LOFAR: Lessons From its Design and Construction

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Abstract

LOFAR is a new radio telescope with 40 stations in the Netherlands and a further 8 in Germany, France, Sweden and the UK. It operates in the 30-240 MHz frequency range using unique and innovative techniques, many of which will find their way in future telescopes such as the SKA. With the construction of LOFAR almost complete we look back at its design and construction as well as the ongoing commissioning phase, and draw some conclusions on both successes and disappointments encountered along the way.

Summary

LOFAR, the Low Frequency Array, is a next generation radio telescope designed by ASTRON and under construction in the north of the Netherlands and across Europe. Utilizing a novel phased-array design, LOFAR is optimized for the largely unexplored low frequency range from 30-240 MHz. In the Netherlands, a total of 40 LOFAR stations are nearing completion with 8 international stations being deployed in Germany, France, Sweden, and the UK. Digital beam-forming techniques make the LOFAR system agile and allow for rapid repointing of the telescope as well as the potential for multiple simultaneous observations. With its dense core array and long interferometric baselines, LOFAR has the potential to achieve unparalleled sensitivity and spatial resolution in the low frequency radio regime. LOFAR will be operated as an international facility open to the astronomical community and will be one of the first radio observatories to feature automated processing pipelines to deliver fully calibrated science products to its user community.

The LOFAR radio telescope shares much of its infrastructure with two other "observatories" that are also part of the LOFAR project. One aimed at studying geophysical activity, largely due to oil and gas production using passive seismic interferometry techniques - similar to those used by radio astronomers. The second using microbarometers for the study of infrasound waves (sound waves below the cut-off of human hearing at about 20 Hz), which can be produced by many different phenomena (e.g. volcanic eruptions and earthquakes or man-made events such as explosions, or jets breaking the sound barrier). The astronomical antennas, the geophones and microbarometers share a common infrastructure: the stations on which the sensors are built and the glass fibre network that connects them to a central processing facility. The multidisciplinary nature of LOFAR (which also includes research into the use of sensor networks in precision agriculture) as well as its spin-off outside these disciplines has been a valuable asset for the project.

LOFAR started in the late 1990's as a precursor to the Square Kilometer Array - using the technology of aperture arrays that had been under development at ASTRON since the early part of that decade. The preliminary design was completed in 2003, the final (critical) design was completed in 2007. Along the way, two prototype test stations were built. Since 2007 procurement and construction have taken place. The scale of the project means that many of the parts that make up the system (two types of antennas, the electronics that carry out the first stage of processing, station construction and the central processing clusters) have been procured in accordance with EU regulations. The challenges encountered during this process provide valuable lessons for future large projects, not just its (project) management and the interaction with industry, but also in terms of logistics and planning.

The astronomical software pipelines that are needed to carry out LOFAR's key (early) science projects build on a central calibration, imaging and beamforming system. These dedicated pipelines have been developed in close collaboration with colleagues at ASTRON and four Dutch universities that have each focussed on one Key Science Project: Amsterdam - Transients and Pulsars, Groningen - the Epoch of Reionization, Leiden - Extragalactic Surveys and Nijmegen - Cosmic Rays. Since expansion of the project with international partners in 2006, two further KSP's have joined: Cosmic Magnetism led by the Max Planck Institute for Radio Astronomy in Bonn and Solar Physics and Space Weather led by Astrophysical Institute in Potsdam. This distributed software development effort and the ongoing commissioning activities also provide challenges that will be even more apparent in future large international collaborations such as the Square Kilometer Array.

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