Contrib. Astron. Obs. Skalnaté Pleso **49**, 539 – 545, (2019)

Quest to find Changing Look-Quasars

T. Pursimo[1], **L. Ighina**[2,3], **N. Ihanec**[4], **N. Mandarakas**[5,6], **K. Skillen**[7] **and S. Terefe**[8]

[1] *Nordic Optical Telescope, Apartado 474, E-38700 Santa Cruz de La Palma, Spain (E-mail: tpursimo@not.iac.es)*

[2] *Dipartimento di Fisica G. Occhialini, Università degli Studi Milano-Bicocca, Piazza della Scienza 3, I-20126 Milano, Italy*

[3] *INAF, Osservatorio Astronomico di Brera, via Brera 28, I-20121 Milano, Italy*

[4] *Warsaw University Astronomical Observatory, Al. Ujazdowskie 4, 00-478 Warsaw, Poland*

[5] *Department of Physics, University of Crete, GR-71003, Heraklion, Greece*

[6] *Foundation for Research and Technology - Hellas, IESL & Institute of Astrophysics, Voutes, 7110 Heraklion, Greece*

[7] *School of Physics, Trinity College Dublin, The University of Dublin, Dublin 2, Ireland*

[8] *Ethiopian Space Science and Technology Institute, Department of Astronomy and Astrophysics*

Received: July 31, 2019; Accepted: September 25, 2019

Abstract. We present the optical analysis of a sample of quasars selected for their significant variation in optical emission. Photometric analysis was carried for 22 sources and it was found that the colour change for the majority of the sample follows a typical behavior of Changing Look Quasars (CLQs) as suggested in the literature. Spectroscopic analysis was carried out on 2 sources to identify the origin of the observed variation.

Key words: galaxy:active – quasars: emission lines – quasars: general

1. Introduction

Optical properties of Quasi-Stellar Objects (QSOs) have been well characterized in the past decade thanks to large-scale surveys such as the Sloan Digital Sky Survey (SDSS, Vanden Berk et al. 2004) and, more recently, Pan-STARRS1 (PS1, Simm et al. 2015). Observations from different surveys show the typical variation of the optical continuum of QSOs is of the order of ~ 0.2 mag, ranging in timescales from several months to years (e.g. MacLeod et al. 2012). These changes in the optical emission are usually associated with instabilities and inhomogeneities of the accretion disk (e.g. Kokubo 2015). Their spectral features, especially the Broad Emission Lines (BELs), however, are generally more stable and lagged with respect to the continuum (e.g. Shen et al. 2015).

Yet, a few exceptions of quasars with very large variability in the optical continuum (~ 1 mag) have been discovered with the concurrent emergence or disappearance of BELs (e.g. Denney et al. 2014). In some of these sources, the variations are on timescales of a few months and can be related to Tidal Disruption Events (e.g. Gezari et al. 2015), slow Microlensing Outbursts (e.g. Bruce et al. 2017) or, in the case of Blazars, to the presence of a jet (e.g. Marscher et al. 2008). The most challenging to explain are the Changing Look Quasars (CLQs) (MacLeod et al. 2016), where the large spectral variability is on the timescale of years (e.g. LaMassa et al. 2015). The number of known sources of this kind is very limited, but in recent years, all-sky space surveys such as Gaia (Gaia Collaboration et al., 2016) present a remarkable opportunity to increase the size of this population. With a sufficiently large sample of CLQs, it will be possible to revise current models of the accretion disk and the Broad Line Region (BLR) structures in Active Galactic Nuclei (AGNs) to account for this new class of sources.

2. Observations and data reduction

Half of the targets used in this project were selected from ESA's highly precise astrometic mission Gaia, which scans the whole sky and can detect variability in magnitude with precision of 0.001, down to 20 mag. In particular, they were chosen from Gaia Science Alerts program[1], which searches for transient phenomena that show sudden changes in magnitude and thus is ideal for the discovery of CLQs. The other half of the sample was selected by comparing Gaia and SDSS DR 12 data (Kostrzewa-Rutkowska et al. 2018).
To fully classify these transients, photometric and spectroscopic follow-up observations were carried out at the Nordic Optical Telescope (NOT, La Palma, Spain). Photometric data were obtained for 22 targets using the Alhambra Faint Object Spectrograph and Camera (ALFOSC) on NOT in the SDSS g, r and i band filters. We obtained low resolution spectrum for two objects using ALFOSC, the same night as the photometric data, with the spectral range of 3200-9200Å at a resolution of R=330. The data were processed using the standard IRAF reduction and calibration. The apparent magnitudes of the targets were deduced with aperture photometry, using archival SDSS data for magnitudes of comparison stars.

3. Results and Discussion

3.1. Photometry

The results of the photometric analysis are presented in appendix A together with comparison archival data from SDSS. Figure 1 shows the variation of g-

[1] http://gsaweb.ast.cam.ac.uk/alerts/

r (new - historic) colour as a function of the difference between the new and historic magnitudes in the g band. Most of the sources seem to follow the known

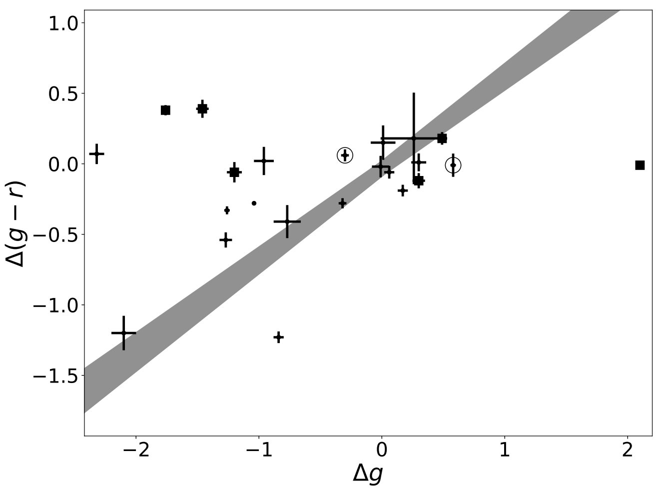

Figure 1. Variation of the g-r colour (new - historic) as a function of magnitude variability g-g_{SDSS}. The shaded region represents the observational relation (with its 1σ uncertainty) found in Yang et al. (2018) for CLQs. The few QSOs detected also in the radio band are depicted with squares, while the sources whose spectrum is discussed in this work have been highlighted with a circle.

trend for confirmed CLQs ("bluer-when-brighter") found by Yang et al. 2018 using a sample of 21 CLQs. However, there are a few objects, among which most of the radio detected ones (reported as squares), that do not follow a clear pattern. It is probable that in these cases the change in magnitude is caused by external (to the AGN structure) events, such as the ones mentioned in Section 1.

3.2. Spectroscopy

We performed spectroscopic analysis for two targets; Gaia19bwn and Gaia18dsk. Figure 2 shows the comparison between the observed spectra and archival SDSS spectra (right panel), together with their respective light curves (left column). The Gaia19bwn spectrum (Figure 2, top panel) is dominated by strong, slightly broadened Balmer lines, visible down to Hη (3866 Å). The archival SDSS spectrum has strong Hα and the Hβ and forbidden [OIII] lines (4862 Å and 5008

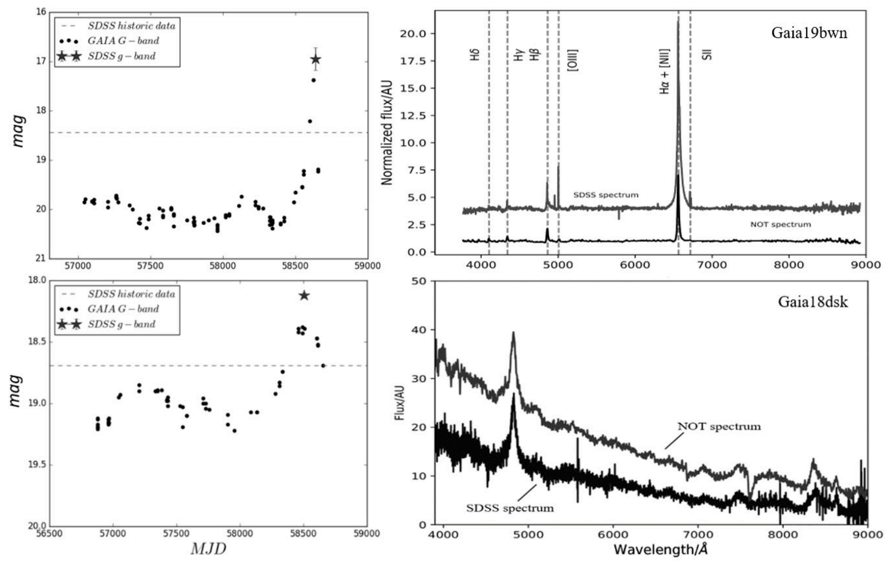

Figure 2. Light curves (left) and optical spectra (right) for Gaia19bwn (top) and Gaia18dsk (bottom). The Gaia19bwn spectra have been normalized and the SDSS spectrum has an offset for clarity

Å respectively) have similar fluxes, but the new NOT spectrum shows weaker Hα and the Hβ flux is now four times stronger then the [OIII]. We estimate the redshift based on Balmer lines to z=0.009, which is consistent with the SDSS archival value. The spectrum displays brightening in the continuum and its BELs, as well as some narrow emission features, typically not found in the quasar spectra. Interestingly, using GELATO[2], we classified Gaia19bwn as a Type II supernova, with a 92% confidence level (Pursimo et al., 2019), however the SDSS classification is broad line AGN.

In the case of Gaia19dsk (Figure 2, bottom panel), the variation in magnitude was related to an increase of the overall optical continuum. Though the NOT observation was carried out during the peak of the light curve, the spectral features of the source remained unchanged, suggesting that the structure of the BLR did not vary during this event.

Acknowledgements. We are very thankful to H. Korhonen and to all the team for organizing the summer school *Observational astrophysics: from proposal to publication.* The authors would also like to acknowledge support from ERASMUS+ grant number 2017-1-CZ01-KA203-035562, and the European Union's Horizon 2020 research and innovation programme under grant agreement No 730890 (OPTICON). This work has

[2]https://gelato.tng.iac.es/

made use of data from the European Space Agency (ESA) mission *Gaia*, processed by the *Gaia* Data Processing and Analysis Consortium (DPAC) and the Photometric Science Alerts Team. Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement. In this work we also made use of SDSS data. Funding for the Sloan Digital Sky Survey IV has been provided by the Alfred P. Sloan Foundation, the U.S. Department of Energy Office of Science, and the Participating Institutions. SDSS acknowledges support and resources from the Center for High-Performance Computing at the University of Utah. The data presented here were obtained with ALFOSC, which is provided by the Instituto de Astrofisica de Andalucia (IAA) under a joint agreement with the University of Copenhagen and NOTSA.

References

Becker, R. H., White, R. L., & Helfand, D. J., The FIRST Survey: Faint Images of the Radio Sky at Twenty Centimeters. 1995, *Astrophys. J.*, **450**, 559, DOI: 10.1086/176166

Bruce, A., Lawrence, A., MacLeod, C., et al., Spectral analysis of four 'hypervariable' AGN: a micro-needle in the haystack? 2017, *Mon. Not. R. Astron. Soc.*, **467**, 1259

Condon, J. J., Cotton, W. D., Greisen, E. W., et al., The NRAO VLA Sky Survey. 1998, *Astron. J.*, **115**, 1693, DOI: 10.1086/300337

Denney, K. D., De Rosa, G., Croxall, K., et al., The Typecasting of Active Galactic Nuclei: Mrk 590 no Longer Fits the Role. 2014, *Astrophys. J.*, **796**, 134, DOI: 10.1088/0004-637X/796/2/134

Gaia Collaboration, Prusti, T., de Bruijne, J. H. J., et al., The Gaia mission. 2016, *Astron. Astrophys.*, **595**, A1

Gezari, S., Chornock, R., Lawrence, A., et al., PS1-10jh Continues to Follow the Fallback Accretion Rate of a Tidally Disrupted Star. 2015, *Astrophys. J., Lett.*, **815**, L5

Kokubo, M., Constraints on the temperature inhomogeneity in quasar accretion discs from the ultraviolet-optical spectral variability. 2015, *Mon. Not. R. Astron. Soc.*, **449**, 94

Kostrzewa-Rutkowska, Z.and Jonker, P. G., Hodgkin, S. T., Wyrzykowski, ., et al., Gaia transients in galactic nuclei. 2018, *MNRAS*, **481**

LaMassa, S. M., Cales, S., Moran, E. C., et al., The Discovery of the First "Changing Look" Quasar: New Insights Into the Physics and Phenomenology of Active Galactic Nucleus. 2015, *Astrophys. J.*, **800**, 144

MacLeod, C. L., Ivezić, Ž., Sesar, B., et al., A Description of Quasar Variability Measured Using Repeated SDSS and POSS Imaging. 2012, *Astrophys. J.*, **753**, 106, DOI: 10.1088/0004-637X/753/2/106

MacLeod, C. L., Ross, N. P., Lawrence, A., et al., A systematic search for changing-look quasars in SDSS. 2016, *Mon. Not. R. Astron. Soc.*, **457**, 389

Marscher, A. P., Jorstad, S. G., D'Arcangelo, F. D., et al., The inner jet of an active galactic nucleus as revealed by a radio-to-γ-ray outburst. 2008, *Nature*, **452**, 966

Pursimo, T., Galindo-Guil, F., Dennefeld, M., et al., Spectroscopic follow-up of transient Gaia19bwn. 2019, *The Astronomer's Telegram*, **12911**

Shen, Y., Brandt, W. N., Dawson, K. S., et al., The Sloan Digital Sky Survey Reverberation Mapping Project: Technical Overview. 2015, *Astrophys. J., Suppl.*, **216**, 4

Simm, T., Saglia, R., Salvato, M., et al., Pan-STARRS1 variability of XMM-COSMOS AGN. I. Impact on photometric redshifts. 2015, *Astron. Astrophys.*, **584**, A106

Vanden Berk, D. E., Wilhite, B. C., Kron, R. G., et al., The Ensemble Photometric Variability of ~25,000 Quasars in the Sloan Digital Sky Survey. 2004, *Astrophys. J.*, **601**, 692

Yang, Q., Wu, X.-B., Fan, X., et al., Discovery of 21 New Changing-look AGNs in the Northern Sky. 2018, *Astrophys. J.*, **862**, 109, DOI: 10.3847/1538-4357/aaca3a

A. Photometric data

In this appendix, the full data set calculated in the photometric analysis of this investigation is presented.

Table 1. Apparent magnitudes and errors of our targets in SDSS *g,r* filters along with archival magnitude from SDSS. We also report the sky coordinates of the sources (RA, DEC expressed in degrees), if the target has been detected either NVSS (The NRAO VLA Sky Survey, Condon et al. 1998) or FIRST (Faint Images of the Radio Sky at Twenty-cm, Becker et al. 1995) surveys and the date of the observation with NOT.

Object	RA	DEC	Date	Radio	g-mag ± er.	SDSS-g	Δg (NOT-SDSS)	r-mag ± er.	SDSS-r
Gaia18dry_1	215.62654	32.38623	2019-01-25	NVSS	17.32 (0.03)	19.08	-1.76	17.01 (0.02)	19.15
Gaia18dry_2			2019-01-26	NVSS	17.62 (0.05)	19.08	-1.46	17.30 (0.04)	19.15
Gaia18dsk	191.86398	22.55420	2019-01-21		18.39 (0.03)	18.69	-0.30	18.41 (0.03)	18.77
Gaia18dtm	218.84144	20.35494	2019-01-26	NVSS	18.00 (0.06)	19.20	-1.20	17.64 (0.04)	18.78
Gaia18due	359.99444	-1.20707	2019-01-24		18.70 (0.01)	18.69	0.01	18.54 (0.07)	18.68
Gaia19abd	218.83473	1.21172	2019-01-24		19.23 (0.18)	20.12	-0.89	18.98 (0.11)	20.03
Gaia19aul	133.69072	46.10460	2019-03-16		18.20 (0.10)	20.30	-2.10	18.92 (0.07)	19.82
Gaia19auy	250.74506	39.81031	2019-04-16	NVSS	17.79 (0.02)	15.69	2.10	17.50 (0.02)	15.39
Gaia19axp	216.94333	29.51063	2019-03-16		18.64 (0.01)	19.68	-1.04	18.39 (0.01)	19.15
Gaia19bbw	232.42584	35.14759	2019-04-16		17.30 (0.02)	18.56	-1.26	17.13 (0.02)	18.06
Gaia19buq	124.36008	10.20280	2019-05-28		16.47 (0.06)	18.79	-2.32	15.85 (0.04)	18.24
Gaia19bwn	173.34991	55.07108	2019-06-05		16.95 (0.02)	16.37	0.58	16.80 (0.08)	16.21
GNTJ015804-00522	29.51981	-0.872742	2019-01-23		17.35 (0.05)	18.62	-1.27	17.35 (0.02)	18.08
GNTJ025514-040655	43.809466	-4.11552	2019-01-23		18.43 (0.11)	19.20	-0.77	18.05 (0.04)	18.41
GNTJ080115+110156	120.31654	11.03237	2019-01-26		17.38 (0.27)	17.12	0.26	16.36 (0.18)	16.28
GNTJ081152+252521	122.96712	25.42259	2019-01-25		19.01 (0.03)	19.33	-0.32	18.32 (0.02)	18.36
GNTJ085554+005111	133.97614	0.85306	2019-01-26	FIRST	16.95 (0.05)	16.65	0.30	16.37 (0.02)	15.95
GNTJ130638+072124	196.66031	7.35670	2019-03-16		17.31 (0.07)	17.35	-0.04	16.90 (0.03)	16.89
GNTJ131428+054307	198.61703	5.71869	2019-03-16		17.31 (0.04)	18.18	-0.87	17.98 (0.01)	17.59
GNTJ131839+463016	199.66412	46.50460	2019-05-29		17.86 (0.04)	17.80	0.06	17.33 (0.02)	17.21
GNTJ150906+611640	227.27625	61.27780	2019-04-16		16.76 (0.04)	16.59	0.17	16.33 (0.01)	15.97
GNTJ155513+564416	238.80611	56.73792	2019-05-29	FIRST	19.28 (0.04)	18.79	0.49	18.42 (0.02)	18.11
GNTJ171955+414049	259.98271	41.68040	2019-04-16		18.36 (0.06)	18.06	0.30	17.84 (0.02)	17.55