X-RAY VARIABILITY OF ACTIVE GALACTIC NUCLEI

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INTRODUCTION

X-ray variability of active galactic nuclei is commonplace on scales from days to years. It also occurs, although rarely, on time scales as short as 200 seconds. Both these statements must be strongly qualified by the irregularity and insensitivity of the available observations. In the X-rays we expect that we are seeing deep within the active nucleus, near what is usually taken to be a massive black hole. The X-ray variability time scales may then give us the fundamental structural length scales. We would like to review data on active galaxies, present our new data on Einstein observations of BL Lac objects, and discuss all these in terms of a statistical quantification of the observations.

In Figure 1 we plot all the most extreme (in the sense defined below) published time variations from active galactic nuclei. We use $H_o = 50 km\ s^{-1} Mpc^{-1}$. Our method of plotting alphanumerics without error bars reflects the fact that these existence measurements are somewhat nominal in their values.

Cavallo and Rees (1978) considered the smallest expected time scales of fluctuations. These are limited by the optical depth due to electron scattering in the same material which is being accreted. If the corresponding rest mass was converted into radiation with efficiency η, then for isotropic emission $\Delta t \geq 0.5\ (\Delta L_{42})/\eta$ seconds, with ΔL_{42} the change in luminosity in units of 10^{42} ergs/s, in the time interval Δt (Fabian 1979). Models of black holes have led many workers to consider $\eta = 10\%$ as an upper limit to this efficiency, and this is plotted as the solid diagonal line in Figure 1. We have chosen to plot only those objects for which time variations have an apparent efficiency $\eta > 10^{-4}$. Since the measurements are only over a limited observational bandwidth, they are only lower limits to ΔL or to η. It turns out that the objects plotted are quasars, BL Lac type, or Seyferts.

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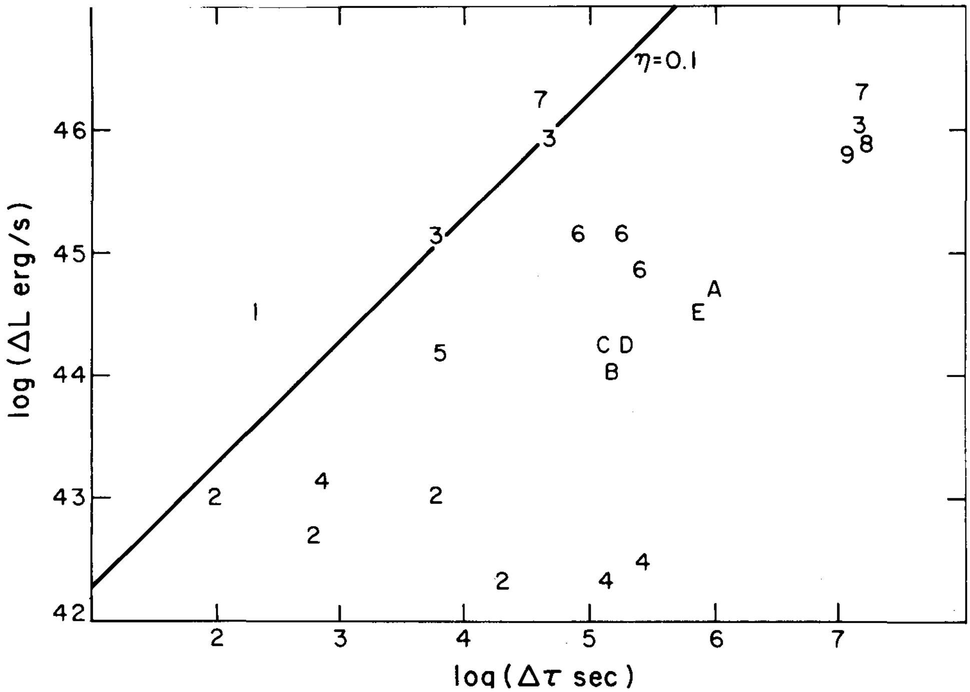

Figure 1. Variability measurements implying an efficiency $\eta > 10^{-4}$ (see text). Code: 1 = 1525+227, Matilsky et al. 1982. 2 = NGC 6814, Tennant et al. 1981, Tananbaum 1980. 3 = 3C 273, Tananbaum 1980, Bradt et al. 1979, Marshall et al. 1981. 4 = NGC 4151, Tananbaum et al. 1978, Mushotsky et al. 1978, Elvis et al. 1978. 5 = OX 169, Tananbaum et al. 1979. 6 = Mrk 421, Ricketts et al. 1976, Marshall et al. 1981. 7 = PKS 2155-304, Snyder et al. 1980, Schwartz et al. 1979. 8 = 3C66A, Maccagni 1981, 9 = OJ 287, Worrall et al. 1982. A = PKS 0548-322, Urry et al. 1982. B = 3C 371, Snyder et al. 1982. C = NGC 7469, Marshall et al. 1981. D = 2S0241+622, Marshall et al. 1981. E = Mrk 509, Dower et al. 1980.

Two objects show significantly higher efficiencies than 10%. In the case of PKS 2155-304 this is not conclusive because the redshift z = 0.17 (Charles et al. 1979) is tentative. Matilsky et al. (1982) have stressed the unique case of 1525+227 as clearly requiring $\eta > 0.1$. They conclude that either $H_0 \geq 100$km s^{-1} Mpc^{-1} or that the X-ray emission is anisotropic, e.g. from relativistic beaming.

A SURVEY FOR BL LAC VARIABILITY

As part of their class definition BL Lac type objects are among the most variable at optical and radio wavelengths. This has been noted for many BL Lac objects in the X-ray band as well (cf. Schwartz et al. 1979. As part of our joint Einstein Observatory study of the class properties of BL Lac objects by the Center for Astrophysics and Columbia Astrophysics Laboratory, we report here preliminary results of a survey for X-ray time variability. Our survey includes both the original, lineless BL Lacs, and related optically violent variable (OVV) quasars.

Nine objects were observed on two or more occasions by the Einstein Imaging Proportional Counter (IPC) over a time interval of 1/2 year or more. The precision of each measurement is limited to a nominal 30% due to uncertainties in the IPC gain and in the assumed spectral shape. However, if we define a "variable" source as showing an amplitude change of a factor of two and a "constant" source as remaining within 30% of the overall average the results are unambiguous.

Figure 2 shows the variable and Figure 3 the constant objects according to this definition. Clearly our division is very much prejudiced by the observational coverge. Many other BL Lacs are known to vary by a factor of two in X-ray emission: 3C 371, Mrk 421, 3C66A, PKS0548-322, PKS2155-304 (see Figure 1 for references to these 5 objects), Mrk 180 (Mufson and Hutter 1981), and 2A 1219+304 (Wilson et al. 1979). Only Mrk 501 would be considered constant, based on observations prior to Einstein. Thus, at least 11 of 16 BL Lac objects vary by more than a factor of 2.

We have searched for variability on scales less than 1000 seconds from the 12 BL Lac/OVV objects which had a rate greater than 0.05 per second in the IPC. The total counts are binned in either 100, 200, 400, or 800, seconds of real time. We applied a ^{2} test, based on the approximation that the number of counts in each bin has a Gaussian distribution. We take

$$\chi^2 = \sum (C_k - \langle N\rangle_k)^2/(\langle N\rangle_k + \sigma_o^2)$$

where C_k is the actual and $\langle N\rangle_k$ the expected number of counts in each bin, and where σ_o^2 is the variance intrinsic to the source on the given time scale, assumed to be independent of time.

To determine the limits in Table 1, we require $P(\chi^2) < 98\%$ giving an upper limit to σ_u, and $P(\chi^2) > 2\%$, giving a lower limit σ_1.For 11 of the sources $\sigma_1 = 0$ is allowed, i.e., there need be no variation greater than Poisson statistics. For Mrk 501 the counting rate is much greater and we determine a finite range for σ_o. To the eye, the results for Mrk 501 appear as a discrete event, a dip of about 25% and a recovery, in a 500 second interval.

CONCLUSIONS

1. About 1/3 of the Active Galactic Nuclei show X-ray variability.

2. We have not measured the characteristic variability time scale of any object or class of objects (as distinct from the time scale of an individual event); however, we infer that it lies between 10^3 and 10^7

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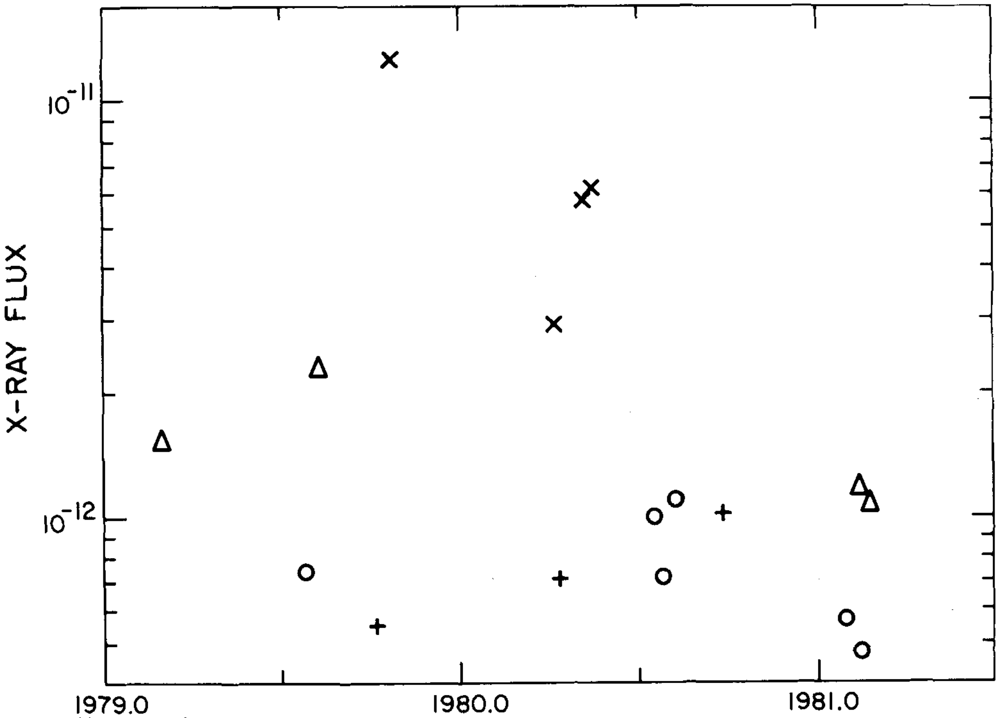

Figure 2. Einstein observations of BL Lac objects showing factor of 2 variability. X-ray flux refers to 0.5 to 3 keV band, at the earth. Δ = AP Lib, X = OJ 287, + = PKS 0537-44, O = AO 0235.

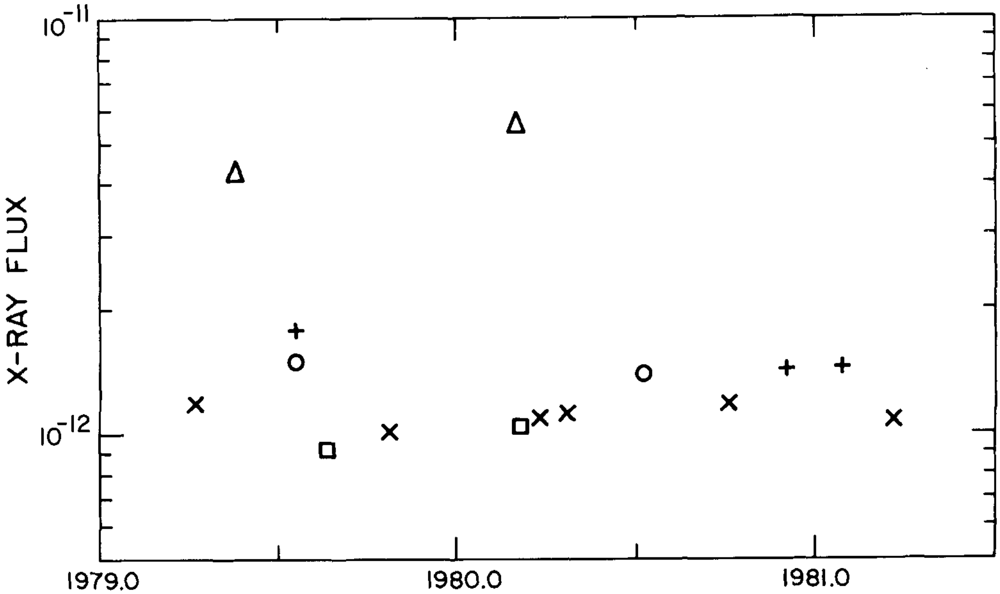

Figure 3. Einstein observations of BL Lac objects for which we do not observe variations on six month time scales. + = 3C 371, X = PKS 0735+178, O = B21308+32, □ = PKS 0422+00, Δ = 3C 446.

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seconds. More generally, we have not even measured the characteristic nature of the variability. We do not know if it occurs as unique events, continual fluctuations (e.g., a shot noise process), or discrete states of the source. To address this we require the equivalent of power spectra measured from 10^{-7} to 10^{-3} Hz.

3. The largest variations and larger percentage of objects varying occur among BL Lac/OVV objects, compared to Seyferts and quasars.

Table 1

Object	IPC Rate s^{-1}	Luminosity 10^{44} ergs/s	Percentage Variability 100s	200s	400s	800s
0521-36	0.17	0.63	<30	<30	<72	
0735+178	0.075	12.		<25	<19	<31
0851+202	0.38	43.	<20	<27	<20	<100
1215+303	0.16		<28	<25	<30	<20
1308+32	0.051	110.		<64	<60	<93
1514-24	0.096	0.24		<30	<53	
1652+39	2.86	5.	7.1-17	7-24	8-45	>10
1807+698	0.076	0.2		<57		
2200+42	0.22	1.2	<17	<19	<10	<10
2201+04	0.060	0.05		<96		
2232-05	0.22	700.	<28	<20	<70	<70
2251+58	0.13	130.	<30	<11	<25	<85

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