Double AGN: Binary-Lens Lighthouses in VRO’s 10-year Survey

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1 Introduction

When two galaxies merge, the black holes (BHs) at their hearts start journeys toward the center of the new, combined galaxy. These BHs can be bright due to gas accretion, even once they form into a binary. During an extended interval prior to merger, each BH can serve as a gravitational lens to its accreting companion, temporarily magnifying emission across wavebands. Model lightcurves are shown in Fig. 1. At least one candidate binary-self-lensing AGN is being monitored by Chandra and Swift as well as from the ground. The Large Survey of Space and Time (LSST) to be conducted by the Vera C. Rubin Observatory is ideal for the detection and study of binary self lensing by binary supermassive BHs. Models of self-lensing lightcurves (Fig. 1) coupled with state-of-the-art supermassive BH binary population models show that 10’s to 100’s of such events could be uncovered by the Rubin Observatory (Fig. 2), possibly leading to the first definitive detections of sub-parsec separation supermassive BH binaries. Results will not only shed light on the elusive supermassive black hole pairs, and implications for their merger and low-frequency gravitational wave astronomy, but also the mutual evolution of supermassive BHs and their host galaxies, providing important insight into galaxy evolution.

Figure 1: Lensing light curve for a typical MBH binary. The left two panels use the point-source approximation for the primary (blue), secondary (orange), and total luminosity (black), including both lensing and Doppler boosting. Lensing flares are uniquely identified by their symmetric shape and location at a unique phase of the Doppler-boost modulation. Panel (a) is without noise, while panel (b) includes intrinsic AGN variability (modeled as a ‘damped random walk’ [DRW]). The first, larger lensing peak corresponds to the secondary lensed by the primary. The right two panels show light curves in each SDSS band, incorporating finite-size effects with a thin-disk emission model. The dashed lines are the brightness in each band without lensing, and the dotted grey curve is the point-source approximation. Panel (c) is without noise, and panel (d) includes DRW variations, and shows an example sampling with 3-day cadence (dots).

M = 10⁹ M⊙, q = 0.25, P_o = 2.00 yr, i = 0.050, f_{bol} = 1.00

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2 Survey Footprint

Q1: Are there any science drivers that would strongly argue for, or against, increasing the WFD footprint from 18,000 sq. deg. to 20,000 sq.deg.?

No. The WFD footprint is well designed for observing AGN.

Q2: Assuming that current system performance estimates will hold up, we plan to utilize the additional observing time (which may be as much as 10% of the survey observing time) for visits for the mini-surveys and the DDFs. What is the best scientific use of this time?

Our targets will be well studied in any plan for additional time that discovers supernovae. The lensing events are more diverse in their durations and brightenings than supernovae, but generally speaking, changes on day-to-month time scales are expected, similar to supernovae. The decline times of supernovae and other energetic explosive events can extend over times comparable to a year. Observations of AGN populations over years-long time scales provide opportunities to determine the frequency of lensing-like behavior that could produce false positives. It also has the advantage of allowing model validation if the orbital cycle is shorter than 10 years.

3 Exposure time per visit

Q3: Are there any science drivers that would strongly argue for, or against, the proposal to change the u band exposure from 2x15 sec to 1x50 sec?

No.

4 Allocation of observing time per band

Q4: Are there any science drivers that would strongly argue for, or against, further changes in observing time allocation per band (e.g., skewed much more towards the blue or the red side of the spectrum)?

The magnification is largest at the shortest wavelength. Signal detection therefore favors short wavelengths, as long as internal absorption is not problematic. As described below, the wavelength dependence of the signal makes observations in multiple filters a priority. This helps to make reliable identifications, and to accurately model both lensing and absorption.

5 Time sampling and revisit offsets

Q5: Are there any science drivers that would strongly argue for, or against, obtained two visits in a pair in the same (or different) filter? Or the benefits or drawbacks of dedicating a portion of each night to obtaining a third (triplet) visit?
The validation of binary-self lensing in AGN would benefit significantly from two visits in a pair of different filters. This is because self-lensing posits specific multi-wavelength predictions, in both the ‘point-source’ and ‘finite-source’ regimes. In the former, lensing is achromatic and will result in a symmetric flare with the same magnification across bands (Fig. 1, a & b). In the latter, finite-source case, the accretion disk is large compared to the Einstein radius of the lens, and magnification is dependent on the size of the source at each wavelength (Fig. 1, c & d). For accretion disks, the signature of lensing is largest at short wavelengths, corresponding to the smaller, inner portion of the disk. A triplet during the same night in a different filter would be ideal. The magnification in each band will not generally change significantly during the course of one night. Thus, a triplet in different filters in one night would provide important input for modeling the event and eliminating false positives.

Q6: Are there any science drivers that would strongly argue for, or against, the rolling cadence scenario? Or for or against varying the season length?

AGN lensing observations would benefit most from maintaining as few long duration (> 10 day) gaps throughout the 10-yr survey. Due to the rarity of short-period binary AGN, we expect to be event-rate limited, in which case maintaining the shortest cadence possible for the largest fraction of each year will produce the highest chances of detecting events. As shown in Fig. 2 (right panel), the detection rate drops significantly for cadences longer than ~ 10 days. If a rolling cadence produces observing gaps longer than this, then any lensing events in that period of time are likely to be missed. For reference, the expected duration of detectable lensing signals are 35 (30) – 105 (135) days for 68% (95%) of our simulated population. For example, a 30 day lensing event that has a single 10 day observation gap, but an average of 3 day cadence otherwise, would produce ~ 6 – 7 observations. This is likely sufficient to identify the event. A longer gap, however, would prevent the event from being distinguished from an AGN flare. Similarly, maintaining continual observations of AGN is also crucial for measuring their intrinsic variability to accurately characterize their noise and rule out false positives (e.g. flares in single AGN).

Q7: Are there any science drivers pushing for or against particular dithering patterns (either rotational dithers or translational dithers?)

No.

References