Abstract.
The rareness of blazars, combined with the previous history of relatively shallow, single-band surveys, has dramatically colored our perception of these objects. Despite a quarter-century of research, it is not at all clear whether current samples can be combined to give us a relatively unbiased view of blazar properties, or whether they
present a view so heavily affected by biases inherent in single-band surveys that a synthesis is impossible. We will use the coverage of X-ray/radio flux space for existing surveys to assess their biases. Only new, deeper blazar surveys approach the level needed in depth and coverage of parameter space to give us a less biased view of blazars. These surveys have drastically increased our knowledge of blazars’ properties. We will specifically review the discovery of “blue” blazars, objects with broad emission lines but broadband spectral characteristics similar to HBL BL Lac objects.

## I MYTHS AND FACTS ABOUT BLAZAR SURVEYS

Every survey has its biases, whether imposed by its flux limits or selection techniques - despite the best efforts of the scientists involved. Proper analysis of the results of any survey requires one to understand the impact of these biases on both the range of parameter space to which the survey is sensitive, and also on the broader scheme, including properties which do not form part of the survey definition, but which nevertheless represent characteristics of the class and/or important diagnostics.

Historically, our knowledge of blazar properties began with radio surveys, which tend to be dominated by radio-bright objects. As we discovered in the 1980s, such objects are the most luminous of all AGN, as well as violently variable and radio core dominated. Indications that these properties were not typical of all blazars did not come until the publication of the first large X-ray survey, the *Einstein* EMSS (Stocke et al. 1991). The EMSS BL Lacs are considerably less luminous, less variable, less polarized, and less core dominated than their radio-selected cousins (Perlman & Stocke 1993; Jannuzi, Elston & Smith 1994; Kollgaard et al. 1996; Giommi et al. 1995; Rector et al. 2000). They also have synchrotron peaks in the UV/X-ray rather than IR/optical (Giommi et al. 1995, Sambruna et al. 1996, Fossati et al. 1998). Various explanations for these differences have been proposed (see the review by Urry & Padovani 1995, and also Ghisellini et al. 1998 and Georgopoulous & Marscher 1998). But it was not until the mid-1990s that opinions began to come full circle.

Even if one assumes an unbiased identification process (not always the case, see e.g., Marcha & Browne 1993, 1996; Perlman et al. 1996; Rector et al. 1999) each survey’s flux limits affect its sensitivity to parameter space. In his paper, Paolo Padovani presented two figures (Padovani 2000, Figures 1 and 2) which illustrate the sensitivity of various surveys to X-ray/radio parameter space, using their flux limits. For completeness and for the sake of minimum bias, one wants surveys that are: (1) as close as possible to the diagonal lines defined by the inverse-Compton and synchrotron peak limits - which are also the extrema for known HBLs and LBLs respectively; and (2) large enough that all spectral shape classes are represented in statistically significant numbers. Yet even with surveys meeting these requirements, some biases remain, since each flux limit imposes diagonal “completeness contours” on the \((\alpha_{ox}, \alpha_{ro})\) plane. Thus even a survey which is near an extreme line in the \((f_x, f_r)\) plane does not have uniform sensitivity to all regions
FIGURE 1. The $(\alpha_{ox}, \alpha_{ro})$ plane for BL Lacs. We have outlined the HBL "box" to guide the eye. The 1 Jy, Slew and EMSS contain very few intermediate objects. The results of the new DXRBS and RGB surveys show this to be a selection effect.

Figure 1 illustrates these biases for the case of BL Lacs. Due to their small sizes and high flux limits, each of the “classical” surveys (EMSS, 1 Jy and Slew) was sensitive only to a small diagonal swath of $(\alpha_{ox}, \alpha_{ro})$ parameter space. As a result, they presented an almost completely disjoint picture of BL Lac properties (it is an instructive exercise to plot the X-ray, radio and optical fluxes of the EMSS, 1 Jy and Slew BL Lacs on three planes - we omit this here for lack of space). As this diagram shows, the new DXRBS survey fills in the gap very nicely, covering a much wider range of the $(\alpha_{ox}, \alpha_{ro})$ plane much more evenly, and nicely revealing objects in the intermediate range. That intermediate range is also covered by RGB, but not as evenly because of its high optical flux limit.

II THE DISCOVERY OF X-RAY BRIGHT FSRQ: A CASE IN POINT

As shown above, the classical surveys are are far too small and shallow to contain significant amounts of objects in all spectral shape classes. Thus, even when lumped together, they present a view that is overwhelmingly colored by biases. For example,
by comparing the broadband spectral shapes of the EMSS and 1 Jy BL Lacs, and
the S5 FSRQ, Sambruna et al. (1996) predicted that there should be no FSRQ
with $\alpha_{rx} \gtrsim 0.78$ - the historical dividing line between HBL and LBL type objects.
This prediction was proven incorrect by the findings of a newer, deeper radio-
limited survey, the DXRBS (Perlman et al. 1998, Landt et al. 2000), which found
that approximately 1 in 4 FSRQ had $\alpha_{rx} \gtrsim 0.78$. A subsequent cross-correlation
of emission line objects in the RGB (Laurent-Muehleisen et al. 1998) revealed an
even higher percentage of these objects ($\sim 40\%$, Padovani et al. in prep, Perlman
2000).

We will talk more about these objects (called “HFSRQ”) below, but first a
historical comment is useful. As is well known, the Slew and EMSS both included
radio observations at 5 GHz in their identification process, but not radio spectral
indices. The biases that imposed were not appreciated for several years, even
though both Stocke et al. (1991) and Elvis et al. (1992) noted the presence of
radio-loud quasars in both surveys. Only after the results of DXRBS began to
come out was this bias considered, and corrected. Cross-correlation of the Slew and
EMSS object lists with lower-frequency radio surveys reveal small, but significant
samples of FSRQ in both (22 and 16 objects respectively; Perlman et al. 1999
and in prep.), of which about 40% are HFSRQ. By comparison, the very high radio
flux limit of the 1 Jy sample makes it almost completely insensitive to these objects
(Perlman et al. 1998). Figure 2 summarizes these findings by comparing the FSRQ
content of the new and classical surveys.

As was the case for HBL, HFSRQ cover a different region of ($L_x, L_r$) parameter
space than previously known FSRQ, and dominate increasingly at lower luminosi-
ties. As was pointed out by Urry & Padovani (1995), the knee of the FSRQ radio
luminosity function sits at $L_r = 10^{33-33.5}\text{ergs}^{-1}\text{Hz}^{-1}$. A quick look at Figure 2 is
enough to convince the reader that the 1 Jy survey had basically no sensitivity be-
low that luminosity (in fact only 2 of its objects have lower radio luminosities), yet
it is precisely at these luminosities where the HFSRQ become increasingly common.

**III X-RAY OBSERVATIONS OF HFSRQs**

In order to understand the full spread of blazar properties, and develop appro-
priate constraints upon their physics, it is imperative to investigate the properties
of HFSRQ in the same depth as has already been done for their BL Lac cousins.
To start the process, we have observed four of the X-ray brightest HFSRQ with
SAX to analyze their 0.1-10 keV spectra. In so doing, we aim to investigate the
general trend noted in Perlman (2000) that DXRBS HFSRQ tend to have some-
what steeper ROSAT spectra (as defined by their hardness ratios) than their more
radio-bright cousins. In Table 1, we give the results of these observations (a full
accounting of these results will be presented in a later paper).

As can be seen, we find flat spectra, more similar to LBL BL Lacs and previ-
ously known FSRQ (Sambruna et al. 1996) for three of four objects. Only one
FIGURE 2. The X-ray and Radio luminosities of FSRQ in the EMSS, Slew, 1 Jy, DXRBS and RGB surveys. The 1 Jy contains only 14 FSRQ, (∼5%) of FSRQ to the right of the HBL/LBL dividing line (dotted). By comparison, 25% of DXRBS FSRQ, and 40% of EMSS, Slew and RGB FSRQ, fall into this category.

| Name               | $N_H$ $10^{20}$ cm$^{-2}$ | $\alpha_x$  | $F_{1keV}$ $\mu$Jy | $\chi^2$/d.o.f. |
|--------------------|--------------------------|------------|-----------------|-----------------|
| WGA J0546.6-6415   | 8.54 fix                 | 0.72 ± 0.08 | 0.64 ± 0.07     | 1.07/41         |
| RGB J1629+401      | 0.852 fix                | 1.50 ± 0.06 | 0.66 ± 0.05     | 0.90/28         |
| RGB J1722+243      | 4.95 fix                 | 0.62 ± 0.22 | 0.16 ± 0.05     | 0.63/18         |
| S5 2116+81:        |                          |            |                 |                 |
| ...29/2/98         | 7.41 fix                 | 0.73 ± 0.04 | 2.71 ± 0.17     | 0.96/61         |
| ...12/10/98        | 7.41 fix                 | 0.77 ± 0.07 | 2.15 ± 0.19     | 0.98/46         |
| ...........sum     | 7.41 fix                 | 0.73 ± 0.04 | 2.75 ± 0.16     | 1.04/62         |

Note: the errors are at 90% conf. level for one parameter of interest.
object (RGBJ1629+401) has a steep, HBL-like spectrum. This represents the first systematic observation of objects with demonstrably HBL-like broadband continua based upon their \( \alpha_{ox} \) and \( \alpha_{ro} \) values. The ASCA observations of “blue” FSRQ by Sambruna et al. (2000) achieved an outwardly similar result, with all objects having flat hard X-ray spectra. However, the Sambruna et al. result cannot really be considered as an observation of HFSRQ, as their selection criteria was for steep ROSAT spectra and not \((\alpha_{ox}, \alpha_{ro})\) values indicative of a high frequency peak – and indeed, some of the Sambruna et al. objects are not in the HBL region of the \((\alpha_{ox}, \alpha_{ro})\) plane.

In this light, it is unclear how we should interpret the broadband spectra of HFSRQ. The most straightforward interpretation would be that in all cases except for RGB J1629+401 we are seeing only inverse-Compton emission at \(>0.1\) keV. However, extreme caution is required. At the very least these objects have two emission components (both synchrotron and emission line) which can serve as seeds for inverse-Compton emission - and therefore it is likely that the synchrotron to inverse-Compton ratio is considerably higher for HFSRQ than it is for HBL BL Lacs. It is of course unclear where this additional emission might evidence itself, but according to the models of Sikora, Begelman & Rees (1994), inverse-Compton scattered emission-line photons should evidence themselves at energies of order 1-100 keV. Thus it is very likely that for HFSRQ of a given peak frequency the synchrotron to inverse-Compton ratio is considerably higher than for an HBL of the same peak frequency (see Georganopoulos 2000 for an interesting discussion of exactly this point). Thus it is still quite feasible that these objects have peak energies as high as \(\sim 10^{16}\) keV. By contrast, for RGB J1629+401 the most consistent explanation of its broadband spectrum would be that we are seeing synchrotron emission all the way up to 10 keV.

IV DISCUSSION

It is now worthwhile to reassess the analysis of Fossati et al. (1998). Figure 3 shows the \((\alpha_{rx}, L_r)\) plane for blazars when all five blazar surveys are added to the diagram. As discussed in Urry & Padovani (1995), an object’s \(\alpha_{rx}\) value is related to the location of its synchrotron peak, with \(\alpha_{rx} \approx 1\) representing \(\nu_{peak} \sim 10^{12}\) Hz, and \(\alpha_{rx} \approx 0.5\) representing \(\nu_{peak} \sim 10^{17}\) Hz. Thus, as explained by Fossati et al., the correlation between these two parameters was meant to explore the relationship between total luminosity and peak frequency. As can be seen, this correlation still persists, but when all five samples are added, it grows quite a bit broader - in fact, most of the horizontal extent in the graph is taken up by the “outlier” sections in the lower left and upper right hand corners. These corners represent areas where only one or two surveys had overwhelming sensitivity. If one only examines the middle section of the graph, the correlation is still very significant, but its physical meaningfulness is far less persuasive. And in fact, when individual surveys are examined no such correlation is present! This is shown convincingly by Figure 4,
FIGURE 3. The $(\alpha_{\text{xy}}, L_r)$ plane for blazars including the EMSS, Slew, RGB, DXRBS and 1 Jy samples. Note how much broader the correlation becomes after all surveys are included. While the correlation is still $> 99.99\%$ significant, the most prominent feature of this graph is the prominent “outlier” regions at the upper left and lower right hand corners, representing extreme objects.
which is the same plot with only DXRBS objects shown. It is therefore impossible to tell whether the \((\alpha_{rx}, L_r)\) plot represents a physically important correlation, or is merely reflective of the parameter space sensitivity of each survey.

The comparison of Figures 3 and 4 illustrate quite well the dangers inherent in combining surveys with very different biases and sensitivities, and attempting to derive correlations. These biases will continue to color our perception of blazar properties until either radio and X-ray selected samples become large and deep enough to include significant numbers of objects in every spectral shape class. DXRBS is the first radio-limited survey to accomplish this, but it will take much deeper radio and optical surveys to accomplish this for an X-ray flux limited sample, even with ROSAT data (see Padovani 2000). Thus to fully understand the findings of surveys whose parameter space coverage lies in the middle of the Padovani diagrams (e.g., REX, RGB), significant modeling will be required.

Fossati (2000) has described a promising avenue for such modeling efforts. However, it is instructive to note that the error bars on his models are still quite large, probably because of the almost disjoint parameter space coverage of the EMSS, Slew and 1 Jy surveys. Once Fossati has included deeper surveys such as DXRBS in his seed samples, it will be interesting to see whether the resulting error bars are sufficiently small that the technique can be used to predict the outcomes of future blazar surveys. A similar comment applies to the modelling efforts of Georganopoulos & Marscher.

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FIGURE 4. The same plot as Figure 3, but with only DXRBS objects shown. As can be seen, the Fossati et al. correlation does not persist when only single surveys are considered, making it quite conceivable that the observed correlation reflects the parameter space sensitivity of each survey rather than a physically relevant correlation.
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