-Jackson Relation for Seyfert Galaxies

Seyfert and normal galaxies can be compared using relationships between virial parameters. In this paper I will describe our results for the Faber-Jackson relation usually stated as $L \propto \sigma_*^n$, where L is the luminosity of the spheroidal component, and the exponent is typically $n \simeq 3-4$. For the Seyferts we have applied a correction for the luminosity of the active nucleus based on the fluxes of the emission lines and estimates of the strength of the featureless continuum. In addition, since surface photometry separating bulge and disk light is not available for our sample we use the relationship between Hubble type and bulge-to-total ratio obtained by Simien & de Vaucouleurs (1986) to convert total magnitudes to bulge magnitudes. The results are shown Figure 1.

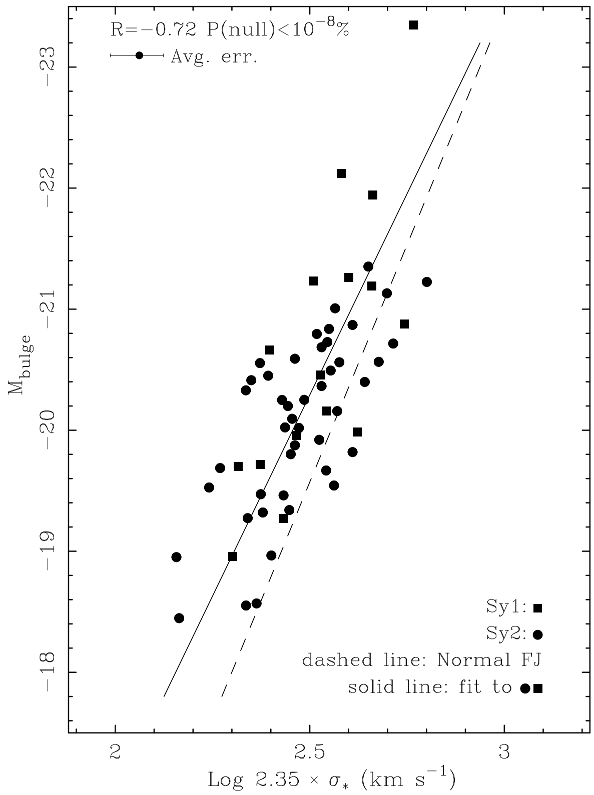

Fig. 1. The Faber-Jackson relation for Seyfert galaxies. Note that the velocity dispersion is plotted as $\log 2.35 \times \sigma_*$.

We find a strong correlation for the Seyferts similar to that found for normal galaxies with a best fit (solid line) yielding a value for the exponent $n \simeq 3$. The tightness of the correlation indicates that our σ_* values are reliable. More importantly, it suggests that Seyferts have essentially normal stellar kinematics. However, the dashed line shows the Faber-Jackson relation for normal galaxies determined by Whittle (1992b) using published data for normal ellipticals and spiral bulges. Notice that the Seyferts are offset from this relation having lower σ_* at a given value of M_{bul} ($\Delta \log \sigma_* \simeq -0.1$) or alternatively having brighter bulges ($\Delta M_{bul} \simeq -0.6$ mag) for a given σ_*. We believe this offset is real since we consider our σ_* values to be accurate, the mean correction for AGN light is small ($\langle \Delta m_A GN \rangle = 0.04$) and the Hubble types used for the bulge corrections would have to be systematically 2 stages too early (Sa is really Sb) to account for the effect (see Nelson & Whittle 1996, hereafter NW96).

Why should Seyferts be offset from the Faber-Jackson relation for normal galaxies? One possibility is that Seyferts have massive black holes which alter the nuclear stellar kinematics. However, the observed shift is in the wrong direction since we would expect higher values of σ_* in objects with massive black holes. Furthermore, our apertures are too large ($\sim 1-2''$ corresponding to several hundred pc) to detect the kinematic influence of even a very large black hole.

Spheroidal stellar systems follow a planar relationship in the parameter space defined by σ_*, M_{bul} and $\langle \mu \rangle$, the mean surface brightness, known as the fundamental plane. The Faber-Jackson relation is a projection of this onto the σ_*-M_{bul} plane. Thus it is possible that Seyferts, although offset from the Faber-Jackson relation, lie on the fundamental plane but have systematically different surface brightnesses. If true, Seyferts would have fainter surface brightnesses than normal galaxies by ~ 1 mag. We consider this possibility unlikely since Seyferts are generally considered to be systems with prominent bulges, although surface photometry of Seyferts explicitly separating bulge, disk and nuclear emission is clearly important.

The most likely explanation of the Faber-Jackson offset is that Seyferts have lower mean mass-to-light ratios, indicating younger stellar populations than those found in the bulges of normal galaxies. Comparing the Faber-Jackson residuals for the Seyfert and normal galaxies we find that the Seyferts, although shifted, are actually less scattered (NW96). In fact if we interpret these residuals solely in terms of differences in M/L we find that Seyferts do not have excessively low M/L but rather seem to avoid objects with high M/L. Thus, those systems which have only small amounts of interstellar gas in their nuclei and are unable to sustain even moderate star formation rates make poor candidates for Seyfert galaxies. We have also found that Seyferts follow the same relationship between rotation amplitude, $V_{\max}$, and σ_* as normal galaxies suggesting normal stellar kinematics and that it is the photometric parameter, M_{bul}, and not the kinematic one, σ_*, that is primarily responsible for the offset (NW96).

5 Stellar and Gaseous Kinematics in Seyfert Galaxies

We now turn to a comparison of the stellar and gaseous kinematics in Seyfert galaxies. In Figure 2 we plot the FWHM of the [OIII] $\lambda 5007$ emission line against

$2.35 \times \sigma_* = \mathrm{FWHM}_*$. The Seyferts are loosely grouped around the $X = Y$ (dashed) line with a moderately strong correlation and a number of objects showing rather high emission line widths relative to their stellar widths. Thus for most objects it appears that $\mathrm{FWHM}_{[\mathrm{OIII}]} \simeq \mathrm{FWHM}_*$. This suggests that the primary influence on the NLR kinematics is the host galaxy potential and confirms Whittle's (1992a,b) previous results using indirect virial parameters.

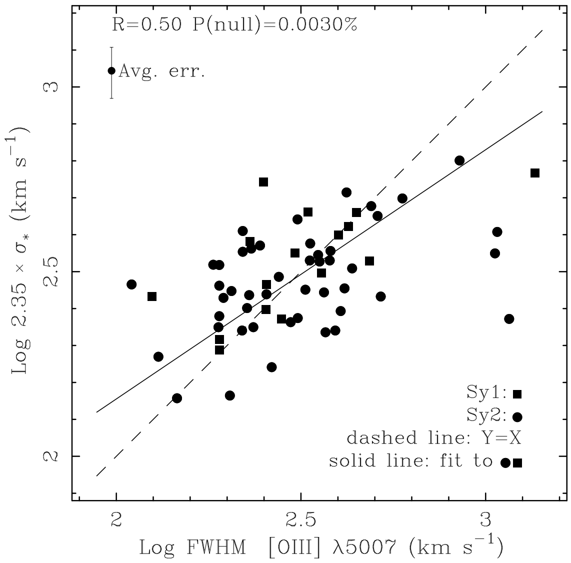

Fig. 2. $\mathrm{FWHM}_{[\mathrm{OIII}]}$ vs. FWHM_* is shown. The solid line is a fit to the data and the dashed line shows $X = Y$.

We note however that the scatter in this diagram is larger than the measurement error indicating that a significant portion of it is real. (The mean error on σ_* is indicated in the upper left corner of Figure 2). Thus we can look for secondary influences on the gas kinematics by searching for trends in the scatter about the mean relation.

We first consider trends with radio morphology. Four of the five objects with the largest emission line widths (NGC 1068, NGC 1275, Mkn 78, Mkn 3) are known to have linear radio sources. The fifth (Mkn 622) may also be a linear radio source because of its peculiar rectangular shaped [OIII] profile which is considerably different from its much narrower Hβ line. Flagging other objects with linear radio sources also shows a tendency for the more luminous of these to lie on the high emission line width side of the fit to the remaining objects (NW96). A similar deviation for linear radio sources was found by Whittle (1992a,b). These results suggest that interaction between the radio plasma and the ionized gas provides additional acceleration and broadens the emission lines.

We also find that interacting and morphologically disturbed objects tend to have higher emission line widths at a given σ_* than the remaining galaxies (NW96). Thus, galaxy interactions can also perturb the NLR velocity field. Barred galaxies show only a weak tendency to have broader lines at a given velocity dispersion and instead are more scattered about the mean relation. Similar results were found by Whittle (1992a,b).

6 Active Properties and the Gravitational Potential

We now consider links between the host galaxy and properties more directly associated with the active nucleus. We begin by noting that Seyfert type was not a distinguishing parameter in any of the previous analysis. If the observed differences in Seyfert 1 and Seyfert 2 galaxies are due to differences in the orientation of an obscuring molecular torus, as postulated in unified models of AGN, then we conclude that the kinematics of stars and gas show no preference for motion in the plane of the torus.

In Figure 3 we plot the radio luminosity at 1415 MHz, L_{1415}, versus σ_* showing a moderately strong correlation. Objects flagged with + symbols are linear radio sources and have higher radio luminosity for a given value of σ_*. A similar correlation exits between the luminosity of the [OIII] λ5007 line and σ_*.

These relationships demonstrate that the strength of the emission from the NLR scales with the depth of the host galaxy potential. The simplest explanation is that galaxies with more massive bulges have more powerful central engines perhaps as a result of more massive nuclear black holes. However, it is also possible that physical conditions in the NLR are set by the bulge potential. For example, the pressure in the hot ISM of the bulge may well depend on the depth of the potential. Since the emissivity of the radio plasma depends on the pressure, more luminous radio sources may be produced in galaxies with more massive bulges all other things being equal. We have also found that this correlation extends to the cores of radio galaxies (NW96) suggesting a continuity in the galactic scale radio properties of radio quiet (e.g. Seyferts) and radio loud AGN.

7 HST Snapshot Imaging of Markarian Seyferts

We also discuss some results from an imaging survey of 52 Seyfert and 50 non-Seyfert Markarian galaxies obtained with the Hubble Space Telescope (HST). These observations were taken using WF/PC-1 in a near-infrared bandpass (the F785LP filter) which is virtually free of emission lines. Therefore, these images are almost entirely continuum emission from starlight and nuclear processes. The goals of this project are to study the small-scale structure in Seyfert galaxies and to examine the host galaxy bulge. We find that several galaxies possess

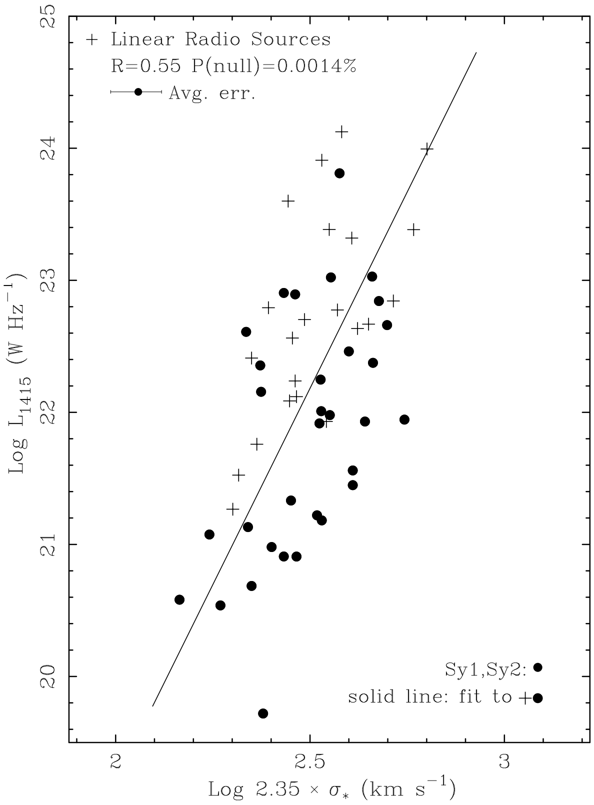

Fig. 3. Radio luminosity at 1415 MHz is plotted against σ_*. We find a moderately strong correlation and a significant tendency for objects with linear radio sources to have relatively higher [OIII] luminosity at a given σ_*.

stellar bars less than a kiloparsec in length and several others have double nuclei (MacKenty *et al.* 1994, MacKenty *et al.* 1996).

We have also found a striking difference in the appearance of Seyfert 1 and Seyfert 2 nuclei in this sample (Nelson *et al.* 1996). The nuclei of Seyfert 1 galaxies are dominated by a strong point source consistent with being the nuclear continuum source viewed directly. Seyfert 2 galaxies by contrast are weaker, often resolved and have luminosity profiles typical of normal bulges. Since dominant point sources are not detected in the Seyfert 2s the featureless continuum emission seen in these objects must arise in an extended source perhaps as large as $50 - 100$ parsecs across. In unified models of AGN the continuum seen in Seyfert 2 galaxies is seen only as scattered light “reflected” over the edge of the obscuring molecular torus (see *e.g.* Antonucci, 1993) and is therefore highly polarized. However, Tran (1995) has found that a substantial amount of nuclear continuum is unpolarized and thus viewed directly. Another possibility is that since the profiles of Seyfert and non-Seyfert Markarian galaxies are similar, there may be a substantial contribution from circumnuclear star formation in the type 2 Seyferts. All of these possible contributors to the continuum emission in Seyfert 2 galaxies are expected to be extended sources in agreement with our observations.

8 Summary

In order to study the relationship between the host galaxy and the active nucleus in Seyfert galaxies we have obtained stellar and gaseous kinematic measurements for a large sample. Our results show that Seyfert galaxies follow a tight relation between σ_* and M_{bul} similar to the Faber-Jackson relation although offset from the one found for normal galaxies. This indicates that Seyfert bulges have lower mean M/L than those in normal galaxies suggesting younger stellar populations. We have also found that the gravitational potential is the primary influence on the NLR gas kinematics. Secondary influences are related to the effects of kpc scale linear radio sources and galaxy interactions. Correlations of emission line and radio luminosities with σ_* show that the mass of the bulge is also linked to the strength of the NLR emission.

Results from a WF/PC-1 imaging survey of Markarian Seyfert galaxies are also reported. We find that a number of these objects contain double-nuclei and small scale bars. Also differences in the appearance of Seyfert 1 and Seyfert 2 nuclei indicate that the featureless continua in the type 2s are likely to be extended sources in agreement with expectations from unified models of AGN.

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