FINDING THE RAREST OBJECTS IN THE UNIVERSE:

A New, Efficient Method for Discovering BL Lacertae Objects

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Introduction

While recent objective prism, UVX, radio and X-ray surveys have dramatically increased the number of known QSOs (typical discovery rate now averages one per day), the number of BL Lac Objects known has increased only very slowly (average rate about 5 per year) over the last twenty years. And while recent X-ray surveys (*Einstein*, EXOSAT and ROSAT) are dramatically increasing the number of known BL Lacs, the rarity of these objects (BL Lacs account for only $\sim 5 - -10\%$ of all faint X-ray sources) still requires a substantial commitment of optical observing time to find them. For example, the 36 new BL Lacs found in the *Einstein* Extended Medium Sensitivity Survey (EMSS; Gioia *et al.* 1990; Stocke *et al.* 1991) required $\sim$ 8 years of optical spectroscopy to identify. Other methods for finding BL Lacs (high frequency radio surveys or optical polarization or color surveys) have similarly low success rates for finding new BL Lacs; e.g. $0 - 10\%$.

We present a new, efficient method for discovering new BL Lac Objects based upon the results of the EMSS. We have found that all X-ray selected BL Lacs are radio emitters (Stocke *et al.* 1990) and further that in a "color-color" diagram (radio/optical and optical/X-ray) the BL Lac Objects occupy an area distinct from both radio loud quasars and the radio quiet QSOs and Seyferts which dominate X-ray selected samples. After obtaining radio counterparts via VLA "snapshot" observations of a large sample of unidentified X-ray sources, the list of candidates is reduced to those which fall in the correct area of Figure 1. These candidates then can be confirmed with optical spectroscopy and/or polarimetry. Since $> 70\%$ of these sources are expected to be BL Lacs, the optical observations are very efficient.

We have tested this method using unidentified sources found in the *Einstein* Slew Survey (Elvis *et al.* 1992). 162 Slew Survey X-ray source positions were observed with the VLA in a mixed B/C configuration at 6 cm resulting in $\sim$ 60 detections within 1.5 position error circle radii. These X-ray/optical/radio sources were then plotted on Figure 1 and $\sim$ 40 BL Lac candidates were identified.

To date **10** candidates have been spectroscopically observed resulting in **10** new BL Lac objects! Radio flux, optical magnitude, and polarization statistics (obtained in white light with the Steward Observatory 2.3 m CCD polarimeter) for each is given in Table 1.

The Method

The key to finding BL Lacs is to exploit three facts:

1. All BL Lacs are radio loud;
2. BL Lacs have distinctive radio/optical/X-ray colors (Figure 1, also Stocke *et al.* 1991); and
3. The surface density of X-ray-selected BL Lacs flattens at fluxes below $10^{-12} ergs\ s^{-1}\ cm^{-2}$ (Wolter *et al.* 1991).

Therefore wide-angle, high-flux surveys are better for detecting BL Lacs than deeper, narrow-beam surveys.

Together these properties allow us to define a multi-step approach to identify new X-ray selected BL Lacs in the Slew Survey:

1. Choose sources at high galactic latitudes ($|b| > 15°$) with moderate positional uncertainties ($\sim 1'$ at 90% certainty for the Slew Survey).
2. Observe them with the VLA, giving an accurate radio flux and position ($1 - 2$" is sufficient).
3. Use the radio positions to find optical counterparts and magnitudes from digitized sky survey plates.
4. Place objects in the radio/optical/X-ray color-color plot (Figure 1).
5. Obtain optical spectra only for candidates with correct colors.

Results

Approximately 40 Slew Survey BL Lac candidates have been selected using the above method. Of these, **10** have been observed spectroscopically, resulting in the confirmation of **10** new BL Lacs — already an increase in the known number of BL Lacs by 10%! The identification program will continue this September at the Kitt Peak 2.1 meter telescope. Based on these results, we expect approximately 30 more BL Lacs to be discovered in the Slew Survey. If this method is applied to the bright sources in the ROSAT all-sky survey, nearly 1000 BL Lacs should be discovered!

Table 1. New Slew Survey BL Lac Objects

Object Name	$f(6cm)$,mJy	V	P(%)	θ
1. 1ES0229 + 200	41.5	18.0	—	—
2. 1ES0347 − 121:	7.6	19.1	—	—
3. 1ES0502 + 675	31.3	16.5	3.89 ± 0.45	$124.3° \pm 3.3$
4. 1ES0647 + 250	61.0	15.3	—	—
5. 1ES0806 + 524	169	15.3	1.68 ± 0.50:	—
6. 1ES1028 + 511	42.5	17.0	8.13 ± 0.39	$17.3° \pm 1.4$
7. 1ES1440 + 122	40.2	15.3	≤ 1.8	—
8. 1ES1544 + 820	45.1	15.3	1.81 ± 0.41:	—
9. 1ES1959 + 650	241	14.6	2.76 ± 0.25	$147.1° \pm 2.6$
10. 1ES2343 − 151:	7.7	19.2	—	—

A colon after the name indicates either that the identification as a BL Lac is not certain due to low SNR spectra at present (objects 2 and 10); a colon after the polarization percentage indicates that the polarization detection is only possible (objects 5 and 8).

References

Elvis, M., Plummer, D., Schachter, J., and Fabbiano, G., 1992, *Ap. J. Supp.* **80**, 227.

Gioia, I., *et al.*, 1990, *Ap. J. Supp.* **72**, 567.

Stocke, J., *et al.*, 1991, *Ap. J. Supp.* **76**, 813.

Stocke, J., *et al.*, 1990, *Ap. J.* **348**, 141.

Stocke, J., *et al.*, 1989, in *BL Lac Objects*, ed. L. Maraschi, T. Maccacaro, and M.-H. Ulrich (Springer-Verlag), p.242.