Science and Technology Facilities Council **PATT2**
Polaris House, North Star Avenue, Swindon, SN2 1SZ **Version 02/2013**
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APPLICATION FOR TELESCOPE TIME (OPTICAL AND INFRARED)

1 TELESCOPE *(AAT, UKST, WHT, INT or UKIRT)*	INT	Reference:	Date stamp:
2 SEMESTER	2021B	3 SCIENTIFIC CATEGORY	4

4 COORDINATED PATT PROPOSALS: *AAT:*☐ *UKST:*☐ *WHT:*☐ *INT:*☐ *UKIRT:*☐ *JCMT:*☐ *GEMINI:*☐ *LT:*☐ *MERLIN:*☐

5 PRINCIPAL APPLICANT

Surname: Lawrence Title: Prof First name: Andy
Post held: Regius Prof
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6 COLLABORATORS

Name:	Institute:	Observer?
P.Short	IfA Edin	Yes
H.Rendell-Bhatti	IfA Edin	Yes
M.Ward	Durham	No
D.Homan	AIP Potdsam	No

7 SHORT TITLE OF PROPOSAL *(maximum 12 words)*

Is long term variability the missing factor in the quasar eigenvector picture?

8 SUMMARY OF PROPOSED OBSERVATIONS

Our recent work on long term AGN monitoring has led us to believe that much of the scatter in the "eigen vectors" describing quasar diversity is due to long term variability, in addition to, and muddying, the often claimed dependence on mass, luminosity and orientation. We propose to test this by obtaining a high quality spectroscopic snapshot of all 87 quasars in the Boroson and Green (1992) Bright Quasar Sample (BQS), together with 42 further low-redshift quasars drawn from the atlas of Marziani et al (2003), combining with further SDSS observations. We will then have multiple epochs spaced over three decades for 129 quasars. This will enable us to revisit the principal components analysis of quasar properties and reconsider its physical interpretation.

9 FOCAL STATION, INSTRUMENT AND DETECTOR

Focal station:	Instrument:	Detector(s):	Gratings/Filters:
Cass	IDS	RED2	R300V

10 OBSERVING TIME REQUESTED THIS SEMESTER

	Dark:	Grey:	Bright:	specify nights *or* weeks:
Time requested this semester		4		N
Minimum useful allocation this semester		3		

UKIRT applicants requiring dark time must justify this in section 18

11 COMPLETE THIS SECTION ONLY IF THIS IS A LONG TERM PROPOSAL

	Dark:	Grey:	Bright:	specify nights *or* weeks:
Total time requested		9		

12 SCHEDULING INFORMATION

Preferred dates:	Nov optimal. Need runs in Sem-B,A with several months between.
Impossible dates:	None
Give justification for impossible dates	RA's
If observations are to be simultaneous with other telescopes or satellites, give details:	
Any other scheduling constraints: *Include likely clashes with other time applications, constraints on lunar position or quarter, instrument preparation requirements, etc*	

13 SERVICE OBSERVING

yes: [ ] no: [ ] maybe: [x]

14 SUPPORT ASTRONOMER REQUESTED AT TELESCOPE

every night: [ ] no: [ ] first night only: [x]

15 LIST OF PRINCIPAL TARGETS

Object(s):	RA(h,m):	Dec(degs):	Mag(type):	Colour:	Exp. Time:

Bright Quasar Sample (BQS): 87 BQS quasars with B<16.3, z <0.5; RA gaps 2H-8H and 17-20H
From Boroson and Green, 1992: subset of PG quasar sample

M03 sample: 42 quasars with $z < 0.5$ in ranges 2H-8H and 17-20H
From the atlas of Marziani et al 2003
(Note: the BQS sample is also in the Marziani atlas).

Additional bright local Seyfert galaxies may be observed as time permits, or as required to fill gaps.

16 LIST ALL SIMILAR/SUPPORTING APPLICATIONS TO ANY PATT OR OTHER TIME ASSIGNMENT COMMITTEE

You must include a brief description of any other applications whose targets or science goals are similar to those requested here

Telescope/satellite:	Title/Description of programme:
none	

17 SCIENTIFIC JUSTIFICATION

Case not to exceed this A4 page. Figures and/or references can be included on page 4a

Introduction: quasar eigenvectors. In a seminal paper, Boroson and Green (1992; BG92) analysed the spectroscopic properties of a complete sample of 87 bright quasars at $z < 0.5$, showing that the majority of diversity arises from two "Eigen Vectors (EV)". EV1 is a mixture of narrow [OIII] strength, FeII strength, and velocity width (FWHM), which they identified tentatively as due to L/L_{Edd} or equivalently L/M_H. EV2 is a mixture of absolute magnitude, HeII strength, and spectral shape (α_{ox}), which they identified as due to spectral energy distribution (SED) depending on L. However in both cases, key diagrams are more like wedges than correlations (see e.g. Fig. 3), showing that diversity is not yet explained. A number of authors have argued that the scatter in EV1 related diagrams is due to *orientation* (e.g. Sulentic 1989; Boroson 2002; Marziani et al 2003 (M03); Shen and Ho 2014; Sulentic and Marziani 2015; Runnoe and Boroson 2020), but the evidence is indirect, cannot explain all the scatter in EV1, and does not explain the scatter in EV2.

Lessons from thirty years of MKN110: long term variability. We have analysed archival and new spectra of MKN110 from over thirty years (Homan *et al* 2021). It has undergone dramatic changes, but especially in HeII - the flux at 5100Å has ranged by a factor of 9, but broad HeII by a factor of 40 (Fig.1). We argue that HeII traces the true EUV luminosity of the AGN; using it as a proxy of the ionising continuum is very revealing, for example clarifying the dependence of responsivity on the BLR's excitation level, set by long term variability, and showing that both the line velocity width and velocity offset vary along with luminosity changes (Fig.2) - an example of the "BLR breathing" caused by the fact that the BLR is an extended and radially stratified structure. In Fig. 3 we show our MKN110 data overplotted on the key BG92 EV2 diagram, HeII/Hβ versus absolute magnitude. Remarkably, it spans the range shown by the population of lower luminosity quasars. This suggests that the "wedge" in EV2, and possibly in EV1 as well, largely arises from taking a snapshot of a population whose properties vary over decades.

MKN110 is not alone. Fig. 4 shows both the mean and RMS spectrum for the well studied local AGN NGC 7469; it is clear that HeII is much more variable than either Hβ or the continuum; this effect can also be seen in the intra-year monitoring program of Barth et al 2015. Photometrically, the seven year monitoring of a subset of BQS objects by Giveon et al 1999 shows that variability of several tenths of a magnitude is normal, and variations of a magnitude or more are not uncommon (see Fig. 6). From DES repeat observations, Rumbaugh et al (2018) argue that over 15 years, 30-50% of quasars change by a magnitude or more. Finally, we have made a preliminary inspection of the original BG92 spectra (kindly provided by T.Boroson) and found that HeII velocity offsets similar to those in MKN110 are also common, and seem to correlate with velocity width.

New observations. We propose repeat observations of an extended BQS sample at similar resolution and S/N, centred on the [OIII], Hβ, HeII, FeII region. We will measure accurate fluxes for those features, as well as Hβ shape parameters - as also measured by BG92 and M03, quantifying changes in apparent EV1 and EV2. *If MKN110 is anything like typical of low luminosity quasars, with higher luminosity quasars still variable but less so, this could completely explain the scatter in BG92 diagrams; but this remains to be proved.* Our sample comprises 129 bright quasars at $z < 0.5$ selected from the spectral atlas of M03, including the whole of the original BG92 BQS sample. All objects will have two epochs separated by $\sim$ 20 years between us and M03; the 87 original BQS objects will have three epochs, with an additional shorter gap between M03 and BG92; and 30 objects have a fourth epoch, as they were also observed by SDSS in between M03 and the proposed new observations. Finally, 28 BQS objects were also the subject of a reverberation campaign by Kaspi et al (2000).

Questions to answer.

(1) Do all quasars show significant long term spectral variability?

(2) Is that variability especially marked in HeII?

(3) Do HeII and Hβ show changes in velocity width and offset, like MKN110?

(4) Does this variability explain the scatter in EV1 and EV2 diagrams?

We will have tracks in the EV1,EV2 diagrams, including α_{ox} changes from ROSAT and eROSITA observations. All objects have M_H estimates from the "single epoch" method, and 28 have reliable reverberation masses. It may be that after allowance for variability, *only* L and M_H are required to explain quasar behaviour; but if there is still a third required parameter (e.g. orientation), it will be on a firmer footing.

Our sample covers the whole RA range and so cannot be observed in a single run. We therefore request 9 nights split across two semesters. We are fairly flexible about when the runs are scheduled, as long as they are reasonably far apart. November and April are fairly much optimal.

Give details of the technical feasibility of the proposal (S/N,etc) AND any non-standard technical requirements

Proposed setup. We will use the IDS with the default detector (RED2) with grating R300V which gives 1.87Å per pixel. For the unvignetted range of 2275 pixels this gives a wavelength range of 4254Å.

Wavelength setting. Our aim is to keep life simple and use a fixed grating setting. The target lines are HeIIλ4686, H$\beta\lambda$4861, [OIII]λ5007, and the FeII complexes either side of Hβ. The targets range up to z <0.5 at which point [OIII] is at 7510Å . We will therefore use a grating setting giving us 3750-8000Å . We then get our target lines for all objects. As a bonus we get Hα for about a third of the sample, and HeIλ5876 for half the sample. For the other (higher redshift) half, we get MgIIλ2798 as the bonus.

Resolution. With R300V and an assumed resolution of 2.5 pixels, our velocity resolution will be $\sim$250 km s^{-1}. This is good enough to resolve the narrow [OIII], and get accurate line shape parameters for Hβ and HeII, and also good enough to do the FeII subtraction (see below). The resolution is closely similar to the original BG92 spectra and the SDSS spectra.

FeII removal. Measuring the strength of the FeII complexes is part of the science goals, but it is also necessary to get an accurate measurement of HeII in many cases. This requires the use of an FeII model template, blurred with the observed BLR velocity width, as first clearly demonstrated by BG92. We have copies of the original BG92 spectra, so can check that this modelling is reproducible.

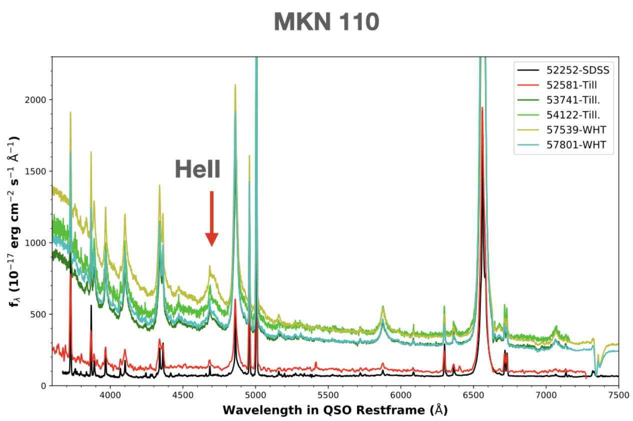
S/N and exposure. To achieve accurate shape measurements as well as the FeII modelling, we need moderately high signal-to-noise, roughly similar to that obtained by BG92. At m=17 in 20 minutes we can achive 1400 cts/pixel i.e. SNR$\sim$38. Allowing for calibration and acquisition overheads, depending on the time of year, we should be able to get 15 targets per night and complete the project in 9 nights; 4 in semester B and 5 in semester A.

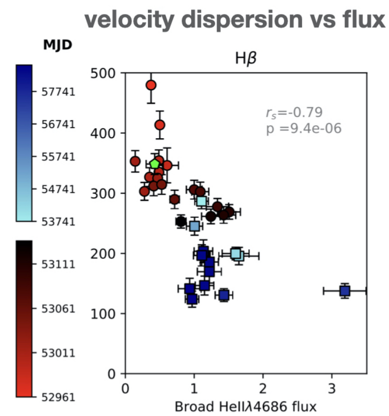
Conditions. Targets are bright enough that dark time is not necessary, but bright time should be avoided. We need reasonably transparent but not photometric conditions - all targets are being covered every few nights by ZTF, which gives us g-band calibration. Also, the main measurement targets are line ratios and/or equivalent widths. We do need an absolute magnitude, but this varies slowly enough that a ZTF observation reasonably close in time is adequate.

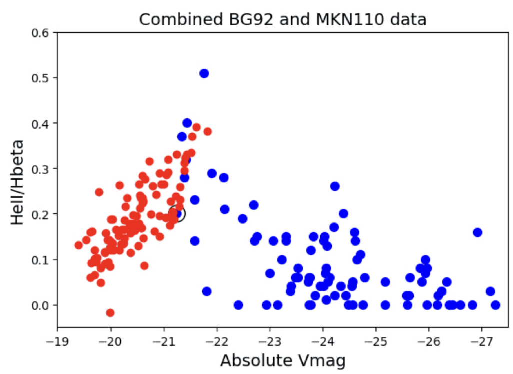
Scheduling. As our targets cover all RAs, scheduling is not too critical, but we do need a run in each semester separated by several months, and avoiding the Milky Way prime time in July and August.

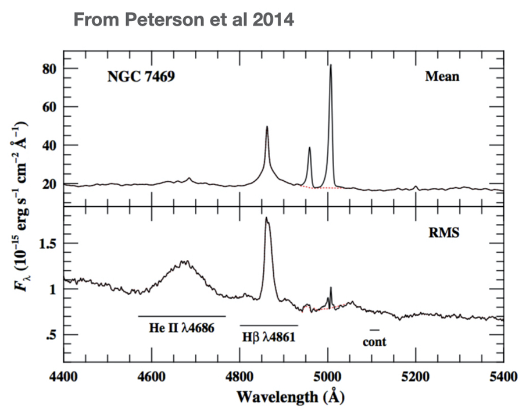
References

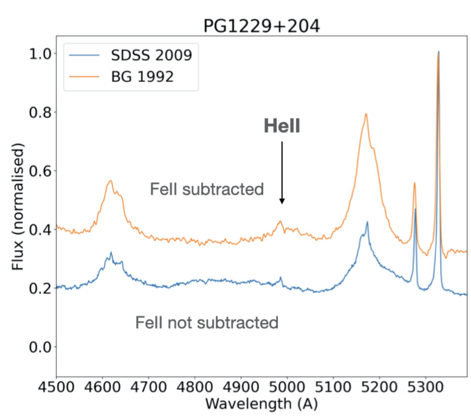
Barth et al 2015 ApJSupp 217,26; Boroson and Green 1992 Ap J 80, 109 (**BG92**); Boroson 2002 ApJ 565, 78; Giveon et al 1999 MNRAS 306, 637; Homan et al 2021 in prep (**H21; available at** https://www.roe.ac.uk/~al/exvar-papers); Marziani et al 2003 ApJSupp 145, 199; Peterson et al 2014 ApJ 795, 149; Rumbaugh et al 2018 ApJ 854, 160; Runnoe and Boroson 2020 ArXiv 2004.0719; Shen and Ho 2014 Nature 513, 210; Sulentic 1989 ApJ 343, 54; Sulentic and Marziani 2015 Front.Astron.Sp.Sci Vol 2, Art.6











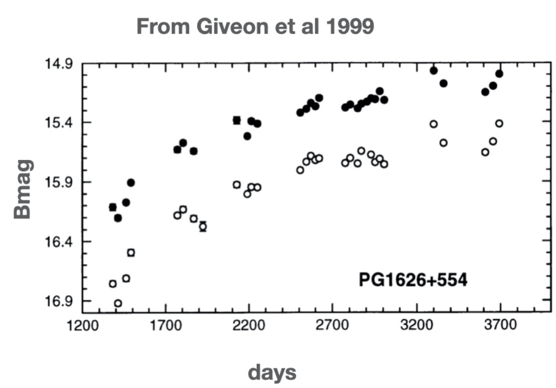


Fig.1, top left: Example spectra of MKN110 from H21. **Fig.2, top right:** Velocity dispersion versus HeII flux, from H21. **Fig.3, middle left:** HeII/Hβ vs luminosity. Blue=BG92 (large circle=MKN110), red=MKN110 from H21. **Fig.4, middle right:** Mean and RMS spectra of N7469, showing extreme HeII variability. **Fig.5, bottom left:** PG1229+204 in BG92 and SDSS. HeII, Hβ, and Hβ profile have all changed with respect to [OIII]. It is also clear that quantifying the HeII change requires FeII subtraction. **Fig.6, bottom right:** Factor four luminosity change in PG1626+554 over seven years. Filled circles R-band; empty circles B-band vertically shifted for clarity.

19 SUMMARY OF BACKUP PROGRAMME FOR POOR OBSERVING CONDITIONS
If instrumentation or setup differs from main programme, give full details

Observe brighter members of the sample.

20 RELATED PATT APPLICATIONS OVER THE LAST FOUR SEMESTERS *(including unsuccesful applications)*

PATT reference:	Award:	Clear nights:	Comments:
none			

21 PUBLICATIONS BASED ON PATT TIME PUBLISHED DURING THE LAST FOUR SEMESTERS *(maximum 6)*

No PATT runs in last four semesters, but multiple recent publications based on other telescopes, and on PATT time from the previous few years. For a full list of recent papers by the Lawrence extreme variability group, see https://www.roe.ac.uk/~al/exvar-papers

22 EXPERIENCE OF INTENDED OBSERVERS WHO HAVE NOT PREVIOUSLY USED THIS TELESCOPE

Lawrence, Ward, Short, Homan and Nicholl all experienced on multiple telescopes; Lawrence, Ward and Short have all used INT; first observing for new student Rendell-Bhatti

23 COMPLETE IF THE OBSERVATIONS ARE PRIMARILY FOR A STUDENT RESEARCH TRAINING PROGRAMME

Name of student:	Harry Rendell-Bhatti
Project title:	Long term variability of quasars

24 COMPLETE IF THE OBSERVATIONS ARE ASSOCIATED WITH A CURRENT STFC RESEARCH GRANT

Name of principal investigator:	
Grant title:	
Grant number:	

25 NON-STANDARD TRAVEL AND SUBSISTENCE REQUIREMENTS *(UK observers only)*

Justify requests for travel and subsistence for more than one person:

Details of any other expenditure (eg freight, remote observing):