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Study of Optical Properties of X-ray Sources

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This report covers the period 1 July 1972 to 30 June 1973; the status of work completed earlier but not yet reported in the literature will also be reviewed.

#### A. Simultaneous Optical and X-ray Observations

The results of previous optical observations made simultaneously with X-ray observations have not yet appeared in the literature; delays have been produced largely by the slowness with which other optical observers have reduced their data and the press of activities at the X-ray satellite institutions (ASE & MIT). We hope the March 1971 Sco X-1 data taken with Uhuru, the April 1972 Sco X-1/Cyg X-1 data taken with Apollo 16, the June 1972 Sco X-1 data taken with OSO-8 and the July 1972 Cyg X-2 data taken with OSO-8, will all be analyzed soon for correlated X-ray optical behavior.

The June 1972 observations of Sco X-1 were discussed in last year's final report; we note here that a paper discussing the color behavior of flaring in Sco X-1 has appeared in Pub. Ast. Soc. Pac., 85, 177.

On the night of July 15 (UT), 1972 we observed Cyg X-2 as part of the world-wide Cyg X-2 watch to provide optical coverage for X-ray observations by OSO-8. The 36" telescope at McDonald Observatory was used to take continuous 5<sup>s</sup> integrations of Cyg X-2 with an open photometer (no filter). These data have been corrected for extinction and plotted. The plots have been forwarded to the OSO-8 team at MIT. We note that Cyg X-2 has not in these or any other observation over the past two years showed the variability present in the early observations by Kristian et al. Apparently the source has changed its optical behavior over the past few years.

#### B. Coronal Line Search in the Cygnus Loop

The failure to detect the forbidden Fe lines  $\lambda\lambda 6374, 5303$  in the Cygnus Loop even though the X-ray data is best fit by a thermal bremsstrahlung spectrum with a temperature of  $2 \times 10^6$ °K has been reported earlier. A paper describing this search has been published in Astrophys. J. 178, 701 (1972). Further searches of the most intense X-ray emitting regions in the Cygnus Loop with a superior nebular spectrograph constructed by J.R.P. Angel (Columbia University) have revealed no coronal lines to the limit given in the above paper for the entire nebula. Lately, B. Woodgate of Columbia University has found evidence for the  $\lambda 5303$  line at the limit set in earlier work. This was done by increasing the chopping rate to reduce effects of night-sky lines. We have discontinued work on this project; Columbia observers may take more data.

C. Her X-1 = HZ Her Observations

Following the suggestion by W. Liller that the variable star HZ Her could be the optical counterpart of the X-ray pulsar Her X-1, we dropped our program of Cyg X-2 spectroscopy and took a spectrum (July 13, UT) of HZ Her using the Meinel spectrograph of the 107-inch telescope at McDonald Observatory. The spectrum obtained extended from  $H_{\gamma}$  to  $H_{\beta}$ ; the  $H_{\beta}$  was asymmetric with a radial velocity of +47 Km/sec at the peak to +250 Km/sec in the center of the feature. Whether the high velocity was produced by gas-streaming or by an actual motion in the system, we felt it was evidence for the identification with Her X-1 and reported this in IAU Circular #2424.

During August 10-14 (UT), 1972 we obtained several spectrograms using the UVITS spectrograph on the 107-inch and 82-inch reflectors at McDonald Observatory. These spectra show variable CaII K absorption,  $\lambda$  4640-50 and  $\lambda$  4686 emission, and HeI absorption features. The emission is rapidly varying - sometimes as fast as 30<sup>m</sup> time scales. These spectra have been analysed in a paper which appeared in the Astrophys. J. 178, L5 (1972).

Additional spectra were obtained during the week of September 11-17, 1972 of HZ Her using the UVITS and 82-inch reflector. These later spectra have been reduced and together with the earlier spectra have been analysed for radial velocities using a Grant measuring engine at the MSFC, Houston. Two graduate students, B. Bopp and G. Grupsmith have been responsible for taking the spectra and reducing the data. It was not possible to extract radial velocities from these spectra due to the low dispersion (150 Å/mm) and the relatively large asymmetric widths of the hydrogen lines, which are the only ones strong enough to easily measure.

During 14-25 May 1973 we obtained additional excellent spectra of HZ Her using the 82-inch telescope at a dispersion of 30 Å/mm. Fe lines are present in these spectra which should allow good radial velocities to be measured. The analysis of these plates is in progress.

D. Cyg X-1 Observations

During August 1972 we obtained 8 excellent coude spectra of Cyg X-1 at a dispersion of 18Å/mm. These are currently being analysed for radial velocities which will be forwarded to T. Bolton (Toronto) who is computing a definitive orbit for the system. We have examined the spectra for the presence of HeII  $\lambda$  4686 emission and

find little agreement with the profiles of Smith et al. [Ap. J. 179, L125 (1973)]. We do agree with their general conclusion that the emission profile is combined with a varying absorption component.

A spectrum of X Per, suggested candidate for 2U 0352+30 is featureless; we will not pursue this source further.

#### E. Sco X-1 Radio Companion Observations

The positions of the radio sources which are companions to Sco X-1 were examined for  $H_{\alpha}$  emission in an effort to link them more tightly to the X-ray source by discovering optical nebulosity. The count rate through an  $H_{\alpha}$  interference filter at the position of the NW radio source was compared with the count rate from a nearby sky position. The negative result obtained strengthens the evidence that these sources are non-thermal; their association with Sco X-1 will have to come from proper motion studies. An article describing these observations appeared in Nature Phys. Sci., 240, 43 (1972).

#### F. Personnel

Grant funds were used for a total of 2-1/4 months of P/I summer salary support, 1-3/4 months in 1972 and 1/2 month in 1973. Mr. G. Grupsmith was paid from grant funds as a graduate student research assistant for 9 months. Unsupported personnel, all graduate students, include: B. Bopp, C. Sneden, and T. Moffett.

#### G. Equipment Purchased

Grant funds were used to purchase a Hewlett-Packard Model 35 Calculator for data reductions and a Tenelec Model 616A Amplifier for use in a multi-channel spectrometer under development. This instrument, when finished, will be an extremely powerful tool for investigating the optical spectra of X-ray sources.

- (1) HIGH-SPEED UBV PHOTOMETRY OF SCORPIUS X-1 FLARES  
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Astron. Soc. Pacific, Vol. 85, April 1973  
(A73-30646)
  
- (2) SEARCH FOR HOC EMISSION FROM THE COMPANION RADIO SOURCES OF SCO X-1  
P. A. Vanden Bout, G. Grupsmith, B. W. Bopp  
Nature Physical Science, Vol. 240, No. 98, Pages 43-44, 11-13-72  
(A73-13374)
  
- (3) SPECTROSCOPIC OBSERVATIONS OF HZ HERCULIS  
B. W. Bopp, G. Grupsmith, P. Vanden Bout  
Astrophysical Journal, Vol. 178, Pages L5-L8, 11-15-72  
(A73-15684)
  
- (4) SEARCH FOR CORONAL LINE EMISSION FROM THE CYGNUS LOOP  
D. W. Kurtz, P. A. Vanden Bout, J. R. P. Angel  
Astrophysical Journal, Vol. 178, Pages 701-706, 12-15-72  
(A73-15684)