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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 $M_\bullet$ – σ_* 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, σ_*, 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 Observations

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 spectra were centered on the Ca II Triplet lines at $\sim$ 8600 Å and analyzed using the Fourier Correlation Quotient (FCQ) technique (Bender, 1990). The resulting line-of-sight velocity distributions (LOSVD) were fitted with Gauss-Hermite polynomials to obtain σ_*. An example spectrum is shown in Figure **??**, including an F5 III template broadened by the LOSVD from FCQ. Note the strong Paschen absorption line (λ 8597) between the two strongest Ca II Triplet lines in this galaxy indicating the presence of young stars. The rather early type template does a good job of matching the galaxy spectrum.

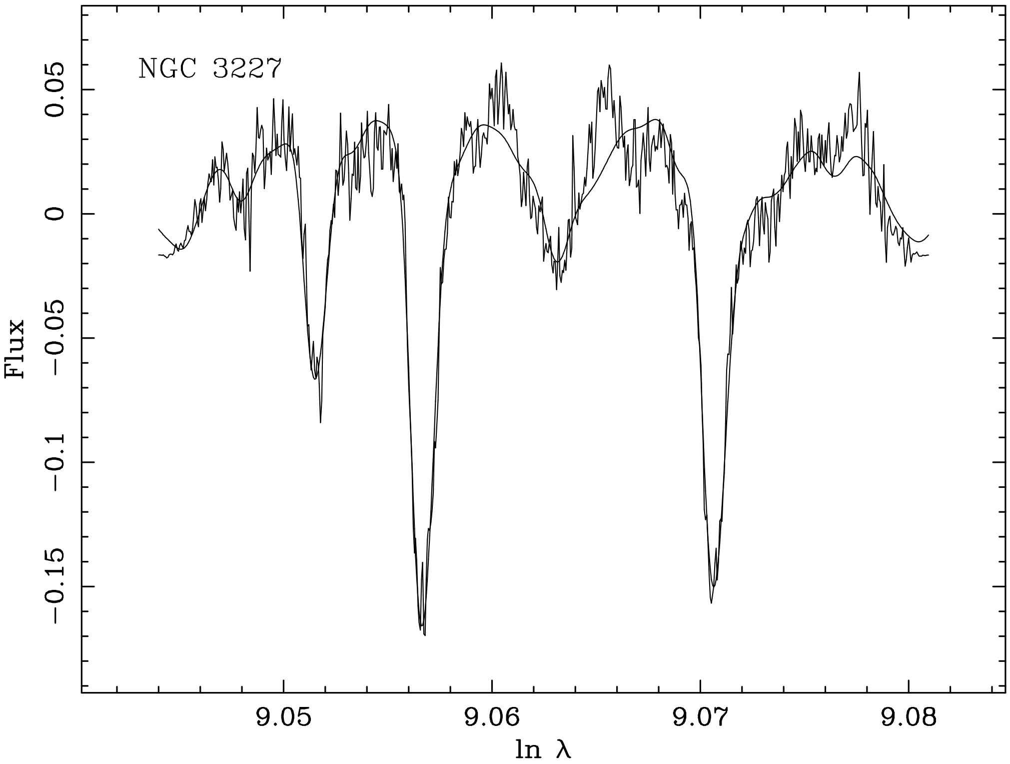

Fig. 1.1. The Ca II triplet lines in NGC 3227 are shown with the spectrum of a broadened template of spectral type F5. The high order Paschen lines indicative of young stars are well fit by the template.

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

Figure **??** 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 follow the same relation as normal galaxies in agreement with similar studies (Gebhardt et al. 2000b, Nelson 2000, Ferrarese et al. 2001). However, 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 $\sim$5 (Ho 1999), or that black holes in AGN are smaller than in non-active galaxies of the same M_{bul} (Wandel 1999).

1.4 Lower M/L in Seyfert Bulges

The discrepancies noted above 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 ($L \propto \sigma^{\mathsf{n}}, \mathsf{n} \simeq 3-4$) and found that Seyferts

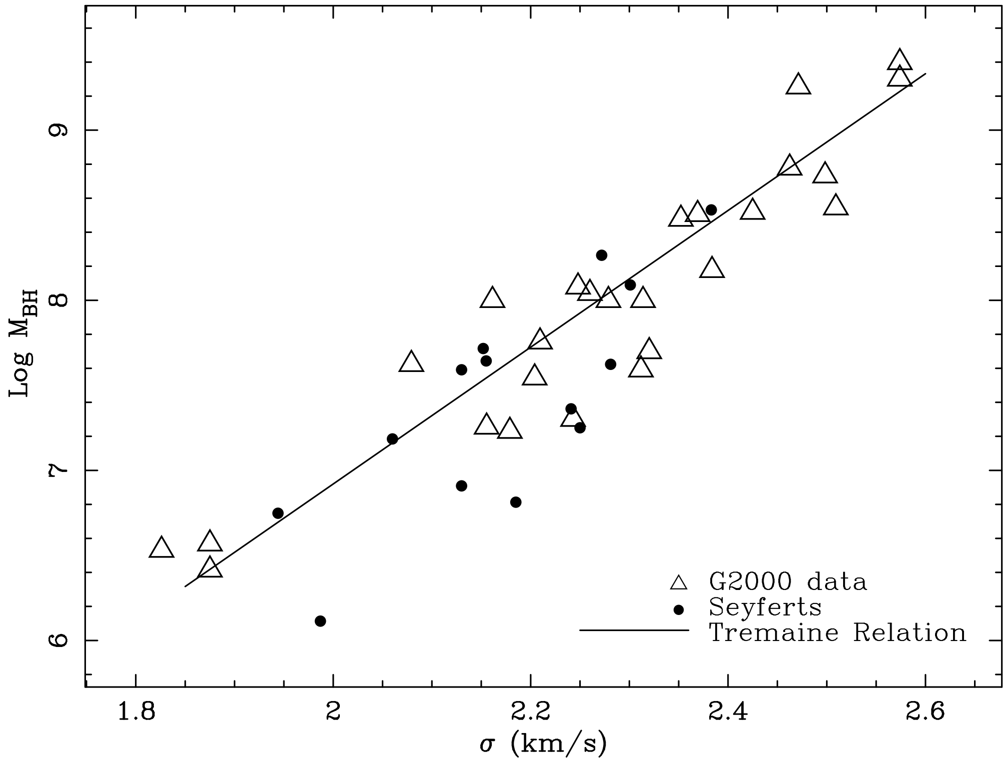

Fig. 1.2. The $M_\bullet$ — σ_* relation is shown for Seyfert galaxies (•) and for normal galaxies (△) from Gebhardt et al. (2000). The solid line is the fit from Tremaine et al. 2002).

were offset from normal galaxies. Seyfert bulges are brighter by $\sim 0^{\rm m}\!.6$ at a given σ_*. This most naturally suggests a lower M/L for Seyferts perhaps as a result of higher recent star formation rates. Thus a systematically younger stellar population may account for the previous discrepancies between M_{bul} and $M_\bullet$.

1.5 [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 $z < 0.5$. Preliminary results for the reverberation mapped quasars (Kaspi et al. 2000) are shown in Figure **??**. Seyfert galaxies from the literature are also plotted. These results show that [OIII] line width tracks σ_* although with increased scatter. This suggests that in the absence of stellar kinematic measurements, gas kinemtaics can be used to infer the virial speeds and therefore the black hole masses, but with less accuracy. Further analysis of the entire sample including the influence of profile shape will provide guidelines for this technique.

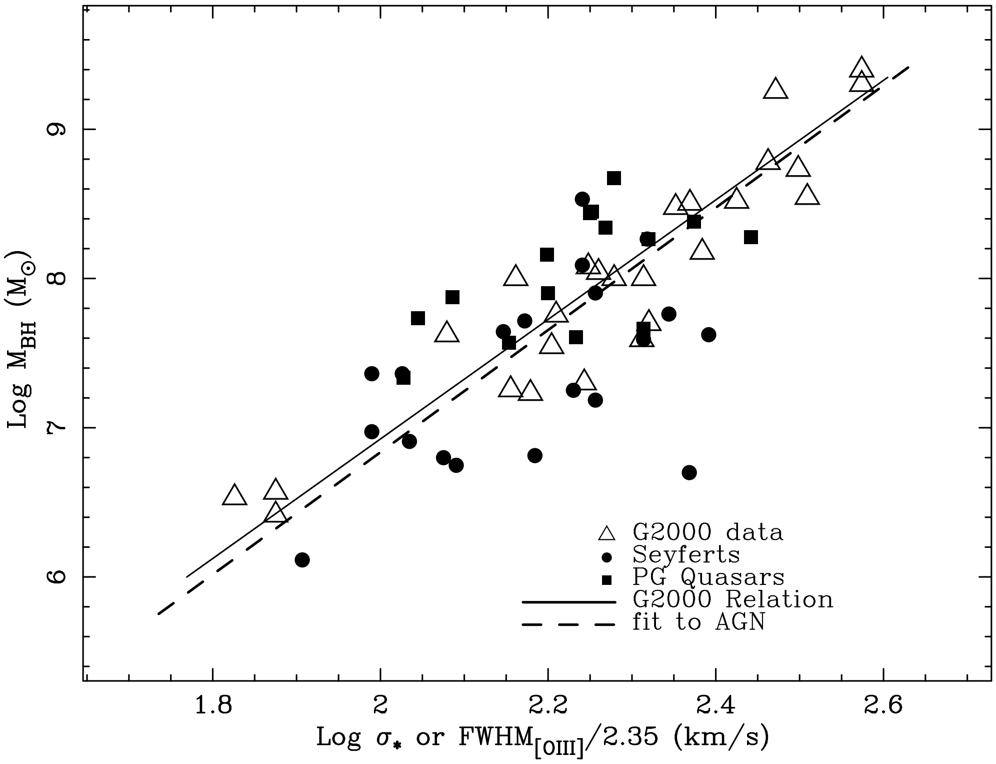

Fig. 1.3. [OIII] emission line widths converted to σ_* are plotted on the $M_\bullet$ — σ_* relation.

1.6 Conclusions

Using velocity dispersion measurements for Seyfert 1 galaxies with $M_\bullet$ determined by reverberation mapping, we find that Seyfert galaxies follow the same $M_\bullet$ – σ_* 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 $M_\bullet$ – σ_* relation, but with less accuracy due to the increased scatter.

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