1+2

NASA

Technical Memorandum 86098

LHEA CONTRIBUTIONS TO THE FUTURE OF ULTRAVIOLET ASTRONOMY BASED ON SIX YEARS OF IUE RESEARCH

(NASA-TM-86098) LHEA CONTRIBUTIONS TO THE FUTURE OF ULTRAVIOLET ASTRONOMY BASED ON SIX YEARS OF IUE RESEARCH (NASA) 15 p HC A02/MF A01 CSCL 03A N84-25559 THRU N84-25561 Unclas G3/89 13357

R. F. Mushotzky and C. M. Urry

APRIL 1984

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

D1

Ultraviolet and X-ray Observations of Active Galactic Nuclei: Constraints on Models of the Broad Emission Line Region

Richard Mushotzky
Laboratory for High Energy Astrophysics
NASA/Goddard Space Flight Center

In this talk we will be considering the extensive ultraviolet spectra of broad line active nuclei and the large body of X-ray photometry and spectroscopy of these objects, and the constraints that these data place on the photoionization models of the broad emission line region (BLR) of these objects. Many active galactic nuclei, in particular quasars and Seyfert I's, are characterized by strong, broad (full width > 2000 km/sec), emission lines from permitted transitions in abundant elements. In the simplist models these lines originate in clouds located at some characteristic distance from the central ionizing source in a quasi-spherical distribution. While the dynamics of these clouds are quite important we will not consider them here. Instead, we will concentrate on how to derive the observed line strengths and line ratios.

The main inputs into these photoionization models (see Davidson and Netzer (1979) for an extensive review) are:

1) Atomic Physics
2) The continuum spectrum
3) The Cloud Model
4) The global geometry of the region
5) The influence of dust, if any
6) The chemical composition of the gas-that is the metallicity

The main output of these codes are the absolute line strengths and the ratios of these, the "distance" to the clouds, and the general properties of the clouds and the intercloud medium.

Atomic physics, that is the relevant cross sections and reaction rates of the most important processes and the identification of these processes, is perhaps the most crucial input for these models. Unfortunately, at present, not all of these values are known with sufficient precision. However, enough progress has been made that most model builders have been using a consistent set of data (see Mendoza 1983). Thus the relative agreement of the models with the observations is a weak sign that most of the relevant processes and cross sections are understood. It is anticipated that future revisions in the relevant atomic physics will not make a strong change in the modeling results. It must be kept in mind, however, that such changes have happened in the past.

The Continuum

The form of the continuum is perhaps the quantity most susceptible to observation. Of course, it is the interaction of the continuum photons with the ions in the cloud that provides most of the ionization in the broad line region. Thus the continuum is the engine that drives the entire model. There are several distinct regions in which the "ionizing" continuum is observed:

1) The ultraviolet, E<13.6 eV: observed for low redshift objects by IUE and for high redshift objects by ground based observers.

2) The ionizing extreme ultraviolet (XUV) 13.6<E<500 eV: observed over part of this range for high redshift objects by IUE but, for the most part, has to be inferred from observations of lines originating from ions with high ionization potentials or by continuity arguments between the UV and soft X-ray spectra.

3) The soft X-ray range .5<E<7 keV: observed over the energy range by a combination of spectrometers on the Einstein observatory and HEAO-1.

4) The "hard" X-ray range E< 7 keV: observed by spectrometers on HEAO-1; in this energy range atomic processes are not very important and the major interactions of photons with ions is through the Thompson cross-section.

X-ray Spectrum

The observed X-ray spectra of broad emission line objects (primarily Seyfert I's) over the energy range E>3 keV (Mushotzky 1984; Rothschild et al. 1983) is quite simple. It is well fit over the range from 3 -100 keV by a power law with mean spectral slope of 0.7 and with a very small dispersion of +/-0.15. There does not seem to exist any dependence of this slope on total luminosity, optical spectral type or radio properties and thus this slope can be considered to be one of the defining characteristics of broad line active galaxies. For high luminosity objects, log L(x)>43.7 in the 2-10 keV band, this characteristic slope continues down to 0.5 keV (Petre et al. 1984). However lower luminosity objects (Mushotzky 1982, Reichert et al. 1984) show a rollover at lower energies due to the photoelectric absorption of X-rays by "cool", log T<7.5 K, material.

The relationship of the X-ray to "optical" (by optical one typically refers to flux in the 2500-10,000 angstrom range) has been well determined by a wide variety of observers with data obtained from the Einstein observatory (see Kriss 1984 for a recent review). If we use $\alpha(ox)$, a parameter which is related to the logarithmic slope of the mean X-ray to optical fluxes $\alpha(ox) = (\log f(opt) - \log f(x))/\delta \log\nu)$ (Tananbaum et al. 1979), one finds that this quantity is narrowly distributed with almost all the objects having $\alpha(ox)$ between 0.8 and 1.7. However this narrow distribution in $\alpha(ox)$ is misleading because the logarithmic compression "hides" the wide range in the ratio of X-ray to optical luminosities (Reichert et al. 1982). The ratio of luminosities is $\log (L(x)/L(opt)=3.125-2.605\alpha(ox)$. Thus the ratio of X-ray to optical luminosity varies by a factor of over 300.

The Ultraviolet-Optical Spectrum

The nature of the UV continuum is a much more complicated subject. Despite the apparent simplicity, detailed analysis has shown that the form of the continuum in the 500-10,000 angstrom range is quite complicated and not well understood at present. Wu, Boggess and Gull (1983) have noted that the UV continuum is not grossly different from object to object and seems moderately well fit over the entire IUE range by a simple powerlaw. Malkan and co-workers (e.g. Malkan 1983) have fit a model to the IR-UV spectrum of a fairly large sample of active galaxies. They find that most objects require two continuum components to fit the data. A power law of index near 1.2, and an additional component which we will refer to as the "blue bump" (Grandi 1982). These authors feel that the mean spectral index does not vary much from object to object but that the ratio of the blue bump to power law component is quite variable. Green and co-workers (e.g. Bechtold et al. 1984) have found that the spectrum of several high redshift quasars seems to be considerably steeper than Malkan's mean power law at wavelengths shorter than the Lyman limit. It is not clear at present if this steepening is due to absorption due to intervening hydrogen clouds between the observer and the continuum source, to a steepening of the power law component or to the high frequency exponential roll over of the blue bump.

To considerably confuse the situation, detailed studies of several Seyfert I galaxies (such as NGC 4151, NGC 4593, NGC 3783 etc.) seem to show that the slope of the power law in the IUE band is strongly correlated with luminosity, that is the instantaneous luminosity of the galaxy seems to be correlated with the spectral slope, with the steeper spectra being associated with lower luminosity. There is no correlation between the absolute luminosity of a galaxy and the slope of the UV continuum. However there is at present some controversy over whether this effect is real and, if real, whether it is due to an intrinsic change in the continuum form, to variable reddening, or to a change in the blue bump.

The nature of the blue bump is unclear at present. The present speculation centers around three possible origins, viz. an extremely strong Balmer continuum of rather peculiar shape (see Oke, Shields and Korycansky 1984), a "black body component" due to the accretion disk around a massive black hole, or a forest of FeII emission lines (see Netzer et al. in this symposium). It is most likely that the observed component is due to the sum of two or more of these possibilities (or perhaps something else). The detailed data available from IUE on NGC 4151 (Perola et al. 1982) indicates that this blue component does not contribute much to the ionization of CIV and, while strongly correlated to the power law continuum, sometimes may vary out of phase with it. The Oke et al. results show that the bump is strongly correlated with H β but not with Mg II. IUE data on moderate redshift objects z=0.5+/-.2 where the Lyman and Balmer lines, the strong permitted UV lines and the continuum over a broad band is directly observable, will be of great use in understanding the nature of the bump.

Given all these complications most models of the ionizing continuum have used a simple two power law form with a relatively steep, $\alpha \sim 1.2$ UV continuum and a flat, $\alpha \sim 0.7$ x-ray continuum. To avoid over-predicting the soft X-ray flux (Petre et al. 1984) the UV continuum is required to steepen at some energy greater than 13.6 eV. However the energy at which this occurs and the form of the steepening are poorly determined observationally.

Cloud Model and Geometry

The X-ray data on absorption due to cold material in the line of sight provides unique information on the column density, covering fraction and global geometry of the clouds. The direct observation in the X-ray of absorption in several objects gives an observed range in the total column density from 2-13 $\times 10^{22}$ atms/cm^2. This result is in quite good agreement with models developed to "explain" the anomalous Balmer decrement in AGN (e.g. Kwan and Krolik 1981), which require thick clouds of column density greater than 10^{22} in addition to X-ray heating of these deep, warm regions. This agreement, if not fortuitous, indicates that the X-ray absorption is due directly to the clouds responsible for the optical emission lines (and of course that the models developed to explain these lines have some predictive capability).

The fact that some objects do show absorption in the X-ray band indicate that most of the line of sight to the central X-ray source is covered by cloud(s). If this is not circumstantial then this means that the clouds have a large covering factor in these objects. Analysis of relatively large sample of objects (Mushotzky 1982, Reichert et al. 1984) shows that the probability that an object will be absorbed is inversely related to its luminosity. However a detailed analysis of these data (Reichert et al. 1984), in particular explaining why some objects seem to be only "partially covered" (Holt et al. 1981), indicates that this luminosity effect is probably due to the matching of cloud and continuum sizes. That is, the intrinsic cloud size probably is constant from object to object but the continuum source in the lower luminosity sources are small. Thus at low luminosities the projected solid angle to the clouds is the same size, or larger, than the continuum source and when a cloud "gets in the way" we have a total eclipse. For higher luminosity objects a single cloud is too small to occult all the radiation from the large continuum source and the source looks either unabsorbed or partially covered.

The ratio of the strength of the X-ray iron 6.4 keV fluorescent line to the depth of the X-ray Fe K absorption edge optical depth is a measure of the global geometry of the absorbing region (see Mushotzky et al. 1978). If the line is strong relative to the edge we are probably observing a disklike system face on, while if the edge is strong relative to the line the system is edge on. Unfortunately only two objects are bright enough to have had these parameters well determined, Cen-A (Mushotzky et. al. 1978) and NGC 4151 (Holt et al. 1980). In these two systems the data are consistent with a spherical absorbing region.

Dust and Metallicity

The effect of dust on the ultraviolet emission lines is potentially very important. Not only does one have to correct the observed line strengths for the effect of reddening but also correct the form of the continuum. In the UV even a small amount of dust has a very large effect. For E(B-V)=0.1 the flux in Lyman α is changed by a factor of 8 and CIV by a factor of 7. The slope of the spectrum in the ultraviolet is changed by $\delta\alpha = 2.5E(B-V)$. The UV spectrum of Seyfert galaxies and quasars does not evince a strong 2200 Å feature which is indicative of dust in our galaxy. However, as demonstrated by the reddening curve in the LMC (Hutchings this symposium) it is not clear that all dust has this feature. More detailed measurements, especially in the infrared wavelengths where silicates and ices show spectral features, will be necessary to determine the amount of dust. In addition, if the partial covering models are correct, the analysis of the reddening will have to include the effect of light leaking through the holes (Mushotzky 1982). This can be an extremely important effect in the UV; for example the Seyfert II NGC 1068 has a very large amount of dust in the line of sight as determined by IR observations (see Rieke and Lebofsky 1979) but also has a strong UV continuum (Neugebauer et al 1980). Thus in this system the UV light must either originate in a different region from the IR flux or there must be holes.

The metallicity of the gas in the broad line region is poorly determined. As pointed out in Ferland and Mushotzky (1984) since the cooling in the BLR clouds is primarily due to the strong emission lines of the metals (as well has hydrogen) their intensities cannot change greatly in an energy conserving model. Thus from the strength of the emission lines we can only conclude that the clouds must have a metal abundance roughly consistent with solar because the models do not need peculiar abundances to reproduce these line strengths. X-ray absorption measurements of the strength of the K absorption lines in AGN can potentially determine the column density of the heavy elements (in particular Fe, Si and S) if the column density is greater than 10^{22}. In the case of NGC 4151 it appears as if the Fe abundance is twice solar. With future X-ray spectroscopy missions, such as OSS-2, it should be possible to determine these abundances in many more objects.

Model Building and Results

In developing the models there have been two general approachs, a constant pressure, and a constant density model. In the these two cases the value of the ionization parameter U is defined differently. In the constant density model the parameter is dimensionally L/nR^2, where L is the luminosity, or number of ionizing photon, n is the density in the cloud and R is the distance of the cloud from the ionizing source. In the constant pressure models (see Kallman and McCray 1982) the ionization parameter is L/R^2P where P is the pressure. As one can see both models have two essentially adjustable parameters once all the other inputs are specified.

Both models can adequately fit the observed AGN spectra with a fair amount of detail (see table in Ferland and Mushotzky 1982). In particular, in the constant density models it is found that virtually all the AGN spectra (Mushotzky and Ferland 1984) can be fit with values of log density between 9 and 10.2 and values of log U between -0.5 and -3.0. These models adequately account for virtually all the strong emission lines (but see below) and can explain apparent trends in the data. In particular, the Baldwin effect, the fact that higher luminosity objects have a smaller equivalent width of CIV, appears to be related to a luminosity dependent mean value of U, with the higher L objects having a lower value of U (Mushotzky and Ferland 1984). In addition, these models more or less correctly predict the size of the BLR. In the case of NGC 4151 Ferland and Mushotzky (1982) calculated a size of 16 $(n/3x10^9)^{-1/2}$ light days. The observations of Ulrich et al. give a size of 13 light days.

Despite the relative success of these models there still are many difficulties in understanding the broad line regions. First and foremost is the problem of dynamics (Mathews 1982). How do the clouds acquire their high velocities, are these velocities inflow, outflow, turbulent or rotational? Furthermore, the detailed IUE studies of several Seyfert I galaxies show that the line profiles of different lines (e.g. CIV vs. Mg II) are different and change with time. In particular Ulrich et al. (1984) claim that these effects require the existence of several regions of emission of the broad lines. It is also not clear what the detailed geometry of the broad line region is. How are the clouds distributed and what are the shapes of the clouds themselves (pancakes, spheres etc). In addition, the field of absorption line spectroscopy of Seyfert galaxies is in its infancy (Penston et al. 1979). It seems clear that in those objects with a large covering fraction, such as NGC 4151, that high resolution absorption line studies of the CIV absorption line will give detailed information on the number of clouds and their sizes relative to the continuum .

In addition to these general problems there still are considerable difficulties in fitting certain lines, in particular the He lines (MacAlpine 1981) and the FeII lines (Netzer et al. this symposium). These two difficulties are rather vexing as the He lines should be easily predictable and the very strong UV lines make the estimates of the total cooling of the deep cool regions where the Hβ lines originate very uncertain. Of course, the nature of the "blue bump" is still very uncertain. If it is related to the lines, then the photoionization models must be able to account for it.

It seems clear that, at present, we have at least some understanding of the origin of the broad lines in active galaxies and have developed models that, at least computationally, are self consistent and account for many of the observed properties of these objects. However, there is much left to do and many observations are needed to constrain the (more complicated) models that will be developed. While the Space Telescope will be of great use, the monitoring capability of IUE for these variable objects will continue to be very important (see Wamsteker et al. these proceedings). The future of X-ray spectroscopy is much more problematical and hopefully we will not have to wait until AXAF to obtain new results.

Apology : I have not been able in this short paper to truly reference all the excellent work in this field and I apologize to the various workers in the field for over-referencing my own papers. In such a vast subject one's prejudices have too much room to operate.

Acknowledgments: I would like to thank Gary Ferland and Greg Shields who have taught me what little I know about photoionization models. I also thank Tim Kallman and Dick McCray for very useful discussions. I also thank Yoji Kondo for the opportunity to speak at this symposium.

References

Bechtold, J., Green, R.F., Weymann, R.J., Schmidt, M., Estabrook, F.B., Sherman, R.D., Walhquist, H.D. and Heckman, T.M. 1984, Ap.J. in press
Davidson, K. and Netzer, H. 1979, Rev. Mod. Phys. 51, 715
Ferland, G.J. and Mushotzky, R.F 1982, Ap.J. 262, 564
Ferland, G. and Mushotzky, R.F. 1984, Ap.J. submitted.
Grandi, S.A. 1982, Ap.J. 255, 25
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. Lett 241, L13
Kallman, T.R. and McCray, R.A. 1982, Ap.J. Suppl 50, 263
Kwan, J. and Krolik, J. 1981, Ap.J. 250, 478
Kriss, G.A. 1984, Ap.J. 277, 496
MacAlpine, G. 1981, Ap. J. 251, 465
Malkan, M.A. 1983, Ap.J. 268, 582
Mathews, W.G. 1982, Ap.J. 252, 39
Mendoza, C. 1983, in Planetary Nebulae, IAU Symposium No. 103, D.R. Flower editor
Mushotzky, R.F. 1982, Ap. J. 256, 92
Mushotzky, R.F. and Ferland, G.J. 1984, Ap. J. in press
Mushotzky, R.F. 1984, in IAU/COSPAR Meeting on High Energy Astrophysics and Cosmology Rojen Bulgaria
Neugebauer G. et al. 1980, Ap.J. 238, 502
Oke, J.B., Shields, G.A. and Korycansky, D.G. 1984, Ap.J. 277, 64
Penston, M.V., Clavel, J., Snijders, M., Boksenberg, A. and Fosbury, R. 1979, MNRAS 189, 45p
Perola, G.C. et al. 1982, MNRAS 200, 293
Petre, R., Mushotzky, R.F., Krolik, J. and Holt, S.S. 1984, Ap. J. in press
Reichert, G., Mushotzky, R.F., Petre, R. and Holt S.S. 1984, in prep
Reichert, G., Mason, K., Thorstensen, J., and Bowyer, S. 1982, Ap.J. 260,437
Rieke, G.H. and Lebofsky, M.J. 1979, Ann. Rev. Astron. and Astrophys. 17, 477
Rothschild, R., Mushotzky, R.F., Baity, W., Gruber, D., Matteson, J. and Peterson, L.E. 1983, Ap.J. 269, 423
Ulrich, M.H. et al. 1984, MNRAS in press
Wu, C.C., Boggess, A. and Gull, T.R. 1983, Ap.J. 266, 28

N84 25561

VERY RECENT IUE OBSERVATIONS OF 2 BL LACERTAE OBJECTS

C.M. Urry[1,2], Y. Kondo[2], K.R.H. Hackney[3],
R.L. Hackney[3], S.L. Mufson[4], and W. Wisniewski[5]

ABSTRACT

IUE observations of two BL Lacertae objects, consisting of 2 spectra of 1218+304 and 12 spectra of Mrk 421, are presented. The former object has never been observed with IUE, possibly because it is very faint, but the fact that it is an X-ray source, and a highly variable one, makes it particularly interesting. Mrk 421 has been observed many times with IUE as part of a continuing monitoring program. The present observations indicate an intensity decrease of ~25% on a timescale of one month, with little if any associated spectral change. With one exception, the spectra of these two objects show no discrete features, and the continua are well fit by power law models. The one exception is a long SWP exposure of Mrk 421, from 1984 March 9, which shows a broad emission feature near ~1580 Å. The validity of this feature has not yet been established.

INTRODUCTION

As part of a continuing program of monitoring the broad band spectra of BL Lacertae objects, 1218+304 and Mrk 421 were observed with IUE in January, February, and March of this year (1984). Here we present the IUE data, and where possible, mention the simultaneous coverage in other bands.

1218+304

The BL Lac object 1218+304, first detected with the Ariel V X-ray satellite, was the first BL Lac to be discovered as an X-ray source (Wilson et al. 1979). In the X-ray, it has been seen to vary both in intensity (Wilson et al.) and in spectral shape (Worrall et al. 1981, Urry 1984). It was also detected in the HEAO-1 X-ray All Sky Survey (Piccinotti et al. 1982), and is one of the few extragalactic sources from that survey that has not been observed with IUE. (Because its visual magnitude is ~16, it is one of the faintest objects that can be successfully observed with IUE.)

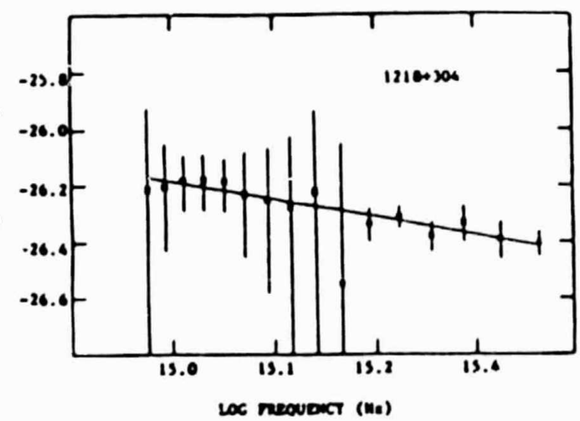
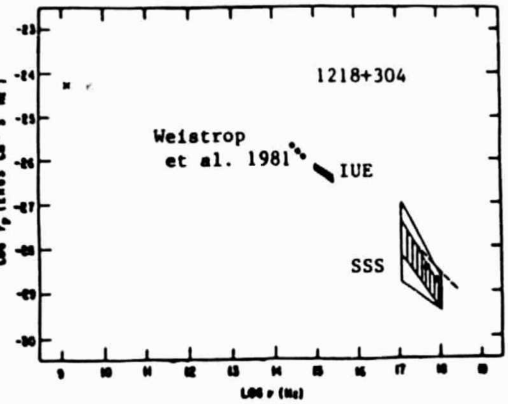


Figure 1. IUE Spectrum of 1218+304

On 1984 February 2, we obtained two images, SWP 22167 (exposed 395 minutes during US 1) and LWP 2733 (exposed 210 minutes during a very low background US 2). The binned data ($\Delta\lambda$~125Å) are shown in Figure 1, with error bars determined from the standard deviation from the mean, and with a line indicating the best fit power law model of the form $F_\nu = (A/10^{26})(\nu/10^{15})^{-\alpha}$ ergs/cm^2/s/Hz, where $A=0.66\pm0.08$ and $\alpha=0.64\pm0.19$. The integrated ultraviolet flux from this object

[1]Johns Hopkins University, now at MIT. [2]NASA/Goddard Space Flight Center.
[3]Western Kentucky University. [4]Indiana University. [5]University of Arizona.



is $(7.2\pm0.9)\times10^{-12}$ ergs/cm^2/s. The composite spectrum, compiled from non-simultaneous data (the simultaneous X-ray, optical, and infrared data are not yet reduced), is shown in Figure 2. Because of the reported variability, it is difficult to comment on this spectrum, beyond saying that it has the typical flat radio-to-optical appearance, followed by a break around 10^{14}-10^{15} Hz, with a steeper spectrum extending smoothly into the X-ray regime. The IUE spectrum seems too flat, flatter than the optical, and we intend to improve the definition of the continuum with a gaussian extraction method, to see if this flat index changes (see Hackney, Hackney, and Kondo, this volume).

Mrk 421

Mrk 421 is one of the brightest BL Lac objects observed with IUE, and has been monitored steadily since the launch of the satellite (Boksenberg et al 1978, Ulrich et al. 1984). The observations discussed here were made on 5 different days: 3 days at the end of January and beginning of February, and 2 days at the beginning of March. The date, image number, and duration of each observation is given in Table 1. In the one month between the two groups of observations, the intensity of Mrk 421 decreased dramatically, confirming it as one of the most variable BL Lac objects. The ultraviolet and optical intensities both decreased by about 20-25% in the space of 4 weeks; there was no obvious variability between the observations that were separated by only a few days. This is illustrated by the light curve in Figure 3, in which we have plotted the ultraviolet and V band fluxes (values taken or adapted from Table 1).

Table 1. Recent IUE Observations of Mrk 421

Date	Image	Length (min)	A	α	F_{uv}	V
1984 Jan 23	LWP 2699 SWP 22082 LWP 2700	75 100 210	6.65±0.12	1.04±0.04	6.01±0.11	13.33
1984 Jan 28	LWP 2711 SWP 22128 LWP 2712	80 33 210	6.35±0.20	1.01±0.07	5.82±0.11	13.34
1984 Feb 2	LWP 2732	90	6.77±0.15*	1.13±0.20*	5.88±0.18*	13.32
1984 Mar 3	LWP 2881 SWP 22398 LWP 2882	80 240 60	5.24±0.18	1.10±0.08	4.61±0.16	13.61
1984 Mar 9	LWP 2915 SWP [illegible]	95 260	5.04±0.21	1.12±0.08	4.38±0.14	13.60

*Determined from LWP spectrum only, extrapolated where necessary.

For each day's observations, the LWP and SWP spectra were combined (except for the February 2 observation, when only 1 LWP spectrum was taken), and the continuum was fit with a power law of the form given earlier. The parameters A and α are listed in Table 1. In Figure 3, the spectral index determined for each set of spectra has been plotted, and confirming previous findings for this and other BL Lac objects (Urry et al. 1982, Maraschi et al. 1983, Ulrich et al. 1984), we see no evidence for strong spectral variability accompanying the more obvious intensity variability.

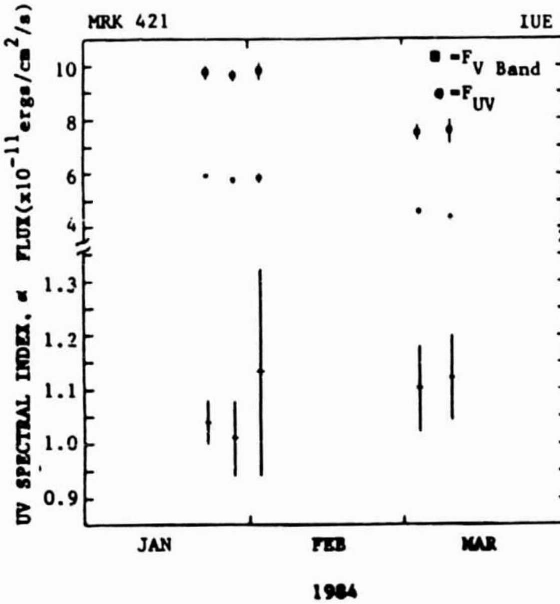


Figure 3. Light Curve of Mrk 421

UV flux, V band flux, and UV spectral index as a function of time.

In each case, the power law model provided a good fit to the data. The details of the simultaneous measurements in other wavebands are not yet available, although we know that the X-ray flux was weak during January and March 1984, relative to previous X-ray observations (Y. Tanaka, private communication). We have assembled a composite spectrum of Mrk 421, shown in Figure 4, from non-simultaneous observations. This figure suggests that like other BL Lac objects, Mrk 421 has a smooth spectrum extending from radio to X-ray frequencies, with a break near 10^{13} or 10^{14} Hz. Detailed analysis of the broad band spectrum will be postponed until the simultaneous observations are assembled.

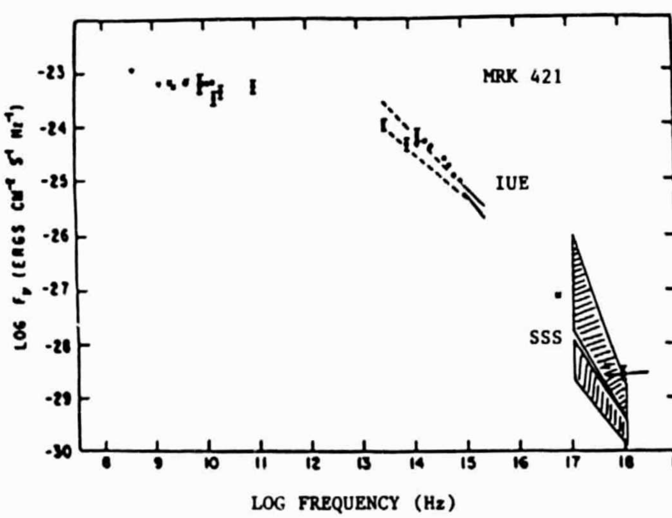


Figure 4. Composite Spectrum of Mrk 421

In the final SWP spectrum of Mrk 421 there is a dramatic, broad emission feature near 1580 Å, with equivalent width 10±1 Å. The 4 SWP spectra are shown in Figure 5. The reality of this feature is in doubt for at least 3 reasons: (1) it was not present in the SWP image obtained 6 days earlier (there is a suggestion of a weaker feature, EW~2 Å, displaced ~5 Å shortward); (2) it may be related to a hot spot in the SWP camera near 1570 Å (Hackney, Hackney, and Kondo 1982); and (3) if it is CIV, it is at a redshift z=0.017±0.002, not the reported [optical] redshift of the galaxy (z=0.0308, Ulrich et al. 1975). However, other facts must also be considered. First, BL Lac objects are highly variable, and Mrk 421,

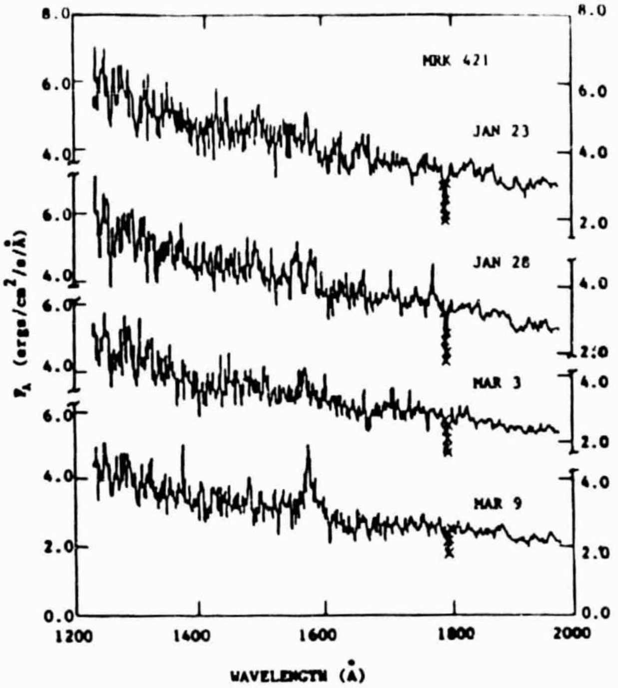


Figure 5. SWP Spectra of Mrk 421

which is one of the most variable, is certainly variable on the timescale of a day. Second, the observed emission feature is broader than a typical cosmic ray hit, and lies directly on top of the spectrum, centered at line 28 (as is the rest of the spectrum). Third, there may be reasons to expect discrete features to be blue-shifted relative to the source frame; in particular, the emission or absorption might arise in a cloud that is moving an a relativistic jet closely aligned with our line of sight, as was suggested to explain the absorption feature seen in the X-ray spectrum of another BL Lac object, PKS 2155-304 (Canizares and Kruper 1984). Further investigation of the validity of this feature, including examination of the photowrites from the IUE observations immediately preceding and following the March 9 observation (to look for spurious emission near 1580 Å); examining reprocessed 110x110 files to determine more precisely the profile and location of the feature in the cross-dispersion direction; and repeating the observations, in the ultraviolet and/or visual bands, will be attempted as soon as possible.

REFERENCES

Boksenberg, A. et al. 1978, Nature, 275, 404.
Canizares, C. R. and Kruper, J. 1984, Ap.J., in press.
Hackney, R. L., Hackney, K. R. H., and Kondo, Y. 1982, in Advances in Ultraviolet Astronomy: Four Years of IUE Research, eds Y. Kondo, J. M. Mead, and R. D. Chapman, (Greenbelt, MD: NASA Conference Publication 2238), p.335.
Maraschi, L., Tanzi, E. G., and Treves, A. 1984, in Proceedings of the COSPAR/IAU Symposium, in press.
Piccinotti, G., Mushotzky, R. F., Boldt, E. A., Holt, S. S., Marshall, F. E., Serlemitsos, P. J., and Shafer, R. A. 1982, Ap.J., 253, 485.
Ulrich, M.-H., Hackney, K.R.H., Hackney, R.L., and Kondo, Y. 1984, Astr.Ap., in press.
Ulrich, M.-H., Kinman, T.D., Lynds, C., Rieke, G., and Ekers, R. 1975, Ap.J., 198, 261.
Urry, C. M. 1984, Ph.D. Thesis, The Johns Hopkins University.
Urry, C.M., Holt, S., Kondo, Y., Mushotzky, R., Hackney, K., and Hackney, R. 1982, in Advances in Ultraviolet Astronomy: Four Years of IUE Research, eds. Y. Kondo, J. Mead, and R. Chapman, (Greenbelt, MD: NASA Conference Pub. 2238), p. 177.
Wilson, A.S., Ward, M.H., Axon, D., Elvis, M. and Meurs, E. 1979, M.N.R.A.S., 187, 109.
Worrall, D., Boldt, E., Holt, S., Mushotzky, R., and Serlemitsos, P. 1981, Ap.J., 243, 53.