COMPARISON AND CONTROL STARS AROUND QUASARS SUITABLE FOR THE ICRF – GAIA CRF LINK

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Introduction

- *Linking GAIA CRF – ICRF, and R and V magnitudes of the selected quasars* – PhD thesis (mentor Dr. G. Damljanović)

- Intra Day, Short term, and Long term variabilities

- Taris et al. 2018

Introduction

Table 1. Main properties of the objects.

Object	$\alpha_{J2000.0}(^o)$	$\delta_{J2000.0}(^o)$	z	Type	Observation duration		No. of observations
					dd mm yyyy	dd mm yyyy	V, R
0049+003	13.02321	0.593930	0.399714	FSRQ	06 09 2013	08 08 2019	30, 40
0907+336	137.65431	33.49012	0.354000	BL Lac	14 04 2013	06 04 2019	39, 42
1034+574	159.43461	57.19878	1.095700	BL Lac	09 07 2013	07 04 2019	47, 47
1212+467	183.79143	46.45420	0.720154	FSRQ	09 07 2013	31 03 2019	50, 50
1242+574	191.29167	57.16510	0.998229	BL Lac	02 04 2014	06 08 2019	49, 57
1429+249	217.85787	24.70575	0.406917	Blazar	04 04 2014	06 08 2019	43, 47
1612+378	243.69564	37.76869	1.531239	FSRQ	09 07 2013	06 08 2019	38, 42

Instruments

At Astronomical Station Vidojevica (ASV) of Astronomical Observatory of Belgrade (AOB):

- 60 cm Cassegrain (long.=21.5°, lat.=43.1°, h=1136m),

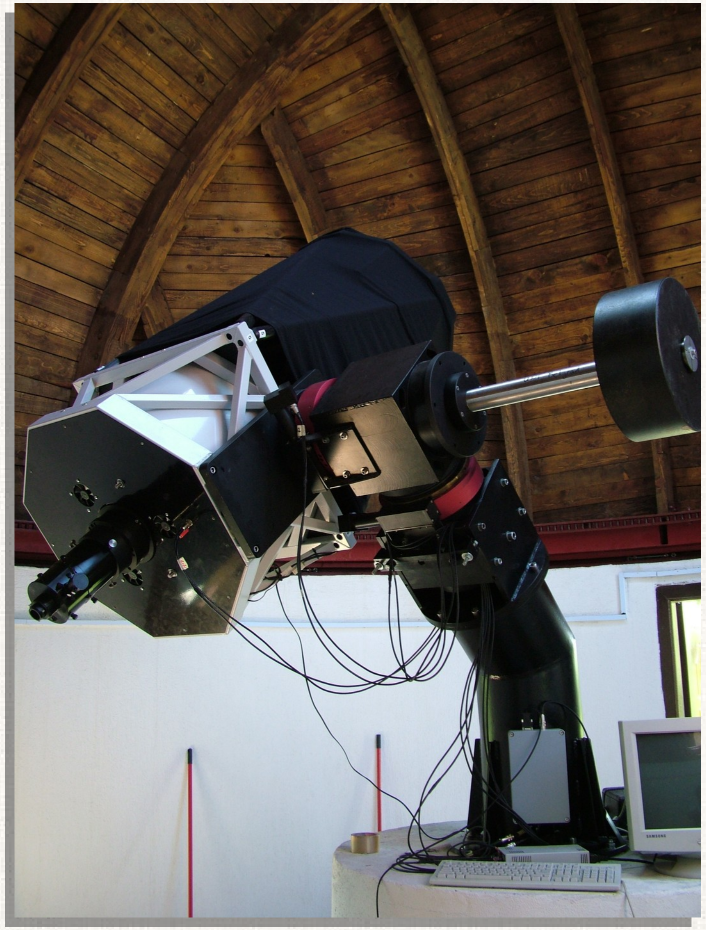


Fig. 1. *ASV 60cm in dome.*

Instruments

At Astronomical station Vidojevica (ASV) of Astronomical observatory of Belgrade (AOB):

- 60 cm Cassegrain (long.=21.5°, lat.=43.1°, h=1136m),
- 1.4 m Ritchey-Chrétien (21.6, 43.1, 1143).

Fig. 2. *Dome of ASV 1.4m with telescope.*

Instruments

At Astronomical station Vidojevica (ASV) of Astronomical observatory of Belgrade:

- 60 cm Cassegrain (long.=21.5°, lat.=43.1°, h=1136m),
- 1.4 m Ritchey-Chrétien (21.6, 43.1, 1143).

At Observatori Astronòmic del Montsec, Spain, robotic Joan Oró Telescope (TJO):

- 80 cm Ritchey-Chrétien (0.7, 42.1, 1570).

Fig. 3. *TJO 80cm in dome.*

Instruments

At Rozhen National Astronomical Observatory of Bulgarian Academy of Sciences:

- 2 m Ritchey-Chrétien (24.7, 41.7, 1730),
- 60 cm Cassegrain (24.7, 41.7, 1759),
- 50/70 cm Schmidt-camera (24.7, 41.7, 1759).

At Belogradchik Observatory, Bulgaria:

- 60cm Ritchey-Chrétien (22.7, 43.6, 650).

At Leopold Figl-Observatorium für Astrophysik (LFOA), Vienna, Austria:

- 1.5 m Ritchey-Chrétien (15.9, 48.1, 880).

Instruments

Table 2. Telescopes and cameras.

Telescope	CCD Camera	CCD resolution	Pixel size (μm)	Pixel scale (arcsec pix^{-1})	Field of view (arcmin)
ASV 60cm	Apogee Alta U42	2048x2048	13.5x13.5	0.466	15.8x15.8
	SBIG ST10 XME	2184x1472	6.8x6.8	0.230	8.4x5.7
	Apogee Alta E47	1024x1024	13.0x13.0	0.450	7.6x7.6
ASV 1.4m	Apogee Alta U42	2048x2048	13.5x13.5	0.243	8.3x8.3
	Andor iKon-L	2048x2048	13.5x13.5	0.244	8.3x8.3
TJO 80cm	FLI PL4240-1-B	2048x2048	13.5x13.5	0.364	12.3x12.3
	Andor iKon-L	2048x2048	13.5x13.5	0.361	12.3x12.3
Rozhen 2m	Andor iKon-L	2048x2048	13.5x13.5	0.176	6.0x6.0
	VersArray 1300B	1340x1300	20.0x20.0	0.261	5.6x5.6
Rozhen 60cm	FLI PL09000	3056x3056	12.0x12.0	0.330	16.8x16.8
Rozhen 50/70cm	FLI PL16803	4096x4096	9.0x9.0	1.080	73.7x73.7
Belogradchik 60cm	FLI PL09000	3056x3056	12.0x12.0	0.335	16.8x16.8
LFOA 1.5m	SBIG ST10 XME	2184x1472	6.8x6.8	0.150	5.6x3.8

Data reduction

- 2 x CCD images in V and R filters, per object
- Bias, Dark and Flat frames
- IRAF scripting language
- Hot and dead pixel map
- Cosmic rays map - Laplacian Cosmic Ray Identification method *L.A.Cosmic* (Pieter G. van Dokkum 2001)

Photometry

MaxIm DL software for differential photometry

- SDSS DR14 catalogue
- 2 x comparison + control stars (2016 -2019 and TJO)
- Criteria: non-variable, close to blazars,…
- SDSS ugriz -> BVRI (Chonis & Gaskel 2008):

$$V = g - (0.587 \pm 0.022)(g - r) - (0.011 \pm 0.013),$$

$$R = r - (0.272 \pm 0.092)(r - i) - (0.159 \pm 0.022).$$

$$14.5 < g, r, i < 19.5,\ 0.08 < r - i < 0.5, \text{ and } 0.2 < g - r < 1.4$$

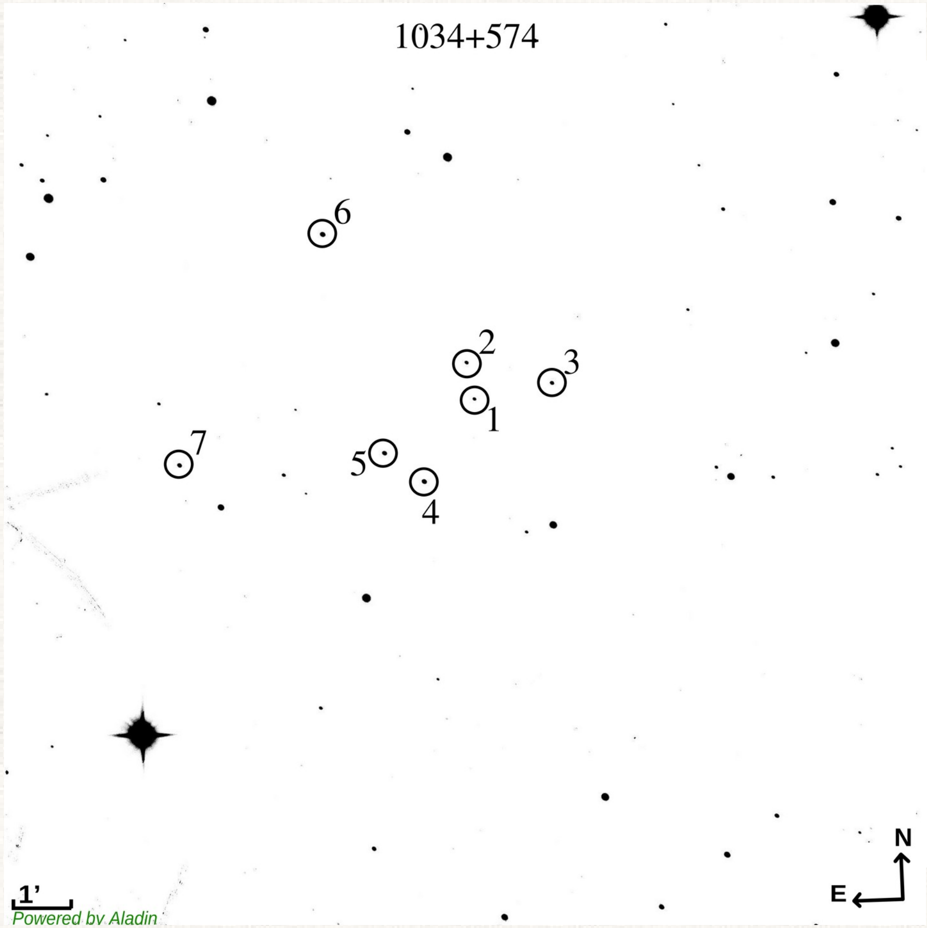


Fig. 4. *Field of view of 1034+574.*

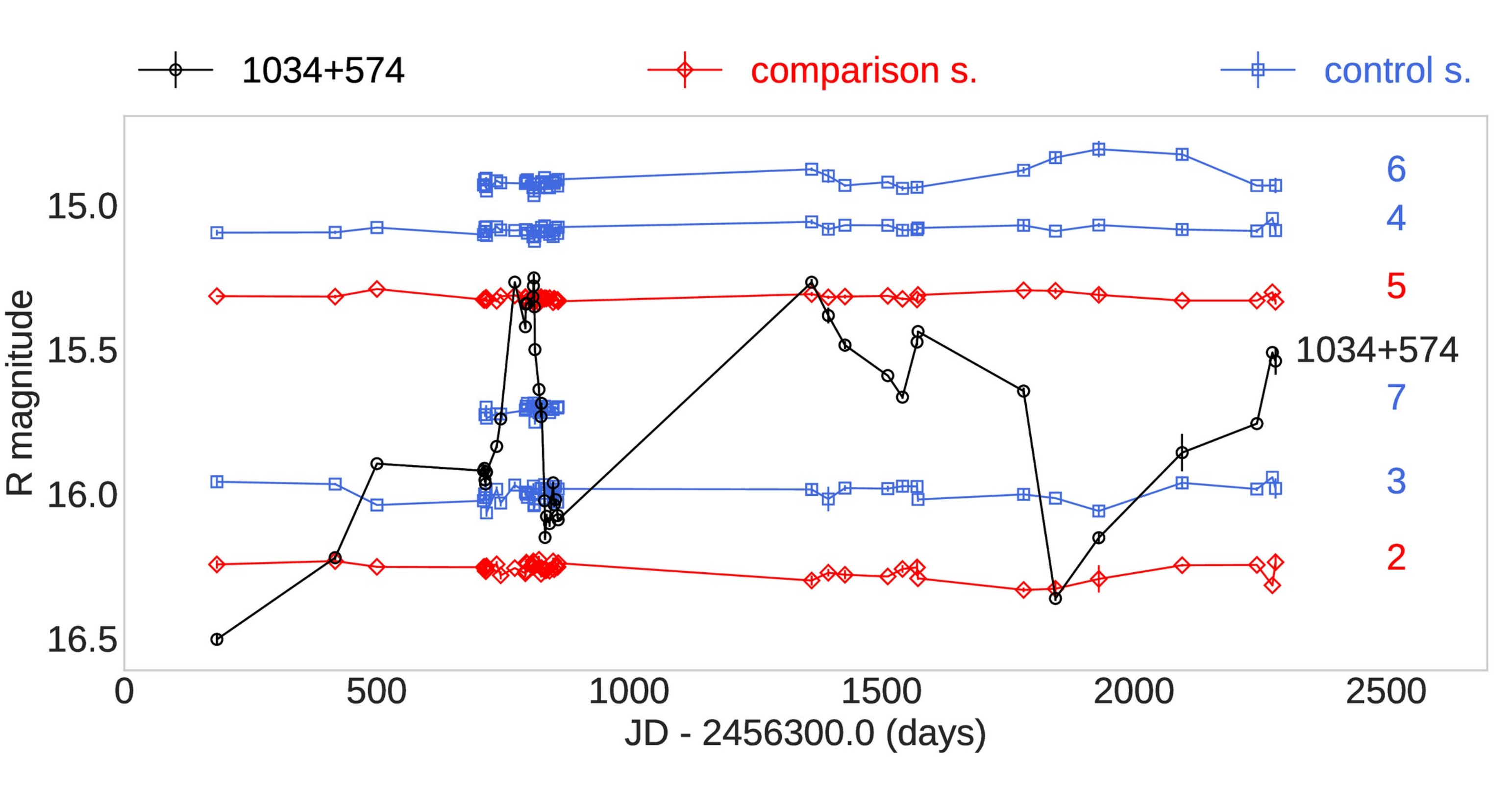


Fig. 5. *The light curve of R magnitude of 1034+674 and light curves of its comparison and control stars.*

Table 3. V and R magnitudes with standard errors of comparison and control stars for objects 0049+003, 0907+336, 1034+574, 1212+467, 1242+574, and 1429+249.

star	$V_C \pm \sigma_{V_C}$(mag)	$R_C \pm \sigma_{R_C}$(mag)	$V_O \pm \sigma_{V_O}$(mag)	N_{V_O}	$R_O \pm \sigma_{R_O}$(mag)	N_{R_O}
			0049+003			
2^A	16.721 ± 0.039	15.830 ± 0.068	16.715 ±0.026	30	15.835 ±0.013	40
3^B	16.303 ± 0.036	15.680 ± 0.042	16.307 ±0.018	30	15.673 ±0.010	40
4	17.253 ± 0.030	16.859 ± 0.033	17.265 ±0.075	26	16.876 ±0.049	36
5	16.367 ± 0.038	15.547 ± 0.053	16.333 ±0.044	20	15.509 ±0.034	27
6	16.821 ± 0.039	15.914 ± 0.067	16.796 ±0.043	15	15.902 ±0.022	24
7	16.988 ± 0.026	16.655 ± 0.027	16.973 ±0.060	26	16.637 ±0.035	36
8	17.392 ± 0.034	16.804 ± 0.040	17.402 ±0.063	26	16.795 ±0.049	35
			0907+336			
2^A	16.947 ± 0.027	16.493 ± 0.032	16.981 ±0.043	39	16.535 ±0.031	42
3^B	15.152 ± 0.025	14.765 ± 0.029	15.143 ±0.010	36	14.754 ±0.009	39
4	16.754 ± 0.023	16.402 ± 0.029	16.727 ±0.048	37	16.392 ±0.045	38
6	15.595 ± 0.036	14.787 ± 0.053	15.664 ±0.019	13	14.817 ±0.011	13
7	16.600 ± 0.031	15.964 ± 0.042	16.676 ±0.028	12	15.998 ±0.014	12
8	15.840 ± 0.024	15.596 ± 0.025	15.842 ±0.041	13	15.581 ±0.027	13
9	15.412 ± 0.028	14.910 ± 0.031	15.442 ±0.019	10	14.922 ±0.008	10
10	16.320 ± 0.028	15.817 ± 0.033	16.347 ±0.027	4	15.839 ±0.019	4
			1034+574			
2^A	16.764 ± 0.028	16.252 ± 0.036	16.77 ±0.025	47	16.262 ±0.024	47
5^B	15.874 ± 0.029	15.329 ± 0.040	15.872 ±0.011	47	15.323 ±0.011	47
3	16.654 ± 0.032	15.993 ± 0.046	16.662 ±0.041	47	15.999 ±0.027	47
4	15.714 ± 0.031	15.103 ± 0.042	15.708 ±0.024	47	15.088 ±0.014	47
6	15.351 ± 0.027	14.904 ± 0.034	15.349 ±0.048	41	14.918 ±0.032	41
7	16.480 ± 0.038	15.688 ± 0.056	16.509 ±0.035	25	15.709 ±0.016	24

star	$V_C \pm \sigma_{V_C}$(mag)	$R_C \pm \sigma_{R_C}$(mag)	$V_O \pm \sigma_{V_O}$(mag)	N_{V_O}	$R_O \pm \sigma_{R_O}$(mag)	N_{R_O}
			1212+467			
3^A	16.053 ± 0.028	15.760 ± 0.030	16.036 ±0.020	49	15.749 ±0.020	49
2^B	15.782 ± 0.029	15.445 ± 0.032	15.802 ±0.017	50	15.46 ±0.019	50
4	16.455 ± 0.033	16.089 ± 0.035	16.404 ±0.029	16	16.036 ±0.021	16
5	17.171 ± 0.031	16.715 ± 0.035	17.124 ±0.057	25	16.671 ±0.047	25
			1242+574			
3^A	15.605 ± 0.036	15.123 ± 0.031	15.62 ±0.012	49	15.138 ±0.008	57
6^B	16.806 ± 0.034	16.428 ± 0.032	16.77 ±0.029	43	16.383 ±0.022	51
2	16.184 ± 0.035	15.773 ± 0.031	16.186 ±0.021	49	15.781 ±0.023	57
4	15.837 ± 0.034	15.462 ± 0.029	15.84 ±0.023	49	15.459 ±0.017	57
5	15.190 ± 0.031	14.790 ± 0.029	15.146 ±0.018	49	14.761 ±0.016	56
7	16.593 ± 0.039	16.227 ± 0.029	16.559 ±0.026	42	16.192 ±0.033	50
8	15.869 ± 0.044	14.974 ± 0.071	15.857 ±0.066	42	14.935 ±0.060	47
			1429+249			
2^A	16.336 ± 0.034	15.778 ± 0.039	16.34 ±0.028	43	15.786 ±0.031	47
6^B	17.459 ± 0.032	17.019 ± 0.033	17.452 ±0.043	36	16.995 ±0.033	40
3	16.622 ± 0.033	16.102 ± 0.039	16.586 ±0.038	29	16.053 ±0.054	29
4	17.391 ± 0.028	17.042 ± 0.032	17.373 ±0.065	20	16.988 ±0.057	21
5	16.377 ± 0.032	15.999 ± 0.030	16.344 ±0.039	32	15.973 ±0.047	32
8	16.753 ± 0.031	16.378 ± 0.031	16.711 ±0.032	29	16.338 ±0.038	29
			1612+378			
4^A	17.007 ± 0.032	16.489 ± 0.041	17.018 ±0.033	32	16.515 ±0.022	36
2^B	15.529 ± 0.028	15.225 ± 0.033	15.53 ±0.014	38	15.223 ±0.018	42
3	15.096 ± 0.029	14.739 ± 0.034	15.082 ±0.012	38	14.722 ±0.022	42
5	16.433 ± 0.029	16.070 ± 0.034	16.407 ±0.039	38	16.024 ±0.048	42
8	15.039 ± 0.030	14.627 ± 0.035	15.032 ±0.031	32	14.609 ±0.038	36

Analysis methods

- 3-σ rule, Shapiro Wilk test of normality,
- Abbe's criterion

$$q = \frac{\sigma_{AV}}{\sigma_D} = \frac{\frac{1}{2(n-1)}\sum_{i=1}^{n-1}(x_{i+1} - x_i)^2}{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} = \frac{1}{2}\frac{\sum_{i=1}^{n-1}(x_{i+1} - x_i)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

$$q_c = 1 + u_\alpha / \sqrt{n + 0.5(1 + u_\alpha)^2}$$

The hypothesis about stochastic independence of the sample units is accepted under

$$q > q_c$$

Analysis methods

- 3-σ rule, Shapiro Wilk test of normality,
- Abbe's criterion
- F – test

1) $H_1\colon Var(S-A) = Var(S-B)$
   $H_{a1}\colon Var(S-A) > Var(S-B)$ alternative,

2) $H_2\colon Var(S-A) = Var(A-B)$
   $H_{a2}\colon Var(S-A) > Var(A-B)$ alternative,

3) $H_3\colon Var(S-B) = Var(A-B)$
   $H_{a3}\colon Var(S-B) > Var(A-B)$, alternative.

$H_{1,2,3}$ are discarded if $F_{1,2,3} > F_c = F_n^{0.001}$

$$F_1 = \frac{Var(S-A)}{Var(S-B)},$$

$$F_2 = \frac{Var(S-A)}{Var(A-B)},$$

$$F_3 = \frac{Var(S-B)}{Var(A-B)}.$$

Table 4. Results of Abbe's criterion and F–test.

Name star	Band	n	Abbé's criterion q, q_c	Abbé's criterion q_A, q_B, q_c	F–test F_1, F_2, F_3, F_c	Variable
0049+003	V	30		0.18 , 0.15 , 0.48	1.30 , 20.64 , 15.92 , 1.86	V
2		30	0.65 , 0.48			
3		30	0.59 , 0.48			
4		26		0.79 , 0.77 , 0.45	1.03 , 2.88 , 2.80 , 1.96	NV
5		20		0.87 , 0.36 , 0.39	1.48 , 1.01 , 1.50 , 2.17	NV
6		15		0.83 , 0.83 , 0.33	1.11 , 1.25 , 1.12 , 2.48	NV
7		26		0.42 , 0.53 , 0.45	1.84 , 2.60 , 1.41 , 1.96	NV
8		26		0.87 , 0.76 , 0.45	1.29 , 2.41 , 1.86 , 1.96	NV
0049+003	R	40		0.15 , 0.15 , 0.54	1.23 , 48.16 , 39.14 , 1.70	V
2		40	0.55 , 0.54			
3		40	0.37 , 0.54			
4		36		0.57 , 0.67 , 0.52	1.11 , 6.03 , 5.42 , 1.76	NV
5		27		0.47 , 0.39 , 0.46	1.95 , 1.91 , 3.73 , 1.93	PV
6		24		0.89 , 0.46 , 0.43	1.48 , 1.04 , 1.55 , 2.01	NV
7		36		0.38 , 0.65 , 0.52	1.81 , 3.86 , 2.13 , 1.76	PV
8		35		0.58 , 0.69 , 0.51	1.18 , 5.91 , 5.02 , 1.77	NV
1034+574	V	47		0.20 , 0.21 , 0.57	1.00 , 83.77 , 83.96 , 1.63	V
2		47	1.07 , 0.57			
5		47	1.07 , 0.57			
3		47		0.82 , 0.82 , 0.57	1.55 , 2.00 , 1.29 , 1.63	NV
4		47		0.88 , 0.63 , 0.57	2.49 , 1.48 , 3.67 , 1.63	NV
6		41		0.73 , 0.55 , 0.55	1.15 , 1.96 , 1.71 , 1.69	NV
7		25		0.77 , 0.99 , 0.44	1.06 , 1.31 , 1.39 , 1.98	NV

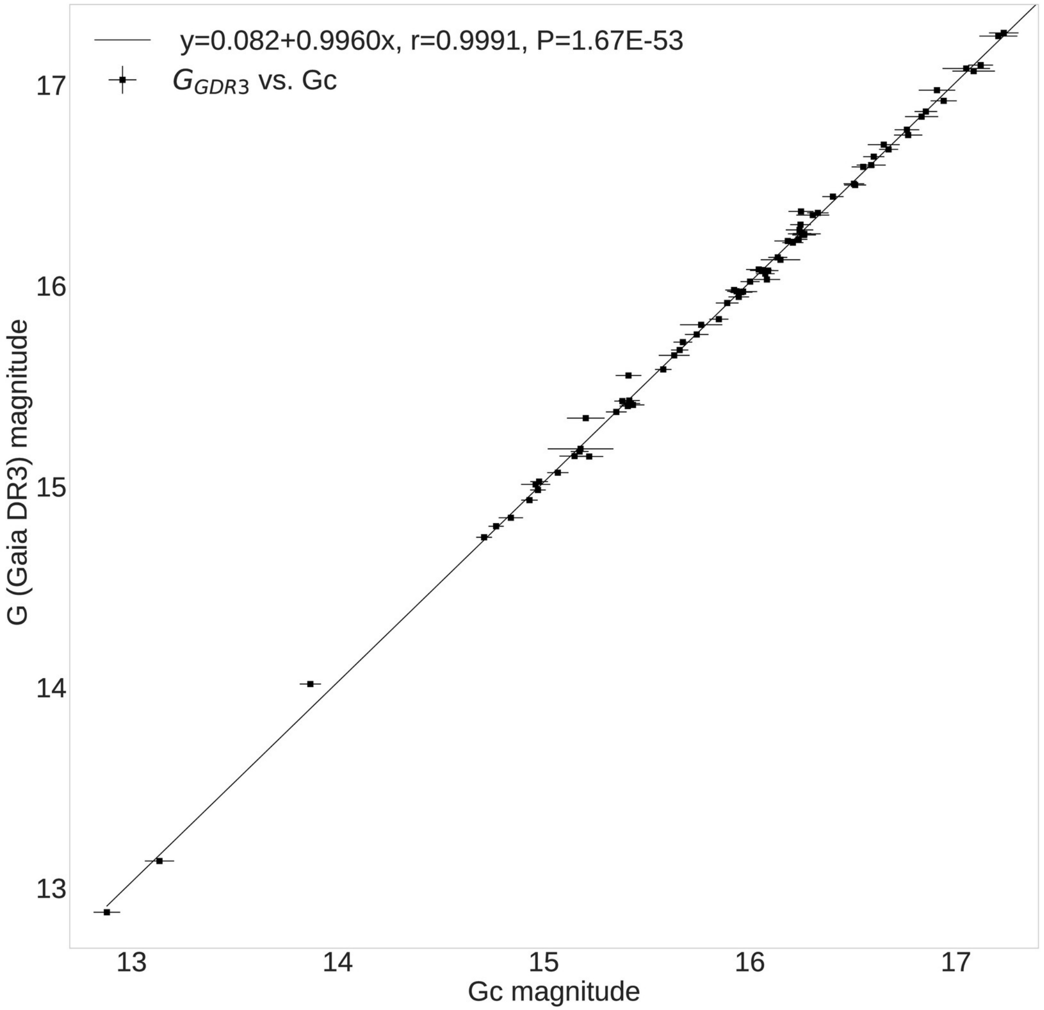
Name star	Band	n	Abbé's criterion q, q_c	Abbé's criterion q_A, q_B, q_c	F–test F_1, F_2, F_3, F_c	Variable
0907+336	V	36		0.19 , 0.19 , 0.52	1.02 , 10.87 , 10.64 , 1.76	V
2		39	0.81 , 0.54			
3		36	0.52 , 0.52			
4		34		1.14 , 1.29 , 0.51	1.62 , 2.14 , 1.32 , 1.79	NV
6		13		1.44 , 1.28 , 0.29	1.40 , 1.43 , 2.01 , 2.69	NV
7		12		0.70 , 0.76 , 0.28	2.60 , 2.67 , 1.03 , 2.82	NV
8		13		1.19 , 1.30 , 0.29	1.21 , 2.76 , 2.29 , 2.69	NV
9		10		0.86 , 0.89 , 0.24	1.64 , 1.65 , 2.72 , 3.18	NV
0907+336	R	39		0.13 , 0.10 , 0.54	1.06 , 25.44 , 24.09 , 1.72	V
2		42	0.89 , 0.55			
3		39	0.33 , 0.54			
4		35		1.34 , 1.33 , 0.51	1.86 , 2.70 , 1.45 , 1.77	NV
6		13		1.26 , 1.21 , 0.29	4.70 , 1.12 , 5.27 , 2.69	NV
7		12		0.41 , 0.54 , 0.28	3.07 , 1.10 , 3.39 , 2.82	NV
8		13		1.27 , 1.34 , 0.29	1.70 , 1.84 , 1.08 , 2.69	NV
9		10		1.10 , 0.77 , 0.24	9.79 , 1.05 , 10.31 , 3.18	NV
1034+574	R	47		0.23 , 0.22 , 0.57	1.01 , 96.54 , 97.13 , 1.63	V
2		47	0.62 , 0.57			
5		47	0.67 , 0.57			
3		47		0.79 , 0.95 , 0.57	1.16 , 1.15 , 1.33 , 1.63	NV
4		47		0.61 , 0.78 , 0.57	6.64 , 1.04 , 6.92 , 1.63	NV
6		41		0.37 , 0.49 , 0.55	1.67 , 2.19 , 1.31 , 1.69	NV
7		24		0.81 , 0.66 , 0.43	1.47 , 1.04 , 1.53 , 2.01	NV

Table 4. Results of Abbe's criterion and F–test.

Name star	Band	n	Abbé's criterion q, q_c	Abbé's criterion q_A, q_B, q_c	F–test F_1, F_2, F_3, F_c	Variable
1212+467	V	49		0.23 , 0.23 , 0.58	1.02 , 51.11 , 50.25 , 1.62	V
3		49	1.22 , 0.58			
2		50	0.81 , 0.58			
4		16		1.19 , 0.90 , 0.34	1.78 , 2.23 , 3.98 , 2.40	NV
5		25		1.16 , 0.99 , 0.44	1.12 , 4.07 , 3.64 , 1.98	NV
1212+467	R	49		0.19 , 0.17 , 0.58	1.06 , 36.06 , 33.89 , 1.62	V
3		49	1.06 , 0.58			
2		50	0.85 , 0.58			
4		16		1.32 , 0.58 , 0.34	1.18 , 1.76 , 1.49 , 2.40	NV
5		25		0.87 , 0.84 , 0.44	1.98 , 2.83 , 1.43 , 1.98	NV
1242+574	V	43		0.25 , 0.26 , 0.56	1.04 , 28.77 , 27.66 , 1.67	V
3		49	0.56 , 0.58			
6		43	0.67 , 0.56			
2		43		0.81 , 0.57 , 0.56	3.88 , 3.92 , 1.01 , 1.67	NV
4		43		1.09 , 0.95 , 0.56	2.95 , 3.69 , 1.25 , 1.67	NV
5		43		0.54 , 0.84 , 0.56	3.41 , 4.76 , 1.40 , 1.67	PV
7		42		0.92 , 1.00 , 0.55	1.72 , 1.88 , 1.10 , 1.68	NV
8		42		**0.26** , **0.39** , 0.55	1.00 , **3.06** , **3.04** , 1.68	**V**
1242+574	R	51		0.24 , 0.27 , 0.59	1.10 , 58.77 , 64.44 , 1.60	V
3		57	0.75 , 0.61			
6		51	0.67 , 0.59			
2		51		0.64 , 0.45 , 0.59	1.12 , 1.85 , 1.66 , 1.60	NV
4		51		0.71 , 0.60 , 0.59	2.31 , 2.96 , 1.28 , 1.60	NV
5		50		0.64 , 0.73 , 0.58	2.80 , 3.16 , 1.13 , 1.61	NV
7		50		0.86 , 0.95 , 0.58	1.16 , 1.53 , 1.78 , 1.61	NV
8		47		**0.20** , **0.33** , 0.57	1.46 , **6.76** , **4.63** , 1.63	**V**

Name star	Band	n	Abbé's criterion q, q_c	Abbé's criterion q_A, q_B, q_c	F–test F_1, F_2, F_3, F_c	Variable
1429+249	V	36		0.48 , 0.55 , 0.52	1.51 , 2.49 , 3.77 , 1.76	NV
2		43	1.02 , 0.56			
6		36	0.69 , 0.52			
3		22		0.29 , 0.60 , 0.41	1.17 , 1.23 , 1.44 , 2.08	NV
4		14		1.06 , 0.94 , 0.31	1.19 , 2.44 , 2.91 , 2.58	NV
5		25		0.99 , 0.66 , 0.44	1.94 , 2.33 , 1.20 , 1.98	NV
8		29		0.79 , 0.93 , 0.47	2.80 , 3.77 , 1.34 , 1.88	NV
1429+249	R	40		0.51 , 0.52 , 0.54	1.30 , 2.40 , 3.13 , 1.70	PV
2		47	1.10 , 0.57			
6		40	0.73 , 0.54			
3		22		0.35 , 0.60 , 0.41	1.78 , 1.30 , 2.30 , 2.08	NV
4		15		0.87 , 1.04 , 0.33	1.76 , 1.21 , 2.13 , 2.48	NV
5		25		0.56 , 0.73 , 0.44	1.14 , 1.40 , 1.60 , 1.98	NV
8		29		0.67 , 0.79 , 0.47	1.17 , 2.06 , 1.76 , 1.88	NV
1612+378	V	32		0.14 , 0.14 , 0.49	1.32 , 12.51 , 9.46 , 1.82	V
4		32	0.68 , 0.49			
2		38	0.58 , 0.53			
3		32		0.84 , 0.48 , 0.49	8.25 , 1.20 , 9.94 , 1.82	PV
5		32		0.88 , 0.80 , 0.49	1.36 , 1.36 , 1.84 , 1.82	NV
8		32		0.73 , 0.35 , 0.49	1.44 , 1.08 , 1.56 , 1.82	NV
1612+378	R	36		0.15 , 0.13 , 0.52	1.02 , 13.28 , 12.96 , 1.76	V
4		36	0.79 , 0.52			
2		42	0.48 , 0.55			
3		36		0.57 , 0.63 , 0.52	1.22 , 1.88 , 2.29 , 1.76	NV
5		36		0.45 , 0.45 , 0.52	2.03 , 4.31 , 2.12 , 1.76	NV
8		36		0.44 , 0.54 , 0.52	1.91 , 3.15 , 1.65 , 1.76	NV

Gaia DR3 (25 July 2014 - 28 May 2017)



- Johnson-Cousins relationships, by Sartoretti et al. (2022)

$$Gc = V - 0.03088 - 0.04653(V - R) - 0.8794(V - R)^2 + 0.1733(V - R)^3, \sigma = 0.0352$$

- Comparison and control stars of 12 sources.
- Variable C2 – 1722+119, and 5 – 1242+574.

Conclusions

- Most of the comparison and control stars are useful for differential photometry
- Star 8 – 1242-574 variable
- Repeat differential photometry
- Continue with observation

References

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- Sartoretti, P., Marchal, O., Babusiaux, C., et al. 2022, A&A accepted, arXiv:2206.05725
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Thanks for your attention!

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