JOINT DISCUSSION NO. 4

ULTRAVIOLET ASTRONOMY-

NEW RESULTS FROM RECENT SPACE EXPERIMENTS

(Commissions 28, 29, 34, 44, 45)

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https://doi.org/10.1017/S1539299600003968 Published online by Cambridge University Press

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https://doi.org/10.1017/S1539299600003968 Published online by Cambridge University Press

ULTRAVIOLET EMISSION FROM STRONG X-RAY SOURCES AS OBSERVED WITH IUE

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I. INTRODUCTION

In 1972, when the request for observing programs for the International Ultraviolet Explorer (IUE) was first made by NASA, ESA and the United Kingdom, a number of scientists recognized that observations in the ultraviolet of the strong galactic X-ray sources could be a fruitful activity. The underlying nature of those objects was understood. Their binary nature had been discovered through the X-ray observations which, combined with extensive optical observations and the insight gained through the tie to traditional ideas of stellar evolution, led to a picture whose general features are still accepted. The strong X-ray sources were taken to be close binary systems in which one object was a compact star, either a neutron star or a black hole, and the other object a common star in a stage of its life when it was undergoing great mass loss, either as a stellar wind or through Roche-lobe overflow.

It was further known that the X-ray sources exhibited a high degree of variability, both periodic as resulting from the binary motion, and erratic or quasi-periodic, arising for less clearly understood reasons. Because both the accretion disks and the photospheres of the giant/supergiant components of these systems were presumed to contain gas at temperatures of a few times 10^4 degrees, studies at ultraviolet wavelengths---1000 to 3000Å---were, from the time of their discovery in the late '60's and early '70's, deemed important to completing our understanding of the physical processes involved. However, before the launch of IUE, no satellite had both the sensitivity and spectroscopic resolution required for an adequate study. Table 1 lists some of the more prominent papers that were published on the basis of the very limited observational material obtainable before IUE. In addition, the information in the OAO Catalog (Code and Meade, 1979) and the TD-1 Catalog (Jamar et al, 1976) for stars of similar spectral type proved invaluable in enabling us to determine proper exposure times for the IUE observations. Recognizing that IUE observing time was a precious commodity and that many observations would be needed to sort out the various changes that occurred, the investigators involved in this work decided to pool some fraction of their observing time in order to provide

Patrick A. Wayman (ed.), Highlights of Astronomy, Vol. 5, 231–245.

Table 1. Papers based on observations before IUE.

OAO-2 Satellite

"Ultraviolet Photometry of Globular Clusters", Welch and Code (1972).
"OAO-2 Observations of HD 153919 = 2U 1700-37", Heap (1973).

Orion-2 Satellite

"Ultraviolet Continuous Spectra of Gamma Cassiopeia", Gurzadyan (1975).

Copernicus Satellite

"Ultraviolet and Optical Spectral Variability in the Be Star γ Cassiopeiae: A Coronal Model for the Emission", Marlborough, Snow and Slettebak (1978).

ANS satellite

"Far-ultraviolet Observations of the Globular Cluster 47 Tucanae", de Boer and van Albada (1976).

"Ultraviolet Photometric Observations of the X-ray Binary HD 153919 (3U 1700-37)", Hammerschlag-Hensberge and Wu (1977).

"Interstellar Extinction and Ultraviolet Flux Distribution of Scorpius X-1", Wu (1979).

extensive observations of a selected number of those objects.

Table 2 lists the investigators who initially joined in this collaborative effort. The numbers of scientists involved is by now very extensive as evidenced by the authorship of the various papers that have emerged. Table 3 lists the observations made by those groups, both those as part of the initial collaboration and those carried out as part of more limited collaborations. We also list those conducted by the investigators at the Harvard/Smithsonian Center for Astrophysics. Table 4 lists the research papers that have resulted from the observations listed in Table 3. We include papers written as part of the commissioning activity since certain results contained there are not published elsewhere.

Since so much of the material is now or will soon be in print, we will not review all of it here; rather, we will try to summarize the highlights in order to demonstrate where our understanding of these fascinating objects has improved and to indicate where future observational results may be taking us. For this purpose, the paper divides itself naturally into three parts--discussion of the low mass binaries (e.g. HZ Her), the high mass binaries (e.g. Cyg X-1) and the globular clusters.

Table 2. List of collaborators in the International Collaborative Program to observe X-ray binaries with IUE

Institution	Investigators*	Name of IUE Guest Investigator Program
Univ. College, London	Wilson, R.	The ultraviolet spectra and variability of galactic and extragalactic X-ray sources
Mullard Space Sci. Lab.	Culhane, J. L.	
Mullard Space Sci. Lab.	Glencross, W. M.	
Osserv. Astrof. Asiago	Barbon, R.	Optical counterparts of galactic X-ray sources
	Bernacca, P. L.	
	Ciatti, F.	
Lab. Fis. Cosmica, Milano	Reina, C.	
	Treves, A.	
Steward Obs., Tucson (transferred to ESO, Geneva)	Tarenghi, M.	
Astr. Inst., Utrecht	van den Heuvel, E.P.J.	The study of X-ray binaries
Space Res. Lab., Utrecht	Lamers, H. J.	
Univ. Texas--Austin	Vanden Bout, P. A.	Ultraviolet spectroscopy of X-ray emitting binary systems
Harvard College Obs.	Dupree, A. K.	Ultraviolet investigations of stellar X-ray sources
	Black, J. H.	
Amer. Science & Eng. Inc. (transferred to Smithsonian Astrophys. Obs.)	Gursky, H.	Study of the ultraviolet spectra of selected galactic X-ray sources
	Matilsky, T.	
	Kellogg, E. M.	
Princeton Univ. (transferred to Mt. Stromolo Obs.)	Morton, D. C.	Ultraviolet spectroscopy of stellar and extragalactic objects

*Additional collaborators, not listed in the proposals, were included as co-authors of the 4 collaborative papers.

Table 3. Summary of IUE observations of X-ray sources.

Object	Observations during Commissioning		Observations by Collaborators		Observations by Center for Astrophysics	
	Long	Short	Long	Short	Long	Short
I. Full International Collaboration						
Cygnus X-1	0	2	1	3	3	4
HZ Herculis	0	3	4	5	1	8
Scorpio X-1	0	0	8	26	1	1
Vela X-1	0	0	5	3	3	7
II. Separate Special Collaborations						
3U 1700-37	1	3	5	16	3	22
V861 Scorpii*	0	0	6	6	1	3
III. Other Strong X-ray Binaries						
LMC X-4*	0	0	0	0	1	1
SMC X-1	0	0	0	0	1	4
Cygnus X-2	0	0	0	0	0	2
IV. Globular Clusters						
M15	0	0	0	0	3	2
M92	0	0	0	0	3	4
NGC 1851	0	0	0	0	1	1
NGC 6624	0	0	0	0	1	2
NGC 6752	0	0	0	0	3	8
47 Tucanae	0	0	0	0	2	2
V. Other X-ray Sources						
γ Cassiopeiae*	0	0	0	0	1	1
VW Cephei	0	0	0	0	3	2
SS Cygni	0	2	0	0	1	11
U Geminorum	0	0	0	0	0	6
HD 20210	0	0	0	0	1	2
AM Herculis*	0	0	0	0	6	17
HZ 43	0	1	0	0	3	2
θ^2 Orionis A	0	0	0	0	0	2
θ^2 Orionis B	0	0	0	0	0	1
X Persei	0	0	0	0	1	3
Totals	1	11	29	59	43	118

*In addition, ESA/SRC investigators observed these objects, plus 3U 1145-61, as part of their individual research programs.

Table 4. Papers resulting from IUE collaboration

Commissioning Phase Papers

"IUE" Observations of X-ray Sources: HD153919 (4U1700-37),HDE226868 (Cyg X-1), HZ Her (Her X-1)".Dupree, et al, (1978).

"IUE Observations of Hot Stars: HZ43, BD+75^{O}325, NGC6826, SS Cygni, ηCarinae".Heap, et al, (1978).

X-Ray Collaborative Papers

"Ultraviolet, Visible, Infrared, and X-Ray Observations of Sco X-1". Willis, et al, (1979).

"IUE Observations of the X-Ray Source HZ Herculis/Her X-1".Gursky, et al, (1979).

"Simultaneous Ultraviolet, Optical, and X-Ray Observations of the X-Ray Source Vela X-1 (HD 77581)".Dupree, et al, (1979a).

"Ultraviolet, X-Ray and Infrared Observations of HD 226868 = CYG X-1". Treves, et al, (1979).

Other Papers

"Ultraviolet Observations of AM Herculis with IUE".Raymond, et al, (1979).

"Ultraviolet Spectroscopic Measurements of Globular Clusters".Dupree, et al, (1979b).

"Ultraviolet and Coordinated Visible and X-Ray Observations of the Be Stars HD 102567 (4U1145-61), X Per and γ Cas".Hammerschlag-Hensberge, et al, (1979).

II. THE PHENOMENOLOGY OF THE STRONG X-RAY SOURCES

While it is likely that there is a continuum of X-ray luminosities ranging from objects as bright as any in the galaxy down to those as dim as the sun, the objects discussed here, whose properties define the binary X-ray stars, have X-ray luminosities in the range 10^{36}-10^{38} erg/sec. This power is so great that it cannot result as an inconsequential aspect of some larger reservoir of emitted energy. It can easily be surmised, based on distributional and other evidence, that there are perhaps a hundred such sources in the Galaxy and that they appear to be divided into two groups (c.f. Gursky and Schreir, 1975). One group, as typified by Sco X-1, Cyg X-2 and Her X-1 (HZ Her) contain late type stars (≈F). The mechanism for mass transfer is believed to

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be Roche-lobe overflow as would occur if the stars are in a giant phase. Their spatial distribution is typical of population II--both Sco X-1 and HZ Her are far removed from the galactic plane, and Cyg X-2 shows a high velocity (≈200 km/sec) with respect to the sun. The other group is associated with early type stars (O and B), certain of which are supergiants. The mass transfer mechanism is believed to be the capture, by the compact companion, of a small fraction of an intense stellar wind emanating from the atmosphere of its hot, massive neighbor.

The compact member of the binary system that is actually the X-ray source is most likely to be a neutron star or a black hole. For either object only a modest mass capture rate ($\approx 10^{-7}$-10^{-8} $M_\odot$/yr) is sufficient to power the most luminous X-ray source. Also there is direct evidence for these objects as the source; for example, short period pulsing as the signature of a neutron star.

In these objects there is a wealth of phenomena that relate to the presence of the X-ray source that should be observable in the ultra-violet: Stellar winds are revealed through P Cygni profiles, mass flow generally produces hot gas streams, mass capture must result in accretion discs, and the x-radiation field will produce anomolous heating of any nearby surfaces and ionization of local gases.

Much of this phenomenology is observed in the X-ray and the optical wavelengths. However, certain characteristics will best be studied in the ultraviolet because of some particular combination of radiation and atomic physics.

The globular clusters represent a special case; they do contain strong X-ray sources, some of which are X-ray bursters. The bursters were only discovered in 1976 (Grindlay et al, 1976) and may not be binaries (Gursky, 1977). But they are strong X-ray sources, justifying their inclusion here.

III. LOW MASS BINARIES

HZ Herculis has provided the most clear evidence of the nature of the low mass binaries systems. The binary nature is positively established through the observation of X-ray eclipses and doppler shifts of the X-ray pulse period. The optical light curve is extraordinarily complex, but equally regular as evidenced by the work of Boynton and others. Much of this complexity can be represented by a model combining a heated photosphere that is seen to vary with the orbital period of 1.7 days and a precessing accretion disc that varies with the 35 day X-ray on-off cycle. (Petterson, 1975; Gerend and Boynton, 1976).

IUE results on HZ Herculis have been reported by Dupree et al, (1978) as part of the commissioning phase and more extensively by Gursky et al, (1979). As seen from Table 3, a total of 21 exposures were made of HZ Herculis, of which 16 were taken at short wavelength (1000 to 2000A). These data are sufficient to establish that variations in the ultraviolet largely mimic what is seen in the optical; more significantly the data yield striking confirmation of the Milgrom-Salpeter (1975) predictions for the emission from a heated photosphere as illustrated in figure 1 which shows the UV spectrum compared to the predicted spectrum.

Figure 2 shows the light curve at 1500Å for the 1.7 day binary period. To increase the density of data, the curve is folded around $\phi = 0.5$. The solid curve is the prediction by Milgrom-Salpeter and agrees very well with the observations near quadrature in both shape

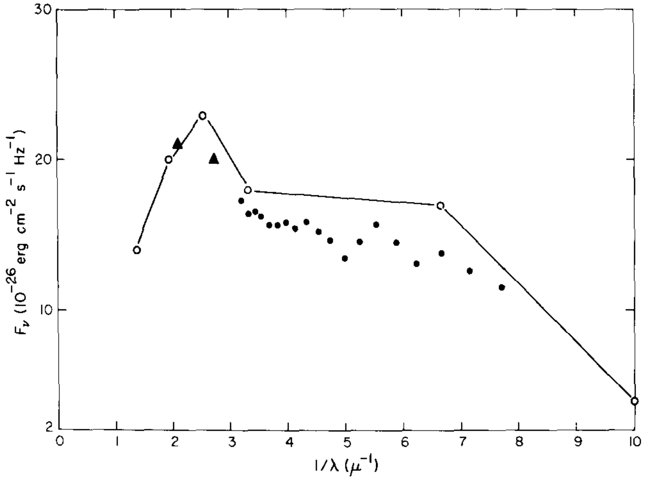

Fig. 1 Comparison of observed and predicted spectra of HZ Her near maximum light. Filled circles: IUE data. Open circles: M-S model prediction. Tiangles: U,B.

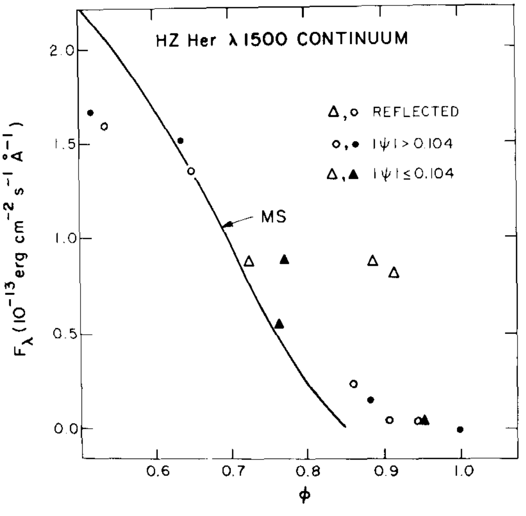

Fig. 2 Comparison of observed and predicted light curves of HZ Her near 1500A. reflected around $\phi = 0.5$.

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and intensity. The deviations from the prediction near phases 0.5 and 0 are expected from the optical data and apparently result from the accretion disc. The high points at $\phi \approx 0.9$ occur at a time in the 35 day cycle when the accretion disc is predicted to be in its most face-on aspect with respect to the Earth and its radiation is expected to be the greatest.

Typical short wavelength spectra from HZ Herculis are shown in figure 3. Emission lines from N V and C IV are quite prominent; weaker emission is seen from O V, Si IV, He II and probably other high excitation lines. The power in the N V and C IV lines tends to vary in the same way as the continuum, indicating that the lines are formed near the photosphere. The lines may be formed in a complex region of large temperature gradients or high opacity since the ratio N V/C IV is so much different from what is expected from a gas in radiative equilibrium. The ratio, N V/C IV, varies more or less smoothly around the orbit, from ≈ 2 near phase 0.5 to ≈ 1 near eclipse.

Except for the variation in N V/C IV there are no large differences between the spectrum observed when we expect to see mostly photospheric emission compared to when we expect to see moslty accretion disc emission, suggesting that the same model for the radiation may apply to both. Thus the principal source of heating of the outer portions of the accretion disc may be the absorption of X-rays produced in the inner portion rather than the conversion of the gravitational energy falling through the outer portions.

Sco X-1 was the subject of an extensive program of correlated ultraviolet visible, infrared and X-ray observations as reported by Willis et al, (1979). Fortunately data were obtained during both the "high" and "low" states of the source. As in the visible, the UV flux increases by ≈ 2 during the high state, accompanied by a corresponding increase in line strengths. There do not appear to be intensity variations connected with the 0.8 day orbital period.

As seen in figure 3, the spectrum of Sco X-1 is very similar to that of HZ Her with a ratio N V/C IV appropriate to the near-eclipse observations of HZ Her. Based on the fact that a ratio N V/C IV near unity is so unexpected it is tempting to attribute the UV emission from Sco X-1 to an accretion disc.

The spectrum of Cyg X-2, (also shown in fig. 3), has the same continuum shape as Sco X-1 and HZ Her, but the N V/C IV is now >3. In the visible, Cyg X-2 does not display any significant X-ray heating effect on its stellar companion. Thus if the UV originates in an accretion disc, the N V/C IV ratio is not an invariant characteristic of these discs.

IV. HIGH MASS BINARIES

In the case of the low mass systems, the ordinary star can be barely seen, if at all. In the high mass system, in the visible range, the light from the star dominates that from the X-ray source by about a factor of $\approx 10^3$. Since these are very hot stars, the same is expected in the UV. Thus the influence of the X-ray source is expected to be

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rather subtle if observed at all. The one effect that we have observed in two sources is an orbital dependence in the appearance of the P-cygni profiles as predicted by Hatchett and McCray (1977). This results from the X-ray source affecting the density of specific ions in its vicinity, which in turn changes the absorption profile of the line. This is best seen in the data from Vela X-1 shown in figure 4 taken from Dupree et al, (1979a) where the absorption portion of the Si IV line is considerable filled in at the blueward (high velocity) portion of the line at phases close to 0.5. At this phase, the X-ray source is in front of the star and the x-radiation is increasing the temperature of the stellar wind with high negative velocity. In this region Si IV is

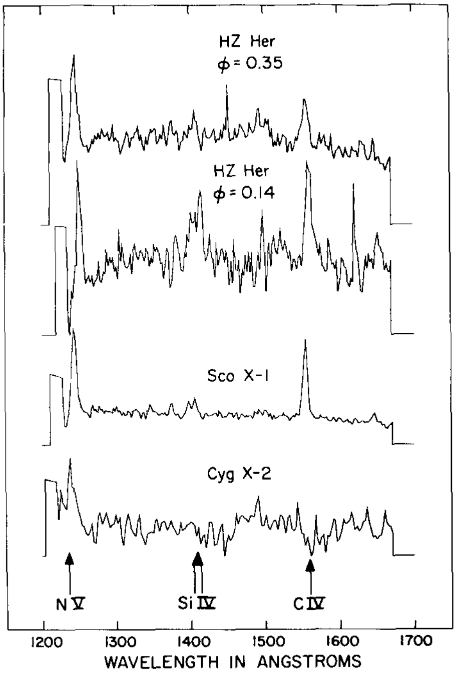

Fig. 3 Comparison of IUE short-wavelength spectra of HZ Her, Sco X-1, and Cyg X-2.

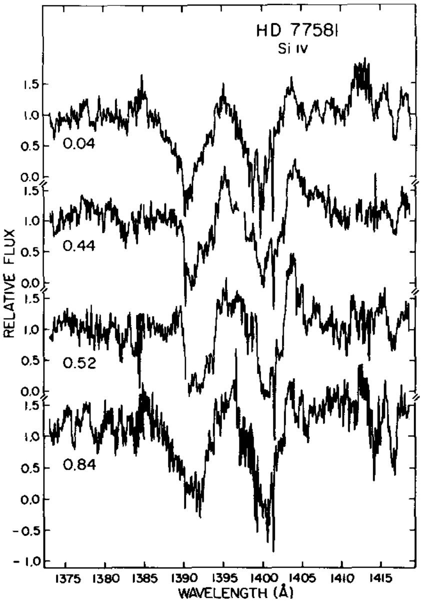

Fig. 4 Si IV lines in Vela X-1 as a function of phase from IUE high dispersion spectra.

depleted compared to elsewhere around the system.

The same effect may be occurring in Cygnus X-1 (Treves et al, 1979). Figure 5 shows low dispersion spectra of this source at several phases. The Si IV and C IV lines show significant variations with phase; however, because of the low resolution, these changes cannot be uniquely ascribed to a given mechanism.

The source 3U1700-37 (Dupree et al, 1978) shows no changes in the P-Cygni profiles with phase. This may be a result of very high opacity in the lines; that is, if the opacity in the stellar wind is very high,

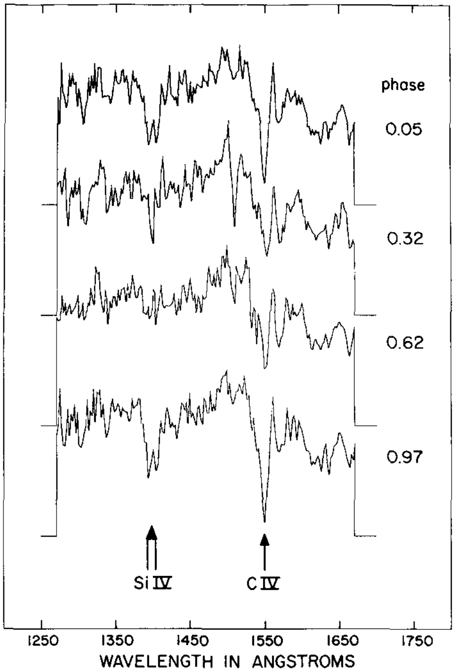

Fig. 5 Cyg X-1 spectra as a function of phase from IUE low dispersion.

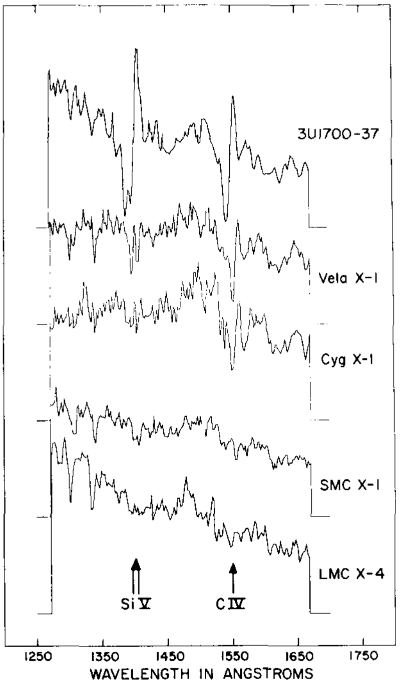

Fig. 6 Comparison of IUE short-wavelength spectra of 3U1700-37, Vela X-1, Cyg X-1, and LMC X-4.

changing the ionization state of a portion of the wind many not have a significant effect on the absorption portion of the P-Cygni profile.

Figure 6 shows the short-wavelength, low dispersion spectra of five high mass systems (Vela X-1, 3U1700-37, Cygnus X-1, SMC X-1, LMC X-4). The sources in the Magallanic Clouds show little if any trace of Si IV and C IV. This is presumably a reflection of the lower metallicity of the Clouds, by factors of two to five, compared to the Galaxy; (Peimbert, 1975).

V. GLOBULAR CLUSTERS

As noted, several globular clusters are known to contain strong X-ray sources. Certain of these are known to be bursters and are likely to be rather different from the two categories of X-ray sources discussed above. By now six globular clusters have been observed by IUE and certain of their characteristics are listed in Table 5.

Three of the clusters are known to contain X-ray sources; the others were chosen to have the same range of compactness and metallicity.

Table 5. Summary of observations

Cluster	M15	M92	NGC 6752	NGC 1851	NGC 6624	47 Tuc
[Fe/H]	-2.0	-2.0	-1.5	-1.0	-0.7	-0.5
E_{B-V}	0.12	0.02	0.00	0.14	0.25	0.02
X-ray?	yes	no	no	yes	yes	no
$\log r_t/r_c$	1.96	1.78	1.84	2.21	---	2.03
r_c (arcsec)	14	16.5	30	8	9.5	28
R(kpc)	10.0	8.0	5.0	9.5	8.0	4.9
F_{1500}+	1.2	.83	2.0	.83	.22	<.24
F_{3000}/F_{1500}	2.4	1.5	0.7	2.0	3.1	>7
r_{1400}#	4.2	8.5	>20	3.3	<4	---
r_{3000}#	7	14	>20	5.2	4.5	>10
t_{ex} SWP (min)	90-100	75-180	45-180	180	180	180-260
t_{ex} LWR (min)	60-100	30-40	30-40	60	90	18-30

*Optical data from Peterson and King (1975) and Liller and Carney (1978)

+Fλ = flux observed in the large aperture (≃20" x 10") at wavelength λ (in Angstroms), in units of 10^{-13} erg cm^{-2} s^{-1} $Å^{-1}$, corrected for interstellar extinction using the standard extinction curve of Bless and Savage (1972).

#r_λ = observed half-width at half-maximum of light distribution at λ, in units of arc seconds. The point-source widths are r^*_{1400} = 2".7 and r^*_{3000} = 3".0.

Several of the globular clusters were found to have a bright core at the short UV wavelength that appeared to be narrower than what was seen at long wavelength or in the visual range (Dupree et al, 1979b). Further analysis suggests that single stars may be influencing the result. Figure 7 shows the spatial distribution at 1500A and 2900A from M15. These data were obtained from two separate exposures, one centered on the cluster and the other displaced by 15" in the direction of the slit. The two UV distributions are compared to visual data from Newell and O'Neill (1978) folded through the IUE spectrometer slit resolution function on a logarithmic intensity scale.

It is apparent that the bulk of the UV radiation at 1500A appears in a core that is narrower (FWHM ≃8") than that at 2900A or at visual wavelengths (FWHM ≃12"). However, it is possible to fit the 1500A

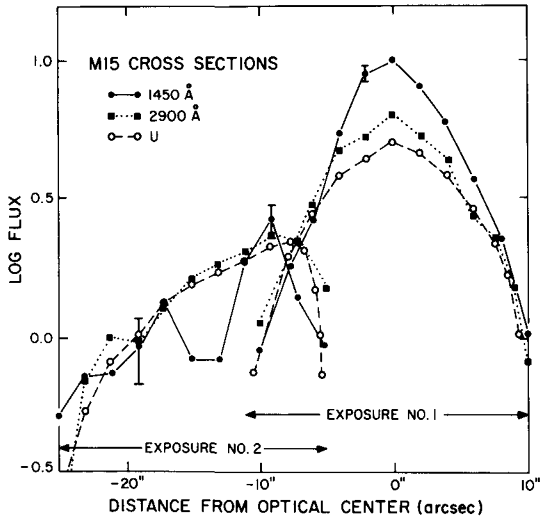

Fig. 7 Comparison of angular distribution of light in M15 between ground-based (U, ≃λ 3650) and IUE (λλ2900, 1450).

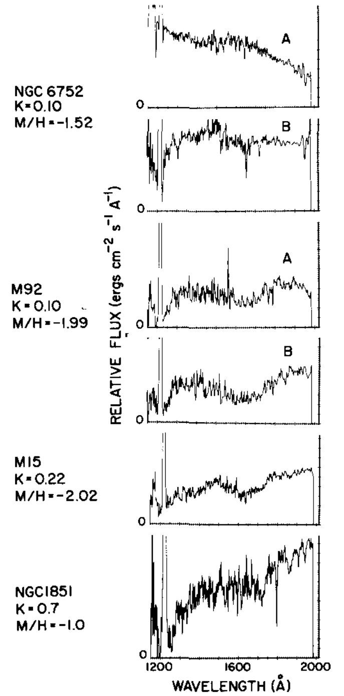

Fig. 8 Comparison of spectra for metal-poor globular clusters: NGC 6752, M92, M15, and NGC 1851.

distribution with a broader distribution that matches the observation at visual plus a single star near displacement of zero with about 2/3 the peak amplitude. Such a star would have a brightness perhaps one or two magnitudes above the blue end of the horizontal branch for this cluster.

In NGC 6752 and M92 the "core" consists of double peaks, inviting the idea that the spatial distribution is dominated by single stars. Figure 8 shows individual short-wavelength spectra for these clusters and M15 and NGC 1851. The spectra are of the dominant peaks, two each from NGC 6752 and M92, and single ones from the other two. Assuming that these spectra are originating primarily from single stars, the data appear to comprise a stellar sequence in the range B to A. The sequence fits in well with the known distribution of stars along the horizontal branch for these clusters. As indicated by the Kukarkin index K, NGC 6752 has the most blue stars on its horizontal branch, and NGC 1851 the least. Since the bluest stars will also be the brightest in the short-wavelength range they will tend to dominate the "image" here in the same way that red giants dominate a visual image.

The spectra from M92 and M15 contain a broad feature, centered at 1650Å that may be the blend of a large number of metal absorption lines. A narrower feature is present at 1700A in NGC 1851 that may have a similar origin. These features do not appear in the extensive simulations of stellar atmospheres of Kurucz (1979) but may appear in the B9V star, αPeg, as seen by OAO 2 (Code and Meade, 1979).

In the metal rich clusters, the blue end of the horizontal branch may be totally absent. In NGC 6624 we do see faint emission from a single object that may be emanating from the X-ray source in that cluster. The spectral shape and continuum level are consistent with the extrapolation from the X-rays of a simple brehmsstrahlung spectrum.

VI. SUMMARY

Observations in the ultraviolet of the strong X-ray sources have provided some valuable insights into the nature of these systems. For the high mass systems, it is clear that observations of variations of the P-Cygni profiles will prove an important diagnostic tool for learning about the pattern of mass flow around the massive companion star. For the low mass systems it is possible that the HZ Her data will reveal a signature for an accretion disc through the anomalous N V/C IV ratio.

It is still the case that these are faint objects and IUE has only a rather modest aperture. Thus exposures are long and limited in both spatial and spectral resolution. Nevertheless continued observations of these and similar systems will provide information that cannot be obtained in any other wavelength band.

REFERENCES:

Bless, R.C., and Savage, B.D.: 1972, Ap. J., 171, 293.

Code, A.D., and Meade, M.R.: 1979, Ap. J. Suppl., 39, 195.

de Boer, K.S., and van Albada, T.S.: 1976, Astr. & Ap., 52, 59.

Dupree, A.K., Davis, R.J., Gursky, H., Hartmann, L.W., Raymond, J.C., Boggess, A., Holm, A., Kondo, Y., Wu, C.C., Macchetto, F., Sandford, M.C.W., Willis, A.J., Wilson, R., Ciatti, F., Hutchings, J.B., Johnson, H.M., Jugaku, J., Morton, D.C., Treves, A., and van den Heuvel, E.P.J.: 1978, Nature, 275, 400.

Dupree, A.K., Gursky, H., Black, J.H., Davis, R.J., Hartmann, L., Matilsky, T., Raymond, J.C., Hammerschlag-Hensberge, G., van den Heuvel, E.P.J., Lamers, H.J.G.L.M., VandenBout, P.A., Morton, D.C., de Loore, C., Burger, M., van Dessel, E.L., Menzies, J.W., Whitelock, P.A., Watson, M., and Sanford, P.W.: 1979a, submitted to Ap. J. (August).

Dupree, A.K., Hartmann, L., Black, J.H., Davis, R.J., Matilsky, T.A., Raymond, J.C., and Gursky, H.: 1979b, Ap. J., 230, L89.

Gerend, D., and Boynton, P.E.: 1976, Ap. J., 209, 562.

Grindlay, J.H., Gursky, H., Schnopper, H., Parsignault, D.R., Heise, J., Brinkman, A.C., and Schrijrer, J.: 1976, Ap. J., 205, L127.

Gursky, H.: 1977, Ann. N.Y. Acad. Sci., 302, 197.

Gursky, H., and Schreier, E.: 1975, in Neutron Stars, Black Holes and Binary X-ray Sources (Ed. H. Gursky & R. Ruffini), Dordrecht, Holland: Reidel. pp. 175-220.
Gursky, H., Dupree, A.K., Hartmann, L.W., Raymond, J., Davis, R.J., Black, J., Matilsky, T.A., Howarth, I.D., Willis, A.J., Wilson R., Sandford, M.C.W., Vanden Bout, P., Sanner, F., Hammerschlag-Hensberge, G., van den Heuvel, E.P.J., Lamers, H.J.G.L.M., Burger, M., de Loore, C., and Treves, A.: 1979, submitted to Ap. J. (August).
Gurzadyan, G.A.: 1975, Ast. & Ap., 40, 447.
Hammerschlag-Hensberge, G., and Wu, C.C.: 1977, Astr. & Ap., 56, 433.
Hammerschlag-Hensberge, G., van den Heuvel, E.P.J., Lamers, H.J.G.L.M., de Loore, C., Burger, M., Glencross, W., Howarth, I., Willis, A.J., Wilson, R., Menzies, J., Whitelock, P.A., van Dessel, E.L., Sanford P.: 1979, submitted to Astr. & Ap. (June).
Hatchett, S., and McCray, R.: 1977, Ap. J., 211, 552.
Heap, S.R.: 1973, Ap. J., 181, L71.
Heap, S.R., Boggess, A., Holm, A., Klinglesmith, D.A., Sparks, W., West, D., Wu, C.C., Boksenberg, A., Willis, A., Wilson, R., Macchetto, F., Selvelli, P.L., Stickland, D., Greenstein, J.L., Hutchings, J.B., Underhill, A.B., Viotti, R., and Whelan, J.A.J.: 1978, Nature, 275, 385.
Jamar, C., Macau-Hercot, D., Monfils, A., Thompson, G.I., Houziaux, L., and Wilson, R.: 1976: Ultraviolet Bright-Star Spectrophotometric Catalogue (ESA SR-27). Paris: European Space Agency.
Kurucz, R.L.: 1979, Ap. J. Suppl., 40, 1.
Liller, M.W., and Carney, B.W.: 1978, Ap. J., 224, 383.
Marlborough, J.M., Snow, T.P., Jr., and Slettebak, A.: 1978, Ap. J., 224, 157.
Milgrom, M., and Salpeter, E.E.: 1975, Ap. J., 196, 589.
Newell, B., and O'Neill, E.J.O.: 1978, Ap. J. Suppl., 37, 27.
Peimbert, M.: 1975, Ann. Rev. Astr. & Ap., 13, 113.
Peterson, C.J., and King, I.R.: 1975, Ap. J., 180, 427.
Petterson, J.A.: 1975, Ap. J., 201, L61.
Raymond, J.C., Black, J.H., Davis, R.J., Dupree, A.K., Gursky, H., Hartmann, L., and Matilsky, T.A.: 1979, Ap. J., 230, L95.
Treves, A., Chiappetti, L., Tanzi, E.G., Tarenghi, M., Gursky, H., Dupree, A.K., Hartmann, L.W., Raymond, J., Davis, R.J., Black, J., Matilsky, T.A., Vanden Bout, P., Sanford, P.W., Joseph, R.D., and Meikle, W.P.S.: 1979, submitted to Ap. J. (September).
Welch, G.A., and Code, A.D.: 1972, in The Scientific Results from the Orbiting Astronomical Observatory (OAO-2) (NASA SP-310), Washington: NASA. pp. 541-558.
Willis, A.J., Wilson, R., Vanden Bout, P., Sanner, F., Burger, M., de Loore, C., van Dessel, E., Whitelock, P., Menzies, W.P.S., Sanford, P., Black, J., Davis, R.J., Dupree, A.K., Gursky, H., Hartmann, L., Raymond, J., and Sandford, M.C.W.: 1979, submitted to Ap. J.(June).
Wu, C.C.: 1979, Ap. J., 227, 291.

DISCUSSION:

L. Carrasco: The presence of the UV continuum and lines in globular cluster cores could be due to the inclusion of a few UV-bright stars within the field of the spectograph slit, instead of the inclusion of large numbers of blue horizontal branch stars, which are not only fainter but cooler as well.

H. Gursky: That is a possibility, except that we may have problems with the numbers. For every star above the horizontal branch, I must have 100 blue horizontal-branch stars. It then becomes necessary to explain why the horizontal branch stars are not present.

https://doi.org/10.1017/S1539299600003968 Published online by Cambridge University Press