Final report
PERG02-GA-2007-224897 — WIDEMAP

Summary

The ERG project 'WIDEMAP' supported our activities in the field of radio interferometry, particularly Very Long Baseline Interferometry (VLBI) and LOFAR. The funding was used to finance a ten-node computer cluster with more than 100TB of disk space to store the data, and equipped with a number of powerful graphics processing units (GPUs) for efficient processing.

1 Wide-field VLBI

The VLBI technique offers the highest resolution of all available observing techniques, orders of magnitude higher than the Hubble Space Telescope. This extremely high resolution has the disadvantage that the fields of view are generally tiny. The main reason is that billions (or many more) pixels have to be processed for wide fields. In addition, large fields of view require very high resolutions of the raw data in time and frequency. The computing demands of standard methods scale very badly with field size. We have invented and implemented a much more efficient method, "Fast Wide Field Mapping" (FWFM), that overcomes this problem. It makes wide-field VLBI possible on modest computer systems. A number of test observations have shown the success of this method. It will prove to be essential for future instruments like the SKA (Square Kilometre Array), which pose huge computational challenges. This is already true for LOFAR, one of the main SKA pathfinders.

The computer cluster funded by the ERG has been (and still is) an enormous help in these developments. We can not only analyse the correlated data, but also do the correlations themselves, in which the signals from world-wide arrays of radio telescopes are combined to form a virtual telescope the size of the Earth.

2 LOFAR

The Low Frequency Array (LOFAR) is a new array of radio telescopes, mostly in the Netherlands, but some spread over Europe, that for the first time allows high-quality imaging observations with high resolution in the lowest available frequencies (from 10 to 270 MHz). One of our main motivations to work with LOFAR is a project to use this revolutionary new system to search for gravitational lenses. This project relies on the highest resolutions that can only be achieved by the longest baselines that are provided by the international stations.

The developments for long-baseline LOFAR are led by Olaf Wucknitz, the researcher supported by the ERG. Over the past years, he has very successfully pioneered high resolution observations and data analysis with LOFAR. The ERG-funded computer cluster turned out to be essential for these developments. LOFAR data sets are huge (typically many TB), and their analysis requires the fastest computers. Having a powerful cluster at our disposal made quick developments and implementations of new algorithms possible.

The first success was the detection of first “fringes” between international stations. Quickly thereafter followed the first high-quality images at very low frequencies (Fig. 1). In the higher bands, we are now able to achieve sub-arcsec resolution routinely. We have produced the highest-resolution images of a number of important radio sources (e.g. 3C196, 3C147 or the first gravitational lens Q0957+561). In addition, our developments proved to be very useful also for lower resolution observations. They have led to the first LOFAR images of the Sun, and to the first LOFAR images of the Crab nebula. Recently we have also started to observe Jupiter with the highest resolutions at the lowest frequencies reachable, which for the first time allows to test the existing models of radio emission processes.

The ERG funding has thus made the first long-baseline LOFAR results possible and will form the basis of future work in this field.

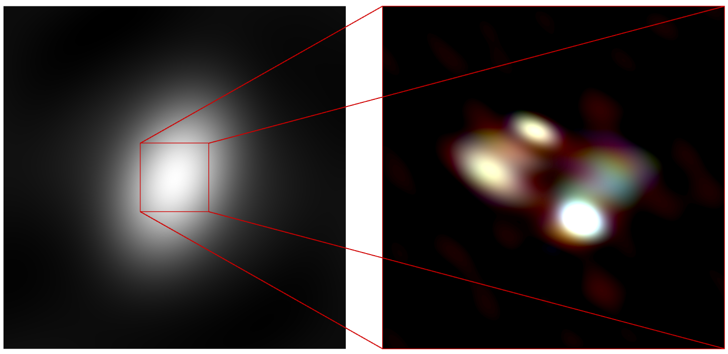

Figure 1: 3C196 with LOFAR at 30–80 MHz. Left: Dutch array (resolution $35'' \times 22''$, right: international array (resolution twenty times better, $1''\!.5 \times 0''\!.9$). The colours are chosen to resemble what the human eye would see if it were sensitive to radiation at a wavelength ten million times larger than visible light.

As a by-product, we were able to use LOFAR as a passive radar and detect airplanes up to distances of several hundred km and measure their position and trajectory in three dimensions.

3 Gravitational lenses

Another part of the project consisted of modelling gravitational lenses using radio interferometric data. This was mostly done by the PhD student Filomena Volino who was supervised by Olaf Wucknitz. The computer cluster turned out to be extremely helpful also for this part of the project, by making modelling efforts possible that could not have been done on standard PCs.

The efforts led to very much improved models for MG J0414+0534. This system is particularly important, because the lensing magnification has allowed us to detect emission from a water maser in the lensed background source. This is by far the most distant (and thus earliest) detection of water in the universe. The lens models are required for a proper interpretation of the data.