FINDING THE INSTABILITY STRIP FOR ACCRETING PULSATING WHITE DWARFS FROM HUBBLE SPACE TELESCOPE AND OPTICAL OBSERVATIONS

Paula Szkody\textsuperscript{1}, Anjum Mukadam\textsuperscript{1}, Boris T. Gansicke\textsuperscript{2}, Arne Henden\textsuperscript{3}, Matthew Templeton\textsuperscript{3}, Jon Holtzman\textsuperscript{4}, Michael H. Montgomery\textsuperscript{5}, Steve B. Howell\textsuperscript{6}, Atsuko Nitta\textsuperscript{7,8}, Edward M. Sion\textsuperscript{9}, Richard D. Schwartz\textsuperscript{10}, and William Dillon\textsuperscript{3}

\textsuperscript{1} Department of Astronomy, University of Washington, Box 351580, Seattle, WA 98195, USA
\textsuperscript{2} Department of Physics, University of Warwick, Coventry CV4 7AL, UK
\textsuperscript{3} American Association of Variable Star Observers, 25 Birch Street, Cambridge, MA 02138, USA
\textsuperscript{4} Department of Astronomy, New Mexico State University, Box 30001, Las Cruces, NM 88003, USA
\textsuperscript{5} Department of Astronomy, University of Texas, C1400, Austin, TX 78712, USA
\textsuperscript{6} NOAO, 950 North Cherry Avenue, Tucson, AZ 85719, USA
\textsuperscript{7} Gemini Observatory, 670 North A’ohoku place, Hilo, HI 96720, USA
\textsuperscript{8} Subaru Telescope, 650 North A’ohoku place, Hilo, HI 96720, USA
\textsuperscript{9} Department of Astronomy & Astrophysics, Villanova University, Villanova, PA 19085, USA
\textsuperscript{10} Galaxy View Observatory, Sequim, WA 98382, USA

Received 2009 December 10; accepted 2009 December 22; published 2010 January 14

ABSTRACT

Time-resolved low resolution Hubble Space Telescope ultraviolet spectra together with ground-based optical photometry and spectra are used to constrain the temperatures and pulsation properties of six cataclysmic variables containing pulsating white dwarfs (WDs). Combining our temperature determinations for the five pulsating WDs that are several years past outburst with past results on six other systems shows that the instability strip for accreting pulsating WDs ranges from 10,500 to 15,000 K, a wider range than evident for ZZ Ceti pulsators. Analysis of the UV/optical pulsation properties reveals some puzzling aspects. While half the systems show high pulsation amplitudes in the UV compared to their optical counterparts, others show UV/optical amplitude ratios that are less than one or no pulsations at either wavelength region.

Key words: stars: dwarf novae – stars: oscillations – ultraviolet: stars – white dwarfs

1. INTRODUCTION

In the decade since the white dwarf (WD) in the cataclysmic binary system GW Lib was found to show nonradial pulsations (Warner & van Zyl 1998), a number of studies have been discovered (Warner & Woudt 2004; Woudt & Warner 2004; Araujo-Betancor et al. 2005b; Vanlandingham et al. 2005; Patterson et al. 2005a, 2005b; Mukadam et al. 2007; Gansicke et al. 2006; Nilsson et al. 2006; Patterson et al. 2008; Pavlenko 2009). For convenience, we will refer to the objects found from the Sloan Digital Sky Survey as SDSShhmm±deg, i.e., SDSS0745±45. The work on the known objects has allowed some progress toward understanding how accretion affects the instability zones. While normal non-interacting WDs with hydrogen atmospheres (DAVs or ZZ Ceti stars) show pulsations if they have temperatures in the range of 10,800–12,300 K with some dependence of the temperature range on log g (Koester & Holberg 2001; Bergeron et al. 2004; Gianninas et al. 2006; Mukadam et al. 2006; Castanheira et al. 2007), the WDs in cataclysmic variables (CVs) are known to be heated by accretion (summaries in Sion 1991, 1999; Townsley & Gansicke 2009). Moreover, CV WDs typically rotate an order of magnitude more rapidly than single DA pulsators, and have solar composition or subsolar metal composition accreted atmospheres. With very few exceptions, the temperatures of non-magnetic WDs in CVs are above 12,000 K and so they were previously not expected to be ZZ Ceti type pulsators. However, Hubble Space Telescope (HST) ultraviolet observations of GW Lib clearly showed high amplitude pulsations as well as a high temperature (Szkody et al. 2002a). In addition, the best fit to the data occurred with a two-temperature model, with 63% of the WD at a temperature of 13,300 K and the rest at 17,100 K. It was not known if the dual temperature was related to the pulsation or to the presence of a hotter boundary layer where the accretion disk meets the WD.

The existence of the pulsations at such a high temperature led to speculation that the pulsations in GW Lib could be due to a higher mass WD (Townsley et al. 2004) since a shift in g of about a factor of 10 can shift the blue edge of the H/He i instability strip to hotter temperatures by about 2000 K. They also stated that the effects of accretion, i.e., heavier elements in the atmosphere of the WD, or a faster spin than present in ZZ Ceti pulsators could affect their models. Arras et al. (2006) accomplished a more detailed study that showed that the atmospheric composition of the accreting WD is significant for determining the location of the instability strip. They discovered that accreting model WDs with a high He abundance (>0.38) would form an additional hotter instability strip at ~15,000 K due to He i ionization.

However, the discovery of pulsations in V455 And (Araujo-Betancor et al. 2005b) and a subsequent snapshot HST spectrum showed that this WD was in the normal ZZ Ceti instability zone (within the uncertainties), with T_wd ~ 10,500 K and log g = 8, thus very different from GW Lib. Arras et al. (2006) suggested that the differences in the two objects could be due to differences in the mass of the WD and to the He abundance in the driving zone. Temperatures determined for three more accreting pulsators provided further confusion (Szkody et al. 2007), as all three systems (SDSS0131−09, SDSS1610−01, SDSS2205+11) showed WDs with temperatures of 14,500–15,000 K. Thus, it was not clear if GW Lib or V455 And was the
normal case for pulsating WDs in CVs. Further complicating the issue was the fact that the other known cool non-magnetic WD in a CV (EG Cnc) shows no evidence of pulsations even though its temperature is 12,300 K (Szkody et al. 2002b) and there are several CVs with \( T_{\text{eff}} \) near 15,000 K as well that do not pulsate, e.g., WZ Sge, BC UMa, and SW UMa (Sion et al. 1995; Gänsicke et al. 2005). The situation for CVs containing magnetic WDs is similar. Araujo-Betancor et al. (2005a) determined temperatures for seven systems with magnetic WDs and found a range of 10,800–14,200 K but none are known to show any signs of pulsations.

Our past HST observations of GW Lib, SDSS0131−09, SDSS1610−01, and SDSS2205+11 showed similar pulsation frequencies in the UV as the optical, with increased amplitudes (6–17) in the UV over the optical. This amplitude ratio is consistent with low order modes (Robinson et al. 1995). Each mode identification technique based on this effect. While the amplitude ratios for SDSS1610−01 were consistent with those expected for an \( \ell = 1 \) mode and \( T_{\text{eff}} = 12,500 \) K WD, the derived temperature from the spectral fit was 14,500 K (Szkody et al. 2007). In addition, long term optical coverage of GW Lib (van Zyl et al. 2004) and SDSS0131−09 (Szkody et al. 2007) showed that there is a high degree of variability in the amplitudes of the pulses so that at times, some of the periods are not visible. This is normal behavior (termed amplitude modulation) that is observed in the cool ZZ Ceti stars, e.g., Kleinman et al. (1998) and Mukadam et al. (2007).

In order to gain further insight into the location of the instability strip for accreting WD pulsators, and to constrain the mode identification of the observed pulsation periods, we obtained HST and nearly simultaneous optical observations of six other CV systems known to contain pulsating WDs (PQ And, REJ1255+26, SDSS1514+45, SDSS1339+48, SDSS0745+45, SDSS0919+08, and SDSS1514+45). The basic properties known for these six objects, along with the full SDSS names, are given in Table 1. Some preliminary results appear in Mukadam et al. (2009).

## 2. Observations

### 2.1. HST Ultraviolet Data

The HST Solar Blind Channel (SBC) on the Advanced Camera for Surveys (ACS) was used to observe each of the six objects for five satellite orbits with either grating PR110L or PR130L. While both gratings provide spectra from \( \sim 1200 \) Å to \( \sim 2000 \) Å, the PR110L extends slightly bluer while the PR130L has increased sensitivity near 1300 Å. In both cases, the prism produces nonlinear resolution, with about 2 Å pixel\(^{-1}\) (PR110L) and 1 Å pixel\(^{-1}\) (PR130L) at 1200 Å and about 40 Å pixel\(^{-1}\) at 2000 Å. Since there is no time-tag mode for ACS, 60 or 61 s integrations times were used throughout five HST orbits on each source. With the setup time during the first orbit, there were 134 or 138 integrations on each object. The dead-time between integrations was 40 s so the time resolution is 100 or 101 s. The initial exposure and centering of the target was done with the F140LP filter with integration times of 25–60 s depending on the brightness of the source. The observation times and gratings are summarized in Table 2.

The HST data were analyzed with the reduction package aXe1.6 provided by STScI. The targets were extracted with different widths that were determined to optimize the spectral and light-curve results. For the spectra, a wide extraction (±17 pixels corresponding to ±0.5 arcsec) was used to maximize the flux level, whereas a narrower extraction of 5 (PQ And, REJ1255+26), 7 (SDSS0745+45, SDSS1514+45), 11 (SDSS1339+48), and 13 (SDSS0919+08) pixels was used for the light curves to optimize the best signal-to-noise ratio for each system. To obtain light curves that could be analyzed for periodicity, all the narrow extractions were summed over the useful wavelength range to obtain one UV flux point per integration time interval.

The entire set of wide-extraction spectra during the five HST orbits were added together to produce an average final spectrum for each object. These average spectra are shown in Figure 1 ordered by increasing far-UV flux from top to bottom. While the resolution is poor, the emission line of C iv (1550 Å) is apparent in all systems. It is clear from this figure that there is a large range in temperature as well as emission line flux for the six objects.

### Table 1

| Name     | Mag | P_{obs} (minutes) | Opt Pulse P (s) | Amp (mma) | Outbursts (yr) | References |
|----------|-----|-------------------|-----------------|-----------|----------------|------------|
| PQ And   | 19.1(V) | 80.6             | 1263, 1286      | 25        | 1938, 1967, 1988 | 1, 2, 3     |
| SDSS0745* | 19.0(g) | 77.8             | 1166–1290       | 45–70     | 2006           | 4          |
| SDSS0919 | 18.2(g) | 81.3             | 260             | 7–16      | None           | 4          |
| SDSS1339 | 17.7(g) | 82.5             | 641             | 12        | None           | 5          |
| SDSS1514 | 19.7(g) |                 | 559             | 12        | None           | 6          |
| REJ1255* | 19.1(g) | 119.5            | 668, 1236, 1344 | 7–30      | 1994           | 7          |

Note.

* Full names of objects are: SDSS J074531.92+453829.6; SDSS J091945.11+085710.0; SDSS J133941.11+484727.5; SDSS J151413.72+454911.9; RE J1525+266.

References. (1) Schwarz et al. 2004; (2) Patterson et al. 2005a; (3) Vanlandingham et al. 2005; (4) Mukadam et al. 2007; (5) Gänsicke et al. 2006; (6) Nilsson et al. 2006; (7) Patterson et al. 2005b.
2.2. Optical Data

Due to the remote but possible chance of an outburst during the *HST* observations that could produce more UV light than the limits of the ACS detector, each system was monitored prior to and during each *HST* observation by amateurs (from the American Association of Variable Star Observers) and professional astronomers worldwide. These observations showed all six systems to be close to quiescent values. The outburst history of the six objects is given in Table 1. While PQ And and REJ1255+26 had published outbursts in the literature, the previous outburst of SDSS0745+45 was only found from the Catalina Real-time Transient Survey (Drake et al. 2009) which recorded an outburst with a minimum amplitude of 5 mag in 2006 October, with the system brightness declining to its quiescent level over many months.\(^\text{11}\)

Time-resolved ground-based observations as close in time as possible to the *HST* UV observations were also coordinated in order to determine the amplitude and period of optical pulsations that would aid in mode identification. Seven observatories (Table 2) participated in providing observations. The Apache Point Observatory (APO) 3.5 m telescope was used with the time-series photometric system Agile which uses a frame-transfer CCD and a BG40 filter to provide broadband blue light. The McDonald Observatory (MO) 2.1 m telescope with their time-series system Argos (Nather & Mukadam 2004) and a BG40 filter was used in a similar fashion. The 1 m New Mexico State University (NMSU) telescope with a CCD and BG40 filter and the 1 m US Naval Observatory Flagstaff Station (NOFS) telescope with a BG38 filter were also used for several nights. The 0.35 m Schmidt–Cassegrain telescope equipped with an unfiltered SBIG CCD also provided data from the Sonoita Research Telescope (SRO) in Arizona. In addition to the observations obtained close in time to the *HST* times, further data on SDSS0919+08 (APO) and on PQ And (using the WIYN 3.5 m telescope equipped with OPTIC and a BG39 filter) were taken a year after the *HST* observations. All photometric points were made using differential photometry with respect to comparison stars on the frames and light curves were constructed using standard IRAF\(^\text{12}\) programs for sky-subtracted aperture photometry. To search for periodicities, a discrete Fourier transform (DFT) up to the Nyquist frequency was computed for each object, after first converting the light curves to a fractional amplitude scale by dividing by the mean and then subtracting one. A summary of the optical observations is also given in Table 2.

3. SPECTRAL RESULTS

Figure 1 shows that there is a large range in continuum flux and shape as well as in the emission line flux of C\textsc{iv} (1550 Å) for the six objects. Since the core of Ly\(\alpha\) does not reach zero for any of the objects, there is an additional source of continuum light other than the WD, although this contribution is small in most cases. This “second component” has been observed in UV observations of most quiescent dwarf novae, and has been modeled in terms of a hot boundary layer (e.g., Long et al. 1993) or an accretion belt (e.g., Gänscie & Beuermann 1996; Sion et al. 1996). Long et al. (2009) showed that the WD parameters inferred from a composite fit depend only very mildly on the details of the model assumed for the second component.

The C\textsc{iv} (and to a lesser extent C\textsc{iii} at 1335 Å, S\textsc{iv} at 1400 Å, and N\textsc{v} at 1240 Å) emission lines probably originate in the

---

\(^{11}\) Click on object link in the table at http://nesssi.cacr.caltech.edu/catalina/20050301/SDSSCV.html.

\(^{12}\) IRAF (Image Reduction and Analysis Facility) is distributed by the NOAO, which is operated by AURA, Inc., under cooperative agreement with the National Science Foundation.
Figure 1. *HST* SBC average spectra of all 6 of our objects using a 17 pixel extraction.

For completeness, we also include in the table the results for the three objects observed with the SBC in the past (Szkoody et al. 2007) that were re-analyzed with the new aXe1.6 software and refit in the same manner as for our six new observations. An example of the fits for the three spectral shapes of the disk are shown for SDSS1339+48 in Figure 2 while the fitting results using a blackbody for the disk contribution are shown for all six of our new objects in Figure 3.

As a check on the WD temperature, the g magnitude for the resulting WD model is also listed and compared to the observed SDSS photometric values in Table 3. All the WD values are fainter than observed, which is reasonable given that the accretion disk will have some contribution to the optical light above that of the WD.

For a further exercise in the total spectral fit, we combined the *HST* data with the available SDSS spectra for five of our objects. REJ1255+26 only has SDSS photometry as a spectrum was not obtained. For this object, the ugriz magnitudes were converted to fluxes. The disk component (using the constant distribution) was then subtracted from the SBC spectrum and the result plotted with the optical spectrum. Figure 4 shows the combined UV and optical data for each system along with the best-fit WD temperature models within \( \sim 2000 \) K. These plots show the goodness of our temperature fits as well as the amount of the disk contribution to the optical flux (the excess seen in the observed fluxes over the model WD).

4. LIGHT CURVES

We computed DFTs of all the *HST* and available optical light curves, and used linear and nonlinear least squares analyses to determine periods, amplitudes, and phases of any coherent variability present in the data. White noise was determined
Table 3
Model Fits to SBC Spectra

| Obj+Model          | $T_{wd}$ (K) | $d$ (pc) | $T_{BB}/PL$ | $g_{wd}$ |
|--------------------|--------------|----------|-------------|---------|
| SDSS1514+const     | 10,500       | 408      | ...         | 20.0    |
| SDSS1514+BB        | 10,000       | 358      | 9500        | 19.9    |
| SDSS1514+PL        | 10,500       | 416      | 1.0         | 20.1    |
| PQ And+const       | 12,000       | 340      | ...         | 19.3    |
| PQ And+BB          | 12,000       | 361      | 16,500      | 19.4    |
| PQ And+PL          | 12,000       | 337      | −0.16       | 19.2    |
| REJ1255+const      | 12,500       | 191      | ...         | 17.9    |
| REJ1255+BB         | 12,000       | 543      | 11,500      | 20.3    |
| REJ1255+PL         | 12,000       | 420      | 0.90        | 19.7    |
| SDSS1339+const     | 12,500       | 187      | 25,000      | 17.9    |
| SDSS1339+BB        | 12,500       | 187      | ...         | 17.9    |
| SDSS1339+PL        | 12,500       | 187      | ...         | 17.9    |
| SDSS0919+const     | 13,500       | 319      | ...         | 18.9    |
| SDSS0919+BB        | 13,500       | 333      | 15,500      | 19.0    |
| SDSS0919+PL        | 13,500       | 330      | 1.0         | 19.0    |
| SDSS0131+const     | 14,000       | 388      | ...         | 19.3    |
| SDSS0131+BB        | 14,500       | 432      | 14,000      | 19.4    |
| SDSS0131+PL        | 14,000       | 371      | 0.66        | 19.2    |
| SDSS1610+const     | 14,000       | 504      | ...         | 19.8    |
| SDSS1610+BB        | 14,500       | 611      | 13,500      | 20.2    |
| SDSS1610+PL        | 14,500       | 562      | 1.0         | 20.0    |
| SDSS2205+const     | 14,000       | 859      | ...         | 21.0    |
| SDSS2205+BB        | 15,000       | 919      | 11,000      | 21.0    |
| SDSS2205+PL        | 14,000       | 862      | 0.66        | 21.0    |
| SDSS0745+constb    | 17,000       | 445      | ...         | 19.2    |
| SDSS0745+BB        | 17,000       | 474      | 19,000      | 19.3    |
| SDSS0745+PL        | 17,000       | 463      | −0.02       | 19.3    |

Notes.

- $T_{BB}$ is the black body temperature of the second component and PL is the slope of the power law for the second component.
- As this object underwent an outburst one year prior to the HST observation, the white dwarf is likely not yet at its quiescent temperature.

by a light-curve shuffling technique where each time value of fractional intensity was randomly reassigned to another existing time value. This shuffling destroys coherent frequencies but keeps the same time sampling and white noise as the original data. The DFT of the shuffled light curve provides the noise at each frequency; the mean of the average noise from 10 shufflings is taken as the white noise of the light curve and 3 times this value is quoted in our paper as a detection limit for pulsations. The amplitudes are given in millimodulation amplitudes (mma) where 1 mma is a 0.1% change in intensity. The DFTs for the HST data are shown in Figure 5 along with the window functions. The window function is the DFT of a single frequency noiseless sinusoid sampled exactly the same times as the actual light curve. These functions look quite similar to each other as the HST data for all six systems is sampled in almost the same way (since we deleted data points when the background noise was too high, the sampling is not completely identical for all six targets). A summary of the observed periods and limits from the HST and optical data is contained in Table 4, and the details for each system are discussed below.

4.1. PQ And

For this system, the ground and space observation time overlaps for 4 hr (Table 2), so periods and amplitudes can be optimally compared. Figures 5 and 6 show the DFTs for the UV and optical data obtained on 2007 September 13. The ground data were obtained with a smaller telescope but the observation interval is longer so that the mean noise is lower (5 mma) than for the UV data (14 mma). While the optical data show the presence of two periods (2337 and 1285 s) with amplitudes near 20 mma, there is no significant pulsation evident in the UV. This lack of UV pulsations is surprising and without explanation. The 1285 s optical period is the pulsation period reported by Vanlandingham et al. (2005; Table 1) and the data on 2007 September 15 and 17 show a similar period within the errors. Thus, we regard this as the nonradial pulsation. The 2337 s period is not repeated on the other dates and is likely due to flickering noise.

Since the four previous systems observed with HST had shown pulsation amplitudes at least 6 times higher in the UV
than the optical, consistent with $\ell = 1$ or 2 modes, we would expect a UV amplitude of at least 60 mma at the 1285 s period that was evident in the optical within the same time interval. Thus, the lack of detection of any pulsation in the UV implies a high $\ell$ mode in this system, if the optical periodicity at 1285 s is a nonradial pulsation. High $\ell$ modes ($\ell > 2$) have never been clearly and unambiguously identified in the ZZ Ceti stars. For example, Thompson et al. (2004) identified the 141.9 s period in PY Vul (G185−32) as an $\ell = 4$ mode, but Pech & Vauclair (2006) suggest that it is an $\ell = 2$ mode. Furthermore, they explain that the low value of UV/optical amplitude could be attributed to a resonance between the $\ell = 2$ mode and nearby $\ell = 3$ and $\ell = 5$ modes, which remain undetectable.

The high quality WIYN data obtained a year after the HST observation show an even higher amplitude new periodicity at 679 s along with its sub-harmonic at 1355 s (Figure 7). Harmonics and linear combinations in our data could arise as a result of nonlinearities introduced by relatively thick convection zones (Brickhill 1992; Brassard et al. 1995; Wu 2001; Montgomery 2005). However, since we observe a sub-harmonic at $2P = 1355$ s and do not detect a harmonic at $P/2 = 339.5$ s, we can rule out convection as the likely cause of the observed nonlinearity. Since there is only one observation of this new periodicity, it is possible that both the 679 s period and its sub-harmonic at 1355 s were caused by flickering. Should frequent monitoring of the system fail to reveal the 679 s period again, then the flickering hypothesis is likely. If, however, the 679 s mode proves to be persistent, then it might be an unusual pulsation mode with an observed sub-harmonic instead of a typical harmonic. As a pulsation mode, we could explain its appearance and the absence of previously observed modes as due to amplitude modulation. Amplitude modulation is apparent.

Figure 3. White dwarf plus blackbody + Gaussian lines model fits to the SBC data for our six objects.
in GW Lib (Van Zyl et al. 2004) and SDSS0131−09 (Szkody et al. 2007) and also the ZZ Ceti G29−38 (Kleinman et al. 1998). We currently favor the idea that the 679 s mode and its sub-harmonic at 1355 s are caused by flickering.

4.2. SDSS0745+45

The HST observations of this system took place in the midst of a ground-based run of several nights at MO and SRO. Both observatories overlapped with HST times for about 2.5 hr (Table 2). While the light curve is highly modulated in both the UV and optical, the modulation is at the long period of 86 minutes (and its second harmonic at 43 minutes and third harmonic at 28 minutes), not within the previously observed range of pulsation periods between 1166−1290 s that were clearly evident during seven nights from 2005 October through 2006 January (Mukadam et al. 2007). Figure 8 shows the intensity curves and DFTs for the 2007 data in comparison to that of 2006. While the pulsation is clearly evident in the light curves in 2006, it disappeared at the time of the HST observation. Combining the four nights of optical data from 2007 October 30–November 2, we obtain a 3σ limit to the pulsation amplitude of 8.5 mma. The same limit from the HST data is 12 mma (Figure 5).

Further complicating the issue of the disappearance of the pulsation is the origin of the 86 minute modulation. This period (or its harmonics) was evident in two of the seven nights in 2005−2006 where it was presumed to be the orbital period (Mukadam et al. 2007). However, recent spectroscopy (J. Southworth 2009,
private communication) has revealed an orbital period of $77.8 \pm 1.5$ minutes. Combining the four nights of photometry listed in Table 4, we obtain periods of $89.3 \pm 0.02$ minutes and $43.23 \pm 0.01$ minutes. Averaging these numbers (weighted inversely as the squares of the uncertainties), we obtain a photometric period of $87.4 \pm 1.3$ minutes. Clearly, the spectroscopic period is significantly less than the photometric period. Photometric periods that are 2%–4% longer than spectroscopic periods...
are usually ascribed to superhumps, a phenomenon usually observed following outbursts in short period systems due to precession of an eccentric disk caused by the heating from the outburst (Warner, 1995; Patterson 2001). While it is unusual to have a superhump present at quiescence, one is also apparent in V455 And (Araujo-Betancor et al. 2005b). It is perhaps even more unusual that the periods are so different in SDSS0745+45 (12%). Even if the error bars are underestimated by a factor of 2, the difference between the spectroscopic and photometric periods is still 5%. While this difference is 2.8% in V455

**Figure 6.** Normalized intensity (top panel), DFT (middle panel), and window function (bottom panel) of the NOFS data on PQ And taken simultaneously with the SBC on 2007 September 13. The two major peaks occur at 2337 s and 1285 s.

**Figure 7.** Intensity, DFT, and window function for the WIYN data on PQ And obtained one year after the SBC data.

**Figure 8.** Comparison of SDSS0745+45 data from 2006 with the four nights surrounding the 2007 HST observations. Note the visible difference of the light curve as well as the changes in the period evident in the DFTs. Dashed lines show the $3\sigma$ values for the noise for each data set.
And, there is a one-day alias in the photometric period so the difference could possibly be as large as 9.2%, similar to what we find for SDSS0745+45.

As previously noted, the detection of an outburst around 2006 mid-October from the Catalina Sky Survey data means it is likely that the WD in SDSS0745+45 had not completely cooled to its quiescent temperature by the time of the HST observation. Indeed, this object is the hottest one of all the objects we have observed, which is consistent with it having been heated during the outburst. Past work on the cooling times of WDs following outbursts, e.g., WZ Sge (Slevinsky et al. 1999; Long et al. 2003; Sion et al. 2003; Godon et al. 2006), and AL Com (Szkody et al. 2003) have shown that this cooling can take more than three years. The outburst could have caused some increase in the eccentricity of the disk that causes the long period modulation to be more prominent than pre-outburst. We expect the WD to continue to cool during the next two years and the pulsations to resume, while the long period modulation decreases.

4.3. SDSS0919+08

Whereas five out of six past optical light curves of this object from 2005 December to 2007 March showed a period near 260 s with amplitudes of 7–16 mma (Mukadam et al. 2007), Figure 5 shows that the HST data in 2007 November only reveals a harmonic of the orbital period at 40.75 minutes, with a limit of 15 mma to any shorter term periodicity in the UV (the two peaks on both sides of the 40 minute period are aliases). Optical data obtained 2 days prior to the HST observations also reveal no period to a limit of 4 mma (Figure 9) and the data at the end of 2008 show no pulsation to a limit of 7 mma (Table 4). Since there are no known outbursts of this system, and the WD temperature is not high, it is not at all clear why the WD in this system has stopped pulsating. Mukadam et al. (2007) thought the 260 s period was a close doublet and the one night it was not observed in their data could be a beating of the two frequencies. However, the lack of periods on the three separated days of observations in our data and especially the lack of pulsations in the UV indicates this system has actually stopped pulsating. It is possible that if this system is close to the edge of its instability strip, accretion related heating could push it outside. However, the amount of accretion would need to be small enough that it would not noticeably affect the visual magnitude of the system.

4.4. SDSS1339+48

From three nights of photometry in 2005, Gänsicke et al. (2006) identified a prominent pulsation at a period of 641 s, as well as a long period at either 320 or 344 minutes but no modulation at the spectroscopically determined period of 82.52 minutes. Neither our HST data (Figure 5) nor our ground-based photometry obtained 2 days prior to the HST data (Figure 10) show the pulsation period of 641 s. The HST data do show one significant long period at 7.4 hr and two short periods (210.3 and 229.6 s) that are close to the Nyquist frequency for the data resolution but just below the 3σ noise level of 53 mma. The optical data reveal none of these periods but do show a period consistent with the orbital period (within the error bars), as well as a period at 1539 s. Due to the limited data, it is difficult to conclude that any of these periods result from anything other than flickering or accretion effects. However, it is clear that there is no large amplitude UV pulsation at the previously determined optical period of 641 s.

4.5. SDSS1514+45

Our optical data from APO (Figure 11) have about 1.5 hr of overlap with the HST UV data for this source. Neither wavelength shows the 559 s period previously reported by Nilsson et al. (2006). As that period has not been evident since their data in 2005, further observations are needed to confirm if this really is a pulsator with a changing amplitude.

The DFT from the UV data (Figure 5) does show a longer period at 88.8 minutes which could be the orbital period. The faintness of this system has precluded the determination of an orbital period from spectroscopy at the current time. There is a period near 700 s that is almost at the 3σ limit, but as this is not evident in the optical, it is likely related to flickering.
4.6. REJ1255+26

Our APO optical time-resolved data on this system only encompass one light curve on the night following the HST observations. The UV data show the 1.9 hr orbital period but a limit of 52 mma to any shorter periods. The optical data (Figure 12) reveals two short periods at 654.5 and 582.1. Patterson et al. (2005b) had previously found a period of 668 s. As in PQ And, the presence of optical periods without detection in the UV at a higher amplitude implies a high ℓ mode of pulsation, if the periods are due to nonradial pulsations.

5. DISCUSSION

Figures 1, 3, 4 and Table 3 show that the nine systems with similar SBC data show a range of temperatures from 10,000 to 17,000 K. The hottest temperature WD exists in SDSS0745+45. However, since that system underwent an outburst only one year prior to the HST observation, it is likely that its WD has not cooled to its quiescent value. This is corroborated by the lack of pulsations evident in the HST data. Long term studies of the WD cooling in low accretion rate CVs with short orbital periods have shown that it takes more than 3 yr for the WD to cool following outburst (Piro et al. 2005; Godon et al. 2006). Eliminating SDSS0745+45 and adding in the temperatures derived from Space Telescope Imaging Spectrograph observations of GW Lib (15,400 for a black body disk contribution; Szkody et al. 2002a) and V455 And (11,500; Araujo-Betancor et al. 2005b), and from the eclipse modeling of SDSS1507+52 (11,000; Littlefair et al. 2008), gives an instability range of 10,000–15,000 K with the CV pulsators spread throughout this range. Thus, if the higher temperatures of pulsating accretors relative to ZZ Ceti stars is due to mass or composition, then no unique parameter characterizes the accreting pulsators. Half of the 11 temperatures lie within the ZZ Cet instability strip (within the error bars and with a log g of 8) and half are hotter. Figure 13 shows our 11 quiescent temperatures along with the ZZ Ceti empirical instability strip (Gianninas et al. 2007). While a few of the systems could fall within the strip if they have massive WDs (higher log g), it would be difficult to have mass be the primary cause of the width of the strip. Arras et al. (2006) can account for increased width with an increase in He in the driving zone.

Besides the width of the instability strip for accreting pulsators, the other oddity is why all CVs with WDs in the temperature range of the known pulsators do not show pulsations. Table 6 lists all the WDs with reliable temperature determinations (from the recent summary in Townsley & Gansicke 2009, with the addition of SDSS1507+52 from Littlefair et al. 2008) and they are also plotted in Figure 13. The two closest systems to the ZZ Ceti instability strip are EG Cnc (at the blue edge) and SDSS1035+05 (at the red edge). Further monitoring of these systems is needed to determine if they never pulsate or if they were observed during a hiatus of their pulsations.

GW Lib still stands out as the only system among the 11 with available UV spectra in which the best fit is obtained with a dual temperature WD rather than a WD plus an accretion disk. It is the only system in which the core of Lyα does reach zero. If this dual temperature is due to a boundary layer ring that is hotter due to the accretion, it is not clear why this is not the case in the other 10 systems, especially for SDSS0745+45 which is heated by the recent outburst.

Within the limited numbers, there does not seem to be any correlation of WD temperature with orbital period as would be
expected if the WDs are cooling due to decreasing mass accretion rate as they evolve to shorter orbital periods (Howell et al. 2001). Figures 2–4 give some indication of the accretion luminosity (hence WD mass and accretion rate) from the contribution of the accretion disk to the light. Excluding SDSS0745+45, whose WD is likely not at its quiescent temperature, the WDs in our models contribute 75%–89% of the UV light and 42%–75% of the optical light for the other eight objects in Table 3. The three hottest WDs (SDSS2205+11, SDSS0131−09, and SDSS1610−01) do have the three highest disk contributions to the optical light (50%, 58%, and 41%), which is consistent with a higher mass WD or a higher accretion rate that would heat the WD.

Figure 14 shows the accreting pulsators as well as the non-accreting WDs (Table 6) as a function of their orbital period. The limits of the ZZ Ceti instability strip for log g = 8 (Giammaria et al. 2007) are shown as dashed lines.

### Table 5

| Object    | UV Periods (s) | Opt Periods (s) | UV/Opt Amplitude |
|-----------|----------------|-----------------|------------------|
| GW Lib    | 648, 376, 236  | 646, 376, 237   | 6–17             |
| SDSS0131  | 213            | 211             | 6                |
| SDSS1610  | 608, 304, 221  | 608, 304, 221   | 6                |
| SDSS2205  | 576            | 575             | 6                |
| PQ And    | ...            | 1285            | <1               |
| REJ1255   | ...            | 582, 655        | <1               |
| SDSS0745  | ...            | ...             | ...              |
| SDSS0919  | ...            | ...             | ...              |
| SDSS1339  | ...            | ...             | ...              |
| SDSS1514  | ...            | ...             | ...              |

Figure 14. Temperatures of accreting pulsators (solid dots) and of non-pulsating CV white dwarfs (triangles) as a function of orbital period. The limits of the ZZ Ceti instability strip for log g = 8 (Giammaria et al. 2007) are shown as dashed lines.

### Table 6

| Name            | P$_{orb}$ (hr) | T$_{eff}$ (K) | Pulsating |
|-----------------|----------------|---------------|-----------|
| SDSS1507+52     | 1.11           | 11,000 ± 500  | Y         |
| GW Lib          | 1.28           | 13,300 ± 17,100 | Y        |
| BW Scl          | 1.50           | 14,800 ± 900  | N         |
| LL And          | 1.32           | 14,300 ± 1000 | N         |
| PQ And          | 1.34           | 12,000 ± 1000 | Y         |
| SDSS1610−01     | 1.34           | 14,500 ± 1500 | Y         |
| V455 And        | 1.35           | 10,500 ± 750  | Y         |
| AL Com          | 1.36           | 16,300 ± 1000 | N         |
| SDSS0919+08     | 1.36           | 13,500 ± 1000 | Y         |
| WZ Sge          | 1.36           | 14,900 ± 250  | N         |
| SW UMa          | 1.36           | 13,900 ± 900  | N         |
| SDSS1035+05     | 1.37           | 10,500 ± 1000 | N         |
| HV Vir          | 1.37           | 13,300 ± 800  | N         |
| SDSS1339+48     | 1.38           | 12,500 ± 1000 | Y         |
| SDSS2205+11     | 1.38           | 15,000 ± 1000 | Y         |
| WX Cet          | 1.40           | 13,500 ± 1000 | N         |
| EG Cnc          | 1.41           | 12,300 ± 700  | N         |
| XZ Eri          | 1.47           | 15,000 ± 1500 | N         |
| SDSS1514+45     | 1.47?          | 10,000 ± 1000 | ?         |
| VY Aqr          | 1.51           | 14,500 ± 1000 | N         |
| OY Car          | 1.52           | 15,000 ± 2000 | N         |
| SDSS0131−09     | 1.63           | 14,500 ± 1000 | Y         |
| HT Cas          | 1.77           | 14,000 ± 1000 | N         |
| REJ1255+26      | 1.99           | 12,000 ± 1000 | Y         |
| EF Peg          | 2.00           | 16,600 ± 1000 | N         |

A pure instability strip with non-pulsators outside and only pulsators within, implies that pulsations are an evolutionary phase along the cooling track (Fontaine et al. 1982, 2003; Bergeron et al. 2004; Castanheira et al. 2007). In other words, all accreting WDs would undergo the pulsation phase. An impure instability strip with pulsators and non-pulsators mixed implies that parameters other than the WD temperature and mass are at play in deciding whether the star will pulsate or not (Kepler & Nelan 1993; Mukadam et al. 2004). Our preliminary results indicate an impure strip with 13 non-pulsators in the range of 10,500−15,400 K; this lends credence to the theory that He abundance is the third parameter that determines the instability strip with pulsators and non-pulsators mixed in a narrow period range near 82 minutes. It is easy to explain why longer period systems are not evident as pulsators, as those typically have increased mass accretion rates which can hide the WD, and thus make pulsations harder to detect. But it is not obvious why the pulsations would not be present in systems with shorter orbital periods and why the transition is so abrupt.

The absence of pulsations in SDSS0745+45 can be explained by its recent outburst, which likely heated its WD and moved it out of the instability strip. This explanation is corroborated by the lack of optical and UV pulsations of GW Lib following its recent outburst (Szkody et al. 2009; Copperwheat et al. 2009). SDSS1514+45 suffers from insufficient data to confirm pulsations. However, there is no clear explanation for SDSS0919+08 and SDSS1339+48. Recent observations of SDSS2205+11 (Southworth et al. 2008).
also show a lack of pulsation on two nights as compared to previous years (Warner & Woudt 2004; Szkody et al. 2007). While SDSS1339+48 is just outside the blue edge of the ZZ Ceti instability strip for $\log g = 8$ (Figure 13), which might account for its lack of pulsation if its WD underwent a slight temperature increase, SDSS0919+08 and SDSS2205+11 are much further away from this edge. Southworth et al. (2008) discuss several possible reasons for the lack of pulsations (destructive interference, changes in the thermal state of the driving region, or changing visibility of the modes over the surface of the WD) but conclude further observations over long timescales are needed to sort out the cause. While different frequencies are known to be dominant at different times during the course of several years in GW Lib (van Zyl et al. 2004) and in SDSS0131−09 (Szkody et al. 2007), information as to the length of time that systems show no pulsations at all is not available.

6. CONCLUSIONS

Our recent ultraviolet and optical data on six systems combined with past data on six others produces a data set of 12 accreting pulsating WDs with temperatures (Tables 3 and 6) and ten with pulsation properties determined from UV through optical wavelengths (Table 5). These data sets are beginning to contain enough objects to begin to see some trends as well as to reveal some abnormalities.

1. The temperature range for the 11 objects that have been in quiescence for years are in the range of 10,500−15,000 K. This range includes the temperatures found in ZZ Ceti pulsators but extends to higher temperatures. The temperatures appear to uniformly spread throughout the entire range, but we are still in the domain of small number statistics. Since we do not have masses or He abundances for these 11 systems, it is difficult to test the predictions of (Arras et al. 2006) as to the cause of the width of the strip.

2. Several CVs are known to have WDs with temperature within this range of 10,500−15,000 K but they are not pulsating. Table 6 presents a list of the WDs in disk-accreting CV that have reliable quiescent temperatures (from Townsley & Gänsicke 2009; Littlefair et al. 2008, and this work) and whether they have shown pulsations. It is unclear why not all CVs in this temperature range are pulsating. In addition to the disk-accretors, there are an additional 11 highly magnetic WDs in CVs (Polars) in the Townsley & Gänsicke (2009) list within this temperature range, none of which show pulsations.

3. GW Lib is the only system among the 11 with UV spectra in which the best fit is obtained with a dual temperature WD rather than a WD plus a disk contribution.

4. The object that is one year past outburst (SDSS0745+45) has a hotter temperature (17,000 K) and is no longer pulsating. This corroborates past work that shows the WDs in CVs are heated for several years following outburst (Piro et al. 2005; Godon et al. 2006) and it is likely that this object has moved out of the instability strip.

5. Four systems (GW Lib, SDSS0131−09, SDSS1610−01, and SDSS2205+11) show identical pulsation periods in the UV and optical with high amplitude ratios of UV/opt. These four are similar to the low order modes evident in ZZ Ceti stars; however, the temperatures of all four are 14,000−15,000, far outside the range for ZZ Ceti objects.

6. Two objects (PQ And and REJ1255+26) have UV/optical amplitude ratios that are less than 1. Both of these objects have WD temperatures of 12,000 K, just inside the blue edge of the ZZ Ceti instability strip (Figure 13). If the optical periods observed are nonradial pulsations, this implies a high $\ell$ mode not unambiguously observed in ZZ Ceti pulsators. It remains a problem for theorists to determine if the differences between accreting and non-accreting WDs could cause this effect.

7. Four objects (SDSS0745+45, SDSS0919+08, SDSS1339+48, and SDSS1514+45) did not show pulsations in either UV nor optical. The lack of pulsations in SDSS0745+45 can be explained by its outburst only one year prior to the HST data, while SDSS1514+45 has had only minimal observational data in the past (Nilsson et al. 2006), so further data are needed to confirm it as an accreting pulsator. For the other two systems, there is no clear explanation for why the pulsations that were evident from several nights of ground-based data in the past have disappeared. Both of these objects are in the intermediate temperature zone (12,500−13,500 K) between the normal ZZ Ceti instability edge and the hotter temperatures of the four pulsators that do show UV pulsations of high amplitude. Since the temperatures are not high (as in SDSS0745+45), it is unlikely that an outburst has occurred in these two systems. It is possible that these pulsators were close to the edge of the instability strip (SDSS0919+08 would have to be high mass to be near the edge), and changes in accretion heating take them in and out of the instability zone. We intend to keep observing these objects to determine if pulsations return at the previous periods.

8. Two objects (V455 And and SDSS0745+45) show photometric periods that are longer than the spectroscopic periods by 3%−12%. The presence of such periods are typically due to superhumps caused by precessing, eccentric disks in short orbital period CVs during an outburst. If this is the case in these two objects, it is unusual to find the superhumps during quiescence and even more unusual to have such a large percentage difference in the periods.

To make progress toward understanding the edges of the instability strip and the pulsation modes that relate to the appearance/disappearance of periods at different times, further data are needed. Mass determinations of a few of the hot versus cool WDs can determine how this parameter effects the width of the strip. Continued observations of the systems that have undergone outbursts in 2006−2007 (SDSS0745+45, GW Lib, V455 And, and SDSS0804+51) as they re-enter the instability strip following the heating during the outburst will provide valuable information about the modes and depth of heating. Long observation sequences for the objects in Table 6 that are not known to pulsate are needed to place stringent limits on the amplitudes of possible pulsations. The identification of further accreting pulsating systems will help to enlarge the database on which to draw conclusions about the stability of periods and the behavior as a function of the temperature of the WD.

We gratefully acknowledge the many amateur and professional observers who monitored our objects prior to and during the HST observations which allowed the UV observations to proceed with the knowledge that the objects were at quiescence. Special thanks go to Agatha Raup, Joanne Hughes, and Gary Walker. This research was supported by NASA grant HST-GO-11163.01-A from the Space Telescope Science Institute which is
operated by the Association of Universities for Research in Astronomy, Inc., for NASA, under contract NAS 5-26555. B.T.G. was supported by a PPARC Advanced Fellowship.

REFERENCES

Araujo-Betancor, S., et al. 2005a, ApJ, 622, 589
Araujo-Betancor, S., et al. 2005b, A&A, 430, 629
Arras, P., Townsley, D. M., & Bildsten, L. 2006, ApJ, 643, L119
Bergeron, P., Fontaine, G., Billeres, M., Boudreault, S., & Green, E. M. 2004, ApJ, 600, 404
Brassard, P., Fontaine, G., & Wesemael, F. 1995, ApJS, 96, 545
Brickhill, A. J. 1992, MNRAS, 259, 529
Castanheira, B. G., et al. 2007, A&A, 462, 989
Copperwheat, C. M., et al. 2009, MNRAS, 393, 515
Drake, A. J., et al. 2009, ApJ, 696, 870
Fontaine, G., Bergeron, P., Billeres, M., & Charpinet, S. 2003, ApJ, 591, 1284
Fontaine, G., Lacombe, P., McGraw, J. T., Dearborn, D. S. P., & Gustafson, J. 1982, ApJ, 258, 651
Gansicke, B. T., & Beuermann, 1996, A&A, 309, L47
Gansicke, B. T., Szkody, P., Howell, S. B., & Sion, E. M. 2005, ApJ, 629, 451
Gansicke, B. T., et al. 2006, MNRAS, 365, 969
Gansicke, B. T., et al. 2009, MNRAS, 397, 2170
Gianninas, A., Bergeron, P., & Fontaine, G. 2006, AJ, 132, 831
Gianninas, A., Bergeron, P., & Fontaine, G. 2007, in ASP Conf. Ser. 372, A Progress Report on the Empirical Determination of the ZZ Ceti Instability Strip, ed. R. Napiwotzki & M. R. Burleigh (San Francisco, CA: ASP), 577
Godon, P., Sion, E. M., Cheng, F., Long, K. S., Gansicke, B. T., & Szkody, P. 2006, ApJ, 642, 1018
Howell, S. B., Nelson, L. A., & Rappaport, S. 2001, ApJ, 550, 897
Hubeny, I., & Lanz, T. 1995, ApJ, 439, 875
Kepler, S. O., & Nelan, E. P. 1993, AJ, 105, 608
Kleinman, S. J., et al. 1998, ApJ, 495, 424
Koester, D., & Holberg, J. B. 2001, in ASP Conf. Ser. 226: 12th European Workshop on White Dwarfs, ed. J. L. Provencal et al. (San Francisco, CA: ASP), 299
Littlefair, S., et al. 2008, MNRAS, 388, 1582
Long, K. S., et al. 1993, ApJ, 405, 327
Long, K. S., et al. 2003, ApJ, 591, 1172
Montgomery, M. H. 2005, ApJ, 635, 1142
Mukadam, A. S., Montgomery, M. H., Winget, D. E., Kepler, F. O., & Clemens, J. C. 2006, ApJ, 640, 956
Mukadam, A. S., Szkody, P., Giantsicke, B. T., & Nitta, A. 2009, J. Phys. Conf. Ser., 172, 012069
Mukadam, A. S., et al. 2004, ApJ, 612, 1052
Mukadam, A. S., et al. 2007, ApJ, 667, 433
Nather, R. E., & Mukadam, A. S. 2004, ApJ, 605, 846
Nilsson, R., Uthas, H., Ytre-Eide, M., Solheim, J.-E., & Warner, B. 2006, MNRAS, 370, L56
Patterson, J. 2001, PASP, 113, 736
Patterson, J., Thorstensen, J. R., Armstrong, E., Henden, A. A., & Hynes, R. I. 2005a, PASP, 117, 922
Patterson, J., Thorstensen, J. R., & Kemp, J. 2005b, PASP, 831, 427
Patterson, J., et al. 2008, PASP, 120, 510
Pavlenko, E. 2009, J. Phys. Conf. Ser., 172, 012071
Pech, D., & Vauclair, G. 2006, A&A, 453, 219
Piro, A. L., Arras, P., & Bildsten, L. 2005, ApJ, 628, 401
Robinson, E. L., Kepler, S. O., & Nather, R. E. 1982, ApJ, 259, 219
Robinson, E. L., et al. 1995, ApJ, 438, 908
Schwarz, G. J., et al. 2004, PASP, 116, 1111
Sion, E. M. 1991, AJ, 102, 295
Sion, E. M. 1999, PASP, 111, 532
Sion, E. M., et al. 1995, ApJ, 439, 957
Sion, E. M., et al. 1996, ApJ, 471, L41
Sion, E. M., et al. 2003, ApJ, 592, 1137
Slevinsky, R. J., Stys, D., West, S., Sion, E. M., & Cheng, F. H. 1999, PASP, 111, 1292
Southworth, J., Townsley, D. M., & Gansicke, B. T. 2008, MNRAS, 388, 709
Szkody, P., Gansicke, B. T., Howell, S. B., & Sion, E. M. 2002a, ApJ, 575, L79
Szkody, P., Gansicke, B. T., Sion, E. M., & Howell, S. B. 2002b, ApJ, 574, 950
Szkody, P., et al. 2003, AJ, 126, 1451
Szkody, P., et al. 2007, ApJ, 658, 1188
Szkody, P., et al. 2009, in ASP Conf. Ser. 404, The Accreting, Pulsating White Dwarfs in Cataclysmic Variables, ed. B. Soonthornthum, S. Komonjinda, K. S. Cheng, & K. C. Leung (San Francisco, CA: ASP), 229
Thompson, S. E., Clemens, J. C., van Kerkwijk, M. H., O’Brien, M. S., & Koester, D. 2004, ApJ, 610, 1001
Townsley, D. M., Arras, P., & Bildsten, L. 2004, ApJ, 608, L105
Townshley, D. M., & Gansicke, B. T. 2009, ApJ, 693, 1007
Vanlandingham, K. M., Schwarz, G. J., & Howell, S. B. 2005, PASP, 117, 928
van Zyl, L., et al. 2004, MNRAS, 350, 307
Warner, B. 1995, in Cataclysmic Variable Stars (New York: Cambridge Univ. Press)
Warner, B., & van Zyl, L. 1998, in IAU Symp. 185, New Eyes to See Inside the Sun and Stars, ed. F.-L. Deubner, J. Christensen-Dalsgaard, & Don Kurtz (Dordrecht: Kluwer), 321
Warner, B., & Woudt, P. 2004, in ASP Conf. Ser. 310, Variable Stars in the Local Group, ed. D. W. Kurtz & K. R. Pollard (San Francisco, CA: ASP), 382
Woudt, P., & Warner, B. 2004, MNRAS, 348, 599
Wu, Y. 2001, MNRAS, 323, 248