MULTIFREQUENCY OBSERVATIONS OF
BL LAC OBJECTS AND VIOLENTLY VARIABLE QUASARS

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ABSTRACT

We report on the status of our program to obtain simultaneous multifrequency spectra of BL Lac objects and violently variable quasars from the X-ray through radio wavebands. We illustrate the importance of the ultraviolet data in defining the overall shape of optically thin synchrotron emission, its relation to the X-ray emission, and the determination of basic physical parameters of the continuum emitting region.

INTRODUCTION

We have been pursuing a program of obtaining ultraviolet observations of BL Lac objects and violently variable quasars that are simultaneous with observations made in the radio, infrared, optical, and X-ray regions. Eleven sources have been observed in this multifrequency mode, most of them more than once, and a few unusually active sources many times. The general goal of this program is to develop a better understanding of the continuum emission in these sources. In particular, we are concerned with determining the fundamental properties in the nonthermal continuum emitting regions (size, magnetic field, density, bulk motion) and the relationship between the emitting regions which dominate the observed flux in the various wavebands (radio, ultraviolet, X-ray). Here we summarize the progress that we have made in this program.

The approach of obtaining data across as much of the electromagnetic spectrum as is possible requires a variety of instruments on a variety of telescopes. Due to the limitation of telescopes and detectors, nine different telescopes have been used to obtain data from 10^8-10^{18}Hz, which is the range of frequencies that we attempt to sample. It is obviously impossible for one group to obtain all the necessary data, and we are deeply indebted to our collaborators, who have been essential in the success of this project (Table 1).

RESULTS

Due to the limitation of instruments as well as extinction due to the atmosphere and interstellar gas, emission from quasars was conveniently divided up into three spectral regions, which, broadly speaking, are the radio (10^8-10^{11}Hz), the optical (10^{13}-$10^{15.4}$Hz), and the X-ray regions ($10^{16.5}$-10^{18}Hz). Although far-infrared and submillimeter observations are now able to provide data in the gap between the optical and radio regions, it is still useful to consider the three regions separately.

The radio continuum, which is fairly flat in most of our sources, is probably created by several partially optically thick synchrotron sources (e.g. Cotton et al. 1980). The IR-UV continuum, which probably arises from optically thin synchrotron emission, is steeper than the radio continuum. Before data in the far-infrared gap was available, the multifrequency data suggested that the change in slope occurred in the 10^{10}-$10^{12.5}$ Hz region (Bregman et al. 1983, Glassgold et al. 1983, Bregman et al. 1984). Now that data has become available in this far-infrared gap, the region of the spectral turnover can be located with greater accuracy and is near 300 GHz for OJ 287 and 3C 345, and OV-236 (Fig. 1). Because the radio region is known to be optically thick while the optical region is not, it is often suggested that the frequency of the spectral break occurs where the optical depth first reaches unity. If correct, the location of the spectral break region is of fundamental importance to determining the properties of the continuum emitting region.

Because the IR-UV emssion is optically thin synchrotron radiation, its shape yields information on the energy distribution of the electrons responsible for the emission. The slope of the continuum in the infrared and far-infrared region can usually be fit with a single power-law with a slope of about -1, although the slopes range from -0.7 to -1.5 in our sample. Some sources show little or no spectral steepening in the optical and ultraviolet regions (IZw-187; Bregman et al. 1983), some display slow but steady spectral steepening (e.g. OJ 049), while others display extremely rapid steepening in the ultraviolet region (BL Lac and 3C 446). Furthermore, the shape of the IR-UV continuum is generally preserved when the source changes its brightness, although spectral variation is sometimes detected (1156+295, Glassgold et al 1983; 0735+178, Bregman et al 1984).

One of the most common broad-band features seen in the opical-ultraviolet spectrum of non-variable quasars is the 3000 A bump. This feature is generally absent in our sample, with the exception of the BL Lac object IZw-187, which has a weak 3000 A bump (Bregman et al. 1983). We argued that at 3000 A bump in a BL Lac object would be evidence that the bump is not associated with emission line gas, as has been suggested (e.g. Grandi 1982). However, during a subsequent observation of this source, weak optical emission line were discovered that had not previously been detected.

Another feature of interest is the extremely sharp turnover seen in the spectrum of BL Lac and 3C 446. This turnover, which would not have been discovered without ultraviolet observations, is similar in shape to that found in the class of objects known as Red QSOs. The difference is that the turnover occurs in the infrared region for Red QSOs instead of in the ultraviolet region. The turnover has been attributed to an abrupt cutoff in the electron distribution function. The location of the turnover depends not only upon the magnetic field but upon the energy of the electrons, which has proved an elusive property to measure (Bregman et al. 1981, Beichman et al 1981).

The multifrequency spectra can be used to discuss the connection between the IR-UV and the X-ray regions. In our sample, the ultraviolet continuum, when extended to higher frequencies, would nearly always pass below the X-ray datum. This implies that the X-rays are not simply an extension of the IR-UV emission (although IZw-187 is an exception to this rule, Bregman et al. 1983). In the BL Lac object 0735+178 (Bregman et al. 1984), the lack of variation in the X-ray flux during periods of violent variability of the IR-UV continuum suggest that the X-rays are not produced cospatially by a different process. Rather, the X-rays are produced in an entirely different region, possibly by a different process. Whether this behavior is common for this class of objects is the subject of our current program.

We have examined the correlation of the X-ray emission with the optical and radio flux for the sample of sources in which the X-ray flux cannot be an extension of the ultraviolet continuum. We find that the X-ray emission is better correlated with the radio flux than with the infrared, optical, or ultraviolet flux. This is similar to findings by Owen, Helfand, and Spangler (1981) and Zamorani et al. (1981) for differently selected samples.

A comparison of the continuum emission between BL Lac objects and violently variable quasars yields few differences. The spectral shape of 3C 446 is nearly identical to that for BL Lac (although the luminosity is different). Several BL Lac objects (e.g. IZw-187) are very abundant in ionizing photons, so the lack of lines in these sources must be due to a lack of available gas, not a lack of ionizing photons.

The physical conditions in the optically thin emitting region can be determined from the multifrequency spectra if one adopts a model, such as the synchrotron-self-Compton model (e.g. Jones, O'Dell, and Stein 1974). In doing so, we find that the opically thin region has a size between a light week and a few light months, the magnetic field is 0.1 - 100 G, and the Lorentz factor of bulk motion of the emitting plasma is 1-5. The energy of the electrons extends up to about 10 GeV, and the energy densities in electrons, photons, and magnetic field are comparable. By comparing this to VLBI data, we see that the radio emission comes from a larger region of lower magnetic field and where the energy density is nearly entirely in the particles (e.g Kellermann and Pauliny-Toth 1981).

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Zamorani, G. et al. 1981, Ap.J., 245, 357.

Table 1: Collaborators

Name or Group	Institution	Waveband
Dent, Balonek, O'Dea	U. Mass	radio-mm
Aller, Aller, Hodge	U. Mich	radio
Werner, Rollig	NASA/Ames	submm-IR
Neugebauer	Caltech	IRAS, IR
Rieke, Lebofsky, Rudy, Wisniewski	Steward Obs.	IR-optical
Impey, Williams, Brand	UKIRT, Caltech, RGO	IR
Hackwell	U. Wyoming	IR
Smith, Pollock, Pica, Webb	U. Florida	optical
J.Miller	Lick Obs.	optical
Wills, Wills, Lester	U. Texas	IR-optical
Spinrad	U.C. Berkeley	optical
Henry	U. Michigan	optical
Bregman, Glassgold, Huggins	N.Y.U.	ultraviolet
Ku, Helfand	Columbia U.	X-rays
Tananbaum, Schwartz	C.F.A.	X-rays