Highlights of Astronomy, Volume 14
IAU XXVI General Assembly, 14-25 August 2006
Karel A. van der Hucht, ed.

doi:10.1017/S174392130701112X

A very brief description of LOFAR – the Low Frequency Array

Heino D. Falcke[1,2,†], Michiel P. van Haarlem[1], A. Ger de Bruyn[1,3], Robert Braun[1], Huub J.A. Röttgering[4], Benjamin Stappers[1,5], Wilfried H.W.M. Boland[4], Harvey R. Butcher[1], Eugène J. de Geus[1], Leon V. Koopmans[3], Robert P. Fender[5,6], H. Jan M.E. Kuijpers[2], George K. Miley[4], Richard T. Schilizzi[7,4], Corina Vogt[1], Ralph A.M.J. Wijers[5], Michael W. Wise[5], Willem N. Brouw[3], Johan P. Hamaker[1], Jan E. Noordam[1], Thomas Oosterloo[1], Lars Bähren[1,2], Michiel A. Brentjens[1,3], Stefan J. Wijnholds[1], Jaap D. Bregman[1], Wim A. van Cappellen[1], André W. Gunst[1], G.W. (Dion) Kant[1], Jan Reitsma[1], Kjeld van der Schaaf[1], and Cornelis M. de Vos[1]

[1]ASTRON, Postbus 2, NL-7990AA Dwingeloo, the Netherlands
email: falcke@astron.nl

[2]Department of Astronomy, Radboud University, Nijmegen, the Netherlands

[3]Kapteyn Astronomical Institute, Groningen University, Groningen, the Netherlands

[4]Leiden Observatory, Leiden University, Leiden, the Netherlands

[5]Astronomical Institute Anton Pannekoek, University of Amsterdam, the Netherlands

[6]School of Physics & Astronomy, University of Southampton, Southampton, SO17 1BJ, UK

[7]International SKA Project Office, c/o ASTRON, Dwingeloo, the Netherlands

Abstract. LOFAR (Low Frequency Array) is an innovative radio telescope optimized for the frequency range 30 - 240 MHz. The telescope is realized as a phased aperture array without any moving parts. Digital beam forming allows the telescope to point to any part of the sky within a second. Transient buffering makes retrospective imaging of explosive short-term events possible. The scientific focus of LOFAR will initially be on four key science projects (KSPs): (*i*) Detection of the formation of the very first stars and galaxies in the universe during the so-called epoch of reionization by measuring the power spectrum of the neutral hydrogen 21-cm line (Shaver *et al.* 1999) on the $\sim 5'$ scale; (*ii*) Low-frequency surveys of the sky with of order 10^8 expected new sources; (*iii*) All-sky monitoring and detection of transient radio sources such as γ-ray bursts, X-ray binaries, and exo-planets (Farrell *et al.* 2004); and (*iv*) Radio detection of ultra-high energy cosmic rays and neutrinos (Falcke & Gorham 2003) allowing for the first time access to particles beyond 10^{21} eV (Scholten *et al.* 2006). Apart from the KSPs open access for smaller projects is also planned. Here we give a brief description of the telescope.

Keywords. instrumentation: interferometers, telescopes, cosmology: observations, cosmic rays

1. LOFAR – how it works

In its first phase LOFAR will consist of 77 *stations* distributed within a ring of ~ 100 km diameter; 32 stations will be clustered in a central core of ~ 2 km diameter located in the northeastern Netherlands near the village of Exloo. Each station has two antenna systems: the Low-Band and High-Band Antennas (LBA, HBA). The LBA system operates primarily in the frequency range 30 - 80 MHz with a switch to observe over a 10 - 80 MHz

† Visiting Miller Professor, Astronomy Department, University of California at Berkeley

band as well. The HBA is optimized for the range 110 - 240 MHz with a possibility to observe up to 270 MHz with lower sensitivity. The LBA field is 60 m in diameter and contains 96 inverted-V crossed dipoles oriented NE-SW and SE-NW (i.e., dual polarization) in a randomized distribution with a slight exponential fall-off in density with radius. The HBA field consists of 96 tiles distributed in an as yet undetermined manner over roughly 50 m. Each tile consists of a 4×4 array of bowtie-shaped crossed dipoles with an analog 5-bit beam former using true time delays. Radio waves are sampled with a 12-bit A/D-converter – to be able to cope with expected interference levels – operating at either 160 or 200 MHz in the first, second or third Nyquist zone (i.e., 0 - 100, 100 - 200, or 200 - 300 MHz band respectively for 200 MHz sampling). The data from the receptors is filtered in 512×195 kHz sub-bands (156 kHz subbands for 160 MHz sampling) of which a total of 3 MHz bandwidth (164 channels) can be used at any time. Data from each receptor can be buffered in a transient buffer board (TBB) for as long as $\sim 10\,\mathrm{min}/(\Delta\nu/196\,\mathrm{kHz})$. Subbands from all antennas are combined on a station-level in a digital beamformer allowing eight independently steerable beams which are sent to the central processor via a glas fibre link that handles a $0.7\,\mathrm{Tbit\,s^{-1}}$ data rate. The beams from all stations are further filtered into 1-kHz channels, cross-correlated and integrated on typical timescales of 1 - 10 s. The integrated visibilities are then calibrated on 10-s intervals to remove the effects of the ionosphere and images are produced. Channels with disturbing radio frequency interference (RFI) are dropped. For the correlation we use four of the six racks of an IBM Blue Gene/L machine in Groningen with a total of $\sim 12\,000$ processors. We expect a typical input rate of $\sim 0.5\,\mathrm{Tbit\,s^{-1}}$. Unix clusters are used as input and output nodes for pre- and postprocessing.

The expected $3\,\sigma$ point source sensitivities of LOFAR for one hour integration over 4 MHz bandwidth dual-polarization are 2 mJy, 1.3 mJy, 70 μJy, and 60 μJy at, respectively, 30, 75, 120, and 200 MHz. The resolution will be $25''$, $10''$, $6''$, and $3.5''$ for the same frequencies. The field of view is $3°$ at 150 MHz (HBA) and $7.5°$ at 50 MHz (LBA).

The project is currently in discussions with consortia in Germany, U.K., France, Italy, and Sweden to expand the baseline and increase the resolution by up to a factor of ten.

National funding of LOFAR has been obtained at a level of ~ 75 MEuro plus various in-kind contributions. Construction of the first station was completed in 2006 September. Further stations are expected to be rolled out in the course of 2007, so that commissioning and start of operation is foreseen in 2008.

2. Outlook and conclusions

With its new concept (Bregman 2000) of a broad-band aperture array and digital beamforming LOFAR is expected to pave the way for a new generation of telescopes and to be an important pathfinder for the Square Kilometre Array. LOFAR will improve the resolution and sensitivity of previous telescopes for continuum observations by roughly two orders of magnitude over a wide frequency range. It will also provide instantaneous access to a large fraction of the sky at low frequencies at once, making serious and regular all-sky radio monitoring possible for the first time. With these unusual properties LOFAR promises a wealth of new discoveries.

References

Bregman, J. D. 2000, in: H.R. Butcher (ed.), *Radio Telescopes*, Proc. SPIE 4015, 19
Falcke, H., & Gorham, P. 2003, *Astropart. Phys.*, 19, 477
Farrell, W. M., Lazio, T. J. W., Zarka, P., *et al.* 2004, *Planet. Space Sci.*, 52, 1469
Scholten, O., Bacelar, J., Braun, R., *et al.* 2006, *Astropart. Phys.*, 26, 219
Shaver, P. A., Windhorst, R. A., Madau, P., & de Bruyn, A. G. 1999, *A&A*, 345, 380