The cosmological evolution of BL Lacs: The REX point of view

A. Caccianiga
Observatório Astronómico de Lisboa, Lisbon, Portugal

T. Maccacaro, A. Wolter, R. Della Ceca
Osservatorio Astronomico di Brera, Milan, Italy

I.M. Gioia
Istituto di Radioastronomia del CNR, Bologna, Italy

Abstract. We present the results on the cosmological evolution of BL Lac objects as derived from a statistically complete sample of 44 BL Lacs selected from the X-ray bright tail of the REX survey. With this sample, we have investigated the cosmological properties of BL Lacs taking into account the radio, optical and X-ray limits. We infer that no evolution is clearly visible down to the flux limits reached by our sample. On the other hand, deeper samples are probably needed in order to detect the negative evolution found in the EMSS sample. The identification of such deeper sample, extracted from the REX survey, is in progress.

1. Introduction

The first study of the evolutionary behavior of BL Lac objects was based on EMSS data. By studying the surface density of the BL Lacs as a function of the flux (Maccacaro et al. 1989, Wolter et al. 1991) and by applying the $V_e/V_\alpha$ test (Morris et al. 1991; Wolter et al. 1994), evidence for negative evolution (objects less numerous/luminous in the past) has been found. At the same time, the analysis of the 1 Jy radio selected sample of BL Lacs did not show any strong evidence for cosmological evolution (Stickel et al. 1991) in contradiction with what had been found in the X-ray band. These results were based on small samples containing 22 and 34 objects respectively. Because of the difficulty of selecting larger complete samples of BL Lacs a revision of their cosmological evolution is still a difficult task. Nevertheless, the recent availability of large radio and X-ray surveys boosted the attempts of selecting large sample of BL Lacs (e.g. the REX survey, Maccacaro et al. 1998, Caccianiga et al. 1999, the DXRBS, Perlman et al. 1998, the RGB, Laurent-Muehleisen et al. 1998). Using the ROSAT All Sky Survey, Bade et al. (1998) selected a complete sample of 33 BL Lacs with a flux limit of $8 \times 10^{-13}$ ergs cm$^{-2}$ s$^{-1}$ in the 0.5-2.0 keV band. They have applied the $V/V_{max}$ test to compute the cosmological evolution of BL Lacs, finding hints of negative evolution ($< V/V_{max } >= 0.40 \pm 0.06$).
Moreover, they have found that the negative evolution depends on the optical-to-X-ray spectral index ($\alpha_{OX}$) being more extreme ($<V/V_{max}> = 0.34 \pm 0.06$) for “X-ray” extreme ($\alpha_{OX} \leq 0.91$) objects. A negative evolution has been found also by Giommi, Menna & Padovani (1999) in a sample of HBLs ($\alpha_{RX} \leq 0.56$). The analysis of this sample gives evidence for a negative evolution which depends on the radio flux limit, being stronger for radio flux limit of 3.5 mJy ($<V_e/V_a> = 0.42 \pm 0.02$) and consistent with no-evolution for a flux limit of 20 mJy ($<V_e/V_a> = 0.49 \pm 0.04$). In this paper we present an independent study of the cosmological evolution of BL Lacs based on the REX survey.

### 2. The X-ray bright REXs

The REX survey is the result of a positional cross-correlation between the NRAO VLA Sky Survey (NVSS, Condon et al. 1998) at 1.4 GHz and an X-ray catalogue of about 17,000 serendipitous sources detected in ~1200 pointed ROSAT PSPC fields. The flux limit in the radio band (at 1.4 GHz) is 5 mJy. In the X-ray band the flux limits range from $\sim 3.5 \times 10^{-14}$ erg s$^{-1}$ cm$^{-2}$ to $\sim 2 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$ in the 0.5–2.0 keV band. The area covered at the highest flux limit is about 2200 deg$^2$. The cross-correlation has produced a catalogue of ~1600 Radio Emitting X-ray sources (REXs). The spectroscopical identification of the sample is in progress and, so far, about 36% of the sample has been identified. In this paper, we present a complete sample, the X-ray Bright REX sample (XB-REX), selected from the REX survey with the following additional criteria:

1. X-ray flux ($f_X$) in the 0.5-2.0 keV band $\geq 4 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$;
2. Magnitude (APM O) brighter than 20.4

The radio flux limit is the same of the whole REX survey (5 mJy). The resulting sample contains 190 objects. About 93% of these objects have been already identified, either from literature or from our own spectroscopy. The classification of a BL Lac is based on the following criteria: 1) Equivalent width of any emission lines $\leq 5$Å; 2) Ca II contrast at 4000Å (B) $\leq 40\%$. The last criterium is an extension of the “classical” one (B$\leq 25\%$), firstly used by Stocke et al. (1989). There are many evidences, in fact, that the limit of 25% is too restrictive and can miss some true BL Lac objects.

In total, the XB-REX sample contains 44 BL Lacs. Given its relatively high X-ray flux limit we do not expect to significantly detect the cosmological evolution found in the EMSS sample. In fact, the X-ray flux limit of the XB-REX sample corresponds to a flux limit of $7.2 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$ in the 0.3-3.5 keV band (the Einstein IPC energy band) assuming $\alpha_X=1$, which is higher than the deepest flux limit of the EMSS complete sample of BL Lacs ($f_{(0.3-3.5)} = 5 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$). The flux limit of the XB-REX is in the region where the LogN-LogS produced from the EMSS survey (Wolter et al. 1991) starts to flatten and, thus, we are probably not sampling the region where the negative evolution is more evident.
3. The $V_e/V_a$ analysis

In order to compute the cosmological evolution of BL Lacs we have applied the $<V_e/V_a>$ method described in Avni & Bachall (1980) where the $V_a$ is the smallest “available” volume among the $V_a$ computed in the three selection bands (X-ray, optical, radio). For the objects without a redshift, we have assumed $z=0.27$ (the mean value for the sample). We have also assumed $\alpha_R = 0$, $\alpha_O = 1.5$ and $\alpha_X = 1$ for the spectral indices in the radio, optical and X-ray bands, respectively. The resulting value of the $<V_e/V_a>$ is reported in Tab. 1.

| Sample       | N. of objects | $<V_e/V_a>$ value | Error$^a$ | KS prob.($\%$) |
|--------------|---------------|-------------------|-----------|-----------------|
| Total        | 44            | 0.52              | 0.04      | 94              |
| “classical” BL | 35            | 0.50              | 0.05      | 84              |
| $\alpha_{OX} \leq 0.91$ | 16            | 0.52              | 0.07      | 91              |
| $\alpha_{RX} \leq 0.62$ | 20            | 0.53              | 0.06      | 97              |
| EL AGNs      | 78            | 0.64              | 0.03      | 2               |

$^a1/\sqrt{12N}$, where N=number of objects

The X-ray band is the limiting one in many cases (20) but also the radio and the optical bands play an important role (they are the limiting band in 13 and 11 cases, respectively). The K-S test shows that the $<V_e/V_a>$ values are uniformly distributed between 0 and 1 (probability=94%). The result, as expected, is not significantly affected by the missing $z$. If we ignore the objects without $z$ we obtain $<V_e/V_a> = 0.52 \pm 0.05$ while if we assign to all the objects without a measured $z$ the maximum value observed in the sample ($z=0.6$) we obtain $<V_e/V_a> = 0.54 \pm 0.04$.

We have then divided the sample in different ways and applied the $V_e/V_a$ analysis to these sub-samples. The results are reported in Table 1. First of all, we have investigated whether the “extended” criteria used to define a BL Lac in the XB-REX sample, namely the Ca break below 40% instead of 25%, affects the result of the $<V_e/V_a>$ analysis. To this end, we have computed the $<V_e/V_a>$ by using only the “classical” BL Lacs, i.e. defined with the most restrictive limit on the Ca break (25%). The 35 “classical” BL Lacs still have a $<V_e/V_a>$ consistent with no-evolution. We have then checked if there is any dependence of the $<V_e/V_a>$ value on the “type” of BL Lac. We have thus considered only the 17 BL Lacs with an “extreme” X-ray/optical ratio ($\alpha_{OX} \leq 0.91$). According to the results found by Bade et al. (1998) these sources should show an extremely negative evolution. Instead, we do not see any evidence for negative evolution and the $V_e/V_a$ value is still consistent with 0.5. We have also divided the sample according to the ratio between the X-ray and the radio flux and considered only the typical X-ray selected BL Lacs (HBL type) with $\alpha_{RX} \leq 0.62$. Again, the resulting $<V_e/V_a>$ is consistent with 0.5.

For comparison, we have computed the $V_e/V_a$ for the 78 Emission Line AGNs found in the XB-REX sample. In this case, the most limiting band is the X-ray one (60 objects limited by the X-ray) while the optical and the radio bands
play a marginal role. The result is fully consistent with what found in the EMSS sample \(< V_e/V_a > =0.62 \pm 0.01\), Della Ceca et al. 1992). The distribution of the \(V_e/V_a\) values is clearly not uniform (KS probability of 2%).

4. Discussion and conclusions

The analysis of the complete sample of 44 BL Lacs presented here shows no evidence for cosmological evolution down to the explored flux limits. Even if we restrict the analysis to the most “X-ray extreme” objects (i.e. \(\alpha_{OX} \leq 0.91\) or \(\alpha_{RX} \leq 0.62\)), we do not find any sign of negative evolution. As stated before, the XB-REX sample is probably not deep enough to see the negative evolution detected in the EMSS survey. Instead, the RASS sample has an X-ray limit a factor 2 higher than the XB-REX sample and the negative evolution found by Bade et al. (1998) should have been detected in our analysis. In any case, a deeper sample will be instrumental to assess if a negative evolution affects the population of BL Lacs. At a flux limit \(2.8 \times 10^{-13}\) erg s\(^{-1}\) cm\(^{-2}\) (0.5-2.0 keV band), which corresponds to the lowest limit in the EMSS-C sample, the REX survey is identified at the 80% level, with the same radio and optical constraints of the XB-REX sample presented here. After the identification of the remaining sources is completed, we should be able to make a firmer statement on the cosmological evolution of the sample.

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