Multi-Object AGN Reverberation Mapping with MSE

Yue Shen, Pat Hall et al.

Science case Spectroscopic reverberation mapping (RM) campaigns with MSE will yield groundbreaking results in AGN and galaxy formation science. RM is a technique to study the structure and kinematics of the AGN broad-line region (BLR) by observing time-resolved and velocity-resolved reverberation of the broad-line flux to the continuum variations. With an understanding of BLR dynamics via RM, one can derive reliable dynamical supermassive black hole (SMBH) masses, which will benefit all branches of astrophysics involving SMBH masses (fundamental BH accretion physics, AGN feedback, BH-galaxy coevolution, etc.). Over the past two decades, RM has proven to be a practical tool. However, the high demand of observing time and scheduling difficulties in traditional RM have prevented this method from being applied to large samples of AGN, or beyond $z{\sim}0.3$. As a result, there are only ~ 50 local AGN with existing RM measurements. Most of them are for the Hβ line, which shifts outside the optical window at $z \gtrsim 1$. Given the paramount importance of measuring AGN BH masses, a new age of multi-object RM in the era of massive spectroscopic surveys and time-domain photometric surveys is needed.

We are pioneering a pilot multi-object spectroscopic RM program with the 2.5-m SDSS telescope and the BOSS spectrograph (SDSS-RM, Shen et al. 2014). Such a program performs RM on a uniform (flux-limited) AGN sample free of selection biases, and is able to measure reverberation lags in a much more efficient fashion than traditional RM, for a wide range of AGN luminosities and redshifts. SDSS-RM (2014A-2016A) monitors a single 7 deg^2 field with 849 AGN targets to $i < 21.7$, and will inform similar but more ambitious RM programs with future facilities.

The key improvements of MSE over SDSS in terms of RM are: 1) 3 magnitudes fainter than SDSS in a nominal 2-hr exposure, therefore greatly expanding the dynamic range in AGN luminosity (of critical importance in constraining the $R_{\rm BLR} - L$ relation); 2) availability of LSST photometric light curves (necessary for AGN continuum monitoring).

Technical requirements Given the FoV of MSE (1.8 deg^2) and sky density of (broad-line) AGN ($\sim$600 deg^{-2} down to i=24 based on the Hopkins et al. 2007 LF), we require $\sim$1000-1500 fibers for AGN targets (depending on the final i-band limit) per pointing. To sample both short lags (days) and long lags (years), we envision a multi-year program with a cadence of several days in the first year, and reduced cadence in each successive year, totaling $\gtrsim 60$ epochs per field over 3-5 years. Per epoch exposure time will be $\sim$2 hrs to obtain the needed continuum S/N$\sim$10 per pixel.

Accurate spectrophotometry is critical to facilitate the detection of flux variability at the $\gtrsim$10% level. With SDSS-RM, we achieved a 5% absolute flux calibration. Systematic errors come from uncertainties in modeling standard star spectra, position-dependent atmospheric differential refraction (ADR), and pointing errors. Better spectrophotometry will require optimal planning of calibration sources (sky and flux standards), perhaps a denser sampling on the focal plane than ordinarily needed (200-500 fibers), and better theoretical modeling of stellar spectra.

With near-IR spectral coverage beyond 1.3μm, *many more AGN would have multiple-line RM measurements: an unmatched asset for RM science and a unique MSE advantage.*

Synergy with other programs We expect there will be of order 1000-1500 spare fibers in the RM plates, which can be used for other science. The MSE-RM program can be integrated with at least two types of survey programs: 1) a wide extragalactic survey, where the RM field(s) will be frequently revisited within the annual visibility window and the spare fibers can be used for special targets for *extremely* deep coadded spectroscopy; 2) a combined RM and transient follow-up program in one or more pointings in the LSST footprint, placing some fibers on transient targets during every RM program visit. In fact, it doesn't matter whether the transient program or the RM program is the primary program, as long as the field is re-visited at the required RM cadence.