INTEGRAL AND XMM-NEWTON OBSERVATIONS OF BLAZARS IN OUTBURST

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ABSTRACT

We ask for 2 observations of 400 ks each to observe in target-of-opportunity (TOO) up to 2 blazars, conditional to stringent and well defined triggering criteria based on optical and/or X-ray brightening. Serendipitous INTEGRAL detections of bright blazars (∼20 mCrab) will also be instrumental to TOO activation. By coordinating these INTEGRAL observations with XMM-Newton campaigns we will guarantee the coverage of a crucial energy range for determining the overall spectral distribution of blazars in a flaring state, and thus for constraining any emission model, as proved by the success of a similar program conducted in past years with BeppoSAX.

SCIENTIFIC JUSTIFICATION

Rationale

The continuum emission from Active Galactic Nuclei (AGN) is both highly luminous and rapidly variable, especially for the blazar class (BL Lac objects and Flat Spectrum Radio Quasars, FSRQ). Determining the continuum production mechanism is critical for understanding the central engine in AGN, a fundamental goal in extragalactic astrophysics. Blazar emission is dominated by relativistic jets at small angle to the line of sight [21], and early multiwavelength studies provided the first strong evidence for bulk relativistic motion, later confirmed directly with VLBI observations [22]. The structure of the jet, however, remains largely unknown, as the models are under-constrained by single epoch spectra [23]. Since blazars emit over the entire electromagnetic spectrum, a key for understanding blazar variability is the construction of multiwavelength spectra during major flaring episodes. Time-resolved spectra of blazars are available only for a few sources, and have been obtained through monitorings at many wavelengths, thanks to the joint and simultaneous effort of many ground and space-based facilities. Examples are S5 0716+71 [6], 3C 279 [24], Mkn501 [15], PKS 0528+134 [7], BL Lac [2,16,17], ON 231 [19], PKS 2005-489 [20].

According to most blazar radiation models, the soft gamma-ray spectrum can be produced either by synchrotron radiation during outburst (in High-Frequency-Peaked BL Lacs, or HBL, whose synchrotron spectrum peaks at optical/UV wavelengths in quiescence [14]), or by the inverse Compton radiation (in FSRQ and Low-Frequency-Peaked BL Lacs, LBL, having the synchrotron component peaking at far- to near-IR wavelengths), or both (intermediate blazars). Most of the recent multiwavelength studies of blazars have critically benefitted from the extended energy range of BeppoSAX, and particularly from the coverage above ∼15 keV, which has allowed, for the first time, the detection of high energy synchrotron tails (Mkn 501 [15], 1ES 2344+514 [9], 1426+428 [4], PKS 2005-489 [20], see e.g. Fig. 1, left panel), or has sampled in detail the energy range in which the synchrotron and inverse Compton components connect (Fig. 1, right panel), or finally has constrained the position of the inverse Compton peak (Fig. 2, left panel).

The largest amplitude flux variations are observed at the highest energies. Different models predict different variability as a function of energy. Therefore, only by coupling spectral and temporal information one can constrain the jet physics, so that a detailed sampling, both in time and energy, of the blazar spectrum in the soft gamma-rays can critically direct the interpretation to the correct scenario. Elucidating the structure of blazar jets, possible through multiwavelength monitoring, is an essential precursor for understanding their formation and thus the extraction of energy from the central engine. This allows one to know the energetics involved in the flare as a function of frequency, the relative amplitude of variability at different energies (constraining the flaring spectrum and any amount of diluting and more quiescent emission), and possibly the time delays between flux variations at different frequencies. This information is the base of any model.

Objectives

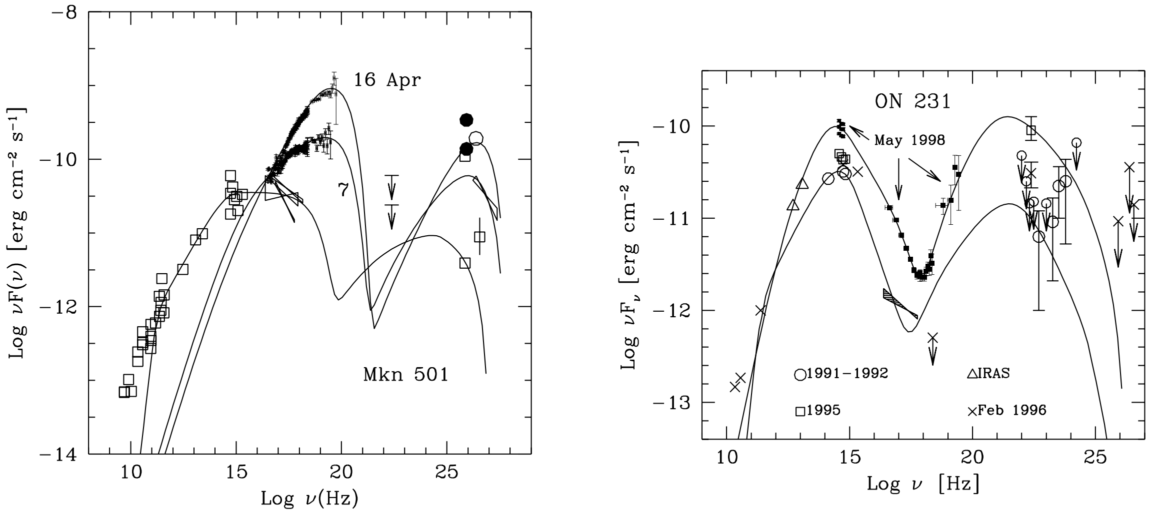

Figure 1: *Left:* Multiwavelength energy distributions of the HBL Mkn 501 in historical state (lowest flux level), and during the outburst detected in X-rays by BeppoSAX and at TeV energies by Cherenkov telescopes on 7 and 16 April 1997 (intermediate and high level, respectively). A homogeneous synchrotron self-Compton model has been adopted to fit the spectra. See [15] for details on the data and on the model. *Right:* Multiwavelength energy distributions of the ON 231 at various epochs and in May 1998, during an outburst detected first in the optical, and then in X-rays with a BeppoSAX follow-up [19]. The BeppoSAX PDS data ($E > 13$ keV) confirm the indication, provided by the lower energy instruments, that the X-ray spectrum is concave, i.e., in this region the two fundamental components of the blazar spectrum overlap. This makes ON 231 an intermediate source between LBL and HBL. This characteristic imposes constraints for the modeling and for blazar demographics. Bright intermediate blazars could make good targets for IBIS detection of concave spectra.

With the requested INTEGRAL observations (see next section) we will:

1) construct simultaneous multiwavelength spectral energy distributions of blazars in high state by primarily using the INTEGRAL gamma- and X-ray data and by complementing this information with XMM-Newton and Swift/XRT data, optical data from the INTEGRAL OMC, Swift/UVOT and from ground, and with ground-based radio/millimetric data, thus sampling the evolution of the overall spectral shape;

2) derive from the spectral energy distributions and from the direct VLBI imaging observations the physical and geometrical parameters of the emitting region, as well as their energy dependence and temporal evolution, and thus constrain the blazar models;

3) identify, by comparison of the quiescent and outburst states the critical changes in the physical conditions of the nuclear regions, which determine the production of the observed dramatic flares;

4) resolve confusion problems: over 50% of AGNs detected by EGRET probably suffer by contamination from other nearby sources [10], which IBIS imaging could remove;

5) investigate the duty cycle of high energy variability in blazars.

This proposal is the continuation of a similar INTEGRAL TOO proposal approved for the AO1. We had no chance of activating the proposal during AO1, also due to the relatively short duration of that cycle. However, we can now count on more optical monitoring facilities than in AO1 (especially robotic) and on an additional large field-of-view detector for blazar survey, Swift/BAT (as of April 2004). Moreover, the INTEGRAL AO2 will largely overlap with extended optical monitoring campaigns of the blazars AO 0235+16 and 3C 66A taking place all over the world (WEBT, http://www.to.astro.it/blazars/webt/). Finally, we have revised and improved our trigger conditions based on IBIS QLA detection of flaring blazars. Therefore, we expect that our chance of catching a suitable target in outburst will significantly increase in INTEGRAL AO2.

PROPOSED OBSERVATIONS

We propose to activate TOO observations of blazars detected in flaring state in the optical and/or in X-rays by monitoring surveys, or in the soft gamma-rays by INTEGRAL itself. In addition, we request proprietary rights on the

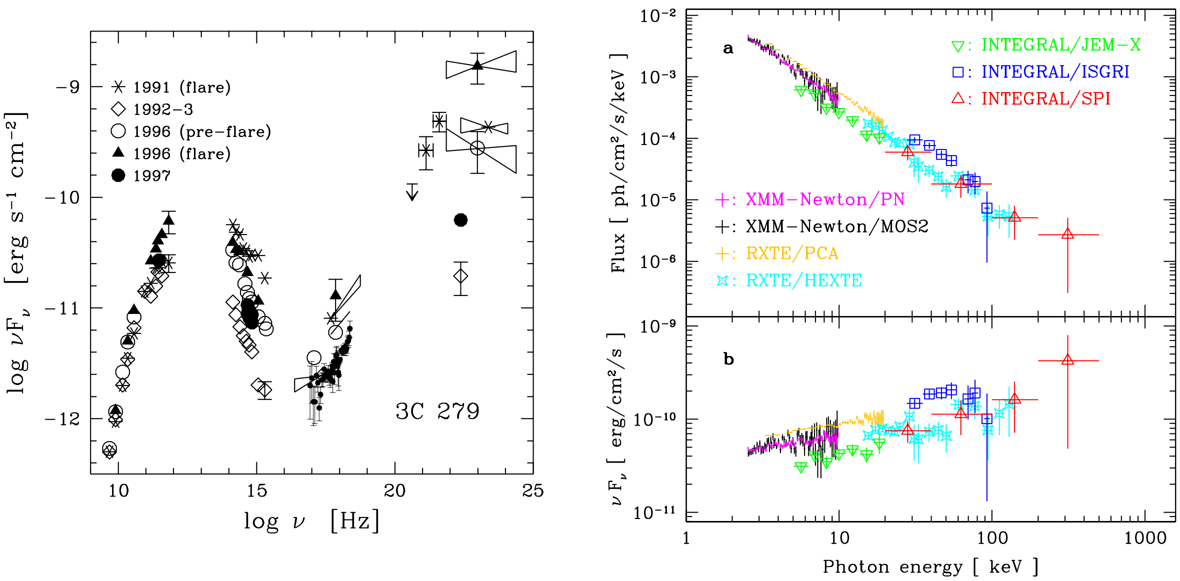

Figure 2: *Left:* Multiwavelength energy distributions of the 3C 279 at various epochs in different brightness states (from [1,24]). The BeppoSAX spectrum of 1997 in low state is also reported. *Right:* X- to gamma-ray spectral energy distribution of 3C 273 in January 2003 as measured by INTEGRAL, XMM-Newton and RXTE (in f_ν and νf_ν representation, from [5]). The spectral index is $\alpha = 0.73 \pm 0.02$ ($f_\nu \propto \nu^{-\alpha}$).

INTEGRAL data of flaring blazars (as defined in the "trigger criteria" section below) serendipitously detected during an INTEGRAL Open Time pointing. The IBIS instrument onboard INTEGRAL, with its good spectral coverage and resolution and its unprecedented angular resolution in the soft gamma-rays, offers an excellent opportunity of constraining the existing models for the high energy emission, by providing information over a crucial energy range of blazar spectra and by removing any possible contamination from sources at small angular distances from the target (see for instance the case of PKS 0528+134 [7]). The data simultaneously obtained with the X-ray monitor JEM-X will fruitfully complement the simultaneous coverage at energies where high amplitude variations are also expected. The data of the OMC (we expect our targets to be generally brighter than the OMC limit) will also preciously add to the optical monitoring performed from ground, considering the usual limitations suffered by ground-based optical observations (day time avoidance, bad weather conditions, target visibility periods not completely matching those of INTEGRAL).

Sample selection

We will consider as targets for the present proposal all blazars undergoing a major flaring event. These have been selected among AGNs detected by CGRO EGRET [10] and/or OSSE [3,12] and/or by the BeppoSAX PDS, which makes them good candidates for soft gamma-ray detection. To these we have added blazar sources frequently monitored by the RXTE-ASM, and/or in the optical at the Observatories of Turin, Perugia, and by the automatic telescopes TAROT (Calern, France), BART (Ondrejov, Czech Republic) and BOOTES-1 (Spain). Many sources in the southern hemisphere will also be frequently monitored by the robotic telescope Rapid Eye Mount (REM), which has been recently installed at La Silla (Chile) and will become fully operational in early 2004. These automatic telescopes, albeit primarily dedicated to the real-time follow-up of optical counterparts of Gamma-Ray Bursts, are also conducting a systematic survey of AGN (typically 4-5 sources per night).

Finally, we have included in our target list the 1 Jy catalog sources [18], the EMSS sources [13], strongly polarized blazars [11], and the identified BL Lacs in the Sedentary Multi-frequency Survey ([8], plus still unpublished sources) having ROSAT fluxes larger than 1.0×10^{-11} erg s^{-1} cm^{-2}. The BL Lac objects in this survey are all X-ray bright, therefore the sources in the subset we have selected are good candidates for bright soft gamma-ray emission during synchrotron flares. The complete list of our potential targets is attached to the submitted proposal.

In case of serendipitous INTEGRAL detection of a flaring blazar in the IBIS FOV, we would also like to activate an INTEGRAL TOO follow-up under the trigger conditions specified in the next sub-section. Some of our targets may also be detected in flaring state by the BAT onboard Swift (launch time: April 2004), which will perform a survey of the gamma-ray sky thanks to its large FOV.

The present proposal is meant to be complementary to a companion TOO proposal submitted by G. Ghisellini, based on different trigger conditions (blazar detections at TeV energies). Therefore, the partial overlap of selected targets in that proposal and the present one does not represent a conflict. In case of approval of both proposals, if a blazar will be detected in high state both at TeV and X-ray energies, the PIs will sort out internally the priority for request of INTEGRAL observations activation. Similarly, the inclusion of Mkn 501 in our target list does not represent a conflict with the Core Program observations of Mkn 501 because that TOO program is based on a trigger at TeV energies.

Trigger criteria

We propose to trigger a TOO observation when **at least one of the conditions** listed below will be satisfied by a blazar:

- The optical flux brightens by more than 2 magnitudes (in one of the most commonly used filters BVRI) with respect to the mean quiescent level of the source, as measured during the previous year. This criterion holds particularly for FSRQ and LBL, because they exhibit large variability at optical frequencies. Optical flaring states last some months, so that the "base" flux level of a source can be defined accurately, and is monitored every year. For HBLs, somewhat lower amplitude optical variations are expected, and we will relax this criterion and accept a lower threshold for optical changes (0.5-1 mag). In fact, for HBLs the most effective criterion is the X-ray variation (see below);

- The optical flux brightens by more than 1 magnitude (in one of the most commonly used filters BVRI) in a week. The same comment as above applies here, concerning the difference between LBLs and HBLs;

- The X-ray flux, measured by other high-energy missions like the RXTE-ASM, Chandra, XMM-Newton, the WXM and SXC cameras onboard HETE-2, the XRT onboard Swift, brightens by more than a factor 3 with respect to the mean level and remains high ($> 10^{-11}$ erg s^{-1} cm^{-2}) for at least 3 days;

- The gamma-ray flux as measured by IBIS/ISGRI is more than 20 mCrab in the 15-40 keV range (corresponding to a 6-7 σ detection in a typical 2 ks Science Window).

About 30 of our targets are daily monitored by the RXTE-ASM and we are checking their light curve every other day. Useful X- or gamma-ray triggers can also come from other satellites: Chandra, XMM-Newton, HETE-2, Swift, INTEGRAL itself. Some of the Co-Is of this proposal are involved in longstanding programs of optical monitoring of many blazars, ensuring that a prompt alert will be given when a source undergoes a major brightening event (as done for instance for activation of BeppoSAX TOO observations of ON 231 and BL Lac [16,19]). Each object belonging to the optical monitoring lists is observed at least once per night, if located at the suitable right ascension. The brightest and most variable objects are observed several times per night.

Once we will be informed of a blazar outburst state (by direct alert from an optical telescope or X-ray satellite, or by browsing the RXTE-ASM reports) we will immediately contact the INTEGRAL Planning Team to ascertain the feasibility of the TOO and, in positive case, request the scheduling. As for flaring blazars detected by INTEGRAL itself, these should be identified at Quick-Look Analysis level by the INTEGRAL SDC after systematic comparison of the INTEGRAL images with the source list accompanying the present proposal. In case of a detection of a source of 20 mCrab or higher in the 15-40 keV band, we request to be notified as soon as possible in order to plan successive actions and to intensify the optical monitoring of that particular target. Some Co-Is of the present proposal will timely and systematically do an off-line analysis of the Core Program pointings in search of blazars matching our TOO criteria, and possibly missed during the QLA screening. The presence of INTEGRAL instrument scientists in our proposing team ensures a rapid and effective reduction and analysis of the acquired data.

Observing strategy

Considering both "external" triggers (X-ray and/or optical) of blazars in outburst and high state blazars detected by INTEGRAL itself, *we conservatively plan to activate 2 observations of 400 ks each for a maximum of 2 sources, to be coordinated with 2 XMM-Newton pointings of 50 ks each granted to a program led by one of us (G. Tagliaferri) for TOO observation of blazars (carried over from an XMM-Newton AO2 program).* The observations will be devoted either to the same source in case it exhibits an extended period of activity, or to two different flaring sources. Repeated observations of the same source in high state are extremely important because they allow us to study the evolution of the gamma-ray spectrum in such extreme conditions over a large energy band and to compare the spectral properties in different high states. The effectiveness of this strategy has already been proven by BeppoSAX observations of blazars.

Therefore, once an observation will have been triggered, if the successive optical/X-ray monitoring will still show the source to be in a high state, we propose to observe it again with INTEGRAL 1-2 weeks after the first observation, to monitor its spectral variability.

We prefer to use the hexagonal dither pattern to avoid sensitivity degradation and to guarantee background removal from SPI data.

Feasibility

Although our targets may be relatively feeble in quiescence, when in outburst they are very strong and have very hard spectra: in the energy band covered by IBIS and SPI they can be as intense as $\sim$50 mCrab. Based on the in-orbit sensitivity of the IBIS/ISGRI instrument, 400 ks are needed to achieve a detection of at least 6 σ up to 200 keV, corresponding to a minimum flux of 8×10^{-6} ph s^{-1} cm^{-2} keV^{-1}, for a source with a spectral shape and brightness level similar to 3C 273, which has been observed by INTEGRAL in January 2003 (see Figure 2, right panel).

The requested S/N is necessary to determine the spectral slope with a good accuracy, i.e., we need a significant flux detection in a minimum of 7-8 energy bins. Figure 2 (left panel) illustrates the importance of this requirement for the typical FSRQ 3C 279: the soft gamma-ray portion of its spectrum has been explored so far (with limited significance) only by OSSE. In a 1997 BeppoSAX observation, not scheduled as a TOO, the PDS detected the source in a very low state, and only below 30 keV. During a bright state of 3C 279, IBIS could sample its inverse Compton spectrum. INTEGRAL is the only currently available facility which can perform long, uninterrupted exposures in gamma-rays and therefore it is important to exploit it to secure good measurements up to the highest IBIS energies.

Moreover, we need good S/N measurements to construct light curves with a time resolution of few hours, at least at the lower gamma-ray energies, adequate to make a meaningful comparison with the X-ray and optical light curves. The total time request implied by the present proposal is of 800 ks. To this should be added the data, obtained at no extra time expense, of serendipitous INTEGRAL detections of blazars. The good S/N data obtained with JEM-X and the OMC during the exposure will be used to complement our IBIS spectra.

Coordinated and supporting observations

This proposal is closely coordinated with an approved XMM-Newton TOO program. Our team includes astronomers who are pursuing monitoring programs of blazars at optical/near-infrared frequencies and have access to telescopes in both hemispheres (Perugia, Turin, Canary Islands, TAROT, BOOTES-1, BART, REM). They will guarantee a good coverage of our targets, both for what concerns the trigger of INTEGRAL observations and the photometric and polarimetric follow-up monitoring of a source in bright state. Follow-up programs at X-ray and optical frequencies with the Swift narrow field instruments XRT and UVOT will also be organized. TeV ground-based simultaneous observations of blazars with flaring synchrotron components will be timely activated, if feasible (MAGIC, VERITAS, HESS). Radio follow-up observations of suitable candidates will be performed at the Metsahovi Radio Research Station (Finland). We also have an on-going TOO program at the VLBA to carry out polarimetric VLBI follow-up observations of a flaring source. This will provide us direct images of the source in milliarcsecond scale at six different frequencies (5–86 GHz) together with polarization information.

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