PROCEEDINGS OF SCIENCE

Preliminary Results from a Recent Reverberation Mapping Campaign

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We have completed observations for a 125-night reverberation mapping campaign to measure new or improved black hole masses in six AGNs. From these observations we can further constrain broad line region kinematics and improve the observed relation between the radius of the BLR and the AGN luminosity (the $R-L$ relation), which allows us to accurately estimate black hole masses for large samples of AGNs. High-quality reverberation mapping datasets are difficult to obtain, as well-spaced observations over long timescales are required. Some reverberation campaigns in the past have not yielded satisfactory results due to inadequate time sampling; this campaign is part of a larger effort to improve the reverberation mapping database.

Narrow-Line Seyfert 1 Galaxies and their place in the Universe - NLS1,
April 04-06, 2011
Milan Italy

*Speaker.

PoS(NLS1)052

1. Introduction

Reverberation mapping uses observations of continuum and emission-line variability to probe the structure of the broad line region (BLR) and has been extensively used to estimate the physical size of the BLR and the mass of central black holes in AGNs. While this is an extremely effective method, high-quality datasets are difficult to obtain, as they require well-spaced observations over long timescales. An extensive set of objects with reliable black hole masses allows us to explore the connection between black holes and AGN evolution over cosmologically interesting timescales; it is therefore in our interest to obtain as many accurate measurements as possible. To further improve the current set of reverberation-mapped AGNs, we carried out a reverberation campaign in the fall of 2010. The results presented in these proceedings are preliminary and are being prepared for publication (Grier et al., in preparation).

2. Observations

Spectra were obtained nightly (weather permitting) using the Boller and Chivens CCD spectrograph (CCDS) on the 1.3m McGraw-Hill telescope at MDM Observatory. We used a $5''$ slit with the grating centered at 5150 Å, giving us spectral coverage from $\sim$4400-5900 Å. The observations at MDM spanned 125 nights, beginning 2010 August 31 and ending on 2011 January 3.

We also obtained spectroscopic and photometric observations from other observatories to supplement the MDM spectra. These include WISE Observatory, the Wyoming Infrared Observatory, SMARTS, MAGNUM, and the Crimean Astrophysical Observatory (CrAO). The additional photometric monitoring extended the campaign to a total of 131 nights.

3. Preliminary Analysis and Results

We used the [O III] $\lambda\lambda$ 4959, 5007 emission lines to effect a relative flux calibration of the MDM spectra; our preliminary light curves were made using a quick flux-scaling routine. Our light curves were created by measuring the flux in the continuum at 5100 Å and the Hβ emission lines, and the He II λ4686 flux in Mrk 335. These preliminary light curves were run through our time-series analysis to obtain an initial estimate of the time delay for each object. Preliminary emission-line lags are given in Table 1. Our final analysis will also include the subtraction of host-galaxy starlight and the removal of long-term secular variability in the light curves.

Clear reverberation signals can be seen in nearly all of the Hβ light curves. Examination of the RMS spectrum of the narrow-line Seyfert 1 galaxy (NLS1) Mrk 335 reveals a high level of variability in the region of the spectrum containing He II emission, and the He II light curve also shows a clear reverberation signal. We measure a lag of 2.6 ± 0.8 days, which, when combined with the line widths, yields a black hole mass consistent with previous estimates. This is the first lag measurement obtained from a high ionization line in a NLS1 galaxy. Several of the Hβ light curves have sufficient time sampling that we expect to be able to obtain velocity-resolved results as well.

References

[1] Collier, S. J. et al. 1998, ApJ, 500, 162

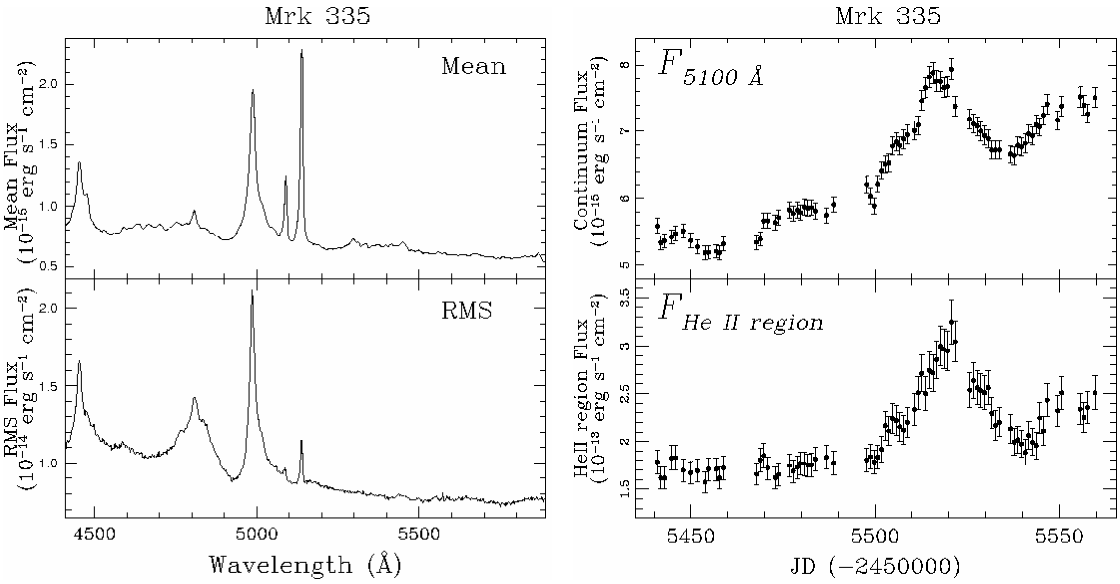
[2] Grier, C. J. et al. 2008, ApJ, 688, 837

[3] Kaspi, S. et al. 2000, ApJ, 533, 631

[4] Peterson, B. M. et al. 1998, ApJ, 501, 82

Galaxy	RA (J2000)	DEC (J2000)	z (NED)	Previously Measured $\tau_{\rm cent}$ (days)	Ref.	New Preliminary $\tau_{\rm cent}$ (days)	Emission Line
PG 2130+099	21 32 27.8	+10 08 19	0.063	200^{+67}_{-18}	(1)	24 ± 6	Hβ
				$22.9^{+4.7}_{-4.6}$	(2)		
NGC 7469	23 03 15.6	+08 52 26	0.016	$4.5^{+0.7}_{-0.8}$	(3)	14 ± 3	Hβ
Mrk 335	00 06 19.5	+20 12 10	0.026	$16.8^{+4.80}_{-4.20}$	(4)	< 27	Hβ
				...		2.6 ± 0.8	He II
Mrk 1501	00 10 31.0	+10 58 30	0.089	...		12 ± 4	Hβ
3C 120	04 33 11.1	+05 21 16	0.033	$38.1^{+21.3}_{-15.3}$	(4)	26 ± 2	Hβ
Mrk 6	06 52 12.2	+74 25 37	0.019	...		8 ± 3	Hβ

Table 1: Preliminary Lag Measurements. References: (1) Kaspi et al. 2000; (2) Grier et al. 2008; (3) Collier et al. 1998; (4) Peterson et al. 1998



(a) Mean and RMS spectrum of Mrk 335 in the observed frame

(b) Preliminary continuum and He II light curves

Figure 1: Preliminary reverberation results for the NLS1 Mrk 335