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)*	WHT	Reference:	Date stamp:
2 SEMESTER	2019A	3 SCIENTIFIC CATEGORY	5

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

5 PRINCIPAL APPLICANT

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Is the applicant a possible observer? Yes

6 COLLABORATORS

Name:	Institute:	Observer?
A. Bruce, D. Homan, A. Lawrence	Univ. Edinburgh	Yes
K.E.S. Ford, B. McKernan	City University of New York	No
M. Graham, D. Stern	California Institute of Technology	Yes
C. MacLeod	Harvard-Smithsonian CfA	No

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

Optical Properties of Quasars that have rapidly Rising and Falling Infrared flux

8 SUMMARY OF PROPOSED OBSERVATIONS

"Changing-look" quasars (CLQs) vary much faster than expected from classic, thin, Shakura-Sunyaev accretion disks. Our team has recently demonstrated that infrared-selected CLQs allow us to probe the very central regions of quasars, including the innermost stable circular orbit (ISCO) and potentially test predictions of General Relativity. We have extracted a set of 21 IR-selected CLQs from the SDSS using new data from the NEOWISE-R mission. These objects have striking falling and rising mid-IR fluxes, but have representative SDSS spectra from ≈6 to 14 years ago (rest-frame). We propose the first systematic study of IR-selected CLQs and request 2 dark nights in order to reveal the recent optical spectral state of these quasars. Our baseline expectation is that WHT spectra of the IR Risers (Faders) will show hotter, bluer (cooler, redder) disks with larger (smaller) EW broad lines than seen with SDSS. Any departure from this expectation will further inform us how the classical model breaks down.

9 FOCAL STATION, INSTRUMENT AND DETECTOR

Focal station:	Instrument:	Detector(s):	Gratings/Filters:
Cass	ISIS	EEV12/RED+	R300B+R158R

10 OBSERVING TIME REQUESTED THIS SEMESTER

	Dark:	Grey:	Bright:	specify nights *or* weeks:
Time requested this semester	2			N
Minimum useful allocation this semester	1			

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				

12 SCHEDULING INFORMATION

Preferred dates:	None
Impossible dates:	July
Give justification for impossible dates	Our targets are setting fast, and there is not ample exposure time between Twilight and very high airmass to obtain our required SNR
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: [x] maybe: [ ]

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:

ID	RA (J2000)	Dec (J2000)	SDSS g-band	Redshift z
"Faders" (16 in total)				
J1014+0918	10:14:15.14	+09:18:39.3	18.22	0.252
J1028+0600	10:28:30.56	+06:00:58.4	18.57	0.312
J1102+0834	11:02:48.02	+08:34:04.2	18.00	0.274
"Risers" (5 objects in total)				
J1211+0103	12:11:42.58	+01:03:37.1	18.46	0.293
J1253+1454	12:53:27.70	+14:54:56.0	18.15	0.252
J1509+1110	15:09:52.19	+11:10:47.0	18.16	0.285

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:
PATT: Liverpool Telescope	18B, XPL18A06 PL18B07 P.I. Nicholas P. Ross, 58.2 hours awarded, B-band *The Optical Monitoring of IR-variable Quasars: New theories, new tests*
PATT: Liverpool Telescope	18A, XPL18A06 PL18A06 P.I. Nicholas P. Ross, 52 hours awarded, C-band *The Optical Monitoring of IR-variable Quasars: New theories, new tests*
	Both proposals are for optical $ugriz$ monitoring for a sample of 72 quasars with interesting infrared light curves. This includes the 21 objects here, but no data for our current proposal were obtained in 2018A.

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

"Changing-look" quasars (CLQs) vary much faster than expected from classic, thin, Shakura-Sunyaev accretion disks, and lead to the current situation that has been dubbed the "Quasar viscosity crisis" where the CLQs have broken standard viscous accretion disk models ([1]). Infrared (IR) observations allow us to rule out obscuration as a cause of the extreme variability. As we showed in [2] and [3], optical variability of IR-selected CLQs is so fast and of such large amplitude that the driver is most likely changes in a puffed-up, viscous inner accretion disk, close to the innermost stable circular orbit (ISCO).

As a result, IR-selected CLQs ([4] and this proposal) allow us to probe the innermost regions of quasars, including the ISCO, the plunging region and to investigate predictions of General Relativity in strong gravity. The role of IR-selection is key to revealing these powerful probes of disks and spacetime close to the black hole.

IR emission from quasars is widely believed to be produced in dusty gas by reprocessed continuum UV emission. We have extracted a set of $z \approx 0.3$ quasars that exhibit striking 'falling' (Fig. 1; top) and 'rising' (Fig. 1; bottom) mid-IR fluxes over a period of ≈4 years. In each case we have representative SDSS spectra (see Fig. 2) from before this fade/rise and we have established that these objects are not blazars by removing objects that would fulfil a traditional "radio loud" criterion.

WHT spectra of these quasars will allow us to carry out a simple test of the IR "Risers" and "Faders". Since IR emission is reprocessed continuum emission from the disk, our baseline expectation (null hypothesis) is that WHT spectra of the "Risers" will show hotter, bluer disks with larger EW broad lines than seen with SDSS. Likewise, WHT optical spectra of the "Faders" will show cooler, redder disks with smaller EW broad lines than seen by SDSS. *Here we propose the first ever systematic study of IR-selected CLQs. We request two dark nights in order to reveal the optical spectral properties of these quasars.*

Crucially, we have first epoch spectral data from SDSS, and thus can perform an "absolute" (i.e. 1st epoch vs. 2nd epoch) measurement as well as a "relative" (2nd epoch Risers vs. 2nd epoch Faders) test. By comparing the disk luminosity between the 1st epoch SDSS spectra and the 2nd epoch WHT spectra we will be able to constrain the change in the accretion rate and inner disk temperature for each quasar. This difference should be directly comparable to the magnitude of IR rise or fall in that quasar between epochs. Thus, we have a strict and simple null hypothesis test. A confirmation of the null hypothesis in our sample gives us some confidence that IR-selection of CLQs is probing what we think it should, i.e. dusty gas beyond the regular broadline region. Any departure from the null hypothesis reveals a flaw in our simple expectations and a flaw in the IR-selection criterion of CLQs. It will provide grounds for both follow-up theoretical work and follow-up observations on a larger sample of risers and faders. The latter will test the rate of departure from our null hypothesis for CLQs.

Our sample spans a period of ≈6-14 years in the rest-frame since the SDSS spectra were obtained, see Figure 3, and these objects also generally have Eddington ratios $\approx 1\% - 10\%$. Calculating if there has been an increase/decrease in the Eddington ratio in 2019A will again give key insights on the mechanisms powering extremely variable quasars.

If our hypothesis is supported by the data, we will be able to quantify the expected variability in the IR due to optical continuum changes. This will enable us to further investigate the relationship between the optical continuum source and the IR source in AGN, and, in particular how changes of the innermost accretion disk (near the ISCO) impact AGN structures at parsec (and perhaps larger) scales.

Finally, we note that obtaining time-domain spectroscopy for IR-variable quasars, links directly to the WEAVE science case and observations of radio AGN and galaxies in the medium deep LOFAR surveys and quasars detected in ESA *Gaia*.

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

Our proposal is to obtain new spectroscopic epochs for 21 objects that have been identified due to their startling rising or falling mid-infrared light curves.

Sample construction. Take SDSS DR14Q (Pâris et al., 2018, A&A, 613A, 51; 526,356 quasars) and limit to $0.25 \leq z \leq 0.35$ in order to access Mg II, Hβ and Hα in WHT/ISIS spectra; sample drops to 3193 quasars. For this redshift range, WISE W1 (W2) accesses rest-frame 2.52-2.72 (3.33-3.60) μm, so still corresponding to hot dust. Limit to Decl. $\delta \leq +20$ deg to enable follow-up from Southern Hemisphere; sample drops to 1233 quasars. Obtain the NEOWISE-R 2018DR light curves, and apply additional requirement that $w1snr > 2$ for individual L1b frames; sample drops to 1219 quasars. Visually inspect all 1219 NEOWISE-R light curves for interesting objects (i.e., quasars with obviously rising or fading NEOWISE-R light curves) and concentrate on objects with $120 < R.A./deg < 250$ for 2019A. This yields a sample of 23 objects (17 "Faders", 6 "Risers").

We then checked for blazars via the CRATES Flat-Spectrum Radio Source Catalog (heasarc.gsfc.nasa.gov/W3Browse/radio-catalog/crates.html), finding no matches. We also checked with VLA FIRST Catalog Database (2014dec17) and removed two objects, one with a FIRST detection, and one radio-undetected source that might fit the radio-to-optical flux ratio definition of radio-loud (e.g., Stern et al., 2000, AJ, 132, 1526) given its faint optical magnitude. **We arrive at a sample of 21 objects with 16 of these being "Faders" and 5 being "Risers".**

Observing Notes: Our sample of 21 targets ranges from $g = 16.97 - 19.30$ mags, though all but two are brighter than $g = 18.97$ mag from their SDSS photometry. The sample naturally breaks down into a "Bright" $g < 18.5$ subsample with 13 objects and a "Fainter" subsample with 8 objects having $18.50 < g < 19.30$.

Time requirement. Based on recent experience (with the CLQ sample in 16A/17A), and given the estimated g-band magnitudes of these objects, we estimate 2×450sec science exposures for our Bright subsample (for a total of 900sec×13=11,700secs) and 2×900sec science exposure for our "Fainter" sample (for a 1800sec×8=14,400secs) for a 26,100sec = 7.25 hours total science exposure time. Given these exposure times, our past experience, and values from SIGNAL (1.00" seeing, 1.20 airmass, 1.00" slit width, Dark time) we achieve, SNR of ≈10-20/pixel for all our targets. We *nota bene* that *if* any of our objects have faded in the optical to the extent that these exposure times are *not* sufficient, that in of itself is a key discovery and fascinating result.

With this Total Science Exposure time and including all the ISIS overheads using the TOTE (42 telescope pointings; 21 autoguiding preparations; 21 object acquisitions: 42 detector readouts; 2 changes of grating, no changes of the dichroic and 22 spectroscopic arcs) we have a **total estimated time of 43,424 sec = 12:06 hours and therefore request two full Dark nights.** We require Dark Time in order to maximise SNR in the blue and in particular for the Mg II line, continuum slope and SED measurements. *At a minimum, we request 1.00 dark night to observe 8-10 targets, e.g. the full "Risers" sample and an equivalent number of "Faders".*

Spectroscopic set up. WHT+ISIS is the ideal instrument as has been repeatedly demonstrated on our previous observing runs. The sensitivity and wide wavelength coverage with the two arms is essential for detecting Mg II, Hβ and Hα over the redshift range of the targets ($z = 0.25$–0.35). Indeed, our redshift range is specifically chosen so that WHT+ISIS can access these broadlines.

We need medium resolution so that the broadlines are well resolved, and ideally so that the narrow lines (width ~ 500 km/s) are at least marginally resolved. We use grating R300B in the blue arm, with 0.86Å/pixel, and with a $1''$ slit giving resolution 3.4Å, equivalent to velocity resolution of 200km/s at 5200Å. With the red arm we use R158R which gives a similar velocity resolution at 7000Å. This combination gives complete wavelength coverage with reasonable resolution.

References and Figures

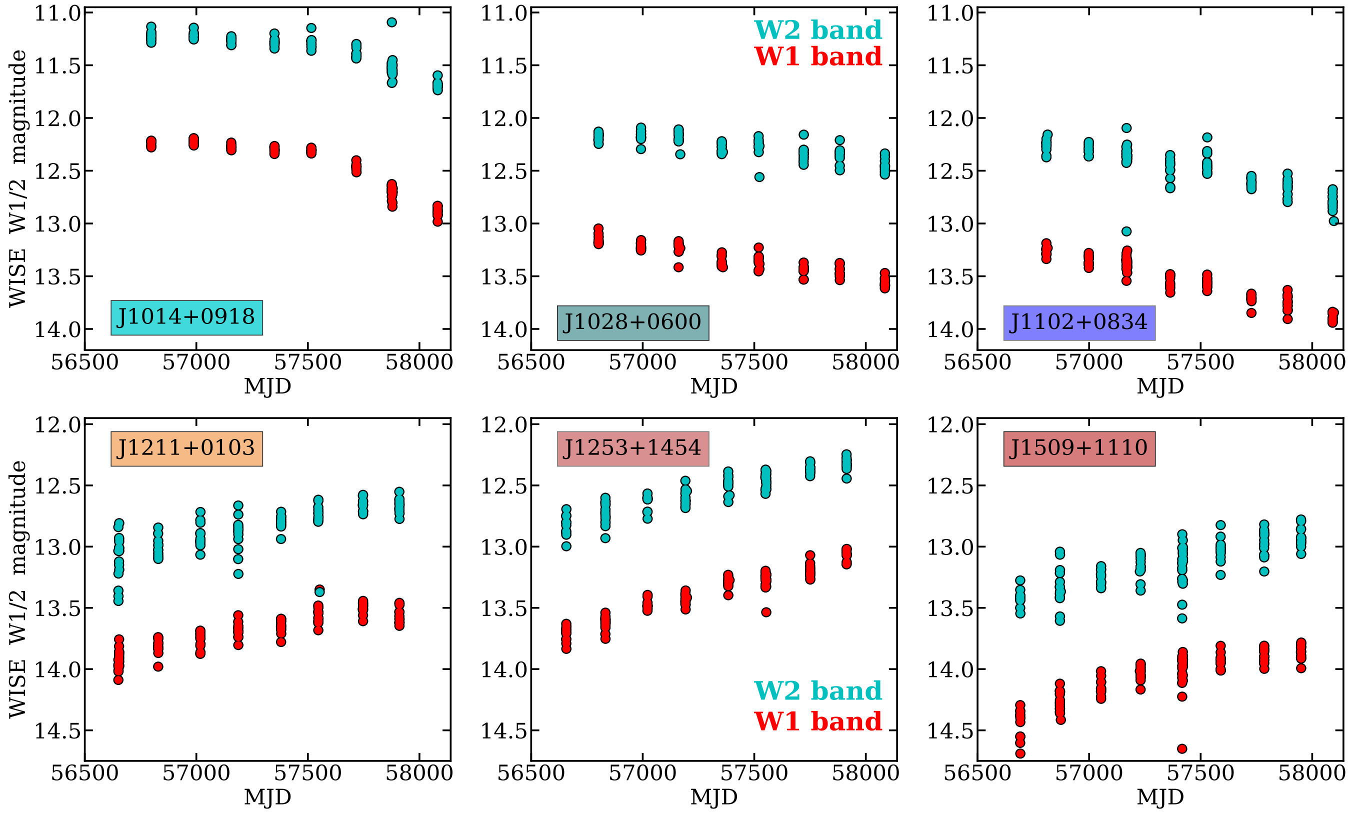

Figure 1: The NEOWISER light curves of the first three "Faders" and first three "Risers" in our target list. These data are typical of our sample and show very clear and dramatic changes in 3.4μm W1 and 4.6μm W2 flux.

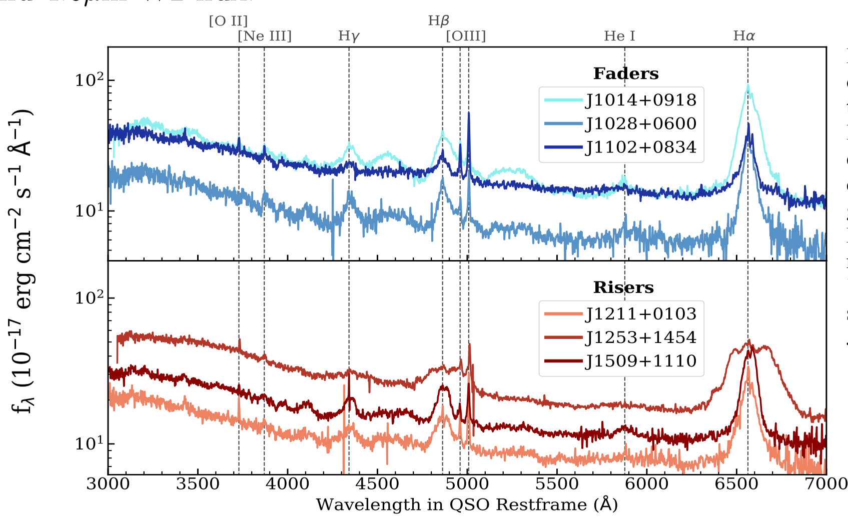

Figure 2 (left): The SDSS spectra of six of our targets, in the rest-frame. In the top panel are the quasars with fading IR light curves (***"Faders"***; blue colours), and in the bottom panel are the quasars with IR light curves that are getting brighter (***"Risers"***; red colours). Key emission lines are marked. We note no dramatic difference between the 'Faders' and the 'Risers' spectra, but do see non-standard line profiles e.g. Hα in J1253+1454.

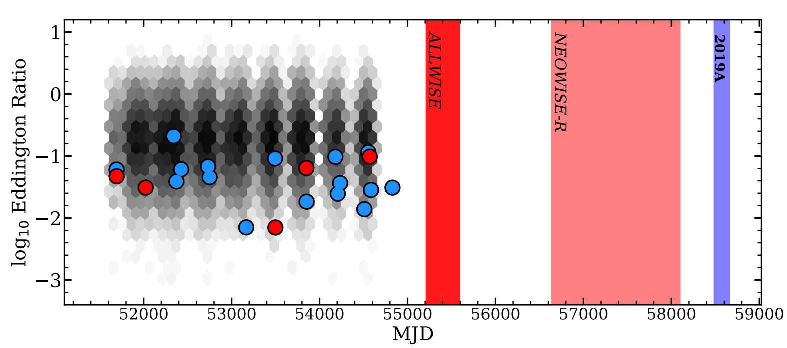

Figure 3 (right): The distribution in MJD and ($\log_{10}$) Eddington ratio for our full sample (blue circles are the Faders; red circles are Risers) compared to the full SDSS DR7Q population (grey-scale hexagons). The temporal coverage of ALLWISE (red), NEOWISE-R (salmon area) and 2019A (violet) is also shown.

References:

[1]Lawrence, 2018, NatAs, 2, 102
[2]Stern et al. 2018, ApJ, 864, 27;
[3]Ross et al., 2018, MNRAS, 480, 4468
[4]Graham et al. 2018, ApJ; in advanced prep.
[5]Pâris et al., 2018, A&A, 613A, 51
[5]Stern et al., 2000, AJ, 132, 1526

19 SUMMARY OF BACKUP PROGRAMME FOR POOR OBSERVING CONDITIONS

If instrumentation or setup differs from main programme, give full details

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

PATT reference:	Award:	Clear nights:	Comments:
LT 18A/B: PL18A08	B 14h		"Continued reduced cadence monitoring of large amplitude microlensing events"
LT 17A/B: PL17A09	A 21h		"Continued monitoring programme for high-value, slow, smooth AGN hypervariables"
WHT 17A/B:	2D2G (17A) 1D1G+ 1DS1GS (17B)		Continuing: SW2017b05 "Mapping the transverse structure of the BLR and torus in hypervariable AGN"

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

Bruce, A., Lawrence, A., MacLeod, C., et al. 2017, MNRAS, 467, 1259
Collinson et al. (incl. Lawrence, Bruce, MacLeod), 2018, MNRAS, 474, 3565
Kankare, E. (incl. Lawrence, Bruce), Nature Astronomy, 1, 865
MacLeod et al (2018), ApJ, collaboration submitted.

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

All proposers experienced WHT observers except Ross, who is an experienced user of AAT and similar US telescopes

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

Name of student:	
Project title:	

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

Name of principal investigator:	N.P. Ross
Grant title:	STFC Ernest Rutherford Fellowship
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):