Stellar Dynamical Modeling of AGN for Comparison with Reverberation Mapping

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Introduction

The well-studied galaxy and AGN scaling relationships, which AGN winds may play a role in shaping, critically depend on our confidence of supermassive black hole masses (M_{SMBH}). Obtaining the same resultant mass through multiple methods for a single galaxy can enhance confidence in inherent assumptions made for each method. However, there exist only a few galaxies to which we can apply these cross-checks. Comparison of reverberation mapping (RM) and stellar dynamical (SD) modeling for AGN is one such test, and has been examined for NGC 4151 [1]; [13], [14]; (see **Figure 1**) and NGC 3227 [11], [10]. However, the stellar dynamical modeling code used for these objects only accounted for axisymmetric orbits, and both AGN host galaxies are weakly barred. Omitting this consideration can lead to overestimates of M_{SMBH} [7]; the stellar dynamics must be re-examined with non-axisymmetric bar optimized modeling capability (Valluri+'s 2017 adaptation of [16]). We present our reanalysis of NGC 4151 and discuss future comparison of SD modeling and RM for AGN.

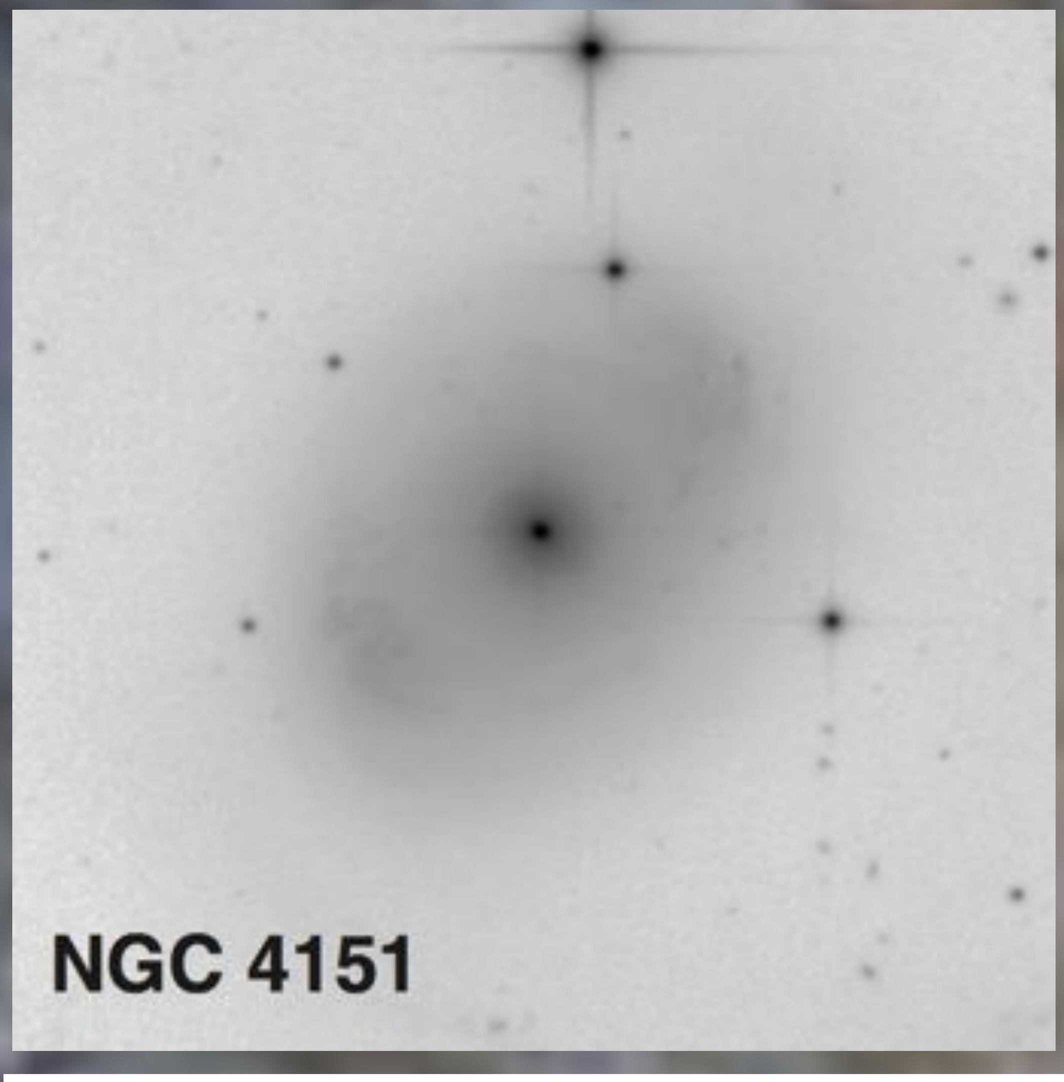

Figure 1. Weakly barred AGN NGC 4151, one target for stellar dynamical modeling with bar optimized code [2], (Harris V-band, 5' x 5', north up, east left).

Data

We examine NGC 4151, observed on the Gemini NIFS IFU in February of 2008 in the H-band with the ALTAIR adaptive optics system [13], [14]. The spatial resolution capability is 0".05, the field of view of the detector is 3" x 3", and R ~ 5000. The IFU spectroscopy was flat-fielded, wavelength-calibrated, spatially rectified, telluric-corrected, and combined into a final data cube.

Our treatment of the data differs from that of Onken et al. 2014 in two ways: i. the past treatment of binning is re-examined; we need only bin 0".05 x 0".05 rather than the previous 0".2 x 0".2, and ii. the data will be modeled with a bar optimized code as described here.

Stellar spectral templates must then be convolved to fit the stellar absorption lines in the galaxy using the penalized pixel fitting method pPXF [9]. Multi-band imaging constrains the stellar M/L ratio and surface brightness profiles [12], [8], [17].

Our timeline for project completion is seen in **Table 1**.

Table 1 – Timeline

Step	Status/Completion Date
Re-reduction of the data cubes	Completed
pPXF analysis	In progress
Beginning the modeling	September 2017
Analysis completion, writing	December 2017

Modeling

Brown et al. 2013 show how axisymmetric stellar dynamical modeling codes used for M_{SMBH} determinations can result in overestimates of the mass of a central SMBH when applied to barred systems (see **Figure 2**). They demonstrate two details: first, the projection of the bar orbits results in apparently larger velocity dispersions (σ). Second, in barred systems the σ values within the SMBH sphere of influence are actually inflated by the growth of the SMBH. Axisymmetric modeling codes will require larger enclosed masses to fit these large σ measurements, overestimating M_{SMBH}. As such, it is imperative that these systems be treated with code representing the dynamics of barred galaxies. We (Valluri et al.) are developing the first ever bar optimized Schwarzschild modeling code and we will re-examine the stellar dynamics of barred galaxies with black hole mass determinations.

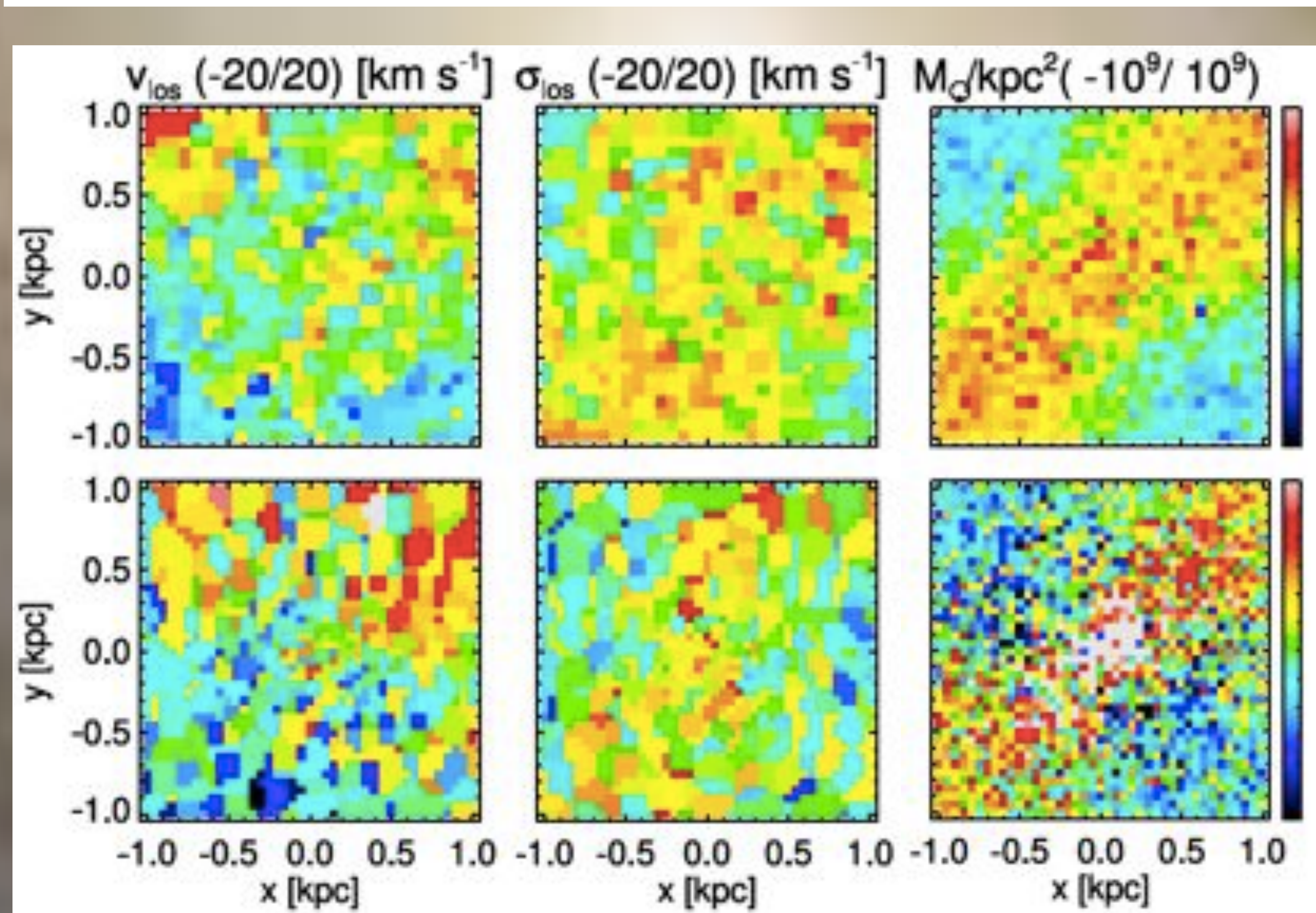

Figure 3. Differences between measured V_{los}, σ, and surface mass density as determined from galaxy models with and without a bar [7]. The top row shows the differences between a barred disk galaxy and a disk galaxy, and the bottom row shows the differences between a barred disk+bulge galaxy and disk+bulge galaxy. The presence of a bar inflates both the measured central σ and surface mass density (shown by red and yellow residuals in these central regions).

Future Work

In addition to remodeling NGC 4151 with the bar optimized code, we will also re-examine NGC 3227 [10]. Our group is actively working to increase the comparison sample of M_{SMBH} from RM and SD (see **Table 2, Figure 3**).

Table 2 – M_{SMBH} Comparisons

● Completed ⊙ In progress ○ In prep ⃠ Not necessary/Possible

AGN	Morphology	RM	SD	SDBO
NGC 4151	Weakly barred	● [1]	● [13], [14]	⊙ (This work)
NGC 3227	Weakly barred	● [11]	● [10]	
NGC 6814	Weakly barred	● [3]	⊙ (Batiste)	
NGC 5273	Unbarred early type	● [4]	⊙ (Batiste)	⃠
NGC 4395	Unbarred late type	● [15]	⃠	⃠
MCG-06-30-15	Unbarred late type	● [5]	○ (Bentz)	⃠
UGC06728	Bar unknown, late type	● [6]		
NGC 3783	Strongly barred	⊙ (Bentz)		

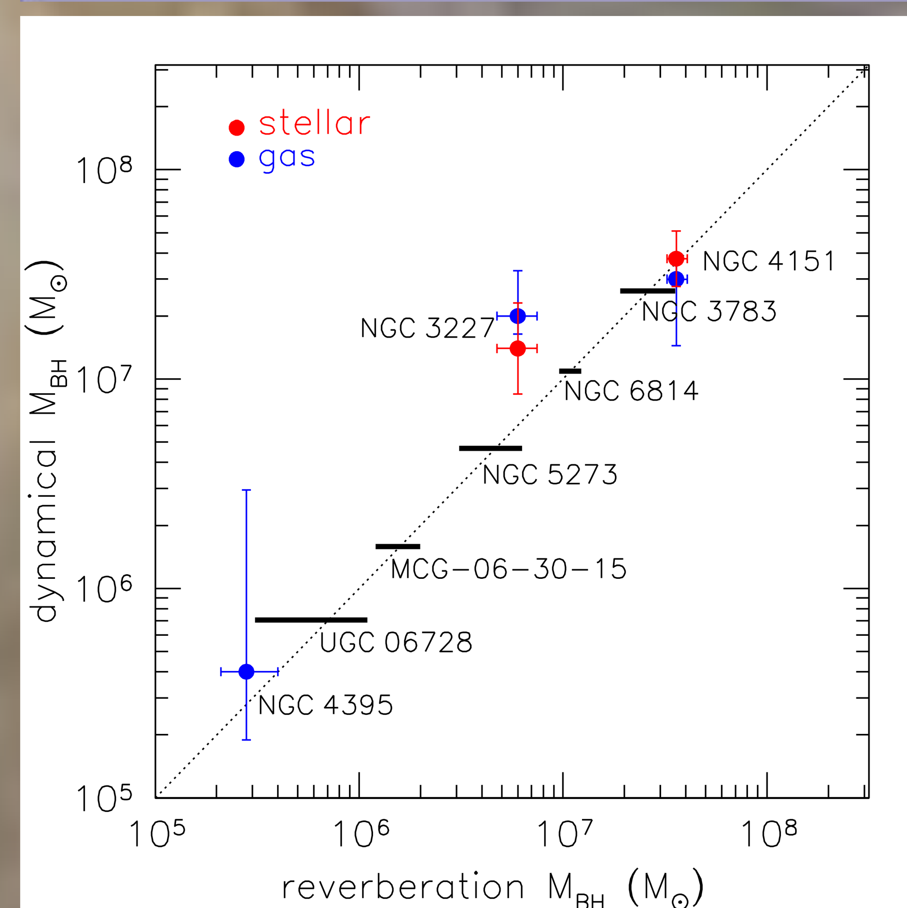

Figure 3. Current progress in comparisons of dynamical and reverberation black hole masses (Bentz).

Acknowledgements and References

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[15] Peterson+ 05, ApJ, 632, 799
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