Publications of the Astronomical Society of the Pacific, **112**:363–366, 2000 March

Long-Term *VRI* Photometry of ρ Cassiopeiae

John R. Percy and David L. Kolin
Erindale Campus, and Department of Astronomy, University of Toronto, Mississauga, ON L5L 1C6, Canada; jpercy@erin.utoronto.ca
and
Gregory W. Henry
Center of Excellence in Information Systems, Tennessee State University, Nashville, TN 37203-3401; henry@schwab.tsuniv.edu

Received 1999 November 17; accepted 1999 December 15

ABSTRACT. We report over 5700 days (15 years) of *VRI* photometry of the yellow hypergiant variable star ρ Cassiopeiae. The $V-I$ color curve is generally in phase with the V light curve on timescales of a few hundred days, but there is a 4000 day variation in $V-I$ which is absent from the light curve. The approximate ratio of $\Delta(V-I)/\Delta V$ is 0.46. The most conspicuous period in the light curve, in the autocorrelation diagram, and in the power spectrum is about 820 days. Less significant periods of 380, 510, and 645 days also appear in the power spectrum, and there are many subcycles in the light curve with lengths of 200–500 days. Since the most recent comprehensive analysis of the light curve of ρ Cas found a dominant period of 300 days, we conclude that the behavior of the star is quite variable with time.

1. INTRODUCTION

The yellow hypergiant variable ρ Cassiopeiae (HR 9045, HD 224014) is one of the most luminous stars in the Galaxy. Its variability was discovered by L. D. Wells in 1900 (Pickering 1901); since then, the variability has been monitored visually, photographically, and, more recently, photoelectrically. The star appears to undergo irregular low-level pulsational variability, on which are superimposed shell-ejection episodes (most recently in 1985/86), which are detected both photometrically and spectroscopically. The spectral type of the star varies from F through G to M during a deep photometric minimum in 1946/47. The most recent comprehensive review and analysis of its photometric variability was by Zsoldos & Percy (1991). The spectroscopic variability has been discussed by Sheffer & Lambert (1986) and by Lobel et al. (1994, 1998). Israelian, Lobel, & Schmidt (1999) have determined the effective temperature of the star and have pointed out that ρ Cas is approaching the "yellow evolutionary void"; see the excellent recent review by de Jager (1998) for a discussion of this and other aspects of ρ Cas and related stars.

Zsoldos & Percy (1991) analyzed photometric observations between 1963 and 1989 (though with some gaps); they found at least one conspicuous period—299 days—which was apparently constant since 1963. The effect of the shell-ejection episodes on the light curve—especially one in 1985/86—made it difficult to identify other periods and assess their significance. Previous estimates of the period ranged from 250 to 483 days from photometry, to 520 days from spectroscopy (Zsoldos & Percy 1991). We note that, although 299 days was the highest peak in Zsoldos & Percy's (1991) power spectrum, there was significant power at longer periods.

2. DATA AND METHODS

Our photometric data come from two sources. We acquired 1598 differential group observations through Johnson *VRI* filters between 1986 and 1999 with the Fairborn-10 (T2) 0.25 m automatic photoelectric telescope (APT) located at Fairborn Observatory in southern Arizona.[1] This telescope uses an uncooled photodiode detector to make group observations in the sequence K, sky, C, V, C, V, C, V, C, sky, K, where K is the check star HR 9020 (HD 223421, F2 IV), C is the comparison star HR 9010 (HD 223173, K3 IIb), and V is ρ Cas. Three V − C and two K − C differential magnitudes are calculated and averaged together to create group means. These group means are then corrected for differential extinction (determined nightly since 1995), transformed to the Johnson system with yearly mean transformation coefficients, and treated as single observations thereafter. External precision of the group means, based on standard deviations for pairs of

---

[1] The APT data are available from G. W. Henry. Further details on the APT and its operation can be found in Henry (1995a, 1995b) and on the Web at http://schwab.tsuniv.edu/.

constant stars, averages 0.010 mag on good nights. Since the APT is programmed to acquire data anytime it can find stars, observations taken in nonphotometric conditions are automatically removed from the data set if the standard deviation of the group-mean differential magnitude exceeds 0.02 mag. The few poor observations that escape this "cloud-filtering" process are removed by inspection of the light curves. The first 2 years of observations are poorly calibrated and tend to show an offset relative to the rest of the data. Therefore, we use these early data only for determining times of maximum and minimum brightness. The check minus comparison star differential magnitudes demonstrate that both HR 9020 and HR 9010 are constant to 0.017 mag.

Additional Johnson V data was obtained from the American Association of Variable Star Observers (AAVSO) photoelectric photometry program (Landis, Mattei, & Percy 1992; H. J. Landis 1999, private communication, data from the AAVSO photoelectric photometry archive).[2] The data are also differential, and are corrected for differential extinction, and transformed to the Johnson system using the catalog $B-V$ color of the star, assuming it to be constant. The precision of the data is typically 0.01 mag. The same comparison star was used, but HR 9008 (HD 223165, K1 III) was used as the check star. The observers, and the number of observations provided by each, are as follows: Ted Beresky (61), Jack Crast (71), David Curott (52), Frank Dempsey (17), Sergio Dallaporta (93), Susan D'Amato (5), Ales Dolzan (3), George Fortier (59), Robert Johnsson (2), George Kohl (46), Phil Kuebler (1), Gene Lopata (2), Kenneth Luedeke (47), Howard Landis (29), Thomas Langhans (16), Russell Milton (44), Phil Manker (12), Donald Pray (36), Harry Powell (1), Donald Shannon (4), Lee Snyder (1), Hans Sorensen (10), Robert Schmidt (4), Nick Stoikidis (5), David B. Williams (7), Jim Wood (6), and Thomas Walker (3).

The two V data sets were merged for period analysis. No offset was noted between the two data sets. The two data sets are complementary; note for instance that the AAVSO measurements fill the gaps in the APT data caused by the Arizona monsoon season.

3. RESULTS

3.1. Light and Color Curves

The merged APT plus AAVSO PEP V light curve and APT $V-I$ color curve are shown in Figure 1. The coverage is almost complete for over 4500 days. At the beginning of the coverage, one can see the large cycle associated with the shell ejection in 1985/86, discussed by Zsoldos & Percy (1991), followed by four declining cycles of about 400 days each. In this much longer data set, one sees five longer cycles with an average length of 830 days.

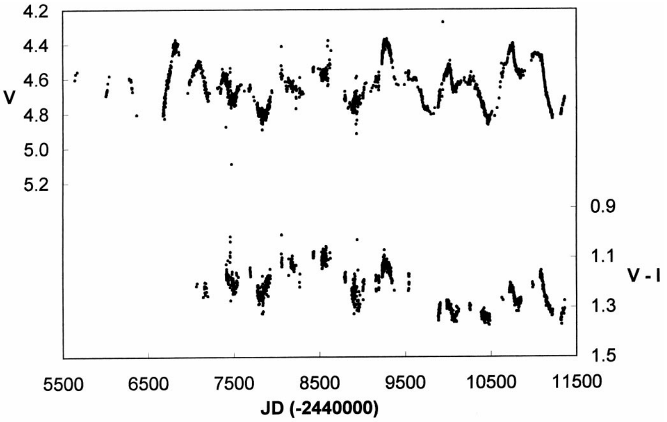

FIG. 1.—Long-term V-magnitude and $V-I$ color curves for ρ Cas, based on APT and AAVSO photometry. There are conspicuous variations on a timescale of 800 days, but there are also variations on shorter timescales.

3.2. Times of Maximum and Minimum Brightness

The following Julian Dates (less 2,400,000) of maximum and minimum were determined graphically, from the light curve: maxima: 46,186, 46,846, 47,112, 47,400, 47,620, 48,058, 48,636, 49,006, 49,293, 49,544, 50,013, 50,320, 50,770, 51,068; minima: 46,542, 46,940, 47,280, 47,524, 47,836, 48,322, 48922, 49,096, 49,460, 49,818, 50,080, 50,487, 50,894, 51,260.

3.3. Period Analysis of the Light Curves

The power spectrum of the merged V-magnitude data was determined using the Period98 program (Sperl 1998).[3] The highest peak was at 821 days (Fig. 2), but there were additional peaks at shorter periods (382, 512, and 645 days), consistent with the light curve in Figure 1. Autocorrelation analysis (Percy, Ralli, & Sen 1993) was carried out using a program written by M. Szczesny (Percy, Attard, & Szczesny 1996); there were minima (Fig. 3) at Δt of 800, 1500, and 2500 days, suggesting a timescale of about 800 days. Cycle lengths were determined from the V light curve in Figure 1; a histogram of cycle lengths shows many values in the range 200–500 days, but these would probably be considered "subcycles" of the more conspicuous 800 day cycles shown in Figure 1.

---

[2] The AAVSO data is available from the Director, AAVSO, 25 Birch Street, Cambridge, MA 02138-1205; e-mail: aavso@aavso.org.

[3] Period98 is made publicly available at the Delta Scuti Network Web site (http://dsn.astro.univie.ac.at/~period98).

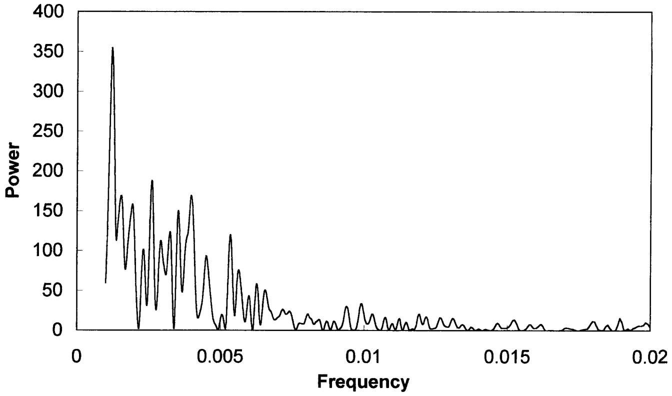

FIG. 2.—Power spectrum of the measurements shown in Fig. 1 (but with the few outliers removed). The highest peak is at a period of 821 days, but there are additional peaks at shorter periods.

3.4. Light and Color Curves: Amplitude and Phase Relations

The $V-I$ data are not as complete as the V data, but it can be seen from Figure 1 that the two curves tend to be in phase. This is true in general, but not in detail; there is "fine structure" in one curve which is not present in the other, and there is a 4000 day variation in $V-I$ which is not apparent in the light curve. The ratio of $\Delta(V-I)/\Delta V$ is about 0.46. This is similar to the ratio which is found in Cepheid variables, which are radial pulsators. Zsoldos & Percy (1991) found that the $B-V$ color curve tended to be in phase with the V light curve.

3.5. Ephemeris and Period Changes

Zsoldos & Percy (1991) suggested that the times of maximum brightness could be fit by the equation $t(\max) = 2{,}438{,}159.73 + 299.01E$. This equation fits our times of maxima in the region of overlap between the two data sets (epochs 27–31). Thereafter, the $O-C$ values are 50–100 days or more, which suggests that the star no longer follows this ephemeris.

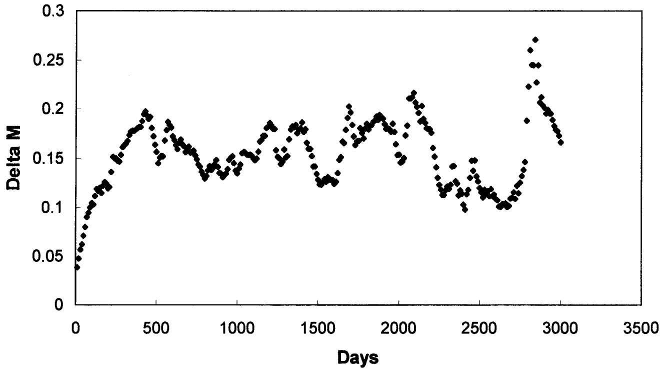

FIG. 3.—Autocorrelation diagram of the measurements shown in Fig. 1 (but with the few outliers removed). There are minima at about 800–1000, 1500, and 2500 days, which suggests a timescale of 800 days, but the complexity of the diagram suggests that additional timescales are present.

4. DISCUSSION

Sheffer & Lambert (1986), on the basis of several years of spectroscopic observations, conclude that ρ Cas is undergoing radial pulsation with a dominant period of 500 days. Lobel et al. (1994) argue, also on the basis of spectroscopic observations, that this star was pulsating nonradially—at least in 1970; this conclusion is partly based on an application of the Baade-Wesselink test. Sheffer & Lambert (1986) note that the period of 500 days is longer than the radial fundamental period predicted by the Cepheid period-luminosity-color relation. It is not clear whether an extreme object like ρ Cas, which is on the borderline of dynamical stability, can be compared with Cepheids. Similarly, we do not attempt to calculate an observed pulsation constant for this star, even though de Jager (1998) gives estimates of its mass and radius, since it is not clear whether it is possible to calculate a theoretical pulsation constant (and hence deduce the pulsation mode) for such an extreme, unstable star. De Jager (1998), in his excellent recent review, suggests that ρ Cas may be pulsating in a complex mixture of pressure and gravity modes.

Since the analysis of the 1963–1989 data revealed a conspicuous period of 299 days (Zsoldos & Percy 1991), and the present analysis of the 1985–1999 data reveals an equally conspicuous period of 820 days, then either the behavior of the star is changing with time or the behavior is irregular in a way which produces different results for different subsets of the data. The first of these possibilities is not out of the question, given the evolutionary status of ρ Cas (de Jager 1998).

5. CONCLUSIONS

On the basis of over 15 years of *VRI* photometry, we have confirmed that the yellow hypergiant ρ Cas varies by up to a magnitude (but more typically by half a magnitude) in V. There is no strict period, but there are several cycles which are approximately 800 days long, as well as variations on timescales of 200–500 days. It also varies in $V-I$ color: there are variations on a timescale of 4000 days, and also variations which are approximately in phase with the variations in V. These results, along with recent spectroscopic results, suggest that this star is pulsating in a complex mixture of radial and nonradial modes, on which are superimposed the effects of occasional shell ejections. To quote Israelian et al. (1999): "monitoring of stars approaching the (yellow evolutionary) void will help to understand the nature of the instabilities and the hydrodynamics of unstable atmospheres, and finally to answer the most important question of whether or not these stars can pass (through) the void."

We are grateful to Lou Boyd at Fairborn Observatory for his continuing operation of the Fairborn-10 APT, and to Irwin Shapiro and Sallie Baliunas for their support of the APT when it was located on Mount Hopkins. Astronomy with automated telescopes at Tennessee State University (TSU) has been supported by the National Aeronautics and Space Administration, most recently through NASA grants NCC5-96 and NCC5-228, which funds TSU's Center for Automated Space Science, and the National Science Foundation, most recently through NSF grant HRD-9706268, which funds TSU's Center for Systems Science Research. David Kolin was a participant in the Summer Career Placement Program of the Government of Canada. We thank the AAVSO photoelectric observers, and the archivist Howard J. Landis, for their essential role in this project. John Percy acknowledges, with thanks, a research grant from the Natural Sciences and Engineering Research Council of Canada. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

REFERENCES

de Jager, C. 1998, A&A Rev., 8, 145

Henry, G. W. 1995a, in ASP Conf. Ser. 79, Robotic Telescopes: Current Capabilities, Present Developments, and Future Prospects for Automated Astronomy, ed. G. W. Henry & J. A. Eaton (San Francisco: ASP), 37

———. 1995b, in ASP Conf. Ser. 79, Robotic Telescopes: Current Capabilities, Present Developments, and Future Prospects for Automated Astronomy, ed. G. W. Henry & J. A. Eaton (San Francisco: ASP), 44

Israelian, G., Lobel, A., & Schmidt, M. R. 1999, ApJ, 523, L145

Landis, H. J., Mattei, J. A., & Percy, J. R. 1992, Inf. Bull. Variable Stars, 3739, 1

Lobel, A., de Jager, C., Nieuwenhuijzen, H., Smolinski, J., & Gesicki, K. 1994, A&A, 291, 226

Lobel, A., Israelian, I., de Jager, C., Musaev, F., Parker, J. W., & Mavrogiorgou, A. 1998, A&A, 330, 659

Percy, J. R., Attard, A., & Szczesny, M. 1996, A&AS, 117, 255

Percy, J. R., Ralli, J., & Sen, L. V. 1993, PASP, 105, 287

Pickering, E. C. 1901, Harvard Circ. 54

Sheffer, Y., & Lambert, D. L. 1986, PASP, 98, 914

Sperl, M. 1998, Comm. Asteroseismology (U. Vienna), 112, 1

Zsoldos, E., & Percy, J. R. 1991, A&A, 246, 441