Chapter 8

Micro-variability in PHFS Sources

One of the distinctive features of blazar AGN is rapid flux variability, which is seen in every region of the electromagnetic spectrum (Wagner and Witzel 1995). This variability can be on timescales as short as hours to minutes – in this case, it is termed "micro-variability". In the optical, these variations can be of the order of ~ 0.1 mag per night (see the review by Miller and Noble 1996). While some radio-quiet quasars have been shown to exhibit micro-variability (Jang and Miller 1997), it is seen most commonly in radio-loud (mostly blazar-type) AGN. The duty cycle[1] for radio-loud AGN is $\sim 68\%$, compared with $\sim 7\%$ for radio-quiet quasars (Romero et al. 1999) – the figure may be even higher ($\sim 80\%$) for radio-selected BL Lacs (Heidt and Wagner 1996).

Based on these numbers, it is reasonable to expect to see micro-variability in quasars and BL Lacs from the PHFS, and this chapter contains an investigation into the existence of micro-variability in three such sources. With the above figures, if three objects are observed there is a probability of $\gtrsim 97\%$ of seeing micro-variability in at least one source.

[1] The fraction of time that an object in a given class is variable. This figure is determined observationally by taking the ratio of the time for which objects of a given class are variable to the total observing time for objects in that class.

8.1 Observations

On the night of the 3rd of August, 1999, three PHFS AGN were observed[2] multiple times in three NIR filters over the course of ~ 7.5 hours, in an attempt to detect short timescale micro-variability. The observations were made with the *CASPIR* near-infrared detector on the Australian National University's 2.3m telescope, at Siding Spring Observatory, NSW.

The three objects chosen were the following:

2243−123: A quasar, $z = 0.63$, that has been described as an optically variable quasar. Its optical/NIR SED takes the form of a blue power law ($B - K = 2.15$, fitted power law from Chapter 5 of $\alpha = -1.92$). Its optical spectrum shows strong broad Balmer lines and [O III] lines of small equivalent width (Tadhunter et al. 1993).

2240−260: A BL Lac object at $z = 0.774$. It has a redder optical/NIR SED ($B - K = 4.43$, fitted with a strong synchrotron component). High polarisation has been observed in this source (15.1%, Wills et al. (1992)), and only weak, if any, emission lines have been seen. This object was seen to exhibit intra-day variability by Heidt and Wagner (1996).

2233−148: A candidate for a BL Lac (according to Padovani and Giommi (1995)), at $z > 0.609$. This has a similar optical/NIR SED to 2240−260.

Three-colour images of each of these sources are shown in Fig. 8.1, indicating the location of the source and the comparison stars used.

These sources were chosen primarily on the basis of their position on the sky (to enable constant observations for the second half of a night, and to minimise the time required for the telescope to move between each source), and also to examine the potential for micro-variability in both BL Lacs (2240−260 and 2233−148) and blue radio-loud quasars (2243−123).

These objects were observed in three filters: J, H and K_n. Each source was observed eight times in each filter. 2240−260 was observed a ninth time

[2] By the author, with the assistance of Alicia Oshlack.

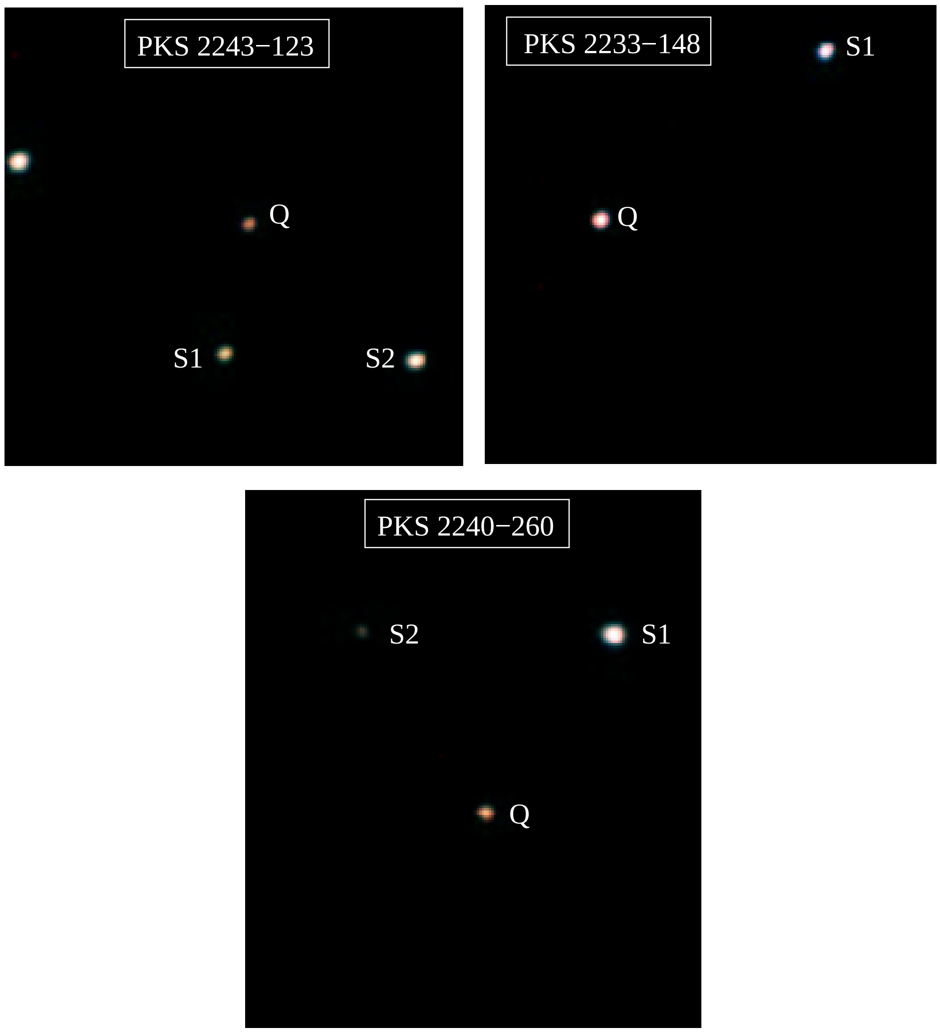

Figure 8.1: Three-colour composite NIR images of the sources used for the micro-variability analysis. The source in question is indicated by a "Q", while the comparison stars are indicated by "S1" and "S2". In all images, north is up and east is to the left.

as well, but a low altitude (and consequent high airmass) meant that the observations were unreliable. Standard stars were also observed several times during the night. This enables photometric calibration of the observations, and also calculation of fluxes and spectral indices.

Each of the images comprised of 2×2 dithered 60 second images, each made up of twelve averaged 5 sec exposures in K_n, six averaged 10 sec exposures in H, and two averaged 30 sec exposures in J. The flat field was created from the difference of dome exposures with the lamps on and off – this removes any telescope emission, improving greatly the photometric accuracy. The sky emission was removed by using a median of the four dithered images of the same band taken at the same time. The four images were then aligned and combined using the median (to remove any residual errors). The photometry was done with the *apphot* package in IRAF, using circular apertures with the sky background level determined by the median flux in an annulus around the source. The errors in the photometry shown on the light-curves are purely the random errors from the photometry calculations.

8.2 Measuring the variability

In order to construct light-curves for each of the sources, the differential magnitude of the quasar is measured relative to comparison stars in the same field. This differential magnitude is $\Delta m = m_q - m_c$, where m_q and m_c are the magnitudes of the quasar and the comparison star respectively. This differential magnitude is then compared to the comparison differential magnitude $\Delta m' = m_c - m_{c'}$, where $m_{c'}$ is the magnitude of a second comparison star in the same field. This second differential magnitude acts as a check – a change in flux in the quasar will change Δm but not $\Delta m'$, while a change that occurs in both will not be intrinsic to the quasar. The light-curves are presented in Fig. 8.2. For clarity, they are given an arbitrary offset – the offsets required to obtain the correct differential magnitudes are listed in Table 8.1.

It must be noted here that 2233−148 did not have a second comparison star in the small ($\sim 2'$) field of view of *CASPIR*. This means that the full variability analysis cannot be done for this source. However, a light-curve for Δm is presented, using the one available star.

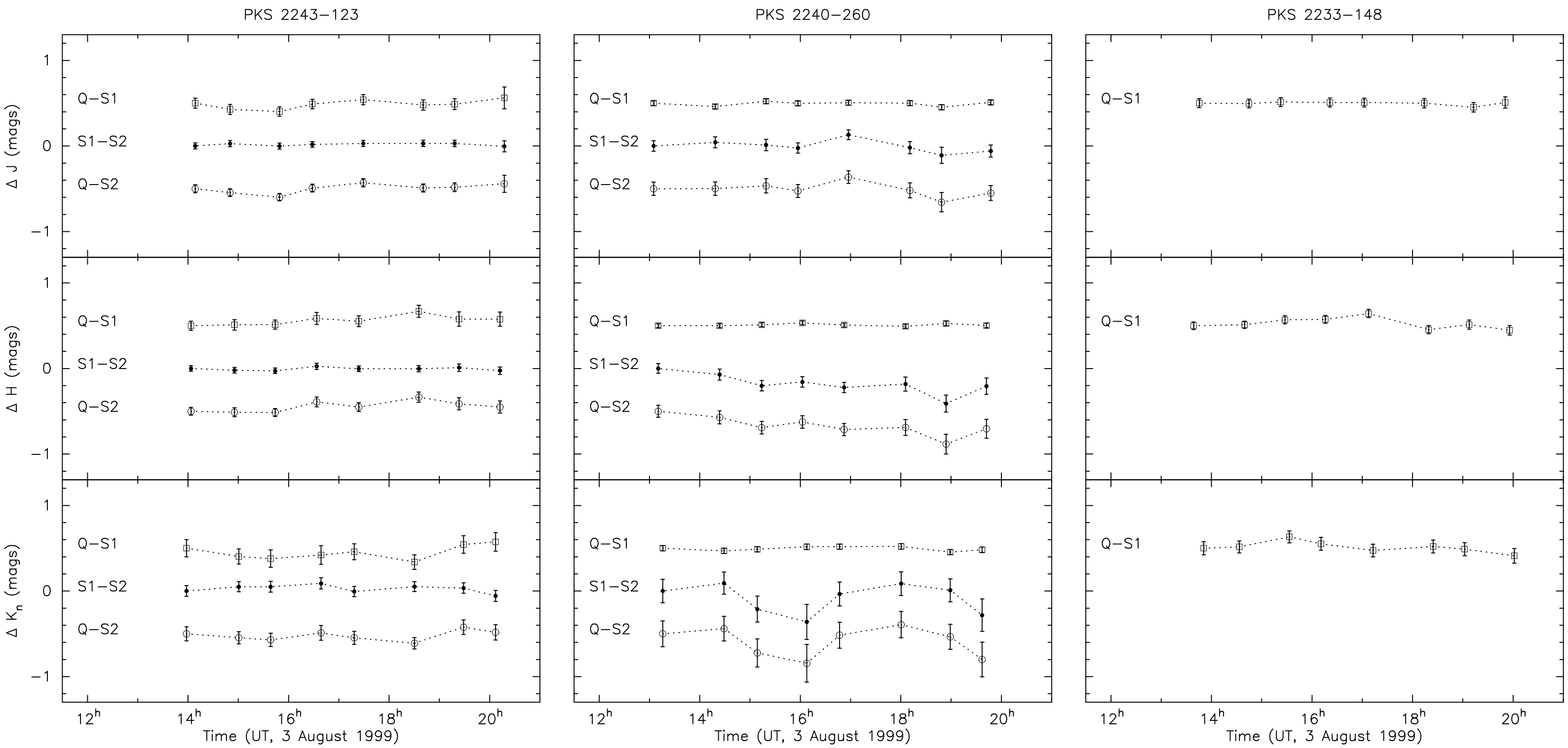

Figure 8.2: Differential light-curves for three PHFS sources. Shown are the quasar-star light-curves for each comparison star, and, where possible, the star-star comparison light-curve. The vertical offsets of each curve are set arbitrarily for clarity of presentation. The values of the offsets are given in Table 8.1.

Source	Band	Q−S1	Q−S2	S1−S2
2243−123	J	0.156	2.365	1.209
2243−123	H	0.292	2.227	0.935
2243−123	K_n	0.004	1.829	0.825
2240−260	J	2.102	−0.971	−4.073
2240−260	H	1.660	−0.964	−3.624
2240−260	K_n	0.990	−1.649	−3.639
2233−148	J	−0.116	–	–
2233−148	H	−0.423	–	–
2233−148	K_n	−1.022	–	–

Table 8.1: Offsets for the micro-variability light-curves presented in Fig. 8.2. To obtain the correct differential magnitude for each light-curve, add the corresponding number from the table to the values in the figure.

To determine whether a given source is variable, we use the 99% criterion from Jang and Miller (1997) and Romero et al. (1999). We define the variability confidence level $C = \sigma_T/\sigma$, where σ_T and σ are the standard deviations of the target (quasar-star) and comparison (star-star) light-curves. The variability criterion requires that, for a source to be variable, $C > 2.576$.

For a variable source, we also define (after Romero et al. (1999)) the variability amplitude to be

$$A = \frac{\sqrt{(D_{\max} - D_{\min})^2 - 2\sigma^2}}{\langle D \rangle},$$

where $D_{\min}$ and $D_{\max}$ are the minimum and maximum of the differential light-curve respectively. Table 8.2 shows the values for σ_T for each source with respect to each comparison star, as well as the confidence level C and, when the source is variable, the amplitude A.

8.3 Conclusions

8.3.1 Results

Clear micro-variability is detected in one source, 2243−123. There is strong variability in both J and H bands, while at K band, despite both the $Q - S$ curves showing variability, there is also significant noise present in the comparison light-curve, making it impossible to say with confidence that

Source Name	Band	σ_T (mag)		C		A (%)	
		Star 1	Star 2	Star 1	Star2	Star 1	Star 2
2243−123	J	0.049	0.051	3.39	3.49	24.55	8.98
2243−123	H	0.051	0.060	3.01	3.48	19.51	9.96
2243−123	K_n	0.077	0.055	1.80	1.30	–	–
2240−260	J	0.023	0.077	0.34	1.15	–	–
2240−260	H	0.013	0.106	0.12	0.95	–	–
2240−260	K_n	0.023	0.160	0.14	0.99	–	–
2233−148	J	0.060	–	–	–	–	–
2233−148	H	0.061	–	–	–	–	–
2233−148	K_n	0.018	–	–	–	–	–

Table 8.2: Micro-variability results for the three sources. The standard deviation of the comparison curves of the quasar with respect to each of the comparison stars, in each band. The values of the variability confidence level C are shown where there is more than one comparison star, and the variability amplitude A is shown for the cases where $C > 2.576$.

the quasar itself is varying.

The other two sources show at best only minimal evidence for variability. 2240−260, from its C values, shows no significant variability (in fact, the second comparison star is the cause for any variability seen in the light-curves – this may simply be because it is faint and subject to errors in the photometry). The lack of a second comparison star for 2233−148 means no conclusions can be drawn about the significance of its fluctuations.

It is interesting that the micro-variability was detected in the quasar, and not in either of the BL Lac objects. This quasar was described as an optically violent variable by Shen et al. (1998), although they did not give a reference for this classification (it possibly comes from the description as variable in Hewitt and Burbidge (1993)).

8.3.2 Interpretation

The origin of micro-variability in blazar AGN is not very well understood. There are two main types of models that have been developed to explain the observations. Firstly, there are models that use a shock-in-jet setup. This type of model has been used to explain the radio variability seen in blazars (Marscher and Gear 1985). To produce the optical micro-variability, a thin relativistic shock within a jet encounters a feature, such as a bend in the jet or an inhomogeneity in the density, which causes an enhancement of the observed jet emission (see, for example, Gopal-Krishna and Wiita 1992; Qian et al. 1991).

A second suggestion for the cause of micro-variability moves away from the jet and looks instead at the accretion disk. Perturbations or instabilities on the surface of an accretion disk (such as "hot-spots" – regions of high temperature and/or density) can create micro-variations in the emission (see Mangalam and Wiita 1993, and references therein). It is likely that both models are important for micro-variability in AGN, and the relative importance for individual sources depends on the relative strengths of the jet and disk emission.

The quasar 2243−123 has a blue optical/NIR SED (the photometry from these observations gives the same NIR slope as the photometry presented in Table B.1), and is modelled in Chapter 5 by a blue power law. It thus shows no evidence for synchrotron emission in its optical spectrum (a fact also supported by its observed strong emission lines). Hence, it is unlikely that fluctuations in the jet emission will cause the observed micro-variations, unless the jet is present at a very low level and experiences relatively large fluctuations. It seems that the micro-variability in this source is more likely to be explained by the accretion disk instability model. Such a scenario is consistent with observations of micro-variability in radio-quiet quasars (de Diego et al. 1998; Gopal-Krishna et al. 2000).

This is an important result that deserves following up. A good way to do so would be to select a small sample of quasars (and BL Lacs) that has some sources with synchrotron dominated SEDs (this part of the sample would contain the BL Lacs, based on the modelling in this thesis), and some with blue power law SEDs (in the manner of 2243−123). The observations would ideally cover a greater period of time than that described in this chapter, to increase the probability of seeing variability. The relative amounts of variability in the two types of sources could then be gauged accurately, hopefully giving an indication of how important each model is for micro-variability in radio-loud AGN.