The Internet as a Virtual Observatory: New Elements for Ten Long Period Variables in Aquila

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Abstract Data freely available on the Internet—CCD images from Stardial, data from the Northern Sky Variability Survey (NSVS), the Automated All-Sky Survey (ASAS), the Hipparcos Epoch Photometry Annex, and visual observations from the American Association of Variable Star Observers (AAVSO)—are combined to characterize the behavior of 10 long period variables (LPVs) in Aquila. We present updated light elements for VV Aql, EF Aql, GX Aql, GY Aql, V502 Aql, V543 Aql, V544 Aql, V558 Aql, V893 Aql, and V1541 Aql.

1. Introduction

The authors are developing a manual for extraction and analysis of online data on variable stars that can be used in high school- to introductory college-level courses (Richwine *et al.* 2004)—in essence a virtual observatory. This manual is centered on the use of Stardial (McCullogh and Thakkar 1997) images to locate variable stars by the blinking method and using common software to extract positional and photometric data on them. Once variable stars are identified, online tools such as VIZIER (Ochsenbein *et al.* 2000) are used to identify stars and gather additional data. As part of the development process and as a demonstration, we have acquired and analyzed data on 10 long period variables (LPVs) in Aquila: VV Aql, EF Aql, GX Aql, GY Aql, V502 Aql, V543 Aql, V544 Aql, V558 Aql, V893 Aql, and V1541 Aql.

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2. Results

CCD observations reduced from Stardial FITS images, and photometry obtained online from the Northern Sky Variability Survey (NSVS, Wozniak 2004), the Automated All-Sky Survey (ASAS, Pojmanski 2002), the Hipparcos Epoch Photometry Annex (Perryman *et al.* 1997), and visual observations from the American Association of Variable Star Observers (AAVSO, Waagen 2004) have been combined to determine maxima and describe the recent behavior of 10 long period variable (LPV) stars. Most of these stars have had no data published since their discovery announcements, and four had either no or uncertain published period and type.

The data gathered on each star were entered on a spreadsheet program, and plotted on a graph for analysis. Transforming the observations to a common system would be quite involved because of differences in zero-point and spectral response of the detectors of each data set, and such transformation we considered to be above the intended level of the project. We used observed times of maximum, regardless of the source, to determine periods. In all cases, the stars observed drop below detectability in Stardial images as they approach minimum, so minima were not recorded. Some drop below the faint limit of ASAS as well, and NSVS contains information on minima only if the star happened to be above NSVS' faint limit and observable at minimum during NSVS' one-year observing window. Using the methods described by Hoffmeister *et al.* (1985), Julian dates of maxima seen in each data set were determined and a simple graphical solution using all maxima was done, resulting in a best-fit period to the recent data. If historical maxima were published, we attempted to link those to the current series.

Once each star's period was determined, the amplitude of variation, shape of the light curves, O–C fit, and previously published information were considered to classify each star according to the system used in the *General Catalogue of Variable Stars* (GCVS, Kholopov *et al. 1998)*. The Stardial camera, with its red-sensitive Kodak KAF-400 CCD and RG-1 filter, is quite biased towards the easy detection of red variables. Most stars in this sample are Miras, classified as such based on their red color, period, large amplitude in *V*, and relatively regular variations. One is SRa, based on its small amplitude, and one SR, based on its historically irregular variations.

Table 1 gives our current findings on each star. We include the *V* magnitude range as determined from AAVSO visual observations and ASAS *V*-band photometry.

3. Remarks on individual stars

For each star, we present a table listing observed maxima, the O–C value based on the period we determine, and the source of the data defining that maximum, encoded as follows: S = Stardial images; N = NSVS; A = ASAS; Av = AAVSO visual.

VV Aql. Heise (1923) reported this star as having a period of 259 days; the GCVS (Kholopov *et al.* 1998) reports the type of variability as M. Six observed maxima (Table 2) fit a period of 257.7 days and confirm the type as a Mira.

EF Aql. No information on type or period has been found in the literature. Four observed maxima (Table 3) fit a period of 329.4 days. The observed period and amplitude >2.4 magnitudes support its classification as a Mira.

GX Aql. Parenago (1931) published no type determination and an uncertain period based on 24 positive estimates from photographic plates. Our nine observed maxima (Table 4) fit a period of 272.6 days, and support classification as a Mira. The maximum at JD 2451405 shows a pronounced hump on the ascending branch in all three data sets: Stardial, NSVS, and AAVSO visual.

GY Aql. A large-amplitude semiregular star, with a visual range of magnitude 8.0 at brightest maximum to 16.0 at faintest minimum. The GCVS lists a period of 204 days; Lysaght (1989) proposed periods of 231 or 456 days. Our eight observed maxima (Table 5) fit well with a period of 463.2 days.

V502 Aql. Ahnert (1944) found a period of 286.5 days using 4 maxima for JD 2426972–2429848. Connecting those with our additional six maxima (Table 6) gives a very good fit to a period of 287.9 days.

V543 Aql. Solov'ev (1943) published a period of 152.0 days. Note, however, that reverse engineering of Solov'ev's numbers show that his O–C figures are actually based on a period of 151 days. From Solov'ev's own data, we calculate that a period of 254.9 days better fits the early maxima (Table 7). Recent maxima best fit a period of 251.5 days (Table 8). Attempts to connect the two sets of maxima—separated by 59 years—with a linear fit failed. This is probably due to cumulative cycle-to-cycle random variation, and not to true period change, as first shown by Eddington and Plakidis (1929). A possible anomalous minimum occurred near JD 2451427, perhaps 2 magnitudes brighter than usual.

V544 Aql. Ahnert *et al.* (1949) determined a period of 125.4 days. The recent observations (Table 9) fit a period of 123.0 days. Though the period is fairly regular, the relatively small amplitude (2.0 magnitudes in *V* according to ASAS, agreeing well with Ahnert's 1.6-magnitude photographic range) confirms this star's type as SRa.

V558 Aql. Ahnert *et al.* (1949) determined a period of 374 days, possibly an alias of 187 days. Four recent maxima (Table 10) fit a period of 381.9 days, confirming the longer period. As with V543 Aql, a linear fit between the two widely separated sets of data is not possible.

V893 Aql. Götz *et al.* (1957) published a period of 316.7 days. Three recent maxima (Table 11) fit a period of 321.8 days. Huth's data and ours show fairly large cycle-to-cycle variations, but the mean period has apparently changed little, if at all.

V1541 Aql. Kato (2000) classified this star as a Mira variable without giving an epoch of maximum or period. Six observed maxima (Table 12) define a period of 289.4 days.

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Table 1. Long period variables observed and their light elements.

Star	*Type*	*Epoch of Max (JD)*	*Period (days)*	*V Range (mag)*
VV Aql	M	2450686.3	257.7	11.7–<16.2
EF Aql	M	2451086.8	329.4	12.6–<15.0
GX Aql	M	2448121.8	272.6	11.0–14.6
GY Aql	SR	2448015.4	463.2	8.0–16.0
V502 Aql	M	2450291.9	287.9	11.5–<14.3
V543 Aql	M	2451013.2	251.5	11.1–<15.0
V544 Aql	SRA	2450640.5	123.0	12.4–<14.4
V558 Aql	M	2450627.1	381.9	10.8–<12.0
V893 Aql	M	2451799.0	321.8	12.0–<13.8
V1541 Aql	M	2451071.0	289.4	12.5–<14.6

Table 2. Observed maxima of VV Aql.

Cycle	*JD*	*O–C (P = 257.7d)*	*Source*
0	2450681	−5.3	S
3	2451460	0.6	S, N
4	2451725	7.2	S
8	2452747	−3.6	A
10	2453263	−0.3	A
11	2453519	−2.0	A

Source of maximum data as follows: S = Stardial images; N = NSVS; A = ASAS; Av = AAVSO visual

Table 3. Observed maxima of EF Aql.

Cycle	*JD*	*O–C (P = 329.4d)*	*Source*
0	2451087	0.2	S
1	2451411	−5.2	S, N
2	2451755	9.4	S
3	2452070	−5.0	A

Source of maximum data as follows: S = Stardial images; N = NSVS; A = ASAS; Av = AAVSO visual

Table 4. Observed maxima of GX Aql.

Cycle	*JD*	*O–C (P = 272.6d)*	*Source*
0	2448119	−2.8	Av
4	2449217	4.8	Av
7	2450024	−6.0	Av
8	2450305	2.4	Av, S
12	2451405	12.0	Av, N, S
15	2452190	−20.8	A, S
16	2452466	−17.4	A, S
17	2452780	24.0	A, S
18	2453030	1.4	A

Source of maximum data as follows: S = Stardial images; N = NSVS; A = ASAS; Av = AAVSO visual

Table 5. Observed maxima of GY Aql.

Cycle	*JD*	*O–C (P = 463.2d)*	*Source*
0	2448008	−7.4	Av
1	2448454	−24.6	Av
3	2449420	15.0	Av
4	2449881	12.8	Av
5	2450350	18.6	Av
8	2451725	4.0	Av
9	2452180	−4.2	Av
11	2453097	−13.6	A

Source of maximum data as follows: S = Stardial images; N = NSVS; A = ASAS; Av = AAVSO visual

Table 6. Observed maxima of V502 Aql.

Cycle	*JD*	*O–C (P = 287.9d)*	*Source*
−81	2426972	0.0	Ahnert
−80	2427264	4.1	Ahnert
−76	2428401	−10.5	Ahnert
−71	2429848	−3.0	Ahnert
0	2450303	11.1	S
4	2451450	6.5	S, N
5	2451727	−4.4	S
6	2452020	0.7	A
9	2452882	−1.0	S, A
10	2453169	−1.9	A

Source of maximum data as follows: S = Stardial images; N = NSVS; A = ASAS; Av = AAVSO visual

Table 7. Solov'ev's maxima of V543 Aql.

Cycle (Solov'ev)	*JD*	*Solov'ev O–C (P = 151d)*	*Cycle (This paper)*	*This paper O–C (P = 254.9d)*
0	2423615	0.0	0	−7.0
17	2426181	−1.0	10	10.0
22	2426942	5.0	13	6.3
37	2429220	18.0	22	−9.8
39	2429487	17.0	23	2.3

Table 8. Recent maxima of V543 Aql.

Cycle	*JD*	*O–C (P = 251.5d)*	*Source*
0	2451015	1.8	S
3	2451762	−5.7	S
4	2452025	5.8	A
6	2452524	1.8	A, S
7	2452766	−7.7	A
9	2453281	4.3	A

Source of maximum data as follows: S = Stardial images; N = NSVS; A = ASAS; Av = AAVSO visual

Table 9. Observed maxima of V544 Aql.

Cycle	*JD*	*O–C (P = 123.0d)*	*Source*
0	2450645	4.5	S
6	2451370	−8.5	S
9	2451756	8.5	S, N
15	2452470	−15.5	A
17	2452727	−4.5	A
18	2452870	2.6	S

Source of maximum data as follows: S = Stardial images; N = NSVS; A = ASAS; Av = AAVSO visual

Table 10. Observed maxima of V558 Aql.

Cycle	*JD*	*O–C (P = 381.9d)*	*Source*
0	2450623	−4.1	S
1	2451010	1.0	S
2	2451397	6.1	S, N
3	2451767	−5.8	S

Source of maximum data as follows: S = Stardial images; N = NSVS; A = ASAS; Av = AAVSO visual

Table 11. Observed maxima of V893 Aql.

Cycle	*JD*	*O–C (P = 321.8d)*	*Source*
0	2451791	−8.0	S
1	2452133	12.2	A, S
3	2452760	−4.4	A

Source of maximum data as follows: S = Stardial images; N = NSVS; A = ASAS; Av = AAVSO visual

Table 12. Observed maxima of V1541 Aql.

Cycle	*JD*	*O–C (P = 289.4d)*	*Source*
0	2451071	0.4	S
1	2451370	10.0	N, S
4	2452204	−24.2	A
5	2452516	−1.6	A
6	2452822	15	S
7	2453105	8.6	A

Source of maximum data as follows: S = Stardial images; N = NSVS; A = ASAS; Av = AAVSO visual