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The LOFAR long baseline snapshot calibrator survey

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With a current maximum baseline of 1300 km, the International LOFAR array is capable of attaining an angular resolution of 0.4 arcsec at a frequency of 140 MHz, opening for the first time the possibility of true subarcsecond imaging at wavelengths longer than 1 m. We used the multi-beaming capability of LOFAR to conduct a fast and computationally inexpensive survey to inspect 630 sources in two hours to determine if they possess a sufficiently bright compact component to be usable as LOFAR delay calibrators. Here we summarize the characteristics of the survey, and its main results. In particular we have obtained the density of calibrators on the sky that are sufficiently bright to calibrate dispersive and non-dispersive delays for the International LOFAR.

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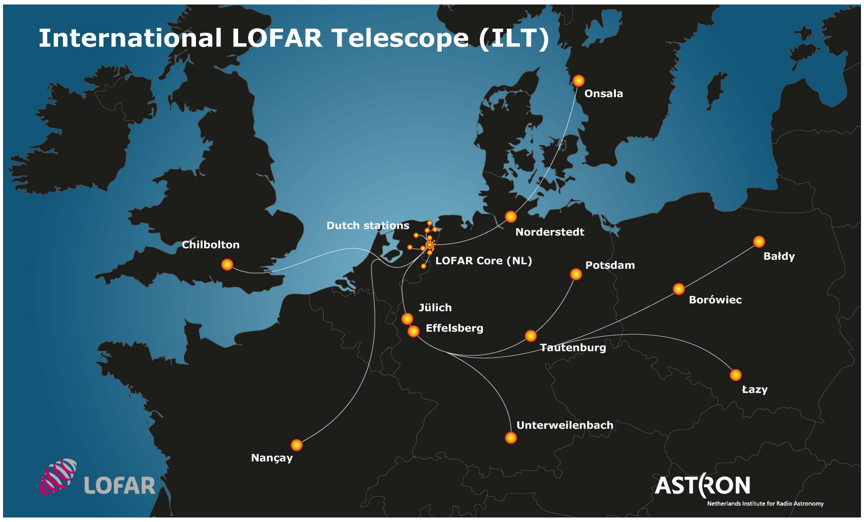

Figure 1: Locations of current and planned stations of LOFAR and the name of the international stations.

1. The LOFAR array

LOFAR is composed of 24 core stations and 13 remote stations in the Netherlands, and 8 (+4 planned) international stations [1]. In Figure 1 we show the distribution of the LOFAR stations in Europe. LOFAR covers the largely unexplored low-frequency range from 10–240 MHz, and offers a range of capabilities such as beam-forming, multiple simultaneous observations, or rapid repointing. LOFAR's new capabilities, techniques and modus operandi make it an important pathfinder for the Square Kilometre Array (SKA).

The early attempts of using international baselines of LOFAR are described by [2]. This includes the first ever long-baseline LOFAR images that were produced of 3C196 in the low band (30-80 MHz) with a resolution of about one arcsec. More recently, a high band (110–160 MHz) observation with the LOFAR long baselines was presented in [3], where subarcsecond images of M82 were presented.

2. Sample selection

We conducted a survey of 630 sources in two regions of the sky based on existing catalogs (VLSS, WENSS, NVSS). For field 1 (represented in Figure 2) we explored the brightest sources, and for field 2, not shown here, we explored relatively faint sources. We computed a discrete quality factor, q, for each source, assigning $q = 3$ to bright and compact sources (i.e. good primary calibrators), $q = 2$ to partially resolved sources, and $q = 1$ to resolved or faint sources. The quality factor q is based on how many international stations can be fringe fitted using a particular source to give a satisfactory station delay. The average density of good calibrators is 1.0 per square degree.

3. Spectral properties of good calibrators

We showed that a number of properties from lower angular resolution data are correlated with the likelihood of being a suitable calibrator. High flux density, a flat low-frequency spectrum, and

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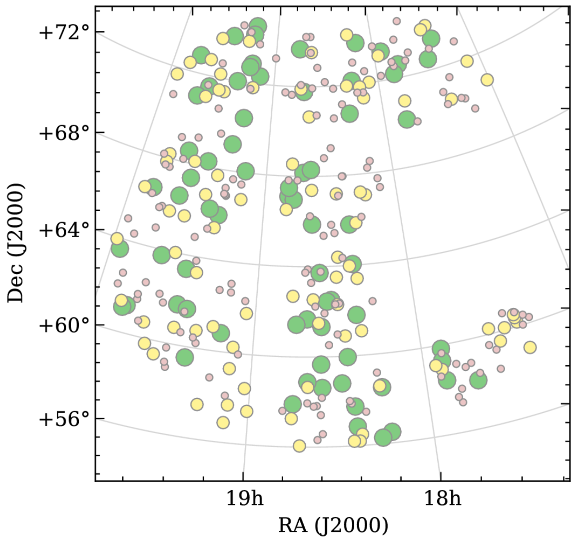

Figure 2: Sky distribution of the sources in observation 1, with markers indicating good primary calibrators, $q = 3$ (big green circles), potentially good primary calibrators, $q = 2$ (medium-size yellow circles), and sources that are resolved or faint or both, $q = 1$ (small red circles). The gap in right ascension 17–18$^{\mathrm{h}}$ and declination 60–68° is caused by the failure of two scans. Figure from [4].

compactness in the NVSS catalogue are all useful predictors of calibrator suitability. The spectral index at higher frequency, in contrast, is a poor predictor. Figure 3 shows the distribution of quality factor with low- and high-frequency spectral index. By selecting a source with spectral index > -0.6, the chance probability of the source having $q = 3$ is 51% if we use the low-frequency spectral index, and only 36% if we use the high-frequency spectral index. The right panel of Figure 3 shows the relative prevalence of a spectral turnover (where the low-frequency spectral index is flatter than the high-frequency spectral index) for the three quality bins. Good primary calibrator sources ($q = 3$) are more likely to have a spectral turnover.

4. Conclusions

1. With a survey speed of ∼30 targets in 5 minutes in "snapshot" survey mode, identifying the optimal calibrator for an International LOFAR observation can be cheaply performed before the main observation.

2. The density of suitable long-baseline calibrators at ∼140 MHz is around 1 per square degree – high enough that a suitable calibrator should be found virtually anywhere in the sky (excluding regions of high scattering such as the Galactic plane).

3. We have identified the key parameters from low-frequency catalogs to select potential suitable calibrators. High flux density, a flat low-frequency spectrum, and compactness in the NVSS catalogue are all useful predictors of calibrator suitability. The spectral index at higher frequency, in contrast, is a poor predictor.

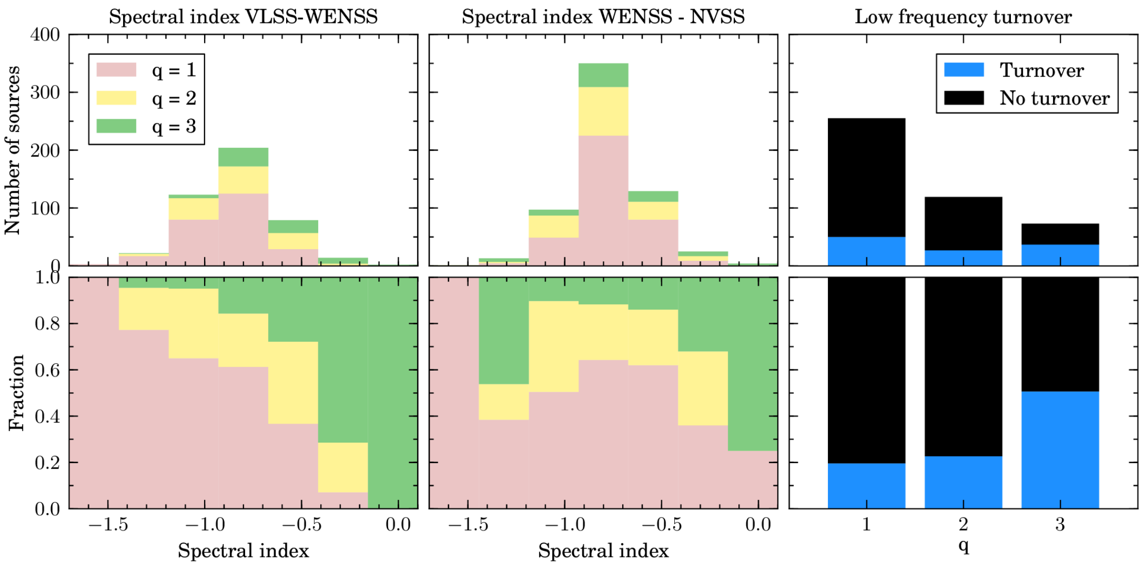

Figure 3: Source quality distribution as a function of spectral properties. The spectral index between 74 and 327 MHz and the presence of a turnover are good indicators of a source being a suitable calibrator ($q = 3$).

The details on the calibration techniques for meter-VLBI, observation strategy, and expected calibration distribution on the sky and their suitability will be published in [4].

Acknowledgments

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References

[1] M. P. van Haarlem, M. W. Wise, A. W. Gunst, et al., *LOFAR: The LOw-Frequency ARray. A&A* **556** (2013) A2.

[2] O. Wucknitz, *Long baseline experiments with LOFAR.* In *ISKAF2010 Science Meeting* (2010).

[3] E. Varenius, J. E. Conway, I. Martí-Vidal, et al., *Subarcsecond international LOFAR radio images of the M82 nucleus at 118 MHz and 154 MHz. A&A accepted* (2015).

[4] J. Moldón, A. T. Deller, O. Wucknitz, et al., *The LOFAR long baseline snapshot calibrator survey. A&A accepted* (2015).