APEX sub-mm monitoring of gamma-ray blazars

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So far, no systematic long-term blazar monitoring programs and detailed variability studies exist at sub-mm wavelengths. Here, we present a new sub-mm blazar monitoring program using the APEX 12-m telescope. A sample of about 40 γ-ray blazars has been monitored since 2007/2008 with the LABOCA bolometer camera at 345 GHz. First light curves, preliminary variability results and a first comparison with the longer cm/mm bands (F-GAMMA program) are presented, demonstrating the extreme variability characteristics of blazars at such short wavelengths.

1. INTRODUCTION

“Blazars” comprise a sub-class of radio-loud AGN showing a broad-band, double-humped spectral energy distribution (SED). They differ from all other types of AGN chiefly because of their extreme phenomenological characteristics such as the extreme and broad-band flux density and polarisation variability, high degree of polarisation, fast superluminal motion and almost uniquely broad-band emission characteristics including a bright and highly variable component of γ-ray emission [11].

Despite many efforts over the last decades, several key questions still remain unanswered in fully understanding the blazar phenomenon. For instance:

- which are the dominant, broad-band emission processes involved (synchrotron self-Compton/inverse-Compton)?
- which mechanisms drive their often violent, broad-band variability? (e.g. relativistic shocks, colliding plasma shells or changing geometry due to helical/precessing jets; see e.g. [3] [4] [5])
- what is the typical duty cycle of their activity?
- does the γ-ray emission originate from the base/foot-point of the jet or further out in the same shocked regions as the radio cm/mm/sub-mm band emission?

Observations that can ascertain whether a relationship exists between the γ-ray and radio emission will be important for the effort to answer these questions. Consequently, variability studies furnish important clues about the size, structure, physics and dynamics of the emitting region making AGN/blazar monitoring programs of uttermost importance in providing the necessary constraints for understanding the origin of energy production. Here, observations at short-mm/sub-mm bands are crucial, as they probe the innermost nuclear region and provide the important direct link between the longer wavelength radio bands and the more energetic IR/optical to γ-ray regimes.

Until now, there has been no systematic long-term blazar monitoring program and detailed variability study at sub-mm bands. Consequently, little is known about the variability characteristics of AGN at sub-mm bands. Important parameters which need to be determined are e.g. the variability amplitude and time scales and how the variability is related to other bands, e.g. correlation strengths and time lags. The knowledge of the variability behavior at sub-mm bands will thus better constrain the modeling of the variability and spectral evolution in the synchrotron branch of blazar SEDs.

In this framework, we initiated a blazar monitoring program using the APEX sub-mm telescope. The
aim of this effort, which is part of the F-GAMMA program [2, 3], is to perform the first long-term systematic study of blazar variability characteristics at sub-mm wavelengths. Here we present first light curves and some preliminary results on the relative variability for our sample of sources. Details including the full first years of data and analysis will be presented in Fuhrmann et al. (in prep.).

2. APEX observations with LABOCA

The APEX 12 m sub-mm telescope is located at 5100 m altitude on Llano Chajnantor, Chile. The observations are obtained with the LABOCA camera [10], which consists of 295 channels arranged in 9 concentric hexagons. LABOCA has a total field of view of 11.4 arcmin and allows observations in the 870 micrometer (345 GHz) atmospheric window (bandwidth: 60 GHz).

The quasi-regular observations of our program started in 2008 and are performed during several dedicated MPI, Swedish and ESO APEX LABOCA time-blocks per year. In addition, we are aiming at denser, more regular sampling through the regular and frequent pointing observations performed at APEX since 2007 using our sources in the framework of other projects and APEX technical time. Observations within the F-GAMMA program are typically performed in spiral observing mode with a raster of four spirals of 20 or 35 seconds of integration each, depending on the source brightness at 345 GHz. At each run, skydip measurements for opacity correction and frequent calibrator measurements are performed. The number of observations per source range from 2 to 177.

3. The Sample

At APEX, a sub-sample of 25 prominent, famous, frequently active and usually strong \(\gamma\)-ray blazars from the F-GAMMA sample is observed together with a sample of 14 interesting southern hemisphere \(\gamma\)-ray AGN. The complete list of APEX monitored sources is given in Table 1.

4. FIRST RESULTS: Sub-mm variability properties of gamma-ray AGN

Some examples of source light curves are shown in Figure 1. All the monitored sources, except one, show excess variability (over that expected from measurement noise). The exception is Mkn 501, which we exclude from the following variability analysis. For all the remaining 38 sources the \(\chi^2\)-analysis gives a probability of less than 0.1% that the observed variability is due to measurement noise. In a preliminary variability analysis, without taking the time sampling into account, the modulation index was calculated as \(m = 100 \times \text{rms/mean}\). For most sources the modulation index is in the range 10 - 50 %, but there is a tail in the distribution which extends up to \(m = 90\%\) as shown in Figure 2. The mean and

| 2FGL Name | Source Name  | Source Class |
|-----------|--------------|--------------|
| J0210.7-5102 | PKS 0208-512 | Blazar       |
| J0217.9+0143 | PKS 0215+015 | FSRQ         |
| J0237.8+2846 | 4C +28.07   | FSRQ         |
| J0238.7+1637 | PKS 0235+164 | FSRQ         |
| J0303.5-6209 | PKS 0302-623 | FSRQ         |
| J0339.4-0144 | PKS 0336-01 | FSRQ         |
| J0403.9-3604 | PKS 0402-362 | FSRQ         |
| J0423.2-0120 | PKS 0420-01 | FSRQ         |
| J0530.8+1333 | PKS 0528+134 | FSRQ         |
| J0538.8-4405 | PKS 0537-441 | BLLac        |
| J0854.8+2005 | OJ 287      | BLLac        |
| J0909.1+0121 | J0909+0121  | FSRQ         |
| J1058.4+0133 | 4C +01.28   | BLLac        |
| J1057.0-8004 | PKS 1057-79 | BLLac        |
| J1159.5+2914 | J1159+292   | FSRQ         |
| J1211.4+2814 | W Comae     | BLLac        |
| J1229.1+0202 | 3C 273      | FSRQ         |
| J1256.1-0547 | 3C 279      | FSRQ         |
| J1315.9-3339 | PKS 1313-333 | FSRQ         |
| J1325.6-4300 | Cen A       | RG           |
| J1428.0-4206 | PKS 1424-418 | FSRQ         |
| J1457.4-3540 | PKS 1454-354 | FSRQ         |
| J1504.3+1029 | PKS 1502+106 | FSRQ         |
| J1512.8-0906 | PKS 1510-08 | FSRQ         |
| J1626.1-2948 | PKS 1622-29 | FSRQ         |
| J1635.2+3810 | 4C +38.41   | FSRQ         |
| J1642.9+3949 | 3C 345      | FSRQ         |
| J1653.9+3945 | Mkn 501     | BLLac        |
| J1733.1-1307 | PKS 1730-13 | FSRQ         |
| J1751.5+0938 | PKS 1749+096 | BLLac       |
| J1958.2-3848 | PKS 1954-388 | FSRQ         |
| J2056.2-4715 | PKS 2052-47 | FSRQ         |
| J2157.9-1501 | PKS 2155-152 | FSRQ         |
| J2158.8-3013 | PKS 2155-304 | BLLac       |
| J2202.8+4216 | BL Lac      | BLLac        |
| J2225.6-0454 | 3C 446      | FSRQ         |
| J2232.4+1143 | CTA 102     | FSRQ         |
| J2253.9+1609 | 3C 454.3    | FSRQ         |
| J2258.0-2759 | PKS 2255-282 | FSRQ         |
Figure 1: Examples of long-term light curves for several blazars monitored at sub-mm wavelengths with LABOCA on the APEX telescope. All sources show strong variability in this band.
median modulation indexes are 37 and 31% respectively. A number of sources show variations by a factor of 10 or more between minimum and maximum flux. This is significantly larger than at the longer cm- and also short-mm bands. The variability is in general also faster and more directly correlated with the high energy emission\[7\]. This is most likely an effect of opacity/synchrotron self-absorption increasing towards the longer radio wavelengths and indicates that the sub-mm emission regions are more co-spatial with the optical/γ-ray ones.

In an analysis of the spectral evolution observed by the cm/mm F-GAMMA program \[2\], it has been shown that the radio flares and multi-frequency variability can be well described by only two physical processes: (i) achromatic variability (possibly related to helical or precessing jets) or (ii) evolving synchrotron flares or shocks inside the relativistic jets (as described in e.g. \[8\]). In such synchrotron scenario of evolving AGN outbursts, the flux-density variability first appears at higher frequencies (IR/optical/UV/X-ray) and then propagates through the spectrum towards longer wavelengths. The formation and evolution of shocks is expected to start at high synchrotron frequencies during their growth stage where the synchrotron self-absorption peak moves to lower frequencies while the peak flux and variability amplitude is increasing (mm/sub-mm bands) up to the plateau stage, followed by a subsequent decay stage (cm-bands). Here, the variability in the sub-mm band is expected to be much more pronounced and faster than at longer cm-radio bands\[12\]. This was confirmed to 1 mm wavelength by the earlier observations (Fuhrmann et al. in prep.): the mean strength of variability (modulation index) steadily increases from 9.5% at 110 mm to 30% at 1 mm. Our new LABOCA observations imply that this trend continues into the sub-mm band. According to the three different regimes of shock evolution (growth, plateau, decay), such continued increase (or flattening) would then indicate that, on average, flares reach their plateau/decay phase at sub-mm bands well before they do at cm bands. A more extensive analysis and discussion of the variability properties will be presented in a forthcoming paper.

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