HD 121620: A Previously Unreported Variable Star with Unusual Properties

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Abstract During a study of the δ Scuti star V1393 Centauri by digital single lens reflex photometry, it was found that two of the chosen comparison stars were variable. This paper reports the subsequent investigation of one of them, HD 121620, which revealed irregular light variations of 0.8 magnitude in V within a time frame of approximately 24 hours. Photometry in the Hipparcos and Tycho databases from December 1989 to February 1993 revealed an average VT magnitude of 7.25 and little scatter in the data, indicating that the star was then either constant or only slightly variable. Photometry in the ASAS-3 V database between January 2001 and September 2009 showed a similar pattern, with an average magnitude of 7.1. Variability is documented in the ASAS-SN V database from February 2016 to September 2019, and in the ASAS-SN g database from June 2018 to September 2019. Inspection of the author's light curves and Fourier analysis of the author's data show a time frame of one day, but no regular periodicity. Since HD 121620 has a spectral type of G6/8III, it belongs to a population of stars which are least likely to be variable. The nature of its variability has not been determined.

1. Introduction

During a digital single lens reflex (DSLR) photometric study of the δ Scuti star V1393 Cen, the light curves of the variable and check stars were found to have anomalous features, indicating that the comparison star is variable. Photometry of several stars in the field of view revealed that two of them, HD121191 and HD121620, are variable. HD121191 is a previously unreported δ Scuti star (Axelsen 2019). HD121620, a 7th magnitude G6/8III high proper-motion star at R.A. 13 57 56.44, Dec. –53 42 15.34 (ICRS, J2000 from SIMBAD) (Wenger *et al.* 2000) was found to have unusual features of variability, which are reported herein.

2. Methods

Time series photometry was performed on 12 nights from 26 May to 23 June 2019. RAW format images were captured with a Canon EOS 500D DSLR camera through an 80-mm f/7.5 refractor on an equatorial mount. Autoguided exposures of 180 seconds were taken at ISO 400, with a 5-second gap between consecutive exposures.

Images were converted to the FITS format and pre-processed in IRIS (Buil 1999–2018) using dark, bias, and flat frames. Images from the blue and green channels were extracted and imported into ASTROIMAGEJ (Collins *et al.* 2017) for aligning and aperture photometry. Comparison and check stars were HD 120858 and HD 121277, respectively. Data listed in SIMBAD for the variable, comparison, and check stars are shown in Table 1.

Flux values from ASTROIMAGEJ were imported into an EXCEL spreadsheet. Instrumental magnitudes and transformed magnitudes in B and V were calculated using transformation coefficients derived from photometry of images of standard stars from the E regions (Menzies *et al.* 1989). Atmospheric extinction corrections were not applied. The data were analyzed in VSTAR (Benn 2012).

Position searches in SIMBAD (http://simbad.u-strasbg.fr/simbad/sim-fid), the SAO/NASA ADS Custom Query Form (http://adsabs.harvard.edu/abstract_service.html), and the *General Catalogue of Variable Stars* (GCVS; Samus *et al.* 2017, http://www.sai.msu.su/gcvs/cgi-bin/search.htm) failed to find any specific report of variability in HD 121620.

Evidence for variability of HD 121620 was also sought in *The Hipparcos and Tychco Catalogues* (Perryman *et al.* 1997) via the I/239/hip_main table in Vizier (http://vizier.u-strasbg.fr/viz-bin/VizieR-3), in the All Sky Automated Survey (ASAS-3 V) database (Pojmanski 2002), and in the All-Sky Automated Survey for Supernovae (ASAS-SN, http://www.astronomy.ohio-state.edu/~assassin/index.shtml) (Shappee *et al.* 2014; Kochanek *et al.* 2017).

3. Results

3.1. New photometry of HD 121620

The transformed V magnitude of HD 121620 from the author's data was determined for 1,439 time points over the 12 nights of observation, during a total observing time of 78 hr 50 min. The shortest duration of observation during one night was 3 hr 16 min and the longest 8 hr 38 min. The magnitudes

Table 1. Data from SIMBAD for the variable, comparison, and check stars.

Star	*Component*	*R.A.* h m s	*Dec.* ° ′ ″	*V*		*B*		*B–V*
HD 121620	Variable star	13 57 56.44	–53 42 15.34	7.088	(0.010)	8.043	(0.015)	0.955
HD 120858	Comparison star	13 53 21.11	–53 14 29.96	8.71	(0.01)	10.00	(0.03)	1.29
HD 121277	Check star	13 55 55.68	–53 14 58.72	9.16	(0.02)	10.04	(0.04)	1.24

ranged from 7.05 to 7.83, but were not distributed uniformly across the observing nights. During the first six nights, the magnitude ranged from 7.05 to 7.37, whereas the range during the last six nights was 7.34 to 7.83.

Light curves are shown in Figures 1 and 2. Figure 1 includes all observations in B and V and shows their distribution in time across the twelve nights. When the star was brighter, during the first six nights, B–V was greater than it was during the last six nights. Figure 2 illustrates in more detail the light curves for each of the twelve nights. It should be noted that the check star light curves in Figure 2 are shifted so that in each panel the variable and check star light curves are both optimally visualized. HD 121620 brightened during the five nights from 26–27 May to 30–31 May. The observations for the night of 11–12 June exhibit a pattern suggesting the light curve may have been approaching a peak. On the nights of 12–13 and 13–14 June the light curves are descending. Troughs are present for the nights of 17–18 and 18–19 June. The light curve is again descending for the short period of observation before midnight on 19 June. A pronounced trough is seen in observations from 22–23 June. Thus, although no regular periodicity is evident from inspection of the light curves, there is variability with a time frame of about 24 hours.

Another feature is the presence of short, low amplitude flares, seen on 27–28 May just after the beginning of the light curve, and on 30–31 May, possibly at the beginning of the light curve, and again about two thirds of the way along its length. At least two and probably more flares are seen on 13–14 June.

3.2. Photometry of HD 121620 in published databases

The light curve of all data on HD 121620, from the author's observations and from professional sky surveys, is plotted in Figure 3. The sources of the data are: The Hipparcos and Tycho Database (VT magnitudes); ASAS-3 V; ASAS-SN V and g; and the author's V data.

The Hipparacos and Tycho Database contains 129 observations of the VT magnitude of HD 121620 between December 1989 and February 1993. The magnitude varies between 7.21 and 7.28, with 87% of the observations lying in the range 7.23 to 7.26. Thus, the star was either constant, or varied only slightly during this time.

Observations were sourced from the ASAS-3 V database between December 2000 and September 2009. Saturation in survey images between December 2000 and September 2001 resulted in large scatter. These observations are unreliable and were not used. From 2002 onwards exposure times were reduced, thereby avoiding saturation. From these, 615 observations between January 2001 and September 2009 were extracted for analysis in this paper. These observations had little scatter and a mean magnitude of 7.1.

ASAS-SN yielded data in the V and g photometric systems. At the time the data were accessed on 12 December 2019, 813 V-band observations were found from February 2016 to September 2018 and 776 g-band observations were found from June 2018 to September 2019. Thus, only ASAS-SN g-band data are available for the time the personal observations were made. ASAS-SN V magnitudes range from 7.066 to 8.170, with 80% of the observations lying in the range 7.4 to 7.7, whereas the g magnitudes vary from 7.487 to 9.219 (excluding two 11th magnitude outliers), with only 5% of observations being brighter than magnitude 7.9. In comparison with the ASAS-SN V data, the g magnitude range is greater, since the g passband is roughly equivalent to the combined Johnson B and V passbands. There is also a larger scatter in the data, particularly for the fainter magnitudes.

A note of caution is needed concerning ASAS-SN data for bright stars, because the sensors usually saturate between magnitudes 10 and 11 in V. ASAS-SN uses a procedure that improves the data for saturated stars and enables useful photometric information to be obtained, although the degree of improvement is conditional. The best improvement occurs when the charge bleeding from saturated pixels is conservative, and the saturated star is relatively isolated (Kochanek *et al.* 2017). We consider that the improvement in the ASAS-SN photometry for HD 121620 does yield valid data, because inspection of Figure 3 herein reveals that the amplitude of the author's V data is similar to that of the ASAS-SN V data.

3.3. Period analysis

Inspection of Figure 1 suggests a time scale of approximately 24 hours, since light curves taken on consecutive nights are in several instances approximately parallel. Period analysis using Date Compensated Discrete Fourier Transform (DC DFT) in VStar for the period range 0 to 10 days and a resolution of 0.01 reveals the most prominent period to be 1 day with semi-amplitude of 0.35 magnitude (Figure 4).

Analysis of the ASAS-SN V data within a period range of 0 to 50 d and a resolution of 0.01 reveals that the most prominent period is 29.66 d, with a low amplitude of 0.042 magnitude (Figure 5). Analysis of the same data but for the period range 0 to 6 d and a higher resolution (0.001) reveals a prominent peak representing a period of 0.997 d with a low amplitude of 0.053 magnitude (Figure 6).

A similar analysis of the ASAS-SN g observations reveals three peaks close to the noise level of the data. They represent periods of 0.99 d, 6.44 d, and 0.2 d, respectively, with amplitudes of 0.073, 0.071, and 0.064 magnitude (Figure 7). Their significance is uncertain, and they are not considered further in this paper.

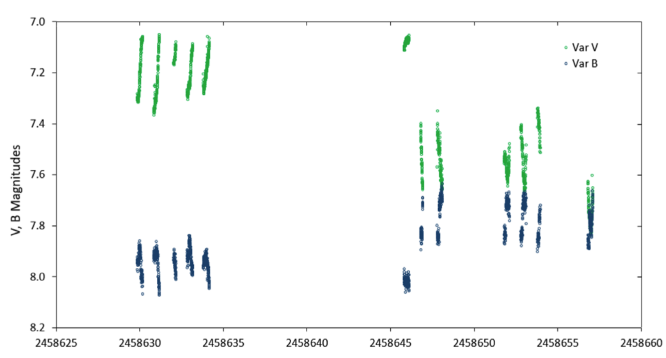

Figure 1. Light curve of HD 121620 from the author's DSLR photometric data obtained during 12 observing nights from 26 May to 23 June 2019. Green and blue represent Johnson V and B data, respectively. This illustration gives an overall view of the entire dataset, showing the magnitude range and the distribution of data across time.

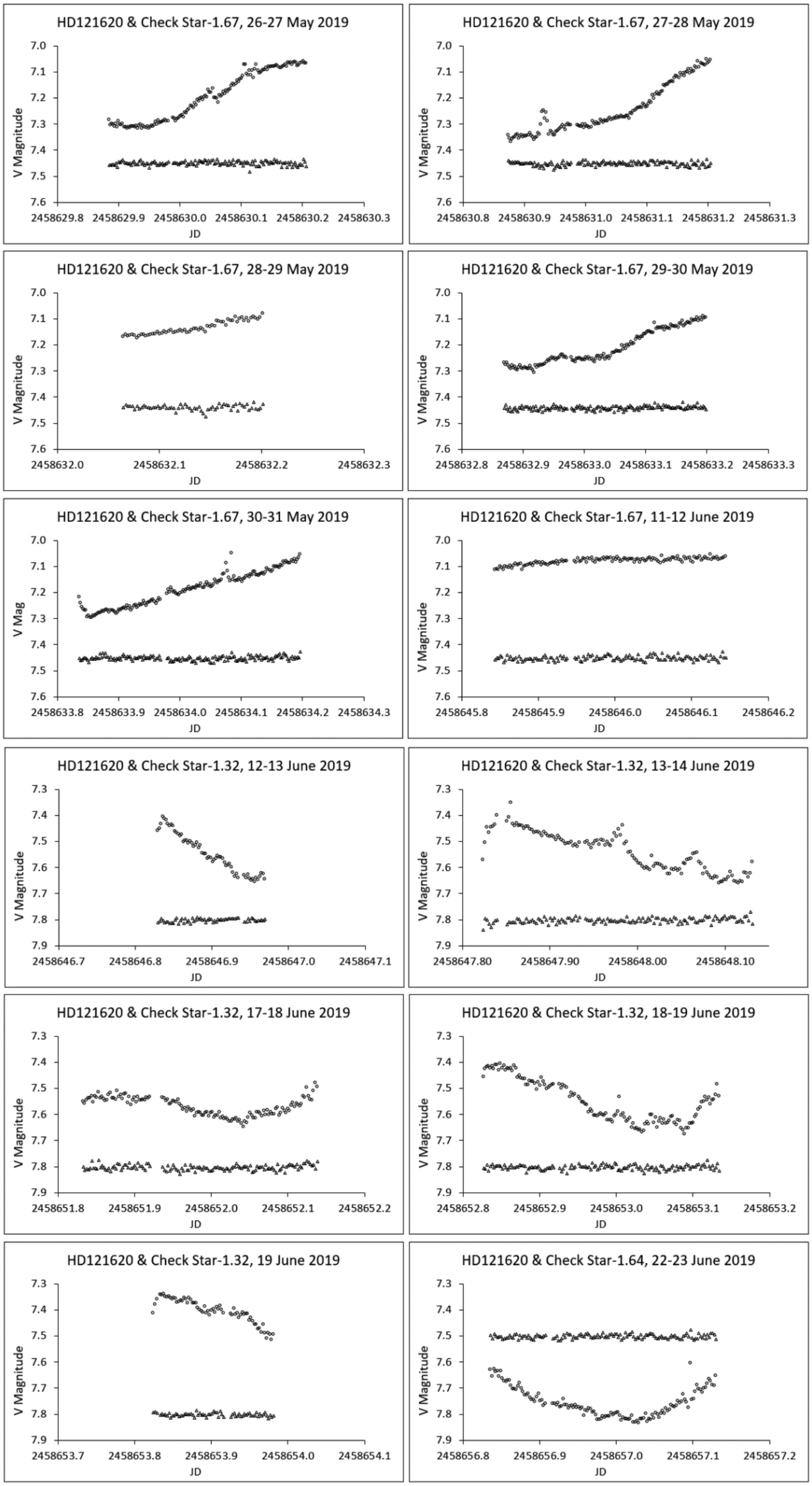

Figure 2. V Light curves of HD 121620 and the check star from the author's data for each of the 12 observing nights. The check star magnitude is offset by various values to allow optimal visualization of the data. The value of the offset is shown in the title of each panel.

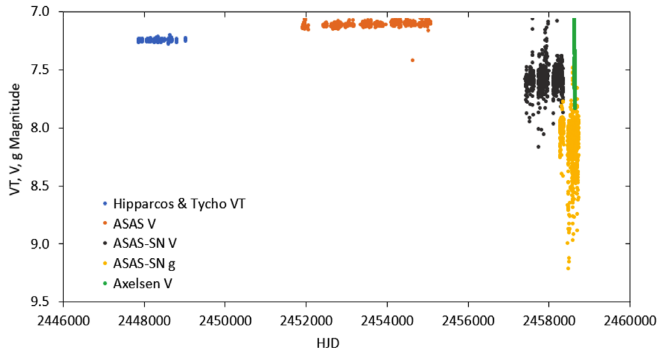

Figure 3. Light curve of HD 121620 from all data sources, 1989–2019. Two outlying 11th magnitude data points have been omitted from the ASAS-SN g data. The author's data are in green.

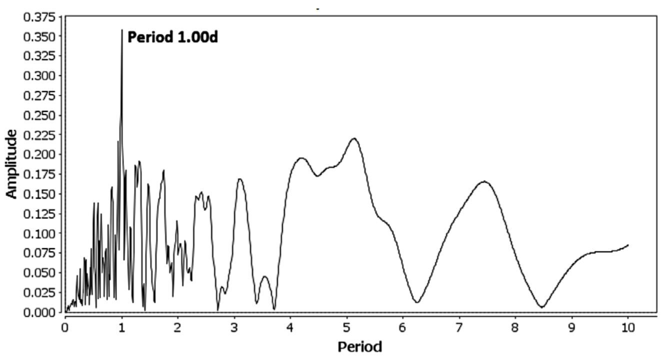

Figure 4. Amplitude versus period plot for HD 121620 at a resolution of 0.01 day from VSTAR using the author's observations. A period of 1 day is most prominent, with amplitude of about 0.35 magnitude.

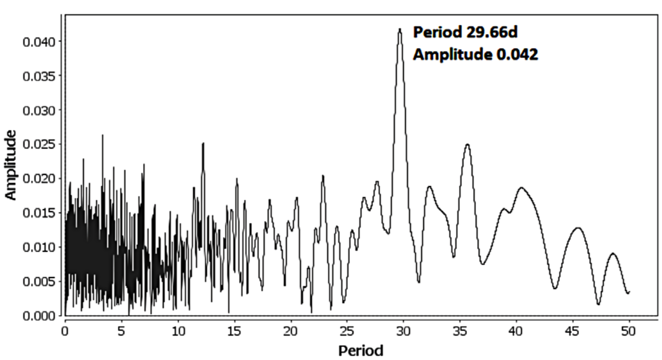

Figure 5. Amplitude versus period plot from 0 to 50 days at a resolution of 0.01 day for HD 121620 from VSTAR using the Johnson V data from ASAS-SN. The amplitude of the data is small. The most prominent peak, 29.66 d, is close to the synodic period of the Moon, and is likely to be spurious (see text).

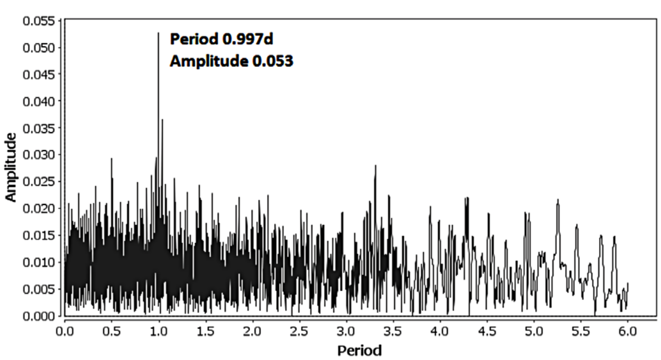

Figure 6. Amplitude versus period plot from 0 to 6 days at a resolution of 0.001 day for HD 121620 from VSTAR using the Johnson V data from ASAS-SN. The amplitude is small. The most prominent peak represents a period 0.997 d.

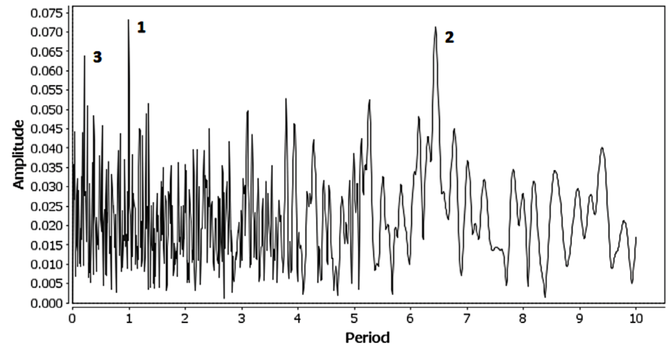

Figure 7. Amplitude versus period plot from 0 to 10 days at a resolution of 0.01 day for HD 121620 from VSTAR using the Sloan g data from ASAS-SN. The three most prominent peaks, numbered 1 to 3 in the above, are not far above the noise level of the data. They represent periods of 0.99d, 6.44d, and 0.2d respectively, with amplitudes of 0.073, 0.071, and 0.064 magnitude, respectively.

4. Discussion

Photometry of HD 121620 is available in five datasets: The Hipparcos and Tycho Database from December 1989 to September 1993; the ASAS-V data from December 2000 to September 2009; the ASAS-SN V band data from January 2017 to September 2018; the ASAS-SN g band data from June 2018 to September 2019; and the author's V data, from 26 May to 23 June 2019.

Perhaps the most remarkable thing about this star is that it was either constant or variable with a very low amplitude when the Hipparcos observations were made, and for most of the time during which ASAS-3 V data is available. Seven years and four months after the last ASAS-3 observations, at the time of the earliest ASAS-SN data in January 2017, variability of HD 121620 was evident, with an amplitude of several tenths of a magnitude in V. This behavior has continued through to the most recent data, with the author's data showing similar overall amplitude to that seen in the ASAS-SN V data. The amplitude of the ASAS-SN g data is greater, and the mean magnitude fainter. These differences would be expected, since the ASAS-SN g passband approximates the combined passbands of Johnson V and B filters, and since the B-V color index varied from 1 to 0 approximately in the author's data.

The cadences of the ASAS-SN V and g data vary from one to several days, with three closely spaced observations about 105 to 110 seconds apart on each day that observations are made. The cadence of the author's data is about 185 seconds for time series photometry over several hours each observing night. Thus, the latter data captures properties of variability that are not revealed by the professional surveys.

Visual inspection and period analysis of the author's and ASAS-SN light curves did not find a consistent regular period; hence a phased light curve could not be constructed. There is, however, a time frame of variation of approximately 24 hours, clearly evident in Figure 1, where several light curves are approximately parallel. Period analysis of the author's data also shows a period of 1 day (Figure 4). This could be an artefact imposed on the data by the time frame inherent in the nightly observing schedule, but the results of the Fourier analysis are supported by the visual evidence from the light curves themselves.

A period of 29.66 d was revealed by Fourier analysis of the ASAS-SN Johnson V data (Figure 5). This duration is very close to the synodic period of the Moon. Percy (2015) has shown that a period of this length is likely to be spurious, representing an alias of much shorter periods. A similar period was also found on analysis of the ASAS-SN g data, but has not been illustrated in this paper.

A period of 0.997d was found in the ASAS-SN V data, but with low amplitude of 0.053 magnitude (Figure 6). The period very close to one day supports a similar value found on visual inspection of the author's light curves, and by Fourier analysis of the author's data. However, as the ASAS-SN observation schedule has an inherent time frame of one day and as the amplitude of the 0.997 d period is very low, it may not reflect a true period.

Analysis of the ASAS-SN g data reveals three peaks representing periods of 0.99 d, 6.44 d, and 0.2 d respectively, all with low amplitudes (0.064 to 0.073 magnitude) and all close to the noise level of the data (Figure 7). The comments applied to the low amplitude period of 0.997d from the ASAS-SN V data in the previous paragraph also apply to the 0.99 d period in the ASAS-SN g data. The other periods, 6.44 d and 0.2 d, have not been found in any other analysis. Because of this and because of their low amplitudes they are not considered to be significant. The type of variability exhibited by HD 121620 has not been determined. Henry *et al.* (2000) found variability in only 19% of G6 to G9 giants, the least variable spectral classes. In contrast he found that 100% of K5 and later type giants in a large sample were variable. From Table 1 of Henry *et al.* (2000), the shortest time scale of variability of a G type star was 25 days, and the periods of variable rotating G6/8 stars from Kepler data are reported to be about 9 to 15 days (from Figure 2 of Nielsen *et al.* 2013). These periods are much longer than the time frame of about one day found in the author's data.

Flares seen in the author's data from three of the twelve nights that HD 161620 was observed would be expected in G type stars (Maehara *et al.* 2012; Shibayama *et al.* 2013).

5. Conclusion

The variability of HD 121620 is unusual. First, Hipparcos observations between December 1989 and February 1993 and ASAS-3 V observations between January 2001 and September 2009 indicate the star was either constant or variable with very low amplitude at those times. Second, despite the fact that this is a bright star of 7th magnitude, its variability is not recorded in either the GCVS or SIMBAD, nor does it appear to receive any specific mention in the searchable publications of the NASA Astrophysics Data System. Third, a time frame of about 1d, without regular periodicity, is strongly suggested by the author's data, both from inspection of the light curves and from period analysis. However, a period as short as this would not be expected in variable G type stars. The nature of variability of HD 121620 is therefore not defined.

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