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FINAL REPORT, NAG5-1832, Covering the 25k grant over 12/01/91 – 11/30/93
Principal Investigator: Dr. R.E.Stencel, University of Colorado at Boulder

IUE Guest Observer Projects, under NAG5-1832:
VVNRS (1991): Variable Phenomena in VV Cephei

PURPOSE AND OBJECTIVES

The current research project [VVNRS] involves VV Cephei, which is a binary system in which a 20 solar mass main sequence star orbits within the extended atmosphere of the 40 solar mass M-type supergiant primary. Although the period of the system is 20.3 years, the components are close enough for a stream of matter from the primary to form an accretion disk around the hot secondary.

We had previously completed an ADP-sponsored study of 12 years of archival spectra of this system (paper 1) and were surprised to find intermittent changes in the line profiles of the chromosphere-like absorption spectrum. This we think may be related to the accretion process. The previously existing spectra were not closely spaced enough in time to clearly delineate the nature of these changes.

Therefore, we proposed and were granted 11 half-shifts to obtain closely spaced IUE spectra during IUE's 14th year of operations ('91/92).

PROGRESS DURING THE GRANT TERM:

1. This grant went onto No Cost Extension status on 12/1/92.
2. Analysis of the spectra lead to the submission of a report entitled: "Rapid Mass-Loss Transients in VV Cephei" which was submitted to Publications of the Astronomical Society of the Pacific. We responded to the reviewer's concerns and the work has appeared in print, 1993 PASP 105:45 (Jan issue) – Stencel, Potter and Bauer (abstract attached).
3. My new student affiliate with IUE, Mr. Daniel Potter, an undergraduate Physics major at CU, has acquired useful experience with IUE observing and data reduction, and is co-author in the report. He was first author on the AAS Phoenix poster paper reporting these results (paper 66.13, Jan.93), abstract attached.
4. We continued the analysis of other portions of the 23 SWP and LWP high resolution spectra obtained during 1991, to determine, for example, whether the neutral and doubly ionized lines of Fe behave in the systematic ways found for Fe II.

5. An update to the VV Cep analysis was presented at the Interacting Binaries meeting of the Astronomical Society of the Pacific in July'93 (abstract attached).
6. Development of a theoretical model for the discontinuous transfer of mass and the homogenization of the material in the accretion disk continues. Mr. Potter is expected to advance this aspect of the work as well as he begins graduate and thesis work. We note observational similarities to effects computed by Spruit and colleagues, illustrated in the Nov.93 ApJ video edition.

7. This grant is an example of how modest funding can enable undergraduates to be attracted

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105: 45–50, 1993 January

Rapid Mass-Loss Transients in VV Cephei

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ABSTRACT. Biweekly ultraviolet observations of the red supergiant–hot dwarf binary VV Cephei during 1991, obtained near third quadrature, have revealed the existence of short-term continuum variations. We infer these are superposed on an underlying emission-line spectrum. The viewing geometry of this long-period system suggests we are seeing a process associated with nonuniform mass transfer to an accretion disk. This rapid variability can be related to global instabilities in the stellar wind and mass loss from the red supergiant.

1. INTRODUCTION

VV Cephei is a very long-period binary, comprised of an M2 Iab (supergiant) primary plus a hot companion (type B1–B2) orbiting within the extended atmosphere of the primary star. The eccentric orbit and the Hα disk around the B star, inferred by Wright (1977), suggests mass transfer. The orbit is sufficiently eccentric that the primary may fill its Roche lobe near periastron, triggering transient mass loss (Guinan et al. 1985). During a recent analysis of 12 years' worth of ultraviolet spectroscopy of VV Cep, reported by Bauer et al. (1991, hereafter, referred to as BNS91), evidence for transient absorption features was detected. During 1991, the phase of the 20.3-yr binary placed the system near third quadrature, and we report here the results of a new series of regularly spaced *IUE* observations. The detection of systematic, rapid variations is relevant to both the study of the mass-loss physics of the evolved M supergiant, and the processes connected with mass transfer and accretion onto the B star companion. Section 2 discusses the observed variations. Section 3 explores a mass-transfer model. Section 4 summarizes our conclusions and suggests future observational efforts.

2. OBSERVED VARIATIONS

We made use of the *International Ultraviolet Explorer* (*IUE*) satellite (Boggess et al. 1978) to obtain low- and high-dispersion mid- and far-ultraviolet spectra of VV Cep every two weeks between 1991 early June through 1991 late October. Details of the high-dispersion observations are given in Table 1. Low-dispersion observations accompanied these, with 3-min SWP (1150–2000 Å) and 20-s LWP (2000–3200 A) exposure times.

2.1 Continuum

Figure 1 illustrates the light variation extremes for low-dispersion spectra, as observed during 1991. Table 2 documents the integrated flux over the full wavelength range, and selected wavelength-continuum flux levels in the SWP and LWP low-dispersion spectra at each of the 11 dates those spectra were obtained. As Fig. 2 illustrates, the integrated ultraviolet light varies considerably on the 2-week time scales in which the observations were obtained. A semiperiodic alternation between minima and maxima is apparent on a 2–4-week time scale, although faster and slower variations cannot be ruled out. Integrated continuum changes as large as 88% were found in SWP spectra, and 53% in the LWP region.

We began our investigation of the detailed nature of these variations by selecting a series of continuum points throughout the SWP and LWP region, which were found by scanning the high-dispersion spectra at bright phases. These points are probably "pseudocontinuum points," because the spectrum is rich with absorption and emission features (see figures in BNS91). These "continuum" points reflect spectral plateaus, typically 1–2 A wide, selected because they were separated from strong lines and instrument defects. We initially assumed the variation is mostly due to additional absorption in the spectra rather than variable emission. Table 2 displays these high-dispersion continuum points as a function of time and wavelength, and it is clear that the shorter wavelengths are the more variable. By averaging four low-continuum-brightness spectra and five high-continuum-brightness spectra, we derived a continuum ratio as a function of wavelength (Fig. 3). This shows at least 70% variation of extinction in the SWP region, and less than 20% variation in the Fe II and Mg II line rich LWP region (2650–2800 A). This relatively

to astronomical research and end up pursuing graduate work and potentially career efforts in the field. Mr. Potter is an exceptionally bright and capable individual, who will contribute in the future to this subject area of interacting binaries, because of his early exposure to the topic via this grant effort. This is also the last to expire of my grants held at the University of Colorado, in a continuous series of grants starting in 1986. While most of the period was productive, for the record, it has been increasingly difficult to garner the needed resources to pursue this work in Boulder, precipitating my move to another institution.

PUBLICATIONS CITING SUPPORT OF NAG5-1832:

1. "Twelve Years of IUE Spectra of the Interacting Binary VV Cep"
   W. Bauer, R. Stencel and D. Neff
   1991 Astron. Astrophys. Suppl. **90**, pp. 175-190.

2. "Rapid Mass-Loss Transients in VV Cep"
   R. Stencel, D. Potter and W. Bauer
   1993 Publ. Astron. Soc. Pacific **105**, pp. 45-50.

3. "Rapid Mass-Loss Transients in VV Cephei"
   D.Potter, R.Stencel and W.Bauer
   1993 Bulletin Amer. Astron. Soc. 24 (Phoenix meeting poster 66.13).

1. "VV Cephei: Transient Phenomena in an Accretion Disk around a 20 $M_{\odot}$ Star"
   W.H.Bauer and R.Stencel
   1993 Astron. Soc. Pacific Symposium on Interacting Binaries (7/93).

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VV CEPHEI: TRANSIENT PHENOMENA IN AN ACCRETION DISK AROUND A 20 MO MAIN-SEQUENCE STAR

Wendy Hagen Bauer (Wellesley College) and Robert E. Stencel (University of Denver)

VV Cephei is an interacting binary composed of an M2 Iab supergiant primary with a hot B1-2 V companion orbiting within the extended supergiant atmosphere. Although the period is 20.3 years long, the system is close enough to show interaction between the components, and transient phenomena on time scales as short as two weeks have been seen. The M supergiant primary fills its Roche Lobe at periastron, and a stream of material from the primary to the secondary has been mapped out. The B star is surrounded by an accretion disk of about 650 RO which shows numerous emission lines at both optical and ultraviolet wavelengths.

The ultraviolet spectrum as observed by the IUE satellite is filled with both emission and absorption lines. A sharp chromosphere-like absorption spectrum arising from mainly singly ionized elements persists throughout the cycle thus far observed, which extends from emergence from primary eclipse through third quadrature. More than half of the spectra show additional broad absorption (up to 200 km/sec) superimposed on the sharp chromosphere-like spectrum. In some spectra, these features are red-shifted, and in some blue-shifted. They may represent accretion events onto the companion and outbursts of the accretion disk respectively. Signficant changes in these additional absorption and emission features have been seen on time scales as short as two weeks.

Ultraviolet observations with IUE were made at approximately bi-weekly intervals for several months in 1991. The integrated ultraviolet light varies considerably over a two-week time scale with changes as large as 88% in the IUE SWP region and 53% the the LWP region. These variations have been modelled as due to the hot star and disk being irregularly occulted by clumpy material in the extended M star atmosphere. Since the accretion disk is apparently being fed with a clumpy stream, it probably takes time to homogenize, and should be extremely interesting for dynamical studies.

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The 181st Meeting of the American Astronomical Society,
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66.13

Rapid Mass-Loss Transients in VV Cephei

D.Potter and R.E.Stencel (CASA, Univ. Colorado), W.H.Bauer (Whitin Obs., Wellesley College)

Biweekly ultraviolet observations of the red supergiant plus hot dwarf binary, VV Cephei during 1991, obtained near third quadrature, have revealed the existence of short-term continuum variations. We infer these are superposed on an underlying emission-line spectrum. The viewing geometry of this long period system suggests we are seeing a process associated with non-uniform mass transfer to an accretion disk. This rapid variability can be related to global instabilities in the stellar wind and mass loss from the red supergiant.

A complete report has been submitted to the Publications of the Astronomical Society of the Pacific. This research was supported in part by IUE–NASA grant NAG5-1832.

NGC 6888 is an oblong, clumpy shell of emission surrounding a WN6 star. It is ~ 15 ' long at its major axis, lies at a distance of about 1.5 kpc, and is expanding with a velocity of 85 km s^{-1}. The shell is especially prominent in Hα and [N II], but also has an [O III] 'skin' which is tied to the shell in the NE and SW, but which extends well beyond it in the NW and SE where the shell appears to have been breached. We have used the Wide Field version of the imaging Fabry-Perot system developed for the 60" Palomar telescope to obtain narrow band [O III] and Hα images of NGC 6888. The instrument has a 16' X 16' field of view, a total system speed of f/1.65, and a velocity resolution of 20 km s^{-1}. The spatial resolution was 0.96 "/pixel with integration times of 15 minutes for [O III] and 5 minut · for Hα at each etalon setting. The [O III] skin around NGC 6888 appears to consist of wind-driven radiative shocks. Material behind the shocks has presumably cooled to the point of photoionization equilibrium with the radiation field of the star. The extremely high ratio of [O III]/Hβ in these back-illuminated shocks (> 20) shows that they are optically thin to ionizing radiation. Further, the absence of a bright Hα halo indicates that the ambient medium has a lower density than was previously claimed, which in turn supports the idea of a significant contribution to the shell from stellar mass loss. Dynamically, shocks to the NW fountain from the breach rather than radiating from the star, suggesting a shock driven by internal pressure , and not a simple wind-driven shell. The patterns of the local shock velocities around the breaches in the shell allow us to estimate the time at which Rayleigh-Taylor instabilities became important.

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