1

Velocity Dispersion and Black Hole Mass in Seyfert 1 Galaxies

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Abstract

Bulge stellar velocity dispersions, σ_*, in Seyfert 1 galaxies are combined with the $M_\bullet - \sigma_*$ relation to validate reverberation mapping as a means of determining nuclear black hole masses. Seyfert galaxies follow the same relation as non-active galaxies, indicating that reverberation mapping is consistent with other methods. A similar result is obtained using new high resolution profiles of the [OIII] λ 5007 line for PG quasars. Reconsidering the $M_{bul} - M_\bullet$ relation, we attempt to explain differences between Seyfert and non-active galaxies. We suggest that Seyfert bulges are systematically brighter than non-active galaxies, having lower M/L and younger stellar populations.

1.1 Introduction

Reverberation mapping techniques have been successfully applied to the broad line regions (BLR) of three dozen AGN providing measurements of the central black hole mass, $M_\bullet$ (e.g. Peterson's contribution to these proceedings). The primary assumption is that the BLR gas dynamics are dominated by gravity. This is supported by the Keplerian decline in velocity with radius which has been found in NGC 5548, NGC 7469 & 3C 390.3, (Peterson & Wandel 2000). The recent discovery of a correlation between $M_\bullet$ and the bulge stellar velocity dispersion, in normal galaxies (Gebhardt et al. 2000a hereafter G2000; Ferrarese & Merritt 2000) suggests a straightforward method for verifying these reverberation mapping $M_\bullet$ measurements.

1.2 AGN and the $M_\bullet - \sigma_*$ Relation

Longslit spectroscopy of Seyfert 1 galaxies with reverberation mapping $M_\bullet$ values was obtained with the KPNO 4-meter telescope in April and November 2001. The details of the Ca II Triplet spectroscopy are described in Green, Nelson and Boroson (these proceedings).

Figure 1.1 plots $M_\bullet$ vs. σ_* for 14 active galaxies and the normal galaxies from G2000. The solid line shows the fit from Tremaine et al. (2002). Due to the small sample size we prefer not to perform a fit to the Seyferts. Nevertheless, we find that Seyferts appear to follow the same relation as normal galaxies in agreement with similar studies (Gebhardt et al. 2000b, Nelson 2000, Ferrarese et al. 2001). These

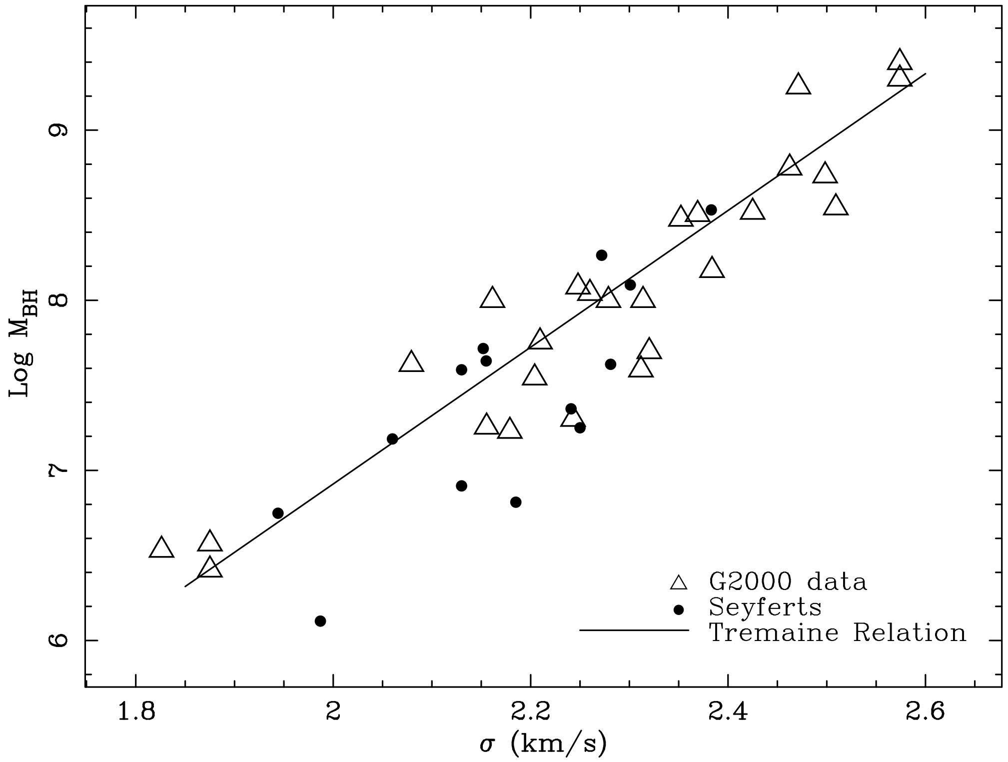

Fig. 1.1. The $M_\bullet$ — σ_* relation is shown for Seyfert galaxies ($\bullet$) and for normal galaxies ($\triangle$) from Gebhardt et al. (2000). The solid line is the fit from Tremaine et al. 2002).

results verify that the black hole masses obtained from the reverberation mapping technique are comparable to those obtained from modeling of the stellar dynamics.

1.3 [OIII] Line Widths in PG Quasars

Since absorption lines in bright AGN are difficult or impossible to measure, Nelson (2000), using published line width measurements, explored the use of [OIII] line width as a replacement for σ_*. We have recently obtained [OIII] profiles for all PG quasars with $z < 0.5$ using the Kitt Peak 4-meter telescope. Results of a similar study are reported in Green, Nelson and Boroson (these proceedings) and in Boroson (2003). Preliminary results for the reverberation mapped quasars (Kaspi et al. 2000) are shown in Figure 1.2. Seyfert galaxies from the literature with high quality [OIII] profiles are also plotted. As found in Nelson (2000), [OIII] lines are correlated with $M_\bullet$ and closely follow the relation found using stellar velcoity dispsersion, although with increased scatter. This suggests that in the absence of stellar kinematic measurements, gas kinematics can be used to infer the virial speeds

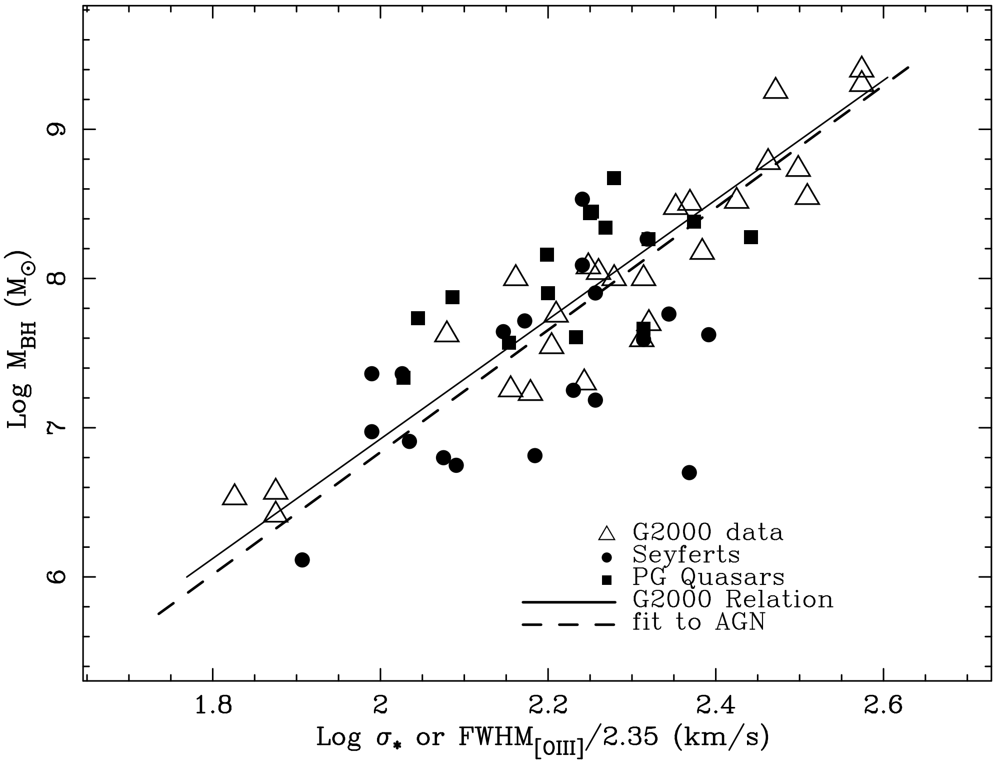

Fig. 1.2. [OIII] emission line widths converted to σ_* are plotted on the $M_\bullet$ — σ_* relation.

and therefore the black hole masses, but with less accuracy. Further analysis of the entire sample including the influence of profile shape are planned.

1.4 Lower M/L in Seyfert Bulges

Previous comparisons of active and normal galaxies using the correlation between $M_\bullet$ – M_{bul} found offsets between active and normal galaxies suggesting either a systematic trend for reverberation mapping to underestimate $M_\bullet$ by a factor of ∼5 (Ho 1999), or that black holes in AGN are smaller than in non-active galaxies of the same M_{bul} (Wandel 1999). Having demonstrated good agreement between black hole mass estimates determined from stellar dynamical techniques and from reverberation mapping, we now consider the origin of the differences in $M_\bullet$ – M_{bul}.

We suggest that these discrepancies can be interpreted as a difference in the mean age of the bulge stellar population in Seyfert and normal galaxies. Nelson & Whittle (1996) plotted the Faber-Jackson relation ($L \propto \sigma^{n}, n \simeq 3-4$) and found that Seyferts were offset from normal galaxies, with Seyfert bulges brighter by at a given σ_*. This most naturally suggests a lower M/L for Seyferts perhaps as a result of higher recent star formation rates. In figure 1.3 we reproduce the Nelson & Whittle (1996) result

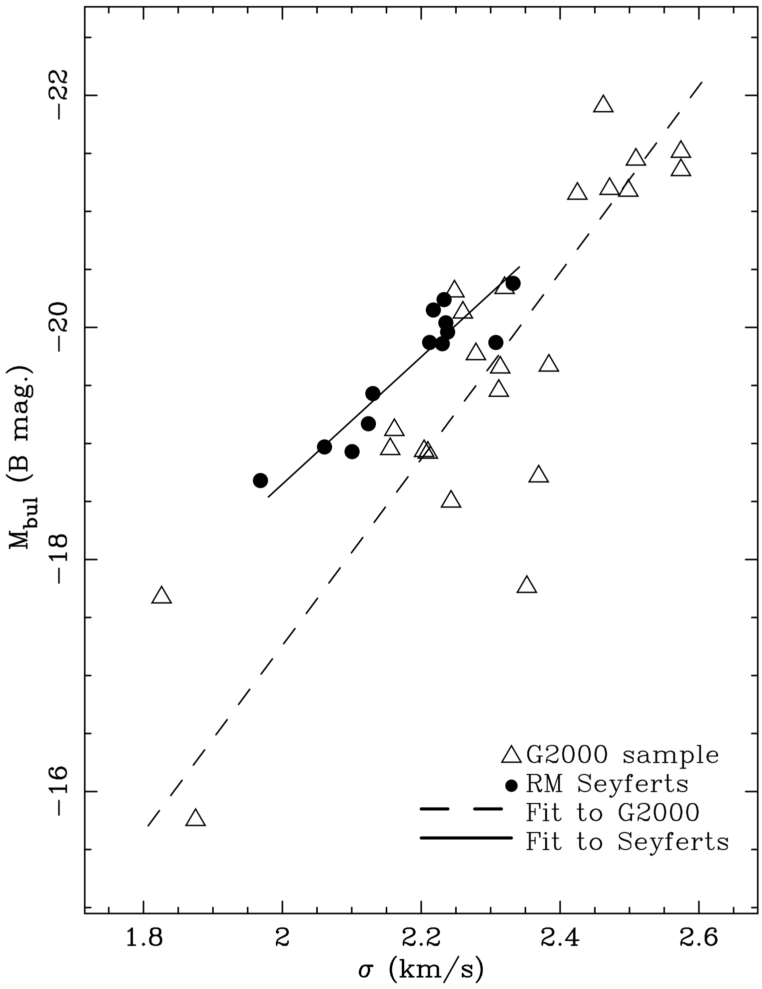

Fig. 1.3. The Faber-Jackson relation for the Seyferts and for the sample of Gebhardt et al. (2000). The Seyfert sample is offset to lower M/L suggesting a younger stellar population.

using the same objects plotted in figure 1.1. As in that paper, M_{bul} is determined from the mean bulge-to-disk ratio as a function of Hubble stage. The fit to the Seyfert galaxies is statistically identical to that found by Nelson & Whittle (1996). The offset toward brighter bulges at a given σ_* provides a natural explanation of the the discrepancies in M_{bul} vs. M_{bul}. The tempting speculation is that the mechanism responsible for fueling the current episode of activity in galaxies is also produces a reservoir of material for burst of star formation.

1.5 Conclusions

Using velocity dispersion measurements for Seyfert 1 galaxies with $M_\bullet$ determined by reverberation mapping, we find that Seyfert galaxies follow the same $M_\bullet - \sigma_*$ relation as normal galaxies. We find no systematic difference between $M_\bullet$ determined from reverberation mapping and dynamical modeling, thereby reaffirming the value of this technique. Previous reports to the contrary can be understood in terms of lower M/L in Seyferts than normal galaxies, perhaps as a result of higher recent star formation rates. We also confirm that [OIII] line widths can be used to estimate $M_\bullet$ through the $M_\bullet - \sigma_*$ relation, but with less accuracy due to the increased scatter.

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