

CAL-1683

134760  
118

EXOSAT DATA ANALYSIS PROGRAM  
FINAL TECHNICAL REPORT

NASA Grant NAG 8-570

Submitted to:

National Aeronautics and Space Administration  
George C. Marshall Space Flight Center  
Marshall Space Flight Center, AL 35812

Title of Research:

VARIABLE SPECTRA OF ACTIVE GALAXIES

Prepared by:

Jules P. Halpern  
Columbia Astrophysics Laboratory  
Departments of Astronomy and Physics  
Columbia University  
New York, New York 10027

Submitted by:

Columbia University  
Box 20, Low Memorial Library  
New York, New York 10027

(NASA-CR-182094) VARIABLE SPECTRA OF ACTIVE  
GALAXIES Final Technical Report (Columbia  
Univ.) 11 p CSCL 03A

N88-21091

Unclas  
G3/39 0134760

May 1988

EXOSAT DATA ANALYSIS PROGRAM

FINAL TECHNICAL REPORT

NASA Grant NAG 8-570

Submitted to:

National Aeronautics and Space Administration  
George C. Marshall Space Flight Center  
Marshall Space Flight Center, AL 35812

Title of Research:

VARIABLE SPECTRA OF ACTIVE GALAXIES

Prepared by:

Jules P. Halpern  
Columbia Astrophysics Laboratory  
Departments of Astronomy and Physics  
Columbia University  
New York, New York 10027

Submitted by:

Columbia University  
Box 20, Low Memorial Library  
New York, New York 10027

May 1988

There are no new technology items reportable under this contract.

SUMMARY

This grant supported the participation of J. Halpern as a coinvestigator on the analysis of EXOSAT spectra of active galaxies in collaboration with the University of Leicester. The objects examined for X-ray spectral variability were MR 2251-178 and 3C 120. This report describes the results of these investigations, as well as additional results on X-ray spectral variability related to EXOSAT observations of active galaxies. In addition, the participation of J. Halpern as a coinvestigator on the EXOSAT observations of the dipping X-ray source 4U1624-49 was also supported by this grant.

MR 2251-178

MR 2251-178 was the first X-ray selected QSO and the second after 3C 273 to be detected as an X-ray source. The spectrum was measured by the Einstein Observatory on two occasions approximately 1 year apart. Power-law fits to the MPC 2-10 keV data yielded energy indices  $\alpha$  of  $0.52 \pm 0.17$  and  $0.72 (+0.35, -0.30)$  (Halpern 1984). There was evidence for an increase in absorbing column density by a large factor over the 1 year interval. Simultaneous measurements with the HRI showed that the highly absorbed spectrum ( $N_{\text{H}} \sim 2 \times 10^{22} \text{ cm}^{-2}$ ) must have excess emission below 1 keV. Two possible causes of variable X-ray absorption in active galactic nuclei were discussed. The favored model was one in which photoionization by the X-ray continuum ionizes a cloud or shell of material, so that the emergent spectrum is transparent below the K-edge of O VII at 739 eV, but highly absorbed above this energy. The required change in the ionization parameter by a factor of 3 could be due to a number of causes, such as varying luminosity, radial motions, and density changes. The alternative model, in which the variable absorption is due to the passage of cold clouds across the line of sight to the X-ray source, was thought to be less likely, primarily because the size of the broad line clouds ( $\sim 10^{13} \text{ cm}$ ) is probably much smaller than that of the X-ray source ( $\sim 10^{15} \text{ cm}$ ).

The purpose of the EXOSAT observations of MR 2251-178 was to investigate in more detail the time history of the changes in column density in order to address the proposed models for the location and physical conditions of the absorbing material. Nine observations over a period of 80 days were obtained using the ME instrument and the CMA with thin Lexan filter (Stewart et al. 1985). Figure 1 shows the count rates in each instrument. While variability

by at least a factor of 2 was seen, the lack of a correlation between the LE and ME fluxes implies that the spectral shape of the source must vary. Spectral fits to the ME data show column densities varying between 0 and  $3 \times 10^{22} \text{ cm}^{-2}$  (Figure 2), similar to the Einstein results (Halpern 1984). Such large changes were not seen in the LE count rates, which confirms the Einstein HRI results.

The EXOSAT results do not unambiguously distinguish between the two hypotheses which were suggested to explain the variable absorption, although they do show that the absorption can change on a time scale of 1 month. Sensitive X-ray grating spectroscopy would help to distinguish between cold and warm absorbers, as the energies of the oxygen edges could be directly observed. Any future observation of column density variations on time scales of 10,000 s or less would be strong evidence for X-ray heating effects, as opposed to varying covering by cold clouds.

### 3C 120

In contrast to the previous source, 3C 120 is a object in which the spectral index was observed by Einstein to vary, while the column density remained constant (Halpern 1985). The spectral luminosity varied by a factor of 2.5 on time scales of days to months. The spectral slope of the 2-10 keV X-rays was steeper when intensity was higher, and varied from  $0.51 \pm 0.13$  at minimum to  $0.83 \pm 0.03$  at maximum, with a continuous variation in between. The results were interpreted (Halpern 1985) in terms of a composite spectrum consisting of variable beamed synchrotron emission from a relativistic jet, and a stationary isotropic component. This interpretation is rendered plausible by the fact that 3C 120 is a rapidly varying superluminal radio

source.

The objectives of the EXOSAT monitoring were to confirm the Einstein results on X-ray variability and to search for the multicomponent spectra suggested by the Einstein data. Five observations were done in October 1984 and one in February 1985. Unfortunately, the flux and spectral index remained constant throughout these observations, with  $\alpha = 1.8 \pm 0.2$ , and  $N_H$  consistent with the galactic value.

### Mrk 335

Einstein HRI observations of Mrk 335 showed a soft X-ray flare with an amplitude of a factor of 2.5 and a rise time of only 10,000 s (Lee et al. 1988). The MPC flux varied by a much smaller amplitude. The HRI flux implies that there is a soft excess above the extrapolation of the best fit  $\alpha = 1.25 \pm 0.19$  to the MPC data. This is the first observation of rapid, large amplitude variability in a soft excess component, which restricts the size of the emitting region to less than  $3 \times 10^{14}$  cm. Similar results on Mrk 335 were obtained in EXOSAT observations (Pounds et al. 1987; Turner and Pounds 1988). Thus, the theory that soft X-ray excesses arise near the inner edge of an accretion disk around a black hole is strongly supported. In this case, the mass would be  $10^7 - 10^8 M_\odot$ . Origin in a hot medium confining the emission-line clouds is ruled out, at least for Mrk 335.

4U 1624-49

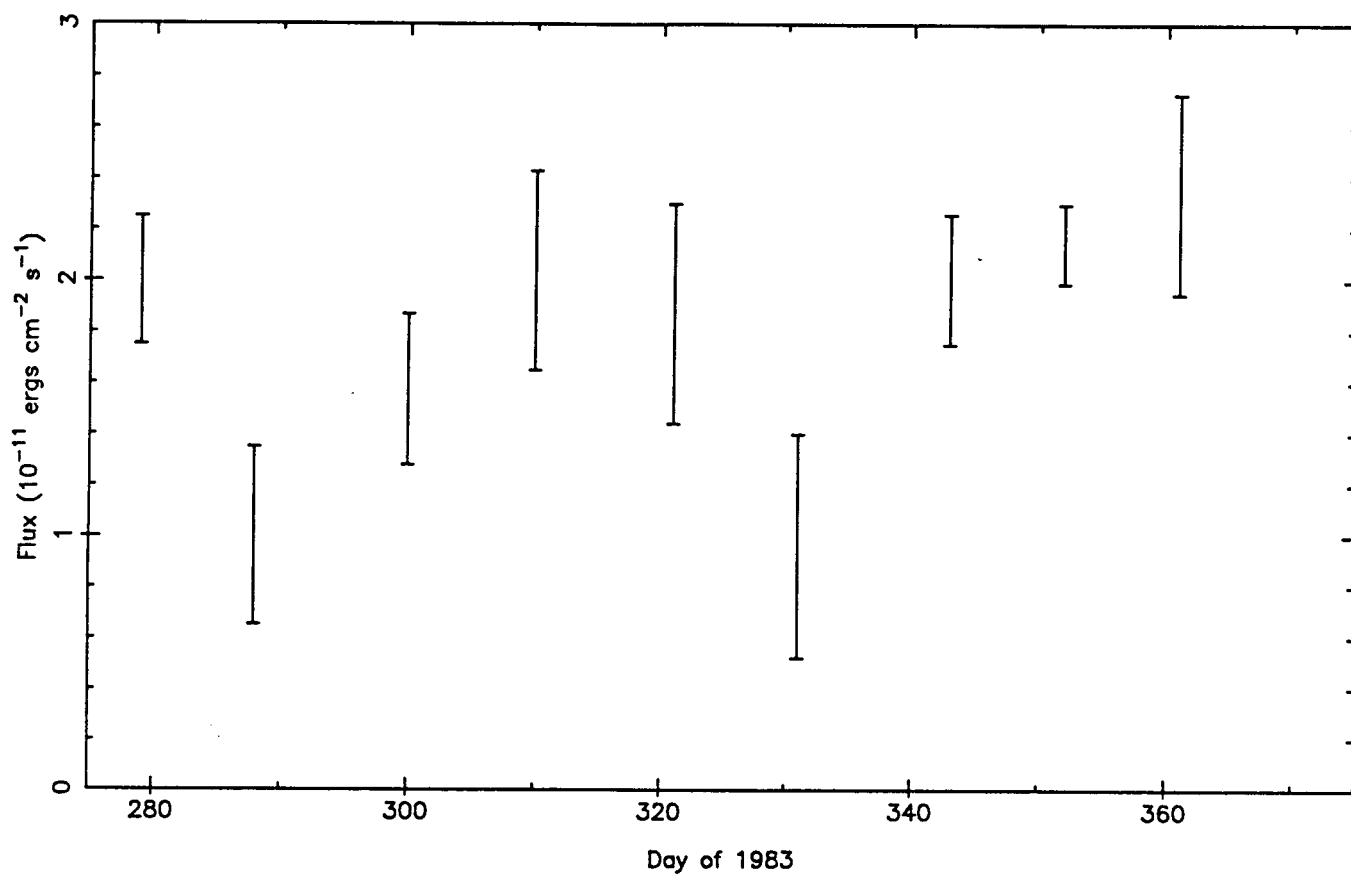
J. Halpern was a coinvestigator on two EXOSAT observations of 4U 1624-49, a low mass X-ray binary for which a "dip" was seen in a short Einstein observation. The first EXOSAT observation, of duration 6 hours, resulted in the detection of a series of dips in which the flux fell to ~ 25% of the steady level on a timescale of seconds (Watson et al. 1985). The data are shown in Figure 3. The dips were accompanied by strong variations in spectral hardness consistent with large changes in the absorbing column density. A second observation, of approximately 56 hours duration, showed that the dips recur with a period of  $21 \pm 2$  hours, presumably the binary period of the system, which gives 4U 1624-29 the distinction of having the longest orbital period of the 8 dip sources (Watson et al. 1985). Subsequently, the 21 hour period was confirmed in HEAO A-1 data (P. Hertz, private communication).



REFERENCES

- Halpern, J.P., "Variable X-ray Absorption in the QSO MR 2251-178", Ap. J.,  
281, 90 (1984).
- Halpern, J.P. 1985, "X-ray Spectrum and Variability of 3C 120", Ap. J., 290,  
130 (1985).
- Lee, M.G., Balick, B., Halpern, J.P., and Heckman, T.M., "A Soft X-ray Flare  
in the Seyfert 1 Galaxy Mrk 335", Ap. J., in press (1988).
- Pounds, K.S., Stanger, V.J., Turner, T.J., King, A.R., and Czerny, B.,  
M.N.R.A.S., 224, 443 (1987).
- Stewart, G.C., Pounds, K.A., and Stanger, V.A., Space Science Reviews, 40  
(1985).
- Turner, T.J., and Pounds, K.A., M.N.R.A.S., in press (1988).
- Watson, M., Willingale, R., King, A., Grindlay, J., and Halpern, J., "The Big  
Dipper: 4U1624-49", Space Science Reviews, 40, 195 (1985).
- Watson, M., Willingale, R., King, A.R., Grindlay, J.E., and Halpern, J., "4U  
1624-49", IAU Circular No. 4051 (1985).

Figure 1 - EXOSAT ME 2-6 keV Flux of MR 2251-178



- EXOSAT LE Count Rate for MR 2251-178

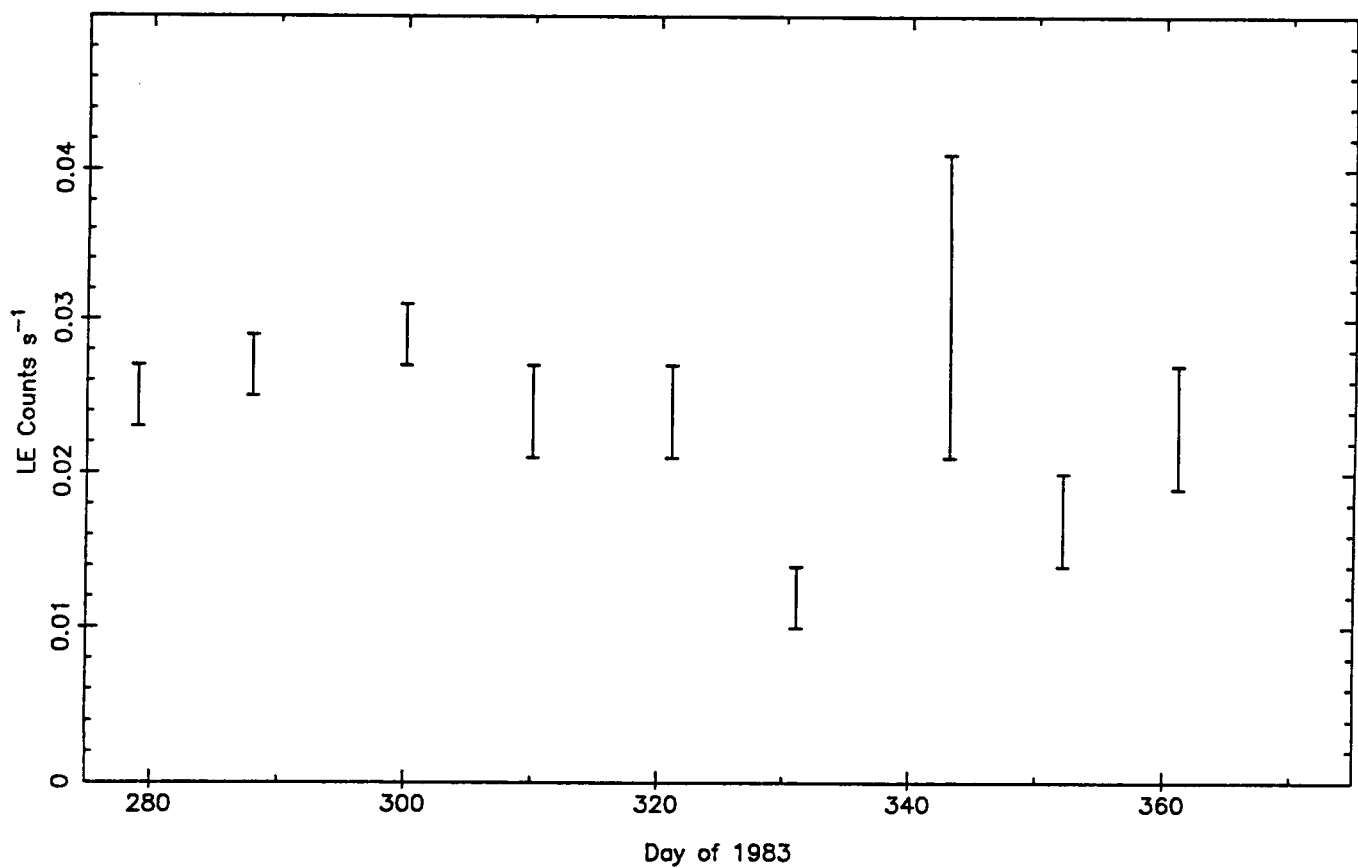


Figure 2 - EXSOAT ME Column Density for MR 2251-178

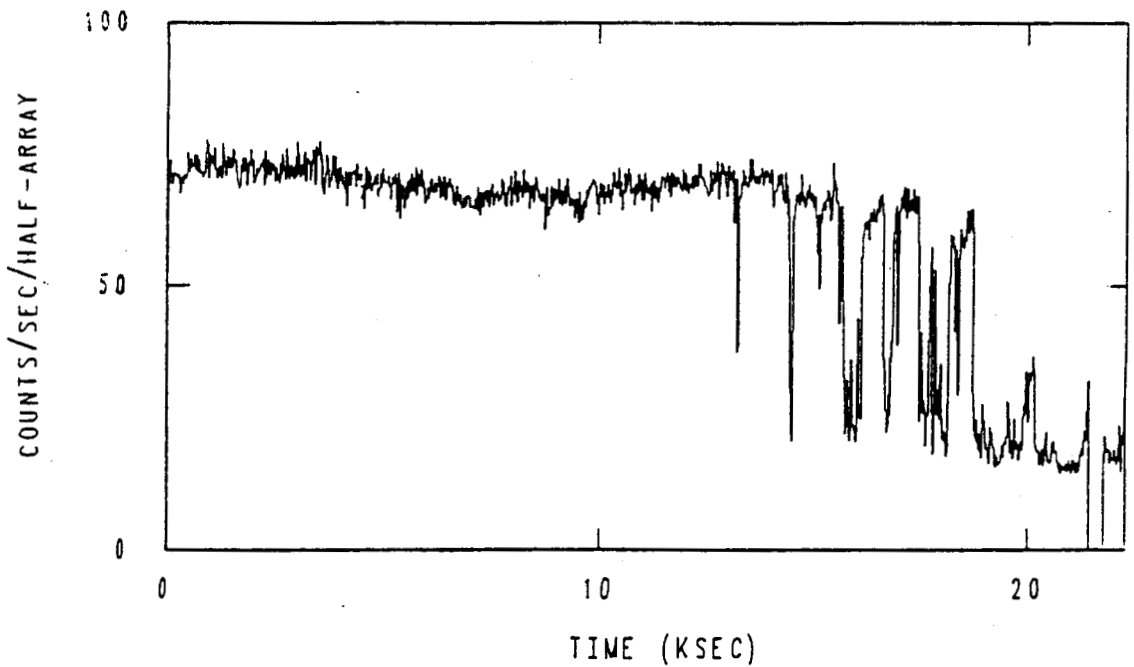
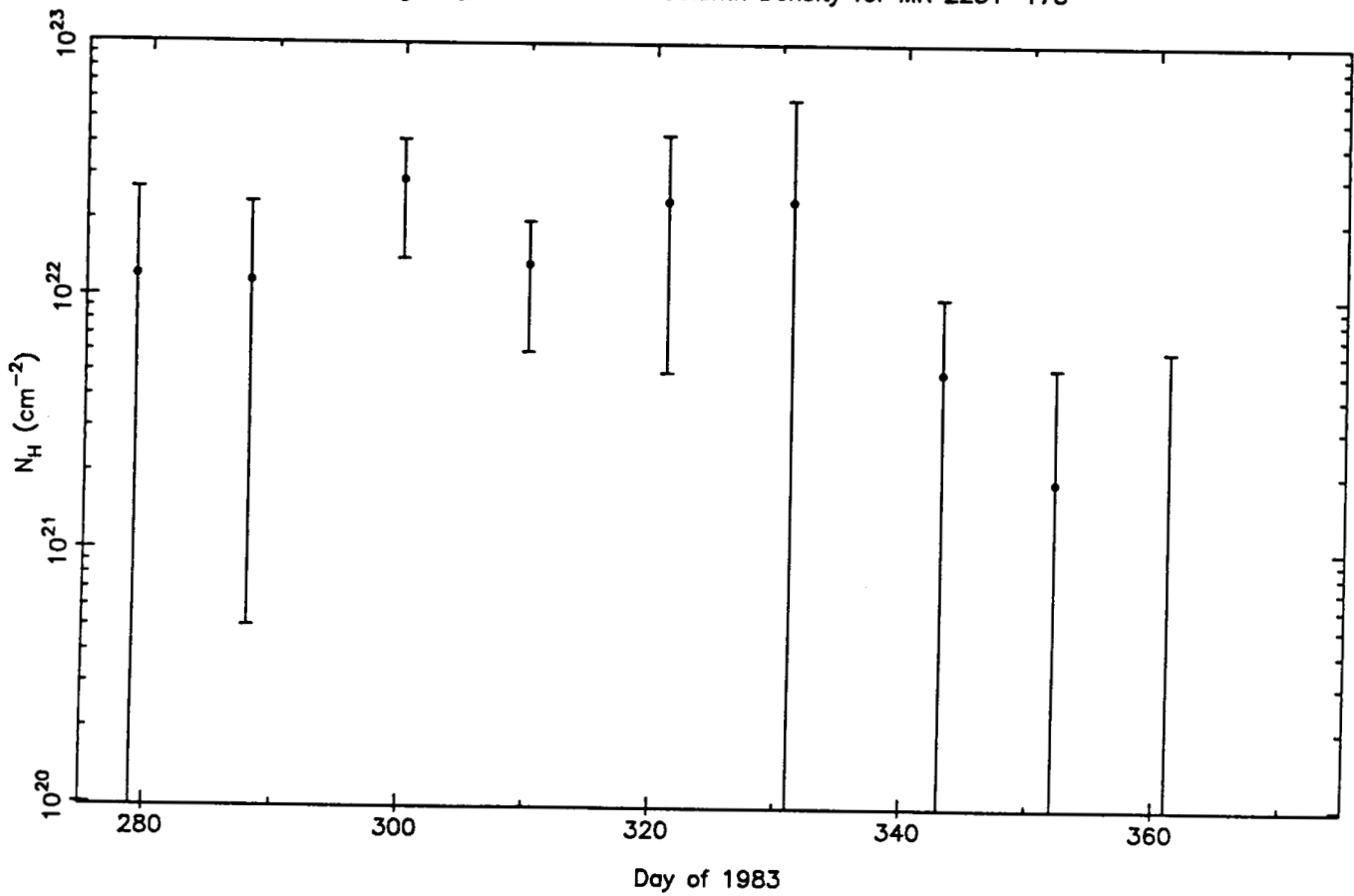


Figure 3. The complete EXOSAT ME X-ray light curve of 4U1624-49 ( $\sim 2$ -10 keV) shown with 20s time resolution. Start time on this plot is 1984 March 5, 12:23 UT.