# INAF – TIME ALLOCATION COMMITTEE

**Application for observing time** **Category: B**

**Period AOT39 (April 2019 – September 2019)** **Submit using: www.tng.iac.es/submit.html**

**1. Title**

Reverberation mapping of low-z Population B quasars

**2. Abstract**

Reverberation mapping of active galactic nuclei in the local Universe (redshift z < 0.4) has been successfully performed for studying the physics of accreting massive black holes over a broad range of accretion rates. This proposal focuses on spectroscopic observation of low-accretors (Population B quasars) that generally show the distinguishing observational property of broad-line profiles of the Balmer emission lines with a strong redward asymmetry. We propose monitoring observations of a prototypical low-$z$ quasar with a strong H$\beta$ asymmetry, to carry out velocity-resolved reverberation mapping. The new observations are needed to distinguish between the two main physical mechanisms proposed to account for this as-yet-unexplained feature.

**3a. Number of requested hours per telescope and instrument**

| TNG | | | | | REM | |
|---|---|---|---|---|---|---|
| DOLORES | DOLOR.+MOS | NICS | HARPS-N | GIANO-B | ROSS | REMIR |
| 11 | | | | | | |

**3b. Observing modes**

| | | | | | | |
|---|---|---|---|---|---|---|
| TNG: | | Visitor | X | Service | | ToO |
| REM: | | Rapid Response | | Queuing | | ToO |

**4a. Preferred months**

first choice: apr-jun second choice: may-jul

**4b. Other scheduling constraints** (use also box 14)

Obs. at fixed cadence 3 d

**5a. Past and future of the project**

a) Hours already awarded to the project: 0

b) Hours foreseen to complete the project: 0
(not including this request)

**6. Principal investigator**

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**7. Co-investigators (name and institution)**

Jian-Min Wang (Institute of High Energy Physics, Chinese Academy of Sciences)
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Giovanna M. Stirpe (INAF-Bologna)
Paola Mazzei (INAF-Padua)
Du Pu (Institute of High Energy Physics, Chinese Academy of Sciences)

## 8. Status of the project

| Telescope | Instrument | Date | Hours | Notes |
|---|---|---|---|---|

**Description**

**Publications**

**9a. If this proposal is a part of a PhD thesis, write here the name of the student, the thesis title and briefly describe the relevance of these observations for the thesis goals.**

**9b. Is this, or a similar application submitted to other time allocation committees (e.g. ESO, TNG-CAT, ITP)? If yes, please specify which and explain if and why the proposals should be considered complementary.**

**10. Description of the programme (max. 3 pages, including references, tables, and figures.)**

*A) Scientific rationale* Reverberation mapping (RM) has proved to be one of the most powerful tools to analyze the sub-parsec structure of quasars (e.g. Horne et al. 2004, PASP, 116, 465). RM measures the delayed response ($\Delta\tau$) of broad emission lines to the variation of continuum flux. Nowadays data exist for about 100 low-luminosity quasars monitored in the H$\beta$ emission line. An important result emerging from the most recent campaigns reveals that response times (which provide the "radius" of the broad line emitting region, BLR) depend on Eddington ratio $L/L_{\rm Edd}$ (Du et al. 2015, ApJ, 806, 22) and are therefore different for objects in different location along the quasar main sequence (MS) described by Sulentic et al. 2000 (ARAAp 38, 521) and by many authors afterwards (e.g., Shen & Ho, 2014, Nature, 513, 210). It is ultimately expected that the structure of the BLR depends on accretion flow structure and on the relative balance of gravitation and radiation as well. The MS is expected to trace systematic changes in the spectral properties of quasars which involves the effect of both $L/L_{\rm Edd}$ and orientation.

Beyond just determining a single global time lag, high-quality reverberation mapping can provide time lags as a function of velocity. Data in different radial velocity ranges can be used to investigate the geometry and kinematics of the broad-line regions (BLRs, e.g., Pancoast et al. 2011, ApJ, 730, 139) and determine the BH masses in AGNs (e.g., Peterson et al. 2004, ApJ, 613, 682). Such velocity-resolved time lags are diagnostic of the BLR structure itself. These and other advanced analysis products such as velocity-delay maps and dynamical models commonly find that the BLR is made of an optically thick Keplerian disk (e.g., Du et al. 2016, ApJ, 820, 27). A flattened disk could be common in AGNs and quasars. The BLR, however, appears significantly more complex in many objects. A strong redward asymmetry is observed in about 50% of optically selected samples. The asymmetries of H$\beta$ profiles significantly correlate with the ratio of Fe II to H$\beta$ (Marziani et al. 2003, MNRAS, 345, 1133): it is observed in the part of the MS associated with low Eddington ratio and relatively large black hole masses.

Which is the physical and dynamical origin of the redward asymmetry? Single epoch observations cannot address this question. Since the BLR are not spatially resolved, only a measurement of the relative time delay ($\Delta\tau$) in different radial velocity ranges can constrain the gas motion velocity field. Dedicated, monitoring observations with spectral resolution sufficient to resolve the core of the line (mostly unshifted) and the redward asymmetry are needed, so that the relative response time to continuum changes can be measured with good precision. Preliminary results indicate a variety of dynamical configurations if composite/irregular profiles are analyzed (Du et al. 2018, arxiv:1810.11996v1). In the present proposal we focus on a specific class of profiles with small redward peak displacement and significant redward asymmetry which are the most frequent in the low-$L/L_{\rm Edd}$ Population B (class AR,R following the classification scheme of Sulentic 1989, ApJ, 343, 54; see Fig. 1 for a schematic interpretation of the line profile).

We envisage the following basic scenarios: (1) the profile is dominated by virial ($\equiv$ Keplerian) motions, and the line base of the profile is simply emitted closer than the core (as a result of the stratification of the BLR, see Gaskell (2009, NAR, 53, 140, and references therein); (2) the profile is associated with a significant radial infall (+ obscuration). These first two cases can be distinguished on the basis of the difference in response time between the line base and the core. In case (1), the line base should respond first; in case (2), only the red wing should respond first. The third possibility is that (3) the red-ward asymmetry is associated with a second BLR in a binary black hole configuration. Considering the relative prevalence of the blueward and redward asymmetries in Pop. B objects (blue less frequent than red), we cannot exclude that a fraction of the Pop. B sources may host a binary BLR. This latter case allows for tight predictions on the behavior of the line profile: a width "oscillation" is expected according to relative position with respect to the line-of-sight of the two black holes following their orbital motion (see Bon et al. 2012, ApJS, 759, 118 for a convincing example). Previous sparse monitoring by Kaspi et al. (2000, ApJ, 533, 631) over 8yr (a significant fraction of the BLR dynamical timescale) indicate that the binary BLR model is likely not appropriate in the case of our selected target, PG 1613+658. Therefore, the proposed monitoring campaign can be focused on testing case (1) and (2).

*B) Scientific aim* Present-day research should be oriented toward two goals. First, to obtain data on quasars in selected regions of the main sequence that are as yet poorly studied. Secondly, one has to consider that the historical monitoring campaigns were unsatisfactory in terms of sampling that was uneven and sparse. The aim is therefore to monitor a prototypical source with well-defined, common properties, as well as with preliminary data about photometric and spectroscopic variability to ensure the success of a velocity-resolved monitoring campaign. This means a quasar like PG 1613+658, whose H$\beta$ profile shows a slight redward peak displacement and an extended redward asymmetry (i.e., it belongs to the AR,R class, see Fig. 1, upper panel) and that shows significant variability on a timescale of 1 month. For this source we consider H$\beta$ $\Delta\tau$ expected on the basis of previous sparse observations, 40 d (Kaspi et al 2000), and the one from the innermost part of the BLR. The cadence should be a small fraction of the response time expected for the innermost BLR. We assume it to be in correspondence of the peak of CIV$\lambda$ 1549, about $1/2$ the one of H$\beta$, and hence $\approx 3$d, according to the stratification found by Peterson & Wandel (2000, ApJ, 540, 13). The source is relatively bright ($m \sim 14.5$) and will be observed with a broad slit, so that the total requirement of spectroscopic observing time is relatively modest ((3m x 2) x 10 obs/month) = 60m per month, for a total time of ≈3h of open shutter in 3 months of semester AOT39. The resolution obtainable with grism VHR-V and a 4arcsec slit is sufficient to resolve three radial velocity regions corresponding to the blue, core and red side of H$\beta$.

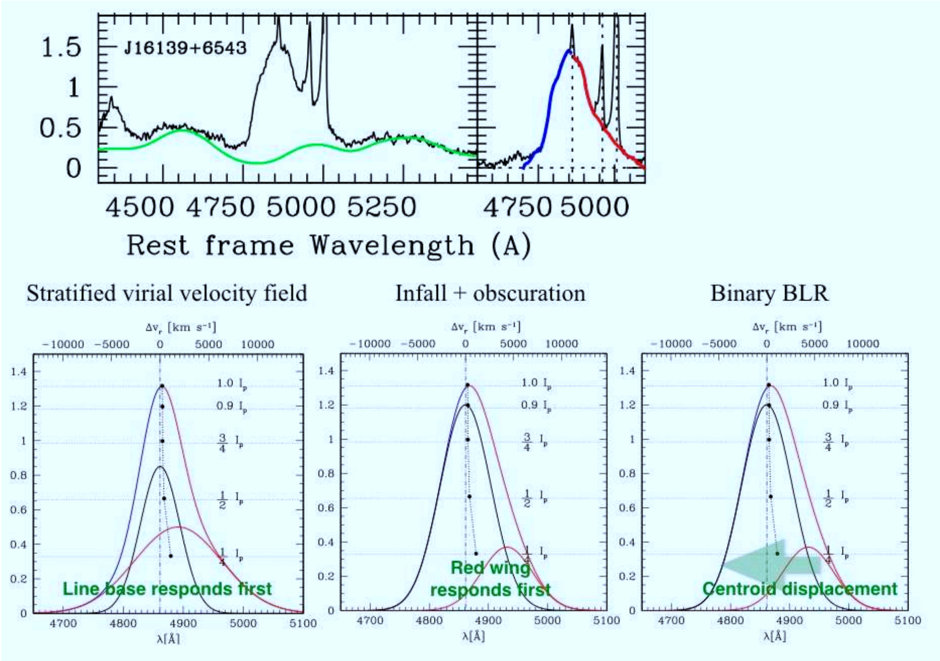


Figure 1. The upper panel shows the spectrum of PG 1613+658 (after continuum subtraction) in the H$\beta$ spectral range, with a zoom on the H$\beta$ profile. The lower panels show a schematic interpretation of the H$\beta$ broad component profile in Pop. B sources such as PG 1613+658: left, the case ionization stratification and predominance of virial motion would imply that the line base would respond first; the middle panel is the interpretation with a second component that may be due to infalling gas; the right panel shows that a significant centroid shift (as well as a change in FWHM) is expected over the dynamical timescale of the emitting region, if the profile asymmetry is associated with a binary emitting region ultimately associated with two binary black holes orbiting around their common center of mass.

**11. List of targets** (note that the absence of a proper object list and information may weaken the proposal)

| Name | $\alpha$ | $\delta$ | Epoch | Mag. | Time | Additional Information |
|---|---|---|---|---|---|---|
| PG 1613+658 | 16 13 57.2 | +65 43 10 | J2000 | V14.5 | 180s | z=0.129; Obs. repeated every 3d for 3 months. |

**12. Observational strategy and justification of requested time, including overheads.**

This is a monitoring project. The campaign at TNG could start in 2019 early Apr and end in 2019 late June (90 days). The sampling interval should approximately 3 days (with a tolerance of $\pm 1$ day) for one target. Therefore, the target will have 30 spectroscopic epochs at TNG in one semester.

At each target visit, we ask for 2 consecutive spectroscopic exposures using the VHR-V Grism (Setup 1) and 2 consecutive image exposures with SDSS r'-band filter (Setup 2) for each target. The consecutive exposures are used for cosmic correction and systematic-uncertainty estimate. When doing the spectroscopic observation for each target, we need to rotate the slit (4"-width) to take a comparison star in the same field of view in the slit simultaneously (In the field of PG 1613+658 there are 3 stars within 1 and 2.5 arcmin that are suitable as calibrators). The comparison star will be used as standard to calibrate the spectra of the target. The image observations will be used to generate the SDSS r'-band light curves through differential photometry of the other several stars in the field. The corresponding bias, flat field, wavelength lamp are also needed.

For the RM observation, the S/N ratios of the spectra should be 50-100 (e.g., Du et al. 2018, and references therein). Using the exposure time calculator, the total spectroscopic exposure time with the VHR-V grism should be 3m x 2 = 6m (assuming bright moon and mediocre seeing conditions). Overhead for spectroscopic observations are 10m. The exposure time for imaging observations should be 10s for 2 exposures, for a total of $\approx$ 1m including readout times. Therefore each target visit would require about 17m including overheads. Considering a cadence of 10 observations per month, 170m x 3 = 510 m $\approx$ 9h will be needed including overheads.
Spectrophotometric standard stars could be observed according to standard calibration plans for the correction of the wavelength-dependent sensitivity of the atmosphere, right before or after the target observations, at least once every three observations. This will require an additional 12m x 10 =120m.

The total observing time we ask for is 11h.

**13. Requested instrument(s) setup**

| Id | Instrument | Binning | Filter(s) | Slit | Grism | Time | Additional Information |
|---|---|---|---|---|---|---|---|
| 1 | Dolores | 1x1 | none | 4'' | VHR-V | 3mx2 | Time of open shutter, without overhead |
| 2 | Dolores | 1x1 | SDSS r | none | none | 10sx2 | Time of open shutter, without overhead |

**14a. Moonlight constraints**

Max. # of days from new moon $\boxed{14}$

**14b. Scheduling constraints, special requirements and other remarks**
(please include justification of constraints in 14a)

The observations should be repeated every 3d for four months. Since adequate sampling is needed, the observations at TNG will be carried out in synergy with the Asiago Copernico telescope of INAF and with the Lijiang telescope which will provide *occasional* backup facilities in case of bad weather at TNG. The calibration technique applied is adequate for the reliable inter-comparison of observations with different telescopes and instruments.

**15. Observational background of the applicants**

**Name of the observer(s) at TNG:**

**Experience of the observer(s) with the requested TNG instrument(s)**

**Experience of the observer(s) with other telescopes/instruments**