Thesis subject

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Title of the thesis subject : **Probing the magnetosphere of Jupiter from the systematic analysis of high resolution observations of its auroral radio emissions with the Nançay radiotelescopes and Juno**

Description of the thesis subject :

The Nançay Decameter Array (NDA, supported by CNES) [1] and NenuFAR (CNRS IR), two radiotelescopes of the Nançay Radio Observatory in the Sologne forest, regularly observe the auroral radio emissions of Jupiter's magnetosphere between 10 and 40 MHz, bringing a unique ground-based support to the Juno spacecraft, which explores the Jovian auroral regions in-orbit since 2016. The Jovian polar magnetosphere produces the most powerful auroral emissions of the solar system, dissipating tens of 10^{12} W of input power at radio and UV wavelengths, radiated above and within the upper atmosphere, respectively. Such emissions are powered by magnetospheric electrons accelerated at relativistic energies (1-500 keV) along high latitude magnetic field lines. The rich diversity of auroral components visible in the UV images of Fig. 1, probes very different acceleration mechanisms, sustained by huge (~10^6A) field-aligned electric currents.

The auroral, non-thermal radio emissions are ranging from 10 kHz to 40 MHz, corresponding to kilometric, hectometric and decametric wavelengths. Their discovery from the ground in the 1950s provided the first evidence of a Jovian magnetosphere. The waves are radiated near the electron cyclotron frequency, proportional to the magnetic field amplitude, thus corresponding to radio sources extending from the atmosphere up to several planetary radii above it [2]. They also display a strongly anisotropic beaming and are associated to the UV aurorae. The prominent Jovian radio component is the long-known decametric emission driven by Io (Io-DAM), associated with a bright UV spot near the magnetic footprint of the moon, which results from the interaction between Jupiter and Io. Similar, although different, decametric emissions driven by Europa and Ganymede, each associated with a UV footprint, have also been identified recently by our team, opening a window for comparative planetology. The remaining complex zoo of emissions is thought to be associated with the main UV auroral oval, itself supplied by electron acceleration driven by the fast planetary rotation. The nature of auroral acceleration processes driving the various auroral components have been recently challenged by the arrival the Juno NASA orbiter at Jupiter mid-2016, which explores the Jovian radiosources and acceleration regions for the first time, with radio and particle in situ measurements.

For instance, the dynamics of Jovian auroral processes at timescales below a few seconds is poorly known. This window can only be accessed by high cadence (heavy) radio data such as those taken by the NDA [1], NenuFAR or Juno. Io-DAM emissions in particular host well-known millisecond bursts (S-bursts), observed ≤10% of the emission time, drifting toward low frequencies at a few 10 MHz/s (see NDA data on Fig. 1). This drift probes individual radiosources moving away from Jupiter with the resonant electrons. It can thus be inverted to map the electron kinetic energy along the Io magnetic flux tube all around Jupiter. Tracking fine structures is therefore a powerful remote diagnostic of acceleration processes driving radio emissions. Most recently, through a proof-of-concept study analyzing 1 month of NDA high resolution data, we detected ubiquitous millisecond radio bursts associated with Io, Ganymede and auroral emissions unrelated to moon, showing that S-bursts and the underlying electron acceleration mechanism apply ubiquitously in the Jovian magnetosphere [3] This result takes a particular significance while similar bursts have been detected from active stars such as AD Leo [4]

The proposed PhD thesis will consist of statistically analyzing the full NDA high resolution dataset collected since 2016, now >150 TB large, whose access is restricted to our team. A similar analysis will possibly be also applied to NenuFAR and Juno/Waves waveform snapshots (Fig. 2, the supervisors have a PI-co-Iship status for all the 3 observatories). A systematic search for drifting bursts will be carried on with a new algorithm [3], which will be challenged by alternate state-of-the-art Machine Learning techniques. We will track any radio fine structures observed from 2016 to 2025 and map electron energies and potential drops as a function of altitude, longitude and hemisphere. The obtained 3D electron energy maps will provide unique insights to the community working on outer magnetospheres and will form a reference the the analysis of in situ electron measurements of Juno and remote UV measurements obtained by Juno or the Hubble Space Telescope. They will in particularly be used to constrain the auroral acceleration processes driving the observed auroral radio emissions.

This work aims at strengthening the low frequency radio community in France, and the emergence of this expertise at LAM, which organized in June 2025 the 10th edition (and the first one in France) of the international conference on Planetary Radio Emissions : http://prex.sciencesconf.org
This work more generally places itself in the context of the arrival of the Square Kilometer Array (SKA) under construction, which will tracks Jupiter-like auroral radio emissions from 1000s of exomagnetospheres in the galaxy. It is worth noting that NenuFAR is the french SKA pathfinder and starts to detect auroral radio emissions from stars [4].

References :

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[4] Zhang, J. […] P. Zarka et al., Fine structures of radio bursts from flare star AD Leo with FAST observations, The Astrophys. J. 953, 65, 2023.

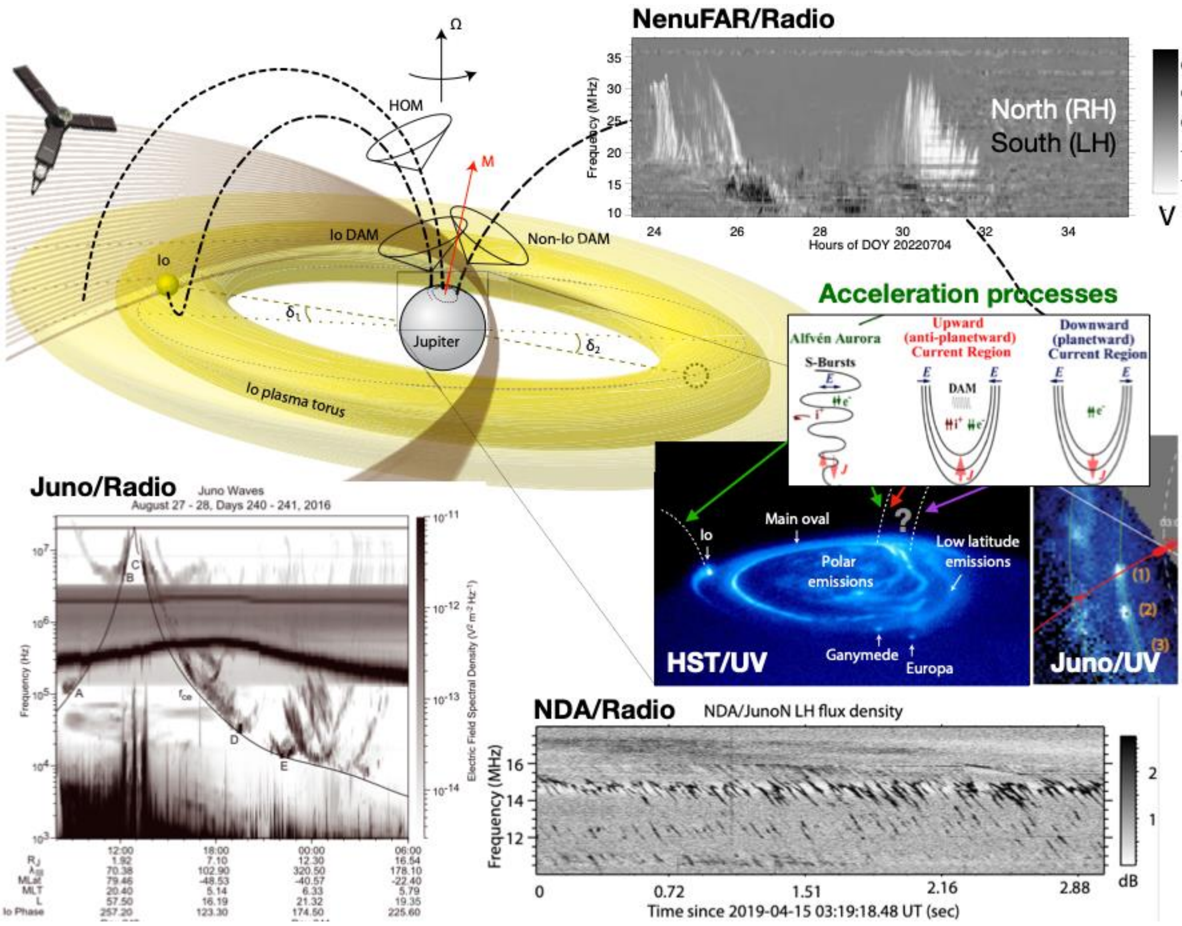

Figure 1 : Schematics of the Jovian auroral regions. High latitude accelerated electrons produce UV aurorae in the atmosphere and strongly-beamed (unresolved) radio emissions above it. Time-frequency spectrograms of the latter, observed in situ by Juno/Waves (survey mode) and remotely by the Nançay Decameter Array (high cadence) and NenuFAR (in degree of circular polarization) are displayed in black and white. Images of the UV aurorae obtained from the Hubble/STIS and Juno/UVS spectro-imagers are displayed in blue.

Figure 2 : The NDA and NenuFAR in Nançay perform radio observations of Jupiter in support to Juno.