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# Blazar monitoring with LOFAR

**Sara Turriziani[1], Martin Hardcastle[2], James Miller-Jones[3], Jess Broderick[4] and Sera Markoff[5]**
**(on behalf of the Transients Key Science Project)**

[1]Dip. Fisica, Università degli studi di Roma "Tor Vergata"
via della Ricerca Scientifica 1, 00133 Roma, Italy
email: sara.turriziani@roma2.infn.it

[2] School of Physics, Astronomy and Mathematics, University of Hertfordshire
College Lane, Hatfield AL10 9AB, UK email: m.j.hardcastle@herts.ac.uk

[3] International Centre for Radio Astronomy Research, Curtin University
GPO Box U1987, Perth, WA 6845, Australia
email: james.miller-jones@curtin.edu.au

[4] Astrophysics, Department of Physics, Oxford University
Keble Road, Oxford OX1 3RH
email: Jess.Broderick@astro.ox.ac.uk

[5] Astronomical Institute "Anton Pannekoek", University of Amsterdam
Science Park 904, 1098XH, Amsterdam, the Netherlands
email: s.b.markoff@uva.nl

**Abstract.** We have been monitoring some well-known bright blazars with short LOFAR observations since February 2013 with fortnightly cadence using the full available bandwidth of the High Band Antennas (i.e., 48 MHz centred at 226 MHz). The sources were chosen to be bright at low frequencies and to exhibit strong GHz-frequency radio variability on timescales of weeks to years. None of the five objects selected have been monitored previously in the MHz band. Here we report some preliminary results on flux variability obtained so far with LOFAR. These observations are scientifically valuable in their own right and also act as a proof of principle for broader, higher-cadence monitoring of the extragalactic sky with LOFAR and possibly SKA.

**Keywords.** galaxies: active, galaxies: jets, radio continuum: galaxies, techniques: interferometric

## 1. Introduction

The LOw Frequency ARray (LOFAR, van Haarlem *et al.* (2013)) is a network of radio telescopes that is centered in the Netherlands, but with international stations distributed across Europe, located in Germany, Sweden, the UK and France. It started as a new and innovative effort to force a breakthrough in sensitivity for astronomical observations at radio-frequencies below 250 MHz. Thanks to its high sensitivity and superb angular resolution, it allows us to systematically image and monitor blazars at the lowest available frequencies (corresponding to the lowest-energy electrons accessible to us) for the first time. Time variability is in fact the most powerful key we have now to understand these puzzling sources, in particular regarding the measurement of the physical parameters of the emission region, which can in turn put unique constraints on emission models and also on the poorly-understood low energy end of the particle energy spectrum.

## 2. LOFAR blazar monitoring

Refractive interstellar scintillation (RISS), caused by scattering in the turbulent ISM of our Galaxy, is commonly invoked to explain the low frequency variability of quasars

**Table 1.** LOFAR Blazar Monitoring: the targets

| **Source** | R.A. | Dec | Estimated Flux[a] (Jy bm$^{-1}$) | LOFAR Flux[b,⋆] (Jy bm$^{-1}$) | Light curve[⋆] (any trend?) |
|---|---|---|---|---|---|
| AO 0235+164 | $02^h$ $38^m$ $38.930^s$ | $16^d$ 36' 59.275" | - | $\sim 0.8$ | no |
| S5 0716+714 | $07^h$ $21^m$ $53.448^s$ | $71^d$ 20' 36.363" | 1.6 | $\sim 1.9$ | no |
| Mrk 501 | $16^h$ $53^m$ $52.217^s$ | $39^d$ 45' 36.609" | 1.9 | $\sim 1.6$ | yes |
| BL Lac | $22^h$ $02^m$ $43.291^s$ | $42^d$ 16' 39.980" | 1.8 | $\sim 2.1$ | yes |
| 3C 454.3 | $22^h$ $53^m$ $57.748^s$ | $16^d$ 08' 53.561" | - | $\sim 9.5$ | yes |

*Notes:* [a] Estimated HBA fluxes are taken from the WENSS survey (Rengelink *et al.* 1997).
[b] The LOFAR flux at 225 MHz is the mean of the preliminary fluxes at this frequency from LOFAR Cycle 1 observations. [⋆] Caveat: Please keep in mind that LOFAR flux calibration is still preliminary and the quality of these measurements has not been assessed yet.

(Rickett *et al.* 1984), which, if intrinsic to the sources, would be in excess of $10^{18}$ K. It has been suggested that the variability at wavelengths longer than 6 cm is due to a combination of scintillation and intrinsic variability, with the former becoming increasingly dominant with increasing wavelength. Disentangling the two requires analysis of the frequency dependence of the variability, and can be aided by the identification of the annual cycles in the variations that would arise from scintillation. Monitoring a sample of blazars over a wide range of radio frequencies allows us to distinguish the effects of intrinsic variability from extrinsic effects such as interplanetary scintillation and to quantify the importance of the latter as a function of frequency. In conjunction with regular VLBI monitoring (e.g., the MOJAVE project, Lister *et al.* (2009)), this can improve our understanding of the nature of the extreme variability and therefore the structure and dynamics of the parsec-scale jets in blazars (e.g., Marscher *et al.* (2010)). To this end, we are carrying out the first ever metre-wavelength monitoring of a sample of five blazars on a fortnightly basis since February 2013, as part of the LOFAR Transients Key Science Project work (Fender *et al.* 2006).

Our targets (see Table 1) are selected to be representative of the blazar population, sampling sources with synchrotron peaks all the way from the infrared (e.g., AO 0235+164) to the ultraviolet or X-ray bands (e.g., Mrk 501). All are being monitored at cm/mm wavelengths, e.g. with the VLBA within the MOJAVE project and the OVRO 40-m telescope at 2 cm (Richards *et al.* 2011). Snapshot observations with the full available bandwidth of the High Band Antennas (i.e., 48 MHz centred at 226 MHz) give constraints on fluxes that are dominated by calibration uncertainties, and certainly good enough to track the observed order-of-magnitude variability seen at GHz frequencies. Moreover, the cadence (fortnightly) matches that of GHz monitoring.

So far, LOFAR light curves are revealing a quite smooth behaviour; however, some of them show trends on time-scales of months which we believe to be real and could only be detected with a long-term monitoring campaign such as ours. On-going monitoring will allow us to investigate it deeper.

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