

## The LOFAR Transients Key Project

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LOFAR, the Low Frequency Array, is a new radio telescope under construction in the Netherlands, designed to operate between 30 and 240 MHz. The Transients Key Project is one of the four Key Science Projects which comprise the core LOFAR science case. The remit of the Transients Key Project is to study variable and transient radio sources detected by LOFAR, on timescales from milliseconds to years. This will be achieved via both regular snapshot monitoring of historical and newly-discovered radio variables and, most radically, the development of a 'Radio Sky Monitor' which will survey a large fraction of the northern sky on a daily basis.

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## 1. LOFAR

LOFAR (the **LO**w **F**requency **AR**ray) is a new radio telescope under construction in The Netherlands, which will operate between 30 and 240 MHz, providing unprecedented sensitivity and resolution with which to explore the low-frequency radio sky. It will initially comprise 77 stations, 32 located in the 3 km  $\times$  2 km core and the remaining 45 forming more extended baselines, with a maximum baseline of about 100 km. The station locations have been selected to provide the best possible  $uv$ -coverage both for snapshot observations and for full aperture syntheses. The stations will return a total of 32 MHz of bandwidth with a basic integration time of 1 s. This 32 MHz of bandwidth may be divided between multiple beams, e.g. 8 beams of 4 MHz each. Key operational parameters are outlined in Table 1. Each station will consist of 96 station units, each comprising one low-band dipole (optimised for the range 30–80 MHz) and a  $4 \times 4$  array of high-band tiles (optimised for 120-240 MHz).

Frequency (MHz)	$A_{\text{Eff}}$ (km <sup>2</sup> )	Full array			24-beam Radio Sky Monitor		
		$\Omega$ (deg <sup>2</sup> )	$\theta$ (arcsec)	S (mJy bm <sup>-1</sup> )	$\Omega$ (deg <sup>2</sup> )	$\theta$ (arcmin)	S (mJy bm <sup>-1</sup> )
30	0.19	120	25	118	2700	21	290
75	0.03	20	10	80	420	8	200
120	0.19	7	6	4	170	5	10
200	0.07	3	3	4	60	3	9

**Table 1:** Key operational parameters of LOFAR, assuming a total bandwidth of 4 MHz, an integration time of 1 s and a maximum baseline of 100km.  $A_{\text{Eff}}$  is the effective area of the telescope,  $\Omega$  is the field of view, and  $\theta$  is the angular resolution.

Four Key Science Projects have currently been identified for LOFAR, each of which is associated with a university in The Netherlands:

Key Project	Leading institution	Project Leader
The Epoch of Reionization	Groningen	de Bruyn
Extragalactic Surveys	Leiden	Röttgering
Transients	Amsterdam	Fender/Wijers/Stappers
Cosmic Rays	Nijmegen	Kuijpers/Falcke

In this brief article we will focus on the Transients Key Project.

## 2. The Transients Key Science Project

The Transients Key Science Project (TKP) aims to study all variable sources detected by LOFAR. The scientific remit of the project has been subdivided into five basic categories: jet sources, pulsars (and related neutron star phenomena), planets, flare stars and serendipity.

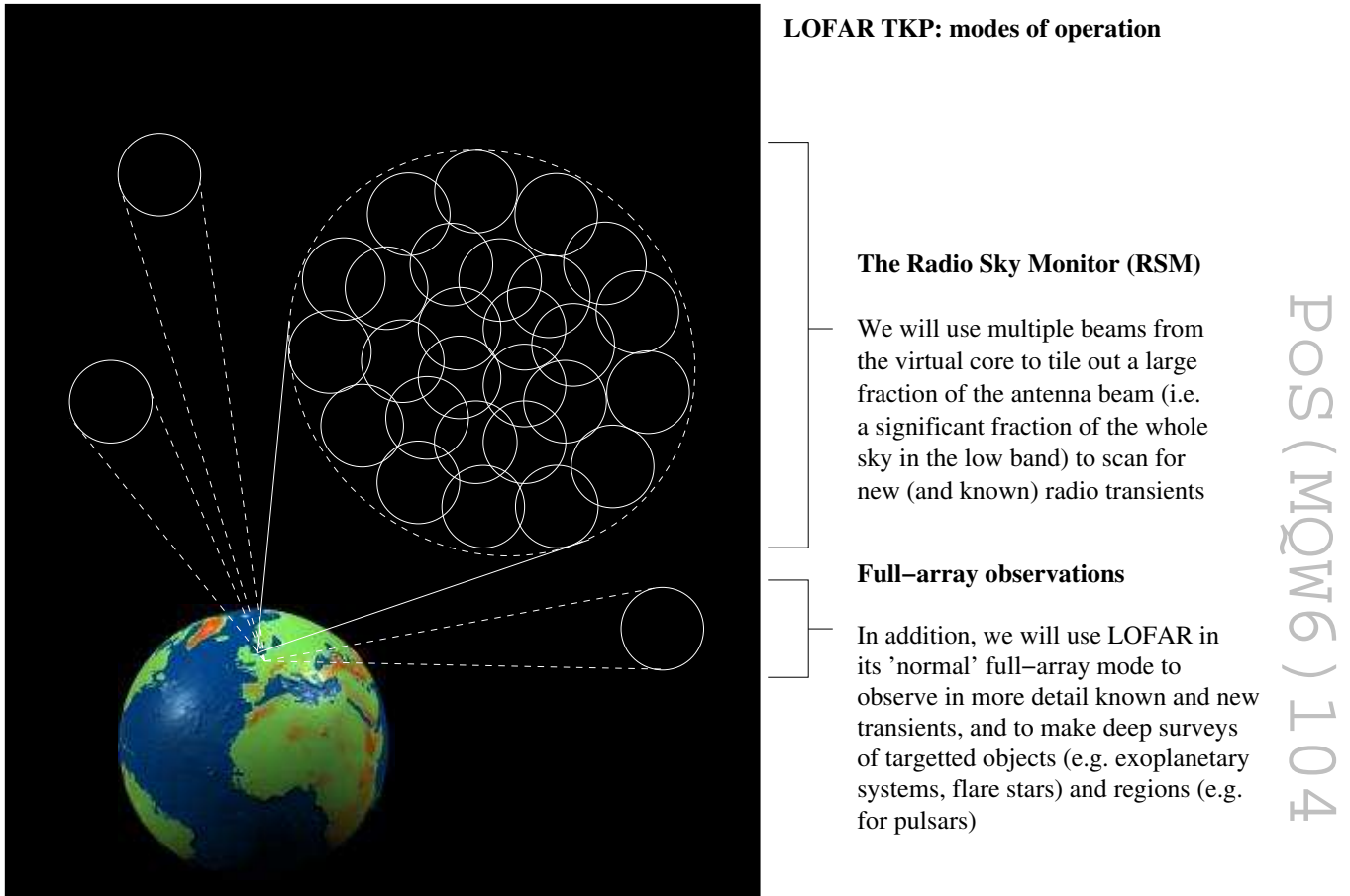
- The class of jet sources includes all objects producing radio emission from (often relativistic) outflows, including Active Galactic Nuclei (AGN), Gamma Ray Bursts, and accreting white dwarfs, neutron stars and ‘stellar mass’ black holes (i.e. ‘microquasars’). Incoherent synchrotron radiation is the primary emission mechanism, although there could be the possibility of detecting coherent prompt emission from Gamma Ray Bursts.
- A major survey of classical radio pulsars will be undertaken, as well as the study of related objects such as Anomalous X-ray Pulsars (AXPs) and Rotating Radio Transients (RRATs). LOFAR will provide the sensitivity to allow us to study the individual pulses from an unprecedented number of pulsars including millisecond pulsars and the bandwidth and frequency agility to study them over a wide range which will provide vital new input for models of pulsar emission.
- LOFAR will also study radio emission from planets within the Solar System. This includes imaging Jupiter’s magnetosphere at high spatial and time resolution, imaging Jupiter’s radiation belts, and studying planetary lightning from the other planets within the Solar System. It is hoped that radio bursts from nearby so-called ‘hot Jupiter’ exoplanets might also be detected, and a survey will be carried out.
- Flare stars and active binaries are likely to be present in almost every LOFAR beam, giving off highly circularly-polarised radio bursts from coherent emission processes. Potential targets include M dwarf flare stars, active binaries and low mass L and T dwarfs.
- It is highly likely that probing such a large region of hitherto-unexplored parameter space, we will detect new classes of astrophysical objects. This possibility is especially enhanced by the wide-field monitoring mode of the Radio Sky Monitor (see below). We aim to follow up such serendipitous discoveries both ‘internally’ with LOFAR and target-of-opportunity observations on other facilities, both at higher radio frequencies and in other wavebands.

### **3. The radio sky monitor (RSM)**

LOFAR is a software telescope. The individual dipoles are sensitive to the entire hemisphere of sky above them, but by dividing up the total bandwidth and electronically inserting delays in the signal path, multiple beams may be created to give simultaneous directional sensitivity in several different directions.

The wide field of view of the compact LOFAR core is ideal for observing large areas of sky. The 32 core stations will ultimately be able to return up to 24 individual beams (each of reduced total bandwidth), which will tile out a patch of sky in a radio sky monitor mode. The total area tiled out will be a sizeable fraction of the individual antenna response, i.e. a large fraction of the sky at the lowest frequencies. In parallel to this, depending on useage of computer resources, other beams using all LOFAR stations (core and remote stations) may be able to simultaneously carry out separate observing programmes.

Thus, for the first time, it will be possible to have a Radio Sky Monitor (RSM) which will be able to observe more or less the entire sky visible from the Netherlands on a daily basis. The



**Figure 1:** Modes of operation of LOFAR for the Transients Key Project. As well as utilising ‘normal’ full-array modes, we plan to regularly sweep the sky with a ‘Radio Sky Monitor’ in which we use multiple beams from the virtual core of the array to tile a large fraction of the sky.

results of this monitoring programme will be made available to the community in the form of alerts when new transients are detected and real-time lightcurves for most sources under observation. We will create and maintain a database of all known transient radio sources, constantly updated as new observations are made. Bright transients may result in internal triggers allowing full-array observations and arcsec-accuracy localisation within tens of seconds. We envisage this mode as being a key resource for the discovery and localisation of new transients for the high-energy astrophysics community. Furthermore, this mode may act as a prototype for a low-frequency core of the Square Kilometer Array.

#### 4. The transient buffer boards: looking back in time

Sufficient memory will be available to record one second of raw data for each LOFAR antenna at full bandwidth. By trading bandwidth for time, the length of time stored in the buffer could potentially be increased by a large factor. On detection of a LOFAR transient, or on reception of a trigger from an external telescope, the data in the buffers will be frozen, and fed back to the

processing cluster, to allow us to go ‘back in time’ and take a more detailed look at the onset of the transient event, or to probe the event on shorter timescales.

## 5. Strategy

The sky will be searched for transients by making differenced images on a logarithmically-spaced range of timescales, ranging (initially) from 1 s up to  $10^4$  s, thus probing a wide variety of transient events (targetted observations of pulsars, flare stars and planets will necessarily be made with much higher time resolution). In order to provide real-time transient alerts, and if necessary reconfigure the telescope to better localise a new transient, all data processing must be fully automated. The automated pipeline must keep pace with the incoming data, taking no more than 1 s to process the shortest-timescale maps. Each timestep, a difference image will be made comparing the current image with the previous one. A source extraction routine will be run on the differenced image to detect new transients. Any sources detected will be subjected to RFI (radio frequency interference) and noise checking, and measurements of the source parameters (flux density, spectrum, polarisation and position) will be made. When searching for very rapid events, real-time de-dispersion must also be applied. After comparison with the existing database, new sources will be classified using a probability-based scheme based on the measured parameters, and the parameters of known sources will be used to update the monitoring database. New transients may be followed up using pointed LOFAR observations and target of opportunity proposals at external observatories. In order to probe shorter timescale events, a tied-array mode will be available to provide  $5 \mu\text{s}$  time resolution to enable the study of pulsars, planetary bursts, and other sources of coherent emission.

## 6. Timeline

The first LOFAR station (Core Station 1; CS 1) is already in place and is undergoing commissioning. Once the scientific testing phase begins, we will be in a position to detect a bright transient event with CS 1. The central LOFAR core will be constructed over the course of 2007, increasing the available sensitivity and bringing the RSM online. It is hoped that long-baseline international stations (in Germany, The UK, France and beyond) will begin to be added at this stage. The full array is planned to be completed by the end of 2008, with science operations beginning in early 2009. LOFAR will ultimately be fully international and open time will be available via competitive merit-based proposals.

## References

For more information on LOFAR, see:

<http://www.lofar.org>

For more information on the LOFAR Transients Key Project, see:

[http://www.astro.uva.nl/lofar\\_transients](http://www.astro.uva.nl/lofar_transients)