# The giant X-ray flares of Mrk 421 in spring-summer 2006

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**Abstract**

In spring/summer 2006 the BL Lac object Mrk 421 reached its largest ever recorded flux in the X-rays, up to about one tenth of Crab in the 2.0-10.0 keV band, and showed a synchrotron SED peak at approximately 10 keV. We present results of a spectral analysis of three observations performed by the *UVOT* , the *XRT* and the *BAT* telescopes on board the *SWIFT* satellite. According to the widely accepted SSC scenario, the expected flux in the GLAST LAT instrument, for such a bright X-ray state, should result in a counting statistics sufficient for a determination of the gamma-ray spectral shape.

## 1 Introduction

The HBL object Mrk 421 is one of the nearest BL Lac objects at $z$=0.031. It was the first extragalactic source to be detected at TeV energies (Punch et al 1992). In spring/summer 2006 Mrk 421 reached its largest ever recorded flux in the X-rays, up to about one tenth of Crab in the 2.0-10.0 keV band, and showed a synchrotron SED peak at approximately 10 keV. We present preliminary results in the UV/X-ray band, concerning three *SWIFT* pointings performed between April and July 2006, when the source became so bright that the high energy experiment *BAT* pointed it automatically. The log of UV/X-ray observations is reported in Table 1.

## 2 The X-ray spectrum of Mrk 421.

### 2.1 *UVOT+BAT+XRT* data spectral analysis

The X-ray spectra of this object shows strong evidence for intrinsic spectral curvature that can be described very well by a log-parabolic law (LP )(e.g. Massaro et al. 2004). We performed spectral analysis using the standard XSPEC v. 11.3.2t software package. The $N_{\rm H}$ absorbing column density was fixed to the Galactic value of 1.61 $10^{20}$cm$^{-2}$ and for the photon flux we used a log-parabolic law (LP):

$$F(E) = K\ E^{-(a+bLog(E))} \qquad (1)$$

where $a$ is the spectral slope (given by the log-derivative) at 1 keV and $b$ measures the spectral curvature. An equivalent functional relationship, useful to obtain independent estimates of $b$, of the peak energy $E_p$, and of the SED peak height $S_p$, is (LPS):

$$S(E) = S_p 10^{-b\ [Log(E/E_p)]^2} \qquad (2)$$

where $S_p = E_p^2 F(E_p)$.

The estimate of the curvature parameter $b$ is sensitive to changes of the source state during a single pointing (Tramacere et al. 2007a) and it results that time averaged spectra may have curvatures smaller than those obtained from time resolved analysis. To avoid such a bias, we split each pointing in data sets (labels a,b,c in Tab. 1) with time intervals spanning from $5 \cdot 10^3$ to $10^4$ s.
First we fitted only *XRT* data, and then fitted simultaneously *XRT* and *BAT* data (X+B label in Tab. 1). Temporal overlapping among *XRT* and *BAT* exposures occurs only for the 23 06 2006 observation, whereas the other two pointings exposures have a lag of about an hour. In order to obtain the intercalibration factor among *XRT* and *BAT* we fitted simultaneously *XRT* and *BAT* data for the Crab nebula. The value obtained was 0.71 $\pm$ 0.03, consistent with the value of 0.75 $\pm$ 0.02 given by Cusumano G. (private communication).

### 2.2 UV/X-ray spectral behaviour

During the *SWIFT* pointings, the source was always very bright, and the observed fluxes represent the historical maximum for this object. The highest previous state was recorded by *BeppoSAX* observations in May 2000 (Massaro et al. 2004), when it reached a $S_p$ of about 0.6 $10^{-9}$erg cm$^{-2}$ s$^{-1}$, peaking at about 5 keV. In the *SWIFT* observations of 23 June and 15 July 2006, the source has more than doubled this value of $S_p$; the same happens for the $E_p$ value recorded on 23 06 2006 (see Tab.1, label X+B).
The values of $S_p$ and $E_p$ follow the long trend correlation presented by Tramacere et al. (2007a) (see Fig. 2, left panel), confirming that when the source is brighter it systematically peaks at higher energies, even if the brightest state not always match the highest peak energies. This happens on the 15 07 2006 observation, when the source has reached its brightest state with a $E_p$ value lower than the one reached on 23 06 2006 .
Also the $E_p$ and $b$ values follows the trend presented by Tramacere et al. (2007a) (see Fig. 2, right panel), with the highest peak energy reached when the curvature is lower. In this case, as for the $S_p$-$E_p$ correlation, the observation of 15 07 2006 maximally deviates from the long trend of the source.

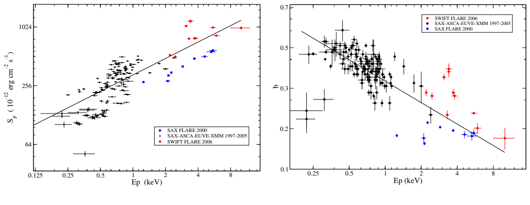


**Figure** 1: Left: The scatter plot of the $E_p$ and $S_p$. Right: The scatter plot of $E_p$ and $b$.

The UV data are not compatible with the extrapolation of X-ray best fit model to the *UVOT* spectral window, even using a LP distribution that turns into a power-law at low energies. Only for the case of the low state of the 31 03 2005, the UV data may be described by the X-ray model changing the curvature parameter, but with a variation of 5 $\sigma$ with respect to the statistical error. This behaviour and its physical interpretation requires a deeper analysis that will be addressed in a next forthcoming paper (Tramacere et al. 2007b).

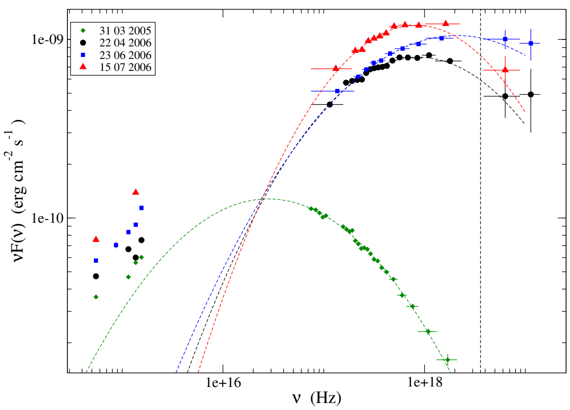


**Figure** 2: The UV/X-ray SED of Mrk 421 observed by *SWIFT* during spring-summer 2006 compared with the previous low state observed by *SWIFT* on 31 03 2005 (green diamonds). The vertical dashed line defines the beginning of the *BAT* spectral window. *BAT* and *XRT* data were fitted simultaneously using as intercalibration constant the value of 0.75.

| Date | $a$ | $b$ | $S_p$ $10^{-9}$erg cm$^{-2}$ s$^{-1}$ | $E_p$ keV | $\chi^2_r$/dof | Flux(2-10 keV) $10^{-9}$erg cm$^{-2}$ s$^{-1}$ |
|---|---|---|---|---|---|---|
| 22-04 a | 1.67(0.01) | 0.30(0.01) | 0.784(0.005) | 3.7(0.1) | 1.12(307) | 1.22 |
| 22-04 b | 1.770(0.007) | 0.29(0.01) | 0.507(0.002) | 2.46(0.07) | 1.29(290) | 0.76 |
| 22-04 c | 1.792(0.007) | 0.30(0.01) | 0.528(0.002) | 2.20(0.05) | 1.08(300) | 0.77 |
| 22-04 X+B | 1.66(0.01) | 0.29(0.01) | 0.784(0.005) | 3.8(0.2) | 1.05(365) | 1.22 |
| 23-06 a | 1.681(0.007) | 0.21(0.01) | 0.837(0.008) | 5.9(0.4) | 1.23(371) | 1.31 |
| 23-06 b | 1.638(0.006) | 0.244(0.001) | 1.011(0.006) | 5.5(0.3) | 1.10(438) | 1.58 |
| 23-06 c | 1.752(0.007) | 0.24(0.01) | 0.778(0.003) | 3.3(0.1) | 1.04(351) | 1.21 |
| 23-06 X+B | 1.62(0.01) | 0.19(0.02) | 1.02(0.03) | 10(2) | 1.14(220) | 1.52 |
| 15-07 a | 1.60 (0.01) | 0.38(0.02) | 1.18(0.01) | 3.4(0.2) | 1.04(207) | 1.81 |
| 15-07 b | 1.65 (0.01) | 0.35(0.01) | 1.05(0.05) | 3.1(0.1) | 1.16(286) | 1.60 |
| 15-07 X+B | 1.60(0.01) | 0.37(0.02) | 1.17(0.01) | 3.4(0.1) | 1.16(295) | 1.81 |

**Table** 1: Spectral parameters and fluxes of the log-parabolic model for the *XRT* and *XRT+BAT* (X+B) observations of Mrk 421. The letters a,b,c show the segmentation of the *SWIFT* observation in shorter time intervals.

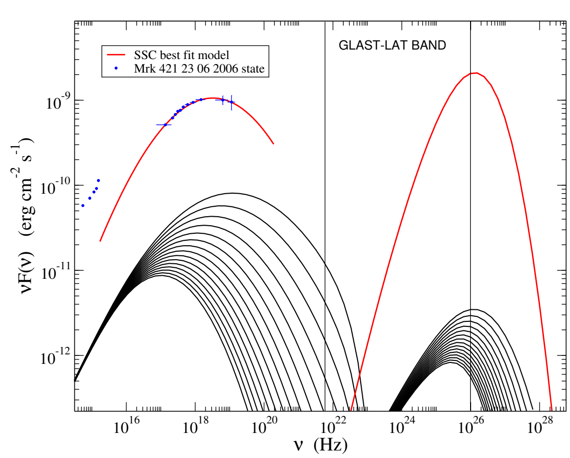


**Figure** 3: Expected SSC SED emitted by log-parabolic electron energy distribution, with resulting synchrotron curvature in the range 0.1 - 0.4 (black lines) . The vertical lines define the GLAST-LAT spectral window. The red lines correspond to the SSC best fit model for the 23 06 2006 state. The peak energy of the IC component falls at the high energy edge of the LAT range and the expected fluxes at GeV energies are in small excess with respect to the X-ray ones. During a bright flare, like the one presented in this poster, the LAT telescope may obtain accurate spectra to be compared with those coming from TeV telescopes and useful for the EBL constraining.

## 3 Conclusions

During the *SWIFT* pointings the source fluxes reached the historical maximum for this object. These data confirm that the X-ray spectrum of Mrk 421 is actually curved with a LP shape. The values of $E_p$, $S_p$ and $b$ obtained from spectral analysis are consistent with the long period trends presented by Tramacere et al. (2007a). The relevance of this analysis consists in presenting for the first time simultaneous UV to hard X-rays data, that offer the opportunity to test for multicomponent emission in the sub-parsec scale of the HBL jet. From the GLAST point of view, according to the widely accepted SSC scenario, such a bright X-ray flare may result in a counting statistics at MeV/GeV energies sufficient for an accurate determination of the gamma-ray spectral shape. Massaro et al. (2006) have shown that in the case of LP curved synchrotron spectra, in the SSC framework, is expected an intrinsic curvature in the inverse Compton component too (see Fig. 3). The main consequence is that lower ELB densities are required to explain the observed TeV spectra. In this case, the study of the GeV/TeV shape of the SED offers the possibility of better constraining the EBL models and the intrinsic source spectral shape.

## References

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