ASTROMETRIC AND PHOTOMETRIC VARIABILITY IN QUASARS

A.H. ANDREI[1,2,3], S. BOUQUILLON[3], J.I.B. de CAMARGO[1], J.L. PENNA[1], F. TARIS[3], J. SOUCHAY[3], D.N. da SILVA NETO[2,4], R. VIEIRA MARTINS[1,2], M. ASSAFIN[2],
[1] Observatório Nacional/MCT
R. Gal. José Cristino 77, Rio de Janeiro, Brazil
[2] Observatório do Valongo/UFRJ
Lad. Pedro Antônio 43, Rio de Janeiro, Brazil
[3] SYRTE, Observatoire de Paris, CNRS, UPMC
61 Av. de l'Observatoire, Paris, France
[4] Centro Universitário Estadual da Zona Oeste
Av. Manuel Caldeira de Alvarenga, Rio de Janeiro, Brazil
e-mail: oat1@on.br

ABSTRACT. Quasars are the choicest objects to define a quasi-inertial reference frame. At the same time they are active galactic nuclei powered by a massive black hole. As the astrometric precision approaches the limit set by the forthcoming GAIA mission, the astrometric stability can be investigated. Though the optical emission from the core region usually exceeds the other components by a factor of hundred, the variability of those components must surely imply in some measure of variability on the astrometric barycenter. To investigate the correlation between long term optical variability and what is dubbed as the random walk of the astrometric center, a program is being pursued at the WFI/ESO2.2m. A sample of quasars was selected by the large amplitude and long term optical variability. The observations are typically made every two months. The treatment is all differential, comparing the quasar position and brightness against a basket of selected stars for which the average relative distances and magnitudes remain constant. The provisional results for four objects bring strong support to the hypothesis of a degree of relationship between astrometric and photometric variability.

1. INTRODUCTION

The rapid flux variation seen in quasars is a convincing indication of the smallness of the emitting region. And the amplitude of variation, at cosmological redshifts, tells of the enormous output being produced. At the same time, since longer, year-like, and large amplitude variation are also recorded, the same reasoning would suggest that the other quasar's elements aren't at a standstill. There are several mechanisms apt to generate the optical and positional variability. Some of such proposed mechanisms are (Cheung et al., 2003; Eliztur, 2006): opacity changes around the core regions; instabilities propagated across the accretion disk; emission from a precessing jet; variability powered by supernovae explosions; or conversely, variability triggered by tidal disruption of stellar masses; emission from regions at superluminal speeds; luminosity disturbance brought by the host galaxy; microlensing.

Whatever the causes, the goal here is to search whether an observed long term, high amplitude optical variability can relate to astrometric variability of the quasar photocentre (Johnston et al., 2003). If verified, the relationship could indicate that high photometric variation would make a given quasar less apt to materialize a stable extragalactic reference frame, as the one from the GAIA mission.

2. THE OBSERVATIONAL PROGRAM

The long term program required by the monitoring of optical fluctuations in large cycles can only be established by ground based observations. Therefore an astrometric limit is established at the level of few mas. This level, in turn, demands for good seeing and telescope imaging, as well as relative astrometry. In order to maximize the chances of register the investigated relationship, quasars from the sample of Teerkopi (2000), and light curves from Smith et al.(1993), were selected on basis of long period and large photo-variability. The observations are run under the Observatório Nacional/MCT, Brasil, telescope time contracted to ESO at the Max Planck 2.2m telescope at La Silla, Chile.

Table 1: WFI/ESO 2.2m Telescope Observational Program

QSO	RA	DEC	<V>	B-V	z	Δm	Slots
0210−5101	02:10:46.2	−51:01:02	16.9	0.56	1.003	∼1	P13,P21,P22,P33
0339−0146	03:39:30.9	−01:46:36	18.4	0.35	0.852	1.1	P13,P22,P23,P33
0407−121	04:07:48.4	−12:11:37	15.3	0.16	0.574	0.6	P22,P23
0442−0017	04:42:38.7	−00:17:43	19.2	0.37	0.850	3.2	P23,P23
0522−6107	05:22:34.4	−61:07:57	18.1	-.05	1.400	∼1	P13,P22,P23,P31,P33
0538−4405	05:38:43.5	−44:05:05	17.5	0.46	0.894	3.7	P13,P21,P22,P23,P31,P33
0739+0137	07:39:18.0	+01:37:05	16.5	0.43	0.191	0.9	P21,P23,P31
0813+0150	08:13:53.0	+01:50:50	18.0	0.18	0.402	1.4	P22,P31,P32
0858+1651	**08:58:52.6**	**+16:51:27**	**17.7**	**0.40**	**1.449**	**0.6**	**P22,P23,P31,P32**
0925+1444	09:25:07.3	+14:44:03	17.8	0.54	0.896	2.0	P22,P31
1218+0200	**12:18:55.8**	**+02:00:02**	**18.1**	**0.02**	**0.240**	**1.5**	**P22,P23,P31,P32**
1254+1141	12:54:38.3	+11:41:06	17.0	0.35	0.870	1.3	P31,P32
1512−0905	**15:12:50.5**	**−09:06:00**	**16.9**	**0.20**	**0.361**	**1.5**	**P11,P12,P13,P23,P31,P32,P33**
1620+1724	16 20 11.3	+17 24 28	16.8	0.17	0.114	2.1	P11,P13,P23,P31,P32,P33
1620+1736	16 20 21.8	+17 36 24	16.4	0.12	0.555	1.1	P11,P13,P23,P31,P32,P33
1751+0939	**17:51:32.8**	**+09:39:01**	**18.4**	**0.68**	**1.360**	**∼1**	**P11,P12,P13,P23,P31,P32,P33**

Table 1: For each object of the program are given the pointing equatorial coordinates, the reference magnitude and color index, the redshift, and the expected optical variability. The quasars here treated are shown in bold types. The slots for which were made observations of a given object are presented in the last collumn. The periods codes are, P11=April/2007; P12=June/2007; P13=September/2007; P21=October/2007; P22=January/2008; P23=February/2008; P31=April/2008; P32=May/2008; P33=August/2008.

The program started in April 2007 and it will extend till 2009, with observations nearly every two months. Table 1 brings the program sources, some of their characteristics, and the epochs for which there are already reduced observations.

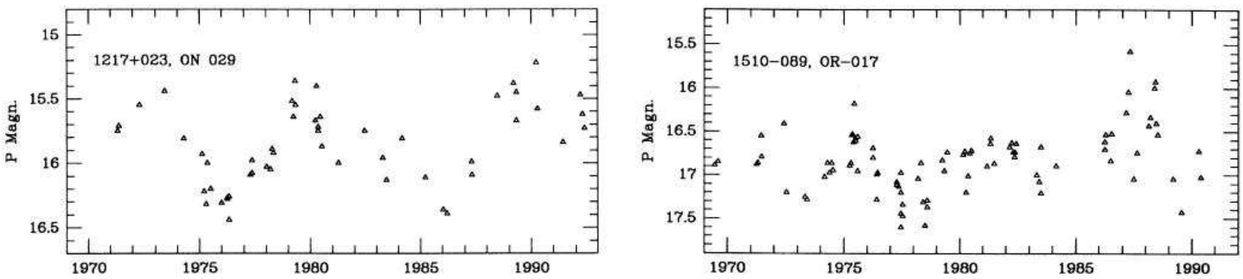

Figure 1: Examples of optical variability, as given by Smith et al. (1993)

3. DATA TREATMENT AND DATA REDUCTION

The ESO2p2 WFI direct image camera is compound of 8 CCDs, each covering a field of 7.5 × 15.0 arcmin, to scale of 0.238 arcsec/px. For all the observations the same CCD was used, keeping the quasar on a clean spot, at about 1/3 of the diagonal starting from the optical axis. The same configuration is repeated for all the observations of a same quasar, jittering allowed. The observations as a rule are made within 2h of hour angle. Red (Rc/162, peak 651.7nm, FWHM 162.2nm) and blue (BB#B/123, peak 451.1nm, FWHM 135.5nm) filters are used for each run. Depending on the quasar magnitude, typically from 3 to 5 images are taken with each filter. The integration times are never longer than 30 min., yet as long as possible to provide good imaging of the target and of the surrounding stars. The combined S/N ratio is always close to 1000 for each run.

All images are treated by IRAF MSCRED for trimming, bias, flat, bad-pixel and split. Typically

Table 2: Measures of Precision (pixel)

N(tot)	E(X)	E(Y)	E(M)	N(R)	E(X)	E(Y)	E(M)	N(B)	E(X)	E(Y)	E(M)
10229	0.017	0.017	0.001	7373	0.017	0.015	0.001	2856	0.018	0.021	0.001
24407	0.036	0.038	0.002	16527	0.034	0.034	0.002	7880	0.047	0.047	0.001

Table 2: Average precision (1512-0905 sample), in units of pixel. On the upper row are the average values for the best imaged objects, while on the second row are the averages for all imaged objects (above threshold 4). Counts and averages are for the R and B filters sets, as well as for the combined (tot) set.

the image treatment enhances the SNR by a factor of 2. IRAF DAOFIND and PHOT are employed for the determination of centroids and (instrumental) magnitudes, with the entry parameters adjusted for each frame. Centroids and fluxes are obtained from the adjustment of bi-dimensional Gaussians. The inner ring where the object counting is made and the outer ring where the sky background is counted are variable for each object and frame, but their ratio is kept constant. The plate scale and frame orientation are derived by IRAF IMCOORDS, from UCAC2 catalogue stars (though, since the astrometry is totally relative, their values are of no great deal to define the correlation under study).

4. FIRST RESULTS

The first results regard to separate R and B filter solutions, for the four sources for which the light curve is more populated. The procedure initially adjusts the frames one on top of the other, on coordinates and magnitudes, by the quasar. Next, frame after frame, on basis of the PHOT outcomes, the objects common to all frames are stored, provided that the (X,Y) coordinates and the magnitudes do not vary above a chosen threshold.

The common objects (X,Y) coordinates and magnitudes are then adjusted by a complete 3^{rd} degree polynomial to a mean frame (eq. 1). On eq.1, **C** stands either for X, Y or M.

$$C_n^m - < C >_n = C_0 + \sum_{i,j,k}^{1,3} A_{i,j,k}^m X^i Y^j M^k \qquad object\ \mathbf{n}\ of\ frame\ \mathbf{m} \qquad (1)$$

Finally, a further round of analysis discard the objects which (X,Y) or magnitude variation are above the threshold of optimum precision (Fig. 2). The averages on (X,Y) and magnitude of the remaining

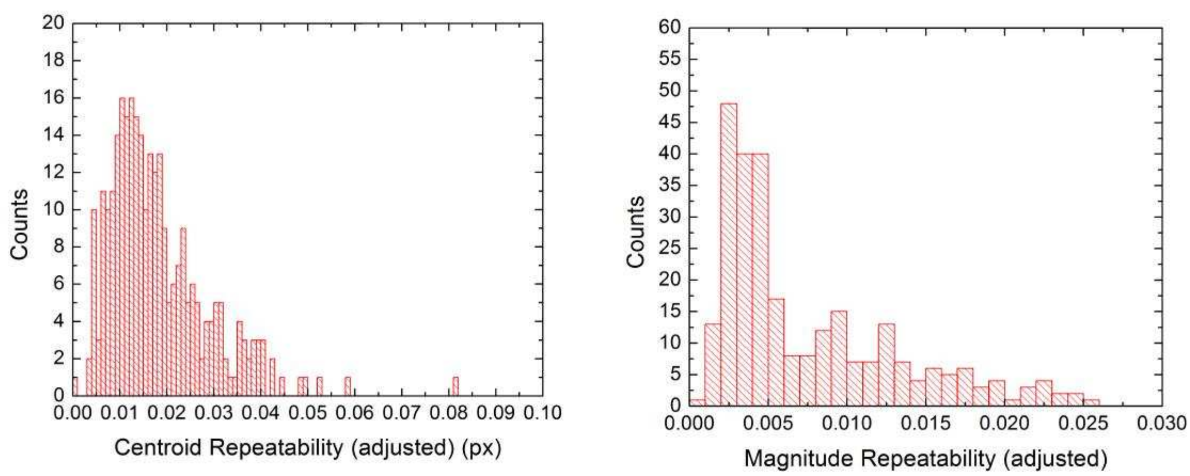

Figure 2: (X,Y) and magnitude repeatability after eq.1 adjustment to the mean frame.

objects (referred to the quasar as fixed origin) are obtained and correlated against the time-line and against each other. Table 3 summarizes the results.

Table 3: ESO2p2 program quasar's magnitude and (X,Y) coordinates time and crossed correlations.

QSO	Nf (R)	Ns	Mag×t	Amp (mag)	X×t	Xamp (mas)	Y×t	Yamp (mas)	X×Mag	Y×Mag
0858+1651	10	5	**0.82**	**0.025**	0.06	4	**0.79**	**4**	0.17	**0.61**
			(0.001)		(0.86)		**(0.002)**		(0.59)	**(0.04)**
1218+0200	4	8	**0.98**	**0.022**	**0.50**	**5**	**0.60**	**3**	0.35	**0.59**
			(0.03)		**(0.39)**		**(0.29)**		(0.57)	**(0.41)**
1512−0905	14	3	**0.94**	**0.072**	**0.41**	**4**	0.33	9	**0.52**	0.15
			(0.01)		**(0.27)**		(0.39)		**(0.16)**	(0.70)
1751+0939	8	26	**0.98**	**1.233**	**0.97**	**6**	0.23	7	**0.91**	0.04
			(0.13)		(0.15)		(0.85)		**(0.27)**	(0.98)

R filter time and cross-correlation for magnitude and (X,Y) coordinates. **Nf** brings the number of used frames, that is those in which large numbers of common stars with the other frames are found. **Ns** is the final number of common stars. The statistical significance of the correlations is given in brackets in the line below. Most significant values are marked by boldface types.

QSO	Nf (B)	Ns	Mag×t	Amp (mag)	X×t	Xamp (mas)	Y×t	Yamp (mas)	X×Mag	Y×Mag
0858+1651	8	1	**0.89**	**0.010**	**0.58**	**6**	**0.54**	**4**	**0.72**	**0.76**
			(0.007)		**(0.17)**		**(0.21)**		**(0.07)**	**(0.05)**
1218+0200	6	2	**0.66**	**0.043**	0.20	5	**0.55**	**6**	0.30	**0.90**
			(0.34)		(0.80)		**(0.45)**		(0.70)	**(0.10)**
1512−0905	13	1	**0.74**	**0.262**	0.30	5	**0.92**	**5**	**0.54**	**0.63**
			(0.02)		(0.40)		**(0.001)**		**(0.11)**	**(0.05)**
1751+0939	9	1	**0.99**	**0.438**	**0.66**	**5**	0.29	7	**0.66**	0.24
			(0.001)		**(0.11)**		(0.52)		**(0.11)**	(0.61)

Same as above for filter B. Notice that less common stars are retained.

5. CONCLUSION AND PERSPECTIVES

This program is still contemplated on five forthcoming slots of observation at the WFI/ESO2p2 telescope. They will enable to populate the variability monitoring of the remaining quasars of the program. On the reduction practice, the R and B frames can be combined in order to derive a chromatic refraction correction. Also the frames taken in sequence can be co-added to amplify the S/N ratio.

The presented results must therefore be considered as provisional. At the same time, notice that the magnitude time correlation and variation amplitude follow what was expected from previous independent programs. The photometric and astrometric process of relative treatment are the same, using successive adjustments of the frames towards a common average. It brings support to the correlations found.

The preliminary results strongly prompt for the continuation of this program. With more sources, and longer monitoring, a clearer understanding on the subject can be addressed.

6. REFERENCES

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