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Long-Term Photometric Behaviour of the RS CVn Binary IM Pegasi

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Abstract
IM Pegasi (HR 8703) is a long-period RS CVn binary whose brightness changes as large starspots rotate in and out of view. We study Johnson V-band photoelectric photometer (PEP) measurements of the star from the American Association of Variable Star Observers (AAVSO) International Database for the seasons 2001–2008. Seven observing windows, one in each of 2001–2006 and 2008, are examined season by season, and a Lomb–Scargle period search is run on the whole series and on each window. In 2001–2004 the star stays near a mean of V ≈ 5.79 and moves up and down by about 0.12–0.24 mag, with successive faint or bright phases 22–28 d apart. The Lomb–Scargle periodogram of the 406 measurements peaks at about 24.9 d (false-alarm probability $\sim 10^{-25}$), within one resolution element (0.24 d) of the 24.649 d orbital period. Six of the seven single-season periods lie between 23.3 and 26.1 d and average 24.66 ± 1.02 d; the seventh, from 2005, is a 0.5 d sampling artefact. Single seasons cannot separate the orbital period from the slightly shorter photometric period reported in the literature. The mean level then slips to V ≈ 5.87 in 2006 and V ≈ 5.89 in 2008, which echoes the changing spot coverage found in earlier light-curve modelling, but sparse sampling and possible zero-point drift mean that a real fading is not yet established.

Keywords: Variable Stars; IM Pegasi; Photometry; Photoelectric Photometer (PEP); RS CVn; Starspots; Period Analysis

1. Introduction

RS Canum Venaticorum (RS CVn) stars are close binaries in which at least one component is a rapidly rotating, magnetically active cool star. Large cool spots darken part of its surface, so the system gets fainter and brighter as the star turns. The rotation is usually close to synchronous with the orbit, which means the light curve repeats about once per orbital cycle. When the spots grow, shrink or move, the amplitude, shape and mean level of the light curve change from one season to the next (Dar et al. 2018).

IM Pegasi (HR 8703, HD 216489) is one of the best-known members of the class. Its visible component is a K-type giant or subgiant. Herbst (1973) classified it K1 IV–III, while Cao et al. (2022) describe a K2 III primary with an unseen companion in a nearly circular orbit of about 24.6 days (Berdyugina et al. 1999). The orbital period of 24.649 d comes from the spectroscopic orbit of Harper (1935); Zellem et al.

(2010) quote about 24.69 d, as cited by Dar et al. (2018). The star also has a special place in astrophysics as the guide star of the Gravity Probe B mission (Dar et al. 2018).

Its variability has been known for a long time. Herbst (1973) found an amplitude near 0.16 mag in V but could not fit his data with the orbital period. Percy and Welch (1982) later recovered a photometric period of 24.3 ± 0.3 d from observations made in 1979. Eaton et al. (1983) combined three seasons of photometry from eight observatories (1978–1981). They found a photometric period of 24.39 ± 0.03 d, about 1% shorter than the orbital period, a V range of 5.60–5.85 and an amplitude of 0.13–0.20 mag that changed from year to year. Dar et al. (2018) summarized variations of up to 0.3 mag in V and, with a two-spot model, showed that the total spotted area changed markedly between 1978 and 2016. Doppler imaging has revealed spots on the star (Berdyugina et al. 2000), and Cao et al. (2022) found flare-like events and evolving active longitudes in their spectroscopic monitoring of 2015. An ultraviolet flare has also been reported (Ramsey and Buzasi 1986).

Most of this photometric work covers only a few seasons at a time. Long, homogeneous series are scarce, yet they are what lets us tell fast rotational modulation apart from slow changes in overall activity. Here we take a first look at one such series, the Johnson V-band PEP measurements of IM Peg in the AAVSO International Database (Kafka 2021) for 2001–2008. We examine the light curve of selected observing windows season by season, compare the mean brightness of each season, and run a Lomb–Scargle period search on the whole series and on each window. Our aim is to see what these data can and cannot say about the timescale and the long-term level of the variability.

2. Data and Methods

2.1 The AAVSO photometry

The measurements are Johnson V-band photoelectric photometry of IM Peg taken from the AAVSO International Database (Kafka 2021). The main analysis in this paper uses the observations from 2001 to 2008. Coverage is very uneven within that interval. The seasons 2001–2004 and 2006 are well observed, while 2005 and 2008 are covered by a shorter run of measurements. There are no measurements in 2007 in the plots used here. The selection also holds a handful of points from 2009, 2010 and 2011, which are far too sparse to define a light curve and are mentioned only briefly in Section 3.2. The results are therefore a series of observed seasons and not a continuous monitoring record.

2.2 Observing windows and plots

For each season from 2001 to 2006 and for 2008 we show one continuous observing window as Julian Date (JD) against V magnitude (Figures 2–8; Table 1). The windows last between 41 and 129 days, which is between about two and five orbital cycles. An overview plot of all seven seasons on one JD axis is shown in Figure 1. The magnitude axis is inverted so that brighter values point upward, and every panel uses the same window, V = 5.4–6.4, so that seasons can be compared directly by eye. Every point carries its reported uncertainty. Most error bars are smaller than about 0.01 mag and a few reach 0.02–0.03 mag, so the variations of 0.1–0.4 mag discussed below are far larger than the measurement errors. Figures 1 and 7 label JD in units of 10^6 days, whereas the other panels use an offset such as 2,452,000 +. In the text we quote JD − 2,450,000 throughout.

2.3 Quantities taken from the plots

Magnitude ranges, mean magnitudes and the times of faint and bright phases in Tables 1–3 were measured from the plotted points. They are accurate to about 0.01–0.02 mag in V and about 1–2 d in time. Where many markers overlap, as in the densest runs of 2002 and 2004, the point counts are lower limits. The spacing between successive faint (or bright) phases is a rough, by-eye guide to the timescale of the variation. It is complemented by the formal period search described next.

2.4 Period search

We computed Lomb–Scargle periodograms (Lomb 1976; Scargle 1982) of the whole 2001–2008 series, for periods of 1–100 d, and of the measurements of each season separately. For the strongest peak of each series we list the best period, a rough period uncertainty and the false-alarm probability (FAP). The whole series spans about seven years, so its frequency resolution is about $P^2/T \approx 0.24$ d at P = 24.65 d. A single window of 41–129 d gives a resolution of several days. The FAP expresses how likely a peak of that height would be if the data were pure noise. It does not measure how precisely the period is known, and it assumes uncorrelated noise, which spot evolution can violate.

2.5 Software

The analysis was done in Python. Pandas was used to import, select, clean and group the observations, NumPy for numerical operations and for deciding the number of plotting panels, and Matplotlib to draw the light curves, the magnitude histogram and the periodograms.

3. Results

Table 1 lists the observing window shown in each figure, with the approximate number of points, magnitude range and mean magnitude. Section 3.1 goes through the individual windows, Section 3.2 turns to the mean level of each season, Section 3.3 compares the timing of the faint and bright phases, Section 3.4 describes the distribution of the magnitudes, and Sections 3.5 and 3.6 give the periodogram of the whole series and of the individual seasons.

Table 1. Observing windows plotted in Figures 2–8. N is the approximate number of points (a lower limit where markers overlap). Magnitudes are read from the plots (±0.02 mag).

Fig.	Season	JD − 2,450,000	Span (d)	N	V range	Mean V
2	2001	2178.8–2254.5	76	≳81	5.60–5.90	5.79
3	2002	2555.7–2623.5	68	≳33	5.69–5.92	5.80
4	2003	2867.9–2980.2	112	≳54	5.63–5.87	5.80
5	2004	3213.7–3280.3	67	≳45	5.70–5.94	5.77
6	2005	3589.7–3630.4	41	≳24	5.69–5.94	5.81
7	2006	3962.5–4091.4	129	≳43	5.79–5.95	5.87
8	2008	4714.8–4775.2	60	≳14	5.81–5.97	5.89

3.1 Seasonal windows

Figure 1 shows seven clusters of measurements, one for each season. The seasons 2001–2005 are very similar in their mean level, V ≈ 5.78–5.82, but they differ in how much the star varies inside a season. The standard deviation is only 0.04 mag in 2003 and 0.06 mag in 2001 and 2002, and it rises to 0.09–0.10 mag

in 2004 and 2005. The 2004 season has the widest range of all, V = 5.59–5.98, or 0.39 mag, with three bright points at V ≈ 5.59–5.63 near JD 2453313–2453336 and the faintest point of the season, V ≈ 5.98, in between them. In 2005 the star ranges from V ≈ 5.65 early in the season to V ≈ 5.97–5.98 at the end. In 2001 an isolated point at V ≈ 5.60 lies about 0.1 mag above the other measurements of the season, and in 2003 a single point at V ≈ 5.63 stands out in the same way.

The seasons 2006 and 2008 are different. In 2006 the star varies only between V = 5.79 and 5.95, and its mean, V ≈ 5.87, is about 0.07 mag fainter than the mean of the 2001–2005 seasons. The 2008 season is a short run of measurements over about 80 days, with a mean of V ≈ 5.89 and a range of V = 5.81–5.97. The shift to a fainter level is modest. It is about the same size as the standard deviation of the quiet seasons, and it is smaller than the full range inside any single season.

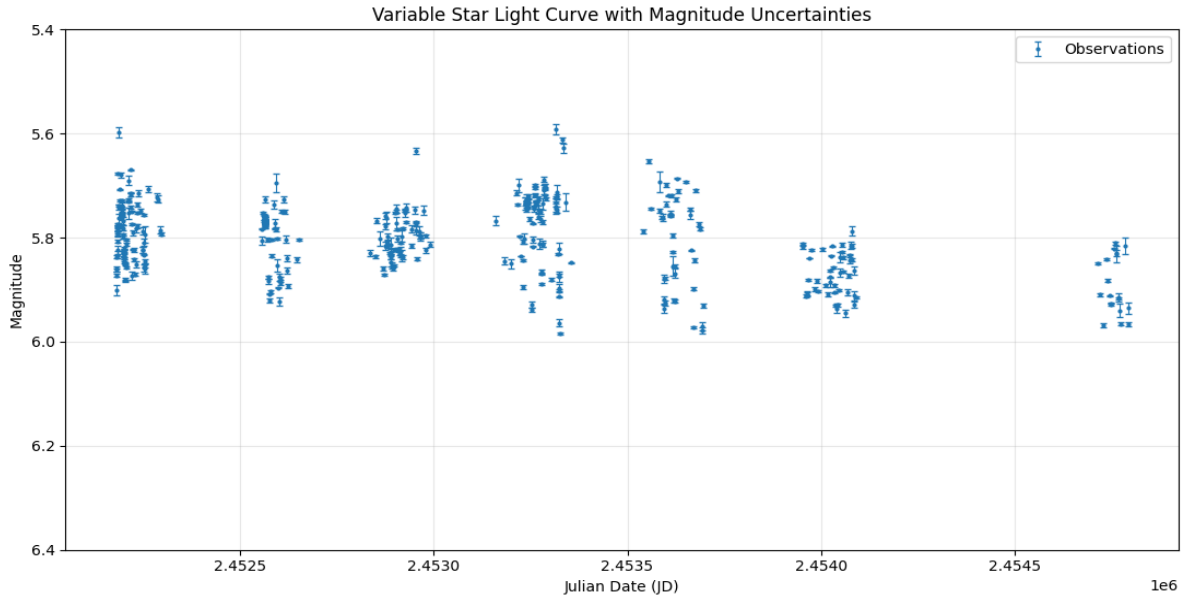


Figure 1. Overview of the IM Peg V-band observations used in this paper, 2001–2008, on one JD axis (JD in units of 10^6 days). From left to right the clusters are the seasons 2001, 2002, 2003, 2004, 2005, 2006 and 2008. The mean level is steady near V ≈ 5.8 until 2005 and becomes fainter and somewhat more scattered afterwards.

2001 (Figure 2). This is the best-sampled window, with at least 81 points over 76 days. The star moves between V ≈ 5.70 and 5.90 in a clear repeating wave. Faint phases fall near JD 2452179 (V ≈ 5.90), 2452203 (5.86–5.88), 2452227 (5.87) and 2452251 (5.85), each about 24 d after the previous one. Bright phases (V ≈ 5.71–5.74) occur near JD 2452189, 2452215 and 2452236. One isolated point at V ≈ 5.60 (JD 2452186.7), about 0.1 mag above the neighbouring points, falls outside the pattern. The peak-to-peak size of the wave, about 0.2 mag, is in line with the 0.13–0.20 mag found by Eaton et al. (1983).

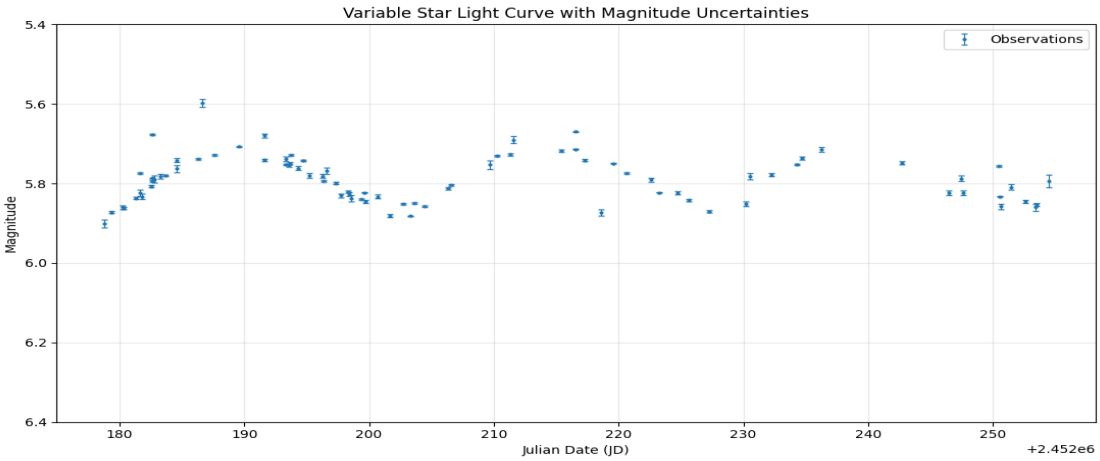


Figure 2. Light curve of IM Peg in 2001 (JD 2,452,179–2,452,255), Johnson V with uncertainties. Faint phases near JD 2,452,179, 203, 227 and 251 are separated by about 24 d. The isolated point at V ≈ 5.60 is about 0.1 mag brighter than its neighbours.

2002 (Figure 3). The window is 68 days long and its coverage is uneven. A very dense stretch near JD 2452562 holds many measurements taken within a day or two at V ≈ 5.76–5.78, and the rest of the window is sampled every few days. The star fades to V ≈ 5.88–5.92 around JD 2452574–2452577, brightens to V ≈ 5.73–5.75 near 2452587, fades again to V ≈ 5.88–5.92 near 2452601, and brightens once more near 2452611–2452613. A further decline starts after JD 2452618 and has reached V ≈ 5.89 when the window ends. The total range is V = 5.69–5.92.

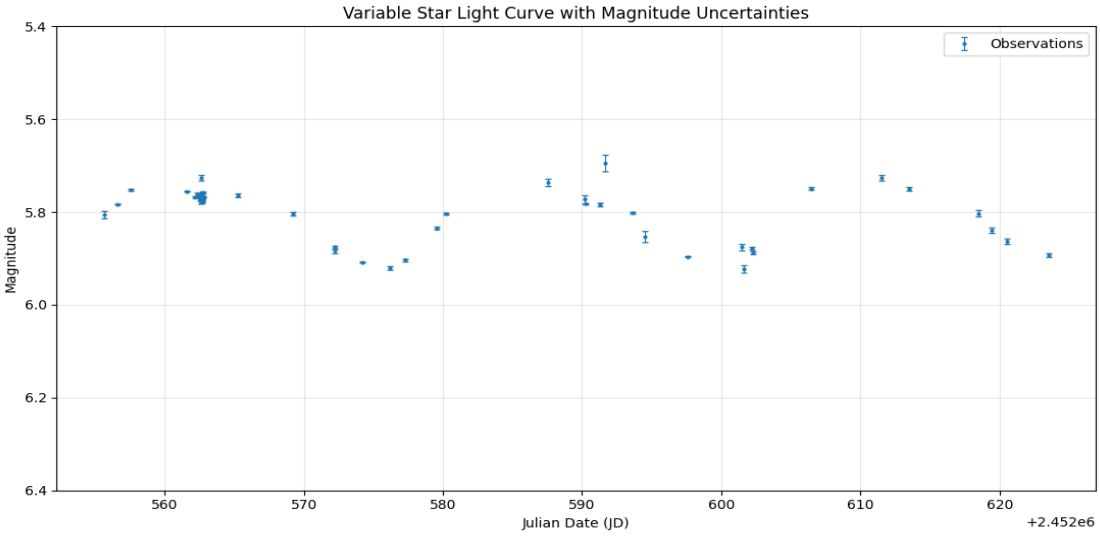


Figure 3. Light curve of IM Peg in 2002 (JD 2,452,556–2,452,624). The dense cluster near JD 2,452,562 lies at V ≈ 5.77. Faint phases near JD 2,452,575 and 2,452,601 reach V ≈ 5.88–5.92.

2003 (Figure 4). This is the quietest of the windows. Nearly all points lie between V = 5.74 and 5.87, so the wave is only about 0.12 mag from top to bottom. The brightest phases (V ≈ 5.75) occur near JD 2452876, 2452900, 2452926, 2452951 and 2452975, a very regular spacing of 24–26 d. One bright point at V ≈ 5.63 on JD 2452952.6 stands well above the rest, about 0.12 mag brighter than the nearby maximum. Although the amplitude is small, the repetition of the maxima is the clearest of any season.

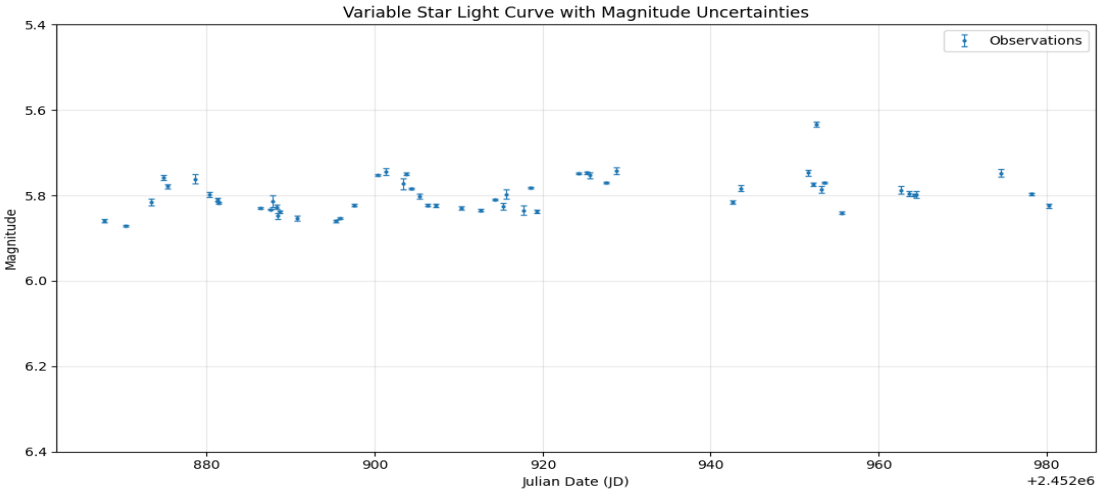


Figure 4. Light curve of IM Peg in 2003 (JD 2,452,868–2,452,980). The variation is small, mostly V = 5.74–5.87, with maxima near V ≈ 5.75 about every 25 d. One bright point at V ≈ 5.63 (JD 2,452,952.6) departs from the pattern.

2004 (Figure 5). The window covers the first 67 days of a longer season. The star is near V ≈ 5.70–5.74 at the beginning (JD 2453214–2453217) and fades to V ≈ 5.84 near JD 2453223–2453229. It recovers to V ≈ 5.73–5.74 between JD 2453235 and 2453246, drops to its faintest in this window, V ≈ 5.93–5.94, near JD 2453250–2453252, returns to V ≈ 5.70–5.74 between JD 2453259 and 2453268 and starts to fade again by JD 2453277–2453280 (V ≈ 5.81–5.89). Faint phases near JD 2453226, 2453251 and 2453279 are 25 and 28 d apart. The wave is about 0.24 mag peak to peak here and the star spends most of its time near the bright end. The full 2004 season in Figure 1 is wider still, V = 5.59–5.98, or 0.39 mag.

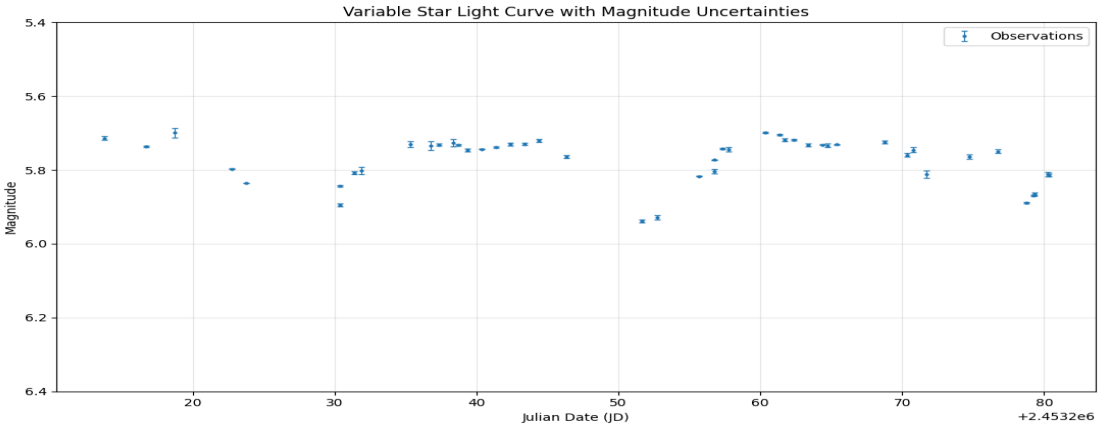


Figure 5. Light curve of IM Peg in 2004 (JD 2,453,214–2,453,280; JD in units of 2,453,200 +). Fading episodes near JD 2,453,226, 251 and 279 interrupt a bright state at V ≈ 5.70–5.74.

2005 (Figure 6). This is the shortest window, only 41 days, with at least 24 points. It covers nearly two orbital cycles and spans V = 5.69–5.94. At the start the star is at V ≈ 5.76, fades to V ≈ 5.88–5.94 between JD 2453593 and 2453597, brightens to V ≈ 5.70–5.76 between JD 2453600 and 2453614, fades again to V ≈ 5.86–5.92 between JD 2453616 and 2453623, and returns to V ≈ 5.69–5.73 by JD 2453625–2453630. The two faint phases (near JD 2453595.5 and 2453621) are about 25 d apart, so the window shows one full cycle with an amplitude of about 0.25 mag.

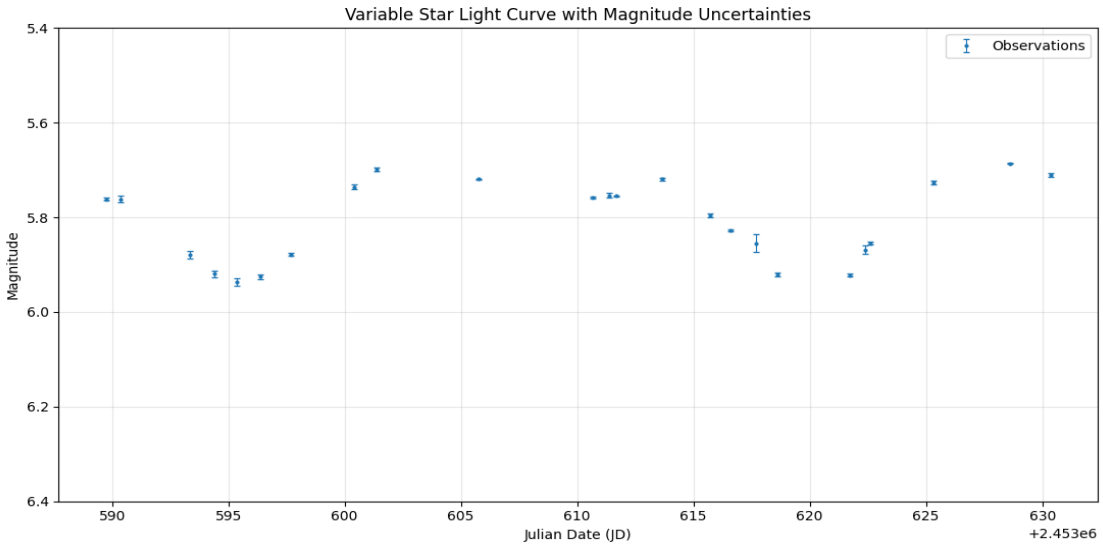


Figure 6. Light curve of IM Peg in 2005 (JD 2,453,590–2,453,630; JD in units of 2,453,000 +). Two faint phases about 25 d apart, with an amplitude of about 0.25 mag.

2006 (Figure 7). The window lasts 129 days and holds at least 43 points between V = 5.79 and 5.95. The range is only about 0.15 mag and the mean, V ≈ 5.87, is about 0.07 mag fainter than the mean of 2001–2004. The modulation is shallow. Faint phases (V ≈ 5.91–5.94) fall near JD 2453964, 2453987, 2454017, 2454040, 2454062 and 2454086, and brighter ones (V ≈ 5.80–5.84) near JD 2453973, 2454003, 2454027, 2454053 and 2454078. In the second half of the window the faint phases are 22–24 d apart. The first half is less regular.

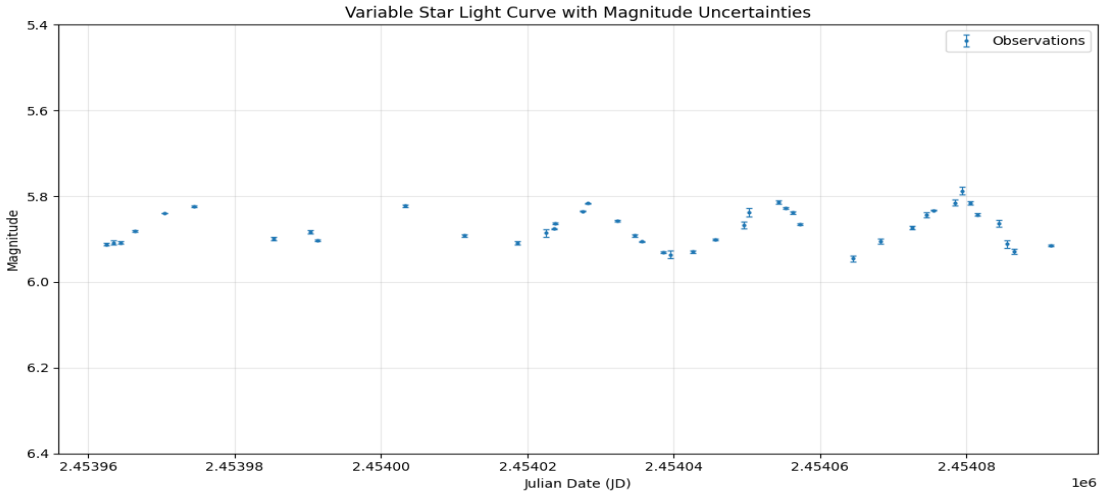


Figure 7. Light curve of IM Peg in 2006 (JD 2,453,962–2,454,091; JD in units of 10^6 days). The star is fainter on average (V ≈ 5.87) and varies by only about 0.15 mag.

2008 (Figure 8). The window is 60 days long with only 14 points, between V = 5.81 and 5.97 (mean V ≈ 5.89). The data show a slow undulation. Faint points occur near JD 2454729 (V ≈ 5.97), 2454748 (5.93) and 2454775 (5.97), and brighter ones near JD 2454739 (5.84) and 2454760 (5.81). The intervals of about 20–26 d resemble the orbital timescale, but with this few points we can only note the resemblance. The mean level is about 0.1 mag fainter than in 2001–2004.

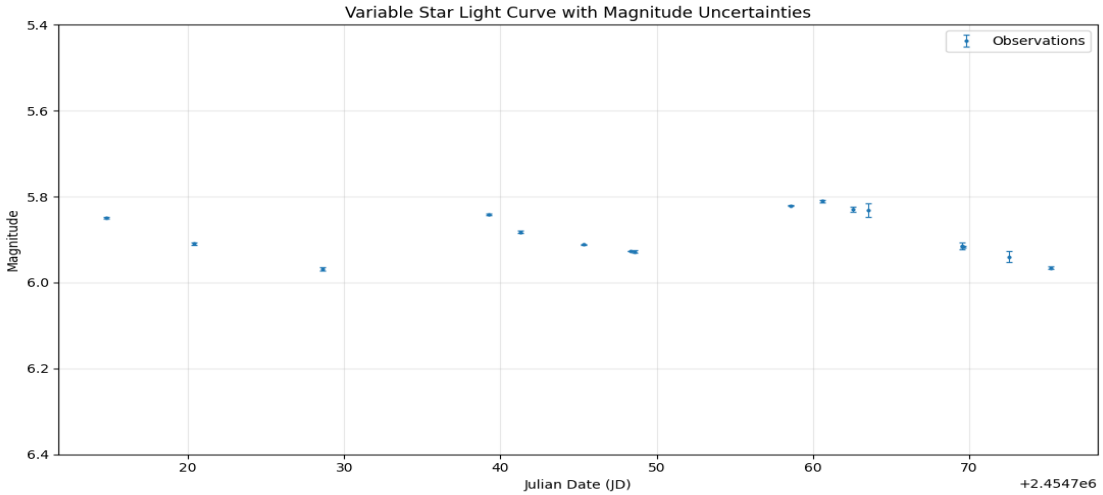


Figure 8. Light curve of IM Peg in 2008 (JD 2,454,715–2,454,775; JD in units of 2,454,700 +). Only 14 points are available. Faint points near JD 2,454,729, 748 and 775 are 19–27 d apart.

3.2 The mean level over 2001–2008

Table 2 gives the magnitude range and mean magnitude of every season in the overview (Figure 1). The seasons 2001–2005 are almost identical in their means, V ≈ 5.78–5.81, even though their ranges differ. The mean is fainter in 2006 (V ≈ 5.87) and 2008 (V ≈ 5.89). The change is about 0.1 mag, which is smaller than the range seen inside any single season, so it does not stand out clearly above the scatter. The fading, if real, is gradual and not a sudden step.

The selection also contains a few later measurements that are not part of Figure 1. Seven points in 2009 and five in 2010 average V ≈ 5.97 and 5.96, and four points in 2011 average V ≈ 6.1 and span V = 5.86–6.31. These are about 0.17 mag and 0.3 mag fainter than 2001–2004, but so few points cannot define a seasonal mean, and the 2011 value rests on four widely scattered measurements. We list them for completeness and do not draw conclusions from them.

Table 2. Magnitude range and approximate mean V of each season in the overview (Figure 1). Means are accurate to about 0.02 mag. The number of points is given only where the markers do not overlap. The 2005 values are those of the plotted window (Table 1) and the season range quoted in Section 3.1.

Season	V range	Mean V	Points
2001	5.60–5.90	5.79	89
2002	5.69–5.92	5.80	58
2003	5.63–5.87	5.79	69
2004	5.59–5.98	5.78	82
2005	5.65–5.98	5.81	44
2006	5.79–5.95	5.87	45
2008	5.81–5.97	5.89	19

3.3 Timing of the faint and bright phases

Table 3 collects the times of the faint and bright phases read from Figures 2–8 and the average spacing between successive ones. Pooling all 30 intervals gives a mean of 24.7 d with a scatter of 2.4 d. Most

intervals are between 22 and 28 d, the extremes being 19 d (2008) and 30 d (2006), and the averages for the individual seasons lie between 21 and 27 d. The orbital period is 24.649 d, and the photometric period found by Eaton et al. (1983) is 24.39 ± 0.03 d. None of our intervals can be distinguished from either value. Spacing's read off a few cycles carry uncertainties of one to two days in each interval, and spot evolution can move the apparent maxima and minima by a similar amount. The formal period search in Sections 3.5 and 3.6 puts this impression on a firmer footing.

Table 3. Faint and bright phases read from the light curves, as JD − 2,450,000, and the mean spacing between successive phases of the same kind.

Fig.	Season	Faint phases	Bright phases	Mean spacing (d), faint / bright
2	2001	2179, 2203, 2227, 2251	2189, 2215, 2236	24.0 / 23.5
3	2002	2575.5, 2601.5	2562, 2587, 2611.5	26.0 / 24.8
4	2003	—	2876, 2900, 2926, 2951, 2975	— / 24.8
5	2004	3226, 3251, 3279	3216, 3240, 3263	26.5 / 23.5
6	2005	3595.5, 3621	3601, 3628.5	25.5 / 27.5
7	2006	3964, 3987, 4017, 4040, 4062, 4086	3973, 4003, 4027, 4053, 4078	24.4 / 26.3
8	2008	4729, 4748, 4775	4739, 4760	23.0 / 21.0

3.4 Distribution of the magnitudes

The histogram in Figure 9 has 406 measurements. The mean is V = 5.811 and the median is V = 5.803. The mean is slightly the larger of the two because of the tail of faint points. If the single measurement at V ≈ 7.4 is left out, the mean falls to 5.807. The distribution is compact: about 387 measurements (95%) lie between V ≈ 5.7 and 5.95. Four bins between V ≈ 5.74 and 5.85 hold 229 measurements (56%), with 62, 62, 46 and 59 measurements in them. The slight dip to 46 between two maxima near V ≈ 5.77 and 5.83 gives the top of the distribution a flat or double shape.

The two sides of the distribution are very different. On the bright side the number of measurements falls abruptly, from 32 in the bin near V ≈ 5.72 to 13 near 5.69, and only seven measurements are brighter than V ≈ 5.67. The star evidently does not get much brighter than V ≈ 5.60. On the faint side the decline is more gradual, with 40, 31, 27, 15 and 7 measurements in the successive bins from V ≈ 5.86 to 5.98. About a dozen measurements are fainter than V ≈ 5.97. Most of them lie just beyond it, at V ≈ 6.00–6.04, but one is at V ≈ 6.19 and one at V ≈ 7.38, which is 1.6 mag fainter than the mean. These faint points are not visible in the overview of Figure 1, whose faintest plotted point is V ≈ 5.98, so their dates have still to be identified.

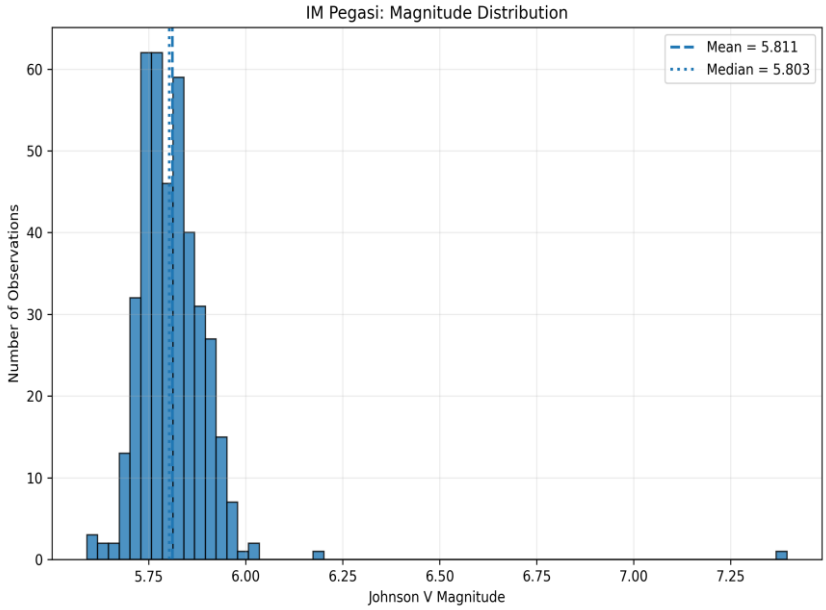


Figure 9. Distribution of the 406 V measurements. The dashed line marks the mean (V = 5.811) and the dotted line the median (V = 5.803). The distribution drops sharply on the bright side near V ≈ 5.68 and has a tail of faint points, including isolated measurements at V ≈ 6.19 and V ≈ 7.38.

3.5 Periodogram of the whole series

The Lomb–Scargle periodogram of the whole series (Figure 10) has its highest peak at 24.9151 d, with a power of 0.118. A separate false-alarm calculation on the same series lists the best period as 24.8603 d with FAP = 2.1×10^{-25} (Table 5). The two values differ by 0.05 d, far less than the resolution of 0.24 d, and we treat them as one peak at P ≈ 24.9 d. At periods shorter than about 20 d the power stays below 0.035 and has no clear peak. This is the noise floor. Between 21 and 28 d the picture changes and a group of narrow peaks rises well above it. The strongest are listed in Table 4. Next to the main peak there are peaks at about 24.4 d (power ≈ 0.09) and at about 23.3 d (≈ 0.088), and others at about 26.2 d (≈ 0.06) and 26.6–26.7 d (≈ 0.073). Further peaks near 31 d and 34 d (≈ 0.04–0.05) are weaker. The weak broad features at 90 d and 97 d (≈ 0.02) are at the end of the period range and we do not interpret them.

The peaks of the group are very narrow, about 0.1–0.2 d wide, because the data cover about seven years. The main peak lies 0.27 d (1.1%) above the orbital period of 24.649 d, which is about one resolution element. The peaks at 23.3 d and 26.6 d lie 1.6–1.7 d on either side of the main peak, in agreement with the 1.7 d expected for yearly aliases, so they are probably not independent signals. The peak at 24.4 d is separated from the main peak by 0.5 d, or about two resolution elements. It lies within 0.1 d of the photometric period of 24.39 ± 0.03 d found by Eaton et al. (1983), but it is lower than the main peak and sits inside the alias pattern, so we do not read it as an independent detection.

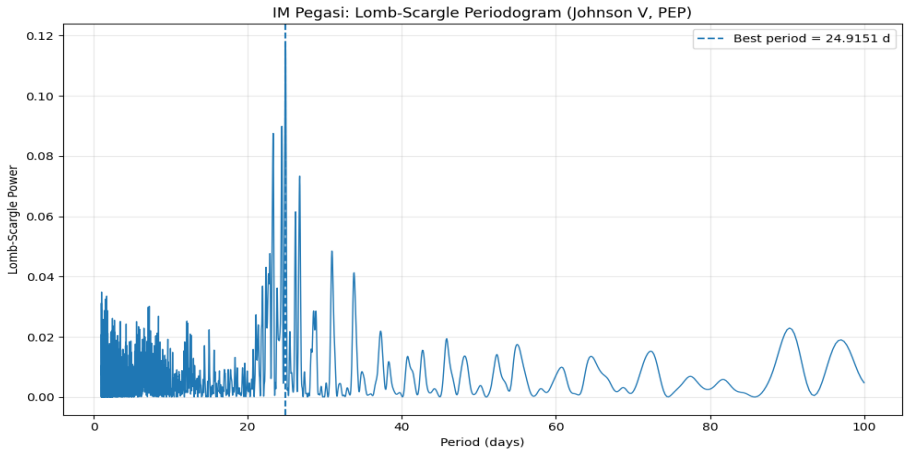


Figure 10. Lomb–Scargle periodogram of the whole series for periods of 1–100 d. The highest peak is at 24.9151 d (power ≈ 0.118; dashed line). A group of narrow peaks, including yearly aliases near 23.3 and 26.6 d, lies between 21 and 28 d, while the power stays below 0.035 at periods shorter than 20 d.

Table 4. The strongest peaks of the periodogram in Figure 10, read from the plot (periods ±0.1 d, powers ±0.005). The orbital period is 24.649 d (Harper 1935).

Period (d)	Power	P − P_orb (d)	Comment
24.92	0.118	+0.27	Highest peak
24.4	0.09	−0.25	Close to 24.39 d (Eaton et al. 1983)
23.3	0.088	−1.35	Yearly alias of the main peak
26.6–26.7	0.073	+2.0	Yearly alias of the main peak
26.2	0.062	+1.6	Alias or window feature
31 and 34	0.04–0.05	—	Weak, not interpreted

3.6 Period search season by season

Table 5 gives the best Lomb–Scargle period of each season. Six of the seven seasons return a period between 23.3 and 26.1 d. Their mean is 24.66 d with a scatter of 1.02 d between seasons (standard error 0.42 d), which is within 0.02 d of the orbital period. The individual uncertainties are large, 1.5–5.0 d, or 6–20% of the period. Each season is therefore consistent with the orbital period (the largest departure, 1.5 d in 2001, is well inside its own uncertainty of 5.0 d), but no single season can tell the orbital period from a photometric period 1% shorter. All six periods have formally very small false-alarm probabilities, from 2×10^{-5} (2002) and 4×10^{-5} (2006) down to 10^{-30} (2001). These say that a periodic signal is present in each season, which agrees with the repeating waves in Figures 2–8, but they do not say how accurate the period is.

The exception is 2005, where the strongest peak is at 0.5047 d with an extremely small FAP. A half-day period is not credible for a K giant whose orbit lasts 24.65 d, and a short window of only about 24 points is exactly where sampling artefacts appear. We regard it as a sampling artefact. The 2005 light curve nevertheless shows two faint phases about 25 d apart (Figure 6 and Table 3), so a repeat of the search with the period range limited to, say, and 5–60 d should recover the expected signal.

Table 5. Lomb–Scargle period search of the whole series and of each season: best period, approximate period uncertainty and false-alarm probability (FAP) of the strongest peak. The whole-series peak in Figure 10 is at 24.9151 d; no valid period uncertainty is available for it, and its resolution is 0.24 d.

Series	Best period (d)	Period error (d)	FAP
Whole series	24.8603	31872	2.1×10^{-25}
2001	26.1094	5.0210	2.4×10^{-30}
2002	23.3239	1.7283	2×10^{-5}
2003	24.3509	1.5233	5.5×10^{-14}
2004	24.8911	2.0160	4.0×10^{-9}
2005	0.5047	0.0001	3.2×10^{-31}
2006	23.8765	3.6176	4.2×10^{-5}
2008	25.4150	3.8507	1.2×10^{-28}

4. Discussion

4.1 Timescale and the orbit

Three independent readings of the data agree on the timescale. The faint and bright phases in the windows recur every 24.7 ± 2.4 d (Table 3), the single-season periodograms average 24.66 ± 1.02 d (Table 5), and the whole-series periodogram peaks at 24.9 d (Figure 10). All three sit on the 24.649 d orbital period. That is what we expect if the star rotates synchronously with its orbit and the spotted regions stay at roughly fixed longitudes. In 2003 and 2001 the repetition is remarkably regular (spacing's 24–26 d), whereas 2004 and 2006 show intervals of 21–30 d. We attach no weight to the differences between seasons. The windows cover only two to five cycles, the sampling is uneven, and the apparent timing of a maximum shifts when spots evolve. Cao et al. (2022) reported active longitudes on IM Peg that changed within five orbital cycles, which would be enough to account for a scatter of a few days.

Eaton et al. (1983) found a photometric period about 1% shorter than the orbital one and explained it as a wave that migrates slowly in orbital phase over about 6.5 years. A shift of 1% amounts to only 0.25 d per cycle. That is comparable to the resolution of the whole series (0.24 d) and far below the uncertainty of any single season. Our whole-series peak lies 0.27 d above the orbital period, not below it, and the peak near 24.4 d is weaker and sits within the alias pattern. We therefore can neither confirm nor refute the migrating wave. A decisive test needs the phase of minimum followed year by year on a fixed ephemeris (Section 4.5).

4.2 Amplitude of the wave

The peak-to-peak size of the modulation in the windows is about 0.2 mag in 2001 and 2002, 0.12 mag in 2003, 0.24 mag in 2004, 0.25 mag in 2005, 0.15 mag in 2006 and 0.16 mag in 2008. The full 2004 season is larger, 0.39 mag. Eaton et al. (1983) found 0.13–0.20 mag over 1978–1981 and Dar et al. (2018) quote up to 0.3 mag, so most of our windows are inside the earlier range and 2004–2005 reach its top edge. The year-to-year changes in amplitude, from 0.12 mag in 2003 to 0.25 mag in 2005, are what one expects if the spot distribution changes, because a more uniform spot belt reduces the modulation and a concentrated

spot group enhances it. The smaller amplitude of 2006 and 2008 alongside the fainter mean could arise from more spots spread over a wider range of longitude. This is speculation, because we have no spot model for these seasons.

4.3 A slow fading after 2005?

The mean V is close to 5.79 in 2001–2005, 5.87 in 2006 and 5.89 in 2008. All of these seasons are fainter than the 1978–1981 range of V = 5.60–5.85 (Eaton et al. 1983) and the maximum brightness of V = 5.63 listed by Dar et al. (2018). One reading is that the star was more heavily spotted in the later seasons, so that more of its disc was darkened. The two-spot models of Dar et al. (2018) show a total spotted area that rose from about 8–10% around 1978–1986 to about 24% in 1996 and fell to about 12% in 2016, so changes of this size are within the range of the star. Our data cover none of those dates, so we cannot test the model directly. A second reading, noted by Dar et al. (2018) from the Doppler images of Marsden et al. (2007), is that a spot near the pole can dim the star without producing rotational modulation. A third possibility is instrumental. A series made up of several observers can drift in zero point, and the thin seasons after 2006 are the most easily shifted. The few measurements of 2009–2011 look fainter still, but they are too sparse to count as evidence. Until observer codes and comparison stars have been checked, a real fading cannot be told apart from an instrumental one.

4.4 Isolated bright points

IM Peg is known to flare. Ramsey and Buzasi (1986) report an ultraviolet flare that brightened emission lines by up to a factor of five, and Cao et al. (2022) identified three flare-like events in their 2015 Hα spectra. Two isolated bright points appear in our windows: V ≈ 5.60 on JD 2452186.7 (Figure 2) and V ≈ 5.63 on JD 2452952.6 (Figure 4). Each is about 0.1 mag above the surrounding points, and each has an error bar of about 0.01 mag or less, so they are not a result of the quoted uncertainty. They are not obviously part of the wave, and we cannot say whether they are small optical flares, measurement errors or short real excursions. The very faint points in the tail of Figure 9, at V ≈ 6.19 and 7.38, need the same check. Both the bright and the faint outliers should be compared with the original observation records.

4.5 Limitations and next steps

Sampling is the main limitation. A season with fewer than ten points cannot define a light curve, and the seasons after 2008 are of that kind. The windows plotted here are also only part of each season. The next steps are as follows.

1. Check duplicates, uncertainties and observer codes, and verify the isolated bright and faint points against the original records.
2. Convert all epochs to one JD convention and compute seasonal means, standard deviations and peak-to-peak ranges with documented quality cuts, so that the possible fading can be tested quantitatively.
3. Repeat the season-by-season period search with a sensible period range (for example 5–60 d) so that the 2005 artefact is removed, and state how the period uncertainties are derived.
4. Fold each season on the orbital ephemeris used by Cao et al. (2022), HJD 2,450,342.905 + 24.64877 E (from Marsden et al. 2005), and follow the phase of minimum from year to year.
5. Only if the change in mean level survives these checks, compare it with the spot-area changes found by Dar et al. (2018).

5. Conclusions

From the Johnson V-band PEP photometry of IM Peg in the AAVSO database for 2001–2008 we conclude the following.

1. In 2001–2004 the star is steady at a mean of V ≈ 5.79 and varies by about 0.12–0.24 mag within each window, reaching 0.39 mag over the whole of 2004.
2. In every well-sampled window the faint and bright phases recur every 22–28 d, 24.7 ± 2.4 d on average, which is consistent with the 24.65 d orbital period.
3. The Lomb–Scargle periodogram of the 406 measurements peaks at about 24.9 d (FAP ~10^{-25}), 0.27 d above the orbital period and within one resolution element (0.24 d). Six single-season periods, 23.3–26.1 d, average 24.66 ± 1.02 d. The 0.5 d period found for 2005 is a sampling artefact. These data cannot tell the orbital period from the 24.39 d photometric period of Eaton et al. (1983).
4. The mean level becomes fainter after 2005, V ≈ 5.87 in 2006 and 5.89 in 2008. This echoes the changing spot coverage of Dar et al. (2018), but the change is about as large as the scatter within a season, and zero-point drift has not been excluded, so it has not been shown to be a real brightness change.
5. Isolated bright points (V ≈ 5.60 in 2001 and V ≈ 5.63 in 2003) and a few very faint points (V ≈ 6.19 and 7.38) need to be checked against the original records.

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