Letter of Intent: A MOS-RM Program within AS4

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Scientific Background: The next decade will see the maturity of large-scale time-domain sky surveys such as the LSST. Well-sampled, high-quality photometric light curves from these imaging surveys will benefit a broad range of science applications, including the study of AGN variability with unprecedented data. The scientific yield can be considerably increased by an accompanying multi-object spectroscopic (MOS) program. This LoI is linked to the AS4 White Paper on MOS reverberation mapping (RM) using the SDSS (optical) MOS facilities in the 2020-2025 timeframe. RM is a technique that measures the size and structure of the AGN broad-line region (BLR) by cross correlating the continuum and broad-line variability, which in turn can provide a means to estimate the dynamical mass of the black hole. RM is one of the most powerful tools to study the inner ($\lesssim$parsec scale) structures of AGN and quasars, and the primary method to estimate the BH mass in distant active galaxies. Over the past ~ 2 decades, RM has proven to be an effective technique. However, the current RM AGN sample has a few major limitations: It does not probe a uniform parameter space of the general population of quasars (limited to ~ 60 systems at $z \lesssim 0.3$), and past efforts have largely focused only on the Hβ emission line.

We are carrying out a pilot MOS-RM program within the SDSS-III and IV surveys (SDSS-RM). This program monitors a single 7 deg^2 field with ~ 850 quasar targets at $0.1 < z < 4.5$ with SDSS spectroscopy ($\sim 10-30$ epochs per observing semester) and accompanying photometry (to provide continuum flux measurements). The main purpose of SDSS-RM is to test if MOS-RM works at $z \gtrsim 0.3$, and to provide up to ~ 200 BLR lag measurements to $z \sim 4.5$ for a representative sample of high-z quasars using a range of broad lines (e.g., Hα, Hβ, Mg II, C IV). SDSS-RM is the first step to advance significantly the RM field to the high-z and high-luminosity regime where most of the BH accretion activity takes place. This is a crucial regime to understand the growth of SMBHs, and to evaluate the possibility of using these luminous cosmic beacons as standard candles for cosmology.

SDSS-RM was designed to perform a proof-of-concept study of MOS-RM, with a chosen cadence just sufficient to detect a lag. The sampling is not appropriate for deriving precise lags, and the success rate is expected to be low ($\lesssim 20\%$). As a natural step forward, higher-cadence sampling is required to improve lag measurements, detect more lags, and provide more accurate RM BH masses and better recipes for derived mass estimators. These improvements are necessary to maximize the power of the RM technique, and to truly transform the AGN field in the coming era of large MOS and time-domain imaging surveys.

Objectives: Building on early demonstration by SDSS-RM of the general feasibility and potential of MOS-RM for high-z quasars, we propose an advanced MOS-RM program using the SDSS facility in the 2020-2025 timeframe. The focus of this AS4 RM program is to obtain more and higher-quality lag detections than the pilot SDSS-RM program. Specifically, we aim to perform state-of-the-art high-cadence RM monitoring as for local AGN, but in a more important regime of SMBH growth (i.e., high-z and high luminosity). **With 5 monitoring fields (5 pointings), each visited $\sim$ 60 times (e.g., $\sim$ 3-day cadence, 2-hr exposure per visit) per year over $\sim$ 6 years**, we aim to detect lags for up to $\gtrsim 1000$ quasars to $z \lesssim 4.5$ with a precision of $\sim 20\%$, which is a factor of $\gtrsim 5$ improvement in the number of lag detections and a factor of ~ 2 improvement in the quality of lag measurements over SDSS-RM.

A much more ambitious version of the program would be to extend the monitoring fields to cover a significant portion of Stripe 82. By monitoring a larger sky area we will be able to increase the sample of successful RM measurements in proportion, and this may better integrate with other science programs (e.g., spectral variability of rare AGN or follow-up of rare bright transients identified from LSST).

Technical requirements: The proposed program requires an optical spectrograph similar to the BOSS spectrographs, with similar wavelength coverage and spectral resolution. This is a dedicated program and we expect to use > 500 fibers per field for the RM targets and calibration sources (currently SDSS-RM uses 850 fibers for science targets down to $i = 21.7$, 70 for flux standards and 80 for sky; if we target a brighter subset of quasars to monitor, the extra fibers can be used to accommodate other science targets). We are flexible with either the APO2.5m or the LCO2.5m or both for this spectroscopic monitoring program. The default forecast was based on the field of view of the APO2.5m. From the APO site we can access the Stripe 82 region and northern fields with concurrent or precursory photometric light curves. From LCO we will have a larger area of overlap with LSST light curves, but we will need an optical MOS on the LCO2.5m. Some potential target fields include several PS1 Medium Deep Fields for which multi-year, high-cadence optical photometric light curves as well as ample multi-wavelength data already exist: MD07 (SDSS-RM field), MD01, MD02, and MD04 (the last 3 are also LSST Deep-Drilling Fields).

The most significant technical upgrade that would benefit the RM program by providing improved spectrophotometry is an efficient robotic fiber positioner that can re-center fibers between exposures to better correct for differential fiber loss and ADR effects in hour-long exposures. Superb flux calibration is crucial to the success of detecting broad-line variability and hence measuring a lag since the typical level of broad-line flux variability is less than $\sim 10\%$. With SDSS-RM, we are achieving rms spectrophotometry of $\sim 5\%$, and further improvement will be particularly useful for high-z quasars that vary at similar amplitudes. Further technical studies on such a fiber positioner are highly desirable.

Data infrastructure: Currently SDSS-RM has two parallel archives. All pipeline-processed SDSS spectroscopic data are distributed within the standard SDSS data releases. Custom data products are archived and distributed with our own data servers. For the AS4 program, we envision a similar data infrastructure and access tools and potentially the merger of different archives. Several institutions (such as NCSA at UIUC) could be the potential host and distribution center for all AS4 data[1].

Synergy and integration: Measuring accurate RM BH masses with this program will have tremendous value to all science cases related to AGN physics and SMBH growth. For example, the combination of BH masses from this program and continuum lags measured from LSST (or other imaging surveys such as ZTF) can provide powerful constraints on accretion disk models; robust RM BH masses at high-z can be used to study the evolution of the scaling relations between BH mass and galaxy (bulge) properties.

This program is highly integrable and scalable, and it would be beneficial to consider this program in the general context of time-domain spectroscopic observations in the era of LSST. In the default 5-field scenario, it will use 600 on-source hours per year (mostly dark/grey time). Within our program we can incorporate additional science cases such as transient follow-ups and deep coadded spectroscopy for extremely faint targets, but the RM program will remain the driving component due to the stringent cadence requirement. Science-wise, this RM program is complementary to the AS4 All-Quasar Multi-Epoch Spectroscopy program (PI Green) over much wider areas, and will provide many-epoch spectroscopy for a subset of that sample. We are happy to discuss possible program integration scenarios.

Summary: We propose a multi-year MOS-RM program that combines the strengths of multiplex spectroscopy and large-scale time-domain imaging surveys in the 2020-2025 timeframe. **This program holds the potential to transform RM studies into industrial-scale production and dramatically improve quasar BH mass estimation across a wide range of quasar properties and throughout the entire cosmic history of SMBH growth.** The main science goal (i.e., measuring BLR lags and RM masses for an unprecedented quasar sample) will have tremendous impact on all SMBH-related science (e.g., accretion physics, inner structures of AGN, SMBH demographics, co-evolution of BHs and galaxies), and the versatile time-domain data set will enable complementary approaches to study quasars (e.g., spectral variability) and motivate novel statistical approaches in these studies.

In the 2020-2025 timeframe, there will be several other MOS facilities potentially usable for similar RM programs (e.g., 4m/4MOST, 4m/DESI, Subaru/PFS). However it is currently unclear if any of these will offer public access for a MOS-RM program. In any case, the SDSS facility will remain competitive in the 2-4m class before 2025, given its large field-of-view and demonstrated performance, and our program would be a critical pathfinder for next-generation MOS-RM with the planned 10-m MSE beyond 2025.

[1] NCSA is also the Data Management center for LSST, which is a key data component in the proposed MOS-RM program.

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