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THE 1991–2012 LIGHT CURVE OF THE OLD NOVA HR LYRAE

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ABSTRACT

The 22 yr light curve of HR Lyr, acquired with a typical cadence of 2–6 days, is examined for periodic and quasi-periodic variations. No persistent periodicities are revealed. Rather, the light curve variations often take the form of nearly linear rises and falls having typical *e*-folding times of about 100 days. Occasional ∼0.6 mag outbursts are also seen, with properties similar to those of small outbursts found in some nova-like cataclysmic variables. When the photometry is formed into yearly averages, a decline of 0.012 ± 0.005 mag yr^{-1} is apparent, consistent with the fading of irradiation-induced $\dot{M}$ following the nova. The equivalent width of Hα is tabulated at three epochs over the interval 1986–2008 in order to compare with a recent result for DK Lac in which Hα was found to be fading 50 yr after the nova. However, our results for such a fading in HR Lyr are inconclusive.

Key words: novae, cataclysmic variables – stars: individual (HR Lyr)

Online-only material: machine-readable table and VO table

1. INTRODUCTION

HR Lyr was a magnitude 6.5 nova in 1919. Although the light curve near maximum light was sparsely observed, the decline from outburst was fairly well covered and showed a rapid ($t_3 \simeq$ 80 days) and smooth decline. Shears & Poyner (2007) have provided a review of the photometric history of HR Lyr, finding that the system has been relatively stable at $V \simeq 16$ ever since occasional post-nova monitoring (initially visual observations) began in 1925. HR Lyr has been the subject of several more recent long-term monitoring programs using CCD detectors. These include the Indiana program of long-term monitoring of selected cataclysmic variables (CVs; for which a preliminary report on HR Lyr was provided by Kafka & Honeycutt 2004), a 5 yr monitoring program by Leibowitz et al. (1995), who reported a periodicity at 64 days, and monitoring by Shears & Poyner (2010), who detected a deep fade of HR Lyr to fainter than $V = 17$ in 2010.

Apart from photometric monitoring the system has not received much attention. Early work showed or described the spectrum as very blue, with neither absorption nor emission lines (Humason 1938; Kraft 1964; Williams 1983). Modern photometry (Bruch 1984) found $B - V = 0.1$–0.3, which is indeed blue, but not unprecedented for nova-like CVs. The colors of nova-like CVs can be substantially affected by interstellar reddening, which is often quite uncertain for individual CVs.

In this paper we combine photometry from the Indiana monitoring program with photometry from the Bunbury Observatory and from the AAVSO to produce a nearly continuous light curve in 1991–2012, which is analyzed for the presence of outbursts, possible periodicities, and long-term trends. We also describe Hα spectroscopy of HR Lyr.

2. DATA ACQUISITION

Most of our HR Lyr photometry was acquired from unattended 0.41 m and 1.25 m telescopes at the Morgan-Monroe Observatory (MMO) of Indiana University. All of the MMO images were in the *V* band, with exposure times of 2–4 minutes. A full description of the facility, the data acquisition process, the data reductions, and the observing programs can be found in Honeycutt et al. (2013). The telescopes employed, the CCD and filters used, and the data reduction procedures varied somewhat over the 22 yr interval 1991–2012, leading us to divide the data into five campaigns, each having common properties such as transformation coefficients, and using separate reductions. The technique of incomplete ensemble photometry (Honeycutt 1992) was used to produce the light curves. This method uses all the field stars found in each exposure (even though the number and identity vary among exposures) to make a least squares solution for the light curve of each object in the field, plus the magnitude by which the constant stars in each exposure differs from that of other exposures. For our relatively inhomogeneous long-term photometry this approach has advantages in that the ensemble comparison stars can vary from exposure to exposure, and a robust estimate of the total error at each point of the light curve of the variable is provided by appealing to the scatter in constant field stars having brightness similar to that of the variable. Secondary standards from Henden & Honeycutt (1997) were used to establish the zeropoint of the MMO photometry.

MMO photometry is not available for much of 2005, 2006, and 2010. During intervals when the MMO data was sparse, the light curve was augmented by the addition of photometry acquired at the Bunbury Observatory, and by AAVSO data. All of the Bunbury and AAVSO data used in this paper are CCD measurements. Most of this non-MMO data is through the *V* filter, but the Bunbury exposures and a portion of the AAVSO data were acquired using a "clear" filter, whose zeropoint was established using *V* secondary standards. Table 1 summarizes the reduction process for the 1422 usable *V*-band exposures from the MMO. The last line of Table 1 is for the AAVSO/Bunbury data.

Table 2 shows a sample of the light curve data. The full version of Table 2 appears only in machine-readable and VO formats.

Spectra of HR Lyr were obtained on four nights between 1993 July 23 (UT) and 1993 August 13. The region ∼5950–6850 Å

Table 1
HR Lyr Photometry by Observing Campaign

Campaign[a]	Tel	CCD	Years	No. Pts[b]	Ens Stars[c]	Mean Err[d]	Sec Stds[e]	Zeropt Err[f]
A	0.41 m	TI 800	90–91	31	142	0.027	12	0.009
B	0.41 m	Tek 512	91–05	924	142	0.027	12	0.009
C	1.25 m	Tek 1024	07–09	175	135	0.023	10	0.008
D	1.25 m	Kodak 1024	10–12	186	134	0.025	12	0.007
E	0.41 m	Kodak 1024	11–12	107	116	0.035	11	0.007
AAVSO			05–11	230				

Notes.
[a] The campaign designation is described more fully in Honeycutt et al. (2013).
[b] Number of usable exposures.
[c] Number of ensemble field stars in the photometric solution.
[d] Mean error of the variable from the incomplete ensemble solution.
[e] Number of secondary standards used (from Henden & Honeycutt 1997).
[f] Error in the light curve zeropoint using the secondary standards.

Table 2
HR Lyr Light Curve Data

JD	V (mag)	Error	Campaign
2448411.73536	15.631	0.021	A
2448417.83464	16.018	0.059	A
2448444.72907	15.687	0.018	A
2448469.63813	15.831	0.021	A
2448470.74176	15.885	0.019	A
. . .	. . .	. . .	. . .
. . .	. . .	. . .	. . .
. . .	. . .	. . .	. . .
2455893.261	16.045	. . .	AAVSO V from C
2455896.50723	16.027	0.024	E
2455897.49838	16.021	0.019	D
2455899.367	16.17	. . .	AAVSO V from C
. . .	. . .	. . .	. . .
. . .	. . .	. . .	. . .

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal. A portion is shown here for guidance regarding its form and content.)

was covered at ∼3 Å resolution using the GoldCam spectrograph with grating 26 (600 lines mm^{-1}) on the KPNO[6] 2.1 m telescope. These spectra were acquired under the KPNO Queue Program. Spectra of HR Lyr were also obtained on two nights, 2008 June 7 and 2008 June 8, using nearly the same equipment and setup. Reductions used standard IRAF[7] procedures.

3. LIGHT CURVE DESCRIPTION

Figure 1 shows the full 1991–2012 light curve of HR Lyr. Over this 22 yr interval the system is seen to mostly vary over the range $V = 15.2$–16.3, with occasional excursions to $V \simeq 17$. Figures 2–9 show the yearly light curves on an expanded scale, where we have distinguished the data points as originating from either V exposures from the MMO, V exposures from the AAVSO, or "clear" exposures from Bunbury Observatory and the AAVSO. In overlapping intervals the agreement of the three data sources seems generally satisfactory.

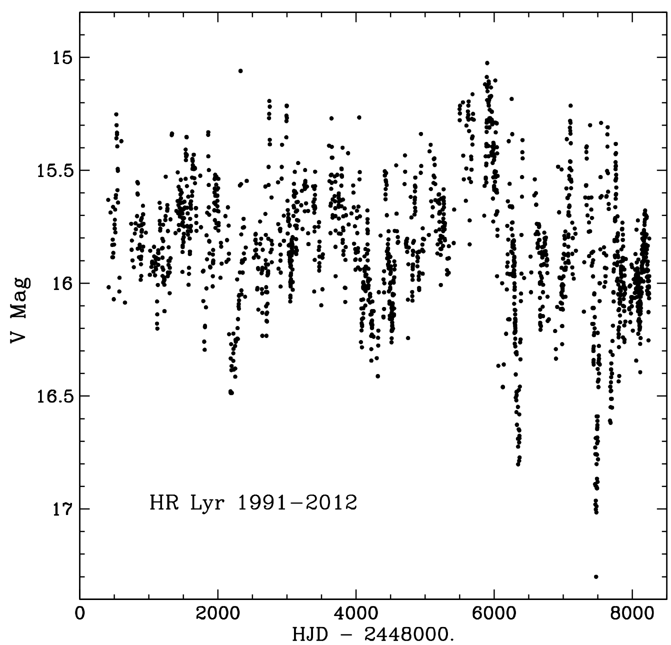

Figure 1. Full light curve of HR Lyr from 1991 June 4 to 2012 November 14 (UT). Error bars have been omitted for clarity.

These yearly light curves display a variety of features, including occasional outburst-like events having typical amplitudes of 0.6 mag and typical FWHM of 15–40 days. Examples can been seen in Figures 3 and 4. Depending on the criteria adopted, as many as 6–8 outbursts appear in Figures 2–9. These outbursts appear to be relatively symmetrical, with rise times being similar to decline times. Also visible in Figures 2–9 are linear (on a magnitude scale) rising and declining light curve segments, which we will refer to as "ramps." These ramps can last 100 days or more, being terminated by either a data gap or by an abrupt change in direction. This gives the light curve at times a sawtooth appearance, as opposed to a smooth oscillation. The faster ramps sometimes overlap in appearance with the rising and falling portions of the slower outbursts.

4. ANALYSIS AND DISCUSSION

This section discusses the appearance of a number of features in the long-term light curve of HR Lyr, including long nearly straight-line "ramps," possible periodicities, and slow fading of the system brightness over 22 yr. Also, we present our occasional

[6] Kitt Peak National Observatory is a division of the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
[7] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

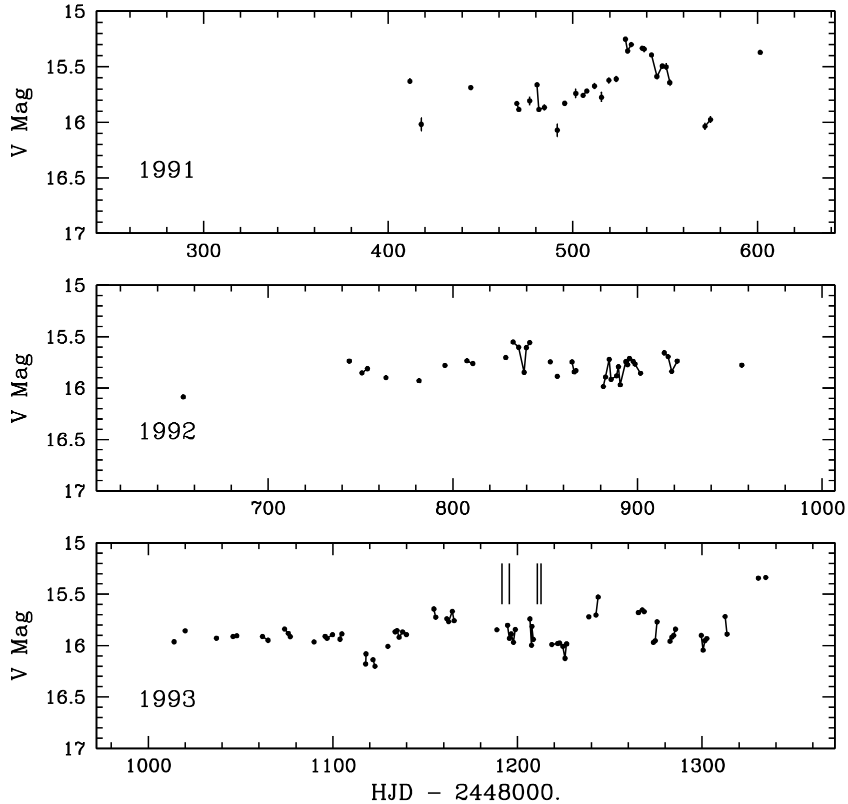

Figure 2. Light curves of HR Lyr for three seasons. Points separated by less than 3.5 days are connected by straight lines. Error bars are shown but are often too small to be seen. The four vertical bars in 1993 mark four nights in which spectra were acquired. Data in Figures 2–5 are from the Morgan-Monroe Observatory.

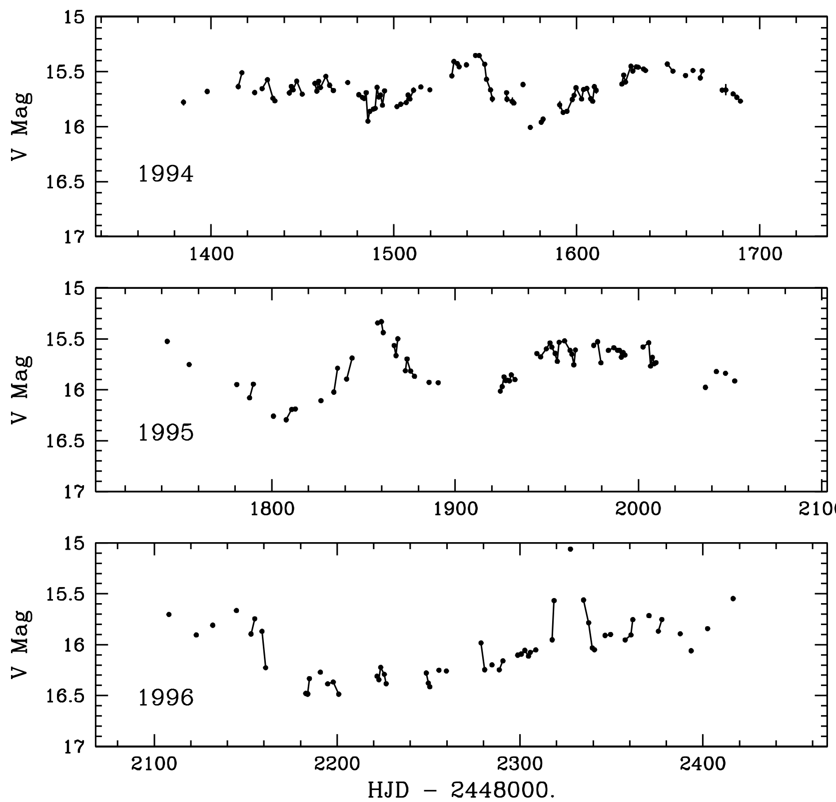

Figure 3. Similar to Figure 2, but for three additional seasons.

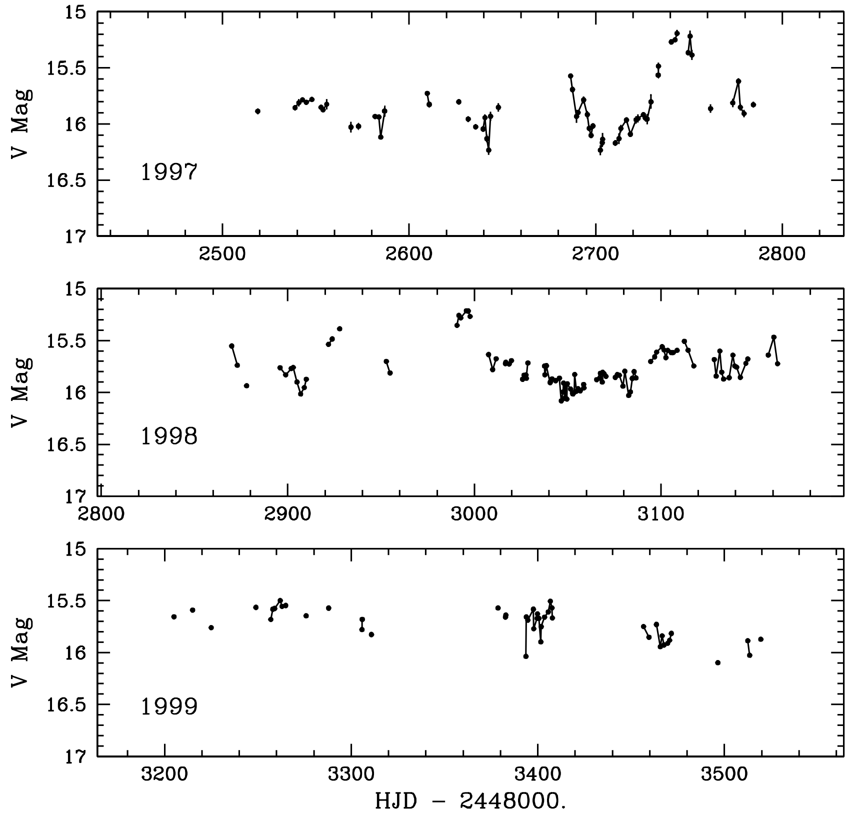

Figure 4. Similar to Figure 2, but for three additional seasons.

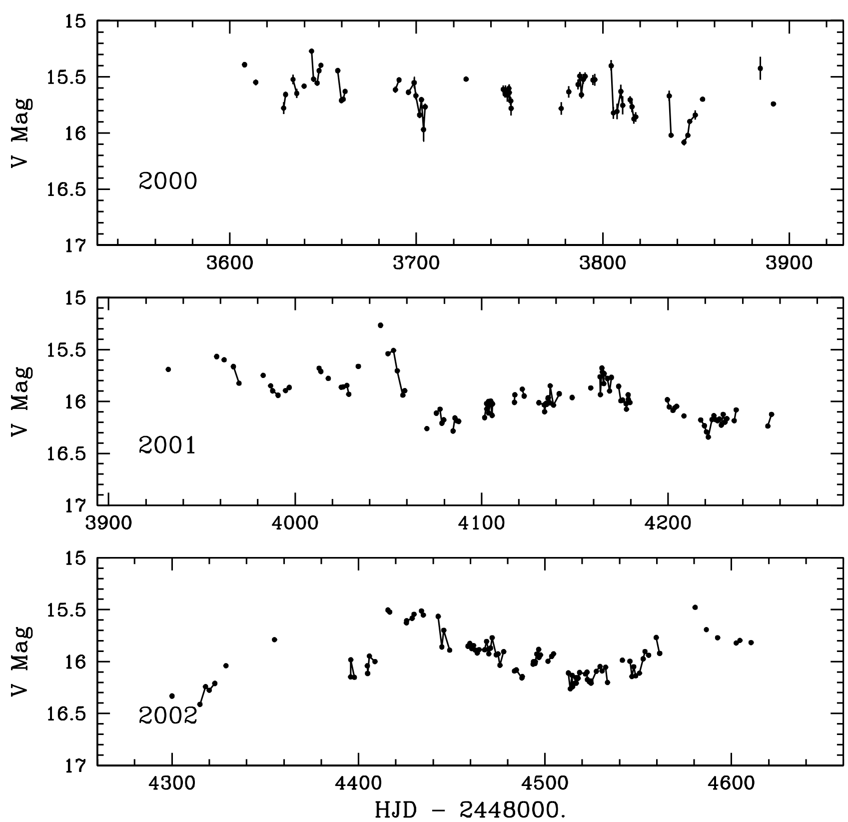

Figure 5. Similar to Figure 2, but for three additional seasons.

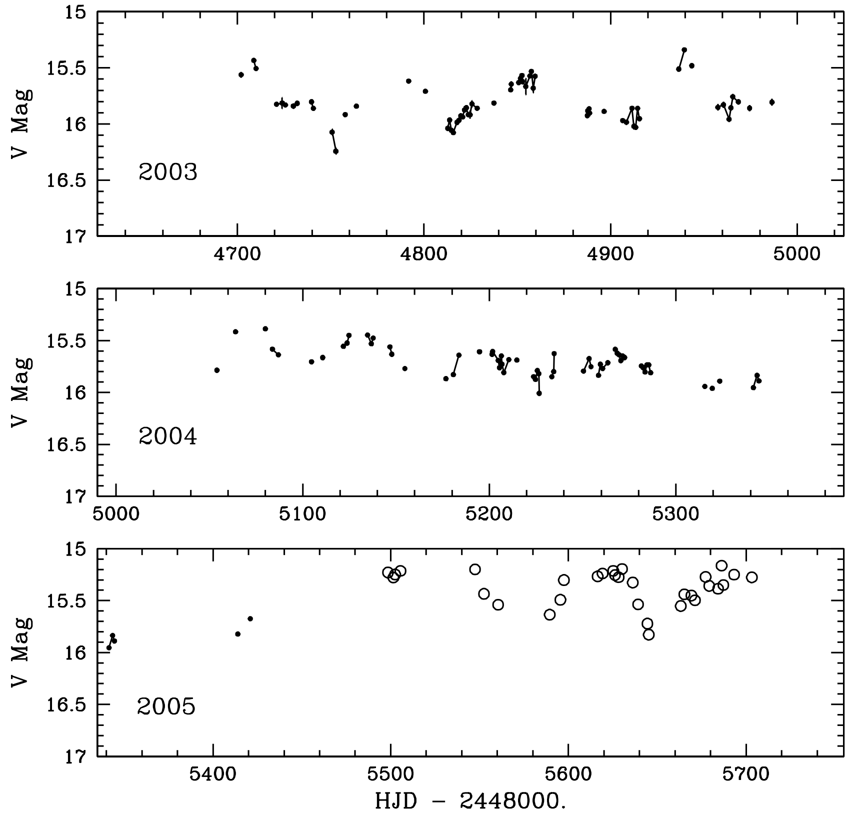

Figure 6. Light curves for three additional seasons. In Figures 6–8 solid points are from the Morgan-Monroe Observatory (MMO) and crosses are *V* CCD magnitudes from the AAVSO. Open circles are Clear filter data from the AAVSO and from Bunbury Observatory, using a *V*-bandpass zeropoint. MMO data (only) are connected by straight lines if the separation is <3.5 days.

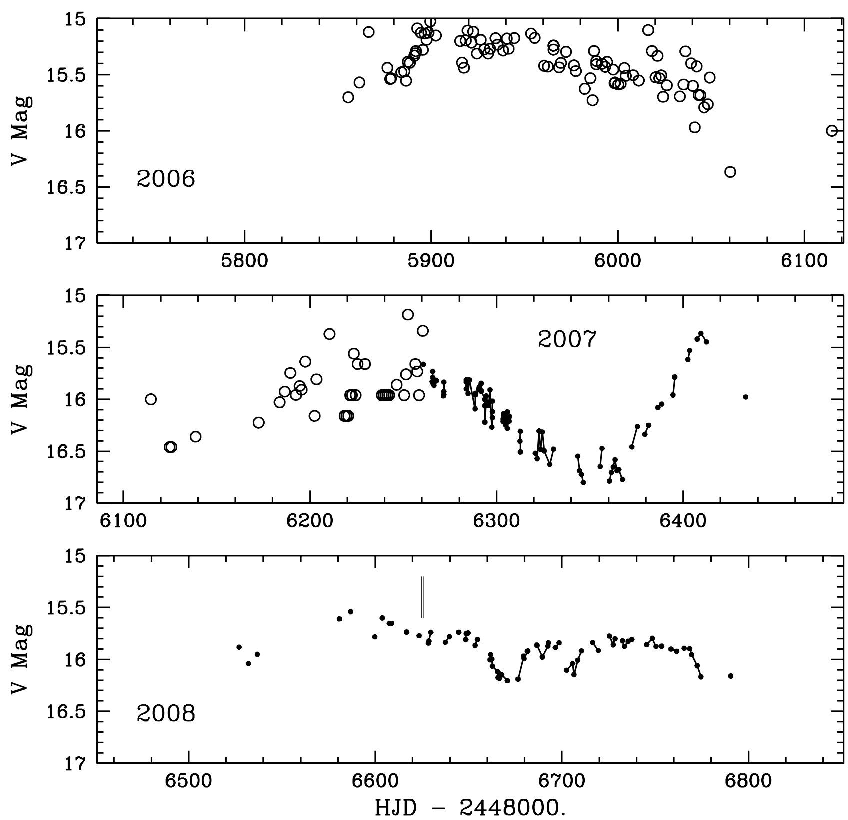

Figure 7. Similar to Figure 6, but for three additional seasons. The two (unresolved) vertical bars in 2008 mark nights in which spectra were acquired.

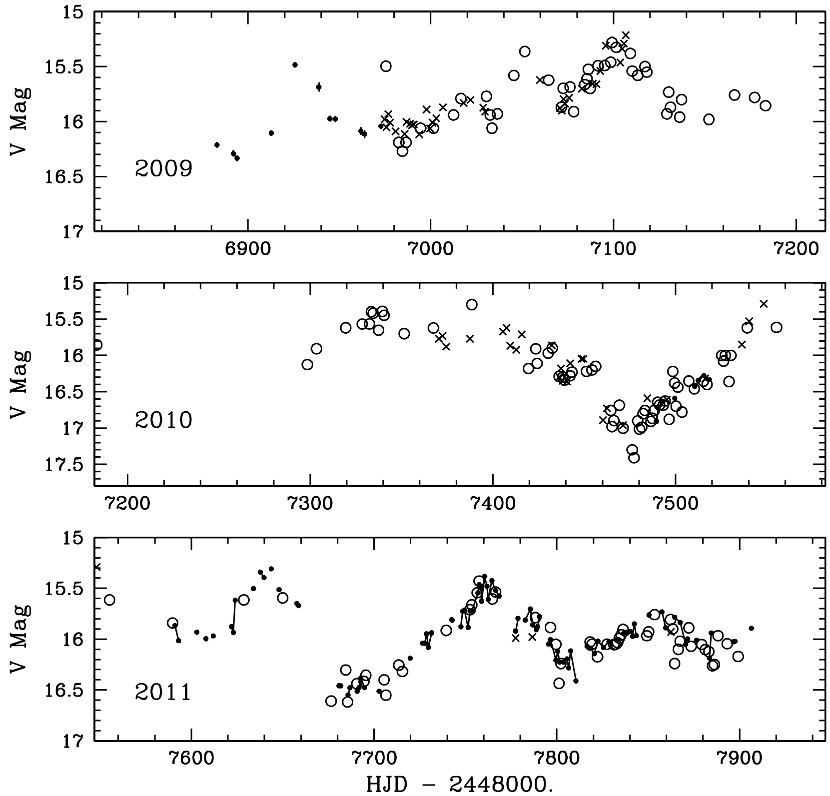

Figure 8. Similar to Figure 6, but for three additional seasons.

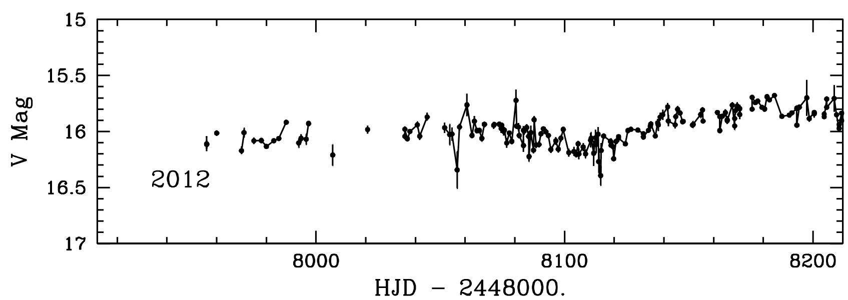

Figure 9. Similar to Figure 6, but for one additional season.

Hα spectra of HR Lyr, and discuss the spectral changes that are found.

4.1. The Ramps

Many of the features in Figures 2–9 consist of rising and falling segments which are nearly straight lines. Some of these linear segments (ramps) could be considered portions of near-sinusoidal variations, but the dominant shape appears to be segments with little curvature. We measured the *e*-folding times τ (calculated as 1.086/(mag day^{-1})) of 28 ramps, shown in Figure 10. The *e*-folding times have a range ∼30–350 days with a typical value near 100 days. There is no apparent systematic change with time, nor is there any systematic difference between the speeds of the rises and the falls.

4.2. Periodicities or Quasi-periodicities

Leibowitz et al. (1995) acquired photometry of HR Lyr over the interval 1991–1995 using the Whole Earth Telescope, and discussed possible periodicities in their data set. For most years continuous exposures were taken for a few hours during each night of the project. These sequences were used to study variations on timescales of minutes/hours and they reported a significant periodogram peak near 0.1 days. They also studied the night-to-night variations, finding a periodicity at 63.8 days. Leibowitz et al. (1995) concluded that "the appearance of the 63.8 day periodicity in the light curve of HR Lyr is statistically highly significant..." The 22 yr length of our data span, along with a typical cadence of 2–6 days, should provide good sensitivity to a 63.8 day period. In the top portion of Figure 11 we have plotted the periodogram of our full data set over the relevant range of 50–300 days, finding no peak at or near 63.8 days.

The first 5 yr of our HR Lyr photometry is coincident with the 5 yr interval studied by Leibowitz et al. (1995). Therefore we produced the lower periodogram in Figure 11 using just our 1991–1995 data. Again we find no peak at or near 63.8 days.

The Leibowitz et al. data set and the MMO data set have overlapping time intervals but have different cadences that might help explain these conflicting results. The Leibotitz data set is rich, having 2300 points. But the number of separate nights (which is relevant to the detection of a 63.8 day signal) is not provided. A very rough estimate from their figures is 75–100 nights. Over that same 5 yr interval we have 257 points on 254 different nights from the MMO data.

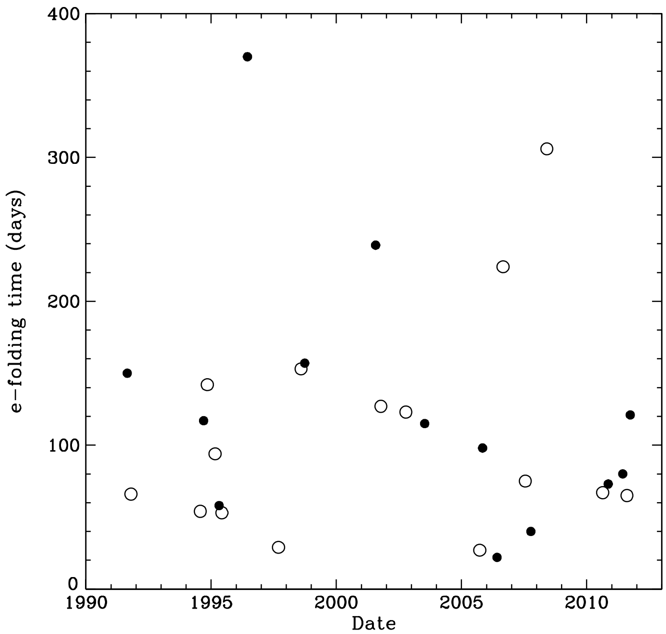

Figure 10. *e*-folding times of the linear ramps in the HR Lyr light curve plotted vs. the date. Solid points are rising ramps while open circles are declining ramps; see the text for details.

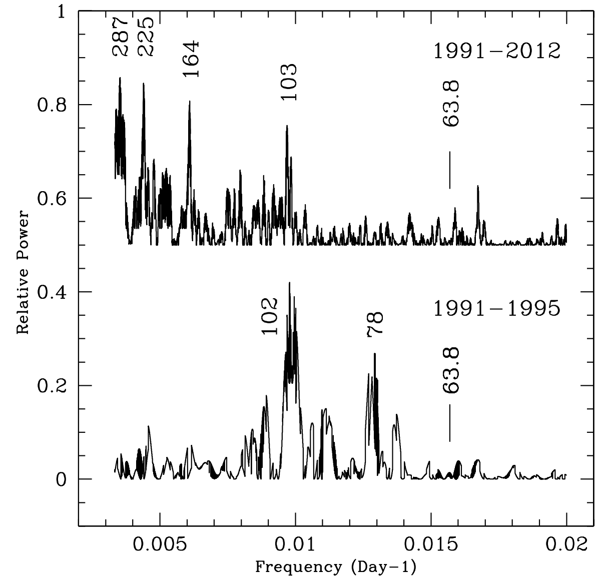

Figure 11. Top: periodogram of our HR Lyr light curve in 1991–2012 over the period range 50–300 days. The four highest peaks are labeled with the days corresponding to the peak. Bottom: periodogram of the HR Lyr light curve 1991–1995. The amplitude of this periodogram has been multiplied by five to enhance the features. The two major peaks at 102 and 78 days are labeled, but there is considerable power spread over the range 70–130 days. The interval 1991–1995 was chosen to coincide with the observing interval used by Leibowitz et al. (1995), who reported a significant oscillation at 63.8 days; this location is also marked on the plots.

Our inability to confirm the 63.8 day period reported by Leibowitz et al. (1995) emphasizes the long-recognized difficulty in providing reliable estimates of the significance of periodogram peaks. In fact, the comparison is so discouraging that we think it is unlikely that any of the periodogram peaks in our Figure 11 correspond to persistent, reproducible periodicities, a conclusion reinforced by the lack of significant coherent variation when the data is folded on the various periodogram peaks. Perhaps the safest description of the weeks/months variability in HR Lyr is that the distribution of the variability power ranges widely and is often concentrated between 60 and 300 days, with the peaks themselves changing on yearly timescales.

Old nova and nova-like CVs often have significant quasi-periodic photometric activity on timescales $\gtrsim$25 days. Such variations have been studied in connection with possible chromospheric activity cycles on the secondary star in the range 3–15 yr (e.g., Warner 1988; Bianchini 1990). However, shorter variations in the range 30–50 days have also been reported for some old novae (e.g., Della Valle & Rosino 1987; Hoard et al. 2000). In HR Lyr the quasi-periodic variations occur mostly in the range 60–300 days, and mostly take the form of sawtoothed-like ramps in the light curve. These timescales are near the thermal/viscous timescales for CV accretion disks. In general, high-state disks in old novae and nova-like CVs are expected to be stable against accretion disk instabilities. However, in nova-like CVs this timescale sometimes shows up in the characteristic recurrence interval for stunted outbursts. Stunted outbursts (Honeycutt et al. 1998; Honeycutt 2001) have amplitudes $\sim$0.5–1.0 mag at mostly irregular recurrence intervals, and may arise in disks for which the inner disk does not participate in a dwarf-nova-like eruption. Small outbursts that resemble stunted outbursts are found in our HR Lyr light curve, where they have amplitudes of 0.4–0.9 mag and occur at intervals of $\sim$1–4 yr.

4.3. Long-term Fading

The initial fall in $\dot{M}$ (and therefore in system brightness) following the nova eruption is thought to be due to declining irradiation of the donor star as the white dwarf cools following the nova eruption (Duerbeck 1992, and references therein). Kovetz et al. (1988) modeled the decrease in $\dot{M}$ at times $\sim$50 yr past nova outburst, leading to a predicted fading rate of $\sim$0.007 mag yr^{-1} due to the gradual reduction in irradiation-induced $\dot{M}$ from the secondary star. Vogt (1990) found from a sample of 97 novae a value of 0.021 ± 0.006 mag yr^{-1}. Duerbeck (1992) used fewer old novae (only 13) but with higher quality data, finding a mean rate of 0.010 ± 0.003 mag yr^{-1} at an average time of 43 yr past the nova outburst. These observed rates are statistical results and the decline rates of individual systems can deviate substantially, even appearing to brighten. The Duerbeck (1992) sample includes HR Lyr, for which a value of 0.010 ± 0.007 mag yr^{-1} is provided, which is just at the mean for the Duerbeck sample.

We have used our new 1991–2012 photometry of HR Lyr to measure the decline rate. This is a shorter baseline than earlier studies, but the data quality is superior. We calculated the mean magnitude for each calendar year using the data shown in Figure 1. The results are shown in Figure 12. The two high outlying data points for years 2005 and 2006 are uniquely dominated by AAVSO/Bunbury data (see Figures 6 and 7). Despite repeated attempts to improve the zeropoints for this data, the apparent 0.5 mag difference compared to the MMO data for adjacent years has persisted (in spite of the fact that overlapping photometry of MMO with AAVSO/Bunbury data in other years is reasonably consistent). Faced with this dilemma we have omitted the two years 2005 and 2006 from the fit. This fit, shown as the straight line in Figure 12, has a slope of 0.012 ± 0.005 mag yr^{-1}, which agrees well with the Duerbeck value. Considering the errors in the two measurements, the strength of this agreement must be partly fortuitous.

A similar procedure was followed using MMO data for DK Lac = Nova Lac 1950 (Honeycutt et al. 2011), finding

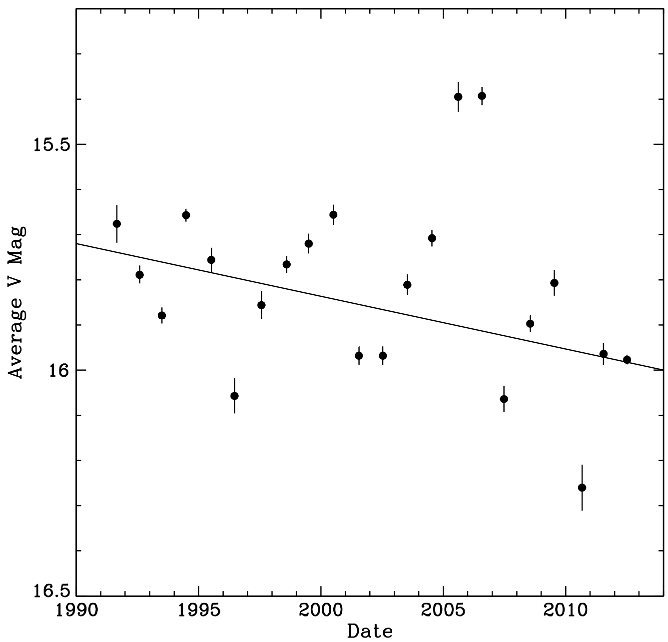

Figure 12. Average magnitude of HR Lyr by calendar year, which is also by observing season. Error bars are standard deviation of the mean. The fitted line, which excludes the two high points for years 2005 and 2006 (see the text for details) has a slope of 0.012 mag per year.

Table 3
Hα Emission Line EWs in HR Lyr

UT Date	Source	EW (Å)
1986	Shara[a]	8
1993 Jul/Aug	KPNO 2.1 m	5.4 ± 0.3
2008 Jul	KPNO 2.1 m	6.5 ± 0.9

Note. [a] Quoted in Warner (1987), with reference to M. Shara (1986, private communication).

0.011 ± 0.002 mag yr^{-1} when the prominent VY Scl-type low state is ignored. Overall it appears that the use of ∼20 yr of MMO data can be a useful method for augmenting earlier studies of the decline rates of old novae, a method which effectively trades improved photometric accuracy for length of baseline.

4.4. HR Lyr Spectra

Might there be spectral changes in old novae that also trace the progress of the system toward a post-nova state? Such an effect has been suggested for DK Lac (Honeycutt et al. 2011) in which it was found that ∼50 yr following this 1950 nova, the equivalent width (EW) of the Hα emission line was falling by 0.42 ± 0.04 Å yr^{-1}. This result is based on only five data points in 1991–2008, but the relationship has surprisingly little scatter. Figure 13 shows the Hα profile of HR Lyr in 1993 and in 2008. It is composed of a sharp central peak having a FWHM of ∼10 Å, plus a broad shallow base with typical FWHM of ∼40 Å. In the 1993 spectra no changes were visible from night to night, so all four spectra were combined. However the line profile changed between the two adjacent 2008 nights, so the means for the two nights are plotted separately. The presence of a sharp central peak alongside a broader base is not common among old novae, but is similar to the emission line profile described for the old nova DQ Her (Bianchini et al. 2004).

Table 3 lists the EW of Hα in HR Lyr at three epochs in 1986–2008, where we have added a 1986 point from Shara.

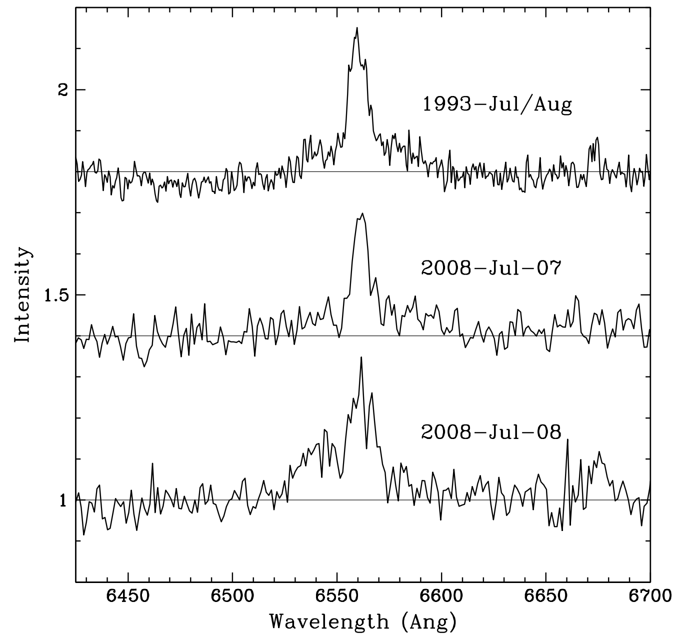

Figure 13. Top: a median-combined Hα profile in HR Lyr from four spectra over four nights in 1993. The continuum has been normalized to unity. Middle: an average of two spectra obtained during a single night in 2008. Bottom: an average of two spectra on the night following the middle spectrum. The upper two spectra have been offset by 0.4 and 0.8 intensity units to avoid overlap.

Unfortunately no conclusive results regarding the long-term behavior of the EW of the Hα line in HR Lyr can be drawn from the data in Table 3.

5. SUMMARY AND CONCLUSIONS

The long-term behavior of HR Lyr displays the following characteristics.

1. The most conspicuous photometric variation consists of linear rising and fading ramps having typical *e*-folding times of ∼100 days, typical full amplitudes 0.5–1.5 mag, and typical recurrence intervals of 175 days. There are no systematic differences in the rising and the falling ramps. The ramps seem to be present about half the time we observed but sometimes disappear into less repeatable light curve variations of smaller amplitude. Because these ramps constitute the largest portion of the variability, it seems likely that they are responsible for most of periodgram peaks that come and go in the range 60–300 days.
2. Small 0.4–0.9 mag outbursts occasionally appear in the light curve.
3. The periodogram peaks change from year to year and do not represent persistent periodicities. We find no evidence of the previously reported periodic/quasi-periodic variation at 63.8 days.
4. During the interval 1991–2012 the average HR Lyr magnitude declined by 0.012 mag yr^{-1}, consistent with earlier results.
5. We find no convincing evidence for a decline in the Hα EW over the interval 1986–2008.

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