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INTEGRAL AND SWIFT OBSERVATIONS OF BLAZARS IN OUTBURST

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RESUMEN

Hemos monitoreado a los blazares 3C 454.3 y PKS 0537-441 que son brillantes y variables con diversos instrumentos incluyendo *Swift* e *INTEGRAL*, y hemos interpretado sus variaciones como consecuencia de choques internos en un jet relativista. En este modelo, todas las cantidades físicas pueden parametrizarse como funciones del factor de Lorentz. Por tanto, esto depende de donde se encuentra localizado el choque interno con respecto al núcleo. Se pueden reproducir grandes variaciones en distintas parte del espectro, aún cuando la cantidad de energía inyectada al jet sea constante.

ABSTRACT

We have monitored the bright and variable blazars 3C 454.3 and PKS 0537-441 with various facilities, including *Swift* and *INTEGRAL*, and have interpreted their variations as the consequence of internal shocks in a relativistic jet. In this model, all physical quantities can be parameterized as functions of the bulk Lorentz factor. This depends in turn from the location of the internal shock with respect to the nucleus. Large variations in different parts of the spectrum can be reproduced, even if the amount of energy injected in the jet is constant.

Key Words: galaxies: active

1. INTRODUCTION

Blazars are the most powerful manifestation of extragalactic relativistic jets (Urry & Padovani 1995). The viewing angle —close to the jet axis— favors the investigation of their innermost nuclear regions. Many long and intensive multiwavelength observing campaigns on blazars have followed their variability. An example is the blazar class prototype, BL Lac, the spectrum of which has been repeatedly monitored by many observing groups, including the group in México led by Deborah Dultzin (Boettcher et al. 2003).

It is commonly accepted that synchrotron radiation dominates the spectrum from the radio to the UV (and occasionally X-ray) domain, while inverse Compton scattering off synchrotron photons (synchrotron self-Compton) or off disk or broad line region (BLR) photons (external Compton) prevails at higher energies. However, the mechanism by which the energy is transferred from the central engine to the jet during the outbursts, then dissipated in the jet so that complex multiwavelength variability is produced but it is not understood.

Katarzińsky & Ghisellini (2007) have developed a model based on the internal shocks (Rees 1978; Mészáros & Rees 1994; Sari & Piran 1997). Relativistic plasma blobs of different velocity —direct evidence of which comes from VLBI observations on larger angular scales than those probed by intraday variability (e.g. Jorstad et al. 2001)— collide within the jet (internal shocks), merge into a single blob and produce an outburst. The distance at which the blobs collision occurs from the jet apex is proportional to the square of the lower Lorentz factor. Therefore, slower blobs collide closer to the nucleus than faster blobs.

All physical quantities scale with the distance from the nucleus. Close to the nucleus, the magnetic field experienced by the plasma is stronger, and the influence of the BLR is weaker; this suggests a more significant synchrotron emission with respect to external Compton. The opposite is true when the collision occurs farther from the nucleus: the magnetic field has lower strength and the BLR photon density is larger. Thus, at different sites along the jet, the synchrotron and inverse Compton (primarily external Compton) components may have different ratios, even if the injected total energy is the same. We have endeavored to test the multiwavelength variability predicted by this model with the current orbiting and ground-based facilities.

2. THE OBSERVING CAMPAIGNS

We observed with *INTEGRAL* the Flat Spectrum Radio Quasar 3C 454.3 ($z = 0.859$) in May 2005, following the dissemination of an optical alert: the source was in an unusually bright state ($V \sim 12$). Many orbiting and ground-based observatories, including the robotic telescope REM, located at ESO

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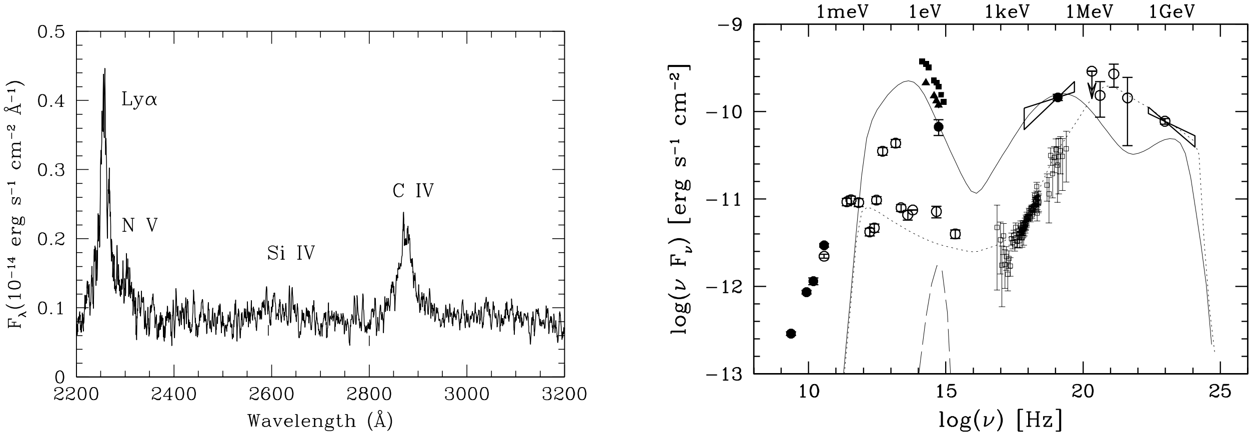

Fig. 1. *Left:* HST FOS observed spectrum of 3C 454.3 in August 1995. The spectral flux is smoothed with a 5 Å-wide boxcar. Prominent emission lines are overimposed on the continuum (from Pian et al. 2005). *Right:* Multiwavelength energy distributions of 3C 454.3 in observer frame. The filled symbols refer to observations in spring 2005, when the source was in outburst (the hard X-ray spectrum is from *INTEGRAL*). The open symbols are data taken at previous epochs. All data have been corrected for Galactic extinction. Overplotted are model curves of synchrotron radiation and inverse Compton scattering in May 2005 (solid) and historical (dotted) state, according to Katarzyński & Ghisellini (2007). The dashed curve is the black body component associated with an accretion disk underlying the blazar (see details in Pian et al. 2006).

(La Silla, Chile), started a monitoring (Giommi et al. 2006; Fuhrmann et al. 2006; Pian et al. 2006; Villata et al. 2007). The spectral energy distributions of the blazar in Spring 2005 and at previous epochs are reported in Figure 1 (right).

Both the "historical" and the 2005 spectral energy distributions can be modeled with synchrotron and inverse Compton radiation produced during the collision of plasma blobs occurring *within* the BLR (Figure 1, left). However, in the historical state the collision occurs farther from the nucleus, so that the BLR radiation density is higher and the inverse Compton scattering radiation is enhanced. Therefore, the MeV-GeV part of the spectrum is very bright, and the optical and X-ray parts are depressed. The opposite occurs in spring 2005. Accordingly, the bulk Lorentz factors in the 2 states are different, but by less than a factor 2: we predict $\Gamma = 6.25$ in May 2005 and $\Gamma = 11$ in the historical state. Thus, a relatively small difference in the bulk Lorentz factor can reproduce, alone, the dramatic observed multiwavelength variability.

The blazar PKS 0537-441 ($z = 0.896$) has been observed at various epochs at many wavelengths and is known for its remarkable variability (see Pian et al. 2007, and references therein). Like 3C 454.3, it has a luminous BLR (Pian et al. 2005). In 2005 it has been monitored in the optical and infrared by REM (Dolcini et al. 2005) and observed by all instruments of *Swift* in January, July and November. Figure 2 reports the spectral energy distributions of the blazar from the present campaign (right) and those obtained using data from previous epochs (left). Note that in 2005 the flux varied considerably both in optical and X-rays, but the optical variation amplitude is more than a factor of 50, much larger than in X-rays (factor of 4).

We have modeled all multiwavelength spectra with the Katarzyński & Ghisellini (2007) model, by accounting for the multiwavelength variability only with variations of the bulk Lorentz factor Γ and by parameterizing every other physical quantity as a function of Γ. The fitting curves reproduce very satisfactorily the data. The variability is due to rather small variations of Γ: from a minimum of $\Gamma \simeq 10$ in the most luminous state of February 2005 to a maximum of $\Gamma \simeq 15$ in the dimmest states of November 2005 as well as in the low states prior to 2005. Note the highly predictive power of the model in the MeV-GeV domain. The *AGILE* satellite gamma-ray observations of this source in July 2007 have allowed an excellent test of the model (Ghisellini et al. 2007).

3. CONCLUSIONS

The blazars 3C 454.3 and PKS 0537-441 have luminous BLRs and therefore represent a benchmark for the economic jet model of Katarzyński & Ghisellini (2007). In this model, the flares are pro-

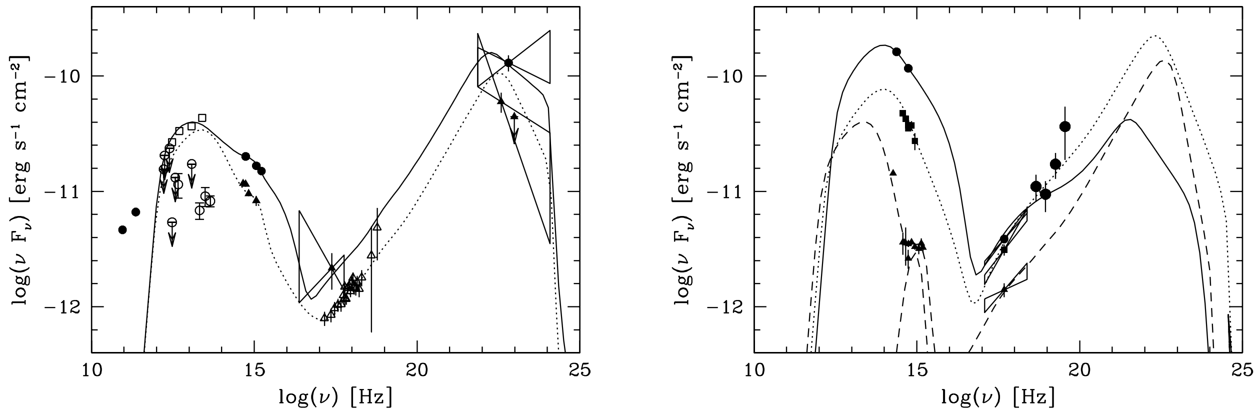

Fig. 2. *Left:* Historical spectral energy distributions of PKS 0537-441: the gamma-ray, soft X-ray, UV, optical and millimetric data have been acquired in 1991–1992 (filled squares) and 1995 (filled circles). The far-infrared data taken by IRAS and ISO and the X-ray BeppoSAX data are not simultaneous and are represented as open squares, open circles and open triangles, respectively (see Pian et al. 2007, and references therein). The data have been modelled according to Katarzyński & Ghisellini (2007). The model curves for the 1991–1992 and 1995 states are dotted and solid, respectively. They are both compatible with a bulk Lorentz factor $\Gamma \sim 15$. *Right:* Observed spectral energy distributions of PKS 0537-441 on 24–25 February 2005 (small filled circles), 12 July 2005 (filled squares) and 24 November 2005 (filled triangles). The X-ray spectra are from Swift/XRT and the optical/UV data have been acquired both by Swift/UVOT and by the ground-based robotic telescope REM. The big filled circles represent the BAT data. The data are corrected for Galactic extinction. The jet models of Katarzyński & Ghisellini (2007) are reported as solid (24–25 February 2005, $\Gamma \simeq 10$), dotted (12 July 2005, $\Gamma \simeq 12$), dashed (24 November 2005, $\Gamma \simeq 15$) curves. The thermal component required to account for the observed optical-UV flux is also reported as a dashed curve.

duced *within* the BLR, at different locations along the jet, from the collision of two consecutively emitted plasma blobs. Synchrotron-dominated multiwavelength blazar spectra are produced by collisions occurring closer to the jet apex, while the external Compton component, mainly responsible for the production of the MeV-GeV spectra, dominates when the flare is generated farther from the nucleus and closer to the BLR.

For blazars with no luminous BLR, the economic jet model —the concept of which is based on the relative distance of the dissipation site from the nucleus and from the BLR— cannot be adequately tested. While internal shocks can take place in these objects as well, their observed multiwavelength variability must be explained with intrinsic changes of other physical quantities, besides Γ (see e.g. the 2006 TeV flare of PKS 2155-304, Foschini et al. 2007).

Parameter changes independent from Γ can obviously take place also in objects with a rich BLR, but our purpose here is to demonstrate that this is not necessary: the very different observed multiwavelength states in these sources *can* be described by the dissipation of a fixed amount of energy at any given epoch.

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