

Photometric Monitoring of Active Galactic Nuclei using the Thai Robotic Telescope in Chile

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Abstract

We report the ongoing variability monitoring program for a well-defined, flux-limited sample of active galactic nuclei (with $B_j < 18$ mag) through a multi-band optical campaign using Thailand's 0.6-m remotely-operated telescope at Cerro Tololo Inter-American Observatory, Chile. Our goal is to search for variability on various time scales (monthly, yearly, and long-term up to 20 years) to identify potential targets for spectroscopic follow-up to estimate the broad-line region size through reverberation mapping technique. We have developed a Python pipeline based on the publicly available SWARP and SExtractor software to efficiently perform photometry and produce light-curves in the B, V and R bands. Our photometric measurements over 2014 -2015 typically achieve an uncertainty of < 0.05 mag for targets at 14-15 mag under optimal conditions with an average cadence of two days or better for a number of objects. Here, we demonstrate the use of our machinery to monitor PG1302-102, which has recently been found to be the first candidate of a binary supermassive black holes at sub-kpc distance, at accuracy approaching 0.1 mag over 14 months.

Keywords: Active Galactic Nuclei, reverberation mapping, Python, monitoring program

Introduction

Active Galactic Nucleus (AGN) results from accretion of supermassive blackhole (SMBH) at the center of galaxies, which produces emission in broad wavelengths, often outshines the host galaxy either partially or totally. Optical emission of AGN is powered by accretion disk, a dense disk of materials infalling to the SMBH, whose structure can be studied by the reverberation mapping technique whenever an AGN outburst occurs. However, spectroscopic campaigns to do this require a lot of telescope time, and hence a careful target selection for such a campaign is necessary. Our main objective in this work is to monitor a large number of AGNs for outburst using a group of robotic telescopes augmented with a fast and accurate detection pipeline. After we have surely determined that an outburst has occurred then we try to follow up with spectroscopic observations. Our second objective is to monitor their short-term variability and finally using the current

observation in comparison with the original observations, we can study the local AGN accretion history over the past 20 years. To achieve this, we have created a set of python algorithms based upon publicly available software. We are aiming to use these python scripts as a general way to calculate magnitudes and analyze data.

Methods and Materials

The Sample

The sample we used is a group of well-defined quasars drawn from the Hamburg/ESO survey (HES). The HES is a wide-angle survey QSOs in the southern sky using the 1-m Schmidt telescope and its 4-degree prism at La Silla observatory. The survey consists of 380 fields covering 9000 deg² containing QSOs with magnitudes between $13 < B_j < 18$ with redshifts ranging from $z = 0 - 3$ with the majority in redshifts of $0 < z < 1$. More details regarding the HES survey is in Schulze et al. 20092. In this study we are interested in

bright QSOs with low redshifts therefore we have selected all the objects with $0 < z < 0.3$ which is approximately 330 objects however; we also include a few objects to $z = 1$. Also, our targets blackhole mass (LogBH) range from 7 – 9 and bolometric luminosity of 43-46.

The Algorithms

To obtain the data, we used Thailand's 0.6m PROMPT telescope managed by the University of North Carolina, USA. The PROMPT telescope is a robotic Ritchey-Chrétien. Users can submit jobs and download data via a PHP based web browser.

We've created three sets of Python pipelines based on publicly available SWARP and SExtractor to obtain photometric values. The pipelines include: a long-term average magnitude algorithm, a short term variability algorithm using relative photometry and a long-term variability algorithm using absolute photometry. Each set has a group of sub-algorithms that produces a text that is passed in to the next one. Before we are to run the scripts we are required to separate the images in to different folders by the filters for ease of file management.

Average magnitude algorithm

The first algorithm has 4 sub algorithms. The first sub-algorithm utilizes SWARP to co-add images taken in the observation into one combined image. After that the objects in the image are extracted using SExtractor. This algorithm produces a text file generated from SExtractor which contains a list of objects in the image and other photometric values and a second text which contains settings from the telescope which is pulled from the image header using Pyfits this includes the JD, median JD, air mass etc.

The second algorithm checks that the image satisfies a set criterions which is "is the AGN present or not?" a single Y/N character is then added to the end of the text.

The third algorithm calculates the zero point by using a group of reference stars from the USNO-A2. The stars must have a flux of more than two times the flux of the AGN in interest and must not be overexposed. Then we reduce the error through sigma-clipping techniques to obtain the final ZP and error. The zero point and error is then printed to the end of a text file generated by the last program.

The last algorithm calculates the magnitude and error of our object by pulling the zero point from the text file generated by the zero point algorithm and obtains the flux of our object from the SExtractor file. Lastly, it generates a text file which contains results of the algorithm.

Short term variability algorithm

Our short-term variability algorithm consists of 5 sub algorithms. This algorithm uses relative photometry to detect an outburst. The output of the pipeline is a short-term light curve showing the variability of our objects and a set of text files containing values from the pipeline. The first algorithm co-adds the image taken in the same day using SWARP and extracts the objects using SExtractor.

The second sub-algorithm is used to select comparison stars which are used in the last algorithm's flux scaling process. We determine comparison stars by a flux comparison method. The basic concept used is the fact that the fluxes of constant stars do not change much over time therefore the ratio of the fluxes between constant stars should not change much either. Since in practice, the ratio does change, we use stars whose ratio change as little as possible. In our algorithm we set the limit at 0.05 of the standard deviation from the first day. In the end the algorithm will produce a text file containing a list of stars, their right ascension, declination and magnitudes.

The third algorithm calculates the zero point in each day. We use stars from the Guide Star Catalog 2.3 with magnitudes between 13-16 magnitudes however these numbers may be changed. We then check our images for these stars, if any star does not appear in all observations those stars are discarded leaving only stars that are present in every day since the start of our observation. We further narrow down our stars by choosing a reference frame by hand and then selecting stars which have more than 2 times the flux of the AGN and the position difference between position in the GSC catalog and the SExtractor file must not exceed more than 3 arc seconds. We then apply a sigma clip. If a star's zero point differs more than a selected value times the standard deviation from the mean value of the reference frame that star is discarded. We then calculate the zero point of each day using the reduced list of stars. If any star's zero point differs more than a set limits, that star is discarded. The remaining stars zero points are then averaged in each day and exported as a text file.

The fourth algorithm calculates the magnitude of the AGN in interest and exports a text file containing the information we need to plot a variability light curve. In this algorithm a flux scaling process is used to set up constant stars which we would later use to compare with our AGN in order to detect outbursts. The scaling process starts by creating a factor that manipulates the fluxes of our selected comparison star to make it a constant star. This factor is then applied to all objects in the field. We then proceed to use these

fluxes to calculate the magnitudes we need to create a light curve.

Lastly, the final python script is used to combine the magnitude numbers and zero point information in order to create the variability light curve.

Long-term variability algorithm

Our long-term variability algorithm consists of 3 sub-algorithms. This algorithm is different from the short term algorithm because it employs absolute photometry in contrast to the short-term variability algorithm which employs relative photometry.

The first algorithm co-adds the images with the same JD using SWARP then and extracts the objects in the frames using SExtractor. This algorithm also functions as an automatic image quality checker by using a set of criterions that will determine good frames from the bad frames. The good frames that are determined in this algorithm are allowed to pass into other algorithms while the bad frames are not.

The second algorithm determines the reference stars that shall be used to calculate the zero point of our target. The stars we used are drawn from the USNO-A2 catalog. To determine the reference star we shall be using in the next algorithm, we use the same flux comparison method as in the short-term variability algorithm. We select a group of stars in the catalog that are present in all good observation nights with the least change in the flux ratio. In the end we would have a small selection of 3-5 stars per object.

The last algorithm calculates the magnitude we need to create a light curve. This algorithm uses the stars that we have determined to show very small variability to calculate the zero point in each day. The algorithm finds our targets and proceeds to calculate the magnitudes. After we have calculated the magnitudes throughout the observation, we use this information to plot our long term variability light curve.

Results and discussion

Average magnitude calculations

We have used our average magnitude algorithm to monitor a subsample of 50 objects with a median period of 50 days in typically one observing run. After applying our algorithm we find that 14 objects which is approximately 30 % of our subsample has shown a change in magnitudes of more than 0.5 magnitudes. Typically we achieve an error of approximately 0.05 magnitudes. Since this subsample is statistically representative with no further sample bias or systematic that would apply, we conclude that approximately 30% of our total sample of

approximately 330 objects will show a change of similar level.

Accretion History over 20 years

Without spectroscopy we can only assume that an outburst has occurred. But we can use our average magnitudes as a second epoch in direct comparison with the original observations 20 years ago. We make the rather crude assumptions that our black hole's mass has not changed and all the magnitude change we detect shows a change in AGN continuum luminosity. In other words the Eddington luminosity is constant. If applied to the 14 objects which show a rather large long-term variability we find that our measured magnitude change would correspond to a change in Eddington ratio of about 0.2-0.4 dex.

Short-term Variability detection

We demonstrate the use of our algorithm by creating a variability light curve for one of our objects. The object in interest is HE1310-1051 which has a Bj magnitude of 16.39 and a redshift of 0.034. Here we show two short-term variability light curves over 89 observation nights with a cadence of 1.2 days using two stars as comparison stars. Two fields are combined for each night. Our typical error for each night is approximately 0.1 magnitude.

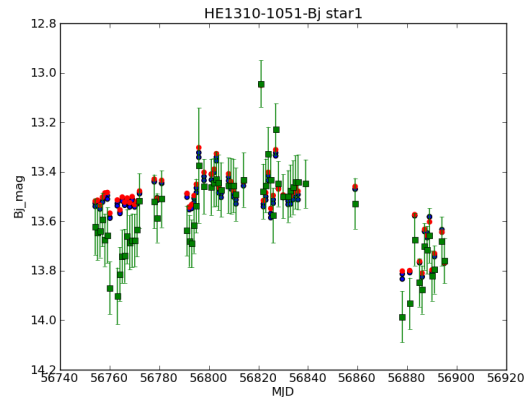


Figure 1. Short-term variability light curve of HE1310-1051 using a star with a bj magnitude of 13.6

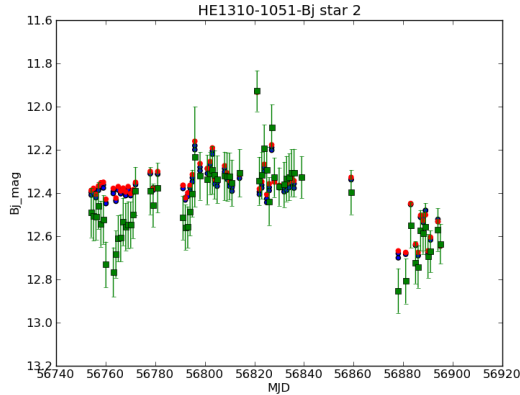


Figure2. Short-term variability light curve of HE1310-1051 using a star with bj magnitude of 12.4

From the plots you can see that both plots show a similar trend. At the start of the observation HE1310 shows a steady increase in magnitudes until mid-observation (MJD 56820). After that HE1310 shows a decrease in magnitudes until the end of our observation.

Long-term Variability detection

We shall demonstrate the use of our algorithms by creating a long-term variability light curve of PG1302-102 (HE1302-0102 in HES) using our long-term variability algorithm. PG1302 is a supermassive black hole binary at sub-pc system which shows sinusoidal variability in optical wavelengths. The variability has a period of 1884.4 days and 0.14 mag amplitude [MJD, 2015]1. Here is a long-term variability light curve over 90 observation nights with a cadence of 2 day. Two fields are combined for each night and later on 5 fields per night.

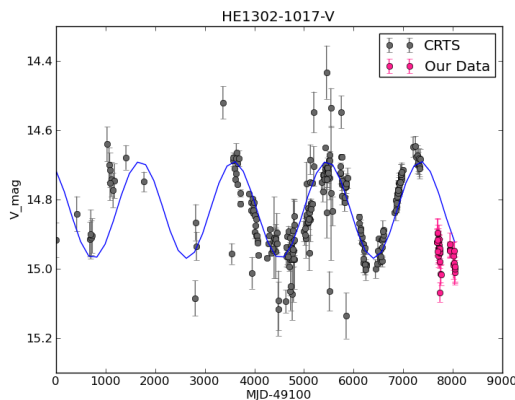


Figure3. A long-term variability light curve of PG1302-102, CRTS data in grey and PROMPT8 data in pink.

From the light curve we are seeing the same variability as the CTRS observation program and we are following the same sinusoidal trend. We can predict that in a few months PG1302 will become brighter. Monitoring is ongoing.

Conclusions

First, we have used Thailand's 0.6m robotic telescope to monitor 50 objects for outburst in order to conduct reverberation mapping. Approximately 30% has shown a magnitude change of more than 0.5 magnitude.

Second, we have developed a self-consistent photometric pipeline with uncertainties of less than 0.05 for average magnitude calculations and 0.1 magnitude in variability calculations.

Third, our pipeline is applicable with other data from Thailand's PROMPT8 telescope however some modification may need to be applied. Lastly, we are monitoring PG1302-102 with approximate uncertainties of 0.1 magnitude. Monitoring is ongoing.

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References

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