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STUDIES AND OBSERVATIONS

OF ULTRAVIOLET AND X-RAY SOURCES

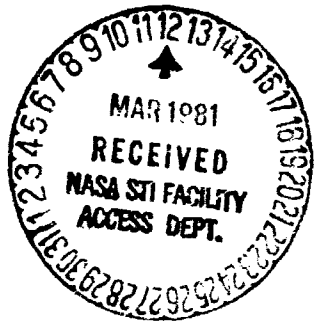
NASA Grant NAG 5-5

Final Report

For the period 1 January 1980 to 31 December 1980

Principal Investigators:

Herbert Gursky
Margaret Geller
Giuseppina Fabbiano



February 1981

Prepared for

National Aeronautics and Space Administration
Washington, DC 20546

Smithsonian Institution
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Cambridge, MA 02138

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Final Report

Introduction

This report summarizes the status of research undertaken with the IUE satellite for programs on strong binary X-ray stars, X-ray globular clusters, variable Seyfert galaxies, and cataclysmic variables.

a) High-Luminosity X-ray Sources

A major campaign to observe the binary systems Vela X-1 involving international collaboration was successfully completed (1). This work showed that changes in the UV resonance-line profiles of the primary star's stellar wind due to ionization by the X-ray source could be observed with IUE. These observations were shown to be remarkably consistent with model calculations performed by us based on a simple approximation to the Hachett and McCray theory of X-ray ionization of stellar winds establishing consistent parameters of X-ray luminosity, mass loss rate, and stellar winds ionization.

We have attempted to apply these results to Cyg X-1, using both the low-dispersion spectra obtained in an international collaborative effort (2) and our own long-exposure, high dispersion spectra, intended to obtain the wind terminal velocities. Our preliminary results indicate that the mass of the primary star can be estimated at ~ 23-30 $M_{\odot}$ based on the wind terminal velocity and Abbot's relation between V_T and the escape velocity. From the variations of the line equivalent widths with phase we are able to estimate crude limits on the inclination of the system, which result in a new estimate of the compact object's mass ~ 5-13 $M_{\odot}$, consistent with, but independent of, previous determinations.

A study of the early-type X-ray binary HD 152667 was also made in colla-

boration with J. Hutchings (3), which examined the evidence for variations in the stellar wind.

We also obtained a series of exposures on Her X-1 through eclipse which were designed to determine the accretion disk size and characteristic temperature more precisely, but which are in rough agreement with the results of a collaborative paper (4). We are now pursuing theoretical calculations with R. London intended to model both the X-ray heated photosphere and the disk spectra.

b) Globular Clusters

We have continued to analyze the spatial distribution of light near the centers of compact globular clusters. This work has shown that the central excess concentration of blue stars (dominating the cluster light at wavelengths $\lesssim$ 1500Å) relative to red giants is a general feature of several clusters. Since the most likely mechanism of segregation is selection by mass, we can use the observed excess light to determine the average mass of the blue stars. The result (5) is $M \sim 2\ M_{\odot}$, which strongly suggests that the stars are members of binary systems. This finding may have important implications for the formation of X-ray binaries in globular clusters.

c) Variability of Seyferts

A number of Type I Seyfert nuclei show radio, optical and/or X-ray variability on timescales ranging from minutes to years. Correlated observations at a variety of wavelengths can place important constraints on the mechanisms for nuclear continuum emission. Thermal and nonthermal mechanisms make distinct predictions which can be tested in part by observations in the UV. We have obtained some information about three fundamental aspects of the origin of the UV continuum: (1) is the UV radiation predominantly thermal or nonthermal in origin, (2) how large is the emission region, and (3) does the UV flux

originate in the same region responsible for radio, IR, optical and/or X-ray continuum emission?

We have monitored the Seyfert galaxies Mk 509 and III Zw 2. The two galaxies differ markedly in their radio properties. III Zw 2 is a strong source with a highly variable compact component, while Mk 509 is a very weak source. Both galaxies show significant variations in X-rays and Mk 509 has shown variations at optical wavelengths as well.

For III Zw 2, the amplitude of the variations in the UV-O-IR range is less than or of order 15% whereas in the X-ray and high frequency radio the variations exceed 50%. The amplitude of the variations in Mk 509 decreases steadily from the X-ray to the infrared.

For both objects, the overall energy distribution appears to be nonthermal. It has been suggested that the IR continuum in III Zw 2 is due to dust, however the optical and UV observations of III Zw 2 and Mk 509 suggest that this is not the case. The $H\alpha/H\beta/H\gamma$ ratios in both objects indicate little reddening for the region of permitted line formation and the equivalent widths of the optical and UV lines do not vary. The IR-UV spectra of III Zw 2 and Mk 509 have the same shape. There is no evidence for the 2200Å feature in the long wavelength spectrum of Mk 509.

If the IR is not thermally reradiated UV flux, the low amplitude of variability in UV IR indicates that the region in which this radiation originates is not the same as that in which the radio and X-rays are produced. The simultaneous appearance of bursts in the radio and X-ray in III Zw 2 implies that the X-radiation is inverse Compton-scattered flux produced in the compact radio component.

The variability observations indicate that the physical conditions in these two objects differ markedly even though their optical properties and overall

energy distributions from IR to X-ray are very similar.

A preliminary version of these results was reported at the 2nd year IUE conference at GSFC, May 5-7, and will appear in that symposium volume. When the data from our most recent observing session is reduced, papers on III Zw 2 and Markarion 509 will be submitted for publication.

d) Cataclysmic Variables

The analysis of the IUE data on AM Her, SS Cyg, and U Gem, and their comparison with the simultaneous Einstein data has led to the discovery of an UV short wavelength component of the continuum spectrum of SS Cyg and U Gem in quiescence. This component follows a ν^2 power law, similar to what was observed in the UV spectrum of AM Her spectrum (Raymond *et al.* 1978). We also confirm the presence of the ν^2 component in AM Her. If this feature represents the Rayleigh-Jeans end of a black body with KT $\geq$ 10 eV (20-30 eV in AM Her), the UV and soft X-ray integrated luminosity would be far greater than expected from models of gravitational accretion (Lamb and Masters 1979). For U Gem we show that this radiation is likely to originate from the boundary layer of the accretion disk. In both SS Cyg and AM Her the UV component originates from an area of the same order as the X-ray emitting area, and in AM Her, in particular, the black body UV flux is eclipsed in phase with the X-ray flux. We suggest that nuclear burning of the accreting material might be responsible for the UV emission. In this hypothesis we find that AM Her, SS Cyg and U Gem can be explained within a scenario of accretion in different magnetic regimes. A strong magnetic field (~ 10^8G) in AM Her would be responsible for polar radial accretion, as suggested by many authors (see review of Chiappetti *et al.* 1980). A re-examination of the data collected on SS Cyg both at maximum and at minimum, together with our new observations, shows the presence of a magnetic field ~ 10^5-10^6 G, as suggested by Ricketts *et al.*

(1979). SS Cyg at minimum looks remarkably similar to AM Her, consistent with a picture of polar magnetic accretion. But the magnetic field is not so intense as to inhibit completely the formation of a disk, as shown by the observations of Walker and Chincarini (1968). The increased accretion at maximum causes the magnetosphere to move closer to the white dwarf with the consequent building up of a disk. In U Gem instead, the magnetic field is so low as to make polar accretion impossible even at a minimum, as shown by the lack of emission lines in the UV.

We have presented our data and the results of our analysis at the HEAD meeting of the AAS in Cambridge, Massachusetts (30 January 1980), at the 5th Workshop on Cataclysmic Variables and Related Objects in Austin, Texas (24-26 March 1980) and at the IUE symposium in GSFC (7-9 May 1980). A paper has been accepted by *Ap. J.*

IUE PUBLICATIONS

1) Simultaneous UV, Optical and X-Ray Observations of the X-Ray Source Vela X-1, Dupree *et al.* 1980, *Ap. J.*, in press.

2) Ultraviolet X-Ray, and IR Observations of HD 226868 = Cyg X-1, Treves *et al.* 1980, submitted to *Ap. J.*

3) The Ultraviolet Spectrum and Flux of HD 152667 (= X-Ray Source 1653-40), Hutchings and Dupree 1980, *Ap. J.*, in press.

4) IUE Observations of the X-Ray Source HZ Herculis/Her X-1, Gursky *et al.* 1980, *Ap. J.*, in press.

5) Ultraviolet Observations of X-Ray Globular Clusters, Hartmann 1980, NATO ASI on Galactic X-Ray Sources, J. Wiley, in press.

6) Combined X-Ray, UV and Optical Observations of Binary Sources Associated with Degenerate Dwarfs, G. Fabbiano, G. Branduardi, A. K. Dupree, L. Hartmann, J. C. Raymond, and T. Matilsky, 1979 BAAS, Vol. 11, p. 788.

7) Coordinated Optical, UV and X-Ray Observations of U Gem, SS Cyg and AM Her, G. Fabbiano, J. Steiner, L. Hartmann, and J. Raymond, presented in the symposium "The Universe in Ultraviolet Wavelengths: The first two years of IUE", GSFC May 7-9, 1980.

8) Coordinated X-Ray, Ultraviolet and Optical Observations of AM Her, U Gem and SS Cyg, G. Fabbiano, L. Hartmann, J. Raymond, J. Steiner, G. Branduardi-Raymont 1981, *Ap. J.*, in press.