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THE NOIRE STUDY

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Abstract. NOIRE (Nanosats pour un Observatoire Interférométrique Radio dans l'Espace; Nanosats for a space borne interferometric radio observatory) is an ongoing feasibility study with CNES and in collaboration with Dutch colleagues. The goal is to assess the feasibility of a low frequency space radio interferometer using nanosatellites.

Keywords: Radioastronomy, Interferometry, Space, Nanosatellites

1 Introduction

During the last decades, space physics and radioastronomy have dramatically changed our knowledge of the Universe and his evolution. However our view is still incomplete at the lowest frequencies range (below 30 MHz), which remains the last unexplored spectral band. Below 30 MHz, ionospheric fluctuations strongly perturb ground based radioastronomy observations. They are impossible below 10 MHz due to the ionospheric cutoff. Furthermore, man made radio interferences make these observations even more difficult. Deploying a space borne radio observatory is the only way to open the last window on the Universe. This spectral window starts at a few kHz, which is the local solar wind radio cutoff frequency and ends between 10 and 30 MHz. The science objectives of this observatory are diverse and numerous: the dark ages of the Universe, the mapping of the Galaxy, pulsars and astrophysical transients, space weather, the atmosphere and magnetospheres of solar system planets and exoplanets. Figure 1 is illustrating the cosmological science objectives.

NOIRE (Nanosats pour un Observatoire Interfromtrique Radio dans l'Espace; Nanosats for a space borne interferometric radio observatory) is an ongoing feasibility study with PASO (Plateau d'Architecture des Systèmes Orbitaux; Space Systems Architecture Service) at CNES that assesses the feasibility of a low frequency space radio interferometer using nanosatellites.. It is conducted in collaboration with Dutch colleagues involved in several space borne low frequency radio interferometers projects (OLFAR, DEx, SURO, DSL...) Bentum et al. (2011). The goal spectral range of NOIRE is 0.1 to 100 MHz. The technologies and methods (particularly interferometric imaging) developed for LOFAR, NenuFAR or SKA are useful ingredients for such a project.

2 Low Frequency Radio Signal in Space nearby Earth

In the low frequency range (namely below 100 MHz), the sky brightness temperature can be as high as 10^7 K at about 1 MHz. Figure 2 is showing the main radio sources and components observable in space near Earth.

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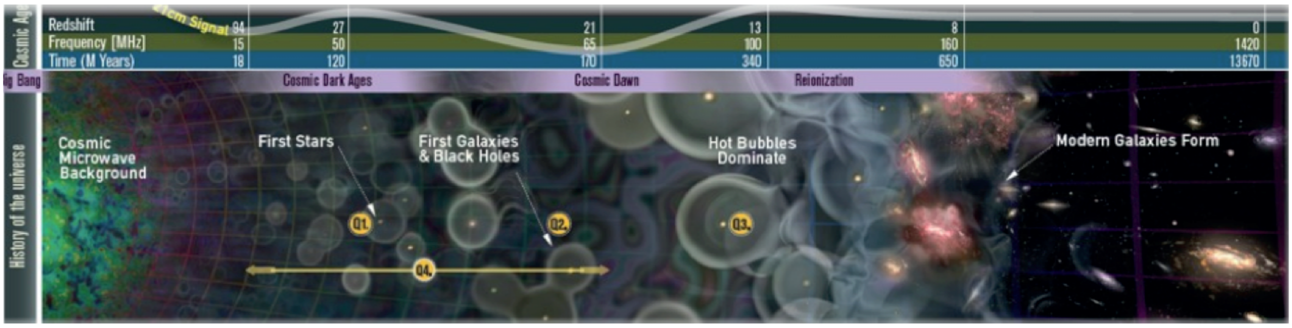

Fig. 1. Cosmological science objectives for low frequency observations, adapted from Klein-Wolt & Falcke (2013)

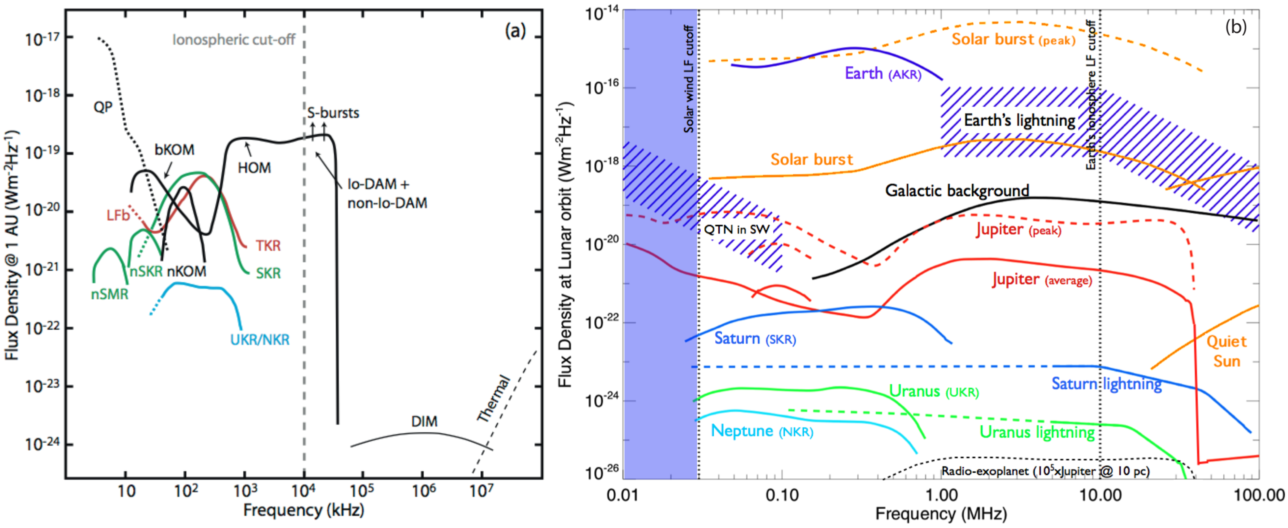

Fig. 2. (a) Solar system radio source normalized spectra, as observed from a distance of 1 AU (Astronomical Unit). Radio emission spectra from Jupiter, Saturn, Earth, Uranus/Neptune are traced in black, green, red and blue. (b) The radio component spectra observed from Earth, including solar radio emissions, earth and planetary auroral and atmospheric radio emissions, galactic emission and local plasma noise on the antenna. Figure adapted from Zarka et al. (2012) and Cecconi (2014).

3 Science Opportunities

Astrophysical science objectives start with the low frequency sky mapping, see the discussion Cecconi et al. (2016) in this issue, followed by the monitoring of radio sources (radio galaxies, large scale structures, clusters with radio halos, cosmological filaments), including polarization, down to a few MHz. NOIRE would provide pathfinder measurements of the red-shifted HI line that originates from before the formation of the first stars (dark ages, recombination). In case NOIRE is in lunar orbit, ultra-high energy cosmic rays and neutrinos will be studied through their interaction with the lunar surface. The detection of pulsars down to very low frequencies has implications with interstellar radio propagation. The low frequency cutoff of the temporal broadening would provide information on the largest scale of turbulence in the interstellar medium, putting limits on low frequency transient observation capabilities.

Solar and planetary science objectives are focussed on the magnetized and electrified environments. The low frequency radio bursts from the Sun are probing the interplanetary medium from 1.5 Rs (Solar Radii) to 1 AU. Imaging these radio bursts will provide completely new insights on the inner heliosphere, with application in Space Weather. Monitoring the terrestrial and planetary auroral radio emissions are also a key element of the understanding of the interaction between the solar wind and the magnetospheres. The four the giant planets magnetospheres are very dynamical objects, and long term studies are required to understand their rotation periods, the modulations by satellites and the solar wind or the seasonal effects. Such an observatory would

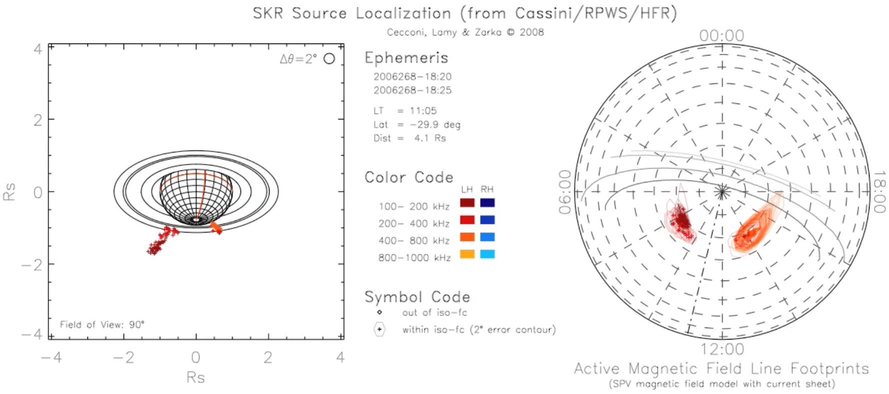

Fig. 3. Saturn auroral kilometric radiation observed with Cassini/RPWS. The direction of arrival and polarization retreived with goniopolarimetric analysis are shown on the left-hand side panel (directions projected on the plane of the sky, and polarization coded in color). The right-hand side panel shows an extra step derivation where the radio sources are mapped in the atmosphere, in order to be compared with observation of atmospheric aurora. Figure adapted from Cecconi et al. (2009).

be a first opportunity in decades to study Uranus and Neptune magnetospheres. The terrestrial and planetary radiation belts can also be observed and imaged. The local plasma at the place of the observatory can also be studied through: (i) quasi thermal noise spectroscopy (Meyer-Vernet & Perche 1989) and (ii) sampling the raw waveforms of local plasma waves (Briand et al. 2016).

Finally, the unknown remains to be discovered in this unexplored spectral band.

4 Space Radio Instrumentation

Current radio instrumentation with goniopolarimetric capabilities is described in Cecconi (2014) and references therein. Goniopolarimetric instruments are using a triad of electric short dipoles to derived polarization and direction of arrival characteristics of radio waves on a single spacecraft. Figure 3 shows the result of a goniopolarimetric analysis conducted with the Cassini/RPWS radio receiver (Gurnett et al. 2004) at Saturn. Current radio instrumentation characteristics (BepiColombo/MMO/RPW or SolarOrbiter/RPW radio receivers) are summarized as follows: superheterodyne radio receiver with 3 MHz bandwidth, sensitivity about 5 $\mathrm{nV}/\sqrt{\mathrm{Hz}}$, 80 to 100 dB dynamical range, about 1 W power consumption and a few 100 g. Future instruments (JUICE/RPWI or SolarProbePlus/Fields) are proposing base band radio receiver clocked at 100 MHz. Developments are ongoing (Mohellebi et al. 2014) to try to reduce the front-end power consumption while keeping performances.

5 Design of of Radio Interferometry

Current space radio instruments are capable of deriving direction of arrival, flux and polarization of radio waves passing at the place of a spacecraft. Imaging capabilities require interferometric instrumentation. The characteristics of such observatory must derives from a sound and detailed assessment of the science objectives, described in terms of measurement performance resulting into instrument, platform and system requirements. In case of a swarm of interferometric nodes, the instrument itself is the combination of the radio receivers, the nodes (platform) and the swarm (system).

Some preliminary requirements specific to radioastronomy can be stated easily. The nodes must be clean of radio frequency interferences (RFI). The current space engineering standard for electromagnetic compatibility (ECSS secretariat 2012) is not setting any constraint in most of the NOIRE observation band, so that most COTS (commercial off-the-shelf) components are unlikely to be suitable for NOIRE. Automated RFI mitigation software could be implemented, but its effect and interferometric processing must be assessed.

The NOIRE study team has drafted the science objectives and derived the corresponding measurement performance requirements. The translation into instrument specification is ongoing. The instrument parameter space includes at receiver level: sensitivity, temporal, and spectral sampling and resolution; at system level: number of nodes, knowledge and/or control of attitude, absolute location and relative location, clock synchronisation and ranging, inter-spacecraft communication and uplink/downlink capabilities, algorithms, etc. The current status of the assessment is not showing fundamental show stoppers. For all pieces of the system technologies are available, but not necessarily space qualified. Should the current design goal (a swarm of identical nodes) be disqualified, escape routes are also kept in mind.

This assessment is also making use of existing studies done for previous projects, such as OLFAR (Orbiting Low Frequency Array, see Rajan et al. (2010)) or DEx (Dark Ages Explorer, see Klein-Wolt & Falcke (2013)). Discussions with teams in the USA are also ongoing.

Concerning the ultimate goal of the Dark Ages of the Universe, the preliminary discussions show that the current sensitivity and calibration stability of the space radio receivers are not suitable, requiring specification studies and instrumental developments.

6 Conclusion

The NOIRE concept is very promising and innovative. Similar concepts are studied by many teams in the world. The current status of the study is not showing any show stopper. The study will resulting in a road map drafting a series a demonstrators towards a full scale observatory.

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