CORRELATED GROUND BASED OBSERVATIONS IN SUPPORT OF THE HEAO-1 X-RAY OBSERVATORY

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In this program our intent was to explore the physics associated with cosmic X-ray sources. Our objective was to be achieved by combining X-ray fluxes obtained by the A-1 experiment aboard the HEAO-1 observatory with ground based optical and near infrared photometry and optical spectroscopy. The objects whose properties we have chosen for our study fall into two categories: (1) energetic, compact extragalactic sources, and (2) compact, galactic X-ray emitters like X Persei. In our investigation of the program sources, we observed UBVRI fluxes, and at times optical spectra, during periods chosen to coincide with observations made by the HEAO-1 satellite. In addition to simultaneous experiments, a significant effort was made to monitor the sources. Since HEAO-1 only observes objects near dawn and dusk, we utilized the remainder of our observing sessions to establish optical baselines against which longer term X-ray variability could be compared.

The photometric data obtained during the HEAO-1 mission represent observations made on 53 nights, extending back to the date originally planned for the HEAO-1 launch, April 1977. These data include 11 simultaneous X-ray and optical experiments performed during the HEAO-1 mission. In addition, we have obtained seven nights of high time resolution optical spectroscopy in connection with our program. These data include three simultaneous experiments. In many cases we are currently continuing our optical observations of the program objects.

In Figure 1 we show our UBVRI photometric data for BL Lacerta, an example of one type of compact, extragalactic source we have studied. Optical emission lines are absent in this source, so our optical photometry, like X-ray photometry, is directly sampling the central engine without complications introduced by intervening gas [1]. An average straight line has been drawn through this compilation of our photometric data. Clearly BL Lac has a predominantly nonthermal spectrum. The triangles are a set of observations obtained on one night, a snapshot, in which the spectrum was thought to be like the average spectrum, and the x's are a snapshot of the spectrum when it was considerably different from its average. As is usual in BL Lac objects, the spectral shape varies quite considerably in the course of time. The variations in the intensity of optical emission with time scales of days suggest the central engine in this source is quite small.

In Figures 2 and 3 we see two low energy BL Lac objects, Markarian (Mrk) 421 and Mrk 501, which have been identified with X-ray sources. The mini-lacertids in both these objects are embedded in giant elliptical galaxies [2]. These optical spectra are again predominantly nonthermal. Mrk 421 shows especially large variations in optical activity. The notation in these figures is the same as that used in Figure 1, where triangles mark a snapshot of an average spectrum and the x's show an example of a peculiar spectrum. In his talk this morning, Dr. Schwartz made a very interesting point. From May 1977 to May 1978, the continuous X-ray spectrum of Mrk 421 was seen to steepen quite considerably [3,4]. In Figure 2, the x's represent the optical spectrum of Mrk 421 in May 1978 and the average line is representative of the optical spectrum in May 1977. From May 1977 to May 1978 the optical spectrum, like the X-ray spectrum, was seen to steepen considerably. This correlated X-ray and optical behavior is what one would expect from a synchrotron-Compton source [5].

The combined UBVRI photometry for another BL Lac object we have studied closely — B2 1308+32 — is shown in Figure 4. The intensity variations seen in this source are enormous. Our observational record also shows the optical spectrum has often changed its shape. A cosmological interpretation of its $z = 0.996$ redshift [6] implies B2 1308+32 has a peak luminosity of 10^{48} ergs/sec; this luminosity is near the maximum observed in the most energetic quasars [7]. On the first pass by HEAO-1, the A1 experiment found only an upper limit to the X-ray flux in the energy range $\frac{1}{2}$-20 keV. But as can be seen in Figure 5, the combination of our B band photometry with other published values shows that the source was very quiescent during this satellite observation, and so not likely to have been seen in the X-ray. This figure also shows that B2 1308+32 flared very brightly in 1974 and 1977, flared moderately in 1975 and 1978, and was probably quite weak in 1976 and 1979. We suggest the source will again be brightly flaring in 1980, and so will be an excellent candidate for a combined X-ray and optical study.

The characteristic form of an optical burst has been followed now through almost three cycles. In Figure 5, the optical emission can be seen to rise slowly to a maximum, and then abruptly fall off. During spring 1978, such an outburst was particularly well marked. In Figure 6 we display our UBV photometry during this burst using flux values normalized with the frequency independent units of energy flux (ergs/cm^2-sec). The energy flux rises more slowly than it falls at all colors. The radio emission at 15 GHz during this outburst (H. Aller and T. Balonek, private communications) also rises gradually to a maximum in June. But the radio emission falls off far more slowly than the optical.

In Figure 7, we show the UBVRI energy flux measurements during one night of monitoring observations. Variations at all colors can easily be seen. However, variations at different colors do not appear to be correlated. As seen in Figures 4 through 7, our optical studies so far imply the existence of two engines in this source — one for the long term intensity variations which are correlated from radio to optical wavelengths, and one for the emission of the rapid, uncorrelated intensity fluctuations observed at all colors.

In Figure 8 we give our photometric data for the X-ray quasar 3C 273. Our data for December 22, 1978 (x's) — near both HEAO-1 and HEAO-2 observations — shows that 3C 273 was brighter than any time since 1965 [8]. Even on December 27, at the time of HEAO-A1 pointed observations, this source was significantly brighter than average.

Finally, in the second phase of our program, we have been investigating the photometric and spectroscopic properties of X Persei, an unusual Be star associated with an intrinsically weak X-ray source. Both its X-ray and optical emission show complex variability on many different time scales. At X-ray wavelengths the flux is observed to vary with a period of 13.9 min [9]; there is in addition some evidence for a period of 22.4 hr. A period of 580 days is well observed in the radial velocity of the Balmer lines [10]. X Persei is most often interpreted as a BOe star with a neutron star companion.

On August 23, 1978 we monitored the Hα emission line during a HEAO-A1 pointed observation. The spectroscopic observations were made at the Goethe Link Observatory of Indiana University using an I-SIT spectrograph. The spectral resolution of this instrument is 2 Å, and each observation lasted 90 sec. In Figure 9 we show the equivalent width of Hα versus time for the two dates August 23, 1978 and September 25, 1978. Our optical spectroscopy recorded a remarkable event during the simultaneous experiment. Between 9:28 and 9:31 UT the equivalent width dropped from 7.3 to 3.3 Å. This was followed by a more extended event of 540 sec duration in which the equivalent width dropped from 7.7 to 2.6 Å. Standard stars were observed and the event does not appear to be instrumental in origin. During this event, the central wavelength increased and the line widths became narrower. This suggests a weakening of an unresolved, blueshifted line component. In the past observations of similar events have been reported [11,12]. The X-ray data from this experiment is not yet available. On September 25, 1978 the equivalent width was higher (10.2 Å) and showed only a hint of variability over a three hour period.

REFERENCES

1. Stein, W. A., 1978, in Pittsburgh Conference on BL Lac Objects, A. M. Wolfe (ed.), Pittsburgh: University of Pittsburgh Press, p. 1.

2. Ulrich, M. H., Kinman. T. D., Lynds, C. R., Rieke, G. H., and Ekers, R. D., 1975, Ap. J., 198, 261.

3. Schwartz, D. A., Doxsey, R. E., Griffiths, R. E., Johnson, M. D., and Swarz, J., 1979, Ap. J. (Letters), 229, L53.

4. Mushotzky, R. F., Boldt, E. A., Holt, S. S., and Serlemitsos, P. J., 1979, preprint.

5. Jones, T. W., O'Dell, S. L., and Stein, W. A., 1974, Ap. J., 188, 353.

6. Miller, J. S., French, H. B., and Hawley, S. A., 1978, in Pittsburgh Conference on BL Lac Objects, p. 176.

7. Moore, R. L., Angel, J. R. P., Rieke, G. H., Lebofsky, M. J., Wisniewski, W. Z., Mufson, S. L., and others, 1979, Ap. J., preprint.

8. Bradt, H. J., Doxsey, R. E., Johnson, M. D., Schwartz, D. A., Burkhead, M. S., Dent, W. A., Liller, W., and Smith, A. G., 1979, Ap. J. (Letters), preprint.

9. White, N. E., Mason, K. D., and Sanford, P. W., 1976, M.N.R.A.S., 176, 201.

10. Hutchings, J. B., Cowley, A. P., Crampton, D., and Redman, R. O., 1974, Ap. J. (Letters), 191, L101.

11. Murdin, P., Penstron, M. V., and Penny, A. J., 1976, M.N.R.A.S., 176, 233.

12. Campisi, I. E., and Treves, A., 1976, M.N.R.A.S., 176, 225.

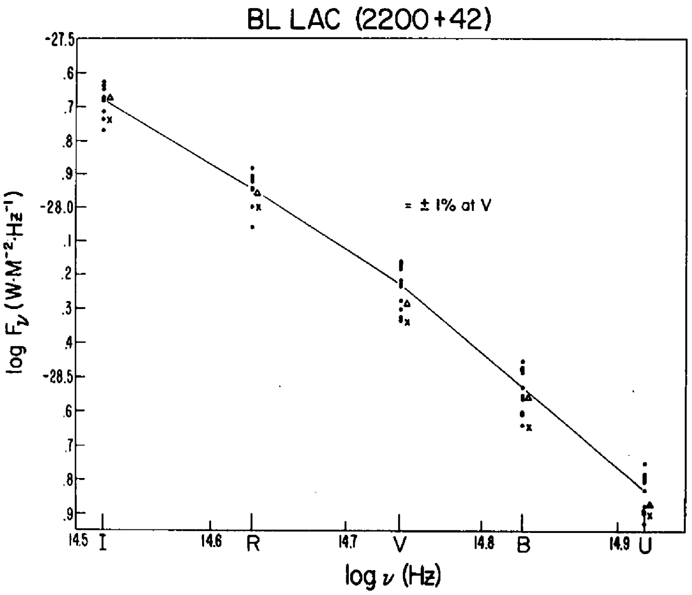

Figure 1

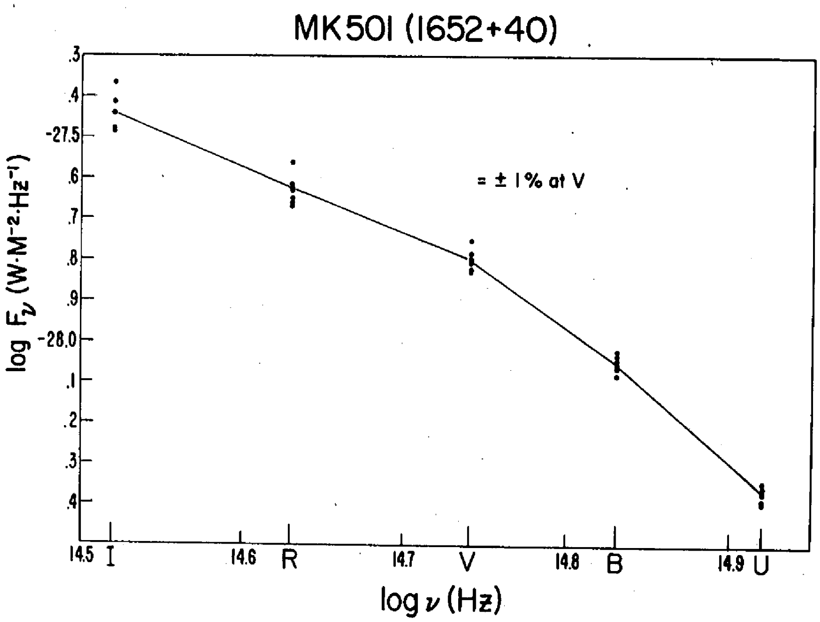

Figure 2

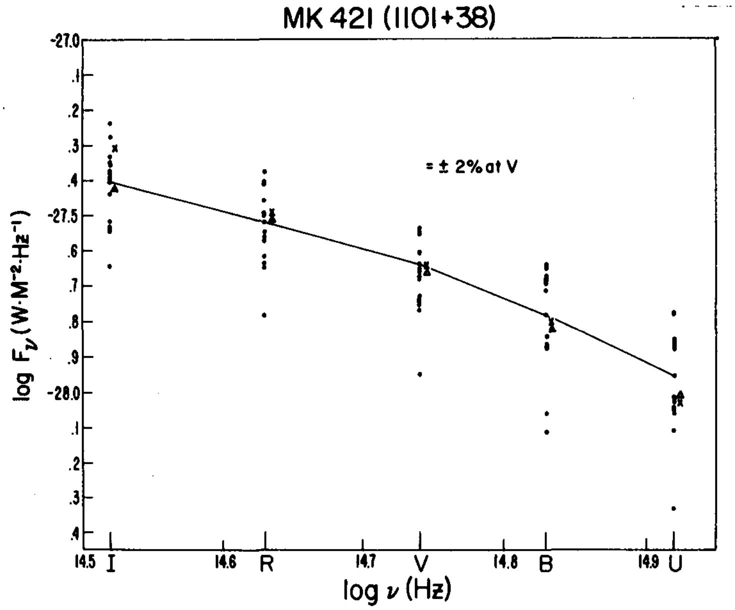

Figure 3

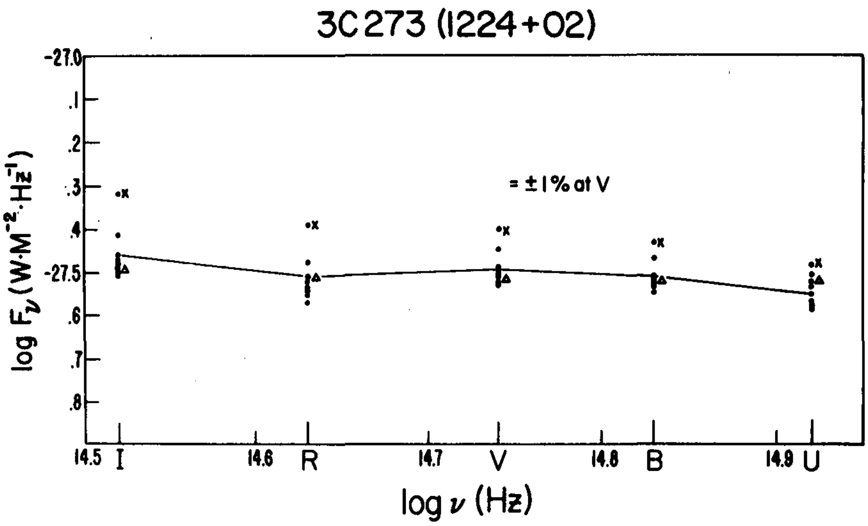

Figure 4

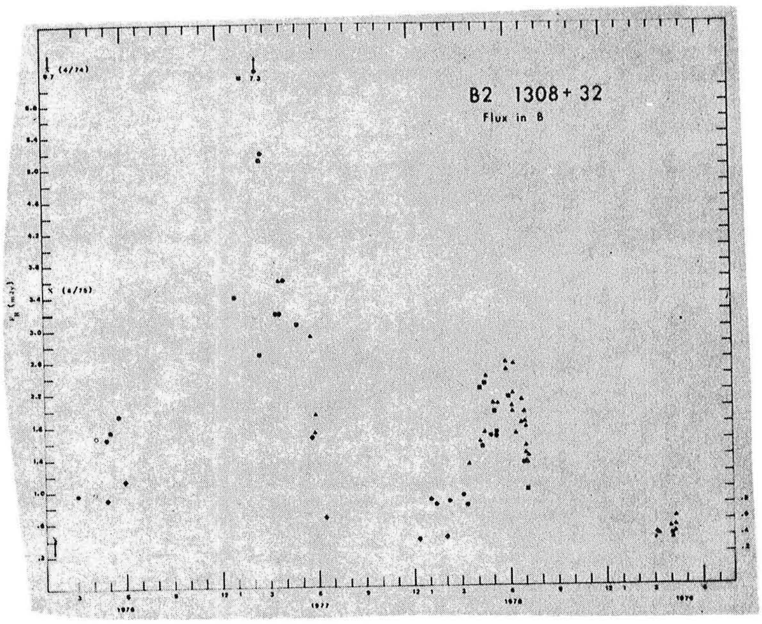

Figure 5

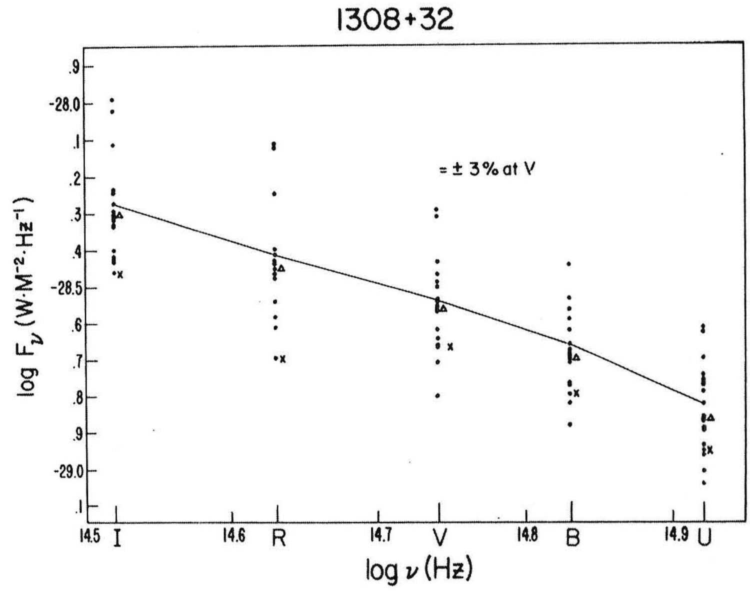

Figure 6

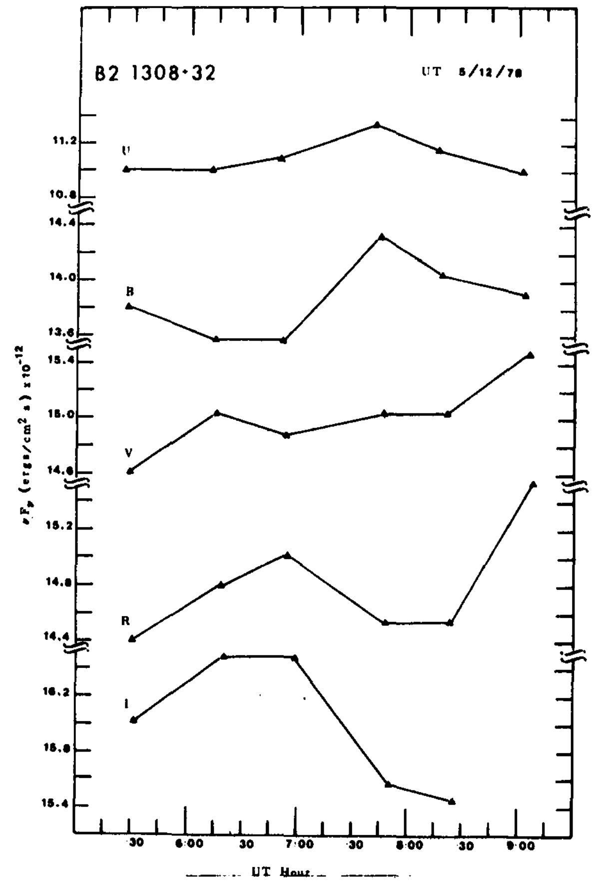

Figure 7

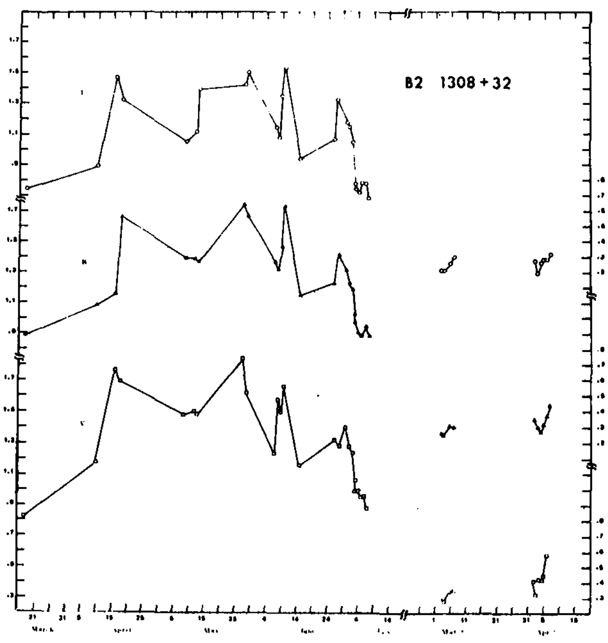

Figure 8

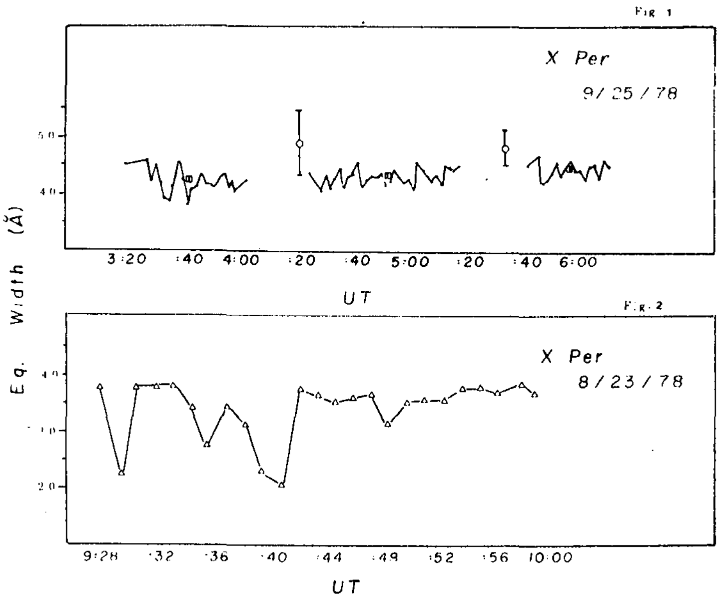
Fig. 1
X Per
9/25/78
Eq. Width (Å)
3:20
:40
4:00
:20
:40
5:00
:20
:40
6:00
UT
Fig. 2
X Per
8/23/78
9:28
:32
:36
:40
:44
:48
:52
:56
10:00
UT

Figure 9