Poster contributions of the "Advanced Lectures on the Starburst-AGN Connection", Eds. R. Mújica, I. Aretxaga & D. Kunth, 2001, INAOE Electronic Edition (http://www.inaoep.mx/∼agn00/posters.html), pp. 29-32

QSO Variability: Light Curves of a Monitoring Campaign

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Abstract. Some results of a photometric monitoring of a sample of QSOs observed from 1993 until 1999 are presented here. This campaign was conducted at the Pico dos Dias Observatory, in Brazil, using a telescope of 60 cm equipped with a CCD camera, allowing us to obtain a typical photometric accuracy of 2% in the V band. The sample, originally with 50 QSOs, was increased with 13 new objects during the 1996 INAOE Conference on Starburst Activity in Galaxies, in a collaboration with this institution. We present here a very preliminary analysis of all data set now available, also in the context of the Poissonian models.

1. Introduction

Although variability is a well-known property of quasars and Seyfert 1 galaxies, many of its properties are still a subject of debate. As noticed by Pica & Smith (1983), studying the dependence of the variability on the luminosity may allow the verification of whether the variability is Poissonian or not, i.e., whether the source is intrinsically multiple like compact supernova remnants evolving in a nuclear starburst (e.g. Terlevich et al. 1992), or it may be considered as a single coherent source (like an accretion disc around a massive black hole, e.g., Rees 1984).

The main prediction of the sub-units model, as sometimes the Poissonian model is called, is that the excess variability should be anti-correlated with the source luminosity. Such behaviour was observed in some early studies (e.g. Uomoto, Wills & Wills 1976, Pica & Smith 1983) and, more recently, in the analysis of the samples SA 94 (Cristiani, Vio Andreani 1990) and SA 57 (Trevese et al 1994), as well as in the study of the SGP sample (Hook et al 1994). These three samples were jointly revisited by Cristiani et al (1996), who confirmed the anti-correlation obtained previously. However, most of these studies obtained a logarithmic slope for the relation between variability and luminosity that is shallower than the value expected in the simple Poissonian model. The same result was achieved by Paltani & Courvoisier (1997), who analysed the ultraviolet continuum of all Seyfert 1 galaxies, radio-quiet quasars and low polarization radio-loud quasars contained in the IUE database. But others have indeed shown evidence for a Poissonian behaviour; for instance, Cid Fernandes, Aretxaga & Terlevich (1996) analysed the variability of the SGP sample with respect to the luminosity and redshift , obtaining a logarithmic slope consistent with the expected value of the model. Also, Aretxaga, Cid Fernandes & Terlevich (1997) have shown that the variability in this sample can be well-reproduced by a random superposition of discrete events. The analysis conducted by Garcia et al (1999, hereafter G99) on the variability of a subsample of 50 quasars observed between 1993 and 1996, has also confirmed the Poissonian behaviour, both in the variability vs. luminosity relation as in the pulse energy estimates. We present below a pre-analysis of the whole data set, containing observations from 1993 to 1999.

Even the very existence of an anti-correlation between variability and luminosity has been disputed. For instance, Lloyd (1984), Cimatti, Zamorani & Marano (1993), and Netzer et al (1996) have found no dependence of variability on absolute magnitude. Such controversy probably arises from the different characteristics of the samples studied and procedures used to analyse them. Only recently have charge-coupled devices (CCDs) been introduced in quasar monitoring campaigns, improving the accuracy of data and allowing the detection of low levels of variability (see, for instance, Borgeest & Schramm 1994, Netzer et al 1996, and Giveon et al 1999 - the latter making a good compilation of the most significant monitorings of quasar continuum). Besides, most of the monitored samples present a strong coupling between luminosity and redshift, typical of flux-limited samples. Undoubtedly, this is a major problem of the available data sets, including our own, because it prevents one from disentangling the real dependence of the variability on these two parameters. In particular, Cristiani et al (1996) divided their data into slices in luminosity and redshift, and concluded that there was a significant positive correlation of the variability with redshift. This trend had already been detected by Giallongo, Trevese & Vagnetti (1991), and was interpreted as resultant of a variability vs. wavelength dependence. Cid Fernandes, Aretxaga & Terlevich (1996) also supported

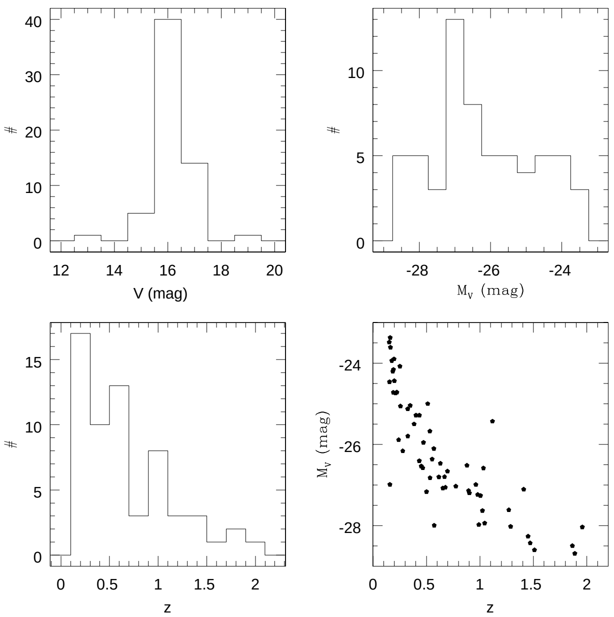

Fig. 1. Properties of the sample.

this hypothesis to explain the positive correlation between variability and redshift found in their fits.

2. Sample and Observations

Our sample has been initially selected from the Véron-Cetty & Véron catalog (1987) - for details see G99 - and in 1996 was increased with most of the remaining objects, mainly selected from then S. Cristiani's sample. There are 28 radio-quiet (5 are BAL) and 35 radio-loud (3 are HP) objects. Their requirements to have $m_V \approx 16$ and $z > 0.15$ ensured a good photometric accuracy (typical error of 2%), and avoided significant host galaxy contribution in our measurements. All observations have been carried out in the V band with a 60 cm telescope, located at the Pico dos Dias Observatory, in Brazil. Reductions were made using the standard routines of the IRAF package, and magnitudes calculated through differential photometry.

The main characteristics of the sample and observations are displayed in table 1 and figure 1. We adopted H_0=50 km s^{-1} Mpc^{-1}, q_0=0.5, and a power-law spectral index of -0.3 for the quasars. Our measurements were corrected from Galactic reddening using A_V values taken from the NED (Schlegel et al 1998)

3. Time Series Analysis

Two examples of light curves can be seen in figure 2. In order to quantify the amount of variability (in terms of luminosity) of each quasar, we adopted the variability index of Hook et al (1994), as in G99. It corresponds to the

Table 1. Some median values of the sample and observations

V absolute magnitude	-26.5 mag
V apparent magnitude	16.2 mag
Redshift	0.53
Time-span (observer-frame)	5.38 years
Time-span (quasar-frame)	3.07 years
Number of observations	15/object

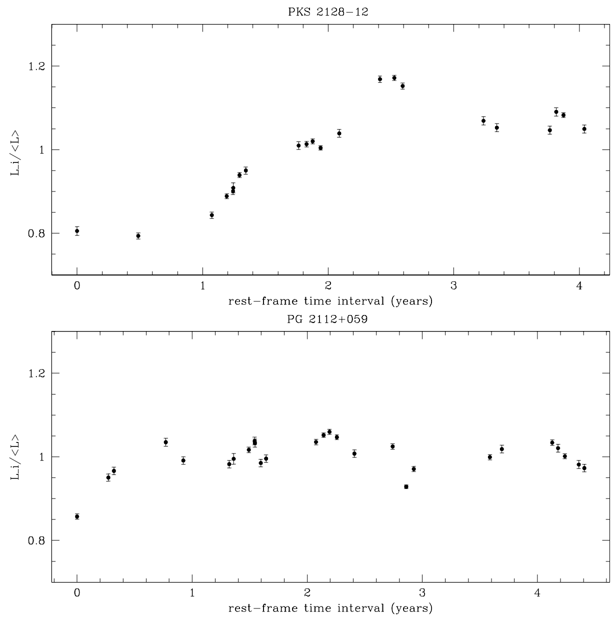

Fig. 2. Examples of observed light curves: PKS 2128-12, and the BAL radio-quiet PG 2112+059.

absolute deviation normalized by a constant, whose role is to reduce this index to the standard deviation, in the case of a Gaussian distribution of data points.

The excess variance was then calculated, subtracting in quadrature the measurement errors from the calculated variability index, and dividing it by the squared average quasar luminosity. We adopted the same correction formula used in G99) to bring all variability estimates to the quasars' rest-frame V band. This correction takes into account the hardenning of the quasar spectrum as the luminosity increases, and has proven to give a good fit to the multi-wavelength data of NGC 4151. Hereafter, we will denote the excess variance, corrected by the measurements errors and brought to the rest-frame V band, by δ^2_{rest}.

4. Variability × Luminosity in the Context of the Poissonian Models

Figure 3 shows the excess variance as a function of the quasar average luminosity, both for the radio-loud

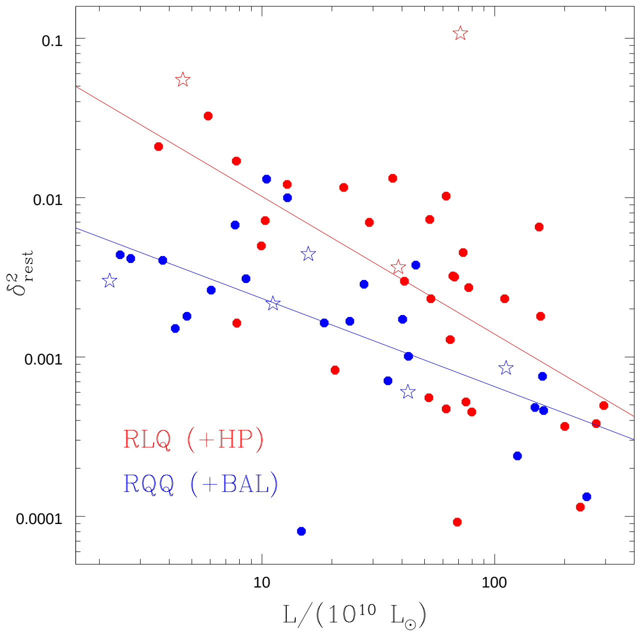

Fig. 3. Variability vs. luminosity relation obtained considering all data, from 1993 until 1999. Compared to the earlier result (G99), the relation is now flatter for both radio-quiet (blue) and radio-loud (red) subsamples.

(red) and radio-quiet (blue) subsamples. Stars denote HP quasars in the first group, or BALs in the second one.

As in G99, we will assume that this relation is the only one real in the variability × redshift × luminosity trio, for the reasons explained in the introduction. If so, the simple Poissonian hypothesis can be revisited and tested in an easy way.

The simple Poissonian model assumes that the light curve of a quasar can be described by a random superposition of independent events (Cid Fernandes, Aretxaga & Terlevich 1996; G99). Shot-noise statistics then give us predictions about the behaviour of the variability making use only of a small number of parameters: the rate of events, their energy and effective timescale. Assuming that the variable component of the light curve is a constant fraction of the total luminosity (as in the Starburst model, Terlevich et al 1992), it can be shown that $\delta^2_{rest} \propto L^{-1}$, where the proportionality constant gives information about the parameters mentioned above (for details see G99).

The logarithmic slopes calculated through a robust linear regression of data shown in figure 3 are -0.56±0.12, -0.55±0.09 and -0.86±0.17, for all data, for the radio-quiet and radio-loud subsamples, respectively (errors have been calculated by bootstrap re-sampling). Compared to the results obtained using the same procedure in G99 (slopes of 1.20, 1.22 and 1.43, respectively), we can notice that:

- as in G99 work, radio-quiet objects continue presenting flatter slopes than radio-loud objects;
- all subsamples have decreased their slopes by 45-60% with respect to previous results;
- the simple Poissonian hypothesis is only acceptable within 1σ in the case of the radio-loud subsample.

5. Discussion and Conclusions

Preliminary results from the analysis of the whole data set indicate a significant flattening of the logarithmic slopes in the variability vs. luminosity relation with respect to the ones derived in G99. One possible explanation for this behaviour is the bias introduced in the variability estimates by the finite length of the light curves. Notice in Figure 1 (right-bottom) that the most luminous objects have the highest redshifts, what makes their rest-frame time intervals of observations shorter, because of time dilation effects. Simulations of shot-noise processes have shown that the estimation of the variability is a strong function of τ/T, where τ is the effective variability timescale, and T, the rest-frame length of the light curve, mainly for larger values of this ratio. Notice, however, that this flattening still does not rule out a more generalized Poissonian model, where the pulse parameters are allowed to vary from object to object. In fact, there is no way to disprove such hypothesis, based only on the argument of the logarithmic slopes. Depending on the Poissonian scenario, one has to look for other indications that can help to check it, or even run simulations to test if the observable parameters obtained are not an artifact of poor and finite sampling.

Acknowledgements. We are grateful to the INAOE for its great hospitality at the Advanced Lectures, and also for providing an excellent opportunity to learn and discuss many relevant aspects of AGN physics with experts of this field. A.G-R gratefully acknowledges the financial support from FAPESP fellowship 97/14416-0. This work is based on data collected at CNPq/Laboratório Nacional de Astrofisica.

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