Perseus in Sicily: From Black Hole to Cluster Outskirts
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Update on the Multi-Frequency Monitoring of Blazars with Medicina and Noto

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Abstract. The Medicina and Noto radiotelescopes have been employed for over 14 years to monitor the flux density variations of a vast sample of blazars at different radio frequencies. Radio data are essential components of blazar spectral energy distribution (SED, spanning from radio waves to gamma rays), whose trend with luminosity and shape changes provide decisive information on the physics of extra-galactic jets and, eventually, on the mechanism extracting energy from the central black hole in radio-loud AGN. Observations presently carried out at 5, 8 and 24 GHz have taken advantage of the continually evolving control system installed at the antennas. A new, batch-wise analysis tool was also produced, in order to easily handle and reduce the datasets acquired in monthly sessions. We here describe the latest developments and achievements.

Keywords. radio continuum: galaxies, galaxies: active

1. Overview

The name Blazars identifies a family of radio-loud Active Galactic Nuclei (AGN) showing a rather complex phenomenology: extreme variability at all wavelengths, polarization, strong gamma-ray emission and brightness temperatures exceeding the Compton limit. The large amount of work done in the last decade has led to a rather general consensus on the global mechanism responsible for the emission: a rotating black hole surrounded by a massive accretion disk with an intense relativistic plasma jet closely aligned to the line of sight. Relativistic electrons produce the soft photons through synchrotron emission, while hard photons are likely produced by inverse Compton scattering. This overall scenario, however, still presents a large number of poorly understood details which, in turn, lead to a wide variety of models and call for long term and multi-wavelength campaigns capable of providing the necessary observational constraints.

Variability measurements provide key information on the AGN structure, down to linear scales or flux density levels not accessible even with interferometric imaging. The mechanisms for variability are still not well understood. Possibilities discussed in the literature include shocks in jets, changes in the direction of forward beaming due, e.g., to helical trajectories of plasma, to a precessing binary black-hole system, or to a rotation of a helical jet, introducing flares due to the lighthouse effect and variability due to colliding relativistic plasma shells. Thus, variability furnishes important clues into size, structure, physics and dynamics of the radiating source region.

2. Our project

Since blazars are highly variable it is important to take simultaneous broad-band radio spectra. We proposed such simultaneous observations back in 2004, and in 2007 our project was approved as a key project at INAFs Institute of Radioastronomy. We have hence performed monthly multi-frequency (5, 8, 22/24 and 43 GHz) observations on a vast sample of blazars, which includes some of the brightest and most studied blazars detected in gamma rays by Fermi and AGILE. Details are provided on the project website (Bach *et al.*). Data from this project have produced about 40 refereed publications, mostly resulting from the participation to multi-wavelength campaigns by the Whole Earth Blazar Telescope (WEBT).

Since December 2011, all the sessions taking place in Medicina have been carried out using a new control software, developed to fully exploit the single-dish potential of the Italian radio telescopes. We achieve a good characterization of the source flux density with a few cross-scans on each target source. On the brightest targets, each scan provides an estimate of the flux density to within 10%, while for the faintest sources stacking of the individual scans yields a good signal-to-noise detection. Since 2017, also the Noto sessions are carried out using such system. As the 43 GHz receiver is now under maintenance, the only observations performed in Noto are the 5 GHz acquisitions. This constitutes a precious contribution, as such frequency band is highly polluted by RFI in Medicina.

3. Dealing with an evolving dataset: introducing CAP (Cross-scan Analysis Pipeline)

During the 12+ years of acquisitions, a large dataset was formed, evolving during the development of the overall control system. To handle it, we produced a new, comprehensive reduction pipeline able to perform a batch (re-)analysis on the data, if needed, of any epoch. Such tool has very recently been completed and made available on a GitHub repository, which also provides a basic wiki.

CAP is devoted to the integration, analysis and calibration of the total power cross-scans produced by the Italian radio telescopes, including the soon-to-be-operative Sardinia Radio Telescope. It is a set of IDL-programming-language (Exelis) tools, developed to process cross-scans (FITS files) acquired on point-like targets. It allows the users to perform the analysis through the following phases:

- rearrange the date-based datasets, separating acquisition in frequency-based folders;
- visually inspect and flag the data [optional];
- estimate the atmospheric opacity via the observed “skydips” [optional];
- retrieve the proper calibration factors from cross-scans acquired on flux density calibrators (considering Perley & Butler 2013);
- integrate scans on the target sources and obtain flux density measurements, taking into account both the atmospheric opacity (if provided) and the antenna gain curve, also correcting for pointing offset;
- reprocess the measurement list and average measurements recorded in different takes [optional].

The final output products comprise (but are not limited to): tables listing the measurements obtained on calibrators and the raw-counts-to-Jy conversion factors hence derived, tables with the raw amplitudes and calibrated flux densities measured on the targets, plots showing the single acquisitions and the integrated scans, with overlaid fitted data - both for flux density calibrators and targets. Two examples of the achieved results are provided in Fig. 1.

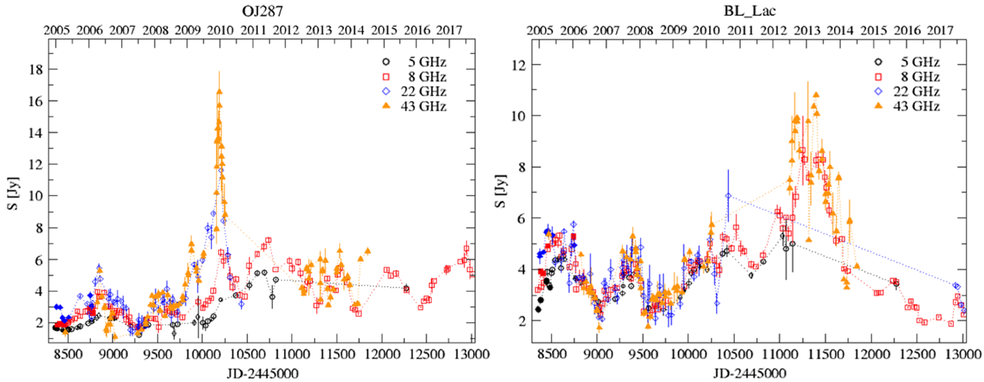

Figure 1. Radio flux density measurements of two of the monitored sources. The temporary unavailability of some of the receivers, the occurrence of stops due to HW and SW upgrades and the increasing incidence of RFI in low-frequency bands have affected the timeline. However, the visible lack of 22-GHz measurements since 2011 is mostly due to the analysis still being underway.

References

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