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ABSTRACT

We report X-ray spectral and temporal observations of 6 narrow emission line galaxies (NELG's) NGC 526a, NGC 2110, NGC 2992, MCG-5-23-16, NGC 5506, and NGC 7582. All of these sources are well fit by power law X-ray spectra of energy slope $\alpha \sim 0.8$. For 3 of them a power law is a significantly better fit than an isothermal bremsstrahlung spectrum. All of these objects, with the possible exception of NGC 526a, have column densities in the line of sight $> 1 \times 10^{22}$ at/cm². There is evidence for Fe spectral features in 3 of these objects.

On time scales of 6 months three of these objects, NGC 526a, NGC 2110, and MCG-5-23-16, are variable in their X-ray flux. On timescales less than one week, NGC 2110, MCG-5-23-16, NGC 5506 and NGC 7582 showed detectable variability in at least one observation. However, in only 5 out of 17 observations of these sources was variability detected. The observed timescales are a few days. The measured X-ray properties of the NELG's strongly resemble those for previously measured Seyfert I's of the same X-ray

luminosity and we conclude that, from an X-ray spectral and temporal standpoint, the NELG's are extremely similar to low luminosity Seyfert I's. We discuss the implications of our observations on the structure of the optical line emitting region in these galaxies.

Subject headings: galaxies: Seyfert - radiation mechanisms -
X-rays: sources - X-rays: spectra

I. INTRODUCTION

In the last few years there has been presented evidence (Ward et al. 1978, Schnopper et al. 1978, Bradt et al. 1978) for a new class of X-ray emitting galaxies, the so called narrow emission line galaxies (NELG's). There has been extensive discussion of whether their optical properties are truly different from Seyfert type II's (Rubin 1978, Shuder 1980, Veron et al. 1980) and if they form a new class of objects. Recent work (Lawrence and Elvis 1981) suggests that NELG's may be a type of transition object from Seyfert I's to Seyfert II's.

To date, of the ~ 6 presently known NELG's, only NGC 5506 (Stark, Bell-Burnell and Culhane 1978) has had its X-ray spectrum published (but see Maccacaro and Perola 1981). In this paper we report HEAO-1 results on the X-ray spectra and the time variability characteristics of NGC 526a, NGC 2110, NGC 2992, MCG-5-23-16, NGC 5506, and NGC 7582.

II. DATA ANALYSIS

We have used pointed and scanning HEAO-1 data (see Table 1) to derive the spectral properties of these objects. The HEAO-1 A-2 experiment has been described in detail by Rothschild et al. (1979). The time variability for scales from 6 hours to 18 months was obtained from HEAO-1 scanning data.

The spectra were analyzed in a manner identical to that in Mushotzky et al. (1980) and the intensity data were analyzed in a manner identical to that in Mushotzky and Marshall (1980). For the intensity data from the scans we have only considered data when the source was at $> 25\%$ transmission efficiency for our $3^\circ \times 3^\circ$ FWHM collimator (Table 1). At lower collimator transmission efficiencies there is a high probability of contamination of the X-ray "light curve" by weak confusing sources. The timing data derived from the pointed observations will be presented in another paper (Tennant et al. 1981).

III. RESULTS

A. Continuum Shape

The X-ray spectra from the pointed observations of all 6 of these sources (see Section D for a discussion of the spectrum of NGC 7582) can be well fit by a power law of photon index $\Gamma \sim 1.8$ with low energy X-ray absorption by cold material in the line of sight (Figs. 1 and 2 and Table 2). In the cases of NGC 5506, NGC 2992 and MCG-5-23-16 spectral features due to iron are significant at $\gtrsim 90\%$ confidence. When the iron features are taken into account the reduced χ^2 is ~ 1 for all these sources for fits to a power law model. In the high energy detector data for these 3 sources the best fit to a thermal model has χ^2 greater by ~ 10 than the best fits to a power law model (for 19 degrees of freedom). That is, these detectors, which are sensitive from 2 to 40 keV, do not see the roll over at high energies expected for a pure isothermal bremsstrahlung spectrum which is as steep as the observed spectrum is below 15 keV. We consider this change in χ^2 to be significant on the assumption that all the errors are statistical in nature. One way of attempting to quantify what we mean by "significant" is to compare the likelihood of the best fit for a given model to that of another model. Likelihood here is used in the same sense as that of Edwards (1972) (see pg. 33ff). The ratio of likelihoods, L_1/L_2 for two models, in this construct is

$$L_1/L_2 = \exp[(\chi_2^2 - \chi_1^2)/2] = \exp(\Delta\chi^2/2)$$

where χ_1^2 and χ_2^2 are the chi square for fits to models 1 and 2 respectively. This likelihood ratio is "the ratio of the frequencies with which, in the long run, the two hypotheses will deliver the observed data" (Edwards 1972, pg. 33). The change in χ^2 of ~ 10 found for NGC 5506, NGC 2992 and MCG-5-23-16

gives a ratio of likelihoods of ~ 140 for the power law versus the thermal model for each observation. We therefore feel that power law models are significantly better fits than thermal bremsstrahlung models for these 3 NELG's. We caution the reader that we cannot reject the hypothesis that a thermal bremsstrahlung model is correct. We can only state that it is less likely, than a power law model, to be the "correct" model.

The data from scan 1 for these sources is of high enough quality to state that the spectra of these sources did not change within measurement error. The statistics from scans 2 and 3 are of lower quality and are only sufficient to state that the power law indices for these observations are consistent with the pointed data and scan 1.

The values of the power law indices and the range of column densities (Sec IIIB) are quite similar to those for low luminosity Seyfert I galaxies as discussed in Mushotzky et al. (1980) (Fig. 3). Thus the X-ray continua of these objects is indistinguishable from that of Seyfert I galaxies of similar luminosity.

All the spectra continue with a constant slope out to the highest energies we can detect. Therefore their 2-40 keV luminosities are considerably (~ 4 times) larger than the 2-6 keV luminosities. Furthermore, because of the high column densities seen in these objects, the measured flux in the Einstein Observatory energy band (0.5-3.5 keV) will be considerably less than simple extrapolation from the 2-6 keV fluxes using a 1.8 power law photon index.

B. X-Ray Absorption

All the NELG's (with the possible exception of N526a) considered in this paper show evidence for the presence of considerable X-ray column density, N_X (Figs. 1 and 2 and Table 2). This is consistent with the pattern seen by

Mushotzky et al. (1980) and Mushotzky (1981) in their sample of 18 Seyfert I galaxies: only the low X-ray luminosity active galaxies showed measurable X-ray column densities. Recently Hayes et al. (1980) have reported that MK 464, a relatively high luminosity ($L_X \sim 3 \times 10^{44}$) source, has an X-ray column density of $\sim 2.5^{+2.8}_{-1.3} \times 10^{23}$ at/cm², which clearly violates our proposed correlation. However analysis of HEAO-1 data for this source puts an upper limit on $N_X < 2 \times 10^{22}$ at the 99% confidence level (Mushotzky 1981). Either MK 464 shows extremely variable X-ray absorption or one of these measurements is incorrect. In any case the statement that only low luminosity active galaxies as measured by the HEAO-1 experiment A-2 show measurable X-ray column still holds. We note that Lawrence and Elvis (1981) also find a similar correlation in their Einstein data for a sample of ~ 20 active galaxies. The range of X-ray column densities seen in the NELG's is compared to the sample of Mushotzky et al. (1980) and Mushotzky (1981) in Figure 4, where the anti-correlation between L_X and N_X is easily seen.

In a forthcoming paper we will discuss in detail the Einstein SSS determination of the column densities and X-ray covering factors for these sources (e.g. Holt et al. 1980) but we note here that the N_X values derived by the SSS are in good agreement with the HEAO-1 values. In the light of the discussion of Holt et al. (1980) we suggest that this anti-correlation between X-ray luminosity and X-ray column density is a covering factor phenomenon. The anti-correlation suggests that the higher luminosity objects have on average a lower covering factor than the low luminosity objects.

C. Fe Features

Given the relatively large column densities measured in these sources it is natural (Mushotzky et al. 1978, Holt et al. 1980) to see if these sources have detectable Fe spectral features (emission lines and edges) in the 6.4-7.9

keV energy range. Because of the relatively low total number of counts in these observations compared to previous results on Cen A and NGC 4151 we cannot strongly constrain the Fe line or edge values (Table 3). However, the observed values of the optical depth, τ , and equivalent width of the lines are consistent with what one might expect for fluorescent line emission due to cold material in the line of sight which is responsible for both the photoelectric absorption seen in the X-ray continuum and the Fe features.

D. The X-Ray Spectrum of the 2A 2315-428 Region

Recent Einstein Observatory imaging results of this region (Maccacaro and Perola 1981; Charles and Phillips 1981) show that there are at least 4 X-ray sources in the HEAO-1 field of view whose X-ray flux in the IPC band is greater than or equal to 1/3 of that of NGC 7582. The two highest flux objects in the IPC band are clusters of galaxies Sersic 159-03 and Sersic 159-02.

When we fit the X-ray spectrum derived from the HEAO-1 pointed observation at 2A2315-428, a power model with $\Gamma = 1.35$ and $N_H < 1 \times 10^{22}$ at/cm² gave an acceptable fit to both the HED3 and MED data. However, based on the Einstein imaging results a different model was also tried, that of a power law (appropriate for an active galaxy) plus a thermal bremsstrahlung spectrum (appropriate for the clusters). This model gave marginally better fits in both detectors ($\Delta\chi^2 = 5.2$ for the MED and 4.1 for HED3) with a best fit power law slope of $\Gamma = 1.69 \pm .15$, similar to the other NELG's, and a best fit temperature for the (presumed) cluster contribution of 3.1 ± 1 keV (1σ errors in Γ and KT). This model also required an absorption of $N_H > 5 \times 10^{22}$ atom/cm² for the power law component, consistent with the spectral analysis of Maccacaro and Perola. The best fitting model is shown in Figure 5. The 2-10 keV flux of the power law component was 1.4×10^{-11} ergs/cm² sec

while that of the thermal component was 1.8×10^{-11} ergs/cm² sec. The predicted .5 - 3.5 keV flux of the thermal component of 2.5×10^{-11} ergs/cm² sec is also consistent with the measured sum of the IPC fluxes of the two clusters of $\sim 1.7 \times 10^{-11}$ ergs/cm² sec. We therefore conclude that all the present data are consistent with NGC 7582 having an X-ray spectrum very similar to the other NELG's.

IV. INTENSITY VARIABILITY

A. Average Rates

We have averaged the X-ray flux seen from these objects over the time of observation to derive an average intensity (Table 4) for each of the observations. We note that NGC 526a, NGC 2110 and MCG-5-23-16 are definitely variable on a 6 month timescale at > 99% confidence. NGC 526a was previously noted as possibly variable by Marshall, Warwick, and Pounds 1981 (hereafter MWP). As seen in Table 4, NGC 2992 and NGC 5506 were stable to within 10% in their intensities averaged over 5 days. We have defined percentage change in intensity as

$$\left(\frac{I_i - \bar{I}}{\bar{I}} \right)_{\max} = R.$$

where \bar{I} is the average intensity over the observing period while I_i is the intensity in bin i . The total flux from the region containing NGC 7582 varied by less than 20%, this places a lower limit of $\sim 40\%$ on the possible variation of NGC 7582 alone. NGC 2110 and MCG-5-23-16 varied by $\sim 25\%$ but this is due to variation seen within each individual observation (see next section). NGC 526a varied by $\sim 50\%$ on timescales of 6 months without strong evidence for variability on daily timescales. We note that previous experiments (MWP and references therein) could only measure $R > .3$. It therefore seems that only

NGC 626a would have shown variability in previous samples if the values of R seen by HEAO-1 are typical.

B. Shorter Timescales

The HEAO-1 data have sufficient sensitivity in the scanning mode to obtain a $> 4\sigma$ determination of the flux from most of these objects on a 6-12 hour timescale for the central 3-5 days of a given observation. In Figure 6 and Table 5 we give a summary of the count rate vs. time for the 17 observations of these 6 sources. We note that, in general, these sources are not strongly variable on timescales less than 4 days.

An autocorrelation analysis of the count rates, sensitive to timescales from 2 hours to 2 days shows that none of these objects, in these observations, showed any detectable power on such time scales.

We have 5 observations out of a total of ~ 17 which have a χ^2 per degree of freedom such that the source has less than a 5% probability of being constant (Table 5). In Table 6 we show the approximate time scales for variability defined as

$$w = \left(\frac{d \ln I}{dt} \right)^{-1} = \overline{I} (\Delta t / \Delta I) ,$$

where ΔI is the change in intensity over a time Δt . We find that the variable sources, as expected from the autocorrelation analysis, have timescales $\gtrsim 2$ days.

1. MCG-5-23-16

This source shows two strong episodes of variability with characteristic timescales of 3 and 5 days, however the middle observation shows no variability. We stress that since we have not observed a total "event", that is both the rise and fall times, that our estimates of the

timescales are probably only lower limits to the true timescale. The total variation in these events is large with $\Delta I/I \sim 2$. MWP previously noted that this source was variable when comparing various experiments.

2. NGC 5506

This source was reported to be variable by Marshall et al. (1980) with 1 flare with a timescale of ~ 1 day being seen in 30 days of observation. It is difficult to place a value on the timescale of variation seen in our data because the "events" are of low amplitude. There is an indication of two "events" with $\Delta I/I \sim .2$ and a time between events of $\sim 1 \frac{1}{2}$ days. Variations of such a low amplitude would not have been detected by Marshall et al. (1980).

3. NGC 7582

This is the only observation in which we have a clear indication of a "flare" (Fig. 7). The observed $\Delta I/I$ for this flare is $\sim .90$ and $t \sim 1.5$ days. However since NGC 7582 only contributes roughly half the 2-10 keV baseline flux the true $\Delta I/I$ is larger. This event is therefore very similar to the one day flares reported by MWP. Neither of the two other observations of this source showed a similar event. We conclude that such events are rare (less than 1 per 12 days) and are true "events" and are probably not part of a general shot noise process where the individual shots are similar to the observed flares (Lawrence 1980); however, we cannot rule out shot noise like processes in general. Maccacaro and Perola (1980) have reported that this source varies by a factor of four on timescales of 6 months. NGC 7582 is severely confused in HEAO-1 (Maccacaro and Perola 1981; Charles and Phillips 1981) with 2 clusters and at least 2 other galaxies. Therefore it is possible that the variability is due to NGC 7552 or NGC 7590 rather than NGC 7582. This would have meant $\Delta I/I > 10$ for these weaker sources.

We conclude that the NELG's, in general, are likely to be relatively stable on timescales from hours to months and that episodes of strong variability are relatively rare. Observations capable of examining time scales from a few minutes to hours (Tennant et al. 1981) are also consistent with this conclusion.

V. DISCUSSION

A. The Nature of the X-Ray Sources in NELG's

These X-ray observations confirm the hypothesis of Veron et al (1980) that the X-ray emitting NELG's are very similar in their properties to low luminosity X-ray emitting Seyfert I galaxies. Since their underlying continuum, at least at X-ray wavelengths, is so similar to that of the Seyfert I's one must consider models in which NELG's differ from Seyfert I's primarily in the geometry, size or density of the broad line region (Lawrence and Elvis 1981). Time variability seen in several such objects (MWP, this paper; Ward et al. (1978)) also argues for an underlying source similar to that seen in low luminosity Seyfert I galaxies.

The space density of such objects is difficult to estimate, given such a small sample, but if we assume that all such objects of $L_X > 1 \times 10^{43}$ out to $z \sim .01$ have been detected (consistent with the HEAO-1 all sky survey limit from Piccinotti et al. 1981) then we find that these objects have a volume density similar to the volume density of Seyfert I galaxies of similar X-ray luminosity (Piccinotti et al. 1981). We therefore conclude that the underlying nuclear X-ray source properties of the NELG's are totally consistent with their being identical to those of low luminosity Seyfert I galaxies.

B. X-Ray Absorption and Optical Reddening

Several authors (Ryter, Cesarsky and Audouze 1975; Gorenstein 1975; Reina

and Tarengi 1973) have noted that X-ray absorption N_X is simply related to optical reddening, A_V , given a "typical galactic dust to gas ratio and cosmic abundances", by $A_V \sim 4.5 \times 10^{-22} N_X \text{ mag}$. In Table 7 we show the A_V predicted from the measured X-ray column density, A_V^X , compared to the optically measured A_V for these objects. We see that for NGC 2110, NGC 5506 and MCG-5-23-16 that the optical extinction predicted from the X-ray measured column density is considerably higher than that actually measured. This is very similar to the situation in NGC 4151 (Mushotzky et al. 1979) and for NGC 7582 (Maccacaro and Perola 1981). Two possible explanations are either a considerably lower dust to gas ratio in these galaxies than in our own or a source of extinction that covers the X-ray source more or less totally but only partially covers the broad line region. Ward et al. (1980) have considered geometries of this type to explain the very low reddening observed in the UV compared to the higher values derived from optical data in NGC 7582. But in this source they conclude that "we view the non-thermal compact source through holes in the ionized gas", exactly the opposite conclusion that we have reached for NGC 5506, NGC 2110 and MCG-5-23-16. That is, comparison of the X-ray and optically determined "reddenings" seems to indicate that the optical emission lines are shining through "holes" in the clouds absorbing the X-rays; comparison of the UV continuum and optically determined reddenings seems to suggest that the UV shines through holes in the clouds which absorb the optical photons. Therefore if one assumes that the UV and X-ray continuum arise in the same location a paradox results.

We believe that part of the discrepancy may be in the inconsistency of the models used to fit the optical-UV data. If there is not a covering factor of unity, absorption features will tend to get "filled in" by the unabsorbed continuum. Similarly the Balmer line ratios will be different from that

assumed for a uniform covering factor in the sense that they will be less reddened if the absorber is patchy. Therefore the inferred 2200 Å absorption feature would be smaller than the "true" depth of the absorption and the Balmer line ratios more "case B like". A correction for this effect might make the inferred UV and optical reddenings similar and perhaps more in line with the measured X-ray column density.

We note that these high values of the X-ray column density are unlikely to be due to extinction caused by material in the narrow line region (see Maccacaro and Perola 1981) and could be used as an argument for the existence of a "broad line region" in these galaxies. However the lack of high X-ray column densities in objects known to have an optical broad line region (Mushotzky 1981) makes the argument a weak one.

C. X-Ray Time Variability

It is generally assumed (Rees 1979) that X-ray time variability measurements will strongly constrain the size of the energy source of active galactic nuclei. Our data are relatively ambiguous on this point. We note that, most of the time, most of these objects are not highly variable (as compared, for example, to galactic X-ray sources). This argues that whatever mechanism powers the emission (accretion, rotation or whatever) it must be, in general, relatively stable. Yet it must also be capable of occasionally "flaring" or varying strongly.

The timescales seen in our data are suggestive of light travel time sizes, $R \sim ct_{\text{var}}$, of $\sim 10^{16}$ cm. One must be very careful of such arguments, since there is no reason one cannot have timescales for variability much greater than the light crossing time. For example, many galactic objects show variability timescales 1000 times the light travel time across a neutron star. But, given that we have at present no other constraints, we shall

assume that $R \equiv ct_{\text{var}}$. If one interprets this size as constraining the mass of a putative central object (and assuming that the X-ray flux originates at ~ 10 gravitational radii) then one derives a "mass" M_X for this object of

$$M_X \sim \frac{c^2 R}{10G} \quad \text{or} \quad \sim 10^9 M_\odot.$$

Since these objects emit a few times 10^{43} ergs/sec over the observed range (optical + UV + X-ray), the Eddington limit for these luminosities would then imply a $\sim 10^5 M_\odot$ object.

Therefore, either these objects emit at $\lesssim 10^{-3}$ of the Eddington limit for a supermassive object whose mass is defined by the observed X-ray variability time scale, or the observed time scale does not tell us much about such a massive object (that is the scale size of the central object is less than ct_{var}). If the latter case is true one might want to consider models in which the X-ray emitting volume is considerably larger than 10 Schwarzschild radii of a super massive object.

D. Why Are NELG's "Narrow" Line Galaxies?

1. Dust and Geometry

First of all NELG's do possess (with the possible exception of NGC 7582) (Shuder 1980; Veron et al. 1980) broad $H\alpha$ lines. The total luminosity in these broad $H\alpha$ components, corrected for reddening, is quite similar to that in broadline galaxies of similar X-ray luminosity. For example the reddening corrected value of the broadline $H\alpha$ luminosity, $L(H\alpha)$, for NGC 2992 of $\sim 2 \times 10^{42}$ erg/sec for the broad line component, is quite similar to $L(H\alpha)$ for NGC 3783 a "typical" Seyfert I with a similar X-ray luminosity (Osmer, Smith, and Weedman 1974) of 9×10^{41} erg/sec (uncorrected for any reddening). If one looks at the $L(H\alpha)$ vs. L_X relation for broadline galaxies

of Phillips et al. (1979) one would predict $L(H\alpha)$ of 10^{41-42} from the measured 2-10 keV X-ray luminosities of the NELG's. This is indeed what is seen if the observed broad line flux from these objects is corrected for the 2-5 magnitudes of reddening at $H\alpha$. (We use $H\alpha$ instead of $H\beta$ as a calibration because of the lesser effect of reddening at these wavelengths. Even small errors in E_{B-V} will produce large errors at $H\beta$ relative to $H\alpha$). If one uses the X-ray column density as a measure of reddening then these galaxies would be vastly overluminous in $H\alpha$ for their X-ray luminosities. We thus agree with Lawrence and Elvis (1981) that a likely explanation for the NELG's low broad line flux is dust in and/or just outside the broadline region. However the dust must have a geometrical distribution that does not obscure the source of the relatively strong narrow lines from the photoionization continuum source.

The "easiest" way to do that is to have dust mixed into or just in back of the clouds in the broadline region. The BLR has "holes" in it for the continuum to pass through in order to ionize the forbidden lines. However the covering fraction for X-ray absorption must be rather large (Holt et al. 1980) in order to see any absorption in X-rays. This may suggest that we are seeing a disk-like geometry (Lawrence and Elvis 1981) in which our line of sight is parallel to the disk, similar to Osterbrock's (1979) suggestion. Of course one difficulty with this idea is that only the low L_X sources show X-ray absorption in the HEAO-1 sample. This might suggest that the thickness of the disks is a function of L_X (see Lawrence and Elvis 1981). High statistical weight X-ray observations of the ratio between the depth of the Fe edge and the strength of the Fe fluorescent line, similar to that already done for Cen-A and NGC 4151 (Mushotzky et al. 1979; Holt et al. 1980), will strongly constrain the geometry of the X-ray absorbing region.

2. Size and Ionization Parameter

If one assumes that the X-rays are absorbed in the line emitting regions of these objects one can use case B calculations to estimate the X-ray column density. That is, one can calculate the amount of material necessary to give the observed $H\alpha$ flux from these objects under the assumption that the emission line clouds are optically thin in the Balmer lines but thick to $Ly\alpha$. If one then assumes that it is this material that is the cause of the photoelectric absorption seen by the X-rays, one can, under the assumption of "normal cosmic abundances", calculate N_X from the measured reddening corrected flux of $H\alpha$. While case B calculations may not be "correct" for the broad line region (Kwan and Krolik 1979; Canfield and Puetter 1980) they are illustrative, and in particular, for the broad line region case B calculations overestimate the amount of gas necessary to produce the observed Balmer line fluxes. Case B calculations predict $N_X \sim 10^{23.5} U$ and $N_X \sim 8 \times 10^{-23} L(H\alpha) n_9^{-1} r_{pc}^{-2} \text{ cm}^{-2}$ (where r_{pc} is the size of the region in parsecs, n_9 is the electron density in units of $10^9/\text{cm}^3$, (Shields and Mushotzky 1979) the ionization parameter U is

$$U = \frac{L_c}{4\pi n_e r_c^2}$$

L_c is the continuum luminosity at 1 Rydberg, n_e is the electron density, and where one assumes that the same material that is absorbing the X-rays that emits the Balmer lines and it has a unitary covering factor). The value of U is $\sim 10^{-2} - 10^{-3}$ in order to explain the observed ratio of CIII]/CIV (Davison and Netzer 1979) seen in the broadline region of QSO's. In order to account for the observed X-ray column density in the NELG's being caused by ionized line emitting gas in the broadline region, one needs $U \sim .1 - .01$ (Shields and Mushotzky 1979). This implies, if we require $U \sim 10^{-2.5}$, that either the

X-ray absorption occurs in optically thick neutral portions of the broadline clouds (Kwan and Krolik 1979) or in an optically thin "hot" medium which does not emit Balmer radiation but which is cool enough to absorb X-rays.

Alternatively we can let $U \sim .1$. This would decrease the CIII]/CIV ratio relative to what is seen in QSO's by a large amount and somewhat weaken $\text{Ly}\alpha$. This effect would not be easily measurable in the NELG's because of the large effect of dust in reducing the ultra-violet line fluxes. However recent IUE observations of NGC 5506 (Bergeron, Maccacaro and Perola 1981) indicate that this object has a CIII]/CIV ratio of ~ 1 , which is larger than that seen in QSO's. If this ratio is not strongly affected by the large column density measured in the X-ray it indicates a value of $U \ll .1$.

NGC 4151, which also has a rather similar "problem" in comparing the observed high value of N_X to "typical" values of U , has a CIII]/CIV ratio (Penston et al. 1981) $\sim 1/2 - 1/4$ that of QSO's, as if it had a higher U value. Inspection of Figure 7 of Davidson and Netzer (1979) shows that changing U by 3 changes CIII]/CIV by ~ 4 (for U in the range $10^{-3} - 10^{-2}$). That is, QSO's have $U \sim 10^{-2.4}$ while NGC 4151 has $U \sim 10^{-2}$. However this value of U would imply an X-ray column density of only $10^{21.5}$, which is too low by an order of magnitude to explain the observed X-ray column density.

This postulated higher value of U could be due to either a smaller size, r for a given n_e , or a lower electron density n_e for a given r . In either case there is no difficulty in accounting for the observed (dereddened) Balmer line flux. If this scenario is correct one might expect to see a rather wide dispersion in the $L(\text{H}\alpha)$ vs. L_X (2-10 keV) relation (where we have assumed that the UV ionizing continuum is related to the observed X-ray flux) if either r or n_e vary strongly from object to object. This could be the origin of the "optically dull" (Elvis et al. 1981) galaxies which have high X-ray fluxes but

weak optical lines. Clearly high statistical weight UV observations and more extensive modeling are needed to test whether this hypothesis is viable as an explanation of the high column densities in the X-ray for the low luminosity sources.

CONCLUSION

HEAO-1 A-2 observations of the narrow emission line galaxies show them to have X-ray spectral and temporal properties very similar to those of low luminosity Seyfert I galaxies. Their X-ray spectra in the 2-40 keV band are well described as power laws with photoelectric absorption. The mean energy slope of the power law, $\alpha \approx 0.8$, is consistent with the Seyfert I sample reported by Mushotzky et al. (1980). The observed column densities are rather high with 4 of the 5 objects having $N_H > 1.0 \times 10^{22}$ at/cm, and are consistent with the pattern seen in Seyfert I's of only the low luminosity active galaxies showing measurable X-ray photoelectric absorption. The X-ray fluxes are slightly variable on 6 month time scales, with NGC 526a, MCG-5-23-16 and NGC 2110 showing measurable variability. Five out of 17 observations of these NELG's show variability on time scales from 2-4 days at $> 95\%$ confidence.

The X-ray spectra of the narrow emission line galaxies resemble, in every respect, that seen from low luminosity Seyfert I galaxies. We feel that this supports the claim of Veron et al. (1980) that the NELG's are Seyfert I galaxies in disguise. We therefore still do not know, because of the lack of X-ray spectra, whether "true" Seyfert II galaxies have an X-ray active galactic nucleus (however see Lawrence and Elvis 1981).

The X-ray determined column densities in the line of sight to the active nucleus are, in general, quite a bit larger than those inferred from optical and UV reddening measurements. This suggests that either these objects have an abnormally low dust to gas ratio or that there are holes in the X-ray

absorbing cloud or a disk like geometry. Moderate resolution (~ 200 eV) X-ray spectroscopy of these objects should be able to distinguish between these possibilities. If the observed timescale for X-ray variability is related to the size of the energy source for these objects we infer that the NELG's emit at $\lesssim 10^{-3}$ of their Eddington luminosities.

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TABLE 1
OBSERVATION DATES OF NELGs

NAME	POINTED OBSERVATION	SCAN 1	SCAN 2	SCAN 3
NGC 526a	162	356-361	173-178	356-361
NGC 2110	282	261-265	75-79	261-266
NGC 2992	144	328-332	143-147	329-332
MCG-5-23-16	132	336-341	152-156	339-341
NGC 5506	209	385-389	204-208	---
NGC 7582	153	325-330	141-145	326-330

For pointed observations dates are day of 1978

For SCAN 1 dates are day of 1977

For SCANS 2 and 3 dates are day of 1978

TABLE 2
BEST FIT POWER LAW SPECTRA FOR NELG's FROM THE HIGH ENERGY DETECTOR⁽⁶⁾

NAME	N ⁽⁵⁾	Γ ⁽¹⁾	$N_X \times 10^{22}$ ⁽¹⁾	χ^2_{ν} ⁽⁴⁾	NOTES
NGC 526a	.0045	$1.52^{+.25}_{-.22}$	< 3.6	.76	
NGC 2110	.024	$1.80^{+.20}_{-.17}$	$7.4^{+2.8}_{-2.9}$.84	
NGC 2992	.029	$1.79^{+.13}_{-.09}$	$1.6^{+1.1}_{-.9}$	1.24, .98	2,3
MCG-5-23-16	.036	$1.84^{+.16}_{-.17}$	$5.0^{+2.2}_{-2.0}$.94, .77	2,3
NGC 5506	.018	$1.75^{+.17}_{-.15}$	$4.1^{+2.2}_{-1.8}$	1.33, .93	2,3

(1) all errors are 90% combined confidence ($\chi^2_{\min} + 4.6$)

(2) significantly better fit for a power law rather than thermal model

(3) indication of Fe spectral features

(4) power law fit; if two values, second is for fit with Fe feature. A power law model has degrees of freedom, inclusion of an Fe features results in 17 degrees of freedom.

(5) N is the normalization for a fit of the form

$$\frac{dI}{dE} = N_C E^{-\Gamma} \exp(-\sigma N_X) \text{ ph/cm}^2 \text{ sec keV}$$

(6) The high energy detector fits are valid for the 2-40 keV band.

TABLE 3

Fe LINE AND EDGE VALUES

NAME	E.W. (eV)	τ	$\Delta\chi^2$
NGC 2110	< 360	< .3	---
NGC 2992	140 ± 60	< .4	7.0
MCG-5-23-16	130^{+140}_{-80}	$.3^{+.2}_{-.25}$	6.2
NGC 5506	250 ± 130	$.3^{+.6}_{-.2}$	8.3

E.W. is the equivalent width of a Fe emission line.

τ is the optical depth of a Fe absorption line

$\Delta\chi^2$ is the change in χ^2 from adding Fe spectral features to a power law model

Errors are 1σ

TABLE 4
2-10 keV FLUXES FOR THE NELG's

NAME	SCAN 1	SCAN 2	SCAN 3	$(\frac{I_{\max} - \bar{I}}{\bar{I}})_{\max}$	\bar{L}_x	NOTES
NGC 526a	4.38 \pm .32	2.11 \pm .46	2.38 \pm .56	.48	4.1	Variable
NGC 2110	3.56 \pm .32	3.43 \pm .37	4.89 \pm .46	.23	.98	Variable
NGC 2992	7.40 \pm .48	8.38 \pm .32	7.21 \pm .64	.09	1.85	
MCG-5-23-16	7.27 \pm .32	12.52 \pm .53	10.50 \pm .60	.24	2.91	Variable
NGC 5506	4.04 \pm .32	4.53 \pm .56	---	.06	.68	
NGC 7582	4.74 \pm .30	6.15 \pm .41	6.60 \pm .46	.13	.60	For 2A2315-428 region

NOTES: Fluxes for scans 1, 2, 3 are in units of 10^{-11} ergs/cm² sec, 1σ errors

\bar{L}_x is in units of 10^{43} ergs/sec in the 2-10 keV band, $H_0 = 50$ Km/sec Mpc

TABLE 5

VARIABILITY OF NELG's ON DAY TO DAY TIME SCALE

NAME	SCAN 1			SCAN 2			SCAN 3		
	χ^2_{ν}	ν	P	χ^2_{ν}	ν	P	χ^2_{ν}	ν	P
NGC 526a	.95	14	.50	1.42	8	.076	1.83	6	.09
NGC 2110	4.0	3	.0075	1.78	4	.13	.67	6	.67
NGC 2992	.91	9	.73	.84	9	.58	.83	9	.59
MCG-5-23-16	3.07	21	$< 10^{-6}$.97	11	.47	4.22	8	5.4×10^{-5}
NGC 5506	2.04	9	.03	.84	8	.57	--	--	---
NGC 7582	1.64	7	.12	2.26	9	.016	.98	8	.44

NOTES: χ^2_{ν} is the reduced chisquare on the assumption of a constant source

ν is the number of degrees of freedom

P is the probability of this large a value of χ^2 occurring by chance for a given observation.

TABLE 6

TIME SCALE FOR VARIABILITY OF NELGS

NAME	SCAN #	t(days)	NOTES
MCG-5-23-16	1	~ 3	
MCG-5-23-16	3	~5	
NGC 5505	1	~ 3.5	Poorly determined
NGC 7582	2	~ 2	Rise time faster than decay time

TABLE 7

COMPARATIVE VALUES OF X-RAY AND OPTICAL EXTINCTIONS

NAME	A_V^X	A_V
NGC 2110	27 ± 12	2.19 a
NGC 299?	$8^{+5.5}_{-4.7}$	4.71a, 3.96b, 4.2c
MCG-5-23-16	23 ± 9	~ 4.0 d
NGC 5506	16^{+11}_{-7}	2.76a, 1.2e

A_V^X is the predicted visual extinction from the measured X-ray column density

References for optical reddening A_V :

- a) Shuder 1980
- b) Ward et al. 1978
- c) Ward et al. 1980
- d) Wilson, Ward and Griffiths 1981
- e) Bergeron, Maccacaro and Perola 1981

REFERENCES

- Bergeron, J., Maccacaro, T. and Perola, C. 1981, *Astron & Astrophys.* 97, 94.
- Bradt, H.V., Burke, B.F., Canizares, C.R., Greenfield, P.E., Kelley, R.L.,
McClintock, J.E., van Paradijs, J. and Koski, A.T. 1978, *Ap. J. (Letters)*
226, L111.
- Canfield, R.C. and Puetter, R.C. 1980, *Ap. J. (Letters)* 236, L7.
- Charles, P. and Phillips, M. 1981, preprint.
- Davidson, K. and Netzer, H. 1979, *Rev. Mod. Phy.* Vol. 51, 715.
- Edwards, A.W.F. 1972, *Likelihood*, Cambridge University Press.
- Elvis, M., Schreier, J., Tonry, J., Davis, M., and Huchra, J.P. 1981, *Ap. J.*
246, 20.
- Gorenstein, P. 1975, *Ap. J.* 198, 95.
- Hayes, M.J.C., Culhane, J.L. and Bell-Burnell, S.J. 1980, *M.N.R.A.S.* 192, 1p.
- Holt, S.S., Mushotzky, R.F., Becker, R.H., Boldt, E.A., Serlemitsos, P.J.,
Szymkowiak, A.E. and White, N.E. 1980, *Ap. J. (Letters)* 241, L13.
- Kwan, J. and Krolik, J. 1979, *Ap. J. (Letters)* 233, L91.
- Lawrence A. 1980, *M.N.R.A.S.* 192, 83.
- Lawrence, A. and Elvis, M.S. 1981, preprint.
- Maccacaro, T. and Perola, G.C. 1981, *Ap. J. (Letters)* 246, L11.
- Marshall, N., Warwick, R.S. and Pounds, K.A. 1981, *M.N.R.A.S.* 194, 987.
- Mushotzky, R.F. 1981, in preparation.
- Mushotzky, R., Marshall, F.E., Boldt, E., Holt, S., Serlemitsos, P. 1980, *Ap.*
J. 235, 377.
- Mushotzky, R.F., Holt, S.S. and Serlemitsos, P.J. 1978, *Ap. J. (Letters)* 225,
L115.

- Mushotzky, R.F. and Marshall, F.E. 1980, Ap. J. (Letters) 239, L5.
- Osmer, P.S., Smith, M.G. and Weedman, D.W. 1974, Ap. J. 189, 187.
- Osterbrock, D.E. 1979, A.J. 84, 901.
- Penston, M. et al. 1981, preprint.
- Phillips, M.M., Feldman, F.R., Marshall, F.E., Wamstecker, W. 1979, Astron & Astrophys 76, L14.
- Piccinotti, G., Mushotzky, R.F., Boldt, E.A., Holt, S.S., Marshall, F.E., and Serlemitsos, P.J. 1982, Ap. J., in press.
- Rees, M. 1979, X-Ray Astronomy, ed. R. Giacconi and G. Setti, D. Reidel, pg. 339.
- Reina, C. and Tarengi, M. 1973, Astr. Ap. 26, 257.
- Rothschild, R., Boldt, E., Holt, S., Serlemitsos, P., Garmire, G., Agrawal, P., Riegler, G., Bowyer, S., and Lampton, M. 1979, Space Science Instrumentation 4, 265.
- Rubin, V.C. 1978, Ap. J. (Letters) 224, L55.
- Ryder, C., Cesarsky, C., Audouze, J. 1975, Ap. J. 198, 103.
- Shields, G. and Mushotzky, R. 1979, Astron. & Astrophys. 79, 56.
- Schnopper, H., Davis, M., Delvaille, J.P., Geller, M.J. and Huchra, J.P. 1978, Nature 275, 719.
- Shuder, J.M. 1980, Ap. J. 240, 32.
- Stark, J.P., Bell Burnell, J. and Culhane, J.L. 1978, M.N.R.A.S. 182, 23.
- Tennant, A., Mushotzky, R.F., Swank, J. and Boldt, E. 1981, in preparation.
- Veron, P., Lindblad, P.O., Zuiderwijk, E.J. and Veron, M.P. 1980, Astron. & Astrophys. 87, 245.
- Ward, M.J., Wilson, A.S., Penston, M.V., Elvis, M., Maccacaro, T. and Tritton, K.P. 1978, Ap. J. 223, 788.

Ward, M., Penston, M.V., Blades, J.C. and Turtle, A.J. 1980, M.N.R.A.S. 193,
563.

Wilson, A., Ward, M., and Griffiths, R. 1981, private communication.

FIGURE CAPTIONS

Figure 1 - Photon spectra for 5 NELG's from the xenon detector (HED 3). All the spectra shown are from pointing data. The spectra have been unfolded from the pulse height distribution using the best fit power law model.

Figure 2 - Probability plots for the power law index Γ and the column density N_X for 5 NELG's. These curves give the increase in χ^2 ($\Delta\chi^2$) when the free parameter has the value on the abscissa and all other parameters are free to assume the value that gives the local minimum in χ^2 space. In this construct $\chi^2 + 4.6$ gives the 90% confidence boundary for 2 parameters of interest. These curves therefore give a "one-dimensional cut" in the N-dimensional χ^2 probability space. The dotted lines gives these curves for the xenon (HED 3) and the solid line for argon (MED) detector.

Figure 3 - The distribution of the best fit power law energy indices α for Seyfert I's (solid dot, labeled broadlines) and the 5 well determined NELG (crosses) versus their X-ray luminosity. The vertical dashed lines define the approximate width of the distribution. The 1σ error in α for these sources is roughly 0.15.

Figure 4 - The distribution of observed column densities. The dotted line represents a general HEAO-1 upper limit. Individual objects have been published in this paper, Mushotzky et al. 1980 and Mushotzky 1981.

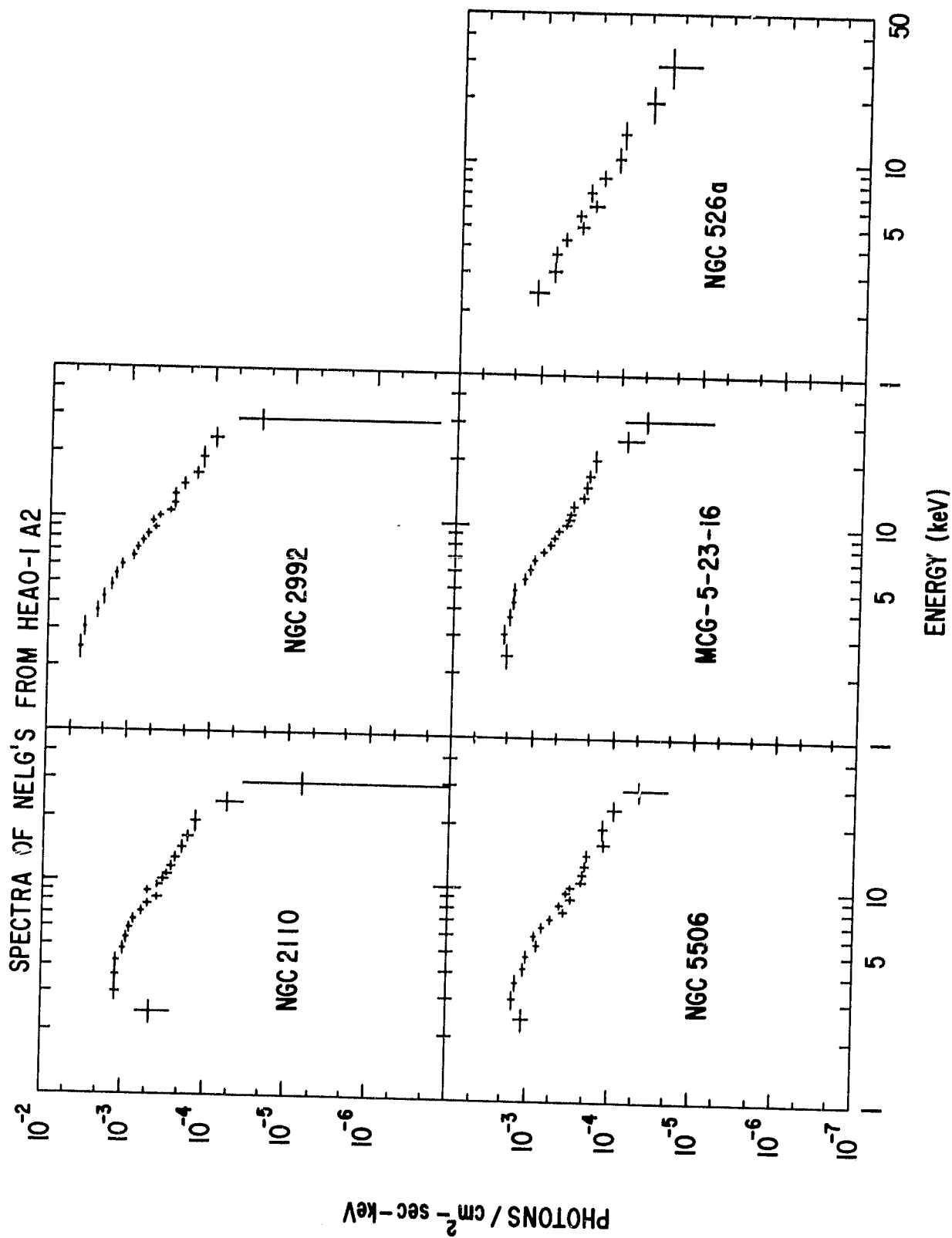
Figure 5 - The best fitting two component model for the 2315-425 region is

shown superimposed on the data. The line labeled sum is the linear superposition of the best fitting thermal bremsstrahlung and power law components.

Figure 6 - The counting rates for the 17 scanning observations of the NELG's. The units are 10^{-2} cts/cm² sec. The bin sizes are either 6 or 12 hours depending on the source flux. The panels correspond exactly to the entries in Table 5.

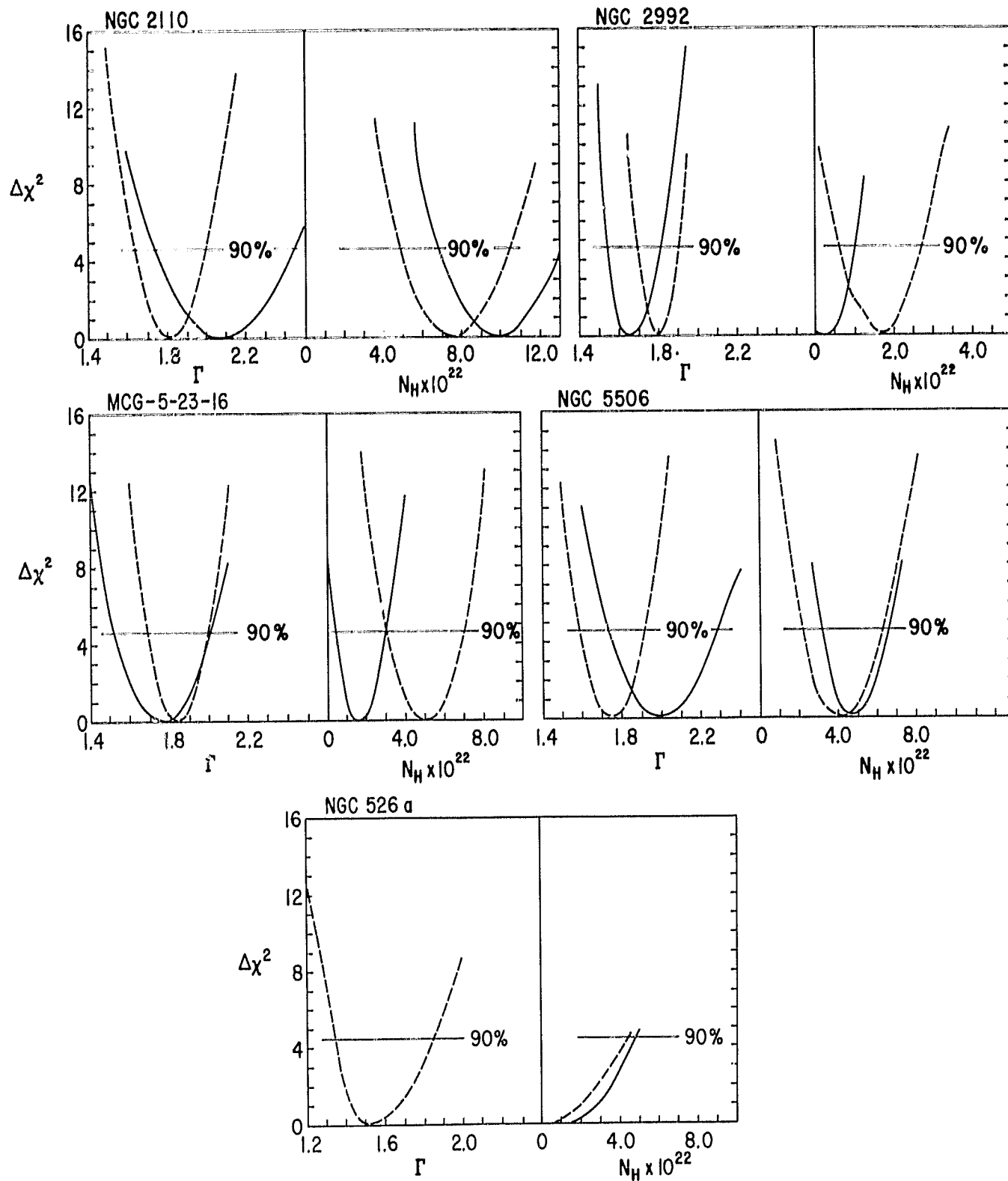
Figure 7 - The light curve of the second observation of NGC 7582 enlarged. The bin sizes is 6 hours. There seems to be an obvious "flare".

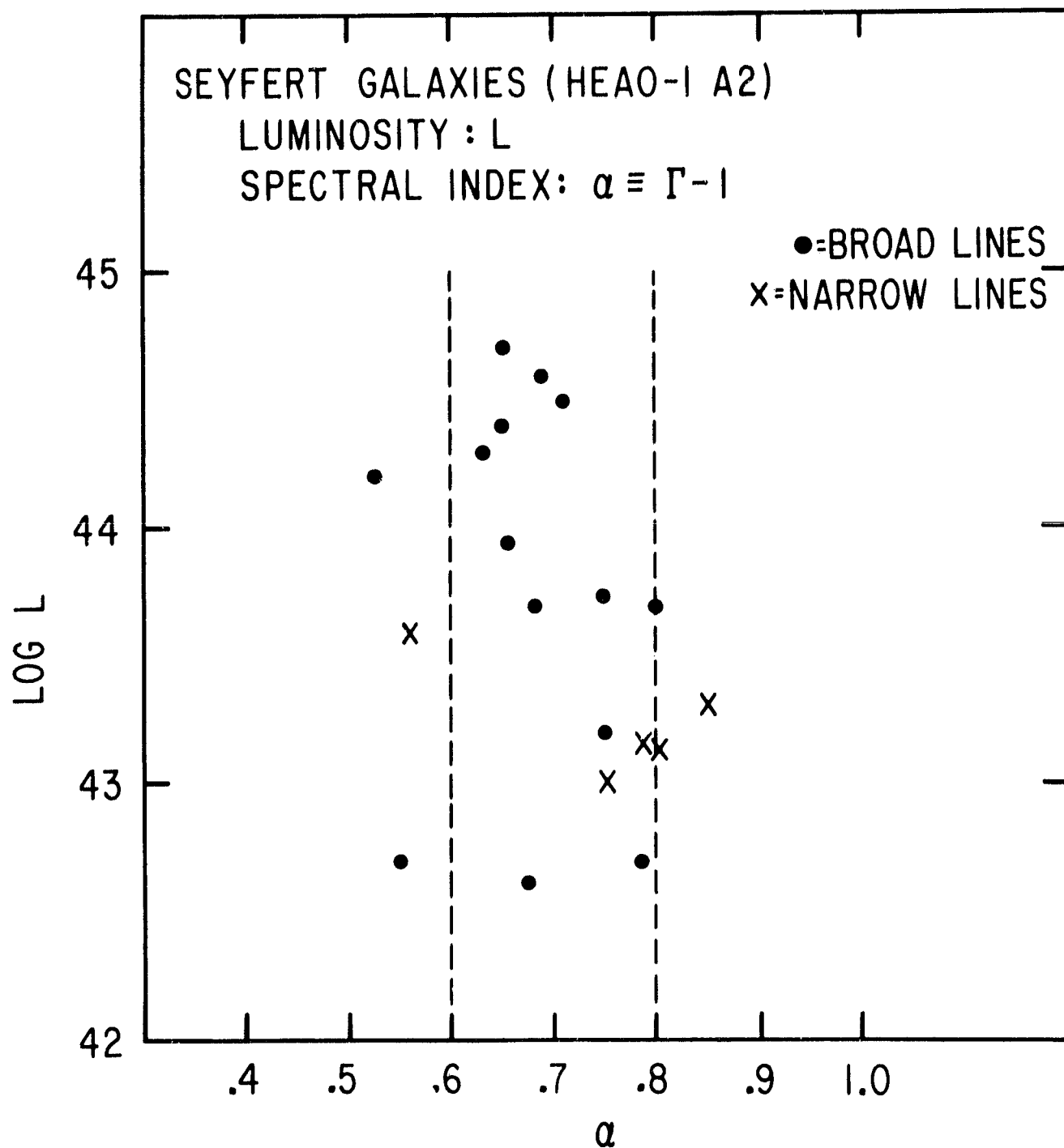
R.F. MUSHOTZKY, Code 661, Laboratory for High Energy Astrophysics,
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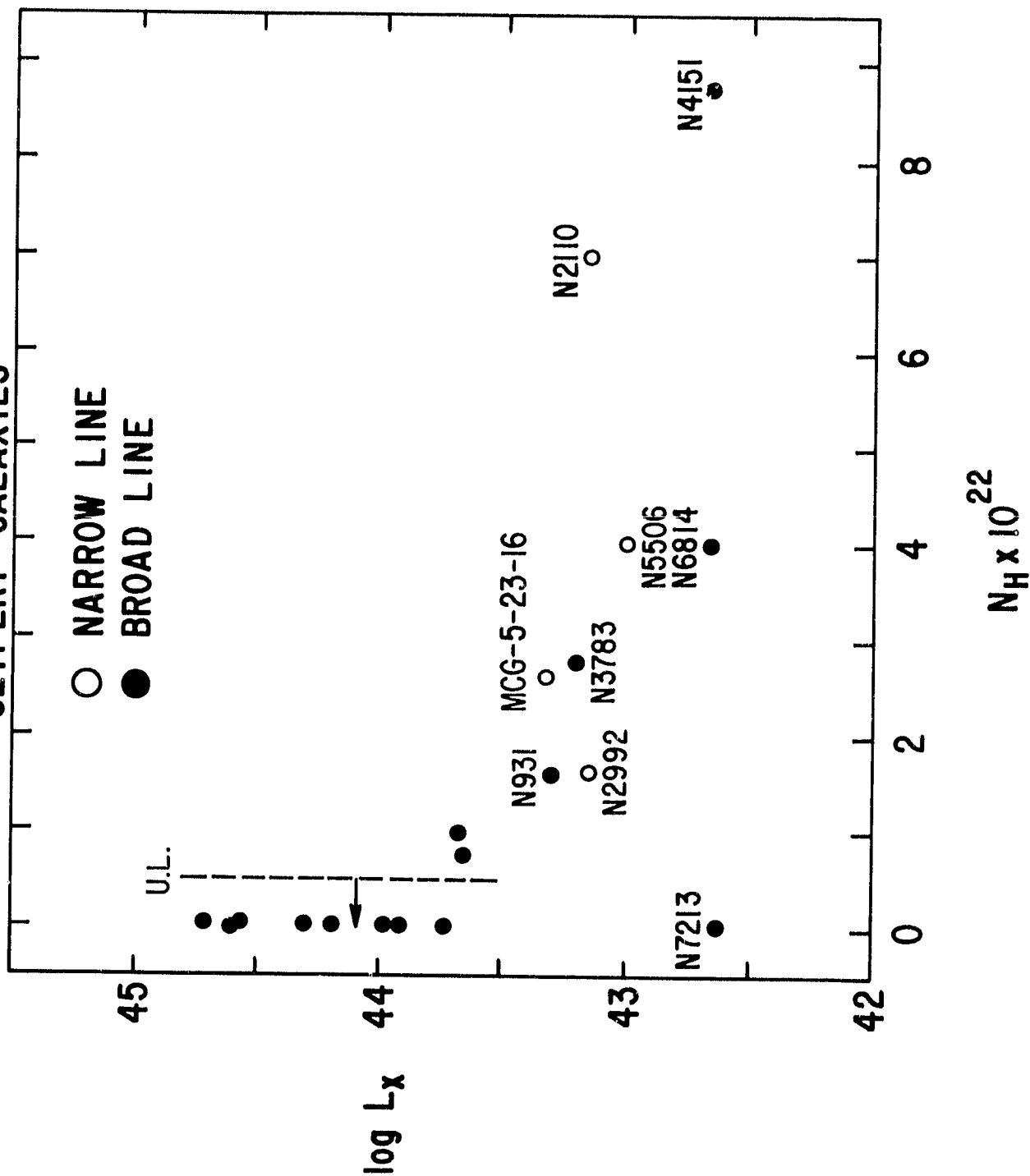
ERROR CONTOURS FOR POWER LAW INDICES AND COLUMN DENSITIES (FOR NELG'S)

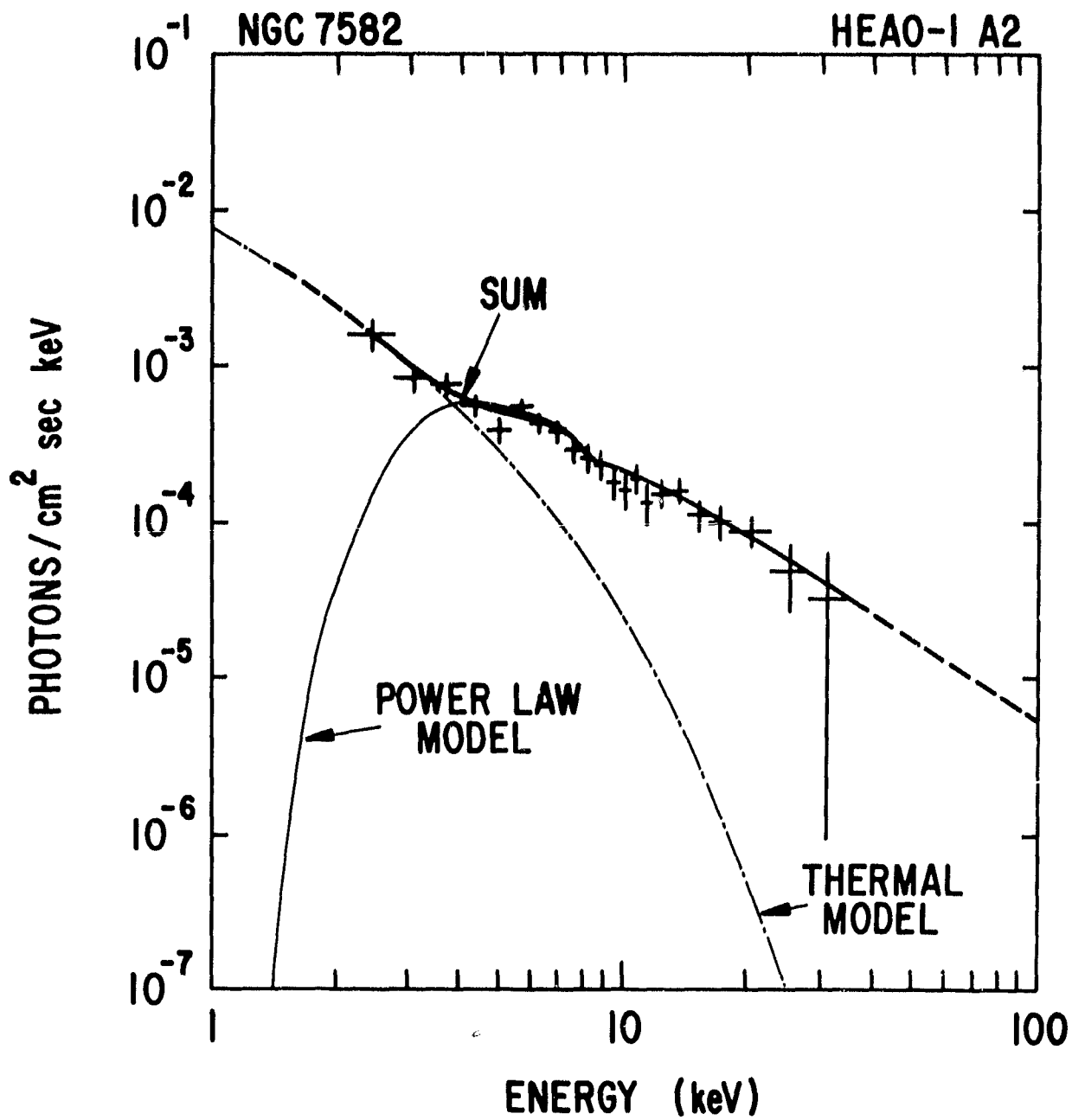
— HEAO-1 A2 MED --- HEAO-1 A2 HED





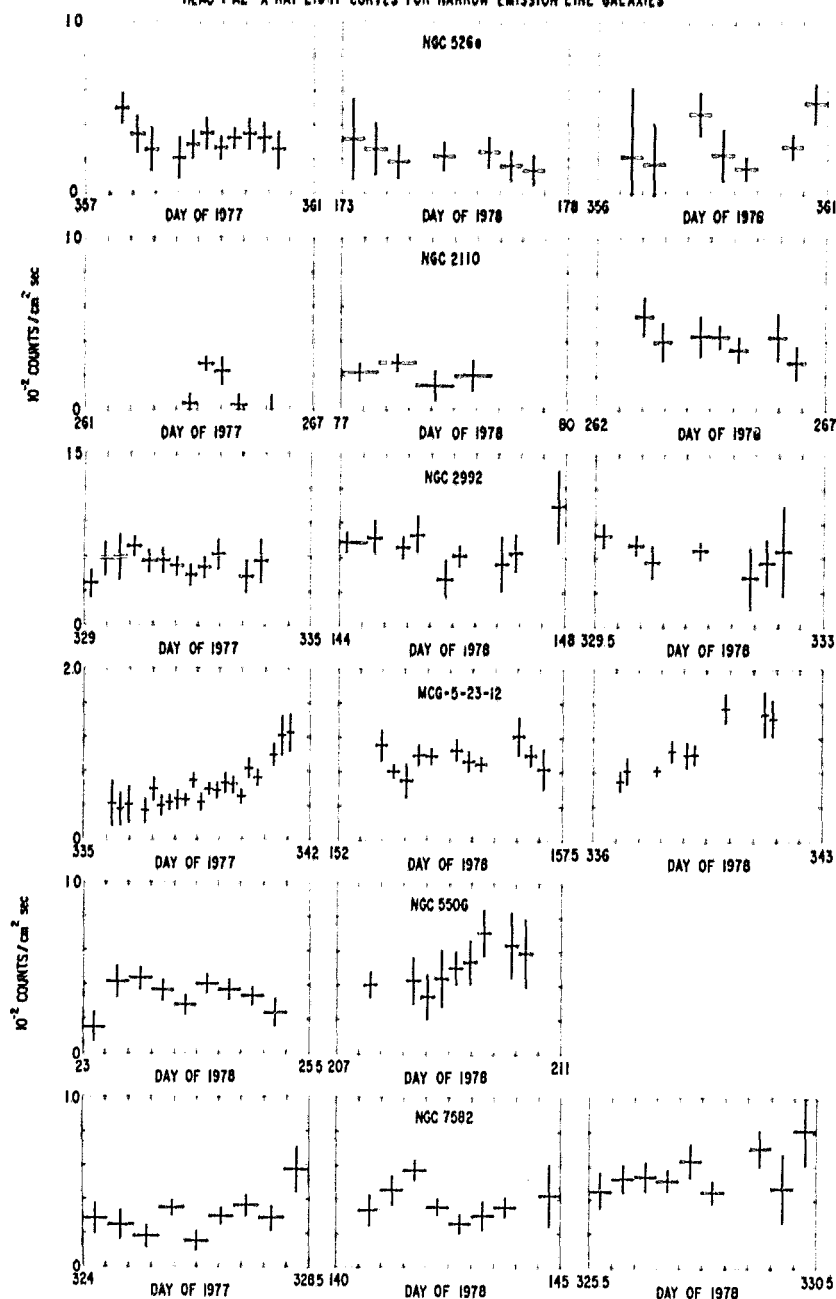
X-RAY COLUMN DENSITY vs. LUMINOSITY FOR SEYFERT GALAXIES





OF

HEAD 1 A2 X-RAY LIGHT CURVES FOR NARROW EMISSION LINE GALAXIES



NGC 7582

