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Review

Swift for blazars

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ABSTRACT

I will review recent advances in the field of blazars, highlighting the contribution of *Swift*. Together with other operating satellites (most notably *Fermi*, but also *AGILE*, *WISE*, *Planck*) and ground based facilities such as Cherenkov telescopes, *Swift* was (and is) crucial for improving our understanding of blazars. The main advances in the blazar field made possible by *Swift* includes the opening of the time domain investigation, since there are several sources with hundreds of simultaneous optical, UV and X-ray data taken at different times; the possibility to measure the black hole mass in very powerful blazars, that show clear signs of accretion disk emission; the possibility to classify blazar candidates, through X-ray observations; the finding of the most powerful and distant blazars, emitting strongly in the hard X-ray band accessible to *Swift*/BAT. All these improvements had and have a great impact on our understanding on how relativistic jets are formed and emit, on their power, and on how the heavy black holes in these systems first formed and grew.

1. Introduction

After the launch of the *Compton Gamma Ray Observatory, CGRO*, we discovered that blazars (i.e. quasars with jets pointing nearly at us) were the most important class of persistent γ-ray emitters. This was somewhat unexpected, despite the fact that the previous γ-ray satellite *COSB* already detected 3C 273 as a γ-ray source (Swanenburg et al., 1978; Bignami et al., 1979). It was not completely clear that the production of γ-rays was associated with relativistic jets, even if all the necessary ingredients were known since the early seventies: superluminal motion and the presence of relativistic electrons in the source, producing synchrotron and self-Compton radiation (the external Compton idea was yet to come).

The discovery of the strong γ-ray emission of 3C 279 in 1991 by *CGRO* was soon followed by the realisation that blazars are γ-ray emitters as a class, and this triggered a frantic phase of theoretical developments (Maraschi et al., 1992; Dermer and Schlickeiser, 1993; Sikora et al., 1994; Ghisellini and Madau, 1996; Bloom and Marscher, 1996). At the same time, the (few) multi-wavelength campaigns showed coordinated variability of the flux at different frequencies, and this made the jet paradigm to shift from a multi-zone jet, producing the highest frequencies (γ-rays) in the innermost regions and the IR–optical further out (Marscher, 1980; Königl, 1981; Ghisellini et al., 1985), to the much simpler "one-zone" jet in which most of the emission was produced in a single region, i.e. the same electron population producing the synchrotron was also responsible for the high energy flux (but not the radio, due to the synchrotron self-absorption). This required a strong effort, especially on the observational side, because it was not easy to organise multiwavelength campaigns joining space and ground observatories.

When *Swift* was launched what was a dream became routine: simultaneous optical, UV, and X-ray observations became easily accessible and flexible planning allowed to use Target of Opportunity observations to follow extraordinary events. Then, when *Fermi* joined in, we could have a really complete view of the behaviour of blazars, and not only of the 3 or 4 brightest ones, but of hundreds of them.

The *Swift* and *Fermi* satellite, together with ground based facility like the Cherenkov telescopes, made a quantum jump in our knowledge of the physics of blazars, and led the way to use them not only to understand the high energy physical processes that characterise their emission, but also to use blazars as a probe of the far Universe.

What follows is a partial view of the recent advances in blazar science allowed by *Swift*.

2. Multi-wavelength campaigns

Both planned observations together with other instruments and target of opportunity (ToO) observations (performed after even a very short notice) have secured the optical–UV and X-ray observations of hundreds of blazars. Fig. 1 shows the observed spectral energy distribution (SED) of blazars together with the observing band of *Swift* and *Fermi*/LAT. *Swift*/UVOT and XRT cover the peak

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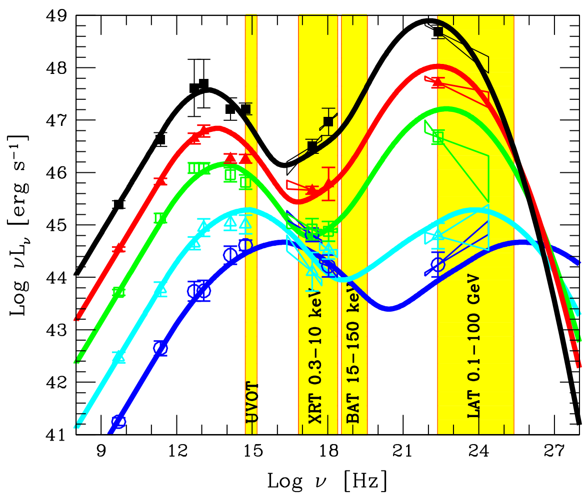

Fig. 1. The "blazar sequence": blazars have SEDs that change according to the bolometric observed jet luminosity. Low powerful lineless BL Lacs are "blue": their synchrotron and Compton hump peaks at high frequencies, and the corresponding luminosities are about equal. Powerful flat spectrum radio quasars (with broad emission lines) are redder, and the Compton hump dominates. This has been explained as due to radiative cooling: electrons in more powerful sources suffer more severe losses, and this limits their typical energies to values smaller than the one in low powerful BL Lacs, in which the cooling is less severe (Ghisellini et al., 1998). In this respect, the presence or absence of the broad emission lines can play a crucial role, since they can largely enhance the inverse Compton emission and the corresponding radiative cooling. The indicated yellow vertical stripes correspond to the observing bands of *Swift* and *Fermi*/LAT. Adapted from Fossati et al. (1998), Donato et al. (2001). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

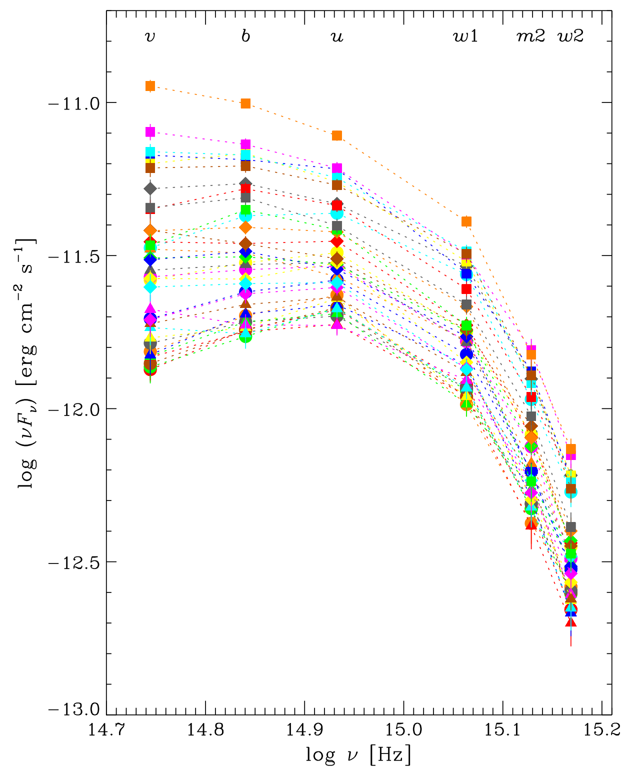

Fig. 2. The *Swift*/UVOT SED of the blazar B3 1633+382 (alias 4C 38.41), at different epochs. The flux is the sum of the steep tail of the synchrotron jet emission and the thermal component produced by the accretion disk. From Raiteri et al. (2012).

of the synchrotron emission of low power line-less BL Lacs, the best candidate to be TeV emitters, while *Swift*/BAT can be more effective in observing and even discover powerful flat spectrum radio quasars (FSRQ) with broad emission lines at high redshift. For this class of objects, *Swift*/UVOT can observe the thermal emission produced by their accretion disk.

This thermal component may be elusive for intermediate redshift and intermediate power FSRQs, because in these objects the beamed non-thermal flux can hide the thermal continuum. One example 3C 454.3 (Vercellone et al., 2009; Bonnoli et al., 2011; Raiteri et al., 2008), whose thermal emission was revealed through the optical and UV monitoring involving *Swift*/UVOT (Raiteri et al., 2011). Another example is B3 1633+382 ($z = 1.814$), discovered as a γ-ray source by CGRO and well monitored by *Swift*, *Fermi* and *AGILE* (Raiteri et al., 2012). As Fig. 2 shows, *Swift* was instrumental to reveal the contribution of the accretion disk.

Fig. 3 shows data from *Swift* and *NuSTAR* of the high-redshift blazars PKS 2149−306 ($z = 2.345$) (Tagliaferri et al., submitted for publication). Together, *Swift*/XRT and *NuSTAR* cover the 0.3–70 keV band. The bottom panel of Fig. 3 shows the X-ray SED, with the two observations of *Swift*+*NuSTAR* together with other archival observations. It can be seen that *Swift* is crucial to describe the behaviour of the X-ray spectrum, that does not change at low energies, while it becomes harder when brighter above ∼4 keV (13 keV rest frame). The addition of the *Fermi*/LAT makes clear that the hard X-ray behaviour corresponds to a shift in the high energy peak frequency, that becomes smaller in the (slightly) lower state. In this case we have a behaviour opposite to the blazar sequence (see Fig. 1).

3. Time domain

The accumulation of data during the life of *Swift* implies that a source has the chance to be observed several times, with all the three *Swift* instruments. The most famous blazars (PKS 2155−304, Mkn 421, Mkn 510, 3C 454.3) have been observed *hundreds* of times. All data are public, and the *Swift* archive is a resource for the years to come, still to be fully exploited. As in many other branches of science, the amount of data is becoming too large to be analysed by humans (or, at least, by single humans), and as automatic tools have been developed for Gamma Ray Bursts, there has been the initiative of the ASI Science Data Center (ASDC) to offer tools to build the SED of all sources (not only blazars) with the option to select slices of time, or of frequencies. This is a very important service, publicly available, that I wish to thank.

4. Accretion disks in blazars

The non-thermal continuum of blazars often dominates in the optical–UV bands, making the accretion disk invisible. And yet, in FSRQs, we do see broad emission lines, that should be produced by clouds photo-ionised by the disk flux. The old idea of the beamed continuum being even stronger in BL Lacs, such to hide also the emission lines (besides the disk flux) is in general wrong, but it may still be true in a few cases. Now we believe that the "genuine" BL Lacs intrinsically lack the broad emission lines, because their accretion disks are in the low radiative regimes (ion supported tori (Rees et al., 1982), ADAF (Narayan et al., 1997), CDAF (Narayan et al., 2000), ADIOS (Blandford and Begelman, 1999)) and therefore have mass accretion rates below a critical value in units of Eddington, corresponding to disk luminosities $L_{\rm disk}/L_{\rm Edd} \lesssim 10^{-2}$ (Narayan and Yi, 1995; Sbarrato et al., 2014). There is then a "divide" in terms of $L_{\rm disk}/L_{\rm Edd}$ (or, equivalently, in terms of the accretion rate $\dot{m}$ in Eddington units), distinguishing BL Lacs and FSRQ (Ghisellini et al., 2009a). Since we believe that the corresponding parent populations are FR I and FR II radio-galaxies, they should be characterised by the same divide (Ghisellini and Celotti, 2001a). All these issues require the knowledge of the mass of the black hole $M_{\rm BH}$. There are mainly four methods for estimating it.