Neutron Stars and Gamma Ray Bursts with LOFAR

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Abstract

LOFAR, the Low Frequency Array, is an innovative new radio telescope currently under construction in the Netherlands. With its continuous monitoring of the radio sky we expect LOFAR will detect many new transient events, including GRB afterglows and pulsating/single-burst neutron stars. We here describe all-sky surveys ranging from a time resolution of microseconds to a cadence span of years.

Key words: LOFAR, neutron stars, GRBs

1 Introduction

New possibilities for neutron-star (NS) and gamma-ray burst (GRB) research are emerging from radio interferometry using large numbers of low-cost receivers, such as in the currently operational ATA (Bower 2007) and the planned SKA (Kramer 2003). We here investigate the prospects of finding neutron stars – be it classical radio pulsars, AXPs or RRATs – and GRBs with LOFAR (for details see van Leeuwen & Stappers 2009). Besides these the Transients Key Science Project aims to study all variable and transient LOFAR sources, including jet sources such as AGN or supernovae as well as accreting white dwarfs, neutron stars and stellar-mass black holes. Sources will also include exo- or solar-system planets, flare stars, brown dwarfs, and active binaries; as well as short radio bursts, generally unexplored parameter space, ETI and the unknown (for an overview, see Fender et al. 2008).
2 LOFAR - The Low Frequency Array

With the first stations operational and the first pulsars detected LOFAR is on track to officially start operation early 2010. Using two different types of dipoles, LOFAR can observe in a low and a high band that range from 30-80 MHz and 110-240 MHz respectively. The sensitivity using the high-band antenna (HBA) is several times that of the low-band antenna (LBA) so we will here briefly outline the HBA characteristics.

Sets of 4x4 dipoles form an antenna 'tile'. Tiles are grouped together in stations that increase in collecting area with their distance from the array center. The innermost 6 split stations are are packed tightly in a 'superstation'. Spread over the 2-km core there are 12 more split HBA stations. Next are 18 Dutch 'remote', while the ∼8 large international stations are spread over Europe. Signals from these stations are next sent to the central processor supercomputer for correlation, addition and/or different types of beam forming.

3 Neutron Stars

In van Leeuwen & Stappers (2009) we have investigated the number and type of radio pulsars that will be discovered with LOFAR. We consider different search strategies (such as “coherent” versus “incoherent”, cf. Backer, 1999) for the Galaxy, for globular clusters and for other galaxies. We show that a 25-day all-sky Galactic survey can find approximately 900 new pulsars, probing the local pulsar population to a very deep luminosity limit. For targets of smaller angular size such as globular clusters and galaxies more LOFAR stations can be combined coherently, to make use of the full sensitivity. Searches of nearby northern-sky globular clusters can find new low luminosity millisecond pulsars (eg. several millisecond pulsars in a 10-hour observation of M15). Giant pulses from Crab-like extragalactic pulsars can be detected out to over a Mpc.

This survey will produce a complete local census of radio-emitting neutron stars, such as radio pulsars and AXPs and with the long pointings possible it is particularly sensitive to transient-type neutron stars like RRATs (McLaughlin et al., 2006) and intermittent pulsars (Kramer et al., 2006) – for an overview see Hessels et al. (2009). This census provides insight into neutron birth rates and properties, hence elucidating core collapse energetics and asymmetry, the velocities and spatial distribution of pulsars, and the physics of neutron stars in general.
4 Gamma Ray Bursts

Prompt emission and (orphan) afterglows from GRBs can be picked up in one of several Transients KSP surveys: in the high time resolution (pulsar, exoplanet) dedicated all-sky survey; in the piggyback survey that will search all LOFAR observations to look for variable and transient sources, by comparing with previous images of that region of sky; in targeted deep high-resolution observations (cf. GRB 030329 van der Horst et al. 2008) triggered by other facilities such as orbiting X-ray/γ-ray observatories, groundbased optical telescopes; or in the dedicated Radio Sky Monitor, rapid regular scans of a large fraction of the entire northern sky that we will describe in some more detail below.

The RSM could operate in several modes. Rapid All-Sky monitoring mode: fast shallow (∼1mJy) hemispherical surveys could be performed on short timescales (∼1min pointings, daily) in order to survey for rapid transients.

Zenith monitoring mode: staring at the zenith optimises the sensitivity and beam stability of the telescope, whilst providing a sizeable and repeatedly monitored part of the sky. Galactic plane monitoring: most of the northern galactic plane is visible from LOFAR and could be monitored for galactic transients.
Fig. 2. Comparison of approximate Radio Sky Monitor (RSM) fields of view and the angular size on the sky of M31, the Virgo cluster and the northern galactic plane. Figure from Fender et al. (2008).

Every second calibrated images are produced of each beam. These are accumulated over logarithmic intervals to integrated maps, and analysed in real-time to check for flux changes of known objects or for new transients. High-confidence events will initiate LOFAR follow up observations as well as trigger alerts directly to partner observatories, and to the broader community.

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