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Monitoring the radio spectra of selected blazars in the Fermi-GST era

The Effelsberg 100-m telescope covering the cm band

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Abstract. The analysis of the SED variability at frequencies from radio to TeV is a powerful tool in the investigation of the dynamics, the physics and the structure evolution occurring at the most exotic flavor of active galaxies, the blazars. In particular, the presence of *Fermi-GST* is providing a unique opportunity for such studies delivering γ-ray data of unprecedented quality. Here we introduce a monitoring program that runs at the Effelsberg 100-m telescope since January 2007, pivoting a broad multi-frequency collaboration of facilities that cover the band from radio to infrared. 61 selected blazars are observed monthly between 2.64 to 43 GHz. The calibration accuracy is less than a few percent as it is demonstrated with some preliminary examples.

Key words. Galaxies: active – Galaxies: nuclei – Radio continuum: galaxies – BL Lacertae objects: general

1. Introduction

Being among the most dramatic manifestations of the activity induced in the nuclei of active galaxies, blazars comprise a unique probe to the exotic physics at play in such systems. Their phenomenology is dominated by extreme characteristics; among them: (a) high degree of linear polarization (b) intense variability – both in total power and polarization – at all wavebands (c) apparent motions of features in their radio structure which are often highly superluminal and (d) brightness temperatures exceeding the Compton limit (see e.g. Urry 1999). To much extend, this violent behavior is attributed to relativistic jets with their axes oriented very close ($\leq 20 - 30°$) to the line-of-sight (see e.g. Urry & Padovani 1995). Their Spectral Energy Distribution (SED) is characterized by the presence of two peaks. The lower energy one, spreading from radio to far ultraviolet and soft x-ray wavelengths, is believed to be due to relativistic electrons emitting via synchrotron mechanism. The high energy part of the SED, reaching up to TeV energies is believed to be produced by synchrotron self-Compton and/or external Compton scattering.

Despite the overall general understanding of the blazar phenomenon, many details remain unclear and subject to models attempting their clarification. For instance, several ideas have been put forth to explain

Send offprint requests to: E. Angelakis the origin of their variability. Some of them, the shock-in-jets model (e.g. Marscher & Gear 1985; Aller et al. 1985; Marscher 1996) or the relativistic plasma shells (e.g. Spada et al. 2001; Guetta et al. 2004). Alternatively, it has been suggested that light-house effect could be causing variability in cases of rotating helical jets or the helical trajectories of plasma elements (e.g. Begelman et al. 1980; Camenzind & Krockenberger 1992).

A powerful tool in the investigation of the details occurring in blazars and the understanding of the dynamics, the physics and the structure of the radiating regions is the analysis of the variability of their SEDs at frequency ranges as broad as possible (from radio to TeV). Such an approach can shed light on linear scales unaccessible even to interferometric techniques and most importantly discriminate between different variability scenarios. Particularly, the presence of *Fermi-GST* is providing a unique opportunity for these studies providing the γ-ray data of unprecedented quality.

In order to fully benefit from the newly flying *Fermi-GST* telescope a broad collaboration of facilities that aim at understanding the blazar phenomenon via the broad-band SED variability monitoring has been initiated by Fuhrmann et al. (2007). A sample of 61 selected sources are monitored monthly and in tight coordination with other facilities covering the cm, mm, optical and infrared bands (Fuhrmann et al. in prep.). Here we present a very brief introduction of the activities in the centimetric band with the 100-m Effelsberg telescope and show some preliminary examples.

2. The 100-m telescope monitoring program

Observationally, the goal of the currently discussed project is the monthly radio spectrum monitoring for a sample of the 61 sources shown in table 1 with the Effelsberg 100-m telescope. The broad collaboration involves also mainly the 30-m IRAM mm and the 40-m Owens Valley telescope (Fuhrmann et al. 2007). The former is covering the band between roughly 86 up to 270 GHz whereas the latter is focusing on 15 GHz alone in order to monitor a few hundred sources per day and acquire information about their variability index. The coherency time between Effelsberg and IRAM telescopes is of order of one to maximum a few days. The monitoring program at Effelsberg runs continuously since January 2007 providing a remarkable flow of data.

Table 1. The monitored sources.

Target sources		
0003−066	0814+425	1611+343
0059+581	0827+243	1633+382
0215+015	0836+710	1641+399
0219+428	0851+202	1652+398
0234+285	0954+658	1730−130
0235+164	1038+064	1803+784
0238−084	1101+384	1807+698
0300+470	1127−145	1823+568
0316+413	1133+704	1957+40
0317+185	1156+295	1959+650
0333+321	1128+592	2155−152
0336−019	1219+285	2155−304
0355+508	1222+216	2200+420
0415+379	1226+023	2201+315
0420−014	1228+126	2223−052
0430+052	1253−055	2230+114
0502+675	1308+326	2251+158
0528+134	1406−076	2344+514
0716+714	1426+428	2345−16
0735+178	1510−089	
0748+126	1544+820	

3. The sample

The sources in table 1 have been selected from the “high-priority blazars” list of the *Fermi-GST* AGN team. There is a remarkable overlap with other studies such as 2 cm-VLBA survey/MOJAVE program (Kellermann et al. 1998; Zensus et al. 2002; Kellermann et al. 2004), the Boston 43 GHz VLBI survey (Jorstad et al. 2001), the IRAM 30-m telescope polarization monitoring program, the OVRO monitoring program at 15 GHz and other multi-frequency campaigns.

4. Observations and data reduction

For our monitoring program the receivers at 2.64, 4.85, 8.35, 10.45, 14.60, 23.00, 42.00 and 32.00 GHz have been employed. Almost all of them deliver polarization information which provides another useful tool in the exploration of blazar physics. They are all heterodyne and they are installed in the secondary focus of the 100-m telescope.

The measurements are conducted with the newly installed adaptive secondary reflector characterized by low surface RMS that induces higher sensitivity (up to 50% increase at 43 GHz). The so-called "cross-scan" observing technique has been applied. The advantage of this method is mainly the fact that it allows the direct detection of cases of confusion as well as the correction for pointing offset errors. The individual spectra are measured quasi-simultaneously within ≈ 40 min to guarantee that they are free of source variability of time-scales longer than that.

Considerable effort is put in applying some necessary post-observational corrections to the raw data. Namely, *pointing offset correction*, *gain correction*, *opacity correction* and *sensitivity correction*. A more detailed description can be found in Angelakis et al. (2008). The sensitivity correction is done with reference to standard calibrators (e.g. table 2). There, the average flux densities are given along with the modulation index, *mi*, over a number of measurements ($mi = 100 \cdot \frac{rms}{<S>}$). The modulation index serves as a measure of the source variability. Hence, this table is a demonstration of the system repeatability and the achievable precision on the assumption that the calibrators are intrinsically non-variable.

Table 2. The average flux densities for two of our main calibrators after preliminary analysis along with the modulation index *mi*. This gives a pragmatic picture of the system repeatability. For frequencies above 10.45 GHz the NGC 7027 reported flux density is in average smaller than those from the literature by 5%. That is due to the extension of its brightness distribution relative to the FWHM of the telescope beam at those frequencies.

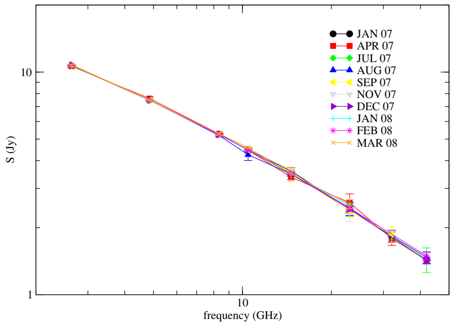
ν	3C286		NGC 7027[†]	
	S	mi	S	mi
(GHz)	(Jy)	(%)	(Jy)	(%)
2.64	10.7	0.7	3.7	1.1
4.85	7.5	0.6	5.5	0.2
8.35	5.2	0.7	5.9	0.6
10.45	4.5	1.8	5.9	2.3
14.60	3.5	1.9	5.8	1.5
23.05	2.5	2.8	5.3	2.6
32.00	1.9	2.8	5.2	2.3
43.00	1.4	2.1	5.0	5.0

5. Spectra

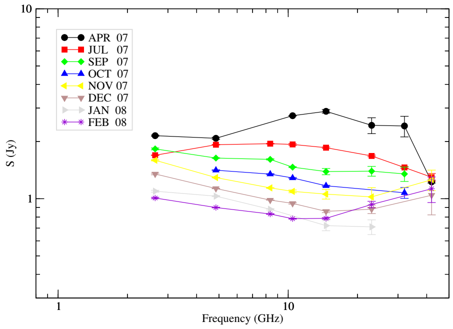
In figure 1 are collected two preliminary examples. The comparison of these spectra with that of 3C286 in figure 1(a) illustrates the significance of the observed variability. Remarkably, intense variability appears already in the cm band. Its correlation with that in other bands or possible changes in the structure of interferometric imaging is under examination. It is important to mention that the admittedly larger uncertainties at the higher frequencies is solely due to atmospheric variations.

6. Discussion

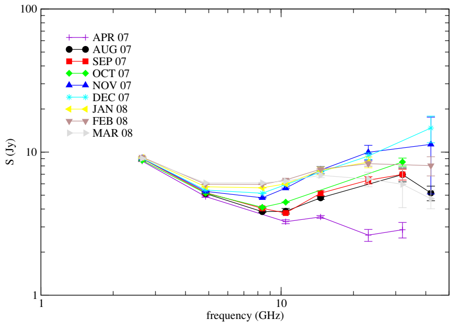
Provided that the calibrators are presumably not intrinsically variable, figure 1(a) serves as an excellent means of estimating the system repeatability. In table 2 the calibration precision is of the order of a few percent. Factors that induce such variations are primarily tropospheric variations, opacity effects, confusion, system instabilities etc. At higher frequencies (23 GHz and above), the atmospheric factor becomes particularly important. The plots in figure 1 show how intensive and fast the variability of the spectrum may be. This very fact urges for dense frequency coverage especially of the millimeter regime from where the evolution of a flaring event in the radio band is expected to start. Nevertheless, the evolution of the spectrum over time is among the first-priority studies. That justifies the necessity of tight coordination of the different participating



(a) 3C286



(b) 0235+164



(c) 3C111

Fig. 1. Examples of sources that exhibit intense spectrum variability in the cm band. The top panel shows the spectrum variability of one of the main calibrators, namely 3C286, for comparison.

stations as has been managed so far. It is noteworthy the activity taking place in the centimeter band alone. Whether this activity is correlated with that at other bands and especially that at high energies, or with changes in the structure is examples of questions to be addressed at first. What is the behavior of the polarization when such an event occurs is also among the most important issues to be investigated.

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