

LOFAR, the Low Frequency Array : Low-frequency Radioastronomy at a resolution of a few arcseconds and Astroparticles – Towards a french participation ...

Report on the workshop held at CIAS (Meudon), March 28-29 2006.

This workshop aimed at assessing the scientific interest that would present a french participation in LOFAR. This instrument is a large array of low-frequency antennae (<30 to 240 MHz), that will allow an improvement by 1 to 2 orders of magnitude in sensitivity and angular resolution compared to existing instruments. Permitting wide-field, multi-frequency and multi-beams imaging with high sensitivity and angular, spectral and temporal resolutions, and including full polarization measurements, LOFAR will be the first general-purpose low-frequency telescope, as well as the first spectro-imager at frequencies < 100 MHz. The key scientific objectives include a deep sky survey, the study of the reionization of the Universe, of transient sources such as pulsars, jets, flaring stars, of planets and exoplanets, the detection of very-high energy cosmic rays and the physics of the interplanetary medium. LOFAR is a Dutch project led by the institute ASTRON in Dwingeloo. Presently under construction, the instrument will be operational in 2007-2008 with maximal interferometric bases of ~100 km (angular resolution between 2.5" at 240 MHz and 20" at 30 MHz). The project is now open to European contributions, in particular through a physical extension of the array (adding distant stations will improve the angular resolution by one order of magnitude), and an increased potential for scientific data analysis. Germany (the GLOW consortium) and Sweden have already joined the project, and universities in the UK have declared their interest.

The workshop was highly successful, despite perturbations related to the national strike on the 28th. It Project Scientist brought together about 40 participants, including two representatives of ASTRON (H. Falcke, and M. Van Haarlem, Technical Project Scientist). The program and the content of the presentations can be found at <http://www.obspm.fr/~presidence/LOFAR/>. Furthermore, some scientific themes of interest could not be presented (supernova remnants, star formation, AGN, pulsar wind nebulae) but concerned scientists have expressed their interest and will participate in the writing of a Science Case.

After a presentation of science with LOFAR and of the present state of the project by the ASTRON representatives, scientific talks have allowed to explore most of the scientific themes: Cosmology (Epoch of Reionization, galaxy clusters, formation and structure of galaxies), about 9 participants; physics of the Galaxy and the interstellar medium (3 participants). Planets and exoplanets (3), solar physics (4), electric phenomena in the upper atmosphere (sprites) (1), and radio observation of high-energy cosmic-ray showers. Other talks have addressed the French participation in SKA, the instrumental developments at Nançay, and the expertise gained in massive data processing for Planck. Although a detailed report cannot be given here, a real interest appears in the French community in all these themes, some of which haven't yet been already explored by ASTRON or the German consortium GLOW.

Round table discussions were organized in parallel sessions, in interaction with the ASTRON representatives. They have allowed to discuss in more details some specific aspects: Cosmology, Cosmic-ray showers, data processing, and arcsecond resolution.

- **Cosmology** : the three-year results of WMAP, published just before the workshop, place the Epoch of Reionization exactly in the range of redshifts accessible to LOFAR. This is a

global result, and LOFAR should thus bring a detailed view of this epoch by probing the neutral, not yet ionized gas. The Planck satellite on the other hand will probe the ionized gas by its polarized signal, and the secondary anisotropies. The French participants would like to join the existing Key Project on reionization. They also express a strong interest in extragalactic surveys and their use in cosmology and structure formation (non-thermal phenomena in galaxy clusters, structure and magnetism of galaxies, baryonic oscillations...), in particular in correlation with X-ray observations (XMM-Newton, ROSAT, Simbol-X GLAST) and naturally Planck.

- **High angular resolution:** The project of a LOFAR station in Nançay would allow, by extending the baseline to ~ 1000 kms, to reach an arcsecond resolution. Although many talks have shown the interest of this improved resolution, many interested participants could not attend this round table, which was thus limited to a discussion with ASTRON. We note that ASTRON will organize a workshop in May on this subject. Furthermore, the first tests on the role of the ionosphere in the correlation at this scale (VLBI-LF) are under way, and the first results should be available within a few weeks.
- **Cosmic ray showers:** the German experiment LOPES of radio observation of cosmic ray showers is part of the LOFAR project. The French experiment CODALEMA, which has obtained in Nançay similar results, uses a different technique which presents certain advantages, in particular self-triggering from the radio signal while LOPES still requires an external trigger. Its representatives argue that, even using the central core of LOFAR (much more extended than the station considered at Nançay), the energy of the observed showers could not significantly exceed 10^{18} eV, due to the low flux at higher energies, while the main interest of astroparticle physics is presently beyond 10^{19} eV. They may rather concentrate on ongoing projects and the installation of antennae at Auger. However collaborations with LOPES/LOFAR remain possible and should be explored, although this cannot be the main goal of a French participation in LOFAR.
- **Data processing:** Nançay develops generic techniques for RFI mitigation (elimination of interferences of anthropic origin). These methods can be applied to SKA, FASR and LOFAR. Dutch science teams suggest that the corresponding processing should be applied at the central level, rather than in individual stations. However it is noted that a local treatment, by significantly reducing the dynamical range of the signal, might allow to reduce the necessary bandwidth for the high-speed data connection to the central station. Also, a station in Nançay would not be in permanent use by LOFAR. It would thus remain available locally for R&T, education and training, especially in preparation of SKA.

The structure of the data pipeline is not yet fully defined or documented, making it difficult to define possible French inputs, but leaving open many possibilities. ASTRON suggests to consider these possibilities from declarations of interest mentioning the specific expertise available. An important share of the data processing and archiving will be the responsibility of the Key Projects, which prepare and structure the scientific exploitation, and it is thus in part with these Key Projects that possible contributions should be discussed. However, contrary to what was initially planned, ASTRON considers returning to some centralization of the archiving. An important role should be devolved to Science Centers, as already planned in Germany. A Science Center should, in practice, be equipped with a cluster of about 100 processors, with a fast data link

Summary and prospective:

LOFAR is an instrument of an entirely new type, technically a precursor (from the concept of aperture synthesis to the data processing tools) of the European concept (SKA-DS) proposed for

SKA. It promises an important gain in sensibility and resolution in a frequency domain which has been little explored thus far, and opens (in itself or as a precursor of SKA) exciting scientific perspectives in many fields. It also offers interesting prospects, already explored by ASTRON, of interdisciplinary collaborations with fields like geophysics or agronomy, which, on the same concept of a large number of simple detectors coordinated by data processing, might use the basic infrastructure of LOFAR. The link with these disciplines might allow to consider building other stations, after the one proposed in Nançay, which would permit to better fill the u-v plane.

A French participation might weight much more than its arithmetic weight (one station, compared with 77 in the Netherlands, 4 and up to 12 in Germany, a few considered in the UK), taking into account our specific contributions: an important gain is angular resolution, the expertise in Nançay, methods of massive data processing developed for Planck, but also access, for correlation studies, to data (and the corresponding expertise) from Planck, XMM, Simbol-X, GLAST... It would also allow, with operations starting in the next few years, to maintain and develop, test and teach the techniques necessary for the preparation of SKA.

In the above-mentioned scientific fields, the interest raised by the workshop exceeded the expectations of the organizers. Many of these fields are original, compared to those already explored by ASTRON or the German consortium GLOW, and could allow the creation of new Key Projects (one can already mention the role of P. Zarka as P.I. of the Science Working Group "Planets/Exoplanets", within the Transients Key Project). ASTRON suggests that the French participation be coordinated by a consortium similar to GLOW. ASTRON will consider with the Key Projects the suggestion that, in an interim phase, French participants may attend as observers their meetings, to better assess the possible participations and collaborations.

This scientific interest will have to be considered in regard of existing constraints, in particular: workload at Nançay, overlap with the strong French participation in SKA, availability of teams involved in other projects; it will also need to come with a clear vision of the necessary budgets (investment, personnel and operations).

The institutions represented at the workshop (Observatoire de Paris-Meudon, INSU, IN2P3) have expressed their support to the undergoing exploratory phase. They proposed to rely on to the organizing committee of the workshop (N. Aghanim, N. Dubouloz, E. Parizot, P. Zarka, joined by M. Tagger) the redaction of a Science Case, upon which they will base their final decision of a French participation in LOFAR.